A Novel Reclustering Algorithm for Jet Quenching

André Cordeiro

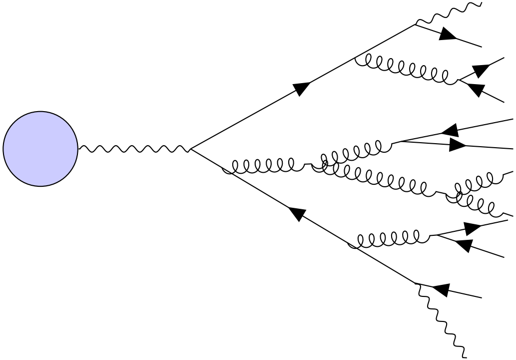
Based on: "Time reclustering for jet quenching studies"
(L. Apolinário, A. Cordeiro, K. Zapp) Eur. Phys. J. C 81, 561 (2021)

5 September, 2021

QGP and Parton Showers

Parton Showers

- QCD shower as a series of emissions over a wide range of scales.
- One can construct jets — Multi-scale observables.



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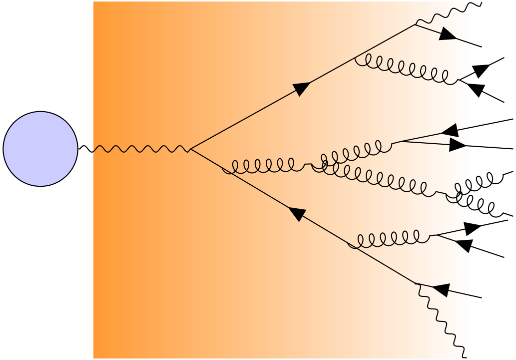
- QCD emissions + Expanding medium → jets encode the integrated effects of medium evolution.



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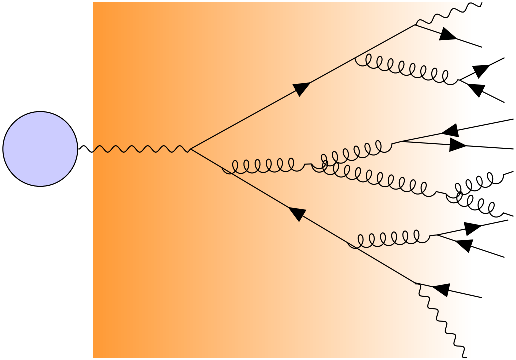

Probing jet substructure may allow for precision measurements of QGP structure.

Jet Reconstruction and Subtructure

Jet Clustering

Sequential Algorithms

- Jet: Cluster of final-state particles.

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Sequential algorithms: Minimise distance iteratively.

$$d_{ij} = \min(p_{\mathrm{T,i}}^{2p}, p_{\mathrm{T,j}}^{2p}) \left(\frac{\Delta R_{ij}}{R}\right)^2$$

$$p = 0 : \mathrm{Cambridge - Aachen}$$
$$p = -1 : \mathrm{Anti - k_T}$$
$$p = 1/2 : \tau$$

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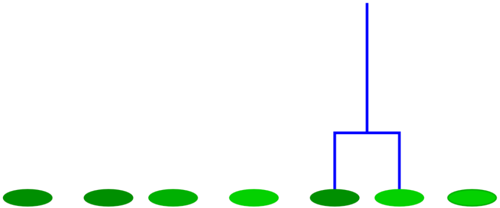

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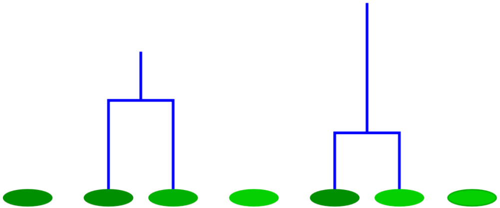

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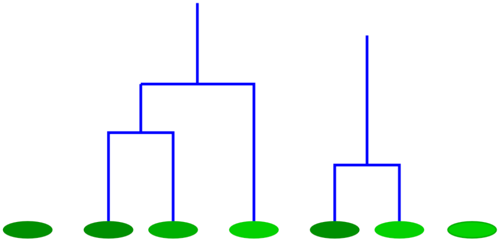

