Quarkonium Results at the LHC

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1 Introduction

Despite the first observation of Quarkonium states like J/ψ dates back to almost forty years ago, the mechanism of hadro-production is still unclear. Several models exist, for example the Color-Singlet (CS) and Color-Octect(CO) within the Non Relativistic QCD framework, or the Color Evaporation Model. So far none of the models is able to correctly reproduce both the measured production cross sections and polarisation. At the centre-of-mass energy of 7 TeV reached at the Large Hadron Collider (LHC) the ALICE, ATLAS, CMS and LHCb experiments have the potential to elucidate the model of Quarkonium production as well as probe the existence of the new states recently observed.
The experiments started the operations in late 2009, and collected roughly 40 pb^{-1} of pp data by Summer 2010. All the experiments were fully operational during the data taking periods considered here, with efficiencies close to or above 90%. The two central experiments, ATLAS and CMS, cover a rapidity range of approximately $-2 < y < 2$ for the analyses considered here, while ALICE and LHCb have a more asymmetric coverage extending in the region of $2.5 < y < 4$ and $2 < y < 4.5$ respectively. In this paper the production cross sections of single and double J/ψ, Υ and $\psi(2S)$ in the dimuon decay channel are presented . The first results on $X(3872)$ are also briefly discussed.

2 J/ψ Production

Three sources of J/ψ production in pp collisions need to be considered when comparing experimental observables and theoretical calculations: direct J/ψ production, feed- down J/ψ from the decay of other prompt charmonium states, and J/ψ from b-hadron decay chains. The sum of the first two sources will be called "*prompt* J/ψ", the third "J/ψ *from b*". The measurement of the differential production cross-section of both *prompt* J/ψ and J/ψ from b as a function of the J/ψ p_{T} and rapidity (y) is discussed in the four LHC experiments [1, 4]. The *prompt* component is separated from the "*from B*" one using the pseudo proper time variable t_z defined as $t_z = \frac{(z_{J/\psi} - z_{\rm PV}) \times M_{J/\psi}}{p}$, where $z_{J/\psi}$ and $z_{\rm PV}$ are the positions along the z-axis of the J/ψ decay vertex and of the primary vertex; p_z is the measured J/ψ momentum in the z direction and $M_{J/\psi}$ the nominal J/ψ mass. The details of the measurements are summarised in Table 1. The cross-sections are obtained assuming no J/ψ polarisation and the third uncertainty indicates the acceptance uncertainty due to this, while the results in the individual $p_{\rm T} - y$ bins are given for the three scenarios, unpolarised, totally transverse and totally longitudinal polarisation [1, 4]. Fig. 1 shows the J/ψ inclusive cross section as a function of $J/\psi\, p_{\rm T}$ for the four experiments, and the fraction of J/ψ *from B* for the ATLAS and LHCb experiments [5]. The results agree given the different $p_{\rm T}$ and y ranges. The fraction *from B* agrees at low $p_{\rm T}$ and shows a saturation at larger $p_{\rm T}$ values.

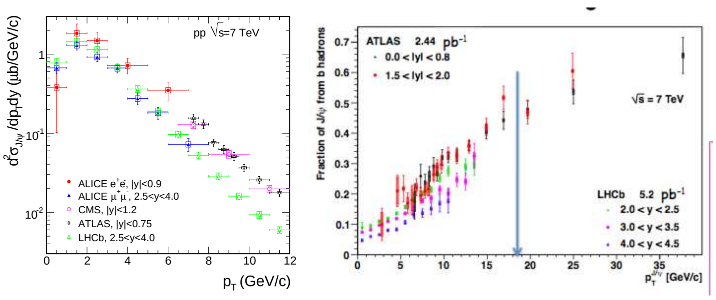

Figure 1: Left: Inclusive J/ψ cross section as a function of $J/\psi\, p_{\rm T}$ for the four LHC experiments. Right: Fraction of J/ψ *from B* as a function of $J/\psi\, p_{\rm T}$ measured by ATLAS and LHCb.

LHCb has also reported the first observation of double J/ψ production at a hadron collider [6]. The cross section has been measured in the range $2.0 < y < 4.5$ and $p_{\rm T} < 10\,{\rm GeV/c}$ for a sample of 136.7±17.5 candidates in 37.5 pb^{-1} and found to be $\sigma_{J/\psi J/\psi} = 5.1 \pm 1.0 \pm 1.1$ nb, in agreement with the theoretical expectations [7] of 4.3 nb.

