Heavy-flavour production in proton-proton collisions with the ALICE experiment

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Workshop on Heavy Ion Physics

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Laszlo Gyulai on behalf of the ALICE Collaboration
Wigner RCP, Budapest
Budapest University of Technology and Economics

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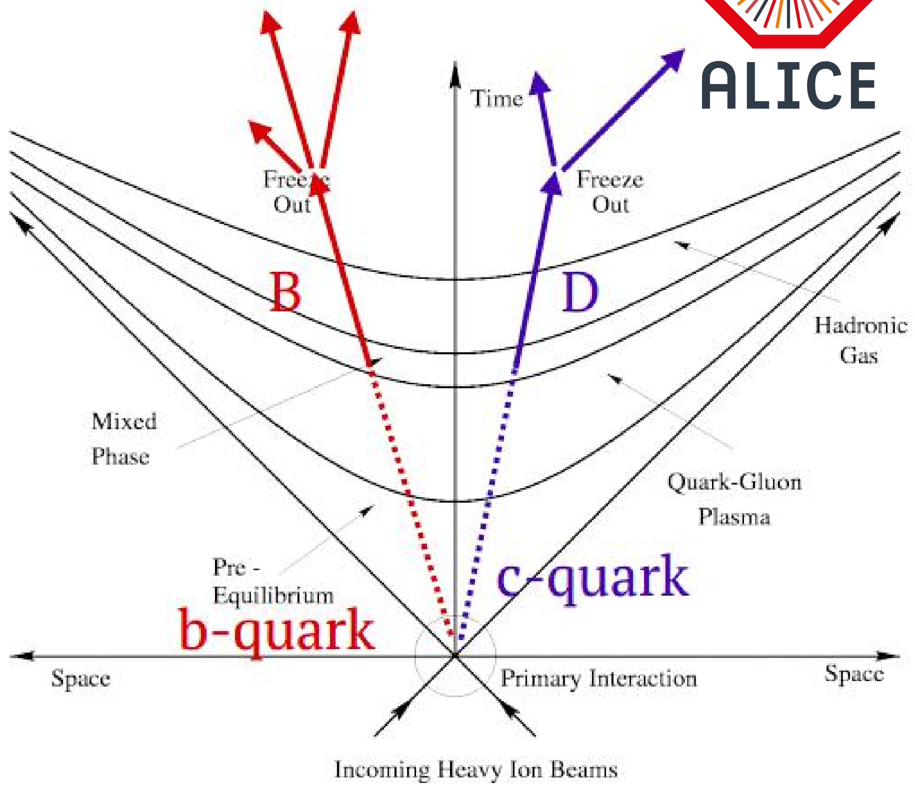
Motivation

Heavy-flavour (c and b) quarks are produced in the initial hard scattering processes.

The formation time of c and b quarks is smaller, than that of the quark-gluon plasma (QGP), and they have a lifetime which is longer, than the duration of QGP.



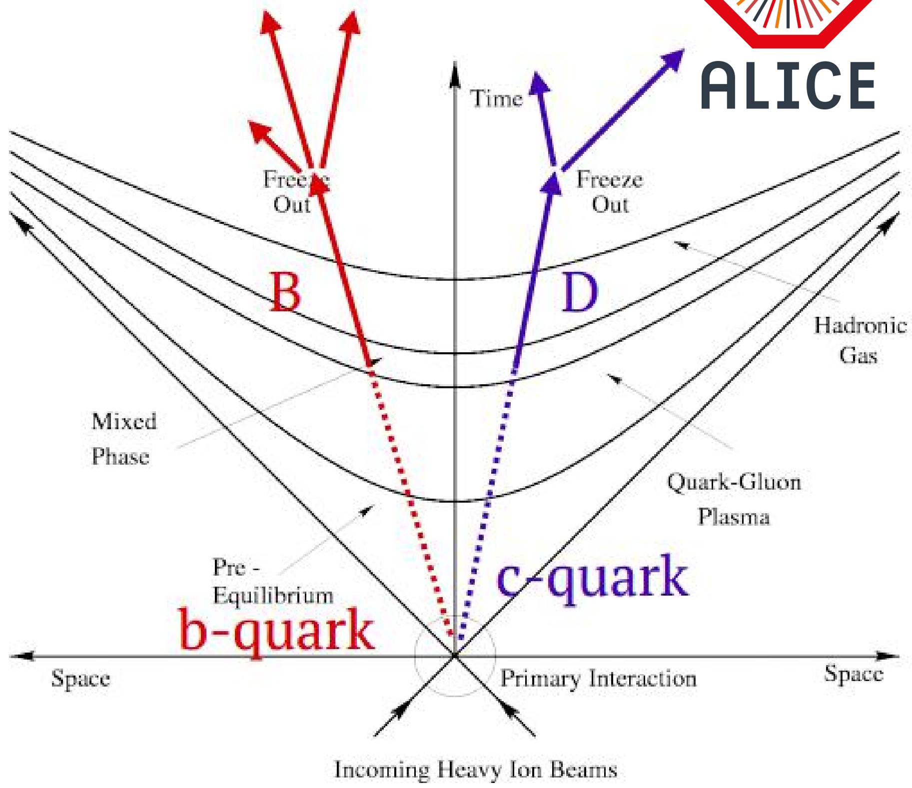
Thus heavy flavours probe the whole evolution of a system.

Motivation

In pp collisions heavy flavours are used for:

- testing perturbative QCD models;
- studying the fragmentation processes (baryons vs. mesons);
- studying the multiplicity dependent production (e.g. multiple parton interactions).

pp measurements are a baseline for studying nuclear modification in heavy-ion collisions.



