Elucidating QCD using charm-tagged jet substructure with ALICE

Preeti Dhankher

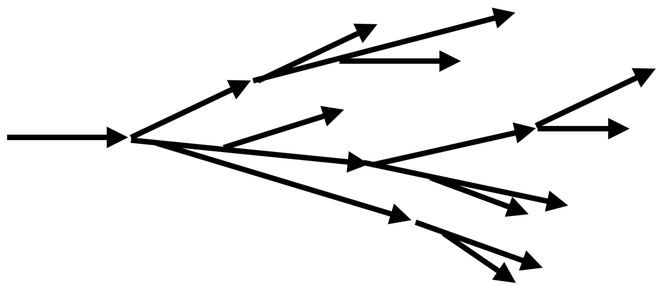
On behalf of the ALICE collaboration

University of California, Berkeley

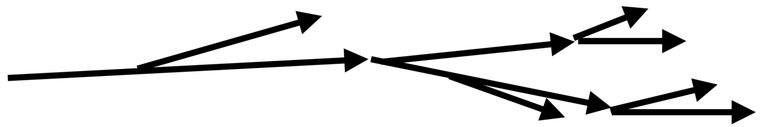
3 August, 2023

Flavour dependence in the QCD shower

Gluon-initiated shower



Quark-initiated shower



$$\frac{C_A}{C_F} = \frac{9}{4}$$

Casimir color factors

Gluon-initiated showers are expected to have a broader and softer fragmentation profile than quark-initiated showers

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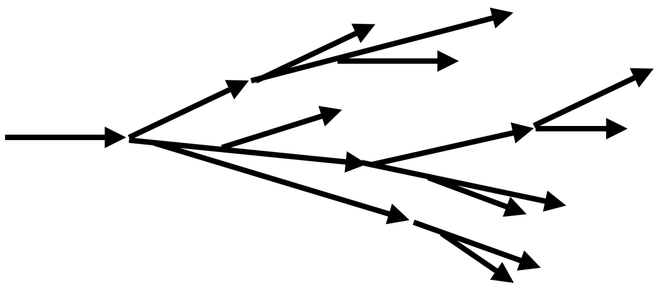

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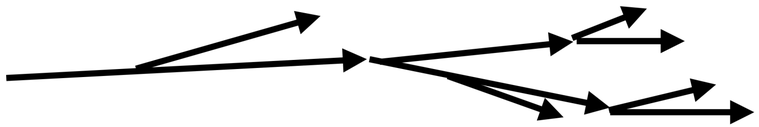
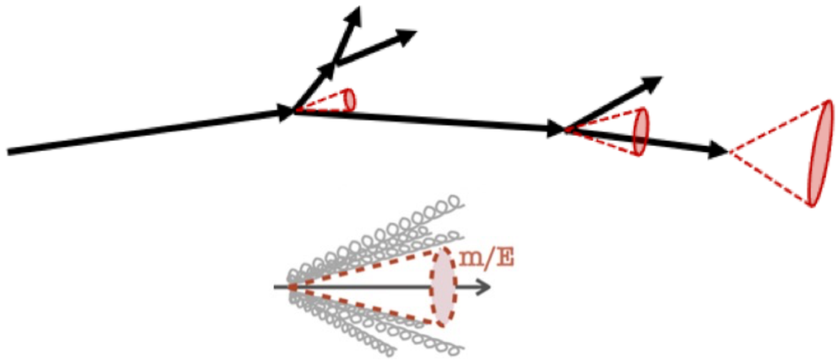


Heavy-quark-initiated shower



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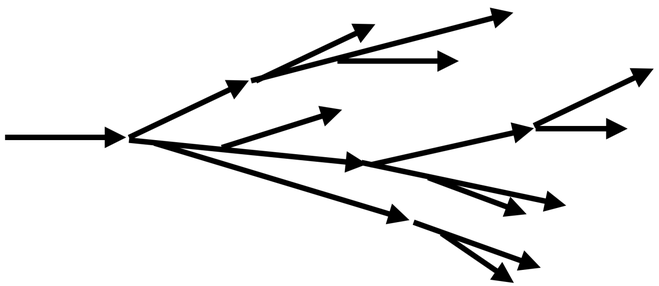

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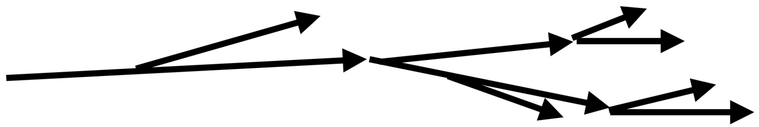

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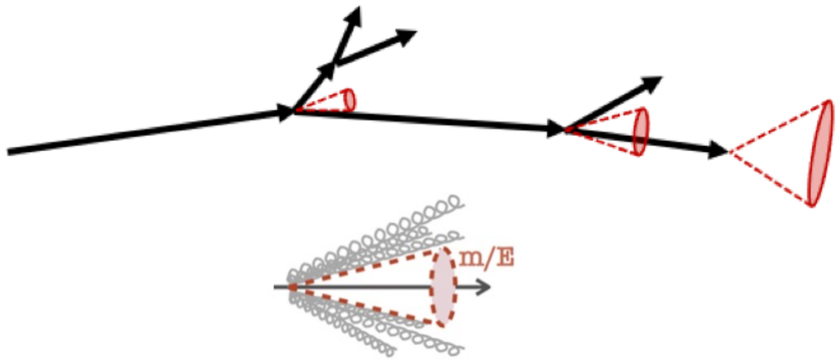

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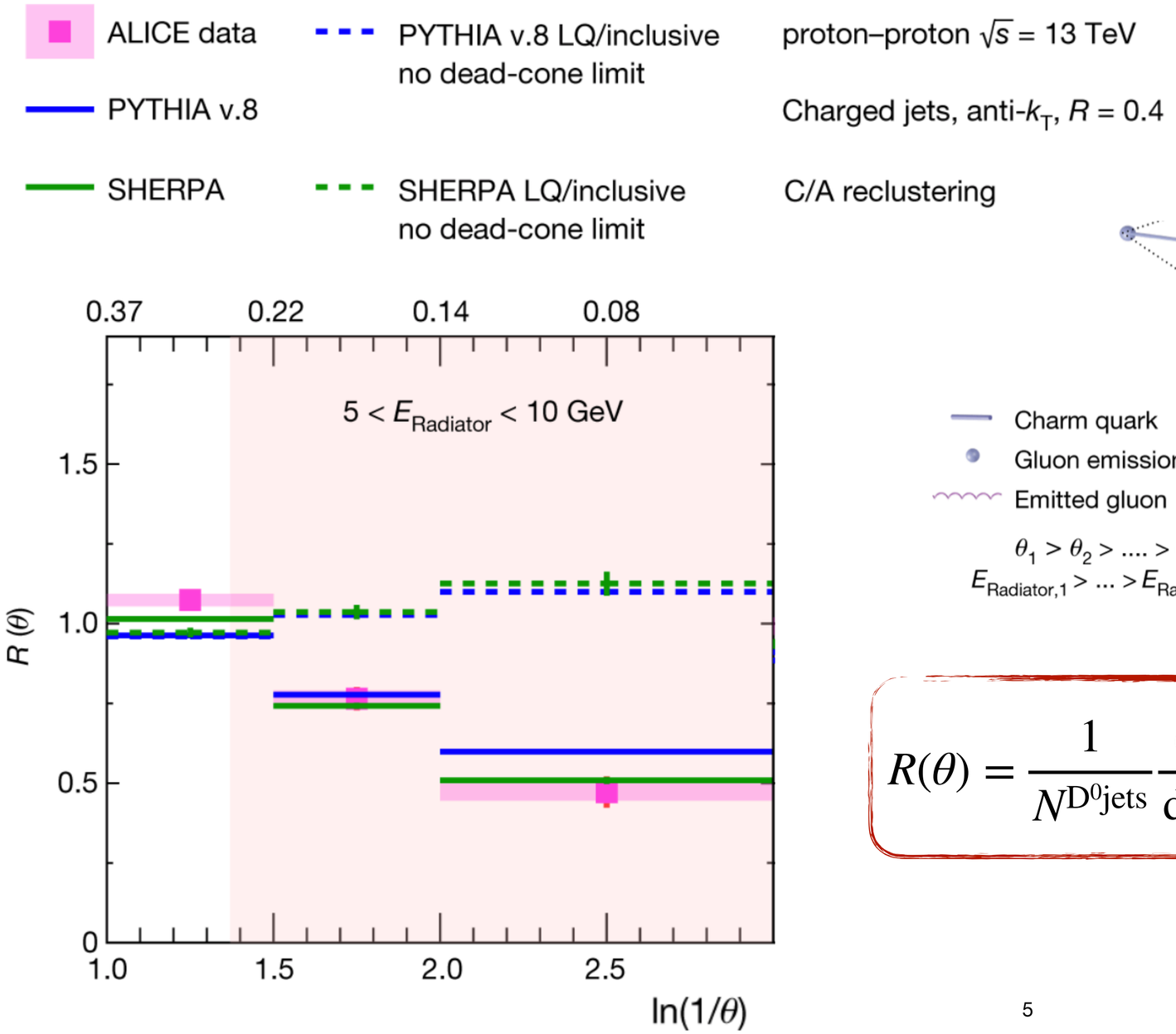
A harder fragmentation is expected in low energy heavy-quark initiated showers due to the presence of a dead cone which suppresses radiation close to the heavy-quark

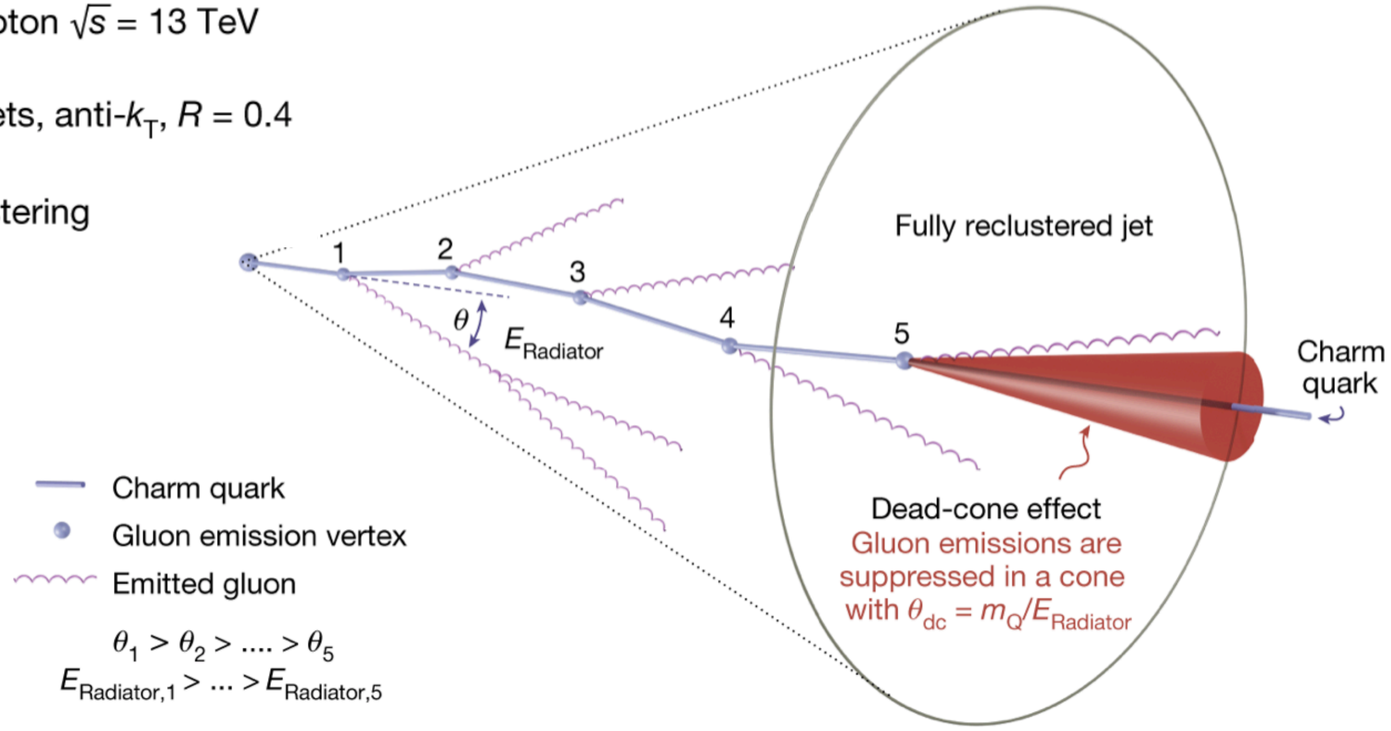
Mass effects are dominant at low p_T

→ ALICE has excellent capabilities of heavy-flavor physics down at low p_T

ALICE, Nature 605 (2022) 440–446

First direct observation of the dead-cone effect





$$R(\theta) = \frac{1}{N^{D^0\text{jets}}} \frac{dn^{D^0\text{jets}}}{d\ln(1/\theta)} \Big/ \frac{1}{N^{\text{inclusive jets}}} \frac{dn^{\text{inclusive jets}}}{d\ln(1/\theta)} \Big|_{k_T, E_{Radiator}}$$

