Study of beauty-quark production, hadronisation and cold nuclear matter effects via measurements of non-prompt charm hadrons in pp and p–Pb collisions with ALICE

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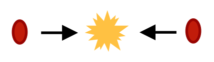
Introduction

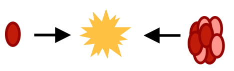
- Given the large masses of heavy quarks (charm, beauty), they are produced in hard-scattering process and hence their production can be calculated with pQCD
- Cross section of charm- and beauty-hadron production is typically calculated using the factorisation approach:

$$\frac{d\sigma^{pp\to H_q}}{dp_T} = f_i(x_1,\mu_f^2) f_j(x_2,\mu_f^2) \times \frac{d\sigma^{ij\to q}}{dp_T}(x_1,x_2,\mu_f^2) \times D_{q\to H_q}\left(z_q = \frac{p_{H_q}}{p_q}, \mu_f^2\right)$$

parton distribution functions (PDFs) — hard scattering cross section (pQCD) — fragmentation function (hadronisation)

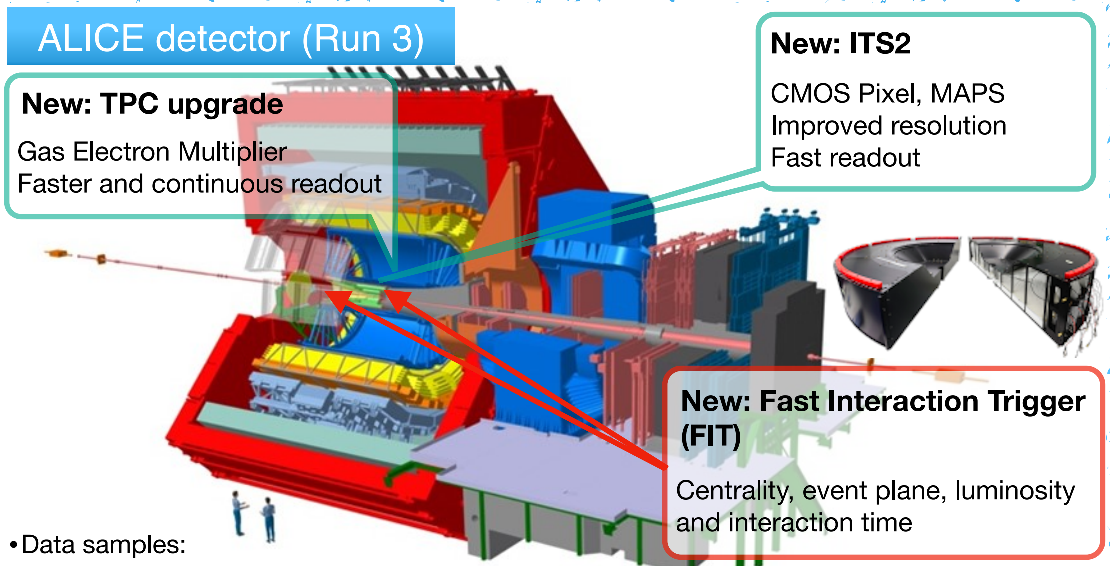


Proton–proton collision:
- Test of pQCD calculations (FF assumed to be universal across collision systems)
- Reference for p–Pb collisions



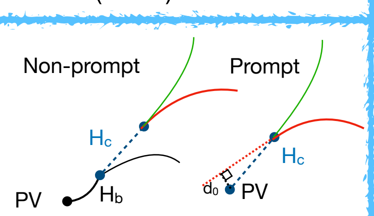
Proton–Pb collision:
Cold nuclear matter effects
- Modification of parton distribution functions (PDFs) in bound nuclei

ALICE detector (Run 3)

