Production of D_s^+ and D^+ in proton-lead collisions with the LHCb detector

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on behalf of LHCb collaboration

November 16th, 2023 @Shanghai, China

第九届中国LHC物理年会 The 9th China LHC Physics Workshop

- **Introduction**
- **LHCb detector and datasets**
- **Results in pPb collisions at LHCb**
  - Prompt D_s^+ and D^+production at $\sqrt{s_{NN}} = 5.02$ and 8.16TeV

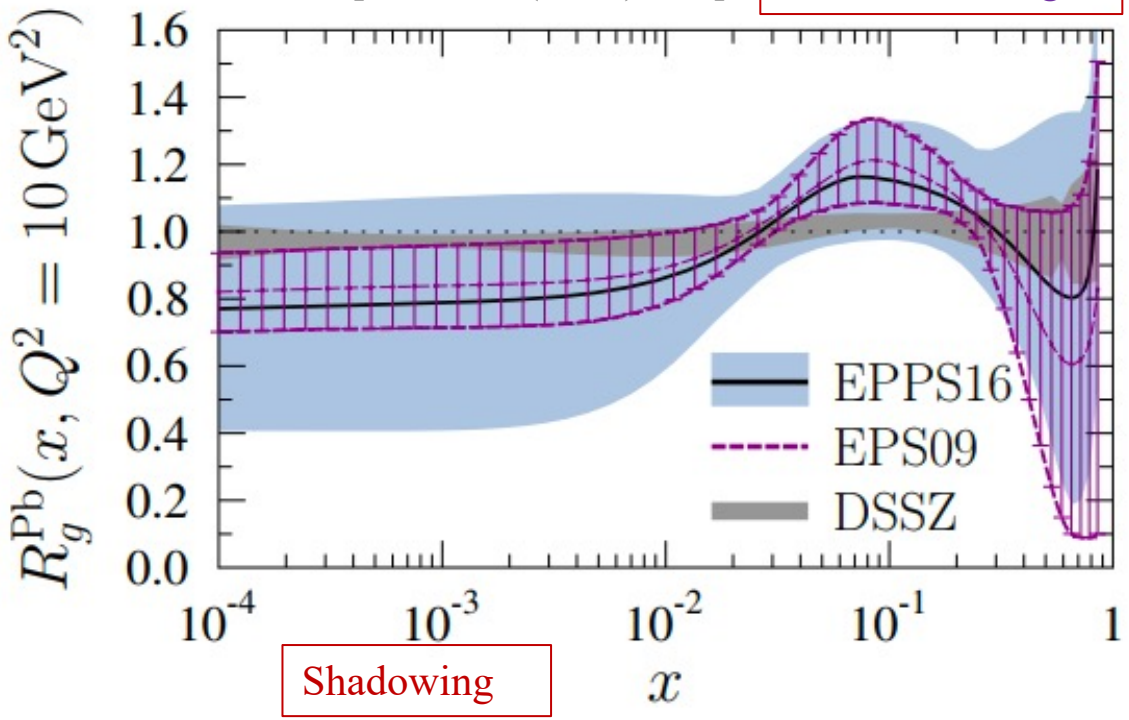
    [arXiv:2309.14206; arXiv:2311.08490]
- **Summary**

Introduction

- Cold nuclear matter effects (CNM) are assumed to be dominant in pPb collisions
  - ➢ Modification of nuclear parton distribution functions (nPDFs).
  - ➢ Other initial/final state effects.
- Production of open charm (D_s^+, D^+) are used to probe CNM and constrain nPDFs at small-x and mid-x region in pPb collisions at LHCb.

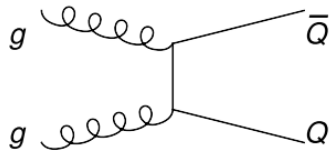
[JHEP 05 (2020) 037]

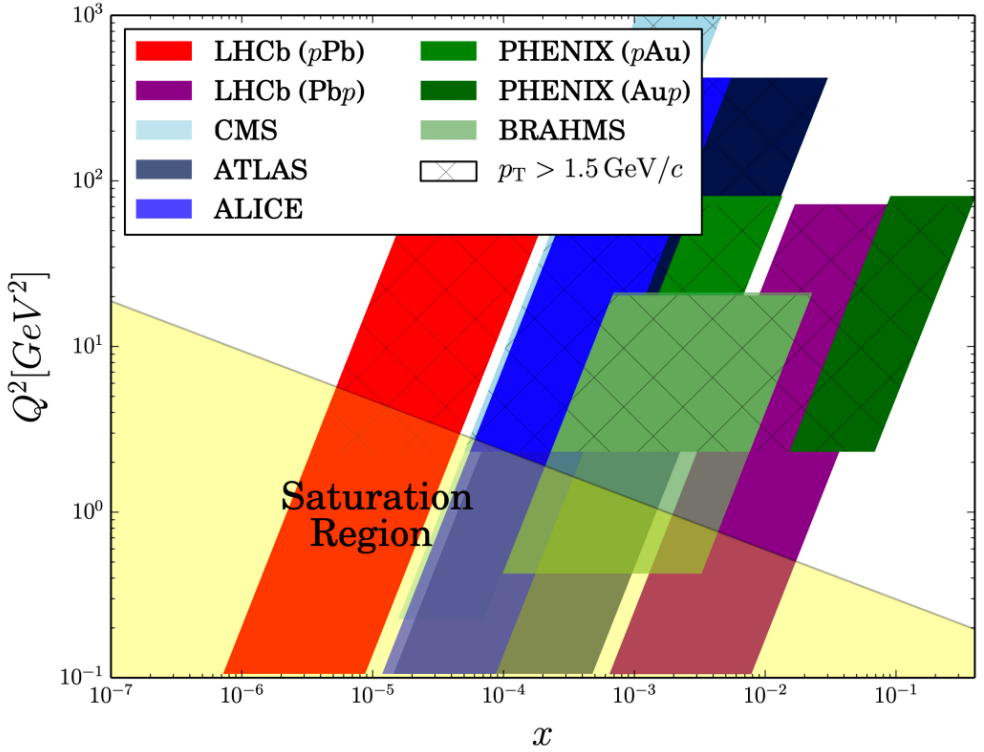
Anti-Shadowing



Shadowing

$$R_i^{\mathrm{Pb}}(x, Q^2) = \frac{f_i^{\mathrm{Pb}}(x, Q^2)}{A f_i^{p}(x, Q^2)}, i = g, q, \bar{q}$$





