Quarkonia Production in Ultraperipheral PbPb collisions at LHCb

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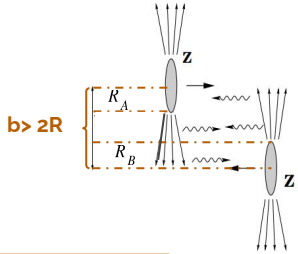
28th March, 2023

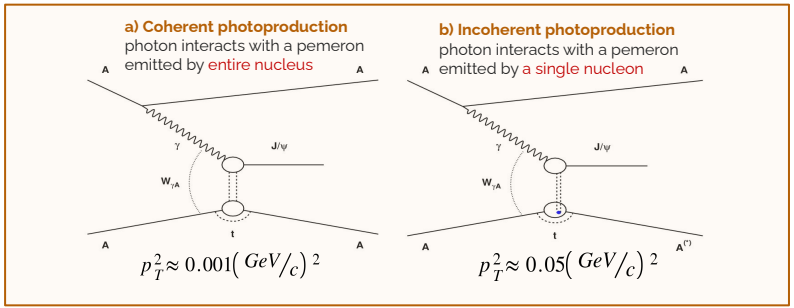
UPC v.s PC

[Phys.Rept. 458 (2008) 1-171]

Ultra-peripheral collisions:

- Occurs when impact parameter(b) is **larger** than the sum of their radii.
- Hardonic interaction strongly suppressed.
- **Photon-induced interactions** are enhanced by the strong EM field of the nucleus.

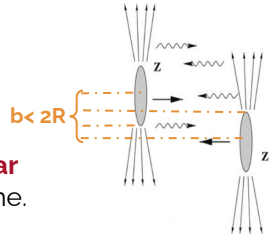


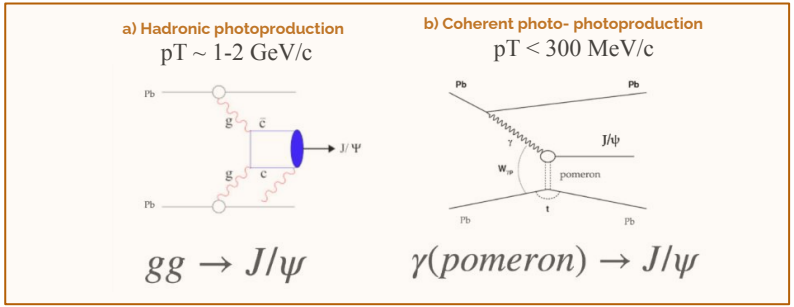


- Cross section of coherent charmoium production:
  - ➢ constrain the gluon Desity Distribution Functions in nuclear.
- Ratio of cross section of coherent charmoium production:
  - ➢ constrain the choice of the vector meson wave function in dipole scattering models. [PLB 772 (2017) 832, PRC (2011) 011902]
  - ➢ systematic and luminosity uncertainty largely cancelled out.

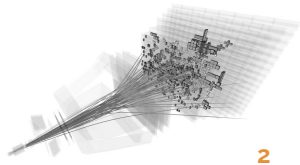
Peripheral collisions:

- Impact parameter(b) is **smaller** than the sum of their radii.
- **Hardonic interaction** and **Photon-nuclear** interactions are expected at the same time.





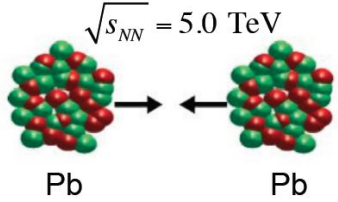
- A precise measurement of the postulated coherent J/ψ production in hadronic collisions will shed light on:
  - ➢ the coherence of the interaction
  - ➢ and the profile of the photon flux in peripheral Pb-Pb collisions



The LHCb detector

[Int. J. Mod. Phys. A 30, 1530022 (2015)]

- Single arm forward spectrometer fully instrumented in pseudo-rapidity range **2 < η < 5**.
- Design for the study of particles containing b or c quarks.
- Can also use for ***heavy ion studies.***

