UPC Quarkonium Production at LHCb

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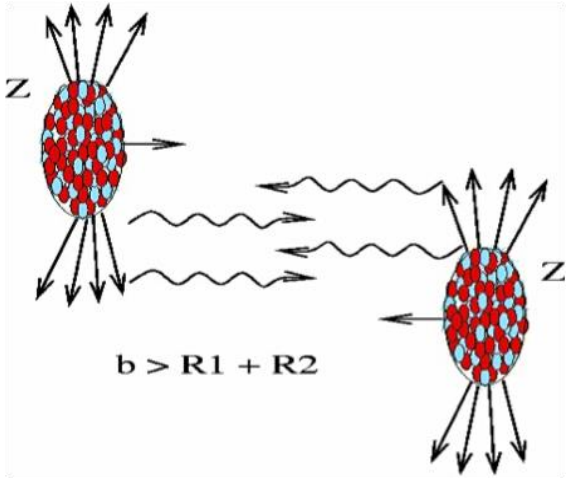
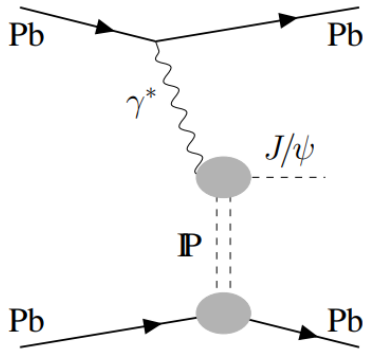
on behalf of the LHCb collaboration

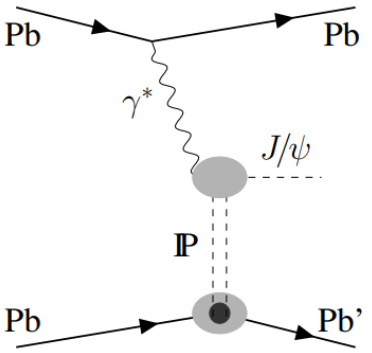
CEP in Ultra-peripheral collisions

- **Ultra-peripheral collisions (UPC)**: Two nuclei bypass each other with an impact parameter greater than the sum of their radii
- **Photon-induced interactions are enhanced by the strong electromagnetic field of the nucleus**
  - Coherent J/ψ and ψ(2S) production gives constraints on the gluon Probability Density Functions,
  - (J/ψ) / ψ(2S) ratio measurement is helpful to constrain the choice of the vector meson wave function in dipole scattering models [e.g. PLB 772 (2017) 832, PRC (2011) 011902]





Coherent J/ψ production: photon interact with the whole nucleus coherently



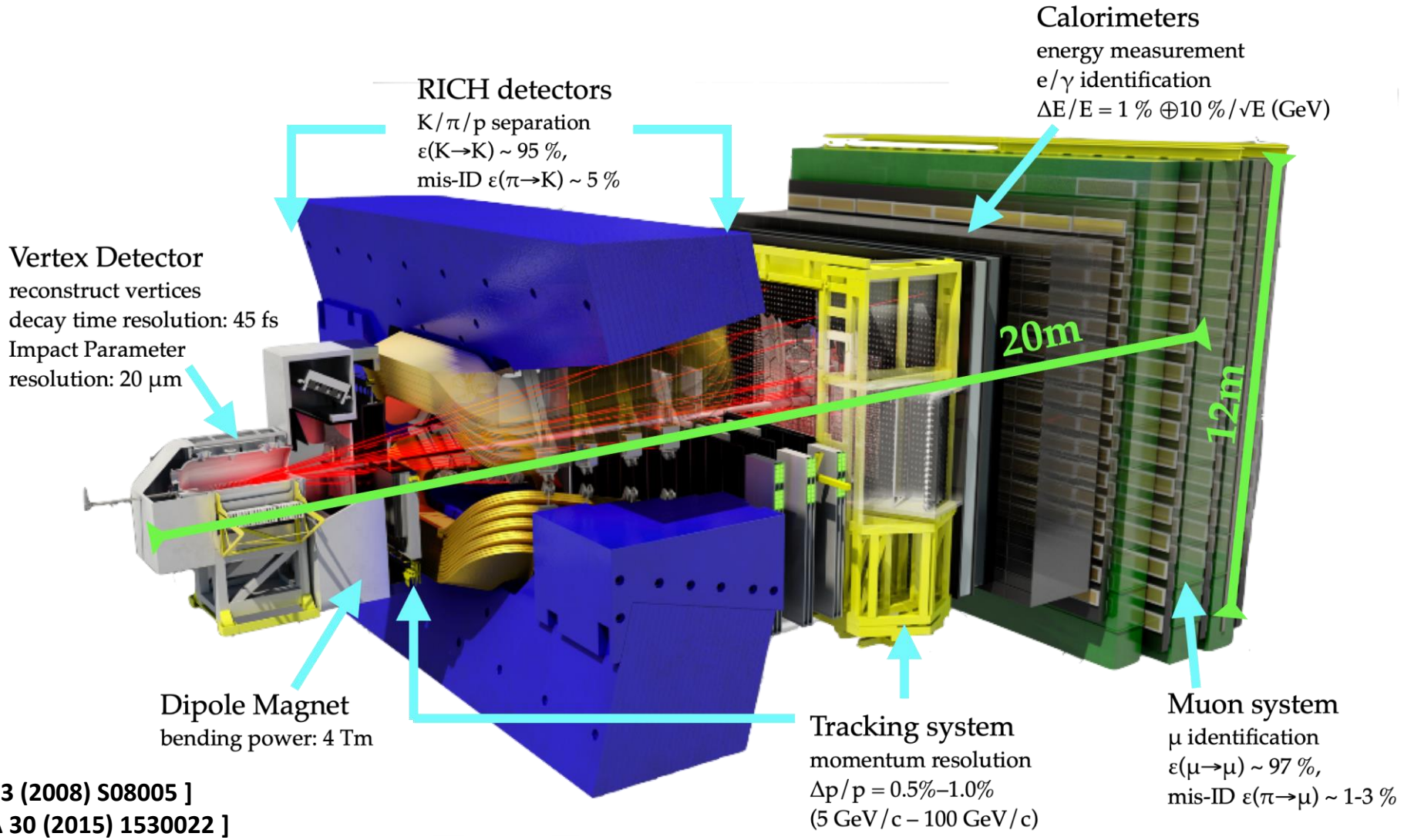
Incoherent J/ψ production: photon interact with particular nucleons in the nucleus

