The Compact Muon Solenoid Experiment

Conference Report

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Charmonia in pp, pPb and PbPb with CMS

Dong Ho Moon for the CMS Collaboration

Abstract

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The mechanisms through which charmonia production is modified in the high-density medium created in ultra-relativistic heavy-ion collisions are still not quantitatively understood. In order to disentangle different scenarios, a multi-dimensional analysis in a wide kinematic range is needed, in pp and AA collisions, looking at many observables that have different sensitivities to the various aspects of charmonia production. We will report on the prompt J/ψ measurements with the CMS detector, using the $150 \mu\text{b}^{-1}$ of PbPb data recorded in 2011. The azimuthal anisotropy in PbPb collisions at 2.76 TeV will be presented. In addition, the comparison of the excited charmonium state ($\psi(2S)$) and the ground state (J/ψ) between PbPb and pp is updated, utilizing the pp sample from 2013, which has a factor of 20 higher statistical precision than the 2011 pp data previously presented.

Keywords: LHC, CMS, Quarkonia, suppression, J/ψ , $\psi(2S)$, double ratio, azimuthal anisotropy, v_2

1. Introduction

Strongly interacting matter consists of a deconfined and chirally-symmetric system of quarks and gluons, called Quark-Gluon-Plasma (QGP) at large energy densities and high temperatures. One strong signature of the existence for a QGP is charmonium suppression, because charmonium should melt in a QGP when the Debye screening radius of the medium, which decreases with increasing the temperature of QGP, becomes smaller than the binding radius of the charmonium state [1]. Charmonium production is also affected by Cold Nuclear Matter (CNM) effects, such as nuclear parton distribution functions (nPDFs) [2], parton energy loss, and the Cronin effect [3, 4].

The result of study of the prompt J/ψ azimuthal anisotropy will be reported in this paper. Expected effects contributing to an observed non-zero elliptic anisotropy include recombination of thermalized charm quarks and (or) a path-length difference for absorption of quarkonia traversing the different direction of the almond-shaped hot and dense medium created in mid-central PbPb collisions.

This paper also reports the result of the prompt $\psi(2S)$ and J/ψ yields measured in PbPb and pp collisions, as the form of a double ratio, $(N_{\psi(2S)}/N_{J/\psi})_{\text{PbPb}}/(N_{\psi(2S)}/N_{J/\psi})_{\text{pp}}$, so that efficiency and acceptance corrections cancel to a large extent, reducing the uncertainties.

2. Environmental setup and analysis procedure

The central feature of the CMS apparatus is a superconducting solenoid, providing an axial magnetic field of 3.8 T. Immersed in the magnetic field are the silicon pixel and strip tracker, the lead-tungstate crystal electromagnetic calorimeter, and the brass/scintillator hadron calorimeter. Muons are measured in gas ionization detectors embedded in the steel return yoke and in the pseudorapidity window $|\eta| < 2.4$, with detection planes made of three technologies: Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers. Matching the muons to the tracks measured in

Figure 1. Invariant-mass spectra (left) and pseudo-proper decay length distribution (right) of $\mu^+\mu^-$ pairs integrated over centrality. The spectra are integrated over the rapidity range $0 < |y| < 2.4$ and the p_T range $6.5 < p_T < 30$ GeV/c. The projections of the two-dimensional fit onto the respective axes are overlaid as solid black lines. The dashed red lines show the fitted contribution of non-prompt J/ψ . The fitted background contributions are shown as dotted blue lines [6].

Figure 2. Invariant-mass distributions measured in pp (left) and 0-20% most central PbPb (right) collisions, for $1.6 < |y| < 2.4$ and $3 < p_T < 30$ GeV/c. The results of unbinned maximum likelihood fits are shown as solid lines (signal plus background) and dashed lines (background only). The dotted line on the left panel indicates the shape corresponding to the $\psi(2S)$ to J/ψ ratio found in the 0-20% PbPb collisions. The shaded bands represent the statistical uncertainties on the fit parameters. [7].

the silicon tracker results in a transverse momentum resolution better than 1.5% for p_T smaller than 100 GeV/c. A more detailed description of the CMS detector can be found in Ref. [5].

The pp data used in the study corresponded to an integrated luminosity of 5.4 pb^{-1} and the PbPb data were collected with a corresponding integrated luminosity of $150 \mu\text{b}^{-1}$ at a center-of-mass energy $\sqrt{s_{NN}} = 2.76$ TeV.

The invariant mass spectrum of $\mu^+\mu^-$ pairs used in the PbPb analysis of the prompt J/ψ is shown in the left of Figure 1. The black curve is an extended unbinned maximum likelihood fit to the spectrum, using the sum of a Crystal Ball (CB) and a Gaussian function for signal, and an exponential for the background. To measure the fraction of non-prompt J/ψ (the so called b-fraction), the pseudo-proper decay length $l_{J/\psi}$, as shown in the right of Figure 1, is computed as an estimate of the b-fraction decay length by $L_{xy} m_{J/\psi} / p_T$. Here, the L_{xy} is defined as,

$$L_{xy} = \frac{\hat{u}^T S^{-1} \vec{r}}{\hat{u}^T S^{-1} \hat{u}}, \quad (1)$$

where $\hat{u}$ is the unit vector in the direction of the J/ψ p_T and S is the sum of the primary and secondary vertex covariance matrices. In the final step, the invariant mass spectrum of $\mu^+\mu^-$ pairs and their $l_{J/\psi}$ distribution are fitted simultaneously in a two-dimensional (2D), extended unbinned maximum likelihood fit.

