SQM 2024

The 21st International Conference on Strangeness in Quark Matter
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UPC Quarkonium Production at LHCb

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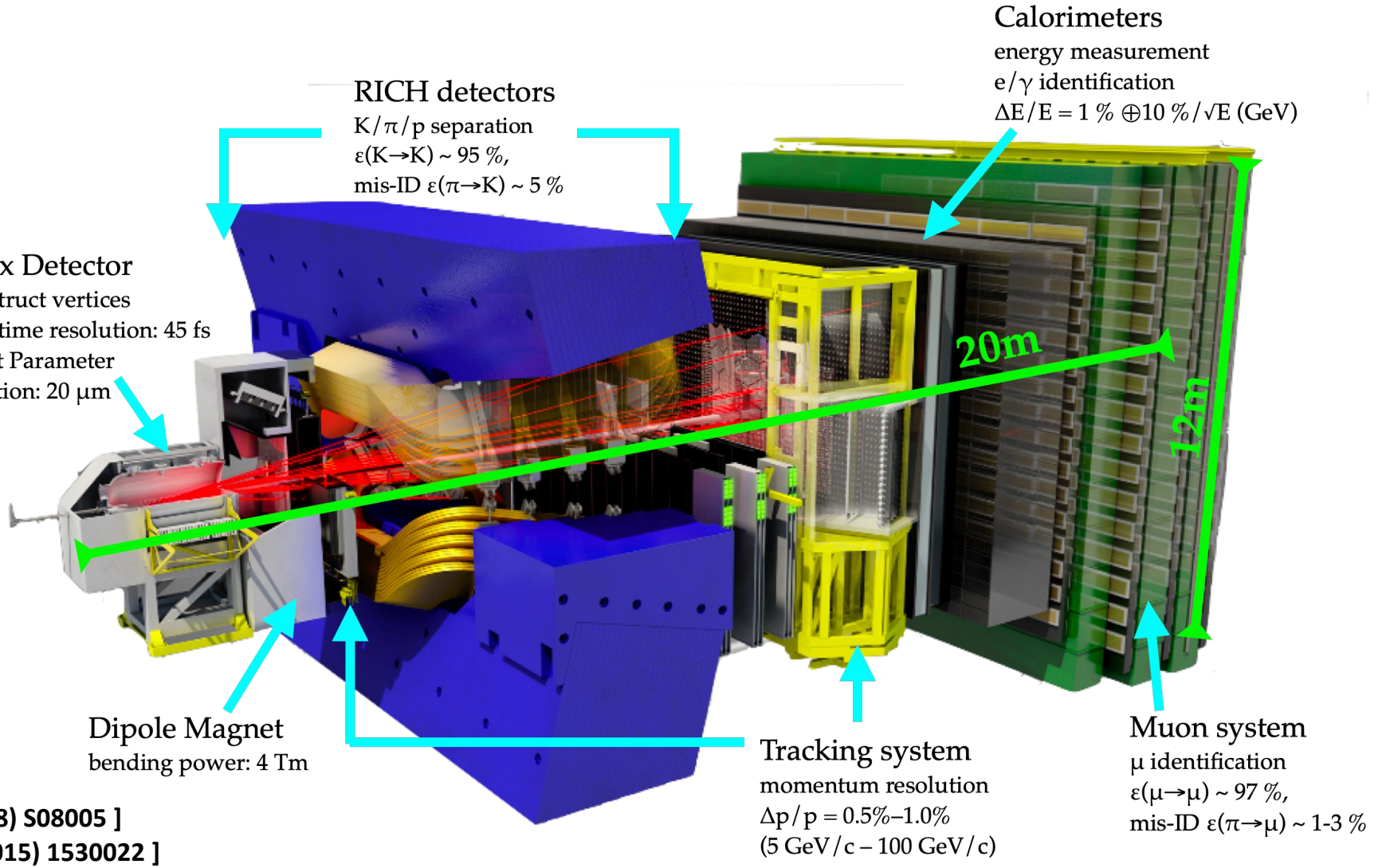
on behalf of the LHCb collaboration

The LHCb detector

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

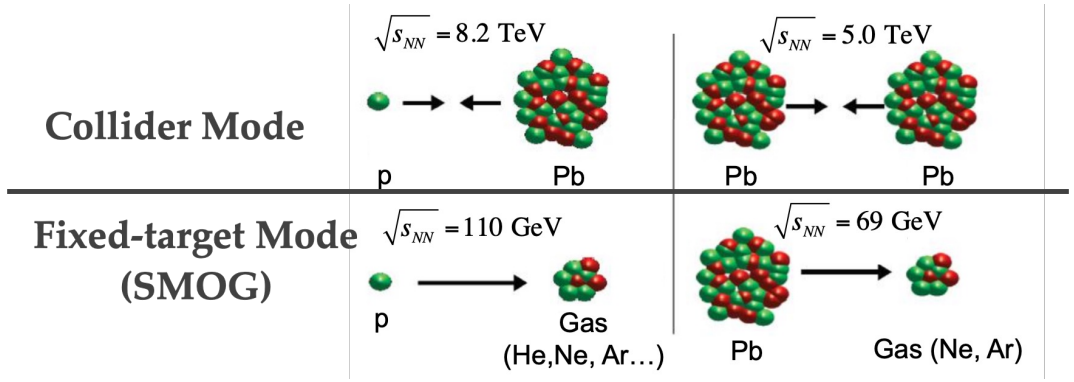
  $2 < \eta < 5$
- A high precision device, down to very low-p_T, excellent particle ID, precise vertex and track reconstruction.