The LHCb detector

- LHCb is the only dedicated detector (at LHC) fully instrumented in forward region
- Unique kinematic coverage

  $2 < \eta < 5$

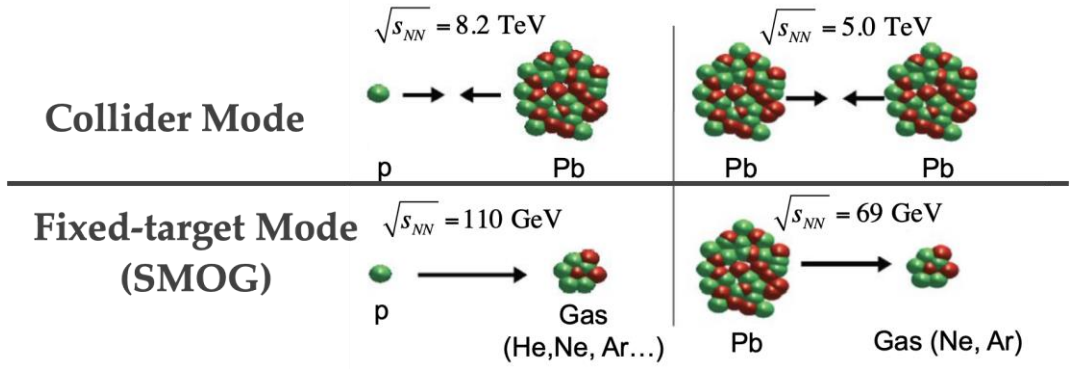
- A high precision device, down to very low-p_T, excellent particle ID, precise vertex and track reconstruction.



[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]

LHCb running modes and kinematic coverage

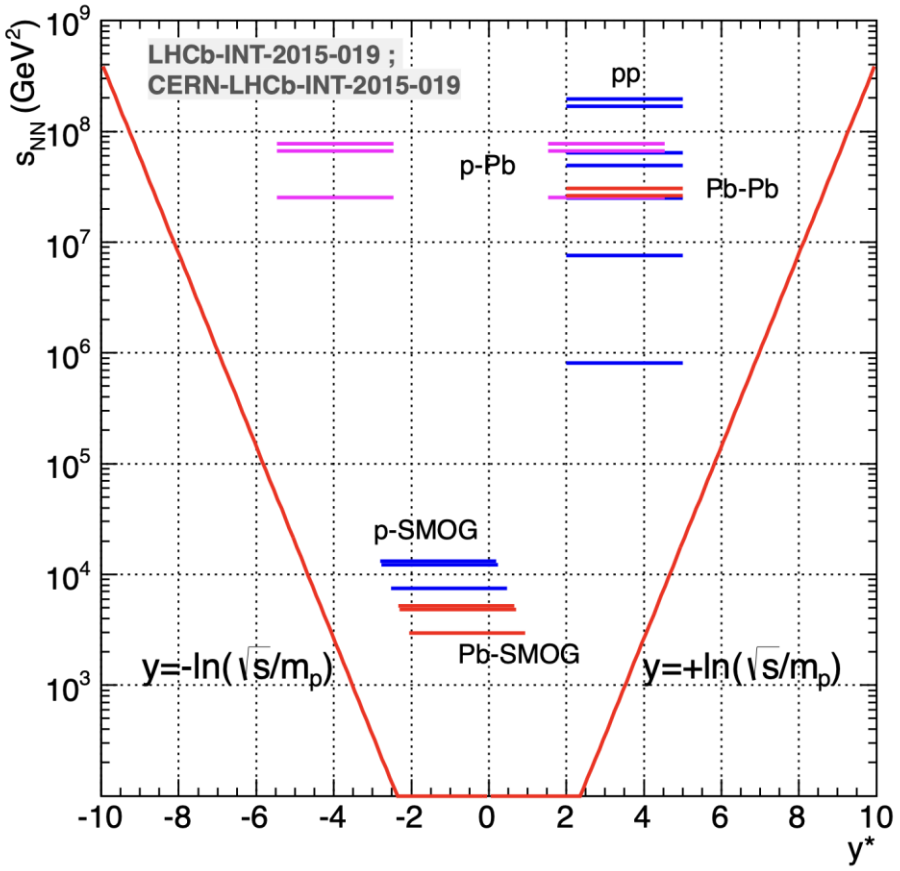
Both the collider mode and fixed-target mode running at the same time



Collider mode datasets:

$\sqrt{s_{NN}}$	2013 5.02 TeV		2016 8.16 TeV		2015 5.02 TeV	2017 5.02 TeV	2018 5.02 TeV
	pPb	Pbp	pPb	Pbp	PbPb	XeXe	PbPb
$\mathcal{L}$	1.1 nb^{-1}	0.5 nb^{-1}	13.6 nb^{-1}	20.8 nb^{-1}	10 μb^{-1}	0.4 μb^{-1}	$\sim$ 210 μb^{-1}

Kinematic acceptance



Event selection

- **Dataset: PbPb collisions in 2018 at 5.02 TeV, $228 \pm 10\ \mu\mathrm{b}^{-1}$**
- **Cross-sections of coherent J/ψ and $\psi(2S)$ photon-production are measured as:**

