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Recent ALICE results on photon-induced J/ψ production

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The strong electromagnetic fields generated by ultra-relativistic heavy ions provide the possibility to study photon-induced processes at the LHC in new kinematic regions. ALICE has measured the coherent photoproduction of J/ψ in Pb–Pb and p–Pb collisions at a center-of-mass energy per nucleon pair of 5.02 TeV. These collisions correspond to photon–proton and photon–Pb interactions, respectively. In these cases, the mass of the charm quark allows for perturbative QCD computations addressing the phenomena of saturation and nuclear shadowing, thus the study of such collisions provides information about the initial state of hadrons.

The evolution of the exclusive J/ψ photoproduction cross section off protons is measured with p–Pb data. The new Pb–Pb data from LHC Run 2 cover a larger kinematic range with smaller experimental uncertainties than in the past. Both measurements from p–Pb and Pb–Pb collisions, are compared with predictions of available models.

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1. Introduction

One of the main parameters of relativistic heavy ion collisions, which determines the physics nature of interactions, is the impact parameter. If the impact parameter is larger than the sum of the nuclear radii, the so-called ultra-peripheral collisions (UPC) can occur. The nucleon electric charges work coherently and produce intense (growing with the square of the charge) and energetic photon fluxes which can be described by an equivalent photon approximation (EPA) [1].

The photon induced reactions at the LHC are presented either due to pure electromagnetic photon–photon processes or due to photon–nuclear reactions. The latter corresponds to the process when the photon fluctuates to a bound $q\overline{q}$ system (a vector meson) which then elastically scatters (via Pomeron exchange) off the nucleus as a whole, or incoherently, where the photon couples to a single nucleon.

UPC results on the exclusive vector meson production obtained so far by RHIC and LHC experiments [2] are limited and new experimental data are needed to extend UPC studies to new domains. This contribution presents ALICE results on J/ψ photoproduction cross section measurements in Pb–Pb and in p–Pb UPC.

2. Experimental setup

A detailed description of ALICE is given elsewhere [3]. Only the sub-detectors relevant to vector meson photoproduction measurements are briefly described below:

- the Muon Spectrometer (MS) reconstructs large rapidity ($-4 <$y< -2.4) muons from J/ψ decays. It consists of a composite absorber, a large dipole magnet and ten planes of tracking chambers. Four chambers behind the muon filter of MS are used for muon identification and triggering;

- the Inner Tracking System (ITS), a six-layer, silicon vertex detector ($|\eta < 0.9|$), and the Time-Projection Chamber (TPC, $|\eta < 0.8|$) to measure final state particles from J/ψ decays at midrapidity. The TPC also measures the specific energy loss ($\mathrm{d}E/\mathrm{d}x$) used for particle identification;

- trigger detectors - Silicon Pixel Detector (SPD) of ITS, forward scintillator detectors V0 and AD and trigger chambers of MS.

3. Coherent J/ψ photoproduction

Under the leading order QCD calculations, the cross section of coherent J/ψ ($c\overline{c}$ bound state) photoproduction is expected to scale with the square of the gluon density function in a nucleus. Next-to-leading order effects and energy scale uncertainties make the extraction of gluon PDFs from J/ψ photoproduction more complicated, the related uncertainties in the ratio of cross sections off nuclei and off protons are cancelled and coherent J/ψ photoproduction off a nuclei provides a tool to study gluon shadowing effects at low Bjorken-x values in range 10^{-5} to 10^{-2} at LHC energies.

The analysis is based on data taken in the 2015 and 2018 Pb–Pb LHC runs, selected with a dedicated trigger. The integrated luminosity about 750 μb^{-1}. The trigger requires two muons with transverse momentum p_T above 1 GeV/c and no hits in the forward scintillators opposite to MS in order to reject hadronic collisions. Coherently produced J/ψ are selected by criteria that an event has to contain a pair of muons (dimuon) with opposite electric charges and $p_T < 250$ MeV/c to suppress most of the incoherent photoproduction of J/ψ .

The invariant mass spectrum of selected dimuons is shown in Fig. 1 together with a fit to a Crystall Ball function for the J/ψ resonance and a polynomial function for the $\gamma\gamma \to \mu\mu$ continuum. According to the fit result, around twenty two thousand events with J/ψ produced in UPC are reconstructed. Different sources of remaining background (incoherent J/ψ photoproduction, dimuon production in $\gamma\gamma$ collisions and feed-down from ψ(2S) decays) are estimated based on the dimuon transverse momentum distribution.

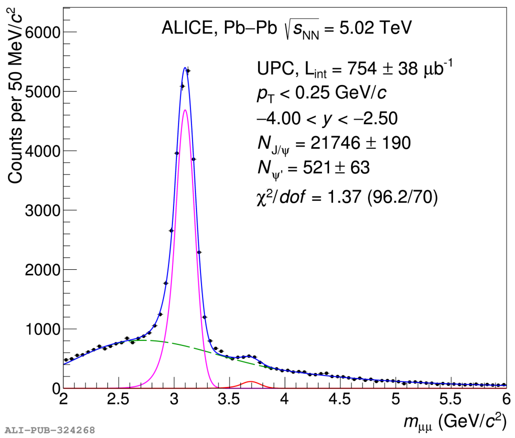

Figure 1: Invariant mass of forward dimuons in Pb–Pb UPC [5].

