Study of open heavy-flavour hadron production in pp and p-Pb collisions with ALICE

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Open heavy flavour in pp and p-Pb collisions

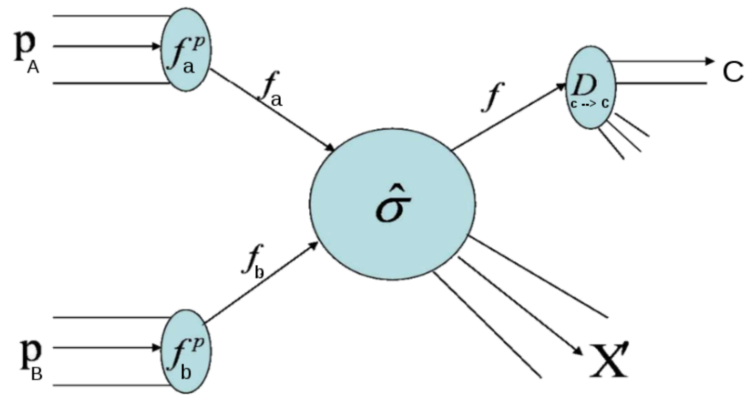
Heavy quarks (**charm and beauty**), have a large mass: $m_c \sim 1.3$ GeV/c^2 , $m_b \sim 4.2$ GeV/c^2.

➔ Produced via initial hard scatterings at the early stages of the collision.

➔ Production cross-section calculable perturbatively down to low p_T.

$$d\sigma^{hard}_{AB\to C} = \sum_{a,b} f_{a/A}(x_a, Q^2) \otimes f_{b/B}(x_b, Q^2) \otimes d\sigma^{hard}_{ab\to c}(x_a, x_b, q^2) \otimes D_{c\to C}(z, Q^2)$$

Parton Distribution Function (PDF) | **Partonic hard scattering cross-section** | **Fragmentation function**

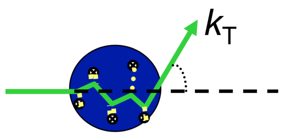


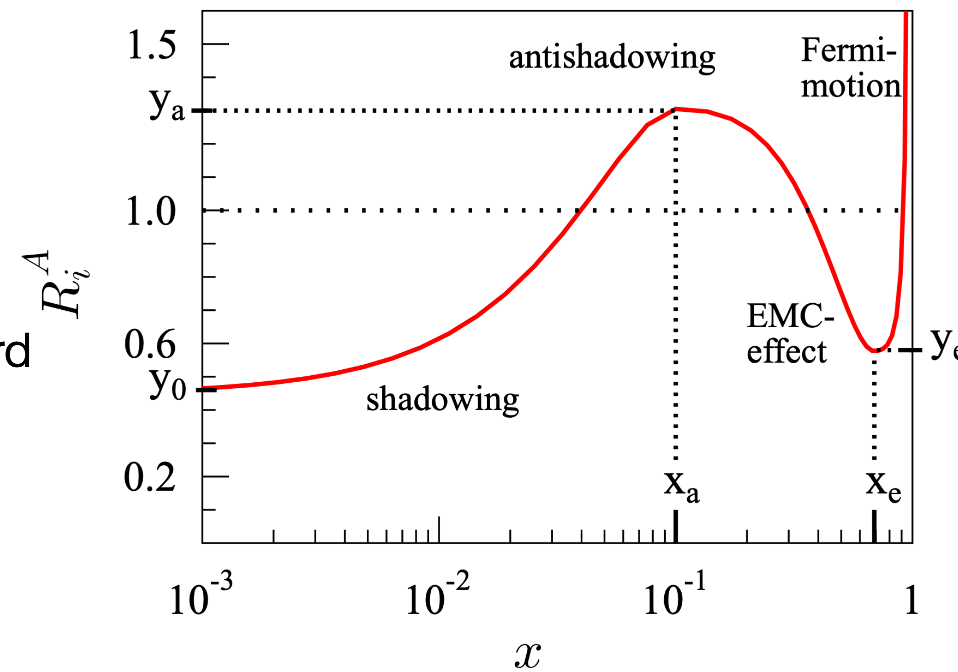
In pp collisions:

- Important test of perturbative QCD calculations
- Reference for nuclear effects in pA, AA collisions.

In p-Pb collisions:

- Studies provide access to **cold nuclear matter (CNM)** effects. HF yield can be modified by
  - **Nuclear modification of the PDFs**
  - **k_T broadening**: Multiple elastic scattering of the parton before the hard scattering. Modifies the p_T distribution.
  - **Energy loss in cold nuclear matter** (in the initial or final state)
- Address possible collective effects and effects related to the (possible) formation of a QGP in p-Pb collisions





JHEP 0904:065,2009

Open heavy flavour in pp and p-Pb collisions

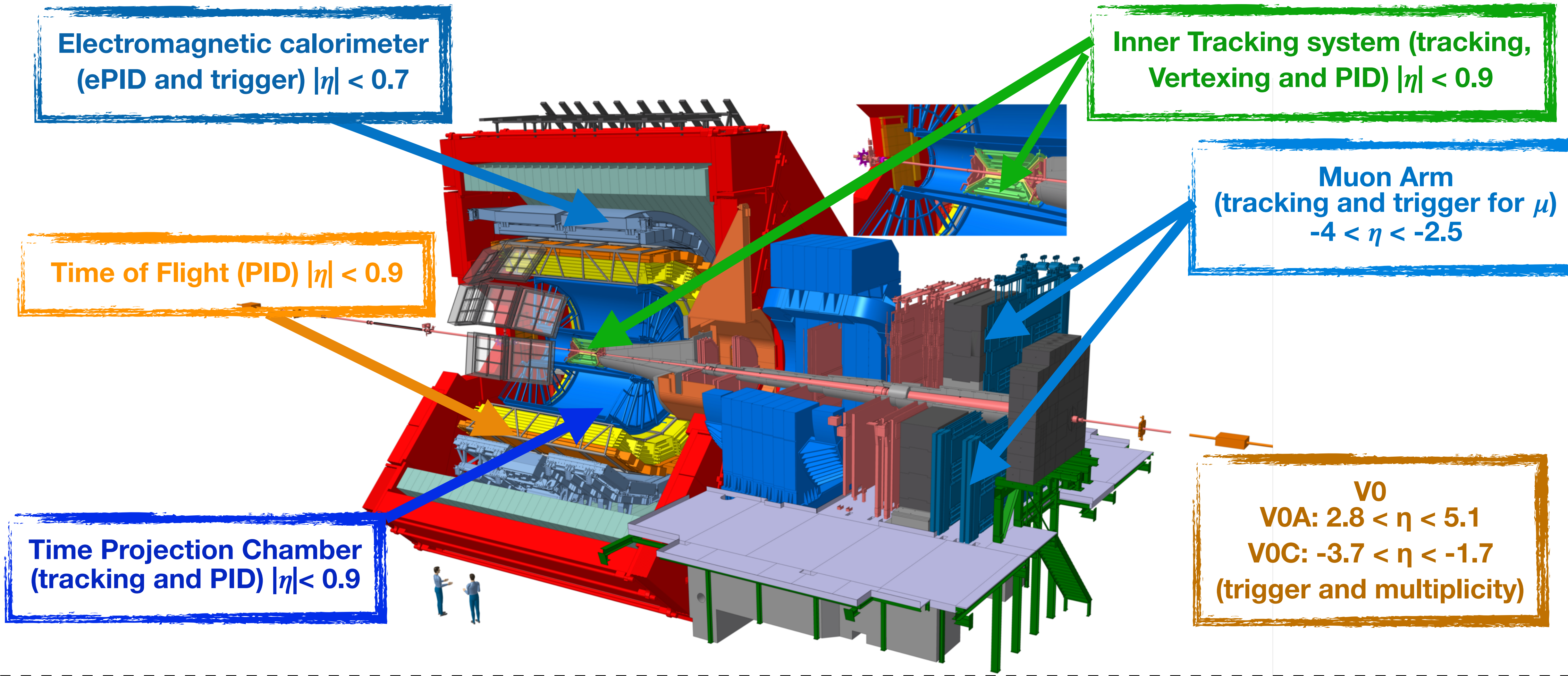
Particle production as a function of multiplicity → More differential measurement
Multiplicity is defined as the number of charged particles per event.

High multiplicity pp and p-Pb collisions have shown similar features reminiscent of those observed in Pb-Pb
Azimuthal correlations (ridge formation) and mass dependent hardening of p_T distributions.

High multiplicity pp collisions reach similar number of charged particles as in peripheral Pb-Pb collisions

- Investigate the possible influence of **multiple partonic interactions (MPI)** to the particle production.
- Study the interplay between soft and hard process.
- Understand the collective behaviour in small system.

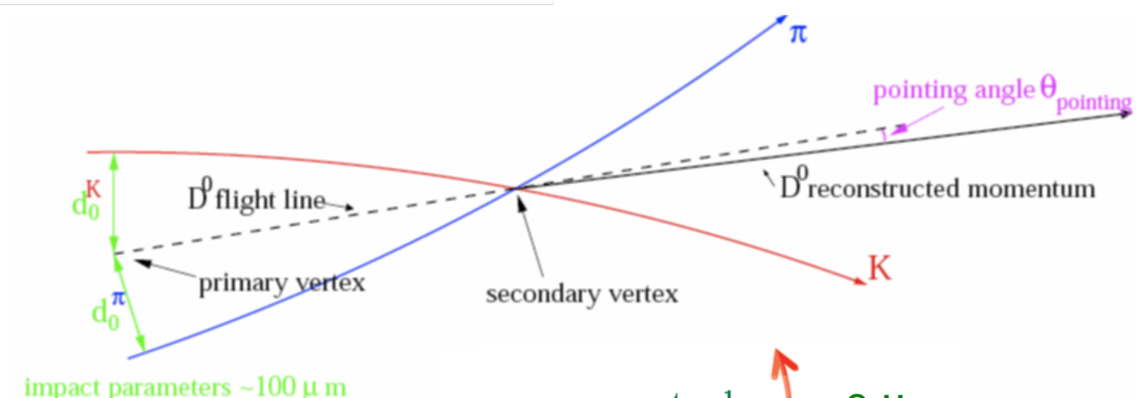
Open heavy-flavour reconstruction in ALICE



Fully reconstructed **D meson** and Λ_c hadronic decays:

ITS, TPC, TOF

$D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D^{*+} \to D^0\pi^+$,
$D_s^+ \to \Phi\,\pi^+ \to K^-K^+\pi^+$, $\Lambda_c^+ \to \pi^+K^-p$, $\Lambda_c^+ \to p\,K^0_s$