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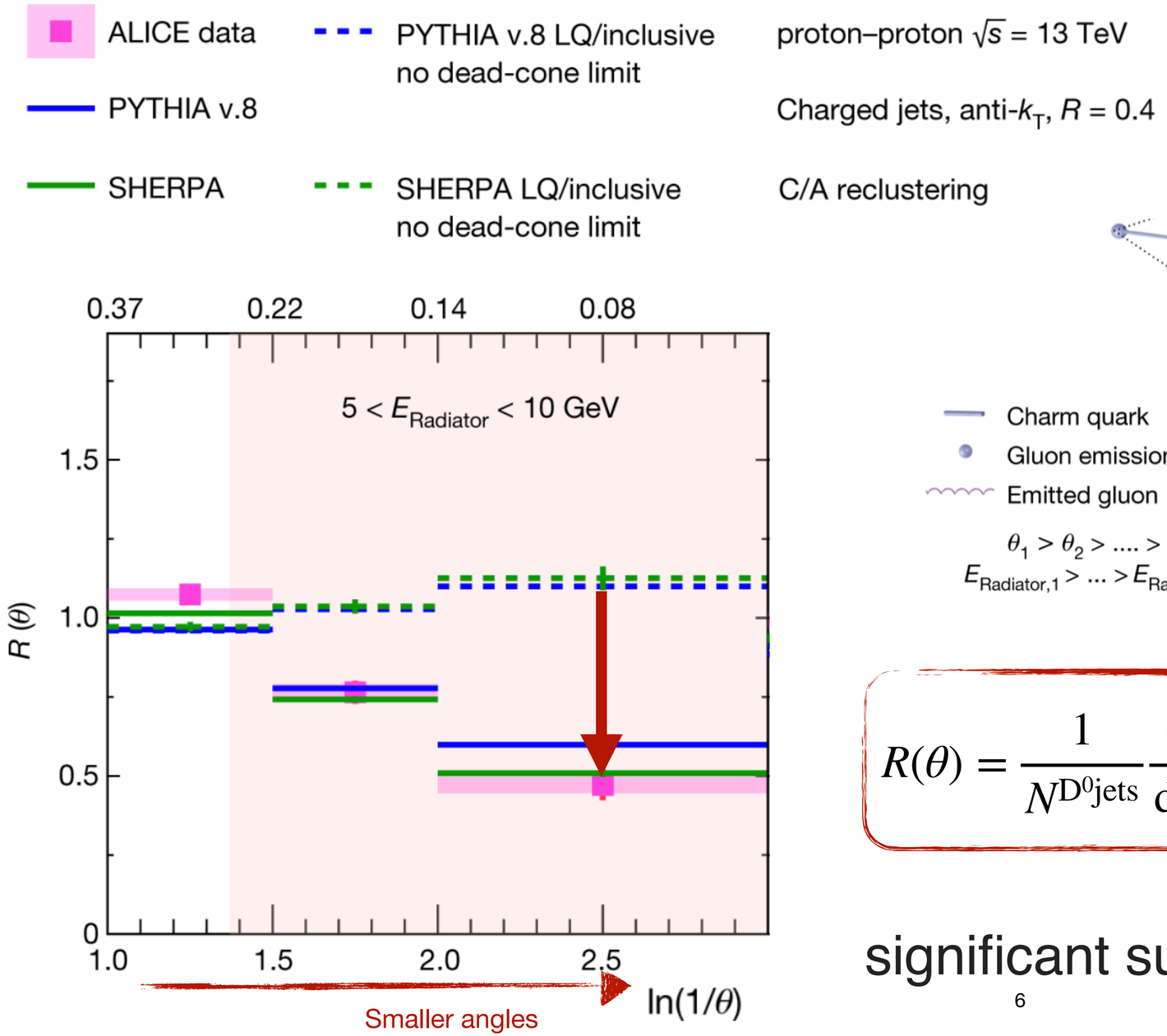

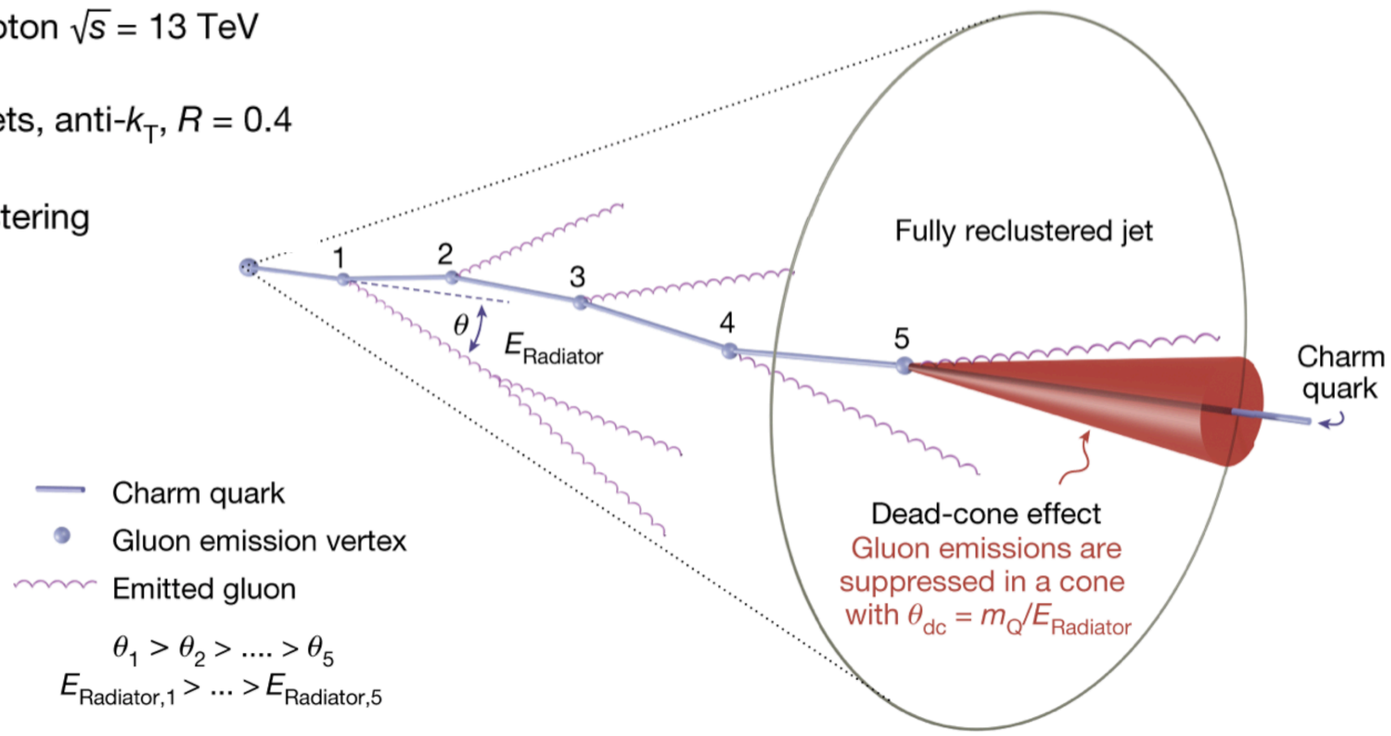

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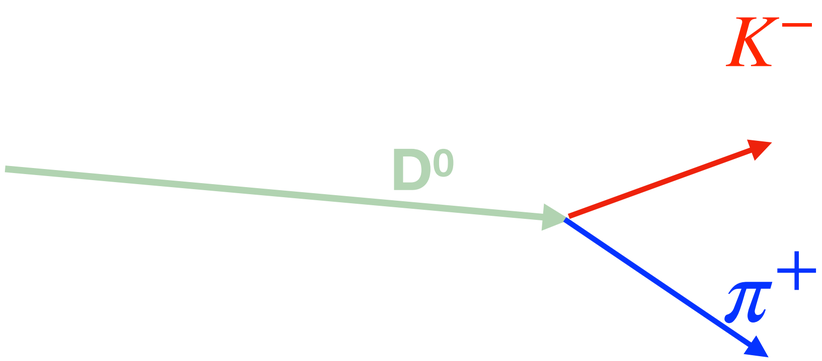
significant suppression of small-angle emissions

Heavy-flavor jet tagging with ALICE

$$\mathrm{D}^0 \rightarrow \mathrm{K}^- + \pi^+$$



$$2 \leq p_{\mathrm{T,D^0}} \leq 36\ \mathrm{GeV}/c$$

D^0-meson selection: Fully reconstructing hadronic decay

- topological cuts on the D^0 decay
- particle ID on decay daughters

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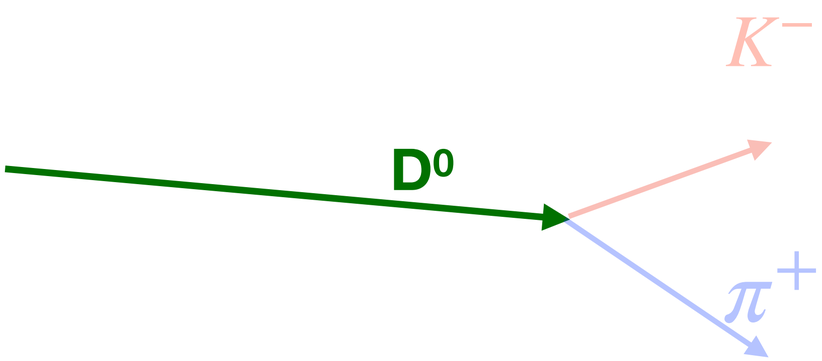

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$K^{\mp}\pi^{\pm}$ pairs replaced by D^0 candidate

- Full D^0 momentum always inside the jet cone

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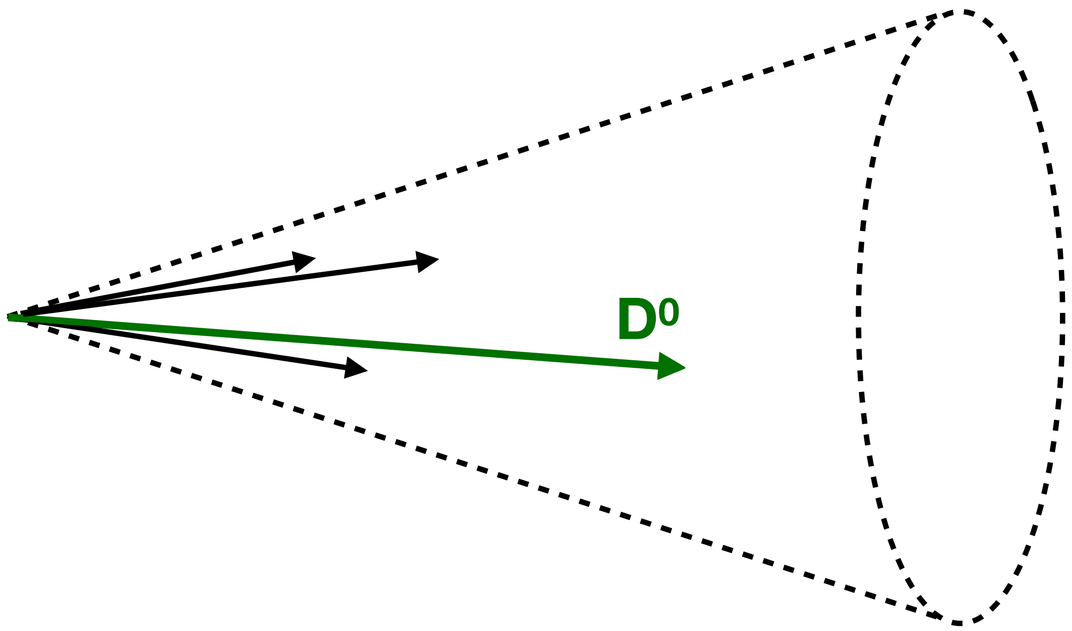

$$2 \leq p_{T,D^0} \leq 36 \text{ GeV}/c$$

$$5 \leq p_{T,\text{ch. jet}} \leq 50 \text{ GeV}/c$$

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- Full D^0 momentum always inside the jet cone

Jet finding:

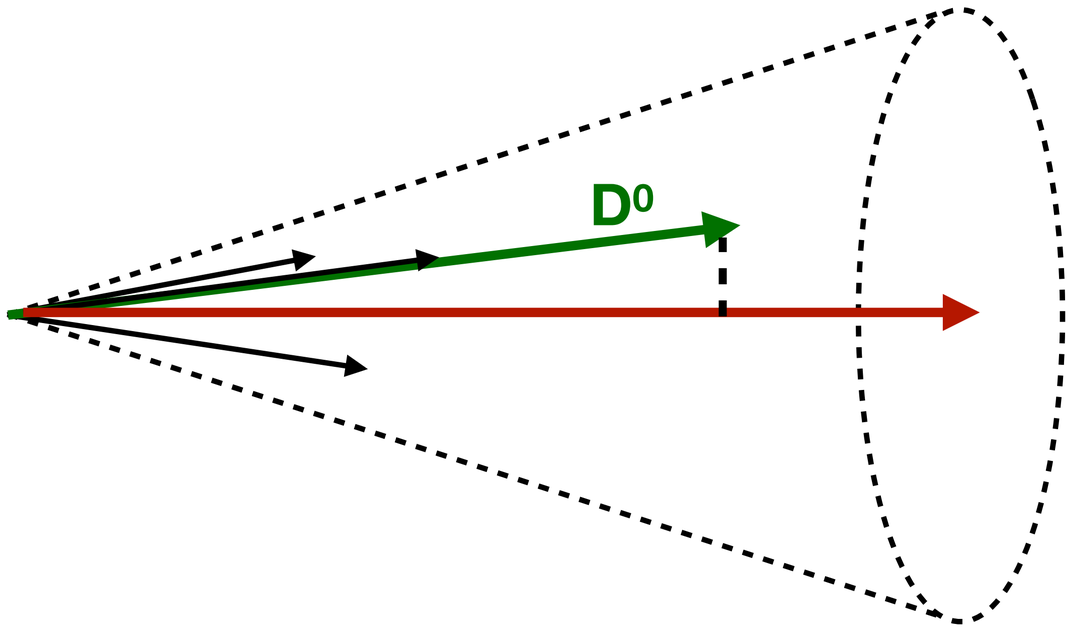
- anti-k_T algorithm

→ **D^0-tagged charged jets**

Heavy-flavor in-jet fragmentation

Fraction of jet momentum carried by the D^0 meson

$$z_{||}^{\mathrm{ch}} = \frac{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{D^0}}}{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{ch\ jet}}}$$



