Quarkonium production measurements and searches for exotic quarkonia at CMS

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Abstract. The CMS experiment at the LHC studies conventional and exotic quarkonia. CMS measured the quarkonium polarization of prompt Ψ(nS) and Υ(nS) states, using 2011 data taken in pp collisions at $\sqrt{s} = 7$ TeV. No strong polarization was observed in any of the states. The prompt Ψ(nS) differential production cross section was determined up to and even beyond 100 GeV. The production of X(3872) in its decay to $J/\psi\pi^+\pi^-$ was also measured, using data taken in pp collisions at $\sqrt{s} = 7$ TeV. The cross section times the branching fraction of the X(3872) relative to the one of ψ(2S) and the fraction of X(3872) originating from B decays were determined. The prompt X(3872) differential cross section times branching fraction as a function of p_T was extracted. Furthermore, a search for the exotic quarkonium X_b, decaying to $\Upsilon(1S)\ \pi^+\pi^-$ in the mass range of 10 to 11 GeV, was conducted using data collected in pp collisions at $\sqrt{s} = 8$ TeV. No evidence of a X_b signal was observed. An upper limit on the relative inclusive production cross section times branching ratio of the X_b and Υ(2S) states at was set.

1. Introduction

Quarkonia are ideal systems to study how the strong interaction binds quarks into hadrons since the formation of the initial quark-antiquark pair and the transformation into a bound state happens at very different timescales [1]. Quarkonium production and polarization are strongly intertwined. This paper starts with a short discussion of CMS quarkonium polarization measurements followed by recent results on quarkonium cross sections. CMS also conducted searches and studies of exotic quarkonia, which are presented in Section 4.

2. Quarkonium polarization

Quarkonium polarization measurements are very challenging. The polarization of $J^{PC} = 1^{--}$ quarkonium states can be studied through the angular decay distribution of the leptons (here muons). The most general observable distribution of a parity-conserving dilepton decay of vector particles can be written as

$$W(\cos\vartheta, \varphi|\vec{\lambda}) = \frac{3/(4\pi)}{(3+\lambda_\vartheta)}(1 + \lambda_\vartheta \cos^2\vartheta\, + \lambda_\varphi \sin^2\vartheta \cos 2\varphi + \lambda_{\vartheta\varphi} \sin 2\vartheta \cos\varphi)\,, \quad (1)$$

where $\vec{\lambda} = (\lambda_\vartheta,\ \lambda_\varphi,\ \lambda_{\vartheta\varphi})$ represents the frame-dependent polarization parameters and ϑ and φ are the polar and azimuthal angles of the positive muon with respect to the z-axis of the

