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

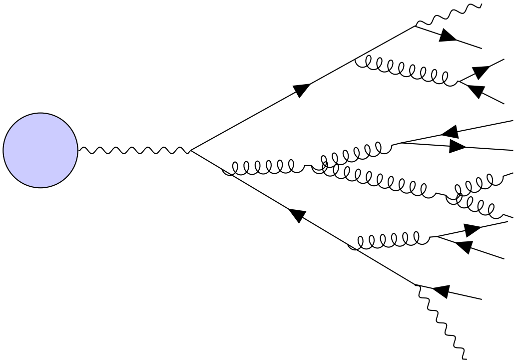
LIP

TÉCNICO LISBOA

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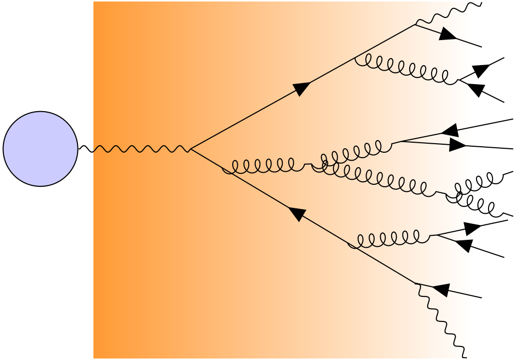
- QCD emissions + Expanding medium → jets encode the integrated effects of medium evolution.



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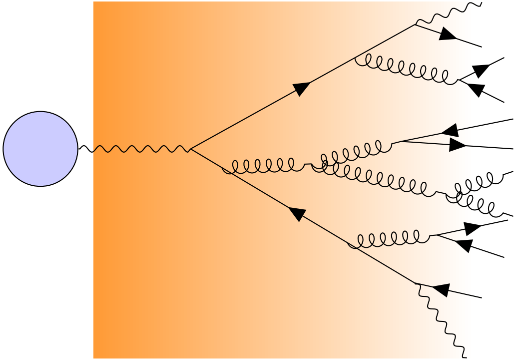

Probing jet substructure may allow for precision measurements of QGP structure.

Jet Reconstruction and Subtructure

Jet Clustering
Sequential Algorithms

- Jet: Cluster of final-state particles.

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Sequential Algorithms

From: K. Zapp, INT 21-2b 2021

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Sequential algorithms: Minimise distance iteratively.

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

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

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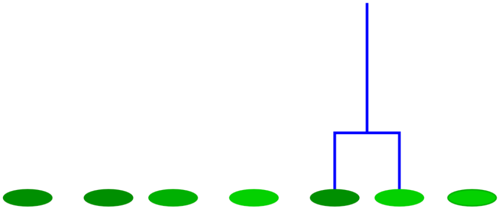

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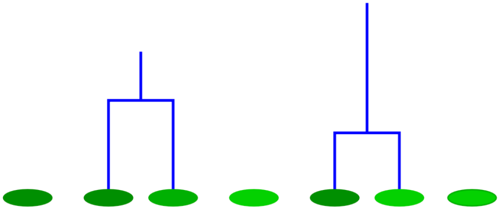

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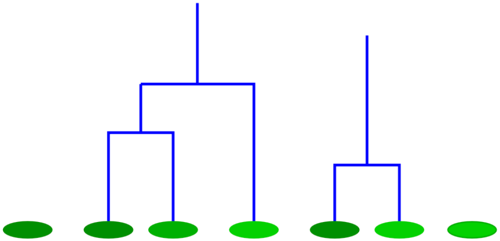

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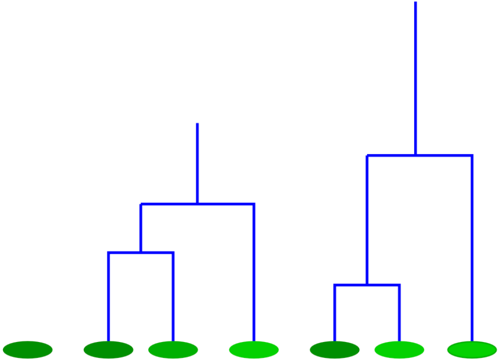

