ICHEP 2024 | PRAGUE

Study of beauty-quark production, hadronization and CNM effects via non-prompt charm-hadrons in pp and p–Pb collisions with ALICE

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July 19th, 2024

Heavy-flavor hadron production

- Given the large mass of heavy-quarks, they are produced in hard-scattering process in hadronic collisions **c** $m_c \sim 1.3$ GeV/c **b** $m_b \sim 4.2$ GeV/c
  - can be calculated with perturbative QCD
- Heavy-flavor hadron production cross section is typically calculated in a factorization approach
  - Key assumption: fragmentation functions are universal across collision systems

$$\frac{d\sigma^{\mathrm{pp}\to H_q}}{dp_{\mathrm{T}}} = f_i(x_1,\mu_f^2) f_j(x_2,\mu_f^2) \otimes \frac{d\sigma^{ij\to q}}{dp_{\mathrm{T}}}(x_1,x_2,\mu_f^2) \otimes D_{q\to H_q}(z_q = \frac{p_{H_q}}{p_q},\mu_f^2)$$

parton distribution functions (PDFs) | hard scattering cross section (pQCD) | fragmentation function (hadronization)

➡ Ratios of particle species - a sensitive probe to heavy-quark hadronization

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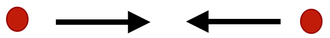
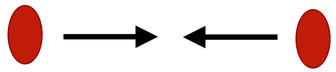
e^+e^-



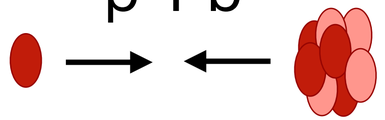
- "Point-like" interaction
- Pure fragmentation "vacuum"

pp



- Superposition of many "point-like" interactions
- Modified hadronization by MPI and CR?

p–Pb



- Cold nuclear matter effects
- Modified PDF in bound nuclei and hadronization?

ALICE experiment in Run 2

Non-prompt charm-hadron measurements performed in the central barrel ($|\eta| < 0.9$), using:

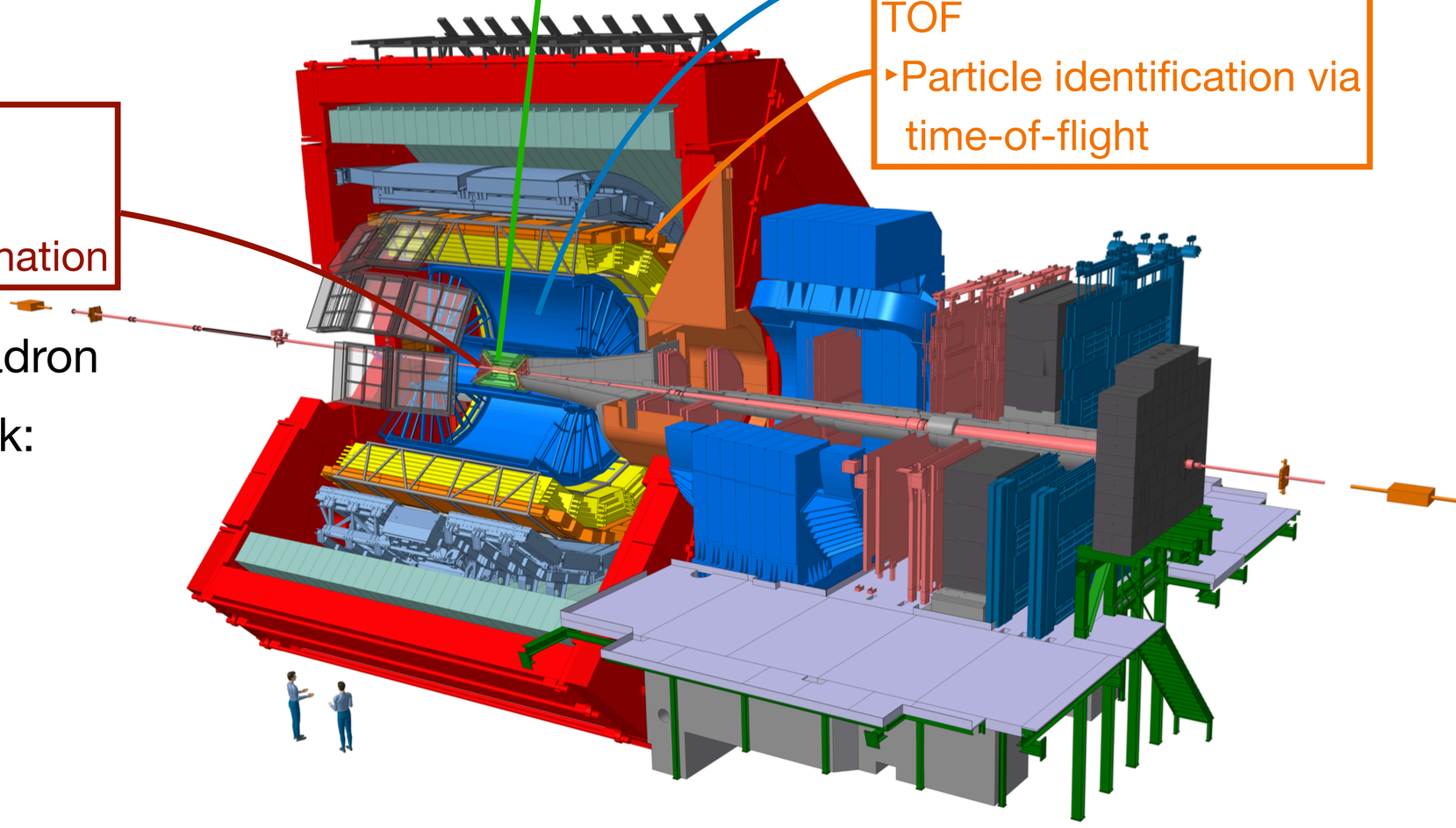
- Inner Tracking System
- Time Projection Chamber
- Time-of-Flight detector
- V0 detectors

ITS
- Track reconstruction
- Primary and decay vertex reconstruction

TPC
- Charged track reconstruction
- Particle identification via energy loss

TOF
- Particle identification via time-of-flight

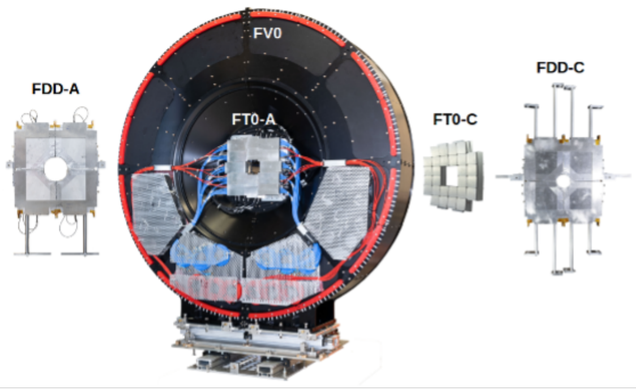
V0
- Trigger
- Centrality determination



Reconstructed non-prompt charm-hadron from beauty-hadron decays in this talk:

$$D^0(c\bar{u}) \rightarrow K^-\pi^+$$
$$D^+(c\bar{d}) \rightarrow K^-\pi^+\pi^+$$
$$D_s^+(c\bar{u}) \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$$
$$\Lambda_c^+(udc) \rightarrow pK_S^0$$
$$\Lambda_c^+(udc) \rightarrow pK^-\pi^+$$

ALICE experiment in Run 3



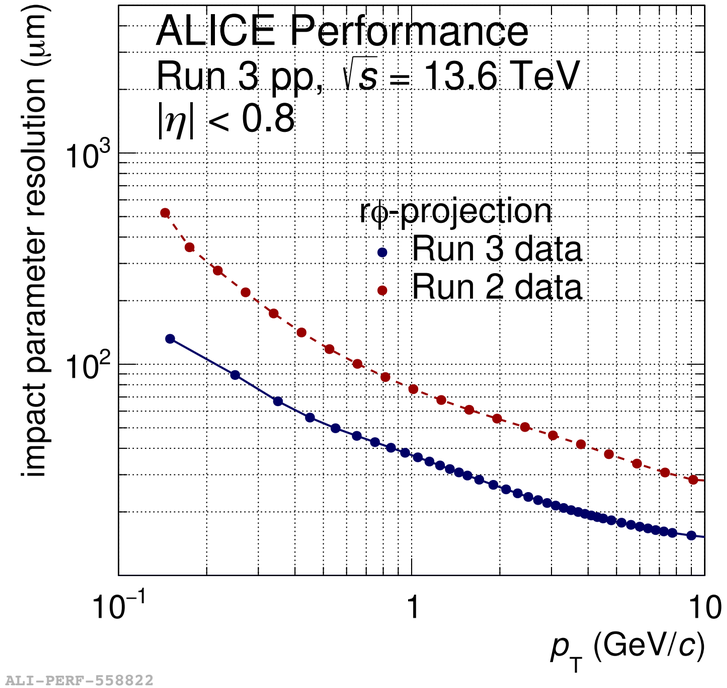
New: Fast Interaction Trigger (FIT)
Interaction trigger, luminosity and multiplicity

