Charmonium production in pp, pPb and PbPb with CMS

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Abstract. We report on the analysis of charmonia in pp, pPb and PbPb collisions with the CMS experiment with various observables. The cross section for coherent J/ψ photoproduction is measured in ultra-peripheral PbPb collisions at 2.76 TeV. The ratio of prompt J/ψ yields at forward (proton-going direction) and backward (Pb-going direction) is studied as a function of p_{T}, rapidity, and the event activity in pPb collisions at 5.02 TeV. The nuclear modification factor of prompt J/ψ in PbPb collisions at 2.76 TeV is presented as a function of centrality, p_{T}, and rapidity. Finally, the production yields of $\psi(2S)$ and J/ψ in pp and PbPb collisions have been compared.

1. Introduction

In the early stage of high-energy heavy ion collisions, the transition from a hadronic phase into a deconfined system of quarks and gluons, the Quark-Gluon Plasma (QGP), is predicted. Due to the Debye screening of the heavy-quark potential in QGP, charmonium states are expected to dissociate sequentially according to their binding energies [1]. As an example, $\psi(2S)$ is less bound than J/ψ and hence, is expected to melt at a lower temperature. Given the abundance of charm quarks at LHC energies, charmonia can also be produced at the hadronization stage by the recombination of initially uncorrelated charm and anticharm quarks [2]. This type of process has as result an enhancement of charmonium yields in lead-lead (PbPb) collisions relative to those in proton-proton (pp) collisions. Aside from the formation of QGP, the charmonium production can also be affected by the so-called "cold nuclear matter" (CNM) effects, including modifications of the nuclear parton distribution functions (nPDFs), initial or final state parton energy loss, and nuclear absorption [3]. Such effects are best probed in proton-lead (pPb) collisions and ultra-peripheral collisions (UPC). In particular, the depletion of gluon PDFs in nuclei from those in a free proton can lead to the charmonium suppression at small values of the momentum fraction carried by a parton (x), a process known as shadowing. The values of x probed at the LHC correspond to $10^{-5} < x < 10^{-2}$. This conference proceeding reports the measurement of J/ψ in PbPb UPC, and in pPb collisions. The nuclear modification factor of prompt J/ψ, and the ratio of $\psi(2S)$ to J/ψ yields in pp and PbPb collisions are also presented.

2. Analysis methods and Results

2.1. J/ψ in Ultra Peripheral PbPb collisions

The CNM effects can be probed by the photon-induced reactions in UPC with impact parameters larger than the sum of the radii of the colliding nuclei [4]. If the photon interacts with the whole nucleus, the produced J/ψ is classified as coherent and dominantly distributed at $p_{\mathrm{T}} < 60$ MeV/c for PbPb collisions at 2.76 TeV. The UPC events are selected requiring a low energy deposition in the forward hadronic calorimeter, and only two muon tracks from J/ψ. In order to separate the coherent signal contribution from background (incoherent J/ψ and $\gamma\gamma \to \mu^+\mu^-$ interactions), a maximum likelihood fit is performed simultaneously to the dimuon invariant mass and p_{T} distributions determined from STARLIGHT simulation.

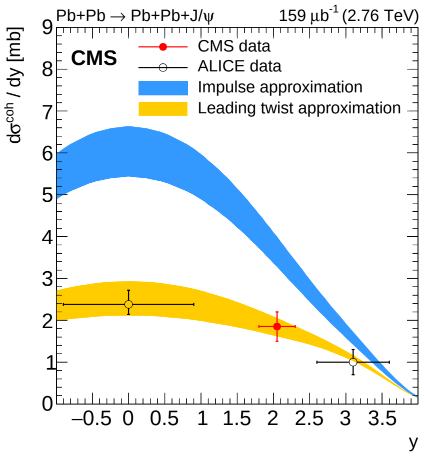


Figure 1. Differential cross sections of coherent J/ψ production as a function of rapidity in ultra-peripheral PbPb collisions at 2.76 TeV, measured by CMS (a filled circle) and ALICE (open circles) [5, 6]. The horizontal bars display the range of rapidity bins, and the vertical error bars represent the statistical and systematic uncertainties. The impulse approximation and the leading twist approximation calculations are also shown [7, 8].

