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Measurement of Quarkonium polarization with the CMS detector

João Seixas on behalf of the CMS Collaboration

Abstract

This talk presents results from a large data sample collected at 7 TeV, from which CMS extensively studied the polarization of the three Υ states, as a function of p_T in two rapidity windows, conducting a complete analysis, including the polar and azimuthal anisotropies, and in three different polarization frames.

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Measurement of Quarkonium polarization with the CMS detector

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This talk presents results from a large data sample collected at 7 TeV, from which CMS extensively studied the polarization of the three Υ states, as a function of p_T in two rapidity windows, conducting a complete analysis, including the polar and azimuthal anisotropies, and in three different polarization frames.

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Despite decades of considerable effort both from the theoretical and experimental sides, the understanding of quarkonium production is still far from satisfactory [1]. The description of the production cross section has presently reached a reasonable level of accuracy in the context of nonrelativistic quantum chromodynamics (NRQCD) [2, 3], where the purely perturbative colour-singlet production is complemented by processes including possible nonperturbative transitions from coloured quark pairs to the observable bound states. The expected polarization of prompt S-wave quarkonium is, however, in disagreement with all available theoretical expectations. Indeed, NRQCD [4] predicts that at high transverse momentum (p_T) the directly produced S-wave quarkonia should be transversely polarized with respect to their direction of motion, while the color singlet model (CSM) [5] indicates a significant longitudinal polarization. The available measurements by the CDF Collaboration [6, 7] have instead shown a slightly longitudinal polarization for inclusive prompt J/ψ, $\Upsilon(1S)$ and $\Upsilon(2S)$ states, while the $\Upsilon(3S)$ has a mixed behaviour going from slightly longitudinal to slightly transverse polarization as a function of p_T at central rapidity. Considering also the the results obtained by the D0 Collaboration [8], together with the ensemble of fixed-target experiments, the picture that emerges is confusing and often contradictory [9].

This talk presents the measurement of $\Upsilon(nS)$ polarization using the lepton angular distribution in the $\mu^+\mu^-$ decay channel [10]. For symmetric collider experiments the most general form for this distribution is

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

where ϑ and φ are the polar and azimuthal angles, respectively, of the μ^+ with respect to the z axis of the chosen polarization frame, and the parameters $\vec{\lambda}$=(λ_ϑ, λ_φ, $\lambda_{\vartheta\varphi}$) characterize the distribution in this frame.

The CMS Collaboration measured the dimuon angular distributions resulting from the decay of $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ mesons produced in pp collisions at a centre-of-mass energy of 7 TeV [11]. The analysis is based on a dimuon sample collected in 2011, corresponding to an integrated luminosity of 4.9 fb^{-1} and containing $\sim$222 000 $\Upsilon(1S)$, $\sim$82 000 $\Upsilon(2S)$, and $\sim$51 000 $\Upsilon(3S)$ mesons (after all selection criteria), with $p_T > 10$ GeV and rapidity $|y| < 1.2$. The $\vec{\lambda}$ parameters are determined as a function of the $\Upsilon(nS)$ p_T and in two $|y|$ ranges, to mitigate the effects of averaging the results over the production kinematics and to allow for a better comparison with theoretical calculations and other measurements. The analysis uses an unbinned likelihood approach, completely independent of theoretical hypotheses on the production kinematics, and with the lepton efficiencies as the only external input. The results are obtained in three polarization frames: the center-of-mass helicity (HX) frame, the Collins–Soper (CS) frame [12], and the perpendicular helicity (PX) frame [13].

The central feature of the CMS apparatus [14] is a superconducting solenoid of 6 m internal diameter, providing a 3.8 T field. The main subdetectors used in this analysis are the silicon tracker and the muon system. The silicon tracker, composed of pixel and strip detector modules, is immersed in the magnetic field and enables the measurement of charged-particle momenta over the pseudorapidity range $|\eta| < 2.5$. Muons are measured in the range $|\eta| < 2.4$ using gas-ionization detectors embedded in the steel return yoke of the magnet and made using three technologies: drift tubes, cathode strip chambers, and resistive plate chambers.