	$\int\mathcal{L}$ (pb^{-1})	$p_{\rm T}$ range (GeV/c)	y range	$\sigma^{J/\psi}_{inclusive}\times\mathcal{B}(J/\psi\to\mu\mu)$	$\sigma^{J/\psi}_{prompt}\times\mathcal{B}(J/\psi\to\mu\mu)$	$\sigma^{J/\psi}_{fromB}\times\mathcal{B}(J/\psi\to\mu\mu)$
ALICE	0.0156	0-12	2.5< y <4.0			$(6.31\pm0.25\pm0.76^{+0.95}_{-1.96}\mu{\rm b})\times\mathcal{B}(J/\psi\to\mu\mu)$
ATLAS	2.3	>7	$\lvert y\rvert$ <2.4	$59\pm1\pm8^{+9}_{-6}\pm2$ nb	$23.0\pm0.6\pm2.8\pm0.2\pm0.8$ nb	$81\pm1\pm10^{+25}_{-20}\pm3$ nb
ATLAS	2.3	$1-70$	1.5< $\lvert y\rvert$ <2	$450\pm70^{+90+90}_{-110-110}\pm20$ nb	$61\pm24\pm19\pm1\pm2$ nb	$510\pm70\pm^{+80+920}_{-120-130}\pm20$ nb
CMS	0.314	6.5-30	$\lvert y\rvert$ <2.4		70.9±2.1±3.0±7.8 nb	26.0±1.4±1.6±2.9 nb
LHCb	5.2	0-14	2.0< y <4.5		$(10.52\pm0.04\pm1.40^{+1.64}_{-2.20}\ \mu{\rm b})\times\mathcal{B}(J/\psi\to\mu\mu)$	$(1.14\pm0.01\pm0.16\ \mu{\rm b})\times\mathcal{B}(J/\psi\to\mu\mu)$

Table 1: Summary of the J/ψ results from the four LHC experiments ($\mathcal{B}(J/\psi \to \mu\mu)$ = 0.059). The first uncertainty is statistical, the second systematic and the third due to the unknown J/ψ polarisation.

3 $\psi(2S)$ Production

LHCb recently measured [8] the production cross section of the $\psi(2S)$ meson in both its decay channel to $\mu\mu(\mathcal{B} = (7.7 \pm 0.8) \times 10^{-3})$ and $J/\psi(\to \mu\mu)\pi\pi(\mathcal{B} = (19.9 \pm 0.3) \times 10^{-3})$. Despite the larger rate, the second decay mode suffers from large combinatorial background and has to go through stricter selection criteria, thus sensibly reducing the statistics and efficiency. The signal corresponds to 89374±718 $\psi(2S) \to \mu\mu$ and 11234±174 $\psi(2S) \to J/\psi\pi\pi$ events, in 37 pb^{-1} of data. The inclusive cross section has been measured in the range ($2.0 < y < 4.5$, $p_{\mathrm{T}} < 12$ GeV/c) and ($2.0 < y < 4.5$, $3 < p_{\mathrm{T}} < 16$ GeV/c) for the $\mu\mu$ and $J/\psi\pi\pi$ mode respectively, and found to be $\sigma_{\psi(2S)\to\mu\mu} = 1.88 \pm 0.02 \pm 0.31^{+0.25}_{-0.48}\,\mu b$ $\sigma_{\psi(2S)\to J/\psi\pi\pi} = 0.62 \pm 0.04 \pm 0.12^{+0.27}_{-0.14}\,\mu b$, where the first uncertainty is statistical, the second systematic and the third is due to the unknown $\psi(2S)$ polarisation. This result is in agreement with the theory predictions [9]. This measurement is currently being updated with the separation of the *prompt* component and the component *from B* decays, of particular theoretical interest.

4 Υ Production

Three of the bottomonium Υ states can be reconstructed in their dimuon decay channel, $\Upsilon(1S)$,$\Upsilon(2S)$ and $\Upsilon(3S)$. Due to the larger momentum, the background is lower than for the J/ψ and the Υ states can be cleanly identified at all four experiments. CMS [10] and LHCb [11] have presented measurements of the Υ cross sections as a function of the Υ p_{T} and y, as reported in Table 2. The double differential cross section and the one integrated over p_{T} as a function of y are shown in Fig. 2. Although there is no overlapping region in rapidity between the two experiments, the measurements show the same trend and are both consistent with the theory models examined. ATLAS has also recently measured the Υ cross sections finding consistent results [12].

