Heavy-flavour production as a function of event activity in pp collisions at the ALICE experiment

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QCD@Work
International Workshop on QCD Theory and Experiment

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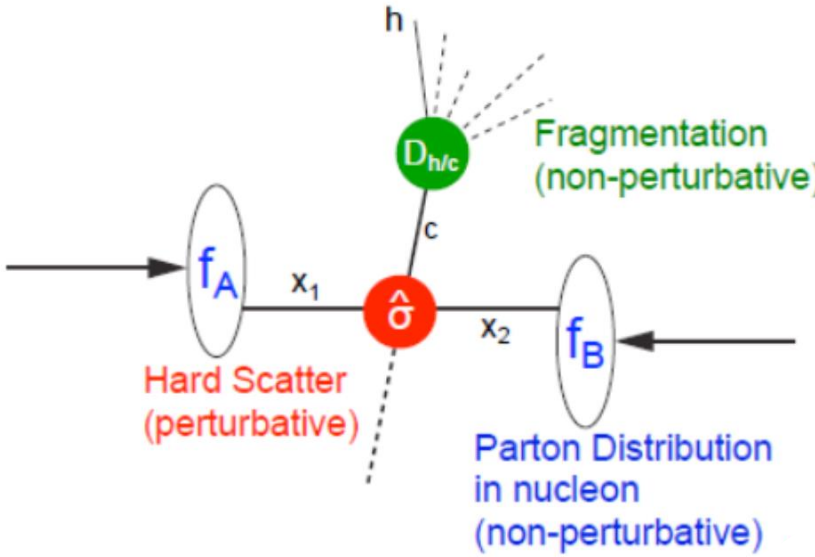
Introduction

- Heavy-flavour (c and b) quarks are produced in the **initial stages** of hadronic collisions in hard partonic scatterings

- Heavy-flavour hadron production cross section calculated in pQCD using a **factorisation approach**: $\sigma_{hh\to H} = f_a(x_1,Q^2) \otimes f_b(x_2,Q^2) \otimes \sigma_{ab\to q\bar{q}} \otimes D_{q\to H}(z_q,Q^2)$

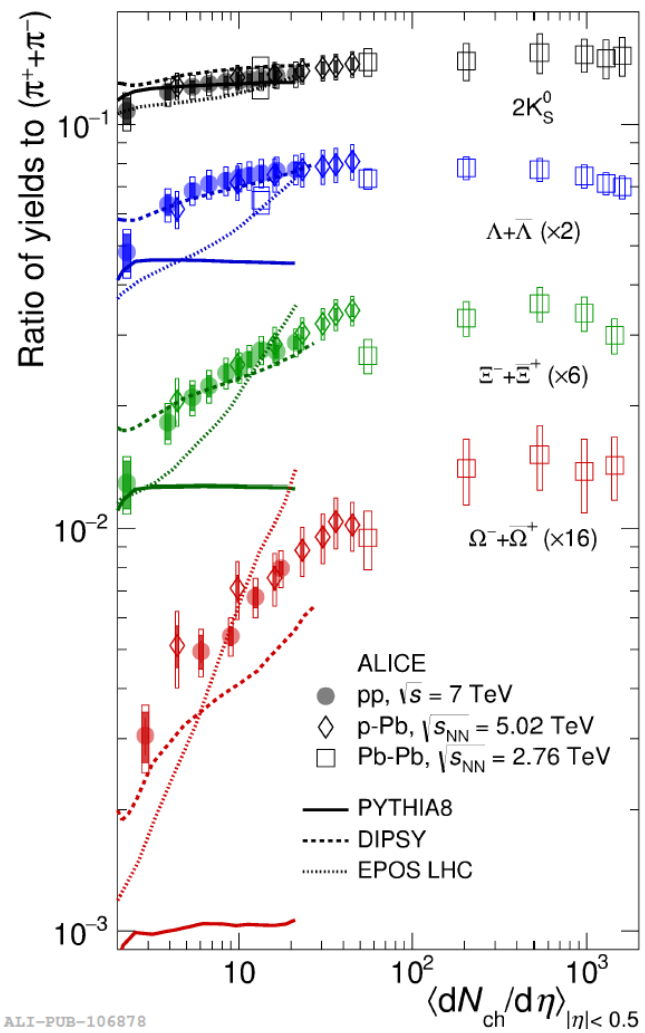


- In proton–proton collisions heavy flavour measurements are generally used for **testing the pQCD** and flavour-dependent fragmentation. Additionally, they provide a **baseline for heavy-ion collisions**

Introduction

- **High-multiplicity pp collisions** show similar signatures to those observed in heavy-ion collisions where the formation of a quark-gluon plasma (QGP) is expected:

