



# Heavy-flavour jet substructure for probing the flavour dependences of QCD parton showers with ALICE

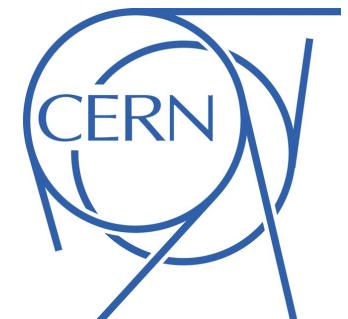


Nima Zardoshti

On behalf of the ALICE collaboration

Quark Matter 2023

06/09/2023

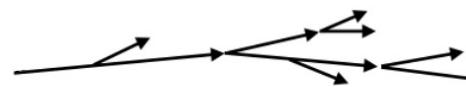


### Casimir colour factors

Different emission properties due to the different amounts of colour charge carried by quarks and gluons

#### Quark-initiated shower

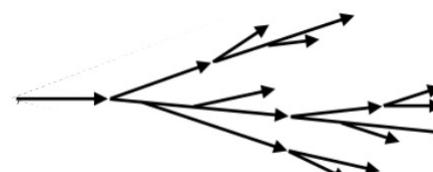
Narrower shower profile



Fewer emissions in the shower

#### Gluon-initiated shower

Broader shower profile



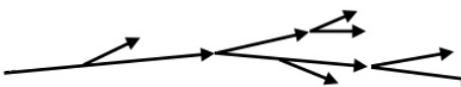
Higher number of emissions

### Casimir colour factors

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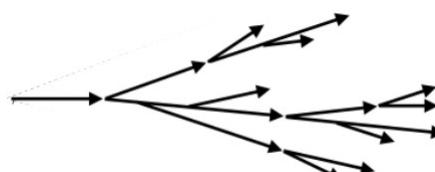
#### Quark-initiated shower

Narrower shower profile  
Fewer emissions in the shower



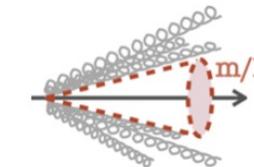
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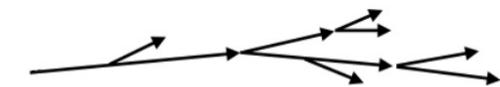
### The dead-cone effect

A suppression of emissions in a cone of size  $m/E$  around the direction of the emitter



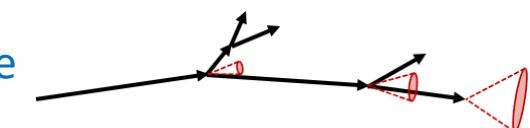
#### Light-quark-initiated shower

Narrower shower profile  
Fewer emissions in the shower



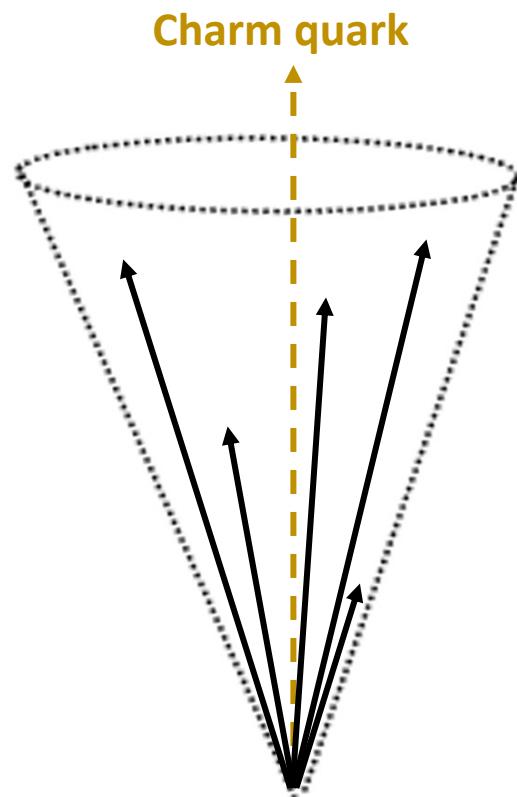
#### Heavy-quark-initiated shower

Suppression of small angle emissions  
Harder fragmentation



## Well controlled probe

Heavy-flavour jet production is perturbatively calculable down to low  $p_T$



## Casimir effects

Heavy-flavour jets allow access to a high purity quark sample for jets and splittings

## Clean connection to the shower

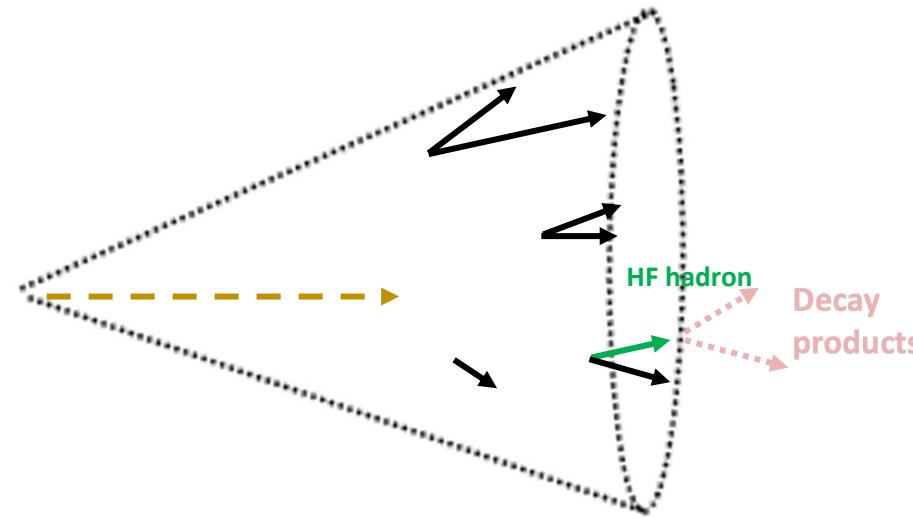
The large mass of the heavy-quark suppresses thermal production and production during the process of hadronisation

## Mass effects

At low energies heavy-quarks provide unique access to mass effects in the shower

# Fully reconstructing the HF hadron

The kinematics of the jet provides access to the kinematics of the initial scattered HF quark

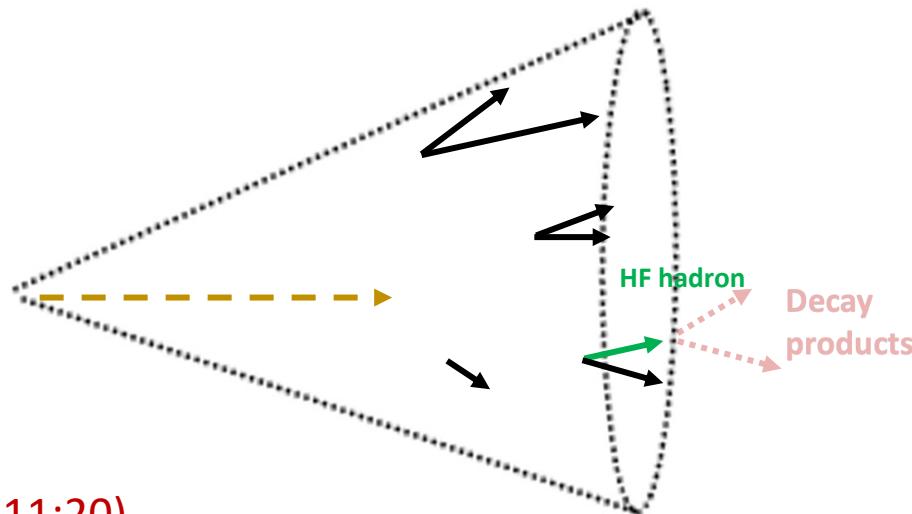


The HF hadron is our best proxy for the final kinematics of the heavy-quark in the shower

# Fully reconstructing the HF hadron

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See Hannah Bossi's talk (Tuesday 11:20)  
for inclusive-jet measurements

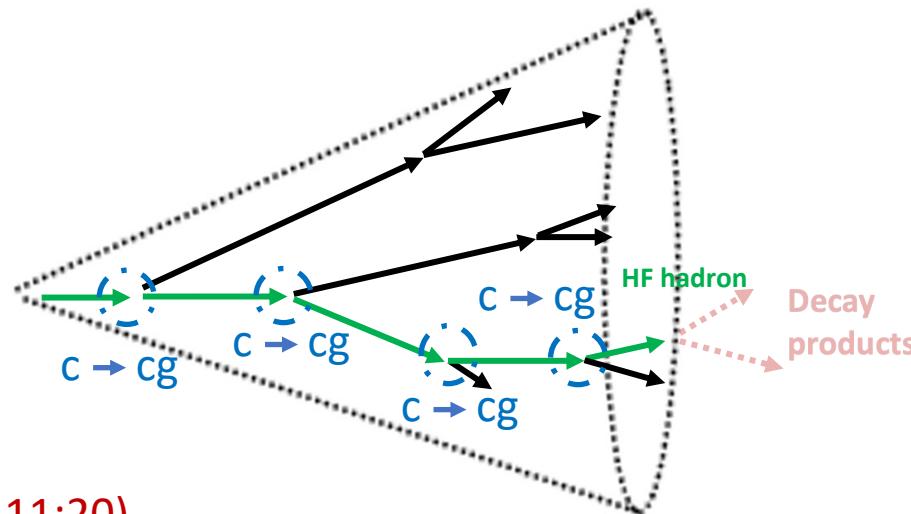
## Substructure observables

Access shower properties by combining the information from the initial and final states of the heavy-flavour shower

Angularities, jet-axis differences, ...

