PROCEEDINGS OF SCIENCE

Vector meson photoproduction in ultra-peripheral p-Pb collisions measured using the ALICE detector

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The strong electromagnetic fields generated by ultra-relativistic heavy ions offer the possibility to study gamma-gamma, gamma-nucleus and gamma-proton processes at the LHC in ultra-peripheral Pb-Pb and p-Pb collisions (UPC). As exclusive photoproduction of vector mesons is sensitive to the gluon distribution of the interacting target it allows one to study saturation and shadowing phenomena.

Here we report on the ALICE measurement of vector meson photoproduction in p-Pb UPC at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. In these asymmetric collisions, the photon is most likely coming from the Pb nucleus. As a result, the center-of-mass energy of the photon-proton system is constrained by the rapidity of the vector meson which is measured in the laboratory frame with respect to the proton beam direction. We present the results on vector meson photoproduction in several intervals of the photon-proton center-of-mass energy.

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1. Introduction

Ultra-peripheral collisions (UPC) are collisions of charged particles in which the interactions are mediated mostly by electromagnetic forces. The impact parameter of such collisions is larger than the sum of the radii of the interacting objects. The electromagnetic field in a UPC can be described as a flux of virtual photons, whose intensity is proportional to the square of the electric charge of the source object. In UPC, we may observe interactions of photons on hadronic targets (protons or lead nuclei), or mutual photon interactions. Interactions of photons on hadronic targets are sensitive to saturation phenomena and nuclear gluon shadowing. Reviews of physics of UPC are given in [1, 2, 3].

2. Photoproduction of J/ψ in photon-proton interactions

The ALICE collaboration has measured exclusive photoproduction of J/ψ off protons in proton-lead collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV [4]. As the flux of the photons is proportional to the square of the electric charge, the source of photons is most likely (at about 95%) the lead ion. The diagram for the photoproduction is shown in Figure 1, along with the kinematic variables characterizing the interaction.

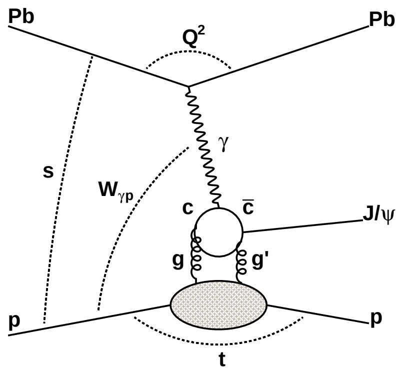

Figure 1: Exclusive J/ψ photoproduction in p-Pb interactions.

Of particular interest is the measurement of the photon-proton cross section $\sigma(\gamma+{\rm p} \to J/\psi+{\rm p})$ as a function of the photon-proton center-of-mass energy $W_{\gamma{\rm p}}$. Because the source of the photons is known, the kinematics for the reaction is constrained:

$$W^2_{\gamma{\rm p}} = 2E_p M_{J/\psi} \exp(-y), \tag{2.1}$$

where y is the rapidity of the J/ψ measured along the direction of the proton beam, E_p is the energy of the proton beam and $M_{J/\psi}$ is the mass of the J/ψ. During the p-Pb run, the LHC used both beam directions, therefore, for the J/ψ measured outside mid-rapidity ($y \neq 0$), the energy $W_{\gamma{\rm p}}$ is lower when $y > 0$ (denoted as p-Pb), and higher when $y < 0$ (denoted as Pb-p).

Exclusive photoproduction of J/ψ off protons at high energies can be modeled in perturbative Quantum Chromodynamics (pQCD) by an exchange of two gluons [5], like it is shown in Figure 1, or using the approach based on the color dipole formalism [6]. At leading order (LO) pQCD, the cross section is proportional to the square of the gluon distribution $xg(x,Q^2)$ at the scale $Q^2 \approx M^2_{J/\psi}/4$ where the momentum fraction x of the probed gluons is given as $x = (M_{J/\psi}/W_{\gamma\mathrm{p}})^2$.