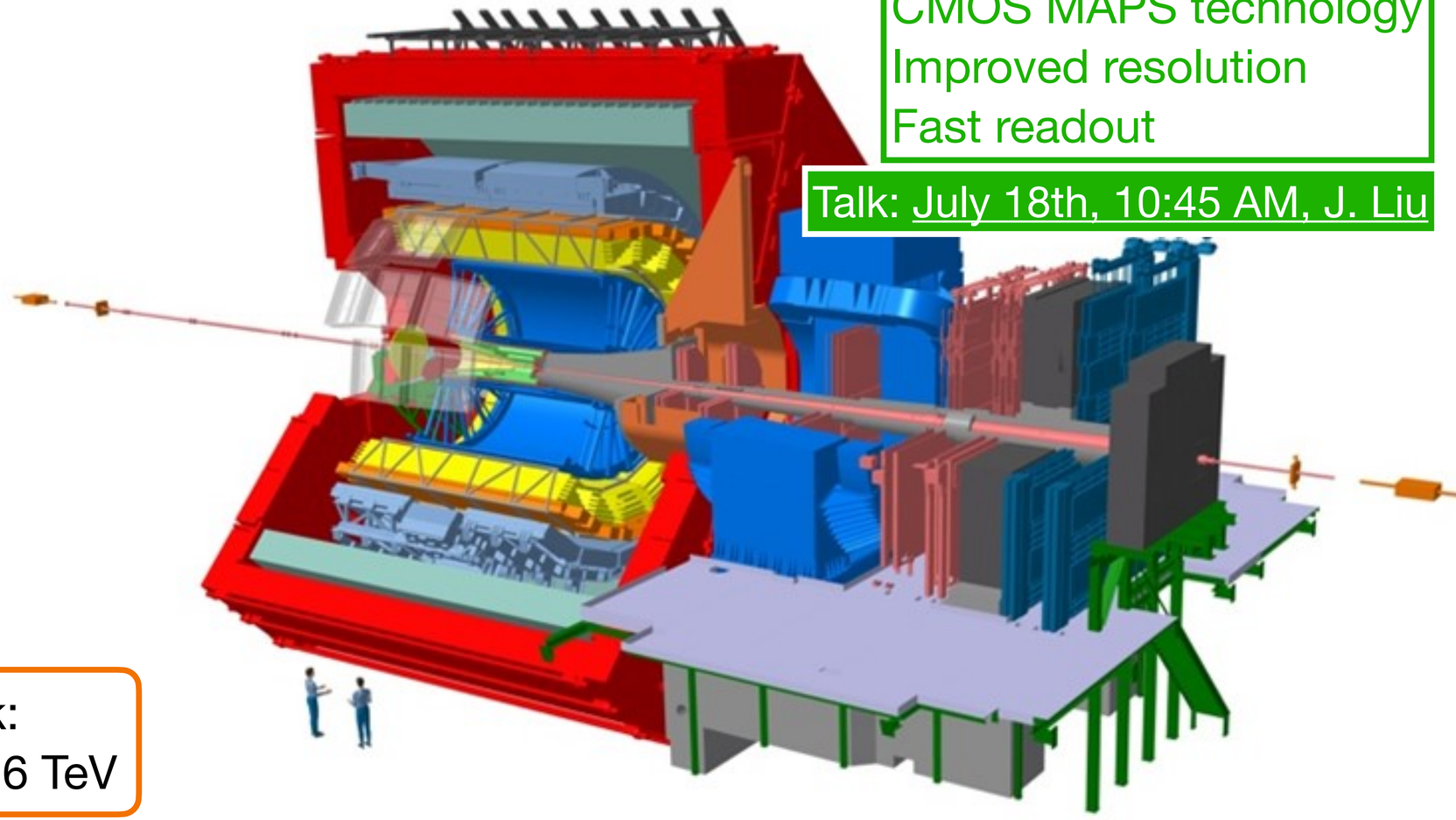
Talk: July 19th, 08:48 AM, Y. Melikyan

New TPC readout
Gas Electron Multiplier
Continuous readout

New: ITS2
CMOS MAPS technology
Improved resolution
Fast readout

Talk: July 18th, 10:45 AM, J. Liu





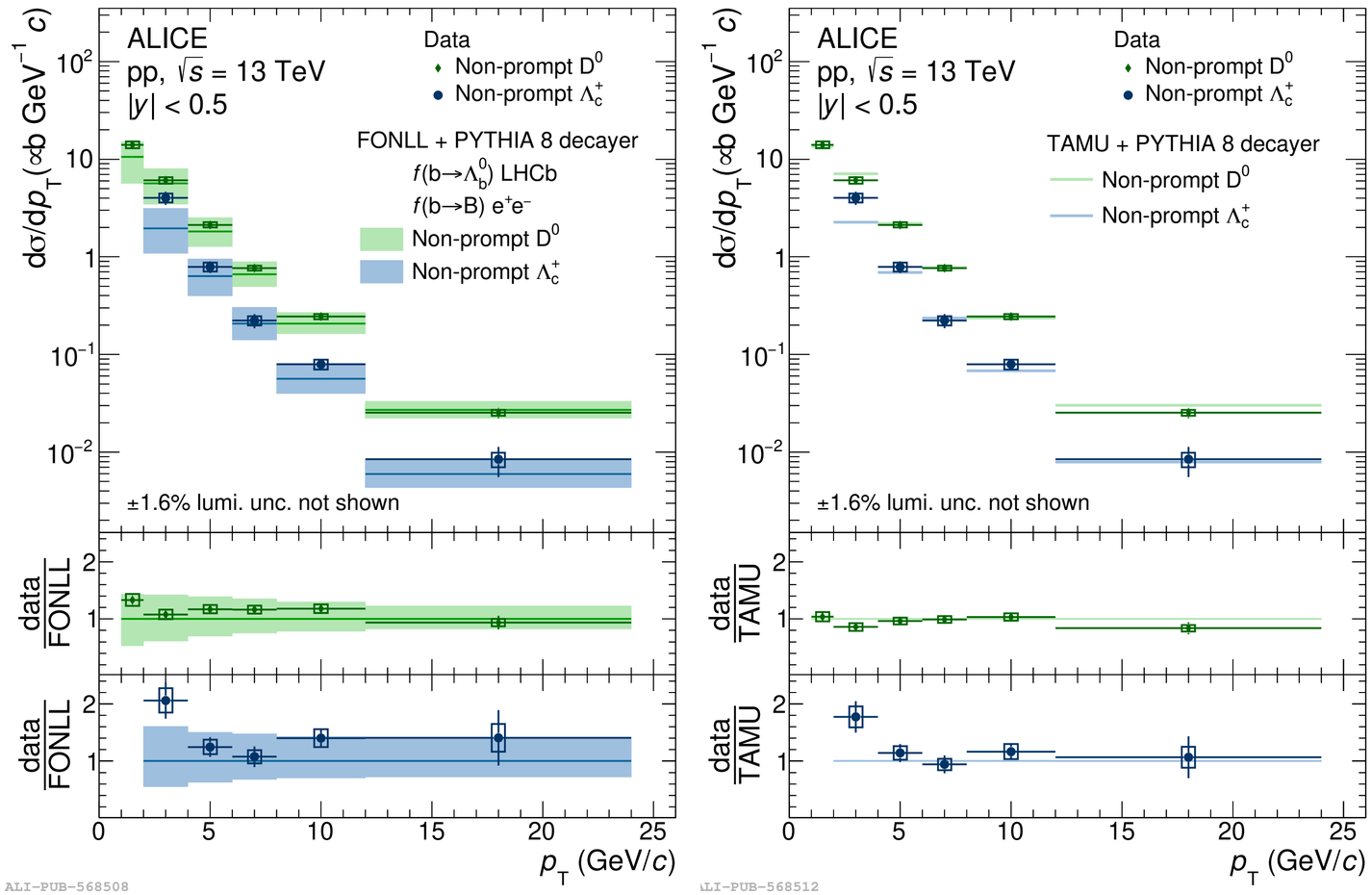
Run 3 measurement in this talk:
Non-prompt D^0 fraction in pp at 13.6 TeV

