J/ψ production in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=2.76 TeV in the ALICE experiment

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Abstract. Quarkonium states are expected to provide essential information on the properties of the high-density strongly-interacting system formed in the early stages of heavy-ion collisions. In particular the J/ψ suppression via color screening is a direct consequence of deconfinement. ALICE is the LHC experiment specifically designed to study nucleus-nucleus collisions. The production of heavy quarkonium states is measured by ALICE down to zero transverse momentum via the $\mu^+\mu^-$ decay channel in the Forward Muon Spectrometer ($2.5 < y < 4$) and via the e^+e^- decay channel in the central barrel at mid rapidity ($|y| < 0.9$). The analysis of the inclusive J/ψ production in Pb-Pb collisions at a center of mass energy per nucleon pair $\sqrt{s_{\rm NN}}$=2.76 TeV is presented. The inclusive J/ψ nuclear modification factor as a function of centrality, transverse momentum and rapidity is shown and compared to similar measurements by other experiments and to theoretical predictions. Finally, a hint of a low transverse momentum J/ψ yield excess, with respect to the expected hadronic channel production, is discussed.

For more than 25 years, J/ψ production in heavy-ion collisions has been a promising probe of Quark Gluon Plasma (QGP), motivated by the prediction of Matsui and Satz in 1986 [1] of J/ψ dissociation due to color-screening in the QGP. J/ψ suppression has been extensively studied experimentally in heavy-ion collisions, first at the SPS and then at RHIC and it was found to be significantly larger than the suppression expected from cold nuclear matter effects, such as shadowing and nuclear absorption. However, in spite of the different center of mass energy of the two accelerators, the observed suppression patterns present similar features. This could be explained by an additional J/ψ production mechanism in heavy-ion collisions via the combination of initially uncorrelated charm and anti-charm quarks [2–5]. Another possibility is that directly produced J/ψ are not suppressed at both SPS and RHIC, and that the ∼40% suppression due to hot matter is due to the suppression of the J/ψ coming from the decay of $\psi(2S)$ and χ_c quarkonia [6]. The measurement of J/ψ suppression is of special interest at the Large Hadron Collider (LHC), where the high energy density of the medium and the large number of charm quark pairs produced in central Pb-Pb collisions should help to disentangle the suppression and recombination scenarios. In the following we describe the measurement by the ALICE experiment at the LHC of charmonium production at forward and mid-rapidity. The dependence of the J/ψ nuclear modification factor ($R_{\rm AA}$) on centrality, transverse momentum and rapidity are compared to previous measurements and theoretical predictions. Finally, an intriguing observation of a low transverse momentum J/ψ yield excess with respect to the expected hadronic channel production is discussed.

The ALICE experiment, described in detail in [7], is specifically designed to study nucleus-nucleus collisions. The dielectron analysis is based on a data sample of 12.8 million Pb-Pb collisions (0-80% most central) from the 2010 runs and 17.5 million Pb-Pb collisions (10 million 0-10% and 7.5 million 10-40%) from the 2011 runs, both collected with a minimum bias (MB) trigger. This corresponds to an integrated luminosity $\mathcal{L}_{\rm int}{\sim}15\mu{\rm b}^{-1}$. Electrons are reconstructed in the central barrel using the high precision tracking and particle identification of the Inner Tracking System (ITS) and of the Time Projection Chamber (TPC). Particle identification (PID) is achieved via the measurement of the specific energy loss of particles in the TPC, with dE/dx resolution of $\sim$ 5%. For the dimuon analysis at the same center of mass energy, 17.7 million Pb-Pb events were collected in 2011 with a dimuon trigger. This corresponds to an integrated luminosity $\mathcal{L}_{\rm int}{\sim}70\mu{\rm b}^{-1}$. Muons are reconstructed in the forward muon spectrometer, which consists of a front absorber to remove hadrons, followed by five tracking stations, the third one being embedded in a 3 Tm dipole magnet. The muon spectrometer also includes a triggering system located downstream of a 1.2 m iron wall, which absorbs secondary hadrons and low momentum muons, mainly from light hadron decays. Two scintillator arrays (VZERO), located on either side of the interaction vertex, are used for triggering, centrality determination and background removal. To further reject electromagnetic interactions and satellite collisions, the two Zero Degree Calorimeters, placed at ±114 m from the collision, are used. The analysis was limited to 90% most central collisions, for which the MB trigger is fully efficient.

