



ALICE

Heavy-flavour jet measurements with ALICE

Yoshini Bailung

**Institut de Physique des Deux Infinis (IP2I) de Lyon
on behalf of the ALICE Collaboration**

QCD@LHC

University of Oxford

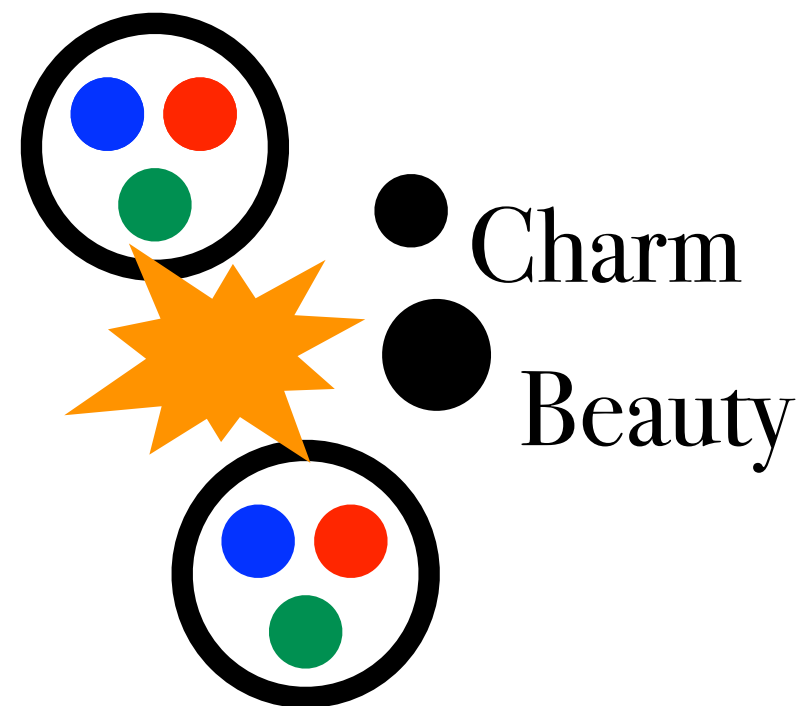
28 September 2026

Introduction to heavy-flavour jets



Heavy-flavour quarks

- ☑ Early production in hard processes
- ☑ Test of perturbative QCD calculations



Introduction to heavy-flavour jets

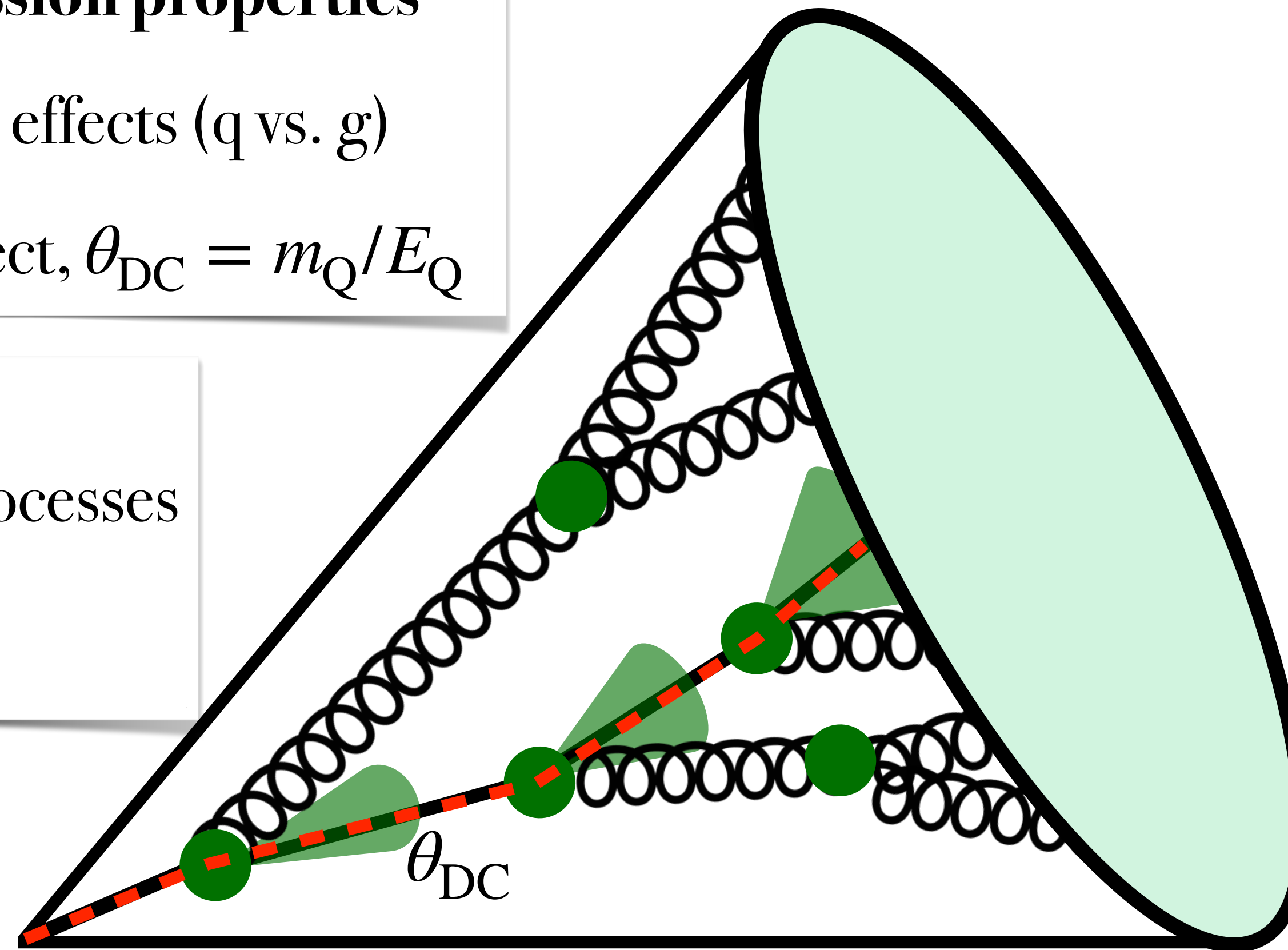
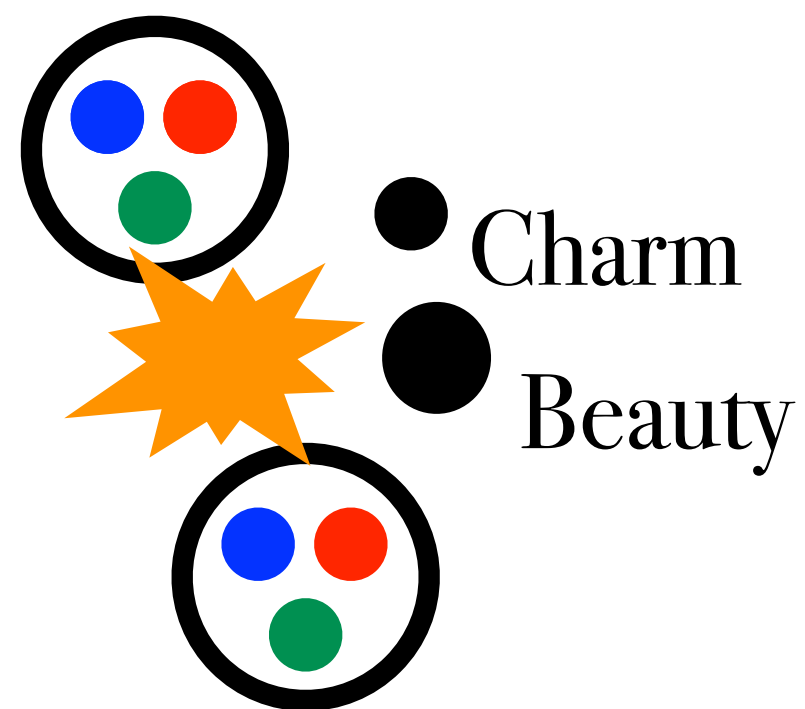


Probe gluon emission properties

- ☑ Casimir colour effects (q vs. g)
- ☑ Dead-cone effect, $\theta_{\text{DC}} = m_Q/E_Q$

Heavy-flavour quarks

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Experimentally traceable
parton-shower pattern

Introduction to heavy-flavour jets

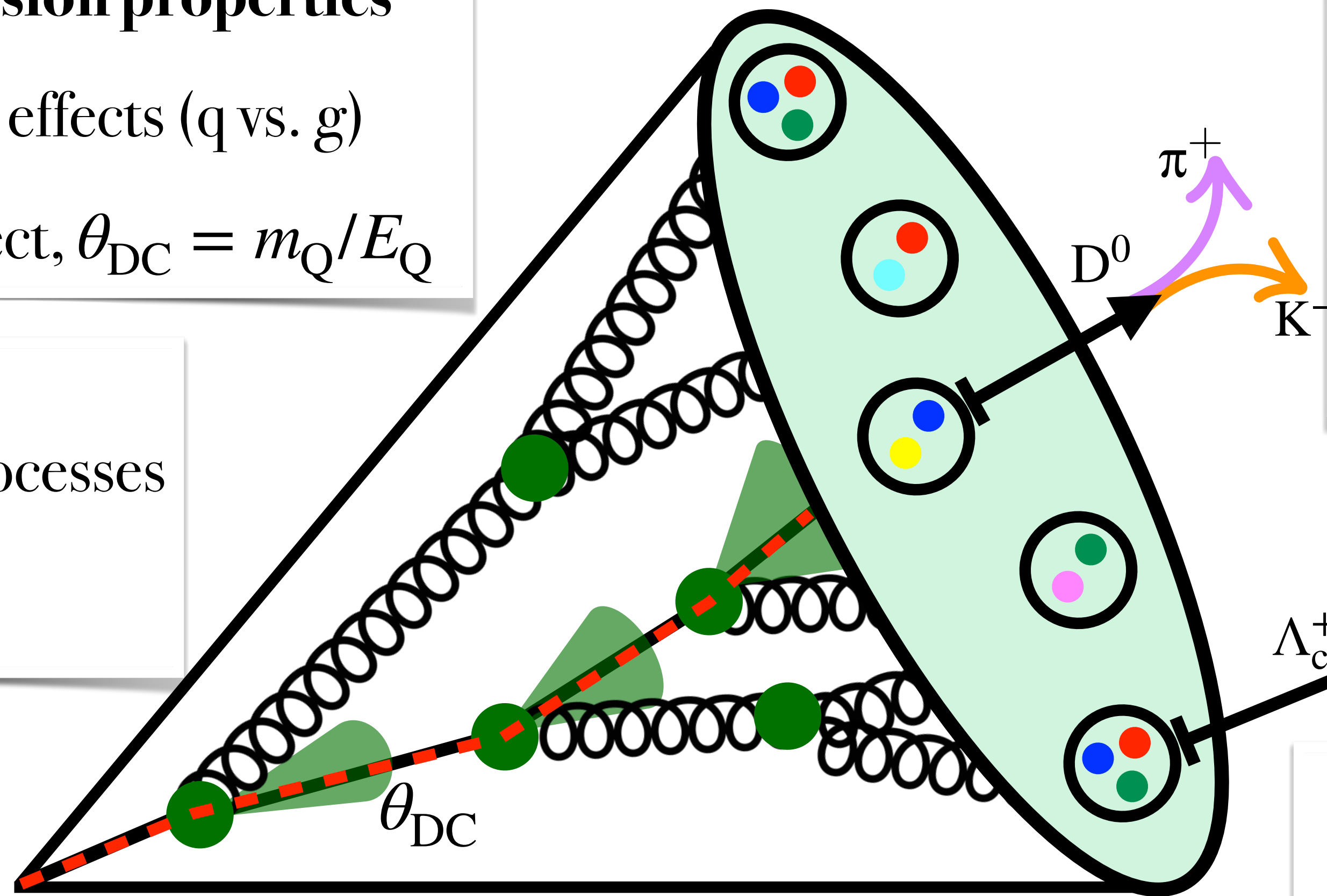
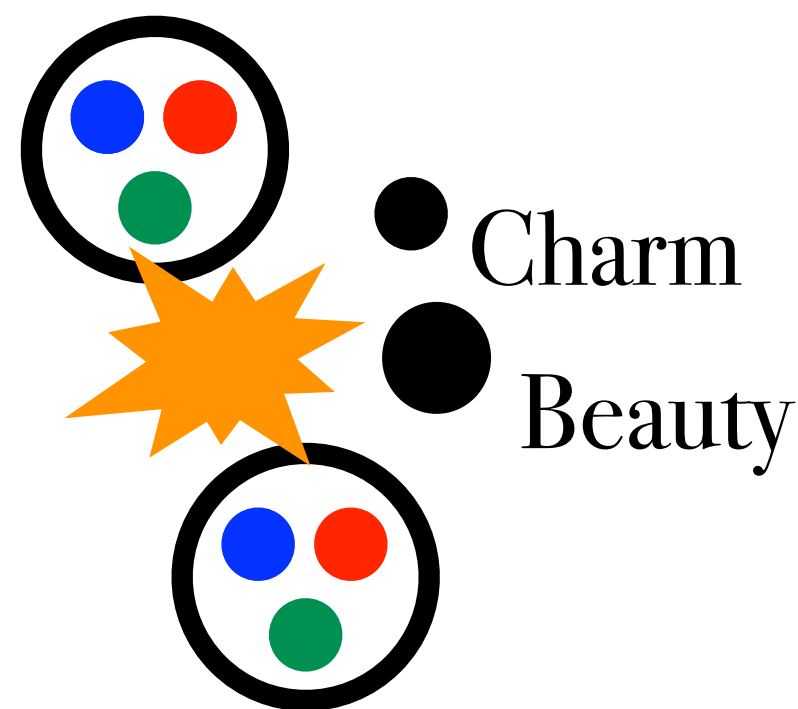


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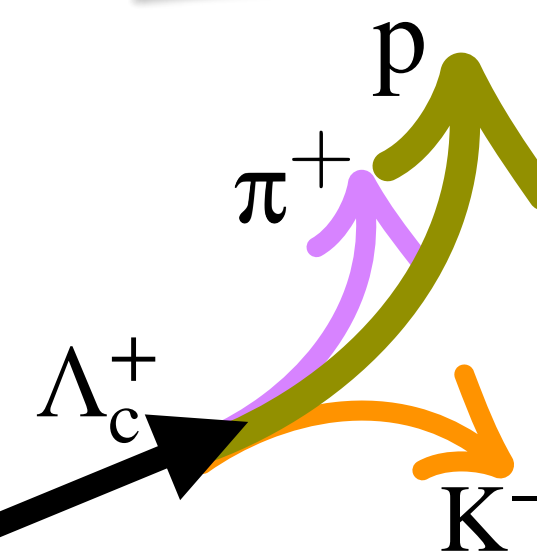


Experimentally traceable
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Hadronisation mechanisms



Species dependence?

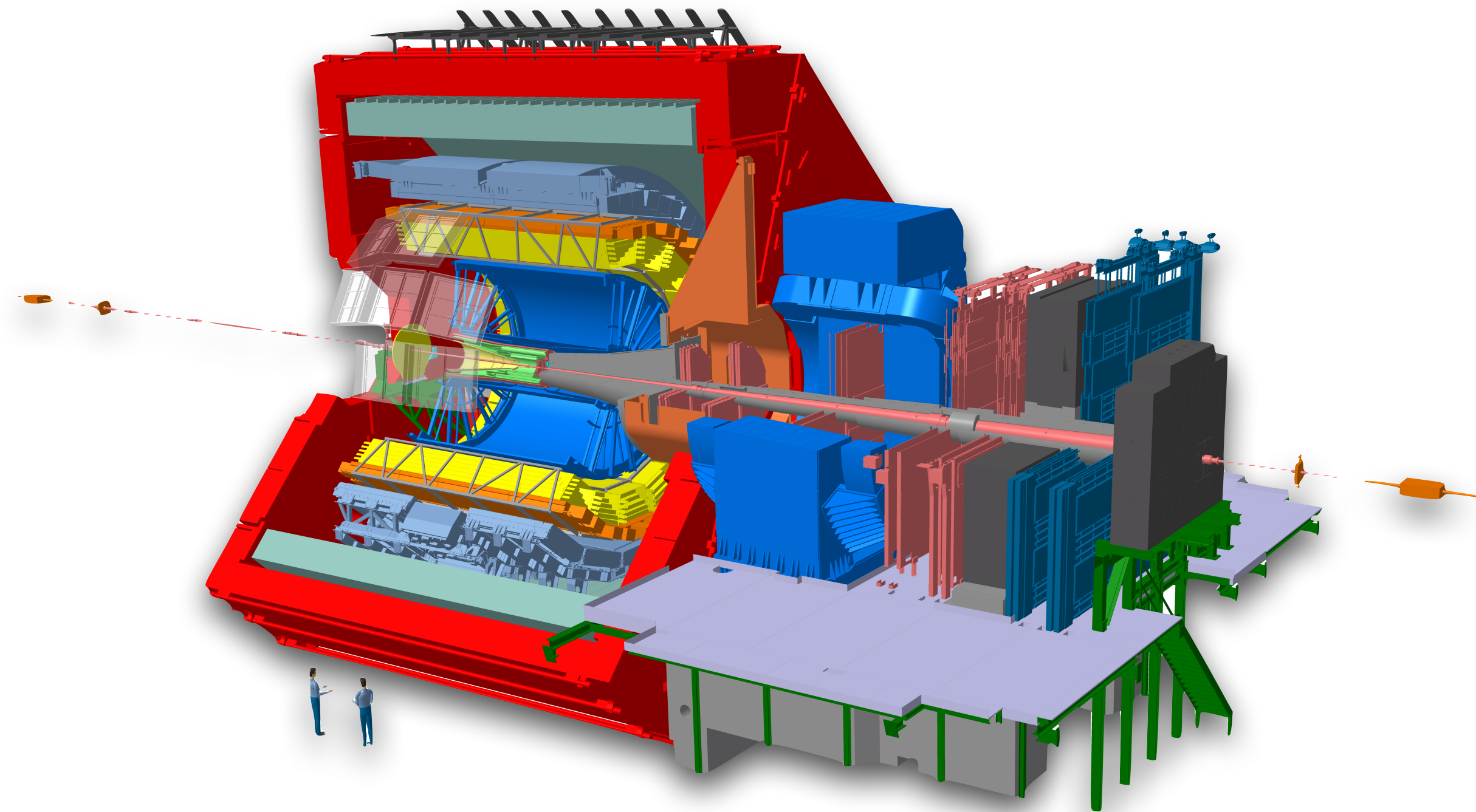


4-momenta of decay
daughters replaced with
parent 4-momentum in
jet finding.

