ALICE inclusive jet and jet substructure measurements

13th International Workshop on High-p_{T} Physics in the RHIC/LHC era

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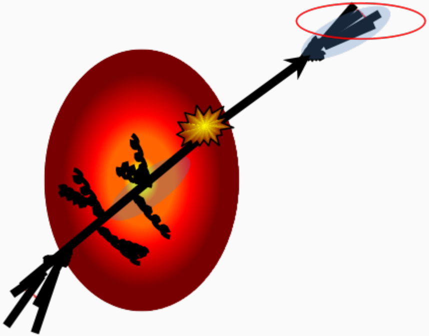
Jets in the Medium

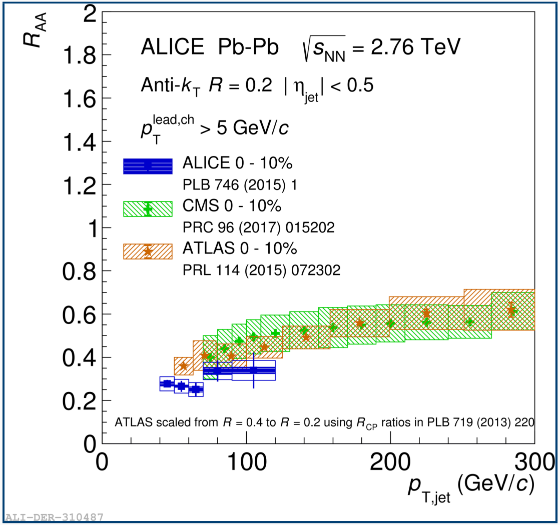
- Jet-medium interactions are expected to modify the internal structure of the jet.
- How can we observe these effects experimentally?
  - Inclusive jet measurements
  - Jet substructure measurements
  - Jet shapes, correlations, etc
- Constrain and compare with models to gain insight into the underlying physics.



Inclusive Jet Spectra and Jet Suppression

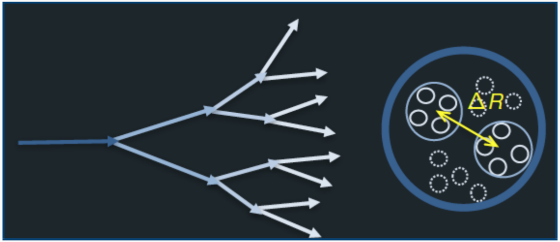
$$R_{AA} = \frac{\frac{1}{\langle T_{AA} \rangle} \frac{1}{N_{event}} \frac{d^2 N}{dp_T d\eta}\Big|_{AA}}{\frac{d^2\sigma}{dp_T d\eta}\Big|_{pp}}$$

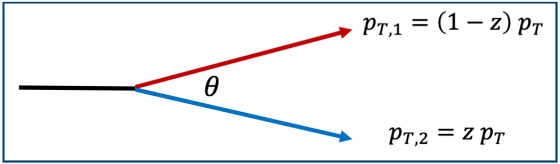
- Jet suppression often characterized via R_{AA}.
  - Stronger $p_{T,jet}$ dependence at low $p_{T,jet}$.
- In both pp and Pb–Pb, how well do the models describe the data?
  - Can measurements help differentiate between different models?
- ALICE can measure down to lower $p_{T,jet}$ than other LHC experiments.
- Can provide additional constraints by measuring observables for multiple jet radii.



Jet Substructure Measurements

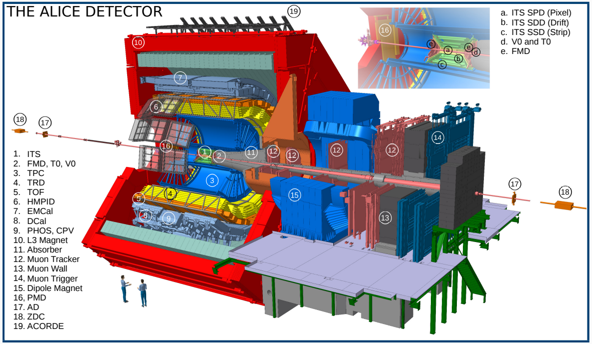
- Explore splittings within the jet to characterize its properties.
  - Iterative declustering provides the means to access these splittings.
- Can select subset of splittings to isolate regions of interest.
- Provide additional constraints on models by requiring description of jet evolution.
- Take advantage of the precision of ALICE tracking.





ALICE Jet Measurements

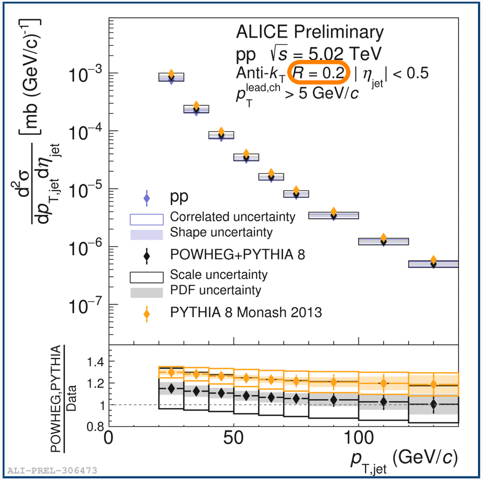
- Reconstructs jets at mid-rapidity ($|\eta| < 0.7$) in pp, p–Pb, and Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76 - 13$ TeV
- Track-based jets utilize the high precision tracking to use tracks with $p_{\mathrm{T,track}} > 150$ MeV$/c$.
- Full jets combine charged particle information with electromagnetic calorimeter clusters with $p_{\mathrm{T,cluster}} > 300$ MeV$/c$.
  - Subtract charge particle contamination from clusters to avoid double counting.