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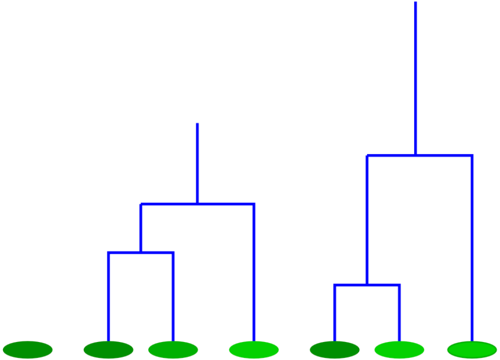

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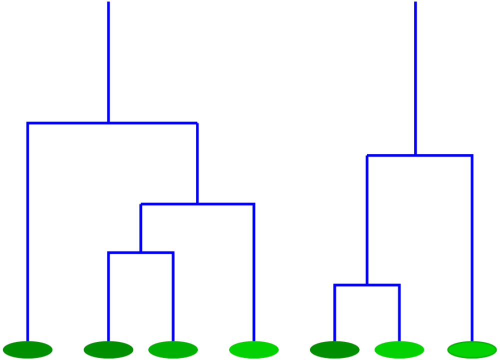

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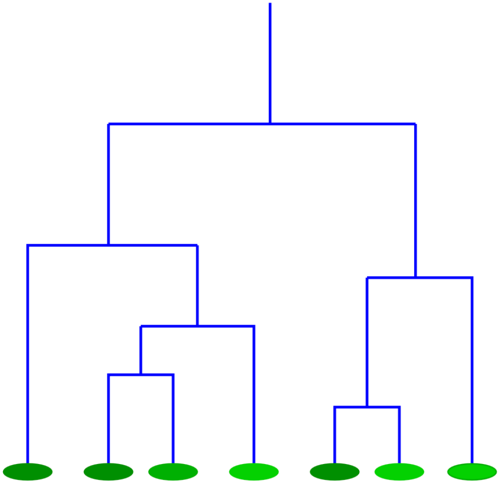

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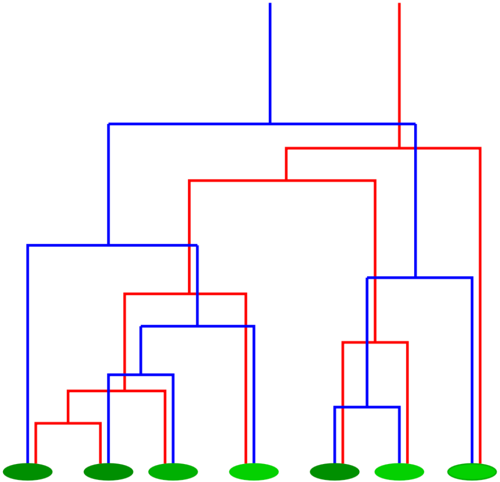

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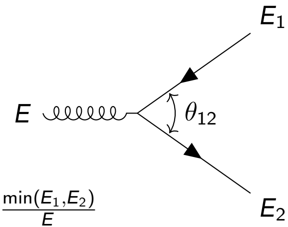

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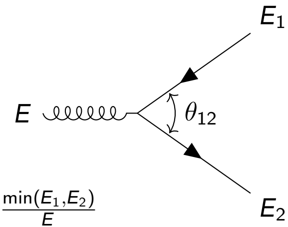

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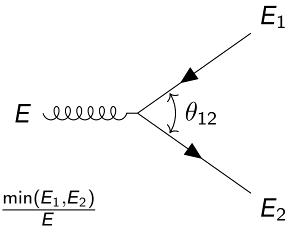

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From now on called the τ algorithm, can be used for jet reclustering.

Monte Carlo Analysis

Sampled jet populations using vacuum references (PYTHIA8 + JEWEL Vac) and jet quenching (JEWEL w/ rec and JEWEL w/o rec).

Different orderings crucial in evaluating algorithm performance: k_T-ordering (PYTHIA8), Q^2 ordering (JEWEL vacuum), Q^2 ordering + τ_{form} veto (JEWEL medium).

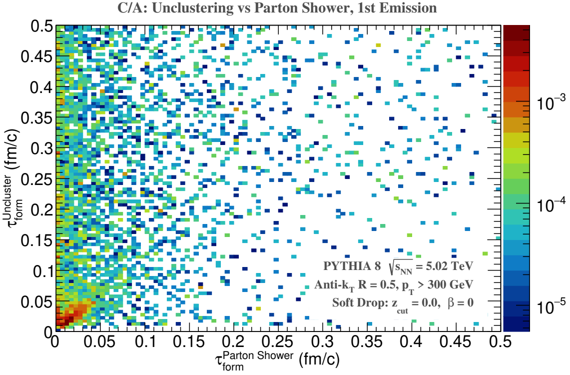
Hard scattering tuned for dijet events at $\sqrt{s_{NN}} = 5.02$ TeV, trigger on leading jet.

