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Quarkonia production in ultra-peripheral PbPb collisions at LHCb

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The exclusive coherent quarkonia photo-production in (ultra-)peripheral collisions is sensitive to the partonic structure of nuclei, to the choice of the vector meson wave function and to the profile of coherence of the interactions. LHCb has a good capability to measure coherent J/ψ and ψ(2*S*) photo-production in (ultra-)peripheral PbPb collisions at a nucleon-nucleon centre-of-mass energy of 5.02 TeV at the forward rapidity region. In this document, we will present the measurement of coherent J/ψ and ψ(2*S*) photo-production in ultra-peripheral PbPb collisions and coherent J/ψ photo-production in peripheral PbPb collisions at LHCb, as well as the respective comparison with the latest theoretical predictions. Prospects for future quarkonia photo-production measurements at LHCb will be discussed.

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1. Introduction

Relativistic heavy-ion collisions provide a rich and fruitful field to investigate the nucleus structure. Ultra-peripheral collisions (UPCs) occur when two nuclei collide with an impact parameter larger than the sum of their radii [1]. In UPCs, the hadronic interactions are strongly suppressed, while the electromagnetic interactions dominate. Thus, the formation of a quark-gluon plasma (QGP) is not expected, and the final-state particles can be efficiently reconstructed with very low multiplicity. Peripheral collisions (PCs) occur when the impact parameter is between one and two times the radius of the nucleus. In PCs, both hadronic interactions and photon-nuclear interactions are expected at the same time. The coherent photo-production can be described as the interaction of a photon with a pomeron emitted by the entire nucleus, while the incoherent process involves the interaction with a single nucleon. Studying the coherent charmonium photo-production in UPCs helps to constrain the gluon distribution functions in the nucleus at a hard momentum transfer (Q^2) about $m^2_{J/\psi}/4$. The cross-section ratio of coherent charmonium photo-production contributes to constraining the choice of the vector meson wave function in dipole scattering models [2]. The precise measurement of coherent J/ψ photo-production in PCs sheds light on the coherence of the interaction and the profile of the photon flux [3].

The LHCb detector is a fully instrumented single-arm spectrometer in the forward region covering a pseudorapidity acceptance of $2 < \eta < 5$, providing precise vertex reconstruction and excellent tracking momentum resolution down to a very low transverse momentum [4]. Thanks to the flexibility of the LHCb detector and its data processing strategy, LHCb is now a general-purpose experiment and particularly allows several analyses of heavy-ion interest. For UPC physics, the HeRSCheL detector is used to classify events in high pseudorapidity region ($5 <| \eta |< 10$) [5].

2. Study of charmonium production in ultra-peripheral PbPb collisions at LHCb

The exclusive coherent J/ψ and $\psi(2S)$ photo-productions in PbPb UPCs at a nucleon-nucleon centre-of-mass energy of 5.02 TeV are measured using a data sample collected by the LHCb experiment in 2018 corresponding to an integrated luminosity of $228 \pm 10\,\mu b^{-1}$ [6]. The J/ψ and $\psi(2S)$ candidates are reconstructed through the decays $J/\psi \to \mu^+\mu^-$ and $\psi(2S) \to \mu^+\mu^-$, within the rapidity range $2.0 < y^* < 4.5$, where y^* represents the rapidity in the nucleus-nucleus centre-of-mass frame.

The measured differential cross-sections for coherent J/ψ (left) and $\psi(2S)$ (right) photo-production as a function of y^* and p_T^* are shown in Fig. 1 and Fig. 2, respectively. The cross-section ratio of coherent photo-production between $\psi(2S)$ and J/ψ as a function of y^* is shown in Fig. 3. Results are compared to several theoretical predictions. The models grouped in red are based on perturbative QCD (pQCD) calculations under the leading-logarithm approximation, with different assumptions on the nuclear shadowing effect [7, 8] . They well describe the J/ψ and $\psi(2S)$ cross-sections as a function of y^*, especially at the high values and the cross-section ratio in Fig. 3. On the other hand, data for both J/ψ and $\psi(2S)$ are underestimated in the low rapidity region and as a function of p_T^*. The models grouped in blue are colour-dipole models based on the colour-glass-condensat (CGC) theory, with different tuning options for sub-nucleon fluctuation and different choices for the boosted–Gaussian (BG) or the Gauss-LC (GLC) vector-meson wave function [9–

14]. They are in good agreement with data at low rapidity, but the normalization factor should be tuned for the cross-sections as a function of p_T^* and their ratio as a function of y^*.