Nature Phys. **13** (2017) 535-539



Strangeness enhancement

Introduction

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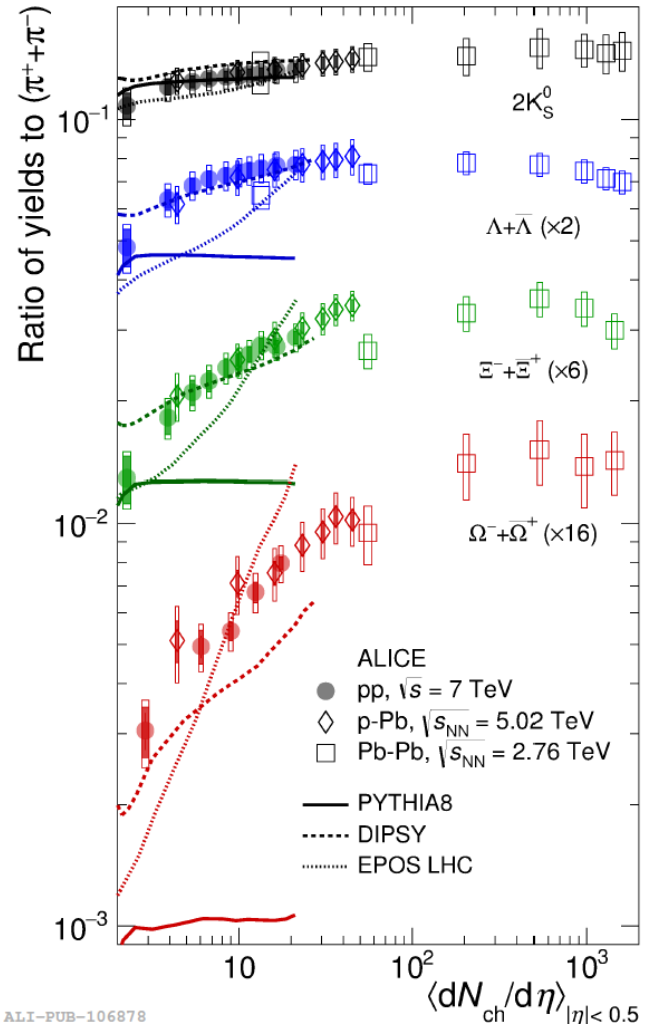
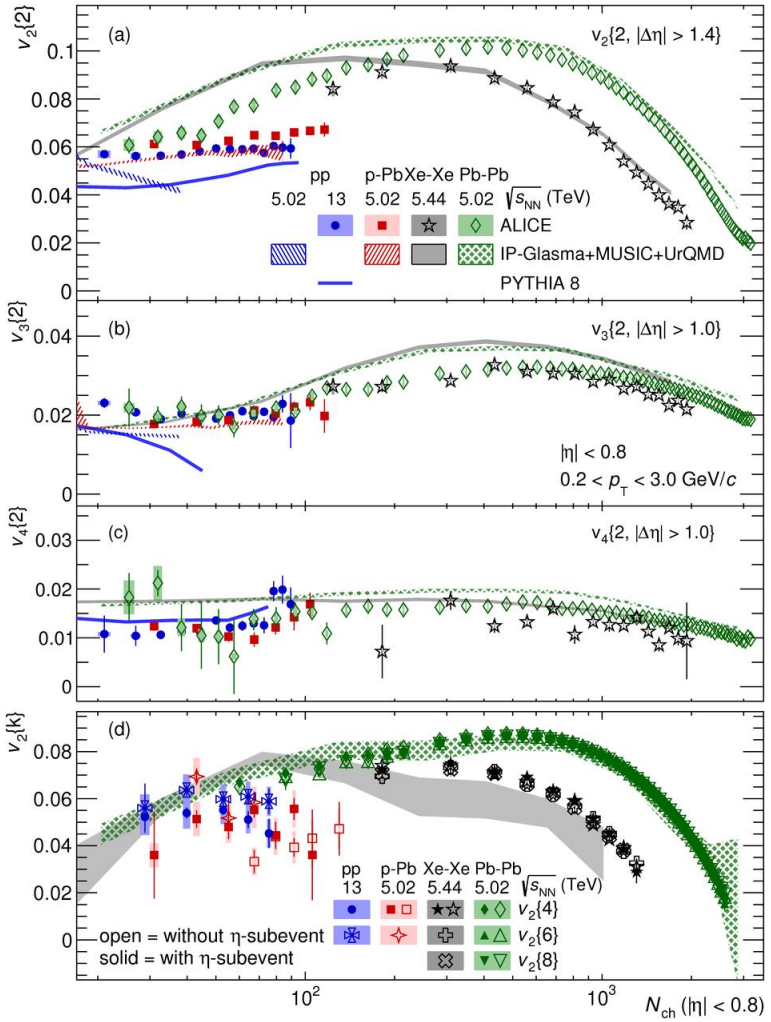


Phys. Rev. Lett. **123** (2019) 142301



Strangeness enhancement

Anisotropic flow

(long-range multiparticle correlations)

