Parton cascades at DLA: the role of the evolution variable

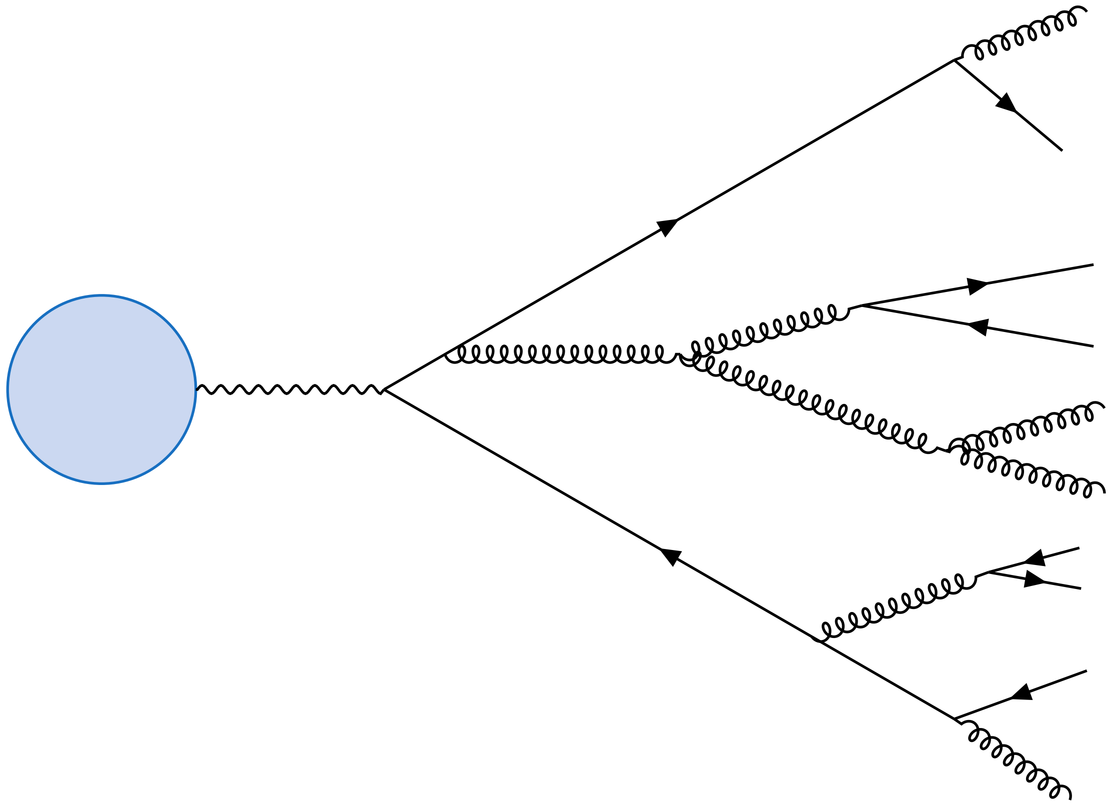
André Cordeiro

In collaboration with:

Carlota Andrés, Liliana Apolinário, Nestor Armesto, Fabio Dominguez, Guilherme Milhano

Quark Matter, 5th September 2023

Why do we care about parton showers?



