Investigating Hard Splittings via Jet Substructure in pp and Pb–Pb Collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with ALICE

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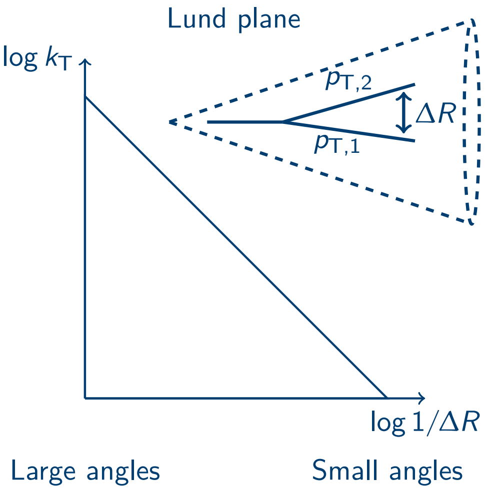
10th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions (Online)

(Groomed) Jet Substructure

- Jet substructure provides access to the evolution of jet splittings.
- Can visualize the splitting phase space via the Lund Plane.
- Three variables define our splittings via the leading (1) and subleading (2) subjets:
  - $\Delta R = \sqrt{(\varphi_1 - \varphi_2)^2 + (\eta_1 - \eta_2)^2}$
  - $z = \frac{p_{\mathrm{T}}^{\mathrm{sublead}}}{p_{\mathrm{T}}^{\mathrm{lead}} + p_{\mathrm{T}}^{\mathrm{sublead}}}$
  - $k_{\mathrm{T}} = p_{\mathrm{T}}^{\mathrm{sublead}} * \sin \Delta R$
- Selecting on these variables provides a lever for exploring the phase space.
- pp: Limit contamination of QCD background.
- Pb–Pb: Select hard component of quenched jets.



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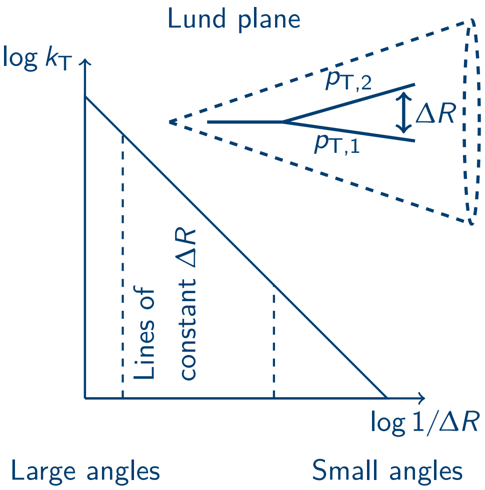

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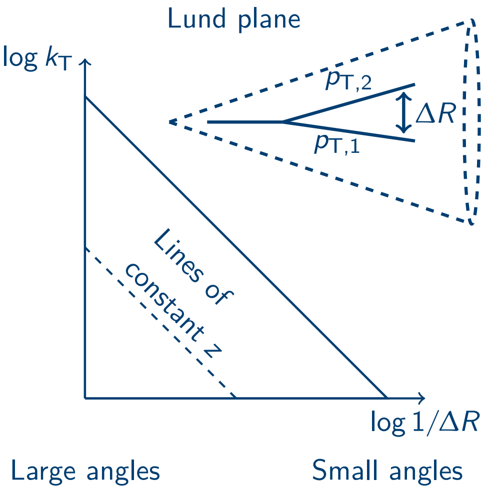

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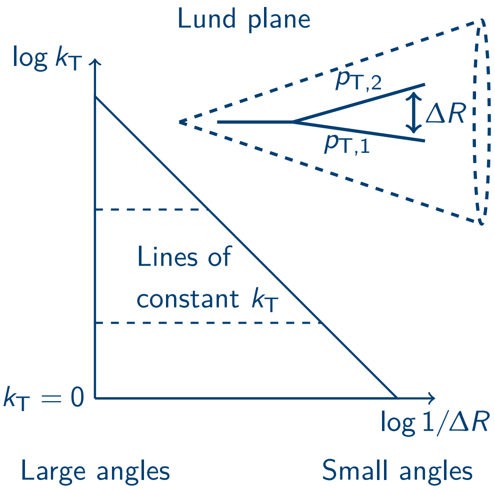
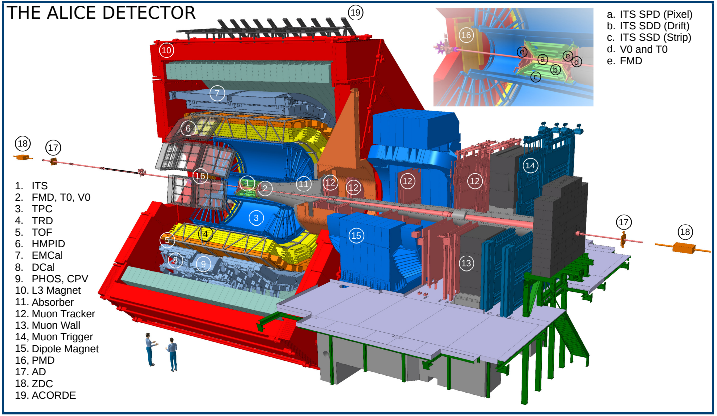


