QUARKONIA PRODUCTION IN ULTRAPERIPHERAL PbPb COLLISIONS AT THE LHCb*

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Received 6 August 2022, accepted 7 September 2022, published online 14 December 2022

We report on the measurement of charmonia in both peripheral and ultraperipheral PbPb collisions recorded by the LHCb detector. The measurement of J/ψ in ultraperipheral PbPb collisions provides unique opportunities to study the low-x gluons constituent of the Pb nuclei, while the precise measurement of the low-$p_{\rm T}$ J/ψ confirms coherent production in hadronic collisions.

DOI:10.5506/APhysPolBSupp.16.1-A95

1. Introduction

The LHCb detector at CERN [1] showed unique capabilities in recent years, in particular in the field of Central Exclusive Production (CEP) studies [2], in which high precision at low transverse momentum ($p_{\rm T}$) is crucial. Thanks to the CEP studies, the gluon distributions inside protons were investigated through the measurement of vector mesons. In a similar approach, charmonia produced by the large photon flux emitted by ultrarelativistic Pb nuclei is a powerful way to probe the generalized parton distribution functions (GPDs) for nuclei [3]. In Ultra-Peripheral Collisions (UPC) the impact parameter of the collision is greater than the sum of the radii of the two nuclei, thus the only interactions possible are "long"-distance photon exchanges. In those coherent reactions, the two nuclei are intact and some particles such as vector mesons or dileptons can be produced. The measurement of J/ψ is of particular interest as its decay into dimuons leaves a clear signal in the detector and its production is proportional to the GPDs of the target nucleus. Unique among the different experiments at the LHC, the

* Presented at the 29$^{\rm th}$ International Conference on Ultrarelativistic Nucleus–Nucleus Collisions: Quark Matter 2022, Kraków, Poland, 4–10 April, 2022.

LHCb detector has shown great performance over the years with excellent capabilities for particle identification, vertex reconstruction, and momentum measurement down to $p_{\mathrm{T}} = 0$. From the physics point of view, the pseudorapidity coverage ($2 < \eta < 5$) allows to explore low-x_{Bjorken} parton distributions.

2. J/ψ production in UPC

Coherent J/ψ are produced in PbPb UPCs through the reaction of photons emitted by one of the nuclei with the gluons of the target nucleus. The gluons system is usually represented as a colorless object called Pomerons; the reaction of photons and Pomerons can produce vector mesons such as J/ψ and $\psi(2S)$. The analysis production of these photo-produced J/ψ is performed using PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV recorded in 2015 and 2018 by the LHCb Collaboration [4, 5]. Considering the collision energy, the mass of the J/ψ and the rapidity coverage of the LHCb detector, these measurements should provide information on the Generalized Parton Distribution (GDP's) of gluons at low-x between 10^{-5} and 10^{-2}, possibly sensible to the gluon saturation region [6]. The J/ψ candidates are reconstructed through their decay into two opposite-sign muons. To avoid any contamination from J/ψ produced in hadronic collisions, only events with low activity in the detector are kept. Additionally, the high-rapidity shower counter (HeRSChel) detector [7] allows to differentiate UPC-like events from hadronic collisions by detecting rapidity gaps. The J/ψ and $\psi(2S)$ are first observed through the dimuon-invariant mass spectrum. The number of coherent J/ψ is extracted using a template fit to the $\log(p_{\mathrm{T}}^2)$ distribution that includes contributions from coherent and incoherent charmonium modeled using the STARlight package [8], non-resonant background, and possible feed-down from $\psi(2S) \to J/\psi\pi^+\pi^-$ decays.

After corrections by the detector efficiencies, the cross section is computed in several intervals of the J/ψ's rapidity for the 2015 dataset as observed in Fig. 1. The results are compared with many theoretical predictions based on perturbative QCD (with different assumptions on the shadowing strength [9]) or color-dipole models including or not saturation effects and subnucleon fluctuations [10]. The predictions are generally based on results from *pp* collisions translated to the ion case using the Glauber–Gribov methodology. A direct comparison with the results is challenging due to the high source of systematics uncertainty from the luminosity, thus no model is clearly preferred.

A similar analysis was performed using the larger 2018 PbPb data sample, with a luminosity of around 210 μb^{-1}. The same strategy as in 2015 is used, the signal extraction for both the J/ψ and $\psi(2S)$ is presented in Fig. 2 and the corresponding differential cross sections in Fig. 3. One can observe the much greater precision achieved for the J/ψ. Among the different proposed models, the perturbative theory with a weak nuclear shadowing hypothesis describes the data better.