LHCb forward: small-x

Shadowing

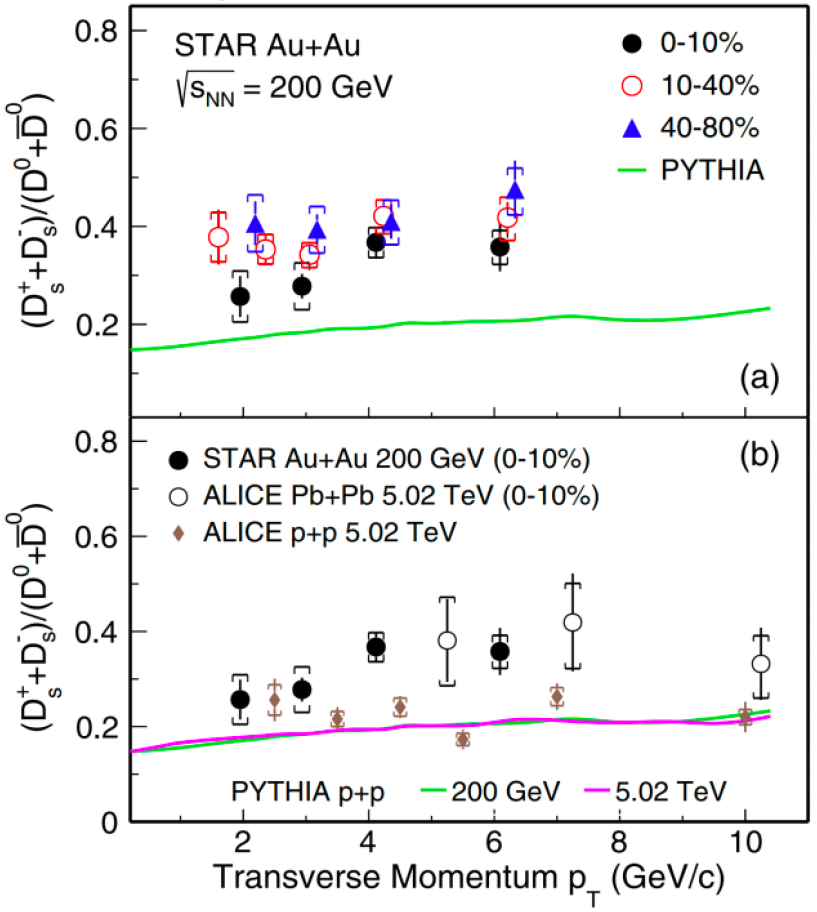
LHCb backward: mid-x

Anti-Shadowing

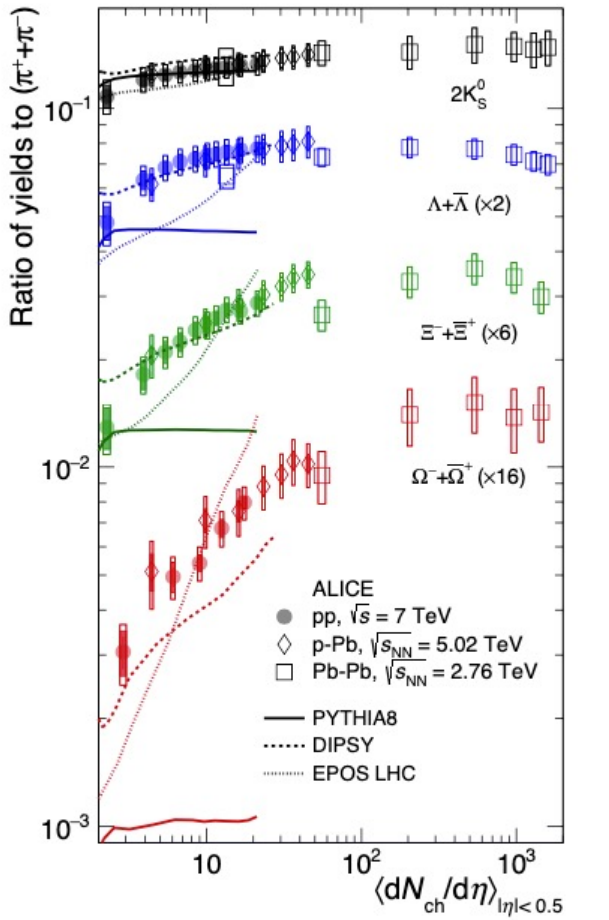
Introduction

- Modification of heavy quark hadronization and strangeness enhancement
  - Since the enhanced *s* quark abundance in the QGP, an increased D_s^+ in heavy-ion collisions relative to *pp* has been predicted.
  - The *s* quark enhancement was also observed in high-multiplicity *pp* collisions.
  - D_s^+/D^+ ratios increase versus multiplicity is also expected.

[Phys. Rev. Lett., 2021, 127: 092301]

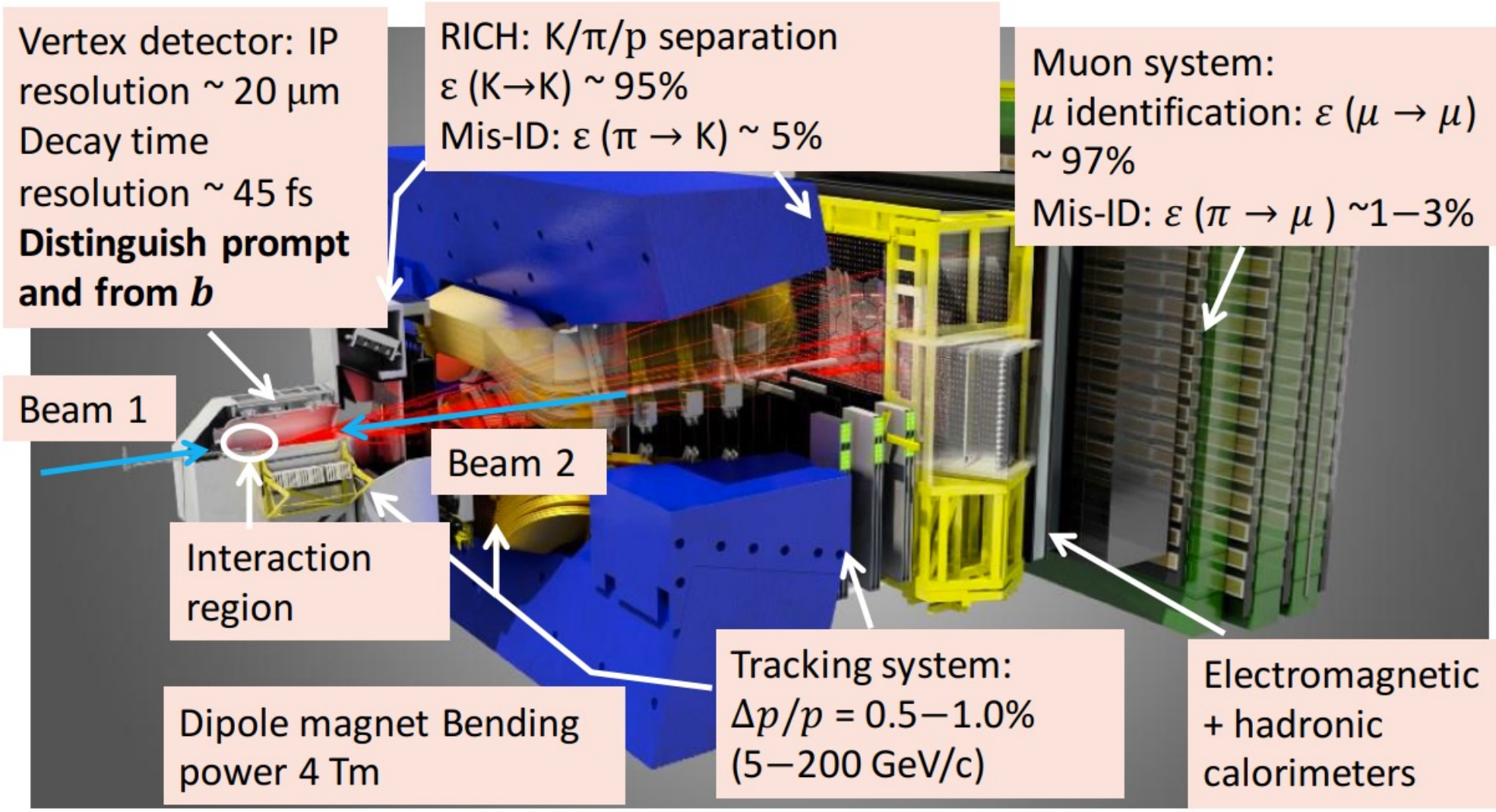


[Nature Phys 13, 535–539 (2017)]



LHCb detector

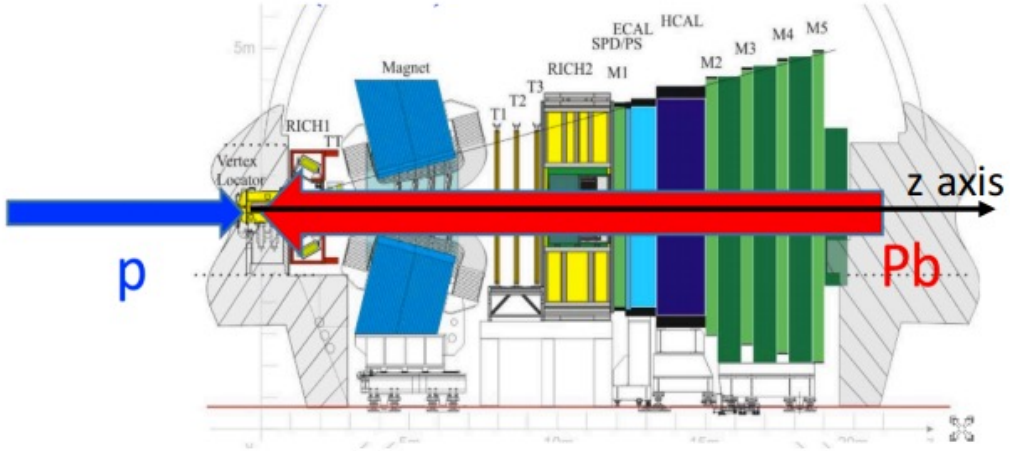
- A single-arm forward spectrometer, covering the range of $2 < \eta < 5$.
- Designed for studying particles containing b or c quarks.