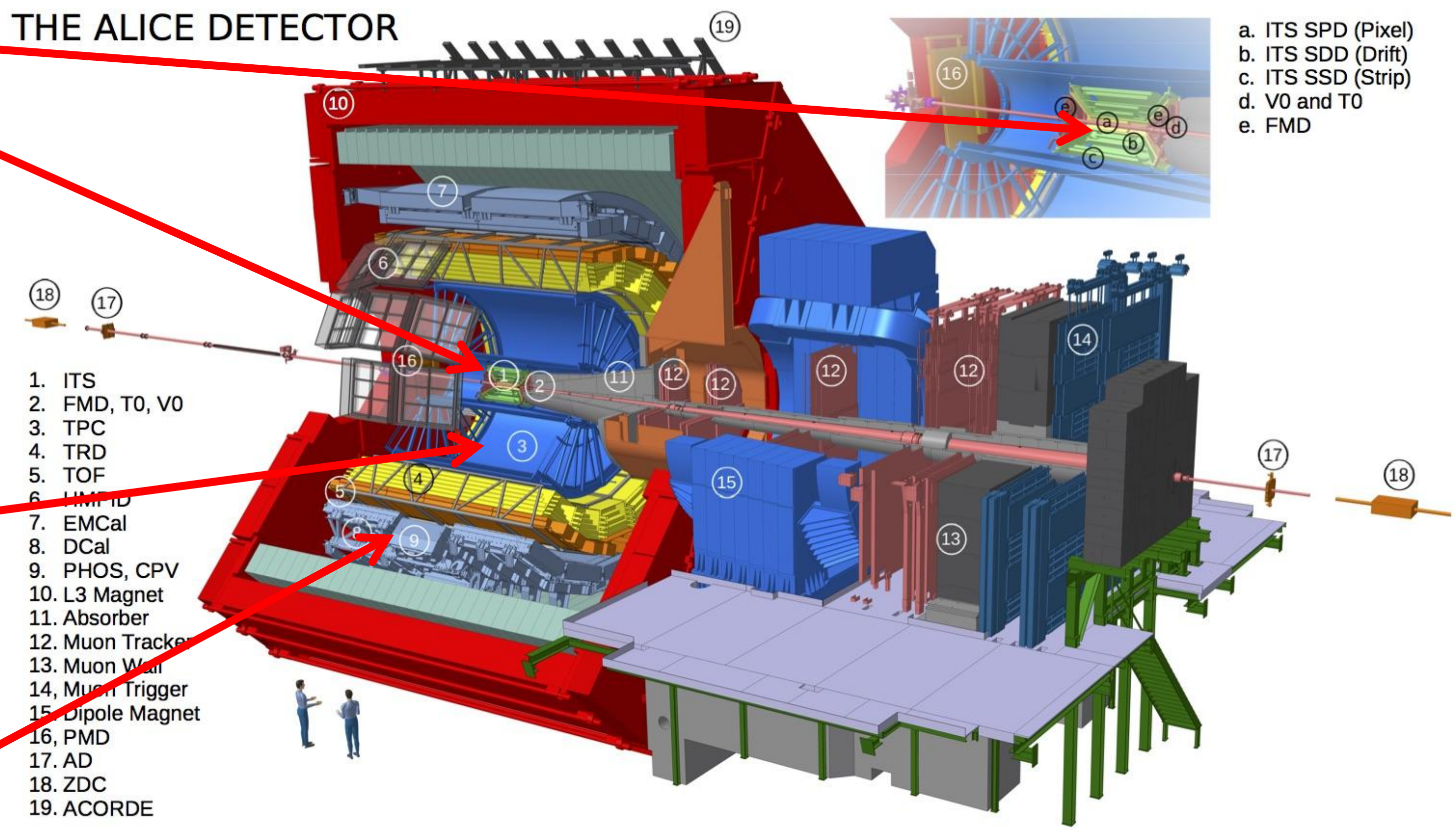
The ALICE experiment

Inner Tracking System (ITS):
- Silicon detectors
- Track reconstruction
- High precision: down to ~100 µm

$c\tau_{\mathrm{D}} = 100 - 300\ \mu m$
$c\tau_{\mathrm{B}} = 400 - 500\ \mu m$

Time Projection Chamber (TPC):
- Multiwire gas chamber
- Tracking
- Particle identification via specific energy loss

Time of Flight detector (TOF):
- Scintillators
- Particle identification via time-of-flight measurement



Heavy-flavour hadron reconstruction

Hadrons containing heavy quarks have a mean free path up to few milimeters - they cannot be detected directly.

Reconstruction channels:

- via hadronic decays
- via semi-leptonic decays

$D^0 \rightarrow K^-\pi^+$

$D^+ \rightarrow K^-\pi^+\pi^+$

$D_s^+ \rightarrow K^-K^+\pi^+$

$\Lambda_c^+ \rightarrow pK^-\pi^+$

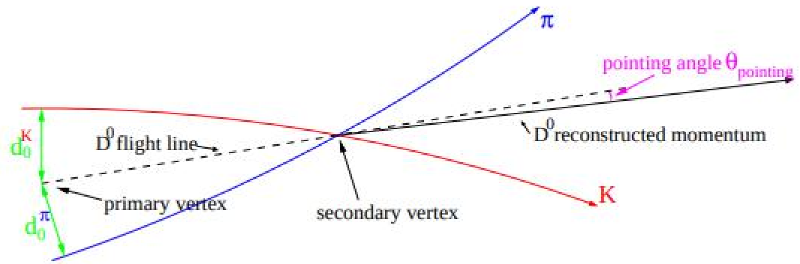
$\Lambda_c^+ \rightarrow pK_s^0$

$\Sigma_c^0 \rightarrow \Lambda_c^+\pi^-$

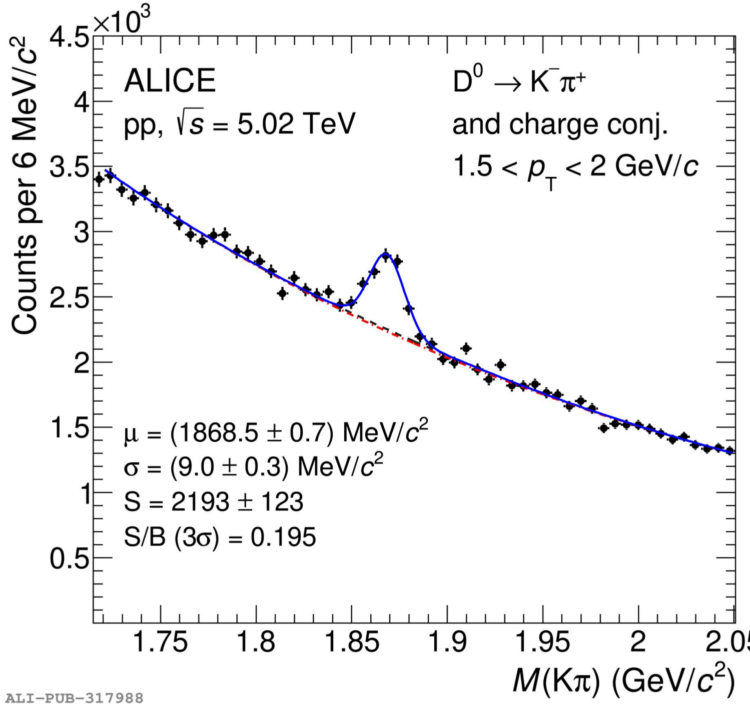
$\Sigma_c^{++} \rightarrow \Lambda_c^+\pi^+$