- Parton showers in vacuum vs medium

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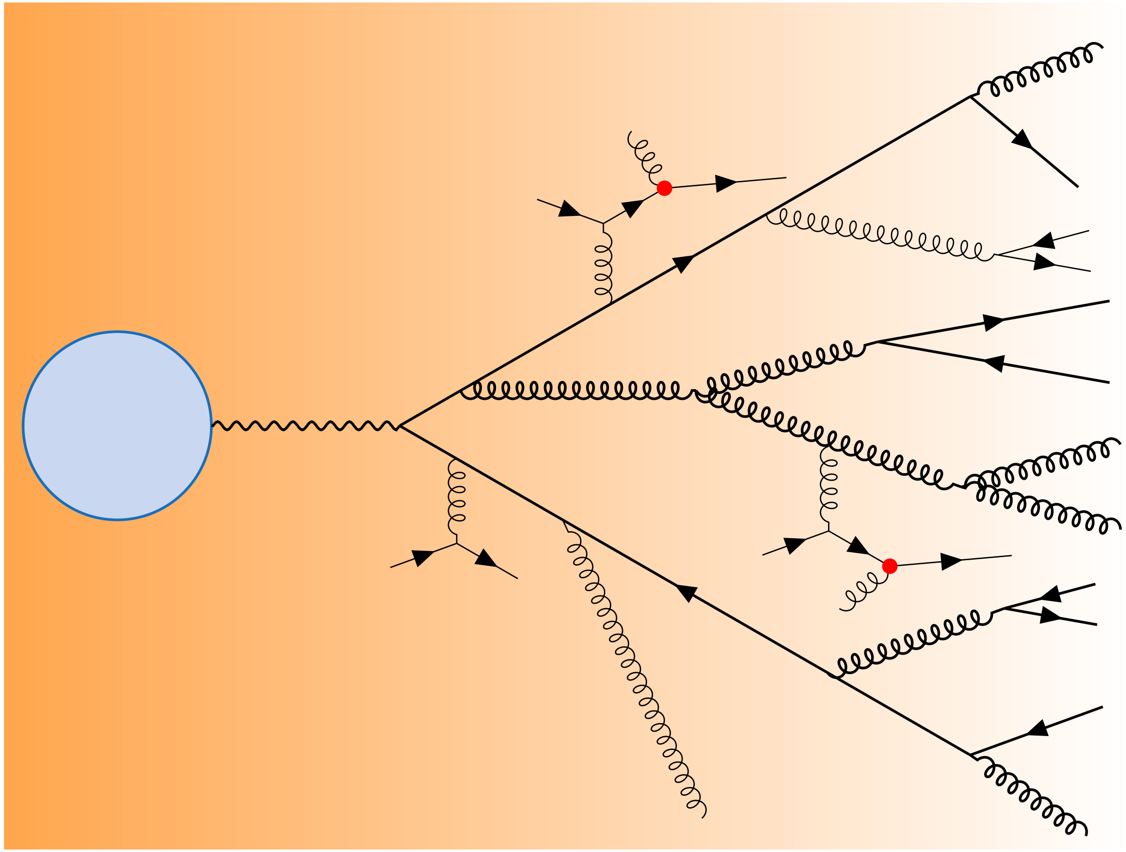

- Parton showers in vacuum vs medium
- Medium properties probed by jet quenching
- Time-ordered picture needed for medium interface

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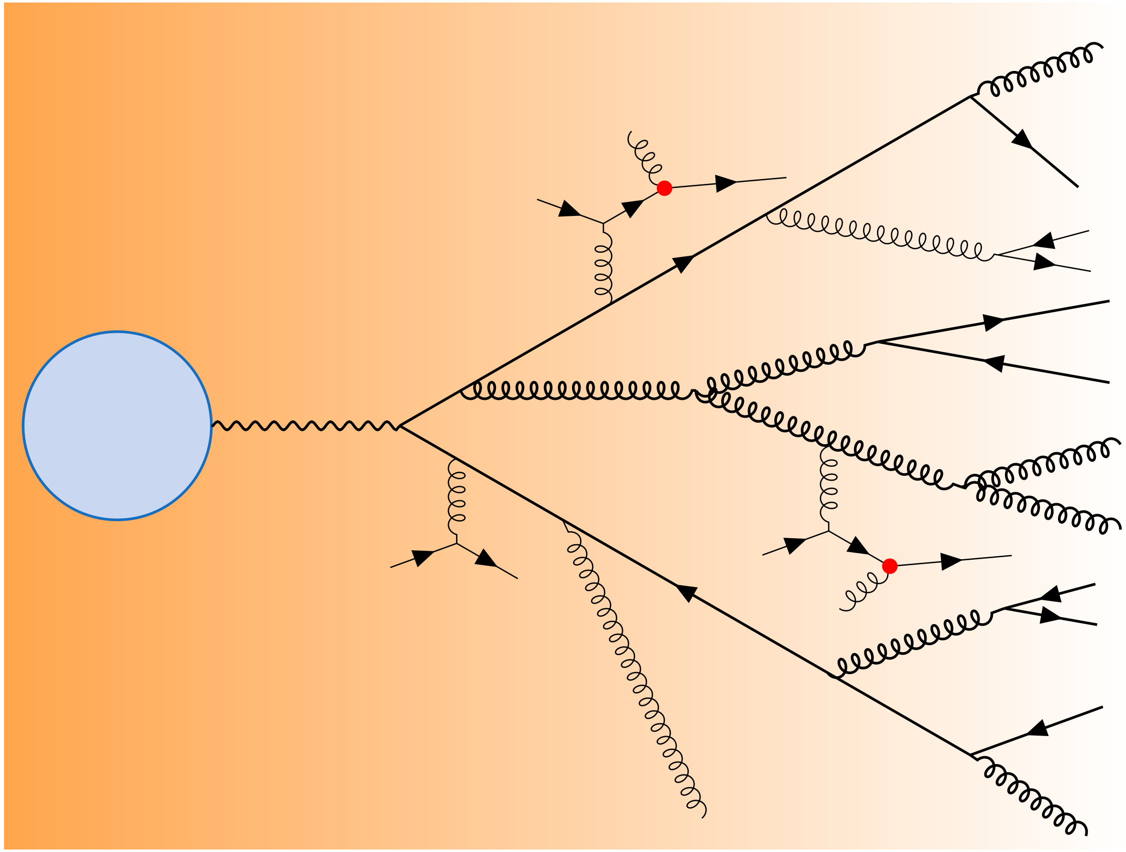

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Is jet quenching sensitive to the ordering of vacuum-like splittings?