Introduction

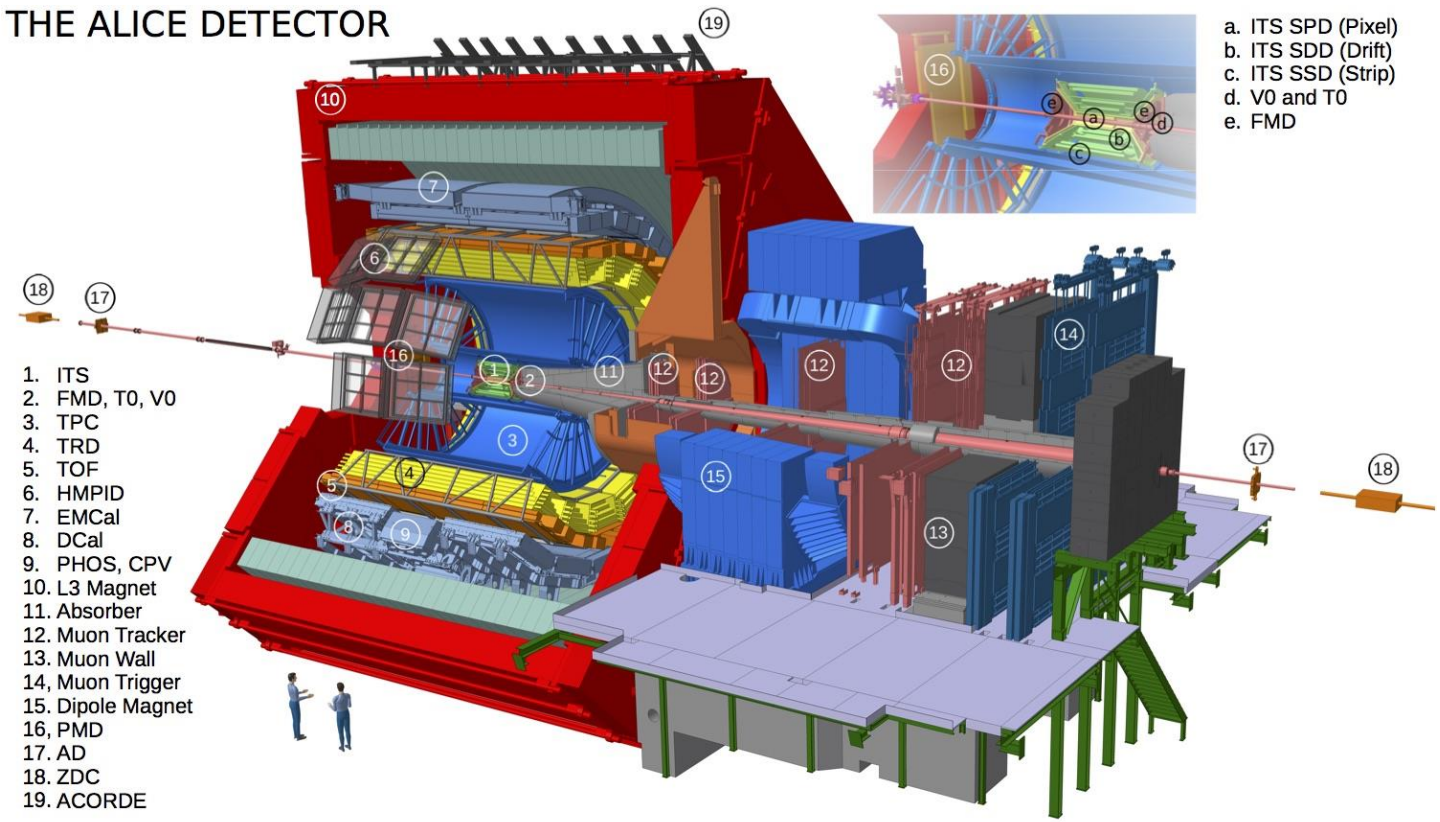
In addition to the search of QGP-like effects, the measurement of heavy-flavour production as a function of charged-particle multiplicity and event-activity observables also allows us to investigate:

- Interplay between the hard and soft particle production
- Role of multiparton interactions (MPI) in heavy-quark production processes
- The assumed universality of charm fragmentation across different collision systems

The ALICE detector (Run 2)

The ALICE detector is excellent in reconstructing identified particles over a broad momentum range and in reconstructing primary and displaced secondary vertices

- **Inner Tracking System** (vertexing, tracking, PID, $|\eta| < 0.9$)
- **Time Projection Chamber** (tracking, PID, $|\eta| < 0.9$)
- **Time-Of-Flight detector** (PID, $|\eta| < 0.9$)
- **V0 detectors** (multiplicity and event activity determination, triggering, $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$)

