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Measurement of charmonium production in Pb–Pb and p–Pb collisions at the LHC with ALICE

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Among the many possible probes to study the quark–gluon plasma (QGP), a high energy-density medium formed in relativistic heavy-ion collisions, heavy quarks are particularly interesting as they are expected to be produced in the initial stages of the collisions, by hard partonic scatterings, and to experience the full evolution of the medium. In particular, charmonia (bound $c\bar{c}$ states) production have been measured in nucleus-nucleus collisions with high precision at the LHC leading to the observation of new signatures of deconfinement (QGP) such as the regeneration of $c\bar{c}$ pairs into charmonium states. In this contribution, the latest ALICE results on the J/ψ nuclear modification factor ($R_{\rm AA}$) in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV will be presented as a function of centrality, J/ψ $p_{\rm T}$, and rapidity. This will be complemented by a discussion of the recent results on the elliptic and triangular flow coefficients of inclusive J/ψ which can be inherited from flowing charm quarks. In addition, results on J/ψ and $\psi(2S)$ measurements in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 and 8.16 TeV will be presented as a tool to study cold nuclear matter effects which may alter the quarkonium production in heavy-ion collisions. All the shown results will be compared to various theoretical calculations.

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1. Introduction

Heavy-ion collisions at (ultra-)relativistic energies offer the possibility to study the quark–gluon plasma (QGP), the deconfined state of nuclear matter occurring at high temperature and energy density. Heavy quarks, e.g. charm (c), are produced during the initial hard parton-parton scatterings, thus they will experience the entire evolution of the system. The production of charmonium, bound states of charm quark-antiquark pairs, is a sensitive probe of the in-medium QCD force and the medium properties. It was first proposed in [1] that if the QGP is created, a suppression of the charmonium yields is expected due to color screening between color charges and hence between a c and $\bar{c}$ quark. At ultra-high collision energies, the number of produced charm quark pairs becomes large and that would cause an enhancement of the charmonium production due to the stronger regeneration effects [2, 3]. In nucleus-nucleus collisions, the hot medium effects need to be separated from the cold nuclear matter effects (CNM), i.e., nuclear parton shadowing/gluon saturation, and parton energy loss. This can be achieved by studying other collision systems like proton-nucleus where the CNM effects are expected to be the dominant source of nuclear modifications.

The ALICE detector is capable to measure charmonium down to zero transverse momentum (p_{T}) in two rapidity intervals. At midrapidity ($|y| < 0.9$), the J/ψ mesons are reconstructed in the dielectron decay channel using the central barrel detectors. In addition, it is also possible to separate between the prompt and non-prompt J/ψ (the latter coming from beauty hadron decays). At forward rapidity ($2.5 < y < 4$), both J/ψ and $\psi(2S)$ mesons can be reconstructed in the dimuon decay channel using the muon spectrometer. A more detailed overview of the ALICE detectors can be found in [4].

2. Results

The nuclear modification of the charmonium production yields is quantified using the nuclear modification factor, R_{AA} [5], the ratio between the charmonium yields in Pb–Pb and the ones in pp scaled by the number of binary collisions. The left panel of Fig. 1 shows the R_{AA} of inclusive J/ψ measured at midrapidity as a function of centrality in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The results are compared to several model predictions which include charmonium regeneration. The transport models (TM1, TM2) [6, 7] assume a continuous dissociation and regeneration of the charmonium states both in the QGP and the hadronic phase, while in the statistical hadronization model (SHM) [8], all primordial J/ψ are fully suppressed and the J/ψ mesons are created only at chemical freeze-out. In the case of the "co-mover" model [9], the charmonium dissociation is due to the interaction with the comoving medium and a regeneration component is also included. In the right panel of Fig. 1 the p_{T} dependence of the inclusive J/ψ R_{AA} in different rapidity ranges for central collisions is shown. In the low p_{T} region ($p_{\mathrm{T}} < 5$ GeV/c), the J/ψ is less suppressed at midrapidity compared to the forward rapidity and this can be explained within the regeneration scenario by a higher charm cross section at midrapidity. At high p_{T} ($p_{\mathrm{T}} > 5$ GeV/c), the J/ψ suppression is stronger and it is independent of rapidity.

