

Charmonium production in pPb and PbPb collisions at 5.02 TeV with CMS

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Charmonium states, such as J/ψ and $\psi(2S)$ mesons, are excellent probes of the Quark-Gluon Plasma (QGP). The understanding of charmonium production in PbPb collisions requires the inclusion of many phenomena, such as dissociation in the QGP and statistical recombination, on top of cold nuclear matter effects (modifications of nPDFs, initial-state energy loss, nuclear break-up). Measurements of charmonium production in pPb collisions are crucial in order to disentangle the QGP-related effects from cold nuclear matter effects. In these proceedings, final results on the ratio of $\psi(2S)$ meson to J/ψ meson yields in PbPb collisions normalized to pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV, are reported. In addition, final prompt and nonprompt J/ψ meson results in pPb collisions at 5.02 TeV are also shown, using the 2015 pp data taken at the same energy. At last, final results are reported regarding prompt $\psi(2S)$ meson production in pPb collisions at 5.02 TeV, as a function of rapidity.

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1. Introduction

The study of charmonium production in heavy-ion collisions has played an important role in the understanding of the Quark-Gluon Plasma (QGP), the state of matter where quarks and gluons are deconfined. Charmonium mesons are good probes of the QGP, since they are created at the beginning of the collision and their yields are modified by the presence of the medium. The high quark density in the QGP can lead to a sequential suppression of the charmonium production due to the Debye color screening of the charm-quark potential [1]. Since higher excited states of charmonium require less energy to be dissociated, the production of $\psi(2S)$ mesons is expected to be more suppressed than that of J/ψ mesons in the QGP [1]. Moreover, it is also predicted that charmonium mesons can be regenerated in the QGP. In the Large Hadron Collider (LHC), the collision of lead ions at high energies produce a significant amount of charm quarks increasing the probability that uncorrelated charm and anticharm quarks recombine during hadronization, enhancing the measured charmonium yields [2].

Apart from the effects due to QGP, the charmonium production can be modified by cold nuclear matter (CNM) effects, such as parton energy loss [3], nuclear absorption and modification of the parton distribution functions due to the nuclear environment (nPDF) [4]. The comparison between proton-proton (pp) and proton-lead (pPb) collisions are used to study the CNM effects, since the QGP is not expected to be formed. Charmonia can also be affected by the interaction with the co-moving matter, which can dissociate the charmonium mesons, having a larger impact on the excited states that are less tightly bounded like the $\psi(2S)$ meson [5].

2. Analysis Procedure

The results presented here make use of the data recorded by the Compact Muon Solenoid (CMS) experiment. The CMS is a general-purpose detector built around a superconducting solenoid magnet of 3.8 T and it is divided in several sub-detectors: the silicon tracker, the lead-tungstate crystal electromagnetic calorimeter, the brass/scintillator hadron calorimeter, and the muon chambers. Muons are measured in the pseudo-rapidity window $|\eta| < 2.4$ using gas-ionization detectors made of three different technologies: resistive plate chambers, cathode strip chambers and drift tubes. More details of the CMS apparatus can be found in Ref. [6].

The analysis of charmonium is done via its $\mu^+\mu^-$ decay channel. Charmonia are classified in two categories: prompt and non-prompt. Prompt charmonia include direct production or through feed-down from higher excited states, while non-prompt charmonia include those originating from b hadron decays. Since b hadrons decay after travelling a measureable path length, the separation of prompt and non-prompt charmonia is done using the pseudo-proper decay length, $l_{J/\psi} = L_{xyz}m_{J/\psi}/p_T$, where L_{xyz} is the distance between the primary vertex and the $\mu^+\mu^-$ vertex computed in the laboratory frame. For the analysis of J/ψ mesons in pPb collisions, the prompt charmonium yields are extracted by performing a bidimensional unbinned maximum likelihood fit of the invariant-mass and $l_{J/\psi}$ distributions of dimuons. And for the analysis of $\psi(2S)$ mesons in pPb collisions and the results in PbPb collisions, the non-prompt charmonia are suppressed by applying a selection on $l_{J/\psi}$. The final results are corrected taken into account the contamination from non-prompt charmonia.

3. Charmonium results in pPb collisions

The charmonium production is studied in pPb and pp collisions at 5.02 TeV [7]. The prompt charmonium cross sections are measured as a function of the centre-of-mass rapidity at intermediate ($6.5 < p_T < 10$ GeV/c) and high ($10 < p_T < 30$ GeV/c) transverse momenta. The cold nuclear effects are then quantified through the nuclear modification factor (R_{pPb}), defined as the ratio of the cross section in pPb collisions normalized to the cross section in pp collisions scaled by the number of nucleons (208) in the Pb ion.

