STUDY OF J/ψ PRODUCTION IN Pb–Pb COLLISIONS AT 2.76 TeV WITH THE ALICE EXPERIMENT AT THE LHC*

Hongyan Yang

for the ALICE Collaboration

SPhN/Irfu, CEA-Saclay, l'Orme des Merisiers, 91191 Gif-sur-Yvette, France

(Received December 12, 2011)

We present the measurement of J/ψ nuclear modification factor in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at both mid- and forward rapidity, from data collected in 2010 by the ALICE experiment. Results are compared to RHIC data and results from other experiments at LHC, as well as with existing models. The current status of two ongoing analyses on J/ψ production in ultra-peripheral collisions and J/ψ elliptic flow is also discussed.

DOI:10.5506/APhysPolBSupp.5.567
PACS numbers: 25.75.–q, 25.75.Nq, 25.20.Lj, 25.75.Ld

1. Introduction

J/ψ suppression in heavy ion collisions due to color-screening induced dissociation was proposed as a signature of the quark-gluon plasma (QGP), which is expected to be produced in high energy heavy ion collisions, by Matsui and Satz 25 years ago [1]. Since then, J/ψ production in heavy ion collisions has been intensively studied at SPS and RHIC from a center-of-mass energy of 17.2 to 200 GeV per nucleon–nucleon collision. The PHENIX experiment at RHIC measured a similar J/ψ suppression at mid-rapidity in Au–Au collisions at $\sqrt{s_{NN}} = 200$ GeV to that measured in Pb–Pb collisions at the SPS top energy ($\sqrt{s_{NN}} = 17.2$ GeV) [2, 3]. It was surprising to observe less suppression at mid-rapidity than at forward rapidity in central Au–Au collisions ($N_{\text{part}} > 100$) at RHIC [4]. The existing measurements have not been able to help us disentangle the cold and hot nuclear matter effects at the SPS energies. At RHIC energy, it was argued that both cold and hot nuclear matter effects also play their roles [4]. It has been proposed that a J/ψ regeneration mechanism from charm quarks in the QGP can

* Presented at the Conference "Strangeness in Quark Matter 2011", Kraków, Poland, September 18–24, 2011.

compete with the expected color-screening suppression [5, 6], especially at the LHC energy. The J/ψ elliptic flow is thought to be a crucial test of this regeneration scenario [7].

Ultra-peripheral collisions (UPC, defined as collisions for which the impact parameter is larger than the diameter of the colliding nucleus) can be used to study nuclear effects on J/ψ production since the photoproduction of J/ψ can be calculated by perturbative QCD (pQCD) by a 2-gluon exchange process [8]. This can provide us the nuclear gluon distribution which is used to understand cold nuclear matter effects, such as gluon shadowing.

The expected high abundance of charm quarks produced at LHC (up to a factor of 10 higher than at RHIC) makes it an ideal place to study J/ψ production mechanisms [9]. In this paper, we will present the study of J/ψ production in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV measured by the ALICE experiment at the LHC.

2. ALICE experiment and data analysis

The ALICE experiment [10] at the LHC is capable of measuring J/ψ production in Pb–Pb collisions at both mid- ($|y| < 0.8$) and forward rapidity ($2.5 < y < 4$) via its dielectron and dimuon decay channels, respectively [11]. At mid-rapidity, the time projection chamber (TPC) and the inner tracking system (ITS) are used for tracking, and the TPC is used for electron identification. At forward rapidity, the muon spectrometer is used for muon detection.