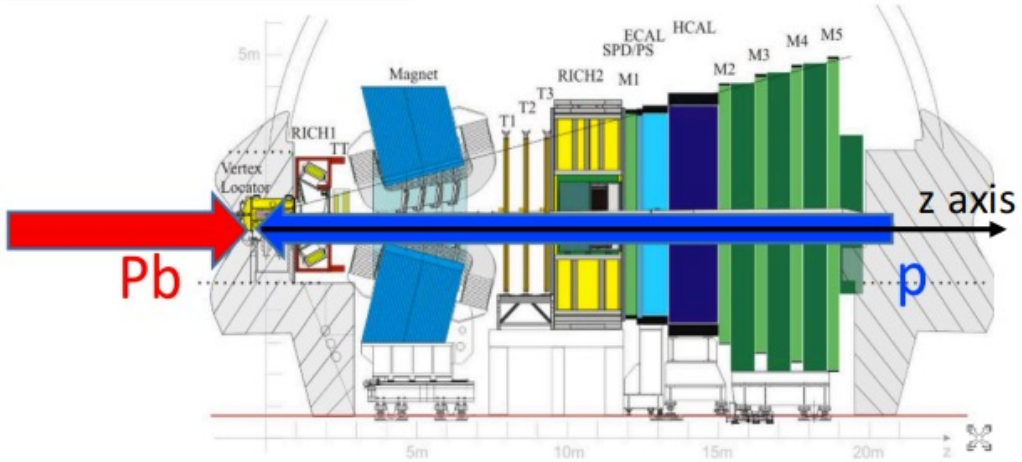
[LHCb, JINST 3 (2008) S08005]
[LHCb, IJMPA 30 (2015) 1530022]

LHCb datasets

Forward: pPb



Backward: Pbp



- Rapidity coverage:
  - y^*: rapidity in nucleon-nucleon cms
  - $y_{cms} = \pm 0.45$
  - Forward: $1.5 < y^* < 4.0$s
  - Backward: $-5.0 < y^* < -2.5$
  - common region: $2.5 < |y^*| < 4.0$

- $\sqrt{s_{NN}} = 5.02$TeV (Run I, 2013)
  - Luminosity: pPb($1.06\ \mathrm{nb}^{-1}$) + Pbp ($0.52\ \mathrm{nb}^{-1}$)

- $\sqrt{s_{NN}} = 8.16$TeV (Run II, 2016)
  - Luminosity: pPb($13.6\ \mathrm{nb}^{-1}$) + Pbp ($20.8\ \mathrm{nb}^{-1}$)

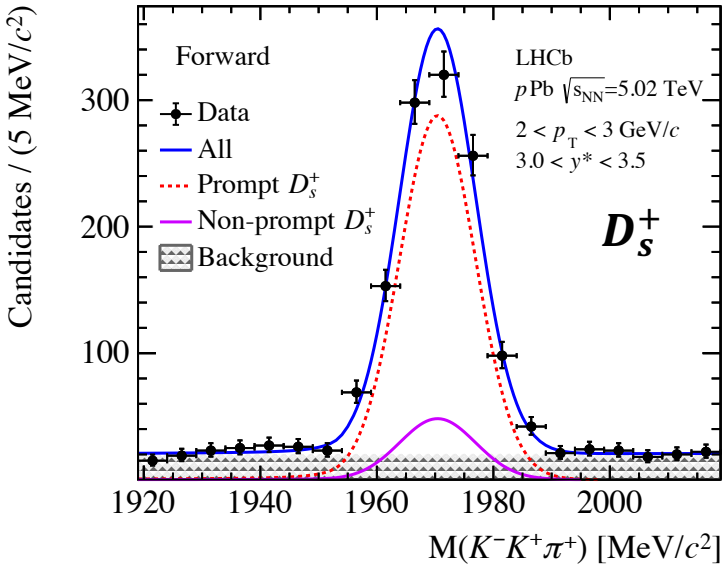
- Decay modes:
  - $\boldsymbol{D^+ \to K^- \pi^+ \pi^+}$ & $\boldsymbol{c.c}$
  - $\boldsymbol{D_s^+ \to K^- K^+ \pi^+}$ & $\boldsymbol{c.c}$

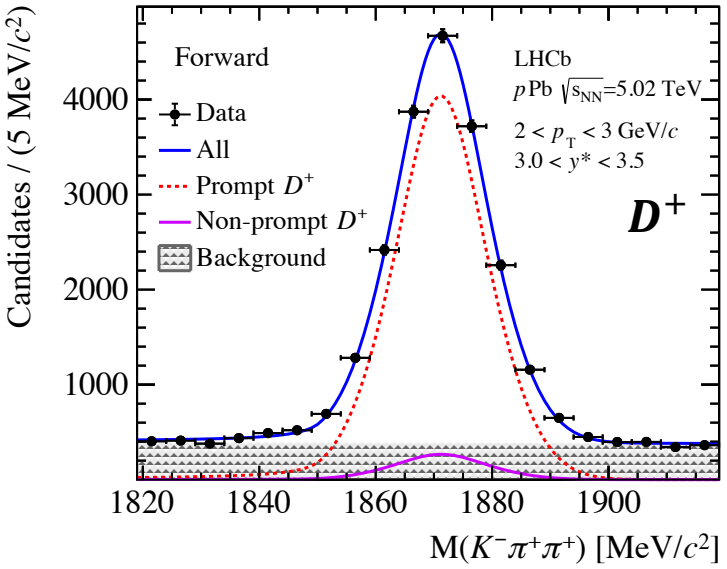
Prompt D_s^+ and D^+ production in pPb at $\sqrt{s_{NN}} = 5.02$ and 8.16 TeV

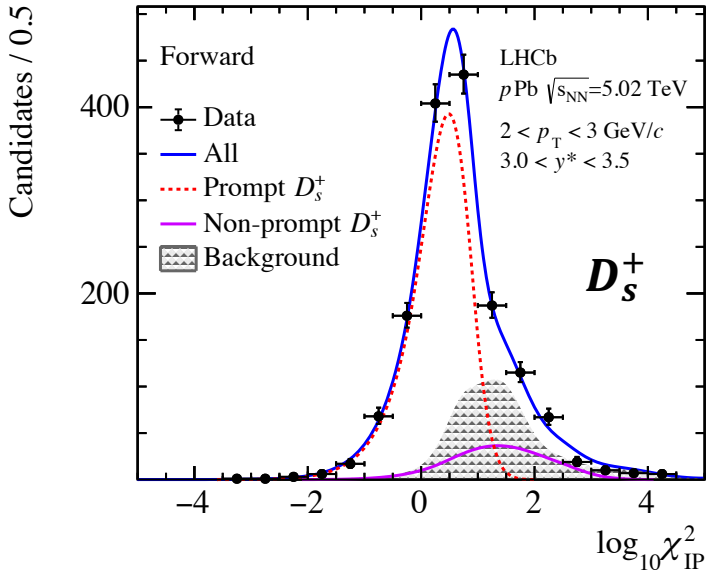
[arXiv:2309.14206; arXiv:2311.08490]

