PROCEEDINGS OF SCIENCE

J/ψ and ψ(2S) production in p-Pb collisions with ALICE at the LHC

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The ALICE collaboration has studied the inclusive J/ψ and $\psi(2S)$ production in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at the CERN LHC. The J/ψ measurement is performed in the $\mu^+\mu^-$ (- 4.46 < y_{cms} < - 2.96 and 2.03 < y_{cms} < 3.53) and in the e^+e^- (- 1.37 < y_{cms} < 0.46) decay channels, down to zero transverse momentum. The results are in fair agreement with theoretical predictions based on nuclear shadowing, as well as with models including, in addition, a contribution from partonic energy loss. Finally, the $\psi(2S)$ measurement in the $\mu^+\mu^-$ decay channel has been performed. In particular, a significantly smaller $\psi(2S)$ nuclear modification factor, with respect to the J/ψ one, has been observed.

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1. Introduction

The suppression of charmonia, bound states of c and $\bar{c}$ quarks, was proposed by T. Matsui and H. Satz [1] as a clean signature of Quark-Gluon-Plasma (QGP) formation in heavy-ion collisions. The available data from SPS [2, 3] and RHIC [4, 5] are showing "anomalous-suppression", which could be indicating the charmonia suppression. In this situation, ALICE results [6], which show smaller J/ψ suppression compared to lower energy experiments, indicate clearly the importance of a process for creating J/ψ in case of heavy ion collisions at LHC energy. Partonic transport models [7, 8] as well as statistical generation models [9], explain this effect as caused by a regeneration of J/ψ along the collision history and/or hadronization, favoured by the large $c\bar{c}$ multiplicity typical at the LHC energies. In addition to the color screening mechanism, it became soon clear that other effects may contribute to the charmonium suppression. In particular, nuclear effects (shadowing [10 – 14] and initial state parton energy loss [15 – 17]) are expected to play a role, contributing to the suppression of charmonium states. For this reason it is clear that is very important to study the production of charmonium in pA collisions, since it gives access to nuclear effects and it consequently allows to disentangle the suppression contribution related to them (cold nuclear matter effects) from that associated to the formation of a QGP (hot nuclear matter effects).

2. ALICE detector and data taking conditions

ALICE (A Large Ion Collider Experiment) is the dedicated heavy-ion detector at the LHC. The detectors of the central region ($|\eta| < 0.9$) are embedded in a large solenoidal magnet with a maximum field of 0.5 T. The main tracking devices are the Inner Tracking System (ITS), made of six layers of silicon detectors around the beam pipe, and the Time Projection Chamber (TPC), a large cylindrical gas detector. The TPC is also used to identify particles via the measurement of the energy loss dE/dx. The Muon Spectrometer, which covers the forward region ($-4 < \eta < -2.5$), is composed of a set of absorbers, a 3 T$\cdot$m dipole magnet, ten planes of tracking chambers and four planes of trigger chambers. Two VZERO hodoscopes ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$) are used for triggering and the Zero Degree Calorimeters (ZDC), placed 112.5 m from the interaction point, are used to reject satellite collisions. More details about the experimental setup can be found in [18]. In this analysis the J/ψ resonance is detected both in the dielectron decay channel (using the central barrel detectors) and in the dimuon decay channel (using the forward muon spectrometer), while the $\psi(2S)$ is detected only in the dimuon decay channel. Due to the energy asymmetry of the LHC beams in p-Pb collisions, (E_{p} = 4 TeV, E_{Pb} = 1.58 $\cdot A_{\mathrm{Pb}}$ TeV, where $A_{\mathrm{Pb}} = 208$) the nucleon-nucleon center-of-mass system doesn't coincide with the laboratory system, but is shifted by $\Delta y = 0.465$ in the direction of the proton beam. This results in asymmetric rapidity coverages with respect to y=0: -4.46 < y_{cms} < -2.96 at backward rapidity, -1.37 < y_{cms} < 0.46 at midrapidity and 2.03 < y_{cms} < 3.53 at forward rapidity. In the case of the e^+e^- decay channel the presented results are based on a Minimum Bias trigger (L_{int} = 52 μb^{-1}) and on a dimuon trigger in the case of the $\mu^+\mu^-$ decay channel with (L_{int} = 5.0 (5.8) μb^{-1}) at forward (backward) rapidity respectively.

