Coherent photoproduction of J/ψ mesons in ultraperipheral PbPb collisions at CMS

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In this contribution we briefly describe the CMS results on J/ψ photoproduction in PbPb collisions in which the coherent J/ψ photoproduction cross section as a function of the photon-nucleus center-of-mass energy ($W_{\gamma\mathrm{N}}^{\mathrm{Pb}}$) was measured up to 400 GeV. The cross section is observed to plateau above $W_{\gamma\mathrm{N}}^{\mathrm{Pb}} \approx 40$ GeV and up to 400 GeV, accessing very small Bjorken-x values of $\approx 6 \times 10^{-5}$.

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1 Introduction

The extreme limit of an off-center collision is one in which a nucleus miss each other, so that the impact parameter is greater than sum of the nuclear radii. In these ultraperipheral collisions (UPCs), the strong electromagnetic fields surrounding the relativistic nuclei enhance photon-photon and photon-nucleus interactions over hadronic processes. Indeed these photo-induced processes dominate the total nucleus-nucleus cross section.

The photoproduction of vector mesons, where the sub process is $\gamma\mathrm{A} \rightarrow V\mathrm{A}$ with $V = \mathrm{J}/\psi, \Upsilon(nS), \rho^0$ etc., represents a powerful probe of the nuclear structure, particularly at very small Bjorken-x region, where the gluon saturation is expected to be found. These interactions are usually classified depending on whether the projectile photon interacts with the target ion as a whole (coherent) or if it interacts with a single nucleon inside the ion (incoherent). The coherent production is of particular interest since at LO in pQCD, the photo-nuclear cross section is proportional to the square of the gluon distribution of the target nucleus.

In symmetric collisions, such as PbPb, one of the main difficulties to access small Bjorken-x values is the two-energy photon ambiguity which comes from the fact that either nucleus could serve as the photon emitter or the target. A novel solution to this problem was proposed in [1,2] in which the main idea is to control the collision impact parameter by detecting forward neutrons emitted via electromagnetic dissociation and classifying events in forward neutron multiplicity categories.

The CMS Collaboration exploited the above mentioned strategy to access the small-x region in J//ψ photoproduction in PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV [3]. The zero-degree calorimeters (ZDCs) [4] were used to tag forward neutrons and disentangle the low and high energy photon contributions.

2 Dataset and event selection

This analysis used PbPb UPCs collisions collected at the CMS experiment at the LHC in 2018. The data correspond to an integrated luminosity of 1.52 nb^{-1}. The event candidates are online selected with a trigger that requires at least one muon candidate coincident with a Pb-Pb bunch crossing. For the off-line analysis, events are required to have a primary vertex formed by using two or more tracks. In addition, in order to suppress hadronic interactions, the selected events are required to have energy depositions less than 7.3 and 7.6 GeV in forward calorimeters with positive and negative rapidities, respectively.

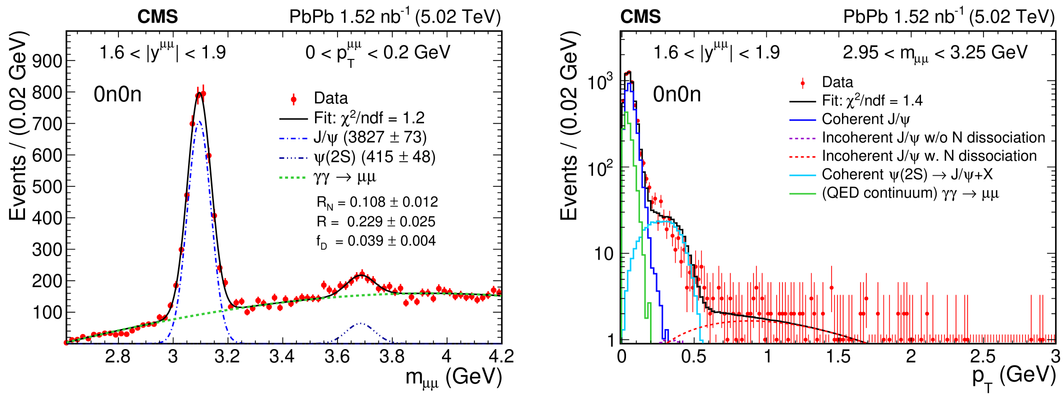

Figure 1 – Invariant mass (left) and transverse momentum distribution (right) of $\mu^+\mu^-$ pairs in the 0n0n neutron class.

