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J/ψ production measurement at midrapidity from pp to Pb-Pb collisions with ALICE

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Abstract. The charmonium states provide essential information on the properties of a new state of matter predicted to be formed at extreme energy densities and temperatures, the Quark Gluon Plasma (QGP). ALICE is an experiment at LHC dedicated to the study of the QGP state in heavy ion collisions. The ALICE results on the J/ψ production using the dielectron decay channel in pp collisions at 7 TeV and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV will be discussed. Due to its excellent vertexing capabilities, ALICE can separate the non-prompt J/ψ component thus allowing for a measurement of the beauty production. beauty production. ALICE is the only experiment that measures the charmonium production at central rapidity (|y| < 0.9) down to p_T=0.

1 Introduction

In ultra-relativistic heavy-ion collisions hadronic matter reaches extreme energy densities and temperatures and a phase transition to a deconfined state is predicted to occur. This QCD state, namely the Quark Gluon Plasma (QGP), is short lived (< 10 fm/c at LHC energies) and partons are not confined anymore in nucleons. The production rates of charmonium states are sensitive to the temperature, density and as well the dynamics of the deconfined nuclear medium. The extreme color charge density may lead to a color screening effect which is expected to suppress the charmonium and bottomonium formation [1]. Within such a hot and dense QCD medium the range of the interaction between heavy quarks is inversely proportional to the temperature. Therefore the resonance state can only be formed if the temperature of the medium is low enough. Different charmonium states have different binding energies and radii and thus different melting temperatures : the dissociation affects first the ψ' state, then the χ_c and finally the J/ψ, thus causing a sequential suppression of the inclusive J/ψ production [2]. At the LHC energies, the large multiplicity of free charm quarks may also lead to a further regeneration of bound states in the dense medium during the final hadronization phase [3] which is a competing effect to the previosly mentioned suppression. On top of these competing phenomena, also cold nuclear matter effects may come into play (e.g.: initial state energy loss, gluon shadowing due to the small x at LHC energies and nuclear absorption). The benchmarks to understand the role of these effects in AA collisions are represented by the J/ψ production in pp and in pPb collisions.
Furthermore the inclusive J/ψ yield contains also a significant contribution from b-hadron decays, in addition to the source of non-direct J/ψ coming from ψ' and χ_c. Due to the long lifetime of the b-hadron (O(500) μm/c), this contribution should not suffer from color screening, but instead reflects

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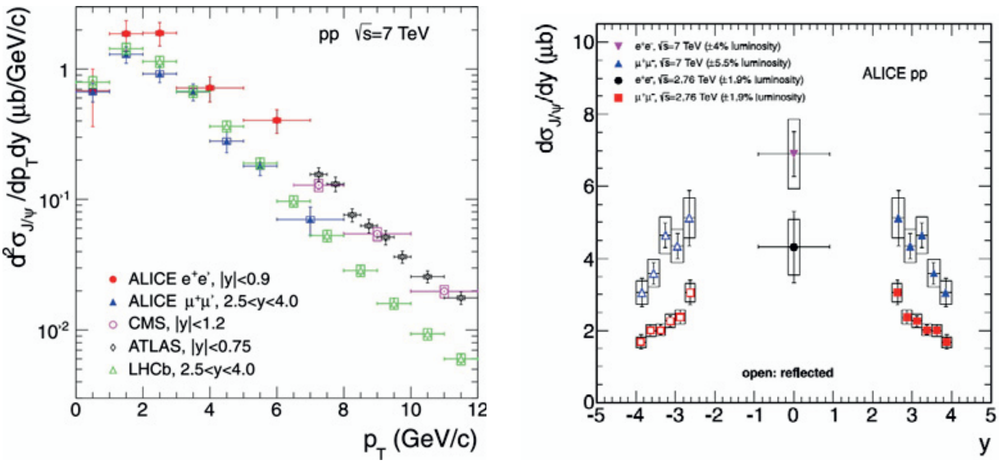