3. Data analysis

The signal extraction is performed by analyzing the invariant mass spectra, both in the e^+e^- and

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in the $\mu^+\mu^-$ channel. In the e^+e^- channel the signal extraction is performed after subtracting the combinatorial background, obtained from the like-sign spectrum, normalized to match the integral of the opposite-sign dielectron in the invariant mass region 3.2-4.9 GeV/c^2. The signal events are then obtained by bin counting in the invariant mass region 2.92-3.16 GeV/c^2. In the dimuon decay channel, the J/ψ and $\psi(2S)$ signals are extracted with a fit of the opposite sign mass spectrum, using a Crystal Ball function [19] or a pseudo-gaussian functions [20] for the resonances and a variable-width-gaussian or the product of a 4^{th} order-polynomial and an exponential for the background. Figures 1 and 2 show the invariant mass spectra and the results of the signal extraction, in the dielectron and in the dimuon decay channel respectively.

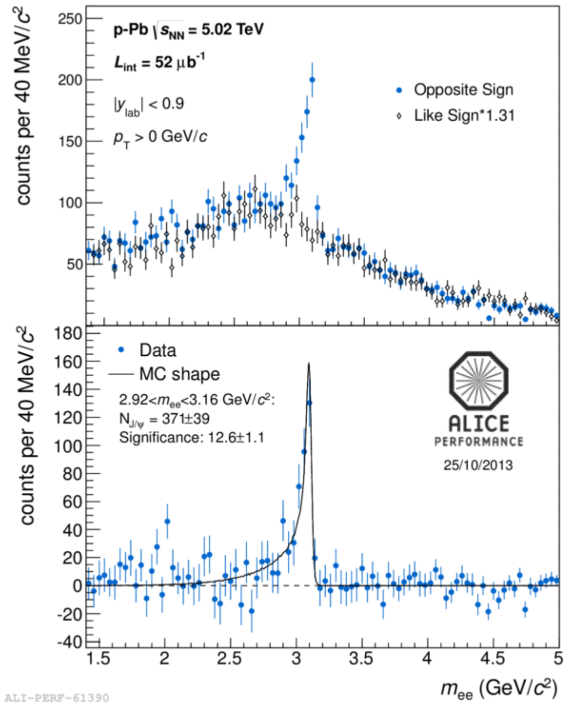

Figure 1: Opposite-sign dielectron invariant mass spectrum at midrapidity.

4. Results

4.1 J/ψ

The nuclear effects on J/ψ production in p-Pb collisions are quantified using the nuclear modification factor $R_{\rm pPb}$, which, in the J/$\psi \to \mu^+\mu^-$ decay channel, is defined by:

$$R_{\rm pPb} = \frac{N^{\rm cor}_{{\rm J}/\psi\to\mu\mu}}{\langle T_{\rm pPb}\rangle \cdot {\rm N_{MB}} \cdot {\rm B.R.}({\rm J}/\psi \to \mu\mu) \cdot \sigma_{\rm pp}^{{\rm J}/\psi}}$$

where $\sigma_{\rm pp}^{{\rm J}/\psi}$ is the production cross section in pp collisions in the same kinematical range at the same energy and $\langle T_{\rm pPb}\rangle$ is the nuclear thickness function estimated through the Glauber model