# Fully reconstructing the HF hadron

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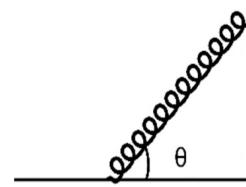
## Reclustering observables

The information can be used to reconstruct and trace the full shower of the HF quark

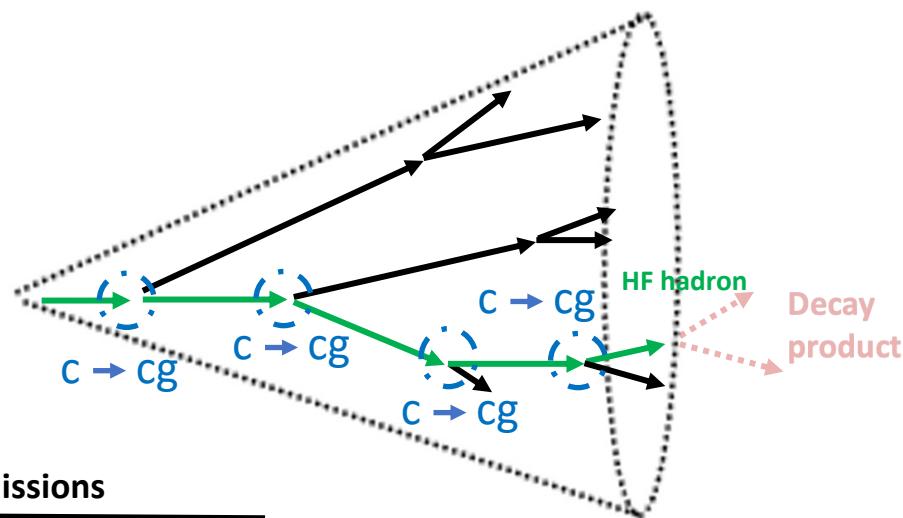
Shared momentum fraction of splittings, opening angle of splittings, number of perturbative emissions, ....

# Fully reconstructing the HF hadron

The kinematics of the jet provides access to the kinematics of the initial scattered HF quark

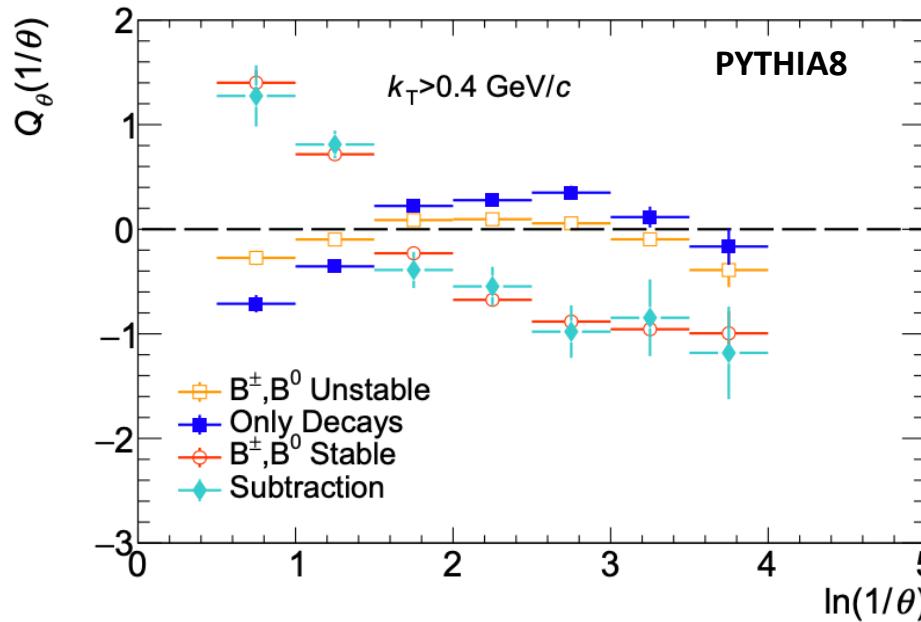


Angular distribution of reconstructed  $b \rightarrow b\gamma$  emissions

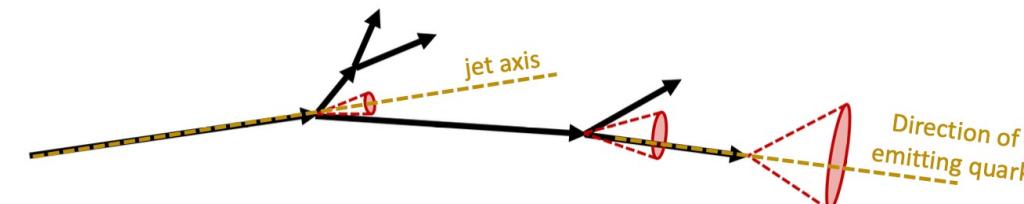


The HF hadron is our best proxy for the final kinematics of the heavy-quark in the shower

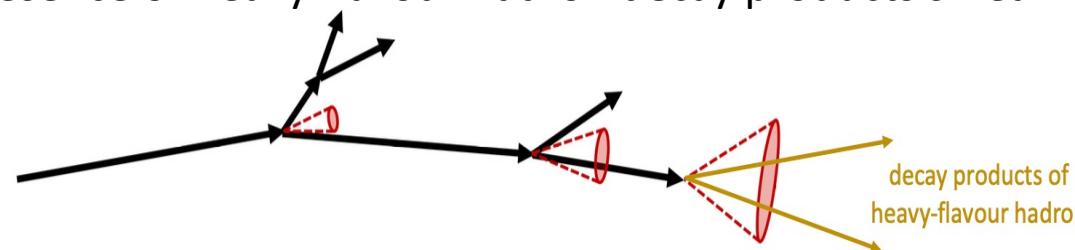
Angular distribution of reconstructed light quark and gluon emissions

