QUARKONIA PRODUCTION IN ULTRA-PERIPHERAL PbPb COLLISIONS AT THE LHCb*

Xiaolin Wang

on behalf of the LHCb Collaboration

Guangdong Provincial Key Laboratory of Nuclear Science
Guangdong-Hong Kong Joint Laboratory of Quantum Matter
Institute of Quantum Matter, South China Normal University, Guangzhou, China

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Measurements of coherent charmonium production cross sections together with their ratio in ultra-peripheral PbPb collisions are studied at a nucleon–nucleon centre-of-mass energy of 5.02 TeV. The differential cross-sections are measured as a function of rapidity and transverse momentum, separately. The photo-production of J/ψ mesons at low transverse momentum is studied in peripheral PbPb collisions and coherent J/ψ production in hadronic collisions is confirmed. These latest results significantly improve previous measurements and are compared with some theoretical predictions.

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1. Introduction

The LHCb detector is a single-arm forward spectrometer covering the pseudorapidity range of $2 < \eta < 5$ [1, 2], which has great performance with precise vertex reconstruction, high particle momentum resolution, and excellent particle identification capability. Measurements of quarkonia production in (ultra-)peripheral heavy-ion collisions play an important role in studying the photon–nucleus interaction, the mechanism of vector meson production, and the partonic structure of nuclei. Meanwhile, coherent photo-production would provide an excellent laboratory to study the nuclear shadowing effects and the initial state of heavy-ion collisions at small-x at the LHC [3].

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2. Charmonia production in ultra-peripheral PbPb collisions at the LHCb [4]

Ultra-peripheral collisions (UPCs) occur when the impact parameter is larger than the sum of the radii of two incoming nuclei [5]. The two ions interact via their cloud of semi-real photons, and photon-nuclear interactions dominate. In UPCs, J/ψ and $\psi(2S)$ mesons are produced from the colorless reaction of a photon from one nucleus and a Pomeron from the other. If the photon interacts with a Pomeron emitted by the whole nucleus, there would be no nucleus break-up, and this is called coherent production, which is the process we are going to study.

The charmonia candidates are reconstructed through the $J/\psi \to \mu^+\mu^-$ and $\psi(2S) \to \mu^+\mu^-$ decay channels using a PbPb data sample corresponding to an integrated luminosity of 228 ± 10 $\mu\mathrm{b}^{-1}$, which was collected by the LHCb experiment in 2018. According to the characteristics of UPCs, only events with low activity could be kept in the selection. After that, the signal

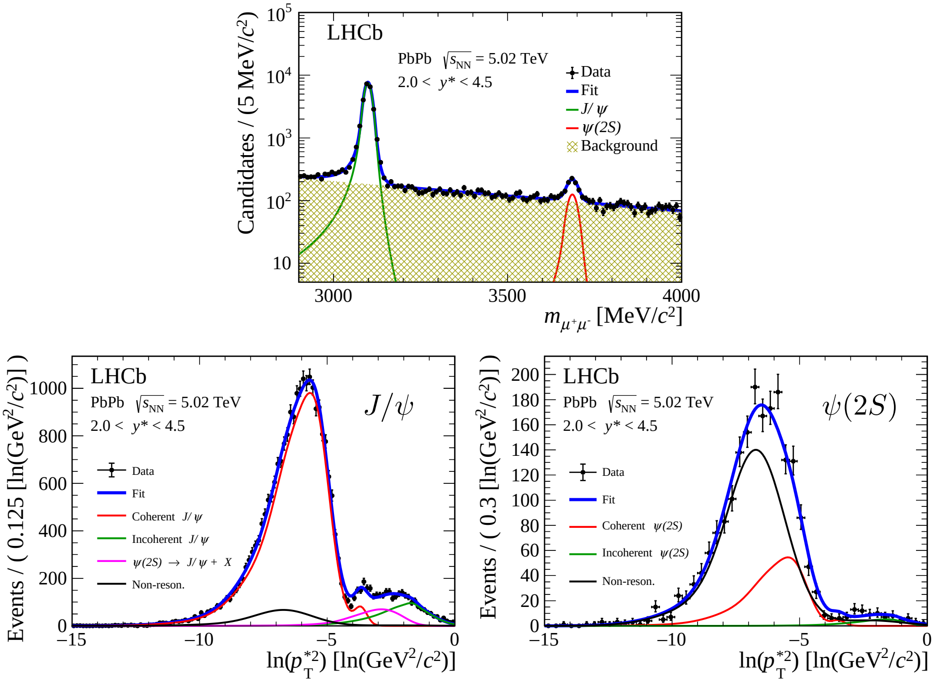

Fig. 1. Fit to the invariant mass distribution of dimuon candidates (top) and the $\ln(p_T^{*2})$ distribution fit of dimuon candidates within the $2.0 < y^* < 4.5$ range for J/ψ candidates (bottom left) and $\psi(2S)$ candidates (bottom right), where the starred notation indicates that the observable is defined in the nucleus–nucleus centre-of-mass frame.

extraction is done through two steps. A fit on the dimuon-invariant mass spectrum is needed to estimate the non-resonant background yields within the J/ψ and $\psi(2S)$ mass windows, then the fits to J/ψ and $\psi(2S)$ transverse momentum distributions of selected candidates are performed to determine the coherent production events from the inclusive charmonia yields, as shown in Fig. 1.