As we can see, interactions at higher energies $W_{\gamma\mathrm{p}}$ probe gluons in the proton at smaller x. Previous measurements of the cross section have been done at HERA [7, 8] in an interval of energies $20 < W_{\gamma\mathrm{p}} < 305$ GeV. The cross section was described by a power law fit as $\sigma \propto W^{\delta}_{\gamma p}$, indicating a steady growth of the cross section with increasing energy, which is compatible with increasing density of the gluons. However, it is expected that the gluon density saturates at small Bjorken-x. Effect of the saturation should suppress the growth of the cross section above a certain energy. The experimental task is to find the $W_{\gamma\mathrm{p}}$ for onset of saturation.

3. The ALICE experiment at the LHC

The ALICE experiment [9, 10] provides tracking of particles in overall central acceptance $|\eta| < 0.9$ with the Inner Tracking System (ITS) consisting of 6 layers of semiconductor position sensitive detectors, gaseous Time Projection Chamber (TPC) and the time-of-flight detector (TOF). The central detectors cover the full azimuthal angle. Tracking of muons in the forward direction is performed by the forward muon spectrometer at $-4.0 < \eta < -2.5$.

For triggering and imposing exclusivity requirements in the UPC analyses there are the forward scintillator detectors V0A and V0C at $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$ respectively and the Zero Degree Calorimeters (ZDC) at $|\eta| > 8.8$ for detection of very forward neutrons.

4. Measurements of exclusive $J/\psi \to l^+l^-$ in p-Pb UPC with ALICE

As the J/ψ is the only produced particle, we expect only products of the decays $J/\psi \to e^+e^-$ or $J/\psi \to \mu^+\mu^-$ in the detector. The selection criteria are based on requiring just two tracks in an otherwise empty detector. Different intervals of laboratory rapidity of the J/ψ, which can be reached by combining of the forward and central tracking, are shown in Figure 2.

According to Eq. (2.1), lower energies $W_{\gamma\mathrm{p}}$ are probed in the forward rapidities and high energies correspond to rotated beams in the LHC, indicated as backward intervals in Figure 2. Dimuon decays of the J/ψ are measured in the forward and semi-forward intervals, whereas at mid-rapidity it is possible to measure both dielectron and dimuon decays. The cross section measurement will be shown for forward (and backward) rapidities, the results from the semi-forward and mid-rapidity intervals are in the final stages of paper preparation.

The signal of exclusive J/ψ photoproduction is extracted from data by fitting the p_T distribution of J/ψ candidates using the templates for exclusive J/ψ in photon-proton interactions, two-photon interactions $\gamma\gamma \to \mu^+\mu^-$ and coherent production of the J/ψ off the Pb-nuclei, which were obtained using the STARLIGHT MC [11]. The template for non-exclusive J/ψ and $\gamma\gamma \to \mu^+\mu^-$ was obtained from data using special selection criteria.

5. ALICE cross section for exclusive J/ψ photoproduction off protons

Results of the measurement of the cross section are given in Figure 3. The forward interval in rapidity (p-Pb) has been divided into three bins, corresponding to three different mean energies

