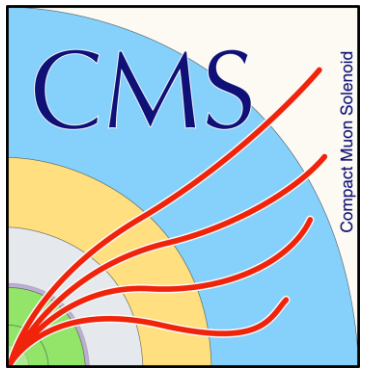
# Search of hot QCD effects via dynamics and productions of heavy flavor quarks in small systems with CMS detector




Yousen Zhang

Rice University

for CMS collaboration

28 Mar 2023

RICE

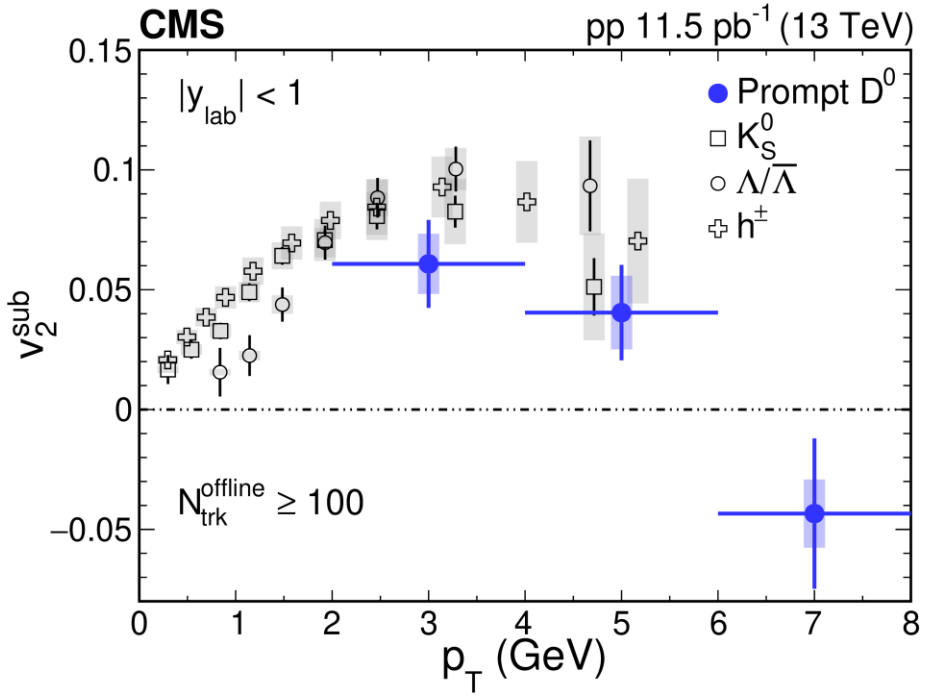
Supported by

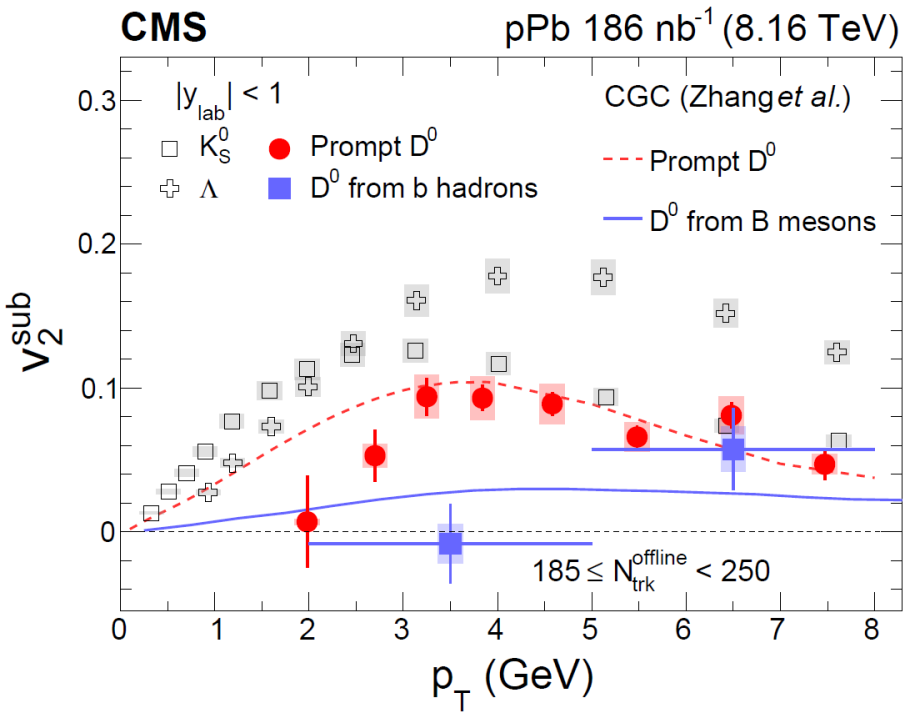
U.S. DEPARTMENT OF ENERGY

Office of Science

# Conjectured QGP liquid in small systems?

- Significant elliptic flow even for charm quarks in small systems
- Tiny QGP droplet in small systems?
  - Initial state effects vs final state effects

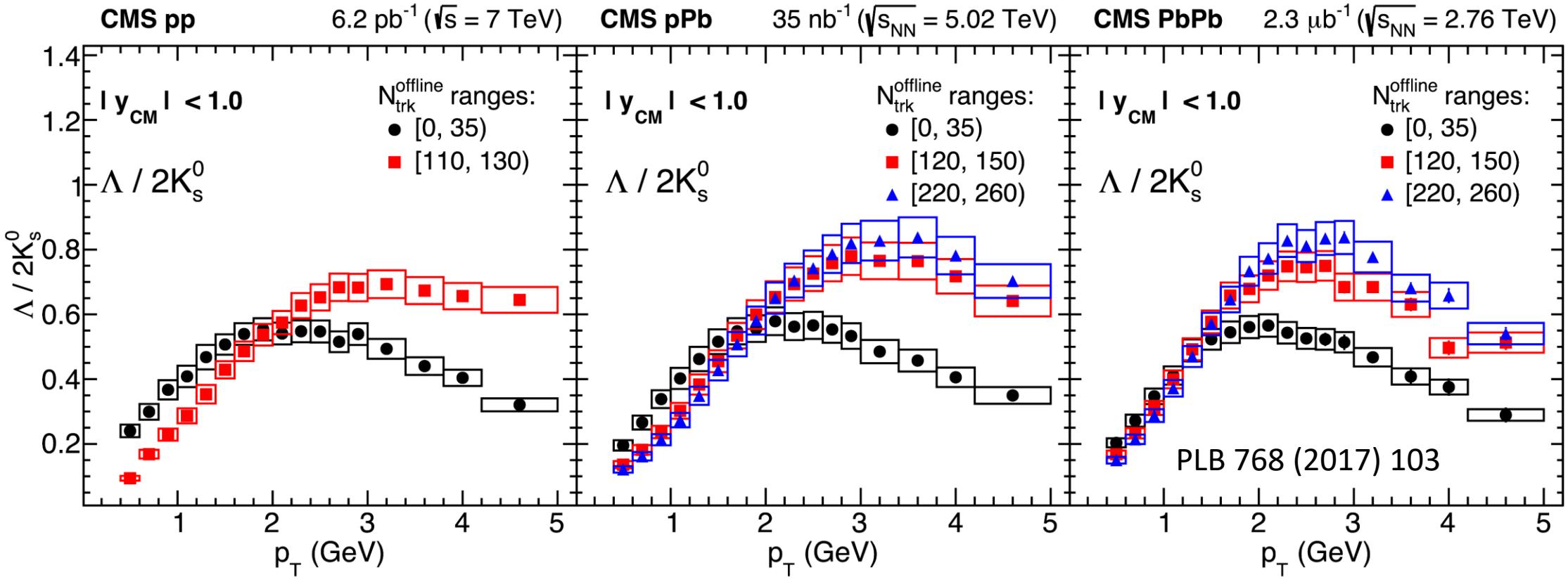



PLB 813 (2021) 136036

# Insights from baryon vs meson production

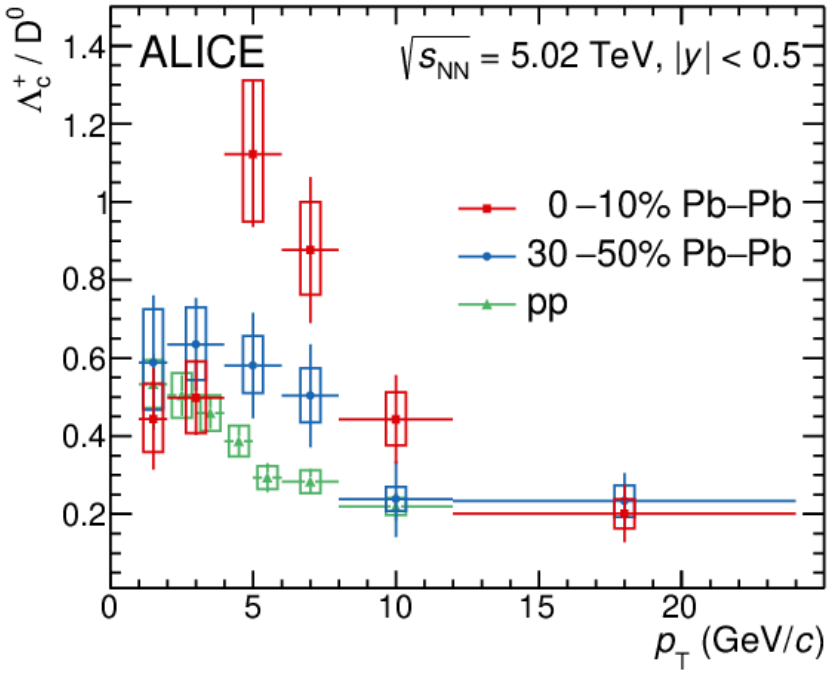
- Insights from baryon vs. meson productions
  - Significant enhancement of baryon to meson ratios from low to high multiplicities across all systems
  - Coalescence processes become stronger as the medium density increases



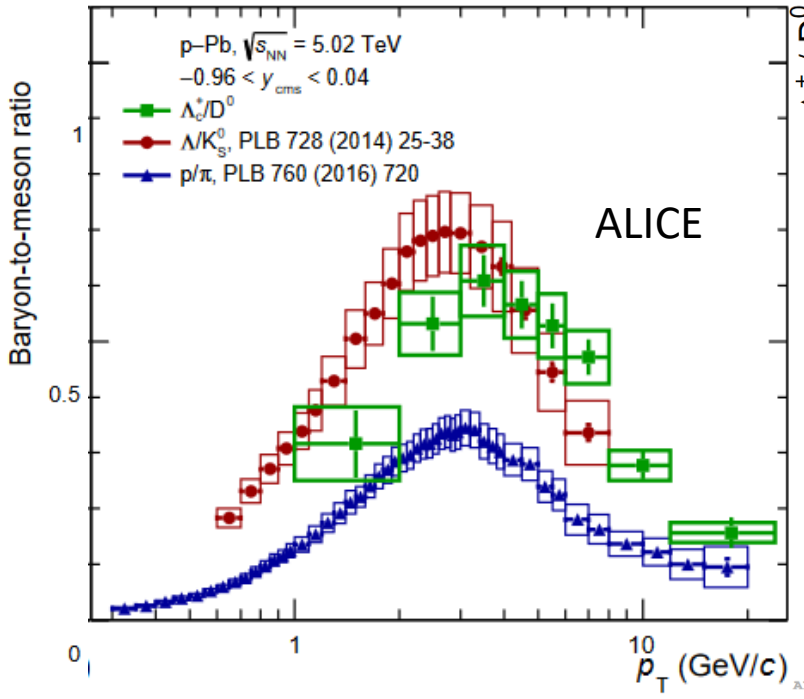
# Charm baryon vs meson studies

- Enhancement in PbPb (esp. 0-10%) compared to pp reference
- Similarity between strange and charm in minimum bias pPb
- Separations between (very) low and high multiplicity in pp systems

