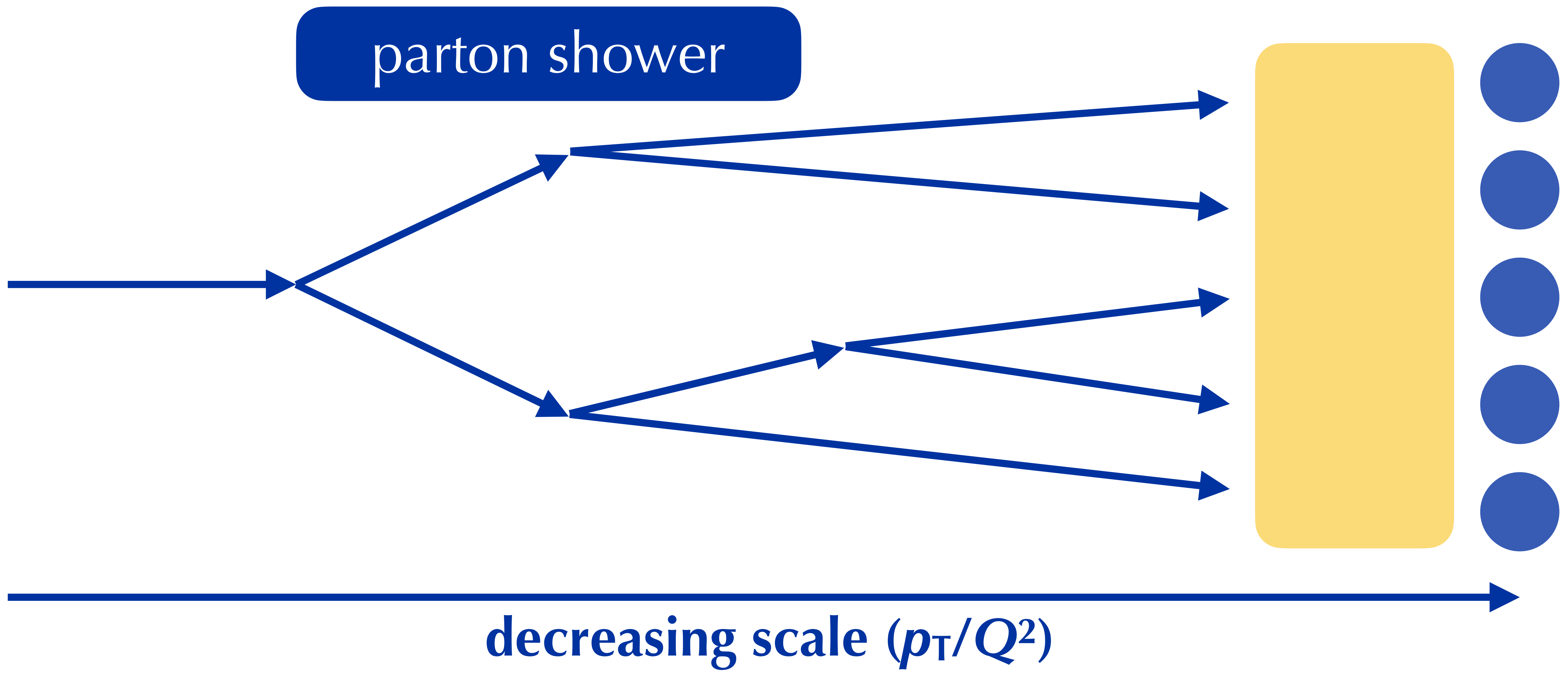
Differential measurements of in-jet fragmentation of charmed mesons and baryons in pp collisions with ALICE

Jochen Klein (CERN)
on behalf of the ALICE Collaboration

12th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

Nagasaki, Japan, 25th September 2024

In-jet fragmentation



- **Evolution of a highly-virtual parton** from hard scattering described by a **parton shower**
  - probabilities for splittings described by splitting functions

$$\mathrm{d}P_{i\to jk} = \frac{\mathrm{d}\theta}{\theta}\,\mathrm{d}z\, P_{i\to jk}(z)$$

- **Evolution at non-perturbative scales**, incl. hadronisation, evades pQCD
  - characterisation through phenomenological modelling
- **Heavy-flavour content** retained and traceable through jet evolution
  - selective access to heavy-quark jets

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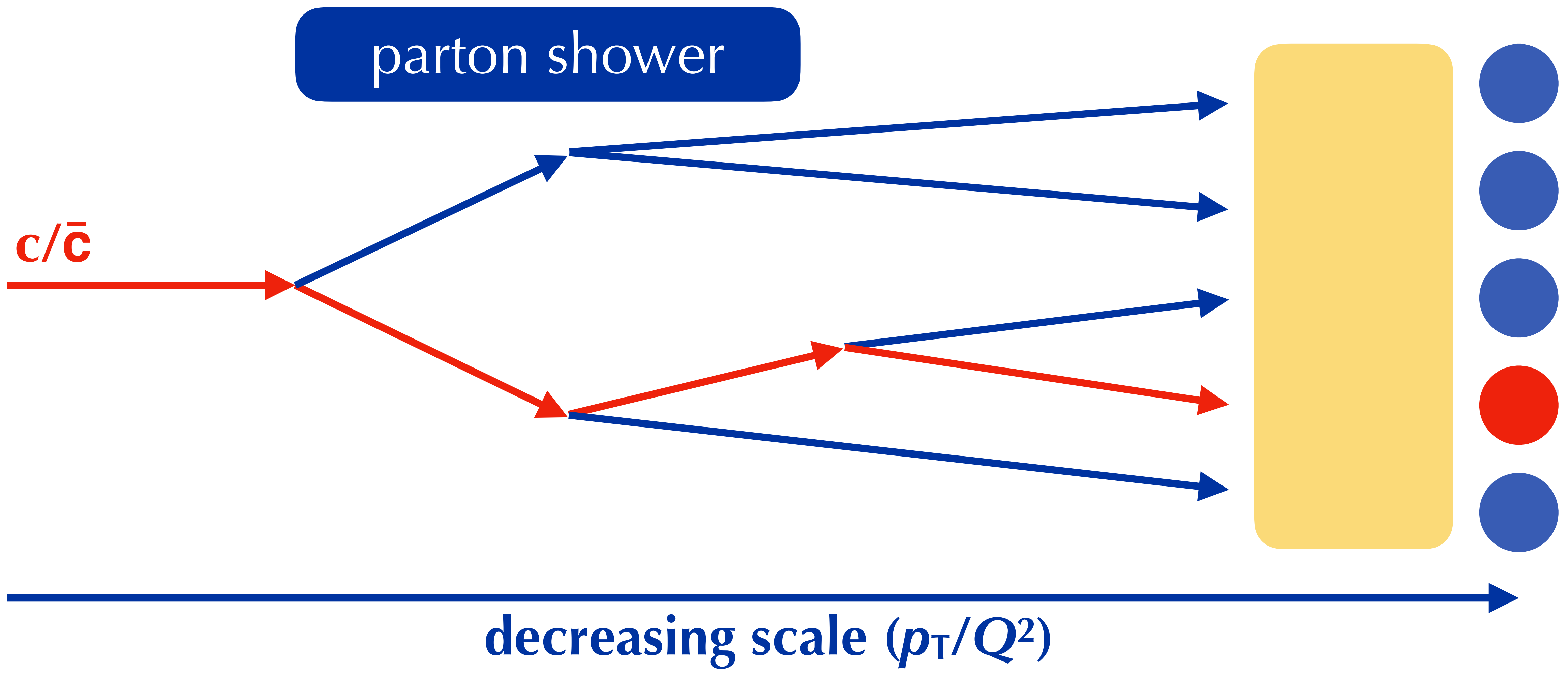