Non-prompt charm-hadron cross section in pp

PRD 108 (2023) 112003

♦ Non-prompt D^0

● Non-prompt Λ_c^+

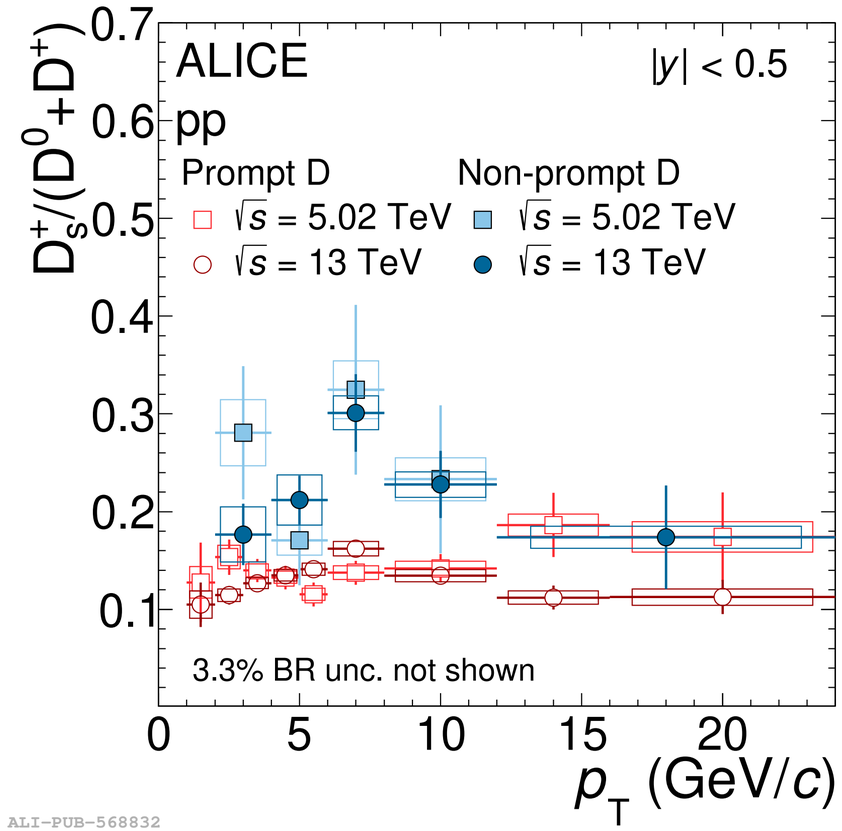


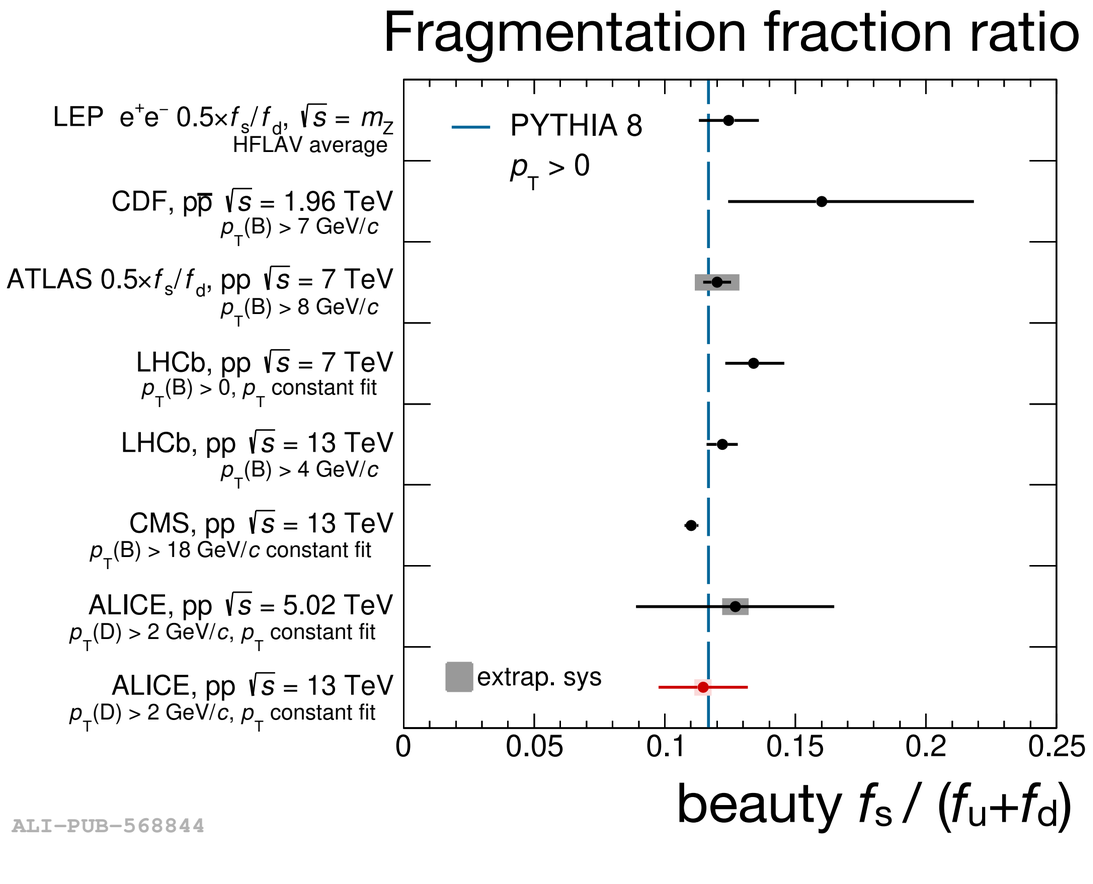
- **Precise** measurements of **non-prompt charm hadron cross sections**
- **FONLL (FF from e^+e^-)** and **TAMU (statistical hadronization approach) describe well** the **non-prompt D meson** cross section
- The production of **non-prompt Λ_c^+** shows a hint of **underestimation at low p_T** by both **FONLL (with $b \to \Lambda_b^0$ tuned on LHCb data)** and **TAMU**

PRD 100 (2019) 031102(R)