Another observable that is used to characterize the evolution and the properties of the system is the anisotropic flow. The magnitude of the anisotropic flow can be quantified by the flow

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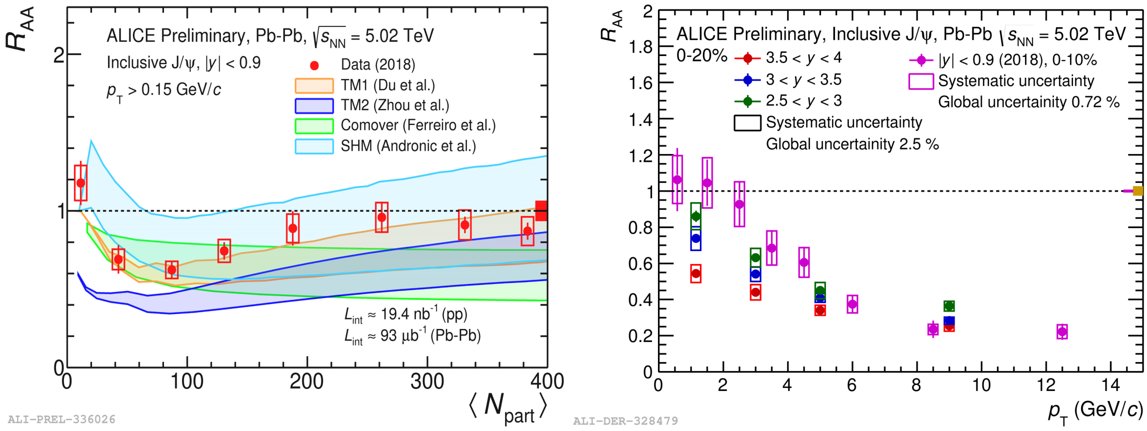

Figure 1: Left: R_{AA} of inclusive J/ψ measured at midrapidity as a function of centrality in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV compared to several model calculations. Right: Inclusive J/ψ R_{AA} as a function of p_T in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV measured in different rapidity intervals in central collisions.

coefficients, v_n, in a Fourier decomposition of the J/ψ azimuthal distribution with respect to the symmetry planes Ψ_n [10]. The second coefficient, v_2, known as elliptic flow gives the largest contribution to the asymmetry due to the almond shape of the overlap region, while the triangular flow, v_3, arises due to the event-by-event fluctuations of the energy deposition by the collision in the transverse plane. Figure 2 shows the J/ψ v_2 measured in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at forward and midrapidity as a function of p_T for different centrality intervals [11]. When comparing to charged pions [12] and D-mesons [13, 14], in the low p_T region (p_T < 5 GeV/c) a clear mass ordering ($v_{2,\pi} > v_{2,D} > v_{2,J/\psi}$) can be observed. At high p_T, v_2 does not depend on the particle species which might suggest a common origin, like the path length dependent energy loss. However, current model calculations do not consider sizable energy loss effects for J/ψ and fail to describe the v_2 at p_T > 4 GeV/c [11]. In addition, a positive J/ψ v_3 at forward rapidity was also measured and a weak centrality dependence is observed as illustrated in Fig. 3. Similarly to v_2, at low p_T the mass ordering also holds for v_3, while at high p_T the magnitude is compatible to those of charged pions and D-mesons.

Figure 4 shows the R_{pPb} of J/ψ and $\psi(2S)$ as a function of center-of-mass rapidity, y_{cms}, at $\sqrt{s_{NN}}$ = 8.16 TeV [15]. The R_{pPb} of the charmonium states is measured in two beam configurations with either Pb or protons going towards the muon spectrometer and this corresponds to the backward (-4.46 < y_{cms} < -2.96) and forward (2.03 < y_{cms} < 3.53) rapidity, respectively. At backward rapidity the $\psi(2S)$ is more suppressed than the J/ψ while at forward rapidity the suppression is similar. Models that include only initial state effects and coherent energy loss cannot distinguish between the charmonium states at backward rapidity as observed in the left panel of Fig. 4. Theoretical calculations that include final state effects like interactions with comovers can explain the $\psi(2S)$ and J/ψ difference (right panel of Fig. 4). The p_T dependence of the J/ψ and $\psi(2S)$ R_{pPb} at backward and forward rapidity is shown in Fig. 5. The results show a stronger suppression for $\psi(2S)$ than J/ψ over the whole p_T range.