The results of the rapidity dependence of the R_{pPb} of the prompt J/ψ meson are shown in Figure 1. The R_{pPb} of the prompt J/ψ meson at high p_T is slightly larger than one in the whole rapidity range, while a decreasing trend is observed with respect to rapidity at intermediate p_T . The results of the R_{pPb} of the prompt J/ψ meson are compared to the next-to-leading order (NLO) EPS09 and nCTEQ15 nuclear models including shadowing effects [8]. The model calculations are systematically below the measured results in all rapidity bins.

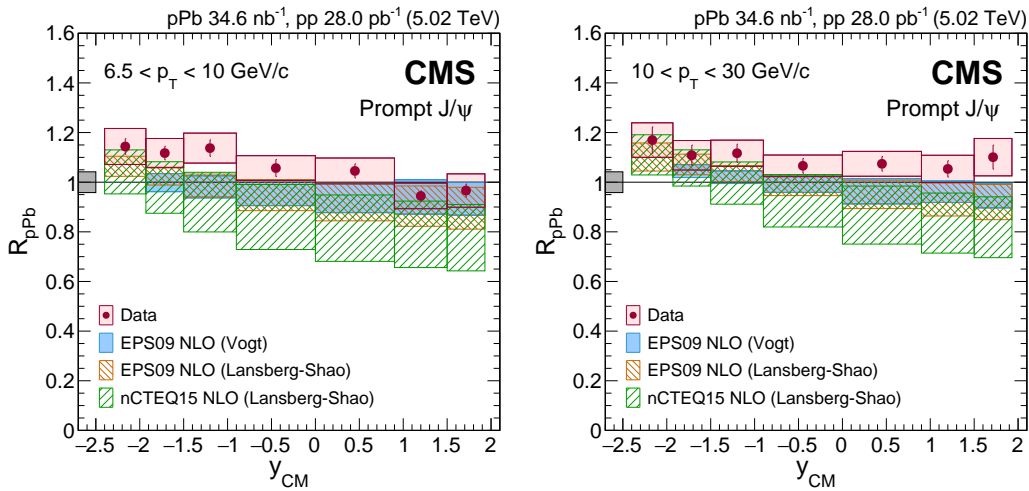


Figure 1: R_{pPb} of the prompt J/ψ meson versus rapidity divided in two p_T ranges: $6.5 < p_T < 10$ GeV/c (left) and $10 < p_T < 30$ GeV/c (right) [7]. The statistical (systematic) uncertainties are represented by the vertical bars (shaded boxes). The fully correlated global uncertainty is shown as a gray box at $R_{pPb} = 1$. The EPS09 and nCTEQ15 shadowing calculations are also displayed [8].

The rapidity dependence of the R_{pPb} of the prompt $\psi(2S)$ meson is also measured and compared to the R_{pPb} of the prompt J/ψ meson in two p_T bins, $6.5 < p_T < 10$ GeV/c and $10 < p_T < 30$ GeV/c, as shown in the left and right plots of Fig. 2, respectively [9]. The R_{pPb} of the prompt $\psi(2S)$ meson is consistently lower than for the prompt J/ψ meson. The different models used to describe the CNM effects expect similar production rates for J/ψ and $\psi(2S)$ mesons, so these measurements provide an insight into further possible final-state effects affecting differently the $\psi(2S)$ and J/ψ mesons. The suppression of the $\psi(2S)$ meson due to the interaction with the co-moving matter might explain the level of suppression observed [5].

3.1 Charmonium results in PbPb collisions

To quantify the level of modification between the different charmonium states in the presence

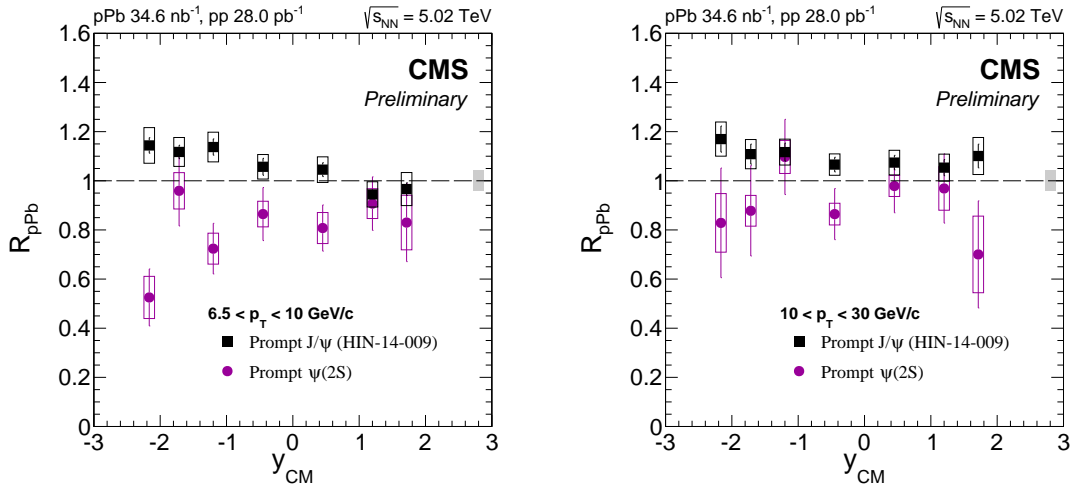


Figure 2: R_{pPb} of prompt $\psi(2S)$ and prompt J/ψ mesons versus rapidity divided in two p_T ranges: $6.6 < p_T < 10$ GeV/c (left) and $10 < p_T < 30$ GeV/c (right) [9]. The statistical (systematic) uncertainties are represented by the error bars (boxes). The fully correlated global uncertainty is shown as a gray box at $R_{pPb} = 1$.