$\vec{p}_{\mathrm{D^0}}$ is the total D^0-meson momentum

$\vec{p}_{\mathrm{ch\ jet}}$ is the total jet momentum

Heavy-flavor in-jet fragmentation

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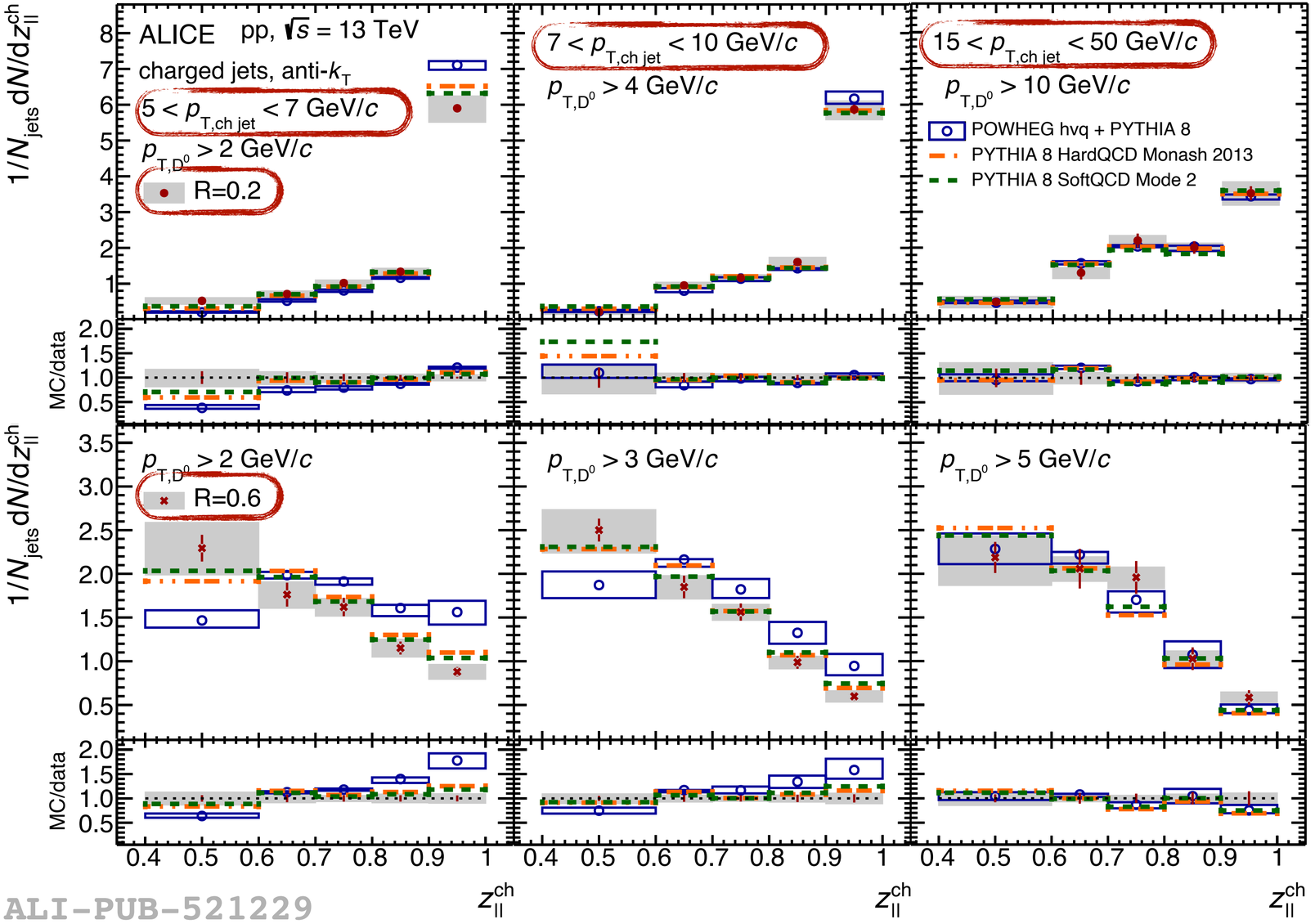

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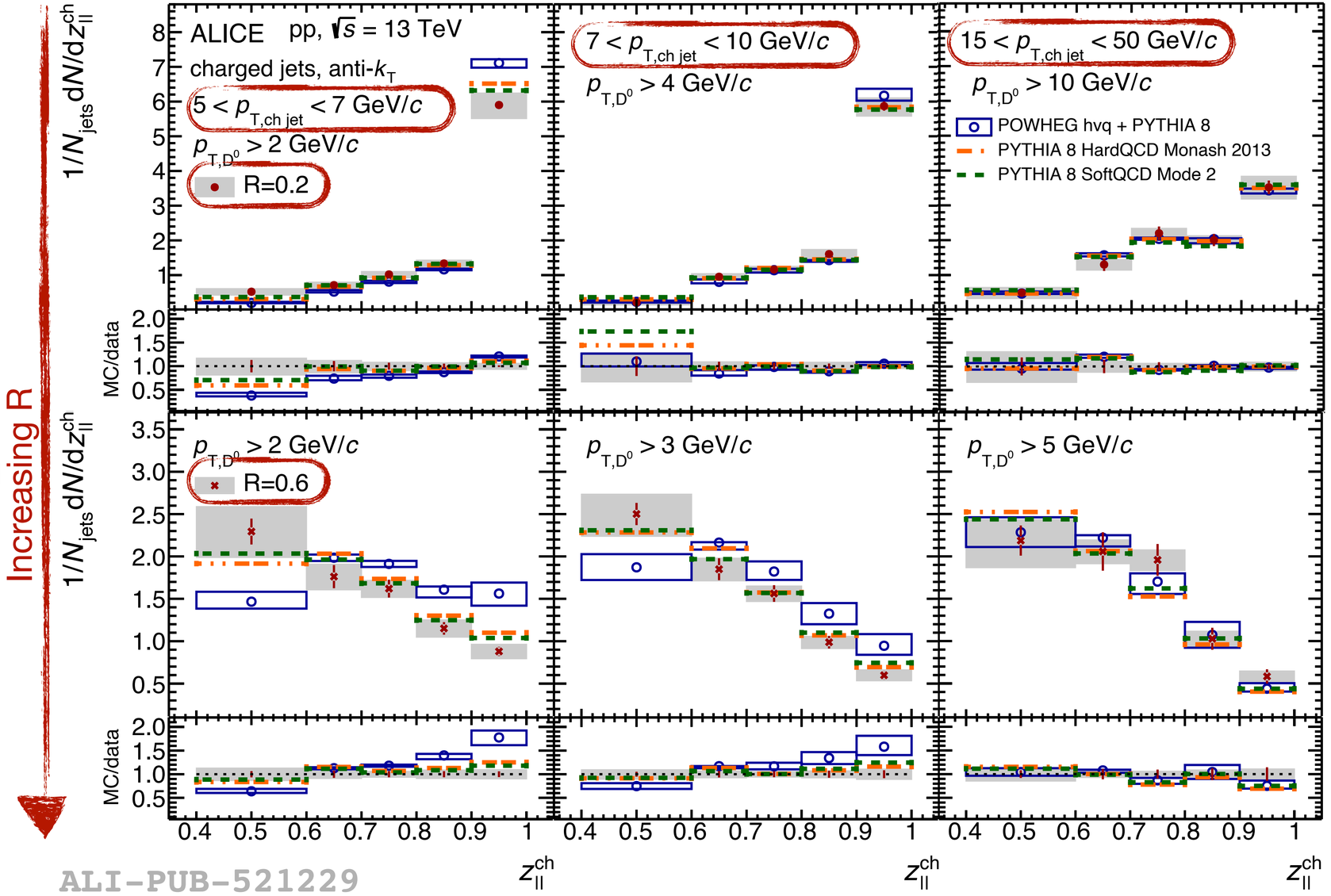

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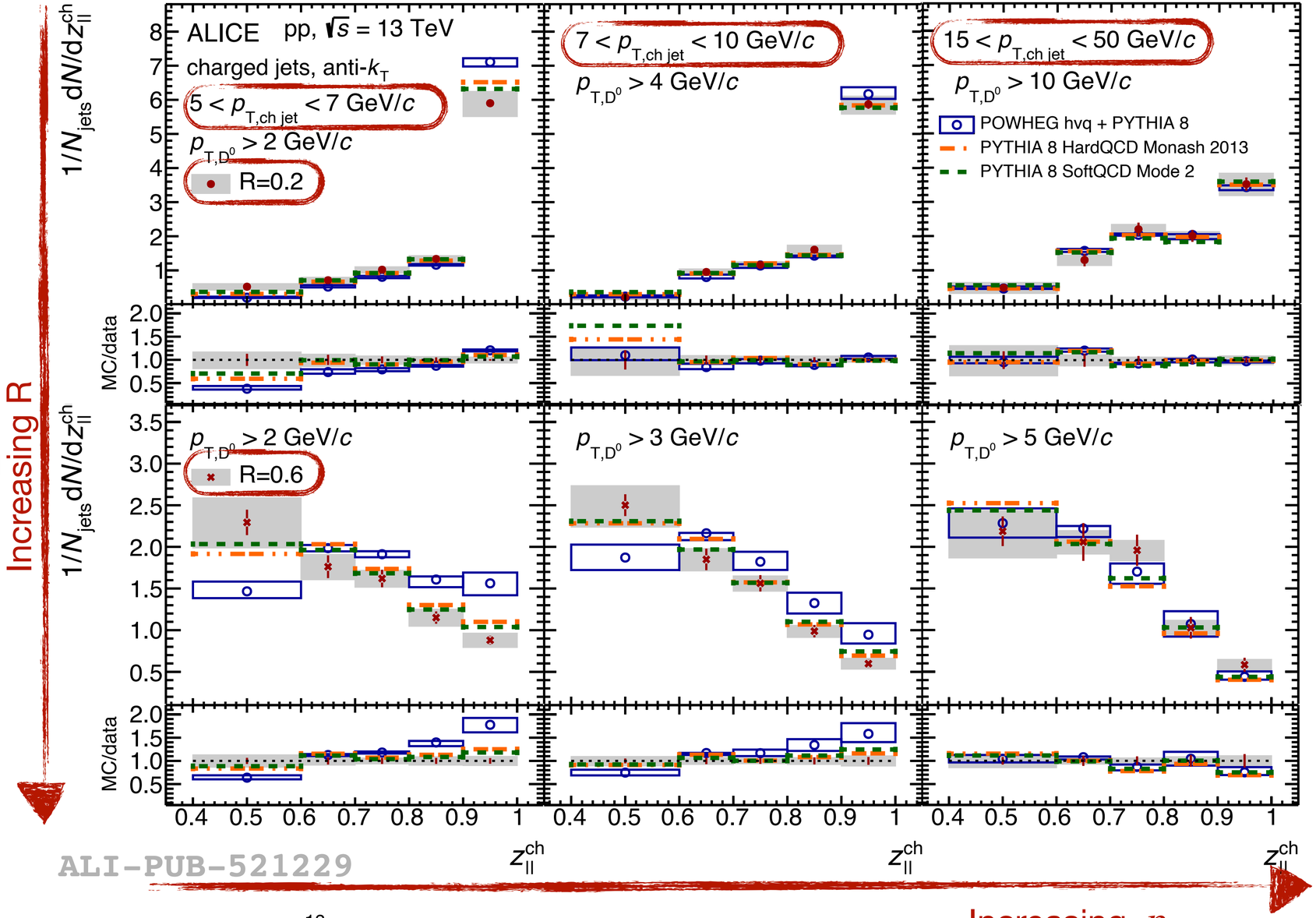
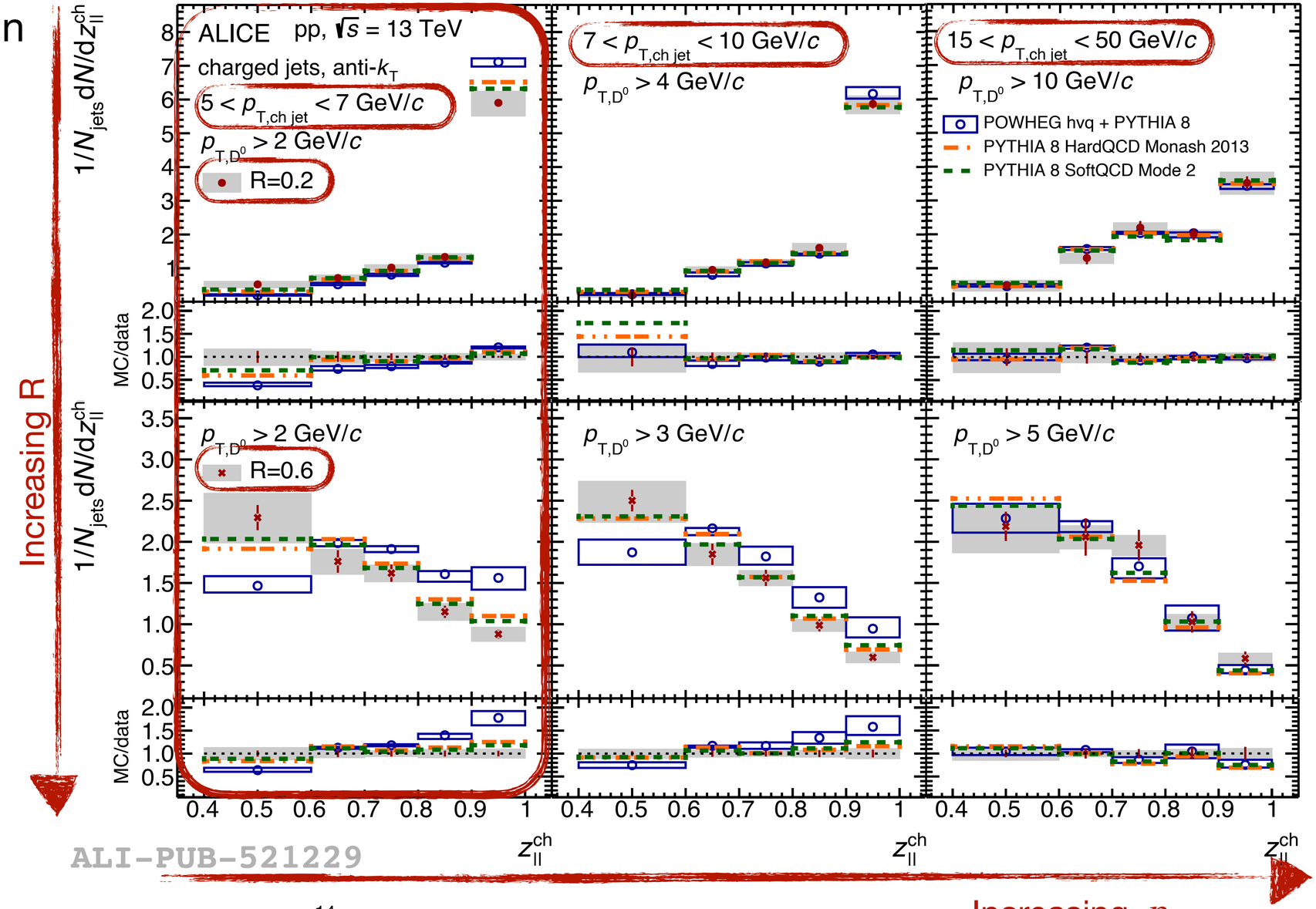


Heavy-flavor in-jet fragmentation

- **Hint of a softer fragmentation** in data with respect to model predictions for low $p_{T,ch\ jet}$ and larger *R*.