Heavy-flavour jets to probe mass/colour effects in jet evolution

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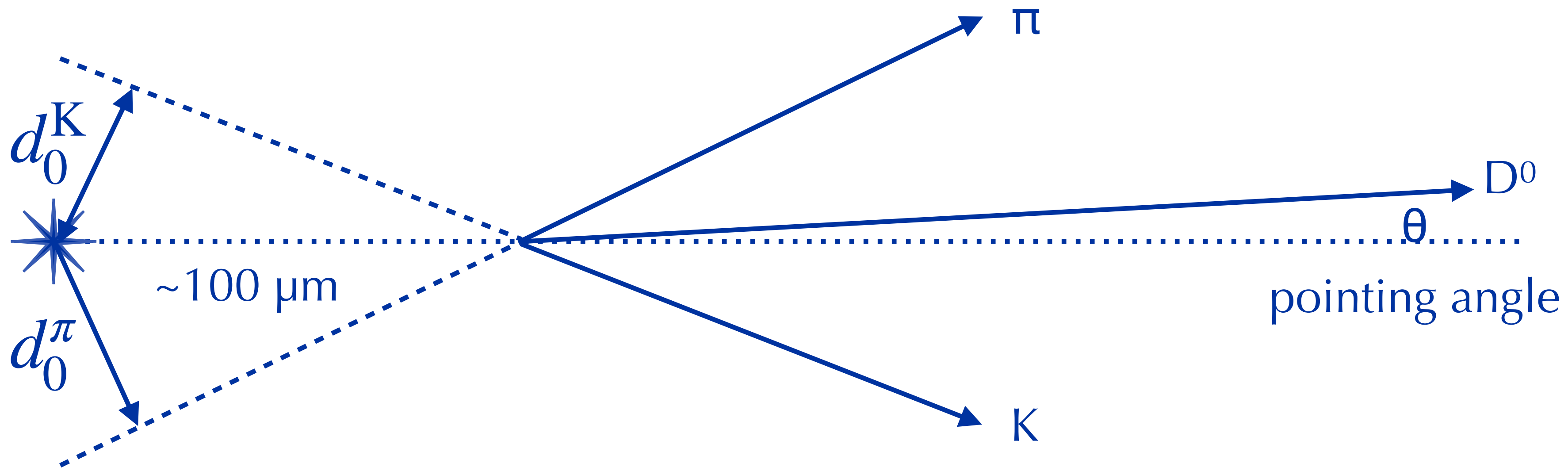
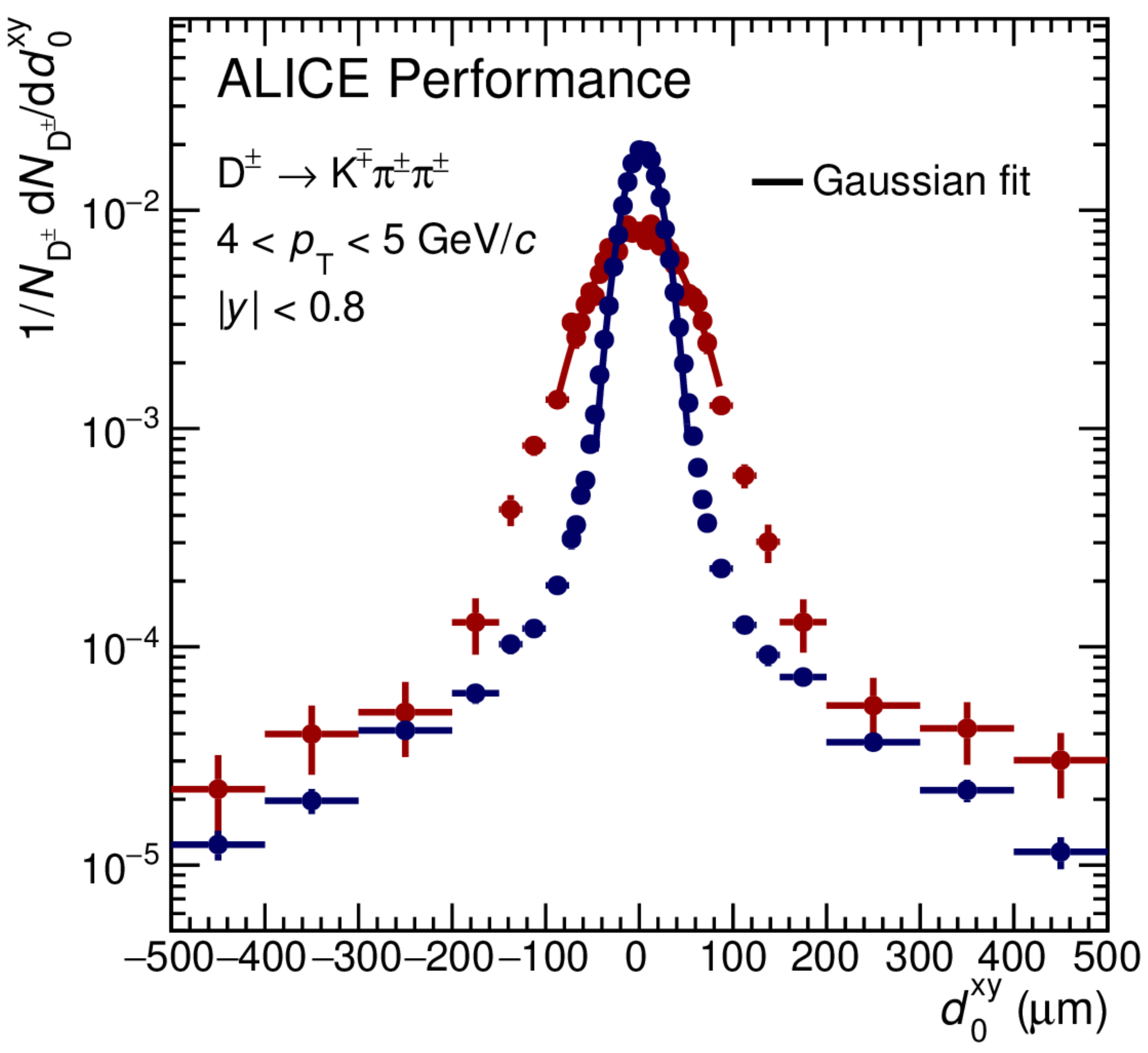
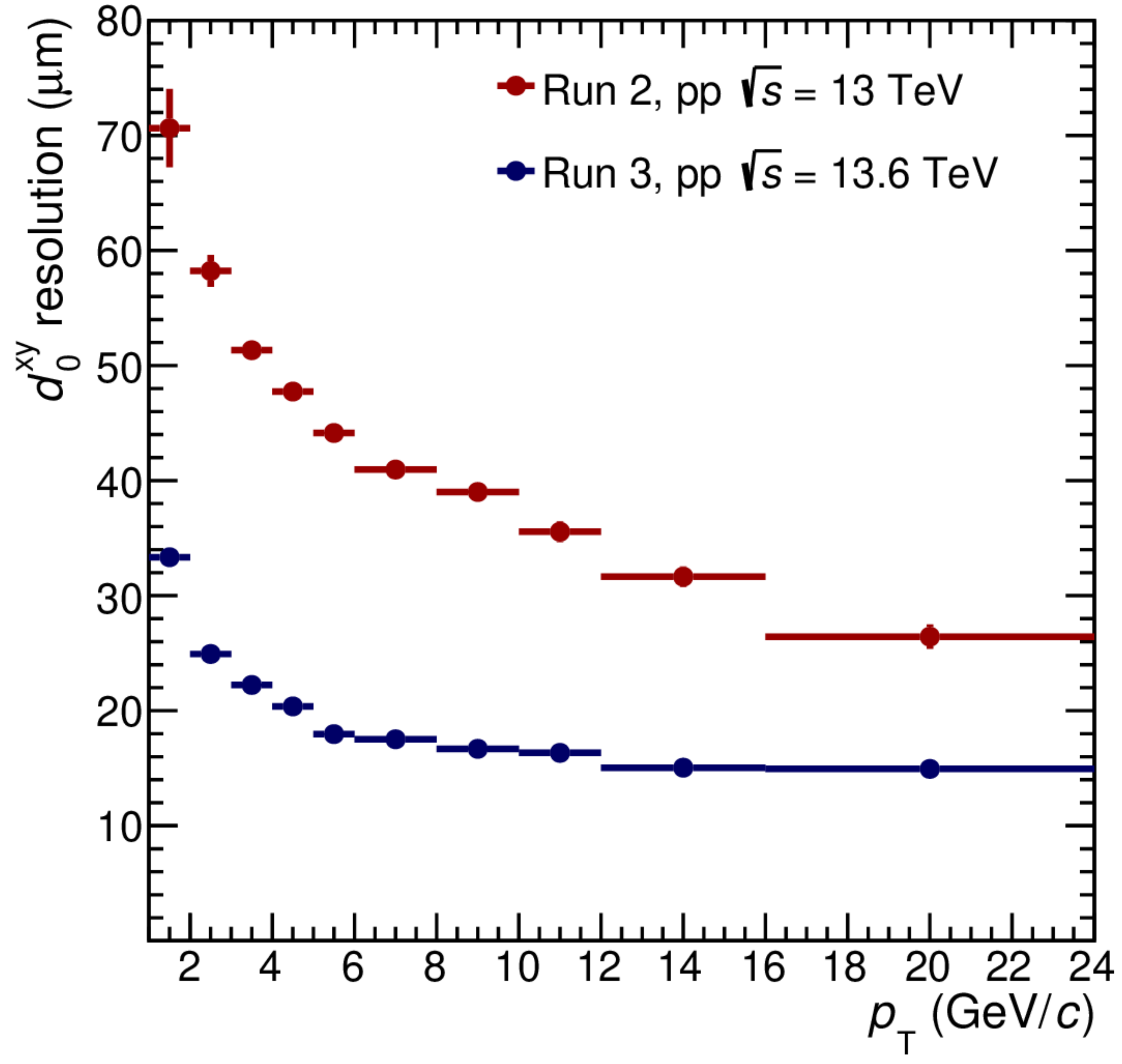
Reconstruction of heavy-flavour

- **Heavy-flavour candidates (D^+, D^0, Λ_c^+)** reconstructed using topological variables and particle identification in a two-step selection:
  - preselection with rectangular cuts
  - refined selection with boosted decision trees







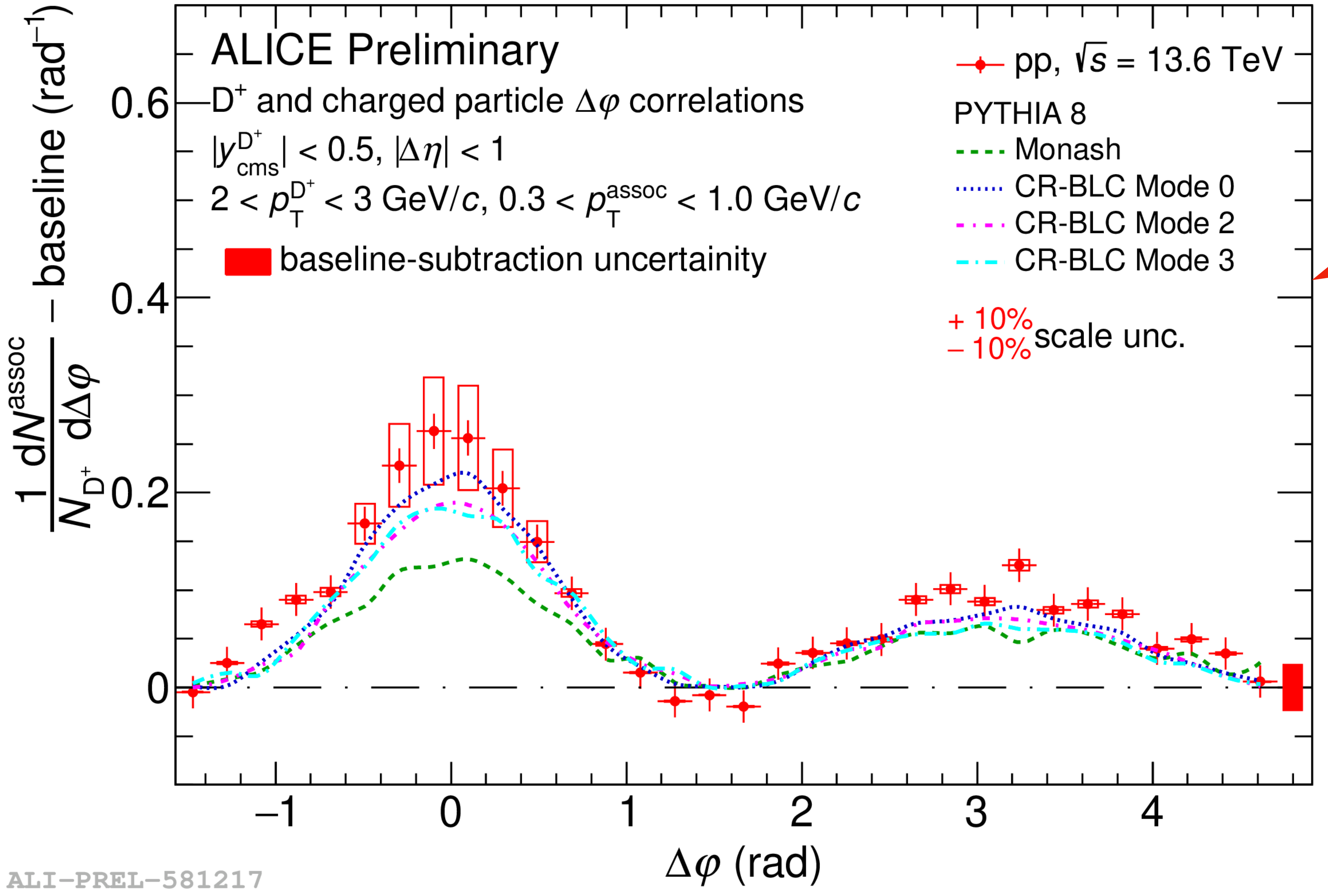
Impact parameter resolution significantly improved with ALICE 2