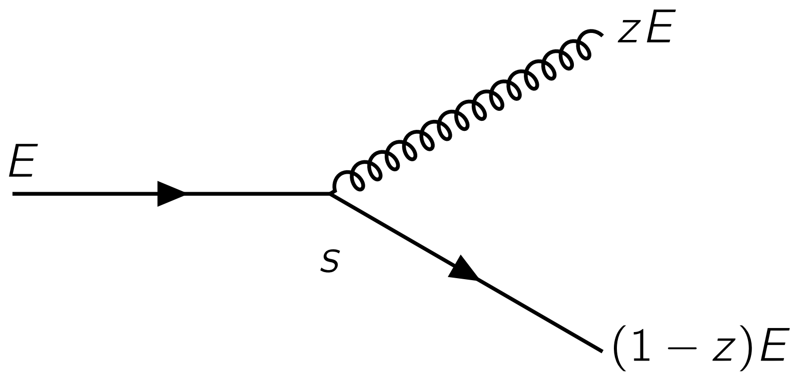
First, a look at vacuum showers

Building differently ordered cascades

No-emission probability:

$$\Delta(s_{\text{prev}}, s) = \exp\left\{-\frac{\alpha C_R}{\pi}\int_s^{s_{\text{prev}}}\frac{\mathrm{d}\mu}{\mu}\int_{z_{\text{cut}}(\mu)}^{1}\frac{\mathrm{d}z}{z}\right\}$$

Splitting variables:



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Interpretations for the scale:

$$s \to p^2 = \frac{|\boldsymbol{p}_{\text{rel}}|^2}{z(1-z)}$$

(Virtuality)

$$s \to t_{\text{form}}^{-1} = \frac{p^2}{E} = \frac{|\boldsymbol{p}_{\text{rel}}|^2}{Ez(1-z)}$$

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$$s \to \zeta = \frac{p^2}{E^2 z(1-z)}$$

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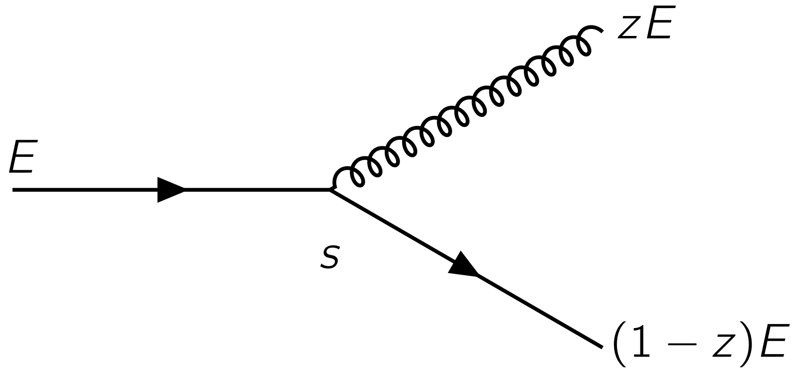

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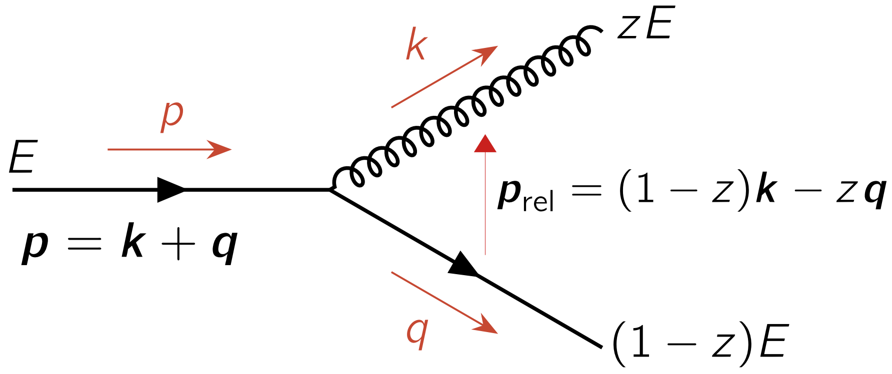
To generate a splitting:



