Measurements of $\mathrm{J}/\psi \rightarrow \mathrm{e}^+\mathrm{e}^-$ with ALICE at the LHC

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Abstract. The ALICE detector provides excellent capabilities to study quarkonium production at the Large Hadron Collider (LHC). Heavy quarkonia, bound states of charm or beauty quark anti-quark pairs such as the J/ψ, are expected to be produced by initial hard processes. Thus they will provide insight into the earliest and hottest stages of AA collisions where the formation of a Quark-Gluon Plasma (QGP) is expected. Furthermore, high-precision data from pp collisions represent an essential baseline for the measurement of nuclear modifications in heavy-ion collisions and serve also as a crucial test for several models of quarkonium hadroproduction. In addition, the study of pA collisions allows to investigate nuclear modifications due to Cold Nuclear Matter (CNM) effects. In ALICE, J/ψ were measured in pp and Pb–Pb collisions down to $p_{\mathrm{T}} = 0$ via their di-electron decay channel in the central barrel ($|y| < 0.8$). Results on the nuclear modification factor (R_{AA}) at central rapidities in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV will be shown and their implications discussed. A separation of the prompt and non-prompt components is also possible down to p_{T} of the J/ψ of 2 GeV/c.

The production of heavy quarkonia involves both perturbative and non-perturbative mechanisms of Quantum-Chromo-Dynamics (QCD). In proton-proton collisions, several models [1, 2] attempted to describe the quarkonia production, but failed in reproducing simultaneously cross-sections, polarization, transverse momentum and rapidity dependence as measured at the Tevatron [3, 4] and RHIC [5] colliders. Results in proton-proton collision at the new LHC energies have provided additional constraints to those models as well as the baseline reference for AA analyses. At the high temperatures and large energy densities reached in relativistic heavy-ion collisions, the matter consists of deconfined quarks and gluons, in the state referred to as "Quark-Gluon-Plasma" (QGP) [6]. According to the prediction by Matsui and Satz [7], in the deconfined medium formed in nucleus-nucleus collisions quarkonium production is suppressed relative to that in proton-proton collisions due to the color analogue of the Debye screening mechanism. The observable to quantify the nuclear medium effects is the so-called "nuclear modification factor" R_{AA}, defined as

$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \frac{\mathrm{d}^2 N^{\mathrm{AA}}_{\mathrm{J}/\psi}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}{\mathrm{d}^2 \sigma^{\mathrm{pp}}_{\mathrm{J}/\psi}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}$$

where $\mathrm{d}^2 N^{\mathrm{AA}}_{\mathrm{J}/\psi}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y$ represents the J/ψ production yield in AA collisions, $\mathrm{d}^2 \sigma^{\mathrm{pp}}_{\mathrm{J}/\psi}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y$ is the cross section in pp collisions at the same energy and $\langle T_{\mathrm{AA}} \rangle$ is the nuclear overlap function determined by Glauber model calculations. The J/ψ suppression observed at SPS and RHIC [8, 9, 10] is not completely understood yet. Open points are in particular the observation of a similar J/ψ suppression at the two different centre-of-mass energies and a stronger suppression at forward-rapidity (∼40%) compared to mid-rapidity at RHIC. Two theoretical models were proposed in order to reproduce RHIC and SPS data and provide predictions for the LHC: *i)* the “regeneration” mechanism from deconfined quarks in the medium to compete the J/ψ suppression in the QGP [11, 12]; *ii)* the statistical hadronization of charm quarks at phase boundary [13, 14]. The interpretation of the experimental results is still under debate due to the large experimental uncertainty on the total c$\bar{\text{c}}$ production cross section, which prevents more precise model calculations, as well as the lack of an exhaustive understanding of Cold Nuclear Matter (CNM) effects, strongly dependent on the centre-of-mass energy of the system and determined from pA collisions. Furthermore, other important contributions are J/ψ from the decays of higher mass charmonium states (e.g. χ_c and ψ') and beauty hadrons (non-prompt J/ψ). In particular, measuring the fraction of non-prompt J/ψ, f_B, gives access to the R_AA of both prompt and non-prompt produced J/ψ mesons and the latter reflects directly the nuclear modification factor of beauty hadrons. According to the QCD predictions [15] the parton energy loss in the QGP implies the following hierarchy in the measured R_AA: $R^\pi_\text{AA} < R^\text{D}_\text{AA} < R^\text{B}_\text{AA}$. Therefore the comparison between the R_AA of non-prompt J/ψ with the R_AA of other hadrons could offer an important insight onto the parton energy loss mechanisms in the QGP.