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

LHCb Run2 heavy ion data

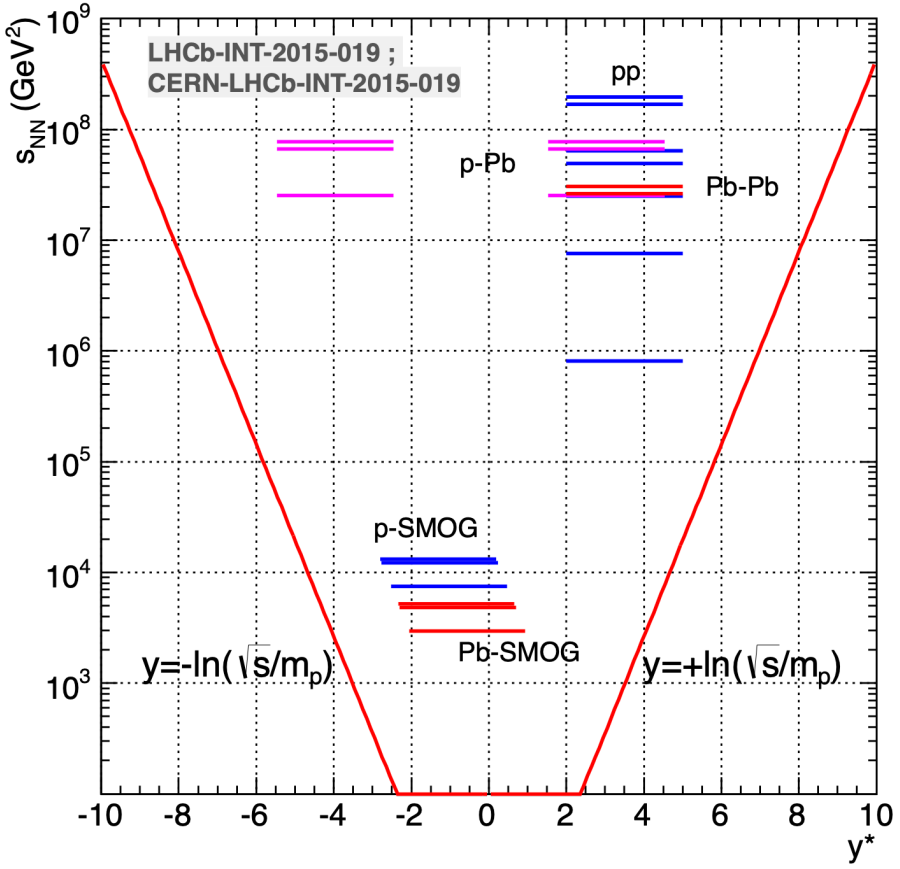
Both the collider mode and fixed-target mode running at the same time



Collider mode datasets:

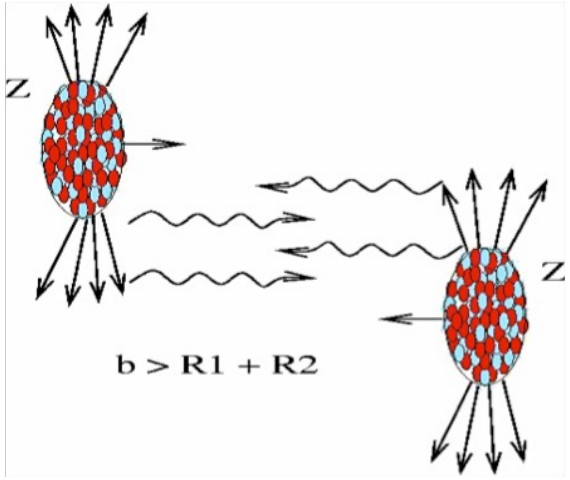
$\sqrt{s_{NN}}$	2013 5.02 TeV		2016 8.16 TeV		2015 5.02 TeV	2017 5.02 TeV	2018 5.02 TeV
	pPb	Pbp	pPb	Pbp	PbPb	XeXe	PbPb
$\mathcal{L}$	1.1 nb^{-1}	0.5 nb^{-1}	13.6 nb^{-1}	20.8 nb^{-1}	10 μb^{-1}	0.4 μb^{-1}	$\sim$ 210 μb^{-1}

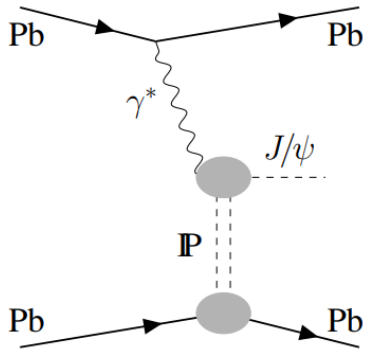
Kinematic acceptance



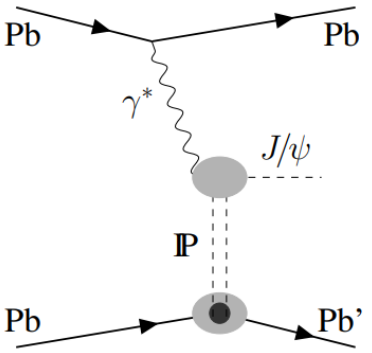
CEP in Ultra-peripheral collisions

- **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

Rich photon-induced physics program at LHCb

- CEP J/ψ production in pp collisions has already been measured at LHCb at 7 TeV pp
- Focusing on the CEP charmonium production in 2018 PbPb collisions

CEP J/ψ and $\psi(2S)$ @ 7 TeV	J. Phys. G40 (2013) 045001
Updated CEP J/ψ and $\psi(2S)$ at 7 TeV	J. Phys. G41 (2014) 055002
CEP Υ @ 7 TeV	JHEP 09 (2015) 084
CEP J/ψ and $\psi(2S)$ @ 13 TeV	JHEP 10 (2018) 167
CEP J/ψ @ 8.16 TeV 2015 PbPb UPC	JHEP 07 (2022) 117
CEP J/ψ and $\psi(2S)$ @ 8.16 TeV 2018 PbPb UPC	**JHEP 06 (2023) 146**

