Table 282 Experimental results and world averages for $\mathcal{B}(D^+ \to \ell^+\nu_\ell)$ and $f_D|V_{cd}|$. The first uncertainty is statistical and the second is experimental systematic. The third uncertainty in the case of $f_{D^+}|V_{cd}|$ is due to external inputs (dominated by the uncertainty of τ_D)

Mode	$\mathcal{B}$ (10^{-4})	$f_D\lvert V_{cd}\rvert$ (MeV)	References
$\mu^+\nu_\mu$	$3.82 \pm 0.32 \pm 0.09$	$46.4 \pm 1.9 \pm 0.5 \pm 0.2$	CLEO-c [1103]
	$3.71 \pm 0.19 \pm 0.06$	$45.7 \pm 1.2 \pm 0.4 \pm 0.2$	BESIII [1205]
	$3.74 \pm 0.16 \pm 0.05$	$45.9 \pm 1.0 \pm 0.3 \pm 0.2$	Average
$e^+\nu_e$	<0.088 at 90% C.L.		CLEO-c [1103]
$\tau^+\nu_\tau$	<12 at 90% C.L.		CLEO-c [1103]

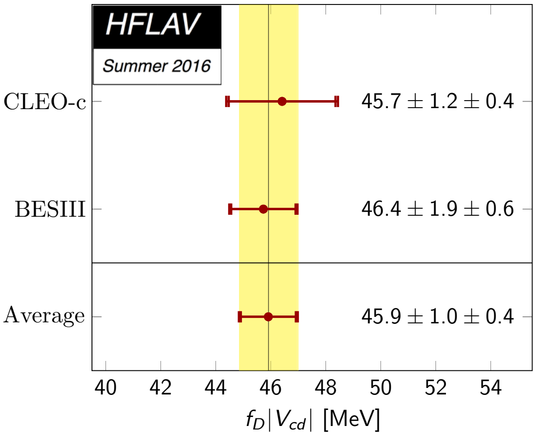

Fig. 205 WA value for $f_D|V_{cd}|$. For each point, the first error listed is the statistical and the second error is the systematic error

where the uncertainties are from the experiments and lattice calculations, respectively. All input values and the resulting world averages are summarized in Table 282 and plotted in Fig. 205.

The upper limit on the ratio of branching fractions is found to be $R^{D}_{\tau/\mu} < 3.2$ at 90% C.L., which is just slightly above the SM expected value.

8.6.2 $D_s^+ \to \ell^+\nu_\ell$ decays and $|V_{cs}|$

We use measurements of the absolute branching fraction $\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$ from CLEO-c [1137], BABAR [1206], Belle [1207], and BESIII [1204], and obtain a WA value of

$$\mathcal{B}^{\text{WA}}(D_s^+ \to \mu^+\nu_\mu) = (5.54 \pm 0.23) \times 10^{-3}. \tag{270}$$

The WA value for $\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$ is also calculated from CLEO-c, BABAR, Belle, and BESIII measurements. CLEO-c made separate measurements for $\tau^+ \to e^+\nu_e\overline{\nu}_\tau$ [1208], $\tau^+ \to \pi^+\overline{\nu}_\tau$ [1137], and $\tau^+ \to \rho^+\overline{\nu}_\tau$ [1209], BABARmade separate measurements for $\tau^+ \to e^+\nu_e\overline{\nu}_\tau$ [1206] and $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$, Belle made separate measurements for $\tau^+ \to e^+\nu_e\overline{\nu}_\tau$, $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$, and $\tau^+ \to \pi^+\overline{\nu}_\tau$ [1207], and BESIII made measurements using $\tau^+ \to \pi^+\overline{\nu}_\tau$ [1204] decays. Combining all of them we obtain the WA value of

$$\mathcal{B}^{\text{WA}}(D_s^+ \to \tau^+\nu_\tau) = (5.51 \pm 0.24) \times 10^{-2}. \tag{271}$$

The ratio of branching fractions is found to be

$$R^{D_s}_{\tau/\mu} = 9.95 \pm 0.57, \tag{272}$$

and is consistent with the value expected in the SM.

From the average values of branching fractions of muonic and tauonic decays we determine[42] the product of D_s meson decay constant and the $|V_{cs}|$ CKM matrix element to be

$$f_{D_s}|V_{cs}| = (250.3 \pm 4.5)\ \text{MeV}, \tag{273}$$

where the uncertainty is due to the uncertainties on $\mathcal{B}^{\text{WA}}(D_s^+ \to \mu^+\nu_\mu)$ and $\mathcal{B}^{\text{WA}}(D_s^+ \to \tau^+\nu_\tau)$ and the external inputs. All input values and the resulting world averages are summarized in Table 283 and plotted in Fig. 206. To obtain the averages given within this subsection and in Table 283 we have taken into account the correlations within each experiment[43] for the uncertainties related to: normalization, tracking, particle identification, signal and background parameterizations, and peaking background contributions.

Using the LQCD value for f_{D_s} from Table 281, we finally obtain the magnitude of the CKM matrix element V_{cs} to be

$$|V_{cs}| = 1.006 \pm 0.018(\text{exp.}) \pm 0.005(\text{LQCD}), \tag{274}$$

where the uncertainties are from the experiments and lattice calculations, respectively.

8.6.3 Comparison with other determinations of $|V_{cd}|$ and $|V_{cs}|$

Table 284 summarizes and Fig. 207 shows all determinations of the CKM matrix elements $|V_{cd}|$ and $|V_{cs}|$. As can be seen, the most precise direct determinations of these CKM

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[42] We use the following values (taken from PDG 2014 edition [327]) for external parameters entering Eq. (266): $m_\tau = (1.77686 \pm 0.00012)$ GeV/c^2, $m_{D_s} = (1.96830 \pm 0.00010)$ GeV/c^2 and $\tau_{D_s} = (500 \pm 7) \times 10^{-15}$ s.

[43] In the case of BABAR we use the covariance matrix from the errata of Ref. [1206].

Table 283 Experimental results and world averages for $\mathcal{B}(D_s^+ \to \ell^+\nu_\ell)$ and $f_{D_s}|V_{cs}|$. The first uncertainty is statistical and the second is experimental systematic. The third uncertainty in the case of $f_{D_s}|V_{cs}|$ is due to external inputs (dominated by the uncertainty of τ_{D_s}). We have recalculated $\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$ quoted by CLEO-c and BaBar using the latest values for branching fractions of τ decays to electron, muon, or pion and neutrinos [6]. CLEO-c and BaBar include statistical uncertainty of number of D_s tags (denominator in the calculation of branching fraction) in the statistical uncertainty of measured $\mathcal{B}$. We subtract this uncertainty from the statistical one and add it to the systematic uncertainty

Mode	$\mathcal{B}\ (10^{-2})$	$f_{D_s}\lvert V_{cs}\rvert$ (MeV)	References
$\mu^+\nu_\mu$	$0.565 \pm 0.044 \pm 0.020$	$250.8 \pm 9.8 \pm 4.4 \pm 1.8$	CLEO-c [1137]
	$0.602 \pm 0.037 \pm 0.032$	$258.9 \pm 8.0 \pm 6.9 \pm 1.8$	BaBar [1206]
	$0.531 \pm 0.028 \pm 0.020$	$243.1 \pm 6.4 \pm 4.6 \pm 1.7$	Belle [1207]
	$0.517 \pm 0.075 \pm 0.021$	$239.9 \pm 17.4 \pm 4.9 \pm 1.7$	BESIII [1204]
	$0.554 \pm 0.020 \pm 0.013$	$248.2 \pm 4.4 \pm 2.8 \pm 1.7$	Average
$\tau^+(e^+)\nu_\tau$	$5.31 \pm 0.47 \pm 0.22$	$246.1 \pm 10.9 \pm 5.1 \pm 1.7$	CLEO-c [1209]
$\tau^+(\pi^+)\nu_\tau$	$6.46 \pm 0.80 \pm 0.23$	$271.4 \pm 16.8 \pm 4.8 \pm 1.9$	CLEO-c [1137]
$\tau^+(\rho^+)\nu_\tau$	$5.50 \pm 0.54 \pm 0.24$	$250.4 \pm 12.3 \pm 5.5 \pm 1.8$	CLEO-c [1208]
$\tau^+\nu_\tau$	$5.57 \pm 0.32 \pm 0.15$	$252.0 \pm 7.2 \pm 3.4 \pm 1.8$	CLEO-c average
$\tau^+(e^+)\nu_\tau$	$5.08 \pm 0.52 \pm 0.68$	$240.7 \pm 12.3 \pm 16.1 \pm 1.7$	BaBar [1206]
$\tau^+(\mu^+)\nu_\tau$	$4.90 \pm 0.46 \pm 0.54$	$236.4 \pm 11.1 \pm 13.0 \pm 1.7$	BaBar [1206]
$\tau^+\nu_\tau$	$4.95 \pm 0.36 \pm 0.58$	$237.6 \pm 8.6 \pm 13.8 \pm 1.7$	BaBar average
$\tau^+(e^+)\nu_\tau$	$5.37 \pm 0.33^{+0.35}_{-0.31}$	$247.4 \pm 7.6^{+8.1}_{-7.1} \pm 1.7$	Belle [1207]
$\tau^+(\mu^+)\nu_\tau$	$5.86 \pm 0.37^{+0.34}_{-0.59}$	$258.5 \pm 8.2^{+7.5}_{-13.0} \pm 1.8$	Belle [1207]
$\tau^+(\pi^+)\nu_\tau$	$6.04 \pm 0.43^{+0.46}_{-0.40}$	$262.4 \pm 9.3^{+10.0}_{-8.7} \pm 1.8$	Belle [1207]
$\tau^+\nu_\tau$	$5.70 \pm 0.21 \pm 0.31$	$254.9 \pm 4.7 \pm 6.9 \pm 1.8$	Belle average
$\tau^+(\pi^+)\nu_\tau$	$3.28 \pm 1.83 \pm 0.37$	$194 \pm 54 \pm 11 \pm 1$	BESIII [1204]
$\tau^+\nu_\tau$	$5.51 \pm 0.18 \pm 0.16$	$250.9 \pm 4.0 \pm 3.7 \pm 1.8$	All average
$\mu^+\nu_\mu + \tau^+\nu_\tau$		$250.3 \pm 3.1 \pm 2.7 \pm 1.8$	All average
$e^+\nu_e$	<0.0083 at 90% C.L.		Belle [1207]

matrix elements are those from leptonic and semileptonic $D_{(s)}$ decays. The values are in agreement within uncertainties with the values obtained from the global fit assuming CKM matrix unitarity.

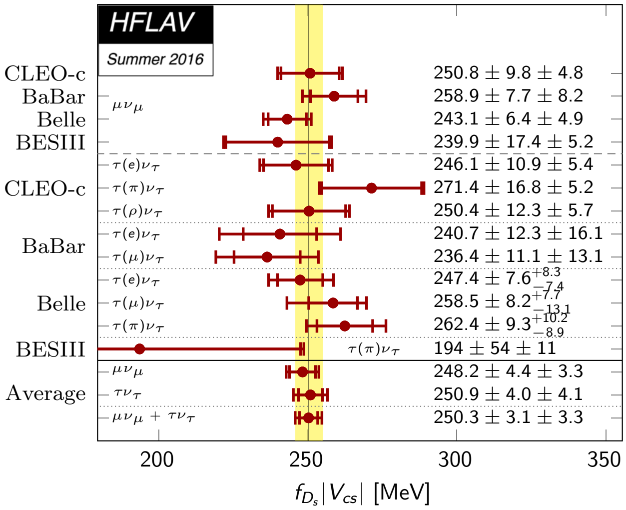


Fig. 206 WA value for $f_{D_s}|V_{cs}|$. For each point, the first error listed is the statistical and the second error is the systematic error

8.6.4 *Extraction of $D_{(s)}$ meson decay constants*

Assuming unitarity of the CKM matrix, the values of the elements relevant in the case of (semi-)leptonic charm decays are known from the global fit of the CKM matrix and are given in Table 284. These values can be used to extract the D and D_s meson decay constants from the experimentally measured products $f_D|V_{cd}|$ and $f_{D_s}|V_{cs}|$ using Eq. (268) and Eq. (273), respectively. This leads to the experimentally measured $D_{(s)}$ meson decay constants to be:

$$f_D^{\text{exp}} = (203.7 \pm 4.9)\ \text{MeV}, \tag{275}$$

$$f_{D_s}^{\text{exp}} = (257.1 \pm 4.6)\ \text{MeV}, \tag{276}$$

and the ratio of the constants is determined to be

$$f_{D_s}^{\text{exp}}/f_D^{\text{exp}} = 1.262 \pm 0.037. \tag{277}$$

The values are in agreement with the LQCD determinations given in Table 281 within the uncertainties. The largest discrepancy is in the determinations of the ratio of the decay constants where the agreement is only at the level of 2.4σ.

Table 284 Average of the magnitudes of the CKM matrix elements $|V_{cd}|$ and $|V_{cs}|$ determined from the leptonic and semileptonic D and D_s decays. In the calculation of average values we assume 100% correlations in uncertainties due to LQCD. The values determined from neutrino scattering or W decays and determination from the global fit to the CKM matrix are given for comparison as well

Method	References	Value
		$\|V_{cd}\|$
$D \to \ell\nu_\ell$	This section	0.2164 ± 0.0050(exp.) ± 0.0015(LQCD)
$D \to \pi\ell\nu_\ell$	Section 8.5	0.2141 ± 0.0029(exp.) ± 0.0093(LQCD)
	Average	0.216 ± 0.005
νN	PDG [6]	0.230 ± 0.011
Global CKM Fit	CKMFitter [252]	$0.22529^{+0.00041}_{-0.00032}$
		$\|V_{cs}\|$
$D_s \to \ell\nu_\ell$	This section	1.006 ± 0.018(exp.) ± 0.005(LQCD)
$D \to K\ell\nu_\ell$	Section 8.5	0.967 ± 0.005(exp.) ± 0.025(LQCD)
	Average	0.997 ± 0.017
$W \to c\bar{s}$	PDG [6]	$0.94^{+0.32}_{-0.26} \pm 0.13$
Global CKM Fit	CKMFitter [252]	$0.973394^{+0.000074}_{-0.000096}$

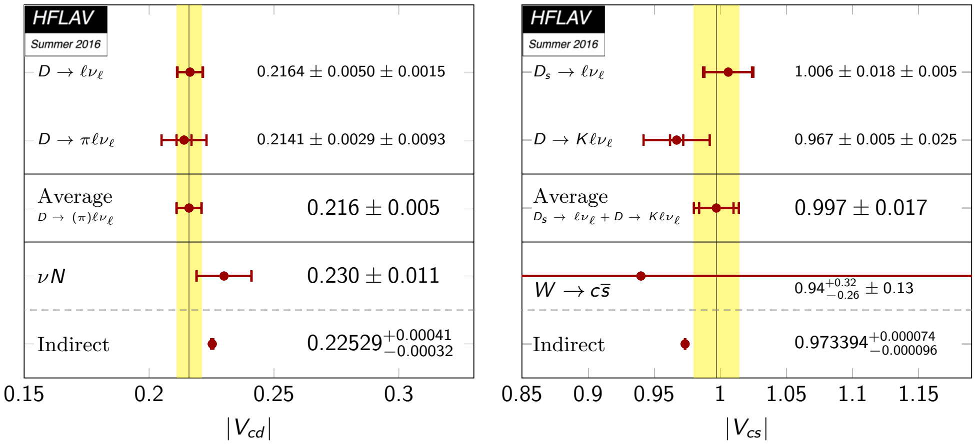


Fig. 207 Comparison of magnitudes of the CKM matrix elements $|V_{cd}|$ (*left*) and $|V_{cs}|$ (*right*) determined from the (semi-)leptonic charm decays and from neutrino scattering data or W decays and determination from the global fit assuming CKM unitarity [252]

8.7 Hadronic decays of D_s mesons

BaBar, CLEO-c and Belle collaborations have measured the absolute branching fractions of hadronic decays, $D_s^+ \to K^-K^+\pi^+$, $D_s^+ \to \overline{K}^0\pi^+$, and $D_s^+ \to \eta\pi^+$. The first two decay modes are the reference modes for the measurements of branching fractions of the D_s^+ decays to any other final state. Table 285 and Fig. 208 summarise the individual measurements and averaged values, which are found to be

$$\mathcal{B}^{\rm WA}(D_s^+ \to K^-K^+\pi^+) = (5.44 \pm 0.14)\%, \tag{278}$$

$$\mathcal{B}^{\rm WA}(D_s^+ \to \overline{K}^0\pi^+) = (3.00 \pm 0.09)\%, \tag{279}$$

$$\mathcal{B}^{\rm WA}(D_s^+ \to \eta\pi^+) = (1.71 \pm 0.08)\%, \tag{280}$$

where the uncertainties are total uncertainties. These averages are the same as in our previous report from 2014. The $\mathcal{B}(D_s^+ \to K^-K^+\pi^+)$ is for a phase space integrated decay and therefore includes all intermediate resonances.

8.8 Two-body hadronic D^0 decays and final state radiation

Measurements of the branching fractions for the decays $D^0 \to K^-\pi^+$, $D^0 \to \pi^+\pi^-$, and $D^0 \to K^+K^-$ have reached sufficient precision to allow averages with $\mathcal{O}(1\%)$ relative uncertainties. At these precisions, Final State Radiation (FSR) must be treated correctly and consistently across the input measurements for the accuracy of the averages to match the precision. The sensitivity of measurements to FSR arises because of a tail in the distribution of radiated energy that extends to the kinematic limit. The tail beyond $\sum E_\gamma \approx 30$ MeV causes typical selection variables like the hadronic invariant mass to shift outside the selection range dictated by experimental resolution, as shown in Fig. 209. While the differential rate for the tail is small, the integrated rate amounts to several percent of the total $h^+h^-(n\gamma)$ rate because of the tail's extent. The tail therefore trans-

Table 285 Experimental results and world averages for branching fractions of $D_s^+ \to K^-K^+\pi^+$, $D_s^+ \to \overline{K}^0K^+$, and $D_s^+ \to \eta\pi^+$ decays. The first uncertainty is statistical and the second is experimental systematic. CLEO-c reports in Ref. [1138] $\mathcal{B}(D_s^+ \to K_S^0K^+)$. We include it in the average of $\mathcal{B}(D_s^+ \to \overline{K}^0K^+)$ by using the relation $\mathcal{B}(D_s^+ \to \overline{K}^0K^+) \equiv 2\mathcal{B}(D_s^+ \to K_S^0K^+)$

Mode	$\mathcal{B}$ (10^{-2})	References
$K^-K^+\pi^+$	5.78 ± 0.20 ± 0.30	BaBar [1206]
	5.55 ± 0.14 ± 0.13	CLEO-c [1138]
	5.06 ± 0.15 ± 0.21	Belle [1207]
	5.44 ± 0.09 ± 0.11	Average
$\overline{K}^0K^+$	3.04 ± 0.10 ± 0.06	CLEO-c [1138]
	2.95 ± 0.11 ± 0.09	Belle [1207]
	3.00 ± 0.07 ± 0.05	Average
$\eta\pi^+$	1.67 ± 0.08 ± 0.06	CLEO-c [1138]
	1.82 ± 0.14 ± 0.07	Belle [1207]
	1.71 ± 0.07 ± 0.08	Average

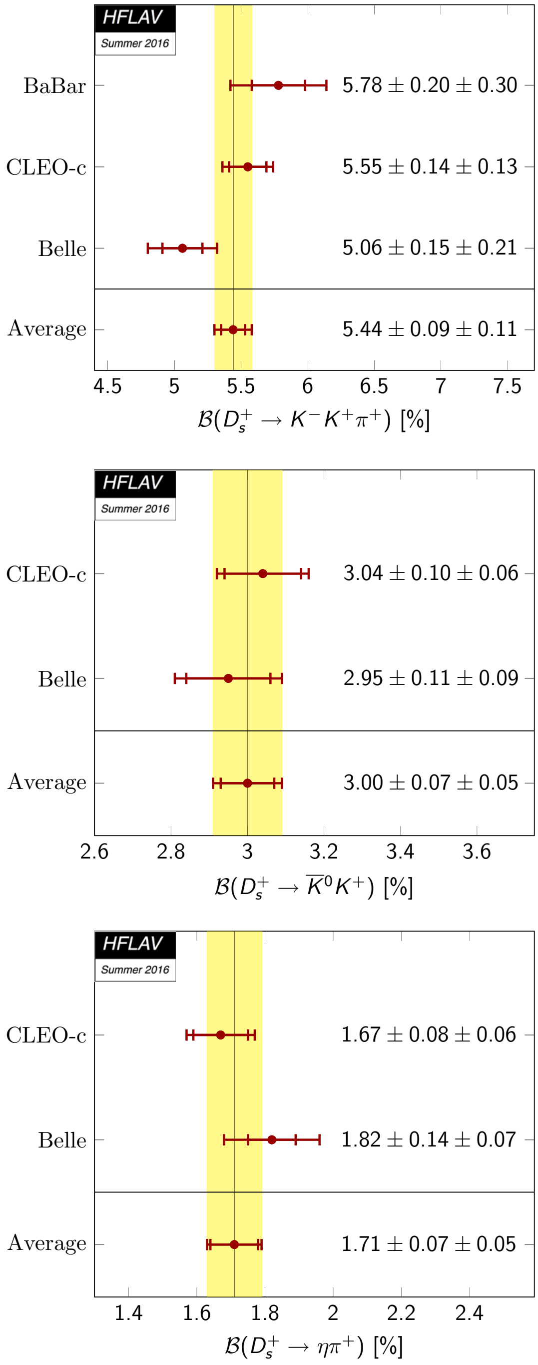


Fig. 208 WA values for $\mathcal{B}(D_s^+ \to K^-K^+\pi^+)$ (*top*), $\mathcal{B}(D_s^+ \to \overline{K}^0\pi^+)$ (*middle*), $\mathcal{B}(D_s^+ \to \eta\pi^+)$ (*bottom*). For each point, the first error listed is the statistical and the second error is the systematic error

lates directly into a several percent loss in experimental efficiency.

All measurements that include an FSR correction have a correction based on the use of PHOTOS [1210–1213] within the experiment's Monte Carlo simulation. PHOTOS itself, however, has evolved, over the period spanning the set of measurements. In particular, the incorporation of interference between radiation off the two separate mesons has proceeded in stages: it was first available for particle–antiparticle pairs in version 2.00 (1993), extended to any two-body, all-charged, final states in version 2.02 (1999), and further extended to multi-body final states in version 2.15 (2005). The effects of interference are clearly visible, as shown in Fig. 209, and cause a roughly 30% increase in the integrated rate into the high energy photon tail. To evaluate the FSR correction incorporated into a given measurement, we must therefore note whether any correction was made, the version of PHOTOS used in correction, and whether the interference terms in PHOTOS were turned on.

8.8.1 Branching fraction corrections

Before averaging the measured branching fractions, the published results are updated, as necessary, to the FSR prediction of PHOTOS 2.15 with interference included. The correction will always shift a branching fraction to a higher value: with no FSR correction or with no interference term in the correction, the experimental efficiency determination will be biased high, and therefore the branching fraction will be biased low.

Most of the branching fraction analyses used the kinematic quantity sensitive to FSR in the candidate selection criteria. For the analyses at the $\psi(3770)$, this variable was ΔE, the difference between the candidate D^0 energy and the beam energy (e.g., $E_K + E_\pi - E_{\text{beam}}$ for $D^0 \to K^-\pi^+$). In the remainder of the analyses, the relevant quantity was the reconstructed hadronic two-body mass $m_{h^+h^-}$. To make the correction, we only need to evaluate the fraction of decays that FSR moves outside of the range accepted for the analysis.

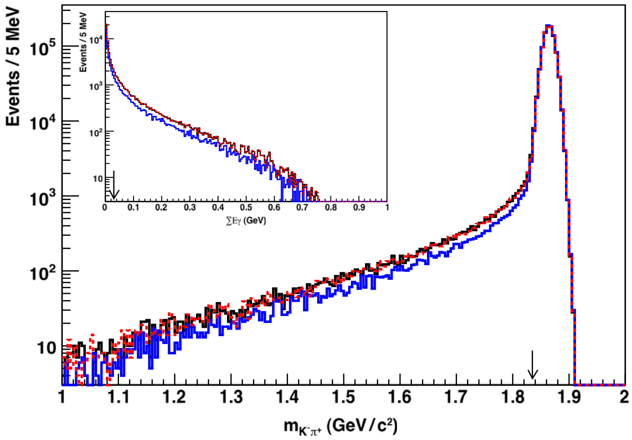


Fig. 209 The $K\pi$ invariant mass distribution for $D^0 \to K^-\pi^+(n\gamma)$ decays. The three curves correspond to three different configurations of PHOTOS for modeling FSR: version 2.02 without interference (*blue/grey*), version 2.02 with interference (*red dashed*) and version 2.15 with interference (*black*). The true invariant mass has been smeared with a typical experimental resolution of 10 MeV/c^2. *Inset* The corresponding spectrum of total energy radiated per event. The *arrow* indicates the $\sum E_\gamma$ value that begins to shift kinematic quantities outside of the range typically accepted in a measurement

The corrections were evaluated using an event generator (EvtGen [1214]) that incorporates PHOTOS to simulate the portions of the decay process most relevant to the correction. We compared corrections determined both with and without smearing to account for experimental resolution. The differences were negligible, typically of $\mathcal{O}(1\%)$ of the correction itself. The immunity of the correction to resolution effects comes about because most of the long FSR-induced tail in, for example, the $m_{h^+h^-}$ distribution resides well away from the selection boundaries. The smearing from resolution, on the other hand, mainly affects the distribution of events right at the boundary.

For measurements incorporating an FSR correction that did not include interference, we update by assessing the FSR-induced efficiency loss for both the PHOTOS version and configuration used in the analysis and our nominal version 2.15 with interference. For measurements that published their sensitivity to FSR, our generator-level predictions for the original efficiency loss agreed to within a few percent of the correction. This agreement lends additional credence to the procedure.

Once the event loss from FSR in the most sensitive kinematic quantity is accounted for, the event loss in other quantities is very small. For example, analyses using D^{*+} tags show little sensitivity to FSR in the reconstructed $D^{*+} - D^0$ mass difference, i.e., in $m_{K^-\pi^+\pi^+} - m_{K^-\pi^+}$. In this case the effect of FSR tends to cancel in the difference of reconstructed masses. In the $\psi(3770)$ analyses, the beam-constrained mass distributions ($\sqrt{E^2_{\text{beam}} - |\vec{p}_K + \vec{p}_\pi|^2}$) also show much smaller sensitivity than does the two-body mass.

The FOCUS [1215] analysis of the branching fraction ratios $\mathcal{B}(D^0 \to \pi^+\pi^-)/\mathcal{B}(D^0 \to K^-\pi^+)$ and $\mathcal{B}(D^0 \to K^+K^-)/\mathcal{B}(D^0 \to K^-\pi^+)$ obtained yields using fits to the two-body mass distributions. FSR will both distort the low end of the signal mass peak, and will contribute a signal component to the low side tail used to estimate the background. The fitting procedure is not sensitive to signal events out in the FSR tail, which would be counted as part of the background.

A more complex toy Monte Carlo procedure was required to analyze the effect of FSR on the fitted yields, which were published with no FSR corrections applied. A detailed description of the procedure and results is available on the HFLAV web site, and a brief summary is provided here. Determining the correction involved an iterative procedure in which samples of similar size to the FOCUS sample were generated and then fit using the FOCUS signal and background parameterizations. The MC parameterizations were tuned based on differences between the fits to the toy MC data and the FOCUS fits, and the procedure was repeated. These steps were iterated until the fit parameters matched the original FOCUS parameters.

The toy MC samples for the first iteration were based on the generator-level distribution of $m_{K^-\pi^+}$, $m_{\pi^+\pi^-}$, and $m_{K^+K^-}$, including the effects of FSR, smeared according to the original FOCUS resolution function, and on backgrounds generated using the parameterization from the final FOCUS fits. For each iteration, 400–1600 individual data-sized samples were generated and fit. The means of the parameters from these fits determined the corrections to the generator parameters for the following iteration. The ratio between the number of signal events generated and the final signal yield provides the required FSR correction in the final iteration. Only a few iterations were required in each mode. Figure 210 shows the FOCUS data, the published FOCUS fits, and the final toy MC parameterizations. The toy MC provides an excellent description of the data.

The corrections obtained to the individual FOCUS yields were 1.0298 ± 0.0001 for $K^-\pi^+$, 1.062 ± 0.001 for $\pi^+\pi^-$, and 1.0183 ± 0.0003 for K^+K^-. These corrections tend to cancel in the branching ratios, leading to corrections of 1.031 ± 0.001 for $\mathcal{B}(D^0 \to \pi^+\pi^-)/\mathcal{B}(D^0 \to K^-\pi^+)$, and 0.9888 ± 0.0003 for $\mathcal{B}(D^0 \to K^+K^-)/\mathcal{B}(D^0 \to K^-\pi^+)$.

Table 286 summarizes the corrected branching fractions. The published FSR-related modeling uncertainties have been replaced by with a new, common, estimate based on the assumption that the dominant uncertainty in the FSR corrections comes from the fact that the mesons are treated like structureless particles. No contributions from structure-dependent terms in the decay process (e.g., radiation off individual quarks) are included in PHOTOS. Internal studies done by various experiments have indicated that in $K\pi$ decays, the PHOTOS corrections agree with data at the 20–

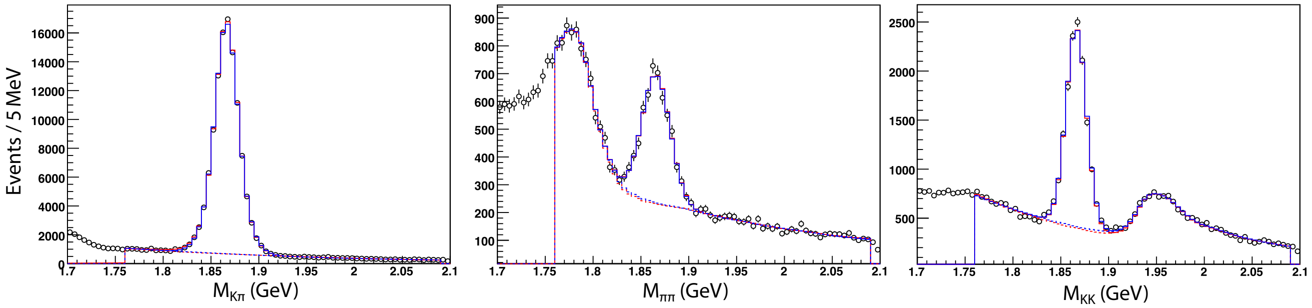


Fig. 210 FOCUS data (*dots*), original fits (*blue*) and toy MC parameterization (*red*) for $D^0 \to K^-\pi^+$ (*left*), $D^0 \to \pi^+\pi^-$ (*center*), and $D^0 \to \pi^+\pi^-$ (*right*)

Table 286 The experimental measurements relating to $\mathcal{B}(D^0 \to K^-\pi^+)$, $\mathcal{B}(D^0 \to \pi^+\pi^-)$, and $\mathcal{B}(D^0 \to K^+K^-)$ after correcting to the common version and configuration of PHOTOS. The uncertainties are statistical and total systematic, with the FSR-related systematic estimated in this procedure shown in parentheses. Also listed are the percent shifts in the results from the correction, if any, applied here, as well as the original PHOTOS and interference configuration for each publication

Experiment (acronym)	Result (rescaled)	Correction (%)	PHOTOS
$D^0 \to K^-\pi^+$			
CLEO-c 14 (CC14) [1106]	$3.934 \pm 0.021 \pm 0.061(31)\%$	–	2.15/yes
BaBar 07 (BB07) [1216]	$4.035 \pm 0.037 \pm 0.074(24)\%$	0.69	2.02/no
CLEO II 98 (CL98) [1217]	$3.920 \pm 0.154 \pm 0.168(32)\%$	2.80	None
ALEPH 97 (AL97) [1218]	$3.930 \pm 0.091 \pm 0.125(32)\%$	0.79	2.0/no
ARGUS 94 (AR94) [1219]	$3.490 \pm 0.123 \pm 0.288(24)\%$	2.33	None
CLEO II 93 (CL93) [1220]	$3.960 \pm 0.080 \pm 0.171(15)\%$	0.38	2.0/no
ALEPH 91 (AL91) [1221]	$3.730 \pm 0.351 \pm 0.455(34)\%$	3.12	None
$D^0 \to \pi^+\pi^-/D^0 \to K^-\pi^+$			
CLEO-c 10 (CC10) [1104]	$0.0370 \pm 0.0006 \pm 0.0009(02)$	–	2.15/yes
CDF 05 (CD05) [1222]	$0.03594 \pm 0.00054 \pm 0.00043(15)$	–	2.15/yes
FOCUS 02 (FO02) [1215]	$0.0364 \pm 0.0012 \pm 0.0006(02)$	3.10	None
$D^0 \to K^+K^-/D^0 \to K^-\pi^+$			
CLEO-c 10 [1104]	$0.1041 \pm 0.0011 \pm 0.0012(03)$	–	2.15/yes
CDF 05 [1222]	$0.0992 \pm 0.0011 \pm 0.0012(01)$	–	2.15/yes
FOCUS 02 [1215]	$0.0982 \pm 0.0014 \pm 0.0014(01)$	−1.12	None

30% level. We therefore attribute a 25% uncertainty to the FSR prediction from potential structure-dependent contributions. For the other two modes, the only difference in structure is the final state valence quark content. While radiative corrections typically come in with a $1/M$ dependence, one would expect the additional contribution from the structure terms to come in on time scales shorter than the hadronization time scale. In this case, you might expect Λ_{QCD} to be the relevant scale, rather than the quark masses, and therefore that the amplitude is the same for the three modes. In treating the correlations among the measurements this is what we assume. We also assume that the PHOTOS amplitudes and any missing structure amplitudes are relatively real with constructive interference. The uncertainties largely cancel in the branching fraction ratios. For the final average branching fractions, the FSR uncertainty on $K\pi$ dominates. Note that because of the relative sizes of FSR in the different modes, the $\pi\pi/K\pi$ branching ratio uncertainty from FSR is positively correlated with that for the $K\pi$ branching fraction, while the $KK/K\pi$ branching ratio FSR uncertainty is negatively correlated.

The $\mathcal{B}(D^0 \to K^-\pi^+)$ measurement of reference [1223], the $\mathcal{B}(D^0 \to \pi^+\pi^-)/\mathcal{B}(D^0 \to K^-\pi^+)$ measurements of references [1122] and [1081], and the $\mathcal{B}(D^0 \to K^+K^-)/\mathcal{B}(D^0 \to K^-\pi^+)$ measurement of reference [1081] are excluded from the branching fraction averages presented here. These measurements appear not to have incorporated any FSR corrections, and insufficient information is available to determine the 2–3% corrections that would be required.

Table 287 The correlation matrix corresponding to the full covariance matrix. Subscripts h denote which of the $D^0 \to h^+h^-$ decay results from a single experiment is represented in that row or column

	CC14	BB07	CL98	AL97	AR94	CL93	AL91	$\mathrm{FO02}_\pi$	$\mathrm{CD05}_\pi$	$\mathrm{CC10}_\pi$	$\mathrm{FO02}_K$	$\mathrm{CD05}_K$	$\mathrm{CC10}_K$
CC14	1.000	0.139	0.057	0.084	0.031	0.033	0.023	0.070	0.103	0.068	−0.019	−0.032	−0.085
BB07	0.139	1.000	0.035	0.051	0.019	0.020	0.014	0.042	0.062	0.041	−0.012	−0.019	−0.051
CL98	0.057	0.035	1.000	0.021	0.008	0.298	0.006	0.017	0.026	0.017	−0.005	−0.008	−0.021
AL97	0.084	0.051	0.021	1.000	0.011	0.012	0.116	0.025	0.038	0.025	−0.007	−0.012	−0.031
AR94	0.031	0.019	0.008	0.011	1.000	0.004	0.003	0.009	0.014	0.009	−0.003	−0.004	−0.011
CL93	0.033	0.020	0.298	0.012	0.004	1.000	0.003	0.010	0.015	0.010	−0.003	−0.005	−0.012
AL91	0.023	0.014	0.006	0.116	0.003	0.003	1.000	0.007	0.010	0.007	−0.002	−0.003	−0.009
$\mathrm{FO02}_\pi$	0.070	0.042	0.017	0.025	0.009	0.010	0.007	1.000	0.031	0.021	−0.006	−0.010	−0.026
$\mathrm{CD05}_\pi$	0.103	0.062	0.026	0.038	0.014	0.015	0.010	0.031	1.000	0.031	−0.009	−0.014	−0.038
$\mathrm{CC10}_\pi$	0.068	0.041	0.017	0.025	0.009	0.010	0.007	0.021	0.031	1.000	−0.006	−0.010	−0.025
$\mathrm{FO02}_K$	−0.019	−0.012	−0.005	−0.007	−0.003	−0.003	−0.002	−0.006	−0.009	−0.006	1.000	0.003	0.007
$\mathrm{CD05}_K$	−0.032	−0.019	−0.008	−0.012	−0.004	−0.005	−0.003	−0.010	−0.014	−0.010	0.003	1.000	0.012
$\mathrm{CC10}_K$	−0.085	−0.051	−0.021	−0.031	−0.011	−0.012	−0.009	−0.026	−0.038	−0.025	0.007	0.012	1.000

8.8.2 Average branching fractions

The average branching fractions for $D^0 \to K^-\pi^+$, $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$ decays are obtained from a single χ^2 minimization procedure, in which the three branching fractions are floating parameters. The central values are obtained from a fit in which the full covariance matrix – accounting for all statistical, systematic (excluding FSR), and FSR measurement uncertainties – is used. Table 287 presents the correlation matrix for this nominal fit. We then obtain the three reported uncertainties on those central values as follows: The statistical uncertainties are obtained from a fit using only the statistical covariance matrix. The systematic uncertainties are obtained by subtracting (in quadrature) the statistical uncertainties from the uncertainties determined via a fit using a covariance matrix that accounts for both statistical and systematic measurement uncertainties. The FSR uncertainties are obtained by subtracting (in quadrature) the uncertainties determined via a fit using a covariance matrix that accounts for both statistical and systematic measurement uncertainties from the uncertainties determined via the fit using the full covariance matrix.

In forming the full covariance matrix, the FSR uncertainties are treated as fully correlated (or anti-correlated) as described above. For the covariance matrices involving systematic measurement uncertainties, ALEPH's systematic uncertainties in the θ_{D^*} parameter are treated as fully correlated between the ALEPH 97 and ALEPH 91 measurements. Similarly, the tracking efficiency uncertainties in the CLEO II 98 and the CLEO II 93 measurements are treated as fully correlated.

The averaging procedure results in a final χ^2 of 11.0 for 10 (13 − 3) degrees of freedom. The branching fractions obtained are

$$\mathcal{B}(D^0 \to K^-\pi^+) = (3.962 \pm 0.017 \pm 0.038 \pm 0.027)\,\%, \tag{281}$$

$$\mathcal{B}(D^0 \to \pi^+\pi^-) = (0.144 \pm 0.002 \pm 0.002 \pm 0.002)\,\%, \tag{282}$$

$$\mathcal{B}(D^0 \to K^+K^-) = (0.399 \pm 0.003 \pm 0.005 \pm 0.002)\,\%. \tag{283}$$

The uncertainties, estimated as described above, are statistical, systematic (excluding FSR), and FSR modeling. The correlation coefficients from the fit using the total uncertainties are

	$K^-\pi^+$	$\pi^+\pi^-$	K^+K^-
$K^-\pi^+$	1.00	0.71	0.76
$\pi^+\pi^-$	0.71	1.00	0.53
K^+K^-	0.76	0.53	1.00

As the χ^2 would suggest and Fig. 211 shows, the average value for $\mathcal{B}(D^0 \to K^-\pi^+)$ and the input branching fractions agree very well. With the estimated uncertainty in the FSR modeling used here, the FSR uncertainty dominates the statistical uncertainty in the average, suggesting that experimental work in the near future should focus on verification of FSR with $\sum E_\gamma \gtrsim 100$ MeV. Note that the systematic uncertainty excluding FSR is still larger than the FSR uncertainty; in the most precise measurements of these branching fractions, the largest systematic uncertainty is the uncertainty on the tracking efficiency. The $\mathcal{B}(D^0 \to K^+K^-)$ and $\mathcal{B}(D^0 \to \pi^+\pi^-)$ measurements inferred from the branching ratio measurements also agree well (Fig. 212).

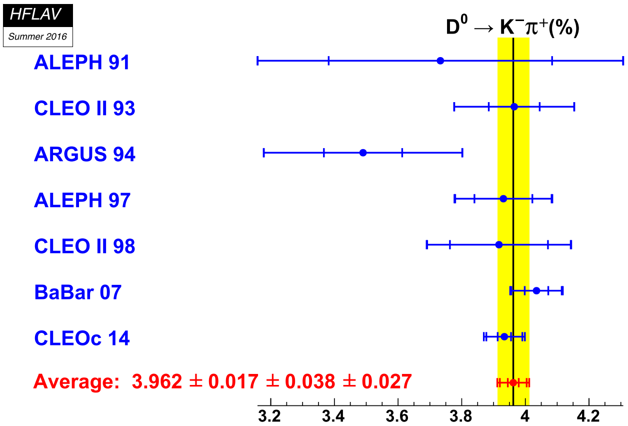


Fig. 211 Comparison of measurements of $\mathcal{B}(D^0 \to K^-\pi^+)$ (*blue*) with the average branching fraction obtained here (*red*, and *yellow band*)

The $\mathcal{B}(D^0 \to K^-\pi^+)$ average obtained here is approximately two statistical standard deviations higher than the 2016 PDG update average [6]. Table 288 shows the evolution from a fit similar to the PDG's (no FSR corrections or correlations, reference [1223] included) to the average presented here. There are two main contributions to the difference. The branching fraction in reference [1223] is low, and its exclusion shifts the result upwards. The dominant shift (+0.017%) is due to the FSR corrections, which as expected shift the result upwards.

There is no reason to presume that the effects of FSR should be different in $D^0 \to K^+\pi^-$ and $D^0 \to K^-\pi^+$ decays, as both decay to one charged kaon and one charged pion. Measurements of the relative branching fraction ratio between the doubly Cabibbo-suppressed decay $D^0 \to K^+\pi^-$ and the Cabibbo-favored decay $D^0 \to K^-\pi^+$ (R_D, determined in Sect. 8.1) are now approaching $\mathcal{O}(1\%)$ relative uncertainties. This makes it worthwhile to combine our R_D average with the $\mathcal{B}(D^0 \to K^-\pi^+)$ average obtained in Eq. (281), to provide measurements of the branching fraction:

$$\mathcal{B}(D^0 \to K^+\pi^-) = (1.379 \pm 0.023) \times 10^{-4} \text{ (assuming no } CPV\text{)}, \tag{284}$$

$$\mathcal{B}(D^0 \to K^+\pi^-) = (1.383 \pm 0.023) \times 10^{-4} \text{ (}CPV\text{ allowed)}. \tag{285}$$

Note that, by definition of R_D, these branching fractions do not include any contribution from Cabibbo-favored $\overline{D}^0 \to K^+\pi^-$ decays.

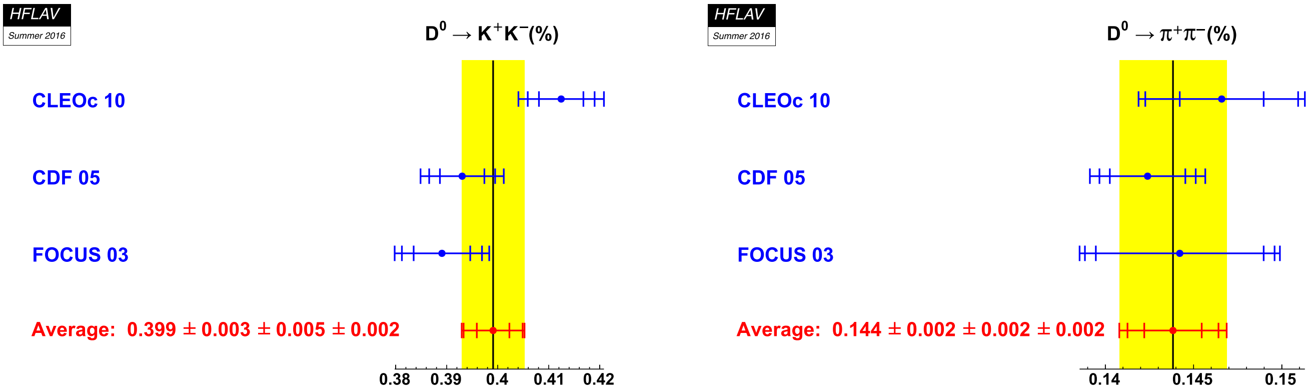


Fig. 212 The $\mathcal{B}(D^0 \to K^+K^-)$ (*left*) and $\mathcal{B}(D^0 \to \pi^+\pi^-)$ (right) values obtained by scaling the measured branching ratios with the $\mathcal{B}(D^0 \to K^-\pi^+)$ branching fraction average obtained here. For the measurements (*blue points*), the error bars correspond to the statistical, systematic and $K\pi$ normalization uncertainties. The average obtained here (*red point*, *yellow band*) lists the statistical, systematics excluding FSR, and the FSR systematic

Table 288 Evolution of the $D^0 \to K^-\pi^+$ branching fraction from a fit with no FSR corrections or correlations (similar to the average in the PDG 2016 update [6]) to the nominal fit presented here

Modes fit	Description	$\mathcal{B}(D^0 \to K^-\pi^+)$ (%)	χ^2/(deg. of freedom)
$K^-\pi^+$	PDG 2016 [6] equivalent	3.930 ± 0.017 ± 0.042	4.5/(8 − 1) = 0.64
$K^-\pi^+$	Drop Ref. [1223]	3.938 ± 0.017 ± 0.042	4.5/(7 − 1) = 0.75
$K^-\pi^+$	Add FSR corrections	3.955 ± 0.017 ± 0.038 ± 0.018	3.5/(7 − 1) = 0.58
$K^-\pi^+$	Add FSR correlations	3.956 ± 0.017 ± 0.038 ± 0.027	3.6/(7 − 1) = 0.60
All	–	3.962 ± 0.017 ± 0.038 ± 0.027	11.0/(13 − 3) = 1.10

Table 289 Recent measurements of mass and width for different excited D_s mesons. The column J^P list the most significant assignment of spin and parity. If possible an average mass or width is calculated

Resonance	J^P	Decay mode	Mass (MeV$/c^2$)	Width (MeV)	Measured by	References
$D_{s0}^*(2317)^\pm$	0^+	$D_s^+\pi^0$	$2319.6 \pm 0.2 \pm 1.4$		BABAR	[1244]
		$D_s^+\pi^0$	$2317.3 \pm 0.4 \pm 0.8$		BABAR	[1227]
			2318.0 ± 0.8		Our average	
$D_{s1}(2460)^\pm$	1^+	$D_s^{*+}\pi^0$, $D_s^+\pi^0\gamma$, $D_s^+\gamma$, $D_s^+\pi^+\pi^-$	$2460.1 \pm 0.2 \pm 0.8$		BABAR	[1244]
		$D_s^+\pi^0\gamma$	$2458 \pm 1.0 \pm 1.0$		BABAR	[1227]
			2459.6 ± 0.7		Our average	
$D_{s1}(2536)^\pm$	1^+	$D^{*+}K_S^0$	$2535.7 \pm 0.6 \pm 0.5$		DØ	[1245]
		$D^{*+}K_S^0$, $D^{*0}K^+$	$2534.78 \pm 0.31 \pm 0.40$		BABAR	[643]
		$D_s^+\pi^+\pi^-$	$2534.6 \pm 0.3 \pm 0.7$		BABAR	[1244]
		$D^{*+}K_S^0$, $D^{*0}K^+$	$2535.0 \pm 0.6 \pm 1.0$		E687	[1246]
		$D^{*0}K^+$	$2535.3 \pm 0.2 \pm 0.5$		CLEO	[1247]
		$D^{*+}K_S^0$	$2534.8 \pm 0.6 \pm 0.6$		CLEO	[1247]
		$D^{*0}K^+$	$2535.2 \pm 0.5 \pm 1.5$		ARGUS	[1248]
		$D^{*+}K_S^0$	$2535.6 \pm 0.7 \pm 0.4$		CLEO	[1249]
		$D^{*+}K_S^0$	$2535.9 \pm 0.6 \pm 2.0$		ARGUS	[1250]
		$D^{*+}K_S^0$		$0.92 \pm 0.03 \pm 0.04$	BABAR	[1251]
			2535.10 ± 0.26	0.92 ± 0.05	Our average	
$D_{s2}^*(2573)^\pm$	2^+	D^0K^+, $D^{*+}K_S^0$	$2568.39 \pm 0.29 \pm 0.26$	$16.9 \pm 0.5 \pm 0.6$	LHCb	[1252]
		$D^+K_S^0$, D^0K^+	$2569.4 \pm 1.6 \pm 0.5$	$12.1 \pm 4.5 \pm 1.6$	LHCb	[1253]
		$D^+K_S^0$, D^0K^+	$2572.2 \pm 0.3 \pm 1.0$	$27.1 \pm 0.6 \pm 5.6$	BABAR	[1254]
		D^0K^+	$2574.25 \pm 3.3 \pm 1.6$	$10.4 \pm 8.3 \pm 3.0$	ARGUS	[1255]
		D^0K^+	$2573.2^{+1.7}_{-1.6} \pm 0.9$	$16^{+5}_{-4} \pm 3$	CLEO	[1256]
			2569.08 ± 0.35	16.9 ± 0.8	Our average	
$D_{s1}^*(2700)^\pm$	1^-	$D^{*+}K_S^0$, $D^{*0}K^+$	$2732.3 \pm 4.3 \pm 5.8$	$136 \pm 19 \pm 24$	LHCb	[1241]
		D^0K^+	2699^{+14}_{-7}	127^{+24}_{-19}	BABAR	[1257]
		$D^{*+}K_S^0$, $D^{*0}K^+$	$2709.2 \pm 1.9 \pm 4.5$	$115.8 \pm 7.3 \pm 12.1$	LHCb	[1239]
		DK, D^*K	$2710 \pm 2^{+12}_{-7}$	$149 \pm 7^{+39}_{-52}$	BABAR	[1238]
		D^0K^+	$2708 \pm 9^{+11}_{-10}$	$108 \pm 2^{+36}_{-31}$	Belle	[731]
			2712.0 ± 1.5	121.5 ± 10.2	Our average	
$D_{s1}^*(2860)^\pm$	1	D^0K^+	$2859 \pm 12 \pm 24$	$159 \pm 23 \pm 77$	LHCb	[1240]
$D_{s3}^*(2860)^\pm$	3^-	$D^{*+}K_S^0$, $D^{*0}K^+$	$2867.1 \pm 4.3 \pm 1.9$	$50 \pm 11 \pm 13$	LHCb	[1241]
		D^0K^+	$2860.5 \pm 2.6 \pm 6.5$	$53 \pm 7 \pm 7$	LHCb	[1240]
			2865.0 ± 3.9	52.2 ± 8.6	Our average	
$D_{sJ}(3040)^\pm$	Unnatural	D^*K	$3044 \pm 8^{+30}_{-5}$	$239 \pm 35^{+46}_{-42}$	BABAR (m and Γ) + LHCb(J^P)	[1238]+[1241]

8.9 Excited $D_{(s)}$ mesons

Excited charm meson states have received increased attention since the first observation of states that could not be accommodated by QCD predictions [1224–1227]. Tables 289, 290 and 291 summarize recent measurements of the masses and widths of excited D and D_s mesons, respectively. If a preferred assignment of spin and parity was measured it is listed in the column J^P, where the label natural denotes $J^P = 0^-, 1^+, 2^- \dots$ and unnatural $J^P = 0^+, 1^-, 2^+ \dots$. If possible, an average mass and width are calculated. The calculation of the averages assumes no correlation between individual measurements. A summary of the averaged masses and widths is shown in Fig. 213.

The masses and widths of narrow ($\Gamma < 50$ MeV) orbitally excited D mesons (1P states, denoted D^{**}), both neutral

Table 290 Recent measurements of mass and width for different excited D mesons. The column J^P list the most significant assignment of spin and parity. If possible an average mass or width is calculated

Resonance	J^P	Decay mode	Mass (MeV/c^2)	Width (MeV)	Measured by	References
$D_0^*(2400)^0$	0^+	$D^+\pi^-$	$2297 \pm 8 \pm 20$	$273 \pm 12 \pm 48$	BaBar	[711]
		$D^+\pi^-$	$2308 \pm 17 \pm 32$	$276 \pm 21 \pm 63$	Belle	[710]
		$D^+\pi^-$	$2407 \pm 21 \pm 35$	$240 \pm 55 \pm 59$	FOCUS	[1228]
			2318.2 ± 16.9	267.4 ± 35.6	Our average	
$D_0^*(2400)^\pm$	0^+	$D^0\pi^+$	$2349 \pm 6 \pm 1 \pm 4$	$217 \pm 13 \pm 5 \pm 12$	LHCb	[602]
		$D^0\pi^+$	$2360 \pm 15 \pm 12 \pm 28$	$255 \pm 26 \pm 20 \pm 47$	LHCb	[1258]
		$D^0\pi^+$	$2403 \pm 14 \pm 35$	$283 \pm 24 \pm 34$	FOCUS (m and Γ) + Belle(J^P)	[1228] + [1259]
			2350.6 ± 5.9	233.7 ± 15.5	Our average	
$D_1(2420)^0$	1^+	$D^{*+}\pi^-$	$2419.6 \pm 0.1 \pm 0.7$	$35.2 \pm 0.4 \pm 0.9$	LHCb	[1165]
		$D^{*+}\pi^-$	$2423.1 \pm 1.5^{+0.4}_{-1.0}$	$38.8 \pm 5^{+1.9}_{-5.4}$	Zeus	[1260]
		$D^{*+}\pi^-$	$2420.1 \pm 0.1 \pm 0.8$	$31.4 \pm 0.5 \pm 1.3$	BaBar	[1164]
		$D^{*+}\pi^-$	$20.0 \pm 1.7 \pm 1.3$		CDF	[1261]
		$D^0\pi^+\pi^-$	$2426 \pm 3 \pm 1$	$24 \pm 7 \pm 8$	Belle	[622]
		$D^{*+}\pi^-$	$2421.4 \pm 1.5 \pm 0.9$	$23.7 \pm 2.7 \pm 4.0$	Belle	[710]
		$D^{*+}\pi^-$	$2421^{+1}_{-2} \pm 2$	20^{+6+3}_{-5-3}	CLEO	[1262]
		$D^{*+}\pi^-$	$2422 \pm 2 \pm 2$	$15 \pm 8 \pm 4$	E687	[1246]
		$D^{*+}\pi^-$	$2428 \pm 3 \pm 2$	23^{+8+10}_{-6-4}	CLEO	[1249]
		$D^{*+}\pi^-$	$2414 \pm 2 \pm 5$	$13 \pm 6^{+10}_{-5}$	ARGUS	[1263]
		$D^{*+}\pi^-$	$2428 \pm 8 \pm 5$	$58 \pm 14 \pm 10$	TPS	[1264]
			2420.5 ± 0.5	31.7 ± 0.7	Our average	
$D_1(2420)^\pm$	1^+	$D^{*0}\pi^+$	$2421.9 \pm 4.7^{+3.4}_{-1.2}$		Zeus	[1260]
		$D^+\pi^-\pi^+$	$2421 \pm 2 \pm 1$	$21 \pm 5 \pm 8$	Belle	[622]
		$D^{*0}\pi^+$	$2425 \pm 2 \pm 2$	$26^{+8}_{-7} \pm 4$	CLEO	[1265]
		$D^{*0}\pi^+$	$2443 \pm 7 \pm 5$	$41 \pm 19 \pm 8$	TPS	[1264]
			2423.2 ± 1.6	25.2 ± 6.0	Our average	
$D_1(2430)^0$	1^+	$D^{*+}\pi^-$	$2427 \pm 26 \pm 25$	$384^{+107}_{-75} \pm 74$	Belle	[710]
$D_2^*(2460)^0$	2^+	$D^{*+}\pi^-$	$2464.0 \pm 1.4 \pm 0.5 \pm 0.2$	$43.8 \pm 2.9 \pm 1.7 \pm 0.6$	LHCb	[716]
		$D^{*+}\pi^-$	$2460.4 \pm 0.4 \pm 1.2$	$43.2 \pm 1.2 \pm 3.0$	LHCb	[1165]
		$D^+\pi^-$	$2460.4 \pm 0.1 \pm 0.1$	$45.6 \pm 0.4 \pm 1.1$	LHCb	[1165]
		$D^{*+}\pi^-$, $D^+\pi^-$	$2462.5 \pm 2.4^{+1.3}_{-1.1}$	$46.6 \pm 8.1^{+5.9}_{-3.8}$	Zeus	[1260]
		$D^+\pi^-$	$2462.2 \pm 0.1 \pm 0.8$	$50.5 \pm 0.6 \pm 0.7$	BaBar	[1164]
		$D^+\pi^-$	$2460.4 \pm 1.2 \pm 2.2$	$41.8 \pm 2.5 \pm 2.9$	BaBar	[711]
		$D^+\pi^-$		$49.2 \pm 2.3 \pm 1.3$	CDF	[1261]
		$D^+\pi^-$	$2461.6 \pm 2.1 \pm 3.3$	$45.6 \pm 4.4 \pm 6.7$	Belle	[710]
		$D^+\pi^-$	$2464.5 \pm 1.1 \pm 1.9$	$38.7 \pm 5.3 \pm 2.9$	FOCUS	[1228]
		$D^+\pi^-$	$2465 \pm 3 \pm 3$	$28^{+8}_{-7} \pm 6$	CLEO	[1262]
		$D^+\pi^-$	$2453 \pm 3 \pm 2$	$25 \pm 10 \pm 5$	E687	[1246]
		$D^{*+}\pi^-$	$2461 \pm 3 \pm 1$	$20^{+9}_{-12}{}^{+9}_{-10}$	CLEO	[1249]
		$D^+\pi^-$	$2455 \pm 3 \pm 5$	15^{+13+5}_{-10-10}	ARGUS	[1266]
		$D^+\pi^-$	$2459 \pm 3 \pm 2$	$20 \pm 10 \pm 5$	TPS	[1264]
			2460.49 ± 0.17	47.52 ± 0.65	Our average	

Table 291 Recent measurements of mass and width for different excited D mesons. The column J^P list the most significant assignment of spin and parity. If possible an average mass or width is calculated

Resonance	J^P	Decay mode	Mass (MeV/c^2)	Width (MeV)	Measured by	References
$D_2^*(2460)^\pm$	2^+	$D^0\pi^+$	$2468.6 \pm 0.6 \pm 0.0 \pm 0.3$	$47.3 \pm 1.5 \pm 0.3 \pm 0.6$	LHCb	[602]
		$D^0\pi^+$	$2465.6 \pm 1.8 \pm 0.5 \pm 1.2$	$46.0 \pm 3.4 \pm 1.4 \pm 2.9$	LHCb	[1258]
		$D^0\pi^+$	$2463.1 \pm 0.2 \pm 0.6$	$48.6 \pm 1.3 \pm 1.9$	LHCb	[1165]
		$D^{*0}\pi^+$, $D^0\pi^+$	$2460.6 \pm 4.4^{+3.6}_{-0.8}$		Zeus	[1260]
		$D^0\pi^+$	$2465.4 \pm 0.2 \pm 1.1$		BaBar	[1164]
		$D^0\pi^+$	$2465.7 \pm 1.8^{+1.4}_{-4.8}$	$49.7 \pm 3.8 \pm 6.4$	Belle	[1259]
		$D^0\pi^+$	$2467.6 \pm 1.5 \pm 0.8$	$34.1 \pm 6.5 \pm 4.2$	FOCUS	[1228]
		$D^0\pi^+$	$2463 \pm 3 \pm 3$	$27^{+11}_{-8} \pm 5$	CLEO	[1265]
		$D^0\pi^+$	$2453 \pm 3 \pm 2$	$23 \pm 9 \pm 5$	E687	[1246]
		$D^0\pi^+$	$2469 \pm 4 \pm 6$		ARGUS	[1267]
			2465.55 ± 0.40	46.7 ± 1.2	Our average	
$D(2550)^0$	0^-	$D^{*+}\pi^-$	$2539.4 \pm 4.5 \pm 6.8$	$130 \pm 12 \pm 13$	BaBar	[1164]
$D(2580)^0$	Unnatural	$D^{*+}\pi^-$	$2579.5 \pm 3.4 \pm 5.5$	$117.5 \pm 17.8 \pm 46.0$	LHCb	[1165]
$D(2600)^0$	Natural	$D^+\pi^-$	$2608.7 \pm 2.4 \pm 2.5$	$93 \pm 6 \pm 13$	BaBar	[1164]
$D(2600)^\pm$	Natural	$D^0\pi^+$	$2621.3 \pm 3.7 \pm 4.2$		BaBar	[1164]
$D^*(2640)^\pm$	1^-	$D^{*+}\pi^+\pi^-$	$2637 \pm 2 \pm 6$		Delphi	[1268]
$D^*(2650)^0$	Natural	$D^{*+}\pi^-$	$2649.2 \pm 3.5 \pm 3.5$	$140.2 \pm 17.1 \pm 18.6$	LHCb	[1165]
$D(2740)^0$	Unnatural	$D^{*+}\pi^-$	$2737.0 \pm 3.5 \pm 11.2$	$73.2 \pm 13.4 \pm 25.0$	LHCb	[1165]
$D(2750)^0$		$D^{*+}\pi^-$	$2752.4 \pm 1.7 \pm 2.7$	$71 \pm 6 \pm 11$	BaBar	[1164]
$D_1^*(2760)^0$	1^+	$D^+\pi^-$	$2781 \pm 18 \pm 11 \pm 6$	$177 \pm 32 \pm 20 \pm 7$	LHCb	[716]
		$D^{*+}\pi^-$	$2761.1 \pm 5.1 \pm 6.5$	$74.4 \pm 3.4 \pm 37.0$	LHCb	[1165]
		$D^+\pi^-$	$2760.1 \pm 1.1 \pm 3.7$	$74.4 \pm 3.4 \pm 19.1$	LHCb	[1165]
		$D^+\pi^-$	$2763.3 \pm 2.3 \pm 2.3$	$60.9 \pm 5.1 \pm 3.6$	BaBar	[1164]
			2762.1 ± 2.4	65.1 ± 5.8	Our average	
$D_3^*(2760)^\pm$	3^-	$D^0\pi^+$	$2798 \pm 7 \pm 1 \pm 7$	$105 \pm 18 \pm 6 \pm 23$	LHCb	[602]
		$D^0\pi^+$	$2771.7 \pm 1.7 \pm 3.8$	$66.7 \pm 6.6 \pm 10.5$	LHCb	[1165]
		$D^0\pi^+$	$2769.7 \pm 3.8 \pm 1.5$		BaBar	[1164]
			2773.9 ± 3.3	72.3 ± 11.5	Our average	

Table 292 Product of B meson branching fraction and (daughter) excited D meson branching fraction

Resonance	Decay	$\mathcal{B}\,[10^{-4}]$	Measured by	References
$D_0^*(2400)^0$	$B^- \to D_0^*(2400)^0(\to D^+\pi^-)\pi^-$	$6.1 \pm 0.6 \pm 1.8$	Belle	[710]
		$6.8 \pm 0.3 \pm 2.0$	BaBar	[711]
		6.4 ± 1.4	Our average	
	$B^- \to D_0^*(2400)^0(\to D^+\pi^-)K^-$	$0.061 \pm 0.019 \pm 0.005 \pm 0.014 \pm 0.004$	LHCb	[716]
$D_0^*(2400)^\pm$	$\overline{B}^0 \to D_0^*(2400)^+(\to D^0\pi^+)\pi^-$	$0.77 \pm 0.05 \pm 0.03 \pm 0.03 \pm 0.04$	LHCb	[602]
		$0.60 \pm 0.13 \pm 0.27$	Belle	[1259]
		0.76 ± 0.07	Our average	
	$\overline{B}^0 \to D_0^*(2400)^+(\to D^0\pi^+)K^-$	$0.177 \pm 0.026 \pm 0.019 \pm 0.067 \pm 0.20$	LHCb	[1258]
$D_1(2420)^0$	$B^- \to D_1(2420)^0(\to D^{*+}\pi^-)\pi^-$	$6.8 \pm 0.7 \pm 1.3$	Belle	[710]
	$B^- \to D_1(2420)^0(\to D^0\pi^+\pi^-)\pi^-$	$1.85 \pm 0.29 \pm 0.27 \pm 0.41$	Belle	[622]
	$\overline{B}^0 \to D_1(2420)^0(\to D^{*+}\pi^-)\omega$	$0.7 \pm 0.2^{+0.1}_{-0.0} \pm 0.1$	Belle	[598]
$D_1(2420)^\pm$	$\overline{B}^0 \to D_1(2420)^+(\to D^+\pi^-\pi^+)\pi^-$	$0.89 \pm 0.15 \pm 0.22$	Belle	[622]
$D_1(2430)^0$	$B^- \to D_1(2430)^0(\to D^{*+}\pi^-)\pi^-$	$5.0 \pm 0.4 \pm 1.08$	Belle	[710]
	$\overline{B}^0 \to D_1(2430)^0(\to D^{*+}\pi^-)\omega$	$2.5 \pm 0.4^{+0.7+0.4}_{-0.2-0.1}$	Belle	[598]
$D_2^*(2460)^0$	$B^- \to D_2^*(2460)^0(\to D^+\pi^-)\pi^-$	$3.4 \pm 0.3 \pm 0.7$	Belle	[710]
		$3.5 \pm 0.2 \pm 0.5$	BaBar	[711]
		3.4 ± 0.3	Our average	
	$B^- \to D_2^*(2460)^0(\to D^{*+}\pi^-)\pi^-$	$1.8 \pm 0.3 \pm 0.4$	Belle	[710]
	$B^- \to D_2^*(2460)^0(\to D^{*+}\pi^-)\omega$	$0.4 \pm 0.1^{+0.0}_{-0.1} \pm 0.1$	Belle	[598]
	$B^- \to D_2^*(2460)^0(\to D^+\pi^-)K^-$	$0.232 \pm 0.011 \pm 0.006 \pm 0.010 \pm 0.016$	LHCb	[716]
$D_2^*(2460)^\pm$	$\overline{B}^0 \to D_2^*(2460)^+(\to D^0\pi^+)\pi^-$	$2.44 \pm 0.07 \pm 0.10 \pm 0.04 \pm 0.12$	LHCb	[602]
		$2.15 \pm 0.17 \pm 0.31$	Belle	[1259]
		2.38 ± 0.16	Our average	
	$\overline{B}^0 \to D_2^*(2460)^+(\to D^0\pi^+)K^-$	$0.212 \pm 0.010 \pm 0.011 \pm 0.011 \pm 0.25$	LHCb	[1258]
$D_1^*(2760)^0$	$B^- \to D_1^*(2760)^0(\to D^+\pi^-)K^-$	$0.036 \pm 0.009 \pm 0.003 \pm 0.007 \pm 0.002$	LHCb	[716]
$D_3^*(2760)^\pm$	$\overline{B}^0 \to D_3^*(2760)^0(\to D^0\pi^+)\pi^-$	$0.103 \pm 0.016 \pm 0.007 \pm 0.008 \pm 0.005$	LHCb	[602]

and charged, are well-established. Measurements of broad states ($\Gamma \sim 200$–400 MeV) are less abundant, as identifying the signal is more challenging. There is a slight discrepancy between the $D_0^*(2400)^0$ masses measured by the Belle [710] and FOCUS [1228] experiments. No data exist yet for the $D_1(2430)^\pm$ state. Dalitz plot analyses of $B \to \overline{D}^{(*)}\pi\pi$ decays strongly favor the assignments 0^+ and 1^+ for the spin-parity quantum numbers of the $D_0^*(2400)^0/D_0^*(2400)^\pm$ and $D_1(2430)^0$ states, respectively. The measured masses and widths, as well as the J^P values, are in agreement with theoretical predictions based on potential models [496,1229–1231].

Tables 292 and 293 summarize the branching fractions of B meson decays to excited D and D_s states, respectively. It is notable that the branching fractions for B mesons decaying to a narrow D^{**} state and a pion are similar for charged and neutral B initial states, while the branching fractions to a broad D^{**} state and π^+ are much larger for B^+ than for B^0. This may be due to the fact that color-suppressed amplitudes contribute only to the B^+ decay and not to the B^0 decay (for a theoretical discussion, see Refs. [1232,1233]). Measurements of individual branching fractions of D mesons are difficult due to the unknown fragmentation of a c quark to D^{**} or due to the unknown $B \to D^{**}X$ branching fractions.

The discoveries of the $D_{s0}^*(2317)^\pm$ and $D_{s1}(2460)^\pm$ have triggered increased interest in properties of, and searches for, excited D_s mesons (here generically denoted D_s^{**}). While the masses and widths of $D_{s1}(2536)^\pm$ and $D_{s2}^*(2573)^\pm$ states are in relatively good agreement with potential model predictions, the masses of $D_{s0}^*(2317)^\pm$ and $D_{s1}(2460)^\pm$ states are significantly lower than expected (see Ref. [1234] for a discussion of $c\bar{s}$ models). Moreover, the mass splitting between these two states greatly exceeds that between the $D_{s1}(2536)^\pm$ and $D_{s2}(2573)^\pm$. These unexpected properties have led to interpretations of the $D_{s0}^*(2317)^\pm$ and $D_{s1}(2460)^\pm$ as exotic four-quark states [1235,1236].