Figure 1. Left : Double differential J/ψ production cross section as a function of p_T measured by ALICE (red points) and other LHC experiments [6]. The error bars represent the quadratic sum of the statistical and systematic errors, while boxes show the systematic uncertainties due to the luminosity determination. Right : Differential J/ψ production cross section at both $\sqrt{s}$ = 2.76 TeV and $\sqrt{s}$ = 7 TeV in both dielectron decay channels [6] and [5]. The vertical error bars show the statistical errors while the boxes the systematic uncertainties. The systematic uncertainties due to the luminosity are not included.

the b-quark production in the medium. Separating non-prompt J/ψ from the inlcusive yield allows to study the beauty production in pA and AA colllisions.

2 J/ψ detection in ALICE

The ALICE detector can investigate inclusive J/ψ production at central rapidities down to p_T=0 via the dielectron decay channel $J/\psi \rightarrow e^+e^-$. The two main tracking detectors are the Time Projection Chamber (TPC) and the Inner Tracking System (ITS). They have a barrel geometry with excellent tracking performances within |y|<0.9. The TPC provides also electron identification with a 3 sigma separation from proton and pions down to p_T=1 GeV/c, making the identification of inclusive J/ψ in a momentum range complementary to the measurements done by other LHC experiments (CMS, ATLAS). The ITS provides a secondary vertex resolution at low momenta, which allows for the separation of the non-prompt J/ψ contribution also in the lowest accessible momentum range. In particular the measurement of the secondary J/ψ is performed by means of the pseudoproper decay length x which is defined as :

$$x = \frac{c \cdot L_{xy} \cdot m_{J/\psi}}{p_T^{J/\psi}} \qquad L_{xy} = \frac{\overrightarrow{L} \cdot \overrightarrow{p_T^{J/\psi}}}{p_T^{J/\psi}} \tag{1}$$

where $\overrightarrow{L}$ is the vector from the primary vertex to the J/ψ decay vertex.
ALICE can also identify charmonium in the forward region in the $J/\psi \rightarrow \mu^+\mu^-$ channel. Muons are tracked and identified by the MUON arm in the rapidity region $2.5 < y < 4$.
In nucleus nucleus collisions the interaction region between two nuclei may vary between a complete overlap of the nuclei and a partial overlap where only a few nucleons collide. Collision geometry can

be quantified by the collision *centrality* which varies from 0 % (most central collisions) up to 100 % or the mean number of participant nucleons (see [4] for further details).

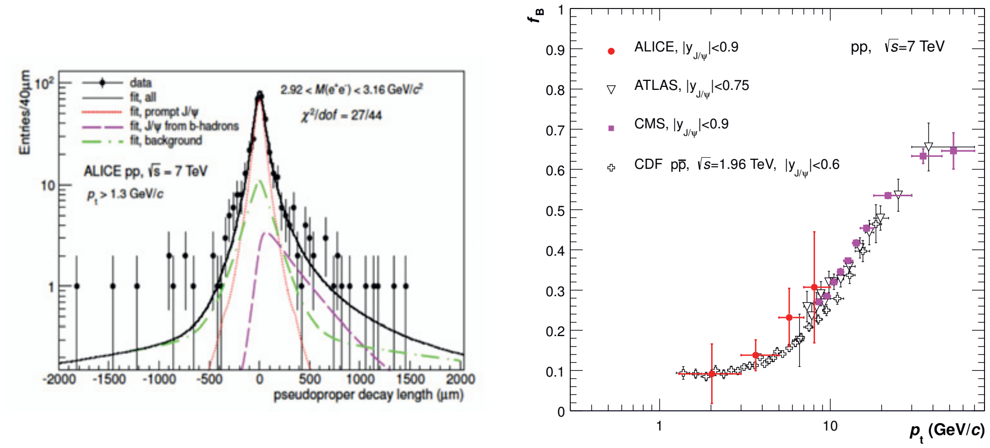

Figure 2. Left: pseudoproper decay length distribution of inclusive J/ψ together with a fit of the different contributions [7] . Right : The fraction of J/ψ from b-hadron decays at midrapidity in four momentum bins [7] compared to the results from CMS, ATLAS and CDF experiments in a similar rapidity range ([8])