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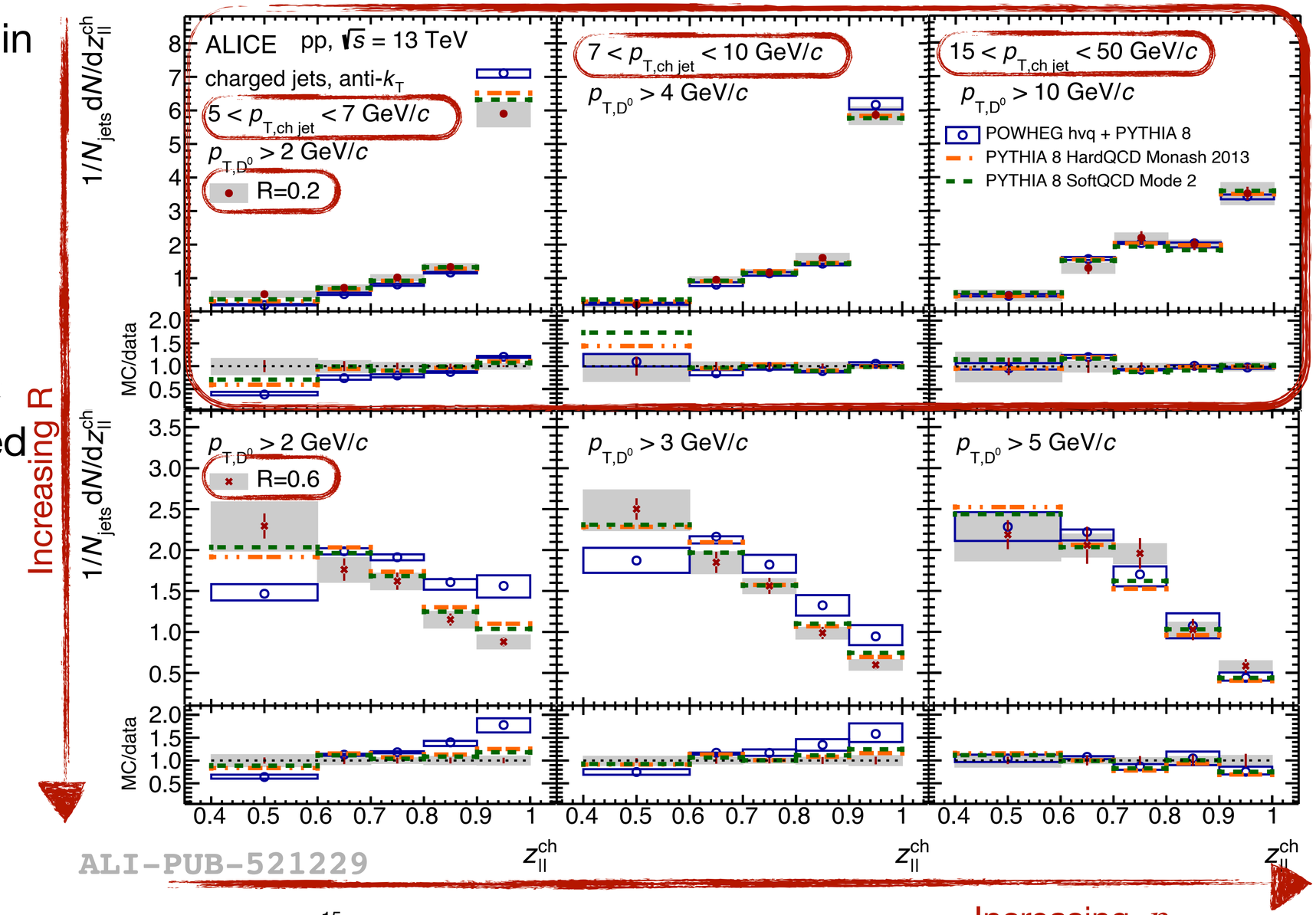

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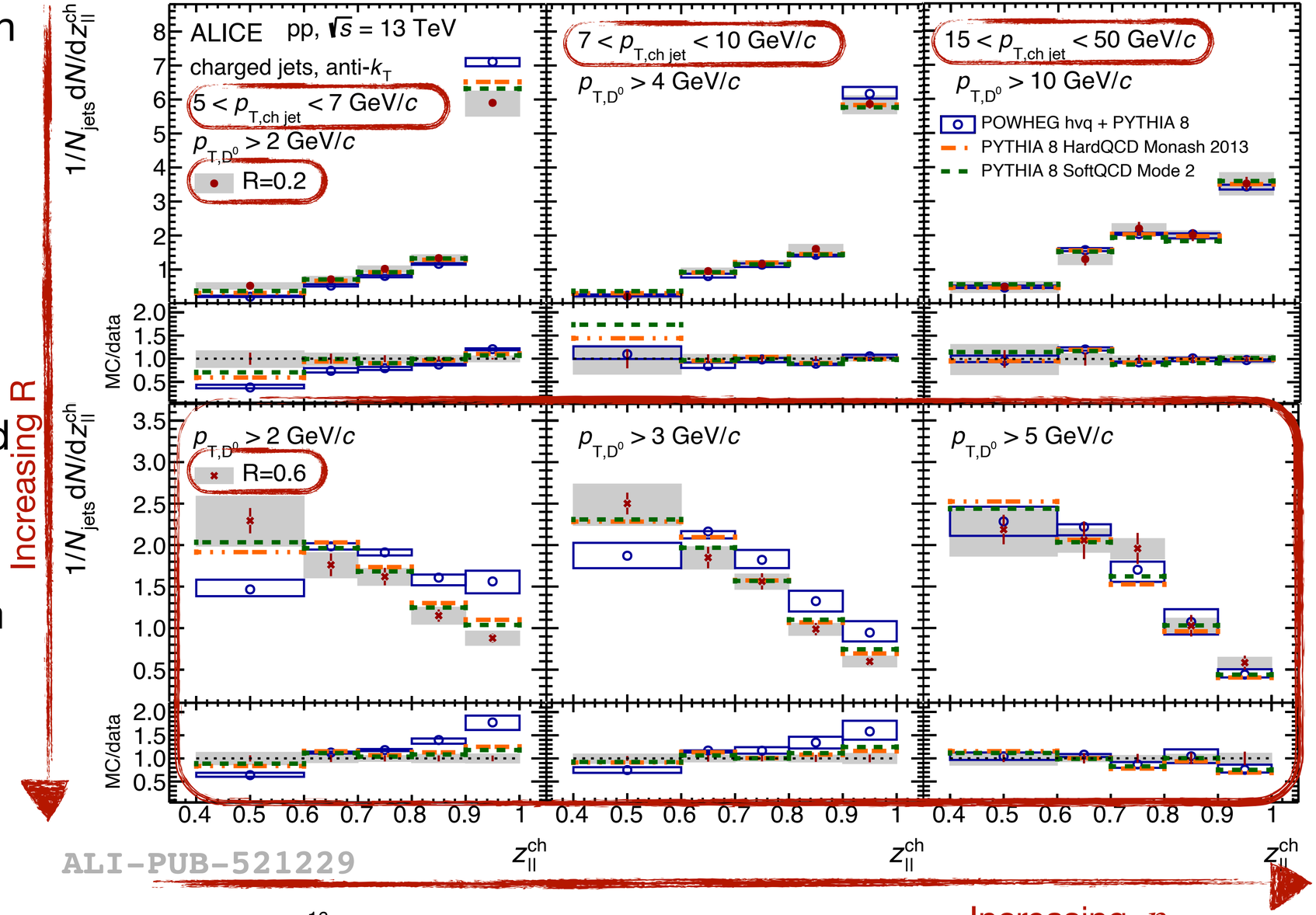
- At large angles (R>0.2) the charm quark emissions are recovered



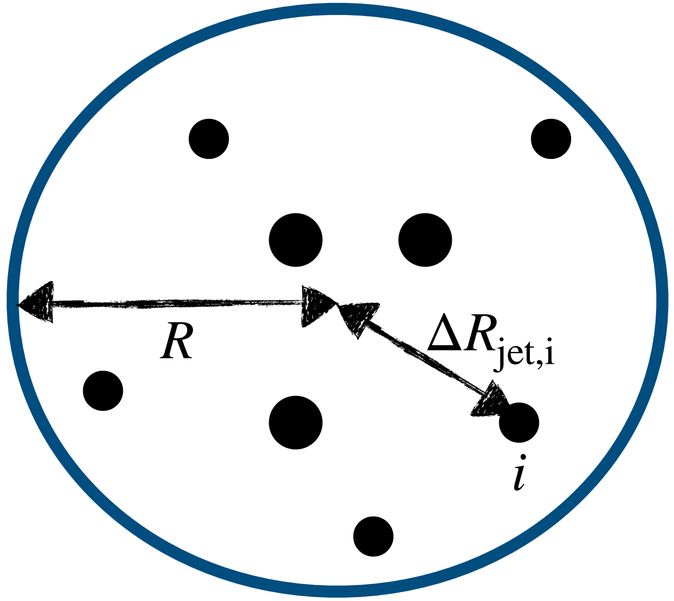
What are the jet angularities?

A. Larkoski, J. Thaler, W. Waalewijn
JHEP 11 (2014) 129

Ezra Lesser
Thursday 11 am

- A set of **substructure observables** which are dependent on the p_T and angular distribution of tracks within jets:

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



Jet p_T fraction carried by constituent i

$\Delta R_{\mathrm{jet,i}}$ distance of constituent i to the jet axis

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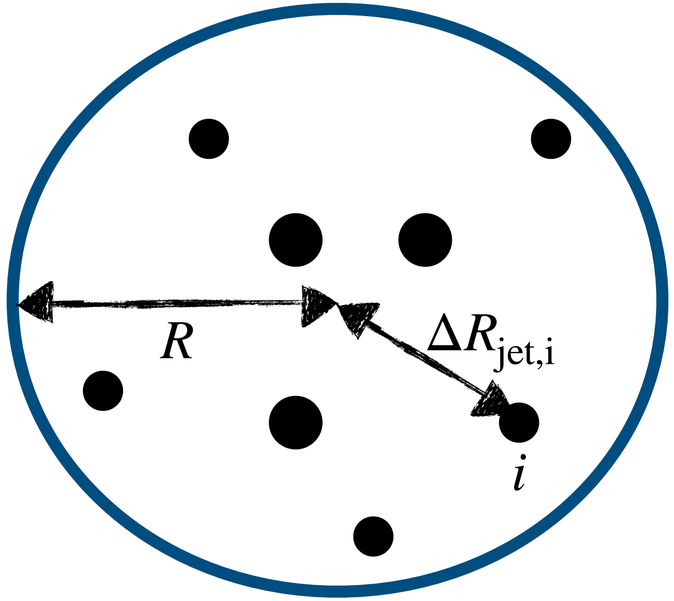

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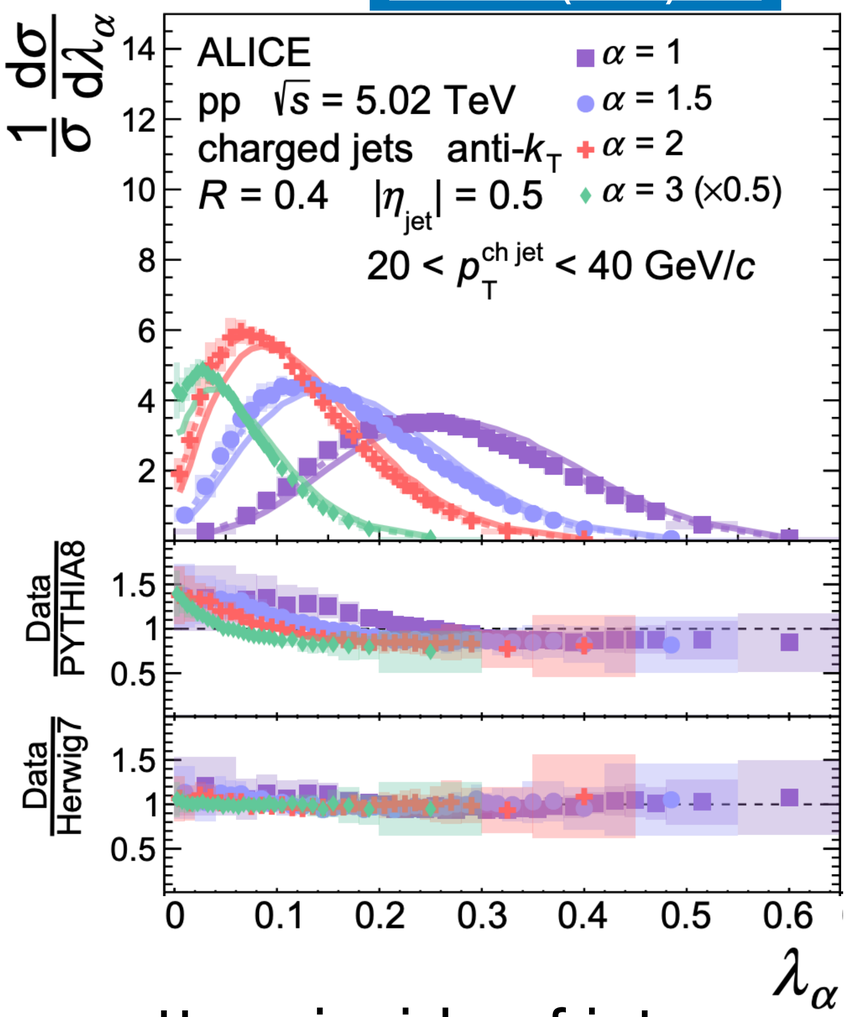
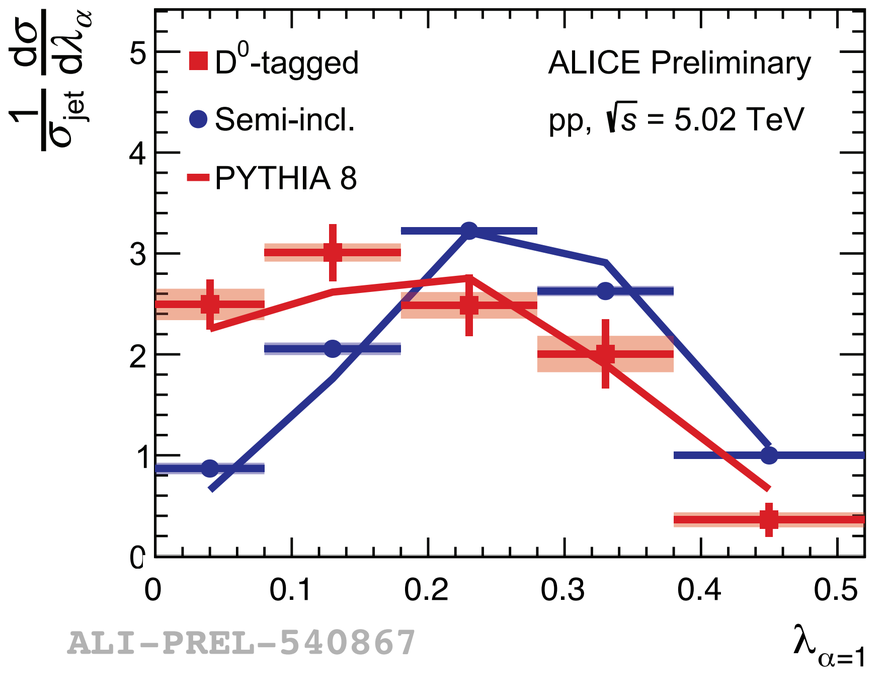
JHEP05 (2022) 061