ALI-PERF-577966

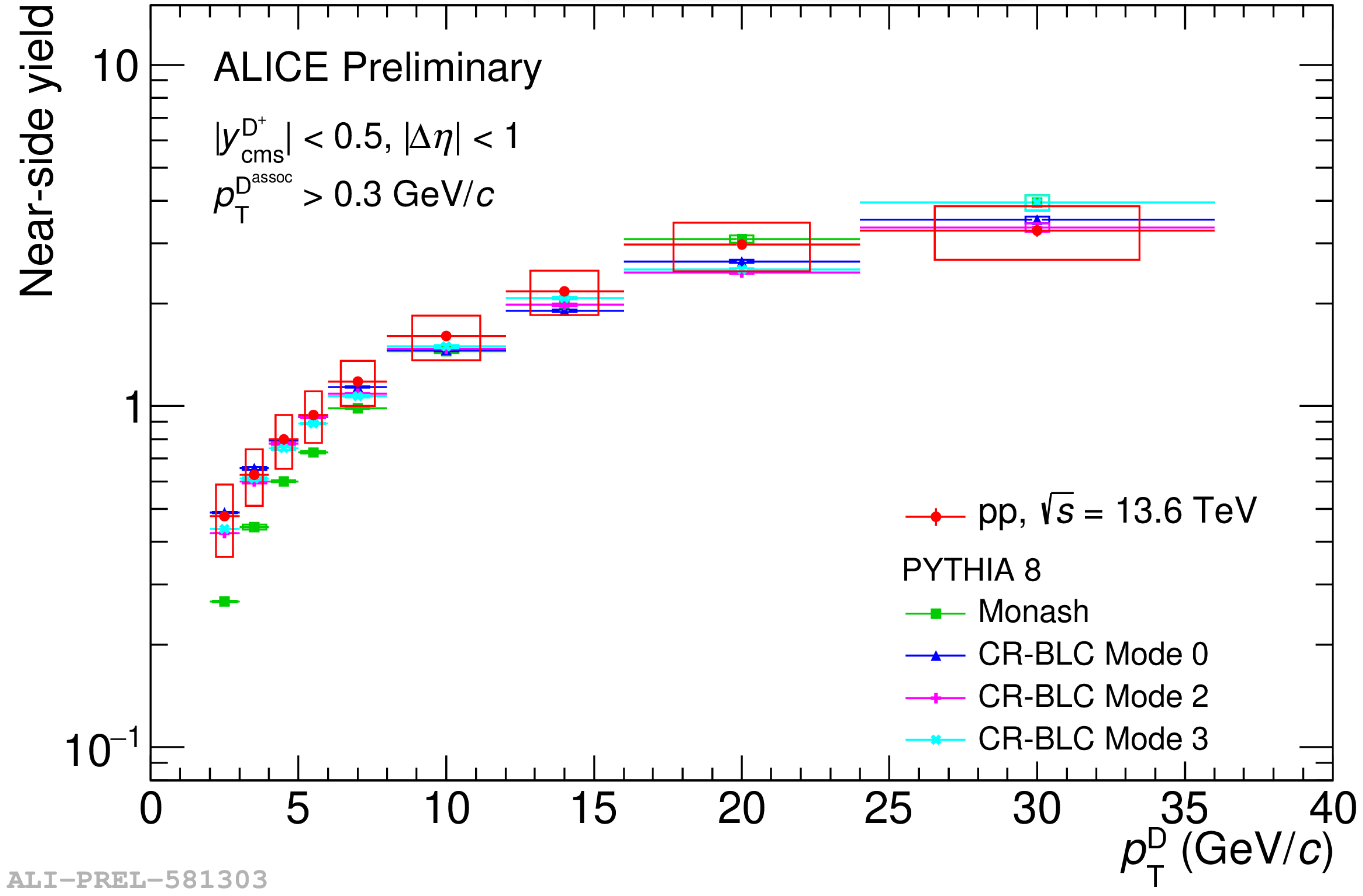
Correlation of D+ and hadrons

- Azimuthal correlation of D+ meson with charged hadrons
  - probes **fragmentation of charm quarks, incl. hadronisation**
  - improved precision, extended kinematic reach
  - PYTHIA 8 reproduces distributions well

pp, $\sqrt{s}$ = 13.6 TeV

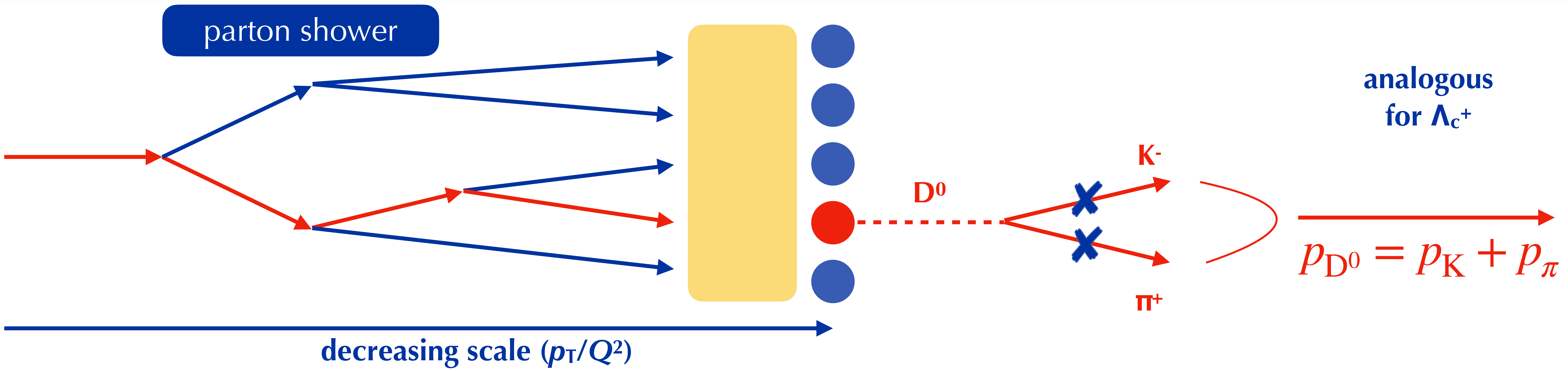


New Run 3



PYTHIA: [arXiv:2203.11601, arXiv:1404.5630, arXiv:1505.01681]

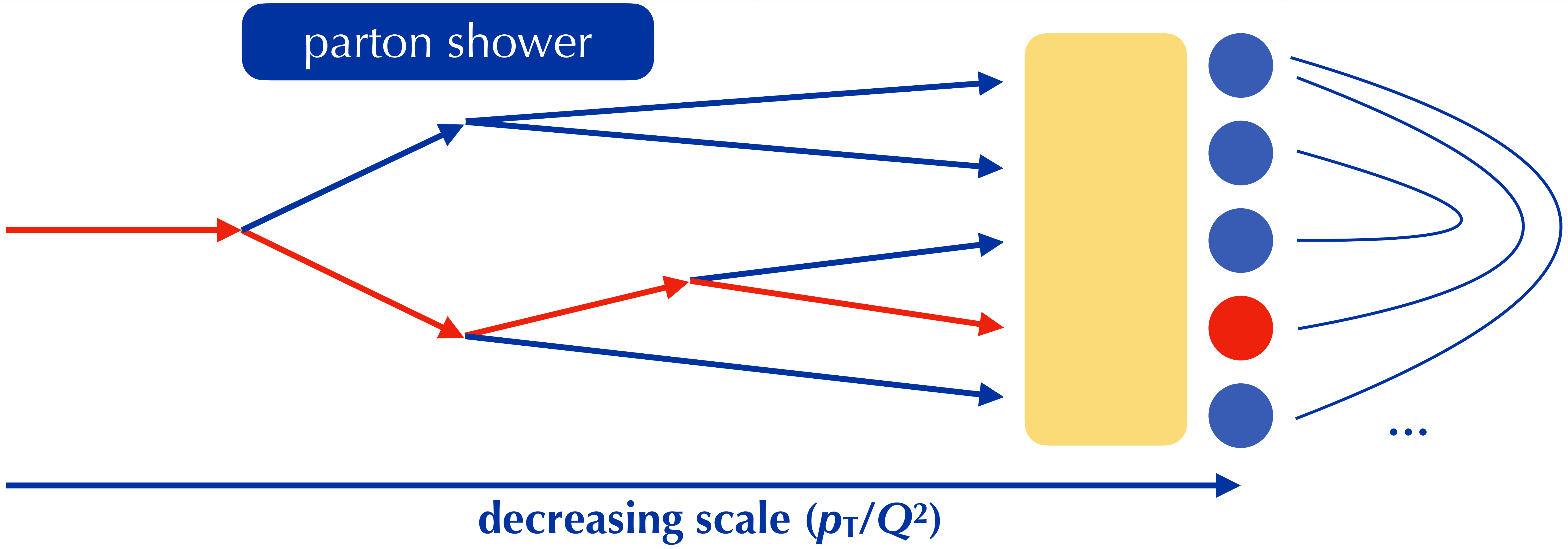
Reconstruction of heavy-flavour jets



- **Heavy-flavour daughters replaced by candidates**
- **Heavy-flavour jets** reconstructed with anti-k_T algorithm
  - $R = 0.4$
  - $p_T^{trk} > 150\,\mathrm{MeV}/c$
  - $|\eta^{jet}| < 0.5$

Energy-energy correlators

→ A. Nambrath, A. Rai (Tue 9:00, 12:10)



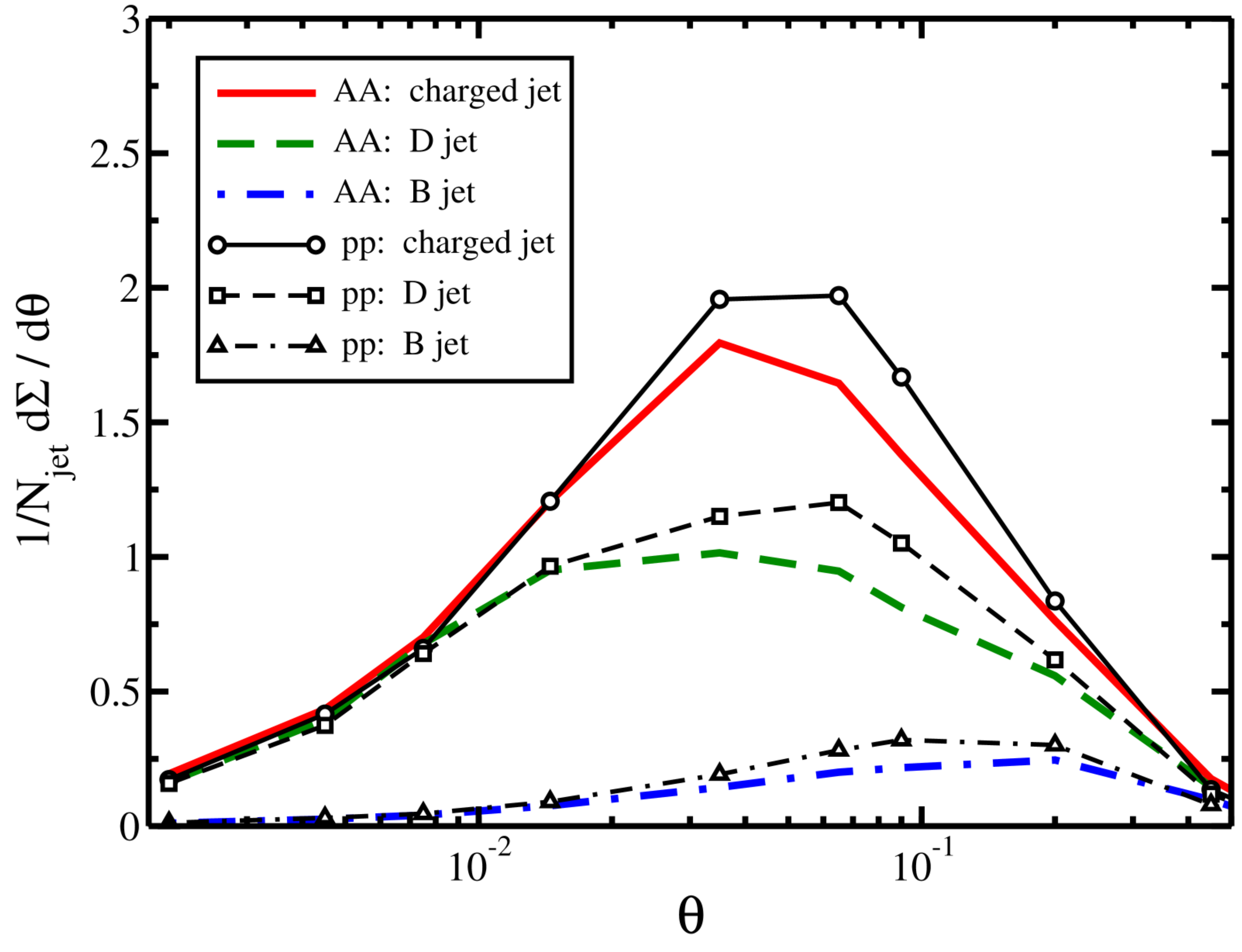
Energy-weighted distance calculated for all pairs in jet

$$R_{L,ij} = \sqrt{\Delta\varphi_{ij} + \Delta\eta_{ij}}$$

$$w_{ij} = \frac{p_{T,i}\, p_{T,j}}{p_{T,\mathrm{jet}}^2}$$

[Phys. Rev. D 102 (2020) 054012]

