

Jet substructure as a tool for energy loss studies

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Based on ongoing work with Liliana Apolinario^a and Korinna Zapp^b

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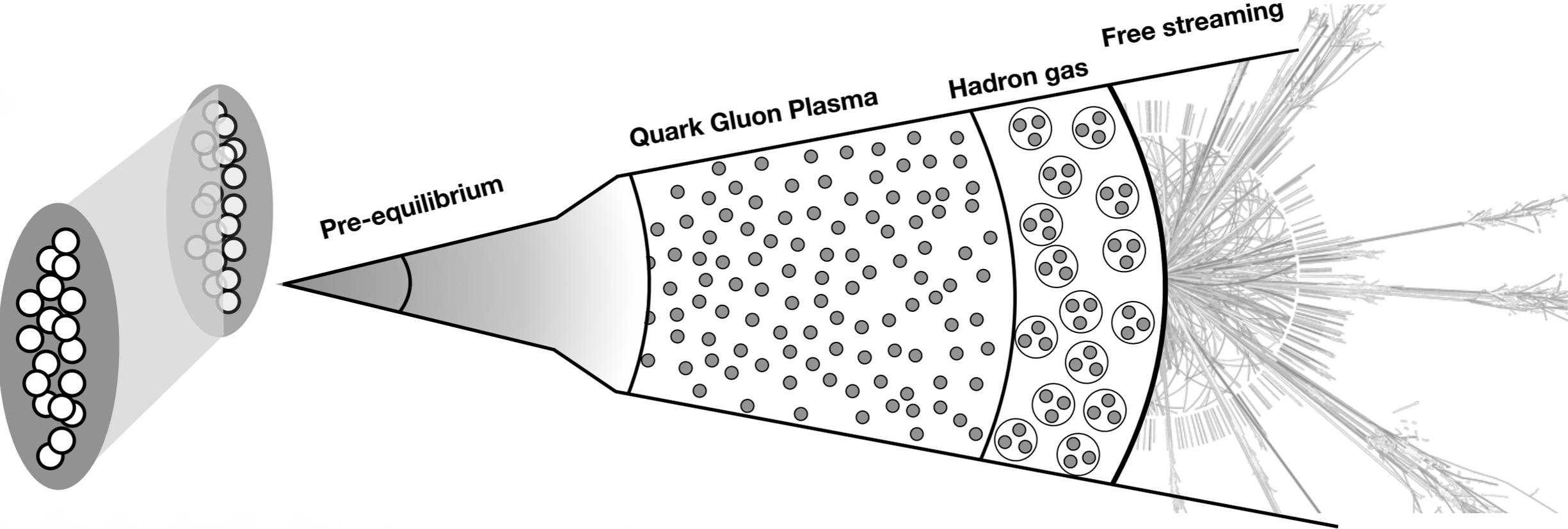
Jet quenching as a tool for QGP tomography

- *Can we use jets to access the time structure of the Quark Gluon Plasma?*
- *Can we use that information to study jet energy loss?*



Jet quenching as a tool for QGP tomography

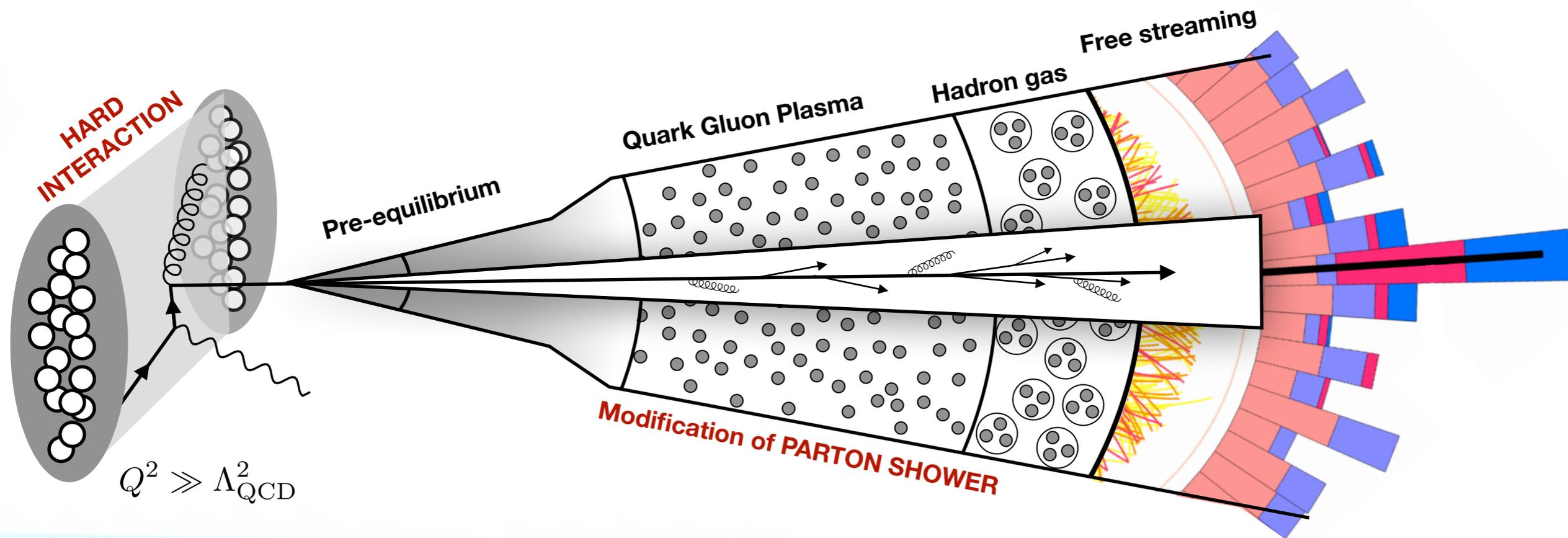
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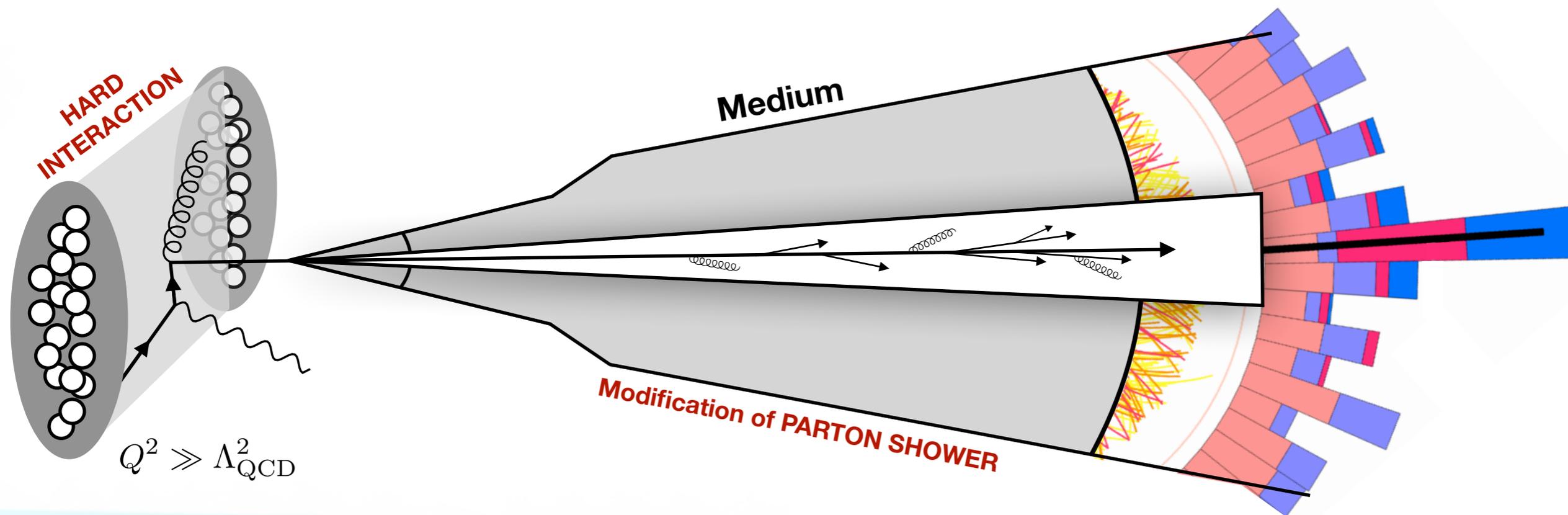
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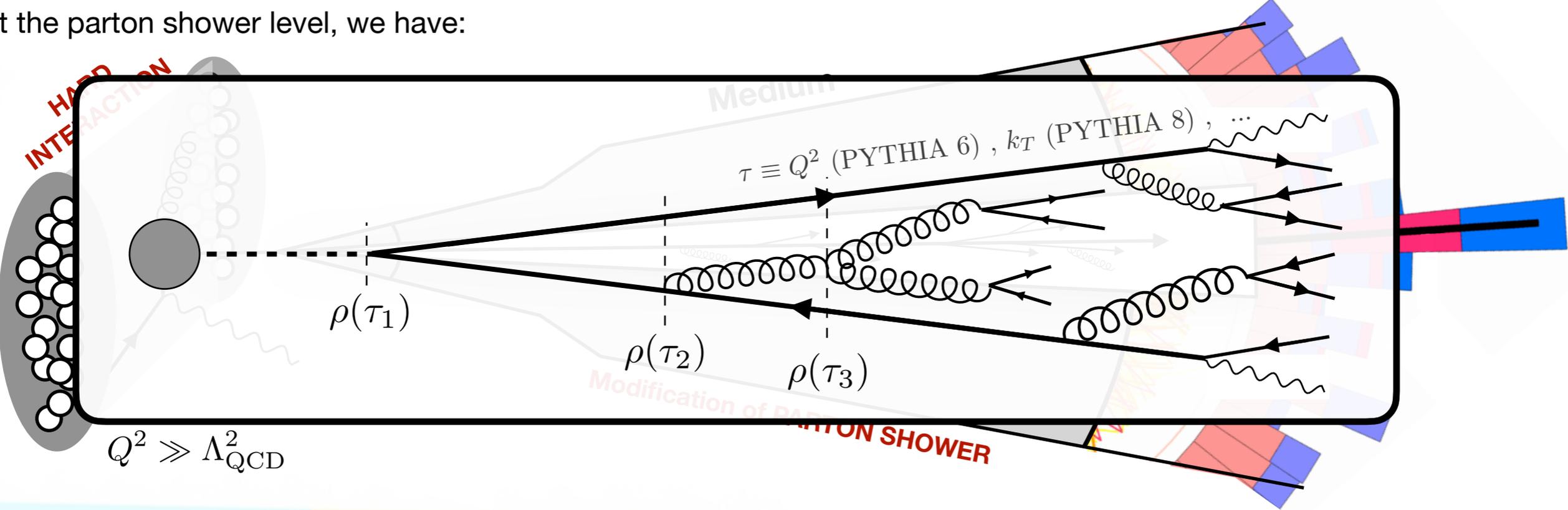
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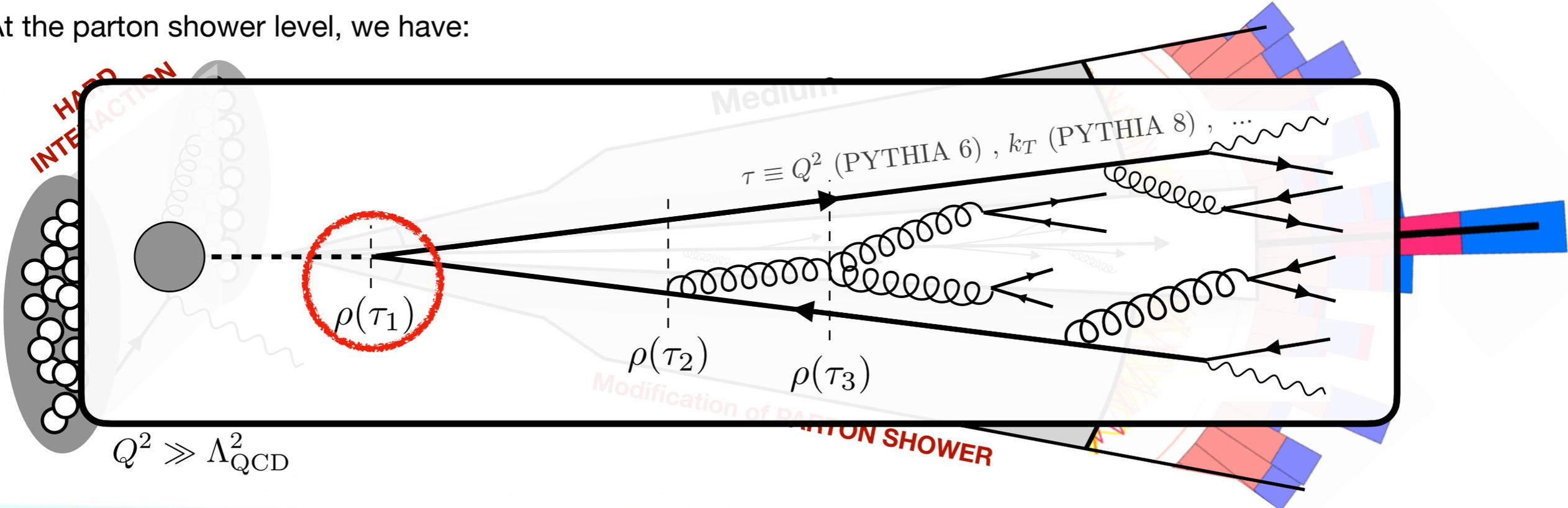
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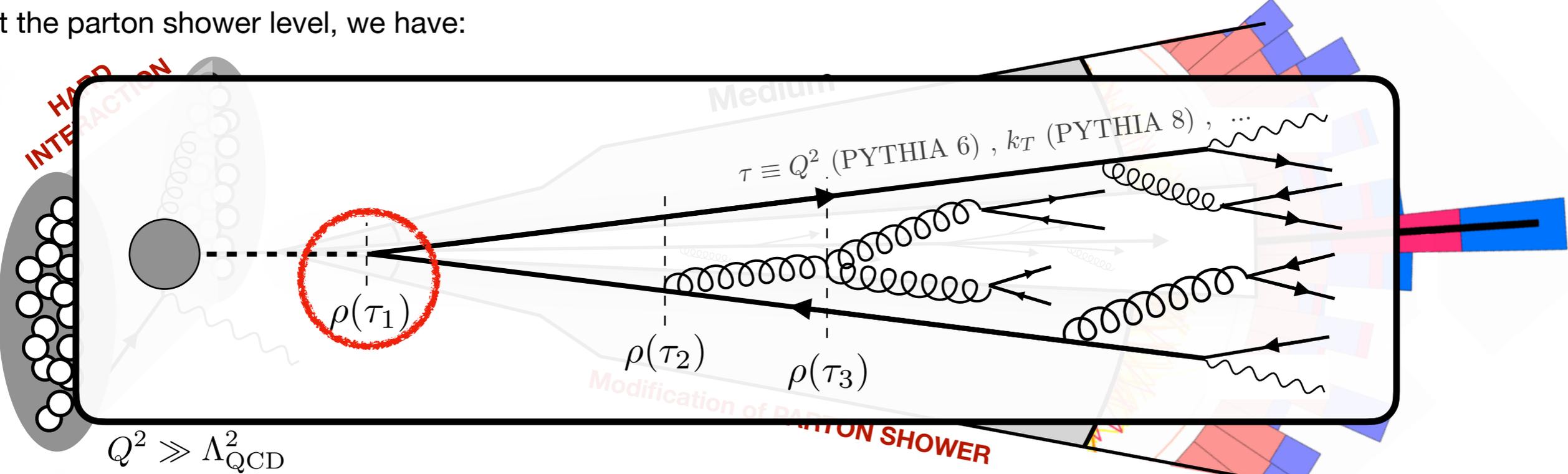
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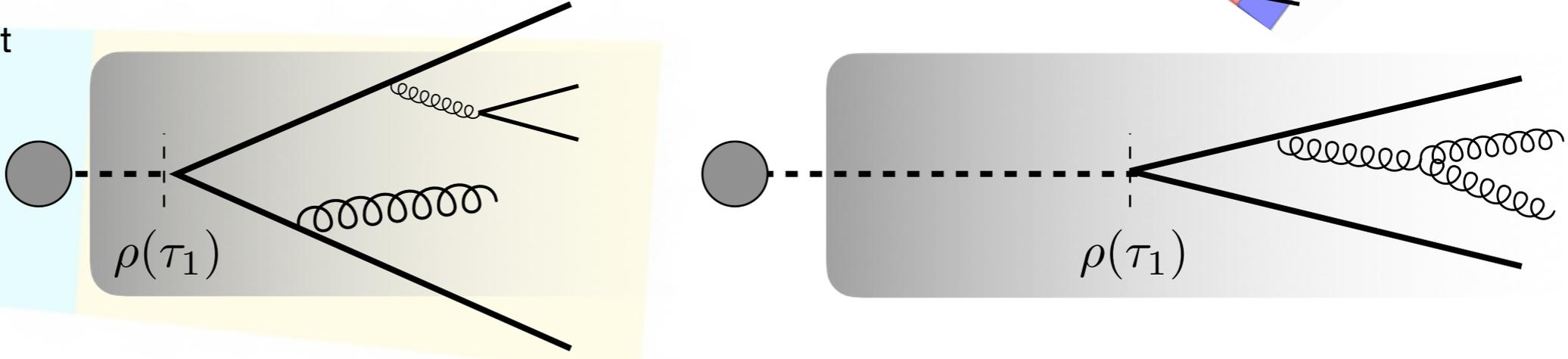


