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Nuclear Physics A 967 (2017) 576–579

NUCLEAR PHYSICS A

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ALICE measurement of the J/ψ nuclear modification factor at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

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Abstract

ALICE at the LHC provides unique capabilities to study charmonium production at low transverse momenta (p_{T}). At central rapidity, ($|y| < 0.8$), ALICE can reconstruct J/ψ via their decay into two electrons down to zero p_{T}. Results at mid-rapidity on the inclusive J/ψ nuclear modification factor R_{AA} as a function of centrality in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and comparisons to lower energies and models are shown. In addition, the yield of the J/ψ produced with very low p_{T} in the most peripheral collisions and the J/ψ elliptic flow (v_2) are also presented.

Keywords: Heavy-ion, ALICE, Quark-Gluon Plasma, Charmonium, J/ψ, Recombination

1. Introduction

The suppression of charmonium production induced by color screening of quarks was proposed more than 30 years ago as a probe of the formation of the Quark Gluon Plasma (QGP) [1]. At LHC energies, the number of $c\bar{c}$ pairs per events is one order of magnitude larger than at RHIC, therefore new mechanisms, like (re)generation, start playing a role in charmonium production. A charmonium enhancement was predicted for the most central A-A collisions [2, 3]. The inclusive nuclear modification factor of the J/ψ (R_{AA}) measured by ALICE [4, 5] at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, showed a striking enhancement compared to the one measured at lower energies [6, 7], supporting the models including (re)generation. The transport and comovers models assume the creation the charmonium states due to continuous dissociation and (re)generation throughout the lifetime of the medium [8, 9, 10]. On the other hand the statistical hadronization model [11] assumes creation of charmonium at the hadronization stage.

Due to the increase of the initial number of $c\bar{c}$ pairs relative to the total number of quarks, a small increase of the R_{AA} with the collision energy is predicted by all the models. The measurement at $\sqrt{s_{\mathrm{NN}}} =$ 5.02 TeV and the comparison to lower energies provides important information for the suppression and (re)generation picture.

2. Analysis and results

The ALICE experiment [12] allows to measure J/ψ at mid-rapidity ($|y| < 0.8$) in the decay channel e^+e^-. Two main detectors are used for the electron reconstruction. The Inner Tracking System (ITS), consisting of

http://dx.doi.org/10.1016/j.nuclphysa.2017.06.026
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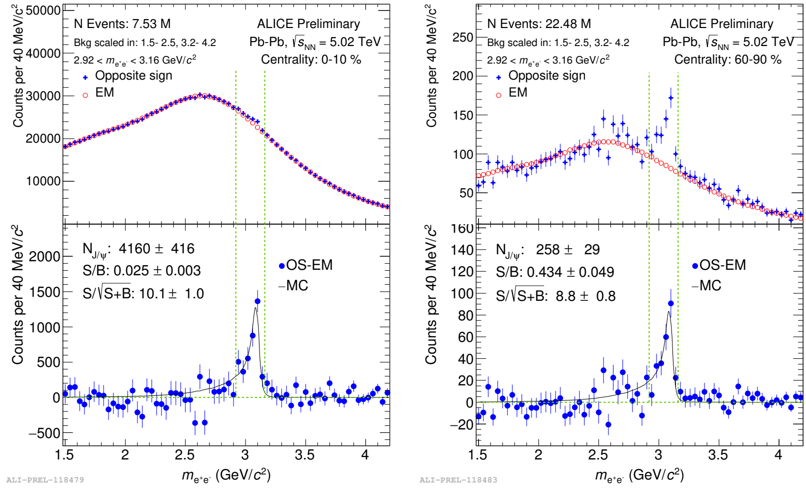

Fig. 1. Invariant mass distribution in two centrality classes: 0-10% (left), and 60-90% (right).

six layers of silicon detectors located around the interaction point, is used for tracking, vertex determination and triggering. The Time Projection Chamber (TPC) is the main tracking detector, and is also used for particle identification via the measurement of the specific energy loss in the detector gas (dE/dx). The electrons are identified using the TPC information, and the invariant mass distribution is reconstructed using opposite sign pairs.

The analysis presented here is based on 75 millions minimum bias events in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. This allows to measure the J/ψ production in 5 different centrality classes: 0-10%, 10-20%, 20-40%, 40-60% and 60-90%, which represents a similar amount of the statistics collected by ALICE during LHC Run 1 for central events, and more than 10 times of the statistics collected for peripheral events.

