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ALICE measurements of coherent ρ^0 photoproduction in Pb–Pb ultra-peripheral collisions

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The powerful photon fluxes of relativistic nuclei provide the possibility to study photonuclear and two-photon interactions in ultra-peripheral collisions (UPC), where the nuclei do not overlap and no strong nuclear interactions occur. Within the Vector Meson Dominance Model (VDM), the ρ^0 contribution dominates the QCD part of the photon structure function. The $\gamma + \mathrm{A} \rightarrow \rho^0 + \mathrm{A}$ process in heavy-ion UPC is an excellent tool to test the black disk regime, where the target nucleus appears like a black disk and the total $\rho^0 + \mathrm{A}$ cross section reaches its limit. RHIC and first LHC results have deviated from some Glauber+VDM calculations, which thus call for new data. The ALICE Collaboration reports [1] the first measurements of coherent rho photoproduction accompanied by electromagnetic dissociation (EMD) with data taken at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The rapidity-dependent cross section of coherent ρ^0 photoproduction is measured and it is compared with theoretical models. In addition, a resonance-like structure around 1.7 GeV/c^2 is observed.

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1. Introduction

The LHC is not only the most powerful collider for proton–proton and heavy-ion collisions, but it is also the most powerful source of photon collisions. The ultra-relativistic Pb ions carry an electromagnetic field, which can be viewed as a flux of quasi-real photons that can interact on the opposite target nucleus. When the impact parameter of these ions is larger than the sum of their radii, it is called an ultra-peripheral collision (UPC) [2]. In such collisions, hadronic interactions are suppressed and photoproduction of vector mesons becomes the dominant process.

A quasi-real photon is emitted from off the nucleus and interacts with the target nucleus. The formalism of the interaction depends on the model. It can be viewed as an interaction through the Pomeron in the Regge theory, a fluctuation of the photon into a vector meson in the Vector Dominance Model, or a fluctuation into a quark–antiquark pair in the Color Dipole Model. However, in such interactions the mean transverse momentum of the final vector meson is related to the target size, hence quite low ($\approx 60\,\mathrm{MeV}/c^2$); this is called a coherent photoproduction in which the target nucleus remains intact. However, an additional photon exchange can occur, that may lead to excitation of the nuclei to the Giant Dipole Resonance (GDP). This causes nucleon dissociation by the emission of neutron(s) at zero rapidities, along the beam.

The photoproduction of ρ^0 in Pb–Pb UPC collisions is an excellent tool to study the black-disk limit regime of QCD because of its large cross section. The differential cross section can be expressed as a sum of two contributions:

$$\frac{\mathrm{d}\sigma_{\mathrm{PbPb}}(y)}{\mathrm{d}y} = N_{\gamma\mathrm{Pb}}(y,\{b\})\cdot\sigma_{\gamma\mathrm{Pb}}(y) + N_{\gamma\mathrm{Pb}}(-y,\{b\})\cdot\sigma_{\gamma\mathrm{Pb}}(-y), \tag{1}$$

where $N_{\gamma\mathrm{Pb}}(y,\{b\})$ is the photon flux of a lead ion and $\sigma_{\gamma\mathrm{Pb}}(y)$ is the γ–Pb cross section. Both contributions can be distinguished using a different process as is suggested in Ref. [3].

2. Detector and signal extraction

The analysed data were taken with the ALICE detector [4] at the end of 2015, when the LHC was running on Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$. The data were collected using an UPC trigger setup that asked for low activity with back-to-back topology in the inner tracking system (ITS) and no activity in veto detectors V0 and AD. The ρ^0 is studied using the $\pi^+\pi^-$ decay channel. The tracks were measured using the ITS and time-projection chamber (TPC) that provides momentum measurement and particle identification (PID). The forward neutrons at beam rapidities were measured using the two neutron zero degree calorimeters located at ±112.5 m from the nominal interaction point (ZNA and ZNC).

The information from both neutron calorimeters is used to split the data sample into several subsamples based on the neutron activity: 0n0n — neither of the colliding nuclei emits neutrons; 0nXn (0nXn or Xn0n) — one of the nuclei emits at least one neutron while another one does not; XnXn — both nuclei emit neutrons.

The invariant mass distribution was corrected for acceptance and efficiency of the detector and normalized by the luminosity of the sample. The ρ^0 signal is extracted using a fit in the invariant mass. The fit function is a sum of the Söding formula [5] and template M to take into account the $\gamma\gamma \to \mu^+\mu^-$ background:

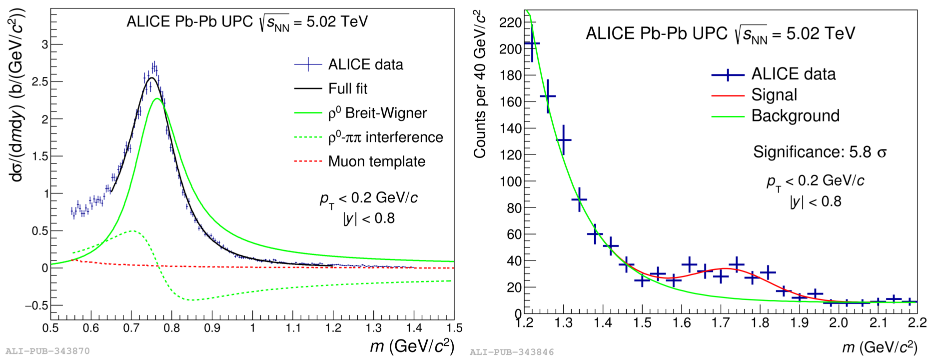

Figure 1: (Left) Corrected and normalized invariant mass distribution. (Right) Uncorrected invariant mass distribution of pion pairs for large invariant masses. The lines correspond to the fit components described in the text. Taken from [1].

$$\frac{\mathrm{d}\sigma}{\mathrm{d}m\,\mathrm{d}y} = |A \cdot BW_\rho + B|^2 + M, \tag{2}$$

where A is the normalisation factor of the ρ^0 Breit-Wigner (BW_ρ) function, and B is the non-resonant amplitude. The values found for the ρ^0 mass and width are 769.5 ± 1.2 (stat.) $\pm$ 2.0 (syst.) MeV/c^2 and 156 ± 2 (stat.) $\pm$ 3 (syst.) MeV/c^2, respectively. These values are consistent with those reported by the PDG [6].

