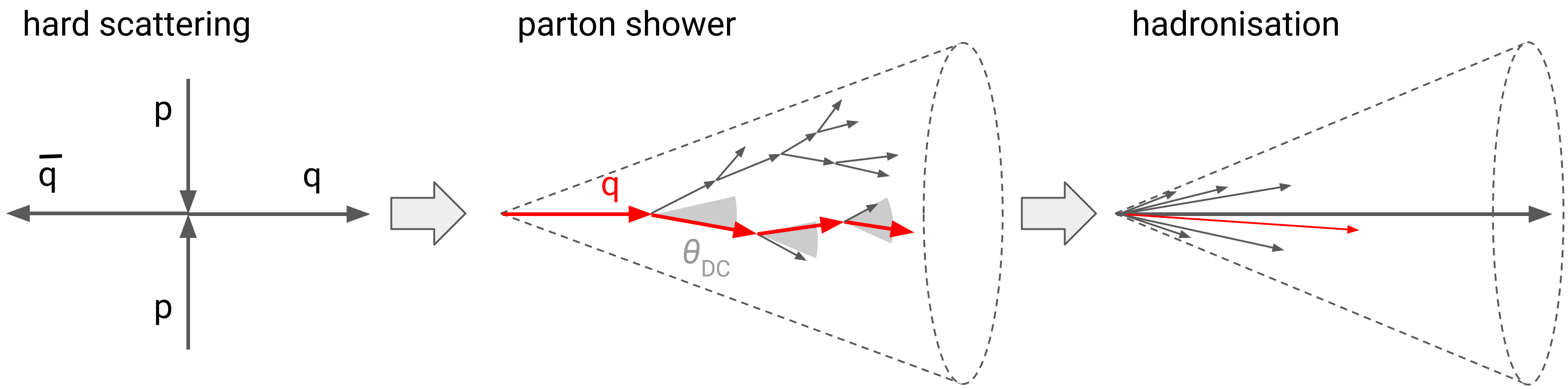
Heavy-flavour jet measurements by ALICE

Vít Kučera (Inha Univ.)
for the ALICE Collaboration

4 July 2022
QCD 22

Physics motivation for heavy-flavour jets



Early perturbative production
→ tests for pQCD down to low p_T

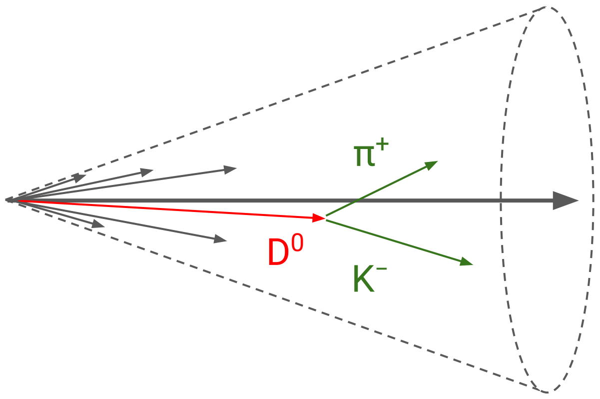
Heavy flavour conserved in the parton shower and experimentally traceable
→ access to properties of gluon emissions (e.g. splitting function)

- Dead-cone effect, $\theta_{DC} = m_q/E_q$
- Casimir colour factors
- Modification in QGP

