Measurements of Quarkonium Production at CMS

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DOI: `http://dx.doi.org/10.3204/DESY-PROC-2012-02/238`

Recent quarkonium results obtained at the CMS experiment in proton-proton collisions at a centre-of-mass energy of 7 TeV are presented. These measurements include the differential production cross sections of prompt and non-prompt J/ψ and ψ(2S) mesons in a wide range of transverse momentum and rapidity, which are compared to theory calculations. The measurement of the differential production cross sections of Υ(1S), Υ(2S), and Υ(3S) as a function of transverse momentum and rapidity. In addition, the reconstruction of the radiative decay of the χ_c(nP) states is demonstrated. Finally, results obtained from studies of the X(3872) state are described.

1 Introduction

The description of the process of quarkonium production is a challenge to theory, since it involves both the production of the quark system and the formation of the bound state. Significant progress has been made over the last decade, from both the experimental and the theoretical sides, and the experiments at the LHC provide great opportunities to further extend our understanding of quarkonia.

The Compact Muon Solenoid (CMS) has been collecting data for quarkonia using triggers based on the presence of two identified muons. In the year 2010 an integrated luminosity of 40 pb^{-1} at $\sqrt{s} = 7$ TeV was collected at peak instantaneous luminosities of up to 2×10^{32} cm^{-2} s^{-1}. The 2011 data taking period was characterized by a steep increase of the LHC instantaneous luminosity and the total integrated luminosity recorded was about 5 fb^{-1}. While in 2010 it was possible to operate an inclusive two-muon trigger configuration, in 2011, to cope with the higher instantaneous luminosity and event rates, dedicated trigger paths were implemented for each analysis.

2 S-Wave Quarkonium Production Cross Sections

In CMS, the S-wave charmonium states (J/ψ and ψ(2S) and Υ(nS)) are reconstructed in their decays into a pair of opposite-charged muons. The differential cross section is measured as

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\mathrm{d}y}(Q\overline{Q}) \cdot \mathcal{B}(Q\overline{Q} \to \mu^+\mu^-) = \frac{N_\mathrm{signal}(Q\overline{Q})}{\int L\,\mathrm{d}t \cdot A \cdot \epsilon \cdot \Delta p_\mathrm{T} \cdot \Delta y} \quad . \tag{1}$$

The yield $N_\mathrm{signal}(Q\overline{Q})$ is extracted using unbinned maximum-likelihood fits to the dimuon invariant mass spectra, separately in different intervals of transverse momentum (p_T) and

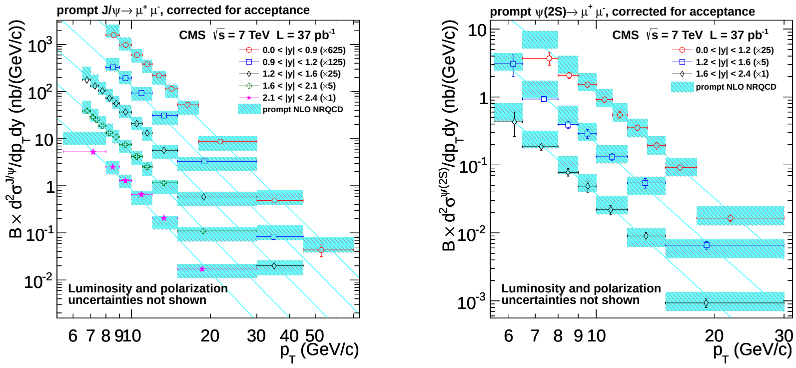

Figure 1: Measured differential cross section for prompt J/ψ and $\psi(2S)$ production (left and right, respectively) as a function of p_T for different rapidity bins. The coloured (dark) bands indicate the theoretical predictions from NRQCD calculations.

rapidity(y). The acceptance correction A reflects the geometrical coverage of the CMS detector and the kinematic reach of the muon trigger and reconstruction. The muon efficiency ϵ is measured from data for muons in the acceptance, in several $(p_T^{\mu}\eta^{\mu})$ bins, and is based on the tag-and-probe method, using independent triggers. Different assumptions of the - as yet unmeasured - polarization states of the quarkonia, lead to changes of the acceptance, and consequently the measured cross sections, of order 20%.