1. Sample a scale from $\Delta(s_{\text{prev}}, s)$
2. Sample a fraction from $\hat{P}(z) \propto 1/z$

Ensure that $|\boldsymbol{p}_{\text{rel}}|^2 > \Lambda^2$

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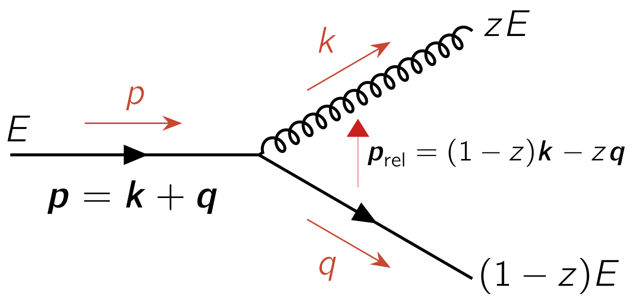

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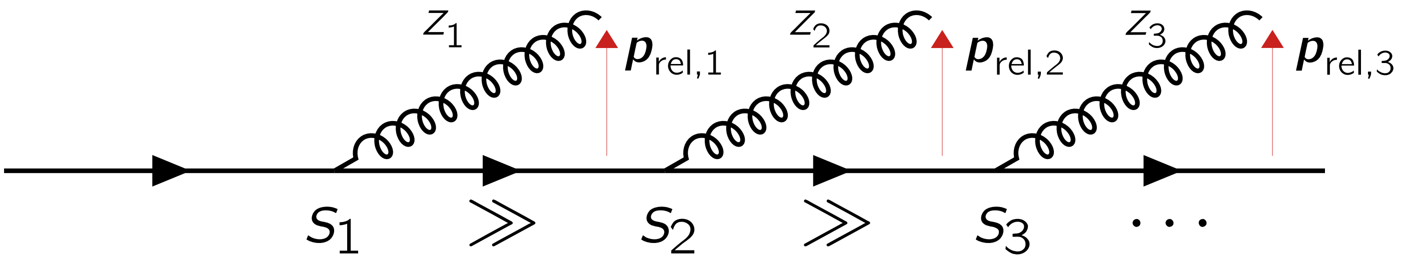
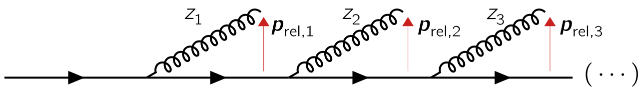


This results in the strong ordering of scales

Parton Shower Details



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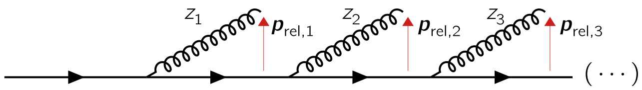

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- Splittings must happen above an hadronisation scale: $|\boldsymbol{p}_{\mathrm{rel}}|^2 > \Lambda^2$
  - This provides a **soft cutoff:** $z > z_{\mathrm{cut}}(s)$

    e.g.: Formation time ordering $|\boldsymbol{p}_{\mathrm{rel}}|^2 > \Lambda^2 \Longleftrightarrow z(1-z) > \dfrac{\Lambda^2}{t_{\mathrm{form}}^{-1} E}$

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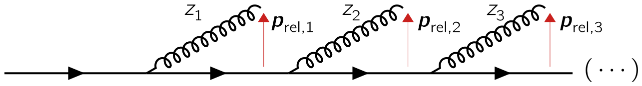

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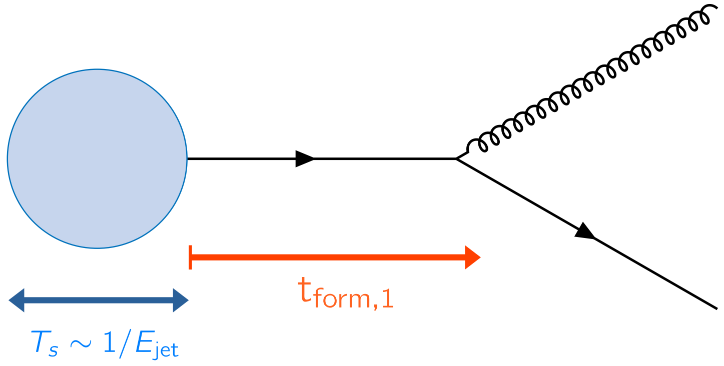