- Infra-Red and Collinear (IRC) safe observable for $\kappa = 1$, $\alpha > 0$ → calculable from pQCD.
- Each α defines a different observable
→ varying α systematically characterizes the radiation pattern inside of jets

D^0-tagged vs. semi-inclusive jet angularity



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- Fully unfolded measurement

- Semi-inclusive baseline requires p_T > 5.33 GeV/c for the leading track
  - Corresponds to transverse mass of a D^0 meson with p_T = 5 GeV/c

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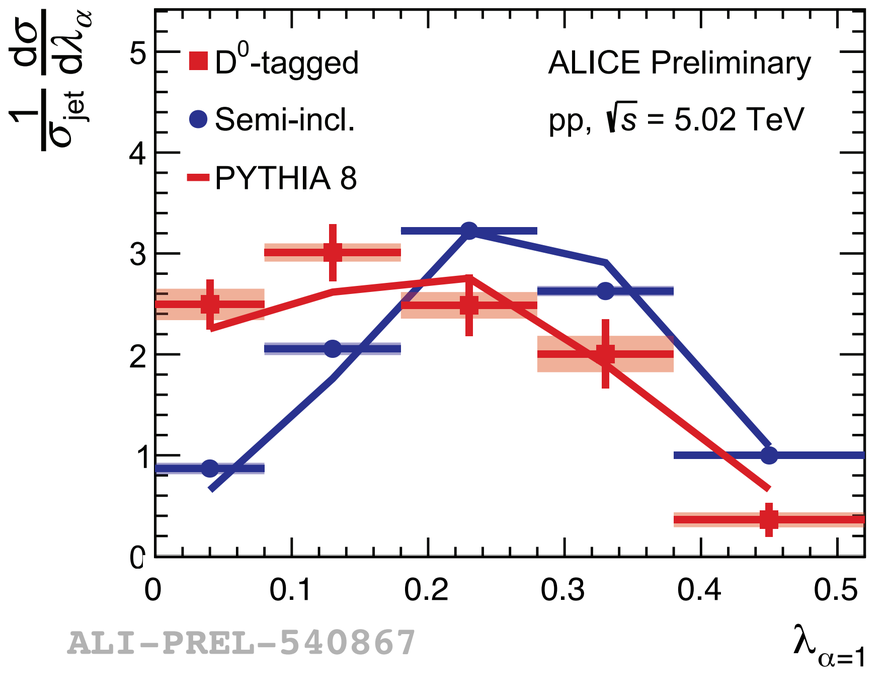

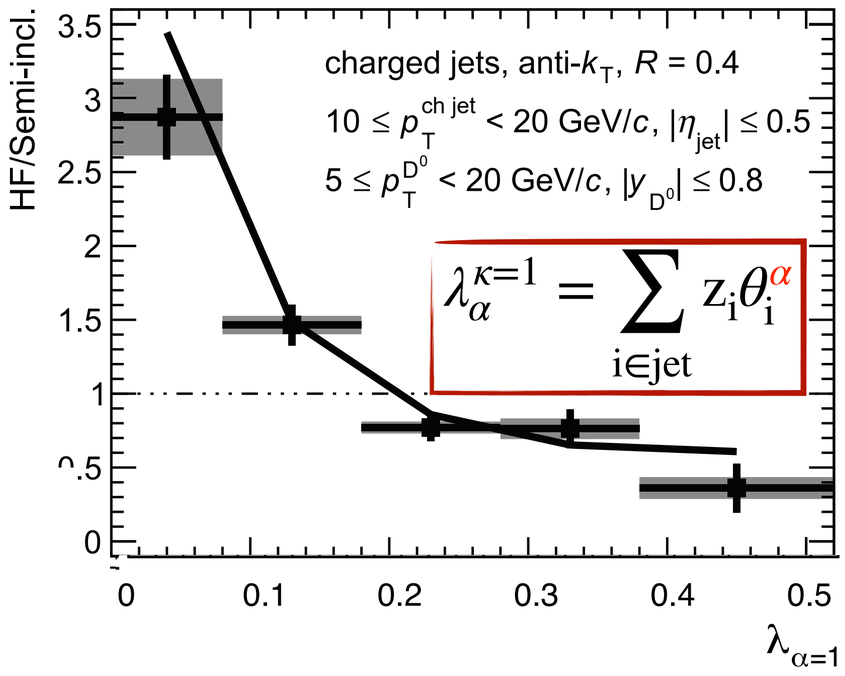

- **D^0-tagged jets have lower angularities than semi-inclusive jets**
  - HF jets more ‘collimated’ than semi-inclusive jets
  - Collimation due to:
    - The smaller color charge of quarks compared to gluons
    - The dead cone around the charm quark: charm quark fragments less

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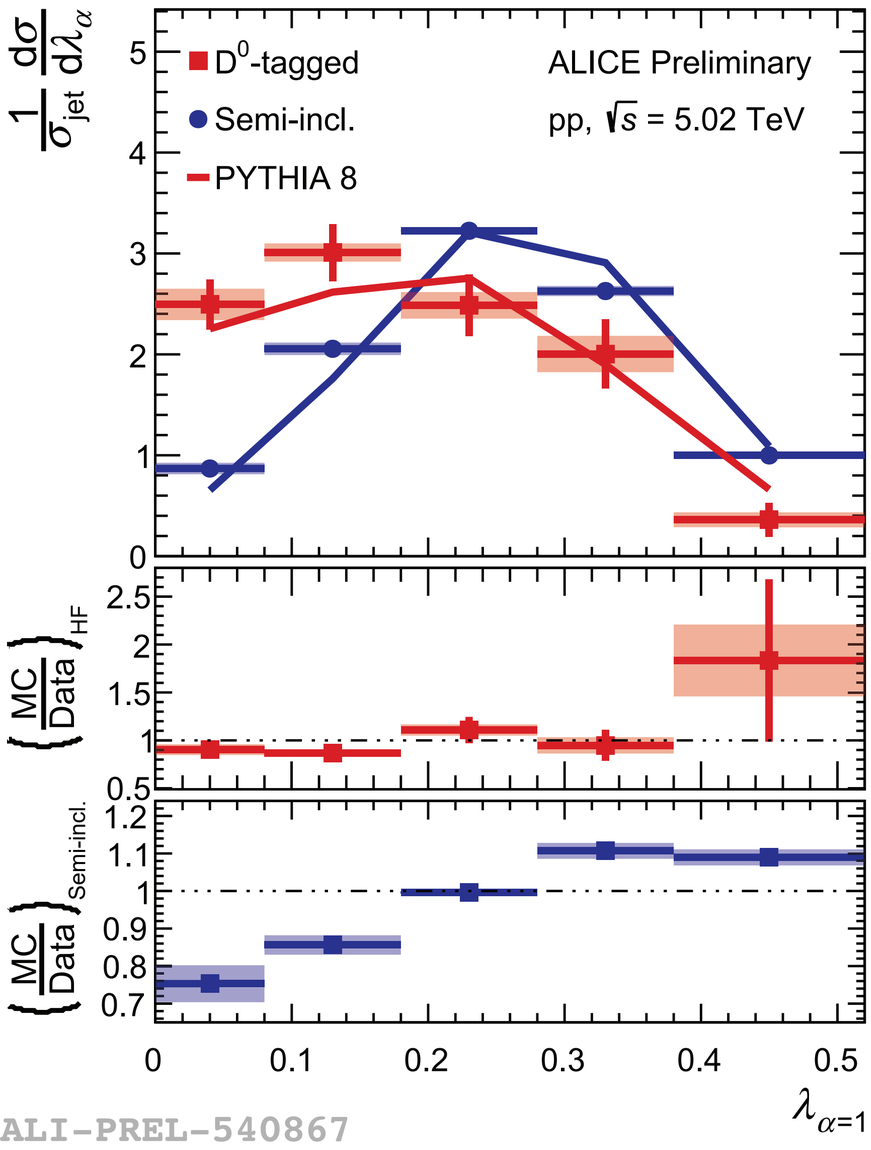

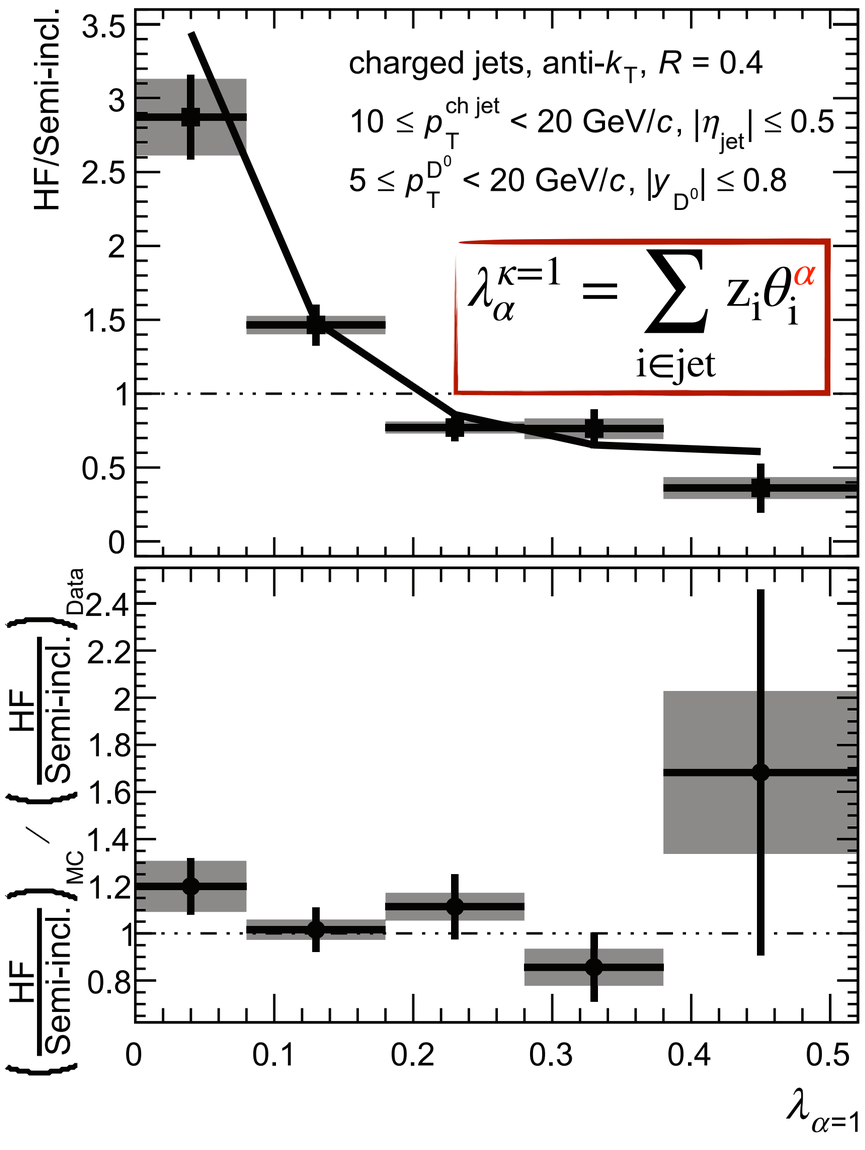

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  - Collimation due to:
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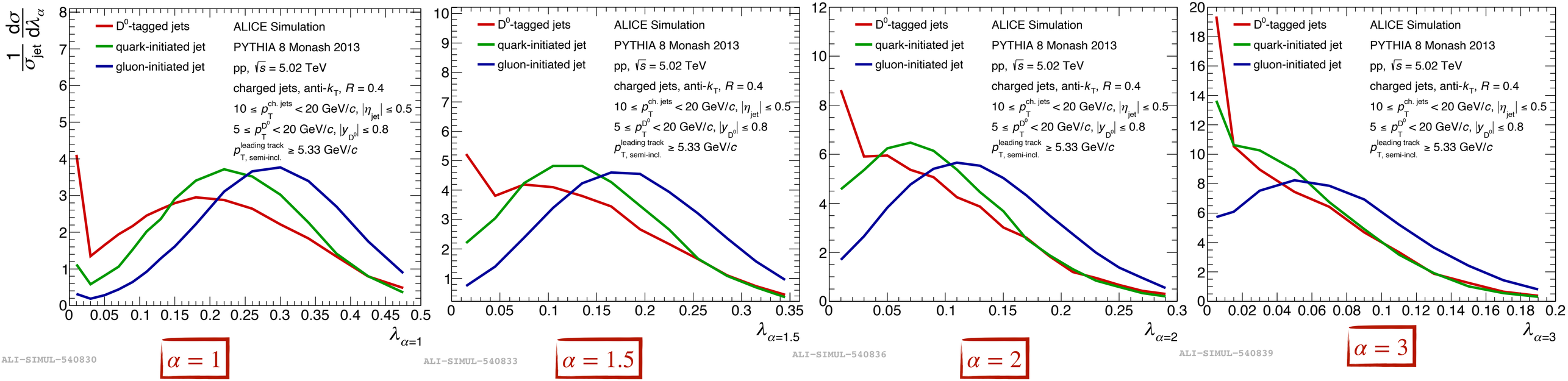
- Do PYTHIA simulations do a better job of describing charm-tagged jet angularities compared to semi-inclusive?

Tuning the flavor dependence by varying alpha

$$\lambda_\alpha^{\kappa=1} = \sum_{i \in jet} z_i \theta_i^\alpha$$

- How much of this modification is due to the D0 jet being a **quark jet** versus being a **HF jet**?