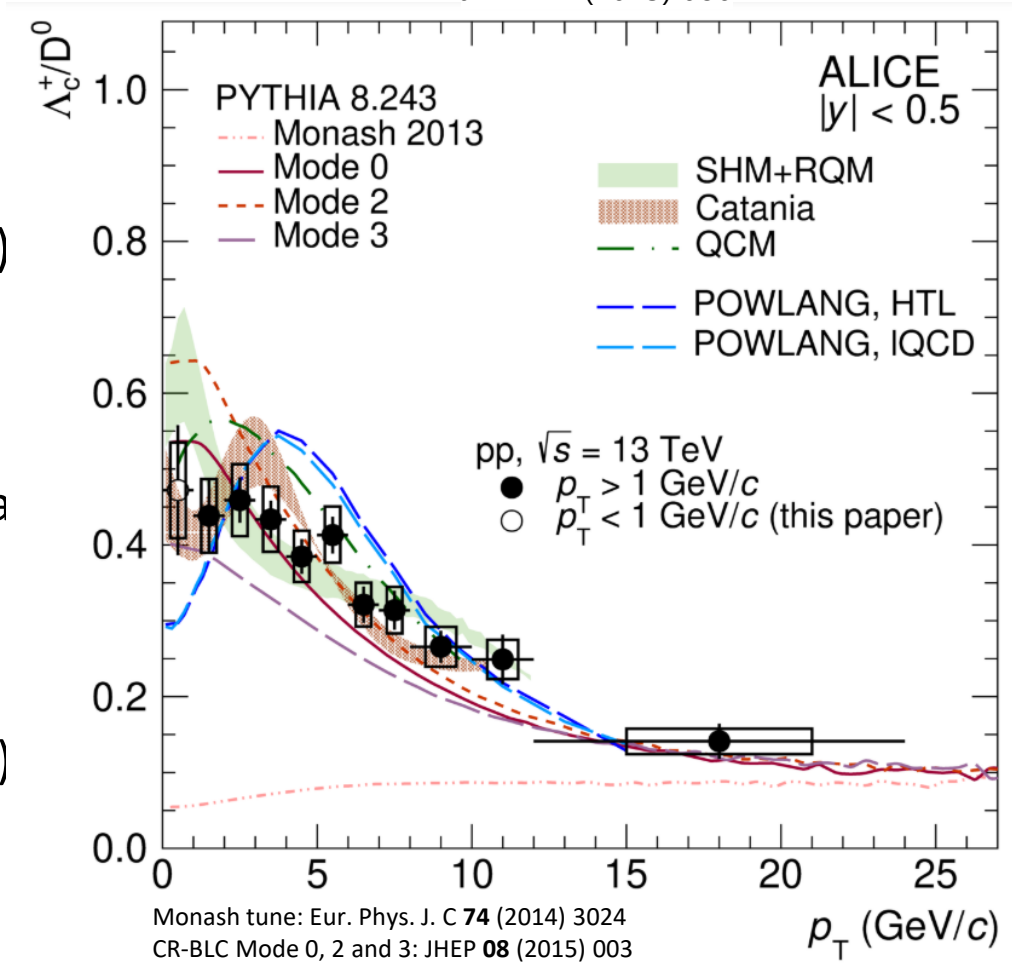


Charm-hadron yield ratios

Λ_c^+/D^0 (baryon-to-meson):

- Significant enhancement at low and intermediate p_T w.r.t. e^+e^- and e^+p collision measurements (LEP average is 0.113±0.013±0.006)
- PYTHIA 8 with Monash tune (based on e^+e^- and e^+p fragmentation) fails to describe the trends
- Several other models with modified fragmentation or augmented feed-down to charm baryons reproduce well the behaviour of data
  - ✓ Colour-reconnection models (CR-BLC Mode 0, 2, 3)
  - ✓ Statistical hadronisation model (SHM+RQM)
  - ✓ Quark coalescence models (Catania and QCM)
  - ✓ POWLANG (which assumes the formation of QGP-like medium)

JHEP **12** (2023) 086



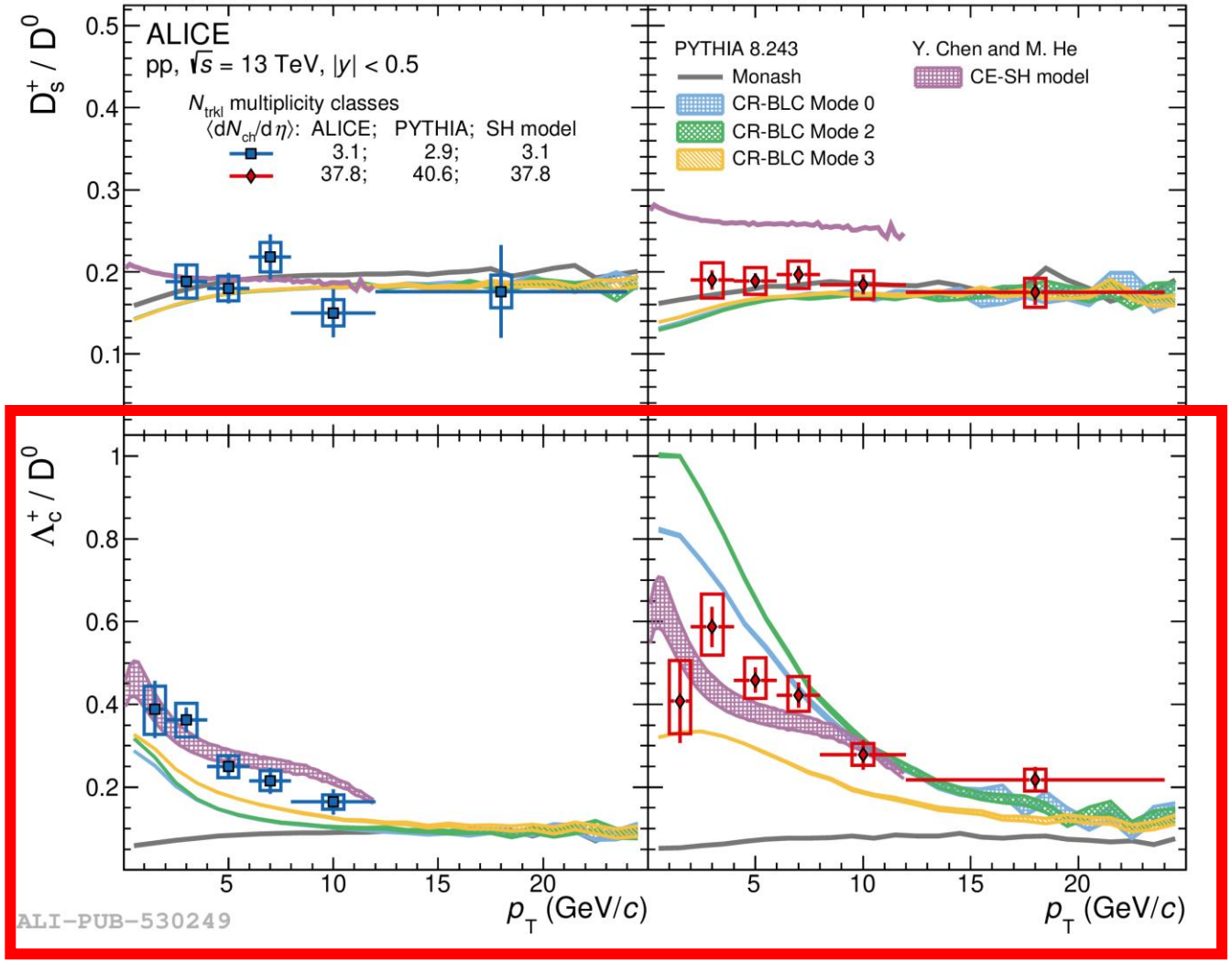
Monash tune: Eur. Phys. J. C **74** (2014) 3024
CR-BLC Mode 0, 2 and 3: JHEP **08** (2015) 003
SHM+RQM: Phys. Lett. B **795** (2019) 117
Catania: Phys. Lett. B **821** (2021) 136622
QCM: Eur. Phys. J. C **78** (2018) 344
POWLANG: Phys.Rev.D **109** (2024) 1

