ψ(2S) production and nuclear modification factor in nucleus–nucleus collisions with ALICE

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Abstract. Charmonium production is sensitive to deconfinement in nucleus-nucleus collisions. The production via regeneration within the QGP or at the phase boundary has been identified as an important ingredient for the description of the centrality and transverse momentum dependence (p_{T}) of the J/ψ nuclear modification factor (R_{AA}) at the LHC. ψ(2S) production relative to J/ψ is one possible discriminator between the two different regeneration scenarios. At the LHC, there is so far no significant observation of the ψ(2S) in central nucleus-nucleus collisions at low-p_{T}, where regeneration is expected to play an important role. The combined Run 2 data set of ALICE allows one to extract a significant ψ(2S) signal in this kinematic region at forward rapidity, in the dimuon decay channel. In this contribution, we present for the first time results on the ψ(2S)-to-J/ψ single ratio and double ratio (to pp collisions) as well as the ψ(2S) nuclear modification factor, in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. The ψ(2S)-to-J/ψ double ratio and ψ(2S) R_{AA} are calculated using a new proton-proton reference with improved precision. Results are compared with model calculations.

1 Introduction

Charmonia, a bound state of $c\bar{c}$ pairs, are considered unique probes of the deconfined hot and dense medium made of free quarks and gluons, known as quark-gluon plasma (QGP), created in ultra-relativistic heavy-ion collisions [1]. In such medium, charmonium production yield is expected to be significantly suppressed with respect to the yield measured in proton-proton (pp) collisions at the same centre-of-mass energy, scaled by the number of binary nucleon-nucleon collisions, due to color screening of the $q\bar{q}$ potential [1] or dissociation [2]. The temperature required for dissociating a specific charmonium state depends on its binding energy, or equivalently on its radius. Hence, the strongly bound charmonium states, such as J/ψ, should melt at higher temperatures compared to more loosely bound states, namely ψ(2S) and χ_c. This is known as sequential dissociation. As a consequence, the in-medium dissociation probability of such states should provide an estimate of the medium temperature [3], assuming that the charmonium dissociation is the main mechanism at play. At the LHC energies, a large number of $c\bar{c}$ pairs is expected to be produced in central Pb–Pb collisions, leading to the possibility to form charmonia via recombination of c and $\bar{c}$ quarks, either in medium [4] or at the phase boundary [5, 6]. This new additional source of charmonium production is couterbalancing the suppression mechanism. The regeneration

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mechanism has been identified as an important ingredient for the description of the observed centrality, rapidity (y) and p_T dependence of the J/ψ production in Pb–Pb collisions at the LHC [7, 8]. The measurement of the single (double) ratio between the ψ(2S) and J/ψ cross sections in Pb–Pb collisions (with respect to pp collisions), is predicted to be very sensitive to the details of the recombination mechanism. Experimentally, the single ratio is interesting as most of the systematic uncertainties cancel, with the remaining systematic uncertainties being only due to the signal extraction and some uncorrelated components related to the acceptance times efficency evaluation. On the theory side, this ratio is also weakly dependent on the total charm production cross section employed as inputs to the models.

2 Experimental set-up and data analysis

The ALICE collaboration has studied the ψ(2S) production in Pb–Pb collisions down to zero transverse momentum through its dimuon decay channel. The details of the ALICE detector are described in Ref. [9]. Muons coming from quarkonium decays are recontructed in the muon spectrometer, covering a pseudorapidity range -4 < η < -2.5. The two innermost layers of the inner tracking system (ITS), which consist of silicon pixel detectors, provide primary vertex reconstruction. The VZERO detectors, two scintillator arrays covering the pseudo-rapidity intervals 2.8 ≤ η ≤ 5.1 and -3.7 ≤ η ≤ -1.7, provide the minimum-bias trigger, the determination of the collision centrality and help to remove the beam-induced background. Two sets of zero degree calorimeters (ZDC) are used to suppress the background from electromagnetic processes in Pb–Pb collisions.