In 2010, ALICE collected Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with a minimum-bias (MB) trigger, which is based on signals measured in the forward scintillators (VZERO) and in the Silicon Pixel Detector (SPD), in coincidence with the LHC bunch-crossing signal [12]. The centrality of Pb–Pb collision is determined from a geometrical Glauber model fit to the VZERO amplitude distribution [13]. The J/ψ yield is extracted from the invariant mass distribution of opposite sign dilepton pairs. At mid-rapidity, the background is estimated by a track rotation method. After the background is subtracted, the J/ψ yield is extracted by bin counting in the invariant mass window [2.88, 3.2] GeV/c^2 [14]. At forward rapidity, the invariant mass distribution of opposite sign dimuons is fit within the range [2, 5] GeV/c^2. To obtain the raw J/ψ yield, a Crystal Ball (CB) function is used for the signal and the sum of two exponential functions for the background [15]. The obtained number of J/ψ in a given centrality and rapidity bin is corrected by the acceptance and efficiency (AccEff), the branching ratio (BR), and further normalized by the total number of events in this bin (N_{evt}) to form the corrected yield $Y_{J/\psi} = \frac{N^{J/\psi}}{\mathrm{BR}\times\mathrm{AccEff}\times N_{\mathrm{evt}}}$. The nuclear modification factor in a given centrality bin is defined as $R_{AA} = \frac{Y_{J/\psi}}{\langle T_{AA}\rangle\times\sigma^{pp}_{J/\psi}(\mathrm{inclusive})}$, where the corrected J/ψ yield is normalized by the product of the nuclear overlap function $\langle T_{AA}\rangle$ and the inclusive J/ψ cross section in pp collisions at the same energy measured by ALICE: $\sigma^{pp}_{J/\psi}(\text{inclusive, } 2.76\text{ TeV}) = 3.46 \pm 0.13(\text{stat.}) \pm 0.32(\text{syst.}) \pm 0.28(\text{syst.lumi.})\ \mu\text{b}$ [16]. The pp reference is roughly approximated by the J/ψ yield in the most peripheral bin (40–80%) to form the central to peripheral ratio, $R_{\text{CP}} = \frac{Y_{J/\psi}\times\langle T^{40-80\%}_{AA}\rangle}{\langle T_{AA}\rangle\times Y^{40-80\%}_{J/\psi}}$.

3. Results

Figure 1 shows the inclusive J/ψ R_{AA} for $p_{\text{T}} > 0$ at forward rapidity $2.5 < y < 4$. We have measured $R^{0-80\%}_{AA} = 0.49 \pm 0.03(\text{stat.}) \pm 0.11(\text{syst.})$, and no significant centrality dependence is observed. Our inclusive J/ψ R_{AA} is compared to the same measurement for Au–Au collisions from the PHENIX experiment at RHIC at different rapidities ($|y| < 0.35$ and $1.2 < |y| < 2.2$). We can clearly see that, at forward rapidity, J/ψ in Pb–Pb collisions at LHC is less suppressed than J/ψ in Au–Au collisions at RHIC. For the most central collisions our J/ψ R_{AA} at forward rapidity is also higher than the one at mid-rapidity at RHIC.

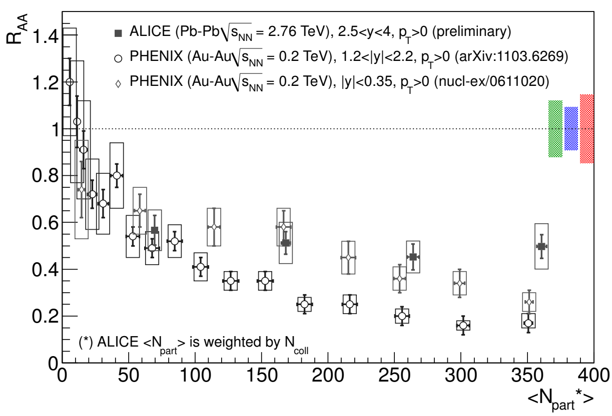

Fig. 1. ALICE J/ψ R_{AA} *versus* $\langle N^{\star}_{\text{part}}\rangle$ for Pb–Pb collisions measured at forward rapidity in comparison to PHENIX results for Au–Au collisions at mid- and forward rapidity [4], where $\langle N^{\star}_{\text{part}}\rangle$ is the average number of participants ($\langle N_{\text{part}}\rangle$) weighted by the number of binary collisions (N_{coll}).

Figure 2 shows the centrality dependence of the inclusive J/ψ R_{CP}. The ALICE measurements at both mid- and forward rapidity are compared to the ATLAS results for J/ψ with $p_{\text{T}} > 6.5$ GeV/c within the rapidity range $|y| < 2.5$ [17]. We see less suppression at forward rapidity and low p_{T} than ATLAS at mid-rapidity and high p_{T}. Our R_{CP} measurement at mid-rapidity has large statistical uncertainties which prevent us from drawing firm conclusions for the moment.

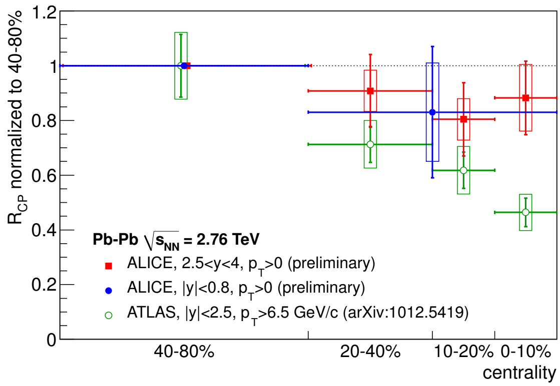

Fig. 2. Centrality dependence of J/ψ $R_{\rm CP}$ from ALICE compared with results from ATLAS [17].