While there are few measurements of the J^P values of $D_{s0}^*(2317)^\pm$ and $D_{s1}(2460)^\pm$, the available data favor 0^+ and 1^+, respectively. A molecule-like (DK) interpre-

Table 293 Product of B meson branching fraction and (daughter) excited D_s meson branching fraction

Resonance	Decay	$\mathcal{B}\,[10^{-4}]$	Measured by	References
$D^*_{s0}(2317)^\pm$	$B^0 \to D^*_{s0}(2317)^+(\to D_s^+\pi^0)D^-$	$8.6^{+3.3}_{-2.6} \pm 2.6$	Belle	[640]
		$18.0 \pm 4.0^{+6.7}_{-5.0}$	BaBar	[641]
		$10.1^{+1.3}_{-1.2} \pm 1.0 \pm 0.4$	Belle	[642]
		10.2 ± 1.5	Our average	
	$B^+ \to D^*_{s0}(2317)^+(\to D_s^+\pi^0)\overline{D}^0$	$8.0^{+1.3}_{-1.2} \pm 1.0 \pm 0.4$	Belle	[642]
	$B^0 \to D^*_{s0}(2317)^+(\to D_s^+\pi^0)K^-$	$0.53^{+0.15}_{-0.13} \pm 0.16$	Belle	[623]
$D_{s1}(2460)^\pm$	$B^0 \to D_{s1}(2460)^+(\to D_s^{*+}\pi^0)D^-$	$22.7^{+7.3}_{-6.2} \pm 6.8$	Belle	[640]
		$28.0 \pm 8.0^{+11.2}_{-7.8}$	BaBar	[641]
		24.7 ± 7.6	Our average	
	$B^0 \to D_{s1}(2460)^+(\to D_s^{*+}\gamma)D^-$	$8.2^{+2.2}_{-1.9} \pm 2.5$	Belle	[640]
		$8.0 \pm 2.0^{+3.2}_{-2.3}$	BaBar	[641]
		8.1 ± 2.3	Our average	
	$D_{s1}(2460)^+ \to D_s^{*+}\pi^0$	$(56 \pm 13 \pm 9)\%$	BaBar	[635]
	$D_{s1}(2460)^+ \to D_s^{*+}\gamma$	$(16 \pm 4 \pm 3)\%$	BaBar	[635]
$D_{s1}(2536)^\pm$	$B^0 \to D_{s1}(2536)^+(\to D^{*0}K^+)D^-$	$1.71 \pm 0.48 \pm 0.32$	BaBar	[643]
	$B^0 \to D_{s1}(2536)^+(\to D^{*+}K^0)D^-$	$2.61 \pm 1.03 \pm 0.31$	BaBar	[643]
	$B^0 \to D_{s1}(2536)^+(\to D^{*0}K^+)D^{*-}$	$3.32 \pm 0.88 \pm 0.66$	BaBar	[643]
	$B^0 \to D_{s1}(2536)^+(\to D^{*+}K^0)D^{*-}$	$5.00 \pm 1.51 \pm 0.67$	BaBar	[643]
	$B^+ \to D_{s1}(2536)^+(\to D^{*0}K^+)\overline{D}^0$	$2.16 \pm 0.52 \pm 0.45$	BaBar	[643]
	$B^+ \to D_{s1}(2536)^+(\to D^{*+}K^0)\overline{D}^0$	$2.30 \pm 0.98 \pm 0.43$	BaBar	[643]
	$B^+ \to D_{s1}(2536)^+(\to D^{*0}K^+)\overline{D}^{*0}$	$5.46 \pm 1.17 \pm 1.04$	BaBar	[643]
	$B^+ \to D_{s1}(2536)^+(\to D^{*+}K^0)\overline{D}^{*0}$	$3.92 \pm 2.46 \pm 0.83$	BaBar	[643]
$D^*_{s2}(2573)^\pm$	$B^0 \to D^*_{s2}(2573)(\to D^0K^+)D^-$	$0.34 \pm 0.17 \pm 0.05$	BaBar	[1257]
	$B^+ \to D^*_{s2}(2573)(\to D^0K^+)\overline{D}^0$	$0.08 \pm 14 \pm 0.05$	BaBar	[1257]
$D_{s1}{}^*(2700)^\pm$	$B^+ \to D_{s1}{}^*(2700)^+(\to D^0K^+)\overline{D}^0$	$11.3 \pm 2.2^{+1.4}_{-2.8}$	Belle	[731]
		$5.02 \pm 0.71 \pm 0.93$	BaBar	[1257]
		5.83 ± 1.09	Our average	
	$B^0 \to D_{s1}{}^*(2700)^+(\to D^0K^+)D^-$	$7.14 \pm 0.96 \pm 0.69$	BaBar	[1257]

tation of the $D^*_{s0}(2317)^\pm$ and $D_{s1}(2460)^\pm$ [1235,1236] that can account for their low masses and isospin-breaking decay modes is tested by searching for charged and neutral isospin partners of these states; thus far such searches have yielded negative results. Therefore the subset of models that predict equal production rates for different charged states is excluded. The molecular picture can also be tested by measuring the rates for the radiative processes $D^*_{s0}(2317)^\pm/D_{s1}(2460)^\pm \to D_s^{(*)}\gamma$ and comparing to theoretical predictions. The predicted rates, however, are below the sensitivity of current experiments.

Another model successful in explaining the total widths and the $D^*_{s0}(2317)^\pm - D_{s1}(2460)^\pm$ mass splitting is based on the assumption that these states are chiral partners of the ground states D_s^+ and D_s^* [1237]. While some measured branching fraction ratios agree with predicted values, further experimental tests with better sensitivity are needed to confirm or refute this scenario. A summary of the mass difference measurements is given in Table 294.

Measurements by BaBar [1238] and LHCb [1239] first indicated the existence of a strange-charm $D^*_{sJ}(2860)^\pm$ meson. An LHCb study of $B_s^0 \to \overline{D}^0K^-\pi^+$ decays, in which they searched for excited D_s mesons [1240], showed with 10σ significance that this state is comprised of two different particles, one of spin 1 and one of spin 3. This represents the first measurement of a heavy flavored spin-3 particle, and the first observation of B meson decays to spin 3 particles. A subsequent study of D_{sJ} mesons by the LHCb collaboration [1241] supports the natural parity assignment for this state ($J^P = 3^-$). This study also shows weak evidence for a further structure at a mass around 3040 MeV/c^2 with unnatural parity, which was first hinted at by a BaBar analysis [1238].

Table 294 Mass difference measurements for excited D mesons

Resonance	Relative to	Δm (MeV/c^2)	Measured by	References
$D_1^*(2420)^0$	D^{*+}	$410.2 \pm 2.1 \pm 0.9$	Zeus	[1269]
		$411.7 \pm 0.7 \pm 0.4$	CDF	[1261]
		411.5 ± 0.8	Our average	
$D_1(2420)^\pm$	$D_1^*(2420)^0$	$4^{+2}_{-3} \pm 3$	CLEO	[1265]
$D_2^*(2460)^0$	D^+	$593.9 \pm 0.6 \pm 0.5$	CDF	[1261]
	D^{*+}	$458.8 \pm 3.7^{+1.2}_{-1.3}$	Zeus	[1269]
$D_2^*(2460)^\pm$	$D_2^*(2460)^0$	$3.1 \pm 1.9 \pm 0.9$	FOCUS	[1228]
		$-2 \pm 4 \pm 4$	CLEO	[1265]
		$14 \pm 5 \pm 8$	ARGUS	[1267]
		3.0 ± 1.9	Our average	
$D_{s0}^*(2317)^\pm$	$D_s^\pm$	$348.7 \pm 0.5 \pm 0.7$	Belle	[1226]
		$350.0 \pm 1.2 \pm 1.0$	CLEO	[1225]
		$351.3 \pm 2.1 \pm 1.9$	Belle	[640]
		349.2 ± 0.7	Our average	
$D_{s1}(2460)^\pm$	$D_s^{*\pm}$	$344.1 \pm 1.3 \pm 1.1$	Belle	[1226]
		$351.2 \pm 1.7 \pm 1.0$	CLEO	[1225]
		$346.8 \pm 1.6 \pm 1.9$	Belle	[640]
		347.1 ± 1.1	Our average	
	$D_s^\pm$	$491.0 \pm 1.3 \pm 1.9$	Belle	[1226]
		$491.4 \pm 0.9 \pm 1.5$	Belle	[1226]
		491.3 ± 1.4	Our average	
$D_{s1}(2536)^\pm$	$D^*(2010)^\pm$	$524.83 \pm 0.01 \pm 0.04$	BaBar	[1251]
		$525.30^{+0.44}_{-0.41} \pm 0.10$	Zeus	[1269]
		$525.3 \pm 0.6 \pm 0.1$	ALEPH	[1270]
		524.84 ± 0.04	Our average	
	$D^*(2007)^0$	$528.7 \pm 1.9 \pm 0.5$	ALEPH	[1270]
$D_{s2}^*(2573)^\pm$	D^0	$704 \pm 3 \pm 1$	ALEPH	[1270]

Recent evidence shows that the 1D family of charm resonances can be explored in the Dalitz plot analyses of B-meson decays in the same way as seen for the charm-strange resonances. The LHCb collaboration performed an analysis of $B^0 \to \overline{D}^0\pi^+\pi^-$ decays, in which they measured the spin-parity assignment of the state $D_3^*(2760)^\pm$, which was observed previously by BaBar [1164] and LHCb [1165], to be $J^P = 3^-$. The measurement suggests a spectroscopic assignment of $^3D_3$. This is the second observation of a spin-3 charm meson.

Other observed excited D_s states include $D_{s1}^*(2700)^\pm$ and $D_{s2}^*(2573)^\pm$. The properties of both (mass, width, J^P) have been measured and determined in several analyses. A theoretical discussion [1242] investigates the possibility that the $D_{s1}(2700)^\pm$ could represent radial excitations of the $D_s^{*\pm}$. Similarly, the $D_{s1}^*(2860)^\pm$ and $D_{sJ}(3040)^\pm$ could be excitations of $D_{s0}^*(2317)^\pm$ and $D_{s1}(2460)^\pm$ or $D_{s1}(2536)^\pm$, respectively.

Table 295 Measurements of polarization amplitudes for excited D mesons

Resonance	A_D	Measured by	References
$D_1(2420)^0$	$7.8^{+6.7+4.6}_{-2.7-1.8}$	ZEUS	[1260]
	5.72 ± 0.25	BaBar	[1164]
	$5.9^{+3.0+2.4}_{-1.7-1.0}$	ZEUS	[1269]
	$3.8 \pm 0.6 \pm 0.8$	BaBar	[502]
	5.61 ± 0.24	Our average	
$D_1(2420)^\pm$	$3.8 \pm 0.6 \pm 0.8$	BaBar	[502]
$D_2^*(2460)^0$	-1.16 ± 0.35	ZEUS	[1260]
$D(2750)^0$	-0.33 ± 0.28	BaBar	[1164]

Table 295 summarizes measurements of the helicity parameter A_D (also referred to as polarization amplitude). In D^{**} meson decays to $D^{**} \to D^*\pi$, $D^* \to D\pi$, the helicity distribution varies like $1 + A_D \cos^2\theta_H$, where θ_H is

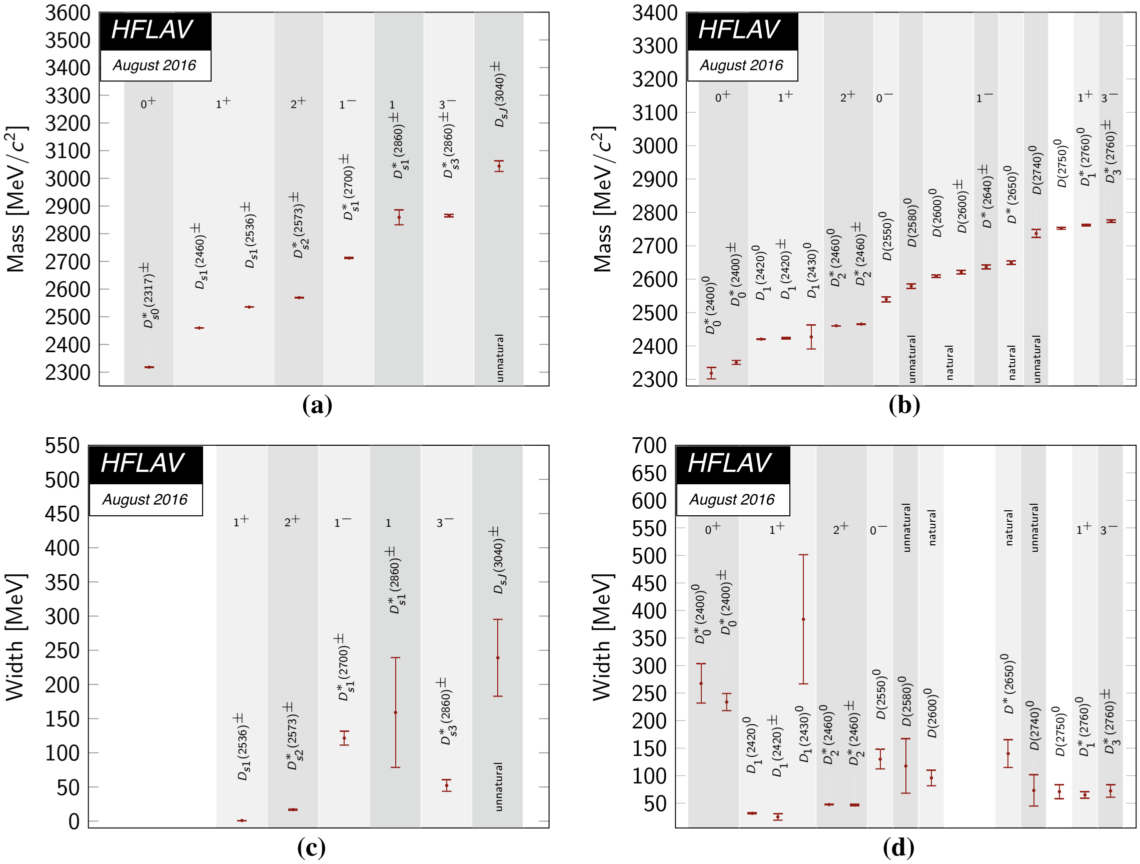


Fig. 213 Averaged masses for excited D_s mesons are shown in (**a**) and for D mesons in (**b**). The average widths for excited D_s mesons are shown in (**c**) and for excited D mesons in (**d**). The *vertical shaded regions* distinguish between different spin parity states

the angle in the D^* rest frame between the two pions emitted by decay $D^{**} \to D^*\pi$ and the $D^* \to D\pi$. The parameter is sensitive to possible S-wave contributions in the decay. In the case of a D meson decay decaying purely via D-wave, the helicity parameter is predicted to give $A_D = 3$. Studies of the $D_1(2420)^0$ meson by the ZEUS and BABAR collaborations suggest that there is an S-wave admixture in the decay, which is contrary to Heavy Quark Effective Theory calculations [476,1243].

8.10 Λ_c^+ branching fractions

Charmed baryon decays play an important role in studies of weak and strong interactions. For example, they provide crucial input for measurements of exclusive and inclusive decay rates of b-flavored mesons and baryons, and also for measurements of fragmentation fractions of charm and bottom quarks. In spite of this importance, experimental data on Λ_c^+ baryon decays was scarce until 2014, when Belle published the first model-independent measurement of the branching fraction for $\Lambda_c^+ \to pK^-\pi^+$ [1271]. This measurement improved upon the precision of previous (model-dependent) measurements by a factor of five. Since then the precision of other Λ_c^+ branching fractions has improved due to measurements based on threshold data performed by BESIII [531]. BESIII also reported the first measurement of the branching fraction for the semileptonic decay $\Lambda_c^+ \to \Lambda e^+ \nu_e$ [1272]. Here we present a global fit for branching fractions of Cabbibo-favored Λ_c^+ decays, taking into account all relevant experimental measurements and their correlations. All measurements used assume unpolarised production of the Λ_c^+.

The measurements listed in Table 296 are input to a least-squares fit minimizing a χ^2 statistic. The fitted quantities are the Λ_c^+ branching fractions for twelve hadronic modes and one semileptonic mode. The measurements are labelled using the Γ_n notation employed by the Particle Data Group [6], where n is an integer that specifies the decay mode. The fitted output consists of 13 quantities – twelve hadronic and one semileptonic branching fraction. The advantage of our fit is that it takes into account correlations among measurements from the same experiment, i.e., systematic uncertainties related to normalization, track-finding efficiency, particle identification efficiency, and π^0, K_S^0, and Λ reconstruction efficiencies. For the twelve hadronic branching fractions

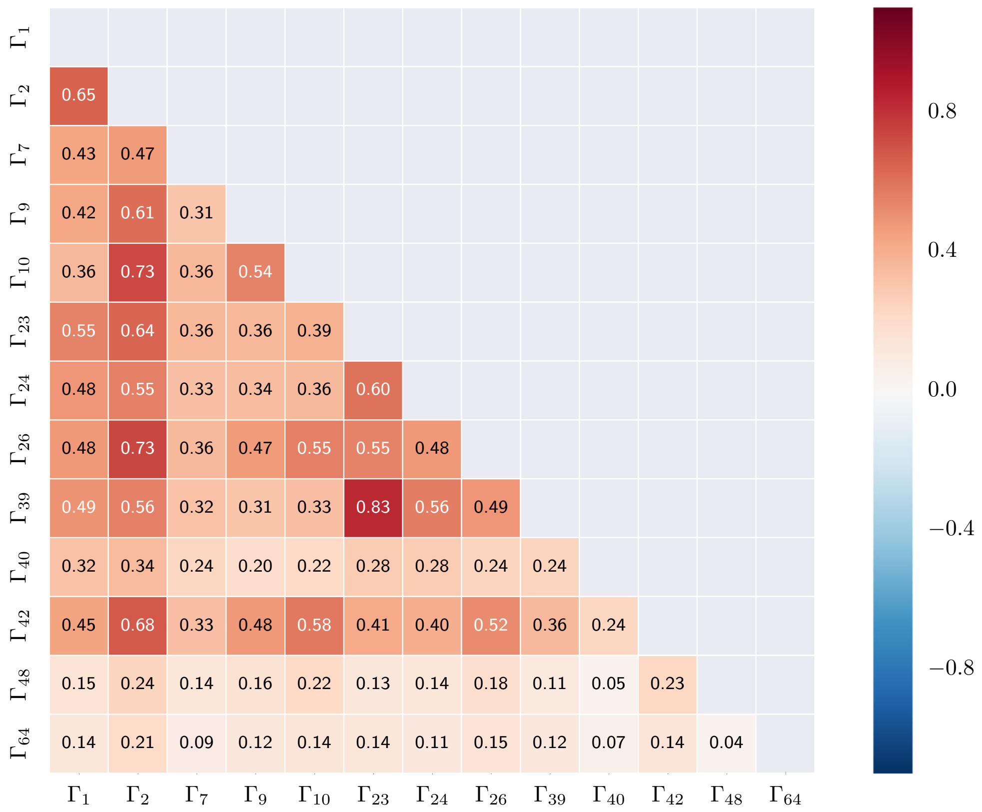
Table 296 Experimental results and world averages for branching fractions of twelve hadronic and one semileptonic Λ_c^+ decay. The first uncertainty is statistical and the second is systematic

Λ_c^+ branching fraction	Value	References
$\Gamma_1 = pK^0_S$	$(1.59 \pm 0.07)\%$	HFLAV Fit
BESIII	$(1.52 \pm 0.08 \pm 0.03)\%$	[531]
$\frac{\Gamma_1}{\Gamma_2} = \frac{pK^0_S}{pK^-\pi^+}$	0.246 ± 0.009	HFLAV Fit
CLEO	$0.22 \pm 0.04 \pm 0.03$	[1273]
CLEO	$0.23 \pm 0.01 \pm 0.02$	[1274]
$\Gamma_2 = pK^-\pi^+$	$(6.46 \pm 0.24)\%$	HFLAV Fit
Belle	$(6.84 \pm 0.24^{+0.21}_{-0.27})\%$	[1271]
BESIII	$(5.84 \pm 0.27 \pm 0.23)\%$	[531]
$\Gamma_7 = pK^0_S\pi^0$	$(2.03 \pm 0.12)\%$	HFLAV Fit
BESIII	$(1.87 \pm 0.13 \pm 0.05)\%$	[531]
$\frac{\Gamma_7}{\Gamma_2} = \frac{pK^0_S\pi^0}{pK^-\pi^+}$	0.314 ± 0.017	HFLAV Fit
CLEO	$0.33 \pm 0.03 \pm 0.04$	[1274]
$\Gamma_9 = pK^0_S\pi^+\pi^-$	$(1.69 \pm 0.11)\%$	HFLAV Fit
BESIII	$(1.53 \pm 0.11 \pm 0.09)\%$	[531]
$\frac{\Gamma_9}{\Gamma_2} = \frac{pK^0_S\pi^+\pi^-}{pK^-\pi^+}$	0.261 ± 0.013	HFLAV Fit
CLEO	$0.22 \pm 0.06 \pm 0.02$	[1273]
CLEO	$0.26 \pm 0.02 \pm 0.03$	[1274]
$\Gamma_{10} = pK^-\pi^+\pi^0$	$(5.05 \pm 0.29)\%$	HFLAV Fit
BESIII	$(4.53 \pm 0.23 \pm 0.30)\%$	[531]
$\frac{\Gamma_{10}}{\Gamma_2} = \frac{pK^-\pi^+\pi^0}{pK^-\pi^+}$	0.781 ± 0.031	HFLAV Fit
CLEO	$0.67 \pm 0.04 \pm 0.11$	[1274]
$\Gamma_{23} = \Lambda\pi^+$	$(1.28 \pm 0.06)\%$	HFLAV Fit
BESIII	$(1.24 \pm 0.07 \pm 0.03)\%$	[531]
$\frac{\Gamma_{23}}{\Gamma_2} = \frac{\Lambda\pi^+}{pK^-\pi^+}$	0.198 ± 0.008	HFLAV Fit
CLEO	$0.18 \pm 0.03 \pm 0.03$	[1273]
ARGUS	$0.18 \pm 0.03 \pm 0.04$	[1275]
FOCUS	$0.217 \pm 0.013 \pm 0.020$	[1276]
$\Gamma_{24} = \Lambda\pi^+\pi^0$	$(7.09 \pm 0.36)\%$	HFLAV Fit
BESIII	$(7.01 \pm 0.37 \pm 0.19)\%$	[531]
$\frac{\Gamma_{24}}{\Gamma_2} = \frac{\Lambda\pi^+\pi^0}{pK^-\pi^+}$	1.10 ± 0.05	HFLAV Fit
CLEO	$0.73 \pm 0.09 \pm 0.16$	[1277]
$\Gamma_{26} = \Lambda\pi^+\pi^-\pi^+$	$(3.73 \pm 0.21)\%$	HFLAV Fit
BESIII	$(3.81 \pm 0.24 \pm 0.18)\%$	[531]
$\frac{\Gamma_{26}}{\Gamma_2} = \frac{\Lambda\pi^+\pi^-\pi^+}{pK^-\pi^+}$	0.577 ± 0.022	HFLAV Fit
CLEO	$0.65 \pm 0.11 \pm 0.12$	[1273]
FOCUS	$0.508 \pm 0.024 \pm 0.024$	[1276]
ARGUS	$0.61 \pm 0.16 \pm 0.04$	[1278]
$\Gamma_{39} = \Sigma^0\pi^+$	$(1.31 \pm 0.07)\%$	HFLAV Fit
BESIII	$(1.27 \pm 0.08 \pm 0.03)\%$	[531]
$\frac{\Gamma_{39}}{\Gamma_2} = \frac{\Sigma^0\pi^+}{pK^-\pi^+}$	0.202 ± 0.009	HFLAV Fit
CLEO	$0.21 \pm 0.02 \pm 0.04$	[1277]
ARGUS	$0.17 \pm 0.06 \pm 0.04$	[1275]
$\frac{\Gamma_{39}}{\Gamma_{23}} = \frac{\Sigma^0\pi^+}{\Lambda\pi^+}$	1.02 ± 0.03	HFLAV Fit
FOCUS	$1.09 \pm 0.11 \pm 0.19$	[1276]
BABAR	$0.997 \pm 0.015 \pm 0.051$	[1279]
$\Gamma_{40} = \Sigma^+\pi^0$	$(1.25 \pm 0.09)\%$	HFLAV Fit
BESIII	$(1.18 \pm 0.10 \pm 0.03)\%$	[531]
$\frac{\Gamma_{40}}{\Gamma_2} = \frac{\Sigma^+\pi^0}{pK^-\pi^+}$	0.193 ± 0.014	HFLAV Fit
CLEO	$0.20 \pm 0.03 \pm 0.03$	[1280]
$\Gamma_{42} = \Sigma^+\pi^+\pi^-$	$(4.64 \pm 0.24)\%$	HFLAV Fit
BESIII	$(4.25 \pm 0.24 \pm 0.20)\%$	[531]
$\frac{\Gamma_{42}}{\Gamma_2} = \frac{\Sigma^+\pi^+\pi^-}{pK^-\pi^+}$	0.719 ± 0.028	HFLAV Fit
CLEO	$0.74 \pm 0.07 \pm 0.09$	[1280]
$\Gamma_{48} = \Sigma^+\omega$	$(1.77 \pm 0.21)\%$	HFLAV Fit
BESIII	$(1.56 \pm 0.20 \pm 0.07)\%$	[531]
$\frac{\Gamma_{48}}{\Gamma_2} = \frac{\Sigma^+\omega}{pK^-\pi^+}$	0.274 ± 0.031	HFLAV Fit
CLEO	$0.54 \pm 0.13 \pm 0.06$	[1280]
$\Gamma_{64} = \Lambda e^+\nu_e$	$(3.18 \pm 0.32)\%$	HFLAV Fit
BESIII	$(3.63 \pm 0.38 \pm 0.20)\%$	[1272]
$\frac{\Gamma_{64}}{\Gamma_2} = \frac{\Lambda e^+\nu_e}{pK^-\pi^+}$	0.492 ± 0.049	HFLAV Fit
CLEO	0.43 ± 0.08	[1281]
ARGUS	0.36 ± 0.14	[1282]

measured by BESIII, we use BESIII's published correlation matrix [531].

The resulting fitted values for the branching fractions are given in Table 296. The overall χ^2 of the fit is 30.0 for 23 degrees of freedom, which corresponds to a p value of 0.149. The correlation matrix for the fitted branching fractions is shown in Fig. 214, and constraints from individual measurements for pairs of fitted branching fractions are shown in Fig. 215. The branching fraction of the normalisation decay $\Lambda_c^+ \to pK^-\pi^+$ is found to be

$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (6.46 \pm 0.24)\%.$$



	Γ_1	Γ_2	Γ_7	Γ_9	Γ_{10}	Γ_{23}	Γ_{24}	Γ_{26}	Γ_{39}	Γ_{40}	Γ_{42}	Γ_{48}	Γ_{64}
Γ_1													
Γ_2	0.65												
Γ_7	0.43	0.47											
Γ_9	0.42	0.61	0.31										
Γ_{10}	0.36	0.73	0.36	0.54									
Γ_{23}	0.55	0.64	0.36	0.36	0.39								
Γ_{24}	0.48	0.55	0.33	0.34	0.36	0.60							
Γ_{26}	0.48	0.73	0.36	0.47	0.55	0.55	0.48						
Γ_{39}	0.49	0.56	0.32	0.31	0.33	0.83	0.56	0.49					
Γ_{40}	0.32	0.34	0.24	0.20	0.22	0.28	0.28	0.24	0.24				
Γ_{42}	0.45	0.68	0.33	0.48	0.58	0.41	0.40	0.52	0.36	0.24			
Γ_{48}	0.15	0.24	0.14	0.16	0.22	0.13	0.14	0.18	0.11	0.05	0.23		
Γ_{64}	0.14	0.21	0.09	0.12	0.14	0.14	0.11	0.15	0.12	0.07	0.14	0.04	

Fig. 214 Correlation coefficients between averaged Λ_c^+ branching fractions

8.11 Excited charm baryons

In this section we summarize the present status of excited charmed baryons, decaying strongly or electromagnetically. We list their masses (or the mass difference between the excited baryon and the corresponding ground state), natural widths, decay modes, and assigned quantum numbers. The present ground-state measurements are: $M(\Lambda_c^+) = 2286.46 \pm 0.14\ \mathrm{MeV}/c^2$ measured by BABAR [1283], $M(\Xi_c^0) = (2470.85^{+0.28}_{-0.04})\ \mathrm{MeV}/c^2$ and $M(\Xi_c^+) = (2467.93^{+0.28}_{-0.40})\ \mathrm{MeV}/c^2$, both dominated by CDF [145], and $M(\Omega_c^0) = (2695.2 \pm 1.7)\ \mathrm{MeV}/c^2$, dominated by Belle [1284]. Should these values change, so will some of the values for the masses of the excited states.

Table 297 summarizes the excited Λ_c^+ baryons. The first two states listed, namely the $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$, are well-established. The measured masses and decay patterns suggest that they are orbitally excited Λ_c^+ baryons with total angular momentum of the light quarks $L = 1$. Thus their quantum numbers are assigned to be $J^P = (\frac{1}{2})^-$ and $J^P = (\frac{3}{2})^-$, respectively. Their mass measurements are dominated by CDF [1285]: $M(\Lambda_c(2595)^+) = (2592.25 \pm 0.24 \pm 0.14)\ \mathrm{MeV}/c^2$ and $M(\Lambda_c(2625)^+) = (2628.11 \pm 0.13 \pm 0.14)\ \mathrm{MeV}/c^2$. Earlier measurements did not fully take into account the restricted phase-space of the $\Lambda_c(2595)^+$ decays.

The next two states, $\Lambda_c(2765)^+$ and $\Lambda_c(2880)^+$, were discovered by CLEO [1286] in the $\Lambda_c^+\pi^+\pi^-$ final state. CLEO found that a significant fraction of the $\Lambda_c(2880)^+$ decays proceeds via an intermediate $\Sigma_c(2445)^{++/0}\pi^{-/+}$. Later, BABAR [1287] observed that this state has also a $D^0 p$ decay mode. This was the first example of an excited charmed baryon decaying into a charm meson plus a baryon; previously all excited charmed baryon were found in their hadronic transitions into lower lying charmed baryons. In the same analysis, BABARobserved for the first time an additional state, $\Lambda_c(2940)^+$, decaying into $D^0 p$. Studying the $D^+ p$ final state, BABAR found no signal; this implies that the $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ are Λ_c^+ excited states rather than Σ_c excitations. Belle reported the result of an angular analysis that favors 5/2 for the $\Lambda_c(2880)^+$ spin hypothesis. Moreover, the measured ratio of branching fractions $\mathcal{B}(\Lambda_c(2880)^+ \to \Sigma_c(2520)\pi^\pm)/\mathcal{B}(\Lambda_c(2880)^+ \to \Sigma_c(2455)\pi^\pm) = (0.225 \pm 0.062 \pm 0.025)$, combined with theoretical predictions based on HQS [496,1288], favor even parity. However this prediction is only valid if the P-wave portion of $\Sigma_c(2520)\pi$ is suppressed. The current open questions in the excited Λ_c^+ family include the determination of quantum numbers for the other states, and the nature of the $\Lambda_c(2765)^+$ state, in particular whether it is an excited Σ_c^+ or Λ_c^+. However, there is no doubt that the state exists, as it is clearly visible in Belle data.

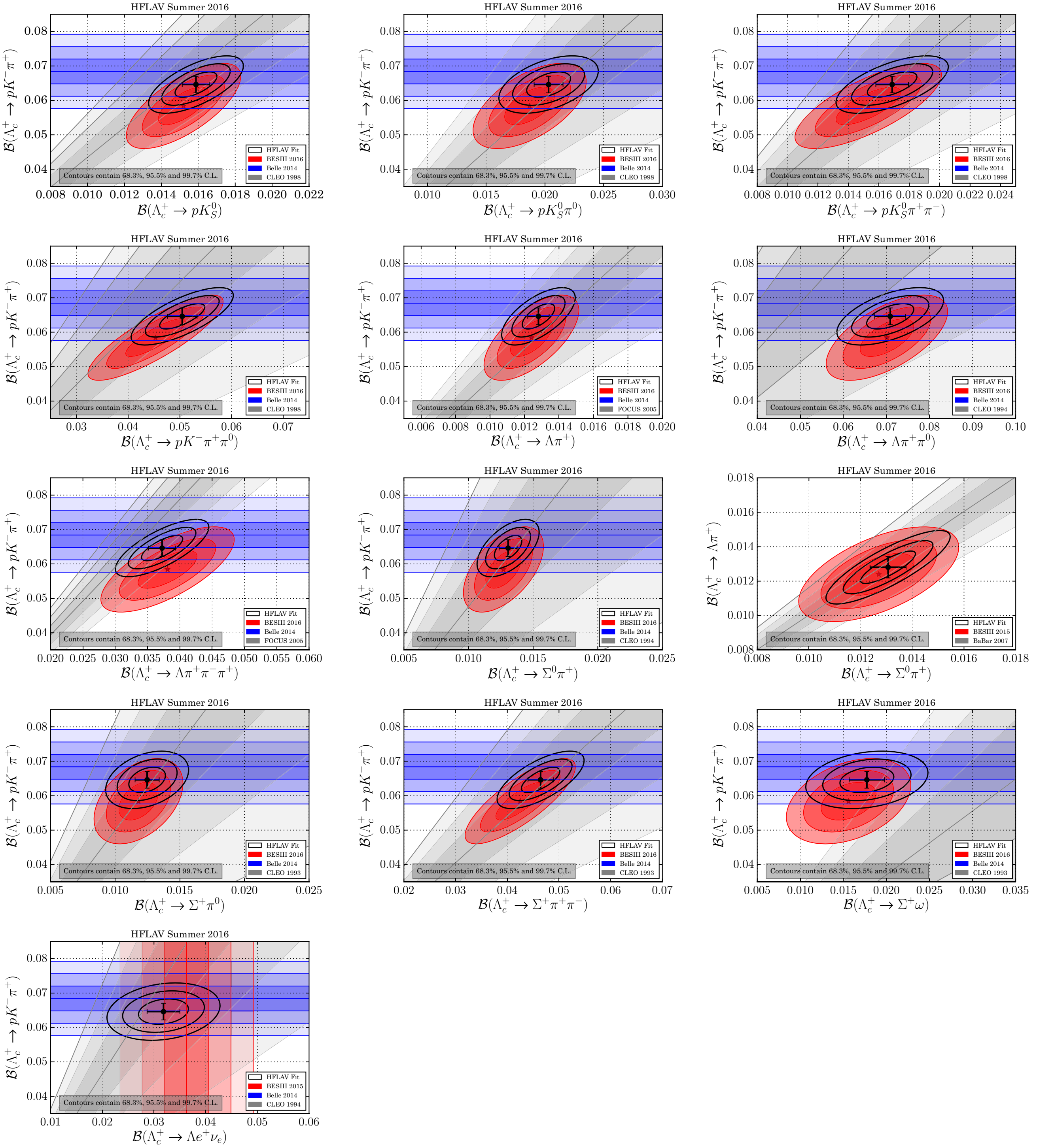


Fig. 215 Plots of all individual measurements and the fitted averages. Individual measurements are plotted as bands (*ellipses*) showing their $\pm 1\sigma$, $\pm 2\sigma$, and $\pm 3\sigma$ ranges. The best fit value is indicated by a *cross* showing the one-dimensional errors. In cases where multiple ratio measurements exists (Γ_i / Γ_j), only the most precise one is plotted

Table 297 Summary of excited Λ_c^+ baryons

Charmed baryon excited state	Mode	Mass (MeV/c^2)	Natural width (MeV)	J^P
$\Lambda_c(2595)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c(2455)\pi$	2592.25 ± 0.28	$2.59 \pm 0.30 \pm 0.47$	$1/2^-$
$\Lambda_c(2625)^+$	$\Lambda_c^+\pi^+\pi^-$	2628.11 ± 0.19	<0.97	$3/2^-$
$\Lambda_c(2765)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c(2455)\pi$	2766.6 ± 2.4	50	?
$\Lambda_c(2880)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c(2455)\pi$, $\Sigma_c(2520)\pi$, D^0p	2881.53 ± 0.35	5.8 ± 1.1	$5/2^+$
$\Lambda_c(2940)^+$	D^0p, $\Sigma_c(2455)\pi$	$2939.3^{+1.4}_{-1.5}$	17^{+8}_{-6}	?

Table 298 Summary of the excited $\Sigma_c^{++,+,0}$ baryon family

Charmed baryon excited state	Mode	ΔM (MeV/c^2)	Natural width (MeV)	J^P
$\Sigma_c(2455)^{++}$	$\Lambda_c^+\pi^+$	167.510 ± 0.17	$1.89^{+0.09}_{-0.18}$	$1/2^+$
$\Sigma_c(2455)^+$	$\Lambda_c^+\pi^0$	166.4 ± 0.4	<4.6 @ 90% C.L.	$1/2^+$
$\Sigma_c(2455)^0$	$\Lambda_c^+\pi^-$	167.29 ± 0.17	$1.83^{+0.11}_{-0.19}$	$1/2^+$
$\Sigma_c(2520)^{++}$	$\Lambda_c^+\pi^+$	$231.95^{+0.17}_{-0.12}$	$14.78^{+0.30}_{-0.40}$	$3/2^+$
$\Sigma_c(2520)^+$	$\Lambda_c^+\pi^0$	231.0 ± 2.3	<17 @ 90% C.L.	$3/2^+$
$\Sigma_c(2520)^0$	$\Lambda_c^+\pi^-$	$232.02^{+0.15}_{-0.14}$	$15.3^{+0.4}_{-0.5}$	$3/2^+$
$\Sigma_c(2800)^{++}$	$\Lambda_c^+\pi^+$	514^{+4}_{-6}	75^{+18+12}_{-13-11}	$3/2^-$?
$\Sigma_c(2800)^+$	$\Lambda_c^+\pi^0$	505^{+15}_{-5}	62^{+37+52}_{-23-38}	
$\Sigma_c(2800)^0$	$\Lambda_c^+\pi^-$	519^{+5}_{-7}	72^{+22}_{-15}	
	$\Lambda_c^+\pi^-$	$560 \pm 8 \pm 10$	86^{+33}_{-22}	

Table 299 Summary of excited $\Xi_c^{+,0}$ and Ω_c^0 baryon families. For the first four iso-doublets, the mass difference with respect to the ground state is given, as the uncertainties are dominated by the uncertainty in the ground state mass. In the remaining cases, the uncertainty on the measurement of the excited state itself dominates

Charmed baryon excited state	Mode	Mass or mass difference (MeV/c^2)	Natural width (MeV)	J^P
$\Xi_c'^+$	$\Xi_c^+\gamma$	110.5 ± 0.4		$1/2^+$
$\Xi_c'^0$	$\Xi_c^0\gamma$	108.3 ± 0.4		$1/2^+$
$\Xi_c(2645)^+$	$\Xi_c^0\pi^+$	178.5 ± 0.1	2.1 ± 0.2	$3/2^+$
$\Xi_c(2645)^0$	$\Xi_c^+\pi^-$	174.7 ± 0.1	2.4 ± 0.2	$3/2^+$
$\Xi_c(2790)^+$	$\Xi_c'^0\pi^+$	320.7 ± 0.5	9 ± 1	$1/2^-$
$\Xi_c(2790)^0$	$\Xi_c'^+\pi^-$	323.8 ± 0.5	10 ± 1	$1/2^-$
$\Xi_c(2815)^+$	$\Xi_c(2645)^0\pi^+$	348.8 ± 0.1	2.43 ± 0.23	$3/2^-$
$\Xi_c(2815)^0$	$\Xi_c(2645)^+\pi^-$	349.4 ± 0.1	2.54 ± 0.23	$3/2^-$
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	2931.6 ± 6	36 ± 13	?
$\Xi_c(2970)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Xi_c(2645)^0\pi^+$	2967.2 ± 0.8	21 ± 3	?
$\Xi_c(2970)^0$	$\Xi_c(2645)^+\pi^-$	2970.4 ± 0.8	28 ± 3	?
$\Xi_c(3055)^+$	$\Sigma_c^{++}K^-$, ΛD	3055.7 ± 0.4	8.0 ± 1.9	?
$\Xi_c(3055)^0$	ΛD	3059.0 ± 0.8	6.2 ± 2.4	?
$\Xi_c(3080)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Sigma_c(2520)^{++}K^-$, ΛD	3077.8 ± 0.3	3.6 ± 0.7	?
$\Xi_c(3080)^0$	$\Lambda_c^+K_S^0\pi^-$, $\Sigma_c^0K_S^0$, $\Sigma_c(2520)^0K_S^0$	3079.9 ± 1.0	5.6 ± 2.2	?
$\Omega_c(2770)^0$	$\Omega_c^0\gamma$	2765.9 ± 2.0	$70.7^{+0.8}_{-0.9}$	$3/2^+$

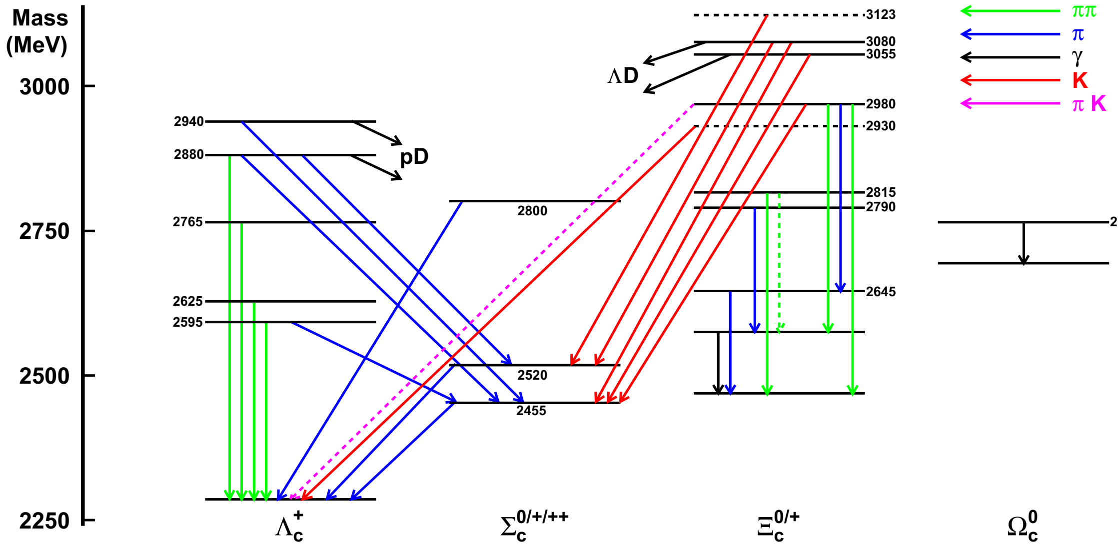


Fig. 216 Level diagram for multiplets and transitions for excited charm baryons

Table 298 summarizes the excited $\Sigma_c^{++,+,0}$ baryons. The ground iso-triplets of $\Sigma_c(2455)^{++,+,0}$ and $\Sigma_c(2520)^{++,+,0}$ baryons are well-established. Belle [1289]precisely measured the mass differences and widths of the doubly charged and neutral members of this triplet. The short list of excited Σ_c baryons is completed by the triplet of $\Sigma_c(2800)$ states observed by Belle [1290]. Based on the measured masses and theoretical predictions [1291,1292], these states are assumed to be members of the predicted Σ_{c2} $3/2^-$ triplet. From a study of resonant substructure in $B^- \to \Lambda_c^+ \bar{p}\pi^-$ decays, BaBar found a significant signal in the $\Lambda_c^+\pi^-$ final state with a mean value higher than measured for the $\Sigma_c(2800)$ by Belle by about 3σ (Table 298). The decay widths measured by Belle and BaBar are consistent, but it is an open question if the observed state is the same as the Belle state.

Table 299 summarizes the excited $\Xi_c^{+,0}$ and Ω_c^0 baryons. The list of excited Ξ_c baryons has several states, of unknown quantum numbers, having masses above 2900 MeV/c^2 and decaying into three different types of decay modes: $\Lambda_c/\Sigma_c n\pi$, $\Xi_c n\pi$ and the most recently observed ΛD. Some of these states ($\Xi_c(2970)^+$, $\Xi_c(3055)$ and $\Xi_c(3080)^{+,0}$) have been observed by both Belle [1293–1295] and BaBar [694] and are considered well-established. The $\Xi_c(2930)^0$ state decaying into $\Lambda_c^+K^-$ is seen only by BaBar [1296] and needs confirmation. The $\Xi_c(3123)^+$ observed by BaBar [694] in the $\Sigma_c(2520)^{++}\pi^-$ final state has not been confirmed by Belle [1294] with twice the statistics; thus its existence in doubt and it is omitted from Table 299.

Several of the width and mass measurements for the $\Xi_c(3055)$ and $\Xi_c(3080)$ iso-doublets are only in marginal agreement between experiments and decay modes. However, there seems little doubt that the differing measurements are of the same particle.

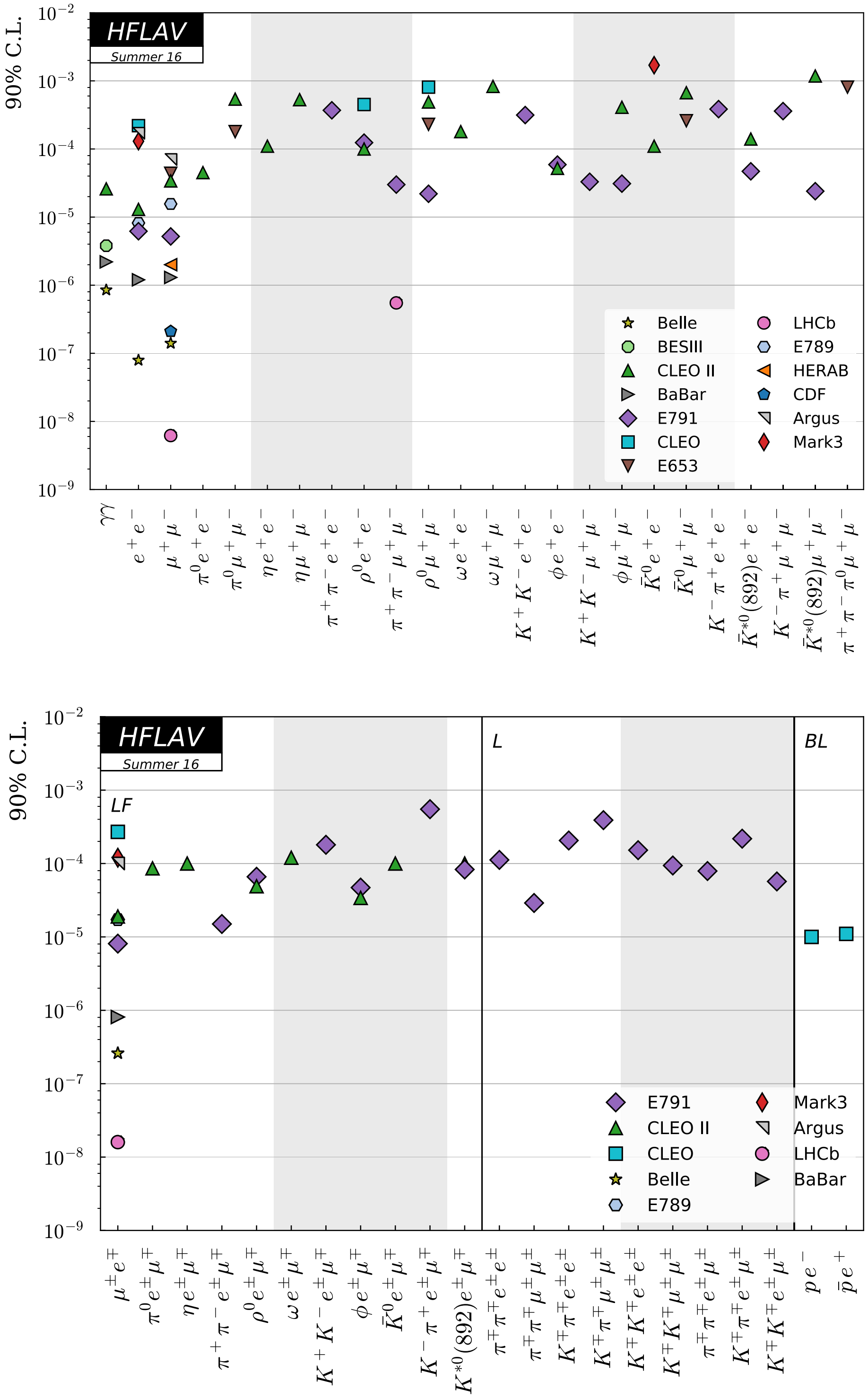
Belle [1297] has recently analyzed large samples of Ξ_c', $\Xi_c(2645)$, $\Xi_c(2790)$, $\Xi_c(2815)$ and $\Xi_c(2970)$ decays. From this analysis they obtain the most precise mass measurements of all five iso-doublets, and the first significant width measurements of the $\Xi_c(2645)$, $\Xi_c(2790)$ and $\Xi_c(2815)$. The level of agreement in the different measurements of the mass and width of the $\Xi_c(2970)$, formerly named by the PDG as the $\Xi_c(2980)$, is not satisfactory. This leaves open the possibility of there being other resonances nearby or that threshold effects have not been fully understood. The present situation in the excited Ξ_c sector is summarized in Table 299.

The excited Ω_c^0 doubly strange charmed baryon has been seen by both BaBar [1298] and Belle [1284]. The mass differences $\delta M = M(\Omega_c^{*0}) - M(\Omega_c^0)$ measured by the experiments are in good agreement and are also consistent with most theoretical predictions [1299–1302]. No higher mass Ω_c states have yet been observed.

Figure 216 shows the levels of excited charm baryons along with corresponding transitions between them, and also transitions to the ground states.

We note that Belle and BaBar recently discovered that transitions between families are possible, i.e., between the Ξ_c and Λ_c^+ families of excited charmed baryons [694,1293] and that highly excited states are found to decay into a non-charmed baryons and a D meson[1287,1295].

Fig. 217 Upper limits at 90% C.L. for D^0 decays. The *top plot* shows flavor-changing neutral current decays, and the *bottom plot* shows lepton-flavor-changing (LF), lepton-number-changing (L), and both baryon- and lepton-number-changing (BL) decays



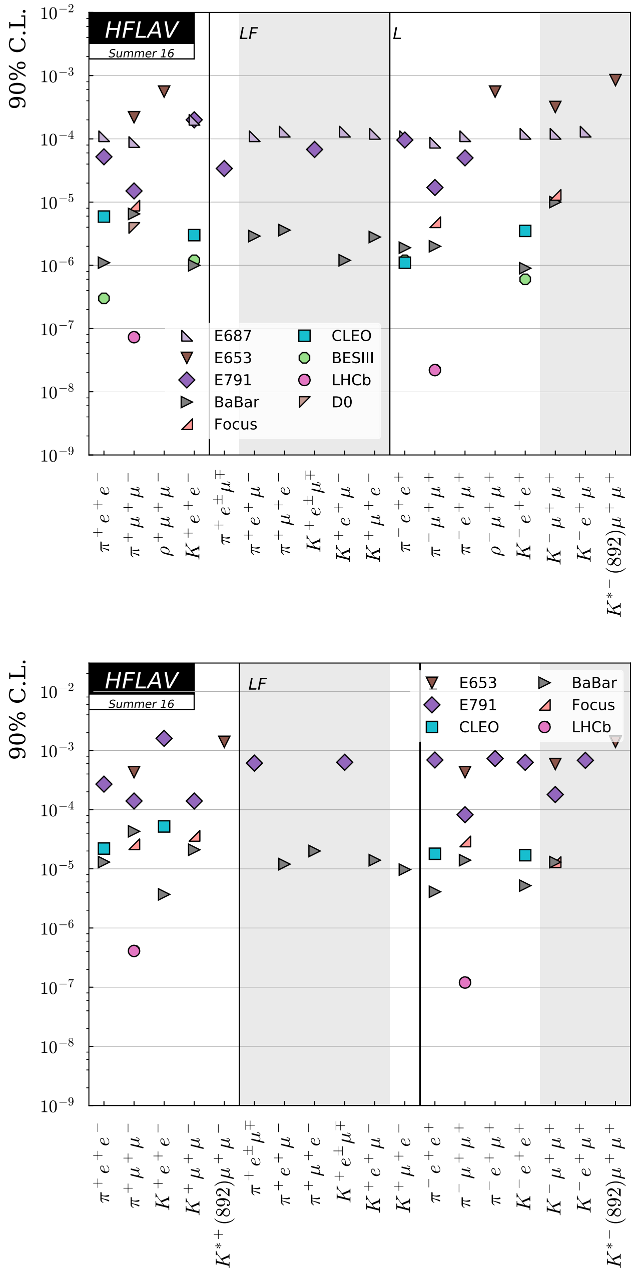


Fig. 218 Upper limits at 90% C.L. for D^+ (*top*) and D_s^+ (*bottom*) decays. *Each plot* shows flavor-changing neutral current decays, lepton-flavor-changing decays (LF), and lepton-number-changing (L) decays

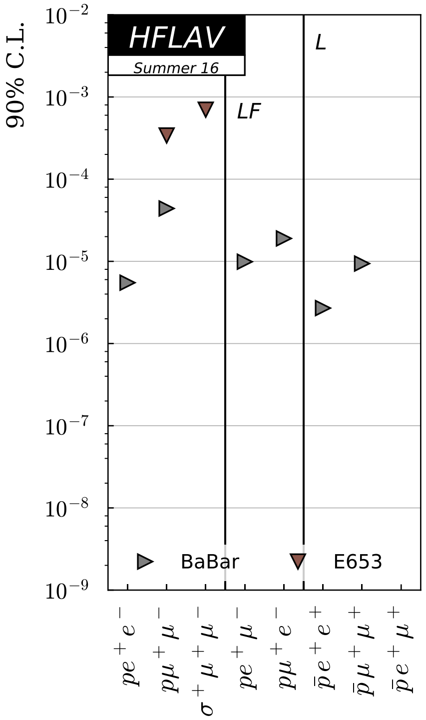


Fig. 219 Upper limits at 90% C.L. for Λ_c^+ decays. Shown are flavor-changing neutral current decays, lepton-flavor-changing (LF) decays, and lepton-number-changing (L) decays

8.12 Rare and forbidden decays

This section provides a summary of searches for rare and forbidden charm decays in tabular form. The decay modes can be categorized as flavor-changing neutral currents, lepton-flavor-violating, lepton-number-violating, and both baryon- and lepton-number-violating decays. Figures 217, 218 and 219 plot the upper limits for D^0, D^+, D_s^+, and Λ_c^+ decays. Tables 300, 301, 302 and 303 give the corresponding numerical results. Some theoretical predictions are given in Refs. [1303–1310].

In several cases the rare-decay final states have been observed with the di-lepton pair being the decay product of a vector meson. For these measurements the quoted limits are those expected for the non-resonant di-lepton spectrum. For the extrapolation to the full spectrum a phase-space distribution of the non-resonant component has been assumed. This applies to the CLEO measurement of the decays $D_{(s)}^+ \to (K^+, \pi^+)e^+e^-$ [1311], to the D0 measurements of the decays $D_{(s)}^+ \to \pi^+\mu^+\mu^-$ [1312], and to the BABAR measurements of the decays $D_{(s)}^+ \to (K^+, \pi^+)e^+e^-$ and $D_{(s)}^+ \to (K^+, \pi^+)\mu^+\mu^-$, where the contribution from $\phi \to l^+l^-$ $(l = e, \mu)$ has been excluded. In the case of the LHCb measurements of the decays $D^0 \to \pi^+\pi^-\mu^+\mu^-$ [1313] as well as the decays $D_{(s)}^+ \to \pi^+\mu^+\mu^-$ [1314] the contributions from $\phi \to l^+l^-$ as well as from $\rho, \omega \to l^+l^-$ $(l = e, \mu)$ have been excluded.

Table 300 Upper limits at 90% C.L. for D^0 decays

Decay	Limit $\times 10^6$	Experiment	References
$\gamma\gamma$	26.0	CLEO II	[1315]
	3.8	BESIII	[1316]
	2.2	BaBar	[1317]
	0.85	Belle	[1318]
e^+e^-	220.0	CLEO	[1319]
	170.0	Argus	[1320]
	130.0	Mark3	[1321]
	13.0	CLEO II	[1322]
	8.19	E789	[1323]
	6.2	E791	[1324]
	1.2	BaBar	[1325]
	0.079	Belle	[1326]
$\mu^+\mu^-$	70.0	Argus	[1320]
	44.0	E653	[1327]
	34.0	CLEO II	[1322]
	15.6	E789	[1323]
	5.2	E791	[1324]
	2.0	HERAb	[1328]
	1.3	BaBar	[1325]
	0.21	CDF	[1329]
	0.14	Belle	[1326]
	0.0062	LHCb	[1330]
$\pi^0 e^+e^-$	45.0	CLEO II	[1322]
$\pi^0 \mu^+\mu^-$	540.0	CLEO II	[1322]
	180.0	E653	[1327]
$\eta\, e^+e^-$	110.0	CLEO II	[1322]
$\eta\, \mu^+\mu^-$	530.0	CLEO II	[1322]
$\pi^+\pi^- e^+e^-$	370.0	E791	[1331]
$\rho^0 e^+e^-$	450.0	CLEO	[1319]
	124.0	E791	[1331]
	100.0	CLEO II	[1322]
$\pi^+\pi^-\mu^+\mu^-$	30.0	E791	[1331]
	0.55	LHCb	[1313]
$\rho^0\mu^+\mu^-$	810.0	CLEO	[1319]
	490.0	CLEO II	[1322]
	230.0	E653	[1327]
	22.0	E791	[1331]
$\omega\, e^+e^-$	180.0	CLEO II	[1322]
$\omega\, \mu^+\mu^-$	830.0	CLEO II	[1322]
$K^+K^-e^+e^-$	315.0	E791	[1331]
$\phi\, e^+e^-$	59.0	E791	[1331]
	52.0	CLEO II	[1322]
$K^+K^-\mu^+\mu^-$	33.0	E791	[1331]
$\phi\, \mu^+\mu^-$	410.0	CLEO II	[1322]
	31.0	E791	[1331]
$\overline{K}^0 e^+e^-$	1700.0	Mark3	[1332]
	110.0	CLEO II	[1322]
$\overline{K}^0 \mu^+\mu^-$	670.0	CLEO II	[1322]
	260.0	E653	[1327]
$K^-\pi^+e^+e^-$	385.0	E791	[1331]
$\overline{K}^{*0}(892)e^+e^-$	140.0	CLEO II	[1322]
	47.0	E791	[1331]
$K^-\pi^+\mu^+\mu^-$	360.0	E791	[1331]
$\overline{K}^{*0}(892)\mu^+\mu^-$	1180.0	CLEO II	[1322]
	24.0	E791	[1331]
$\pi^+\pi^-\pi^0\mu^+\mu^-$	810.0	E653	[1327]
$\mu^\pm e^\mp$	270.0	CLEO	[1319]
	120.0	Mark3	[1333]
	100.0	Argus	[1320]
	19.0	CLEO II	[1322]
	17.2	E789	[1323]
	8.1	E791	[1324]
	0.81	BaBar	[1325]
	0.26	Belle	[1326]
	0.016	LHCb	[1334]
$\pi^0 e^\pm\mu^\mp$	86.0	CLEO II	[1322]
$\eta\, e^\pm\mu^\mp$	100.0	CLEO II	[1322]
$\pi^+\pi^- e^\pm\mu^\mp$	15.0	E791	[1331]
$\rho^0 e^\pm\mu^\mp$	66.0	E791	[1331]
	49.0	CLEO II	[1322]
$\omega\, e^\pm\mu^\mp$	120.0	CLEO II	[1322]
$K^+K^-e^\pm\mu^\mp$	180.0	E791	[1331]
$\phi\, e^\pm\mu^\mp$	47.0	E791	[1331]
	34.0	CLEO II	[1322]
$\overline{K}^0 e^\pm\mu^\mp$	100.0	CLEO II	[1322]
$K^-\pi^+e^\pm\mu^\mp$	550.0	E791	[1331]
$K^{*0}(892)e^\pm\mu^\mp$	100.0	CLEO II	[1322]
	83.0	E791	[1331]
$\pi^\mp\pi^\mp e^\pm e^\pm$	112.0	E791	[1331]
$\pi^\mp\pi^\mp\mu^\pm\mu^\pm$	29.0	E791	[1331]
$K^\mp\pi^\mp e^\pm e^\pm$	206.0	E791	[1331]
$K^\mp\pi^\mp\mu^\pm\mu^\pm$	390.0	E791	[1331]
$K^\mp K^\mp e^\pm e^\pm$	152.0	E791	[1331]
$K^\mp K^\mp\mu^\pm\mu^\pm$	94.0	E791	[1331]
$\pi^\mp\pi^\mp e^\pm\mu^\pm$	79.0	E791	[1331]
$K^\mp\pi^\mp e^\pm\mu^\pm$	218.0	E791	[1331]
$K^\mp K^\mp e^\pm\mu^\pm$	57.0	E791	[1331]
$p\, e^-$	10.0	CLEO	[1335]
$\overline{p}\, e^+$	11.0	CLEO	[1335]

Table 301 Upper limits at 90% C.L. for D^+ decays

Decay	Limit $\times 10^6$	Experiment	References
$\pi^+ e^+ e^-$	110.0	E687	[1336]
	52.0	E791	[1324]
	5.9	CLEO	[1311]
	1.1	BaBar	[1337]
	0.3	BESIII	[1338]
$\pi^+ \mu^+ \mu^-$	220.0	E653	[1327]
	89.0	E687	[1336]
	15.0	E791	[1324]
	8.8	Focus	[1339]
	6.5	BaBar	[1337]
	3.9	D0	[1312]
	0.073	LHCb	[1314]
$\rho^+ \mu^+ \mu^-$	560.0	E653	[1327]
$K^+ e^+ e^-$	200.0	E687	[1336]
	3.0	CLEO	[1311]
	1.2	BESIII	[1338]
	1.0	BaBar	[1337]
$\pi^+ e^\pm \mu^\mp$	34.0	E791	[1324]
$\pi^+ e^+ \mu^-$	110.0	E687	[1336]
	2.9	BaBar	[1337]
$\pi^+ \mu^+ e^-$	130.0	E687	[1336]
	3.6	BaBar	[1337]
$K^+ e^\pm \mu^\mp$	68.0	E791	[1324]
$K^+ e^+ \mu^-$	130.0	E687	[1336]
	1.2	BaBar	[1337]
$K^+ \mu^+ e^-$	120.0	E687	[1336]
	2.8	BaBar	[1337]
$\pi^- e^+ e^+$	110.0	E687	[1336]
	96.0	E791	[1324]
	1.9	BaBar	[1337]
	1.2	BESIII	[1338]
	1.1	CLEO	[1311]
$\pi^- \mu^+ \mu^+$	87.0	E687	[1336]
	17.0	E791	[1324]
	4.8	Focus	[1339]
	2.0	BaBar	[1337]
	0.022	LHCb	[1314]
$\pi^- e^+ \mu^+$	110.0	E687	[1336]
	50.0	E791	[1324]
$\rho^- \mu^+ \mu^+$	560.0	E653	[1327]
$K^- e^+ e^+$	120.0	E687	[1336]
	3.5	CLEO	[1311]
	0.9	BaBar	[1337]
	0.6	BESIII	[1338]
$K^- \mu^+ \mu^+$	320.0	E653	[1327]
	120.0	E687	[1336]
	13.0	Focus	[1339]
	10.0	BaBar	[1337]
$K^- e^+ \mu^+$	130.0	E687	[1336]
$K^{*-}(892) \mu^+ \mu^+$	850.0	E653	[1327]

Table 302 Upper limits at 90% C.L. for D_s^+ decays

Decay	Limit $\times 10^6$	Experiment	References
$\pi^+ e^+ e^-$	270.0	E791	[1324]
	22.0	CLEO	[1311]
	13.0	BaBar	[1337]
$\pi^+ \mu^+ \mu^-$	430.0	E653	[1327]
	140.0	E791	[1324]
	43.0	BaBar	[1337]
	26.0	Focus	[1339]
	0.41	LHCb	[1314]
$K^+ e^+ e^-$	1600.0	E791	[1324]
	52.0	CLEO	[1311]
	3.7	BaBar	[1337]
$K^+ \mu^+ \mu^-$	140.0	E791	[1324]
	36.0	Focus	[1339]
	21.0	BaBar	[1337]
$K^{*+}(892) \mu^+ \mu^-$	1400.0	E653	[1327]
$\pi^+ e^\pm \mu^\mp$	610.0	E791	[1324]
$\pi^+ e^+ \mu^-$	12.0	BaBar	[1337]
$\pi^+ \mu^+ e^-$	20.0	BaBar	[1337]
$K^+ e^\pm \mu^\mp$	630.0	E791	[1324]
$K^+ e^+ \mu^-$	14.0	BaBar	[1337]
$K^+ \mu^+ e^-$	9.7	BaBar	[1337]
$\pi^- e^+ e^+$	690.0	E791	[1324]
	18.0	CLEO	[1311]
	4.1	BaBar	[1337]
$\pi^- \mu^+ \mu^+$	430.0	E653	[1327]
	82.0	E791	[1324]
	29.0	Focus	[1339]
	14.0	BaBar	[1337]
	0.12	LHCb	[1314]
$\pi^- e^+ \mu^+$	730.0	E791	[1324]
$K^- e^+ e^+$	630.0	E791	[1324]
	17.0	CLEO	[1311]
	5.2	BaBar	[1337]
$K^- \mu^+ \mu^+$	590.0	E653	[1327]
	180.0	E791	[1324]
	13.0	BaBar	[1337]
$K^- e^+ \mu^+$	680.0	E791	[1324]
$K^{*-}(892) \mu^+ \mu^+$	1400.0	E653	[1327]

Table 303 Upper limits at 90% C.L. for Λ_c^+ decays

Decay	Limit $\times 10^6$	Experiment	References
pe^+e^-	5.5	BaBar	[1337]
$p\mu^+\mu^-$	340.0	E653	[1327]
	44.0	BaBar	[1337]
$\sigma^+\mu^+\mu^-$	700.0	E653	[1327]
$pe^+\mu^-$	9.9	BaBar	[1337]
$p\mu^+e^-$	19.0	BaBar	[1337]
$\overline{p}\,e^+e^+$	2.7	BaBar	[1337]
$\overline{p}\,\mu^+\mu^+$	9.4	BaBar	[1337]

9 Tau lepton properties

We present averages of a selection of τ lepton quantities with the goal to provide the best tests of the universality of the charged-current weak interaction (Sect. 9.2) and of the Cabibbo–Kobayashi–Maskawa (CKM) matrix coefficient $|V_{us}|$ from τ decays (Sect. 9.4). We focus on the averages that benefit most from the adoption of the HFLAV methodology [420], namely a global fit of the τ branching fractions that best exploits the available experimental information. Since the 2016 edition, the HFLAV-Tau group has collaborated to the determination of the τ-lepton branching fractions based on a global fit and to the related mini-review that are included in the "Review of particle physics" [6]. The differences between the PDG 2016 fit and the fit presented here are detailed in Sect. 9.1.4.

All relevant published statistical correlations are used, and a selection of measurements, particularly the most precise and the most recent ones, was studied to take into account the significant systematic dependencies from external parameters and common sources of systematic uncertainty.

Finally, we report in Sect. 9.5 the latest limits on the lepton-flavour-violating τ branching fractions and in Sect. 9.6 we determine the combined upper limits for the branching fractions that have multiple experimental results.

The τ lepton results are obtained from inputs available through summer 2016 and have been published on the web in 2016 with the label "Summer 2016". However, there have been minor revisions since then, and we have updated tables and plots in this report with the label "Spring 2017".

9.1 Branching fraction fit

A global fit of the available experimental measurements is used to determine the τ branching fractions, together with their uncertainties and statistical correlations. The τ branching fractions provide a test for theory predictions based on the Standard Model (SM) EW and QCD interactions and can be further elaborated to test the EW charged-current universality for leptons, to determine the CKM matrix coefficient $|V_{us}|$ (and the QCD coupling constant α_s at the τ mass).

The measurements used in the fit are listed in Table 304 and consist of either τ decay branching fractions, labelled as Γ_i, or ratios of two τ decay branching fractions, labelled as Γ_i/Γ_j. A minimum χ^2 fit is performed for all the measured quantities and for some additional branching fractions and ratios of branching fractions, and all fit results are listed in Table 304. Some fitted quantities are equal to the ratio of two other fitted quantities, as documented with the notation Γ_i/Γ_j in Table 304. Some fitted quantities are sums of other fitted quantities, for instance $\Gamma_8 = B(\tau \rightarrow h^-\nu_\tau)$ is the sum of $\Gamma_9 = B(\tau \rightarrow \pi^-\nu_\tau)$ and $\Gamma_{10} = B(\tau \rightarrow K^-\nu_\tau)$. The symbol h is used to mean either a π or K. Section 9.1.7 lists all equations relating one quantity to the sum of other quantities. In the following, we refer to both types of relations between fitted quantities collectively as constraint equations or constraints. The fit χ^2 is minimized subject to all the above mentioned constraints, listed in Table 304 and Sect. 9.1.7. The fit procedure is equivalent to that employed in the previous HFLAV reports [5,234,420].