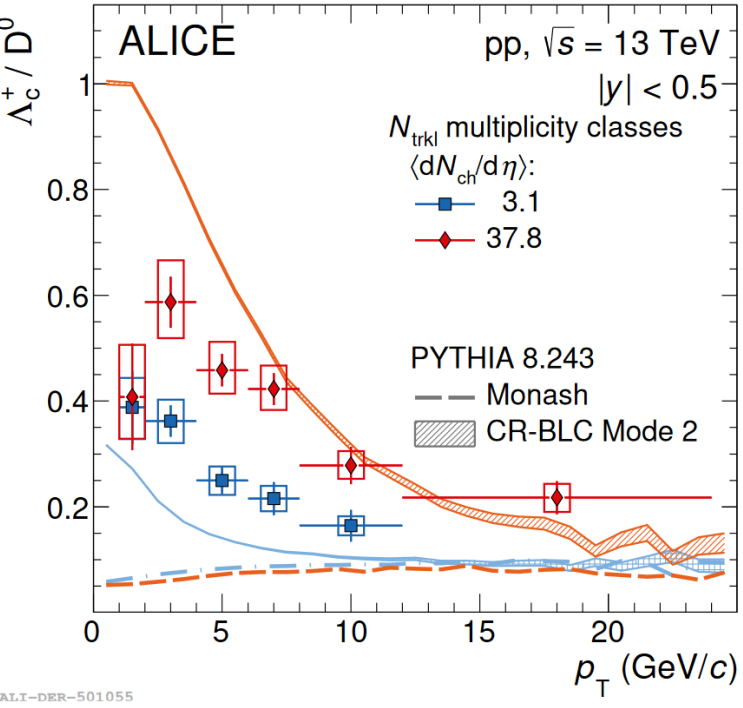
PLB 839 (2023) 137796




PRL 127 (2021) 20, 202301




PLB 829 (2022) 137065

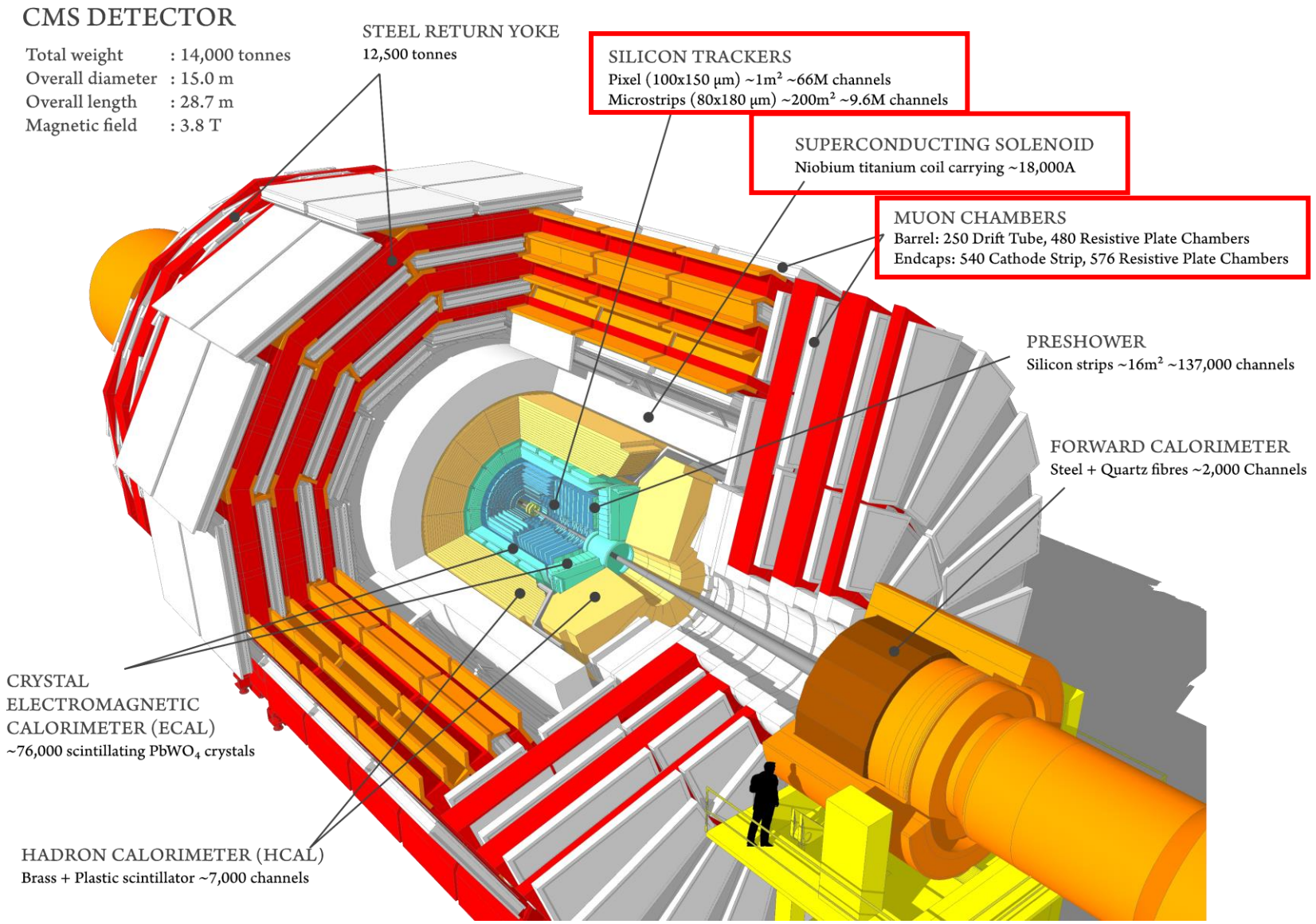



How would charm baryon to meson production evolve over a wide multiplicity range in pPb collisions?

# CMS detector and heavy flavor

Requirements for heavy flavor reconstructions

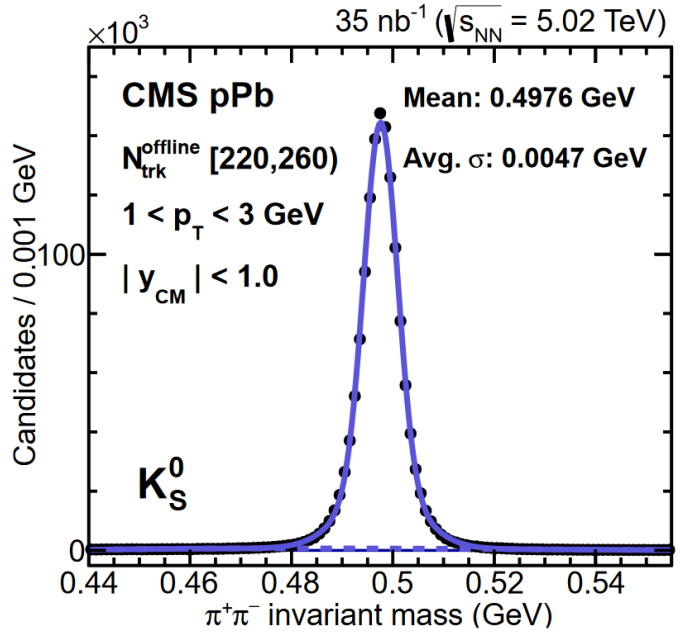
- Fast TDAQ ☺
- Tracking and secondary vertexing ☺
- Hadron identifications
- Lepton identifications ☺

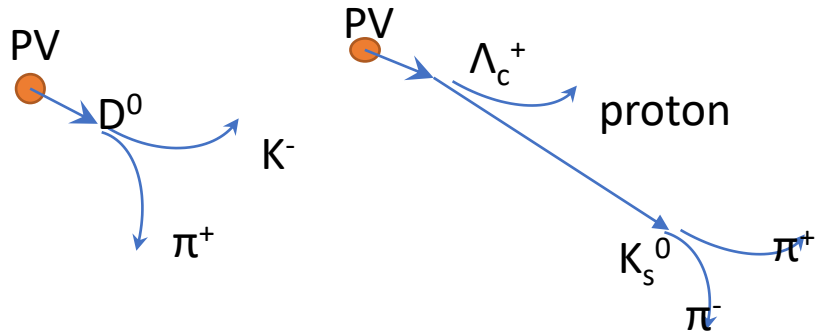


# Reconstructions for $\Lambda_c^+$ and $D^0$

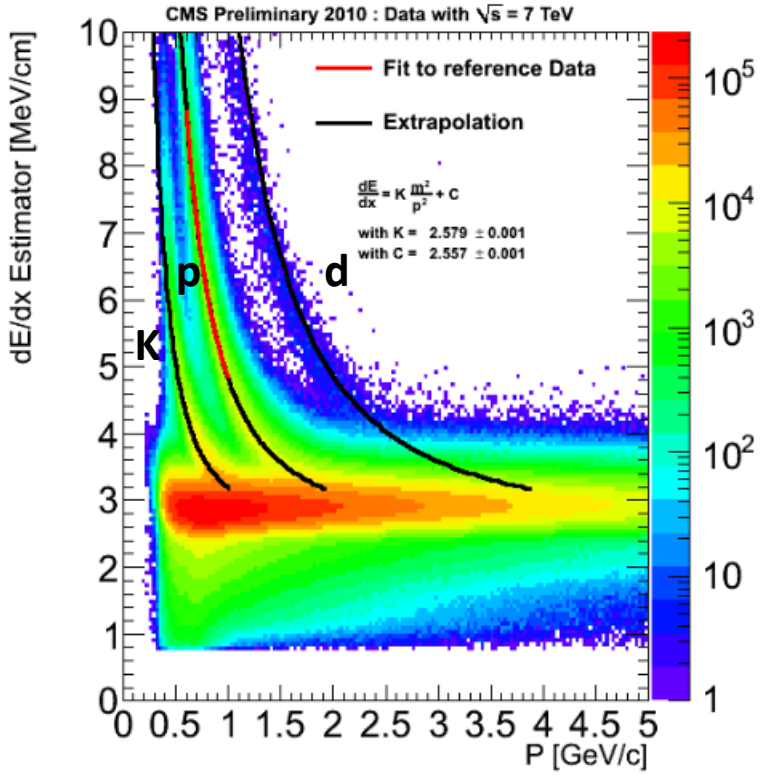
- Topological reconstructions for $\Lambda_c^+$ and $D^0$
  - $\Lambda_c^+ \rightarrow K_s^0 p$
  - $D^0 \rightarrow K\pi$
  - Further MVA for $D^0$ with topological information
- Particle identifications via $K_s^0$
  - $\Lambda_c^+ \rightarrow \pi K p$ ☹ (B.R. 6.35%)
  - $\Lambda_c^+ \rightarrow K_s^0 p$ ☺ (B.R. 1.59%)
- Further selections by MVA
  - Proton pseudo-rapidity and momenta
  - Energy loss by proton tracks
  - Cosine of pointing angle

