Quarkonia production in ultra-peripheral PbPb collisions at LHCb

Xiaolin Wang[1,*] on behalf of the LHCb collaboration

[1]South China Normal University

Abstract. Quarkonia production in ultra-peripheral PbPb collisions at a nucleon-nucleon centre-of-mass energy of 5.02 TeV had been studied at LHCb using the 2015 and 2018 datasets, separately. While only J/ψ production studies could be done in 2015, thanks to the increased statistics of the 2018 data sample, $\psi(2S)$ has been accessed as well.

1 Introduction

The ultra-peripheral collision (UPC) occurs when the distance between two colliding nuclei centers is greater than the sum of their radii. In this process the colliding nuclei remain intact. With the emission of intense electromagnetic fields by the colliding nuclei and the exchange of colorless particles, photon-nucleus interactions can be studied. In particular, measurements of quarkonia production in UPC play an important role in studying the mechanism of vector meson production, the study of nuclear PDFs, and the search for exotic phenomena. Meanwhile, coherent photo-production, in which the photon interacts with a pomeron emitted by the whole nucleus, provides an excellent laboratory to study nuclear shadowing effects and the initial state of heavy-ion collisions at small-x at the LHC [1].

Experimentally, LHCb is an excellent detector for UPC studies, as it is fully instrumented with a pseudorapidity coverage from 2 to 5, operates in low pile-up conditions, and has special low-multiplicity and low p_T triggers. In lead-lead collisions, the number of visible interactions per bunch-crossing in LHCb is very small, resulting in rich samples of UPC data. Besides, in 2015, a new sub-detector, HeRSCheL [2], consisting of five planes of scintillator was installed on both sides of LHCb in the LHC tunnel to extend the pseudorapidity region to include $5 < |\eta| < 10$ and remove those backgrounds from which the nuclei dissociate and have the large momentum. The physics improvement that HeRSCheL brings was crucial during the measurement of charmonium productions in lead-lead UPC collisions. In this article, the LHCb measurement of J/ψ and $\psi(2S)$ production with 2018 data will be discussed and compared to that performed in 2015.

2 Charmonia production in ultra-peripheral PbPb collisions at LHCb [3]

Candidates for J/ψ and $\psi(2S)$ are reconstructed in UPC PbPb collisions considering the $J/\psi \rightarrow \mu^+\mu^-$ and $\psi(2S) \rightarrow \mu^+\mu^-$ decay channels and using data sample corresponding to an

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*e-mail: xiaolin.wang@cern.ch

integrated luminosity of $228 \pm 10\,\mu\mathrm{b}^{-1}$, which was collected by the LHCb detector in 2018. Dimuon candidates are selected requiring the two reconstructed muons with an invariant mass consistent with that of the J/ψ and $\psi(2S)$ mesons. Because there is no nucleus breakup in the process of coherent J/ψ production, all we have in the detector is two long tracks, and no additional particles. For the same reason, only those with low transverse momentum could be kept in the selection, typically less than 1 GeV, and the two muons are required to be almost back to back in transverse space.

As the invariant mass and transverse momentum distributions are different between the signal and background yields, we could distinguish and extract the signal events through the fit of these distributions, as shown in Fig. 1.
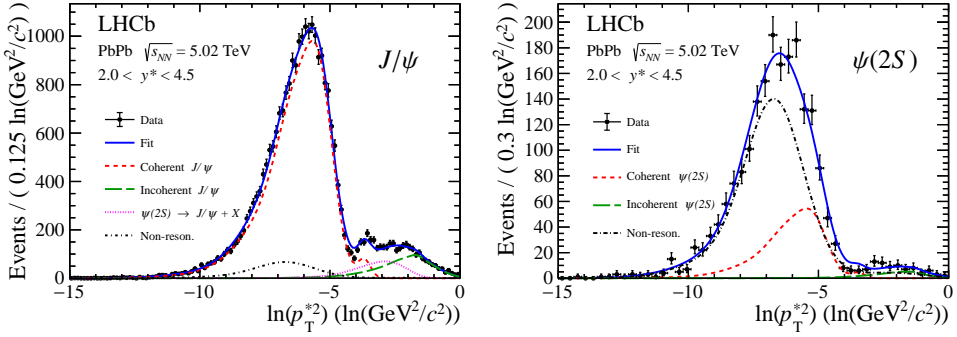

Figure 1. The $\ln(p_T^{*2})$ distribution fit of dimuon candidates within the $2.0 < y^* < 4.5$ range for J/ψ (left) and $\psi(2S)$ (right), where the starred notation indicates that the observable is defined in the nucleus-nucleus centre-of-mass frame.

The measured differential cross sections as a function of y^* and p_T^{*2} of coherent J/ψ and $\psi(2S)$ are shown in Fig. 2 and Fig. 3. One can see that the error for the J/ψ case is very small because we do have relatively large statistics. It is the most precise measurement to date. The products of the cross-section times branching fractions for the mesons decay to dimuons, where both muons are in the pseudorapidity range $2.0 < \eta < 4.5$, are measured to be

$$\sigma_{J/\psi}^{coh} = 5.965 \pm 0.059 \pm 0.232 \pm 0.262 \text{ mb and}$$
$$\sigma_{\psi(2S)}^{coh} = 0.923 \pm 0.086 \pm 0.028 \pm 0.040 \text{ mb },$$

where the first uncertainties are statistical, the second are systematic, and the third are due to the luminosity determination. 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. 4. The ratio is measured to be $\sigma_{\psi(2S)}/\sigma_{J/\psi} = 0.155 \pm 0.014 \pm 0.003$, where the luminosity contribution cancels in the ratio. Compared with theoretical predictions, which are grouped as perturbative-QCD calculations [4–6] and colour-glass-condensate (CGC) models [7–12], it could be found that the measurements are in agreement with most of the prediction curves. By looking at the cross-sections evolution in Fig. 2 and Fig. 3, pQCD models appear to describe with more precision the data. With increased statistics, better discrimination between models will be possible.

