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Charmonium production in Pb-Pb and p-Pb collisions at forward rapidity measured with ALICE

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Abstract

The ALICE collaboration has measured the inclusive charmonium production at forward rapidity in Pb-Pb and p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV, respectively. In Pb-Pb collisions, the J/ψ and ψ(2S) nuclear modification factors (R_{AA}), as well as the J/ψ elliptic flow (v_2) and averaged squared transverse momentum ($\langle p_{\mathrm{T}}^2 \rangle$), are presented. In p-Pb collisions, the J/ψ nuclear modification factor (R_{pPb}) as a function of p_{T} and rapidity is presented. In both systems, our measurements are compared to theoretical calculations and to the results at lower energies.

Keywords: ALICE, heavy-ion collisions, charmonium production

1. Introduction

The measurement of the charmonium production in heavy-ion collisions was first proposed in [1] as a probe for the de-confinement of the QGP through the color screening dissociation mechanism. Moreover, due to the different dissociation temperatures of the charmonium states, sequential suppression was believed to serve as a QGP thermometer. As an opposite effect to the dissociation, charmonia can be regenerated at different stages of the collision due to the increasing number of initially produced $c\bar{c}$ pairs with collision energy. This regeneration component was introduced in [2, 3] and its presence in models was important in describing the J/ψ RHIC results at $\sqrt{s_{\mathrm{NN}}}$= 200 GeV [4]. In Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV the inclusive J/ψ suppression measured by ALICE [5] was found to be smaller than the one at RHIC, strengthening the argument for the presence of regeneration. However, the regeneration itself is not yet well understood and different models [2, 6, 7, 8] treat it differently. Studies on charmonium multi-differential R_{AA} (in rapidity, p_{T}, and centrality) are important for models to handle the balance between the suppression and regeneration mechanisms. Furthermore, different models have different predictions concerning the (ψ(2S)/J/ψ) ratio, arising the importance of measuring it. Finally, the elliptic flow acquired by the charm quarks in the medium can be further transferred to the regenerated charmonia.Therefore, measuring the J/ψ elliptic flow provides an additional test for the existence of regeneration and a constraining tool for models that implement it. In addition to the competitive dissociation and regeneration mechanisms, Cold Nuclear Matter (CNM) effects can affect the J/ψ and ψ(2S) production in the absence of the hot medium. Measuring charmonium production in p-A collisions is needed in order to better understand and quantify such effects.

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2. Analysis and results

A detailed description of the ALICE detector can be found in [9]. The results presented below correspond to inclusive charmonia (J/ψ and ψ(2S)) reconstructed via the dimuon decay channel using the forward muon spectrometer that covers the pseudorapidity range $-4 < \eta < -2.5$. In Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, the analysis was performed using an integrated luminosity $\sim 225\mu b^{-1}$ ($\sim$ 3 times larger than the Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV data sample). The centrality was estimated by fitting the V0 detector amplitude by a MC Glauber [10]. In p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 8.16 TeV, due to the asymmetry of the energy-per-nucleon of the proton and Pb beams, the muon spectrometer covers two different center-of-mass rapidity ($y_{\rm cms}$) regions, depending on the beam directions. Two periods that correspond to the p-going direction ($2.03 < y_{\rm cms} < 3.53$) and Pb-going direction ($-4.46 < y_{\rm cms} < -2.96$) were analyzed. The integrated luminosities collected in these two periods are respectively $\sim$ 8.7nb^{-1} and $\sim$ 12.9nb^{-1} ($\sim$ 2 times larger than the p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV samples). The raw numbers of reconstructed charmonia were obtained by fitting the dimuon invariant mass spectra with a superposition of signal and background functions. Different signal and background shapes as well as different fitting ranges were adopted in order to evaluate the systematic uncertainty on the extracted yields. In the Pb-Pb analysis, subtracting the combinatorial background using the event-mixing technique was also considered. The raw yields were further corrected by the detector acceptance times efficiency obtained via MC simulations.