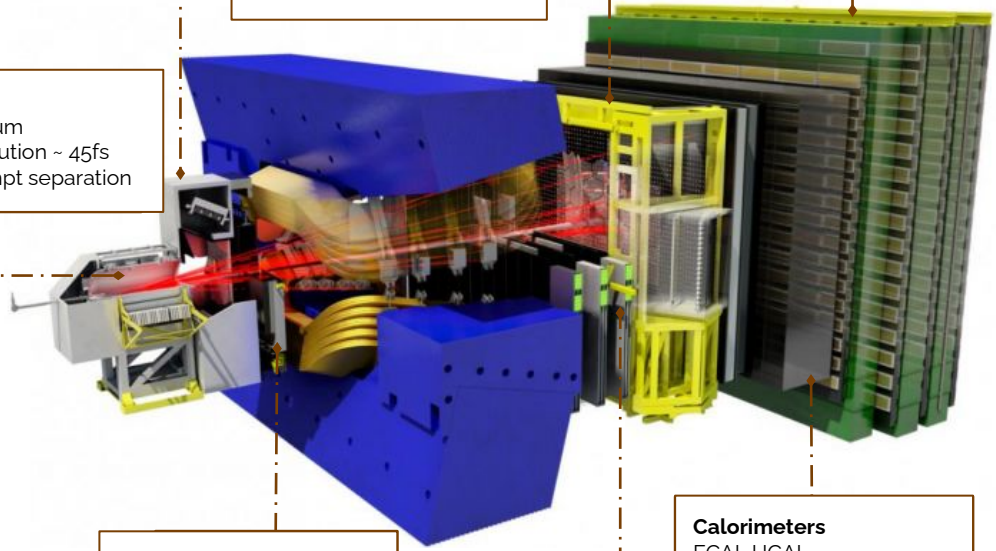


Data Taking	2015 PbPb	2018 PbPb
Luminosity	$10\mu b^{-1}$	$228\mu b^{-1}$

Cherenkove Dectectors
K/p/π separation
ε(K→K)~95%
ε(π→K)~5% misID

Muon Station
hardware μ trigger
ε(μ→μ)~97%, ε(π→μ)~ 1–3% misID

Vertex Locator
IP resolution~20μm
decay time resolution ~ 45fs
prompt/no prompt separation



Tracking System
TT and OT
Δp/p=0.5%–1.0%
(5GeV/c - 100GeV/c)

Calorimeters
ECAL,HCAL
e/γ identification
ΔE/E=1%⊕10%/√E(GeV)

Today's topic

UPC at LHCb:

1. Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{NN}}$=5TeV *[JHEP07(2022)117]*

2. Study of the coherent charmonium production in ultra-peripheral lead-lead collisions*[arXiv:2206.08221]*

New

PC at LHCb:

3. J/ψ photoproduction in Pb-Pb peripheral collisions at $\sqrt{s_{NN}}$ = 5TeV @**LHCb** *[Phys. Rev. C 105, L032201]*

Coherent charmonium photo-production in UPC

Analysis strategy is similar for 2015 and 2018 UPC:

- **Data sets:** PbPb collisions at 5.02 TeV at LHCb:
  - 2015 PbPb ([JHEP07 (2022) 117]) and 2018 PbPb([arXiv:2206.08221]).

- **Cross-section** of charmonium photo-production can be measured by:

$$\frac{\mathrm{d}\sigma_{\psi}^{\mathrm{coh}}}{\mathrm{d}x} = \frac{N_{\psi}^{\mathrm{coh}}}{\mathcal{L} \times \varepsilon_{\mathrm{tot}} \times \mathcal{B}(\psi \to \mu^{+}\mu^{-}) \times \Delta x} \qquad \frac{\mathrm{d}\sigma_{\psi(2S)}^{\mathrm{coh}}/\mathrm{d}y^{*}}{\mathrm{d}\sigma_{J/\psi}^{\mathrm{coh}}/\mathrm{d}y^{*}} = \frac{N_{\psi(2S)}^{\mathrm{coh}} \times \varepsilon_{J/\psi} \times \mathcal{B}(J/\psi \to \mu^{+}\mu^{-})}{N_{J/\psi}^{\mathrm{coh}} \times \varepsilon_{\psi(2S)} \times \mathcal{B}(\psi(2S) \to \mu^{+}\mu^{-})}$$

- **Event selection:**
  - Very low multiplicity in the detector, only two tracks reconstructed within LHCb acceptance region:

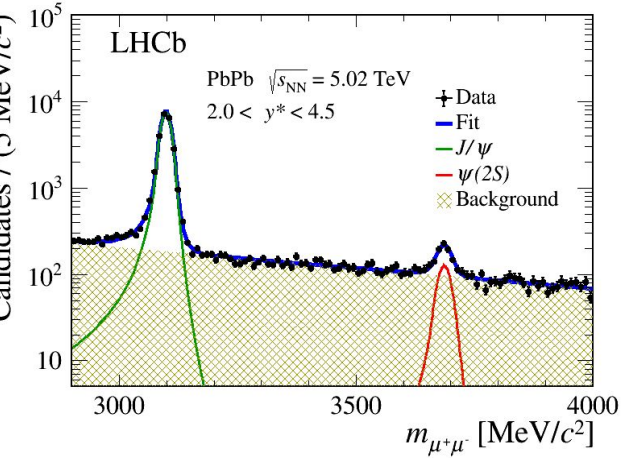
$$p_T^{\mu\mu} < 1GeV \ , \ |\Delta\phi_{\mu\mu}| > 0.9\pi$$
$$2.0 < \eta^{\mu} < 4.5 \ , \ p_T^{\mu} > 700MeV$$

  - HeRSCheL detector is used to further purify the signal candidates.

