PROCEEDINGS OF SCIENCE

Prompt J/ψ and b $\rightarrow$ J/ψ X production in pp collisions at $\sqrt{s} = 7$ TeV

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The production of J/ψ mesons in proton–proton collisions at $\sqrt{s} = 7$ TeV is studied with the LHCb detector using the decay mode $J/\psi \rightarrow \mu^+\mu^-$. The differential production cross–section $d\sigma/dp_T$ is measured with the J/ψ transverse momentum in the range $p_T \in$[0; 10] GeV/c and rapidity in the range y$\in$[2.5; 4]. The analysis is based on a sample of 14.2 nb^{-1} collected between April and June 2010 at the Large Hadron Collider. The J/ψ from b–hadron decays are separated from prompt J/ψ using the J/ψ pseudo–propertime. From a fit to the invariant mass and to the pseudo–propertime distributions, we measure:

$$\sigma(\text{inclusive } J/\psi, p_T < 10\ \text{GeV/c}, 2.5 < y < 4) = 7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}\ \mu\text{b}$$

$$\sigma(J/\psi \text{ from b}, p_T < 10\ \text{GeV/c}, 2.5 < y < 4) = 0.81 \pm 0.06 \pm 0.13\ \mu\text{b},$$

where the first error is statistical and the second one systematic. For the inclusive cross–section, the third error indicates the acceptance uncertainty due to the unknown J/ψ polarization. By using PYTHIA 6.4 the above result is extrapolated to the average cross–section to produce b or $\overline{\text{b}}$–flavoured hadrons, H_b, in the pseudorapidity region covered by LHCb $2 < \eta < 6$ and to the full angular acceptance:

$$\sigma(pp \rightarrow H_b X,\ 2 < \eta(H_b) < 6) = 84.5 \pm 6.3 \pm 15.6\ \mu\text{b}$$

$$\sigma(pp \rightarrow b\bar{b}X) = 319 \pm 24 \pm 59\ \mu\text{b}$$

where the first error is statistical and the second one systematic and no additional uncertainty is assigned to the extrapolation method.

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1. Introduction

The J/ψ production mechanism in hadron collisions is still not well understood. There are three major sources of J/ψ production in pp collisions: direct J/ψ production; feed–down J/ψ from the decay of heavier prompt $c\bar{c}$ states; J/ψ from b–hadron decay chains. The first two sources will be called "prompt J/ψ" while the third will be abbreviated as "J/ψ from b". In this paper the measurement of the production cross–sections $d\sigma/dp_T$(inclusive J/ψ), σ(inclusive J/ψ) and σ(J/ψ from b), in the range $p_T \in$[0; 10] GeV/c and $y \in$[2.5; 4] is studied using the decay channel $J/\psi \to \mu^+\mu^-$. The J/ψ from b cross–section is used to extrapolate to the full LHCb angular acceptance with PYTHIA 6.4 program [1], and to measure the total $b\bar{b}$ cross–section at $\sqrt{s} = 7$ TeV. The study reported here is based on 14.2 nb^{-1}of pp collision data collected by the LHCb experiment [2] at the Large Hadron Collider between April and June 2010. Additional details on this analysis can be found in [3].

2. J/ψ selection and separation of prompt J/ψ and J/ψ from b

The first level (L0) trigger selection applied for this analysis requires one muon candidate with p_T > 320 MeV/c. The High Level Trigger (HLT) then requires the confirmation of the L0 muon candidate, with a harder p_T cut p_T > 1.3 GeV/c or the presence of a second muon such that $M_{\mu\mu}$ > 2.5 GeV/c^2. The J/ψ candidates are formed from pairs of opposite sign tracks reconstructed in the full tracking system with p_T > 700 MeV/c, identified as muons, with $\chi^2_{fit}/ndof < 4$ and sharing a common vertex with Prob(χ^2_{vertex}) > 0.001%. The J/ψ candidates are selected in the range $p_T \in$[0; 10] GeV/c and y∈[2.5; 4]. The resulting number of signal events is obtained by fitting the distribution of $M_{\mu\mu}$ with a Crystal Ball function [4] to describe the signal, and a first order polynomial for the background. The fit result is $N_{J/\psi} = 2872 \pm 73$ with a signal–to–background ratio of 1.3 within $\pm 3\sigma_M$ where $\sigma_M = 15.0 \pm 0.4$ MeV/c^2 and $M = 3088.3 \pm 0.4$ MeV/c^2 are the fitted mass resolution and mass central value respectively. The deviation from the nominal J/ψ mass is due to the not yet optimal calibration and alignment of the spectrometer for the data sample analysed. The mass distribution of all reconstructed J/ψ candidates is shown in Fig. 1 along with the result of the fit. To separate the prompt J/ψ component from J/ψ from b, the relatively long lifetime of b–hadrons is exploited. The two J/ψ components are discriminated by means of the pseudo–propertime defined as $t_z(J/\psi) = d_z \times M_J/\psi/p_z$ where d_z is the distance along the z–axis between the J/ψ decay vertex and the primary vertex, p_z is the measured J/ψ momentum z–component and $M_{J/\psi}$ is the nominal J/ψ mass. For events with several primary vertices (11% of the events), the one closest to the J/ψ vertex in the z direction is selected.