In ALICE the J/ψ production is measured at central rapidity ($|y| < 0.8$) in the dielectron channel J/$\psi \to \text{e}^+\text{e}^-$ and at forward rapidity ($2.5 < y < 4$) in the dimuon channel J/$\psi \to \mu^+\mu^-$ reaching in both cases $p_\text{T} = 0$. The focus of this paper is on the results obtained at mid-rapidity. The main tracking detectors used in this analysis are the Inner Tracking System (ITS), which allows for the measurement of the J/ψ fraction from beauty hadron decays, and the Time Projection Chamber (TPC), which is used for tracking and electron identification via specific energy deposition measurement.

In the left-hand panel of Fig. 1 the inclusive J/ψ cross sections in pp collisions as a function of rapidity are shown at both $\sqrt{s} = 7$ TeV ($L^{\text{e}^+\text{e}^-}_\text{int} = 5.6\ \text{nb}^{-1}$ and $L^{\mu^+\mu^-}_\text{int} = 15.6\ \text{nb}^{-1}$) and $\sqrt{s} = 2.76$ TeV ($L^{\text{e}^+\text{e}^-}_\text{int} = 1.1\ \text{nb}^{-1}$ and $L^{\mu^+\mu^-}_\text{int} = 19.9\ \text{nb}^{-1}$) [16]. The measurement at $\sqrt{s} = 2.76$ TeV represents the reference used for the R_AA analysis in Pb–Pb. The currently large uncertainties on this reference limit the accuracy on the R_AA determination.

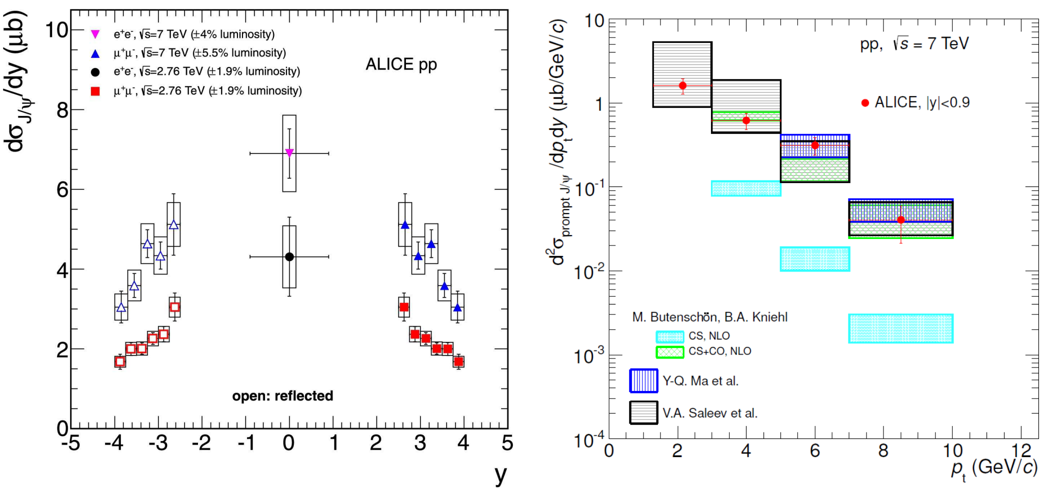

Figure 1. Left: Inclusive J/ψ cross section as a function of rapidity measured in pp collisions at $\sqrt{s} = 7$ TeV and 2.76 TeV [16]. Right: Prompt J/ψ cross section as a function of p_T compared to several theoretical predictions [17].

