

Measurements of quarkonium production and polarization in Pb–Pb collisions with ALICE

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Abstract. Quarkonia are excellent probes of deconfinement in heavy-ion collisions. For J/ψ , a bound state of $c\bar{c}$ quarks, the (re-)generation is found to be the dominant production mechanism at the LHC energies. Production measurements of non-prompt J/ψ , originating from beauty-hadron decays, allow one to access the interaction of beauty-quarks with the quark-gluon plasma (QGP). Polarization and spin alignment measurements can be used to investigate the characteristics of the formed medium. Moreover, it has been hypothesized that quarkonium states can be polarized by the strong magnetic field generated in the initial state of the collision and by the large angular momentum of the medium in non-central heavy-ion collisions.

In these proceedings, the measurements of the inclusive, prompt, and non-prompt J/ψ nuclear modification factor R_{AA} in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are shown. The measured non-prompt J/ψ fraction extends down to very low p_T with a significantly improved precision compared to previous publications. The results from the first publication on the J/ψ polarization with respect to the event-plane in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at forward rapidity are presented as well. The results are compared with available calculations.

1 Introduction

Heavy quarks (charm and beauty) are an excellent probe to study the quark-gluon plasma (QGP), the strongly interacting medium created in high-energy heavy-ion collisions. They are mainly produced via initial hard partonic scatterings and thus experience the entire QGP evolution. Quarkonia are bound states composed of a heavy quark and its corresponding anti-quark. In the QGP, the color screening of the surrounding medium may prevent the heavy quark and anti-quark from forming their bound states depending on the QGP temperature and binding energy of the state [1]. A new charmonium production mechanism, known as (re-)generation [2–4], is found to be significant at the LHC energies due to the increase of heavy quark densities in the QGP [5, 6]. Moreover, the measurement of non-prompt J/ψ production can provide insights into the beauty quark energy loss mechanisms in the QGP. The nuclear modification factor (R_{AA}) is an interesting observable to study the medium influence on particle production yields and it is defined as the ratio of the yield in heavy-ion collisions to that in pp collisions at the same center-of-mass energy, scaled by the number of binary nucleon-nucleon collisions. Finally, it has been argued that the strong electromagnetic field created at the very early stage of the heavy-ion collision [7], as well as the angular momentum of the medium in non-central collisions [8], may affect vector meson polarization.

2 Analysis and Results

In ALICE, inclusive J/ψ -mesons are reconstructed by employing the e^+e^- decay channel at midrapidity ($|y| < 0.9$) and the $\mu^+\mu^-$ decay channel at forward rapidity ($2.5 < y < 4$). The analysis techniques are discussed in detail in Refs. [5, 9]. The ALICE detector is described in Ref. [10].

The left panel of Fig. 1 shows the p_T -integrated inclusive J/ψ R_{AA} measured at midrapidity as a function of the average number of participant nucleons ($\langle N_{part} \rangle$) in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. In order to exclude J/ψ photoproduction processes [11], a selection of the dielectron with $p_T > 0.15$ GeV/c is applied. The R_{AA} exhibits a sizeable increase in moving from semi-central to central collisions, described by models including (re-)generation. The right panel of Fig. 1 compares the p_T -differential inclusive J/ψ R_{AA} in 0–10% and 0–20% centrality intervals at midrapidity and forward rapidity, respectively. A larger R_{AA} is observed at midrapidity and low p_T as a consequence of the higher $c\bar{c}$ density, which leads to larger J/ψ yields being produced via (re-)generation. The statistical hadronization model [12] describes data at low p_T and underestimates them at high p_T . The transport model agrees with data in the whole measured p_T region [3].

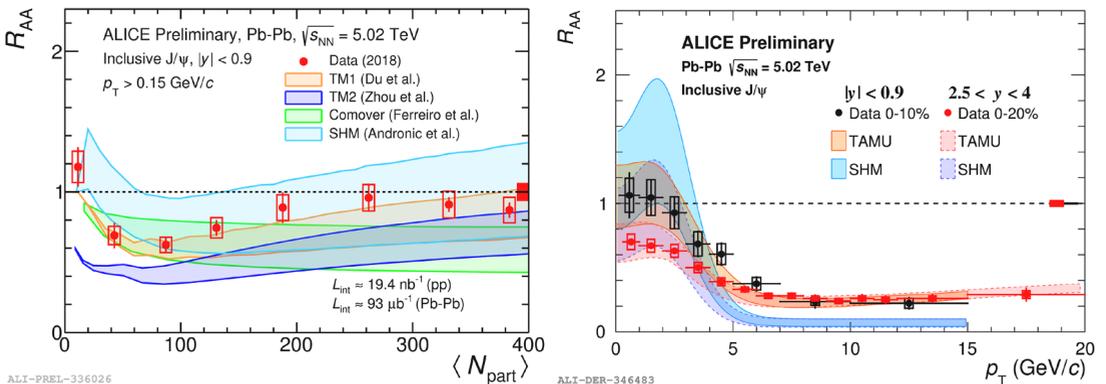


Figure 1. Left panel: Inclusive J/ψ R_{AA} at midrapidity, integrated over p_T , as a function of $\langle N_{part} \rangle$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Right panel: p_T dependence of the inclusive J/ψ R_{AA} at midrapidity and forward rapidity in the 0–10% and 0–20% centrality intervals, respectively. The results are compared to model calculations from Refs. [3, 4, 12, 13].

