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

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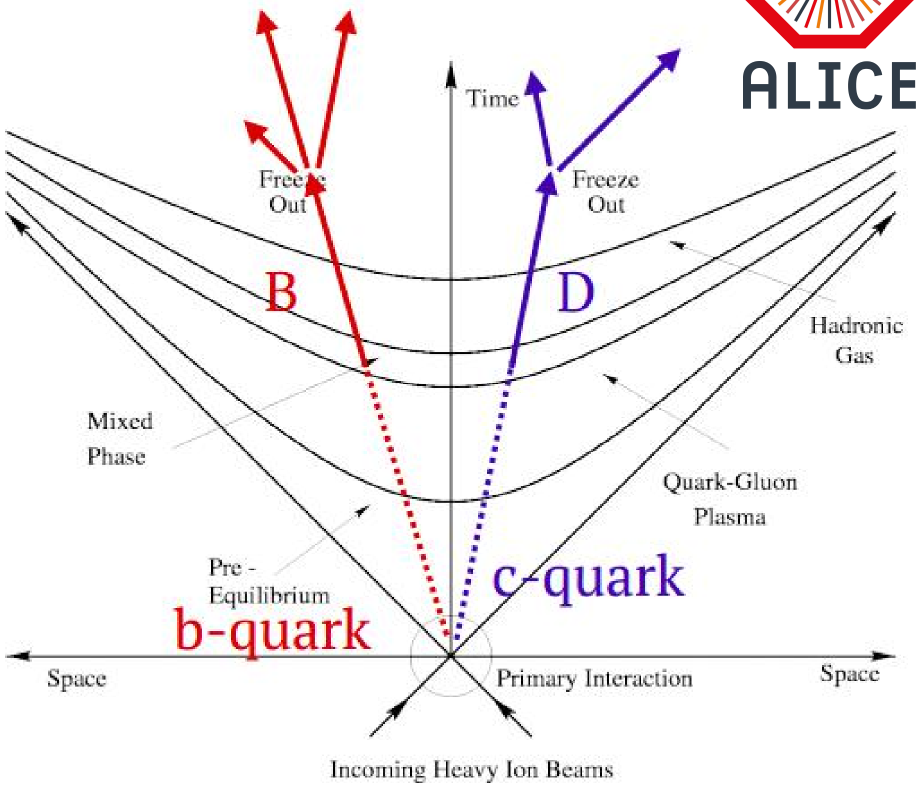
Motivation

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

Heavy flavours (HF) probe the whole evolution of the system.



In pp collisions heavy flavour is used for:

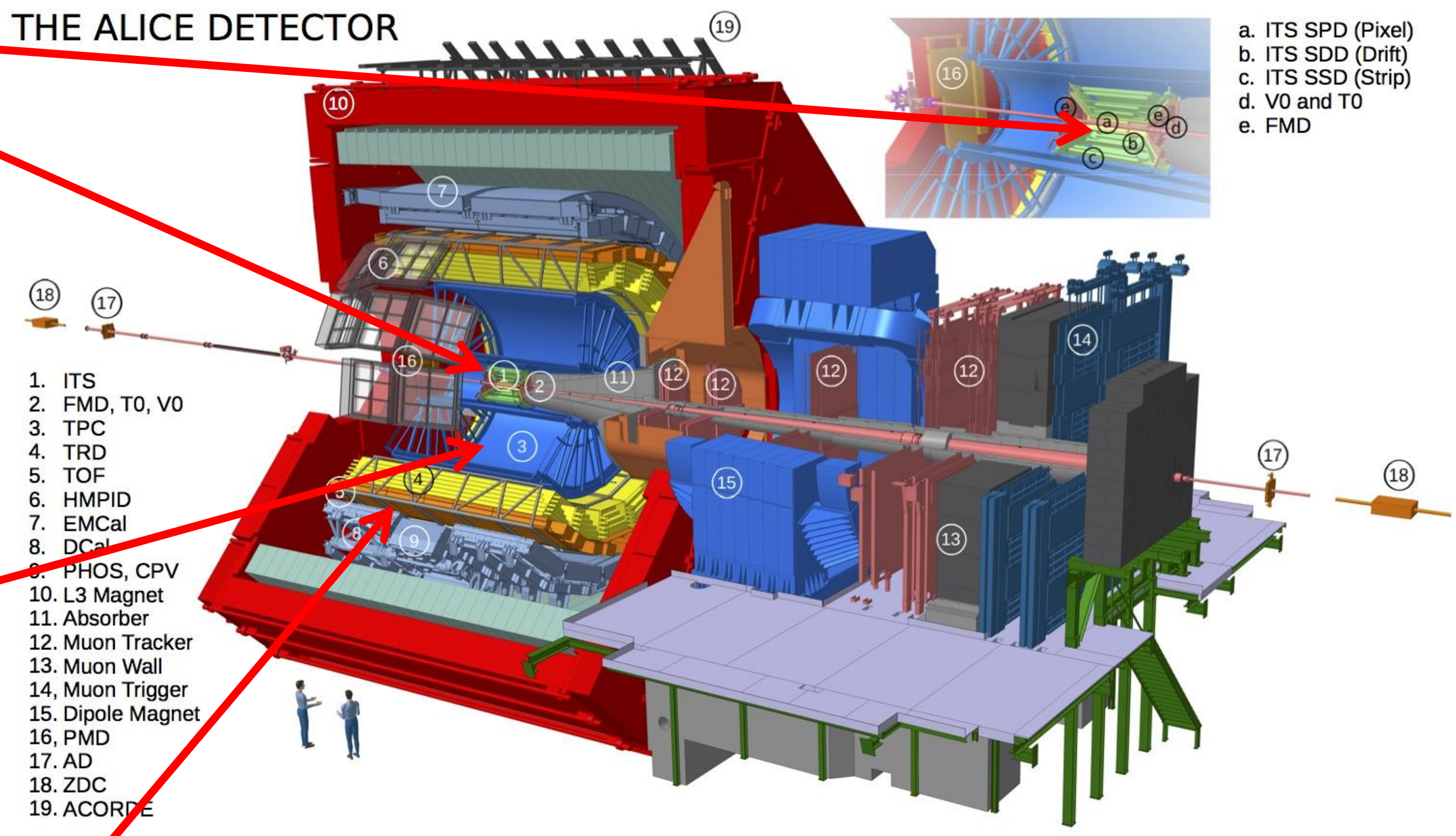
- testing perturbative QCD models;
- studying the fragmentation processes (baryons vs. mesons);
- studying the multiplicity dependent production (Multiple Particle Interactions).