The invariant mass distribution, constructed with opposite sign pairs of electron candidates ($m_{e^+e^-}$), is shown in the top panel in Fig.1. The combinatorial background is mainly composed by uncorrelated pairs and is subtracted using an event mixing technique. The background is scaled to match the opposite sign distribution in two mass ranges: $1.5 < m_{e^+e^-} < 2.5$ GeV/c^2 and $3.25 < m_{e^+e^-} < 4.2$ GeV/c^2, where no J/ψ signal is present, and then subtracted from the opposite sign distribution. The bottom panel in Fig.1 shows the signal after background subtraction. A good agreement of the shape of the J/ψ signal expected from Monte-Carlo (MC) and the data is observed. The origin of the invariant mass shift towards smaller values than the nominal J/ψ mass is the electron energy loss in the detector material via bremsstrahlung and the contribution of the radiative decay channel J/$\psi \rightarrow e^+e^-\gamma$, where the soft photon contribution is neglected. The raw yields are extracted by bin counting in the range $2.92 < m_{e^+e^-} < 3.16$ GeV/c^2. The raw yields are corrected by the detector acceptance times efficiency estimated from MC simulations.

The R_{AA} is calculated as the ratio of the corrected J/ψ yield measured in Pb-Pb collisions and the J/ψ cross section measured in pp collisions ($\sigma_{\mathrm{pp}}^{\mathrm{J}/\psi}$) scaled by mean nuclear overlap factor ($\langle T_{\mathrm{AA}}\rangle$). The $\sigma_{\mathrm{pp}}^{\mathrm{J}/\psi}$ was calculated as an interpolation of different measurements at mid-rapidity by PHENIX [13], CDF [14] and ALICE [15, 16].

The inclusive R_{AA}, containing both prompt and non-prompt contribution at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV as a function of centrality is shown in the left panel of Fig. 2 compared to the ALICE measurement at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV at mid-rapidity [5]. The centrality dependence, characterized by an increasing suppression with centrality is similar at the two energies, however an increase of 18% is observed in the most central collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. Within our systematic uncertainties the results at both energies are compatible. The main systematic uncertainty is due to the $\sigma_{\mathrm{pp}}^{\mathrm{J}/\psi}$ and corresponds to 16%.

An excess of very low p_{T} J/ψ, observed already by ALICE [17] at forward rapidity, suggested an important contribution of J/ψ originated via photo-production. The cross section for this process at LHC energies

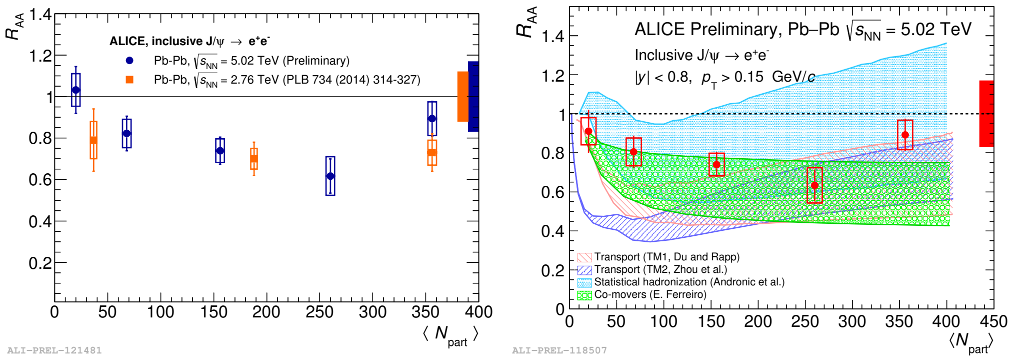

Fig. 2. *Left:*R_{AA} at mid-rapidity ($|y|$ <0.8) as a function of centrality. *Right:*R_{AA} compared to different theory models.

becomes comparable to the hadronic cross section. Fig. 3 shows the raw J/ψ yield as a function of p_{T} and the agreement with the scaled J/ψ yield measured in Pb-Pb ultra-peripheral collisions [18]. The yield normalized to the number of events is shown in the right panel of Fig. 3. It was calculated assuming the J/ψ photo-produced origin and the J/ψ transversely polarized.

As the contribution of photo-produced J/ψ is not taken into account by the models, a p_{T} cut above 150 MeV/c^2 is applied in order to remove most of the non-hadronic J/ψ. The hadronic R_{AA} is shown in the right panel of Fig. 2. ALICE result is compared to the transport models [8], [9], statistical hadronization model [11] and comovers model [10]. All of them are in agreement with the data due to the large uncertainties, propagated from the uncertainty on the $c\bar{c}$ cross section and shadowing.