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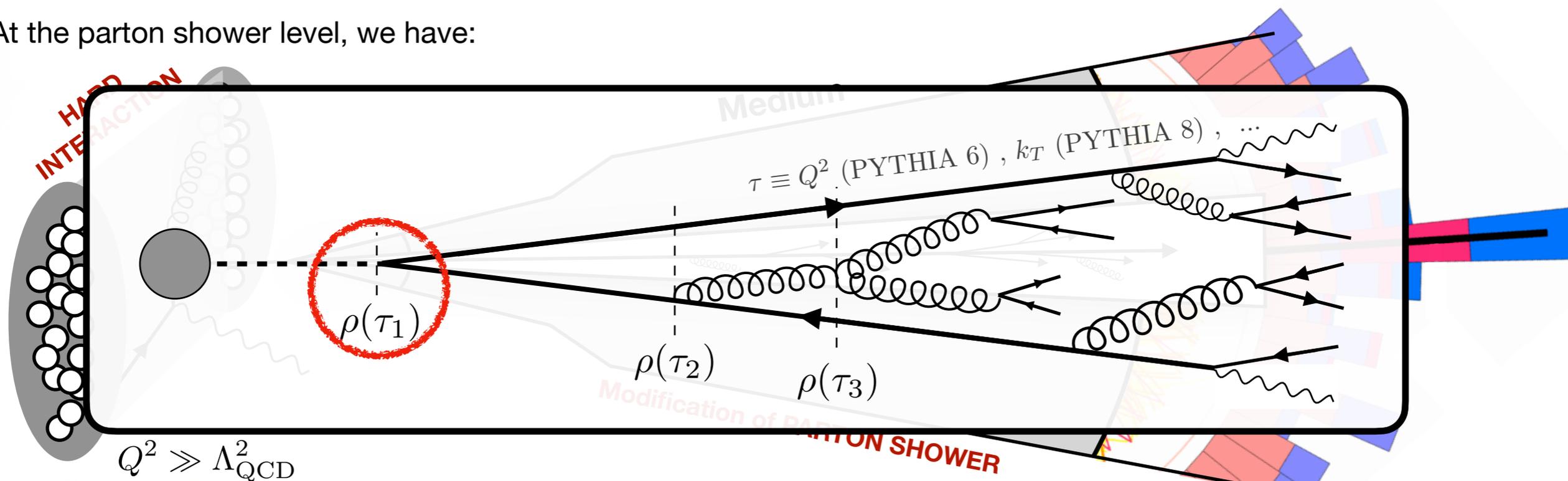
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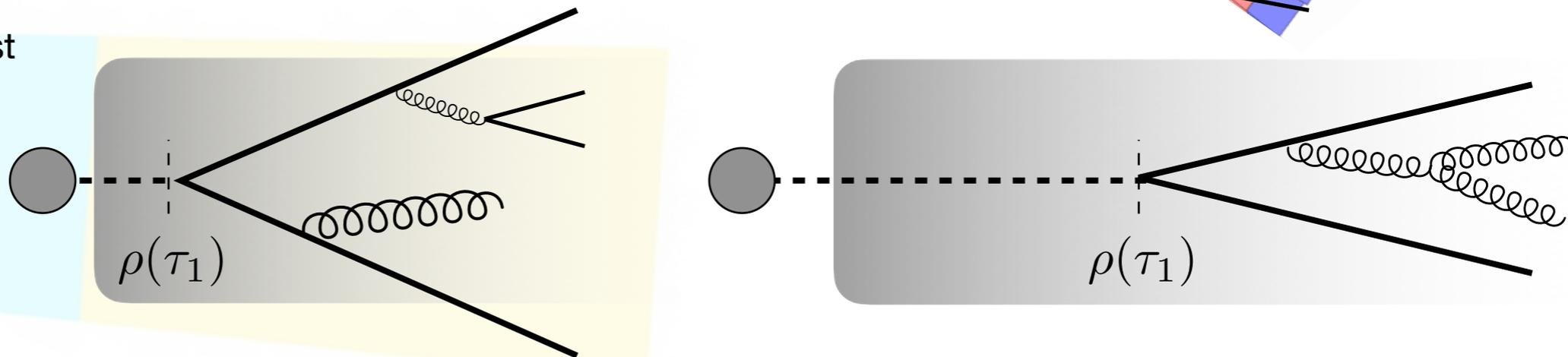


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- ➔ We can use the first splitting to classify our jets:



- BUT how can we access this information?



Jet clustering

- We want to extract information from the internal structure of jets
- *So, how do we make a jet?*

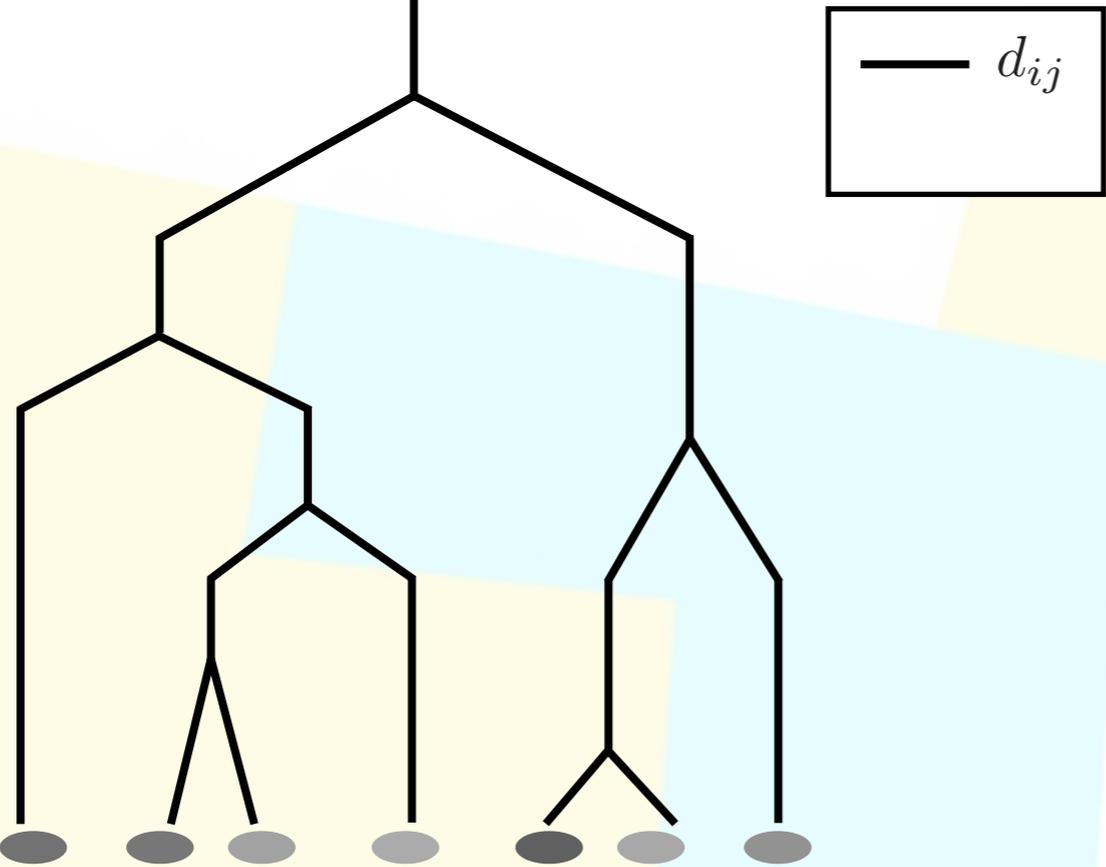




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Sequential combination of particles ordered according to some user-defined distance measure d_{ij}

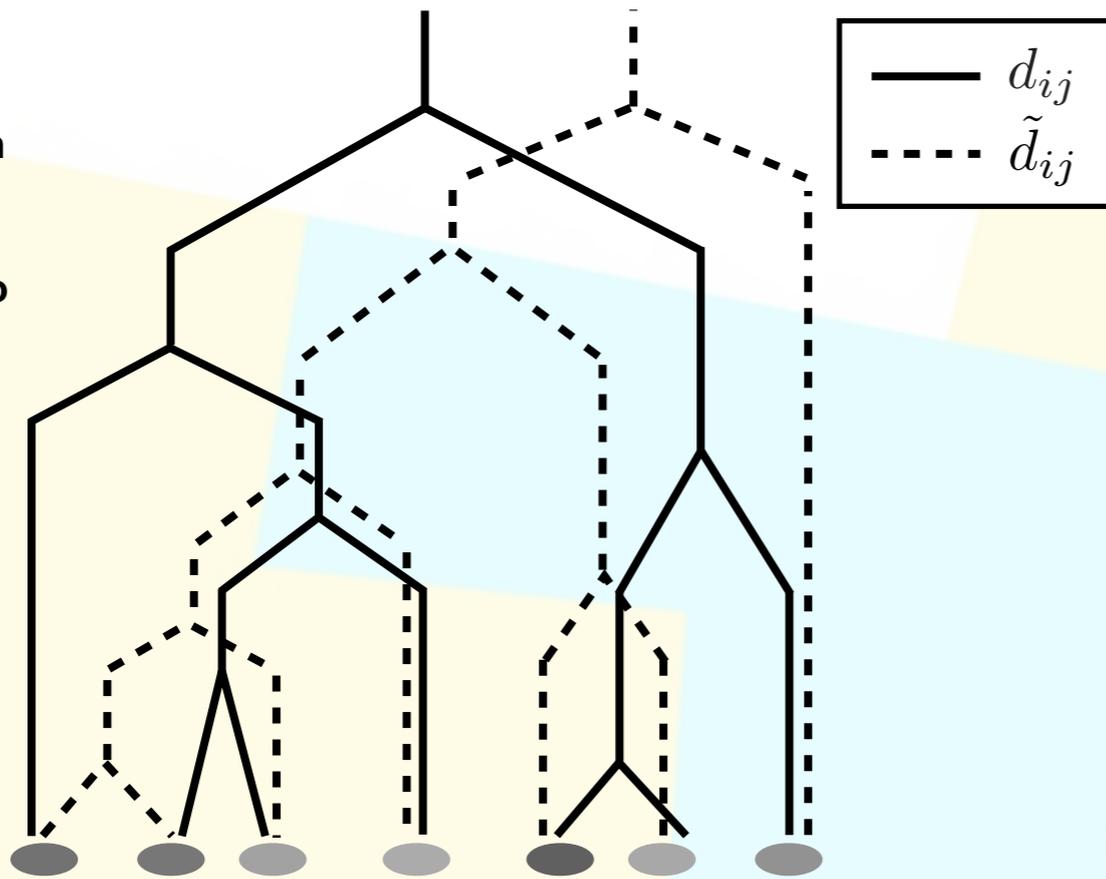




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Cartoon courtesy of K. Zapp

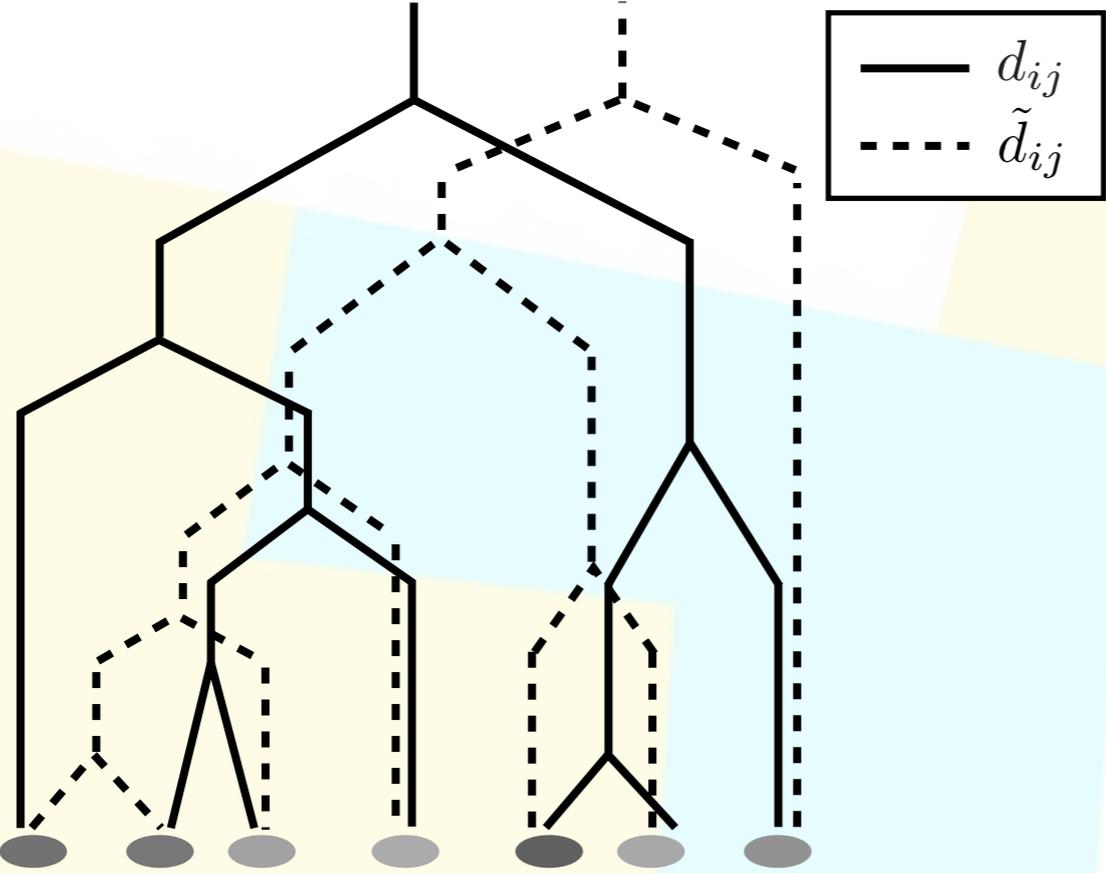




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- We use the **generalized k_t algorithm**

$$d_{ij} = \min(p_{t,i}^{2p}, p_{t,j}^{2p}) \frac{\Delta R_{ij}^2}{R^2}, \text{ with } \Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