Charm-hadron yield ratios vs. multiplicity

Λ_c^+/D^0 (baryon-to-meson):

- Significant dependence on multiplicity at low p_T (5.3σ increase from low to high multiplicity)
- PYTHIA 8 with CR-BLC tunes qualitatively describes the multiplicity dependence
- CE-SH (canonical ensemble + statistical hadronisation) model describes well the multiplicity dependence

Phys.Lett.B **829** (2022) 137065

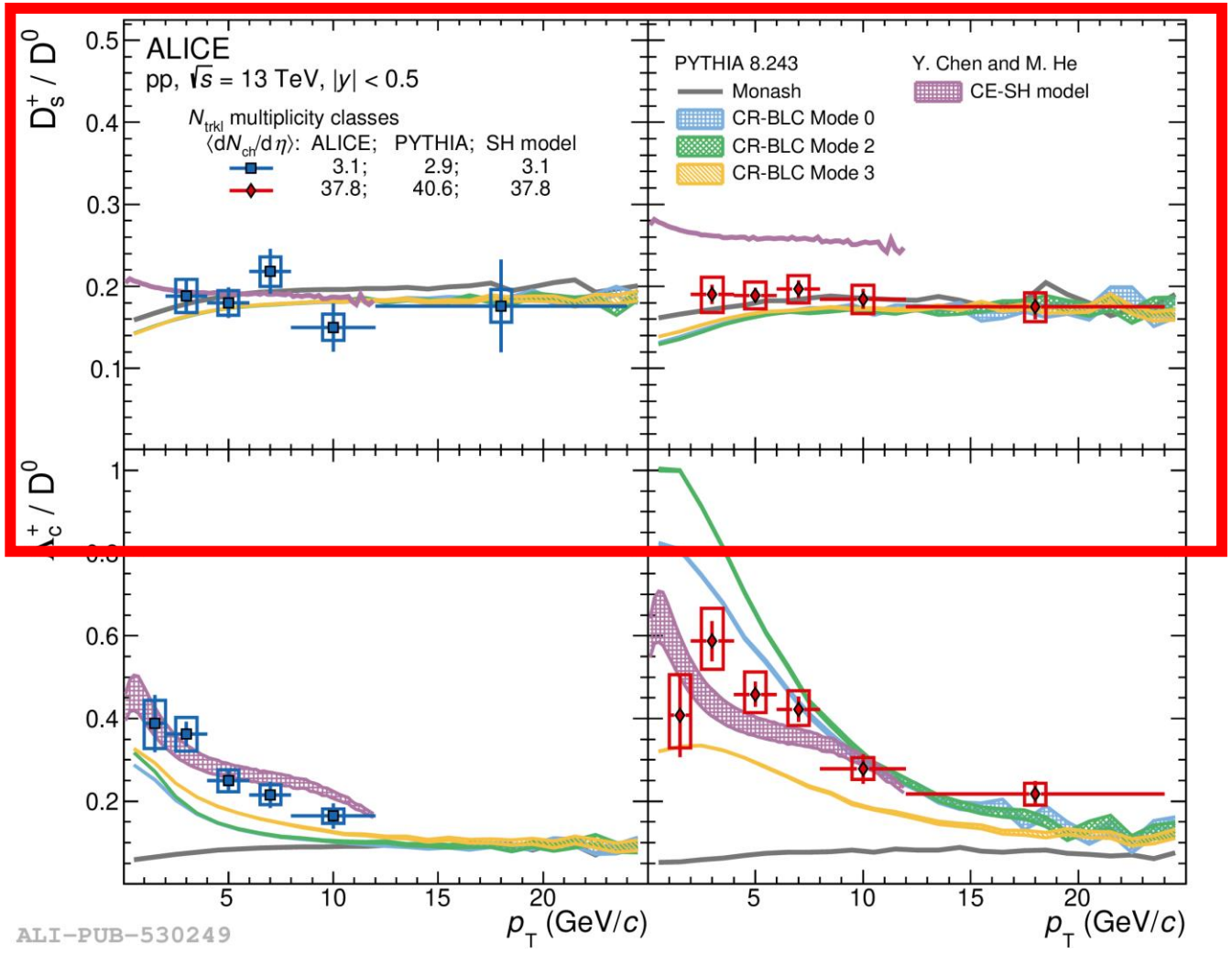


CE-SH: Phys. Lett. B **815** (2021) 136144

Charm-hadron yield ratios vs. multiplicity

D_S^+/D^0 (meson-to-meson):

- Independent of p_T and multiplicity
- Described well by different models, except for the CE-SH model, which overestimates the data at high multiplicities