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

The ALICE experiment

Inner Tracking System (ITS):
- 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):
- Tracking
- Particle identification via specific energy loss

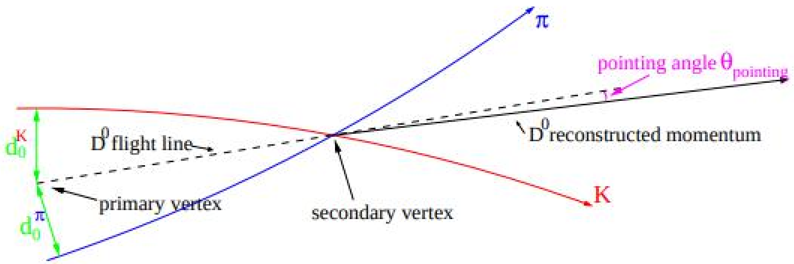
Time of Flight detector (TOF):
- Particle identification via time-of-flight measurement

Reconstruction of heavy flavour

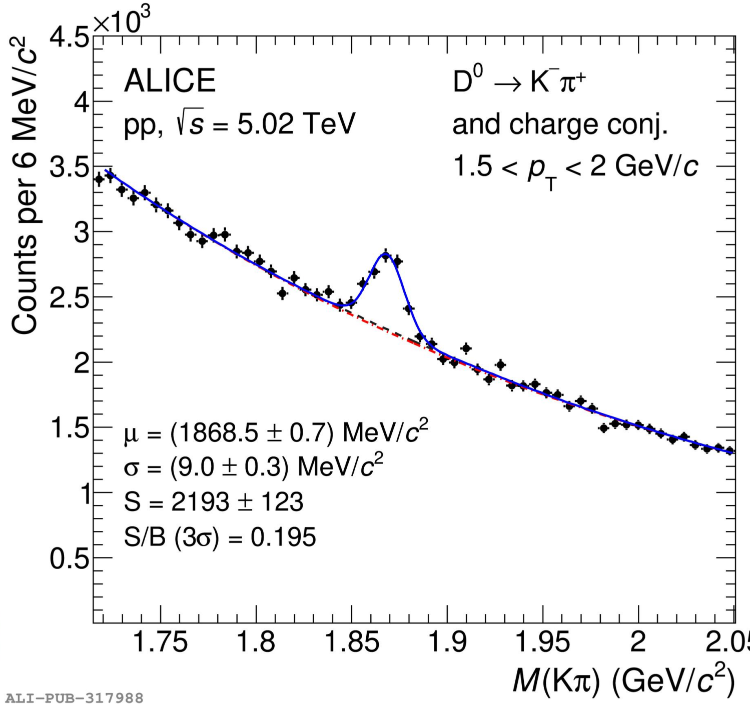
Hadrons containing heavy flavour have a mean free path up to few milimeters - they cannot be detected directly.

Reconstruction channels:
- via hadronic decays
- via semi-leptonic decays

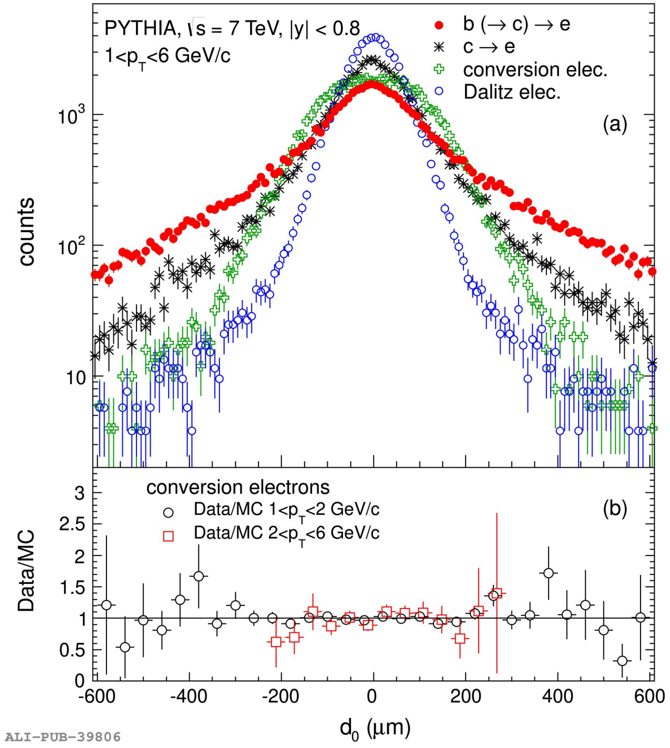
$D^0 \to K^- \pi^+$	$\Lambda_c^+ \to pK^- \pi^+$
$D^+ \to K^- \pi^+ \pi^+$	$\Lambda_c^+ \to pK_s^0$
$D_s^+ \to K^- K^+ \pi^+$	$\Sigma_c^0 \to \Lambda_c^+ \pi^-$
	$\Sigma_c^{++} \to \Lambda_c^+ \pi^+$
	$\Xi_c^0 \to \Xi_c^- \pi^+$
	$\Xi_c^+ \to \Xi_c^- \pi^+ \pi^+$