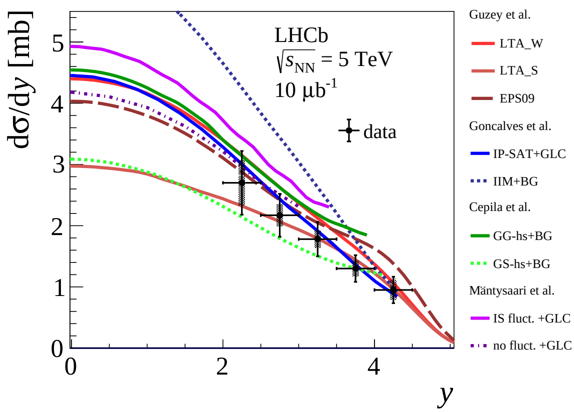

Fig. 1. Differential cross section of the coherent J/ψ production compared to different phenomenological predictions.

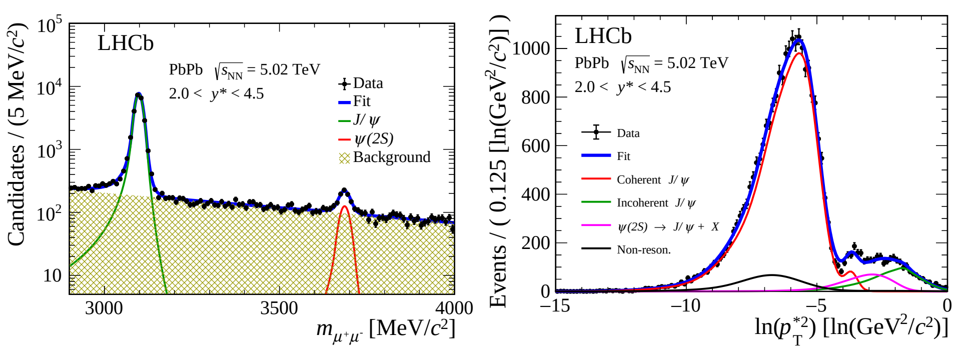

Fig. 2. (Color online) Fit to the invariant mass distribution of dimuon candidates from the 2018 PbPb sample (left). Distribution of the $\log(p_{\mathrm{T}}^2)$ of the dimuon candidates (right). The total fit is shown (blue line) including the non-resonant contribution (black curve), the feed-down (pink), incoherent component (green), and the coherent signal (red). The fit is performed using templates from the STARlight package.

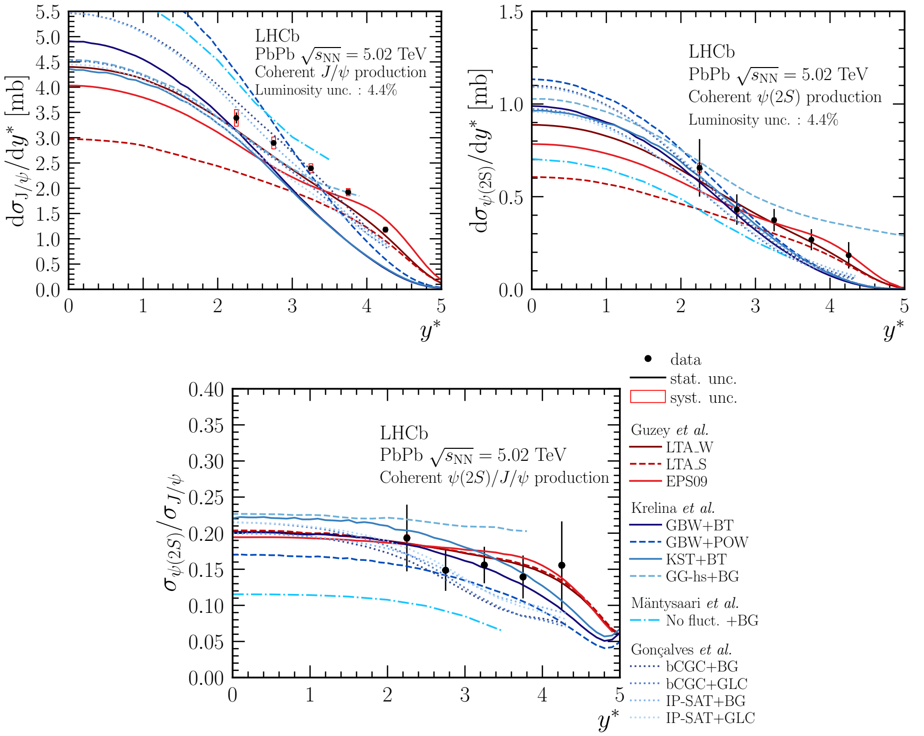

Fig. 3. Differential cross section as a function of rapidity of the coherent J/ψ production compared to different phenomenological predictions (top left), and of the coherent $\psi(2S)$ (top right). Ratio of the J/ψ and $\psi(2S)$ cross sections along with predictions (bottom).

