PROCEEDINGS OF SCIENCE

Exclusive dilepton production in ultraperipheral Pb+Pb collisions in ATLAS*

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Relativistic heavy-ion beams at the LHC are accompanied by a large flux of equivalent photons, leading to multiple photon-induced processes. One of the most basic processes, originating from the photon-photon interactions, is the exclusive production of lepton pairs. This report presents new measurements of exclusive dielectron and dimuon production performed by the ATLAS Collaboration, using the data from ultraperipheral lead-lead collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The differential cross-sections as a function of several dilepton variables were measured in the inclusive sample, and for dielectron pairs also under the requirement of no activity in the forward direction. The results are compared with predictions from STARlight and SuperChic MC generators.

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1. Introduction

The collisions of ultrarelativistic heavy ions provide a mean to study the strong, weak and electromagnetic (EM) interactions that can occur simultaneously due to multiple nucleon-nucleon interactions. However, the EM interactions become dominant in so-called ultraperipheral collisions (UPC), when two interacting nuclei pass each other at the distance larger than twice the ion radius. The large EM fields associated to ultrarelativistic ions can be considered as coherently produced fluxes of photons, according to equivalent photon approximation [1, 2]. The dilepton photoproduction, $\gamma\gamma \to \ell^+\ell^-$, where $\ell^\pm$ stands for $e^\pm$ or $\mu^\pm$, is one of the fundamental processes in UPC and therefore can provide a reference for other processes. Given the large theoretical uncertainty of photon flux modelling, its precise measurement with exclusive dilepton pairs can improve predictions for other photoproduction processes. The results for the $\gamma\gamma \to \mu^+\mu^-$ process using 2015 lead-lead (Pb+Pb) data and for the $\gamma\gamma \to e^+e^-$ process using 2018 Pb+Pb data collected by the ATLAS experiment [3] at the LHC are discussed in following sections.

2. Exclusive dimuon production

Exclusive dimuon production is measured by the ATLAS experiment based on 0.48 nb^{-1} of Pb+Pb collision data at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV collected in 2015. The final-state muons have low transverse momentum, p_{T}, and are produced back-to-back in the azimuthal angle. It is reflected in the definition of the fiducial region of the measurement. Only events with two opposite-charge muons having $p_{\mathrm{T}} > 4$ GeV and $|\eta| < 2.4$ are selected. These requirements are determined by the threshold and acceptance of the muon trigger. Additionally, the dimuon mass, $m_{\mu\mu}$, has to be larger than 10 GeV. Finally, p_{T} of the dimuon system, $p_{\mathrm{T}}^{\mu\mu}$, has to be below 2 GeV, what reflects a back-to-back topology. After the full event selection, the irreducible background from events with nucleus dissociation remains. These background events occur, when one(both) of the photons is emitted incoherently and the incoming nucleus dissociates (single dissociation). The double dissociation, when both nuclei break up, is also possible.

The selected events are compared with Monte Carlo predictions of the signal process using STARlight [4] generator (for the LO) or STARlight interfaced to Pythia8 [5] generator to account for final-state radiation, FSR. The dissociative background is simulated with LPair [6] generator for pp collisions and normalised in the acoplanarity ($\alpha = 1 - |\Delta\phi/\pi|$) distribution using data.

Selected events can be divided into 3 categories depending on their activity in the forward direction. In the ATLAS detector, this is described with the number of neutrons detected in the Zero-Degree Calorimeters (ZDC): 0n0n class includes events with no neutrons on both sides of the ZDC, Xn0n events have neutrons detected on one side, while XnXn class covers events with neutron signal on both sides of the ZDC. Fractions of dissociative background differ in each ZDC class. Additionally, observed ZDC fractions are affected by the presence of EM pileup and a dedicated correction procedure is applied for this effect.

Measured fiducial cross-section for the exclusive dimuon production is: $\sigma = 34.1 \pm 0.3(\text{stat.}) \pm 0.7(\text{syst.})\mu$b, which can be compared with the prediction from STARlight MC generator: 32.1 μb, and from STARlight+Pythia8: 30.8 μb. Differential cross-sections are measured in several dimuon variables in the inclusive sample: $m_{\mu\mu}$, absolute dimuon rapidity, $|y_{\mu\mu}|$ and scattering angle in the dimuon rest frame, $|\cos(\theta^*)|$ as presented in Figure 1. In general, a good agreement is found with STARlight, however some deviations are seen, especially at large $|y_{\mu\mu}|$ and small $|\cos(\theta^*)|$.