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:**

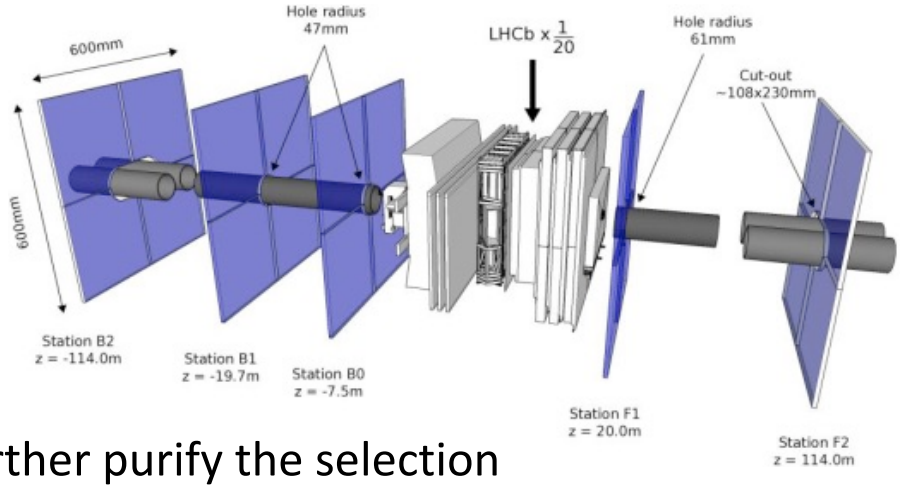
$$\frac{\mathrm{d}\sigma_{\psi}^{\mathrm{coh}}}{\mathrm{d}x} = \frac{N_{\psi}^{\mathrm{coh}}}{\mathcal{L} \times \varepsilon_{\mathrm{tot}} \times \mathcal{B}(\psi \to \mu^{+}\mu^{-}) \times \Delta x}$$

- **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



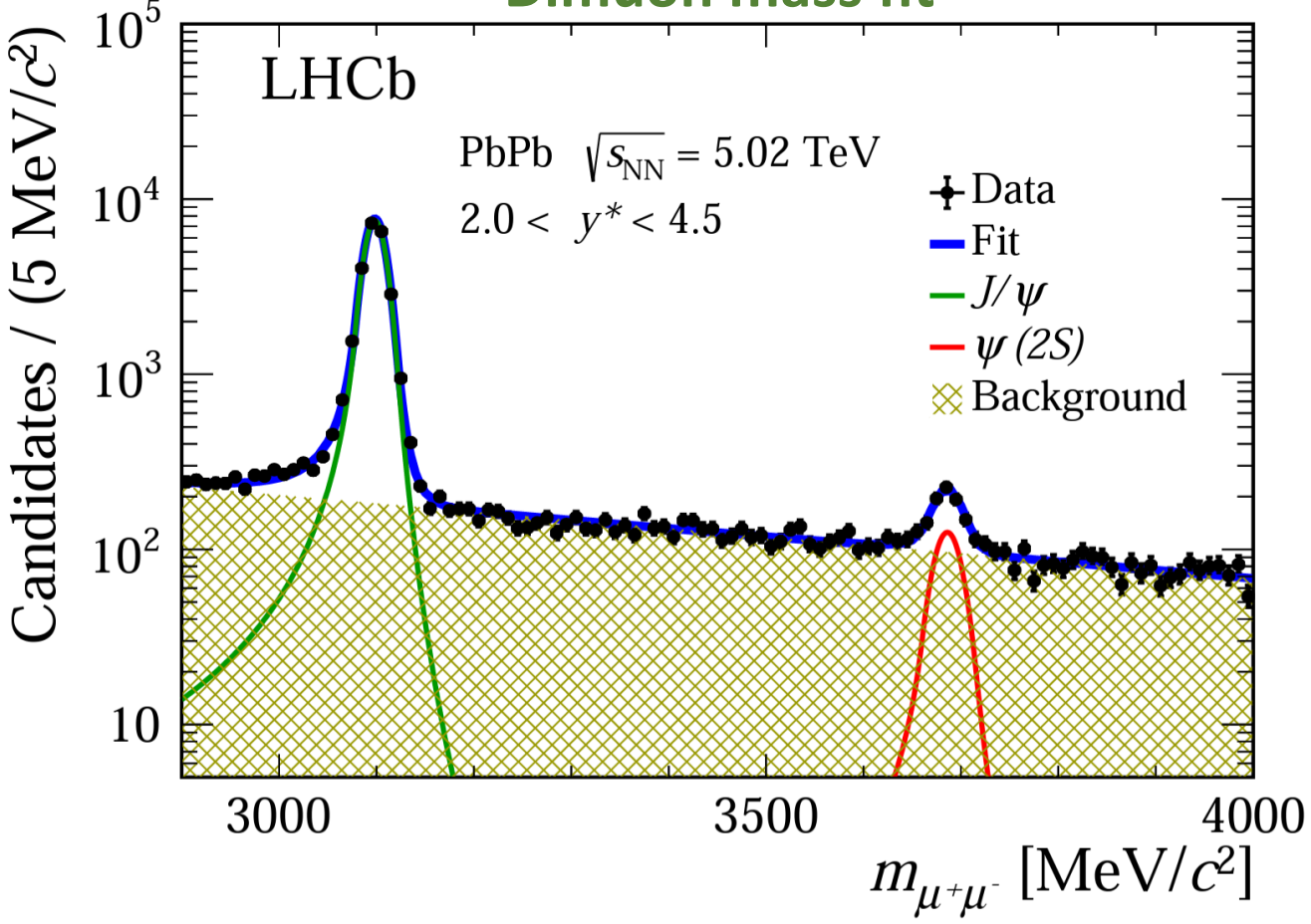
- **HERSCHEL** detector [JINST 13 (2018) 04 P04017] is used to further purify the selection

Signal extraction (1)

JHEP 06 (2023) 146

- **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 $\gamma\gamma \rightarrow \mu\mu$ process)