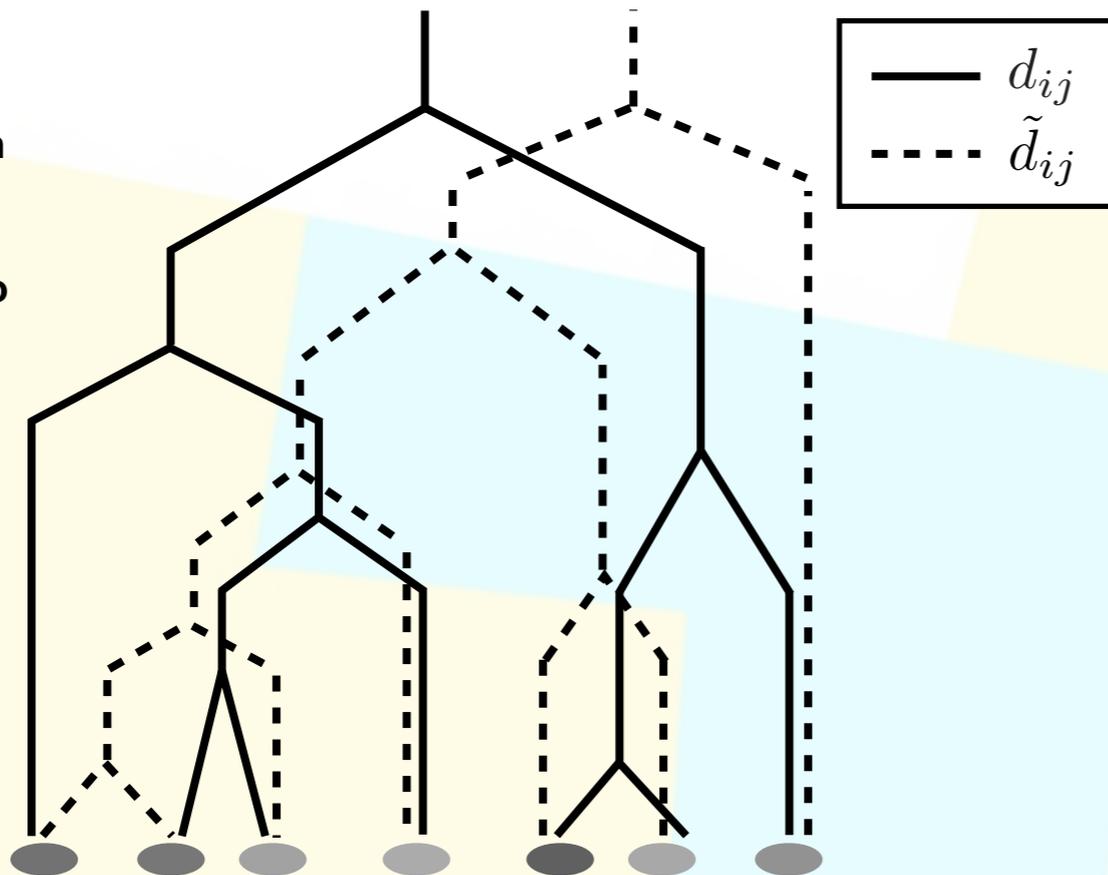
$p = 0 \rightarrow C/A$
 $p = -1 \rightarrow \text{Anti-}k_t$
 $p = 1 \rightarrow k_t$



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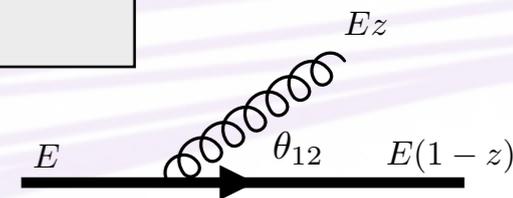
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- We propose using $p = 0.5$. With this setup:

$$d_{ij} \sim p_{T,i} \theta^2 \sim \frac{1}{\tau_{\text{form}}}, \text{ with } \tau_{\text{form}} \approx \frac{E}{Q^2} \stackrel{\text{(High energy limit)}}{\approx} \frac{1}{2Ez(1-z)(1-\cos\theta_{12})}$$

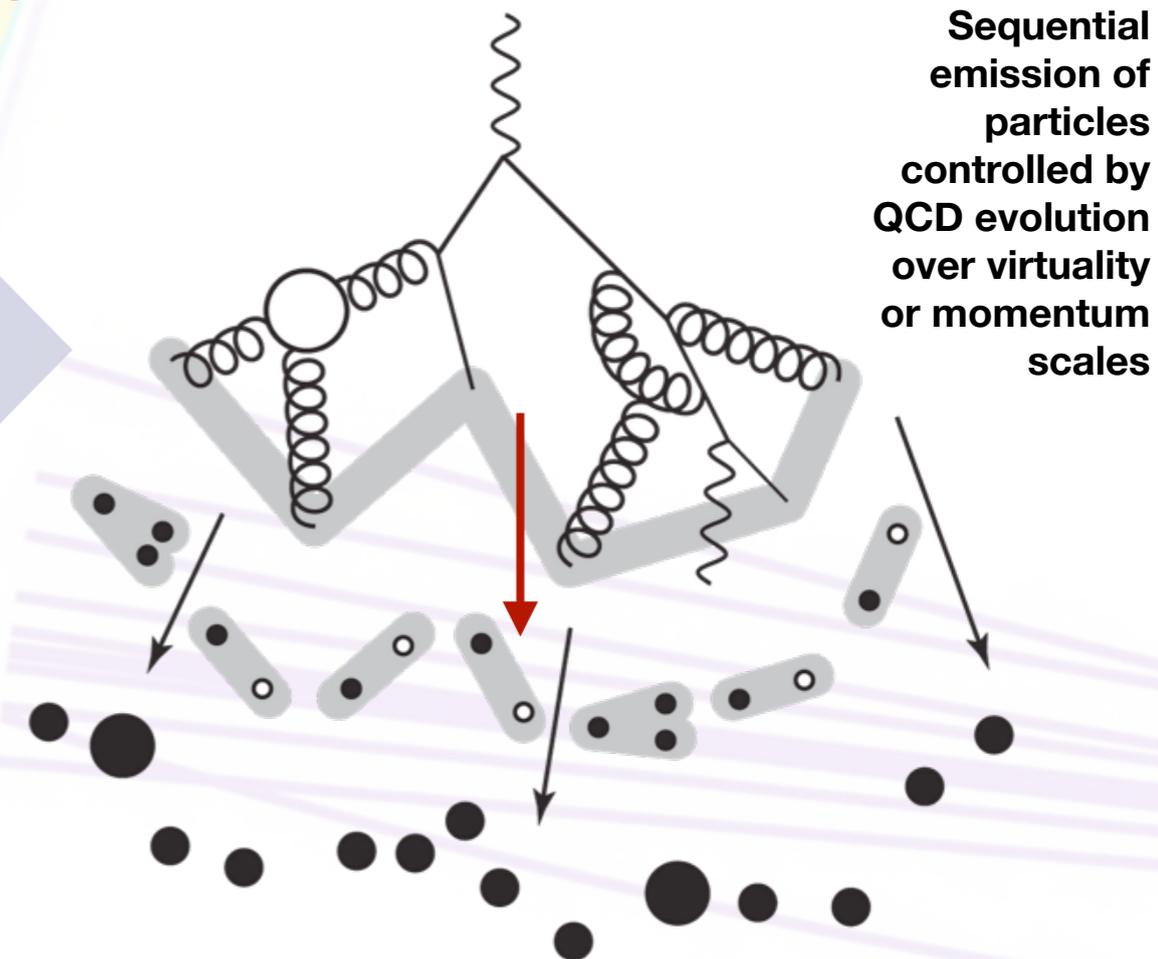
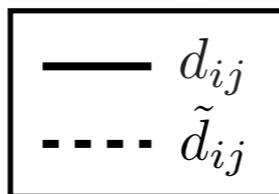
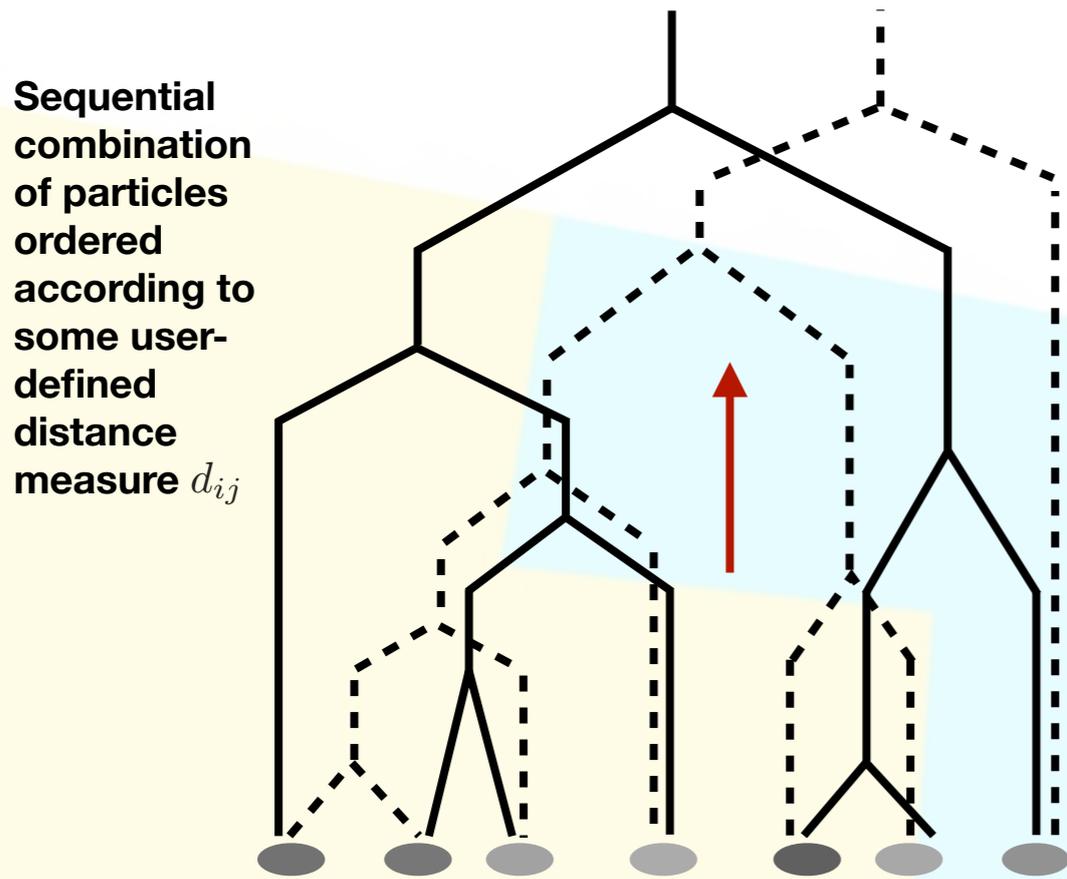
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$p = 1$	\rightarrow k_t
$p = 0.5$	\rightarrow τ





Jet clustering

- We want to extract information from the internal structure of jets
- So, how do we make a jet? Can we relate them to parton showers?



Cartoon courtesy of K. Zapp

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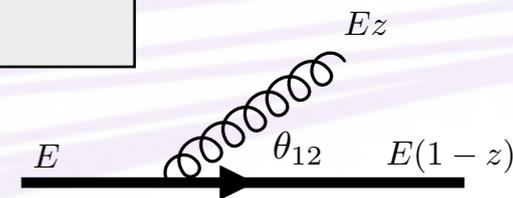
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(High energy limit)

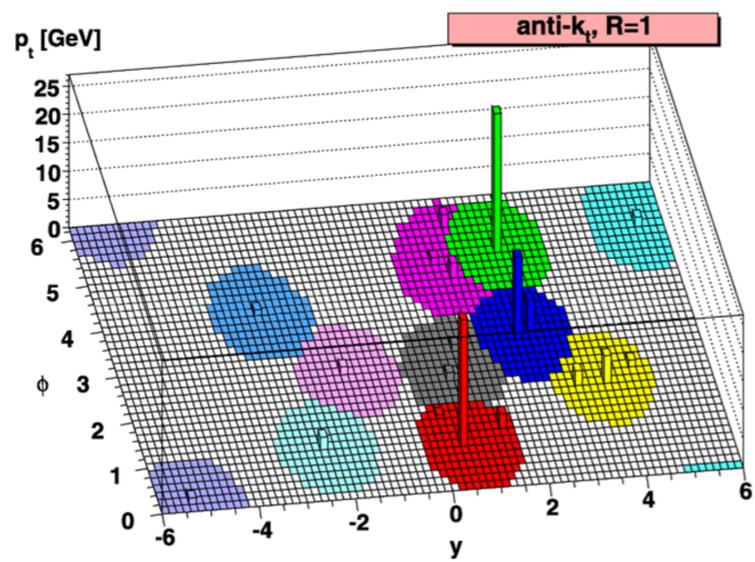


- We can use the clustering history of the jet to reconstruct the parton shower splitting by splitting

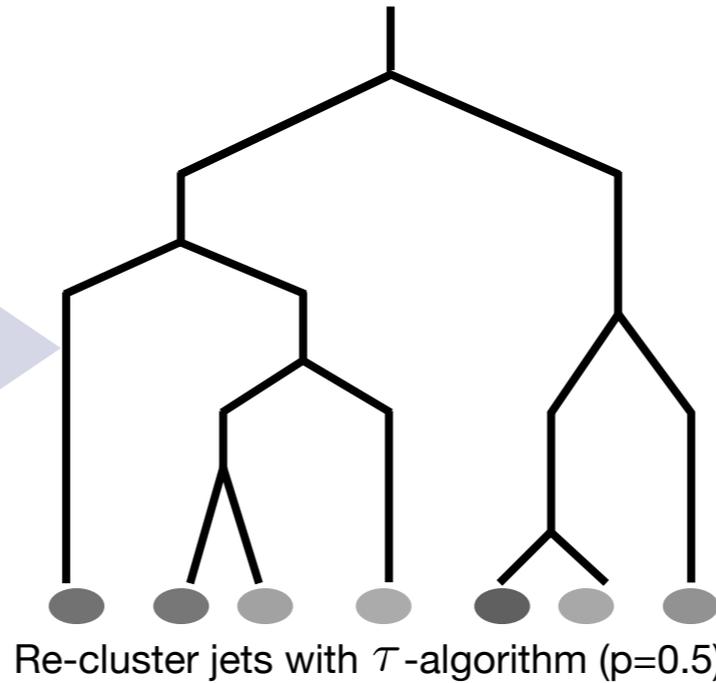
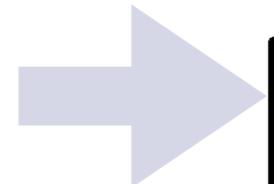


Jet unclustering with the τ -algorithm

- We use the τ -algorithm to extract τ_{form} sequence from jet reclustering history:
$$\tau_{\text{form}} \approx \frac{1}{2Ez(1-z)(1-\cos\theta_{12})}$$



Identify jets applying anti-kt algorithm ($p=-1$)

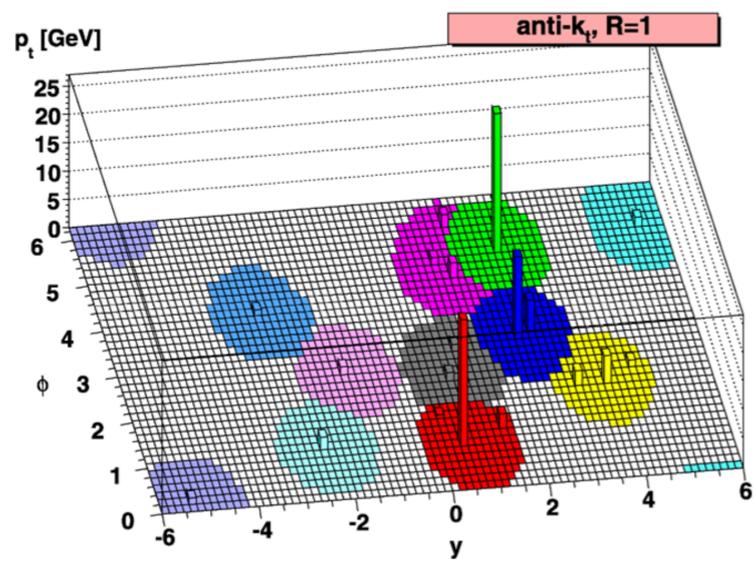


Re-cluster jets with τ -algorithm ($p=0.5$)

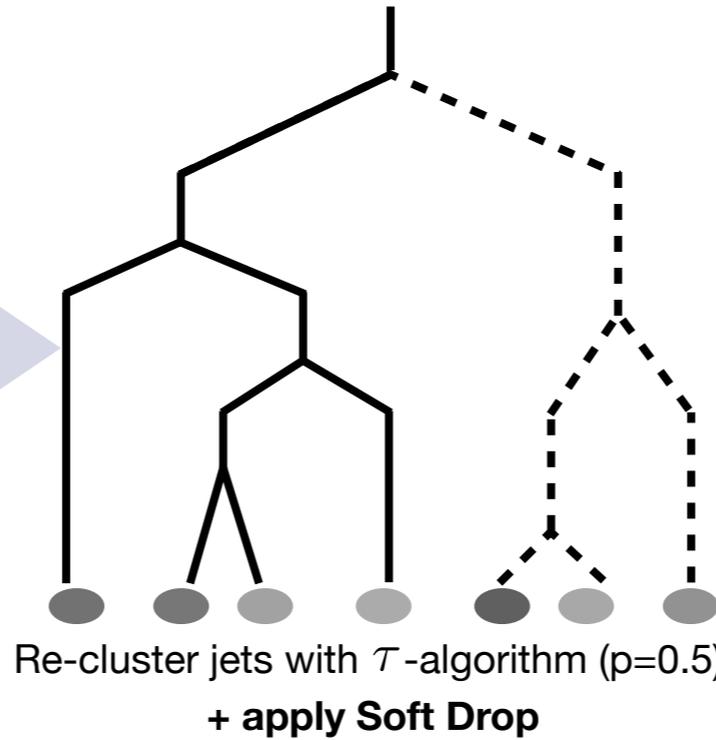
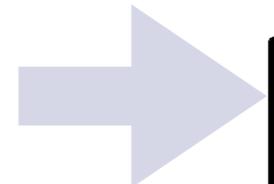