3 Results

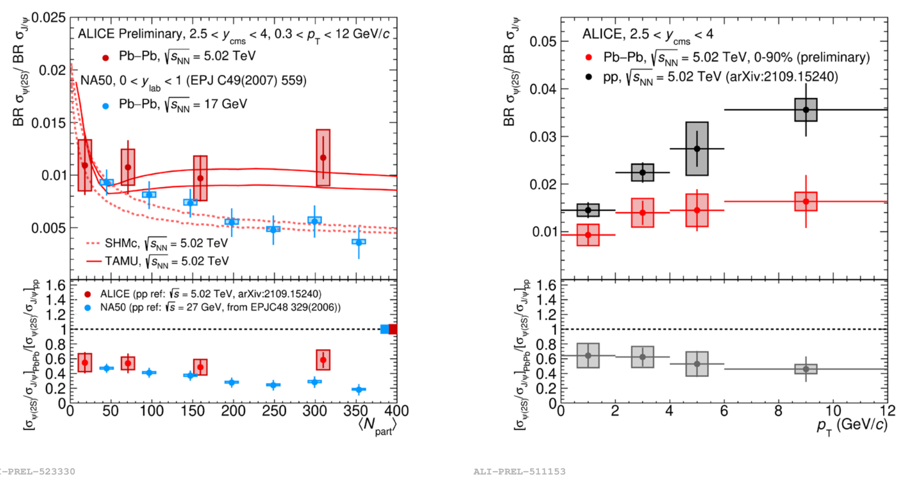

Figure 1. ψ(2S)-to-J/ψ cross section ratio measured by the ALICE collaboration in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV as a function of the average number of participant nucleons ($\langle N_{part}\rangle$) and p_T, in the left and right panel, respectively. In the left panel, NA50 measurements at SPS carried out at $\sqrt{s_{NN}}$ = 17 GeV are also shown. The results, are compared with theoretical predictions from TAMU [10] and SHMc [11, 12]. Bottom panels show the ψ(2S)-to-J/ψ ratio normalized to the corresponding pp value (double ratio).

The left panel of Fig. 1 shows the ψ(2S)-to-J/ψ cross section ratio measured by the ALICE collaboration in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV at forward rapidity as function of centrality (expressed in terms of average number of participant nucleons $\langle N_{\rm part}\rangle$). The bottom panel of Fig. 1 left shows the values of the ψ(2S)-to-J/ψ double ratio, indicating a suppression effect by 40% in Pb–Pb with respect to pp collisions. No significant centrality dependence is observed within uncertainties. The ALICE results in the left panel are also compared with NA50 ones in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 17 GeV in $0 < y_{Lab} < 1$ [13]. Both the ψ(2S)-to-J/ψ single and double cross section ratios measured by NA50 exhibit a stronger centrality dependence, reaching smaller values in central collisions. The ψ(2S)-to-J/ψ single ratio measured by ALICE is compared with theoretical calculations based on a transport approach (TAMU) [10] and with the Statistical Hadronization Model (SHMc) [11, 12]. The TAMU [10] model well reproduces the ψ(2S)-to-J/ψ cross section ratio as a function of centrality, while SHMc [11, 12] tends to underestimate the data in central Pb–Pb collisions.

In the right panel of Fig. 1, the ψ(2S)-to-J/ψ ratio as a function of $p_{\rm T}$ in Pb–Pb collisions is compared with the corresponding ratio in pp collisions. The ψ(2S)-to-J/ψ ratio in Pb–Pb collisions is systematically larger compared to the one measured in pp. The corresponding double ratio shown in the bottom panel, indicates a significant relative suppression in Pb–Pb with respect to pp, with no strong $p_{\rm T}$ dependence and reaching a value of ~ 0.5 at high $p_{\rm T}$.