3. Cross–section determination

The number of signal events for the measurement of the inclusive J/ψ cross–section is estimated from the fit to the invariant mass distribution described in the previous section. The fit is performed independently in ten p_T bins of 1 GeV/c between 0 GeV/c and 10 GeV/c, integrating over the rapidity range y∈[2.5; 4]. The results of the fit are shown in Table 1. The fraction of J/ψ from b, f_b, is determined from a simultaneous fit to the pseudo–propertime t_z and the $\mu^+\mu^-$ invariant mass distributions. The signal t_z distribution is described by a delta function at t_z = 0 for the

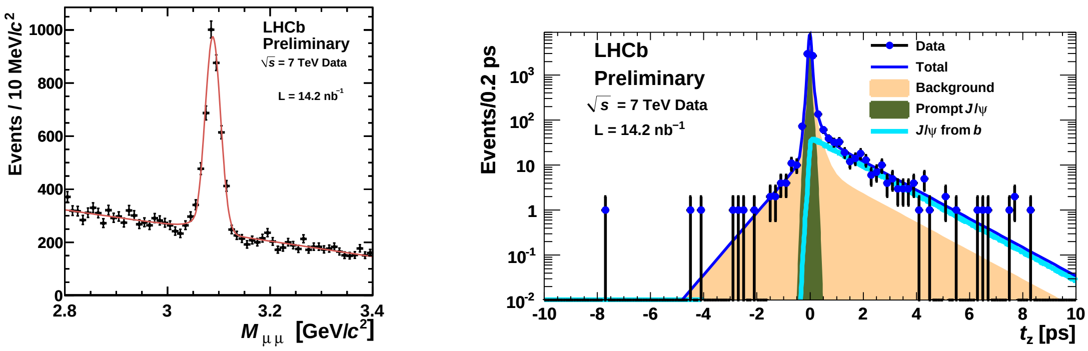

Figure 1: Left: invariant mass distribution for J/ψ candidates with $p_T \in [0; 10]$ GeV/c and y∈[2.5; 4] with the result of the fit described in the text superimposed. Right: t_z distribution of the J/ψ candidates with the result of the fit described in the text superimposed.

prompt J/ψ and an exponential for the J/ψ from b component, convoluted with a double Gaussian resolution function. The background contribution is inferred from the t_z distribution of the events in the J/ψ mass sidebands and is parametrized by an empirical function given by the sum of a Gaussian and three exponential functions convoluted with a Gaussian resolution function. The t_z distribution is fitted with an extended, unbinned maximum likelihood fit that yields a fraction $f_b = 11.1 \pm 0.8\%$, from which the production cross–section of J/ψ from b can be measured. The result of the fit is shown in Fig. 1.

4. Efficiency

The efficiency is estimated in each p_T bin with a sample of fully simulated inclusive unpolarised J/ψ. The result is given in Table 1. The total efficiency is 48.0± 0.1%. The efficiency depends rather strongly on the (unknown) J/ψ polarization. The efficiency variations due to this effect are estimated using Monte Carlo samples with unpolarised, transverse and longitudinal J/ψ (with polarization given in the helicity frame, neglecting any azimuthal dependence) and are taken into account as a systematic error in the cross–section measurement.

5. Systematic uncertainties

The largest systematic error (10%) comes from the luminosity measurement which is obtained using both Van der Meer scans and the *beam–profile* method [5]. The systematic uncertainties from trigger (2.8 % to 9.4 %, bin dependent), muon identification (2.5%) and tracking efficiency (8%) are estimated by a direct evaluation of the same quantities from data using control samples. Other contributions come from track and vertex selection (2.2%) p_T binning (1.4% to 3.9%, bin dependent), number of events in the J/ψ invariant mass radiative tail (1%) and from the error on $\mathscr{B}(J/\psi \to \mu^+\mu^-)$ (1%). All the above errors are correlated between p_T bins. As far as the J/ψ from b cross–section, an additional contribution to the systematic error (4%) comes from the unknown p_T spectrum of the J/ψ which is not directly measured. Finally, the uncertainties on the b hadronization fractions and on the average branching ratio of inclusive b–hadron decays to J/ψ

p_T(GeV/c)	0 – 1	1 – 2	2 – 3	3 – 4	4 – 5
N	427±31	823±40	687±36	398±24	259±18
ε(%)	42.7±0.2	43.0±0.1	44.2±0.1	47.5±0.2	53.0±0.2
σ(nb)	1216±88±202	2327±113±355	1889±99±263	1019±61±141	594±41±85
p_T(GeV/c)	5 – 6	6 – 7	7 – 8	8 – 9	9 – 10
N	163± 13	74± 9	34± 6	23± 5	10± 3
ε(%)	58.6 ±0.3	62.8 ±0.3	66.2 ±0.4	69.3 ±0.6	72.2 ±0.8
σ(nb)	338±27±47	143±17±20	62±11±9	40±9±6	17±5±2