$\Xi_c^0 \rightarrow \Xi_c^-\pi^+$

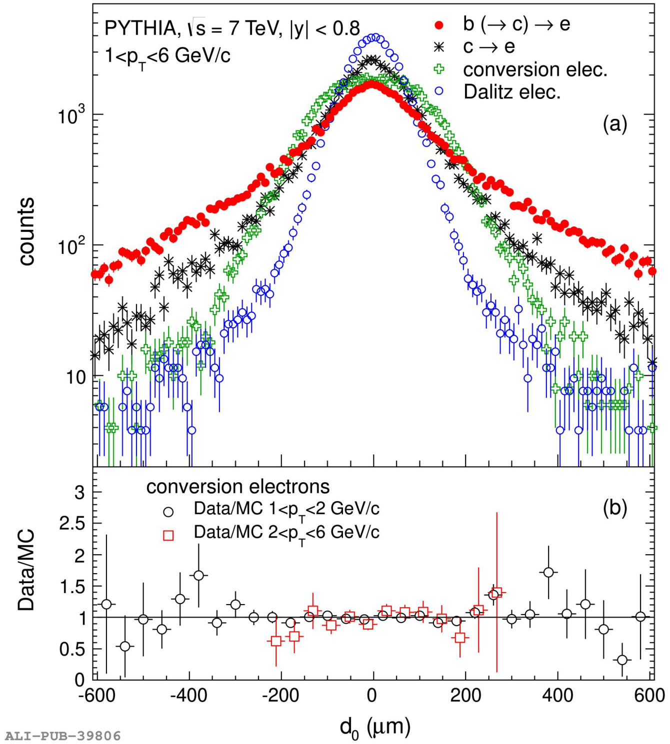
$\Xi_c^+ \rightarrow \Xi_c^-\pi^+\pi^+$



Reconstruction of a D⁰ meson



Invariant mass fit of D⁰ candidates



Impact parameter distribution of e⁻

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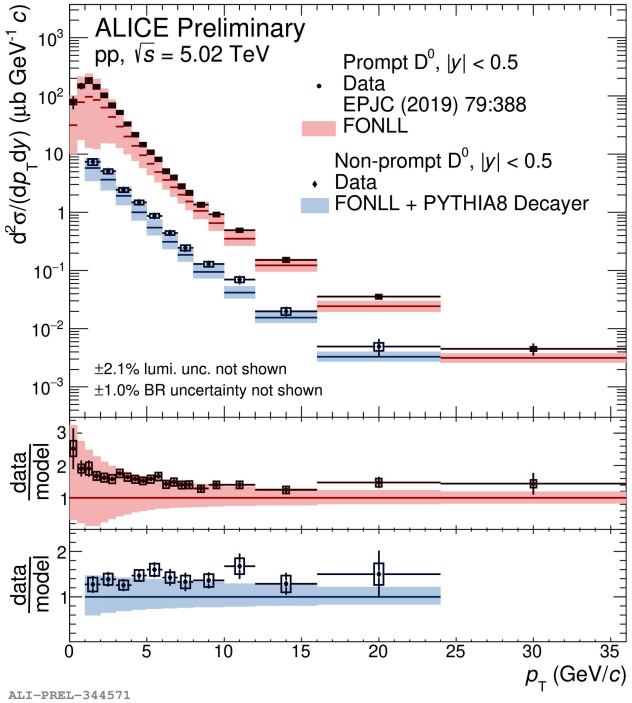
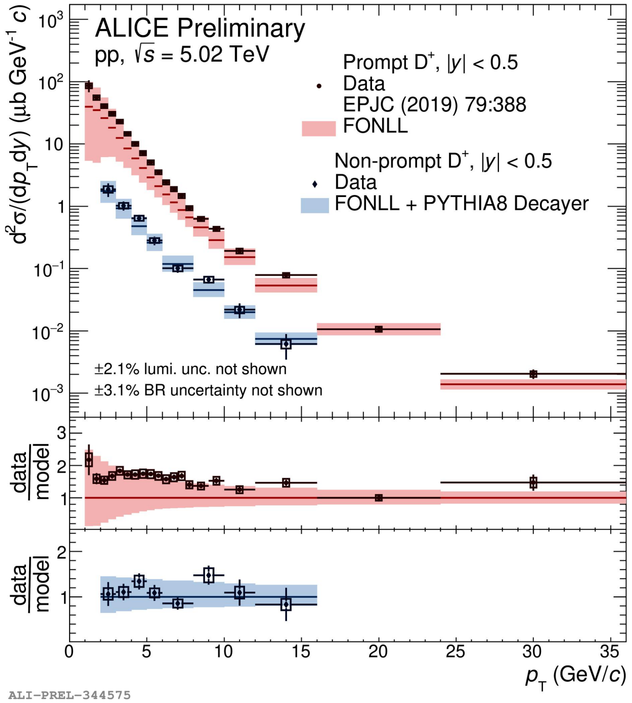
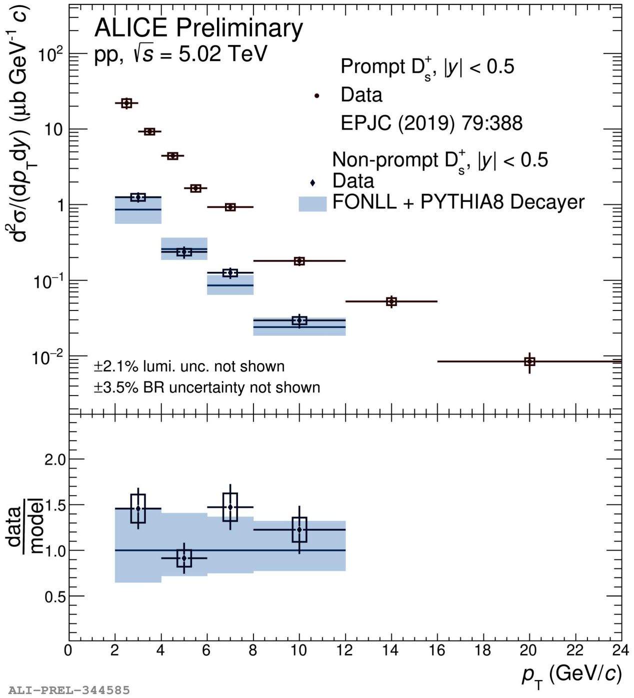
Prompt and non-prompt D mesons production