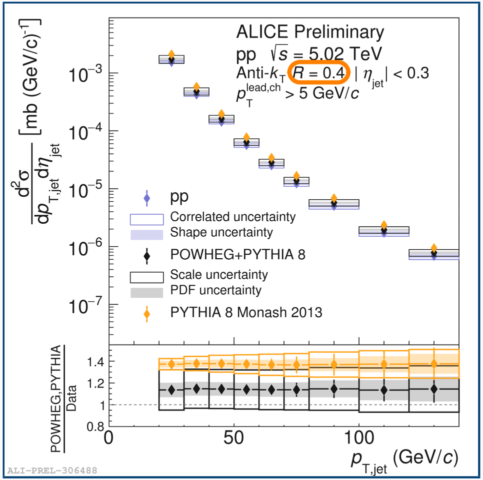


Inclusive Jet Measurements

- $R = 0.2$, 0.4 full jets measured in pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.
  - $p_{\mathrm{T,jet}} = 40 - 140$ GeV/c
- Full jets allow for direct comparison with theory.
- Require leading track bias to reduce combinatorial background.
  - 5 GeV/c for $R = 0.2$.
  - 7 GeV/c for $R = 0.4$.
- Unfold Pb–Pb measurements for detector effects and background fluctuations using embedded PYTHIA.

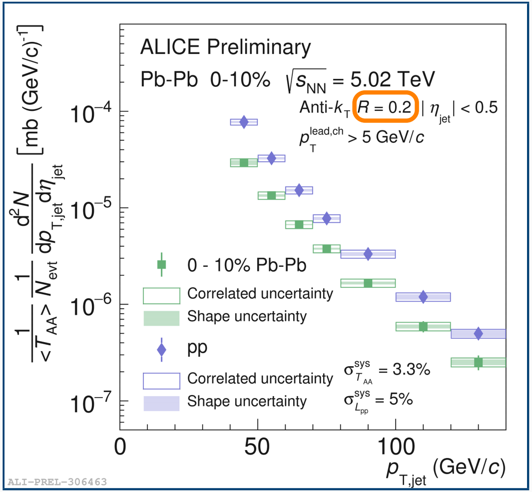
pp Jet Cross-section

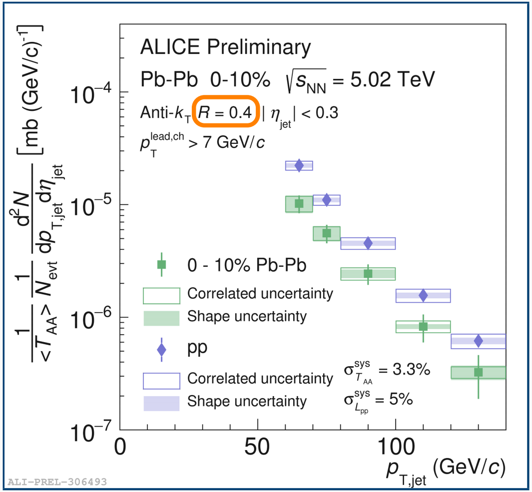




- PYTHIA overpredicts but POWHEG + PYTHIA is consistent with the data.

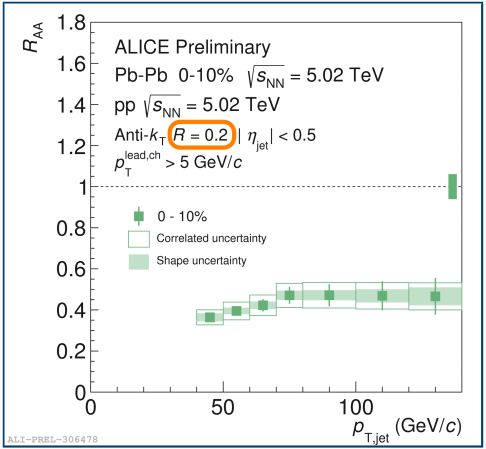
Inclusive Jet Spectra

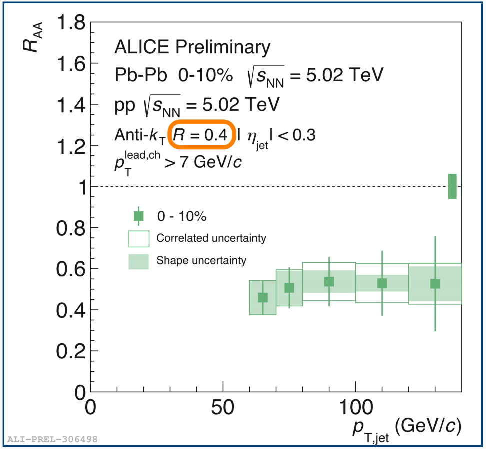




- Measured in 0-10% Pb–Pb collisions between 40-140 GeV/c.

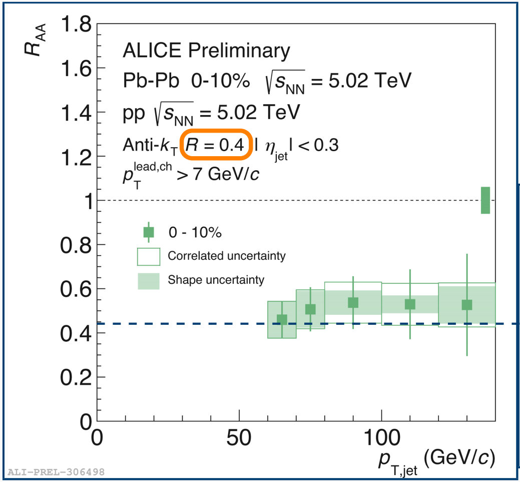
Jet R_{AA}



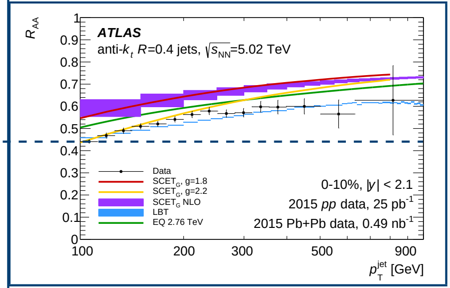


- Jet R_{AA} is measured down to 40 GeV/c.
- Suppression is similar for $R = 0.2$ and $R = 0.4$.

