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Quarkonium production in p-Pb collisions with ALICE

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Abstract

ALICE has measured quarkonium production in p-Pb collisions at backward ($-4.46 < y_{cms} < -2.96$), mid ($-1.37 < y_{cms} < 0.43$) and forward ($2.03 < y_{cms} < 3.53$) 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 $\sqrt{s_{NN}} = 5.02$ TeV and at forward and backward y in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ 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, 2, 3]. 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 [4, 5]. The measurement of the inclusive J/ ψ v₂ is done via a study of the angular correlations between forward and backward J/ ψ and mid-rapidity charged particles [6]. A strong indication of long-range correlations with a sizeable non-zero v₂ 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 $\sqrt{s_{NN}} = 5.02$ 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

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 $-4 < \eta < -2.5$ [9], this results in a forward (2.03 < y_{cms} < 3.53) and backward (- 4.46 < y_{cms} < - 2.96) accessible rapidity regions. Mid rapidity coverage is $-1.37 < y_{cms} < 0.43$. 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 (ZN) 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 [7]. In this method, the determination of the average number of binary nucleon collisions $\langle N_{coll} \rangle$ relies on the assumption that the charged-particle multiplicity measured at mid-rapidity is proportional to the number of participant nucleons ($\langle N_{part} \rangle$). $\langle N_{part} \rangle$ is calculated from the Glauber model [8] which is generally used to calculate geometrical quantities of nuclear collisions. Other assumptions to derive $\langle N_{coll} \rangle$, which are discussed in [7], 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 [9]. Details on the analysis techniques and event selection are reported in Ref. [10, 11, 12, 13, 14].

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.

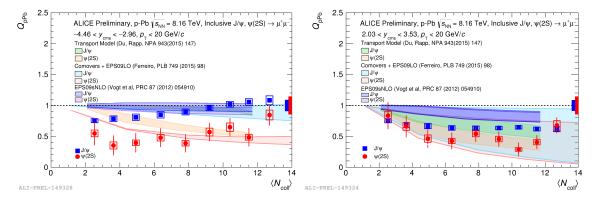


Fig. 1. Q_{pPb} of inclusive J/ ψ and $\psi(2S)$ as a function of $\langle N_{coll} \rangle$ at backward (left) and forward (right) rapidity at $\sqrt{s_{NN}} = 8.16$ TeV.

 Q_{pPb} of J/ ψ and $\psi(2S)$ as a function of $\langle N_{coll} \rangle$ 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 [12], 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 [15] based on EPS09s NLO set of nuclear parton distribution functions (nPDFs). The model is in fair agreement with both J/ ψ and $\psi(2S)$ results at forward-y but can not describe the result at backward-y. At backward-y, final state effects are needed to explain the $\psi(2S)$ behaviour [16, 17]. Theoretical predictions based on a comover approch with EPS09LO set of nPDF [16] and on a transport model [17], 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.

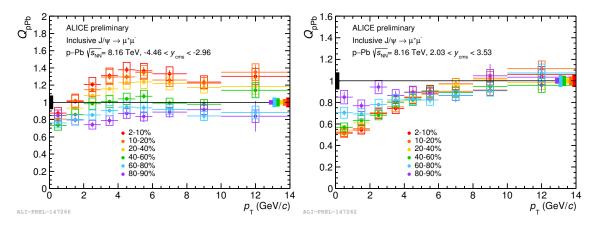


Fig. 2. Inclusive J/ ψQ_{pPb} as a function of p_T at backward (left) and forward (right) rapidity at $\sqrt{s_{NN}} = 8.16$ TeV for different centrality classes.

Fig. 2 shows results on multi-differential study of $J/\psi Q_{pPb}$ 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 backwardy there is an enhancement in most central collisions for $p_T > 3 \text{ GeV}/c$. At forward-y stronger suppression at low p_T in most central collisions is observed and Q_{pPb} is compatible with unity for $p_T > 7 \text{ GeV}/c$ within uncertainties for all centrality intervals.

