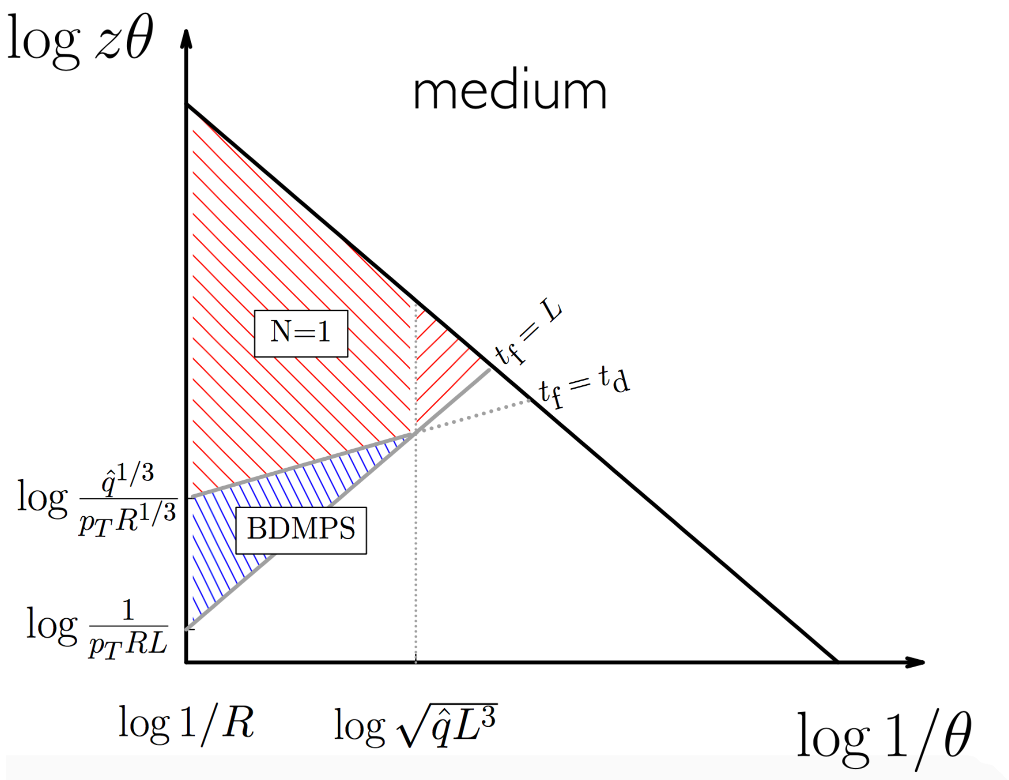
Exploring Phase Space of Jet Splittings at ALICE using Grooming and Recursive Techniques

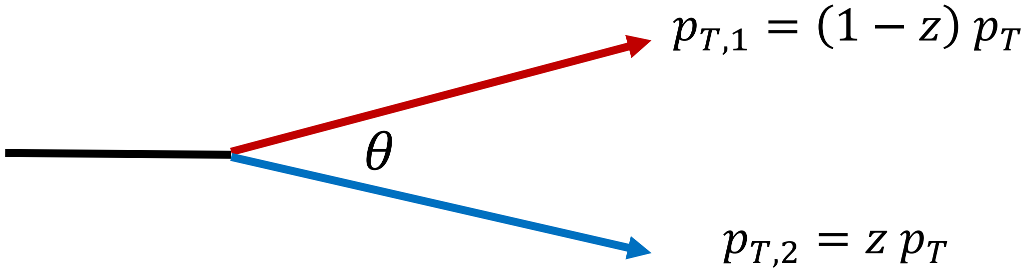
Harry Andrews (University of Birmingham)
on behalf of the ALICE Collaboration

Venezia
2018 Quark Matter

Map of Splittings in Medium

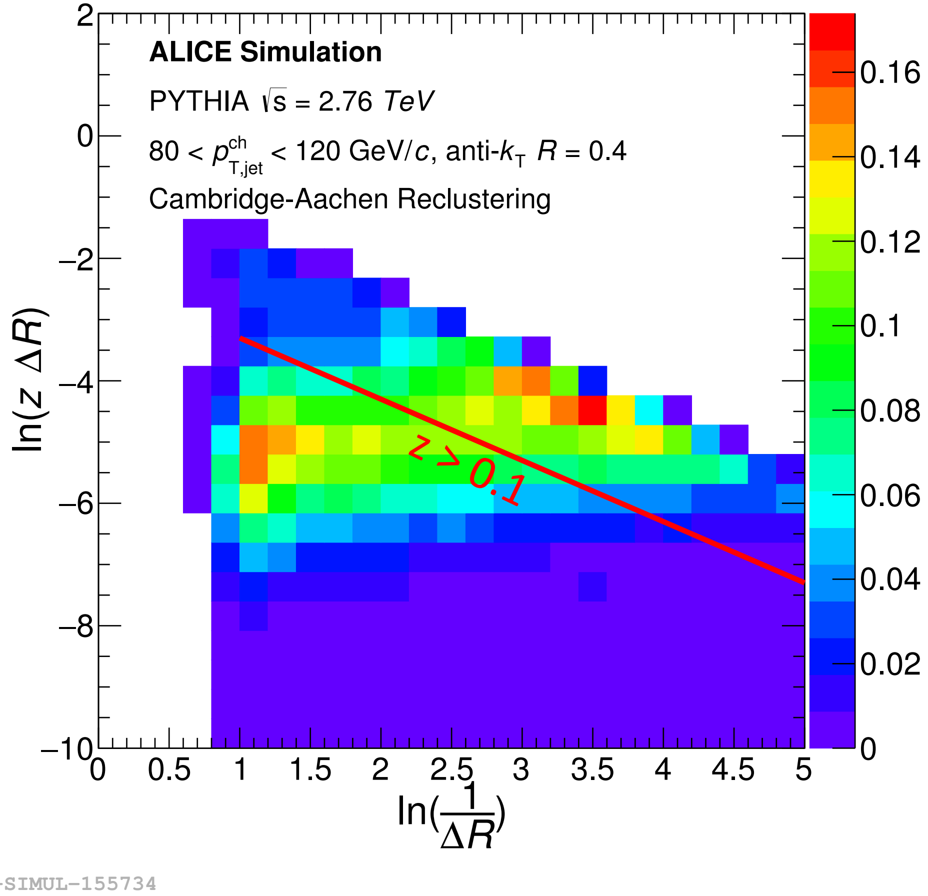


Tywoniuk et al. 5th Heavy Ion Jet Workshop/CERN TH institute



- ❖ Lund diagrams represent phase space of splittings using momentum fraction and opening angle
- ❖ Allow to differentiate regions where different medium induced signal can dominate
- ❖ Relevant medium scales shown on axes

Iterative Declustering



❖ Iterative declustering unwinds jet clustering and stores splitting information

❖ In vacuum Cambridge-Aachen declustering populates Lund diagram with a density proportional to α_s [1]

❖ Imposing different grooming conditions can isolate regions of phase space where medium-induced signal is expected

$$z > z_{cut}\theta^{\beta}$$

Soft Drop[2] /mMDT Grooming[3]

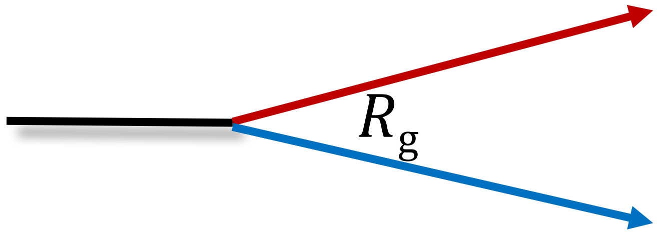
[1] G. Salam gitlab.cern.ch/gsalam/2017-lund-from-MC
[2] M. Dasgupta et al. JHEP 1309 (2013) 029
[3] A. Larkoski et al. JHEP 1405 (2014) 146

Variable Definitions

- This talk will discuss the analysis of jet grooming using Soft Drop

- The algorithm is used to identify hard splittings in jet evolution and parametrise them using 3 observables, the symmetry parameter (z_g), angular separation (R_g) and multiplicity (n_{SD})

- Note: z_g and R_g both measure the first splitting identified by grooming while n_{SD} counts the number of splittings that pass grooming conditions in jet by declustering iteratively



$$p_{T,1} = (1 - z_g)\, p_T$$
$$m_1$$
$$\eta_1$$
$$\varphi_1$$

$$p_{T,2} = z_g\, p_T$$
$$m_2$$
$$\eta_2$$
$$\varphi_2$$

Analysis Details

Common Analysis Details

- **Charged jets** (TPC+ITS tracks) $p_{T,cutoff}^{const}$ = 0.15 GeV/c
- Anti-k_T clustered jets, ***R* = 0.4**, *E*-scheme recombination

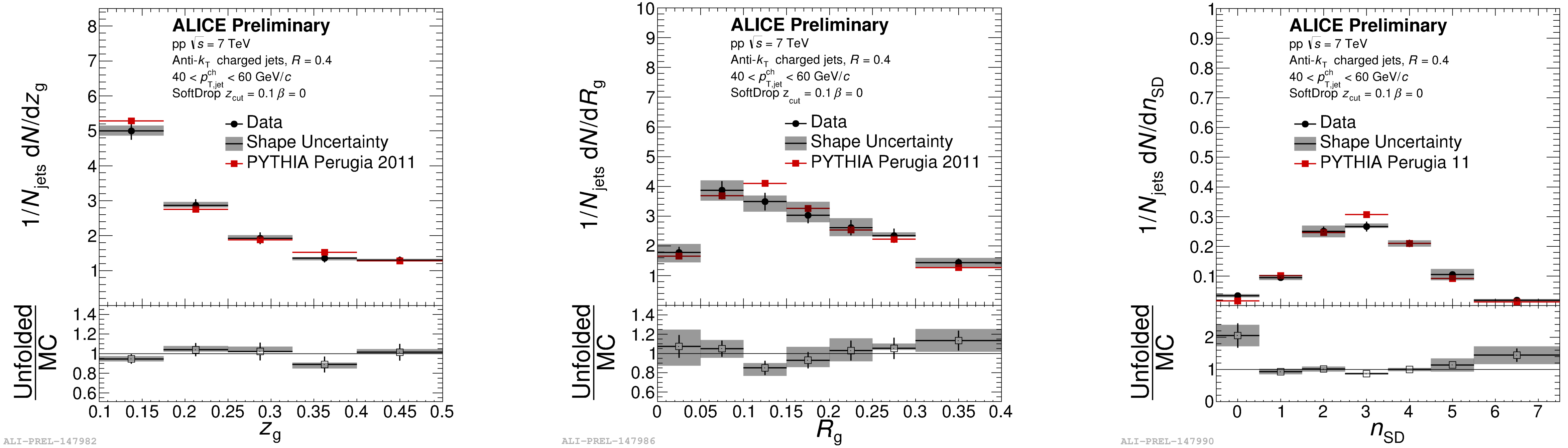
pp Analysis

- MB collisions at $\sqrt{s} = 7$ TeV
- No subtraction
- Particle level corrected measurement p_T range 40-60 GeV/c