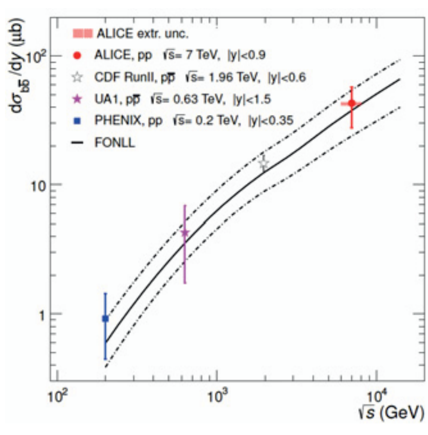

Figure 3. Beauty production cross section at mid-rapidity as a function of $\sqrt{s}$ in pp from ALICE and other experiments (see [7] and references therein).

3 J/ψ measurements in pp collisions

The inclusive J/ψ yield in pp has been measured at $\sqrt{s}$ = 7 TeV in 5 p_T bins and p_T integrated at $\sqrt{s}$ = 2.76 TeV.

The results obtained for 350 millions minimum bias events taken at the highest energy, corresponding to an integrated luminosity of 5.6 nb^{-1}, are shown in left panel of Figure 1. The signal yield has been extracted from the invariant mass distribution of dielectron pairs of opposite sign, after subracting the combinatorial background (see [6] for further details). The prompt contribution, is then obtained by removing the secondary J/ψ fraction. The measurements are compatible with next to leading order non relativistic QCD predictions (NRQCD) where color-octet processes seem to play an important role. Nevertheless the theoretical uncertainties at low p_T are large [7]. The measurement at $\sqrt{s} = 2.76$ TeV was performed on a smaller dataset, which was used as a reference for Pb-Pb collision results at the same center of mass energy per nucleon pair.
The fraction of secondary J/ψ was determined for the 7 TeV dataset. The non-prompt signal extraction follows a dedicated analysis procedure whose the key variable is the pseudoproper decay length. The distribution of this oservable in pp collisions is shown in the left panel of Figure 2. The analysis uses the same event and track quality selection used for the inclusive analysis (more details can be found in [7]). The additional cuts were on the dielectron momentum ($p_T > 1.3$ GeV/c) and the requirements of hits in the first pixel layer. The right panel of Figure 2 shows the measurement of the fraction of non-prompt J/ψ by ALICE in four momentum bins. Furthermore the measurements of non-prompt J/ψ cross section show a quite good agreement with the FONLL predictions [10] and they were used to extrapolate the total $b\bar{b}$ cross section as shown in Figure 3.

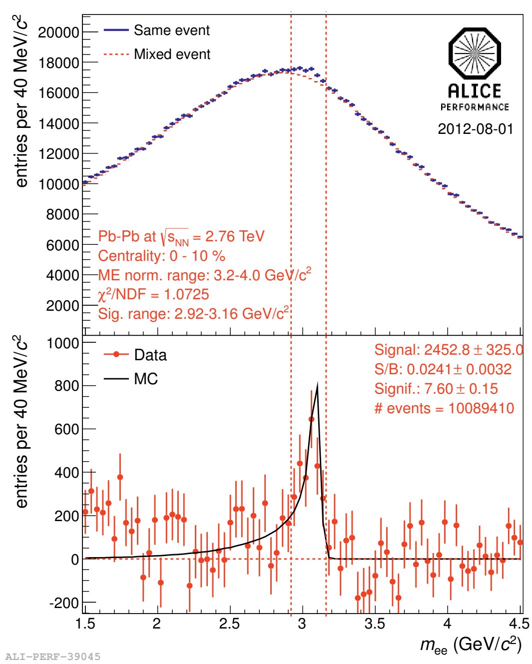

Figure 4. Dielectron invariant mass distribution for Pb-Pb collisions in the 0-10 % centrality range. Top: Same event and mixed event distributions. Bottom: Mixed event background subtracted distribution. Solid line represents the MC signal shape scaled to match the integral of the signal in the counting mass window.

