

# Charmonium production measurements in Pb-Pb collisions with ALICE at the LHC

Lizardo Valencia Palomo for the ALICE Collaboration

Université de Paris-Sud and Institut de Physique Nucléaire d'Orsay, France

E-mail: lvalenci@cern.ch

**Abstract.** ALICE, one of the four main experiments at the LHC, aims to study the Quark-Gluon-Plasma, a state of matter created in high-energy heavy-ion collisions where quarks and gluons behave as free particles, rather than confined into hadrons. In this proceedings I discuss the measurements of charmonium production in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV performed at forward rapidity in the dimuon decay channel.

## 1. Introduction

Ultra-relativistic heavy-ion collisions are used to recreate in the laboratory the high energy densities which are thought to have existed during the first microseconds after the Big Bang. It is expected that, at extreme conditions of temperature and baryon density, ordinary nuclear matter undergoes a phase transition to a deconfined state of quarks and gluons called Quark-Gluon-Plasma (QGP).

Among the possible probes of the QGP, heavy quarks are of particular interest because they are produced in the initial stage of the collision and experience the whole evolution of the system. In particular, in 1980's the charmonium family was proposed as a tool to characterize the QGP: color screening of the heavy quarks potential, in the deconfined state, leads to a suppression of charmonium production [1]. Different charmonium states with different binding energies will have different melting temperatures, since the screening radius depends on the temperature of the medium. The  $J/\psi$  suppression is predicted to occur above a critical temperature of the medium ( $T_C$ ) and sequentially, in order of binding energy [2].

Charmonium production in high energy heavy-ion collisions at the SPS was extensively studied by three different experiments: NA38 [3], NA50 [4, 5] and NA60 [6], all of which performed the measurements in the dimuon decay channel. In central Pb-Pb collisions at 158 GeV/nucleon, the NA50 results show a clear  $J/\psi$  suppression (factor of 2), suggesting the creation of a deconfined medium. At RHIC, the PHENIX experiment has studied the  $J/\psi$  production both at mid rapidity ( $|y| < 0.35$ ) via  $e^+ e^-$  decay and at forward rapidity ( $|y| \in [1.2, 2.2]$ ) via  $\mu^+ \mu^-$  decay in Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. These measurements were performed as a function of the centrality, rapidity and transverse momentum. An important aspect is that PHENIX found a larger suppression at forward rapidity with respect to mid rapidity. Another unexpected feature is that the suppression was found to be similar to that at the SPS energy [8].

The modification of the  $J/\psi$  production is quantified by means of the nuclear modification factor:

$$R_{AA} = \frac{Y}{\langle T_{AA} \rangle \times \sigma^{pp}},$$

$Y$  is the invariant yield of the measured particle in nucleus-nucleus collisions,  $\langle T_{AA} \rangle$  the nuclear thickness function,  $\sigma^{pp}$  the cross section measured in pp at the same energy in the center of mass.

## 2. The ALICE experiment

ALICE (A Large Ion Collider Experiment) [9] is the LHC experiment designed to study heavy-ion collisions. It consists of a central barrel covering  $|\eta| < 0.9$  embedded in a solenoidal magnet and a forward Muon Spectrometer with a  $-4 < \eta < -2.5$  acceptance. Given the variety and complexity of all the subsystems located in the central barrel, only the detectors employed in this analysis are mentioned. The VZERO detector consists of two hodoscope scintillators located at both sides of the interaction point. The VZERO triggers the data taking and determines the centrality of the collisions by using a Glauber based Monte Carlo fit to the VZERO amplitude [10].

The Muon Spectrometer [11] is composed of absorbers, dipole magnet, tracking and trigger chambers. The front absorber filters out hadrons created in the collisions, the beam shield protects the chambers from particles produced at large rapidities, the iron wall absorbs hadrons that punch-through the front absorber and the rear absorber protects the trigger chambers from the background generated by the accelerator. The dipole magnet bends charged particles, allowing to extract the sign of their electric charge and their momenta. Ten tracking chambers, grouped by pairs in five stations, are used to reconstruct the trajectory of the particles. A dedicated trigger system is provided by four trigger chambers with a time resolution of 2 ns.

