LHCb measurements of Quarkonia Production in Ultraperipheral PbPb collisions and Z production in pPb collisions

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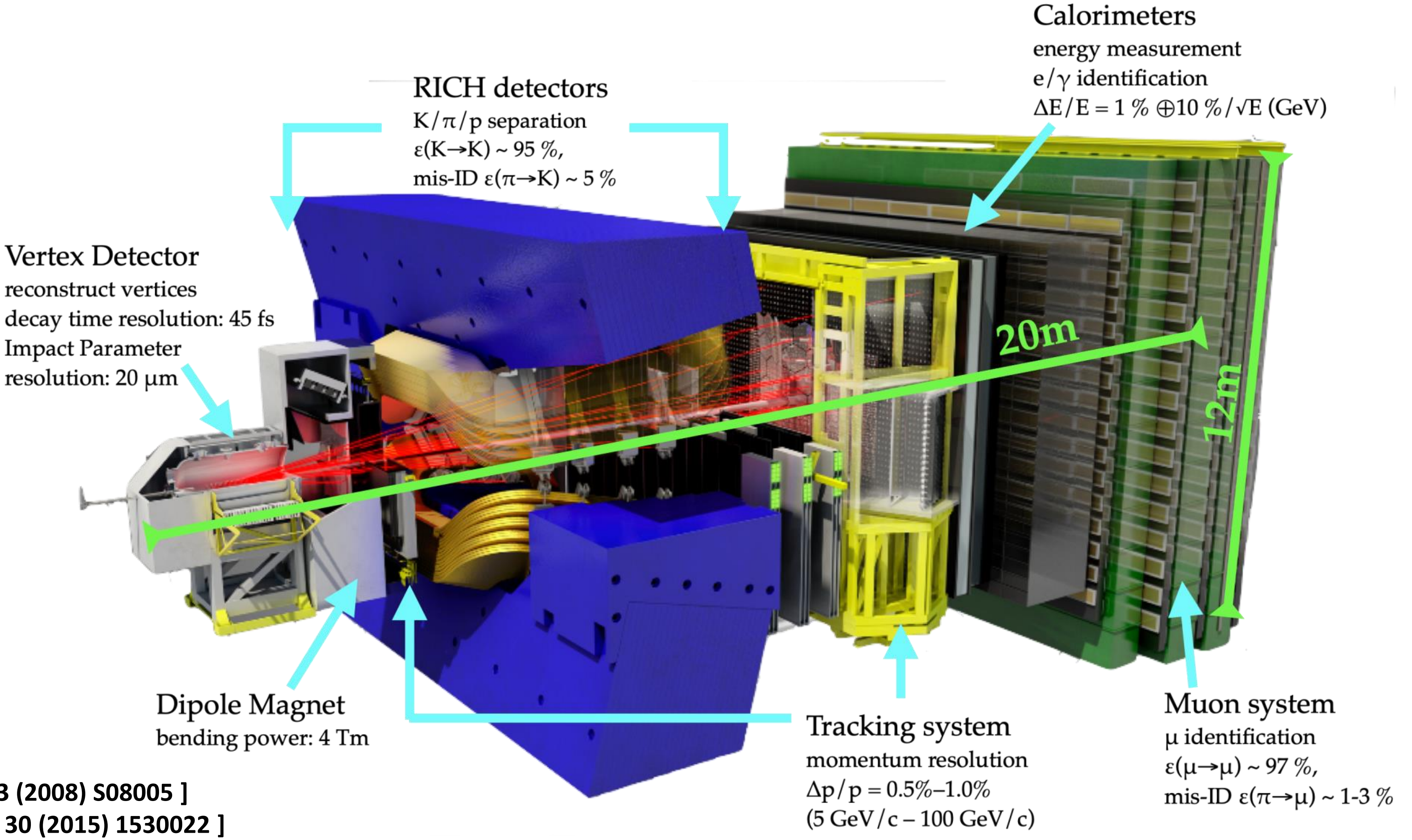
on behalf of the LHCb collaboration

The LHCb detector

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

  $2 < \eta < 5$

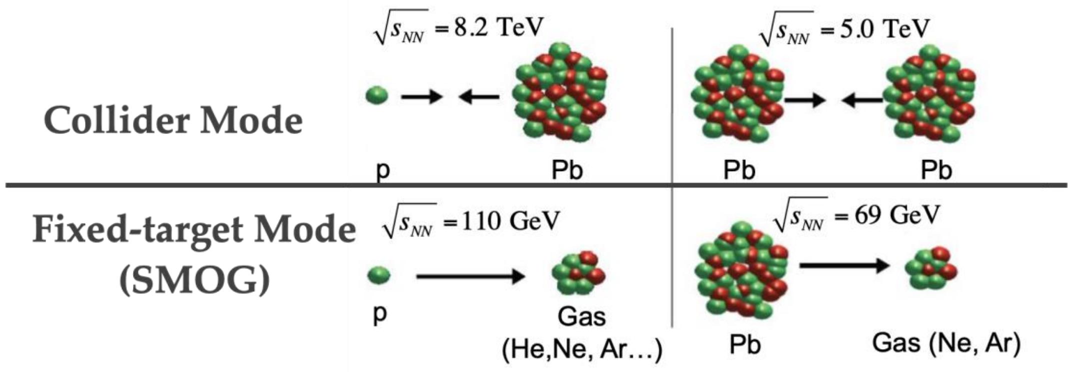
- A high precision device, down to very low-p_T, excellent particle ID, precise vertex and track reconstruction.



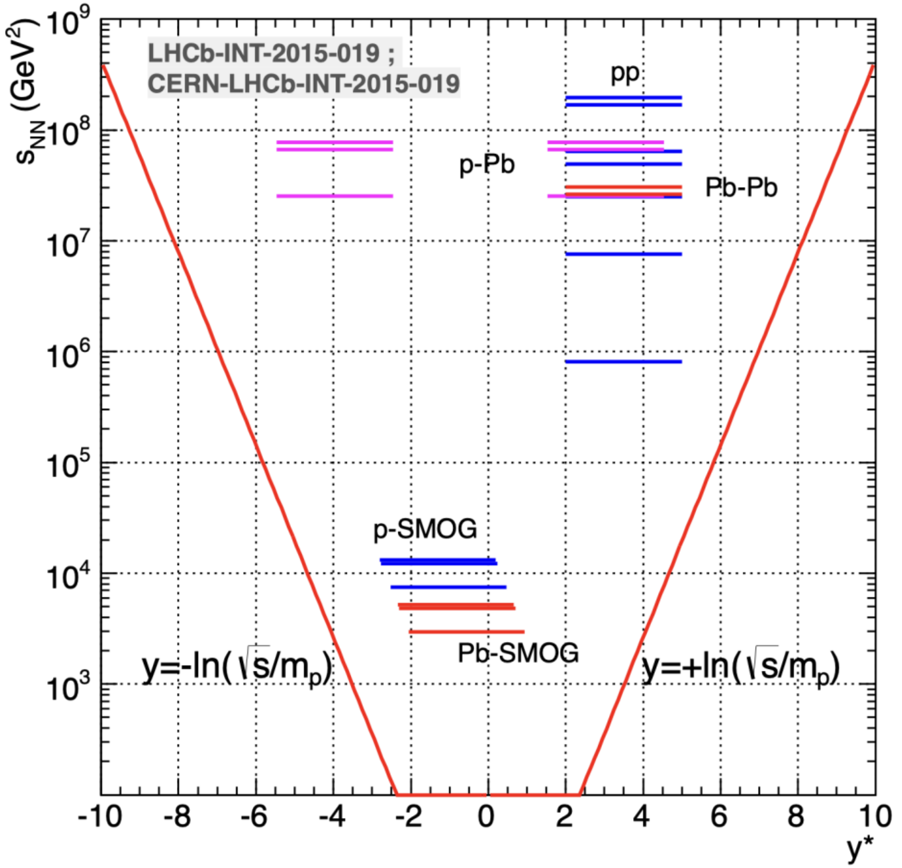
[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]