The J/ψ and ψ(2S) $R_{\rm AA}$ in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV were computed by taking the measurement in pp collisions at the same energy [11] as a reference. On the J/ψ side, the centrality integrated $R_{\rm AA}$ ($p_{\rm T} < 8$ GeV/c) = $0.66 \pm 0.01(stat) \pm 0.05(syst)$ [12] was found to be systematically larger than the one measured at $\sqrt{s_{\rm NN}}$ = 2.76 TeV [5]. However the two measurements are consistent within total uncertainties. The J/ψ $R_{\rm AA}$ as a function of the average number of participating nucleons ($\langle N_{\rm part}\rangle$) at $\sqrt{s_{\rm NN}}$ = 5.02 TeV (Fig. 1 left) shows a clear J/ψ suppression as well as an approximately constant $R_{\rm AA}$ value for $\langle N_{\rm part}\rangle > 100$. The results are compared to different calculations based on transport models [6, 8], statistical hadronization model [13] and a comover interaction model [7]. Although not shown due to space restrictions, all the models can fairly describe the data due to their large uncertainties, that are mainly arising from the choice of the $c\bar{c}$ cross section needed as input for the regeneration component.

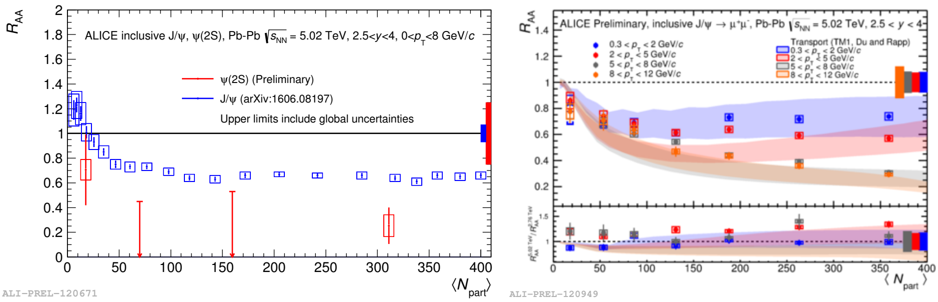

Fig. 1. Left: J/ψ [12] and ψ(2S) $R_{\rm AA}$ as a function of $\langle N_{\rm part}\rangle$, for $p_{\rm T} < 8$ GeV/c. Right: J/ψ $R_{\rm AA}$ as a function of $\langle N_{\rm part}\rangle$ in different $p_{\rm T}$ ranges, compared to calculations from [6].

The left panel of Fig. 1 shows also the results for the centrality dependence of the ψ(2S) $R_{\rm AA}$. Due to the very small signal-to-background ratios in some centrality intervals, an upper limit with a 95% confidence level is assigned (when calculating the upper limit, the global uncertainty shown as filled box around unity is included). In central and semi-central collisions, the ψ(2S) is more suppressed than the J/ψ.

J/ψ multi-differential studies were possible thanks to the large available statistics. In Fig. 1 right, the J/ψ $R_{\rm AA}$ is shown as function of $\langle N_{\rm part}\rangle$ for different $p_{\rm T}$ ranges. At high (low) $p_{\rm T}$, a strong (small) suppression with pronounced (almost no) centrality dependence is seen. The bottom panel of the plot shows the double ratios $R_{AA}(\sqrt{s_{NN}} = 5.02\,\text{TeV})/R_{AA}(\sqrt{s_{NN}} = 2.76\,\text{TeV})$ in different p_T ranges. Similar to the p_T integrated case, the results at two energies are compatible within uncertainties. Available calculations from a transport model [6] are compared to the results and show some discrepancies, mainly at intermediate p_T in semi-central collisions. Figure 2 shows the variable r_{AA} which measures the J/ψ p_T broadening in nucleus-nucleus collisions, defined as the ratio between the J/ψ $\langle p_T^2 \rangle$ in Pb-Pb and pp collisions. The decrease of the r_{AA} with centrality can be explained by the fact that the regeneration is important at low p_T. Calculation from a transport model [6] has difficulty in reproducing the r_{AA} centrality dependence, especially in semi-central collisions.

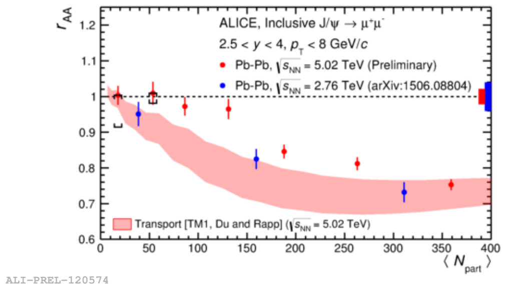

Fig. 2. J/ψ r_{AA} at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$ as a function of $\langle N_{part} \rangle$, compared to results at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$ [14], and to model calculations from [6].