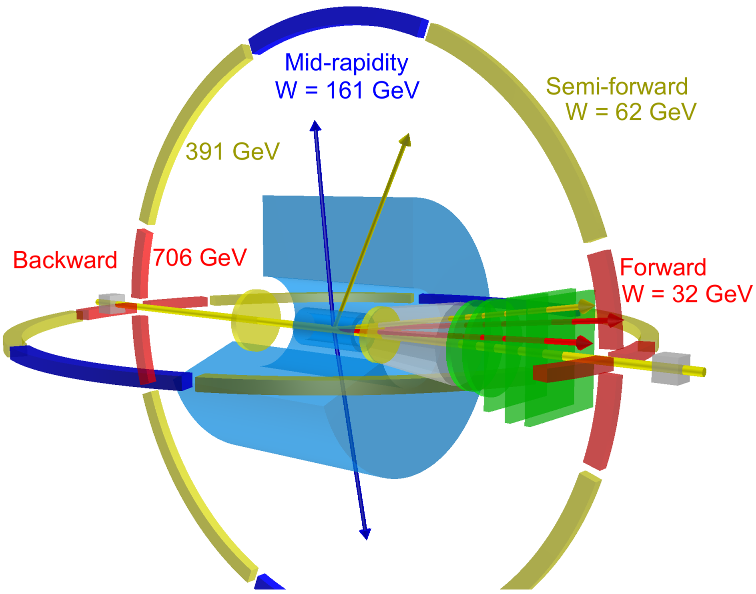

Figure 2: Measurement of leptonic decays of the J/ψ with the ALICE detector in several intervals of rapidity. In blue (red) the case where both leptons are in the central barrel (forward muon spectrometer). In gold where one lepton is measured in the central barrel and the other in the muon spectrometer.

$W_{\gamma p}$ at which the cross section is measured, while the highest energy is reached in the backward interval (Pb-p). Also the previous measurements from HERA are shown [7, 8]. The top energy reached by ALICE is about two times higher than what was achieved at HERA. A fit by power law $\sigma \propto W_{\gamma p}^{\delta}$ is made to ALICE data, giving $\delta_{\mathrm{ALICE}} = 0.68 \pm 0.06$, which is compatible with similar fits to HERA data, which provided $\delta_{\mathrm{H1}} = 0.67 \pm 0.03$ and $\delta_{\mathrm{ZEUS}} = 0.69 \pm 0.04$. The experimental results are compared to theoretical models based on pQCD [5] and the dipole approach [6], and to a parametrization of the previous data used in STARLIGHT [11].

6. New data from semi-forward and mid-rapidity intervals

Measurements in the remaining intervals in rapidity are currently in the final stages of paper preparation. These new data will cover the energy range by HERA and also will provide a new measurement beyond the energies reached at HERA. The invariant mass of dimuons reconstructed in semi-forward (p-Pb) and semi-backward (Pb-p) rapidities is shown in the upper two plots in Figure 4, dielectrons and dimuons at mid-rapidity are shown in the lower two plots in the same figure. In all cases we can see a clear signal of the J/ψ above the expected background from $\gamma\gamma \rightarrow e^+e^-$ or $\gamma\gamma \rightarrow \mu^+\mu^-$. A fit to each distribution is made using the Crystal Ball function [12] for the J/ψ and an exponential function for the background.

The range in energies $W_{\gamma p}$ probed in the semi-forward rapidity is $41 < W_{\gamma p} < 86$ GeV in p-Pb and $287 < W_{\gamma p} < 550$ GeV in Pb-p. At mid-rapidity, the range is $106 < W_{\gamma p} < 235$ GeV. It is the same for p-Pb and Pb-p because of the symmetry around $y = 0$.

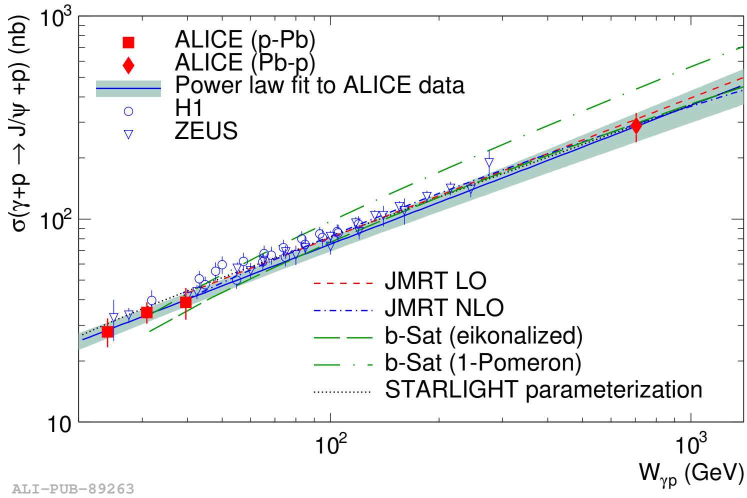

Figure 3: Exclusive J/ψ photoproduction cross section off protons [4].