LHCb running modes and kinematic coverage

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



Kinematic acceptance

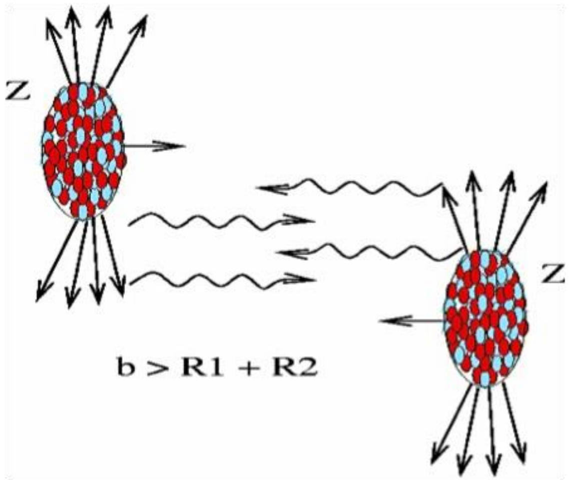


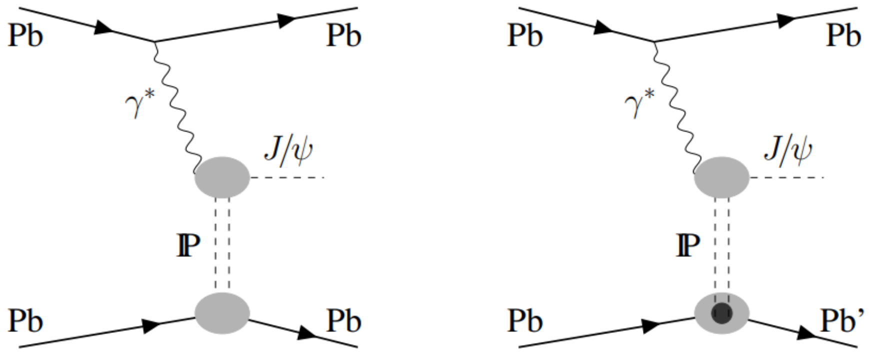
Collider mode datasets:

$\sqrt{s_{NN}}$	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 $\mu\mathrm{b}^{-1}$	0.4 $\mu\mathrm{b}^{-1}$	$\sim$ 210 $\mu\mathrm{b}^{-1}$

Ultra-peripheral production of Charmonium

- **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

Ultra-peripheral and peripheral photon-production

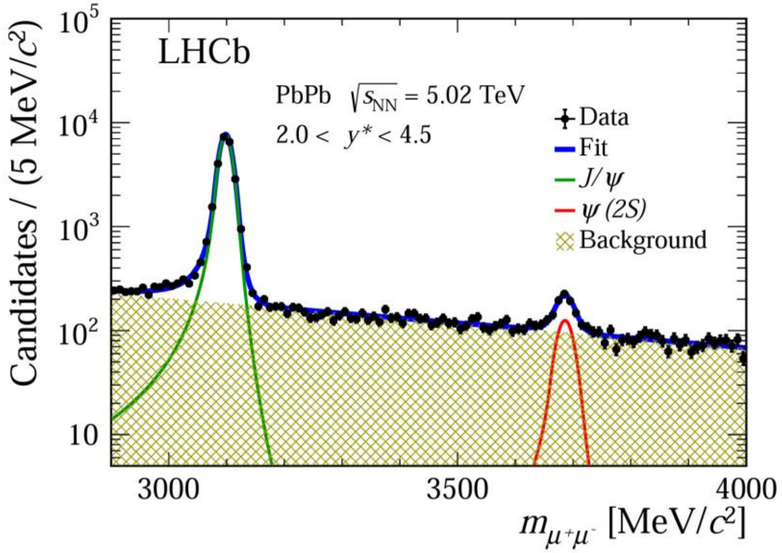
LHCb-PAPER-2022-012, arXiv:2206.08221

- **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:

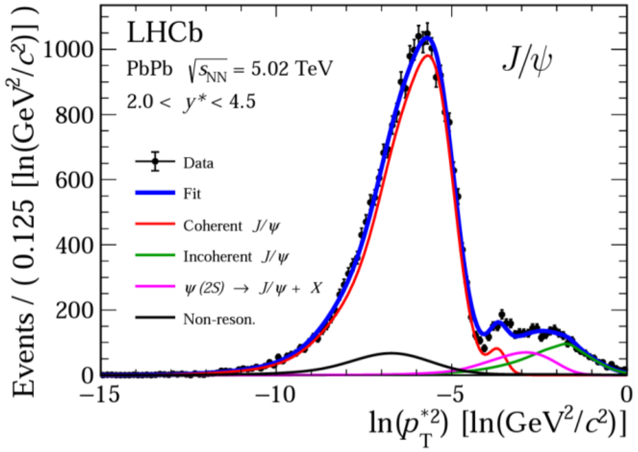
    $2.0 < \eta^{\mu} < 4.5\,, p_{\mathrm{T}}^{\mu} > 700\mathrm{MeV},$

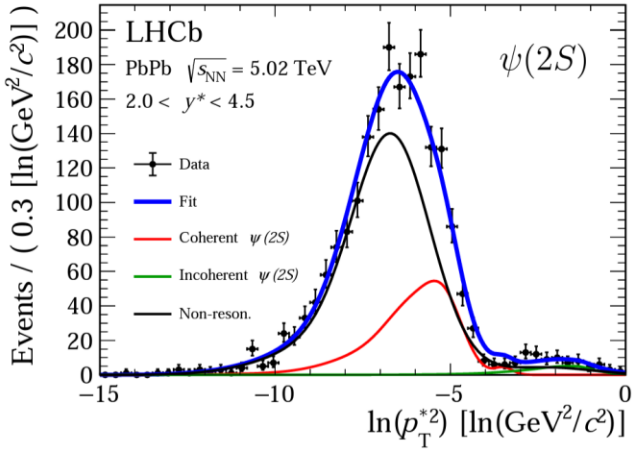
    $p_T^{\mu\mu} < 1\mathrm{GeV}, |\Delta\phi_{\mu\mu}| > 0.9\pi$
  - HERSCHEL detector [JINST 13 (2018) 04 P04017] is used to further purify the selection
- **Signal extraction: The (1) charmonium yields are extracted from dimuon mass fit, then the (2) coherent part is extracted from a $\ln(p_T^2)$ fit**

