

Measurements of J/ψ and impact of coincident photon induced processes in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}} = 5.36$ TeV with the ATLAS detector

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Abstract. The fully stripped ions used in heavy ion collisions at the LHC are an excellent source of high-energy quasi-real photons. These can interact with photons emitted by the oncoming nucleus, or with the nucleus itself, either directly in inelastic processes or diffractively via pomeron exchange. Diffractive photonuclear processes can produce exclusive vector mesons that are uniquely sensitive to the spatial and momentum structure of the nuclear parton distribution functions, as well as spatial fluctuations (hotspots). In Run 3, the ATLAS experiment utilized a low-multiplicity track trigger in heavy ions for the first time, allowing the collection of a large sample of events with a few tracks. A substantial fraction of these are sensitive to dilepton decays of vector mesons, including the J/ψ . First results on coherent J/ψ yields are presented using the widest continuous rapidity range available at the LHC. A discussion of important contributions from multiple-UPC processes is also provided.

1 Introduction

Collisions of hadrons at high energies are usually studied for cases where the hadrons interact via the strong force, producing large particle multiplicities. The electromagnetic fields of the hadrons, however, can also induce interactions at large impact parameters where the strong interaction is not active (ultra-peripheral collisions, UPCs). In the 1930s it was found that the electromagnetic fields produced by the colliding charged particles can be treated as a beam of nearly-real photons emitted coherently [1]. This can give rise to photon–nucleus and photon–photon interactions.

The large Pb+Pb dataset collected by the ATLAS experiment [2] during LHC Run 3 (2023–2024) allows the precise study of various photon-induced interaction processes.

2 Measurement of coherent exclusive J/ψ production in Pb+Pb UPC

Hard-scattering processes in photonuclear interactions provide a novel method for probing nuclear parton distributions in a kinematic region not easily accessible to other measurements. In particular, exclusive diffractive photoproduction of heavy vector mesons (for example, the

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J/ψ meson) is a well-known process that offers unique access to the spatial and momentum structure of the nucleon and nucleus.

The measurement of exclusive $J/\psi \rightarrow \mu^+\mu^-$ photoproduction cross sections in Pb+Pb UPC at $\sqrt{s_{NN}} = 5.36$ TeV, using $76.5 \mu\text{b}^{-1}$ of data recorded in 2023, is performed by ATLAS [3]. Exclusive J/ψ candidates were selected with a dedicated track-sensitive trigger based on the ATLAS transition radiation detector [4]. Although the trigger is sensitive to both leptonic decay modes ($\mu^+\mu^-$ and e^+e^-), the measurement is performed only for the dimuon decay channel. Such low-momentum muons (from the $J/\psi \rightarrow \mu^+\mu^-$ decay) are expected to lose all of their energy in the ATLAS calorimeter material before reaching the muon detectors. As a result, no specific muon identification criteria are applied. Instead, the analysis relies on the reconstruction of dimuon invariant mass for a pair of opposite-sign charged particles that are assumed to be muons. After removal of all known backgrounds, the J/ψ cross-sections are measured differentially as a function of rapidity within $|y| < 2.5$.

The measured differential cross sections are shown in Fig. 1. Measured cross section values are compared with predictions from STARlight [5] and two calculations based on the color glass condensate (CGC) approach [6]. Of the calculations shown, the CGC-based model including the additional fluctuations is found to provide the best description of the data. In order to compare this measurement with previous measurements from the ALICE, CMS and LHCb collaborations at 5.02 TeV [7–10], the measured cross sections are extrapolated from 5.36 TeV to 5.02 TeV. The extrapolation factor is estimated using STARlight and is found to reduce the cross sections by 4-5%, depending on the rapidity. It is observed that while the extrapolated measurement matches quite well previously measured values at forward rapidities ($1.5 < y < 2.5$), the extrapolated results at mid-rapidity ($0 < y < 1$) differ significantly from the existing ALICE measurements. A significant difference between the extrapolated ATLAS measurement and the previous ALICE result may result from the production of additional particle pairs accompanying the produced J/ψ meson, which are rejected by selections on the ALICE forward counters [8]. Such example pairs have been recently measured in ATLAS, as described below.

