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Physics of ultra-peripheral collisions with ALICE at the LHC

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Summary. — The photoproduction of vector mesons in ultra-peripheral collisions (UPC) is a powerful tool to probe the nuclear gluon distribution (Pb-Pb collisions) and the gluon structure function in the proton (p-Pb collisions). The first measurements of coherent photoproduced J/ψ and ψ(2S) in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV, performed with the ALICE detector, are reported and compared to STARLIGHT and QCD based models, in order to investigate nuclear gluon shadowing. The first results of the measurement of exclusive J/ψ photoproduction off protons in p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV performed by the ALICE Collaboration are also mentioned.

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PACS 25.20.Lj – Photoproduction reactions.

1. – Ultra-peripheral collisions

Ultra-peripheral collisions may occur when two accelerated particles are separated by impact parameters larger than the sum of their radii: in this case hadronic interactions are strongly suppressed. Photonuclear processes can be studied in Pb-Pb and p-Pb collisions at the LHC at unprecedentedly high energies. The physics of ultra-peripheral collisions is reviewed in [1, 2].

2. – Physics motivations

Exclusive photoproduction of vector mesons in heavy-ion interactions, where a vector meson but no other particles are produced in the event, is of particular interest since it is expected to probe the nuclear gluon distribution [3], for which there is considerable uncertainty in the low-x region [4].

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2˙1. *Pb-Pb collisions.* – Exclusive photoproduction can be either coherent, if the photon couples coherently to all nucleons, or incoherent, if the photon couples to a single nucleon. Coherent production is characterized by low vector meson transverse momentum ($\langle p_T \rangle \sim 60\,\mathrm{MeV}/c$) and the target nucleus normally does not break up. Incoherent production, corresponding to quasi-elastic scattering off a single nucleon, is characterized by a higher transverse momentum ($\langle p_T \rangle \sim 500\,\mathrm{MeV}/c$) and the target nucleus normally breaks up; except for single nucleons or nuclear fragments in the very forward region no other particles are produced. In what follows, results on coherent J/ψ production in the forward region reconstructed in the dimuon decay channel and coherent J/ψ production at central rapidities in both leptonic decays are presented.

2˙2. *p-Pb collisions.* – In this case, the J/ψ photoproduction is dominated by the γp process and this gives the possibility to study the gluon PDF in the proton down to $x \sim 10^{-5}$. Considering the different rapidity ranges available for the measurement, ALICE can provide the cross section as a function of the γp centre of mass energy, ranging from 21 GeV up to 1160 GeV.

3. – Results and comparison with models

The analysis is based on a sample of events collected during the 2011 Pb-Pb run and the 2013 p-Pb run, selected with dedicated triggers, set up to select events containing two tracks in an otherwise empty detector, in order to select exclusive J/ψ photoproduction events. The ALICE detector [5] consists of a central barrel placed inside a large solenoid magnet ($B = 0.5\,\mathrm{T}$), covering the pseudorapidity region $|\eta| < 0.9$ and a muon spectrometer covering the range $-4.0 < \eta < -2.5$. The detectors used in the analysis (for triggering, tracking, offline selection and PID purposes) are the Silicon Pixel Detector (SPD), the Time Projection Chamber (TPC), the Time-of-Flight detector (TOF), the VZERO scintillator counters, the Electromagnetic Calorimeter (EMCAL), the Forward Multiplicity Detector (FMD), a Muon Tracker and a Muon Trigger system and finally two sets of hadronic Zero Degree Calorimeters (ZDC), used to detect neutrons emitted in the very forward region, such as neutrons produced by electromagnetic dissociation.

3˙1. *Measured cross sections and comparison with theoretical calculations.* – The invariant mass and p_T distributions for the forward region are shown in fig. 1. The peak at the J/ψ mass is clearly visible and has been fitted to an exponential function to describe the background plus a Crystal Ball parameterization to decribe the J/ψ. The clear peak at low values in the transverse momentum distribution of the J/ψ candidates is mainly due to coherent photoproduction. To estimate the fraction of incoherent event in the selected sample, a fit of the p_T distribution was performed, taking into account contributions from coherent and incoherent J/ψ production, as well as from the di-lepton continuum, the feed-down from ψ' and, for the mid-rapidity region, the contamination by the hadronic events. The shapes for the first five fitting functions (Monte Carlo tem plates) were provided by STARLIGHT events folded with the detector simulation, while the last one is extracted from data at higher centralities.