The measured differential cross sections as a function of y^* and p_{T}^* of coherent J/ψ and $\psi(2S)$ are shown in Fig. 2, where the starred notation indicates that the observable is defined in the nucleus–nucleus centre-of-mass frame. The differential cross-section ratio of coherent $\psi(2S)$ to J/ψ production is calculated as a function of rapidity for the first time and shown in Fig. 3. Compared with theoretical predictions, which are grouped as perturbative QCD calculations [6, 7] and colour-glass-condensate (CGC) models [8–15], the measurements can be found in agreement with most of the prediction curves in general.

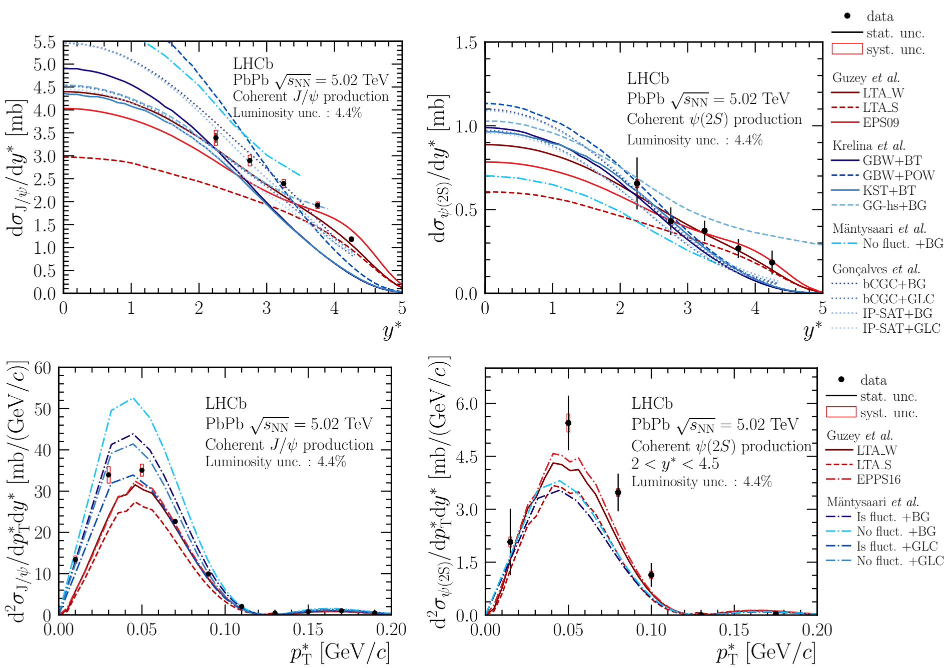

Fig. 2. Differential cross section as a function y^* (top) and p_{T}^* (bottom) for coherent J/ψ (left) and $\psi(2S)$ (right) production, compared to theoretical predictions, which are grouped as perturbative QCD calculations (red lines) and colour-glass-condensate models (blue lines).

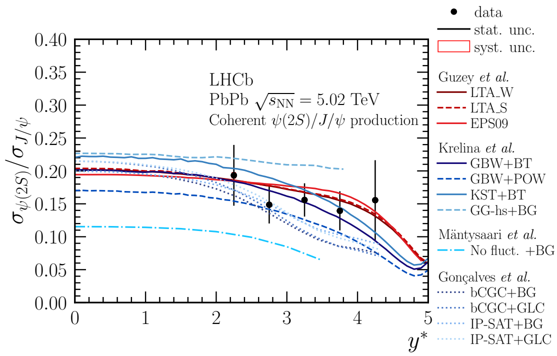

Fig. 3. Differential cross-section ratio of $\psi(2S)$ to J/ψ as a function of y^*, compared to theoretical predictions, which are separated into perturbative QCD calculations (red lines) and colour-glass-condensate models (blue lines).

3. Study of J/ψ photo-production in PbPb peripheral collisions at $\sqrt{s_{NN}} = 5$ TeV [16]

In peripheral collisions, the impact parameter is less than the sum of radii of the two colliding nuclei, so there is not only photo-nuclear interaction but also hadronic interaction. For hadronic productions, the gluon–gluon interaction produces a pair of charm quarks and lastly goes into the J/ψ meson. In this case, J/ψ meson will have transverse momentum typically between 1 and 2 GeV/c, and for coherent photo-production, J/ψ would have a very small transverse momentum, less than 300 MeV/c. Thanks to the high precision of the LHCb experiment, there are two visible clear peaks in the distribution of dimuon $\ln(p_{\mathrm{T}}^{*2})$, which could be used to discriminate photo-produced and hadronically produced J/ψ, as shown in Fig. 4.