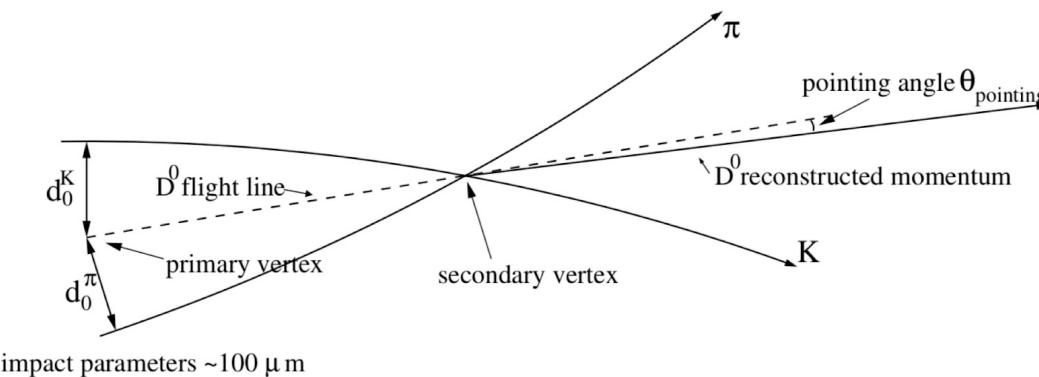


Fully reconstructing the HF hadron is vital for most substructure measurements



Presence of heavy-flavour hadron decay products smear flavour effects





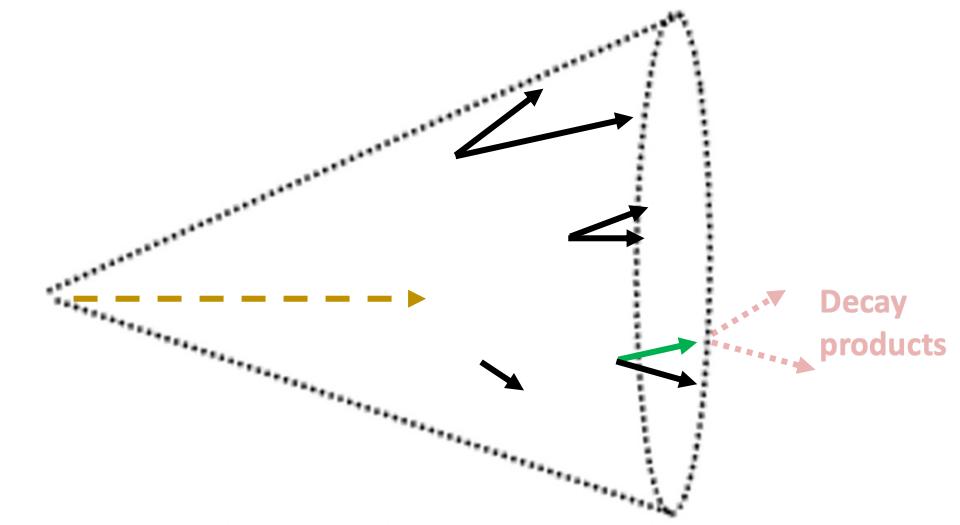
### Charm hadron reconstruction

D<sup>0</sup> hadrons are reconstructed via

$$D^0 \rightarrow K^- \pi^+$$

$$2 \leq p_T^{D^0} < 36 \text{ GeV}/c$$

Topological and kinematic selections on decay products



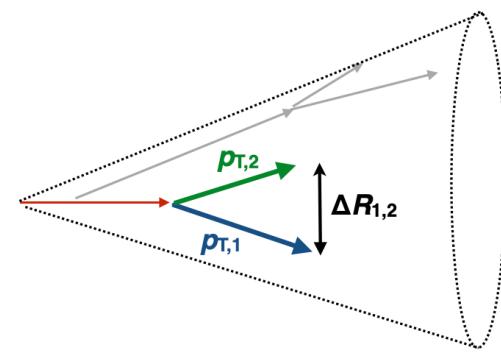
### Jet reconstruction

Jet finding performed after decay daughters are replaced by the HF candidate

Anti- $k_T$  jets with  $R=0.4$

$$5 \leq p_T^{\text{jet}} < 50 \text{ GeV}/c$$

# Accessing the c->cg splitting function



## Soft Drop grooming

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

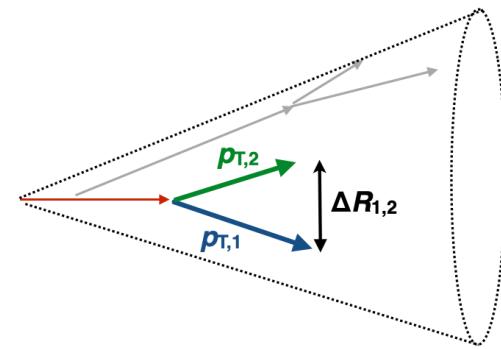
$$z_{\text{cut}} = 0.1, \beta = 0$$

A. J. Larkoski et al. , JHEP 1405 (2014) 146

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

**QCD 1->2 splitting function fundamental  
building block of parton showers**

# Accessing the c->cg splitting function



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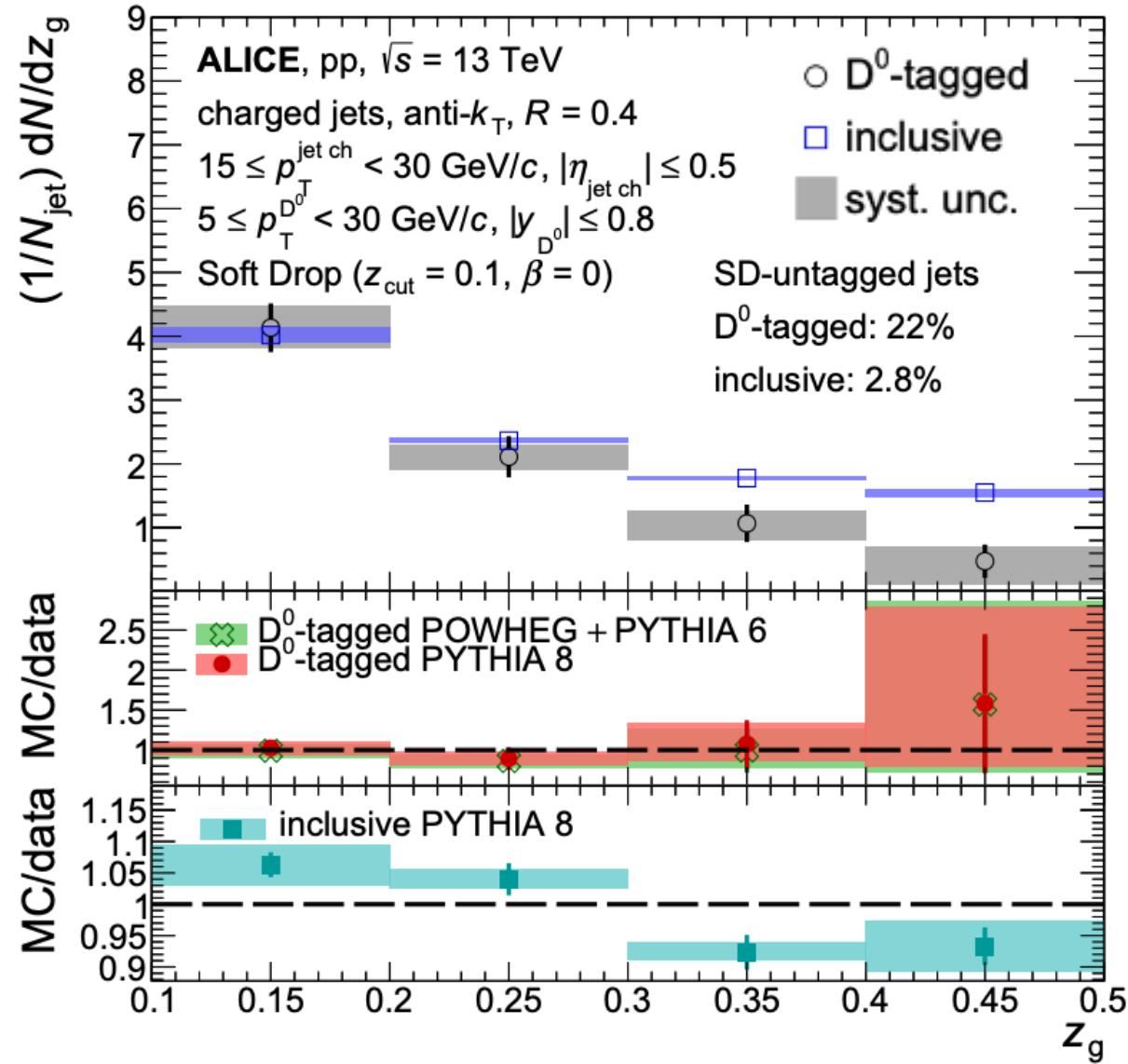
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**QCD 1->2 splitting function fundamental building block of parton showers**

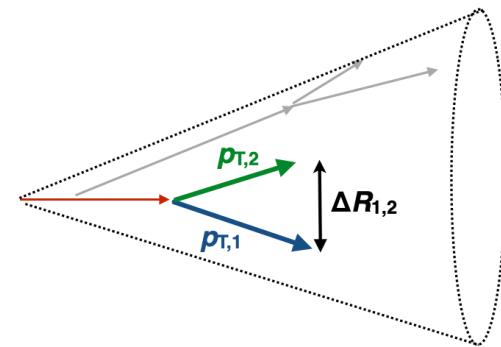
c->cg splittings have fewer symmetric splittings compared to splittings of light quarks and gluons

Expected due to the large dead cone of the charm quark

arXiv:2208.04857



# Accessing the c->cg splitting function



## Soft Drop grooming

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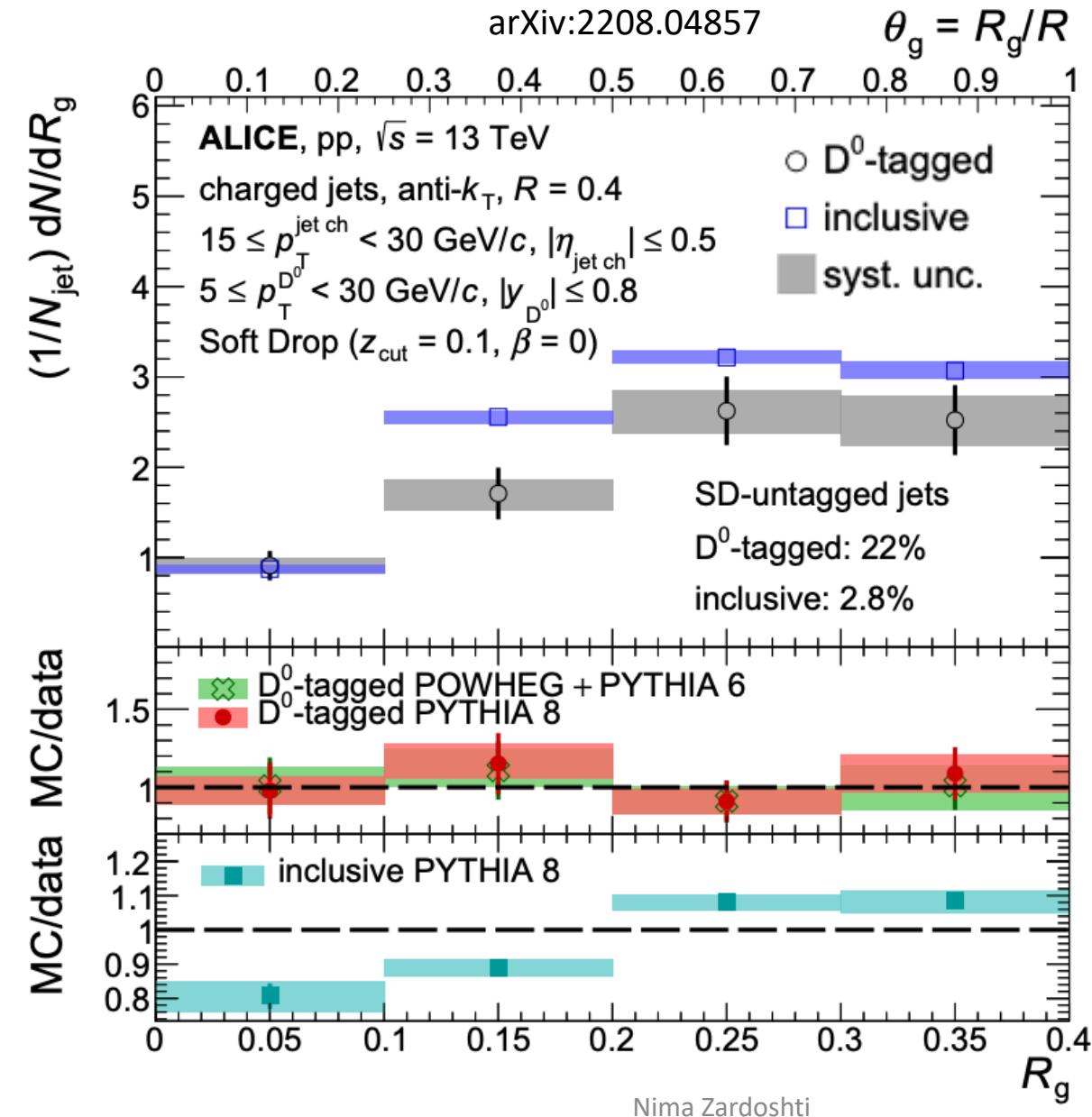
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$$dP_{i \rightarrow jk} = \frac{d\theta}{\theta} dz P_{i \rightarrow jk}(z)$$

**QCD 1->2 splitting function fundamental building block of parton showers**

c->cg splittings are narrower than splittings of the light quarks and gluons sample: due to the larger colour charge of gluons

Competing effect at small angles between narrower quark emissions and large dead-cone angle