Dimuon mass fit

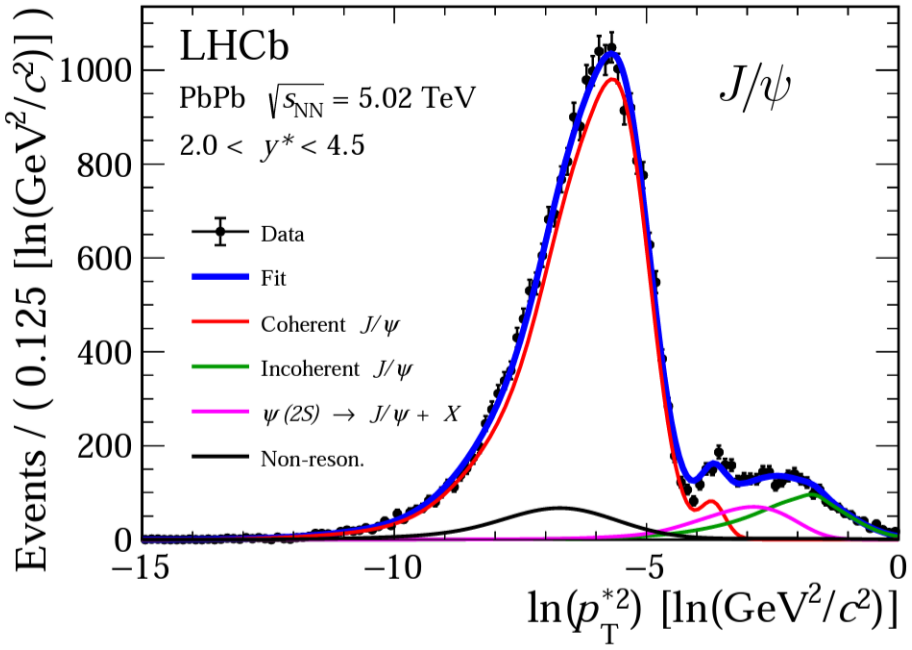


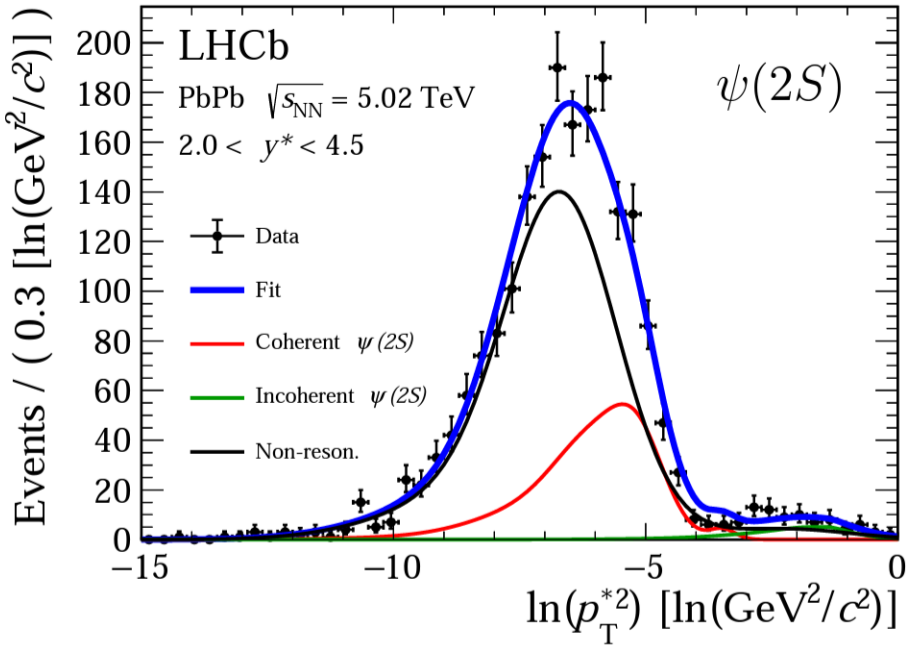
Signal extraction (2)