Hadronisation mechanisms

- Baryons vs mesons
- Beyond vacuum fragmentation in QGP

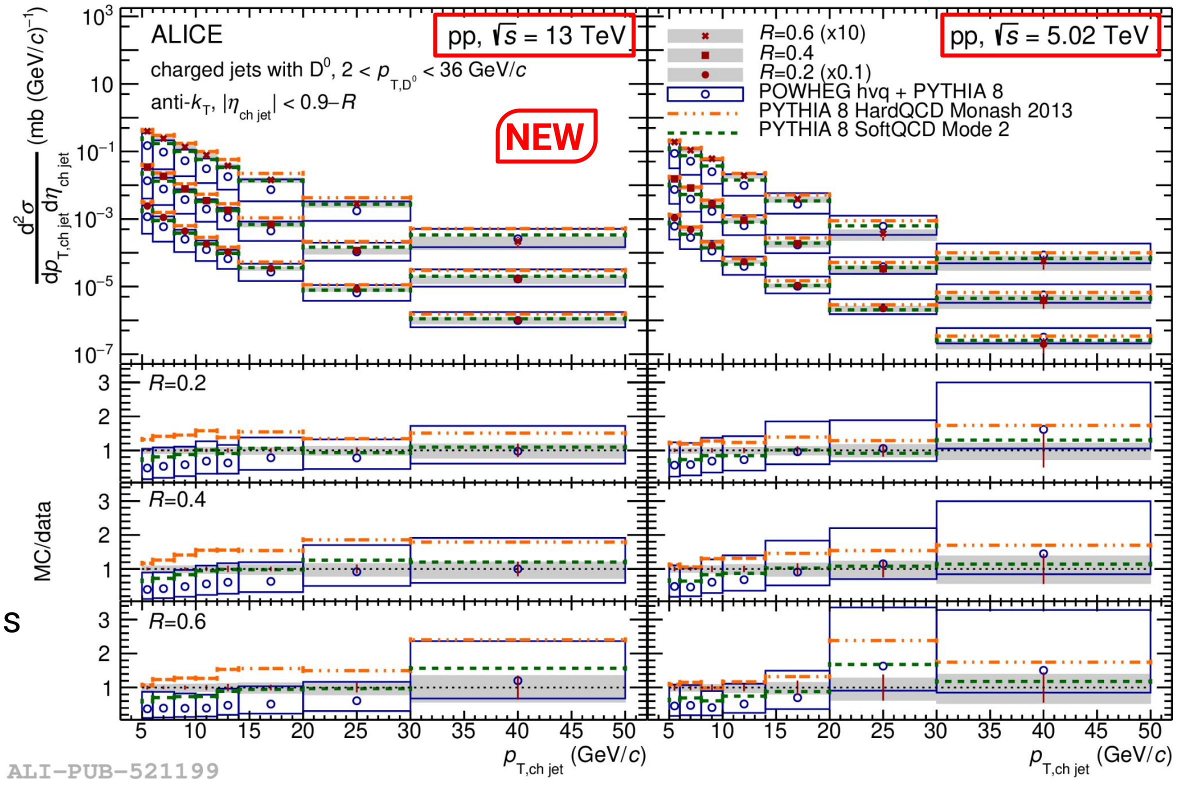
D^0-jet production in pp collisions



Jet resolution parameter (R) dependence allows to probe the angular profile of the parton shower.

Agreement with pQCD in pp collisions → calibrated baseline for Pb–Pb collisions

Hardening of the p_T^{jet} spectra with increasing centre-of-mass energy



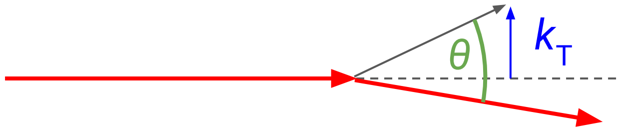
arXiv:2204.10167 [nucl-ex]

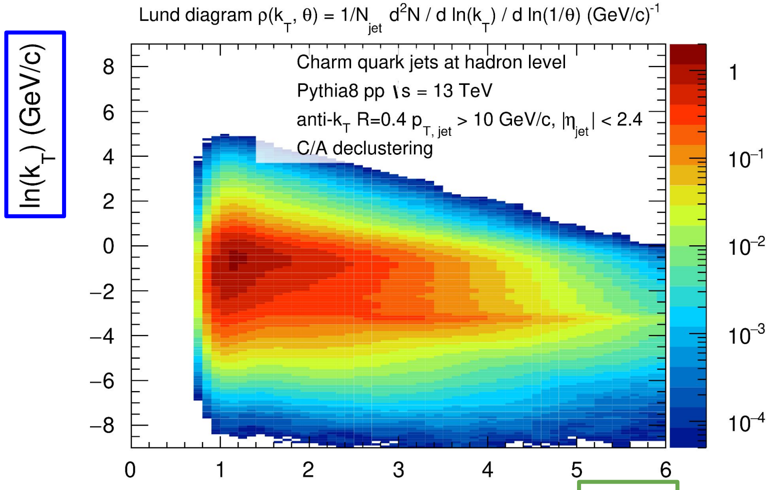
Jet substructure: Lund maps

Lund maps of splittings to access kinematics of parton shower evolution

- Splitting angle θ = ΔR of prongs
- Splitting scale k_T (transverse component of emission momentum)

  Requesting higher k_T suppresses non-perturbative effects.





L. Cunqueiro, M. Płoskoń
Phys. Rev. D **99** (2019) 074027

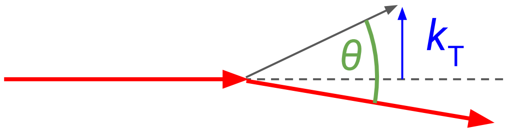
Dead-cone effect

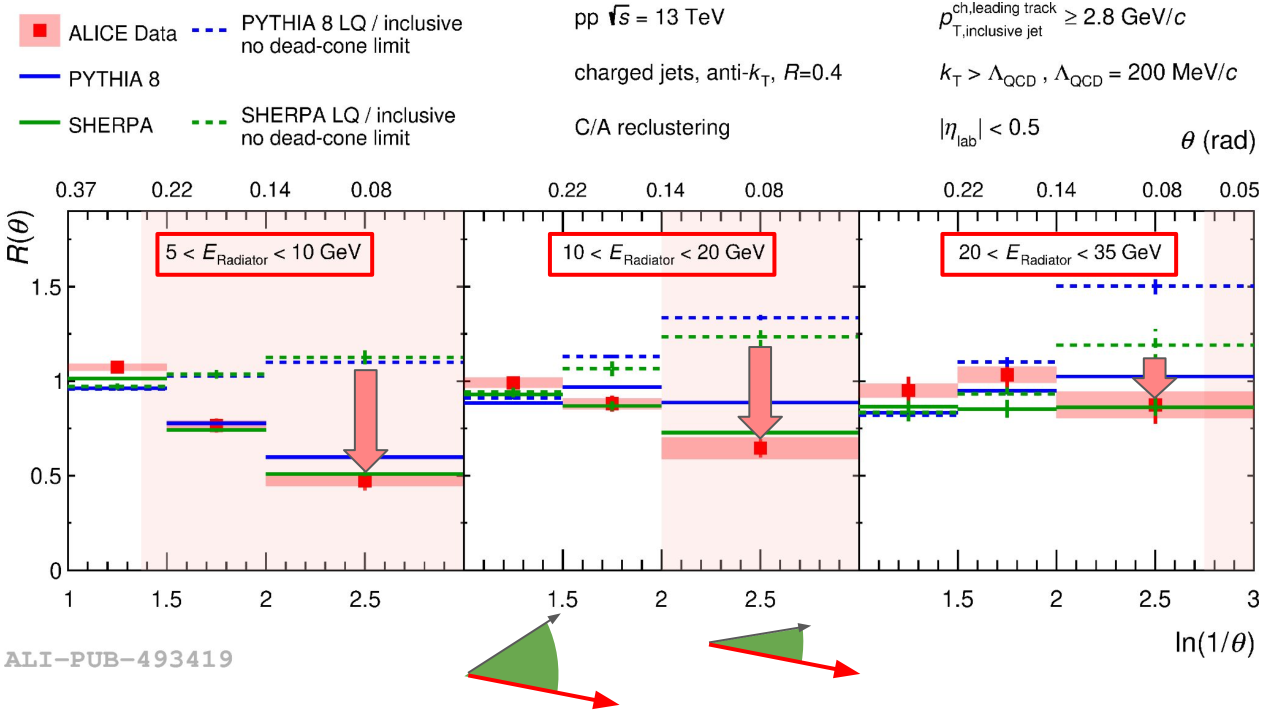
Ratio of Lund map projections for heavy-flavour jets and inclusive jets