Jet R_{AA}

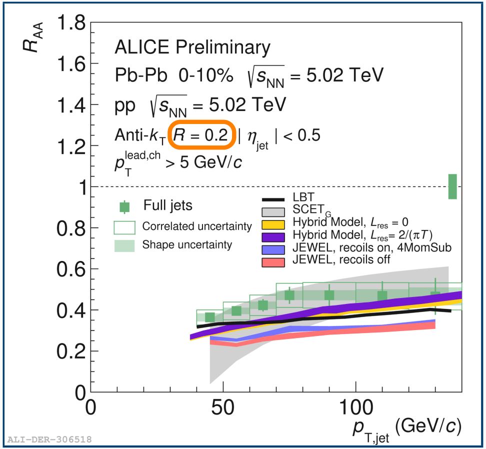


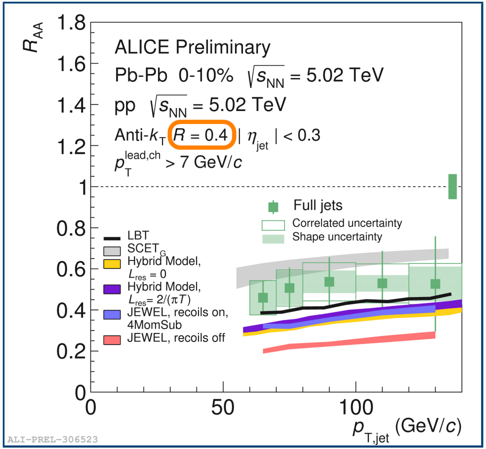
ATLAS
Phys. Lett. B 790 (2019) 108



- Consistent with ATLAS $R = 0.4$ measurement.

Jet R_{AA}

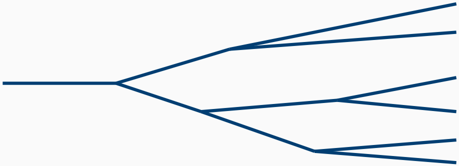




- Qualitatively, the R_{AA} is described by all models.
- Quantitatively, there is slight tension between most models and the data.

Groomed Jet Substructure

- Can provide further constraints by utilizing grooming of jet substructure.
- In pp, grooming retains the majority of perturbative radiation while limiting QCD backgrounds in a controlled manner.
    - z_g is closely related to the Altarelli-Parisi splitting functions
- In Pb–Pb, grooming can select hard substructures within a jet, which are expected to be under better theoretical control

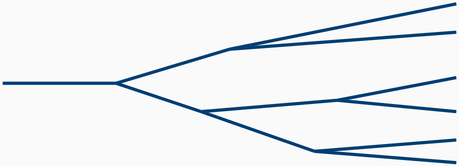


SoftDrop

- Recluster the jet using Cambridge/Aachen algorithm (geometric).
- Undo the last clustering step to get two branches with $p_{\mathrm{T},1}$ and $p_{\mathrm{T},2}$
- Check whether the two branches pass the SoftDrop condition:

$$\frac{min(p_{\mathrm{T},1}, p_{\mathrm{T},2})}{p_{\mathrm{T},1} + p_{\mathrm{T},2}} > z_{\mathrm{cut}}\theta^{\beta} = z_{\mathrm{cut}}\left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$

- If condition passed, use groomed jet.
- If condition failed, take the harder branch and continue by undoing the next splitting of that branch.



Default selections: $(z_{\mathrm{cut}}, \beta) = (0.1, 0)$

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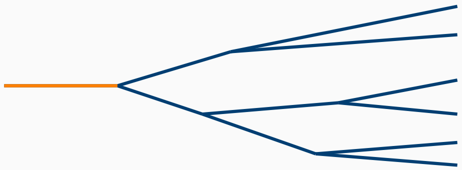

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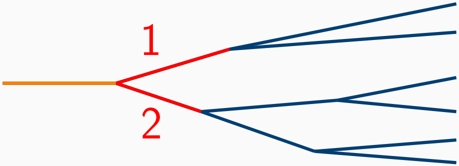

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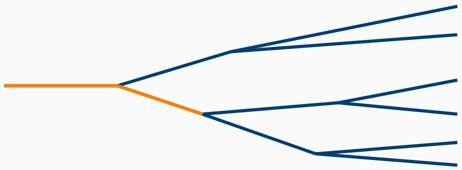

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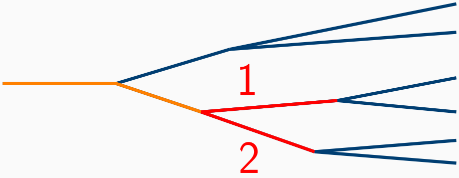

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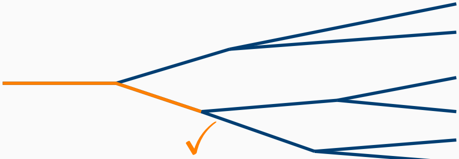
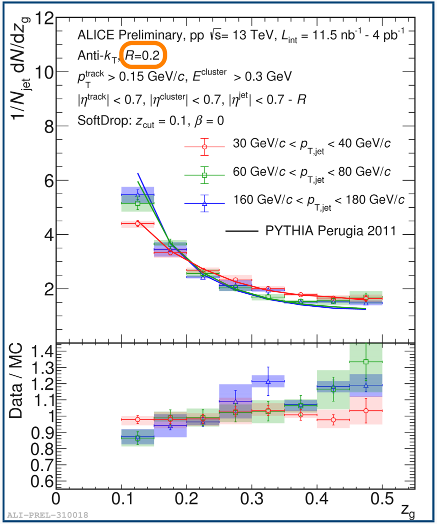