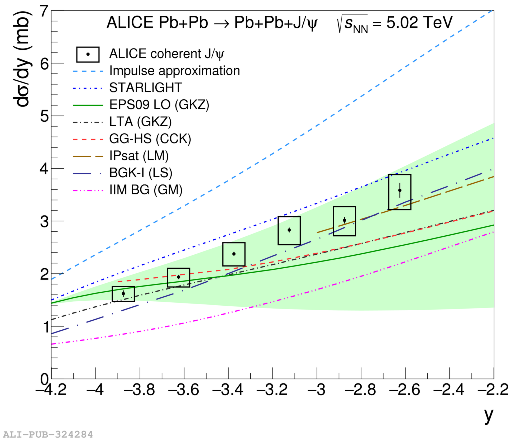

Figure 2: Forward J/ψ photoproduction cross section in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV [5].

The data were corrected for the detector acceptance with a simulation made by the STARlight event generator [4]. The ALICE result on the coherent J/ψ photoproduction cross section in Pb–Pb UPC [5] is shown in Fig. 2 together with theoretical calculations based on the impulse approximation (no nuclear effects), STARlight (vector meson dominance model), predictions using the Color Glass Condensate approach [6], the color-dipole with an energy dependent hot-spot model [7] or within Glauber-Gribov theory [8] and calculations based on the EPS09 framework and on the Leading Twist Approximation (LTA) [9]. The data support moderate gluon shadowing in nuclei and agree with calculations incorporating shadowing according to EPS09.

4. J/ψ photoproduction in p–Pb collisions

The behavior of the gluon structure function in nucleons at small values of the Bjorken-x is a key question of perturbative quantum chromodynamics. Combined results of HERA experiments [10] show that this function rises rapidly toward small-x values. Gluon saturation can slow down the growth of the cross section and the J/ψ photoproduction off a proton becomes a suitable tool to search for saturation effect since its cross section depends on the gluon density in the nucleon.

ALICE analyzed J/ψ photoproduction in collisions of protons with Pb nuclei at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with the data taken in 2016 where 223 (642) J/ψ candidates identified via its dielectron (dimuon) decays with the combined efficiencies around 3% (9%).

Figure 3 shows ALICE measurements [11] for exclusive J/ψ photoproduction in photon-proton mass from 24 to 706 GeV which cover three orders of Bjorken-x lowering to 10^{-5}. All experimental data are fitted by a power law dependence with a good fit quality obtained.

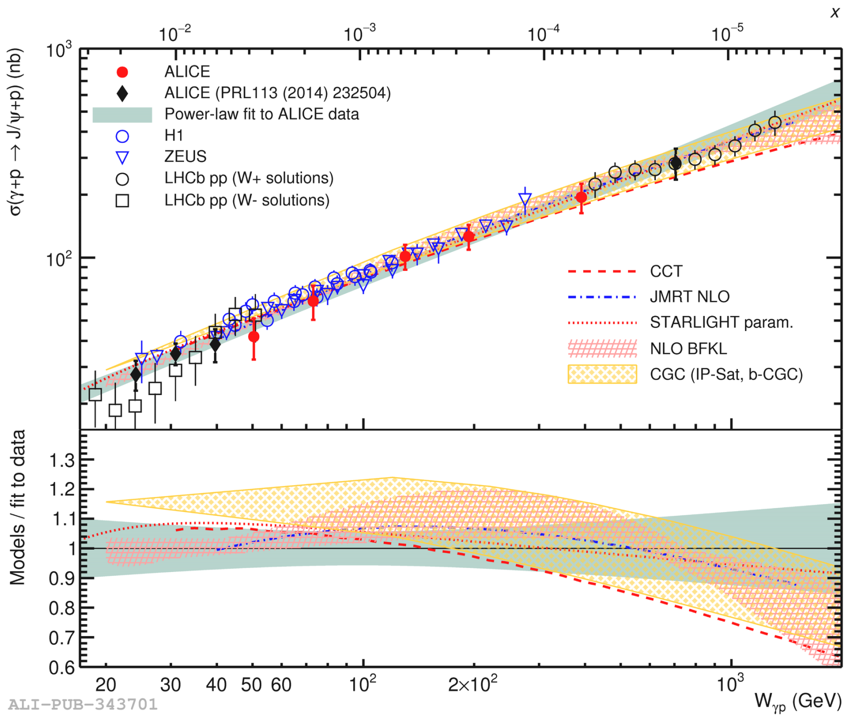

Figure 3: Cross section of J/ψ photoproduction off protons at $\sqrt{s_{\rm NN}}$ = 5.02 as a function of photon–proton center-of-mass energy [11].

In summary, ALICE measured J/ψ cross sections in Pb–Pb ultra-peripheral collisions. The models without the gluon shadowing effect in nuclei clearly disagree with the data which support moderate level of the shadowing. ALICE studied J/ψ photoproduction off protons in a wide interval of photon-proton mass. The ALICE data agree with the LHCb and HERA measurements.

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