The J/ψ elliptic flow was measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$. It is defined as the second order coefficient of the Fourier expansion of the J/ψ azimuthal distribution with respect to the reaction plane. The results in Fig. 3 show a non zero J/ψ v_2, with a 7.6 σ significance in the intermediate p_T range ($4 < p_T < 8\,\text{GeV}/c$). The magnitude of the J/ψ v_2 is similar to the open charm one within uncertainties. The results are compared to model calculations from [6] and [15], which underestimate the v_2 at intermediate and high p_T.

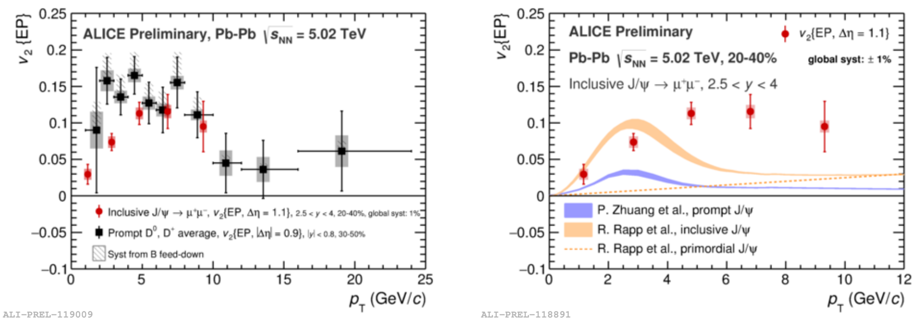

Fig. 3. J/ψ v_2 as a function of p_T, compared to the open charm v_2 (left), and to model calculations from [6] and [15] (right).

To quantify CNM effects on the J/ψ production, ALICE has measured the J/ψ nuclear modification factor (R_{pPb}) in p-Pb collisions at $\sqrt{s_{NN}} = 8.16\,\text{TeV}$ [16]. Measurements of the pp cross section at $\sqrt{s_{NN}} = 8\,\text{TeV}$ from ALICE [17] and LHCb [18], with adequate energy and rapidity corrections, were used for the normalization. The R_{pPb} as a function of y_{cms} is shown in the left panel of Fig. 4. A clear suppression up to about 40% is observed in the positive y_{cms} regions (p-going direction), while at negative y_{cms} (Pb-going direction) the $R_{\rm pPb}$ is compatible with unity within uncertainties. Different model calculations based on shadowing [19, 20], coherent energy loss [21], and color glass condensate [22] were able to describe the data. The J/ψ $R_{\rm pPb}$ as a function of $p_{\rm T}$ is also described by these models, in particular at low $p_{\rm T}$ ($< 4\,{\rm GeV}/c$) where the suppression is important (Fig. 4 right).

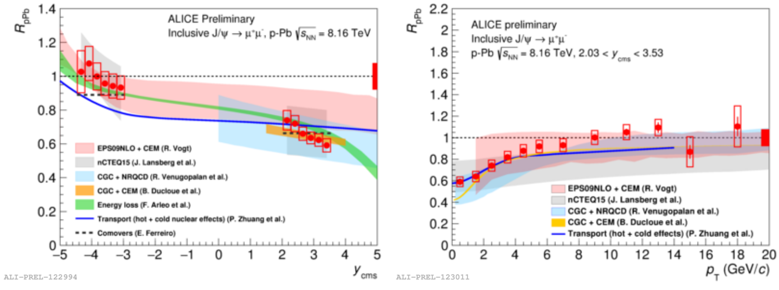

Fig. 4. The J/ψ nuclear modification factor in p-Pb collisions at $\sqrt{s_{\rm NN}} = 8.16\,{\rm TeV}$ as a function of $y_{\rm cms}$ (left) and as a function of $p_{\rm T}$ for $2.03 < y_{\rm cms} < 3.53$ (right).

3. Conclusion

ALICE measured the inclusive J/ψ and ψ(2S) nuclear modification factors in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02\,{\rm TeV}$. The J/$\psi$ $R_{\rm AA}$ decreases with increasing $p_{\rm T}$ and exhibits a strong centrality dependence. The ψ(2S) was found to be more suppressed than the J/ψ in central and semi-central collisions. A non-zero J/ψ v_2 is seen in semi-central collisions with 7.6 σ significance at intermediate $p_{\rm T}$. The amplitude of the J/ψ v_2 is similar to the one of open charm within uncertainties. Finally, results on the J/ψ nuclear modification factor in p-Pb collisions at $\sqrt{s_{\rm NN}} = 8.16\,{\rm TeV}$ show a clear suppression for $2.03 < y_{\rm cms} < 3.53$ with a strong $p_{\rm T}$ dependence.

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