ALICE during LHC Run 3



ALICE received major upgrades during LS2

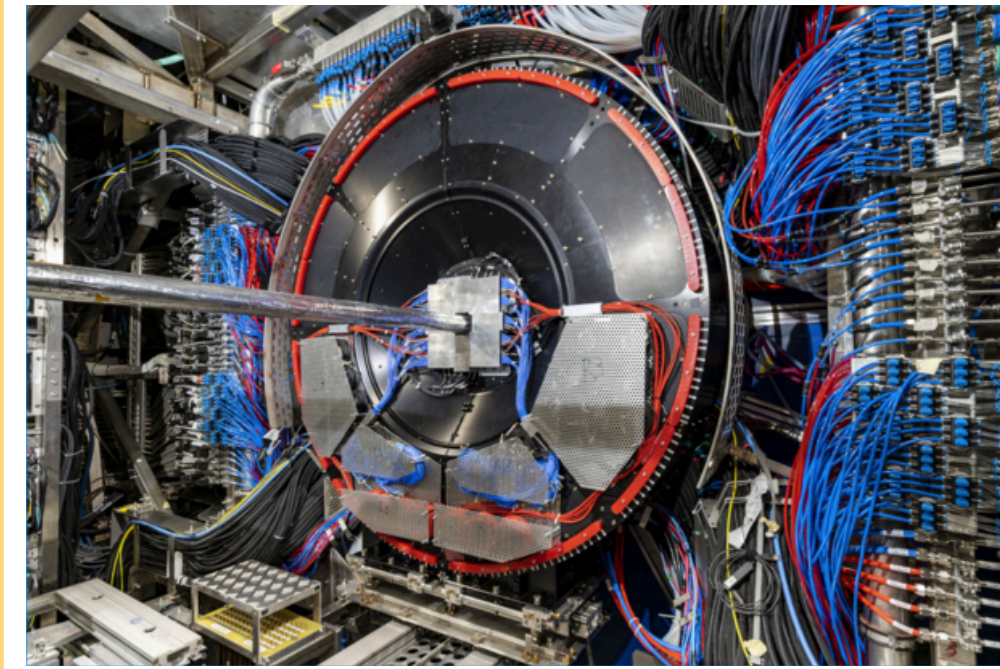


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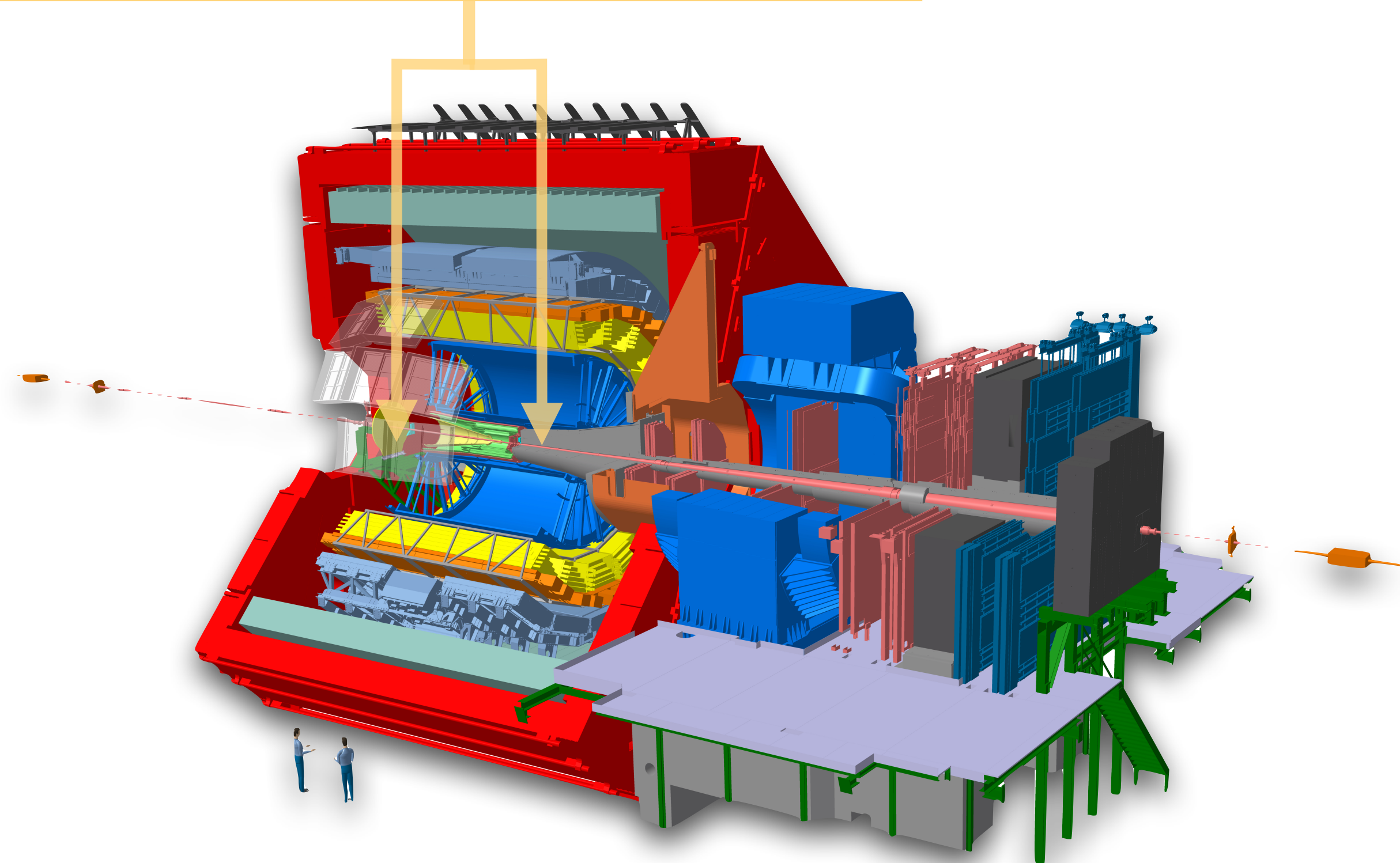
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- ☑ Fast Interaction Trigger (FIT)
- ☑ Two Cherenkov arrays (FT0A, FT0C)



FIT

- Luminosity
- Event selection
- Multiplicity



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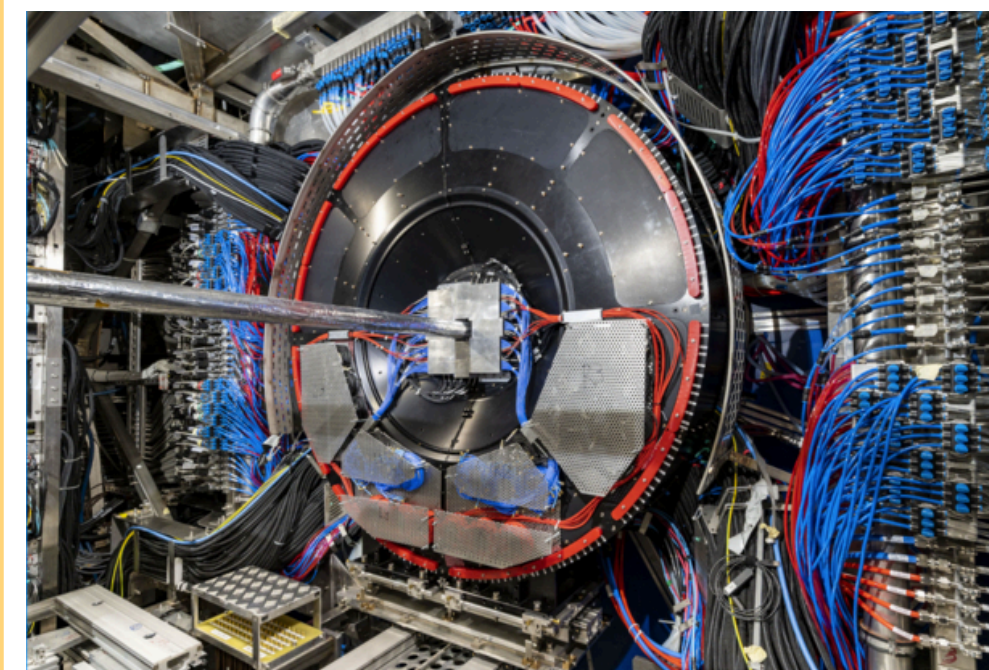


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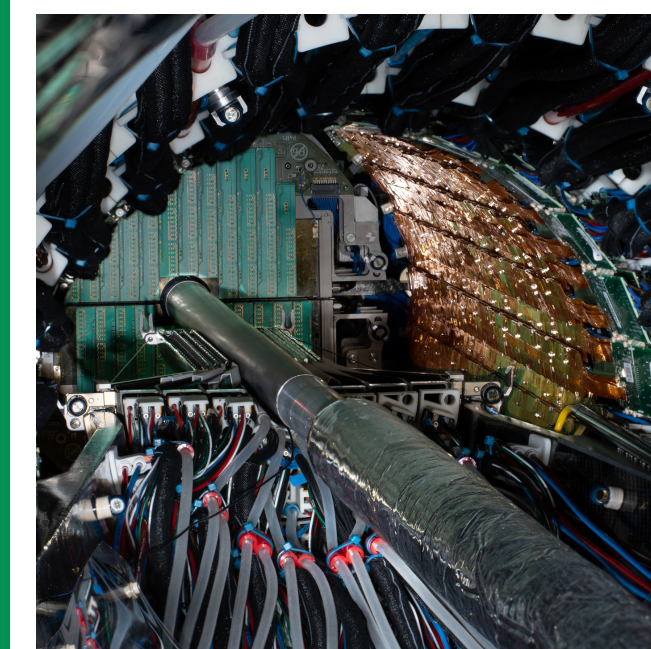
☑ Inner Tracking System (ITS2)

- ☑ 7 layers of MAPS detectors → Improved vertexing, higher readout rate



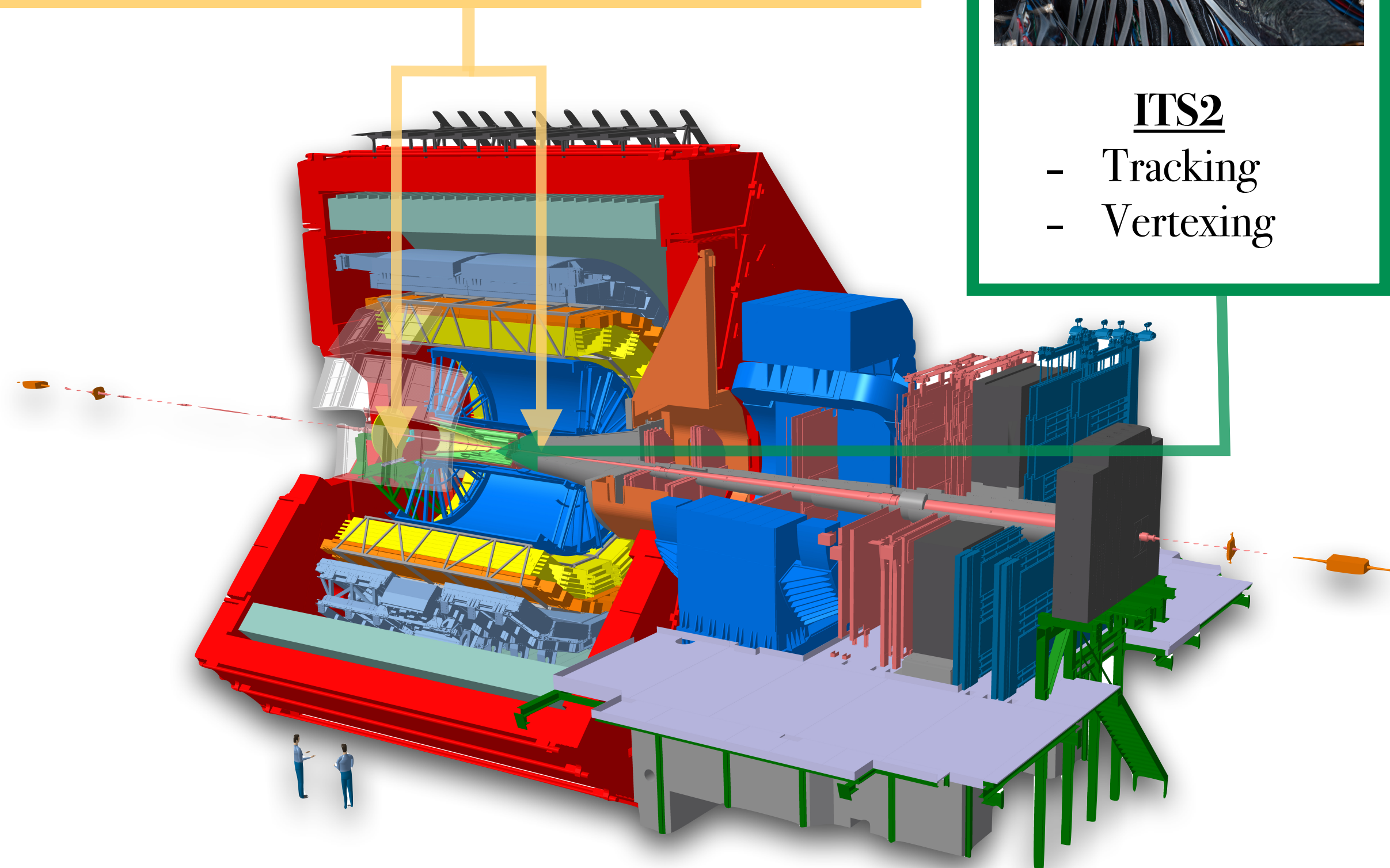
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- Tracking
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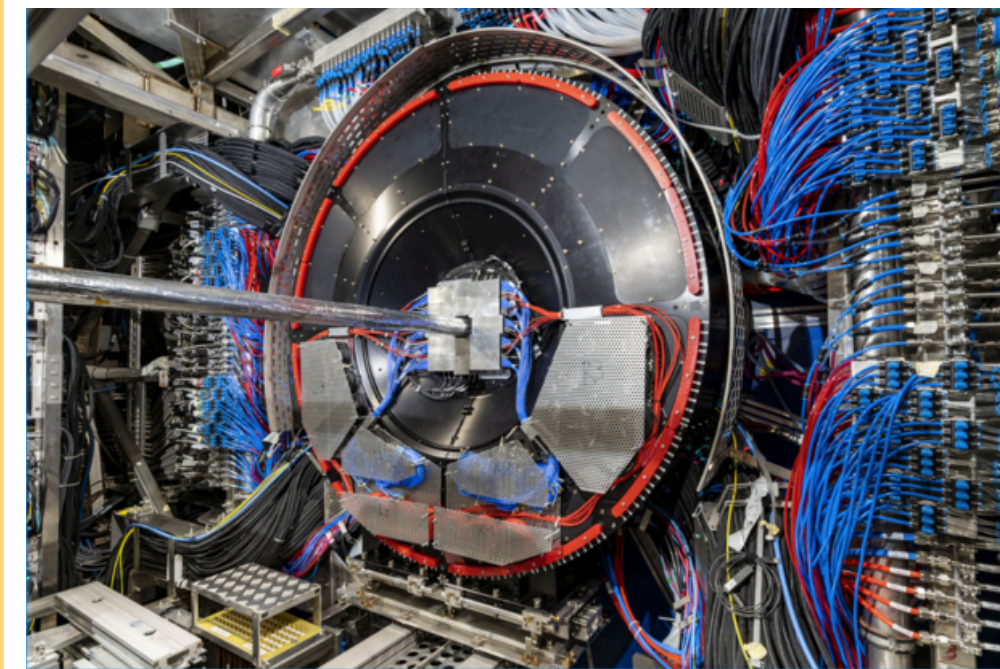
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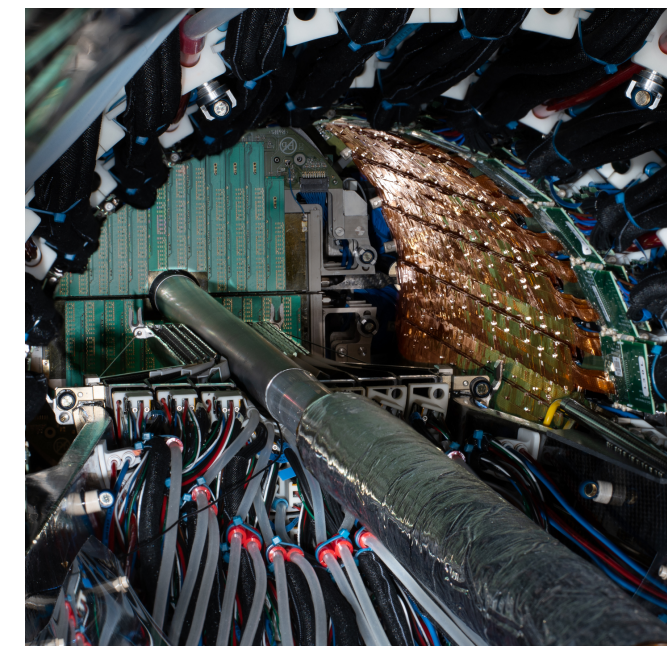
☑ Time Projection Chamber (TPC)

- ☑ GEM readout chambers → Continuous readout



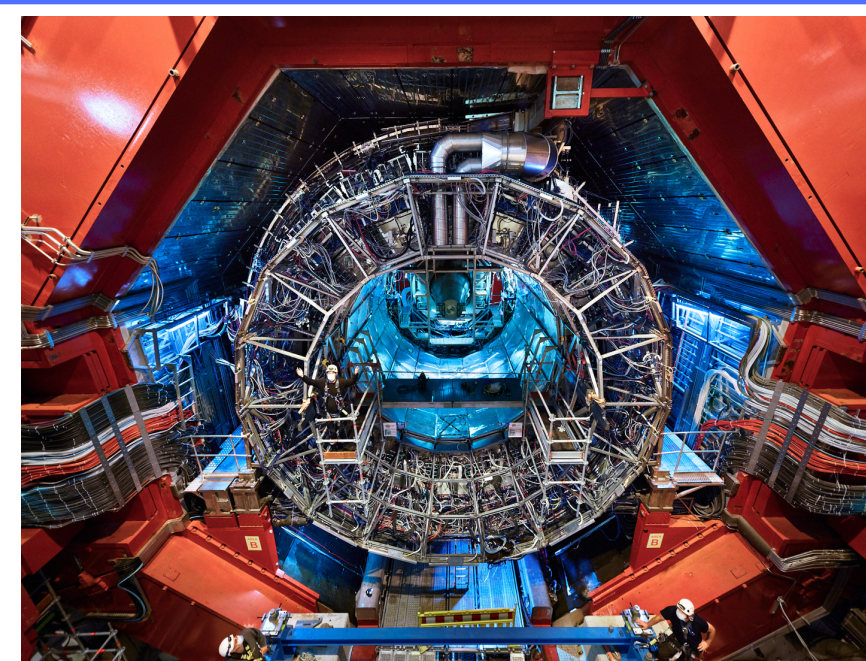
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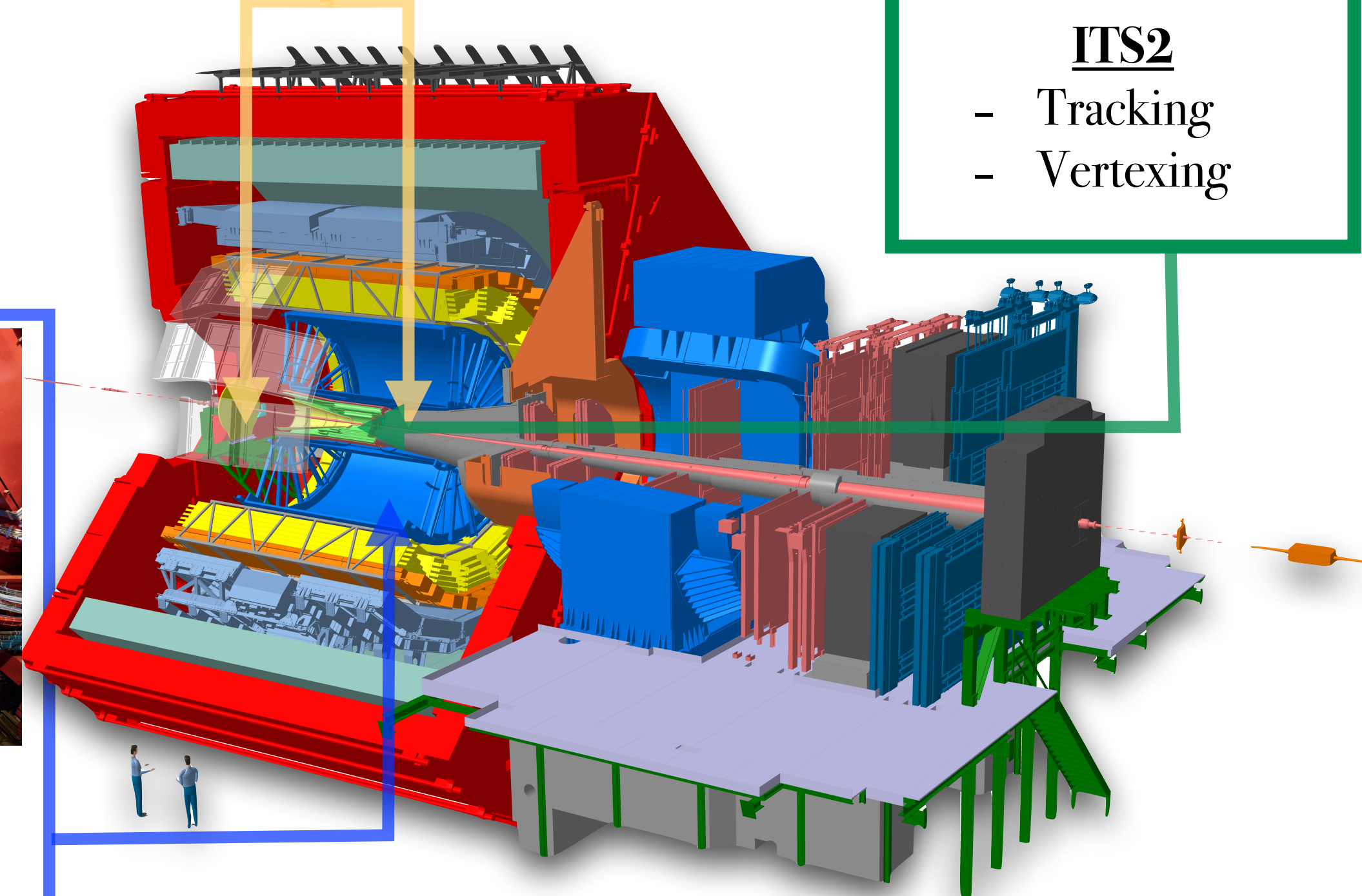
ITS2