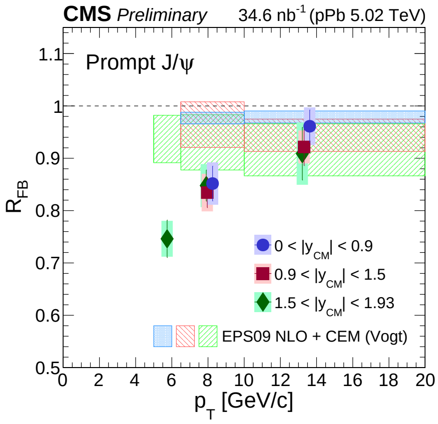
In Fig. 1, the coherent J/ψ production cross sections measured by CMS using 159 μb^{-1} PbPb data (a filled circle) is compared to the ALICE measurement (open circles) [5, 6], and to theoretical calculations [7, 8]. The impulse approximation prediction uses data from $\gamma + p$ collisions to estimate the γ+Pb collisions, neglecting all nuclear effects. The leading twist approximation implements a gluon recombination using a diffractive proton PDF as an input, which results in an effective nuclear gluon shadowing. Experimental results from ALICE and CMS favor a model with shadowing effects and show a steady decrease with rapidity.

2.2. J/ψ in pPb collisions

The processes affecting prompt J/ψ production are also studied using 34.6 nb^{-1} pPb data at 5.02 TeV. The prompt J/ψ and those coming from b-hadron decays are separated using the pseudo-proper decay length, $l_{\mathrm{J}/\psi} = L_{xy}\, m_{\mathrm{J}/\psi}/p_{\mathrm{T}}$, where L_{xy} is the transverse decay length in the laboratory frame. The invariant-mass spectrum and the $l_{\mathrm{J}/\psi}$ distribution of $\mu^+\mu^-$ pairs are fitted simultaneously in an extended unbinned maximum likelihood fit [9]. The rapidity dependence of nuclear effect is investigated using the forward-to-backward production ratio, $R_{\mathrm{FB}}(p_{\mathrm{T}}, y) = [d^2\sigma(p_{\mathrm{T}}, y > 0)/dp_{\mathrm{T}}dy]/[d^2\sigma(p_{\mathrm{T}}, y < 0)/dp_{\mathrm{T}}dy]$, where the $d^2\sigma/dp_{\mathrm{T}}dy$ is the J/ψ production cross section decayed into muon pairs in a given p_{T} and y bin, and forward regions $(y > 0)$ are defined by the proton-going direction.

Figure 2 shows the p_{T} dependence of R_{FB} in three different rapidity ranges. The R_{FB} is closer to unity at high p_{T}, and decreases at low p_{T}. The EPS09 shadowing calculation with next-to-leading order (NLO), based on the Color Evaporation Model (CEM) for the J/ψ production, is also shown by bands [10]. Data shows lower R_{FB} values than the model prediction at $5 < p_{\mathrm{T}} < 6.5$ GeV/c, hinting at other effects beyond the single nPDF parameterization.

The R_{FB} of prompt J/ψ is further analyzed in terms of an event activity variable $E_{\mathrm{T}}^{\mathrm{HF}|\eta|>4}$, the transverse energy deposited in the forward hadronic calorimeter in $4 < |\eta| < 5.2$, as shown in Fig. 3. The data points are plotted at the bin-averaged values. The clear decreasing tendency of the R_{FB} with increasing $E_{\mathrm{T}}^{\mathrm{HF}|\eta|>4}$ has been observed over whole p_{T} and rapidity ranges.



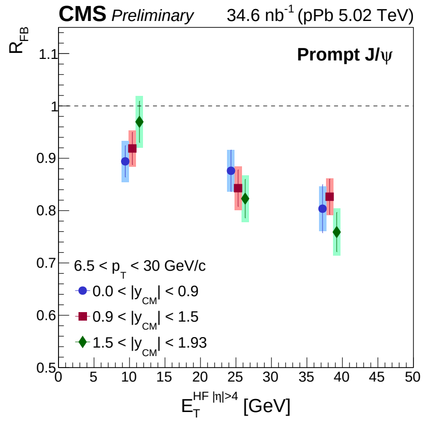


Figure 2. p_T dependence of R_{FB} for prompt J/ψ in three rapidity ranges. The EPS09(NLO) shadowing prediction is also shown. The error bars show the statistical uncertainties, and the shaded boxes represent the systematic uncertainties.

Figure 3. $E_T^{HF|\eta|>4}$ (right) dependence of R_{FB} for prompt J/ψ in three rapidity ranges. The data points are slightly shifted to avoid overlap. The error bars show the statistical uncertainties, and the shaded boxes represent the systematic uncertainties.