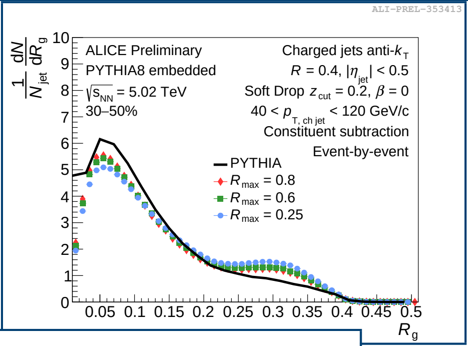
Jet Substructure Measurements in ALICE

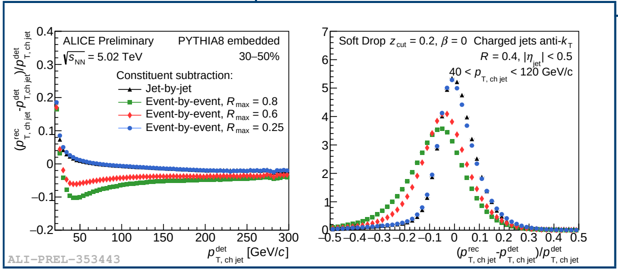
- Jet substructure measurements take advantage of precise ALICE tracking in the ITS and TPC.
  - Provide precise angular resolution down to low p_{T}.
- For these analyses, we measured $R = 0.4$ charged particle jets measured within $|\eta| < 0.9$.
- Jets are measured for $60 < p_{\mathrm{T}\,\mathrm{jet}}^{\mathrm{ch}} < 80$ GeV/c for both 2017 pp and 2018 Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV.



Understanding Background Contributions

- Different strategies used by ALICE to suppress combinatorial background:
  - Measure small R jets.
  - Increase z_{cut}.
  - Measure in semi-central collisions.
    - Reduces jet quenching relative to central, but combinatorial background is heavily suppressed.
  - $\rightarrow$ See **James Mulligan's talk** on Wed. 10:20 for strategies in central collisions.
- Utilize event-wise constituent subtraction JHEP 08 (2019) 175.
  - Parameters optimized for Pb–Pb collisions.

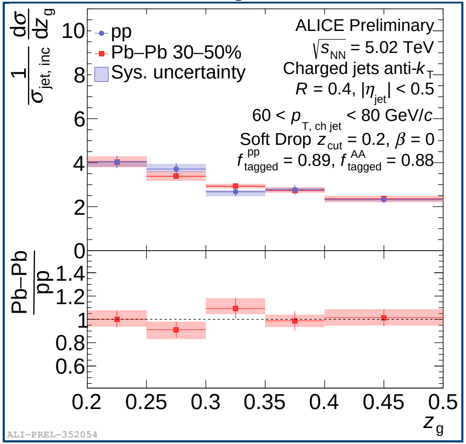




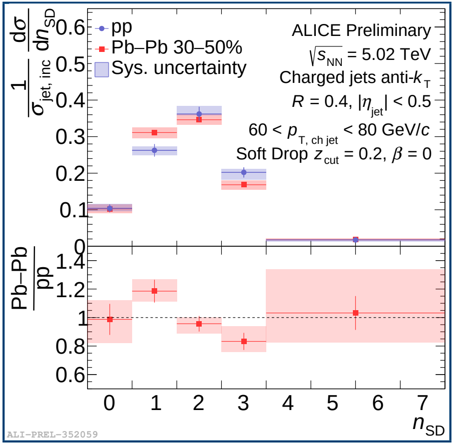
Fully Unfolded z_g, n_{SD} in 30–50% Pb–Pb Collisions

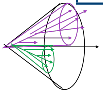
New for HP!

z_g

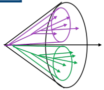


n_{SD}





Consistent with **no modification**.