The J/ψ and $\psi(2S)$ measurement [1] has been performed using 37 pb^{-1} of data collected in 2010. To estimate the prompt component, where the $c\bar{c}$ system is produced directly, from the non-prompt component, originating from B-hadron decays, two-dimensional fits to the lifetime spectra are performed [2]. In the fits the dimuon invariant mass and the "pseudo proper decay length" are used. The latter is defined as the most probable value of the transverse distance between the dimuon vertex and the primary vertex, corrected by the transverse Lorentz-boost of the charmonium.

The measured prompt and non-prompt cross sections for the J/ψ and the $\psi(2S)$ states are shown in Figures 1 and 2 as a function of p_T, for the various rapidity bins. The measurements are compared with theoretical predictions from NRQCD [3] and from FONLL [4]. For the prompt case agreement is found for both J/ψ and the $\psi(2S)$. This is remarkable as the contributions from feed-down from P-wave charmonia is expected to be significantly larger for the J/ψ.

In the non-prompt case, depicted in Figure 2, general agreement is found for the J/ψ at low values of transverse momentum, p_T <30 GeV/c. However, towards large p_T the predictions overestimate the measured differential cross sections. The shape of the $\psi(2S)$ distribution is described over the entire p_T range, but an overall shift in normalization is observed.

The Υ(nS) production cross section measurement [5] is based on 3 pb^{-1} of 2010 data. The measured dimuon spectrum is shown in Figure 3-left. The measured differential Υ(nS) production cross sections are shown in Figure 3-center, for the rapidity interval $|y| < 2$. In the same figure (right) the corresponding cross section ratios of $\Upsilon(2S)$ and $\Upsilon(3S)$ with respect to $\Upsilon(1S)$ for the same rapidity region are presented.

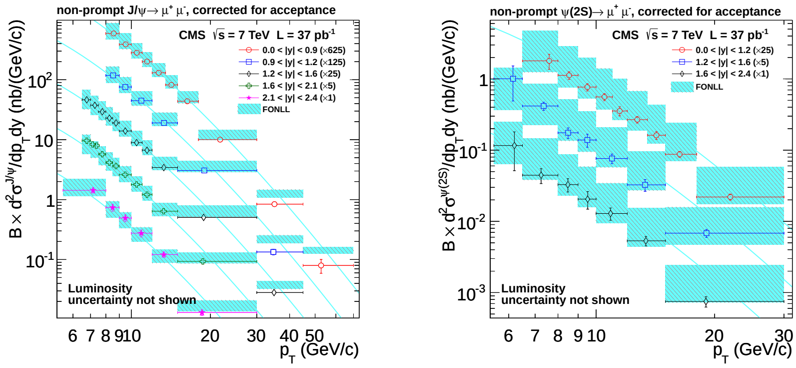

Figure 2: Measured differential cross section for non-prompt J/ψ and $\psi(2S)$ production (left and right, respectively) as a function of p_T for different rapidity bins. The coloured (dark) bands indicate the theoretical predictions from FONLL calculations.