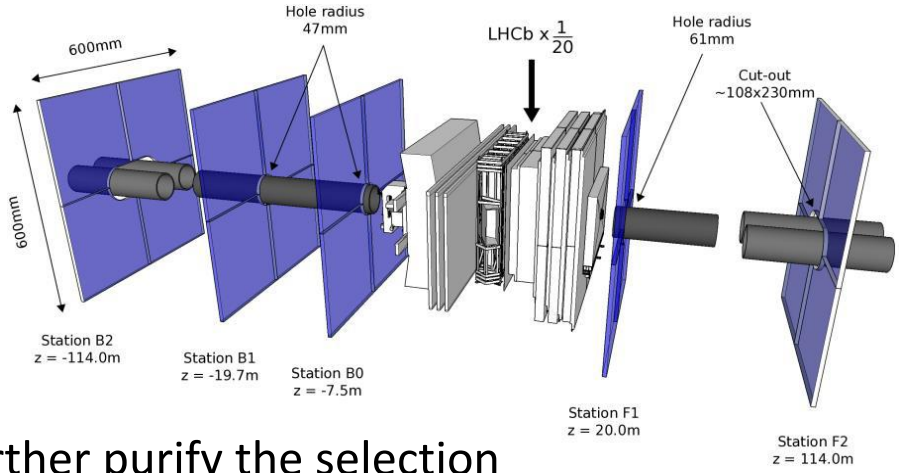
$$\frac{\mathrm{d}\sigma_{\psi}^{\mathrm{coh}}}{\mathrm{d}x} = \frac{N_{\psi}^{\mathrm{coh}}}{\mathcal{L} \times \varepsilon_{\mathrm{tot}} \times \mathcal{B}(\psi \to \mu^{+}\mu^{-}) \times \Delta x}$$

- **Event selection:**
  - require a near empty detector with only two long tracks reconstructed, with acceptance cuts:

$$2.0 < \eta^{\mu} < 4.5\ , p_{\mathrm{T}}^{\mu} > 700\mathrm{MeV},$$

$$p_{T}^{\mu\mu} < 1\mathrm{GeV}, \left|\Delta\phi_{\mu\mu}\right| > 0.9\pi$$

HERSCHEL



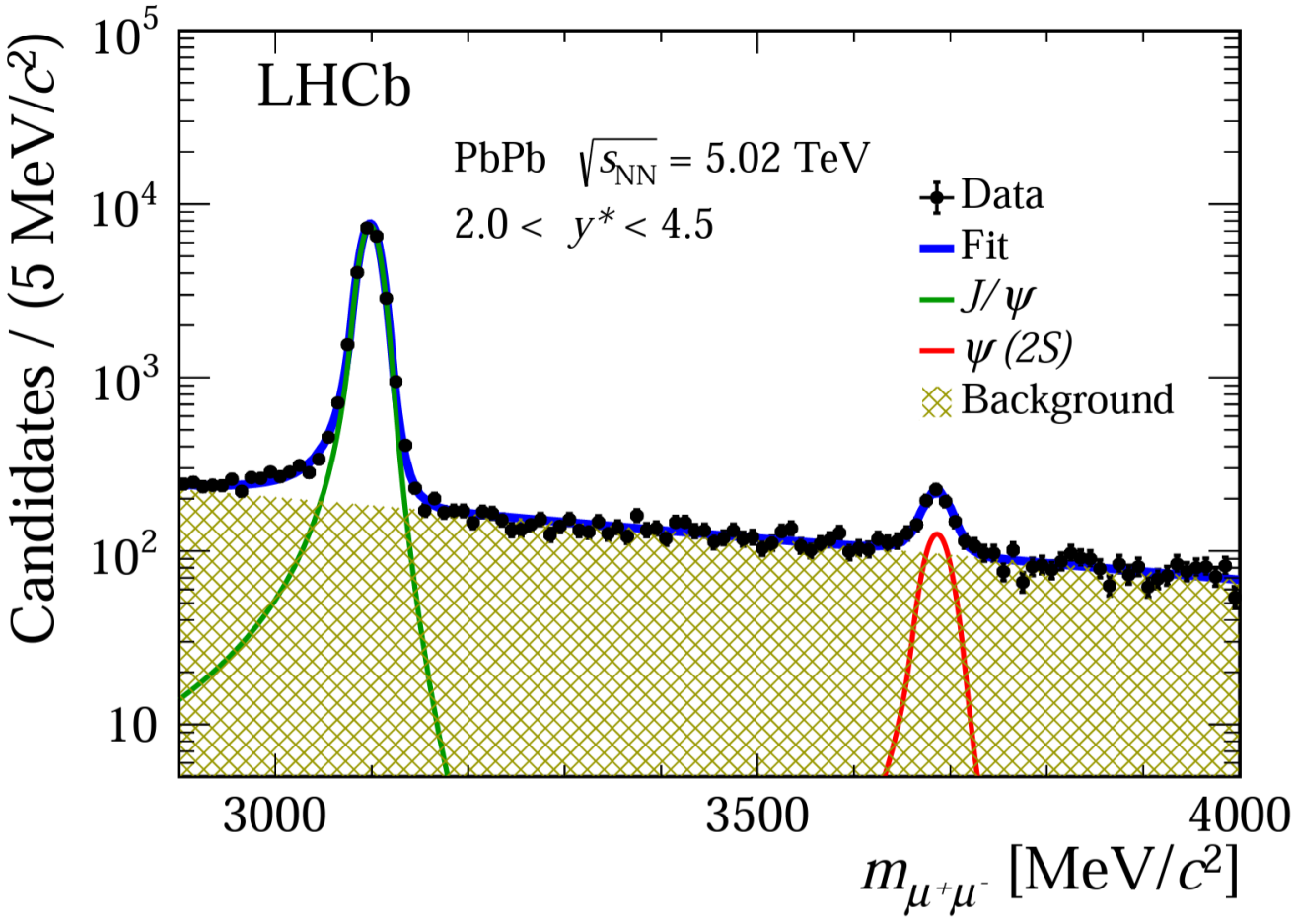
- **HERSCHEL** detector [JINST 13 (2018) 04 P04017] is used to further purify the selection

Signal extraction (1)

LHCb-PAPER-2022-012, arXiv:2206.08221, accepted by JHEP

- **Charmonia yields are extracted from dimuon mass fit**
  - Double sided crystal ball function for the J/ψ and $\psi(2S)$ signals
  - Exponential for the non-resonance background (mainly $\gamma\gamma \to \mu\mu$ process)