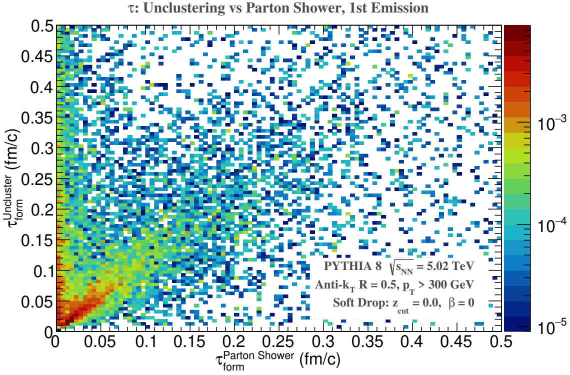
Analysis of jets with $p_T > 300$ GeV and $|\eta| < 1.0$.

Quenching effects achieved by a medium model + Bjorken expansion, with $\tau_{\text{init}} = 0.4$ fm/c and $T_{\text{init}} = 0.44$ GeV.

Jet substructure & Parton Shower history

Correlation of 1st splitting time





Look at correlations between proxies for τ_{form}:

- $\tau_{form}^{Uncluster}$: Jet Variable.
- $\tau_{form}^{PartonShower}$: Monte Carlo Variable.

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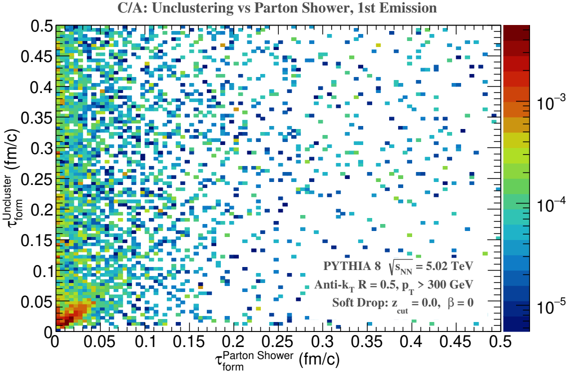

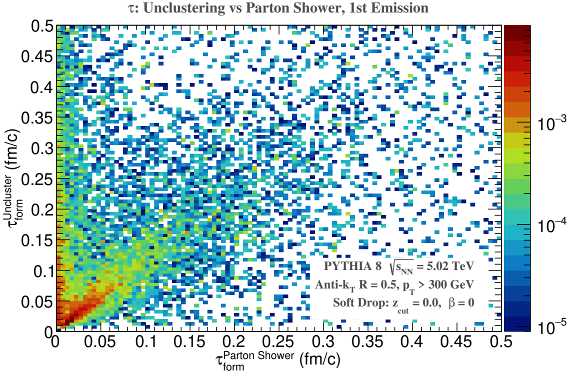

- **Diagonal:** Correlation.
- **Vertical:** Emissions outside of jet cone.