The fraction of J/ψ coming from beauty hadron decays was measured in proton-proton collisions at $\sqrt{s} = 7$ TeV down to $p_\text{T} = 1.3$ GeV/c. In the right-hand panel of Fig. 1 the prompt

J/ψ cross section as a function of transverse momentum is compared to next-to-leading order (NLO) non-relativistic QCD (NRQCD) theoretical calculations (see [17] and references therein), which include color-singlet (CS) and color-octet (CO) contributions; heavier charmonium feed-down is also included. The comparison suggests that the CO processes are important to describe the data.

In Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV the nuclear modification factor $R_{\rm AA}$ of inclusive J/ψ was measured as a function of centrality for $p_{\rm T} > 0$ ($L_{\rm int} = 15\ \mu{\rm b}^{-1}$). This is shown in the left-hand panel of Fig. 2 as a function of the mean number of participant nucleons $\langle N_{\rm part}\rangle$ (estimated from Glauber model) and it is compared with the inclusive J/ψ $R_{\rm AA}$ measured at mid rapidity by PHENIX in Au-Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV [18]. The comparison indicates a reduced suppression for most central collisions in ALICE w.r.t. PHENIX, and this behaviour is in qualitative agreement with a regeneration scenario at LHC energies.

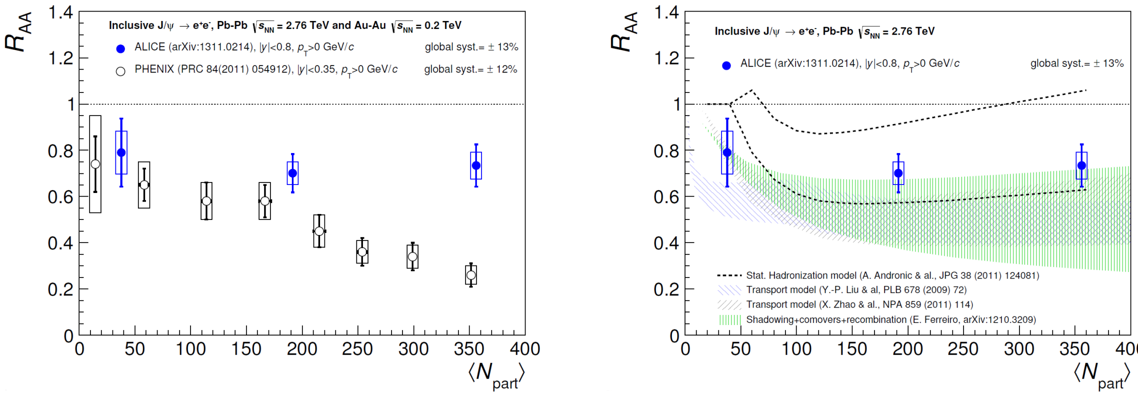

Figure 2. Nuclear modification factor $R_{\rm AA}$ measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV as a function of the mean number of participants $\langle N_{\rm part}\rangle$ compared with PHENIX [18] results at lower energy (left-hand panel) and with theoretical models [11, 12, 19, 20] (right-hand panel).

In the right-hand panel of Fig. 2 the inclusive J/ψ $R_{\rm AA}$ is compared with theoretical models that include the (re)combination of deconfined charm quark pairs from the QGP. In particular, the hashed bands represent the results from two transport models [11, 12] and from the comover interaction model [19] where up to 50% of the J/ψ were produced from deconfined c$\bar{\rm c}$ pairs recombination. The prediction from the statistical hadronization model [20] is also shown by solid lines. All models exhibit a good agreement with data albeit with large uncertainties, due to the large uncertainty on the inclusive c$\bar{\rm c}$ production cross section and CNM effects (e.g. nuclear shadowing). The latter are currently being addressed by measuring J/ψ production in p–Pb collisions.