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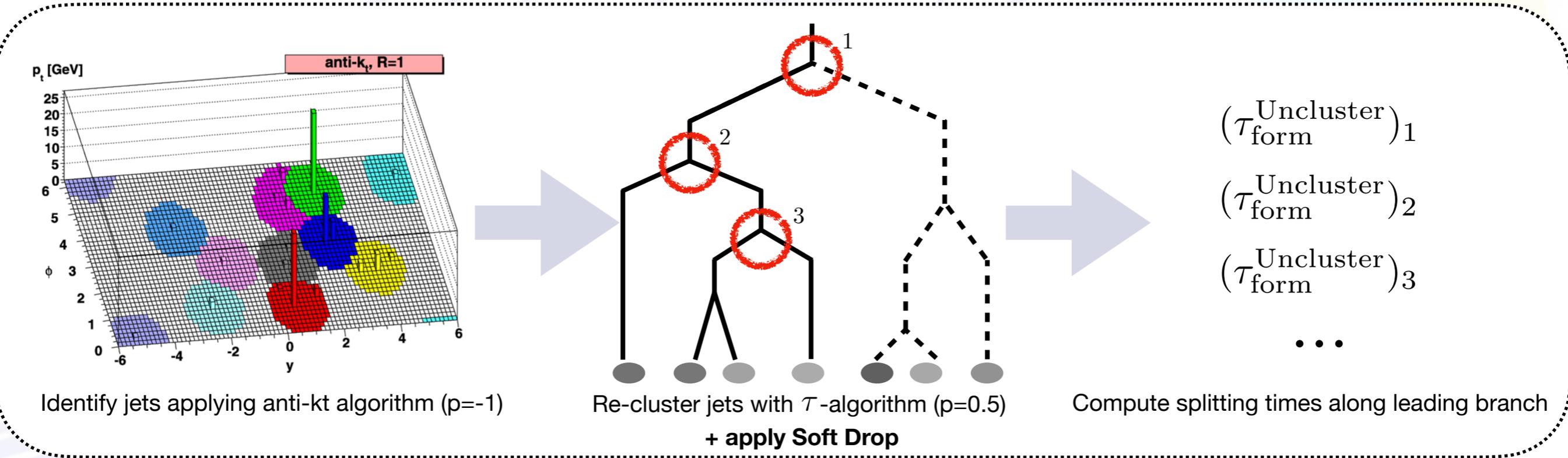


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+ apply **Soft Drop**



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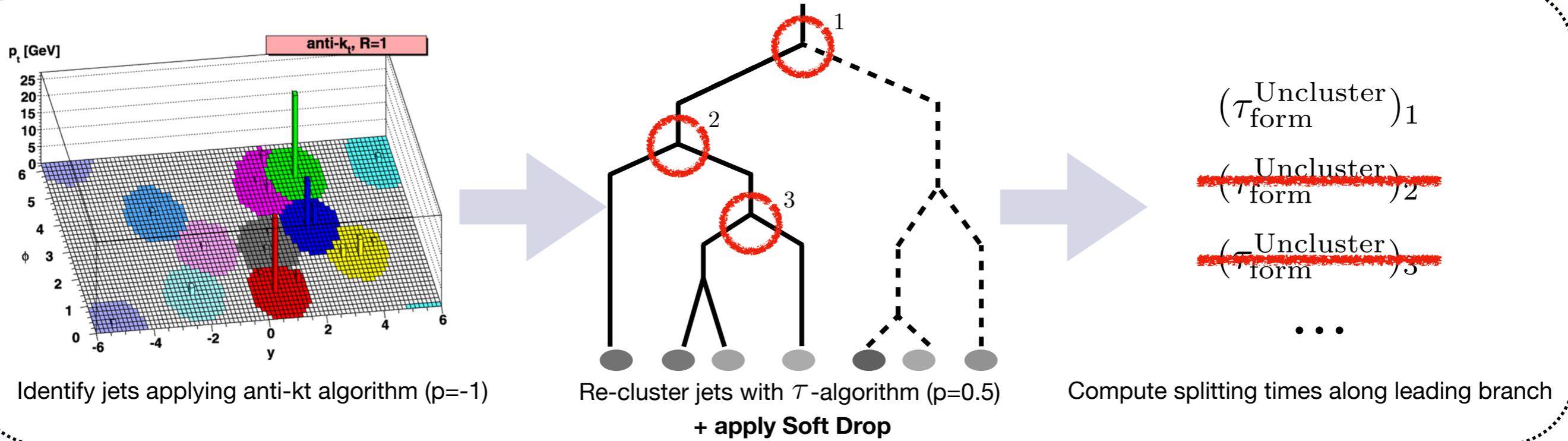
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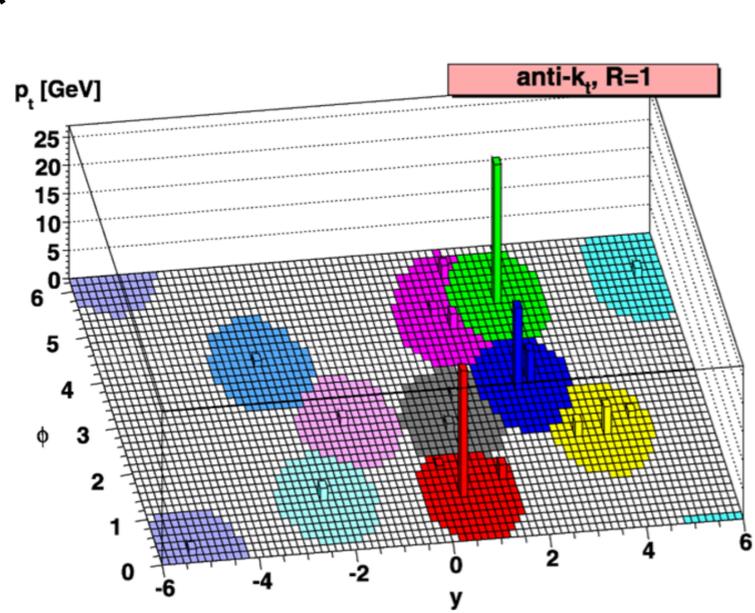


- We apply this method to study energy loss in heavy ion collisions

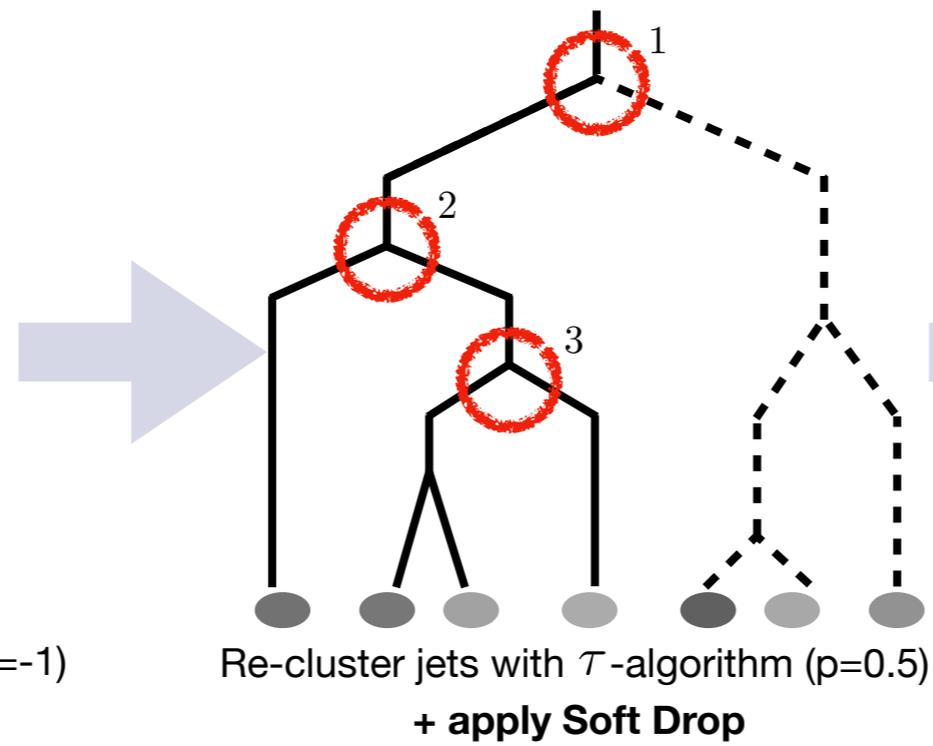


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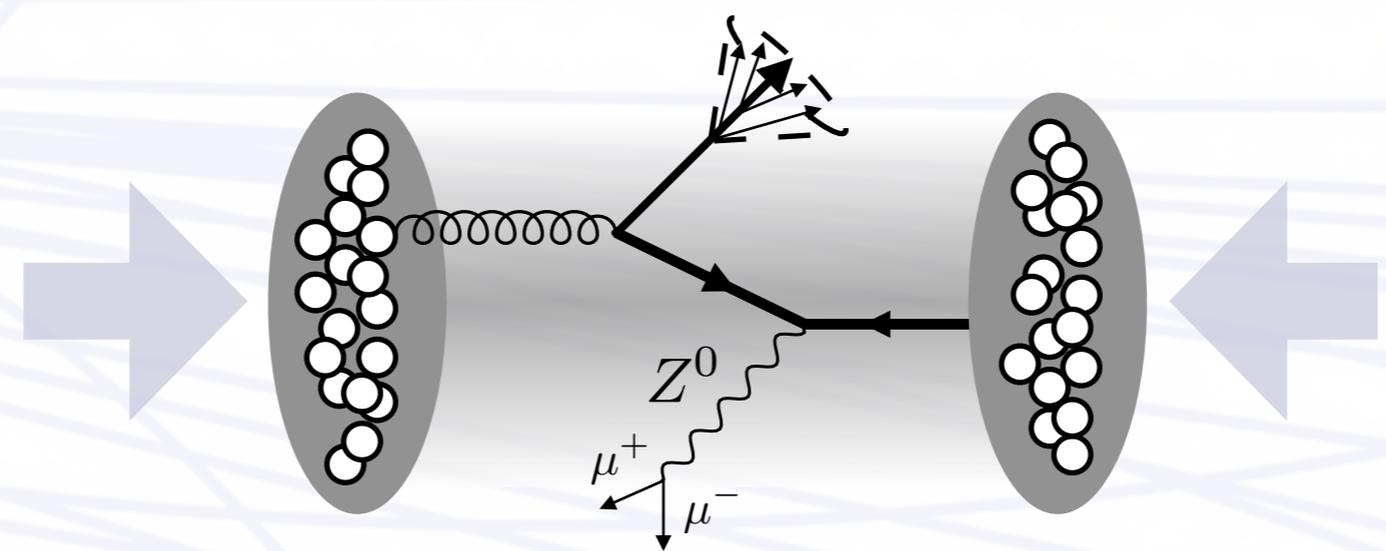


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- $(\tau_{\text{form}}^{\text{Uncluster}})_1$
- ~~$(\tau_{\text{form}}^{\text{Uncluster}})_2$~~
- ~~$(\tau_{\text{form}}^{\text{Uncluster}})_3$~~
- ...

Compute splitting times along leading branch

- We apply this method to study energy loss in heavy ion collisions
- We focus our study on **Z-jet events**: a clean and well calibrated environment for energy loss studies





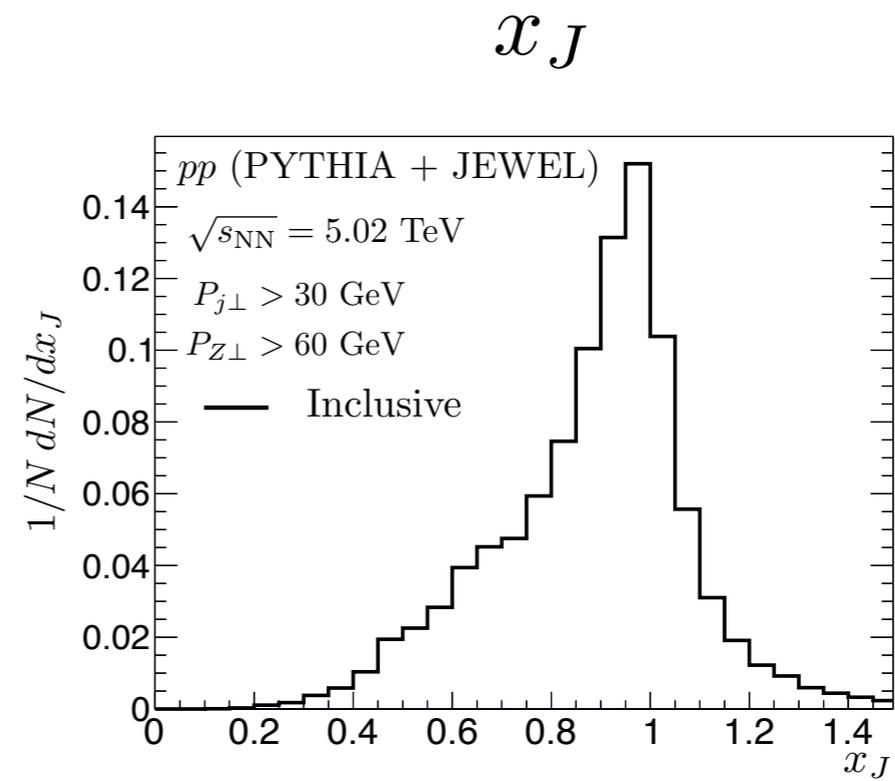
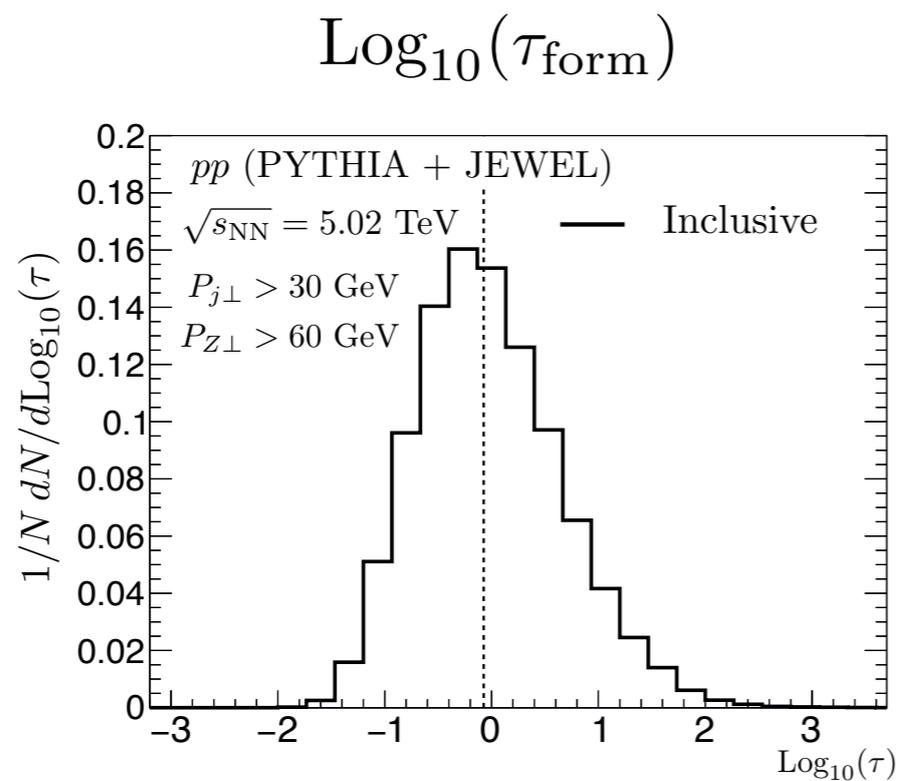
Energy loss in an evolving QCD medium