Coherent charmonium photo-production in UPC

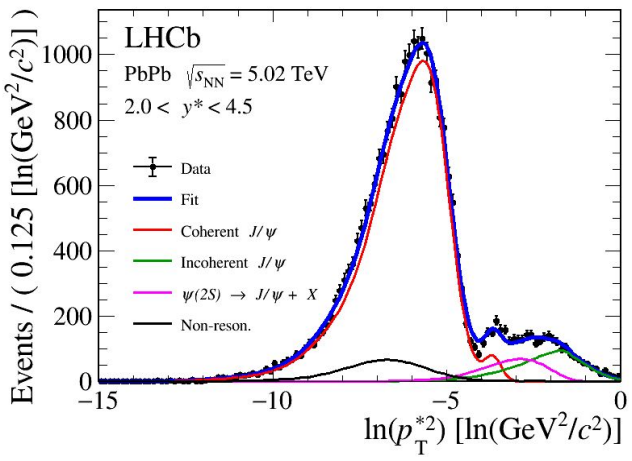
[arXiv:2206.08221]

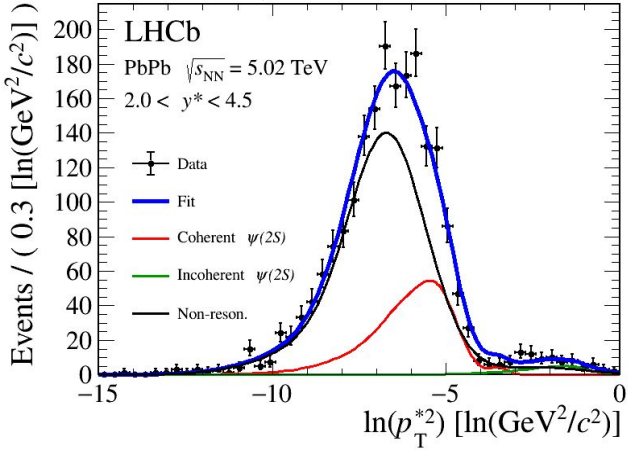
(1) Charmoina yields extracted from dimuon mass fit:



(2) Coherent yields extracted from log(p_T^2) fit:

Up to 35 times higher statistics than 2015!!





(3) Results:

1. Integrated cross-sections of coherent J/ψ and ψ(2S) photoproduction in $2.0 < y^* < 4.5$;

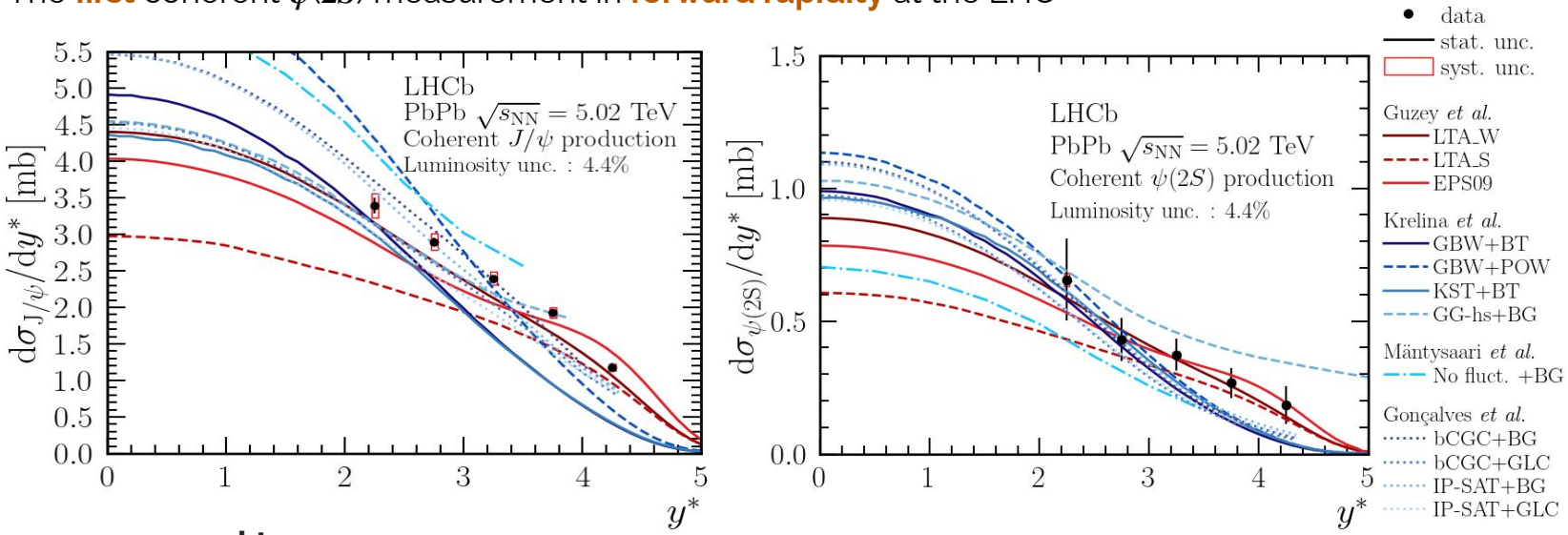
$$\sigma^{\rm coh}_{J/\psi} = 5.965 \pm 0.059\,(\text{stat.}) \pm 0.232\,(\text{sys.}) \pm 0.262\,(\text{lumi.})\ \text{mb}\,, \qquad \sigma^{\rm coh}_{\psi(2S)} = 0.923 \pm 0.086\,(\text{stat.}) \pm 0.028\,(\text{sys.}) \pm 0.040\,(\text{lumi.})\ \text{mb}$$

