Open heavy flavor production in *p*Pb collisions at LHCb

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Hard Probes 2023

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Outline

Open heavy flavor production

The LHCb detector

Prompt Ξ_c^+ production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV **new!**

Prompt D^0 production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV

Conclusion

Open heavy flavor production

probe QGP with heavy quarks in heavy ion collisions

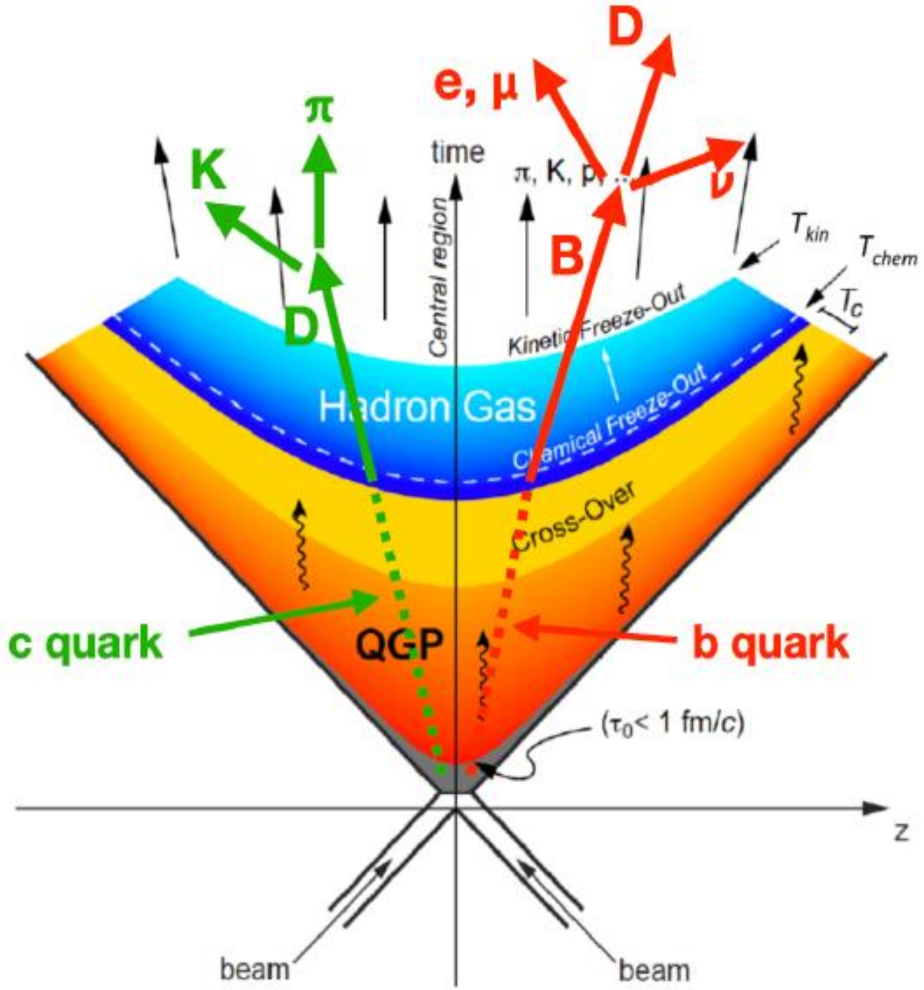
- *Heavy flavor* quarks produced at the early stage of the collision and travel through the medium;
  - carry the information of the collision medium;
- Study of charm hadron production (D, Λ_c, Ξ_c,…), affected by the medium, provides new constraints on theory (e. g. fragmentation function of charm quarks).

***p*Pb collisions (not clear if QGP is present)**

- Useful to study effects which can be mistakenly interpreted as QGP – Cold nuclear matter (CNM) effects.

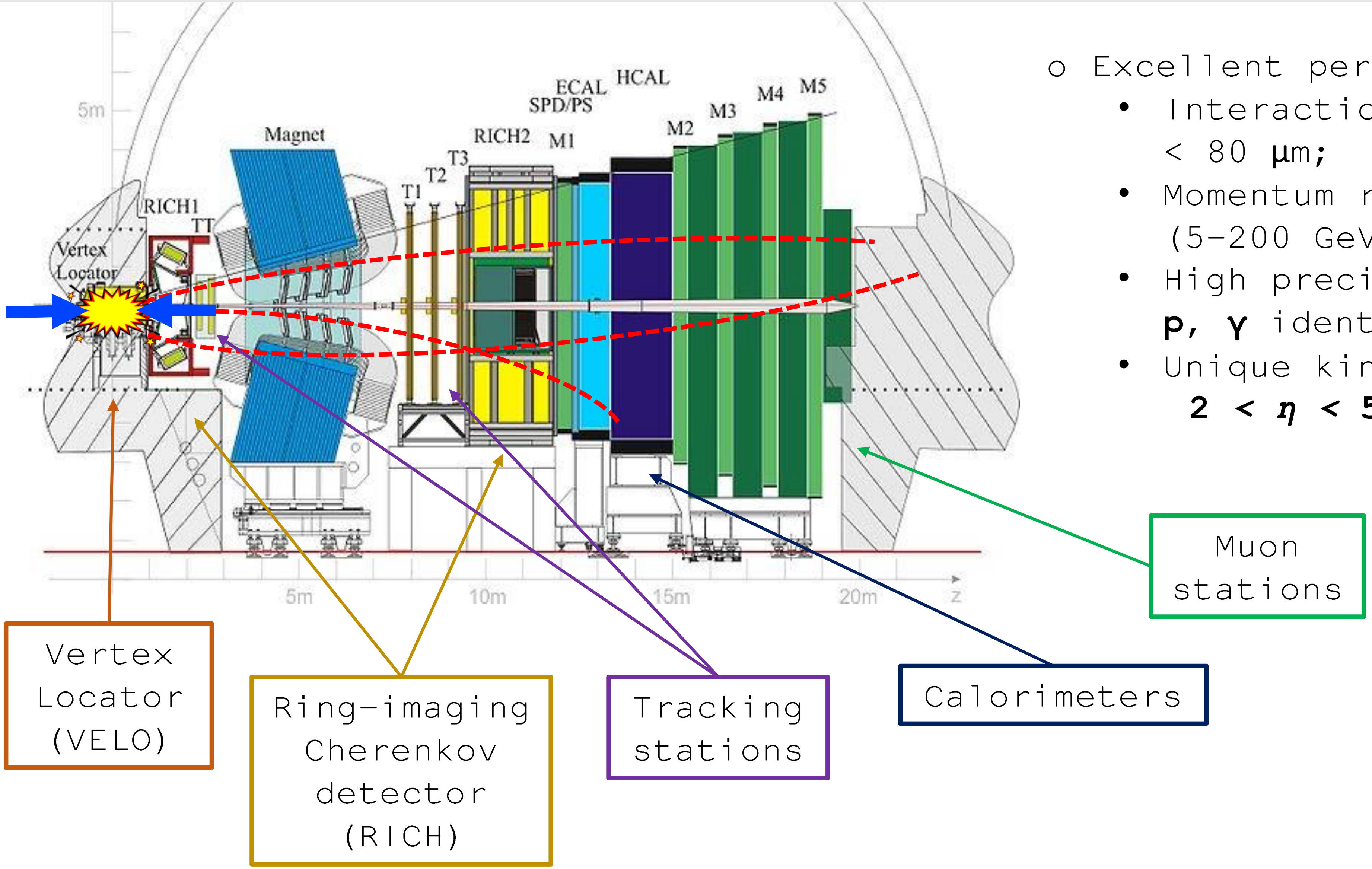
***pp* collisions (no QGP)**

- Reference for *p*–Pb and Pb–Pb collisions.
- Testing ground for perturbative QCD calculations.