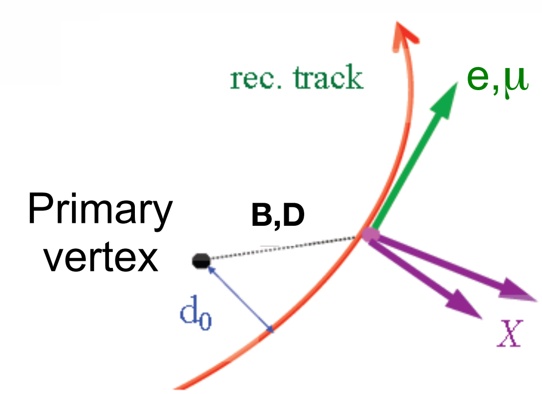


Partially reconstructed **semi-leptonic** decays:

Electrons: **ITS, TPC, TOF, EMCal.** D, B $\to e^{\pm} + X$

Muons: **Forward Muon Spectrometer.** D, B $\to \mu^{\pm} + X$

Λ_c and Ξ_c: **ITS, TPC, TOF.** $\Lambda_c^+ \to e^+\Lambda\nu_e$, $\Xi_c^0 \to e^+\Xi^-\nu_e$



Results in pp collisions

Heavy flavour production cross-sections in pp

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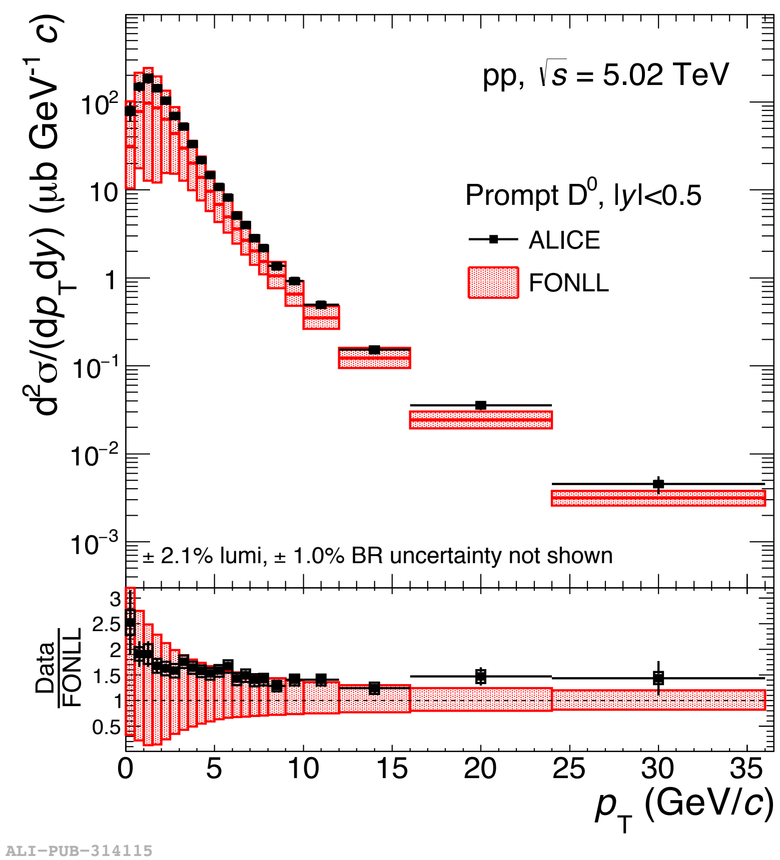
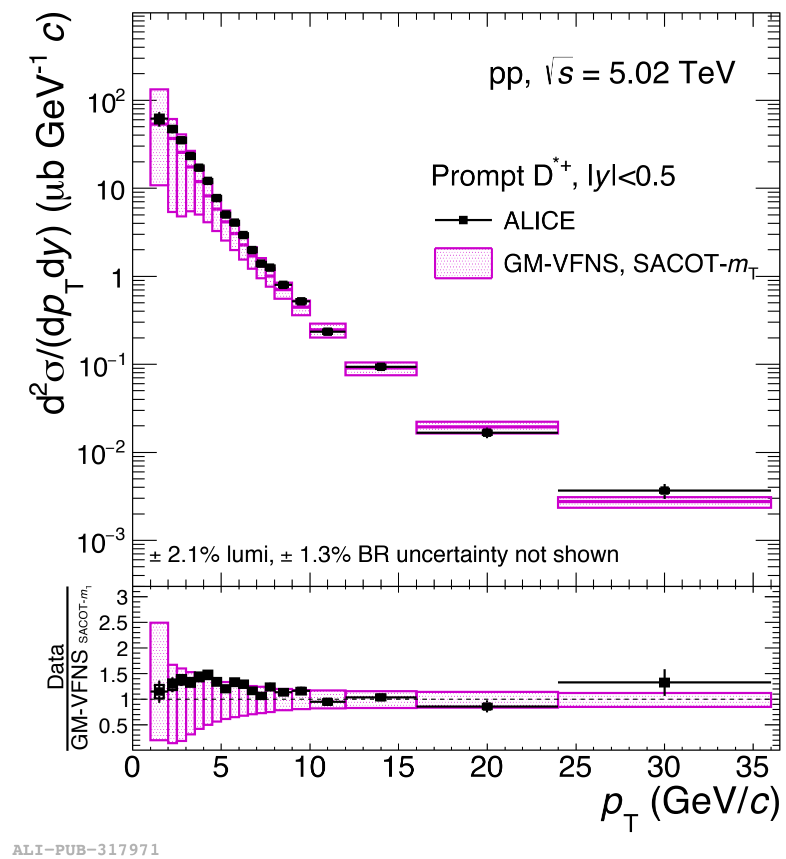
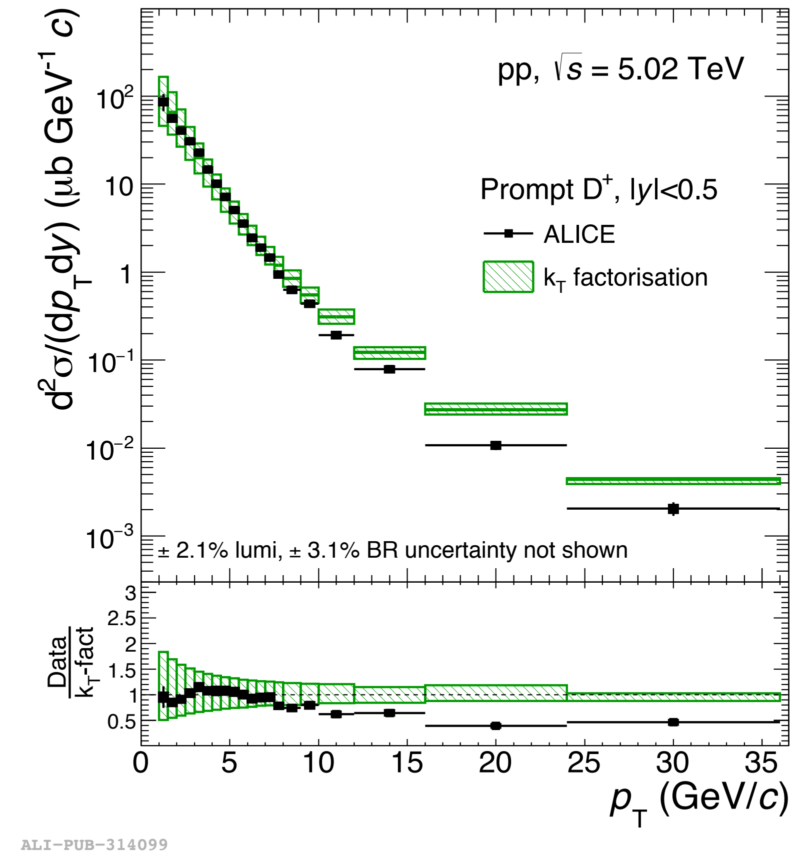






New

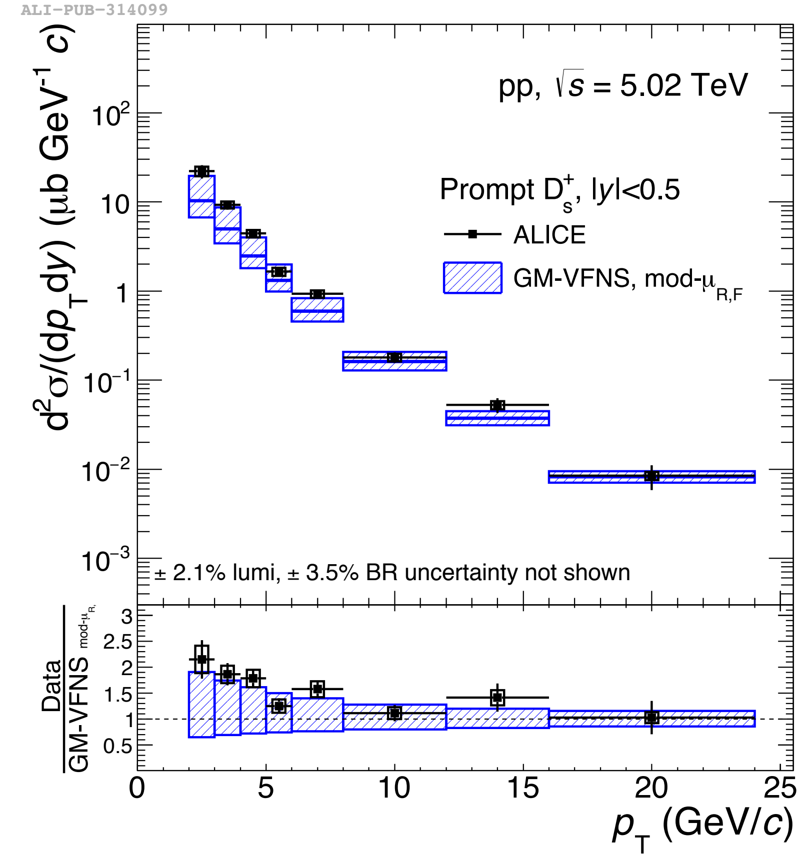
D meson (D^0, D^{*+}, D^+, D_s^+) production cross section in pp at $\sqrt{s}$ = 5 TeV at mid-rapidity.

- Precise pp reference measurement down to low p_T (~ 0 with D^0).