9.1.1 Technical implementation of the fit procedure

The fit computes the quantities q_i by minimizing a χ^2 while respecting a series of equality constraints on the q_i. The χ^2 is computed using the measurements x_i and their covariance matrix V_{ij} as

$$\chi^2 = (x_i - A_{ik}q_k)^t V_{ij}^{-1}(x_j - A_{jl}q_l), \tag{286}$$

where the model matrix A_{ij} is used to get the vector of the predicted measurements x_i' from the vector of the fit parameters q_j as $x_i' = A_{ij}q_j$. In this particular implementation, the measurements are grouped according to the measured quantity, and all quantities with at least one measurement correspond to a fit parameter. Therefore, the matrix A_{ij} has one row per measurement x_i and one column per fitted quantity q_j, with unity coefficients for the rows and column that identify a measurement x_i of the quantity q_j. In summary, the χ^2 given in Eq. (286) is minimized subject to the constraints

$$f_r(q_s) - c_r = 0, \tag{287}$$

where Eq. (287) corresponds to the constraint equations, written as a set of "constraint expressions" that are equated to zero. Using the method of Lagrange multipliers, a set of equations is obtained by taking the derivatives with respect to the fitted quantities q_k and the Lagrange multipliers λ_r of the sum of the χ^2 and the constraint expres-

Table 304 HFLAV Spring 2017 branching fractions fit results

τ lepton branching fraction	Fit value/Exp.	HFLAV fit/Refs.
$\Gamma_1 = \text{(particles)}- \geq 0\,\text{neutrals} \geq 0 K^0 \nu_\tau$	0.8519 ± 0.0011	HFLAV Spring 2017 fit
$\Gamma_2 = \text{(particles)}^- \geq 0\,\text{neutrals} \geq 0 K^0_L \nu_\tau$	0.8453 ± 0.0010	HFLAV Spring 2017 fit
$\Gamma_3 = \mu^- \bar{\nu}_\mu \bar{\nu}_\tau$	0.17392 ± 0.00040	HFLAV Spring 2017 fit
0.17319 ± 0.00077 ± 0.00000	ALEPH	[1344]
0.17325 ± 0.00095 ± 0.00077	DELPHI	[1345]
0.17342 ± 0.00110 ± 0.00067	L3	[1346]
0.17340 ± 0.00090 ± 0.00060	OPAL	[1347]
$\frac{\Gamma_3}{\Gamma_5} = \frac{\mu^- \bar{\nu}_\mu \bar{\nu}_\tau}{e^- \bar{\nu}_e \bar{\nu}_\tau}$	0.9762 ± 0.0028	HFLAV Spring 2017 fit
0.9970 ± 0.0350 ± 0.0400	ARGUS	[1348]
0.9796 ± 0.0016 ± 0.0036	BaBar	[1349]
0.9777 ± 0.0063 ± 0.0087	CLEO	[1350]
$\Gamma_5 = e^- \bar{\nu}_e \bar{\nu}_\tau$	0.17816 ± 0.00041	HFLAV Spring 2017 fit
0.17837 ± 0.00080 ± 0.00000	ALEPH	[1344]
0.17760 ± 0.00060 ± 0.00170	CLEO	[1350]
0.17877 ± 0.00109 ± 0.00110	DELPHI	[1345]
0.17806 ± 0.00104 ± 0.00076	L3	[1346]
0.17810 ± 0.00090 ± 0.00060	OPAL	[1351]
$\Gamma_7 = h^- \geq 0 K^0_L \nu_\tau$	0.12023 ± 0.00054	HFLAV Spring 2017 fit
0.12400 ± 0.00700 ± 0.00700	DELPHI	[1352]
0.12470 ± 0.00260 ± 0.00430	L3	[1353]
0.12100 ± 0.00700 ± 0.00500	OPAL	[1354]
$\Gamma_8 = h^- \nu_\tau$	0.11506 ± 0.00054	HFLAV Spring 2017 fit
0.11524 ± 0.00105 ± 0.00000	ALEPH	[1344]
0.11520 ± 0.00050 ± 0.00120	CLEO	[1350]
0.11571 ± 0.00120 ± 0.00114	DELPHI	[1355]
0.11980 ± 0.00130 ± 0.00160	OPAL	[1356]
$\frac{\Gamma_8}{\Gamma_5} = \frac{h^- \nu_\tau}{e^- \bar{\nu}_e \nu_\tau}$	0.6458 ± 0.0033	HFLAV Spring 2017 fit
$\Gamma_9 = \pi^- \nu_\tau$	0.10810 ± 0.00053	HFLAV Spring 2017 fit
$\frac{\Gamma_9}{\Gamma_5} = \frac{\pi^- \nu_\tau}{e^- \bar{\nu}_e \nu_\tau}$	0.6068 ± 0.0032	HFLAV Spring 2017 fit
0.5945 ± 0.0014 ± 0.0061	BABAR	[1349]
$\Gamma_{10} = K^- \nu_\tau$	$(0.6960 \pm 0.0096) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.6960 \pm 0.0287 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1357]
$(0.6600 \pm 0.0700 \pm 0.0900) \cdot 10^{-2}$	CLEO	[1358]
$(0.8500 \pm 0.1800 \pm 0.0000) \cdot 10^{-2}$	DELPHI	[1359]
$(0.6580 \pm 0.0270 \pm 0.0290) \cdot 10^{-2}$	OPAL	[1360]
$\frac{\Gamma_{10}}{\Gamma_5} = \frac{K^- \nu_\tau}{e^- \bar{\nu}_e \nu_\tau}$	$(3.906 \pm 0.054) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(3.882 \pm 0.032 \pm 0.057) \cdot 10^{-2}$	BaBar	[1349]
$\frac{\Gamma_{10}}{\Gamma_9} = \frac{K^- \nu_\tau}{\pi^- \nu_\tau}$	$(6.438 \pm 0.094) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{11} = \text{h}^- \geq 1\,\text{neutrals} \geq \nu_\tau$	0.36973 ± 0.00097	HFLAV Spring 2017 fit
$\Gamma_{12} = h^- \pi^0 \nu_\tau\ (\text{ex.}K^0)$	0.36475 ± 0.00097	HFLAV Spring 2017 fit
$\Gamma_{13} = h^- \pi^0 \nu_\tau$	0.25935 ± 0.00091	HFLAV Spring 2017 fit
0.25924 ± 0.00129 ± 0.00000	ALEPH	[1344]
0.25670 ± 0.00010 ± 0.00390	Belle	[1361]
0.25870 ± 0.00120 ± 0.00420	CLEO	[1362]
0.25740 ± 0.00201 ± 0.00138	DELPHI	[1355]

Table 304 continued

τ lepton branching fraction	Fit value/Exp.	HFLAV fit/Refs.
$0.25050 \pm 0.00350 \pm 0.00500$	L3	[1353]
$0.25890 \pm 0.00170 \pm 0.00290$	OPAL	[1356]
$\Gamma_{14} = \pi^-\pi^0\nu_\tau$	0.25502 ± 0.00092	HFLAV Spring 2017 fit
$\Gamma_{16} = K^-\pi^0\nu_\tau$	$(0.4327 \pm 0.0149) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.4440 \pm 0.0354 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1357]
$(0.4160 \pm 0.0030 \pm 0.0180) \cdot 10^{-2}$	BaBar	[1363]
$(0.5100 \pm 0.1000 \pm 0.0700) \cdot 10^{-2}$	CLEO	[1358]
$(0.4710 \pm 0.0590 \pm 0.0230) \cdot 10^{-2}$	OPAL	[1364]
$\Gamma_{17} = h^- \geq 2\pi^0\nu_\tau$	0.10775 ± 0.00095	HFLAV Spring 2017 fit
$0.09910 \pm 0.00310 \pm 0.00270$	OPAL	[1356]
$\Gamma_{18} = h^-2\pi^0\nu_\tau$	$(9.458 \pm 0.097) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{19} = h^-2\pi^0\nu_\tau\,(\text{ex.}K^0)$	$(9.306 \pm 0.097) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(9.295 \pm 0.122 \pm 0.000) \cdot 10^{-2}$	ALEPH	[1344]
$(9.498 \pm 0.320 \pm 0.275) \cdot 10^{-2}$	DELPHI	[1355]
$(8.880 \pm 0.370 \pm 0.420) \cdot 10^{-2}$	L3	[1353]
$\frac{\Gamma_{19}}{\Gamma_{13}} = \frac{h^-2\pi^0\nu_\tau\,(\text{ex.}K^0)}{h^-\pi^0\nu_\tau}$	0.3588 ± 0.0044	HFLAV Spring 2017 fit
$0.3420 \pm 0.0060 \pm 0.0160$	CLEO	[1365]
$\Gamma_{20} = \pi^-2\pi^0\nu_\tau\,(\text{ex.}K^0)$	$(9.242 \pm 0.100) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{23} = K^-2\pi^0\nu_\tau\,(\text{ex.}K^0)$	$(0.0640 \pm 0.0220) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.0560 \pm 0.0250 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1357]
$(0.0900 \pm 0.1000 \pm 0.0300) \cdot 10^{-2}$	CLEO	[1358]
$\Gamma_{24} = h^- \geq 3\pi^0\nu_\tau$	$(1.318 \pm 0.065) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{25} = h^- \geq 3\pi^0\nu_\tau\,(\text{ex.}K^0)$	$(1.233 \pm 0.065) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(1.403 \pm 0.214 \pm 0.224) \cdot 10^{-2}$	DELPHI	[1355]
$\Gamma_{26} = h^-3\pi^0\nu_\tau$	$(1.158 \pm 0.072) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(1.082 \pm 0.093 \pm 0.000) \cdot 10^{-2}$	ALEPH	[1344]
$(1.700 \pm 0.240 \pm 0.380) \cdot 10^{-2}$	L3	[1353]
$\frac{\Gamma_{26}}{\Gamma_{13}} = \frac{h^-3\pi^0\nu_\tau}{h^-\pi^0\nu_\tau}$	$(4.465 \pm 0.277) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(4.400 \pm 0.300 \pm 0.500) \cdot 10^{-2}$	CLEO	[1365]
$\Gamma_{27} = \pi^- \geq 3\pi^0\nu_\tau\,(\text{ex.}K^0)$	$(1.029 \pm 0.075) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{28} = K^- \geq 3\pi^0\nu_\tau\,(\text{ex.}K^0, \eta)$	$(4.283 \pm 2.161) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(3.700 \pm 2.371 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1357]
$\Gamma_{29} = h^- \geq 4\pi^0\nu_\tau\,(\text{ex.}K^0)$	$(0.1568 \pm 0.0391) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1600 \pm 0.0500 \pm 0.0500) \cdot 10^{-2}$	CLEO	[1365]
$\Gamma_{30} = h^- \geq 4\pi^0\nu_\tau\,(\text{ex.}K^0, \eta)$	$(0.1099 \pm 0.0391) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1120 \pm 0.0509 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1344]
$\Gamma_{31} = K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma\nu_\tau$	$(1.545 \pm 0.030) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(1.700 \pm 0.120 \pm 0.190) \cdot 10^{-2}$	CLEO	[1358]
$(1.540 \pm 0.240 \pm 0.000) \cdot 10^{-2}$	DELPHI	[1359]
$(1.528 \pm 0.039 \pm 0.040) \cdot 10^{-2}$	OPAL	[1360]
$\Gamma_{32} = K^- \geq 1(\pi^0 \text{ or } K^0 \text{ or } \gamma)\nu_\tau$	$(0.8528 \pm 0.0286) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{33} = K_S^0(\text{particles})\nu_\tau$	$(0.9372 \pm 0.0292) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.9700 \pm 0.0849 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1343]
$(0.9700 \pm 0.0900 \pm 0.0600) \cdot 10^{-2}$	OPAL	[1366]
$\Gamma_{34} = h^-\bar{K}^0\nu_\tau$	$(0.9865 \pm 0.0139) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.8550 \pm 0.0360 \pm 0.0730) \cdot 10^{-2}$	CLEO	[1367]

Table 304 continued

τ lepton branching fraction	Fit value/Exp.	HFLAV fit/Refs.
$\Gamma_{35} = \pi^- \bar{K}^0 \nu_\tau$	$(0.8386 \pm 0.0141) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.9280 \pm 0.0564 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1357]
$(0.8320 \pm 0.0025 \pm 0.0150) \cdot 10^{-2}$	Belle	[1342]
$(0.9500 \pm 0.1500 \pm 0.0600) \cdot 10^{-2}$	L3	[1368]
$(0.9330 \pm 0.0680 \pm 0.0490) \cdot 10^{-2}$	OPAL	[1369]
$\Gamma_{37} = K^- K^0 \nu_\tau$	$(0.1479 \pm 0.0053) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1580 \pm 0.0453 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1343]
$(0.1620 \pm 0.0237 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1357]
$(0.1480 \pm 0.0013 \pm 0.0055) \cdot 10^{-2}$	Belle	[1342]
$(0.1510 \pm 0.0210 \pm 0.0220) \cdot 10^{-2}$	CLEO	[1367]
$\Gamma_{38} = K^- K^0 \nu_\tau \geq 0\pi^0 \nu_\tau$	$(0.2982 \pm 0.0079) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.3300 \pm 0.0550 \pm 0.0390) \cdot 10^{-2}$	OPAL	[1369]
$\Gamma_{39} = h^- \overline{K}^0 \pi^0 \nu_\tau$	$(0.5314 \pm 0.0134) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.5620 \pm 0.0500 \pm 0.0480) \cdot 10^{-2}$	CLEO	[1367]
$\Gamma_{40} = \pi^- \overline{K}^0 \pi^0 \nu_\tau$	$(0.3812 \pm 0.0129) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.2940 \pm 0.0818 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1343]
$(0.3470 \pm 0.0646 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1357]
$(0.3860 \pm 0.0031 \pm 0.0135) \cdot 10^{-2}$	Belle	[1342]
$(0.4100 \pm 0.1200 \pm 0.0300) \cdot 10^{-2}$	L3	[1368]
$\Gamma_{42} = K^- \pi^0 K^0 \nu_\tau$	$(0.1502 \pm 0.0071) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1520 \pm 0.0789 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1343]
$(0.1430 \pm 0.0291 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1357]
$(0.1496 \pm 0.0019 \pm 0.0073) \cdot 10^{-2}$	Belle	[1342]
$(0.1450 \pm 0.0360 \pm 0.0200) \cdot 10^{-2}$	CLEO	[1367]
$\Gamma_{43} = \pi^- \overline{K}^0 \geq 1\pi^0 \nu_\tau$	$(0.4046 \pm 0.0260) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.3240 \pm 0.0740 \pm 0.0660) \cdot 10^{-2}$	OPAL	[1369]
$\Gamma_{44} = \pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex.K^0)	$(2.340 \pm 2.306) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(2.600 \pm 2.400 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1370]
$\Gamma_{46} = \pi^- K^0 \overline{K}^0 \nu_\tau$	$(0.1513 \pm 0.0247) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{47} = \pi^- K_S^0 K_S^0 \nu_\tau$	$(2.332 \pm 0.065) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(2.600 \pm 1.118 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1343]
$(2.310 \pm 0.040 \pm 0.080) \cdot 10^{-4}$	BaBar	[1371]
$(2.330 \pm 0.033 \pm 0.093) \cdot 10^{-4}$	Belle	[1342]
$(2.300 \pm 0.500 \pm 0.300) \cdot 10^{-4}$	CLEO	[1367]
$\Gamma_{48} = \pi^- K_S^0 K_L^0 \nu_\tau$	$(0.1047 \pm 0.0247) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1010 \pm 0.0264 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1343]
$\Gamma_{49} = \pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau$	$(3.540 \pm 1.193) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{50} = \pi^- \pi^0 K_S^0 K_S^0 \nu_\tau$	$(1.815 \pm 0.207) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(1.600 \pm 0.200 \pm 0.220) \cdot 10^{-5}$	BaBar	[1371]
$(2.000 \pm 0.216 \pm 0.202) \cdot 10^{-5}$	Belle	[1342]
$\Gamma_{51} = \pi^- \pi^0 K_S^0 K_L^0 \nu_\tau$	$(3.177 \pm 1.192) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(3.100 \pm 1.100 \pm 0.500) \cdot 10^{-4}$	ALEPH	[1343]
$\Gamma_{53} = \overline{K}^0 h^- h^- h^+ \nu_\tau$	$(2.218 \pm 2.024) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(2.300 \pm 2.025 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1343]

Table 304 continued

τ lepton branching fraction	Fit value/Exp.	HFLAV fit/Refs.
$\Gamma_{54} = h^-h^-h^+ \geq 0\,\text{neutrals} \geq 0K_L^0\nu_\tau$	0.15215 ± 0.00061	HFLAV Spring 2017 fit
$0.15000 \pm 0.00400 \pm 0.00300$	CELLO	[1372]
$0.14400 \pm 0.00600 \pm 0.00300$	L3	[1373]
$0.15100 \pm 0.00800 \pm 0.00600$	TPC	[1374]
$\Gamma_{55} = h^-h^-h^+ \geq 0\,\text{neutrals}\,\nu_\tau\,(\text{ex.}K^0)$	0.14567 ± 0.00057	HFLAV Spring 2017 fit
$0.14556 \pm 0.00105 \pm 0.00076$	L3	[1375]
$0.14960 \pm 0.00090 \pm 0.00220$	OPAL	[1376]
$\Gamma_{56} = h^-h^-h^+\nu_\tau$	$(9.780 \pm 0.054) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{57} = h^-h^-h^+\nu_\tau\,(\text{ex.}K^0)$	$(9.439 \pm 0.053) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(9.510 \pm 0.070 \pm 0.200) \cdot 10^{-2}$	CLEO	[1377]
$(9.317 \pm 0.090 \pm 0.082) \cdot 10^{-2}$	DELPHI	[1355]
$\frac{\Gamma_{57}}{\Gamma_{55}} = \frac{h^-h^-h^+\nu_\tau\,(\text{ex.}K^0)}{h^-h^-h^+ \geq 0\,\text{neutrals}\,\nu_\tau\,(\text{ex.}K^0)}$	0.6480 ± 0.0030	HFLAV Spring 2017 fit
$0.6600 \pm 0.0040 \pm 0.0140$	OPAL	[1376]
$\Gamma_{58} = h^-h^-h^+\nu_\tau\,(\text{ex.}K^0, \omega)$	$(9.408 \pm 0.053) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(9.469 \pm 0.096 \pm 0.000) \cdot 10^{-2}$	ALEPH	[1344]
$\Gamma_{59} = \pi^-\pi^+\pi^-\nu_\tau$	$(9.290 \pm 0.052) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{60} = \pi^-\pi^+\pi^-\nu_\tau\,(\text{ex.}K^0)$	$(9.000 \pm 0.051) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(8.830 \pm 0.010 \pm 0.130) \cdot 10^{-2}$	BABAR	[1378]
$\left(8.420 \pm 0.000^{+0.260}_{-0.250}\right) \cdot 10^{-2}$	Belle	[1379]
$(9.130 \pm 0.050 \pm 0.460) \cdot 10^{-2}$	CLEO3	[1380]
$\Gamma_{62} = \pi^-\pi^-\pi^+\nu_\tau\,(\text{ex.}K^0, \omega)$	$(8.970 \pm 0.052) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{63} = h^-h^-h^+ \geq 1\,\text{neutrals}\,\nu_\tau$	$(5.325 \pm 0.050) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{64} = h^-h^-h^+ \geq 1\pi^0\,\nu_\tau\,(\text{ex.}K^0)$	$(5.120 \pm 0.049) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{65} = h^-h^-h^+ \geq \pi^0$	$(4.790 \pm 0.052) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{66} = h^-h^-h^+ \geq \pi^0\,\nu_\tau\,(\text{ex.}K^0)$	$(4.606 \pm 0.051) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(4.734 \pm 0.077 \pm 0.000) \cdot 10^{-2}$	ALEPH	[1344]
$(4.230 \pm 0.060 \pm 0.220) \cdot 10^{-2}$	CLEO	[1377]
$(4.545 \pm 0.106 \pm 0.103) \cdot 10^{-2}$	DELPHI	[1355]
$\Gamma_{67} = h^-h^-h^+\pi^0\nu_\tau\,(\text{ex.}K^0, \omega)$	$(2.820 \pm 0.070) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{68} = \pi^-\pi^+\pi^-\pi^0\,\nu_\tau$	$(4.651 \pm 0.053) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{69} = \pi^-\pi^+\pi^-\pi^0\,\nu_\tau\,(\text{ex.}K^0)$	$(4.519 \pm 0.052) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(4.190 \pm 0.100 \pm 0.210) \cdot 10^{-2}$	CLEO	[1381]
$\Gamma_{70} = \pi^-\pi^-\pi^+\pi^0\,\nu_\tau\,(\text{ex.}K^0, \omega)$	$(2.769 \pm 0.071) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{74} = h^-h^-h^+ \geq 2\pi^0\,\nu_\tau\,(\text{ex.}K^0)$	$(0.5135 \pm 0.0312) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.5610 \pm 0.0680 \pm 0.0950) \cdot 10^{-2}$	DELPHI	[1355]
$\Gamma_{75} = h^-h^-h^+2\pi^0\,\nu_\tau$	$(0.5024 \pm 0.0310) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{76} = h^-h^-h^+ \geq 2\pi^0\,\nu_\tau\,(\text{ex.}K^0)$	$(0.4925 \pm 0.0310) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.4350 \pm 0.0461 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1344]
$\frac{\Gamma_{76}}{\Gamma_{54}} = \frac{h^-h^-h^+2\pi^0\,\nu_\tau\,(\text{ex.}K^0)}{h^-h^-h^+ \geq 0\,\text{neutrals} \geq 0K_L^0\,\nu_\tau}$	$(3.237 \pm 0.202) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(3.400 \pm 0.200 \pm 0.300) \cdot 10^{-2}$	CLEO	[1382]
$\Gamma_{77} = h^-h^-h^+2\pi^0\,\nu_\tau\,(\text{ex.}K^0, \omega, \eta)$	$(9.759 \pm 3.550) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{78} = h^-h^-h^+3\pi^0\,\nu_\tau$	$(2.107 \pm 0.299) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(2.200 \pm 0.300 \pm 0.400) \cdot 10^{-4}$	CLEO	[1383]
$\Gamma_{79} = K^-h^-h^+ \geq 0\,\text{neutrals}\,\nu_\tau$	$(0.6297 \pm 0.0141) \cdot 10^{-2}$	HFLAV Spring 2017 fit

Table 304 continued

τ lepton branching fraction	Fit value/Exp.	HFLAV fit/Refs.
$\Gamma_{80} = K^-\pi^-h^+\nu_\tau$ (ex.K^0)	$(0.4363 \pm 0.0073) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\frac{\Gamma_{80}}{\Gamma_{60}} = \frac{K^-\pi^-h^+\nu_\tau \text{ (ex.}K^0)}{\pi^-\pi^+\pi^-\nu_\tau \text{ (ex.}K^0)}$	$(4.847 \pm 0.080) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(5.440 \pm 0.210 \pm 0.530) \cdot 10^{-2}$	CLEO	[1384]
$\Gamma_{81} = K^-\pi^-h^+\pi^0\,\nu_\tau$ (ex.K^0)	$(8.726 \pm 1.177)\cdot 10^{-4}$	HFLAV Spring 2017 fit
$\frac{\Gamma_{81}}{\Gamma_{69}} = \frac{K^-\pi^-h^+\pi^0\,\nu_\tau \text{ (ex.}K^0)}{\pi^-\pi^+\pi^-\pi^0\,\nu_\tau \text{ (ex.}K^0)}$	$(1.931 \pm 0.266)\cdot 10^{-2}$	HFLAV Spring 2017 fit
$(2.610 \pm 0.450 \pm 0.420) \cdot 10^{-2}$	CLEO	[1384]
$\Gamma_{82} = K^-\pi^-\pi^+ \geq 0\,\text{neutrals}\,\nu_\tau$	$(0.4780 \pm 0.0137) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\left(0.5800^{+0.1500}_{-0.1300} \pm 0.1200\right) \cdot 10^{-2}$	TPC	[1385]
$\Gamma_{83} = K^-\pi^-\pi^+ \geq 0\pi^0\,\nu_\tau$ (ex.K^0)	$(0.3741 \pm 0.0135)\cdot 10^{-2}$	HFLAV Spring2017 fit
$\Gamma_{84} = K^-\pi^-\pi^+\nu_\tau$	$(0.3441 \pm 0.0070) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{85} = K^-\pi^+\pi^-\nu_\tau$ (ex.K^0)	$(0.2929 \pm 0.0067) \cdot 10^{-2}$	HFLAV Spring2017 fit
$(0.2140 \pm 0.0470 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1386]
$(0.2730 \pm 0.0020 \pm 0.0090) \cdot 10^{-2}$	BaBar	[1378]
$\left(0.3300 \pm 0.0010^{+0.0160}_{-0.0170}\right) \cdot 10^{-2}$	Belle	[1379]
$(0.3840 \pm 0.0140 \pm 0.0380) \cdot 10^{-2}$	CLE03	[1380]
$(0.4150 \pm 0.0530 \pm 0.0400) \cdot 10^{-2}$	OPAL	[1364]
$\frac{\Gamma_{85}}{\Gamma_{60}} = \frac{K^-\pi^+\pi^-\nu_\tau \text{ (ex.}K^0)}{\pi^-\pi^+\pi^-\nu_\tau \text{ (ex.}K^0)}$	$(3.254 \pm 0.074) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{87} = K^-\pi^-\pi^+\pi^0\,\nu_\tau$	$(0.1331 \pm 0.0119)\cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{88} = K^-\pi^-\pi^+\pi^0\,\nu_\tau$ (ex.K^0)	$(8.115 \pm 1.168)\cdot 10^{-4}$	HFLAV Spring 2017 fit
$(6.100 \pm 4.295 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1386]
$(7.400 \pm 0.800 \pm 1.100)\cdot 10^{-4}$	CLE03	[1387]
$\Gamma_{89} = K^-\pi^-\pi^+\pi^0\,\nu_\tau$ (ex.K^0, η)	$(7.761 \pm 1.168) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{92} = \pi^-K^-K^+ \geq 0\,\text{neutrals}\,\nu_\tau$	$(0.1495 \pm 0.0033) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1590 \pm 0.0530 \pm 0.0200) \cdot 10^{-2}$	OPAL	[1388]
$\left(0.1500^{+0.0900}_{-0.0700} \pm 0.0300\right).10^{-2}$	TPC	[1385]
$\Gamma_{93} = \pi^-K^-K^+\nu_\tau$	$(0.1434 \pm 0.0027) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1630 \pm 0.0270 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1386]
$(0.1346 \pm 0.0010 \pm 0.0036) \cdot 10^{-2}$	BaBar	[1378]
$\left(0.1550 \pm 0.0010^{+0.0060}_{-0.0050}\right).10^{-2}$	Belle	[1379]
$(0.1550 \pm 0.0060 \pm 0.0090) \cdot 10^{-2}$	CLE03	[1380]
$\frac{\Gamma_{93}}{\Gamma_{60}} = \frac{\pi^-K^-K^+\nu_\tau}{\pi^-\pi^+\pi^-\nu_\tau \text{ (ex.}K^0)}$	$(1.593 \pm 0.030)\cdot 10^{-2}$	HFLAV Spring2017 fit
$(1.600 \pm 0.150 \pm 0.300) \cdot 10^{-2}$	CLEO	[1384]
$\Gamma_{94} = \pi^-K^-K^+\pi^0\,\nu_\tau$	$(0.611 \pm 0.183) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(7.500 \pm 3.265 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1386]
$(0.550 \pm 0.140 \pm 0.120) \cdot 10^{-4}$	CLE03	[1387]
$\frac{\Gamma_{94}}{\Gamma_{69}} = \frac{\pi^-K^-K^+\pi^0\,\nu_\tau}{\pi^-\pi^+\pi^-\pi^0\,\nu_\tau \text{ (ex.}K^0)}$	$(0.1353 \pm 0.0405) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.7900 \pm 0.4400 \pm 0.1600) \cdot 10^{-2}$	CLEO	[1384]
$\Gamma_{96} = K^-K^-K^+\nu_\tau$	$(2.174 \pm 0.800)\cdot 10^{-5}$	HFLAV Spring 2017 fit
$(1.578 \pm 0.130 \pm 0.123) \cdot 10^{-5}$	BaBar	[1378]
$\left(3.290 \pm 0.170^{+0.190}_{-0.200}\right).10^{-5}$	Belle	[1379]

Table 304 continued

τ lepton branching fraction	Fit value/Exp.	HFLAV fit/Refs.
$\Gamma_{102} = 3h^-2h^+ \geq 0\,\text{neutrals}\,\nu_\tau\ \left(\text{ex. } K^0\right)$	$(0.0985 \pm 0.0037) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.0970 \pm 0.0050 \pm 0.0110) \cdot 10^{-2}$	CLEO	[1389]
$(0.1020 \pm 0.0290 \pm 0.0000) \cdot 10^{-2}$	HRS	[1390]
$(0.1700 \pm 0.0220 \pm 0.0260) \cdot 10^{-2}$	L3	[1375]
$\Gamma_{103} = 3h^-2h^+\nu_\tau\ \left(\text{ex.} K^0\right)$	$(8.216 \pm 0.316) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(7.200 \pm 1.500 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1344]
$(6.400 \pm 2.300 \pm 1.000) \cdot 10^{-4}$	ARGUS	[1391]
$(7.700 \pm 0.500 \pm 0.900) \cdot 10^{-4}$	CLEO	[1389]
$(9.700 \pm 1.500 \pm 0.500) \cdot 10^{-4}$	DELPHI	[1355]
$(5.100 \pm 2.000 \pm 0.000) \cdot 10^{-4}$	HRS	[1390]
$(9.100 \pm 1.400 \pm 0.600) \cdot 10^{-4}$	OPAL	[1392]
$\Gamma_{104} = 3h^-2h^+\pi^0\,\nu_\tau\ \left(\text{ex. } K^0\right)$	$(1.634 \pm 0.114) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(2.100 \pm 0.700 \pm 0.900) \cdot 10^{-4}$	ALEPH	[1344]
$(1.700 \pm 0.200 \pm 0.200) \cdot 10^{-4}$	CLEO	[1383]
$(1.600 \pm 1.200 \pm 0.600) \cdot 10^{-4}$	DELPHI	[1355]
$(2.700 \pm 1.800 \pm 0.900) \cdot 10^{-4}$	OPAL	[1392]
$\Gamma_{106} = (5\pi)^-\,\nu_\tau$	$(0.7748 \pm 0.0534) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{110} = X_s^-\nu_\tau$	$(2.909 \pm 0.048) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{126} = \pi^-\pi^0\,\eta\nu_\tau$	$(0.1386 \pm 0.0072) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(0.1800 \pm 0.0447 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1393]
$(0.1350 \pm 0.0030 \pm 0.0070) \cdot 10^{-2}$	Belle	[1394]
$(0.1700 \pm 0.0200 \pm 0.0200) \cdot 10^{-2}$	CLEO	[1395]
$\Gamma_{128} = K^-\eta\nu_\tau$	$(1.547 \pm 0.080) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\left(2.900^{+1.300}_{-1.200} \pm 0.700\right) .10^{-4}$	ALEPH	[1393]
$(1.420 \pm 0.110 \pm 0.070) \cdot 10^{-4}$	BaBar	[1396]
$(1.580 \pm 0.050 \pm 0.090) \cdot 10^{-4}$	Belle	[1394]
$(2.600 \pm 0.500 \pm 0.500) \cdot 10^{-4}$	CLEO	[1397]
$\Gamma_{130} = K^-\pi^0\,\eta\nu_\tau$	$(0.483 \pm 0.116) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(0.460 \pm 0.110 \pm 0.040) \cdot 10^{-4}$	Belle	[1394]
$(1.770 \pm 0.560 \pm 0.710) \cdot 10^{-4}$	CLEO	[1398]
$\Gamma_{132} = \pi^-\bar{K}^0\eta\nu_\tau$	$(0.937 \pm 0.149) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(0.880 \pm 0.140 \pm 0.060) \cdot 10^{-4}$	Belle	[1394]
$(2.200 \pm 0.700 \pm 0.220) \cdot 10^{-4}$	CLEO	[1398]
$\Gamma_{136} = \pi^-\pi^+\pi^-\eta\nu_\tau\ \left(\text{ex. } K^0\right)$	$(2.184 \pm 0.130) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{149} = h^-\omega \geq 0\,\text{neutrals}\,\nu_\tau$	$(2.401 \pm 0.075) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{150} = h^-\omega\nu_\tau$	$(1.995 \pm 0.064) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$(1.910 \pm 0.092 \pm 0.000) \cdot 10^{-2}$	ALEPH	[1393]
$(1.600 \pm 0.270 \pm 0.410) \cdot 10^{-2}$	CLEO	[1399]
$\frac{\Gamma_{150}}{\Gamma_{66}} = \frac{h^-\omega\nu_\tau}{h^-h^-h^+\pi^0\,\nu_\tau\,(\text{ex. } K^0)}$	0.4332 ± 0.0139	HFLAV Spring 2017 fit
$0.4310 \pm 0.0330 \pm 0.0000$	ALEPH	[1400]
$0.4640 \pm 0.0160 \pm 0.0170$	CLEO	[1377]
$\Gamma_{151} = K^-\omega\nu_\tau$	$(4.100 \pm 0.922) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(4.100 \pm 0.600 \pm 0.700) \cdot 10^{-4}$	CLE03	[1387]
$\Gamma_{152} = h^-\pi^0\,\omega\nu_\tau$	$(0.4058 \pm 0.0419) \cdot 10^{-2}$	HFLAV Spring 2017 fit

Table 304 continued

τ lepton branching fraction	Fit value/Exp.	HFLAV fit/Refs.
$(0.4300 \pm 0.0781 \pm 0.0000) \cdot 10^{-2}$	ALEPH	[1393]
$\frac{\Gamma_{152}}{\Gamma_{54}} = \frac{h^- \omega \pi^0 \nu_\tau}{h^- h^- h^+ \geq 0 \text{neutrals} \geq 0 K_L^0 \nu_\tau}$	$(2.667 \pm 0.275) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\frac{\Gamma_{152}}{\Gamma_{76}} = \frac{h^- \omega \pi^0 \nu_\tau}{h^- h^- h^+ 2\pi^0 \nu_\tau \text{ (ex. } K^0)}$	0.8241 ± 0.0757	HFLAV Spring 2017 fit
$0.8100 \pm 0.0600 \pm 0.0600$	CLEO	[1382]
$\Gamma_{167} = K^- \phi \nu_\tau$	$(4.445 \pm 1.636) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$\Gamma_{168} = K^- \phi \nu_\tau (\phi \to K^+ K^-)$	$(2.174 \pm 0.800) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$\Gamma_{169} = K^- \phi \nu_\tau (\phi \to K_S^0 K_L^0)$	$(1.520 \pm 0.560) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$\Gamma_{800} = \pi^- \omega \nu_\tau$	$(1.954 \pm 0.065) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{802} = K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	$(0.2923 \pm 0.0067) \cdot 10^{-2}$	HFLAV Spring 2017 fit
$\Gamma_{803} = K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	$(4.103 \pm 1.429) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{804} = \pi^- K_L^0 K_L^0 \nu_\tau$	$(2.332 \pm 0.065) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{805} = a_1^- (\to \pi^- \gamma) \nu_\tau$	$(4.000 \pm 2.000) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(4.000 \pm 2.000 \pm 0.000) \cdot 10^{-4}$	ALEPH	[1344]
$\Gamma_{806} = \pi^- \pi^0 K_L^0 K_L^0 \nu_\tau$	$(1.815 \pm 0.207) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$\Gamma_{810} = 2\pi^- \pi^+ 3\pi^0 \nu_\tau$ (ex. K^0)	$(1.924 \pm 0.298) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{811} = \pi^- 2\pi^0 \omega \nu_\tau$ (ex. K^0)	$(7.105 \pm 1.586) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(7.300 \pm 1.200 \pm 1.200) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{812} = 2\pi^- \pi^+ 3\pi^0 \nu_\tau$ (ex. K^0, η, ω, f_1)	$(1.344 \pm 2.683) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(1.000 \pm 0.800 \pm 3.000) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{820} = 3\pi^- 2\pi^+ \nu_\tau$ (ex. K^0, ω)	$(8.197 \pm 0.315) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{821} = 3\pi^- 2\pi^+ \nu_\tau$ (ex. K^0, ω, f_1)	$(7.677 \pm 0.297) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$(7.680 \pm 0.040 \pm 0.400) \cdot 10^{-4}$	BaBar	[1401]
$\Gamma_{822} = K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	$(0.596 \pm 1.208) \cdot 10^{-6}$	HFLAV Spring 2017 fit
$(0.600 \pm 0.500 \pm 1.100) \cdot 10^{-6}$	BaBar	[1401]
$\Gamma_{830} = 3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	$(1.623 \pm 0.114) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{831} = 2\pi^- \pi^+ \omega \nu_\tau$ (ex. K^0)	$(8.359 \pm 0.626) \cdot 10^{-5}$	HFLAV Spring2017 fit
$(8.400 \pm 0.400 \pm 0.600) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{832} = 3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0, η, ω, f_1)	$(3.771 \pm 0.875) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(3.600 \pm 0.300 \pm 0.900) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{833} = K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	$(1.108 \pm 0.566) \cdot 10^{-6}$	HFLAV Spring 2017 fit
$(1.100 \pm 0.400 \pm 0.400) \cdot 10^{-6}$	BaBar	[1401]
$\Gamma_{910} = 2\pi^- \pi^+ \eta \nu_\tau \left(\eta \to 3\pi^0\right)$ (ex. K^0)	$(7.136 \pm 0.424) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(8.270 \pm 0.880 \pm 0.810) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{911} = \pi^- 2\pi^0 \eta \nu_\tau \left(\eta \to \pi^+ \pi^- \pi^0\right) \left(\text{ex. } K^0\right)$	$(4.420 \pm 0.867) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(4.570 \pm 0.770 \pm 0.500) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{920} = \pi^- f_1 \nu_\tau (f_1 \to 2\pi^- 2\pi^+)$	$(5.197 \pm 0.444) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(5.200 \pm 0.310 \pm 0.370) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{930} = 2\pi^- \pi^+ \eta \nu_\tau (\eta \to \pi^+ \pi^- \pi^0)$ (ex. K^0)	$(5.005 \pm 0.297) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(5.390 \pm 0.270 \pm 0.410) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{944} = 2\pi^- \pi^+ \eta \nu_\tau (\eta \to \gamma\gamma)$ (ex. K^0)	$(8.606 \pm 0.511) \cdot 10^{-5}$	HFLAV Spring 2017 fit
$(8.260 \pm 0.350 \pm 0.510) \cdot 10^{-5}$	BaBar	[1401]
$\Gamma_{945} = \pi^- 2\pi^0 \eta \nu_\tau$	$(1.929 \pm 0.378) \cdot 10^{-4}$	HFLAV Spring 2017 fit
$\Gamma_{998} = 1 - \Gamma_{\text{ALL}}$	$(0.0355 \pm 0.1031) \cdot 10^{-2}$	HFLAV Spring 2017 fit

sions multiplied by the Lagrange multipliers λ_r, one for each constraint:

$$\min\left[(A_{ik}q_k - x_i)^t V_{ij}^{-1}(A_{jl}q_l - x_j) + 2\lambda_r(f_r(q_s) - c_r)\right] \tag{288}$$

$$(\partial/\partial q_k, \partial/\partial\lambda_r)\ [\text{expression above}] = 0. \tag{289}$$

Equation (289) defines a set of equations for the vector of the unknowns (q_k, λ_r), some of which may be non-linear, in case of non-linear constraints. An iterative minimization procedure approximates at each step the non-linear constraint expressions by their first order Taylor expansion around the current values of the fitted quantities, $\bar{q}_s$:

$$f_r(q_s) - c_r \simeq f_r(\bar{q}_s) + \left.\frac{\partial f_r(q_s)}{\partial q_s}\right|_{\bar{q}_s}(q_s - \bar{q}_s) - c_r, \tag{290}$$

which can be written as

$$B_{rs}q_s - c'_r, \tag{291}$$

where c'_r are the resulting constant known terms, independent of q_s at first order. After linearization, the differentiation by q_k and λ_r is trivial and leads to a set of linear equations

$$A^t_{ki}V_{ij}^{-1}A_{jl}q_l + B^t_{kr}\lambda_r = A^t_{ki}V_{ij}^{-1}x_j \tag{292}$$

$$B_{rs}q_s = c'_r, \tag{293}$$

which can be expressed as:

$$F_{ij}u_j = v_i, \tag{294}$$

where $u_j = (q_k, \lambda_r)$ and v_i is the vector of the known constant terms running over the index k and then r in the right terms of Eqs. (292) and (293). Solving the equation set in Eq. (294) gives the fitted quantities and their covariance matrix, using the measurements and their covariance matrix.

The fit procedure starts by computing the linear approximation of the non-linear constraint expressions around the quantities seed values. With an iterative procedure, the unknowns are updated at each step by solving the equations and the equations are then linearized around the updated values, until the RMS average of relative variation of the fitted unknowns is reduced below 10^{-12}.

9.1.2 Fit results

The fit output consists of 135 fitted quantities that correspond to either branching fractions or ratios of branching fractions. The fitted quantities values and uncertainties are listed in Table 304. The off-diagonal statistical correlation terms between a subset of 47 "basis quantities" are listed in Sect. 9.1.6. All the remaining statistical correlation terms can be obtained using the constraint equations listed in Table 304 and Sect. 9.1.7.

The fit has χ^2/d.o.f. = 137/123, corresponding to a confidence level CL = 17.84%. We use a total of 170 measurements to fit the above mentioned 135 quantities subjected to 88 constraints. Although the unitarity constraint is not applied, the fit is statistically consistent with unitarity, where the residual is $\Gamma_{998} = 1 - \Gamma_{\text{All}} = (0.0355 \pm 0.1031) \cdot 10^{-2}$.

A scale factor of 5.44 (as in the three previous reports [5, 234,420]) has been applied to the published uncertainties of the two severely inconsistent measurements of $\Gamma_{96} = \tau \to KKK\nu$ by BaBar and Belle. The scale factor has been determined using the PDG procedure, i.e., to the proper size in order to obtain a reduced χ^2 equal to 1 when fitting just the two Γ_{96} measurements.

For several old results, for historical reasons, the table reports the total error (statistical plus systematic) in the position of the statistical error and zero in the position of the systematic error. Since the fit depends only on the total errors, the results are unaffected.

9.1.3 Changes with respect to the previous report

The following changes have been introduced with respect to the previous HFLAV report [5].

Two old preliminary results have been removed:

- $\Gamma_{35} = B(\tau \to \pi K_S \nu)$, BaBar [1340],
- $\Gamma_{40} = B(\tau \to \pi K_S \pi^0 \nu)$, BaBar [1341].

They were announced in 2008 and 2009 but have not been published.

In the 2014 report, for several BaBar and Belle experimental results we used more precise numerical values than the published ones, using internal information from the Collaborations. We revert to the published figures in this report, as the improvements in the fit results were negligible. In so doing, we use in this report the same values that are used in the PDG 2016 fit.

The Belle result on $\tau^- \to K^0_S(\text{particles})^-\nu_\tau$ [1342] has been discarded, because it was determined that the published information does not permit a reliable determination of the correlations with the other results in the same paper. The correlations estimated for the HFLAV 2014 report were inconsistent. As a result, both the covariance matrix of the Belle results and the overall correlation matrix for the branching ratio fit results were non-positive-definite. It has been found that the inconsistency had negligible impact on lepton universality tests and on the $|V_{us}|$ measurements.

The ALEPH result on $\Gamma_{46}(\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau)$ [1329] has been removed from the fit inputs, since it is simply the sum of twice $\Gamma_{47} = \pi^- K^0_S K^0_S \nu_\tau$ and $\Gamma_{48} = \pi^- K^0_S K^0_L \nu_\tau$ from the same paper, hence 100% correlated with them.

Several minor corrections have been applied to the constraints. The list of constraints included in the following fully documents the changes when compared with the same list in the 2014 edition. In some cases the relation equating one decay mode to a sum of modes included some minor terms that did not match the mode definitions. In other cases, the sum included modes with overlapping components. The effects on the 2014 fit results have been found to be modest with respect to the quoted uncertainties. For instance, the definition of the total branching fraction has been updated as follows:

$$\begin{aligned}
\Gamma_{\text{All}} = {} & \Gamma_3 + \Gamma_5 + \Gamma_9 + \Gamma_{10} + \Gamma_{14} + \Gamma_{16} + \Gamma_{20} + \Gamma_{23} \\
& + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + \Gamma_{35} + \Gamma_{37} + \Gamma_{40} + \Gamma_{42} \\
& + \Gamma_{47} \cdot (1 + ((\Gamma_{<K^0|K_L>} \cdot \Gamma_{<\bar{K}^0|K_L>})/(\Gamma_{<K^0|K_S>} \\
& \cdot \Gamma_{<\bar{K}^0|K_S>}))) + \Gamma_{48} + \Gamma_{62} \\
& + \Gamma_{70} + \Gamma_{77} + \Gamma_{811} + \Gamma_{812} + \Gamma_{93} \\
& + \Gamma_{94} + \Gamma_{832} + \Gamma_{833} + \Gamma_{126} + \Gamma_{128} + \Gamma_{802} + \Gamma_{803} \\
& + \Gamma_{800} + \Gamma_{151} + \Gamma_{130} + \Gamma_{132} + \Gamma_{44} + \Gamma_{53} \\
& + \Gamma_{50} \cdot (1 + ((\Gamma_{<K^0|K_L>} \cdot \Gamma_{<\bar{K}^0|K_L>})/(\Gamma_{<K^0|K_S>} \\
& \cdot \Gamma_{<\bar{K}^0|K_S>}))) + \Gamma_{51} \\
& + \Gamma_{167} \cdot (\Gamma_{\phi\to K^+K^-} + \Gamma_{\phi\to K_S K_L}) + \Gamma_{152} + \Gamma_{920} \\
& + \Gamma_{821} + \Gamma_{822} + \Gamma_{831} + \Gamma_{136} + \Gamma_{945} + \Gamma_{805}
\end{aligned}$$

In the 2014 definition, the term $\Gamma_{78} = h^- h^- h^+ 3\pi^0 \nu_\tau$ included the contributions of $\Gamma_{50} = \pi^- \pi^0 K^0_S K^0_S \nu_\tau$ and $\Gamma_{132} = \pi^- \bar{K}^0 \eta \nu_\tau$, which were already included explicitly in Γ_{All}. In the present definition, Γ_{78} has been replaced with modes whose sum corresponds to

$$\Gamma_{810} = 2\pi^- \pi^+ 3\pi^0 \nu_\tau \text{ (ex. } K^0)$$

As in 2014, the total τ branching fraction Γ_{All} definition includes two modes that have overlapping final states, to a minor extent, which we consider negligible:

$$\begin{aligned}
\Gamma_{50} &= \pi^- \pi^0 K^0_S K^0_S \nu_\tau \\
\Gamma_{132} &= \pi^- \bar{K}^0 \eta \nu_\tau .
\end{aligned}$$

Finally, we updated to the PDG 2015 results [327] all the parameters corresponding to the measurements' systematic biases and uncertainties and all the parameters appearing in the constraint equations in Sect. 9.1.7 and Table 304.

9.1.4 *Differences between the HFLAV Spring 2017 fit and the PDG 2016 fit*

As is standard for the PDG branching fraction fits, the PDG 2016 τ branching fraction fit is unitarity constrained, while the HFLAV 2016 fit is unconstrained.

The HFLAV-Tau fit uses the ALEPH measurements of branching fractions defined according to the final state content of "hadrons" and kaons, where a "hadron" corresponds to either a pion or a kaon, since this set of results is closer to the actual experimental measurements and facilitates a more comprehensive treatment of the experimental results correlations [420]. The PDG 2016 fit on the other hand continues to use – as in the past editions – the ALEPH measurements of modes with pions and kaons, which correspond to the final set of published measurements of the collaboration. It is planned eventually to update the PDG fit to use the same ALEPH measurement set that is used by HFLAV.

The HFLAV Spring 2017 fit, as in 2014, uses the ALEPH estimate for $\Gamma_{805} = B(\tau \to a_1^-(\to \pi^-\gamma)\nu_\tau)$, which is not a direct measurement. The PDG 2016 fit uses the PDG average of $B(a_1 \to \pi\gamma)$ as a parameter and defines $\Gamma_{805} = B(a_1 \to \pi\gamma) \times B(\tau \to 3\pi\nu)$. As a consequence, the PDG fit procedure does not take into account the large uncertainty on $B(a_1 \to \pi\gamma)$, resulting in an underestimated fit uncertainty on Γ_{805}. Therefore, in this case an appropriate correction has to be applied after the fit.

9.1.5 *Branching ratio fit results and experimental inputs*

Table 304 reports the τ branching ratio fit results and experimental inputs.

9.1.6 *Correlation terms between basis branching fractions uncertainties*

The following tables report the correlation coefficients between basis quantities, in percent (Tables 305, 306, 307, 308, 309, 310, 311, 312, 313, 314).

9.1.7 *Equality constraints*

We list in the following the equality constraints that relate a branching fraction to a sum of branching fractions. The constraint equations include as coefficients the values of some non-tau branching fractions, denoted e.g., with the self-describing notation $\Gamma_{K_S \to \pi^0\pi^0}$. Some coefficients are probabilities corresponding to modulus square amplitudes describing quantum mixtures of states such as K^0, $\bar{K}^0$, K_S, K_L, denoted with e.g., $\Gamma_{<K^0|K_S>} = |{<}K^0|K_S{>}|^2$. All non-tau quantities are taken from the PDG 2015 [327] fits (when available) or averages, and are used without accounting for

Table 305 Basis quantities correlation coefficients in percent, subtable 1

Γ_{5}	23													
Γ_{9}	7	5												
Γ_{10}	3	5	1											
Γ_{14}	−13	−14	−12	−3										
Γ_{16}	0	−1	2	−1	−16									
Γ_{20}	−5	−5	−7	−1	−40	2								
Γ_{23}	0	0	0	−2	2	−13	−22							
Γ_{27}	−4	−3	−8	−1	0	3	−36	6						
Γ_{28}	0	0	0	−2	2	−13	5	−21	−29					
Γ_{30}	−5	−4	−11	−2	−9	0	6	0	−42	0				
Γ_{35}	0	0	0	0	0	0	0	1	0	1	0			
Γ_{37}	0	0	0	0	0	−2	1	−3	1	−3	0	−22		
Γ_{40}	0	0	0	0	0	1	0	1	−2	1	0	−12	4	
	Γ_{3}	Γ_{5}	Γ_{9}	Γ_{10}	Γ_{14}	Γ_{16}	Γ_{20}	Γ_{23}	Γ_{27}	Γ_{28}	Γ_{30}	Γ_{35}	Γ_{37}	Γ_{40}

Table 306 Basis quantities correlation coefficients in percent, subtable 2

Γ_{42}	0	0	0	0	1	−3	1	−5	1	−5	0	2	−21	−20
Γ_{44}	0	0	0	0	0	0	0	0	0	0	0	−1	0	−4
Γ_{47}	0	0	0	0	0	0	0	0	0	0	0	−1	1	−4
Γ_{48}	0	0	0	0	0	0	0	0	0	0	0	−3	0	−2
Γ_{50}	0	0	0	0	0	0	0	−1	0	−1	0	0	7	0
Γ_{51}	0	0	0	0	0	0	0	0	0	0	0	−1	0	−1
Γ_{53}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{62}	−3	−5	8	0	−4	5	−7	−1	−5	−1	−5	0	0	0
Γ_{70}	−6	−6	−7	−1	−8	−1	−1	0	−1	0	3	0	0	0
Γ_{77}	−1	0	−3	−1	−2	0	0	0	2	0	2	0	0	0
Γ_{93}	−1	−1	3	0	−1	2	−1	0	−1	0	−1	0	0	0
Γ_{94}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{126}	0	0	0	0	0	0	−1	0	0	0	−2	0	0	0
Γ_{128}	0	0	1	0	0	1	0	−1	0	−1	0	0	0	0
	Γ_{3}	Γ_{5}	Γ_{9}	Γ_{10}	Γ_{14}	Γ_{16}	Γ_{20}	Γ_{23}	Γ_{27}	Γ_{28}	Γ_{30}	Γ_{35}	Γ_{37}	Γ_{40}

Table 307 Basis quantities correlation coefficients in percent, subtable 3

Γ_{130}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{132}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{136}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{151}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{152}	−1	0	−3	−1	−2	0	−1	0	2	0	2	0	0	0
Γ_{167}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{800}	−2	−2	−2	0	−3	0	0	0	0	0	1	0	0	0
Γ_{802}	−1	−1	0	0	−1	0	−2	0	−2	0	−1	0	0	0
Γ_{803}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{805}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{811}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{812}	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{821}	0	0	1	0	0	0	−1	0	0	0	−1	0	0	0
Γ_{822}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Γ_{3}	Γ_{5}	Γ_{9}	Γ_{10}	Γ_{14}	Γ_{16}	Γ_{20}	Γ_{23}	Γ_{27}	Γ_{28}	Γ_{30}	Γ_{35}	Γ_{37}	Γ_{40}

Table 308 Basis quantities correlation coefficients in percent, subtable 4

Γ_{831}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{832}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{833}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{920}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{945}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Γ_{3}	Γ_{5}	Γ_{9}	Γ_{10}	Γ_{14}	Γ_{16}	Γ_{20}	Γ_{23}	Γ_{27}	Γ_{28}	Γ_{30}	Γ_{35}	Γ_{37}	Γ_{40}

Table 309 Basis quantities correlation coefficients in percent, subtable 5

Γ_{44}	0													
Γ_{47}	1	0												
Γ_{48}	−1	−6	0											
Γ_{50}	5	0	−7	0										
Γ_{51}	0	−3	0	−6	0									
Γ_{53}	0	0	0	0	0	0								
Γ_{62}	0	0	1	0	0	0	0							
Γ_{70}	0	0	0	0	0	0	0	−20						
Γ_{77}	0	0	0	0	0	0	0	−1	−7					
Γ_{93}	0	0	0	0	0	0	0	14	−4	0				
Γ_{94}	0	0	0	0	0	0	0	0	−2	0	0			
Γ_{126}	0	0	1	0	0	0	0	1	0	−5	0	0		
Γ_{128}	0	0	1	0	0	0	0	2	0	0	1	0	4	
	Γ_{42}	Γ_{44}	Γ_{47}	Γ_{48}	Γ_{50}	Γ_{51}	Γ_{53}	Γ_{62}	Γ_{70}	Γ_{77}	Γ_{93}	Γ_{94}	Γ_{126}	Γ_{128}

Table 310 Basis quantities correlation coefficients in percent, subtable 6

Γ_{130}	0	0	0	0	0	0	0	0	0	−1	0	0	1	1
Γ_{132}	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Γ_{136}	0	0	0	0	0	0	0	0	−1	0	0	0	0	0
Γ_{151}	0	0	0	0	0	0	0	0	12	0	0	0	0	0
Γ_{152}	0	0	0	0	0	0	0	−1	−11	−64	0	0	0	0
Γ_{167}	0	0	0	0	0	0	0	−1	0	0	1	0	0	0
Γ_{800}	0	0	0	0	0	0	0	−8	−69	−2	−1	0	0	0
Γ_{802}	0	0	0	0	0	0	0	16	−6	0	0	0	0	0
Γ_{803}	0	0	0	0	0	0	0	−1	−19	0	0	−2	0	−1
Γ_{805}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{811}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{812}	0	0	0	0	−1	0	0	0	−1	0	0	0	0	0
Γ_{821}	0	0	0	0	0	0	0	0	−1	0	0	0	0	0
Γ_{822}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Γ_{42}	Γ_{44}	Γ_{47}	Γ_{48}	Γ_{50}	Γ_{51}	Γ_{53}	Γ_{62}	Γ_{70}	Γ_{77}	Γ_{93}	Γ_{94}	Γ_{126}	Γ_{128}

Table 311 Basis quantities correlation coefficients in percent, subtable 7

Γ_{831}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{832}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{833}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{920}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Γ_{945}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Γ_{42}	Γ_{44}	Γ_{47}	Γ_{48}	Γ_{50}	Γ_{51}	Γ_{53}	Γ_{62}	Γ_{70}	Γ_{77}	Γ_{93}	Γ_{94}	Γ_{126}	Γ_{128}

Table 312 Basis quantities correlation coefficients in percent, subtable 8

	Γ_{130}	Γ_{132}	Γ_{136}	Γ_{151}	Γ_{152}	Γ_{167}	Γ_{800}	Γ_{802}	Γ_{803}	Γ_{805}	Γ_{811}	Γ_{812}	Γ_{821}	Γ_{822}
Γ_{132}	0													
Γ_{136}	0	0												
Γ_{151}	0	0	0											
Γ_{152}	0	0	0	0										
Γ_{167}	0	0	0	0	0									
Γ_{800}	0	0	0	−14	−3	0								
Γ_{802}	0	0	0	−2	0	1	−1							
Γ_{803}	0	0	0	−58	0	0	9	1						
Γ_{805}	0	0	0	0	0	0	0	0	0					
Γ_{811}	0	−1	20	0	0	0	0	0	0	0				
Γ_{812}	0	−2	−8	0	0	0	0	0	0	0	−16			
Γ_{821}	0	0	47	0	0	0	0	0	0	0	8	−4		
Γ_{822}	0	0	−1	0	0	0	0	0	0	0	0	0	−1	

Table 313 Basis quantities correlation coefficients in percent, subtable 9

	Γ_{130}	Γ_{132}	Γ_{136}	Γ_{151}	Γ_{152}	Γ_{167}	Γ_{800}	Γ_{802}	Γ_{803}	Γ_{805}	Γ_{811}	Γ_{812}	Γ_{821}	Γ_{822}
Γ_{831}	0	0	39	0	0	0	0	0	0	0	14	−4	39	−1
Γ_{832}	0	0	3	0	0	0	0	0	0	0	2	0	3	0
Γ_{833}	0	0	−1	0	0	0	0	0	0	0	0	0	−1	0
Γ_{920}	0	0	21	0	0	0	0	0	0	0	3	−2	35	−1
Γ_{945}	0	−1	25	0	0	0	0	0	0	0	10	−11	10	0

Table 314 Basis quantities correlation coefficients in percent, subtable 10

	Γ_{831}	Γ_{832}	Γ_{833}	Γ_{920}	Γ_{945}
Γ_{832}	−2				
Γ_{833}	−1	−1			
Γ_{920}	17	1	0		
Γ_{945}	17	2	0	4	

their uncertainties, which are however in general small with respect to the uncertainties on the τ branching fractions.

The following list does not include the constraints listed in Table 304, where some measured ratios of branching fractions are expressed as ratios of two branching fractions.

$$\begin{aligned}\Gamma_1 = {} & \Gamma_3 + \Gamma_5 + \Gamma_9 + \Gamma_{10} + \Gamma_{14} + \Gamma_{16}\\ & + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + \Gamma_{35}\\ & + \Gamma_{40} + \Gamma_{44} + \Gamma_{37} + \Gamma_{42} + \Gamma_{47} + \Gamma_{48}\\ & + \Gamma_{804} + \Gamma_{50} + \Gamma_{51} + \Gamma_{806} + \Gamma_{126} \cdot \Gamma_{\eta \to \text{neutral}}\\ & + \Gamma_{128} \cdot \Gamma_{\eta \to \text{neutral}} + \Gamma_{130} \cdot \Gamma_{\eta \to \text{neutral}}\\ & + \Gamma_{132} \cdot \Gamma_{\eta \to \text{neutral}} + \Gamma_{800} \cdot \Gamma_{\omega \to \pi^0 \gamma}\\ & + \Gamma_{151} \cdot \Gamma_{\omega \to \pi^0 \gamma} + \Gamma_{152} \cdot \Gamma_{\omega \to \pi^0 \gamma}\\ & + \Gamma_{167} \cdot \Gamma_{\phi \to K_S K_L}\end{aligned}$$

$$\begin{aligned}\Gamma_2 = {} & \Gamma_3 + \Gamma_5\\ & + \Gamma_9 + \Gamma_{10} + \Gamma_{14} + \Gamma_{16}\\ & + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30}\\ & + \Gamma_{35} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S \to \pi^0 \pi^0}\\ & + \Gamma_{<\bar{K}^0|K_L>}) + \Gamma_{40} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S \to \pi^0 \pi^0}\\ & + \Gamma_{<\bar{K}^0|K_L>}) + \Gamma_{44} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S \to \pi^0 \pi^0}\\ & + \Gamma_{<\bar{K}^0|K_L>}) + \Gamma_{37} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S \to \pi^0 \pi^0}\\ & + \Gamma_{<\bar{K}^0|K_L>}) + \Gamma_{42} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S \to \pi^0 \pi^0}\\ & + \Gamma_{<\bar{K}^0|K_L>}) + \Gamma_{47} \cdot (\Gamma_{K_S \to \pi^0 \pi^0} \cdot \Gamma_{K_S \to \pi^0 \pi^0})\\ & + \Gamma_{48} \cdot \Gamma_{K_S \to \pi^0 \pi^0} + \Gamma_{804}\\ & + \Gamma_{50} \cdot (\Gamma_{K_S \to \pi^0 \pi^0} \cdot \Gamma_{K_S \to \pi^0 \pi^0}) + \Gamma_{51} \cdot \Gamma_{K_S \to \pi^0 \pi^0}\\ & + \Gamma_{806} + \Gamma_{126} \cdot \Gamma_{\eta \to \text{neutral}} + \Gamma_{128} \cdot \Gamma_{\eta \to \text{neutral}}\\ & + \Gamma_{130} \cdot \Gamma_{\eta \to \text{neutral}}\\ & + \Gamma_{132} \cdot (\Gamma_{\eta \to \text{neutral}} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S \to \pi^0 \pi^0}\\ & + \Gamma_{<\bar{K}^0|K_L>})) + \Gamma_{800} \cdot \Gamma_{\omega \to \pi^0 \gamma}\\ & + \Gamma_{151} \cdot \Gamma_{\omega \to \pi^0 \gamma} + \Gamma_{152} \cdot \Gamma_{\omega \to \pi^0 \gamma}\\ & + \Gamma_{167} \cdot (\Gamma_{\phi \to K_S K_L} \cdot \Gamma_{K_S \to \pi^0 \pi^0})\end{aligned}$$

$$\begin{aligned}\Gamma_7 = {} & \Gamma_{35} \cdot \Gamma_{<\bar{K}^0|K_L>} + \Gamma_9 + \Gamma_{804} + \Gamma_{37} \cdot \Gamma_{<K^0|K_L>}\\ & + \Gamma_{10}\end{aligned}$$

$$\Gamma_8 = \Gamma_9 + \Gamma_{10}$$

$$\begin{aligned}\Gamma_{11} =& \Gamma_{14} + \Gamma_{16} + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28}\\
&+ \Gamma_{30} + \Gamma_{35} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+ \Gamma_{37} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+ \Gamma_{40} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+ \Gamma_{42} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+ \Gamma_{47} \cdot (\Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+ \Gamma_{50} \cdot (\Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+ \Gamma_{126} \cdot \Gamma_{\eta\to\text{neutral}} + \Gamma_{128} \cdot \Gamma_{\eta\to\text{neutral}}\\
&+ \Gamma_{130} \cdot \Gamma_{\eta\to\text{neutral}}\\
&+ \Gamma_{132} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{\eta\to\text{neutral}})\\
&+ \Gamma_{151} \cdot \Gamma_{\omega\to\pi^0\gamma}\\
&+ \Gamma_{152} \cdot \Gamma_{\omega\to\pi^0\gamma} + \Gamma_{800} \cdot \Gamma_{\omega\to\pi^0\gamma}\end{aligned}$$

$$\begin{aligned}\Gamma_{12} =& \Gamma_{128} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{30} + \Gamma_{23} + \Gamma_{28} + \Gamma_{14}\\
&+ \Gamma_{16} + \Gamma_{20} + \Gamma_{27}\\
&+ \Gamma_{126} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{130} \cdot \Gamma_{\eta\to 3\pi^0}\end{aligned}$$

$$\Gamma_{13} = \Gamma_{14} + \Gamma_{16}$$

$$\begin{aligned}\Gamma_{17} =& \Gamma_{128} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{30} + \Gamma_{23} + \Gamma_{28}\\
&+\Gamma_{35} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{40} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{42} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{20} + \Gamma_{27} + \Gamma_{47} \cdot (\Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{50} \cdot (\Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{126} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{37} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{130} \cdot \Gamma_{\eta\to 3\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{18} =& \Gamma_{23} + \Gamma_{35} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{20} + \Gamma_{37} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\end{aligned}$$

$$\Gamma_{19} = \Gamma_{23} + \Gamma_{20}$$

$$\begin{aligned}\Gamma_{24} =& \Gamma_{27} + \Gamma_{28} + \Gamma_{30}\\
&+\Gamma_{40} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{42} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{47} \cdot (\Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{50} \cdot (\Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{126} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{128} \cdot \Gamma_{\eta\to 3\pi^0}\\
&+\Gamma_{130} \cdot \Gamma_{\eta\to 3\pi^0}\\
&+\Gamma_{132} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{\eta\to 3\pi^0})\end{aligned}$$

$$\begin{aligned}\Gamma_{25} =& \Gamma_{128} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{30} + \Gamma_{28}\\
&+\Gamma_{27} + \Gamma_{126} \cdot \Gamma_{\eta\to 3\pi^0}\\
&+\Gamma_{130} \cdot \Gamma_{\eta\to 3\pi^0}\\
&+\Gamma_{30} + \Gamma_{28} + \Gamma_{27} + \Gamma_{126} \cdot \Gamma_{\eta\to 3\pi^0}\\
&+\Gamma_{130} \cdot \Gamma_{\eta\to 3\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{26} =& \Gamma_{128} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{27}\\
&+\Gamma_{28} + \Gamma_{40} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{42} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0})\end{aligned}$$

$$\Gamma_{29} = \Gamma_{30} + \Gamma_{126} \cdot \Gamma_{\eta\to 3\pi^0} + \Gamma_{130} \cdot \Gamma_{\eta\to 3\pi^0}$$

$$\begin{aligned}\Gamma_{31} =& \Gamma_{128} \cdot \Gamma_{\eta\to\text{neutral}} + \Gamma_{23}\\
&+\Gamma_{28} + \Gamma_{42} + \Gamma_{16}\\
&+\Gamma_{37} + \Gamma_{10} + \Gamma_{167} \cdot (\Gamma_{\phi\to K_S K_L} \cdot \Gamma_{K_S\to\pi^0\pi^0})\end{aligned}$$

$$\begin{aligned}\Gamma_{32} =& \Gamma_{16} + \Gamma_{23} + \Gamma_{28} + \Gamma_{37}\\
&+\Gamma_{42} + \Gamma_{128} \cdot \Gamma_{\eta\to\text{neutral}}\\
&+\Gamma_{130} \cdot \Gamma_{\eta\to\text{neutral}}\\
&+\Gamma_{167} \cdot (\Gamma_{\phi\to K_S K_L} \cdot \Gamma_{K_S\to\pi^0\pi^0})\end{aligned}$$

$$\begin{aligned}\Gamma_{33} =& \Gamma_{35} \cdot \Gamma_{<\bar{K}^0|K_S>} + \Gamma_{40} \cdot \Gamma_{<\bar{K}^0|K_S>}\\
&+\Gamma_{42} \cdot \Gamma_{<K^0|K_S>}\\
&+\Gamma_{47} + \Gamma_{48} + \Gamma_{50} + \Gamma_{51}\\
&+\Gamma_{37} \cdot \Gamma_{<K^0|K_S>}\\
&+\Gamma_{132} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{\eta\to\text{neutral}})\\
&+\Gamma_{44} \cdot \Gamma_{<\bar{K}^0|K_S>} + \Gamma_{167} \cdot \Gamma_{\phi\to K_S K_L}\end{aligned}$$

$$\Gamma_{34} = \Gamma_{35} + \Gamma_{37}$$

$$\Gamma_{38} = \Gamma_{42} + \Gamma_{37}$$

$$\Gamma_{39} = \Gamma_{40} + \Gamma_{42}$$

$$\Gamma_{43} = \Gamma_{40} + \Gamma_{44}$$

$$\Gamma_{46} = \Gamma_{48} + \Gamma_{47} + \Gamma_{804}$$

$$\Gamma_{49} = \Gamma_{50} + \Gamma_{51} + \Gamma_{806}$$

$$\begin{aligned}\Gamma_{54} =& \Gamma_{35} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^+\pi^-})\\
&+\Gamma_{37} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^+\pi^-})\\
&+\Gamma_{40} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^+\pi^-})\\
&+\Gamma_{42} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^+\pi^-})\\
&+\Gamma_{47} \cdot (2 \cdot \Gamma_{K_S\to\pi^+\pi^-} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{48} \cdot \Gamma_{K_S\to\pi^+\pi^-}\\
&+\Gamma_{50} \cdot (2 \cdot \Gamma_{K_S\to\pi^+\pi^-} \cdot \Gamma_{K_S\to\pi^0\pi^0})\\
&+\Gamma_{51} \cdot \Gamma_{K_S\to\pi^+\pi^-}\\
&+\Gamma_{53} \cdot (\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0} + \Gamma_{<\bar{K}^0|K_L>})\\
&+\Gamma_{62} + \Gamma_{70}\\
&+\Gamma_{77} + \Gamma_{78} + \Gamma_{93}\\
&+\Gamma_{94} + \Gamma_{126} \cdot \Gamma_{\eta\to\text{charged}}\\
&+\Gamma_{128} \cdot \Gamma_{\eta\to\text{charged}} + \Gamma_{130} \cdot \Gamma_{\eta\to\text{charged}}\\
&+\Gamma_{132} \cdot (\Gamma_{<\bar{K}^0|K_L>} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0}\\
&+\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S\to\pi^0\pi^0} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0}\\
&+\Gamma_{<\bar{K}^0|K_S>} \cdot \Gamma_{K_S\to\pi^+\pi^-} \cdot \Gamma_{\eta\to 3\pi^0})\\
&+\Gamma_{151} \cdot (\Gamma_{\omega\to\pi^+\pi^-\pi^0} + \Gamma_{\omega\to\pi^+\pi^-})\\
&+\Gamma_{152} \cdot (\Gamma_{\omega\to\pi^+\pi^-\pi^0} + \Gamma_{\omega\to\pi^+\pi^-})\\
&+\Gamma_{167} \cdot (\Gamma_{\phi\to K^+K^-} + \Gamma_{\phi\to K_S K_L} \cdot \Gamma_{K_S\to\pi^+\pi^-})\\
&+\Gamma_{802} + \Gamma_{803}\end{aligned}$$

$$+\Gamma_{800}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{\omega\to\pi^+\pi^-})$$