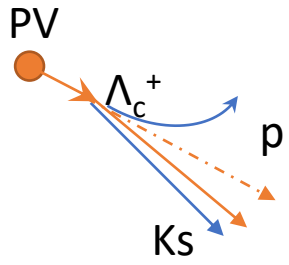
PLB 768 (2017) 103



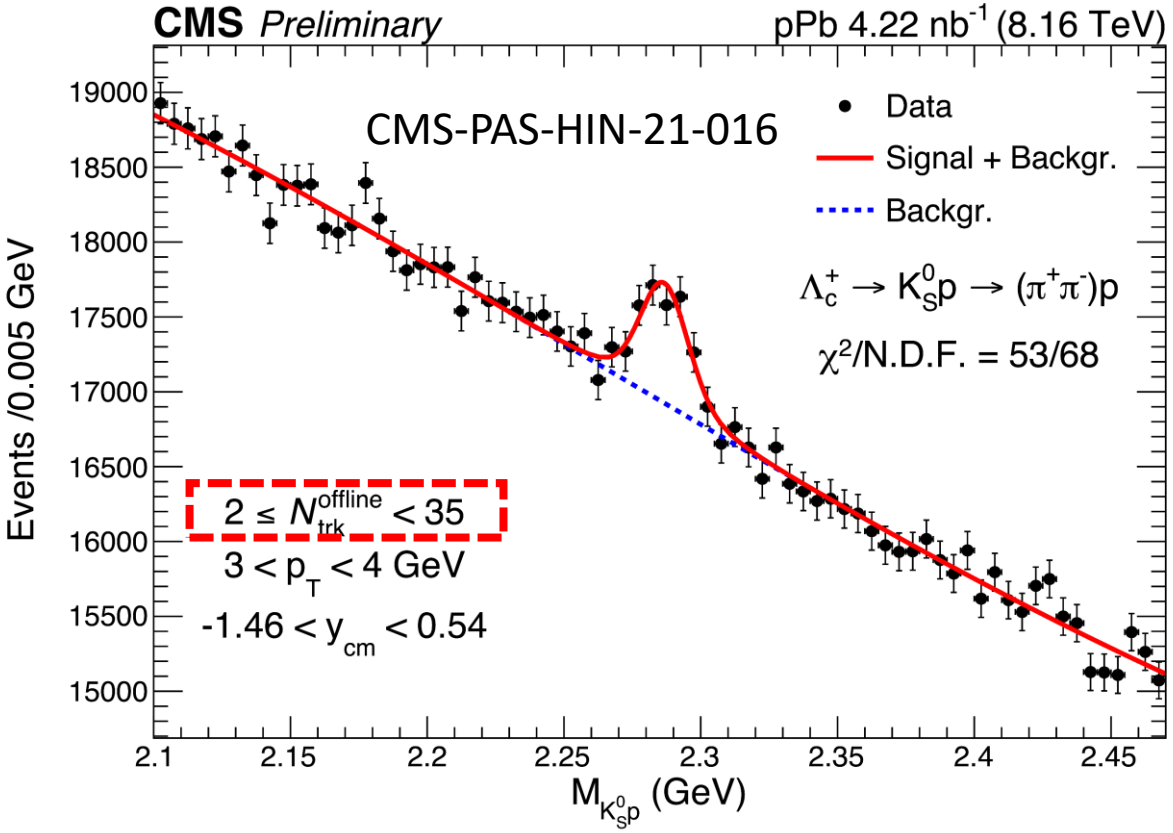

CMS CR -2010/120

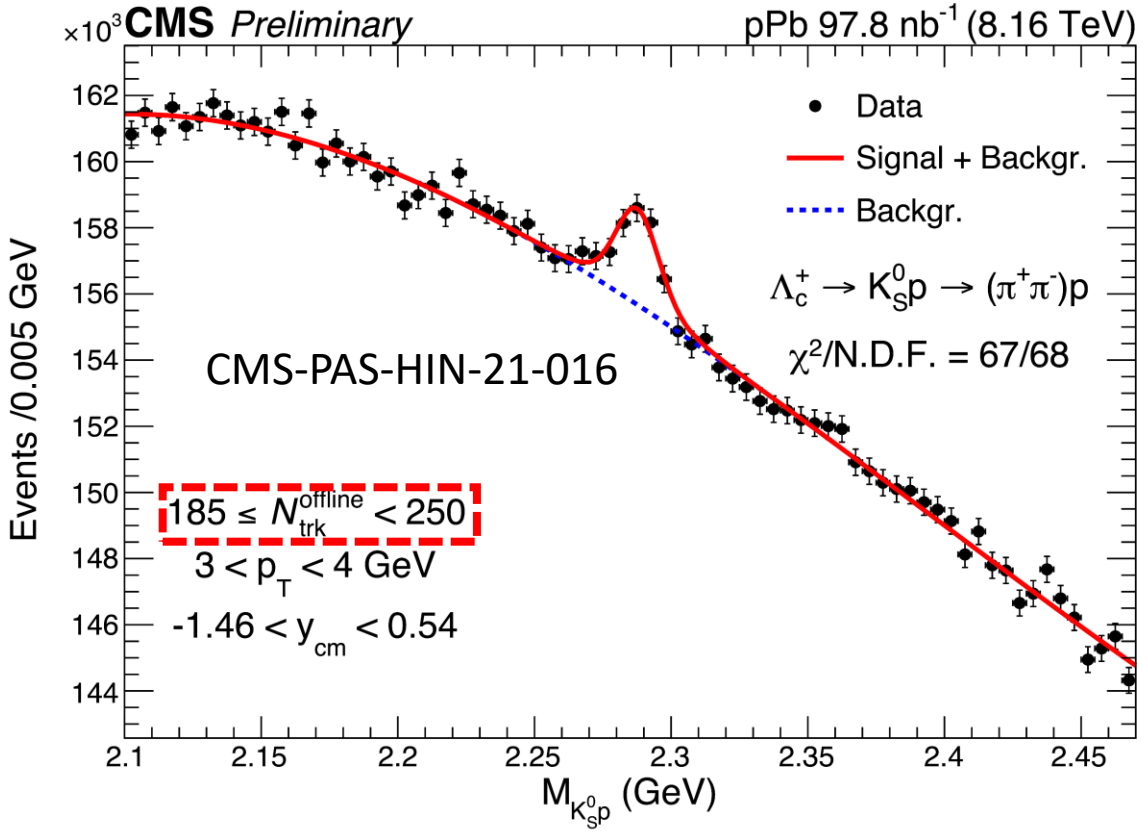


# Reconstructions for $\Lambda_c^+$

- Clear signal in low and high multiplicity events
  - $N_{trk}^{offline}$: N tracks with $p_T$>0.4GeV and |η|<2.4



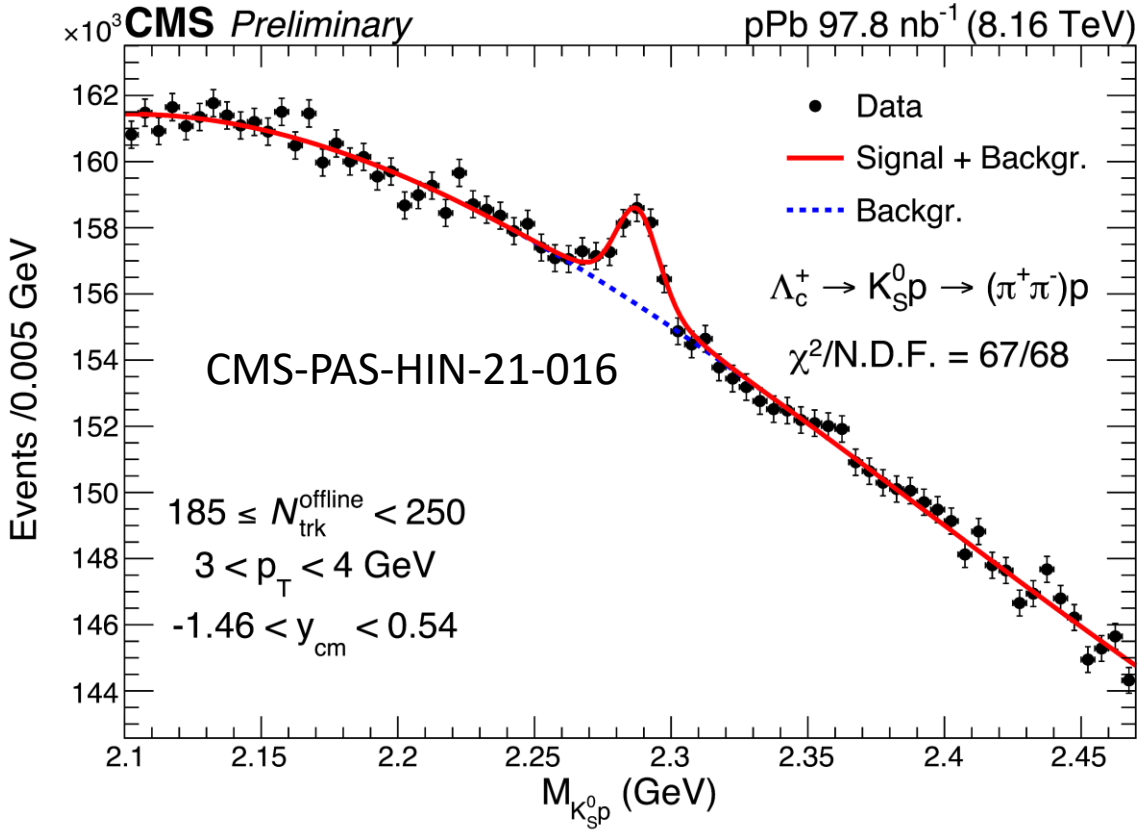



# Spectra for charm hadrons

- Yields per event

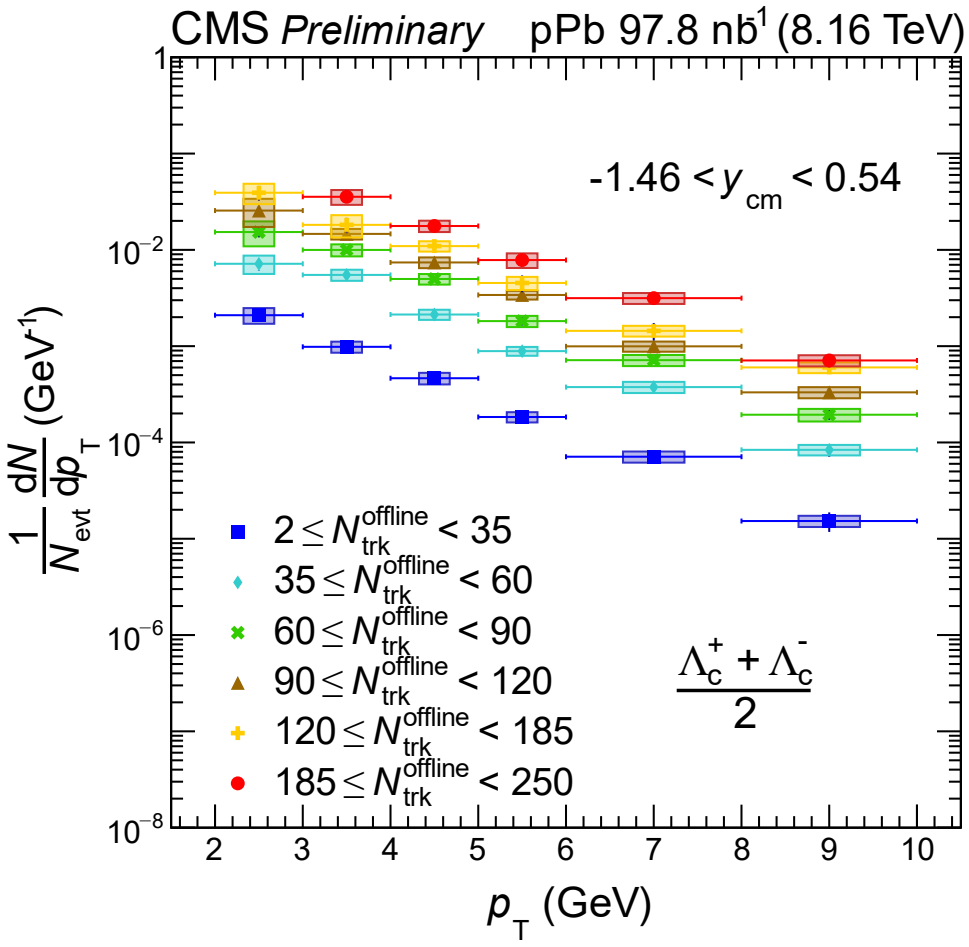
$$\frac{1}{N_{\mathrm{evt}}}\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}} = \frac{1}{N_{\mathrm{evt}}}\frac{f^{\mathrm{prompt}} \times N^{\mathrm{sig}}}{2 \times (\alpha \times \epsilon) \times \Delta p_{\mathrm{T}} \times \mathrm{BR}}$$

