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Erratum

Erratum to: Measurement of $\psi(2S)$ meson production in pp collisions at $\sqrt{s} = 7$ TeV

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Abstract This erratum corrects measurements of the prompt and secondary (from-b) $\psi(2S)$ production cross-sections in the forward region in pp collisions at $\sqrt{s} = 7$ TeV. The original measurements were performed using data collected with the LHCb detector in 2010 and were published in the original article. Corrected results for prompt $\psi(2S)$ and $\psi(2S)$-from-b in the kinematic range $p_T(\psi(2S)) < 16$ GeV/c and $2.0 < y(\psi(2S)) < 4.5$ are

$$\sigma_{\text{prompt}}(\psi(2S)) = 1.37 \pm 0.01 \text{ (stat)} \pm 0.06 \text{ (syst)}^{+0.19}_{-0.38} \text{ (pol) } \mu\text{b},$$
$$\sigma_b(\psi(2S)) = 0.31 \pm 0.01 \text{ (stat)} \pm 0.02 \text{ (syst) } \mu\text{b}.$$

where the last uncertainty on the prompt cross-section is due to the unknown $\psi(2S)$ polarization. With the corrected $\psi(2S)$-from-b cross-section the inclusive branching fraction is updated by

$$\mathcal{B}(b \to \psi(2S)X) = (3.08 \pm 0.07(\text{stat}) \pm 0.36(\text{syst}) \pm 0.27(\mathcal{B})) \times 10^{-3}.$$

1 Erratum to: Eur Phys J C (2012) 72:2100 https://doi.org/10.1140/epjc/s10052-012-2100-4

1.1 Nature of the correction

In Ref. [1], the production rate of $\psi(2S)$ mesons in the rapidity range $2.0 < y < 4.5$ was measured for pp collisions at $\sqrt{s} = 7$ TeV using a sample of data corresponding to 36 pb^{-1}. Both overall and singly differential ($d\sigma/dp_T$) cross-sections were measured by fitting the invariant-mass spectra to obtain background-subtracted signal yields, which are subsequently efficiency corrected. Two decay modes were used: $\psi(2S) \to \mu^+\mu^-$ and $\psi(2S) \to J/\psi(\mu^+\mu^-)\pi^+\pi^-$.

Two sources of $\psi(2S)$ production are expected in this environment: mesons produced promptly in the primary interaction (whether directly or through the decay of an intermediate resonance), and those produced via the decays of b hadrons. The vast majority of b hadrons produced in the LHCb acceptance consist of B^0, B^+, B^0_s mesons and Λ^0_b baryons, all with mean lifetimes of approximately 1.5 ps. Consequently, the two classes of production may be separated according to whether the $\psi(2S)$ originates from the primary vertex (PV) or from a downstream secondary vertex. This separation must be done on a statistical level, since some b hadrons will decay close to the PV on the scale of the experimental resolution.

The pseudo-decay-time t_z was used to distinguish the two sources of production, and is defined as

$$t_z = \frac{(z_{\psi(2S)} - z_{\text{PV}}) \times M_{\psi(2S)}}{p_z}, \tag{1}$$

where $z_{\psi(2S)}$ and z_{PV} are the z coordinates of the reconstructed $\psi(2S)$ decay vertex and the primary vertex, p_z is the z-component of the measured $\psi(2S)$ momentum, $M_{\psi(2S)}$ is the known $\psi(2S)$ mass [2], and the z-axis is the direction of the proton beam pointing downstream into the LHCb acceptance. For a given sample of $\psi(2S)$ candidates, a fit to the t_z distribution was used to obtain the prompt fraction f_p, as described in Sec. 4 of Ref. [1].

Two distinct problems related to the determination of f_p in Ref. [1] have been identified. The first is that a mathematical mistake was made in calculating the systematic uncertainties on the from-b $\psi(2S)$ production cross-sections that arise due to uncertainties in the t_z fit; a factor of $f_p/(1 - f_p)$ was omitted. When this mistake is corrected, those systematic uncertainties increase by a factor 3 to 9, depending on the p_T defined in the range $0 - 16$ GeV/c, with the largest effect at low p_T, where the prompt fraction is close to unity. The correct formula is used in the results below.

The second problem is related to the values of f_p themselves. A mistake appears to have been made in the measurement of f_p via the fits to the t_z distributions used in Ref. [1].