- Tracking
- Vertexing



TPC

- Tracking
- PID

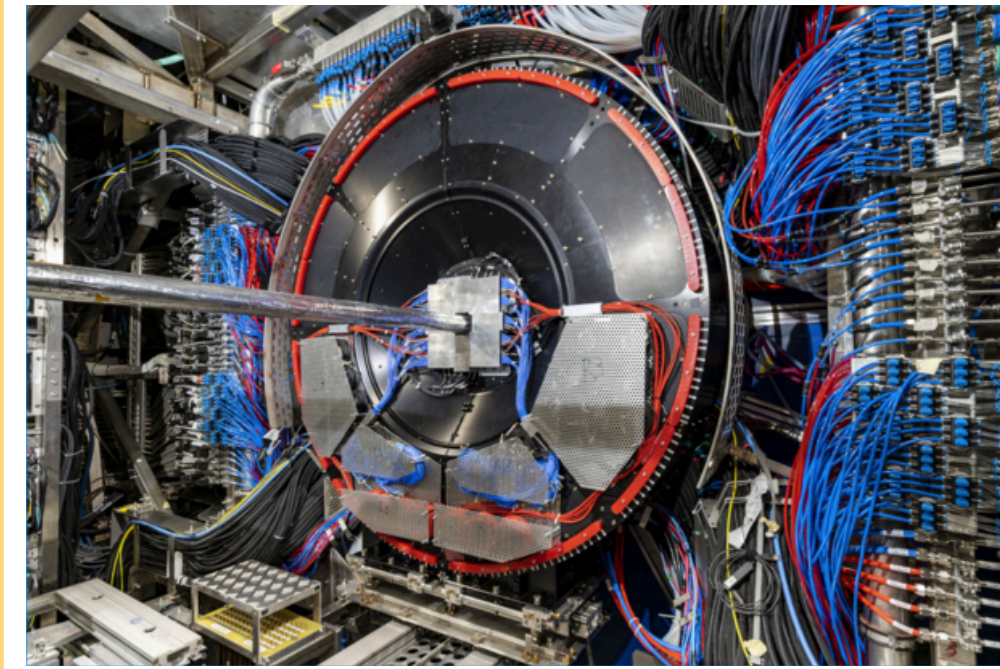


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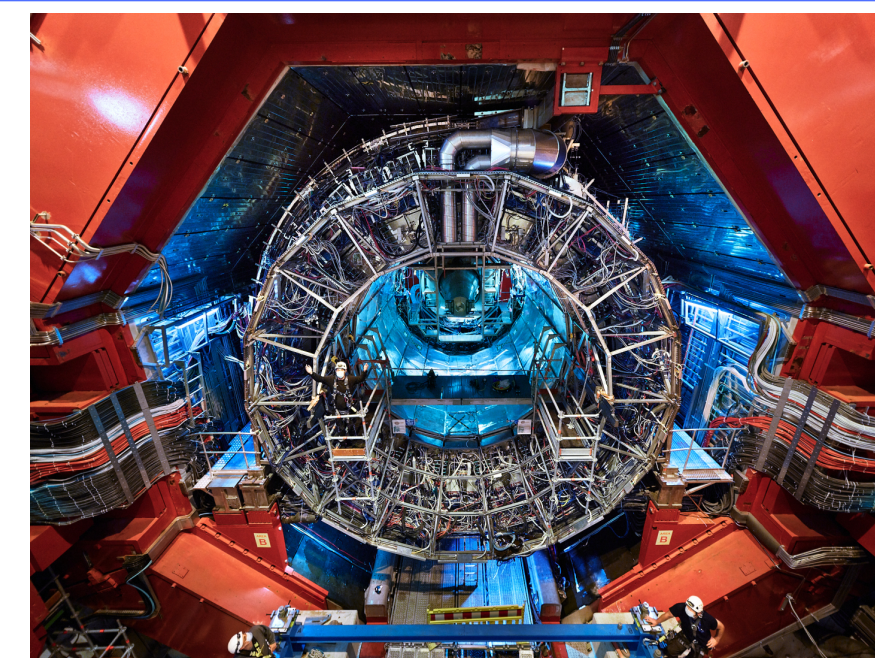
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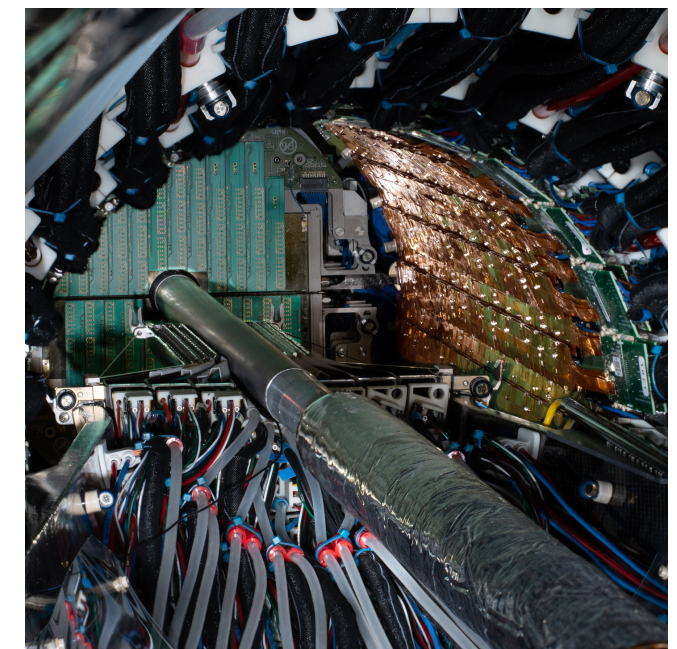
Time-Of-Flight (TOF)

- PID



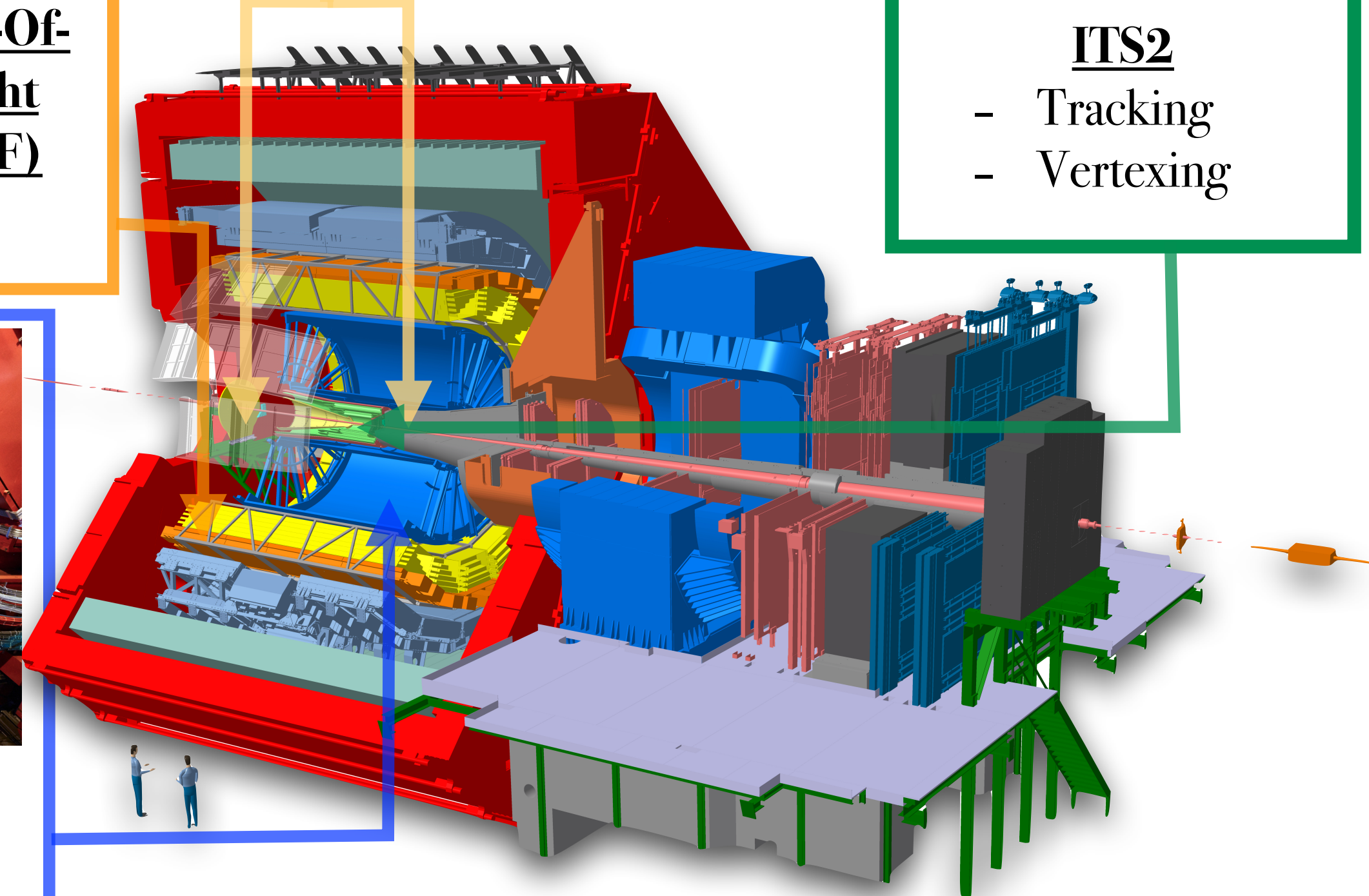
TPC

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ITS2

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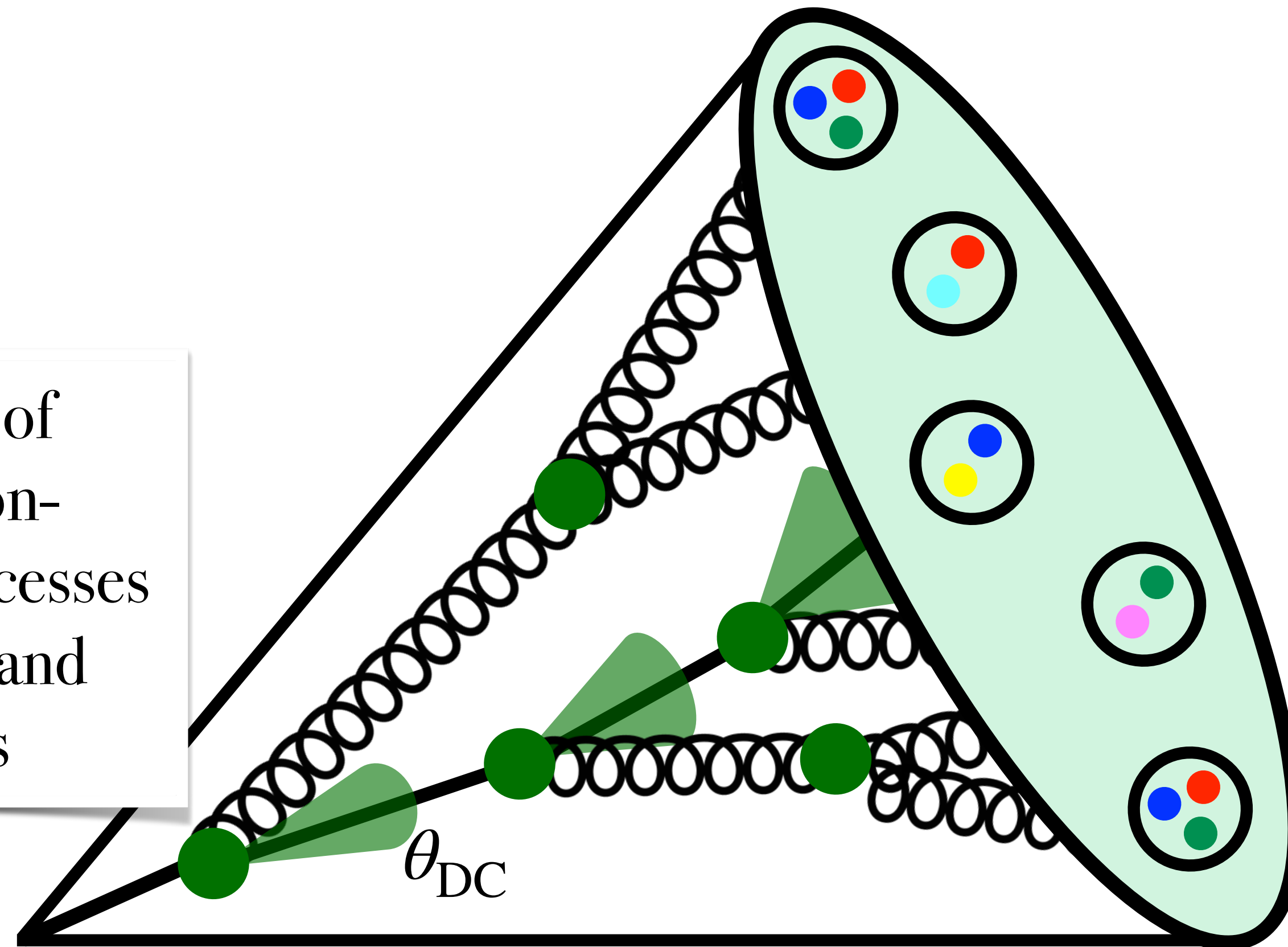
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Jet-axis differences



Sensitive to effects of
perturbative and non-
perturbative QCD processes
in jet fragmentation and
radiation patterns



$$\Delta R_{\text{axis}} = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

Angular difference between different
jet-axis definitions

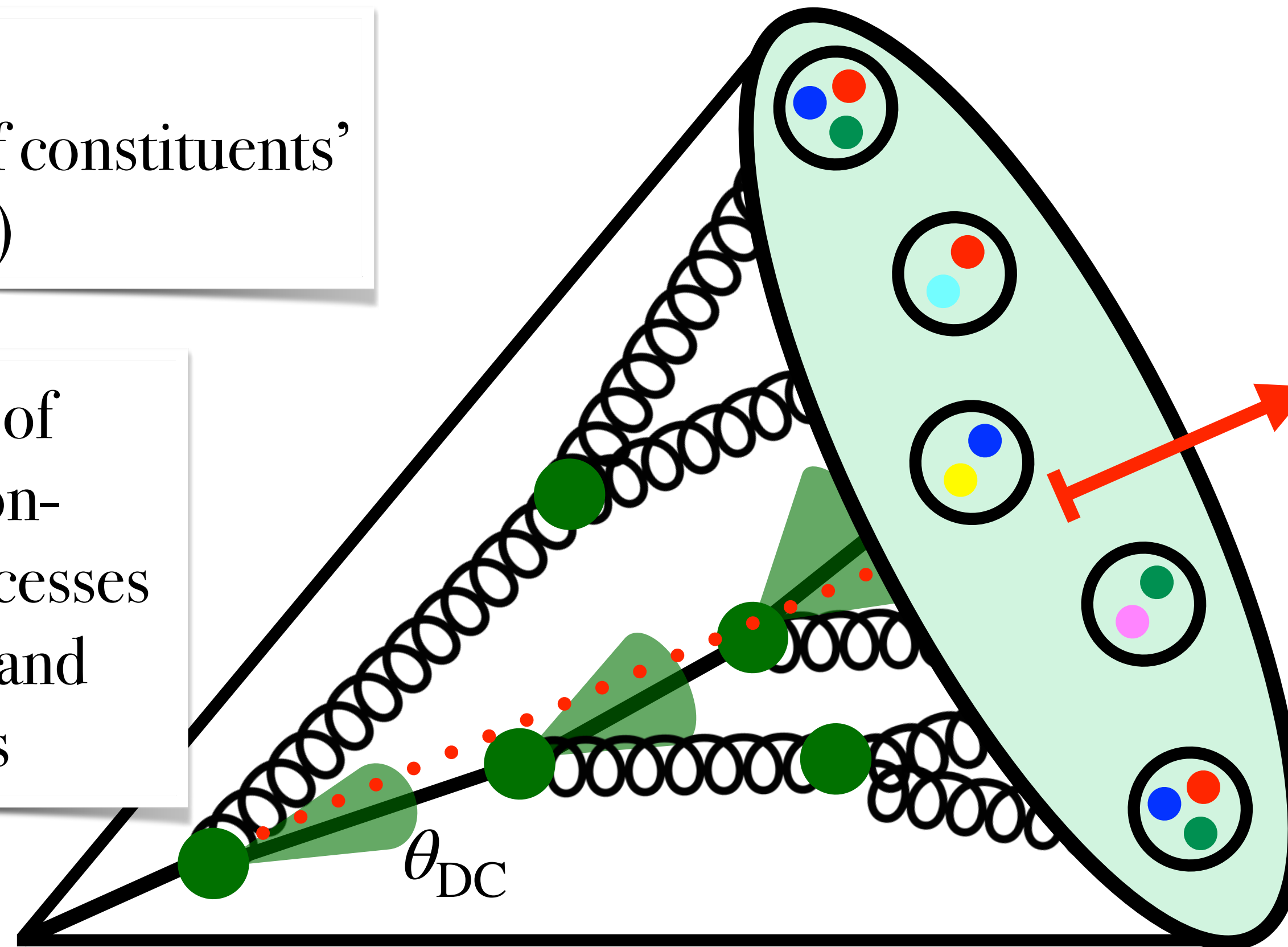
Jet-axis differences



Standard (STD)

Jet axis from the sum of constituents' 4-momenta (E -scheme)

