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Nuclear Physics A 982 (2019) 739–742

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

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

Quarkonium production in p-Pb collisions with ALICE

Biswarup Paul for the ALICE collaboration

University and INFN Torino, Italy

Via Pietro Giuria 1, I-10125 Torino, Italy

Abstract

ALICE has measured quarkonium production in p-Pb collisions at backward ($-4.46 < y_{\rm cms} < -2.96$), mid ($-1.37 < y_{\rm cms} < 0.43$) and forward ($2.03 < y_{\rm cms} < 3.53$) rapidity ($y$) regions down to zero transverse momentum ($p_{\rm T}$). The inclusive J/ψ production has been studied at mid-y in p-Pb interactions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV and at forward and backward y in p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV and 8.16 TeV. The comparison of the J/ψ production to the one of the loosely bound ψ(2S) state is discussed, together with new results on the nuclear modification factors of the Υ(1S) and Υ(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 ψ(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 $\sqrt{s_{\rm NN}}$ = 5.02 and 8.16TeV, 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

https://doi.org/10.1016/j.nuclphysa.2018.11.024
0375-9474/© 2018 Published by Elsevier B.V.

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 ($2.03 < y_{\rm cms} < 3.53$) and backward ($-4.46 < y_{\rm cms} < -2.96$) accessible rapidity regions. Mid rapidity coverage is $-1.37 < y_{\rm cms} < 0.43$. 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 $\langle N_{\rm coll}\rangle$ relies on the assumption that the charged-particle multiplicity measured at mid-rapidity is proportional to the number of participant nucleons ($\langle N_{\rm part}\rangle$). $\langle N_{\rm part}\rangle$ is calculated from the Glauber model [10] which is generally used to calculate geometrical quantities of nuclear collisions. Other assumptions to derive $\langle N_{\rm coll}\rangle$, 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 ($R_{\rm pPb}$) 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 $Q_{\rm pPb}$ due to the possible bias in the determination of centrality.

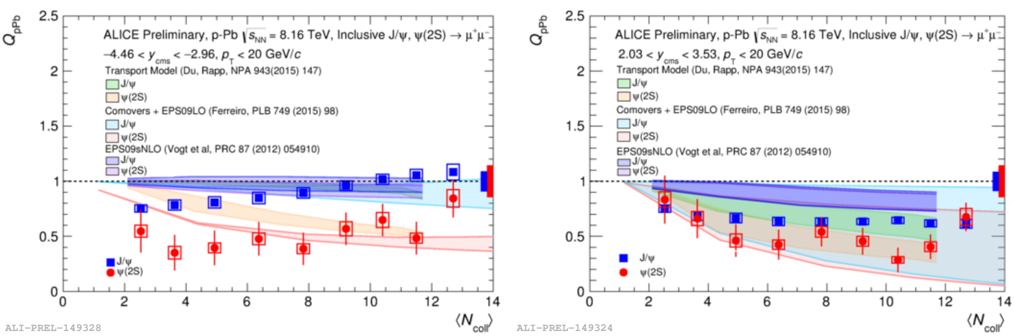

Fig. 1. $Q_{\rm pPb}$ of inclusive J/ψ and ψ(2S) as a function of $\langle N_{\rm coll}\rangle$ at backward (left) and forward (right) rapidity at $\sqrt{s_{\rm NN}} = 8.16$ TeV.

$Q_{\rm pPb}$ of J/ψ and ψ(2S) as a function of $\langle N_{\rm coll}\rangle$ are shown in Fig. 1. The J/ψ $Q_{\rm pPb}$ 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 $Q_{\rm pPb}$. ψ(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 ψ(2S) in both the forward and the backward region. At backward-y, final state effects are needed to explain the ψ(2S) behaviour [18, 19]. Theoretical predictions based on a comover approch 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.

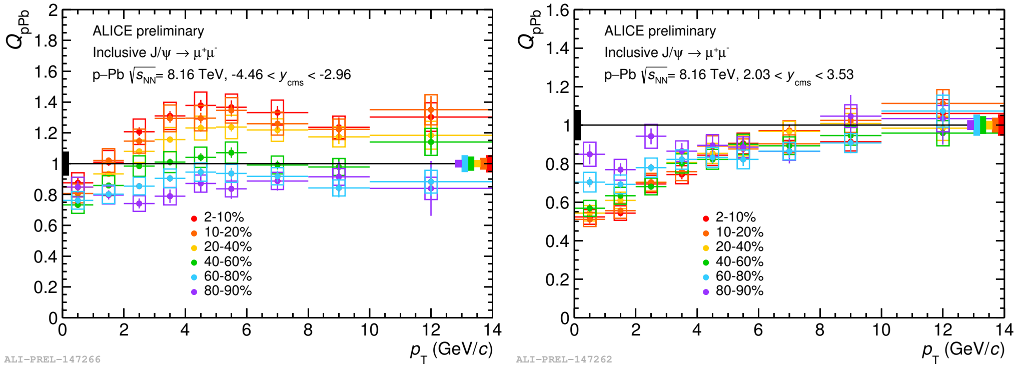

Fig. 2. Inclusive J/ψ Q_{pPb} as a function of p_T at backward (left) and forward (right) rapidity at $\sqrt{s_{NN}}$ = 8.16 TeV for different centrality classes.

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.