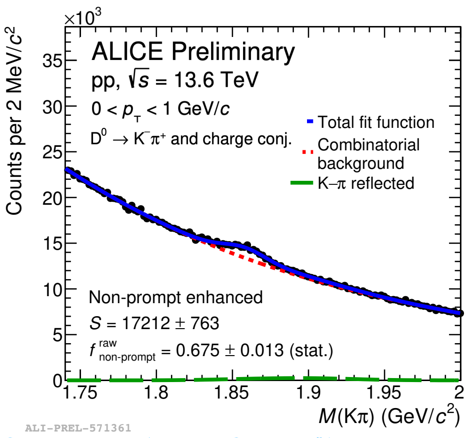


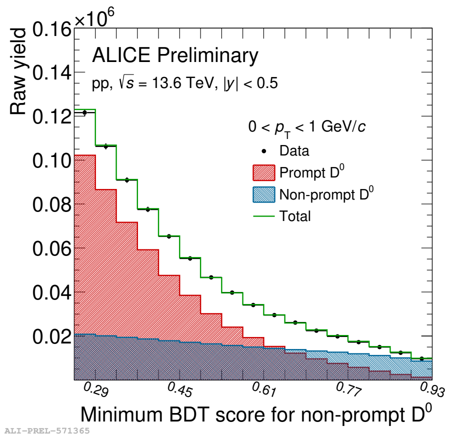
- Data samples:
  - pp 13 TeV —> $\mathscr{L}_{int} \approx 32$ nb^{-1} (Run 2)
  - p–Pb 5.02 TeV —> $\mathscr{L}_{int} \approx 287\ \mu$b^{-1} (Run 2)
  - pp 13.6 TeV – $\mathscr{L}_{int} \approx 1$ pb^{-1} (Run 3)

Analysis strategy

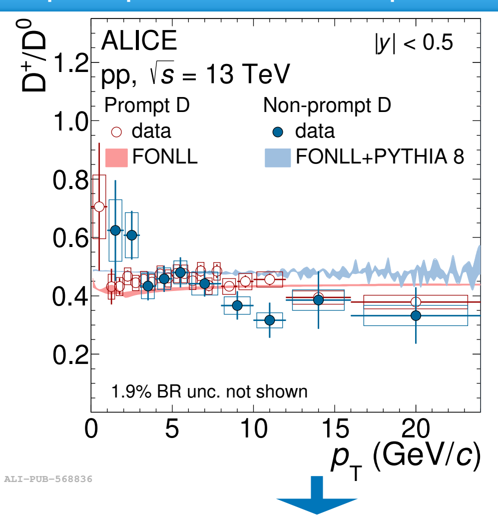


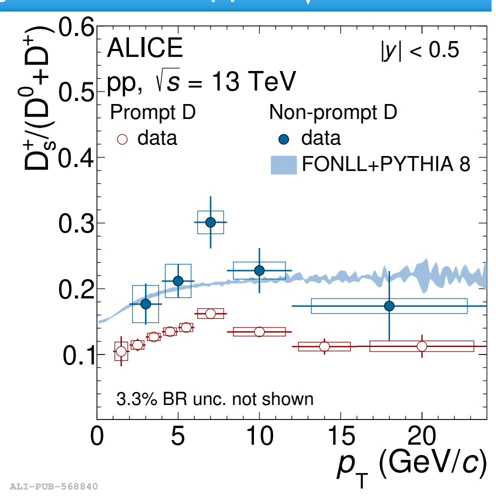
- Reconstructed hadronic decay channels:
$D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to \phi\pi^+ \to K^-\pi^+\pi^+$, $\Lambda_c^+ \to pK_s^0$, $\Lambda_c^+ \to pK^-\pi^+$
- XGBoost multiclass classification machine-learning (ML) algorithm exploiting decay-vertex [1] topology and particle identification variables used to separate prompt D⁰, non-prompt D⁰ and combinatorial background
- Invariant-mass analysis used to extract raw yields
- Non-prompt fraction estimated via χ^2-minimisation approach with variations of the ML-based selections



