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Combined results of searches for the standard model Higgs boson in pp collisions at $\sqrt{s} = 7$ TeV ☆

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Combined results are reported from searches for the standard model Higgs boson in proton–proton collisions at $\sqrt{s} = 7$ TeV in five Higgs boson decay modes: $\gamma\gamma$, bb, $\tau\tau$, WW, and ZZ. The explored Higgs boson mass range is 110–600 GeV. The analysed data correspond to an integrated luminosity of 4.6–4.8 fb^{-1}. The expected excluded mass range in the absence of the standard model Higgs boson is 118–543 GeV at 95% CL. The observed results exclude the standard model Higgs boson in the mass range 127–600 GeV at 95% CL, and in the mass range 129–525 GeV at 99% CL. An excess of events above the expected standard model background is observed at the low end of the explored mass range making the observed limits weaker than expected in the absence of a signal. The largest excess, with a local significance of 3.1σ, is observed for a Higgs boson mass hypothesis of 124 GeV. The global significance of observing an excess with a local significance $\geqslant 3.1\sigma$ anywhere in the search range 110–600 (110–145) GeV is estimated to be 1.5σ (2.1σ). More data are required to ascertain the origin of the observed excess.

1. Introduction

The discovery of the mechanism for electroweak symmetry breaking is one of the goals of the physics programme at the Large Hadron Collider (LHC). In the standard model (SM) [1–3], this symmetry breaking is achieved by introducing a complex scalar doublet, leading to the prediction of the Higgs boson (H) [4–9]. To date, experimental searches for this particle have yielded null results. Limits at 95% confidence level (CL) on its mass have been placed by experiments at LEP, $m_{\mathrm{H}} > 114.4$ GeV [10], the Tevatron, $m_{\mathrm{H}} \notin (162\text{–}166)$ GeV [11], and ATLAS, $m_{\mathrm{H}} \notin (145\text{–}206), (214\text{–}224), (340\text{–}450)$ GeV [12–14]. Precision electroweak measurements, not taking into account the results from direct searches, indirectly constrain the SM Higgs boson mass to be less than 158 GeV [15].

In this Letter, we report on the combination of Higgs boson searches carried out in proton–proton collisions at $\sqrt{s} = 7$ TeV using the Compact Muon Solenoid (CMS) detector [16] at the LHC. The analysed data recorded in 2010–2011 correspond to an integrated luminosity of 4.6–4.8 fb^{-1}, depending on the search channel. The search is performed for Higgs boson masses in the range 110–600 GeV.

The CMS apparatus consists of a barrel assembly and two endcaps, comprising, in successive layers outwards from the collision region, the silicon pixel and strip tracker, the lead tungstate crystal electromagnetic calorimeter, the brass/scintillator hadron calorimeter, the superconducting solenoid, and gas-ionization chambers embedded in the steel return yoke for the detection of muons.

Early phenomenological work on Higgs boson production and decay can be found in Refs. [17–19]. There are four main mechanisms for Higgs boson production in pp collisions at $\sqrt{s} = 7$ TeV. The gluon–gluon fusion mechanism has the largest cross section, followed in turn by vector boson fusion (VBF), associated WH and ZH production, and production in association with top quarks, $\mathrm{t\bar{t}H}$. The cross sections for the Higgs boson production mechanisms and the decay branching fractions, together with their uncertainties, are taken from Ref. [20] and are derived from Refs. [21–66]. The total cross section varies from 20 to 0.3 pb as a function of the Higgs boson mass, over the explored range.

