PROCEEDINGS OF SCIENCE

Quarkonia studies in LHCb: $\Upsilon(1S)$ and double J/ψ production

Julien Cogan (on behalf of the LHCb collaboration)*
CPPM, Aix-Marseille Université, CNRS/IN2P3
E-mail: `cogan@cppm.in2p3.fr`

The measurements of the $\Upsilon(1S)$ and double J/ψ production cross-sections based on $\sim 37\,\mathrm{pb}^{-1}$ of data collected with the LHCb detector at the LHC during the 2010 run are reported.

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*Speaker.

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1. Introduction

The heavy quark production mechanism in high energy hadron collisions is still an unsolved issue in QCD. Although improvements have been made recently in non-relativistic QCD (NRQCD) computations, the relative contribution of the colour-singlet and colour-octet mechanisms is still unclear. The measurement of the $\Upsilon(1S)$ production cross-section as a function of transverse momentum (p_T) is crucial to understand this issue. Further hints are expected by the measurement of the double J/ψ production cross-section . These proceedings present the preliminary measurements of the $\Upsilon(1S)$ and double J/ψ production cross-sections in pp collisions at the center of mass energy of $\sqrt{s} = 7\,\text{TeV}$ performed by the LHCb experiment [1] using the data sample collected between April and November 2010 at the Large Hadron Collider (LHC).

2. $\Upsilon(1S)$ production cross-section

The $\Upsilon(1S)$ double differential production cross-section is measured [2] as a function of the $\Upsilon(1S)$ transverse momentum (p_T) and rapidity (y) over the range $p_T \in [0;15]$ GeV/c and $y \in [2.0;4.5]$ using a data sample corresponding to an integrated luminosity of 32.4 pb^{-1}.

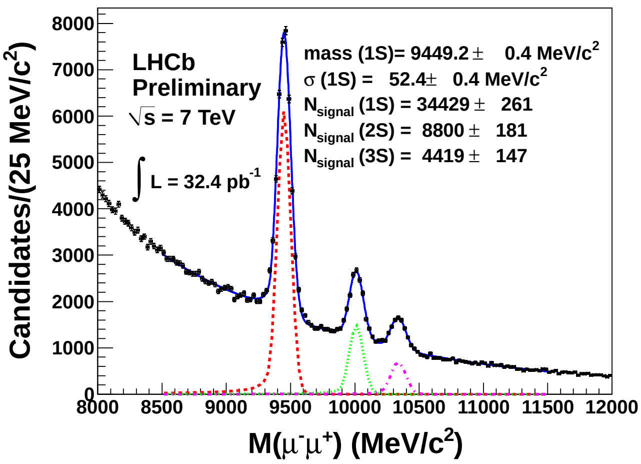

Figure 1: Invariant mass distribution of $\Upsilon(1S) \to \mu^+\mu^-$ candidates. The three peaks correspond to the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ signals (from left to right). The superimposed curves and the signal yields are the result of the fit described in the text.

The $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ states have been observed from their decays into two muons. As seen in Figure 1, the resolution is sufficient to clearly distinguish the three mass peaks. The phase space has been divided into bins of 1 GeV/c in p_T and into bins of one unit of rapidity in y. In each bin, the yields of the three observed Υ states have been extracted from a fit to the di-muon invariant mass distribution using three Crystal Ball functions to model the signal shapes and an exponential to model the background shape (see Figure 1). The detector acceptance and the reconstruction efficiency have been estimated for each p_T and y bin using a sample of fully simulated $\Upsilon(1S)$ events. The correction is obtained assuming unpolarised $\Upsilon(1S)$. The effect of this assumption on the acceptance has been studied by considering two extreme polarisation scenarios (fully transverse and fully longitudinal). This leads to the biggest systematic uncertainty on the result reported here. The trigger efficiency (ε_{trig}) is estimated from data as a function of the sum of the two muons p_T and of the mean of the two muons rapidity using a sample of independently triggered $J/\psi \rightarrow \mu^+\mu^-$ events. Each event in the di-muon invariant mass distribution is weigthed by ε_{trig}^{-1} and the distributions are refitted to get the trigger efficiency corrected yields. The systematic uncertainty associated with this method is evaluated using the sample of simulated $\Upsilon(1S)$ events. The measured $\Upsilon(1S)$ production cross-section, integrated over the fiducial region, is

$$\sigma(pp \rightarrow \Upsilon(1S)X;\, p_T(\Upsilon(1S)) < 15 \text{ GeV}/c;\, 2 < y(\Upsilon(1S)) < 4.5) = 108.3 \pm 0.7^{+30.9}_{-25.8} \text{ nb.}$$

where the first uncertainty is statistical, and the second is systematic.