		$\int \mathcal{L}$ (pb^{-1})	p_{T} range (GeV/c)	y range	$\sigma^{\Upsilon} \times \mathcal{B}(\Upsilon \to \mu\mu)$
LHCb	$\Upsilon(1S)$	32.4	0-15	2.0< y <4.5	$(108.3 \pm 0.7^{+30.9}_{-25.8}\mathrm{nb}) \times \mathcal{B}(\Upsilon \to \mu\mu)$
CMS	$\Upsilon(1S)$	3.1	6.5-30	$\lvert y \rvert$ <2.0	$7.37 \pm 0.13^{+0.61}_{-0.42} \pm 0.81$ nb
	$\Upsilon(2S)$	3.1	6.5-30	$\lvert y \rvert$ <2.0	$1.90 \pm 0.09^{+0.20}_{-0.14} \pm 0.24$ nb
	$\Upsilon(3S)$	3.1	6.5-30	$\lvert y \rvert$ <2.0	$1.02 \pm 0.07^{+0.11}_{-0.08} \pm 0.11$ nb

Table 2: Summary of the Υ results from the CMS and LHCb experiments ($\mathcal{B}(\Upsilon \to \mu\mu)$ 0.02). The first uncertainty is statistical, the second systematic and the third due to the unknown J/ψ polarisation.

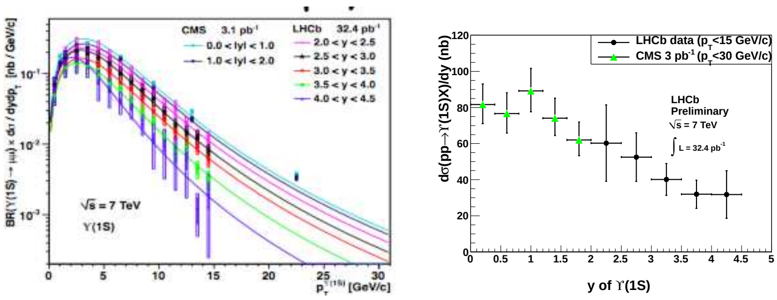

Figure 2: Left: Double differential $\Upsilon(1S)$ cross section as a function of $\Upsilon(1S) p_{\rm T}$, as measured by the CMS and LHCb experiments. Right: $\Upsilon(1S)$ cross section integrated over $p_{\rm T}$ as a function of y for the CMS and LHCb experiments.

5 X(3872) Mass and Production

The X(3872) is a state recently discovered by Belle [13] and later confirmed by other experiments. It decays into $J/\psi\pi\pi$ similarly to the $\psi(2S)$. Little is known of this state yet, and the statistics collected by the LHC is expected to cast light on the X(3872) unknown properties. CMS has identified 548±104 X(3872) signal events and measured the production cross section of the X(3872) into $J/\psi\pi\pi$, relative to the $\psi(2S)$ cross section [14], finding R$=\frac{\sigma_{X(3872)}}{\sigma_{\psi(2S)}} = 0.087 \pm 0.017(stat) \pm 0.009(syst)$ in 40 pb^{-1}. With 585±74 events in 35 pb^{-1}, LHCb has measured the X(3872) mass [15], finding the value of M(X(3872)) = 3871.96±0.46±0.10 MeV/c^2, in excellent agreement with the previous measurements. In the same sample LHCb has also recently measured the X(3872) production cross section [16], finding the value of $\sigma_{X(3872)} = 4.74 \pm 1.10(stat) \pm 1.01(syst)$ nb.

6 Conclusions and Outlook

We reviewed selected results from the four LHC experiments in the field of Quarkonium production. The production cross sections of $J/\psi, \psi(2S), \Upsilon$ have been measured and agree well with the theoretical models considered. The mass and cross section of the X(3872) meson have also been measured, setting the basis for studying the unknown properties of this states, which will be possible with the large statistics collected in the next year. With the better knowledge of the detectors and the larger luminosity, the polarisation measurements for all states will also be performed, which will be crucial in identifying the model of Quarkonium production.

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