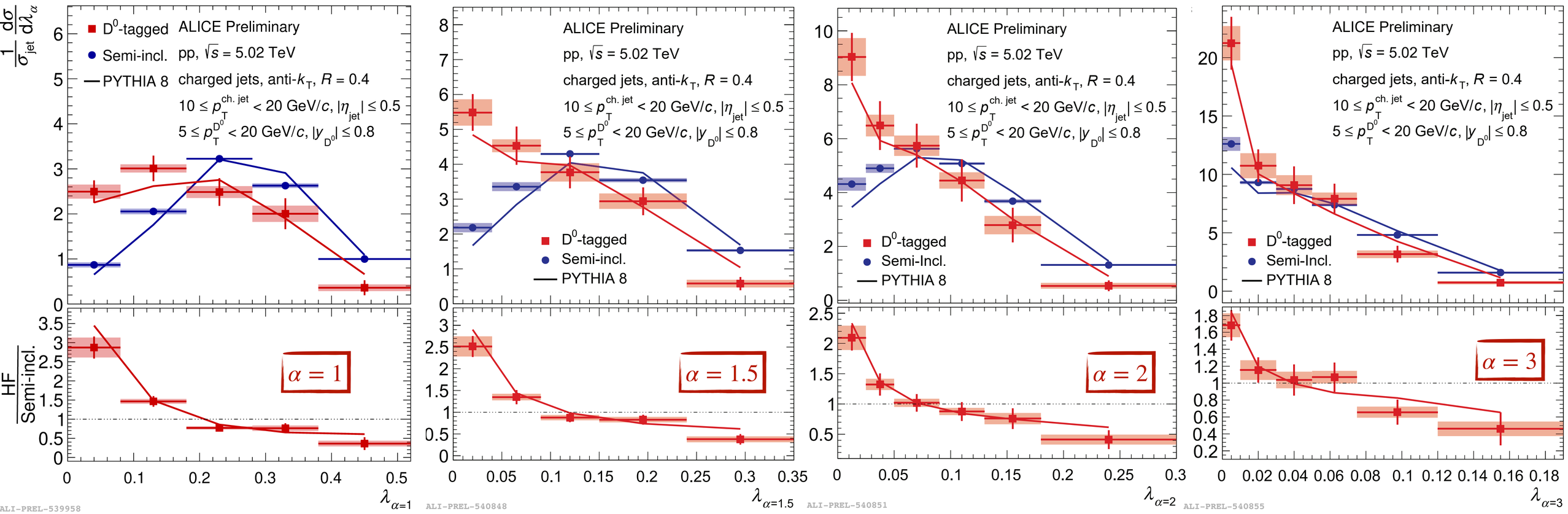
$\alpha = 1$ $\alpha = 1.5$ $\alpha = 2$ $\alpha = 3$

- With increasing α the impact of mass effects is reduced : D0-tagged and quark-initiated distributions become more similar → cleaner sensitivity to Casimir colour effects
- At lower α where the core of the jet has a higher weight → large angle radiation has a lower weight, mass effects are more prominent

Scanning the angular profile of jets

$$\lambda_\alpha^{\kappa=1} = \sum_{i \in jet} z_i \theta_i^{\alpha}$$

Higher α →more weight on wide angle emissions



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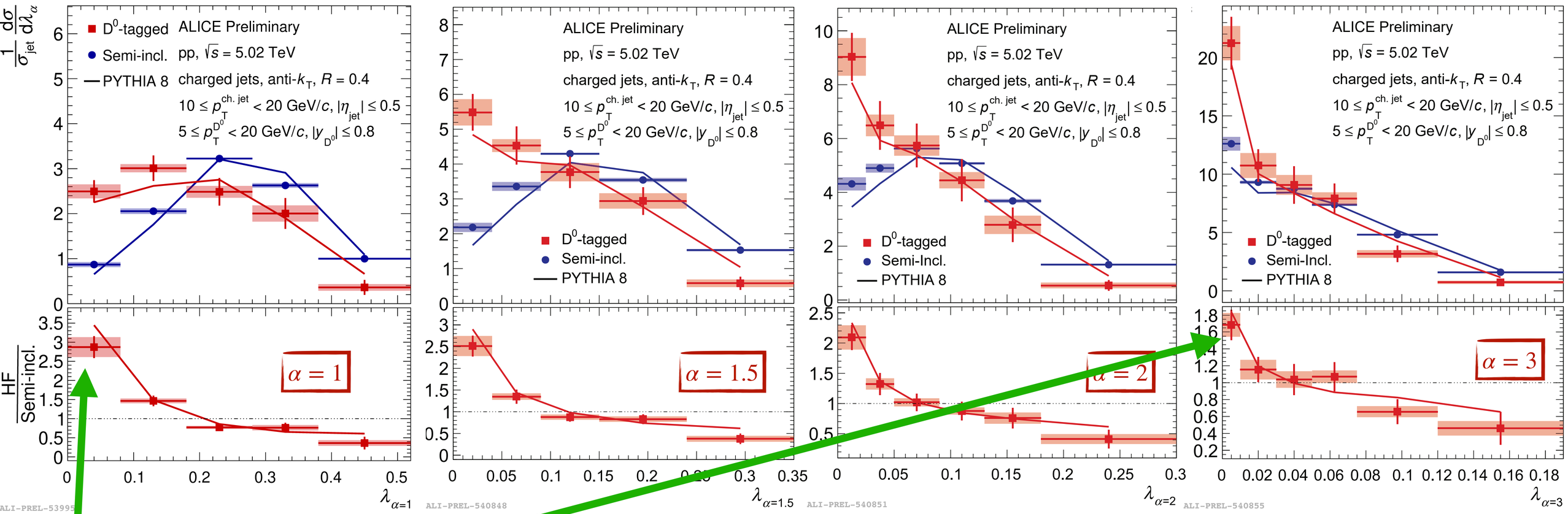

- With increasing α the shape of the charm-tagged and semi-inclusive angularities begin to converge
- Suggests that the largest differences are in the jet core arising from mass effects

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  - **Scanning through different α parameters can control the impact of each of the flavor effects**
  - **D^0-tagged jets have narrower angularities than semi-inclusive jets**, with the distribution shapes becoming more similar at large values of α.

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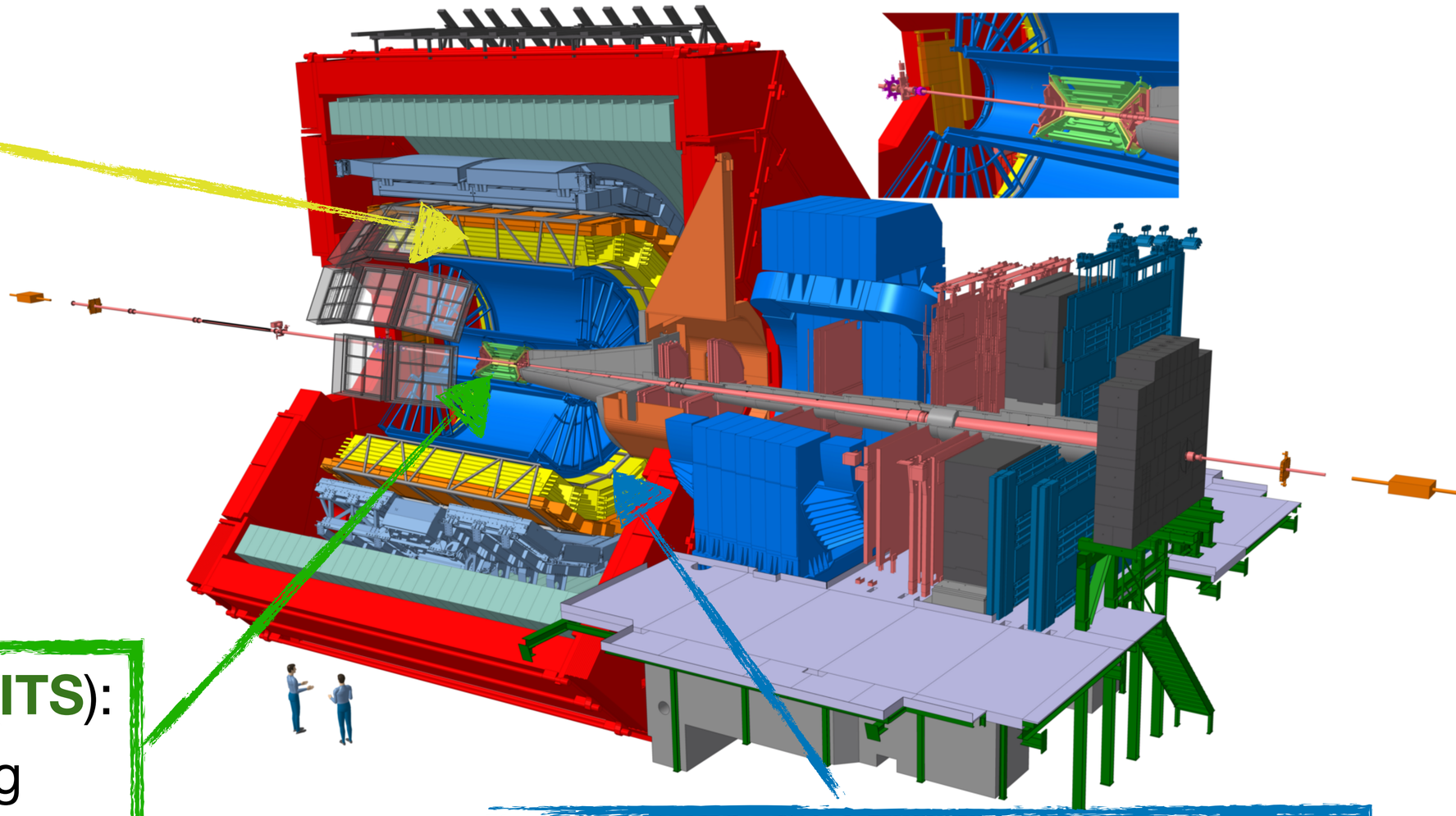
- These measurement are good baseline for p-Pb and Pb-Pb.

Thank you!

Backup slides

A Large Ion Collider Experiment

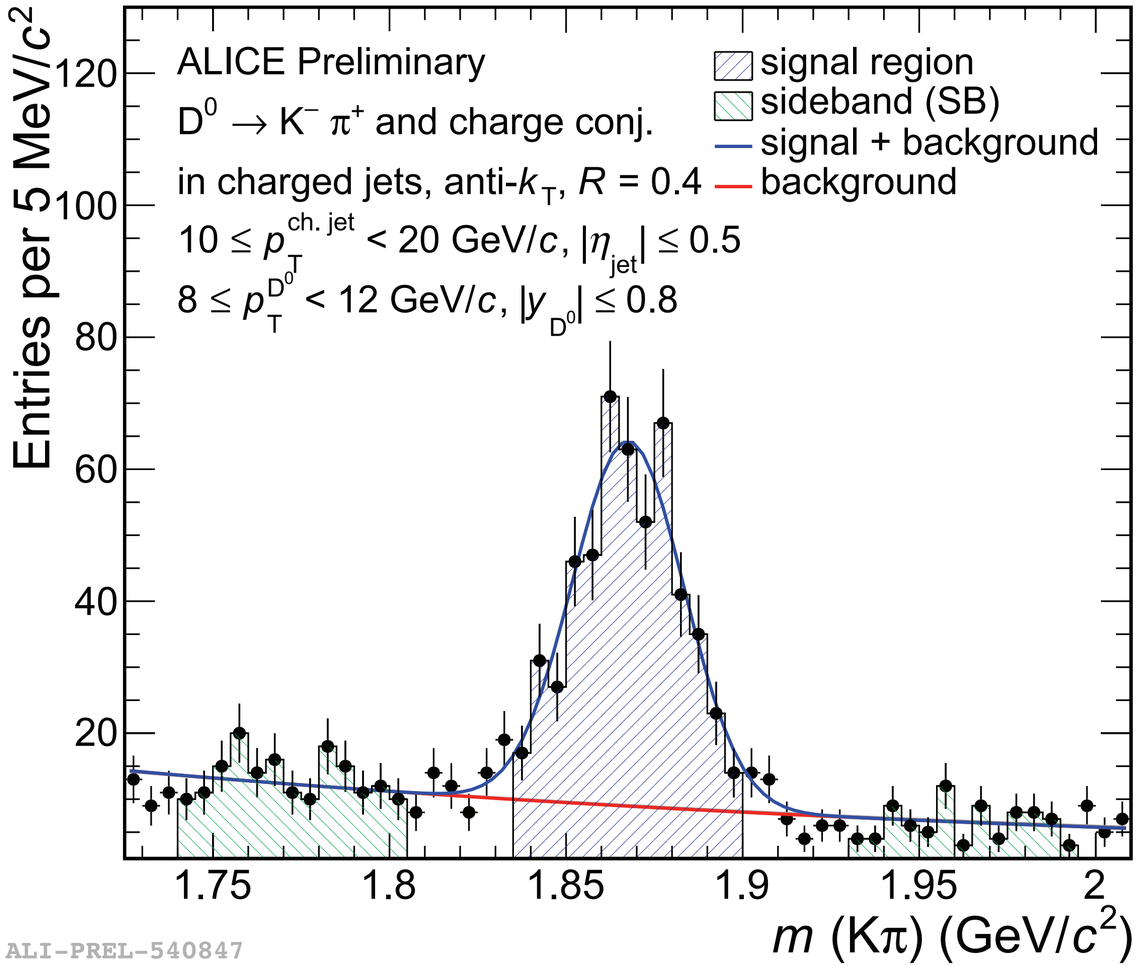
Time-Of-Flight (**TOF**):
PID via time of flight



Inner Tracking System (**ITS**):
tracking and vertexing

Time Projection Chamber (**TPC**):
tracking and PID via d*E*/d*x*

Data-driven signal extraction



- Some combinatorial Kπ pairs pass the D^0 selections
  - Removed via a sideband subtraction method