In order to test for possible collective motion that might be present also in p–Pb collisions, ALICE collaboration measured the J/ψ v_2 using two-particle correlations with large pseudo-rapidity gap [16]. The results are presented in Fig. 6 as a function of p_T and compared to the results in

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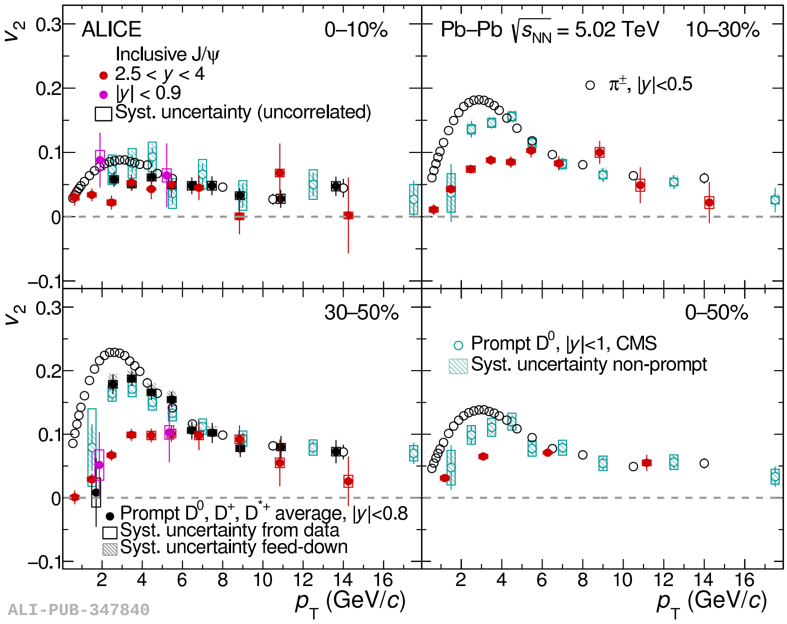

Figure 2: Inclusive J/ψ v_2 as a function of p_{T} measured at forward and midrapidity in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV for different centrality intervals [11].

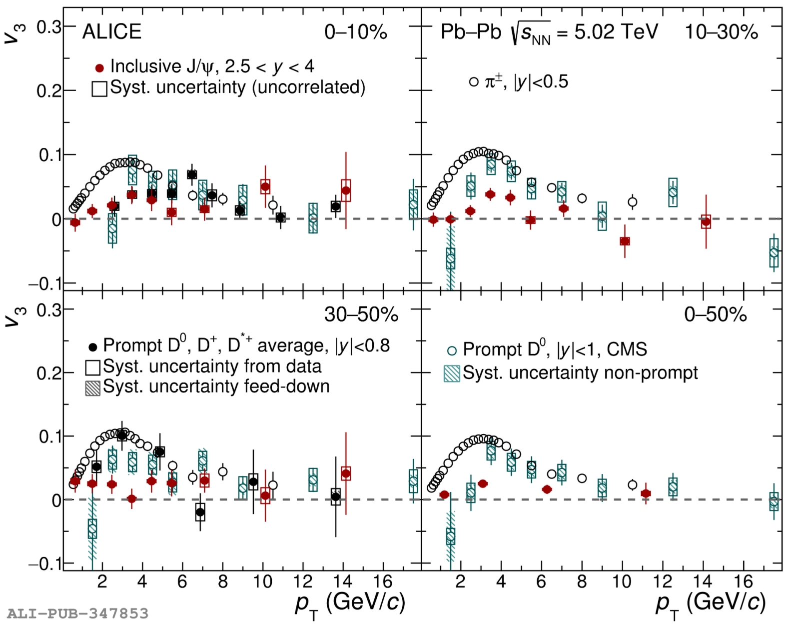

Figure 3: Inclusive J/ψ v_3 as a function of p_{T} measured at forward rapidity in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV for different centrality intervals [11].

semi-central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. For $p_{\mathrm{T}} < 3$ GeV/c, the J/ψ v_2 does not show any significant deviation from zero neither for backward nor forward rapidity. For $p_{\mathrm{T}} > 3$ GeV/c a significant non-zero v_2 is observed with the amplitude almost the same as in semi-central Pb–Pb collisions.