  - $N^{sig}$ raw yields extracted from fit
  - Prompt fraction for charm hadrons
    - Estimated from theory and template fits
  - (αxε) – acceptance and efficiency

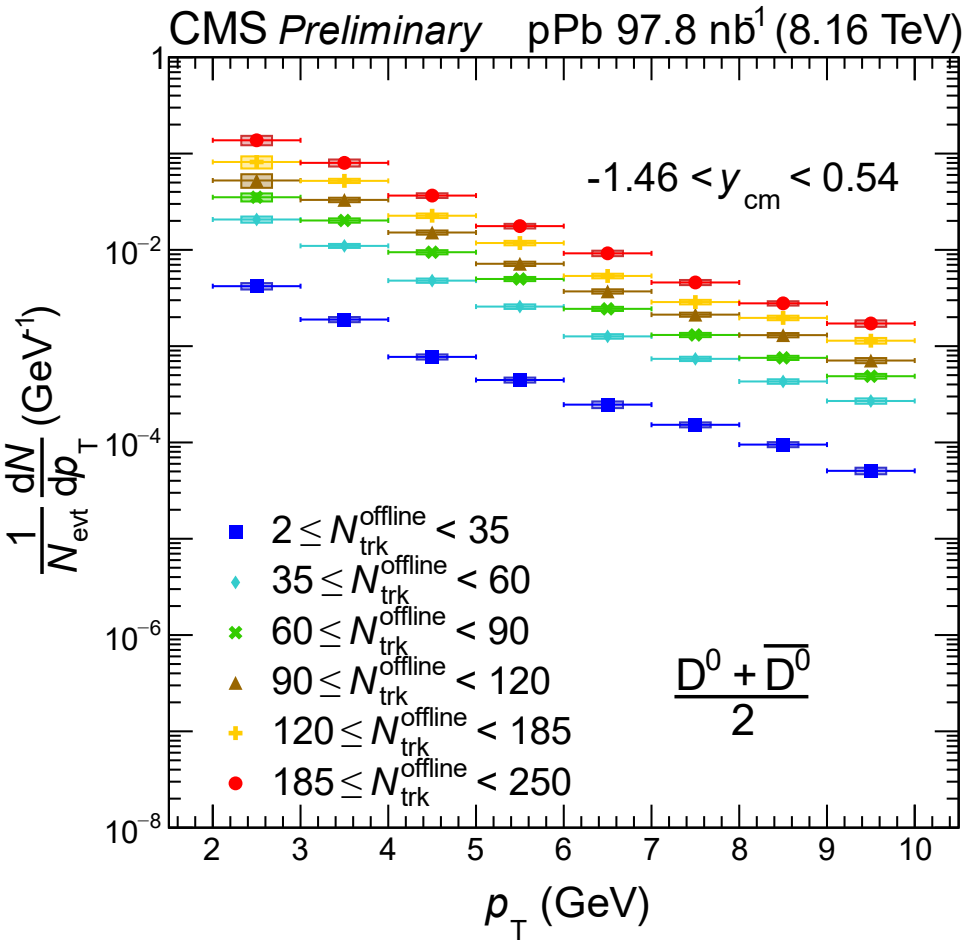


# Spectra for charm hadrons

- Increasing yields per event as multiplicity increases



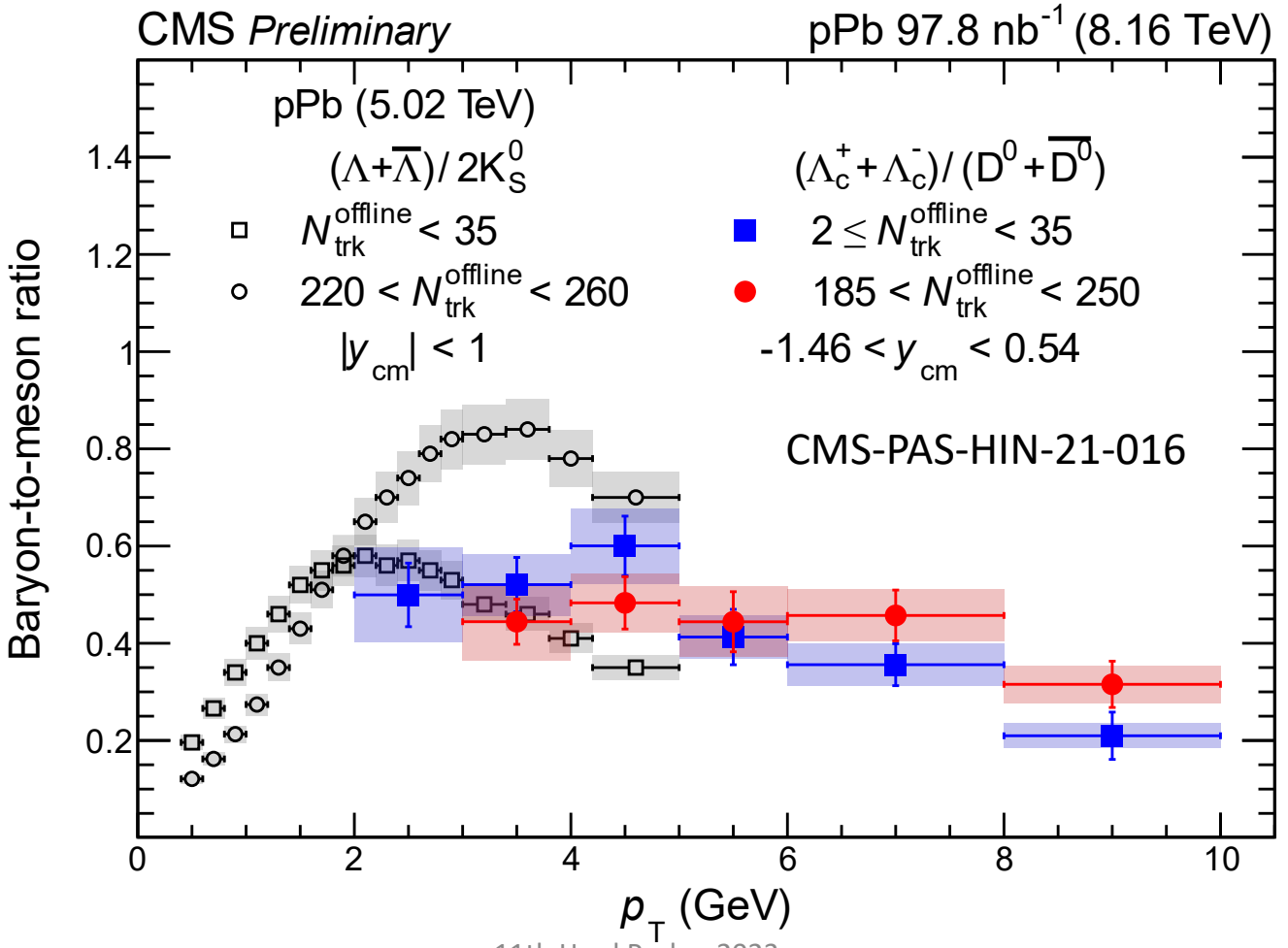

CMS-PAS-HIN-21-016




CMS-PAS-HIN-21-016

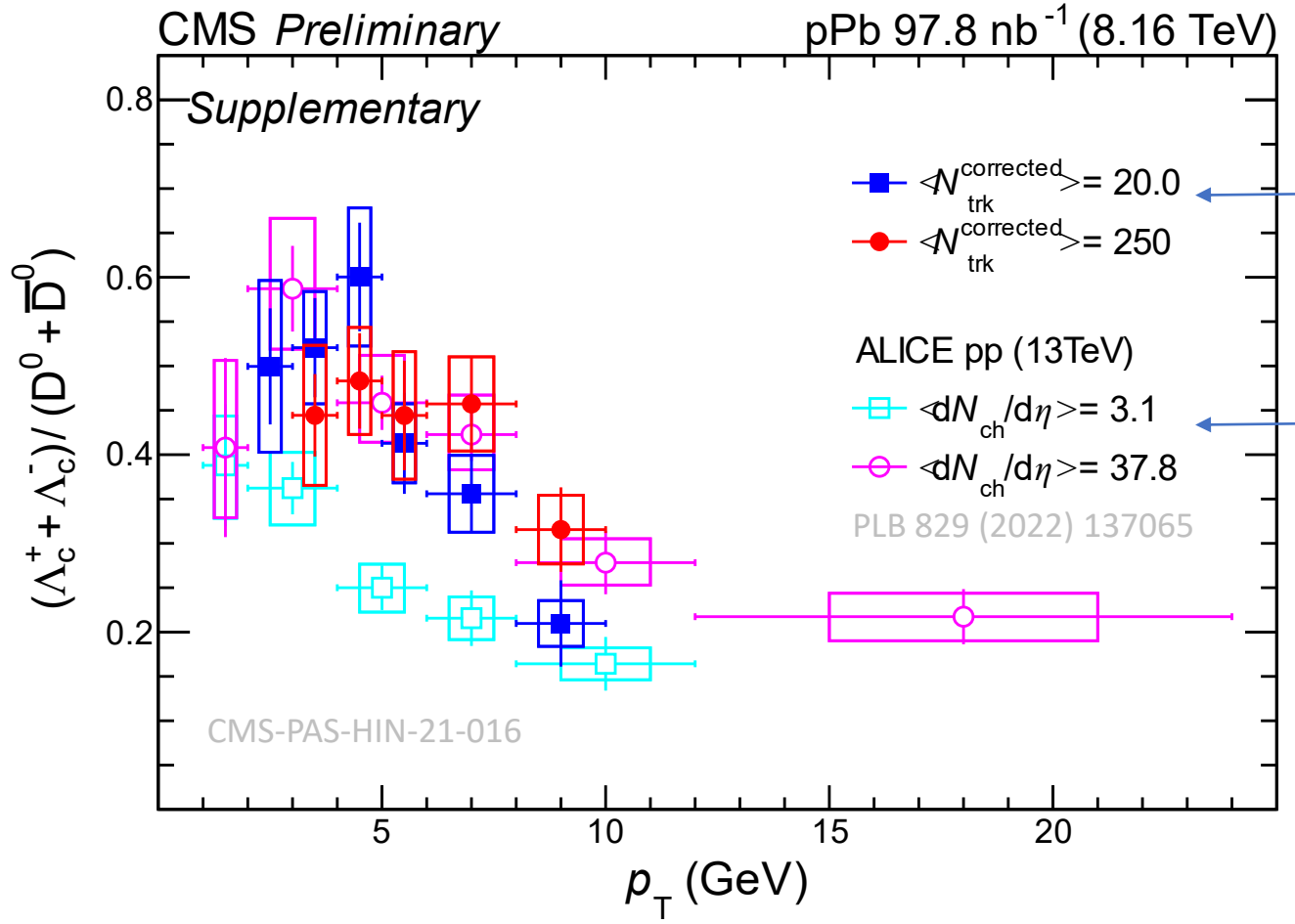
# $p_T$ dependence of $\Lambda_c^+/D^0$ ratios

- No multiplicity dependence over $p_T$ in contrast to strange hadrons
  - Different origin of collectivity or hadronization?