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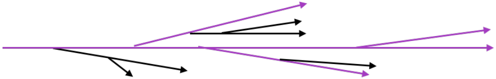
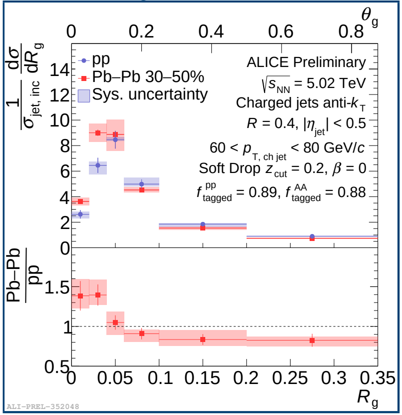


Fully Unfolded R_g in 30–50% Pb–Pb Collisions

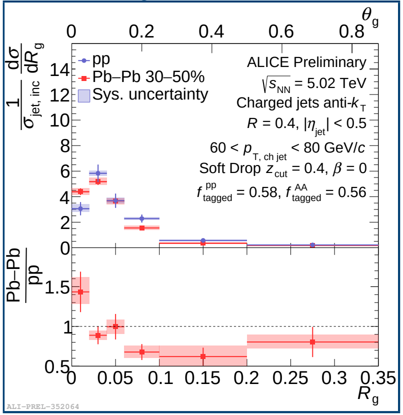
New for HP!

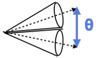
- Suppression of large angles and enhancement of small angles for both z_{cut}.
- Tested for consistency with unity, as determined by χ^2 CDF for sys + stat in quadrature.
  - $z_{cut} = 0.2$: p=0.03
  - $z_{cut} = 0.4$: p=0.029

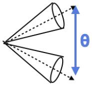
R_g $z_{cut} = 0.2$

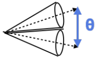


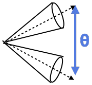
R_g $z_{cut} = 0.4$









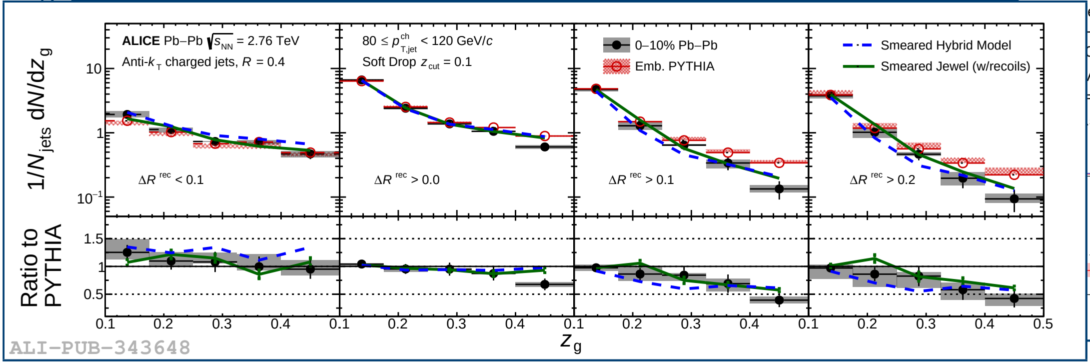


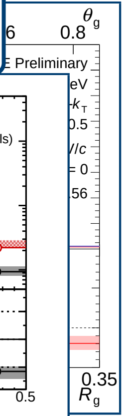
Fully Unfolded R_g in 30–50% Pb–Pb Collisions

New for HP!

More symmetric splittings seem to be more suppressed in agreement with detector level measurements in the $\sqrt{s_{NN}} = 2.76$ TeV data (PLB 2020.135227).

- Supp…
  angle…
-



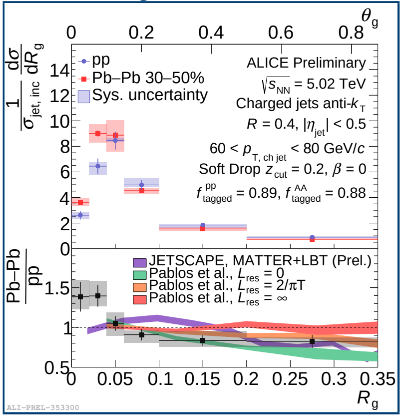


Model Comparisons for R_g in 30–50% Pb–Pb Collisions

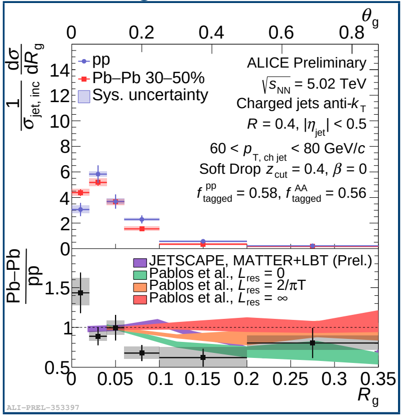
New for HP!