$$\begin{aligned}\Gamma_{55}=\;&\Gamma_{128}\cdot\Gamma_{\eta\to\text{charged}}\\&+\Gamma_{152}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{\omega\to\pi^+\pi^-})+\Gamma_{78}\\&+\Gamma_{77}+\Gamma_{94}+\Gamma_{62}+\Gamma_{70}+\Gamma_{93}\\&+\Gamma_{126}\cdot\Gamma_{\eta\to\text{charged}}\\&+\Gamma_{802}+\Gamma_{803}+\Gamma_{800}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{\omega\to\pi^+\pi^-})\\&+\Gamma_{151}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{\omega\to\pi^+\pi^-})\\&+\Gamma_{130}\cdot\Gamma_{\eta\to\text{charged}}+\Gamma_{168}\end{aligned}$$

$$\begin{aligned}\Gamma_{56}=\;&\Gamma_{35}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{62}+\Gamma_{93}+\Gamma_{37}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{802}+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-}\\&+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-}+\Gamma_{168}\end{aligned}$$

$$\begin{aligned}\Gamma_{57}=\;&\Gamma_{62}+\Gamma_{93}+\Gamma_{802}\\&+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-}\\&+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-}\\&+\Gamma_{167}\cdot\Gamma_{\phi\to K^+K^-}\end{aligned}$$

$$\Gamma_{58}=\Gamma_{62}+\Gamma_{93}+\Gamma_{802}+\Gamma_{167}\cdot\Gamma_{\phi\to K^+K^-}$$

$$\begin{aligned}\Gamma_{59}=\;&\Gamma_{35}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{62}+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-}\end{aligned}$$

$$\Gamma_{60}=\Gamma_{62}+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-}$$

$$\begin{aligned}\Gamma_{63}=\;&\Gamma_{40}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{42}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{47}\cdot(2\cdot\Gamma_{K_S\to\pi^+\pi^-}\cdot\Gamma_{K_S\to\pi^0\pi^0})\\&+\Gamma_{50}\cdot(2\cdot\Gamma_{K_S\to\pi^+\pi^-}\cdot\Gamma_{K_S\to\pi^0\pi^0})\\&+\Gamma_{70}+\Gamma_{77}+\Gamma_{78}\\&+\Gamma_{94}+\Gamma_{126}\cdot\Gamma_{\eta\to\text{charged}}\\&+\Gamma_{128}\cdot\Gamma_{\eta\to\text{charged}}+\Gamma_{130}\cdot\Gamma_{\eta\to\text{charged}}\\&+\Gamma_{132}\cdot(\Gamma_{<\bar{K}^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-}\cdot\Gamma_{\eta\to\text{neutral}}\\&+\Gamma_{<\bar{K}^0|K_S>}\cdot\Gamma_{K_S\to\pi^0\pi^0}\cdot\Gamma_{\eta\to\text{charged}})\\&+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{152}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{\omega\to\pi^+\pi^-})+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{803}\end{aligned}$$

$$\begin{aligned}\Gamma_{64}=\;&\Gamma_{78}+\Gamma_{77}+\Gamma_{94}+\Gamma_{70}\\&+\Gamma_{126}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{128}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{130}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{152}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{\omega\to\pi^+\pi^-})\\&+\Gamma_{803}\end{aligned}$$

$$\begin{aligned}\Gamma_{65}=\;&\Gamma_{40}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{42}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})+\Gamma_{70}+\Gamma_{94}\\&+\Gamma_{128}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{152}\cdot\Gamma_{\omega\to\pi^+\pi^-}\\&+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{803}\end{aligned}$$

$$\begin{aligned}\Gamma_{66}=\;&\Gamma_{70}+\Gamma_{94}+\Gamma_{128}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{152}\cdot\Gamma_{\omega\to\pi^+\pi^-}\\&+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{803}\end{aligned}$$

$$\begin{aligned}\Gamma_{67}=\;&\Gamma_{70}+\Gamma_{94}\\&+\Gamma_{128}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}+\Gamma_{803}\end{aligned}$$

$$\begin{aligned}\Gamma_{68}=\;&\Gamma_{40}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{70}+\Gamma_{152}\cdot\Gamma_{\omega\to\pi^+\pi^-}\\&+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{69}=\;&\Gamma_{152}\cdot\Gamma_{\omega\to\pi^+\pi^-}+\Gamma_{70}\\&+\Gamma_{800}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{74}=\;&\Gamma_{152}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{78}\\&+\Gamma_{77}+\Gamma_{126}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{130}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{75}=\;&\Gamma_{152}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{47}\cdot(2\cdot\Gamma_{K_S\to\pi^+\pi^-}\cdot\Gamma_{K_S\to\pi^0\pi^0})\\&+\Gamma_{77}+\Gamma_{126}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{130}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{76}=\;&\Gamma_{152}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{77}\\&+\Gamma_{126}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\\&+\Gamma_{130}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{78}=\;&\Gamma_{810}+\Gamma_{50}\cdot(2\cdot\Gamma_{K_S\to\pi^+\pi^-}\cdot\Gamma_{K_S\to\pi^0\pi^0})\\&+\Gamma_{132}\cdot(\Gamma_{<\bar{K}^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-}\cdot\Gamma_{\eta\to3\pi^0})\end{aligned}$$

$$\begin{aligned}\Gamma_{79}=\;&\Gamma_{37}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{42}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\\&+\Gamma_{93}+\Gamma_{94}+\Gamma_{128}\cdot\Gamma_{\eta\to\text{charged}}\\&+\Gamma_{151}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{\omega\to\pi^+\pi^-})+\Gamma_{168}+\Gamma_{802}+\Gamma_{803}\end{aligned}$$

$$\Gamma_{80}=\Gamma_{93}+\Gamma_{802}+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-}$$

$$\begin{aligned}\Gamma_{81}=\;&\Gamma_{128}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}+\Gamma_{94}\\&+\Gamma_{803}+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-\pi^0}\end{aligned}$$

$$\begin{aligned}\Gamma_{82}=\;&\Gamma_{128}\cdot\Gamma_{\eta\to\text{charged}}\\&+\Gamma_{42}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})+\Gamma_{802}\\&+\Gamma_{803}+\Gamma_{151}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}+\Gamma_{\omega\to\pi^+\pi^-})\\&+\Gamma_{37}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\end{aligned}$$

$$\begin{aligned}\Gamma_{83}=\;&\Gamma_{128}\cdot\Gamma_{\eta\to\pi^+\pi^-\pi^0}+\Gamma_{802}\\&+\Gamma_{803}+\Gamma_{151}\cdot(\Gamma_{\omega\to\pi^+\pi^-\pi^0}\\&+\Gamma_{\omega\to\pi^+\pi^-})\end{aligned}$$

$$\begin{aligned}\Gamma_{84}=\;&\Gamma_{802}+\Gamma_{151}\cdot\Gamma_{\omega\to\pi^+\pi^-}\\&+\Gamma_{37}\cdot(\Gamma_{<K^0|K_S>}\cdot\Gamma_{K_S\to\pi^+\pi^-})\end{aligned}$$

$$\begin{aligned}
\Gamma_{85} &= \Gamma_{802} + \Gamma_{151} \cdot \Gamma_{\omega\to\pi^+\pi^-} \\
\Gamma_{87} &= \Gamma_{42} \cdot (\Gamma_{<K^0|K_S>} \cdot \Gamma_{K_S\to\pi^+\pi^-}) \\
&\quad +\Gamma_{128} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0} \\
&\quad +\Gamma_{151} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0} + \Gamma_{803} \\
\Gamma_{88} &= \Gamma_{128} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0} + \Gamma_{803} + \Gamma_{151} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0} \\
\Gamma_{89} &= \Gamma_{803} + \Gamma_{151} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0} \\
\Gamma_{92} &= \Gamma_{94} + \Gamma_{93} \\
\Gamma_{96} &= \Gamma_{167} \cdot \Gamma_{\phi\to K^+K^-} \\
\Gamma_{102} &= \Gamma_{103} + \Gamma_{104} \\
\Gamma_{103} &= \Gamma_{820} + \Gamma_{822} + \Gamma_{831} \cdot \Gamma_{\omega\to\pi^+\pi^-} \\
\Gamma_{104} &= \Gamma_{830} + \Gamma_{833} \\
\Gamma_{106} &= \Gamma_{30} + \Gamma_{44} \cdot \Gamma_{<\bar{K}^0|K_S>} \\
&\quad +\Gamma_{47} + \Gamma_{53} \cdot \Gamma_{<K^0|K_S>} \\
&\quad +\Gamma_{77} + \Gamma_{103} + \Gamma_{126} \cdot (\Gamma_{\eta\to 3\pi^0} + \Gamma_{\eta\to\pi^+\pi^-\pi^0}) \\
&\quad +\Gamma_{152} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0} \\
\Gamma_{110} &= \Gamma_{10} + \Gamma_{16} + \Gamma_{23} + \Gamma_{28} + \Gamma_{35} + \Gamma_{40} \\
&\quad +\Gamma_{128} + \Gamma_{802} + \Gamma_{803} + \Gamma_{151} + \Gamma_{130} + \Gamma_{132} \\
&\quad +\Gamma_{44} + \Gamma_{53} + \Gamma_{168} + \Gamma_{169} \\
&\quad +\Gamma_{822} + \Gamma_{833} \\
\Gamma_{149} &= \Gamma_{152} + \Gamma_{800} + \Gamma_{151} \\
\Gamma_{150} &= \Gamma_{800} + \Gamma_{151}
\end{aligned}$$

$$\begin{aligned}
\Gamma_{168} &= \Gamma_{167} \cdot \Gamma_{\phi\to K^+K^-} \\
\Gamma_{169} &= \Gamma_{167} \cdot \Gamma_{\phi\to K_S K_L} \\
\Gamma_{804} &= \Gamma_{47} \cdot ((\Gamma_{<K^0|K_L>} \cdot \Gamma_{<\bar{K}^0|K_L>})/ \\
&\quad (\Gamma_{<K^0|K_S>} \cdot \Gamma_{<\bar{K}^0|K_S>})) \\
\Gamma_{806} &= \Gamma_{50} \cdot ((\Gamma_{<K^0|K_L>} \cdot \Gamma_{<\bar{K}^0|K_L>})/ \\
&\quad (\Gamma_{<K^0|K_S>} \cdot \Gamma_{<\bar{K}^0|K_S>})) \\
\Gamma_{810} &= \Gamma_{910} + \Gamma_{911} + \Gamma_{811} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0} + \Gamma_{812} \\
\Gamma_{820} &= \Gamma_{920} + \Gamma_{821} \\
\Gamma_{830} &= \Gamma_{930} + \Gamma_{831} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0} + \Gamma_{832} \\
\Gamma_{910} &= \Gamma_{136} \cdot \Gamma_{\eta\to 3\pi^0} \\
\Gamma_{911} &= \Gamma_{945} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0} \\
\Gamma_{930} &= \Gamma_{136} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0} \\
\Gamma_{944} &= \Gamma_{136} \cdot \Gamma_{\eta\to\gamma\gamma} \\
\Gamma_{\text{All}} &= \Gamma_{3} + \Gamma_{5} + \Gamma_{9} + \Gamma_{10} + \Gamma_{14} + \Gamma_{16} \\
&\quad +\Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + \Gamma_{35} \\
&\quad +\Gamma_{37} + \Gamma_{40} + \Gamma_{42} \\
&\quad +\Gamma_{47} \cdot (1 + ((\Gamma_{<K^0|K_L>} \\
&\quad \cdot\Gamma_{<\bar{K}^0|K_L>})/(\Gamma_{<K^0|K_S>} \cdot \Gamma_{<\bar{K}^0|K_S>}))) \\
&\quad +\Gamma_{48} + \Gamma_{62} + \Gamma_{70} + \Gamma_{77} + \Gamma_{811} + \Gamma_{812} \\
&\quad +\Gamma_{93} + \Gamma_{94} + \Gamma_{832} + \Gamma_{833} + \Gamma_{126} + \Gamma_{128} \\
&\quad +\Gamma_{802} + \Gamma_{803} + \Gamma_{800} + \Gamma_{151} + \Gamma_{130} + \Gamma_{132} \\
&\quad +\Gamma_{44} + \Gamma_{53} + \Gamma_{50} \cdot (1 + ((\Gamma_{<K^0|K_L>} \cdot \Gamma_{<\bar{K}^0|K_L>})/ \\
&\quad (\Gamma_{<K^0|K_S>} \cdot \Gamma_{<\bar{K}^0|K_S>}))) + \Gamma_{51} + \Gamma_{167} \\
&\quad \cdot(\Gamma_{\phi\to K^+K^-} + \Gamma_{\phi\to K_S K_L}) + \Gamma_{152} + \Gamma_{920} \\
&\quad +\Gamma_{821} + \Gamma_{822} + \Gamma_{831} + \Gamma_{136} + \Gamma_{945} + \Gamma_{805}
\end{aligned}$$

9.2 Tests of lepton universality

Lepton universality tests probe the Standard Model prediction that the charged weak current interaction has the same coupling for all lepton generations. The precision of such tests has been significantly improved since the 2014 edition by the addition of the Belle τ lifetime measurement [1402], while improvements from the τ branching fraction fit are negligible. We compute the universality tests as in the previous report by using ratios of the partial widths of a heavier lepton λ decaying to a lighter lepton ρ [1403],

$$\begin{aligned}
\Gamma(\lambda \to \nu_\lambda \rho \overline{\nu}_\rho(\gamma)) &= \frac{\mathcal{B}(\lambda \to \nu_\lambda \rho \overline{\nu}_\rho)}{\tau_\lambda} \\
&= \frac{G_\lambda G_\rho m_\lambda^5}{192\pi^3}\, f\left(\frac{m_\rho^2}{m_\lambda^2}\right) R_W^\lambda R_\gamma^\lambda,
\end{aligned}$$

where

$$G_\rho = \frac{g_\rho^2}{4\sqrt{2}M_W^2},$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x,$$

$$R_W^\lambda = 1 + \frac{3}{5}\frac{m_\lambda^2}{M_W^2} + \frac{9}{5}\frac{m_\rho^2}{M_W^2} \; [1390-1392],$$

$$R_\gamma^\lambda = 1 + \frac{\alpha(m_\lambda)}{2\pi}\left(\frac{25}{4} - \pi^2\right).$$

We use $R_\gamma^\tau = 1 - 43.2 \cdot 10^{-4}$ and $R_\gamma^\mu = 1 - 42.4 \cdot 10^{-4}$ [1403] and M_W from PDG 2015 [327]. We use HFLAV Spring 2017 averages and PDG 2015 for the other quantities. Using pure leptonic processes we obtain

$$\left(\frac{g_\tau}{g_\mu}\right) = 1.0010 \pm 0.0015,$$

$$\left(\frac{g_\tau}{g_e}\right) = 1.0029 \pm 0.0015,$$

$$\left(\frac{g_\mu}{g_e}\right) = 1.0019 \pm 0.0014.$$

Using the expressions for the τ semi-hadronic partial widths, we obtain

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{B(\tau \to h\nu_\tau)}{B(h \to \mu\bar{\nu}_\mu)} \frac{2m_h m_\mu^2 \tau_h}{(1+\delta R_{\tau/h}) m_\tau^3 \tau_\tau} \left(\frac{1-m_\mu^2/m_h^2}{1-m_h^2/m_\tau^2}\right)^2,$$

where $h = \pi$ or K and the radiative corrections are $\delta R_{\tau/\pi} = (0.16 \pm 0.14)\%$ and $\delta R_{\tau/K} = (0.90 \pm 0.22)\%$ [1407–1410]. We measure:

$$\left(\frac{g_\tau}{g_\mu}\right)_\pi = 0.9961 \pm 0.0027,$$

Table 315 Universality coupling ratios correlation coefficients (%)

$\left(\frac{g_\tau}{g_e}\right)$	53			
$\left(\frac{g_\mu}{g_e}\right)$	−49	48		
$\left(\frac{g_\tau}{g_\mu}\right)_\pi$	24	26	2	
$\left(\frac{g_\tau}{g_\mu}\right)_K$	11	10	−1	6
	$\left(\frac{g_\tau}{g_\mu}\right)$	$\left(\frac{g_\tau}{g_e}\right)$	$\left(\frac{g_\mu}{g_e}\right)$	$\left(\frac{g_\tau}{g_\mu}\right)_\pi$

$$\left(\frac{g_\tau}{g_\mu}\right)_K = 0.9860 \pm 0.0070.$$

Similar tests could be performed with decays to electrons, however they are less precise because the hadron two body decays to electrons are helicity-suppressed. Averaging the three g_τ/g_μ ratios we obtain

$$\left(\frac{g_\tau}{g_\mu}\right)_{\tau+\pi+K} = 1.0000 \pm 0.0014,$$

accounting for statistical correlations. Table 315 reports the statistical correlation coefficients for the fitted coupling ratios.

Since there is 100% correlation between g_τ/g_μ, g_τ/g_e and g_μ/g_e, the correlation matrix is expected to be positive semi-definite, with one eigenvalue equal to zero. Due to numerical inaccuracies, one eigenvalue is expected to be close to zero rather than exactly zero.

9.3 Universality improved $B(\tau \to e\nu\bar{\nu})$ and R_{had}

We compute two quantities that are used in this report and that have been traditionally used for further elaborations and tests involving the τ branching fractions:

- the "universality improved" experimental determination of $B_e = B(\tau \to e\nu\bar{\nu})$, which relies on the assumption that the Standard Model and lepton universality hold;
- the ratio R_{had} between the total branching fraction of the τ to hadrons and the universality improved $\mathcal{B}_e$, which is the same as the ratio of the two respective partial widths.

Following Ref. [1411], we obtain a more precise experimental determination of B_e using the τ branching fraction to $\mu\nu\bar{\nu}$, B_μ, and the τ lifetime. We average:

- the B_e fit value Γ_5,
- the B_e determination from the $B_\mu = B(\tau \to \mu\nu\bar{\nu})$ fit value Γ_3 assuming that $g_\mu/g_e = 1$, hence (see also Sect. 9.2) $B_e = B_\mu \cdot f(m_e^2/m_\tau^2)/f(m_\mu^2/m_\tau^2)$,
- the B_e determination from the τ lifetime assuming that $g_\tau/g_\mu = 1$, hence $B_e = B(\mu \to e\bar{\nu}_e\nu_\mu) \cdot (\tau_\tau/\tau_\mu) \cdot (m_\tau/m_\mu)^5 \cdot f(m_e^2/m_\tau^2)/f(m_e^2/m_\mu^2) \cdot (\delta_\gamma^\tau\delta_W^\tau)/(\delta_\gamma^\mu\delta_W^\mu)$ where $B(\mu \to e\bar{\nu}_e\nu_\mu) = 1$.

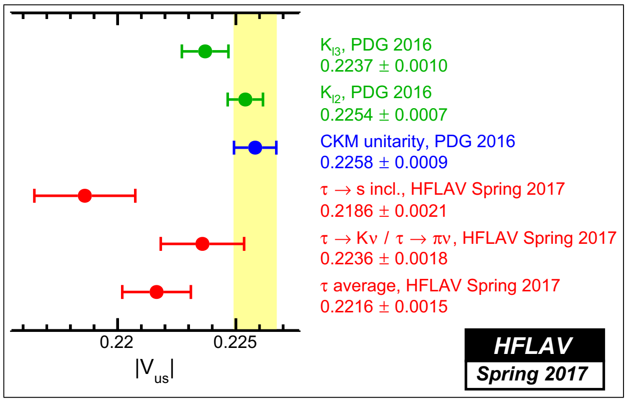


Fig. 220 $|V_{us}|$ averages

Accounting for statistical correlations, we obtain

$$B_e^{\text{uni}} = (17.815 \pm 0.023)\%.$$

We use B_e^{uni} to obtain the ratio

$$R_{\text{had}} = \frac{\Gamma(\tau \to \text{hadrons})}{\Gamma(\tau \to e\nu\bar{\nu})} = \frac{\Gamma_{\text{hadrons}}}{B_e^{\text{uni}}} = 3.6349 \pm 0.0082,$$

where $\Gamma(\tau \to \text{hadrons})$ and $\Gamma(\tau \to e\nu\bar{\nu})$ indicate the partial widths and Γ_{hadrons} is the total branching fraction of the τ to hadrons, or the total branching fraction in any measured final state minus the leptonic branching fractions, i.e., with our notation $\Gamma_{\text{hadrons}} = \Gamma_{\text{All}} - \Gamma_3 - \Gamma_5 = (64.76 \pm 0.10)\%$ (see Sect. 9.1 and Table 304 for the definitions of Γ_{All}, Γ_3, Γ_5). We underline that this report's definition of Γ_{hadrons} corresponds to summing all τ hadronic decay modes, like in the previous report, rather than – as done elsewhere – subtracting the leptonic branching fractions from unity, i.e., $\Gamma_{\text{hadrons}} = 1 - \Gamma_3 - \Gamma_5$.

9.4 $|V_{us}|$ measurement

The CKM matrix element magnitude $|V_{us}|$ is most precisely determined from kaon decays [1412] (see Fig. 220), and its precision is limited by the uncertainties of the lattice QCD estimates of the meson decay constants $f_+^{K\pi}(0)$ and f_K/f_π. Using the τ branching fractions, it is possible to determine $|V_{us}|$ in an alternative way [1413,1414] that does not depend on lattice QCD and has small theory uncertainties (as discussed in Sect. 9.4.1). Moreover, $|V_{us}|$ can be determined using the τ branching fractions similarly to the kaon case, using the same meson decay constants from Lattice QCD.

9.4.1 $|V_{us}|$ *from* $B(\tau \to X_s \nu)$

The τ hadronic partial width is the sum of the τ partial widths to strange and to non-strange hadronic final states, $\Gamma_{\text{had}} = \Gamma_s + \Gamma_{\text{VA}}$. The suffix "VA" traditionally denotes the sum of the τ partial widths to non-strange final states, which proceed through either vector or axial-vector currents.

Dividing any partial width Γ_x by the electronic partial width, Γ_e, we obtain partial width ratios R_x (which are equal to the respective branching fraction ratios B_x/B_e) for which $R_{\text{had}} = R_s + R_{\text{VA}}$. In terms of such ratios, $|V_{us}|$ can be measured as [1413,1414]

$$|V_{us}|_{\tau s} = \sqrt{R_s \Big/ \left[\frac{R_{\text{VA}}}{|V_{ud}|^2} - \delta R_{\text{theory}} \right]},$$

where δR_{theory} can be determined in the context of low energy QCD theory, partly relying on experimental low energy scattering data. The literature reports several calculations [1415–1417]. In this report we use Ref. [1415], whose estimated uncertainty size is intermediate between the two other ones. We use the information in that paper and the PDG 2015 value for the s-quark mass $m_s = 95.00 \pm 5.00\,\text{MeV}$ [327] to calculate $\delta R_{\text{theory}} = 0.242 \pm 0.032$..

We proceed following the same procedure of the 2012 HFLAV report [234]. We sum the relevant τ branching fractions to compute B_{VA} and B_s and we use the universality improved B_e^{uni} (see Sect. 9.3) to compute the R_{VA} and R_s ratios. In past determinations of $|V_{us}|$, for example in the 2009 HFLAV report [420], the total hadronic branching fraction has been computed using unitarity as $B_{\text{had}}^{\text{uni}} = 1 - B_e - B_\mu$, obtaining then B_s from the sum of the strange branching fractions and B_{VA} from $B_{\text{had}}^{\text{uni}} - B_s$. We prefer to use the more direct experimental determination of B_{VA} for two reasons. First, both methods result in comparable uncertainties on $|V_{us}|$, since the better precision on $B_{\text{had}}^{\text{uni}} = 1 - B_e - B_\mu$ is vanified by increased statistical correlations in the expressions $(1 - B_e - B_\mu)/B_e^{\text{univ}}$ and $B_s/(B_{\text{had}} - B_s)$ in the $|V_{us}|$ calculation. Second, if there are unobserved τ hadronic decay modes, they would affect B_{VA} and B_s in a more asymmetric way when using unitarity.

Using the τ branching fraction fit results with their uncertainties and correlations (Sect. 9.1), we compute $B_s = (2.909 \pm 0.048)\%$ (see also Table 316) and $B_{\text{VA}} = B_{\text{hadrons}} - B_s = (61.85 \pm 0.10))\%$, where B_{hadrons} is equal to Γ_{hadrons} defined in Sect. 9.3. PDG 2015 averages are used for non-τ quantities, and $|V_{ud}| = 0.97417 \pm 0.00021$ [1418].

We obtain $|V_{us}|_{\tau s} = 0.2186 \pm 0.0021$, which is 3.1σ lower than the unitarity CKM prediction $|V_{us}|_{\text{uni}} = 0.22582 \pm 0.00089$, from $(|V_{us}|_{\text{uni}})^2 = 1 - |V_{ud}|^2$. The $|V_{us}|_{\tau s}$ uncertainty includes a systematic error contribution of 0.47% from the theory uncertainty on δR_{theory}. There is no significant change with respect to the previous HFLAV report.

Table 316 HFLAV Spring 2017 τ branching fractions to strange final states

Branching fraction	HFLAV Spring 2017 fit (%)
$K^-\nu_\tau$	0.6960 ± 0.0096
$K^-\pi^0\nu_\tau$	0.4327 ± 0.0149
$K^-2\pi^0\nu_\tau$ (ex. K^0)	0.0640 ± 0.0220
$K^-3\pi^0\nu_\tau$ (ex. K^0, η)	0.0428 ± 0.0216
$\pi^-\bar{K}^0\nu_\tau$	0.8386 ± 0.0141
$\pi^-\bar{K}^0\pi^0\nu_\tau$	0.3812 ± 0.0129
$\pi^-\bar{K}^0\pi^0\pi^0\nu_\tau\,(\text{ex.}K^0)$	0.0234 ± 0.0231
$\bar{K}^0h^-h^-h{+}\nu_\tau$	0.0222 ± 0.0202
$K^-\eta\nu_\tau$	0.0155 ± 0.0008
$K^-\pi^0\eta\nu_\tau$	0.0048 ± 0.0012
$\pi^-\bar{K}^0\eta\nu_\tau$	0.0094 ± 0.0015
$K^-\omega\nu_\tau$	0.0410 ± 0.0092
$K^-\phi\nu_\tau(\phi \to K^+K-)$	0.0022 ± 0.0008
$K^-\phi\nu_\tau(\phi \to K_S^0K_L^0)$	0.0015 ± 0.0006
$K^-\pi^-\pi^+\nu_\tau\,(\text{ex.}K^0, \omega)$	0.2923 ± 0.0067
$K^-\pi^-\pi^+\pi^0\nu_\tau\,(\text{ex.}K^0, \omega\eta)$	0.0410 ± 0.0143
$K^-2\pi^-2\pi^+\nu_\tau\,(\text{ex.}K^0)$	0.0001 ± 0.0001
$K^-2\pi^-2\pi^+\pi^0\nu_\tau\,(\text{ex.}K^0)$	0.0001 ± 0.0001
$X_s^-\nu_\tau$	2.9087 ± 0.0482

9.4.2 $|V_{us}|$ *from* $B(\tau \to K\nu)/B(\tau \to \pi\nu)$

We compute $|V_{us}|$ from the ratio of branching fractions $B(\tau \to K^-\nu_\tau)/B(\tau \to \pi^-\nu_\tau) = (6.438 \pm 0.094)$ from the equation [1404]:

$$\frac{B(\tau \to K^-\nu_\tau)}{B(\tau \to \pi^-\nu_\tau)} = \frac{f_K^2|V_{us}|^2}{f_\pi^2|V_{ud}|^2} \times \frac{(m_\tau^2 - m_K^2)^2}{(m_\tau^2 - m_\pi^2)^2} \frac{1 + \delta R_{\tau/K}}{1 + \delta R_{\tau/\pi}} (1 + \delta R_{K/\pi})$$

We use $f_K/f_\pi = 1.1930 \pm 0.0030$ from the FLAG 2016 Lattice averages with $N_f = 2 + 1 + 1$ [222],

$$\frac{1 + \delta R_{\tau/K}}{1 + \delta R_{\tau/\pi}} = \frac{1 + (1.1930 \pm 0.0030)\%}{1 + (0.16 \pm 0.14)\%} \;[1393 - 1396],$$

$$1 + \delta R_{K/\pi} = 1 + (-1.13 \pm 0.23)\% \;[1390, 1405, 1406].$$

We compute $|V_{us}|_{\tau K/\pi} = 0.2236 \pm 0.0018$, 1.1σ below the CKM unitarity prediction.

9.4.3 $|V_{us}|$ from τ summary

We summarize the $|V_{us}|$ results reporting the values, the discrepancy with respect to the $|V_{us}|$ determination from CKM unitarity, and an illustration of the measurement method:

$$\begin{aligned}
|V_{us}|_{\text{uni}} &= 0.22582 \pm 0.00089 \\
&\quad [\text{from } \sqrt{1-|V_{ud}|^2} \quad (\text{CKM unitarity})], \\
|V_{us}|_{\tau s} &= 0.2186 \pm 0.0021 \quad -3.1\sigma \\
&\quad [\text{from } \Gamma(\tau^- \to X_s^- \nu_\tau)], \\
|V_{us}|_{\tau K/\pi} &= 0.2236 \pm 0.0018 \quad -1.1\sigma \\
&\quad [\text{from } \Gamma(\tau^- \to K^- \nu_\tau)/\Gamma(\tau^- \to \pi^- \nu_\tau)].
\end{aligned}$$

Averaging the two above $|V_{us}|$ determinations that rely on the τ branching fractions (taking into account all correlations due to the τ HFLAV and other mentioned inputs) we obtain, for $|V_{us}|$ and its discrepancy:

$$\begin{aligned}
|V_{us}|_\tau &= 0.2216 \pm 0.0015 \quad -2.4\sigma \\
&\quad [\text{average of } 2|V_{us}|\ \tau \text{ measurements}].
\end{aligned}$$

All $|V_{us}|$ determinations based on measured τ branching fractions are lower than both the kaon and the CKM-unitarity determinations. This is correlated with the fact that the direct measurements of the three major τ branching fractions to kaons [$B(\tau \to K^-\nu_\tau)$, $B(\tau \to K^-\pi^0\nu_\tau)$ and $B(\tau \to \pi^-\bar{K}^0\nu_\tau)$] are lower than their determinations from the kaon branching fractions into final states with leptons within the SM [1404,1421,1422].

A recent determination of $|V_{us}|$ [1423,1424] that relies on the τ spectral functions in addition to the inclusive $\tau \to X_s\nu$ branching fraction reports a $|V_{us}|$ value about 1σ lower than the CKM-unitarity determination. This determination uses inputs that are partially different from the ones used in this report. Specifically, the HFLAV average of $B(\tau \to K^-\nu_\tau)$ has been replaced with the SM prediction based on the measured $B(K^- \to \mu^-\bar{\nu}_\mu)$ and the HFLAV average of $B(\tau \to K^-\pi^0\nu_\tau)$ has been replaced with an in-progress BABAR measurement that is published in a PhD thesis. Both changes increase the resulting $\tau \to X_s\nu$ inclusive branching fraction. This study claims that the newly proposed $|V_{us}|$ calculation has a more stable and reliable theory uncertainty, which could possibly have been underestimated in former studies, which are used for the HFLAV $|V_{us}|$ average.

In previous editions of the HFLAV report, we also computed $|V_{us}|$ using the branching fraction $B(\tau \to K\nu)$ and without taking the ratio with $B(\tau \to \pi\nu)$. We do not report this additional determination because it did not include the long-distance radiative corrections in addition to the short-distance contribution, and because it had a negligible effect on the overall precision of the $|V_{us}|$ calculation with τ data.

Figure 220 reports the HFLAV $|V_{us}|$ determinations that use the τ branching fractions, compared to two $|V_{us}|$ determinations based on kaon data [6] and to $|V_{us}|$ obtained from $|V_{ud}|$ and the CKM matrix unitarity [6].

9.5 Upper limits on τ lepton-flavour-violating branching fractions

The Standard Model predicts that the τ lepton-flavour-violating (LFV) branching fractions are too small to be measured with the available experimental precision. We report in Table 317 and Fig. 221 the experimental upper limits on these branching fractions that have been published by the B-factories BABAR and Belle and later experiments. We omit previous weaker upper limits (mainly from CLEO) and all preliminary results presented several years ago. The previous HFLAV report [5] still included a few preliminary results, which have all been removed now.

9.6 Combination of upper limits on τ lepton-flavour-violating branching fractions

Combining upper limits is a delicate issue, since there is no standard and generally agreed procedure. Furthermore, the τ LFV searches published limits are extracted from the data with a variety of methods, and cannot be directly combined with a uniform procedure. It is however possible to use a single and effective upper limit combination procedure for all modes by re-computing the published upper limits with just one extraction method, using the published information that documents the upper limit determination: number of observed candidates, expected background, signal efficiency and number of analyzed τ decays.

We chose to use the CL_s method [1443] to re-compute the τ LFV upper limits, since it is well known and widely used (see the Statistics review of PDG 2013 [6]), and since the limits computed with the CL_s method can be combined in a straightforward way (see below). The CL_s method is based on two hypotheses: signal plus background and background only. We calculate the observed confidence levels for the two hypotheses:

$$\text{CL}_{s+b} = P_{s+b}(Q \le Q_{obs}) = \int_{-\infty}^{Q_{obs}} \frac{dP_{s+b}}{dQ} dQ, \qquad (295)$$

$$\text{CL}_b = P_b(Q \le Q_{obs}) = \int_{-\infty}^{Q_{obs}} \frac{dP_b}{dQ} dQ, \qquad (296)$$

where CL_{s+b} is the confidence level observed for the signal plus background hypotheses, CL_b is the confidence level observed for the background only hypothesis, $\frac{dP_{s+b}}{dQ}$ and $\frac{dP_b}{dQ}$ are the probability distribution functions (PDFs) for the two corresponding hypothesis and Q is called the test statistic.

Table 317 Experimental upper limits on lepton flavour violating τ decays. The modes are grouped according to the properties of their final states. Modes with baryon number violation are labelled with “BNV”

Decay mode	Category	90% CL Limit	Exp.	Refs.
$\Gamma_{156} = e^-\gamma$	ℓ_γ	$3.3 \cdot 10^{-8}$	BABAR	[1425]
$\Gamma_{156} = e^-\gamma$		$1.2 \cdot 10^{-7}$	Belle	[1426]
$\Gamma_{157} = \mu^-\gamma$		$4.4 \cdot 10^{-8}$	BABAR	[1425]
$\Gamma_{157} = \mu^-\gamma$		$4.5 \cdot 10^{-8}$	Belle	[1426]
$\Gamma_{158} = e^-\pi^0$	ℓP^0	$1.3 \cdot 10^{-7}$	BABAR	[1427]
$\Gamma_{158} = e^-\pi^0$		$8.0 \cdot 10^{-8}$	Belle	[1428]
$\Gamma_{159} = \nu^-\pi^0$		$1.1 \cdot 10^{-7}$	BABAR	[1427]
$\Gamma_{159} = \nu^-\pi^0$		$1.2 \cdot 10^{-7}$	Belle	[1428]
$\Gamma_{160} = e^-{K_S}^0$		$3.3 \cdot 10^{-8}$	BABAR	[1429]
$\Gamma_{160} = e^-{K_S}^0$		$2.6 \cdot 10^{-8}$	Belle	[1430]
$\Gamma_{161} = \mu^-{K_S}^0$		$4.0 \cdot 10^{-8}$	BABAR	[1429]
$\Gamma_{161} = \mu^-{K_S}^0$		$2.3 \cdot 10^{-8}$	Belle	[1430]
$\Gamma_{162} = e^-\eta$		$1.6 \cdot 10^{-7}$	BABAR	[1427]
$\Gamma_{162} = e^-\eta$		$9.2 \cdot 10^{-8}$	Belle	[1428]
$\Gamma_{163} = \nu^-\eta$		$1.5 \cdot 10^{-7}$	BABAR	[1427]
$\Gamma_{163} = \nu^-\eta$		$6.5 \cdot 10^{-8}$	Belle	[1428]
$\Gamma_{172} = e^-\eta'(958)$		$2.4 \cdot 10^{-7}$	BABAR	[1427]
$\Gamma_{172} = e^-\eta'(958)$		$1.6 \cdot 10^{-7}$	Belle	[1428]
$\Gamma_{173} = \nu^-\eta'(958)$		$1.4 \cdot 10^{-7}$	BABAR	[1427]
$\Gamma_{173} = \nu^-\eta'(958)$		$1.3 \cdot 10^{-7}$	Belle	[1428]
$\Gamma_{164} = e^-\rho^0$	ℓV^0	$4.6 \cdot 10^{-8}$	BABAR	[1431]
$\Gamma_{164} = e^-\rho^0$		$1.8 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{165} = \mu^-\rho^0$		$2.6 \cdot 10^{-8}$	BABAR	[1431]
$\Gamma_{165} = \mu^-\rho^0$		$1.2 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{166} = e^-\omega$		$1.1 \cdot 10^{-7}$	BABAR	[1433]
$\Gamma_{166} = e^-\omega$		$4.8 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{167} = \mu^-\omega$		$1.0 \cdot 10^{-7}$	BABAR	[1433]
$\Gamma_{167} = \mu^-\omega$		$4.7 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{168} = e^-K^*(892)^0$		$5.9 \cdot 10^{-8}$	BABAR	[1431]
$\Gamma_{168} = e^-K^*(892)^0$		$3.2 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{169} = \mu^-K^*(892)^0$		$1.7 \cdot 10^{-7}$	BABAR	[1431]
$\Gamma_{169} = \mu^-K^*(892)^0$		$7.2 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{170} = e^-\bar{K}^*(892)^0$		$4.6 \cdot 10^{-8}$	BABAR	[1431]
$\Gamma_{170} = e^-\bar{K}^*(892)^0$		$3.4 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{171} = \mu^-\bar{K}^*(892)^0$		$7.3 \cdot 10^{-8}$	BABAR	[1431]
$\Gamma_{171} = \mu^-\bar{K}^*(892)^0$		$7.0 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{176} = e^-\phi$		$3.1 \cdot 10^{-8}$	BABAR	[1431]
$\Gamma_{176} = e^-\phi$		$3.1 \cdot 10^{-8}$	Belle	[1432]
$\Gamma_{177} = \mu^-\phi$		$1.9 \cdot 10^{7}$	BABAR	[1431]
$\Gamma_{177} = \mu^-\phi$		$8.4 \cdot 10^{8}$	Belle	[1432]
$\Gamma_{174} = e^-f_0(980)$	ℓS^0	$3.2 \cdot 10^{8}$	Belle	[1434]
$\Gamma_{175} = \mu^-f_0(980)$		$3.4 \cdot 10^{8}$	Belle	[1434]
$\Gamma_{178} = e^-e^+e^-$	$\ell\ell\ell$	$2.9 \cdot 10^{8}$	BABAR	[1435]
$\Gamma_{178} = e^-e^+e^-$		$2.7 \cdot 10^{8}$	Belle	[1436]
$\Gamma_{179} = e^-\mu^+\mu^-$		$3.2 \cdot 10^{8}$	BABAR	[1435]
$\Gamma_{179} = e^-\mu^+\mu^-$		$2.7 \cdot 10^{8}$	Belle	[1436]

Table 317 continued

Decay mode	Category	90% CL Limit	Exp.	Refs.
$\Gamma_{180} = \mu^- e^+ \mu^-$		$2.6 \cdot 10^{8}$	BABAR	[1435]
$\Gamma_{180} = \mu^- e^+ \mu^-$		$1.7 \cdot 10^{8}$	Belle	[1436]
$\Gamma_{181} = \mu^- e^+ e^-$		$2.2 \cdot 10^{8}$	BABAR	[1435]
$\Gamma_{181} = \mu^- e^+ e^-$		$1.8 \cdot 10^{8}$	Belle	[1436]
$\Gamma_{182} = e^- \mu^+ e^-$		$1.8 \cdot 10^{8}$	BABAR	[1435]
$\Gamma_{182} = e^- \mu^+ e^-$		$1.5 \cdot 10^{8}$	Belle	[1436]
$\Gamma_{183} = \mu^- \mu^+ \mu^-$		$3.8 \cdot 10^{7}$	ATLAS	[1437]
$\Gamma_{183} = \mu^- \mu^+ \mu^-$		$3.3 \cdot 10^{8}$	BABAR	[1435]
$\Gamma_{183} = \mu^- \mu^+ \mu^-$		$2.1 \cdot 10^{8}$	Belle	[1436]
$\Gamma_{183} = \mu^- \mu^+ \mu^-$		$4.6 \cdot 10^{8}$	LHCb	[1438]
$\Gamma_{184} = e^- \pi^+ \pi^-$	ℓhh	$1.2 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{184} = e^- \pi^+ \pi^-$		$2.3 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{185} = e^- \pi^+ \pi^-$		$2.7 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{185} = e^- \pi^+ \pi^-$		$2.0 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{186} = \mu^- \pi^+ \pi^-$		$2.9 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{186} = \mu^- \pi^+ \pi^-$		$2.1 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{187} = \mu^- \pi^+ \pi^-$		$7.0 \cdot 10^{8}$	BABAR	[1439]
$\Gamma_{187} = \mu^- \pi^+ \pi^-$		$3.9 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{188} = e^- \pi^+ K^-$		$3.2 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{188} = e^- K^+ \pi^-$		$3.7 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{189} = e^- K^+ \pi^-$		$1.7 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{189} = e^- K^+ \pi^-$		$3.1 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{190} = e^+ \pi^- K^-$		$1.8 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{190} = e^+ K^- \pi^-$		$3.2 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{191} = e^+ K^- \pi^-$		$7.1 \cdot 10^{8}$	Belle	[1430]
$\Gamma_{192} = e^- K^0_S K^0_S$		$1.4 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{192} = e^- K^+ K^-$		$3.4 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{193} = e^- K^+ K^-$		$1.5 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{193} = e^- K^- K^-$		$3.3 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{194} = \mu^- \pi^+ K^-$		$2.6 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{194} = \mu^- \pi^+ K^-$		$8.6 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{195} = \mu^- K^+ \pi^-$		$3.2 \cdot 10^{7}$	BABAR	[1439]
$\Gamma_{195} = \mu^- K^+ \pi^-$		$4.5 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{196} = \mu^+ \pi^- K^-$		$2.2 \cdot 10^{-7}$	BABAR	[1439]
$\Gamma_{196} = \mu^+ \pi^- K^-$		$4.8 \cdot 10^{-8}$	Belle	[1440]
$\Gamma_{197} = \mu^- K^0_S K^0_S$		$8.0 \cdot 10^{-8}$	Belle	[1430]
$\Gamma_{198} = \mu^- K^+ K^-$		$2.5 \cdot 10^{-7}$	BABAR	[1439]
$\Gamma_{198} = \mu^- K^+ K^-$		$4.4 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{199} = \mu^- K^+ K^-$		$4.8 \cdot 10^{-7}$	BABAR	[1439]
$\Gamma_{199} = \mu^- K^+ K^-$		$4.7 \cdot 10^{8}$	Belle	[1440]
$\Gamma_{211} = \pi^- \Lambda$	BNV	$7.2 \cdot 10^{-8}$	Belle	[1441]
$\Gamma_{212} = \pi^- \bar{\Lambda}$		$1.4 \cdot 10^{-7}$	Belle	[1441]
$\Gamma_{215} = p \mu^- \mu^-$		$4.4 \cdot 10^{-7}$	LHCb	[1442]
$\Gamma_{216} = \bar{p} \mu^+ \mu^-$		$3.3 \cdot 10^{-7}$	LHCb	[1442]

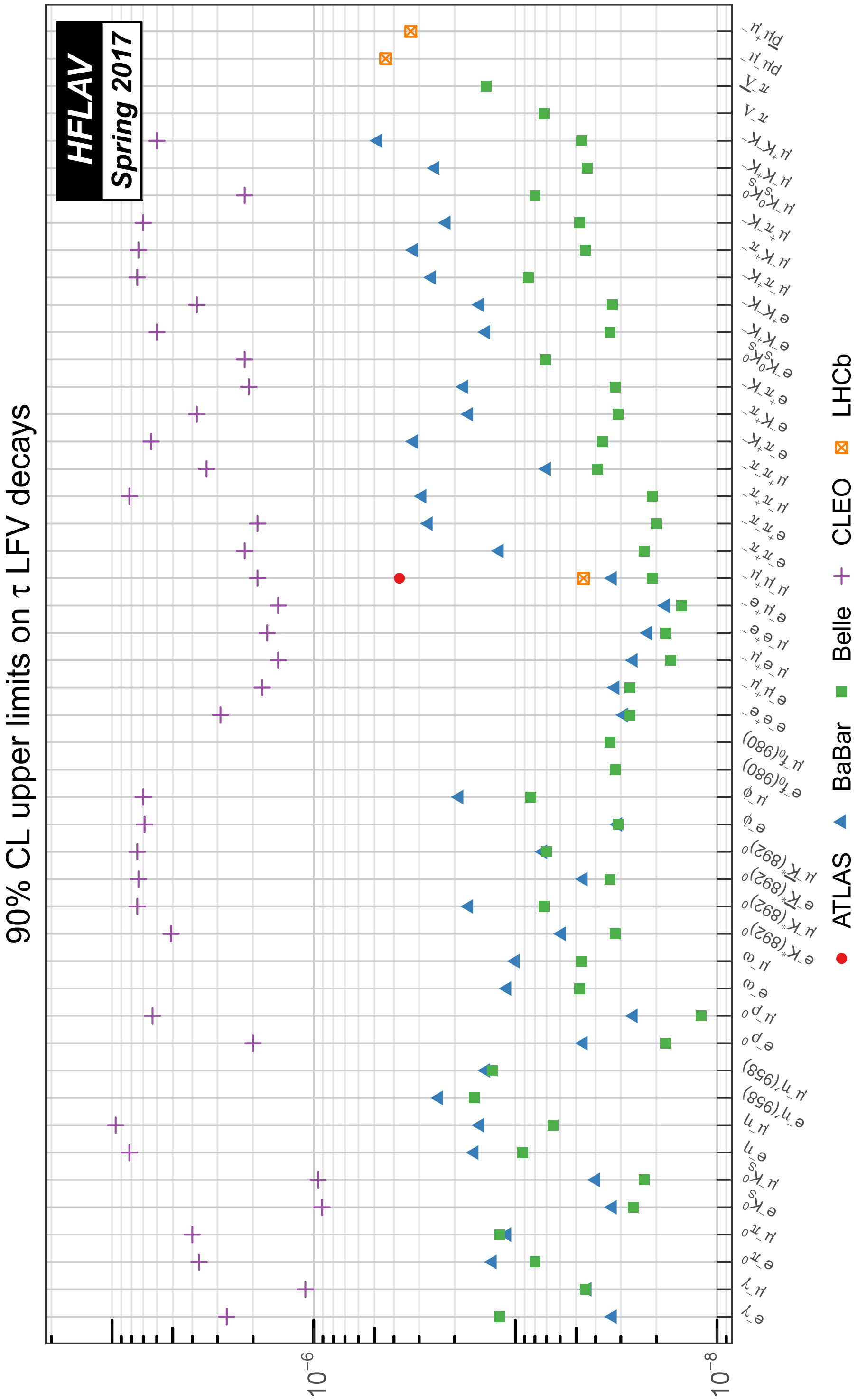


Fig. 221 Tau lepton-flavor-violating branching fraction upper limits summary plot. In order to appreciate the physics reach improvement over time, the plot includes also the CLEO upper limits reported by PDG 2016 [6]

The CL_s value is defined as the ratio between the confidence level for the signal plus background hypothesis and the confidence level for the background hypothesis:

$$\mathrm{CL}_s = \frac{\mathrm{CL}_{s+b}}{\mathrm{CL}_b}. \qquad (297)$$

When multiple results are combined, the PDFs in Eqs. (295) and (296) are the product of the individual PDFs,

$$\mathrm{CL}_s = \frac{\prod_{i=1}^{N}\sum_{n=0}^{n_i}\dfrac{e^{-(s_i+b_i)}(s_i+b_i)^n}{n!}}{\prod_{i=1}^{N}\sum_{n=0}^{n_i}\dfrac{e^{-b_i}b_i^n}{n!}}$$

Table 318 Combinations of upper limits on lepton flavour violating τ decay modes. The modes are grouped according to the properties of their final states. Modes with baryon number violation are labelled with "BNV"

Decay mode	Category	90% CL limit	Refs.
$\Gamma_{156} = e^-\gamma$	$\ell\gamma$	$5.4 \cdot 10^{-8}$	[1425,1426]
$\Gamma_{157} = \mu^-\gamma$		$5.0 \cdot 10^{-8}$	[1425,1426]
$\Gamma_{158} = e^-\pi^0$	ℓP^0	$4.9 \cdot 10^{-8}$	[1427,1428]
$\Gamma_{159} = \mu^-\pi^0$		$3.6 \cdot 10^{-8}$	[1427,1428]
$\Gamma_{160} = e^-K_S^0$		$1.4 \cdot 10^{-8}$	[1429,1430]
$\Gamma_{161} = \mu^-K_S^0$		$1.5 \cdot 10^{-8}$	[1429,1430]
$\Gamma_{162} = e^-\eta$		$5.5 \cdot 10^{-8}$	[1427,1428]
$\Gamma_{163} = \mu^-\eta$		$3.8 \cdot 10^{-8}$	[1427,1428]
$\Gamma_{172} = e^-\eta'(958)$		$9.9 \cdot 10^{-8}$	[1427,1428]
$\Gamma_{173} = \mu^-\eta'(958)$		$6.3 \cdot 10^{-8}$	[1427,1428]
$\Gamma_{164} = e^-\rho^0$	ℓV^0	$1.5 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{165} = \mu^-\rho^0$		$1.5 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{166} = e^-\omega$		$3.3 \cdot 10^{-8}$	[1432,1433]
$\Gamma_{167} = \mu^-\omega$		$4.0 \cdot 10^{-8}$	[1432,1433]
$\Gamma_{168} = e^-K^*(892)^0$		$2.3 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{169} = \mu^-K^*(892)^0$		$6.0 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{170} = e^-\bar{K}^*(892)^0$		$2.2 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{171} = \mu^-\bar{K}^*(892)^0$		$4.2 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{176} = e^-\phi$		$2.0 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{177} = \mu^-\phi$		$6.8 \cdot 10^{-8}$	[1431,1432]
$\Gamma_{178} = e^-e^+e^-$	$\ell\ell\ell$	$1.4 \cdot 10^{-8}$	[1435,1436]
$\Gamma_{179} = e^-\mu^+\mu^-$		$1.6 \cdot 10^{-8}$	[1435,1436]
$\Gamma_{180} = \mu^-e^+\mu^-$		$9.8 \cdot 10^{-9}$	[1435,1436]
$\Gamma_{181} = \mu^-e^+e^-$		$1.1 \cdot 10^{-8}$	[1435,1436]
$\Gamma_{182} = e^-\mu^+e^-$		$8.4 \cdot 10^{-9}$	[1435,1436]
$\Gamma_{183} = \mu^-\mu^+\mu^-$		$1.2 \cdot 10^{-8}$	[1435,1436,1438]

$$\times \frac{\prod_{j=1}^{N}\left[s_i S_i(x_{ij}) + b_i B_i(x_{ij})\right]}{\prod_{j=1}^{N} B_i(x_{ij})}, \qquad (298)$$

where N is the number of results (or channels), and, for each channel i, n_i is the number of observed candidates, x_{ij} are the values of the discriminating variables (with index j), s_i and b_i are the number of signal and background events and S_i, B_i are the probability distribution functions of the discriminating variables. The discriminating variables x_{ij} are assumed to be uncorrelated. The expected signal s_i is related to the τ lepton branching fraction $B(\tau \to f_i)$ into the searched final state f_i by $s_i = N_i \epsilon_i B(\tau \to f_i)$, where N_i is the number of produced τ leptons and ϵ_i is the detection efficiency for observing the decay $\tau \to f_i$. For e^+e^- experiments, $N_i = 2\mathcal{L}_i \sigma_{\tau\tau}$, where $\mathcal{L}_i$ is the integrated luminosity and $\sigma_{\tau\tau}$ is the τ pair production cross section $\sigma(e^+e^- \to \tau^+\tau^-)$ [1444]. In experiments where τ leptons are produced in more complex multiple reactions, the effective N_i is typically estimated with Monte Carlo simulations calibrated with related data yields.

The extraction of the upper limits is performed using the code provided by Tom Junk [1445]. The systematic uncertainties are modeled in the Monte Carlo toy experiments by convolving the S_i and B_i PDFs with Gaussian distributions corresponding to the nuisance parameters.

Table 318 reports the HFLAV combinations of the τ LFV limits. Since there is negligible gain in combining limits of very different strength, the combinations do not include the CLEO searches and do not include results where the single event sensitivity is more than a factor of 5 lower than the value for the search with the best limit.

Figure 222 reports a graphical representation of the limits in Table 318. The published information that has been used to obtain these limits is reported in Table 319.

Fig. 222 Tau lepton-flavour-violating branching fraction upper limits combinations summary plot. For each channel we report the HFLAV combined limit, and the experimental published limits. In some cases, the combined limit is weaker than the limit published by a single experiment. This arises since the CL_s method used in the combination can be more conservative compared to other legitimate methods, especially when the number of observed events fluctuates below the expected background

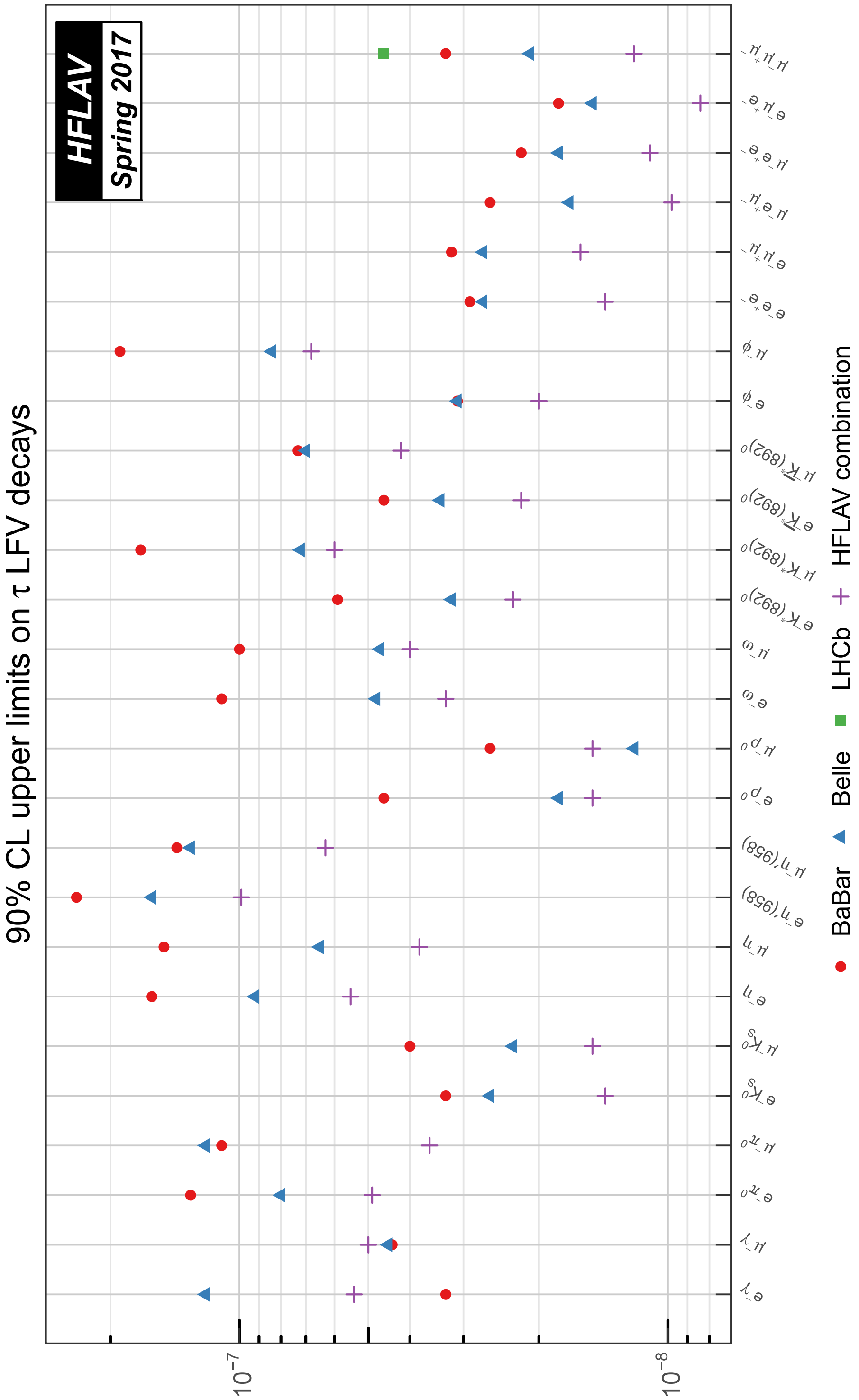


Table 319 Published information that has been used to re-compute upper limits with the CL$_s$ method, i.e. the number of τ leptons produced, the signal detection efficiency and its uncertainty, the number of expected background events and its uncertainty, and the number of observed events. The uncertainty on the efficiency includes the minor uncertainty contribution on the number of τ leptons (typically originating on the uncertainties on the integrated luminosity and on the production cross-section). The additional limit used in the combinations (from LHCb) has been originally determined with the CL$_s$ method

Decay mode	Exp.	Refs.	N_τ (millions)	Efficiency (%)	N_{bkg}	N_{obs}
$\Gamma_{156} = e^-\gamma$	BaBar	[1425]	963	3.90 ± 0.30	1.60 ± 0.40	0
$\Gamma_{156} = e^-\gamma$	Belle	[1426]	983	3.00 ± 0.10	5.14 ± 3.30	5
$\Gamma_{157} = \mu^-\gamma$	BaBar	[1425]	963	6.10 ± 0.50	3.60 ± 0.70	2
$\Gamma_{157} = \mu^-\gamma$	Belle	[1426]	983	5.07 ± 0.20	13.90 ± 5.00	10
$\Gamma_{158} = e^-\pi^0$	BaBar	[1427]	339	2.83 ± 0.25	0.17 ± 0.04	0
$\Gamma_{158} = e^-\pi^0$	Belle	[1428]	401	3.93 ± 0.18	0.20 ± 0.20	0
$\Gamma_{159} = \mu^-\pi^0$	BaBar	[1427]	339	4.75 ± 0.37	1.33 ± 0.15	1
$\Gamma_{159} = \mu^-\pi^0$	Belle	[1428]	401	4.53 ± 0.20	0.58 ± 0.34	1
$\Gamma_{160} = e^-K^0_S$	BaBar	[1429]	862	9.10 ± 1.73	0.59 ± 0.25	1
$\Gamma_{160} = e^-K^0_S$	Belle	[1430]	1274	10.20 ± 0.67	0.18 ± 0.18	0
$\Gamma_{161} = \mu^-K^0_S$	BaBar	[1429]	862	6.14 ± 0.20	0.30 ± 0.18	1
$\Gamma_{161} = \mu^-K^0_S$	Belle	[1430]	1274	10.70 ± 0.73	0.35 ± 0.21	0
$\Gamma_{162} = e^-\eta$	BaBar	[1427]	339	2.12 ± 0.20	0.22 ± 0.05	0
$\Gamma_{162} = e^-\eta$	Belle	[1428]	401	2.87 ± 0.20	0.78 ± 0.78	0
$\Gamma_{163} = \mu^-\eta$	BaBar	[1427]	339	3.59 ± 0.41	0.75 ± 0.08	1
$\Gamma_{163} = \mu^-\eta$	Belle	[1428]	401	4.08 ± 0.28	0.64 ± 0.04	0
$\Gamma_{172} = e^-\eta'(958)$	BaBar	[1427]	339	1.53 ± 0.16	0.12 ± 0.03	0
$\Gamma_{172} = e^-\eta'(958)$	Belle	[1428]	401	1.59 ± 0.13	0.01 ± 0.41	0
$\Gamma_{173} = \mu^-\eta'(958)$	BaBar	[1427]	339	2.18 ± 0.26	0.49 ± 0.26	0
$\Gamma_{173} = \mu^-\eta'(958)$	Belle	[1428]	401	2.47 ± 0.20	0.23 ± 0.46	0
$\Gamma_{164} = e^-\rho^0$	BaBar	[1431]	829	7.31 ± 0.20	1.32 ± 0.17	1
$\Gamma_{164} = e^-\rho^0$	Belle	[1432]	1554	7.58 ± 0.41	0.29 ± 0.15	0
$\Gamma_{165} = \mu^-\rho^0$	BaBar	[1431]	829	4.52 ± 0.40	2.04 ± 0.19	0
$\Gamma_{165} = \mu^-\rho^0$	Belle	[1432]	1554	7.09 ± 0.37	1.48 ± 0.35	0
$\Gamma_{166} = e^-\omega$	BaBar	[1433]	829	2.96 ± 0.13	0.35 ± 0.06	0
$\Gamma_{166} = e^-\omega$	Belle	[1432]	1554	2.92 ± 0.18	0.30 ± 0.14	0
$\Gamma_{167} = \mu^-\omega$	BaBar	[1433]	829	2.56 ± 0.16	0.73 ± 0.03	0
$\Gamma_{167} = \mu^-\omega$	Belle	[1432]	1554	2.38 ± 0.14	0.72 ± 0.18	0
$\Gamma_{168} = e^-K^*(892)^0$	BaBar	[1431]	829	8.00 ± 0.20	1.65 ± 0.23	2
$\Gamma_{168} = e^-K^*(892)^0$	Belle	[1432]	1554	4.37 ± 0.24	0.29 ± 0.14	0
$\Gamma_{169} = \mu^-K^*(892)^0$	BaBar	[1431]	829	4.60 ± 0.40	1.79 ± 0.21	4
$\Gamma_{169} = \mu^-K^*(892)^0$	Belle	[1432]	1554	3.39 ± 0.19	0.53 ± 0.20	1
$\Gamma_{170} = e^-\bar{K}^*(892)^0$	BaBar	[1431]	829	7.80 ± 0.20	2.76 ± 0.28	2
$\Gamma_{170} = e^-\bar{K}^*(892)^0$	Belle	[1432]	1554	4.41 ± 0.25	0.08 ± 0.08	0
$\Gamma_{171} = \mu^-\bar{K}^*(892)^0$	BaBar	[1431]	829	4.10 ± 0.30	1.72 ± 0.17	1
$\Gamma_{171} = \mu^-\bar{K}^*(892)^0$	Belle	[1432]	1554	3.60 ± 0.20	0.45 ± 0.17	1
$\Gamma_{176} = e^-\phi$	BaBar	[1431]	829	6.40 ± 0.20	0.68 ± 0.12	0
$\Gamma_{176} = e^-\phi$	Belle	[1432]	1554	4.18 ± 0.25	0.47 ± 0.19	0
$\Gamma_{177} = \mu^-\phi$	BaBar	[1431]	829	5.20 ± 0.30	2.76 ± 0.16	6
$\Gamma_{177} = \mu^-\phi$	Belle	[1432]	1554	3.21 ± 0.19	0.06 ± 0.06	1
$\Gamma_{178} = e^-e^+e^-$	BaBar	[1435]	868	8.60 ± 0.20	0.12 ± 0.02	0
$\Gamma_{178} = e^-e^+e^-$	Belle	[1436]	1437	6.00 ± 0.59	0.21 ± 0.15	0

Table 319 continued

Decay mode	Exp.	Refs.	N_τ (millions)	Efficiency (%)	N_{bkg}	N_{obs}
$\Gamma_{179} = e^-\mu^+\mu^-$	BaBar	[1435]	868	6.40 ± 0.40	0.54 ± 0.14	0
$\Gamma_{179} = e^-\mu^+\mu^-$	Belle	[1436]	1437	6.10 ± 0.58	0.10 ± 0.04	0
$\Gamma_{180} = \mu^-e^+\mu^-$	BaBar	[1435]	868	10.20 ± 0.60	0.03 ± 0.02	0
$\Gamma_{180} = \mu^-e^+\mu^-$	Belle	[1436]	1437	10.10 ± 0.77	0.02 ± 0.02	0
$\Gamma_{181} = \mu^-e^+e^-$	BaBar	[1435]	868	8.80 ± 0.50	0.64 ± 0.19	0
$\Gamma_{181} = \mu^-e^+e^-$	Belle	[1436]	1437	9.30 ± 0.73	0.04 ± 0.04	0
$\Gamma_{182} = e^-\mu^+e^-$	BaBar	[1435]	868	12.70 ± 0.70	0.34 ± 0.12	0
$\Gamma_{182} = e^-\mu^+e^-$	Belle	[1436]	1437	11.50 ± 0.89	0.01 ± 0.01	0
$\Gamma_{183} = \mu^-\mu^+\mu^-$	BaBar	[1435]	868	6.60 ± 0.60	0.44 ± 0.17	0
$\Gamma_{183} = \mu^-\mu^+\mu^-$	Belle	[1436]	1437	7.60 ± 0.56	0.13 ± 0.20	0

10 Summary

This article provides updated world averages of measurements of b-hadron, c-hadron, and τ-lepton properties using results available through Summer 2016. A small selection of highlights of the results described in Sects. 3–9 is given in Table 320.

Since the previous version of this document [5], the b-hadron lifetime and mixing averages have mostly made gradual progress in precision. Notable exceptions with significant improvement are the averages for the mass difference in the $B^0 - \bar{B}^0$ system (Δm_d) and the *CP* violation parameter in $B^0_s - \bar{B}^0_s$ system ($|q_s/p_s|$). In total eleven new results (of which ten from the LHC Run 1 data and one from the Tevatron data) have been incorporated in these averages. On the other hand, all results that remained unpublished and for which there is no publication plan, have been removed from the averages.

The lifetime hierarchy for the most abundant weakly decaying b-hadron species is well established, with impressive precisions of 5 fs or less for the most common B^0, B^+ and B^0_s mesons, and compatible with the expectations from the Heavy Quark Expansion. However, statistics are still lacking for b baryons heavier than Λ^0_b (Ξ^-_b, Ξ^0_b, Ω_b, and all other yet-to-be-discovered b baryons), but this will surely come from the LHC with sufficient time. A sizable value of the decay width difference in the $B^0_s - \bar{B}^0_s$ system is measured with a relative precision of 7% and is well predicted by the Standard Model (SM). In contrast, the experimental results for the decay width difference in the $B^0 - \bar{B}^0$ system are not yet precise enough to distinguish the small (expected) value from zero. The mass differences in both systems are known very accurately, to the (few) per mil level. On the other hand, *CP* violation in the mixing of either system has not been observed yet, with asymmetries known within a couple per mil but still consistent both with zero and their SM predictions. A similar conclusion holds for the *CP* violation induced by B^0_s mixing in the $b \to c\bar{c}s$ transition, although in this case the experimental precision on the corresponding weak phase is an order of magnitude larger, but now becoming just smaller than the SM central value. Many measurements are still dominated by statistical uncertainties and will improve once new results from the LHC Run 2 become available.

The measurement of $\sin 2\beta \equiv \sin 2\phi_1$ from $b \to c\bar{c}s$ transitions such as $B^0 \to J/\psi K^0_S$ has reached $< 2.5\,\%$ precision: $\sin 2\beta \equiv \sin 2\phi_1 = 0.691 \pm 0.017$. Measurements of the same parameter using different quark-level processes provide a consistency test of the Standard Model and allow insight into possible new physics. All results among hadronic $b \to s$ penguin dominated decays of B^0 mesons are currently consistent with the Standard Model expectations. Measurements of *CP* violation parameters in $B^0_s \to \phi\phi$ allow a similar comparison to the value of $\phi_s^{c\bar{c}s}$; again, results are consistent with the SM expectation (which in this case is very close to zero). Among measurements related to the Unitarity Triangle angle $\alpha \equiv \phi_2$, results from the $\rho\rho$ system allow constraints at the level of $\approx 6°$. These remain the strongest constraints, although results from all of BaBar, Belle and LHCb lead to good precision on the *CP* violation parameters in $B^0 \to \pi^+\pi^-$ decays. Knowledge of the third angle $\gamma \equiv \phi_3$ also continues to improve, with the current world average being $(74.0^{+5.8}_{-6.4})°$. The precision is expected to improve further as more data becomes available at LHCb and Belle II.