Non-prompt D meson production-yield ratios in pp

arxiv: 2402.16417v1

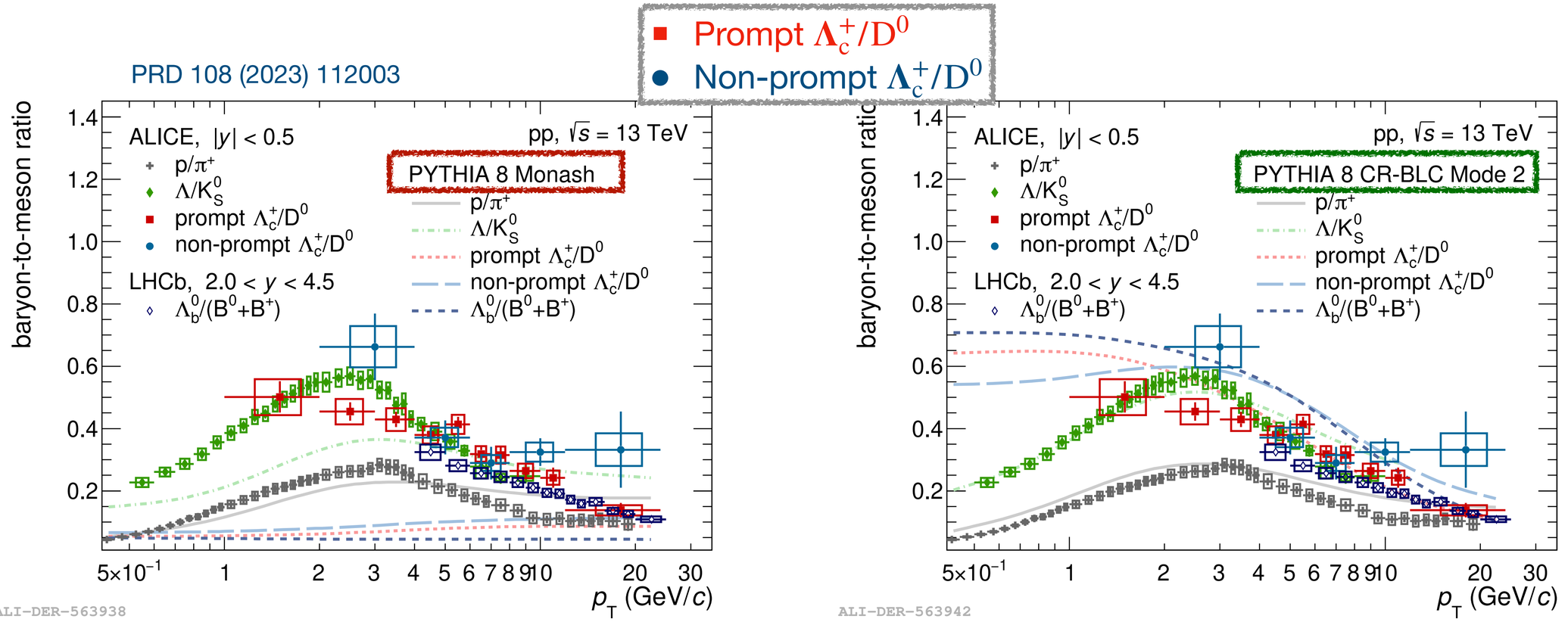




- **No significant p_{T} and $\sqrt{s}$ dependence** for prompt and non-prompt $\mathrm{D_s^+}/(\mathrm{D^0}+\mathrm{D^+})$ ratio
- **Ratio of fragmentation fraction of b to strange / b to non-strange hadrons consistent** with results from other **LHC measurements** and **e⁺e⁻ measurements** at lower energy

Baryon-to-meson ratio - beauty vs. charm (light flavor)

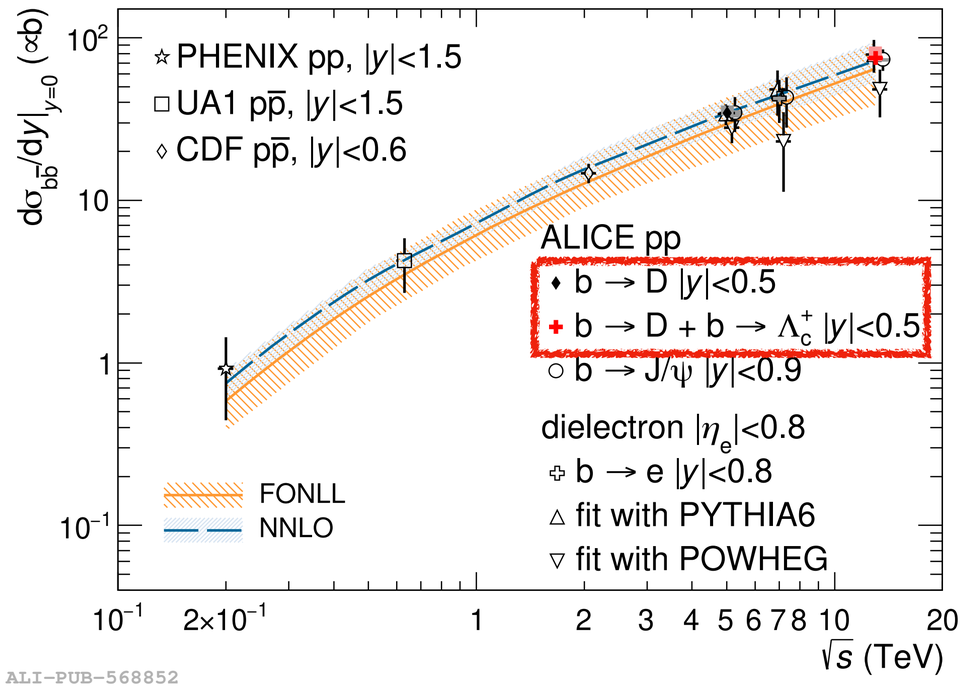
PRD 108 (2023) 112003



- Models using **fragmentation functions based on e^+e^-** significantly **underestimate** the heavy-flavor baryon-to-meson ratios
- Similar p_T trend for charm, beauty, and strange-hadrons, compatible within uncertainties
  - qualitatively similar p_T trend also observed in p/π^+
- **PYTHIA 8 with CR-BLC tune** shows a good **agreement** for **charm and strange** hadrons, **slightly worse** for **beauty**