Significant suppression of small-θ emissions

Dead cone closing with increasing E_{Radiator}

First direct observation in hadron collisions



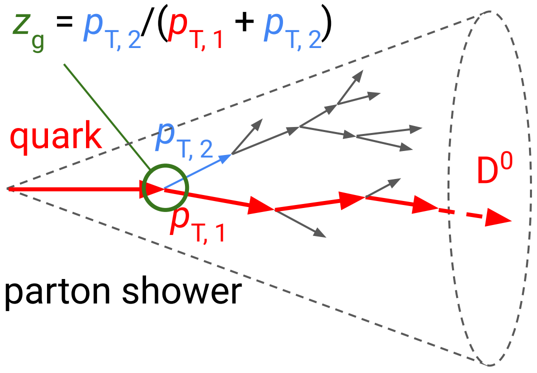


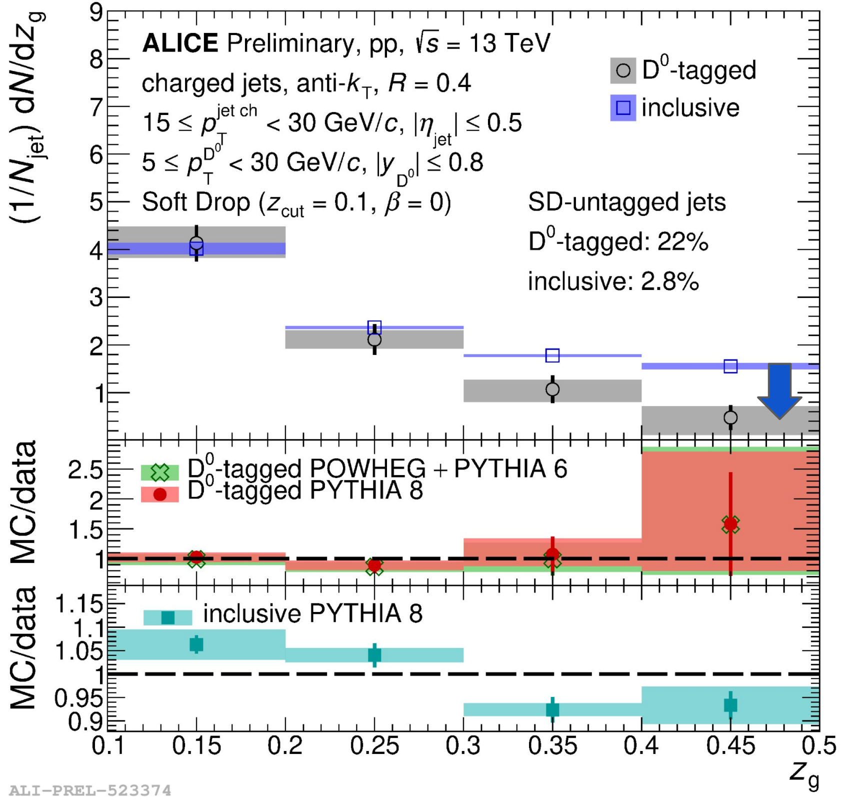
Nature **605** (2022) 440–446

Groomed-charm-jet substructure: z_g

p_T symmetry of the first perturbative splitting

Converges to the splitting function at high jet p_T





First direct experimental constraint of the splitting function of heavy quarks

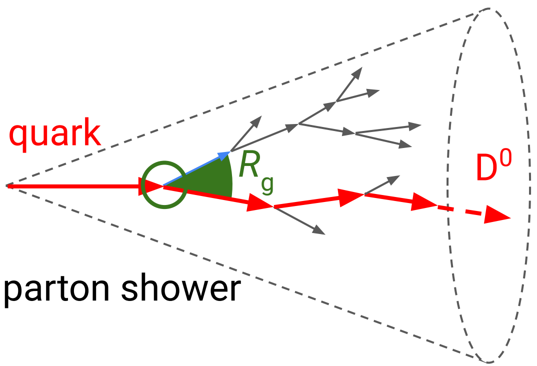
Symmetric emissions from charm quarks suppressed