The events were collected using a two-level trigger system. The first level selects events with two muons while the “high-level trigger” requires an opposite-sign muon pair with invariant mass $8.5 < M < 11.5$ GeV, $|y| < 1.25$, $p_T > 5$ or 7 GeV(depending on the instantaneous luminosity), and vertex fit χ^2 probability greater than 0.5%. No explicit p_T requirement is imposed on the single muons at trigger level. In the offline analysis, dimuons are formed by combining pairs of opposite-sign muons (tracks in the silicon tracker matched to tracks in the muon detectors) that satisfy several quality criteria, including the number of tracker hits, the muon-track fit quality, and the vicinity of the track to the closest primary vertex along the beam line. The selected muons are required to satisfy $|\eta| < 1.6$ and to have p_T above 4.5, 3.5, and 3.0 GeV for $|\eta| < 1.2$, $1.2 < |\eta| < 1.4$, and $1.4 < |\eta| < 1.6$, respectively, to ensure accurately-measured muon detection efficiencies. Subsequent to the offline trigger confirmation, the combinatorial background from uncorrelated muons is reduced by requiring a dimuon vertex fit χ^2 probability larger than 1.0% and a distance between the dimuon vertex and the closest primary vertex less than twice its uncertainty. The analysis is performed in five dimuon p_T bins, of edges 10, 12, 16, 20, 30, and 50 GeV, and two $|y|$ ranges, 0.0–0.6 and 0.6–1.2.

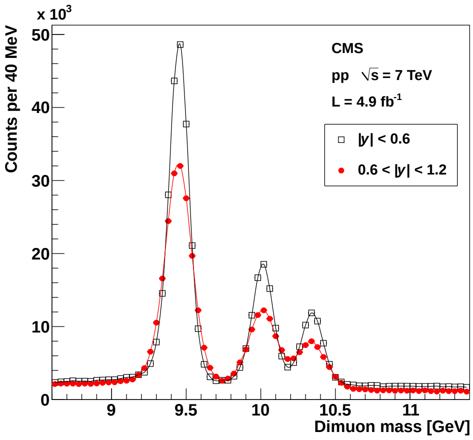

Figure 1: Dimuon mass distributions in the Υ region for the two $|y|$ ranges used in the analysis.

The dimuon mass distribution in the Υ region is shown in Figure 1. The signal region is restricted to ± 1 standard deviation (σ) window around the $\Upsilon(nS)$ masses, to reduce the cross-feed between the $\Upsilon(2S)$ and $\Upsilon(3S)$ to below 4%, and the background fractions to 4–8%, 9–18%, and 12–28% (increasing with decreasing p_T), for the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$, respectively. Events in the mass sidebands, having negligible signal contamination, are used to model the dimuon angular distributions of the background events. The single-muon detection efficiencies are measured with a “tag-and-probe” technique [15] using event samples collected with dedicated triggers enriched in dimuons from J/ψ decays. An accurate determination of trigger and reconstruction efficiencies is of utmost importance in order to avoid any biases in the angular distributions, which could introduce spurious polarization effects. In Figure 2 are shown the $\vec{\lambda}$ angular parameters in the HX frame as a function of p_T for the two considered rapidity bins. Figure 3 displays the results for the frame-invariant parameter $\tilde{\lambda}$ [16]. Good agreement of the results for this parameter in the three frames indicates the inexistence of unaccounted systematic effects. Complete tables of results for