Pb-Pb Analysis

- Central collisions at $\sqrt{s_{NN}} = 2.76$ TeV
- Constituent subtraction
- Detector level measurement p_T range 80-120 GeV/c
- Compared to smeared reference

pp Substructure Results



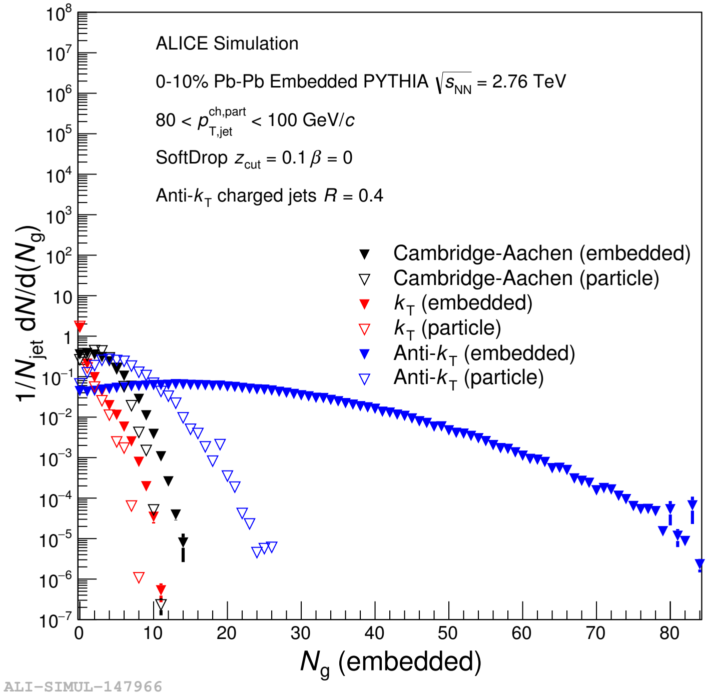
❖Jets satisfying $z > z_{cut} = 0.1$:

1. **Data 97.3(0.5)%**
2. **PYTHIA 98.9(0.1)%**

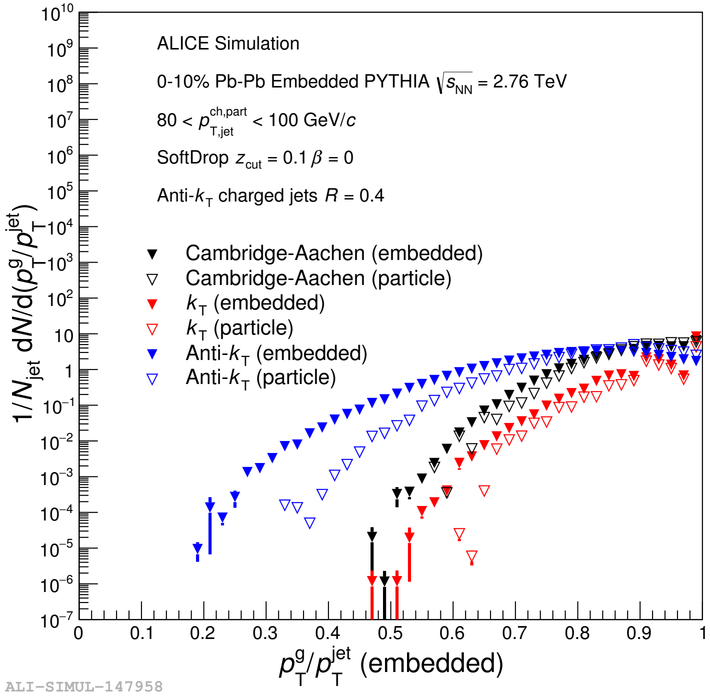
❖Good agreement observed between data and PYTHIA Perugia 2011

Grooming in Heavy Ion Collisions

Groomed Branches



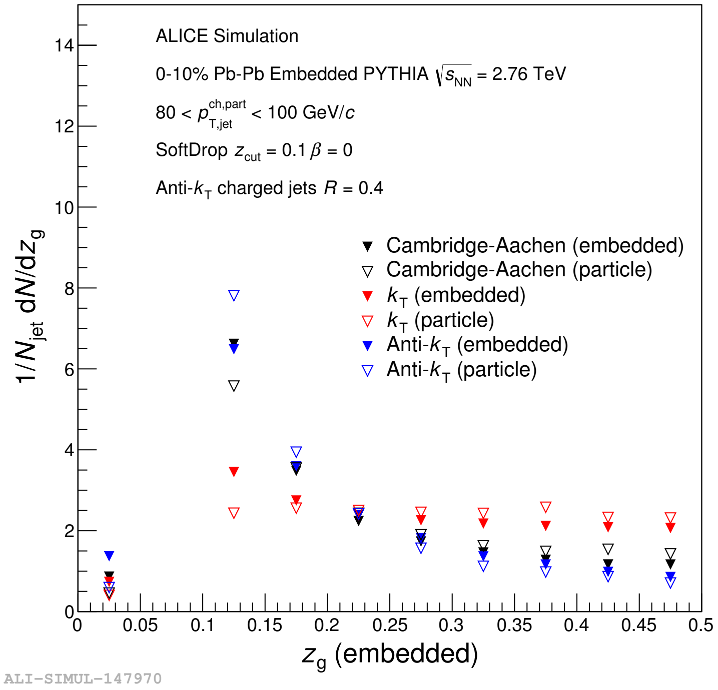
Groomed Momentum Fraction



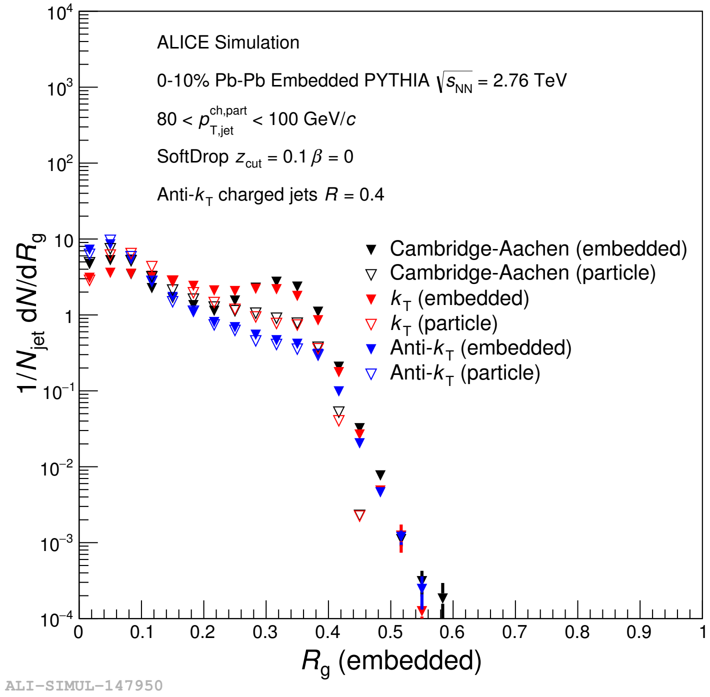
- Grooming behaves differently in the presence of underlying event compared to vacuum
- Algorithm used for declustering reflects the ordering of the clustering strategy
- Can be changed to increase sensitivity to a given process
- For example k_T may be optimal for searching for an induced semi-hard splittings

Grooming in Heavy Ion Collisions

Symmetry Parameter



Groomed Radius



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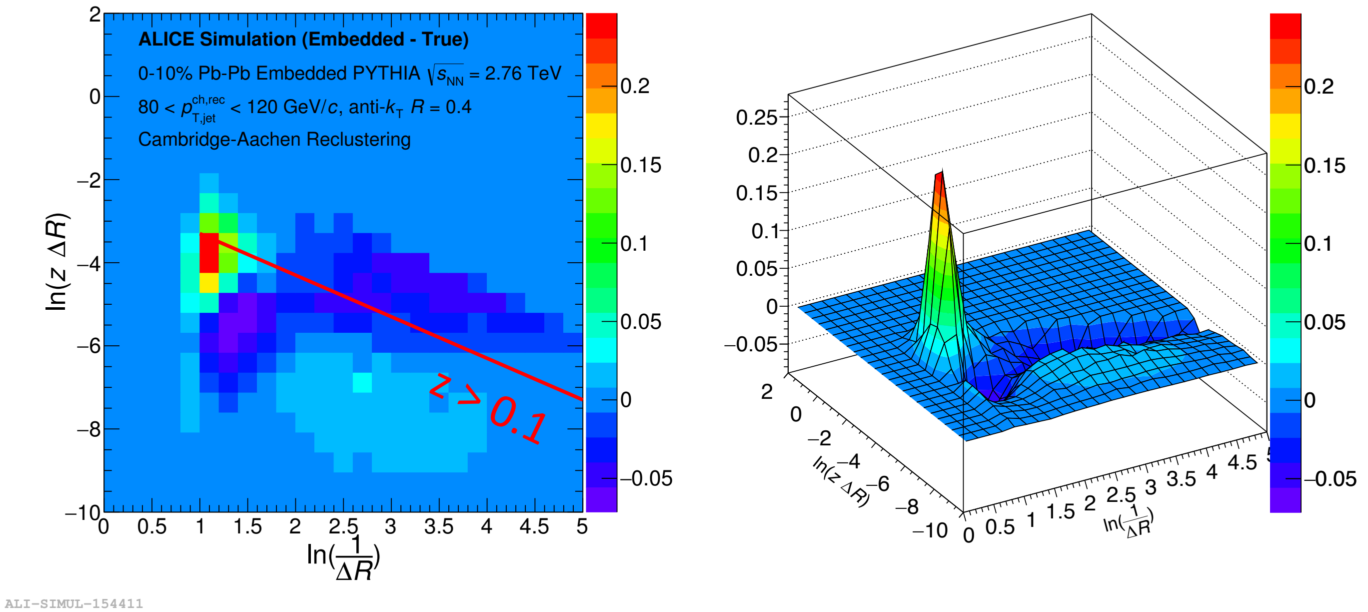
Background Response and Fake Subjets

Splittings map for difference of embedded and true PYTHIA

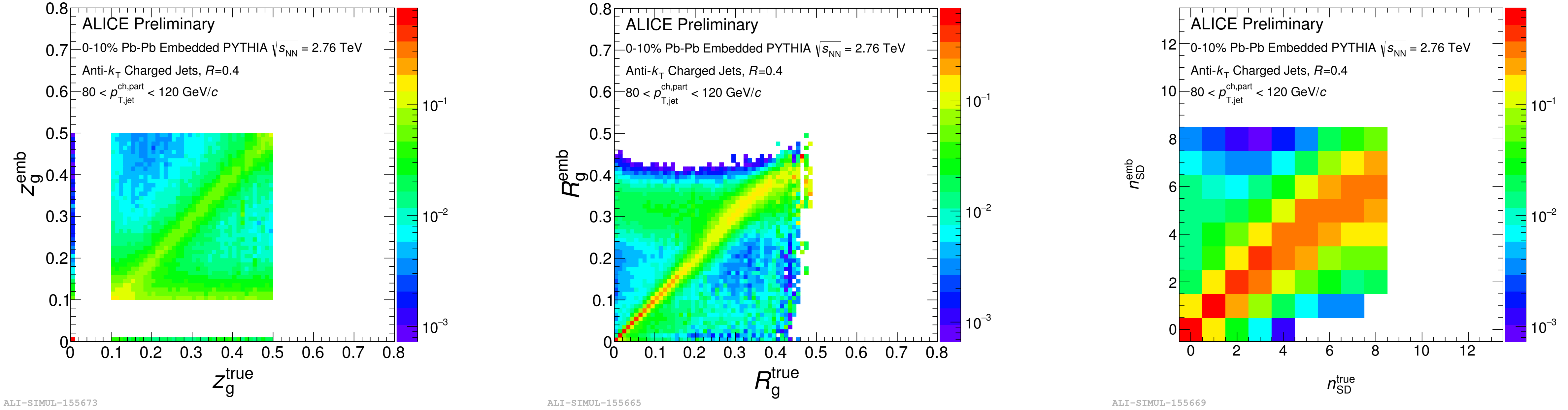


❖Compare Lund diagrams of two populations:

1. PYTHIA jets in vacuum
2. PYTHIA jets embedded into central PbPb

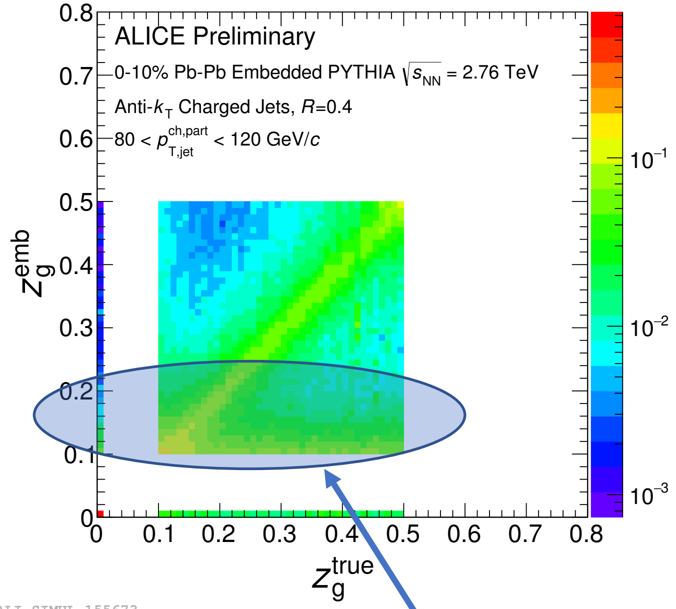
❖Observe a clear enhancement of splittings at large angular separation: purely a background effect, not physical

Background Response and Fake Subjets



- Uncorrelated background can promote subleading subjets above the threshold
- Dominant at low z_g and large R_g

Background Response and Fake Subjets



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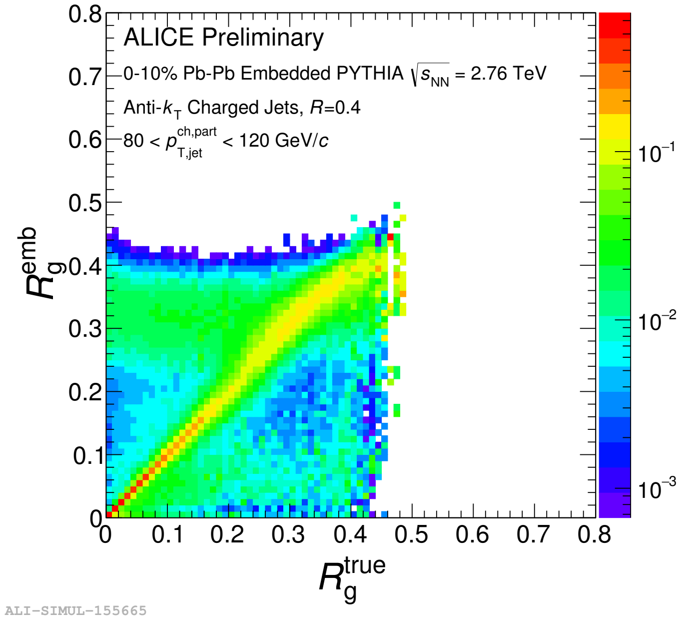

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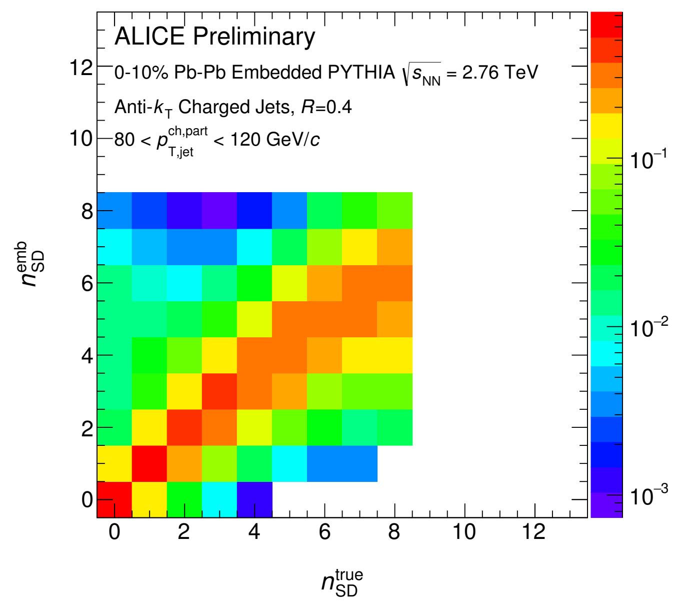

ALI-SIMUL-155669

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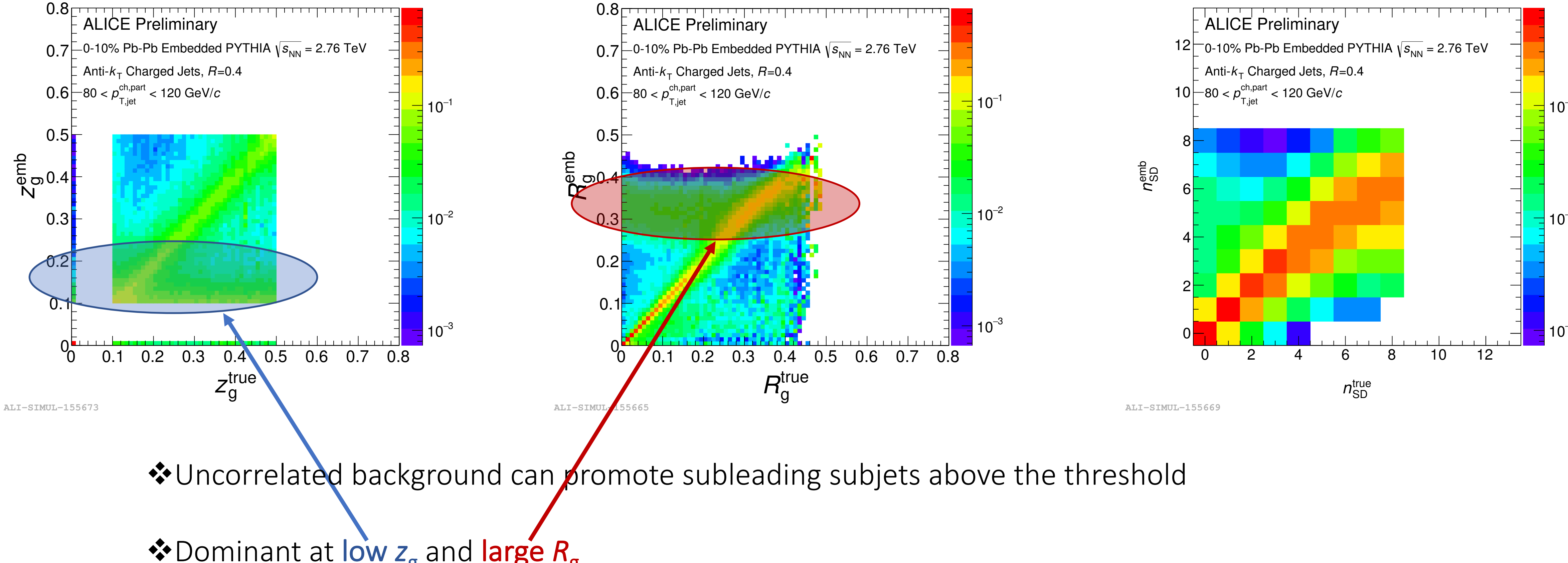

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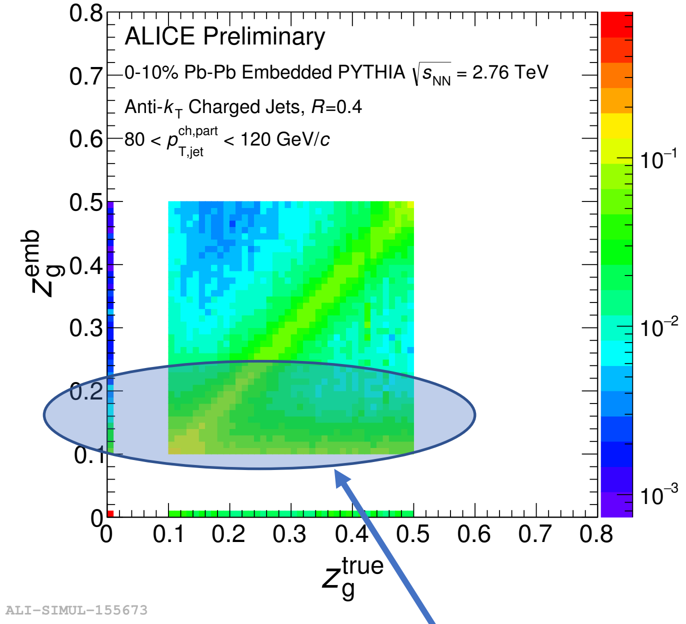
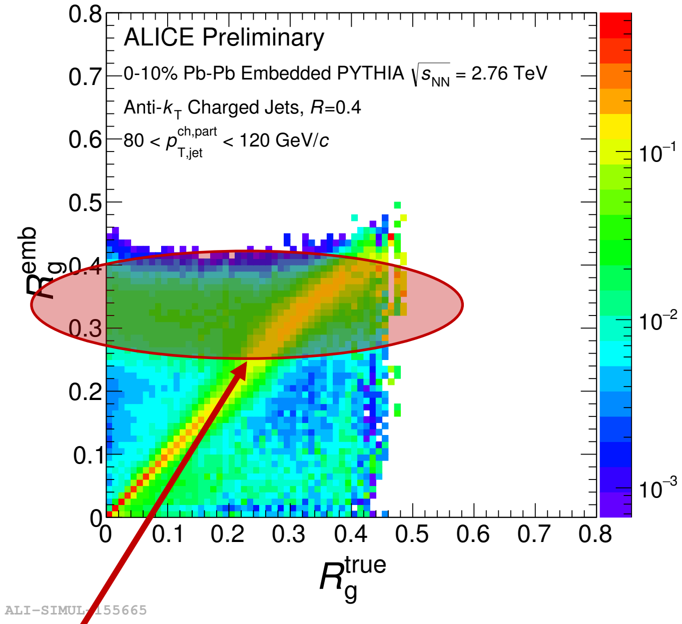
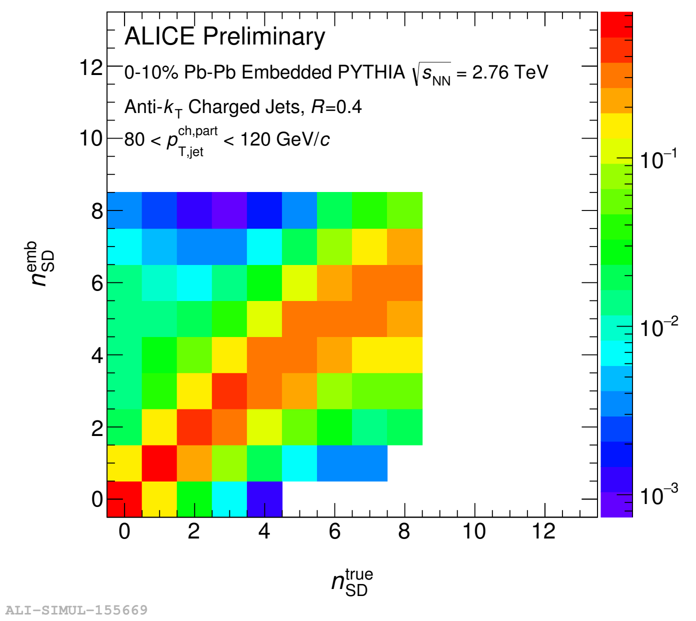