Reconstruction of a D^0 meson



Invariant mass fit of D^0 candidates



Impact parameter distribution of e^-

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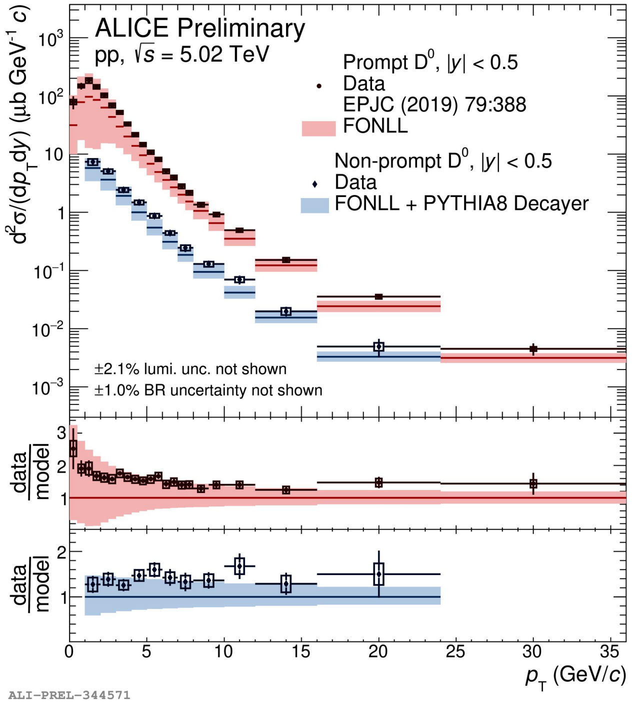
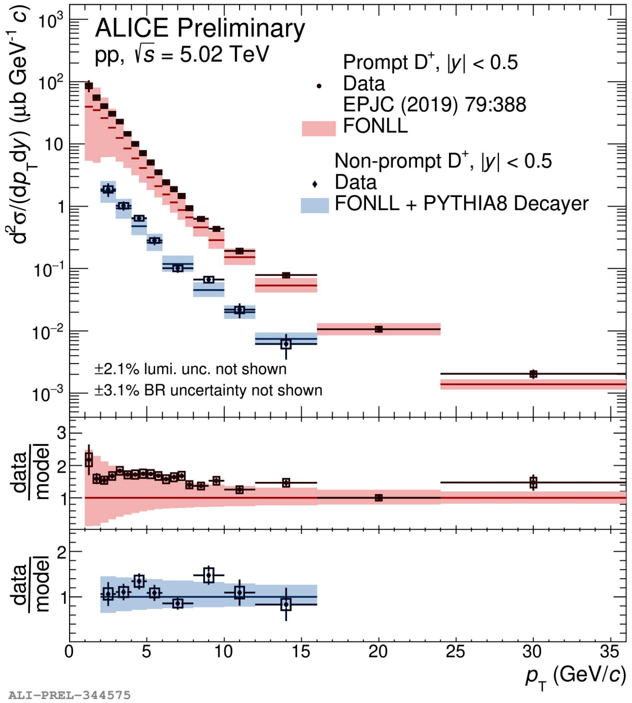
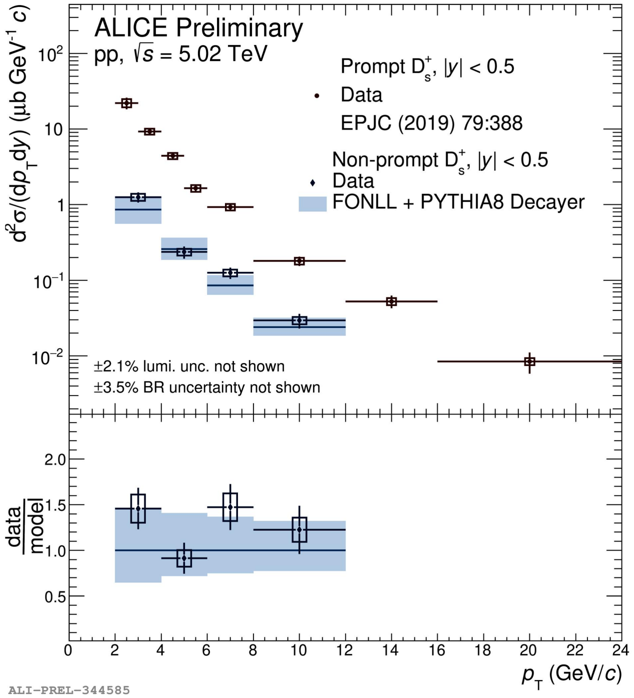
Prompt and non-prompt D mesons production



D^0 production cross section



D^+ production cross section



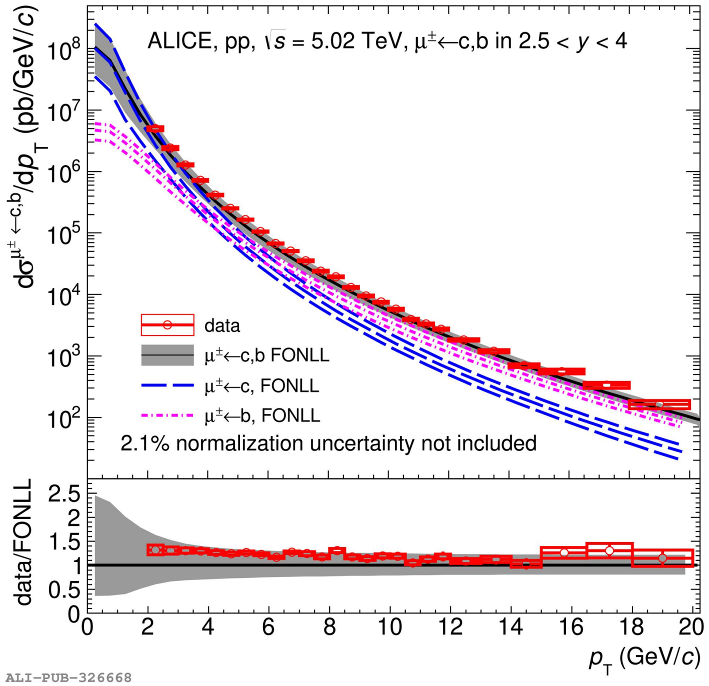
D_s^+ production cross section

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

Data is found towards the upper edge of the uncertainties of the FONLL calculations.