- JETSCAPE: MATTER+LBT arxiv:1903.07706
- Pablos et al. Hybrid model JHEP 01 (2020) 044
  - $L = 0, 2/\pi T, \infty$

R_g $z_{cut} = 0.2$



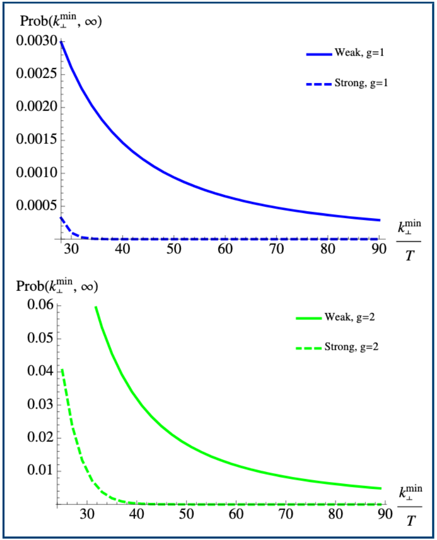
R_g $z_{cut} = 0.4$



James Mulligan, Wed. 10:50 for 0–10%

Jet Substructure as a Tool to Study Medium Structure?/1

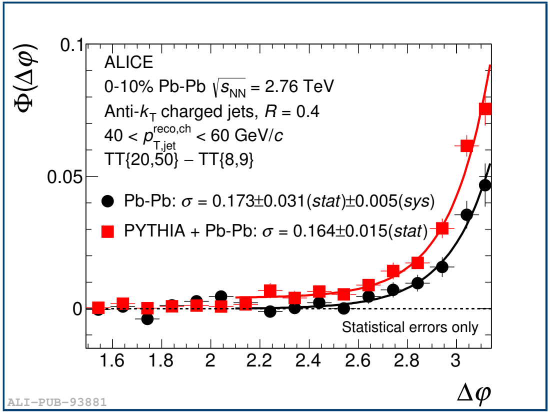
- What is the impact of the medium on jet substructure?
  - Point-like (Moliere) scattering? JHEP 05 (2013) 031, JHEP 01 (2019) 172
- Can we detect with jet substructure observables high-k_{T} emissions which are signature of point-like scatterers in the medium?



JHEP 05 (2013) 031

Jet Substructure as a Tool to Study Medium Structure?/2

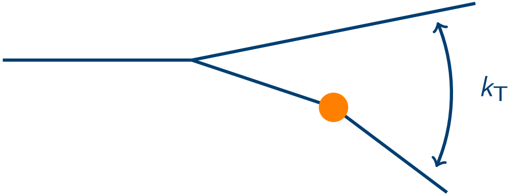
- Searching for signatures of point-like scattering centers in the medium via large-angle hadron-jet decorrelation.
- ALICE has measured large-angle recoil jet deflections in $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV: JHEP 09 (2015) 170.
- Consistent with no acoplanarity of recoil jets within uncertainties.
- ALICE measurements are ongoing in pp and Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV.
  - See Jaime Norman, Monday 12:55.

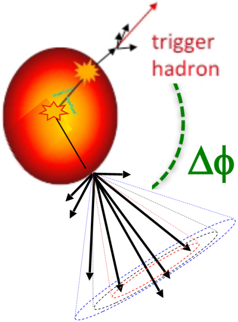


JHEP 09 (2015) 170

Jet Substructure as a Tool to Study Medium Structure?/3

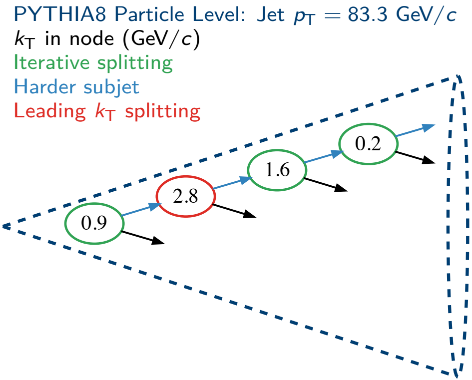
- As an alternative approach, we consider using jet substructure as a tool to search for large angle scatterings.
- If a subjet is deflected at a large angle by a scattering center, it will increase the k_T of that splitting.
  - Point-like scatterers in the medium would appear as an excess of large k_T emissions in Pb–Pb collisions relative to pp collisions.
- Access to the same physics as investigated via hadron-jet decorrelations.