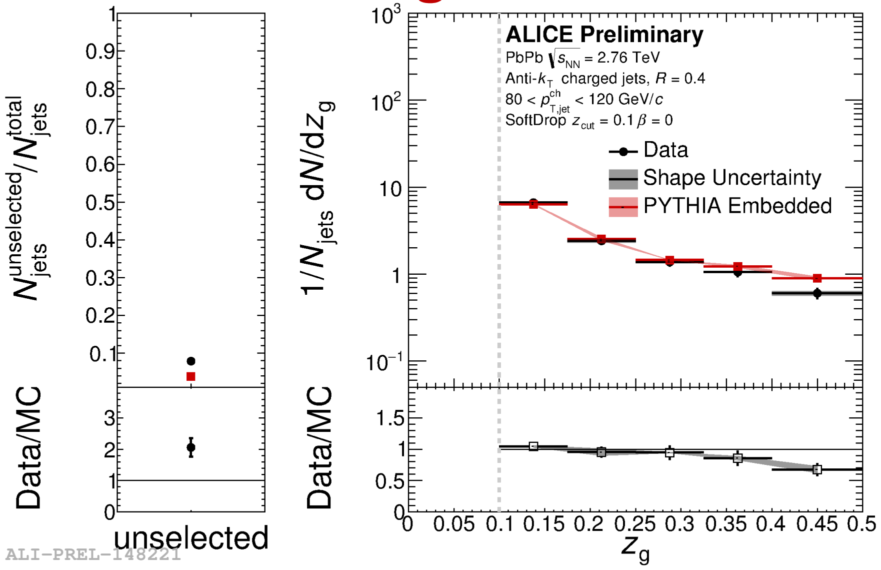


- Uncorrelated background can promote subleading subjets above the threshold
- Dominant at low z_g and large R_g
- **Effects fully accounted for using PYTHIA jets embedded in real events as smeared reference**

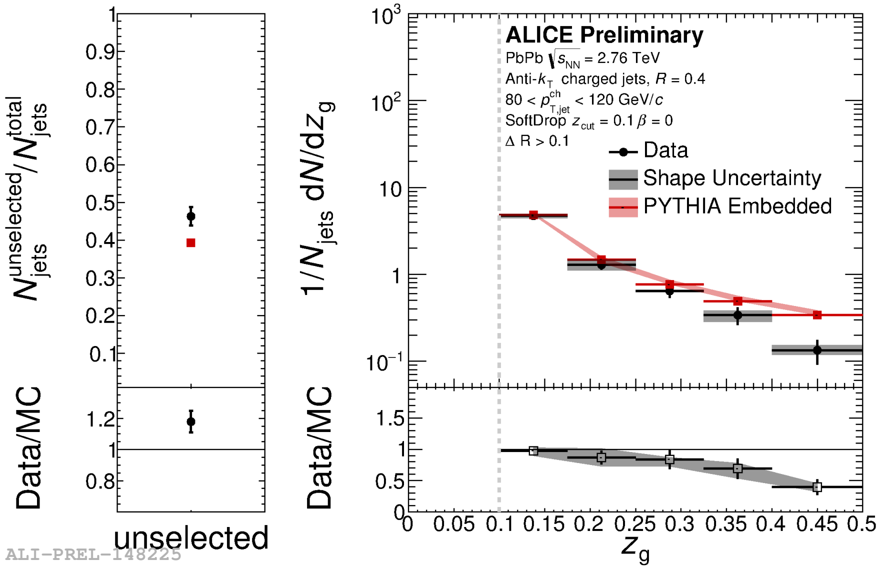
Inclusive Results: Pb-Pb

Unselected = Untagged (SD) + cut by ΔR cut

No angular cutoff



$\Delta R > 0.1$



❖ z_g distribution for inclusive jet sample in Pb-Pb collisions in jet p_T range 80-120 GeV/c
normalising to the total number of jets in the reconstructed p_T^{jet} bin

[1] A. M. Sirunyan *et al.*
Phys. Rev. Lett. **120**, 142302

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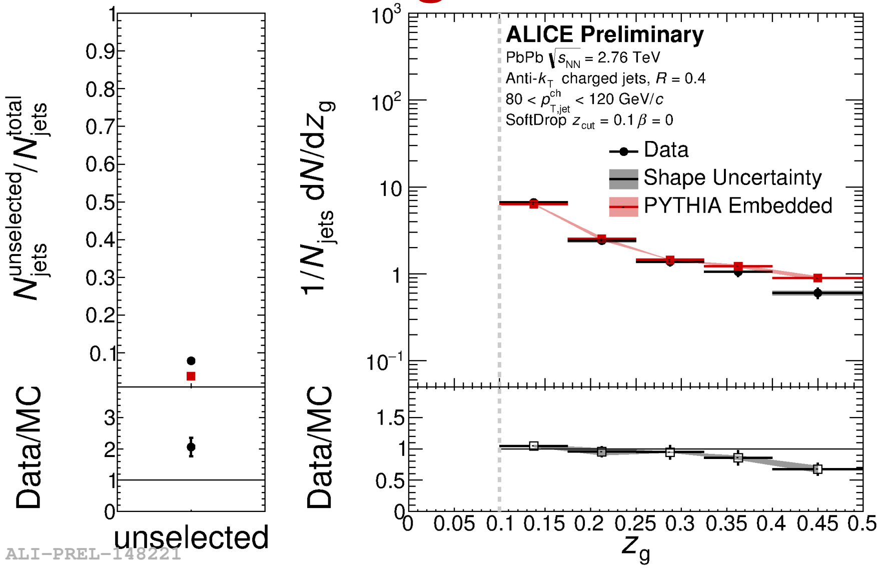

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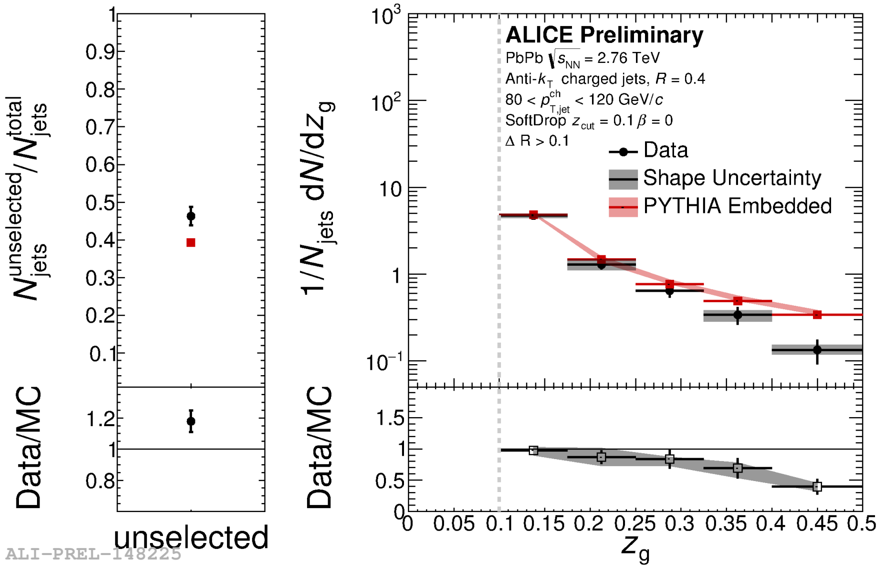

- ❖ z_g distribution for inclusive jet sample in Pb-Pb collisions in jet p_T range 80-120 GeV/c normalising to the total number of jets in the reconstructed p_T^{jet} bin
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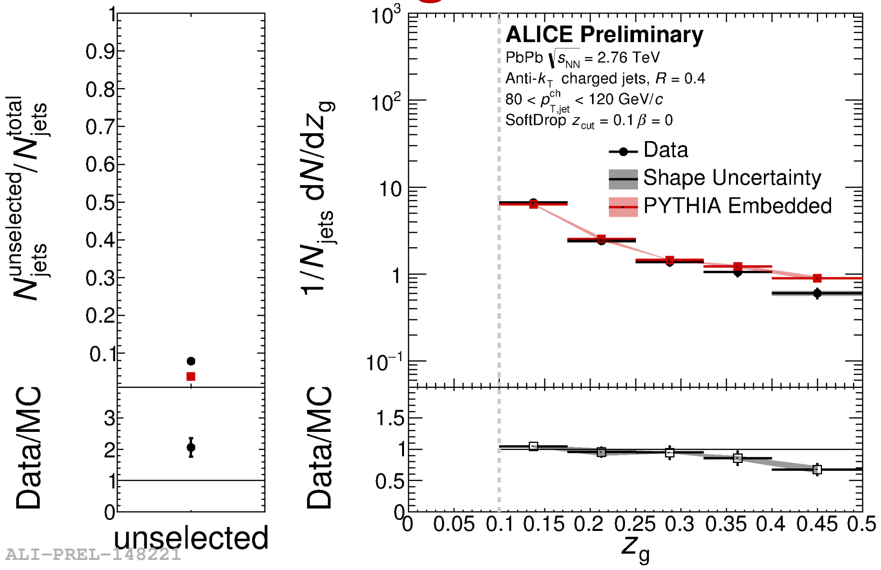

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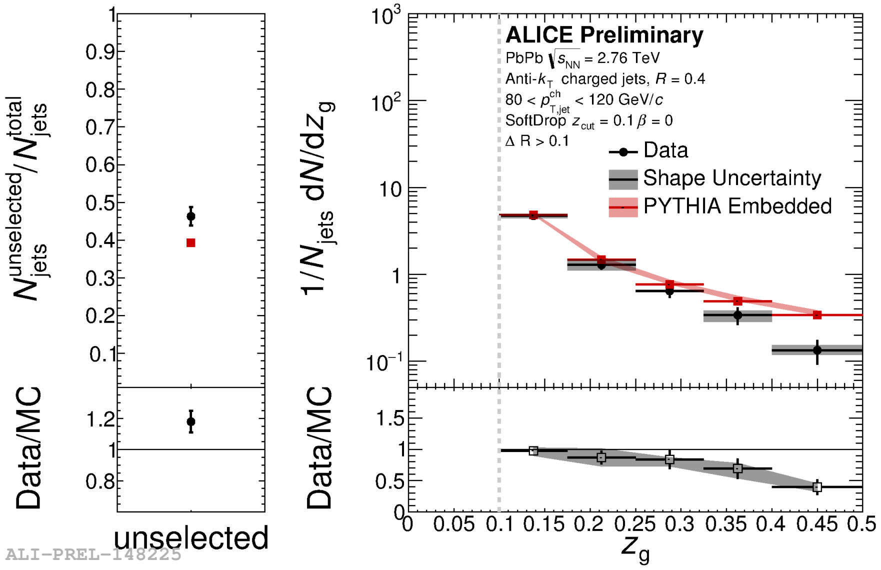