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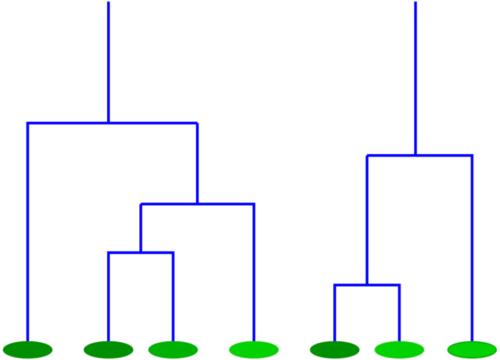

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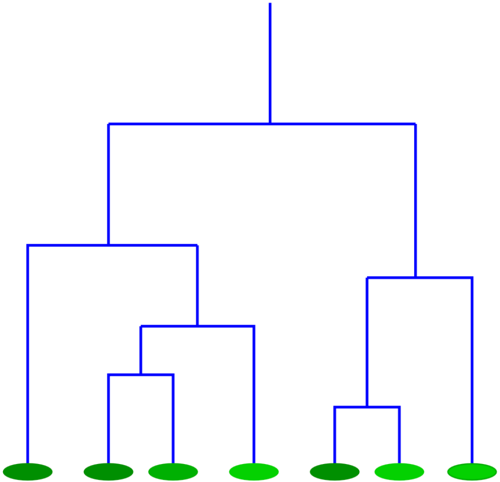

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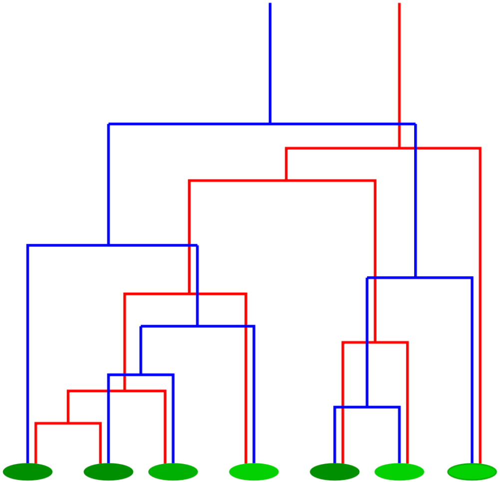

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Estimating Time Scales

The Formation Time

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\begin{aligned}
\tau_{\text{form}} &\propto \frac{1}{Q}\frac{E}{Q} \approx \frac{E}{E_1 E_2 (1-\cos\theta_{12})} \\
&\propto \frac{1}{z(1-z)E(1-\cos\theta_{12})} \approx \\
&\propto \frac{1}{\min(p_{T1}, p_{T2})\,\theta^2}\,.
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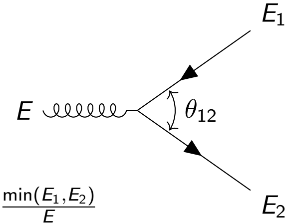

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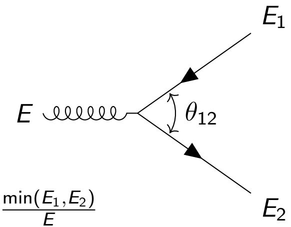

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Since $\Delta R_{ij} \sim \theta$ and $d_{\text{ij}} \propto \min(p_{\text{T,i}}^{2p}, p_{\text{T,j}}^{2p})\,\Delta R_{ij}^2$,

the clustering algorithm with $p = 1/2$ produces jets ordered in τ_{form}^{-1} .

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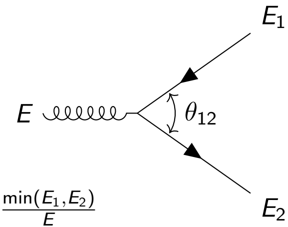

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From now on called the τ algorithm, can be used for jet reclustering.

Monte Carlo Analysis

Monte Carlo Event Generators

Initialization and 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).

