Charmonium production in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV and $\sqrt{s_{\rm NN}}$ = 5.02 TeV measured with ALICE at the LHC

Benjamin Audurier for the ALICE Collaboration

Centre National de la Recherche Scientifique, 3 rue Michel-Ange, 75794 Paris cedex 16, France

E-mail: `benjamin.audurier@subatech.in2p3.fr`

Abstract. We report on the results of the charmonium production in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 and 5.02 TeV measured with the ALICE detector at the LHC. In particular, we focus on the new measurements obtained at $\sqrt{s_{\rm NN}}$ = 5.02 TeV for the J/ψ at forward rapidity in the dimuon decay channel and their comparison with previous measurements at lower energy and model calculations.

1. Introduction

Quantum chromodynamics predicts the existence of a deconfined phase of quarks and gluons at high temperature and density where chiral symmetry is restored [1]. This state of matter is known as the Quark-Gluon Plasma (QGP) [2], and can be formed in high-energy heavy-ion collisions. Its characterization is one of the goals of ultra-relativistic heavy-ion collision studies. The charmonium states (for instance J/ψ and ψ(2S)) are one of the probes studied to investigate the properties of the QGP. Indeed, the presence of a deconfined medium should modify the charmonium production yield, due to the color screening of the charm quark anti-quark potential and interaction with the surrounding medium [3]. Such a suppression was already observed in heavy-ion collisions at SPS and RHIC energies. However, at LHC energies, this suppression is presumably counterbalanced by the so-called regeneration mechanism [4], i.e. a recombination mechanism of c and $\bar{c}$ quarks, occurring during the deconfined phase or at the hadronization. This process is favoured by the increase of the charm cross section at LHC energies.

Two observables are frequently used to quantify the effect of the deconfined state of matter on charmonia. The first one, the so-called *Nuclear Modification Factor* $R_{\rm AA}$, is defined for a given centrality i as

$$R^{i}_{AA} = \frac{dY^{PbPb,i}/dp_T dy}{\langle N_{coll}\rangle dY^{pp}/dp_T dy} \tag{1}$$

where $dY^{PbPb,i}/dp_T dy$ ($dY^{pp}/dp_T dy$) is the differential yield in Pb-Pb (pp) collisions and $\langle N_{\rm coll}\rangle$ is the mean number of binary collisions. Any deviation from unity of the $R_{\rm AA}$ can be interpreted as a suppression ($R_{\rm AA} < 1$) or an enhancement ($R_{\rm AA} > 1$) of the charmonium production yield in Pb-Pb collisions compared to binary scaled pp collisions.

The second observable, the *elliptic flow* v_2 is the second coefficient of the Fourier expansion of the azimuthal particles distributions and is defined as:

$$v^{i}_{2}(p_T, y) = \langle \cos[2(\varphi - \Psi_{RP})]\rangle^{i} \tag{2}$$

where ϕ is the particle azimuthal angle and Ψ_{RP} is the reaction plane angle defined by the beam axis and the impact parameter direction. The elliptic flow is related to the anisotropy of the colliding system. If charmonia are created mainly via the regeneration mechanism, the v_2 measurement can be a stringent test for the degree of thermalization of the charm quarks in the QGP. Those two observables are measured by ALICE for the inclusive J/ψ production.

2. The ALICE Detector

ALICE measures the J/ψ production both at forward ($2.5 < y < 4$) and mid-rapidity ($|y| < 0.9$) through the dimuon and dielectron decay channel, respectively, down to zero transverse momentum. Depending on the rapidity range, central barrel detectors (mid-rapidity) or muon arm detectors (forward rapidity) are involved. A review of the ALICE detectors can be found in [5].

3. Results

The first data campaign at $\sqrt{s_{\rm NN}} = 2.76$ TeV (2011) shows a clear J/ψ suppression both at forward and mid-rapidity [6]. This suppression was already measured by PHENIX [7, 8] at $\sqrt{s_{\rm NN}} = 0.2$ TeV (Fig.1), but the ALICE measurements show a weaker centrality dependence and smaller suppression for central events. This behavior is expected in a regeneration scenario, as more J/ψ should be produced in central with respect to peripheral collisions.