The left panel of Fig. 2 shows the non-prompt J/ψ fraction as a function of p_T , measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, in three different centrality classes. The results are compatible with CMS in the common p_T interval, which refers to the centrality class 0–100% [14]. The right panel of Fig. 2 shows the p_T differential non-prompt J/ψ R_{AA} in the 0–10% centrality class in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, compared to similar results from other experiments as well as with model calculations. The new ALICE data extends the non-prompt J/ψ R_{AA} measurement down to very low p_T and are consistent with CMS [14] and ATLAS [15] data in the overlapping p_T region. The non-prompt J/ψ R_{AA} is comparable to the non-prompt D^0 R_{AA} measurement performed by the ALICE collaboration [16] (small differences could arise from the decay kinematics). The suppression of the non-prompt J/ψ R_{AA} at high p_T can be described by model calculations from Refs. [17, 18]. Both calculations include beauty quark energy loss in the QGP via both radiative [19] and collisional [20] processes.

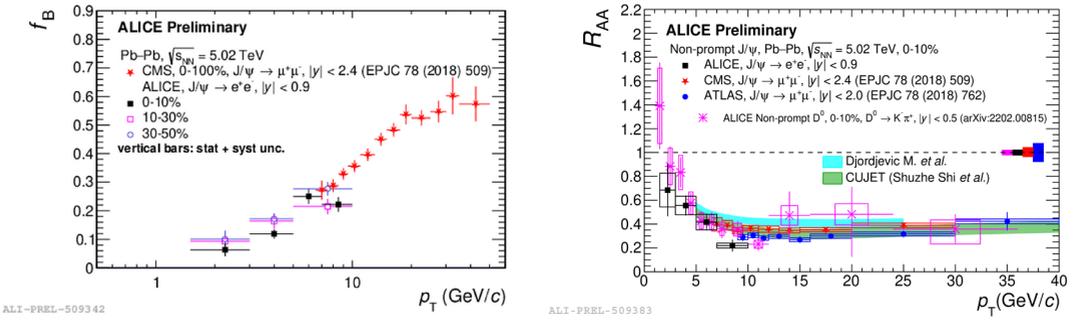


Figure 2. Left panel: p_T dependence of the non-prompt J/ψ fraction in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and midrapidity. The results are compared to the corresponding CMS measurements in the centrality range of 0–100% [14]. Right panel: Non-prompt J/ψ R_{AA} as a function of p_T compared with similar measurements from CMS [14] and ATLAS [15]. Non-prompt D^0 R_{AA} measurements from ALICE [16] are shown as well. Results are compared with model calculations from Refs. [17, 18].

The polarization of the inclusive J/ψ production with respect to the event plane is measured for the first time in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV via the dimuon decay channel at forward rapidity [21]. The left panel of Fig. 3 shows the p_T integrated λ_θ parameter measured in the range $2 < p_T < 6$ GeV/c in different centrality classes. A significant non-zero polarization is found in central and semi-central collisions, in particular in the 40–60% centrality interval, where a 3.5σ effect is observed. The p_T dependence of λ_θ in central (0–20%) and semi-central (30–50%) collisions is shown on the right panel of Fig. 3. The maximum deviation from zero polarization is observed for $2 < p_T < 4$ GeV/c and in the 30–50% centrality range, where the significance of the effect reaches 3.9σ when considering the total uncertainties.

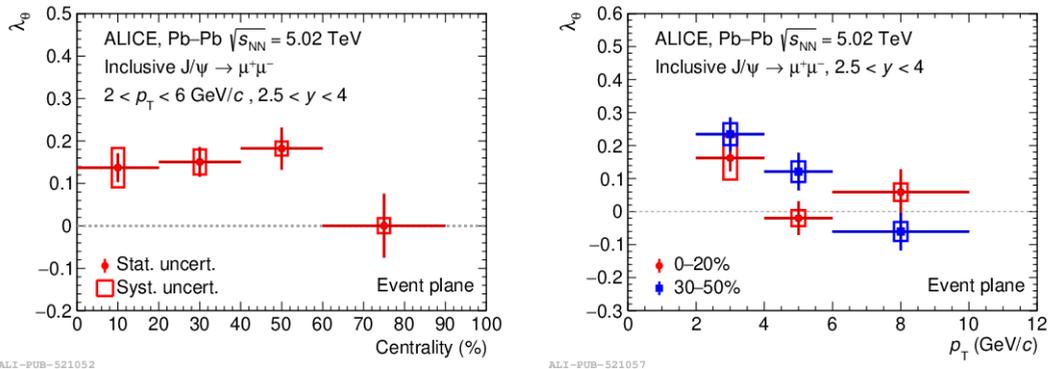


Figure 3. Centrality (left panel) and p_T dependence (right panel) of the λ_θ polarization parameter. The vertical bars and open boxes represent the statistical and systematic uncertainties, respectively [21].

3 Summary

In this contribution, recent measurements of the inclusive and non-prompt J/ψ production in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are reported. The R_{AA} of inclusive J/ψ shows an increasing trend at low p_T and towards more central collisions, which indicates a large contribution of J/ψ production from the (re-)generation process. Non-prompt J/ψ R_{AA} is measured down to $p_T = 1.5$ GeV/c in 0-10% central Pb–Pb collisions. The strong suppression of non-prompt J/ψ at high p_T is well reproduced by models implementing both collisional and radiative energy loss processes of beauty quarks inside the QGP. The first measurement of inclusive J/ψ polarization with respect to the event plane is shown as a function of centrality and p_T in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. A small but significant polarization effect, reaching 3.9σ for $2 < p_T < 4$ GeV/c in the 30-50% centrality interval, is presented.

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