- Energy-energy correlators capture **information of full jet evolution** while separating scales
  - large R_L → perturbative
  - small R_L → non-perturbative
- Heavy-flavour jets → study **impact of mass/colour effects**, calculations available also for AA



[arXiv:2409.12843]

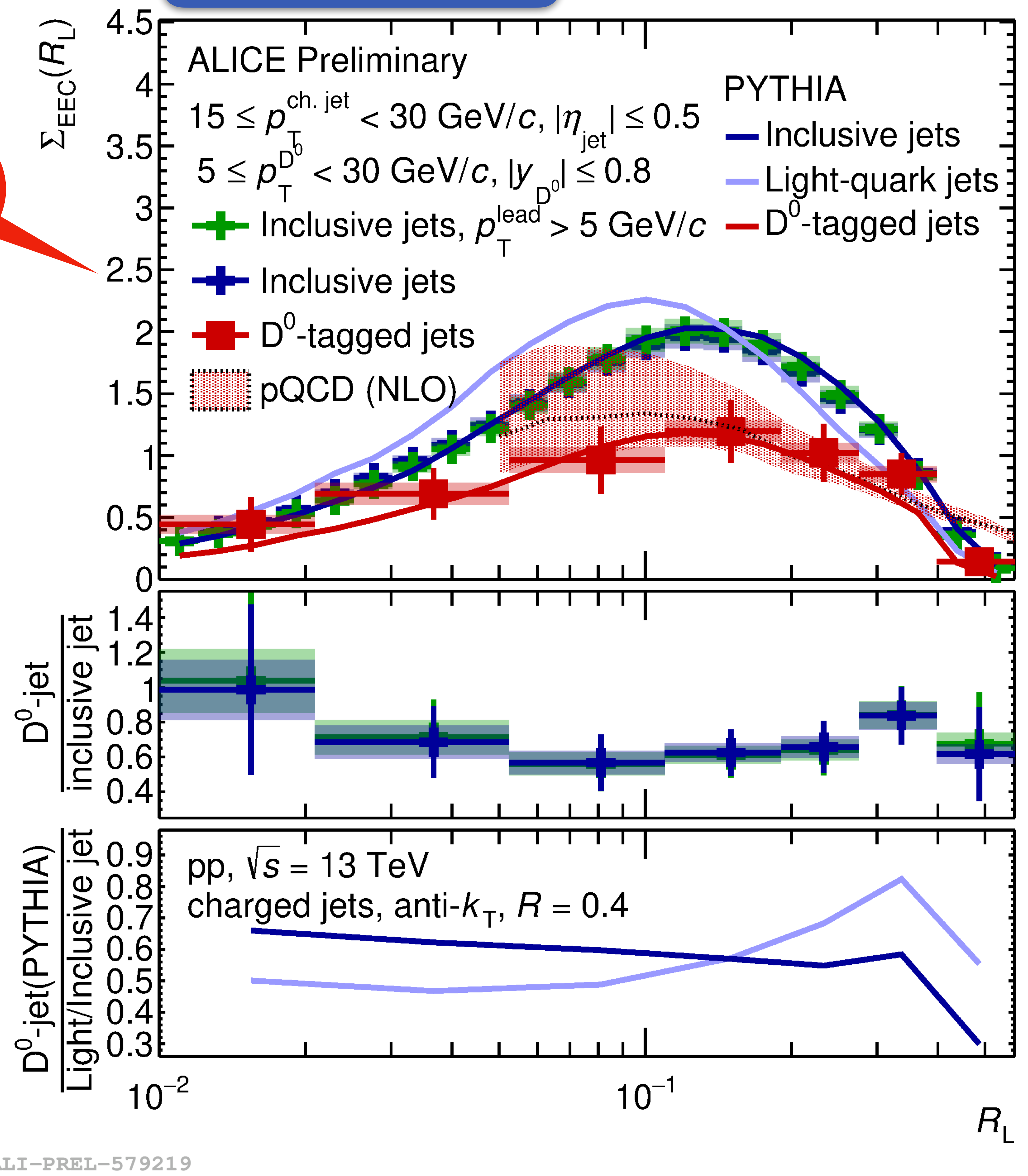
Energy-energy correlators

→ P. Dhankher (poster)

- **Light-quark jets** (Pythia)
- **Inclusive jets** (gluon-dominated)
  - peak shifted towards larger R_L (w.r.t. light-quark expectation)
  - not affected by leading p_T cut
- **D^0 jets**
  - reduced integral → mass effects
  - peak position comparable to inclusive jets, shifted w.r.t. light-quark jet expectation
  - PYTHIA describes data
  - tension with pQCD calculation in peak position?
- **Flavour hierarchy described by theory models**

pp, $\sqrt{s}$ = 13 TeV

New



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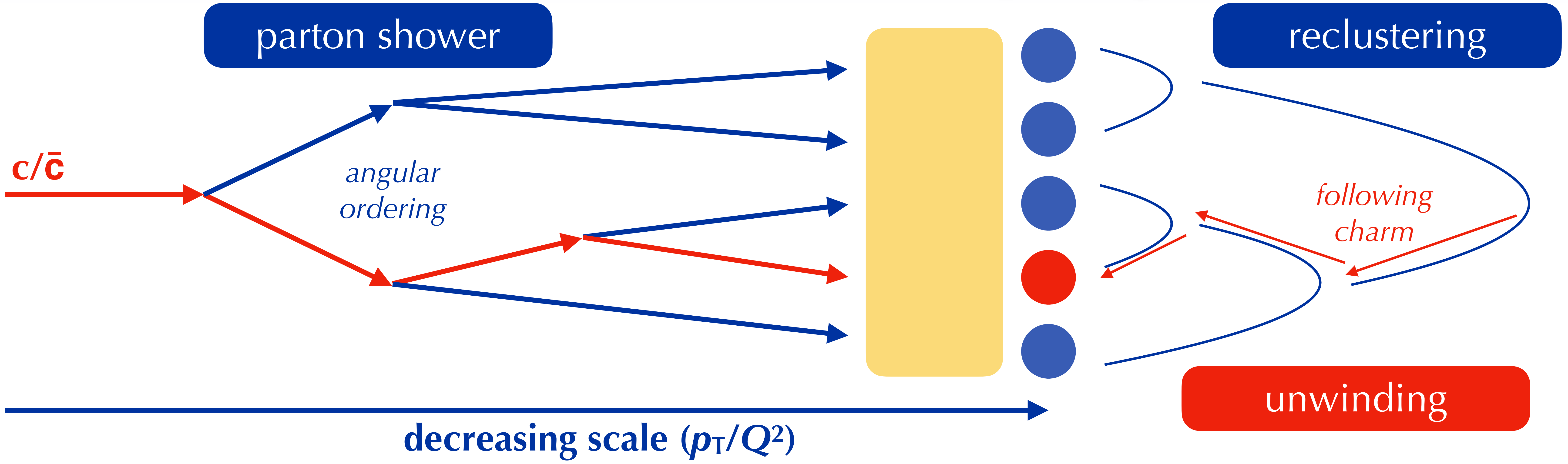
Soft drop grooming



Use soft drop grooming to access perturbative splittings

[JHEP 05 (2014) 146]

- **Recluster jet constituents** to access splitting tree
  - using Cambridge/Aachen algorithm to replicate angular ordering
- **Groom away soft splittings** based on momentum fraction (soft drop)

$$z = \frac{p_{\mathrm{T,g}}}{p_{\mathrm{T,c}} + p_{\mathrm{T,g}}} > z_{\mathrm{cut}} \left(\frac{\Delta R_{\mathrm{c,g}}}{R} \right)^{\beta}, \text{ here } z_{\mathrm{cut}} = 0.1,\ \beta = 0$$

Groomed momentum fraction

- **Momentum fraction**
  of first splitting passing soft drop criterion

$$z_g = \frac{p_{T,g}}{p_{T,c} + p_{T,g}}$$

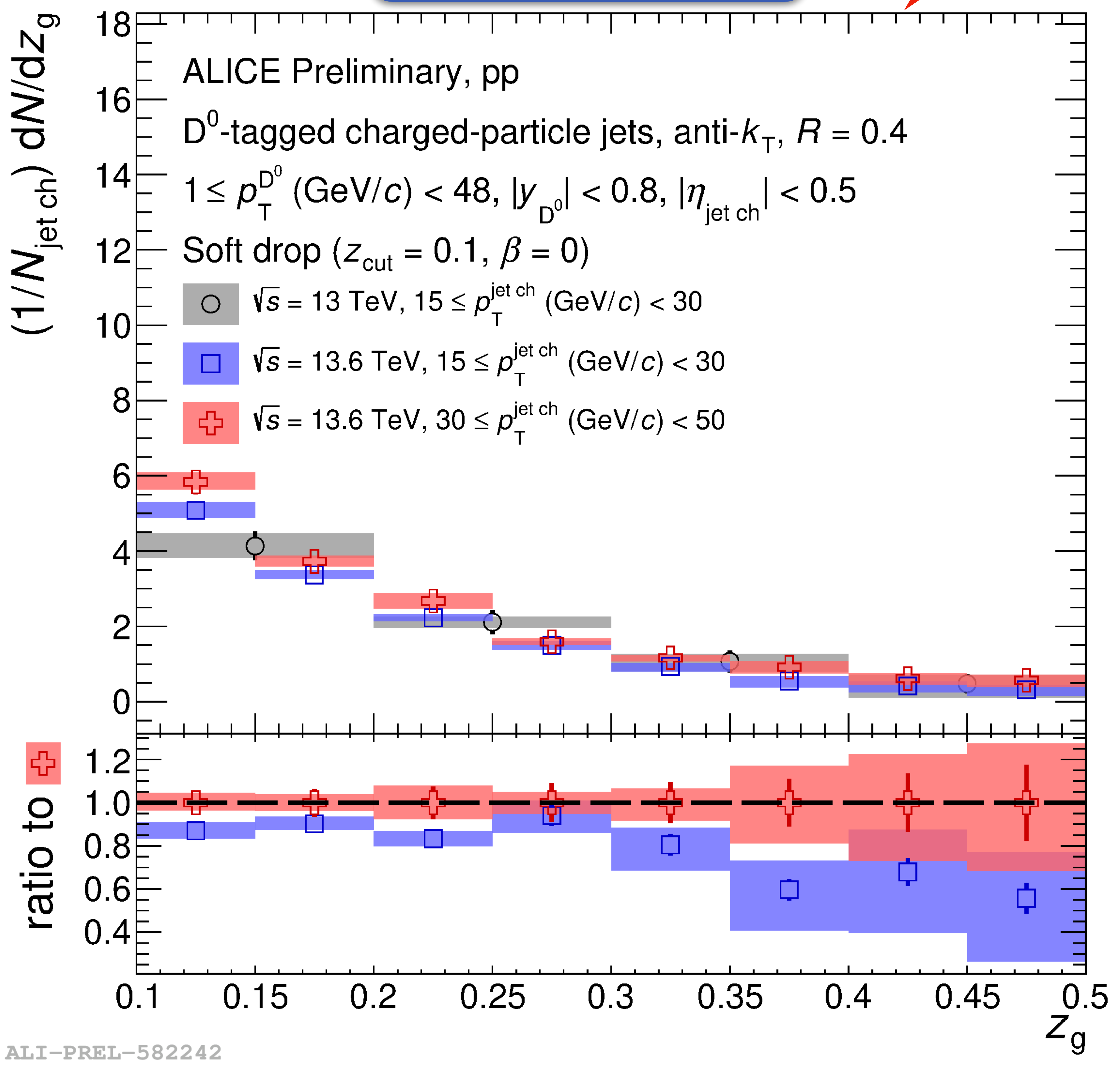
  - converges to splitting function

$$dP_{i\to jk} = \frac{d\theta}{\theta} dz\, P_{i\to jk}(z)$$

- **D⁰ jets**
  - z_g converges onto charm splitting function
  - improved precision, extended kinematic range
  - steeper than inclusive → mass effects
  - integral increasing for larger p_T^{jet}
    → more jets passing soft drop (mass)