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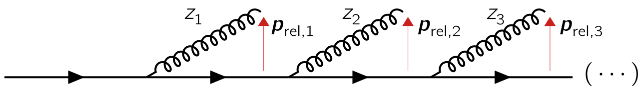

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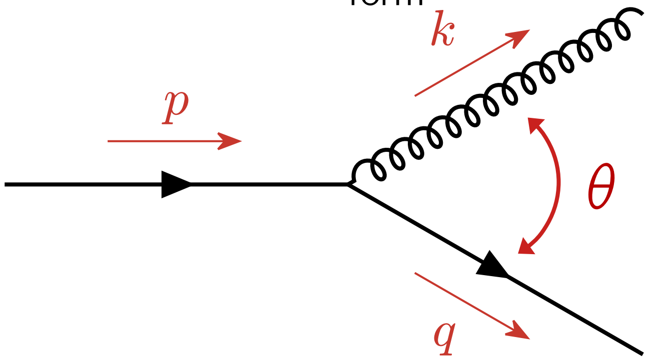
- Initialisation condition for the shower: $t_{\mathrm{form}}^{-1} < E$
  - For consistency between orderings: $\zeta < 4 \implies |\boldsymbol{p}_{\mathrm{rel}}| < \dfrac{E}{2}$

    (Enforced via retrials)

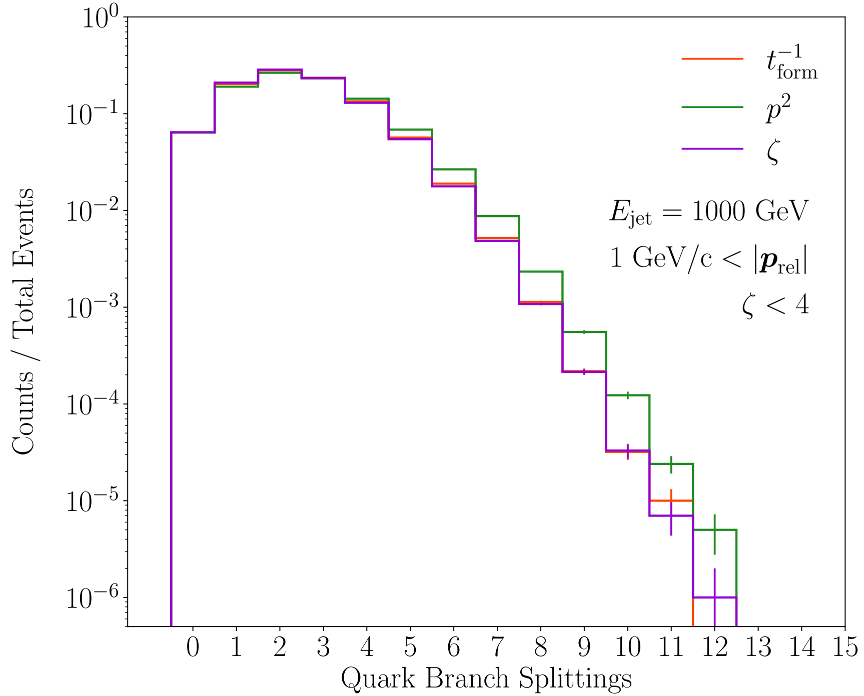


Massless Limit : $\zeta \simeq 2(1-\cos\theta)$

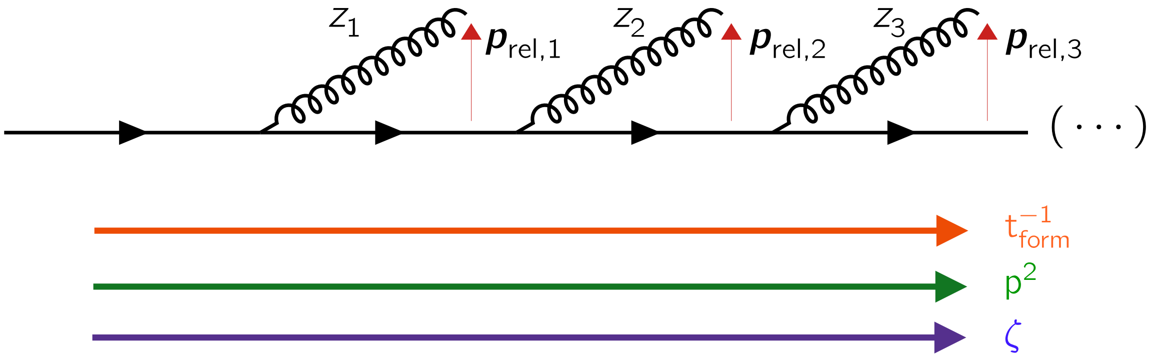
Results (Work in Progress)