- The **momentum imbalance** $x_{jZ} = P_{j\perp}/P_{Z\perp}$ provides an estimate for the **energy loss** of the jet within the medium



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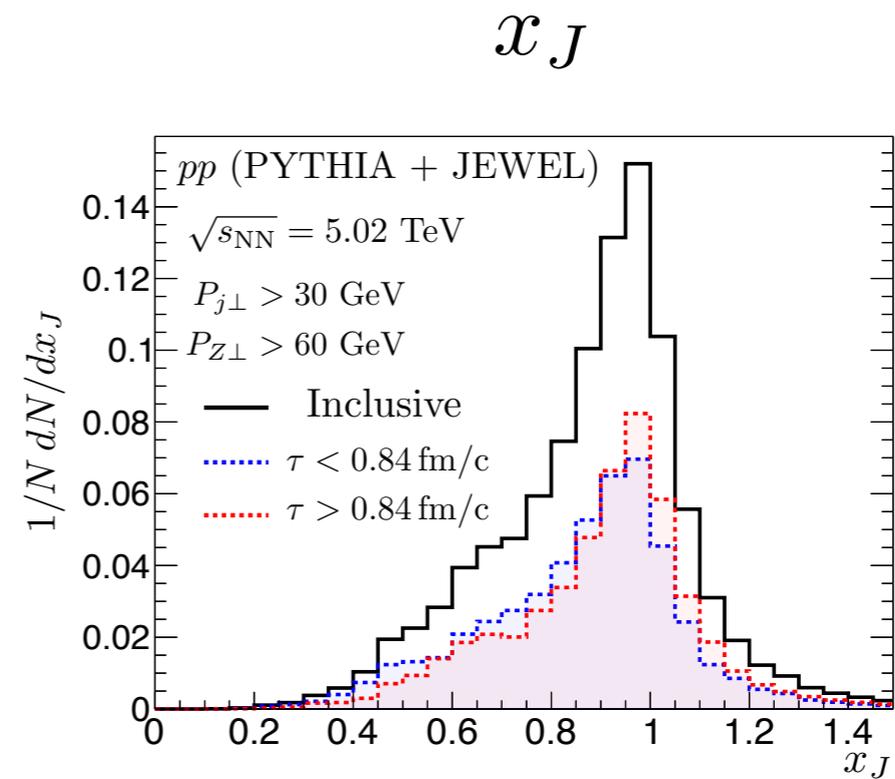
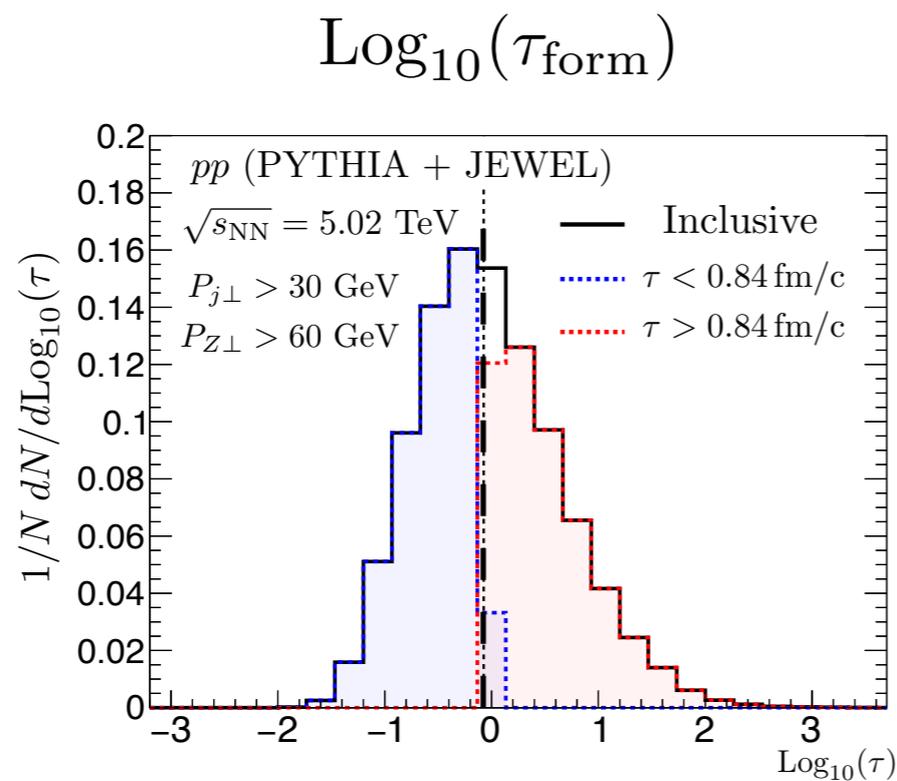
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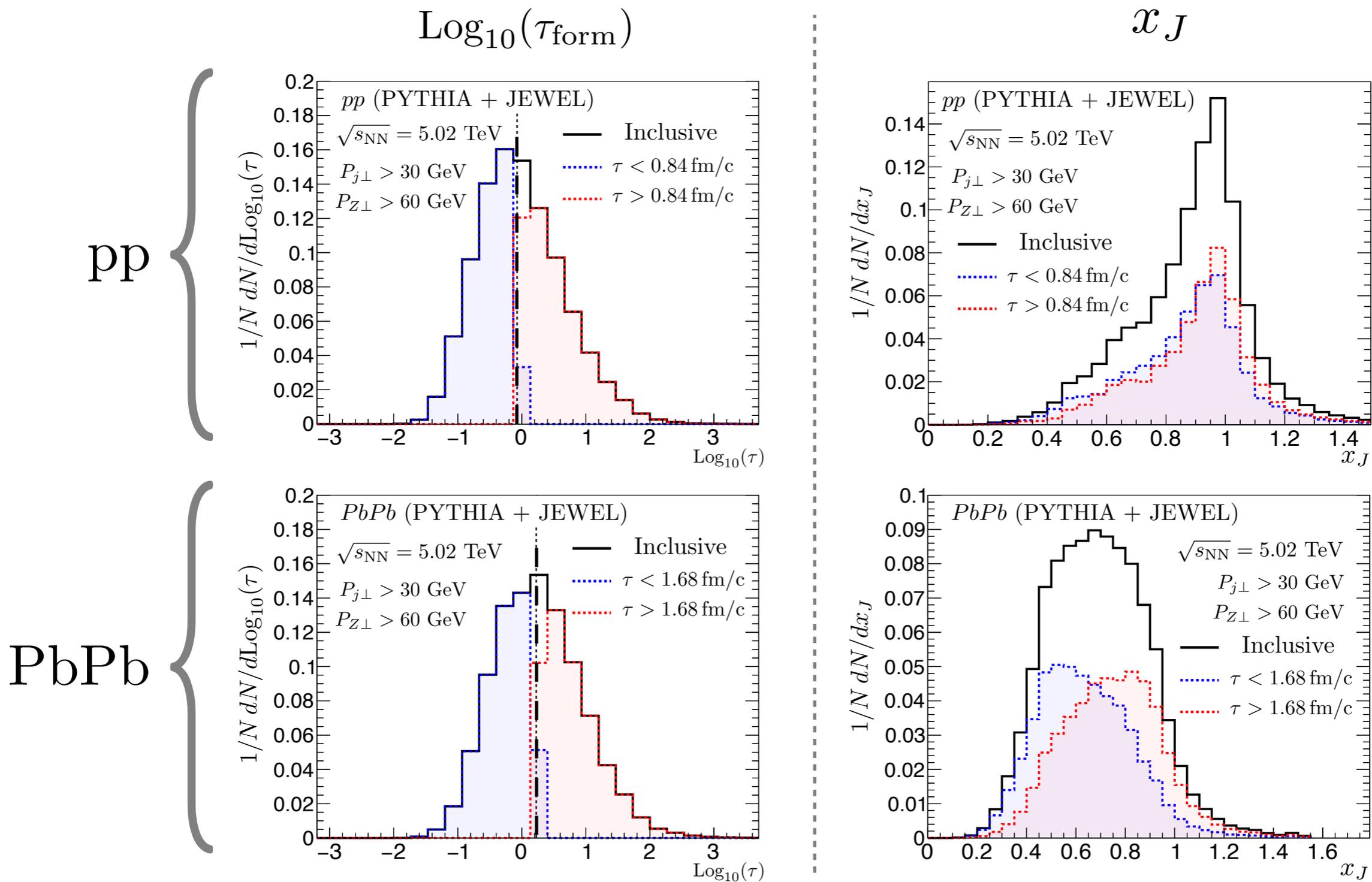
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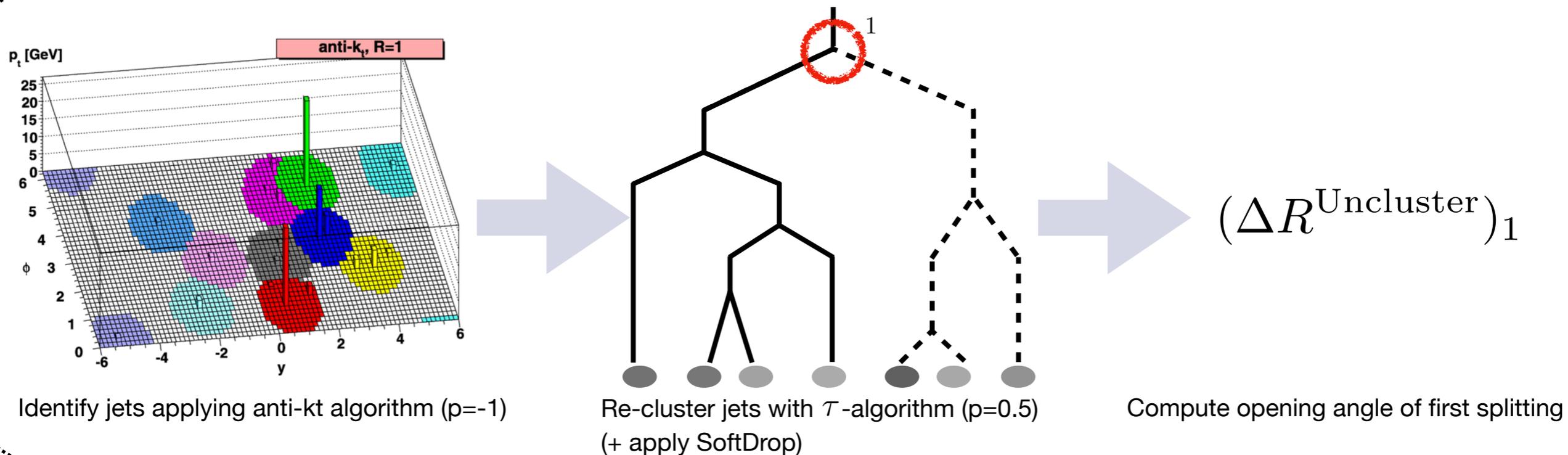


- Our early/late jet selection on τ_{form} allows to evaluate ΔE



τ_{form} or ΔR ?

- This feature is not unique to τ_{form} : a similar selection can be made using ΔR

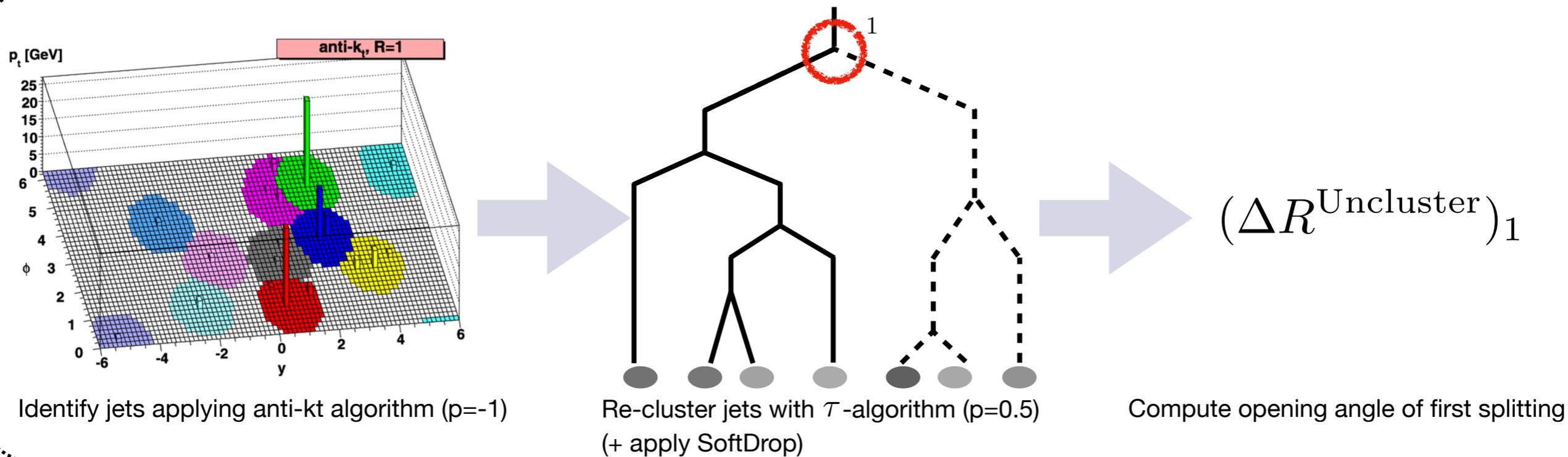


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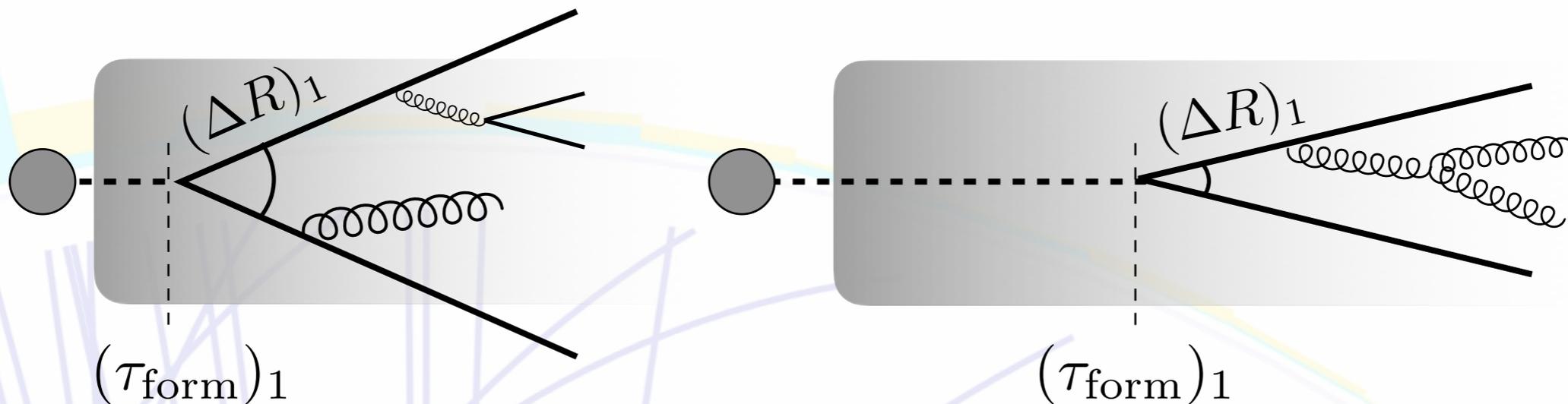