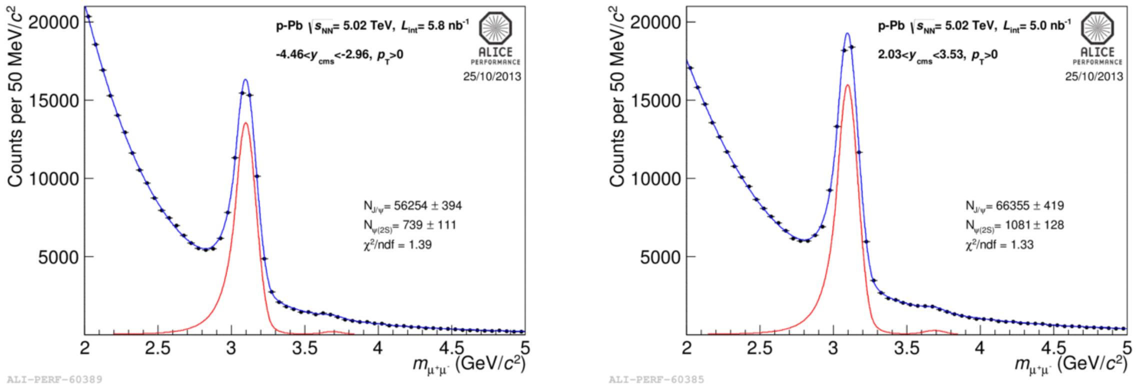

Figure 2: Opposite-sign $\mu^+\mu^-$ invariant mass spectra at backward (left) and forward (right) rapidity. The fits shown in these plots are obtained with an extended Crystal Ball function for the signal (shown as a red line) and a variable width gaussian for the background.

[21]. Since pp data at $\sqrt{s}$ = 5.02 TeV are not available, the reference $\sigma_{pp}^{J/\psi}$ is obtained with an interpolation procedure. In case of the results in the dimuon decay channel, the pp-reference for the nuclear modification factor relies on an interpolation of the ALICE measurements at $\sqrt{s}$ = 2.76 TeV and 7 TeV in the muon spectrometer and is performed bin-by-bin in y or p_T. For the rapidity bins not covered due to the rapidity shift, an extrapolation is used. More details about the explored method as a function of rapidity can be found in [22]. For the dielectron decay channel, the reference cross section was evaluated based on the interpolation of BR $\times\, d\sigma/dy$ measurements in pp (p$\bar{\text{p}}$) collisions at central rapidity published by the PHENIX Collaboration at $\sqrt{s}$ = 200 GeV [23], by the CDF Collaboration at $\sqrt{s}$ = 1960 GeV [24] and the ALICE Collaboration at $\sqrt{s}$ = 2.76 TeV [25] and $\sqrt{s}$ = 7 TeV [26]. The J/ψ $R_{\rm pPb}$, integrated over p_T, is shown in Figure 3.

At mid and forward rapidity, the inclusive J/ψ production is suppressed with respect to that one in binary-scaled pp collisions, whereas it is unchanged at backward rapidity. ALICE results are compared to theoretical models; ones with a EPS09 PDF [27, 28], one with coherent parton energy loss [29] and one with the Color Glass Condensate (CGC) initial state [30]. Models containing shadowing and/or energy loss are in agreement with ALICE data (within uncertainties), while the CGC model overestimates the suppression. In Figure 4 the J/ψ $R_{\rm pPb}$ is shown as a function of p_T, in the three rapidity intervals accessible by ALICE.

The p_T dependence of the J/ψ nuclear modification factor is more pronounced at forward than at backward rapidity. Comparison with the model calculations seems to show that any of the models could not reproduce the experimental trend over the whole p_T comfortably. Since the Bjorken x-values in the Pb nucleus in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are similar to the ones in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, assuming a factorization of shadowing effects, it is possible to estimate the expected size of cold nuclear matter effects in Pb-Pb. This is done by comparing $R_{\rm pPb}$ in p-Pb collisions with the Pb-Pb data. In particular, under the previous hypothesis, the J/ψ $R_{\rm pPb,backward} \cdot R_{\rm pPb,forward} (R^2_{\rm pPb,midrapidity})$ is compared to the $R_{\rm PbPb,forward} (R_{\rm PbPb,midrapidity})$. These results are shown in Figure 5.