Step (1): mass fit



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





Ultra-peripheral and peripheral photon-production

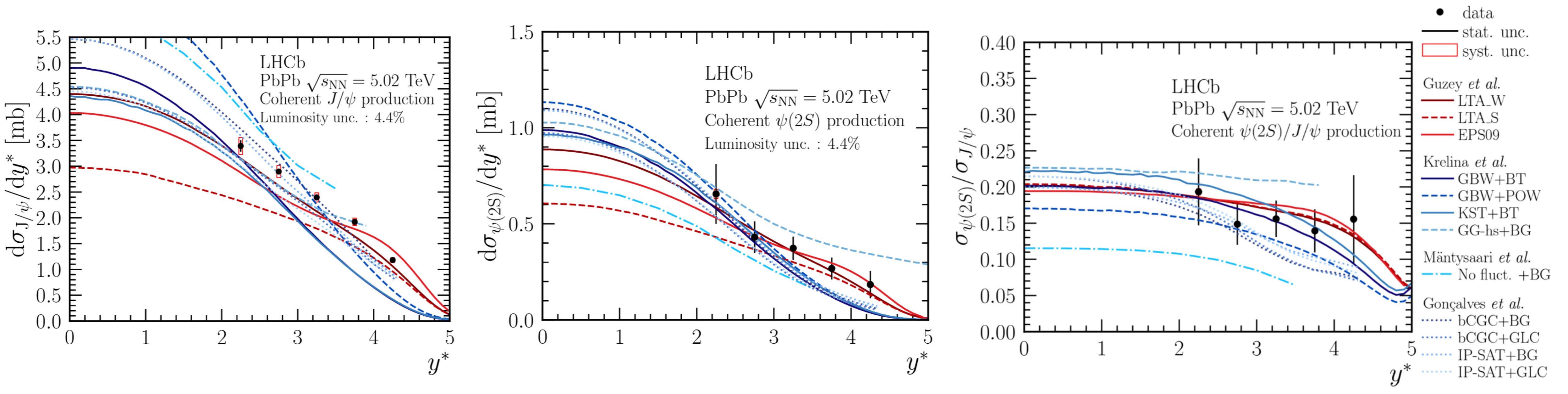
LHCb-PAPER-2022-012, arXiv:2206.08221

- **Integrated cross-section and ratio:**

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

- **Differential cross-section vs. rapidity (compared to pQCD and color-dipole models)**
  - The most precise measurement for coherent J/ψ production in PbPb UPC in the forward rapidity today;
  - The first coherent $\psi(2S)$ measurement in forward rapidity region at the LHC.

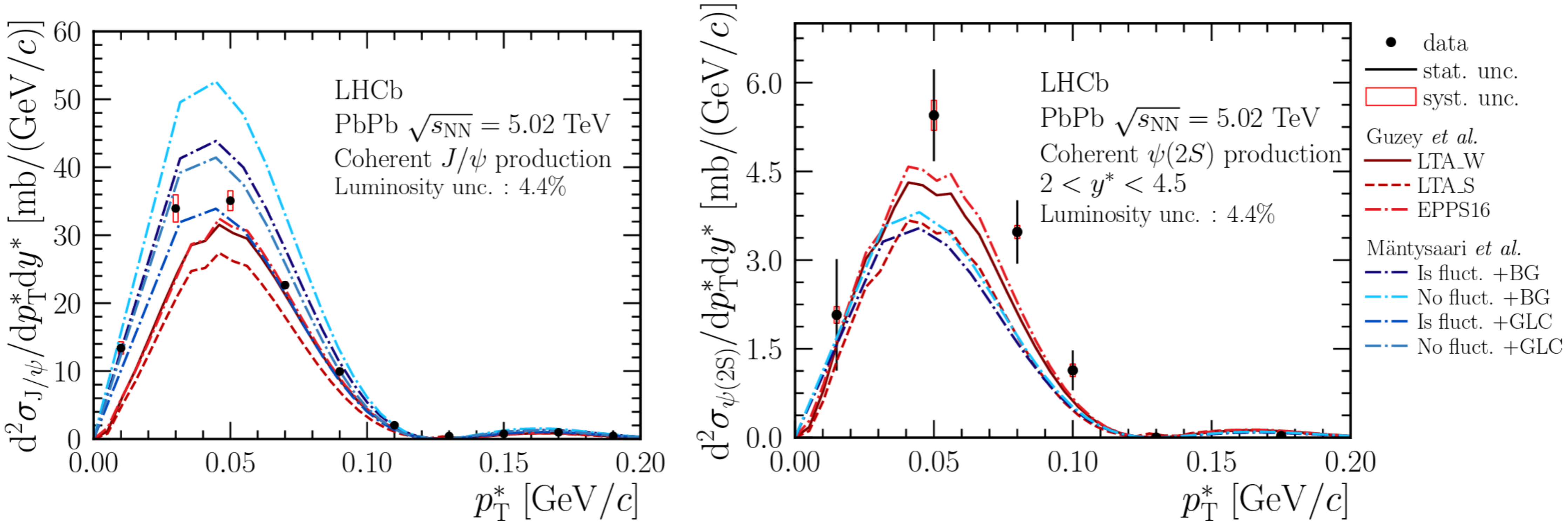
Guzey et al.: PRC 93 (2016) 055206, PRC 95 (2017) 025204,
Krelina et al.: PRC 97 (2018) 024901, arXiv:2008.05116
Mantysaari et al.: PLB 772 (2017) 832, PoS DIS2014 (2014) 069, PRD 74 (2006) 074016
Goncalves et al.: PRD 96 (2017) 094027, EPJC 40 (2005) 519,



Ultra-peripheral and peripheral photon-production

LHCb-PAPER-2022-012, arXiv:2206.08221

- **Differential cross-section vs. charmonium p_T (compared to pQCD and color-dipole models)**
  - **The first and most precise measurement of the coherent J/ψ and $\psi(2S)$ production cross-section vs. p_T in PbPb UPC today.**



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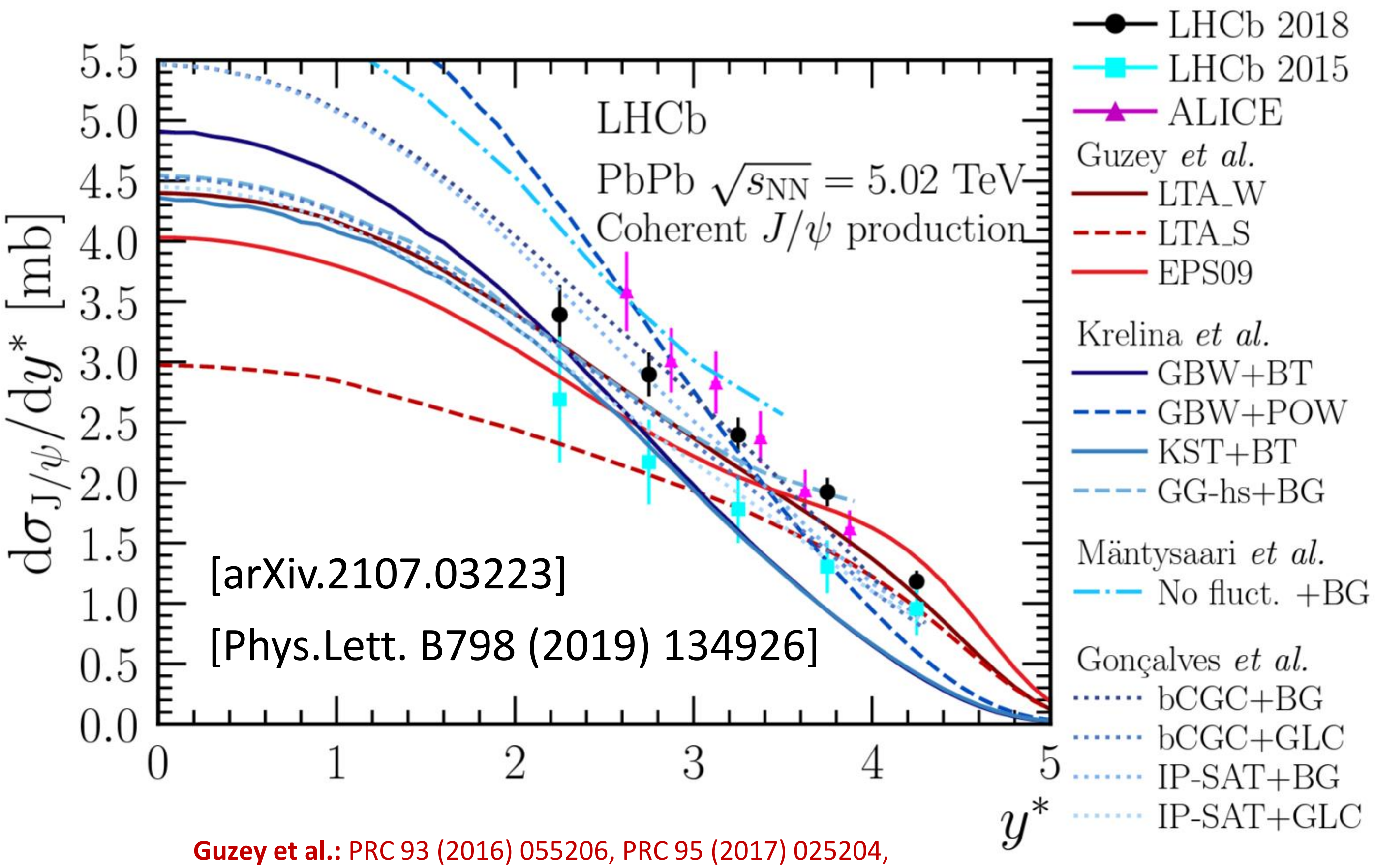
Ultra-peripheral and peripheral photon-production

LHCb-PAPER-2022-012, arXiv:2206.08221

- The J/ψ measurement is compatible with 2015 and ALICE results.
  - The difference between the new results and 2015 measurement is about 2.0σ.