Dimuon mass fit

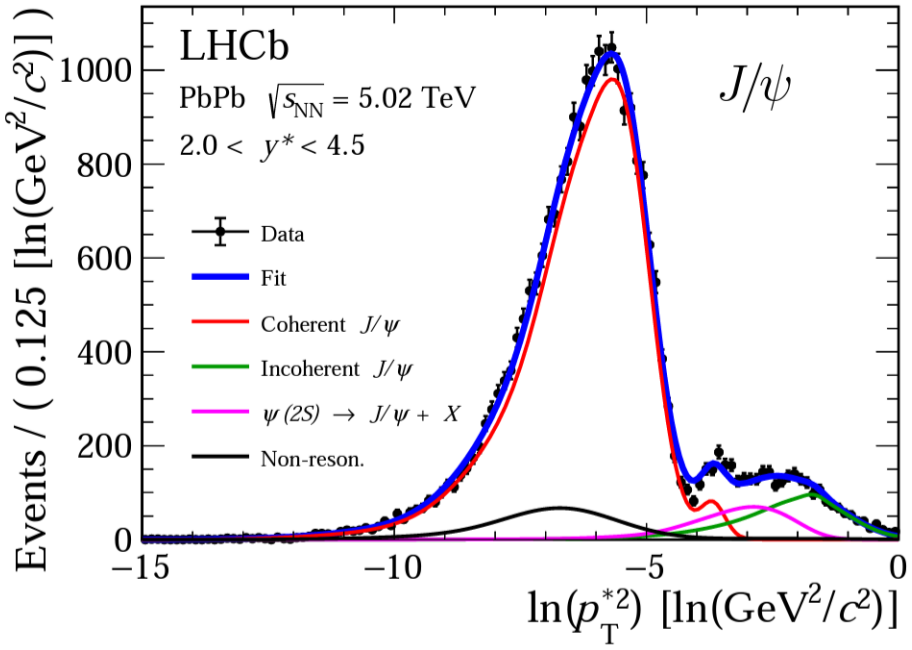


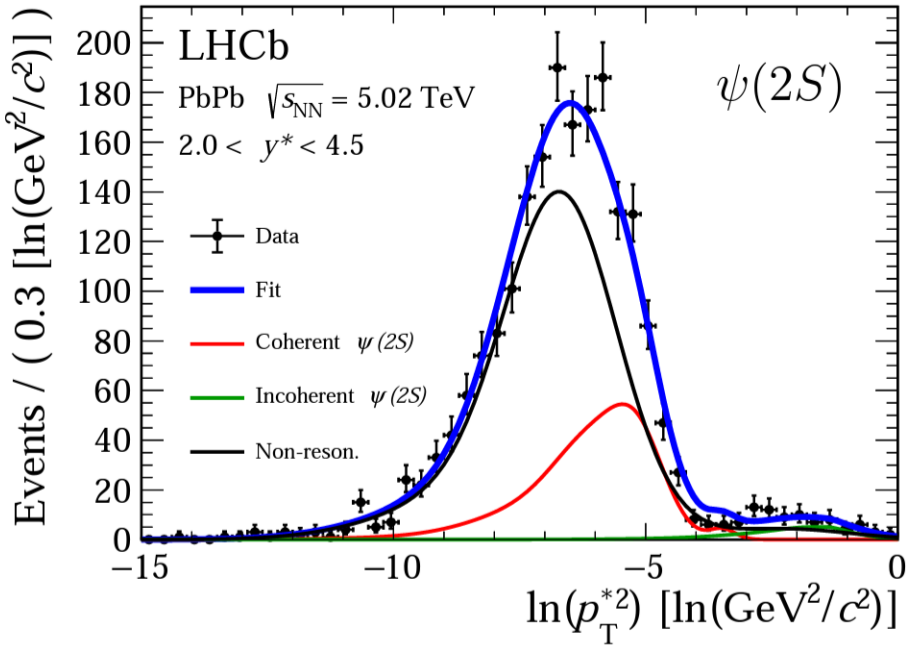
Signal extraction (2)

LHCb-PAPER-2022-012, arXiv:2206.08221, accepted by JHEP

- **Coherent production signal is extracted from a $\ln(p_T^{*2})$ fit**
  - Coherent, incoherent, and feed-down shapes modelled using STARLight + EvtGen + PHOTOs + GEANT4 Simulation
  - Non-resonance shapes determined from data side-band

$\ln(p_T^{*2})$ fit





Integrated cross-section and cross-section ratio

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- **Integrated cross-section and ratio (most precise measurements in the forward region at the moment):**

$$\sigma^{\mathrm{coh}}_{J/\psi} = 5.965 \pm 0.059(stat) \pm 0.232(syst) \pm 0.262(\mathrm{lumi})\ \mathrm{mb},$$
$$\sigma^{coh}_{\psi(2S)} = 0.923 \pm 0.086(stat) \pm 0.028(syst) \pm 0.040(\mathrm{lumi})\ \mathrm{mb},$$
$$\sigma^{coh}_{J/\psi} / \sigma^{coh}_{\psi(2S)} = 0.155 \pm 0.014(stat) \pm 0.003\ (syst).$$

