PROCEEDINGS OF SCIENCE

ALICE results on ultra-peripheral p-Pb and Pb-Pb collisions

PoS(DIS2015)060

Jaroslav Adam *for the ALICE collaboration* *
Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague
E-mail: jaroslav.adam@cern.ch

Ultra-relativistic heavy ions generate strong electromagnetic fields which 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). Exclusive photoproduction of vector mesons is sensitive to the gluon distribution of the interacting target (proton or nucleus). The reactions allow one to study saturation phenomena and nuclear gluon shadowing. Here we present results from the ALICE measurement of coherent photoproduction in Pb-Pb UPC at $\sqrt{s_{NN}} = 2.76$ TeV of J/ψ mesons at forward and central rapidity and ρ^0 and $\psi(2S)$ mesons at central rapidity. Furthermore, we also show our results on the J/ψ photoproduction in p-Pb UPC at $\sqrt{s_{NN}} = 5.02$ TeV in the forward and backward rapidities where the rapidity is measured in the laboratory frame with respect to the proton beam direction.

The XXIII International Workshop on Deep Inelastic Scattering and Related Subjects
April 27 - May 1, 2015
Southern Methodist University
Dallas, Texas 75275

*Speaker.

1. Introduction

The ultra-peripheral collision is a collision of lead ions or protons mediated only by photon-nucleus, photon-proton or photon-photon interactions. Such conditions occur when the ions or protons pass each other at a distance large enough to suppress the short-range strong interactions. If we imagine the ions as spheres of sharp boundary, the ultra-peripheral collision takes place when the impact parameter exceeds the sum of the nuclear radii. The electromagnetic field between the interacting objects is described as a flux of virtual photons where the intensity of the photons is proportional to the square of the electric charge.

Ultra-peripheral collisions of lead ions or lead ions and protons offer the possibility to measure photoproduction reactions of photons on protons, $\gamma\mathrm{p} \to \mathrm{J}/\psi\,\mathrm{p}$, or reactions of photons on lead nuclei, $\gamma\mathrm{Pb} \to \mathrm{J}/\psi\,\mathrm{Pb}$. Since the J/ψ is the only new particle emerging in the reaction, the photoproduction is exclusive. The cross section of exclusive photoproduction of the J/ψ meson can be described by means of LO pQCD, and depends on the square of the gluon distribution in the target [1]. Photoproduction on a nuclear target is coherent when the photon couples to the whole nucleus, while incoherent photoproduction occurs when the photon couples to a single nucleon. The measurement of such photoproduction cross sections is important in the study of saturation phenomena and nuclear gluon shadowing at low Bjorken-x. The most recent review is given in [2].

Prior to the LHC, measurements of photoproduction of J/ψ and ρ^0 in Au-Au UPC have been reported at RHIC [3, 4]. The photoproduction of J/ψ on protons has been measured at HERA [5, 6] in ep collisions and at the Tevatron using $\mathrm{p\bar{p}}$ collisions [7]. The LHCb experiment has measured exclusive J/ψ photoproduction in pp collisions [8] and the CMS experiment has published the preliminary results on coherent J/ψ photoproduction in Pb-Pb UPC [9].

The ALICE experiment has measured coherent J/ψ photoproduction at forward rapidity [10], coherent and incoherent J/ψ photoproduction at central rapidities [11], and coherent ρ^0 photoproduction [12] in Pb-Pb UPC. Exclusive J/ψ photoproduction off protons has been measured by the ALICE experiment in p-Pb UPC [13].

2. The ALICE experiment at the LHC

The ALICE experiment consists of the central tracking detectors with overall acceptance $|\eta| < 0.9$ and a forward muon spectrometer covering the pseudorapidity range $-4.0 < \eta < -2.5$. For triggering purposes and exclusivity selection in the UPC there are the forward scintillators VZERO-A and VZERO-C covering $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$ respectively, and Zero-Degree neutron and proton Calorimeters (ZDC) at $|\eta| < 8.8$ (neutrons) and $6.5 < |\eta| < 7.5$ and $-9.7^\circ < \phi < 9.7^\circ$ (protons), where ϕ is the azimuthal angle.