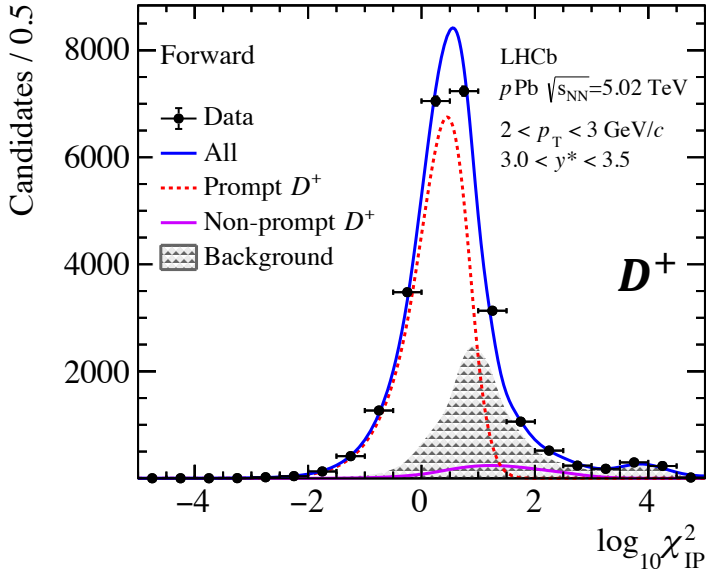
Prompt D_s^+ and D^+ yield determination in pPb at 5.02TeV

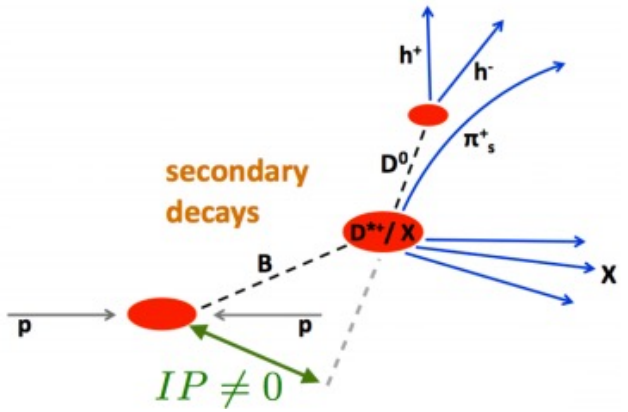
[arXiv:2309.14206]











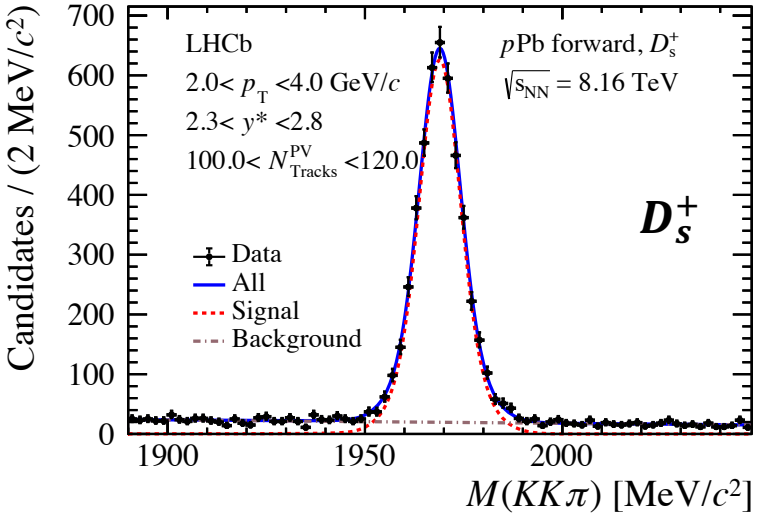
- Prompt and from b yields: distinguished by fitting $\log_{10}\chi^2_{IP}$ distribution.
- Background:

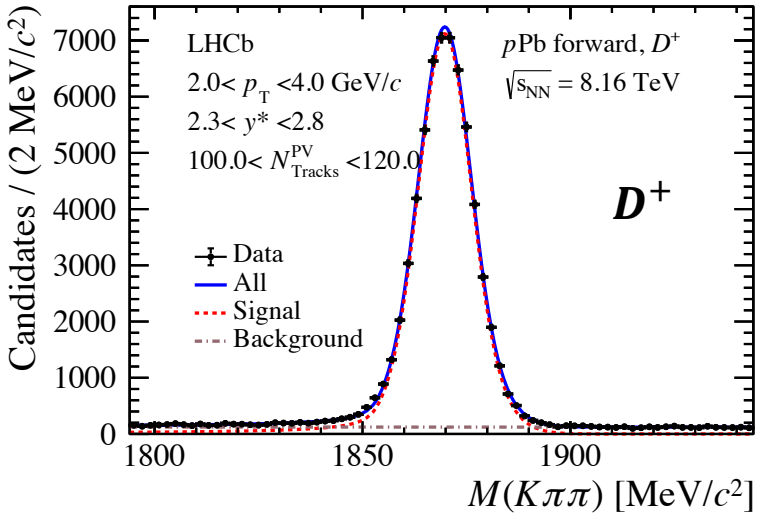
  described with a PDF created from the data side-band regions.

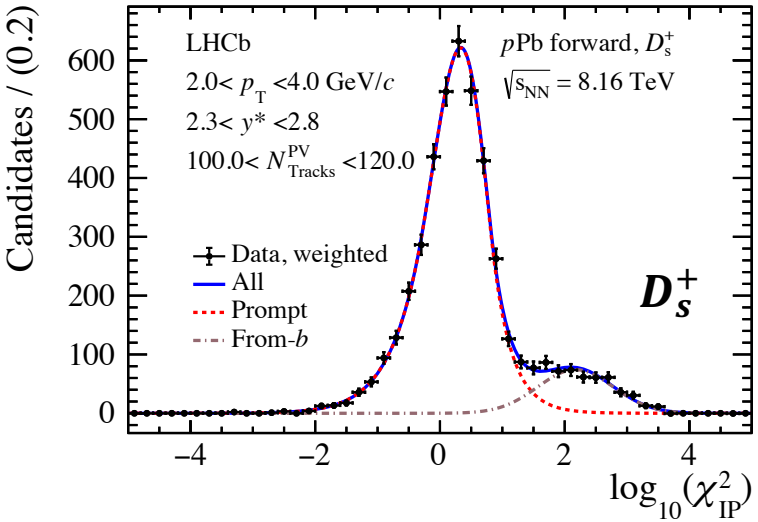
  [Comput. Phys. Commun. 136 (2001),198]

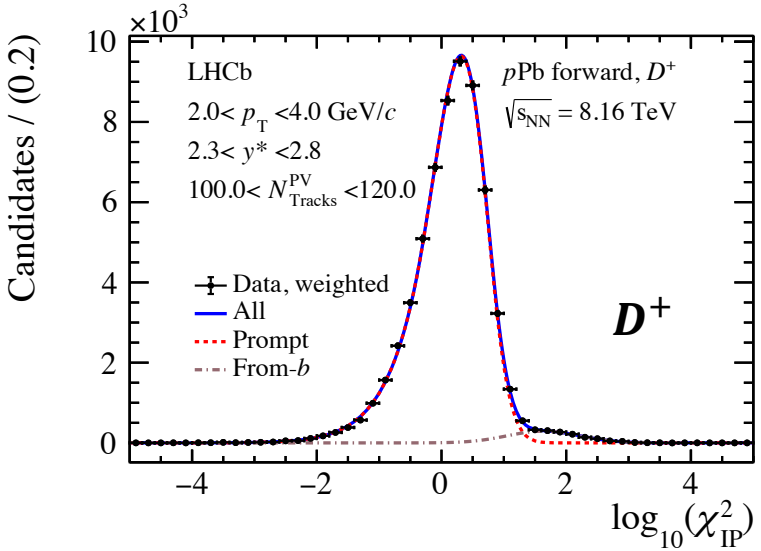
Prompt D_s^+ and D^+ yield determination in pPb at 8.16TeV