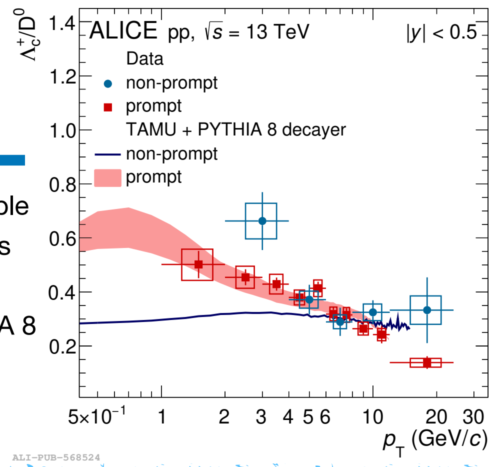


Non-prompt charm-hadron production-yield ratios in pp at $\sqrt{s}$ = 13 TeV

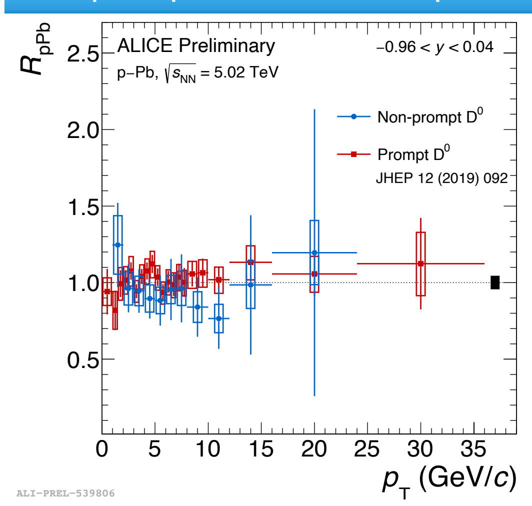


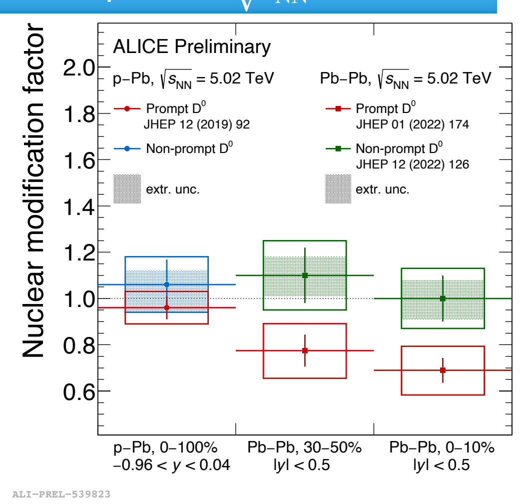


- No significant p_T dependence for the strange-to-non-strange ratio for non-prompt mesons [2]
—> agreement to the FONLL+PYTHIA 8 model prediction
- The prompt and non-prompt Λ_c^+/D^0 are compatible in their common p_T intervals, with a tension of less than 2σ in $2 < p_T < 4$ GeV/c [3]
- Non-prompt Λ_c^+/D^0 compared to TAMU + PYTHIA 8 model predictions
—> well described for $p_T > 4$ GeV/c, while underestimated for $2 < p_T < 4$ GeV/c



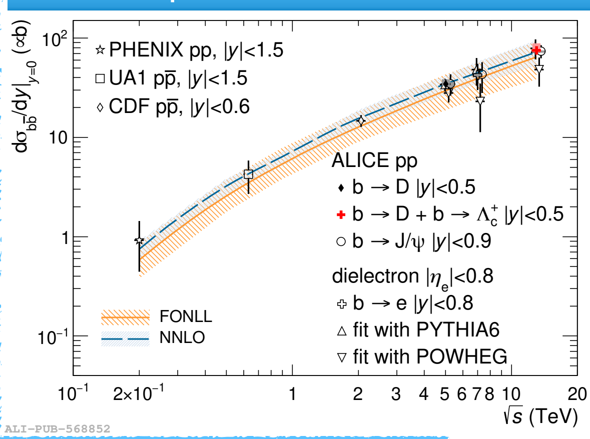
Non-prompt charm-hadron production in p–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV





