Results on ultra-peripheral interactions in Pb-Pb and p-Pb collisions in ALICE

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Ultra-relativistic heavy ions generate strong electromagnetic fields which offer the possibility to study $\gamma$-nucleus and $\gamma$-proton interactions at the LHC in the so called ultra-peripheral collisions (UPC). Here we report ALICE results on $J/\psi$ photoproduction measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

1 Introduction

Collisions between heavy-ions and proton-ion at the LHC can be used to study particle production in photonuclear interactions [1]. These interactions may occur in ultra-peripheral collisions (UPC), where the impact parameter is larger than twice the hadron radius. The events considered here are characterized by a single $J/\psi$ meson but no other particles being produced. The cross section for this process is proportional to the nuclear gluon distribution function. In Pb-Pb collisions this measurement sheds light on the low Bjorken-$x$ region, where the nuclear gluon shadowing is poorly known. In this talk, results on coherent photoproduction of $J/\psi$ vector mesons measured by the ALICE Collaboration at the LHC are presented [2, 3]. The $J/\psi$ is studied through its di-muon decay at forward rapidity and both di-muon and di-electron decay at mid-rapidity. As far as the p-Pb collisions are concerned, the main interest is the study of the $\gamma+ p \rightarrow J/\psi + p$ cross section at high center of mass energy ($W_{\gamma p}$) where gluon saturation effects could manifest. Coherent photoproduction is associated with a low $p_T$ ($< 100$ MeV/c) of the final state. To take into account also the finite detector resolution, a $p_T$ cut is used to define coherent interactions in the di-muon (di-electron) channel for the present analysis.

2 The ALICE Experiment

The ALICE detector [4] consists of a central barrel placed inside a large solenoid magnet (0.5 T) covering the pseudorapidity range $|\eta| < 0.9$, a muon spectrometer covering the range $-4.0 < y < -2.5$, and a set of smaller detectors at forward rapidity. The forward rapidity analysis is based on the muon spectrometer. In addition, the VZERO counters and Zero-Degree Calorimeters (ZDC) are used for triggering UPC and rejecting the contribution from hadronic interactions, respectively. The VZERO counters are arrays of scintillator tiles situated on either side of the primary vertex at pseudorapidities $2.8 < \eta < 5.1$ (VZERO-A, on the opposite side of the muon spectrometer) and $-3.7 < \eta < -1.7$ (VZERO-C, on the same side as the muon spectrometer). The analysis at mid-rapidity makes use of the barrel detectors (SPD, TPC and
TOF), the VZERO counters and the ZDC calorimeters. More information on the detectors used for this analysis can be found in [2, 3].

3 \( \frac{J}{\psi} \) production in Pb-Pb collisions

3.1 Forward rapidity analysis

The analysis at forward rapidity, is based on a sample of \( 3 \times 10^6 \) events collected with a ultra-peripheral collision dedicated trigger (FUPC) during the 2011 Pb-Pb run. The purpose of the FUPC trigger was to select two muons in an otherwise empty detector. It is based on three requirements: a single muon trigger above a 1 GeV/c \( p_T \) threshold; at least one hit in VZERO-C; no hits in VZERO-A. The integrated luminosity for the data collected with this trigger corresponds to about 55 mb\(^{-1} \). Only events with two opposit charged tracks in the muon spectrometer were considered. The analysis was restricted to \( \frac{J}{\psi} \) rapidities between \(-3.6 < y < -2.6 \) and muon pseudorapidities between \(-3.7 < \eta < -2.5 \) to match the acceptance of the VZERO-C and avoid the edges of the spectrometer. More details about the analysis cuts are available in [2]. The invariant mass distribution for the di-muons surviving the analysis cuts are shown in figure 1 (left). The final sample contained 117 \( \frac{J}{\psi} \) candidates in the invariant mass range \( 2.8 < M_{\text{inv}} < 3.4 \text{ GeV/}c^2 \). The number of \( \frac{J}{\psi} \) was extracted by fitting the invariant mass distribution to a Crystal Ball function, for the signal, and an exponential, for the background from two-photon interactions. This gave an extracted number of \( \frac{J}{\psi} \), \( N_{\text{yield}} = 96 \pm 12\text{(stat)} \pm 6\text{(syst)} \). The transverse momentum distribution of \( \frac{J}{\psi} \) candidates is shown in figure 1 (right). The histograms show the expected contribution from coherent \( \frac{J}{\psi} \) production, incoherent \( \frac{J}{\psi} \) production, \( \frac{J}{\psi} \) from the decay \( \psi(2S) \rightarrow \frac{J}{\psi} + X \), and two-photon production of di-muon pairs. The signal region \( p_T < 0.3 \text{ GeV/}c \) contains background contributions from incoherent \( \frac{J}{\psi} \) production as well as feed down from \( \psi(2S) \) decay. The method used to estimate these fractions and the associated uncertainties is explained in detail in [2]. The resulting number of coherent \( \frac{J}{\psi} \) after the above corrections is \( N_{\text{coh}} = 78 \pm 10\text{(stat)} \pm 11\text{(syst)} \). During the 2011 Pb-Pb run, the VZERO detector had a threshold corresponding to an energy deposit above that from a minimum ionizing particle. This made it difficult to accurately simulate the VZERO-C trigger efficiency for low multiplicity events. To avoid these uncertainties, the \( \frac{J}{\psi} \) cross section was obtained by using the number of reconstructed \( \gamma \gamma \rightarrow \mu^+ \mu^- \) events. The \( \frac{J}{\psi} \) section can then be written as