The central detectors, in order of radial position, are the Inner Tracking System (ITS), the Time Projection Chamber (TPC) and the time-of flight detector (TOF). The ITS consists of 6 layers of semiconductor detectors, the two innermost layers of Silicon Pixel Detectors (SPD) have an extended acceptance of $|\eta| < 1.4$. The central detectors are placed in a large solenoid magnet of $B = 0.5$ T.

The forward muon spectrometer consists of a composite absorber, 5 tracking stations consisting of MWPC, a trigger system and a dipole magnet of integrated field of 3 T·m.

PoS(DIS2015)060

The trigger for UPC processes uses the inputs from SPD, TOF, VZERO and the muon spectrometer.

3. Photoproduction of J/ψ in p-Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV

3.1 J/ψ photoproduction on a proton target

Photoproduction probes the gluon distribution in the proton at low-x at a given scale. According to the LO pQCD, the cross section is proportional to the square of the gluon density. The value of x of the gluon is given by the photon-proton center-of-mass energy $W_{\gamma \mathrm{p}}$ and the mass of the J/ψ $M_{J/\psi}$ as $x = (M_{J/\psi}/W_{\gamma p})^2$. Smaller x is therefore probed at higher energy.

The cross section of $\gamma\mathrm{p} \to \mathrm{J}/\psi\mathrm{p}$ can be parametrized as a power law in energy, $\sigma \propto W_{\gamma p}^{\delta}$. This empirical parametrization was found at HERA [5, 6]. The power law proportionality implies that there are more gluons at lower x. Any change in gluon behavior, starting at some $W_{\gamma p}$, may affect the proportionality law.

In p-Pb collisions, the lead-ion is most likely (at ∼95%) to be the source of the photon. The energy is given by the rapidity y of the J/ψ along the direction of the proton beam as $W_{\gamma \mathrm{p}}^2 = 2E_p M_{J/\psi} e^{-y}$, where E_p is the proton beam energy. Higher $W_{\gamma \mathrm{p}}$ energies are reached in the case that the J/ψ is produced in the direction opposite to the proton beam, where the rapidity is negative (backward).

3.2 Signal extraction for the forward J/ψ in p-Pb UPC

We have extracted the J/ψ signal in the dimuon channel, $J/\psi \to \mu^+\mu^-$, for the case where both muons are reconstructed in the forward muon spectrometer. Only two unlike-sign tracks were required in the data analysis, the activity in VZERO-C, which has an acceptance partly overlapping with the one of the muon spectrometer, should be compatible with the presence of such two muons. Further exclusivity requirements were imposed by requiring no activity in SPD, VZERO-A and the ZDCs, leaving thus only two muon tracks in an otherwise empty detector.

The number of *exclusive* J/ψ in $\gamma\mathrm{p}$ interactions was extracted by fitting the transverse momentum spectrum with templates corresponding to the contributing processes. These are (i) J/ψ in $\gamma\mathrm{p}$, (ii) exclusive $\gamma\gamma \to \mu^+\mu^-$ and (iii) inelastic J/ψ and $\gamma\gamma \to \mu^+\mu^-$. The templates for the processes (i) and (ii) have been generated using the STARLIGHT event generator [14] and folded with the detailed detector response, the inelastic template (iii) was obtained by applying special selections to the data.

3.3 Cross section of exclusive J/ψ photoproduction in the forward p-Pb

The differential cross section was calculated using formula 3 in [10] from the number of exclusive J/ψ in $\gamma\mathrm{p}$, the luminosity of the data sample, and the detection efficiency. The photon-proton cross section γ+p $\to J/\psi$+p is related to the differential cross section via the photon flux dN_γ/dk, giving the distribution of photons carrying a momentum k.

The photon-proton cross section as a function of energy $W_{\gamma \mathrm{p}}$ is shown in Figure 1, together with HERA results [5, 6]. The parameters of the power-law fit to ALICE results are consistent with those of HERA, indicating no change in gluon behavior at the LHC energies compared to HERA energy. The left panel of Figure 1 shows comparison of ALICE power-law fit and LHCb results [8].