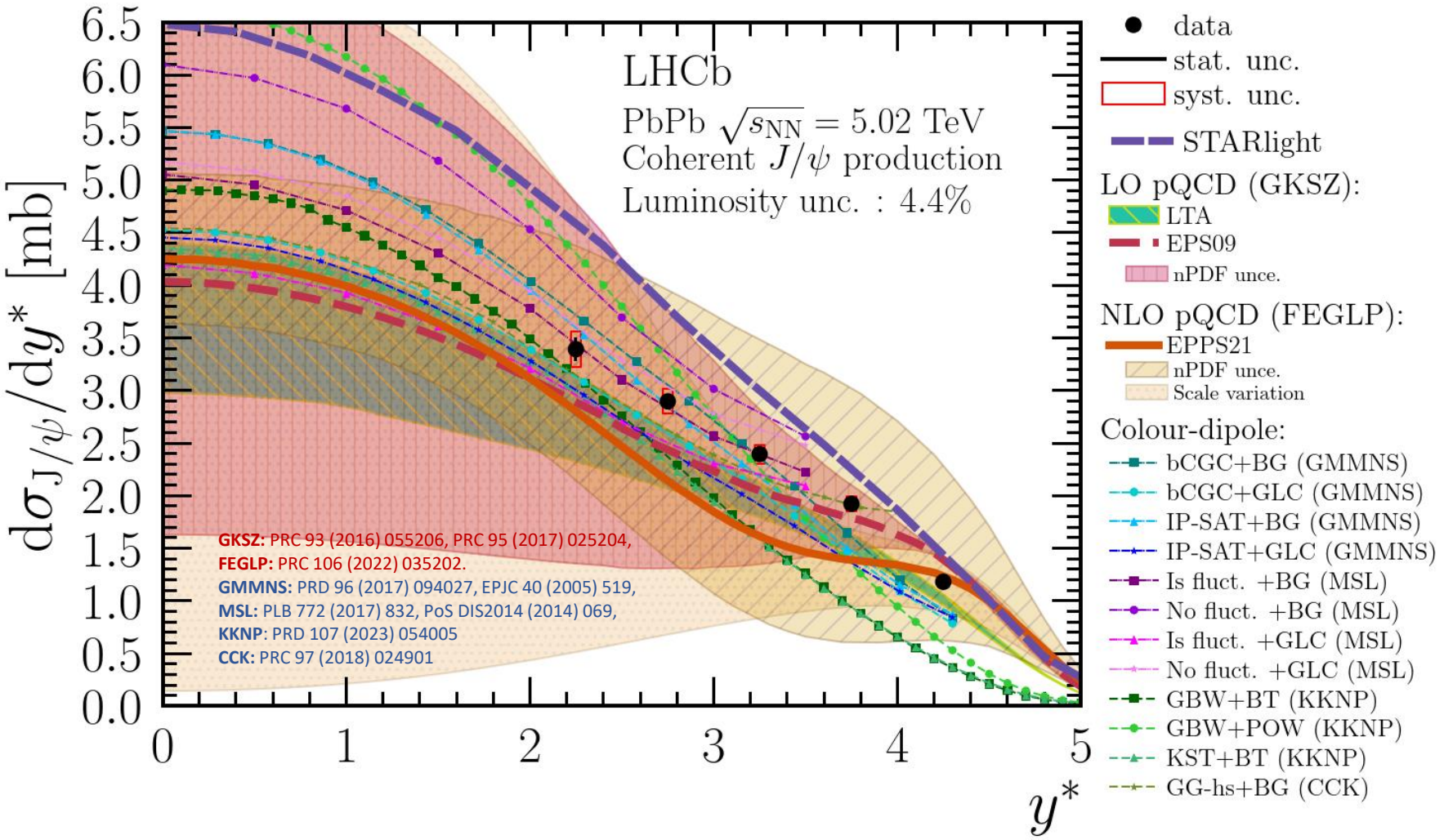
- **Systematic uncertainties:**

Source	Relative uncertainty [%]	
	$\sigma^{\mathrm{coh}}_{J/\psi}$	$\sigma^{\mathrm{coh}}_{\psi(2S)}$
Tracking efficiency	0.5–2.0	0.5–2.0
PID efficiency	0.9–1.6	0.9–1.6
Trigger efficiency	2.7–3.7	2.1–2.5
HERSCHEL efficiency	1.4	1.4
Background estimation	1.2	1.2
Signal shape	0.04	0.04
Momentum resolution	0.9–34	1.3–27
Branching fraction	0.6	2.1
Luminosity	4.4	4.4

Charmonia in UPC

LHCb-PAPER-2022-012, arXiv:2206.08221 , accepted by JHEP

- **The most precise coherent J/ψ production measurement in PbPb UPC in forward rapidity to date**
- **The high precision LHCb data are of great value in theoretical model fine-tuning**
- **Compare to most recent theoretical calculations:**
  - **p-QCD calculations:** include **new NLO p-QCD calculation PDF uncert.** and **factorization / renormalization scale uncert.**
  - **Color-dipole models:** draw different model tuning options as theoretical variations

