PROCEEDINGS OF SCIENCE

Exclusive Charmonium production in PbPb and pp collisions at LHCb

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At the LHC, the highly boosted electromagnetic field of the beam particles represents a source of quasi-real photon. Vector meson photo-production measurements in pp/PbPb collisions are sensitive to the gluon parton distribution functions in the proton/nucleus. LHCb results on charmonium production in ultra-peripheral PbPb collisions at 5.02 TeV and in pp collisions at 13 TeV will be presented.

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1. Introduction

Central Exclusive Production (CEP) events are characterized as low activity collisions with an isolated system of particles surrounded by two rapidity gaps extending down to the intact colliding protons ($p\ p \rightarrow p\ p\ J/\psi$). CEP of vector mesons can also be measured in PbPb collisions when the impact parameter of the two nuclei is greater than the sum of their radii and where an emitted photon from the projectile nucleus interacts coherently to all nucleons, or incoherently to a single nucleon. Here we will discuss the coherent measurement, where both nuclei stay intact. In those collisions, J/ψ photo-production is more likely to happen as the photon flux grows with Z^2 (where Z is the number of proton inside the nucleus). At the LHC energy, those measurements at forward rapidity are sensitive to the gluon partonic distribution functions (PDF) at very low fractional momentum ($x \simeq (m_{J\psi}/\sqrt{s})e^{\pm y} \simeq 10^{-6} - 10^{-2}$, with $m_{J/\psi}$ the mass of the J/ψ, $\sqrt{s}$ the center-of-mass energy of the collision and y the rapidity of the produced particle). More generally, both in pp and PbPb, CEP measurements allow a better characterization of the strong interacting structure of hadronic matter.

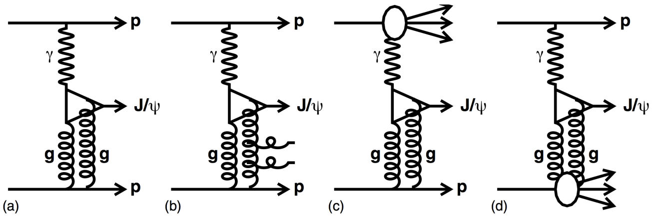

Figure 1: Illustrations of photo-induced J/ψ production: (a): Exclusive production of a vector meson in a proton-proton system (CEP), (b): diffractive production, (c) and (d): inelastic production with proton destruction [1]

Event activity is vetoed both in the forward ($2 < \eta < 5$) and backward region ($-3.5 < \eta < -1.5$) using the VErtex LOcator (VELO) detector [10] , a silicon strip detector that surrounds the interaction. In addition, an extra detector has been added for run 2; the HeRSCheL detector [2], this detector allows to apply a veto to differentiate exclusive from diffractive and inelastic event, by adding counters at very high rapidity ($-7.5 < \eta < -3.5$ and $5.0 < \eta < 8.0$ [1]).

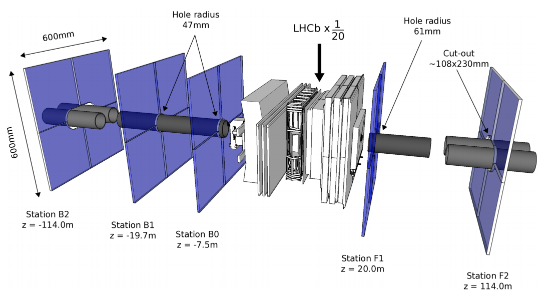

Figure 2: Scaled representation of the HerSCHeL detector, A High Rapidity Shower Counter for LHCb, 5 stations each made of 4 plastic scintillator panels. [1].

LHCb measurements of CEP to date have concentrated on final states muons. This report will focus on charmonium production (J/ψ and $\psi(2S)$) in pp collisions at $\sqrt{s} = 13$ TeV and J/ψ in

PbPb collisions at $\sqrt{s} = 5.02$ TeV.