2. The integrated cross-sections ratio in $2.0 < y^* < 4.5$: $\sigma^{\rm coh}_{\psi(2S)}/\sigma^{\rm coh}_{J/\psi} = 0.155 \pm 0.014\,(\text{stat.}) \pm 0.003\,(\text{sys.})$ *(lumi. uncer. cancelled out)*

Coherent charmonium photo-production in UPC

[arXiv:2206.08221]

3. Diffrential cross section of J/ψ and $\psi(2S)$ as a function of rapidity:
   - The **most precise** coherent J/ψ production measurement in PbPb UPC in **forward rapidity** to date
   - The **first** coherent $\psi(2S)$ measurement in **forward rapidity** at the LHC



Results are compared to:

- **pQCD models:** nPDFs for the nuclear shadowing effect.
- **Colour-dipole models:** draw different model tuning options as theoretical variations.
- In a good agreement with data shape, normalisations are different.

Coherent charmonium photo-production in UPC

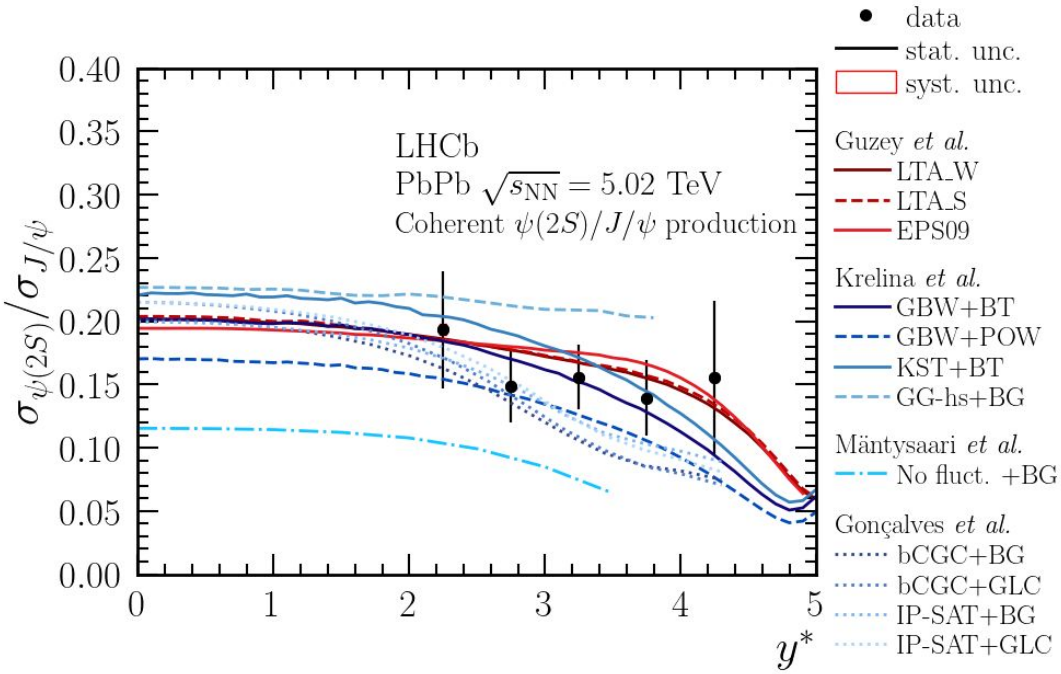
[arXiv:2206.08221]

4. Diffrential cross section ratio of $\psi(2S)$ over J/ψ as a function of rapidity:

- The **first** cross-section ratio between J/ψ and $\psi(2S)$ vs. rapidity in **forward rapidity** region at the LHC.

Results are compared to:

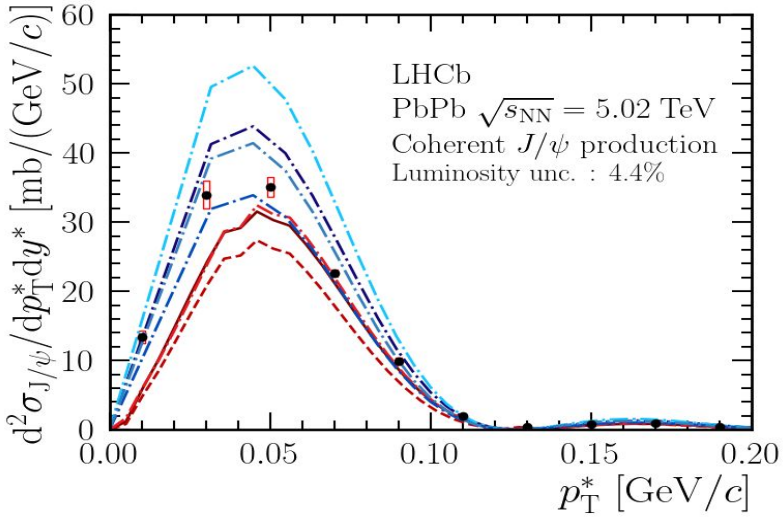
- **pQCD models:** nPDFs for the nuclear shadowing effect.
- **Colour-dipole models:** draw different model tuning options as theoretical variations.
- In a good agreement with data shape, normalisations are different.

