Coherent charmonium production in ultra-peripheral lead-lead collisions at LHCb

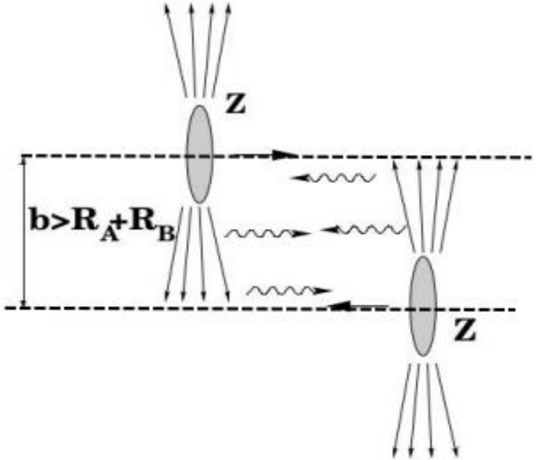
Xiaolin Wang
South China Normal University

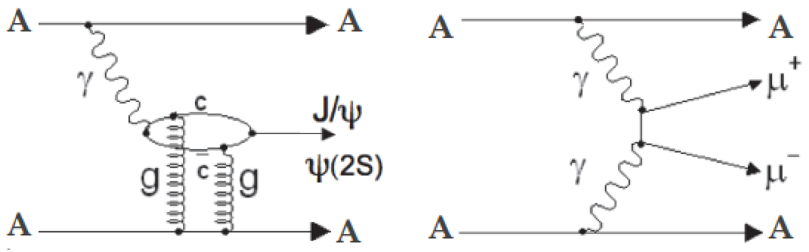
CLHCP2024
2024年11月15日·青岛

Xiaolin Wang
xiaolin.wang@cern.ch

Ultra-peripheral PbPb Collisions

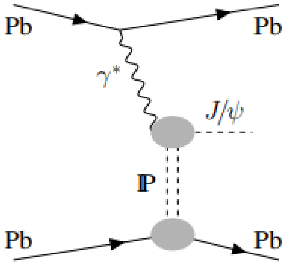
- **Ultra-Peripheral Collisions(UPCs):**
  - Two incoming nuclei bypass each other with an impact parameter greater than the sum of their radii.
  - Reactions in which two ions interact via their cloud of semi-real photons.
  - The photon-induced interactions are enhanced by the strong electromagnetic field of the nucleus.
  - Photon-induced quarkonium production: A $q\bar{q}$ loop created by the photon interaction with a pair of gluon exchange (pomeron) to produce a quarkonium($c\bar{c}, b\bar{b}$).
  - Non-resonant background: $\gamma\gamma \rightarrow \mu^+\mu^-$.



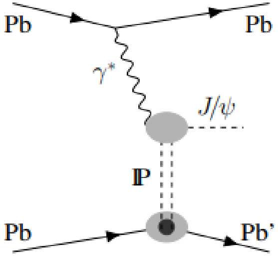


J/ψ production in UPC

- Coherent J/ψ production, photon interacts with a pomeron emitted by the entire nucleus.
- Incoherent J/ψ production, the photon interacts with a pomeron emitted from a single nucleon within the target nucleus.
- J/ψ from the feed-down of coherent and incoherent ψ(2S) production.
- Study of coherent charmonium production could constrain the gluon Parton Distribution Functions in nuclei.
- The ratio of J/ψ and ψ(2S) 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]