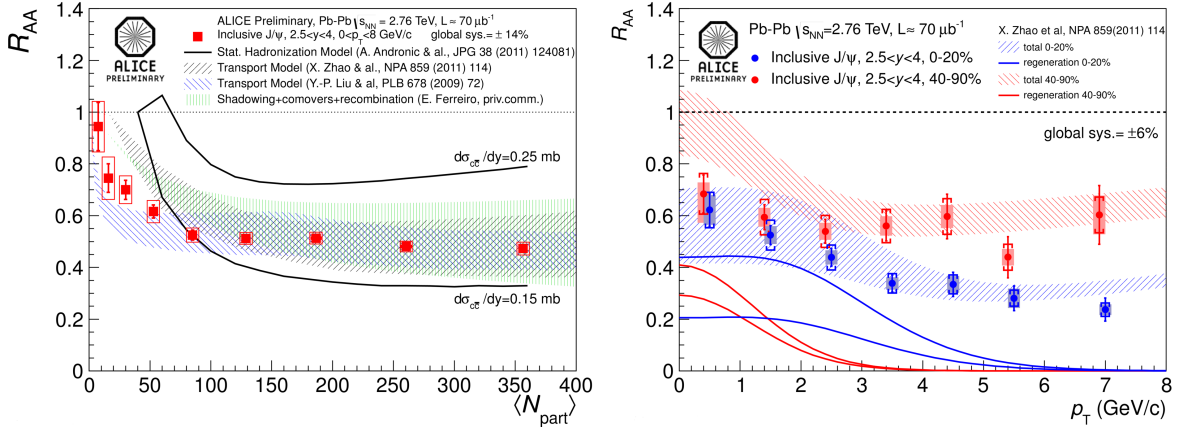
## 3. Analysis

The  $J/\psi \rightarrow \mu^+\mu^-$  analysis with the 2011 Pb-Pb collisions was performed over an integrated luminosity of  $70 \mu\text{b}^{-1}$ , corresponding to approximately 17 million dimuon events collected with the opposite sign dimuon trigger.

The raw yield is extracted with two different methods. In the first one the opposite-sign dimuon invariant mass spectrum is fitted with the sum of a modified Crystal Ball function (CB2) to model the signal plus a Variable Width Gaussian (VWG) for the background. The CB2 consists of a Gaussian core portion plus two power-law tails, one in the low mass range and another in the high mass one with independent parameters. The VWG contains four free parameters, one of which indicates the relation between the Gaussian width and the mass value. In the second approach, the combinatorial background is subtracted using the event mixing technique. The remaining uncorrelated background is fitted with an exponential function, while the CB2 is once again used to describe the signal. The results obtained from the different methods are then combined to extract a weighted mean and the systematic uncertainties on the signal extraction. The raw  $J/\psi$  yield in the 0-90% centrality range with  $0 < p_T < 8 \text{ GeV}/c$  and  $2.5 < y < 4$  amounts to approximately 40 000 counts.

The acceptance times efficiency value,  $A \times \epsilon$ , is obtained by embedding Monte Carlo  $J/\psi$  into real events. The integrated  $A \times \epsilon$  is 14%, with a 8% relative decrease from peripheral to central collisions. The inclusive  $J/\psi$  cross section in pp used for normalization was measured by the ALICE experiment at  $\sqrt{s} = 2.76 \text{ TeV}$  [12].

The most important source of systematic uncertainties (9%) was found to be the pp reference. Other contributions to the systematic uncertainties are the choice of the MC input, the nuclear thickness function, the trigger and tracking efficiencies.



**Figure 1.** *Left:*  $R_{AA}$  vs  $N_{part}$  and the predictions from the Statistical Hadronization Model, Transport Models and shadowing plus comovers plus recombination model. *Right:*  $R_{AA}$  vs  $p_T$  for central and peripheral collisions compared to a transport model.