D^0 production cross section



D^+ production cross section



D_s^+ production cross section

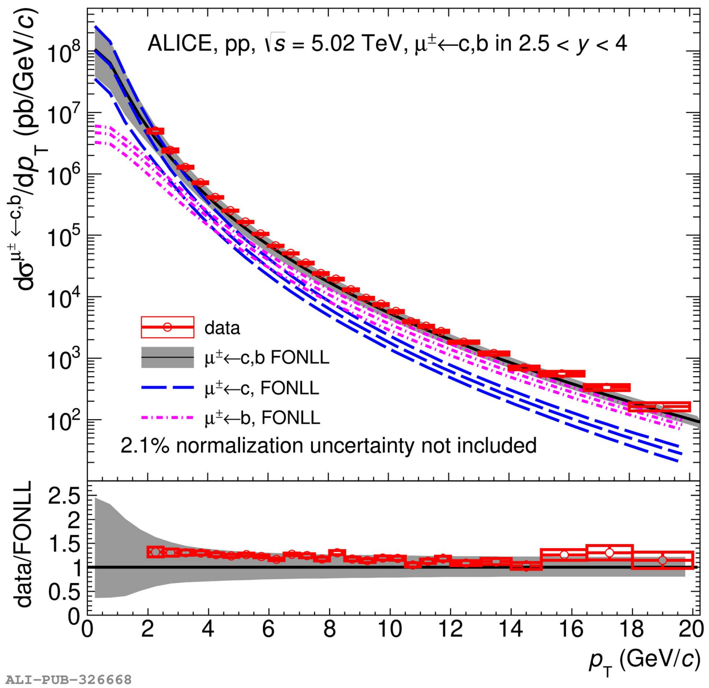
FONLL calculations reproduce well the production of c and b quarks from measurements of the prompt and non-prompt D mesons.

Date lie on the upper edge of the uncertainties of the FONLL calculations.

Muons and electrons from semi-leptonic decays

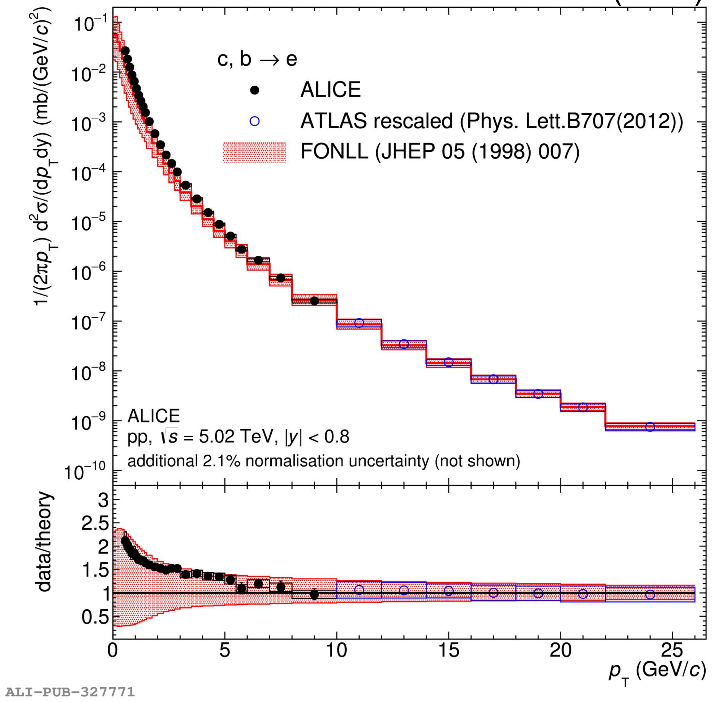
ALICE

JHEP 09 (2019) 008



μ± from HF-hadron decays (forward rapidity)

