EPJ Web of Conferences **316**, 04015 (2025) https://doi.org/10.1051/epjconf/202531604015
SQM 2024

J/ψ photoproduction and polarization in peripheral Pb−Pb collisions with ALICE

Dukhishyam Mallick for the ALICE Collaboration[*]

[1]IJCLab Orsay, CNRS/IN2P3, Université Paris-Saclay, France

Abstract. Ultrarelativistic heavy-ion collisions generate a powerful electromagnetic field that produces photonuclear reactions. These processes have been extensively studied in ultraperipheral collisions, in which the impact parameter is larger than twice the nuclear radius. Recently, coherent photoproduction of J/ψ has been observed in nucleus–nucleus (A–A) collisions with nuclear overlap, based on the measurement of an excess of production with respect to hadron-production expectations in the very low transverse momentum (p_{T}). Such quarkonium measurements provide valuable information about the nuclear gluon distribution at low Bjorken x and high energy. In addition, they can constrain the theory describing photon-induced reactions in A–A collisions with nuclear overlap, including possible interactions of the measured probes with the formed and fast expanding Quark-Gluon Plasma. In order to confirm the photoproduction origin of the very low p_{T} J/ψ yield excess, polarization measurements represent a suitable observable. It is expected that the produced quarkonium inherits the polarization of the incoming photon because of the s-channel helicity conservation. ALICE can measure inclusive and exclusive quarkonium production down to $p_{\mathrm{T}} = 0$, at forward rapidity ($2.5 < y < 4$) and midrapidity ($|y| < 0.9$). In this contribution, new preliminary measurement of the y-differential cross section and the first new polarization analysis at the LHC of coherently photoproduced J/ψ in peripheral Pb–Pb collisions will be presented. These measurements are conducted at forward rapidity in the dimuon decay channel. These results will be discussed together with the recent results on coherent photoproduction as a function of centrality at both mid and forward rapidities. Comparison with models will be shown whenever available.

1 Introduction

Photon-induced processes play an important role in ultraperipheral collisions (UPCs), i.e., collisions in which nuclei are separated by an impact parameter (b) larger than the sum of their radii. In such collisions, hadronic interactions are strongly suppressed, and the cross section of produced vector mesons (VM, e.g., J/ψ) is expected to be significant due to the strong electromagnetic field of the nuclei [1]. In this process, a photon emitted by one of the colliding nuclei fluctuates into a $q\bar{q}$ pair (acts as a color dipole), which can interact with the second nucleus via two gluon exchange at Leading Order (LO). The color dipole finally recombines into a VM. J/ψ photoproduction is one of the cleanest experimental tools for probing the gluon distributions inside the nucleus [2], which are poorly known at low

[*]e-mail: dukhishyam.mallick@cern.ch

Bjorken-x [3]. Photonuclear reactions in UPCs have been extensively studied in ALICE (see for instance a recent measurement in Ref. [4]).

The first experimental signature of photonuclear reactions in peripheral Pb–Pb collisions (PCs) at $\sqrt{s_{\rm NN}}$ = 2.76 TeV was reported by the ALICE Collaboration via the measurement of an excess in the J/ψ yield at very low $p_{\rm T}$ with respect to expectations from hadroproduction [5]. Similar observations were confirmed in Ref. [6, 7], interpreting the excess as the evidence of coherent J/ψ photoproduction in Pb–Pb collisions with nuclear overlap. Recently, the ALICE Collaboration measured Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV and observed a significant J/ψ yield excess at low $p_{\rm T}$ in collisions with nuclear overlap, even in the 30–50% centrality range [8]. Theoretical models describing coherent photoproduction, considering effective photon flux and photonuclear cross sections, were compared with these measurements [9–12]. Polarization measurements of coherently photoproduced VM are important, according to the s-channel helicity conservation (SCHC) hypothesis, the VM should retain the photon's transverse polarization [13]. Recent J/ψ polarization measurements in UPCs [14] confirmed consistency with SCHC. In these proceedings, we present the first rapidity (y) differential cross section measurement of coherent J/ψ photoproduction, and the first polarization measurement of inclusive J/ψ for $p_{\rm T} < 0.3$ GeV/c, at forward rapidity ($2.5 < y < 4.0$) in the 70–90% centrality class in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV.