The original article can be found online at https://doi.org/10.1140/epjc/s10052-012-2100-4.

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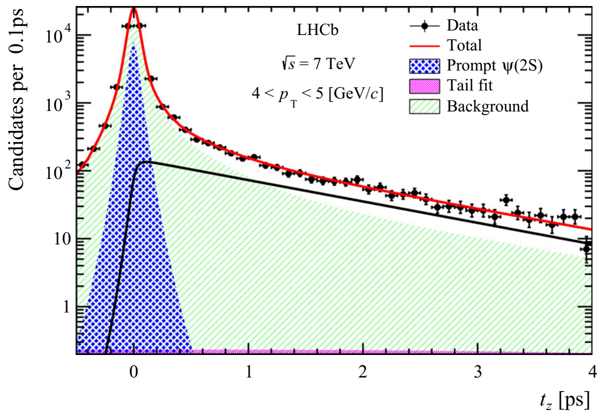

Fig. 3 Pseudo-decay-time t_z distribution for the $\psi(2S) \rightarrow \mu^+\mu^-$ decay mode in the range $4 < p_T \leq 5$ GeV/c, showing the background and prompt contributions

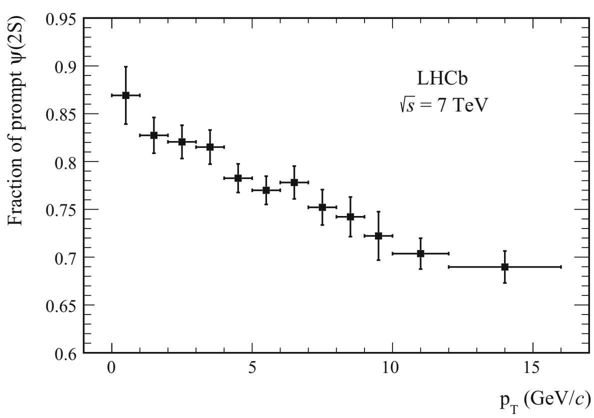

Fig. 4 Fraction of prompt $\psi(2S)$, f_p, as a function of p_T. The error bars include statistical and systematic uncertainties added in quadrature

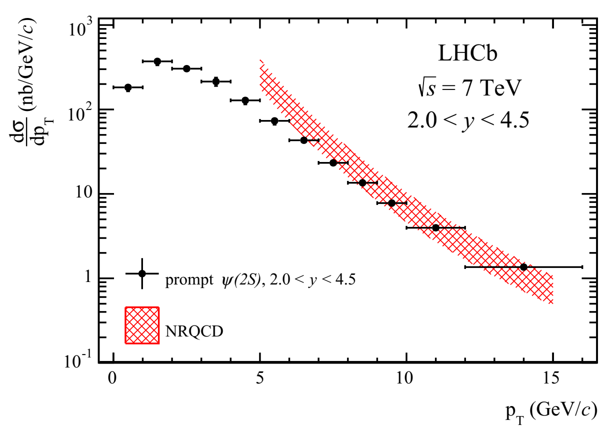

Fig. 7 Differential production cross-section of prompt $\psi(2S)$ as a function of p_T in the range $2.0 < y < 4.5$. The results are compared with the NRQCD calculations [4]. The error bars include statistical and systematic uncertainties added in quadrature

An independent reimplementation of the analysis finds consistently lower values of f_p. This change in f_p is associated with a change in the mean value of t_z seen for the from-b component: values of approximately 1.1 ps were found in the analysis reported in Ref. [1], compared to approximately 1.5 ps (much closer to the mean lifetime of contributing b hadrons) in the reimplementation. This issue has been found using both the original t_z fit function as described in Ref. [1] and the function used in Ref. [3]. The more sophisticated t_z fit function used in Ref. [3] achieves a more precise description of experimental data and is thus used in obtaining corrections as described below. An example of a t_z fit in the p_T range $4 < p_T \leq 5$ GeV/c is shown in Fig. 3.