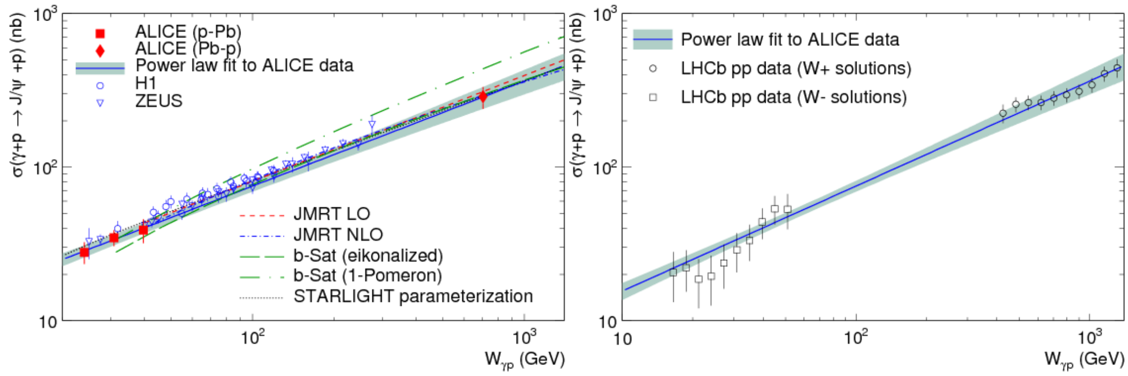

Figure 1: Exclusive J/ψ photoproduction cross section off protons [13].

4. Coherent photoproduction of J/ψ and $\psi(2S)$ in Pb-Pb UPC at $\sqrt{s_{NN}}$ = 2.76 TeV

Exclusive J/ψ photoproduction on a nuclear target is sensitive to the gluon distribution in the nucleus. Coherent photoproduction (the photon couples to the whole nucleus) is sensitive to nuclear gluon shadowing, manifesting itself as a partial depletion of the nuclear (w.r.t. nucleon) gluon density.

J/ψ mesons have been reconstructed through their dimuon decays at forward rapidity and via the di-electron and dimuon decays at central rapidities. The $\psi(2S)$ mesons have been measured either in leptonic decays $\psi(2S) \to l^+l^-$ or in cascade decays of $\psi(2S) \to J/\psi\pi^+\pi^-$ and $J/\psi \to l^+l^-$. Similar analysis procedures to those described in Section 3.3 have been performed to measure the differential photoproduction cross section.

The cross section for coherent J/ψ photoproduction is shown in Figure 2, the right part shows the preliminary results of CMS experiment together with the ALICE results. The cross section of coherent $\psi(2S)$ photoproduction is given in Figure 3. Models which include a nuclear shadowing consistent with the EPS09 parametrization can reproduce the LHC results on coherent J/ψ and $\psi(2S)$ photoproduction.

5. Photoproduction of ρ^0 in Pb-Pb UPC at $\sqrt{s_{NN}}$ = 2.76 TeV

Photoproduction of light vector mesons allows one to probe soft interactions at high energies. The ALICE experiment has measured the decays $\rho^0 \to \pi^+\pi^-$, where the pairs of $\pi^+\pi^-$ have been detected in the central detectors. Particle identification of the π mesons was performed via the specific ionization loss in the TPC.

The transverse momentum distribution of the ρ^0 candidates was fitted by the templates of the coherent and incoherent photoproduction of ρ^0. The templates were generated using the STARLIGHT event generator [14] and folded by detailed detector simulation.

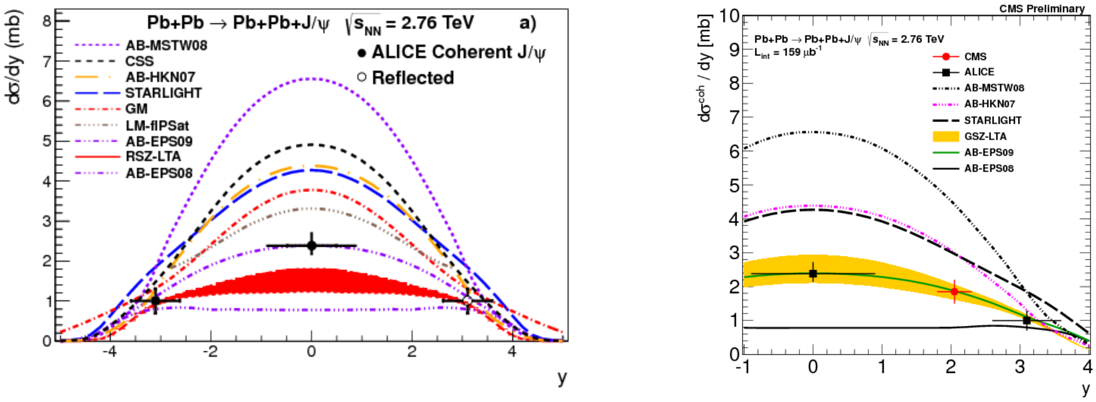

Figure 2: Cross section of coherent J/ψ photoproduction in Pb-Pb UPC measured by ALICE experiment [10, 11] and preliminary results of CMS experiment [9].