In semileptonic B meson decays, the anomalies reported in the last version of the document have remained: The discrepancy between $|V_{cb}|$ measured with inclusive and exclusive decays is of the order of 3σ (3.2σ for $|V_{cb}|$ from $\bar{B} \to D^*\ell^-\bar{\nu}_\ell$, 2.4σ for $|V_{cb}|$ from $\bar{B} \to D\ell^-\bar{\nu}_\ell$). The difference between $|V_{ub}|$ measured with inclusive decays $\bar{B} \to X_u\ell^-\bar{\nu}_\ell$ and $|V_{ub}|$ from $\bar{B} \to \pi\ell^-\bar{\nu}_\ell$ has risen to 3.6σ. An important new contribution to the determination

Table 320 Selected world averages. Where two uncertainties are given the first is statistical and the second is systematic, except where indicated otherwise

b-hadron lifetimes	
$\tau(B^0)$	1.520 ± 0.004 ps
$\tau(B^+)$	1.638 ± 0.004 ps
$\bar{\tau}(B_s^0) = 1/\Gamma_s$	1.505 ± 0.005 ps
$\tau(B^0_{s\mathrm{L}})$	1.413 ± 0.006 ps
$\tau(B^0_{s\mathrm{H}})$	1.609 ± 0.010 ps
$\tau(B_c^+)$	0.507 ± 0.009 ps
$\tau(\Lambda_b^0)$	1.470 ± 0.010 ps
$\tau(\Xi_b^-)$	1.571 ± 0.040 ps
$\tau(\Xi_b^0)$	1.479 ± 0.031 ps
$\tau(\Omega_b^-)$	$1.64^{+0.18}_{-0.17}$ ps
B^0 and B_s^0 mixing/CP violation parameters	
Δm_d	0.5064 ± 0.0019 ps^{-1}
$\Delta\Gamma_d/\Gamma_d$	-0.002 ± 0.010
$\lvert q_d/p_d \rvert$	1.0009 ± 0.0013
Δm_s	17.757 ± 0.021 ps^{-1}
$\Delta\Gamma_s$	$+0.086 \pm 0.006$ ps^{-1}
$\lvert q_s/p_s \rvert$	1.0003 ± 0.0014
$\phi_s^{c\bar{c}s}$	-0.030 ± 0.033
Parameters related to Unitarity Triangle angles	
$\sin 2\beta \equiv \sin 2\phi_1$	0.691 ± 0.017
$\beta \equiv \phi_1$	$(21.9 \pm 0.7)^\circ$
$-\eta S_{\phi K_S^0}$	$0.74^{+0.11}_{-0.13}$
$-\eta S_{\eta' K^0}$	0.63 ± 0.06
$-\eta S_{K_S^0 K_S^0 K_S^0}$	0.72 ± 0.19
$\phi_s(\phi\phi)$	$-0.17 \pm 0.15 \pm 0.03$ rad
$-\eta S_{J/\psi\pi^0}$	0.93 ± 0.15
$-\eta S_{D^+D^-}$	0.84 ± 0.12
$-\eta S_{J/\psi\rho^0}$	$0.66\,^{+0.13}_{-0.12}\,^{+0.09}_{-0.03}$
$S_{K^*\gamma}$	-0.16 ± 0.22
$(S_{\pi^+\pi^-}, C_{\pi^+\pi^-})$	$(-0.68 \pm 0.04, -0.27 \pm 0.04)$
$(S_{\rho^+\rho^-}, C_{\rho^+\rho^-})$	$(-0.14 \pm 0.13, 0.00 \pm 0.09)$
$a(D^{*\pm}\pi^\mp)$	-0.039 ± 0.010
$A_{CP}(B \to D_{CP+}K)$	0.111 ± 0.018
$A_{\mathrm{ADS}}(B \to D_{K\pi}K)$	-0.415 ± 0.055
$\gamma \equiv \phi_3$	$(74.0^{+5.8}_{-6.4})^\circ$
Semileptonic B decay parameters	
$\mathcal{B}(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell)$	$(4.88 \pm 0.10)\%$
$\mathcal{B}(B^- \to D^{*0}\ell^-\bar{\nu}_\ell)$	$(5.59 \pm 0.19)\%$
$\eta_{\mathrm{EW}}\mathcal{F}(1)\lvert V_{cb}\rvert$	$(35.61 \pm 0.43) \times 10^{-3}$
$\lvert V_{cb}\rvert$ from $\bar{B} \to D^*\ell^-\bar{\nu}_\ell$	$(39.05 \pm 0.47_{\mathrm{exp}} \pm 0.58_{\mathrm{th}}) \times 10^{-3}$
$\mathcal{B}(\bar{B}^0 \to D^+\ell^-\bar{\nu}_\ell)$	$(2.20 \pm 0.10)\%$
$\mathcal{B}(B^- \to D^0\ell^-\bar{\nu}_\ell)$	$(2.33 \pm 0.10)\%$
$\eta_{\mathrm{EW}}\mathcal{G}(1)\lvert V_{cb}\rvert$	$(41.57 \pm 1.00) \times 10^{-3}$
$\lvert V_{cb}\rvert$ from $\bar{B} \to D\ell^-\bar{\nu}_\ell$	$(39.18 \pm 0.94_{\mathrm{exp}} \pm 0.36_{\mathrm{th}}) \times 10^{-3}$

Table 320 continued

$\mathcal{B}(\bar{B} \to X_c \ell^- \bar{\nu}_\ell)$	$(10.65 \pm 0.16)\%$
$\mathcal{B}(\bar{B} \to X \ell^- \bar{\nu}_\ell)$	$(10.86 \pm 0.16)\%$
$\lvert V_{cb}\rvert$ from $\bar{B} \to X \ell^- \bar{\nu}_\ell$	$(42.19 \pm 0.78) \times 10^{-3}$
$\mathcal{B}(\bar{B} \to \pi \ell^- \bar{\nu}_\ell)$	$(1.50 \pm 0.06) \times 10^{-4}$
$\lvert V_{ub}\rvert$ from $\bar{B} \to \pi \ell^- \bar{\nu}_\ell$	$(3.67 \pm 0.15) \times 10^{-3}$
$\lvert V_{ub}\rvert$ from $\bar{B} \to X_u \ell^- \bar{\nu}_\ell$	$(4.52 \pm 0.15_{\text{exp}} \pm 0.13_{\text{th}}) \times 10^{-3}$
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ from $\Lambda_b^0 \to p \mu^- \bar{\nu}_\mu / \Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$	$0.080 \pm 0.004_{\text{exp}} \pm 0.004_{\text{th}}$
$\mathcal{R}(D) = \mathcal{B}(B \to D \tau \nu_\tau)/\mathcal{B}(B \to D \ell \nu_\ell)$	0.403 ± 0.047
$\mathcal{R}(D^*) = \mathcal{B}(B \to D^* \tau \nu_\tau)/\mathcal{B}(B \to D^* \ell \nu_\ell)$	0.310 ± 0.017
b-hadron to charmed hadron decays	
$\mathcal{B}(\bar{B}^0 \to D^+ \pi^-)$	$(2.65 \pm 0.15) \times 10^{-3}$
$\mathcal{B}(B^- \to D^0 \pi^-)$	$(4.75 \pm 0.19) \times 10^{-3}$
$\mathcal{B}(\bar{B}_s^0 \to D_s^+ \pi^-)$	$(3.03 \pm 0.25) \times 10^{-3}$
$\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-)$	$(4.30^{+0.36}_{-0.35}) \times 10^{-3}$
$\mathcal{B}(\bar{B}^0 \to J/\psi \bar{K}^0)$	$(0.863 \pm 0.035) \times 10^{-3}$
$\mathcal{B}(B^- \to J/\psi K^-)$	$(1.028 \pm 0.040) \times 10^{-3}$
$\mathcal{B}(\bar{B}_s^0 \to J/\psi \phi)$	$(1.00 \pm 0.09) \times 10^{-3}$
Rare *B* decays	
$\mathcal{B}(B_s^0 \to \mu^+ \mu^-)$	$\left(2.8\,^{+0.07}_{-0.06}\right) \times 10^{-9}$
$\mathcal{B}(B^0 \to \mu^+ \mu^-)$	$\left(0.39\,^{+0.16}_{-0.14}\right) \times 10^{-9}$
$\mathcal{B}(B \to X_s \gamma)$ $(E_\gamma > 1.6$ GeV$)$	$(3.32 \pm 0.16) \times 10^{-4}$
$\mathcal{B}(B^+ \to \tau^+ \nu)$	$(1.06 \pm 0.19) \times 10^{-4}$
$R_K = \mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)/\mathcal{B}(B^+ \to K^+ e^+ e^-)$ in $1.0 < m^2_{\ell^+\ell^-} < 6.0\ \text{GeV}^2/c^4$	$0.745^{+0.090}_{-0.074} \pm 0.036$
$A_{CP}(B^0 \to K^+ \pi^-)$, $A_{CP}(B^+ \to K^+ \pi^0)$	-0.082 ± 0.006, 0.040 ± 0.021
$A_{CP}(B_s^0 \to K^- \pi^+)$	0.26 ± 0.04
Longitudinal polarisation of $B^0 \to \phi K^{*0}$	0.497 ± 0.017
Longitudinal polarisation of $B_s^0 \to \phi \phi$	0.361 ± 0.022
Observables in $B^0 \to K^{*0} \mu^+ \mu^-$ decays in bins of $q^2 = m^2(\mu^+ \mu^-)$	See Sect. 7.5
D^0 mixing and *CP* violation parameters	
x	$(0.32 \pm 0.14)\%$
y	$(0.69\,^{+0.06}_{-0.07})\%$
$\delta_{K\pi}$	$(15.2\,^{+7.6}_{-10.0})^\circ$
A_D	$(-0.88 \pm 0.99)\%$
$\lvert q/p\rvert$	$0.89\,^{+0.08}_{-0.07}$
ϕ	$(-12.9\,^{+9.9}_{-8.7})^\circ$
x_{12} (no direct *CP* violation)	$(0.41\,^{+0.14}_{-0.15})\%$
y_{12} (no direct *CP* violation)	$(0.61 \pm 0.07)\%$
ϕ_{12} (no direct *CP* violation)	$(-0.17 \pm 1.8)^\circ$
a_{CP}^{ind}	$(0.030 \pm 0.026)\%$
$\Delta a_{CP}^{\text{dir}}$	$(-0.134 \pm 0.070)\%$
Leptonic D decays	
f_D	(203.7 ± 4.9) MeV
f_{D_s}	(257.1 ± 4.6) MeV

Table 320 continued

$\lvert V_{cd}\rvert$	$0.2164 \pm 0.0050_{\text{exp}} \pm 0.0015_{\text{LQCD}}$
$\lvert V_{cs}\rvert$	$1.006 \pm 0.018_{\text{exp}} \pm 0.005_{\text{LQCD}}$
Benchmark charm branching fractions	
$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$	$(6.46 \pm 0.24)\%$
$\mathcal{B}(D^0 \to K^-\pi^+)$	$(3.962 \pm 0.017 \pm 0.038 \pm 0.027_{\text{FSR}})\%$
$\mathcal{B}(D^0 \to K^+\pi^-)/\mathcal{B}(D^0 \to K^-\pi^+)$	$(0.349\,^{+0.004}_{-0.003})\%$
$\mathcal{B}(D_s^+ \to K^+K^-\pi^+)$	$(5.44 \pm 0.09 \pm 0.11)\%$
τ parameters, lepton universality, and $\lvert V_{us}\rvert$	
g_τ/g_μ	1.0010 ± 0.0015
g_τ/g_e	1.0029 ± 0.0015
g_μ/g_e	1.0019 ± 0.0014
$\mathcal{B}_e^{\text{uni}}$	$17.815 \pm 0.023\%$
R_{had}	3.6349 ± 0.0082
$\lvert V_{us}\rvert$ from sum of strange branching fractions	0.2186 ± 0.0021
$\lvert V_{us}\rvert$ from $\mathcal{B}(\tau^- \to K^-\nu_\tau)/\mathcal{B}(\tau^- \to \pi^-\nu_\tau)$	0.2236 ± 0.0018
$\lvert V_{us}\rvert$ τ average	0.2216 ± 0.0015

of the values of $|V_{ub}|$ and $|V_{cb}|$ comes from exclusive b-baryon decays. The largest anomaly however is observed in $B \to D^{(*)}\tau\nu_\tau$ decays: The combined discrepancy of the measured values of $\mathcal{R}(D^*)$ and $\mathcal{R}(D)$ to their standard model expectations is found to be 3.9σ.

The most important new measurements of rare b-hadron decays are coming from the LHC. Precision measurements of B_s^0 decays are particularly noteworthy, including several measurements of the longitudinal polarisation fraction from LHCb. ATLAS, CMS and LHCb have significantly improved the sensitivity to the $B_{(s)}^0 \to \mu^+\mu^-$ decays. Recently, CMS and LHCb published a combined analysis that allowed the first observation of the $B_s^0 \to \mu^+\mu^-$ decay to be obtained, and provided three standard deviations evidence of the $B^0 \to \mu^+\mu^-$ decay. The results are compatible with the SM predictions, and yield constrains on the parameter space of new physics models. CMS and LHCb have also performed angular analyses of the $B^0 \to K^{*0}\mu^+\mu^-$ decay, complementing, extending and improving on the precision of results from BaBar and Belle. One of the observables measured by LHCb, P_5', differs from the SM prediction by 3.7σ in one of the $m^2_{\mu^+\mu^-}$ intervals; results from Belle on this observable are consistent but less precise. Improved measurements from LHCb and other experiments are keenly anticipated. A measurement of the ratio of branching fractions of $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$ decays (R_K) has been made by LHCb. In the low $m^2_{\ell^+\ell^-}$ region, it differs from the standard model prediction by 2.6σ. Among the CP violating observables in rare decays, the "$K\pi$ puzzle" persists, and important new results have appeared in three-body decays. LHCb has produced many other results on a wide variety of decays, including b-baryon and B_c^+-meson decays. Belle and BaBar continue to produce new results though their output rates are dwindling. It will still be some years before we see new results from the upgraded SuperKEKB B factory and the Belle II experiment.

About 800 b to charm results from BaBar, Belle, CDF, D0, LHCb, CMS, and ATLAS reported in more than 200 papers are compiled in a list of over 600 averages. The huge samples of b hadrons that are available in contemporary experiments allows measurements of decays to states with open or hidden charm content with unprecedented precision. In addition to improvements in precision for branching fractions of $\bar{B}^0$ and B^- mesons, many new decay modes have been discovered. In addition, there is a rapidly increasing set of measurements available for $\bar{B}_s^0$ and B_c^- mesons as well as for b baryon decays.

In the charm sector, $D^0 - \bar{D}^0$ mixing is now well-established and the emphasis has shifted to searching for CP violation. Measurements of 49 observables from the E791, FOCUS, Belle, BaBar, CLEO, BESIII, CDF, and LHCb experiments are input into a global fit for 10 underlying parameters, and the no-mixing hypothesis is excluded at a confidence level $> 11.5\sigma$. The mixing parameters x and y individually differ from zero by 1.9σ and 9.4σ, respectively. The world average value for the observable y_{CP} is positive, indicating that the CP-even state is shorter-lived as in the $K^0 - \bar{K}^0$ system. The CP violation parameters $|q/p|$ and ϕ are consistent with the no-CP violation hypothesis within 1σ. Thus there is no evidence for CP violation arising from mixing ($|q/p| \neq 1$) or from a phase difference between the mixing amplitude and a direct decay amplitude ($\phi \neq 0$). In addition, the most recent data indicates no direct CP violation in $D^0 \to K^+K^-/\pi^+\pi^-$ decays; performing a global fit to all relevant measurements gives $\Delta a_{CP}^{\rm dir} = (-0.134 \pm 0.070)\%$. The world's most precise measurements of $|V_{cd}|$ and $|V_{cs}|$ are obtained from leptonic $D^+ \to \mu^+\nu$ and $D_s^+ \to \mu^+\nu/\tau^+\nu$ decays, respectively. These measurements have theoretical uncertainties arising from decay constants. However, calculations of decay constants within lattice QCD have improved such that the theory error is $<1/3$ the experimental errors of the measurements.

Since 2016, HFLAV provides the τ branching fraction fit averages for the PDG Review of Particle Physics. For the PDG, a unitarity constrained variant of the fit is performed, using only inputs that are published and included in the PDG. Two preliminary results used in the HFLAV 2014 report have been removed both in the HFLAV and in the PDG variants of the fit. A few minor imperfections of the 2014 fit have been corrected. There are no non-negligible changes to the lepton universality tests and to the $|V_{us}|$ determinations from the τ branching fractions. There is still a large discrepancy between $|V_{us}|$ from τ, $|V_{us}|$ from kaons and $|V_{us}|$ from $|V_{ud}|$ and CKM matrix unitarity. On this topic, recent studies [1423,1424] claim to get a more reliable theory uncertainty on $|V_{us}|$ with a revised calculation method that uses also the τ spectral functions. Just one more τ lepton-flavour-violating branching fraction upper limit has been published, which does not change the computed combined related limit. The list of limits and their combinations has been revised to remove old preliminary results.

Acknowledgements We are grateful for the strong support of the ATLAS, BaBar, Belle, BESIII, CLEO(c), CDF, CMS, D0 and LHCb collaborations, without whom this compilation of results and world averages would not have been possible. The success of these experiments in turn would not have been possible without the excellent operations of the BEPC, CESR, KEKB, LHC, PEP-II, and Tevatron accelerators. We also recognise the interplay between theoretical and experimental communities that has provided a stimulus for many of the measurements in this document. Our averages and this compilation have benefitted greatly from contributions to the Heavy Flavor Averaging Group from numerous individuals. We thank David Kirkby, Yoshihide Sakai, Simon Eidelman, Soeren Prell, and Gianluca Cavoto for their past leadership of HFLAV. We are grateful to Paolo Gambino and Bob Kowalewski for assistance with averages that appear in Sect. 5; to Ruslan Chistov, Lawrence Gibbons, Bostjan Golob, Milind Purohit, and Patrick Roudeau for significant contributions to Sect. 8; and to Michel Davier for providing valuable input to Sect. 9. We especially thank the following for their careful review of the text in preparing this paper for publication: Vanya Belyaev, Guennadi Borissov, Jolanta Brodzicka, Paoti Chang, Paolo Gambino, Martin Jung, Andreas Kronfeld, George Lafferty, Alexander Lenz, Zoltan Ligeti, David London, Vera Lüth, Alexey Petrov, Antonio Pich, and Fernando Martinez Vidal. Finally, we thank the SLAC National Accelerator Laboratory for providing crucial computing resources and support to HFLAV.

Funded by SCOAP^3.

References

1. N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963). https://doi.org/10.1103/PhysRevLett.10.531
2. M. Kobayashi, T. Maskawa, Progr. Theor. Phys. **49**, 652 (1973). https://doi.org/10.1143/PTP.49.652
3. D. Abbaneo et al. (ALEPH, CDF, DELPHI, L3, OPAL, and SLD collaborations), CERN-EP-2000-096 (2000). arXiv:hep-ex/0009052
4. D. Abbaneo et al. (ALEPH, CDF, DELPHI, L3, OPAL, and SLD collaborations), CERN-EP-2001-050 (2001). arXiv:hep-ex/0112028
5. Y. Amhis et al. (Heavy Flavor Averaging Group) (2014). arXiv:1412.7515 [hep-ex]
6. C. Patrignani et al., Particle data group. Chin. Phys. C **40**, 100001 (2016). https://doi.org/10.10z88/1674-1137/40/10/100001
7. J.P. Alexander et al., CLEO collaboration. Phys. Rev. Lett. **86**, 2737 (2001). https://doi.org/10.1103/PhysRevLett.86.2737. arXiv:hep-ex/0006002
8. S.B. Athar et al., CLEO collaboration. Phys. Rev. D **66**, 052003 (2002). https://doi.org/10.1103/PhysRevD.66.052003. arXiv:hep-ex/0202033
9. N.C. Hastings et al., Belle collaboration. Phys. Rev. D **67**, 052004 (2003). https://doi.org/10.1103/PhysRevD.67.052004. arXiv:hep-ex/0212033
10. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **94**, 141801 (2005). https://doi.org/10.1103/PhysRevLett.94.141801. arXiv:hep-ex/0412062
11. B. Barish et al., CLEO collaboration. Phys. Rev. D **51**, 1014 (1995). https://doi.org/10.1103/PhysRevD.51.1014. arXiv:hep-ex/9406005
12. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **95**, 042001 (2005). https://doi.org/10.1103/PhysRevLett.95.042001. arXiv:hep-ex/0504001
13. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **96**, 232001 (2006). https://doi.org/10.1103/PhysRevLett.96.232001. arXiv:hep-ex/0604031
14. A. Sokolov et al., Belle collaboration. Phys. Rev. D **75**, 071103 (2007). https://doi.org/10.1103/PhysRevD.75.071103. arXiv:hep-ex/0611026
15. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 112002 (2008). https://doi.org/10.1103/PhysRevD.78.112002. arXiv:0807.2014 [hep-ex]
16. B. Barish et al., CLEO collaboration. Phys. Rev. Lett. **76**, 1570 (1996). https://doi.org/10.1103/PhysRevLett.76.1570
17. A. Drutskoy et al., Belle collaboration. Phys. Rev. D **81**, 112003 (2010). https://doi.org/10.1103/PhysRevD.81.112003. arXiv:1003.5885 [hep-ex]
18. G.S. Huang et al., CLEO collaboration. Phys. Rev. D **75**, 012002 (2007). https://doi.org/10.1103/PhysRevD.75.012002. arXiv:hep-ex/0610035
19. A. Drutskoy et al., Belle collaboration. Phys. Rev. Lett. **98**, 052001 (2007). https://doi.org/10.1103/PhysRevLett.98.052001. arXiv:hep-ex/0608015
20. S. Esen et al., Belle collaboration. Phys. Rev. D **87**, 031101 (2013). https://doi.org/10.1103/PhysRevD.87.031101. arXiv:1208.0323
21. M. Artuso et al., CLEO collaboration. Phys. Rev. Lett. **95**, 261801 (2005). https://doi.org/10.1103/PhysRevLett.95.261801. arXiv:hep-ex/0508047

22. K.F. Chen et al., Belle collaboration. Phys. Rev. Lett. **100**, 112001 (2008). https://doi.org/10.1103/PhysRevLett.100.112001. arXiv:0710.2577 [hep-ex]
23. A. Garmash et al., Belle collaboration. Phys. Rev. D **91**, 072003 (2015). https://doi.org/10.1103/PhysRevD.91.072003. arXiv:1403.0992 [hep-ex]
24. I. Adachi et al., Belle collaboration. Phys. Rev. Lett. **108**, 032001 (2012). https://doi.org/10.1103/PhysRevLett.108.032001. arXiv:1103.3419 [hep-ex]
25. P. Krokovny et al., Belle collaboration. Phys. Rev. D **88**, 052016 (2013). https://doi.org/10.1103/PhysRevD.88.052016. arXiv:1308.2646 [hep-ex]
26. R. Louvot, PhD thesis #5213, EPFL, Lausanne (2012). https://doi.org/10.5075/epfl-thesis-5213
27. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **85**, 011101 (2012). https://doi.org/10.1103/PhysRevD.85.011101. arXiv:1110.5600 [hep-ex]
28. J. Li et al., Belle collaboration. Phys. Rev. Lett. **106**, 121802 (2011). https://doi.org/10.1103/PhysRevLett.106.121802. arXiv:1102.2759 [hep-ex]
29. R. Louvot et al., Belle collaboration. Phys. Rev. Lett. **102**, 021801 (2009). https://doi.org/10.1103/PhysRevLett.102.021801. arXiv:0809.2526 [hep-ex]
30. P. Abreu et al., DELPHI collaboration. Phys. Lett. B **289**, 199 (1992). https://doi.org/10.1016/0370-2693(92)91385-M
31. P.D. Acton et al., OPAL collaboration. Phys. Lett. B **295**, 357 (1992). https://doi.org/10.1016/0370-2693(92)91578-W
32. D. Buskulic et al., ALEPH collaboration. Phys. Lett. B **361**, 221 (1995). https://doi.org/10.1016/0370-2693(95)01173-N
33. P. Abreu et al., DELPHI collaboration. Z. Phys. C **68**, 375 (1995). https://doi.org/10.1007/BF01620713
34. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **2**, 197 (1998). https://doi.org/10.1007/s100520050133
35. D. Buskulic et al., ALEPH collaboration. Phys. Lett. B **384**, 449 (1996). https://doi.org/10.1016/0370-2693(96)00925-2
36. J. Abdallah et al., DELPHI collaboration. Eur. Phys. J. C **44**, 299 (2005). https://doi.org/10.1140/epjc/s2005-02388-4. arXiv:hep-ex/0510023
37. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **5**, 205 (1998). https://doi.org/10.1007/s100520050263
38. J. Abdallah et al., DELPHI collaboration. Phys. Lett. B **576**, 29 (2003). https://doi.org/10.1016/j.physletb.2003.09.070. arXiv:hep-ex/0311005
39. T. Affolder et al., CDF collaboration. Phys. Rev. Lett. **84**, 1663 (2000). https://doi.org/10.1103/PhysRevLett.84.1663. arXiv:hep-ex/9909011
40. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **77**, 072003 (2008). https://doi.org/10.1103/PhysRevD.77.072003. arXiv:0801.4375 [hep-ex]
41. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **79**, 032001 (2009). https://doi.org/10.1103/PhysRevD.79.032001. arXiv:0810.3213 [hep-ex]
42. F. Abe et al., CDF collaboration. Phys. Rev. D **60**, 092005 (1999). https://doi.org/10.1103/PhysRevD.60.092005
43. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **99**, 052001 (2007). https://doi.org/10.1103/PhysRevLett.99.052001. arXiv:0706.1690 [hep-ex]
44. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **101**, 232002 (2008). https://doi.org/10.1103/PhysRevLett.101.232002. arXiv:0808.4142 [hep-ex]
45. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **80**, 072003 (2009). https://doi.org/10.1103/PhysRevD.80.072003. arXiv:0905.3123 [hep-ex]
46. R. Aaij et al. (LHCb collaboration), Phys. Rev. D **85**, 032008 (2012). https://doi.org/10.1103/PhysRevD.85.032008. arXiv:1111.2357 [hep-ex], with numerical results and full covariance matrix available at https://cdsweb.cern.ch/record/1390838
47. R. Aaij et al. (LHCb collaboration), JHEP **04**, 001 (2013). https://doi.org/10.1007/JHEP04(2013)001. arXiv:1301.5286 [hep-ex], with numerical results and full covariance matrix available at http://cdsweb.cern.ch/record/1507868
48. R. Aaij et al., LHCb collaboration. JHEP **08**, 143 (2014). https://doi.org/10.1007/JHEP08(2014)143. arXiv:1405.6842 [hep-ex]
49. G. Aad et al., ATLAS collaboration. Phys. Rev. Lett. **115**, 262001 (2015). https://doi.org/10.1103/PhysRevLett.115.262001. arXiv:1507.08925 [hep-ex]
50. X. Liu, W. Wang, Y. Xie, Phys. Rev. D **89**, 094010 (2014). https://doi.org/10.1103/PhysRevD.89.094010. arXiv:1309.0313 [hep-ph]
51. S. Schael et al., ALEPH, CDF, DELPHI, L3, OPAL, and SLD collaborations, LEP electroweak working group, SLD electroweak and heavy flavour working groups. Phys. Rep. **427**, 257 (2006). https://doi.org/10.1016/j.physrep.2005.12.006. arXiv:hep-ex/0509008
52. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **74**, 092001 (2006). https://doi.org/10.1103/PhysRevD.74.092001. arXiv:hep-ex/0609014
53. D. Acosta et al., CDF collaboration. Phys. Rev. D **69**, 012002 (2004). https://doi.org/10.1103/PhysRevD.69.012002. arXiv:hep-ex/0309030
54. LHCb collaboration, LHCb-CONF-2013-011 (2013). https://cdsweb.cern.ch/record/1559262
55. M.A. Shifman, M.B. Voloshin, Sov. Phys. JETP **64**, 698 (1986)
56. J. Chay, H. Georgi, B. Grinstein, Phys. Lett. B **247**, 399 (1990). https://doi.org/10.1016/0370-2693(90)90916-T
57. I.I. Bigi, N.G. Uraltsev, A.I. Vainshtein, Phys. Lett. B **293**, 430 (1992). https://doi.org/10.1016/0370-2693(92)90908-M. arXiv:hep-ph/9207214. [Erratum ibid. **297**, 477 (1992). doi:10.1016/0370-2693(92)91287-JPhys.Lett.B]
58. M.A. Shifman (2000). arXiv:hep-ph/0009131
59. I.I.Y. Bigi, N. Uraltsev, Int. J. Mod. Phys. A **16**, 5201 (2001). https://doi.org/10.1142/S0217751X01005535. arXiv:hep-ph/0106346
60. T. Jubb, M. Kirk, A. Lenz, G. Tetlalmatzi-Xolocotzi, Nucl. Phys. B **915**, 431 (2017). https://doi.org/10.1016/j.nuclphysb.2016.12.020. arXiv:1603.07770 [hep-ph]
61. K.G. Wilson, Phys. Rev. **179**, 1499 (1969). https://doi.org/10.1103/PhysRev.179.1499
62. M. Ciuchini, E. Franco, V. Lubicz, F. Mescia, Nucl. Phys. B **625**, 211 (2002). https://doi.org/10.1016/S0550-3213(02)00006-8. arXiv:hep-ph/0110375
63. M. Beneke, G. Buchalla, C. Greub, A. Lenz, U. Nierste, Nucl. Phys. B **639**, 389 (2002). https://doi.org/10.1016/S0550-3213(02)00561-8. arXiv:hep-ph/0202106
64. E. Franco, V. Lubicz, F. Mescia, C. Tarantino, Nucl. Phys. B **633**, 212 (2002). https://doi.org/10.1016/S0550-3213(02)00262-6. arXiv:hep-ph/0203089
65. C. Tarantino, Eur. Phys. J. C **33**, S895 (2004). https://doi.org/10.1140/epjcd/s2003-03-1006-y. arXiv:hep-ph/0310241
66. F. Gabbiani, A.I. Onishchenko, A.A. Petrov, Phys. Rev. D **68**, 114006 (2003). https://doi.org/10.1103/PhysRevD.68.114006. arXiv:hep-ph/0303235
67. F. Gabbiani, A.I. Onishchenko, A.A. Petrov, Phys. Rev. D **70**, 094031 (2004). https://doi.org/10.1103/PhysRevD.70.094031. arXiv:hep-ph/0407004
68. A. Lenz, Int. J. Mod. Phys. A **30**, 1543005 (2015). https://doi.org/10.1142/S0217751X15430058
69. A. Lenz (2014). arXiv:1405.3601 [hep-ph]
70. D. Buskulic et al., ALEPH collaboration. Phys. Lett. B **314**, 459 (1993). https://doi.org/10.1016/0370-2693(93)91265-O

71. P. Abreu et al., DELPHI collaboration. Z. Phys. C **63**, 3 (1994). https://doi.org/10.1007/BF01577539
72. P. Abreu et al., DELPHI collaboration. Phys. Lett. B **377**, 195 (1996). https://doi.org/10.1016/0370-2693(96)00452-2
73. J. Abdallah et al., DELPHI collaboration. Eur. Phys. J. C **33**, 307 (2004). https://doi.org/10.1140/epjc/s2004-01599-5. arXiv:hep-ex/0401025
74. M. Acciarri et al., L3 collaboration. Phys. Lett. B **416**, 220 (1998). https://doi.org/10.1016/S0370-2693(97)01379-8
75. K. Ackerstaff et al., OPAL collaboration. Z. Phys. C **73**, 397 (1997). https://doi.org/10.1007/s002880050329
76. K. Abe et al., SLD collaboration. Phys. Rev. Lett. **75**, 3624 (1995). https://doi.org/10.1103/PhysRevLett.75.3624. arXiv:hep-ex/9511005
77. D. Buskulic et al., ALEPH collaboration. Phys. Lett. B **369**, 151 (1996). https://doi.org/10.1016/0370-2693(95)01586-8
78. P.D. Acton et al., OPAL collaboration. Z. Phys. C **60**, 217 (1993). https://doi.org/10.1007/BF01474617
79. F. Abe et al., CDF collaboration. Phys. Rev. D **57**, 5382 (1998). https://doi.org/10.1103/PhysRevD.57.5382
80. R. Barate et al., ALEPH collaboration. Phys. Lett. B **492**, 275 (2000). https://doi.org/10.1016/S0370-2693(00)01093-5. arXiv:hep-ex/0008016
81. D. Buskulic et al., ALEPH collaboration. Z. Phys. C **71**, 31 (1996). https://doi.org/10.1007/s002880050145
82. P. Abreu et al., DELPHI collaboration. Z. Phys. C **68**, 13 (1995). https://doi.org/10.1007/BF01579800
83. W. Adam et al., DELPHI collaboration. Z. Phys. C **68**, 363 (1995). https://doi.org/10.1007/BF01620712
84. P. Abreu et al., DELPHI collaboration. Z. Phys. C **74**, 19 (1997). https://doi.org/10.1007/s002880050367
85. M. Acciarri et al., L3 collaboration. Phys. Lett. B **438**, 417 (1998). https://doi.org/10.1016/S0370-2693(98)01114-9
86. R. Akers et al., OPAL collaboration. Z. Phys. C **67**, 379 (1995). https://doi.org/10.1007/BF01624581
87. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **12**, 609 (2000). https://doi.org/10.1007/s100520000322. arXiv:hep-ex/9901017
88. G. Abbiendi et al., OPAL collaboration. Phys. Lett. B **493**, 266 (2000). https://doi.org/10.1016/S0370-2693(00)01145-X. arXiv:hep-ex/0010013
89. K. Abe et al., SLD collaboration. Phys. Rev. Lett. **79**, 590 (1997). https://doi.org/10.1103/PhysRevLett.79.590
90. F. Abe et al., CDF collaboration. Phys. Rev. D **58**, 092002 (1998). https://doi.org/10.1103/PhysRevD.58.092002. arXiv:hep-ex/9806018
91. D. Acosta et al., CDF collaboration. Phys. Rev. D **65**, 092009 (2002). https://doi.org/10.1103/PhysRevD.65.092009
92. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **106**, 121804 (2011). https://doi.org/10.1103/PhysRevLett.106.121804. arXiv:1012.3138 [hep-ex]
93. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **102**, 032001 (2009). https://doi.org/10.1103/PhysRevLett.102.032001. arXiv:0810.0037 [hep-ex]
94. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **85**, 112003 (2012). https://doi.org/10.1103/PhysRevD.85.112003. arXiv:1204.2340 [hep-ex]
95. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **114**, 062001 (2015). https://doi.org/10.1103/PhysRevLett.114.062001. arXiv:1410.1568 [hep-ex]
96. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **87**, 201803 (2001). https://doi.org/10.1103/PhysRevLett.87.201803. arXiv:hep-ex/0107019
97. B. Aubert et al. (BaBar collaboration), Phys. Rev. Lett. **89**, 011802 (2002). https://doi.org/10.1103/PhysRevLett.89.011802. arXiv:hep-ex/0202005. [Erratum ibid. **89**, 169903 (2002). doi:10.1103/PhysRevLett.89.169903]
98. B. Aubert et al., BaBar collaboration. Phys. Rev. D **67**, 072002 (2003). https://doi.org/10.1103/PhysRevD.67.072002. arXiv:hep-ex/0212017
99. B. Aubert et al., BaBar collaboration. Phys. Rev. D **67**, 091101 (2003). https://doi.org/10.1103/PhysRevD.67.091101. arXiv:hep-ex/0212012
100. B. Aubert et al., BaBar collaboration. Phys. Rev. D **73**, 012004 (2006). https://doi.org/10.1103/PhysRevD.73.012004. arXiv:hep-ex/0507054
101. K. Abe et al. (Belle collaboration), Phys. Rev. D **71**, 072003 (2005). https://doi.org/10.1103/PhysRevD.71.072003. arXiv:hep-ex/0408111. [Erratum ibid. **71**, 079903 (2005). doi:10.1103/PhysRevD.71.079903]
102. G. Aad et al., ATLAS collaboration. Phys. Rev. D **87**, 032002 (2013). https://doi.org/10.1103/PhysRevD.87.032002. arXiv:1207.2284 [hep-ex]
103. R. Aaij et al., LHCb collaboration. JHEP **04**, 114 (2014). https://doi.org/10.1007/JHEP04(2014)114. arXiv:1402.2554 [hep-ex]
104. R. Aaij et al., LHCb collaboration. Phys. Lett. B **736**, 446 (2014). https://doi.org/10.1016/j.physletb.2014.07.051. arXiv:1406.7204 [hep-ex]
105. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **83**, 032008 (2011). https://doi.org/10.1103/PhysRevD.83.032008. arXiv:1004.4855 [hep-ex]
106. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **94**, 182001 (2005). https://doi.org/10.1103/PhysRevLett.94.182001. arXiv:hep-ex/0410052
107. M. Artuso, G. Borissov, A. Lenz, Rev. Mod. Phys. **88**, 045002 (2016). https://doi.org/10.1103/RevModPhys.88.045002. arXiv:1511.09466 [hep-ph]
108. S. Laplace, Z. Ligeti, Y. Nir, G. Perez, Phys. Rev. D **65**, 094040 (2002). https://doi.org/10.1103/PhysRevD.65.094040. arXiv:hep-ph/0202010
109. M. Ciuchini, E. Franco, V. Lubicz, F. Mescia, C. Tarantino, JHEP **08**, 031 (2003). https://doi.org/10.1088/1126-6708/2003/08/031. arXiv:hep-ph/0308029
110. M. Beneke, G. Buchalla, A. Lenz, U. Nierste, Phys. Lett. B **576**, 173 (2003). https://doi.org/10.1016/j.physletb.2003.09.089. arXiv:hep-ph/0307344
111. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **108**, 241801 (2012). https://doi.org/10.1103/PhysRevLett.108.241801. arXiv:1202.4717 [hep-ex]
112. R. Fleischer, R. Knegjens, Eur. Phys. J. C **71**, 1789 (2011). https://doi.org/10.1140/epjc/s10052-011-1789-9. arXiv:1109.5115 [hep-ph]
113. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **4**, 367 (1998). https://doi.org/10.1007/s100520050215
114. P. Abreu et al., DELPHI collaboration. Eur. Phys. J. C **18**, 229 (2000). https://doi.org/10.1007/s100520000531. arXiv:hep-ex/0105077
115. K. Ackerstaff et al., OPAL collaboration. Eur. Phys. J. C **2**, 407 (1998). https://doi.org/10.1007/s100520050150. arXiv:hep-ex/9708023
116. D. Buskulic et al., ALEPH collaboration. Phys. Lett. B **377**, 205 (1996). https://doi.org/10.1016/0370-2693(96)00451-0
117. F. Abe et al., CDF collaboration. Phys. Rev. D **59**, 032004 (1999). https://doi.org/10.1103/PhysRevD.59.032004. arXiv:hep-ex/9808003
118. P. Abreu et al., DELPHI collaboration. Eur. Phys. J. C **16**, 555 (2000). https://doi.org/10.1007/s100520000415. arXiv:hep-ex/0107077
119. K. Ackerstaff et al., OPAL collaboration. Phys. Lett. B **426**, 161 (1998). https://doi.org/10.1016/S0370-2693(98)00289-5. arXiv:hep-ex/9802002

120. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **107**, 272001 (2011). https://doi.org/10.1103/PhysRevLett.107.272001. arXiv:1103.1864 [hep-ex]
121. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **112**, 111802 (2014). https://doi.org/10.1103/PhysRevLett.112.111802. arXiv:1312.1217 [hep-ex]
122. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **113**, 172001 (2014). https://doi.org/10.1103/PhysRevLett.113.172001. arXiv:1407.5873 [hep-ex]
123. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **94**, 042001 (2005). https://doi.org/10.1103/PhysRevLett.94.042001. arXiv:hep-ex/0409043
124. R. Barate et al., ALEPH collaboration. Phys. Lett. B **486**, 286 (2000). https://doi.org/10.1016/S0370-2693(00)00750-4
125. R. Aaij et al., LHCb collaboration. Phys. Lett. B **707**, 349 (2012). https://doi.org/10.1016/j.physletb.2011.12.058. arXiv:1111.0521 [hep-ex]
126. R. Aaij et al., LHCb collaboration. Phys. Lett. B **762**, 484 (2016). https://doi.org/10.1016/j.physletb.2016.10.006. arXiv:1607.06314 [hep-ex]
127. R. Aaij et al., LHCb collaboration. Nucl. Phys. B **873**, 275 (2013). https://doi.org/10.1016/j.nuclphysb.2013.04.021. arXiv:1304.4500 [hep-ex]
128. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **84**, 052012 (2011). https://doi.org/10.1103/PhysRevD.84.052012. arXiv:1106.3682 [hep-ex]
129. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **94**, 012001 (2016). https://doi.org/10.1103/PhysRevD.94.012001. arXiv:1603.01302 [hep-ex]
130. R. Aaij et al., LHCb collaboration. Phys. Rev. D **87**, 112010 (2013). https://doi.org/10.1103/PhysRevD.87.112010. arXiv:1304.2600 [hep-ex]
131. K. Hartkorn, H.G. Moser, Eur. Phys. J. C **8**, 381 (1999). https://doi.org/10.1007/s100520050472
132. R. Aaij et al., LHCb collaboration. Phys. Lett. B **739**, 218 (2014). https://doi.org/10.1016/j.physletb.2014.10.005. arXiv:1408.0275 [hep-ex]
133. F. Abe et al., CDF collaboration. Phys. Rev. Lett. **81**, 2432 (1998). https://doi.org/10.1103/PhysRevLett.81.2432. arXiv:hep-ex/9805034
134. A. Abulencia et al., CDF collaboration. Phys. Rev. Lett. **97**, 012002 (2006). https://doi.org/10.1103/PhysRevLett.97.012002. arXiv:hep-ex/0603027
135. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **102**, 092001 (2009). https://doi.org/10.1103/PhysRevLett.102.092001. arXiv:0805.2614 [hep-ex]
136. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **87**, 011101 (2013). https://doi.org/10.1103/PhysRevD.87.011101. arXiv:1210.2366 [hep-ex]
137. R. Aaij et al., LHCb collaboration. Eur. Phys. J. C **74**, 2839 (2014). https://doi.org/10.1140/epjc/s10052-014-2839-x. arXiv:1401.6932 [hep-ex]
138. R. Aaij et al., LHCb collaboration. Phys. Lett. B **742**, 29 (2015). https://doi.org/10.1016/j.physletb.2015.01.010. arXiv:1411.6899 [hep-ex]
139. P. Abreu et al., DELPHI collaboration. Eur. Phys. J. C **10**, 185 (1999). https://doi.org/10.1007/s100520050582
140. P. Abreu et al., DELPHI collaboration. Z. Phys. C **71**, 199 (1996). https://doi.org/10.1007/s002880050164
141. R. Akers et al., OPAL collaboration. Z. Phys. C **69**, 195 (1996). https://doi.org/10.1007/s002880050020
142. F. Abe et al., CDF collaboration. Phys. Rev. Lett. **77**, 1439 (1996). https://doi.org/10.1103/PhysRevLett.77.1439
143. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **99**, 182001 (2007). https://doi.org/10.1103/PhysRevLett.99.182001. arXiv:0706.2358 [hep-ex]
144. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **104**, 102002 (2010). https://doi.org/10.1103/PhysRevLett.104.102002. arXiv:0912.3566 [hep-ex]
145. T.A. Aaltonen et al., CDF collaboration. Phys. Rev. D **89**, 072014 (2014). https://doi.org/10.1103/PhysRevD.89.072014. arXiv:1403.8126 [hep-ex]
146. S. Chatrchyan et al., CMS collaboration. JHEP **07**, 163 (2013). https://doi.org/10.1007/JHEP07(2013)163. arXiv:1304.7495 [hep-ex]
147. R. Aaij et al., LHCb collaboration. Phys. Lett. B **734**, 122 (2014). https://doi.org/10.1016/j.physletb.2014.05.021. arXiv:1402.6242 [hep-ex]
148. P. Abreu et al., DELPHI collaboration. Z. Phys. C **68**, 541 (1995). https://doi.org/10.1007/BF01565255
149. R. Aaij et al., LHCb collaboration. Phys. Lett. B **736**, 154 (2014). https://doi.org/10.1016/j.physletb.2014.06.064. arXiv:1405.1543 [hep-ex]
150. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **113**, 242002 (2014). https://doi.org/10.1103/PhysRevLett.113.242002. arXiv:1409.8568 [hep-ex]
151. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **113**, 032001 (2014). https://doi.org/10.1103/PhysRevLett.113.032001. arXiv:1405.7223 [hep-ex]
152. R. Aaij et al., LHCb collaboration. Phys. Rev. D **93**, 092007 (2016). https://doi.org/10.1103/PhysRevD.93.092007. arXiv:1604.01412 [hep-ex]
153. M. Beneke, G. Buchalla, I. Dunietz, Phys. Rev. D **54**, 4419 (1996). https://doi.org/10.1103/PhysRevD.54.4419. arXiv:hep-ph/9605259. [Erratum ibid. **83**, 119902 (2011). doi:10.1103/PhysRevD.83.119902]
154. Y.-Y. Keum, U. Nierste, Phys. Rev. D **57**, 4282 (1998). https://doi.org/10.1103/PhysRevD.57.4282. arXiv:hep-ph/9710512
155. M.B. Voloshin, Phys. Rep. **320**, 275 (1999). https://doi.org/10.1016/S0370-1573(99)00054-X. arXiv:hep-ph/9901445
156. B. Guberina, B. Melic, H. Stefancic, Phys. Lett. B **469**, 253 (1999). https://doi.org/10.1016/S0370-2693(99)01198-3. arXiv:hep-ph/9907468
157. M. Neubert, C.T. Sachrajda, Nucl. Phys. B **483**, 339 (1997). https://doi.org/10.1016/S0550-3213(96)00559-7. arXiv:hep-ph/9603202
158. I.I.Y. Bigi, M.A. Shifman, N. Uraltsev, Ann. Rev. Nucl. Part. Sci. **47**, 591 (1997). https://doi.org/10.1146/annurev.nucl.47.1.591. arXiv:hep-ph/9703290
159. N.G. Uraltsev, Phys. Lett. B **376**, 303 (1996). https://doi.org/10.1016/0370-2693(96)00305-X. arXiv:hep-ph/9602324
160. D. Pirjol, N. Uraltsev, Phys. Rev. D **59**, 034012 (1999). https://doi.org/10.1103/PhysRevD.59.034012. arXiv:hep-ph/9805488
161. P. Colangelo, F. De Fazio, Phys. Lett. B **387**, 371 (1996). https://doi.org/10.1016/0370-2693(96)01049-0. arXiv:hep-ph/9604425
162. M. Di Pierro, C.T. Sachrajda, C. Michael, (UKQCD collaboration), Phys. Lett. B **468**, 143 (1999). https://doi.org/10.1016/S0370-2693(99)01166-1. arXiv:hep-lat/9906031. [Erratum ibid. **525**, 360 (2002). doi:10.1016/S0370-2693(01)01458-7]
163. D. Buskulic et al., ALEPH collaboration. Z. Phys. C **75**, 397 (1997). https://doi.org/10.1007/s002880050483
164. P. Abreu et al., DELPHI collaboration. Z. Phys. C **76**, 579 (1997). https://doi.org/10.1007/s002880050582
165. J. Abdallah et al., DELPHI collaboration. Eur. Phys. J. C **28**, 155 (2003). https://doi.org/10.1140/epjc/s2003-01183-7. arXiv:hep-ex/0303032
166. M. Acciarri et al., L3 collaboration. Eur. Phys. J. C **5**, 195 (1998). https://doi.org/10.1007/s100520050262
167. K. Ackerstaff et al., OPAL collaboration. Z. Phys. C **76**, 417 (1997). https://doi.org/10.1007/s002880050565. arXiv:hep-ex/9707010

168. K. Ackerstaff et al., OPAL collaboration. Z. Phys. C **76**, 401 (1997). https://doi.org/10.1007/s002880050564. arXiv:hep-ex/9707009
169. G. Alexander et al., OPAL collaboration. Z. Phys. C **72**, 377 (1996). https://doi.org/10.1007/s002880050258
170. F. Abe et al., CDF collaboration. Phys. Rev. Lett. **80**, 2057 (1998). https://doi.org/10.1103/PhysRevLett.80.2057. arXiv:hep-ex/9712004
171. F. Abe et al., CDF collaboration. Phys. Rev. D **59**, 032001 (1999). https://doi.org/10.1103/PhysRevD.59.032001. arXiv:hep-ex/9806026
172. F. Abe et al., CDF collaboration. Phys. Rev. D **60**, 051101 (1999). https://doi.org/10.1103/PhysRevD.60.051101
173. F. Abe et al., CDF collaboration. Phys. Rev. D **60**, 072003 (1999). https://doi.org/10.1103/PhysRevD.60.072003. arXiv:hep-ex/9903011
174. T. Affolder et al., CDF collaboration. Phys. Rev. D **60**, 112004 (1999). https://doi.org/10.1103/PhysRevD.60.112004. arXiv:hep-ex/9907053
175. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **74**, 112002 (2006). https://doi.org/10.1103/PhysRevD.74.112002. arXiv:hep-ex/0609034
176. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **88**, 221802 (2002). https://doi.org/10.1103/PhysRevLett.88.221802. arXiv:hep-ex/0112044
177. B. Aubert et al., BABAR collaboration. Phys. Rev. D **66**, 032003 (2002). https://doi.org/10.1103/PhysRevD.66.032003. arXiv:hep-ex/0201020
178. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **88**, 221803 (2002). https://doi.org/10.1103/PhysRevLett.88.221803. arXiv:hep-ex/0112045
179. Y. Zheng et al., Belle collaboration. Phys. Rev. D **67**, 092004 (2003). arXiv:hep-ex/0211065
180. LHCb collaboration, LHCb-CONF-2011-010 (2011). https://cdsweb.cern.ch/record/1331124, this result has been published in Ref. [206]
181. R. Aaij et al., LHCb collaboration. Phys. Lett. B **719**, 318 (2013). https://doi.org/10.1016/j.physletb.2013.01.019. arXiv:1210.6750 [hep-ex]
182. R. Aaij et al., LHCb collaboration. Eur. Phys. J. C **73**, 2655 (2013). https://doi.org/10.1140/epjc/s10052-013-2655-8. arXiv:1308.1302 [hep-ex]
183. R. Aaij et al., LHCb collaboration. Eur. Phys. J. C **76**, 412 (2016). https://doi.org/10.1140/epjc/s10052-016-4250-2. arXiv:1604.03475 [hep-ex]
184. H. Albrecht et al., ARGUS collaboration. Z. Phys. C **55**, 357 (1992). https://doi.org/10.1007/BF01565092
185. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **324**, 249 (1994). https://doi.org/10.1016/0370-2693(94)90415-4
186. J.E. Bartelt et al., CLEO collaboration. Phys. Rev. Lett. **71**, 1680 (1993). https://doi.org/10.1103/PhysRevLett.71.1680
187. B.H. Behrens et al., CLEO collaboration. Phys. Lett. B **490**, 36 (2000). https://doi.org/10.1016/S0370-2693(00)00990-4. arXiv:hep-ex/0005013
188. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **92**, 181801 (2004). https://doi.org/10.1103/PhysRevLett.92.181801. arXiv:hep-ex/0311037
189. B. Aubert et al., BABAR collaboration. Phys. Rev. D **70**, 012007 (2004). https://doi.org/10.1103/PhysRevD.70.012007. arXiv:hep-ex/0403002
190. T. Higuchi et al., Belle collaboration. Phys. Rev. D **85**, 071105 (2012). https://doi.org/10.1103/PhysRevD.85.071105. arXiv:1203.0930 [hep-ex]
191. T. Gershon, J. Phys. G **38**, 015007 (2011). https://doi.org/10.1088/0954-3899/38/1/015007J. arXiv:1007.5135 [hep-ph]. [Erratum ibid. **42**, 119501 (2015). doi:10.1088/0954-3899/42/11/119501]
192. M. Aaboud et al., ATLAS collaboration. JHEP **06**, 081 (2016). https://doi.org/10.1007/JHEP06(2016)081. arXiv:1605.07485 [hep-ex]
193. J. Charles et al. (CKMfitter group), Phys. Rev. D **84**, 033005 (2011). https://doi.org/10.1103/PhysRevD.84.033005. arXiv:1106.4041 [hep-ph], with updated results and plots available at http://ckmfitter.in2p3.fr
194. M. Bona et al. (UTfit collaboration), JHEP **10**, 081 (2006). https://doi.org/10.1088/1126-6708/2006/10/081. arXiv:hep-ph/0606167, with similar updated results and plots available at http://www.utfit.org
195. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **89**, 012002 (2014). https://doi.org/10.1103/PhysRevD.89.012002. arXiv:1310.0447 [hep-ex]
196. U. Nierste, talk presented at the 8th International Workshop on the CKM unitarity Triangle (CKM 2014) (2014). http://indico.cern.ch/event/253826/contributions/567426/
197. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **109**, 171802 (2012). https://doi.org/10.1103/PhysRevLett.109.171802. arXiv:1208.2967 [hep-ex]
198. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **85**, 032006 (2012). https://doi.org/10.1103/PhysRevD.85.032006. arXiv:1109.3166 [hep-ex]
199. G. Aad et al., ATLAS collaboration. Phys. Rev. D **90**, 052007 (2014). https://doi.org/10.1103/PhysRevD.90.052007. arXiv:1407.1796 [hep-ex]
200. G. Aad et al., ATLAS collaboration. JHEP **08**, 147 (2016). https://doi.org/10.1007/JHEP08(2016)147. arXiv:1601.03297 [hep-ex]
201. V. Khachatryan et al., CMS collaboration. Phys. Lett. B **757**, 97 (2016). https://doi.org/10.1016/j.physletb.2016.03.046. arXiv:1507.07527 [hep-ex]
202. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **114**, 041801 (2015). https://doi.org/10.1103/PhysRevLett.114.041801. arXiv:1411.3104 [hep-ex]
203. R. Aaij et al., LHCb collaboration. Phys. Lett. B. **762**, 253 (2016). https://doi.org/10.1016/j.physletb.2016.09.028. arXiv:1608.04855 [hep-ex]
204. A. Lenz, arXiv:1205.1444 [hep-ph] (2012)
205. S. Esen et al., Belle collaboration. Phys. Rev. Lett. **105**, 201802 (2010). https://doi.org/10.1103/PhysRevLett.105.201802. arXiv:1005.5177 [hep-ex]
206. V. Abazov et al., D0 collaboration. Phys. Rev. Lett. **102**, 091801 (2009). https://doi.org/10.1103/PhysRevLett.102.091801. arXiv:0811.2173 [hep-ex]
207. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **100**, 021803 (2008). https://doi.org/10.1103/PhysRevLett.100.021803
208. A. Lenz, U. Nierste, arXiv:1102.4274 [hep-ph] (2011)
209. A. Lenz, U. Nierste, JHEP **06**, 072 (2007). https://doi.org/10.1088/1126-6708/2007/06/072. arXiv:hep-ph/0612167
210. A. Heister et al., ALEPH collaboration. Eur. Phys. J. C **29**, 143 (2003). https://doi.org/10.1140/epjc/s2003-01230-5
211. J. Abdallah et al., DELPHI collaboration. Eur. Phys. J. C **35**, 35 (2004). https://doi.org/10.1140/epjc/s2004-01827-0. arXiv:hep-ex/0404013
212. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **11**, 587 (1999). https://doi.org/10.1007/s100520050658. arXiv:hep-ex/9907061
213. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **19**, 241 (2001). https://doi.org/10.1007/s100520100591. arXiv:hep-ex/0011052
214. K. Abe et al., SLD collaboration. Phys. Rev. D **67**, 012006 (2003). https://doi.org/10.1103/PhysRevD.67.012006. arXiv:hep-ex/0209002

215. K. Abe et al., SLD collaboration. Phys. Rev. D **66**, 032009 (2002). https://doi.org/10.1103/PhysRevD.66.032009. arXiv:hep-ex/0207048
216. F. Abe et al., CDF collaboration. Phys. Rev. Lett. **82**, 3576 (1999). https://doi.org/10.1103/PhysRevLett.82.3576
217. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **97**, 021802 (2006). https://doi.org/10.1103/PhysRevLett.97.021802. arXiv:hep-ex/0603029
218. A. Abulencia et al., CDF collaboration. Phys. Rev. Lett. **97**, 242003 (2006). https://doi.org/10.1103/PhysRevLett.97.242003. arXiv:hep-ex/0609040
219. R. Aaij et al., LHCb collaboration. Phys. Lett. B **709**, 177 (2012). https://doi.org/10.1016/j.physletb.2012.02.031. arXiv:1112.4311 [hep-ex]
220. R. Aaij et al., LHCb collaboration. New J. Phys. **15**, 053021 (2013). https://doi.org/10.1088/1367-2630/15/5/053021. arXiv:1304.4741 [hep-ex]
221. A. Bazavov et al., Fermilab Lattice and MILC collaborations. Phys. Rev. D **93**, 113016 (2016). https://doi.org/10.1103/PhysRevD.93.113016. arXiv:1602.03560 [hep-lat]
222. S. Aoki et al. (FLAG working group), Eur. Phys. J. C **77**, 112 (2017). arXiv:1607.00299 [hep-lat], see also http://itpwiki.unibe.ch/flag/
223. D.E. Jaffe et al., CLEO collaboration. Phys. Rev. Lett. **86**, 5000 (2001). https://doi.org/10.1103/PhysRevLett.86.5000. arXiv:hep-ex/0101006
224. J.P. Lees et al., BABAR collaboration. Phys. Rev. Lett. **114**, 081801 (2015). https://doi.org/10.1103/PhysRevLett.114.081801. arXiv:1411.1842 [hep-ex]
225. F. Abe et al., CDF collaboration. Phys. Rev. D **55**, 2546 (1997). https://doi.org/10.1103/PhysRevD.55.2546
226. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **20**, 431 (2001)
227. J.P. Lees et al. (BABAR collaboration), Phys. Rev. Lett. **111**, 101802 (2013). https://doi.org/10.1103/PhysRevLett.111.101802. arXiv:1305.1575 [hep-ex]. [Erratum ibid. **111**, 159901 (2013). doi:10.1103/PhysRevLett.111.159901]
228. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **96**, 251802 (2006). https://doi.org/10.1103/PhysRevLett.96.251802. arXiv:hep-ex/0603053
229. E. Nakano et al., Belle collaboration. Phys. Rev. D **73**, 112002 (2006). https://doi.org/10.1103/PhysRevD.73.112002. arXiv:hep-ex/0505017
230. M. Beneke, G. Buchalla, I. Dunietz, Phys. Lett. B **393**, 132 (1997). https://doi.org/10.1016/S0370-2693(96)01648-6. arXiv:hep-ph/9609357
231. I. Dunietz, Eur. Phys. J. C **7**, 197 (1999). https://doi.org/10.1007/s100529801005. arXiv:hep-ph/9806521
232. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **86**, 072009 (2012). https://doi.org/10.1103/PhysRevD.86.072009. arXiv:1208.5813 [hep-ex]
233. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **114**, 041601 (2015). https://doi.org/10.1103/PhysRevLett.114.041601. arXiv:1409.8586 [hep-ex]
234. Y. Amhis et al. (Heavy Flavor Averaging Group), arXiv:1207.1158 [hep-ex] (2012)
235. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **110**, 011801 (2013). https://doi.org/10.1103/PhysRevLett.110.011801. arXiv:1207.1769 [hep-ex]
236. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **117**, 061803 (2016). https://doi.org/10.1103/PhysRevLett.117.061803. arXiv:1605.09768 [hep-ex]
237. A. Lenz, private communication (2017)
238. S. Descotes-Genon, J.F. Kamenik, Phys. Rev. D **87**, 074036 (2013). https://doi.org/10.1103/PhysRevD.87.074036. arXiv:1207.4483 [hep-ph]. [Erratum ibid. **92**, 079903 (2015). doi:10.1103/PhysRevD.92.079903]
239. M. Aaboud et al., ATLAS collaboration. JHEP **02**, 071 (2017). https://doi.org/10.1007/JHEP02(2017)071. arXiv:1610.07869 [hep-ex]
240. R. Aaij et al., LHCb collaboration. Phys. Lett. B. **736**, 186 (2014). https://doi.org/10.1016/j.physletb.2014.06.079. arXiv:1405.4140 [hep-ex]
241. R. Aaij et al., LHCb collaboration. Phys. Rev. D. **86**, 052006 (2012). https://doi.org/10.1103/PhysRevD.86.052006. arXiv:1204.5643 [hep-ex]
242. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **113**, 211801 (2014). https://doi.org/10.1103/PhysRevLett.113.211801. arXiv:1409.4619 [hep-ex]
243. R. Aaij et al., LHCb collaboration. Phys. Lett. B **741**, 1 (2015). https://doi.org/10.1016/j.physletb.2014.12.015. arXiv:1408.4368 [hep-ex]
244. L.-L. Chau, W.-Y. Keung, Phys. Rev. Lett. **53**, 1802 (1984). https://doi.org/10.1103/PhysRevLett.53.1802
245. L. Wolfenstein, Phys. Rev. Lett. **51**, 1945 (1983). https://doi.org/10.1103/PhysRevLett.51.1945
246. A.J. Buras, M.E. Lautenbacher, G. Ostermaier, Phys. Rev. D **50**, 3433 (1994). https://doi.org/10.1103/PhysRevD.50.3433. arXiv:hep-ph/9403384
247. C. Jarlskog, Phys. Rev. Lett. **55**, 1039 (1985). https://doi.org/10.1103/PhysRevLett.55.1039
248. C. Jarlskog, Phys. Lett. B. **615**, 207 (2005). https://doi.org/10.1016/j.physletb.2005.04.033. arXiv:hep-ph/0503199
249. P.F. Harrison, S. Dallison, W.G. Scott, Phys. Lett. B **680**, 328 (2009). https://doi.org/10.1016/j.physletb.2009.09.004. arXiv:0904.3077 [hep-ph]
250. P.H. Frampton, X.-G. He, Phys. Lett. B **688**, 67 (2010). https://doi.org/10.1016/j.physletb.2010.03.077. arXiv:1003.0310 [hep-ph]
251. P.H. Frampton, X.-G. He, Phys. Rev. D **82**, 017301 (2010). https://doi.org/10.1103/PhysRevD.82.017301. arXiv:1004.3679 [hep-ph]
252. J. Charles et al. (CKMfitter group), Eur. Phys. J. C **41**, 1 (2005). https://doi.org/10.1140/epjc/s2005-02169-1. arXiv:hep-ph/0406184, see also online updates, http://ckmfitter.in2p3.fr/
253. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **86**, 2515 (2001). https://doi.org/10.1103/PhysRevLett.86.2515. arXiv:hep-ex/0102030
254. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **87**, 091802 (2001). https://doi.org/10.1103/PhysRevLett.87.091802. arXiv:hep-ex/0107061
255. A.B. Carter, A.I. Sanda, Phys. Rev. D **23**, 1567 (1981). https://doi.org/10.1103/PhysRevD.23.1567
256. I.I.Y. Bigi, A.I. Sanda, Nucl. Phys. B **193**, 85 (1981). https://doi.org/10.1016/0550-3213(81)90519-8
257. I. Dunietz, R. Fleischer, U. Nierste, Phys. Rev. D **63**, 114015 (2001). https://doi.org/10.1103/PhysRevD.63.114015. arXiv:hep-ph/0012219
258. R. Aaij et al., LHCb collaboration. Phys. Lett. B. **742**, 38 (2015). https://doi.org/10.1016/j.physletb.2015.01.008. arXiv:1411.1634 [hep-ex]
259. B. Aubert et al., BABAR collaboration. Phys. Rev. D **79**, 032002 (2009). https://doi.org/10.1103/PhysRevD.79.032002. arXiv:0808.1866 [hep-ex]
260. P. Krokovny et al., Belle collaboration. Phys. Rev. Lett. **97**, 081801 (2006). https://doi.org/10.1103/PhysRevLett.97.081801. arXiv:hep-ex/0605023
261. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **99**, 231802 (2007). https://doi.org/10.1103/PhysRevLett.99.231802. arXiv:0708.1544 [hep-ex]

262. V. Vorobyev et al., Belle collaboration. Phys. Rev. D **94**, 052004 (2016). https://doi.org/10.1103/PhysRevD.94.052004. arXiv:1607.05813 [hep-ex]
263. J. Libby et al., CLEO collaboration. Phys. Rev. D **82**, 112006 (2010). https://doi.org/10.1103/PhysRevD.82.112006. arXiv:1010.2817 [hep-ex]
264. T.E. Browder, A. Datta, P.J. O'Donnell, S. Pakvasa, Phys. Rev. D **61**, 054009 (2000). https://doi.org/10.1103/PhysRevD.61.054009. arXiv:hep-ph/9905425
265. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 091101 (2006). https://doi.org/10.1103/PhysRevD.74.091101. arXiv:hep-ex/0608016
266. J. Dalseno et al., Belle collaboration. Phys. Rev. D **76**, 072004 (2007). https://doi.org/10.1103/PhysRevD.76.072004. arXiv:0706.2045 [hep-ex]
267. R. Aaij et al., LHCb collaboration. Phys. Rev. D **90**, 012003 (2014). https://doi.org/10.1103/PhysRevD.90.012003. arXiv:1404.5673 [hep-ex]
268. J.R. Pelaez, Phys. Rep. **658**, 1 (2016). https://doi.org/10.1016/j.physrep.2016.09.001. arXiv:1510.00653 [hep-ph]
269. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **99**, 161802 (2007). https://doi.org/10.1103/PhysRevLett.99.161802. arXiv:0706.3885 [hep-ex]
270. Y. Nakahama et al., Belle collaboration. Phys. Rev. D **82**, 073011 (2010). https://doi.org/10.1103/PhysRevD.82.073011. arXiv:1007.3848 [hep-ex]
271. J.P. Lees et al., BABAR collaboration. Phys. Rev. D. **85**, 112010 (2012). https://doi.org/10.1103/PhysRevD.85.112010. arXiv:1201.5897 [hep-ex]
272. A. Garmash et al., Belle collaboration. Phys. Rev. D **71**, 092003 (2005). https://doi.org/10.1103/PhysRevD.71.092003. arXiv:hep-ex/0412066
273. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 032003 (2006). https://doi.org/10.1103/PhysRevD.74.032003. arXiv:hep-ex/0605003
274. B. Aubert et al., BABAR collaboration. Phys. Rev. D **80**, 112001 (2009). https://doi.org/10.1103/PhysRevD.80.112001. arXiv:0905.3615 [hep-ex]
275. J. Dalseno et al., Belle collaboration. Phys. Rev. D **79**, 072004 (2009). https://doi.org/10.1103/PhysRevD.79.072004. arXiv:0811.3665 [hep-ex]
276. A. Garmash et al., Belle collaboration. Phys. Rev. Lett. **96**, 251803 (2006). https://doi.org/10.1103/PhysRevLett.96.251803. arXiv:hep-ex/0512066
277. B. Aubert, (BABAR collaboration), Phys. Rev. D **72**, 072003 (2005). https://doi.org/10.1103/PhysRevD.72.072003. arXiv:hep-ex/0507004. [Erratum ibid. **74**, 099903 (2006). doi:10.1103/PhysRevD.74.099903]
278. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 012004 (2008). https://doi.org/10.1103/PhysRevD.78.012004. arXiv:0803.4451 [hep-ex]
279. A.E. Snyder, H.R. Quinn, Phys. Rev. D **48**, 2139 (1993). https://doi.org/10.1103/PhysRevD.48.2139
280. H.R. Quinn, J.P. Silva, Phys. Rev. D **62**, 054002 (2000). https://doi.org/10.1103/PhysRevD.62.054002. arXiv:hep-ph/0001290
281. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 012004 (2007). https://doi.org/10.1103/PhysRevD.76.012004. arXiv:hep-ex/0703008
282. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **88**, 012003 (2013). https://doi.org/10.1103/PhysRevD.88.012003. arXiv:1304.3503 [hep-ex]
283. A. Kusaka et al., Belle collaboration. Phys. Rev. Lett. **98**, 221602 (2007). https://doi.org/10.1103/PhysRevLett.98.221602. arXiv:hep-ex/0701015
284. A. Kusaka et al., Belle collaboration. Phys. Rev. D **77**, 072001 (2008). https://doi.org/10.1103/PhysRevD.77.072001. arXiv:0710.4974 [hep-ex]
285. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **99**, 071801 (2007). https://doi.org/10.1103/PhysRevLett.99.071801. arXiv:0705.1190 [hep-ex]
286. T. Aushev et al., Belle collaboration. Phys. Rev. Lett. **93**, 201802 (2004). https://doi.org/10.1103/PhysRevLett.93.201802. arXiv:hep-ex/0408051
287. M. Rohrken et al., Belle collaboration. Phys. Rev. D **85**, 091106 (2012). https://doi.org/10.1103/PhysRevD.85.091106. arXiv:1203.6647 [hep-ex]
288. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **91**, 201802 (2003). https://doi.org/10.1103/PhysRevLett.91.201802. arXiv:hep-ex/0306030
289. C.C. Wang et al., Belle collaboration. Phys. Rev. Lett. **94**, 121801 (2005). https://doi.org/10.1103/PhysRevLett.94.121801. arXiv:hep-ex/0408003
290. B. Aubert et al., BABAR collaboration. Phys. Rev. D **73**, 111101 (2006). https://doi.org/10.1103/PhysRevD.73.111101. arXiv:hep-ex/0602049
291. B. Aubert et al., BABAR collaboration. Phys. Rev. D **71**, 112003 (2005). https://doi.org/10.1103/PhysRevD.71.112003. arXiv:hep-ex/0504035
292. O. Long, M. Baak, R.N. Cahn, D. Kirkby, Phys. Rev. D **68**, 034010 (2003). https://doi.org/10.1103/PhysRevD.68.034010. arXiv:hep-ex/0303030
293. S. Bahinipati et al., Belle collaboration. Phys. Rev. D **84**, 021101 (2011). https://doi.org/10.1103/PhysRevD.84.021101. arXiv:1102.0888 [hep-ex]
294. F.J. Ronga et al., Belle collaboration. Phys. Rev. D **73**, 092003 (2006). https://doi.org/10.1103/PhysRevD.73.092003. arXiv:hep-ex/0604013
295. R. Fleischer, Nucl. Phys. B **671**, 459 (2003). https://doi.org/10.1016/j.nuclphysb.2003.08.010. arXiv:hep-ph/0304027
296. R. Aaij et al., LHCb collaboration. JHEP **11**, 060 (2014). https://doi.org/10.1007/JHEP11(2014)060. arXiv:1407.6127 [hep-ex]
297. D. Atwood, M. Gronau, A. Soni, Phys. Rev. Lett. **79**, 185 (1997). https://doi.org/10.1103/PhysRevLett.79.185. arXiv:hep-ph/9704272
298. D. Atwood, T. Gershon, M. Hazumi, A. Soni, Phys. Rev. D **71**, 076003 (2005). https://doi.org/10.1103/PhysRevD.71.076003. arXiv:hep-ph/0410036
299. B. Grinstein, Y. Grossman, Z. Ligeti, D. Pirjol, Phys. Rev. D **71**, 011504 (2005). https://doi.org/10.1103/PhysRevD.71.011504. arXiv:hep-ph/0412019
300. B. Grinstein, D. Pirjol, Phys. Rev. D **73**, 014013 (2006). https://doi.org/10.1103/PhysRevD.73.014013. arXiv:hep-ph/0510104
301. M. Matsumori, A.I. Sanda, Phys. Rev. D **73**, 114022 (2006). https://doi.org/10.1103/PhysRevD.73.114022. arXiv:hep-ph/0512175
302. P. Ball, R. Zwicky, Phys. Lett. B **642**, 478 (2006). https://doi.org/10.1016/j.physletb.2006.10.013. arXiv:hep-ph/0609037
303. F. Muheim, Y. Xie, R. Zwicky, Phys. Lett. B **664**, 174 (2008). https://doi.org/10.1016/j.physletb.2008.05.032. arXiv:0802.0876 [hep-ph]
304. I.I.Y. Bigi, A.I. Sanda, Phys. Lett. B **211**, 213 (1988). https://doi.org/10.1016/0370-2693(88)90836-2
305. M. Gronau, D. London, Phys. Lett. B **253**, 483 (1991). https://doi.org/10.1016/0370-2693(91)91756-L
306. M. Gronau, D. Wyler, Phys. Lett. B **265**, 172 (1991). https://doi.org/10.1016/0370-2693(91)90034-N
307. D. Atwood, I. Dunietz, A. Soni, Phys. Rev. Lett. **78**, 3257 (1997). https://doi.org/10.1103/PhysRevLett.78.3257. arXiv:hep-ph/9612433

