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Energy dependence of exclusive J/ψ photoproduction in p–Pb interactions at ALICE

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The electromagnetic field of a fast moving lead ion at the LHC is an intense source of quasi-real photons. This makes it possible to study J/ψ exclusive photoproduction off protons in p–Pb collisions, which is sensitive to the gluon content of the target. Measuring the rapidity of the produced vector meson one can compute the centre-of-mass energy $W_{\gamma\mathrm{p}}$ of the photon–proton scattering.

Using LHC Run 1 data, ALICE has measured the cross section for exclusive J/ψ photoproduction in a wide range of scattering angles. In this contribution, we present, for the first time, preliminary measurements of the cross section using the central-barrel detectors of ALICE, as well as cross sections for a novel topology where one of the muons from the decay of the J/ψ is detected with the forward-muon spectrometer and the other muon with the central-barrel detectors. These measurements allow us to study the evolution of the cross section with $W_{\gamma\mathrm{p}}$ in the range from 20 GeV to 700 GeV. The measurements are compared to the newest theoretical models.

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1. The LγHC

The electromagnetic field of a charged particle accelerated at the LHC to relativistic velocities can be interpreted as a flux of quasi-real photons. The intensity of the flux is proportional to the square of the electric charge, while the photon virtuality is restricted to be less than some 30 MeV by the fact that the photons are emitted coherently. The energy of these photons in the laboratory frame is given by the boost of the emitting particle. These properties make the lead beams of the LHC a copious source of high-energy quasi-real photons and transforms the LHC into a photon–hadron collider.

When particles collide at impact parameters larger than the sum of their radii, the strong force is suppressed and only the electromagnetic interaction remains. These cases are called ultra-peripheral collisions (UPC) and have been intensively studied at the LHC [1].

The exclusive photoproduction of J/ψ is a particularly interesting process, because it is sensitive to the gluon content of the proton (see e.g. [2]). In ALICE the J/ψ is measured through its leptonic decay channels. ALICE uses different sets of detectors to measured the leptons in a wide rapidity range. The J/ψ rapidity, measured w.r.t. the proton direction, is related to the photon–proton centre-of-mass energy ($W_{\gamma\mathrm{p}}$). Measurements at different rapidities allow us then to study the energy evolution of the gluon content of the proton.

Here, we present for the first time the preliminary measurement of exclusive J/ψ photoproduction off protons measured by ALICE in proton–lead (p–Pb) UPC at the LHC in two new configurations. These results, along with those published in [3], allow ALICE to explore the energy evolution of this process from 20 GeV to 700 GeV in $W_{\gamma\mathrm{p}}$.

2. The ALICE detector

The ALICE detector is described in [4]. Its performance is reported in [5]. The detector consists of two main sections, a central barrel and a muon spectrometer in the forward direction.

The central barrel consists in a series of concentric detectors immersed in a uniform magnetic field of 0.5 T along the beam line. The inner tracking system (ITS) is closest to the beam line. It has six layers of silicon detectors. From the inside to the outside there are two layers of silicon pixels (SPD), two layers of silicon drift and two layers of silicon strip detectors. The ITS is surrounded by the time-projection chamber (TPC), which is the main tracking device of ALICE. It is a cylindrical gaseous detector with a diameter of 500 cm and a length of 510 cm which can provide up to 159 points for tracking, as well as for energy-loss measurements resulting in good particle-identification (PID) capabilities. The time-of-flight detector (TOF), which surrounds the TPC, is composed of multi-gap resistive plate chambers, which provide an intrinsic time resolution of 80 ps.

The muon spectrometer consists of a tracking and a triggering system. One tracking station is in a field with a 3 Tm field integral, which is produced by a dipole magnet. A ten interaction-length conical front absorber filters out primary hadrons. Muons are measured in five tracking stations, each one made of two planes of Cathode Pad Chambers. An iron wall is placed after the tracking stations and in front of the muon trigger system, which consists of two stations of Resistive Plate Chambers. This system can trigger on single or dimuon signatures with a programable threshold on the transverse momentum of the tracks.