The left panel of Fig. 3 shows the comparison of the ALICE and PHENIX measurement at forward rapidity to the statistical hadronization model calculations [18,19]. The statistical hadronization predicts less J/ψ suppression in central collisions at the LHC than at RHIC. However, this result depends strongly on the input $c\bar{c}$ cross section which is not yet well constrained. Figure 3 (right panel) shows the expected contributions to the J/ψ R_{AA} from initially produced and regenerated J/ψ, with and without shadowing, from the parton transport model [20]. They are compared to our J/ψ R_{AA} at forward rapidity. The comparison suggests that the regeneration becomes more important in central collisions. The calculations from another parton transport model [21,22] also allow similar conclusions.

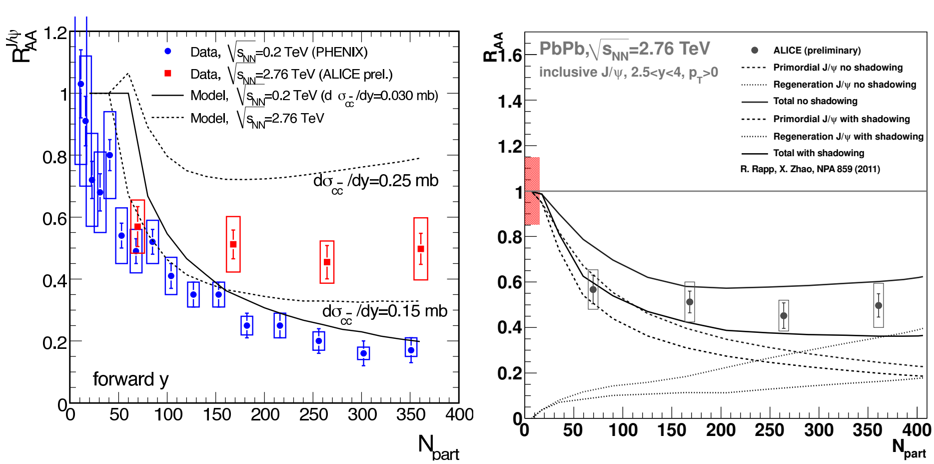

Fig. 3. Centrality dependence of J/ψ nuclear modification factor R_{AA} compared to statistical hadronization model calculations [18,19] (left), and parton transport model calculations [20] (right).

With the data collected in 2010, a couple of dozens of exclusively photo-produced J/ψ in ultra-peripheral Pb–Pb collisions have been reconstructed at both mid- and forward rapidity via dielectron and dimuon decay channels respectively. The expected increase in statistics collected in 2011 should allow quantitative comparisons with pQCD calculations. Due to the limited amount of data collected in 2010, the elliptic flow analysis of inclusive J/ψ at forward rapidity was performed in the centrality range 0–80%. The J/ψ yield is extracted in two $\Delta\phi$ bins: in-plane and out-of-plane, as shown in Fig. 4, where $\Delta\phi$ is the difference between the azimuthal angle of J/ψ candidate and the event plane angle determined by the azimuthal distribution of TPC tracks at mid-rapidity ($|\eta| < 0.8$). With the data collected in 2011, we expect to significantly reduce the statistical uncertainty. Other flow analysis methods, also including other detectors (such as VZERO), are under study.

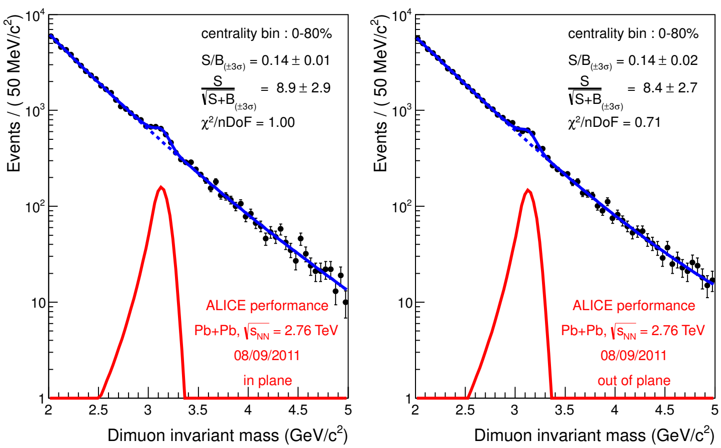

Fig. 4. Invariant mass distribution of opposite sign dimuons in two $\Delta\phi$ bins (left: in-plane, right: out-of-plane) within centrality 0–80%. J/ψ yield extraction by a fit to the distribution with a CB function for signal (grey/red curves) and the sum of two exponential functions as background (dashed lines).