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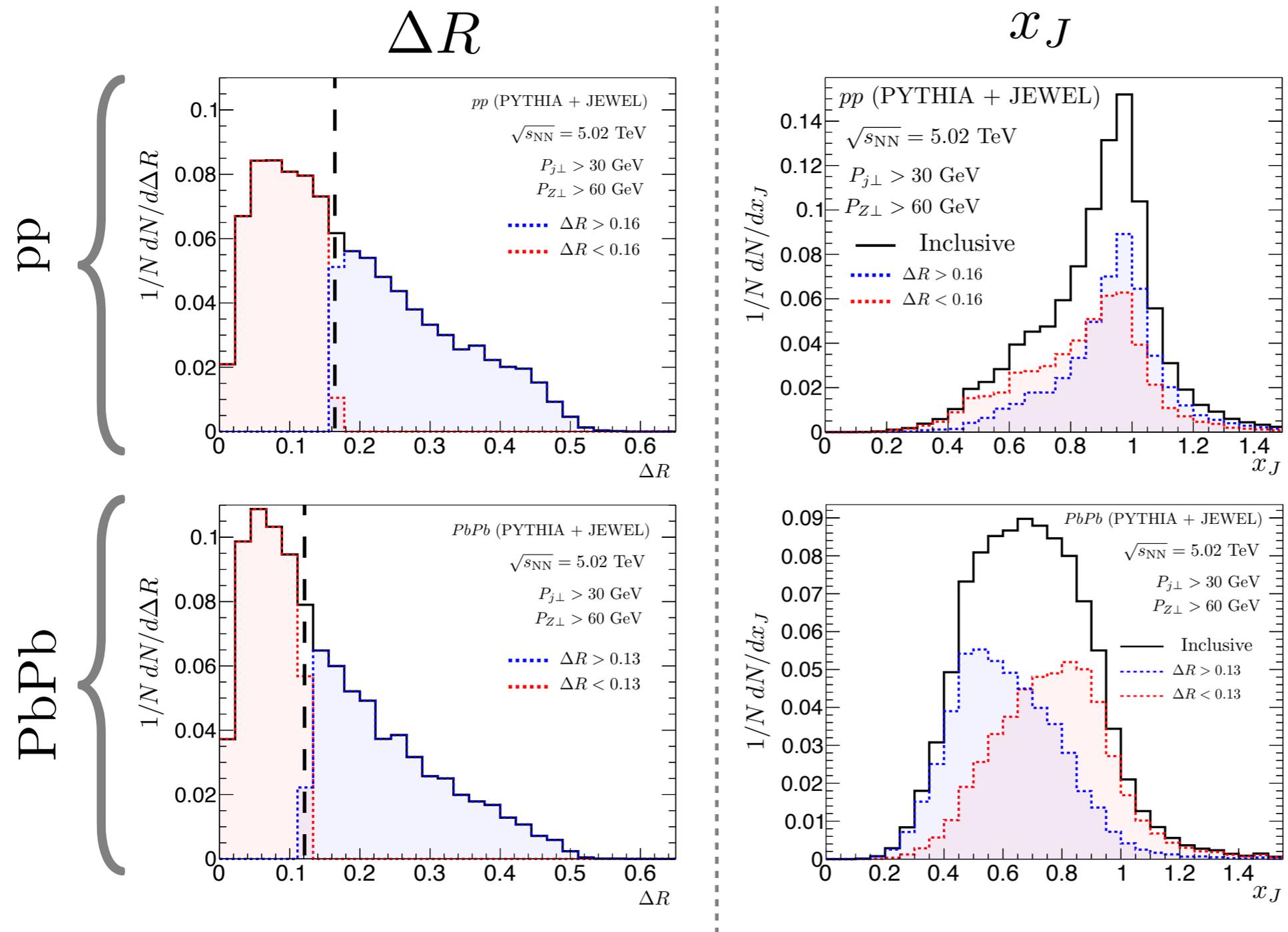
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Energy loss in an evolving QCD medium (revisited)

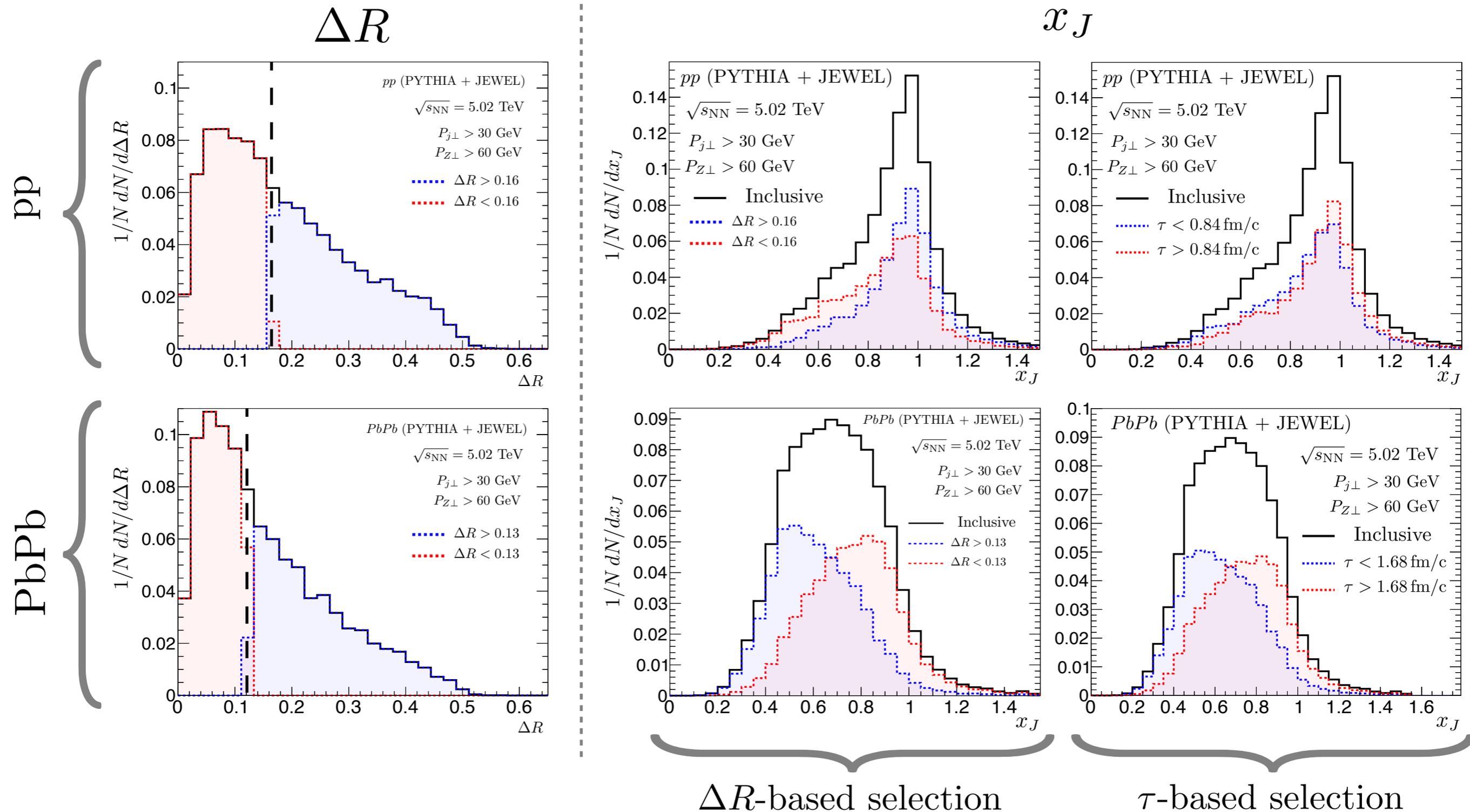
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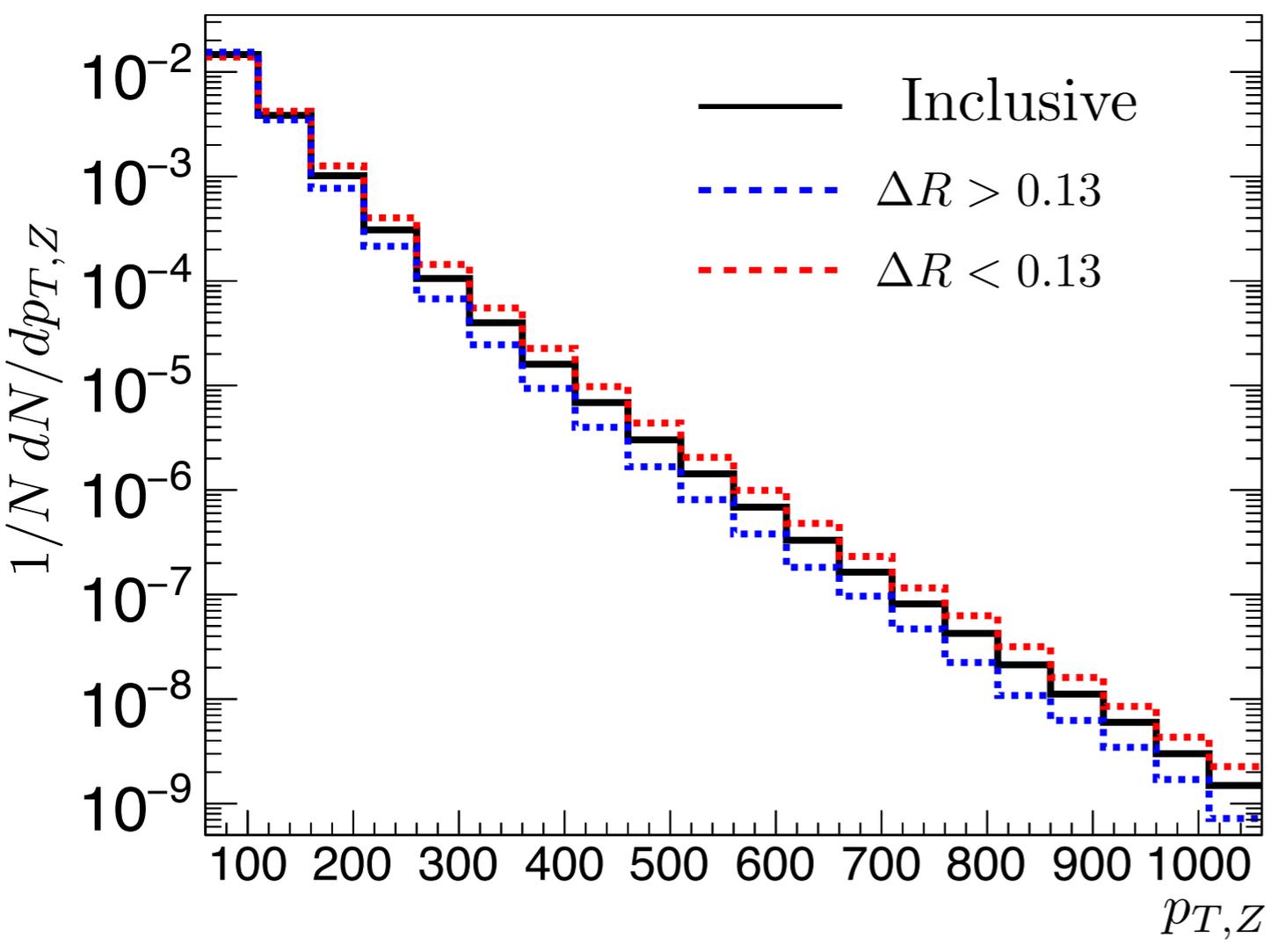


- Same jet selection as with τ_{form} ?



τ_{form} or ΔR : bias comparison

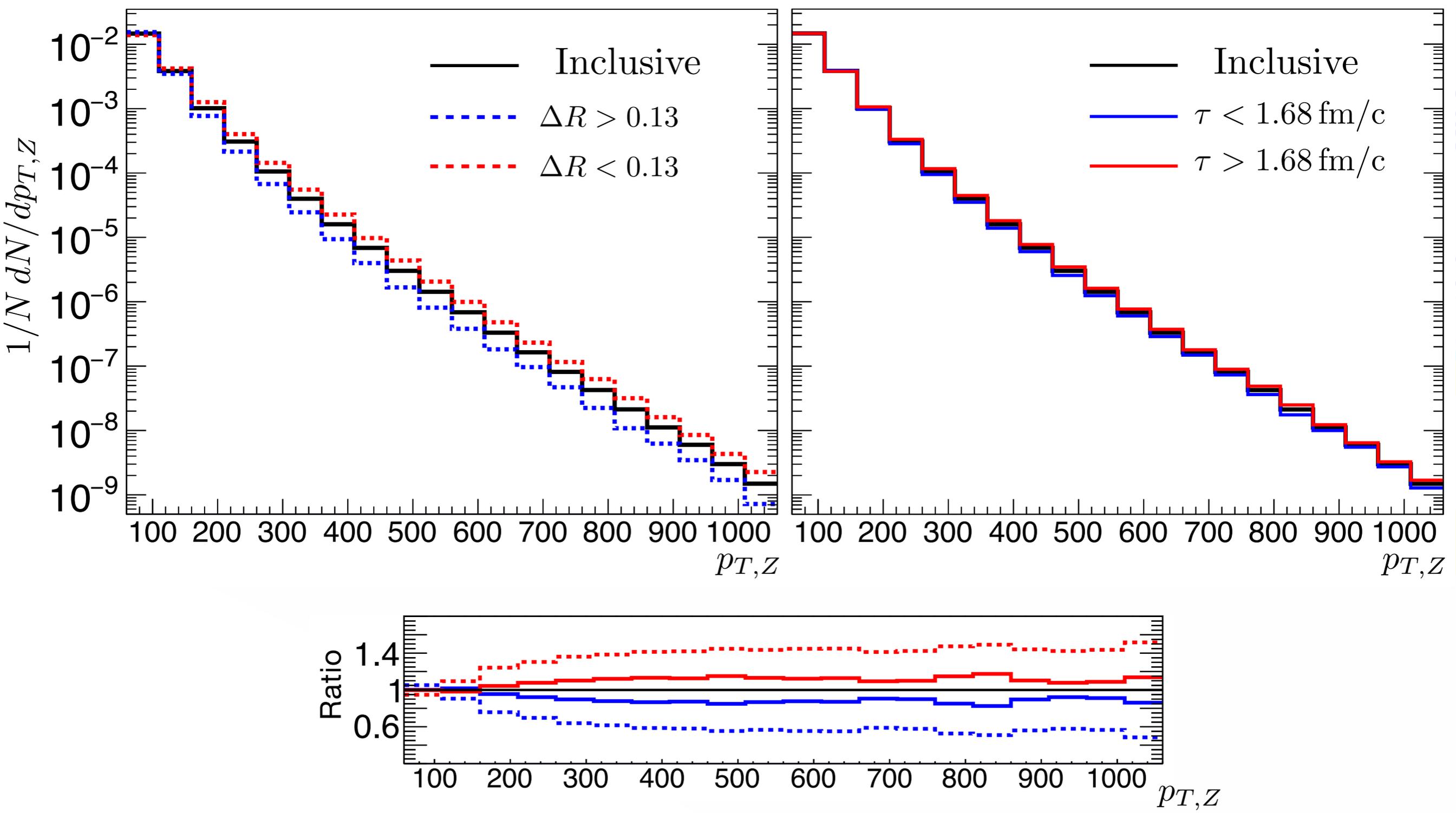
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τ_{form} or ΔR : bias comparison