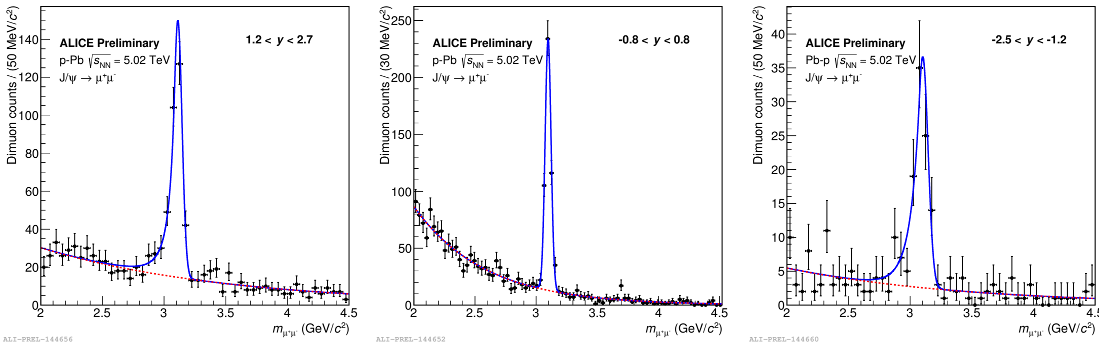

Figure 1: Invariant mass distribution of dimuon candidates for the semi-forward (left), central (middle) and semi-backward (right) configurations. Data are shown as markers, the statistical uncertainty is depicted as bars. The blue line is a fit to a Crystal Ball plus exponential model. The contribution from the exponential part is shown with a red dotted line.

In addition, another two detector systems are used in the presented analysis. The V0 consists of two arrays of 32 scintillator tiles each, covering the ranges $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C). The time resolution of each array is ≤ 1 ns. Two zero-degree calorimeters (ZDC) are located at ± 112.5 m from the interaction point. They are used to detect neutrons produced in the very forward regions.

3. The analysis procedure

The data were recorded in 2013 during p–Pb collisions at a centre-of-mass energy per nucleon pair $\sqrt{s_{\rm NN}} = 5.02$ TeV. The LHC provided collisions in two configurations: with the proton beam travelling in the direction of the muon spectrometer and with the proton travelling in the opposite direction. These configurations are denoted in what follows as p–Pb and Pb–p, respectively.

The general strategy is to measure the decay products of the J/ψ and to make sure that there is nothing else in the detector by vetoing activity in a large pseudorapidity range using the SPD, V0 and ZDC detectors. The luminosity is determined using reference cross sections measured in van der Meer scans [6].

The J/ψ was measured at mid-rapidity separately in the e^+e^- and in the $\mu^+\mu^-$ decay channels, which were distinguished thanks to the PID capabilities of the TPC. The cross sections determined in both channels agree within their uncorrelated uncertainties. Agreement was also found in the analyses of the p–Pb and Pb–p data samples. The J/ψ was also measured at semi-forward (semi-backward) rapidities in p–Pb (Pb–p) collisions by measuring one of the muons in the central barrel and the other in the muon spectrometer. This is the first time that such a configuration has been used in ALICE. Figure 1 shows the invaraint mass distributions for the dimuon candidates in three rapidity ranges. The data are well described by a Crystal Ball parameterisation of the J/ψ invariant mass plus an exponential distribution for the $\gamma\gamma \to \mu^+\mu^-$ process. The signal is clearly seen above a small background.