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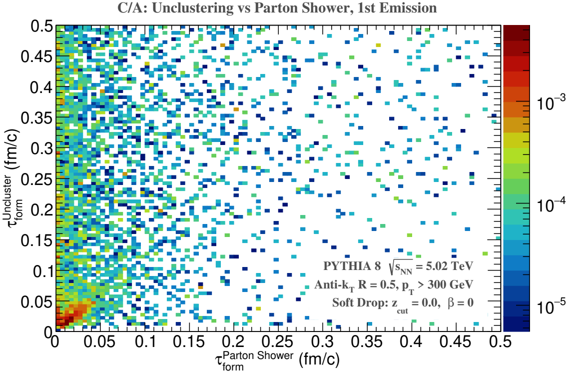
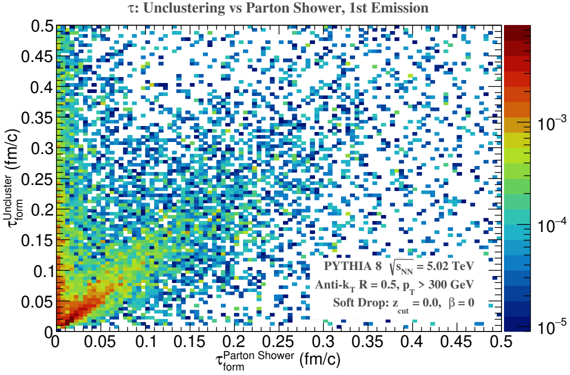
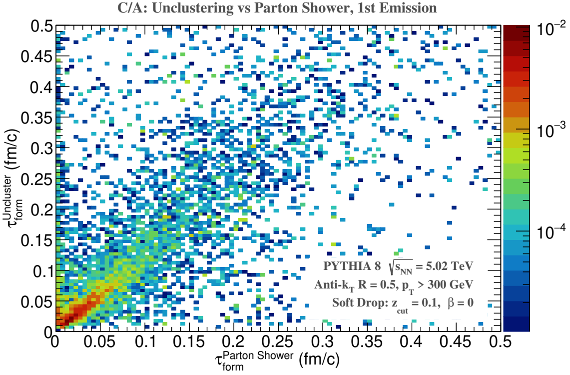
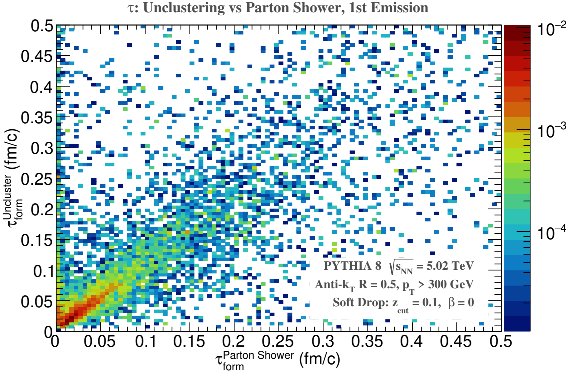




Apply SoftDrop: $$z_g = \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut}\,, \quad \text{with } z_{cut} = 0.1\,.$$

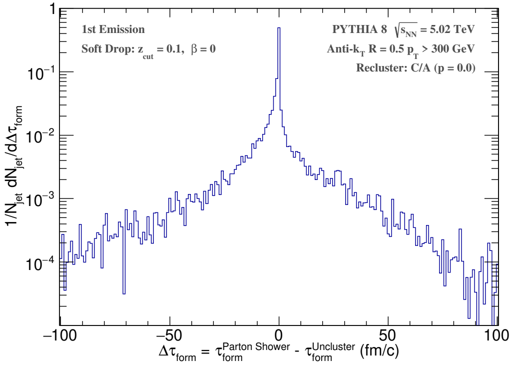
Correlation of 1^{st} splitting time — Groomed Jets





Grooming improves considerably the obtained correlation.

- Consider the distribution of $\Delta\tau_{form} \equiv \tau_{form}^{PartonShower} - \tau_{form}^{Uncluster}$.



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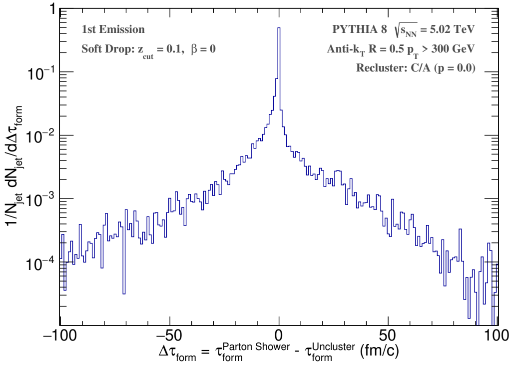

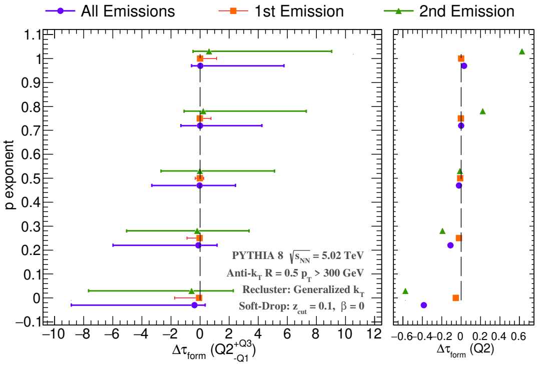

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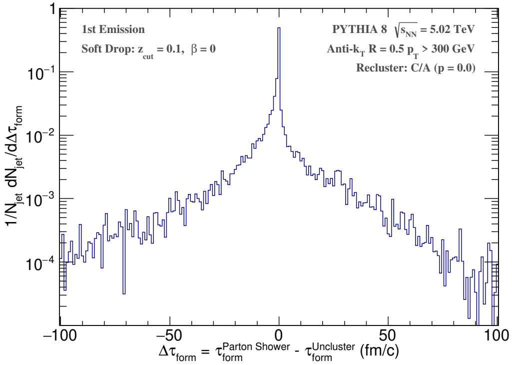