Default selections: $(z_{\mathrm{cut}}, \beta) = (0.1, 0)$

Groomed Momentum Fraction in pp

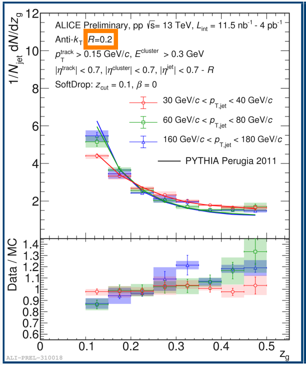
- Full jets measured in pp collisions at $\sqrt{s_{NN}} = 13$ TeV.
  - R = 0.2, 0.3, 0.4, 0.5
  - $p_{T,jet}$ measured from 30-200 GeV/c. Selected $p_{T,jet}$ bins of 30-40, 60-80, 160-180 GeV/c are shown here.
- $z_{cut} = 0.1$, $\beta = 0$.
- No underlying event subtraction is applied.
- For small radii jets, low p_T jets trend towards more symmetric splittings, while higher p_T jets trend towards more asymmetric splittings.

$R = 0.2$

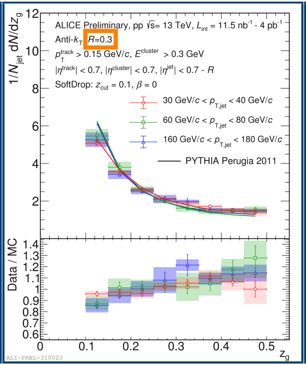


Groomed Momentum Fraction vs R

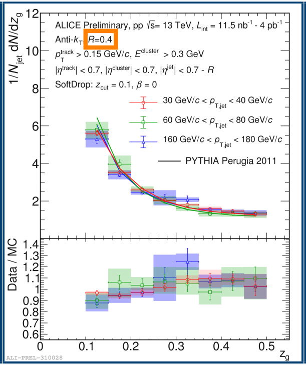
$R = 0.2$



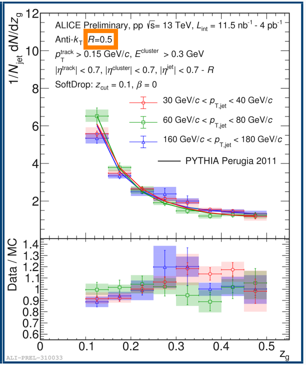
$R = 0.3$



$R = 0.4$



$R = 0.5$

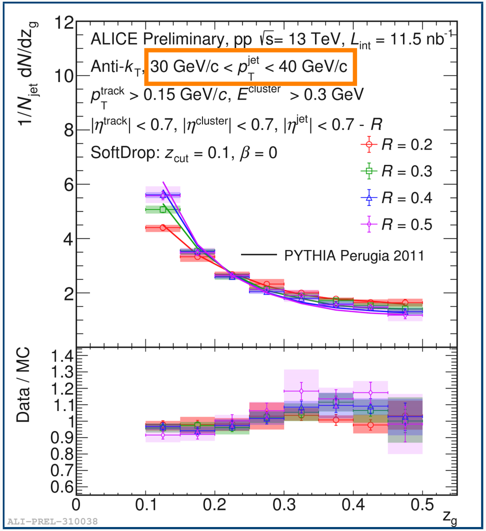


- $p_{T,jet}$ dependence is only for small radii.
- PYTHIA is in good agreement with the data.

Groomed Momentum Fraction vs $p_{T,jet}$

- A trend: more asymmetric splittings for larger radius jets at low p_T
  - Larger jets at low p_T capture more soft radiation
  - Different radii have sensitivity to non-perturbative effects
- PYTHIA can reproduce this trend at low $p_{T,jet}$

$30 < p_{T,jet} < 40$



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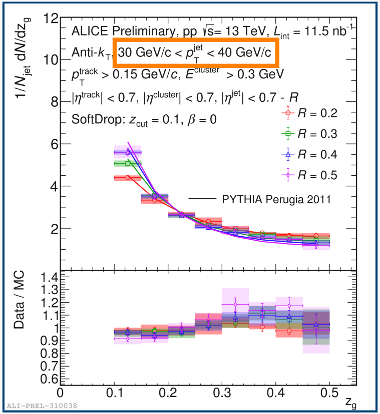
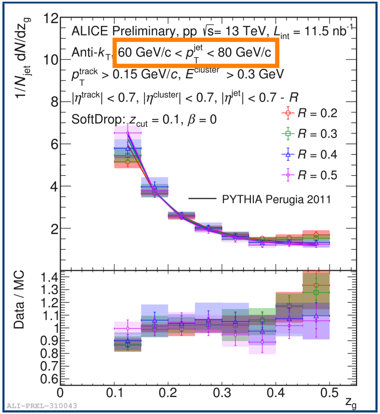
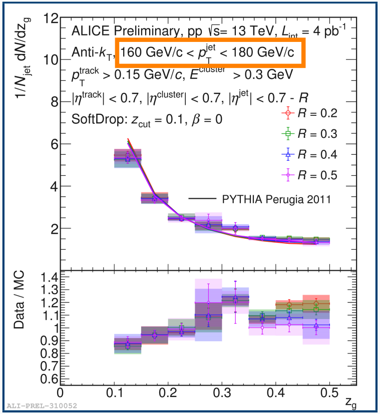