Sensitive to effects of perturbative and non-perturbative QCD processes in jet fragmentation and radiation patterns



$$\Delta R_{\text{axis}} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

Angular difference between different jet-axis definitions

Jet-axis differences



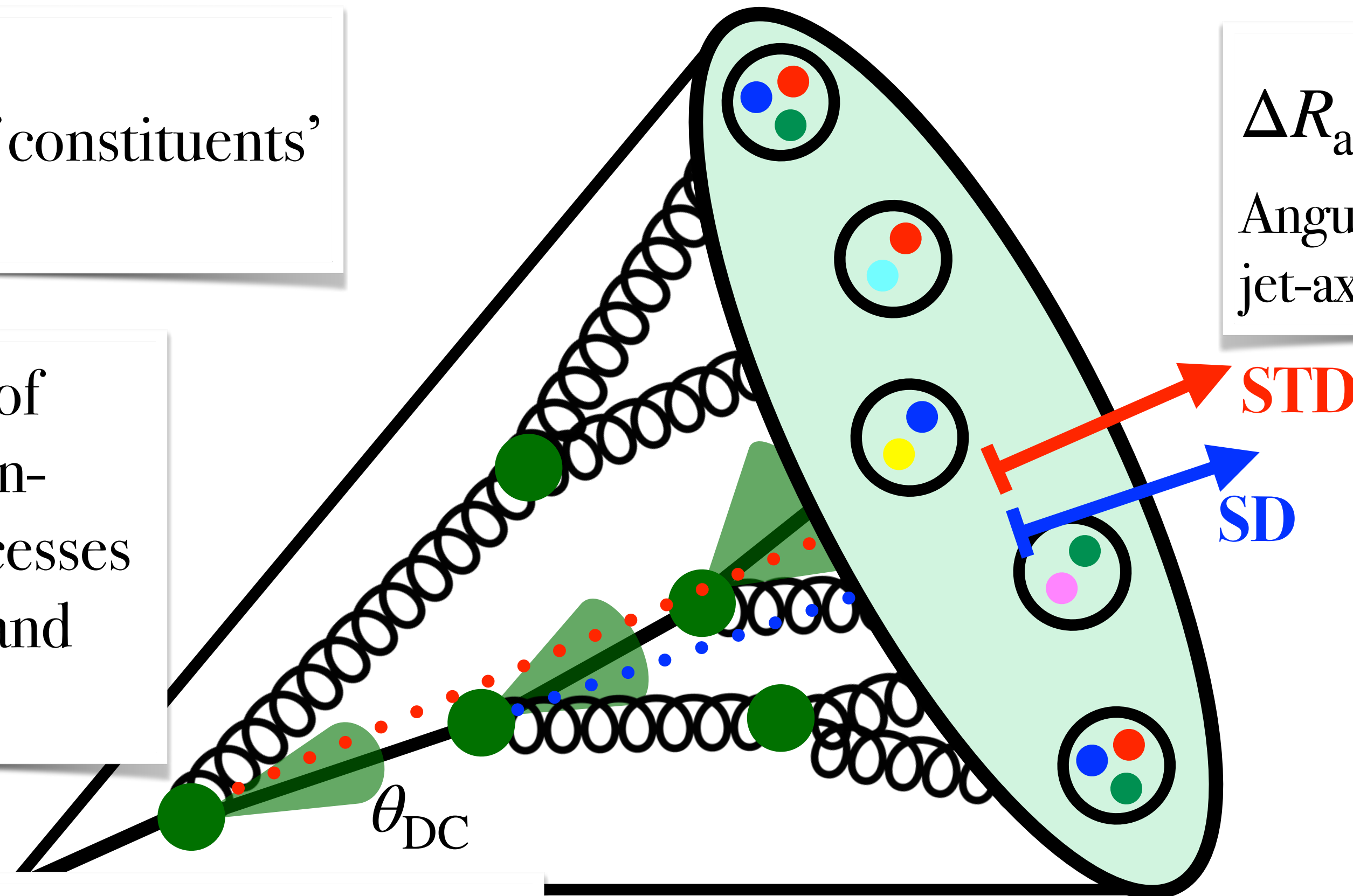
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Soft Drop (SD)

Recluster with Cambridge-Aachen, and then define jet axis from the first splitting that satisfies the SD condition



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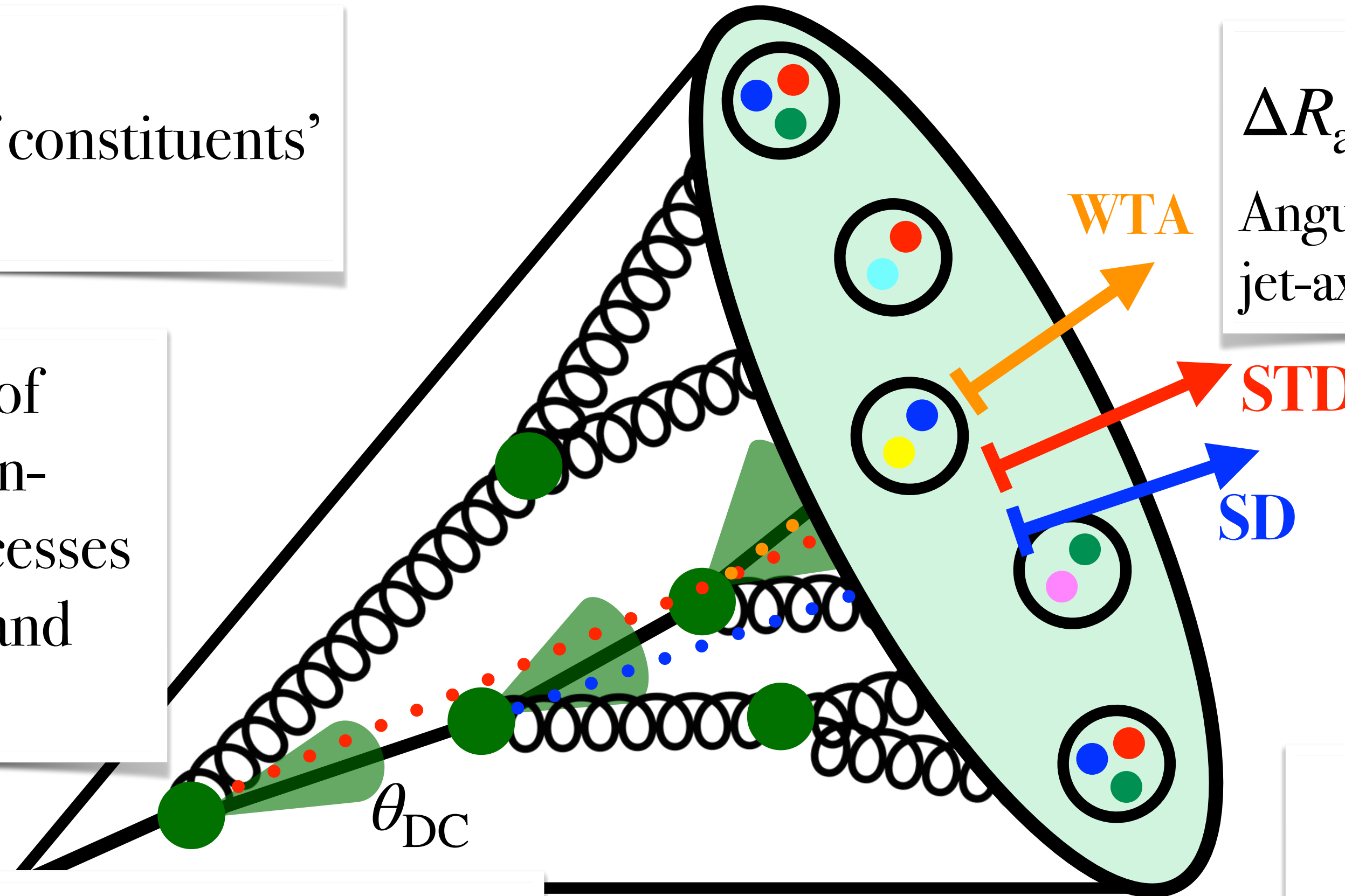
$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0} \right)^\beta$$

$$\Delta R_{\text{axis}} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

Angular difference between different jet-axis definitions

Winner Takes All (WTA)

Recluster with Cambridge-Aachen and then define the jet axis following the hardest subjet at each clustering step



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Jet axis from the sum of constituents' 4-momenta (E -scheme)

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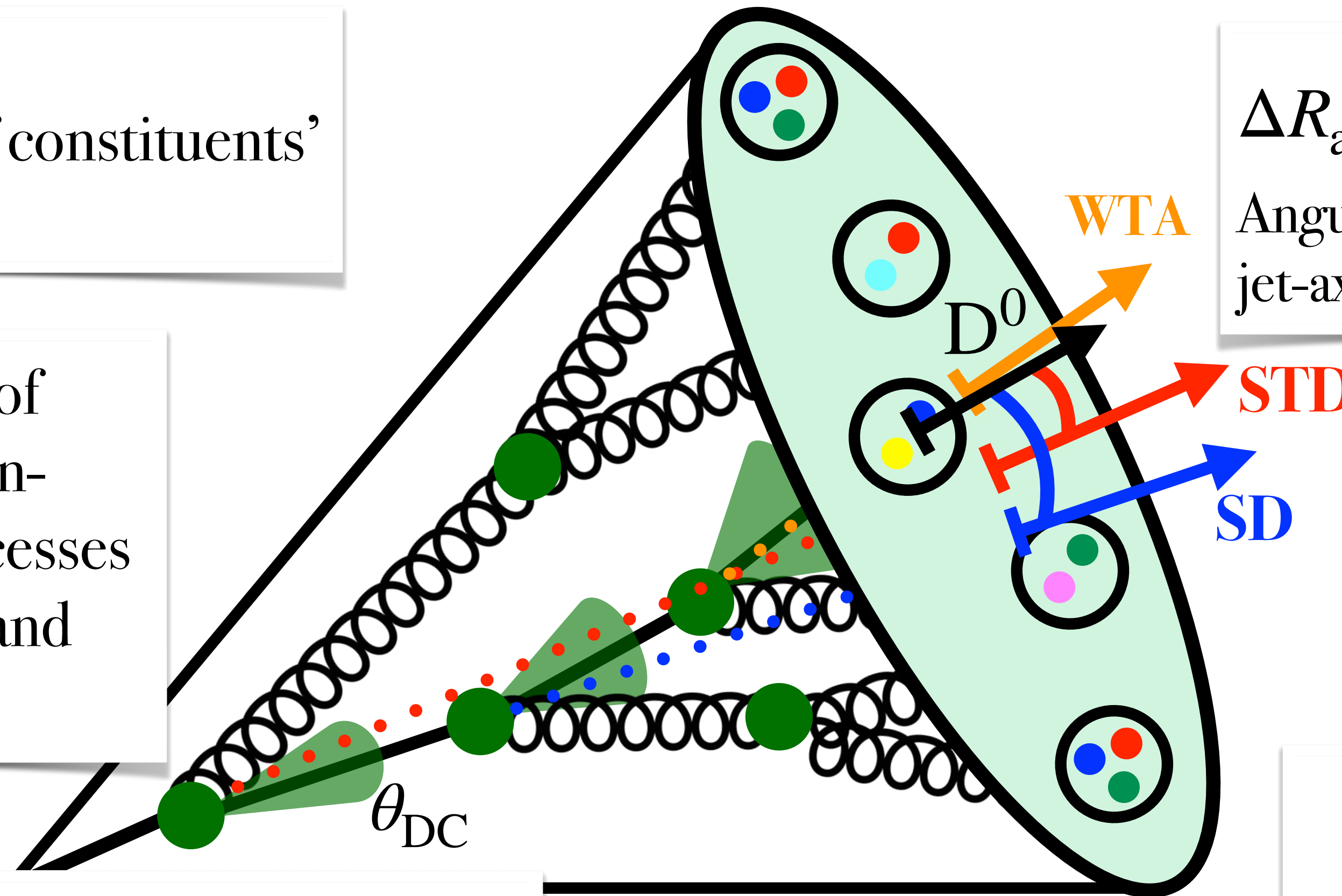
$$\Delta R_{\text{axis}} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

Angular difference between different jet-axis definitions

ΔR_{axis} between jet axis and the D^0 direction

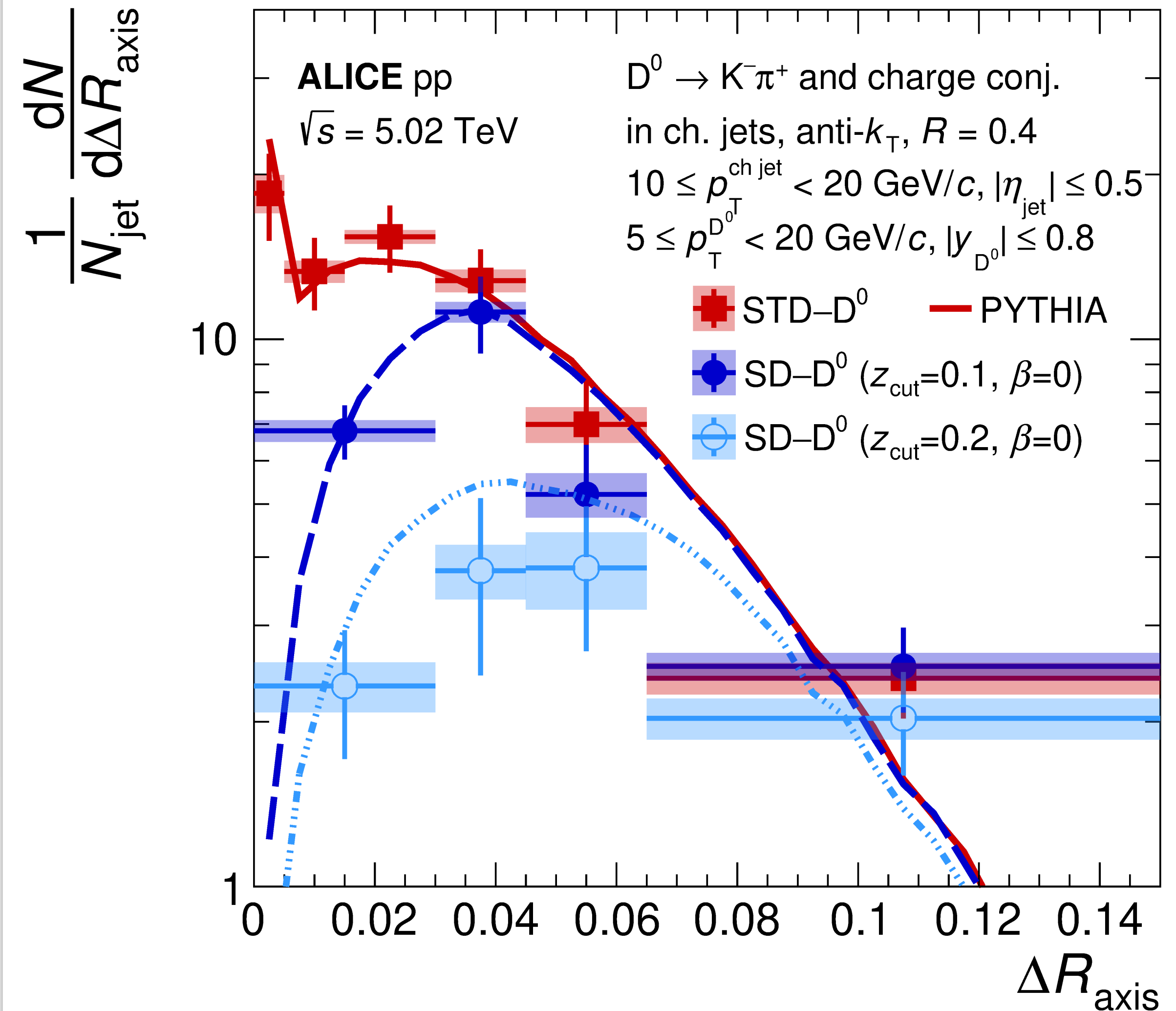
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STD vs. SD for D⁰-tagged jets

*ALICE Collaboration, Phys.Rev.D 112 (2025) 9, 092012



ALI-PUB-618183

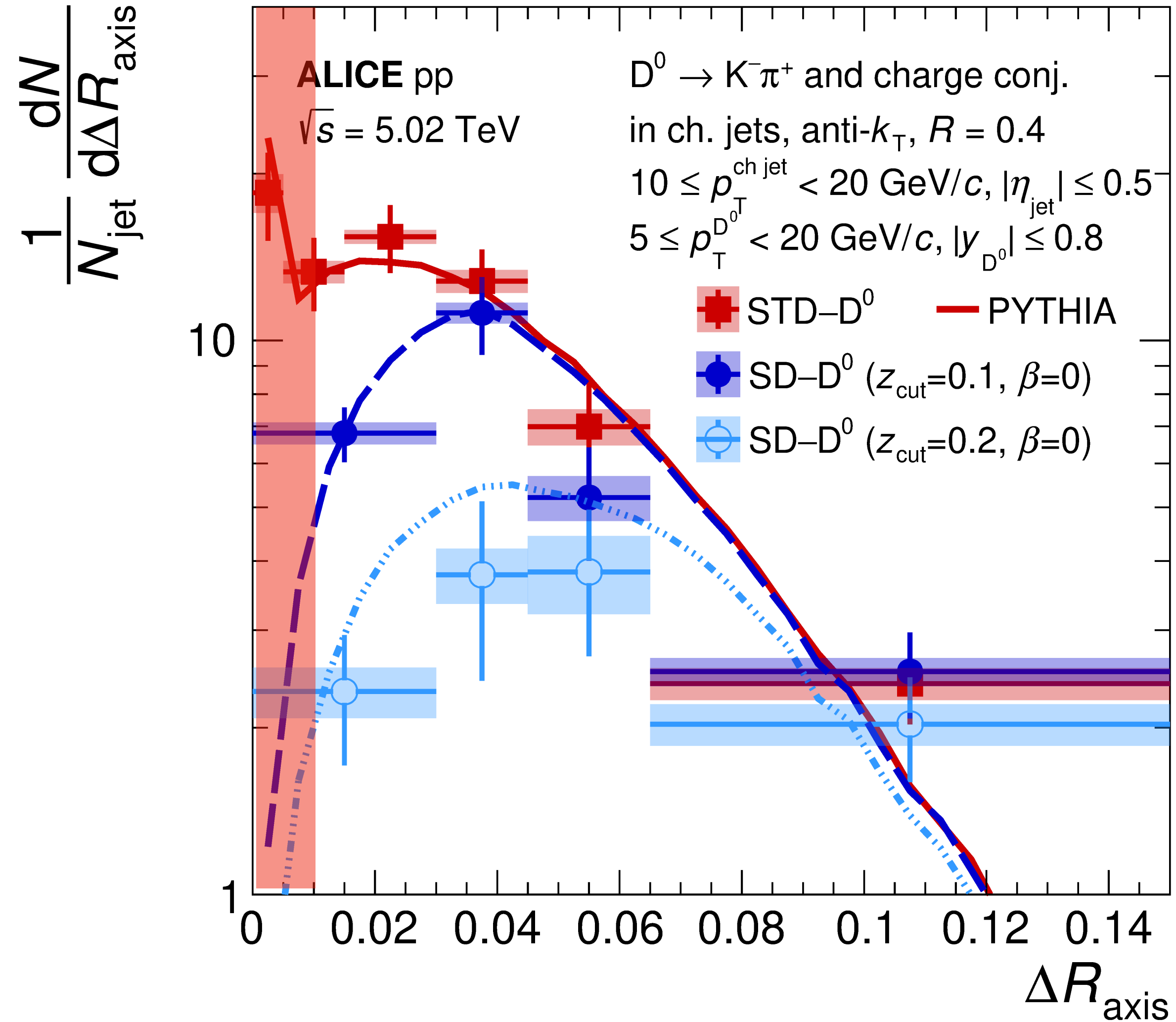
STD vs. SD for D⁰-tagged jets



*ALICE Collaboration, Phys.Rev.D 112 (2025) 9, 092012

STD – D⁰

- ☑ Peaks near $\Delta R_{\text{axis}} = 0$
- ☑ Jets with very soft radiation
- ☑ Single-constituent D⁰ jet