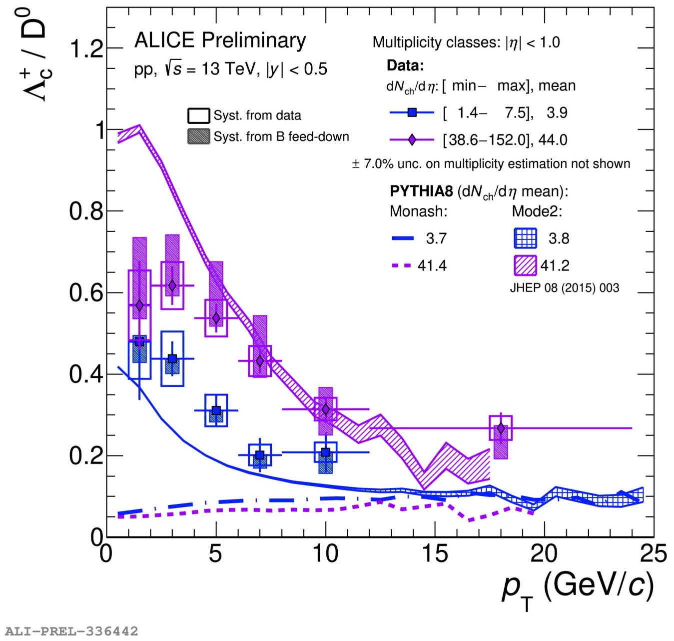
PLB 804 (2020) 135377

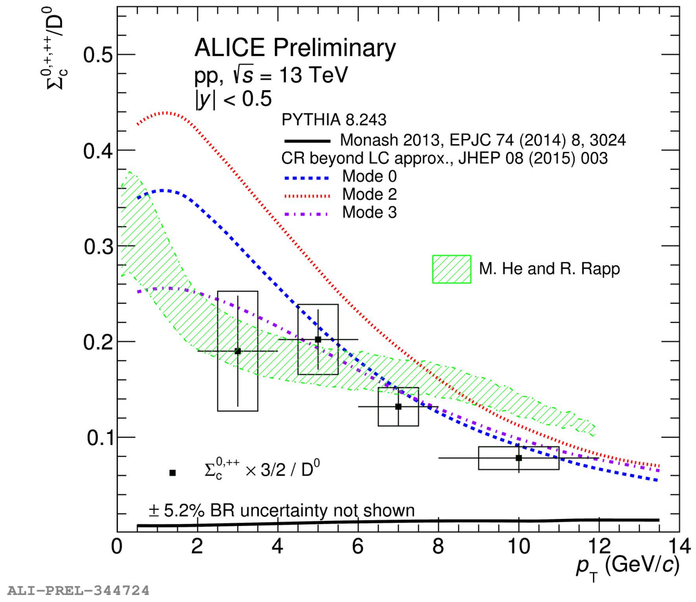


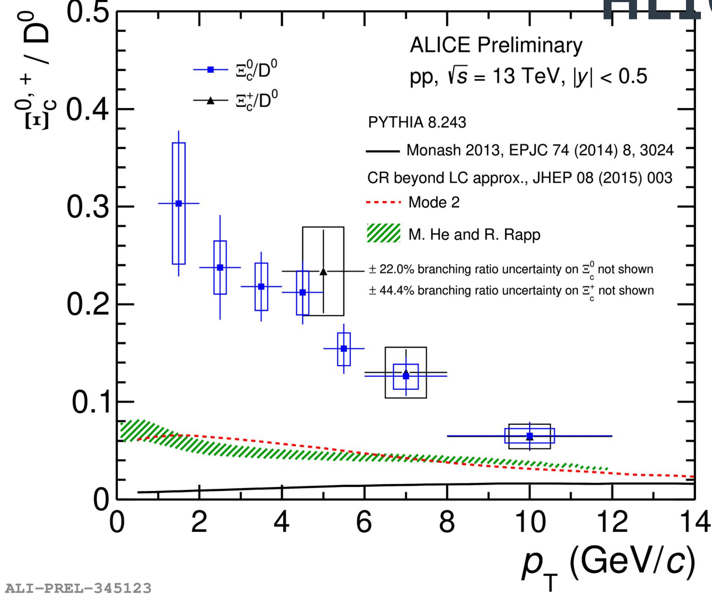
e± from HF-hadron decays (midrapidity)

FONLL reproduces the heavy-flavour production in both rapidity ranges.
Current precision gives opportunity to constrain model calculations.

Charmed baryon-to-meson ratios





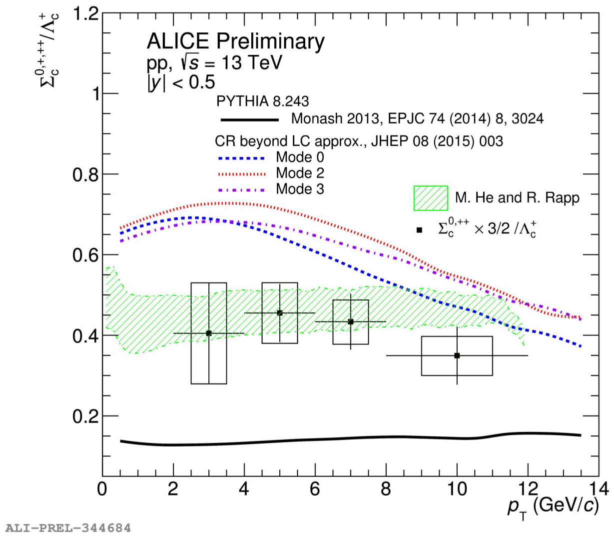


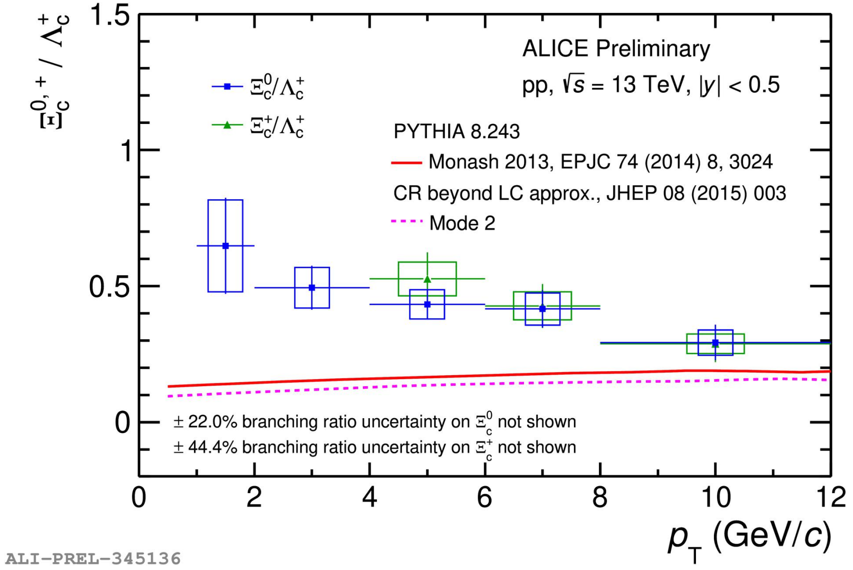
PYTHIA8 Monash tune with fragmentation functions based on e^+e^- collisions fails to describe the ratios of baryons to mesons.

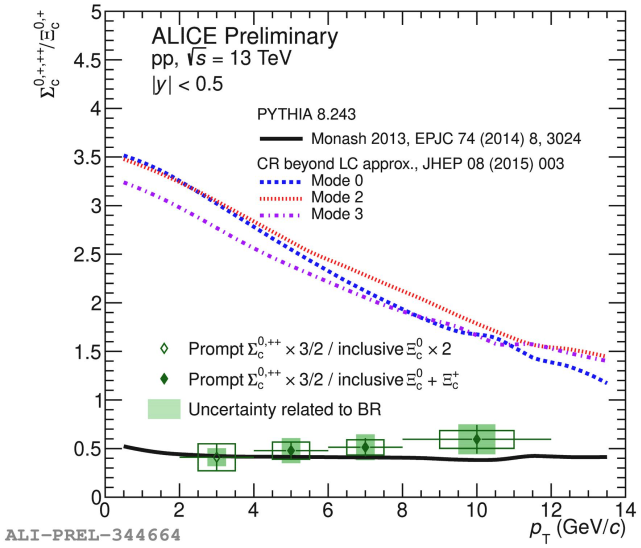
PYTHIA8 with string formation beyond leading colour approximation [Christiansen, Skands, JHEP 1508 (2015) 003], as well as feed-down from augmented set of charm-baryon states in an SHM model [He, Rapp, PLB 795 (2019) 117] tend to better describe the ratios.

Does charm hadronization depend on collision system?