3. Resonance-like structure

The uncorrected invariant mass distribution in the range $m > 1.2$ GeV/c^2 is shown in Figure 1. The distribution was fitted using the same model as used by the STAR Collaboration [7]:

$$\frac{\mathrm{d}N_{\pi\pi}}{\mathrm{d}m} = P_1 \cdot \exp\left(-P_2 \cdot (m - 1.2\,\mathrm{GeV/c^2})\right) + P_3 + P_4 \cdot \exp\left(-(m - M_x)^2/\Gamma_x^2\right), \tag{3}$$

where $N_{\pi\pi}$ is the number of pion pairs, P_i are parameters describing the background and the normalisation of the Gaussian part, and M_x (Γ_x) represent the mass (width) of a potential resonance. The fit yields a χ^2/d.o.f. (degree of freedom) of 13/19. The significance, s, of the Gaussian component defined as $S/\sqrt{S + 2B}$ yields $s = 5.8$ showing a resonance-like structure with a mass of (1725 ± 17) MeV/c^2 and width (143 ± 21) MeV/c^2, where the quoted uncertainties correspond to statistical fluctuations only. This resonance-like object has also very low transverse momentum as expected from a coherent-production process.

4. Photoproduction cross section of ρ^0

The measured cross section of the coherent ρ^0 photoproduction is shown as a function of rapidity in Figure 2. The cross section is extracted in the absolute value of rapidity range and then reflected to negative rapidities for display purposes. The measured data are compared with several models:

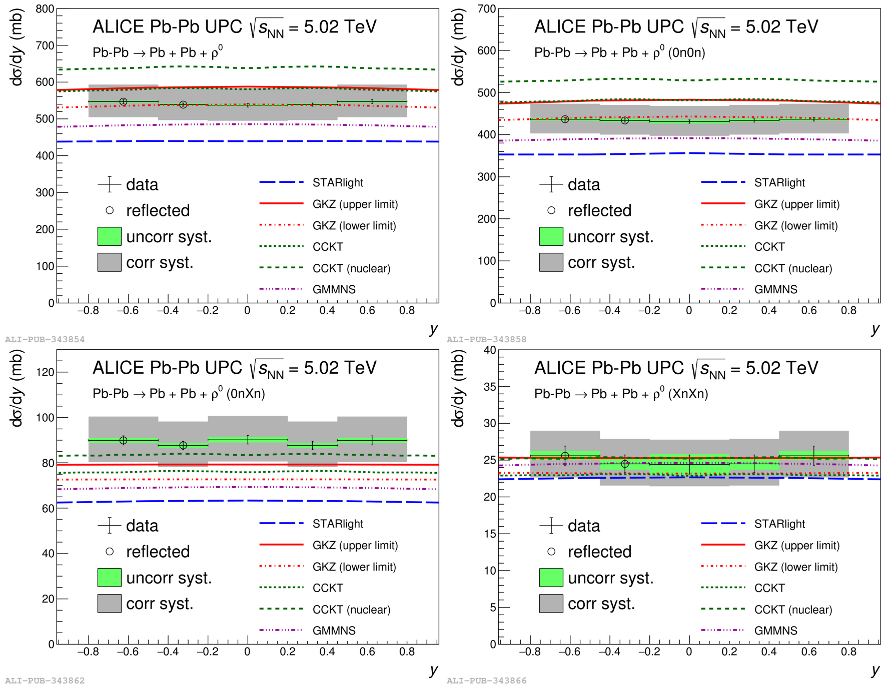

Figure 2: Cross section for the coherent photoproduction of ρ^0 vector mesons in Pb–Pb UPC as a function of rapidity for no forward-neutron selection (top left), and for the 0n0n (top right), 0nXn (bottom left) and XnXn (bottom right) classes. Taken from [1].

STARlight: [8, 9] based on the Vector Meson Dominance model and photoproduction off protons data combined with a Glauber-like approach.

GKZ: [10, 11] Guzey, Kryshen, Zhalov predictions based on the modified Vector Meson Dominance model.

CCKT: [12, 13] model by Cepila, Contreras, Krelina and Tapia based on the Color-Dipole Model with the structure of a nucleon described by hot spots.

GMMNS: [14] model by Gonçalves, Machado, Morerira and dos Santos based on the IIM implementation of gluon saturation within the Color-Dipole Model.

5. Conclusions and outlook

ALICE reports [1] the cross section of ρ^0 photoproduction at midrapidity at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The measured cross section is compatible with all models within around two standard deviations, except for the single neutron emission class (0nXn), where models underestimate data slightly. This suggests that the measurement of coherent vector meson production accompanied by electromagnetic dissociation (EMD) could also be used to separate the low and high energy contributions to the cross section at forward rapidities as suggested in [3].

As shown in Figure 1, there seems to be a resonance-like structure in the region $m > 1.2$ GeV/c^2 decaying into $\pi^+\pi^-$. Such an object was also observed by the STAR Collaboration [7], ZEUS [15] and more recently H1 at HERA [16]. More data are needed to shed light on the origin and structure of this object.

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