$60 < p_{T,jet} < 80$



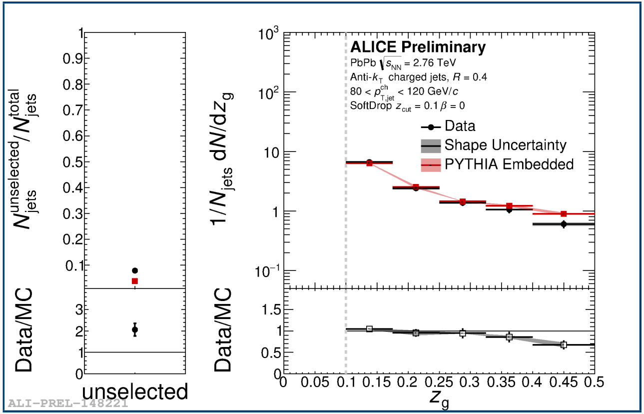
$160 < p_{T,jet} < 180$



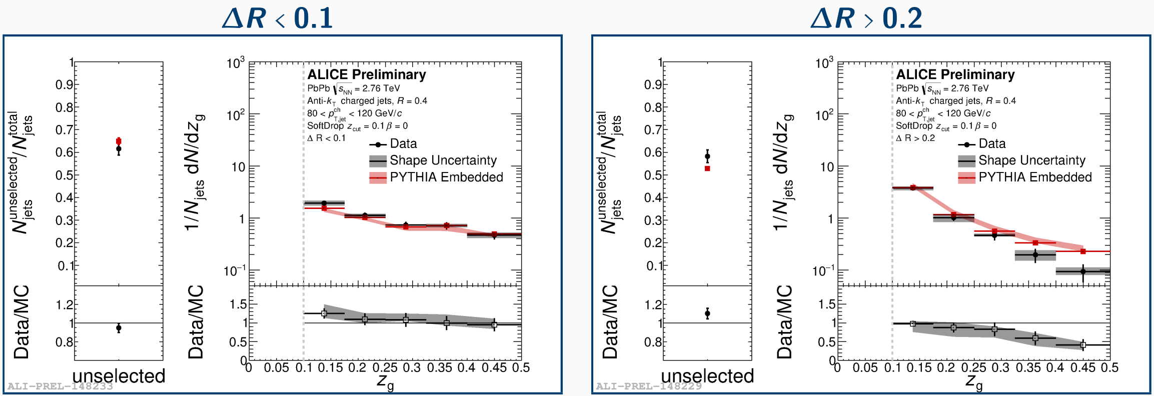
- Jet radii dependence disappears at high $p_{T,jet}$ where jets are dominated by jet core.
- Data is well described by PYTHIA.

Groomed Jet Substructure in Pb–Pb

- Medium recoil is expected to promote soft branches above the threshold.
- $R = 0.4$ track-based jets measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.
  - $p_{\mathrm{T,jet}} = 80 - 120$ GeV/c
- Pb–Pb data measured at detector level.
  - Compared to PYTHIA reference embedded in Pb–Pb.
- Normalization by number of measured jets enables evaluation of absolute differences between data and reference.
- Suppression at large z_{g}.



Angular Dependence

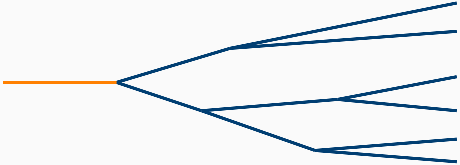


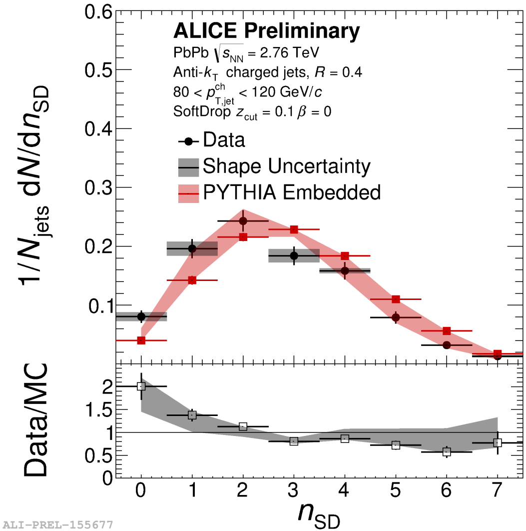
- Unselected jets includes those which failed the SoftDrop condition, as well as those cut by the ΔR selection.
- Slight enhancement of collinear splittings, and suppression of large angle splitting.

Sensitivity to color coherence? (JHEP 04 (2017) 125)

Recursive SoftDrop

- Can medium induced radiation be detected as extra splittings in the jet tree?
  - Explore via recursively applying SoftDrop.





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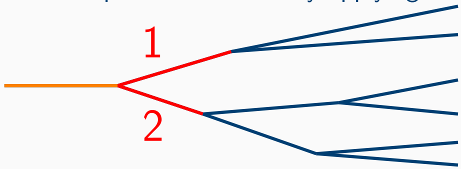

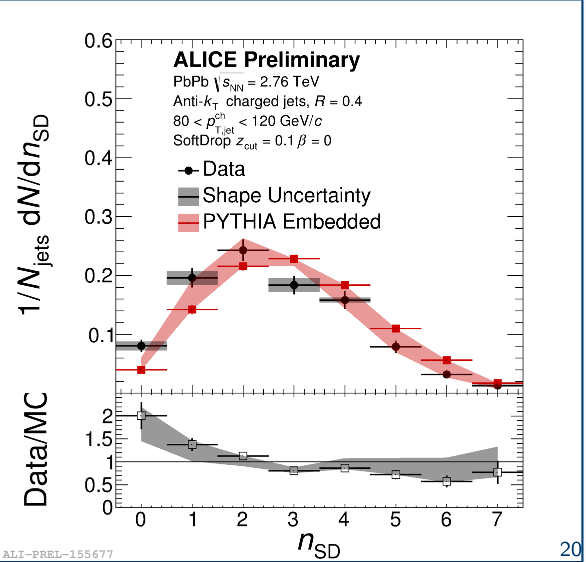

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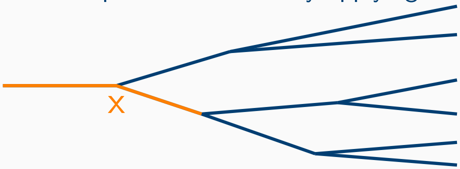