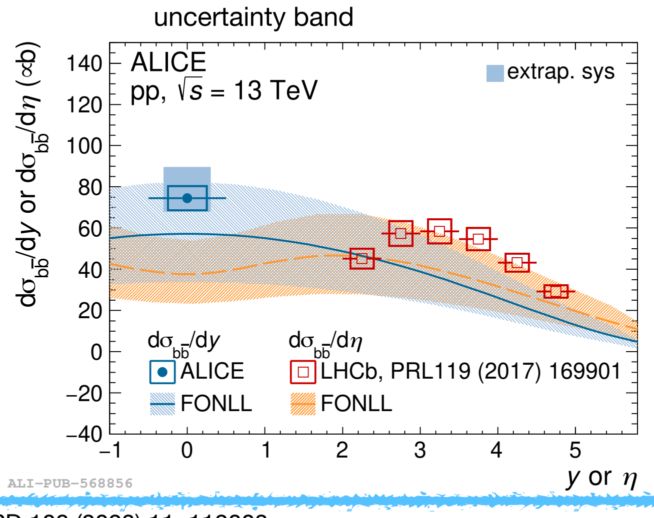
p_T-differential and p_T-integrated R_{pPb} of prompt and non-prompt D⁰ are compatible between each other and with unity within uncertainties —> pointing to mild CNM effects

Total $b\bar{b}$ production cross section in pp at $\sqrt{s}$ = 13 TeV



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

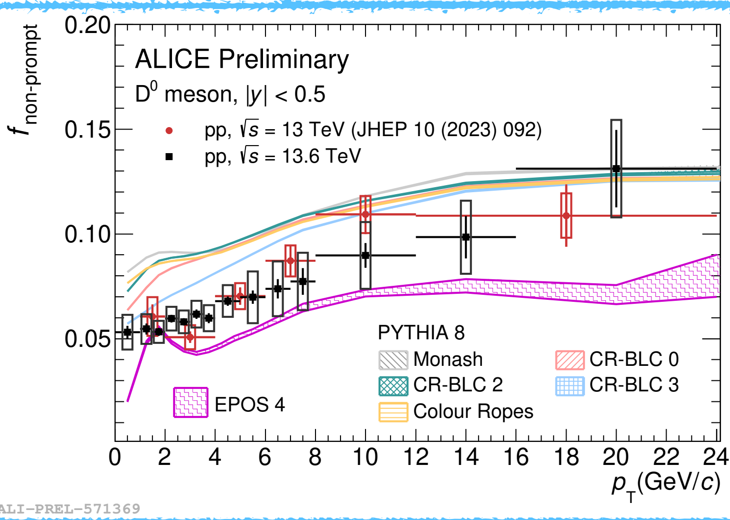
- The $b\bar{b}$ cross section is extrapolated from the measurements of non-prompt charm hadrons [2]
- The $\sqrt{s}$**-dependent** $b\bar{b}$ cross section can be described by the pQCD calculation within theoretical uncertainties [2]
- The **rapidity-dependent** $b\bar{b}$ cross section compared to FONLL predictions
—> generally lie close to the upper boundary of the FONLL theoretical uncertainty band



Non-prompt D⁰ fraction in pp at $\sqrt{s}$ = 13.6 TeV

First non-prompt charm-hadron measurement in Run 3:

- Improvement of the precision
- Direct measurement down to $p_T = 0$
- Better constraints allow to distinguish different hadronisation implementations in models (EPOS, PYTHIA)



References [1] https://github.com/hipe4ml/hipe4ml [2] ALICE Collaboration: arXiv: 2402.16417 [hep-ex] [3] ALICE Collaboration: PRD 108 (2023) 11, 112003