Because the issue found is limited to the determination of f_p and does not affect the combined cross-section, and given that the reimplementation uses a sample of $\psi(2S) \rightarrow \mu^+\mu^-$ events that is correlated with but not identical to the original

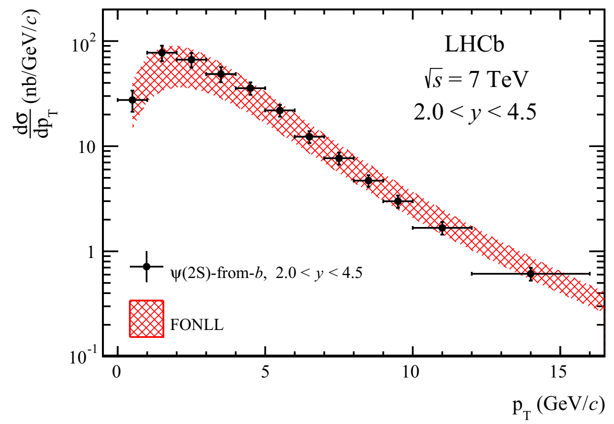

Fig. 8 Differential production cross-section of $\psi(2S)$ from b hadrons as a function of p_T in the range $2.0 < y < 4.5$. The results are compared with the FONLL calculations [5]. The error bars include statistical and systematic uncertainties added in quadrature

Table 2 Differential cross-sections $d\sigma/dp_T$ (in nb/(GeV/c)) of prompt $\psi(2S)$ and $\psi(2S)$-from-b hadrons at $\sqrt{s} = 7$ TeV, integrated over y between 2.0 and 4.5. The first uncertainty is statistical and the second systematic. The third asymmetric uncertainty for the prompt $\psi(2S)$ mesons is due to the unknown polarisation

p_T (GeV/c)	Prompt $\psi(2S)$	$\psi(2S)$-from-b
0–1	$183 \pm 6 \pm 18\ ^{+31}_{-65}$	$28 \pm 3 \pm 6$
1–2	$371 \pm 7 \pm 37\ ^{+58}_{-114}$	$77 \pm 4 \pm 13$
2–3	$304 \pm 6 \pm 26\ ^{+42}_{-84}$	$67 \pm 3 \pm 10$
3–4	$214 \pm 6 \pm 24\ ^{+26}_{-51}$	$49 \pm 3 \pm 8$
4–5	$128 \pm 4 \pm 13\ ^{+15}_{-29}$	$36 \pm 2 \pm 4$
5–6	$73 \pm 2 \pm 7\ ^{+9}_{-17}$	$22 \pm 1 \pm 3$
6–7	$43 \pm 1 \pm 4\ ^{+5}_{-9}$	$12 \pm 1 \pm 1$
7–8	$23 \pm 1 \pm 2\ ^{+3}_{-6}$	$7.7 \pm 0.5 \pm 0.9$
8–9	$14 \pm 1 \pm 1\ ^{+2}_{-3}$	$4.7 \pm 0.3 \pm 0.5$
9–10	$7.8 \pm 0.4 \pm 0.7\ ^{+0.8}_{-1.6}$	$3.0 \pm 0.3 \pm 0.3$
10–12	$4.0 \pm 0.2 \pm 0.4\ ^{+0.5}_{-0.7}$	$1.7 \pm 0.2 \pm 0.2$
12–16	$1.4 \pm 0.1 \pm 0.2\ ^{+0.2}_{-0.3}$	$0.61 \pm 0.05 \pm 0.07$
0–16	$1366 \pm 13 \pm 56\ ^{+190}_{-380}$	$308 \pm 6 \pm 19$