# Accessing the c->cg splitting function

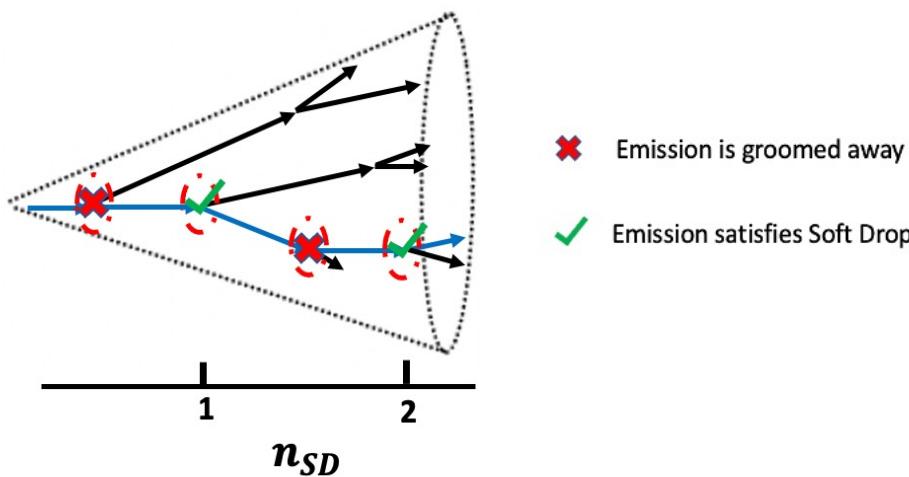
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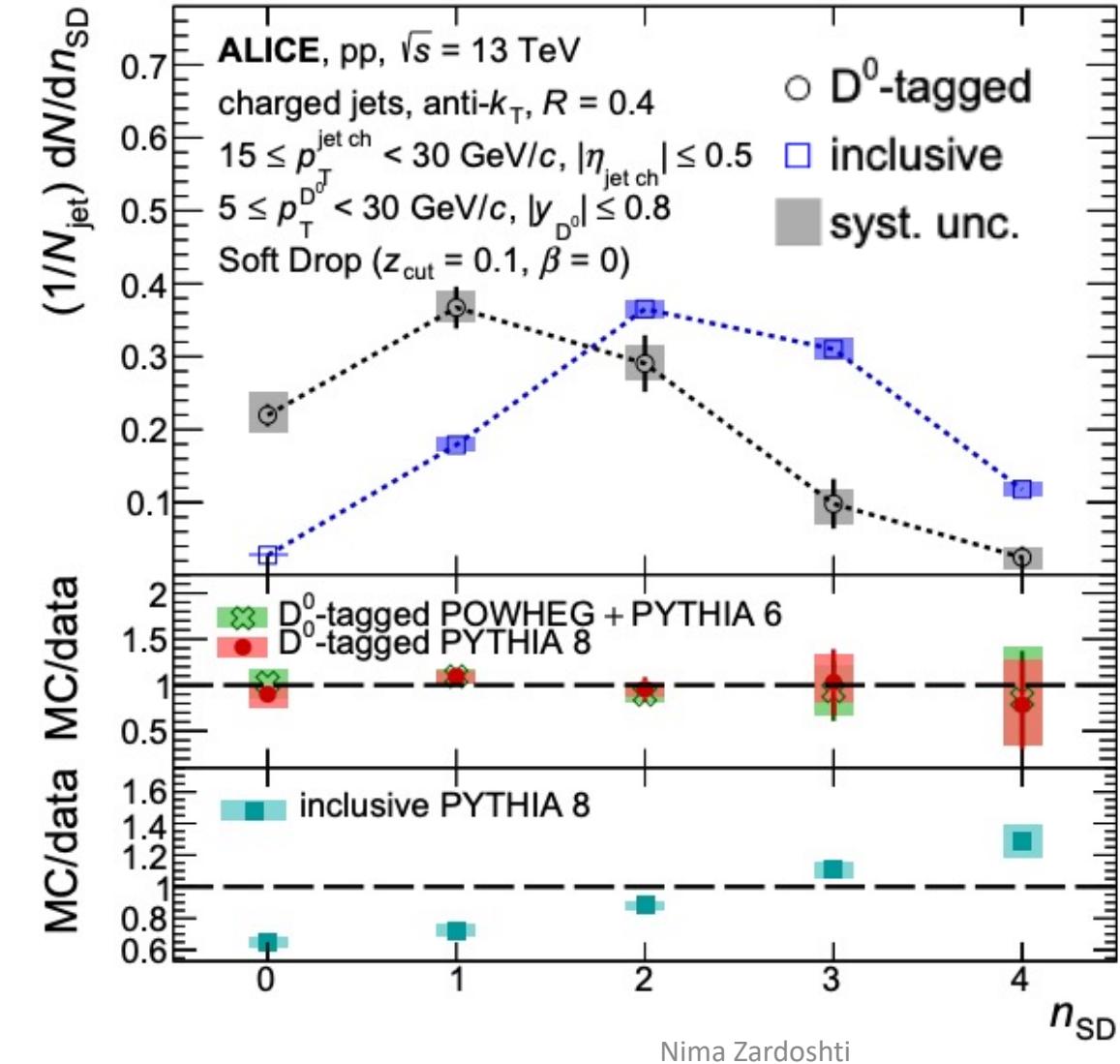
$$z_{\text{cut}} = 0.1, \beta = 0$$

A. J. Larkoski et al., JHEP 1405 (2014) 146



Charm quarks have fewer perturbative emissions compared to light quarks and gluons

Sensitive to the perturbative component of fragmentation functions



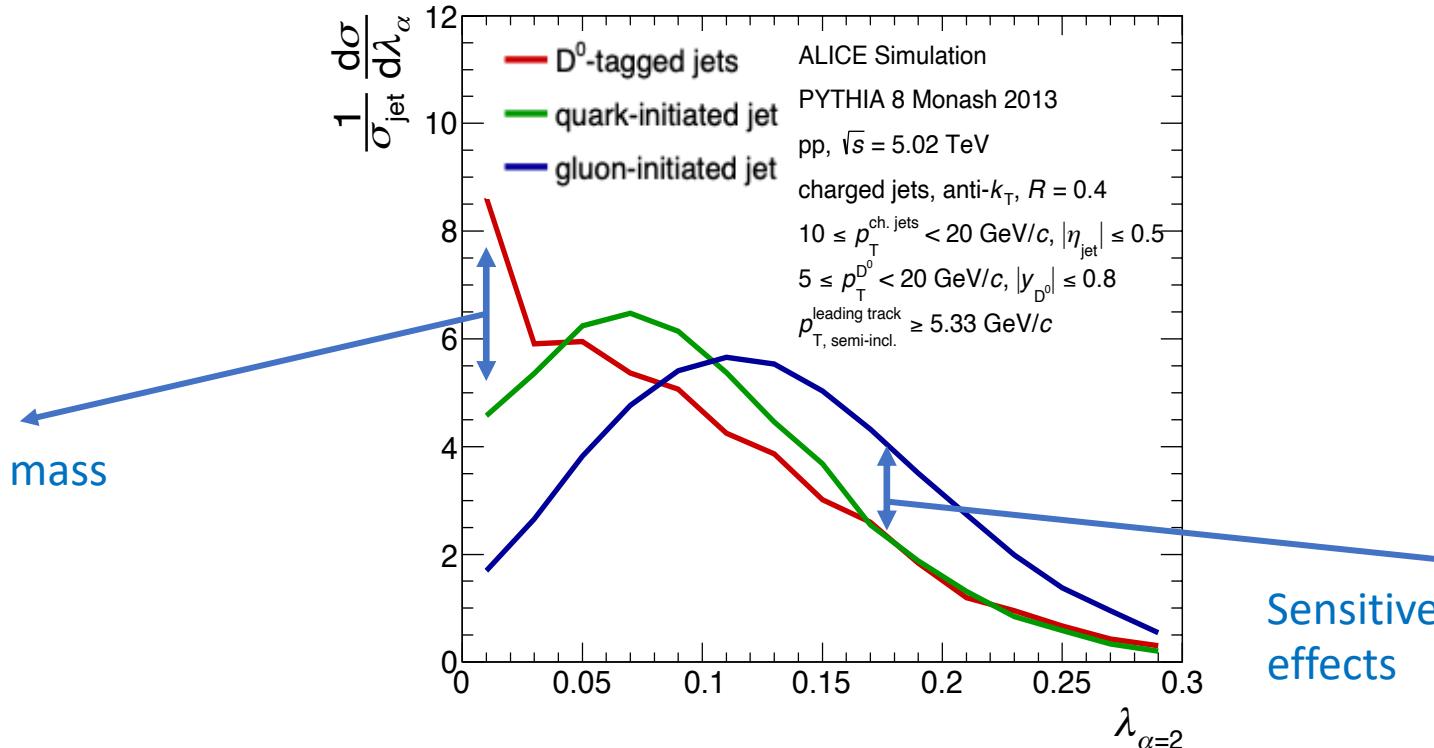
# Generalised angularities

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

Class of IRC safe (for  $\kappa=1$  and  $\alpha > 0$ ) observables characterising the radiation pattern within jets