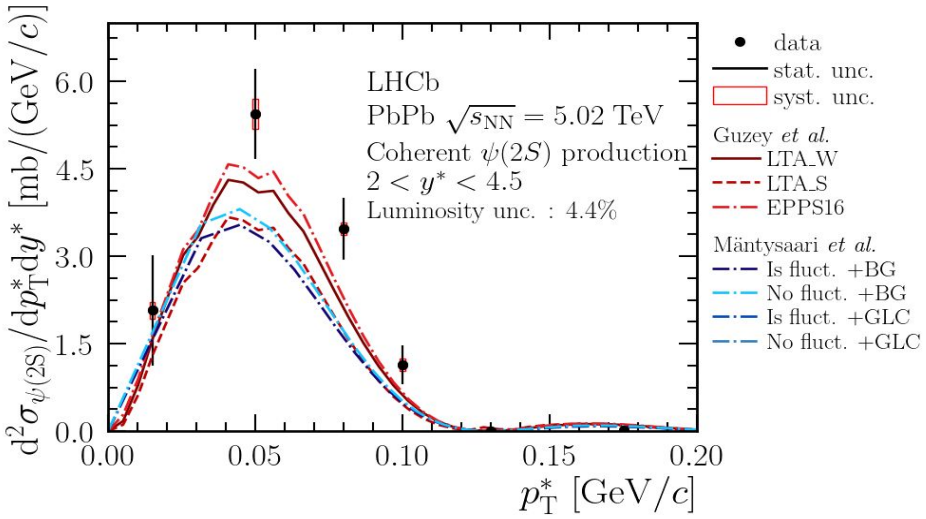


Coherent charmonium photo-production in UPC

[arXiv:2206.08221]

5. Diffrential cross section of J/ψ and $\psi(2S)$ as a function of p_T:
   - ❖ The **first** measurement of the coherent J/ψ and $\psi(2S)$ production cross-section **vs.** p_T in PbPb UPC.





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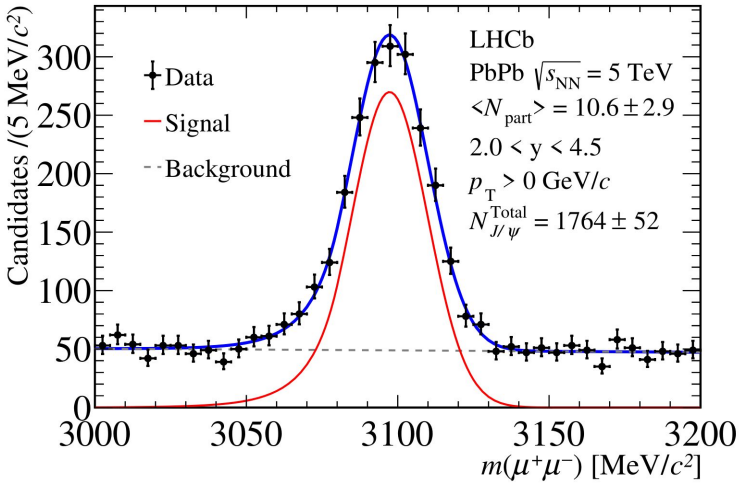
Coherent J/ψ photo-production in PC

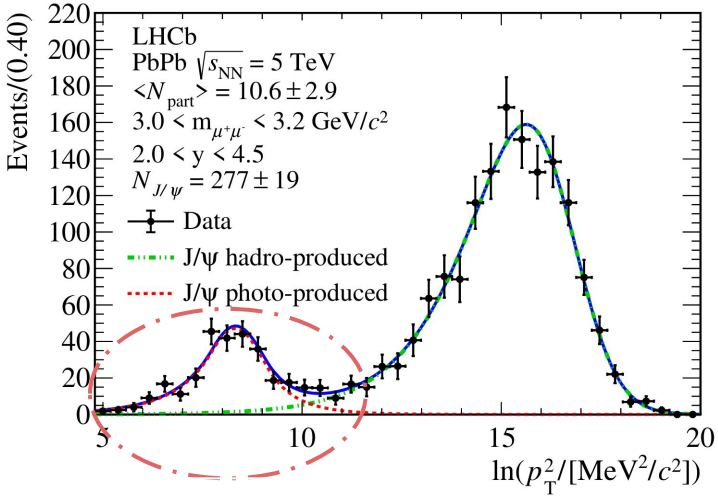
[Phys. Rev. C 105, L032201]

- **Data sets:** PbPb collisions at 5.02 TeV at LHCb in 2018, Centrality: limited to **60-90%.**
- **Event selection:**
  - A minimum energy in the ECAL calorimeter is required to avoid any UPC contamination.
  - Reconstrued with two dimuon channel with $p_T < 15$ GeV.