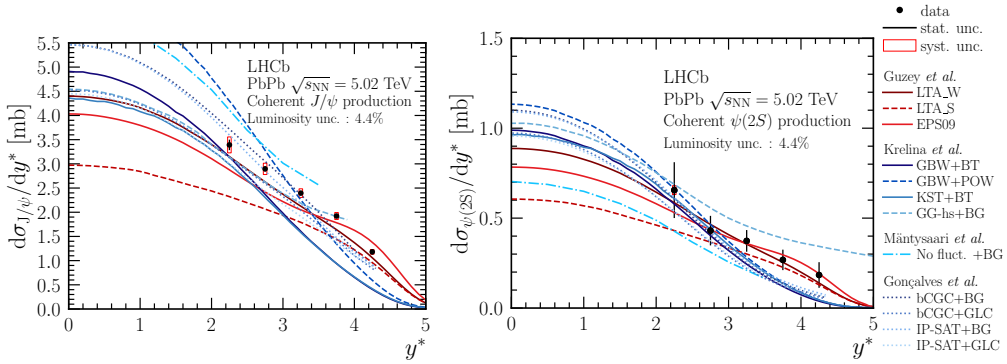

Figure 1: Differential cross-section as a function of y^* for coherent J/ψ (left) and ψ(2S) (right) photo-production, compared to theoretical predictions.

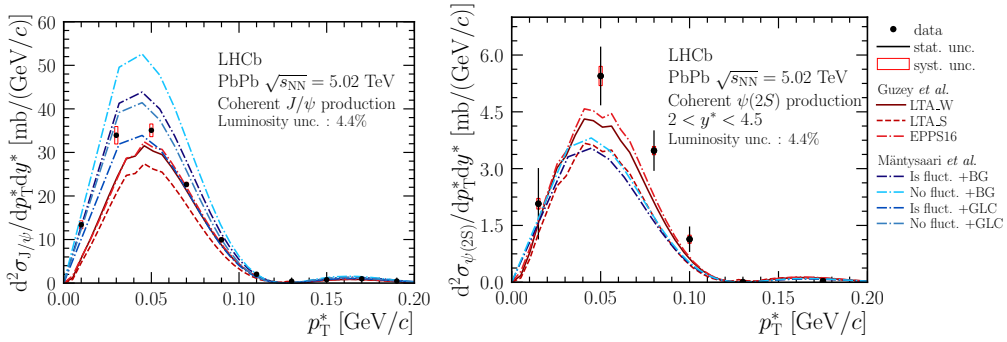

Figure 2: Differential cross-section as a function of p_T^* within the rapidity range $2 < y^* < 4.5$ for coherent J/ψ (left) and ψ(2S) (right) photo-production, compared to theoretical predictions.

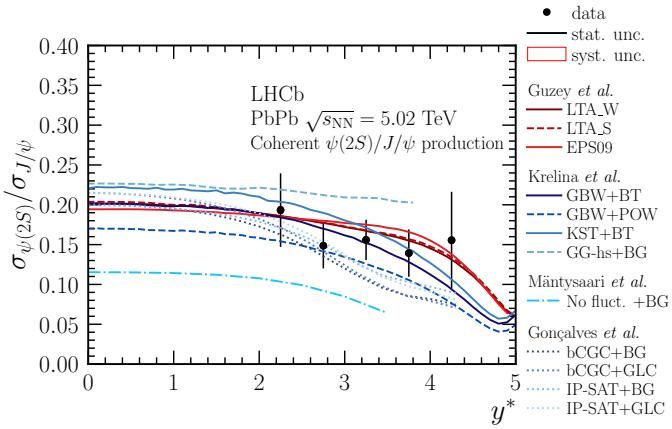

Figure 3: Differential cross-section ratio of ψ(2S) to J/ψ coherent photo-production as a function of y^*, compared to theoretical predictions.

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

The coherent J/ψ photo-production in PCs is measured at LHCb using 2018 PbPb data samples, with the centrality limited to 60-90% [15]. The J/ψ candidates are reconstructed through the decay channel of J/ψ $\rightarrow \mu^+\mu^-$ with $p_{\mathrm{T}} < 15.0\,\mathrm{GeV}/c$. A minimum energy deposit in the electromagnetic calorimeter (ECAL) is required to avoid UPC contamination ($E_{tot} > 585\,\mathrm{GeV}$).