Muons and electrons from semi-leptonic decays

JHEP 09 (2019) 008



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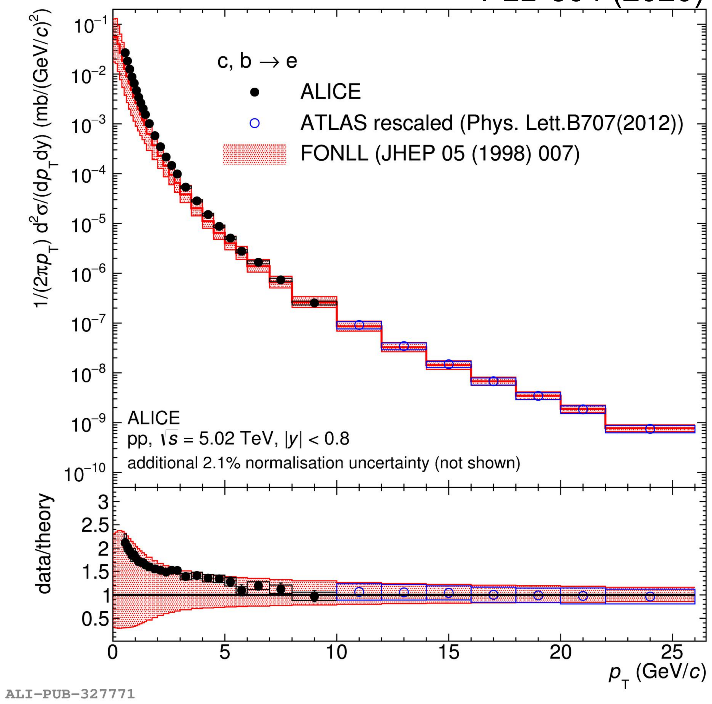
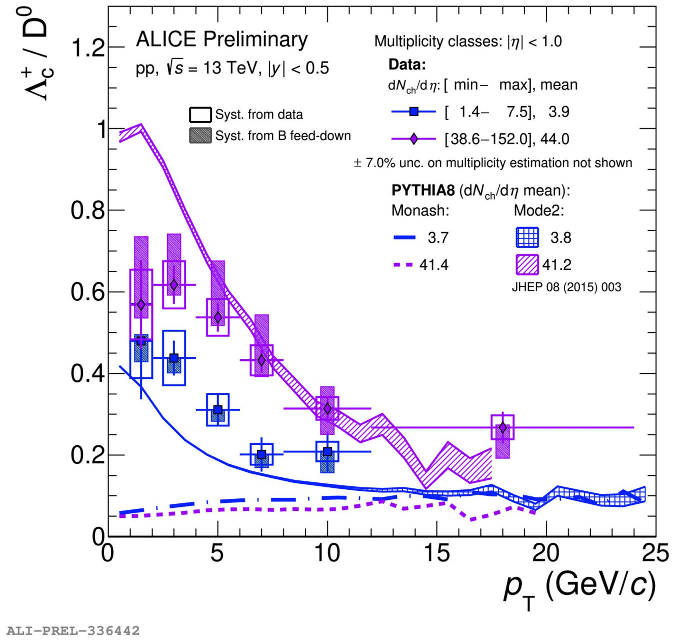


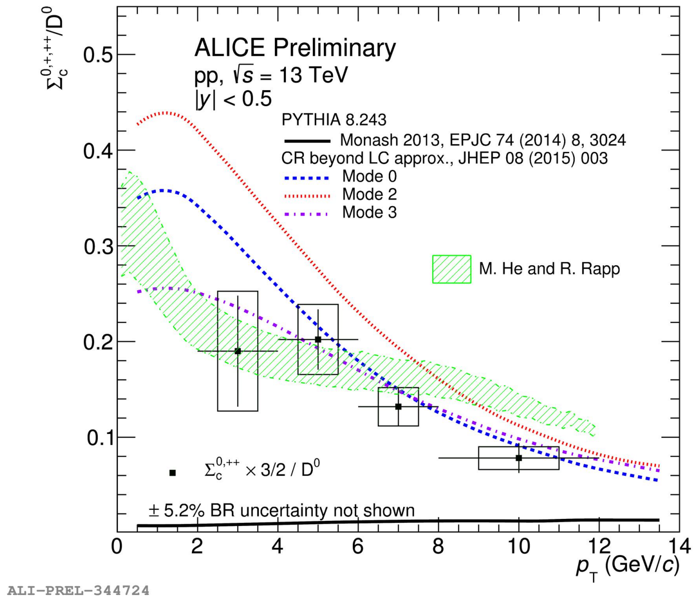
$\mu^{\pm}$ from HF-hadron decays (forward rapidity)

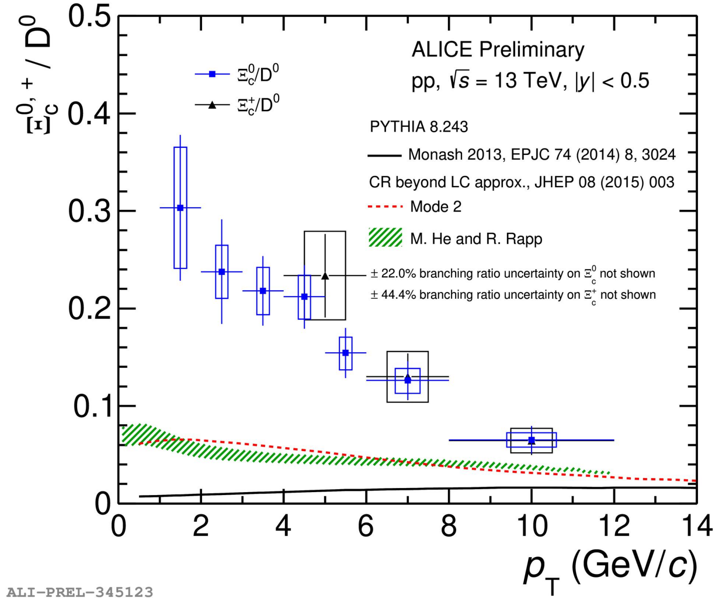
$e^{\pm}$ from HF-hadron decays (midrapidity)