Differences in Ordering Choices

Splittings along the quark branch



Different orderings → Different phase-space for allowed splittings



<u>The strictly decreasing scale is different for the three algorithms</u>

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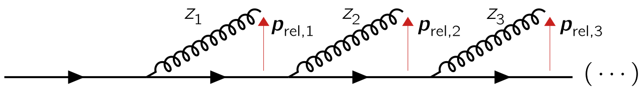
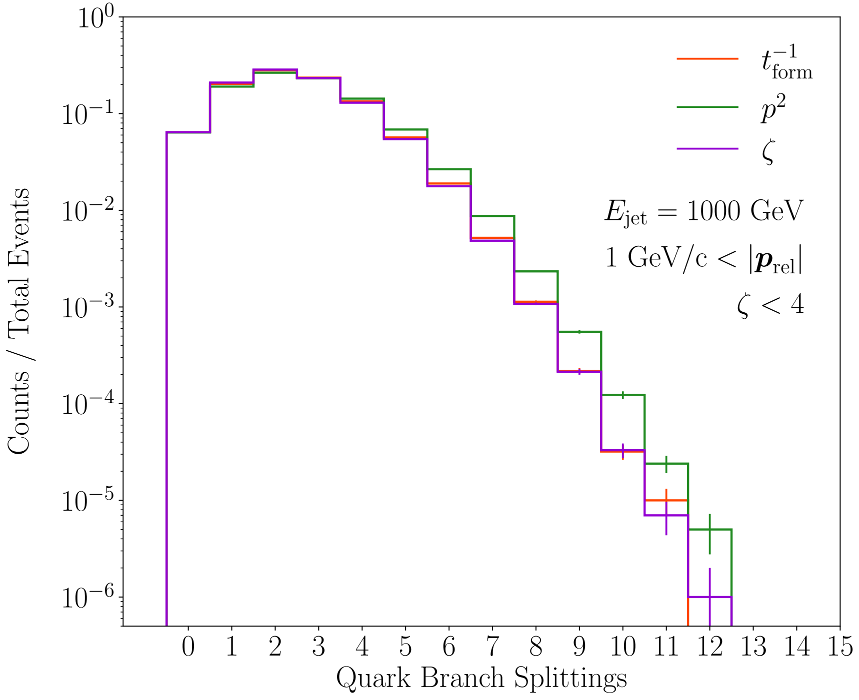


Splittings along the quark branch



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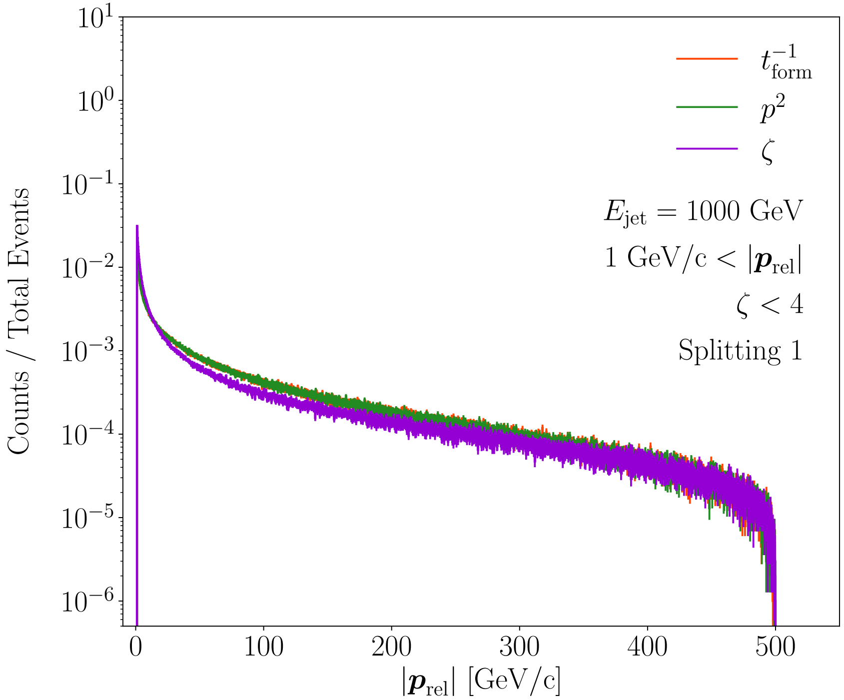
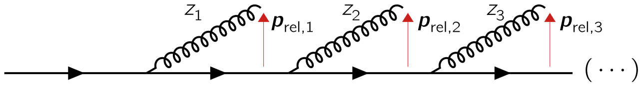
Relative transverse momentum (1st splitting)