*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

ALI-PUB-618183

STD vs. SD for D^0 -tagged jets



*ALICE Collaboration, Phys.Rev.D 112 (2025) 9, 092012

STD – D^0

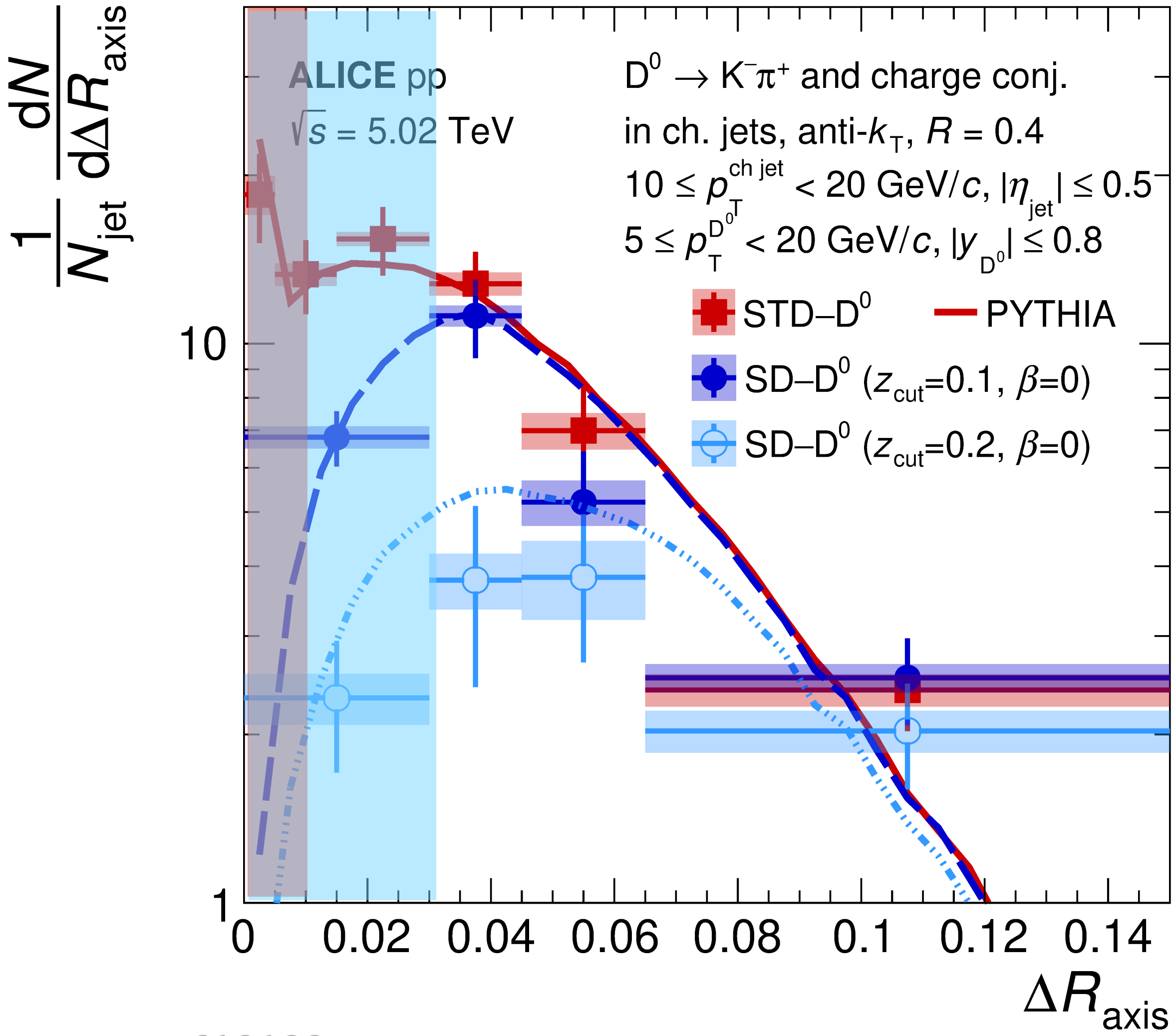
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- ☑ Jets with very soft radiation
- ☑ Single-constituent D^0 jet

SD – D^0

- ☑ ($z_{\text{cut}} = 0.1$) Single-constituent D^0 jets groomed away at small ΔR_{axis}
- ☑ ($z_{\text{cut}} = 0.2$) Grooming pronounced
- ☑ At large ΔR_{axis} jets survive grooming

$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0} \right)^{\beta=0}$$

*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024



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STD vs. SD for D⁰-tagged jets



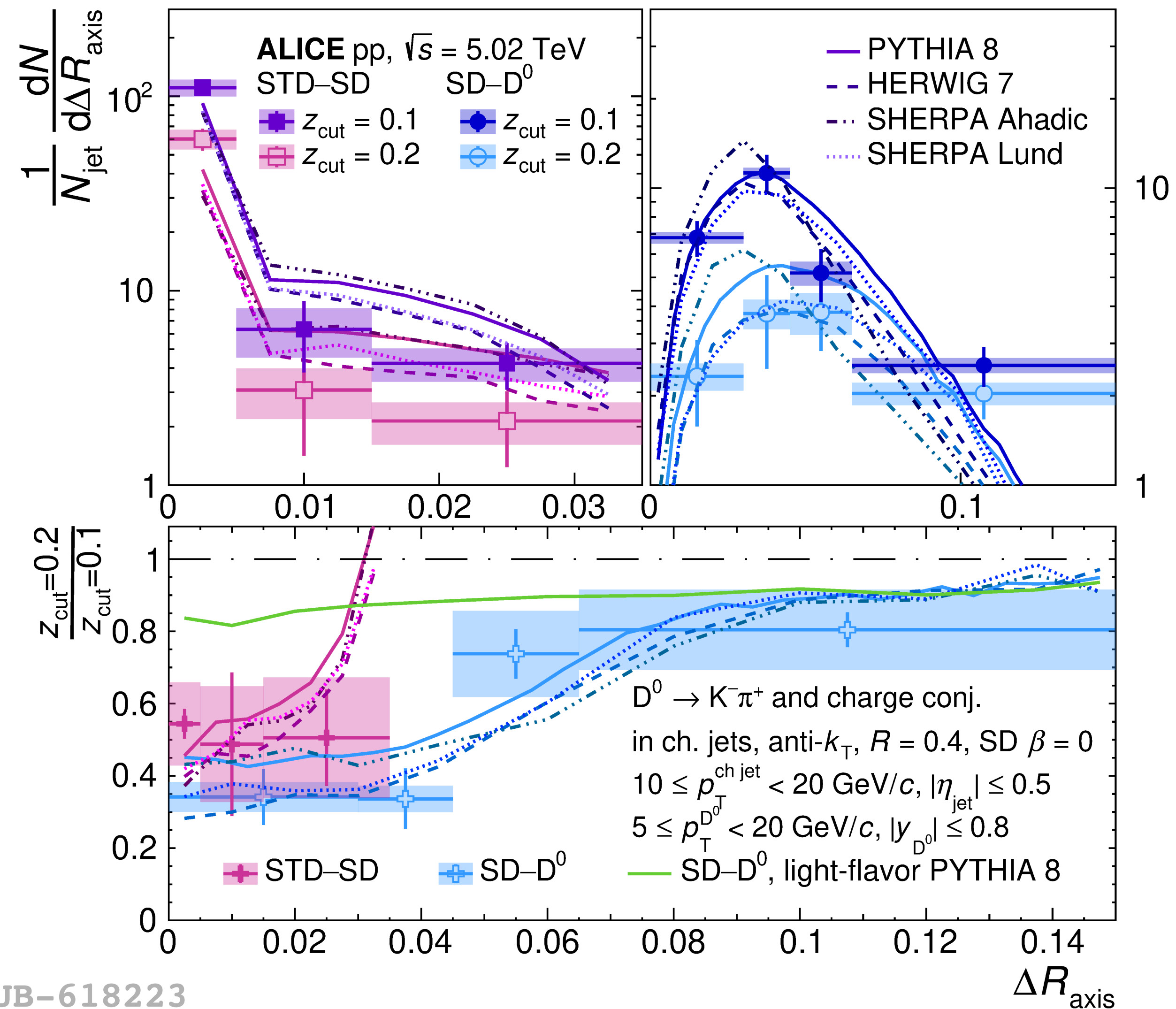
*ALICE Collaboration, Phys.Rev.D 112 (2025) 9, 092012

STD–SD distributions are less affected
by grooming



Effect of soft radiation in the jet direction

String-based models
(PYTHIA and SHERPA Lund)
provide better predictions than
cluster-based models
(HERWIG and SHERPA Ahadic)



ALI-PUB-618223

*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

*SHERPA Collaboration, SciPost Phys. 7 (2019) 3, 034

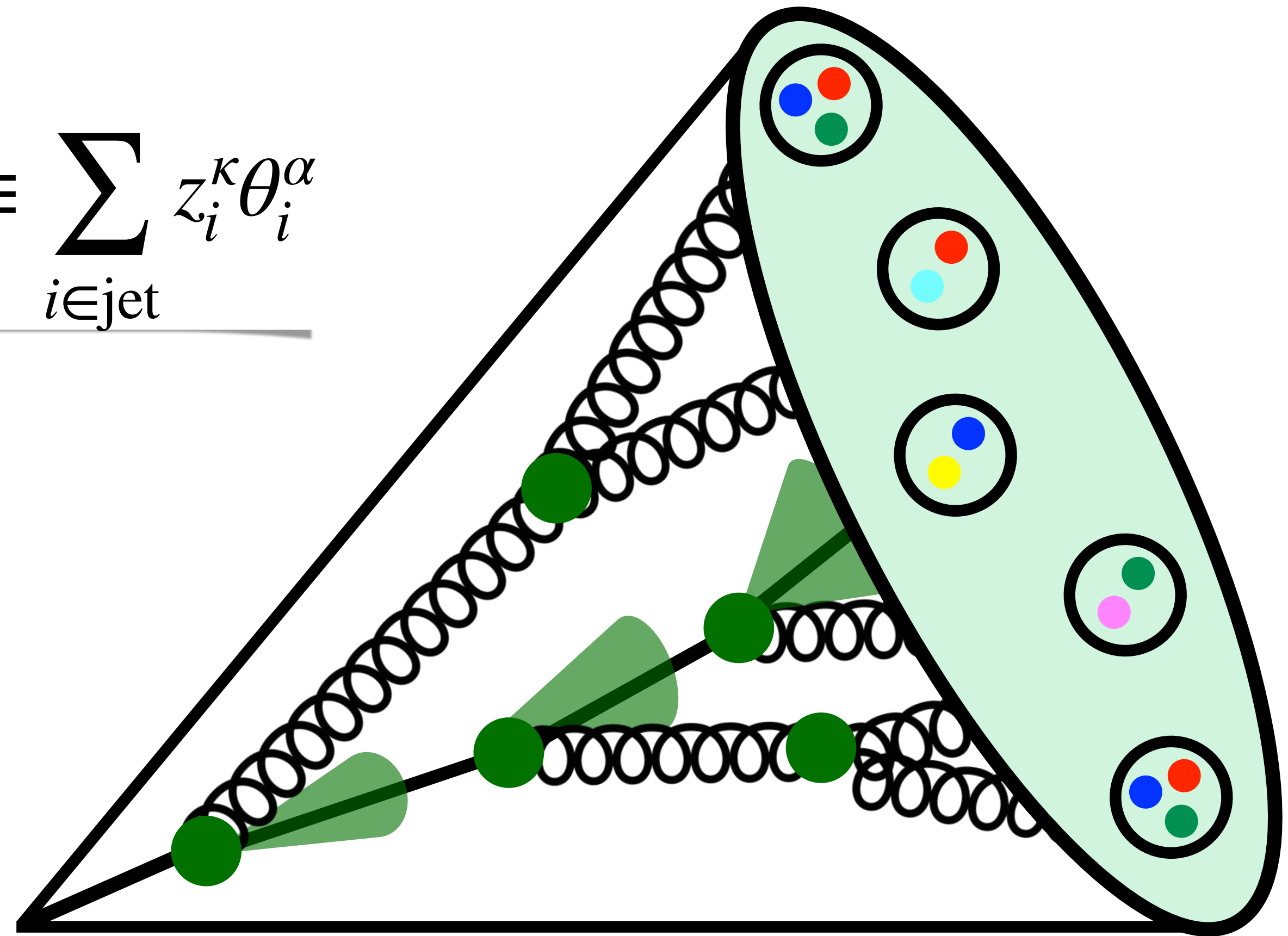
*J. Belim et al, Eur.Phys.J.C 76 (2016) 4, 196

Generalised jet angularities



Characterise p_T and angular distributions of jet constituents

$$\lambda_{\alpha}^{\kappa} \equiv \sum_{i \in \text{jet}} \left(\frac{p_{T,i}}{p_T^{\text{jet}}} \right)^{\kappa} \left(\frac{\Delta R_{\text{jet},i}}{R} \right)^{\alpha} \equiv \sum_{i \in \text{jet}} z_i^{\kappa} \theta_i^{\alpha}$$



Generalised jet angularities



Characterise p_T and angular distributions of jet constituents

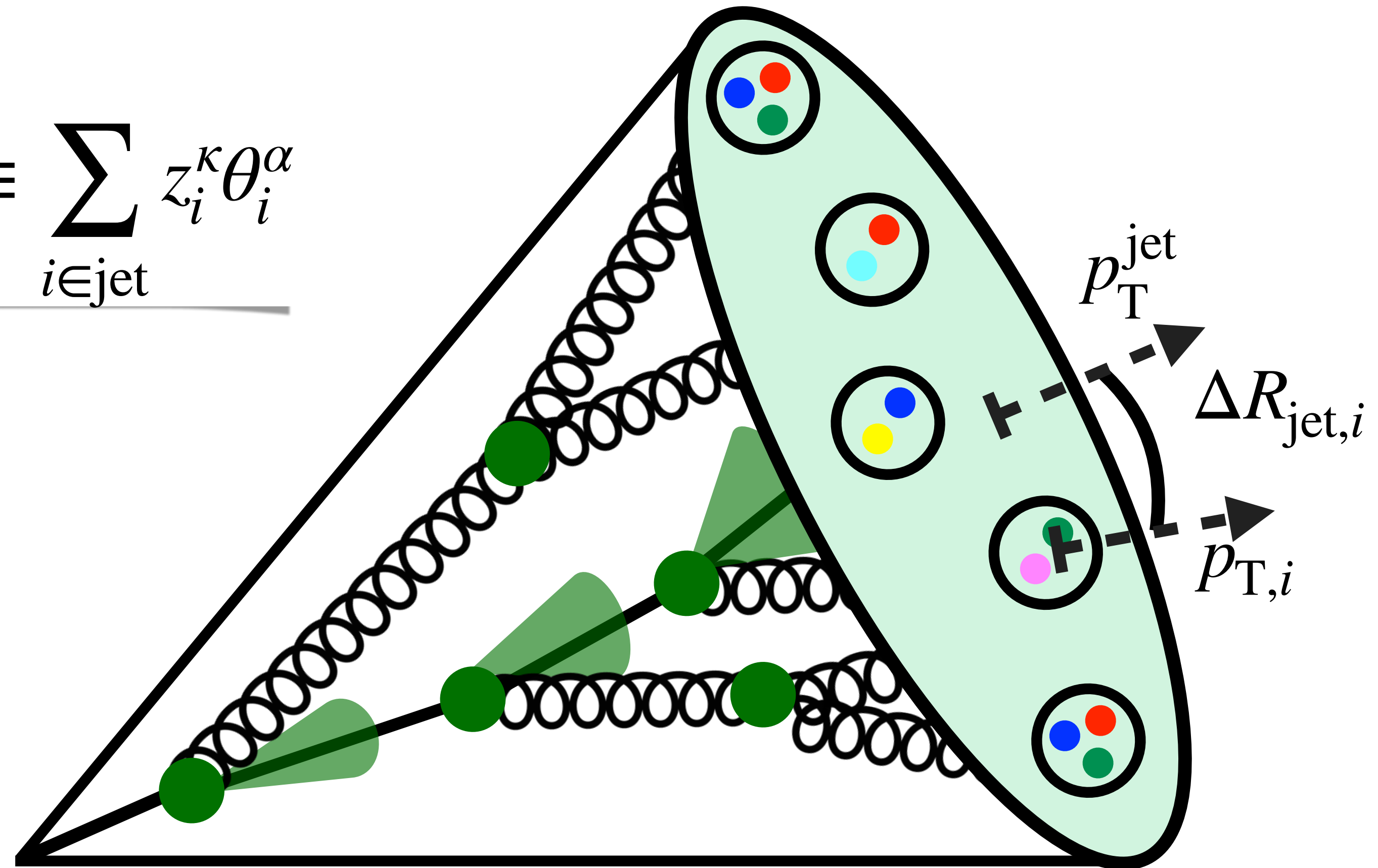
§ IRC safe for $\kappa = 1$ and $\alpha > 0$

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} \left(\frac{p_{T,i}}{p_T^{\text{jet}}} \right)^\kappa \left(\frac{\Delta R_{\text{jet},i}}{R} \right)^\alpha \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

$\alpha = 1, 1.5, 2, \text{ and } 3$

Collinear Wide-angle

Sensitivity to flavour-
dependent fragmentation
and hadronisation



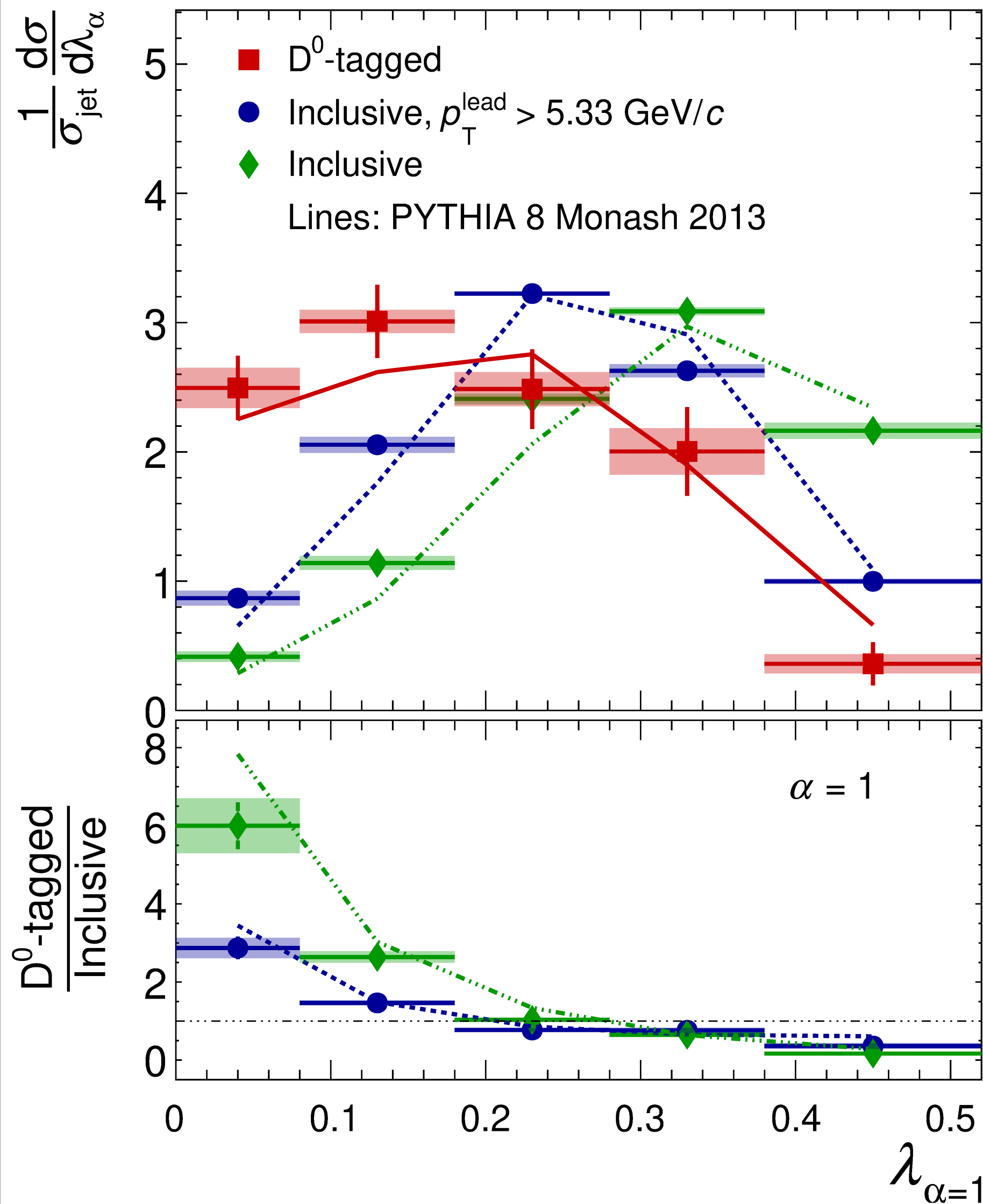
Generalised jet angularities



*ALICE Collaboration, arXiv:2606.20028

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$\alpha = 1$ (Collinear radiation)

