Recent results on ultra-peripheral Pb-Pb and p-Pb collisions at the ALICE experiment

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Abstract. In this paper, we will discuss results on coherent and incoherent J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$, as well as preliminary results on exclusive J/ψ and two-photon production in ultra-peripheral p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Results on four-pion production in ultra-peripheral Pb-Pb collisions will also be given. Finally, the prospects for other UPC measurements in ALICE will be briefly mentioned.

Introduction

The LHC is not only the most powerful collider for proton-proton and heavy-ion collisions, but also for photon-photon and photon-hadron (γp and γPb) interactions, offering a unique opportunity to study fundamental aspects of QED and QCD via photon-induced processes. In ultra-peripheral collisions (UPC), two ions (or protons) pass by each other with an impact parameter at least two times larger than the nuclear radii, and here the hadronic interactions are strongly suppressed. The number of photons scales like Z^2 for a single source, so that in heavy-ion collisions exclusive particle production is dominated by electromagnetic processes. Typical examples are $\gamma\gamma \to l^+l^-$ (where $l^+l^- = e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$) or exclusive $\gamma + p \to J/\psi$ + p, which is modeled in pQCD by the exchange of two-gluons with no net-color transfer.

The experimental challenge for such measurements consists in having dedicated UPC triggers that are often orthogonal to the general trigger strategy of the experiments. Moreover, validating an exclusive analysis requires a good understanding of the trigger efficiency for the exclusivity conditions imposed at the online and offline levels, for which control triggers are usually required.

1. The ALICE experiment

The ALICE experiment [1] is well suited to study UPC vector meson production in a systematic way. The UPC triggers used the VZERO forward detector for vetoing, and the muon spectrometer, Time-of-Flight and Silicon Pixel Detector as triggers. The muon spectrometer covers the range $-4.0 < y < -2.5$, while a central barrel placed inside a large solenoid magnet (0.5 T) covers the pseudorapidity range $|\eta| < 0.9$. The pseudorapidity range $2.8 < \eta < 5.1$ is covered by VZERO-A and $-3.7 < \eta < -1.7$ by VZERO-C, which are scintillator tile arrays with a time resolution better than 1 ns allowing us to distinguish between beam-beam and beam-gas collisions. For the J/ψ analysis at mid-rapidity the TPC provides particle ID information. This is complemented with information provided by other detectors at the offline level, including the

ZDCs, which are located at about 116 m at both sides from the IP, and allow us to study both neutrons and protons emitted in the very forward region. Additional details on the way in which these detectors were used for these analyses are given in [2, 3]

2. Coherent and incoherent J/ψ production in UPC Pb-Pb

The first LHC measurements on exclusive photoproduction of J/ψ vector mesons produced in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV were carried out by ALICE [2, 3]. This measurement is particularly interesting as the UPC J/ψ cross section depends on the nuclear gluon distribution squared [5], making it a very good probe to study nuclear shadowing at low Bjorken-x values. At mid-rapidity J/ψs have a Bjorken-x value of about 10^{-3}. One of ALICE's advantage is that J/ψs can be measured down to zero p_T, which is important here as UPC J/ψs are characterized by their very low p_T. Coherent J/ψ production, where the photon couples coherently to all nucleons, is characterized by an average J/ψ p_T of about 60 MeV/c. For these events the target nucleus usually stays intact. For the incoherent case, the photon couples to a single nucleon, representing the quasi-elastic scattering off a single nucleon and the J/ψ has a somewhat larger average p_T of about 500 MeV/c. The p_T distributions for both coherent-enhanced and incoherent-enhanced data samples are well described by fitting together the expected signals and backgrounds using templates built from MC and data. This was used to extract the measured yield of coherent and incoherent J/ψ candidates. The measured cross sections are $d\sigma_{Coh}^{J/\psi}/dy = 1.00 \pm 0.18$ (stat) $^{+0.24}_{-0.26}$ (syst) mb at $-3.6 < y < -2.6$ and $d\sigma_{Coh}^{J/\psi}/dy = 2.38$ $^{+0.34}_{-0.24}$ (stat+syst) mb at $-0.9 < y < 0.9$. These results were compared to the available model calculations as described in [2, 3]. Best agreement is found with models that include nuclear gluon shadowing, consistent with EPS09 (see Figure 1). Recent model calculations provide ways on how these measurements can be used to extract information on the nuclear gluon density [4]. Furthermore, the incoherent J/ψ cross section was also recently published [3] and provides additional constraints to model calculations.
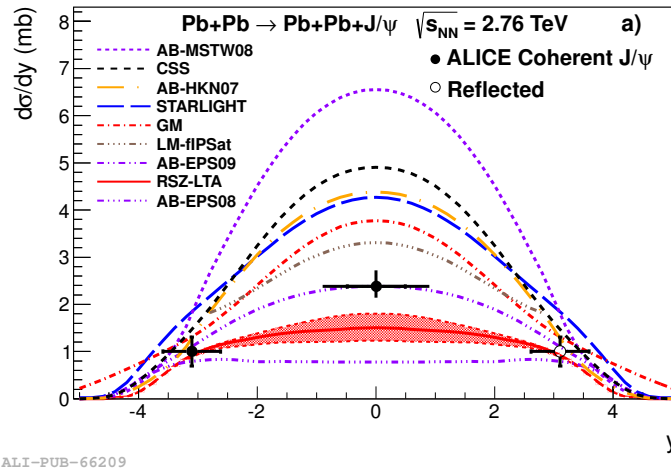

Figure 1. Coherent J/ψ cross section in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV measured by ALICE. Results are compared to theoretical calculations. See text for details.