Charmed baryon-to-baryon ratios







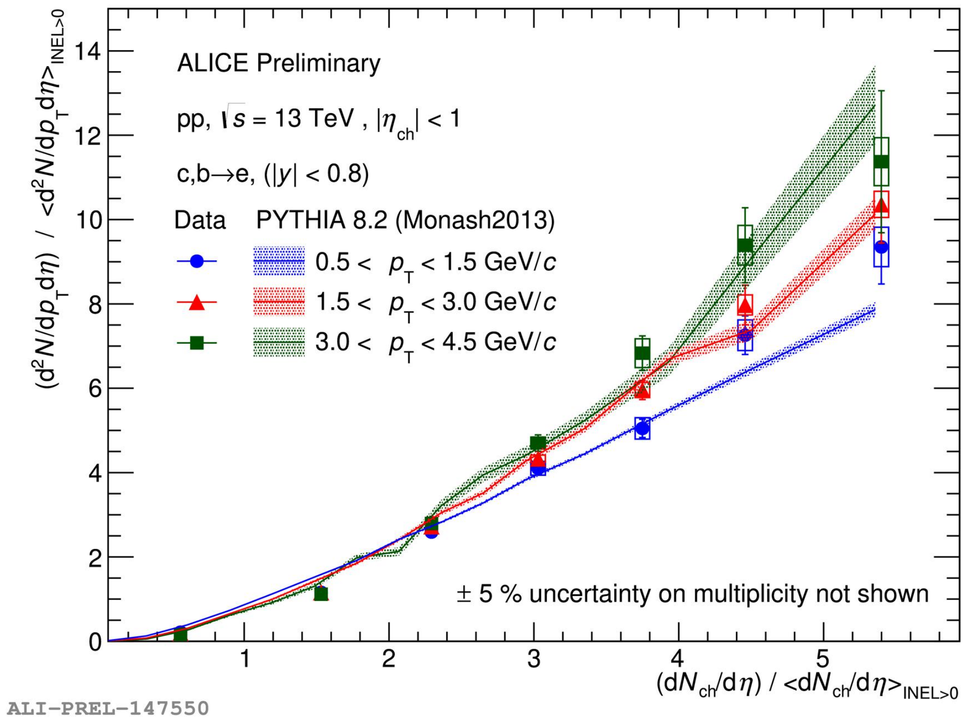
Charmed baryon-to-baryon ratios pose a challenge for most existing model calculations.

Feed-down from augmented set of charm-baryon states in an SHM model [He, Rapp, PLB 795 (2019) 117] provides a good description of the Σ_c / Λ_c ratio.

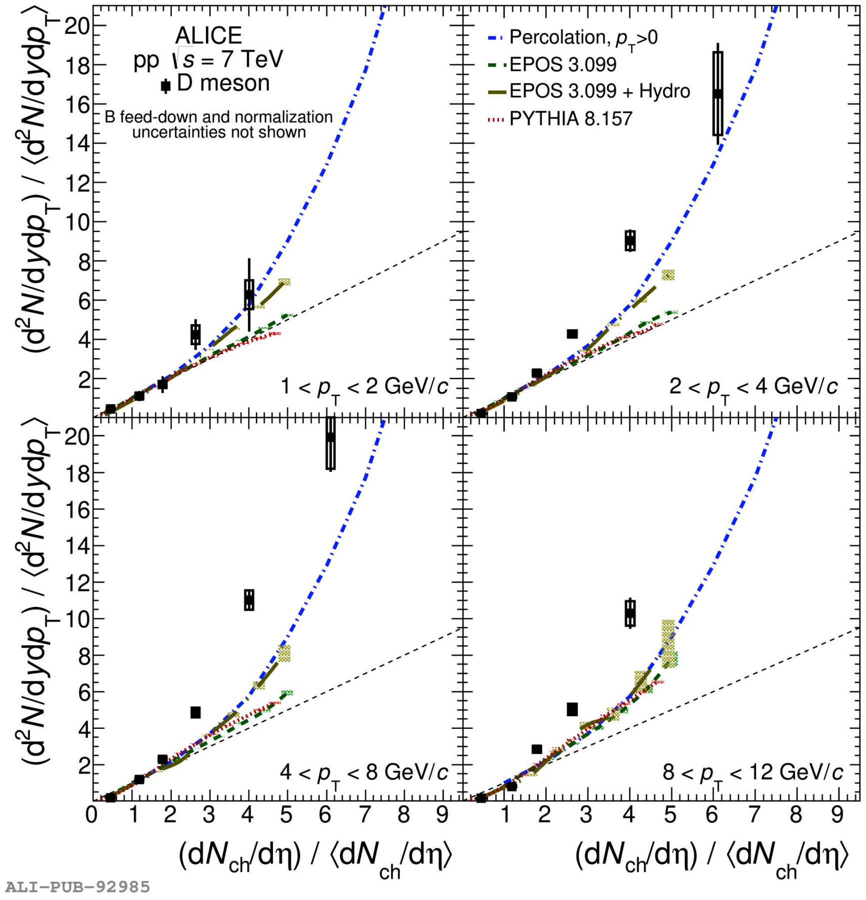
Enhancement of the Ξ baryon, which contains a strange quark, exceeds model predictions