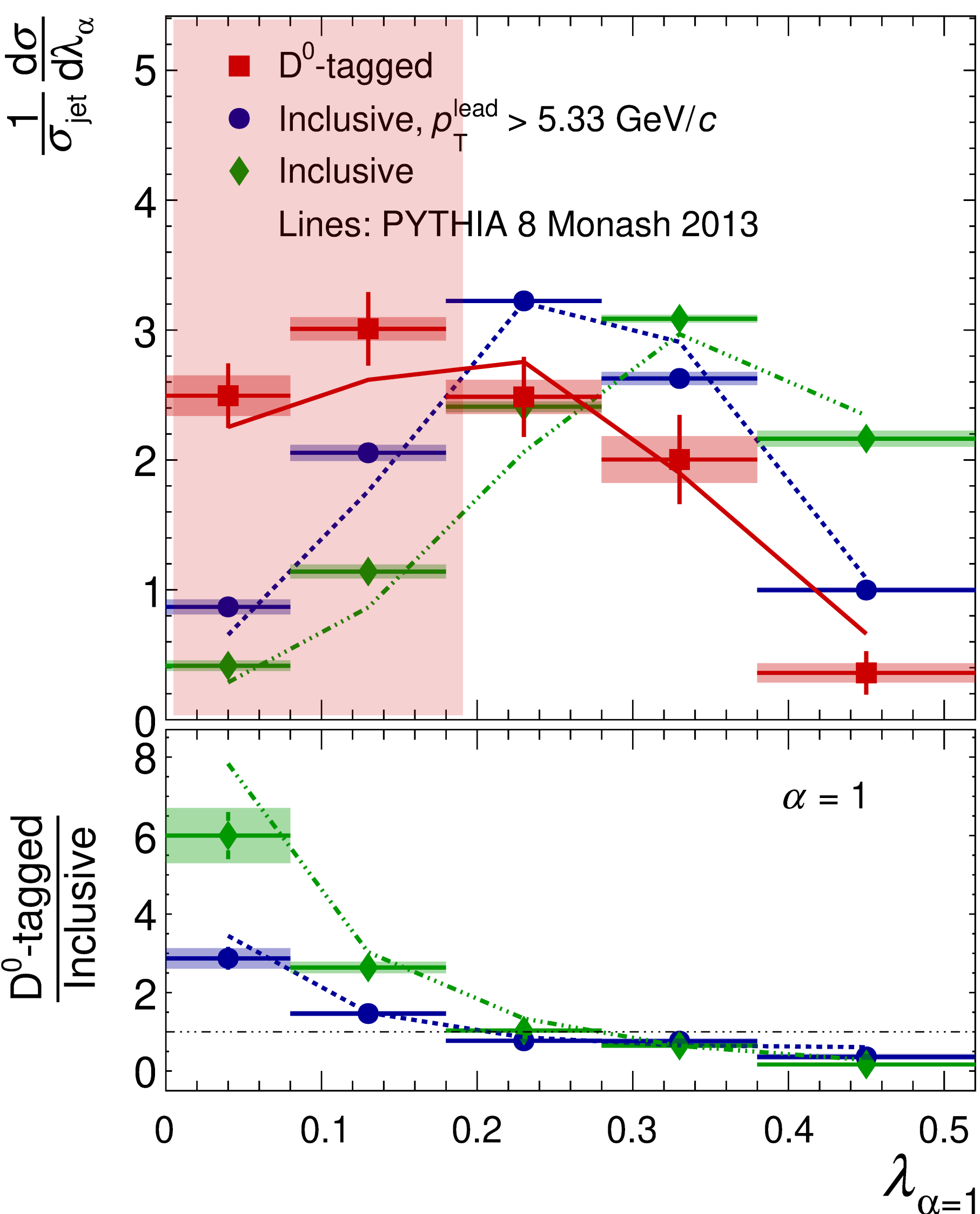


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Generalised jet angularities



*ALICE Collaboration, arXiv:2606.20028

$$\lambda_{\alpha}^{\kappa} \equiv \sum_{i \in \text{jet}} \left(\frac{p_{T,i}}{p_T^{\text{jet}}} \right)^{\kappa} \left(\frac{\Delta R_{\text{jet},i}}{R} \right)^{\alpha}$$

$\alpha = 1$ (Collinear radiation)

- ☑ D⁰-tagged jet angularity larger at small $\lambda_{\alpha=1}$ than inclusive jets
- ☑ Jet fragments more concentrated near jet axis

*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

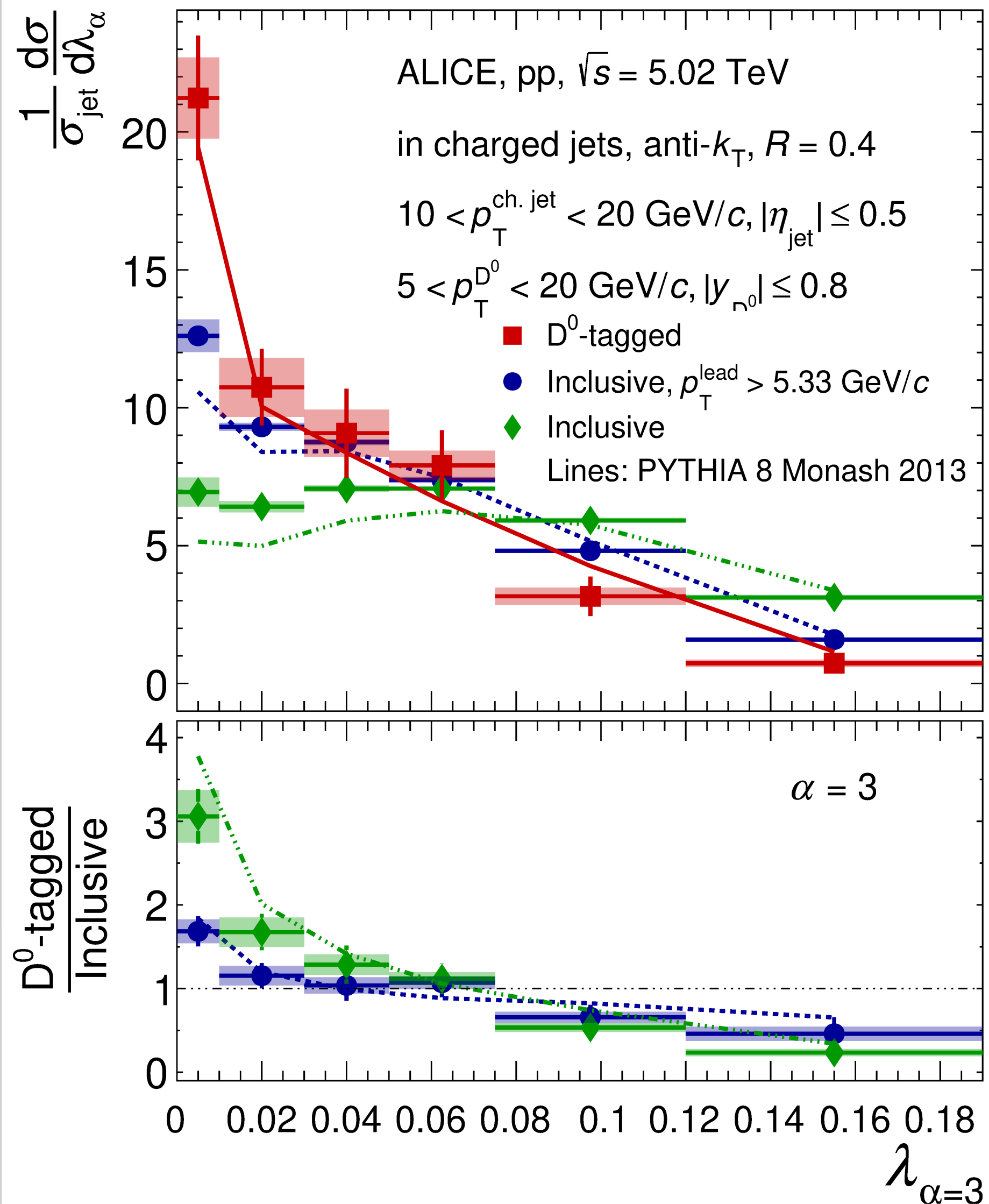
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*ALICE Collaboration, arXiv:2606.20028

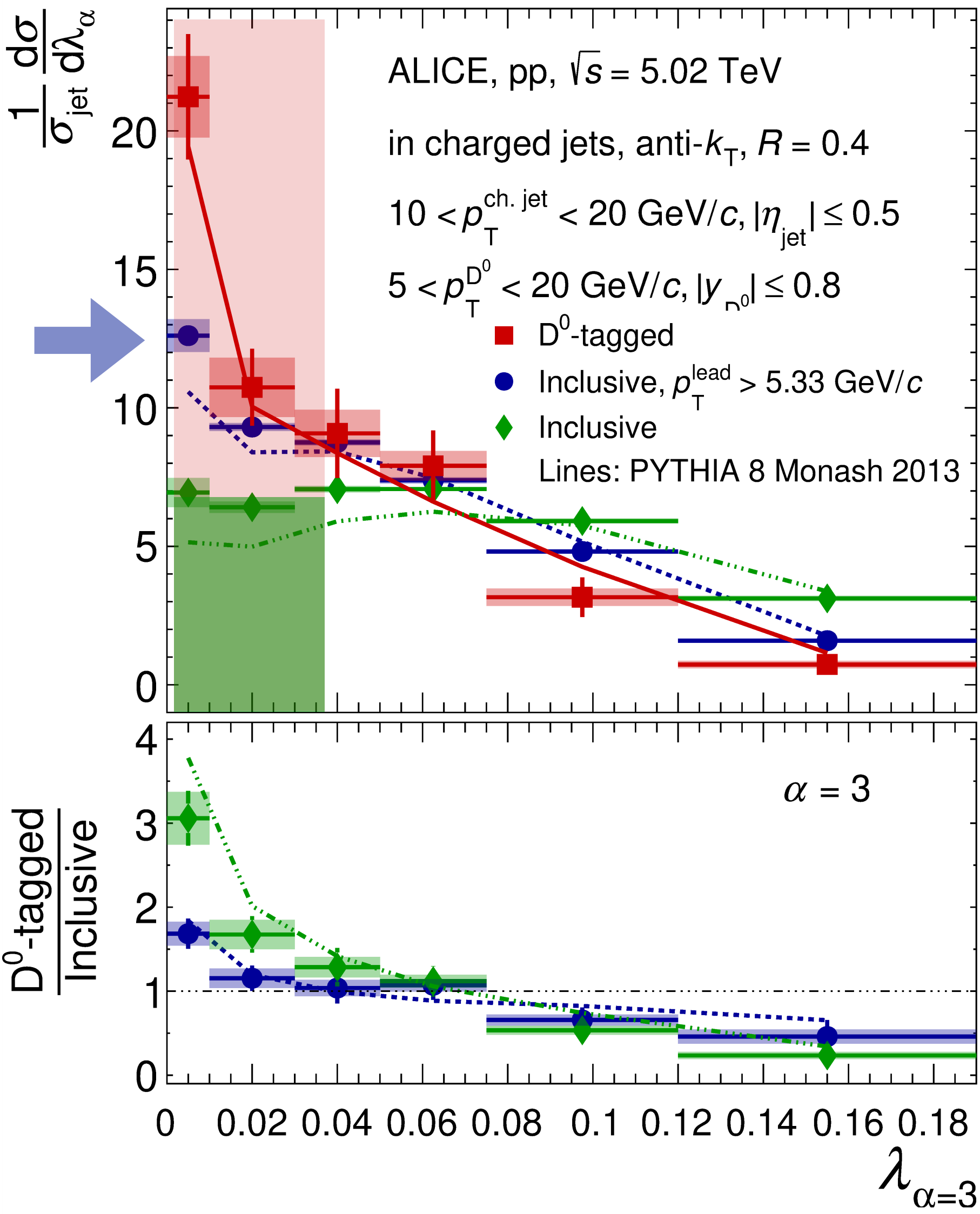
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$\alpha = 3$ (Wide-angle radiation)



ALI-PUB-636139

Generalised jet angularities



*ALICE Collaboration, arXiv:2606.20028

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$\alpha = 3$ (Wide-angle radiation)

- ☒ Difference between D⁰-tagged and inclusive jets persists as expected from Casimir effects
- ☒ Semi-inclusive jets with leading track p_T cut enhances quark jet content
- ☒ Consistent with the dead-cone effect

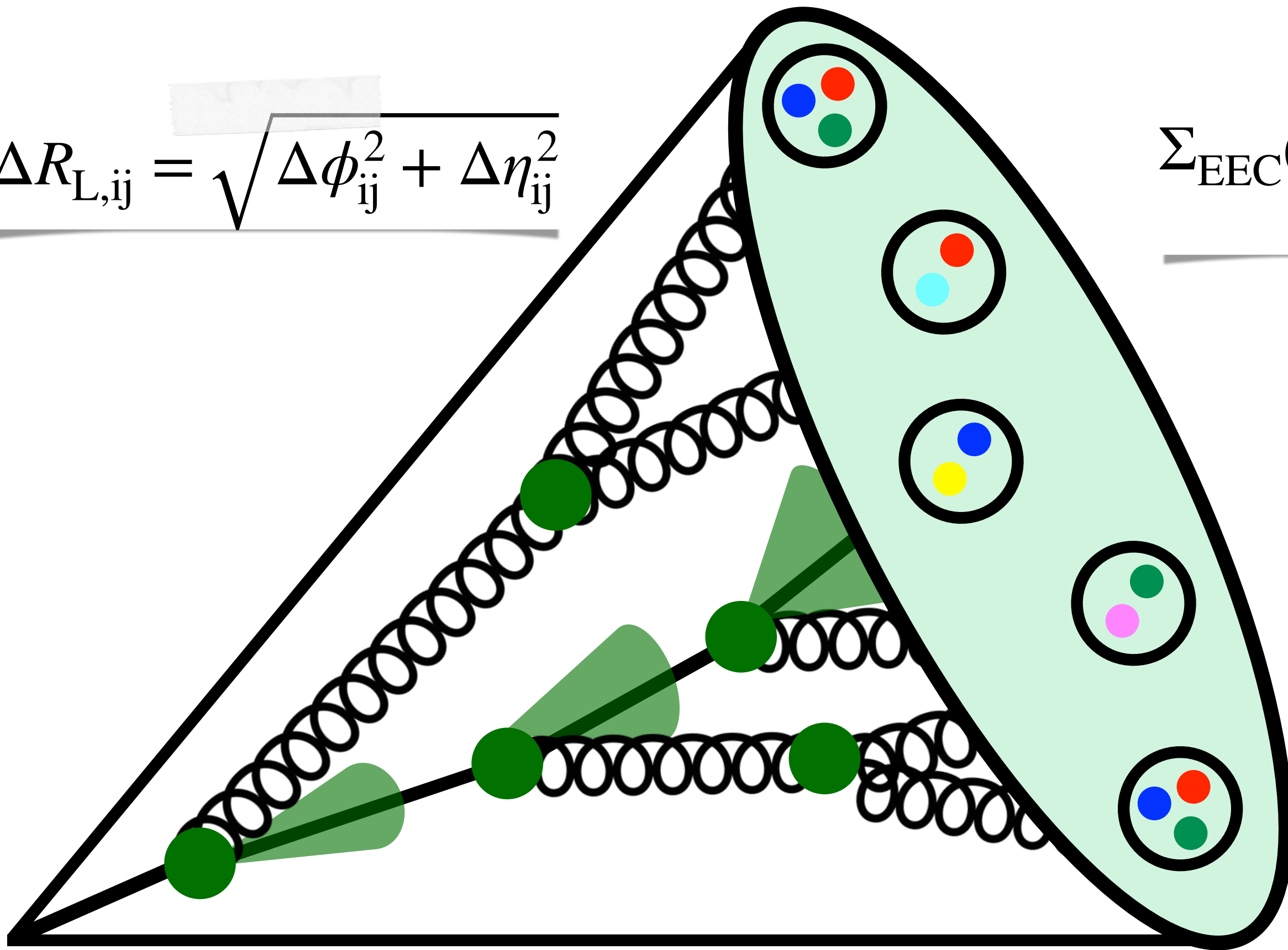
*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

Energy-energy correlators



$$\Delta R_{L,ij} = \sqrt{\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2}$$

$$\Sigma_{\text{EEC}}(R_L) = \frac{1}{N_{\text{jet}}\Delta R_L} \int_{R_L - \frac{1}{2}R_L}^{R_L + \frac{1}{2}R_L} \sum_{\text{jet}} \sum_{i,j \in \text{jet}} \frac{p_{T,i}p_{T,j}}{p_{T,\text{jet}}^2} \delta(R'_L - R_{L,ij}) dR'_L$$



Perturbative

Non-perturbative

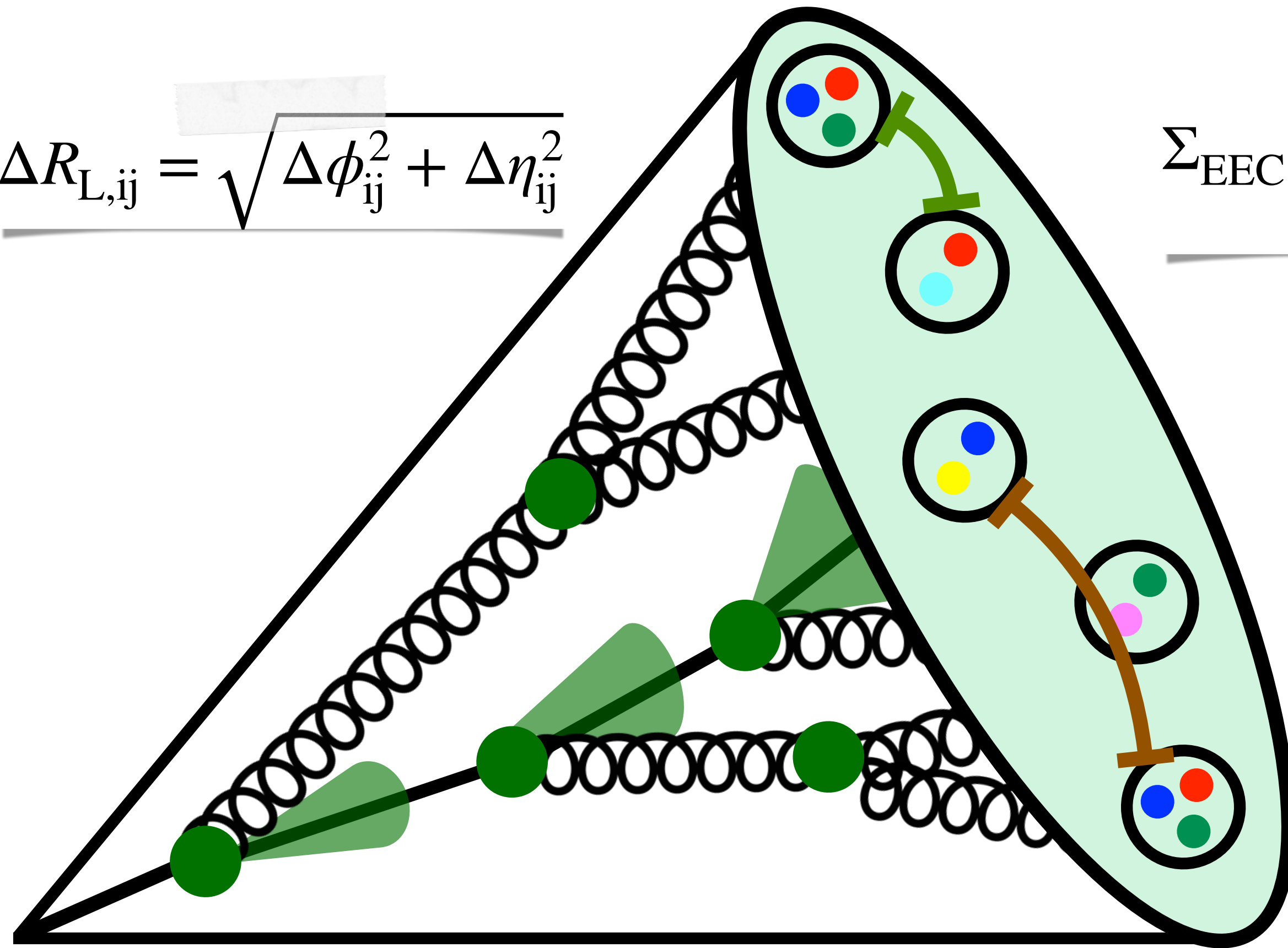
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IRC safe