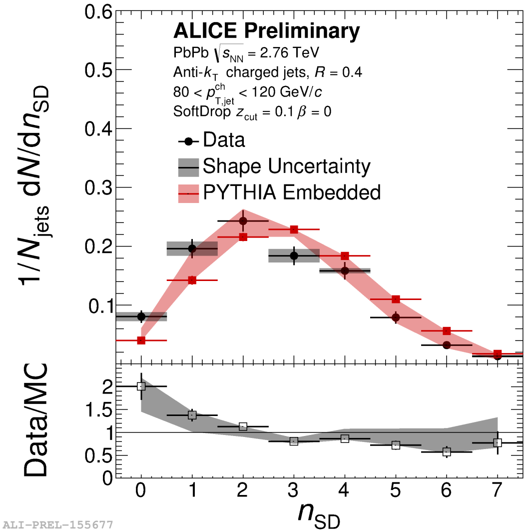

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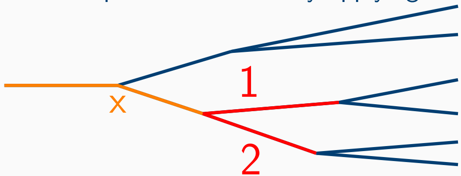

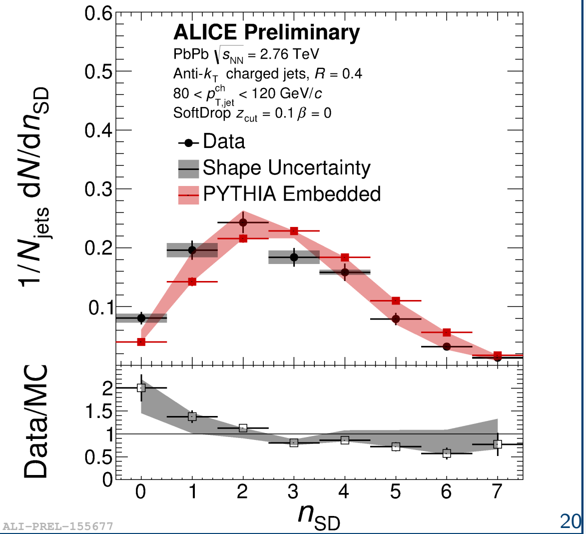

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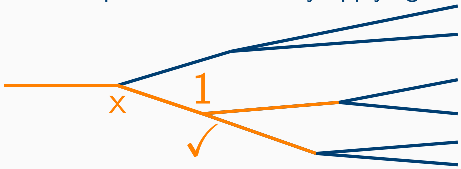

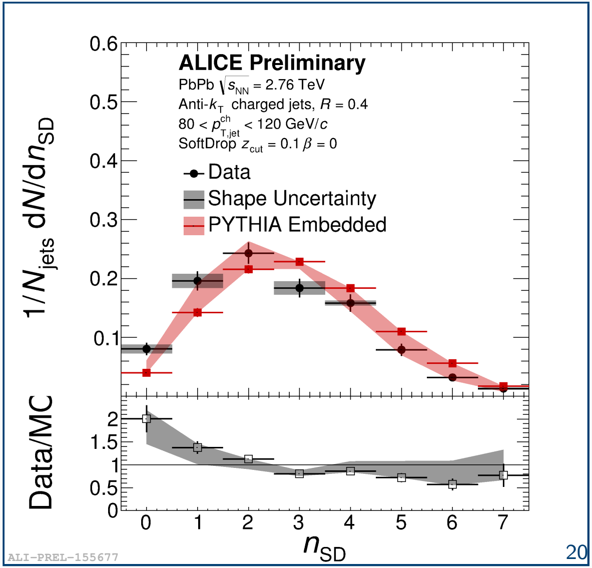

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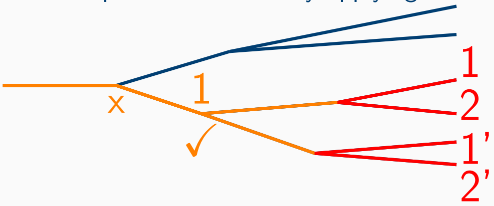

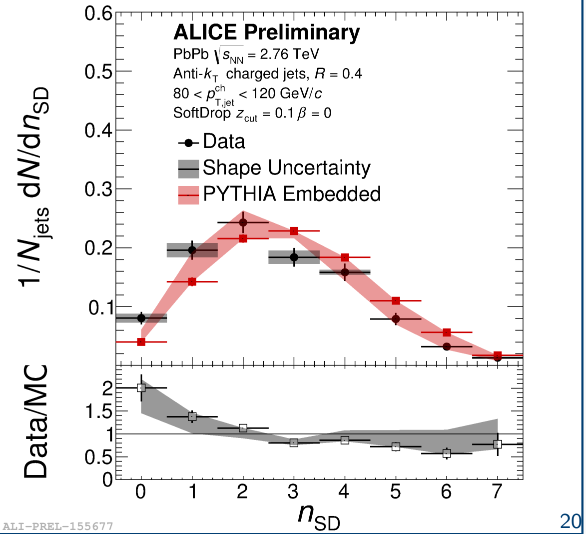

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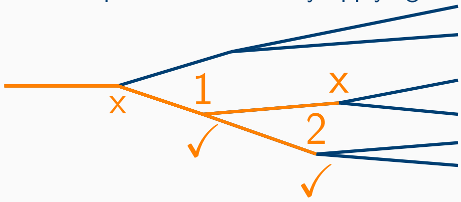