The LHCb detector

10.1142/S0217751X15300227

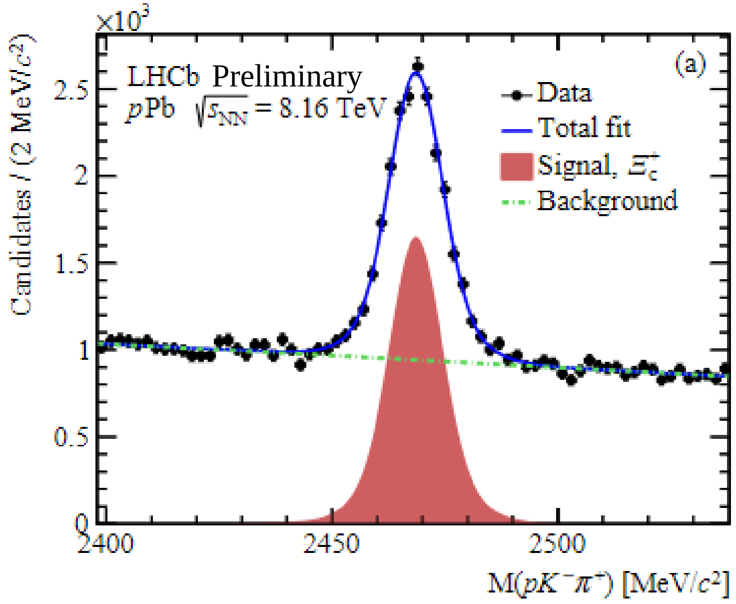


- Excellent performances:
  - Interaction point resolution < 80 μm;
  - Momentum resolution 0.5-1.0% (5-200 GeV/c);
  - High precision **e, μ, π, K, p, γ** identification.
  - Unique kinematic coverage: **2 < *η* < 5**

Upgraded now! (see Chiara's poster for details)

$\Xi_c^+(2467)$ = usc
$\Lambda_c^+(2286)$ = udc
both decay into $\rightarrow p^+ \ K^- \pi^+$

$N_{pPb}^{\Xi_c^+} = 13 \times 10^3$

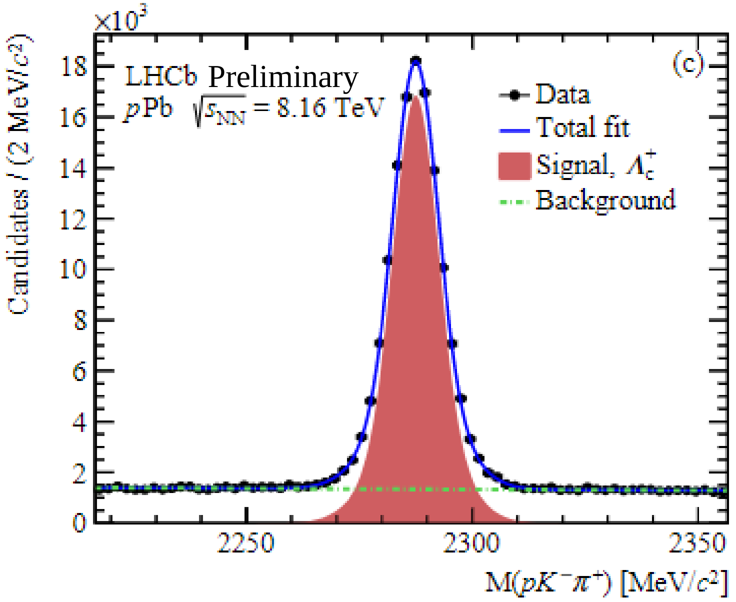


- Cross section ratio: $\Xi_c^+/\Lambda_c^+(D^0)$;
- R_{FB}, the forward-backward asymmetry;

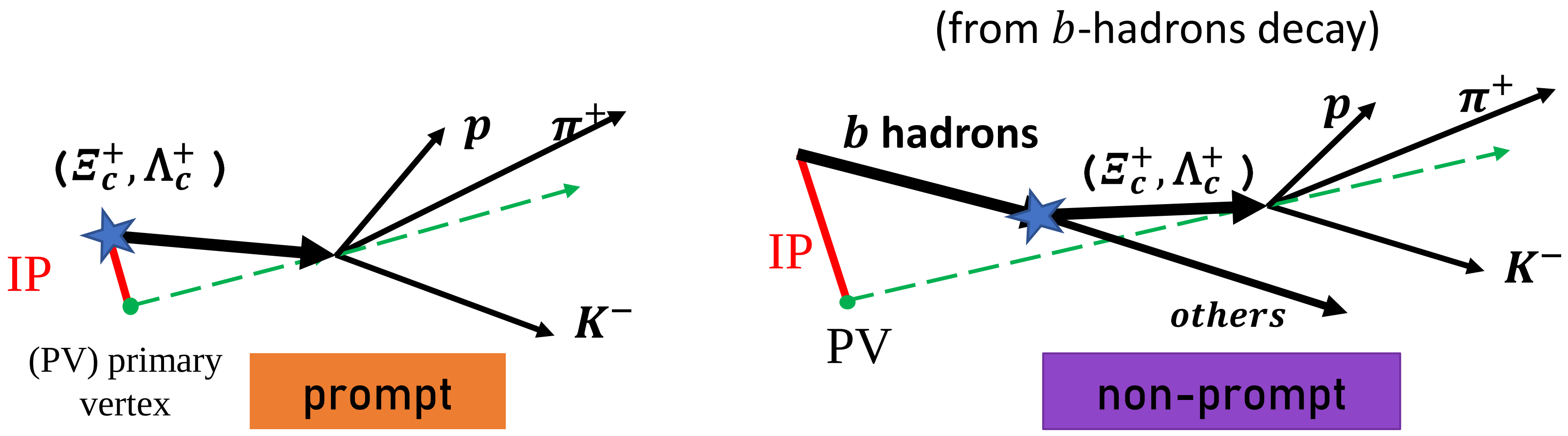
Powerful probe of hadronization:

- charmed baryon formation might not be universal and depends on collision system;
- enhancement can be indication of effects as QGP or recombination (ref.);
- No existing measurement in pPb;

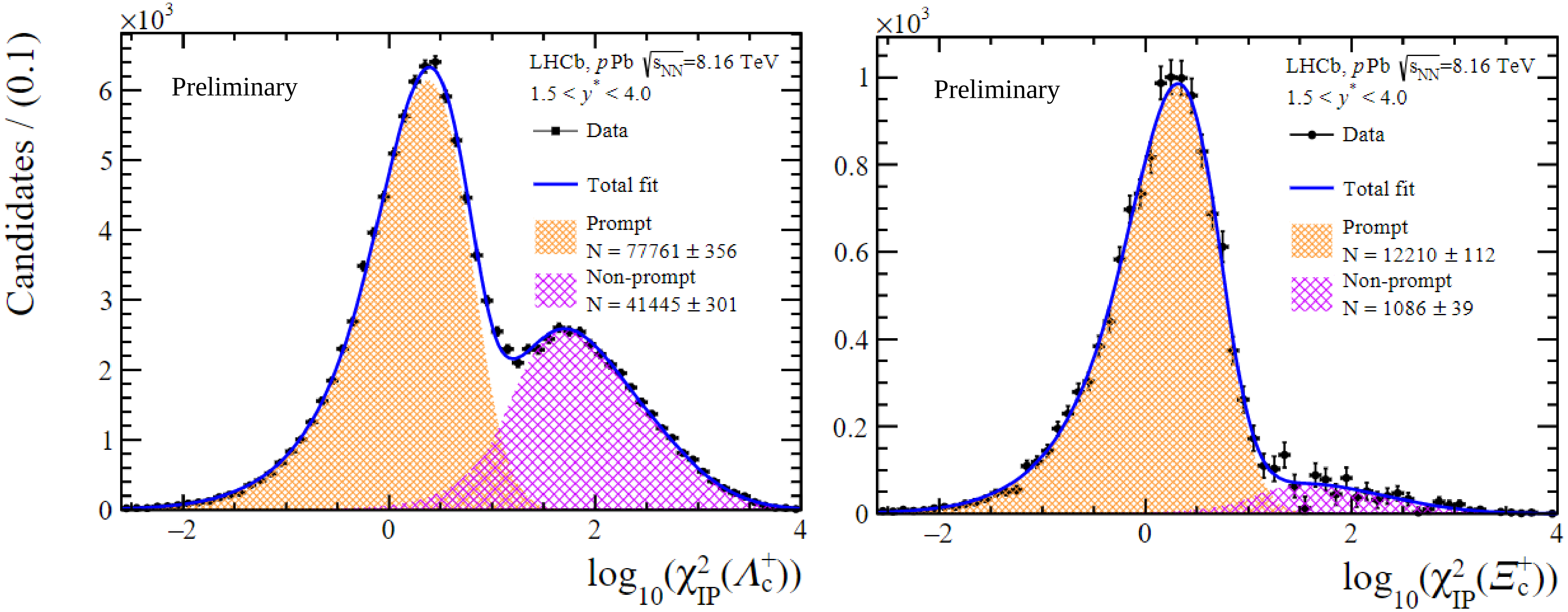
$N_{pPb}^{\Lambda_c^+} = 119 \times 10^3$