4. Conclusions and outlook

The inclusive J/ψ ($p_{\mathrm{T}} > 0$) production in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at both mid- and forward rapidity has been measured by the ALICE experiment at the LHC. We observe less J/ψ suppression in central Pb–Pb collisions at LHC than in central Au–Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC. The J/ψ R_{AA} with $p_{\mathrm{T}} > 0$ at forward rapidity has no significant centrality dependence at the LHC. Both statistical hadronization and parton transport models seem to describe the observed J/ψ suppression at forward rapidity in central Pb–Pb collisions at the LHC. The comparison of our data to models suggests that the J/ψ regeneration mechanism in central

Pb–Pb collisions at LHC energy becomes more important. Since the model uncertainties are still rather large due to the unknown charm cross section and the amount of shadowing, J/ψ production in p–Pb collisions at LHC energy should be a useful tool to estimate initial state effects.

We expect to collect higher statistics for Pb–Pb collisions by the end of 2011, which will enable us to largely reduce the statistical uncertainties in the measurement of the J/ψ nuclear modification factor. The foreseen electron identification improvement by combining the Transition Radiation Detector (TRD), the Time of Flight (TOF) and the TPC, will help us to reduce the uncertainty of J/ψ measurement at mid-rapidity. The measurement of J/ψ production in UPCs and J/ψ elliptic flow will also be possible and will help us to better understand the J/ψ production mechanism.

REFERENCES

[1] T. Matsui, H. Satz, *Phys. Lett.* **B178**, 416 (1986).
[2] L. Ramello [NA50 Collab.], *Nucl. Phys.* **A774**, 59 (2006).
[3] R. Arnaldi [NA60 Collab.], *J. Phys. G* **35**, 104133 (2008).
[4] A. Adare *et al.* [PHENIX Collab.], `arXiv:1103.6269v1 [nucl-ex]`.
[5] A. Andronic, *et al.*, *Phys. Lett.* **B571**, 36 (2003).
[6] L. Yan *et al.*, *Phys. Rev. Lett.* **97**, 232301 (2006).
[7] Y.-P. Liu *et al.*, *Nucl. Phys.* **A834**, 317C (2010) and references therein.
[8] S. Klein, J. Nystrand, *Phys. Rev.* **C60**, 014903 (1999) and references therein.
[9] ALICE Collaboration, *J. Phys. G* **30**, 1517 (2004); **32**, 1295 (2006).
[10] K. Aamodt *et al.* [ALICE Collab.], *JINST* **3**, S08002 (2008).
[11] J. Castillo [ALICE Collab.], talk presented at the Conference "Strangeness in Quark Matter 2011", Kraków, Poland, September 18–24, 2011.
[12] K. Aamodt *et al.* [ALICE Collab.], *Phys. Lett.* **B696**, 30 (2011).
[13] K. Aamodt *et al.* [ALICE Collab.], *Phys. Rev. Lett.* **106**, 032301 (2011).
[14] J. Book, J. Wiechula [ALICE Collab.], poster at Quark Matter Conference 2011, Annecy, France.
[15] P. Pillot [ALICE Collab.], `arXiv:1108.3795v1 [hep-ex]`.
[16] D.T. Takaki [ALICE Collab.], *Acta Phys. Pol. B Proc. Suppl.* **5**, 561 (2012), this issue.
[17] G. Aad *et al.* [ATLAS Collab.], *Phys. Lett.* **B697**, 294 (2011).
[18] A. Andronic, *et al.*, `arXiv:1106.6321 [nucl-th]]` and references therein.
[19] P. Braun-Munzinger, talk presented at the Conference "Strangeness in Quark Matter 2011", Kraków, Poland, September 18–24, 2011.
[20] X. Zhao, R. Rapp, *Nucl. Phys.* **A859**, 114 (2011); private communications.
[21] Y.-P. Liu *et al.*, *Phys. Lett.* **B678**, 72 (2009).
[22] P.-F. Zhuang, talk presented at the Conference "Strangeness in Quark Matter 2011", Kraków, Poland, September 18–24, 2011.