of the QGP, a double ratio is extracted based on the ratio of prompt $\psi(2S)$ meson over J/ψ meson yields in PbPb collisions compared to pp collisions, expressed as $(N_{\psi(2S)}/N_{J/\psi})_{PbPb} / (N_{\psi(2S)}/N_{J/\psi})_{pp}$. The charmonium double ratio measured using pp and PbPb data at 5.02 TeV was recently published by CMS [10]. The dependence of the double ratio on the average number of participating nucleons (N_{part}) is shown for two kinematic regions: $|y| < 1.6$, $6.5 < p_T < 30$ GeV/c and $1.6 < |y| < 2.4$, $3 < p_T < 30$ GeV/c, in Fig. 3. Since the double ratio is below unity in all the bins, the results at 5.02 TeV indicate that the production of the $\psi(2S)$ meson is more suppressed than the J/ψ meson in the measured kinematic range. No strong dependence with the event centrality is observed. The double ratio results at 5.02 TeV are also compared with the CMS results at 2.76 TeV. In the mid rapidity region, a good agreement is observed between 5.02 TeV and 2.76 TeV results, but in the forward rapidity region the 5.02 TeV results are consistently lower than those at 2.76 TeV. The largest difference between the two energies is of the order of 3 standard deviations observed in the centrality integrated sample at mid rapidity. Theoretical calculations are presented using a transport model including a sequential regeneration scenario depending on temperature, where the J/ψ meson regenerates before the $\psi(2S)$ meson in the QGP evolution [11]. The model is able to describe the measurements at the two energies qualitatively well except for the most central collisions.

4. Summary

The R_{pPb} of prompt J/ψ mesons at 5.02 TeV is slightly larger than one at high p_T and decreases with rapidity at lower p_T . Model calculations implementing the effect of shadowing are below the measured values, indicating the presence of other effects beyond those from nuclear parton distribution functions only. Moreover, the R_{pPb} of the prompt $\psi(2S)$ meson at 5.02 TeV is lower than the R_{pPb} of the prompt J/ψ meson. The further suppression of $\psi(2S)$ mesons in pPb collisions is explained considering the possible dissociation of $\psi(2S)$ mesons due to its interaction

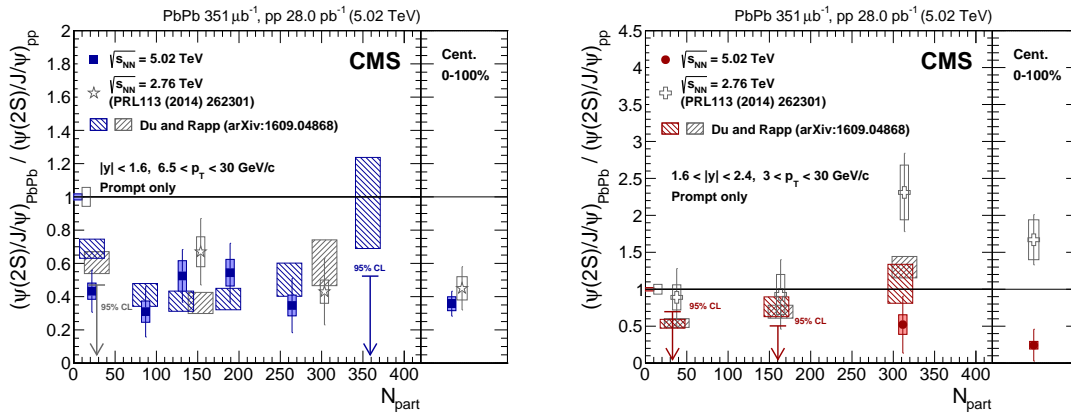


Figure 3: Double ratio of $\psi(2S)$ meson over J/ψ meson yields as a function of centrality at mid rapidity (left) and forward rapidity (right) [10]. The pp uncertainties are shown by boxes at unity while the statistical uncertainties are displayed by bars. The centrality-integrated results are presented in the right panel. The theory calculations by [11] are also shown.

with the co-movers. And finally, the double ratio of prompt $\psi(2S)$ meson to J/ψ meson yields is observed to be below unity in all measured bins, implying that the $\psi(2S)$ meson is more suppressed than J/ψ meson in PbPb collisions at 5.02 TeV.

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