Table 1: Fitted number of J/ψ candidates, efficiency and measured inclusive J/ψ cross–section in bins of J/ψ p_T, where the first error is statistical and the second is systematic

($\mathscr{B}(b \to J/\psi X) = 1.16 \pm 0.10\%$ [6]) give a systematic error of 2% and 9% respectively on the extrapolated b$\bar{\text{b}}$ cross–sections.

6. Results

The measured differential cross–section values, obtained using $\mathscr{B}(J/\psi \to \mu^+\mu^-) = 5.93 \pm 0.06\%$ [7], are shown in Table 1 with their statistical and systematic errors. These results, along with those obtained assuming longitudinally and transversely polarised J/ψ are shown in Fig. 2. The total cross–section for inclusive J/ψ production in the defined acceptance is:

$$\sigma(\text{inclusive } J/\psi, p_T < 10 \text{ GeV/c}, 2.5 < y < 4) = 7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}\ \mu\text{b} \tag{6.1}$$

$$\sigma(J/\psi \text{ from b}, p_T < 10 \text{ GeV/c}, 2.5 < y < 4) = 0.81 \pm 0.06 \pm 0.13\ \mu\text{b} \tag{6.2}$$

where the first error is statistical and the second one systematic. In the inclusive cross–section the third error is due to the efficiency dependence on the polarization. Using the LHCb Monte Carlo

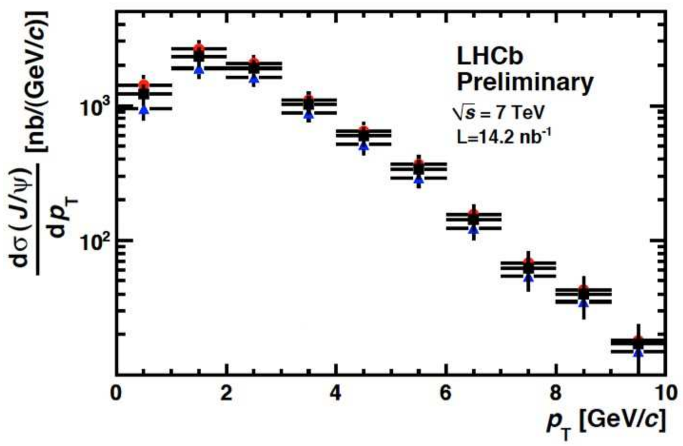

Figure 2: Measured p_T differential cross section for inclusive J/ψ production assuming unpolarised J/ψ (squares), longitudinally polarized J/ψ (triangles) and transversely polarized J/ψ (circles)

simulation based on PYTHIA 6.4 and EvtGen [8], the measurement of Eq. 6.2 is extrapolated to the average cross–section to produce b or $\bar{\text{b}}$–flavoured hadrons, H_b, in the pseudorapidity region covered by LHCb $2 < \eta < 6$ and to the full angular acceptance with the same method.

$$\sigma(pp \to H_b X,\ 2 < \eta(H_b) < 6) = 84.5 \pm 6.3 \pm 15.6\ \mu\text{b} \tag{6.3}$$

$$\sigma(pp \to b\bar{b}X) = 319 \pm 24 \pm 59\ \mu\text{b} \tag{6.4}$$

where the first error is statistical and the second one systematic and no additional uncertainty is assigned to the extrapolation method.

The above results are in excellent agreement with those obtained from $b \to D^0 \mu \nu X$ decays [9]. By combining the two sets of measurements, using the LEP b hadronization fractions, we obtain:

$$\sigma(pp \to H_b X,\ 2 < \eta(H_b) < 6) = 79.1 \pm 4.0 \pm 11.4\ \mu\text{b} \tag{6.5}$$

$$\sigma(pp \to b\bar{b}X) = 298 \pm 15 \pm 43\ \mu\text{b} \tag{6.6}$$

where the first error is statistical and the second one systematic and no additional uncertainty is assigned to the extrapolation method.

7. Prospects for the measurement

With more statistics available, at the level of about 50 pb^{-1}, the measurements discussed in this paper will be extended to a larger phase space ($p_T \in$[0;12] GeV/c, y$\in$[2;4.5]) and a doubly differential cross–section $d^2\sigma/dydp_T$ will be provided for both prompt J/ψ and J/ψ from b; the analysis will be extended to $\psi(2S)$ and other charmonium states. Finally, a measurement of the J/ψ polarization with full angular analysis and in bins of y and p_T will also be performed.

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