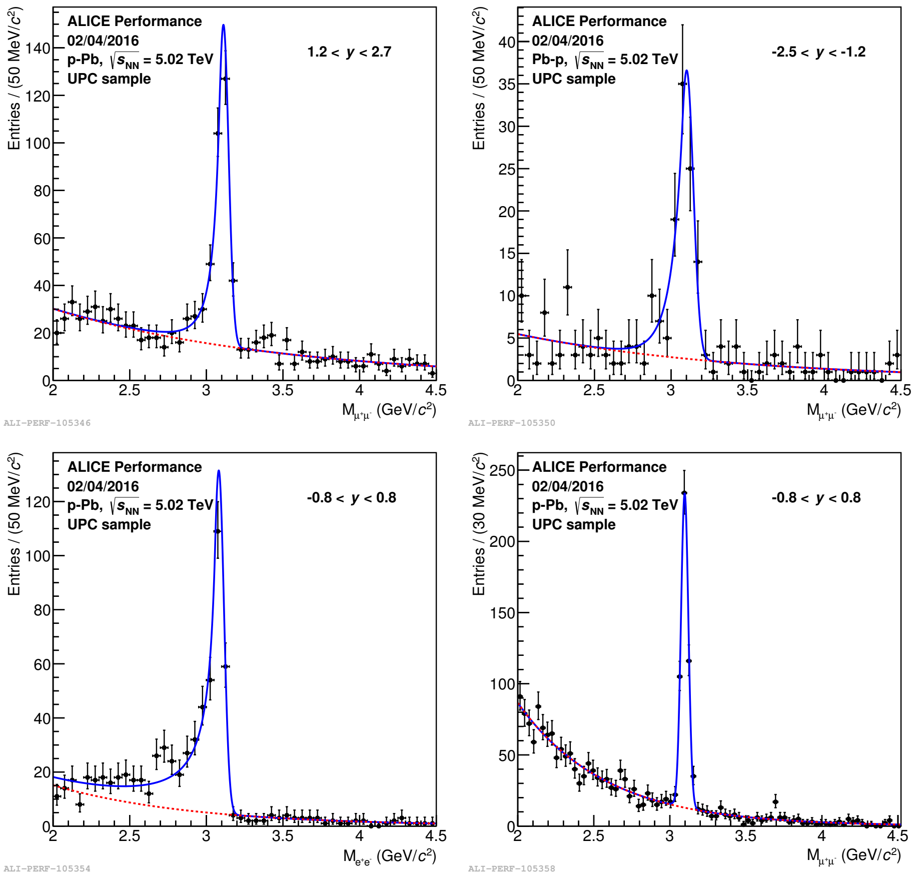

Figure 4: Reconstructed invariant mass at semi-forward rapidity and at mid-rapidity.

7. Conclusions

The ALICE experiment has measured exclusive J/ψ photoproduction off protons. Physics importance and the measurement have been described here, together with new data aimed for a new publication. At the currently available $W_{\gamma p}$ energies and within experimental precision we observe no change in gluon behavior from HERA to LHC energies.

By the end of this year, 2016, a new p-Pb run is planned for the LHC. For the foreseen collision energy of $\sqrt{s_{NN}} = 8$ TeV, the range in photon-proton energies is $30 \lesssim W_{\gamma p} \lesssim 1300$ GeV, almost two times higher than in Run 1. In addition, ALICE is equipped with new very forward scintillators covering $5.5 < |\eta| < 7.5$ which will provide a stronger veto against non-UPC events.

Acknowledgements

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