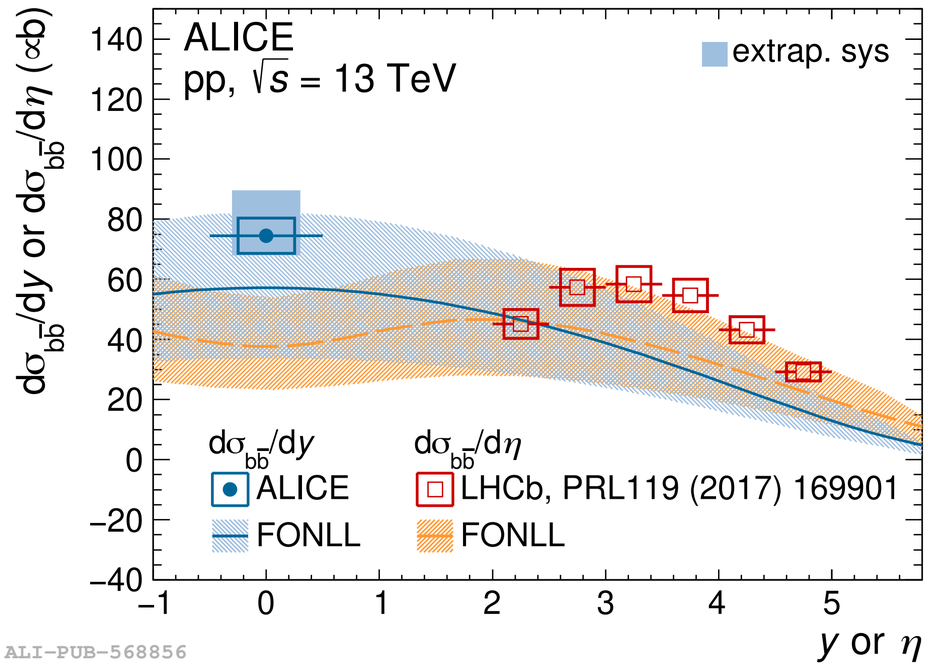
Total $b\bar{b}$ cross section

$b\bar{b}$ cross section vs. $\sqrt{s}$



ALI-PUB-568852

$b\bar{b}$ cross section vs. y

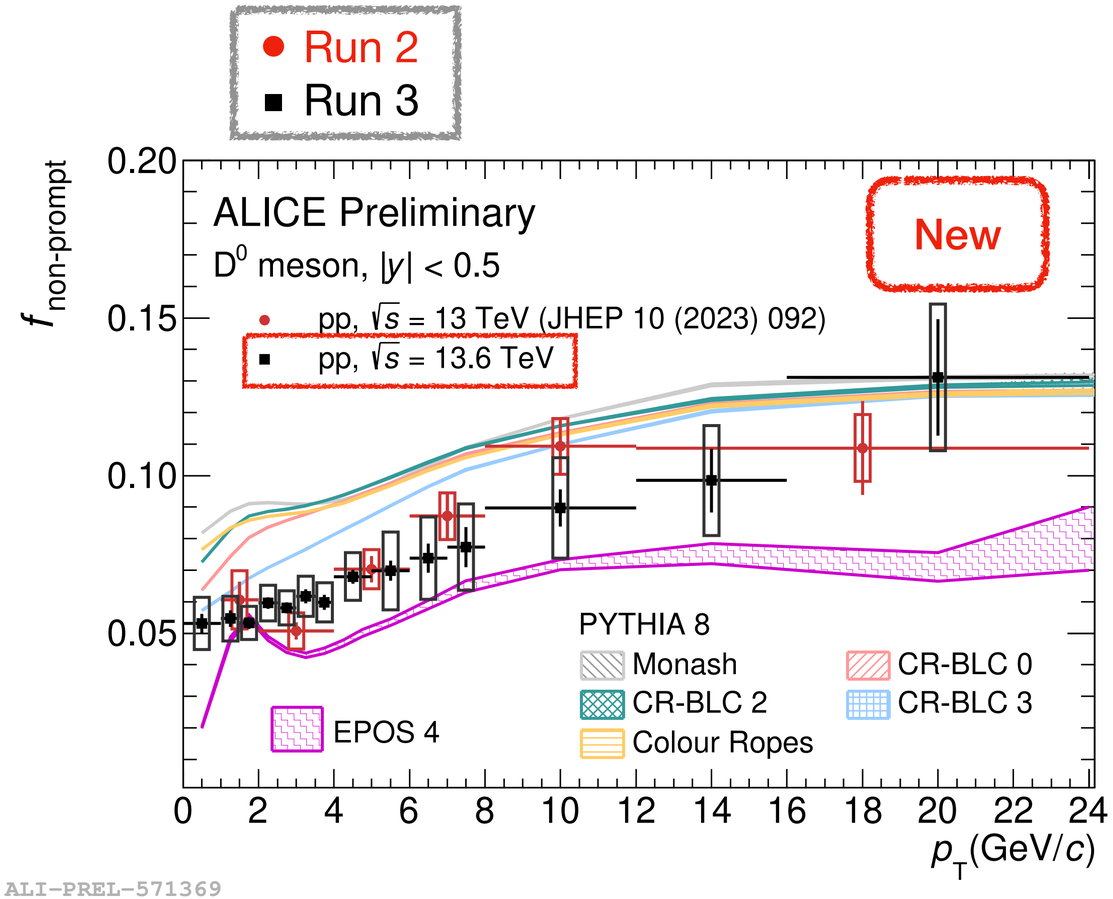


ALI-PUB-568856

arxiv: 2402.16417v1

- The $b\bar{b}$ production cross section at midrapidity is extrapolated from the measurements of non-prompt charm hadrons
- The $\sqrt{s}$- **and *y*-dependent** $b\bar{b}$ cross section generally lies close to the upper boundary of the theoretical uncertainty band

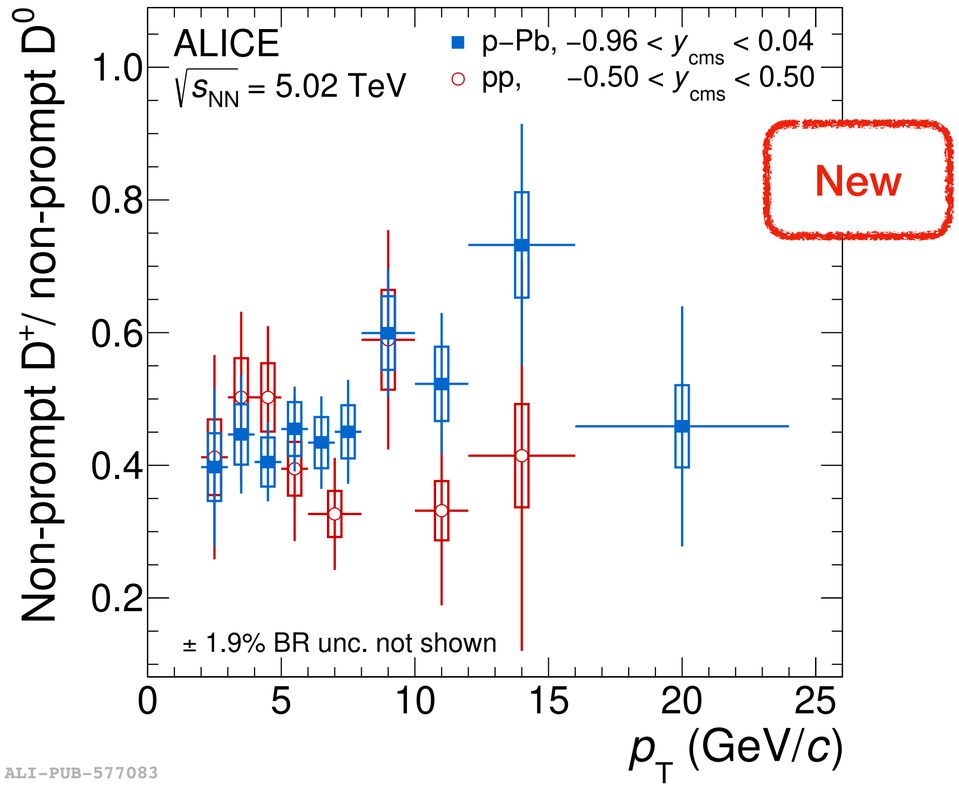
Non-prompt D^0 fraction in pp at 13.6 TeV in Run 3



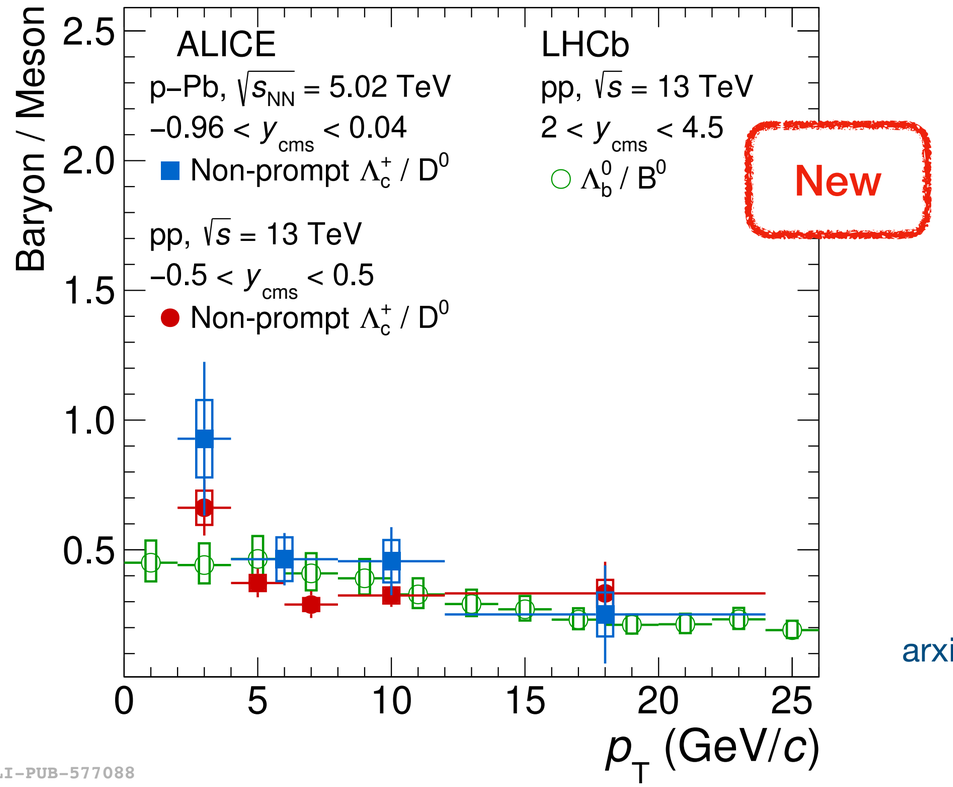
ALI-PREL-571369

- First non-prompt charm-hadron measurement in Run 3
- Measurement **down to p_{T} = 0**, increased granularity w.r.t Run 2 results at 13 TeV
- Constrain modeling of charm and beauty production and hadronization in event generators