# Comparisons with $\Lambda_c^+/D^0$ ratios in pp

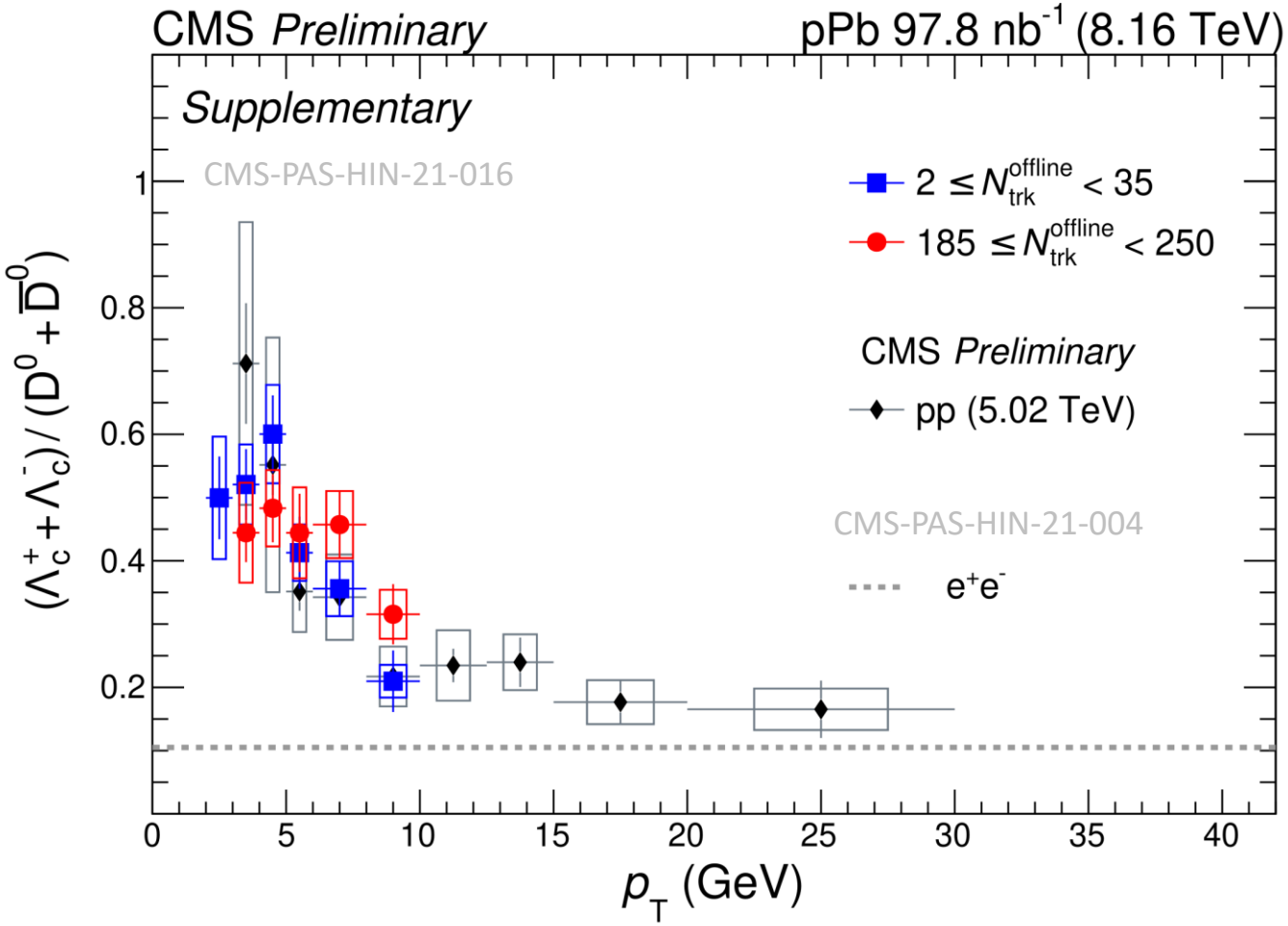
- Comparable with high multiplicity pp events – no multiplicity dependence except for very low multiplicity pp (below MB)

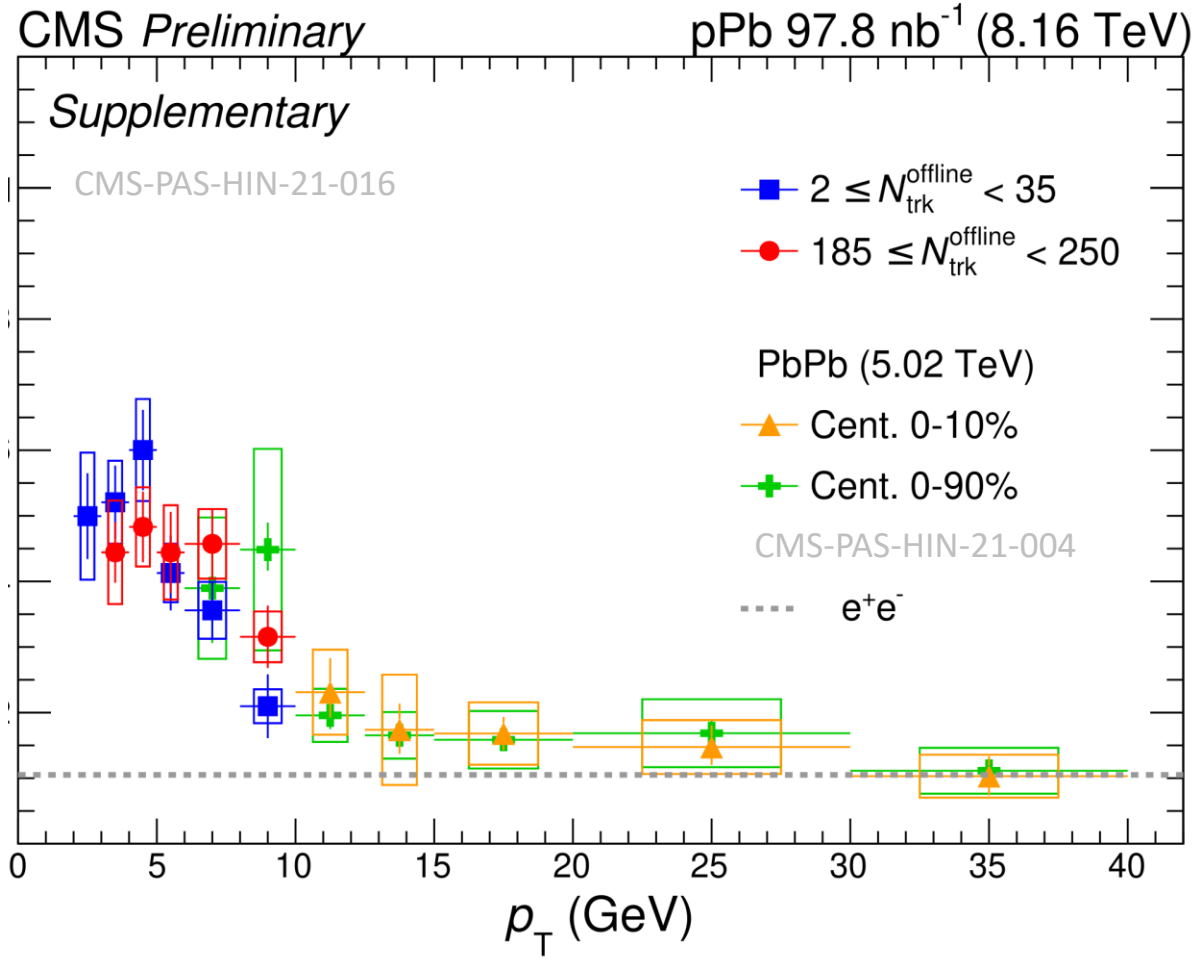


# Comparisons with different systems

- Comparable ratios at low $p_T$ and smooth connection towards high $p_T$ regime different systems