In both channels, the J/ψ yield is extracted from the invariant mass distribution of opposite sign (OS) lepton pairs. In case of the dielectron channel [8], this distribution is dominated by the contribution of uncorrelated pairs, which is subtracted using an event mixing technique. The mixed event background distribution is scaled to match the integral of the signal distribution in the invariant mass range between 3.2 and 4.0 GeV/c^2. The remaining contribution to the J/ψ signal from the correlated e^+e^- continuum is small and is included in the systematic uncertainty. In the dimuon channel, an extended Crystal-Ball function (CB2), which consists of a gaussian core with two power law tails, is fit to the J/ψ signal. These CB2 tails are tuned on a Monte-Carlo (MC) production of J/ψ embedded into real events. The background contribution is described by a gaussian function with a mass-dependent width. Alternatively, an event mixing procedure has also been applied to subtract the background contribution, before fitting the signal. The residual background is then described by an exponential or a first order polynomial function. The raw J/ψ yield is then determined as the average of the results obtained with the two approaches, as detailled in [9]. In both cases, the extracted raw yield is corrected for the acceptance × efficiency ($A\epsilon$) of the apparatus. This correction is evaluated, for the dielectron analysis using simulated Pb-Pb collisions generated by the HIJING event generator enriched with primary J/ψ, while for the dimuon analysis the correction is determined by embedding generated J/ψ particles into real events. The kinematic distributions of the simulated J/ψ are obtained from an interpolation of RHIC, Fermilab and LHC data [10]. For the dielectron channel, $A\epsilon$ is 8%, while for the dimuon channel it is about 14%. A weak dependence (not more than 12%) of the efficiency on the collision centrality is observed in both cases.

The in-medium modification of J/ψ production can be quantified through measurement of the nuclear modification factor, defined as the ratio of the inclusive J/ψ yield measured in Pb-Pb collisions to the expected yield, where the latter is obtained by scaling the pp J/ψ production cross section at the same center of mass energy per nucleon pair by the nuclear overlap function ($T_{\rm AA}$). Details of pp reference in both rapidity intervals are found in [11]. These $R_{\rm AA}$ is measured separately for each kinematic bin under study. The main contribution to the systematic uncertainty for the dielectron channel results from the description of the combinatorial background. The main contribution to the global systematic uncertainty comes from the pp reference cross section. The centrality dependence of the inclusive J/ψ $R_{\rm AA}$, integrated over $p_{\rm T}$ and y, is shown in Fig.1 (left). For the most central 0-10% collisions we obtain at mid-rapidity