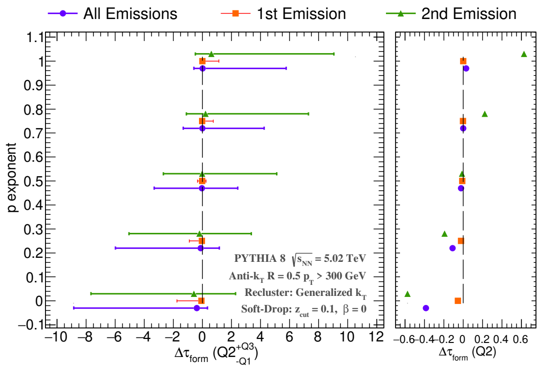

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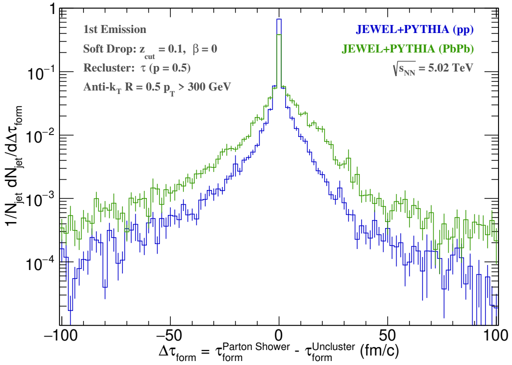
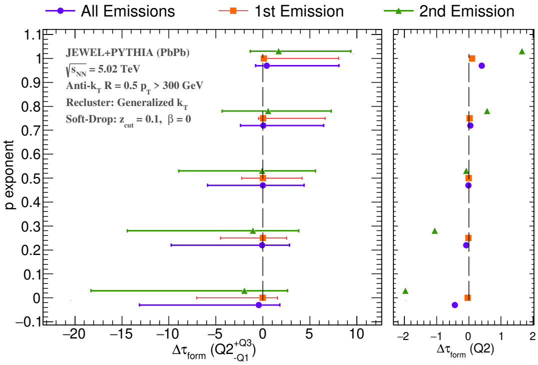
The τ algorithm returns the most centred distributions for PYTHIA8.

Comparing the Generalised-k_T Algorithms

Medium Distributions

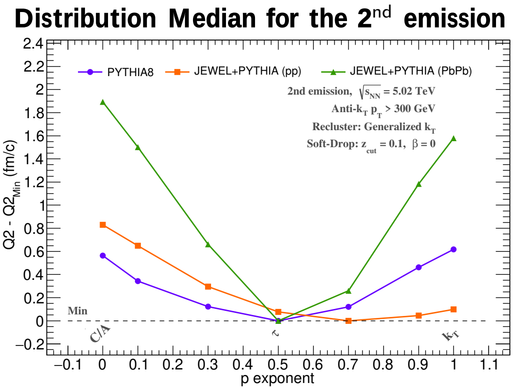
- **For medium-modified jets the distributions widen, but the trend remains.**

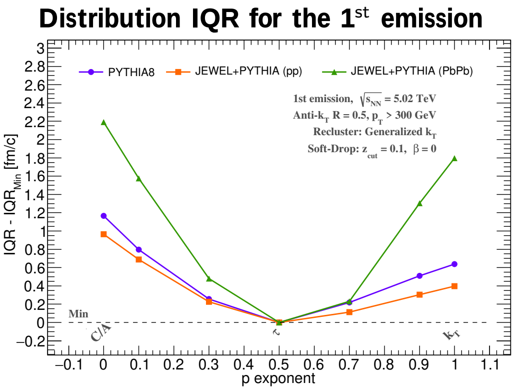




Comparing Monte-Carlo Event Generators

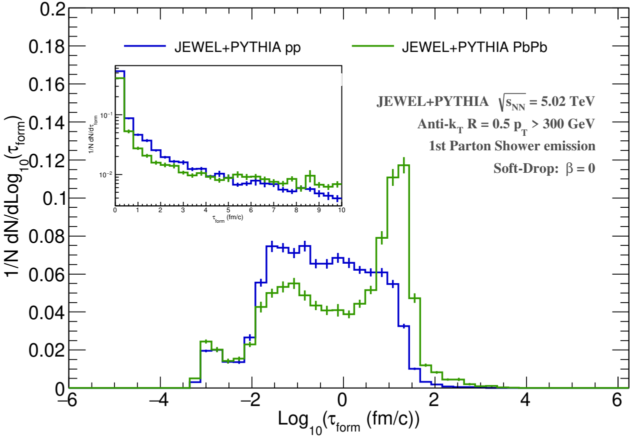
Median and IQR dependence on the algorithm





- Generally, the τ algorithm minimizes both the median and the width of the $\Delta\tau_{form}$ distribution.