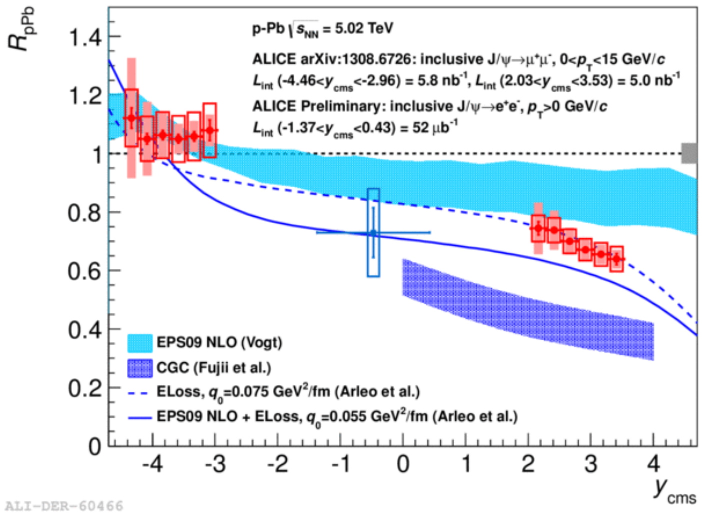

Figure 3: Inclusive J/ψ nuclear modification factor as a function of rapidity. Open boxes are uncorrelated systematic uncertainties, filled area indicate partially correlated uncertainties and the gray box the global uncertainty due to the T_{pPb}. Theoretical models are also shown.

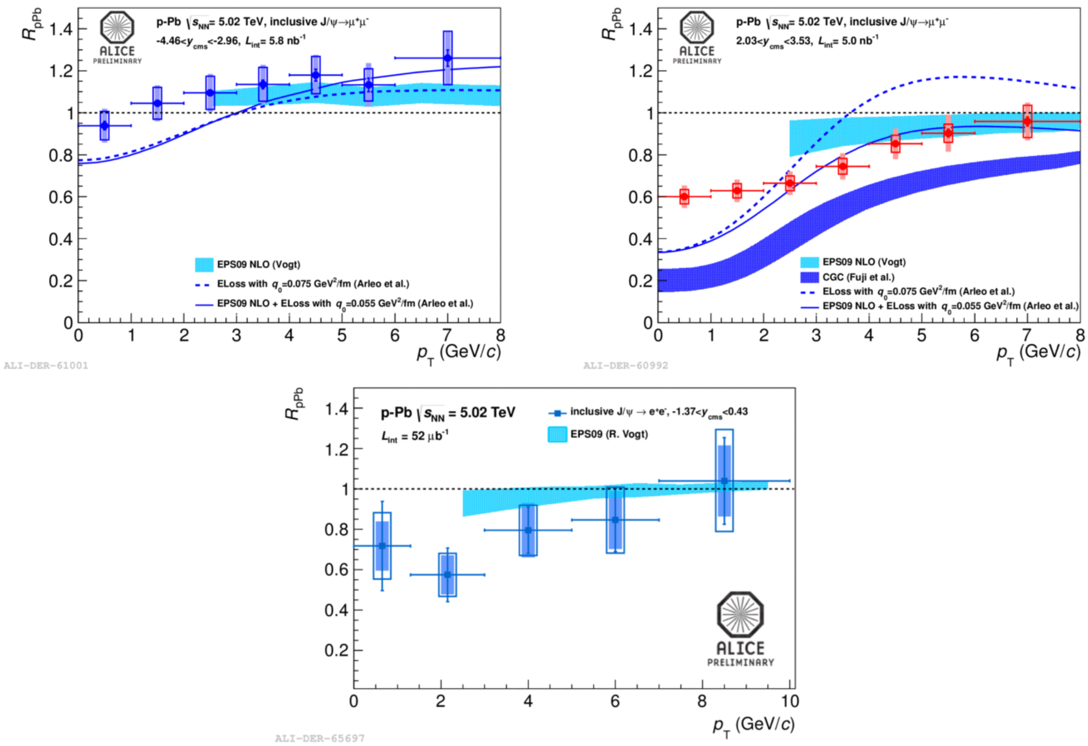

Figure 4: J/ψ R_{pPb} as a function of p_{T} at backward (top-left), forward (top-right) and mid (bottom-center) rapidity. Open boxes are uncorrelated systematic uncertainties, filled area indicate partially correlated uncertainties. The results of theory calculations are also shown.