Good agreement with MC models for charm jets

PYTHIA steeper than the measurement for inclusive jets

Groomed-charm-jet substructure: R_g

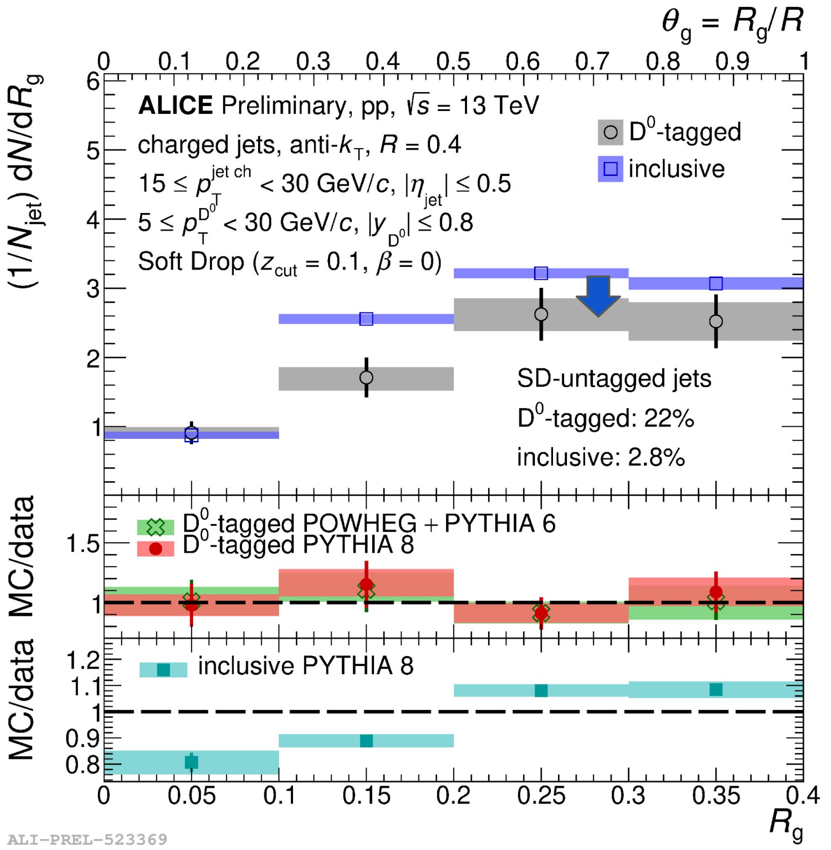
Angular size of the first perturbative splitting



Wide emissions from charm quarks suppressed.

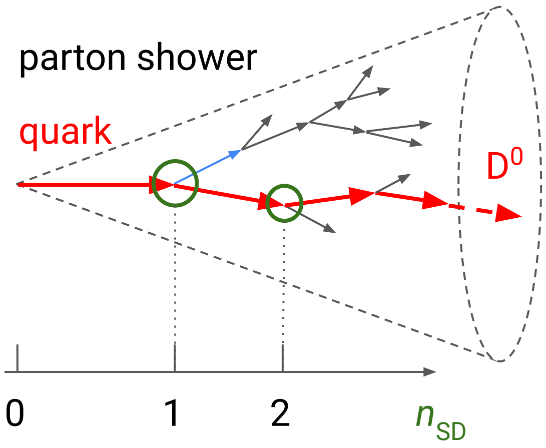
Good agreement with MC models for charm jets

PYTHIA steeper than the measurement for inclusive jets



Groomed-charm-jet substructure: n_{SD}

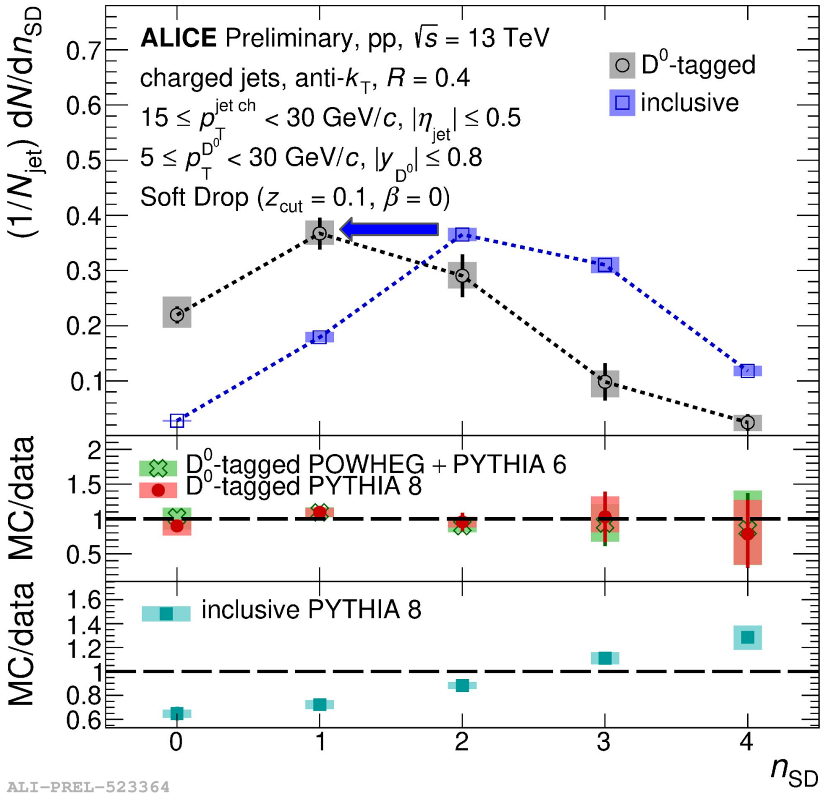
Number of perturbative splittings of the leading branch



Fewer perturbative emissions from charm quarks,
i.e. more likely to emit soft gluons.
Fragmentation of charm quarks is harder.