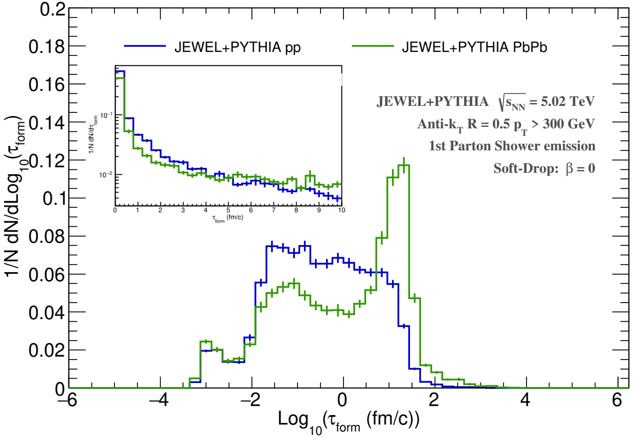
Applications to Jet Quenching Studies



- Longer $\tau_{\text{form}} \longleftrightarrow$ Harder fragmentation.
- Jets with harder fragmentation more likely to stay in the $p_T > 300$ GeV region.

Jet Quenching by the QGP

Jet Quenching Classifier



- Longer τ_{form} $\longleftrightarrow$ Harder fragmentation.
- Jets with harder fragmentation more likely to stay in the $p_{\text{T}} > 300$ GeV region.
- Can select different jets using the τ_{form} variable.

To study shower interactions with the QGP, we introduce the nuclear modification factor,

$$R_{AA}(p_{\mathrm{T}}) = \frac{N_{\mathrm{evt}}^{pp}}{N_{\mathrm{evt}}^{AA}} \frac{dN_{\mathrm{jet}}^{AA}/dp_{\mathrm{T}}}{dN_{\mathrm{jet}}^{pp}/dp_{\mathrm{T}}},$$

as the ratio of leading jet yields in vacuum (proton-proton collision) and medium (Pb-Pb collision).

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as the ratio of leading jet yields in vacuum (proton-proton collision) and medium (Pb-Pb collision).

Compute R_{AA} for different jet populations:

- "Early jets" — $\tau_{\mathrm{form}} < 1$ fm/c
- "Late jets" — $\tau_{\mathrm{form}} > 3$ fm/c

Jet Quenching by the QGP

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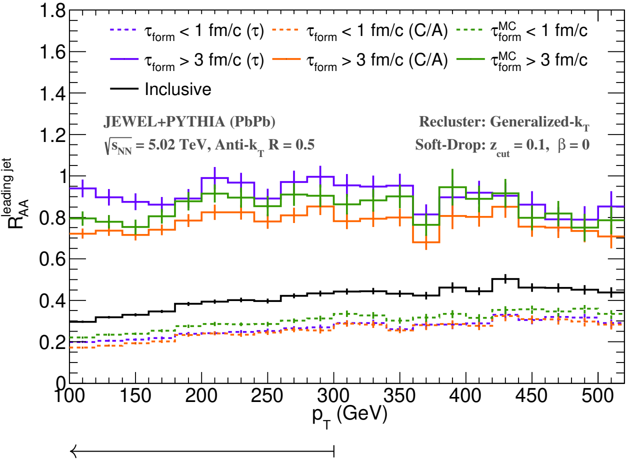

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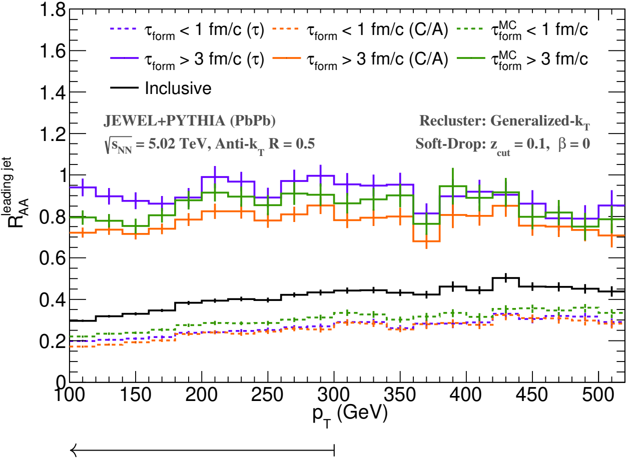