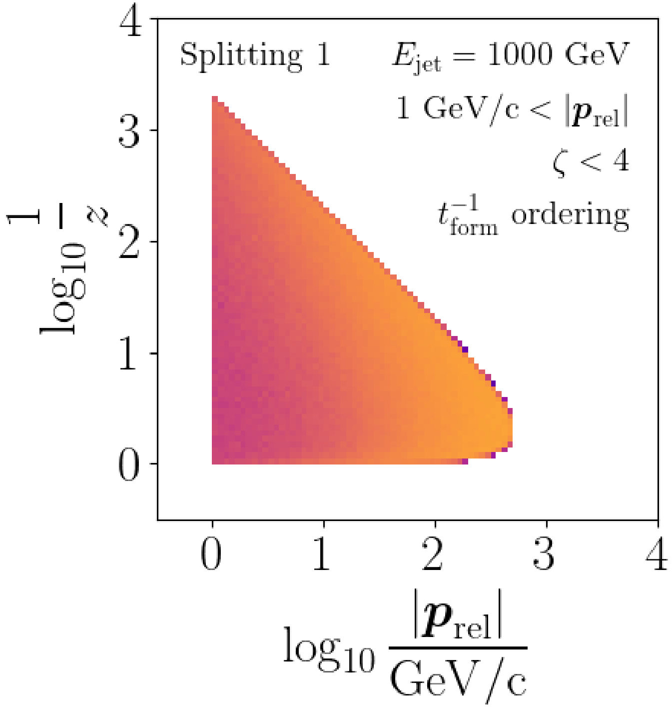


Transverse momentum distributions follow $\frac{\mathrm{d}\boldsymbol{p}_{\mathrm{rel}}^2}{\boldsymbol{p}_{\mathrm{rel}}^2}$

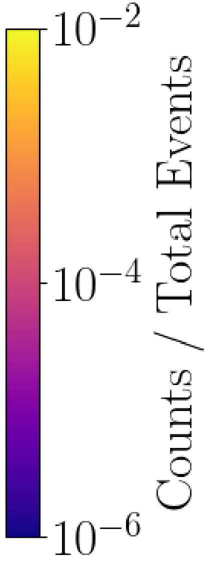
Lund Plane Densities



Consider the shower evolution <u>along the quark branch</u>:



Boundaries in the Lund Plane:



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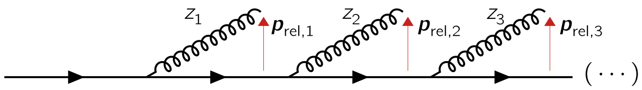

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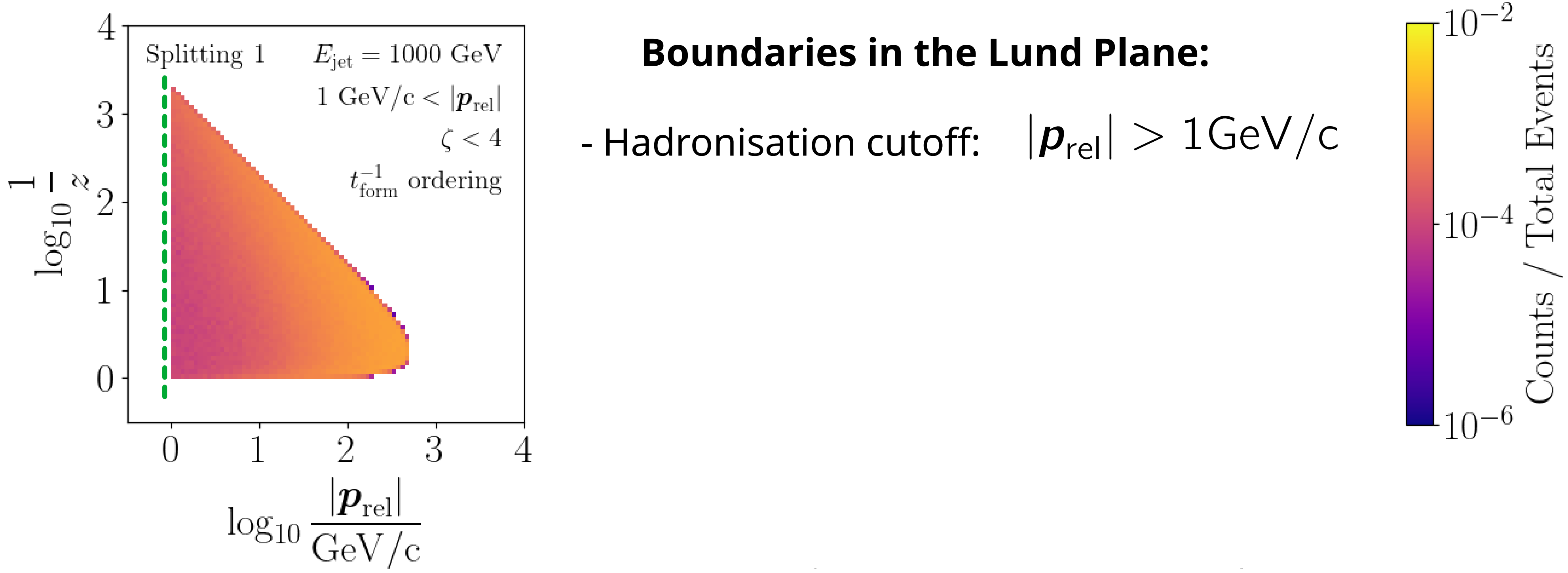