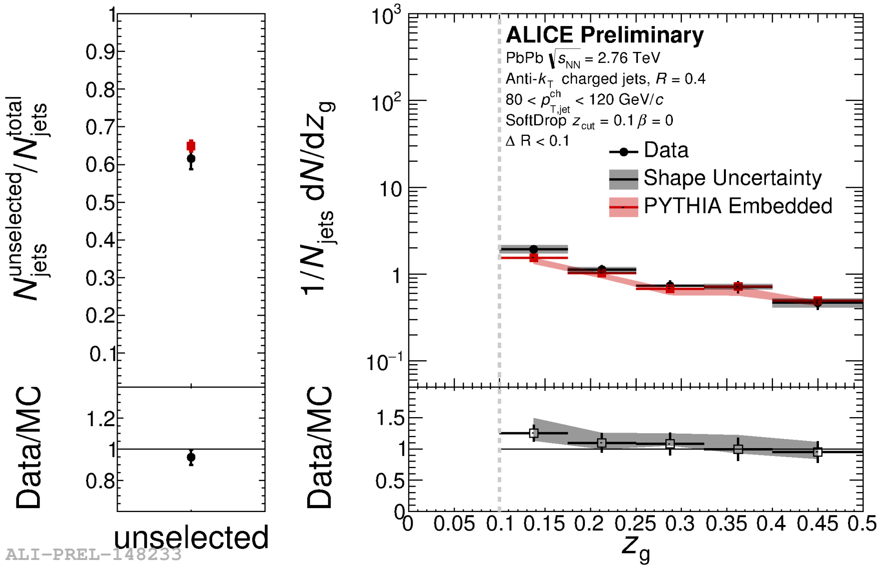
- ❖ z_g distribution for inclusive jet sample in Pb-Pb collisions in jet p_T range 80-120 GeV/c normalising to the total number of jets in the reconstructed p_T^{jet} bin
- ❖ No net enhancement of splittings passing Soft Drop cuts observed at large angles
- ❖ Cutting on angular separation as in other analysis[1] leads to a stronger modification of z_g distribution driven by an increase of fraction unselected jets in data

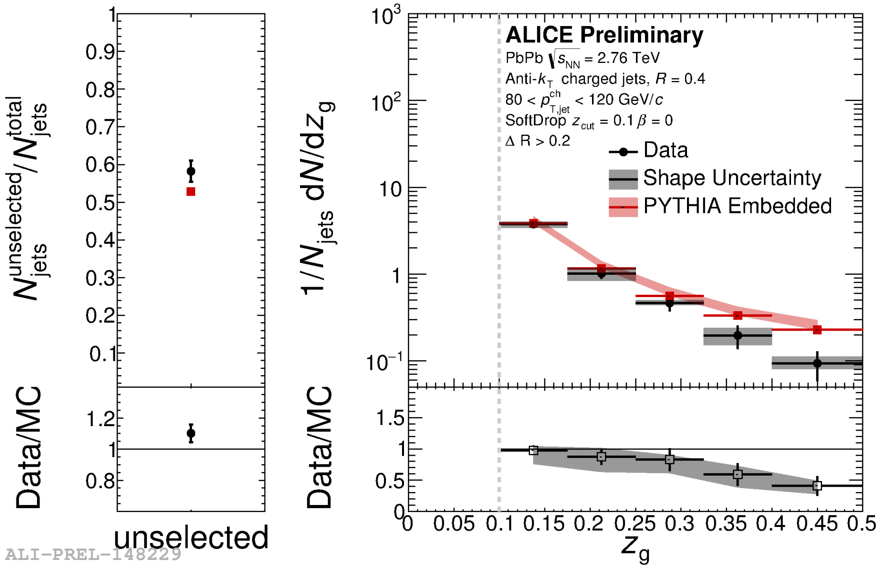
[1] A. M. Sirunyan *et al.* Phys. Rev. Lett. **120**, 142302

Angular Dependence

Unselected = Untagged (SD) + cut by ΔR cut

$\Delta R < 0.1$ $\Delta R > 0.2$



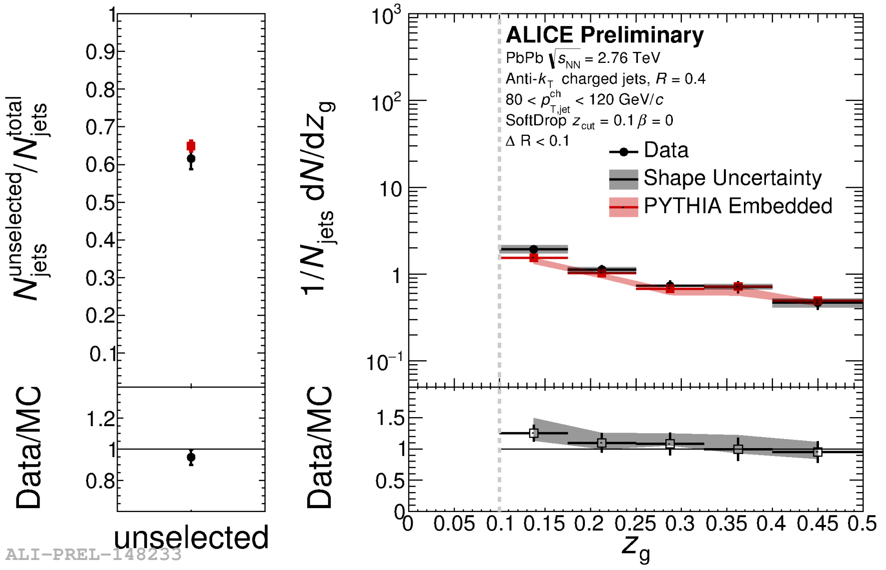


❖Considering the extreme angular limits of collimated (left) and large angle (right) splittings

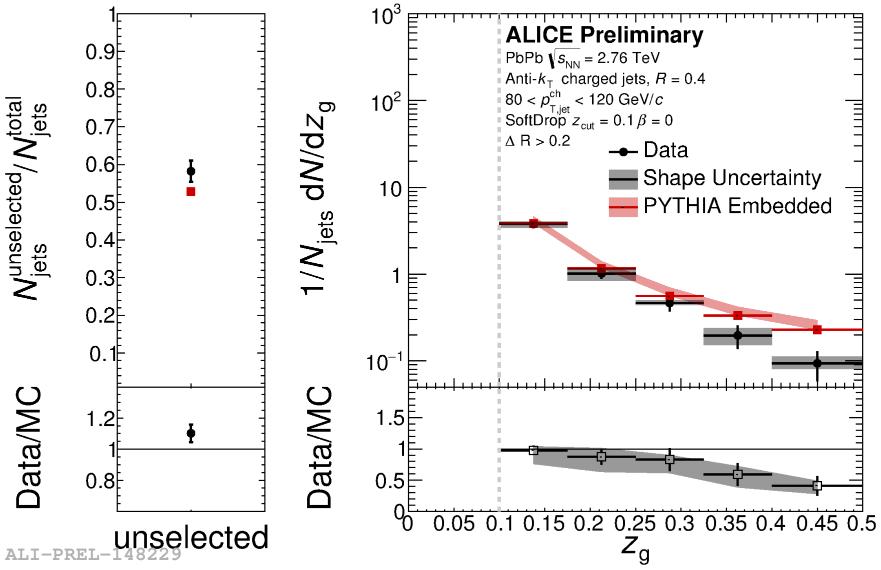
Angular Dependence

Unselected = Untagged (SD) + cut by ΔR cut

$\Delta R < 0.1$



$\Delta R > 0.2$



- Considering the extreme angular limits of collimated (left) and large angle (right) splittings
- Overall enhancement of collimated splittings and suppression of large angle splittings

Angular Dependence

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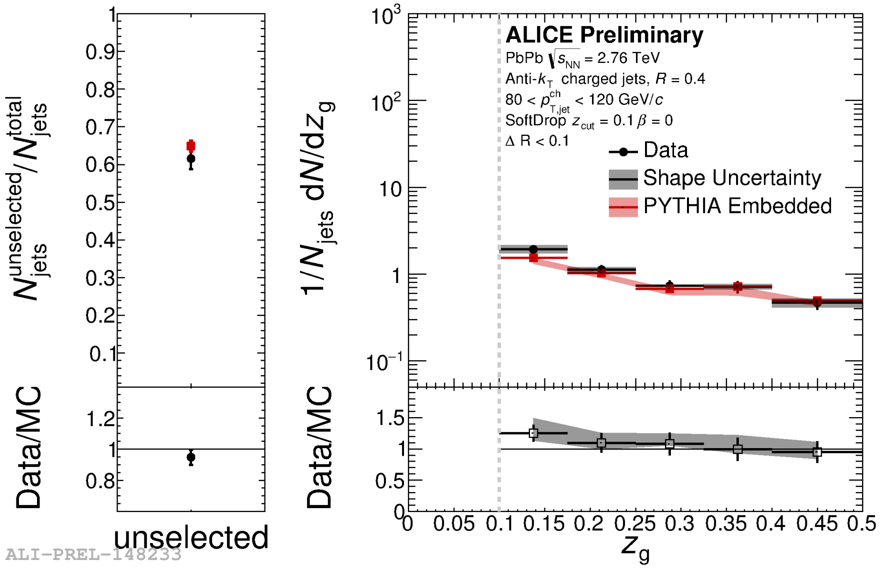