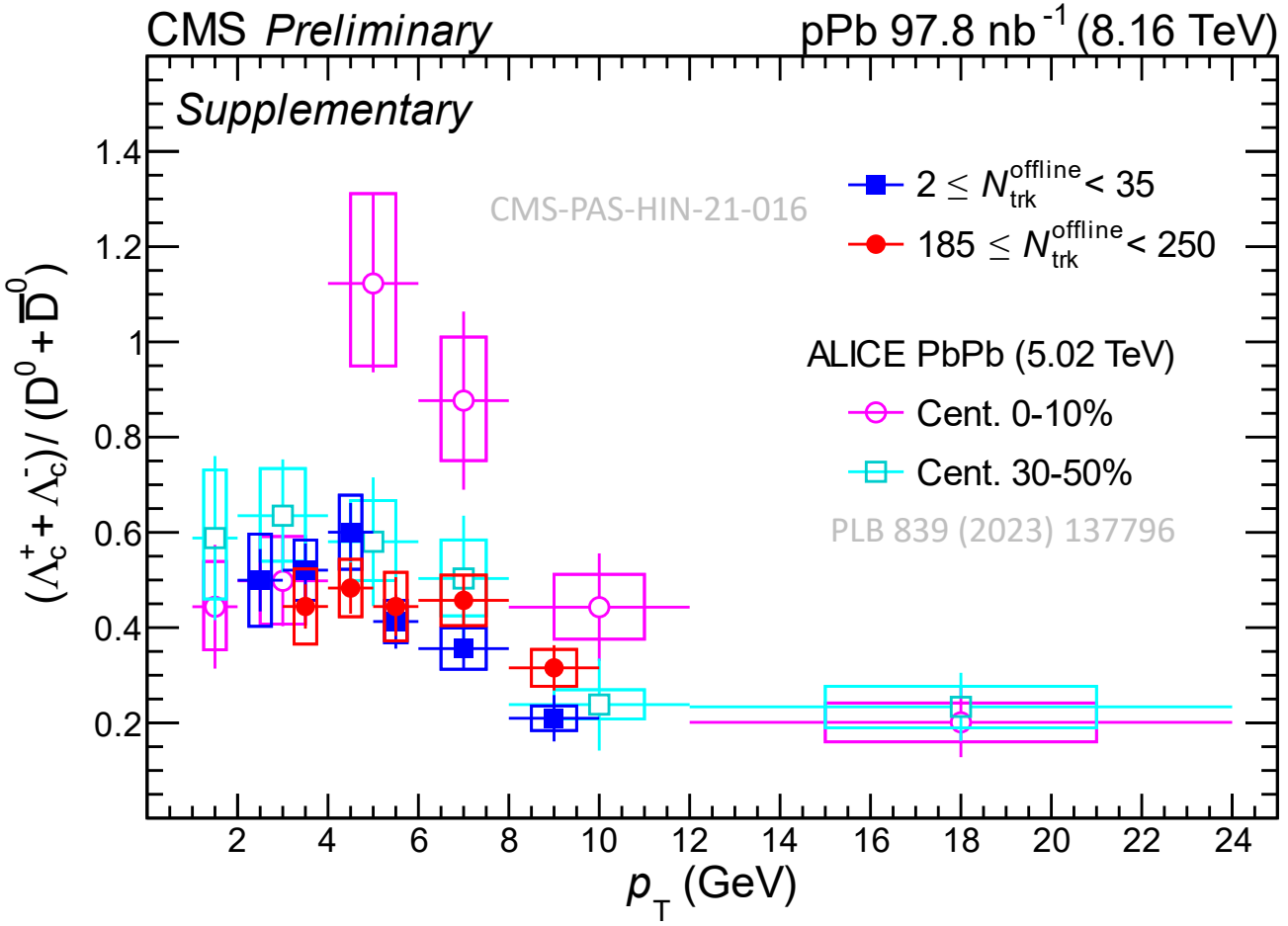
More details in S. Chandra Poster



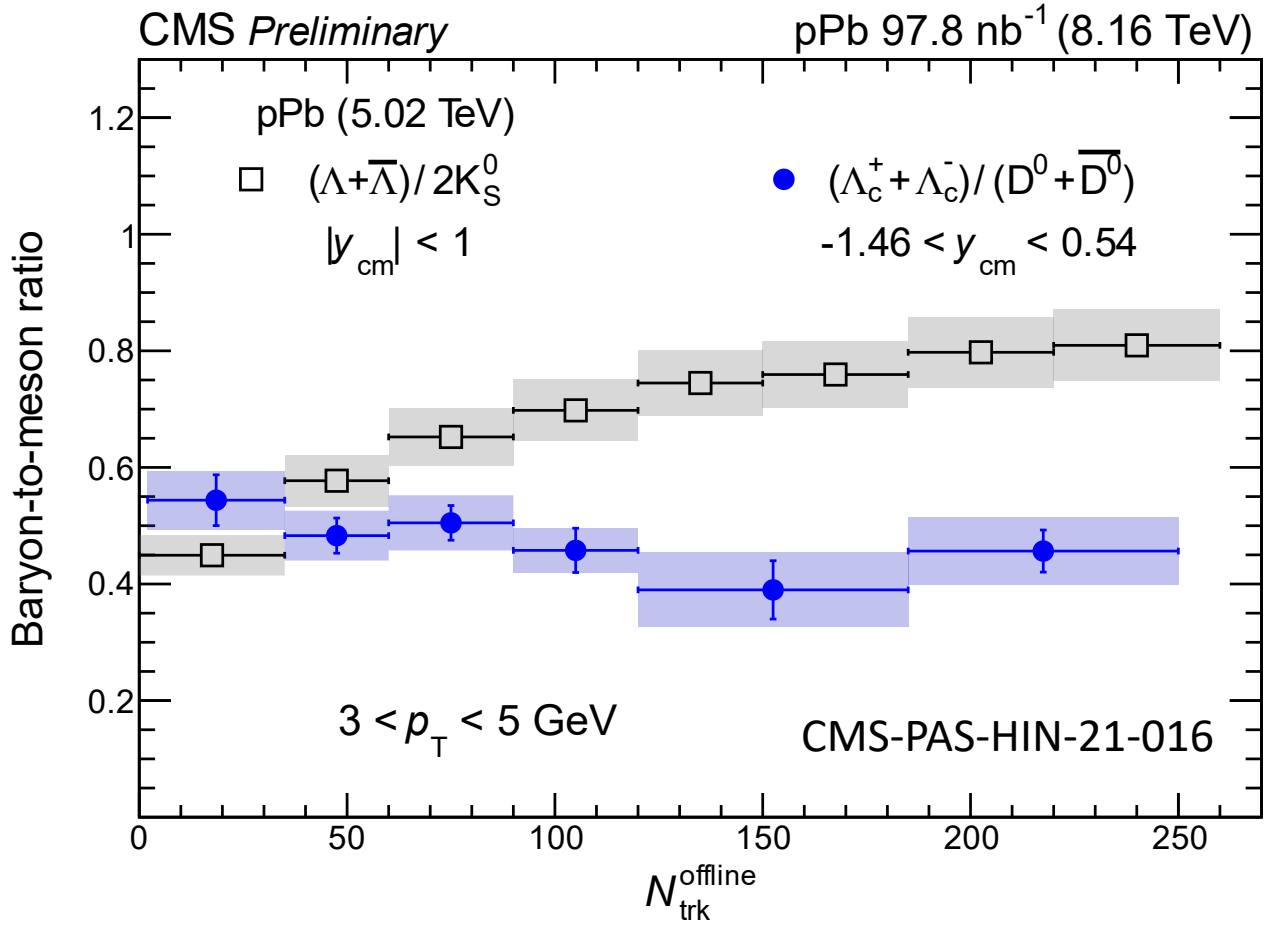
# Comparisons with $\Lambda_c^+/D^0$ ratios in PbPb

- No multiplicity or medium density dependence over a wide range, except for very central PbPb?



# Multiplicity dependence of $\Lambda_c^+/D^0$ ratios

- Flat dependence on multiplicity but light quarks is increasing
  - Different mechanism for hadronization?




Earlier saturation if coalescences presents?

# Future prospects at HL-LHC

- Fast TDAQ ☺
  - CMS DAQ 4 and L1/HLT upgrade
- Tracking and secondary vertexing ☺
  - Tracking upgrade with larger acceptance and better resolutoin
- **Hadron identifications ☺**
  - **Timing resolution 30ps**
- Lepton identifications ☺
- Neutral particle identifications
  - High-granularity calorimeter

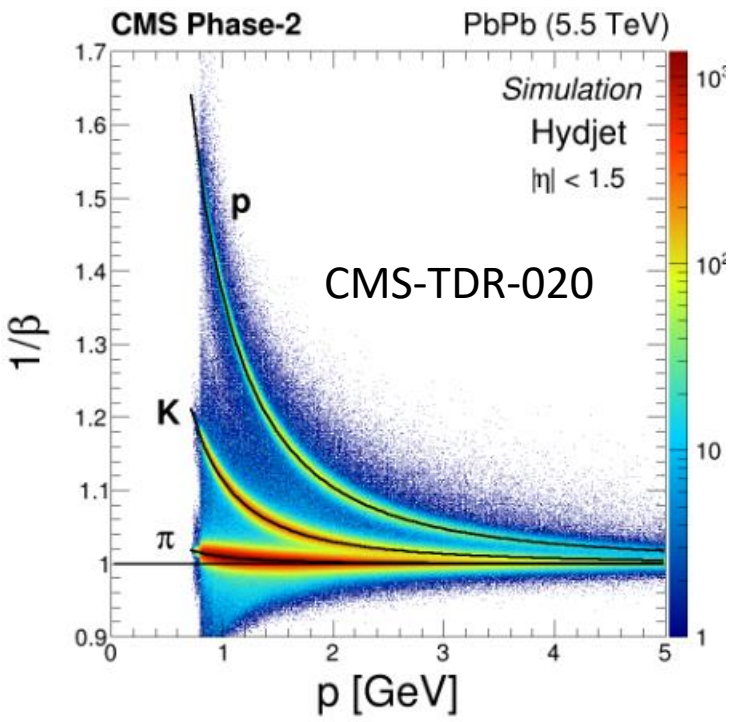
**CERN Courier**

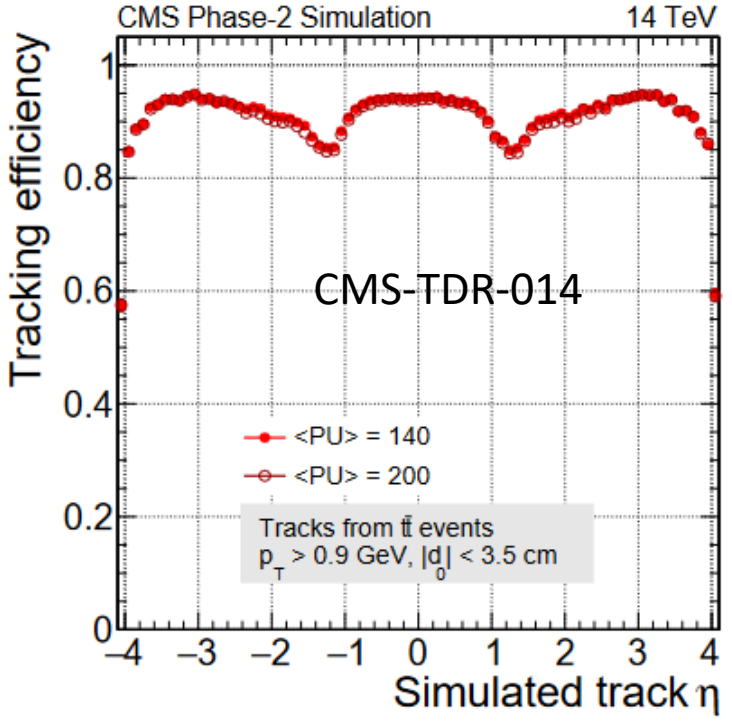
ACCELERATORS | FEATURE

## CMS prepares for Phase II

9 January 2023

Novel and established detectors that push technologies to new heights will allow the CMS collaboration to fully exploit the HL-LHC physics potential.

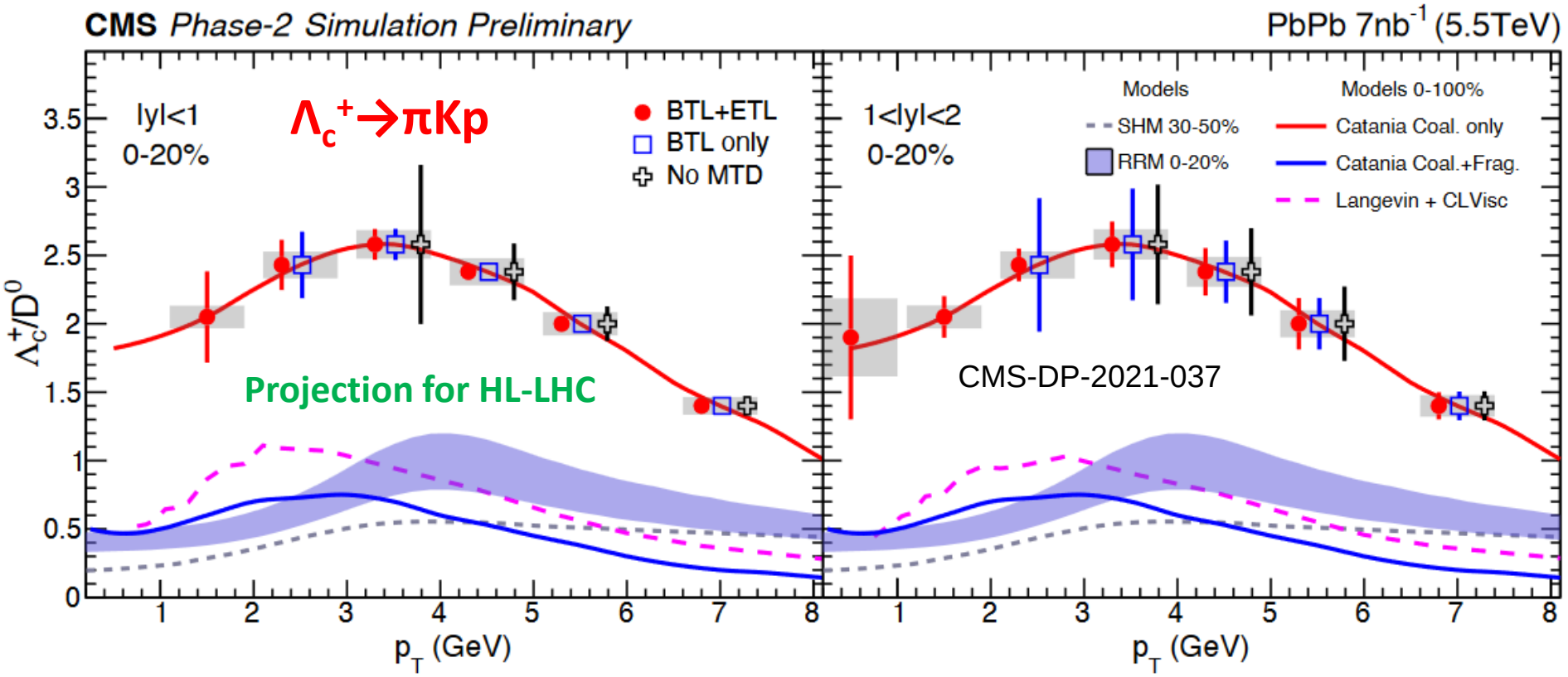


# Coalescence effects of charm hadrons at HL-LHC

- Access full $p_T$ range of $\Lambda_c^+$ *with MTD*
  - Total charm cross section
  - CMS *unique* access over a rapidity range of ***up to 6 (4) units in MB (central)*** *events*