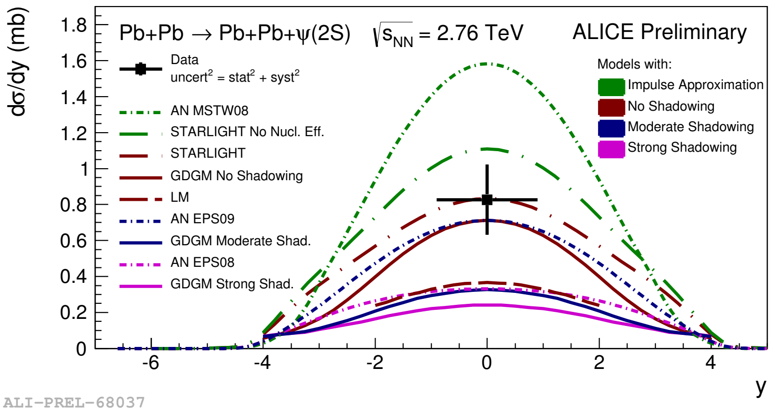

Figure 3: Cross section of coherent $\psi(2S)$ photoproduction in Pb-Pb UPC.

The cross section of coherent ρ^0 photoproduction is shown in the left panel of Figure 4 and the comparison to STAR results [4] is shown in the right panel. The predictions by Gonçalves and Machado (GM) [15] and by STARLIGHT are consistent with the measured cross section.

6. Conclusions

ALICE measurements on photoproduction of J/ψ, $\psi(2S)$ and ρ^0 in ultra-peripheral collisions (UPC) of p-Pb and Pb-Pb have been described.

The results on exclusive J/ψ photoproduction in p-Pb UPC indicate that changes in gluon density from HERA to LHC energy have no effect on the process of J/ψ photoproduction.

The cross section of coherent J/ψ photoproduction in Pb-Pb UPC has been measured in two rapidity intervals by ALICE experiment and in one rapidity interval by CMS. The values of the cross section are consistent with each other. Models which include nuclear gluon shadowing consistent with the EPS09 parametrization are successful in describing the results on coherent photoproduction of J/ψ and $\psi(2S)$.

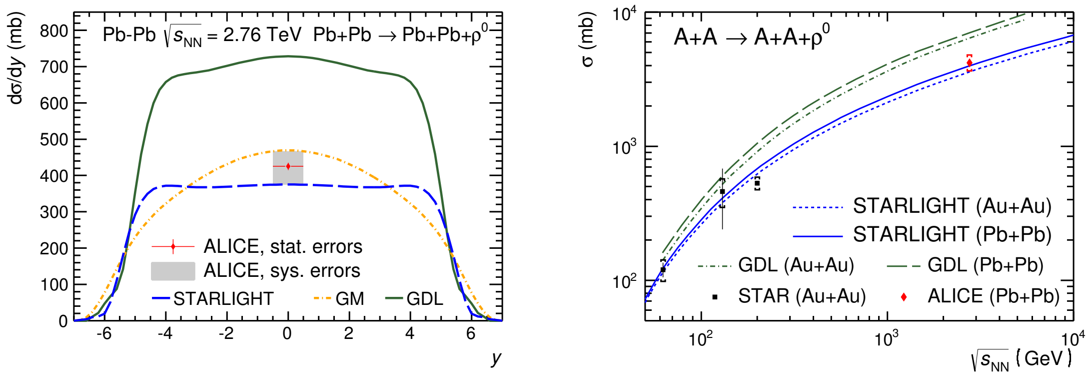

Figure 4: The cross section for coherent photoproduction of ρ^0 in Pb-Pb UPC [12].