3. Exclusive J/ψ photoproduction off protons in UPC p-Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

The lead nucleus acts as a photon emitter (enhanced flux by factor $Z^2 \sim 7000$ compared with the proton photon flux). At LHC the Bjorken-x goes down to 10^{-5} reaching for the first time

the 1 TeV scale for the γp centre-of-mass energy ($W_{\gamma p}$). Once the photon emitter is known, $W_{\gamma p}$ is determined by the J/ψ rapidity: $W_{\gamma p}^2 = 2E_p M_{J\psi} \exp(-y)$, where $M_{J/\psi}$ is the J/ψ mass and $E_p = 4$ TeV is the energy of the proton beam. For the 2013 p-Pb run, apart from the central and forward J/ψ measurements, we introduced a new trigger that allowed us pairing a single muon low p_T (with a trigger threshold of 0.5 GeV/c) using the forward muon spectrometer, together with a muon that can be reconstructed by the central barrel detector (particle ID is provided by the TPC). Because the muon spectrometer is a single-arm detector and we had both p-Pb and Pb-p colliding systems, the following measurements were possible: a) muon-arm p-Pb ($21 \leq W_{\gamma p} \leq 45$ GeV); b) muon+barrel p-Pb ($45 \leq W_{\gamma p} \leq 82$ GeV); c) central barrel p-Pb or Pb-p ($100 \leq W_{\gamma p} \leq 250$ GeV); d) muon+barrel Pb-p ($300 \leq W_{\gamma p} \leq 550$ GeV), and e) muon-arm Pb-p ($500 \leq W_{\gamma p} \leq 1160$ GeV). In what follows, we will only present results for the muon-arm p-Pb. Figure 2 shows the J/ψ p_T distribution, after fitting together signals and backgrounds to data as described above. Contributions from events where the proton dissociates are shown in red. This non-exclusive J/ψ p_T shape was estimated from data by requiring events with more than two hits in VZERO-C. To validate this procedure several cross checks were carried out using control samples. Our results shown in Figure 3 are compatible with HERA measurements. Although not shown in this figure, LHCb recently extracted $\sigma(W_{\gamma p})$ from their measurement of exclusive J/ψ production in pp collisions [6]. Owing to the ambiguity over which proton emitted the photon, for each measured $d\sigma/dy$ there are two coupled solutions for $\sigma(W_{\gamma p})$, one at low energy and one at high energy. In addition, a functional form with a built-in power law dependence was assumed for $\sigma(W_{\gamma p})$. For these reasons, pp measurements cannot provide an unambiguous test of the power-law dependence of the cross section as a function of the γp centre-of-mass energy, which is needed for observing new phenomena at high energies such as saturation.

4. Exclusive two-photon production in γp from UPC p-Pb

Preliminary cross sections for the exclusive two-photon process were also presented for the first time at this conference. They correspond to the first measurement in p-Pb collisions. Indeed, one of the main challenges of measuring J/ψ photoproduction is to have under control background from inelastic processes such as proton dissociation. The measured cross section for this process in the invariant mass range $1.5 < M_{\text{inv}} < 2.5$ GeV/c^2, using the same technique as for the J/ψ, is $\sigma(\gamma\gamma \to \mu^+\mu^-) = 1.76 \pm 0.12$ (stat) $^{+0.16}_{-0.15}$ (syst) μb at forward rapidity. The STARLIGHT prediction is 1.8 μb which is in good agreement with our measurements. This measurement could be used to constraint the inelastic background associated mainly to proton dissociation in hadronic colliders [7].

5. Four-pion production in UPC Pb-Pb

It is interesting to look for excited states of photo-produced ρ^0 mesons. It is not clear how many excited states exist or their quantum numbers (see special PDG review [11]). STAR reported on four-pion production in UPC [12], albeit at much lower centre-of-mass energies. No HERA publications on photo-production of a ρ^0 excited states exist. Figure 4 shows the four-pion p_T distribution, where a clear coherent peak can be seen at low transverse momenta. This corresponds to data collected during the 2011 Pb-Pb run, where we have 10 times more statistics than those published by STAR. One of the current research interesest is understanding the possible production mechanics [13].