Comparison with models:

Data described well by pQCD model

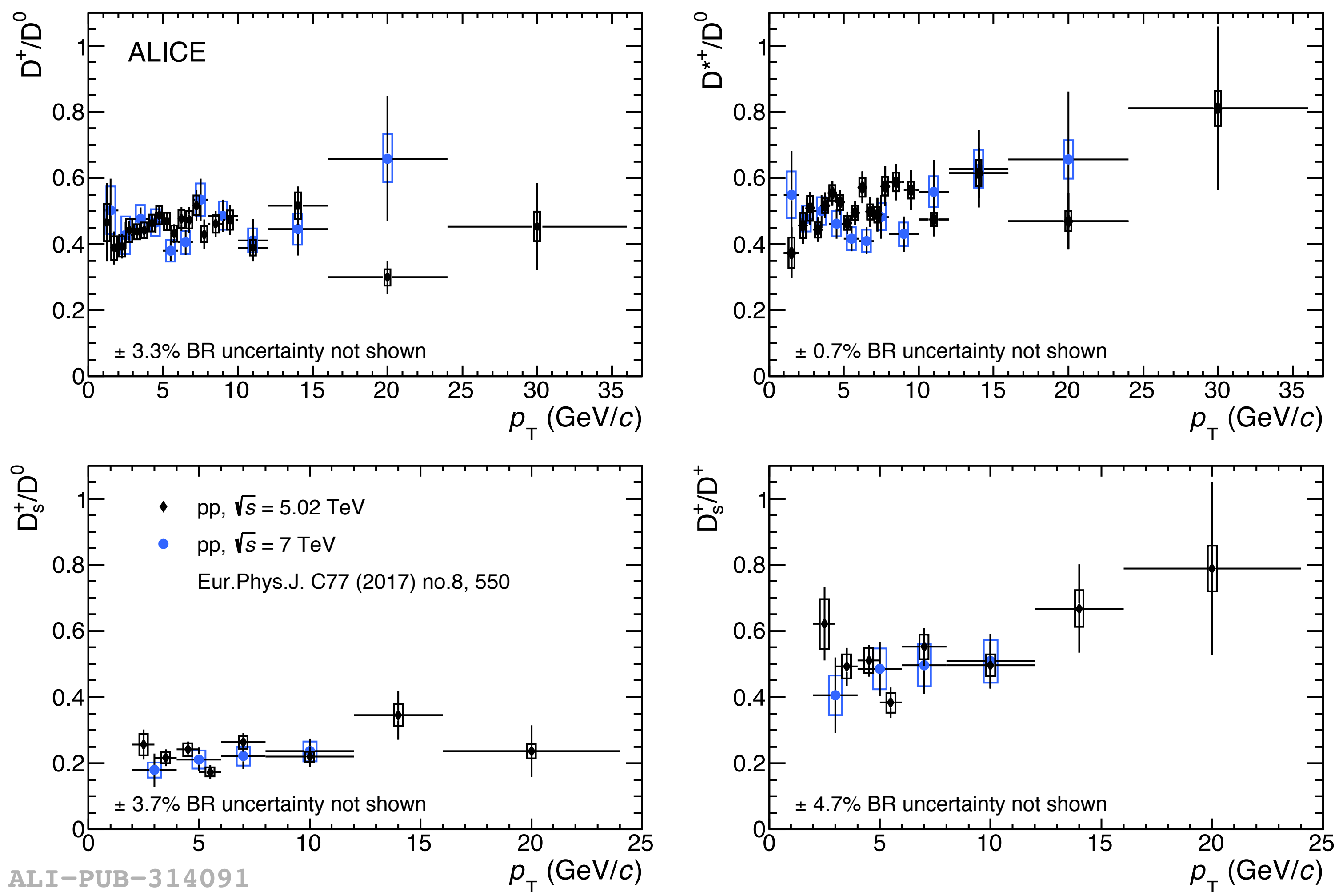
- FONLL (Fixed order with Next-to-Leading Log resummation): Data lies within uncertainty, central value of predictions lies below the data(JHEP 10 (2012) 137)
- GM-VFNS (General- Mass Variable Flavour Number Scheme): Data lies within uncertainty(Eur. Phys. J. C72 (2012) 2082)
- GM-VFNS SACOT-m_T good agreement with data(JHEP05(2018)196)
- k_T-factorisation describes the data at low and intermediate p_T, but overestimates for p_T > 7 GeV/c.(PRD 87 (2013) 094022).



Heavy flavour production cross sections in pp

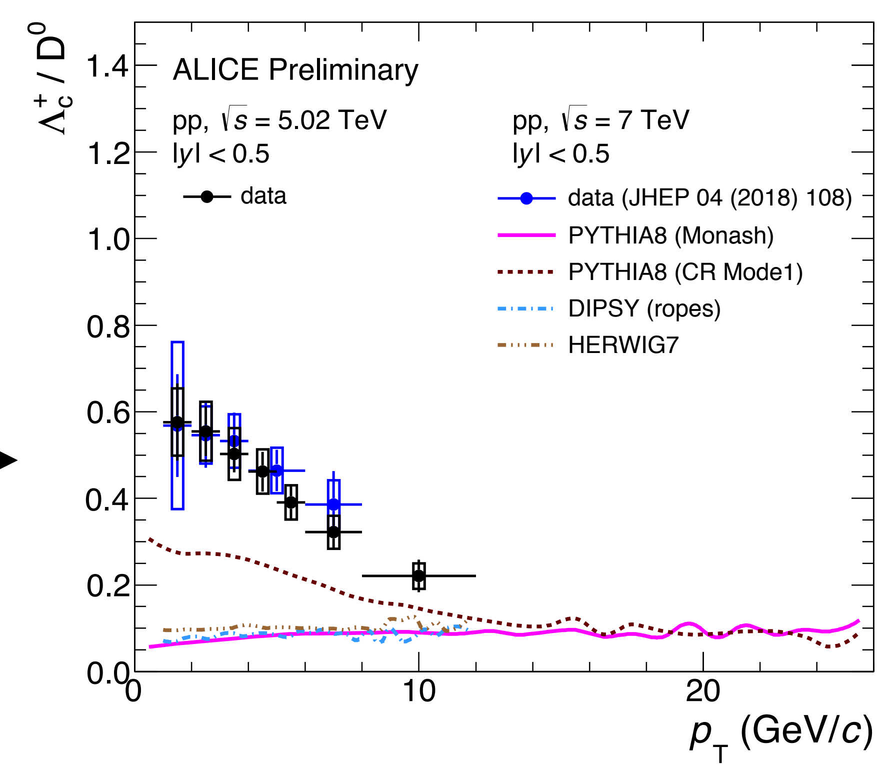
Ratios of the p_T-differential cross sections of D^0, D^{*+}, D^+,D_s^+ mesons and Λ_c at $\sqrt{s}$ = 5.02 TeV and $\sqrt{s}$ =7 TeV.

New



- No significant p_T dependence within the experimental uncertainties.
- Small difference between the fragmentation functions of the different species.
- compatible within uncertainties with the ratios measured in pp collisions at $\sqrt{s}$ = 7 TeV

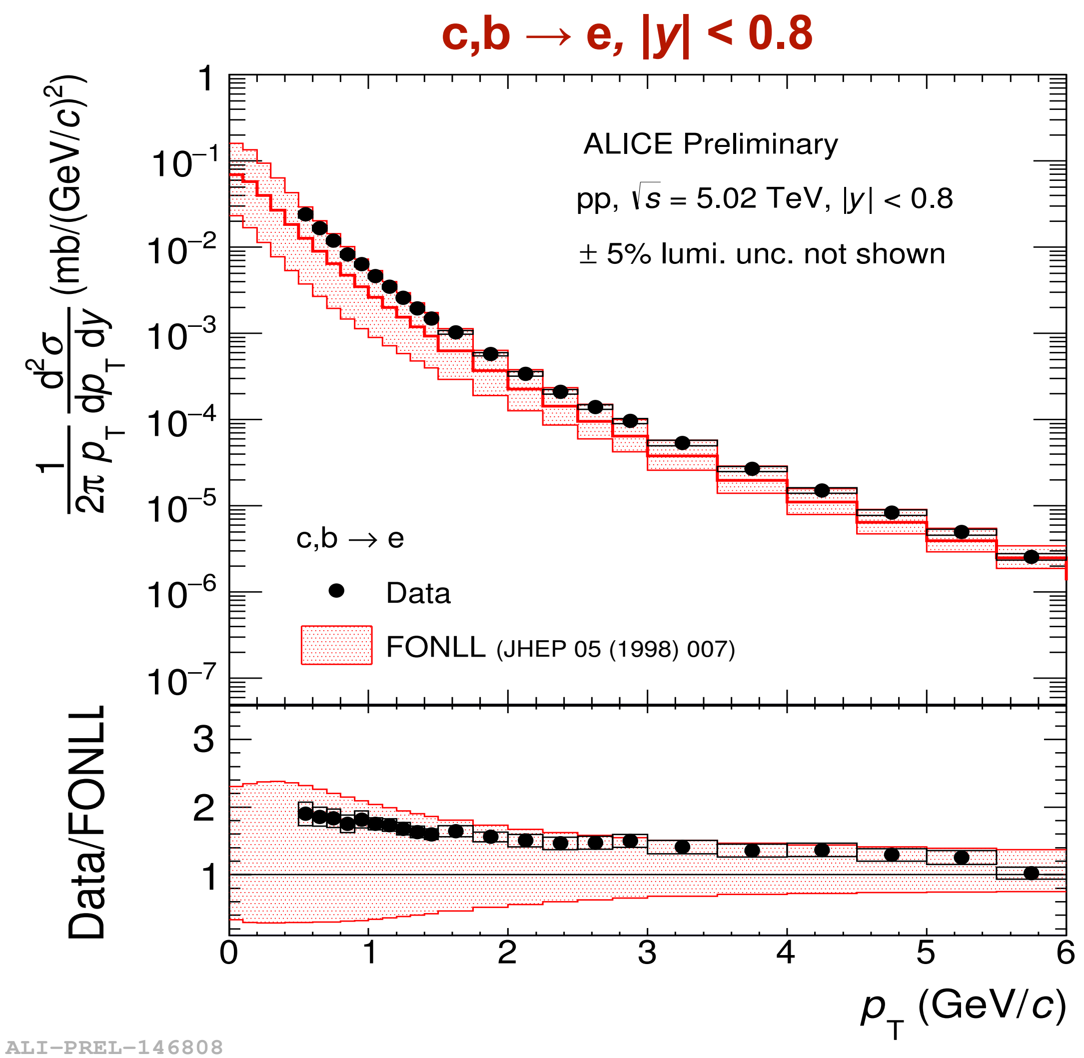
- Λ_c^+/D^0 production is underestimated by theoretical predictions.
- Tensions in Λ_c^+ sector. More details in C. Zampoli's talk.