2. Photo-production of J/ψ, $\psi(2S)$ in pp collisions at $\sqrt{s} = 13$ TeV

J/ψ and $\psi(2S)$ yields have been measured using their decay into dimuons. The signal extraction for CEP is done using the following criteria; two reconstructed muons inside the LHCb acceptance, no additional tracks or energy deposit in the calorimeters, a dimuon invariant mass within 65 MeV/c^2 of the invariant mass of the J/ψ or the $\psi(2S)$, a dimuon squared transverse momentum below 0.8 GeV$^2/c^2$ (photo-produced mesons are expected to have a very low transverse momentum) and a requirement that vetoes the event if activity is seen in the HerSCHeL detector (see Figure 3).

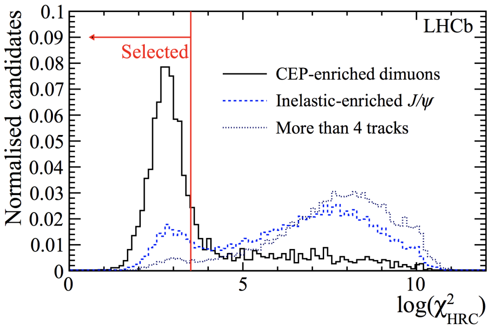

Figure 3: The HRC figure of merits. The variable $log(\chi^2)$ is a proxy variables for the HerSCHeL activity (see [2] for more details).

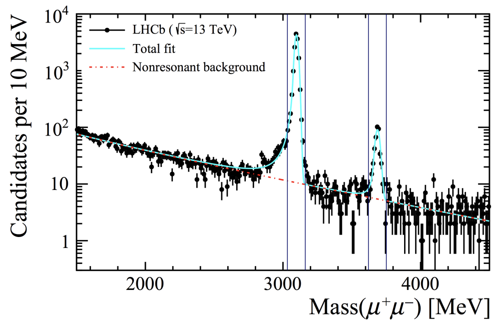

Figure 4: Invariant mass distribution of dimuon candidates. The J/ψ and $\psi(2S)$ mass windows of the signal regions are indicated by the vertical lines [2].

J/ψ and $\psi(2S)$ peaks are visible in Figure 4. The total number of J/ψ ($\psi(2S)$) candidates is $\sim$ 13000 ($\sim$ 380). Background contaminations come from QED production of dimuons via photon propagators and gives a contamination fraction in the signal extraction of 0.009 for J/ψ and 0.05 for $\psi(2S)$. In the case of the J/ψ, feed-down contributions coming from the χ_c and the $\psi(2S)$ are estimated and corrected using Monte Carlo simulations.

A good way to compare with theory is to compute the cross-section in different rapidity bins, $\frac{d\sigma(\mathrm{pp}\to\mathrm{pp}+J/\psi)}{dy} = \frac{P\,N}{\varepsilon \Delta y L_{tot}}$; where P is the purity of the signal, N is the number of selected event, ε is the efficiency, Δy is the width of the rapidity bin and L_{tot} is the integrated luminosity. Results are compared with the Leading Order (LO) and Next to Leading Order (NLO) predictions from JRMT model (Jones, Ryskin, Martin and Teubner [3]). A better agreement between data and theory is found with the NLO ones. Figure 6 shows the comparison between all the experiment with respect to W (center of mass energy of the system proton-photon), this measurement has been first made by the collaboration HERA. All the results are in agreement with the power law derived from the first HERA measurement [2].

3. Photo-production of J/ψ, $\psi(2S)$ in Ultra Peripheral PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Recently, LHCb has presented the coherent J/ψ production in PbPb collisions at

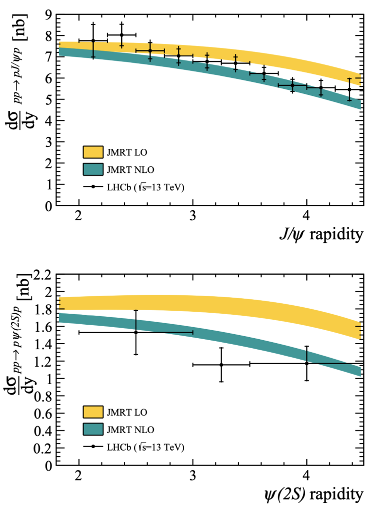

Figure 5: Differential cross-sections compared to LO and NLO theory JMRT predictions for the J/ψ meson (top) and the $\psi(2S)$ meson (bottom) [3] [4]. The inner error bar represents the statistical uncertainty; the outer is the total uncertainty [2].