New Run 3

pp, $\sqrt{s}$ = 13.6 TeV



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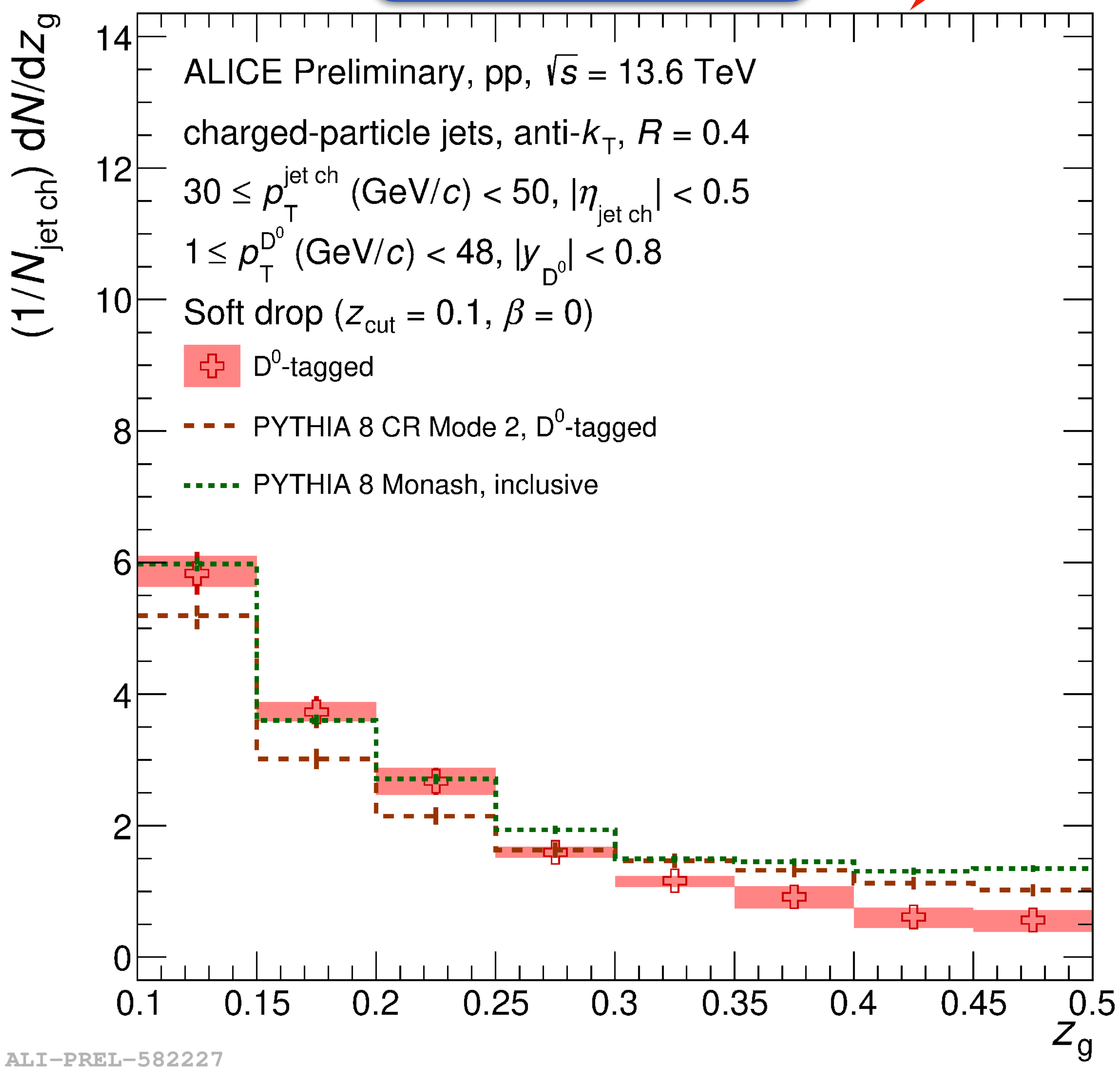

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Groomed opening angle

→ V. Kucera (poster)

- **Opening angle R_g**
  of first splitting passing soft drop criterion
  - targets θ dependence

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- **D^0 jets**
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  - more collimated than inclusive jets → Casimir effect
  - wider jets for lower p_T^{jet}

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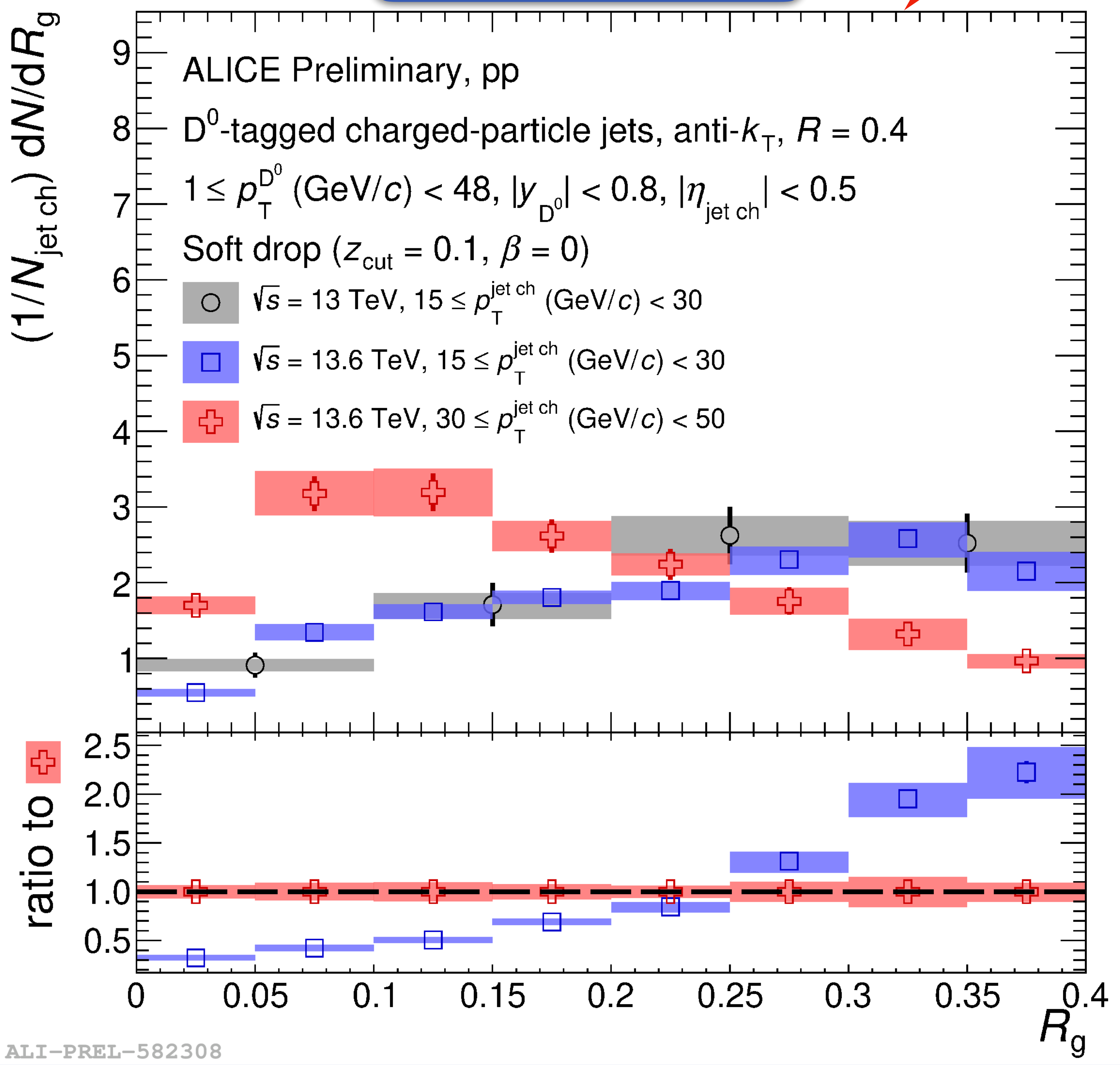

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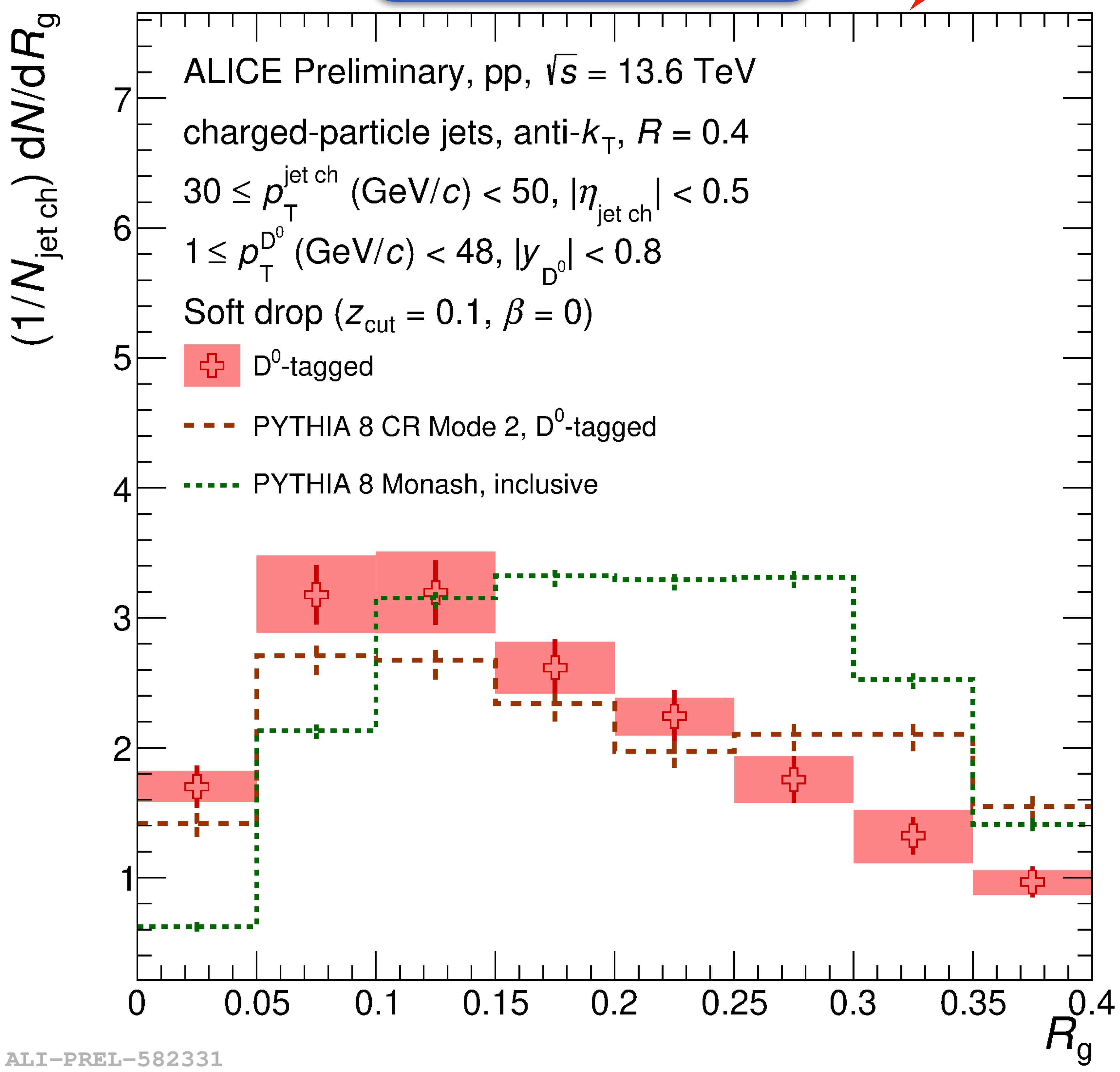