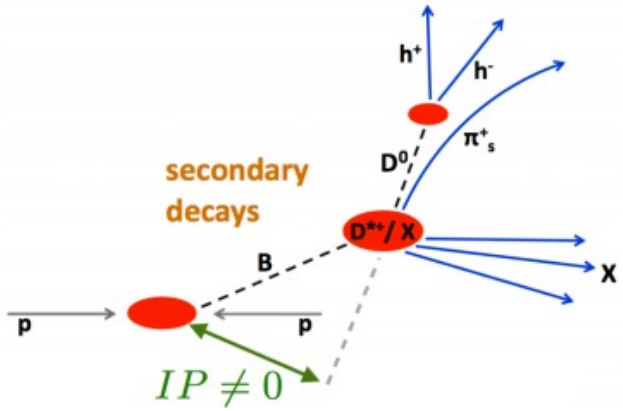
[arXiv:2311.08490]











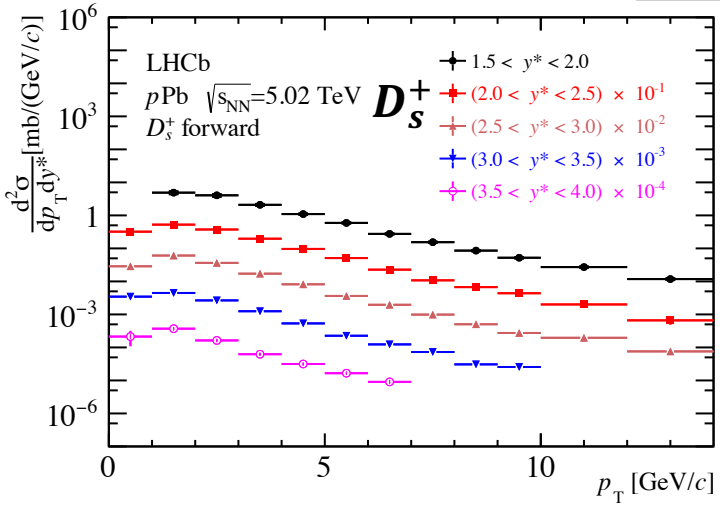
- Prompt and from b yields: distinguished by fitting $\log_{10}\chi^2_{IP}$ distribution.
- Background:

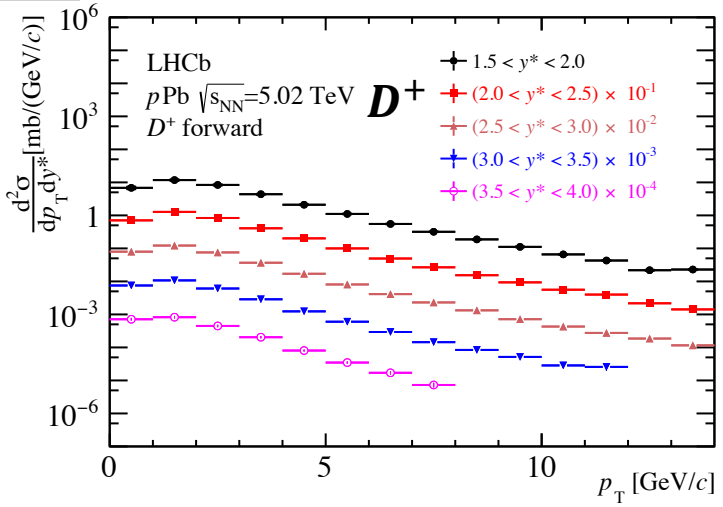
  subtracted by sPlot technique.

  [Nucl. Instrum. Methods Phys.Res., Sect. A 555, 356 (2005)]

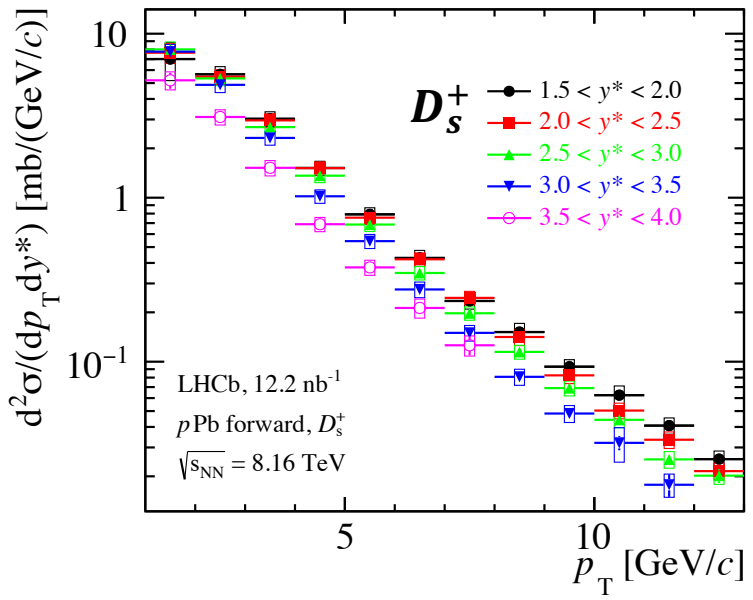
Prompt D_s^+ and D^+ cross-section in pPb at 5.02 & 8.16TeV

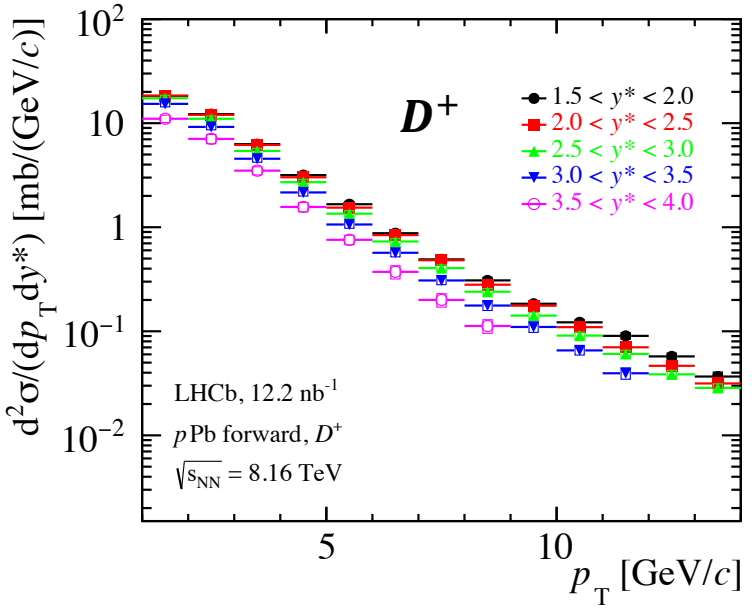
5.02TeV [arXiv:2309.14206]





8.16TeV [arXiv:2311.08490]