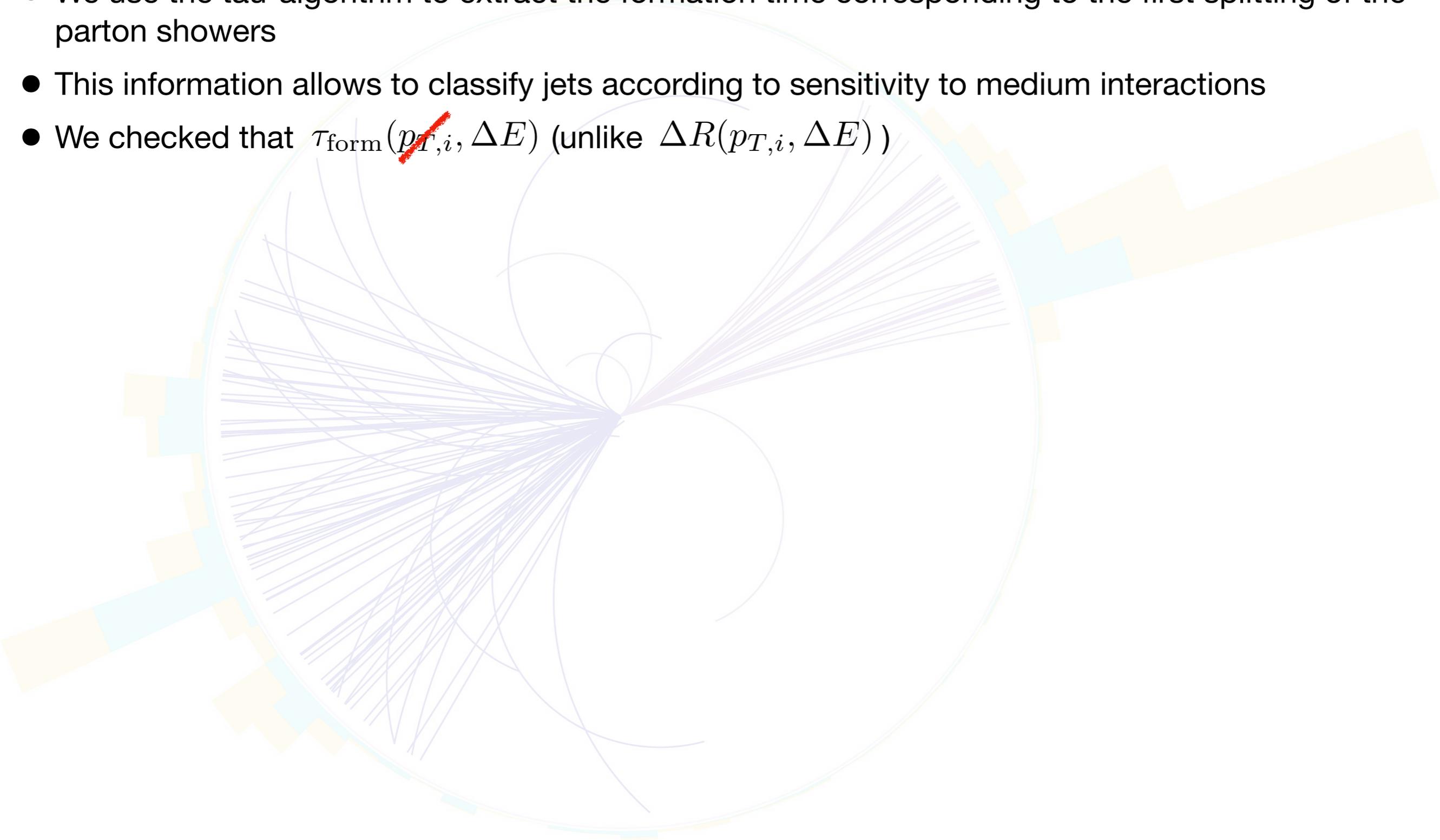
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Summary, future prospects

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- This information allows to classify jets according to sensitivity to medium interactions
- We checked that $\tau_{\text{form}}(p_{T,i}, \Delta E)$ (unlike $\Delta R(p_{T,i}, \Delta E)$)





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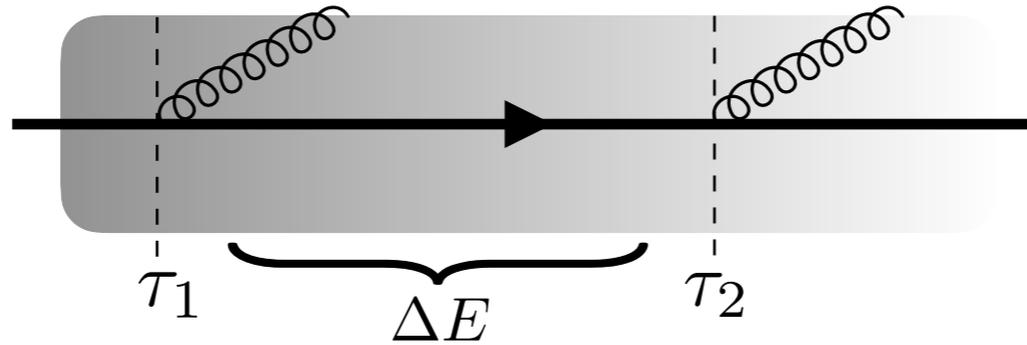
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TO APPEAR SOON IN ARXIV!



Back-up: With regard to the second splitting

- Necessary in order to relate energy loss to path length within the medium

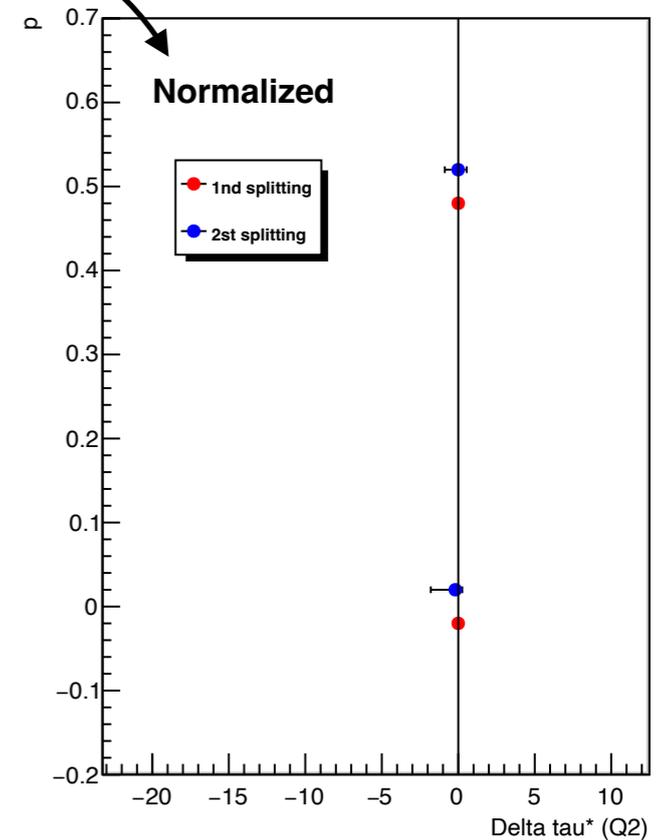
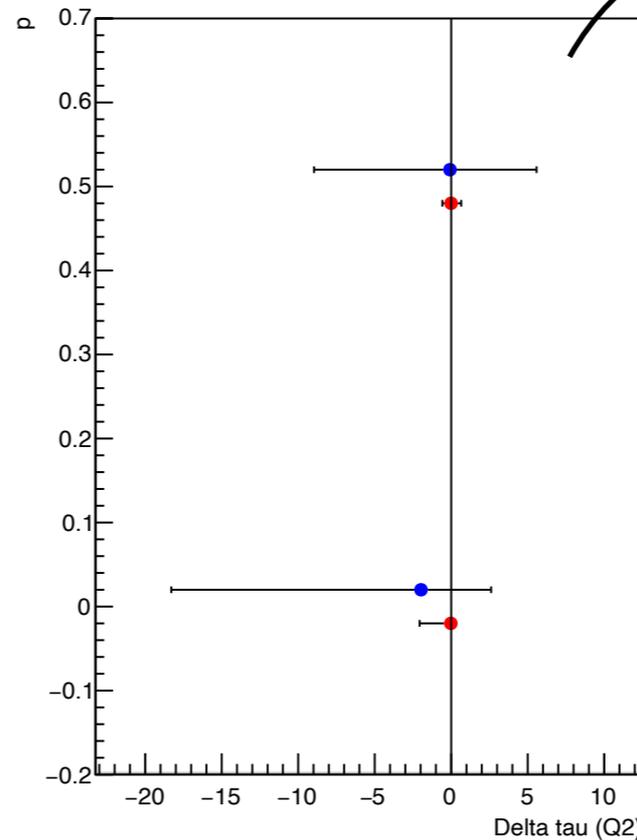
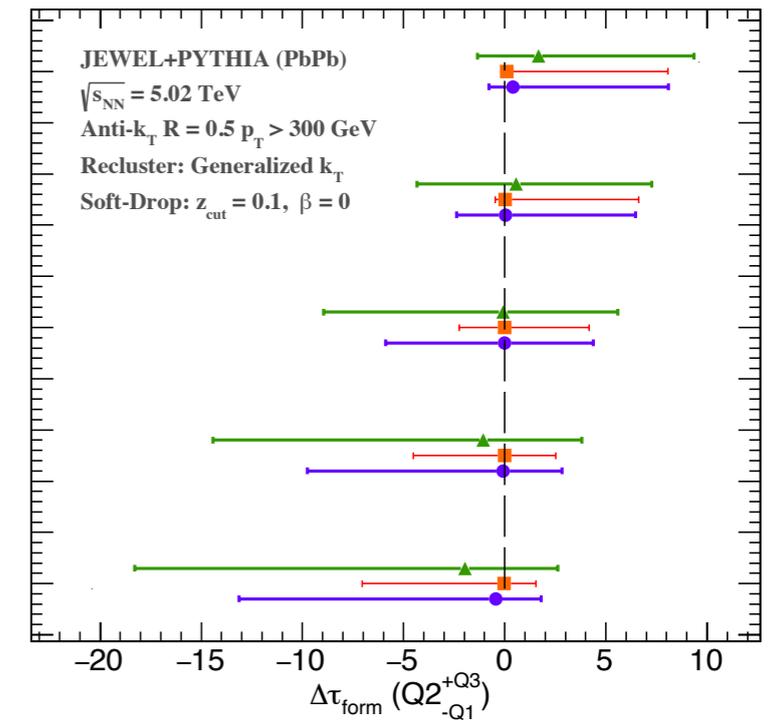
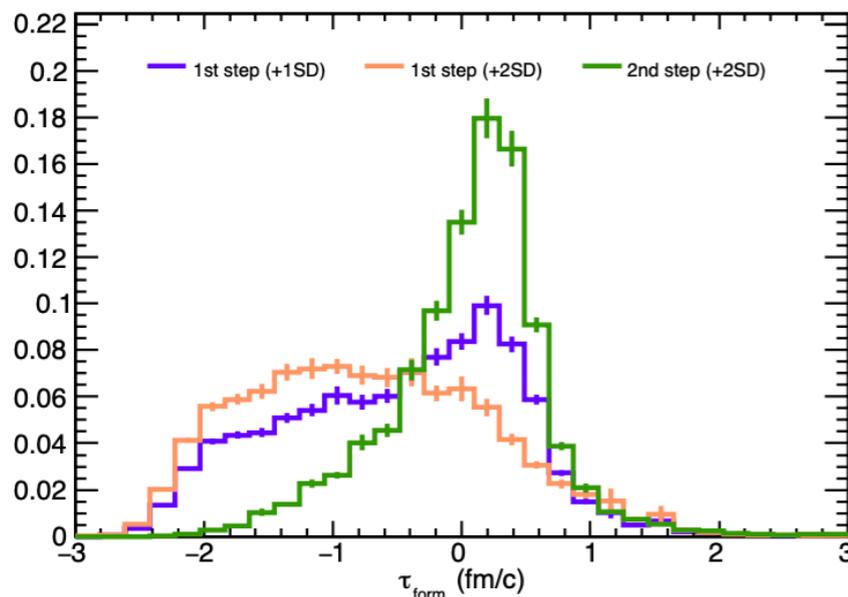


- But the IQR for the second step is significantly larger

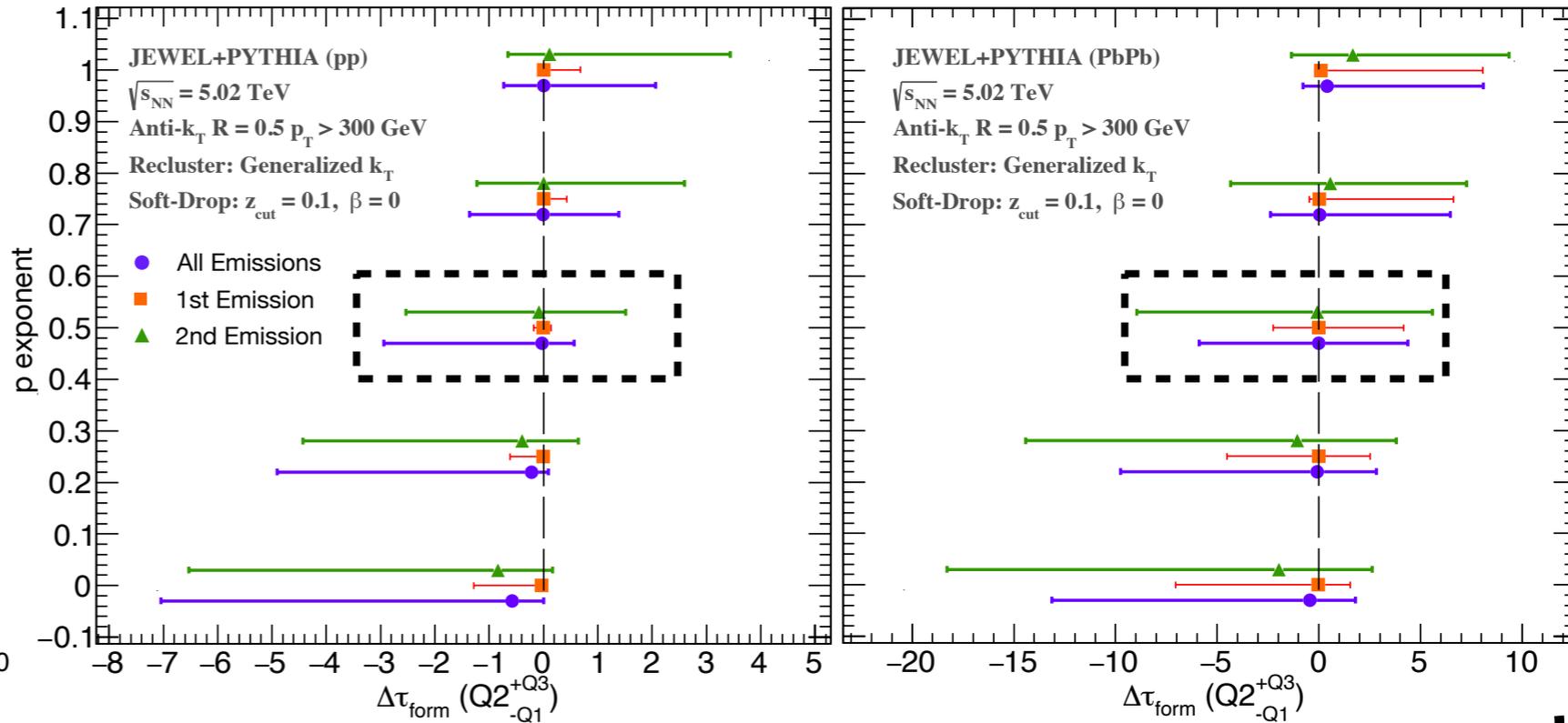
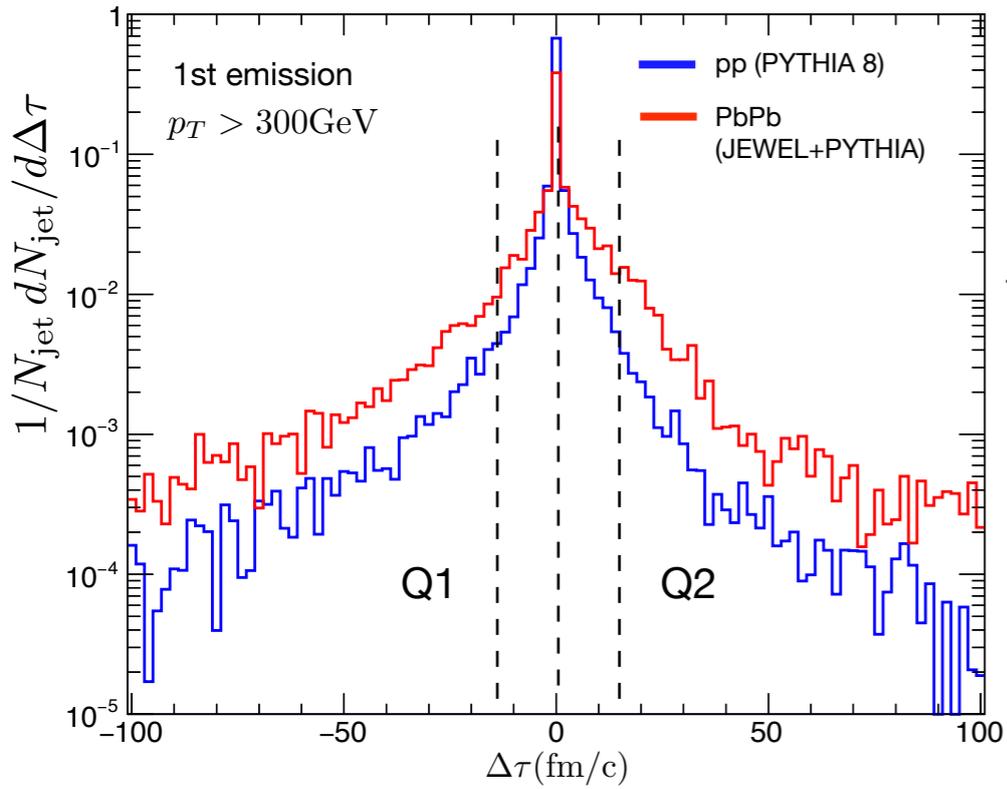
- * However, so is τ_{form} !
- * How about using the *relative* IQR?