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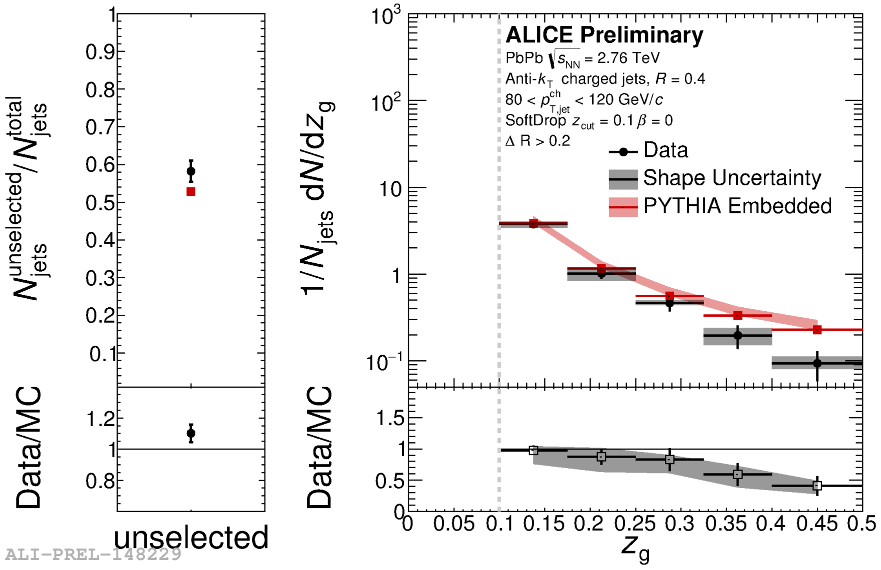
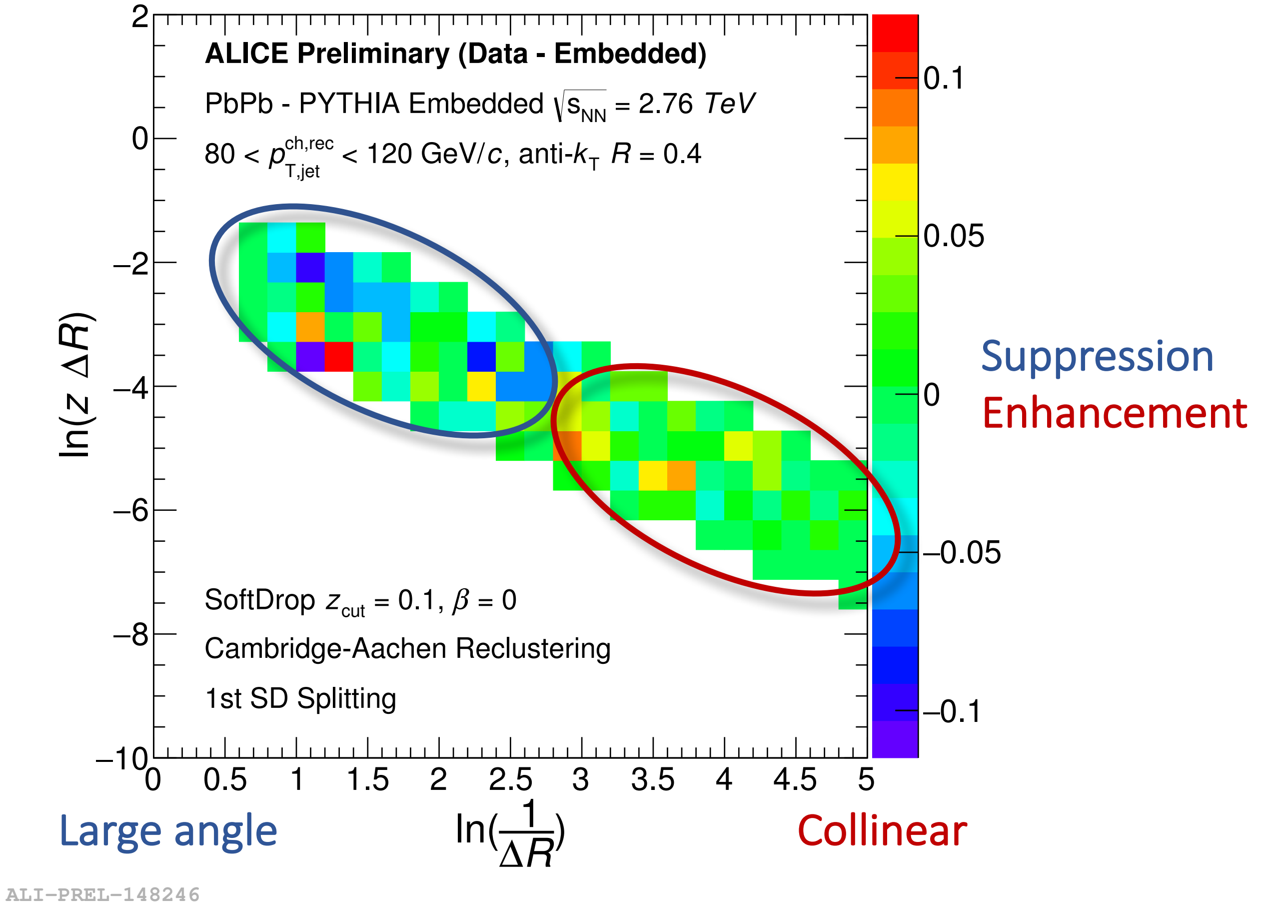


- ❖Considering the extreme angular limits of collimated (left) and large angle (right) splittings
- ❖Overall enhancement of collimated splittings and suppression of large angle splittings
- ❖In large angle limit observe no evidence for excess of low z_g splittings

Recursive Splittings

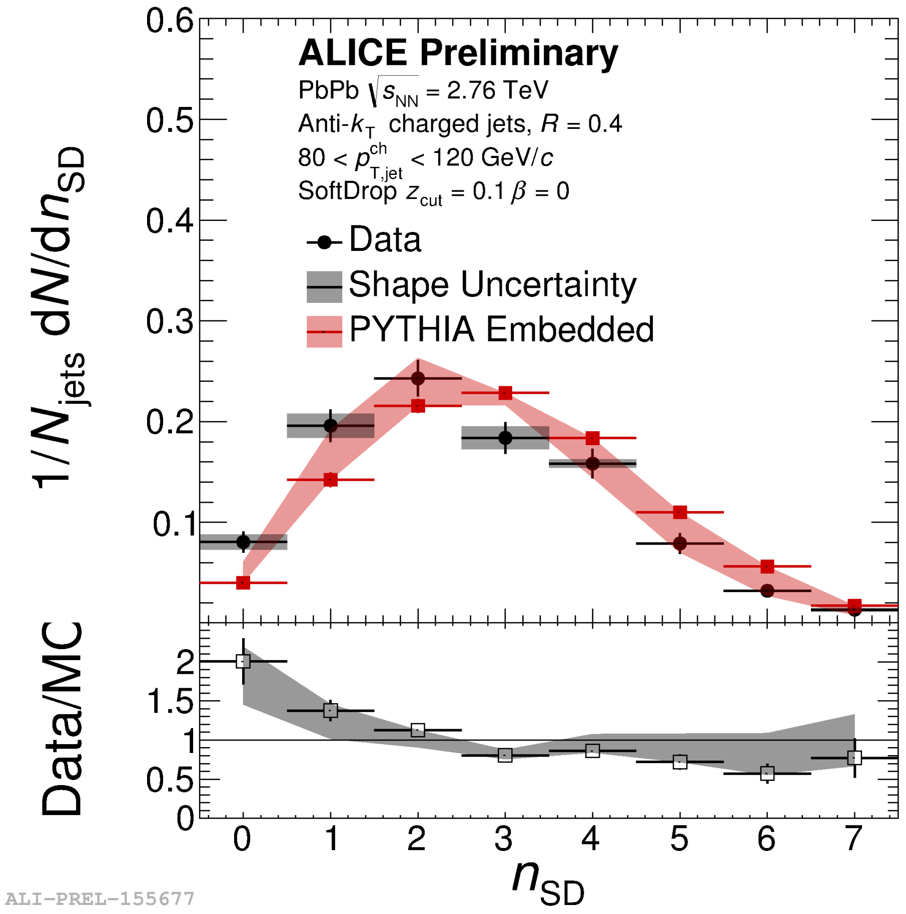
Splittings map for difference of data and embedded PYTHIA



- Lund diagram for the difference in the first hard splitting identified in Pb-Pb jets and embedded PYTHIA jets

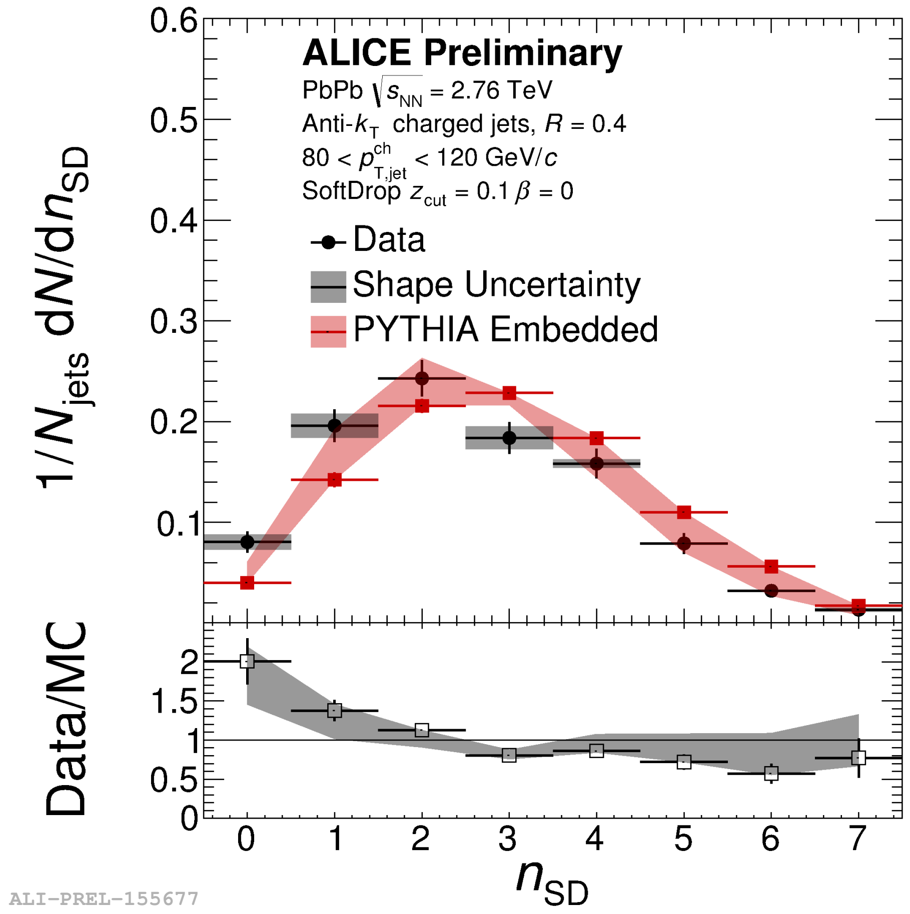
- A suppression of large angle splittings and enhancement of collinear splittings is observed – consistent with observation in z_g measurement

Recursive Splittings



❖No enhancement in the number of splittings passing Soft Drop in medium

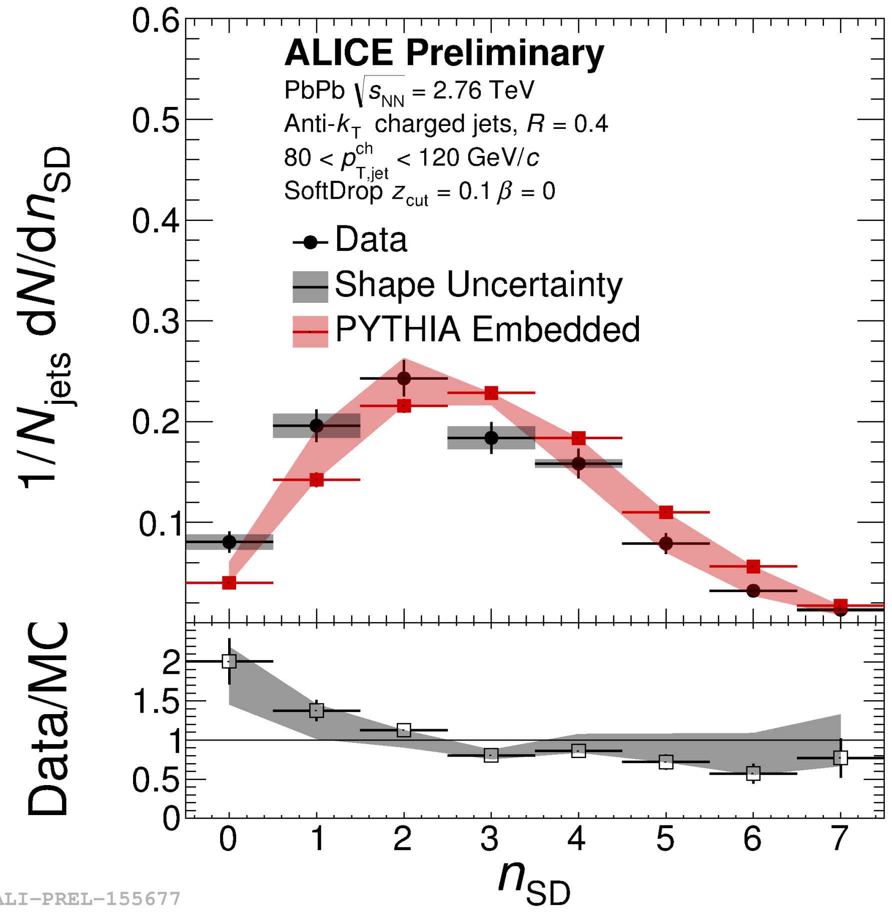
Recursive Splittings



❖ No enhancement in the number of splittings passing Soft Drop in medium

❖ Rather: enhancement in number of untagged jets; trend to lower n_{SD}

Recursive Splittings



- ❖ No enhancement in the number of splittings passing Soft Drop in medium
- ❖ Rather: enhancement in number of untagged jets; trend to lower n_{SD}
- ❖ Contrast to expectations from correlated medium response or coherent collinear emissions