JHEP 06 (2023) 146

- **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

JHEP 06 (2023) 146

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

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

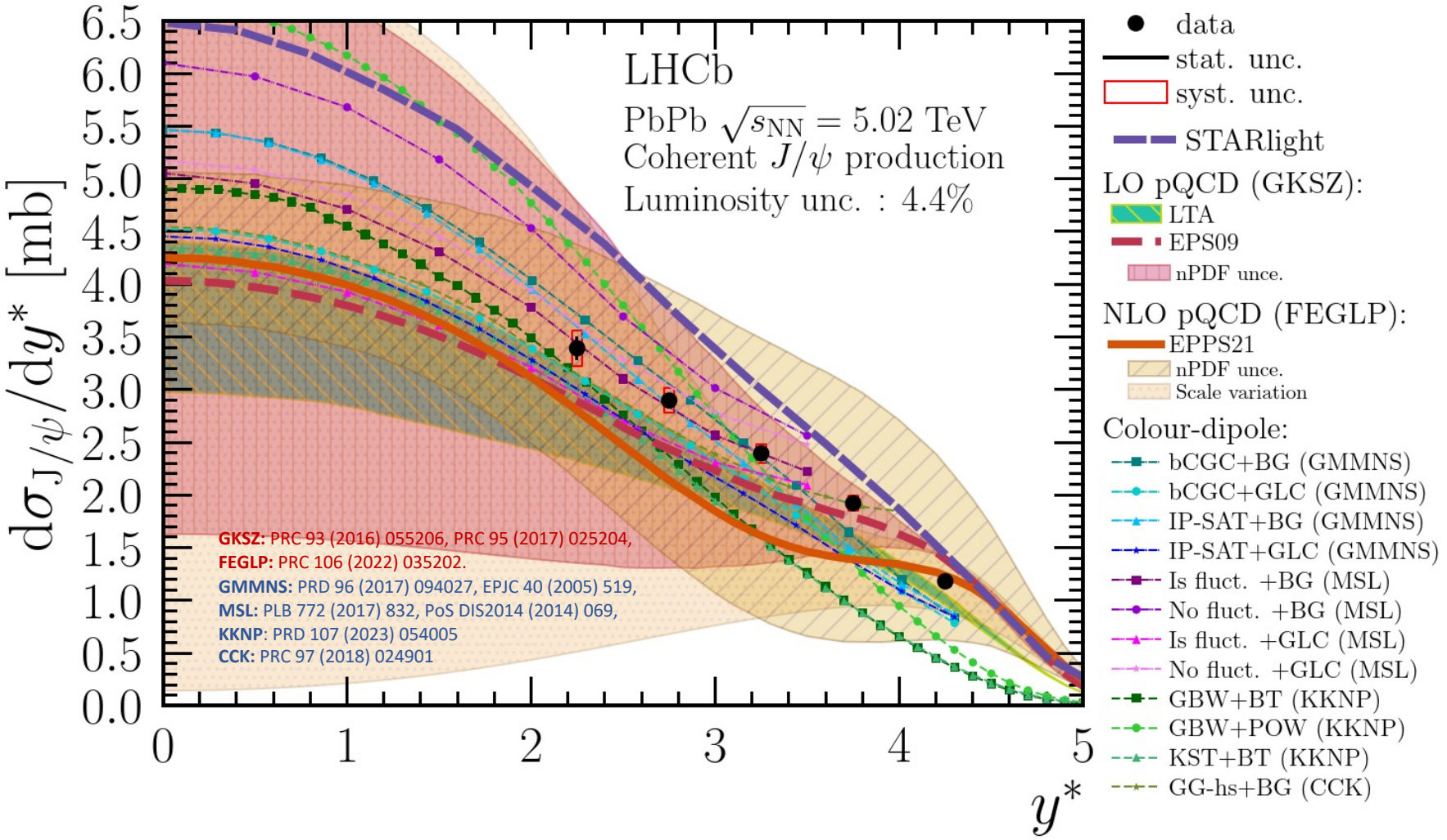
- **Systematic uncertainties:**

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

JHEP 06 (2023) 146