308. D. Atwood, I. Dunietz, A. Soni, Phys. Rev. D **63**, 036005 (2001). https://doi.org/10.1103/PhysRevD.63.036005. arXiv:hep-ph/0008090
309. A. Giri, Y. Grossman, A. Soffer, J. Zupan, Phys. Rev. D **68**, 054018 (2003). https://doi.org/10.1103/PhysRevD.68.054018. arXiv:hep-ph/0303187
310. A. Poluektov et al., Belle collaboration. Phys. Rev. D **70**, 072003 (2004). https://doi.org/10.1103/PhysRevD.70.072003. arXiv:hep-ex/0406067
311. J. Brod, J. Zupan, JHEP **01**, 051 (2014). https://doi.org/10.1007/JHEP01(2014)051. arXiv:1308.5663 [hep-ph]
312. M. Gronau, Phys. Lett. B **557**, 198 (2003). https://doi.org/10.1016/S0370-2693(03)00192-8. arXiv:hep-ph/0211282
313. T. Gershon, Phys. Rev. D **79**, 051301 (2009). https://doi.org/10.1103/PhysRevD.79.051301. arXiv:0810.2706 [hep-ph]
314. T. Gershon, M. Williams, Phys. Rev. D **80**, 092002 (2009). https://doi.org/10.1103/PhysRevD.80.092002. arXiv:0909.1495 [hep-ph]
315. A. Bondar, T. Gershon, Phys. Rev. D **70**, 091503 (2004). https://doi.org/10.1103/PhysRevD.70.091503. arXiv:hep-ph/0409281
316. D. Atwood, A. Soni, Phys. Rev. D **68**, 033003 (2003). https://doi.org/10.1103/PhysRevD.68.033003. arXiv:hep-ph/0304085
317. Y. Grossman, Z. Ligeti, A. Soffer, Phys. Rev. D **67**, 071301 (2003). https://doi.org/10.1103/PhysRevD.67.071301. arXiv:hep-ph/0210433
318. M. Nayak et al., Phys. Lett. B **740**, 1 (2014). https://doi.org/10.1016/j.physletb.2014.11.022. arXiv:1410.3964 [hep-ex]
319. A. Bondar, A. Poluektov, Eur. Phys. J. C **47**, 347 (2006). https://doi.org/10.1140/epjc/s2006-02590-x. arXiv:hep-ph/0510246
320. A. Bondar, A. Poluektov, Eur. Phys. J. C **55**, 51 (2008). https://doi.org/10.1140/epjc/s10052-008-0600-z. arXiv:0801.0840 [hep-ex]
321. T. Gershon, J. Libby, G. Wilkinson, Phys. Lett. B **750**, 338 (2015). https://doi.org/10.1016/j.physletb.2015.08.063. arXiv:1506.08594 [hep-ph]
322. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **99**, 251801 (2007). https://doi.org/10.1103/PhysRevLett.99.251801. arXiv:hep-ex/0703037
323. B. Aubert et al., BaBar collaboration. Phys. Rev. D **76**, 031102 (2007). https://doi.org/10.1103/PhysRevD.76.031102. arXiv:0704.0522 [hep-ex]
324. R. Itoh et al., Belle collaboration. Phys. Rev. Lett. **95**, 091601 (2005). https://doi.org/10.1103/PhysRevLett.95.091601. arXiv:hep-ex/0504030
325. D. Acosta et al., CDF collaboration. Phys. Rev. Lett. **94**, 101803 (2005). https://doi.org/10.1103/PhysRevLett.94.101803. arXiv:hep-ex/0412057
326. R. Aaij et al., LHCb collaboration. Phys. Rev. D **88**, 052002 (2013). https://doi.org/10.1103/PhysRevD.88.052002. arXiv:1307.2782 [hep-ex]
327. K. Olive et al., Particle Data Group. Chin. Phys. C **38**, 090001 (2014). https://doi.org/10.1088/1674-1137/38/9/090001
328. M. Jung, Phys. Rev. D **86**, 053008 (2012). https://doi.org/10.1103/PhysRevD.86.053008. arXiv:1206.2050 [hep-ph]
329. K. De Bruyn, R. Fleischer, JHEP **03**, 145 (2015). https://doi.org/10.1007/JHEP03(2015)145. arXiv:1412.6834 [hep-ph]
330. P. Frings, U. Nierste, M. Wiebusch, Phys. Rev. Lett. **115**, 061802 (2015). https://doi.org/10.1103/PhysRevLett.115.061802. arXiv:1503.00859 [hep-ph]
331. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 072009 (2009). https://doi.org/10.1103/PhysRevD.79.072009. arXiv:0902.1708 [hep-ex]
332. B. Aubert et al., BaBar collaboration. Phys. Rev. D **69**, 052001 (2004). https://doi.org/10.1103/PhysRevD.69.052001. arXiv:hep-ex/0309039
333. I. Adachi et al., Belle collaboration. Phys. Rev. Lett. **108**, 171802 (2012). https://doi.org/10.1103/PhysRevLett.108.171802. arXiv:1201.4643 [hep-ex]
334. R. Barate et al., ALEPH collaboration. Phys. Lett. B **492**, 259 (2000). https://doi.org/10.1016/S0370-2693(00)01091-1. arXiv:hep-ex/0009058
335. K. Ackerstaff et al., OPAL collaboration. Eur. Phys. J. C **5**, 379 (1998). https://doi.org/10.1007/s100520050284. arXiv:hep-ex/9801022
336. A.A. Affolder et al., CDF collaboration. Phys. Rev. D **61**, 072005 (2000). https://doi.org/10.1103/PhysRevD.61.072005. arXiv:hep-ex/9909003
337. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **115**, 031601 (2015). https://doi.org/10.1103/PhysRevLett.115.031601. arXiv:1503.07089 [hep-ex]
338. Y. Sato et al., Belle collaboration. Phys. Rev. Lett. **108**, 171801 (2012). https://doi.org/10.1103/PhysRevLett.108.171801. arXiv:1201.3502 [hep-ex]
339. M. Bona et al. (UTfit collaboration), JHEP **07**, 028 (2005). https://doi.org/10.1088/1126-6708/2005/07/028. arXiv:hep-ph/0501199. see also online updates, http://www.utfit.org/
340. E. Lunghi, A. Soni, Phys. Lett. B **666**, 162 (2008). https://doi.org/10.1016/j.physletb.2008.07.015. arXiv:0803.4340 [hep-ph]
341. G. Eigen, G. Dubois-Felsmann, D. Hitlin, F. Porter, Phys. Rev. D **89**, 033004 (2014). https://doi.org/10.1103/PhysRevD.89.033004. arXiv:1301.5867 [hep-ex]
342. I. Dunietz, H.R. Quinn, A. Snyder, W. Toki, H.J. Lipkin, Phys. Rev. D **43**, 2193 (1991). https://doi.org/10.1103/PhysRevD.43.2193
343. D. Aston et al., Nucl. Phys. B **296**, 493 (1988). https://doi.org/10.1016/0550-3213(88)90028-4
344. M. Suzuki, Phys. Rev. D **64**, 117503 (2001). https://doi.org/10.1103/PhysRevD.64.117503. arXiv:hep-ph/0106354
345. B. Aubert et al., BaBar collaboration. Phys. Rev. D **71**, 032005 (2005). https://doi.org/10.1103/PhysRevD.71.032005. arXiv:hep-ex/0411016
346. Y. Grossman, M.P. Worah, Phys. Lett. B **395**, 241 (1997). https://doi.org/10.1016/S0370-2693(97)00068-3. arXiv:hep-ph/9612269
347. R. Fleischer, Phys. Lett. B **562**, 234 (2003). https://doi.org/10.1016/S0370-2693(03)00582-3. arXiv:hep-ph/0301255
348. R. Fleischer, Nucl. Phys. B **659**, 321 (2003). https://doi.org/10.1016/S0550-3213(03)00225-6. arXiv:hep-ph/0301256
349. A. Abdesselam et al., BaBar and Belle collaborations. Phys. Rev. Lett. **115**, 121604 (2015). https://doi.org/10.1103/PhysRevLett.115.121604. arXiv:1505.04147 [hep-ex]
350. A. Bondar, T. Gershon, P. Krokovny, Phys. Lett. B **624**, 1 (2005). https://doi.org/10.1016/j.physletb.2005.07.053. arXiv:hep-ph/0503174
351. F. Botella, J. Silva, Phys. Rev. D **71**, 094008 (2005). https://doi.org/10.1103/PhysRevD.71.094008. arXiv:hep-ph/0503136
352. B. Kronenbitter et al., Belle collaboration. Phys. Rev. D **86**, 071103 (2012). https://doi.org/10.1103/PhysRevD.86.071103. arXiv:1207.5611 [hep-ex]
353. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **101**, 021801 (2008). https://doi.org/10.1103/PhysRevLett.101.021801. arXiv:0804.0896 [hep-ex]
354. S.E. Lee et al., Belle collaboration. Phys. Rev. D **77**, 071101 (2008). https://doi.org/10.1103/PhysRevD.77.071101. arXiv:0708.0304 [hep-ex]
355. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **117**, 261801 (2016). https://doi.org/10.1103/PhysRevLett.117.261801. arXiv:1608.06620 [hep-ex]

356. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **86**, 112006 (2012). https://doi.org/10.1103/PhysRevD.86.112006. arXiv:1208.1282 [hep-ex]
357. S. Fratina et al., Belle collaboration. Phys. Rev. Lett. **98**, 221802 (2007). https://doi.org/10.1103/PhysRevLett.98.221802. arXiv:hep-ex/0702031
358. R. Fleischer, Eur. Phys. J. C **10**, 299 (1999). https://doi.org/10.1007/s100529900099. arXiv:hep-ph/9903455
359. K. De Bruyn, R. Fleischer, P. Koppenburg, Eur. Phys. J. C **70**, 1025 (2010). https://doi.org/10.1140/epjc/s10052-010-1495-z. arXiv:1010.0089 [hep-ph]
360. R. Aaij et al., LHCb collaboration. JHEP **06**, 131 (2015). https://doi.org/10.1007/JHEP06(2015)131. arXiv:1503.07055 [hep-ex]
361. R. Fleischer, Int. J. Mod. Phys. A **12**, 2459 (1997). https://doi.org/10.1142/S0217751X97001432. arXiv:hep-ph/9612446
362. D. London, A. Soni, Phys. Lett. B **407**, 61 (1997). https://doi.org/10.1016/S0370-2693(97)00695-3. arXiv:hep-ph/9704277
363. M. Ciuchini, E. Franco, G. Martinelli, A. Masiero, L. Silvestrini, Phys. Rev. Lett. **79**, 978 (1997). https://doi.org/10.1103/PhysRevLett.79.978. arXiv:hep-ph/9704274
364. S. Okubo, Phys. Lett. **5**, 165–168 (1963). https://doi.org/10.1016/S0375-9601(63)92548-9
365. G. Zweig, CERN-TH-412 (1964)
366. J. Iizuka, Prog. Theor. Phys. Suppl. **37**, 21–34 (1966). https://doi.org/10.1143/PTPS.37.21
367. T. Gershon, M. Hazumi, Phys. Lett. B **596**, 163 (2004). https://doi.org/10.1016/j.physletb.2004.06.095. arXiv:hep-ph/0402097
368. Y. Grossman, Z. Ligeti, Y. Nir, H. Quinn, Phys. Rev. D **68**, 015004 (2003). https://doi.org/10.1103/PhysRevD.68.015004. arXiv:hep-ph/0303171
369. M. Gronau, J.L. Rosner, Phys. Lett. B **564**, 90 (2003). https://doi.org/10.1016/S0370-2693(03)00702-0. arXiv:hep-ph/0304178
370. M. Gronau, Y. Grossman, J.L. Rosner, Phys. Lett. B **579**, 331 (2004). https://doi.org/10.1016/j.physletb.2003.11.015. arXiv:hep-ph/0310020
371. M. Gronau, J.L. Rosner, J. Zupan, Phys. Lett. B **596**, 107 (2004). https://doi.org/10.1016/j.physletb.2004.06.086. arXiv:hep-ph/0403287
372. H.-Y. Cheng, C.-K. Chua, A. Soni, Phys. Rev. D **72**, 014006 (2005). https://doi.org/10.1103/PhysRevD.72.014006. arXiv:hep-ph/0502235
373. M. Gronau, J.L. Rosner, Phys. Rev. D **71**, 074019 (2005). https://doi.org/10.1103/PhysRevD.71.074019. arXiv:hep-ph/0503131
374. G. Buchalla, G. Hiller, Y. Nir, G. Raz, JHEP **09**, 074 (2005). https://doi.org/10.1088/1126-6708/2005/09/074. arXiv:hep-ph/0503151
375. M. Beneke, Phys. Lett. B **620**, 143 (2005). https://doi.org/10.1016/j.physletb.2005.06.045. arXiv:hep-ph/0505075
376. G. Engelhard, Y. Nir, G. Raz, Phys. Rev. D **72**, 075013 (2005). https://doi.org/10.1103/PhysRevD.72.075013. arXiv:hep-ph/0505194
377. H.-Y. Cheng, C.-K. Chua, A. Soni, Phys. Rev. D **72**, 094003 (2005). https://doi.org/10.1103/PhysRevD.72.094003. arXiv:hep-ph/0506268
378. G. Engelhard, G. Raz, Phys. Rev. D **72**, 114017 (2005). https://doi.org/10.1103/PhysRevD.72.114017. arXiv:hep-ph/0508046
379. M. Gronau, J.L. Rosner, J. Zupan, Phys. Rev. D **74**, 093003 (2006). https://doi.org/10.1103/PhysRevD.74.093003. arXiv:hep-ph/0608085
380. L. Silvestrini, Ann. Rev. Nucl. Part. Sci. **57**, 405 (2007). https://doi.org/10.1146/annurev.nucl.57.090506.123007. arXiv:0705.1624 [hep-ph]
381. R. Dutta, S. Gardner, Phys. Rev. D **78**, 034021 (2008). https://doi.org/10.1103/PhysRevD.78.034021. arXiv:0805.1963 [hep-ph]
382. M. Fujikawa et al., Belle collaboration. Phys. Rev. D **81**, 011101 (2010). https://doi.org/10.1103/PhysRevD.81.011101. arXiv:0809.4366 [hep-ex]
383. K. Abe et al., Belle collaboration. Phys. Rev. D **76**, 091103 (2007). https://doi.org/10.1103/PhysRevD.76.091103. arXiv:hep-ex/0609006
384. B. Aubert et al., BaBar collaboration. Phys. Rev. D **71**, 091102 (2005). https://doi.org/10.1103/PhysRevD.71.091102. arXiv:hep-ex/0502019
385. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 052003 (2009). https://doi.org/10.1103/PhysRevD.79.052003. arXiv:0809.1174 [hep-ex]
386. L. Šantelj et al., Belle collaboration. JHEP **10**, 165 (2014). https://doi.org/10.1007/JHEP10(2014)165. arXiv:1408.5991 [hep-ex]
387. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **85**, 054023 (2012). https://doi.org/10.1103/PhysRevD.85.054023. arXiv:1111.3636 [hep-ex]
388. K.F. Chen et al., Belle collaboration. Phys. Rev. Lett. **98**, 031802 (2007). https://doi.org/10.1103/PhysRevLett.98.031802. arXiv:hep-ex/0608039
389. V. Chobanova et al., Belle collaboration. Phys. Rev. D **90**, 012002 (2014). https://doi.org/10.1103/PhysRevD.90.012002. arXiv:1311.6666 [hep-ex]
390. B. Aubert et al., BaBar collaboration. Phys. Rev. D **76**, 071101 (2007). https://doi.org/10.1103/PhysRevD.76.071101. arXiv:hep-ex/0702010
391. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 092008 (2008). https://doi.org/10.1103/PhysRevD.78.092008. arXiv:0808.3586 [hep-ex]
392. I. Dunietz, FERMILAB-CONF-93-090-T (1993)
393. R. Fleischer, Phys. Lett. B **459**, 306 (1999). https://doi.org/10.1016/S0370-2693(99)00640-1. arXiv:hep-ph/9903456
394. LHCb collaboration, LHCb-CONF-2016-018 (2016)
395. R. Aaij et al., LHCb collaboration. JHEP **10**, 183 (2013). https://doi.org/10.1007/JHEP10(2013)183. arXiv:1308.1428 [hep-ex]
396. M. Raidal, Phys. Rev. Lett. **89**, 231803 (2002). https://doi.org/10.1103/PhysRevLett.89.231803. arXiv:hep-ph/0208091
397. R. Aaij et al., LHCb collaboration. Phys. Rev. D **90**, 052011 (2014). https://doi.org/10.1103/PhysRevD.90.052011. arXiv:1407.2222 [hep-ex]
398. B. Aubert et al. (BaBar collaboration), Phys. Rev. Lett. **97**, 171805 (2006). https://doi.org/10.1103/PhysRevLett.97.171805. arXiv:hep-ex/0608036 [hep-ex]
399. Y. Nakahama et al., Belle collaboration. Phys. Rev. Lett. **100**, 121601 (2008). https://doi.org/10.1103/PhysRevLett.100.121601. arXiv:0712.4234 [hep-ex]
400. S. Akar, Ph.D. thesis, LPNHE, Université Pierre et Marie Curie-Paris VI (2013). https://tel.archives-ouvertes.fr/tel-00998252
401. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **93**, 052013 (2016). https://doi.org/10.1103/PhysRevD.93.052013. arXiv:1512.03579 [hep-ex]
402. J. Li et al., Belle collaboration. Phys. Rev. Lett. **101**, 251601 (2008). https://doi.org/10.1103/PhysRevLett.101.251601. arXiv:0806.1980 [hep-ex]
403. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 071102 (2008). https://doi.org/10.1103/PhysRevD.78.071102. arXiv:0807.3103 [hep-ex]
404. Y. Ushiroda et al., Belle collaboration. Phys. Rev. D **74**, 111104 (2006). https://doi.org/10.1103/PhysRevD.74.111104. arXiv:hep-ex/0608017
405. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 011102 (2009). https://doi.org/10.1103/PhysRevD.79.011102. arXiv:0805.1317 [hep-ex]
406. H. Sahoo et al., Belle collaboration. Phys. Rev. D **84**, 071101 (2011). https://doi.org/10.1103/PhysRevD.84.071101. arXiv:1104.5590 [hep-ex]

407. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **118**, 021801 (2017). https://doi.org/10.1103/PhysRevLett.118.021801. arXiv:1609.02032 [hep-ex]
408. Y. Ushiroda et al., Belle collaboration. Phys. Rev. Lett. **100**, 021602 (2008). https://doi.org/10.1103/PhysRevLett.100.021602. arXiv:0709.2769 [hep-ex]
409. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 052007 (2007). https://doi.org/10.1103/PhysRevD.76.052007. arXiv:0705.2157 [hep-ex]
410. P. Vanhoefer et al., Belle collaboration. Phys. Rev. D **93**, 032010 (2016). https://doi.org/10.1103/PhysRevD.93.032010. arXiv:1510.01245 [hep-ex]
411. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 071104 (2008). https://doi.org/10.1103/PhysRevD.78.071104. arXiv:0807.4977 [hep-ex]
412. I. Adachi et al. (Belle collaboration), Phys. Rev. D **89**, 072008 (2014). https://doi.org/10.1103/PhysRevD.89.072008. arXiv:1212.4015 [hep-ex]. Addendum ibid. **89**, 119903 (2014). doi:10.1103/PhysRevD.89.119903
413. R. Aaij et al., LHCb collaboration. Phys. Lett. B **747**, 468 (2015). https://doi.org/10.1016/j.physletb.2015.06.027. arXiv:1503.07770 [hep-ex]
414. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **98**, 181803 (2007). https://doi.org/10.1103/PhysRevLett.98.181803. arXiv:hep-ex/0612050
415. B. Aubert et al., BABAR collaboration. Phys. Rev. D **81**, 052009 (2010). https://doi.org/10.1103/PhysRevD.81.052009. arXiv:0909.2171 [hep-ex]
416. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **87**, 052009 (2013). https://doi.org/10.1103/PhysRevD.87.052009. arXiv:1206.3525 [hep-ex]
417. I. Adachi et al., Belle collaboration. Phys. Rev. D **88**, 092003 (2013). https://doi.org/10.1103/PhysRevD.88.092003. arXiv:1302.0551 [hep-ex]
418. J. Dalseno et al., Belle collaboration. Phys. Rev. D **86**, 092012 (2012). https://doi.org/10.1103/PhysRevD.86.092012. arXiv:1205.5957 [hep-ex]
419. M. Gronau, D. London, Phys. Rev. Lett. **65**, 3381 (1990). https://doi.org/10.1103/PhysRevLett.65.3381
420. D. Asner et al. (Heavy Flavor Averaging Group), (2010). arXiv:1010.1589 [hep-ex]
421. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **102**, 141802 (2009). https://doi.org/10.1103/PhysRevLett.102.141802. arXiv:0901.3522 [hep-ex]
422. H.J. Lipkin, Y. Nir, H.R. Quinn, A. Snyder, Phys. Rev. D **44**, 1454 (1991). https://doi.org/10.1103/PhysRevD.44.1454
423. M. Gronau, J. Zupan, Phys. Rev. D **73**, 057502 (2006). https://doi.org/10.1103/PhysRevD.73.057502. arXiv:hep-ph/0512148
424. A. Bevan et al., BABAR and Belle collaborations. Eur. Phys. J. C **74**, 3026 (2014). https://doi.org/10.1140/epjc/s10052-014-3026-9. arXiv:1406.6311 [hep-ex]
425. I. Dunietz, Phys. Lett. B **427**, 179 (1998). https://doi.org/10.1016/S0370-2693(98)00304-9. arXiv:hep-ph/9712401
426. M.A. Baak, Ph.D. thesis, Vrije U., Amsterdam (2007). http://www-public.slac.stanford.edu/sciDoc/docMeta.aspx?slacPubNumber=slac-r-858
427. K. De Bruyn, R. Fleischer, R. Knegjens, M. Merk, M. Schiller, N. Tuning, Nucl. Phys. B **868**, 351 (2013). https://doi.org/10.1016/j.nuclphysb.2012.11.012. arXiv:1208.6463 [hep-ph]
428. M. Kenzie, M. Martinelli, N. Tuning, Phys. Rev. D **94**, 054021 (2016). https://doi.org/10.1103/PhysRevD.94.054021. arXiv:1606.09129 [hep-ph]
429. B. Aubert et al., BABAR collaboration. Phys. Rev. D **77**, 071102 (2008). https://doi.org/10.1103/PhysRevD.77.071102. arXiv:0712.3469 [hep-ex]
430. I. Dunietz, R.G. Sachs, Phys. Rev. D **37**, 3186 (1988). https://doi.org/10.1103/PhysRevD.37.3186. [Erratum ibid. **39** (1989). https://doi.org/10.1103/PhysRevD.39.3515]
431. R. Aleksan, I. Dunietz, B. Kayser, Z. Phys. C **54**, 653 (1992). https://doi.org/10.1007/BF01559494
432. LHCb collaboration, LHCb-CONF-2016-015 (2016)
433. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **82**, 072004 (2010). https://doi.org/10.1103/PhysRevD.82.072004. arXiv:1007.0504 [hep-ex]
434. K. Abe et al., Belle collaboration. Phys. Rev. D **73**, 051106 (2006). https://doi.org/10.1103/PhysRevD.73.051106. arXiv:hep-ex/0601032
435. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **81**, 031105 (2010). https://doi.org/10.1103/PhysRevD.81.031105. arXiv:0911.0425 [hep-ex]
436. R. Aaij et al., LHCb collaboration. Phys. Lett. B **760**, 117 (2016). https://doi.org/10.1016/j.physletb.2016.06.022. arXiv:1603.08993 [hep-ex]
437. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 092002 (2008). https://doi.org/10.1103/PhysRevD.78.092002. arXiv:0807.2408 [hep-ex]
438. B. Aubert et al., BABAR collaboration. Phys. Rev. D **80**, 092001 (2009). https://doi.org/10.1103/PhysRevD.80.092001. arXiv:0909.3981 [hep-ex]
439. LHCb collaboration, LHCb-CONF-2016-014 (2016)
440. R. Aaij et al., LHCb collaboration. Phys. Rev. D **92**, 112005 (2015). https://doi.org/10.1103/PhysRevD.92.112005. arXiv:1505.07044 [hep-ex]
441. R. Aaij et al., LHCb collaboration. Phys. Rev. D **90**, 112002 (2014). https://doi.org/10.1103/PhysRevD.90.112002. arXiv:1407.8136 [hep-ex]
442. R. Aaij et al., LHCb collaboration. Phys. Rev. D **93**, 112018 (2016). https://doi.org/10.1103/PhysRevD.93.112018. arXiv:1602.03455 [hep-ex]
443. S. Malde et al., Phys. Lett. B **747**, 9 (2015). https://doi.org/10.1016/j.physletb.2015.05.043. arXiv:1504.05878 [hep-ex]
444. R. Aaij et al., LHCb collaboration. Phys. Rev. D **91**, 112014 (2015). https://doi.org/10.1103/PhysRevD.91.112014. arXiv:1504.05442 [hep-ex]
445. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **82**, 072006 (2010). https://doi.org/10.1103/PhysRevD.82.072006. arXiv:1006.4241 [hep-ex]
446. Y. Horii et al., Belle collaboration. Phys. Rev. Lett. **106**, 231803 (2011). https://doi.org/10.1103/PhysRevLett.106.231803. arXiv:1103.5951 [hep-ex]
447. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **84**, 091504 (2011). https://doi.org/10.1103/PhysRevD.84.091504. arXiv:1108.5765 [hep-ex]
448. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **84**, 012002 (2011). https://doi.org/10.1103/PhysRevD.84.012002. arXiv:1104.4472 [hep-ex]
449. M. Nayak et al., Belle collaboration. Phys. Rev. D **88**, 091104 (2013). https://doi.org/10.1103/PhysRevD.88.091104. arXiv:1310.1741 [hep-ex]
450. B. Aubert et al., BABAR collaboration. Phys. Rev. D **80**, 031102 (2009). https://doi.org/10.1103/PhysRevD.80.031102. arXiv:0904.2112 [hep-ex]
451. K. Negishi et al., Belle collaboration. Phys. Rev. D **86**, 011101 (2012). https://doi.org/10.1103/PhysRevD.86.011101. arXiv:1205.0422 [hep-ex]
452. D.M. Asner et al., CLEO collaboration. Phys. Rev. D **78**, 012001 (2008). https://doi.org/10.1103/PhysRevD.78.012001. arXiv:0802.2268 [hep-ex]
453. N. Lowrey et al., CLEO collaboration. Phys. Rev. D **80**, 031105 (2009). https://doi.org/10.1103/PhysRevD.80.031105. arXiv:0903.4853 [hep-ex]

454. A. Poluektov et al., Belle collaboration. Phys. Rev. D **81**, 112002 (2010). https://doi.org/10.1103/PhysRevD.81.112002. arXiv:1003.3360 [hep-ex]
455. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. Lett. **105**, 121801 (2010). https://doi.org/10.1103/PhysRevLett.105.121801. arXiv:1005.1096 [hep-ex]
456. R. Aaij et al., LHCb collaboration. Nucl. Phys. B **888**, 169 (2014). https://doi.org/10.1016/j.nuclphysb.2014.09.015. arXiv:1407.6211 [hep-ex]
457. A. Poluektov et al., Belle collaboration. Phys. Rev. D **73**, 112009 (2006). https://doi.org/10.1103/PhysRevD.73.112009. arXiv:hep-ex/0604054
458. R. Aaij et al., LHCb collaboration. JHEP **08**, 137 (2016). https://doi.org/10.1007/JHEP08(2016)137. arXiv:1605.01082 [hep-ex]
459. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 072003 (2009). https://doi.org/10.1103/PhysRevD.79.072003. arXiv:0805.2001 [hep-ex]
460. R.A. Briere et al., CLEO collaboration. Phys. Rev. D **80**, 032002 (2009). https://doi.org/10.1103/PhysRevD.80.032002. arXiv:0903.1681 [hep-ex]
461. H. Aihara et al., Belle collaboration. Phys. Rev. D **85**, 112014 (2012). https://doi.org/10.1103/PhysRevD.85.112014. arXiv:1204.6561 [hep-ex]
462. R. Aaij et al., LHCb collaboration. JHEP **10**, 97 (2014). https://doi.org/10.1007/JHEP10(2014)097. arXiv:1408.2748 [hep-ex]
463. K. Negishi et al. (Belle collaboration), PTEP **2016**, 043C01 (2016). https://doi.org/10.1093/ptep/ptw030. arXiv:1509.01098 [hep-ex]
464. R. Aaij et al., LHCb collaboration. JHEP **06**, 131 (2016). https://doi.org/10.1007/JHEP06(2016)131. arXiv:1604.01525 [hep-ex]
465. R. Aaij et al., LHCb collaboration. Phys. Lett. B **733**, 36 (2014). https://doi.org/10.1016/j.physletb.2014.03.051. arXiv:1402.2982 [hep-ex]
466. J. Insler et al., CLEO collaboration. Phys. Rev. D **85**, 092016 (2012). https://doi.org/10.1103/PhysRevD.85.092016. arXiv:1203.3804 [hep-ex]
467. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **87**, 052015 (2013). https://doi.org/10.1103/PhysRevD.87.052015. arXiv:1301.1029 [hep-ex]
468. R. Aaij et al., LHCb collaboration. JHEP **12**, 087 (2016). https://doi.org/10.1007/JHEP12(2016)087. arXiv:1611.03076 [hep-ex]
469. M. Rama, Phys. Rev. D **89**, 014021 (2014). https://doi.org/10.1103/PhysRevD.89.014021. arXiv:1307.4384 [hep-ex]
470. GammaCombo framework for combinations of measurements and computation of confidence intervals, CERN. http://gammacombo.hepforge.org/
471. R. Aaij et al., LHCb collaboration. Phys. Lett. B **726**, 151 (2013). https://doi.org/10.1016/j.physletb.2013.08.020. arXiv:1305.2050 [hep-ex]
472. T. Evans, S. Harnew, J. Libby, S. Malde, J. Rademacker, G. Wilkinson, Phys. Lett. B **757**, 520 (2016). https://doi.org/10.1016/j.physletb.2016.04.037. arXiv:1602.07430 [hep-ex]
473. R. Aaij et al., LHCb collaboration. Phys. Rev. D **93**, 052018 (2016). https://doi.org/10.1103/PhysRevD.93.052018. arXiv:1509.06628 [hep-ex]
474. J.P. Silva, A. Soffer, Phys. Rev. D **61**, 112001 (2000). https://doi.org/10.1103/PhysRevD.61.112001. arXiv:hep-ph/9912242
475. Y. Grossman, A. Soffer, J. Zupan, Phys. Rev. D **72**, 031501 (2005). https://doi.org/10.1103/PhysRevD.72.031501. arXiv:hep-ph/0505270
476. M. Neubert, Phys. Rep. **245**, 259 (1994). https://doi.org/10.1016/0370-1573(94)90091-4. arXiv:hep-ph/9306320
477. A. Sirlin, Nucl. Phys. B **196**, 83 (1982). https://doi.org/10.1016/0550-3213(82)90303-0
478. I. Caprini, L. Lellouch, M. Neubert, Nucl. Phys. B **530**, 153 (1998). https://doi.org/10.1016/S0550-3213(98)00350-2. arXiv:hep-ph/9712417
479. B semileptonic decays common input parameters. http://www.slac.stanford.edu/xorg/hflav/semi/summer16/common/common.param.summer16
480. N.E. Adam et al., CLEO collaboration. Phys. Rev. D **67**, 032001 (2003). https://doi.org/10.1103/PhysRevD.67.032001. arXiv:hep-ex/0210040
481. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 012002 (2009). https://doi.org/10.1103/PhysRevD.79.012002. arXiv:0809.0828 [hep-ex]
482. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 231803 (2008). https://doi.org/10.1103/PhysRevLett.100.231803. arXiv:0712.3493 [hep-ex]
483. W. Dungel et al., Belle collaboration. Phys. Rev. D **82**, 112007 (2010). https://doi.org/10.1103/PhysRevD.82.112007. arXiv:1010.5620 [hep-ex]
484. B. Aubert et al., BaBar collaboration. Phys. Rev. D **77**, 032002 (2008). https://doi.org/10.1103/PhysRevD.77.032002. arXiv:0705.4008 [hep-ex]
485. D. Buskulic et al., ALEPH collaboration. Phys. Lett. B **395**, 373 (1997). https://doi.org/10.1016/S0370-2693(97)00071-3
486. G. Abbiendi et al., OPAL collaboration. Phys. Lett. B **482**, 15 (2000). https://doi.org/10.1016/S0370-2693(00)00457-3. arXiv:hep-ex/0003013
487. P. Abreu et al., DELPHI collaboration. Phys. Lett. B **510**, 55 (2001). https://doi.org/10.1016/S0370-2693(01)00569-X. arXiv:hep-ex/0104026
488. J. Abdallah et al., DELPHI collaboration. Eur. Phys. J. C **33**, 213 (2004). https://doi.org/10.1140/epjc/s2004-01598-6. arXiv:hep-ex/0401023
489. J.A. Bailey et al., Fermilab Lattice and MILC collaborations. Phys. Rev. D **89**, 114504 (2014). https://doi.org/10.1103/PhysRevD.89.114504. arXiv:1403.0635 [hep-lat]
490. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 151802 (2008). https://doi.org/10.1103/PhysRevLett.100.151802. arXiv:0712.3503 [hep-ex]
491. J.E. Bartelt et al., CLEO collaboration. Phys. Rev. Lett. **82**, 3746 (1999). https://doi.org/10.1103/PhysRevLett.82.3746. arXiv:hep-ex/9811042
492. R. Glattauer et al., Belle collaboration. Phys. Rev. D **93**, 032006 (2016). https://doi.org/10.1103/PhysRevD.93.032006. arXiv:1510.03657 [hep-ex]
493. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **104**, 011802 (2010). https://doi.org/10.1103/PhysRevLett.104.011802. arXiv:0904.4063 [hep-ex]
494. J.A. Bailey et al., MILC collaboration. Phys. Rev. D **92**, 034506 (2015). https://doi.org/10.1103/PhysRevD.92.034506. arXiv:1503.07237 [hep-lat]
495. D. Liventsev et al., Belle collaboration. Phys. Rev. D **77**, 091503 (2008). https://doi.org/10.1103/PhysRevD.77.091503. arXiv:0711.3252 [hep-ex]
496. N. Isgur, M.B. Wise, Phys. Rev. Lett. **66**, 1130 (1991). https://doi.org/10.1103/PhysRevLett.66.1130
497. D. Buskulic et al., ALEPH collaboration. Z. Phys. C **73**, 601 (1997). https://doi.org/10.1007/s002880050351
498. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **30**, 467 (2003). https://doi.org/10.1140/epjc/s2003-01322-2. arXiv:hep-ex/0301018
499. A. Anastassov et al., CLEO collaboration. Phys. Rev. Lett. **80**, 4127 (1998). https://doi.org/10.1103/PhysRevLett.80.4127. arXiv:hep-ex/9708035
500. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **95**, 171803 (2005). https://doi.org/10.1103/PhysRevLett.95.171803. arXiv:hep-ex/0507046

501. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **101**, 261802 (2008). https://doi.org/10.1103/PhysRevLett.101.261802. arXiv:0808.0528 [hep-ex]
502. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **103**, 051803 (2009). https://doi.org/10.1103/PhysRevLett.103.051803. arXiv:0808.0333 [hep-ex]
503. J. Abdallah et al., DELPHI collaboration. Eur. Phys. J. C **45**, 35 (2006). https://doi.org/10.1140/epjc/s2005-02406-7. arXiv:hep-ex/0510024
504. D. Benson, I.I. Bigi, T. Mannel, N. Uraltsev, Nucl. Phys. B **665**, 367 (2003). https://doi.org/10.1016/S0550-3213(03)00452-8. arXiv:hep-ph/0302262
505. P. Gambino, N. Uraltsev, Eur. Phys. J. C **34**, 181 (2004). https://doi.org/10.1140/epjc/s2004-01671-2. arXiv:hep-ph/0401063
506. P. Gambino, JHEP **09**, 055 (2011). https://doi.org/10.1007/JHEP09(2011)055. arXiv:1107.3100 [hep-ph]
507. A. Alberti, P. Gambino, K.J. Healey, S. Nandi, Phys. Rev. Lett. **114**, 061802 (2015). https://doi.org/10.1103/PhysRevLett.114.061802. arXiv:1411.6560 [hep-ph]
508. C.W. Bauer, Z. Ligeti, M. Luke, A.V. Manohar, M. Trott, Phys. Rev. D **70**, 094017 (2004). https://doi.org/10.1103/PhysRevD.70.094017. arXiv:hep-ph/0408002
509. B. Aubert et al., BaBar collaboration. Phys. Rev. D **81**, 032003 (2010). https://doi.org/10.1103/PhysRevD.81.032003. arXiv:0908.0415 [hep-ex]
510. B. Aubert et al., BaBar collaboration. Phys. Rev. D **69**, 111104 (2004). https://doi.org/10.1103/PhysRevD.69.111104. arXiv:hep-ex/0403030
511. C. Schwanda et al., Belle collaboration. Phys. Rev. D **75**, 032005 (2007). https://doi.org/10.1103/PhysRevD.75.032005. arXiv:hep-ex/0611044
512. P. Urquijo et al., Belle collaboration. Phys. Rev. D **75**, 032001 (2007). https://doi.org/10.1103/PhysRevD.75.032001. arXiv:hep-ex/0610012
513. D.E. Acosta et al., CDF collaboration. Phys. Rev. D **71**, 051103 (2005). https://doi.org/10.1103/PhysRevD.71.051103. arXiv:hep-ex/0502003
514. S.E. Csorna et al., CLEO collaboration. Phys. Rev. D **70**, 032002 (2004). https://doi.org/10.1103/PhysRevD.70.032002. arXiv:hep-ex/0403052
515. K. Chetyrkin et al., Phys. Rev. D **80**, 074010 (2009). https://doi.org/10.1103/PhysRevD.80.074010. arXiv:0907.2110 [hep-ph]
516. B. Aubert et al., BaBar collaboration. Phys. Rev. D **72**, 052004 (2005). https://doi.org/10.1103/PhysRevD.72.052004. arXiv:hep-ex/0508004
517. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **97**, 171803 (2006). https://doi.org/10.1103/PhysRevLett.97.171803. arXiv:hep-ex/0607071
518. A. Limosani et al., Belle collaboration. Phys. Rev. Lett. **103**, 241801 (2009). https://doi.org/10.1103/PhysRevLett.103.241801. arXiv:0907.1384 [hep-ex]
519. S. Chen et al., CLEO collaboration. Phys. Rev. Lett. **87**, 251807 (2001). https://doi.org/10.1103/PhysRevLett.87.251807. arXiv:hep-ex/0108032
520. P. Gambino, C. Schwanda, Phys. Rev. D **89**, 014022 (2014). https://doi.org/10.1103/PhysRevD.89.014022. arXiv:1307.4551 [hep-ph]
521. C. Schwanda et al., Belle collaboration. Phys. Rev. D **78**, 032016 (2008). https://doi.org/10.1103/PhysRevD.78.032016. arXiv:0803.2158 [hep-ex]
522. R. Aaij et al., LHCb collaboration. Nat. Phys. **11**, 743 (2015). https://doi.org/10.1038/nphys3415. arXiv:1504.01568 [hep-ex]
523. H. Ha et al., Belle collaboration. Phys. Rev. D **83**, 071101 (2011). https://doi.org/10.1103/PhysRevD.83.071101. arXiv:1012.0090 [hep-ex]
524. A. Sibidanov et al., Belle collaboration. Phys. Rev. D **88**, 032005 (2013). https://doi.org/10.1103/PhysRevD.88.032005. arXiv:1306.2781 [hep-ex]
525. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **83**, 032007 (2011). https://doi.org/10.1103/PhysRevD.83.032007. arXiv:1005.3288 [hep-ex]
526. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **86**, 092004 (2012). https://doi.org/10.1103/PhysRevD.86.092004. arXiv:1208.1253 [hep-ex]
527. C. Bourrely, I. Caprini, L. Lellouch, Phys. Rev. D **79**, 013008 (2009). https://doi.org/10.1103/PhysRevD.79.013008. arXiv:0807.2722 [hep-ph]. [Erratum ibid. **82**, 099902 (2010). doi:10.1103/PhysRevD.82.099902]
528. J.A. Bailey et al., Fermilab Lattice and MILC collaborations. Phys. Rev. D **92**, 014024 (2015). https://doi.org/10.1103/PhysRevD.92.014024. arXiv:1503.07839 [hep-lat]
529. J.M. Flynn, T. Izubuchi, T. Kawanai, C. Lehner, A. Soni, R.S. Van de Water, O. Witzel, RBC and UKQCD collaborations. Phys. Rev. D **91**, 074510 (2015). https://doi.org/10.1103/PhysRevD.91.074510. arXiv:1501.05373 [hep-lat]
530. A. Bharucha, JHEP **05**, 092 (2012). https://doi.org/10.1007/JHEP05(2012)092. arXiv:1203.1359 [hep-ph]
531. M. Ablikim et al., BESIII collaboration. Phys. Rev. Lett. **116**, 052001 (2016). https://doi.org/10.1103/PhysRevLett.116.052001. arXiv:1511.08380 [hep-ex]
532. W. Detmold, C. Lehner, S. Meinel, Phys. Rev. D **92**, 034503 (2015). https://doi.org/10.1103/PhysRevD.92.034503. arXiv:1503.01421 [hep-lat]
533. R.N. Faustov, V.O. Galkin, Phys. Rev. D **94**, 073008 (2016). https://doi.org/10.1103/PhysRevD.94.073008. arXiv:1609.00199 [hep-ph]
534. P. Ball, R. Zwicky, Phys. Rev. D **71**, 014015 (2005). https://doi.org/10.1103/PhysRevD.71.014015. arXiv:hep-ph/0406232
535. A. Bharucha, D.M. Straub, R. Zwicky, JHEP **08**, 098 (2016). https://doi.org/10.1007/JHEP08(2016)098. arXiv:1503.05534 [hep-ph]
536. B.H. Behrens et al., CLEO collaboration. Phys. Rev. D **61**, 052001 (2000). https://doi.org/10.1103/PhysRevD.61.052001. arXiv:hep-ex/9905056
537. N.E. Adam et al., CLEO collaboration. Phys. Rev. Lett. **99**, 041802 (2007). https://doi.org/10.1103/PhysRevLett.99.041802. arXiv:hep-ex/0703041
538. T. Hokuue et al., Belle collaboration. Phys. Lett. B **648**, 139 (2007). https://doi.org/10.1016/j.physletb.2007.02.067. arXiv:hep-ex/0604024
539. C. Schwanda et al., Belle collaboration. Phys. Rev. Lett. **93**, 131803 (2004). https://doi.org/10.1103/PhysRevLett.93.131803. arXiv:hep-ex/0402023
540. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **87**, 032004 (2013). https://doi.org/10.1103/PhysRevD.87.032004. arXiv:1205.6245 [hep-ex]
541. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **88**, 072006 (2013). https://doi.org/10.1103/PhysRevD.88.072006. arXiv:1308.2589 [hep-ex]
542. R. Gray et al., CLEO collaboration. Phys. Rev. D **76**, 012007 (2007). https://doi.org/10.1103/PhysRevD.76.012007. arXiv:hep-ex/0703042
543. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 052011 (2009). https://doi.org/10.1103/PhysRevD.79.052011. arXiv:0808.3524 [hep-ex]
544. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **101**, 081801 (2008). https://doi.org/10.1103/PhysRevLett.101.081801. arXiv:0805.2408 [hep-ex]
545. P. Urquijo et al., Belle collaboration. Phys. Rev. Lett. **104**, 021801 (2010). https://doi.org/10.1103/PhysRevLett.104.021801. arXiv:0907.0379 [hep-ex]

546. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **86**, 032004 (2012). https://doi.org/10.1103/PhysRevD.86.032004. arXiv:1112.0702 [hep-ex]
547. C.W. Bauer, Z. Ligeti, M.E. Luke, Phys. Rev. D **64**, 113004 (2001). https://doi.org/10.1103/PhysRevD.64.113004. arXiv:hep-ph/0107074
548. M. Neubert, Phys. Rev. D **49**, 4623 (1994). https://doi.org/10.1103/PhysRevD.49.4623. arXiv:hep-ph/9312311
549. A.K. Leibovich, I. Low, I.Z. Rothstein, Phys. Rev. D **61**, 053006 (2000). https://doi.org/10.1103/PhysRevD.61.053006. arXiv:hep-ph/9909404
550. B.O. Lange, M. Neubert, G. Paz, JHEP **10**, 084 (2005). https://doi.org/10.1088/1126-6708/2005/10/084. arXiv:hep-ph/0508178
551. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **95**, 072001 (2017). https://doi.org/10.1103/PhysRevD.95.072001. arXiv:1611.05624 [hep-ex]
552. R.V. Kowalewski, S. Menke, Phys. Lett. B **541**, 29 (2002). https://doi.org/10.1016/S0370-2693(02)02181-0. arXiv:hep-ex/0205038
553. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **95**, 111801 (2005). https://doi.org/10.1103/PhysRevLett.95.111801. arXiv:hep-ex/0506036
554. A. Bornheim et al., CLEO collaboration. Phys. Rev. Lett. **88**, 231803 (2002). https://doi.org/10.1103/PhysRevLett.88.231803. arXiv:hep-ex/0202019
555. B. Aubert et al., BaBar collaboration. Phys. Rev. D **73**, 012006 (2006). https://doi.org/10.1103/PhysRevD.73.012006. arXiv:hep-ex/0509040
556. A. Limosani et al., Belle collaboration. Phys. Lett. B **621**, 28 (2005). https://doi.org/10.1016/j.physletb.2005.06.011. arXiv:hep-ex/0504046
557. H. Kakuno et al., Belle collaboration. Phys. Rev. Lett. **92**, 101801 (2004). https://doi.org/10.1103/PhysRevLett.92.101801. arXiv:hep-ex/0311048
558. I. Bizjak et al., Belle collaboration. Phys. Rev. Lett. **95**, 241801 (2005). https://doi.org/10.1103/PhysRevLett.95.241801. arXiv:hep-ex/0505088
559. B.O. Lange, M. Neubert, G. Paz, Phys. Rev. D **72**, 073006 (2005). https://doi.org/10.1103/PhysRevD.72.073006. arXiv:hep-ph/0504071
560. S.W. Bosch, B.O. Lange, M. Neubert, G. Paz, Nucl. Phys. B **699**, 335 (2004). https://doi.org/10.1016/j.nuclphysb.2004.07.041. arXiv:hep-ph/0402094
561. S.W. Bosch, M. Neubert, G. Paz, JHEP **11**, 073 (2004). https://doi.org/10.1088/1126-6708/2004/11/073. arXiv:hep-ph/0409115
562. M. Neubert, Eur. Phys. J. C **44**, 205 (2005). https://doi.org/10.1140/epjc/s2005-02360-4. arXiv:hep-ph/0411027
563. M. Neubert, Phys. Lett. B **612**, 13 (2005). https://doi.org/10.1016/j.physletb.2005.02.055. arXiv:hep-ph/0412241
564. M. Neubert, Phys. Rev. D **72**, 074025 (2005). https://doi.org/10.1103/PhysRevD.72.074025. arXiv:hep-ph/0506245
565. J.R. Andersen, E. Gardi, JHEP **01**, 097 (2006). https://doi.org/10.1088/1126-6708/2006/01/097. arXiv:hep-ph/0509360
566. U. Aglietti, G. Ferrera, G. Ricciardi, Nucl. Phys. B **768**, 85 (2007). https://doi.org/10.1016/j.nuclphysb.2007.01.014. arXiv:hep-ph/0608047
567. P. Gambino, P. Giordano, G. Ossola, N. Uraltsev, JHEP **10**, 058 (2007). https://doi.org/10.1088/1126-6708/2007/10/058. arXiv:0707.2493 [hep-ph]
568. U. Aglietti, F. Di Lodovico, G. Ferrera, G. Ricciardi, Eur. Phys. J. C **59**, 831 (2009). https://doi.org/10.1140/epjc/s10052-008-0817-x. arXiv:0711.0860 [hep-ph]
569. U. Aglietti, G. Ricciardi, G. Ferrera, Phys. Rev. D **74**, 034004 (2006). https://doi.org/10.1103/PhysRevD.74.034004. arXiv:hep-ph/0507285
570. U. Aglietti, G. Ricciardi, G. Ferrera, Phys. Rev. D **74**, 034005 (2006). https://doi.org/10.1103/PhysRevD.74.034005. arXiv:hep-ph/0509095
571. U. Aglietti, G. Ricciardi, G. Ferrera, Phys. Rev. D **74**, 034006 (2006). https://doi.org/10.1103/PhysRevD.74.034006. arXiv:hep-ph/0509271
572. M. Duraisamy, P. Sharma, A. Datta, Phys. Rev. D **90**, 074013 (2014). https://doi.org/10.1103/PhysRevD.90.074013. arXiv:1405.3719 [hep-ph]
573. H. Na, C.M. Bouchard, G.P. Lepage, C. Monahan, J. Shigemitsu, (HPQCD collaboration), Phys. Rev. D **92**, 054510 (2015). https://doi.org/10.1103/PhysRevD.92.054510. arXiv:1505.03925 [hep-lat]. [Erratum ibid. **93**, 119906 (2016). doi:10.1103/PhysRevD.93.119906]
574. J.P. Lees et al., BaBar collaboration. Phys. Rev. Lett. **109**, 101802 (2012). https://doi.org/10.1103/PhysRevLett.109.101802. arXiv:1205.5442 [hep-ex]
575. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **88**, 072012 (2013). https://doi.org/10.1103/PhysRevD.88.072012. arXiv:1303.0571 [hep-ex]
576. J.F. Kamenik, F. Mescia, Phys. Rev. D **78**, 014003 (2008). https://doi.org/10.1103/PhysRevD.78.014003Phys. arXiv:0802.3790 [hep-ph]
577. S. Fajfer, J.F. Kamenik, I. Nisandzic, Phys. Rev. D **85**, 094025 (2012). https://doi.org/10.1103/PhysRevD.85.094025. arXiv:1203.2654 [hep-ph]
578. D. Bigi, P. Gambino, Phys. Rev. D **94**, 094008 (2016). https://doi.org/10.1103/PhysRevD.94.094008. arXiv:1606.08030 [hep-ph]
579. A. Matyja et al., Belle collaboration. Phys. Rev. Lett. **99**, 191807 (2007). https://doi.org/10.1103/PhysRevLett.99.191807. arXiv:0706.4429 [hep-ex]
580. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 021801 (2008). https://doi.org/10.1103/PhysRevLett.100.021801. arXiv:0709.1698 [hep-ex]
581. A. Bozek et al., Belle collaboration. Phys. Rev. D **82**, 072005 (2010). https://doi.org/10.1103/PhysRevD.82.072005. arXiv:1005.2302 [hep-ex]
582. M. Huschle et al., Belle collaboration. Phys. Rev. D **92**, 072014 (2015). https://doi.org/10.1103/PhysRevD.92.072014. arXiv:1507.03233 [hep-ex]
583. R. Aaij et al. (LHCb collaboration), Phys. Rev. Lett. **115**, 111803 (2015). https://doi.org/10.1103/PhysRevLett.115.111803. arXiv:1506.08614 [hep-ex]. Addendum ibid. **115**, 159901 (2015). doi:10.1103/PhysRevLett.115.159901
584. Y. Sato et al., Belle collaboration. Phys. Rev. D **94**, 072007 (2016). https://doi.org/10.1103/PhysRevD.94.072007. arXiv:1607.07923 [hep-ex]
585. S. Hirose et al., Belle collaboration. Phys. Rev. Lett. **118**(21), 211801 (2017). https://doi.org/10.1103/PhysRevLett.118.211801. arXiv:1612.00529 [hep-ex]
586. A.J. Lenz, J. Phys. G **41**, 103001 (2014). https://doi.org/10.1088/0954-3899/41/10/103001. arXiv:1404.6197 [hep-ph]
587. S. Choi et al. (Belle collaboration), Phys. Rev. Lett. **91**, 262001 (2003). https://doi.org/10.1103/PhysRevLett.91.262001. arXiv:hep-ex/0309032 [hep-ex]
588. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **110**, 222001 (2013). https://doi.org/10.1103/PhysRevLett.110.222001. arXiv:1302.6269 [hep-ex]
589. S. Choi et al., Belle collaboration. Phys. Rev. Lett. **100**, 142001 (2008). https://doi.org/10.1103/PhysRevLett.100.142001. arXiv:0708.1790 [hep-ex]
590. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **112**, 222002 (2014). https://doi.org/10.1103/PhysRevLett.112.222002. arXiv:1404.1903 [hep-ex]

591. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **115**, 072001 (2015). https://doi.org/10.1103/PhysRevLett.115.072001. arXiv:1507.03414 [hep-ex]
592. K. De Bruyn et al., Phys. Rev. D **86**, 014027 (2012). https://doi.org/10.1103/PhysRevD.86.014027. arXiv:1204.1735 [hep-ph]
593. M. Jung, Phys. Lett. B **753**, 187 (2016). https://doi.org/10.1016/j.physletb.2015.12.024. arXiv:1510.03423 [hep-ph]
594. B. Aubert et al. (BABAR collaboration), Phys. Rev. D **75**, 031101 (2007). https://doi.org/10.1103/PhysRevD.75.031101, arXiv:hep-ex/0610027 [hep-ex]
595. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 111102 (2006). https://doi.org/10.1103/PhysRevD.74.111102. arXiv:hep-ex/0609033
596. G. Majumder et al. (Belle collaboration), Phys. Rev. D **70**, 111103 (2004). https://doi.org/10.1103/PhysRevD.70.111103. arXiv:hep-ex/0409008 [hep-ex]
597. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **94**, 091101 (2016). https://doi.org/10.1103/PhysRevD.94.091101. arXiv:1609.06802 [hep-ex]
598. D. Matvienko et al., Belle collaboration. Phys. Rev. D **92**, 012013 (2015). https://doi.org/10.1103/PhysRevD.92.012013. arXiv:1505.03362 [hep-ex]
599. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 012001 (2006). https://doi.org/10.1103/PhysRevD.74.012001. arXiv:hep-ex/0604009
600. S. Blyth et al., Belle collaboration. Phys. Rev. D **74**, 092002 (2006). https://doi.org/10.1103/PhysRevD.74.092002. arXiv:hep-ex/0607029
601. J.P. Lees et al. (BABAR collaboration), Phys. Rev. D **84**, 112007 (2011). https://doi.org/10.1103/PhysRevD.84.112007. arXiv:1107.5751 [hep-ex]. [Erratum ibid. **87**, 039901 (2013). doi:10.1103/PhysRevD.87.039901]
602. R. Aaij et al., LHCb collaboration. Phys. Rev. D **92**, 032002 (2015). https://doi.org/10.1103/PhysRevD.92.032002. arXiv:1505.01710 [hep-ex]
603. A. Satpathy et al., Belle collaboration. Phys. Lett. B **553**, 159 (2003). https://doi.org/10.1016/S0370-2693(02)03198-2. arXiv:hep-ex/0211022
604. J. Schumann et al., Belle collaboration. Phys. Rev. D **72**, 011103 (2005). https://doi.org/10.1103/PhysRevD.72.011103. arXiv:hep-ex/0501013
605. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **87**, 111801 (2001). https://doi.org/10.1103/PhysRevLett.87.111801. arXiv:hep-ex/0104051
606. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **95**, 171802 (2005). https://doi.org/10.1103/PhysRevLett.95.171802. arXiv:hep-ex/0412040
607. A. Drutskoy et al., Belle collaboration. Phys. Lett. B **542**, 171 (2002). https://doi.org/10.1016/S0370-2693(02)02373-0. arXiv:hep-ex/0207041
608. P. Krokovny et al., Belle collaboration. Phys. Rev. Lett. **90**, 141802 (2003). https://doi.org/10.1103/PhysRevLett.90.141802. arXiv:hep-ex/0212066
609. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 031101 (2006). https://doi.org/10.1103/PhysRevD.74.031101. arXiv:hep-ex/0604016
610. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **96**, 011803 (2006). https://doi.org/10.1103/PhysRevLett.96.011803. arXiv:hep-ex/0509036
611. A. Das et al., Belle collaboration. Phys. Rev. D **82**, 051103 (2010). https://doi.org/10.1103/PhysRevD.82.051103. arXiv:1007.4619 [hep-ex]
612. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 032005 (2008). https://doi.org/10.1103/PhysRevD.78.032005. arXiv:0803.4296 [hep-ex]
613. N. Joshi et al., Belle collaboration. Phys. Rev. D **81**, 031101 (2010). https://doi.org/10.1103/PhysRevD.81.031101. arXiv:0912.2594 [hep-ex]
614. B. Aubert et al., BABAR collaboration. Phys. Rev. D **73**, 071103 (2006). https://doi.org/10.1103/PhysRevD.73.071103. arXiv:hep-ex/0512031
615. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **100**, 171803 (2008). https://doi.org/10.1103/PhysRevLett.100.171803. arXiv:0707.1043 [hep-ex]
616. R. Aaij et al. (LHCb collaboration), Phys. Rev. D **84**, 092001 (2011). https://doi.org/10.1103/PhysRevD.84.092001. arXiv:1109.6831 [hep-ex]. [Erratum ibid. **85**, 039904 (2011). doi:10.1103/PhysRevD.85.039904]
617. R. Aaij et al., LHCb collaboration. Phys. Rev. D **86**, 112005 (2012). https://doi.org/10.1103/PhysRevD.86.112005. arXiv:1211.1541 [hep-ex]
618. R. Aaij et al., LHCb collaboration. Phys. Rev. D **87**, 112009 (2013). https://doi.org/10.1103/PhysRevD.87.112009. arXiv:1304.6317 [hep-ex]
619. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **109**, 131801 (2012). https://doi.org/10.1103/PhysRevLett.109.131801. arXiv:1207.5991 [hep-ex]
620. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **108**, 161801 (2012). https://doi.org/10.1103/PhysRevLett.108.161801. arXiv:1201.4402 [hep-ex]
621. R. Aaij et al., LHCb collaboration. JHEP **05**, 019 (2015). https://doi.org/10.1007/JHEP05(2015)019. arXiv:1412.7654 [hep-ex]
622. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **94**, 221805 (2005). https://doi.org/10.1103/PhysRevLett.94.221805. arXiv:hep-ex/0410091
623. A. Drutskoy et al., Belle collaboration. Phys. Rev. Lett. **94**, 061802 (2005). https://doi.org/10.1103/PhysRevLett.94.061802. arXiv:hep-ex/0409026
624. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **85**, 092017 (2012). https://doi.org/10.1103/PhysRevD.85.092017. arXiv:1111.4387 [hep-ex]
625. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **89**, 151802 (2002). https://doi.org/10.1103/PhysRevLett.89.151802. arXiv:hep-ex/0205083
626. T. Medvedeva et al., Belle collaboration. Phys. Rev. D **76**, 051102 (2007). https://doi.org/10.1103/PhysRevD.76.051102. arXiv:0704.2652 [hep-ex]
627. Y.W. Chang et al., Belle collaboration. Phys. Rev. D **79**, 052006 (2009). https://doi.org/10.1103/PhysRevD.79.052006. arXiv:0811.3826 [hep-ex]
628. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **89**, 112002 (2014). https://doi.org/10.1103/PhysRevD.89.112002. arXiv:1401.5990 [hep-ex]
629. Y.Y. Chang et al., Belle collaboration. Phys. Rev. Lett. **115**, 221803 (2015). https://doi.org/10.1103/PhysRevLett.115.221803. arXiv:1509.03034 [hep-ex]
630. B. Aubert et al., BABAR collaboration. Phys. Rev. D **73**, 112004 (2006). https://doi.org/10.1103/PhysRevD.73.112004. arXiv:hep-ex/0604037
631. I. Adachi et al., Belle collaboration. Phys. Rev. D **77**, 091101 (2008). https://doi.org/10.1103/PhysRevD.77.091101. arXiv:0802.2988 [hep-ex]
632. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **83**, 032004 (2011). https://doi.org/10.1103/PhysRevD.83.032004. arXiv:1011.3929 [hep-ex]
633. G. Gokhroo et al., Belle collaboration. Phys. Rev. Lett. **97**, 162002 (2006). https://doi.org/10.1103/PhysRevLett.97.162002. arXiv:hep-ex/0606055
634. A. Zupanc et al., Belle collaboration. Phys. Rev. D **75**, 091102 (2007). https://doi.org/10.1103/PhysRevD.75.091102. arXiv:hep-ex/0703040

635. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 031103 (2006). https://doi.org/10.1103/PhysRevD.74.031103. arXiv:hep-ex/0605036
636. B. Aubert et al., BABAR collaboration. Phys. Rev. D **67**, 092003 (2003). https://doi.org/10.1103/PhysRevD.67.092003. arXiv:hep-ex/0302015
637. B. Aubert et al., BABAR collaboration. Phys. Rev. D **71**, 091104 (2005). https://doi.org/10.1103/PhysRevD.71.091104. arXiv:hep-ex/0502041
638. B. Aubert et al., BABAR collaboration. Phys. Rev. D **72**, 111101 (2005). https://doi.org/10.1103/PhysRevD.72.111101. arXiv:hep-ex/0510051
639. R. Aaij et al., LHCb collaboration. Phys. Rev. D **87**, 092007 (2013). https://doi.org/10.1103/PhysRevD.87.092007. arXiv:1302.5854 [hep-ex]
640. P. Krokovny et al., Belle collaboration. Phys. Rev. Lett. **91**, 262002 (2003). https://doi.org/10.1103/PhysRevLett.91.262002. arXiv:hep-ex/0308019
641. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **93**, 181801 (2004). https://doi.org/10.1103/PhysRevLett.93.181801. arXiv:hep-ex/0408041
642. S.K. Choi et al. (Belle collaboration), Phys. Rev. D **91**, 092011 (2015). https://doi.org/10.1103/PhysRevD.91.092011. arXiv:1504.02637 [hep-ex]. Addendum ibid. **92**, 039905 (2015). doi:10.1103/PhysRevD.92.039905
643. B. Aubert et al., BABAR collaboration. Phys. Rev. D **77**, 011102 (2008). https://doi.org/10.1103/PhysRevD.77.011102. arXiv:0708.1565 [hep-ex]
644. T. Aushev et al. (Belle collaboration), Phys. Rev. D **83**, 051102 (2011). https://doi.org/10.1103/PhysRevD.83.059902. arXiv:1102.0935 [hep-ex]. [Erratum ibid. **83**, 051102 (2011). doi:10.1103/PhysRevD.83.051102]
645. F. Abe et al., CDF collaboration. Phys. Rev. Lett. **76**, 2015 (1996). https://doi.org/10.1103/PhysRevLett.76.2015
646. K. Abe et al., Belle collaboration. Phys. Rev. D **67**, 032003 (2003). https://doi.org/10.1103/PhysRevD.67.032003. arXiv:hep-ex/0211047
647. K. Chilikin et al., Belle collaboration. Phys. Rev. D **90**, 112009 (2014). https://doi.org/10.1103/PhysRevD.90.112009. arXiv:1408.6457 [hep-ex]
648. F. Abe et al., CDF collaboration. Phys. Rev. D **58**, 072001 (1998). https://doi.org/10.1103/PhysRevD.58.072001. arXiv:hep-ex/9803013
649. R. Aaij et al., LHCb collaboration. JHEP **07**, 140 (2014). https://doi.org/10.1007/JHEP07(2014)140. arXiv:1405.3219 [hep-ex]
650. T. Affolder et al., CDF collaboration. Phys. Rev. Lett. **88**, 071801 (2002). https://doi.org/10.1103/PhysRevLett.88.071801. arXiv:hep-ex/0108022
651. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **82**, 011101 (2010). https://doi.org/10.1103/PhysRevD.82.011101. arXiv:1005.5190 [hep-ex]
652. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **91**, 071801 (2003). https://doi.org/10.1103/PhysRevLett.91.071801. arXiv:hep-ex/0304014
653. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **87**, 161601 (2001). https://doi.org/10.1103/PhysRevLett.87.161601. arXiv:hep-ex/0105014
654. T. Iwashita et al. (Belle collaboration), PTEP **2014**, 043C01 (2014). https://doi.org/10.1093/ptep/ptu043. arXiv:1310.2704 [hep-ex]
655. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **93**, 041801 (2004). https://doi.org/10.1103/PhysRevLett.93.041801. arXiv:hep-ex/0402025
656. R. Mizuk et al., Belle collaboration. Phys. Rev. D **80**, 031104 (2009). https://doi.org/10.1103/PhysRevD.80.031104. arXiv:0905.2869 [hep-ex]
657. V. Bhardwaj et al., Belle collaboration. Phys. Rev. Lett. **111**, 032001 (2013). https://doi.org/10.1103/PhysRevLett.111.032001. arXiv:1304.3975 [hep-ex]
658. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **94**, 171801 (2005). https://doi.org/10.1103/PhysRevLett.94.171801. arXiv:hep-ex/0501061
659. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 091101 (2008). https://doi.org/10.1103/PhysRevD.78.091101. arXiv:0808.1487 [hep-ex]
660. V. Bhardwaj et al., Belle collaboration. Phys. Rev. Lett. **107**, 091803 (2011). https://doi.org/10.1103/PhysRevLett.107.091803. arXiv:1105.0177 [hep-ex]
661. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **102**, 132001 (2009). https://doi.org/10.1103/PhysRevLett.102.132001. arXiv:0809.0042 [hep-ex]
662. V. Bhardwaj et al., Belle collaboration. Phys. Rev. D **93**, 052016 (2016). https://doi.org/10.1103/PhysRevD.93.052016. arXiv:1512.02672 [hep-ex]
663. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **85**, 052003 (2012). https://doi.org/10.1103/PhysRevD.85.052003. arXiv:1111.5919 [hep-ex]
664. N. Soni et al., Belle collaboration. Phys. Lett. B **634**, 155 (2006). https://doi.org/10.1016/j.physletb.2006.01.013. arXiv:hep-ex/0508032
665. F. Fang et al., Belle collaboration. Phys. Rev. Lett. **90**, 071801 (2003). https://doi.org/10.1103/PhysRevLett.90.071801. arXiv:hep-ex/0208047
666. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 092004 (2007). https://doi.org/10.1103/PhysRevD.76.092004. arXiv:0707.1648 [hep-ex]
667. B. Aubert et al., BABAR collaboration. Phys. Rev. D **70**, 011101 (2004). https://doi.org/10.1103/PhysRevD.70.011101. arXiv:hep-ex/0403007
668. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 012006 (2008). https://doi.org/10.1103/PhysRevD.78.012006. arXiv:0804.1208 [hep-ex]
669. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 031101 (2007). https://doi.org/10.1103/PhysRevD.76.031101. arXiv:0704.1266 [hep-ex]
670. M. Chang et al., Belle collaboration. Phys. Rev. D **85**, 091102 (2012). https://doi.org/10.1103/PhysRevD.85.091102. arXiv:1203.3399 [hep-ex]
671. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **112**, 091802 (2014). https://doi.org/10.1103/PhysRevLett.112.091802. arXiv:1310.2145 [hep-ex]
672. R. Kumar et al., Belle collaboration. Phys. Rev. D **78**, 091104 (2008). https://doi.org/10.1103/PhysRevD.78.091104. arXiv:0809.1778 [hep-ex]
673. R. Aaij et al., LHCb collaboration. Phys. Rev. D **88**, 072005 (2013). https://doi.org/10.1103/PhysRevD.88.072005. arXiv:1308.5916 [hep-ex]
674. R. Aaij et al., LHCb collaboration. Phys. Rev. D **87**, 052001 (2013). https://doi.org/10.1103/PhysRevD.87.052001. arXiv:1301.5347 [hep-ex]
675. Y. Liu et al., Belle collaboration. Phys. Rev. D **78**, 011106 (2008). https://doi.org/10.1103/PhysRevD.78.011106. arXiv:0805.3225 [hep-ex]
676. R. Aaij et al., LHCb collaboration. Phys. Rev. D **92**, 112002 (2015). https://doi.org/10.1103/PhysRevD.92.112002. arXiv:1510.04866 [hep-ex]
677. B. Aubert et al., BABAR collaboration. Phys. Rev. D **70**, 091104 (2004). https://doi.org/10.1103/PhysRevD.70.091104. arXiv:hep-ex/0408018
678. R. Aaij et al., LHCb collaboration. JHEP **09**, 006 (2013). https://doi.org/10.1007/JHEP09(2013)006. arXiv:1306.4489 [hep-ex]