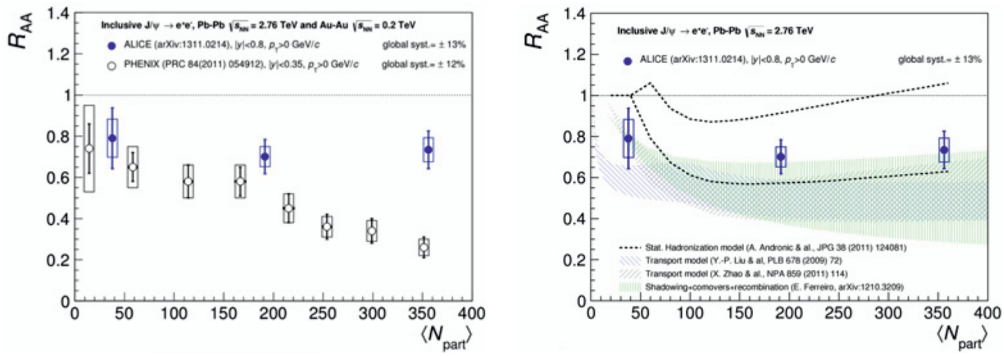

Figure 5. Inclusive J/ψ nuclear modification factor in nucleus-nucleus collisions as a function of centrality. Left: Comparison to PHENIX. Right: Comparison to model calculations.

4 J/ψ measurements in Pb-Pb

The signal extraction in Pb-Pb is challenging due to the presence of a large combinatorial background, expecially in central collisions where the highest number of nucleons participate in the interaction. Figure 4 shows the invariant mass distribution of dielectron pairs for all combinations and the combinatorial background in very central collisions (0-10% most central). Despite the small S/B ratio it is still possible to obtain a significance of roughly 8.
To quantify the medium effects in Pb-Pb collisions with respect to pp collisions, it is used the nuclear modification factor R_{AA} defined as :

$$R_{AA} = \frac{dN_{AA}/dp_T dy}{\langle T_{AA} \rangle d\sigma_{pp}/dp_T dy} \tag{2}$$

where T_{AA} is the nuclear overlap function as estimated by the Glauber model. Results of the inclusive nuclear modification factor at lower energies show a dependence of the J/ψ R_{AA} on the centrality (left panel of Figure 5) as expected within a suppression scenario. The measurements at LHC energies show instead a smaller suppression than at RHIC and a negligible dependence on the centrality, which qualitatively agrees with the regeneration scenario (right panel of Figure 5) a comparison to theoretical models is shown).

The models underlying such theoretical expectations assume that charm is produced in primary hard collisions, nevertheless the evolution of heavy quarks into hadrons is based on two different approaches. On one hand the statistical hadronization model (SHM) [3] assumes that charmed hadrons can equilibrate chemically at the *freeze-out* stage, that is the stage at which hadrons stop interacting among themselves. Within this model, the J/ψ yield in central collisions at LHC energies should be higher than the yield measured at lower energies (SPS or RHIC). On the other hand trasport models describe the J/ψ production by a transport equations which include dissociation and regeneration processes. The collisional dissociation occurs at the initial stages and it is due to the interactions with gluons, whereas the recreation of the resonant $c\bar{c}$ state happens later and it is provided by free heavy quarks thermalized in a hot medium. The final J/ψ yield is described within an hydrodynamical scenario by integrating over time the dissociation and regeneration rates. Figure 5 shows the predictions of the R_{AA} either from the SHM or transport models. The SHM approach results (dashed line) are considered within the expected shadowing contribution at LHC energies (the prediction relies on the