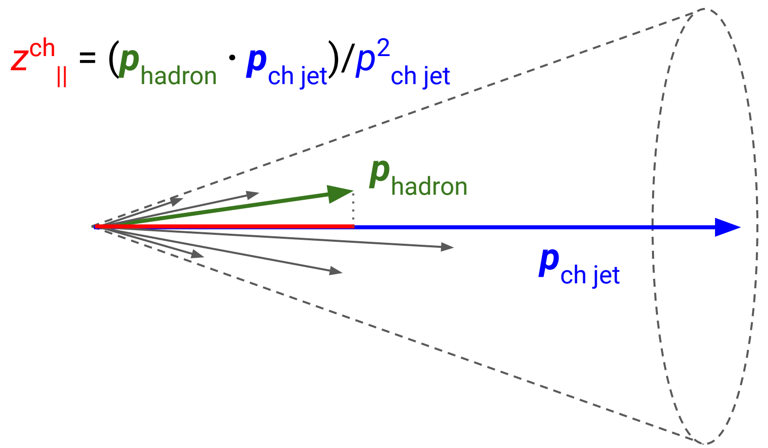
Good agreement with MC models for charm jets

Shift to larger n_{SD} for PYTHIA for inclusive jets



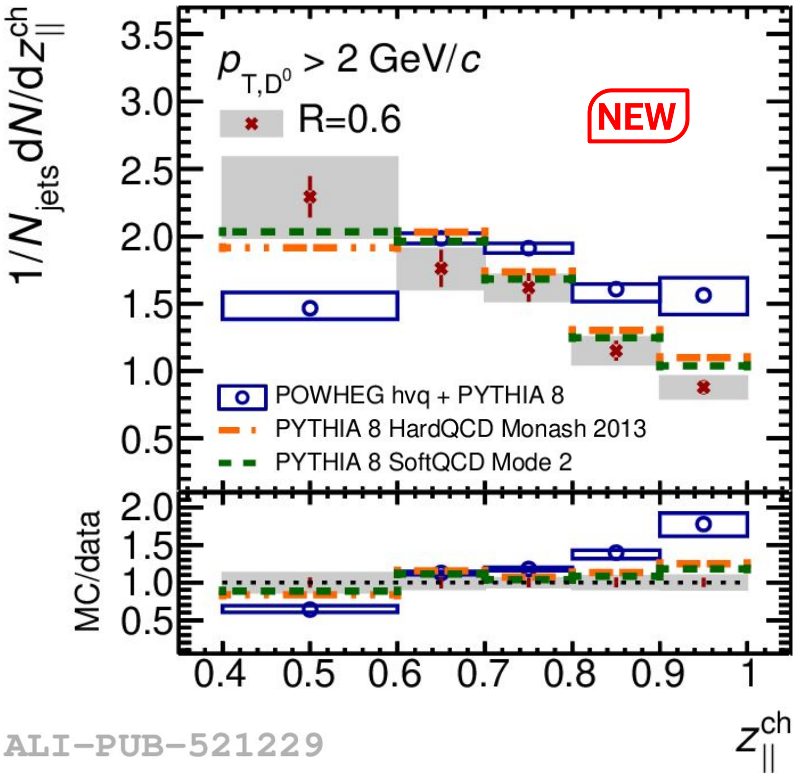
D^0 fragmentation function

Hadronisation stage of charm-quark fragmentation



Measured in a wide phase-space region:
$\sqrt{s}$ = 5.02 TeV, 13 TeV
Jet $p_T \in$ [5, 50] GeV/c
D^0 $p_T \in$ [2, 36] GeV/c
R = 0.2, 0.4, 0.6

arXiv:2204.10167 [nucl-ex]