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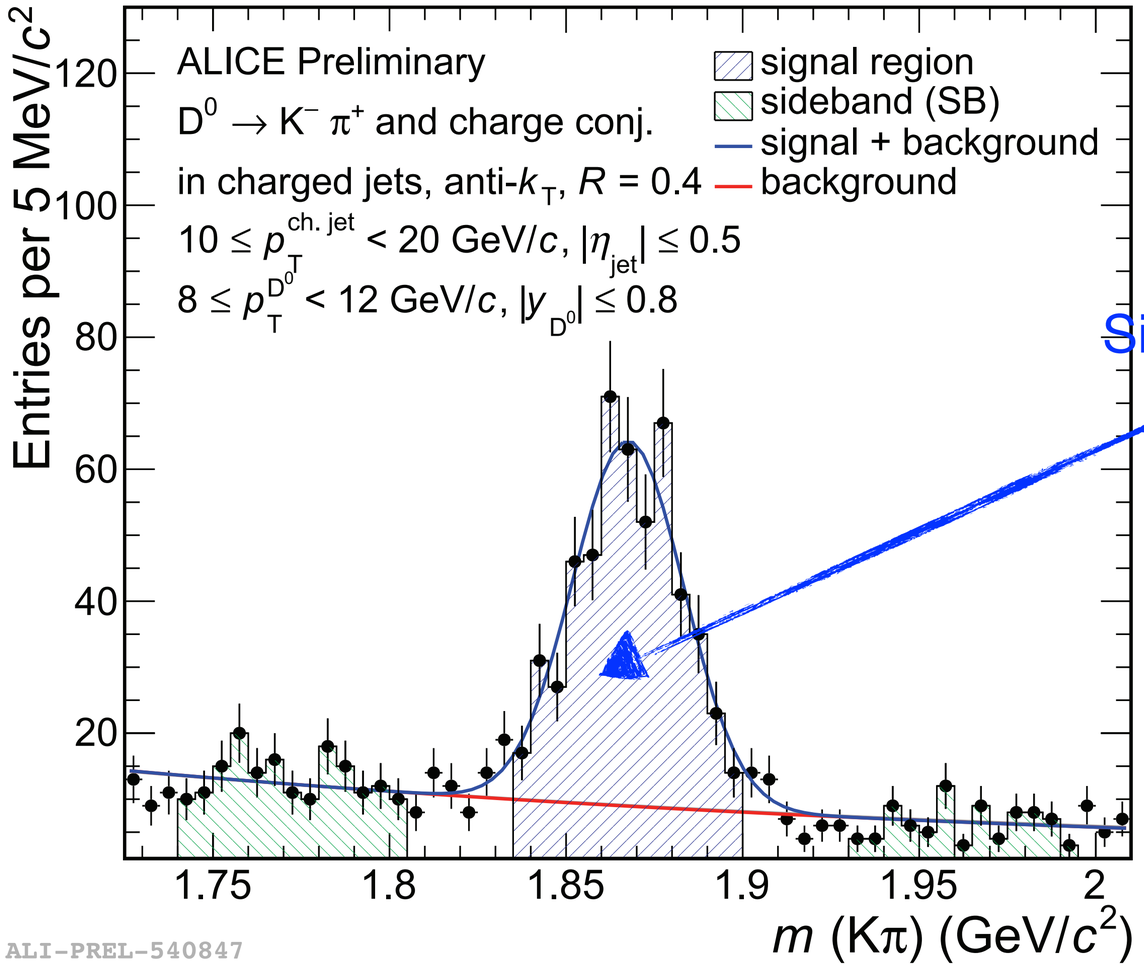
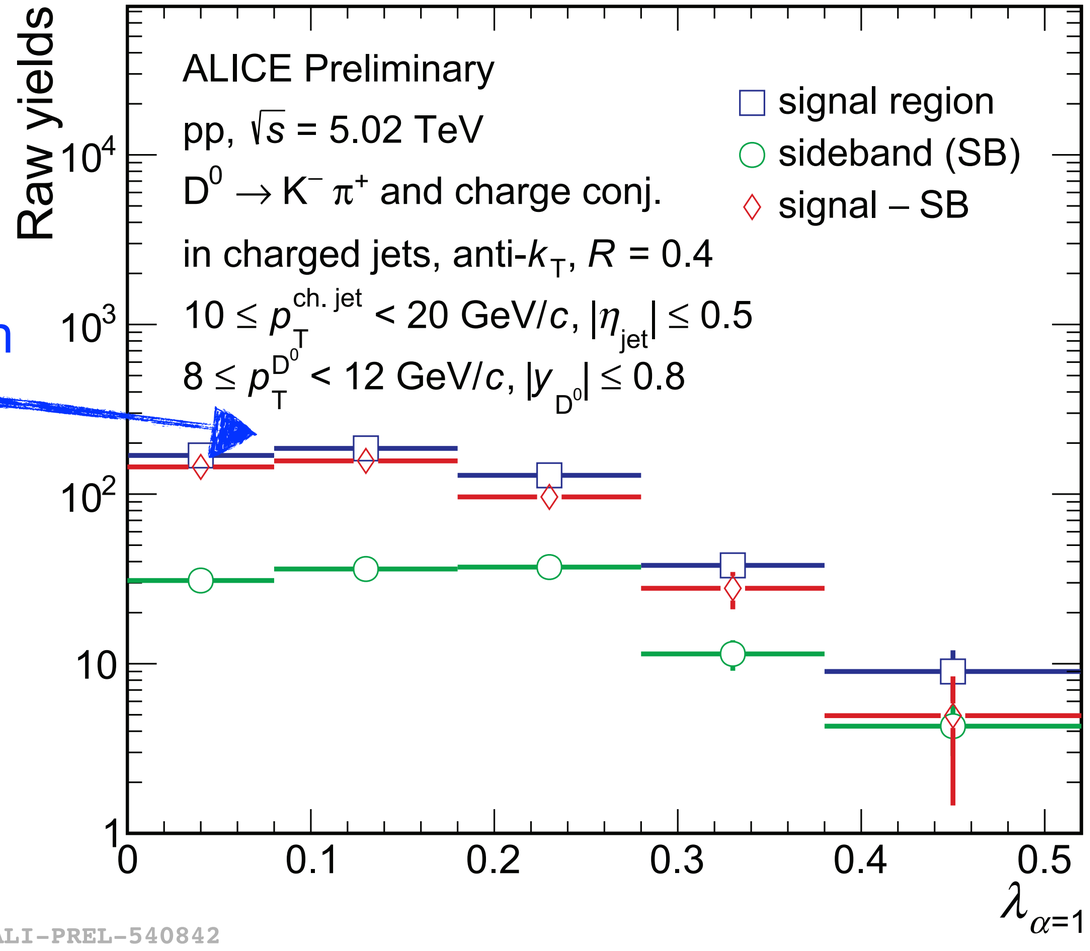
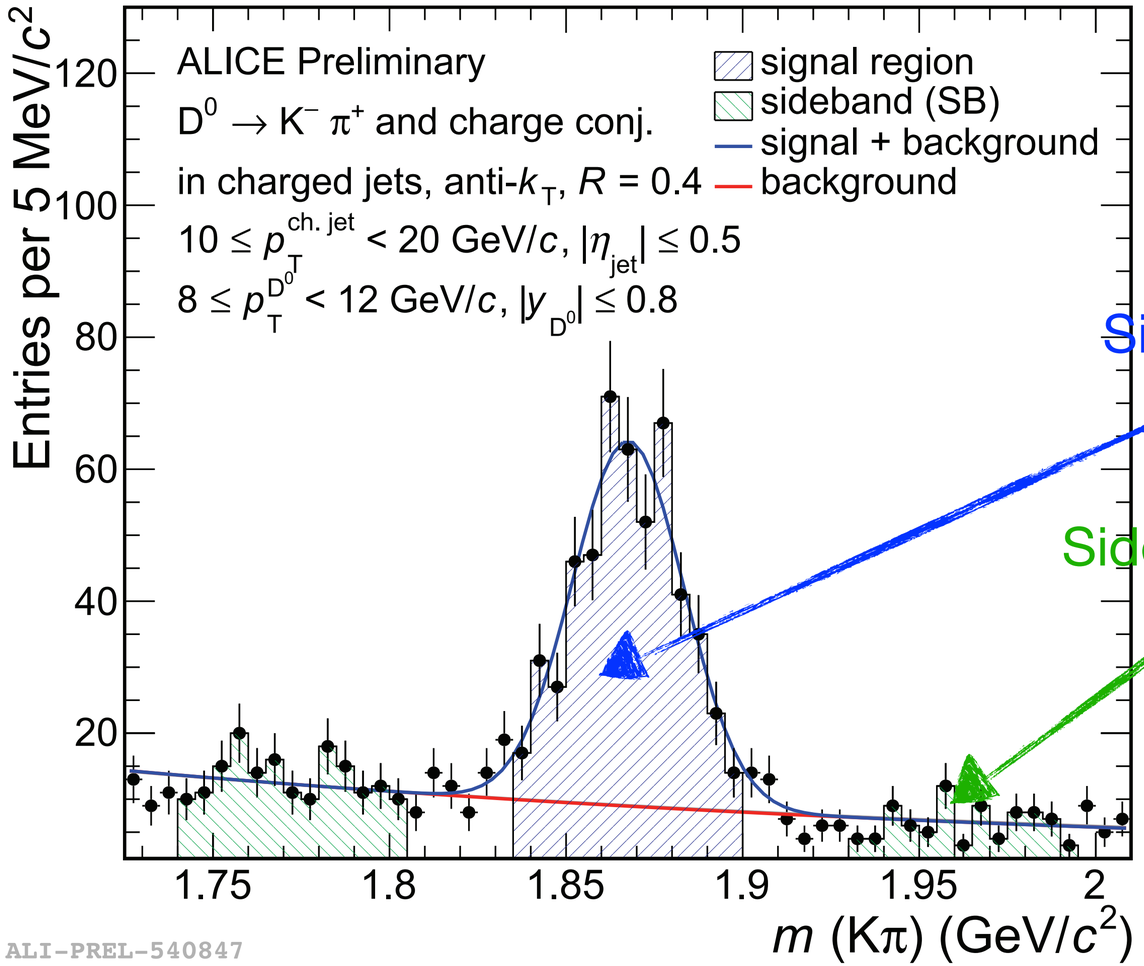


Signal region



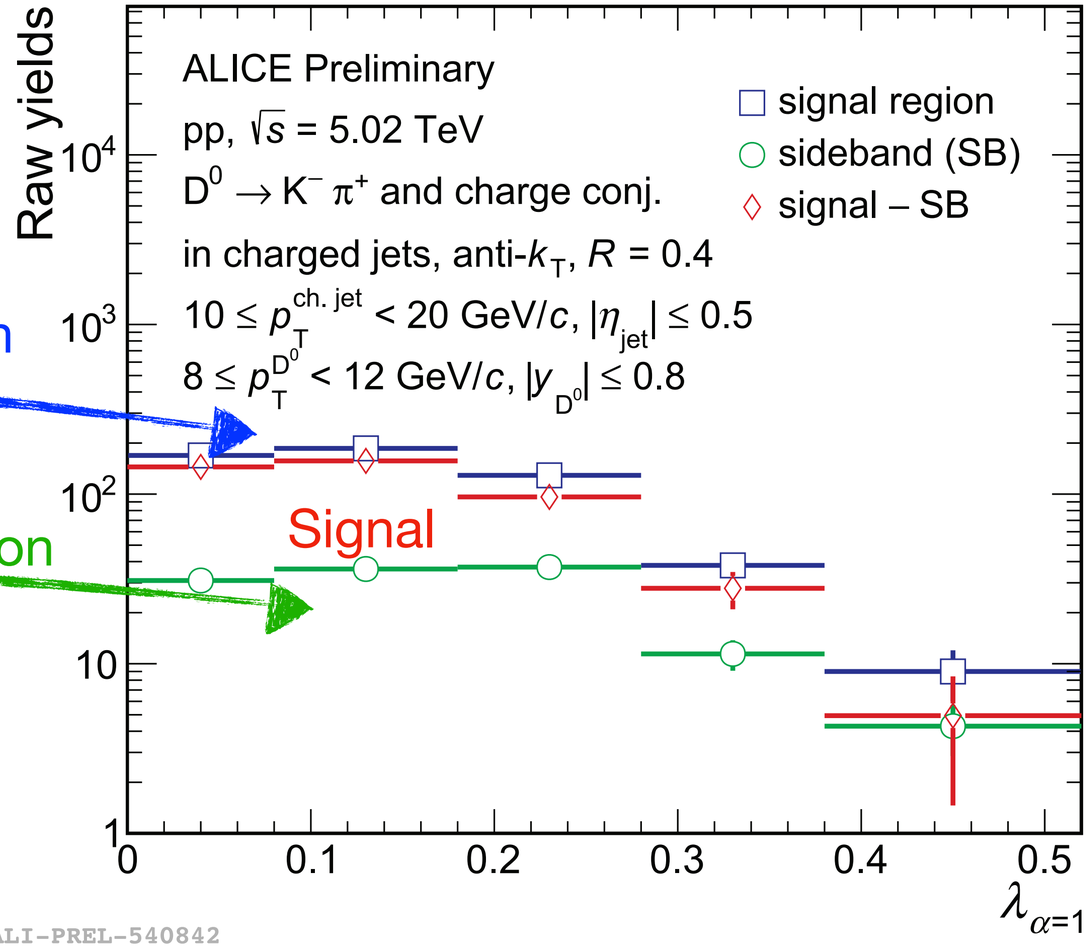
- Some combinatorial Kπ pairs pass the D^0 selections
  - Removed via a sideband subtraction method