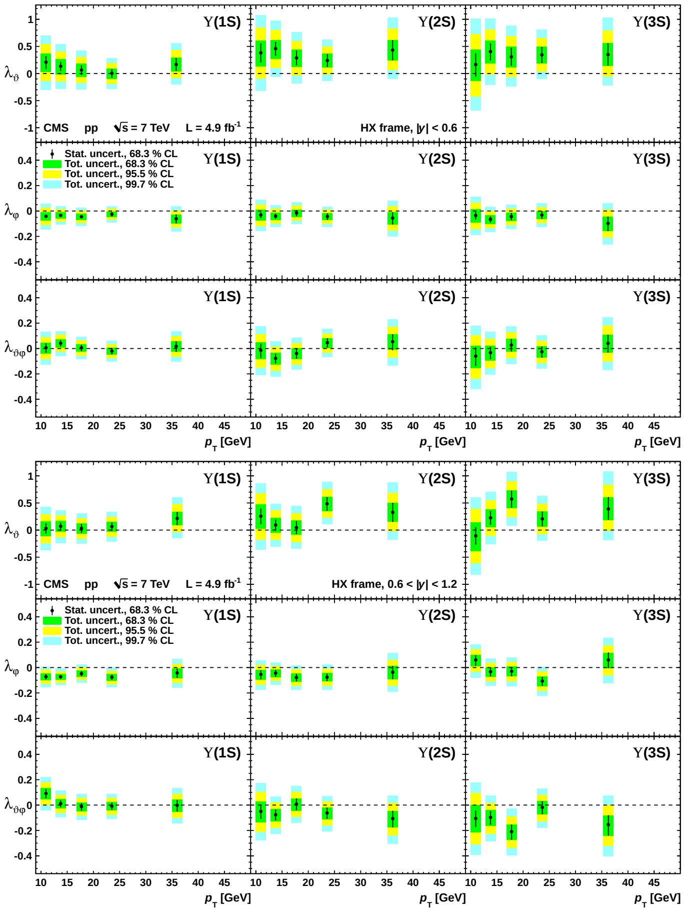

Figure 2: In the top plot: values of the λ_ϑ (top), λ_φ (middle), and $\lambda_{\vartheta\varphi}$ (bottom) parameters for the $\Upsilon(1S)$ (left), $\Upsilon(2S)$ (middle), and $\Upsilon(3S)$ (right), in the HX frame, as a function of the $\Upsilon(nS)$ p_T for $|y| < 0.6$. The error bars indicate the 68.3% confidence level (CL) interval when neglecting the systematic uncertainties. The three bands represent the 68.3%, 95.5%, and 99.7% CL intervals of the total uncertainties. The points are placed at the average p_T of each bin. In the bottom plot: same as above for $0.6 < |y| < 1.2$.

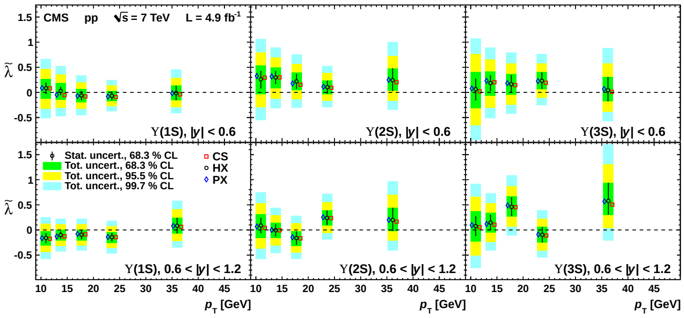

Figure 3: Values of $\tilde{\lambda}$ for the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ states (left to right), in the HX, CS, and PX frames, for the $|y| < 0.6$ (top) and $0.6 < |y| < 1.2$ (bottom) ranges. The bands and error bars have the same meaning as in the previous figures.

$\vec{\lambda}$ and $\tilde{\lambda}$, for the three Υ states and in the three frames considered in this analysis, are available in Ref. [17].

All the polarization parameters are compatible with zero or small values in the three polarization frames, excluding that a significant polarization could remain undetected because of smearing effects induced by unfortunate frame choices. The indication that the $\Upsilon(nS)$ resonances are produced as an unpolarized mixture might be related to the fact that the measurements do not distinguish directly produced Υ mesons from those produced in the decays of heavier bottomonium states.

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https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsBPH11023/SupplementalMaterial.txt.