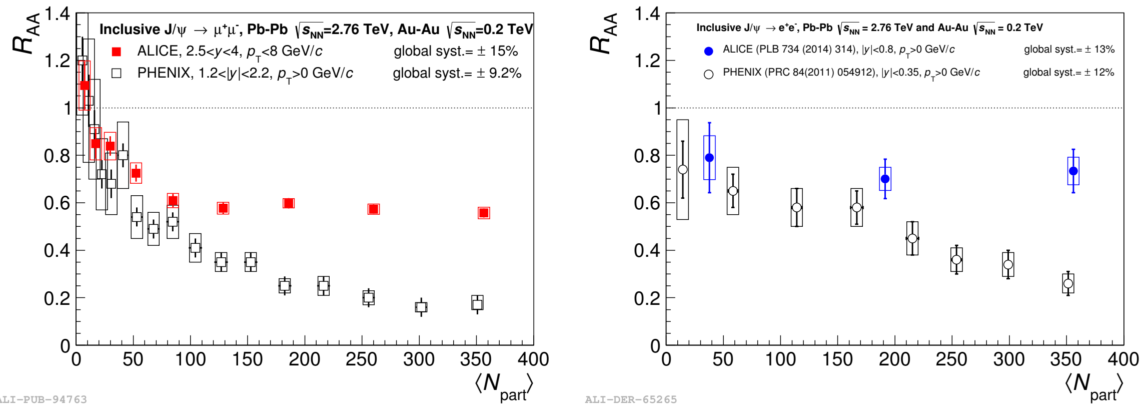

Figure 1: $R_{\rm AA}$ versus the average number of participant $\langle N_{part}\rangle$ in the dimuon (left panel) and dielectron (right panel) channel. The red points are ALICE results in Pb-Pb at $\sqrt{s_{\rm NN}} = 2.76$ TeV, the open points are PHENIX results in Au-Au at $\sqrt{s_{\rm NN}} = 0.2$ TeV. The error bars represent the statistical uncertainties, the boxes around the data points the uncorrelated systematic uncertainties [6].

In addition, the measurement of the J/ψ flow in semi-central collisions at forward rapidity shows a hint of a positive v_2 [9], in agreement within uncertainties with transport models including regeneration mechanism (Fig.2).

Finally, an unexpected excess of J/ψ was measured by ALICE at very low $p_{\rm T}$ [10] in the most peripheral collisions (Fig.3). A possible explanation for this excess is the coherent photoproduction mechanism for Pb-Pb collisions with $b < 2R$, where b and R are the impact parameter and the nuclei radius, respectively.

ALICE recently performed measurements in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. The detailed analysis can be found in [11]. ALICE has collected $\sim 225\ \mu b^{-1}$ integrated luminosity at $\sqrt{s_{\rm NN}} = 5.02$ TeV, representing 7 times more statistics with respect to 2011 data campaign. The fully integrated $R_{\rm AA}$ for inclusive J/ψ production at forward rapidity is $R_{\rm AA} = 0.69 \pm 0.01$(stat) $\pm$ 0.07(syst). Comparing this value with the corresponding one at $\sqrt{s_{\rm NN}} = 2.76$ TeV, $R_{\rm AA} = 0.58 \pm 0.01$ (stat) $\pm$ 0.09 (syst) [6], an increase of $R_{\rm AA}$ by $\sim$19% is found, with a 1.0σ significance. Results versus $\langle N_{\rm part}\rangle$ are shown in Fig. 4. While a significant reduction of the systematic uncertainties has been performed, results are compatible within uncertainties, showing an increasing suppression with centrality up to $\langle N_{\rm part}\rangle \sim 100$, followed by a roughly