Sensitive to mass effects

Sensitive to Casimir colour effects

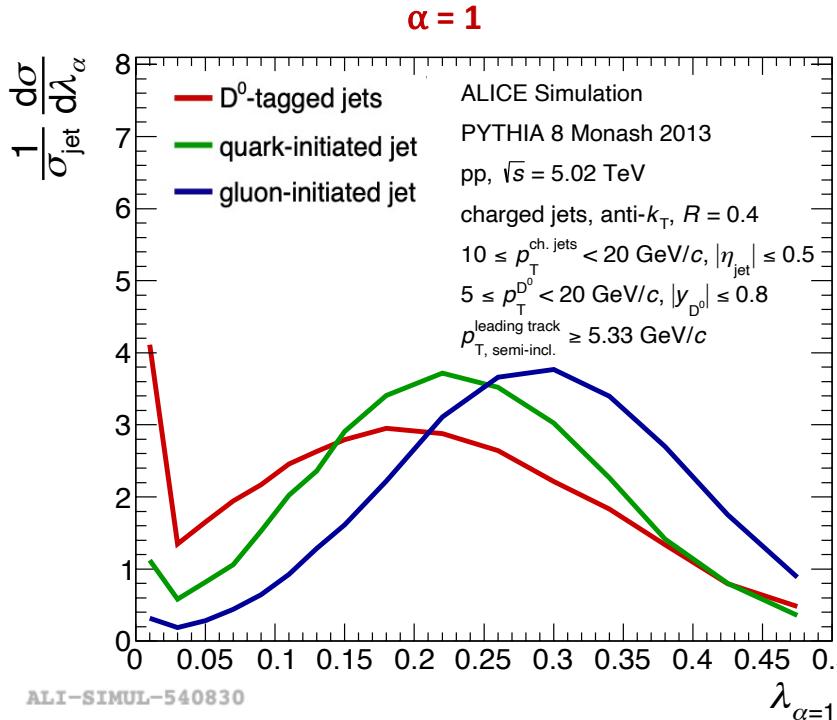


# Generalised angularities

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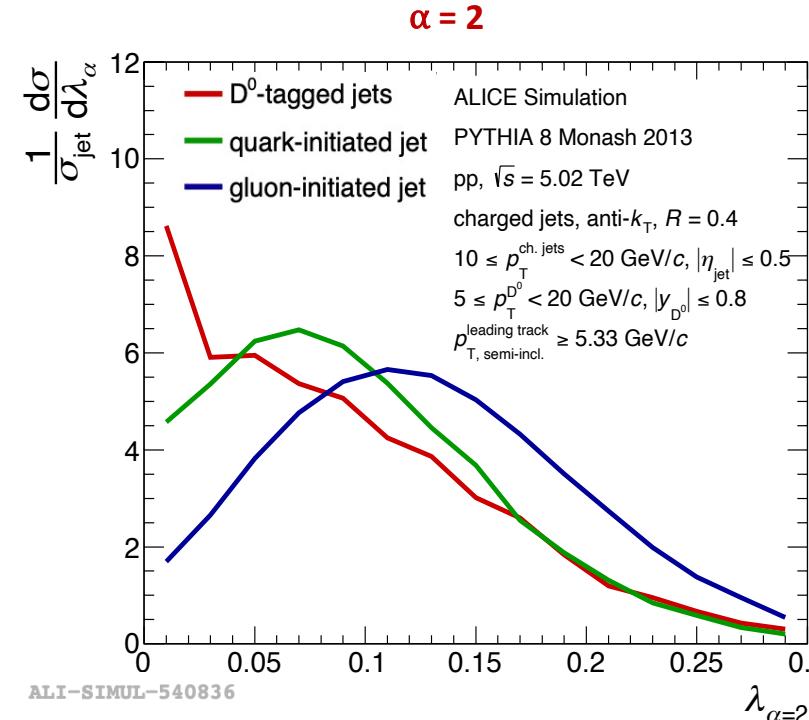
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Increased weight for radiation in the core



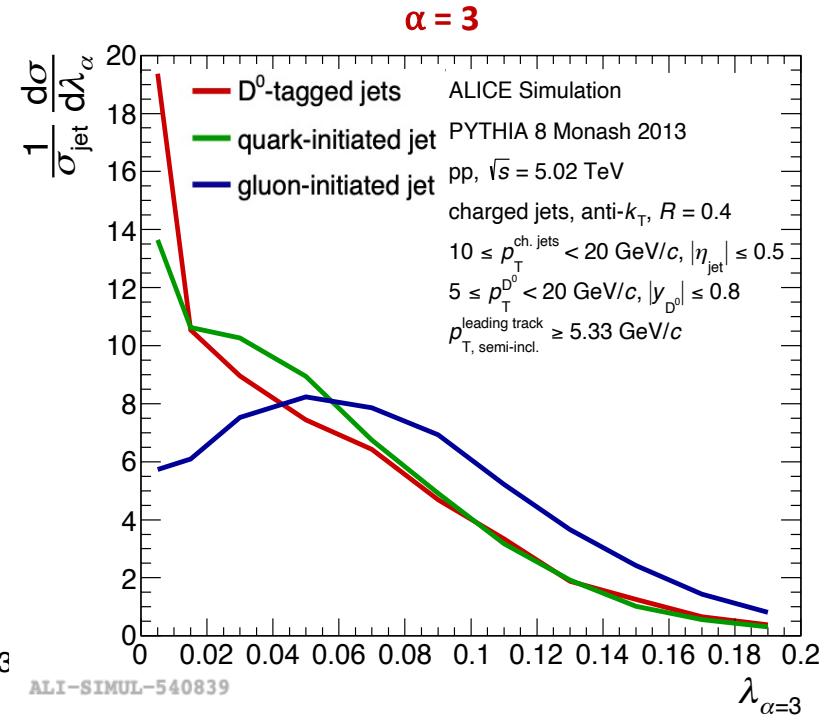
$\alpha$

Increased weight for large angle radiation



$\alpha$

Enhanced sensitivity to mass effects



$\alpha$

Enhanced sensitivity to Casimir colour effects

# Generalised angularities

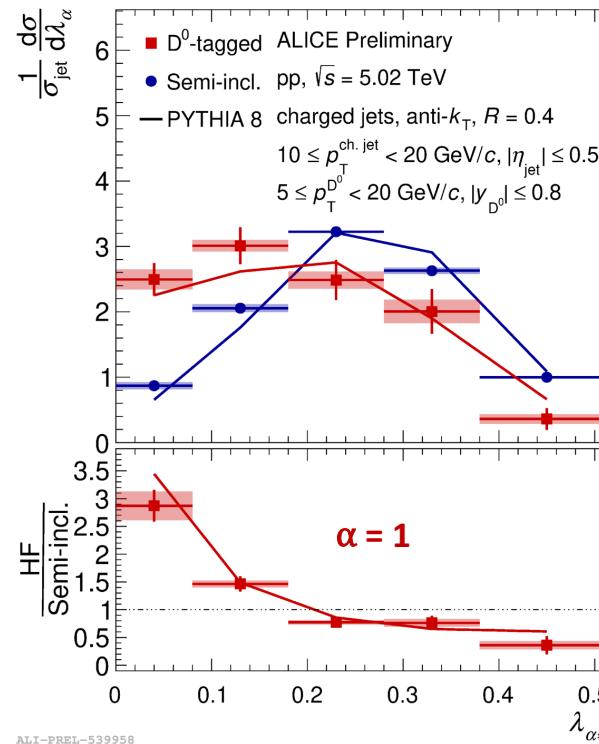
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inclusive : JHEP 05 (2022) 061

NEW

Increased weight for radiation in the core

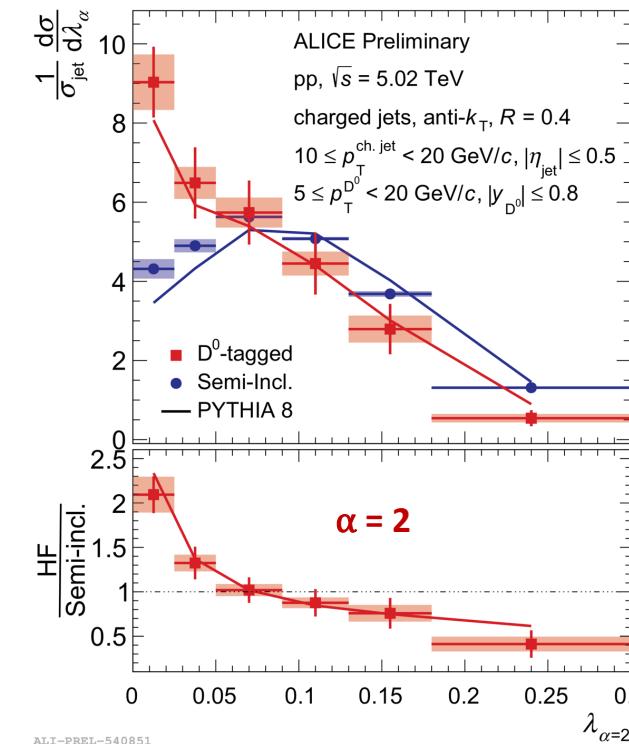


D<sup>0</sup>-tagged and inclusive jets most different in their cores

Differences in the core driven by mass effects

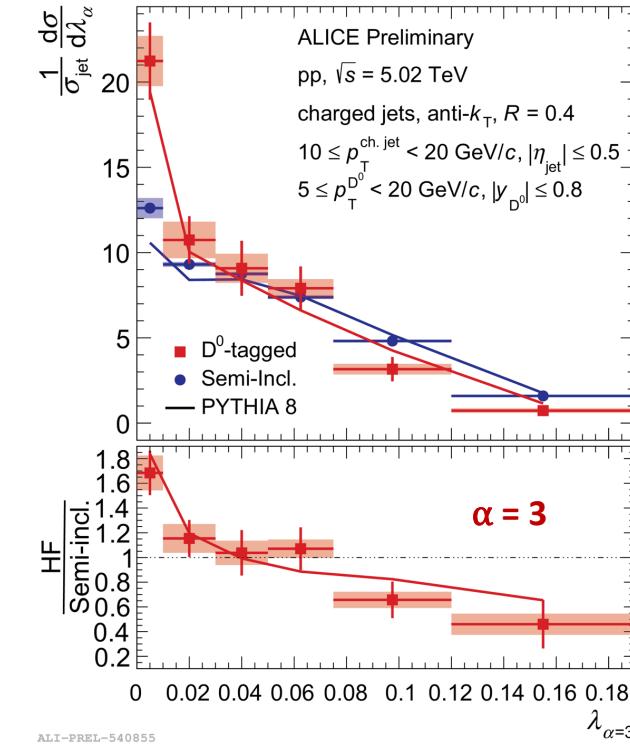
$\alpha$

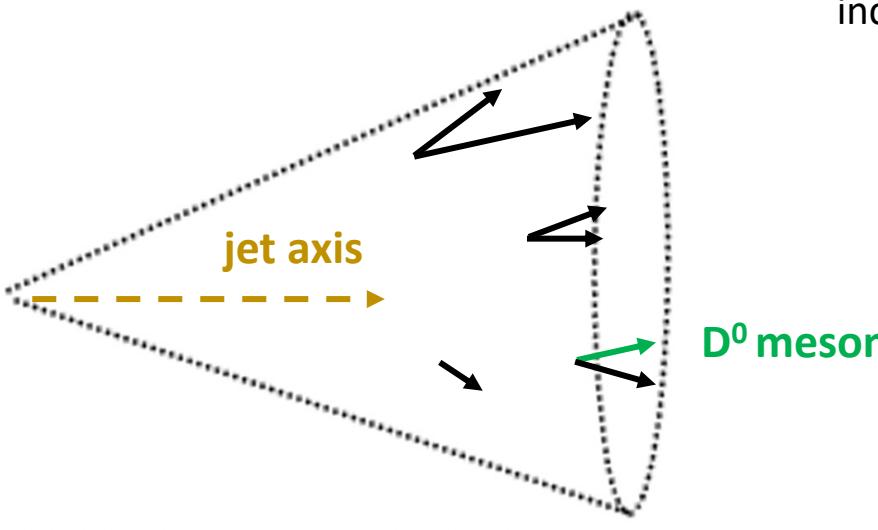
Increased weight for large angle radiation



