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Quarkonium physics at CMS

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Summary. — This article presents the determination of the J/ψ and $\psi(2S)$ differential cross sections in proton-proton collisions at a centre-of-mass energy of 7 TeV, as a function of transverse momentum and in several rapidity ranges, on the basis of the 2010 data collected by the CMS experiment. We also report the measurement of the differential production cross sections of $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ as a function of transverse momentum and rapidity.

PACS 14.40.Pq – Heavy quarkonia.
PACS 13.20.Gd – Decays of J/ψ, Υ, and other quarkonia.

1. – Quarkonium production cross section at CMS

Heavy quarkonia constitute an ideal laboratory for testing the interplay between perturbative and nonperturbative Quantum Chromodynamics. Significant progress has been made over the last decade, from both the experimental and the theoretical sides, but current understanding remains notwithstanding far from satisfactory.

The Compact Muon Solenoid (CMS) at the LHC provides great opportunities to further extend our understanding of quarkonia production.

In the year 2010 an integrated luminosity of $40\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 7\,\mathrm{TeV}$ was recorded by CMS with peak instantaneous luminosities up to $2 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. During this period it was possible to collect a large sample S-wave quarkonium states using an inclusive two-muon trigger configuration.

The differential cross section is measured as

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

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 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

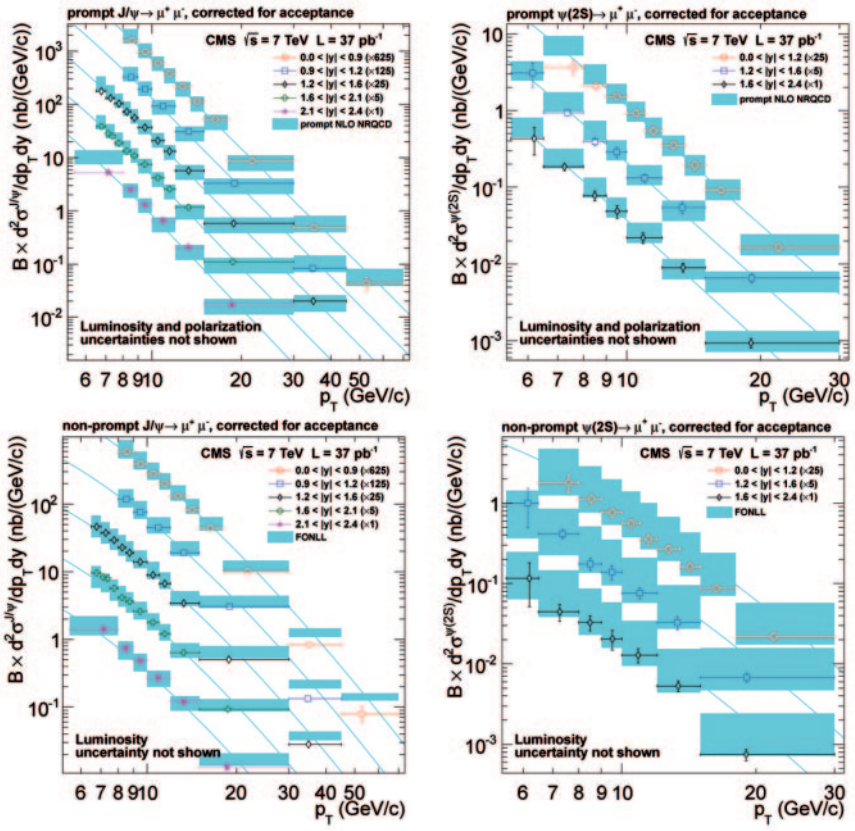

Fig. 1. – Top: measured differential cross section for prompt J/ψ and $\psi(2S)$ production (left and right, respectively) as a function of p_{T} for different rapidity bins. The coloured (dark) bands indicate the theoretical predictions from NRQCD calculations. Bottom: measured differential cross section for non-prompt J/ψ and $\psi(2S)$ production (left and right, respectively). The coloured (dark) bands indicate the theoretical predictions from FONLL calculations.

muon efficiency ϵ is measured from data for muons in the acceptance, in several $(p_{\mathrm{T}}^{\mu}\eta^{\mu})$ 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%.

2. – J/ψ and $\psi(2S)$ differential cross sections

The J/ψ and $\psi(2S)$ measurement [1] has been performed using $37\,\mathrm{pb}^{-1}$ 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 of the dimuon invariant mass and the "pseudo proper decay length" are performed. The latter is defined as the 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 fig. 1 as a function of p_{T}, for the various rapidity bins. The measurements are compared with theoretical predictions from NRQCD [2] and from FONLL [3], respectively.

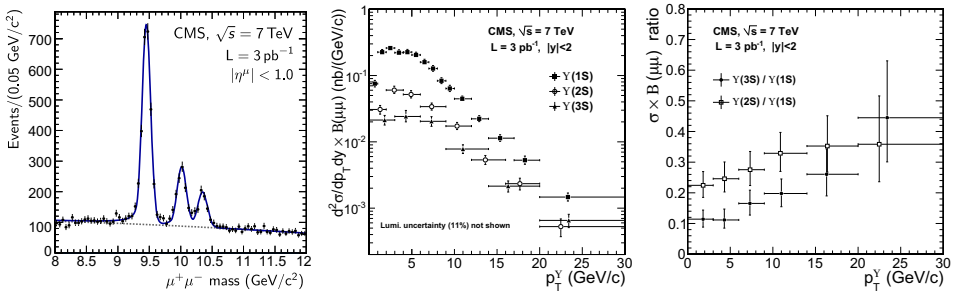

Fig. 2. – Left: The dimuon invariant-mass distribution in the vicinity of the $\Upsilon(nS)$ in the central region of the detector. Center: $\Upsilon(nS)$ differential cross sections for $|y| < 2$. Right: Cross section ratios for $\Upsilon(nS)$ states as a function of p_{T} for $|y| < 2$.

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, general agreement is found for the J/ψ at low values of transverse momentum, $p_{\mathrm{T}} < 30\,\mathrm{GeV}/c$. 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.

3. – $\Upsilon(nS)$ production cross section

The $\Upsilon(nS)$ production cross section measurement [4] is based on $3\,\mathrm{pb}^{-1}$ of 2010 data. The measured dimuon spectrum is shown in fig. 2 (left). The measured differential $\Upsilon(nS)$ production cross sections are shown in fig. 2 (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 shown.

4. – Summary and outlook

The CMS experiment has delivered a significant first set of quarkonium production results using the first data from LHC.

In addition to what have been described in this paper, a series of preliminary results have been produced. These include the observation of the X(3872) state in its decay into $J/\psi\,\pi^+\pi^-$ [5] and the reconstruction of the χ_c states in their radiative decay to J/ψ [6]. The analysis of production properties of these kinds of particles have huge theoretical interest and are being finalized taking advantage of the larger statistics collected in 2011.

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