Perturbative

Non-perturbative

Wider correlations

Large R

Early splittings

Perturbative

Narrower correlations

Small R

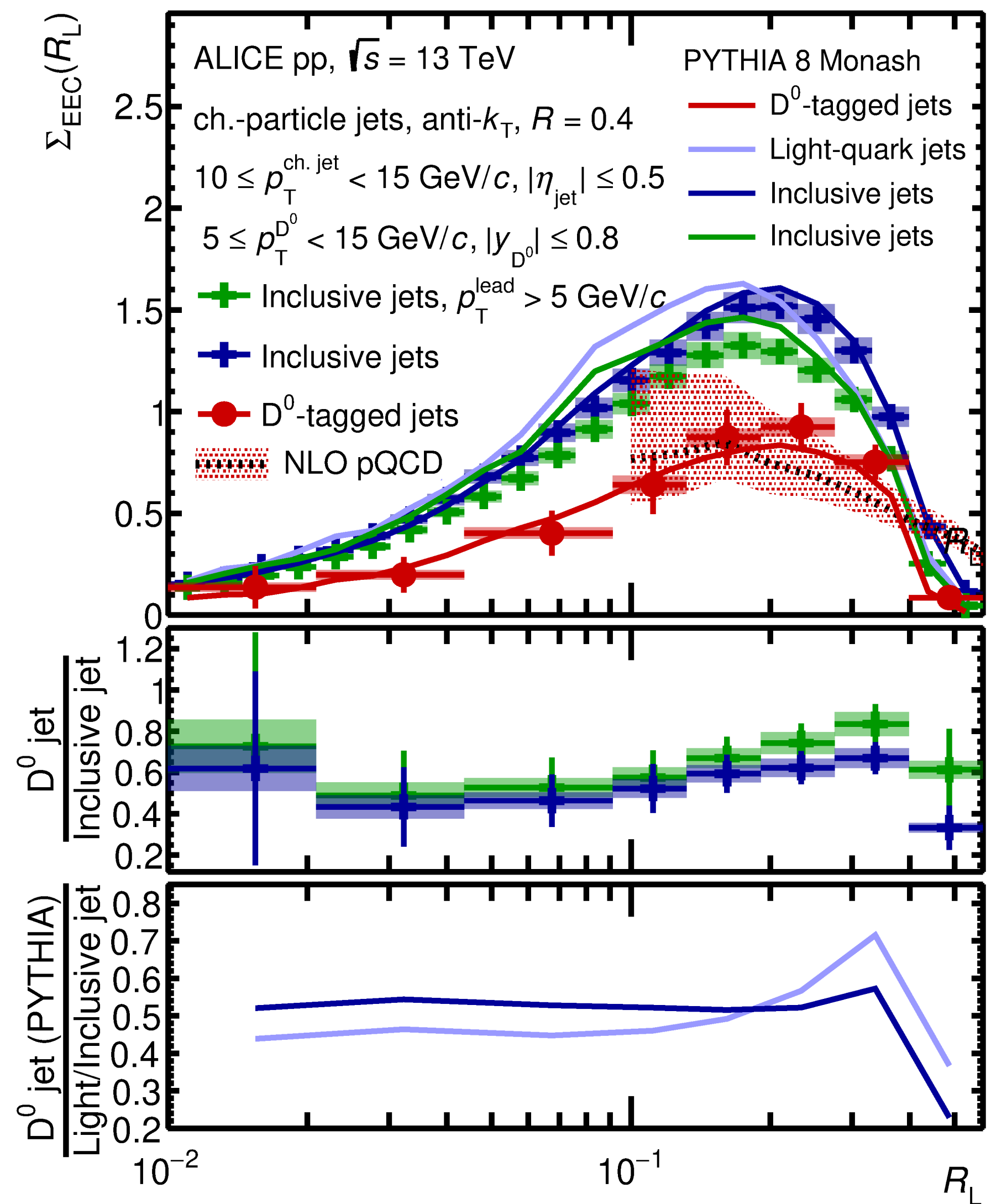
Late splittings

Non-perturbative

Energy-energy correlators



*ALICE Collaboration, arXiv 2504.03431



Inclusive jets → gluon-jet dominated

Light-quark jets from PYTHIA 8 show peak shift

✓ Casimir effects

✓ Baseline for no mass effects

*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

ALI-PUB-604529

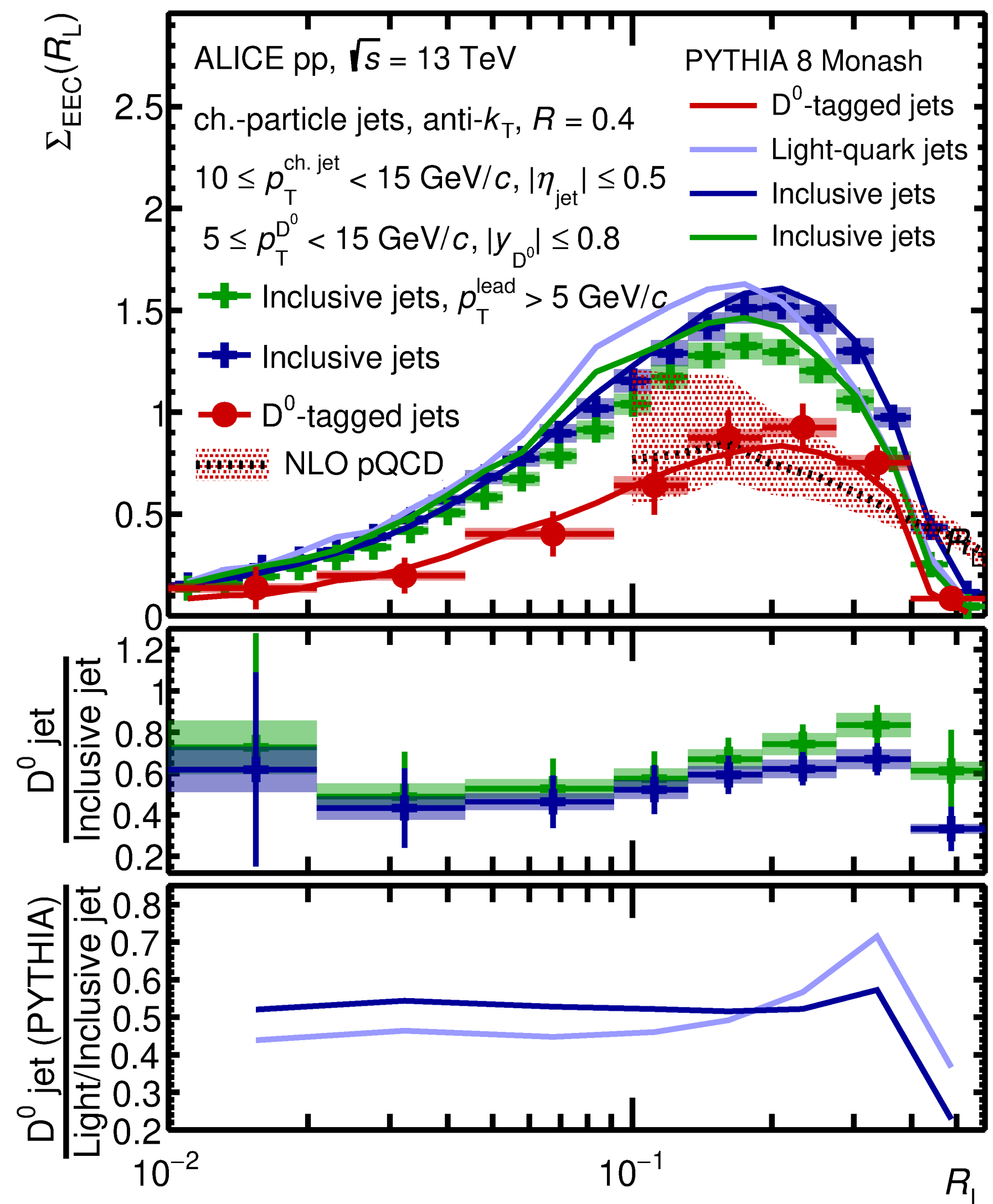
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Energy-energy correlators



*ALICE Collaboration, arXiv 2504.03431



Inclusive jets → gluon-jet dominated

Light-quark jets from PYTHIA 8 show peak shift

✓ Casimir effects

✓ Baseline for no mass effects

D^0 -tagged jets

✓ Suppression from the dead-cone effect

✓ Transition peak position similar to inclusive jets

✓ Interplay between flavour and hadronisation effects

✓ NLO pQCD calculation shows tension near peak region

✓ PYTHIA 8 Monash describes the data

*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

*E. Craft et al, Phys.Rev.D 114 (2026) 3, L031501

ALI-PUB-604529

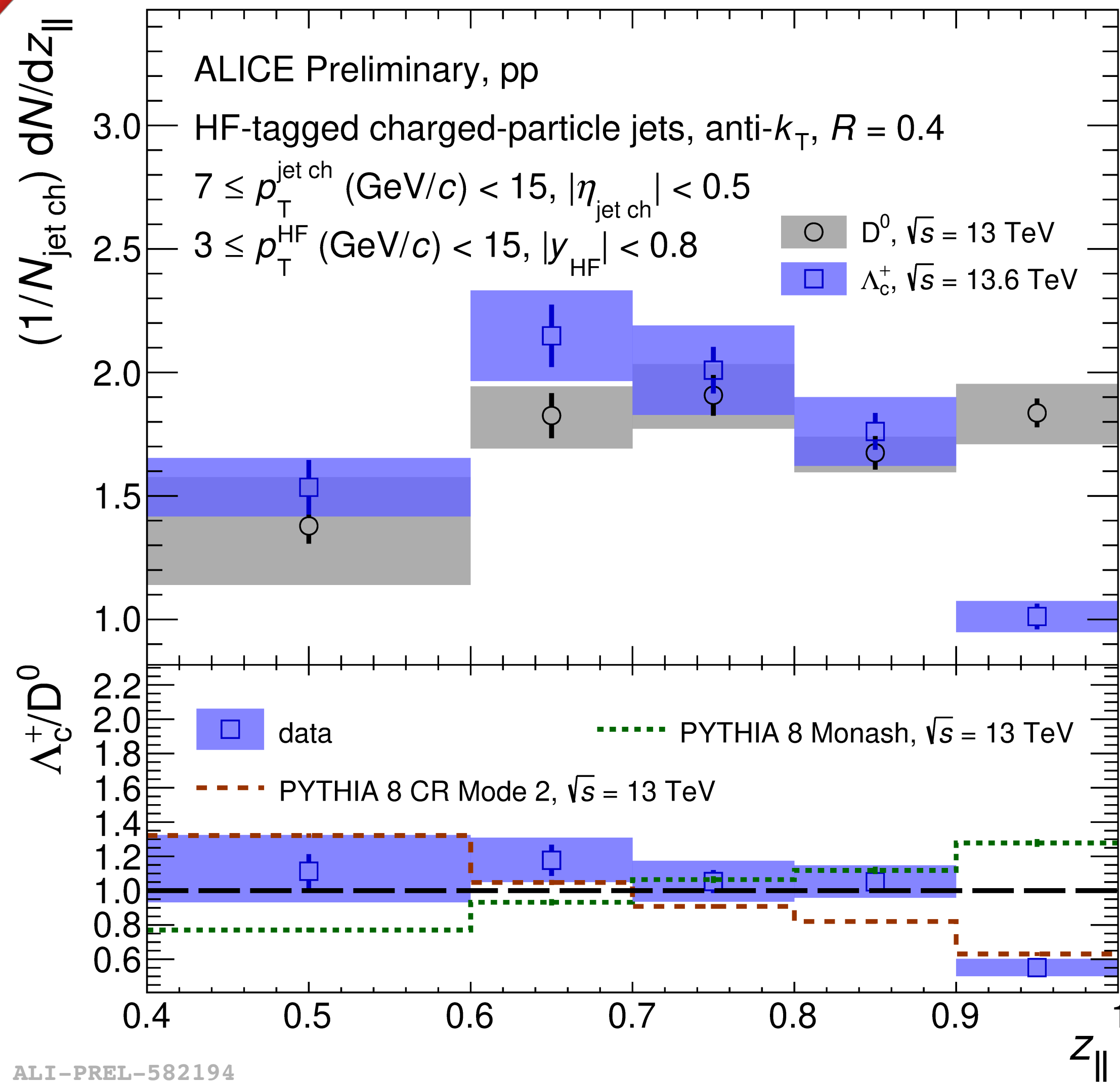
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Charm-jet momentum fraction : baryons vs. mesons



NEW



ALI-PREL-582194

* D^0 -tagged jets, $\sqrt{s} = 13 \text{ TeV}$: ALICE Collaboration, JHEP 06 (2023), 133

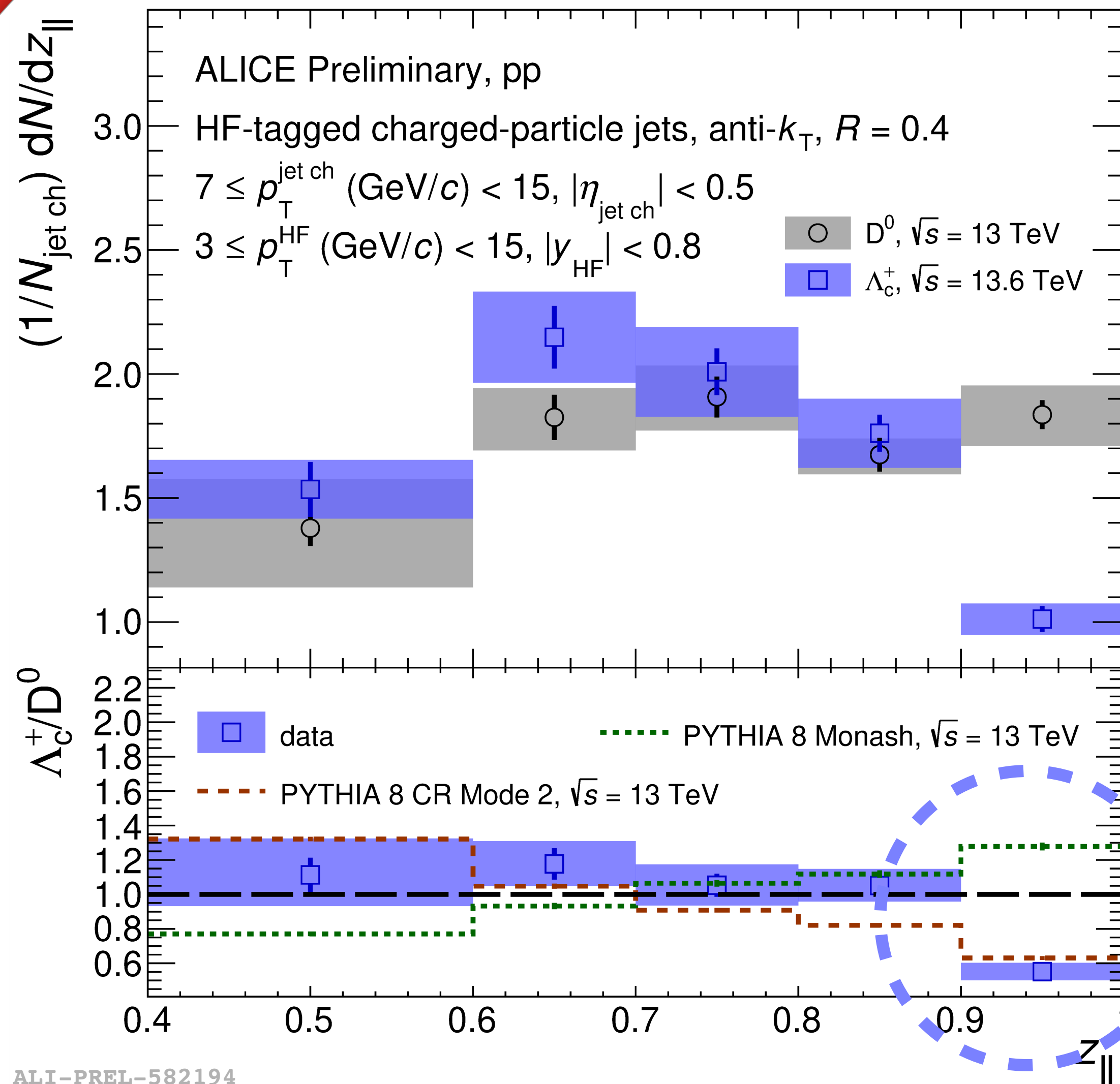
Jet momentum fraction

$$z_{\parallel}^{\text{ch}} = \frac{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{hadron}}}{p_{\text{ch jet}}^2}$$

Charm-jet momentum fraction : baryons vs. mesons



NEW



ALI-PREL-582194

* D^0 -tagged jets, $\sqrt{s} = 13 \text{ TeV}$: ALICE Collaboration, JHEP 06 (2023), 133

Jet momentum fraction

$$z_{\parallel}^{\text{ch}} = \frac{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{hadron}}}{p_{\text{ch jet}}^2}$$

Hint of softer fragmentation into charm **baryons** than into mesons

Better description from **PYTHIA 8** with colour reconnection beyond leading-colour approximation

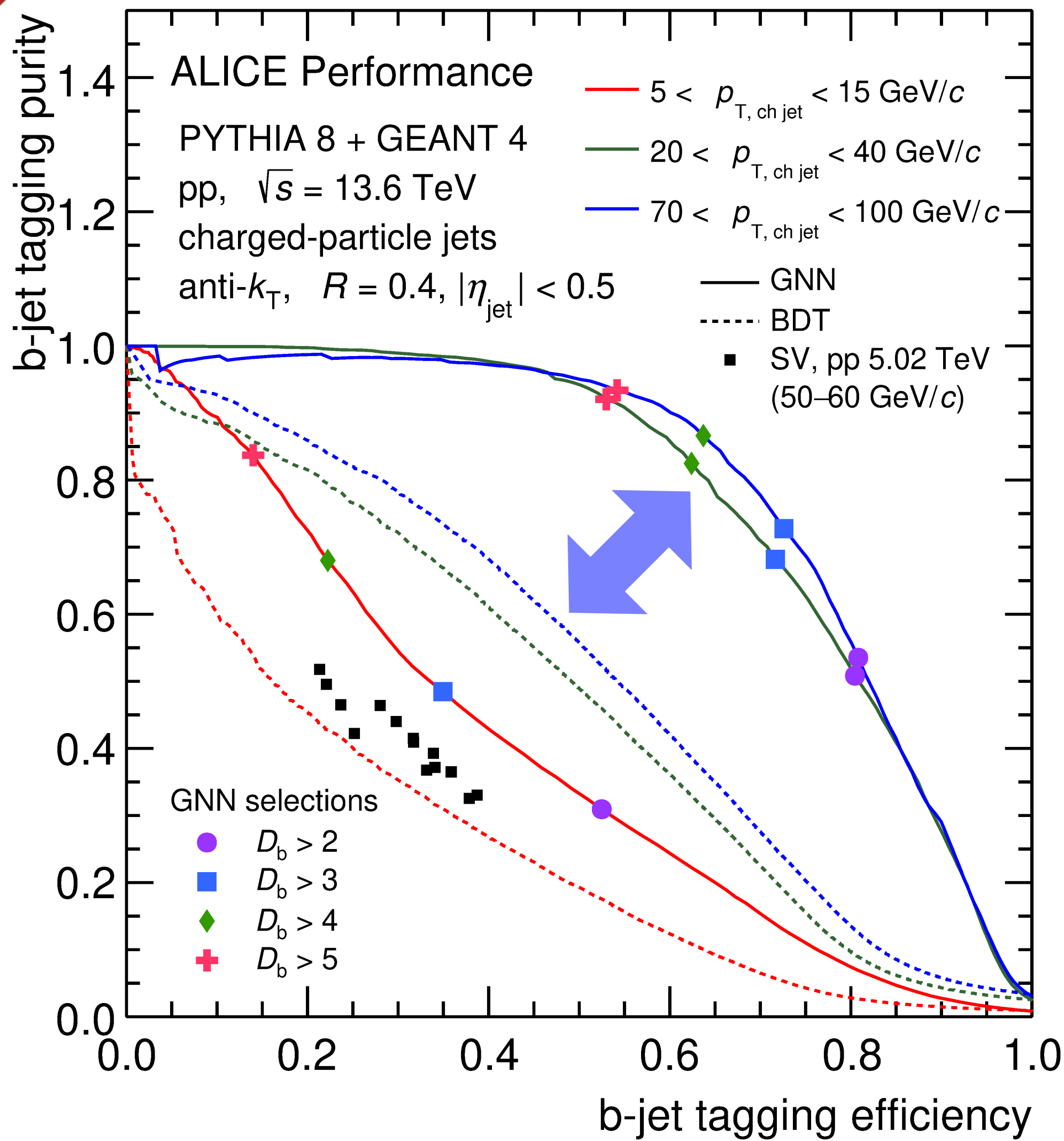
*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