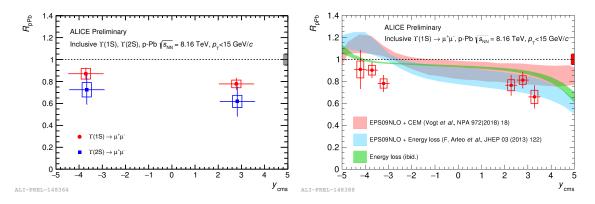


Fig. 3. R_{pPb} of inclusive $\Upsilon(1S)$ and $\Upsilon(2S)$ as a function of center-of-mass rapidity at $\sqrt{s_{\text{NN}}} = 8.16$ TeV (left). $\Upsilon(1S)$ results are compared to the theoretical calculations (right).

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 [3] 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 [19] and ATLAS [20] measurements at mid-y also show that $\Upsilon(2S)$ suppression is stronger than $\Upsilon(1S)$. Theoretical predictions based on shadowing [15] and energy loss (with or without the contribution of the EPS09 nuclear shadowing) [18] describe forward-y $\Upsilon(1S)$ results but slightly overestimate backward-y results, as visible in Fig. 3 (right).

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 [15] describe forward-y results but slightly overestimate backward-y results, where anti-shadowing is predicted

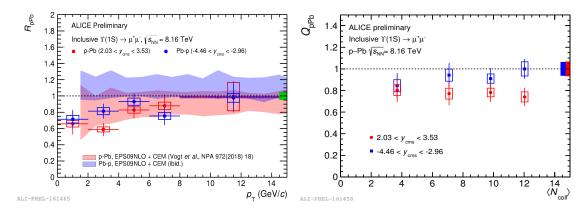


Fig. 4. Left: inclusive $\Upsilon(1S) R_{pPb}$ as a function of p_T compared to the theoretical calculations. Right: inclusive $\Upsilon(1S) Q_{pPb}$ as a function of $\langle N_{coll} \rangle$ at backward and forward rapidity at $\sqrt{s_{NN}} = 8.16$ TeV.

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

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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.

References

- [1] B. Abelev et al., (ALICE Collaboration) JHEP 02 (2014) 073
- [2] J. Adam et al., (ALICE Collaboration) JHEP 11 (2015) 127
- [3] B. Abelev et al., (ALICE Collaboration) Phys. Lett. B740 (2015) 105-117
- [4] B. Abelev et al., (ALICE Collaboration) JHEP 12 (2014) 073
- [5] B. Abelev et al., (ALICE Collaboration) JHEP 06 (2016) 050
- [6] S. Acharya et al., (ALICE Collaboration) Phys. Lett. B780 (2018) 2
- [7] J. Adam et al., (ALICE Collaboration) Phys. Rev. C91 (2015) 064905
- [8] M. L. Miller et al., Ann. Rev. Nucl. Part. Sci. 57 (2007) 205.
- [9] J. Aamodt et al., (ALICE Collaboration), JINST 3, (2008) S08002
- [10] S. Acharya et al., (ALICE Collaboration) ALICE-PUBLIC-2017-001 (arXiv:1805.04381)
- [11] S. Acharya et al., (ALICE Collaboration) ALICE-PUBLIC-2017-007
- [12] S. Acharya et al., (ALICE Collaboration) ALICE-PUBLIC-2018-007
- [13] S. Acharya et al., (ALICE Collaboration) Eur. Phys. J. C78 (2018) 466
- [14] S. Acharya et al., (ALICE Collaboration) ALICE-PUBLIC-2018-008
- [15] Vogt et al., Nucl. Phys. A972 (2018) 18
- [16] E. Ferreiro, Phys. Lett. B749 (2015) 98
- [17] Du and Rapp, Nucl. Phys. A943 (2015) 147
- [18] Arleo et al., JHEP 10 (2014) 073
- [19] S. Chatrchyan et al., (CMS Collaboration) JHEP 04 (2014) 103
- [20] M. Aaboud et al. (ATLAS Collaboration) Eur. Phys. J. C78 (2018) 171