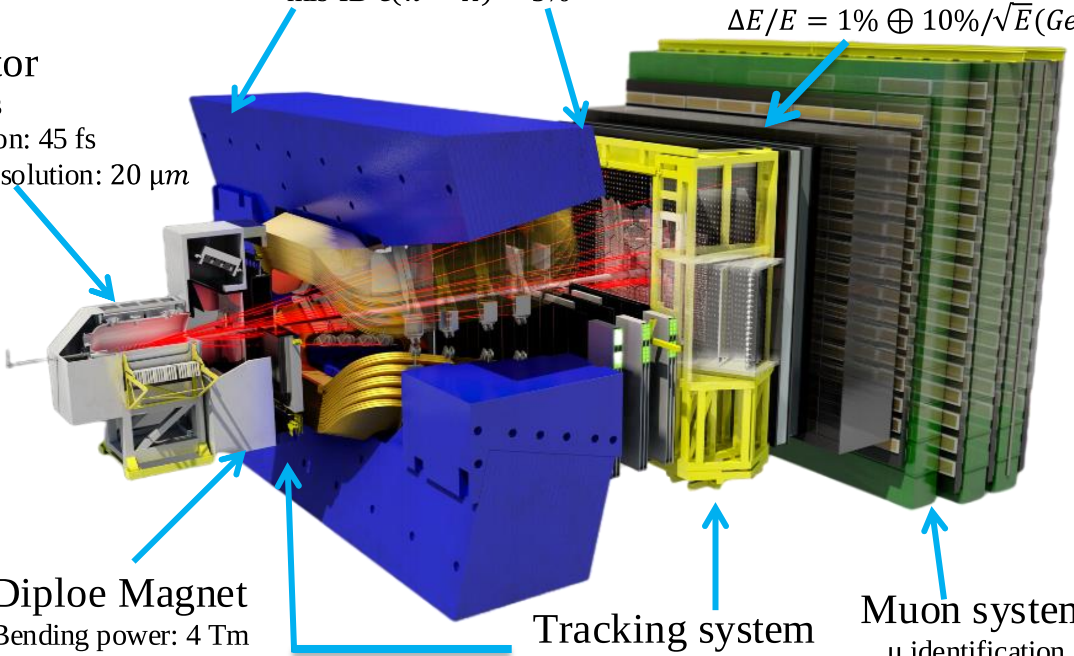
Coherent J/ψ production



Incoherent J/ψ production

LHCb Detector

- LHCb detector is **a single-arm forward spectrometer** fully instrumented in unique kinematic coverage: **$2<\eta<5$**.
- A high precision detector with excellent particle identification, precise vertex and track reconstruction.



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

Event selection

- Dataset: J/ψ → $\mu^+\mu^-$ and ψ(2S) → $\mu^+\mu^-$ events from PbPb collisions at $\sqrt{s}$ = 5.02TeV taken in 2018 with luminosity $228 \pm 10\ \mu b^{-1}$.

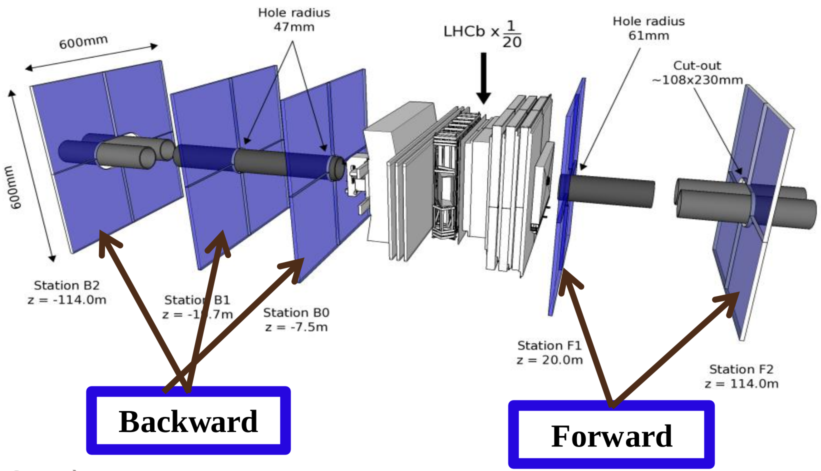
- Differential cross-sections of coherent J/ψ and ψ(2S) photon-production are measured as:

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

- Event selection：
  - only two long tracks reconstructed for muons, with acceptance cuts:

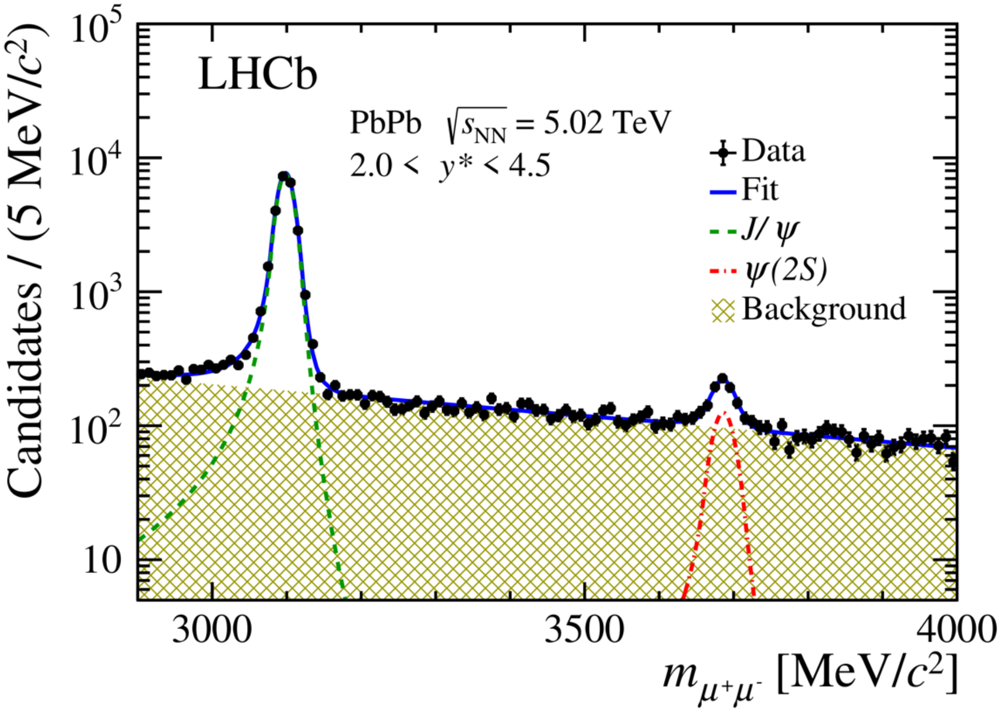
$$2.0 < \eta^{\mu^{\pm}} < 4.5,\ \mathrm{p}_{\mathrm{T}}^{\mu^{\pm}} > 700MeV,$$
$$\mathrm{p}_{\mathrm{T}}^{\mu^{+}\mu^{-}} < 1GeV,\ |\Delta\phi_{\mu^{+}\mu^{-}}| > 0.9\pi$$

  - HeRSCheL detector is used to further purify the selection. [2018 JINST 13 P04017]