$\alpha$

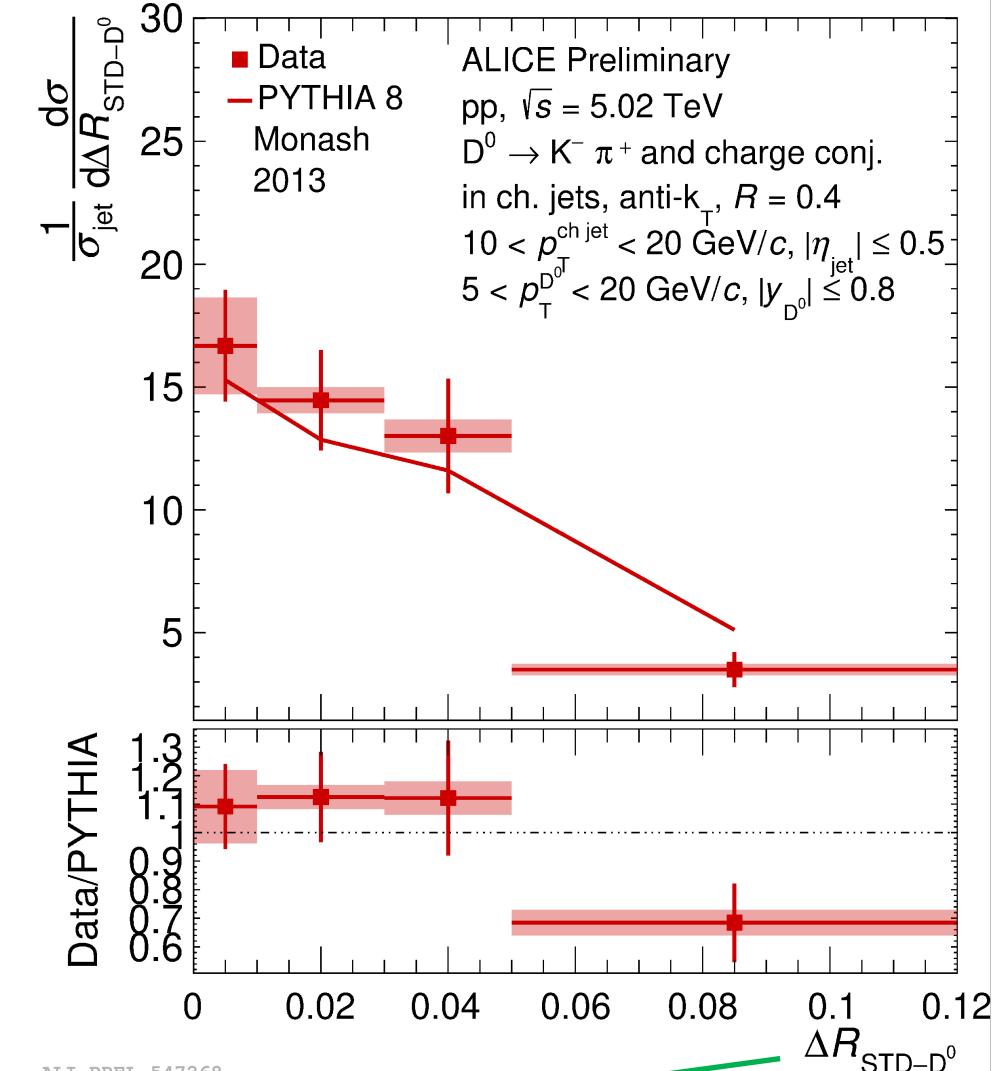
D<sup>0</sup>-tagged and inclusive distributions become more similar





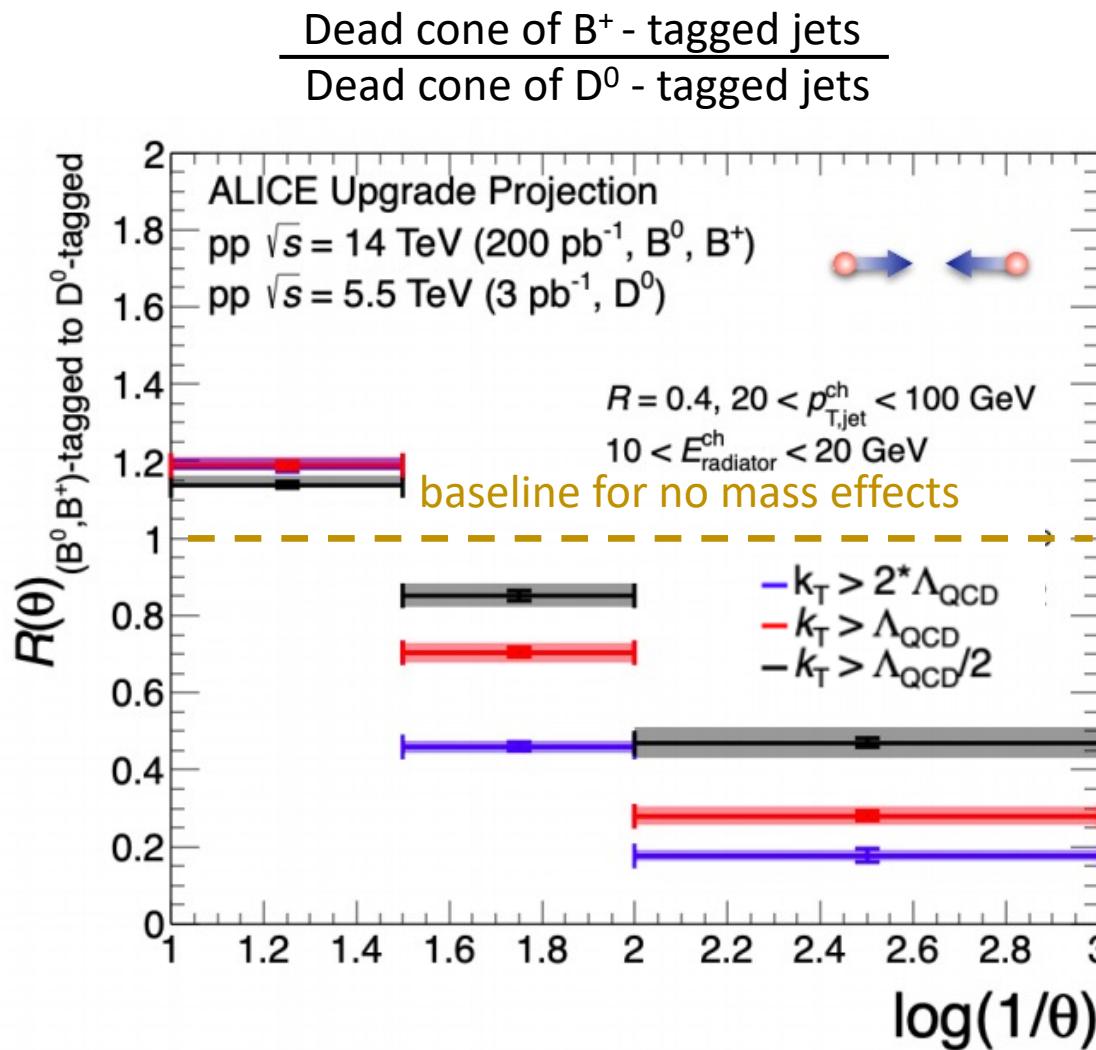
inclusive : JHEP 07 (2023) 201

NEW



Differences between different axis definitions  
inside jets are IRC safe and calculable observables

Addition of more axis definitions will allow us to  
differentially probe different heavy-flavour shower  
properties



Run 3 projection from ALICE

### Accessing Mass Effects

Jets tagged with a charm or beauty hadron represent an enhanced sample of quark jets

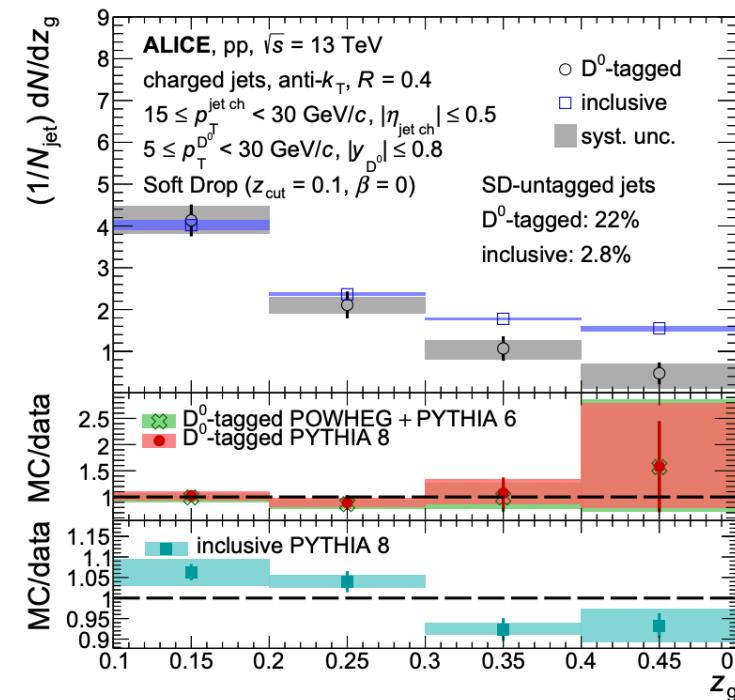
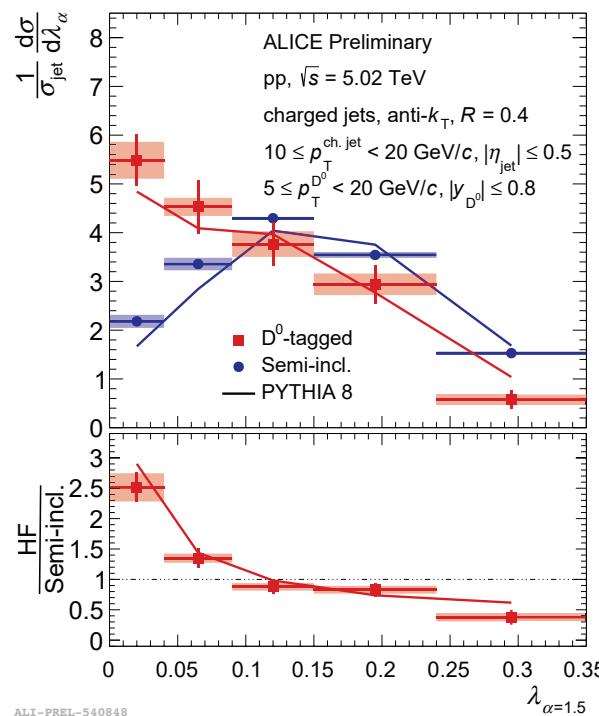
Comparison of  $b \rightarrow bg$  and  $c \rightarrow cg$  emissions is only sensitive to mass effects