D^0 fragmentation function

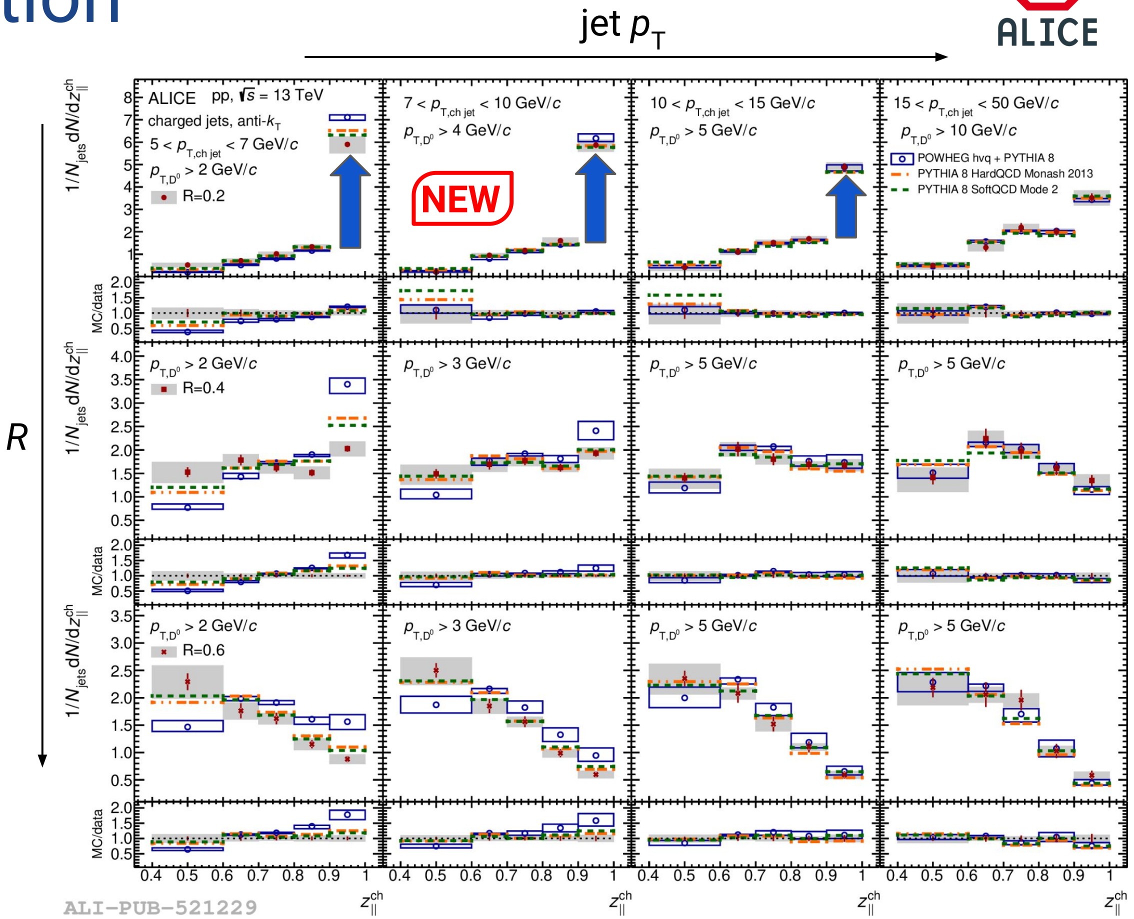
Narrow low-p_T jets are often single D^0.

Fragmentation softens with increasing *R*.

Significant shape transition for *R* = 0.4

Models harder at low jet p_T

Discrepancy larger at larger *R*



arXiv:2204.10167 [nucl-ex]

Λ_c^+ fragmentation function

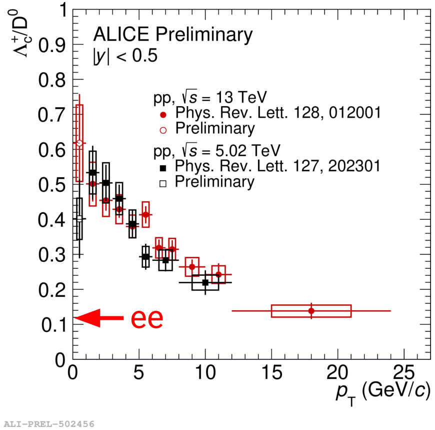
A different look at the baryon–meson ratio enhancement in pp w.r.t. ee/ep collisions

Well described by PYTHIA with colour reconnection beyond the leading-colour approximation[1]

Monash goes in the opposite direction.

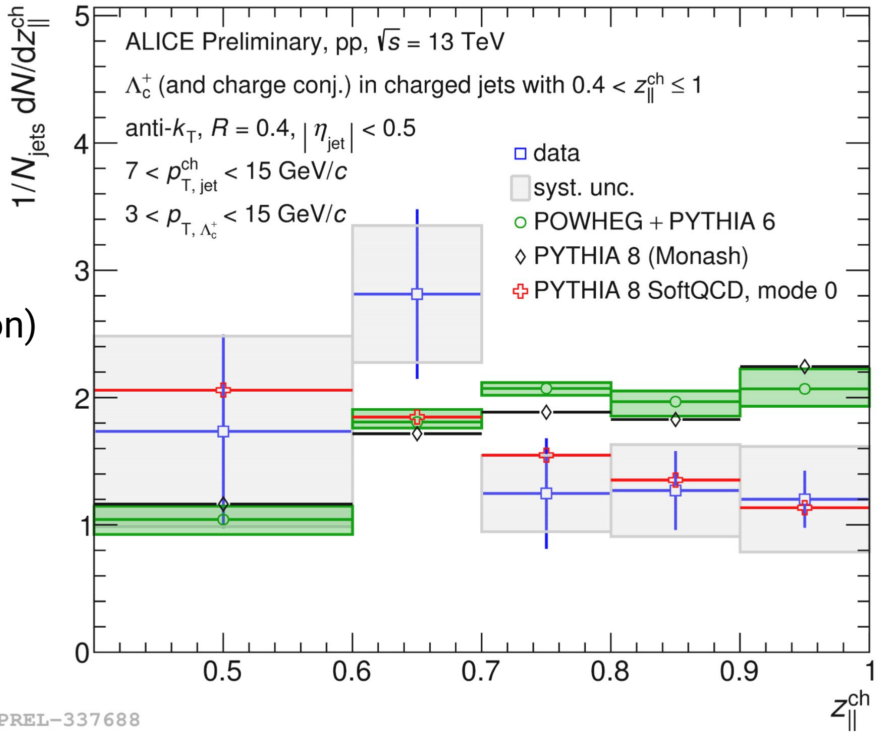
Fragmentation into D^0 harder than into Λ_c^+