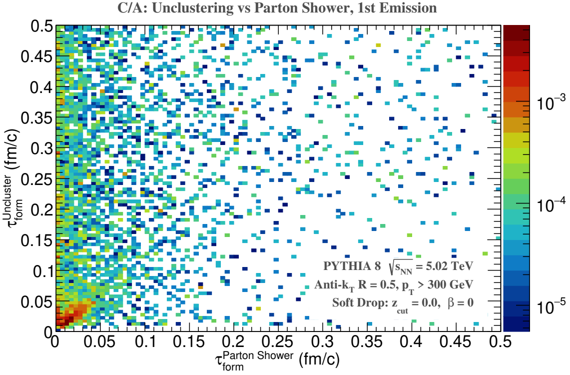
Hard scattering tuned for dijet events at $\sqrt{s_\mathrm{NN}} = 5.02\,\mathrm{TeV}$, trigger on leading jet.

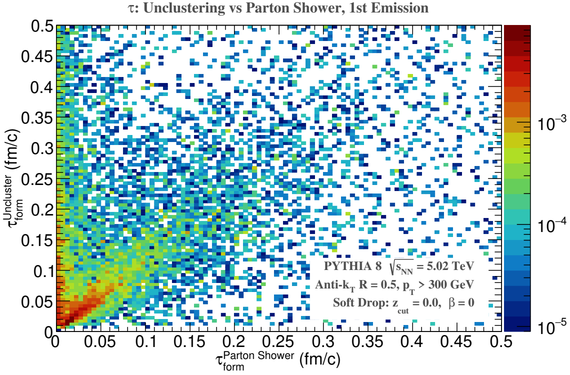
Analysis of jets with $p_\mathrm{T} > 300\,\mathrm{GeV}$ and $|\eta| < 1.0$.

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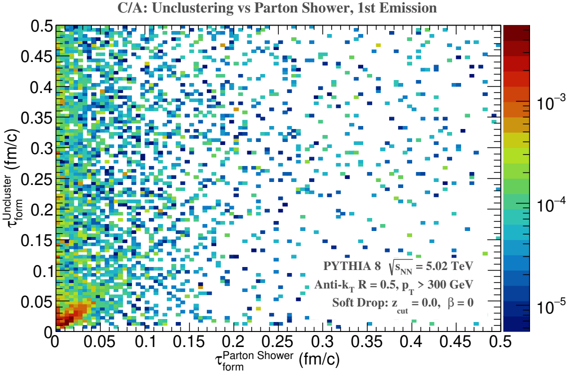

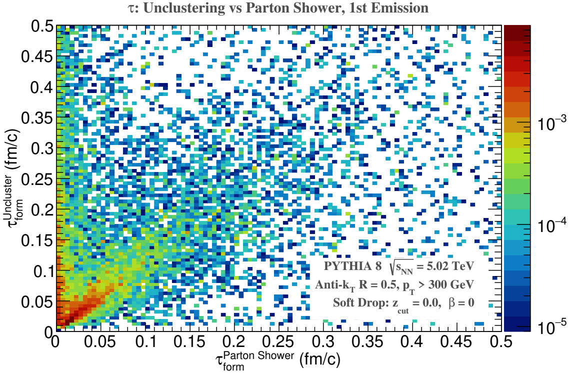

- **Diagonal:** Correlation.
- **Vertical:** Emissions outside of jet cone.