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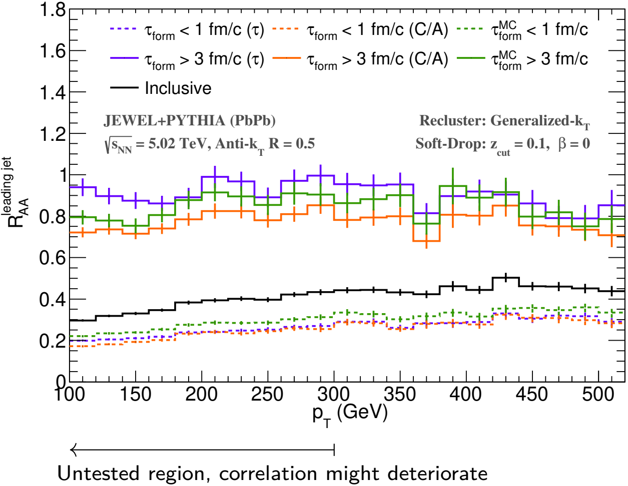

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τ algorithm can be used as a jet quenching classifier.

Summary

- With an appropriate choice of parameters, the generalized-k_T ($p = 0.5 \Rightarrow \tau$) algorithms can be used to produce a jet history (mostly) ordered in time.

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Summary

- With an appropriate choice of parameters, the generalized-k_T ($p = 0.5 \Rightarrow \tau$) algorithms can be used to produce a jet history (mostly) ordered in time.

- With the use of grooming techniques, τ clustered jets show an improvement over C/A.

- A more accurate estimation of τ_{form} provides an inclusive jet-quenching classifier, allowing for precision QGP studies.

Backups

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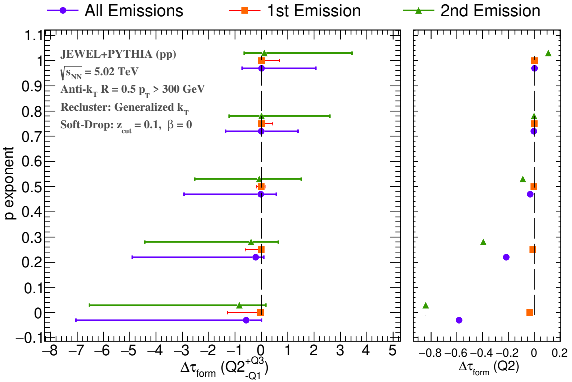
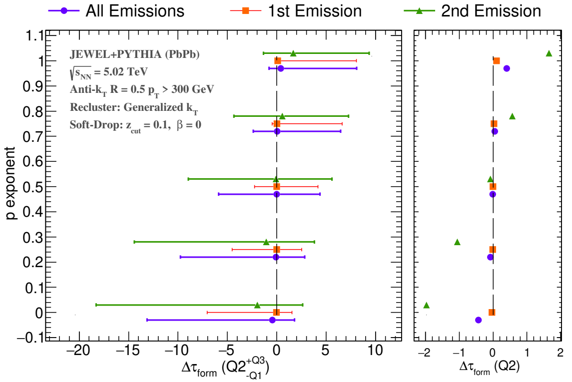


JEWEL+PYTHIA (pp)

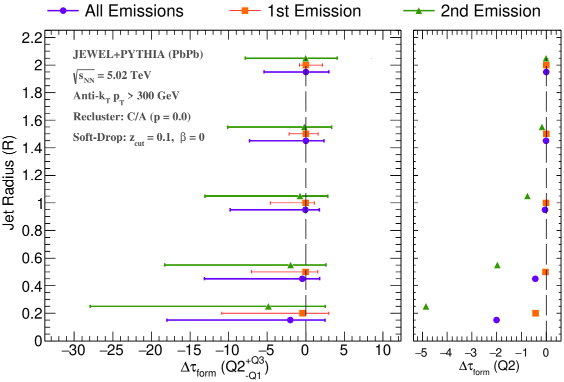


JEWEL+PYTHIA (PbPb)