New way of constraining hadronisation mechanisms (e.g. local parton density dependence of fragmentation)



See the talk by Susanna Costanza

[1] JHEP **08** (2015) 003



Prospects

Run 3

More data and better tracking resolution → better accuracy

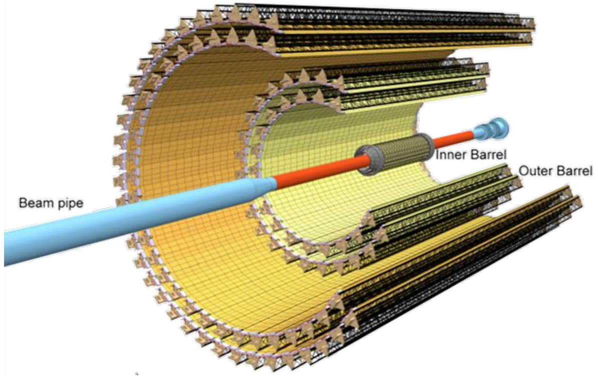
Better characterisation of hadronisation mechanisms from fragmentation functions of Λ_c^+ and D^0

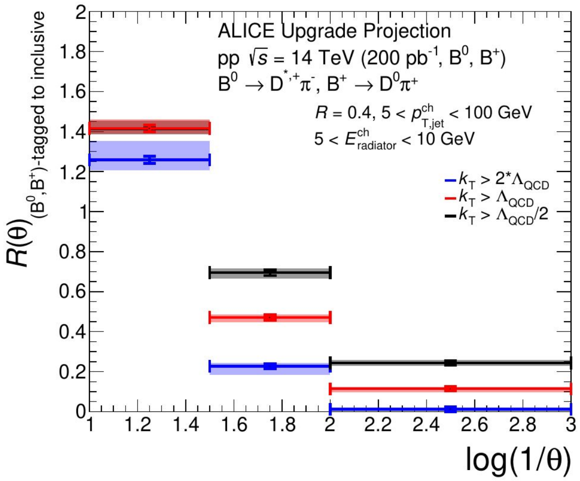
Local parton multiplicity effects

Substructure of b-jets

Low p_T: dead-cone effect for charm vs beauty

High p_T: Casimir colour factors for quarks vs gluons





ALICE Collab. ALICE-PUBLIC-2020-005

Pb–Pb collisions

Probe to study QGP

Modification of heavy-quark fragmentation in QGP

Mass dependence of parton energy loss in medium

Summary

Heavy-flavour jets are an excellent tool to probe perturbative and non-perturbative QCD processes.

Heavy-quark production
→ Jet cross section

Parton shower evolution (dead-cone effect, Casimir colour factors)
→ Jet substructure from low to high jet p_{T}

Hadronisation mechanisms
→ Fragmentation functions of baryons vs mesons

Medium-induced modification of parton radiation
→ Heavy-ion collisions (R_{AA},...)

Thank you for your attention

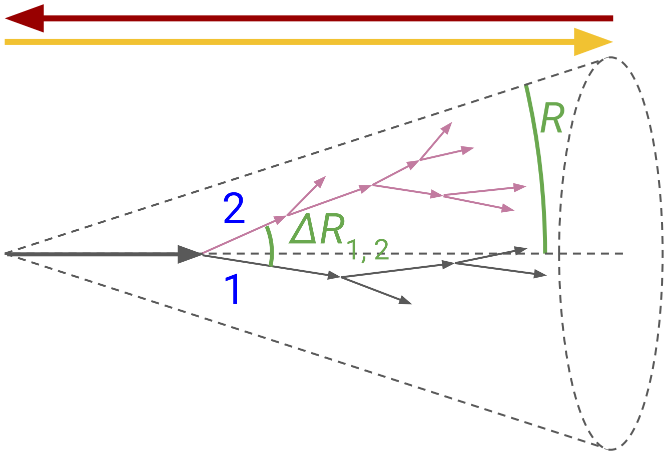
Backup

Jet substructure: *declustering and grooming*

Access evolution of the parton shower: jet splittings (declustering)

Groom away soft radiation at large angles: isolate hard structures inside the jet (grooming)

- **Reclustering** with Cambridge/Aachen (angular ordering)
- **Declustering**: unwind reclustering history → chronologically ordered splittings
- **Grooming** with Soft Drop (SD): groom away soft prongs not satisfying the condition



$$\boxed{\frac{p_{\mathrm{T},2}}{p_{\mathrm{T},1}+p_{\mathrm{T},2}}} > \boxed{z_{\mathrm{cut}}}\left(\boxed{\frac{\Delta R_{1,2}}{R}}\right)^{\boxed{\beta}}$$