679. Q. Xie et al., Belle collaboration. Phys. Rev. D **72**, 051105 (2005). https://doi.org/10.1103/PhysRevD.72.051105. arXiv:hep-ex/0508011
680. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **90**, 231801 (2003). https://doi.org/10.1103/PhysRevLett.90.231801. arXiv:hep-ex/0303036
681. L. Zhang et al., Belle collaboration. Phys. Rev. D **71**, 091107 (2005). https://doi.org/10.1103/PhysRevD.71.091107. arXiv:hep-ex/0503037
682. B. Aubert et al., BaBar collaboration. Phys. Rev. D **71**, 091103 (2005). https://doi.org/10.1103/PhysRevD.71.091103. arXiv:hep-ex/0503021
683. F. Abe et al., CDF collaboration. Phys. Rev. D **54**, 6596 (1996). https://doi.org/10.1103/PhysRevD.54.6596. arXiv:hep-ex/9607003
684. R. Aaij et al., LHCb collaboration. Nucl. Phys. B **867**, 547 (2013). https://doi.org/10.1016/j.nuclphysb.2012.10.021. arXiv:1210.2631 [hep-ex]
685. R. Aaij et al., LHCb collaboration. Eur. Phys. J. C **72**, 2118 (2012). https://doi.org/10.1140/epjc/s10052-012-2118-7. arXiv:1205.0918 [hep-ex]
686. R. Aaij et al., LHCb collaboration. Nucl. Phys. B **871**, 403 (2013). https://doi.org/10.1016/j.nuclphysb.2013.03.004. arXiv:1302.6354 [hep-ex]
687. R. Aaij et al., LHCb collaboration. JHEP **01**, 024 (2015). https://doi.org/10.1007/JHEP01(2015)024. arXiv:1411.0943 [hep-ex]
688. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **93**, 081801 (2004). https://doi.org/10.1103/PhysRevLett.93.081801. arXiv:hep-ex/0404005
689. B. Aubert et al., BaBar collaboration. Phys. Rev. D **82**, 031102 (2010). https://doi.org/10.1103/PhysRevD.82.031102. arXiv:1007.1370 [hep-ex]
690. N. Gabyshev et al., Belle collaboration. Phys. Rev. D **66**, 091102 (2002). https://doi.org/10.1103/PhysRevD.66.091102. arXiv:hep-ex/0208041
691. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **87**, 092004 (2013). https://doi.org/10.1103/PhysRevD.87.092004. arXiv:1302.0191 [hep-ex]
692. K. Park et al., Belle collaboration. Phys. Rev. D **75**, 011101 (2007). https://doi.org/10.1103/PhysRevD.75.011101. arXiv:hep-ex/0608025
693. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **97**, 202003 (2006). https://doi.org/10.1103/PhysRevLett.97.202003. arXiv:hep-ex/0508015
694. B. Aubert et al., BaBar collaboration. Phys. Rev. D **77**, 012002 (2008). https://doi.org/10.1103/PhysRevD.77.012002. arXiv:0710.5763 [hep-ex]
695. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **91**, 031102 (2015). https://doi.org/10.1103/PhysRevD.91.031102. arXiv:1410.3644 [hep-ex]
696. N. Gabyshev et al., Belle collaboration. Phys. Rev. Lett. **90**, 121802 (2003). https://doi.org/10.1103/PhysRevLett.90.121802. arXiv:hep-ex/0212052
697. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 112003 (2008). https://doi.org/10.1103/PhysRevD.78.112003. arXiv:0807.4974 [hep-ex]
698. B. Aubert et al., BaBar collaboration. Phys. Rev. D **80**, 051105 (2009). https://doi.org/10.1103/PhysRevD.80.051105. arXiv:0907.4566 [hep-ex]
699. R. Chistov et al., Belle collaboration. Phys. Rev. D **74**, 111105 (2006). https://doi.org/10.1103/PhysRevD.74.111105. arXiv:hep-ex/0510074
700. Y. Uchida et al., Belle collaboration. Phys. Rev. D **77**, 051101 (2008). https://doi.org/10.1103/PhysRevD.77.051101. arXiv:0708.1105 [hep-ex]
701. J.P. Lees et al. (BaBar collaboration), Phys. Rev. D **84**, 071102 (2011). https://doi.org/10.1103/PhysRevD.84.071102. arXiv:1108.3211 [hep-ex]. [Erratum ibid. **85**, 039903 (2012). doi:10.1103/PhysRevD.85.039903]
702. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **89**, 071102 (2014). https://doi.org/10.1103/PhysRevD.89.071102. arXiv:1312.6800 [hep-ex]
703. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **112**, 202001 (2014). https://doi.org/10.1103/PhysRevLett.112.202001. arXiv:1403.3606 [hep-ex]
704. B. Aubert et al., BaBar collaboration. Phys. Rev. D **77**, 111101 (2008). https://doi.org/10.1103/PhysRevD.77.111101. arXiv:0803.2838 [hep-ex]
705. R. Mizuk et al., Belle collaboration. Phys. Rev. D **78**, 072004 (2008). https://doi.org/10.1103/PhysRevD.78.072004. arXiv:0806.4098 [hep-ex]
706. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **96**, 052002 (2006). https://doi.org/10.1103/PhysRevLett.96.052002. arXiv:hep-ex/0510070
707. B. Aubert et al., BaBar collaboration. Phys. Rev. D **71**, 031501 (2005). https://doi.org/10.1103/PhysRevD.71.031501. arXiv:hep-ex/0412051
708. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 112001 (2009). https://doi.org/10.1103/PhysRevD.79.112001. arXiv:0811.0564 [hep-ex]
709. M. Iwabuchi et al., Belle collaboration. Phys. Rev. Lett. **101**, 041601 (2008). https://doi.org/10.1103/PhysRevLett.101.041601. arXiv:0804.0831 [hep-ex]
710. K. Abe et al., Belle collaboration. Phys. Rev. D **69**, 112002 (2004). https://doi.org/10.1103/PhysRevD.69.112002. arXiv:hep-ex/0307021
711. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 112004 (2009). https://doi.org/10.1103/PhysRevD.79.112004. arXiv:0901.1291 [hep-ex]
712. B. Aubert et al. (BaBar collaboration) (2003). arXiv:hep-ex/0308026
713. S. Swain et al., Belle collaboration. Phys. Rev. D **68**, 051101 (2003). https://doi.org/10.1103/PhysRevD.68.051101. arXiv:hep-ex/0304032
714. B. Aubert et al., BaBar collaboration. Phys. Rev. D **73**, 111104 (2006). https://doi.org/10.1103/PhysRevD.73.111104. arXiv:hep-ex/0604017
715. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **92**, 141801 (2004). https://doi.org/10.1103/PhysRevLett.92.141801. arXiv:hep-ex/0308057
716. R. Aaij et al. (LHCb collaboration), Phys. Rev. D **91**, 092002 (2015). https://doi.org/10.1103/PhysRevD.91.092002. arXiv:1503.02995 [hep-ex]. [Erratum ibid. **93**, 119901 (2016). doi:10.1103/PhysRevD.93.119901]
717. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **82**, 092006 (2010). https://doi.org/10.1103/PhysRevD.82.092006. arXiv:1005.0068 [hep-ex]
718. R. Aaij et al. (LHCb collaboration), Phys. Rev. D **93**, 051101 (2016). https://doi.org/10.1103/PhysRevD.93.051101. arXiv:1512.02494 [hep-ex]. [Erratum ibid. **93**, 119902 (2016). doi:10.1103/PhysRevD.93.119902]
719. B. Aubert et al., BaBar collaboration. Phys. Rev. D **72**, 011102 (2005). https://doi.org/10.1103/PhysRevD.72.011102. arXiv:hep-ex/0505099
720. A. Abulencia et al., CDF collaboration. Phys. Rev. Lett. **96**, 191801 (2006). https://doi.org/10.1103/PhysRevLett.96.191801. arXiv:hep-ex/0508014
721. Y. Horii et al., Belle collaboration. Phys. Rev. D **78**, 071901 (2008). https://doi.org/10.1103/PhysRevD.78.071901. arXiv:0804.2063 [hep-ex]

722. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **92**, 202002 (2004). https://doi.org/10.1103/PhysRevLett.92.202002. arXiv:hep-ex/0311032
723. B. Aubert et al., BaBar collaboration. Phys. Rev. D **71**, 031102 (2005). https://doi.org/10.1103/PhysRevD.71.031102. arXiv:hep-ex/0411091
724. J. Wiechczynski et al., Belle collaboration. Phys. Rev. D **80**, 052005 (2009). https://doi.org/10.1103/PhysRevD.80.052005. arXiv:0903.4956 [hep-ex]
725. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **98**, 171801 (2007). https://doi.org/10.1103/PhysRevLett.98.171801. arXiv:hep-ex/0611030
726. R. Aaij et al., LHCb collaboration. JHEP **02**, 043 (2013). https://doi.org/10.1007/JHEP02(2013)043. arXiv:1210.1089 [hep-ex]
727. B. Aubert et al., BaBar collaboration. Phys. Rev. D **73**, 011103 (2006). https://doi.org/10.1103/PhysRevD.73.011103. arXiv:hep-ex/0512028
728. P. Chen et al., Belle collaboration. Phys. Rev. D **84**, 071501 (2011). https://doi.org/10.1103/PhysRevD.84.071501. arXiv:1108.4271 [hep-ex]
729. O. Seon et al., Belle collaboration. Phys. Rev. D **84**, 071106 (2011). https://doi.org/10.1103/PhysRevD.84.071106. arXiv:1107.0642 [hep-ex]
730. G. Majumder et al., Belle collaboration. Phys. Rev. Lett. **95**, 041803 (2005). https://doi.org/10.1103/PhysRevLett.95.041803. arXiv:hep-ex/0502038
731. J. Brodzicka et al., Belle collaboration. Phys. Rev. Lett. **100**, 092001 (2008). https://doi.org/10.1103/PhysRevLett.100.092001. arXiv:0707.3491 [hep-ex]
732. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **93**, 051803 (2004). https://doi.org/10.1103/PhysRevLett.93.051803. arXiv:hep-ex/0307061
733. K. Abe et al., Belle collaboration. Phys. Lett. B **538**, 11 (2002). https://doi.org/10.1016/S0370-2693(02)01969-X. arXiv:hep-ex/0205021
734. D. Acosta et al., CDF collaboration. Phys. Rev. D **66**, 052005 (2002). https://doi.org/10.1103/PhysRevD.66.052005
735. H. Guler et al., Belle collaboration. Phys. Rev. D **83**, 032005 (2011). https://doi.org/10.1103/PhysRevD.83.032005. arXiv:1009.5256 [hep-ex]
736. B. Aubert et al., BaBar collaboration. Phys. Rev. D **71**, 071103 (2005). https://doi.org/10.1103/PhysRevD.71.071103. arXiv:hep-ex/0406022
737. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **88**, 031802 (2002). https://doi.org/10.1103/PhysRevLett.88.031802. arXiv:hep-ex/0111069
738. A. Vinokurova et al., Belle collaboration. Phys. Lett. B **706**, 139 (2011). https://doi.org/10.1016/j.physletb.2011.11.014. arXiv:1105.0978 [hep-ex]
739. C.-H. Wu et al., Belle collaboration. Phys. Rev. Lett. **97**, 162003 (2006). https://doi.org/10.1103/PhysRevLett.97.162003. arXiv:hep-ex/0606022
740. B. Aubert et al., BaBar collaboration. Phys. Rev. D **72**, 051101 (2005). https://doi.org/10.1103/PhysRevD.72.051101. arXiv:hep-ex/0507012
741. F. Fang et al., Belle collaboration. Phys. Rev. D **74**, 012007 (2006). https://doi.org/10.1103/PhysRevD.74.012007. arXiv:hep-ex/0605007
742. R. Aaij et al., LHCb collaboration. Phys. Rev. D **85**, 091105 (2012). https://doi.org/10.1103/PhysRevD.85.091105. arXiv:1203.3592 [hep-ex]
743. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **92**, 241802 (2004). https://doi.org/10.1103/PhysRevLett.92.241802. arXiv:hep-ex/0401035
744. B. Aubert et al., BaBar collaboration. Phys. Rev. D **72**, 052002 (2005). https://doi.org/10.1103/PhysRevD.72.052002. arXiv:hep-ex/0507025
745. R. Kumar et al., Belle collaboration. Phys. Rev. D **74**, 051103 (2006). https://doi.org/10.1103/PhysRevD.74.051103. arXiv:hep-ex/0607008
746. V. Abazov et al., D0 collaboration. Phys. Rev. D **79**, 111102 (2009). https://doi.org/10.1103/PhysRevD.79.111102. arXiv:0805.2576 [hep-ex]
747. R. Aaij et al., LHCb collaboration. Eur. Phys. J. C **73**, 2462 (2013). https://doi.org/10.1140/epjc/s10052-013-2462-2. arXiv:1303.7133 [hep-ex]
748. F. Abe et al., CDF collaboration. Phys. Rev. Lett. **77**, 5176 (1996). https://doi.org/10.1103/PhysRevLett.77.5176
749. A. Abulencia, CDF collaboration. Phys. Rev. D **79**, 112003 (2009). https://doi.org/10.1103/PhysRevD.79.112003. arXiv:0905.2146 [hep-ex]
750. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **86**, 091102 (2012). https://doi.org/10.1103/PhysRevD.86.091102. arXiv:1208.3086 [hep-ex]
751. S.K. Choi et al., Belle collaboration. Phys. Rev. D **84**, 052004 (2011). https://doi.org/10.1103/PhysRevD.84.052004. arXiv:1107.0163 [hep-ex]
752. B. Aubert et al., BaBar collaboration. Phys. Rev. D **74**, 071101 (2006). https://doi.org/10.1103/PhysRevD.74.071101. arXiv:hep-ex/0607050
753. B. Aubert et al., BaBar collaboration. Phys. Rev. D **73**, 011101 (2006). https://doi.org/10.1103/PhysRevD.73.011101. arXiv:hep-ex/0507090
754. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **118**, 022003 (2017). https://doi.org/10.1103/PhysRevLett.118.022003. arXiv:1606.07895 [hep-ex]
755. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **89**, 012004 (2014). https://doi.org/10.1103/PhysRevD.89.012004. arXiv:1309.6580 [hep-ex]
756. T. Aushev et al., Belle collaboration. Phys. Rev. D **81**, 031103 (2010). https://doi.org/10.1103/PhysRevD.81.031103. arXiv:0810.0358 [hep-ex]
757. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **94**, 182002 (2005). https://doi.org/10.1103/PhysRevLett.94.182002. arXiv:hep-ex/0408126
758. R. Aaij et al., LHCb collaboration. JHEP **06**, 115 (2012). https://doi.org/10.1007/JHEP06(2012)115. arXiv:1204.1237 [hep-ex]
759. R. Louvot et al., Belle collaboration. Phys. Rev. Lett. **104**, 231801 (2010). https://doi.org/10.1103/PhysRevLett.104.231801. arXiv:1003.5312 [hep-ex]
760. R. Aaij et al., LHCb collaboration. JHEP **06**, 130 (2015). https://doi.org/10.1007/JHEP06(2015)130. arXiv:1503.09086 [hep-ex]
761. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **116**, 161802 (2016). https://doi.org/10.1103/PhysRevLett.116.161802. arXiv:1603.02408 [hep-ex]
762. R. Aaij et al., LHCb collaboration. Phys. Lett. B **706**, 32 (2011). https://doi.org/10.1016/j.physletb.2011.10.073. arXiv:1110.3676 [hep-ex]
763. R. Aaij et al., LHCb collaboration. Phys. Rev. D **87**, 071101 (2013). https://doi.org/10.1103/PhysRevD.87.071101. arXiv:1302.6446 [hep-ex]
764. R. Aaij et al., LHCb collaboration. JHEP **08**, 005 (2015). https://doi.org/10.1007/JHEP08(2015)005. arXiv:1505.01654 [hep-ex]
765. A. Abulencia et al., CDF collaboration. Phys. Rev. Lett. **98**, 061802 (2007). https://doi.org/10.1103/PhysRevLett.98.061802. arXiv:hep-ex/0610045
766. R. Aaij et al., LHCb collaboration. Phys. Lett. B **727**, 403 (2013). https://doi.org/10.1016/j.physletb.2013.10.057. arXiv:1308.4583 [hep-ex]

767. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **103**, 191802 (2009). https://doi.org/10.1103/PhysRevLett.103.191802. arXiv:0809.0080 [hep-ex]
768. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **108**, 201801 (2012). https://doi.org/10.1103/PhysRevLett.108.201801. arXiv:1204.0536 [hep-ex]
769. R. Aaij et al., LHCb collaboration. Phys. Rev. D **93**, 092008 (2016). https://doi.org/10.1103/PhysRevD.93.092008. arXiv:1602.07543 [hep-ex]
770. J. Li et al., Belle collaboration. Phys. Rev. Lett. **108**, 181808 (2012). https://doi.org/10.1103/PhysRevLett.108.181808. arXiv:1202.0103 [hep-ex]
771. R. Aaij et al., LHCb collaboration. Phys. Rev. D **87**, 072004 (2013). https://doi.org/10.1103/PhysRevD.87.072004. arXiv:1302.1213 [hep-ex]
772. F. Thorne et al., Belle collaboration. Phys. Rev. D **88**, 114006 (2013). https://doi.org/10.1103/PhysRevD.88.114006. arXiv:1309.0704 [hep-ex]
773. R. Aaij et al., LHCb collaboration. Phys. Lett. B **713**, 172 (2012). https://doi.org/10.1016/j.physletb.2012.05.062. arXiv:1205.0934 [hep-ex]
774. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **83**, 052012 (2011). https://doi.org/10.1103/PhysRevD.83.052012. arXiv:1102.1961 [hep-ex]
775. R. Aaij et al., LHCb collaboration. JHEP **11**, 082 (2015). https://doi.org/10.1007/JHEP11(2015)082. arXiv:1509.00400 [hep-ex]
776. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **108**, 151801 (2012). https://doi.org/10.1103/PhysRevLett.108.151801. arXiv:1112.4695 [hep-ex]
777. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **86**, 092011 (2012). https://doi.org/10.1103/PhysRevD.86.092011. arXiv:1204.5723 [hep-ex]
778. R. Aaij et al., LHCb collaboration. Phys. Lett. B **698**, 115 (2011). https://doi.org/10.1016/j.physletb.2011.03.006. arXiv:1102.0206 [hep-ex]
779. A. Abulencia et al., CDF collaboration. Phys. Rev. Lett. **96**, 231801 (2006). https://doi.org/10.1103/PhysRevLett.96.231801. arXiv:hep-ex/0602005
780. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **85**, 011103 (2012). https://doi.org/10.1103/PhysRevD.85.011103. arXiv:1110.4272 [hep-ex]
781. V. Khachatryan et al., CMS collaboration. Phys. Lett. B **756**, 84 (2016). https://doi.org/10.1016/j.physletb.2016.02.047. arXiv:1501.06089 [hep-ex]
782. R. Aaij et al., LHCb collaboration. JHEP **03**, 040 (2016). https://doi.org/10.1007/JHEP03(2016)040. arXiv:1601.05284 [hep-ex]
783. R. Aaij et al., LHCb collaboration. Phys. Lett. B **747**, 484 (2015). https://doi.org/10.1016/j.physletb.2015.06.038. arXiv:1503.07112 [hep-ex]
784. R. Aaij et al., LHCb collaboration. Phys. Rev. D **89**, 092006 (2014). https://doi.org/10.1103/PhysRevD.89.092006. arXiv:1402.6248 [hep-ex]
785. E. Solovieva et al., Belle collaboration. Phys. Lett. B **726**, 206 (2013). https://doi.org/10.1016/j.physletb.2013.08.057. arXiv:1304.6931 [hep-ex]
786. R. Aaij et al., LHCb collaboration. Phys. Rev. D **87**, 112012 (2013). https://doi.org/10.1103/PhysRevD.87.112012. arXiv:1304.4530 [hep-ex]
787. G. Aad et al., ATLAS collaboration. Eur. Phys. J. C **76**, 4 (2016). https://doi.org/10.1140/epjc/s10052-015-3743-8. arXiv:1507.07099 [hep-ex]
788. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **108**, 251802 (2012). https://doi.org/10.1103/PhysRevLett.108.251802. arXiv:1204.0079 [hep-ex]
789. V. Khachatryan et al., CMS collaboration. JHEP **01**, 063 (2015). https://doi.org/10.1007/JHEP01(2015)063. arXiv:1410.5729 [hep-ex]
790. R. Aaij et al., LHCb collaboration. JHEP **09**, 075 (2013). https://doi.org/10.1007/JHEP09(2013)075. arXiv:1306.6723 [hep-ex]
791. R. Aaij et al., LHCb collaboration. JHEP **11**, 094 (2013). https://doi.org/10.1007/JHEP11(2013)094. arXiv:1309.0587 [hep-ex]
792. R. Aaij et al., LHCb collaboration. Phys. Rev. D **92**, 072007 (2015). https://doi.org/10.1103/PhysRevD.92.072007. arXiv:1507.03516 [hep-ex]
793. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **114**, 132001 (2015). https://doi.org/10.1103/PhysRevLett.114.132001. arXiv:1411.2943 [hep-ex]
794. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **109**, 232001 (2012). https://doi.org/10.1103/PhysRevLett.109.232001. arXiv:1209.5634 [hep-ex]
795. R. Aaij et al., LHCb collaboration. Phys. Rev. D **94**, 091102 (2016). https://doi.org/10.1103/PhysRevD.94.091102. arXiv:1607.06134 [hep-ex]
796. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **111**, 181801 (2013). https://doi.org/10.1103/PhysRevLett.111.181801. arXiv:1308.4544 [hep-ex]
797. R. Aaij et al., LHCb collaboration. Phys. Rev. D **89**, 032001 (2014). https://doi.org/10.1103/PhysRevD.89.032001. arXiv:1311.4823 [hep-ex]
798. R. Aaij et al., LHCb collaboration. Chin. Phys. C **40**, 011001 (2016). https://doi.org/10.1088/1674-1137/40/1/011001. arXiv:1509.00292 [hep-ex]
799. F. Abe et al., CDF collaboration. Phys. Rev. D **55**, 1142 (1997). https://doi.org/10.1103/PhysRevD.55.1142
800. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **84**, 031102 (2011). https://doi.org/10.1103/PhysRevD.84.031102. arXiv:1105.0690 [hep-ex]
801. G. Aad et al., ATLAS collaboration. Phys. Lett. B **751**, 63 (2015). https://doi.org/10.1016/j.physletb.2015.10.009. arXiv:1507.08202 [hep-ex]
802. R. Aaij et al., LHCb collaboration. JHEP **07**, 103 (2014). https://doi.org/10.1007/JHEP07(2014)103. arXiv:1406.0755 [hep-ex]
803. R. Aaij et al., LHCb collaboration. JHEP **05**, 132 (2016). https://doi.org/10.1007/JHEP05(2016)132. arXiv:1603.06961 [hep-ex]
804. G. Aad et al., ATLAS collaboration. Phys. Rev. D **89**, 092009 (2014). https://doi.org/10.1103/PhysRevD.89.092009. arXiv:1404.1071 [hep-ex]
805. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **85**, 032003 (2012). https://doi.org/10.1103/PhysRevD.85.032003. arXiv:1112.3334 [hep-ex]
806. A. Abulencia et al., CDF collaboration. Phys. Rev. Lett. **98**, 122002 (2007). https://doi.org/10.1103/PhysRevLett.98.122002. arXiv:hep-ex/0601003
807. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **115**, 241801 (2015). https://doi.org/10.1103/PhysRevLett.115.241801. arXiv:1510.03829 [hep-ex]
808. Y.T. Duh et al., Belle collaboration. Phys. Rev. D **87**, 031103 (2013). https://doi.org/10.1103/PhysRevD.87.031103. arXiv:1210.1348 [hep-ex]
809. A. Bornheim et al. (CLEO collaboration), Phys. Rev. D **68**, 052002 (2003). https://doi.org/10.1103/PhysRevD.68.052002. arXiv:hep-ex/0302026. [Erratum ibid. **75**, 119907 (2007). doi:10.1103/PhysRevD.75.119907]
810. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 091102 (2007). https://doi.org/10.1103/PhysRevD.76.091102. arXiv:0707.2798 [hep-ex]
811. B. Aubert et al., BABAR collaboration. Phys. Rev. D **80**, 112002 (2009). https://doi.org/10.1103/PhysRevD.80.112002. arXiv:0907.1743 [hep-ex]

812. J. Schumann et al., Belle collaboration. Phys. Rev. Lett. **97**, 061802 (2006). https://doi.org/10.1103/PhysRevLett.97.061802. arXiv:hep-ex/0603001
813. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **82**, 011502 (2010). https://doi.org/10.1103/PhysRevD.82.011502. arXiv:1004.0240 [hep-ex]
814. J. Schumann et al., Belle collaboration. Phys. Rev. D **75**, 092002 (2007). https://doi.org/10.1103/PhysRevD.75.092002. arXiv:hep-ex/0701046
815. C.T. Hoi et al., Belle collaboration. Phys. Rev. Lett. **108**, 031801 (2012). https://doi.org/10.1103/PhysRevLett.108.031801. arXiv:1110.2000 [hep-ex]
816. S.J. Richichi et al., CLEO collaboration. Phys. Rev. Lett. **85**, 520 (2000). https://doi.org/10.1103/PhysRevLett.85.520. arXiv:hep-ex/9912059
817. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **97**, 201802 (2006). https://doi.org/10.1103/PhysRevLett.97.201802. arXiv:hep-ex/0608005
818. C.H. Wang et al., Belle collaboration. Phys. Rev. D **75**, 092005 (2007). https://doi.org/10.1103/PhysRevD.75.092005. arXiv:hep-ex/0701057
819. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **101**, 091801 (2008). https://doi.org/10.1103/PhysRevLett.101.091801. arXiv:0804.0411 [hep-ex]
820. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 031103 (2007). https://doi.org/10.1103/PhysRevD.76.031103. arXiv:0706.3893 [hep-ex]
821. C.P. Jessop et al., CLEO collaboration. Phys. Rev. Lett. **85**, 2881 (2000). https://doi.org/10.1103/PhysRevLett.85.2881. arXiv:hep-ex/0006008
822. B. Aubert et al., BABAR collaboration. Phys. Rev. D **79**, 052005 (2009). https://doi.org/10.1103/PhysRevD.79.052005. arXiv:0901.3703 [hep-ex]
823. B. Aubert et al., BABAR collaboration. Phys. Rev. D **70**, 111102 (2004). https://doi.org/10.1103/PhysRevD.70.111102. arXiv:hep-ex/0407013
824. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **84**, 092007 (2011). https://doi.org/10.1103/PhysRevD.84.092007. arXiv:1109.0143 [hep-ex]
825. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 091102 (2008). https://doi.org/10.1103/PhysRevD.78.091102. arXiv:0808.0900 [hep-ex]
826. A. Garmash et al., Belle collaboration. Phys. Rev. D **69**, 012001 (2004). https://doi.org/10.1103/PhysRevD.69.012001. arXiv:hep-ex/0307082
827. R. Aaij et al., LHCb collaboration. Phys. Lett. B **765**, 307 (2017). https://doi.org/10.1016/j.physletb.2016.11.053. arXiv:1608.01478 [hep-ex]
828. T. Bergfeld et al., CLEO collaboration. Phys. Rev. Lett. **77**, 4503 (1996). https://doi.org/10.1103/PhysRevLett.77.4503
829. E. Eckhart et al., CLEO collaboration. Phys. Rev. Lett. **89**, 251801 (2002). https://doi.org/10.1103/PhysRevLett.89.251801. arXiv:hep-ex/0206024
830. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 011103 (2007). https://doi.org/10.1103/PhysRevD.76.011103. arXiv:hep-ex/0702043
831. B. Aubert et al. (BABAR collaboration), Phys. Rev. D **74**, 051104, (2006). https://doi.org/10.1103/PhysRevD.74.051104. arXiv:hep-ex/0607113 [hep-ex]
832. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **83**, 051101 (2011). https://doi.org/10.1103/PhysRevD.83.051101. arXiv:1012.4044 [hep-ex]
833. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **100**, 051803 (2008). https://doi.org/10.1103/PhysRevLett.100.051803. arXiv:0709.4165 [hep-ex]
834. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 011104 (2008). https://doi.org/10.1103/PhysRevD.78.011104. arXiv:0805.1217 [hep-ex]
835. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **254**, 288 (1991). https://doi.org/10.1016/0370-2693(91)90436-T
836. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **99**, 241803 (2007). https://doi.org/10.1103/PhysRevLett.99.241803. arXiv:0707.4561 [hep-ex]
837. B. Aubert et al., BABAR collaboration. Phys. Rev. D **80**, 051101 (2009). https://doi.org/10.1103/PhysRevD.80.051101. arXiv:0907.3485 [hep-ex]
838. R. Aaij et al., LHCb collaboration. Phys. Lett. B **726**, 646 (2013). https://doi.org/10.1016/j.physletb.2013.09.046. arXiv:1308.1277 [hep-ex]
839. B. Aubert et al., BABAR collaboration. Phys. Rev. D **79**, 051101 (2009). https://doi.org/10.1103/PhysRevD.79.051101. arXiv:0811.1979 [hep-ex]
840. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **99**, 221801 (2007). https://doi.org/10.1103/PhysRevLett.99.221801. arXiv:0708.0376 [hep-ex]
841. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 071103 (2007). https://doi.org/10.1103/PhysRevD.76.071103. arXiv:0706.1059 [hep-ex]
842. H.C. Huang et al., Belle collaboration. Phys. Rev. Lett. **91**, 241802 (2003). https://doi.org/10.1103/PhysRevLett.91.241802. arXiv:hep-ex/0305068
843. B. Aubert et al., BABAR collaboration. Phys. Rev. D **79**, 051102 (2009). https://doi.org/10.1103/PhysRevD.79.051102. arXiv:0901.1223 [hep-ex]
844. Y.M. Goh et al., Belle collaboration. Phys. Rev. D **91**, 071101 (2015). https://doi.org/10.1103/PhysRevD.91.071101. arXiv:1502.00381 [hep-ex]
845. R.A. Briere et al., CLEO collaboration. Phys. Rev. Lett. **86**, 3718 (2001). https://doi.org/10.1103/PhysRevLett.86.3718. arXiv:hep-ex/0101032
846. D. Acosta et al., CDF collaboration. Phys. Rev. Lett. **95**, 031801 (2005). https://doi.org/10.1103/PhysRevLett.95.031801. arXiv:hep-ex/0502044
847. A. Abulencia et al., CDF collaboration. Phys. Rev. D **73**, 032003 (2006). https://doi.org/10.1103/PhysRevD.73.032003. arXiv:hep-ex/0510048
848. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **99**, 201802 (2007). https://doi.org/10.1103/PhysRevLett.99.201802. arXiv:0705.1798 [hep-ex]
849. K.F. Chen et al., Belle collaboration. Phys. Rev. Lett. **91**, 201801 (2003). https://doi.org/10.1103/PhysRevLett.91.201801. arXiv:hep-ex/0307014
850. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **101**, 161801 (2008). https://doi.org/10.1103/PhysRevLett.101.161801. arXiv:0806.4419 [hep-ex]
851. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **82**, 091101 (2010). https://doi.org/10.1103/PhysRevD.82.091101. arXiv:1007.2732 [hep-ex]
852. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **84**, 012001 (2011). https://doi.org/10.1103/PhysRevD.84.012001. arXiv:1105.5159 [hep-ex]
853. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 031105 (2006). https://doi.org/10.1103/PhysRevD.74.031105. arXiv:hep-ex/0605008
854. C. Liu et al., Belle collaboration. Phys. Rev. D **79**, 071102 (2009). https://doi.org/10.1103/PhysRevD.79.071102. arXiv:0902.4757 [hep-ex]
855. B. Aubert et al., BABAR collaboration. Phys. Rev. D **79**, 072006 (2009). https://doi.org/10.1103/PhysRevD.79.072006. arXiv:0902.2051 [hep-ex]

856. A. Gordon et al., Belle collaboration. Phys. Lett. B **542**, 183 (2002). https://doi.org/10.1016/S0370-2693(02)02374-2. arXiv:hep-ex/0207007
857. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **241**, 278 (1990). https://doi.org/10.1016/0370-2693(90)91293-K
858. B. Aubert et al., BaBar collaboration. Phys. Rev. D **75**, 091103 (2007). https://doi.org/10.1103/PhysRevD.75.091103. arXiv:hep-ex/0701035
859. J. Zhang et al., Belle collaboration. Phys. Rev. Lett. **94**, 031801 (2005). https://doi.org/10.1103/PhysRevLett.94.031801. arXiv:hep-ex/0406006
860. J. Zhang et al., Belle collaboration. Phys. Rev. Lett. **91**, 221801 (2003). https://doi.org/10.1103/PhysRevLett.91.221801. arXiv:hep-ex/0306007
861. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **99**, 261801 (2007). https://doi.org/10.1103/PhysRevLett.99.261801/. arXiv:0708.0050 [hep-ex]
862. C.M. Jen et al., Belle collaboration. Phys. Rev. D **74**, 111101 (2006). https://doi.org/10.1103/PhysRevD.74.111101. arXiv:hep-ex/0609022
863. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 011107 (2008). https://doi.org/10.1103/PhysRevD.78.011107. arXiv:0804.2422 [hep-ex]
864. B. Aubert et al., BaBar collaboration. Phys. Rev. D **74**, 011102 (2006). https://doi.org/10.1103/PhysRevD.74.011102. arXiv:hep-ex/0605037
865. J.H. Kim et al., Belle collaboration. Phys. Rev. D **86**, 031101 (2012). https://doi.org/10.1103/PhysRevD.86.031101. arXiv:1206.4760 [hep-ex]
866. R. Aaij et al., LHCb collaboration. Phys. Lett. B **728**, 85 (2014). https://doi.org/10.1016/j.physletb.2013.11.036. arXiv:1309.3742 [hep-ex]
867. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **101**, 201801 (2008). https://doi.org/10.1103/PhysRevLett.101.201801. arXiv:0807.3935 [hep-ex]
868. B. Aubert et al., BaBar collaboration. Phys. Rev. D **77**, 011101 (2008). https://doi.org/10.1103/PhysRevD.77.011101. arXiv:0708.0963 [hep-ex]
869. D. Bortoletto et al., CLEO collaboration. Phys. Rev. Lett. **62**, 2436 (1989). https://doi.org/10.1103/PhysRevLett.62.2436
870. B. Aubert et al., BaBar collaboration. Phys. Rev. D **75**, 012008 (2007). https://doi.org/10.1103/PhysRevD.75.012008. arXiv:hep-ex/0608003
871. S. Sato et al., Belle collaboration. Phys. Rev. D **90**, 072009 (2014). https://doi.org/10.1103/PhysRevD.90.072009. arXiv:1408.6343 [hep-ex]
872. B. Aubert et al., BaBar collaboration. Phys. Rev. D **75**, 111102 (2007). https://doi.org/10.1103/PhysRevD.75.111102. arXiv:hep-ex/0703038
873. R. Ammar et al., CLEO collaboration. Phys. Rev. Lett. **87**, 271801 (2001). https://doi.org/10.1103/PhysRevLett.87.271801. arXiv:hep-ex/0106038
874. P. Goldenzweig et al., Belle collaboration. Phys. Rev. Lett. **101**, 231801 (2008). https://doi.org/10.1103/PhysRevLett.101.231801. arXiv:0807.4271 [hep-ex]
875. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **83**, 112010 (2011). https://doi.org/10.1103/PhysRevD.83.112010. arXiv:1105.0125 [hep-ex]
876. P. Chang et al., Belle collaboration. Phys. Lett. B **599**, 148 (2004). https://doi.org/10.1016/j.physletb.2004.07.063. arXiv:hep-ex/0406075
877. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 052005 (2008). https://doi.org/10.1103/PhysRevD.78.052005. arXiv:0711.4417 [hep-ex]
878. A. Garmash et al., Belle collaboration. Phys. Rev. D **75**, 012006 (2007). https://doi.org/10.1103/PhysRevD.75.012006. arXiv:hep-ex/0610081
879. R. Aaij et al., LHCb collaboration. JHEP **10**, 143 (2013). https://doi.org/10.1007/JHEP10(2013)143. arXiv:1307.7648 [hep-ex]
880. S.H. Kyeong et al., Belle collaboration. Phys. Rev. D **80**, 051103 (2009). https://doi.org/10.1103/PhysRevD.80.051103. arXiv:0905.0763 [hep-ex]
881. B. Aubert et al., BaBar collaboration. Phys. Rev. D **76**, 071104 (2007). https://doi.org/10.1103/PhysRevD.76.071104. arXiv:0708.2543 [hep-ex]
882. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **85**, 072005 (2012). https://doi.org/10.1103/PhysRevD.85.072005. arXiv:1112.3896 [hep-ex]
883. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **108**, 211803 (2012). https://doi.org/10.1103/PhysRevLett.108.211803. arXiv:1111.0485 [hep-ex]
884. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **118**, 081801 (2017). https://doi.org/10.1103/PhysRevLett.118.081801. arXiv:1610.08288 [hep-ex]
885. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **82**, 031101 (2010). https://doi.org/10.1103/PhysRevD.82.031101. arXiv:1003.0640 [hep-ex]
886. B. Aubert et al. (BaBar collaboration), Phys. Rev. D **74**, 072008 (2006). https://doi.org/10.1103/PhysRevD.74.072008. arXiv:hep-ex/0606050 [hep-ex]
887. R. Aaij et al., LHCb collaboration. JHEP **01**, 012 (2016). https://doi.org/10.1007/JHEP01(2016)012. arXiv:1506.08634 [hep-ex]
888. R. Aaij et al., LHCb collaboration. New J. Phys. **16**, 123001 (2014). https://doi.org/10.1088/1367-2630/16/12/123001. arXiv:1407.7704 [hep-ex]
889. V. Gaur et al., Belle collaboration. Phys. Rev. D **87**, 091101 (2013). https://doi.org/10.1103/PhysRevD.87.091101. arXiv:1304.5312 [hep-ex]
890. B. Aubert et al., BaBar collaboration. Phys. Rev. D **80**, 011101 (2009). https://doi.org/10.1103/PhysRevD.80.011101. arXiv:0905.0868 [hep-ex]
891. B. Aubert et al., BaBar collaboration. Phys. Rev. D **74**, 032005 (2006). https://doi.org/10.1103/PhysRevD.74.032005. arXiv:hep-ex/0606031
892. M. Prim et al., Belle collaboration. Phys. Rev. D **88**, 072004 (2013). https://doi.org/10.1103/PhysRevD.88.072004. arXiv:1308.1830 [hep-ex]
893. C.C. Chiang et al., Belle collaboration. Phys. Rev. D **81**, 071101 (2010). https://doi.org/10.1103/PhysRevD.81.071101. arXiv:1001.4595 [hep-ex]
894. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 081801 (2008). https://doi.org/10.1103/PhysRevLett.100.081801. arXiv:0708.2248 [hep-ex]
895. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 051103 (2008). https://doi.org/10.1103/PhysRevD.78.051103. arXiv:0806.4467 [hep-ex]
896. B. Aubert et al., BaBar collaboration. Phys. Rev. D **76**, 051103 (2007). https://doi.org/10.1103/PhysRevD.76.051103. arXiv:0705.0398 [hep-ex]
897. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **106**, 181802 (2011). https://doi.org/10.1103/PhysRevLett.106.181802. arXiv:1103.5762 [hep-ex]
898. R. Aaij et al., LHCb collaboration. JHEP **10**, 037 (2012). https://doi.org/10.1007/JHEP10(2012)037. arXiv:1206.2794 [hep-ex]
899. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **94**, 181803 (2005). https://doi.org/10.1103/PhysRevLett.94.181803. arXiv:hep-ex/0408101
900. B. Pal et al., Belle collaboration. Phys. Rev. D **92**, 011101 (2015). https://doi.org/10.1103/PhysRevD.92.011101. arXiv:1504.00957 [hep-ex]

901. A. Abdesselam et al. (Belle collaboration) (2016). arXiv:1609.03267 [hep-ex]
902. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **89**, 051101 (2014). https://doi.org/10.1103/PhysRevD.89.051101. arXiv:1312.0056 [hep-ex]
903. R. Aaij et al., LHCb collaboration. JHEP **10**, 053 (2015). https://doi.org/10.1007/JHEP10(2015)053. arXiv:1508.00788 [hep-ex]
904. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **93**, 051802 (2004). https://doi.org/10.1103/PhysRevLett.93.051802. arXiv:hep-ex/0311049
905. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **97**, 051802 (2006). https://doi.org/10.1103/PhysRevLett.97.051802. arXiv:hep-ex/0603050
906. A. Somov et al., Belle collaboration. Phys. Rev. Lett. **96**, 171801 (2006). https://doi.org/10.1103/PhysRevLett.96.171801. arXiv:hep-ex/0601024
907. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 031104 (2006). https://doi.org/10.1103/PhysRevD.74.031104. arXiv:hep-ex/0605024
908. B. Aubert et al., BABAR collaboration. Phys. Rev. D **80**, 092007 (2009). https://doi.org/10.1103/PhysRevD.80.092007. arXiv:0907.1776 [hep-ex]
909. R. Aaij et al., LHCb collaboration. Phys. Rev. D **95**, 012006 (2017). https://doi.org/10.1103/PhysRevD.95.012006. arXiv:1610.05187 [hep-ex]
910. J.T. Wei et al., Belle collaboration. Phys. Lett. B **659**, 80 (2008). https://doi.org/10.1016/j.physletb.2007.11.063. arXiv:0706.4167 [hep-ex]
911. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **113**, 141801 (2014). https://doi.org/10.1103/PhysRevLett.113.141801. arXiv:1407.5907 [hep-ex]
912. M.Z. Wang et al., Belle collaboration. Phys. Lett. B **617**, 141 (2005). https://doi.org/10.1016/j.physletb.2005.05.008. arXiv:hep-ex/0503047
913. J.H. Chen et al., Belle collaboration. Phys. Rev. Lett. **100**, 251801 (2008). https://doi.org/10.1103/PhysRevLett.100.251801. arXiv:0802.0336 [hep-ex]
914. Y.T. Tsai et al., Belle collaboration. Phys. Rev. D **75**, 111101 (2007). https://doi.org/10.1103/PhysRevD.75.111101. arXiv:hep-ex/0703048
915. M.Z. Wang et al., Belle collaboration. Phys. Rev. D **76**, 052004 (2007). https://doi.org/10.1103/PhysRevD.76.052004. arXiv:0704.2672 [hep-ex]
916. P. Chen et al., Belle collaboration. Phys. Rev. D **80**, 111103 (2009). https://doi.org/10.1103/PhysRevD.80.111103. arXiv:0910.5817 [hep-ex]
917. B. Aubert et al., BABAR collaboration. Phys. Rev. D **69**, 091503 (2004). https://doi.org/10.1103/PhysRevD.69.091503. arXiv:hep-ex/0403003
918. R. Aaij et al., LHCb collaboration. JHEP **10**, 005 (2013). https://doi.org/10.1007/JHEP10(2013)005. arXiv:1308.0961 [hep-ex]
919. B. Aubert et al., BABAR collaboration. Phys. Rev. D **79**, 112009 (2009). https://doi.org/10.1103/PhysRevD.79.112009. arXiv:0904.4724 [hep-ex]
920. M.Z. Wang et al., Belle collaboration. Phys. Rev. Lett. **90**, 201802 (2003). https://doi.org/10.1103/PhysRevLett.90.201802. arXiv:hep-ex/0302024
921. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **103**, 031801 (2009). https://doi.org/10.1103/PhysRevLett.103.031801. arXiv:0812.4271 [hep-ex]
922. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **107**, 201802 (2011). https://doi.org/10.1103/PhysRevLett.107.201802. arXiv:1107.3753 [hep-ex]
923. R. Aaij et al., LHCb collaboration. Phys. Lett. B **725**, 25 (2013). https://doi.org/10.1016/j.physletb.2013.06.060. arXiv:1306.2577 [hep-ex]
924. R. Aaij et al., LHCb collaboration. JHEP **09**, 006 (2015). https://doi.org/10.1007/JHEP09(2015)006. arXiv:1505.03295 [hep-ex]
925. R. Aaij et al., LHCb collaboration. Phys. Lett. B **759**, 282 (2016). https://doi.org/10.1016/j.physletb.2016.05.077. arXiv:1603.02870 [hep-ex]
926. R. Aaij et al., LHCb collaboration. JHEP **04**, 087 (2014). https://doi.org/10.1007/JHEP04(2014)087. arXiv:1402.0770 [hep-ex]
927. R. Aaij et al., LHCb collaboration. JHEP **05**, 081 (2016). https://doi.org/10.1007/JHEP05(2016)081. arXiv:1603.00413 [hep-ex]
928. R. Aaij et al., LHCb collaboration. JHEP **06**, 115 (2015). https://doi.org/10.1007/JHEP06(2015)115. arXiv:1503.07138 [hep-ex]
929. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **114**, 062004 (2015). https://doi.org/10.1103/PhysRevLett.114.062004. arXiv:1411.4849 [hep-ex]
930. R. Aaij et al., LHCb collaboration. JHEP **05**, 161 (2016). https://doi.org/10.1007/JHEP05(2016)161. arXiv:1604.03896 [hep-ex]
931. C.C. Peng et al., Belle collaboration. Phys. Rev. D **82**, 072007 (2010). https://doi.org/10.1103/PhysRevD.82.072007. arXiv:1006.5115 [hep-ex]
932. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **107**, 261802 (2011). https://doi.org/10.1103/PhysRevLett.107.261802. arXiv:1107.4999 [hep-ex]
933. R. Aaij et al., LHCb collaboration. Phys. Lett. B **743**, 46 (2015). https://doi.org/10.1016/j.physletb.2015.02.010. arXiv:1412.6433 [hep-ex]
934. B. Pal et al., Belle collaboration. Phys. Rev. Lett. **116**, 161801 (2016). https://doi.org/10.1103/PhysRevLett.116.161801. arXiv:1512.02145 [hep-ex]
935. R. Aaij et al., LHCb collaboration. JHEP **07**, 166 (2015). https://doi.org/10.1007/JHEP07(2015)166. arXiv:1503.05362 [hep-ex]
936. R. Aaij et al., LHCb collaboration. JHEP **11**, 092 (2013). https://doi.org/10.1007/JHEP11(2013)092. arXiv:1306.2239 [hep-ex]
937. D. Dutta et al., Belle collaboration. Phys. Rev. D **91**, 011101 (2015). https://doi.org/10.1103/PhysRevD.91.011101. arXiv:1411.7771 [hep-ex]
938. R. Aaij et al., LHCb collaboration. Nucl. Phys. B **867**, 1 (2013). https://doi.org/10.1016/j.nuclphysb.2012.09.013. arXiv:1209.0313 [hep-ex]
939. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **87**, 072003 (2013). https://doi.org/10.1103/PhysRevD.87.072003. arXiv:1301.7048 [hep-ex]
940. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **87**, 072006 (2013). https://doi.org/10.1103/PhysRevD.87.072006. arXiv:1301.4507 [hep-ex]
941. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **111**, 101805 (2013). https://doi.org/10.1103/PhysRevLett.111.101805. arXiv:1307.5024 [hep-ex]
942. S. Chatrchyan et al., CMS collaboration. Phys. Rev. Lett. **111**, 101804 (2013). https://doi.org/10.1103/PhysRevLett.111.101804. arXiv:1307.5025 [hep-ex]
943. M. Aaboud et al., ATLAS collaboration. Eur. Phys. J. C **76**, 513 (2016). https://doi.org/10.1140/epjc/s10052-016-4338-8. arXiv:1604.04263 [hep-ex]
944. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **102**, 201801 (2009). https://doi.org/10.1103/PhysRevLett.102.201801. arXiv:0901.3803 [hep-ex]
945. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **111**, 141801 (2013). https://doi.org/10.1103/PhysRevLett.111.141801. arXiv:1307.4889 [hep-ex]
946. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **110**, 211801 (2013). https://doi.org/10.1103/PhysRevLett.110.211801. arXiv:1303.1092 [hep-ex]
947. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **74**, 031107 (2006). https://doi.org/10.1103/PhysRevD.74.031107. arXiv:hep-ex/0604015

948. R. Aaij et al., LHCb collaboration. JHEP **09**, 179 (2015). https://doi.org/10.1007/JHEP09(2015)179. arXiv:1506.08777 [hep-ex]
949. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **115**, 051801 (2015). https://doi.org/10.1103/PhysRevLett.115.051801. arXiv:1503.07483 [hep-ex]
950. V. Khachatryan et al., CMS and LHCb collaborations. Nature **522**, 68 (2015). https://doi.org/10.1038/nature14474. arXiv:1411.4413 [hep-ex]
951. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **103**, 211802 (2009). https://doi.org/10.1103/PhysRevLett.103.211802. arXiv:0906.2177 [hep-ex]
952. M. Nakao et al., Belle collaboration. Phys. Rev. D **69**, 112001 (2004). https://doi.org/10.1103/PhysRevD.69.112001. arXiv:hep-ex/0402042
953. T.E. Coan et al., CLEO collaboration. Phys. Rev. Lett. **84**, 5283 (2000). https://doi.org/10.1103/PhysRevLett.84.5283. arXiv:hep-ex/9912057
954. H. Yang et al., Belle collaboration. Phys. Rev. Lett. **94**, 111802 (2005). https://doi.org/10.1103/PhysRevLett.94.111802. arXiv:hep-ex/0412039
955. S. Nishida et al., Belle collaboration. Phys. Lett. B **610**, 23 (2005). https://doi.org/10.1016/j.physletb.2005.01.097. arXiv:hep-ex/0411065
956. B. Aubert et al., BABAR collaboration. Phys. Rev. D **74**, 031102 (2006). https://doi.org/10.1103/PhysRevD.74.031102. arXiv:hep-ex/0603054
957. R. Wedd et al., Belle collaboration. Phys. Rev. D **81**, 111104 (2010). https://doi.org/10.1103/PhysRevD.81.111104. arXiv:0810.0804 [hep-ex]
958. B. Aubert et al., BABAR collaboration. Phys. Rev. D **75**, 051102 (2007). https://doi.org/10.1103/PhysRevD.75.051102. arXiv:hep-ex/0611037
959. S. Nishida et al., Belle collaboration. Phys. Rev. Lett. **89**, 231801 (2002). https://doi.org/10.1103/PhysRevLett.89.231801. arXiv:hep-ex/0205025
960. B. Aubert et al. (BABAR collaboration), Phys. Rev. Lett. **98**, 211804 (2007). https://doi.org/10.1103/PhysRevLett.100.189903. arXiv:hep-ex/0507031. [Erratum ibid. **100**, 199905 (2008). doi:10.1103/PhysRevLett.100.199905]
961. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 112001 (2008). https://doi.org/10.1103/PhysRevD.78.112001. arXiv:0808.1379 [hep-ex]
962. N. Taniguchi et al. (Belle collaboration), Phys. Rev. Lett. **101**, 111801 (2008). https://doi.org/10.1103/PhysRevLett.101.111801. arXiv:0804.4770 [hep-ex]. [Erratum ibid. **101**, 129904 (2008). doi:10.1103/PhysRevLett.101.129904]
963. Y.J. Lee et al., Belle collaboration. Phys. Rev. Lett. **95**, 061802 (2005). https://doi.org/10.1103/PhysRevLett.95.061802. arXiv:hep-ex/0503046
964. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **88**, 032012 (2013). https://doi.org/10.1103/PhysRevD.88.032012. arXiv:1303.6010 [hep-ex]
965. J.T. Wei et al., Belle collaboration. Phys. Rev. D **78**, 011101 (2008). https://doi.org/10.1103/PhysRevD.78.011101. arXiv:0804.3656 [hep-ex]
966. R. Aaij et al., LHCb collaboration. JHEP **10**, 034 (2015). https://doi.org/10.1007/JHEP10(2015)034. arXiv:1509.00414 [hep-ex]
967. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **94**, 101801 (2005). https://doi.org/10.1103/PhysRevLett.94.101801. arXiv:hep-ex/0411061
968. O. Lutz et al., Belle collaboration. Phys. Rev. D **87**, 111103 (2013). https://doi.org/10.1103/PhysRevD.87.111103. arXiv:1303.3719 [hep-ex]
969. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **102**, 091803 (2009). https://doi.org/10.1103/PhysRevLett.102.091803. arXiv:0807.4119 [hep-ex]
970. J.T. Wei et al., Belle collaboration. Phys. Rev. Lett. **103**, 171801 (2009). https://doi.org/10.1103/PhysRevLett.103.171801. arXiv:0904.0770 [hep-ex]
971. R. Aaij et al., LHCb collaboration. JHEP **02**, 105 (2013). https://doi.org/10.1007/JHEP02(2013)105. arXiv:1209.4284 [hep-ex]
972. J.P. Lees et al., BABAR collaboration. Phys. Rev. Lett. **118**, 031802 (2017). https://doi.org/10.1103/PhysRevLett.118.031802. arXiv:1605.09637 [hep-ex]
973. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **87**, 112005 (2013). https://doi.org/10.1103/PhysRevD.87.112005. arXiv:1303.7465 [hep-ex]
974. R. Aaij et al., LHCb collaboration. JHEP **06**, 133 (2014). https://doi.org/10.1007/JHEP06(2014)133. arXiv:1403.8044 [hep-ex]
975. R. Aaij et al., LHCb collaboration. JHEP **10**, 064 (2014). https://doi.org/10.1007/JHEP10(2014)064. arXiv:1408.1137 [hep-ex]
976. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **99**, 051801 (2007). https://doi.org/10.1103/PhysRevLett.99.051801. arXiv:hep-ex/0703018
977. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **86**, 012004 (2012). https://doi.org/10.1103/PhysRevD.86.012004. arXiv:1204.2852 [hep-ex]
978. B. Aubert et al., BABAR collaboration. Phys. Rev. D **73**, 092001 (2006). https://doi.org/10.1103/PhysRevD.73.092001. arXiv:hep-ex/0604007
979. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **85**, 071103 (2012). https://doi.org/10.1103/PhysRevD.85.071103. arXiv:1202.3650 [hep-ex]
980. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **112**, 131802 (2014). https://doi.org/10.1103/PhysRevLett.112.131802. arXiv:1401.5361 [hep-ex]
981. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **89**, 011102 (2014). https://doi.org/10.1103/PhysRevD.89.011102. arXiv:1310.8238 [hep-ex]
982. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **108**, 101601 (2012). https://doi.org/10.1103/PhysRevLett.108.101601. arXiv:1110.0730 [hep-ex]
983. B. Aubert et al., BABAR collaboration. Phys. Rev. D **70**, 091105 (2004). https://doi.org/10.1103/PhysRevD.70.091105. arXiv:hep-ex/0409035
984. B. Aubert et al., BABAR collaboration. Phys. Rev. D **72**, 091103 (2005). https://doi.org/10.1103/PhysRevD.72.091103. arXiv:hep-ex/0501038
985. Z. King et al., Belle collaboration. Phys. Rev. D **93**, 111101 (2016). https://doi.org/10.1103/PhysRevD.93.111101. arXiv:1603.06546 [hep-ex]
986. Y.T. Lai et al., Belle collaboration. Phys. Rev. D **89**, 051103 (2014). https://doi.org/10.1103/PhysRevD.89.051103. arXiv:1312.4228 [hep-ex]
987. R. Aaij et al., LHCb collaboration. JHEP **11**, 047 (2016). https://doi.org/10.1007/JHEP11(2016)047. arXiv:1606.04731 [hep-ex]
988. B. Aubert et al., BABAR collaboration. Phys. Rev. D **77**, 051103 (2008). https://doi.org/10.1103/PhysRevD.77.051103. arXiv:0711.4889 [hep-ex]
989. J.P. Lees et al., BABAR collaboration. Phys. Rev. Lett. **109**, 191801 (2012). https://doi.org/10.1103/PhysRevLett.109.191801. arXiv:1207.2690 [hep-ex]
990. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **86**, 052012 (2012). https://doi.org/10.1103/PhysRevD.86.052012. arXiv:1207.2520 [hep-ex]
991. T. Saito et al., Belle collaboration. Phys. Rev. D **91**, 052004 (2015). https://doi.org/10.1103/PhysRevD.91.052004. arXiv:1411.7198 [hep-ex]
992. A. Abdesselam et al. (Belle collaboration) (2016). arXiv:1608.02344 [hep-ex]

993. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **82**, 051101 (2010). https://doi.org/10.1103/PhysRevD.82.051101. arXiv:1005.4087 [hep-ex]
994. J.P. Lees et al., BaBar collaboration. Phys. Rev. Lett. **112**, 211802 (2014). https://doi.org/10.1103/PhysRevLett.112.211802. arXiv:1312.5364 [hep-ex]
995. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **86**, 032012 (2012). https://doi.org/10.1103/PhysRevD.86.032012. arXiv:1204.3933 [hep-ex]
996. K.W. Edwards et al., CLEO collaboration. Phys. Rev. D **65**, 111102 (2002). https://doi.org/10.1103/PhysRevD.65.111102. arXiv:hep-ex/0204017
997. O. Buchmuller, H. Flacher, Phys. Rev. D **73**, 073008 (2006). https://doi.org/10.1103/PhysRevD.73.073008. arXiv:hep-ph/0507253
998. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 091101 (2009). https://doi.org/10.1103/PhysRevD.79.091101. arXiv:0903.1220 [hep-ex]
999. N. Satoyama et al. (Belle collaboration), Phys. Lett. B **647**, 67 (2007). https://doi.org/10.1016/j.physletb.2007.01.068. arXiv:hep-ex/0611045 [hep-ex]
1000. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **88**, 031102 (2013). https://doi.org/10.1103/PhysRevD.88.031102. arXiv:1207.0698 [hep-ex]
1001. B. Kronenbitter et al., Belle collaboration. Phys. Rev. D **92**, 051102 (2015). https://doi.org/10.1103/PhysRevD.92.051102. arXiv:1503.05613 [hep-ex]
1002. B. Aubert et al., BaBar collaboration. Phys. Rev. D **80**, 111105 (2009). https://doi.org/10.1103/PhysRevD.80.111105. arXiv:0907.1681 [hep-ex]
1003. A. Heller et al., Belle collaboration. Phys. Rev. D **91**, 112009 (2015). https://doi.org/10.1103/PhysRevD.91.112009. arXiv:1504.05831 [hep-ex]
1004. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **83**, 032006 (2011). https://doi.org/10.1103/PhysRevD.83.032006. arXiv:1010.2229 [hep-ex]
1005. S. Villa et al., Belle collaboration. Phys. Rev. D **73**, 051107 (2006). https://doi.org/10.1103/PhysRevD.73.051107. arXiv:hep-ex/0507036
1006. B. Aubert et al., BaBar collaboration. Phys. Rev. D **77**, 032007 (2008). https://doi.org/10.1103/PhysRevD.77.032007. arXiv:0712.1516 [hep-ex]
1007. M.C. Chang et al., Belle collaboration. Phys. Rev. D **68**, 111101 (2003). https://doi.org/10.1103/PhysRevD.68.111101. arXiv:hep-ex/0309069
1008. B. Aubert et al., BaBar collaboration. Phys. Rev. D **77**, 011104 (2008). https://doi.org/10.1103/PhysRevD.77.011104. arXiv:0706.2870 [hep-ex]
1009. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **96**, 241802 (2006). https://doi.org/10.1103/PhysRevLett.96.241802. arXiv:hep-ex/0511015
1010. B. Aubert et al., BaBar collaboration. Phys. Rev. D **77**, 091104 (2008). https://doi.org/10.1103/PhysRevD.77.091104. arXiv:0801.0697 [hep-ex]
1011. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **86**, 051105 (2012). https://doi.org/10.1103/PhysRevD.86.051105. arXiv:1206.2543 [hep-ex]
1012. C.L. Hsu et al., Belle collaboration. Phys. Rev. D **86**, 032002 (2012). https://doi.org/10.1103/PhysRevD.86.032002. arXiv:1206.5948 [hep-ex]
1013. Y. Yook et al., Belle collaboration. Phys. Rev. D **91**, 052016 (2015). https://doi.org/10.1103/PhysRevD.91.052016. arXiv:1406.6356 [hep-ex]
1014. B. Aubert et al., BaBar collaboration. Phys. Rev. D **81**, 051101 (2010). https://doi.org/10.1103/PhysRevD.81.051101. arXiv:0912.2453 [hep-ex]
1015. I. Adachi et al., Belle collaboration. Phys. Rev. Lett. **110**, 131801 (2013). https://doi.org/10.1103/PhysRevLett.110.131801. arXiv:1208.4678 [hep-ex]
1016. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **113**, 151601 (2014). https://doi.org/10.1103/PhysRevLett.113.151601. arXiv:1406.6482 [hep-ex]
1017. K. Nishimura et al., Belle collaboration. Phys. Rev. Lett. **105**, 191803 (2010). https://doi.org/10.1103/PhysRevLett.105.191803. arXiv:0910.4751 [hep-ex]
1018. T.E. Browder et al., CLEO collaboration. Phys. Rev. Lett. **81**, 1786 (1998). https://doi.org/10.1103/PhysRevLett.81.1786. arXiv:hep-ex/9804018
1019. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **93**, 061801 (2004). https://doi.org/10.1103/PhysRevLett.93.061801. arXiv:hep-ex/0401006
1020. G. Bonvicini et al., CLEO collaboration. Phys. Rev. D **68**, 011101 (2003). https://doi.org/10.1103/PhysRevD.68.011101. arXiv:hep-ex/0303009
1021. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **83**, 031103 (2011). https://doi.org/10.1103/PhysRevD.83.031103. arXiv:1012.5031 [hep-ex]
1022. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **112**, 161801 (2014). https://doi.org/10.1103/PhysRevLett.112.161801. arXiv:1402.6852 [hep-ex]
1023. R. Aaij et al., LHCb collaboration. JHEP **05**, 159 (2013). https://doi.org/10.1007/JHEP05(2013)159. arXiv:1304.3035 [hep-ex]
1024. R. Aaij et al., LHCb collaboration. JHEP **05**, 082 (2014). https://doi.org/10.1007/JHEP05(2014)082. arXiv:1403.8045 [hep-ex]
1025. A. Abdesselam et al. (Belle collaboration) (2016). arXiv:1604.04042 [hep-ex]
1026. R. Aaij et al., LHCb collaboration. JHEP **04**, 064 (2015). https://doi.org/10.1007/JHEP04(2015)064. arXiv:1501.03038 [hep-ex]
1027. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **93**, 052015 (2016). https://doi.org/10.1103/PhysRevD.93.052015. arXiv:1508.07960 [hep-ex]
1028. R. Aaij et al., LHCb collaboration. JHEP **02**, 104 (2016). https://doi.org/10.1007/JHEP02(2016)104. arXiv:1512.04442 [hep-ex]
1029. V. Khachatryan et al., CMS collaboration. Phys. Lett. B **753**, 424 (2016). https://doi.org/10.1016/j.physletb.2015.12.020. arXiv:1507.08126 [hep-ex]
1030. Y. Sato et al. (Belle collaboration), Phys. Rev. D **93**, 032008 (2016). https://doi.org/10.1103/PhysRevD.93.032008. arXiv:1402.7134 [hep-ex]. Addendum ibid. **93**, 059901 (2016). doi:10.1103/PhysRevD.93.059901
1031. R. Aaij et al., LHCb collaboration. JHEP **12**, 065 (2016). https://doi.org/10.1007/JHEP12(2016)065. arXiv:1609.04736 [hep-ex]
1032. L. Pesántez et al., Belle collaboration. Phys. Rev. Lett. **114**, 151601 (2015). https://doi.org/10.1103/PhysRevLett.114.151601. arXiv:1501.01702 [hep-ex]
1033. R. Aaij et al., LHCb collaboration. Phys. Rev. D **90**, 112004 (2014). https://doi.org/10.1103/PhysRevD.90.112004. arXiv:1408.5373 [hep-ex]
1034. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **97**, 201801 (2006). https://doi.org/10.1103/PhysRevLett.97.201801. arXiv:hep-ex/0607057
1035. K.F. Chen et al., Belle collaboration. Phys. Rev. Lett. **94**, 221804 (2005). https://doi.org/10.1103/PhysRevLett.94.221804. arXiv:hep-ex/0503013
1036. R. Aaij et al., LHCb collaboration. Phys. Rev. D **88**, 052015 (2013). https://doi.org/10.1103/PhysRevD.88.052015. arXiv:1307.6165 [hep-ex]
1037. R. Aaij et al., LHCb collaboration. JHEP **09**, 177 (2014). https://doi.org/10.1007/JHEP09(2014)177. arXiv:1408.0978 [hep-ex]
1038. T.A. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **113**, 242001 (2014). https://doi.org/10.1103/PhysRevLett.113.242001. arXiv:1403.5586 [hep-ex]

1039. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **110**, 221601 (2013). https://doi.org/10.1103/PhysRevLett.110.221601. arXiv:1304.6173 [hep-ex]
1040. R. Aaij et al., LHCb collaboration. JHEP **05**, 069 (2014). https://doi.org/10.1007/JHEP05(2014)069. arXiv:1403.2888 [hep-ex]
1041. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **90**, 092001 (2014). https://doi.org/10.1103/PhysRevD.90.092001. arXiv:1406.0534 [hep-ex]
1042. S. Nishida et al., Belle collaboration. Phys. Rev. Lett. **93**, 031803 (2004). https://doi.org/10.1103/PhysRevLett.93.031803. arXiv:hep-ex/0308038
1043. T.E. Coan et al., CLEO collaboration. Phys. Rev. Lett. **86**, 5661 (2001). https://doi.org/10.1103/PhysRevLett.86.5661. arXiv:hep-ex/0010075
1044. R. Aaij et al., LHCb collaboration. Nat. Phys. **13**, 391 (2017). https://doi.org/10.1038/nphys4021. arXiv:1609.05216 [hep-ex]
1045. J. Zhang et al., Belle collaboration. Phys. Rev. Lett. **95**, 141801 (2005). https://doi.org/10.1103/PhysRevLett.95.141801. arXiv:hep-ex/0408102
1046. R. Aaij et al., LHCb collaboration. Phys. Lett. B **713**, 369 (2012). https://doi.org/10.1016/j.physletb.2012.06.012. arXiv:1204.2813 [hep-ex]
1047. R. Aaij et al., LHCb collaboration. Phys. Lett. B **759**, 313 (2016). https://doi.org/10.1016/j.physletb.2016.05.074. arXiv:1603.07037 [hep-ex]
1048. M. Staric et al., Belle collaboration. Phys. Rev. Lett. **98**, 211803 (2007). https://doi.org/10.1103/PhysRevLett.98.211803. arXiv:hep-ex/0703036
1049. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **98**, 211802 (2007). https://doi.org/10.1103/PhysRevLett.98.211802. arXiv:hep-ex/0703020
1050. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **100**, 121802 (2008). https://doi.org/10.1103/PhysRevLett.100.121802. arXiv:0712.1567 [hep-ex]
1051. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **111**, 251801 (2013). https://doi.org/10.1103/PhysRevLett.111.251801. arXiv:1309.6534 [hep-ex]
1052. S. Bergmann, Y. Grossman, Z. Ligeti, Y. Nir, A.A. Petrov, Phys. Lett. B **486**, 418 (2000). https://doi.org/10.1016/S0370-2693(00)00772-3. arXiv:hep-ph/0005181
1053. I.I.Y. Bigi, N.G. Uraltsev, Nucl. Phys. B **592**, 92 (2001). https://doi.org/10.1016/S0550-3213(00)00604-0. arXiv:hep-ph/0005089
1054. A.A. Petrov (2003). arXiv:hep-ph/0311371
1055. A.A. Petrov, Nucl. Phys. Proc. Suppl. **142**, 333 (2005). https://doi.org/10.1016/j.nuclphysbps.2005.01.057. arXiv:hep-ph/0409130
1056. A.F. Falk, Y. Grossman, Z. Ligeti, Y. Nir, A.A. Petrov, Phys. Rev. D **69**, 114021 (2004). https://doi.org/10.1103/PhysRevD.69.114021. arXiv:hep-ph/0402204
1057. D. Asner et al., CLEO collaboration. Phys. Rev. D **86**, 112001 (2012). https://doi.org/10.1103/PhysRevD.86.112001. arXiv:1210.0939 [hep-ex]
1058. R. Aaij et al., LHCb collaboration. JHEP **07**, 041 (2014). https://doi.org/10.1007/JHEP07(2014)041. arXiv:1405.2797 [hep-ex]
1059. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **103**, 211801 (2009). https://doi.org/10.1103/PhysRevLett.103.211801. arXiv:0807.4544 [hep-ex]
1060. Heavy Flavor Averaging Group: charm physics parameters. http://www.slac.stanford.edu/xorg/hflav/charm/index.html
1061. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **116**, 241801 (2016). https://doi.org/10.1103/PhysRevLett.116.241801. arXiv:1602.07224 [hep-ex]
1062. E.M. Aitala et al., Fermilab E791 collaboration. Phys. Rev. Lett. **77**, 2384 (1996). https://doi.org/10.1103/PhysRevLett.77.2384. arXiv:hep-ex/9606016
1063. C. Cawlfield et al. (CLEO collaboration), Phys. Rev. D **71**, 077101 (2005). https://doi.org/10.1103/PhysRevD.71.077101. arXiv:hep-ex/0502012
1064. B. Aubert et al., BaBar collaboration. Phys. Rev. D **76**, 014018 (2007). https://doi.org/10.1103/PhysRevD.76.014018. arXiv:0705.0704 [hep-ex]
1065. U. Bitenc et al., Belle collaboration. Phys. Rev. D **77**, 112003 (2008). https://doi.org/10.1103/PhysRevD.77.112003. arXiv:0802.2952 [hep-ex]
1066. L.M. Zhang et al., Belle collaboration. Phys. Rev. Lett. **96**, 151801 (2006). https://doi.org/10.1103/PhysRevLett.96.151801. arXiv:hep-ex/0601029
1067. B.R. Ko et al., Belle collaboration. Phys. Rev. Lett. **112**, 111801 (2014). https://doi.org/10.1103/PhysRevLett.112.111801. arXiv:1401.3402 [hep-ex]
1068. T.A. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **111**, 231802 (2013). https://doi.org/10.1103/PhysRevLett.111.231802. arXiv:1309.4078 [hep-ex]
1069. R. Aaij et al., LHCb collaboration. Phys. Rev. D **95**, 052004 (2017). https://doi.org/10.1103/PhysRevD.95.052004. arXiv:1611.06143 [hep-ex]
1070. T. Peng et al., Belle collaboration. Phys. Rev. D **89**, 091103 (2014). https://doi.org/10.1103/PhysRevD.89.091103. arXiv:1404.2412 [hep-ex]
1071. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. Lett. **105**, 081803 (2010). https://doi.org/10.1103/PhysRevLett.105.081803. arXiv:1004.5053 [hep-ex]
1072. R. Aaij et al., LHCb collaboration. JHEP **04**, 033 (2016). https://doi.org/10.1007/JHEP04(2016)033. arXiv:1510.01664 [hep-ex]
1073. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **93**, 112014 (2016). https://doi.org/10.1103/PhysRevD.93.112014. arXiv:1604.00857 [hep-ex]
1074. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 061803 (2008). https://doi.org/10.1103/PhysRevLett.100.061803. arXiv:0709.2715 [hep-ex]
1075. B.R. Ko, (Belle collaboration) (2012). arXiv:1212.5320 [hep-ex]
1076. CDF collaboration, CDF note 10784 (2012). http://www-cdf.fnal.gov/physics/new/bottom/120216.blessed-CPVcharm10fb/
1077. T. Aaltonen et al., CDF collaboration. Phys. Rev. Lett. **109**, 111801 (2012). https://doi.org/10.1103/PhysRevLett.109.111801. arXiv:1207.2158 [hep-ex]
1078. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **116**, 191601 (2016). https://doi.org/10.1103/PhysRevLett.116.191601. arXiv:1602.03160 [hep-ex]
1079. E.M. Aitala et al., Fermilab E791 collaboration. Phys. Rev. Lett. **83**, 32 (1999). https://doi.org/10.1103/PhysRevLett.83.32. arXiv:hep-ex/9903012
1080. J.M. Link et al., FOCUS collaboration. Phys. Lett. B **485**, 62 (2000). https://doi.org/10.1016/S0370-2693(00)00694-8. arXiv:hep-ex/0004034
1081. S.E. Csorna et al., CLEO collaboration. Phys. Rev. D **65**, 092001 (2002). https://doi.org/10.1103/PhysRevD.65.092001. arXiv:hep-ex/0111024
1082. A. Zupanc et al., Belle collaboration. Phys. Rev. D **80**, 052006 (2009). https://doi.org/10.1103/PhysRevD.80.052006. arXiv:0905.4185 [hep-ex]
1083. R. Aaij et al., LHCb collaboration. JHEP **04**, 129 (2012). https://doi.org/10.1007/JHEP04(2012)129. arXiv:1112.4698 [hep-ex]
1084. M. Staric et al., Belle collaboration. Phys. Lett. B **753**, 412–418 (2016). https://doi.org/10.1016/j.physletb.2015.12.025. arXiv:1509.08266 [hep-ex]
1085. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **87**, 012004 (2013). https://doi.org/10.1103/PhysRevD.87.012004. arXiv:1209.3896 [hep-ex]