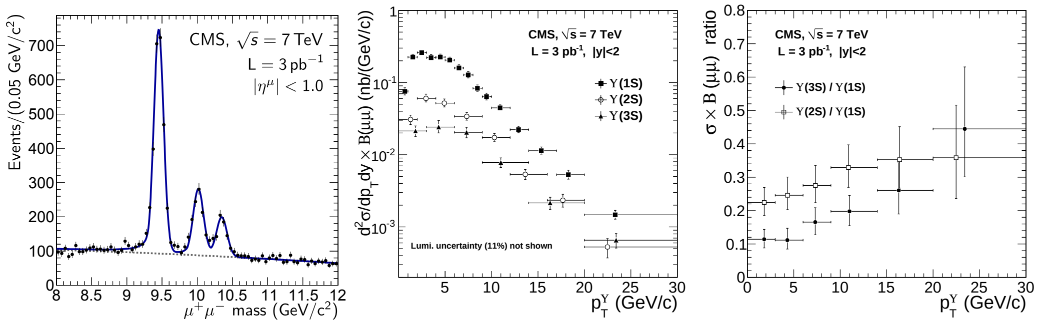

Figure 3: Left: The dimuon invariant-mass distribution in the vicinity of the Υ(nS) in the central region of the detector. Center: Υ(nS) differential cross sections for $|y| < 2$ Right: Cross-section ratios for Υ(nS) states as a function of p_T for $|y| < 2$

3 Reconstruction of χ_c states

The CMS experiment has also made measurements of the P-wave states χ_{c1} and χ_{c2}. These measurements are important for a more thorough understanding of quarkonium production as such, and, in particular, for the determination of the contribution from feed-down to the prompt production of S-wave states, presented above. The χ_c states are reconstructed in their radiative decays into a J/ψ and a photon, where the J/ψ further decays into two muons, and the photons are reconstructed through their conversions into electron-positron pairs. This photon reconstruction method yields a very good photon momentum resolution and consequently a separation of the χ_{c1} and χ_{c2} states in their invariant mass spectrum. This is demonstrated in Figure 4-left, showing a mass distribution of data corresponding to an integrated luminosity of 1.1 fb^{-1} recorded in 2011 [7].

4 Measurement of the $X(3872)$ state

The $X(3872)$ state is the first unexpected state discovered in the charmonium spectroscopy and is still the most intriguing. In CMS the state was measured in the decay channel $J/\psi\,\pi^+\pi^-$ using 40 pb^{-1} of 2010 data [6]. For the reconstruction of the $J/\psi\,\pi^+\pi^-$ system, the J/ψ meson candidates are combined with pairs of oppositely charged pion track candidates with transverse momentum larger than 400 MeV. The dimuon mass is constrained to the J/ψ one and candidates are kept in the kinematic region $p_{\mathrm{T}} > 8$ GeV and $|y| < 2.2$. The resulting $J/\psi\,\pi^+\pi^-$ spectrum is shown in Fig. 4.

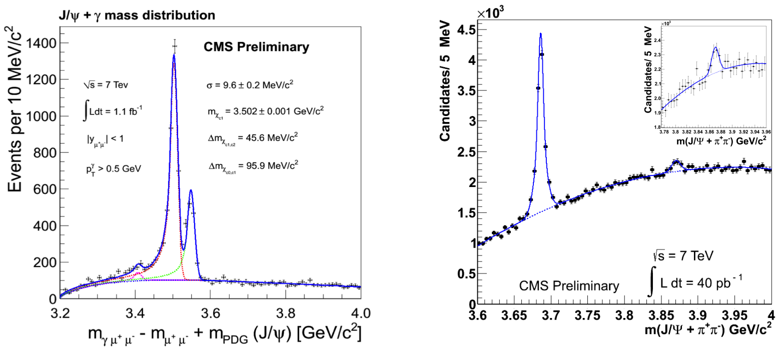

Figure 4: Left: Mass distribution of the $\chi_c \to J/\psi + \gamma$ candidates. Right: $J/\psi\pi^+\pi^-$ invariant mass spectrum. The insert shows the mass region around the $X(3872)$.

A measurement of the ratio of $\sigma \cdot \mathcal{BR}$ between X(3872) and ψ(2S) is performed correcting the observed signal yields for acceptance and efficiencies, as estimated from simulations. The measured ratio is $0.087 \pm 0.017(stat.) \pm 0.009(syst.)$. A more detailed measurement of this ratio, as a function of p_{T}, using the 2011 dataset, is expected soon.

5 Summary

CMS has delivered a significant first set of quarkonium production results using the first-year run of the LHC and paved the way for a wide range of new studies with 2011 statistic.

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