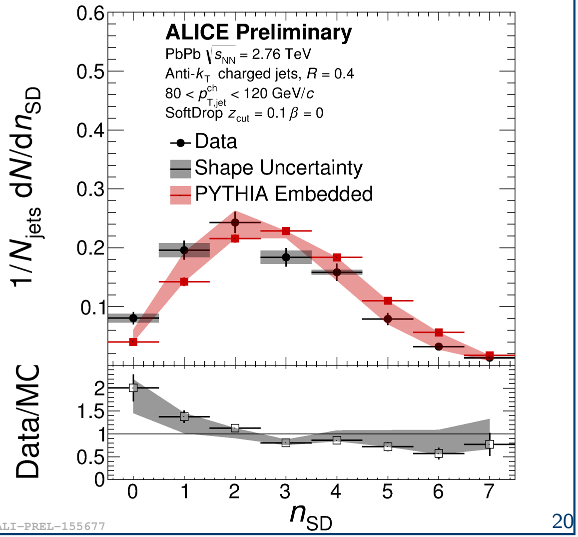

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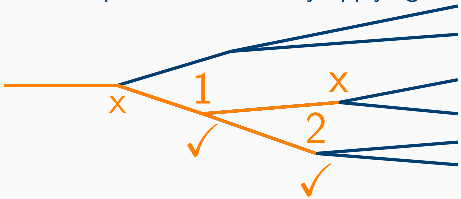
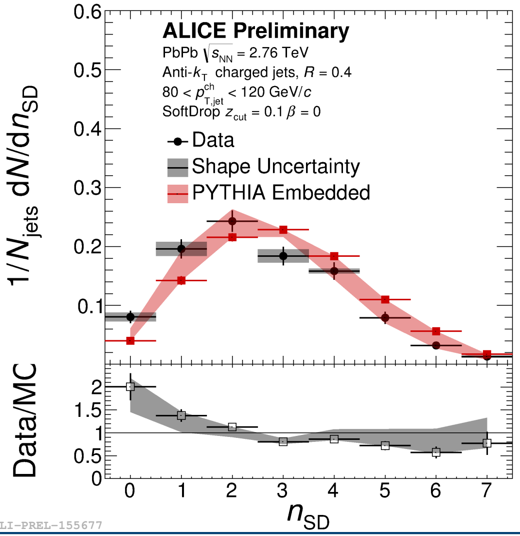
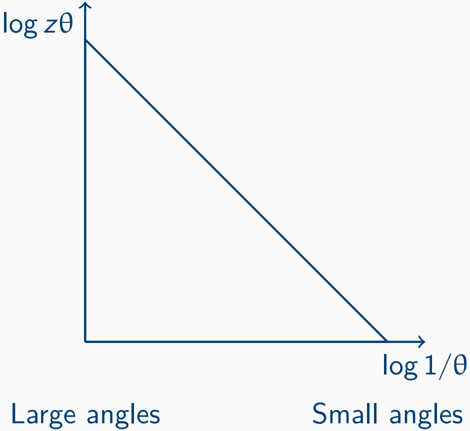


- n_{SD} is the number of splittings that pass the SD condition during Recursive SD.
- Consistent with reference for $n_{SD} > 1$.
- Enhanced number of untagged jets.
  - Different from expectations for correlation medium response.



Lund Diagram

- Enables exploration of the $1 \rightarrow 2$ splitting phase space.
- Can vary z_{cut} and β to select different regions of the phase space.



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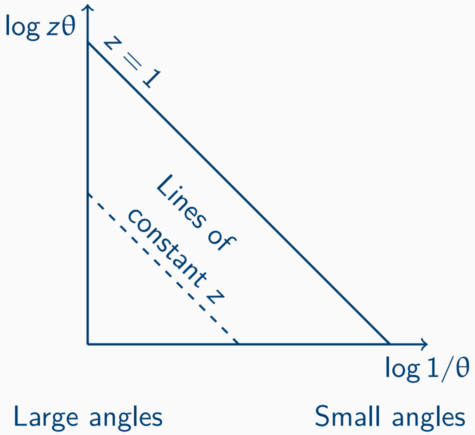

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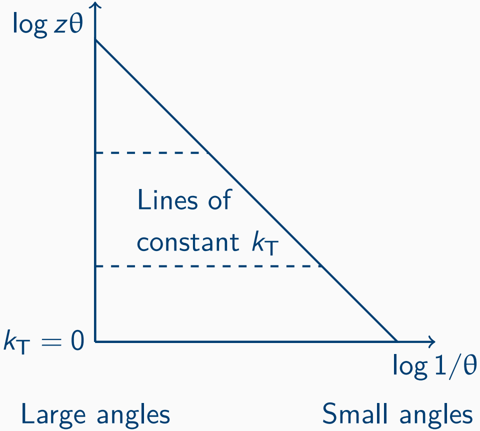

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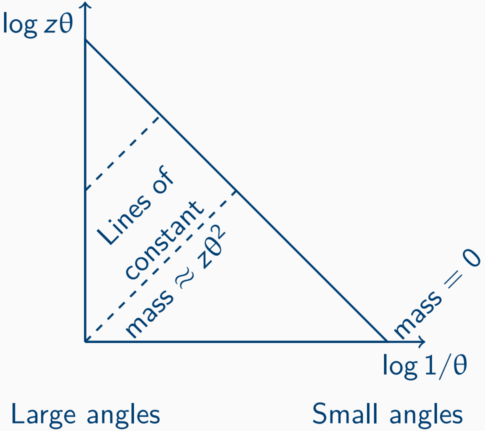

Lund Diagram

- Enables exploration of the $1 \to 2$ splitting phase space.
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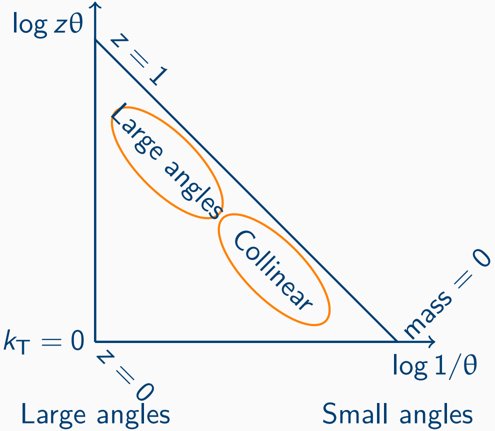
- Large angular separation splittings are expected to be resolved by the medium, resulting in suppression relative to pp.