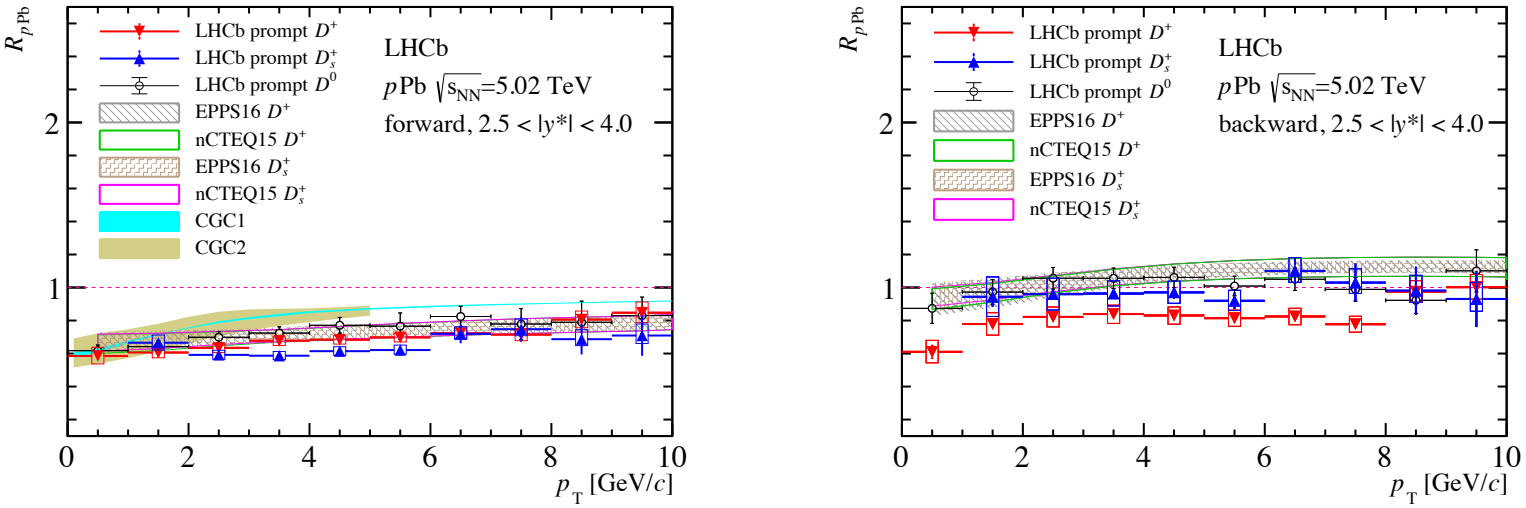


- $$\frac{d^2\sigma}{dp_T dy^*} = \frac{N(p_T,\, y^*)}{\mathcal{L} \times \varepsilon(p_T, y^*) \times \mathcal{B} \times \Delta p_T \times \Delta y^*}$$

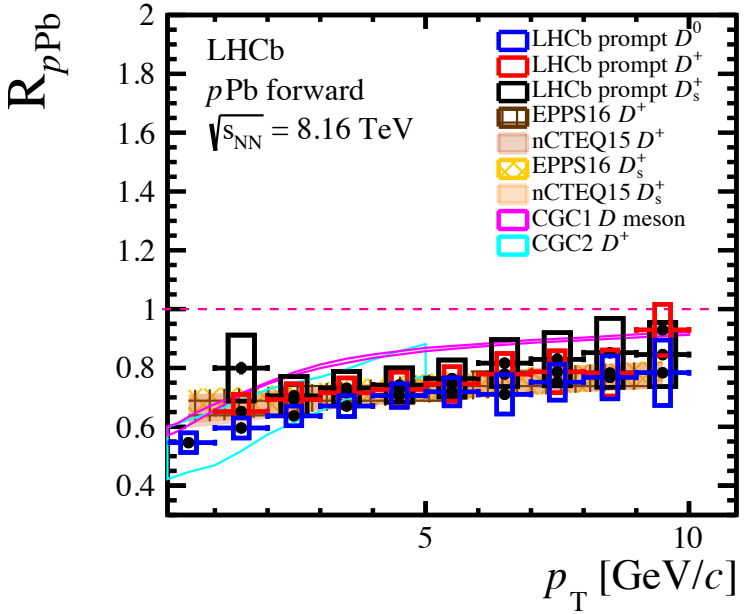
  - $N(p_T, y^*)$: prompt $D^+_{(s)}$ yield in (p_T, y^*)
  - $\varepsilon(p_T, y^*)$: total efficiency correction
  - $\mathcal{L}$: luminosity
  - $\mathcal{B}$: branching fraction
    $D^+ \to K^-\pi^+\pi^+$: 9.38±0.15%; [PDG 2022]
    $D_s^+ \to K^+K^-\pi^+$: 2.24±0.13% [PRL. 100 (2008) 161804]
  - Δp_T and Δy^*: width of Δp_T or Δy^* bin

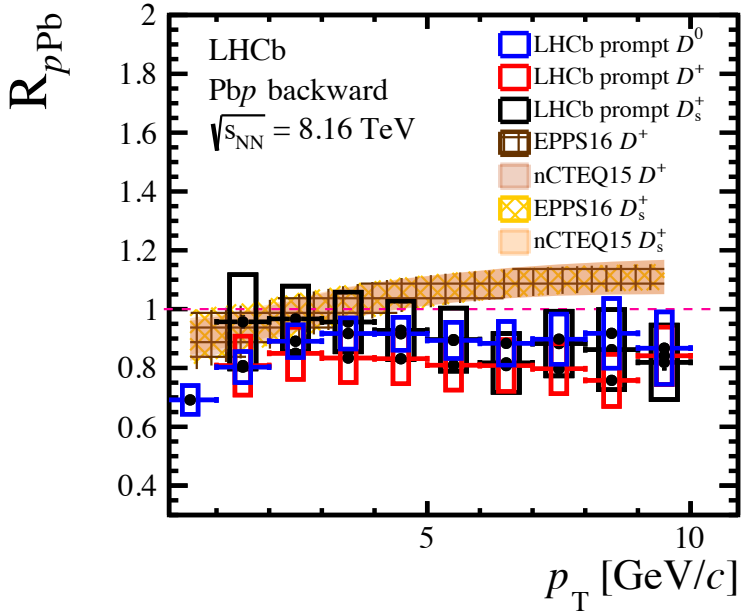
D_s^+ and D^+ nuclear modification factors at 5.02 & 8.16TeV

5.02TeV [arXiv:2309.14206]



8.16TeV [arXiv:2311.08490]



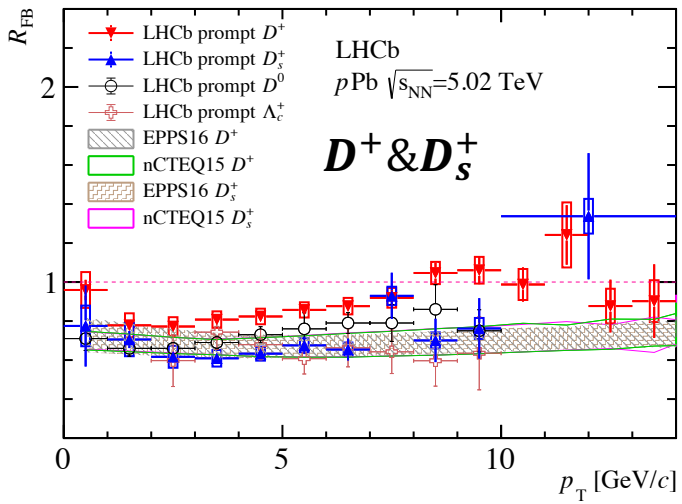


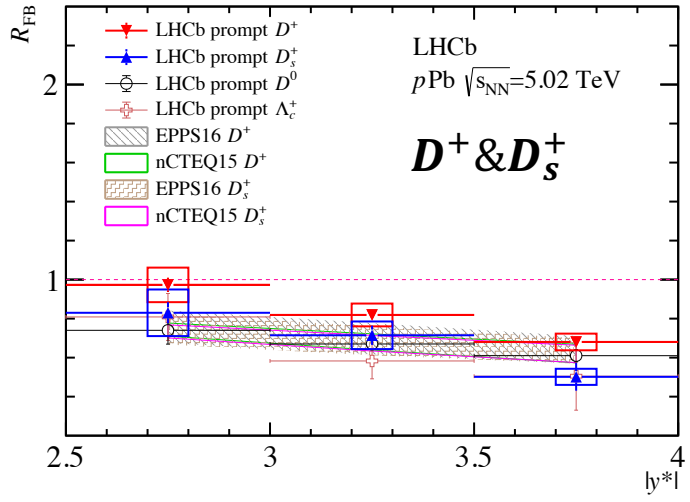
- $R_{p\mathrm{Pb}} = \dfrac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{208\times \sigma_{pp}/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}$
- Forward:
  - $R_{p\mathrm{Pb}}$ is consistent with D^0 and nPDFs and CGC (**5.02 & 8.16TeV**).
- Backward:
  - D^+ data are lower than the nPDFs (**5.02TeV**). Possible change in charm hadronization?
  - D-meson data are lower than the nPDF calculations (**8.16TeV**). Possible other nuclear effects may exist in pPb (initial/final state energy loss, multiple parton scattering…).