Self-normalized multiplicity effects

JHEP 09 (2015) 148



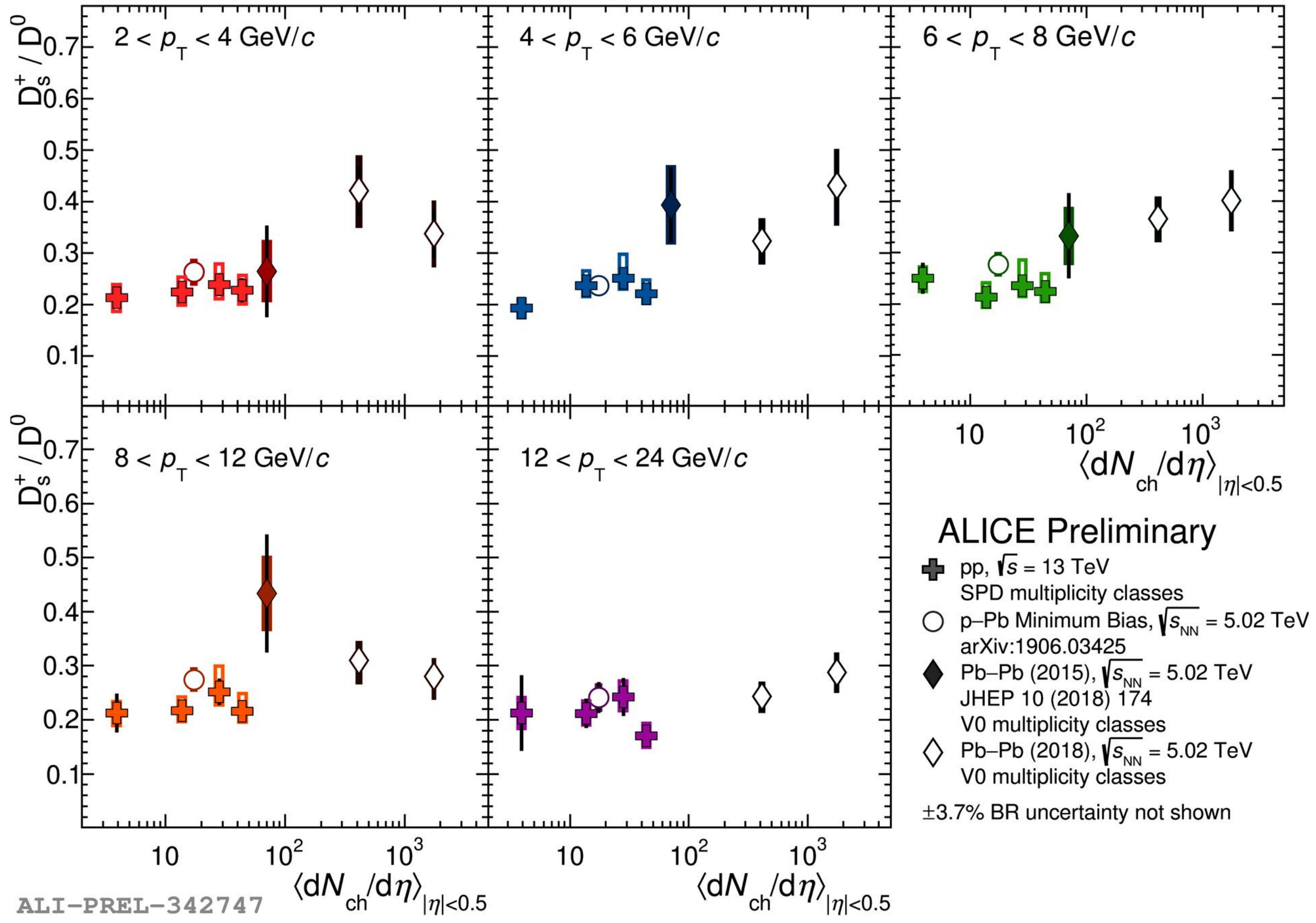
Production of electrons vs multiplicity

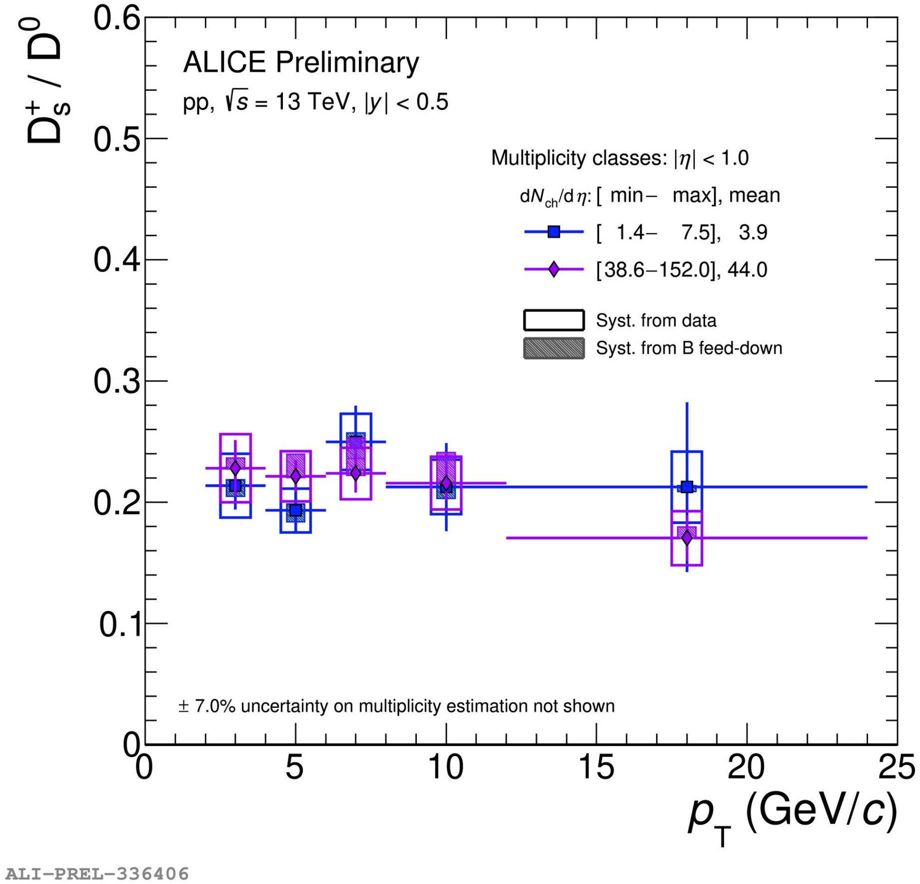


Production of D mesons vs multiplicity

Production of HF increases steeper than linearly with multiplicity.
Some models with multiple parton interaction and colour reconnection (CR) also expect this stronger-than-linear behaviour.