1086. M. Ablikim et al., BESIII collaboration. Phys. Lett. B **744**, 339 (2015). https://doi.org/10.1016/j.physletb.2015.04.008. arXiv:1501.01378 [hep-ex]
1087. T.A. Aaltonen et al., CDF collaboration. Phys. Rev. D **90**, 111103 (2014). https://doi.org/10.1103/PhysRevD.90.111103. arXiv:1410.5435 [hep-ex]
1088. R. Aaij et al., LHCb collaboration. JHEP **04**, 043 (2015). https://doi.org/10.1007/JHEP04(2015)043. arXiv:1501.06777 [hep-ex]
1089. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **118**, 261803 (2017). arXiv:1702.06490 [hep-ex]
1090. F. James, MINUIT–Function Minimization and Error Analysis, Reference Manual Version 94.1, CERN Program Library Long Writeup D506. http://wwwasdoc.web.cern.ch/wwwasdoc/minuit/minmain.html
1091. Y. Grossman, Y. Nir, G. Perez, Phys. Rev. Lett. **103**, 071602 (2009). https://doi.org/10.1103/PhysRevLett.103.071602. arXiv:0904.0305 [hep-ph]
1092. A.L. Kagan, M.D. Sokoloff, Phys. Rev. D **80**, 076008 (2009). https://doi.org/10.1103/PhysRevD.80.076008. arXiv:0907.3917 [hep-ph]
1093. M. Ciuchini et al., Phys. Lett. B **655**, 162 (2007). https://doi.org/10.1016/j.physletb.2007.08.055. arXiv:hep-ph/0703204
1094. Computing and Networks Division, CERNLIB Short Writeups. https://root.cern.ch/sites/d35c7d8c.web.cern.ch/files/cernlib.pdf
1095. I.I.Y. Bigi, A.I. Sanda, Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. **9**, 1 (2000)
1096. Y. Nir (1999). arXiv:hep-ph/9911321
1097. F. Buccella, M. Lusignoli, G. Miele, A. Pugliese, P. Santorelli, Phys. Rev. D **51**, 3478 (1995). https://doi.org/10.1103/PhysRevD.51.3478. arXiv:hep-ph/9411286
1098. Y. Grossman, Y. Nir, JHEP **04**, 002 (2012). https://doi.org/10.1007/JHEP04(2012)002. arXiv:1110.3790 [hep-ph]
1099. I. Bediaga, I.I. Bigi, A. Gomes, G. Guerrer, J. Miranda, A.C.D. Reis, Phys. Rev. D **80**, 096006 (2009). https://doi.org/10.1103/PhysRevD.80.096006. arXiv:0905.4233 [hep-ph]
1100. B. Aslan, G. Zech, J. Stat. Comput. Simul. **75**, 109 (2005). https://doi.org/10.1080/00949650410001661440
1101. J.M. Link et al., FOCUS collaboration. Phys. Lett. B **634**, 165 (2006). https://doi.org/10.1016/j.physletb.2006.01.017. arXiv:hep-ex/0509042
1102. J.W. Hinson et al., CLEO collaboration. Phys. Rev. Lett. **94**, 191801 (2005). https://doi.org/10.1103/PhysRevLett.94.191801. arXiv:hep-ex/0501002
1103. B.I. Eisenstein et al., CLEO collaboration. Phys. Rev. D **78**, 052003 (2008). https://doi.org/10.1103/PhysRevD.78.052003. arXiv:0806.2112 [hep-ex]
1104. H. Mendez et al., CLEO collaboration. Phys. Rev. D **81**, 052013 (2010). https://doi.org/10.1103/PhysRevD.81.052013. arXiv:0906.3198 [hep-ex]
1105. E. Won et al., Belle collaboration. Phys. Rev. Lett. **107**, 221801 (2011). https://doi.org/10.1103/PhysRevLett.107221801. arXiv:1107.0553 [hep-ex]
1106. G. Bonvicini et al., CLEO collaboration. Phys. Rev. D **89**, 072002 (2014). https://doi.org/10.1103/PhysRevD.89.072002. arXiv:1312.6775 [hep-ex]
1107. B.R. Ko et al., Belle collaboration. Phys. Rev. Lett. **109**, 021601 (2012). https://doi.org/10.1103/PhysRevLett.109.021601. arXiv:1203.6409 [hep-ex]
1108. P. del Amo Sanchez et al., BABAR collaboration. Phys. Rev. D **83**, 071103 (2011). https://doi.org/10.1103/PhysRevD.83.071103. arXiv:1011.5477 [hep-ex]
1109. J.M. Link et al. (FOCUS collaboration), Phys. Rev. Lett. **88**, 041602, 159903(E) (2002). https://doi.org/10.1103/PhysRevLett.88.041602. arXiv:hep-ex/0109022
1110. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **87**, 052012 (2013). https://doi.org/10.1103/PhysRevD.87.052012. arXiv:1212.3003 [hep-ex]
1111. B.R. Ko et al., Belle collaboration. JHEP **02**, 098 (2013). https://doi.org/10.1007/JHEP02(2013)098. arXiv:1212.6112 [hep-ex]
1112. R. Aaij et al., LHCb collaboration. JHEP **10**, 25 (2014). https://doi.org/10.1007/JHEP10(2014)025. arXiv:1406.2624 [hep-ex]
1113. R. Aaij et al., LHCb collaboration. Phys. Lett. B **728**, 585 (2014). https://doi.org/10.1016/j.physletb.2013.12.035. arXiv:1310.7953 [hep-ex]
1114. E.M. Aitala et al., Fermilab E791 collaboration. Phys. Lett. B **403**, 377 (1997). https://doi.org/10.1016/S0370-2693(97)00565-0. arXiv:hep-ex/9612005
1115. V.M. Abazov et al., D0 collaboration. Phys. Rev. D **90**, 111102 (2014). https://doi.org/10.1103/PhysRevD.90.111102. arXiv:1408.6848 [hep-ex]
1116. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **87**, 052010 (2013). https://doi.org/10.1103/PhysRevD.87.052010. arXiv:1212.1856 [hep-ex]
1117. P. Rubin et al., CLEO collaboration. Phys. Rev. D **78**, 072003 (2008). https://doi.org/10.1103/PhysRevD.78.072003. arXiv:0807.4545 [hep-ex]
1118. J.M. Link et al., FOCUS collaboration. Phys. Lett. B **491**, 232 (2000). https://doi.org/10.1016/S0370-2693(00)01039-X. arXiv:hep-ex/0005037
1119. J.M. Link et al., FOCUS collaboration. Phys. Lett. B **622**, 239 (2005). https://doi.org/10.1016/j.physletb.2005.07.024. arXiv:hep-ex/0506012
1120. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **85**, 012009 (2012). https://doi.org/10.1103/PhysRevD.85.012009. arXiv:1111.5023 [hep-ex]
1121. M. Staric et al., Belle collaboration. Phys. Lett. B **670**, 190 (2008). https://doi.org/10.1016/j.physletb.2008.10.052. arXiv:0807.0148 [hep-ex]
1122. E.M. Aitala et al., Fermilab E791 collaboration. Phys. Lett. B **421**, 405 (1998). https://doi.org/10.1016/S0370-2693(97)01570-0. arXiv:hep-ex/9711003
1123. N.K. Nisar et al., Belle collaboration. Phys. Rev. Lett. **112**, 211601 (2014). https://doi.org/10.1103/PhysRevLett.112.211601. arXiv:1404.1266 [hep-ex]
1124. G. Bonvicini et al., CLEO collaboration. Phys. Rev. D **63**, 071101 (2001). https://doi.org/10.1103/PhysRevD.63.071101. arXiv:hep-ex/0012054
1125. B.R. Ko et al., Belle collaboration. Phys. Rev. Lett. **106**, 211801 (2011). https://doi.org/10.1103/PhysRevLett.106.211801. arXiv:1101.3365 [hep-ex]
1126. R. Aaij et al., LHCb collaboration. JHEP **10**, 055 (2015). https://doi.org/10.1007/JHEP10(2015)055. arXiv:1508.06087 [hep-ex]
1127. R. Aaij et al., LHCb collaboration. Phys. Lett. B **740**, 158 (2015). https://doi.org/10.1016/j.physletb.2014.11.043. arXiv:1410.4170 [hep-ex]
1128. B. Aubert et al., BABAR collaboration. Phys. Rev. D **78**, 051102 (2008). https://doi.org/10.1103/PhysRevD.78.051102. arXiv:0802.4035 [hep-ex]
1129. K. Arinstein, Belle collaboration. Phys. Lett. B **662**, 102 (2008). https://doi.org/10.1016/j.physletb.2008.02.054. arXiv:0801.2439 [hep-ex]
1130. D. Cronin-Hennessy et al., CLEO collaboration. Phys. Rev. D **72**, 031102 (2005). https://doi.org/10.1103/PhysRevD.72.031102. arXiv:hep-ex/0503052
1131. X.C. Tian et al., Belle collaboration. Phys. Rev. Lett. **95**, 231801 (2005). https://doi.org/10.1103/PhysRevLett.95.231801. arXiv:hep-ex/0507071
1132. G. Brandenburg et al., CLEO collaboration. Phys. Rev. Lett. **87**, 071802 (2001). https://doi.org/10.1103/PhysRevLett.87.071802. arXiv:hep-ex/0105002

1133. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **86**, 032007 (2012). https://doi.org/10.1103/PhysRevD.86.032007. arXiv:1207.0825 [hep-ex]
1134. D.M. Asner et al., CLEO collaboration. Phys. Rev. D **70**, 091101 (2004). https://doi.org/10.1103/PhysRevD.70.091101. arXiv:hep-ex/0311033
1135. R. Aaij et al., LHCb collaboration. Phys. Lett. B **726**, 623 (2013). https://doi.org/10.1016/j.physletb.2013.09.011. arXiv:1308.3189 [hep-ex]
1136. M. Artuso et al., CLEO collaboration. Phys. Rev. D **85**, 122002 (2012). https://doi.org/10.1103/PhysRevD.85.122002. arXiv:1201.5716 [hep-ex]
1137. J. Alexander et al., CLEO collaboration. Phys. Rev. D **79**, 052001 (2009). https://doi.org/10.1103/PhysRevD.79.052001. arXiv:0901.1216 [hep-ex]
1138. P. Onyisi et al., CLEO collaboration. Phys. Rev. D **88**, 032009 (2013). https://doi.org/10.1103/PhysRevD.88.032009. arXiv:1306.5363 [hep-ex]
1139. B.R. Ko et al., Belle collaboration. Phys. Rev. Lett. **104**, 181602 (2010). https://doi.org/10.1103/PhysRevLett.104.181602. arXiv:1001.3202 [hep-ex]
1140. E. Golowich, G. Valencia, Phys. Rev. D **40**, 112 (1989). https://doi.org/10.1103/PhysRevD.40.112
1141. I.I.Y. Bigi (2001). arXiv:hep-ph/0107102
1142. W. Bensalem, A. Datta, D. London, Phys. Rev. D **66**, 094004 (2002). https://doi.org/10.1103/PhysRevD.66.094004. arXiv:hep-ph/0208054
1143. W. Bensalem, D. London, Phys. Rev. D **64**, 116003 (2001). https://doi.org/10.1103/PhysRevD.64.116003. arXiv:hep-ph/0005018
1144. W. Bensalem, A. Datta, D. London, Phys. Lett. B **538**, 309 (2002). https://doi.org/10.1016/S0370-2693(02)02028-2. arXiv:hep-ph/0205009
1145. M. Gronau, J.L. Rosner, Phys. Rev. D **84**, 096013 (2011). https://doi.org/10.1103/PhysRevD.84.096013. arXiv:1107.1232 [hep-ph]
1146. A.J. Bevan (2015). arXiv:1506.04246 [hep-ex]
1147. G. Durieux, Y. Grossman, Phys. Rev. D **92**, 076013 (2015). https://doi.org/10.1103/PhysRevD.92.076013. arXiv:1508.03054 [hep-ph]
1148. R. Aaij et al., LHCb collaboration. JHEP **10**, 005 (2014). https://doi.org/10.1007/JHEP10(2014)005. arXiv:1408.1299 [hep-ex]
1149. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **81**, 111103 (2010). https://doi.org/10.1103/PhysRevD.81.111103. arXiv:1003.3397 [hep-ex]
1150. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **84**, 031103 (2011). https://doi.org/10.1103/PhysRevD.84.031103. arXiv:1105.4410 [hep-ex]
1151. Y. Grossman, A.L. Kagan, Y. Nir, Phys. Rev. D **75**, 036008 (2007). https://doi.org/10.1103/PhysRevD.75.036008. arXiv:hep-ph/0609178 [hep-ph]
1152. M. Gersabeck, M. Alexander, S. Borghi, V. Gligorov, C. Parkes, J. Phys. G **39**, 045005 (2012). https://doi.org/10.1088/0954-3899/39/4/045005. arXiv:1111.6515 [hep-ex]
1153. B.R. Ko, (Belle collaboration), PoS **ICHEP2012**, 353 (2013). arXiv:1212.1975
1154. T. Becher, R.J. Hill, Phys. Lett. B **633**, 61 (2006). https://doi.org/10.1016/j.physletb.2005.11.063. arXiv:hep-ph/0509090
1155. F.J. Gilman, R.L. Singleton, Phys. Rev. D **41**, 142 (1990). https://doi.org/10.1103/PhysRevD.41.142
1156. R.J. Hill, eConf **C060409**, 027 (2006). arXiv:hep-ph/0606023
1157. D. Becirevic, A.B. Kaidalov, Phys. Lett. B **478**, 417 (2000). https://doi.org/10.1016/S0370-2693(00)00290-2. arXiv:hep-ph/9904490
1158. C.G. Boyd, B. Grinstein, R.F. Lebed, Phys. Rev. Lett. **74**, 4603 (1995). https://doi.org/10.1103/PhysRevLett.74.4603. arXiv:hep-ph/9412324
1159. C.G. Boyd, M.J. Savage, Phys. Rev. D **56**, 303 (1997). https://doi.org/10.1103/PhysRevD.56.303. arXiv:hep-ph/9702300
1160. M.C. Arnesen, B. Grinstein, I.Z. Rothstein, I.W. Stewart, Phys. Rev. Lett. **95**, 071802 (2005). https://doi.org/10.1103/PhysRevLett.95.071802
1161. C. Bourrely, B. Machet, E. de Rafael, Nucl. Phys. B **189**, 157 (1981). https://doi.org/10.1016/0550-3213(81)90086-9
1162. D. Becirevic, A.L. Yaouanc, A. Oyanguren, P. Roudeau, F. Sanfilippo (2014). arXiv:1407.1019 [hep-ph]
1163. J.P. Lees et al. (BaBar collaboration), Phys. Rev. D **88**, 052003 (2013). https://doi.org/10.1103/PhysRevD.88.052003. arXiv:1304.5009 [hep-ex]. [Erratum ibid. **88**, 079902 (2013). doi:10.1103/PhysRevD.88.079902]
1164. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **82**, 111101 (2010). https://doi.org/10.1103/PhysRevD.82.111101. arXiv:1009.2076 [hep-ex]
1165. R. Aaij et al., LHCb collaboration. JHEP **09**, 145 (2013). https://doi.org/10.1007/JHEP09(2013)45. arXiv:1307.4556
1166. G. Burdman, J. Kambor, Phys. Rev. D **55**, 2817 (1997). https://doi.org/10.1103/PhysRevD.55.2817. arXiv:hep-ph/9602353
1167. D. Becirevic, A. Le Yaouanc, L. Oliver, J.-C. Raynal, P. Roudeau, J. Serrano, Phys. Rev. D **87**, 054007 (2013). https://doi.org/10.1103/PhysRevD.87.054007. arXiv:1206.5869 [hep-ph]
1168. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **91**, 052022 (2015). https://doi.org/10.1103/PhysRevD.91.052022. arXiv:1412.5502 [hep-ex]
1169. M. Ablikim et al., BESIII collaboration. Phys. Rev. D **92**, 072012 (2015). https://doi.org/10.1103/PhysRevD.92.072012. arXiv:1508.07560 [hep-ex]
1170. M. Ablikim et al., BESIII collaboration. Phys. Rev. D **92**, 112008 (2015). https://doi.org/10.1103/PhysRevD.92.112008. arXiv:1510.00308 [hep-ex]
1171. L. Widhalm et al., Belle collaboration. Phys. Rev. Lett. **97**, 061804 (2006). https://doi.org/10.1103/PhysRevLett.97.061804. arXiv:hep-ex/0604049
1172. B. Aubert et al., BaBar collaboration. Phys. Rev. D **76**, 052005 (2007). https://doi.org/10.1103/PhysRevD.76.052005. arXiv:0704.0020 [hep-ex]
1173. D. Besson et al., CLEO collaboration. Phys. Rev. D **80**, 032005 (2009). https://doi.org/10.1103/PhysRevD.80.032005. arXiv:0906.2983 [hep-ex]
1174. S. Dobbs et al., CLEO collaboration. Phys. Rev. D **77**, 112005 (2008). https://doi.org/10.1103/PhysRevD.77.112005. arXiv:0712.1020 [hep-ex]
1175. G. Huang et al., CLEO collaboration. Phys. Rev. Lett. **94**, 011802 (2005). https://doi.org/10.1103/PhysRevLett.94.011802. arXiv:hep-ex/0407035
1176. J. Link et al., FOCUS collaboration. Phys. Lett. B **607**, 233 (2005). https://doi.org/10.1016/j.physletb.2004.12.036. arXiv:hep-ex/0410037
1177. J. Adler et al., MARK-III collaboration. Phys. Rev. Lett. **62**, 1821 (1989). https://doi.org/10.1103/PhysRevLett.62.1821
1178. K. Kodama et al., Fermilab E653 collaboration. Phys. Rev. Lett. **66**, 1819 (1991). https://doi.org/10.1103/PhysRevLett.66.1819
1179. K. Kodama et al., Fermilab E653 collaboration. Phys. Lett. B **336**, 605 (1994). https://doi.org/10.1016/0370-2693(94)90579-7
1180. P.L. Frabetti et al., Fermilab E687 collaboration. Phys. Lett. B **364**, 127 (1995). https://doi.org/10.1016/0370-2693(95)01368-2
1181. P.L. Frabetti et al., Fermilab E687 collaboration. Phys. Lett. B **315**, 203 (1993). https://doi.org/10.1016/0370-2693(93)90181-G
1182. J.C. Anjos et al., Tagged Photon Spectrometer collaboration. Phys. Rev. Lett. **62**, 1587 (1989). https://doi.org/10.1103/PhysRevLett.62.1587

1183. M. Ablikim et al., BES collaboration. Phys. Lett. B **597**, 39 (2004). https://doi.org/10.1016/j.physletb.2004.07.004. arXiv:hep-ex/0406028
1184. M. Ablikim et al. (BES collaboration) (2006). arXiv:hep-ex/0610019
1185. A. Bean et al., CLEO collaboration. Phys. Lett. B **317**, 647 (1993). https://doi.org/10.1016/0370-2693(93)91385-Z
1186. Y. Zheng, (BESIII collaboration), Presented at the 37th International Conference on High Energy Physics (ICHEP 2014) (2014)
1187. J.G. Korner, G.A. Schuler, Z. Phys. C **46**, 93 (1990). https://doi.org/10.1007/BF02440838
1188. J. Link et al., FOCUS collaboration. Phys. Lett. B **535**, 43 (2002). https://doi.org/10.1016/S0370-2693(02)01715-X. arXiv:hep-ex/0203031
1189. J. Link et al., FOCUS collaboration. Phys. Lett. B **544**, 89 (2002). https://doi.org/10.1016/S0370-2693(02)02386-9. arXiv:hep-ex/0207049
1190. B. Aubert et al., BaBar collaboration. Phys. Rev. D **78**, 051101 (2008). https://doi.org/10.1103/PhysRevD.78.051101. arXiv:0807.1599 [hep-ex]
1191. K.M. Ecklund et al., CLEO collaboration. Phys. Rev. D **80**, 052009 (2009). https://doi.org/10.1103/PhysRevD.80.052009. arXiv:0907.3201 [hep-ex]
1192. R.A. Briere et al., CLEO collaboration. Phys. Rev. D **81**, 112001 (2010). https://doi.org/10.1103/PhysRevD.81.112001. arXiv:1004.1954 [hep-ex]
1193. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **83**, 072001 (2011). https://doi.org/10.1103/PhysRevD.83.072001. arXiv:1012.1810 [hep-ex]
1194. P. Estabrooks et al., Nucl. Phys. B **133**, 490 (1978). https://doi.org/10.1016/0550-3213(78)90238-9
1195. J. Anjos et al., Fermilab E691 collaboration. Phys. Rev. Lett. **65**, 2630 (1990). https://doi.org/10.1103/PhysRevLett.65.2630
1196. K. Kodama et al., Fermilab E653 collaboration. Phys. Lett. B **274**, 246 (1992). https://doi.org/10.1016/0370-2693(92)90530-H
1197. P. Frabetti et al., Fermilab E687 collaboration. Phys. Lett. B **307**, 262 (1993). https://doi.org/10.1016/0370-2693(93)90216-5
1198. E. Aitala et al., Fermilab E791 collaboration. Phys. Rev. Lett. **80**, 1393 (1998). https://doi.org/10.1103/PhysRevLett.80.1393. arXiv:hep-ph/9710216
1199. E. Aitala et al., Fermilab E791 collaboration. Phys. Lett. B **440**, 435 (1998). https://doi.org/10.1016/S0370-2693(98)01243-X. arXiv:hep-ex/9809026
1200. M. Adamovich et al., BEATRICE collaboration. Eur. Phys. J. C **6**, 35 (1999). https://doi.org/10.1007/s100529801012
1201. J. Link et al. (FOCUS collaboration), Phys. Lett. B **607**, 67 (2005). https://doi.org/10.1016/j.physletb.2004.12.037. arXiv:hep-ex/0410067 [hep-ex]
1202. H. Mahlke, eConf **C0610161**, 014 (2006). arXiv:hep-ex/0702014
1203. A. Filipuzzi, J. Portoles, M. Gonzalez-Alonso, Phys. Rev. D **85**, 116010 (2012). https://doi.org/10.1103/PhysRevD.85.116010. arXiv:1203.2092 [hep-ph]
1204. M. Ablikim et al., BESIII collaboration. Phys. Rev. D **94**, 072004 (2016). https://doi.org/10.1103/PhysRevD.94.072004. arXiv:1608.06732 [hep-ex]
1205. M. Ablikim et al., BESIII collaboration. Phys. Rev. D **89**, 051104 (2014). https://doi.org/10.1103/PhysRevD.89.051104. arXiv:1312.0374 [hep-ex]
1206. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **82**, 091103 (2010). https://doi.org/10.1103/PhysRevD.82.091103. arXiv:1008.4080 [hep-ex]
1207. A. Zupanc et al., Belle collaboration. JHEP **09**, 139 (2013). https://doi.org/10.1007/JHEP09(2013)139. arXiv:1307.6240 [hep-ex]
1208. P. Naik et al., CLEO collaboration. Phys. Rev. D **80**, 112004 (2009). https://doi.org/10.1103/PhysRevD.80.112004. arXiv:0910.3602 [hep-ex]
1209. P. Onyisi et al., CLEO collaboration. Phys. Rev. D **79**, 052002 (2009). https://doi.org/10.1103/PhysRevD.79.052002. arXiv:0901.1147 [hep-ex]
1210. E. Barberio, B. van Eijk, Z. Was, Comput. Phys. Commun. **66**, 115 (1991). https://doi.org/10.1016/0010-4655(91)90012-A
1211. E. Barberio, Z. Was, Comput. Phys. Commun. **79**, 291 (1994). https://doi.org/10.1016/0010-4655(94)90074-4
1212. P. Golonka, Z. Was, Eur. Phys. J. C **45**, 97 (2006). https://doi.org/10.1140/epjc/s2005-02396-4. arXiv:hep-ph/0506026
1213. P. Golonka, Z. Was, Eur. Phys. J. C **50**, 53 (2007). https://doi.org/10.1140/epjc/s10052-006-0205-3. arXiv:hep-ph/0604232
1214. EVTGEN-V00-11-07 (2005). http://inspirehep.net/record/707695
1215. J.M. Link et al., FOCUS collaboration. Phys. Lett. B **555**, 167 (2003). https://doi.org/10.1016/S0370-2693(03)00053-4. arXiv:hep-ex/0212058
1216. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 051802 (2008). https://doi.org/10.1103/PhysRevLett.100.051802. arXiv:0704.2080 [hep-ex]
1217. M. Artuso et al., CLEO collaboration. Phys. Rev. Lett. **80**, 3193 (1998). https://doi.org/10.1103/PhysRevLett.80.3193. arXiv:hep-ex/9712023
1218. R. Barate et al., ALEPH collaboration. Phys. Lett. B **403**, 367 (1997). https://doi.org/10.1016/S0370-2693(97)00585-6
1219. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **340**, 125 (1994). https://doi.org/10.1016/0370-2693(94)91308-0
1220. D.S. Akerib et al., CLEO collaboration. Phys. Rev. Lett. **71**, 3070 (1993). https://doi.org/10.1103/PhysRevLett.71.3070
1221. D. Decamp et al., ALEPH collaboration. Phys. Lett. B **266**, 218 (1991). https://doi.org/10.1016/0370-2693(91)90769-M
1222. D.E. Acosta et al., CDF collaboration. Phys. Rev. Lett. **94**, 122001 (2005). https://doi.org/10.1103/PhysRevLett.94.122001. arXiv:hep-ex/0504006
1223. T.E. Coan et al., CLEO collaboration. Phys. Rev. Lett. **80**, 1150 (1998). https://doi.org/10.1103/PhysRevLett.80.1150. arXiv:hep-ex/9710028
1224. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **90**, 242001 (2003). https://doi.org/10.1103/PhysRevLett.90.242001. arXiv:hep-ex/0304021
1225. D. Besson et al. (CLEO collaboration), Phys. Rev. D **68**, 032002 (2003). https://doi.org/10.1103/PhysRevD.68.032002. arXiv:hep-ex/0305100. [Erratum ibid. **75**, 119908 (2007). doi:10.1103/PhysRevD.75.119908]
1226. K. Abe et al., Belle collaboration. Phys. Rev. Lett. **92**, 012002 (2004). https://doi.org/10.1103/PhysRevLett.92.012002. arXiv:hep-ex/0307052
1227. B. Aubert et al., BaBar collaboration. Phys. Rev. D **69**, 031101 (2004). https://doi.org/10.1103/PhysRevD.69.031101. arXiv:hep-ex/0310050
1228. J.M. Link et al., FOCUS collaboration. Phys. Lett. B **586**, 11 (2004). https://doi.org/10.1016/j.physletb.2004.02.017. arXiv:hep-ex/0312060
1229. S. Godfrey, N. Isgur, Phys. Rev. D **32**, 189 (1985). https://doi.org/10.1103/PhysRevD.32.189
1230. S. Godfrey, R. Kokoski, Phys. Rev. D **43**, 1679 (1991). https://doi.org/10.1103/PhysRevD.43.1679
1231. P. Schweitzer, S. Boffi, M. Radici, Phys. Rev. D **66**, 114004 (2002). https://doi.org/10.1103/PhysRevD.66.114004. arXiv:hep-ph/0207230
1232. F. Jugeau, A. Le Yaouanc, L. Oliver, J.-C. Raynal, Phys. Rev. D **72**, 094010 (2005). https://doi.org/10.1103/PhysRevD.72.094010. arXiv:hep-ph/0504206

1233. P. Colangelo, F. De Fazio, R. Ferrandes, Mod. Phys. Lett. A **19**, 2083 (2004). https://doi.org/10.1142/S0217732304015269. arXiv:hep-ph/0407137
1234. R.N. Cahn, J.D. Jackson, Phys. Rev. D **68**, 037502 (2003). https://doi.org/10.1103/PhysRevD.68.037502. arXiv:hep-ph/0305012
1235. T. Barnes, F.E. Close, H.J. Lipkin, Phys. Rev. D **68**, 054006 (2003). https://doi.org/10.1103/PhysRevD.68.054006. arXiv:hep-ph/0305025
1236. H. Lipkin, Phys. Lett. B **580**, 50 (2004). https://doi.org/10.1016/j.physletb.2003.10.117. arXiv:hep-ph/0306204
1237. W.A. Bardeen, E.J. Eichten, C.T. Hill, Phys. Rev. D **68**, 054024 (2003). https://doi.org/10.1103/PhysRevD.68.054024. arXiv:hep-ph/0305049
1238. B. Aubert et al., BaBar collaboration. Phys. Rev. D **80**, 092003 (2009). https://doi.org/10.1103/PhysRevD.80.092003. arXiv:0908.0806 [hep-ex]
1239. R. Aaij et al., LHCb collaboration. JHEP **10**, 151 (2012). https://doi.org/10.1007/JHEP10(2012)151. arXiv:1207.6016 [hep-ex]
1240. R. Aaij et al., LHCb collaboration. Phys. Rev. Lett. **113**, 162001 (2014). https://doi.org/10.1103/PhysRevLett.113.162001. arXiv:1407.7574 [hep-ex]
1241. R. Aaij et al., LHCb collaboration. JHEP **02**, 133 (2016). https://doi.org/10.1007/JHEP02(2016)133. arXiv:1601.01495 [hep-ex]
1242. T. Matsuki, T. Morii, K. Sudoh, Eur. Phys. J. A **31**, 701 (2007). https://doi.org/10.1140/epja/i2006-10287-1. arXiv:hep-ph/0610186
1243. N. Isgur, M.B. Wise, Phys. Lett. B **232**, 113 (1989). https://doi.org/10.1016/0370-2693(89)90566-2
1244. B. Aubert et al., BaBar collaboration. Phys. Rev. D **74**, 032007 (2006). https://doi.org/10.1103/PhysRevD.74.032007. arXiv:hep-ex/0604030
1245. V.M. Abazov et al., D0 collaboration. Phys. Rev. Lett. **102**, 051801 (2009). https://doi.org/10.1103/PhysRevLett.102.051801. arXiv:0712.3789 [hep-ex]
1246. P.L. Frabetti et al., Fermilab E687 collaboration. Phys. Rev. Lett. **72**, 324 (1994). https://doi.org/10.1103/PhysRevLett.72.324
1247. J.P. Alexander et al., CLEO collaboration. Phys. Lett. B **303**, 377 (1993). https://doi.org/10.1016/0370-2693(93)91448-V
1248. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **297**, 425 (1992). https://doi.org/10.1016/0370-2693(92)91282-E
1249. P. Avery et al., CLEO collaboration. Phys. Rev. D **41**, 774 (1990). https://doi.org/10.1103/PhysRevD.41.774
1250. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **230**, 162 (1989). https://doi.org/10.1016/0370-2693(89)91672-9
1251. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **83**, 072003 (2011). https://doi.org/10.1103/PhysRevD.83.072003. arXiv:1103.2675 [hep-ex]
1252. R. Aaij et al., LHCb collaboration. Phys. Rev. D **90**, 072003 (2014). https://doi.org/10.1103/PhysRevD.90.072003. arXiv:1407.7712 [hep-ex]
1253. R. Aaij et al., LHCb collaboration. Phys. Lett. B **698**, 14 (2011). https://doi.org/10.1016/j.physletb.2011.02.039. arXiv:1102.0348 [hep-ex]
1254. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **97**, 222001 (2006). https://doi.org/10.1103/PhysRevLett.97.222001. arXiv:hep-ex/0607082
1255. H. Albrecht et al., ARGUS collaboration. Z. Phys. C **69**, 405 (1996). https://doi.org/10.1007/s002880050040
1256. Y. Kubota et al., CLEO collaboration. Phys. Rev. Lett. **72**, 1972 (1994). https://doi.org/10.1103/PhysRevLett.72.1972. arXiv:hep-ph/9403325
1257. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **91**, 052002 (2015). https://doi.org/10.1103/PhysRevD.91.052002. arXiv:1412.6751 [hep-ex]
1258. R. Aaij et al., LHCb collaboration. Phys. Rev. D **92**, 012012 (2015). https://doi.org/10.1103/PhysRevD.92.012012. arXiv:1505.01505 [hep-ex]
1259. A. Kuzmin et al., Belle collaboration. Phys. Rev. D **76**, 012006 (2007). https://doi.org/10.1103/PhysRevD.76.012006. arXiv:hep-ex/0611054
1260. H. Abramowicz et al., ZEUS collaboration. Nucl. Phys. B **866**, 229 (2013). https://doi.org/10.1016/j.nuclphysb.2012.09.007. arXiv:1208.4468 [hep-ex]
1261. A. Abulencia et al., CDF collaboration. Phys. Rev. D **73**, 051104 (2006). https://doi.org/10.1103/PhysRevD.73.051104. arXiv:hep-ex/0512069
1262. P. Avery et al., CLEO collaboration. Phys. Lett. B **331**, 236 (1994). https://doi.org/10.1016/0370-2693(94)90968-7. arXiv:hep-ph/9403359
1263. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **232**, 398 (1989). https://doi.org/10.1016/0370-2693(89)90764-8
1264. J.C. Anjos et al., Tagged Photon Spectrometer collaboration. Phys. Rev. Lett. **62**, 1717 (1989). https://doi.org/10.1103/PhysRevLett.62.1717
1265. T. Bergfeld et al., CLEO collaboration. Phys. Lett. B **340**, 194 (1994). https://doi.org/10.1016/0370-2693(94)01348-9
1266. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **221**, 422 (1989). https://doi.org/10.1016/0370-2693(89)91737-1
1267. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **231**, 208 (1989). https://doi.org/10.1016/0370-2693(89)90141-X
1268. P. Abreu et al., DELPHI collaboration. Phys. Lett. B **426**, 231 (1998). https://doi.org/10.1016/S0370-2693(98)00346-3
1269. S. Chekanov et al., ZEUS collaboration. Eur. Phys. J. C **60**, 25 (2009). https://doi.org/10.1140/epjc/s10052-009-0881-x. arXiv:0807.1290 [hep-ex]
1270. A. Heister et al., ALEPH collaboration. Phys. Lett. B **526**, 34 (2002). https://doi.org/10.1016/S0370-2693(01)01465-4. arXiv:hep-ex/0112010
1271. A. Zupanc et al., Belle collaboration. Phys. Rev. Lett. **113**, 042002 (2014). https://doi.org/10.1103/PhysRevLett.113.042002. arXiv:1312.7826 [hep-ex]
1272. M. Ablikim et al., BESIII collaboration. Phys. Rev. Lett. **115**, 221805 (2015). https://doi.org/10.1103/PhysRevLett.115.221805. arXiv:1510.02610 [hep-ex]
1273. P. Avery et al., CLEO collaboration. Phys. Rev. D **43**, 3599 (1991). https://doi.org/10.1103/PhysRevD.43.3599
1274. M.S. Alam et al., CLEO collaboration. Phys. Rev. D **57**, 4467 (1998). https://doi.org/10.1103/PhysRevD.57.4467. arXiv:hep-ex/9709012
1275. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **274**, 239 (1992). https://doi.org/10.1016/0370-2693(92)90529-D
1276. J.M. Link et al., FOCUS collaboration. Phys. Lett. B **624**, 22 (2005). https://doi.org/10.1016/j.physletb.2005.08.014. arXiv:hep-ex/0505077
1277. P. Avery et al., CLEO collaboration. Phys. Lett. B **325**, 257 (1994). https://doi.org/10.1016/0370-2693(94)90100-7
1278. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **207**, 109 (1988). https://doi.org/10.1016/0370-2693(88)90896-9
1279. B. Aubert et al., BaBar collaboration. Phys. Rev. D **75**, 052002 (2007). https://doi.org/10.1103/PhysRevD.75.052002. arXiv:hep-ex/0601017
1280. Y. Kubota et al., CLEO collaboration. Phys. Rev. Lett. **71**, 3255 (1993). https://doi.org/10.1103/PhysRevLett.71.3255
1281. T. Bergfeld et al., CLEO collaboration. Phys. Lett. B **323**, 219 (1994). https://doi.org/10.1016/0370-2693(94)90295-X. arXiv:hep-ph/9403326
1282. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **269**, 234 (1991). https://doi.org/10.1016/0370-2693(91)91480-J

1283. B. Aubert et al., BABAR collaboration. Phys. Rev. D **72**, 052006 (2005). https://doi.org/10.1103/PhysRevD.72.052006. arXiv:hep-ex/0507009
1284. E. Solovieva et al., Belle collaboration. Phys. Lett. B **672**, 1 (2009). https://doi.org/10.1016/j.physletb.2008.12.062. arXiv:0808.3677 [hep-ex]
1285. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **84**, 012003 (2011). https://doi.org/10.1103/PhysRevD.84.012003. arXiv:1105.5995 [hep-ex]
1286. M. Artuso et al., CLEO collaboration. Phys. Rev. Lett. **86**, 4479 (2001). https://doi.org/10.1103/PhysRevLett.86.4479. arXiv:hep-ex/0010080
1287. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **98**, 012001 (2007). https://doi.org/10.1103/PhysRevLett.98.012001. arXiv:hep-ex/0603052
1288. H.-Y. Cheng, C.-K. Chua, Phys. Rev. D **75**, 014006 (2007). https://doi.org/10.1103/PhysRevD.75.014006. arXiv:hep-ph/0610283
1289. S.H. Lee et al., Belle collaboration. Phys. Rev. D **89**, 091102 (2014). https://doi.org/10.1103/PhysRevD.89.091102. arXiv:1404.5389 [hep-ex]
1290. R. Mizuk et al., Belle collaboration. Phys. Rev. Lett. **94**, 122002 (2005). https://doi.org/10.1103/PhysRevLett.94.122002. arXiv:hep-ex/0412069
1291. L. Copley, N. Isgur, G. Karl, Phys. Rev. D **20**, 768 (1979). https://doi.org/10.1103/PhysRevD.20.768. [Erratum ibid. **23**, 817 (1981). doi:10.1103/PhysRevD.23.817]
1292. D. Pirjol, T.-M. Yan, Phys. Rev. D **56**, 5483 (1997). https://doi.org/10.1103/PhysRevD.56.5483. arXiv:hep-ph/9701291
1293. R. Chistov et al., Belle collaboration. Phys. Rev. Lett. **97**, 162001 (2006). https://doi.org/10.1103/PhysRevLett.97.162001. arXiv:hep-ex/0606051
1294. Y. Kato et al., Belle collaboration. Phys. Rev. D **89**, 052003 (2014). https://doi.org/10.1103/PhysRevD.89.052003. arXiv:1312.1026 [hep-ex]
1295. Y. Kato et al., Belle collaboration. Phys. Rev. D **94**, 032002 (2016). https://doi.org/10.1103/PhysRevD.94.032002. arXiv:1605.09103 [hep-ex]
1296. B. Aubert et al., BABAR collaboration. Phys. Rev. D **77**, 031101 (2008). https://doi.org/10.1103/PhysRevD.77.031101. arXiv:0710.5775 [hep-ex]
1297. J. Yelton et al., Belle collaboration. Phys. Rev. D **94**, 052011 (2016). https://doi.org/10.1103/PhysRevD.94.052011. arXiv:1607.07123 [hep-ex]
1298. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **97**, 232001 (2006). https://doi.org/10.1103/PhysRevLett.97.232001. arXiv:hep-ex/0608055
1299. J.L. Rosner, Phys. Rev. D **52**, 6461 (1995). https://doi.org/10.1103/PhysRevD.52.6461. arXiv:hep-ph/9508252
1300. L.Y. Glozman, D. Riska, Nucl. Phys. A **603**, 326 (1996). https://doi.org/10.1016/0375-9474(96)80005-C. arXiv:hep-ph/9509269. [Erratum ibid. 620, 510 (1997). doi:10.1016/S0375-9474(97)00200-5]
1301. E.E. Jenkins, Phys. Rev. D **54**, 4515 (1996). https://doi.org/10.1103/PhysRevD.54.4515. arXiv:hep-ph/9603449
1302. L. Burakovsky, J.T. Goldman, L. Horwitz, Phys. Rev. D **56**, 7124 (1997). https://doi.org/10.1103/PhysRevD.56.7124. arXiv:hep-ph/9706464
1303. G. Burdman, E. Golowich, J.L. Hewett, S. Pakvasa, Phys. Rev. D **66**, 014009 (2002). https://doi.org/10.1103/PhysRevD.66.014009. arXiv:hep-ph/0112235
1304. S. Fajfer, A. Prapotnik, S. Prelovsek, P. Singer, J. Zupan, Nucl. Phys. Proc. Suppl. **115**, 93 (2003). https://doi.org/10.1016/S0920-5632(02)01961-8. arXiv:hep-ph/0208201
1305. S. Fajfer, N. Kosnik, S. Prelovsek, Phys. Rev. D **76**, 074010 (2007). https://doi.org/10.1103/PhysRevD.76.074010. arXiv:0706.1133 [hep-ph]
1306. E. Golowich, J. Hewett, S. Pakvasa, A.A. Petrov, Phys. Rev. D **79**, 114030 (2009). https://doi.org/10.1103/PhysRevD.79.114030. arXiv:0903.2830 [hep-ph]
1307. A. Paul, I.I. Bigi, S. Recksiegel, Phys. Rev. D **82**, 094006 (2010). https://doi.org/10.1103/PhysRevD.82.094006. arXiv:1008.3141 [hep-ph]. [Erratum ibid. **83**, 019901 (2011). doi:10.1103/PhysRevD.83.019901]
1308. A. Borisov (2011). arXiv:1112.3269 [hep-ph]
1309. R.-M. Wang, J.-H. Sheng, J. Zhu, Y.-Y. Fan, Y. Gao, Int. J. Mod. Phys. A **29**, 1450169 (2014). https://doi.org/10.1142/S0217751X14501693
1310. S. de Boer, G. Hiller, Phys. Rev. D **93**, 074001 (2016). https://doi.org/10.1103/PhysRevD.93.074001. arXiv:1510.00311 [hep-ph]
1311. P. Rubin et al., CLEO collaboration. Phys. Rev. D **82**, 092007 (2010). https://doi.org/10.1103/PhysRevD.82.092007. arXiv:1009.1606 [hep-ex]
1312. V. Abazov et al., D0 collaboration. Phys. Rev. Lett. **100**, 101801 (2008). https://doi.org/10.1103/PhysRevLett.100.101801. arXiv:0708.2094 [hep-ex]
1313. R. Aaij et al., LHCb collaboration. Phys. Lett. B **728**, 234 (2014). https://doi.org/10.1016/j.physletb.2013.11.053. arXiv:1310.2535 [hep-ex]
1314. R. Aaij et al., LHCb collaboration. Phys. Lett. B **724**, 203 (2013). https://doi.org/10.1016/j.physletb.2013.06.010. arXiv:1304.6365 [hep-ex]
1315. T. Coan et al., CLEO collaboration. Phys. Rev. Lett. **90**, 101801 (2003). https://doi.org/10.1103/PhysRevLett.90.101801. arXiv:hep-ex/0212045
1316. M. Ablikim et al., BESIII collaboration. Phys. Rev. D **91**, 112015 (2015). https://doi.org/10.1103/PhysRevD.91.112015. arXiv:1505.03087 [hep-ex]
1317. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **85**, 091107 (2012). https://doi.org/10.1103/PhysRevD.85.091107. arXiv:1110.6480 [hep-ex]
1318. N.K. Nisar et al., Belle collaboration. Phys. Rev. D **93**, 051102 (2016). https://doi.org/10.1103/PhysRevD.93.051102. arXiv:1512.02992 [hep-ex]
1319. P. Haas et al., CLEO collaboration. Phys. Rev. Lett. **60**, 1614 (1988). https://doi.org/10.1103/PhysRevLett.60.1614
1320. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **209**, 380 (1988). https://doi.org/10.1016/0370-2693(88)90967-7
1321. J. Adler et al., MARK-III collaboration. Phys. Rev. D **37**, 2023 (1988). https://doi.org/10.1103/PhysRevD.37.2023. [Erratum ibid. **40**, 3788 (1989). doi:10.1103/PhysRevD.40.3788]
1322. A. Freyberger et al., CLEO collaboration. Phys. Rev. Lett. **76**, 3065 (1996). https://doi.org/10.1103/PhysRevLett.76.3065
1323. D. Pripstein et al., Fermilab E789 collaboration. Phys. Rev. D **61**, 032005 (2000). https://doi.org/10.1103/PhysRevD.61.032005. arXiv:hep-ex/9906022
1324. E. Aitala et al., Fermilab E791 collaboration. Phys. Lett. B **462**, 401 (1999). https://doi.org/10.1016/S0370-2693(99)00902-8. arXiv:hep-ex/9906045
1325. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **93**, 191801 (2004). https://doi.org/10.1103/PhysRevLett.93.191801. arXiv:hep-ex/0408023
1326. M. Petric et al., Belle collaboration. Phys. Rev. D **81**, 091102 (2010). https://doi.org/10.1103/PhysRevD.81.091102. arXiv:1003.2345 [hep-ex]
1327. K. Kodama et al., Fermilab E653 collaboration. Phys. Lett. B **345**, 85 (1995). https://doi.org/10.1016/0370-2693(94)01610-O
1328. I. Abt et al., HERA-B collaboration. Phys. Lett. B **596**, 173 (2004). https://doi.org/10.1016/j.physletb.2004.06.097. arXiv:hep-ex/0405059

1329. T. Aaltonen et al., CDF collaboration. Phys. Rev. D **82**, 091105 (2010). https://doi.org/10.1103/PhysRevD.82.091105. arXiv:1008.5077 [hep-ex]
1330. R. Aaij et al., LHCb collaboration. Phys. Lett. B **725**, 15 (2013). https://doi.org/10.1016/j.physletb.2013.06.037. arXiv:1305.5059 [hep-ex]
1331. E. Aitala et al., Fermilab E791 collaboration. Phys. Rev. Lett. **86**, 3969 (2001). https://doi.org/10.1103/PhysRevLett.86.3969. arXiv:hep-ex/0011077
1332. J. Adler et al., MARK-III collaboration. Phys. Rev. D **40**, 906 (1989). https://doi.org/10.1103/PhysRevD.40.906
1333. J. Becker et al., MARK-III collaboration. Phys. Lett. B **193**, 147 (1987). https://doi.org/10.1016/0370-2693(87)90473-4
1334. R. Aaij et al., LHCb collaboration. Phys. Lett. B **754**, 167 (2016). https://doi.org/10.1016/j.physletb.2016.01.029. arXiv:1512.00322 [hep-ex]
1335. P. Rubin et al., CLEO collaboration. Phys. Rev. D **79**, 097101 (2009). https://doi.org/10.1103/PhysRevD.79.097101. arXiv:0904.1619 [hep-ex]
1336. P. Frabetti et al., Fermilab E687 collaboration. Phys. Lett. B **398**, 239 (1997). https://doi.org/10.1016/S0370-2693(97)00229-3
1337. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **84**, 072006 (2011). https://doi.org/10.1103/PhysRevD.84.072006. arXiv:1107.4465 [hep-ex]
1338. M.-G. Zhao, (BESIII collaboration) (2016). arXiv:1605.08952 [hep-ex]
1339. J. Link et al., FOCUS collaboration. Phys. Lett. B **572**, 21 (2003). https://doi.org/10.1016/j.physletb.2003.07.079. arXiv:hep-ex/0306049
1340. B. Aubert et al., BABAR collaboration. Nucl. Phys. Proc. Suppl. **189**, 193 (2009). https://doi.org/10.1016/j.nuclphysbps.2009.03.034. arXiv:0808.1121 [hep-ex]
1341. S. Paramesvaran, (BABAR collaboration) (2009). arXiv:0910.2884 [hep-ex]
1342. S. Ryu et al., Belle collaboration. Phys. Rev. D **89**, 072009 (2014). https://doi.org/10.1103/PhysRevD.89.072009. arXiv:1402.5213 [hep-ex]
1343. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **4**, 29 (1998). https://doi.org/10.1007/s100529800879
1344. S. Schael et al., (ALEPH collaboration), HFLAV-tau uses measurements of $\tau \to hX$ and $\tau \to KX$ and obtains $\tau \to \pi X$ by difference; the measurement of $\mathcal{B}\left(\tau^- \to 3h^-2h^+\pi^0\nu_\tau(\text{ex.}K^0)\right)$ has been read as $(2.1 \pm 0.7 \pm 0.6) \times 10^{-4}$ whereas PDG11 uses $(2.1 \pm 0.7 \pm 0.9) \times 10^{-4}$. Phys. Rep. **421**, 191 (2005). https://doi.org/10.1016/j.physrep.2005.06.007. arXiv:hep-ex/0506072
1345. P. Abreu et al., DELPHI collaboration. Eur. Phys. J. C **10**, 201 (1999). https://doi.org/10.1007/s100520050583
1346. M. Acciarri et al., L3 collaboration. Phys. Lett. B **507**, 47 (2001). https://doi.org/10.1016/S0370-2693(01)00294-5. arXiv:hep-ex/0102023
1347. G. Abbiendi et al., OPAL collaboration. Phys. Lett. B **551**, 35 (2003). https://doi.org/10.1016/S0370-2693(02)03020-4. arXiv:hep-ex/0211066
1348. H. Albrecht et al., ARGUS collaboration. Z. Phys. C **53**, 367 (1992). https://doi.org/10.1007/BF01625895
1349. B. Aubert et al., BABAR collaboration. Phys. Rev. Lett. **105**, 051602 (2010). https://doi.org/10.1103/PhysRevLett.105.051602. arXiv:0912.0242 [hep-ex]
1350. A. Anastassov et al., CLEO collaboration. Phys. Rev. D **55**, 2559 (1997). https://doi.org/10.1103/PhysRevD.55.2559. [Erratum ibid. **58**, 119903 (1998). doi:10.1103/PhysRevD.58.119903]
1351. G. Abbiendi et al., OPAL collaboration. Phys. Lett. B **447**, 134 (1999). https://doi.org/10.1016/S0370-2693(98)01553-6. arXiv:hep-ex/9812017
1352. P. Abreu et al., DELPHI collaboration. Z. Phys. C **55**, 555 (1992). https://doi.org/10.1007/BF01561293
1353. M. Acciarri et al., L3 collaboration. Phys. Lett. B **345**, 93 (1995). https://doi.org/10.1016/0370-2693(94)01587-3
1354. G. Alexander et al., OPAL collaboration. Phys. Lett. B **266**, 201 (1991). https://doi.org/10.1016/0370-2693(91)90768-L
1355. J. Abdallah et al., DELPHI collaboration. Eur. Phys. J. C **46**, 1 (2006). https://doi.org/10.1140/epjc/s2006-02494-9. arXiv:hep-ex/0603044
1356. K. Ackerstaff et al., OPAL collaboration. Eur. Phys. J. C **4**, 193 (1998). https://doi.org/10.1007/s100520050197. arXiv:hep-ex/9801029
1357. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **10**, 1 (1999). https://doi.org/10.1007/s100529900146. arXiv:hep-ex/9903014
1358. M. Battle et al., CLEO collaboration. Phys. Rev. Lett. **73**, 1079 (1994). https://doi.org/10.1103/PhysRevLett.73.1079. arXiv:hep-ph/9403329
1359. P. Abreu et al., DELPHI collaboration. Phys. Lett. B **334**, 435 (1994). https://doi.org/10.1016/0370-2693(94)90711-0
1360. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **19**, 653 (2001). https://doi.org/10.1007/s100520100632. arXiv:hep-ex/0009017
1361. M. Fujikawa et al., Belle collaboration. Phys. Rev. D **78**, 072006 (2008). https://doi.org/10.1103/PhysRevD.78.072006. arXiv:0805.3773 [hep-ex]
1362. M. Artuso et al., CLEO collaboration. Phys. Rev. Lett. **72**, 3762 (1994). https://doi.org/10.1103/PhysRevLett.72.3762. arXiv:hep-ph/9404310
1363. B. Aubert et al., BABAR collaboration. Phys. Rev. D **76**, 051104 (2007). https://doi.org/10.1103/PhysRevD.76.051104. arXiv:0707.2922 [hep-ex]
1364. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **35**, 437 (2004). https://doi.org/10.1140/epjc/s2004-01877-2. arXiv:hep-ex/0406007
1365. M. Procario et al., CLEO collaboration. Phys. Rev. Lett. **70**, 1207 (1993). https://doi.org/10.1103/PhysRevLett.70.1207
1366. R. Akers et al., OPAL collaboration. Phys. Lett. B **339**, 278 (1994). https://doi.org/10.1016/0370-2693(94)90645-9
1367. T. Coan et al., CLEO collaboration. Phys. Rev. D **53**, 6037 (1996). https://doi.org/10.1103/PhysRevD.53.6037
1368. M. Acciarri et al., L3 collaboration. Phys. Lett. B **352**, 487 (1995). https://doi.org/10.1016/0370-2693(95)00509-J
1369. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **13**, 213 (2000). https://doi.org/10.1007/s100520000317. arXiv:hep-ex/9911029
1370. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **11**, 599 (1999). https://doi.org/10.1007/s100520050659. arXiv:hep-ex/9903015
1371. J.P. Lees et al., BABAR collaboration. Phys. Rev. D **86**, 092013 (2012). https://doi.org/10.1103/PhysRevD.86.092013. arXiv:1208.0376 [hep-ex]
1372. H. Behrend et al., CELLO collaboration. Phys. Lett. B **222**, 163 (1989). https://doi.org/10.1016/0370-2693(89)90741-7
1373. B. Adeva et al., L3 collaboration. Phys. Lett. B **265**, 451 (1991). https://doi.org/10.1016/0370-2693(91)90081-Z
1374. H. Aihara et al., TPC/Two Gamma collaboration. Phys. Rev. D **35**, 1553 (1987). https://doi.org/10.1103/PhysRevD.35.1553
1375. P. Achard et al., L3 collaboration. Phys. Lett. B **519**, 189 (2001). https://doi.org/10.1016/S0370-2693(01)01099-1. arXiv:hep-ex/0107055
1376. R. Akers et al., OPAL collaboration. Z. Phys. C **68**, 555 (1995). https://doi.org/10.1007/BF01565256
1377. R. Balest et al., CLEO collaboration. Phys. Rev. Lett. **75**, 3809 (1995). https://doi.org/10.1103/PhysRevLett.75.3809

1378. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 011801 (2008). https://doi.org/10.1103/PhysRevLett.100.011801. arXiv:0707.2981 [hep-ex]
1379. M. Lee et al., Belle collaboration. Phys. Rev. D **81**, 113007 (2010). https://doi.org/10.1103/PhysRevD.81.113007. arXiv:1001.0083 [hep-ex]
1380. R.A. Briere et al., CLEO collaboration. Phys. Rev. Lett. **90**, 181802 (2003). https://doi.org/10.1103/PhysRevLett.90.181802. arXiv:hep-ex/0302028
1381. K. Edwards et al., CLEO collaboration. Phys. Rev. D **61**, 072003 (2000). https://doi.org/10.1103/PhysRevD.61.072003. arXiv:hep-ex/9908024
1382. D. Bortoletto et al., CLEO collaboration. Phys. Rev. Lett. **71**, 1791 (1993). https://doi.org/10.1103/PhysRevLett.71.1791
1383. A. Anastassov et al., CLEO collaboration. Phys. Rev. Lett. **86**, 4467 (2001). https://doi.org/10.1103/PhysRevLett.86.4467. arXiv:hep-ex/0010025
1384. S. Richichi et al., CLEO collaboration. Phys. Rev. D **60**, 112002 (1999). arXiv:hep-ex/9810026
1385. D.A. Bauer et al., TPC/Two Gamma collaboration. Phys. Rev. D **50**, 13 (1994). https://doi.org/10.1103/PhysRevD.50.13
1386. R. Barate et al., ALEPH collaboration. Eur. Phys. J. C **1**, 65 (1998). https://doi.org/10.1007/s100520050062
1387. K.E. Arms et al., CLEO collaboration. Phys. Rev. Lett. **94**, 241802 (2005). https://doi.org/10.1103/PhysRevLett.94.241802. arXiv:hep-ex/0501042
1388. G. Abbiendi et al., OPAL collaboration. Eur. Phys. J. C **13**, 197 (2000). https://doi.org/10.1007/s100520000272. arXiv:hep-ex/9908013
1389. D. Gibaut et al., CLEO collaboration. Phys. Rev. Lett. **73**, 934 (1994). https://doi.org/10.1103/PhysRevLett.73.934
1390. B. Bylsma et al., Phys. Rev. D **35**, 2269 (1987). https://doi.org/10.1103/PhysRevD.35.2269
1391. H. Albrecht et al., ARGUS collaboration. Phys. Lett. B **202**, 149 (1988). https://doi.org/10.1016/0370-2693(88)90870-2
1392. K. Ackerstaff et al., OPAL collaboration. Eur. Phys. J. C **8**, 183 (1999). https://doi.org/10.1007/s100529901057. arXiv:hep-ex/9808011
1393. D. Buskulic et al., ALEPH collaboration. Z. Phys. C **74**, 263 (1997). https://doi.org/10.1007/s002880050387
1394. K. Inami et al., Belle collaboration. Phys. Lett. B **672**, 209 (2009). https://doi.org/10.1016/j.physletb.2009.01.047. arXiv:0811.0088 [hep-ex]
1395. M. Artuso et al., CLEO collaboration. Phys. Rev. Lett. **69**, 3278 (1992). https://doi.org/10.1103/PhysRevLett.69.3278
1396. P. del Amo Sanchez et al., BaBar collaboration. Phys. Rev. D **83**, 032002 (2011). https://doi.org/10.1103/PhysRevD.83.032002. arXiv:1011.3917 [hep-ex]
1397. J.E. Bartelt et al., CLEO collaboration. Phys. Rev. Lett. **76**, 4119 (1996). https://doi.org/10.1103/PhysRevLett.76.4119
1398. M. Bishai et al., CLEO collaboration. Phys. Rev. Lett. **82**, 281 (1999). https://doi.org/10.1103/PhysRevLett.82.281. arXiv:hep-ex/9809012
1399. P. Baringer et al., CLEO collaboration. Phys. Rev. Lett. **59**, 1993 (1987). https://doi.org/10.1103/PhysRevLett.59.1993
1400. D. Buskulic et al., ALEPH collaboration. Z. Phys. C **70**, 579 (1996). https://doi.org/10.1007/s002880050134
1401. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **86**, 092010 (2012). https://doi.org/10.1103/PhysRevD.86.092010. arXiv:1209.2734 [hep-ex]
1402. K. Belous et al., Belle collaboration. Phys. Rev. Lett. **112**, 031801 (2014). https://doi.org/10.1103/PhysRevLett.112.031801. arXiv:1310.8503 [hep-ex]
1403. W. Marciano, A. Sirlin, Phys. Rev. Lett. **61**, 1815 (1988). https://doi.org/10.1103/PhysRevLett.61.1815
1404. A. Pich, Prog. Part. Nucl. Phys. **75**, 41 (2014). https://doi.org/10.1016/j.ppnp.2013.11.002. arXiv:1310.7922 [hep-ph]
1405. A. Ferroglia, C. Greub, A. Sirlin, Z. Zhang, Phys. Rev. D **88**, 033012 (2013). https://doi.org/10.1103/PhysRevD.88.033012. arXiv:1307.6900 [hep-ph]
1406. M. Fael, L. Mercolli, M. Passera, Phys. Rev. D **88**, 093011 (2013). https://doi.org/10.1103/PhysRevD.88.093011. arXiv:1310.1081 [hep-ph]
1407. W.J. Marciano, A. Sirlin, Phys. Rev. Lett. **71**, 3629 (1993). https://doi.org/10.1103/PhysRevLett.71.3629
1408. R. Decker, M. Finkemeier, Phys. Lett. B **334**, 199 (1994). https://doi.org/10.1016/0370-2693(94)90611-4
1409. R. Decker, M. Finkemeier, Nucl. Phys. B **438**, 17 (1995). https://doi.org/10.1016/0550-3213(95)00597-L. arXiv:hep-ph/9403385
1410. R. Decker, M. Finkemeier, Nucl. Phys. Proc. Suppl. **40**, 453 (1995). https://doi.org/10.1016/0920-5632(95)00170-E. arXiv:hep-ph/9411316
1411. M. Davier, A. Hocker, Z. Zhang, Rev. Mod. Phys. **78**, 1043 (2006). https://doi.org/10.1103/RevModPhys.78.1043. arXiv:hep-ph/0507078
1412. M. Antonelli et al., FlaviaNet working group on kaon decays. Eur. Phys. J. C **69**, 399 (2010). https://doi.org/10.1140/epjc/s10052-010-1406-3. arXiv:1005.2323 [hep-ph]
1413. E. Gamiz, M. Jamin, A. Pich, J. Prades, F. Schwab, JHEP **01**, 060 (2003). https://doi.org/10.1088/1126-6708/2003/01/060. arXiv:hep-ph/0212230
1414. E. Gamiz, M. Jamin, A. Pich, J. Prades, F. Schwab, Phys. Rev. Lett. **94**, 011803 (2005). https://doi.org/10.1103/PhysRevLett.94.011803. arXiv:hep-ph/0408044
1415. E. Gamiz, M. Jamin, A. Pich, J. Prades, F. Schwab, Nucl. Phys. Proc. Suppl. **169**, 85 (2007). https://doi.org/10.1016/j.nuclphysbps.2007.02.053. arXiv:hep-ph/0612154
1416. E. Gamiz, M. Jamin, A. Pich, J. Prades, F. Schwab, PoS **KAON**, 008 (2008). arXiv:0709.0282 [hep-ph]
1417. K. Maltman, Nucl. Phys. Proc. Suppl. **218**, 146 (2011). https://doi.org/10.1016/j.nuclphysbps.2011.06.025. arXiv:1011.6391 [hep-ph]
1418. J.C. Hardy, I.S. Towner, Phys. Rev. C **91**, 025501 (2015). https://doi.org/10.1103/PhysRevC.91.025501. arXiv:1411.5987 [nucl-ex]
1419. V. Cirigliano, H. Neufeld, Phys. Lett. B **700**, 7 (2011). https://doi.org/10.1016/j.physletb.2011.04.038. arXiv:1102.0563 [hep-ph]
1420. W.J. Marciano, Phys. Rev. Lett. **93**, 231803 (2004). https://doi.org/10.1103/PhysRevLett.93.231803. arXiv:hep-ph/0402299
1421. M. Jamin, A. Pich, J. Portoles, Phys. Lett. B **664**, 78 (2008). https://doi.org/10.1016/j.physletb.2008.04.049. arXiv:0803.1786 [hep-ph]
1422. M. Antonelli, V. Cirigliano, A. Lusiani, E. Passemar, JHEP **10**, 070 (2013). https://doi.org/10.1007/JHEP10(2013)070. arXiv:1304.8134 [hep-ph]
1423. K. Maltman, R.J. Hudspith, R. Lewis, C.E. Wolfe, J. Zanotti (2015), arXiv:1510.06954 [hep-ph]
1424. R.J. Hudspith, R. Lewis, K. Maltman, J. Zanotti (2017), arXiv:1702.01767 [hep-ph]
1425. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **104**, 021802 (2010). https://doi.org/10.1103/PhysRevLett.104.021802. arXiv:0908.2381 [hep-ex]
1426. K. Hayasaka et al., Belle collaboration. Phys. Lett. B **666**, 16 (2008). https://doi.org/10.1016/j.physletb.2008.06.056. arXiv:0705.0650 [hep-ex]
1427. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **98**, 061803 (2007). https://doi.org/10.1103/PhysRevLett.98.061803. arXiv:hep-ex/0610067
1428. Y. Miyazaki et al., Belle collaboration. Phys. Lett. B **648**, 341 (2007). https://doi.org/10.1016/j.physletb.2007.03.027. arXiv:hep-ex/0703009

1429. B. Aubert et al., BaBar collaboration. Phys. Rev. D **79**, 012004 (2009). https://doi.org/10.1103/PhysRevD.79.012004. arXiv:0812.3804 [hep-ex]
1430. Y. Miyazaki et al., Belle collaboration. Phys. Lett. B **692**, 4 (2010). https://doi.org/10.1016/j.physletb.2010.07.012. arXiv:1003.1183 [hep-ex]
1431. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **103**, 021801 (2009). https://doi.org/10.1103/PhysRevLett.103.021801. arXiv:0904.0339 [hep-ex]
1432. Y. Miyazaki, Belle collaboration. Phys. Lett. B **699**, 251 (2011). https://doi.org/10.1016/j.physletb.2011.04.011. arXiv:1101.0755 [hep-ex]
1433. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **100**, 071802 (2008). https://doi.org/10.1103/PhysRevLett.100.071802. arXiv:0711.0980 [hep-ex]
1434. Y. Miyazaki et al., Belle collaboration. Phys. Lett. B **672**, 317 (2009). https://doi.org/10.1016/j.physletb.2009.01.058. arXiv:0810.3519 [hep-ex]
1435. J.P. Lees et al., BaBar collaboration. Phys. Rev. D **81**, 111101 (2010). https://doi.org/10.1103/PhysRevD.81.111101. arXiv:1002.4550 [hep-ex]
1436. K. Hayasaka et al., Belle collaboration. Phys. Lett. B **687**, 139 (2010). https://doi.org/10.1016/j.physletb.2010.03.037. arXiv:1001.3221 [hep-ex]
1437. G. Aad et al., ATLAS collaboration. Eur. Phys. J. C **76**, 232 (2016). https://doi.org/10.1140/epjc/s10052-016-4041-9. arXiv:1601.03567 [hep-ex]
1438. R. Aaij et al., LHCb collaboration. JHEP **02**, 121 (2015). https://doi.org/10.1007/JHEP02(2015)121. arXiv:1409.8548 [hep-ex]
1439. B. Aubert et al., BaBar collaboration. Phys. Rev. Lett. **95**, 191801 (2005). https://doi.org/10.1103/PhysRevLett.95.191801. arXiv:hep-ex/0506066
1440. Y. Miyazaki et al. (Belle collaboration), Phys. Lett. B **719**, 346 (2013). https://doi.org/10.1016/j.physletb.2013.01.032. arXiv:1206.5595 [hep-ex]
1441. Y. Miyazaki et al., Belle collaboration. Phys. Lett. B **632**, 51 (2006). https://doi.org/10.1016/j.physletb.2005.10.024. arXiv:hep-ex/0508044
1442. R. Aaij et al., LHCb collaboration. Phys. Lett. B **724**, 36 (2013). https://doi.org/10.1016/j.physletb.2013.05.063. arXiv:1304.4518 [hep-ex]
1443. A.L. Read, J. Phys. G **28**, 2693 (2002). https://doi.org/10.1088/0954-3899/28/10/313
1444. S. Banerjee, B. Pietrzyk, J.M. Roney, Z. Was, Phys. Rev. D **77**, 054012 (2008). https://doi.org/10.1103/PhysRevD.77.054012. arXiv:0706.3235 [hep-ph]
1445. CDF collaboration, CDF note 8128 (2007). http://www-cdf.fnal.gov/physics/statistics/notes/cdf8128_mclimit_csm_v2.pdf