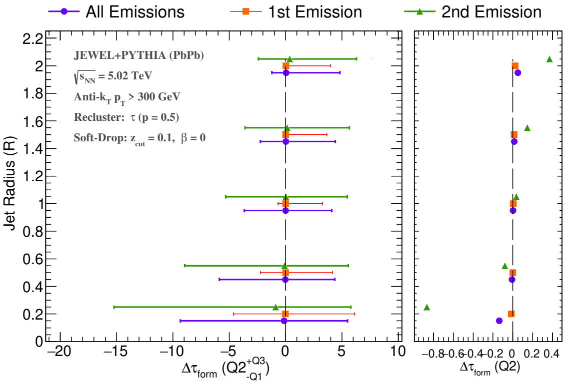
Reclustering algorithms other than C/A produce a more centered $\Delta\tau_{\text{form}}$ distribution, especially for the second emissions, allowing for more accurate substructure.

Impact of the Grooming Parameters

Correlation as a function of the Jet Radius



C/A reclustering

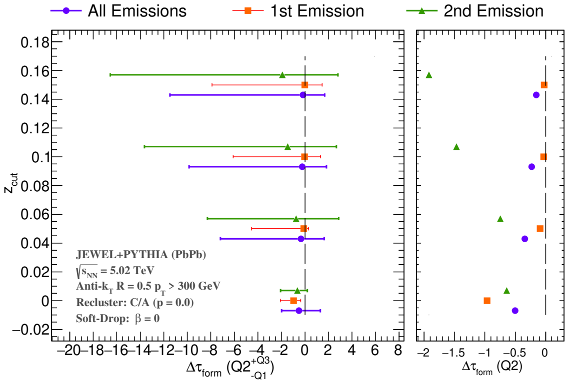


τ reclustering

A jet radius of $R = 1$ seems to be a good compromise for both algorithms.

Impact of the Grooming Parameters

Correlation as a function of z_{cut}



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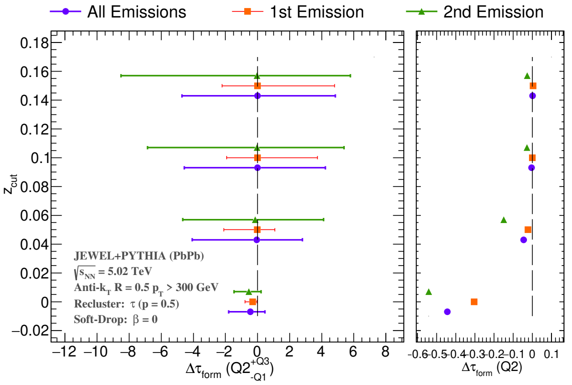
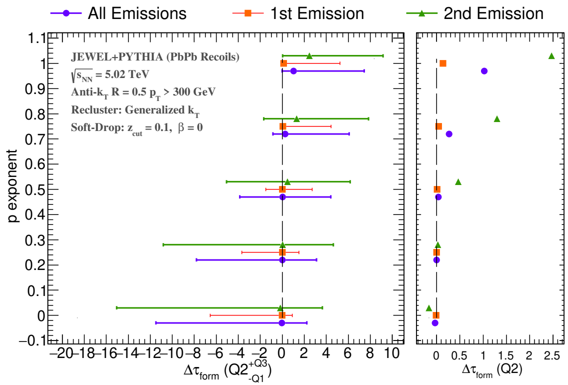


τ reclustering

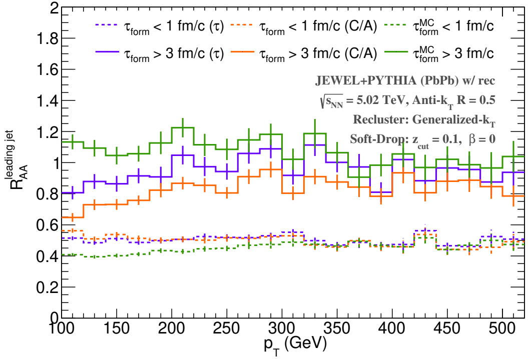
Generally, increasing z_{cut} shifts the distribution to $\Delta\tau_{form} \sim 0$, while also broadening it.

JEWEL PbPb with Medium Recoils

Evolution of $\Delta\tau_{form}$ and jet quenching



Evolution of $\Delta\tau_{form}$



Nuclear modification

When medium recoils are turned on, the nuclear modification effects are even more noticeable.