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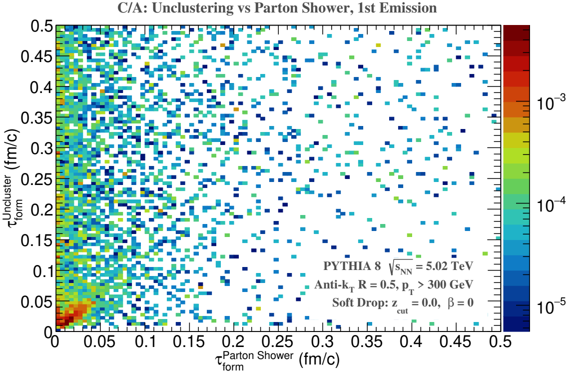
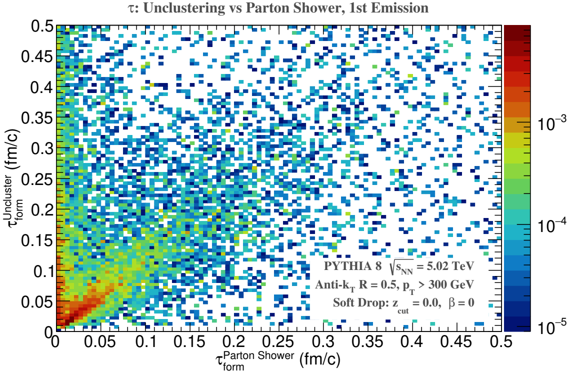
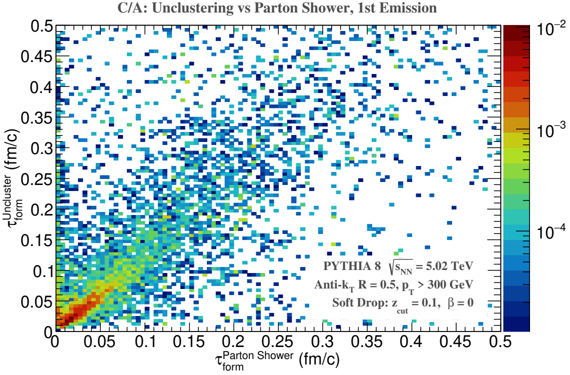
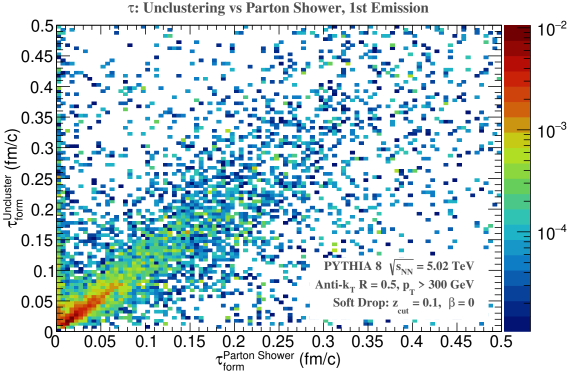




Apply SoftDrop: $$z_g = \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut}\,, \quad \text{with } z_{cut} = 0.1\,.$$

Correlation of 1st splitting time — Groomed Jets

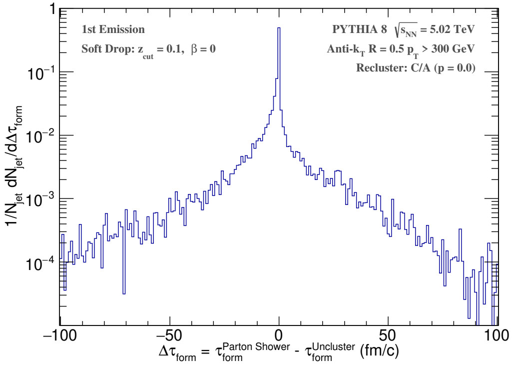




Grooming improves considerably the obtained correlation.

Comparing the Generalised-k_T Algorithms
Vacuum Distributions

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



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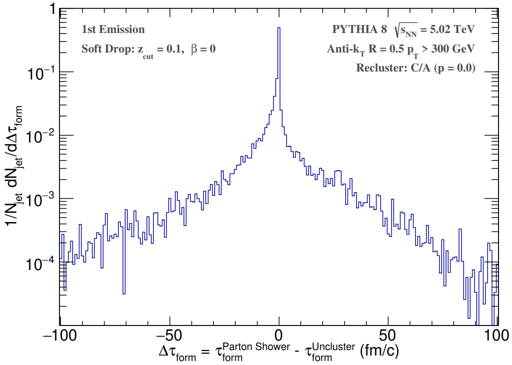