2 Analysis details

A detailed description of the ALICE detector is provided in Ref. [15]. This analysis measures J/ψ production at forward rapidity using opposite-sign dimuon pairs in the 70–90% centrality range for Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. The data, collected in 2015 and 2018, corresponds to an integrated luminosity of 756 ± 19 μb^{-1}. The J/ψ polarization is studied with the angular distribution of opposite sign (OS) dimuon pairs. The polarization is measured in the helicity frame [16], and dimuon angular distribution are expressed as :

$$W(\cos\theta, \varphi) \propto \frac{1}{3+\lambda_\theta}[1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos(2\phi) + \lambda_{\theta\phi} \sin(2\theta)\cos(\phi)]. \quad (1)$$

If (λ_θ, λ_ϕ, $\lambda_{\theta\phi}$) = (0, 0, 0), the particle is unpolarized, if (λ_θ, λ_ϕ, $\lambda_{\theta\phi}$) = (-1, 0, 0), the particle has a longitudinal polarization, and if (λ_θ, λ_ϕ, $\lambda_{\theta\phi}$) = (1, 0, 0), the particle is transversely polarized. In both y-differential cross section and polarization analyses, J/ψ is reconstructed from the invariant mass of opposite-sign dimuon pairs. The signal extraction is performed by fitting the invariant mass distribution with a combined fit function that describes the signal and background components. A likelihood approach is adopted during the signal extraction due to the low statistics.

3 Results and discussion

The J/ψ $p_{\rm T}$ spectra are evaluated for six rapidity intervals in the centrality range 70–90% in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. An excess in the J/ψ raw yield is observed for $p_{\rm T} <$ 0.3 GeV/c in all y intervals with respect to hadroproduction yield. The contribution from hadronically produced J/ψ is subtracted using a data-driven model, as discussed in Ref. [8]. Figure 1 shows the coherent photoproduction cross section as a function of y for $p_{\rm T} < 0.3$ GeV/c in the 70–90% centrality range for Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. The data are compared with model predictions: GG-hs (hot-spot model using the Gribov–Glauber approach) [10], Zha (photon–pomeron coupling scenario) [11], and GBW/IIM (color dipole model) [12]. In the right panel of Fig. 1, three GBW/IIM scenarios are compared to data. The

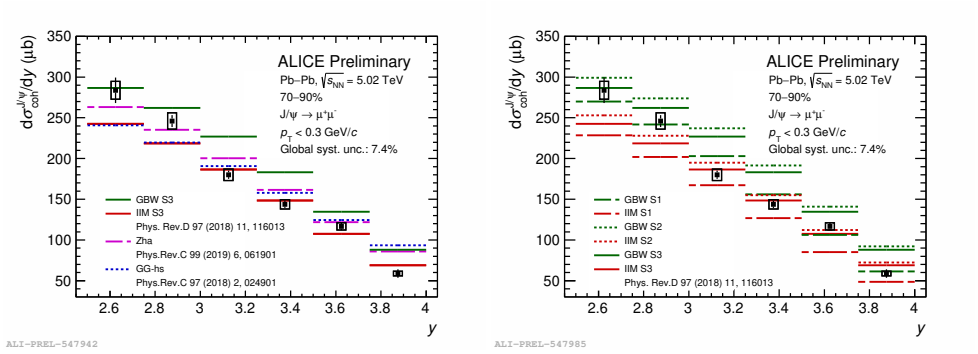

Figure 1. Cross section of coherently photoproduced J/ψ with $p_T < 0.3$ GeV/c as a function of y in the centrality range 70–90% in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Results are compared with model predictions from Refs. [10–12].

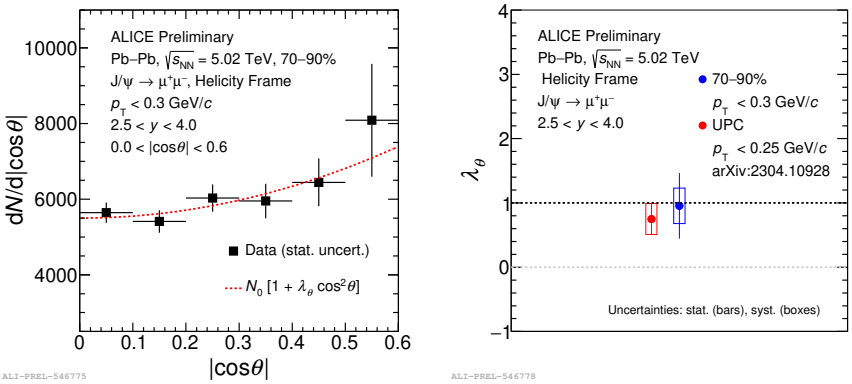

Figure 2. Left: Distribution of J/ψ cosθ in the helicity frame measured in 70–90% Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Reconstructed J/ψ were having $p_T < 0.3$ GeV/c and $2.5 < y < 4.0$. The distribution is fitted with Eq. 1 to extract λ_θ. Right: Comparison of the λ_θ from UPCs (red marker) and PCs (blue marker) in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