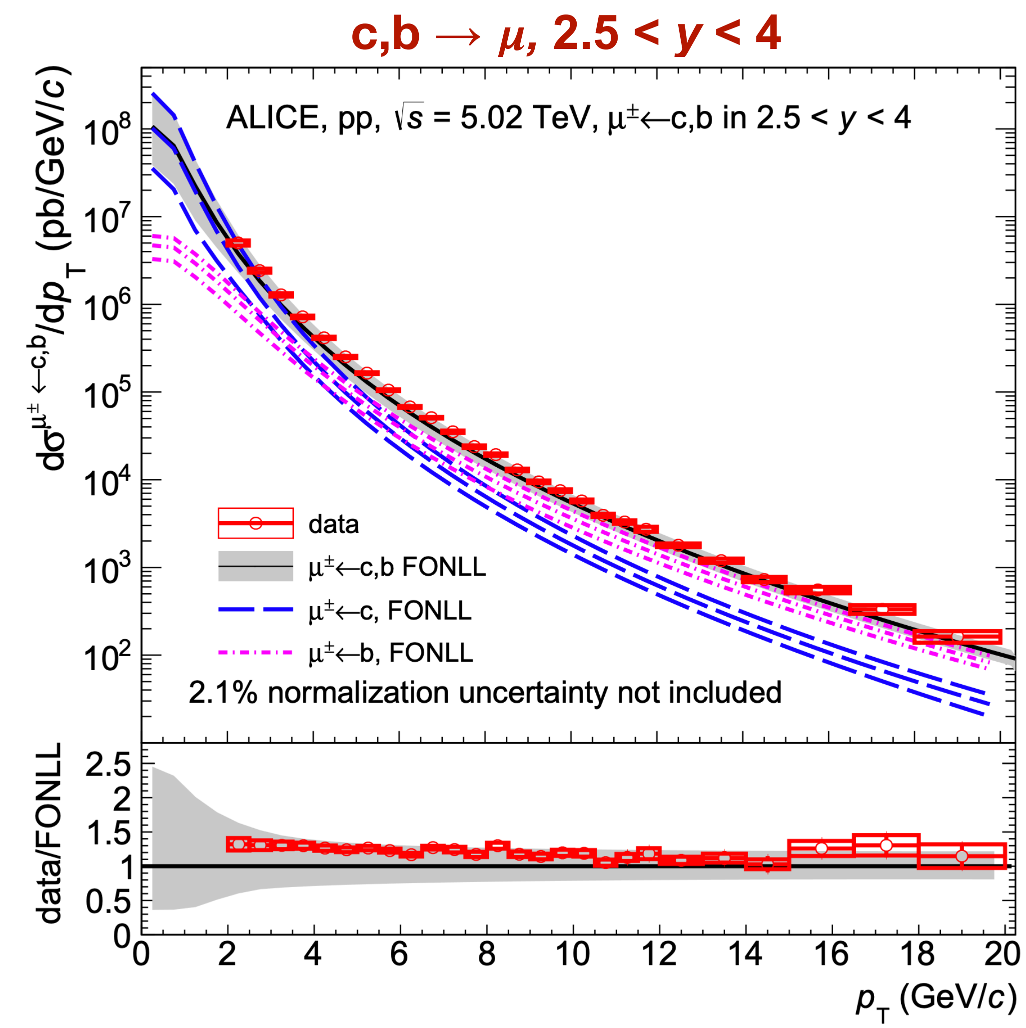


Lucas Anne Vermunt's Poster

Heavy flavour production cross sections in pp

Heavy-flavour hadron decay electron (mid- rapidity, $|y| < 0.8$) and muon (forward rapidity, $2.5 < y < 4$) cross section at $\sqrt{s}$ = 5.02 TeV.



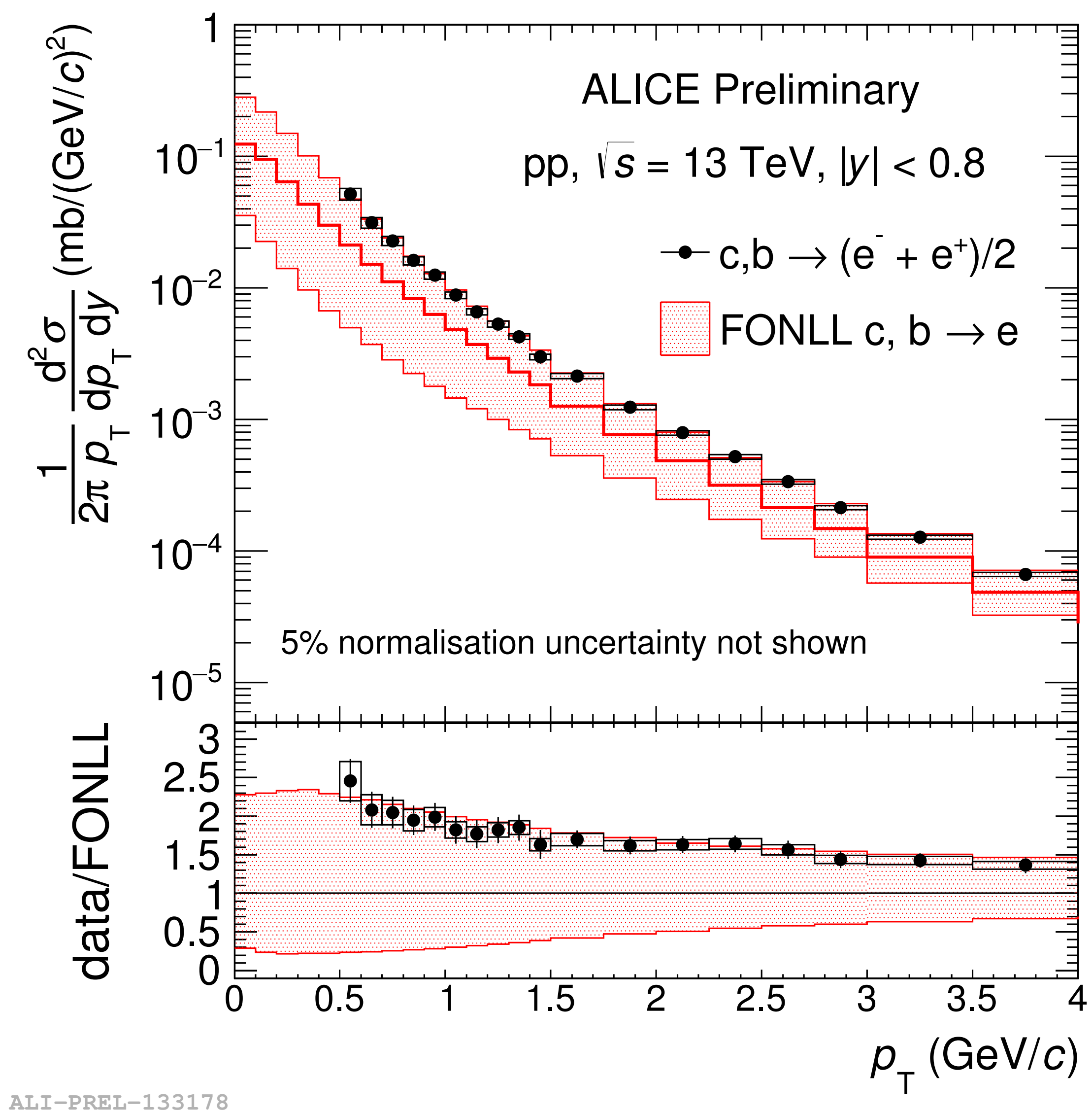


arXiv:1905.07207

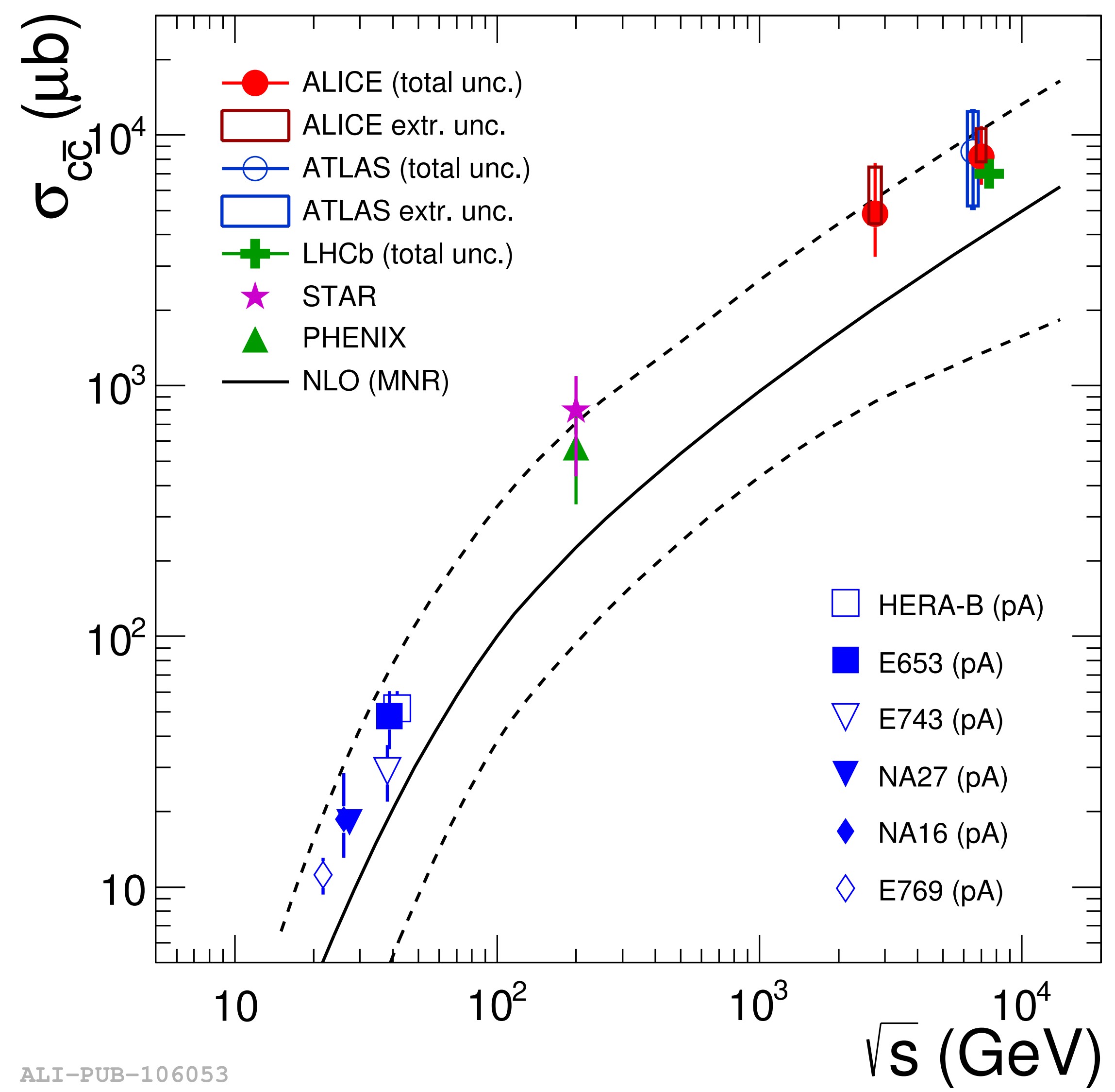
- Data lies on the upper edge of the theoretical (FONLL) uncertainty band for both electrons and muons
- Insight about relative abundance of beauty and charm quarks from the muon cross section
  - At low p_T charm decay is dominant.
  - Beauty is the main component for $p_T >\sim 5$ GeV/c.