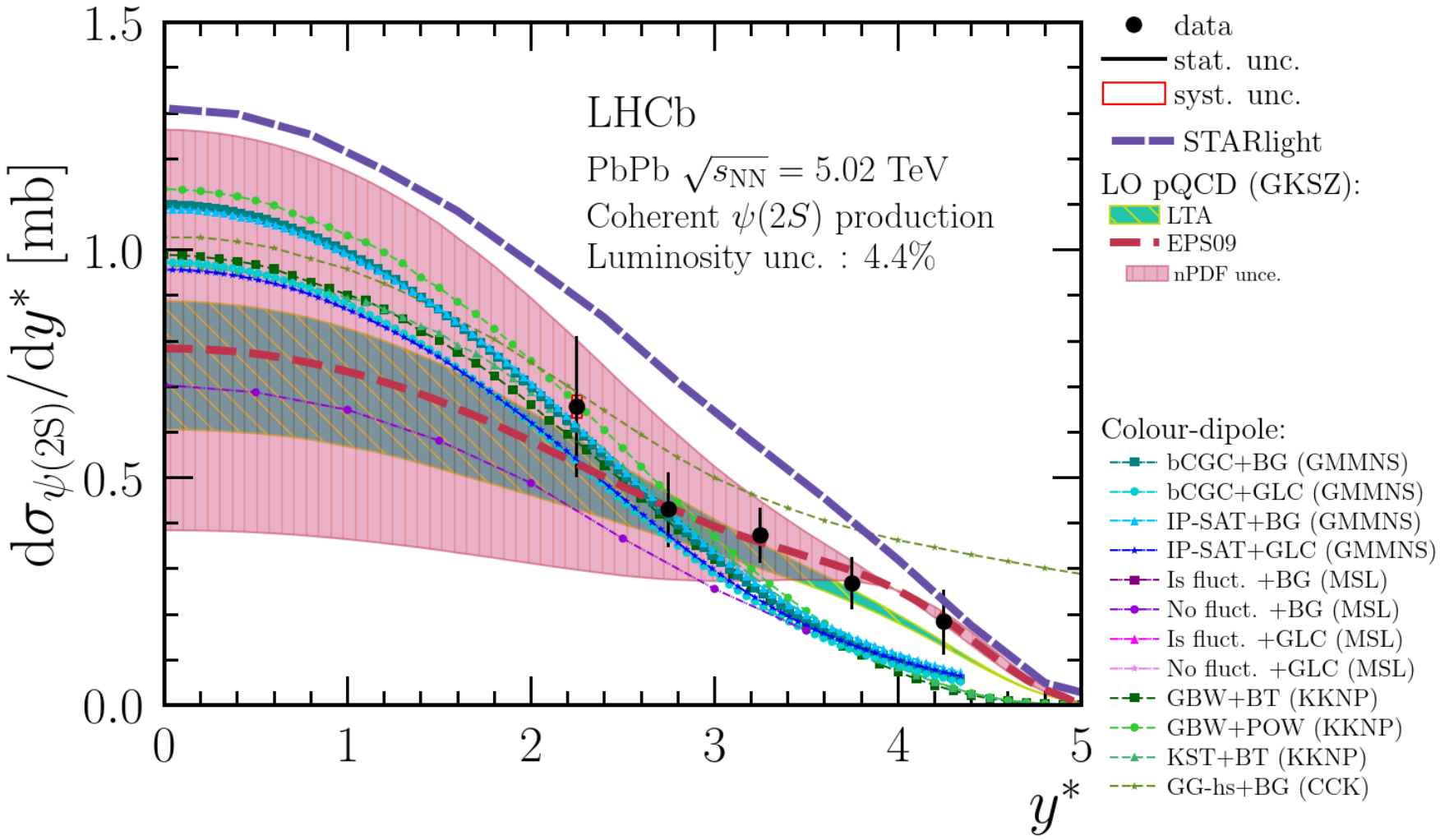


Charmonia in UPC

LHCb-PAPER-2022-012, arXiv:2206.08221, accepted by JHEP

- **The first coherent $\psi(2S)$ measurement in forward rapidity at the LHC**

Compared to pQCD and color-dipole models



GKSZ: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
GMMNS: PRD 96 (2017) 094027, EPJC 40 (2005) 519,
MSL: PLB 772 (2017) 832, PoS DIS2014 (2014) 069,
KKNP: PRD 107 (2023) 054005
CCK: PRC 97 (2018) 024901

Charmonia in UPC

LHCb-PAPER-2022-012, arXiv:2206.08221, accepted by JHEP

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

Compared to pQCD and color-dipole models

GKSZ: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
FEGLP: PRC 106 (2022) 035202.
GMMNS: PRD 96 (2017) 094027, EPJC 40 (2005) 519,
MSL: PLB 772 (2017) 832, PoS DIS2014 (2014) 069,
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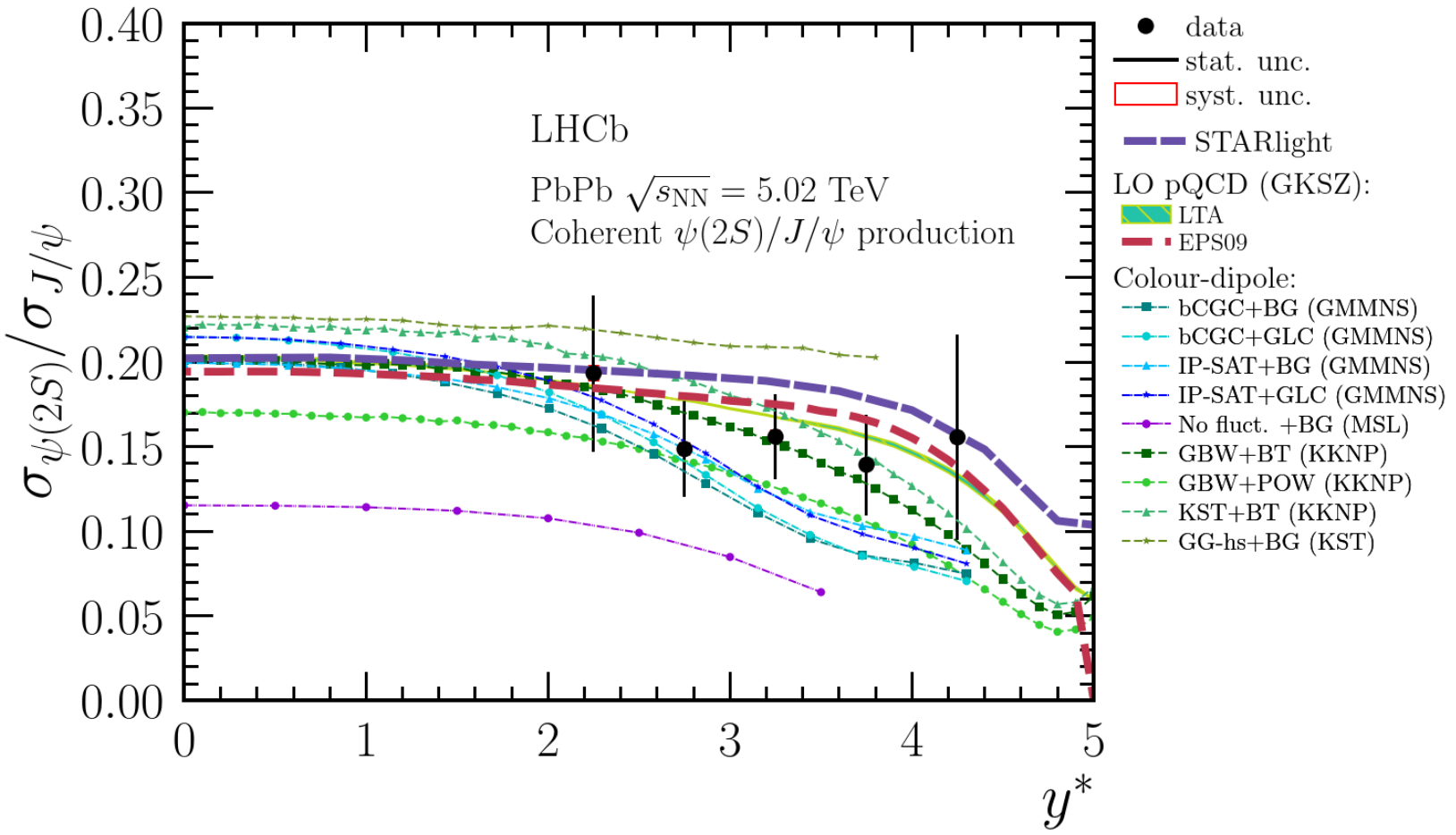
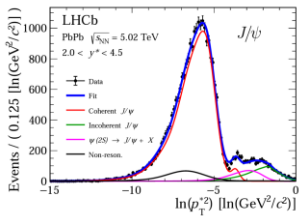