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Number of groomed splittings

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- **Number of splittings** passing soft drop criterion n_{SD}
  - targets number of perturbative emissions
  - qualitatively probes perturbative part of the fragmentation function
- **D⁰ jets**
  - extended kinematic range
  - fewer emissions compared to inclusive → mass effect
  - number of emissions increase with p_T^{jet}

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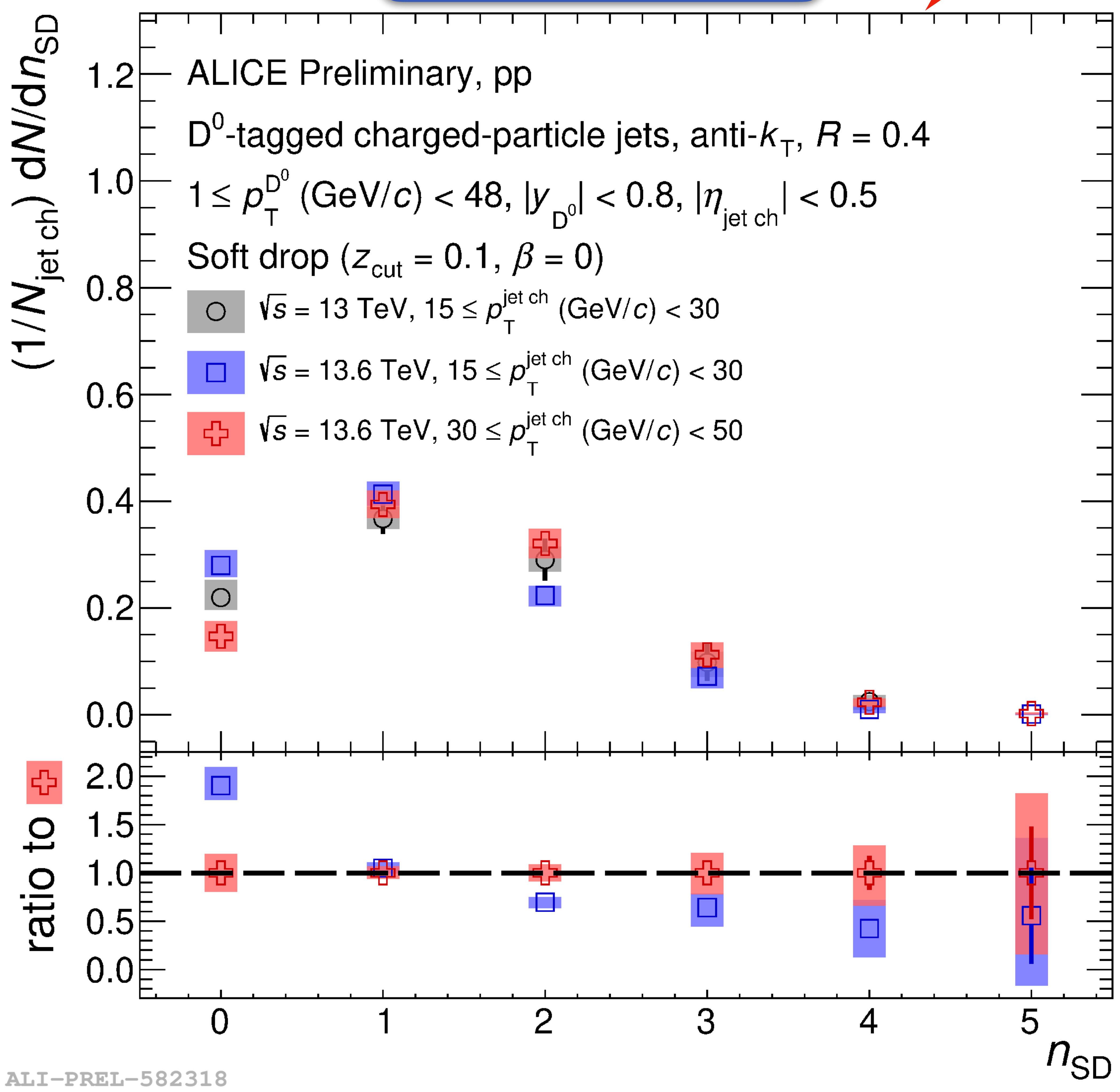

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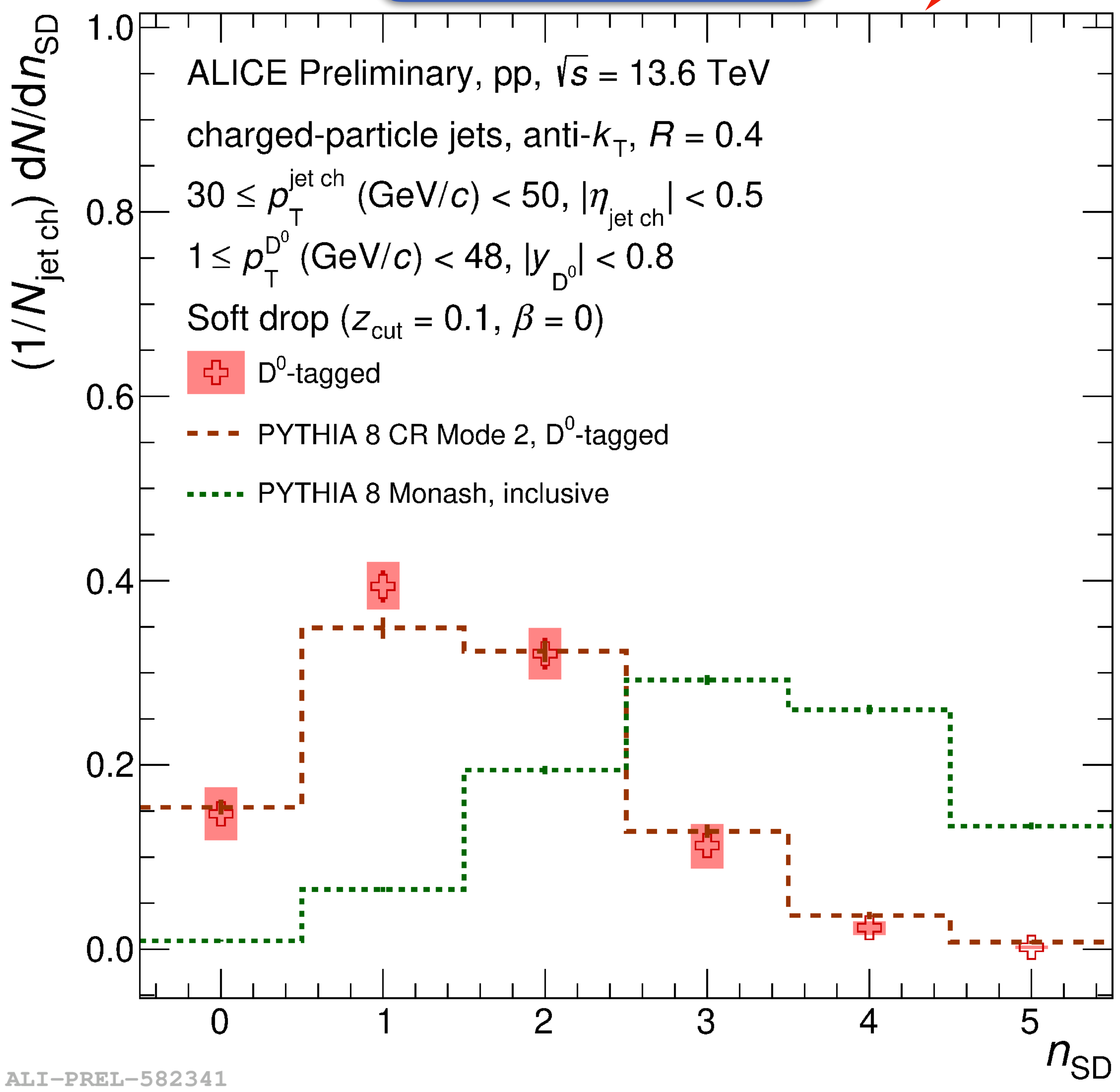