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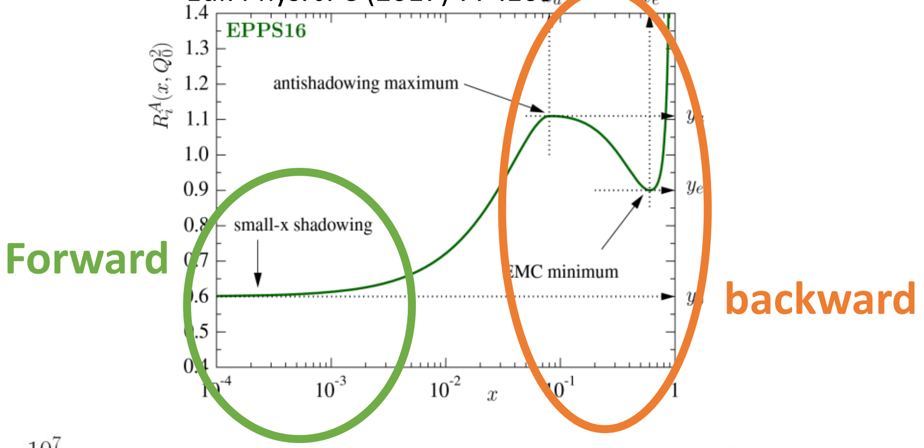
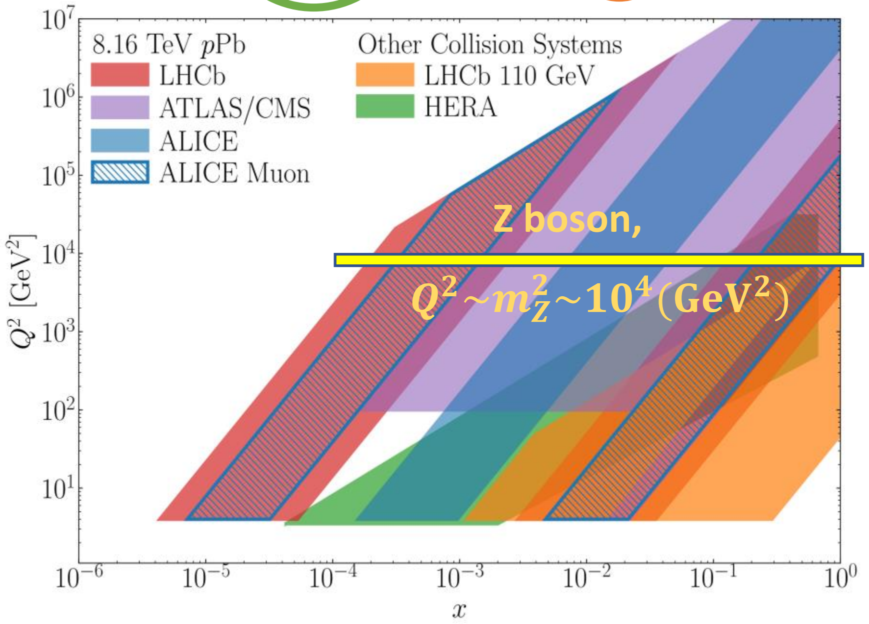
Goncalves et al.: PRD 96 (2017) 094027, EPJC 40 (2005) 519,

Probe nuclear modification with Z boson

- Z bosons are **unmodified** by the hot and dense medium created in heavy ion collisions,
  - Their leptonic decays pass through the medium without being affected by the strong interaction.
  - “conserved” the initial conditions of the collisions.
- Ideal probe of cold nuclear matter effects at Bjorken-x in $10^{-4} < x < 10^{-3}$ and $10^{-1} < x < 1$, with $Q^2 \sim 10^4 \mathrm{GeV}^2$.
- A calibration channel for probing the nuclear modification using other processes such as heavy quark production.

Eur. Phys. J. C (2017) 77 :163





Z production in pPb collisions

LHCb-PAPER-2022-009, arXiv:2205.10213

- **LHCb pPb dataset at 8.16 TeV about 30 nb^{-1}.**
- **Fiducial volume:**

$$p_{\mathrm{T}}^{\mu} > 20 \text{ GeV}, 2.0 < \eta_{\mu} < 4.5,$$
$$60 < m_{\mu\mu} < 120 \text{ GeV}$$

- **Cross-section**:

$$\sigma_{Z\to\mu\mu} = \frac{N_{\mathrm{cand}} \cdot \rho \cdot f_{\mathrm{FSR}}}{\mathcal{L} \cdot \epsilon}$$

- **Forward-backward ratio:**

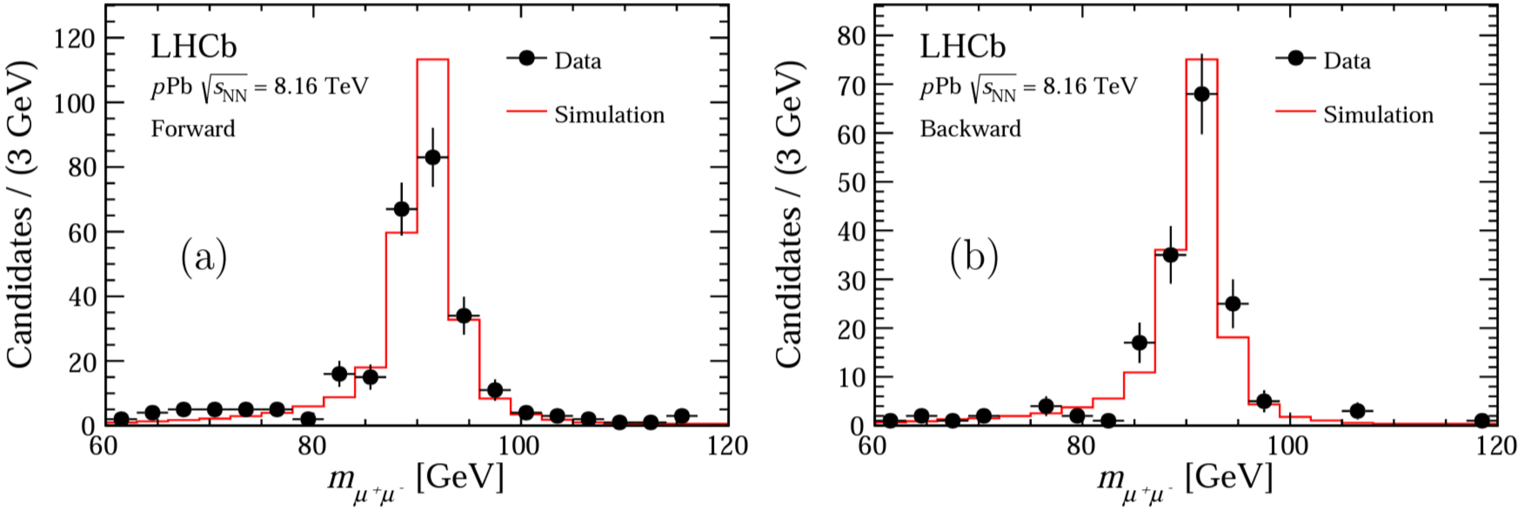
$$R_{\mathrm{FB}} = \frac{\sigma_{(1.53<y_{\mu}^{*}<4.03)}}{\sigma_{(-4.97<y_{\mu}^{*}<-2.47)}} \cdot k_{\mathrm{FB}}$$