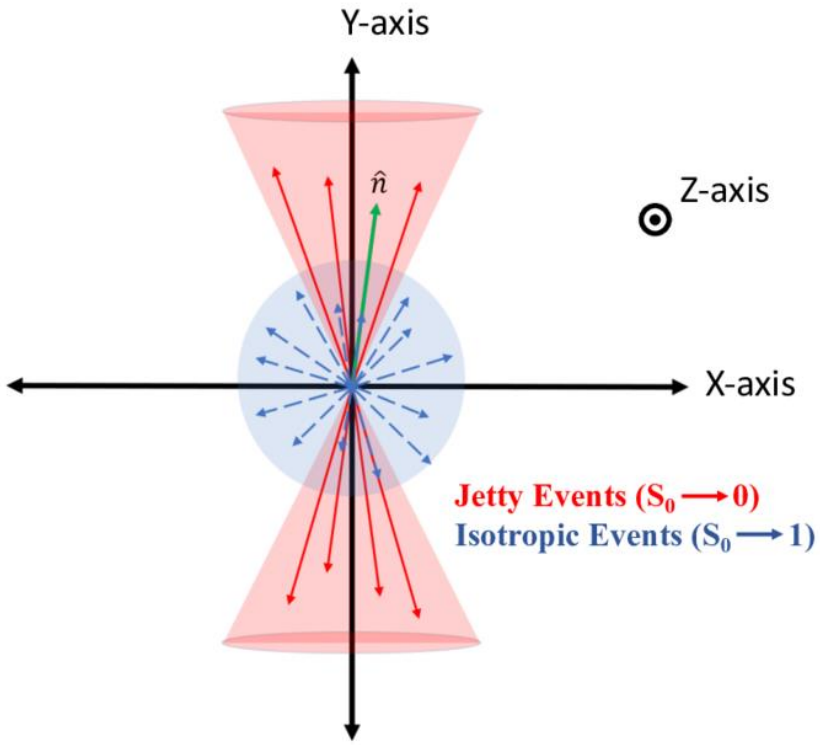
CE-SH: Phys. Lett. B **815** (2021) 136144

Transverse spherocity

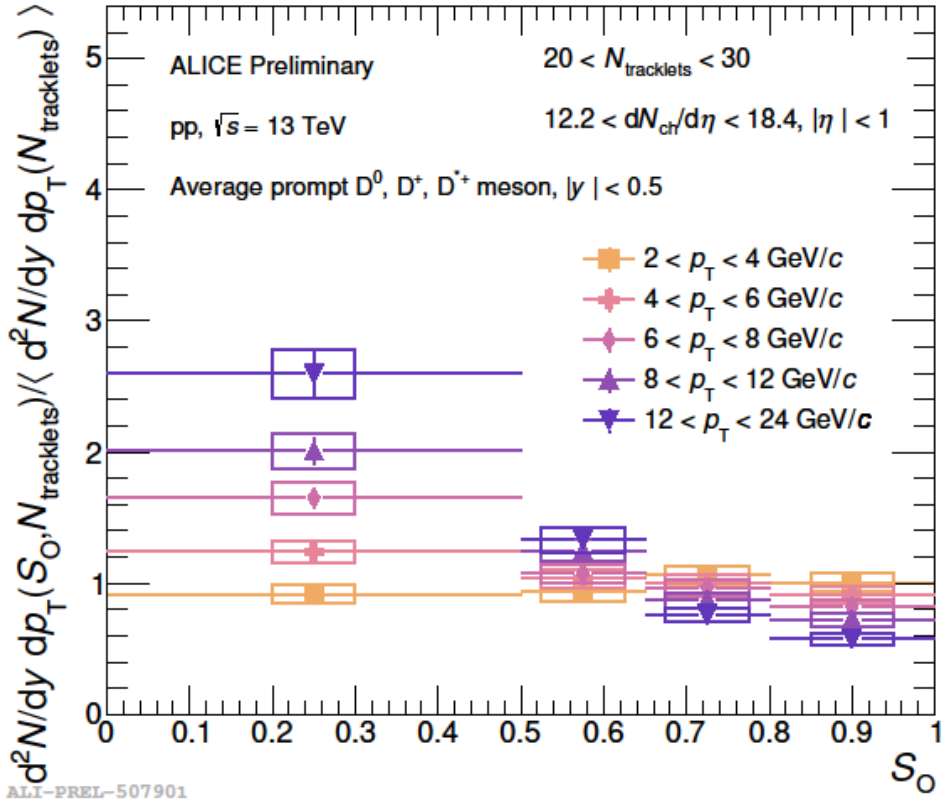
- Event-shape observable

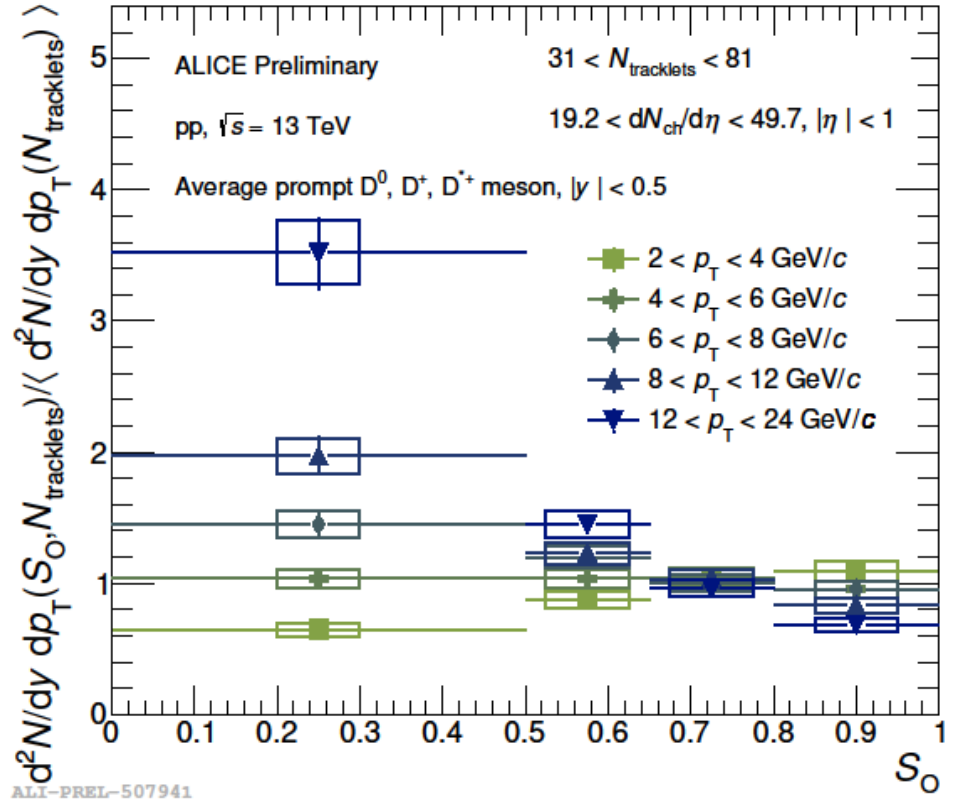
$$S_{\mathrm{O}}^{(p_{\mathrm{T}}=1.0)} = \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left(\frac{\Sigma_i \left| \hat{p}_{\mathrm{T_i}}^{(p_{\mathrm{T}}=1.0)} \times \hat{n} \right|}{N_{\mathrm{tracks}}} \right)^2$$