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

Charmed baryon-to-meson ratios





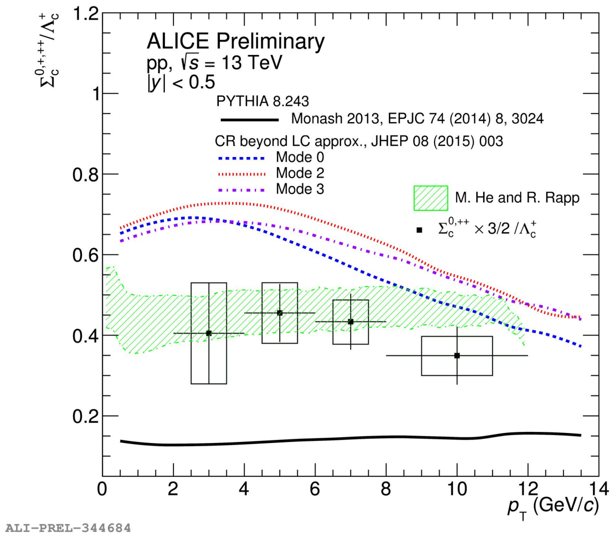


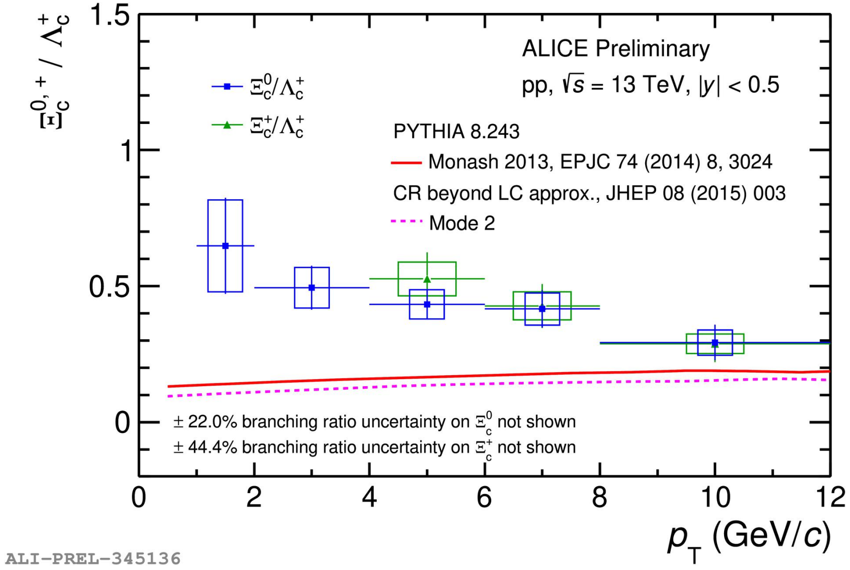
PYTHIA8 with fragmentation functions based on e^+e^- collisions fails to describe the ratios of baryons to mesons.

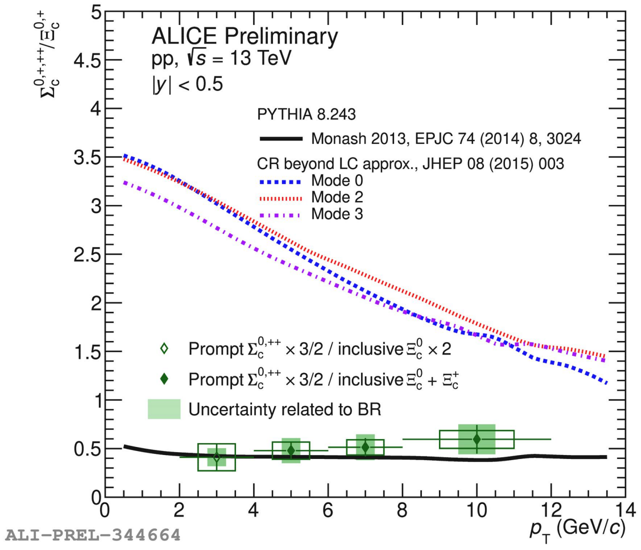
PYTHIA8 with string formation beyond leading colour approximation [Christiansen, Skands, JHEP 1508 (2015) 003], as well as feed-down from augmented set of charm-baryon states in an SHM model [He, Rapp, PLB 795 (2019) 117] tend to better describe the ratios.

Does charm hadronization depend on collision system?