Methods for Extracting Hardest k_{T}

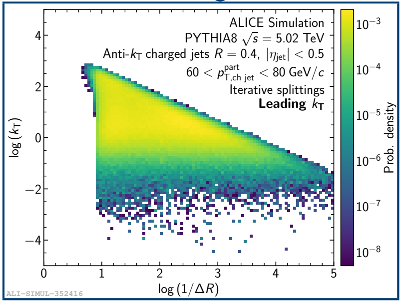
- Use grooming methods to identify the hardest k_{T} splitting in a jet:
  - For each considered splitting i, $k_{\mathrm{T}\,i} = p_{\mathrm{T}\,i} \sin \Delta R_i$
- We compare four main grooming methods:
  - Leading k_{T}: $\max\limits_{i \in \mathrm{C/A}} k_{\mathrm{T}\,i}$
  - Leading k_{T} for all $z > 0.2$ splittings.
  - Dynamical grooming (PhysRevD.101.034004): $\kappa^a = \frac{1}{p_{\mathrm{T}}} \max\limits_{i \in \mathrm{C/A}} \left[z_i (1 - z_i) p_{\mathrm{T}\,i} (\theta_i / R)^a \right]$
    - $a = 1$ - Largest $k_{\mathrm{T}} \sim \kappa^1 p_{\mathrm{T}}$: "$k_{\mathrm{T}}$Drop".
    - $a = 2$ - Shortest splitting time $t_f^{-1} \sim \kappa^2 p_{\mathrm{T}}$: "TimeDrop".



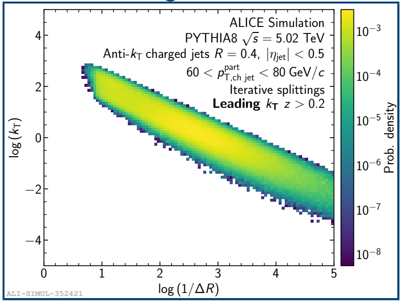
Grooming Method Characteristics/1

Each grooming method has different characteristic behavior in the Lund Plane.

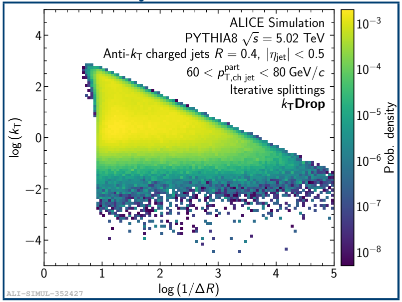
Leading k_T



Leading k_T $z > 0.2$



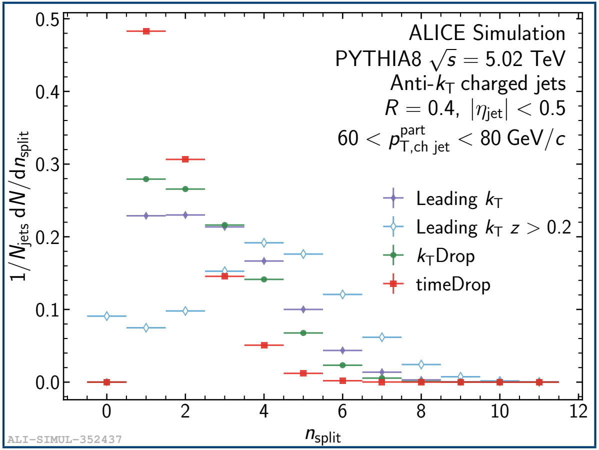
Dynamical k_T



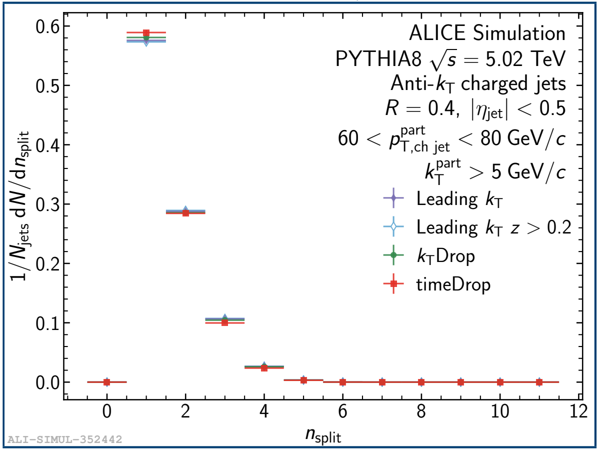
Grooming Method Characteristics/2

Number of splittings until the selected splitting converges at high k_T.

k_T inclusive



$k_T > 5$ GeV/c

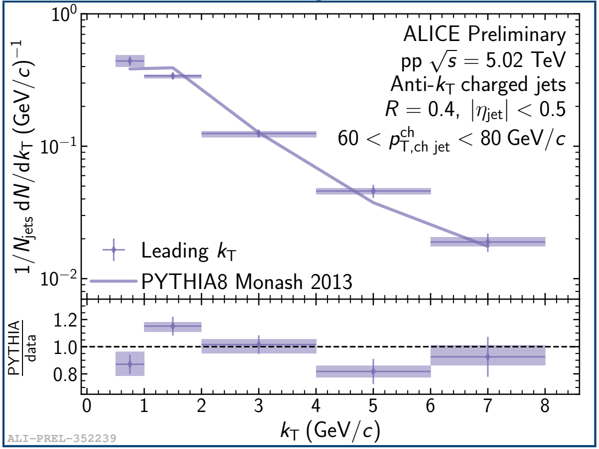


Hardest k_T Measured in pp Collisions

New for HP!