The relevant decay modes of the SM Higgs boson depend strongly on its mass m_{H}. The results presented here are based on the following five decay modes: $\mathrm{H} \to \gamma\gamma$, $\mathrm{H} \to \tau\tau$, $\mathrm{H} \to \mathrm{bb}$, $\mathrm{H} \to \mathrm{WW}$, followed by $\mathrm{WW} \to (\ell\nu)(\ell\nu)$ decays, and $\mathrm{H} \to \mathrm{ZZ}$, followed by ZZ decays to 4ℓ, $2\ell2\nu$, $2\ell2\mathrm{q}$, and $2\ell2\tau$. Here and throughout, ℓ stands for electrons or muons and q for quarks. For simplicity, $\mathrm{H} \to \tau^+\tau^-$ is denoted as $\mathrm{H} \to \tau\tau$, $\mathrm{H} \to \mathrm{b\bar{b}}$ as $\mathrm{H} \to \mathrm{bb}$, etc. The WW and ZZ decay modes are used over the entire explored mass range. The $\gamma\gamma$, $\tau\tau$, and bb decay modes are used only for $m_{\mathrm{H}} < 150$ GeV since their expected sensitivities are not significant compared to WW and ZZ for higher Higgs boson masses.

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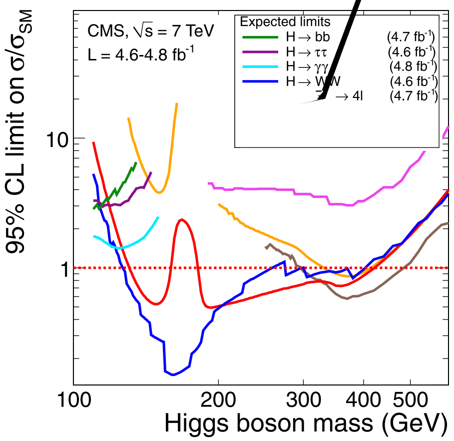
Table 1
Summary information on the analyses included in this combination.

Channel	m_H range (GeV)	Luminosity (fb^{-1})	Sub-channels	m_H resolution	Reference
$H \to \gamma\gamma$	110–150	4.8	2	1–3%	[67]
$H \to \tau\tau$	110–145	4.6	9	20%	[68]
$H \to bb$	110–135	4.7	5	10%	[69]
$H \to WW^* \to 2\ell 2\nu$	110–600	4.6	5	20%	[70]
$H \to ZZ^{(*)} \to 4\ell$	110–600	4.7	3	1–2%	[71]
$H \to ZZ \to 2\ell 2\nu$	250–600	4.6	2	7%	[72]
$H \to ZZ^{(*)} \to 2\ell 2q$	130–164 200–600	4.6	6	3% 3%	[73]
$H \to ZZ \to 2\ell 2\tau$	190–600	4.7	8	10–15%	[74]



of the associated jets: (i) events with the VBF signature, (ii) events with just one jet with large transverse energy E_T, and (iii) events with either no jets or with one with a small E_T. In each of these nine categories we search for a broad excess in the reconstructed $\tau\tau$ mass distribution. The main irreducible background is from $Z \to \tau\tau$ production, whose $\tau\tau$ mass distribution is derived from data by using $Z \to \mu\mu$ events, in which the reconstructed muons are replaced with reconstructed particles from the decay of simulated τ leptons of the same momenta. The reducible backgrounds ($W + \text{jets}$, multijet production, $Z \to ee$) are also evaluated from control samples in data.

The $H \to bb$ search [69] concentrates on Higgs boson production in association with W or Z bosons, in which the focus is on the following decay modes: $W \to e\nu/\mu\nu$ and $Z \to ee/\mu\mu/\nu\nu$. The $Z \to \nu\nu$ decay is identified by requiring a large missing transverse energy E_T^{miss}. The value E_T^{miss} is defined as the modulus of the vector $\vec{E}_T^{\text{miss}}$ computed as the negative of the vector sum of the transverse momenta of all reconstructed objects in the volume of the detector (leptons, photons, and charged/neutral hadrons). The dijet system, with both jets tagged as b-quark jets [75], is also required to have a large transverse momentum, which helps to reduce backgrounds and improves the dijet mass resolution. We use a multivariate analysis (MVA) technique, in which a classifier is trained on simulated signal and background events for a number of Higgs boson masses, and the events above an MVA output threshold are counted as signal-like. The rates of the main backgrounds, consisting of W/Z+jets and top-quark events, are derived from control samples in data. The WZ and ZZ backgrounds with a Z boson decaying to a pair of b-quarks, as well as the single-top background, are estimated from simulation.