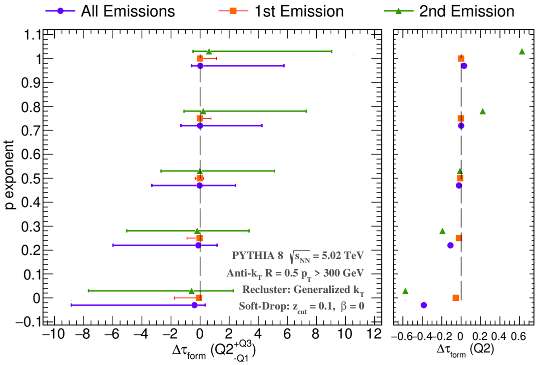

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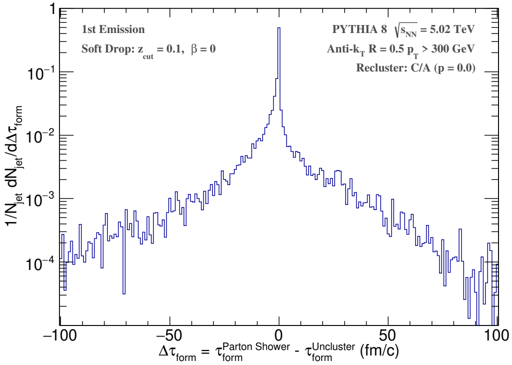
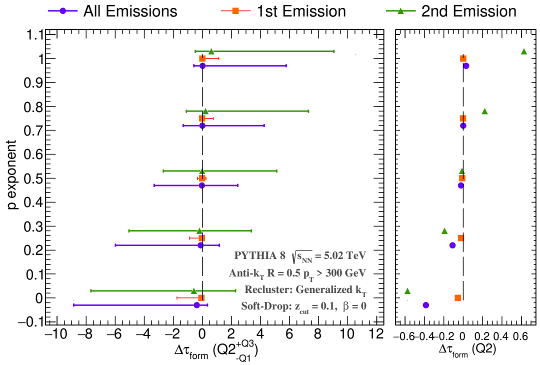
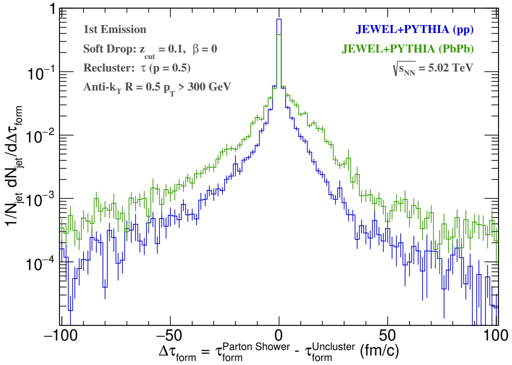


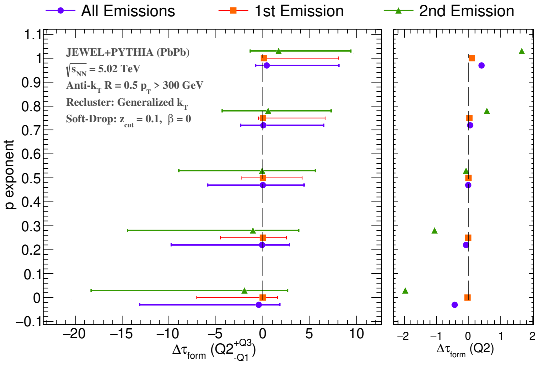


- Represent distribution by *Median* $\pm$ *Quartiles*

The τ algorithm returns the most centred distributions for PYTHIA8.

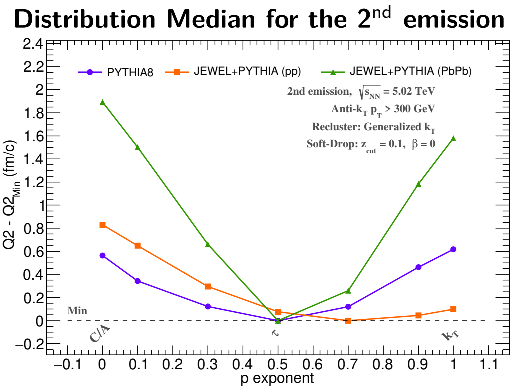
- **For medium-modified jets the distributions widen, but the trend remains.**