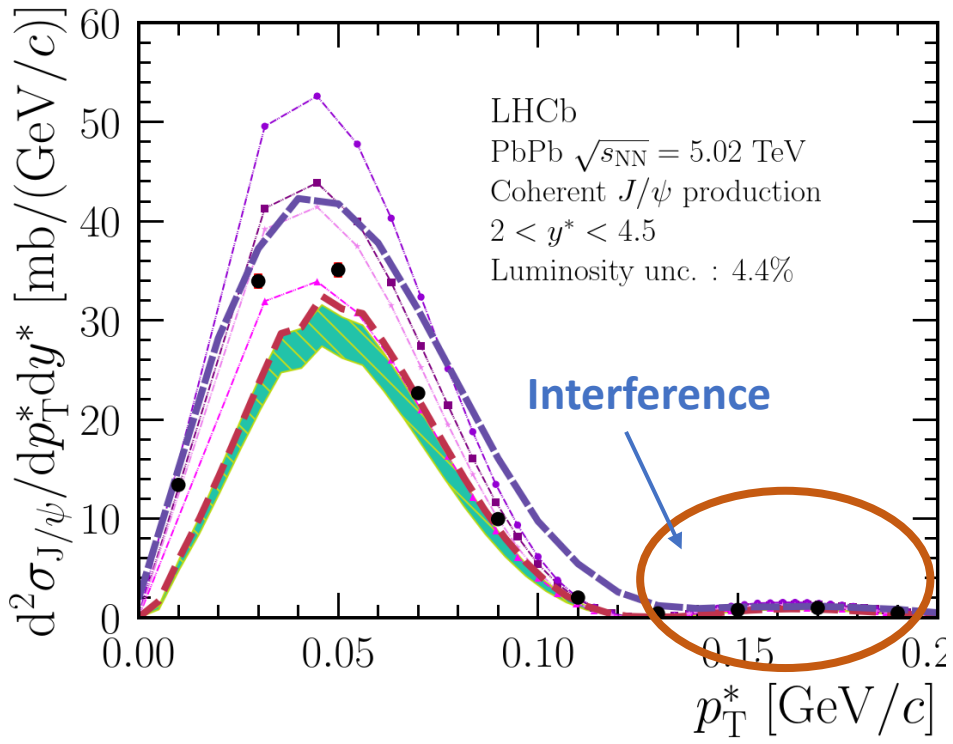
Charmonia in UPC

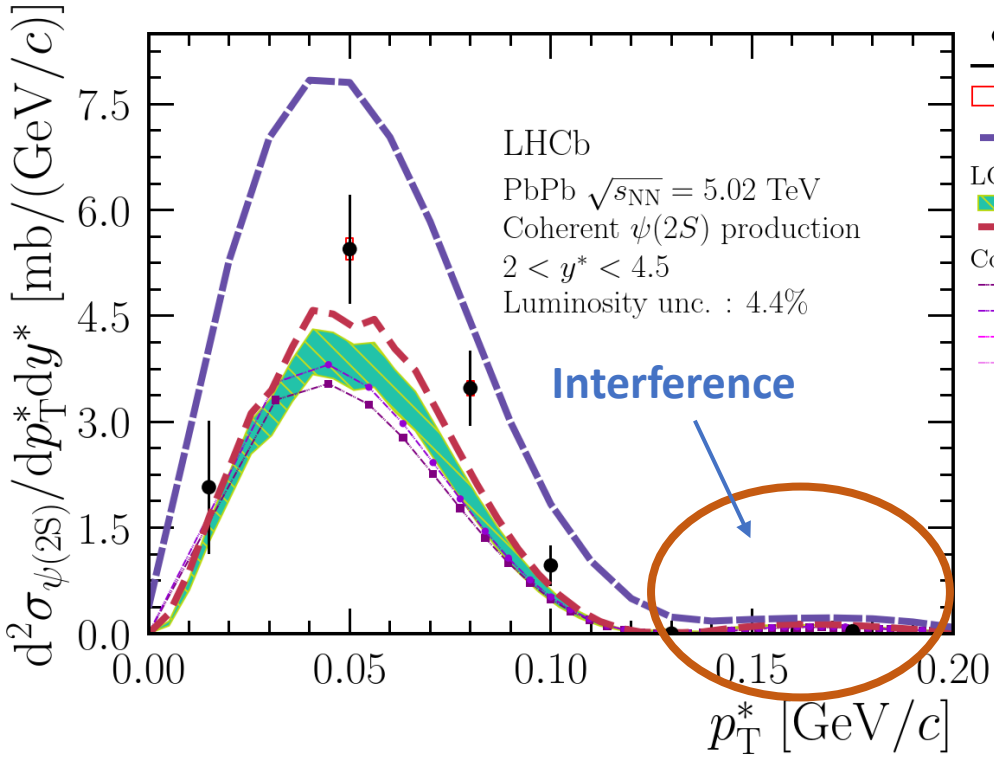
LHCb-PAPER-2022-012, arXiv:2206.08221, accepted by JHEP

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

Compared to pQCD and color-dipole models







GKSZ: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
MSL: PLB 772 (2017) 832, PoS DIS2014 (2014) 069,

Conclusion

- A measurement of exclusive coherent J/ψ and ψ(2S) production and their cross-section ratio in UPC PbPb collisions using 2018 LHCb dataset
  - The most precise coherent J/ψ production measurement and the first coherent ψ(2S) measurement in forward rapidity for UPC at LHC
  - The first measurement of coherent J/ψ and ψ(2S) production cross-section vs. p_{T} in PbPb UPC, interference effects clearly visible in the p_{T} spectra.
- The results are compatible with current theoretical predictions, providing strong constraints for the fine-tuning of the models
- A rich program in photon-induced production studies is ongoing at LHCb.