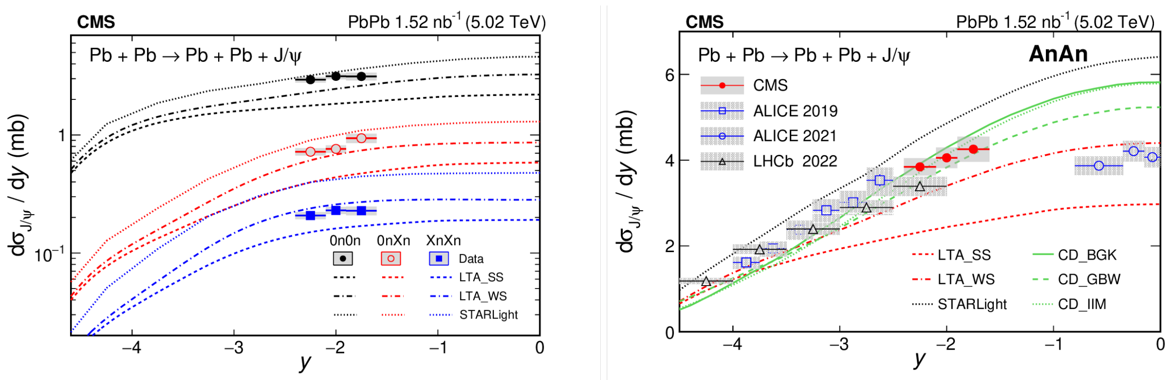

Figure 2 – Differential coherent J/ψ photoproduction cross section as a function of rapidity in different forward neutron multiplicity categories.

Pairs of high-quality muons of opposite sign within an invariant mass in the range $2.6 < m_{\mu\mu} < 4.2$ GeV are selected as J/ψ and ψ(2S) candidates.

3 Signal extraction

The signal extraction strategy relies on studying the dimuon mass and transverse momentum distributions. By looking at the invariant mass spectrum one can separate the raw number of J/ψ signal events from the main background process coming from QED $\gamma\gamma \to \mu\mu$ events, as it is shown in Fig. 1 (left). These raw J/ψ yields are a combination of different physics processes, namely coherent, incoherent (with and without nuclear breakup) and J/ψ mesons obtained from the decay of ψ(2S) (referred as "feed-down"). In order to extract the coherent J/ψ yields, multiple template fits are performed to the transverse momentum spectrum, as it is shown in Fig. 1 (right).

4 Coherent J/ψ cross section

The coherent J/ψ photoproduction differential cross section is obtained as

$$\frac{d\sigma^{\mathrm{coh}}_{\mathrm{J}/\psi}}{dy} = \frac{N_{\mathrm{J}/\psi}}{\epsilon_{\mathrm{J}/\psi}\mathcal{B}_{\mathrm{J}/\psi\to\mu\mu}\mathcal{L}\epsilon_{\mathrm{evtsel}\Delta y}}, \tag{1}$$

where $\epsilon_{\mathrm{J}/\psi}$ and $\epsilon_{\mathrm{evtsel}}$ are the reconstruction and event selection and reconstruction efficiencies, $\mathcal{B}_{\mathrm{J}/\psi\to\mu\mu}$ the J/ψ dimuon branching fraction, $\mathcal{L}$ the integrated luminosity and Δy is the rapidity bin. This is performed in different forward neutron multiplicity categories, namely, 0n0n (no neutron selection), 0nXn (zero neutrons on one side and at least one neutron on the other side), and XnXn (at least one neutron on both sides). Predictions from theoretical calculations are also shown for comparison. The results are shown in Fig. 2.