Prompt Ξ_c^+ production in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV



- Two components observed;
- Bukin function is used to fit both components;



- pPb
$\mathcal{L}$ = 12.2±0.3 nb^{-1};
- Pbp
$\mathcal{L}$ = 18.6±0.5 nb^{-1};

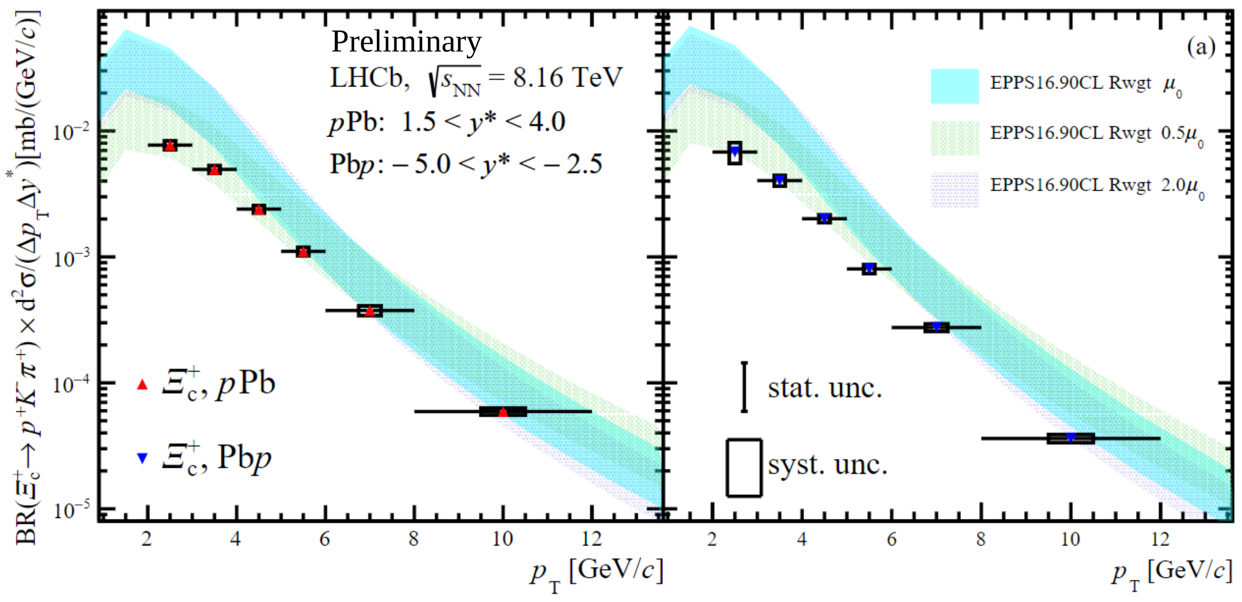
arXiv:1712.07024v2
arXiv:2012.11462

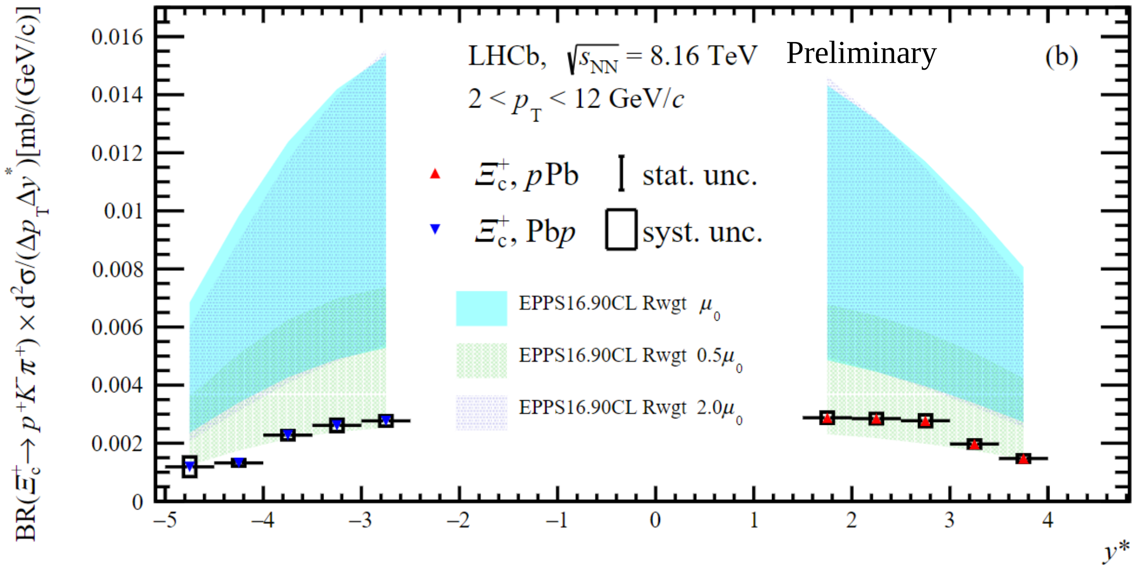
- **EPPS16** theoretical predictions with 3 factorization scales (μ_0, μ_0*0.5, μ_0*2.0)

$$\mathrm{BR} \times \frac{\mathrm{d}^2\sigma_{\Xi_c^+(\Lambda_c^+)}(p_\mathrm{T}, y^*)}{\mathrm{d}p_\mathrm{T}\mathrm{d}y^*} = \frac{N^{\Xi_c^+(\Lambda_c^+)}(p_\mathrm{T}, y^*)}{\mathcal{L}\cdot\epsilon_{tot}(p_\mathrm{T}, y^*)\cdot\Delta p_\mathrm{T}\Delta y^*}$$

BR $(\Xi_c^+ \rightarrow pK^-\pi^+)$ = (0.45 ± 0.21 ± 0.07)%(Belle)
arXiv:1904.12093v3 [hep-ex] 12 Aug 2019
BR $(\Xi_c^+ \rightarrow pK^-\pi^+)$ = (1.135 ± 0.002 ± 0.387)%(LHCb)
arXiv:2007.12096v1[hep-ex] 23 Jul 2020

$$\sigma_{\Xi_c^+}^{p\mathrm{Pb}}(2 < p_\mathrm{T} < 12\,\mathrm{GeV}/c, 1.5 < y^* < 4.0) = 9.69 \pm 0.12 \pm 0.26 \pm 4.72\,\mathrm{mb}$$
$$\sigma_{\Xi_c^+}^{\mathrm{Pb}p}(2 < p_\mathrm{T} < 12\,\mathrm{GeV}/c, -5.0 < y^* < -2.5) = 8.10 \pm 0.11 \pm 0.72 \pm 3.95\,\mathrm{mb}$$