Backups

Charmonia in UPC

- The J/ψ measurement is compatible with 2015 and ALICE results
  - The difference between the new results and 2015 measurement is about 2σ

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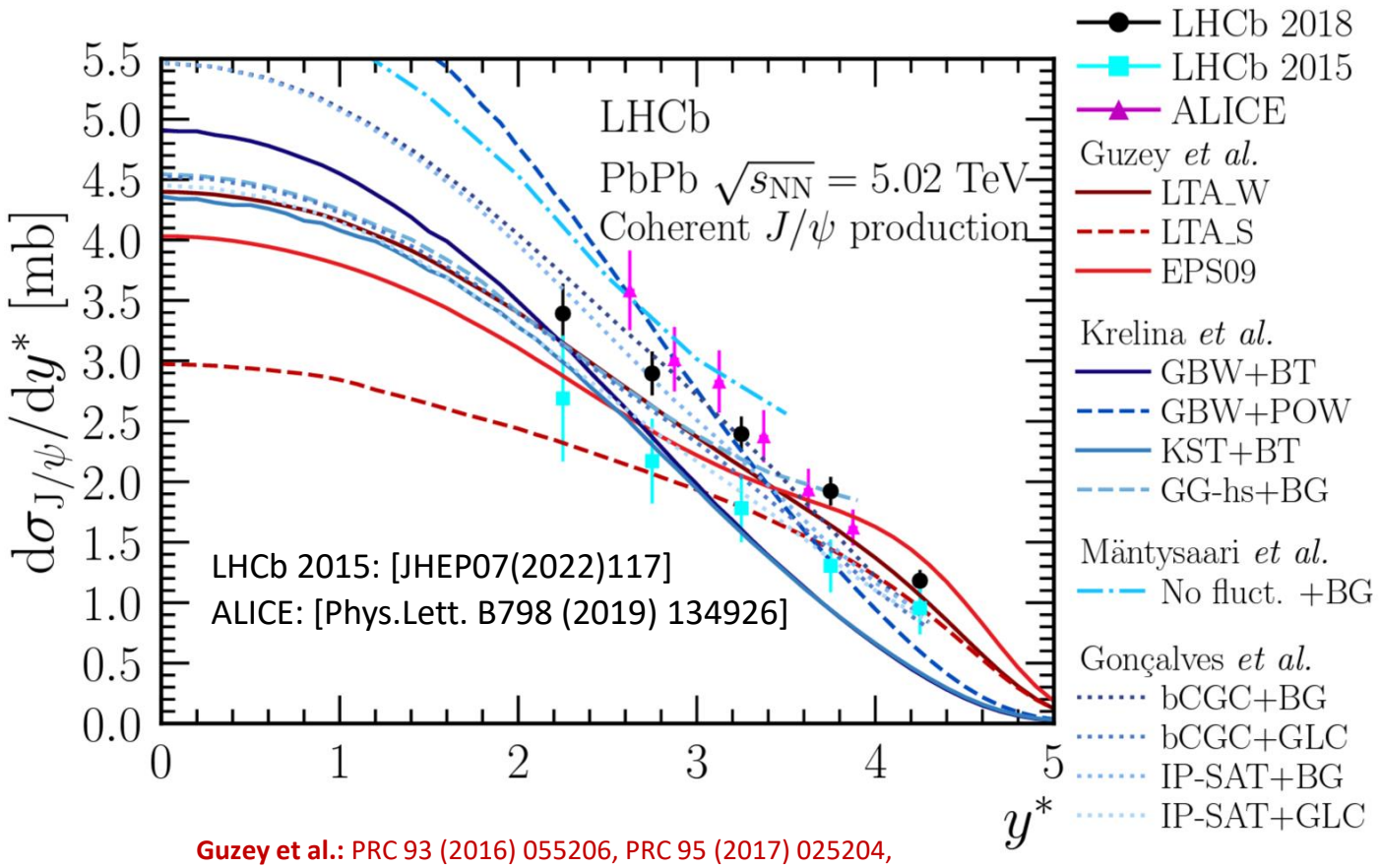

Guzey et al.: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
Krelina et al.: PRC 97 (2018) 024901, arXiv:2008.05116
Mantysaari et al.: PLB 772 (2017) 832, PoS DIS2014 (2014) 069, PRD 74 (2006) 074016
Goncalves et al.: PRD 96 (2017) 094027, EPJC 40 (2005) 519,

Charmonia in UPC

- **PbPb at 5.02 TeV in 2018 ($228 \pm 10\ \mu\mathrm{b}^{-1}$)**
- **Cross-sections:**

$$\frac{\mathrm{d}\sigma_{\psi}^{\mathrm{coh}}}{\mathrm{d}x} = \frac{N_{\psi}^{\mathrm{coh}}}{\mathcal{L} \times \varepsilon_{\mathrm{tot}} \times \mathcal{B}(\psi \to \mu^{+}\mu^{-}) \times \Delta x}$$

- **Event selection:**
  - require a near empty detector with only two long tracks reconstructed, with acceptance cuts: $2.0 < \eta^{\mu} < 4.5\,, p_{\mathrm{T}}^{\mu} > 700\mathrm{MeV}$, $p_T^{\mu\mu} < 1\mathrm{GeV}, \left|\Delta\phi_{\mu\mu}\right| > 0.9\pi$
  - HERSCHEL detector [JINST 13 (2018) 04 P04017] is used to further purify the selection
- **Signal extraction: The (1) charmonium yields are extracted from dimuon mass fit, then the (2) coherent part is extracted from a ln(p_T^2) fit**

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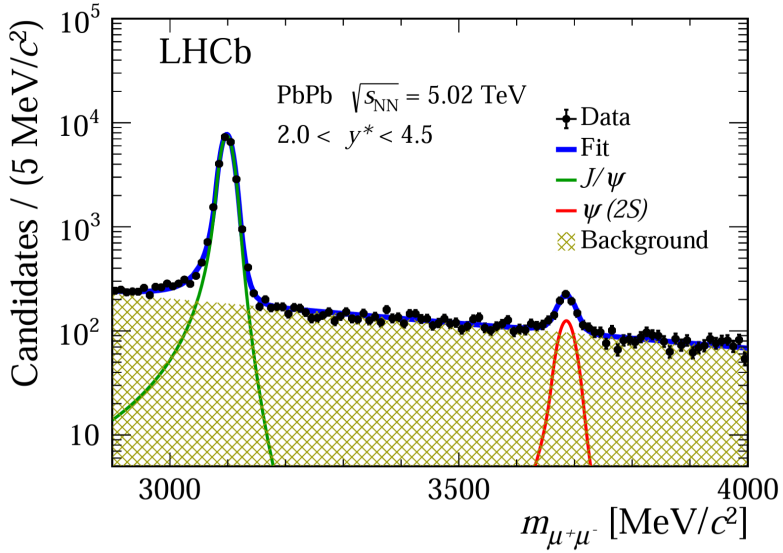
Step (1): mass fit



Step (2): ln(p_T^2) fit