\[
\frac{d\sigma_{\text{coh}}}{dy}_{\frac{J}{\psi}} = \frac{N_{\text{coh}}^{\frac{J}{\psi}} \cdot (\text{Acc} \cdot \epsilon)_{\gamma\gamma} \cdot \sigma_{\gamma\gamma} \cdot \Delta y \cdot BR(\frac{J}{\psi} \rightarrow \mu^+ \mu^-) \cdot (\text{Acc} \cdot \epsilon)_{J/\psi}}{N_{\gamma\gamma} \cdot \Delta y \cdot BR(\frac{J}{\psi} \rightarrow \mu^+ \mu^-) \cdot (\text{Acc} \cdot \epsilon)_{\frac{J}{\psi}}} \]

Here \((\text{Acc} \cdot \epsilon)_{\gamma\gamma}\) and \((\text{Acc} \cdot \epsilon)_{J/\psi}\) are the acceptance and efficiency for two-photon and coherent \( J/\psi \) events, respectively. \( BR(\frac{J}{\psi} \rightarrow \mu^+ \mu^-) \) is the branching ratio for the di-muon decay of the \( \frac{J}{\psi} \) and \( \Delta y = 1.0 \) is the rapidity interval. The number of \( \gamma \gamma \) events, \( N_{\gamma\gamma} \), was obtained by counting the number of events in the invariant mass intervals \( 2.2 < M_{\text{inv}} < 2.6 \text{ GeV/}c^2 \) and \( 3.5 < M_{\text{inv}} < 6.0 \text{ GeV/}c^2 \) to avoid contamination from the \( \frac{J}{\psi} \) peak. A cross section \( d\sigma_{\text{coh}}/dy = 1.00 \pm 0.18\text{(stat)} \pm 0.24\text{(syst)} \text{ mb} \) was obtained in the interval \(-3.6 < y < -2.6 \).

3.2 Mid-rapidity analysis

The \( \frac{J}{\psi} \) production in UPC at mid-rapidity was measured using a sample of \( 6.5 \times 10^6 \) events collected during the 2011 Pb-Pb run. The trigger required a number of fired pad-OR in the
Figure 1: Di-muon invariant mass (left) and $p_T$ (right) distributions in ultra-peripheral collisions at $\sqrt{s_{NN}}=2.76$ TeV.

3.3 Comparison with models

The measured cross section can be compared to the available models [5, 6, 7, 8, 9, 10]. The models by Lappi and Mantysaari [6], Cizek et al. [7], and Goncalves and Machado [8] are based on the Color Dipole Model (CDM). The model by Klein and Nystrand [10], which is incorporated in STARLIGHT [11], uses data from exclusive vector meson production at HERA as input to a Glauber calculation of the cross section for nuclear targets. The models by Rebyakova et al. [5] and Adeluyi and Bertulani [9], calculate the cross section directly from the nuclear gluon distribution with the forward scattering amplitude being proportional to the gluon distribution squared. Rebyakova et al. calculate the modifications to the nuclear gluon distribution in the leading twist approximation, while Adeluyi and Bertulani use standard parameterizations (HKN07, EPS09, and EPS08). The results are shown in figure 2 (left). One can see that models which are based on the color dipole model generally give a higher cross section than those which calculate the cross section directly from the gluon distribution. Best agreement is found for models which include nuclear gluon shadowing consistent with the EPS09 parameterizations.
4 \ J/\psi \ production \ in \ p-Pb \ collisions

Photons produced by a high energy nucleus colliding with a proton, offer the possibility to shed light on the proton structure functions. ALICE can measure the p+Pb→p+Pb+J/\psi cross section in a wide range of rapidities, using forward (two leptons in the muon arm), semi-forward (one lepton in the muon arm and another one in the barrel) and midrapidity (two leptons in the barrel) events. Moreover by reversing the proton and Pb nuclei direction, the 2013 p-Pb run offered the possibility to extend further the rapidity interval. Since the rapidity is connected to the γ+Pb center of mass energy, W_{γPb}, these categories of events allow to study the cross section in the interval 20<W_{γPb}<950 \ GeV. The γ+p→J/\psi+p cross section can be easily obtained by the p+Pb→p+Pb+J/\psi cross section, dividing by the photon spectrum emitted by the Pb nucleus, computed by several Monte Carlo simulations and constrained by a recent ALICE analysis [3]. The study of this cross section is one of the key tools to search for gluon saturation at small Bjorken-x. As a first step ALICE focused on the low energy events (W_{γPb}≈10-40 \ GeV) to check the compatibility between the ALICE measurements with the previous measurements from HERA. Figure 2 (right) shows the three experimental points obtained by ALICE, fully compatible with the previous one. The next step will be the analysis of the highest energy events, going beyond the region already explored by HERA.

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