Preliminary Physics Summary:
Transverse momentum and centrality dependence of inclusive $J/\psi$ production in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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Abstract

Inclusive $J/\psi$ production in minimum bias p–Pb collisions at a collision energy per nucleon–nucleon pair of $\sqrt{s_{NN}} = 5.02$ TeV is studied with a recent dataset from 2016 recorded by ALICE at the CERN-LHC. The production of $J/\psi$ is investigated in the dielectron channel in the central barrel in the centre-of-mass rapidity interval of $-1.37 < y_{\text{cms}} < 0.43$. Preliminary results for the transverse momentum dependence of the nuclear modification factor $R_{pPb}$ shows a suppression at low transverse momentum ($p_T$), decreasing in strength with increasing $p_T$ and becoming consistent with the expectation from pp collisions for $p_T \gtrsim 4$ GeV/c. The centrality dependence of the nuclear modification factor $Q_{pPb}$ is also studied.
1 Introduction

The suppression of charmonium production in ultra-relativistic heavy-ion collisions is one of the most compelling signatures of the formation of the Quark–Gluon Plasma (QGP), a state of matter with quarks and gluons as degrees of freedom. The high colour-charge density in such a state of matter would prevent the formation of charmonium states by screening the charm quarks from each other [1]. While at SPS [2] and RHIC [3, 4] energies, a strong suppression in central heavy-ion collision was observed and could be described by the suppression mechanism, at LHC energies [5–10] a recombination mechanism [11–13] has to be introduced to describe the centrality dependence of charmonium production. This is also supported by the decrease of the suppression towards lower \( p_T \) where recombined \( J/\psi \) pairs are assumed to be primarily produced.

However, it is also expected that nuclear effects, which are not related to the hot and dense medium of the QGP, can have an impact on charmonium production. For example, the modification of the Parton Distribution Function (PDF) of the colliding nucleons can affect charm pair production (see e.g. Ref. [14]). Since \( J/\psi \) mesons are dominantly produced via gluon fusion, the \( J/\psi \) production is particularly sensitive to the possible shadowing of the gluon PDF in nuclei.

Previous measurements in proton–nucleus collisions indeed showed a change in the charmonium production attributed to these cold nuclear matter (CNM) effects [15–18]. A suppression pattern consistent with the expectation of gluon shadowing as a function of \( p_T \) and centrality was observed in measurements performed by ALICE in p–Pb collisions at \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \) in forward, backward, and mid-rapidity compared with binary-scaled pp collisions at the same collision energy [19, 20]. In addition, the production of prompt \( J/\psi \) and \( J/\psi \) coming from beauty hadrons in proton–nucleus collisions at mid-rapidity were also consistent with the expectation from shadowing [21].

This note presents preliminary results on \( J/\psi \) production in minimum bias (MB) p–Pb collisions at \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \) recorded with the central barrel of the ALICE detector system at the LHC in 2016. The transverse momentum and centrality dependence of \( J/\psi \) production is studied. The statistics increased by a factor of 6 compared to the previous dataset [19, 20, 22], reducing the statistical uncertainty significantly, and consequently these results promise to further constrain CNM effects in heavy-ion collisions.

2 Experimental apparatus, data sample and event selection

The analysis is based on a MB trigger, which is defined by a coincidence of V0 detectors and the crossing of the beam (see [23] for details) and results in an integrated luminosity of 256 \( \mu \text{b}^{-1} \) used for this analysis. The Silicon Pixel Detector (SPD) is used to remove events from pile-up collisions and to identify the primary vertex of the interaction. After a quality selection, about \( 5.2 \times 10^8 \) events remain. The Zero Degree Calorimeters (ZDC), composed of two sets of neutron (ZN) and proton (ZP) calorimeters placed at 112.5 m from the interaction point on both side, are used to estimate the centrality of collisions.

In the central barrel of the ALICE detector system [23], \( J/\psi \) production is measured at a pseudorapidity of \( |\eta_{lab}| < 0.9 \) in the dielectron (\( e^+e^- \)) decay channel. Due to the asymmetric beams in the LHC, the nucleon–nucleon centre-of-mass is shifted from \( y = 0 \) by \( \Delta y_{NN} = 0.465 \) in the direction of the p-beam. This note follows the convention that positive rapidity refers to the direction of the p-beam and negative rapidity to the Pb-beam.