- k_T follows characteristic steeply falling shape.
- PYTHIA in broad agreement with the data.

Leading k_T



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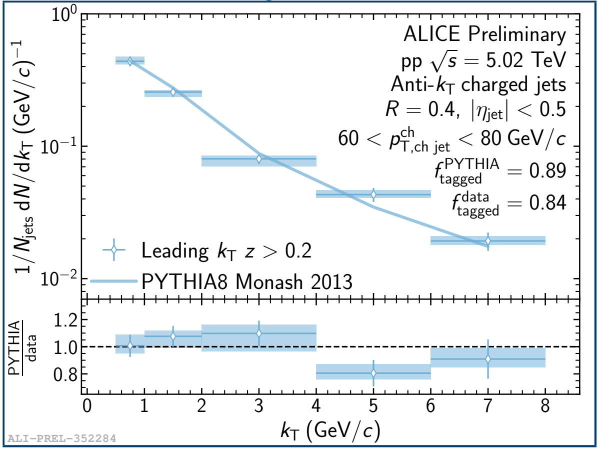
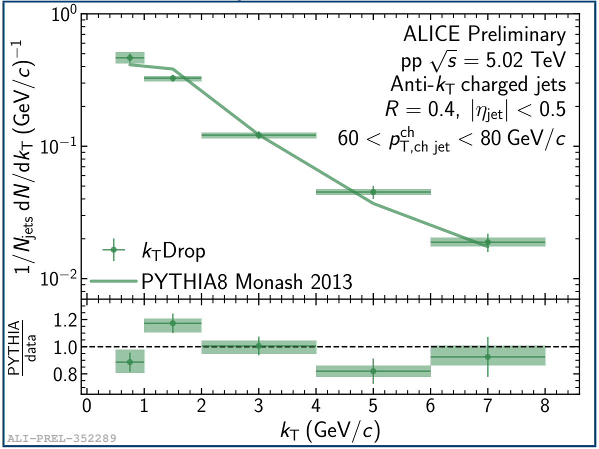


Hardest k_T Measured in pp Collisions

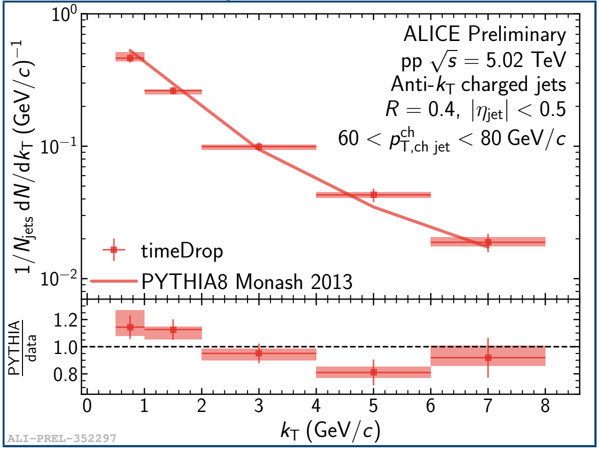
New for HP!

- Dynamical grooming methods show same trends.
- PYTHIA in broad agreement with the data.

Dynamical k_T



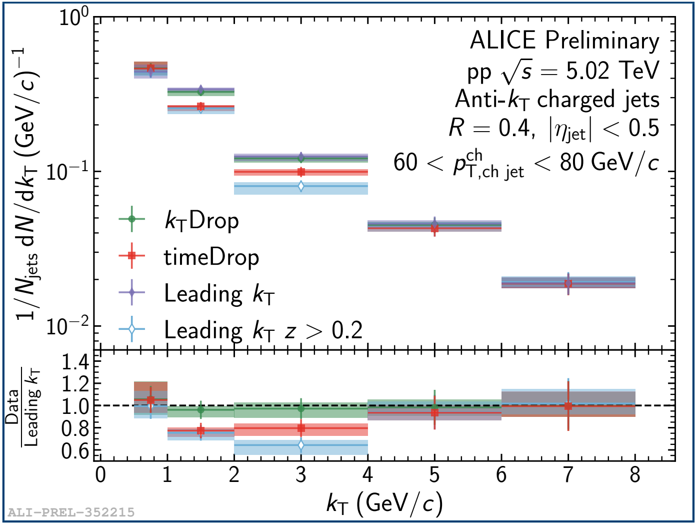
Dynamical time



Comparison Between Grooming Methods

New for HP!