As expected, at low transverse momentum the coherent production dominates. The yield of coherent J/ψ is obtained by a cut on di-lepton momentum and a ZDC cut tuned to select events with less than 6 emitted neutrons. The momentum cut is below $300\,\mathrm{MeV}/c$ at forward rapidity and below $200\,(300)\,\mathrm{MeV}/c$ at mid-rapidity for the di-muon (di-electron) channel.

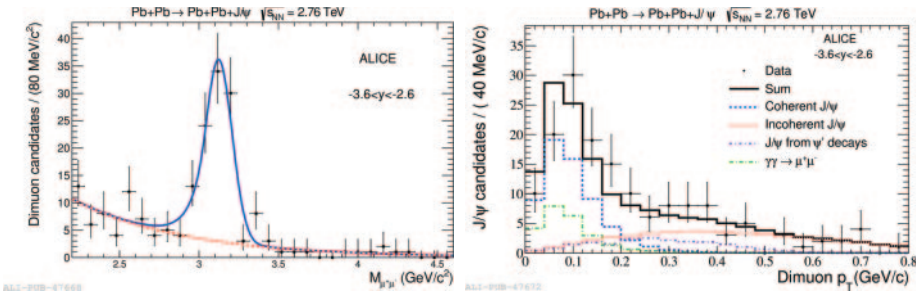

Fig. 1. – Left: invariant mass spectrum of forward $(-3.6 < y < -2.6)$ coherent $J/\psi \to \mu^+\mu^-$ candidates with $p_T < 300\,\mathrm{MeV}/c$ and less than 6 neutrons in the ZDC. Right: J/ψ p_T distribution fitted to a simulation template as described in the text. The same distributions for the mid-rapidity region, for the dielectron and dimuon channels are not shown here and can be found in [7].

The results for the forward and mid rapidity regions have been recently published respectively in [6] and [7]. The coherent differential cross sections per unit rapidity are 1.00 ± 0.18 (stat) $^{+0.24}_{-0.26}$ (syst) mb in the rapidity interval $-3.6 < y < -2.6$ and $2.38^{+0.34}_{-0.24}$ (stat + syst) mb at $\mid y \mid < 0.9$.

The results at forward and central rapidities are compared to theoretical predictions in fig. 2. The predictions can be divided into three categories: models that include no nuclear effects (AB-MSTW08), models that use a Glauber approach to calculate the number of nucleons contributing to the scattering (STARLIGHT, GM, CSS and LM) and partonic models, where the cross section is proportion al to the nuclear gluon distribution squared (AB-EPS08, AB-EPS09, AB-HKN07, and RSZ-LTA). A detailed description of all these models can be found in [7]. The coherent J/ψ cross section is found to be in good agreement with the model which incorporates the nuclear gluon shadowing according to the EPS09 parameterization (AB-EPS09). At the beginning of 2013, ALICE collected a sample of p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ provided by LHC. The preliminary result

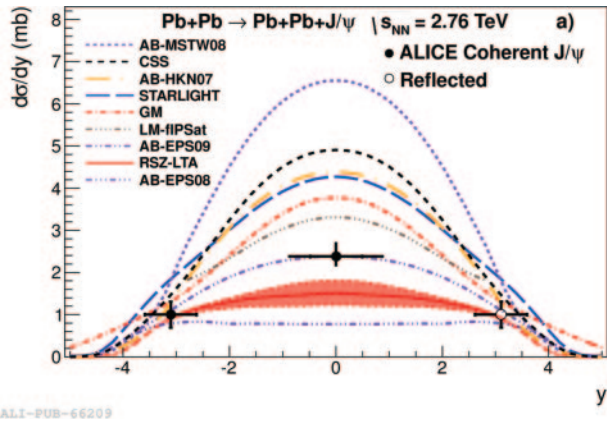

Fig. 2. – Comparison among the published values of the cross section at forward rapidity, at central rapidities and several theoretical models.

at forward rapidity is consistent with a power law dependence of the J/ψ photoproduction cross section in γ p energies from about 20 to 700 GeV, or equivalently, from Bjorken-x between $\sim 2\times10^{-2}$ to $\sim 2\times10^{-5}$, with an exponent compatible with H1 and ZEUS, thus indicating no significant change in the gluon density behaviour of the proton between HERA [8, 9] and LHC energies.

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