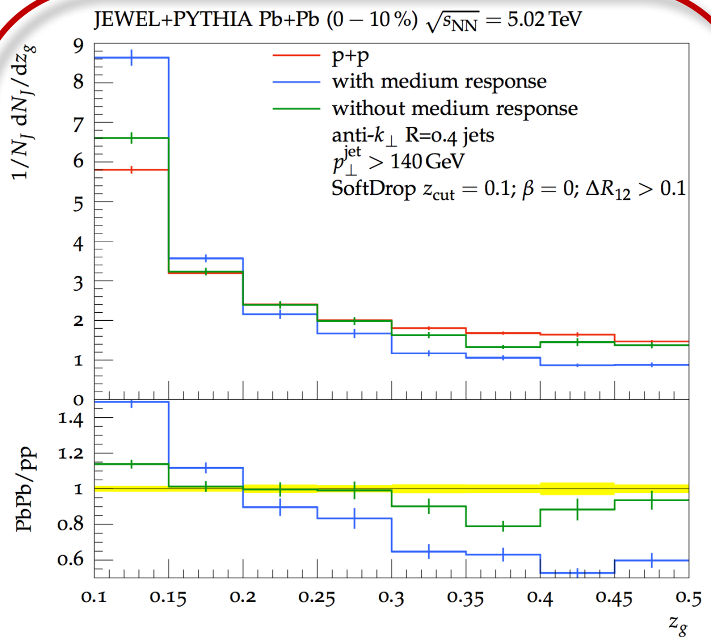
Some Considerations

Medium Recoil

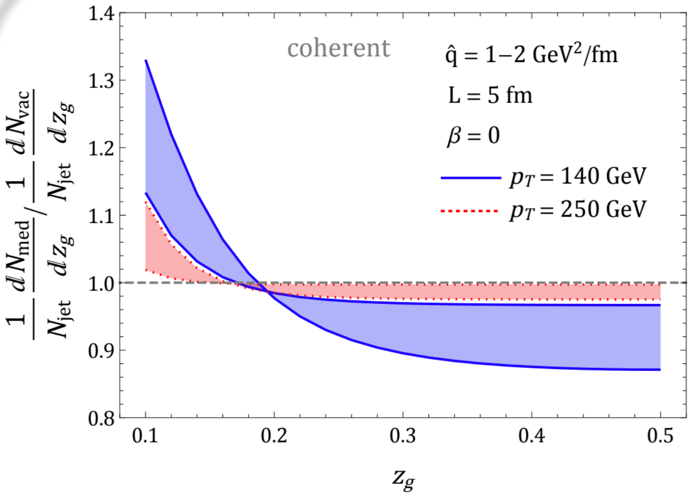
- Medium recoil promotes soft branches above threshold
- Expect to observe additional splittings in jet declustering to pass Soft Drop – **not** observed in n_{SD} measurement

Coherent Collinear Emission

- Coherent hard, rare, BDMPS emissions expected to occur at narrow angles
- Induced splittings increase probability of low z_g splittings



G. Milhano *et al.*
Phys.Lett. B779 (2018) 409-413



Y. Mehtar Tani, K. Tywoniuk
JHEP 1704 (2017) 125

Some Considerations

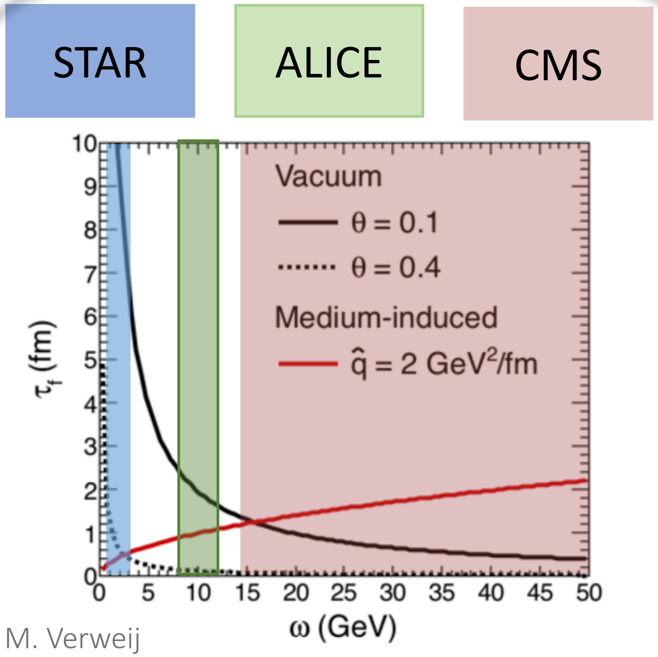
Formation Time

- Vacuum splitting formation time inversely proportional to splitting angle
- Vacuum splittings at large angle and/or large *z* are more likely to form in medium – unmodified vacuum splittings suppressed

Colour Coherence

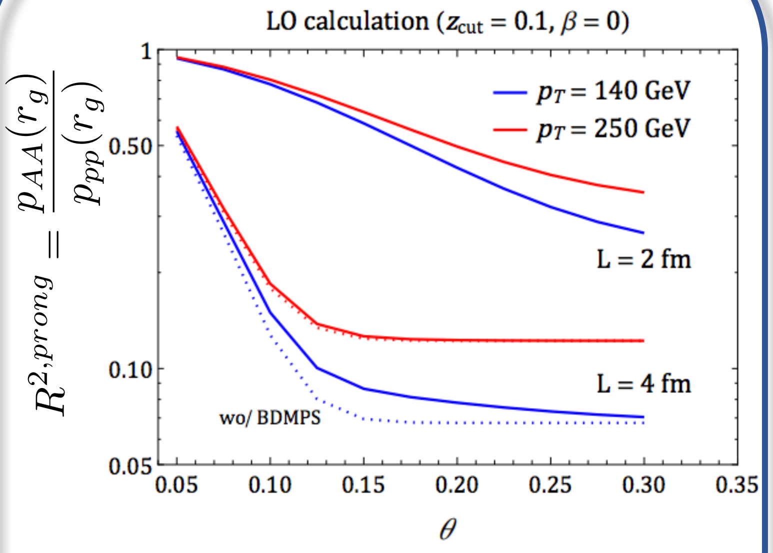
- Decoherence effects also suppress 2-prong probability at large angles
- Predictions of over 50% suppression at large angles, in data observe ≈10% suppression at $\theta = 0.2$

Phase space covered by $z_g = 0.1$



M. Verweij
QM17 Chicago

$$t_f^{vac} \approx \frac{1}{\theta^2 \omega} \qquad t_f^{med} \approx \sqrt{\frac{\omega}{\hat{q}}}$$



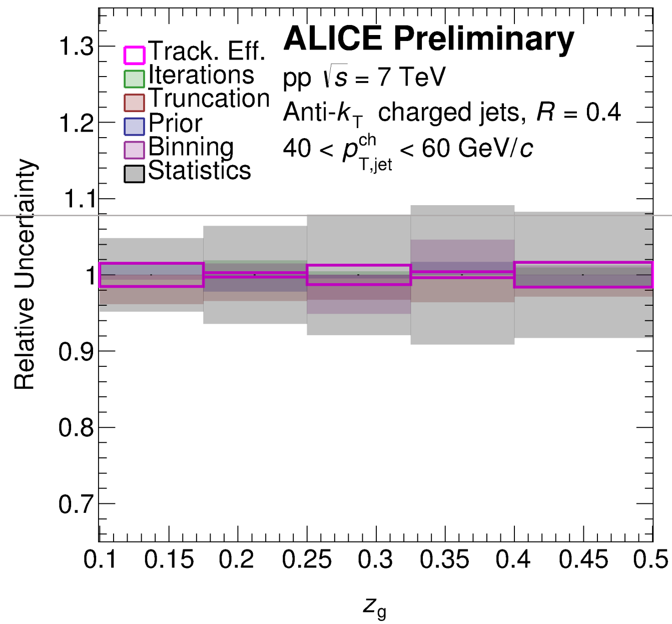
Y. Mehtar Tani
QM17 Chicago

Summary + Outlook

- Results of grooming using Soft Drop $z_{\text{cut}} = 0.1$, $\beta = 0$ have been presented
- Observe significant modification of z_{g} distribution in Pb-Pb collisions
- Large angle splittings suppressed in data
- No enhancement of number of hard splittings in Pb-Pb collisions
- Use pp data as reference with measurements at $\sqrt{s_{NN}} = 5.02$ TeV
- With increased statistics can explore the Lund map of splittings in more detail

Backup

Systematics: pp



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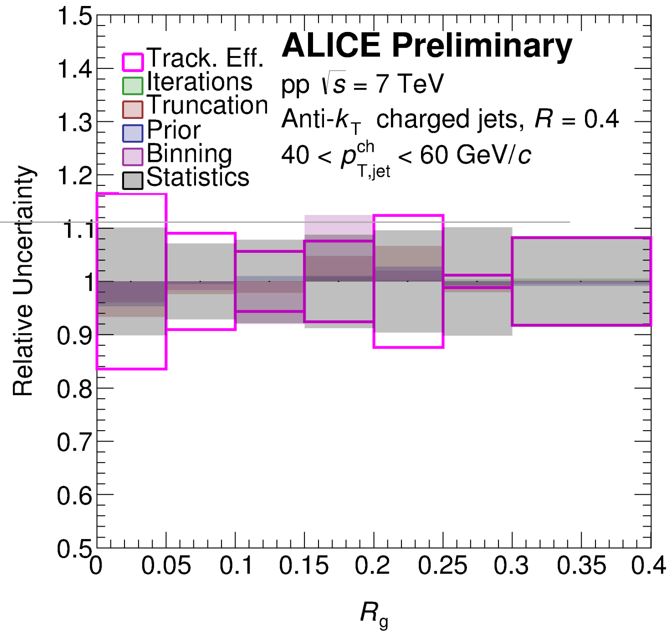
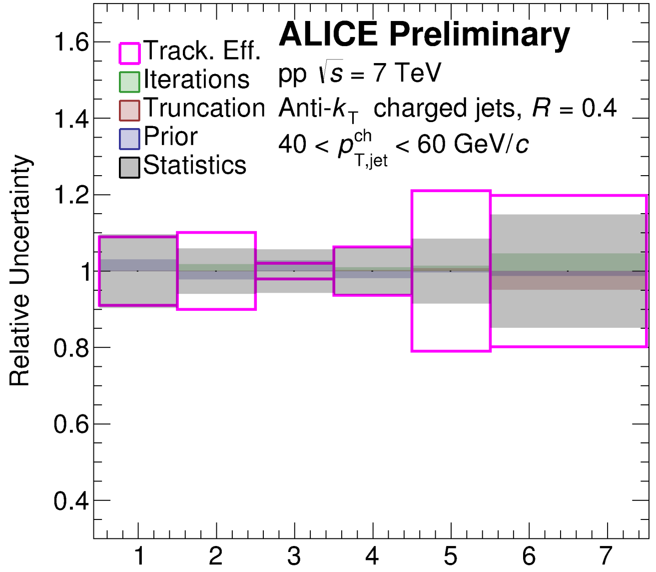