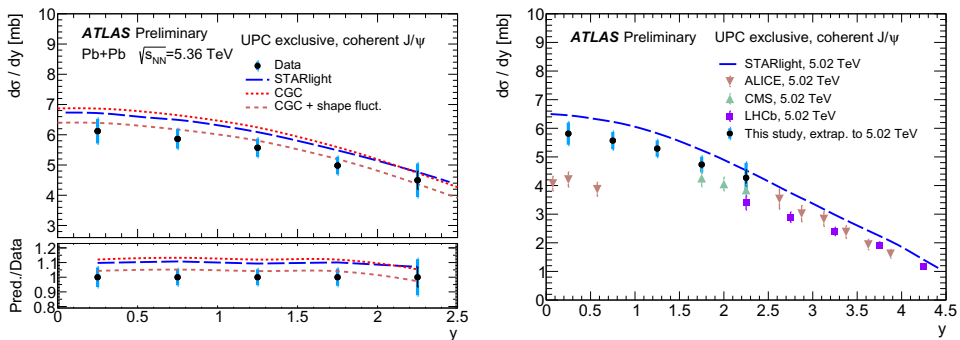


Figure 1. Measured differential cross section for coherent exclusive J/ψ meson production in Pb+Pb UPC at 5.36 TeV as a function of J/ψ rapidity [3]. Data (points) are compared with several model predictions: STARlight 2.0, and two versions of a color glass condensate (CGC) model (left). Measured differential cross section for coherent J/ψ meson production in Pb+Pb UPC at 5.02 TeV as a function of J/ψ rapidity (right). The plot displays the previous results from the ALICE, CMS and LHCb experiments, together with the result of this analysis extrapolated to 5.02 TeV.

3 Measurement of coincident processes in Pb+Pb UPC

The high photon flux of quasi-real photons also enables the occurrence of multiple photon-induced processes in a single collision. The first measurement of the coincident production of $\gamma\gamma \rightarrow \mu^+\mu^-$ and $\gamma + A \rightarrow \rho^0 + A$ in UPC Pb+Pb collisions with the ATLAS detector [11] is presented. The measurements are performed using data recorded at a centre-of-mass energy of 5.02 TeV and 5.36 TeV. Events are tagged by the presence of a $\gamma\gamma \rightarrow \mu^+\mu^-$ process with two identified muons. In these tagged events, those with two additional tracks are used to identify ρ^0 candidates. Template fits to the pair mass of the ρ^0 candidates are used to estimate the background contamination in these tagged events. The coincidence rates are measured in the fiducial acceptance of the ATLAS detector, namely for $|\eta| < 2.5$ and $p_T > 100$ MeV for the pions from the ρ^0 decay.

The rate of coincident ρ^0 production relative to exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$ process is measured differentially, as shown in Fig. 2, in intervals of forward event activity, quantified by the Zero Degree Calorimeters, ZDC [12]. The observed trend can be understood as resulting from selecting a smaller impact parameter with an increasing number of neutrons implying an increase in the probability for the coincidence. Correlations between the dimuon kinematic properties, such as its mass, and the coincident ρ^0 meson production rate, are also presented. For the inclusive ZDC and $\gamma\gamma \rightarrow \mu^+\mu^-$ interval, the relative rate for the coincident ρ^0 production is found to be $(9.3 \pm 0.4(\text{stat.}) \pm 0.2(\text{syst.})) \times 10^{-3}$. These measurements confirm the presence of multi photon-induced processes in UPC collisions, and can provide new insight into the impact parameter dependence of photon-induced vector meson production.

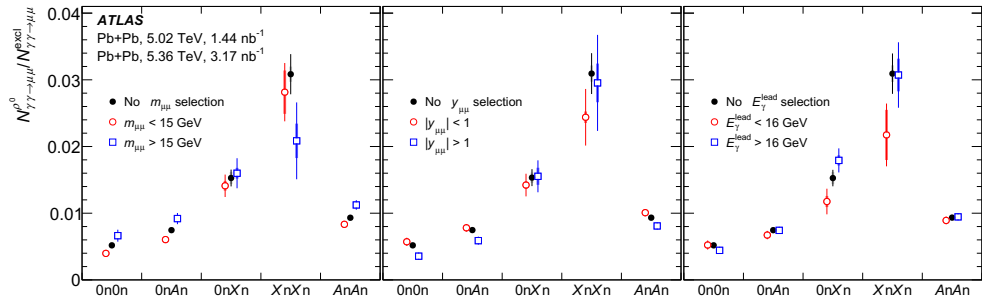


Figure 2. The ratio of the coincident ρ^0 production in $\gamma\gamma \rightarrow \mu^+\mu^-$ events to the number of exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$ events for different ZDC selections [11]. The left, centre and right panels compare different dimuon invariant mass, dimuon rapidity and energy of the leading photon intervals, respectively.