Signal extraction

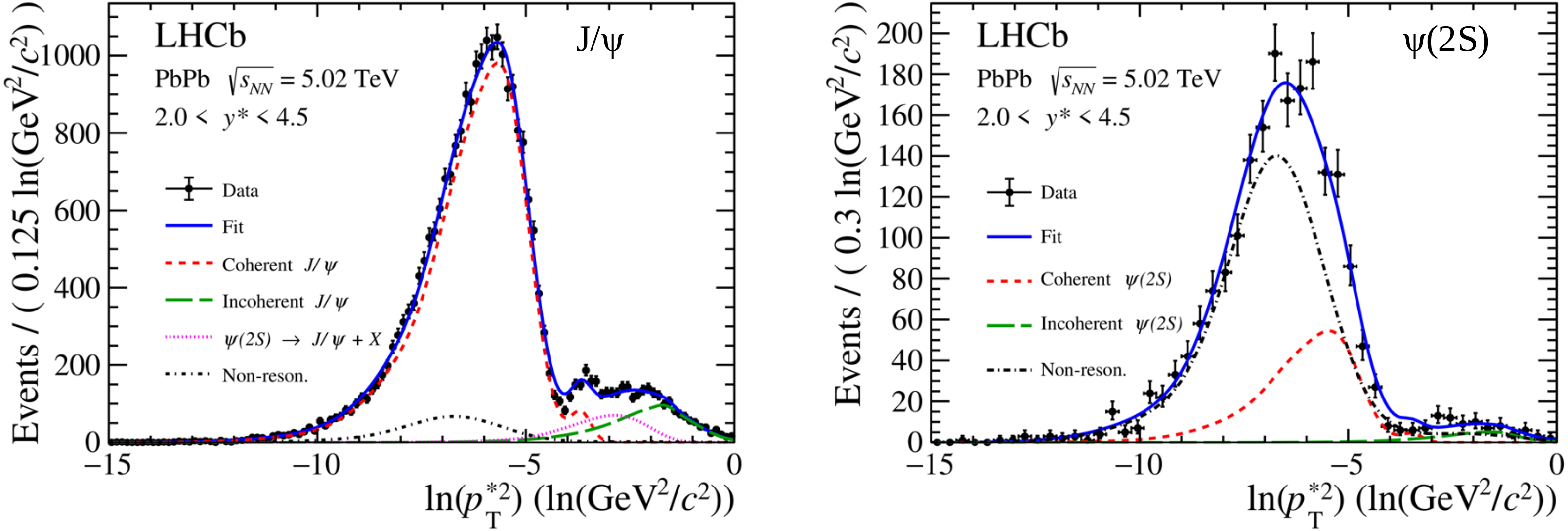
JHEP 06 (2023) 146



- Signal extraction step1: Charmonium yields are extracted from dimuon massfit.
  - Double-sided crystal ball function for the J/ψ and ψ(2S) yields.
  - Exponential function for the non-resonant background are extracted from dimuon massfit.

Signal extraction

JHEP 06 (2023) 146

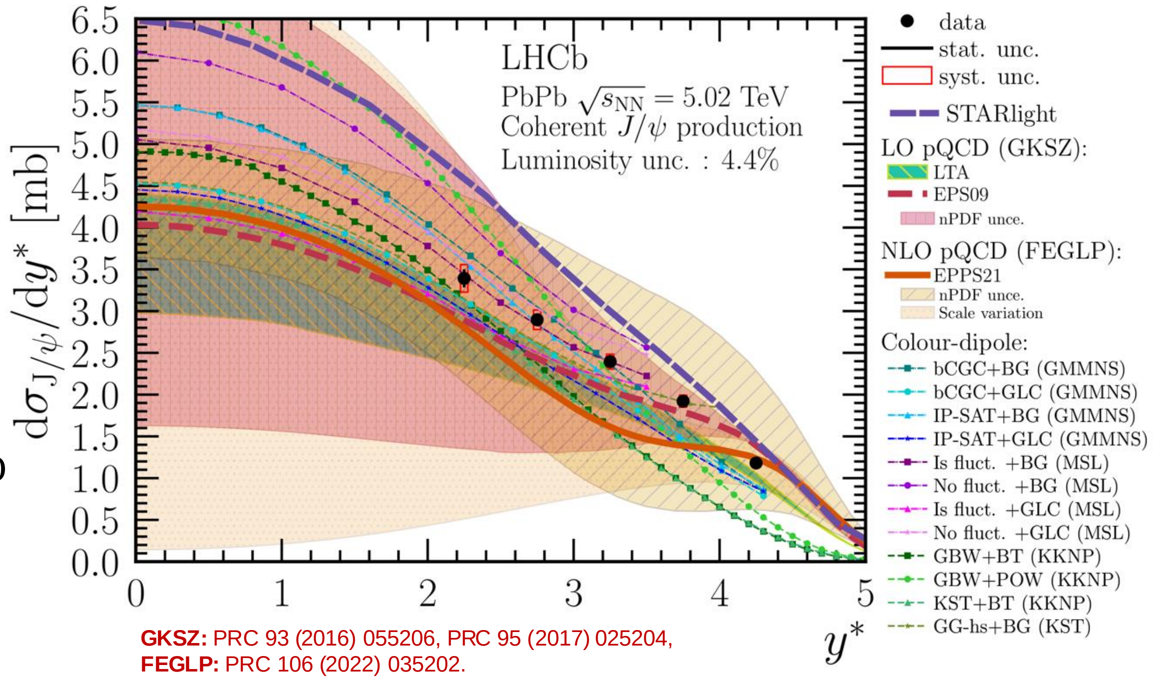


- Signal extraction step2: Coherent component is extracted from a $\ln(p_T^2)$ fit.
- All signal pdfs are estimated using the STARLight generator and the LHCb detector simulation.
- The shape of background taken from the side-band method, then the normalization is fixed from mass fit.

Cross-sections in rapidity

- 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 scale uncert.
  - Color-dipole models: draw different model tuning options as theoretical variations.

