



XXVIIIth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions
(Quark Matter 2018)

Quarkonium production in p-Pb collisions with ALICE

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Abstract

ALICE has measured quarkonium production in p-Pb collisions at backward ($-4.46 < y_{\text{cms}} < -2.96$), mid ($-1.37 < y_{\text{cms}} < 0.43$) and forward ($2.03 < y_{\text{cms}} < 3.53$) rapidity (y) regions down to zero transverse momentum (p_T). The inclusive J/ψ production has been studied at mid- y in p-Pb interactions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV and at forward and backward y in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV and 8.16 TeV. The comparison of the J/ψ production to the one of the loosely bound $\psi(2S)$ state is discussed, together with new results on the nuclear modification factors of the $\Upsilon(1S)$ and $\Upsilon(2S)$ states measured at forward and backward y . All the results will be compared to those obtained at lower energies and with available theoretical calculations.

Keywords: ALICE, quarkonia, cold nuclear matter effect, transport

1. Introduction

The study of quarkonium production in proton-nucleus collisions is an important tool to investigate cold nuclear matter (CNM) effects. Mechanisms such as the modification of the parton distribution functions in nuclei, the presence of a color glass condensate or coherent energy loss of the $c\bar{c}$ or $b\bar{b}$ pair in the medium have been employed to describe the results on J/ψ and Υ production obtained in proton-nucleus collisions from the LHC Run 1 [1, 3, 2, 4, 5]. In addition, final state mechanisms, possibly related to the presence of a dense medium, are required to explain the stronger suppression observed for the loosely bound $\psi(2S)$ state [6, 7]. The measurement of the inclusive J/ψ v_2 is done via a study of the angular correlations between forward and backward J/ψ and mid-rapidity charged particles [8]. A strong indication of long-range correlations with a sizeable non-zero v_2 at high transverse momentum is comparable to the one already observed in Pb-Pb collisions, suggesting a common mechanism. The larger statistics collected in LHC Run 2 allow us a more detailed study of the quarkonium production in p-Pb collisions, at both $\sqrt{s_{\text{NN}}} = 5.02$ and 8.16 TeV, providing further insight on the involved cold nuclear matter mechanisms.

2. Experimental setup and data analysis

The ALICE Collaboration has studied inclusive quarkonium production in p-Pb collisions at mid- y in the dielectron channel and at forward/backward- y in the dimuon channel. Due to the beam-energy asymmetry

during the p-Pb data-taking, the nucleon-nucleon center-of-mass system is shifted in rapidity with respect to the laboratory frame by $\Delta y = 0.465$ towards the proton beam direction. The data have been taken with two beam configurations, obtained by inverting the directions of the p and Pb beams. Since muons are identified and tracked in the Muon Spectrometer, which covers the pseudorapidity range $-4 < \eta < -2.5$ [11], this results in a forward ($2.03 < y_{\text{cms}} < 3.53$) and backward ($-4.46 < y_{\text{cms}} < -2.96$) accessible rapidity regions. Mid rapidity coverage is $-1.37 < y_{\text{cms}} < 0.43$. The Silicon Pixel Detector (SPD) is used for vertex identification. The V0 detector provides the minimum-bias trigger and helps to remove the beam-induced background. Two sets of Zero Degree Calorimeters (ZDCs), each including a neutron (ZN) and a proton (ZP) calorimeter, are used for the centrality estimation. The centrality selection is defined by a selected range of energy deposited by neutrons in the Pb-remnant side of ZN using the hybrid method described in [9]. In this method, the determination of the average number of binary nucleon collisions ($\langle N_{\text{coll}} \rangle$) relies on the assumption that the charged-particle multiplicity measured at mid-rapidity is proportional to the number of participant nucleons ($\langle N_{\text{part}} \rangle$). $\langle N_{\text{part}} \rangle$ is calculated from the Glauber model [10] which is generally used to calculate geometrical quantities of nuclear collisions. Other assumptions to derive $\langle N_{\text{coll}} \rangle$, which are discussed in [9], are used in order to determine the associated systematic uncertainty. The centrality classes 0-2% and 90-100% are excluded due to the possible contamination from residual pile-up events. Events where two or more interactions occur in the same colliding bunch (in-bunch pile-up) or during the readout time of the SPD (out-of-bunch pile-up) are removed using the information from SPD and V0. More details on the experimental apparatus can be found in [11]. Details on the analysis techniques and event selection are reported in Ref. [12, 13, 14, 15, 16].

3. Results

The nuclear modification factor (R_{pPb}) is defined as the ratio of quarkonium production yield in p-Pb collisions to that in pp collisions collected at the same center-of-mass energy scaled with number of binary nucleon-nucleon collisions. For centrality dependent studies in p-Pb collisions in ALICE it is referred to as Q_{pPb} due to the possible bias in the determination of centrality.