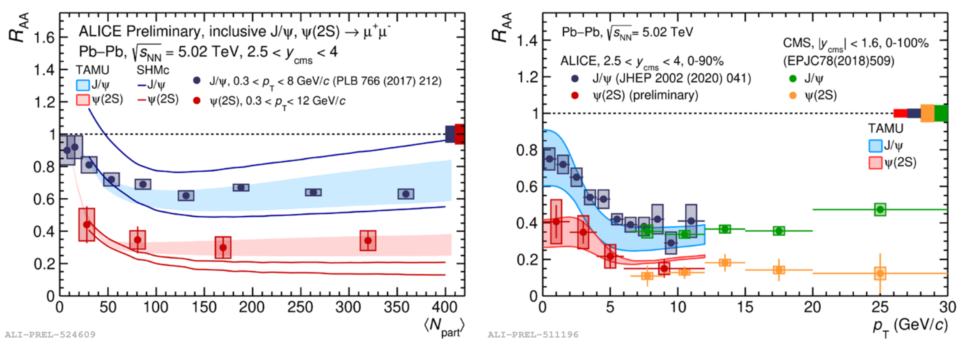

Figure 2. The $R_{\rm AA}$ of ψ(2S) and J/ψ as a function of the average number of participant nucleons ($\langle N_{\rm part}\rangle$) and $p_{\rm T}$, in the left and right panel, respectively. In the right panel, the ALICE data are compared with CMS results [14] for $|y| < 1.6$, $6.5 < p_{\rm T} < 30$ GeV/c and centrality 0 - 100 %. The results are also compared with theoretical predictions from TAMU [10] (left and right plots) and SHMc [11, 12] (left plot).

Figure 2 shows the nuclear modification factor $R_{\rm AA}$ of J/ψ and ψ(2S) measured by the ALICE collaboration as a function of $\langle N_{\rm part}\rangle$ (left panel) and $p_{\rm T}$ (right panel). The ψ(2S) $R_{\rm AA}$ shows significant suppression and no strong centrality dependence (assuming an almost constant value of about 0.4). It is significantly smaller compared to the $R_{\rm AA}$ of the J/ψ, both as a function of $p_{\rm T}$ and centrality. It also hints at less suppression at low-$p_{\rm T}$ with respect to higher $p_{\rm T}$, as also observed with more significance for the J/ψ. This could be a first indication for ψ(2S) production via recombination of $c\bar{c}$ pairs. The (TAMU) model calculation [10] reproduces both the centrality and $p_{\rm T}$ dependence of the $R_{\rm AA}$ for both charmonium states. On the other hand, the SHMc model [11, 12] reproduces the centrality dependence of the J/ψ $R_{\rm AA}$, while it overestimates the ψ(2S) suppression in central events.

The charmonium $R_{\rm AA}$ as a function of $p_{\rm T}$ is compared with CMS measurements [14] carried out for $|y| < 1.6$, $6.5 < p_{\rm T} < 30$ GeV/c and centrality 0 - 100 %. A strong suppression of the ψ(2S) persists up to 30 GeV/c, as shown by the CMS data which agree very well with those from ALICE in the common p_{T} range, in spite of the different rapidity coverages.

4 Summary

The first accurate measurement of the ψ(2S) production in central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and low-p_{T} has been reported by ALICE at forward rapidity. The ψ(2S)-to-J/ψ double ratio shows a relative suppression of ~40 %. No significant p_{T} or centrality dependence is observed within the uncertainties. The double ratio measurements from NA50 show a more pronounced centrality dependence compared to ALICE. The ψ(2S) R_{AA} hints at a decrease as a function of p_{T} similar to the J/ψ one and connected with charm quarks recombination processes. As a function of centrality, the value of the ψ(2S) R_{AA} is almost constant and reaches ~0.4. The ψ(2S) shows more suppression with respect to the J/ψ, both as a function of centrality and p_{T}. The transport model, which includes recombination of charm quarks through the QGP medium and is already able to describe the J/ψ data, shows a fair agreement with ψ(2S) data, especially for central events.

References

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