JHEP 06 (2023) 146



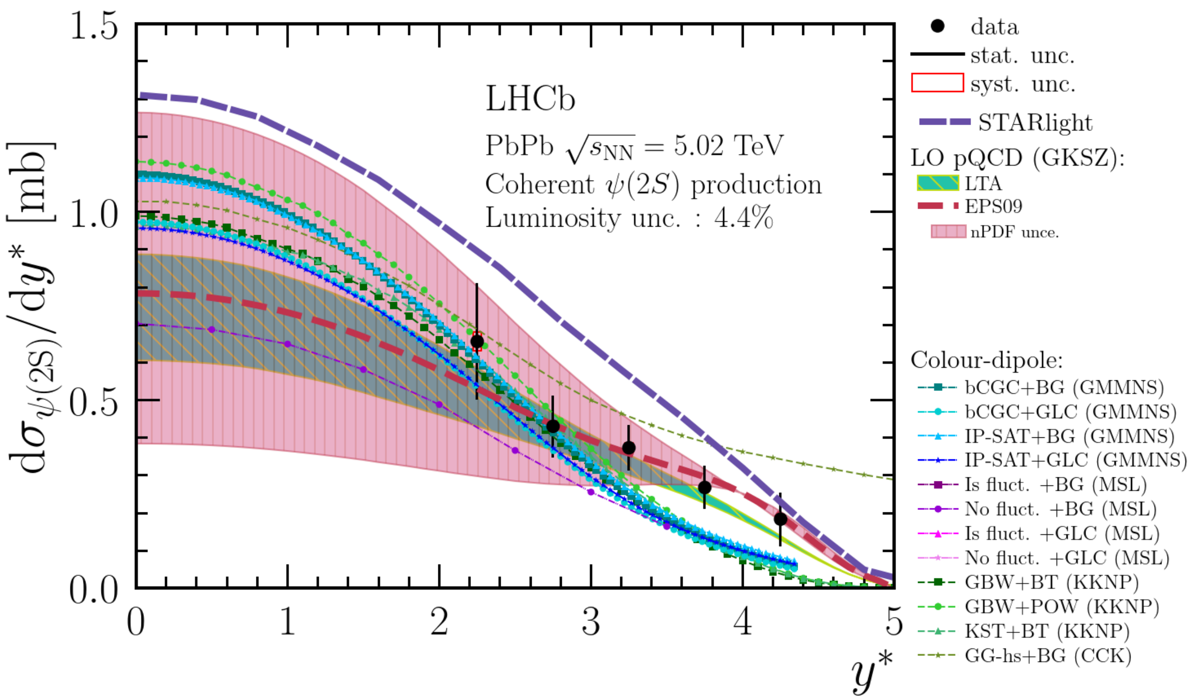
GKSZ: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
FEGLP: PRC 106 (2022) 035202.
GMMNS: PRD 96 (2017) 094027, EPJC 40 (2005) 519,
MSL: PLB 772 (2017) 832, PoS DIS2014 (2014) 069,
KKNP: PRD 107 (2023) 054005
CCK: PRC 97 (2018) 024901

Cross-sections in rapidity

- The first precise coherent ψ(2S) production measurement in PbPb UPC in forward rapidity at LHC.
- Compare to most recent theoretical calculations of p-QCD calculations 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