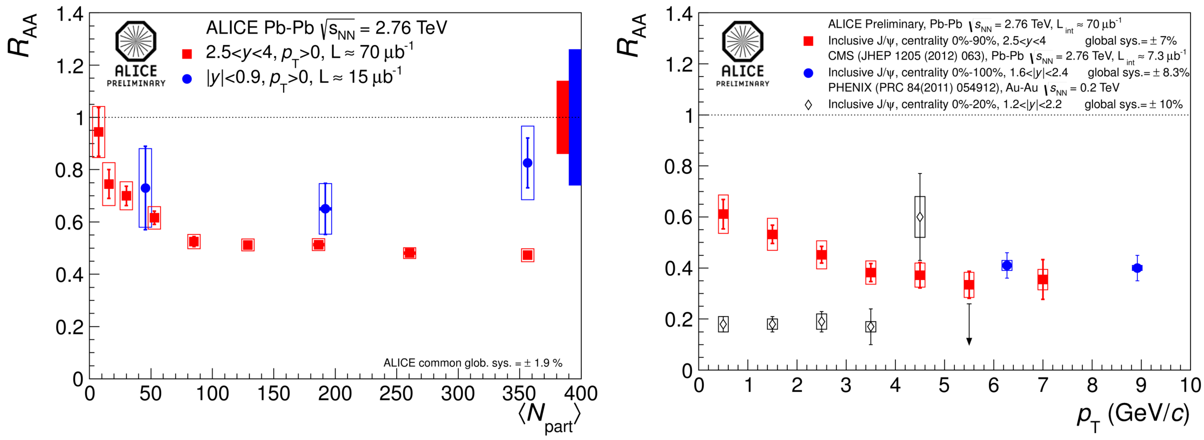

Figure 1: Left: J/ψ $R_{\rm AA}$ as a function of the number of participants at forward and mid-rapidity. Statistical errors are shown as lines, while systematic uncertainties are shown as boxes around the points. Right: J/ψ $R_{\rm AA}$ as a function of $p_{\rm T}$ at forward rapidity. Comparisons to the CMS and PHENIX results are shown.

an $R_{\rm AA}$ value of $0.83 \pm 0.09(stat) \pm 0.26(syst)$. At forward rapidity, the inclusive $R_{\rm AA}$ value averaged over centrality, $p_{\rm T}$ and y is $0.497 \pm 0.006(stat) \pm 0.078(syst)$, exhibiting less suppresion than at RHIC energies. In addition, the observed pattern has weaker centrality dependence and a smaller suppression for central collisions than the PHENIX measurements [12]. The ALICE data suggest that the $R_{\rm AA}$ decreases with increasing rapidity (more details in [8]) and suggest a different interplay of suppression and regeneration mechanisms compared to PHENIX data. Fig.1 (right) shows $R_{\rm AA}$ as a function of $p_{\rm T}$ as measured by ALICE, compared to CMS data [13] as well as to results from PHENIX [12]. $R_{\rm AA}$ is decreasing from 0.6 at low $p_{\rm T}$ to about 0.4 at higher $p_{\rm T}$. The CMS results are in agreement with the ALICE measurements in their common $p_{\rm T}$ range. The lower energy results from PHENIX show a significantly smaller $R_{\rm AA}$. The $p_{\rm T}$ dependence of J/ψ $R_{\rm AA}$ for different centrality classes is shown in the left pannel of Fig.2. The data are fairly well reproduced by theoretical model predictions that include a large fraction of J/ψ produced from regenerated pairs [14]. This contribution is expected to be dominant at low $p_{\rm T}$, especially in central collisions. Additional results on the $<p_{\rm T}>$ of the J/ψ as a function of the centrality [15] and on the J/ψ elliptic flow [16] are in agreement with such a scenario.

The $p_{\rm T}$ yield of OS dimuon pairs in the mass range $2.95 < {\rm M}_{\mu^+\mu^-} < 3.3$ GeV/c^2, integrated over y and for peripheral collisions (70-90%), is shown in Fig.2 (right). In this mass range, the J/ψ contribution dominates, with a signal over background ratio of 3.96 ± 0.52. No $A\epsilon$ correction has been applied. The red line[1] represents the expected contribution from hadronic J/ψ production [10]. A clear excess is observed at very low $p_{\rm T}$, below 300 MeV/c. This excess is also seen in the semi-peripheral collisions 50-70%. J/ψ particles are also be generated via a coherent photo-production mechanism [17], as is measured at forward rapidity in Ultra Peripheral Pb-Pb Collision (UPC) at $\sqrt{s_{\rm NN}}$=2.76 TeV [18]. The unique feature of this mechanism is the production of J/ψ at very low $p_{\rm T}$ ($<p_{\rm T}>\approx 60$ MeV/c). Theoretical photo-production predictions can be found in [19] although the calculations are done for UPC, *i.e.* for an impact parameter larger than twice the nuclear radius. In Pb-Pb peripheral collisions, J/ψ photonic and hadronic production could exhibit similar production cross-sections [20]. The low $p_{\rm T}$ excess shown in Fig.2 (right) could then be due to the contribution of photo-produced J/ψ. Since this production only occurs in the initial stage of the collision, it may be a novel way to study the medium induced dissociation of the J/ψ.