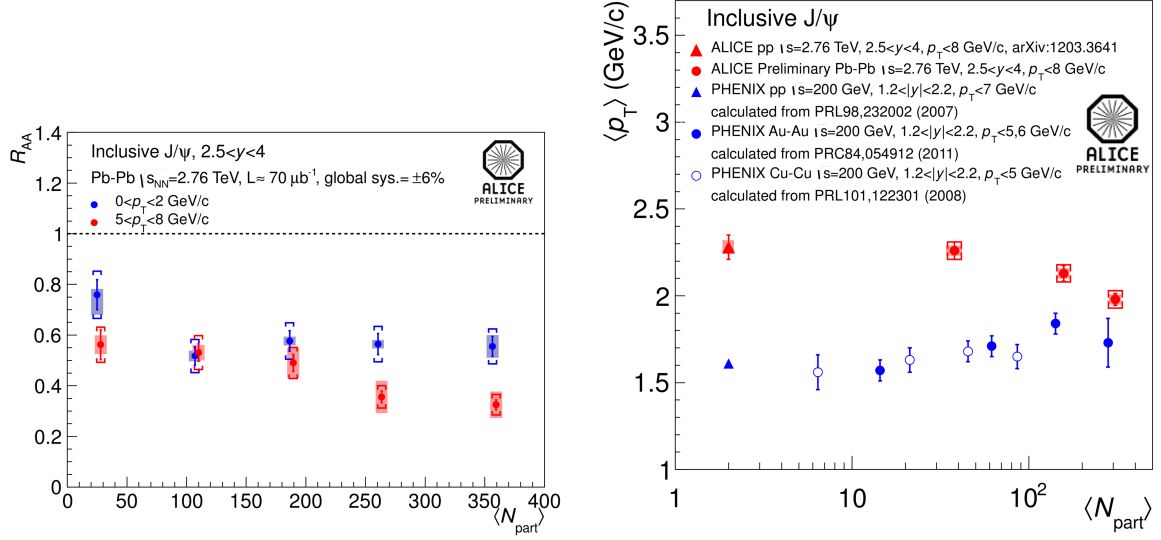
#### 4. Results

The inclusive  $J/\psi$   $R_{AA}$  measured by ALICE at  $\sqrt{s_{NN}} = 2.76$  TeV in the range  $2.5 < y < 4$  and  $0 < p_T < 8$  GeV/c is shown on the left panel of figure 1 as a function of  $N_{part}$ , indicating no significant centrality dependence for  $N_{part} > 70$ . The centrality integrated value is  $R_{AA}^{0-90\%} = 0.497 \pm 0.006$  (stat.)  $\pm 0.078$  (syst.), indicating a clear  $J/\psi$  suppression. This result is in agreement with the measurement performed using the 2010 Pb-Pb collisions data [13]. When compared to RHIC results, the ALICE  $R_{AA}$  is approximately three times larger than the  $R_{AA}$  measured by PHENIX for  $N_{part} > 180$  at forward rapidity [14]. The centrality dependence of the data is compared to four theoretical predictions. In the Statistical Hadronization Model the charmonium production occurs at the phase boundary by statistical hadronization of charm quarks [15]. The two Transport Models use different rate equations of the  $J/\psi$  dissociation and regeneration. In both models, 50% of the measured yield in central collisions is due to regeneration and the other 50% from the initial production [16, 17]. In the model including comovers plus recombination, the  $J/\psi$  are suppressed by partonic comovers [18].

The right panel of figure 1 presents the  $R_{AA}$  vs  $p_T$  for central (0-20%) and peripheral collisions (40-90%) and the results are compared with the predictions of the transport model [16]. The  $R_{AA}$  presents a notable  $p_T$  dependence only in the most central collision. In the 40-90% centrality collisions the model underestimates the suppression for  $p_T < 3$  GeV/c. In both centrality ranges, according to the model,  $J/\psi$  from regeneration have notable dominant contribution in the low- $p_T$  regime. In particular, the regenerated  $J/\psi$  are the dominant contribution for the most central collisions.

The left panel of figure 2 presents the  $R_{AA}$  as a function of the centrality for the low- $p_T$  ( $0 < p_T < 2$  GeV/c) and high- $p_T$  ( $5 < p_T < 8$  GeV/c)  $J/\psi$ . On one side, the suppression for the low- $p_T$   $J/\psi$  shows to be centrality independent when  $N_{part} > 100$ . On the other side, for high- $p_T$   $J/\psi$ , the nuclear modification factor presents a clear centrality dependence.

On the right panel of figure 2 the  $J/\psi$   $\langle p_T \rangle$  measured by ALICE is shown as a function of the centrality together with measurements at RHIC by PHENIX. The  $\langle p_T \rangle$  presents a clear decreasing trend, a striking difference with respect to the one obtained by the PHENIX experiment in Au-Au and Cu-Cu collisions at  $\sqrt{s_{NN}} = 200$  GeV/c in the rapidity interval  $1.2 < |y| < 2.2$



**Figure 2.** *Left:*  $R_{AA}$  vs  $N_{part}$  for low and high  $p_T$   $J/\psi$ . *Right:*  $J/\psi$   $\langle p_T \rangle$  compared to PHENIX measurements.

## 5. Conclusions

The inclusive  $J/\psi$   $R_{AA}$  measured with the ALICE detector in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV has no significant centrality dependence for  $N_{part} > 70$  and, for the most central collisions, it is approximately three times larger than the one measured at forward rapidity at RHIC. The clear decrease of the  $\langle p_T \rangle$  with increasing  $N_{part}$  is a completely different behaviour with respect to lower energy results. Theoretical models which include a full and partial  $J/\psi$  production from charm quarks in a dense partonic phase successfully describe the data. In all the theoretical predictions, the (re)generation component is dominant in the low- $p_T$  regime.

## References

- [1] T. Matsui and H. Satz, Phys. Lett. B 178 (1986) 416.
- [2] S. Digal *et al.*, Phys. Rev. D 64 (2001) 094015.
- [3] NA38 Collaboration, Phys. Lett. B 255 (1991) 459.
- [4] NA50 Collaboration, Phys. Lett. B 477 (2000) 28.
- [5] NA50 Collaboration, Eur. Phys. J. C 39 (2005) 335.
- [6] NA60 Collaboration, Phys. Rev. Lett. 99 (2007) 132302.
- [7] PHENIX Collaboration, Phys. Rev. Lett. 98 (2007) 232301.
- [8] ALICE Collaboration, JINST 3 (2008) S08002.
- [9] ALICE Collaboration, arXiv:1301.4361.
- [10] ALICE Collaboration, CERN-LHCC-1999-022.
- [11] ALICE Collaboration, Phys. Lett. B 718 (2012) 295.
- [12] ALICE Collaboration, Phys. Rev. Lett. 109 (2012) 072301.
- [13] PHENIX Collaboration, Phys. Rev. C 84 (2011) 054912.
- [14] A. Andronic *et al.*, J.Phys. G 38 (2011) 124081.
- [15] X. Zhao and R. Rapp, Nucl. Phys. A 859 (2011) 114.
- [16] Y.-p. Liu *et al.*, Phys. Lett. B 678 (2009) 72.
- [17] E. Ferreira, arXiv:1210.3209.