The signal was extracted by studying the distribution of transverse momentum of the dilepton candidates in the J/ψ mass region. These distributions have contributions from the signal, dilepton

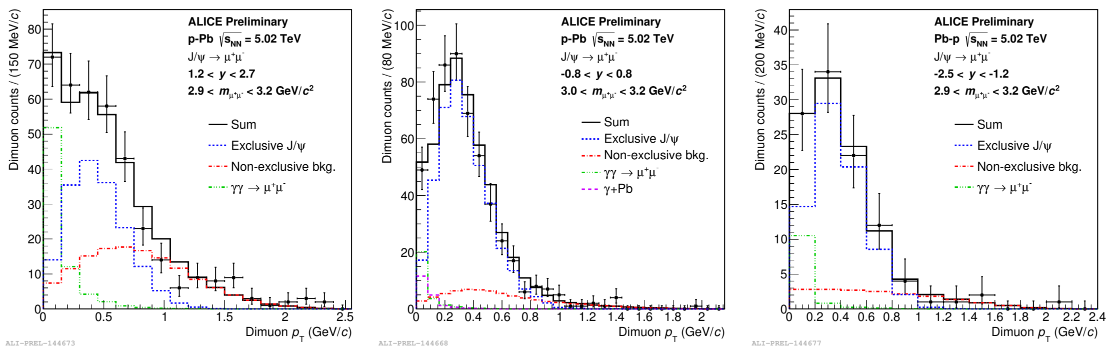

Figure 2: Transverse momentum distribution of dimuon candidates around the J/ψ mass for the semi-forward (left), central (middle) and semi-backward (right) configurations. Data and its statistical uncertainty are shown by markers with bars. The sum of all different templates is shown by the black histogram. The different contributions are explained in the legends inside the figures.

production in photon–photon collisions, and dissociative production (where the proton is excited and decays into a low mass state in the forward direction). There is also a small contribution from coherent production of J/ψ off lead, which was constrained by data [7, 8]. Figure 2 shows the transverse momentum distributions in three rapidity ranges. The data are well described by the sum of all the templates (black histogram) from the different contributions. The template for the non-exclusive background is obtained directly from data showing activity in the direction of the outgoing proton and large rapidity gaps. The templates for signal and for dilepton production are obtained from MC simulations performed with Starlight [9]. The width of the distribution for the signal MC template was varied with rapidity to reflect the behaviour seen in data. We used 4 GeV^{-2}, 5 GeV^{-2} and 5.6 GeV^{-2} in the semi-forward, central and semi-backward samples, respectively.

4. Results

Figure 3 shows the cross section for the exclusive photoproduction of J/ψ off protons as a function of $W_{\gamma p}$. The preliminary measurements presented here are shown with red markers. Previous measurements from ALICE [3] are depicted with black markers. The measurements by ALICE cover a $W_{\gamma p}$ range from 20 GeV to 700 GeV. A model of a power-law dependence of the cross section with energy correctly describes ALICE data; the fit yields an exponent of 0.70 ± 0.05. HERA data [10, 11] agrees with the measurements by ALICE in the region where the corresponding energy ranges overlap ($W_{\gamma p} < 300$ GeV). The measurements also agree with the model dependent solutions found by LHCb in pp collisions [12].

Figure 3 also shows the comparison of the measurements with different models. Starlight [9] is based on a Regge-motivated fit to HERA and fixed target data. JMRT NLO [13] is inspired by the DGLAP formalism and includes some of the contributions considered most important at NLO. The BFKL calculation [14] uses an initial transverse momentum profile of the proton impact factor extracted from BFKL fits to inclusive HERA data and BFKL evolution to describe the energy dependence. The Color-Glass-Condensate (CGC) based calculation [15] includes saturation effects