The $H \to WW^{(*)} \to 2\ell 2\nu$ analysis [70] searches for an excess of events with two leptons of opposite charge, large E_T^{miss}, and up to two jets. Events are divided into five categories, with different background compositions and signal-to-background ratios. For events with no jets, the main background stems from non-resonant WW production; for events with one jet, the dominant backgrounds are from WW and top-quark production. The events with no jets and one jet are split into same-flavour and different-flavour dilepton sub-channels, since the background from Drell–Yan production is much larger for the same-flavour dilepton events. The two-jet category is optimized to take advantage of the VBF production signature. The main background in this channel is from top-quark production. To improve the separation of signal from backgrounds, MVA classifiers are trained for a number of Higgs boson masses, and a search is made for an excess of events in the output distributions of the classifiers. All background rates, except for very small contributions from WZ, ZZ, and $W\gamma$, are evaluated from data.

In the $H \to ZZ^{(*)} \to 4\ell$ channel [71], we search for a four-lepton mass peak over a small continuum background. The 4e, 4μ, $2e2\mu$ sub-channels are analyzed separately since there are differences in the four-lepton mass resolutions and the background rates arising from jets misidentified as leptons. The dominant irreducible background in this channel is from non-resonant ZZ production (with both Z bosons decaying to either 2e, or 2μ, or 2τ with the taus decaying leptonically) and is estimated from simulation. The smaller reducible backgrounds with jets misidentified as leptons, e.g. $Z + \text{jets}$, are estimated from data.

In the $H \to ZZ \to 2\ell 2\nu$ search [72], we select events with a lepton pair (ee or $\mu\mu$), with invariant mass consistent with that of an on-shell Z boson, and a large E_T^{miss}. We then define a transverse invariant mass m_T from the dilepton momenta and E_T^{miss}, assuming that E_T^{miss} arises from a $Z \to \nu\nu$ decay. We search for a broad excess of events in the m_T distribution. The non-resonant ZZ and WZ backgrounds are taken from simulation, while all other backgrounds are evaluated from control samples in data.

In the $H \to ZZ^{(*)} \to 2\ell 2q$ search [73], we select events with two leptons (ee or $\mu\mu$) and two jets with zero, one, or two b-tags, thus defining a total of six exclusive final states. Requiring b-tagging improves the signal-to-background ratio. The two jets are required to form an invariant mass consistent with that of an on-shell Z boson. The aim is to search for a peak in the invariant mass distribution of the dilepton-dijet system, with the background rate and shape estimated using control regions in data.

In the $H \to ZZ \to 2\ell 2\tau$ search [74], one Z boson is required to be on-shell and to decay to a lepton pair (ee or $\mu\mu$). The other Z boson is required to decay through a $\tau\tau$ pair to one of the four final-state signatures $e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$. Thus, eight exclusive sub-channels are defined. We search for a broad excess in the distribution of the dilepton-ditau mass, constructed from the visible products of the tau decays, neglecting the effect of the accompanying neutrinos. The dominant background is non-resonant ZZ production whose rate is estimated from simulation. The main sub-leading backgrounds with jets misidentified as τ leptons stem from $Z + \text{jets}$ (including ZW) and top-quark events. These backgrounds are estimated from data.

3. Combination methodology

The combination of the SM Higgs boson searches requires simultaneous analysis of the data from all individual search channels, accounting for all statistical and systematic uncertainties and their correlations. The results presented here are based on a combination of Higgs boson searches in a total of 40 exclusive sub-channels described in Section 2. Depending on the sub-channel, the input to the combination may be a total number of selected events or an event distribution for the final discriminating variable. Either binned or unbinned distributions are used, depending upon the particular search sub-channel.