(1) J/ψ yields extracted from dimuon mass fit:



(2) Coherent yields extracted from $\log(p_T)^2$ fit:



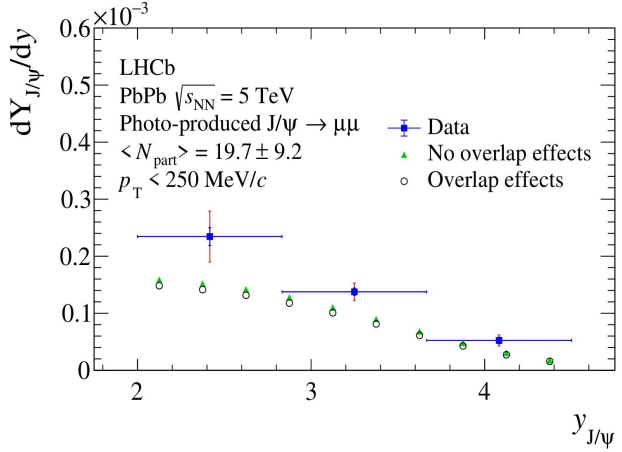
Signal

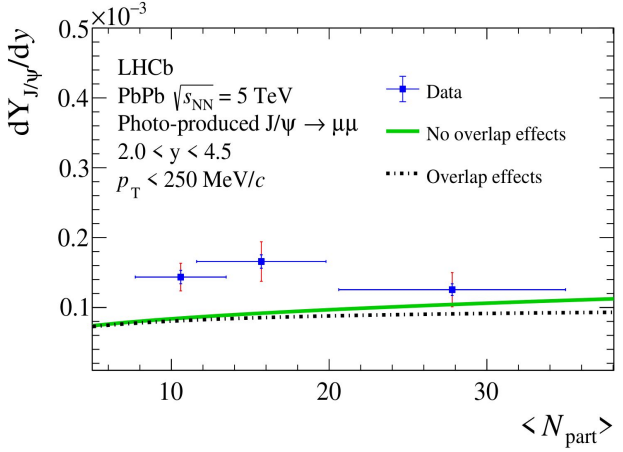
Coherent J/ψ photo-production in PC

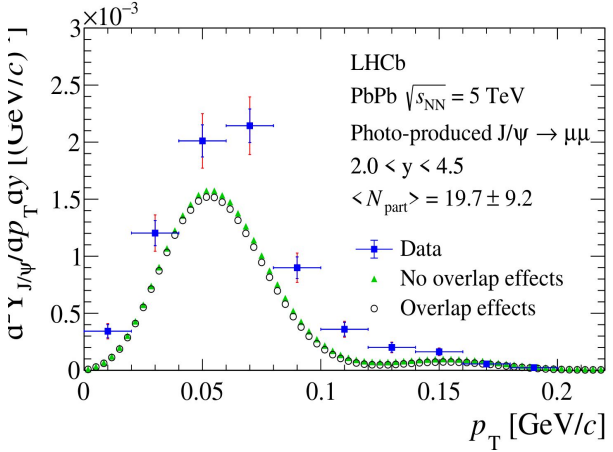
[Phys. Rev. C 105, L032201]

(3) Results:

1. Diffrential yeilds of coherent J/ψ photo-production as a function of **y, p_T, Npart:**







- **First** measurement in PbPb **hadronic** collisions at LHCb.
- Results compare with one model with two assumptions:*([W. Zha et al. Phys. Rev. C97 (2018) 044910 / Phy. Rev. C99, 06901(R)])*
  - **No overlap effects** between the nuclei (UPC-like but small IP)
  - **Overlap Effects**
- Trend is consistent, but the data is over above the predictions.

Summary

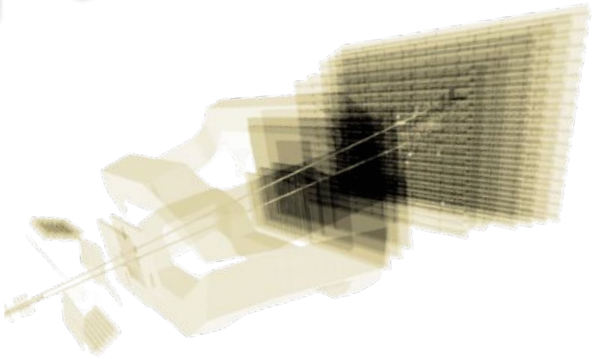
- ***LHCb has good capability in Heavy Ion program with UPC physics:***
  - **2015 UPC:** Study of coherent J/ψ production in lead-lead collisions at 5TeV
  - **2018 UPC:** Study of the coherent charmonium production in ultra-peripheral lead-lead collisions
    - The most **precise** measurement for coherent J/ψ production in PbPb UPC in the **forward** rapidity to date.
    - The **first** measurement of coherent $\psi(2S)$ vs. y, cross section ratio vs. y,, coherent J/ψ and $\psi(2S)$ vs. p_T.
    - Results are compatible with **theoretical predictions**, strong constraints for the fine-tuning of the models.

      SOON ***More theoretical models(STARlight, new NLO pQCD calculation, nPDF uncertainty, renormalization scale uncertainty, etc) is added, will come soon!!***

  - **2018 PC:** Measurement of photo-produced J/ψ in peripheral PbPb collisions
    - **First** result using PbPb **hadronic** collisions in LHCb.

- ***More promising photo-production measurement at LHCb in the future:***
  - Other photo-production measurements in UPCs are on-going: $\phi \rightarrow K^+K^-$, $\rho \rightarrow \pi^+\pi^-$, etc...
  - With Run3 high luminosity:
    - Bottomium, incoherent components, etc.
    - with Fixed target program.