3 Data analysis

In the centrality dependent study, events are selected according to the energy released in ZN calorimeter positioned in the Pb-going direction (ZNA). The average number of collisions (\( \langle N_{\text{coll}} \rangle \)) or the thickness function (\( \langle T_{\text{ppb}} \rangle \)) for each ZNA centrality class is calculated by a hybrid method described in Ref. [24]. This approach assumes the charged-particle multiplicity measured at mid-rapidity is proportional to the number of participant (\( N_{\text{part}} \)). The average number of participant is calculated by the Glauber model [25].
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Fig. 1: (Colour online) The invariant mass distributions of opposite-sign electron pairs (black lines) are shown and are superimposed with the background estimation from weighted mixed event pairs (blue lines) for different $p_T$ ranges. The background subtracted $J/\psi$ signal pairs are shown (red circles).

which is generally used to calculate geometrical quantities of nuclear collisions. Other assumptions to derive $N_{\text{coll}}$ are also considered to estimate the systematic uncertainties. The kinematic acceptance of electron candidates is constrained to $p_T > 1$ GeV/$c$ and $|\eta_{\text{lab}}| < 0.9$. Electrons are identified in the Time Projection Chamber (TPC) via the expectation of their specific energy loss ($dE/dx$) in the gas volume. Tracks are identified as electrons when their energy loss is within $3\sigma$ of the electron expectation and rejected if their energy loss is within $3\sigma$ with the pion or proton assumptions, where $\sigma$ refers to the resolution of the $dE/dx$ measurement. The requirements for electron identification are loosened at higher $p_T$ in order to increase the efficiency. To reduce background from photon conversions, identified electrons are required to produce a signal in one of the SPD layers. Additionally, to further remove photon conversions, electrons forming low mass pairs ($m_{ee} < 0.05$ GeV/$c^2$) with other electrons are removed from the further pair analysis.

The raw number of $J/\psi$ mesons is evaluated after the estimation and subtraction of the background. For
integrated $p_T$ and centrality, a total of $1953 \pm 67$ raw $J/\psi$ is available for the analysis. Background contributions are combinatorial background, which comes from unphysical combinations of electrons and positrons, and background pairs from combinations of correlated semi-leptonic decay pairs of D and B mesons or electrons from jet fragmentation. The combinatorial background is estimated by building dielectron pairs from electrons and positrons from different events with a similar event topology: so-called mixed-event pairs. These pairs are by construction unphysical and do not include any correlation except the pair acceptance. To take into account the correlated background, the mixed event pairs are weighted with an exponential function, which approximates the mass dependence of semi-leptonic heavy-flavour decays.

In Fig. 1 the invariant mass distributions for the $p_T$ bins under study are shown. The opposite-sign dielectron distribution is shown together with the background estimation.

Signal pairs are calculated after background subtraction by bin counting within the mass window $2.92 < m_{ee} < 3.16$ GeV/$c^2$ and extrapolated to the full mass range using Monte Carlo (MC) simulation. The raw number of $J/\psi$ mesons is then corrected for the detector efficiency. To take into account the acceptance and detector inefficiencies, corrections are performed based on MC simulations, where MB p–Pb collisions are simulated by EPOS-LHC [27] and $J/\psi$ signal is inserted with a realistic $p_T$ and rapidity shape based on previous measurements [19]. The pair efficiency is about 7.2% in the lowest $p_T$ bin and increases towards 13.0% towards the highest $p_T$ bin.

The nuclear modification factor $R_{p\text{p}b}$ as a function of transverse momentum is defined as

$$R_{p\text{p}b}(p_T) = \frac{d^2N_{p\text{p}b}^{J/\psi}/dp_Tdy}{\langle T_{p\text{p}b} \rangle \times d^2\sigma_{pp}^{J/\psi}/dp_Tdy},$$

where $d^2N_{p\text{p}b}^{J/\psi}/dp_Tdy$ is the acceptance corrected yield of $J/\psi$ in p–Pb collisions, $\langle T_{p\text{p}b} \rangle$ is the nuclear thickness function and $d^2\sigma_{pp}^{J/\psi}/dp_Tdy$ is the $p_T$ differential reference cross section of $J/\psi$ in pp collisions at the corresponding collision energy. For centrality studies, the nuclear modification factor is named $Q_{p\text{p}b}$, to be distinguished from $R_{p\text{p}b}$ since potential biases from the centrality estimation, unrelated to nuclear effects might be present [24], is also expressed as

$$Q_{p\text{p}b} = \frac{dN_{p\text{p}b,i}^{J/\psi}/dy}{\langle T_{p\text{p}b} \rangle \times d\sigma_{pp}^{J/\psi}/dy},$$

where $i$ is the index of the centrality bins, $dN_{p\text{p}b,i}^{J/\psi}/dy$ is the acceptance corrected yield of inclusive $J/\psi$ for a given centrality bin in p–Pb collisions, and $d\sigma_{pp}^{J/\psi}/dy$ is the total reference cross section of $J/\psi$ in pp collisions at the corresponding collision energy.