The number of sources of systematic uncertainties considered in the combination ranges from 156 to 222, depending on the Higgs boson mass. A large fraction of these uncertainties are correlated across different channels and between signal and backgrounds within a given channel. Uncertainties considered include: theoretical uncertainties on the expected cross sections and acceptances for signal and background processes, experimental uncertainties arising from modelling of the detector response (event reconstruction and selection efficiencies, energy scale and resolution), and statistical uncertainties associated with either ancillary measurements of backgrounds in control regions or selection efficiencies obtained using simulated events. Systematic uncertainties can affect either the shape of distributions, or event yields, or both.

The combination is repeated for 183 Higgs boson mass hypotheses in the range 110–600 GeV. The step size in this scan varies [76] across the mass range and is determined by the Higgs boson mass resolution. The minimum step size is 0.5 GeV at lower masses, where it corresponds to the mass resolution of the $\gamma\gamma$ and 4ℓ channels. The maximum step size is 20 GeV at large masses, where the intrinsic Higgs boson width is the limiting factor.

3.1. General framework

The overall statistical methodology used in this combination was developed by the CMS and ATLAS Collaborations in the context of the LHC Higgs Combination Group. The detailed description of the methodology can be found in Ref. [76]. Below we outline the basic steps in the combination procedure.

Firstly, a signal strength modifier μ is introduced that multiplies the expected SM Higgs boson cross section such that $\sigma = \mu \cdot \sigma_{\mathrm{SM}}$.

Secondly, each independent source of systematic uncertainty is assigned a nuisance parameter θ_i. The expected Higgs boson and background yields are functions of these nuisance parameters, and are written as $\mu \cdot s(\theta)$ and $b(\theta)$, respectively. Most nuisance parameters are constrained by other measurements. They are encoded in the probability density functions $p_i(\tilde{\theta}_i \mid \theta_i)$ describing the probability to measure a value $\tilde{\theta}_i$ of the i-th nuisance parameter, given its true value θ_i.

Next, we define the likelihood $\mathcal{L}$, given the data and the measurements $\tilde{\theta}$:

$$\begin{aligned}&\mathcal{L}\big(\mathrm{data} \mid \mu \cdot s(\theta) + b(\theta)\big)\\ &\quad = \mathcal{P}\big(\mathrm{data} \mid \mu \cdot s(\theta) + b(\theta)\big) \cdot p(\tilde{\theta} \mid \theta),\end{aligned} \tag{1}$$

where $\mathcal{P}(\mathrm{data} \mid \mu \cdot s(\theta) + b(\theta))$ is a product of probabilities over all bins of discriminant variable distributions in all channels (or over all events for sub-channels with unbinned distributions), and $p(\tilde{\theta} \mid \theta)$ is the probability density function for all nuisance parameter measurements.

In order to test a Higgs boson production hypothesis for a given mass, we construct an appropriate test statistic. The test statistic is a single number encompassing information on the observed data, expected signal, expected background, and all uncertainties associated with these expectations. It allows one to rank all possible experimental observations according to whether they are more consistent with the background-only or with the signal + background hypotheses.

Finally, in order to infer the presence or absence of a signal in the data, we compare the observed value of the test statistic with the distribution of values expected under the background-only and under the signal + background hypotheses. The expected distributions are obtained by generating pseudo-datasets from the probability density functions $\mathcal{P}(\mathrm{data} \mid \mu \cdot s(\theta) + b(\theta))$ and $p(\tilde{\theta} \mid \theta)$. The values of the nuisance parameters θ used for generating pseudo-datasets are obtained by maximizing the likelihood $\mathcal{L}$ under the background-only or under the signal + background hypotheses.