Thanks for your listening



Back Ups

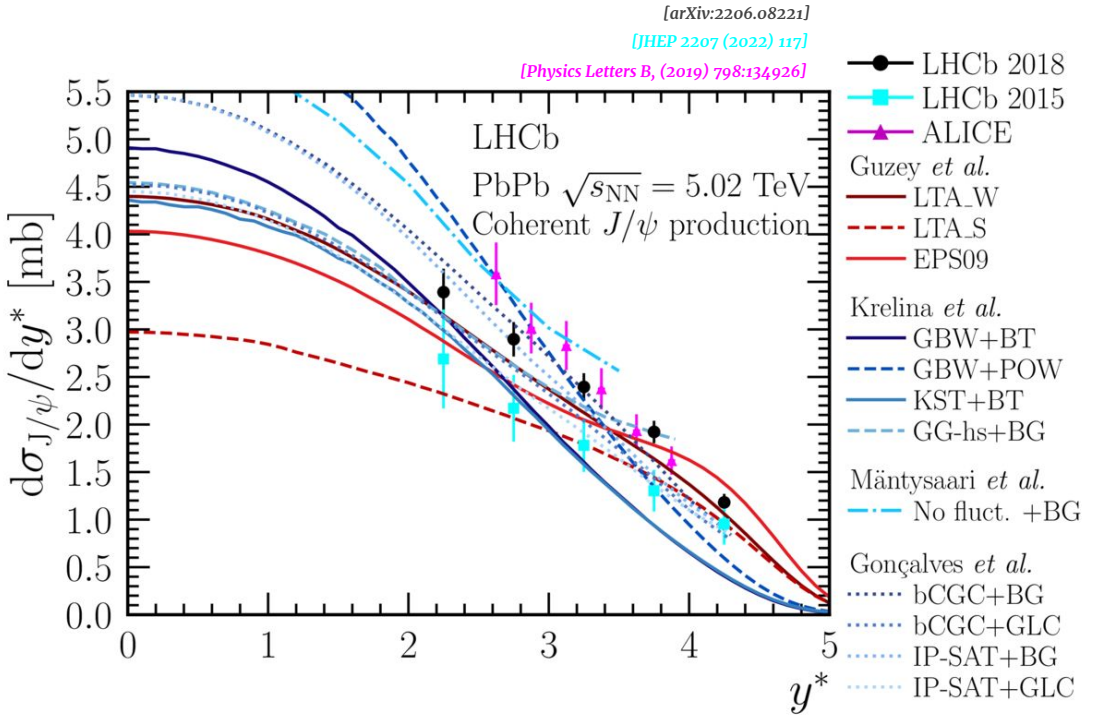
Coherent charmonium photo-production in UPC

[arXiv:2206.08221]

The **LHCb 2018** J/ψ measurement is compatible with **LHCb 2015** and **ALICE** results.

The difference between the **LHCb 2018** and **LHCb 2015** measurement is about **2.0σ**.

LHCb 2018 is compatible with **ALICE** result.

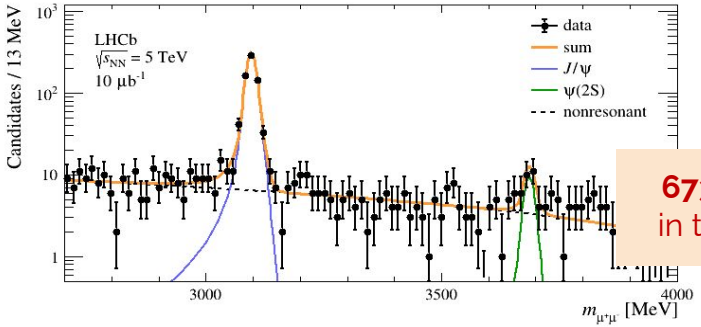


Coherent J/ψ production in 2015 PbPb UPC

[JHEP 2207 (2022) 117]

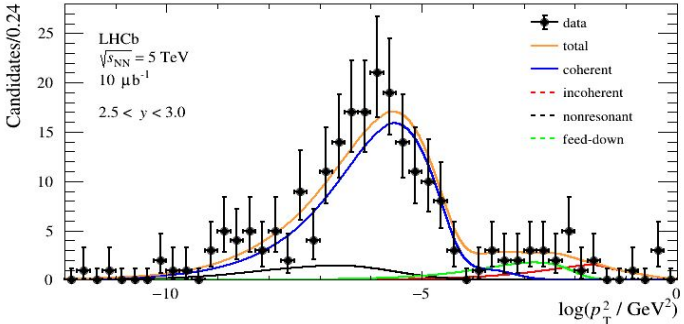
Measurement of coherent J/ψ in UPC, using a data sample collected by the LHCb experiment in 2015 PbPb. **First** UPC results in LHCb - a **baseline** to 2018 PbPb measurement!