- **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

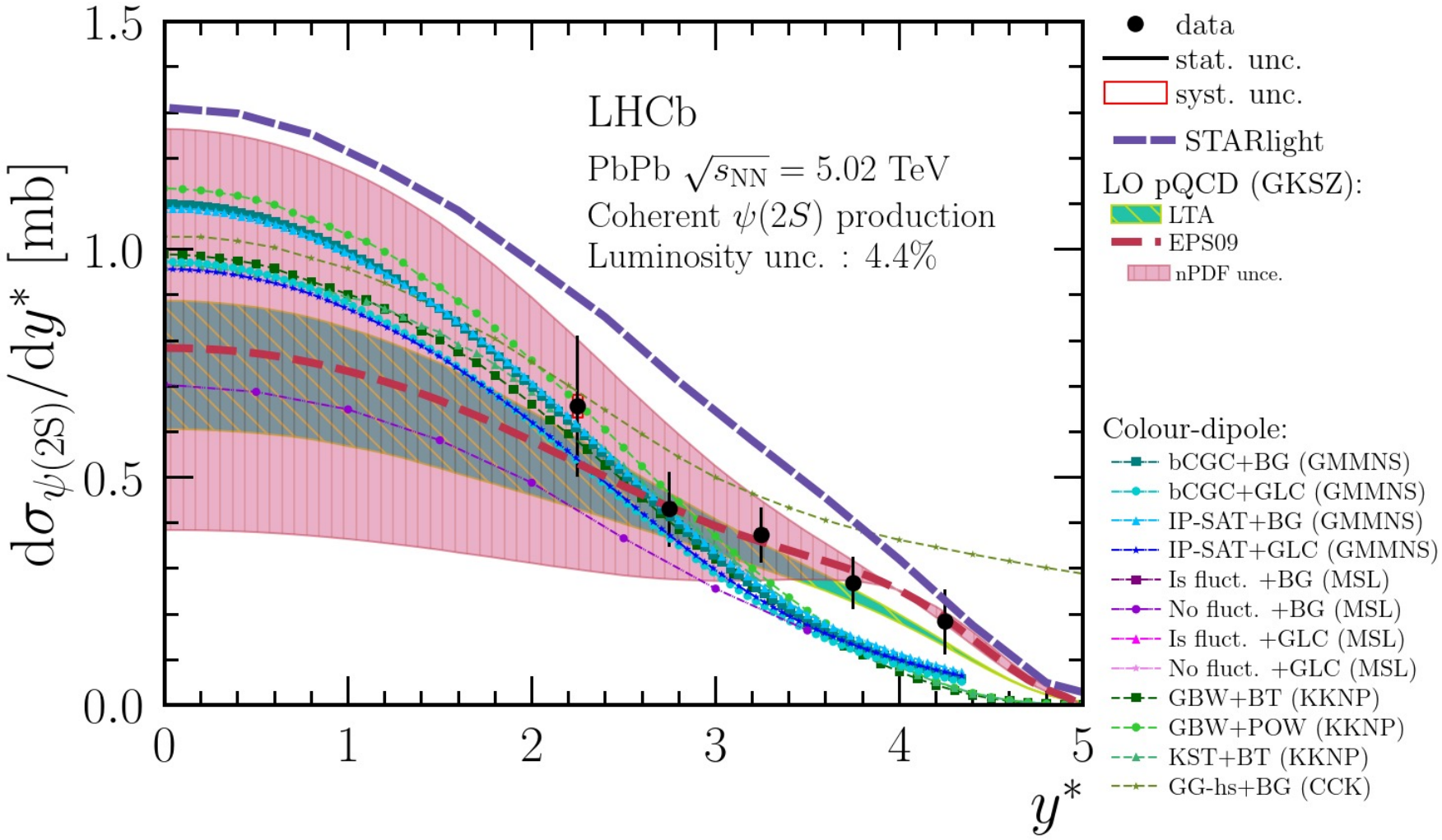


Charmonia in UPC

JHEP 06 (2023) 146

- **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

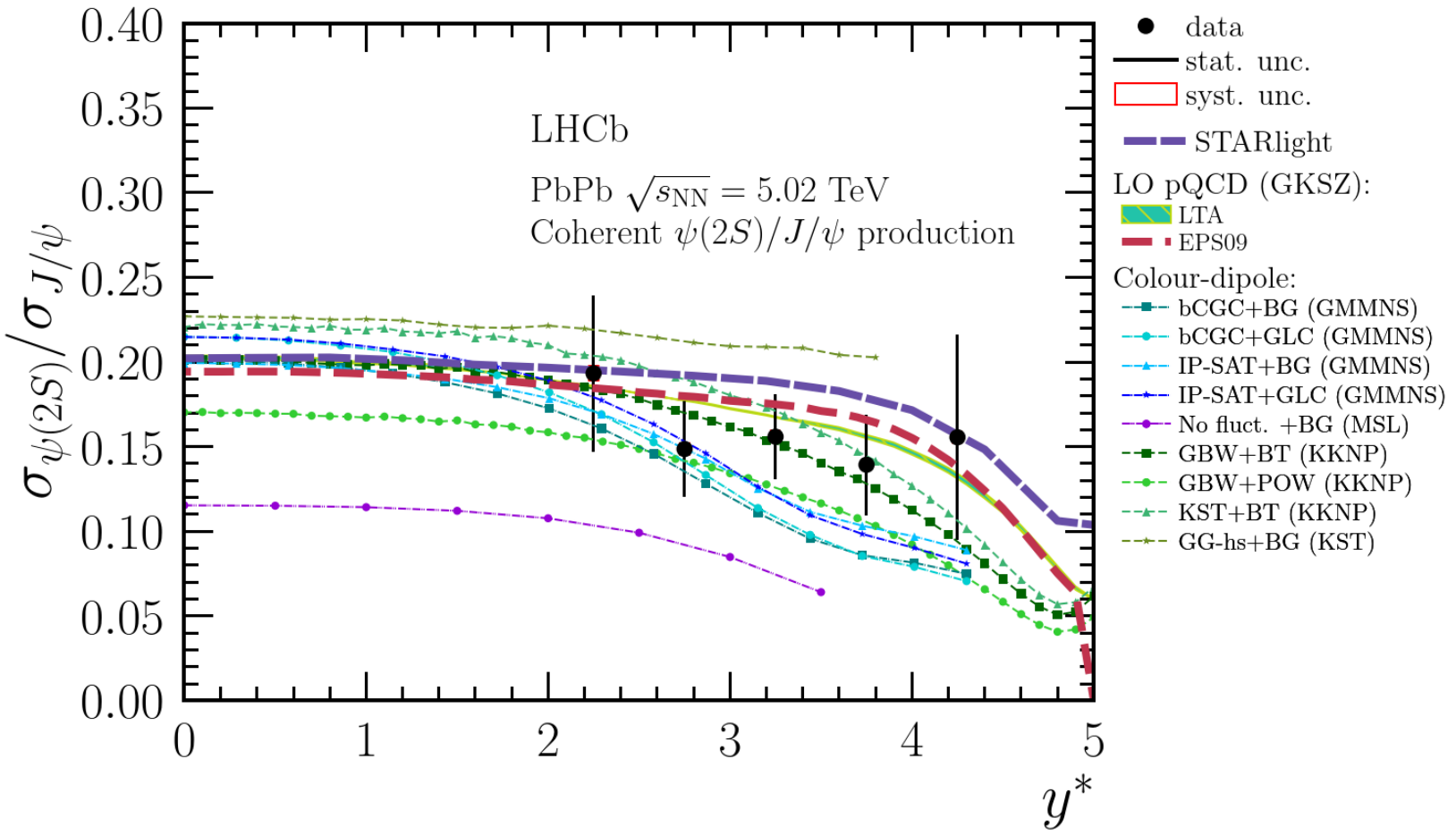
Charmonia in UPC

JHEP 06 (2023) 146

- **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,
KKNP: PRD 107 (2023) 054005
CCK: PRC 97 (2018) 024901