JHEP 06 (2023) 146

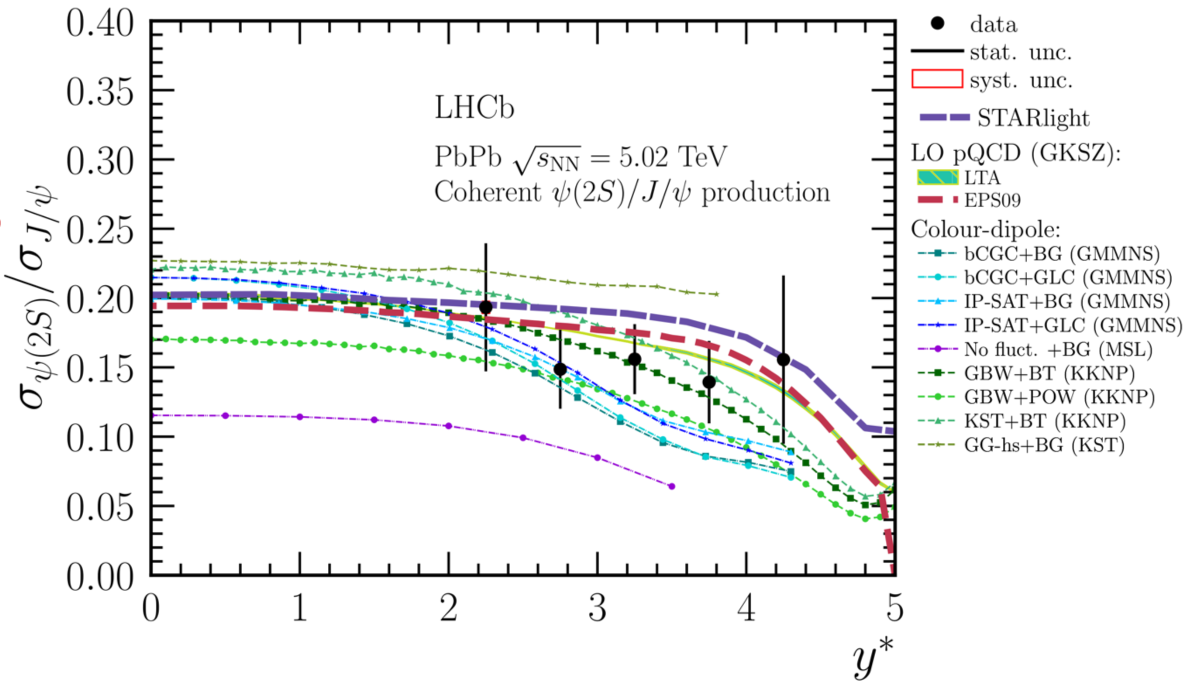


Cross-sections in rapidity

- The first cross-section ratio between coherent J/ψ and ψ(2S) vs. rapidity measurement in forward rapidity region at LHC.
- Compare to most recent theoretical calculations of p-QCD calculations and color-dipole models.

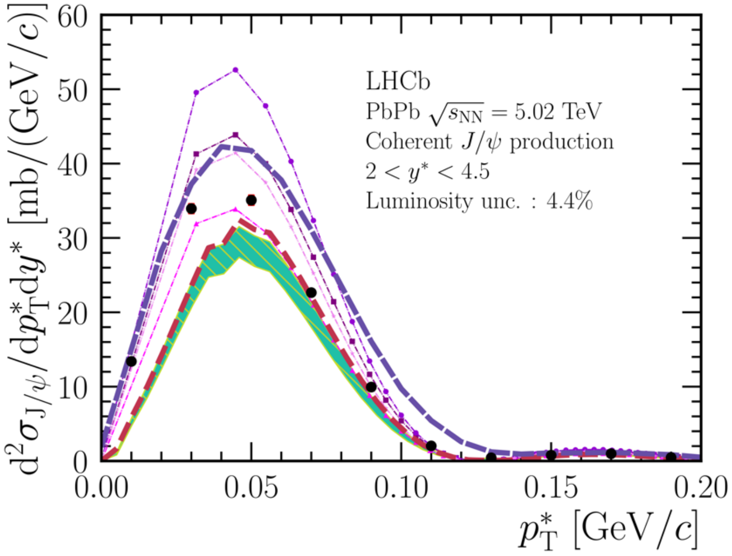
GKSZ: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
GMMNS: PRD 96 (2017) 094027, EPJC 40 (2005) 519,
MSL: PLB 772 (2017) 832, PoS DIS2014 (2014) 069,
KKNP: PRD 107 (2023) 054005
CCK: PRC 97 (2018) 024901