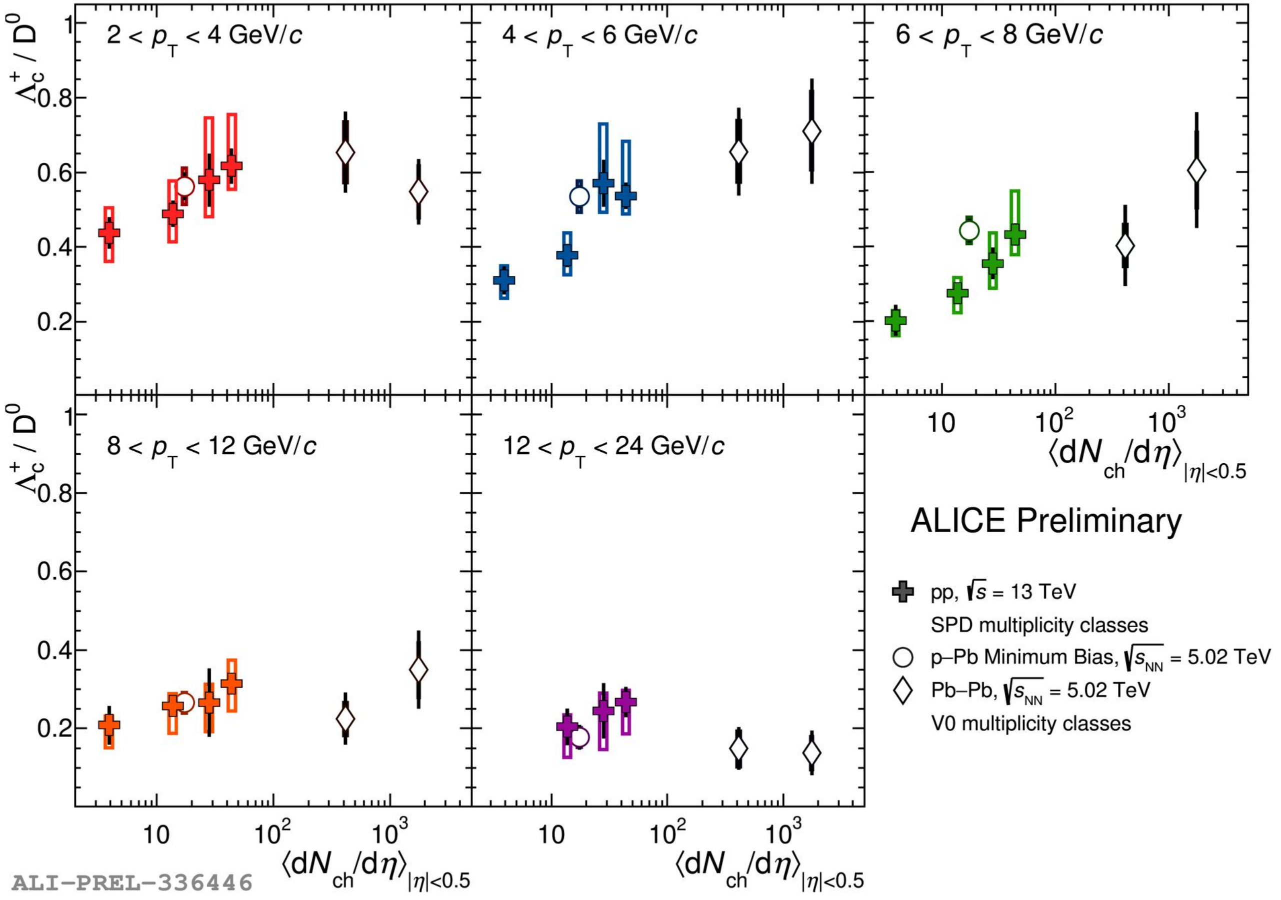
D_s/D^0 vs. multiplicity in pp, p-Pb and Pb-Pb

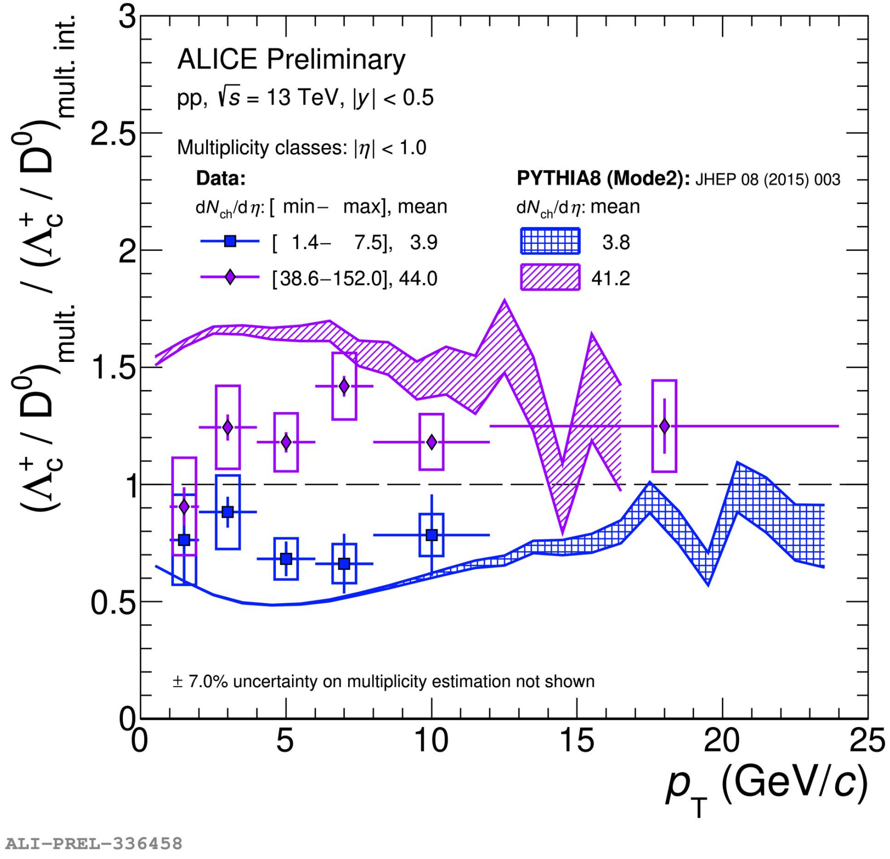




The ratio of strange to non-strange D mesons is almost independent from multiplicity in pp collisions. This behaviour differs from the light flavour [Nature Phys. 13 (2017) 535-539].

Baryon/meson vs. multiplicity in pp, p-Pb and Pb-Pb





Increasing trend from low towards higher multiplicities. PYTHIA8 with string formation beyond leading order (including MPI) effects recreate this behaviour [Christiansen, Skands, JHEP 1508 (2015) 003].

Conclusion

In small collision systems, such as pp, heavy flavours provide precision tests for QCD theoretical calculations. Production of heavy flavour measured from hadronic decays and semi-leptonic decays is within the uncertainties of the FONLL calculations.

Standard PYTHIA8 fails to describe the fragmentation of baryons at low p_T in pp collisions. PYTHIA8 with string formation beyond leading colour approximation, as well as a model with feed-down from augmented set of charm-baryon states provides better descriptions.

Self-normalized heavy-flavour yields increase with multiplicity stronger then linearly. This can be explained by multiple parton interaction. Charmed $\Lambda_c, \Sigma_c, \Xi_c$ baryons show a relative enhancement to charmed D mesons with multiplicity. However, strange D mesons do not show such an enhancement.