Data-driven signal extraction



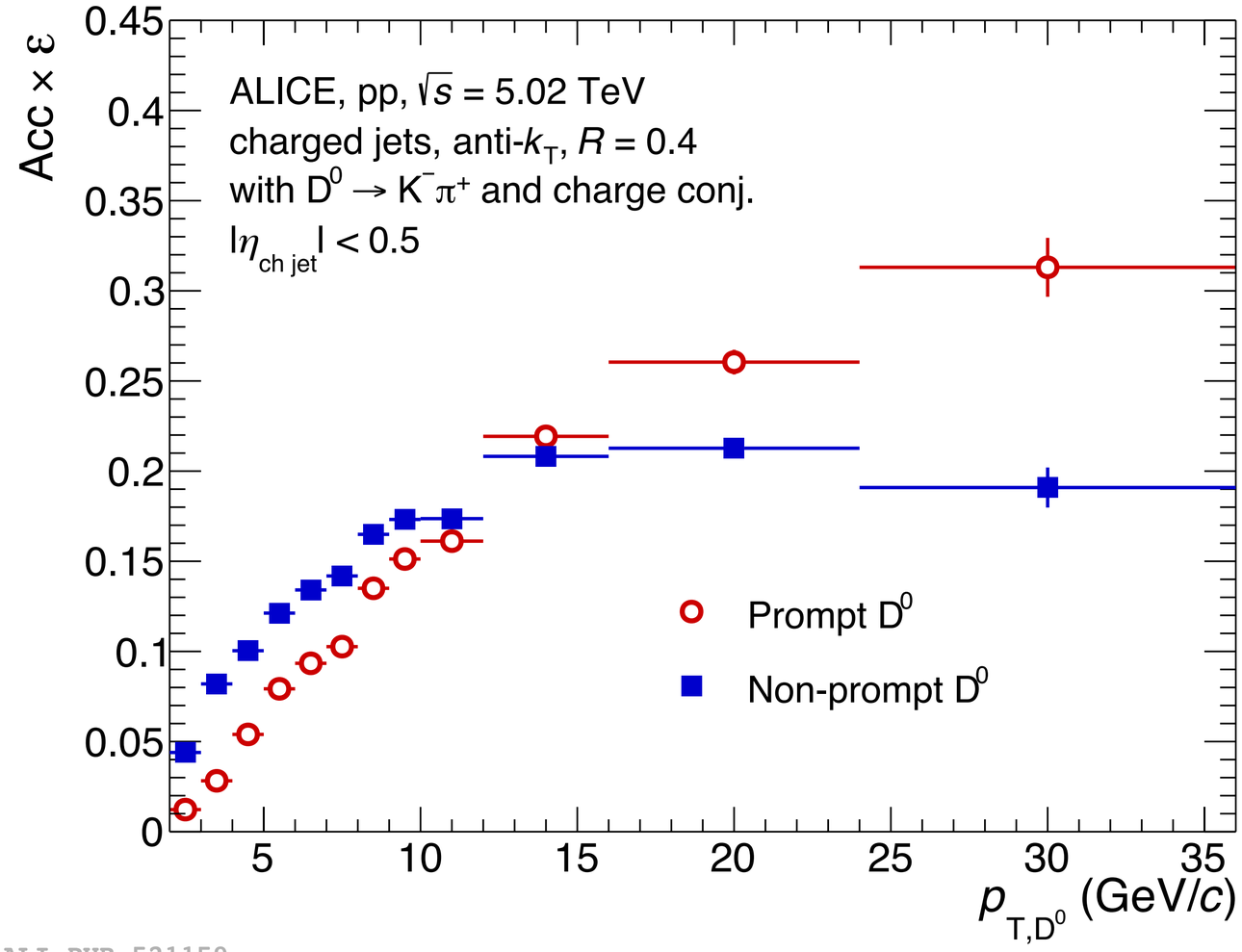
Signal region

Sideband region



- Some combinatorial Kπ pairs pass the D^0 selections
  - Removed via a sideband subtraction method
- Extraction performed in D^0-meson p_T intervals

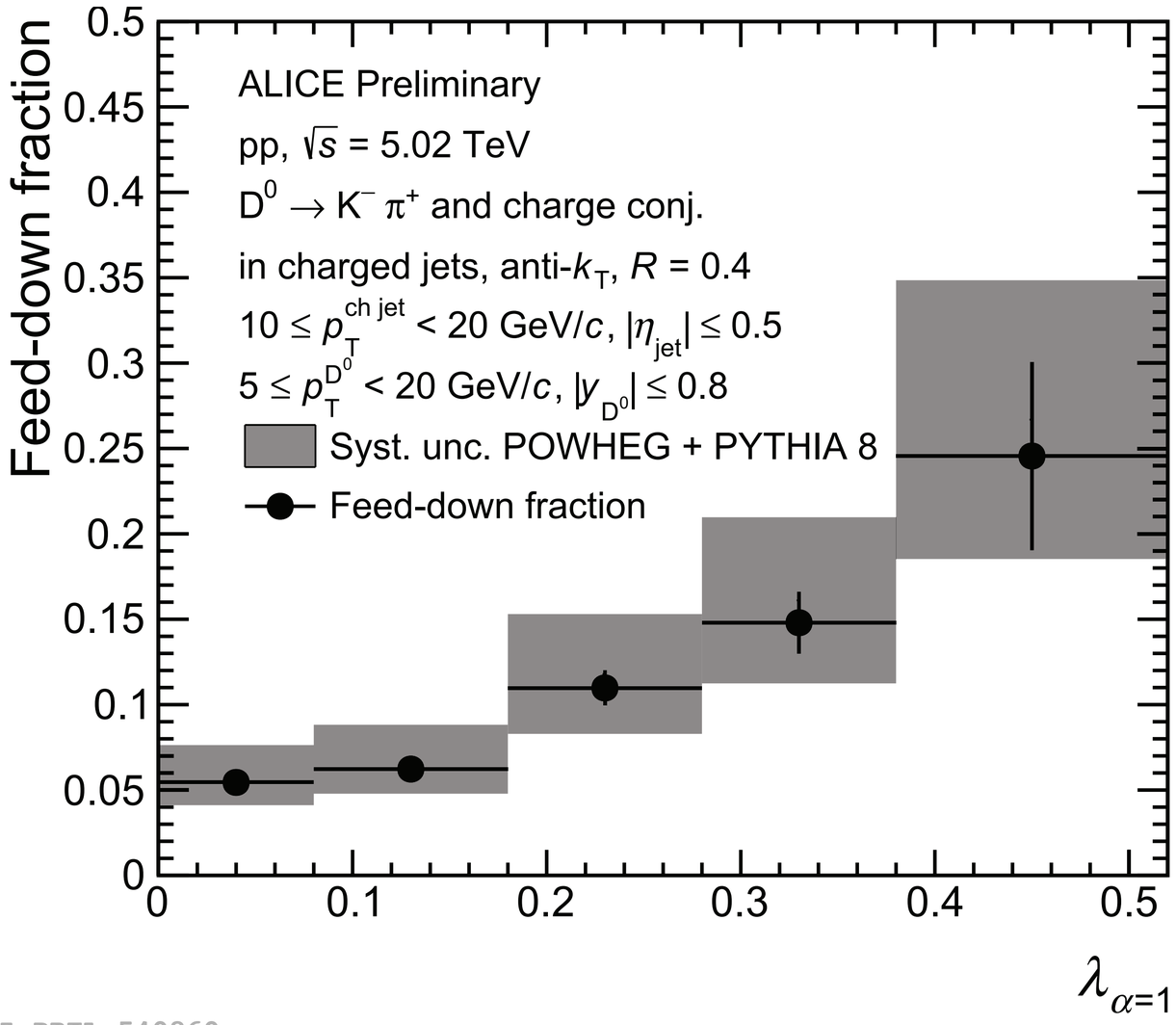
D^0 reconstruction efficiency correction



- Efficiency of the D^0 cut selections is strongly dependent on D^0-meson p_T
- sideband-subtracted distributions are corrected by the D^0 reconstruction and selection efficiency in narrow D^0 p_T intervals
- Efficiency-corrected angularity distributions are integrated over D^0 p_T intervals

Prompt efficiency ($c \rightarrow D^0$) correction

Correcting angularities for $B \rightarrow D^0$ decays



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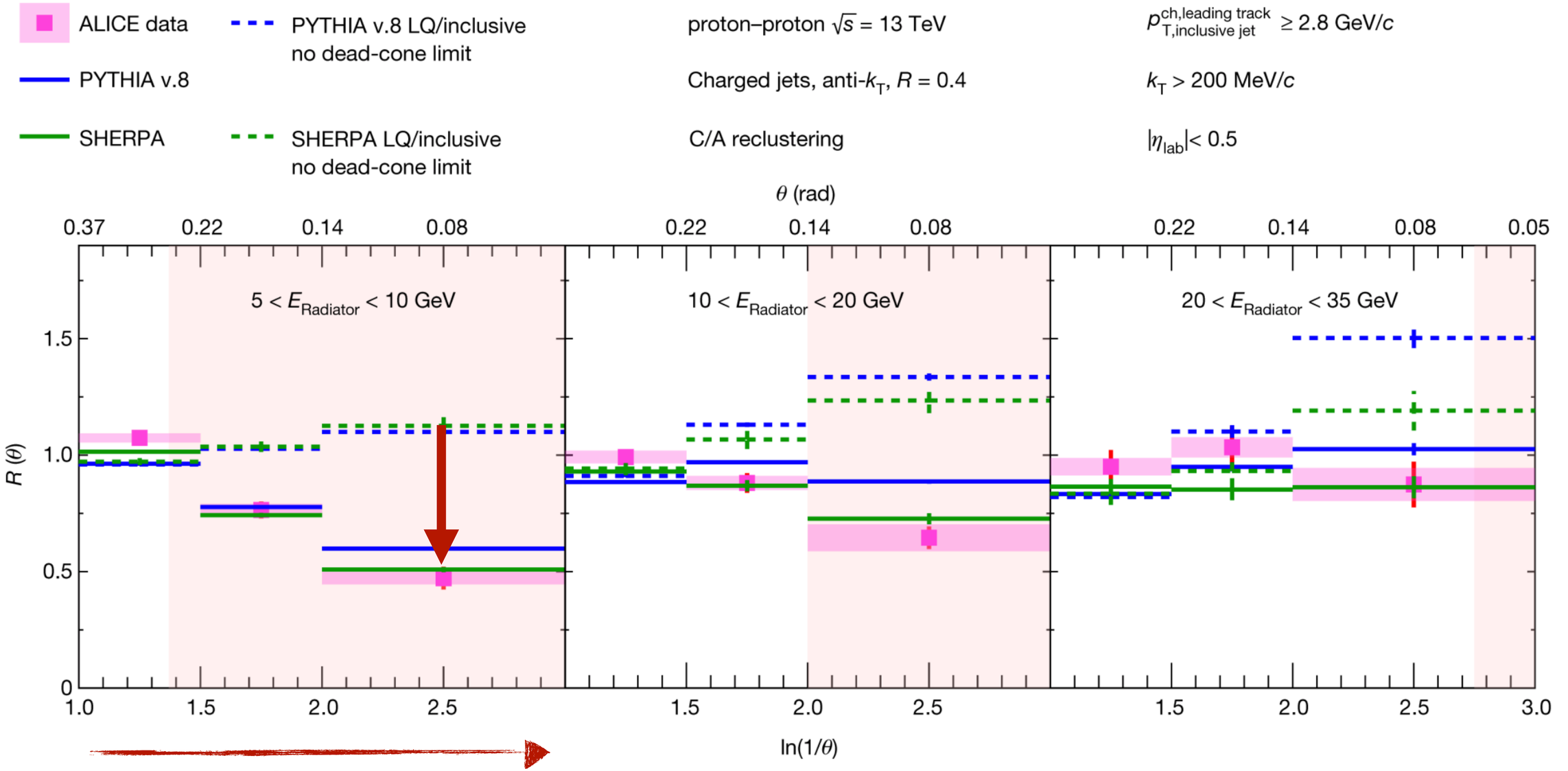
- Beauty feed-down contribution estimated using POWHEG + PYTHIA 8.
- Simulation distribution corrected for non-prompt D^0 reconstruction efficiency and folded to detector level
- The presence of additional track from $B \rightarrow D^0$ decays pushes the angularity to larger values for non prompt D0-tagged jet.

Feed-down subtraction (b →D0)

ALICE, Nature 605 (2022) 440–446

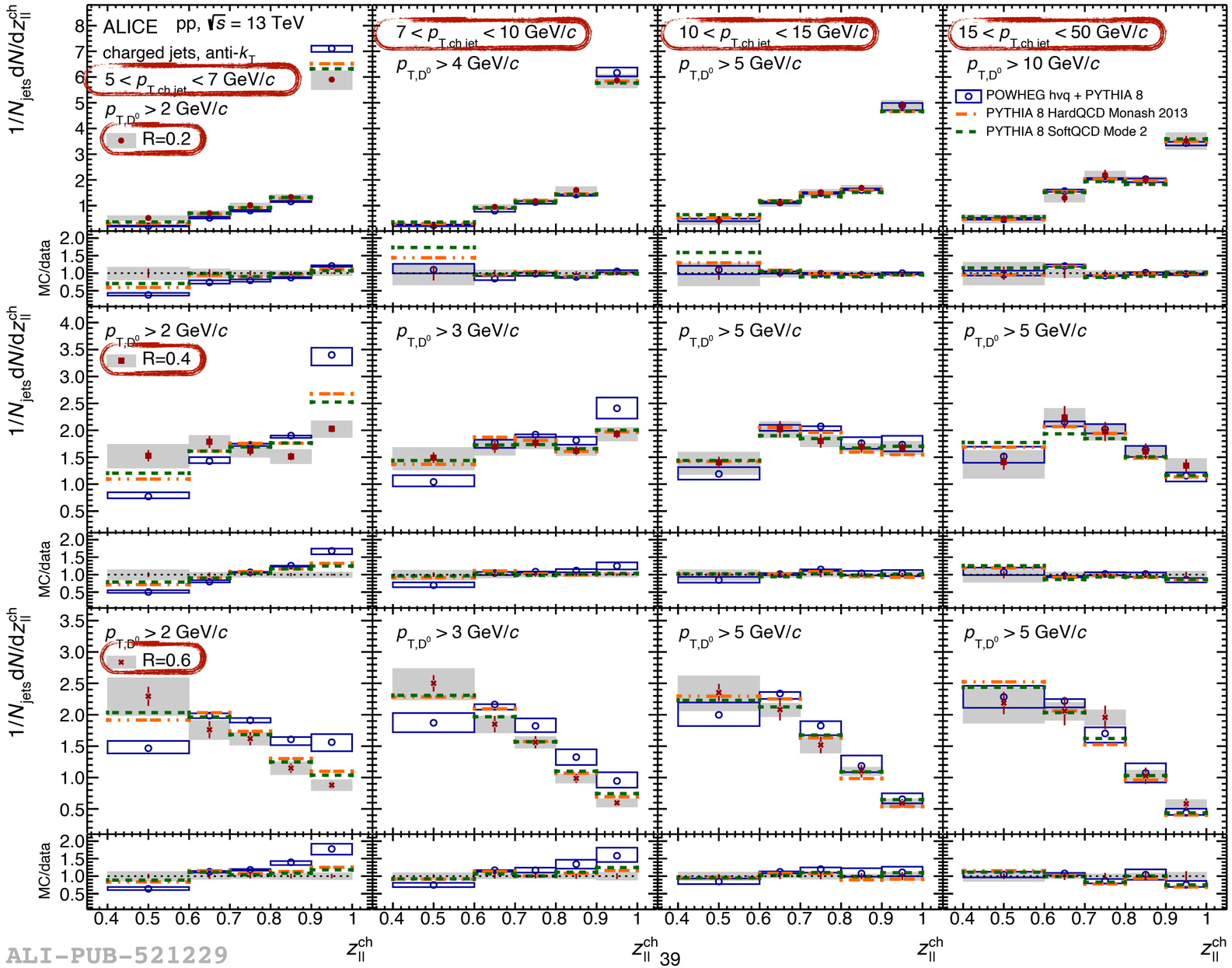
First direct observation of the dead-cone effect



Smaller angles

Increasing energy

Heavy-flavor in-jet fragmentation



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