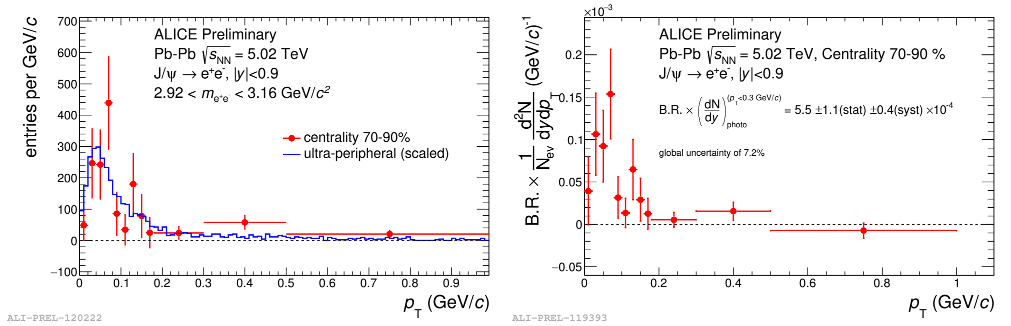

Fig. 3. *Left:*J/ψ yield compared to the scaled J/ψ in ultra-peripheral collisions. *Right:*J/ψ corrected yield as a function of p_{T}.

ALICE also measured the R_{AA} at forward rapidity [19]. The rapidity dependence of the R_{AA} for the centrality class 0-90% is shown in Fig. 4. The result is compatible with a constant or a slightly enhanced J/ψ production towards mid-rapidity.

Apart from the production yields, the elliptic flow can supply insights to learn about the interaction mechanisms within the QGP. The second moment of the final state hadron azimuthal distribution with respect to the reaction plane is called the elliptic flow (v_2). A hint ot the $v_2^{\mathrm{J}/\psi}$ at forward rapidity was measured by ALICE [20] during LHC Run 1. Fig. 4 shows the $v_2^{\mathrm{J}/\psi}$ measured at forward and mid-rapidity in LHC Run 2. Both measurements are in agreement, however the dielectron channel measurement is dominated by the large uncertainties.

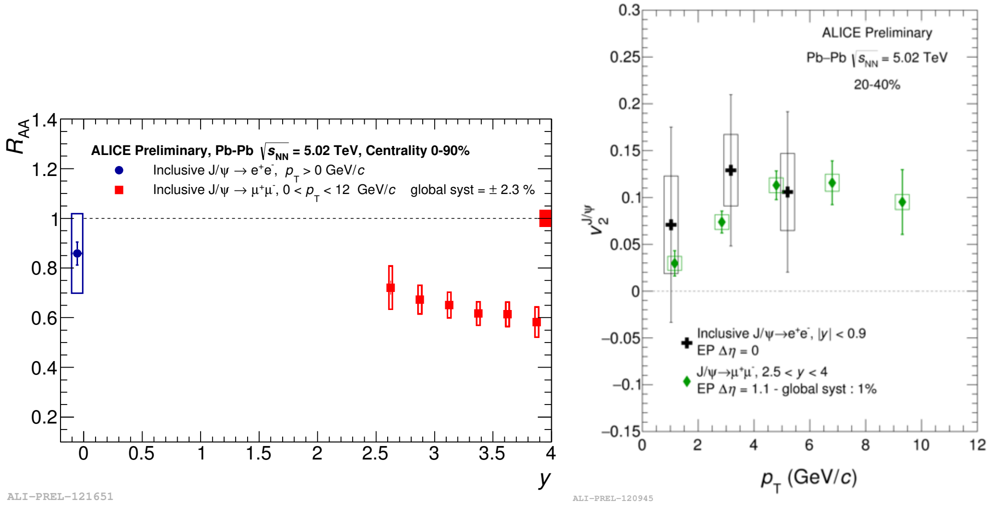

Fig. 4. *Left:*Rapidity dependence of the R_{AA} measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. *Right:*$v_2^{J/\psi}$ in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (20-40% centrality) measured at mid and forward rapidity.

3. Conclusions

The inclusive J/ψ nuclear modification factor has been measured by ALICE as a function of centrality and rapidity in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, down to $p_T = 0$. The measurement is in agreement with all the models. However due to their large uncertainties, it is not possible to discriminate between them. A first measurement of the very low p_T J/ψ yield at mid-rapidity has been obtained. A significant non-zero $v_2^{J/\psi}$ has been observed in semi central collisions at forward rapidity. The mid-rapidity $v_2^{J/\psi}$ values are in agreement with this result, although it is dominated by the large uncertainties.

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