Heavy flavour production cross sections in pp

c,b → e, |y| < 0.8 at 13 TeV



total charm cross-section



Phys. Rev. C 94, 054908 (2016)

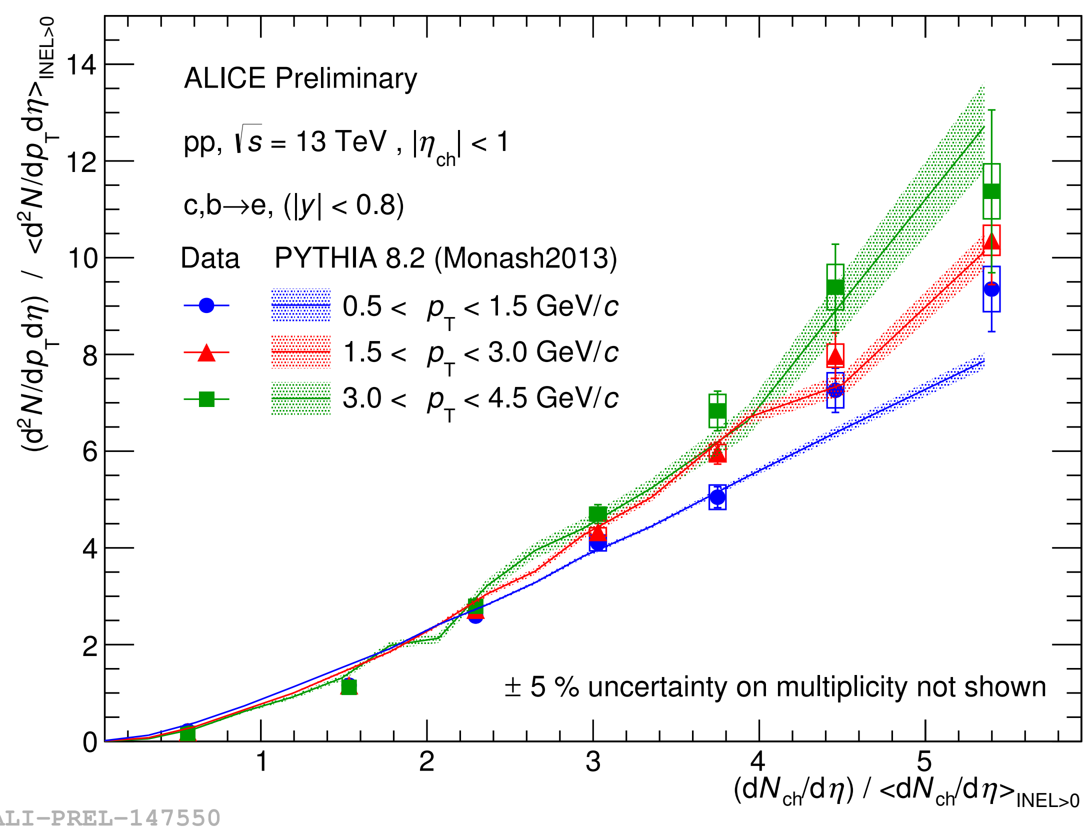
– HFE at 13 TeV: Data lies on the upper edge of the theoretical (FONLL) uncertainty band.

– Contributing more precise charm measurements in pp collisions at different energies.

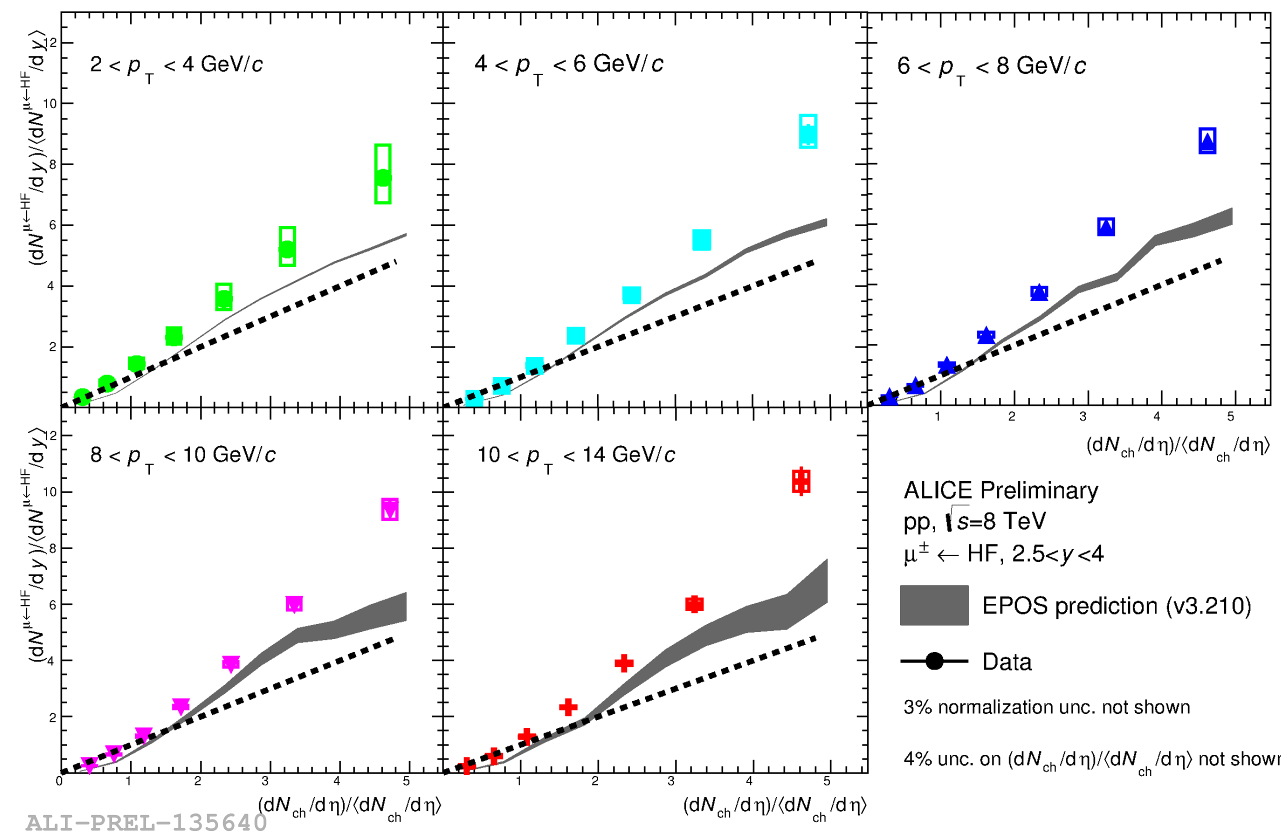
Heavy flavour production vs multiplicity in pp

Self-normalized yield of heavy-flavour decay electrons ($\sqrt{s}$ = 13 TeV, mid-rapidity) and muons ($\sqrt{s}$ = 8 TeV, forward rapidity) versus multiplicity compared with model predictions with p_T dependence:

pp, $\sqrt{s}$ = 13 TeV,
c,b → e, |y| < 0.8



pp, $\sqrt{s}$ = 8 TeV,
c,b → μ, 2.5 < y < 4



– The self-normalized yields show a **faster than linearly increasing trend.**

– **In the high p_T range,** hint for **steeper increase**.

Comparison with model prediction:

☑ c,b → μ data compared to EPOS3.210 prediction without hydrodynamics (Phys. Rev. C 89 (2014) 064903).
EPOS3.210 underestimates data at higher multiplicities for all p_T ranges

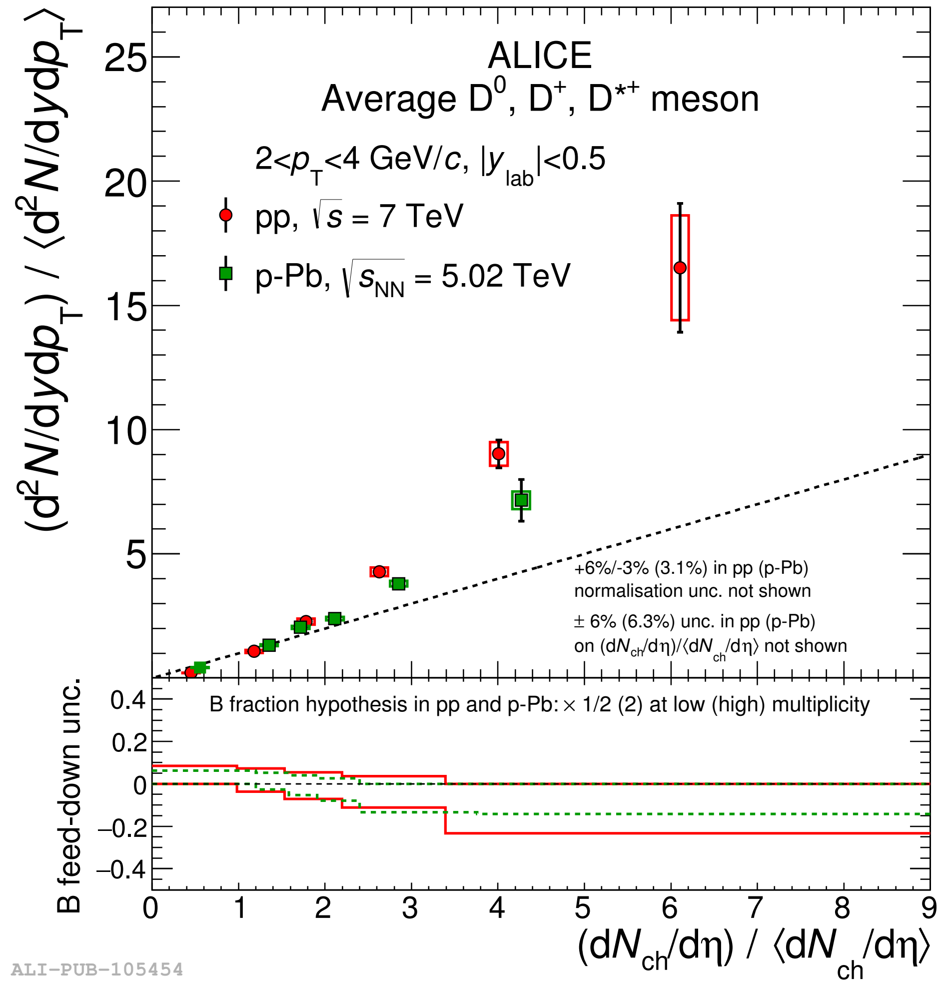
☑ c,b → e data compared to PYTHIA8.2 prediction (Comput. Phys. Commun. 191 (2015) 159).
p_T dependence results qualitatively described by PYTHIA8.2 predictions.