2.3. J/ψ and ψ(2S) in PbPb collisions

The nuclear modification factor, R_{AA} of prompt J/ψ is measured using pp and PbPb data at 2.76 TeV with and integrated luminosity of 150 μb^{-1} and displayed in Fig. 4 [11]. The yields of J/ψ in PbPb are more suppressed compared to those in pp with increasing centrality, implying the signature of QGP. No strong p_T and rapidity dependence is observed.

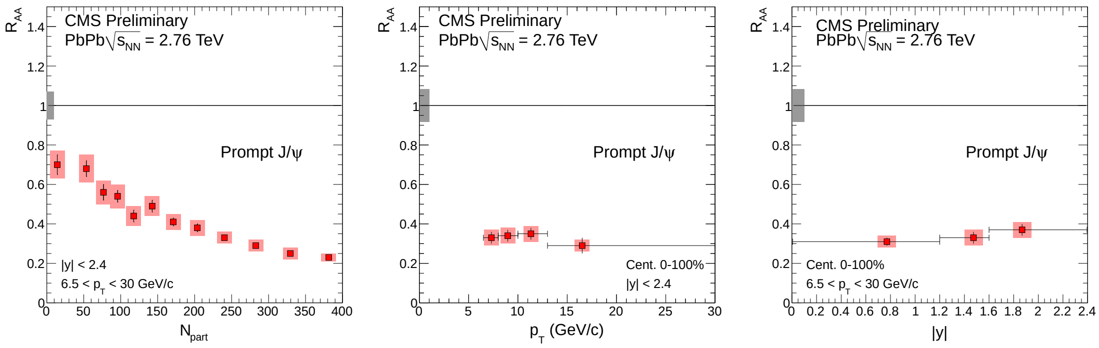


Figure 4. The nuclear modification factor of prompt J/ψ as a function of centrality (left), p_T (middle), and rapidity (right). The gray boxes plotted at unity show the scale of the global uncertainties. The bin boundaries are presented by small horizontal lines.

The results for J/ψ and $\psi(2S)$ are shown as a double ratio $(N_{\psi(2S)}/N_{J/\psi})_{PbPb}/(N_{\psi(2S)}/N_{J/\psi})_{pp}$ in Fig. 5, as a function of centrality [12]. At mid rapidity ($|y| < 1.6$ and $6.5 < p_T < 30$ GeV/c), the double ratio is always below unity without centrality dependence, which means more suppression of $\psi(2S)$ relative to J/ψ in PbPb. At forward rapidity extending down to lower p_T ($1.6 < |y| < 2.4$ and $3 < p_T < 30$ GeV/c), an increase of the double ratio with centrality is observed. The double ratio becomes $2.31 \pm 0.53(stat) \pm 0.37(syst) \pm 0.15(pp)$ in the most central bin, meaning $\psi(2S)$ is more produced than J/ψ in central PbPb collisions with respect to pp.

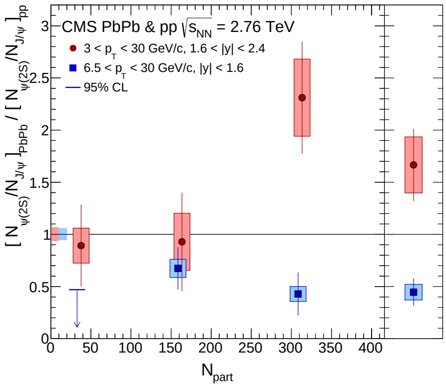


Figure 5. Double ratio of $\psi(2S)$ to J/ψ as a function of centrality for the mid rapidity (squares) and forward rapidity (circles, slightly shifted). Statistical uncertainties are shown as error bars, and systematics uncertainties are displayed as boxes. The boxes at unity represent global uncertainties. The right panel shows the centrality-integrated results.

3. Summary

The measurement of J/ψ in PbPb UPC has been reported. The result is in agreement with the model including nuclear gluon shadowing effects. The R_{FB} of J/ψ in pPb collisions is observed to be consistent with unity at high p_{T} and becomes lower than unity at low p_{T} indicating the presence of nuclear effects. The R_{AA} of prompt J/ψ is below unity and decreases with centrality providing the evidence of QGP. The double ratio results of $\psi(2S)$ to J/ψ are opposite to the expected sequential melting scenario in the forward rapidity bin, implying other physics processes such as recombination.

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