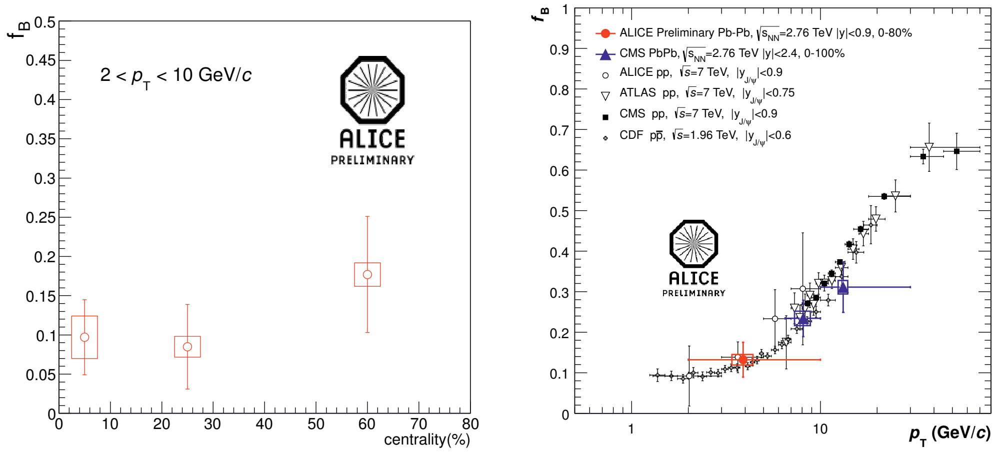

Figure 6. Left: Non-prompt J/ψ fraction as measured by ALICE in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in three centrality bins (statistical and systematic uncertainties areshown by bars and boxes respectively). Right: Fraction of non-prompt J/ψ in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV measured by ALICE and CMS as a function of p_T [9] at central rapidity . Also shown are data for pp collisions at $\sqrt{s} = 7$ TeV from LHC and for $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV from CDF.

charm production cross section). Then, the two transport models differ in the rates of dissociation and regeneration. Another model which reproduces the experimental data is based on the *comover* approach still considering the dissociation and regeneration rates, without thermal equilibrium [11]. The main uncertainties of all the models are from c-cbar cross section and the shadowing contribution (to be investigated with results from the pA collisions).
Preliminary measurements on J/ψ from B decays have also been performed in Pb-Pb collisions, in the interval $2 < p_T < 10$ GeV/c. The measured fraction of non-prompt J/ψ shown in the left panel of Figure 6 does not show a significant dependence on centrality. A summary of the results on the measured fraction of secondary J/ψ in Pb-Pb collisions at LHC (both ALICE and CMS) together with data for pp collisions is shown in the right panel of Figure 6. The trend seen in AA collision data seems to follow the one already obeserved in pp collisions.

5 Conclusions

Detailed measurements of J/ψ production as a function of p_T and rapidity (not covered in this contribution) have been performed by the ALICE experiment. The inclusive J/ψ cross section has been determined at mid rapidity down to $p_T = 0$. Non-prompt J/ψ were measured down to p_T=0 in the same data sample allowing for the extraction of the beauty production cross section. The separation of the prompt J/ψ contribution from the inclusive yield allowed a comparison with corresponding theoretical model predictions. As far as the Pb-Pb collisions are concerned, the J/ψ R_{AA} as a function of N_{part} shows a value smaller than unity without a dependence on the centrality. From a theoretical point of view the regeneration contribution seems to be necessary to describe the ALICE data, nevertheless big uncertainties on the production cross section in pp and the shadowing contribution affect theoretical predictions. The separation of the non-prompt J/ψ contribution was also possible in nucleus nucleus collisions down to $p_T = 2$ GeV/c. The results show that the fraction of secondary J/ψ in Pb-Pb collisions seems to follow the trend already observed in pp collision.

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