S1 scenario does not differ from UPCs, S2 uses an effective photon flux outside the overlap region, and S3 is the same photon flux as S2 and a change in the effective photonuclear cross section to exclude the nuclear overlap. While all models reproduce the overall magnitude, they fail to capture the y-dependence of the photoproduced J/ψ. Similar results were seen in UPC measurements [17]. Figure 2 shows the cosθ angular distribution of J/ψ for $p_T <$ 0.3 GeV/c in Pb–Pb collisions with 70–90% centrality. A dependence on cosθ is observed and the distribution is fitted with Eq. 1 to extract the λ_θ parameter. The λ_θ value in PCs is compared with the value obtained in UPCs, as shown in the right panel of Fig. 2. The results suggest that inclusive J/ψ with $p_T < 0.3$ GeV/c have a transverse polarization and therefore obey the SCHC hypothesis as observed in UPC (see Ref. [14]). Even without subtracting the hadronic J/ψ contribution, this polarization measurement can be regarded as a

proxy for the photoproduced J/ψ polarization as it is established from Ref. [17] that coherent J/ψ photoproduction constitutes 78% of the inclusive J/ψ yield in this kinematic region. This polarization measurement serves as an additional method to test the J/ψ production mechanisms at very low p_{T}, and it is consistent with the picture of a coherent photoproduction origin for the measured J/ψ yield excess.

4 Summary

We report the first measurement of the y-differential coherent J/ψ photoproduction cross section and polarization for $p_{\mathrm{T}} < 0.3$ GeV/c at forward rapidity in the 70–90% centrality range for Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. A significant J/ψ yield excess is observed at low p_{T} in peripheral collisions, interpreted as coherent photoproduction. The y-dependence of the cross section is measured and compared with models, which qualitatively match the data but fail to describe the data across the entire y range. An angular $\cos\theta$ dependence is observed for inclusive J/ψ polarization measurement using the helicity frame for peripheral collisions, and the λ_θ value is compatible with unity within uncertainties. This result is consistent with a transverse polarization scenario and with the UPC results.

These measurements remain a challenge for theoretical studies since the implementation of coherent photoproduction in nuclear collisions is complex and all the aspects should be considered. The J/ψ cross section measurements as a function of y in UPCs and PCs, will be used for the understanding of the photon energy ambiguity as discussed in Ref. [18]. In Run 3 more differential and precise measurements of the coherent J/ψ photoproduction cross section (as well as other VMs) will be achieved in more central collisions, together with polarization measurements.

References

[1] C. A. Bertulani et al., *Ann. Rev. Nucl. Part. Sci. 55, 271–310 (2005)*.
[2] V. Rebyakova, M. Strikman, and M. Zhalov, *Phys. Lett. B 710, 647 (2012)*.
[3] K. J. Eskola, H. Paukkunen, and C. A. Salgado, *JHEP 04, 065 (2009)*.
[4] S. Acharya et al., ALICE Collaboration, *Phys. Lett. B 817, 136280, (2021)*.
[5] J. Adam et al., ALICE Collaboration, *Phys. Rev. Lett. 116, 222301 (2016)*.
[6] J. Adam et al., STAR Collaboration, *Phys. Rev. Lett. 123, 132302 (2019)*.
[7] R. Aaij et al., LHCb Collaboration, *Phys. Rev. C 105, L032201 (2022)*.
[8] S. Acharya et al., ALICE Collaboration, *Phys. Lett. B 846, 137467 (2023)*.
[9] M. Kłusek-Gawenda et al., *Phys. Rev. C 93, 044912 (2016)*.
[10] J. Cepila et al., *Phys. Rev. C 97, 024901 (2018)*.
[11] W. Zha et al., *Phys. Rev. C 97, 044910 (2018)*.
[12] M. Gay Ducati et al., *Phys. Rev. D 97, 116013 (2018)*.
[13] F. J .Gilman et al., *Phys. Lett. B 31, 387–390 (1970)*.
[14] S. Acharya et al., ALICE Collaboration, *arXiv:2304.10928, (2023)*.
[15] K. Aamodt et al., ALICE Collaboration, *JINST 3, S08002 (2008)*.
[16] P. Faccioli et al., *Eur. Phys. J. C 69, 657–673 (2010)*.
[17] S. Acharya et al., ALICE Collaboration, *Phys. Lett. B 798, 134926 (2019)*.
[18] J. G. Contreras, *Phys. Rev. C 96, 015203 (2017)*.