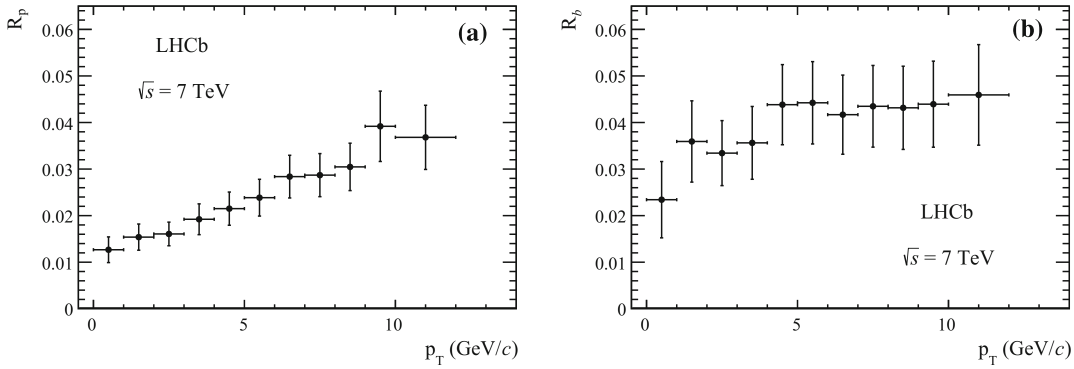

Fig. 9 Ratio of $\psi(2S) \to \mu^+\mu^-$ and $J/\psi \to \mu^+\mu^-$ cross-sections for prompt production (**a**) and for b-hadron decay (**b**), as a fucntion of p_T

analysis, the approach used in this erratum is to use the new and old values of f_p to determine a correction factor to apply to the results of the prompt and from-b cross-sections of the original analysis. (A separate and statistically independent analysis of the larger 7 TeV data sample taken in 2011 has been submitted [3] but is outside the scope of this erratum.) Defining $f_b \equiv 1 - f_p$ for convenience, the ratio

$$\mathcal{R}_b = \frac{f_b \text{ obtained with reimplementation}}{f_b(\psi(2S) \to \mu^+\mu^-) \text{ obtained in original analysis}} \tag{2}$$

is determined in bins of p_T. The correction is then obtained by fitting a linear function to the individual values of R_b. This also allows the correction to be extrapolated to kinematic regions where data were not available for the reimplementation ($p_T < 2\,\text{GeV}/c$, $p_T > 11\,\text{GeV}/c$). This correction is applied to the weighted average of $\psi(2S) \to \mu^+\mu^-$ and $\psi(2S) \to J/\psi\,(\mu^+\mu^-)\pi^+\pi^-$ results as reported by Ref. [1].

After applying the correction to f_b, the systematic uncertainties are recomputed. These are unchanged respect to those of the original analysis (other than relative uncertainties being updated for the new central values) except as described below. First, the the mistake in the computation of the uncertainty associated with the t_z fit is corrected as described above. Second, a new systematic uncertainty associated with the f_b correction estimate is added, and in particular the extrapolation outside the fit region, which is determined by taking the difference between the correction fitted by a first-order and a second-order polynomial.

1.2 Corrected results

The impact on f_p itself and on the cross-section for prompt production is modest: they are both reduced by an amount typically of the order of several percent. However the relative impact on f_b is greater, and the from-b cross-section rises by typically 20–25%.

Corrected versions of all figures and tables in Ref. [1] that were affected by the issue are given in the following. The corrected f_p distribution as a function of p_T is shown in Fig. 4. The singly differential cross-section as a function of p_T is shown for prompt production in Fig. 7, and for production from b-hadrons in Fig. 8. In the figures, the updated cross-sections are compared with theory predictions, namely NRQCD calculations [4] for prompt production and FONLL calculations [5] for production of $\psi(2S)$ from b-hadron decays. The integrated cross-sections in the nominal kinematic range for prompt $\psi(2S)$ and $\psi(2S)$-from-b are found to be

$$\sigma_{\text{prompt}}(\psi(2S)) = 1.37 \pm 0.01\ (\text{stat}) \pm 0.06\ (\text{syst})^{+0.19}_{-0.38}\ (\text{pol})\ \mu\text{b},$$
$$\sigma_b(\psi(2S)) = 0.31 \pm 0.01\ (\text{stat}) \pm 0.02\ (\text{syst})\ \mu\text{b}.$$

The numerical results are given in Table 2.

Corrected ratio of $\psi(2S) \to \mu^+\mu^-$ and $J/\psi \to \mu^+\mu^-$ cross-sections for prompt production (R_p) and for b-hadron decay (R_b) as a function of p_T is shown on Fig. 9.

The inclusive $b \to \psi(2S)X$ branching fraction is computed using the $\psi(2S)$-from-b cross-sections reported above and found to be

$$\mathcal{B}(b \to \psi(2S)X) = (3.08 \pm 0.07(\text{stat}) \pm 0.36(\text{syst}) \pm 0.27(\mathcal{B})) \times 10^{-3}.$$

The last uncertainty is due to those of the branching fractions, and is dominated by the $\mathcal{B}(b \to J/\psi\,X)$ uncertainty.

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