Charmed baryon-to-baryon ratios







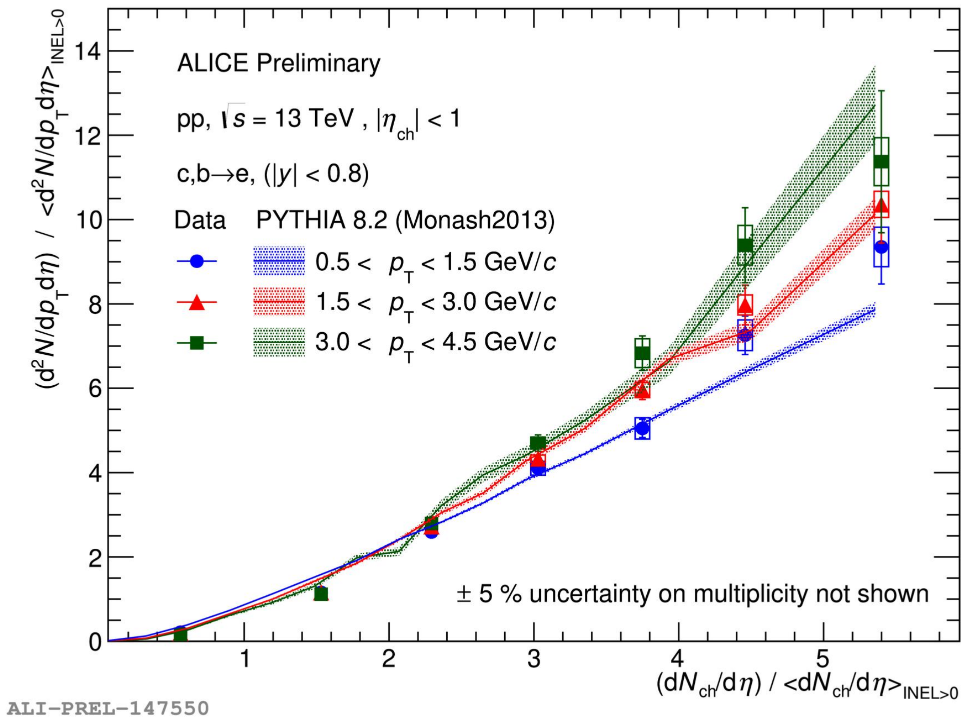
Charmed baryon-to-baryon ratios pose a challenge for most existing model calculations.

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.

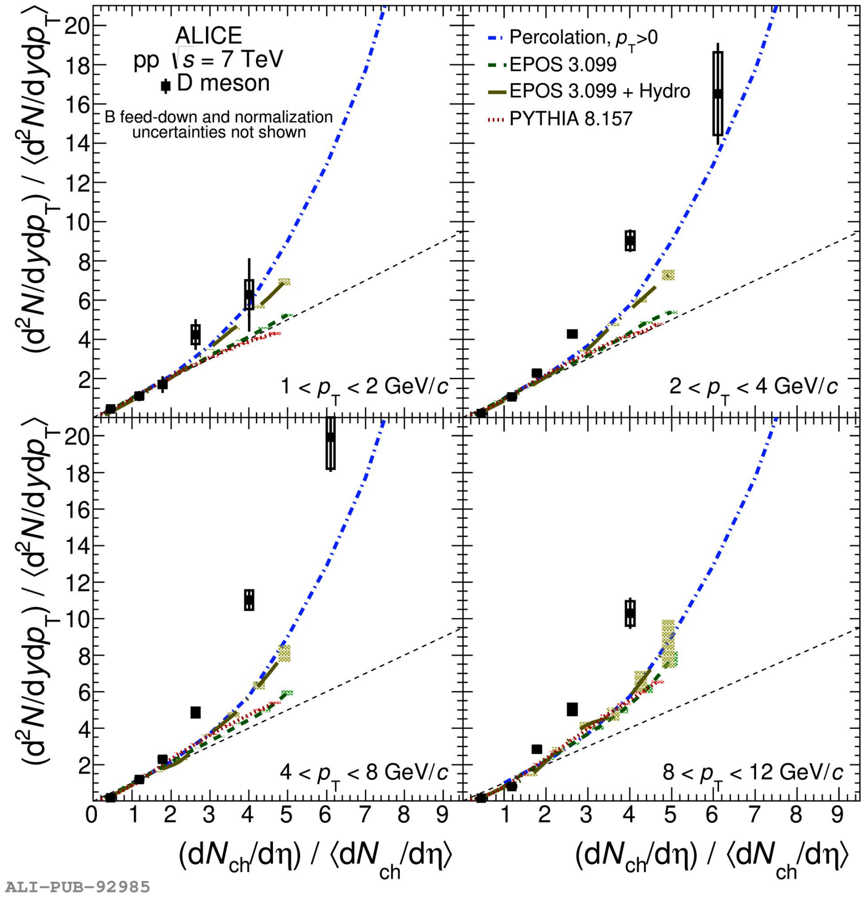
Enhancement of the Ξ baryon, which contains a strange quark, exceeds model predictions