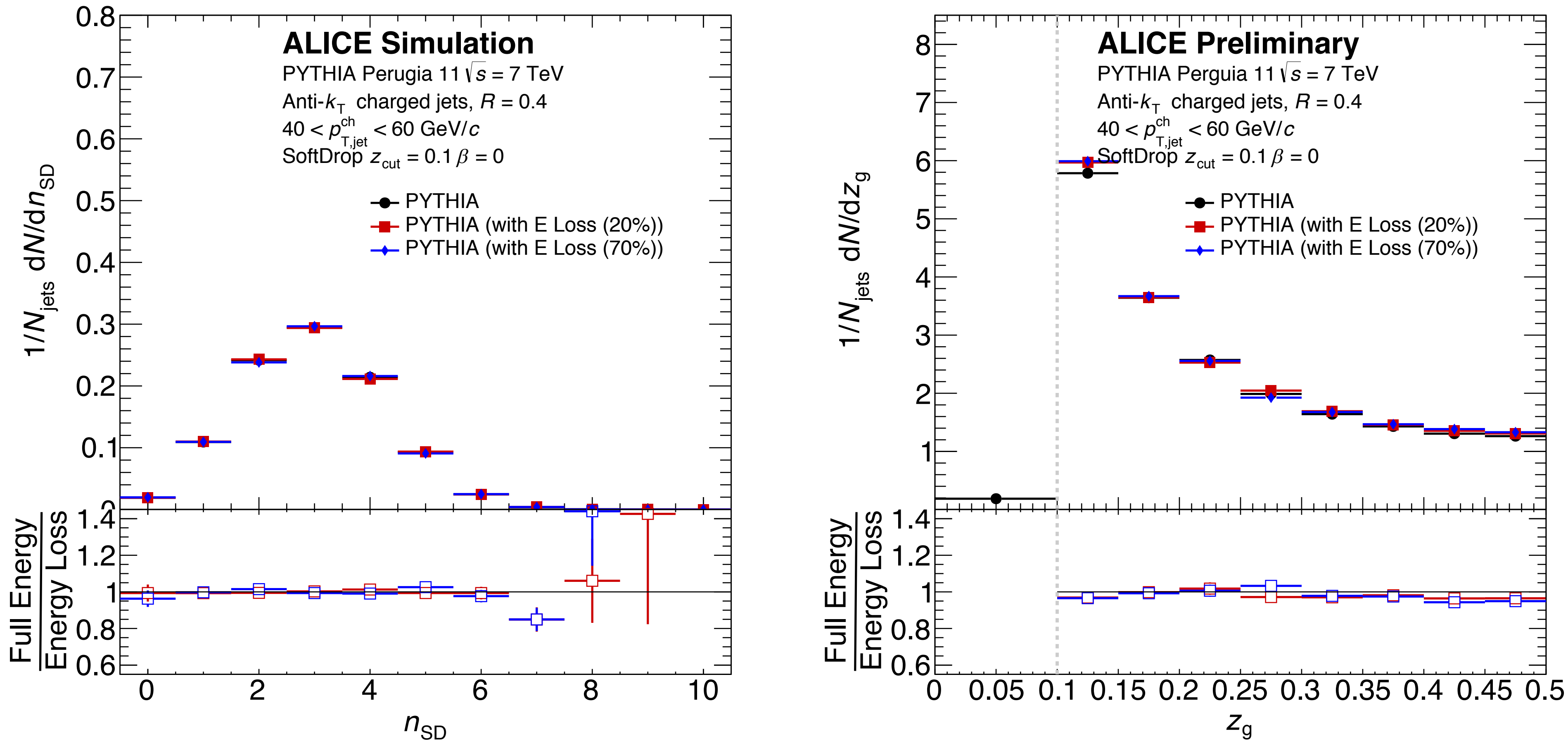
ALI-PREL-148000

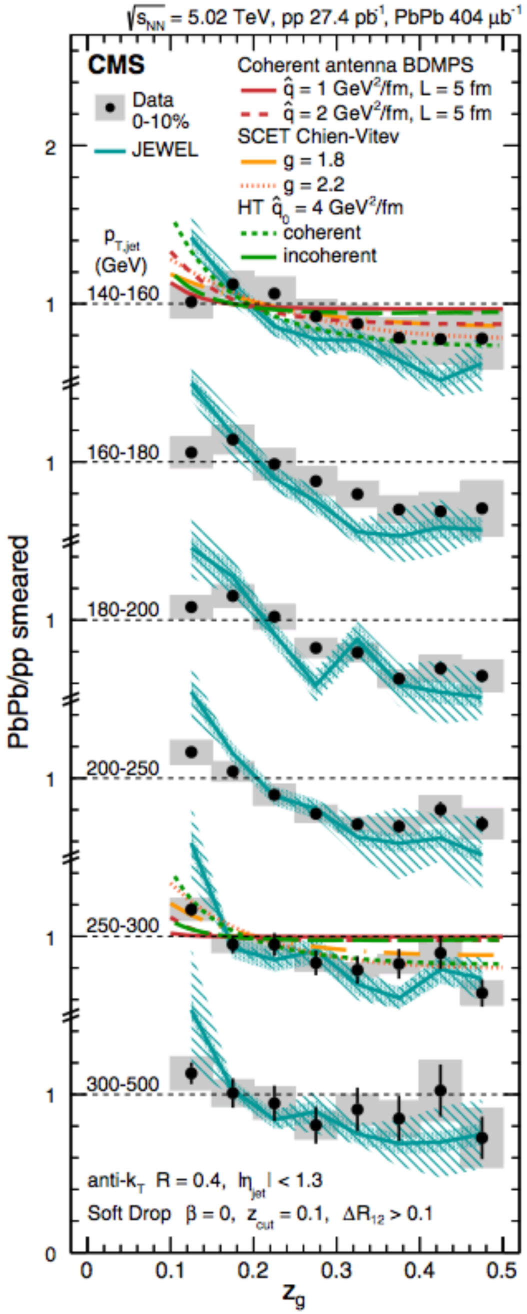
❖Systematic uncertainties include:

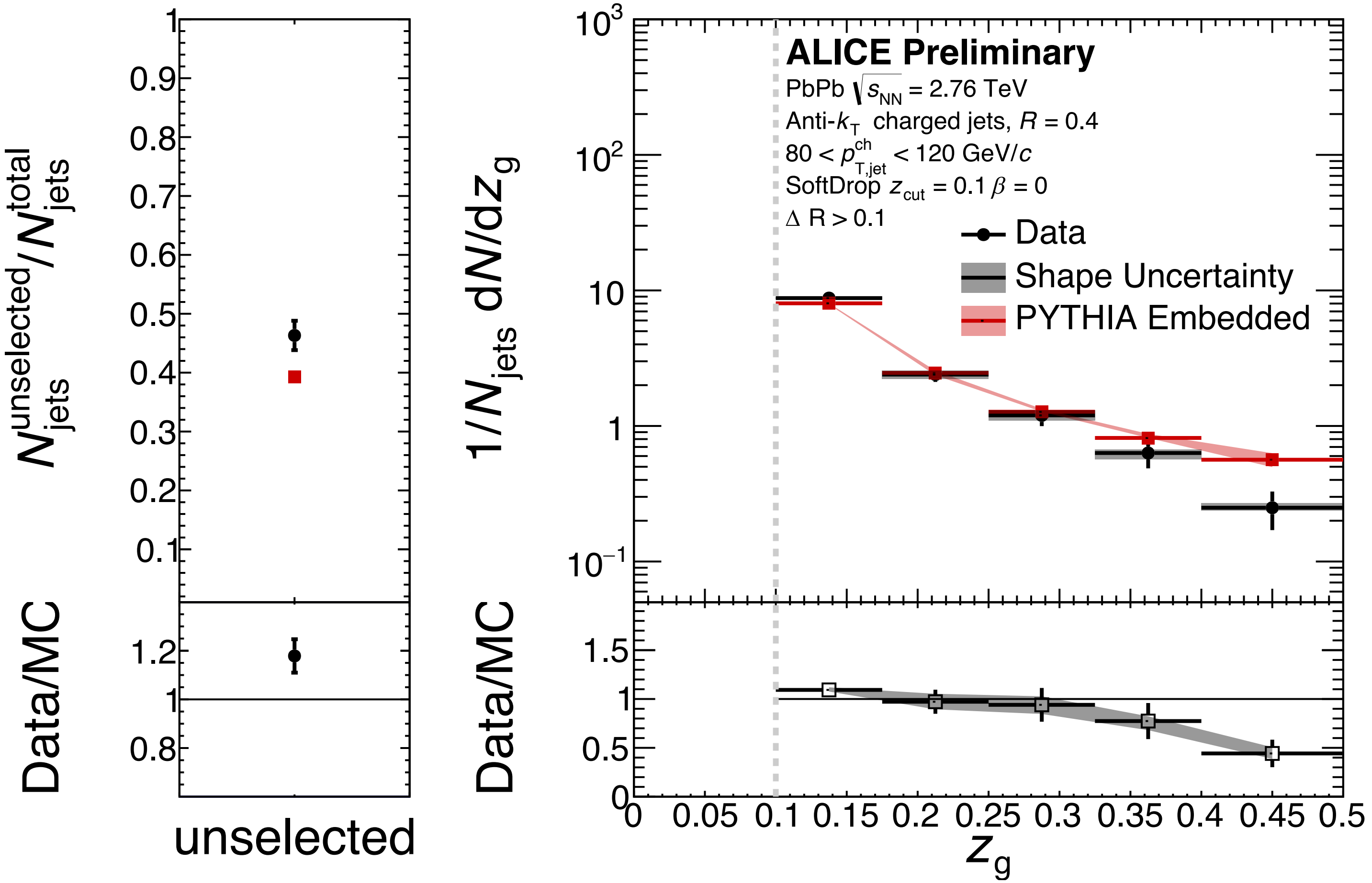
- ❖Tracking efficiency uncertainty
- ❖Unfolding:
  - ❖Regularisation (modifying chosen iteration +/- 1)
  - ❖Truncation (varying input jet p_T cut off by 10 GeV and shape bins to exclude untagged jets)
  - ❖Prior (reweighting prior of unfolding by ratio of chosen unfolded solution and truth distribution)
  - ❖Binning (modification of input binning used in unfolding)



Jet Energy Loss







❖ Normalsing by the population selected by Soft Drop and cut on ΔR

A. M. Sirunyan *et al.*
Phys. Rev. Lett. **120**, 142302