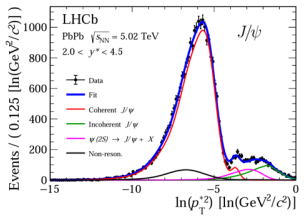


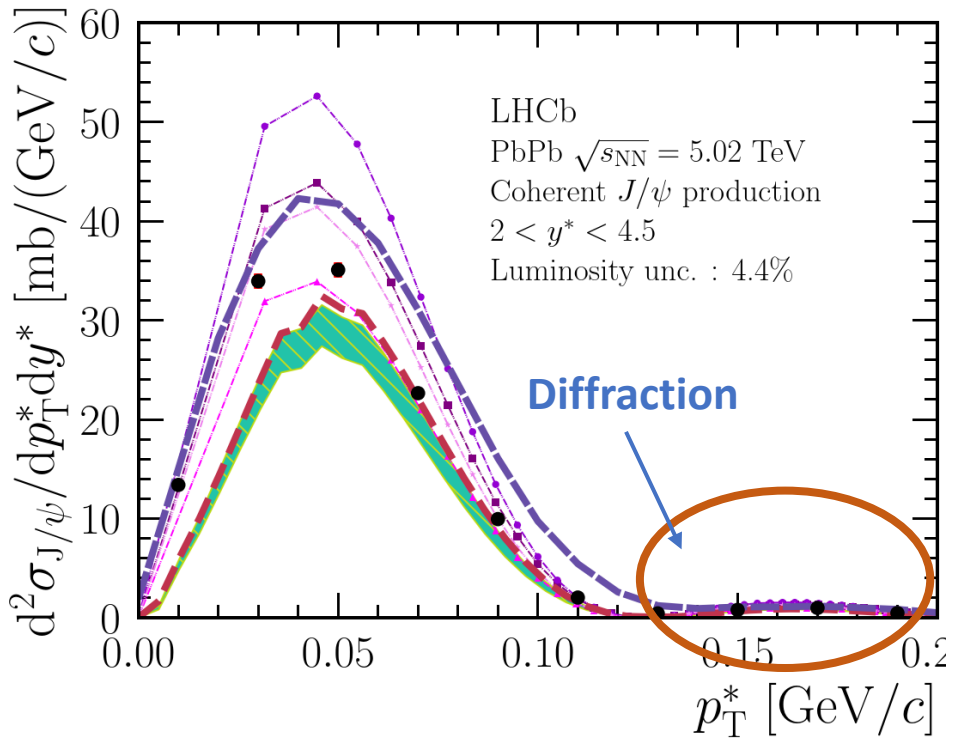
Charmonia in UPC

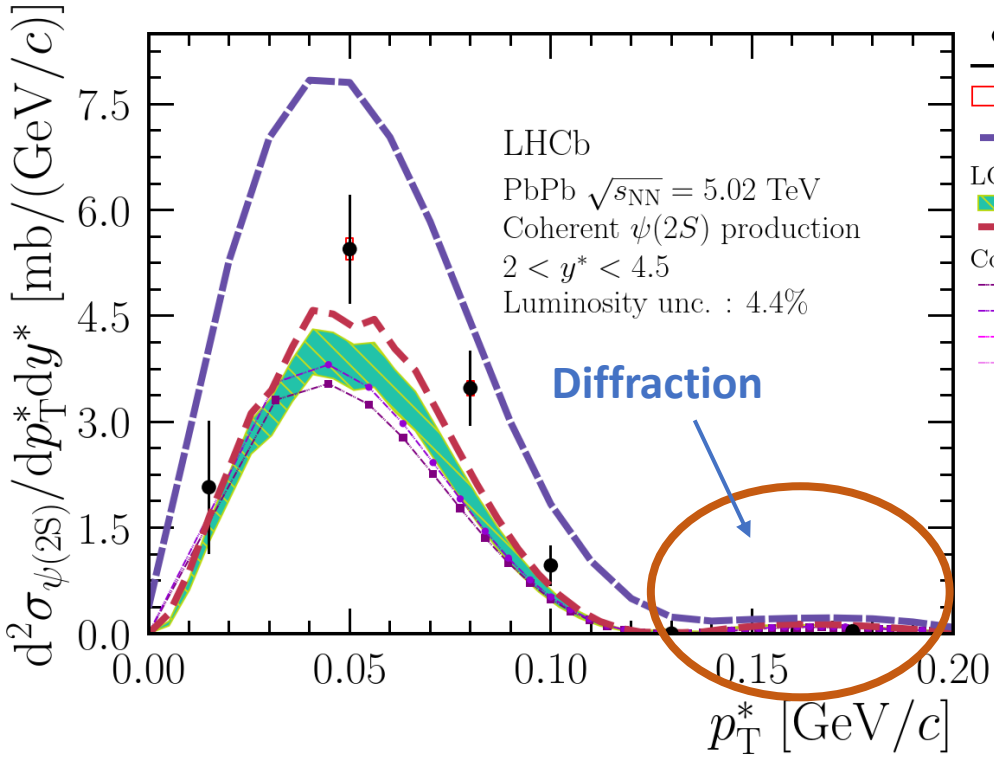
JHEP 06 (2023) 146

- **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





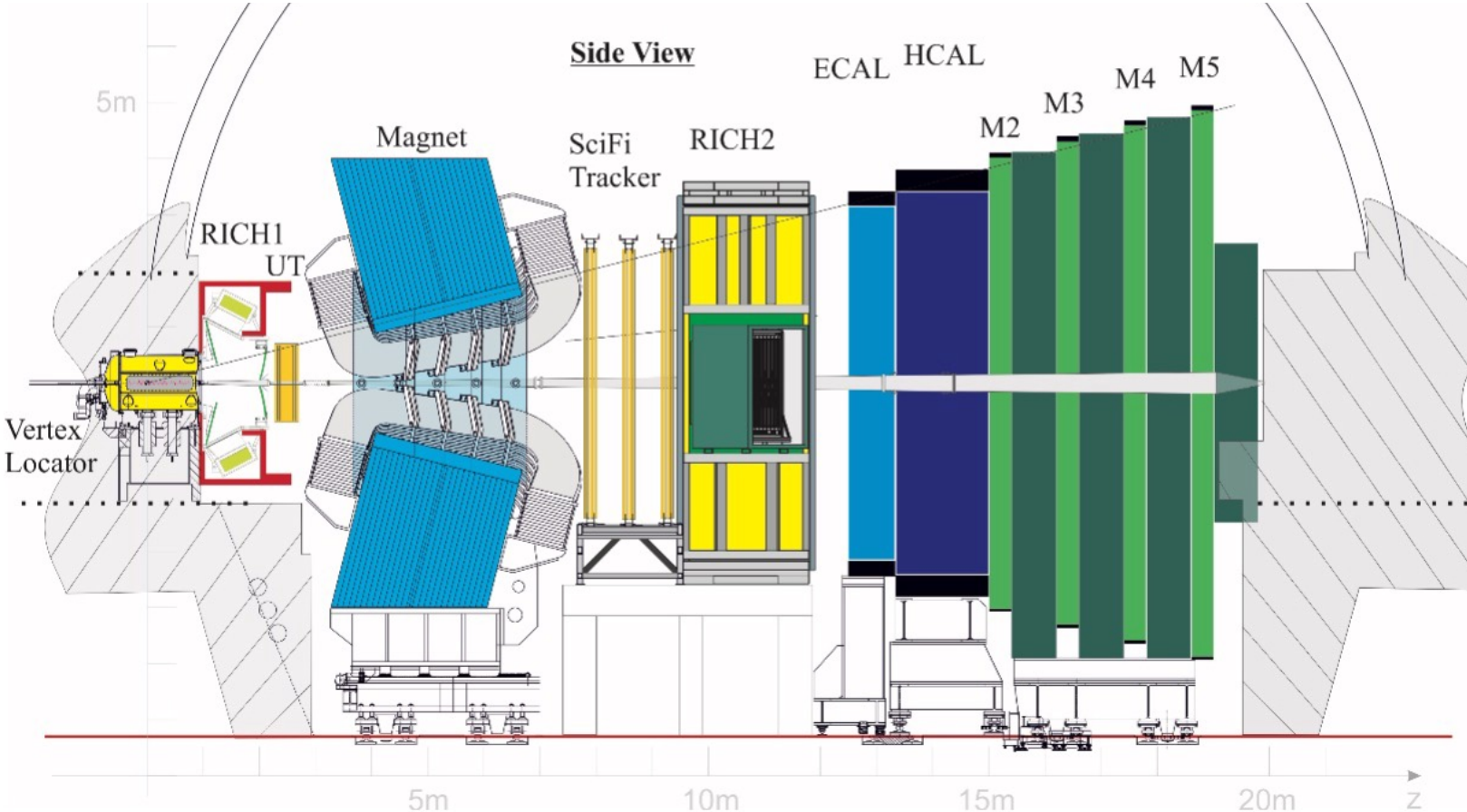


GKSZ: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
MSL: PLB 772 (2017) 832, PoS DIS2014 (2014) 069,