4 Conclusions

The ATLAS experiment has presented new measurements of photon-induced processes in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}} = 5.36$ TeV. A high-statistics sample of coherent J/ψ photoproduction was recorded using a novel track-sensitive trigger, enabling the most precise measurement of its rapidity-dependent cross-section over the widest range at the LHC. The results are best described by color glass condensate models including spatial fluctuations, and show notable differences from previous ALICE results at mid-rapidity, potentially due to differing event selection criteria. Additionally, ATLAS has provided the first measurement of coincident photon-induced processes, confirming the occurrence of multiple interactions in a single UPC event. These findings enhance our understanding of nuclear

structure, photonuclear interactions, and impact parameter dependence in high-energy heavy-ion collisions.

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References

- [1] E. J. Williams, Nature of the high-energy particles of penetrating radiation and status of ionization and radiation formulae, *Phys. Rev.* **45** (1934), 729-730, <https://doi.org/10.1103/PhysRev.45.729>.
- [2] ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, *JINST* **3** (2008), S08003, <https://doi.org/10.1088/1748-0221/3/08/S08003>.
- [3] ATLAS Collaboration, Measurement of coherent exclusive $J/\psi \rightarrow \mu^+\mu^-$ production in ultraperipheral Pb+Pb collisions at $\sqrt{s_{NN}} = 5.36$ TeV with the ATLAS detector, ATLAS-CONF-2025-003, <https://cds.cern.ch/record/2929557/>.
- [4] P. Rybczynski, Performance of the ATLAS L1 Transition Radiation Tracker Trigger in Heavy-ion Collisions at the LHC, *Acta Phys. Pol. B Proc. Suppl.* **17** (2024) 5-A34, <https://doi.org/10.5506/APhysPolBSupp.17.5-A34>.
- [5] S. R. Klein et al., STARlight: A Monte Carlo simulation program for ultra-peripheral collisions of relativistic ions, *Comput. Phys. Commun.* **212** (2017) 258, <https://doi.org/10.1016/j.cpc.2016.10.016>.
- [6] H. Mantysaari, F. Salazar and B. Schenke, Nuclear geometry at high energy from exclusive vector meson production, *Phys. Rev. D* **106** (2022) 7, 074019, <https://doi.org/10.1103/PhysRevD.106.074019>.
- [7] ALICE Collaboration, Coherent J/ψ photoproduction at forward rapidity in ultraperipheral Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *Phys. Lett. B* **798** (2019) 134926, <https://doi.org/10.1016/j.physletb.2019.134926>.
- [8] ALICE Collaboration, Coherent J/ψ and ψ' photoproduction at midrapidity in ultraperipheral Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *Eur. Phys. J. C* **81** (2021) 8, 712, <https://doi.org/10.1140/epjc/s10052-021-09437-6>.
- [9] CMS Collaboration, Probing small Bjorken-x nuclear gluonic structure via coherent J/ψ photoproduction in ultraperipheral PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *Phys. Rev. Lett.* **131** (2023) 262301, <https://doi.org/10.1103/PhysRevLett.131.262301>.
- [10] LHCb Collaboration, Study of exclusive photoproduction of charmonium in ultra-peripheral lead-lead collisions, *JHEP* **06** (2023) 146, [https://doi.org/10.1007/JHEP06\(2023\)146](https://doi.org/10.1007/JHEP06(2023)146).
- [11] ATLAS Collaboration, Measurement of coincident photon-initiated processes in ultraperipheral Pb+Pb collisions with the ATLAS detector, arXiv:2504.07795.
- [12] S. White, The ATLAS zero degree calorimeter, *Nucl. Instrum. Meth. A* **617** (2010) 126, <https://doi.org/10.1016/j.nima.2009.09.120>.