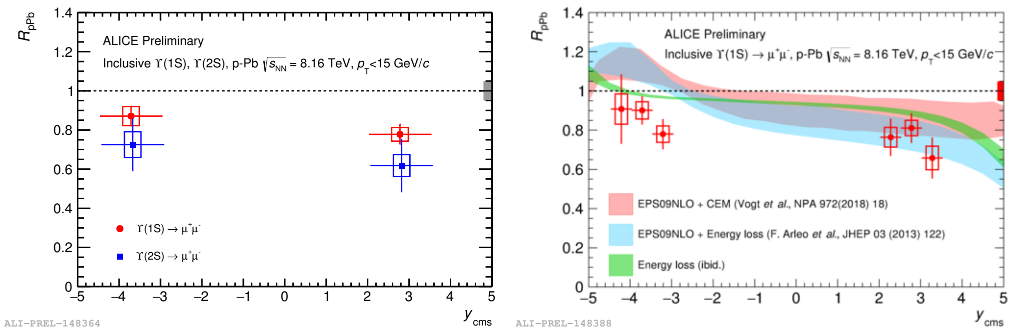

Fig. 3. R_{pPb} of inclusive Υ(1S) and Υ(2S) as a function of center-of-mass rapidity at $\sqrt{s_{NN}}$ = 8.16 TeV (left). Υ(1S) results are compared to the theoretical calculations (right).

The large statistics collected at $\sqrt{s_{NN}}$ = 8.16 TeV allows us to measure Υ(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 Υ(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 Υ(2S) is also shown in Fig. 3 (left). The difference in the R_{pPb} of Υ(2S) and Υ(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 Υ(2S) suppression is stronger than Υ(1S). Theoretical predictions based on shadowing [17] and energy loss (with or without the contribution of the EPS09 nuclear shadowing) [20] describe forward-y Υ(1S) results but slightly overestimate backward-y results, as visible in Fig. 3 (right).

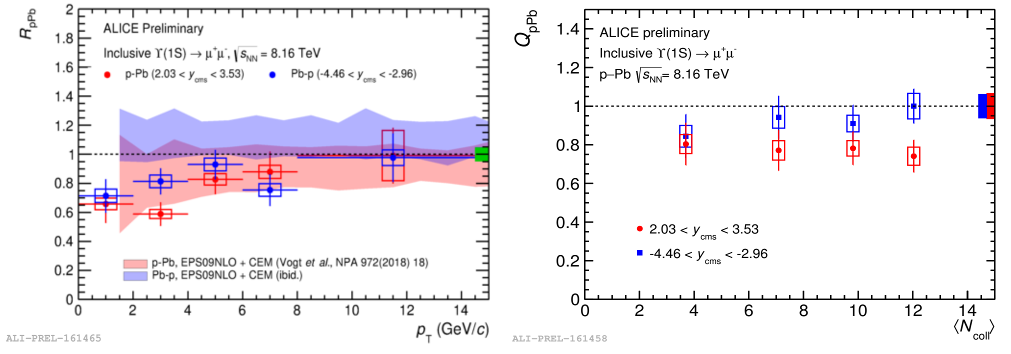

Fig. 4. Left: inclusive Υ(1S) R_{pPb} as a function of p_T compared to the theoretical calculations. Right: inclusive Υ(1S) Q_{pPb} as a function of $\langle N_{coll} \rangle$ at backward and forward rapidity at $\sqrt{s_{NN}}$ = 8.16 TeV.

Fig. 4 shows Υ(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. ψ(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 Υ(1S) and the Υ(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.

References

[1] B. Abelev *et al.*, (ALICE Collaboration) *JHEP* **02** (2014) 073
[2] B. Abelev *et al.*, (ALICE Collaboration) *Phys. Lett.* **B740** (2015) 105
[3] R. Aaij *et al.*, (LHCb Collaboration) *JHEP* **02** (2014) 072
[4] S. Chatrchyan *et al.*, (CMS Collaboration) *JHEP* **04** (2014) 103
[5] M. Aaboud *et al.* (ATLAS Collaboration) *Eur. Phys. J.* **C78** (2018) 171
[6] B. Abelev *et al.*, (ALICE Collaboration) *JHEP* **12** (2014) 073
[7] B. Abelev *et al.*, (ALICE Collaboration) *JHEP* **06** (2016) 050
[8] S. Acharya *et al.*, (ALICE Collaboration) *Phys. Lett.* **B780** (2018) 2
[9] J. Adam *et al.*, (ALICE Collaboration) *Phys. Rev.* **C91** (2015) 064905
[10] M. L. Miller *et al.*, *Ann. Rev. Nucl. Part. Sci.* **57** (2007) 205.
[11] J. Aamodt *et al.*, (ALICE Collaboration), *JINST* **3**, (2008) S08002
[12] S. Acharya *et al.*, (ALICE Collaboration) ALICE-PUBLIC-2017-001 (arXiv:1805.04381)
[13] S. Acharya *et al.*, (ALICE Collaboration) ALICE-PUBLIC-2017-007
[14] S. Acharya *et al.*, (ALICE Collaboration) ALICE-PUBLIC-2018-007
[15] S. Acharya *et al.*, (ALICE Collaboration) *Eur. Phys. J.* **C78** (2018) 466
[16] S. Acharya *et al.*, (ALICE Collaboration) ALICE-PUBLIC-2018-008
[17] Vogt *et al.*, *Nucl. Phys.* **A972** (2018) 18
[18] E. Ferreiro, *Phys. Lett.* **B749** (2015) 98
[19] Du and Rapp, *Nucl. Phys.* **A943** (2015) 147
[20] Arleo *et al.*, *JHEP* **10** (2014) 073