Non-prompt charm-hadron production-yield ratios in p–Pb



New

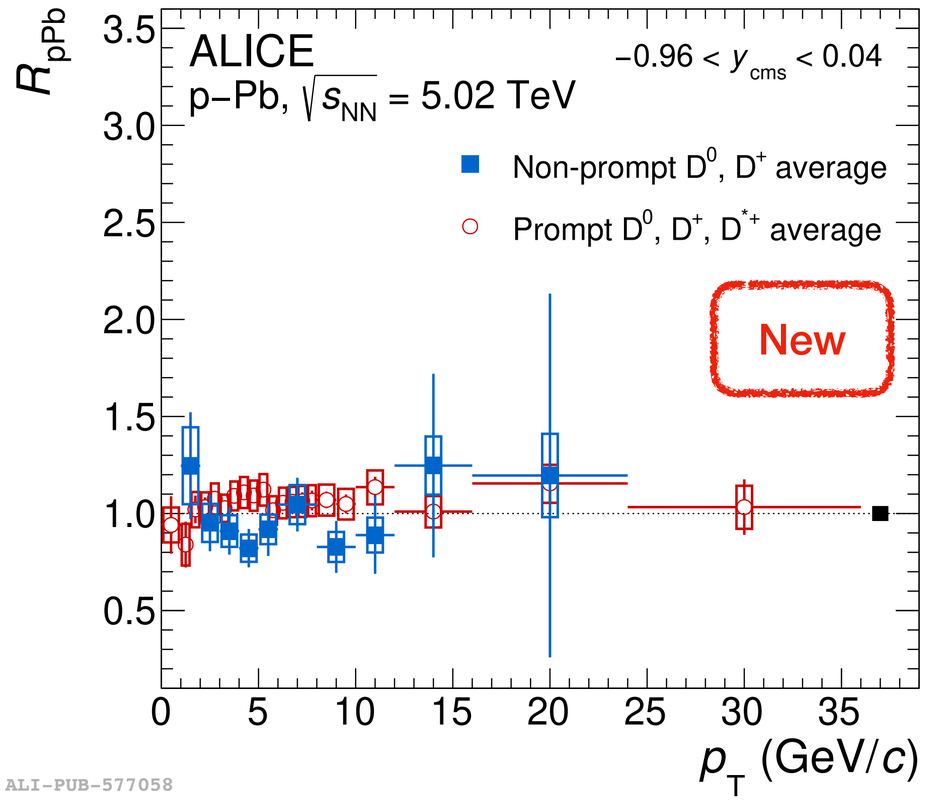


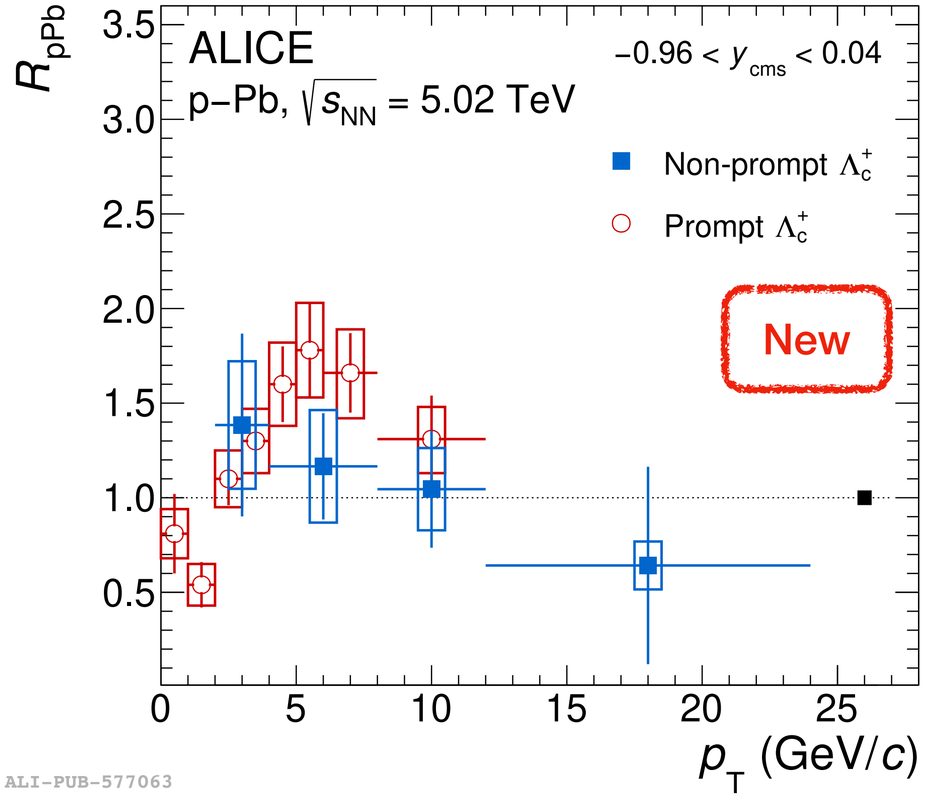
New

arxiv: 2407.10593

- The p_T-differential **non-prompt D^+/D^0** production yield ratios in **pp** and **p–Pb** are **compatible** within uncertainties
- The **non-prompt Λ_c^+/D^0 in p–Pb** hints at a **higher ratio than pp**
  - suggesting a hardening of the beauty-baryon spectra? - lower p_T to be covered to conclude
  - coalescence + radial flow scenario?

Nuclear modification factor - R_{pPb}

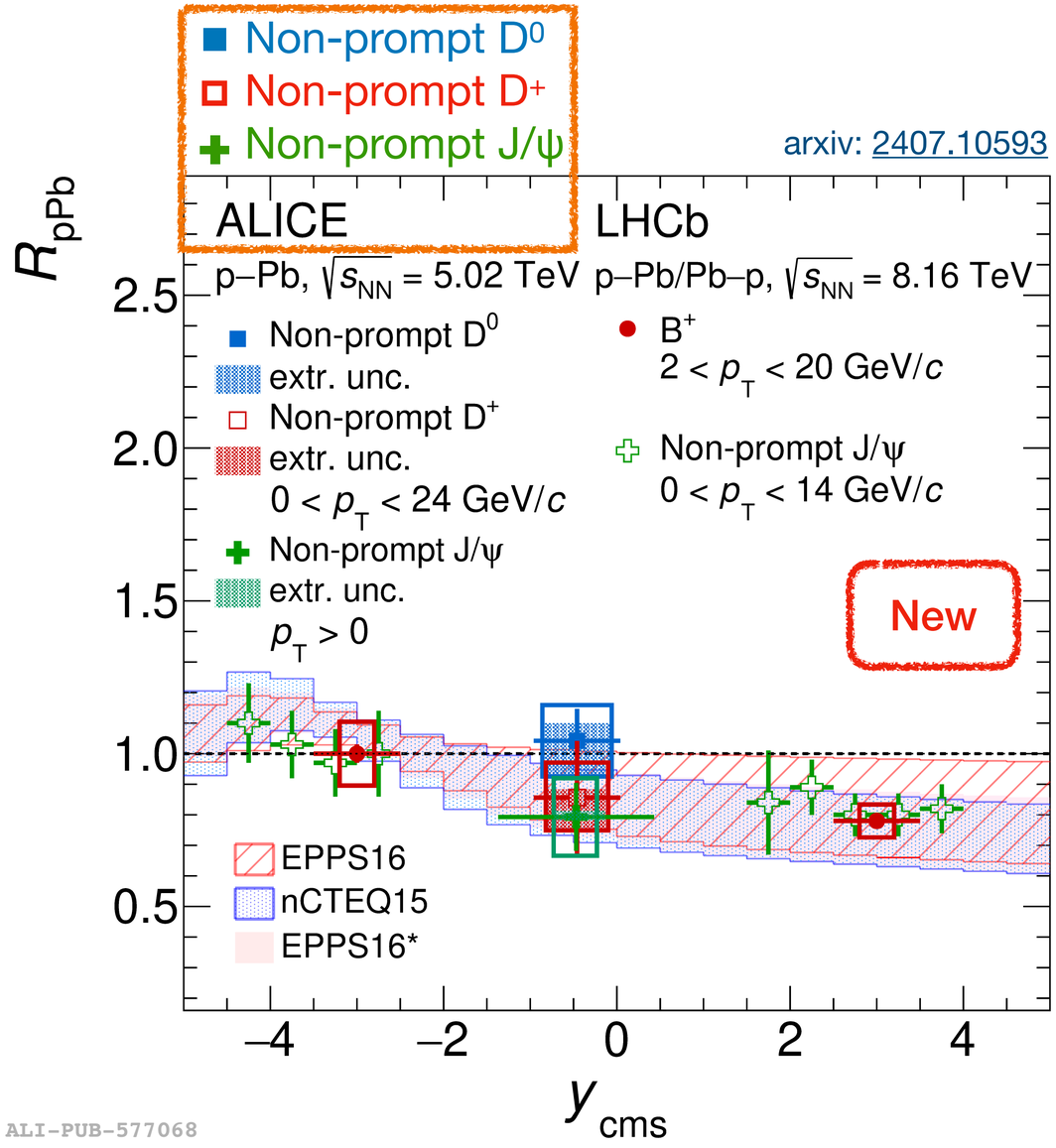




arxiv: 2407.10593

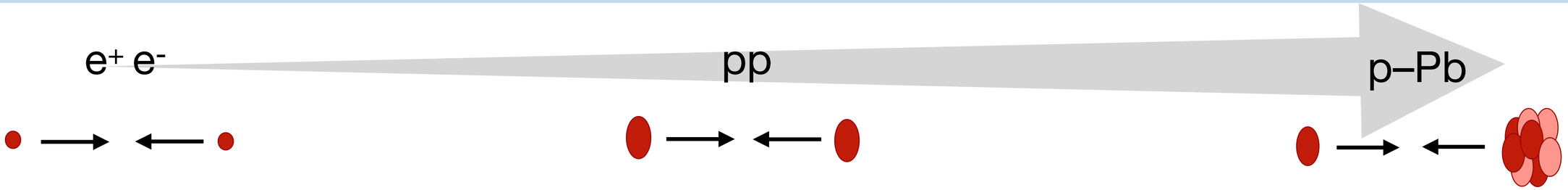
- Nuclear modification factor: $R_{\mathrm{pPb}} = \frac{1}{A_{\mathrm{Pb}}} \frac{\mathrm{d}^2\sigma_{\mathrm{pPb}}/(\mathrm{d}y\mathrm{d}p_{\mathrm{T}})}{\mathrm{d}^2\sigma_{\mathrm{pp}}/(\mathrm{d}y\mathrm{d}p_{\mathrm{T}})}$
- The p_{T}-differential **D meson** $R_{\mathrm{pPb}}^{\mathrm{prompt}}$ **and** $R_{\mathrm{pPb}}^{\mathrm{non-prompt}}$ are **compatible** with each other and with unity within experimental uncertainties
- Due to the large uncertainties, no conclusion about possible p_{T} trend of non-prompt $R_{\mathrm{pPb}}^{\Lambda_c^+}$