The fraction of non-prompt J/ψ were measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV as a function of centrality down to $p_{\rm T}$ = 2 GeV/c, as shown in the left-hand side of Fig. 3. No significant dependence of the non-prompt J/ψ fraction on centrality can be observed. In the right-hand panel of Fig. 3 the fraction of non-prompt J/ψ as a function of transverse momentum measured by ALICE and CMS [21] in Pb–Pb collisions and integrated over centrality is shown, along with the results in pp collisions at $\sqrt{s}$ = 7 TeV by ALICE [17], ATLAS [22] and CMS [23]. The CDF data in p$\bar{\rm p}$ collisions at $\sqrt{s}$ = 1.96 TeV [3] are also reported. Considering the ALICE and CMS results together, an indication for a similar trend of $f_{\rm B}$ as a function of $p_{\rm T}$ in proton-proton and Pb–Pb collisions is observed.

In summary, transverse momentum spectra and rapidity distributions of inclusive J/ψ were measured down to $p_{\rm T}$ = 0 for pp collisions at $\sqrt{s}$ = 2.76 TeV and $\sqrt{s}$ = 7 TeV. NRQCD cal-

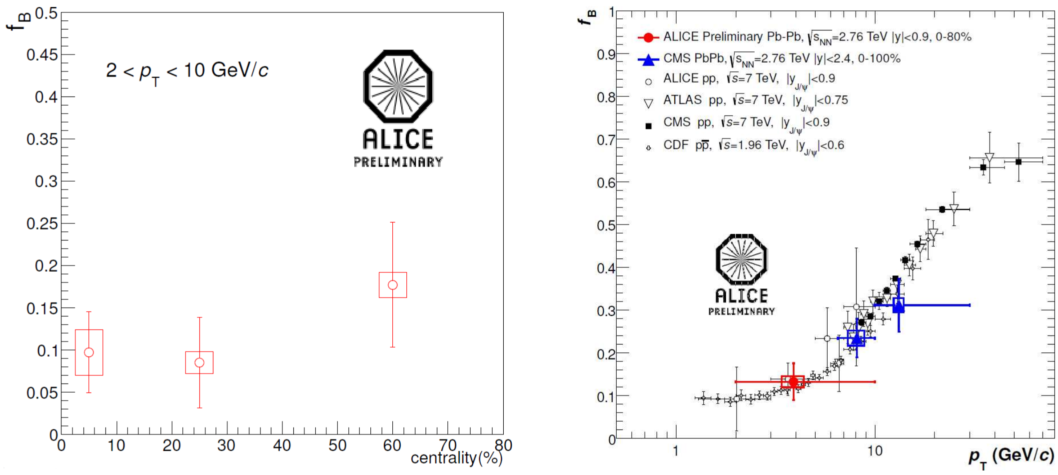

Figure 3. Left: Non-prompt J/ψ fraction measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV as a function of centrality (statistical and systematic uncertainties shown by bars and boxes respectively). Right: Fraction of non-prompt J/ψ in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV measured by ALICE and CMS [21] at central rapidity as a function of $p_{\rm T}$. Results in pp [17, 22, 23] and p$\bar{\rm p}$ [3] collisions are also shown.

culations are consistent with the measured prompt J/ψ production cross section. The nuclear modification factor $R_{\rm AA}$ was measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV down to $p_{\rm T} = 0$, as a function of centrality. The comparison with PHENIX results and theoretical predictions provides an indication for (re)generation of J/ψ from deconfined charm quarks. The non-prompt J/ψ fraction were also measured in Pb–Pb collision as a function of centrality. The combination of ALICE and CMS results in Pb–Pb collisions suggests a trend of $f_{\rm B}$ as a function of $p_{\rm T}$ that is similar to that in pp.

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