- **Nuclear modification factors:**

$$R_{p\mathrm{Pb}}^{\mathrm{fw.}} = \frac{1}{208} \cdot \frac{\sigma_{(p\mathrm{Pb},\, 1.53<y_{\mu}^{*}<4.03)}}{\sigma_{(pp,\, 2.0<y_{\mu}^{*}<4.5)}} \cdot k_{p\mathrm{Pb}}$$

Forward: 268 events

Backward: 167 events



- The cross-section, R_{FB} and $R_{p\mathrm{Pb}}$ are measured as a function of y_Z^*, p_{T}^{Z}, and $\phi_{\eta}^{*} = \tan(\phi_{\mathrm{acop}}/2)\,/\cos(\Delta\eta/2)$ (an angular variable equivalent to p_{T}^{Z} w/o uncertainty from momentum calibration).
- k_{FB} and $k_{p\mathrm{Pb}}$ are the corresponding muon rapidity acceptance correction factors.
- pp reference cross-section at 8.16 TeV is interpolated from LHCb 7, 8 and 13 TeV results.

Z production in *p*Pb collisions

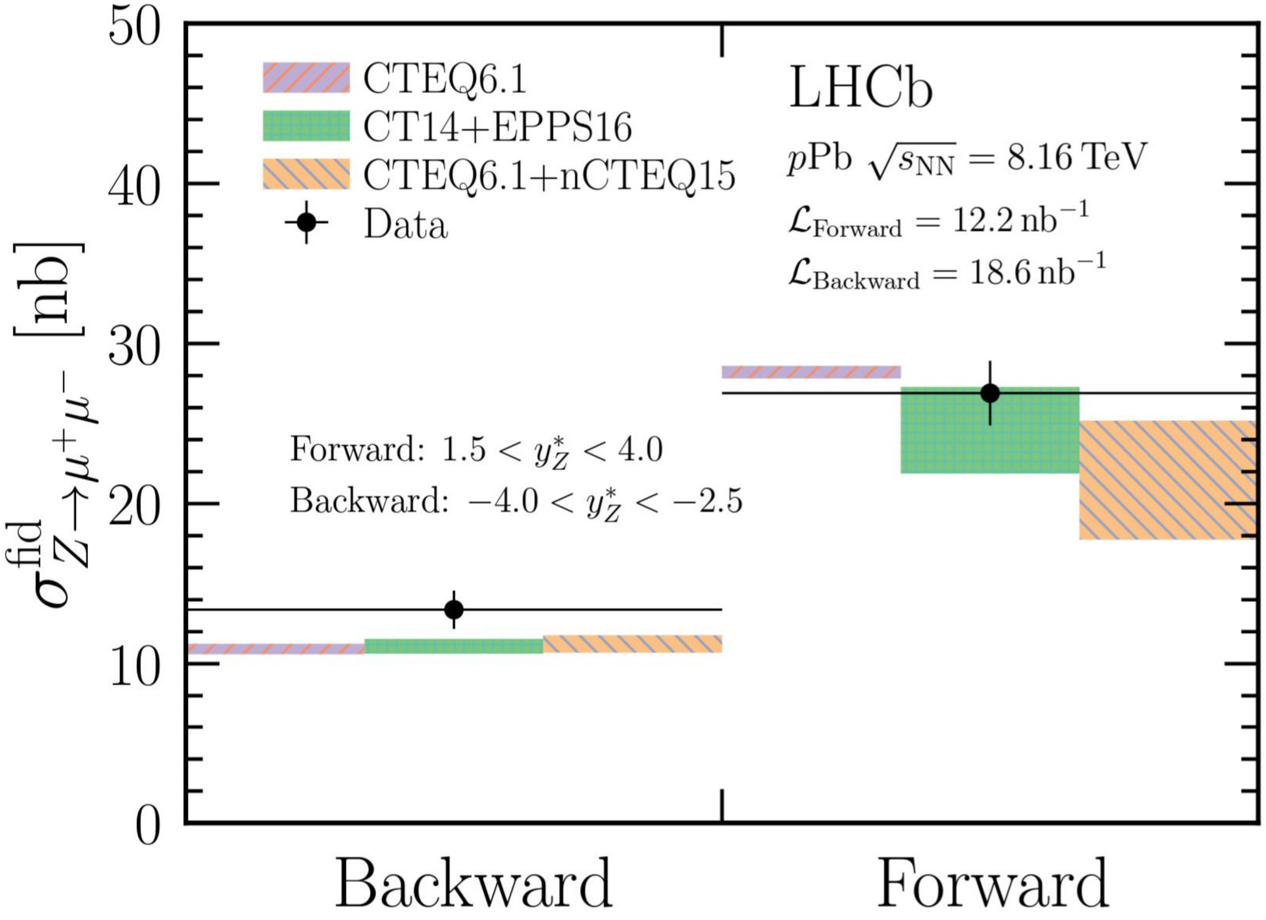
LHCb-PAPER-2022-009, arXiv:2205.10213

- **Total fiducial cross-section**:

  $\sigma_{Z\to\mu\mu,\,\mathrm{fwd.}}$
  $= 26.9 \pm 1.6(\mathrm{stat.}) \pm 0.9(\mathrm{syst.}) \pm 0.7(\mathrm{lumi.})\mathrm{nb}$

  $\sigma_{Z\to\mu\mu,\,\mathrm{bwd.}}$
  $= 13.4 \pm 1.0(\mathrm{stat.}) \pm 0.5(\mathrm{syst.}) \pm 0.3(\mathrm{lumi.})\ \mathrm{nb}$

- Compatible with theoretical calculations using POWHEG v2:
  - CTEQ61 (PDF) for both ***p*** and **Pb**
  - CT14 (PDF) for ***p*** and EPPS16 (nPDF) for **Pb**
  - CTEQ61 (PDF) for ***p*** and nCTEQ15 (nPDF) for **Pb**
- Forward (small Bjorken-x) results show strong constraining power on the nPDFs.