3. Coherent J/ψ production peripheral PbPb collision

The production of the J/ψ mesons might also occur in peripheral PbPb collisions (impact parameter lower than the sum of the two radii of the colliding nuclei). In fact, a similar signal as seen in UPC has been measured in peripheral PbPb collision at the LHCb [11] as we will present in the following.

In Fig. 4, the dimuon invariant mass spectrum around the J/ψ mass using the 2018 data sample is shown. The visible resonance contains both photo-produced and hadronically-produced J/ψ, a closer look at the $\log(p_T^2)$ distribution is needed to discriminate them. Two distinct signals are visible, one at large transverse momentum, formed by the J/ψ mesons produced by the fusion of two partons, and one at low p_T formed by the posited coherent J/ψ mesons. The signal extraction is once more done through this p_{T} distribution and the differential yields *versus* p_{T} and the number of participants in the collisions (N_{part}) are computed and shown in Fig. 5. The results are compared with phenomenological models that include or do not the effect of the overlap of the two nuclei [12]. At present, the measurement is limited to low values of N_{part} due to detector limitation. The results are consistent with the coherent J/ψ photo-production, with a transverse momentum around 70 MeV$/c$, and are the most precise to date.

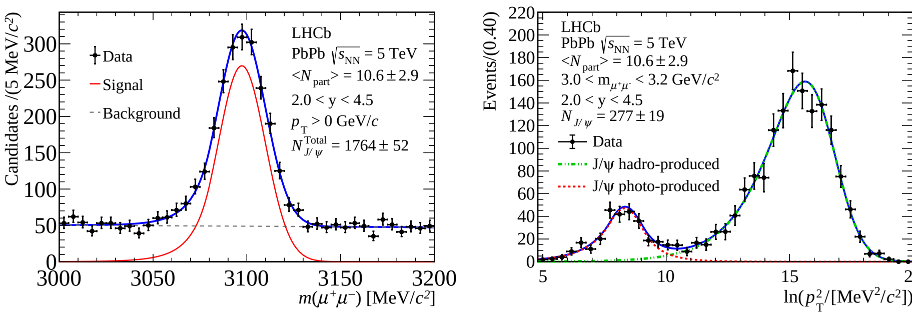

Fig. 4. Fit to the dimuon invariant mass distribution of the J/ψ candidates (left), distribution of the $\log(p_{\mathrm{T}}^2)$ of the dimuon candidates (right).

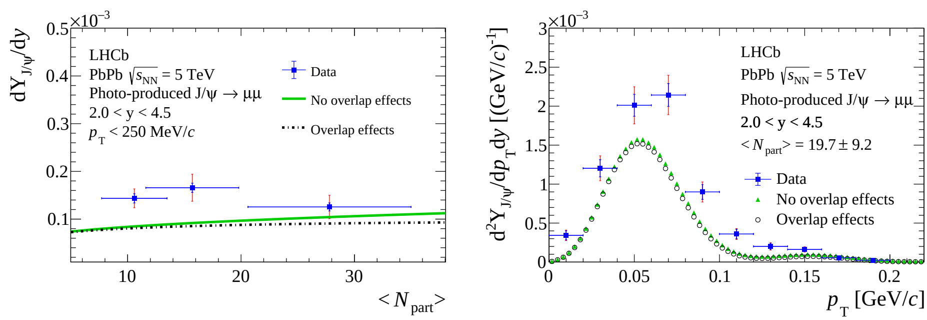

Fig. 5. Differential yields of the coherent J/ψ *versus* the number of participant on the collision N_{part} (left). Double-differential yields of the coherent J/ψ produced in peripheral PbPb collision as a function of p_{T} (right).

4. Conclusion

The cross sections of the coherent J/ψ and $\psi(2S)$ were measured using the 2015 and 2018 PbPb datasets recorded by the LHCb Collaboration. The 2018 results show great precisions in particular for the J/ψ and challenge the current theoretical model. Furthermore, the yield of the "excess" J/ψ was measured in PbPb peripheral collisions using the 2018 dataset. This result is consistent with the posited photo-production and is the most precise to date.

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