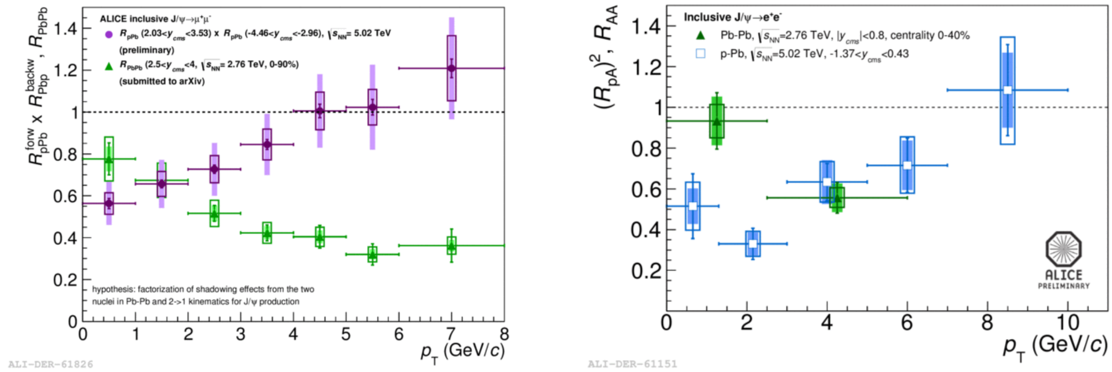

Figure 5: In the left plot the J/ψ $R_{\mathrm{pPb,backward}} \cdot R_{\mathrm{pPb,forward}}$ is compared to the $R_{\mathrm{pPbPb,forward}}$. In the right plot the J/ψ $R^2_{\mathrm{pPb,midrapidity}}$ is compared with $R_{\mathrm{PbPb,midrapidity}}$. Systematic uncertainties are represented in the same way as Figure 4.

In the muon decay channel it is possible to introduce the variable $S_{J/\psi}$ which is given by:

$$S_{J/\psi} = \frac{R_{\mathrm{PbPb}}}{(R^{\mathrm{forward}}_{\mathrm{pPb}} \cdot R^{\mathrm{backward}}_{\mathrm{pPb}})}$$

The $S_{\mathrm{J}/\psi}$ variable, for the inclusive $J/\psi \to \mu^+\mu^-$ is shown, as a function of p_{T}, in Figure 6.

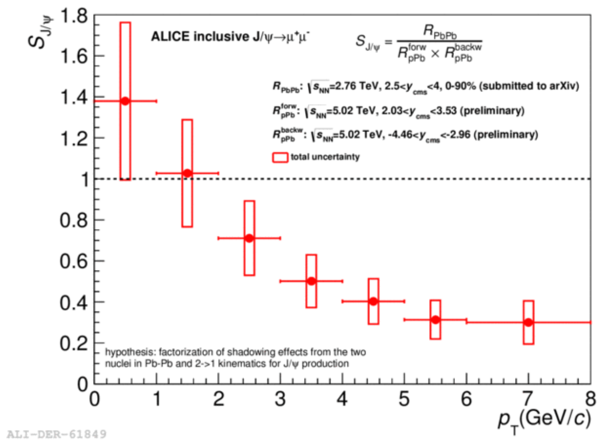

Figure 6: The $S_{J/\psi}$ variable for the inclusive $J/\psi \to \mu^+\mu^-$

The comparison between the suppression pattern in p-Pb and Pb-Pb collisions presented in Fig.6, shows that, at low transverse momentum, there could be a contribution from regeneration (this results is in agreement with partonic transport models [7]) while, at higher transverse momenta, the suppression contribution starts to be dominant.

4.2 ψ(2S)

The ψ(2S) analysis at backward and forward rapidity has been performed analogously to the J/ψ one. In Figure 7 the double ratio $[\psi(2\mathrm{S}))/\mathrm{J}/\psi]_{\mathrm{pPb}}/[\psi(2\mathrm{S}))/\mathrm{J}/\psi]_{\mathrm{pp}}$ is shown as a function of rapidity and it is compared with the PHENIX results in d-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV. ALICE results show a similar trend compared with PHENIX data at midrapidity [31] showing a decrease of the $\psi(2\mathrm{S})/J/\psi$ ratio in p-Pb collisions with respect to the one in pp collisions.