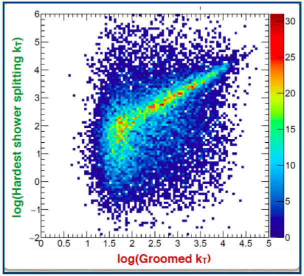
- Comparison of the different grooming methods in pp collisions.
- Ratio is relative to leading k_T.
- At low-mid k_T there is some divergence between the methods.
- All grooming methods converge at high k_T.
- The exact same splitting is selected by all methods at very high k_T.



Toward Hardest k_T in Pb–Pb

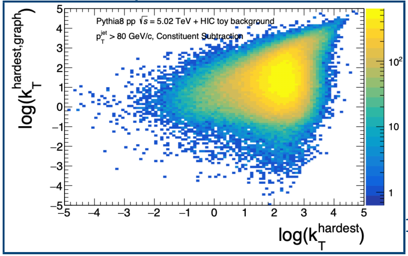
- To access feasibility in Pb–Pb, study the correlation between the hardest k_T splitting in the parton graph and from declustering at particle level.
  - Identified the hardest k_T graph, and then performed declustering for $R = 0.8$ jets.
- Compare pythia graph vs:
  - Particle level PYTHIA (as crosscheck).
  - Particle level PYTHIA + thermal background.
- **Strong correlation** between the hardest emission and the hardest splitting at large k_T.
- Studied at EMMI RRTF Workshop on the space-time structure of jet quenching.

PYTHIA part. level



Y. Chen @ EMMI

PYTHIA part. level + thermal



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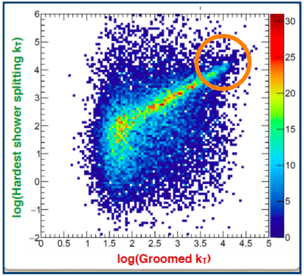

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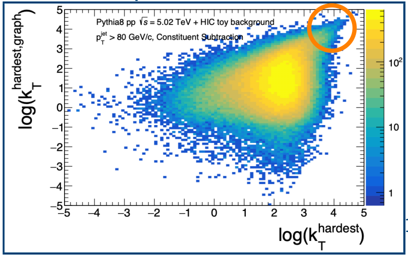
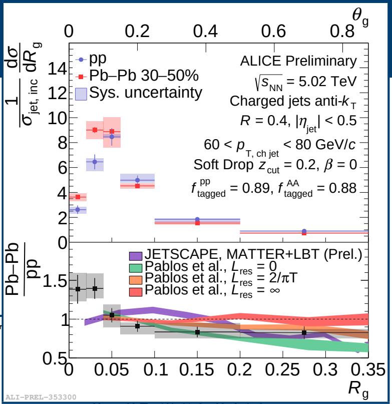
PYTHIA part. level + thermal

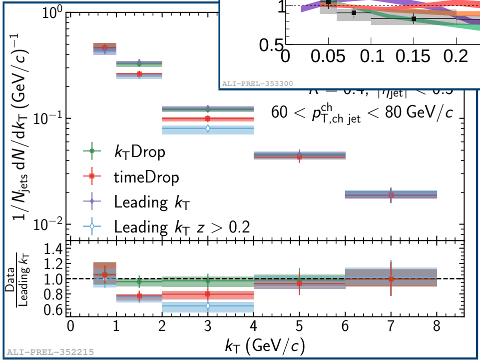


Summary and Outlook

- Measured z_g, R_g, and n_{SD} in 30–50% Pb–Pb and pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV.
  - z_g, n_{SD} consistent with no modification.
  - R_g shows **enhancement at small angles** and **suppression at large angles**.
    - Both for $z_{cut} = 0.2$ and 0.4.
- Measured hardest k_T splittings in pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV.
  - Grooming methods **converge** at high k_T.
  - PYTHIA broadly consistent with data.

- Hardest k_T in Pb–Pb **in progress**.
- Further exploration of larger R jets, jet splitting structure, and grooming methods.