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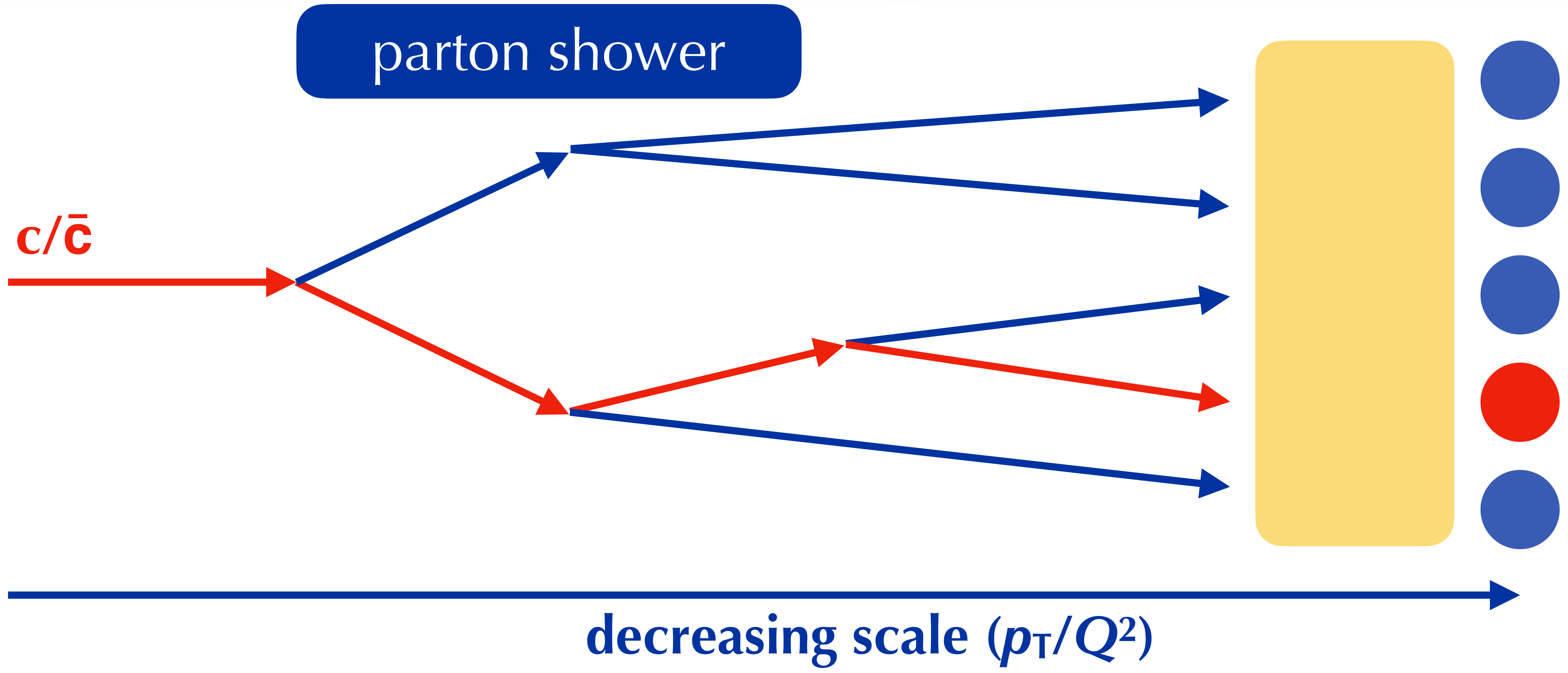
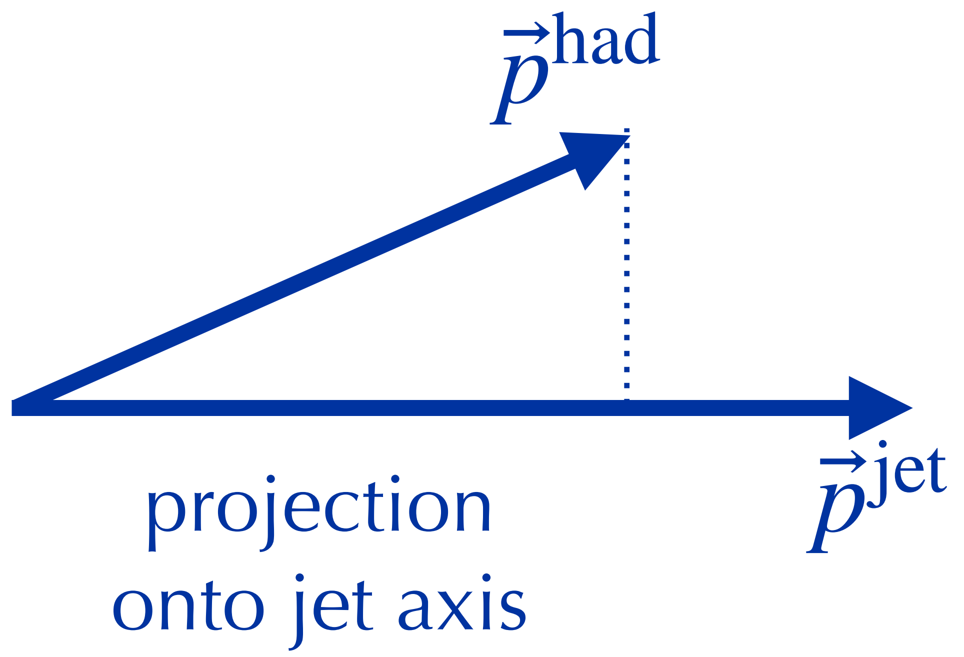
Fragmentation function





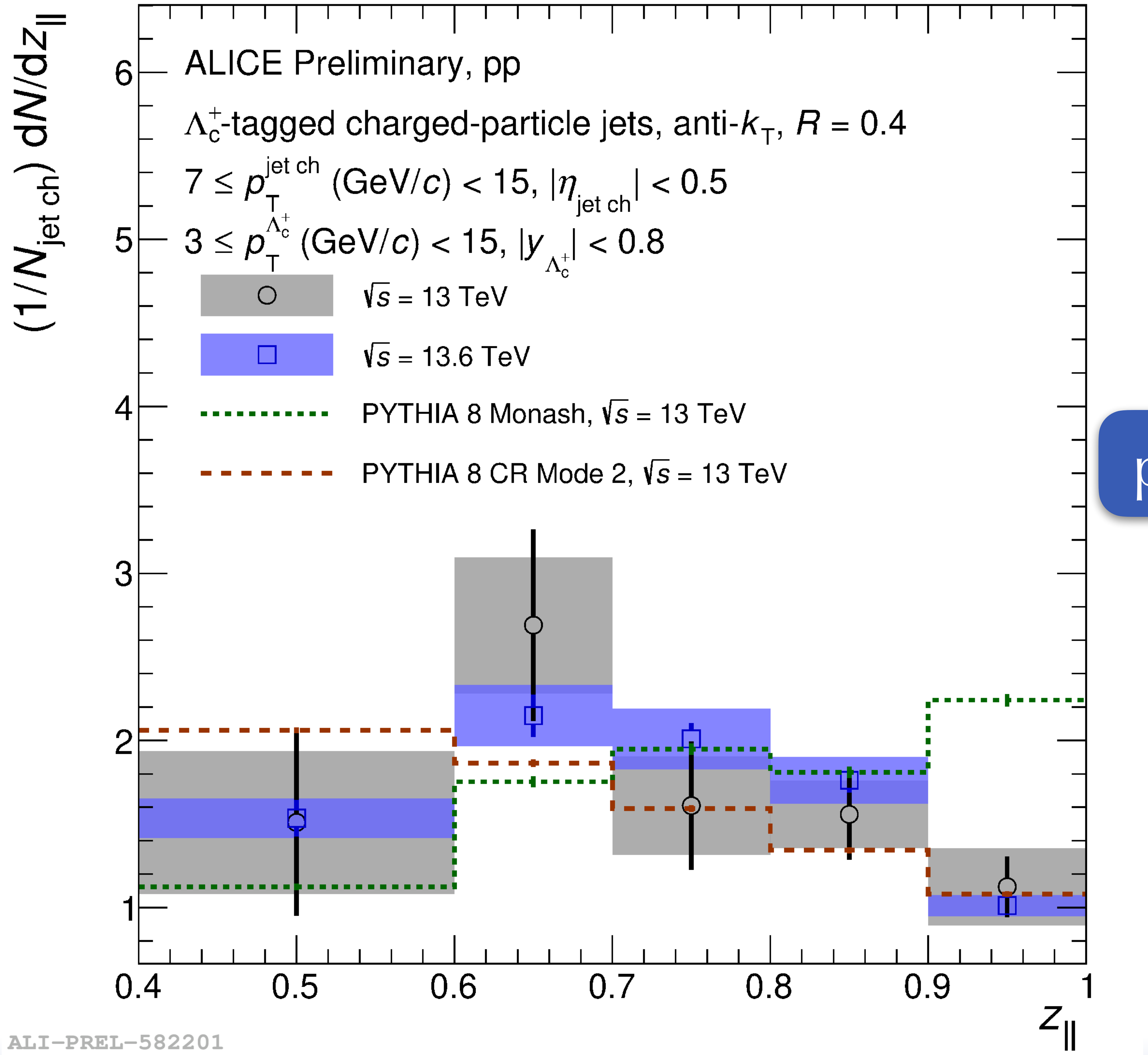
- **Longitudinal momentum fraction** of jet carried by heavy-flavour hadron

$$z_{||} = \frac{\vec{p}^{\,\mathrm{jet}} \cdot \vec{p}^{\,\mathrm{had}}}{\vec{p}^{\,\mathrm{jet}} \cdot \vec{p}^{\,\mathrm{jet}}}$$

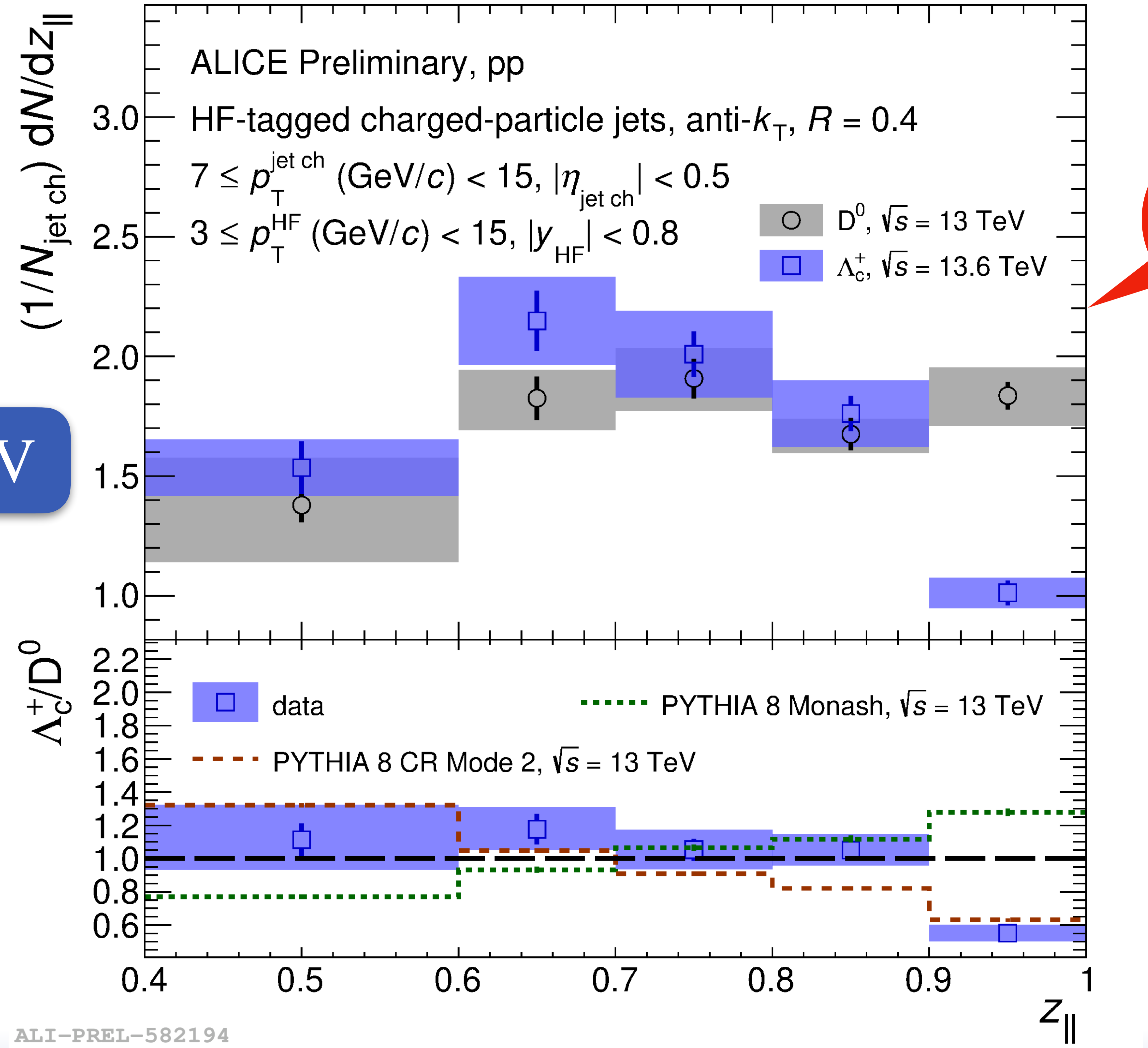
  - targets heavy-flavour fragmentation functions
  - tests (non-)universality of fragmentation