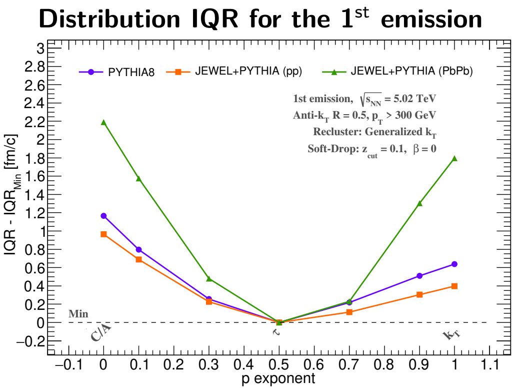




Comparing Monte-Carlo Event Generators

Median and IQR dependence on the algorithm

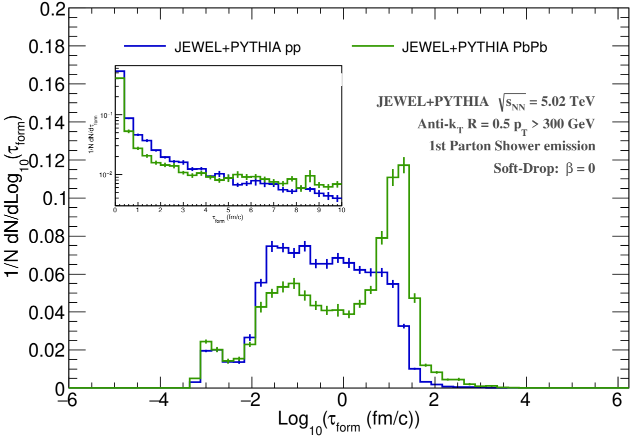




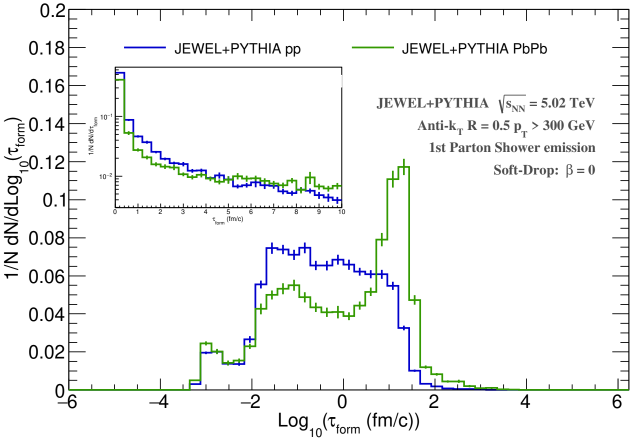
- Generally, the τ algorithm minimizes both the median and the width of the $\Delta\tau_{form}$ distribution.

Applications to Jet Quenching Studies

Jet Quenching by the QGP
Jet Quenching Classifier



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



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- 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).

Jet Quenching by the QGP

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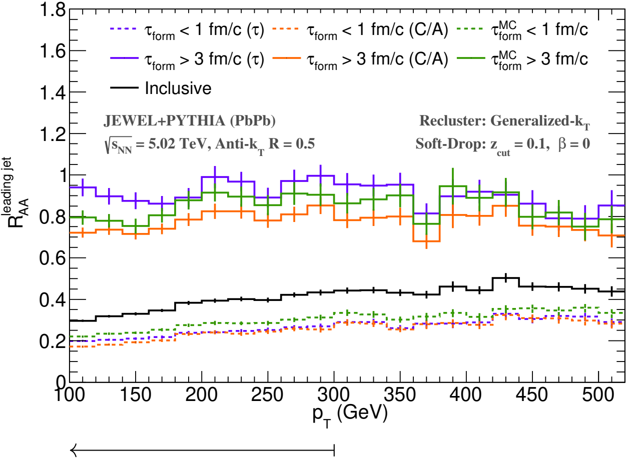
Compute R_{AA} for different jet populations:

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

Nuclear Modification Factor



Untested region, correlation might deteriorate

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Jet Quenching by the QGP

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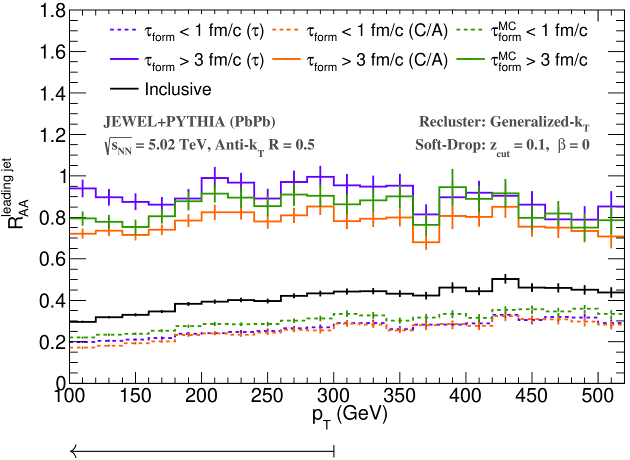

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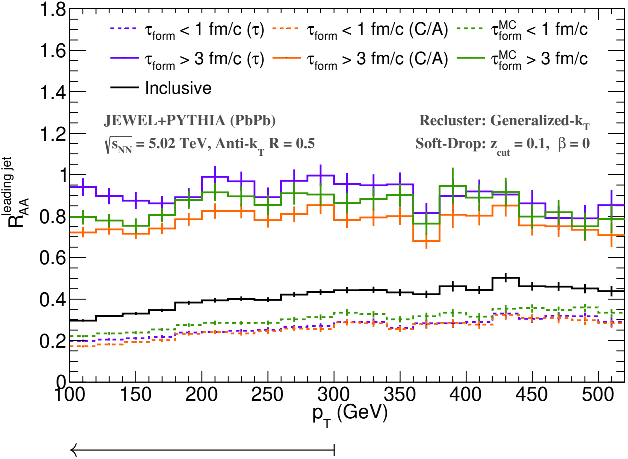

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τ algorithm can be used as a jet quenching classifier.

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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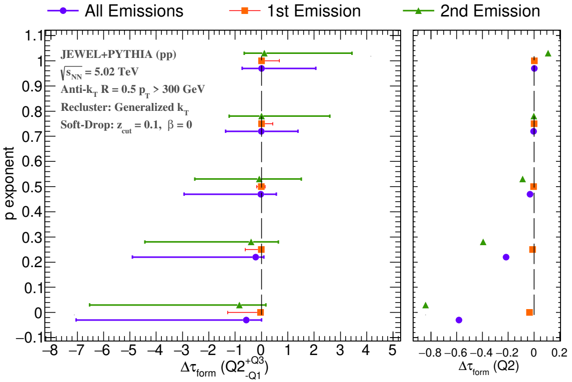
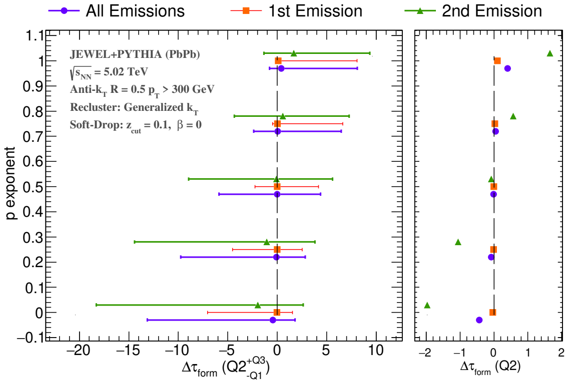


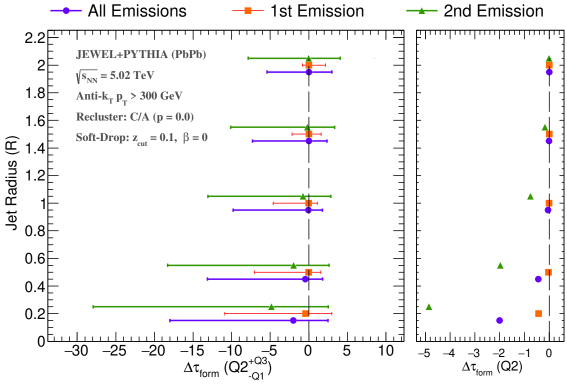
JEWEL+PYTHIA (pp)