No measurement of the cross section $d^2\sigma_{pp}^{J/\psi}/dp_Tdy$ was carried out with the previous pp dataset at $\sqrt{s} = 5.02$ TeV. The estimation of the $p_T$ differential cross section follows a procedure described in [28], which was already applied in Ref. [19]. First, the $p_T$ integrated cross section $d\sigma_{pp}^{J/\psi}/dy$ is calculated from an interpolation of data taken at mid-rapidity at collision energies of $\sqrt{s} = 0.2$ TeV [29], 1.96 TeV [30], 2.76 TeV [31], and 7 TeV [32]. For the interpolation, a set of empirical functions was used and results in $BR \times d\sigma_{pp}^{J/\psi}/dy = 369.1 \pm 36.0$(stat.) $\pm 49.1$(syst.) nb. Afterwards, the $p_T$ differential cross section is estimated by a parametrisation as a function of $p_T/\langle p_T \rangle$ (see Ref. [19] for more details).

Several sources of systematic uncertainties are considered for the resulting nuclear modification factor $R_{p\text{p}b}$. The uncorrelated sources are identified to be the signal extraction including the background estimation (about 5%), the track selection (3–5%) and the interpolation procedure of the pp reference cross section (6–16% increasing with $p_T$). Correlated uncertainties, i.e. acting in the same direction within the full $p_T$ range, are from the pp reference (16.6%) and from the $\langle T_{p\text{p}b} \rangle$ normalisation ($\sim 3\%$). The correlated uncertainty of the pp reference spectrum originates from the poorly known $p_T$ integrated cross section interpolated to $\sqrt{s} = 5.02$ TeV as well as from the interpolated mean transverse momentum of the
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The uncorrelated uncertainty of the pp reference originate from the statistical uncertainty of previous measurements. For $Q_{p\text{p}}$, the uncorrelated sources are identified to be the signal extraction including

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the background estimation (about 5%), the track selection (about 2%) and the $\langle T_{p\text{p}} \rangle$ normalisation (2−8%). Correlated uncertainties for $Q_{p\text{p}}$ are from the pp reference (16.6%), background subtraction (5%), and the $T_{p\text{p}}$ normalisation (~3%).

4 Results

The preliminary nuclear modification factor of inclusive $J/\psi$ as a function of $p_T$ in MB p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV is presented in Fig. 2. At low $p_T$, the $J/\psi$ yield is suppressed in p–Pb collisions when compared to the binary scaled reference cross section in pp. The suppression then decreases with increasing $p_T$ and is consistent with binary scaling of the pp cross section for $p_T \gtrsim 4$ GeV/c. The results are compared to the ALICE published results from the LHC data taking in 2013 [19] and are shown to be consistent within the given $p_T$ range. Moreover, it has been possible to extend the $p_T$ reach of the measurement in this analysis to 14 GeV/c.

Fig. 3 shows the nuclear modification factor of inclusive $J/\psi$ as a function of $N_{\text{coll}}$. The new preliminary result is consistent with the ALICE published result from the LHC data taking in 2013 [20]. The inclusive $J/\psi$ $Q_{p\text{p}}$ shows a $J/\psi$ suppression, without a strong centrality dependence.

5 Summary and conclusion

We presented results on inclusive $J/\psi$ production in minimum bias p–Pb collisions at mid-rapidity at $\sqrt{s_{NN}} = 5.02$ TeV measured with ALICE at the CERN LHC. The nuclear modification factor of inclusive $J/\psi$ as a function of $p_T$ shows a suppression of the yield in p–Pb collisions at low $p_T$ which decreases towards higher $p_T$. The $Q_{p\text{p}}$ is uniformly suppressed with respect to the collision centrality. The results...
Fig. 3: Nuclear modification factor as a function of $\langle N_{\text{coll}} \rangle$ at $\sqrt{s_{\text{NN}}} = 5.02$ TeV is shown for the previous dataset (black squares) [20] and the preliminary result based on the 2016 data sample (red circles). Systematic uncertainties are shown as boxes whereas statistical uncertainties are shown as error bars. The correlated systematic uncertainty is shown as a box around unity and applies to both samples.

are compatible with measurements by ALICE from the previous p–Pb data taking period [19, 20, 22]. The statistical uncertainty is significantly reduced and will help to constrain cold nuclear matter effects in heavy-ion collisions.

References