Fragmentation function

- **Λ_c jets**
  - improve sensitivity to hadronisation mechanisms
  - possible tension with colour reconnection modes (describing hadron yields)
- **Comparison of Λ_c and D^0 jets**
  - comparison of baryon and meson
  - tension with models less pronounced



pp, $\sqrt{s} = 13.6$ TeV



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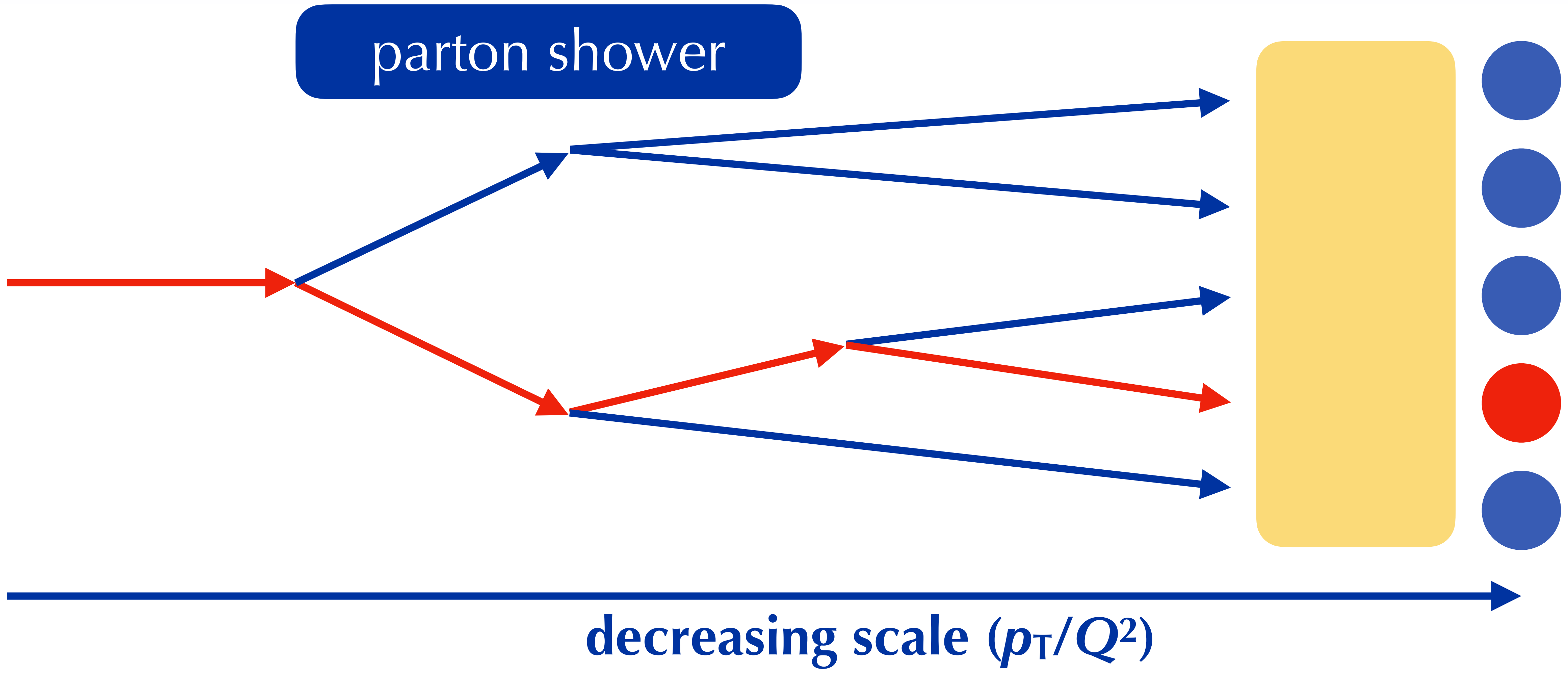
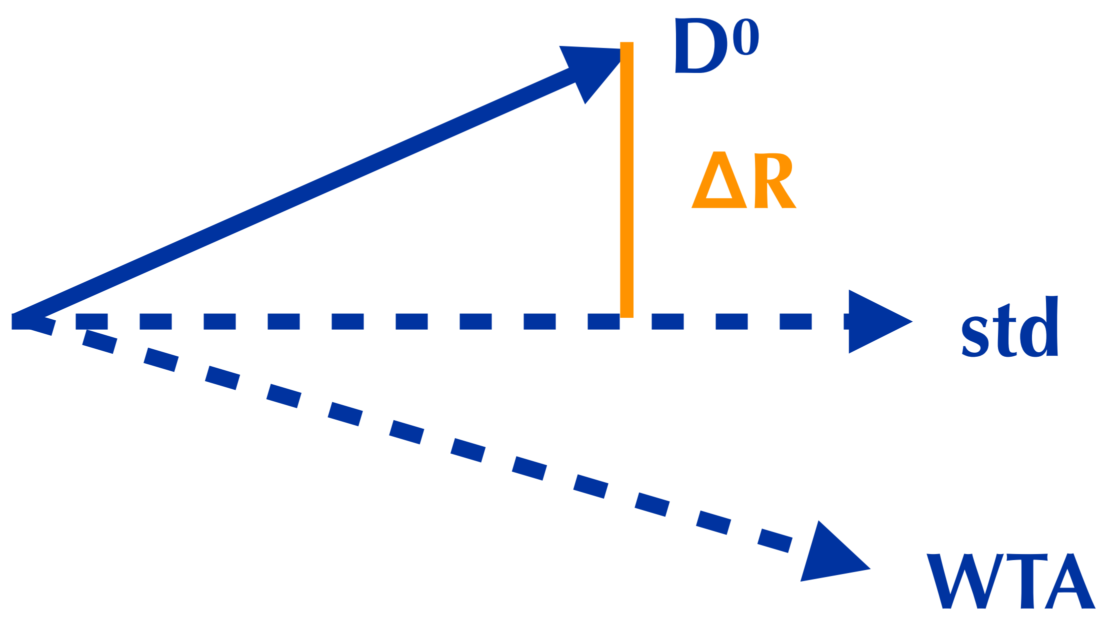
Jet axes differences





- **Radial distance between different axis definitions in jets**

$$\Delta R_{\mathrm{axis}} = \sqrt{(\varphi_{\mathrm{axis},1} - \varphi_{\mathrm{axis},2})^2 + (\eta_{\mathrm{axis},1} - \eta_{\mathrm{axis},2})^2}$$

with standard, winner-takes-all, soft drop, D^0 hadron axes

  - probes radial structure of jet and fragmentation

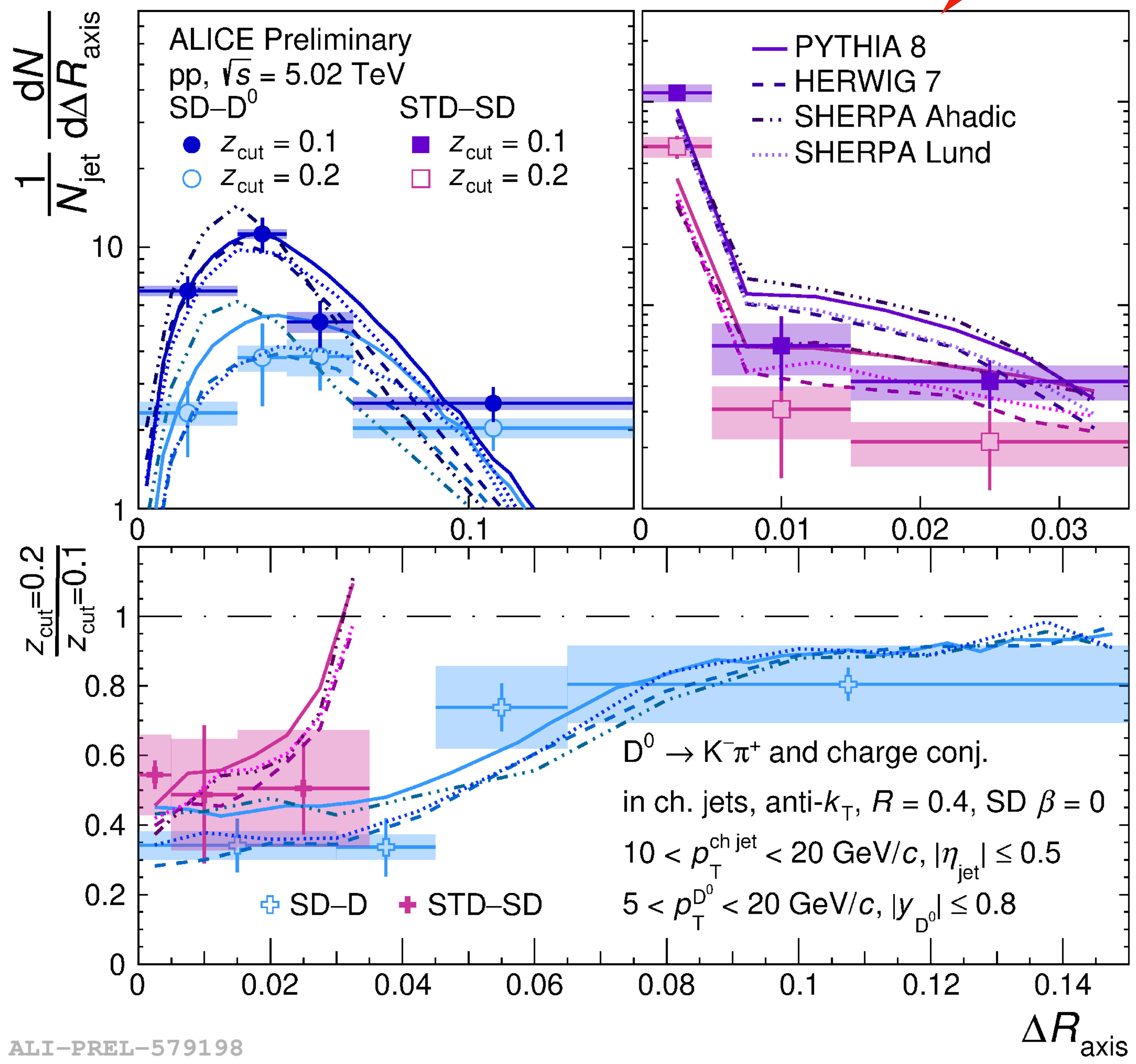
Jet axes differences

→ E. Yeats (poster)

- **Inclusive jets**
  - soft drop and standard axes mostly close for jets surviving grooming
- **D^0 jets**
  - **D^0 adds axis** in the core of the jet
  - **D^0 and WTA axes aligned**
    $\Delta R < 0.01$ for 99% ± 1% of the jets
- **Jets with smaller axis differences more suppressed** by soft drop grooming
  - standard and soft drop axes always closer
  - standard and D^0 axes spread farther apart
- **Data described by PYTHIA 8 and SHERPA** (better with Lund fragmentation)

pp, $\sqrt{s}$ = 13 TeV

New



SHERPA: [SciPost Phys., 7(3):034, 2019, JHEP, 05:026, 2006]
HERWIG: [arXiv:0803.0883, Eur.Phys.J. C76 (2016) no.4, 196]
PYTHIA: [arXiv:2203.11601, arXiv:1404.5630, arXiv:1505.01681]

Conclusions & Outlook

- Heavy-flavour jets give access to **colour and mass effects** with multitude of techniques
  - energy-energy correlators
  - soft groomed substructure observables
  - longitudinal momentum fractions
  - jet axes
- **Great potential of Run 3 data** demonstrated by new measurements
- **Extension of kinematic reach and observables** with improved Run 3 performance ongoing

Thank you for your attention!