### Accessing Casimir Effects

At high energies mass effects reduce

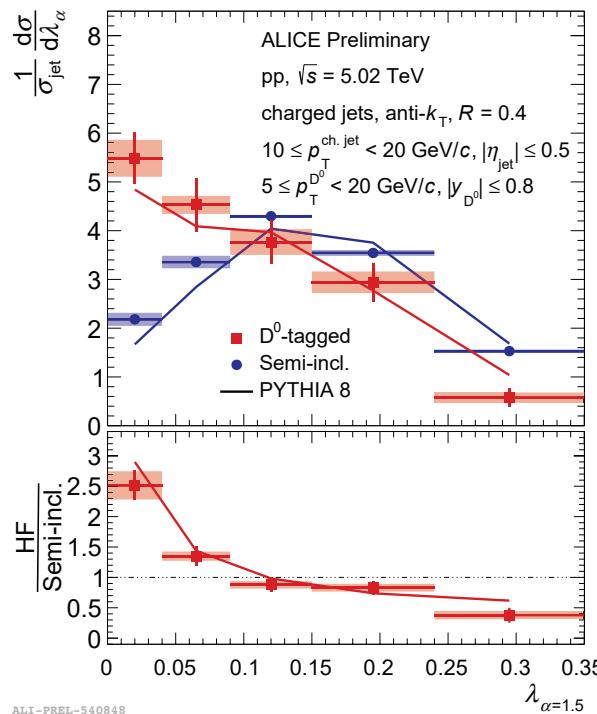
Comparison of  $Q \rightarrow Qg$  and inclusive emissions are only sensitive to Casimir colour effects at high  $p_T$

ALICE is undertaking a systematic program to constrain the flavour dependences of QCD showers using heavy-flavour jets

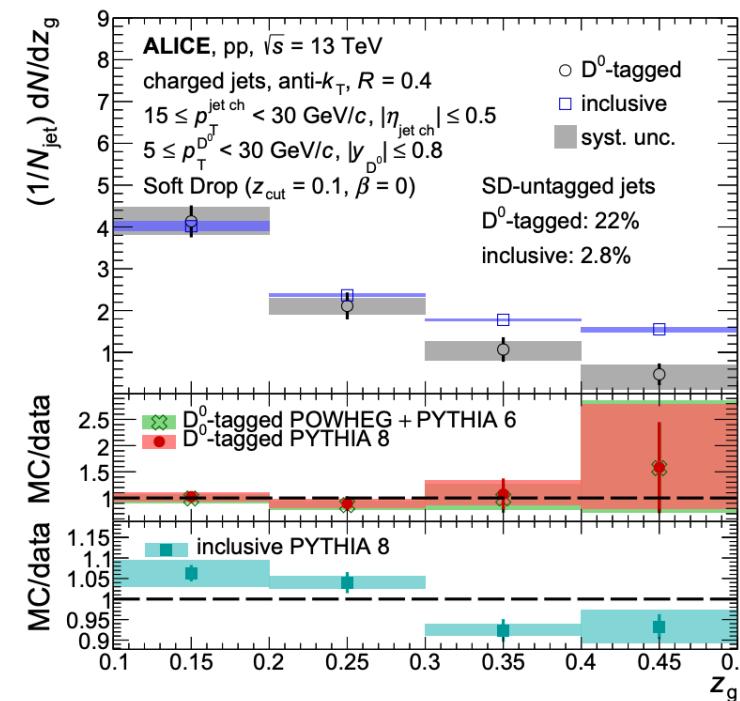


Comparisons of heavy-flavour and inclusive jet measurements at low  $p_T$  are sensitive to Casimir colour and mass effects

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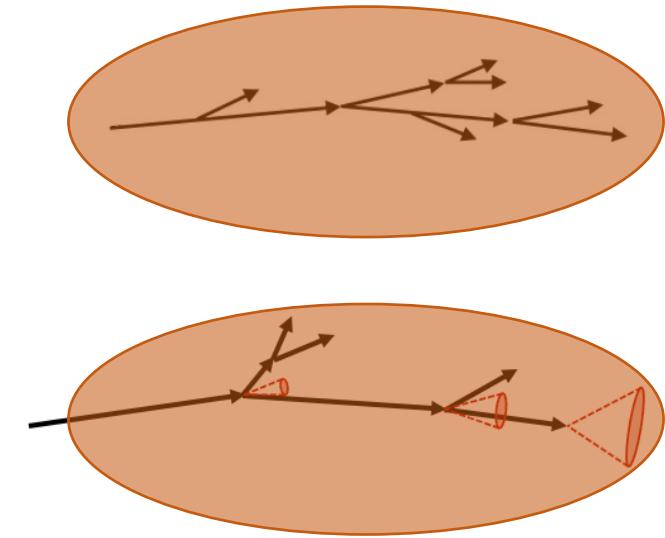
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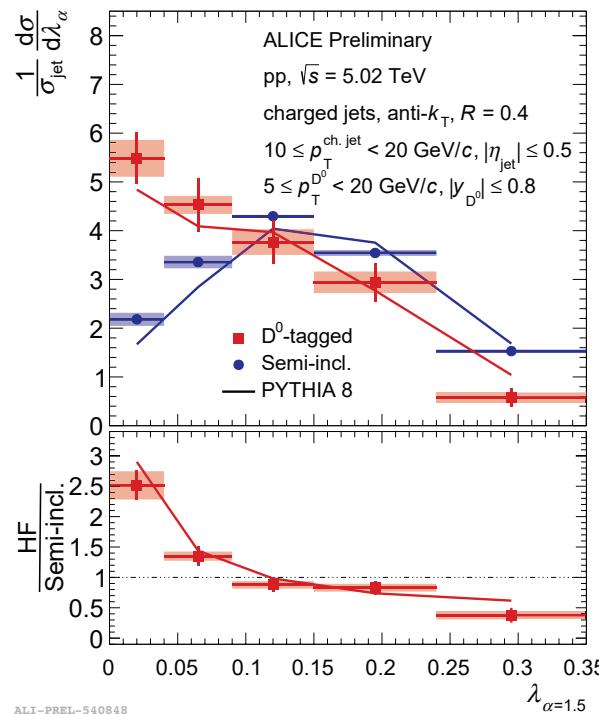
### Run 3

Access to beauty showers and high  $p_T$  jets

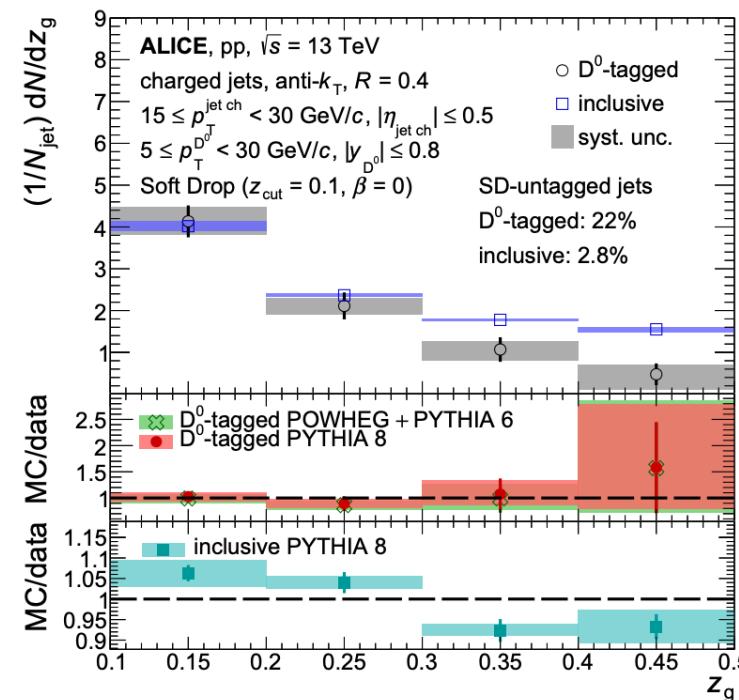
Extension of program to heavy-ion collisions to constrain the flavour dependences of medium interactions



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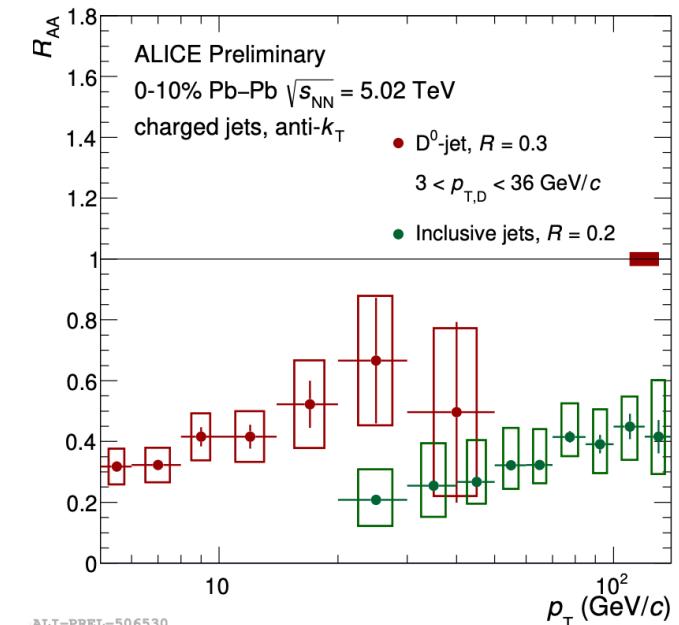
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### Run 3