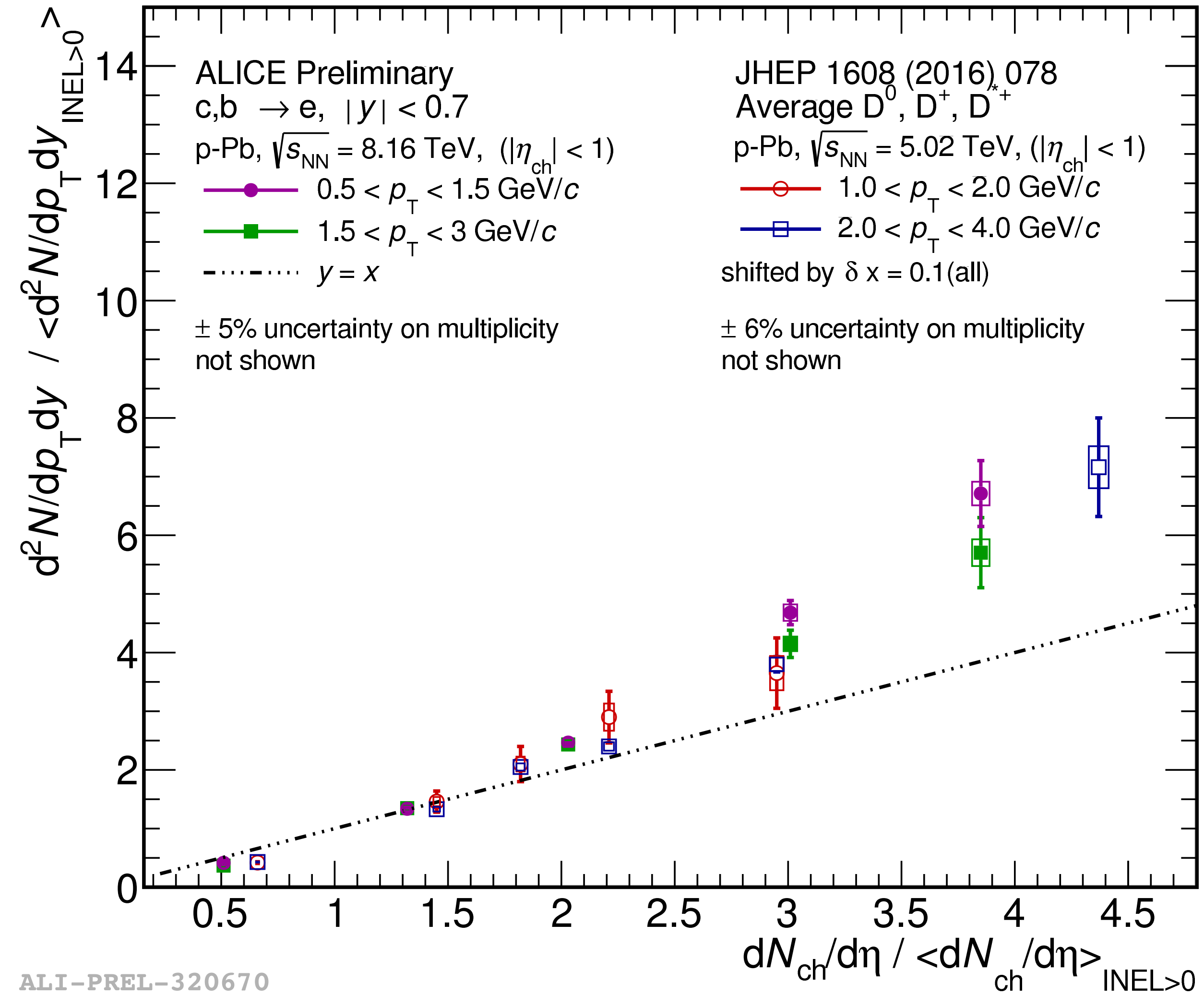
Results in p-Pb collisions

Heavy flavour production vs multiplicity in p-Pb

Self-normalized yield of average D mesons ($\sqrt{s_{NN}}$ = 5.02 TeV) and electrons ($\sqrt{s_{NN}}$ = 8.16 TeV) versus multiplicity at mid-rapidity:

New





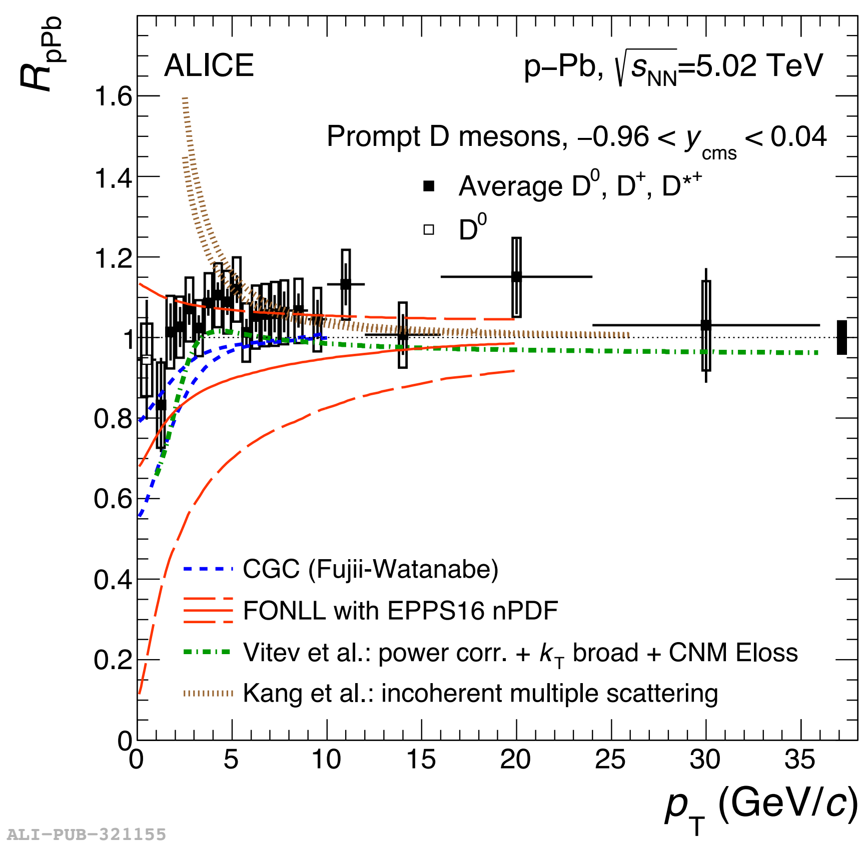
- Similar trend in both pp and p-Pb collisions.
- High-multiplicity p-Pb collisions: MPI (like pp) but also have higher number of binary nucleon-nucleon collisions.
- The trend of HF-decay electrons is compatible with the average D mesons.

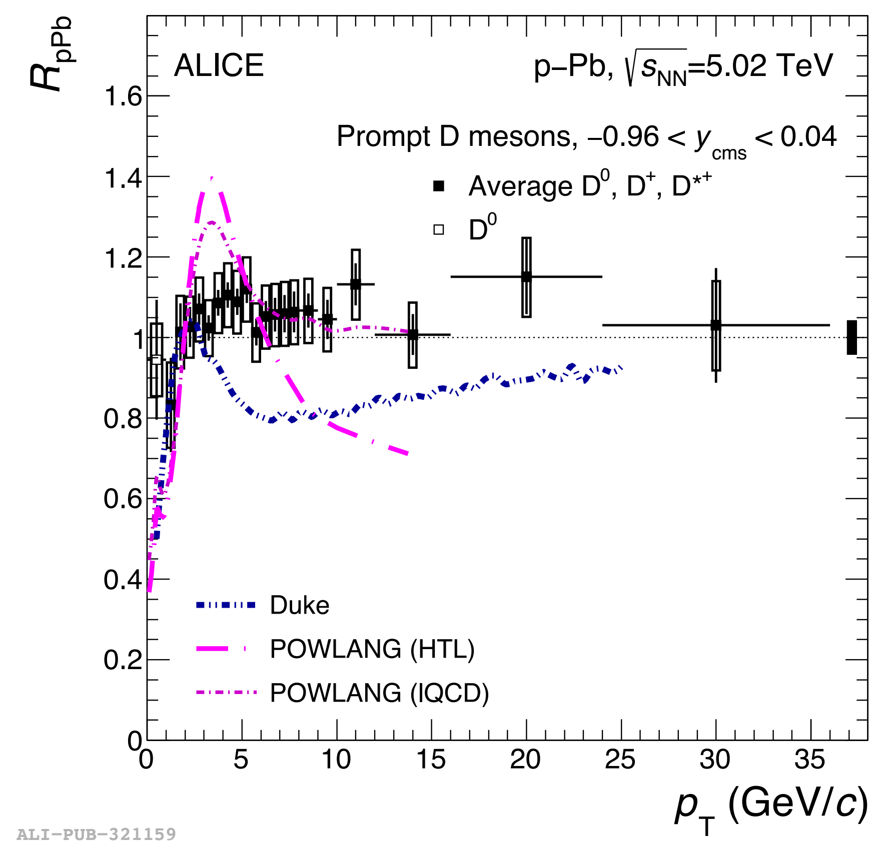
D-meson nuclear modification factor in p-Pb