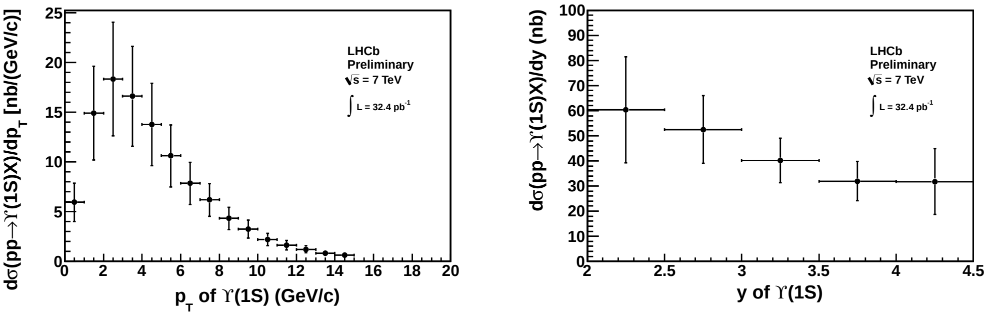

Figure 2: Differential $\Upsilon(1S)$ production cross-sections as a function of p_T (*left*) and as a function of y (*right*)

The measured $\Upsilon(1S)$ differential production cross-sections as a function of p_T and y are shown in Figures 2. Their values are in good agreement with the NL0 NRQCD theoretical predictions taking into account the $\Upsilon(1S)$ feed down of heavier prompt bottomonium states like χ_b or excited Υ states (see Figure 3). The comparison with the recent measurement from CMS has also been performed (see Figure 3). The two measurements nicely complement each other since the CMS measurement region stops at $y = 2$ where the LHCb measurements start.

3. Double J/ψ production cross-section

The production of two J/ψ in the same pp interaction is expected to be rare. The only observation of double J/ψ production in hadronic collisions was done by the NA3 collaboration [5]. Theoretical calculations based on leading order QCD perturbation theory predict that the total cross section of J/ψ pair production in pp interaction at $\sqrt{s} = 7$ TeV is equal to ~ 24.5 nb [6]. At LHCb, the double J/ψ production cross-section has been measured [7] for both J/ψ being produced in the rapidity range $y \in [2.0; 4.5]$ and $p_T < 10\,\text{GeV}/c$. A data sample corresponding to an integrated luminosity of 35.2 pb^{-1} has been used.

The two J/ψ mesons have been reconstructed from their decays into two muons. Events with the two J/ψ mesons originating from a common primary vertex have been selected by constraining the χ^2 of the vertex of the 4 muons. The effect of pile-up, which could lead to a contamination by events with the two J/ψ from two different pp interactions has been found to be negligible. The

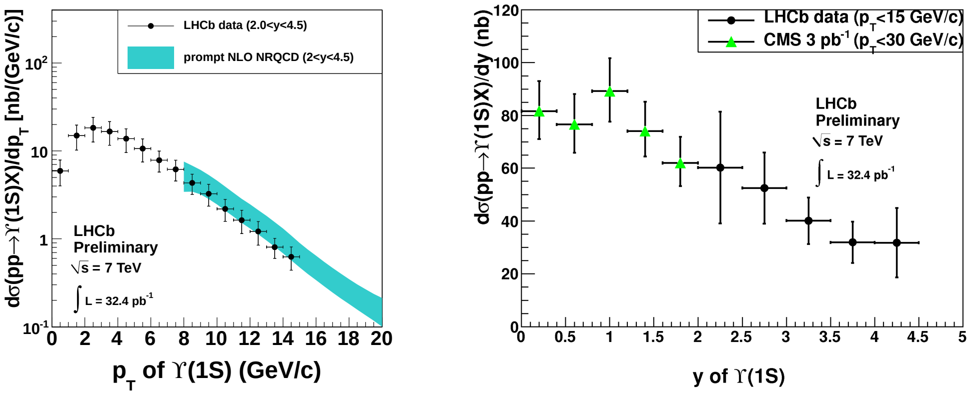

Figure 3: The LHCb differential $\Upsilon(1S)$ production cross-sections as a function of p_T compared with the predictions from NLO NRQCD [3] (*left*) and as a function of y compared with the CMS measurement [4] (*right*).