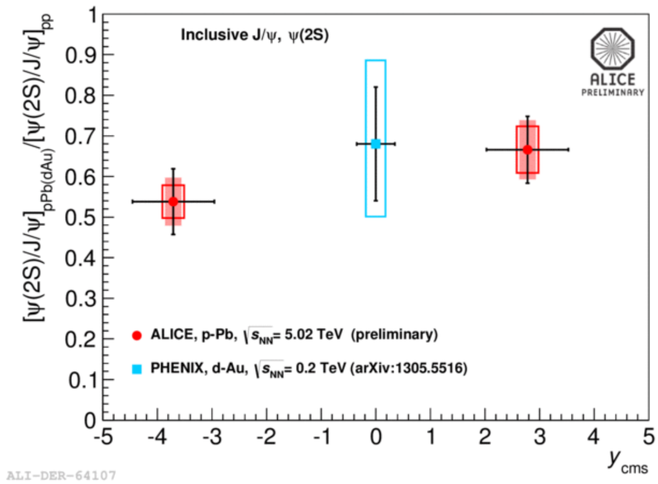

Figure 7: The double ratio $[\psi(2\mathrm{S}))/\mathrm{J}/\psi]_{\mathrm{pPb}}/[\psi(2\mathrm{S}))/\mathrm{J}/\psi]_{\mathrm{pp}}$. PHENIX data at $\sqrt{s_{NN}} = 0.2$ TeV at midrapidity is also shown. The shaded area represents partially correlated systematics while the boxes are correlated systematics.

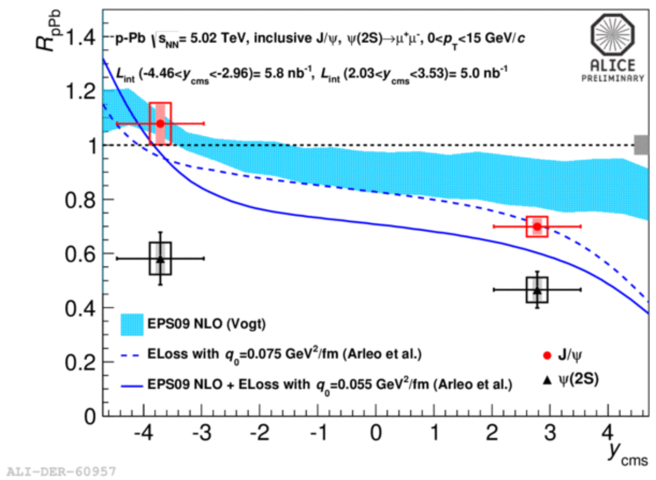

Figure 8: The $R_{\mathrm{pPb}}^{\psi(2S)}$ compared to $R_{\mathrm{pPb}}^{J/\psi}$. Open boxes are uncorrelated systematic uncertainties, filled area indicate partially correlated uncertainties and the gray box the global uncertainty. Theoretical models for the J/ψ [27 – 29], which are also valid for $\psi(2\mathrm{S})$ are shown.

The $\psi(2\mathrm{S})$ nuclear modification factor R_{pPb}, can be obtained in the following way:

$$R_{\mathrm{pPb}}^{\psi(2S)} = R_{\mathrm{pPb}}^{J/\psi} \cdot \frac{\sigma_{\mathrm{pPb}}^{\psi(2S)}}{\sigma_{\mathrm{pPb}}^{J/\psi}} \cdot \frac{\sigma_{\mathrm{pp}}^{J/\psi}}{\sigma_{\mathrm{pp}}^{\psi(2S)}}$$

In Figure 8 the $R_{\mathrm{pPb}}^{\psi(2S)}$ is presented as a function of rapidity and it is compared to $R_{\mathrm{pPb}}^{J/\psi}$.
The $\psi(2\mathrm{S})$ is more suppressed with respect to the J/ψ. These results are compared to theoretical calculations used for the J/ψ [27 – 29], which provide almost identical for the $\psi(2\mathrm{S})$ (shadowing effects are supposed to be identical for J/ψ and $\psi(2\mathrm{S})$ because of the similar kinematic distributions of gluons and, for what concern coherent energy loss, no sensitivity to the final quantum numbers of the charmonium state is expected). The available theoretical predictions do not describe the $\psi(2\mathrm{S})$ suppression: other mechanisms are required to explain it.

5. Conclusions

In summary, the ALICE collaboration has studied the J/ψ and $\psi(2\mathrm{S})$ production in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The J/ψ nuclear modification factor has been shown as a function of rapidity and transverse momentum. Results are in fair agreement with theoretical models based on shadowing and/or energy loss, while the Color Glass Condensate approach overestimates the suppression. The $\psi(2\mathrm{S})$, studied as a function of rapidity, is more suppressed with respect to the J/ψ and the available calculation do not describe the observed nuclear modification factor.

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