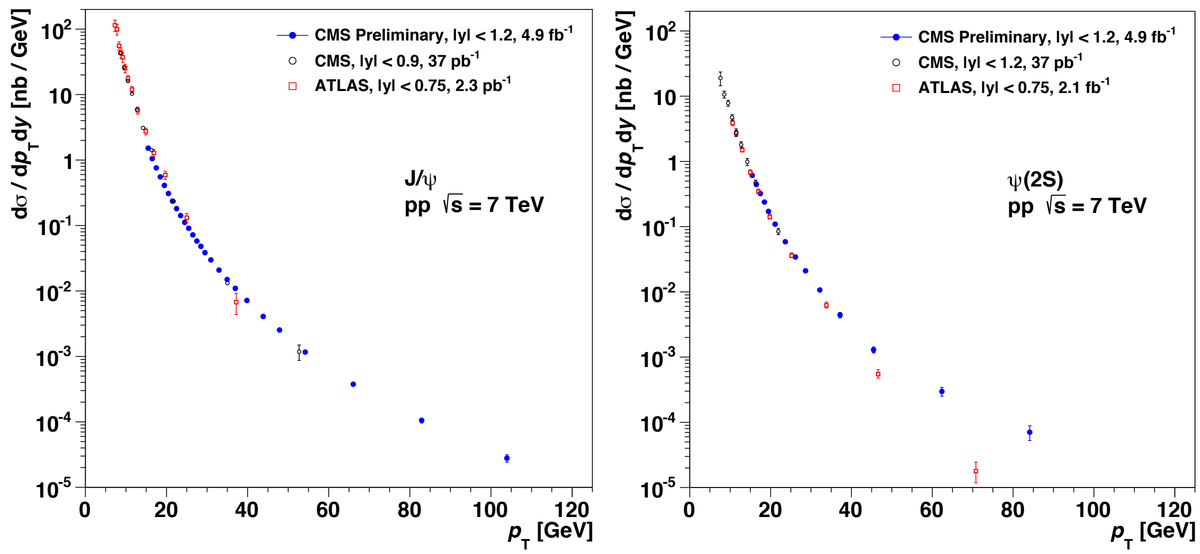

Figure 1. Differential production cross section for the prompt J/ψ (left) and ψ(2S) state (right), for $|y|$ <1.2, compared to previous CMS [10] and ATLAS measurements [11, 12]. In case of the ψ(2S), preliminary ATLAS results are used. The global uncertainties from the integrated luminosity and from the branching fractions are not shown.

chosen reference frame [2, 3]. CMS used three different reference frames: the center-of-mass helicity frame (HX) coinciding with the direction of the quarkonium momentum, the Collins-Soper frame [4] and the perpendicular helicity frame [5].

CMS determined the three frame-dependent polarization parameters and the frame-invariant quantity $\tilde{\lambda} = (\lambda_\vartheta + 3\lambda_\varphi)/(1 - \lambda_\varphi)$ in the three reference frames for the prompt ψ(nS) (n=1,2) and Υ(nS) (n=1,2,3) mesons. A dimuon data sample taken in pp collisions at $\sqrt{s}$ = 7 TeV corresponding to a total integrated luminosity of 4.9 fb^{-1} was used. No strong polarization was observed for any of the states, in the studied dimuon transverse momentum, p_T, and rapidity, $|y|$, ranges [6, 7].

3. Quarkonium cross sections

The measurement of quarkonium cross sections strongly depends on the polarization. The most recent CMS measurement of the prompt ψ(nS) production cross section [8] uses four different polarization scenarios in the acceptance calculation: no polarization, two extreme polarizations ($\lambda_\vartheta^{HX} = \pm 1$) and the polarization as measured by CMS averaged over all dimuon p_T and $|y|$ ranges. The same data sample as in the ψ(nS) polarization measurements was used. The efficiency and acceptance corrected yields of the prompt ψ(nS) mesons were extracted using an unbinned maximum likelihood fit to the dimuon invariant mass and decay length distribution [9].

Figure 1 shows the unpolarized double differential cross section of the prompt ψ(nS) mesons in comparison to CMS measurements using 2010 data [10] and results from ATLAS [11, 12]. The most recent CMS measurement considerably extends the reach in p_T with respect to the previous one. In case of the ψ(2S), the findings of CMS disagree with the preliminary result of ATLAS [12] at high p_T, while agreeing with the final result of ATLAS [13].

4. Exotic quarkonia

In the last decade, a plethora of exotic states decaying into heavy quarkonia have been observed. Amongst the first ones to be discovered was the X(3872) state [14].

CMS studied the production of X(3872) decaying to $J/\psi\pi^+\pi^-$ in pp collisions at $\sqrt{s}$ = 7 TeV [15]. The data used correspond to a total integrated luminosity of 4.8 fb^{-1}. The inclusive cross section times branching fraction of X(3872) relative to the one of ψ(2S) was determined as a function of p_T. Additionally, the fraction of X(3872) originating from B decays was measured to be 6.56 ± 0.29 (stat.) ± 0.65 (syst.)%. Using these results and the prompt ψ(2S) cross section measurement [10], the differential production cross section of X(3872) was calculated. Figure 2 shows a comparison of the measured rate with Non Relativistic Quantum ChromoDynamics (NRQCD) calculations [16]. While the prediction is larger than the measurement, the dependence on p_T is reasonably well modelled.