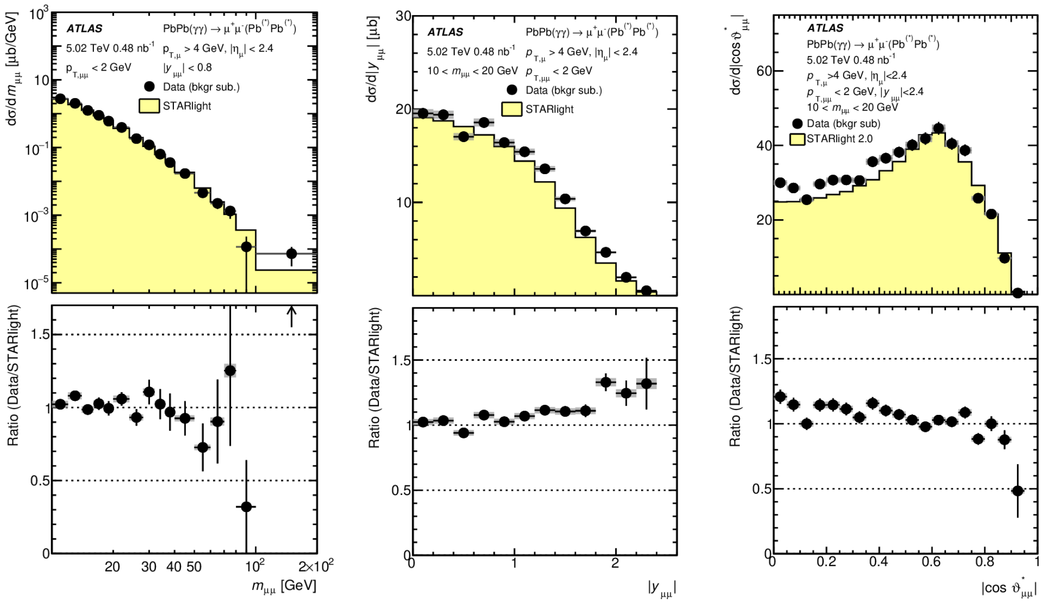

Figure 1: Differential cross-sections for exclusive dimuon production as a function of $m_{\mu\mu}$ (left), $|y_{\mu\mu}|$ (middle) and $|\cos(\theta^*)|$ (right) [7]. Data (points) are compared to STARlight predictions (histograms). The statistical uncertainties on the data are shown as vertical bars, while the systematic uncertainties are represented by the shaded bands. The bottom panels present the data-to-simulation ratio.

3. Exclusive dielectron production

Exclusive dielectron production is measured by the ATLAS experiment based on 1.72 nb^{-1} of Pb+Pb collision data at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV collected in 2018. The event characteristics are similar to the exclusive dimuon production. In the final state two low-p_{T} opposite-sign electrons are observed in the back-to-back configuration. The fiducial region is broader than in the dimuon measurement and is defined by requirements on electron p_{T} to be above 2.5 GeV, $|\eta| < 2.5$, dilectron mass, m_{ee}, to be above 5 GeV and p_{T} of the dielectron system, p_{T}^{ee}, has to be below 2 GeV. A background contribution from dissociative production is estimated based on the SuperChic [8] simulation for pp collisions and normalised in the α distribution using data. The background template fitting is performed separately in three ZDC categories, since dissociative background fractions vary in each ZDC class. Additionally, smaller contributions from Υ decays to electrons and exclusive $\tau^+\tau^-$ production are estimated using dedicated MC samples.