Self-normalized multiplicity effects

JHEP 09 (2015) 148



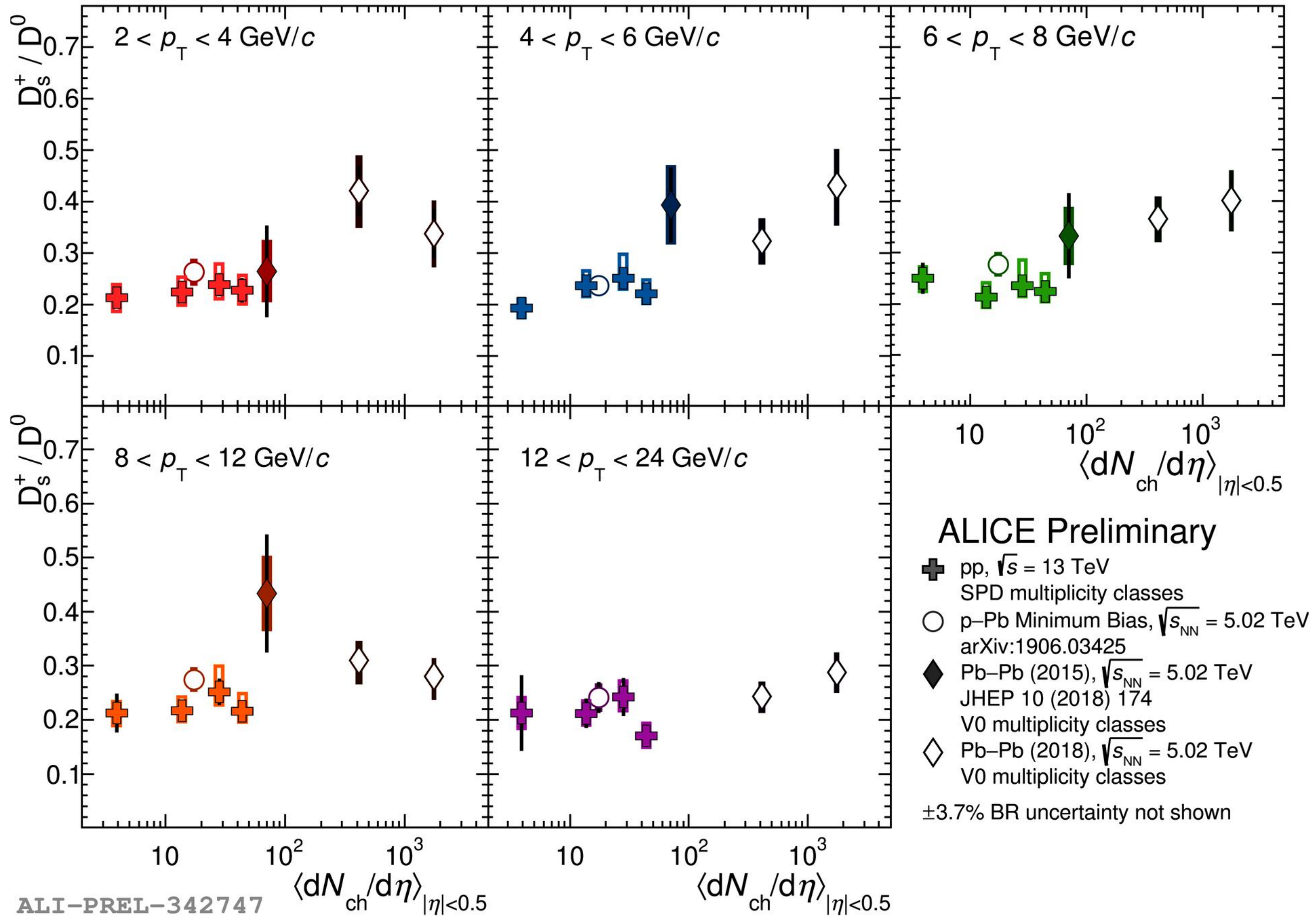
Production of electrons vs multiplicity

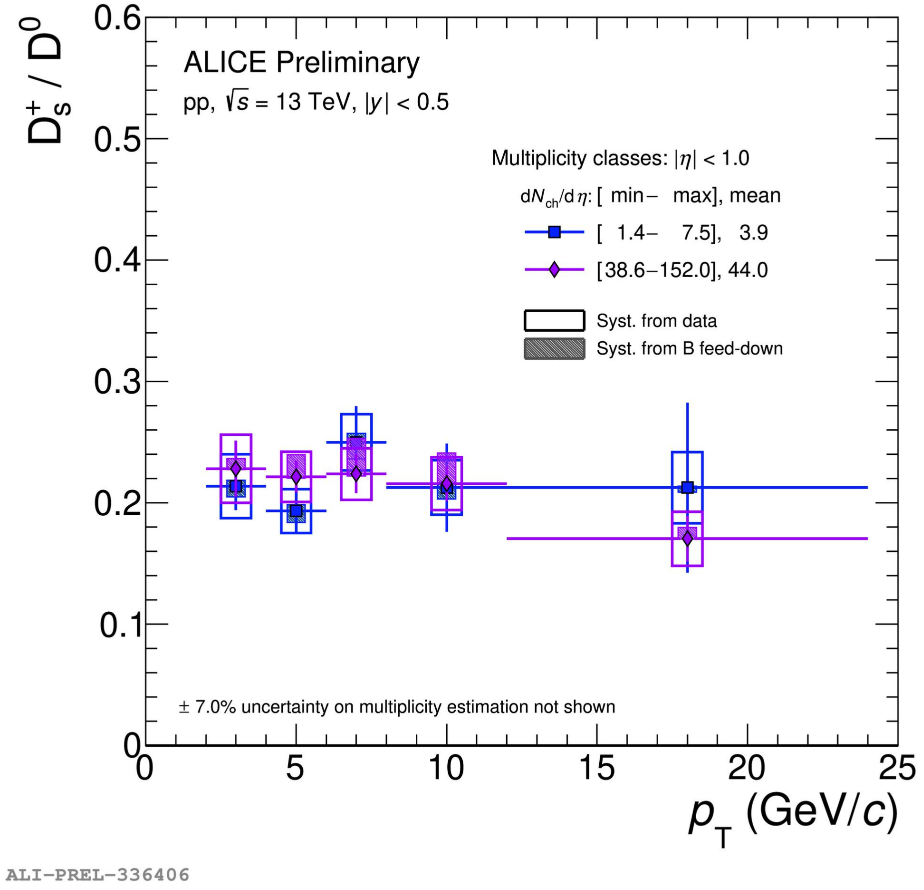


Production of D mesons vs multiplicity

Production of HF increases steeper than linearly with multiplicity.
Some models with MPI also expect this stronger-than-linear behaviour.