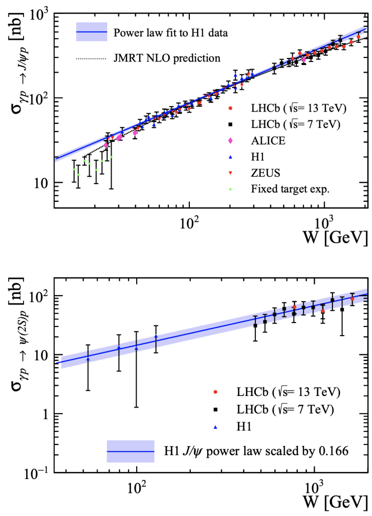

Figure 6: Compilation of photoproduction cross-sections for various experiments. The upper (lower) plot uses the J/ψ ($\psi(2S)$) data.

$\sqrt{s_{NN}}$ = 5.02 TeV. The event selection is the same as described in the previous section, except for the p_T cut ($p_T < 1.0$ GeV/c) and the HeRSCheL veto that is not yet applied. In order to suppress background from central collisions, events with more than 20 deposits in the SPD [10] or additional VELO tra cks are vetoed. Only VELO tracks that have a minimum distance of 1 mm to the J/ψ vertex are considered covering the regions of $-3.5 < \eta < -1.5$ and $1.5 < \eta < 5.0$. The signal extraction is determined in two steps; first a fit to the dimuon invariant mass spectrum (Figure 7) gives the total number of J/ψ, which includes coherent and incoherent J/ψ, and $\psi(2S)$ feed-down components. Then a fit of the J/ψ transverse momentum is done to estimate and separate the coherent form the incoherent contribution based on STARLight [9] templates (see Figure 8).

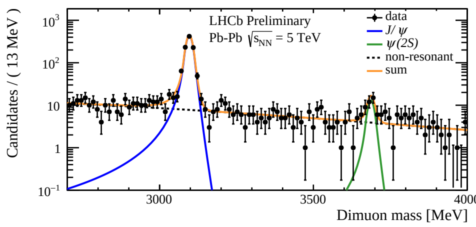

Figure 7: Fit of the dimuon invariant mass spectrum where both the J/ψ and $\psi(2S)$ resonances are visible.

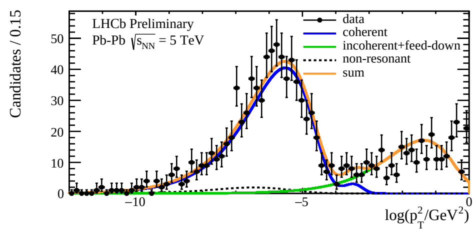

Figure 8: Fit of the dimuon $log(p_T^2/GeV^2)$ distribution.

The integrated cross-section of the coherently photo-produced J/ψ in the LHCb acceptance is $\sigma = 5.3 \pm 0.2 \pm (stat) \pm 0.5\ (syst) \pm 0.7$ (lumi mb).

As for the previous study, the results are compared to models versus rapidity in Figure 9, generally derived either from perturbative QCD or Colour-Dipole formalisms (see [6] [7] [8]). All models describe the data within the uncertainties except for one prediction that includes subnucleonic fluctuations. An update of the cross-section using HerSCHel is ongoing. The new PbPb data recorded in 2018 ($\sim$ 20 times more luminosity) will improve the precision of the measurement.

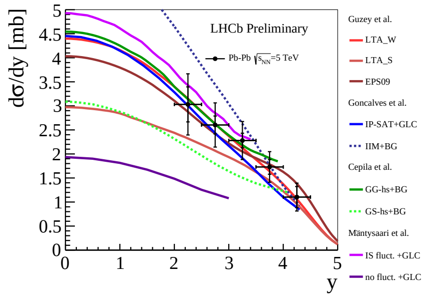

Figure 9: Differential cross-section for coherent J/ψ production compared to different phenomenological predictions. The inner error bar represents the statistical uncertainty; the outer is the total uncertainty.

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