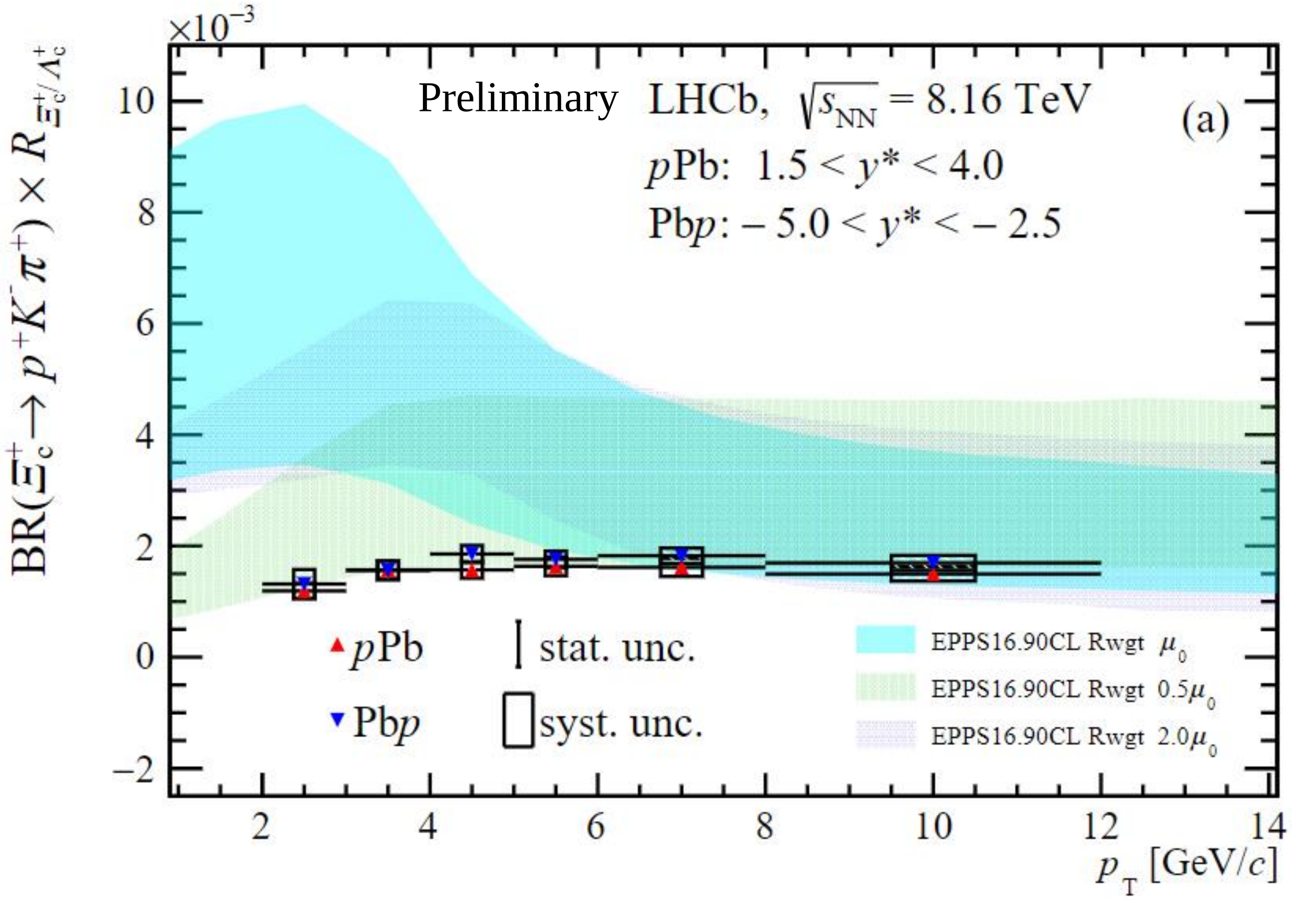




$$R_{\Xi_c^+/\Lambda_c^+}(p_T, y^*) = \frac{N^{\Xi_c^+}(p_T, y^*)}{N^{\Lambda_c^+}(p_T, y^*)} \cdot \frac{\epsilon_{tot}^{\Lambda_c^+}(p_T, y^*)}{\epsilon_{tot}^{\Xi_c^+}(p_T, y^*)} \cdot \frac{\mathcal{B}(\Lambda_c^+ \to p^+K^-\pi^+)}{\mathcal{B}(\Xi_c^+ \to p^+K^-\pi^+)}$$

arXiv:1712.07024v2
arXiv:2012.11462

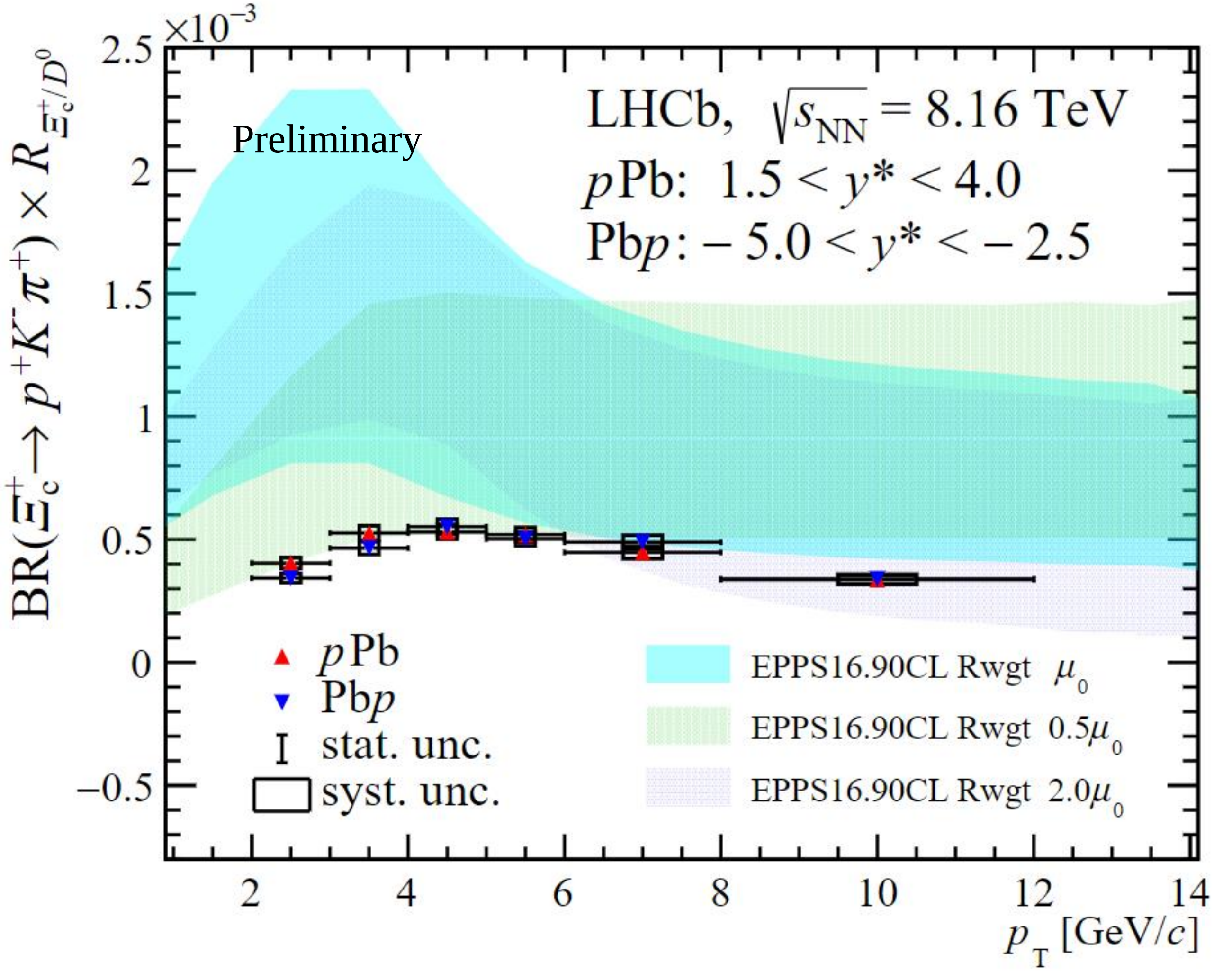
- **EPPS16** theoretical predictions with 3 factorization scales (μ_0, μ_0*0.5, μ_0*2.0)
  - The ratio is roughly constant as a function of p_T;
  - Similar effects governs both baryons production;
  - In agreement with the theoretical prediction.



Prompt Ξ_c^+ production in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

arXiv:1712.07024v2
arXiv:2012.11462

- EPPS16 theoretical predictions with 3 factorization scales (μ_0, μ_0*0.5, μ_0*2.0)