3.2. *Quantifying an excess*

In order to quantify the statistical significance of an excess over the background-only expectation, we define a test statistic q_0 as:

$$q_0 = -2\ln\frac{\mathcal{L}(\mathrm{data} \mid b(\hat{\theta}_0))}{\mathcal{L}(\mathrm{data} \mid \hat{\mu} \cdot s(\hat{\theta}) + b(\hat{\theta}))}, \quad \hat{\mu} \geqslant 0, \tag{2}$$

where $\hat{\theta}_0$, $\hat{\theta}$, and $\hat{\mu}$ are the values of the parameters θ and μ that maximise the likelihoods in the numerator and denominator, and the subscript in $\hat{\theta}_0$ indicates that the maximization in the numerator is done under the background-only hypothesis ($\mu = 0$). Since the Higgs boson signal cannot be negative, the allowed range for $\hat{\mu}$ is $\hat{\mu} \geqslant 0$. With this definition, a signal-like excess, $\hat{\mu} > 0$, corresponds to a positive value of q_0. In the absence of an excess, $\hat{\mu}$ is zero (the lowest allowed value), the likelihood ratio becomes equal to one, and $q_0 = 0$.

An excess can be quantified in terms of the p-value p_0, which is the probability to obtain a value of q_0 at least as large as the one observed in data, q_0^{obs}, under the background-only (b) hypothesis:

$$p_0 = P\big(q_0 \geqslant q_0^{\mathrm{obs}} \,\big|\, b\big). \tag{3}$$

We choose to relate the significance Z of an excess to the p-value via the Gaussian one-sided tail integral:

$$p_0 = \int_Z^{\infty} \frac{1}{\sqrt{2\pi}} \exp\big(-x^2/2\big)\,\mathrm{d}x. \tag{4}$$

The test statistic q_0 has one degree of freedom (μ) and, in the limit of a large number of events, its distribution under the background-only hypothesis converges to a half of the χ^2 distribution for one degree of freedom plus $0.5 \cdot \delta(q_0)$ [77]. The term with the delta function $\delta(q_0)$ corresponds to the 50% probability not to observe an excess under the background-only hypothesis. This asymptotic property allows the significance to be evaluated directly from the observed test statistic q_0^{obs} as $Z = \sqrt{q_0^{\mathrm{obs}}}$ [77].

The local p-value p_0 characterises the probability of a background fluctuation resembling a signal-like excess for a given value of the Higgs boson mass. The probability for a background fluctuation to be at least as large as the observed maximum excess anywhere in a specified mass range is given by the global probability or global p-value. This probability can be evaluated by generating pseudo-datasets incorporating all correlations between analyses optimized for different Higgs boson masses. It can also be estimated from the data by counting the number of transitions from deficit to excess in a specified Higgs boson mass range [76, 78]. The global significance is computed from the global p-value using Eq. (4).

3.3. *Quantifying the absence of a signal*

In order to set exclusion limits on a Higgs boson hypothesis, we define a test statistic q_μ, which depends on the hypothesised signal rate μ. The definition of q_μ makes use of a likelihood ratio similar to the one for q_0, but uses instead the signal + background model in the numerator:

$$q_\mu = -2\ln\frac{\mathcal{L}(\mathrm{data} \mid \mu \cdot s(\hat{\theta}_\mu) + b(\hat{\theta}_\mu))}{\mathcal{L}(\mathrm{data} \mid \hat{\mu} \cdot s(\hat{\theta}) + b(\hat{\theta}))}, \quad 0 \leqslant \hat{\mu} < \mu, \tag{5}$$

where the subscript μ in $\hat{\theta}_\mu$ indicates that, in this case, the maximisation of the likelihood in the numerator is done under the hypothesis of a signal of strength μ. In order to force one-sided limits on the Higgs boson production rate, we constrain $\hat{\mu} < \mu$.

This definition of the test statistic differs slightly from the one used in searches at LEP and the Tevatron, where the background-only hypothesis was used in the denominator. With the definition of the test statistic given in Eq. (5), in the asymptotic limit of a large number of background events, the expected distributions of q_μ under the signal + background and under the background-only hypotheses are known analytically [77].