Figure 2 shows the invariant mass spectrum of all $\mu^+\mu^-$ pairs measured in pp (left) and central (0-20%) PbPb (right) collisions, for the forward rapidity kinematical bin. The result of an unbinned maximum likelihood fit is also shown. Each of the two charmonia is described by the sum of a Gaussian function and a CB function, with a common mean

Figure 3. The $\Delta\phi$ distribution of high- p_T ($6.5 < p_T < 30$ GeV/c) prompt J/ψ raw yields, measured in the rapidity range $|y| < 2.4$ and event centrality 10-50%, and normalized by the bin width and the sum of the yields in all four $\Delta\phi$ bins. The dashed red line in all figures represents the function $1+2v_2\cos(2\Delta\phi)$ used to extract v_2 [6].

Figure 4. Prompt J/ψ centrality (left), p_T (middle) and rapidity (right) dependence of v_2 . The boxes represented point-by-point systematic uncertainties. Horizontal bars indicate the bin width [6].

and independent widths. The background is described by Chebychev polynomials, of order $0 \leq N \leq 3$ independently determined for each analysis bin, with log-likelihood ratio (LLR) test.

3. Results

After extracting the prompt J/ψ yields in each rapidity, p_T , centrality, and $\Delta\phi$ bin, the v_2 is calculated with a fit of the $\frac{1}{N_{total}^{J/\psi}} \frac{dN_{J/\psi}}{d\phi}$ vs $\Delta\phi$ distributions with the function

$$1 + 2v_2\cos(2\Delta\phi). \quad (2)$$

The $N_{total}^{J/\psi}$ is the yield in $\Delta\phi = 2/\pi$ for each kinematic bin. An example of such fits is given in Figure 3, for the centrality integrated case. The measured prompt J/ψ v_2 , for 10-60% event centrality, integrated over $6.5 < p_T < 30$ GeV/c and $|y| < 2.4$ is

$$0.054 \pm 0.013(\text{stat}) \pm 0.006(\text{syst}), \quad (3)$$

with a significance for a nonzero v_2 of 3.8σ . The v_2 results versus centrality, p_T , and rapidity are shown in Figure 4. For each of these results, the dependence on one variable is studied by averaging over the other two. A non-zero v_2 is measured in all the kinematic bins studied. The observed anisotropy shows no strong centrality or rapidity dependence when integrated over rapidity and centrality, respectively. In 10-60% centrality events, the result are compatible with a p_T -independent anisotropy, whether measured at low- p_T ($3 < p_T < 6.5$ GeV/c) in the forward rapidity interval $1.6 < |y| < 2.4$, or at high- p_T ($6.5 < p_T < 30$ GeV/c) in rapidity interval $|y| < 2.4$.

The double ratio of measured yields, $(N_{\psi(2S)}/N_{J/\psi})_{\text{PbPb}}/(N_{\psi(2S)}/N_{J/\psi})_{\text{pp}}$, is shown in Figure 5 as a function of centrality, for both kinematical bins. In the midrapidity bin, where all measured charmonia must have $p_T > 6.5$

Figure 5. Double ratio of measured yields as a function of centrality, for the mid-rapidity (blue squares) and forward-rapidity (red circles) analysis bins. The latter points are shifted by $\Delta N_{part} = 2$ for better visibility. The centrality-integrated results are also displayed, at the rightmost edge. Statistical (systematic) uncertainties are shown as the bars (boxes). The boxes at unity indicate the (global) pp uncertainties [7].

GeV/c, the double ratio is less than unity in all three centrality bins, with a central-integrated value of 0.45 ± 0.13 (stat.) ± 0.07 (syst.), including the global pp uncertainties. In the forward-rapidity bin, which includes charmonia with p_T extending down to 3 GeV/c, the double ratio increases with centrality, reaching the value 2.31 ± 0.53 (stat.) ± 0.38 (syst.) ± 0.15 (pp) in the most central collisions. It indicates that central PbPb collisions produce more $\psi(2S)$ mesons than J/ψ mesons, with respect to the pp reference.

4. Summary

We presented the azimuthal anisotropy of prompt J/ψ that shows a 3.8σ significance for a non-zero v_2 in the centrality 10-60% of high p_T (>6.5 GeV/c) over rapidity range $|y| < 2.4$. No strong centrality, p_T and rapidity dependence is observed within the measured uncertainties for results that integrate the other variables. This result indicates that the parton energy loss could be playing an important role for bound c quarks in this range of transverse momentum.

The results of double ratio, $(N_{\psi(2S)}/N_{J/\psi})_{PbPb}/(N_{\psi(2S)}/N_{J/\psi})_{pp}$, indicates $\psi(2S)$ production is suppressed in the midrapidity bin, as expected in the sequential melting scenario but it is enhanced in the forward-rapidity in contrary to the expectation of theory.

References

- [1] T. Matsui and H. Satz, *Phys. Lett. B* **178** (1986) 416
- [2] R. Vogt, *Phys. Rev. C* **81** (2010) 044903
- [3] R. Sharma and I. Vitev, *Phys. Rev. C* **87** (2013) 044905
- [4] F. Arleo and S. Peigne, *JHEP* **03** (2013) 122
- [5] CMS Collaboration, *JINST* **3** (2008) S08004
- [6] CMS Collaboration, CMS Physics Analysis Summary CMS-HIN-12-001 (2012)
- [7] CMS Collaboration, CMS Physics Analysis Summary CMS-HIN-12-007 (2012)