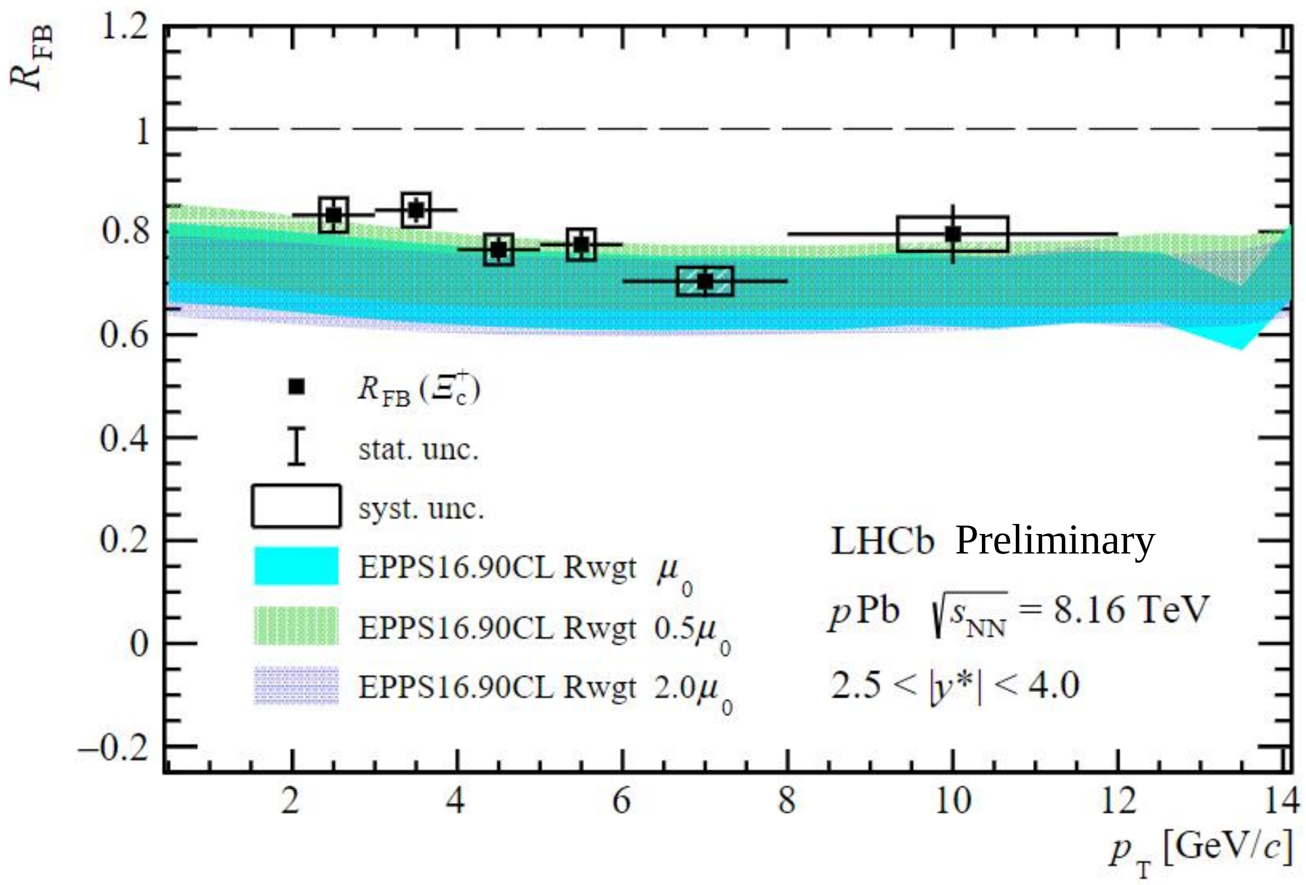


- D^0 cross-section at $\sqrt{s_{NN}}$ = 8.16 TeV is taken from another LHCb analysis [arXiv:2205.03936];
- In agreement with the theoretical prediction.

$$R_{\rm FB}(p_{\rm T}, y^*) \equiv \frac{{\rm d}^2\sigma_{\Xi_c^+}(p_{\rm T}, +|y^*|)/{\rm d}p_{\rm T}{\rm d}y^*}{{\rm d}^2\sigma_{\Xi_c^+}(p_{\rm T}, -|y^*|)/{\rm d}p_{\rm T}{\rm d}y^*}$$

arXiv:1712.07024v2
arXiv:2012.11462

- EPPS16 theoretical predictions with 3 factorization scales (μ_0, μ_0*0.5, μ_0*2.0)
  - Studied in common rapidity range $2.5 < |y^*| < 4.0$;
  - Result is well described by nuclear shadowing;
  - No major final state effects involved;



$D^0(1865) = c\bar{u} \rightarrow K^- \pi^+$

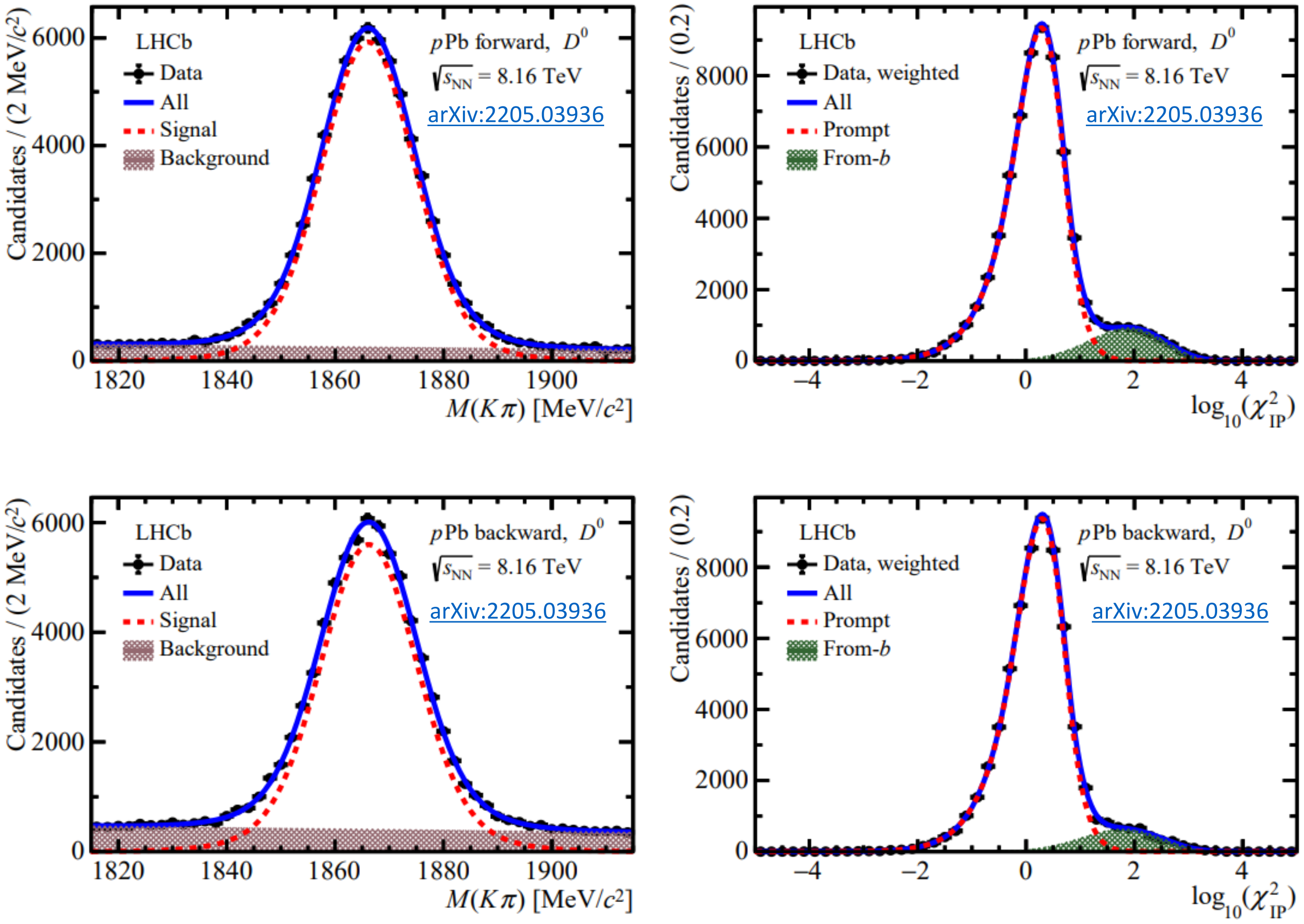
$2.5 < p_T < 3.0$ GeV/c

$3.25 < y^* < 3.50$

- R_{pPb}, nuclear modification factor;
- R_{FB}, the forward-backward asymmetry;

Probe of CNM effects:

- CNM effects are assumed to be dominant in pA collisions;
- can provide constrains on such effects as nuclear shadowing, energy loss, color-glass condensate etc.