For the calculation of the exclusion limit, we adopt the modified frequentist construction $\mathrm{CL_s}$ [79,80]. We define two tail probabilities associated with the observed data; namely, the probability to obtain a value for the test statistic q_μ larger than the observed value q_μ^{obs} for the signal + background ($\mu \cdot s + b$) and for the background-only (b) hypotheses:

$$\mathrm{CL_{s+b}} = P\big(q_\mu \geqslant q_\mu^{\mathrm{obs}} \,\big|\, \mu \cdot s + b\big), \tag{6}$$

$$\mathrm{CL_b} = P\big(q_\mu \geqslant q_\mu^{\mathrm{obs}} \,\big|\, b\big), \tag{7}$$

and obtain the $\mathrm{CL_s}$ value from the ratio

$$\mathrm{CL_s} = \frac{\mathrm{CL_{s+b}}}{\mathrm{CL_b}}. \tag{8}$$

If $\mathrm{CL_s} \leqslant \alpha$ for $\mu = 1$, we determine that the SM Higgs boson is excluded at the $1 - \alpha$ confidence level. To quote the upper limit on

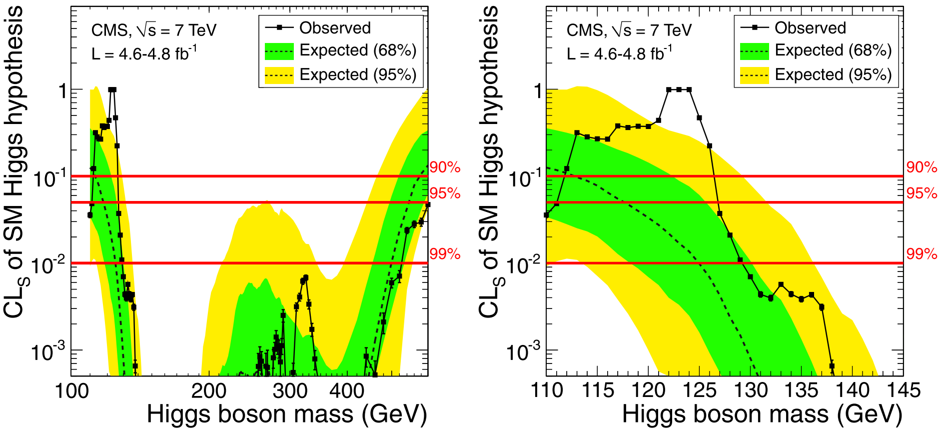


Fig. 2. The $\mathrm{CL_s}$ values for the SM Higgs boson hypothesis as a function of the Higgs boson mass in the range 110–600 GeV (left) and 110–145 GeV (right). The observed values are shown by the solid line. The dashed line indicates the expected median of results for the background-only hypothesis, while the green (dark) and yellow (light) bands indicate the ranges that are expected to contain 68% and 95% of all observed excursions from the median, respectively. The three horizontal lines on the $\mathrm{CL_s}$ plot show confidence levels of 90%, 95%, and 99%, defined as $(1 - \mathrm{CL_s})$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

μ at the 95% confidence level, we adjust μ until we reach $\mathrm{CL_s} = 0.05$.

4. Results

The $\mathrm{CL_s}$ value for the SM Higgs boson hypothesis as a function of its mass is shown in Fig. 2. The observed values are shown by the solid line. The dashed black line indicates the median of the expected results for the background-only hypothesis, with the green (dark) and yellow (light) bands indicating the ranges in which the $\mathrm{CL_s}$ values are expected to reside in 68% and 95% of the experiments under the background-only hypothesis. The probabilities for an observation to lie above or below the 68% (95%) band are 16% (2.5%) each. The observed and median expected values of $\mathrm{CL_s}$ as well as the 68% and 95% bands are obtained by generating ensembles of pseudo-datasets.

The thick red horizontal lines indicate $\mathrm{CL_s}$ values of 0.10, 0.05, and 0.01. The mass regions where the observed $\mathrm{CL_s}$ values are below these lines are excluded with the corresponding $(1 - \mathrm{CL_s})$ confidence levels of 90%, 95%, and 99%, respectively. We exclude a SM Higgs boson at 95% CL in the mass range 127–600 GeV. At 99% CL, we exclude it in the mass range 129–525 GeV.