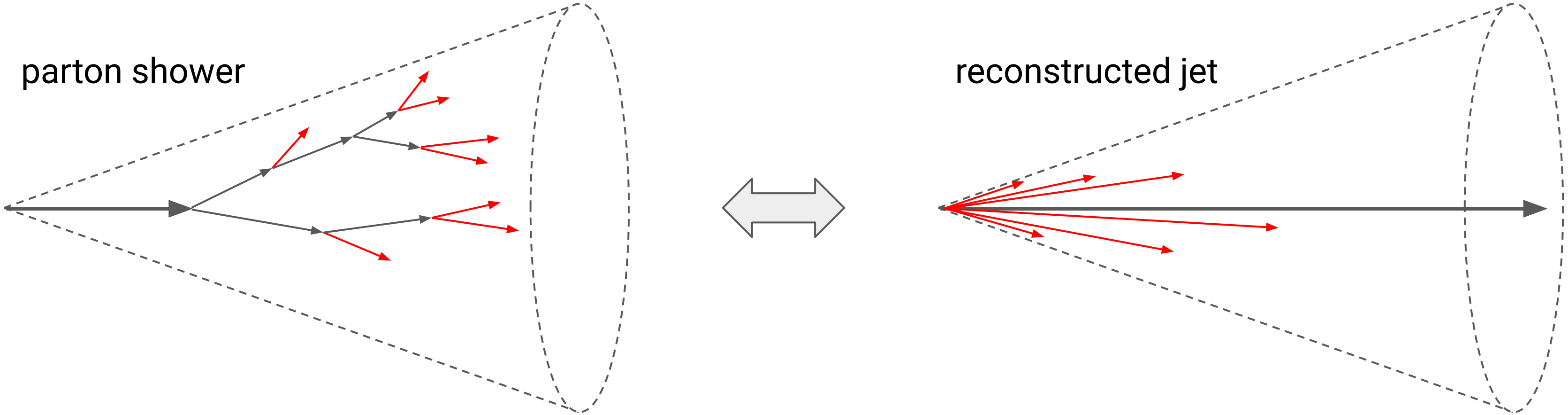
$$\Delta R_{\mathrm{a,b}} \equiv \sqrt{(y_{\mathrm{a}}-y_{\mathrm{b}})^2+(\varphi_{\mathrm{a}}-\varphi_{\mathrm{b}})^2}$$

A. J. Larkoski, S. Marzani, G. Soyez et al. *JHEP* **05** (2014) 146

Jet substructure

Jet substructure observables constructed from jet constituents after jet clustering

- Characterise internal fragmentation pattern of parton shower
- Tests of pQCD predictions
- Insight into nonperturbative phenomena (hadronisation, underlying-event effects)
- Baseline for medium effects of quark–gluon plasma in heavy-ion collisions



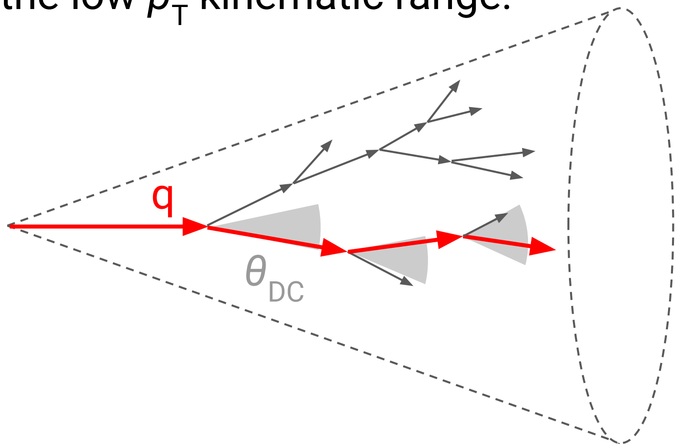
Substructure of heavy-flavour jets

$m_q > \Lambda_{QCD}$ → perturbative production down to low jet p_T

Heavy flavour conserved through the shower evolution

Inclusive vs heavy-flavour jets at low p_T:

- **Casimir colour factors**: different fragmentation of quarks and gluons
- **Dead-cone effect**: suppression of emission phase space for $\theta < \theta_{DC} = m_q/E_q$
  → Mass effects sizeable in the low p_T kinematic range.

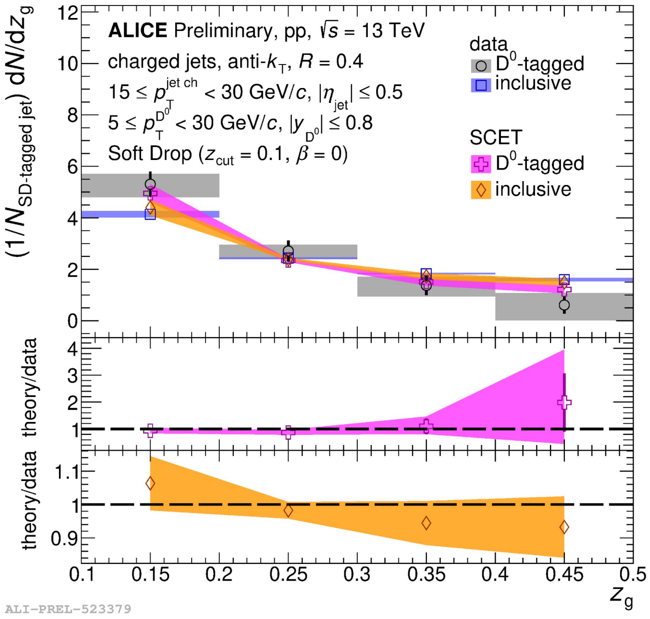


Groomed-jet substructure: z_g

Agreement within uncertainties with Soft-collinear effective theory (SCET)

Same trend as MC models.

NEW



H. T. Li and I. Vitev. *Phys. Lett. B* **793** (2019) 259–264
H. T. Li, Z. L. Liu, and I. Vitev. *Phys. Lett. B* **827** (2022) 137007