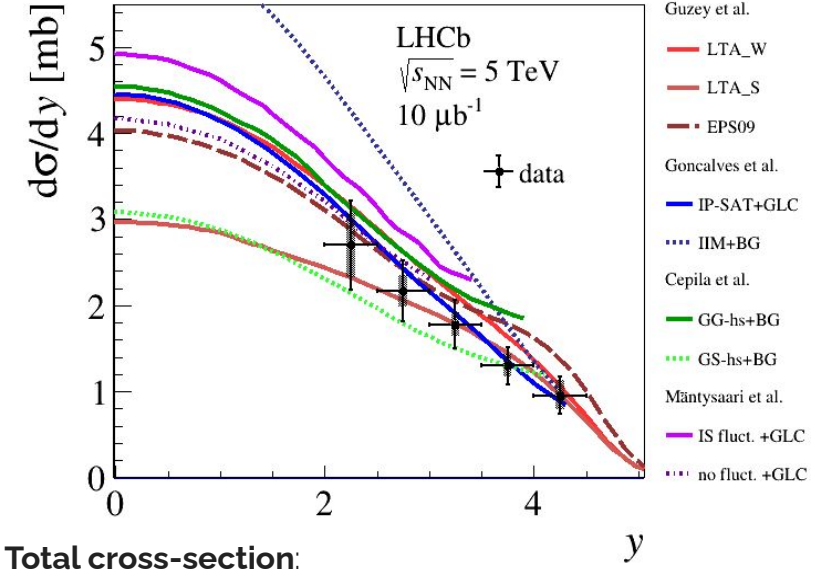
(1) J/ψ yields extracted from dimuon mass fit:



673 J/ψ in total Y

(2) Coherent yields extracted from log(pT2) fit:



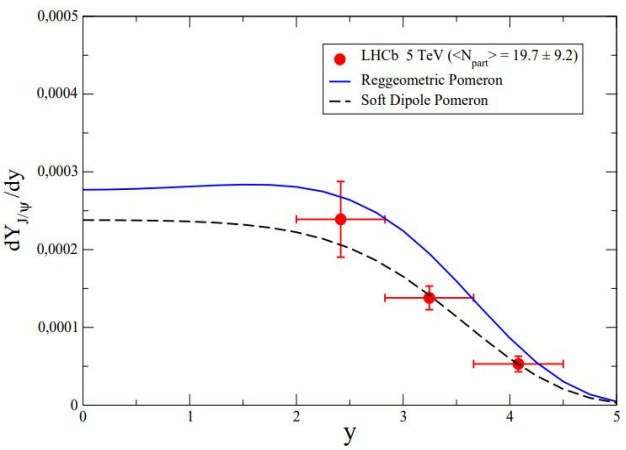


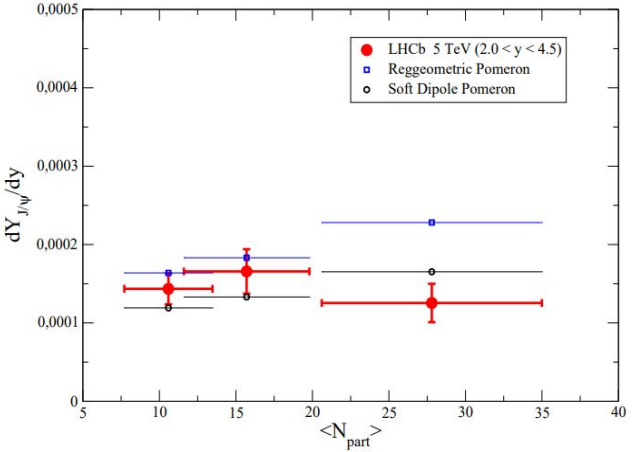
- **Total cross-section**:
  4.45 ± 0.24(stat.) ± 0.18(sys.) ± 0.58(lumi) mb
- **Differential cross-section** are compared to different phenomenological predictions.

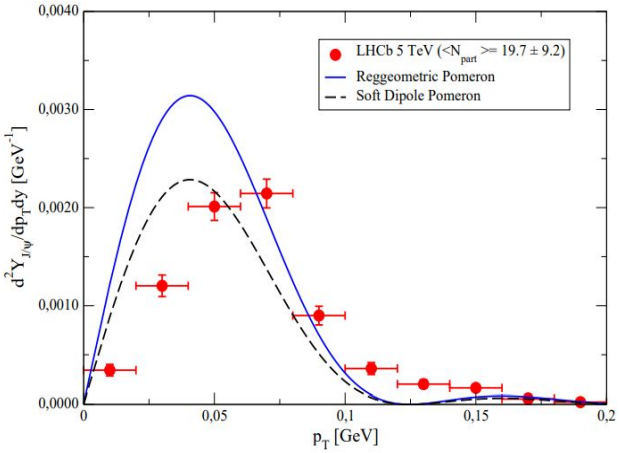
Coherent J/ψ photo-production in PC

[arXiv:2202.02162v2]

- Results are compared to **Reggeometric Pomeron model** and **soft dipole pomeron model**, based on Regge phenomenology formalism







- Recent preprint shows good agreement with the **soft dipole pomeron model**

LHCb HeRSCheL detector

[JINST 13 (2018) no.04, P04017]

High Rapidity Shower Counters for LHCb(HeRSCheL)

- A set of plastic scintillators used in order to detect any activity in high pseudorapidity range **(5 < | η |< 10).**
- **5** Stations(2 Forward + 3 Backward) × **4** Quadrant = **20** channels in total, installed close to the beam.
- **Remove background** activities close to the beam, but also cut a small fraction of signal.