Nuclear modification factor - R_{pPb}



- The p_{T} integrated R_{pPb} of non-prompt D, J/ψ are compared with LHCb measurements of B^{+} and non-prompt J/ψ
- **No significant cold-nuclear matter effects on beauty at midrapidity**
- Rapidity trend of non-prompt D, J/ψ, B^{+} can be described by models with modified nPDFs

Summary



- Universal fragmentation fractions assumption violated for heavy quarks
- Multiple parton interactions in pp
  - system dense enough to modify hadronization w.r.t e^+e^-
- Similar hadronization mechanism of beauty in both pp and p–Pb collisions
- Mild CNM effects, similar in beauty and charm sectors

- Upcoming heavy-flavor measurements with Run 3 data:
  - More precise measurements with extended p_{T} coverage
  - Much higher statistics and new observables
  - Better constraints to theoretical models for heavy-flavor production

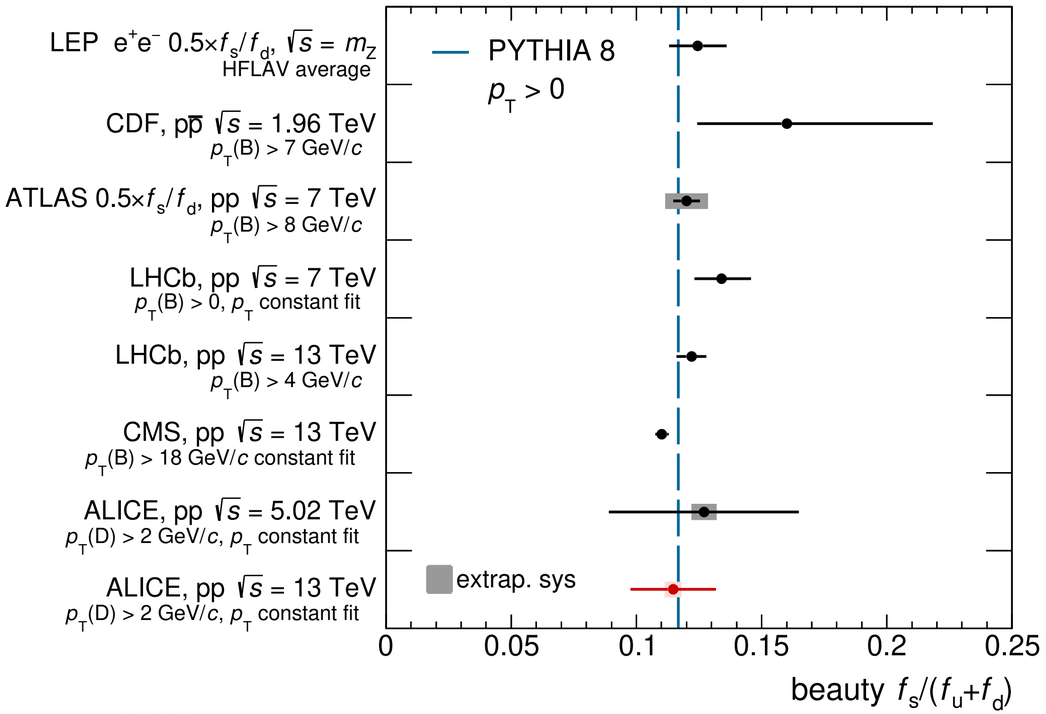
New charm measurements in Run 3:

July 19th 10:45 T. Cheng

Additional slides

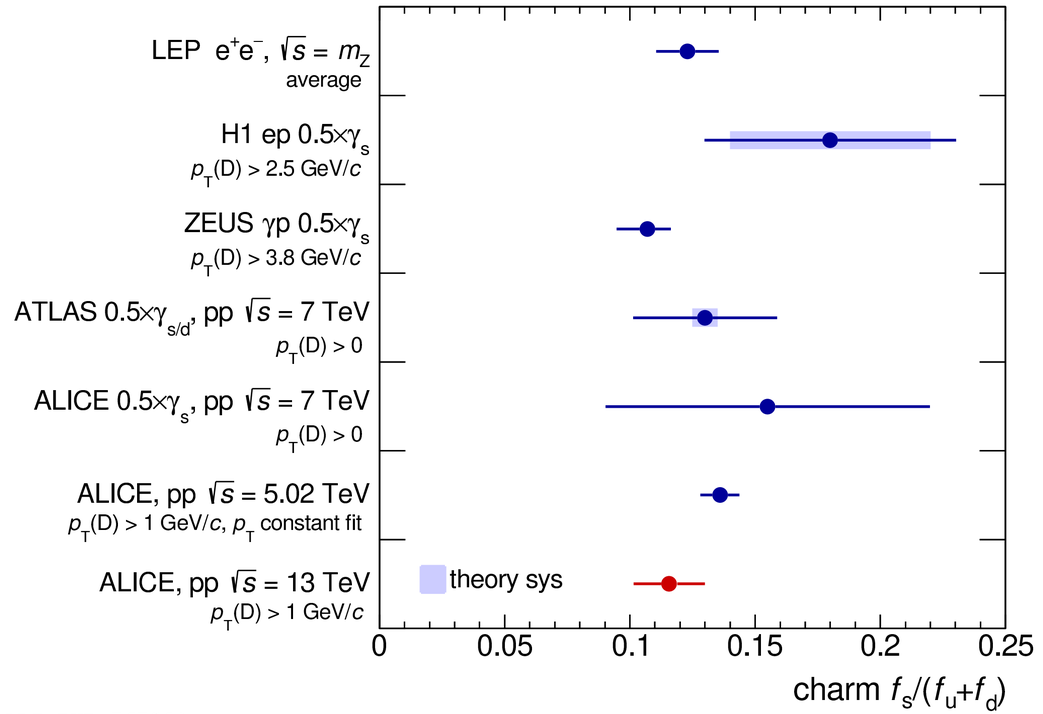
Beauty-quark fragmentation fraction

arxiv: 2402.16417v1



ALI-PUB-568844

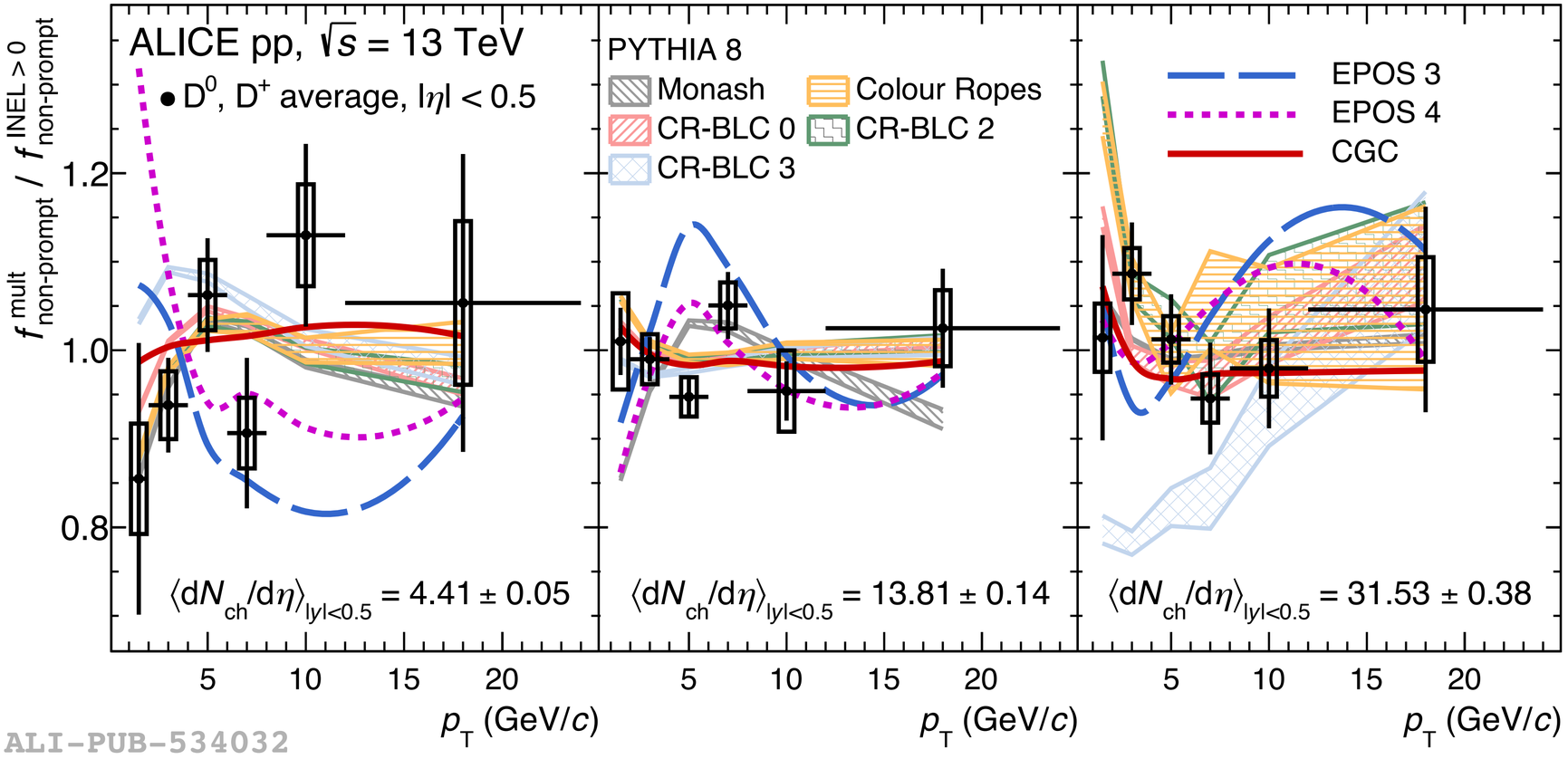
JHEP 12 (2023) 086



ALI-PUB-567901

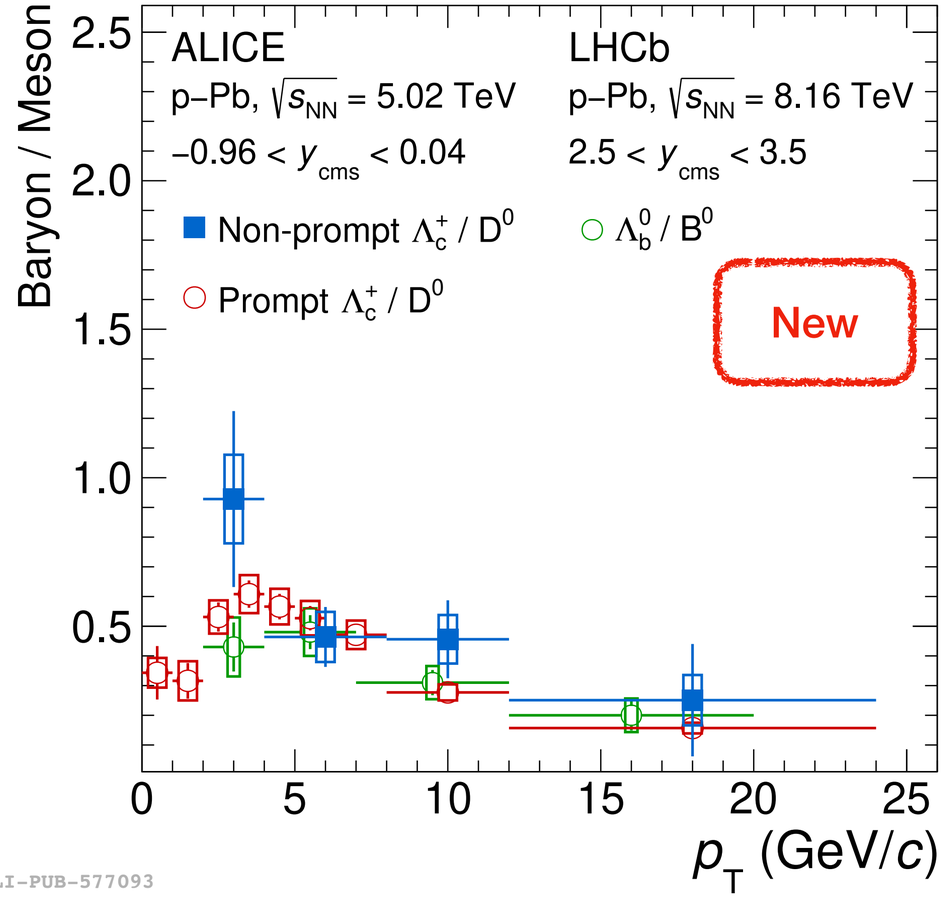
- The beauty quark fragmentation fraction is comparable to charm quarks

Non-prompt D meson fractions



- Average non-prompt D-meson fractions in multiplicity class / minimum-bias class (INEL > 0) is compatible with unity within uncertainties
  - suggesting similar production mechanisms of charm and beauty quarks as a function of multiplicity

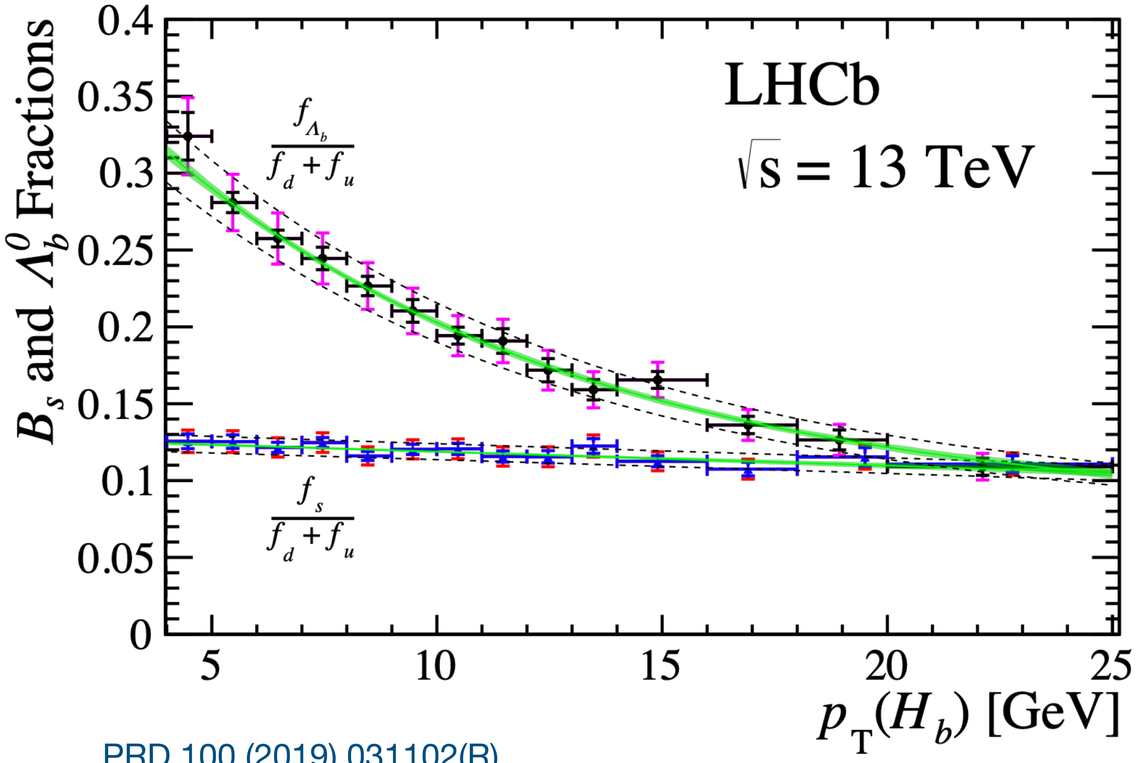
Non-prompt charm-hadron cross section ratio in p–Pb



ALI-PUB-577093

- The non-prompt Λ_c^+/D^0 is compatible with the prompt one and Λ_b^0/B^0 measurement from LHCb
- The hadronization modifications for beauty may mirror those for charm quarks

Fragmentation fraction from LHCb Collboration



PRD 100 (2019) 031102(R)

- Measurement from LHCb Collaboration at forward rapidity
- Large difference at low p_T region