[PhysRevLett.131.102301]

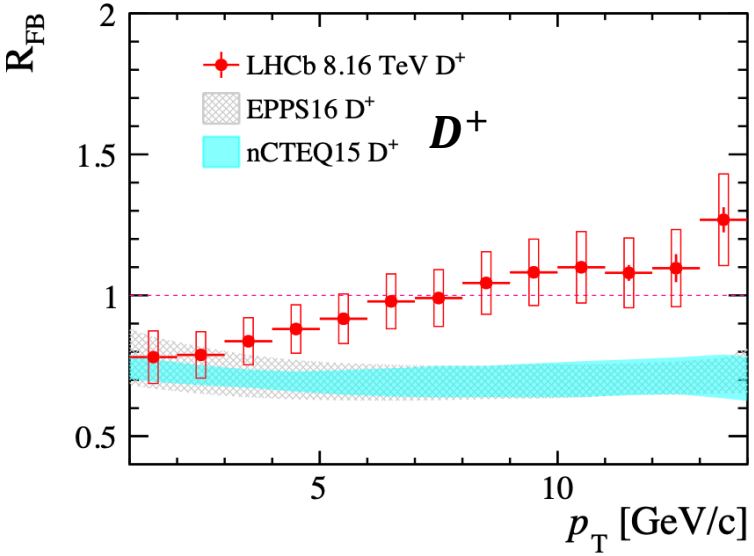
D_s^+ and D^+ forward-backward ratios at 5.02 & 8.16TeV

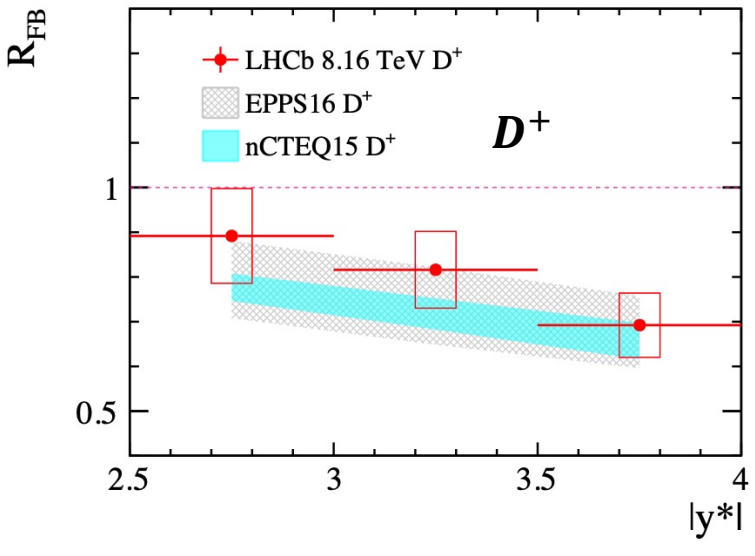
5.02TeV [arXiv:2309.14206]





8.16TeV [arXiv:2311.08490]



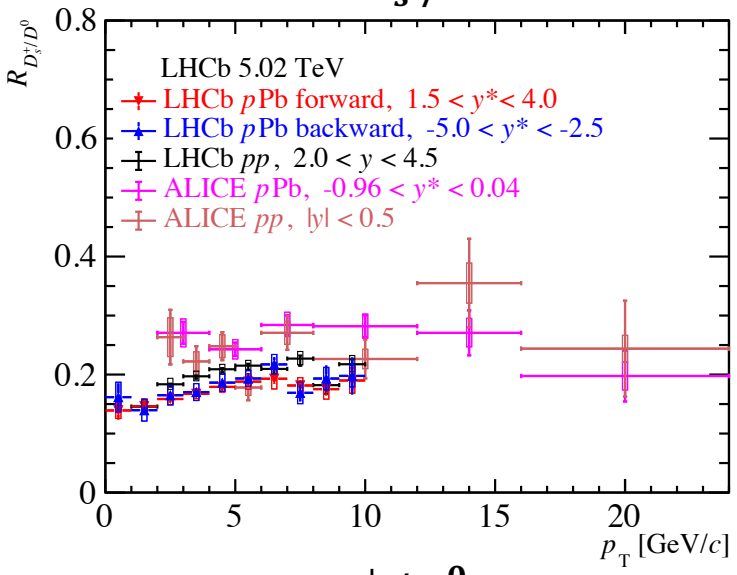


- $R_{FB}(p_T, y^*) = \frac{d^2\sigma_{FWD}(p_T,|y^*|;y^*>0)/dp_T dy^*}{d^2\sigma_{BWD}(p_T,|y^*|;y^*<0)/dp_T dy^*}$
- A a rising trend with p_T (D^+), consistent with nPDFs at low p_T regions.
- A slight y^* dependence (D^+&D_s^+), consistent with nPDFs.

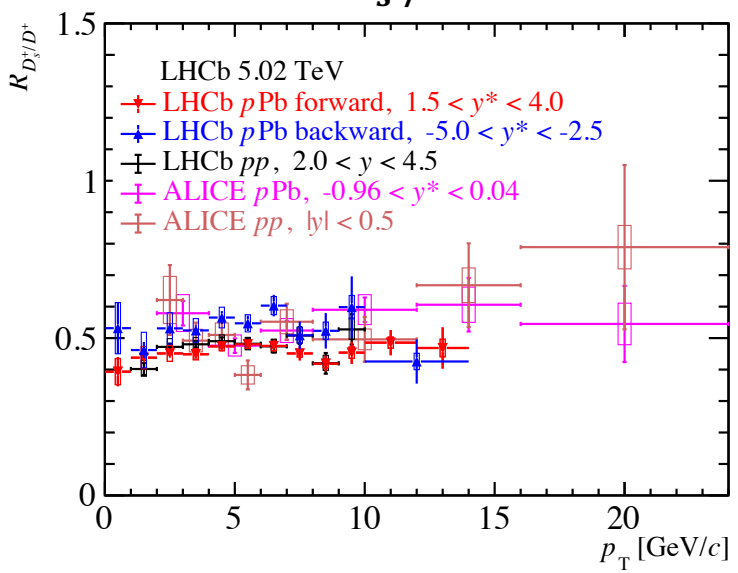
D_s^+ , $D^+$and D^0 production ratios at 5.02TeV

5.02TeV [arXiv:2309.14206]