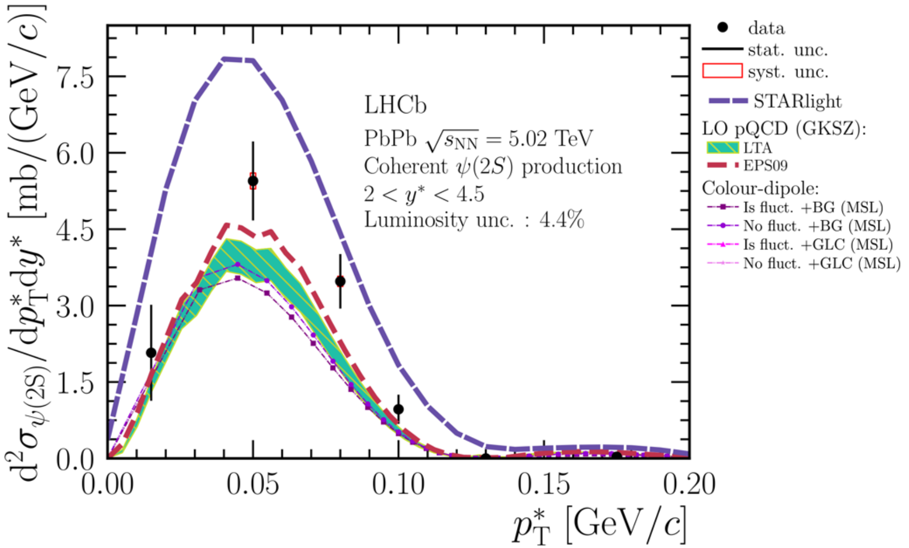
JHEP 06 (2023) 146



Cross-sections in p_T

JHEP 06 (2023) 146





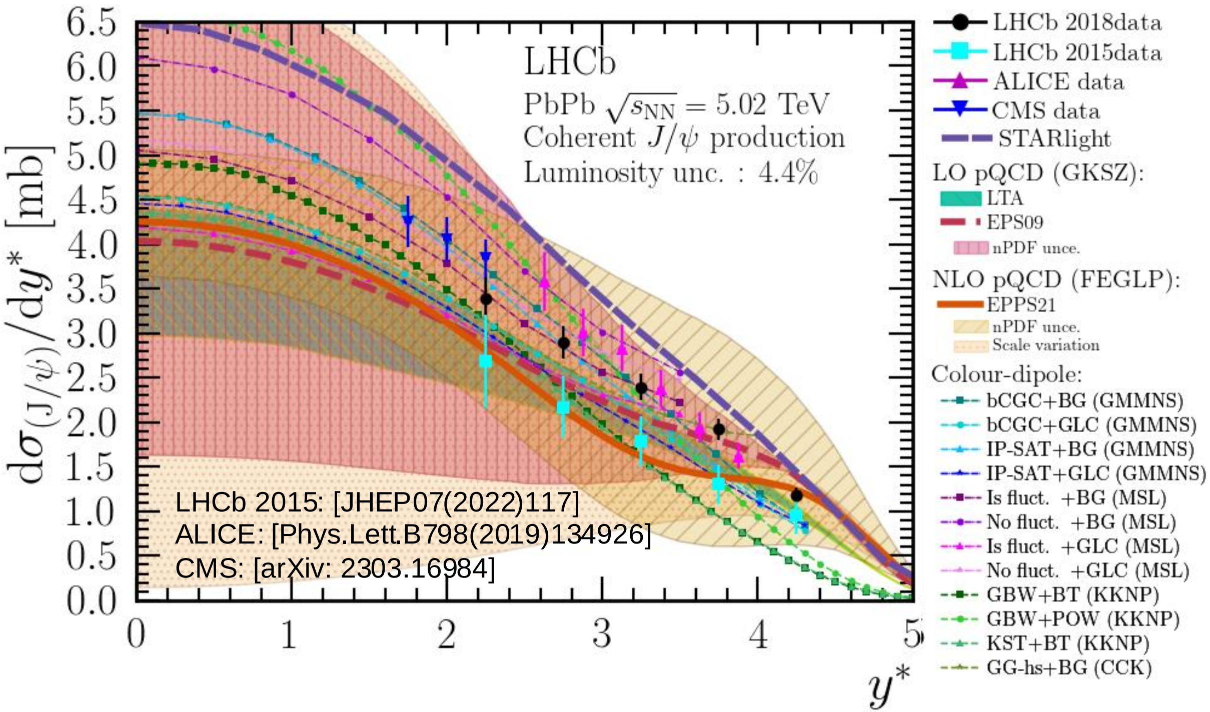
GKSZ: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
MSL: PLB 772 (2017) 832, PoS DIS2014 (2014) 069,

- The first coherent J/ψ and ψ(2S) production measurement in p_T in PbPb UPC.
- Compare to most recent theoretical calculations of p-QCD calculations and color-dipole models.