*J. R. Christiansen et al, JHEP 08 (2015), 003

Towards beauty jets



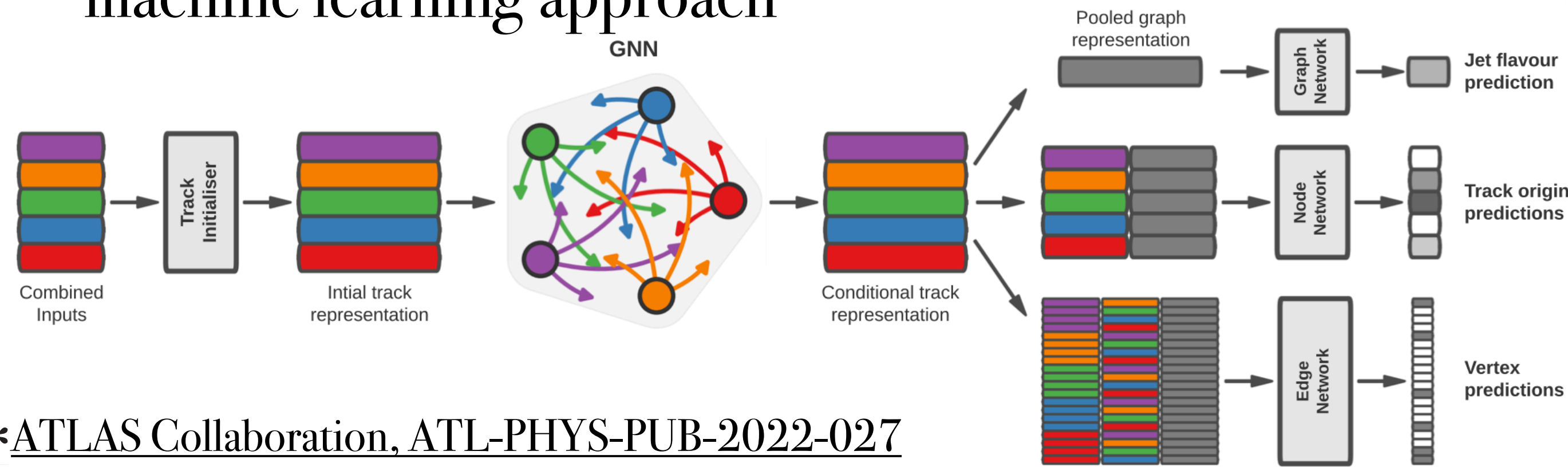
NEW



ALI-PERF-634026

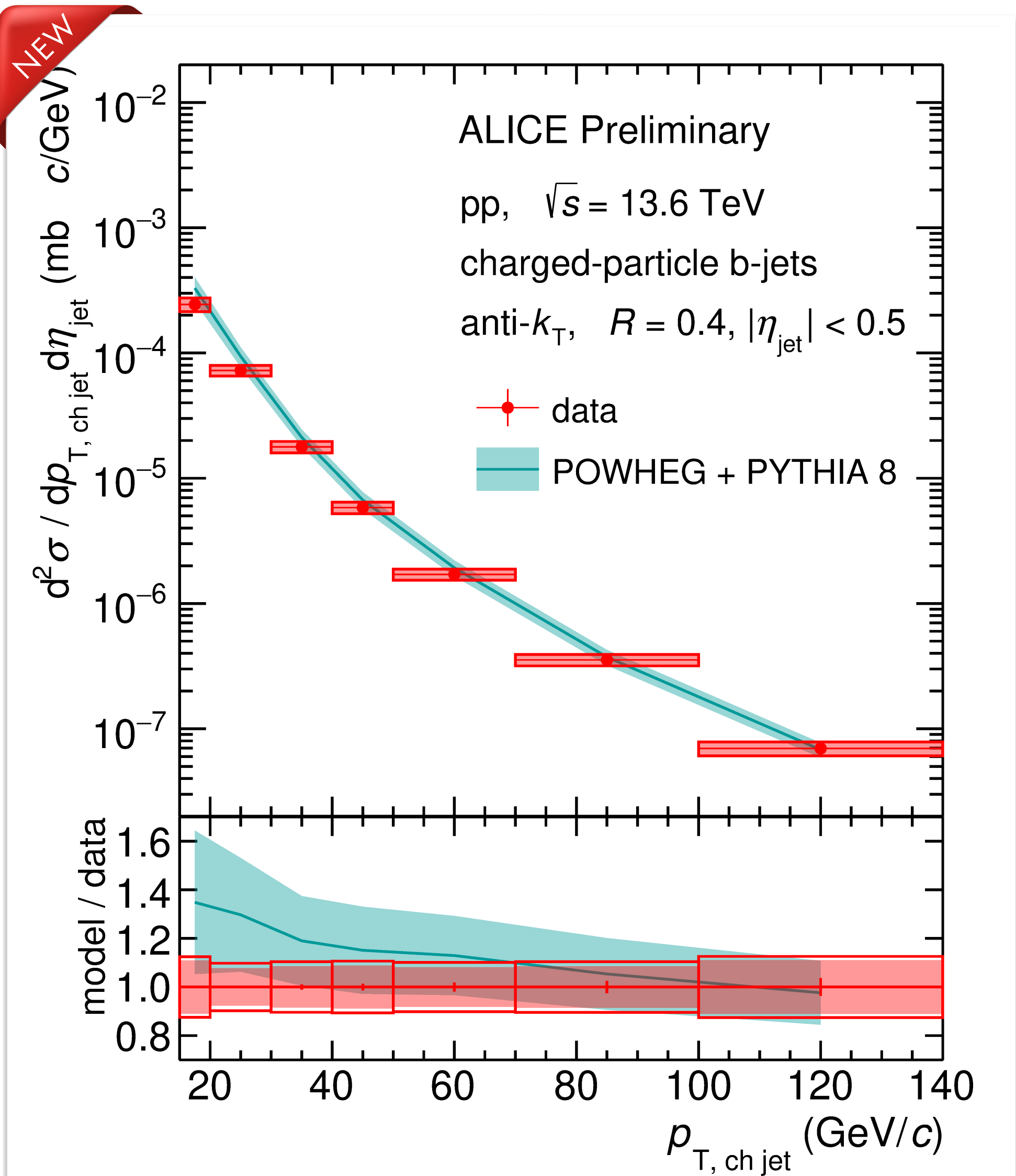
Graph Neural Network (GNN) based b-jet tagging method

- ✓ Relational deep learning of the jet constituents
- ✓ Outperforms classical tagging methods and BDT-based machine learning approach



*ATLAS Collaboration, ATL-PHYS-PUB-2022-027

Towards beauty jets

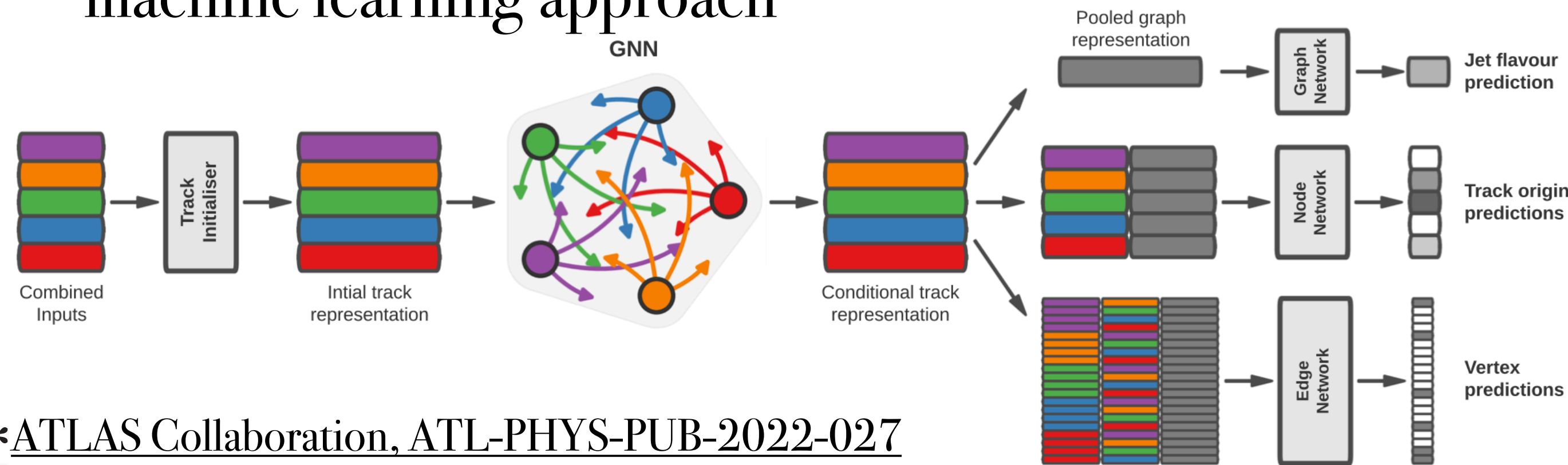


ALI-PREL-633981

Yoshini Bailung

Graph Neural Network (GNN) based b-jet tagging method

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*ATLAS Collaboration, ATL-PHYS-PUB-2022-027

POWHEG + PYTHIA 8 prediction
deviates from the data at low p_T

*S. Alioli et al, JHEP 06 (2010), 043

*P. Skands et al, Eur.Phys.J.C 74 (2014) 8, 3024

Summary and outlook



Jet-substructure observables are increasingly being explored in ALICE to characterise parton fragmentation and its flavour dependence

Charm-hadron-tagged jet substructure measurements probe the interplay of QCD dead-cone and Casimir effects in the parton shower

First measurement of b-jet cross section with deep learning in ALICE → Baseline for heavy-ion studies and substructure measurements

ALICE LS2 upgrade allowed to collect significantly larger data samples in Run 3

- Improved precision and more differential studies
- Possibly enable measurements with B-meson tagged jets → b-jet substructure
- Study medium-induced effects on heavy-quark radiation in Pb–Pb collisions

Thank you!



Additional Slides



D⁰ vs. STD and WTA

*ALICE Collaboration, Phys.Rev.D 112 (2025) 9, 092012



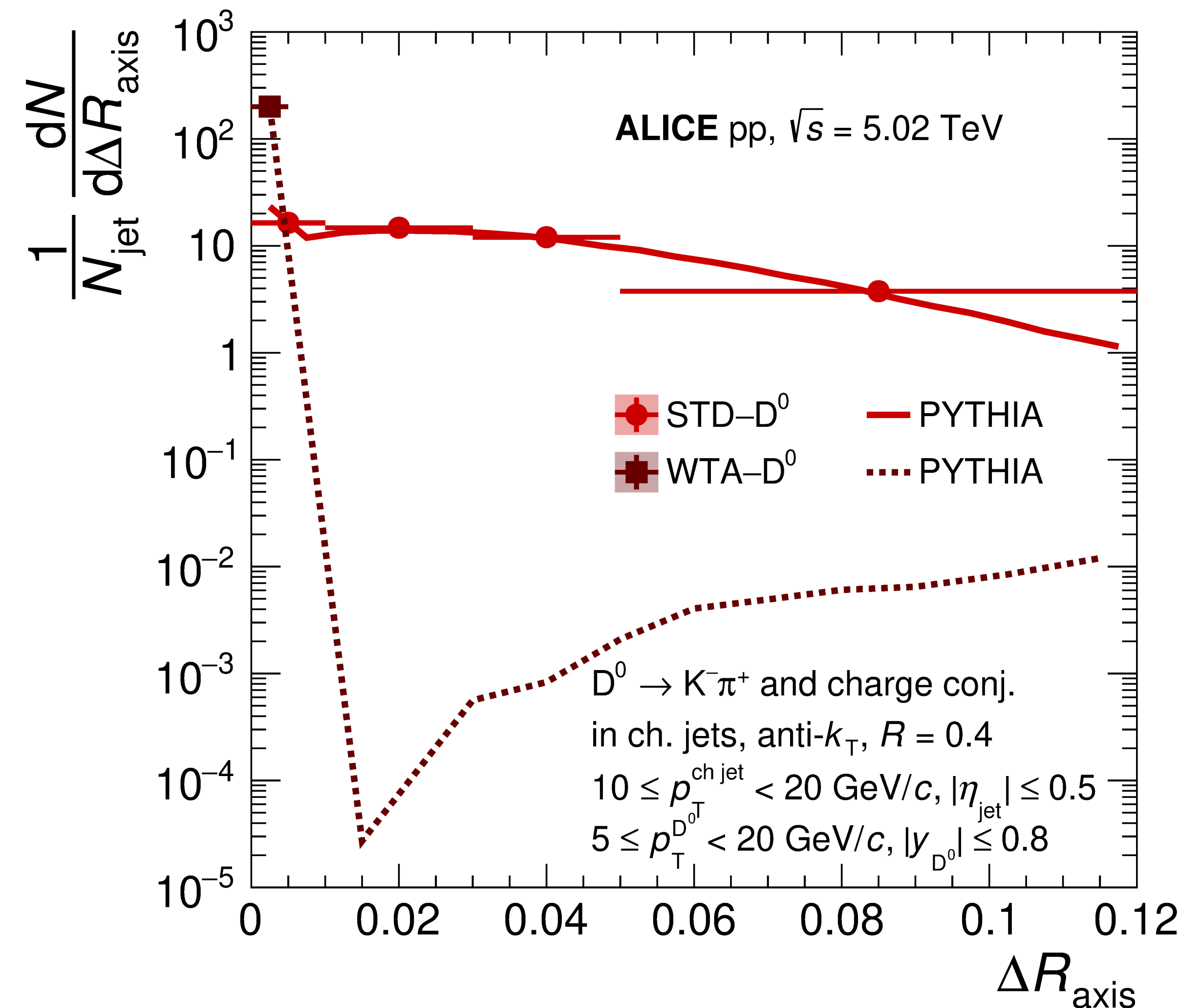
Strong alignment between the WTA and
the D⁰ direction



$$\text{WTA} \cong \text{D}^0$$

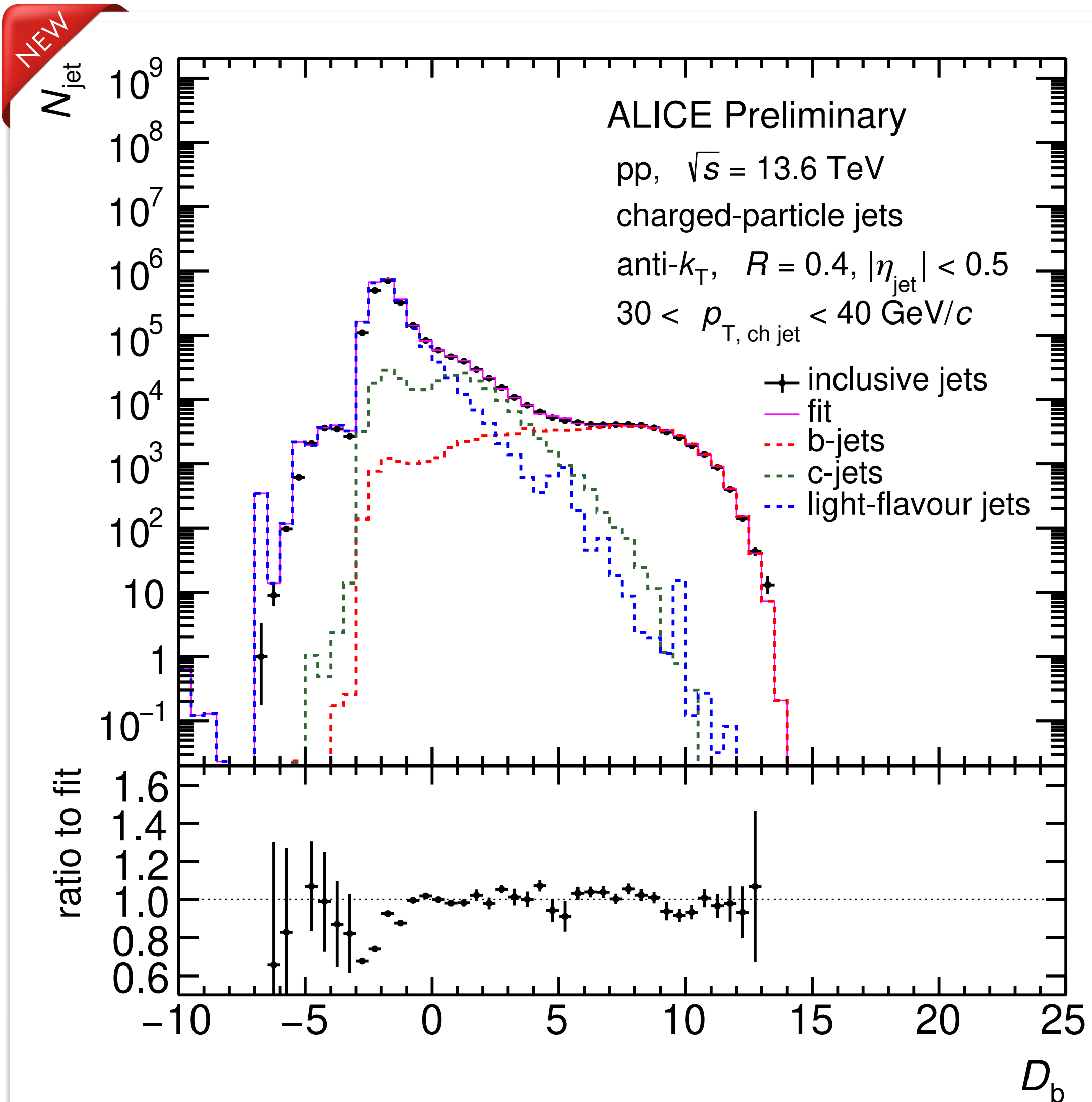


D⁰ is the leading particle of the jet (99%)



ALI-PUB-618173

Towards beauty-jets



ALI-PREL-634010

b-jet yields are extracted from template fitting of the D_b discriminant

$$D_b = \log \left(\frac{p_b}{f_c p_c + (1 - f_c p_{\text{lf}})} \right)$$

p_b , p_c , and p_{lf} are the GNN scores for b, c and lf jets

f_c is a free parameter to optimize relative weight of p_c and p_{lf}