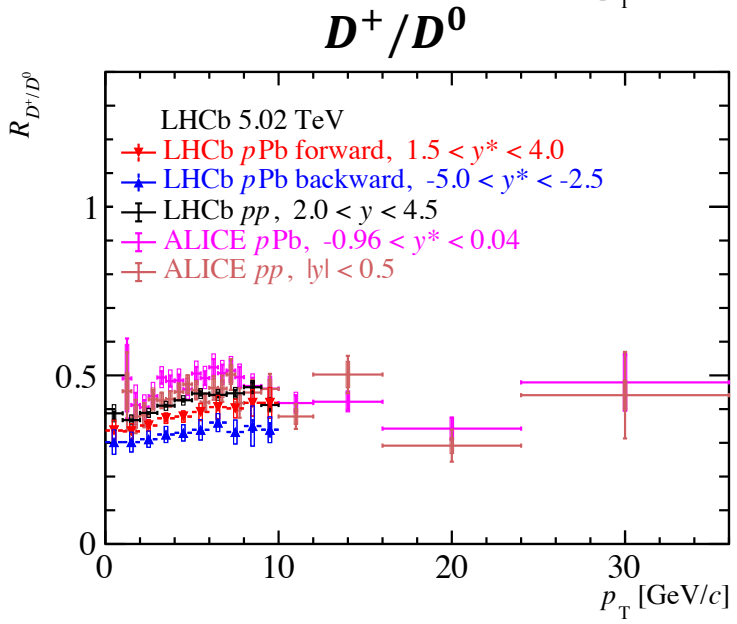
D_s^+/D^0



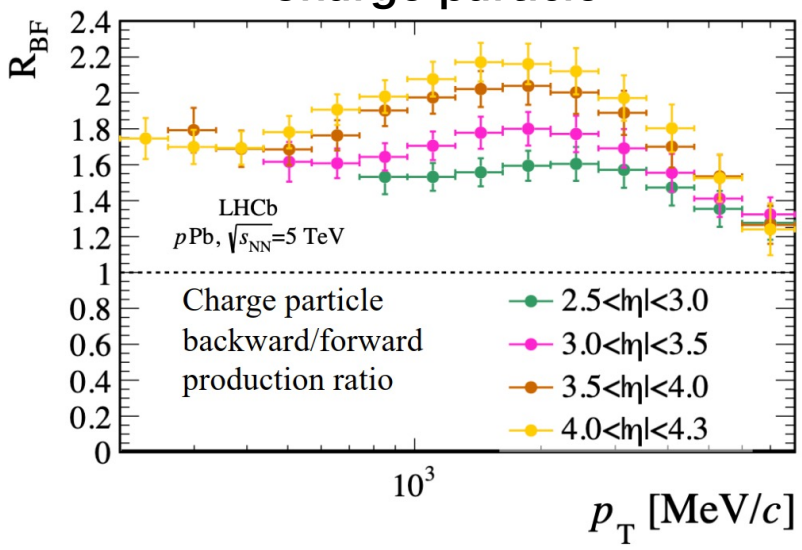
D_s^+/D^+



D^+/D^0



Charge particle



- D_s^+/D^0 and D_s^+/D^+ ratios:
  - ➢ No significant strangeness enhancement in immediate p_T region.
  - ➢ Consistent with previous results at 5.02TeV.
- D^+/D^0 ratio:
  - ➢ pp > forward > backward.
- $R_{FB}(\text{charge}) > 1$
  → average multiplicity:
  - ➢ backward > forward (~1.6x).

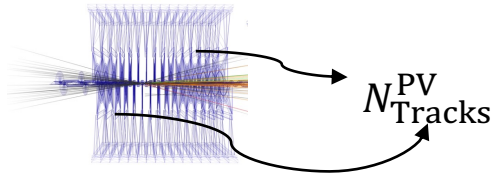
[Phys. Rev. Lett. 128, 142004]

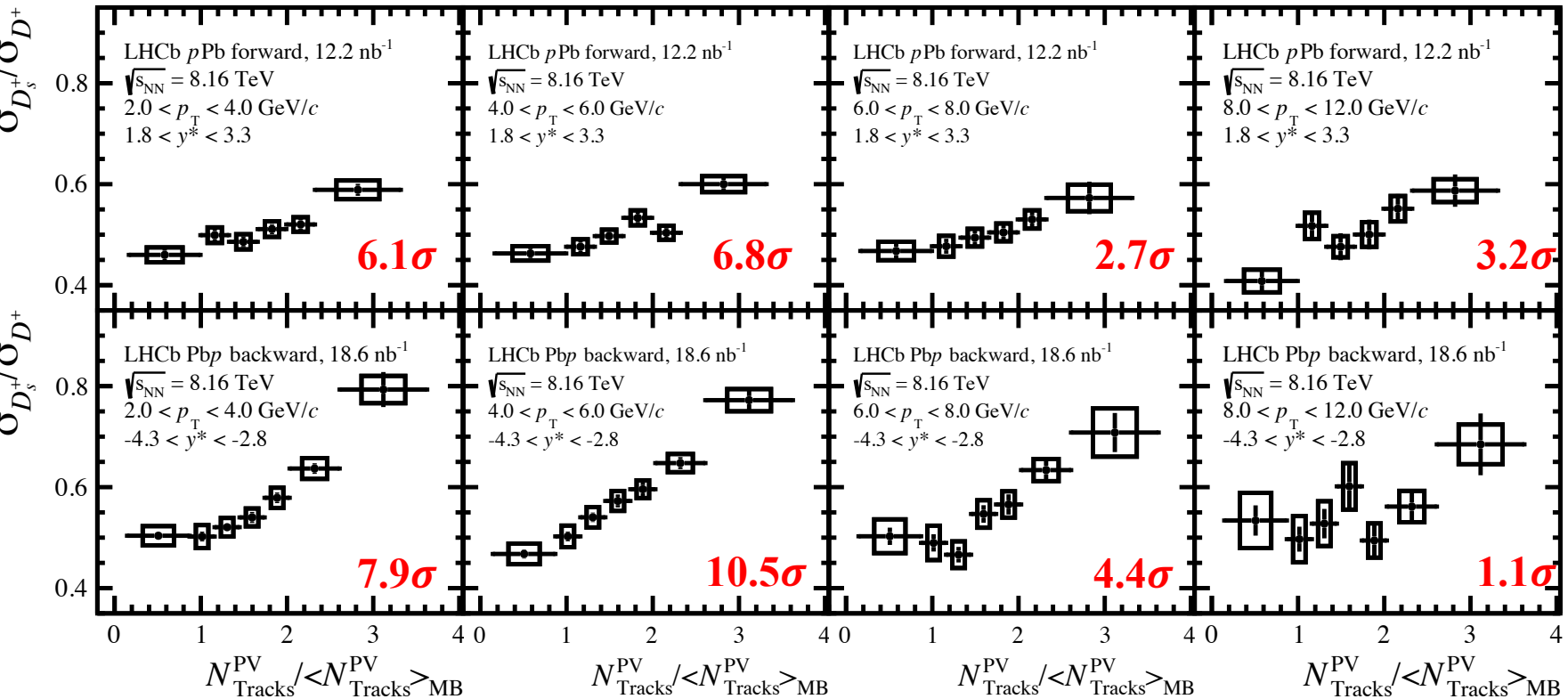
D_s^+/D^+ production ratio vs multiplicity at 8.16TeV

- D_s^+/D^+ ratio increases significantly versus multiplicity ($N_{\mathrm{Tracks}}^{\mathrm{PV}}$).
- D_s^+/D^+ ratio is consistent with ALICE measurements.
- A modification of charm quark hadronization in high multiplicity pPb collisions?

LHCb pPb (8.16TeV)

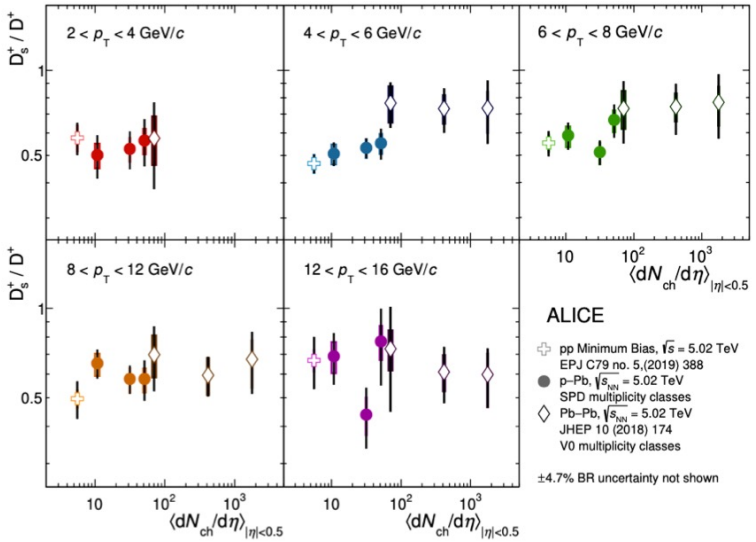
[arXiv:2311.08490]





ALICE pp, pPb, PbPb (5.02TeV)

[JHEP12(2019)092]



Summary

- Prompt D^+ and D_s^+ production has been measured at 5.02 and 8.16TeV with the LHCb detector, constraining nPDFs and CGC models.

- First production measurement of D^+ and D_s^+ in forward and backward rapidity regions at LHCb, down to very low p_{T}.

- Measured $R_{p\mathrm{Pb}}$ and R_{FB} indicate the existence of CNM effects and other nuclear effects.

- D^+/D^0 , D_s^+/D^0 and D_s^+/D^+ ratios are measured in pPb collisions at 5.02TeV and are suited as reference for the PbPb studies.

- In pPb collisions at 8.16TeV, an significant enhancement of D_s^+/D^+ vs multiplicity is observed in the low p_{T} region.

Thank you!