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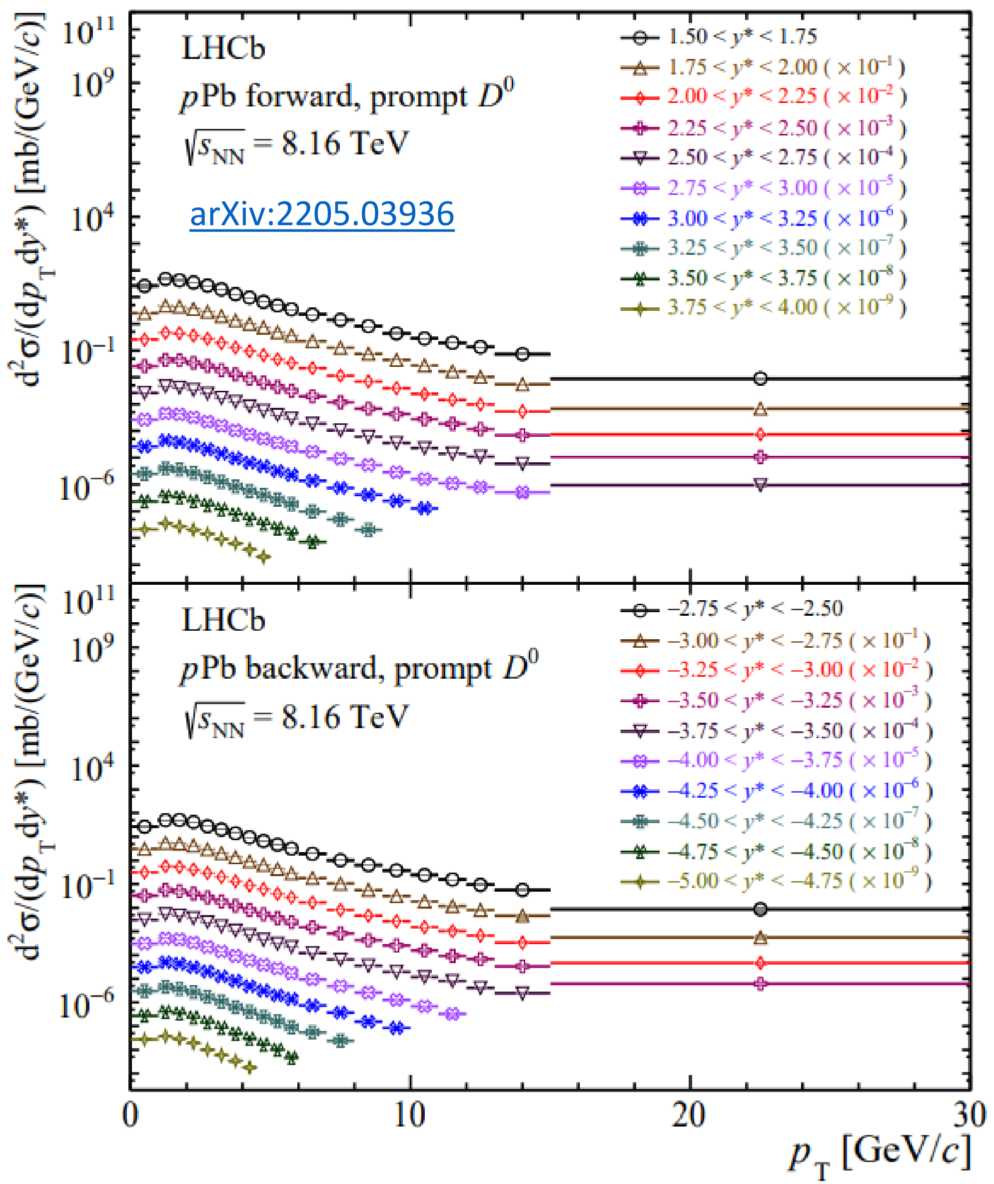
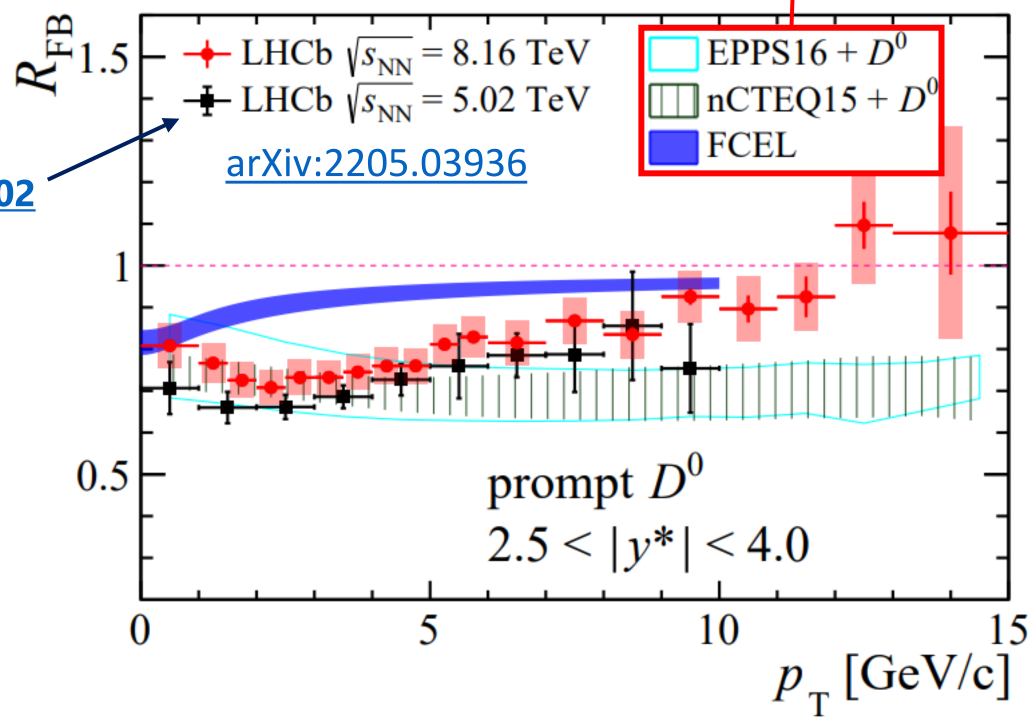


$$R_{\rm FB}(p_{\rm T}, y^*) \equiv \frac{{\rm d}^2\sigma_{D^0}(p_{\rm T}, +|y^*|)/{\rm d}p_{\rm T}{\rm d}y^*}{{\rm d}^2\sigma_{D^0}(p_{\rm T}, -|y^*|)/{\rm d}p_{\rm T}{\rm d}y^*}$$

Eur.Phys.J.C 77 (2017) 3, 163
Phys. Rev. D 93, 085037 (2016)
JHEP 01 (2022) 164

JHEP 02(2019)102



- R_{FB} shows rising trend with $p_{\rm T}$;
- Disagree with nPDF calculations at high $p_{\rm T}$;

Prompt D^0 production in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

arXiv:2205.03936

$$R_{p\mathrm{Pb}}(p_{\mathrm{T}}, y^*) \equiv \frac{1}{A}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_{\mathrm{T}}, y^*)/(\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*)}{\mathrm{d}^2\sigma_{pp}(p_{\mathrm{T}}, y^*)/(\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*)}$$

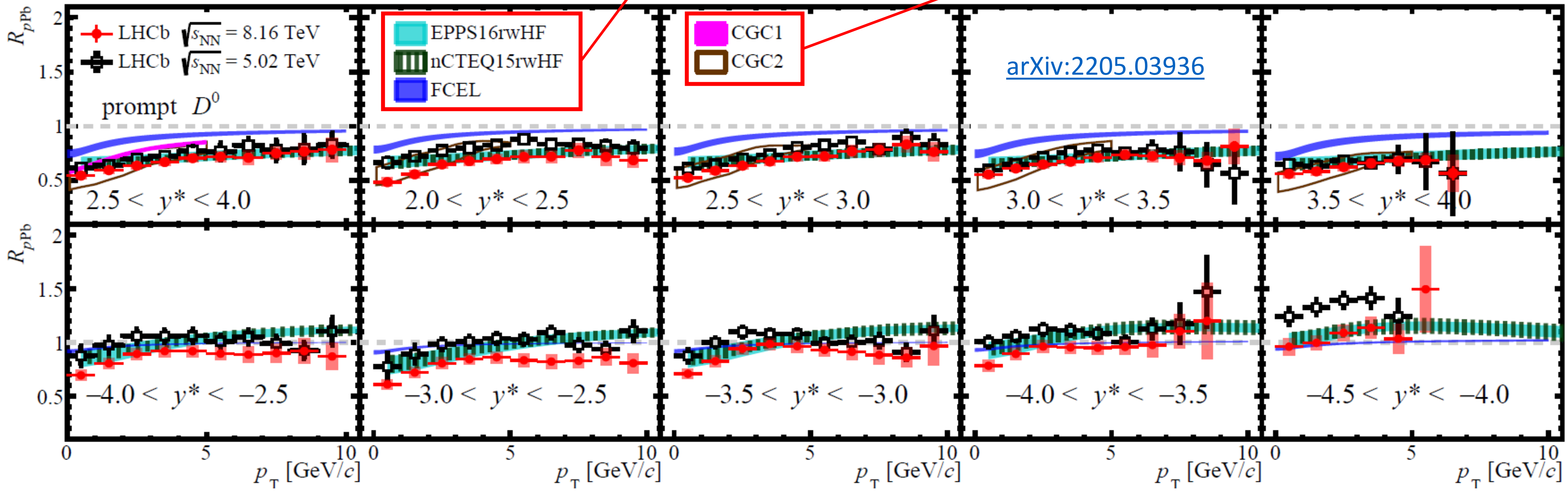
pp reference from interpolation between 5&13 TeV data:

JHEP 06 (2017) 147
JHEP 05 (2017) 074

- nPDF and CGC1 calculations are slightly higher than the data, while the CGC2 calculation shows a better agreement;
- Less suppressed in backward rapidity;

Eur.Phys.J.C 77 (2017) 3, 163
Phys. Rev. D 93, 085037 (2016)
JHEP 01 (2022) 164

Nucl.Part.Phys.Proc. 289-290 (2017) 309-312
Phys. Rev. D 98, 074025 (2018)



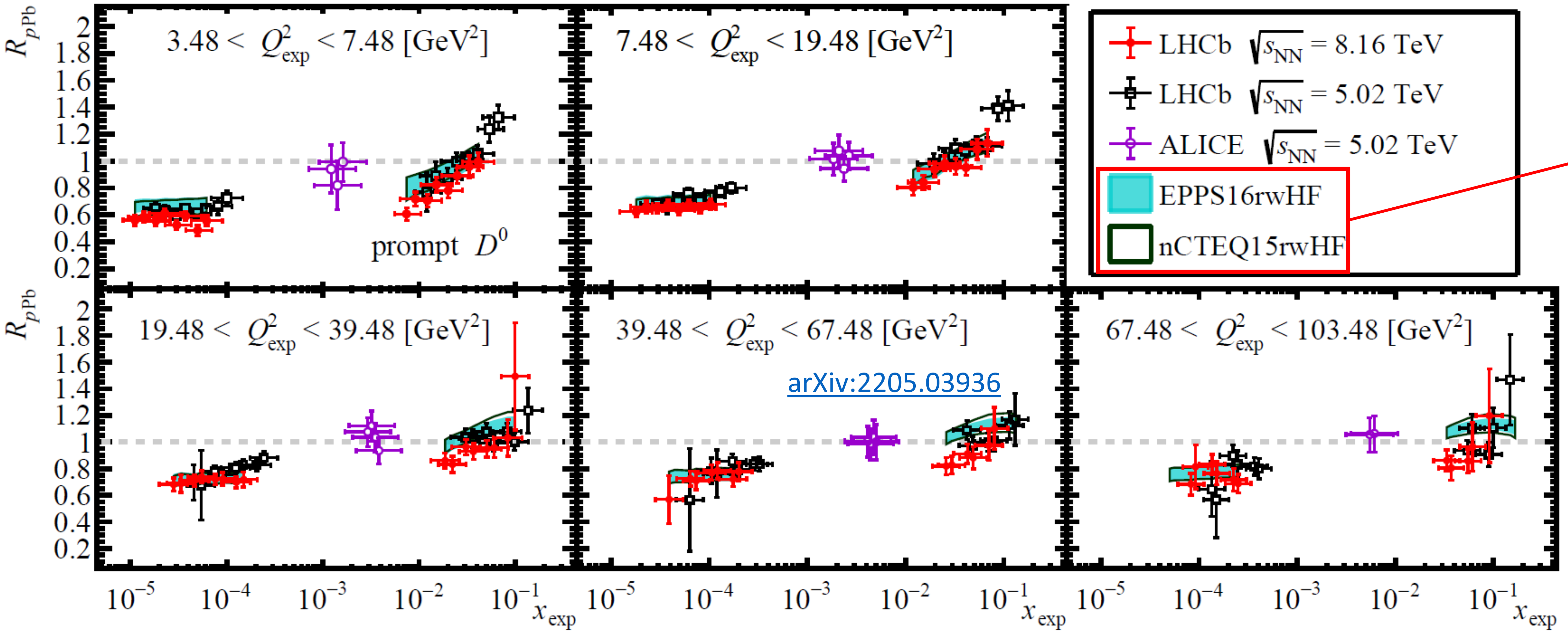
Prompt D^0 production in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

arXiv:2205.03936

- Experimental approximations for x and Q^2 form a continuous trend over wide x_{exp} range;
- Lower than nPDF calculations at large x_{exp} and Q^2_{exp};

$$Q^2_{exp} \equiv m^2_{D^0} + p^2_T$$

$$x_{exp} \equiv 2\frac{Q_{exp}}{\sqrt{s_{NN}}} e^{-y^*}$$



Eur.Phys.J.C 77 (2017) 3, 163

Phys. Rev. D 93, 085037 (2016)

Conclusion

- LHCb has strong capabilities to study heavy flavor in heavy-ion collisions.
- Prompt Ξ_c^+ production in *p*Pb:
  - First measurement in *p*Pb collisions;
  - In agreement with nPDF models;
  - Same analysis in *pp* is ongoing;
- Prompt D^0 production in *p*Pb:
  - R_{FB} found to disagree with theories at high p_{T};
  - $R_{p\mathrm{Pb}}$ is suppressed in forward rapidity;

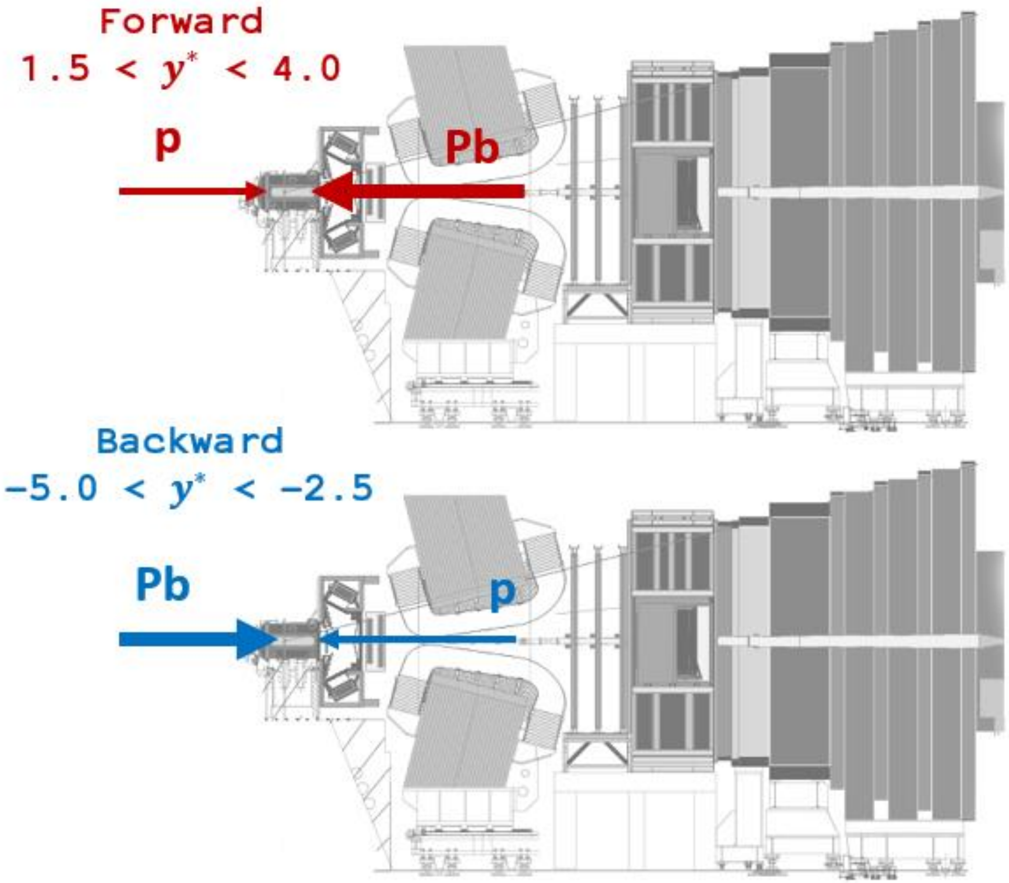
backup

The LHCb detector

pPb data:

- Collected in 2016;
- $\sqrt{s_{NN}}$ = 8.16 TeV;
- E_p = 6.50 TeV; E_{Pb} = 2.56 TeV;
- Two beams' configurations:

  pPb (forward) and Pbp (backward).
- Integrated luminosity:
  - Forward 12.19 ± 0.32 nb^{-1};
  - Backward 18.59 ± 0.46 nb^{-1};



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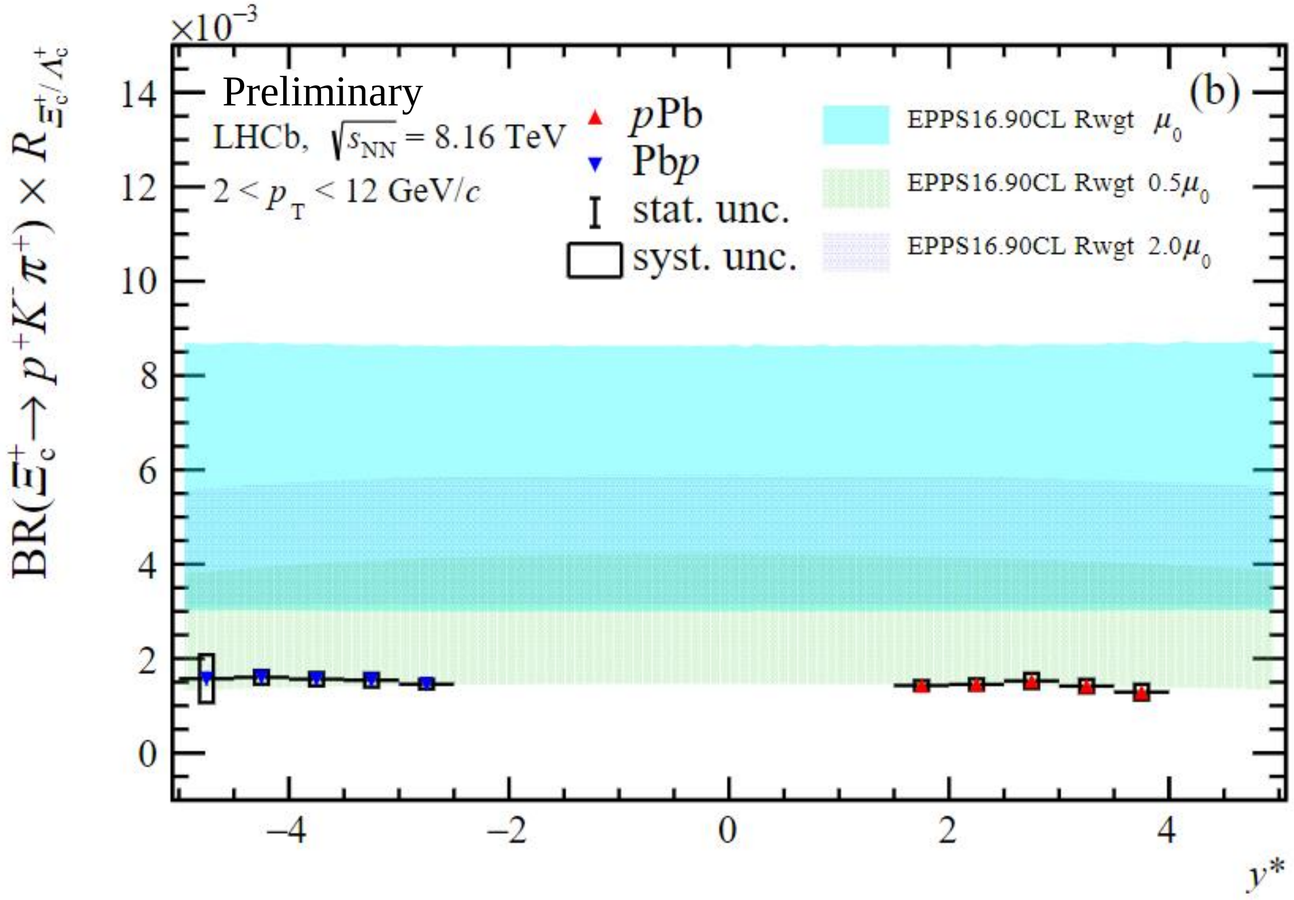
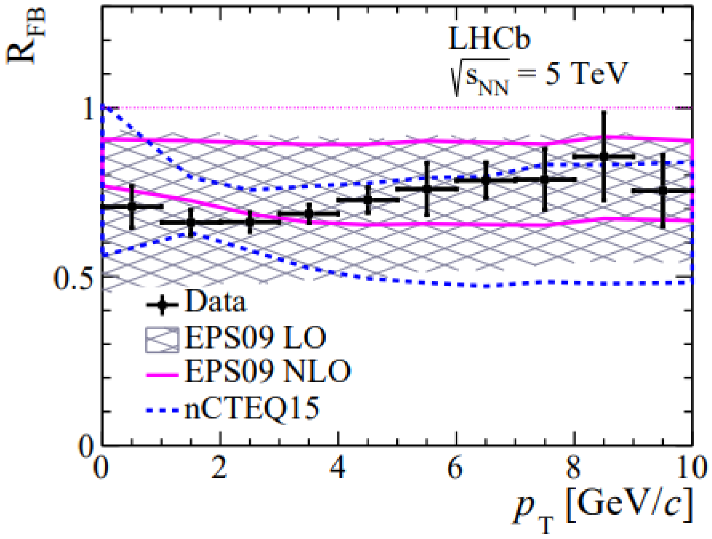
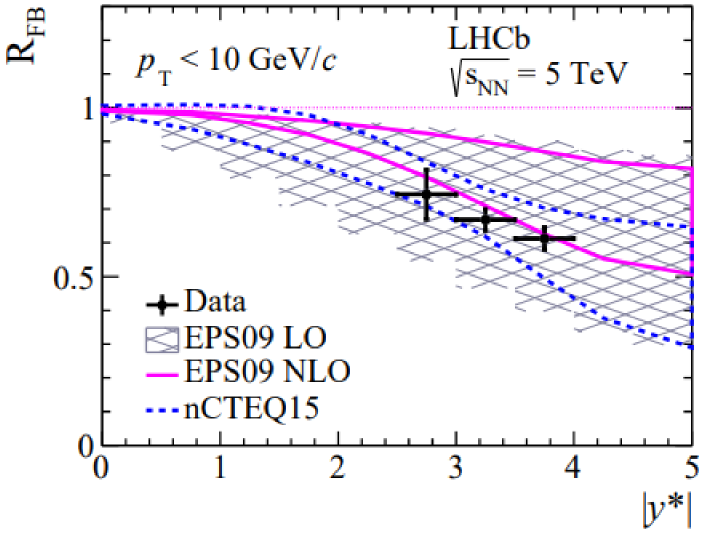
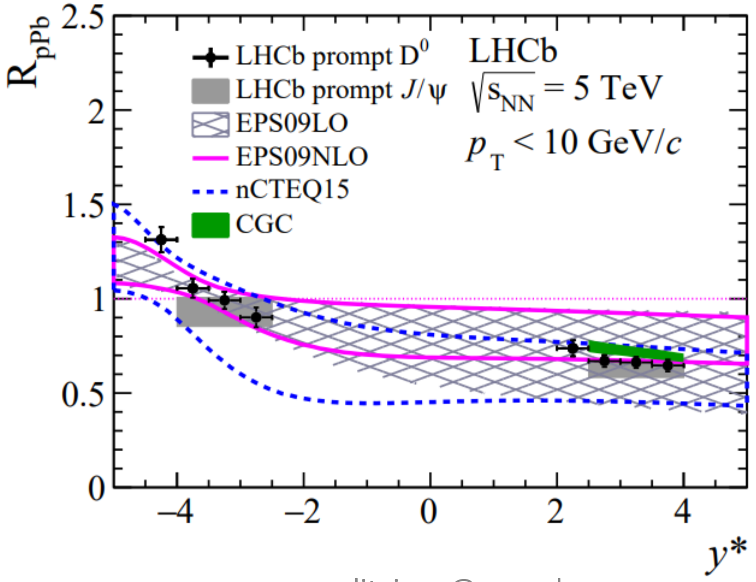


Previous results







Previous results