[1] Also called "red wine" for Hot Quarks participants.

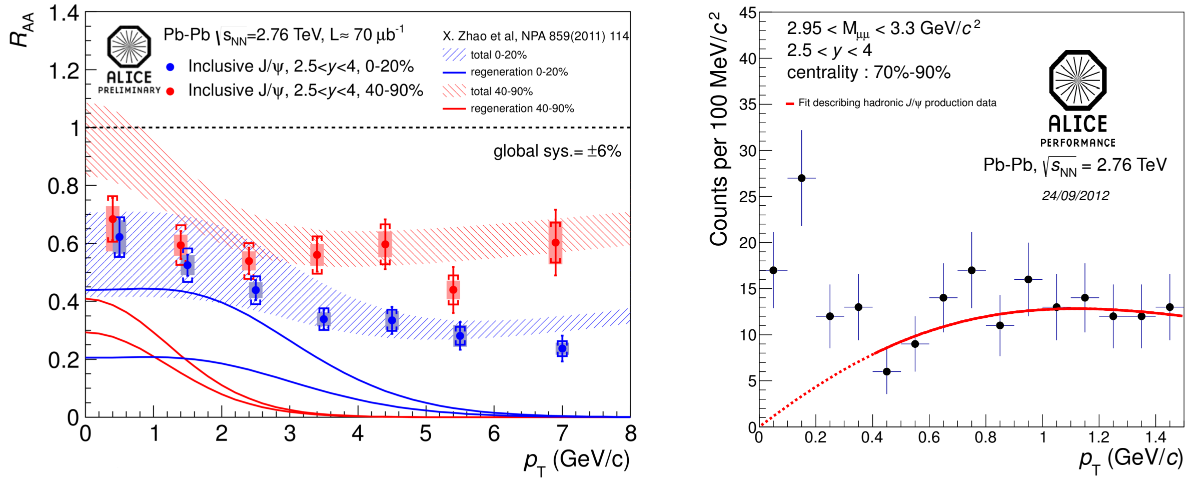

Figure 2: Left: J/ψ $R_{\rm AA}$ $p_{\rm T}$ dependence at forward rapidity for two centrality classes. Systematic uncertainties are split between uncorrelated and partially correlated components, shown, respectively, as boxes and brackets around the points. Right: Dimuon $p_{\rm T}$ distribution from opposite sign invariant mass spectrum around J/ψ mass at forward rapidity.

In summary, ALICE has measured J/ψ $R_{\rm AA}$ as a function of centrality, $p_{\rm T}$ and rapidity, in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=2.76 TeV. At mid-rapidity, the $R_{\rm AA}$ indicates a moderate J/ψ suppression, with no significant centrality dependence. At forward rapidity, the $R_{\rm AA}$ shows a clear reduction of the J/ψ yield, with negligible centrality dependence and clear $p_{\rm T}$ dependence, especially in central collisions. These features can be qualitatively described by theoretical models which include regeneration as an additional mechanism for J/ψ production in heavy-ion collisions. Further insight into J/ψ production and suppression still needs a precise knowledge of the cold nuclear matter effects, which will be studied with p-Pb collisions in early 2013. Finally, a low transverse momentum J/ψ yield excess in hadronic collision has been observed, and may arise from J/ψ photo-production mechanism.

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