Fiducial cross-section for exclusive dielectron production is measured to be: $\sigma = 215 \pm 1(\mathrm{stat.})^{+23}_{-20}(\mathrm{syst.}) \pm 4(\mathrm{lumi.})\mu$b, and is compared to predictions from STARlight: 196.9 μb, and SuperChic: 235.1 μb. Differential cross-sections are measured in several variables: m_{ee}, absolute dielectron rapidity, $|y_{ee}|$, average electron p_{T}, $\langle p_{\mathrm{T}}\rangle$ and $|\cos(\theta^*)|$ both in the inclusive sample and in the 0n0n class. Results, presented in Figure 2 for differential cross-section as a function of m_{ee} and $|y_{ee}|$ in inclusive sample and as a function of $\langle p_{\mathrm{T}}\rangle$ and $|\cos(\theta^*)|$ in the 0n0n class, are compared to predictions from STARlight and SuperChic MC generators. A data to STARlight agreement is consistent between the inclusive and 0n0n class, and between dimuons and dielectrons. Predictions from STARlight and SuperChic differ mainly in normalisation, however SuperChic describes the rapidity dependence better than STARlight.

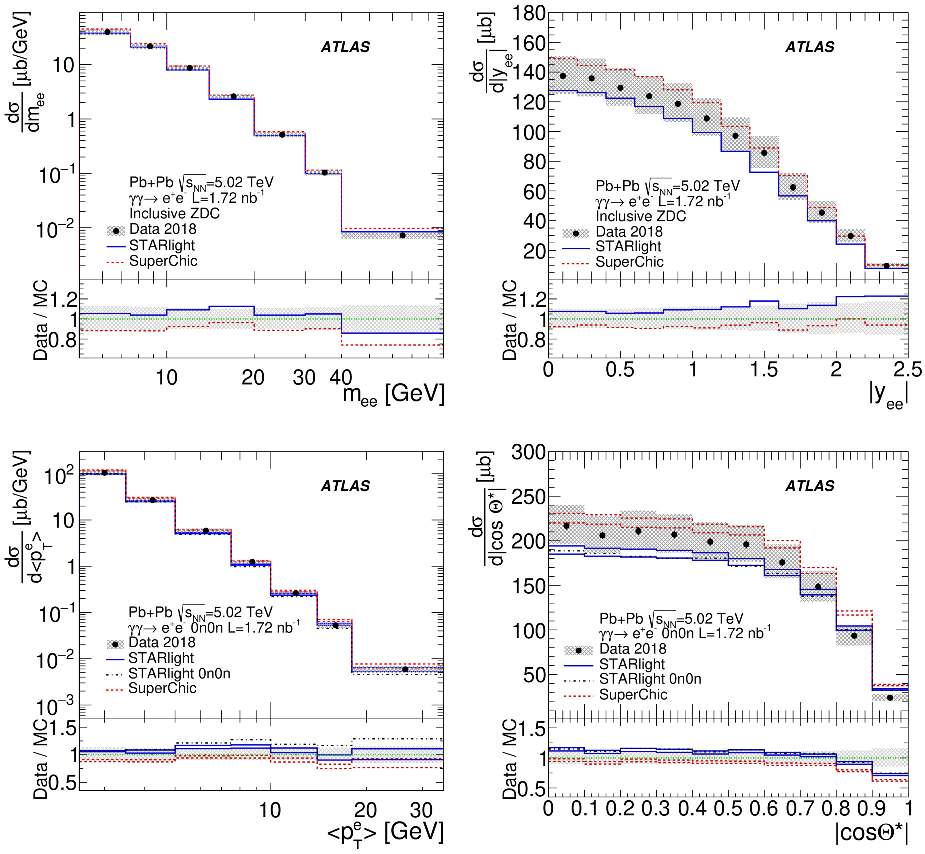

Figure 2: Differential cross-sections for exclusive dielectron production for the inclusive sample: $m_{\mu\mu}$ (top left), $|y_{\mu\mu}|$ (top right) and for the 0n0n class: $\langle p_{\mathrm{T}} \rangle$ (bottom left) and $|\cos(\theta^*)|$ (bottom right) [9]. Data (points) are compared to MC predictions (histograms). The statistical uncertainties on the data are shown as vertical bars, while the systematic uncertainties are represented by the shaded bands. The bottom panels present the data-to-simulation ratio.

4. Conclusions

The exclusive e^+e^- and $\mu^+\mu^-$ productions are measured by the ATLAS experiment at the LHC using ultraperipheral Pb+Pb collision data at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The measured fiducial cross-sections are compared with theory predictions, showing discrepancies at the level of several percent with STARlight underestimating and SuperChic overestimating measured cross-sections. The results of the differential cross-sections provide a reference for other photoproduction processes and for various theoretical approaches to model the photon fluxes.

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