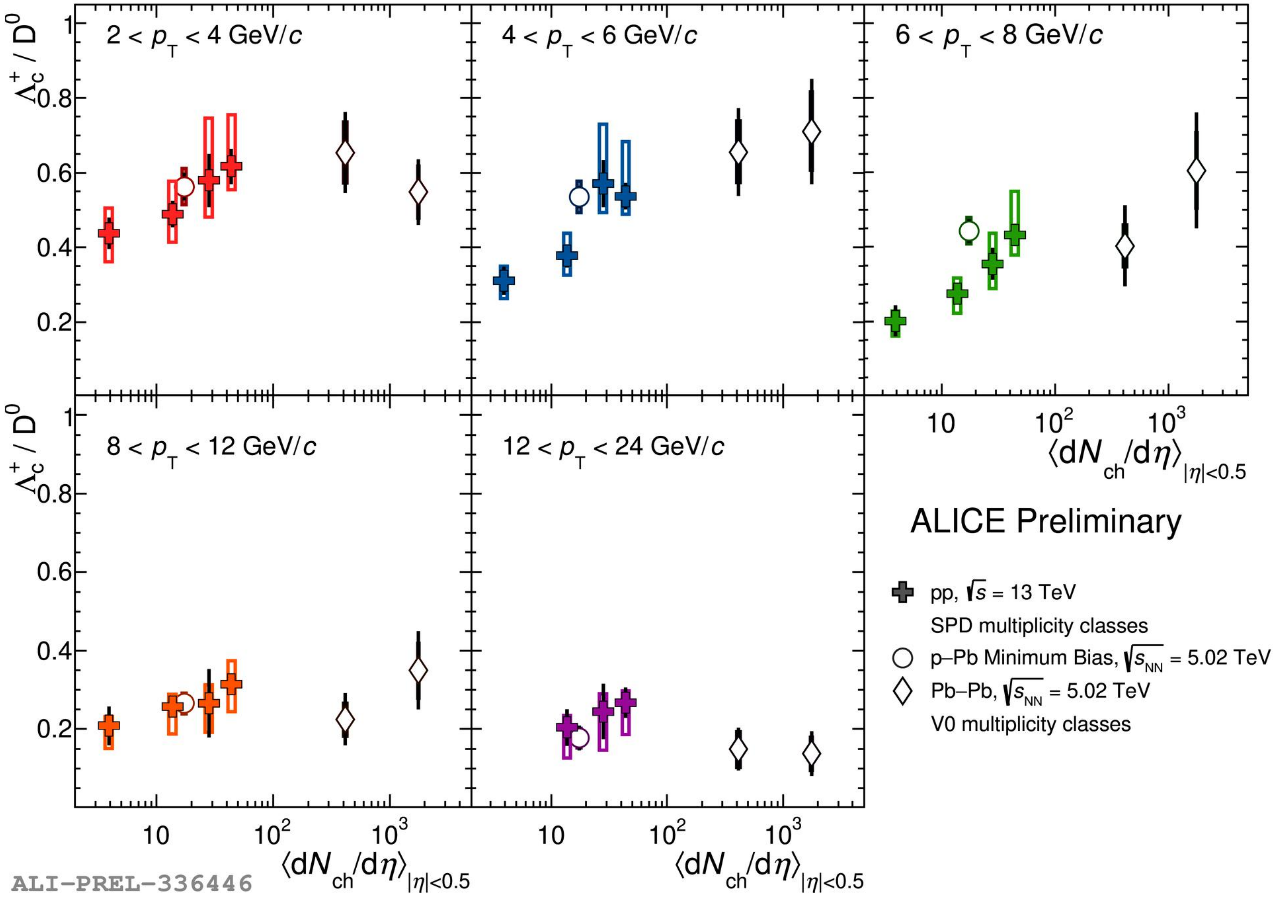
D_s/D^0 vs. multiplicity in pp, p--Pb and Pb--Pb

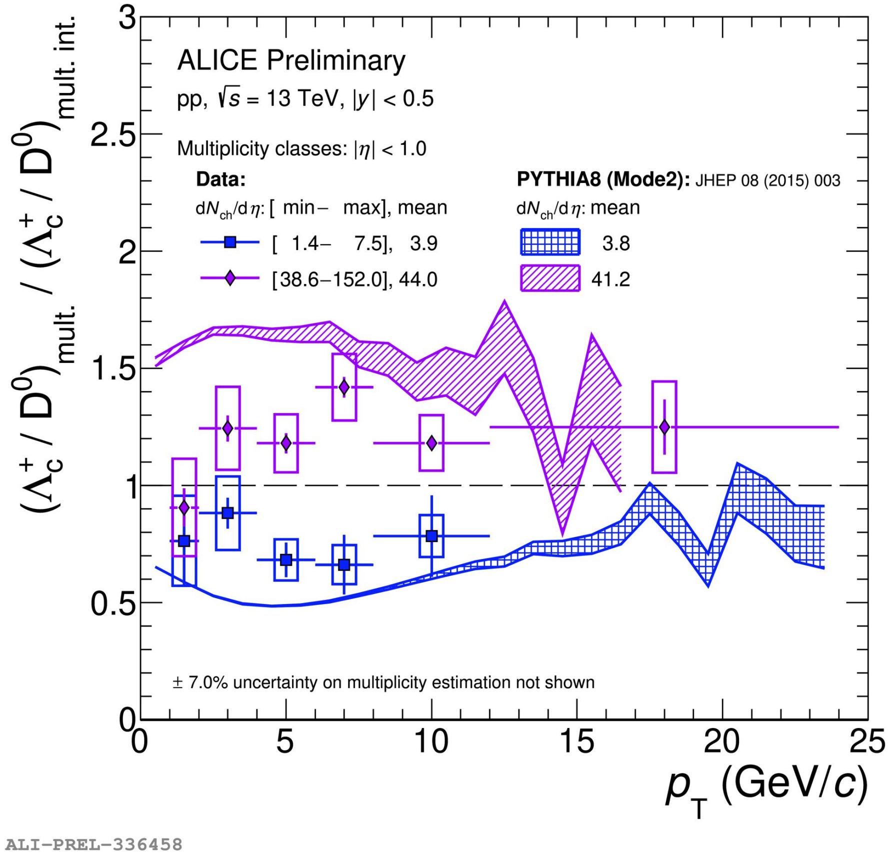




The ratio of strange to non-strange D mesons is almost independent from multiplicity in pp collisions. This behaviour differs from the light flavour [Nature Phys. 13 (2017) 535-539].

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 MPI. Charmed $\Lambda_{\mathrm{c}}, \Sigma_{\mathrm{c}}, \Xi_{\mathrm{c}}$ baryons show a relative enhancement to charmed D mesons with multiplicity. However, strange D mesons do not show such an enhancement.