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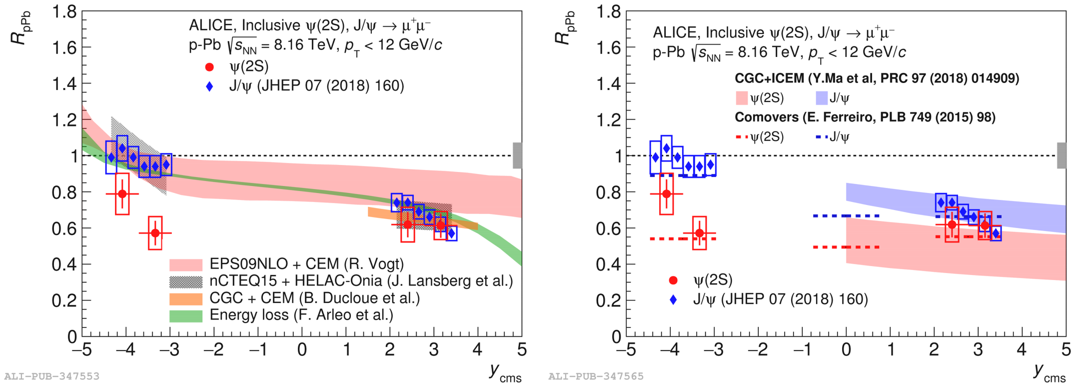

Figure 4: R_{pPb} of J/ψ and ψ(2S) as a function of y_{cms} in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV [15].

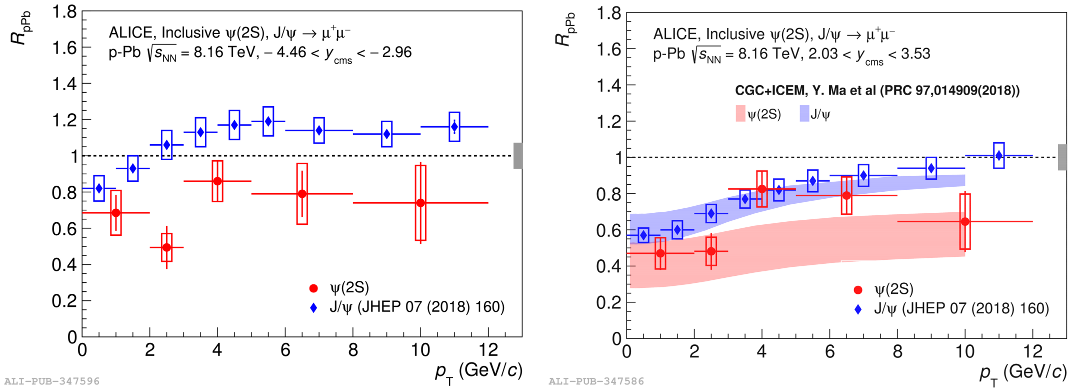

Figure 5: R_{pPb} of J/ψ and ψ(2S) as a function of p_{T} in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV measured at backward (left) and forward (right) rapidity [15].