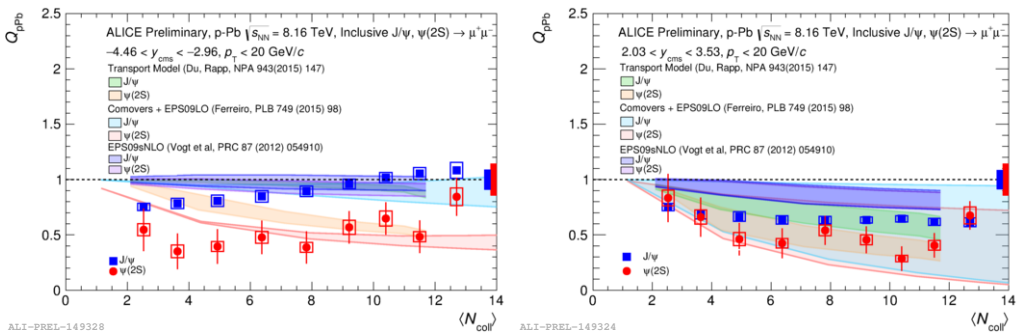


Fig. 1. Q_{pPb} of inclusive J/ψ and $\psi(2S)$ as a function of $\langle N_{\text{coll}} \rangle$ at backward (left) and forward (right) rapidity at $\sqrt{s_{\text{NN}}} = 8.16$ TeV.

Q_{pPb} of J/ψ and $\psi(2S)$ as a function of $\langle N_{\text{coll}} \rangle$ are shown in Fig. 1. The J/ψ Q_{pPb} shows a reduction from peripheral to central collisions at forward-y, while trend is opposite at backward-y. Measurement at mid-y, reported in [14], shows almost no centrality dependence of Q_{pPb} . $\psi(2S)$ suppression is stronger than J/ψ especially at backward-y. The results are compared to a pure nuclear shadowing theory calculation [17] based on EPS09s NLO set of nuclear parton distribution functions (nPDFs). This model describes only J/ψ in the forward region reasonably well, but fails to describe $\psi(2S)$ in both the forward and the backward region. At backward-y, final state effects are needed to explain the $\psi(2S)$ behaviour [18, 19]. Theoretical predictions based on a comover approach with EPS09LO set of nPDF [18] and on a transport model [19], which includes CNM effects and the interaction with the produced medium describe the backward-y results

quite well although some discrepancies are observed between the data and the models in the peripheral collisions. Large uncertainties for the comovers model in the forward-y is due to the large uncertainties in nPDF in that region.

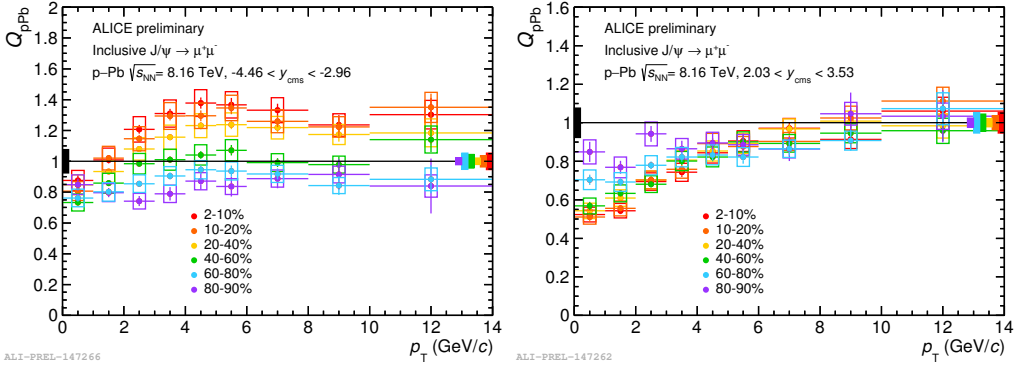


Fig. 2. Inclusive J/ψ Q_{pPb} as a function of p_T at backward (left) and forward (right) rapidity at $\sqrt{s_{NN}} = 8.16$ TeV for different centrality classes.

Fig. 2 shows results on multi-differential study of J/ψ Q_{pPb} as a function of p_T in different centrality classes. A clear evolution of Q_{pPb} as a function of p_T in different centrality classes is observed. At backward-y there is an enhancement in most central collisions for $p_T > 3$ GeV/c. At forward-y stronger suppression at low p_T in most central collisions is observed and Q_{pPb} is compatible with unity for $p_T > 7$ GeV/c within uncertainties for all centrality intervals.