Z production in pPb collisions

LHCb-PAPER-2022-009, arXiv:2205.10213

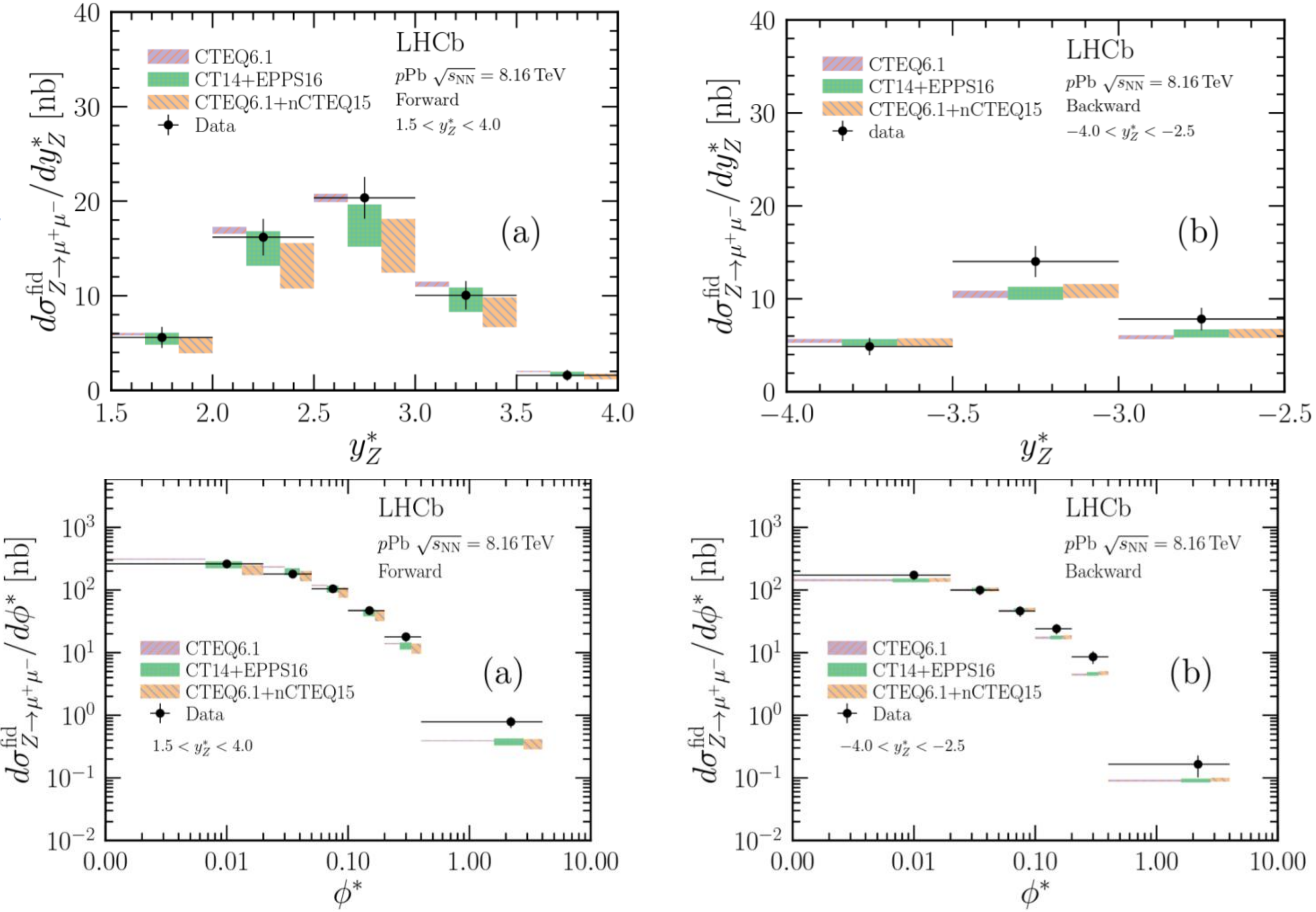
- **Differential cross-section as a function of y_Z^* and ϕ_η^* :**
  - In good agreement with theoretical predictions.
  - Forward: smaller uncertainty than prediction, constraints on nPDFs.
  - Backward: larger uncertainty than predictions.

Forward

backward

y_Z^*

ϕ_η^*



Z production in pPb collisions

LHCb-PAPER-2022-009, arXiv:2205.10213

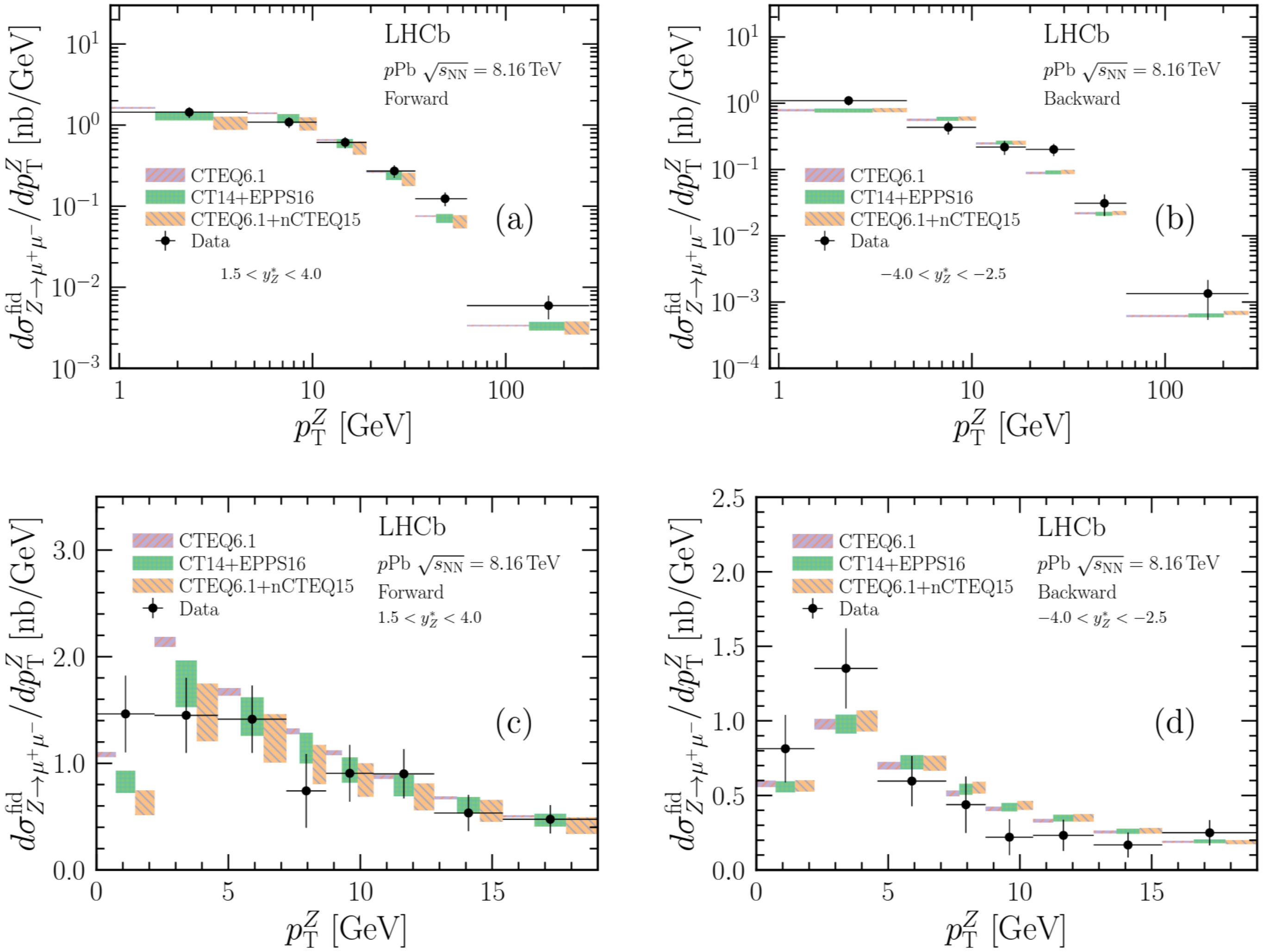
- **Differential cross-section as a function of p_{T}^{Z} :**
  - Compatible with theoretical predictions.
  - Smaller uncertainty than prediction for forward collisions, showing constraints on nPDFs.
  - Low-p_{T}^{Z} results are given, useful for TMD (transverse-momentum-dependent PDFs) studies.