In the mass range 122–124 GeV, the observed results lie above the expectation for the SM signal + background hypothesis. In this case, $\hat{\mu}$ is at its maximum allowed value μ, the test statistic $q_{\mu}^{\mathrm{obs}} = 0$ (Eq. (5)), and $\mathrm{CL_{s+b}}$, $\mathrm{CL_b}$ and hence $\mathrm{CL_s}$ equal unity (Eqs. (6)–(8)).

Fig. 3 shows the 95% CL upper limits on the signal strength modifier, $\mu = \sigma/\sigma_{\mathrm{SM}}$, obtained by generating ensembles of pseudo-datasets, as a function of m_{H}. The ordinate thus shows the Higgs boson cross section that is excluded at 95% CL, expressed as a multiple of the SM Higgs boson cross section.

The median expected exclusion range of m_{H} at 95% CL in the absence of a signal is 118–543 GeV. The differences between the observed and expected limits are consistent with statistical fluctuations since the observed limits are generally within the green (68%) or yellow (95%) bands of the expected limit values. For the largest values of m_{H}, we observe fewer events than the median expected number for the background-only hypothesis, which makes the observed limits in that range stronger than expected. However, at small m_{H} we observe an excess of events. This makes the observed limits weaker than expected in the absence of a SM Higgs boson.

Fig. 4 shows the separate observed limits for the eight individual decay channels studied, and their combination. For masses beyond 200 GeV, the limits are driven mostly by the $\mathrm{H} \to \mathrm{ZZ}$ decay channels, while in the range 125–200 GeV, the limits are largely defined by the $\mathrm{H} \to \mathrm{WW}$ decay mode. For the mass range below 120 GeV, the dominant contributor to the sensitivity is the $\mathrm{H} \to \gamma\gamma$ channel. The observed limits presented in Fig. 4 can be compared to the expected ones shown in Fig. 1. The results shown in both figures are calculated using the asymptotic formula for the $\mathrm{CL_s}$ method.

Fig. 5 shows two separate combinations in the low mass range: one for the $\gamma\gamma$ and $\mathrm{ZZ} \to 4\ell$ channels, which have good mass resolution, and another for the three channels with poor mass resolution (bb, $\tau\tau$, WW). The expected sensitivities of these two combinations are very similar. Both indicate an excess of events: the excess in the $\mathrm{bb} + \tau\tau + \mathrm{WW}$ combination has, as expected, little mass dependence in this range, while the excess in the $\gamma\gamma$ and $\mathrm{ZZ} \to 4\ell$ combination is clearly more localized. The results shown in Fig. 5 are calculated using the asymptotic formula.

To quantify the consistency of the observed excesses with the background-only hypothesis, we show in Fig. 6 (left) a scan of the combined local p-value p_0 in the low-mass region. A broad offset of about one standard deviation, caused by excesses in the channels with poor mass resolution (bb, $\tau\tau$, WW), is complemented by localized excesses observed in the $\mathrm{ZZ} \to 4\ell$ and $\gamma\gamma$ channels. This causes a decrease in the p-values for $118 < m_{\mathrm{H}} < 126$ GeV, with two narrow features: one at 119.5 GeV, associated with three $\mathrm{ZZ} \to 4\ell$ events, and the other at 124 GeV, arising mostly from the observed excess in the $\gamma\gamma$ channel. The p-values shown in Fig. 6 are obtained with the asymptotic formula and were validated by generating ensembles of background-only pseudo-datasets.

The minimum local p-value $p_{\min} = 0.001$ at $m_{\mathrm{H}} \simeq 124$ GeV corresponds to a local significance $Z_{\max}$ of 3.1σ. The global significance of the observed excess for the entire search range of 110–600 GeV is estimated directly from the data following the method described in Ref. [76] and corresponds to 1.5σ. For a restricted range of interest, the global p-value is evaluated using pseudo-datasets. For the mass range 110–145 GeV, it yields a significance of 2.1σ.