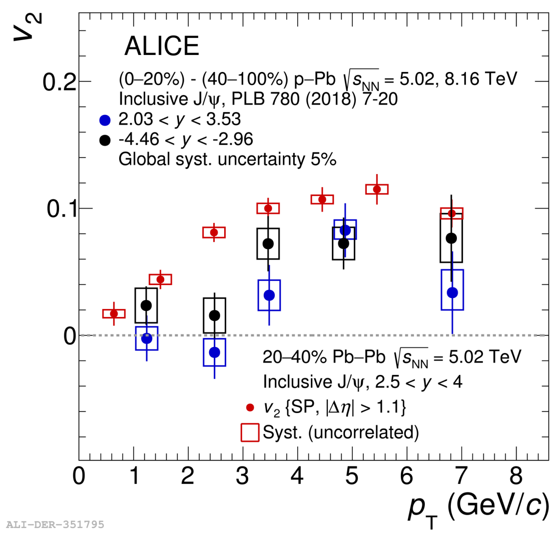

Figure 6: Inclusive J/ψ v_2 as a function of p_{T} in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 and 8.16 TeV. The results are compared to J/ψ v_2 in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV [16].

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In this contribution, selected measurements of charmonium production in p–Pb and Pb–Pb collisions at forward and midrapidity were presented. In Pb–Pb collisions the J/ψ nuclear modification factor, R_{AA} as a function of centrality and p_{T} is shown indicating a significant contribution from regeneration in the low p_{T} region. A positive J/ψ v_2 was observed at central and forward rapidity suggesting that charm quarks thermalize in the QGP. In p–Pb collisions, the difference between J/ψ and $\psi(2S)$ R_{pPb} can be explained by models that take into account final state effects. In addition, a positive v_2 was also measured in p–Pb collisions for $p_{\mathrm{T}} > 3$ GeV/c, suggesting possible final state effects and collective motion.

References

[1] T. Matsui, H. Satz , *"J/ψ suppression by quark-gluon plasma formation"*, Phys. Lett. B 178 (1986) 416

[2] P.Braun-Munzinger, J.Stachel, *"(Non)thermal aspects of charmonium production and a new look at J/ψ suppression"*, Phys. Lett. B 490 (2000) 196

[3] R. L. Thews, M. Schroedter and J. Rafelski, *"Enhanced J/ψ production in deconfined quark matter"*, Phys. Rev. C 63 (2001) 054905

[4] ALICE Collaboration, *"The ALICE experiment at the CERN LHC"*, JINST 3 (2008) S08002.

[5] ALICE Collaboration, *"J/ψ suppression at forward rapidity in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV "*, Phys. Lett. B 766 (2017) 212.

[6] X. Du, R. Rapp, *"Sequential regeneration of charmonia in heavy-ion collisions"*, Nucl. Phys. A 943 (2015) 147.

[7] K. Zhou, N. Xu, Z. Xu, P. Zhuang, *"Medium effects on charmonium production at ultrarelativistic energies available at the CERN Large Hadron Collider"*, Phys. Rev. C 89 (2014) 054911.

[8] A. Andronic, P. Braun-Munzinger, M. Kohler, K. Redlich, J. Stachel, *"Transverse momentum distributions of charmonium states with the statistical hadronization model"*, Phys. Lett. B 797 (2019) 134836.

[9] E. G. Ferreiro, *"Charmonium dissociation and recombination at LHC: Revisiting comovers"*, Phys. Lett. B 731 (2014) 57.

[10] S. Voloshin, Y. Zhang , *"Flow study in relativistic nuclear collisions by Fourier expansion of azimuthal particle distributions"*, Z. Phys. C 70 (1996) 665.

[11] ALICE Collaboration, *"J/ψ elliptic and triangular flow in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV "*, arXiv:2005.14518.

[12] ALICE Collaboration, *"Anisotropic flow of identified particles in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV "*, JHEP 09 (2018) 006.

[13] ALICE Collaboration, *"Transverse-momentum and event-shape dependence of D-meson flow harmonics in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV "*, arXiv:2005.11131.

[14] CMS Collaboration, *"Measurement of prompt D^0 meson azimuthal anisotropy in Pb–Pb collisions $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV "*, Phys. Rev. Lett. 120 (2018) 202301.

[15] ALICE Collaboration, *"Measurement of nuclear effects on $\psi(2S)$ production in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV"*, JHEP 07 (2020) 237.

[16] ALICE Collaboration, *"Search for collectivity with azimuthal J/ψ-hadron correlations in high multiplicity p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ and 8.16 TeV"*, Phys. Lett. B 780 (2018) 7.

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