Forward

backward

p_{T}^{Z}

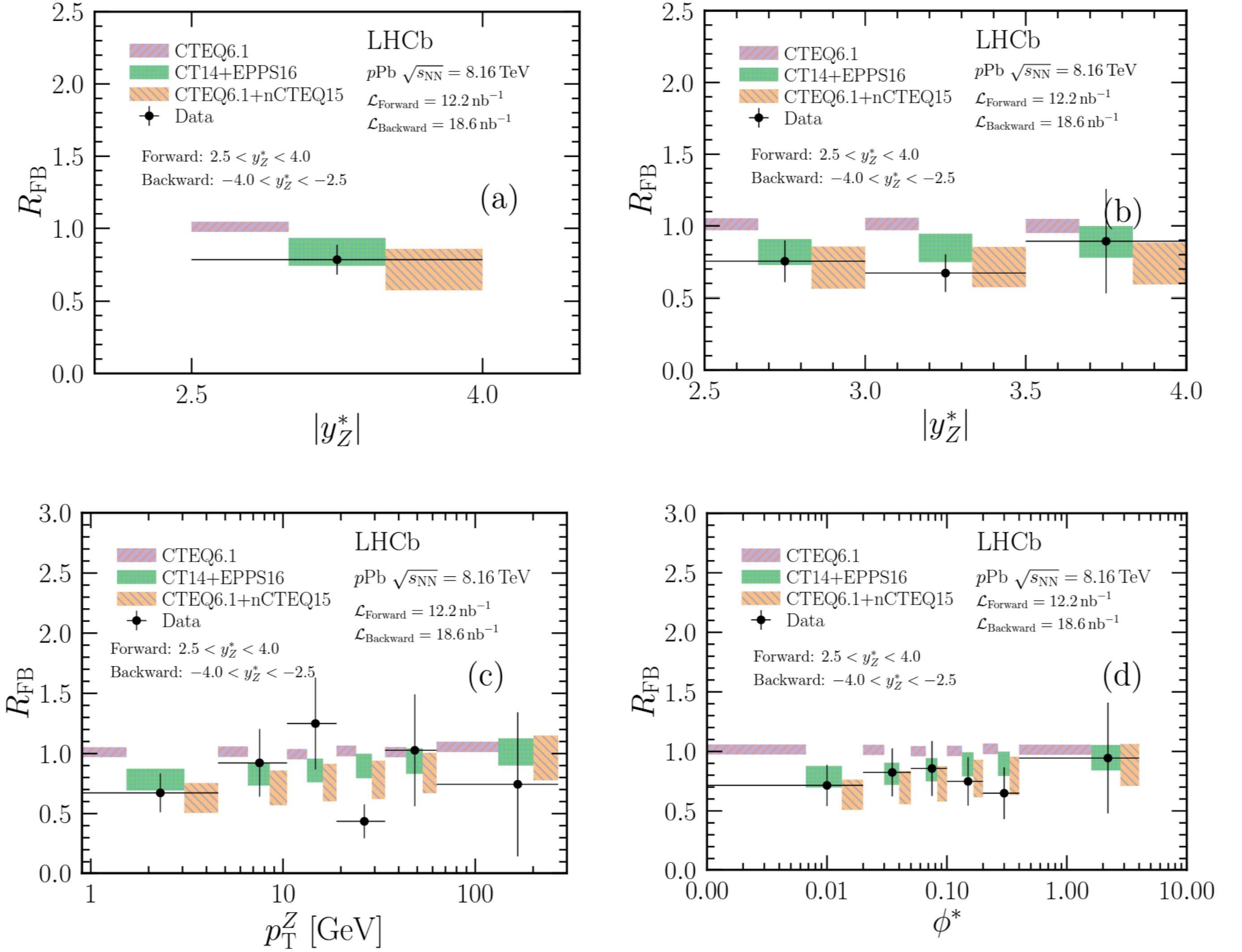
Low-p_{T}^{Z}



Z production in pPb collisions

LHCb-PAPER-2022-009, arXiv:2205.10213

- **Forward-backward ratio** measured in common rapidity window $2.5 < |y_Z^*| < 4.0$:
  - **Total $R_{\mathrm{FB}} = 0.78 \pm 0.10$**
  - **As a function of y_Z^*, p_{T}^Z, and ϕ_η^*, see plots**
- A general suppression below unity.
- Compatible with theoretical predictions.
- Higher precision in total R_{FB} and certain bins as a function y_Z^*, p_T^Z, and ϕ_η^* can constrain the nPDFs.



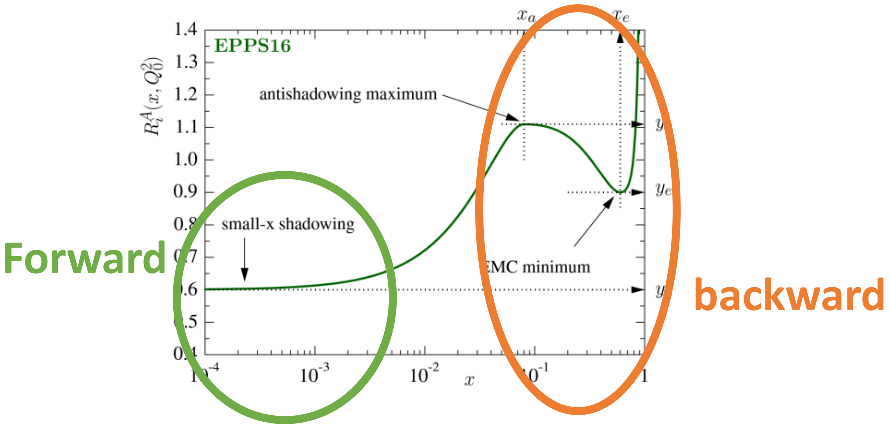
Z production in pPb collisions

- **Inclusive nuclear modification factors:**

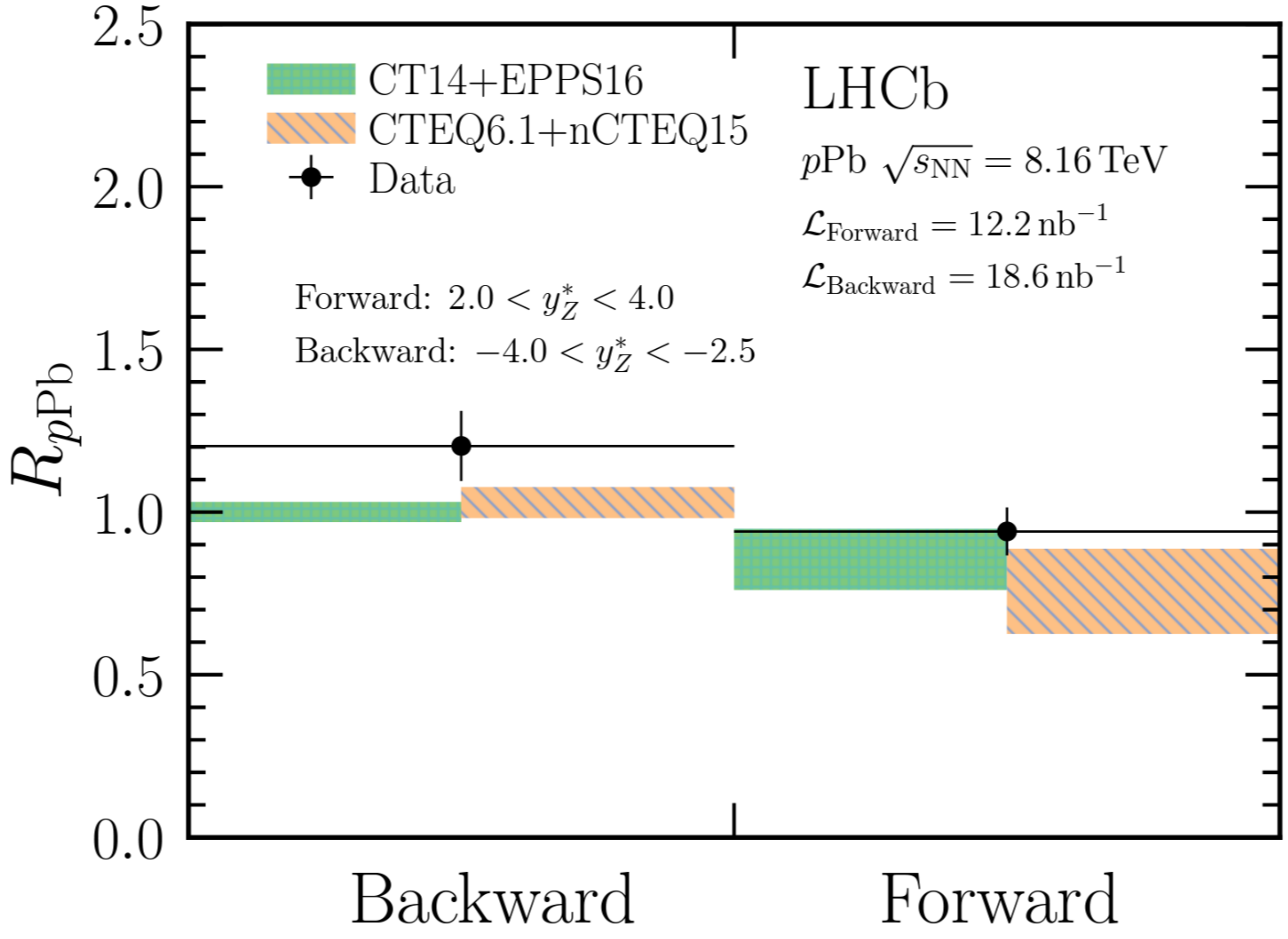
$$R_{p\mathrm{Pb}}^{\mathrm{fw.}} = 0.94 \pm 0.07$$