The p-value characterises the probability of background producing an observed excess of events, but it does not give information about the compatibility of an excess with an expected signal. The latter is provided by the best fit $\hat{\mu}$ value, shown in Fig. 6 (right).

[redacted]

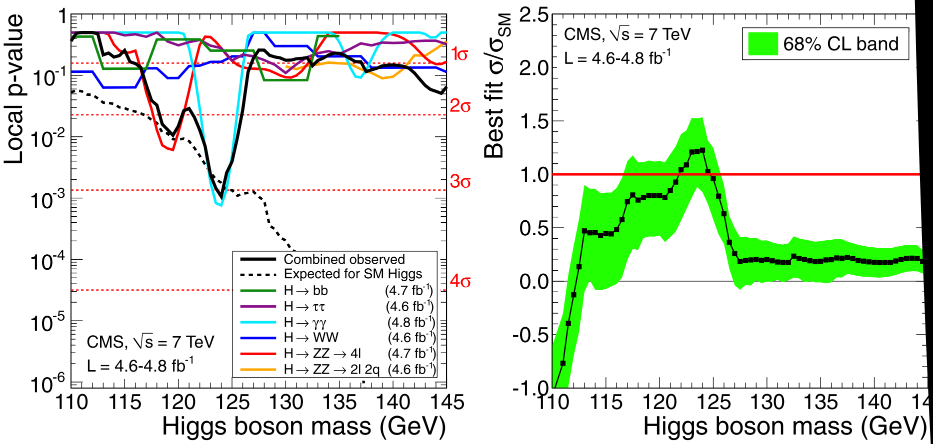
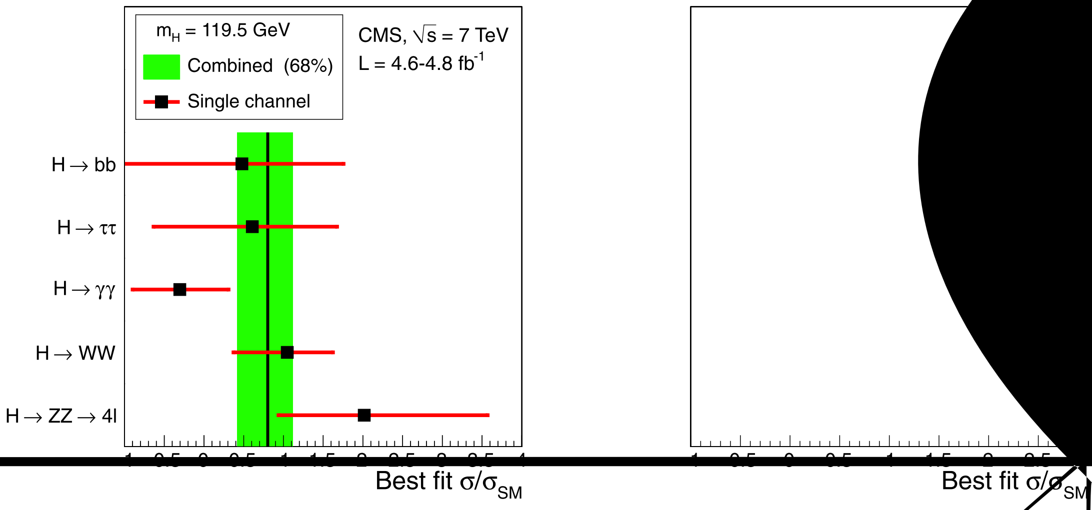


Fig. 6. The observed local p-value p_0 (left) and best-fit $\hat{\mu} = \sigma/\sigma_{\text{SM}}$ (right) as a function of the SM Higgs boson mass in the range 110–145 G
the observed maximum excess (minimum local p-value) in this mass range is about 2.1σ, estimated using pseudo-experiments. The dashed li
expected local p-values $p_0(m_{\text{H}})$, should a Higgs boson with a mass m_{H} exist. The band in the right plot corresponds to the $\pm1\sigma$ uncertainties



DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD (Serbia); MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA).

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