- Nuclear modification factor provides access to **cold nuclear matter (CNM)** effects and the effects related to the (possible) formation of a QGP in p-Pb collisions

$$R_{\rm pPb} = \frac{1}{A}\frac{{\rm d}\sigma_{\rm pA}/{\rm d}p_{\rm T}}{{\rm d}\sigma_{\rm pp}/{\rm d}p_{\rm T}}$$

arXiv:1906.03425





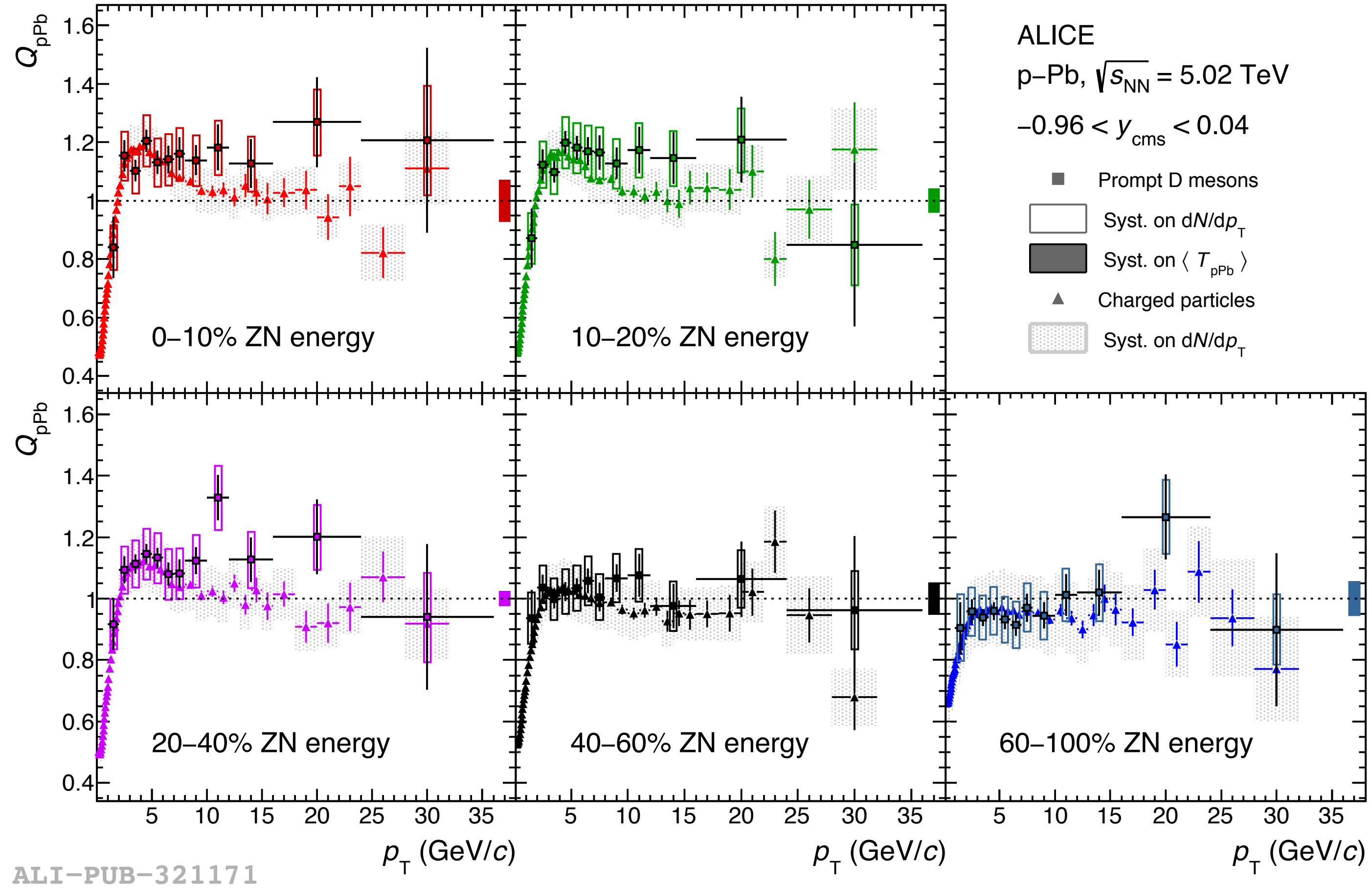
New

- Left: Data **described well** by the models including the **CNM effects**.
- Right: Data compared with the model which predicts the production of a QGP in p-Pb.
  - Tend to predict a suppression on the D mesons $R_{\rm pPb}$ at high $p_{\rm T}$. At present results tend to disfavour suppressions larger than 10-20%.

arXiv:1906.03425

D-meson nuclear modification factor in p-Pb

New



- Q_{pPb}: centrality-dependent nuclear modification factor. → centrality-dependent **CNM effects.**

$$Q_{pPb}^{cent} = \frac{1}{< T_{pPb}^{cent} >} \frac{dN_{pPb}^{cent}/dp_T}{d\sigma_{pp}/dp_T}$$

- Central and peripheral results are **compatible** with each other and with unity for **D mesons.**
- D-meson ***Q*** Q_{pPb} **similar to charged particles** within uncertainties.

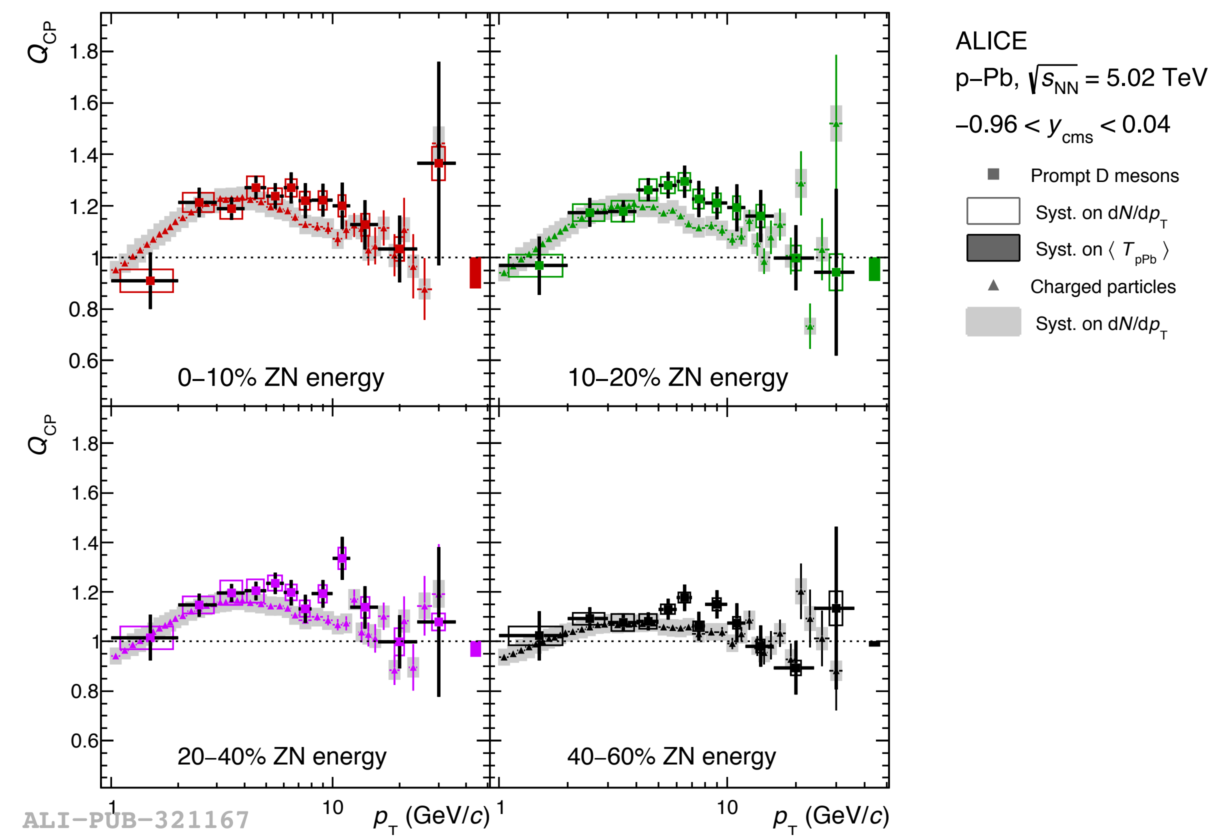
- Q_{cp}: Ratio of most central collisions to the most peripheral collisions spectra.

  Central : 0-10%   Peripheral : 60 - 100%

- Qcp >1 by ~3σ in 3 < p_T < 7 GeV/c in 20-40%.

  → similar trend as charged particles.

  Origin: CGC like Initial or QGP for final state effects? Need models for interpretation.

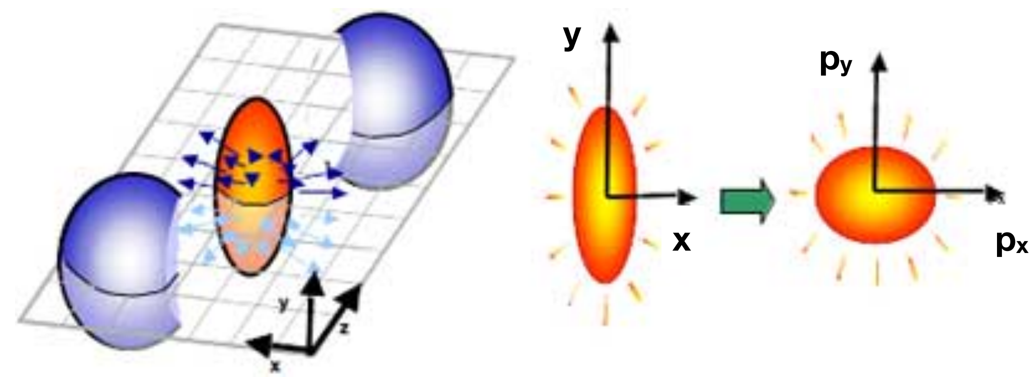


Collectivity in small systems?