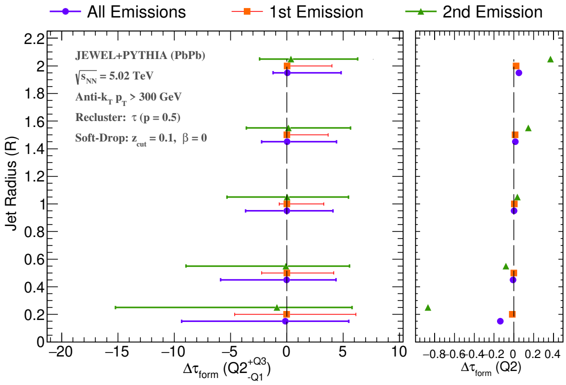
JEWEL+PYTHIA (PbPb)

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

Correlation as a function of the Jet Radius

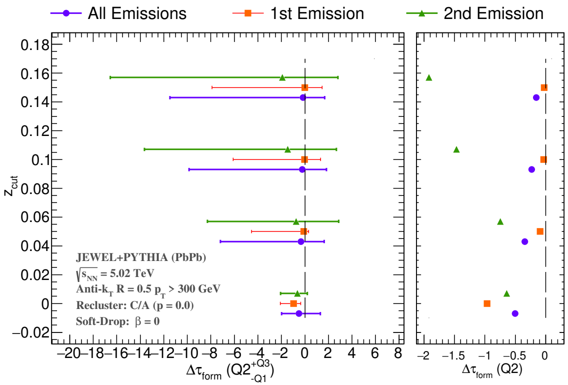


C/A reclustering



τ reclustering

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



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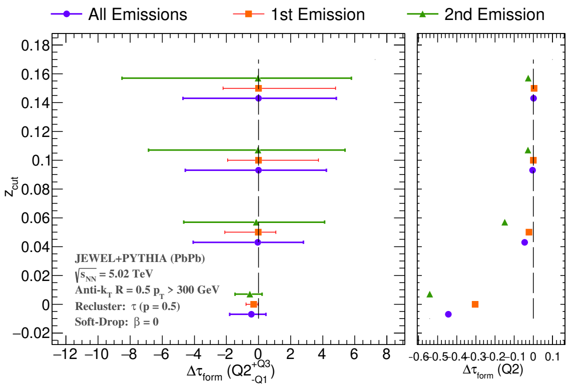
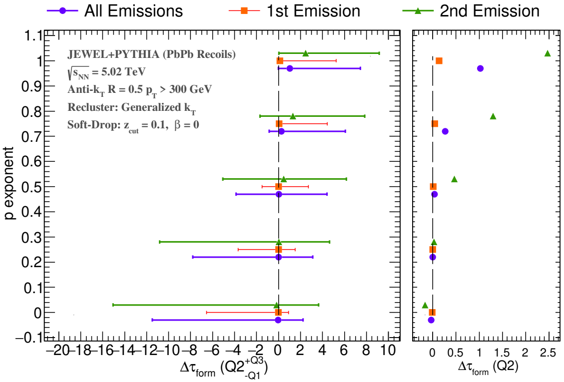


τ reclustering

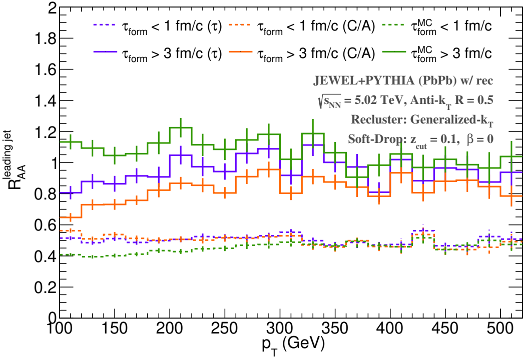
Generally, increasing z_{cut} shifts the distribution to $\Delta\tau_{form} \sim 0$, while also broadening it.

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.