Besides comparing with theoretical predictions, the measurement results are also compared with the results from LHCb published using the 2015 dataset, from the ALICE, and CMS publications [13–15], together with the total uncertainties in Fig. 5. The compatibility between LHCb 2015 and 2018 measurements is about 2σ.
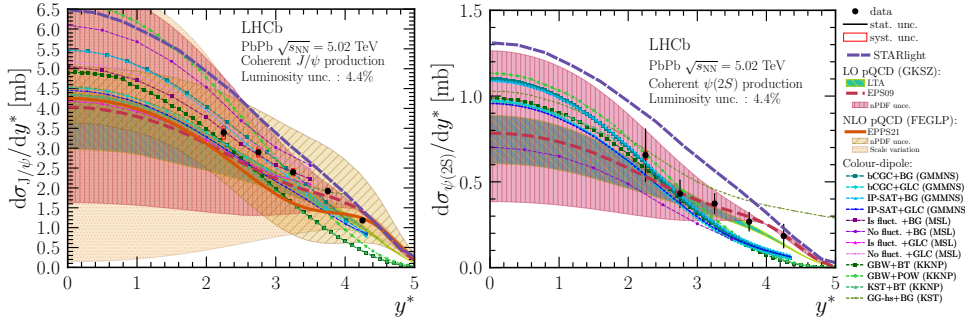
Figure 2. Differential cross-section as a function y^* for coherent J/ψ (left) and $\psi(2S)$ (right) production in UPC, compared to theoretical predictions [4–12].
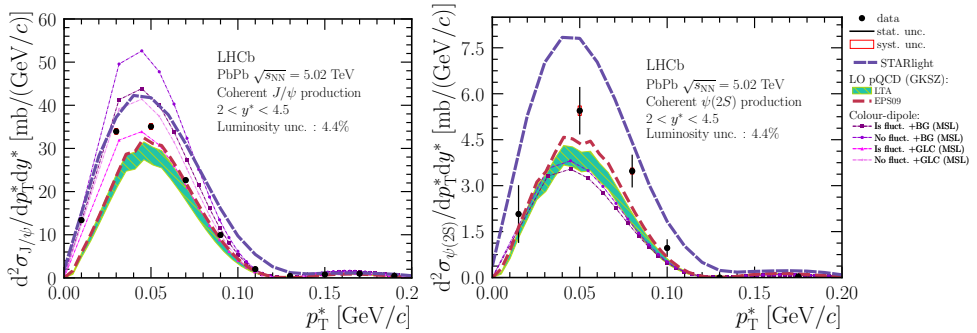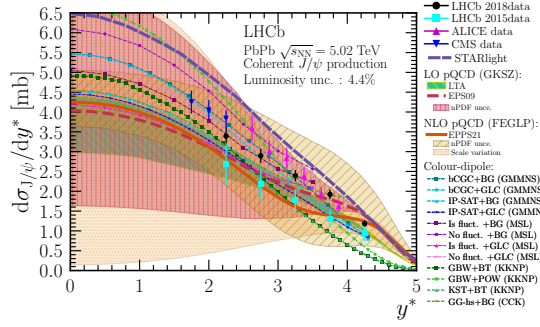

Figure 3. Differential cross-section as a function of p_T^* in the rapidity range $2 < y^* < 4.5$ for coherent J/ψ (left) and $\psi(2S)$ (right) production in UPC, compared to theoretical predictions [4, 5, 9, 10].
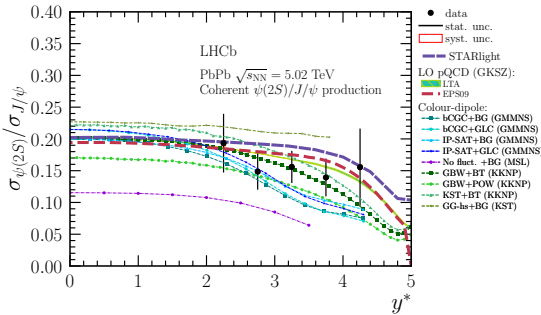
Figure 4. Differential cross-section ratio of $\psi(2S)$ to J/ψ coherent production in UPC as a function of y^*, compared to theoretical predictions [4, 5, 7–12].

3 Conclusion

In this contribution, the most precise measurement of the exclusive coherent J/ψ and $\psi(2S)$ production in lead-lead UPCs for the forward region at 5.02 TeV is presented. The obtained results as a function of y^* and p_T^* are compared to theoretical models based on pQCD or CGC calculations, with the former category slightly preferred by the data. The achieved precision

Figure 5. Differential cross-sections as a function of rapidity for coherent J/ψ production in UPC compared to previous measurements at LHCb [13], ALICE [14] and CMS [15]. The measurements are shown as dots, squares, and triangles, where the error bars represent total uncertainties, theoretical predictions from [4–12] are also shown.

of the experimental results is such that strong constraints on theoretical models fine-tuning are provided.

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