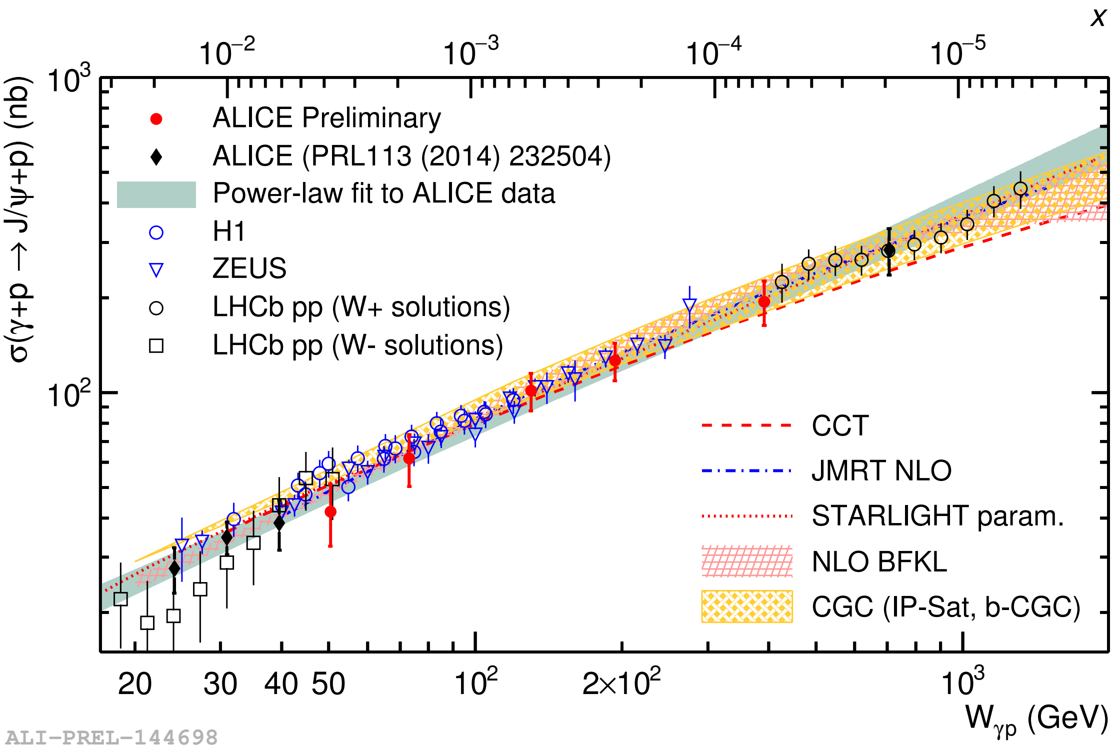

Figure 3: Energy dependence of the cross section for exclusive photoproduction of J/ψ off protons as measured by ALICE (preliminary results in red, published results in black) and compared to HERA data (blue markers) and the LHCb model dependent solutions extracted from measurements in pp collisions (black empty markers). A power-law fit to ALICE data is shown with a celadon green band. Predictions of different theoretical calculations (see text for details) are also shown.

incorporated according to the IP-Sat or b-CGC prescriptions. Finally, the CCT prediction [16] is based on the colour dipole approach; it incorporates both saturation and the energy dependence of geometrical fluctuations of the proton structure in the impact parameter plane. All presented model calculations are compatible with data within the current experimental uncertainties.

5. Summary and outlook

We have presented new preliminary results on the cross section for exclusive photoproduction of J/ψ off protons using two topologies: both leptons from the decay of the J/ψ are measured in the central barrel of ALICE or one of them is measured there and the other is measured with the muon spectrometer. This is the first time that this latter topology has been used in ALICE. These measurements, along with those published in [3] cover a $W_{\gamma p}$ range from 20 GeV to 700 GeV.

The measurements were performed using data taken in 2013, during the so-called LHC Run 1. New p–Pb data at higher energy, $\sqrt{s_{\rm NN}} = 8.16$ TeV, was delivered in 2016 by the LHC in the so called Run 2. It is interesting to remark that according to Fig. 3 at the highest energies the predictions of the models start to diverge. Measurements with Run 2 data are expected to have smaller statistical uncertainty and reach energies up to $W_{\gamma p} \sim 1.5$ TeV and thus could further constrain theoretical models.

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