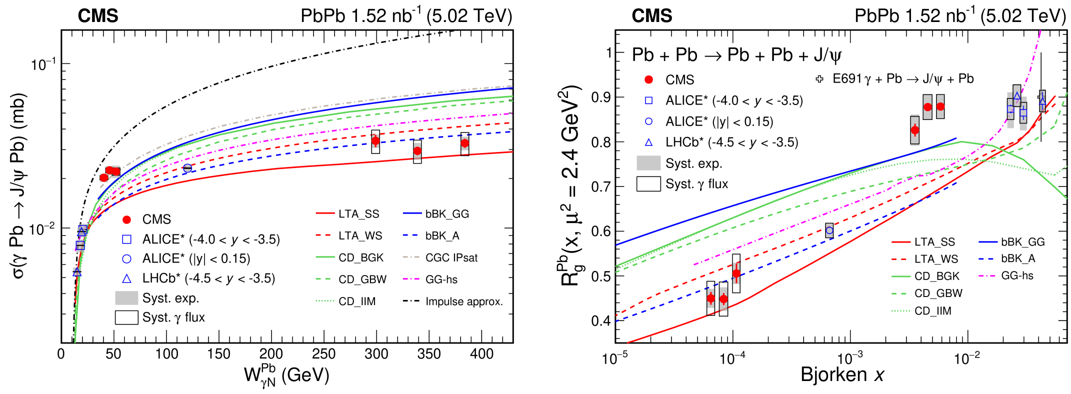

Figure 3 – Left: Coherent J/ψ photoproduction cross section as a function of $W_{\gamma \mathrm{N}}^{\mathrm{Pb}}$. The prediction from several theoretical models are also shown. Right: Nuclear suppression factor R_g^{Pb} as a function of Bjorken-x.

5 Energy dependence of the photo-nuclear cross section

The measured differential cross sections, shown in Fig. 2, for each neutron multiplicity class contains contributions from both low and high energy photons, $\omega = M_{\mathrm{J}/\psi} \exp(\pm y)$. The separation of the cross section in different neutron multiplicities classes allows us to disentangle both contributions and obtain the coherent photo-nuclear J/ψ cross section as a function of the center-of-mass energy of the photon-lead system ($W_{\gamma \mathrm{N}}^{\mathrm{Pb}}$). This measurement, as it is shown in Fig. 3 (left), is obtained up to energies of $W_{\gamma \mathrm{N}}^{\mathrm{Pb}} \approx 400$ GeV. At low $W_{\gamma \mathrm{N}}^{\mathrm{Pb}}$ values from 15 to 40 GeV, we observe a rapid growing energy dependence, consistent with the picture of a fast-growing gluon density at small x. This trend vanishes for $W_{\gamma \mathrm{N}}^{\mathrm{Pb}} > 40$ GeV, and the cross section begins a slow linear increase. This could imply the onset of novel physics, for example the gluon saturation of the Pb nucleus at the corresponding Bjorken-x value.

The nuclear gluon suppression factor $R_g^{\mathrm{Pb}}(x, \mu^2 = 2.4 \mathrm{GeV}^2)$ as a function of x is also obtained. This is defined as defined as $R_g^{\mathrm{Pb}} = \sqrt{\sigma^{\mathrm{Meas}}/\sigma^{\mathrm{IA}}}$, where σ^{Meas} is the measured cross section and σ^{IA} is the prediction from the impulse approximation model. As it is shown in Fig. 3 (right), the suppression in the high-x (low $W_{\gamma \mathrm{N}}^{\mathrm{Pb}}$) region is around 0.8-0.9. As we go to small-x values, the suppression factor starts dropping rapidly to 0.4-0.5 for $x \approx 6 \times 10^{-5}$.

6 Summary

The coherent J/ψ photoproduction cross section in PbPb collisions has been presented in different forward neutron multiplicity classes. This allowed us to solve the two-way ambiguity of high and low energy photons, hence, to measure the photo-nuclear cross section as a function of the photon-nucleus center-of-mass energy $W_{\gamma \mathrm{N}}^{\mathrm{Pb}}$ over a wide range from 40 up to 400 GeV. The data show a slow linear rising trend above 40 GeV. This can be interpreted either as the first direct evidence of gluon saturation in Pb nucleus or that the scattering cross section is near the black-disc limit.

Acknowledgments

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