CMS also looked for the bottomonium counterpart, X_b, of the X(3872) state [17]. The analysis was based on a data sample collected in pp collisions at $\sqrt{s}$ = 8 TeV, corresponding to an integrated luminosity of 20.7 fb^{-1}. The mass of the X_b has been predicted to lie between 10 and 11 GeV [18, 19, 20]. Therefore, a search for the X_b decaying to $\Upsilon(1S)\pi^+\pi^-$ was conducted in this mass range, excluding the Υ(2S) and Υ(3S) regions. No excess signal was observed. Upper limits on the inclusive production cross section times the branching fraction of the X_b relative to the one of Υ(2S) were set at the 95% confidence level (CL). The upper limits are within 0.9–5.4%, as shown in Fig. 3. These are the first upper limits on the production of a possible X_b from a hadron collider.

5. Summary

CMS performed measurements of the polarizations of the prompt ψ(nS) and Υ(nS) states, using data collected in pp collisions at $\sqrt{s}$ = 7 TeV. No strong polarization was observed for any of the quarkonium states studied. The double differential cross sections of the prompt ψ(nS) states were also determined, considerably extending the reach in p_T up to and even beyond 100 GeV.

CMS also conducted studies of exotic quarkonia. The fraction of X(3872) originating from B decays was measured to be (6.56 ± 0.29 (stat.) ± 0.65 (syst.))%. The inclusive cross section times branching fraction of X(3872) relative to the one of ψ(2S) and the cross section times branching fraction of the prompt X(3872) were determined as a function of p_T.

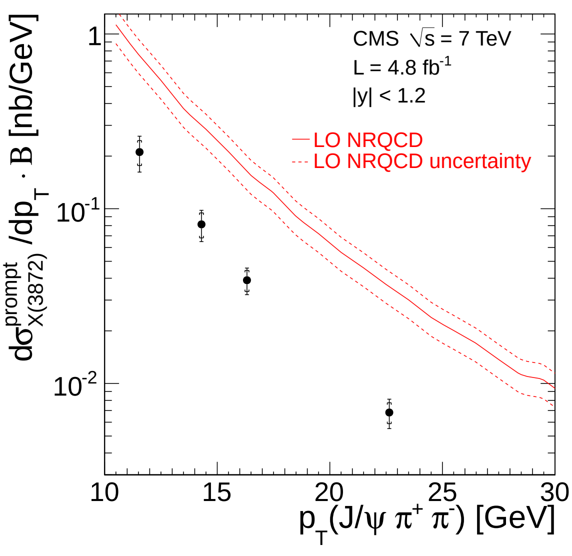

Figure 2. Measured differential cross section for the prompt X(3872) production times branching fraction, B, of the decay to $J/\psi\pi^+\pi^-$ as a function of p_T. The inner error bars represent the statistical uncertainty, while the outer error bars indicate the total uncertainty. The NRQCD calculations [16] are shown by the solid red line with the dotted lines representing the uncertainty.

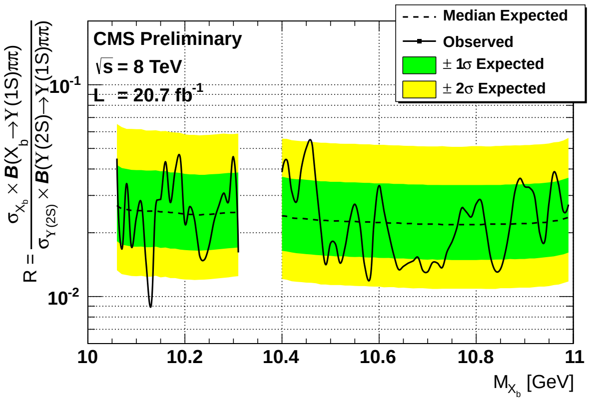

Figure 3. Exclusion limits on the production cross section times the branching fraction of the $X_b \rightarrow \Upsilon(1S)\pi^+\pi^-$ relative to the one of $\Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ as a function of the X_b mass, at 95% CL. The solid curve shows the observed limits, while the dashed curve represents the limits expected for a pure background hypothesis.

A search for the counter part of the X(3872) in the bottomonium spectrum, the X_b, showed no evidence of a signal and upper limits on the relative inclusive production cross section times branching ratio of the X_b and $\Upsilon(2S)$ were set. These are the first upper limits for X_b with hadron collider data.

6. Acknowledgments

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