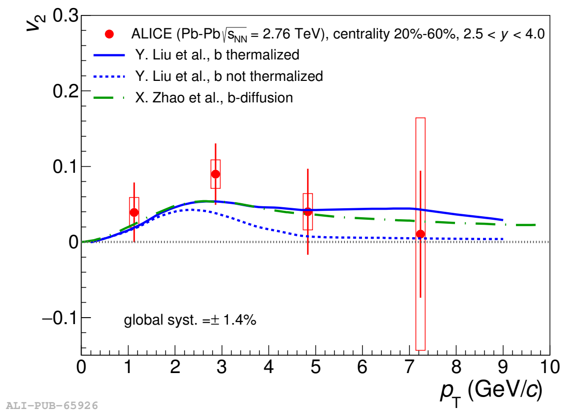

Figure 2: J/ψ elliptic flow as a function of $p_{\rm T}$ in the 20−60% centrality range compared to transport models. The error bars represent the statistical uncertainties, the boxes around the data points the uncorrelated systematic uncertainties [9].

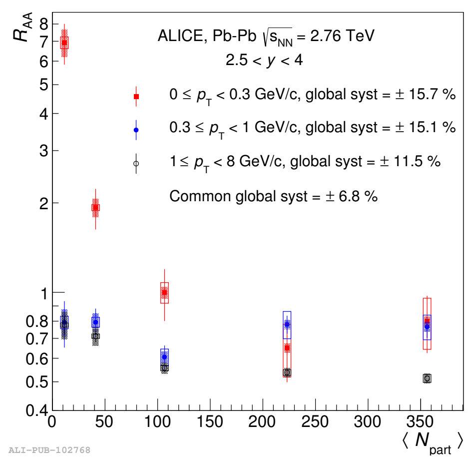

Figure 3: The $R_{\rm AA}$ versus $\langle N_{part}\rangle$ for different $p_{\rm T}$ ranges [10].

constant $R_{\rm AA}$ value. A $p_{\rm T} > 0.3$ GeV/c selection has been applied to the data, removing $\sim 80\%$ of the photoproduced J/ψ mentioned earlier, this production source being a contamination for these hadronic observables. Data are well described by various models, even if they have rather large uncertainties due to the choice of the corresponding input parameters, d$\sigma_{c\bar{c}}/dy$ in particular (see [11] for details). Making assumptions regarding the non-prompt component of the inclusive J/ψ nuclear modification factor, the $R_{\rm AA}$ of prompt J/ψ would be about 10% higher if $R_{\rm AA}^{\text{non-prompt}} = 0$ and about 3-4% (1%) smaller if $R_{\rm AA}^{\text{non-prompt}} = 1$ for central (peripheral) collisions.

The $p_{\rm T}$ dependence of the $R_{\rm AA}$ in central events is shown in Fig. 5. The $p_{\rm T}$ range has been extended up to 12 GeV/c with respect to $\sqrt{s_{\rm NN}} = 2.76$ TeV data due to the higher $p_{\rm T}$ reach for pp measurements at $\sqrt{s_{\rm NN}} = 5.02$ TeV. Similarly to what has been observed studying the centrality dependence of the J/ψ $R_{\rm AA}$, the $p_{\rm T}$ dependent suppression factor for central collisions increases systematically by about 20% with energy with respect to 2011 results. In this case, the region $p_{\rm T} < 0.3$ GeV/c was not excluded, the contribution of J/ψ photoproduction being negligible with respect to the hadronic one for central events [10]. Making the same kind of assumption concerning the non-prompt component, the prompt J/ψ $R_{\rm AA}$ is expected to be 7% larger (1% smaller) for $p_{\rm T} < 1$ GeV/c and 17% larger (20% smaller) for $6 < p_{\rm T} < 8$ GeV/c when the beauty contribution is fully (not) suppressed.