- Sensitive to initial hard scatterings and underlying event
- $S_{\mathrm{O}} \to 0$: jetty events, dominated by hard QCD processes
- $S_{\mathrm{O}} \to 1$: isotropic events, dominated by soft QCD processes



D-meson self-normalised yields vs transverse spherocity



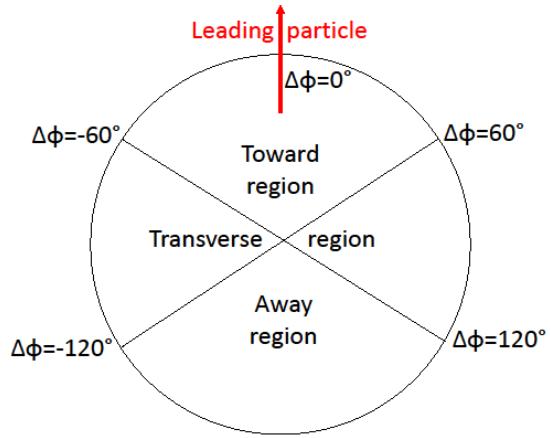


- Hint of enhancement of D-meson production toward higher multiplicity in jetty events
- Effect of hard scatterings leading to average increase in charged-particle multiplicity

Transverse event activity

- Event-activity observable

$$R_{\mathrm{T}} = \frac{N_{\mathrm{T}}^{\mathrm{ch}}}{\langle N_{\mathrm{T}}^{\mathrm{ch}} \rangle}$$



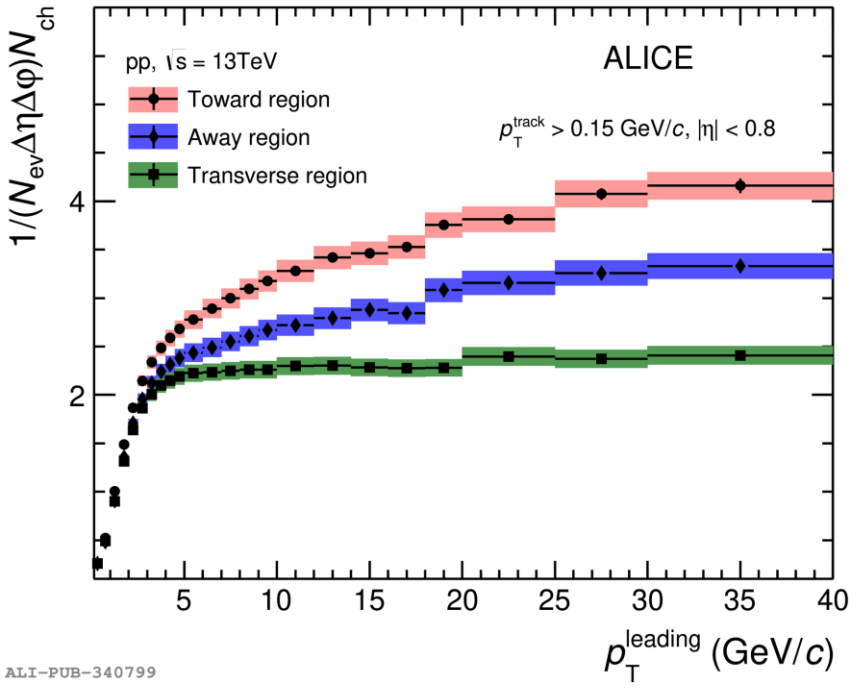
- Transverse region is not influenced by the hard scattering process for leading particle p_{T} >5 GeV/c

- The region is influenced mainly by the underlying event

- $R_{\mathrm{T}} < 1$: low underlying-event activity

- $R_{\mathrm{T}} > 1$: high underlying-event activity

JHEP **04** (2020) 192



D^0-meson yields vs transverse event activity

In toward region:

- At high p_T D^0-meson production is independent of transverse activity – these hadrons are produced in connection to the leading process
- At low p_T a hint of dependence on transverse activity is observed
- PYTHIA 8 with Monash and CR-BLC Mode 2 tunes describe the data well within the uncertainties