This seems to do the trick, but...

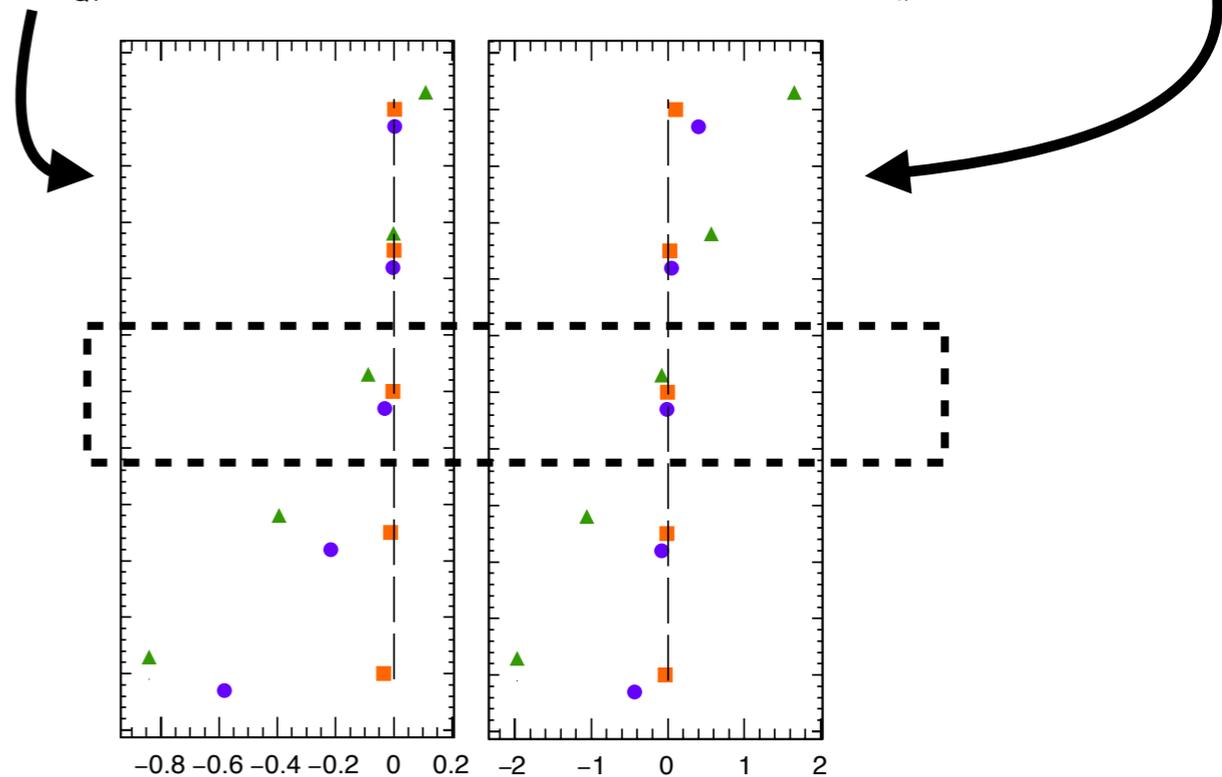
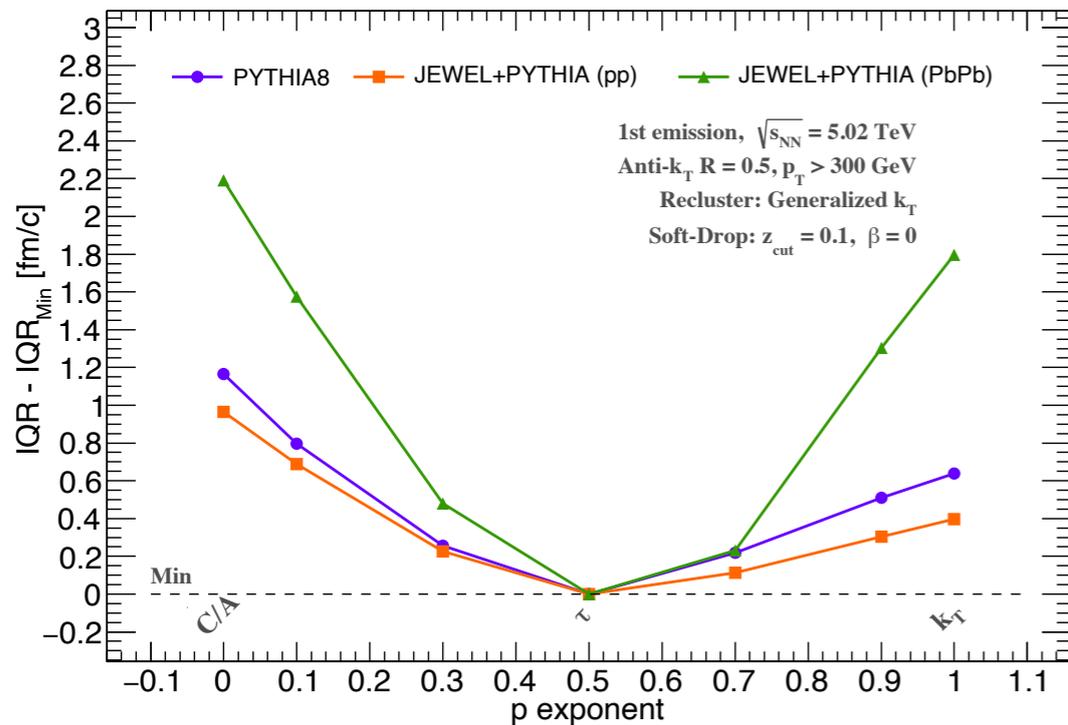
- By looking at jets with at least two splittings, we are introducing new biases



- We want to quantify the correlation between the values of τ_{form} obtained through unclustering and those extracted from MonteCarlo-generated **di-jet events**. We look at $\Delta\tau = \tau_{\text{form}}^{\text{MC}} - \tau_{\text{form}}^{\text{Unclustering}}$ distributions:



- We compare for different algorithms and different parton showers:



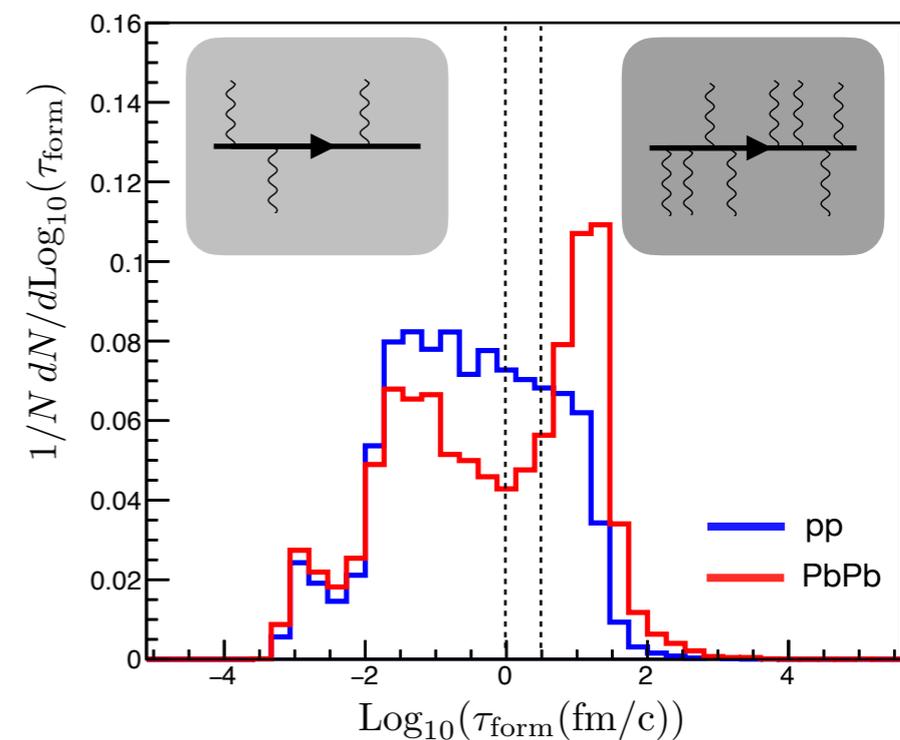


Back-up: The τ -algorithm applied to jet selection (more)

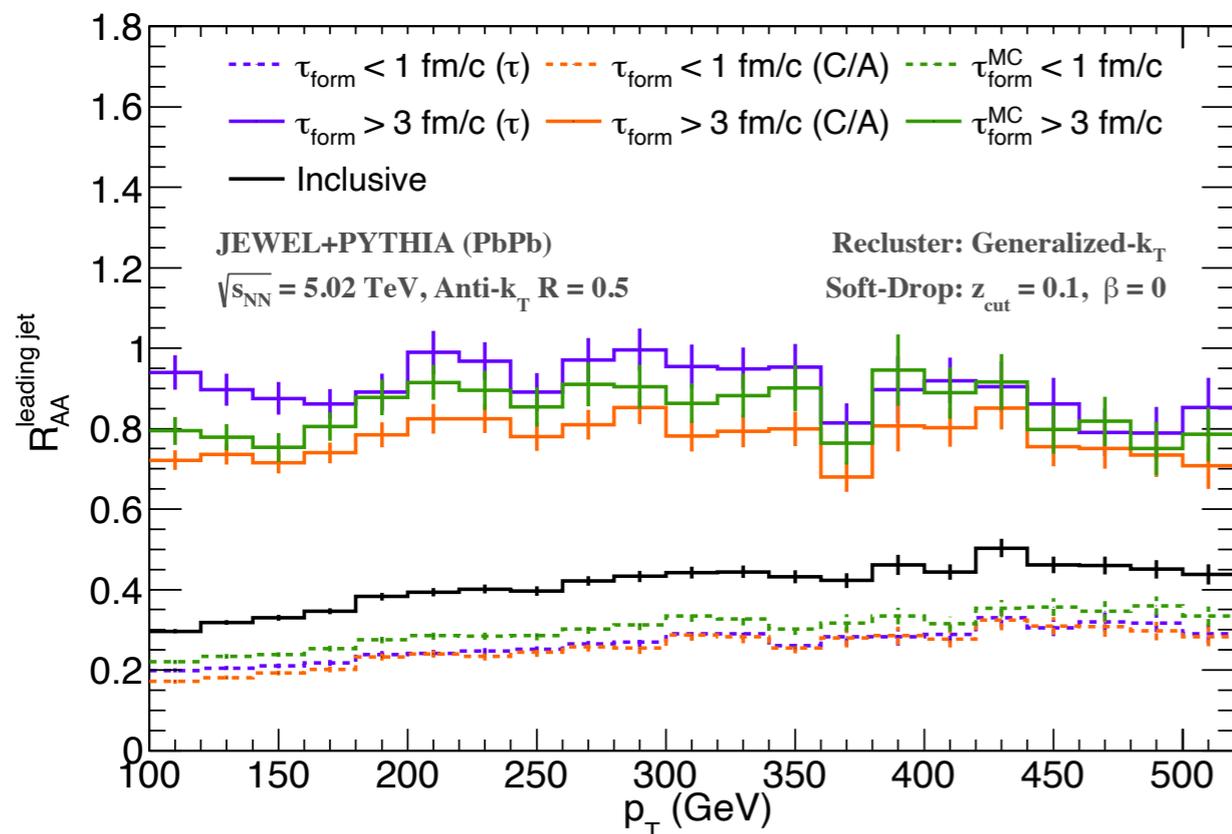
- We define two populations according to the value of $\tau_{\text{form}}^{\text{Unclustering}}$ for the first splitting:

* **Early jets** (first 1 fm/c) \longrightarrow **Strongly modified**

* **Late jets** (after 3 fm/c) \longrightarrow **Weakly modified**



- We compute the **nuclear modification factor** for each population:



$$R_{AB} = \frac{1}{\langle N_{\text{coll}} \rangle} \frac{dN/dp_T|_{A+B}}{dN/dp_T|_{p+p}}$$

\longrightarrow **Weakly modified**

\longrightarrow **Strongly modified**

Back-up: What about the dispersion of the distributions?

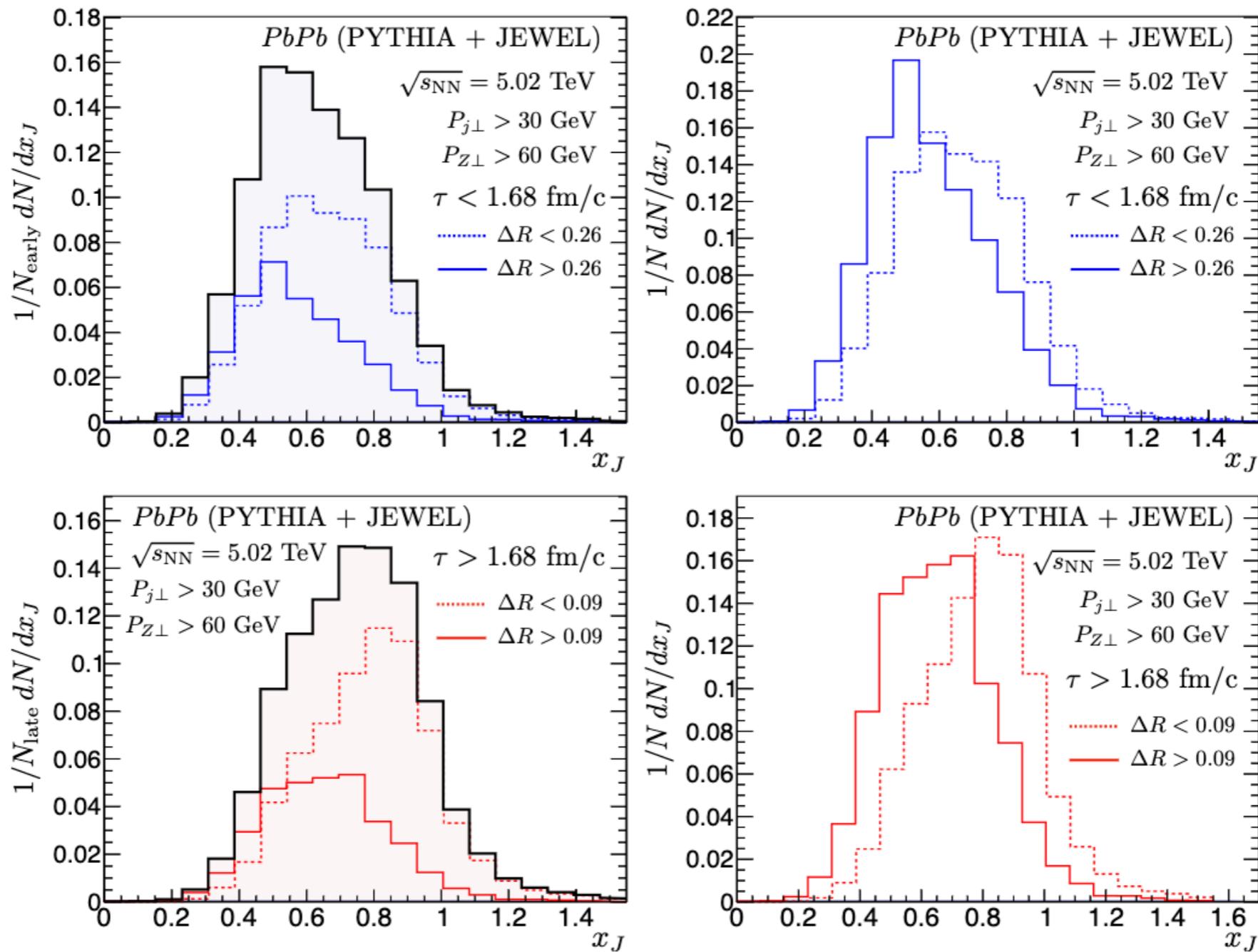


FIG. 2: Comparison of x_{jZ} distributions for narrow (full colored lines) and wide (dashed lines) subsamples taken from the early (top) and late (bottom) PbPb jet selections. The distributions in the left panels are normalized to the size of the corresponding parent jet samples, represented as full black lines above color-shaded areas (note that these same distributions were shown previously in the left bottom plot of Fig. 1). In the right panels we display the narrow and wide subsamples only, each normalized to unity.