The cross section for coherent ρ^0 photoproduction favors STARLIGHT using the Glauber model and the calculation by Gonçalves and Machado which is based on the Color Dipole model.

For the next LHC run, increased luminosity and higher center-of-mass energies of the photon-target system will enable us to perform precision measurements of the J/ψ photoproduction cross section and study Υ photoproduction. Furthermore, ALICE will be equipped by new forward scintillators, extending the pseudorapidity coverage of ALICE towards higher and lower pseudorapidities. When used as a veto, these new detectors, together with the VZERO detectors, will increase the suppression of non-UPC events.

Acknowledgements

This work was supported by grant LK11209 of MŠMT ČR.

References

[1] A. J. Baltz *et al.*, *The Physics of Ultraperipheral Collisions at the LHC*, Phys. Rept. **458**, 1 (2008).

[2] J. G. Contreras and J. D. Tapia Takaki, *Ultra-peripheral heavy-ion collisions at the LHC*, Int. J. Mod. Phys. A **30**, 1542012 (2015).

[3] S. Afanasiev *et al.* [PHENIX Collaboration], *Photoproduction of J/psi and of high mass e+e- in ultra-peripheral Au+Au collisions at s**(1/2) = 200-GeV*, Phys. Lett. B **679**, 321 (2009).

[4] C. Adler *et al.* [STAR Collaboration], *Coherent rho0 production in ultraperipheral heavy ion collisions*, Phys. Rev. Lett. **89**, 272302 (2002).

[5] S. Chekanov *et al.* [ZEUS Collaboration], *Exclusive photoproduction of J / psi mesons at HERA*, Eur. Phys. J. C **24**, 345 (2002).

[6] A. Aktas *et al.* [H1 Collaboration], *Elastic J/psi production at HERA*, Eur. Phys. J. C **46**, 585 (2006).

[7] T. Aaltonen *et al.* [CDF Collaboration], *Observation of exclusive charmonium production and* $\gamma+\gamma$ *to* $\mu^+\mu^-$ *in* $p\bar{p}$ *collisions at* $\sqrt{s} = 1.96$ *TeV*, Phys. Rev. Lett. **102**, 242001 (2009).

[8] R. Aaij *et al.* [LHCb Collaboration], *Updated measurements of exclusive* J/ψ *and* $\psi(2S)$ *production cross-sections in pp collisions at* $\sqrt{s} = 7$ *TeV*, J. Phys. G **41**, 055002 (2014).

[9] CMS Collaboration [CMS Collaboration], *Photoproduction of the coherent J/ψ accompanied by the forward neutron emission in ultra-peripheral PbPb collisions at 2.76 TeV*, CMS-PAS-HIN-12-009.

[10] B. Abelev *et al.* [ALICE Collaboration], *Coherent J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at* $\sqrt{s_{NN}} = 2.76$ *TeV*, Phys. Lett. B **718**, 1273 (2013).

[11] E. Abbas *et al.* [ALICE Collaboration], *Charmonium and e^+e^- pair photoproduction at mid-rapidity in ultra-peripheral Pb-Pb collisions at* $\sqrt{s_{\rm NN}}$*=2.76 TeV*, Eur. Phys. J. C **73**, no. 11, 2617 (2013).

[12] J. Adam *et al.* [ALICE Collaboration], *Coherent ρ^0 photoproduction in ultra-peripheral Pb–Pb collisions at* $\sqrt{s_{\rm NN}} = 2.76$ *TeV*, arXiv:1503.09177 [nucl-ex].

[13] B. B. Abelev *et al.* [ALICE Collaboration], *Exclusive* J/ψ *photoproduction off protons in ultra-peripheral p-Pb collisions at* $\sqrt{s_{\rm NN}} = 5.02$ *TeV*, Phys. Rev. Lett. **113**, no. 23, 232504 (2014).

[14] S. Klein and J. Nystrand, *Exclusive vector meson production in relativistic heavy ion collisions*, Phys. Rev. C **60**, 014903 (1999), http://starlight.hepforge.org/

[15] V. P. Goncalves and M. V. T. Machado, *Vector Meson Production in Coherent Hadronic Interactions: An update on predictions for RHIC and LHC*, Phys. Rev. C **84**, 011902 (2011).

PoS(DIS2015)060