Access to beauty showers and high  $p_T$  jets

Extension of program to heavy-ion collisions to constrain the flavour dependences of medium interactions



# List of related ALICE contributions

## Tuesday 11:20 Hannah Bossi

Exploring medium properties and evolution with ALICE using correlated, groomed, and reclustered jet substructure

## Wednesday 8:50 Wenqing Fan

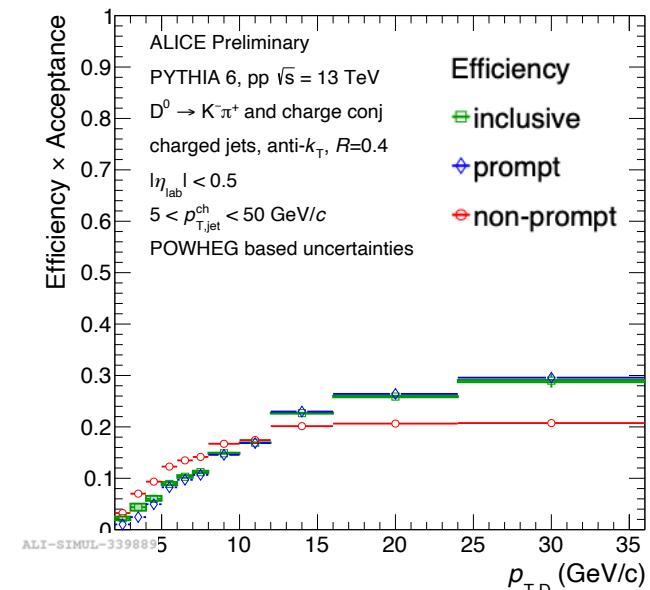
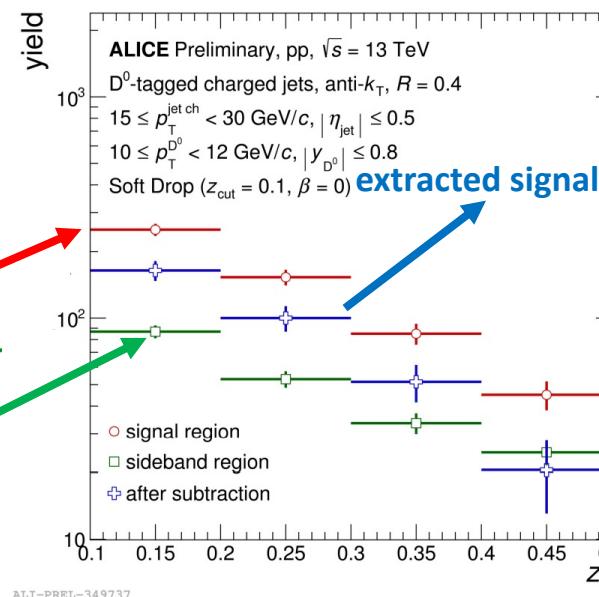
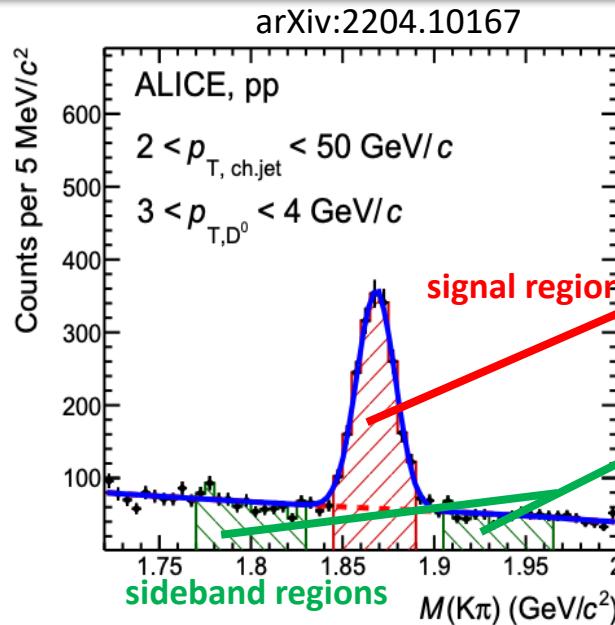
First energy-energy correlators measurements for inclusive and heavy-flavour tagged jets with ALICE

## Poster Emma Yeats

D0-tagged jet axes difference measurement in pp collisions at  $\sqrt{s} = 5.02$  TeV with ALICE

# Backup

23



### Sideband subtraction

Signal extracted in intervals of  $p_T^{D^0}$

Invariant mass distribution fit with Gaussian + exp

Background distribution estimated from sideband region

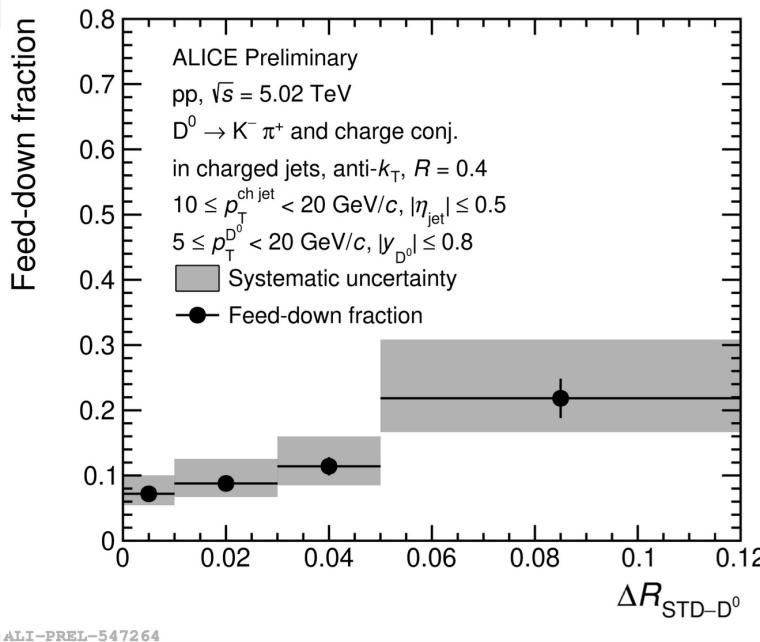
Signal extracted by removing scaled background

### Reconstruction efficiency

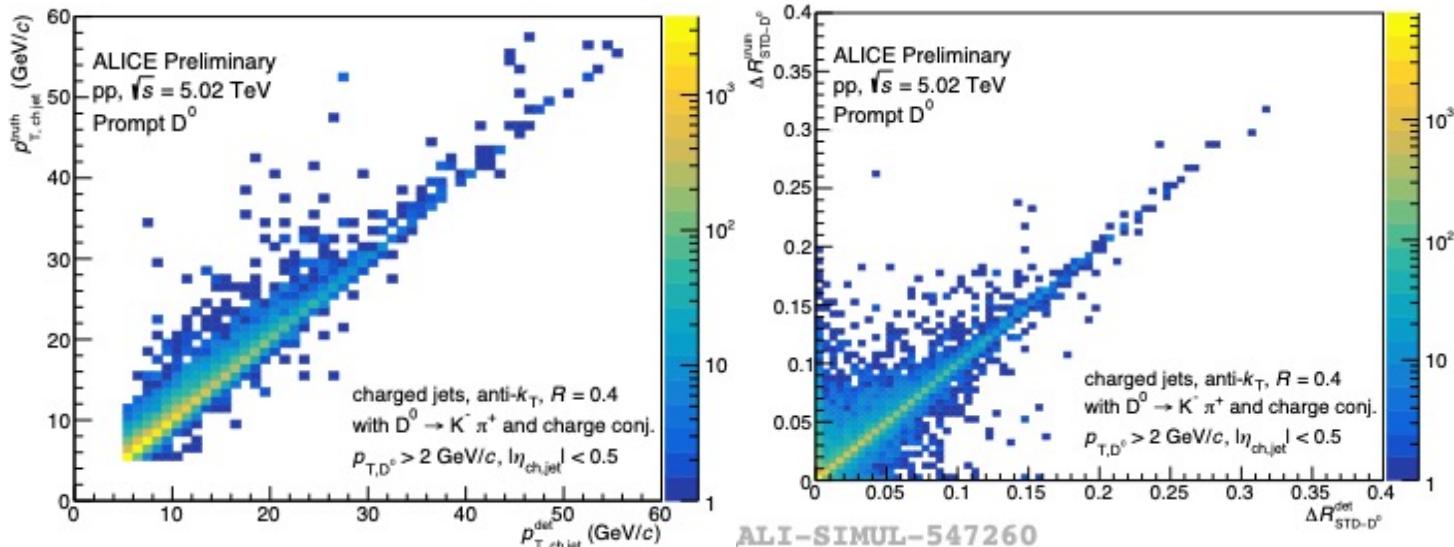
Strongly dependent on  $p_T^{D^0}$

Sideband subtracted distributions scaled by prompt reconstruction efficiency in intervals of  $p_T^{D^0}$

Scaled distributions combined over full  $p_T^{D^0}$  range



ALI-PREL-547264



### Feed-down correction

To isolate properties of the charm-quark shower we remove the contribution of  $D^0$  mesons originating from the decay of beauty hadrons

The non-prompt contribution is estimated through POWHEG + PYTHIA8 simulations

### Unfolding

A full correction of distributions to truth level is performed via a 2D iterative Bayesian unfolding

4D response matrices obtained using PYTHIA8