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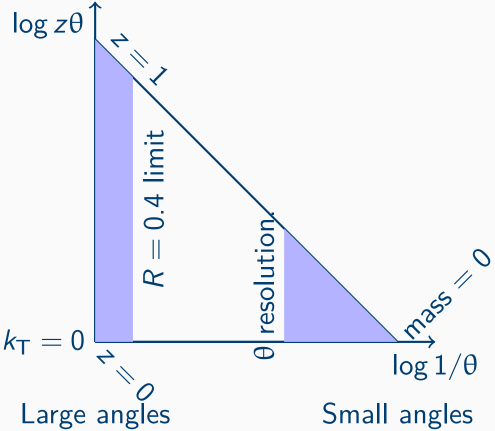

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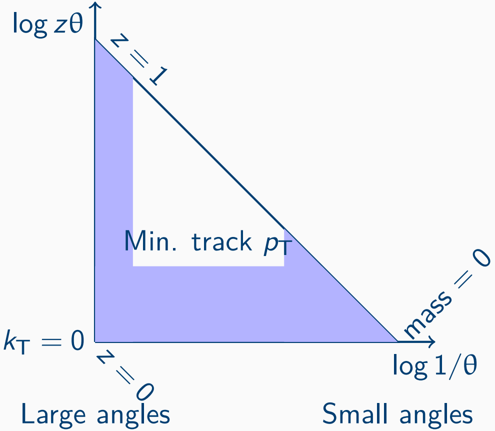

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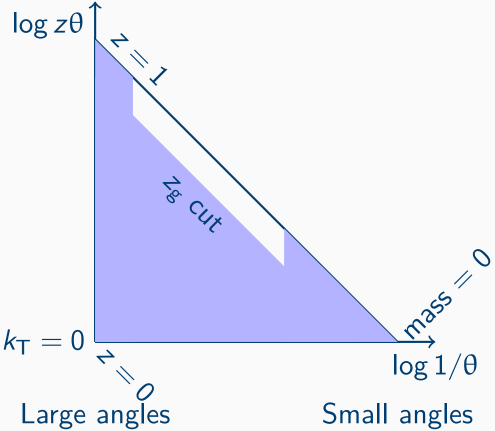
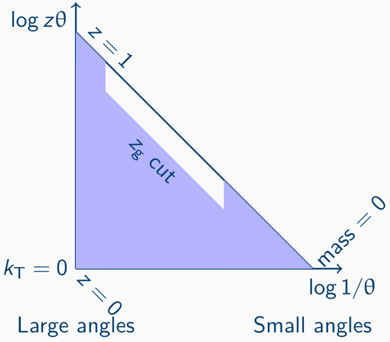
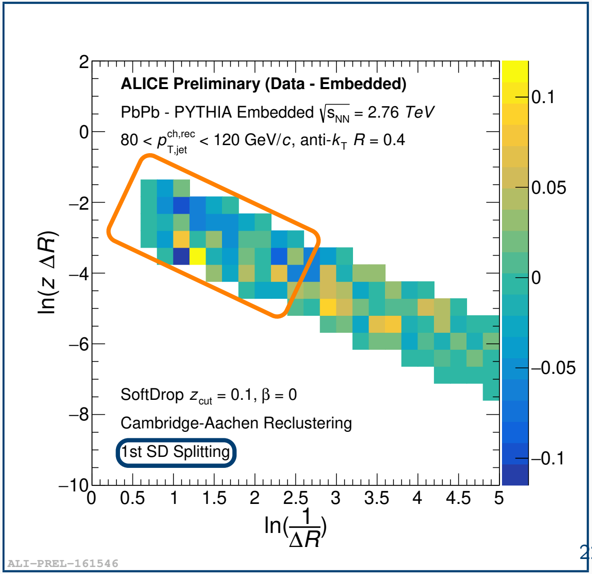


Lund Diagram





- Hint of suppression of large angle splittings.
- Consistent with z_g measurements.

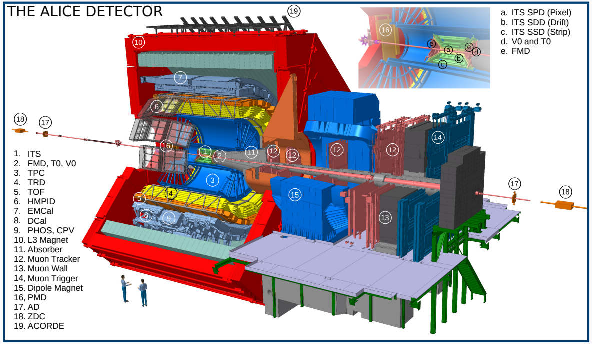
Conclusions

- Inclusive full jet spectra were measured in pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.
- Jet R_{AA} was measured down to 40 GeV/c, showing significant suppression for $R = 0.2$ and 0.4 jets, with a weak increase of the suppression with decreasing p_T for $R = 0.2$ jets.
- z_g was measured in pp collisions at $\sqrt{s} = 13$ TeV, showing no jet p_T dependence except at the lowest $p_{T,jet}$.
- Momentum sharing of two-prong jet substructure exposed via grooming (z_g) was measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, showing suppression of symmetric splittings.

- High statistics Pb–Pb data collected in 2018 will enable more precise measurements. Stay tuned!

Backup

ALICE - A Large Ion Collider Experiment



Calorimetry:

EMCal: $|\eta| < 0.7$, $|\Delta\varphi| < 107°$

DCal: $0.22 < |\eta| < 0.7$, $|\Delta\varphi| < 60°$

→ Remove charged particle contamination

→ Neutral constituents

Tracking:

$|\eta| < 0.9$, $0 < \varphi < 2\pi$

TPC, ITS

→ Charged constituents

→ **Full Jet** ← Neutral constituents