number of double J/ψ events has been extracted using a double background subtraction procedure. The invariant mass distribution of the first J/ψ has been build in bins of the invariant mass of the second J/ψ [1]. In each bin, the yield is extracted fitting a Crystal Ball and an exponential to the J/ψ mass distribution. The total yield is determined from the mass distribution of the second J/ψ by fitting the same function (see Figure 4). A total of 139.6 ± 17.8 double J/ψ candidates have been observed corresponding to a statistical significance $> 6\,\sigma$.

The detector acceptance and the reconstruction efficiency are factorized into the product of efficiency of the first and second J/ψ. The detector acceptance and the reconstruction efficiency of the individual J/ψ mesons have been determined using a sample of simulated J/ψ in bins of p_T, y and $cos(\theta)$, where θ is the angle between the μ^+ momentum in the J/ψ centre-of-mass frame and the direction of the Lorentz boost of the J/ψ with respect to the laboratory frame. The same kind of factorization is applied to extract the trigger efficiency where the individual J/ψ efficiency is directly measured from the data in bins of p_T and y. The corrected event yield is obtained by applying the double background subtraction procedure to mass distributions which have been efficiency corrected event by event. The measured double J/ψ production cross-section in the quoted phase-space region is $\sigma_{J/\psi\, J/\psi} = 5.6 \pm 1.1 \pm 1.2$ nb where the first uncertainty is statistical and the second is systematic. The systematic uncertainty is dominated by the tracking uncertainties related to the four tracks involved in the final states and by the luminosity determination. This result is in good agreement with the theoretical calculation [6] which predicts, in the LHCb fiducial region, 4.34 nb (4.15 nb) with (without) initial state gluon radiation included. The measured double J/ψ invariant mass distribution is shown on Figure 4 together with the theoretical prediction.

4. Conclusion

Preliminary measurements of the $\Upsilon(1S)$ and double J/ψ production cross-sections performed

[1]The first J/ψ is choosen to be the one with lower transverse momentum.

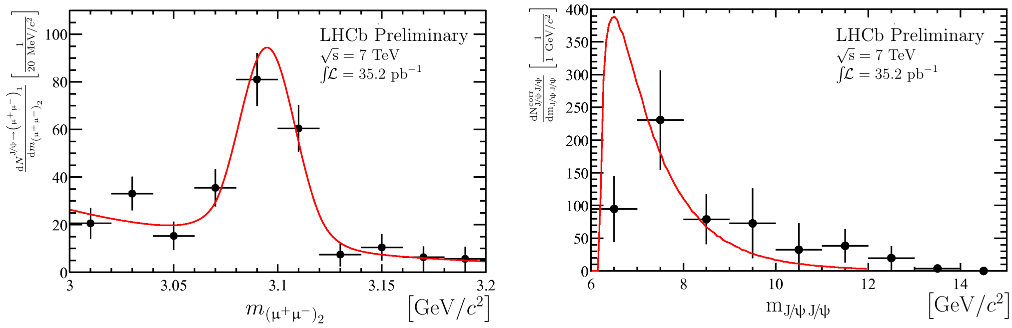

Figure 4: *Left* : the fitted observed yields of $J/\psi \to (\mu^+\mu^-)_1$ in bins of $(\mu^+\mu^-)_2$ invariant mass. The line represents a fit with a double Crystal Ball function for the signal and an exponential function for the background. *Right* : the efficiency corrected yields of $J/\psi\ J/\psi$ events as a function of the invariant mass of the $J/\psi\ J/\psi$ system (points with error bars). The overlayed curve corresponds to the $J/\psi\ J/\psi$ invariant mass spectrum predicted by the model of Ref. [6].

by the LHCb collaboration with the data aquired in 2010 have been presented. These measurements are in good agreement with recent theoretical computations. In the future, LHCb will extend the measurement to the $\Upsilon(2S)$ and $\Upsilon(3S)$ as well as to the $\psi(2S)$.

References

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