LHCb detector at Run3

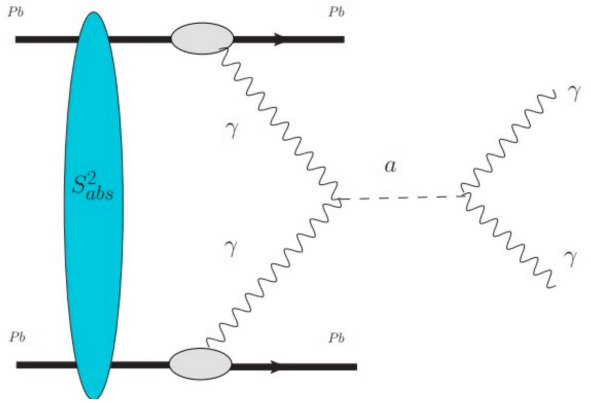
JINST 19 (2024) 05, P05065

- Brand new tracking detectors expand PbPb centrality reach from ~ 60% to 30%.
- Front-end electronics upgraded to read out the full detector at 40 MHz.
- Every collision is processed in software: CSBS 4 (2020) 1, 7

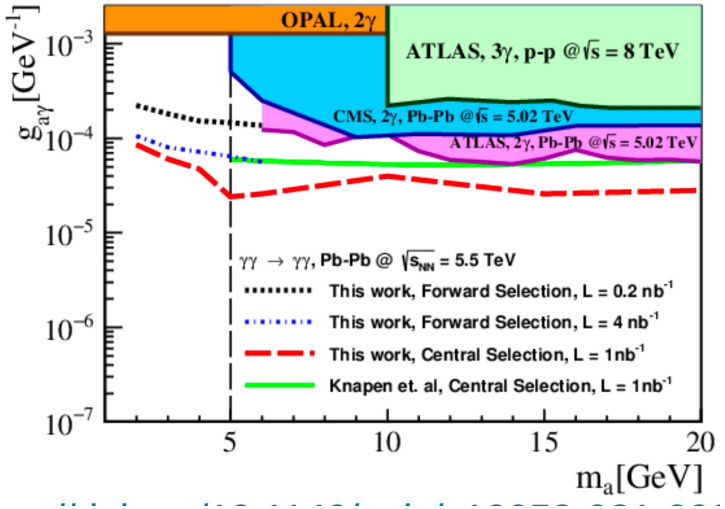


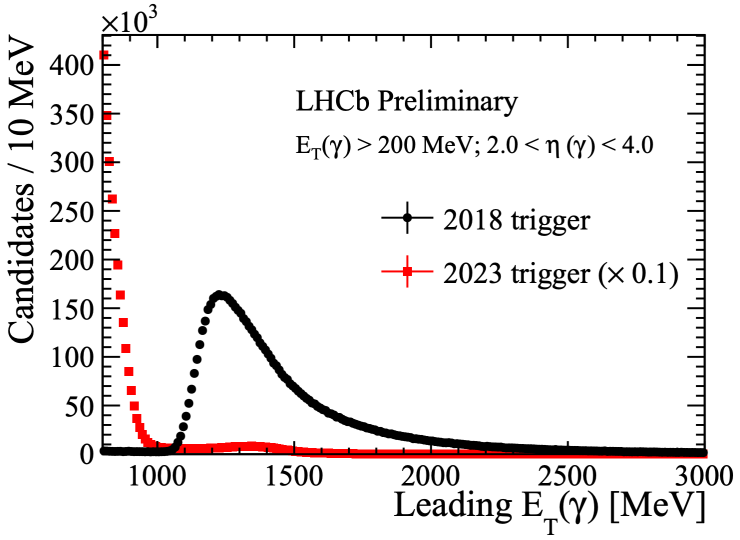
New photon trigger for UPC physics

- Dedicated new low ET photon trigger, opens a window for low mass Axion-like particle searches at UPC.



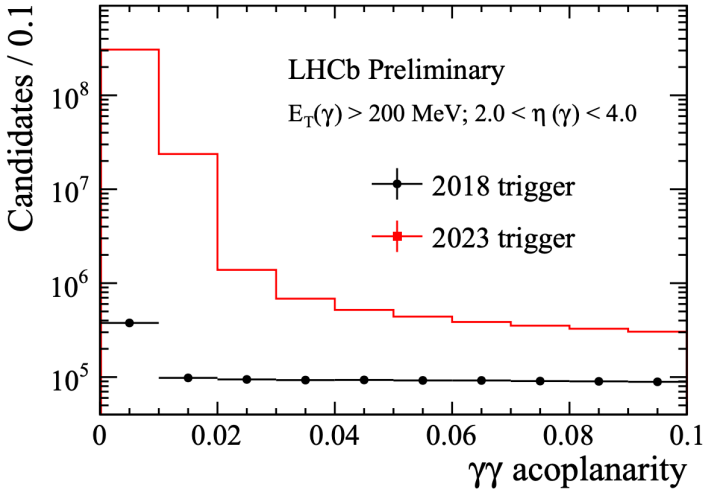
Eur. Phys. J. C (2021) 81 :522





Figures recently approved for LHCC opening session.

[LHCB-FIGURE-2024-012]



Conclusion and outlook

- 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, diffractive 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, in all pp, pPb, PbPb collisions, is ongoing at LHCb:

  e.g. charmonium, bottomonium, K^+K^-, $\pi\pi$, ρ, $\phi\phi$, also ALP, etc…

Backups