Compare with other results

[JHEP 06 (2023) 146](#)

- Comparison with the coherent J/ψ production measurement with LHCb 2015, ALICE and CMS results.
  - The J/ψ measurement is compatible with LHCb2015, ALICE and CMS results.
  - The compatibility between the new results and 2015 measurement is about 2σ.



Conclusion

- Measurements of exclusive coherent J/ψ and ψ(2S) production and their cross-section ratio in UPC PbPb collisions using 2018 dataset.

JHEP 06 (2023) 146

  - The most precise coherent J/ψ production measurement in forward rapidity region in PbPb UPC to date.
  - The first coherent ψ(2S) measurement in forward rapidity region in PbPb UPC at LHC.
  - The first measurement about coherent J/ψ and ψ(2S) production cross-sections vs. p_T in PbPb UPC.

- The results are compatible with current theoretical predictions, providing strong constraints for the fine-tuning of the different models.
- More results are ongoing： $c\bar{c}$, $b\bar{b}$, K^+K^-, $\pi\pi$, ϕ, etc…

Thanks!

Back up

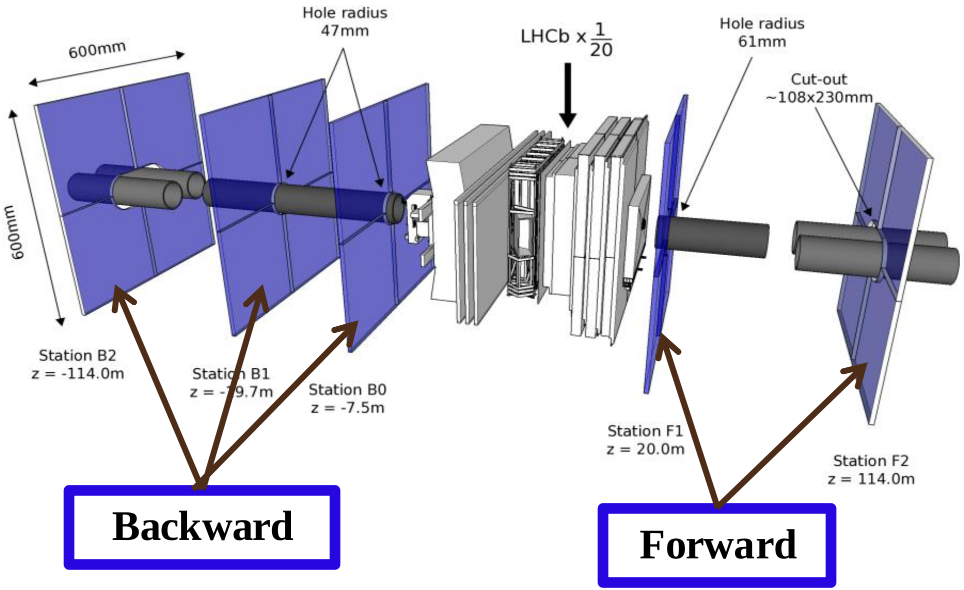
HeRSCheL detector

[2018 JINST 13 P04017]

- HeRSCheL(**High Rapidity Shower Counters for LHCb**), is a set of plastic scintillators located in the LHC tunnel on both sides of the LHCb interaction point, in order to extend the pseudo-rapidity coverage of the LHCb in the high-rapidity regions either side of the interaction point.

- HeRSCheL detector extends the LHCb forward coverage up to a pseudo-rapidity of around 10.

- HeRSCheL detector is used to cut the component with large momentum, for example, the incoherent component.



Cross-sections results

JHEP 06 (2023) 146

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

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

- Systematic uncertainties:

Source	Relative uncertainty [%]	
	$\sigma^{coh}_{J/\psi}$	$\sigma^{coh}_{\psi(2S)}$
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