The differential yields of J/ψ photo-production as a function of rapidity (y), the number of participants in the collisions ($\mathrm{N_{part}}$), and the double-differential yields as a function of transverse momentum (p_{T}) are shown in Fig. 4. The results are compared to theoretical prediction [16, 17] assuming two scenarios that include or do not include the overlap effect of the two colliding nuclei. The trend of the results can be described qualitatively by the theoretical calculations. The difference between these two scenarios is small in peripheral collisions but would become significant in central collisions.

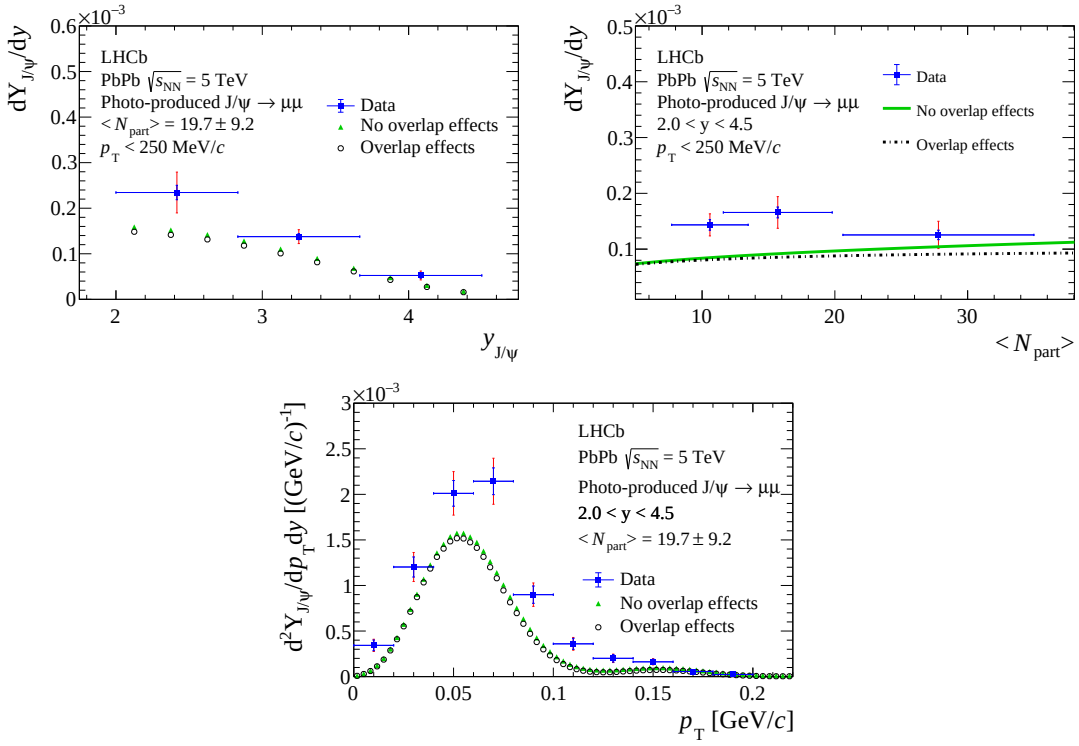

Figure 4: Differential yields of photo-produced J/ψ candidates as a function of y (top left), number of $\mathrm{N_{part}}$ (top right), and double differential yields as a function of p_{T} (bottom), compared with theoretical predictions.

4. Summary and outlook

The LHCb experiment has a good capability in UPC physics. A large number of exclusive coherent charmonium photo-productions are measured at LHCb in (ultra-)peripheral PbPb collisions using a data sample in 2018. These are the most precise measurements for coherent J/ψ photo-productions in UPCs and PCs at forward rapidity to date, including the first measurement of the cross-section ratio as a function of rapidity and the cross-section as a function of transverse

momentum. The high precision results are compatible with theoretical predictions, and contribute to set constraints on the fine-tuning of the models. More measurements of photo-production in UPCs with LHCb Run2 PbPb datasets are ongoing, such as the photo-production of light mesons (ϕ, ρ). With the fixed-target program at LHCb and the upcoming Run3 high luminosity, future UPC analyses are expected to be performed.

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