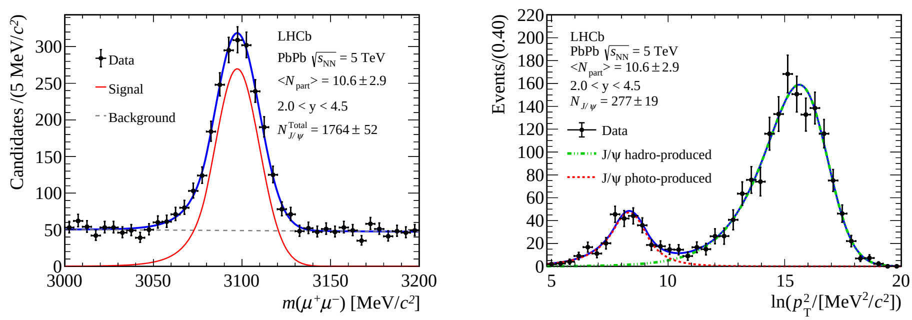

Fig. 4. Fit to the invariant mass spectrum of J/ψ candidates (left) and the $\ln(p_{\mathrm{T}}^2)$ distribution fit for J/ψ candidates (right).

The differential photo-production yields of J/ψ *versus* the rapidity, the number of participants in the collision, and the double-differential J/ψ photo-production yields *versus* transverse momentum are shown in Fig. 5. For the phenomenological models, one scenario does not consider the destructive effect due to the overlap between the two nuclei, whereas the other takes it into account. In general, the trends of J/ψ photo-production measurements and theoretical predictions are consistent. Meanwhile, the two theoretical curves do not show a significant difference because the collisions are peripheral and the nuclear overlapping effect is expected to increase in more central collisions. Currently, the measurement is limited to low values of N_{part} due to detector limitation, and the measurement of p_{T} is consistent with the coherent J/ψ photo-production; the peak value of transverse momentum is around 60 MeV$/c$.

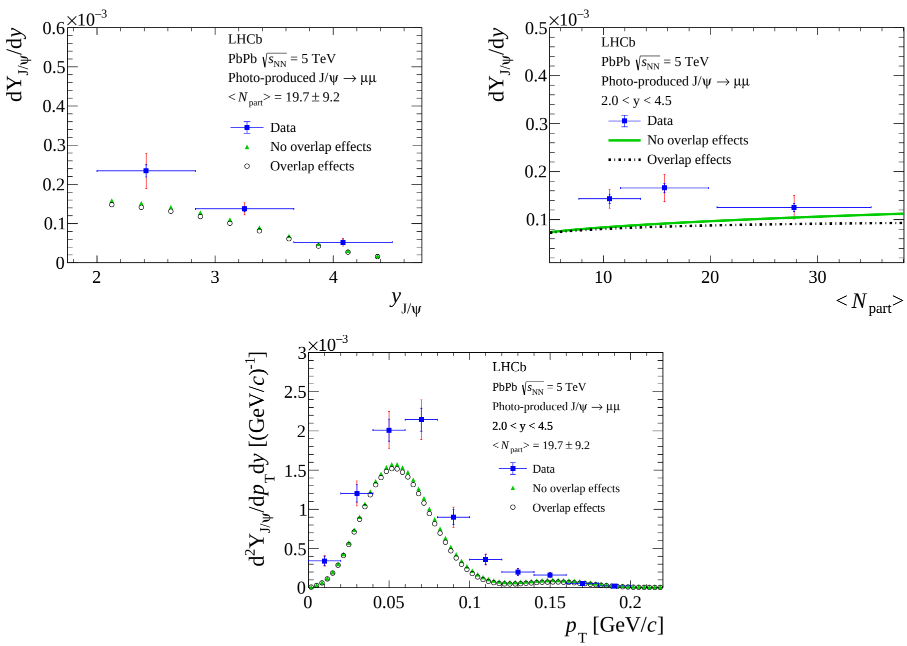

Fig. 5. The results of the differential photo-production yields of J/ψ *versus* the rapidity and the number of participants in collisions. Double-differential yields of the coherent J/ψ produced in peripheral PbPb collisions as a function of p_{T} (bottom).

4. Conclusion

We report the results of coherent J/ψ, $\psi(2\text{S})$ production cross sections in UPCs, as well as their ratio. It is the first coherent $\psi(2S)$ and $\psi(2S)$ to J/ψ ratio measurement in forward rapidity region for UPC at the LHC, and the differential cross section of coherent J/ψ and $\psi(2S)$ production in PbPb UPC is also measured as a function of p_{T}^{*} for the first time. Also, it is the most precise measurement of J/ψ production in UPCs. The production of photo-produced J/ψ mesons in peripheral PbPb collisions is measured and by far, it is the most precise coherent photo-produced J/ψ by the LHCb.

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