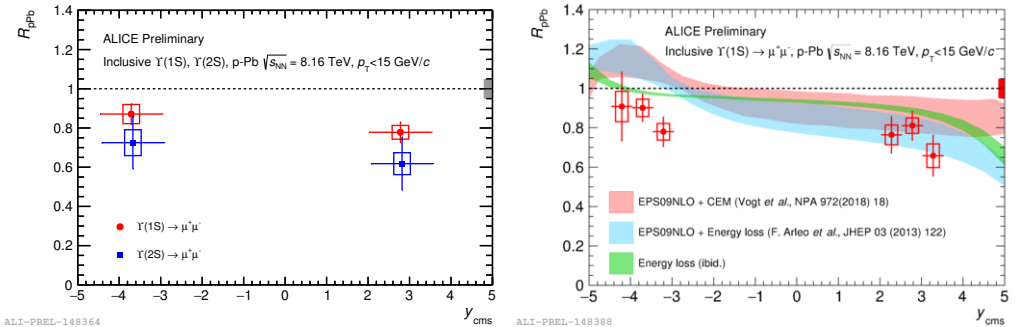


Fig. 3. R_{pPb} of inclusive $\Upsilon(1S)$ and $\Upsilon(2S)$ as a function of center-of-mass rapidity at $\sqrt{s_{NN}} = 8.16$ TeV (left). $\Upsilon(1S)$ results are compared to the theoretical calculations (right).

The large statistics collected at $\sqrt{s_{NN}} = 8.16$ TeV allows us to measure $\Upsilon(1S)$ production in rapidity, p_T and centrality bins whereas at $\sqrt{s_{NN}} = 5.02$ TeV [2] we have results only as a function of rapidity due to low statistics. Results are compatible between the two center-of-mass energies. From Fig. 3 (left) one can see that there is a suppression of the $\Upsilon(1S)$ production in p-Pb collisions, both at forward-y and backward-y, with a hint for a stronger suppression at forward-y. The suppression amounts to 2.8σ and 1.7σ at forward-y and backward-y, respectively. R_{pPb} of $\Upsilon(2S)$ is also shown in Fig. 3 (left). The difference in the R_{pPb} of $\Upsilon(2S)$ and $\Upsilon(1S)$ amounts to 1σ at forward-y and 0.9σ at backward-y. CMS [4] and ATLAS [5] measurements at mid-y also show that $\Upsilon(2S)$ suppression is stronger than $\Upsilon(1S)$. Theoretical predictions based on shadowing [17] and energy loss (with or without the contribution of the EPS09 nuclear shadowing) [20] describe forward-y $\Upsilon(1S)$ results but slightly overestimate backward-y results, as visible in Fig. 3 (right).

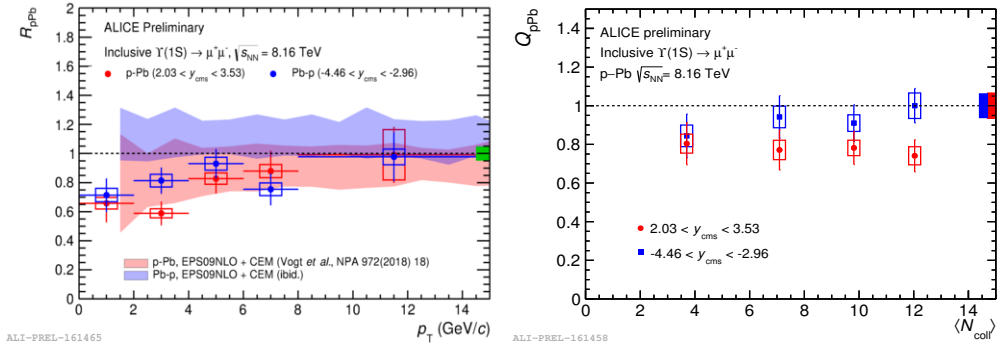


Fig. 4. Left: inclusive $\Upsilon(1S)$ R_{pPb} as a function of p_T compared to the theoretical calculations. Right: inclusive $\Upsilon(1S)$ Q_{pPb} as a function of $\langle N_{coll} \rangle$ at backward and forward rapidity at $\sqrt{s_{NN}} = 8.16$ TeV.

Fig. 4 shows $\Upsilon(1S)$ R_{pPb} (left) and Q_{pPb} (right) as a function of p_T and $\langle N_{coll} \rangle$ at $\sqrt{s_{NN}} = 8.16$ TeV, respectively. The R_{pPb} shows a similar behaviour at both forward and backward- y as a function of p_T , with a hint for a stronger suppression at low p_T . Also in this case, theoretical predictions based on shadowing [17] describe forward- y results but slightly overestimate backward- y results, where anti-shadowing is predicted to play an important role. There is almost no centrality dependence of Q_{pPb} both at forward and backward- y with a hint for a stronger suppression at forward- y .

4. Conclusions

Quarkonium production has been measured with ALICE in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ and 8.16 TeV. Run2 results significantly increase the precision of the measurements, but theoretical models still face some difficulties in describing consistently all results. J/ψ shows a stronger suppression at forward- y than at backward- y and theoretical models based on CNM effects qualitatively describe J/ψ results. $\psi(2S)$ shows a stronger suppression than J/ψ and final state effects are needed to explain its behaviour. New results on the Υ production show a similar suppression for the $\Upsilon(1S)$ and the $\Upsilon(2S)$ which can be described, at forward- y , by shadowing and energy loss models. However, these calculations tend to overestimate Υ yields at backward- y .

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