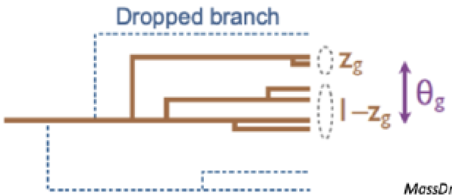




Backup

Jet Substructure Grooming

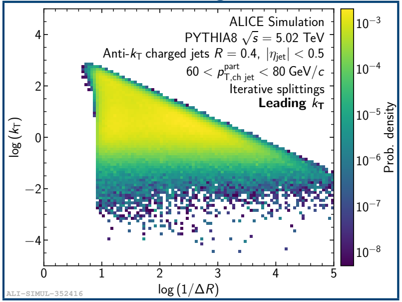
- Groomed jet substructure serves different purposes in pp vs Pb–Pb collisions.
- In pp: Limit contamination of QCD background (and pileup) in a controlled way while retaining bulk of perturbative radiation
- In Pb–Pb: Select hard component of quenched jets.
  - This isolates medium effects, making them easier to calculate.



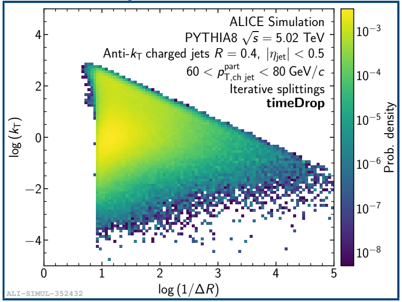
MassDrop/SoftDrop
M.Dasgupta et al, JHEP1309 (2013) 029
A.Larkoski et al, JHEP 1405 (2014) 146

Grooming Method Characteristics - Lund Planes

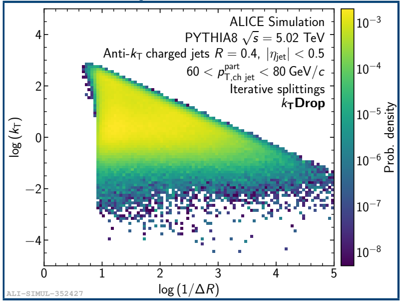
Leading k_T



Dynamical time

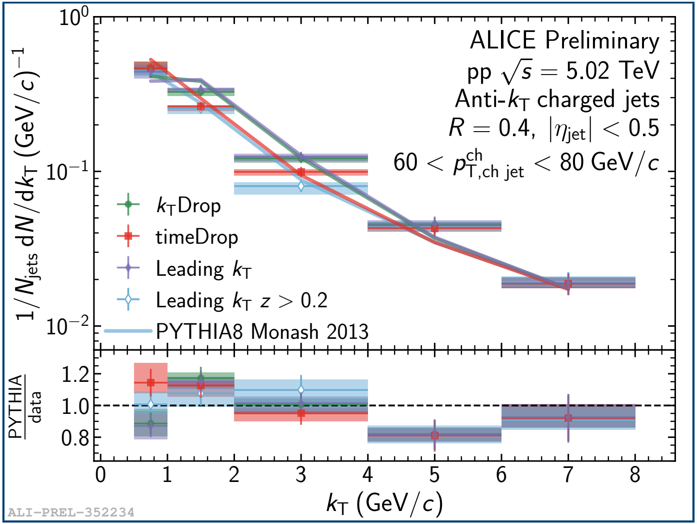


Dynamical k_T



Comparison to PYTHIA

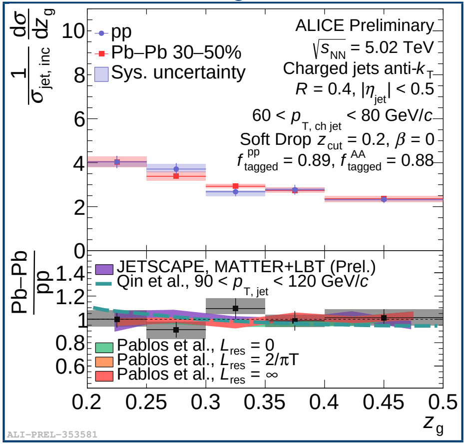
- Comparison of the grooming methods to PYTHIA 8.
- PYTHIA broadly consistent with data within statistical and systematic uncertainties.
- Some hints of shape differences between PYTHIA and the data.
  - Hints are consistent for different grooming methods.



Model Comparisons for z_g, n_{SD} in 30–50% Pb–Pb

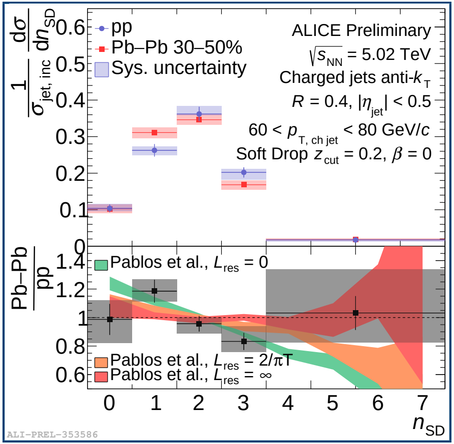
New for HP!

z_g



Consistent with **no modification**.

n_{SD}



Consistent with **no modification**.