More details in Lee's talk
28 Mar 2023, 14:00

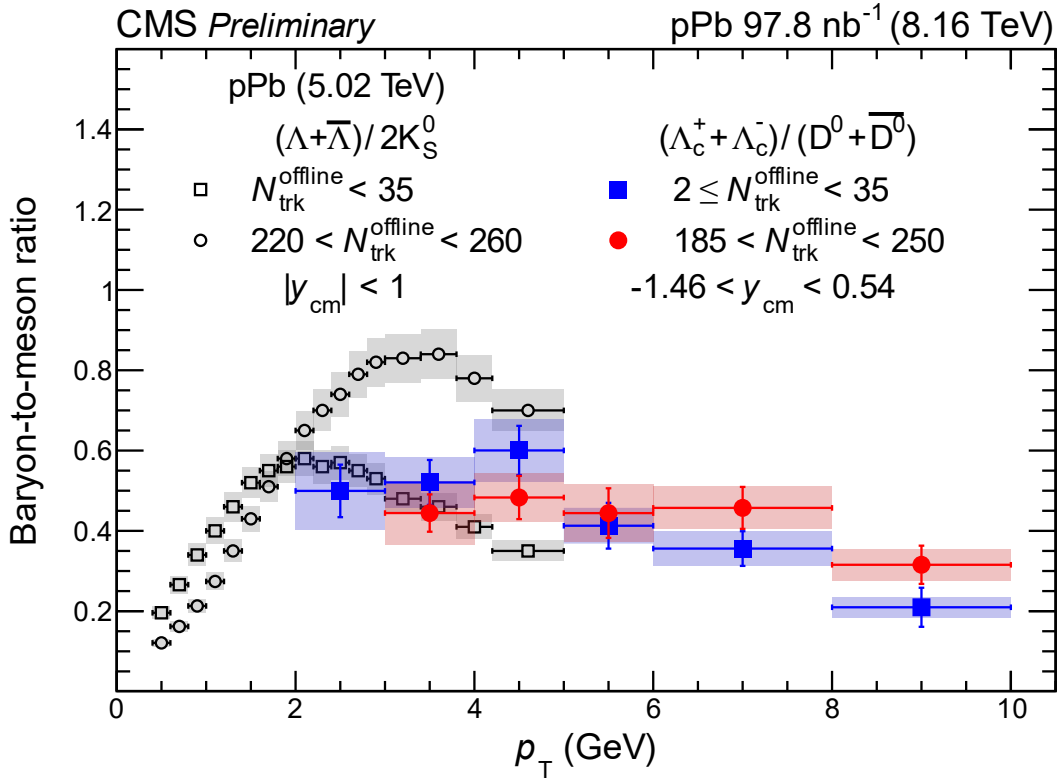


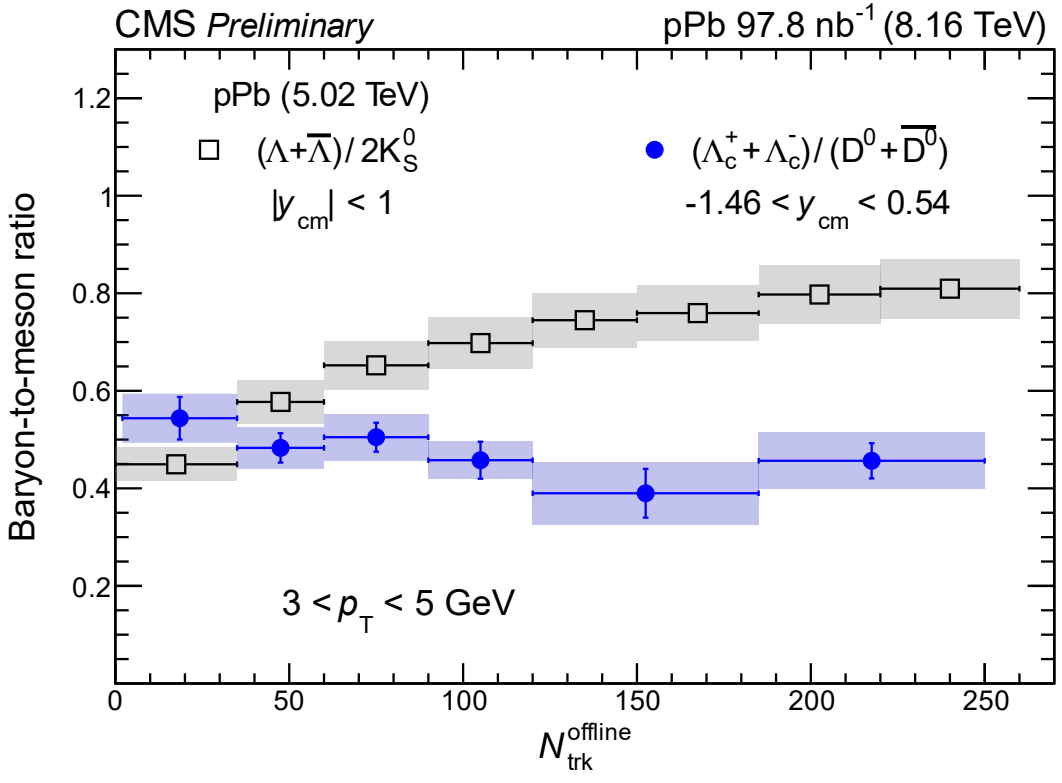
# Summary

- First measurement for multiplicity dependence of $\Lambda_c^+/D^0$ ratios in pPb at 8.16 TeV
- Small multiplicity dependence for $\Lambda_c^+/D^0$ ratios
  - Different hadronization and dynamics for charm and strange hadrons?

CMS-PAS-HIN-21-016

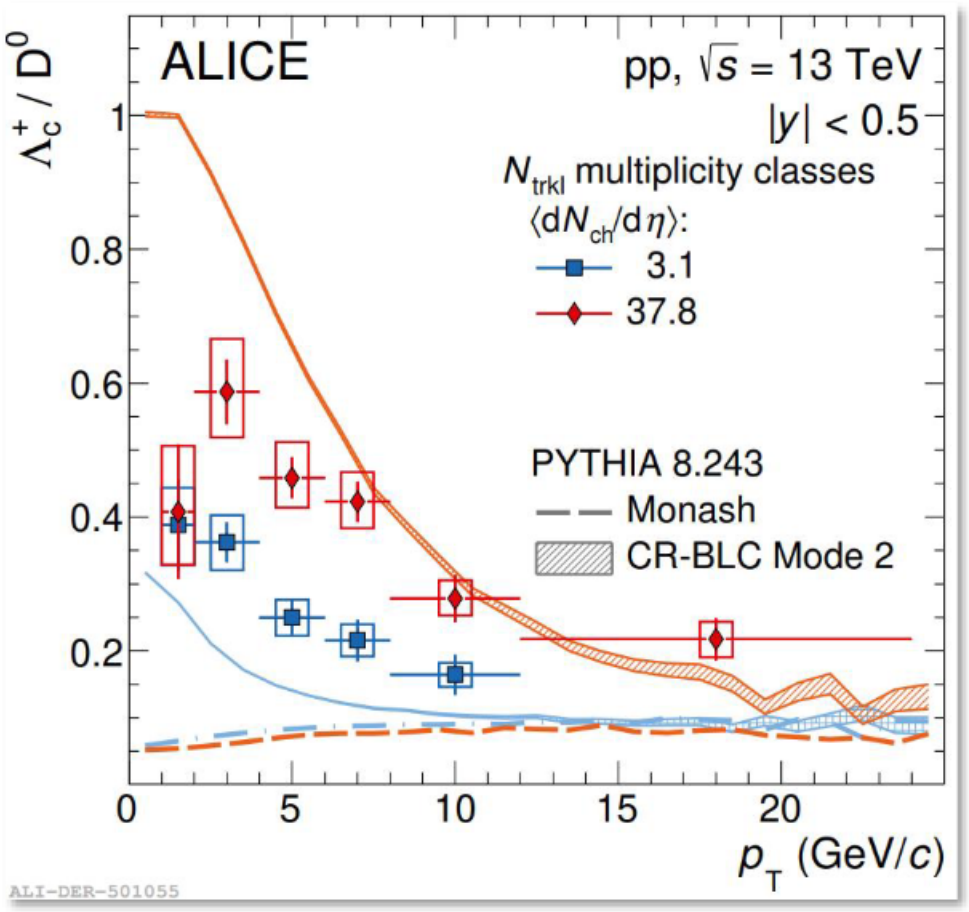
- Exciting opportunities at HL-LHC with CMS Phase II

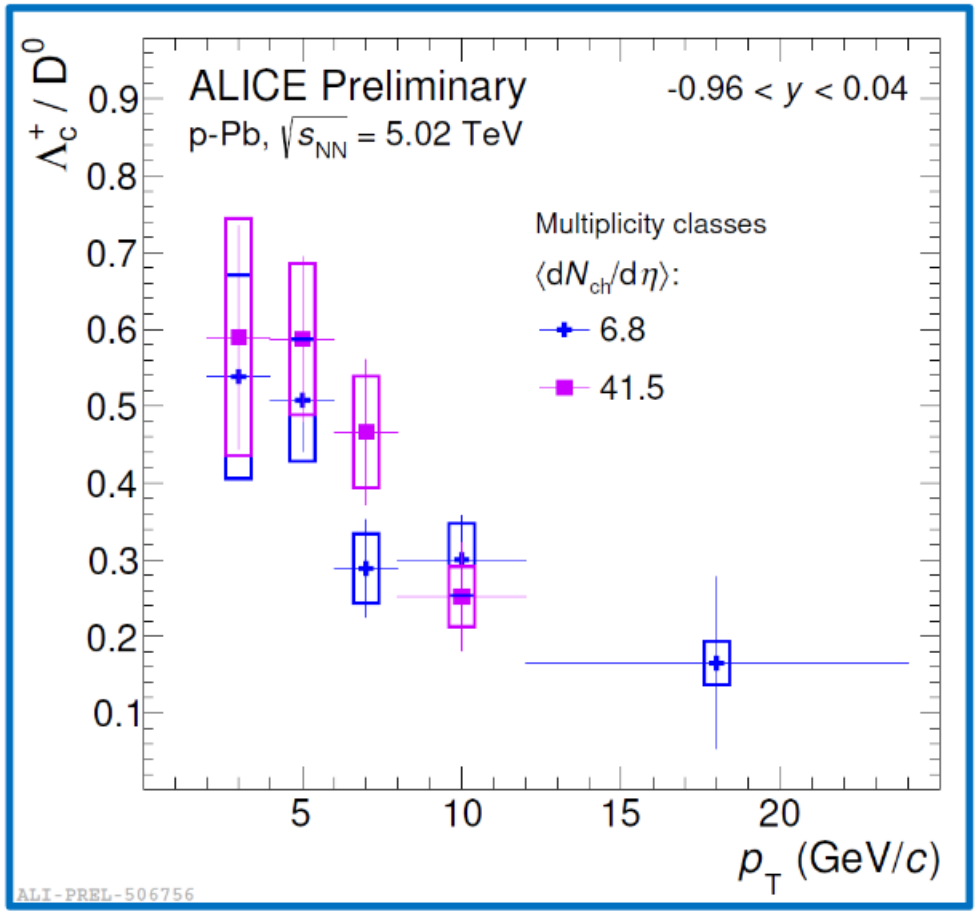


# Backup

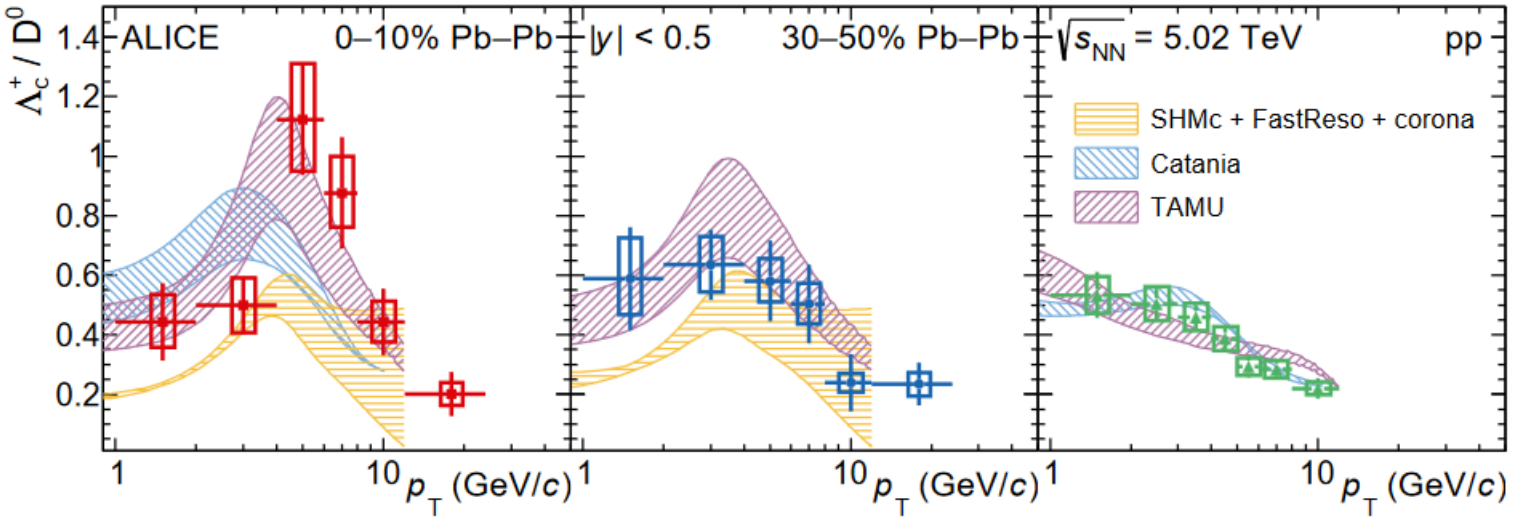
# Studies comparisons between pp and pPb