4. Conclusions

ALICE measures the inclusive J/ψ $R_{\rm AA}$ both at $\sqrt{s_{\rm NN}} = 2.76$ and 5.02 TeV and the J/ψ elliptic flow at $\sqrt{s_{\rm NN}} = 2.76$ TeV. Results at $\sqrt{s_{\rm NN}} = 2.76$ TeV show significant differences with previous results obtained at RHIC at $\sqrt{s_{\rm NN}} = 0.2$ TeV and are in good agreement within uncertainties with theoretical models including both a suppression and a regeneration mechanism affecting the probe. The inclusive J/ψ $R_{\rm AA}$ obtained at $\sqrt{s_{\rm NN}} = 5.02$ TeV is compatible within uncertainties with the $\sqrt{s_{\rm NN}} = 2.76$ TeV measurement while systematic uncertainties has been greatly reduced. The same trend is found both for the $\langle N_{\rm part}\rangle$ and $p_{\rm T}$ dependences of the $R_{\rm AA}$ between $\sqrt{s_{\rm NN}} =$ 2.76 and 5.02 TeV. Data and theoretical models are compatible within uncertainties and support a picture of competing J/ψ suppression and regeneration in the QGP.

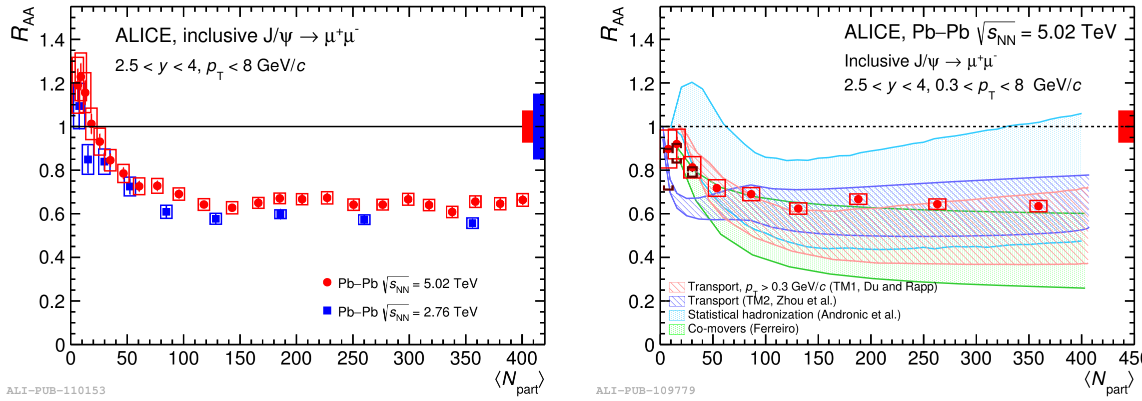

Figure 4: Results for the inclusive J/ψ $R_{\rm AA}$ versus $\langle N_{\rm part}\rangle$ at forward rapidity for $0 < p_{\rm T} < 8$ GeV/c (left panel) and for $0.3 < p_{\rm T} < 8$ GeV/c (right panel). The error bars represent the statistical uncertainties, the boxes around the data points the uncorrelated systematic uncertainties, while the global uncertainties are shown as a filled box around $R_{\rm AA} = 1$ [11].

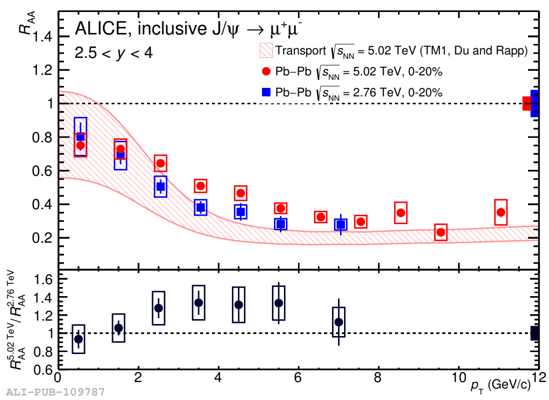

Figure 5: Inclusive J/ψ $R_{\rm AA}$ versus $p_{\rm T}$ at $\sqrt{s_{\rm NN}} = 5.02$ TeV, compared to the corresponding result at $\sqrt{s_{\rm NN}}$ $= 2.76$ and to the prediction of a transport model (see text for reference). The error bars represent statistical uncertainties, the boxes around the points uncorrelated systematic uncertainties, while global uncertainties are shown as a filled box around $R_{\rm AA} = 1$ on the right [11].

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