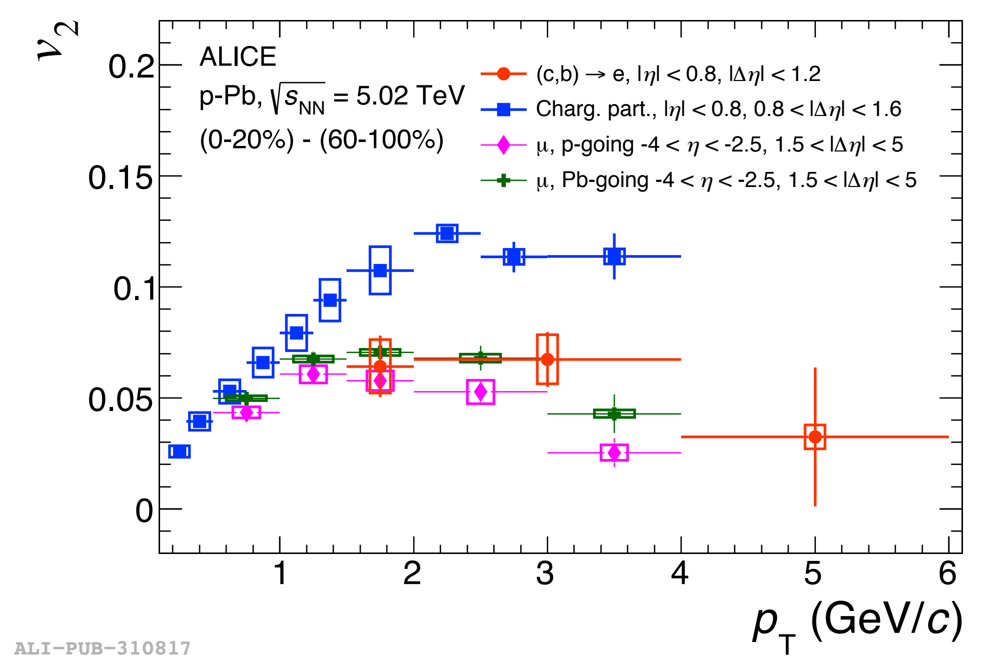
- **Anisotropic flow**: Initial spatial anisotropy translates into final momentum anisotropy (pressure gradients).

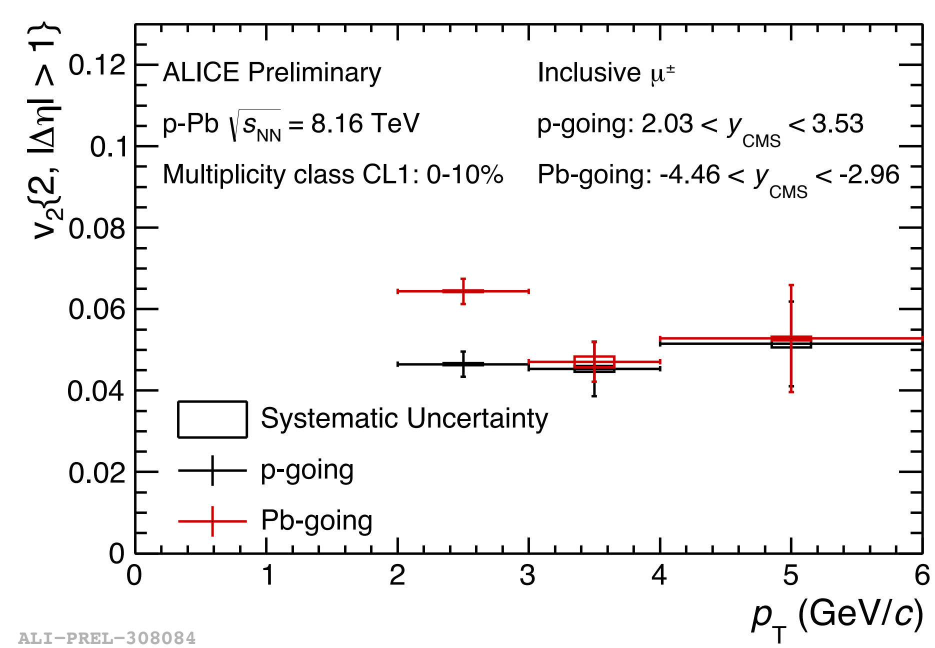
$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T d\eta}\left[1 + 2\sum_{n=1}^{\infty} v_n cos[n(\phi - \psi_n)]\right]$$

$$v_n = \langle cos[n(\phi - \psi_n)]\rangle,\ n = 1,\ 2,\ 3....$$



- Also observed in the small systems.
- Study to understand better the collective behaviour in small system in the HF sector.





Positive v_2 observed for HF-decay electrons and inclusive muons.

- Heavy flavour decay **electron** (mid-rapidity).
  - ☑ effect observed is qualitatively similar to inclusive muons.
  - ☑ Significance: > 5σ for 1.5 < p_T < 4 GeV/*c.*
  - ☑ Origin: CGC like Initial or QGP for final state effects.
- Heavy flavour decay **muon** (forward rapidity).
  - ☑ effect observed is qualitatively similar to HFE

Conclusions

- **D mesons and heavy-flavour decay lepton production** cross-section is measured with good precision. Compared with pQCD calculation. Described well within uncertainty.

- **Heavy flavour production vs multiplicity.**

  - **Self-normalised yield**
    - ☑ Results show **stronger than linear enhancement** as a function charged-particle multiplicity.
    - ☑ pp collisions: **Higher p_T ranges** hint **of steeper increase.**
    - ☑ Particle yield and multiplicity measured at mid-rapidity (possible autocorrelations).

  - **Nuclear modification factor: Q_{pPb}**
    - ☑ **Q_{pPb} compatible with unity** and with charged-particle for D-mesons.
    - ☑ **Hints of $Q_{cp} > 1$,** possible modification of the production. From initial- or final-state effects?

  - **Elliptic flow at high multiplicity.**
    - ☑ **Positive v_2** measured for heavy-flavour decay electrons at mid-rapidity and for inclusive muons at forward rapidity.
    - ☑ **Positive v_2** is also observed for heavy-flavour decay muons at forward rapidity

Thank you for your attention!

Backup Slides

Heavy flavour production cross-sections in pp

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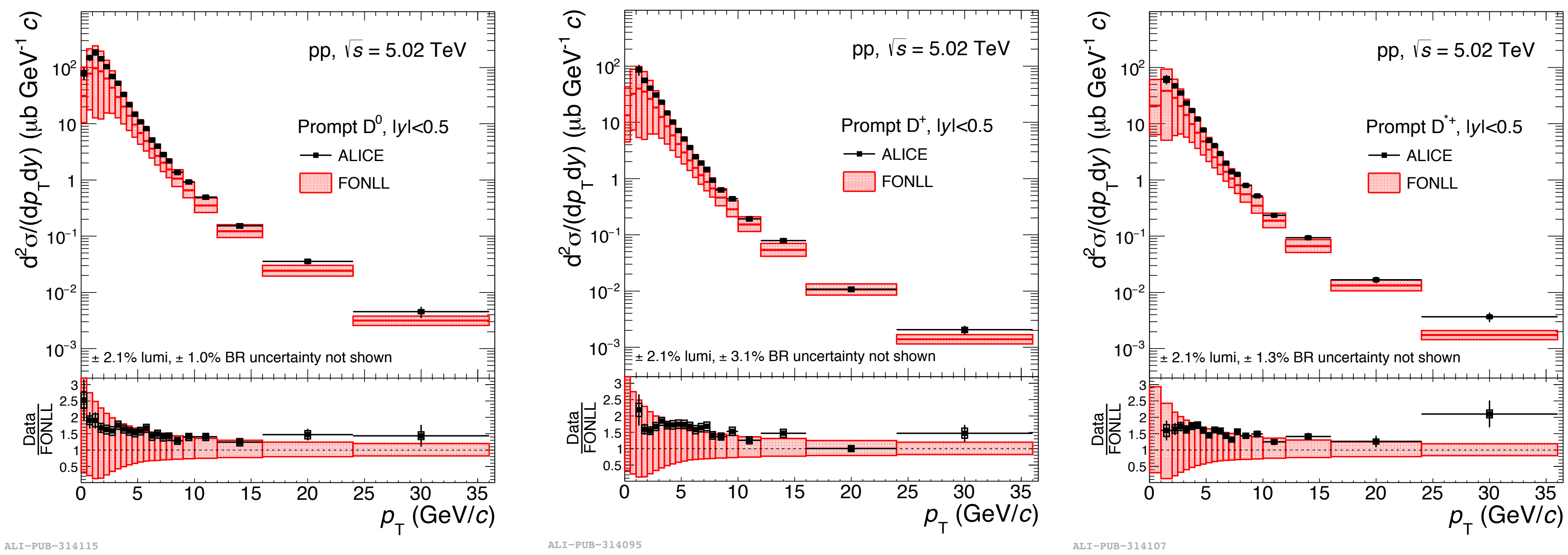

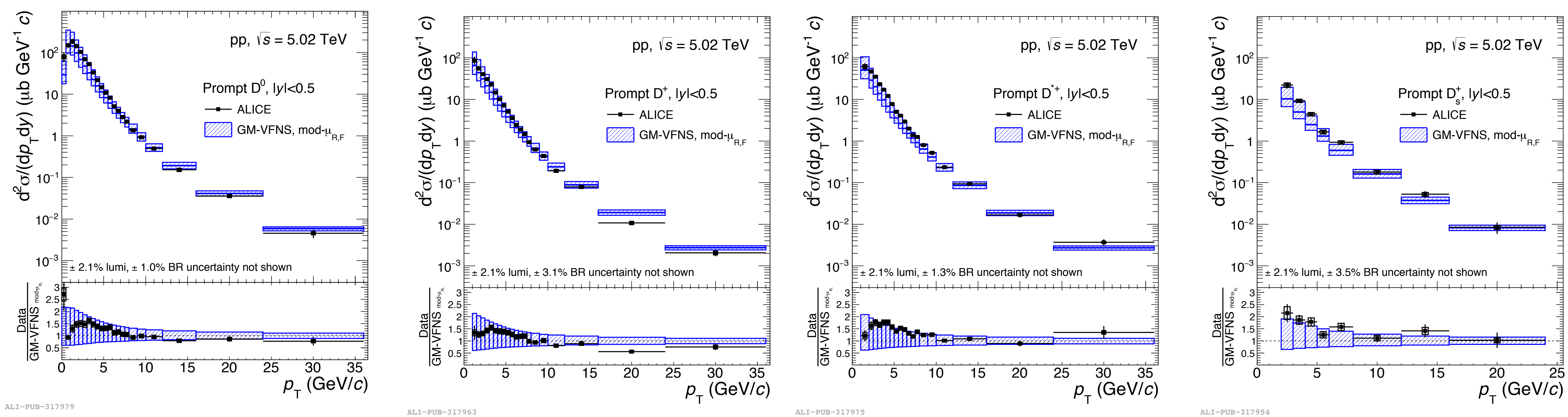

Heavy flavour production cross-sections in pp

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