6. Summary and outlook

ALICE is the first LHC experiment to provide results on ultra-peripheral collisions. Thanks to our collected UPC data we are exploring novel kinematic regimes with the potential for novel and high-profile physics. In UPC J/ψ analyses in γPb we have found a good agreement with models including moderate nuclear gluon shadowing. Two publications are available [2, 3], which include
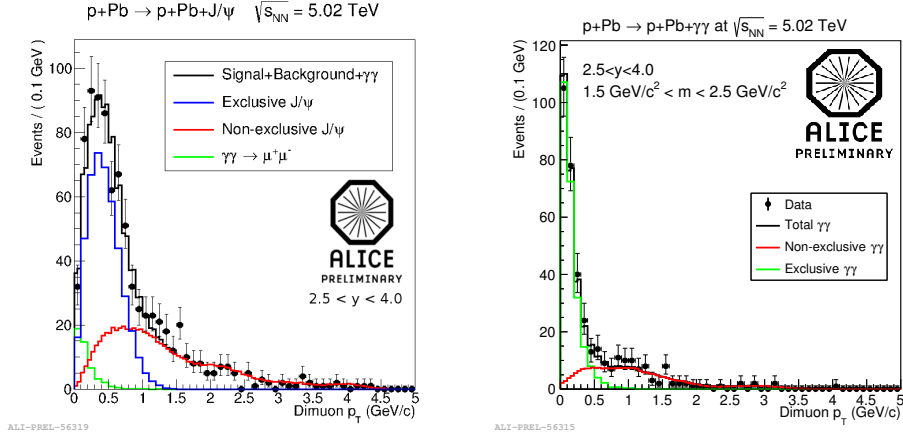
Figure 2. Transverse momentum distribution for events with exactly two oppositely charged muons satisfying the event selection for the forward dimuon samples, in the invariant mass range of the exclusive J/ψ (2.8 < M_{inv} < 3.3 GeV/c^2) and (1.5 < M_{inv} < 2.5 GeV/c^2) in the right and left plots, respectively. The templates for exclusive J/ψ and $\gamma\gamma \to \mu^+\mu^-$ were obtained from STARLIGHT. The non-exclusive templates were obtained from data, as described in the text.
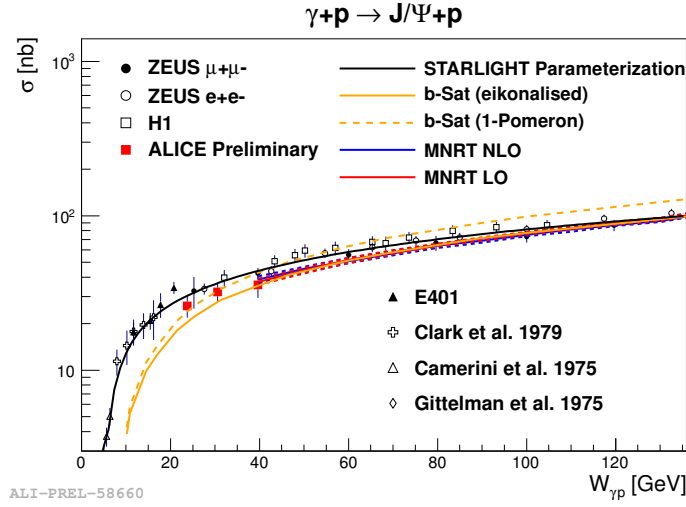

Figure 3. Exclusive J/ψ photoproduction cross section off protons measured by ALICE and compared to existing data from colliders and fixed-target experiments. Comparisons to STARLIGHT, MNRT [8] and the b-Sat models [9] are also shown.

results for coherent and incoherent J/ψ as well as results from exclusive two-photon production. Other ongoing analyses include ρ^0 and four-pion photoproduction in UPC Pb-Pb and p-Pb. In UPC p-Pb, we have studied J/ψ photoproduction from γp at $W_{\gamma\mathrm{p}} \sim$ 30 GeV and two-photon process with their exclusive and inelastic components. Results at higher γp energies from Pb-p collisions reaching the 1 TeV energy scale will be available soon. We also collected UPC triggers in pp running, during the years 2011 and 2012, where similar studies can be carried out.
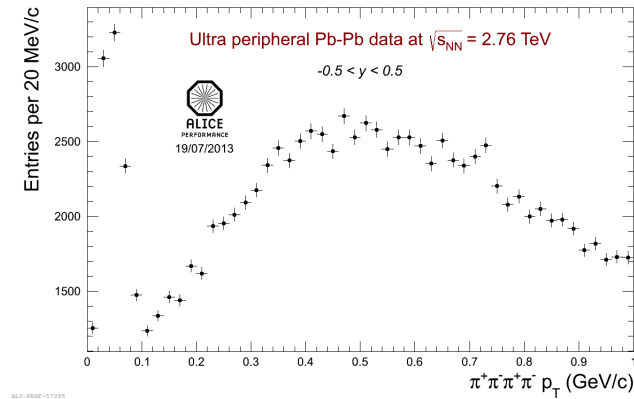
Figure 4. Transverse momentum distribution for the UPC four-pion production. A coherent four-pion peak is clearly visible.

Acknowledgments

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