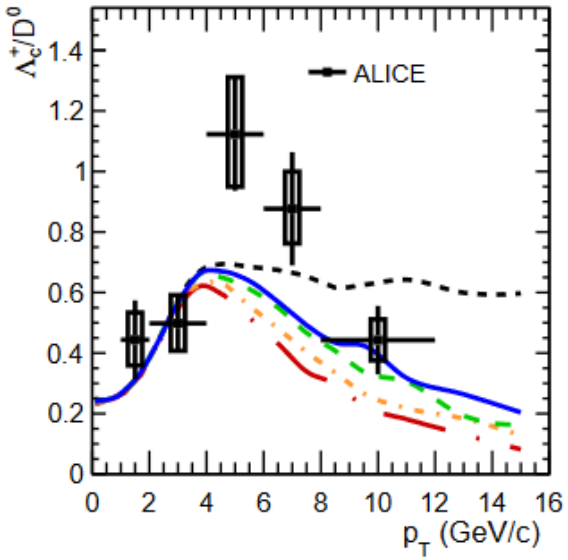


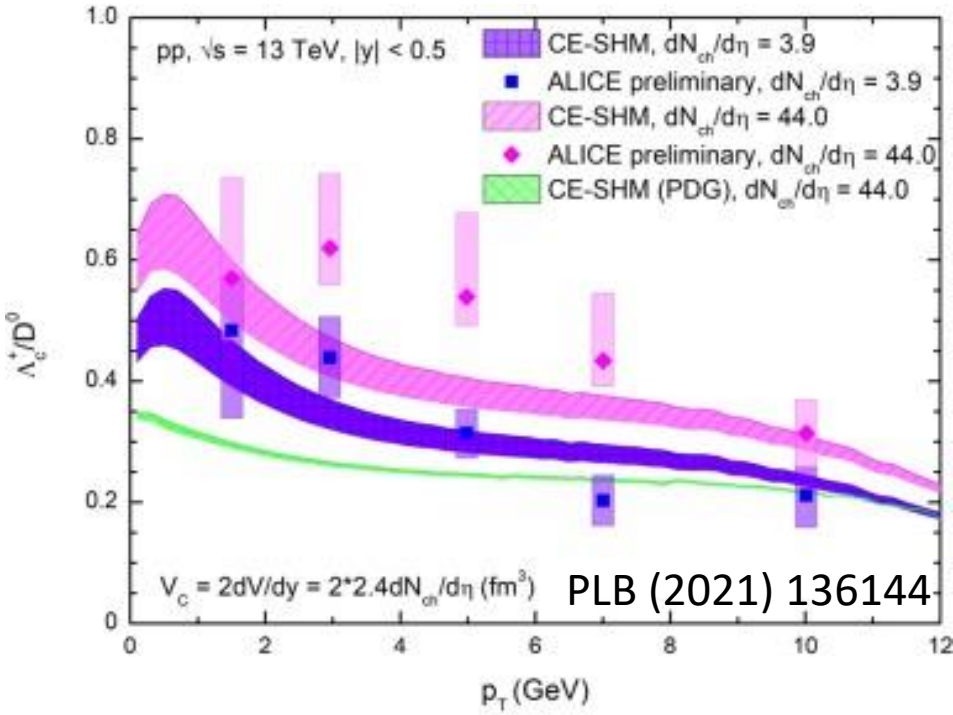
# Studies comparisons between pp and pPb

PLB 839 (2023) 137796




Eur.Phys.J.C 82 (2022) 7, 607

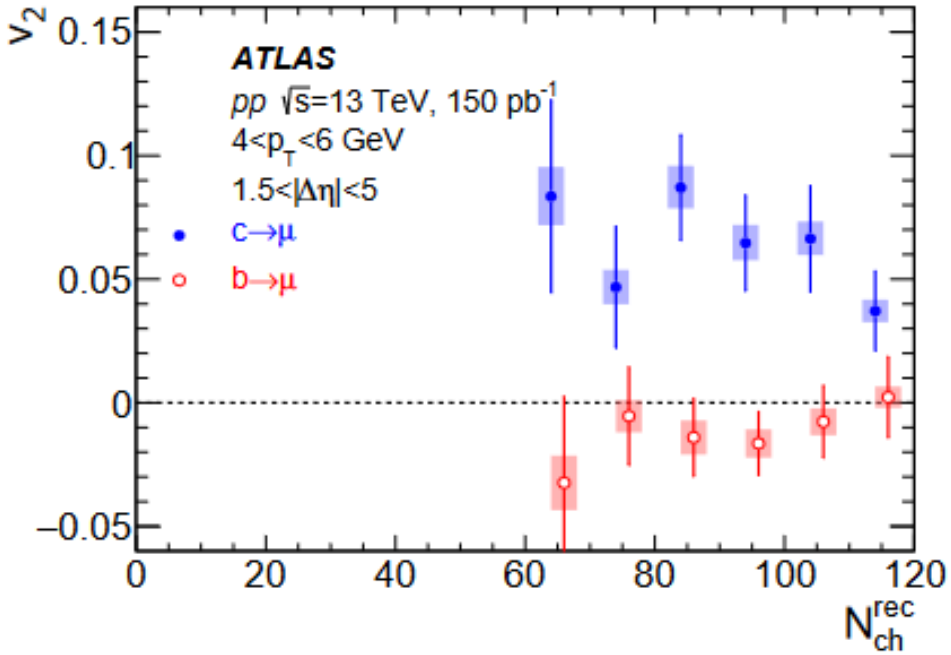


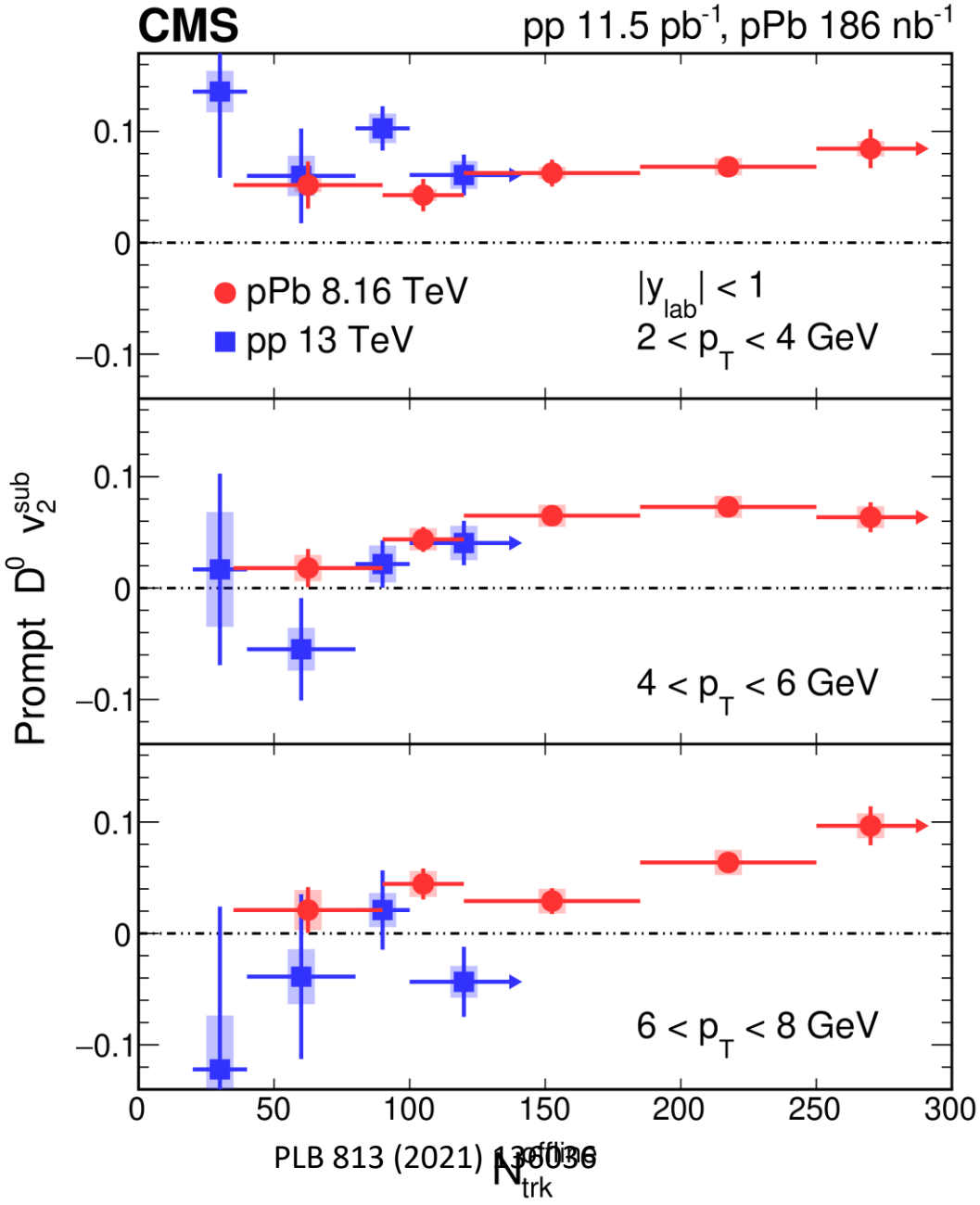

PLB (2021) 136144

# Heavy flavor collectivity

- In pp and pPb

Phys. Rev. Lett. 124, 082301

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# Ntrk table

| Multiplicity interval ($N_{\mathrm{trk}}^{\mathrm{offline}}$) | $\langle N_{\mathrm{trk}}^{\mathrm{offline}} \rangle$ | $\langle N_{\mathrm{trk}}^{\mathrm{corrected}} \rangle$ |
|---|---|---|
| $[2, 35)$ | $16.35 \pm 0.02$ | $20.00 \pm 0.02$ |
| $[35, 60)$ | $46.31 \pm 0.02$ | $56.40 \pm 0.02$ |
| $[60, 90)$ | $72.99 \pm 0.02$ | $88.74 \pm 0.03$ |
| $[90, 120)$ | $102.3 \pm 0.03$ | $124.4 \pm 0.04$ |
| $[120, 185)$ | $140.1 \pm 0.09$ | $169.9 \pm 0.11$ |
| $[185, 250)$ | $202.1 \pm 0.33$ | $244.9 \pm 0.40$ |

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