$$R_{p\mathrm{Pb}}^{\mathrm{bw.}} = 1.21 \pm 0.11$$

- Compatible with theoretical predictions.
- Suppression in the forward and enhancement in the backward are visible.
- Forward (small Bjorken-x) results show strong constraining power on the nPDFs.



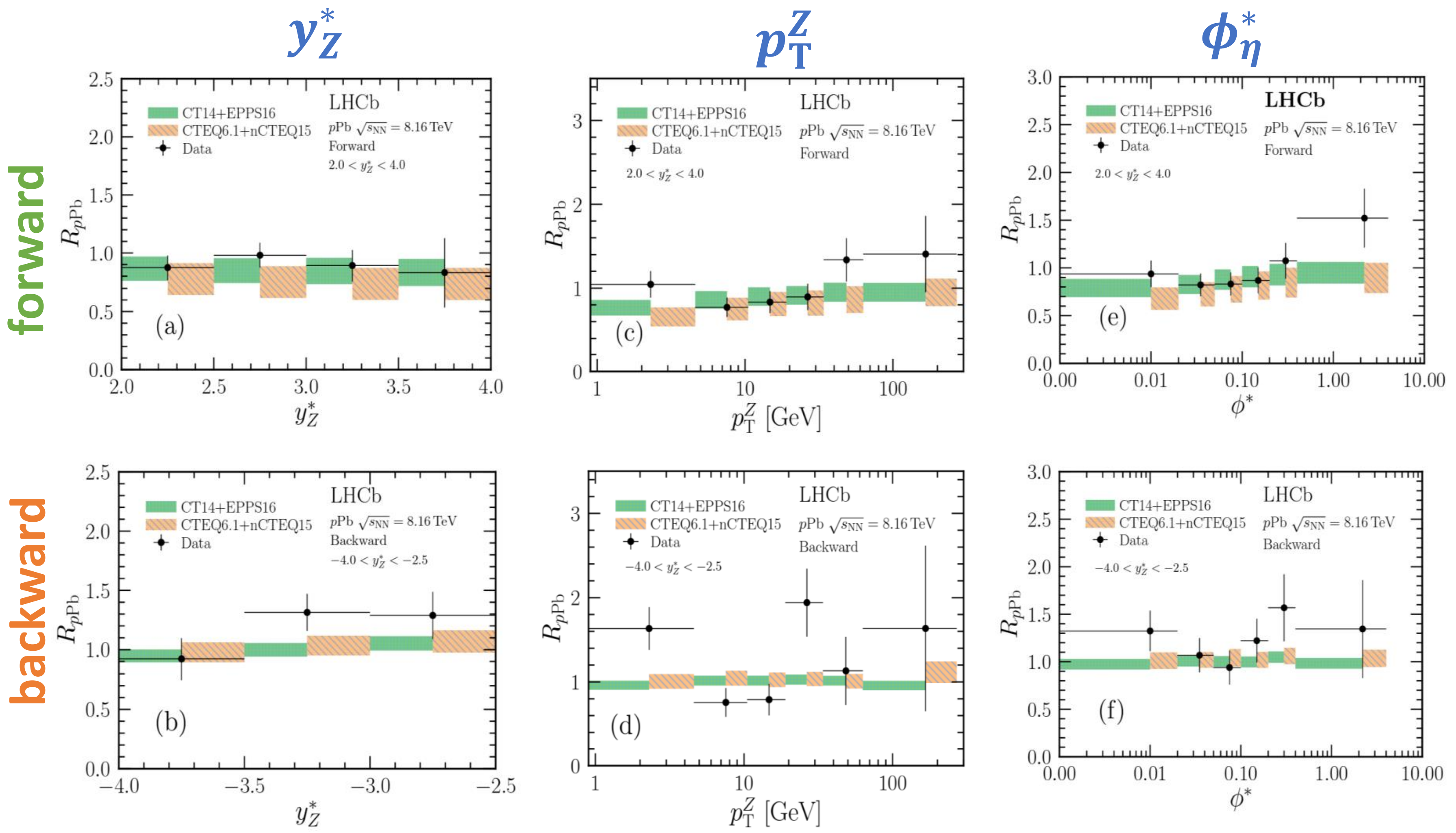
LHCb-PAPER-2022-009, arXiv:2205.10213



Z production in pPb collisions

LHCb-PAPER-2022-009, arXiv:2205.10213

- **Nuclear modification factors as a function of y_Z^*, p_T^Z, and ϕ_η^***
- Compatible with theoretical predictions.
- Constraints on nPDFs are visible in certain bins in case of forward collisions.



Conclusion

- A new measurement of exclusive coherent J/ψ and ψ(2S) production and their cross-section ratio in UPC PbPb collisions using 2018 dataset.
  - The most precise coherent J/ψ production measurement and the first coherent ψ(2S) measurement in forward rapidity region for UPC at LHC.
  - The first measurement of coherent J/ψ and ψ(2S) production cross-section vs. p_{T} in PbPb UPC.
- A new Z boson production measurement in pPb collisions at 8.16 TeV
  - The differential cross-section, R_{FB} and $R_{p\mathrm{Pb}}$ as a function of y_Z^*, p_{T}^Z, and ϕ_η^* are measured for the first time in the forward region at LHCb.
  - The new results are compatible with nCTEQ15 or EPPS16 nPDFs calculations.
  - Forward (small Bjorken-x) results show strong constraining power on the nPDFs.

Backups

Supplementary material for LHCb-PAPER-2022-009

https://lhcbproject.web.cern.ch/Publications/p/LHCb-PAPER-2022-009.html

- Concerning the difference between the fourth data point (19 < pZ T < 34GeV) and the corresponding theoretical prediction in the differential fiducial cross-section measurement as a function of Z boson pT, a detailed study has been performed.
- This study excludes possible bugs from data quality, efficiency estimation, beam crossing angle, geometry acceptance, track reconstruction quality, and possible contributions from missing backgrounds such as standard model ZZ.
- Therefore, it is concluded as a statistical fluctuation.
- The p-value and the corresponding local significance of differences between the measurements and the PowhegBox predictions are shown in Fig. 1. The p-value of the fourth data point corresponds to about a 3-σ significance.