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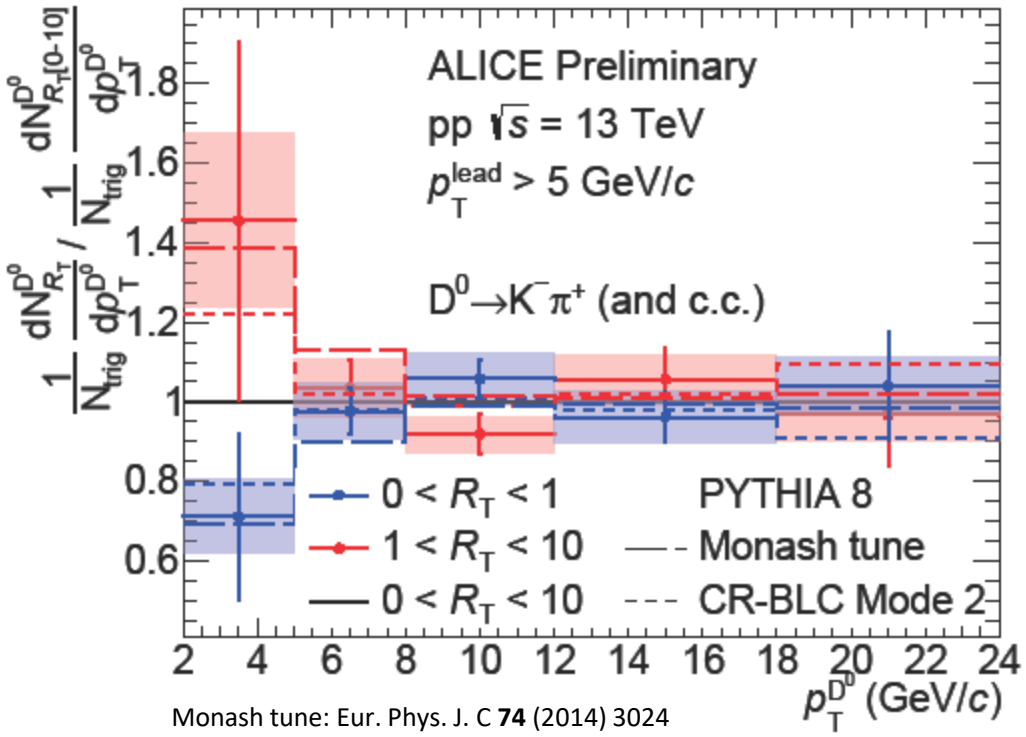

Monash tune: Eur. Phys. J. C **74** (2014) 3024
CR-BLC Mode 0, 2 and 3: JHEP **08** (2015) 003

D^0-meson yields vs transverse event activity

In transverse region:

- PYTHIA 8 with Monash and CR-BLC Mode 2 tunes suggests dependence on transverse activity over all p_T range
- Particle production in this region is strongly influenced by the underlying event

The integrated luminosity expected from the Run 3 will make it feasible to measure D-meson production in transverse region

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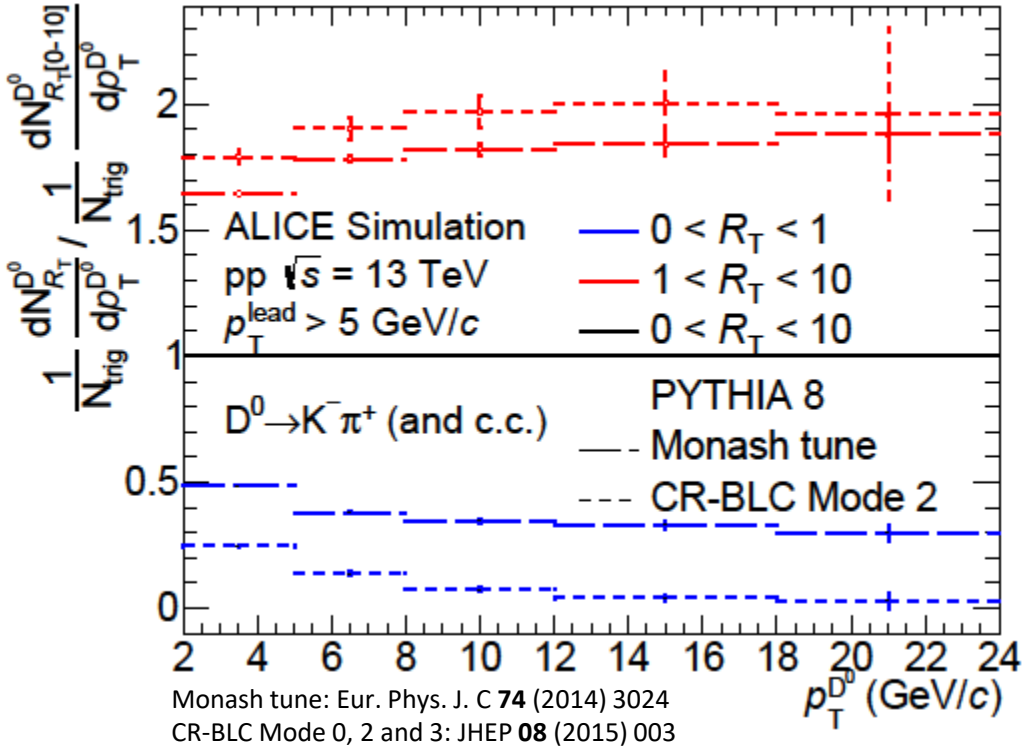

Monash tune: Eur. Phys. J. C **74** (2014) 3024
CR-BLC Mode 0, 2 and 3: JHEP **08** (2015) 003

Conclusions

- Heavy-flavour hadrons are an excellent tool for testing pQCD in pp collisions
- Λ_c^+/D^0 ratios hint to a modification of hadronisation mechanisms with multiplicity, further weakening the claim of fragmentation universality across different collisions systems
- D-meson production vs transverse spherocity hints at enhancement in high-multiplicity jetty events
- D^0-meson production vs transverse event activity suggests a possible dependence on underlying event at low p_T in the toward region

Thank you for attention!