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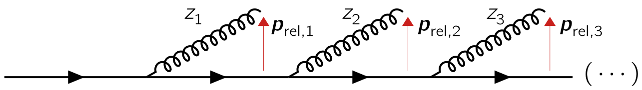

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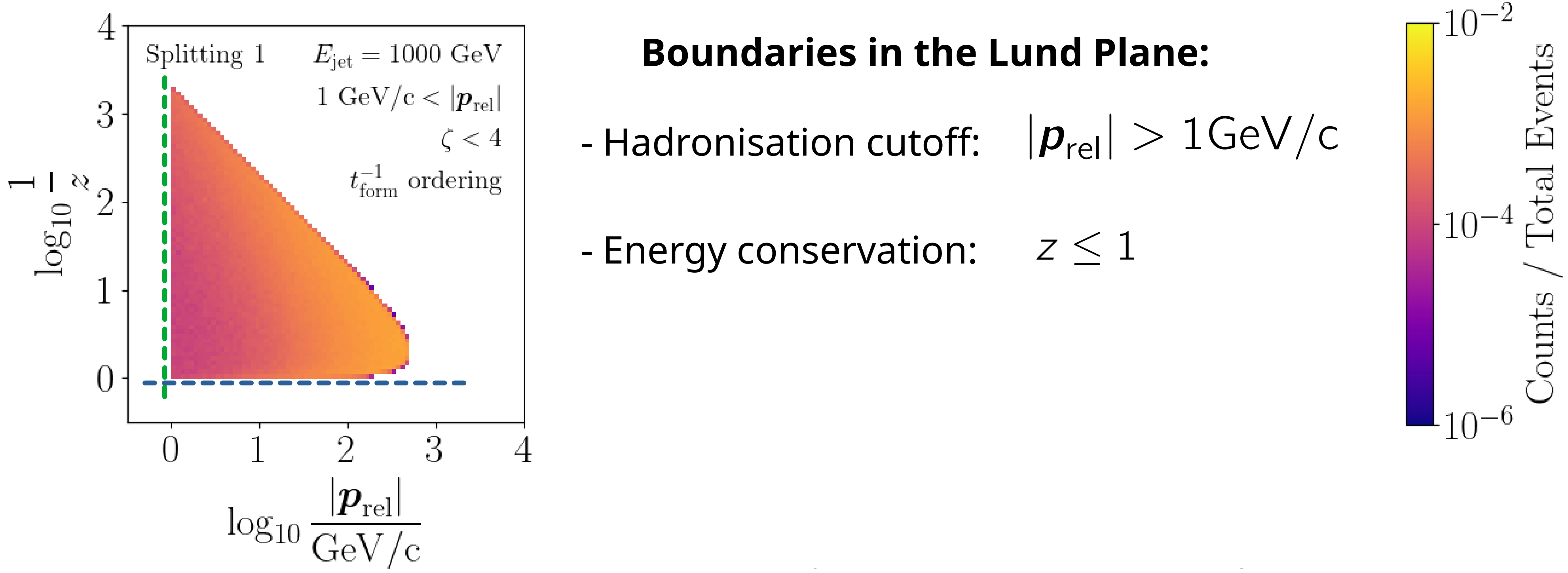

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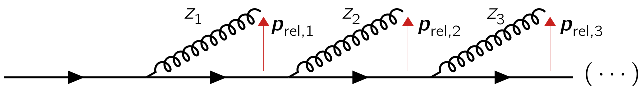

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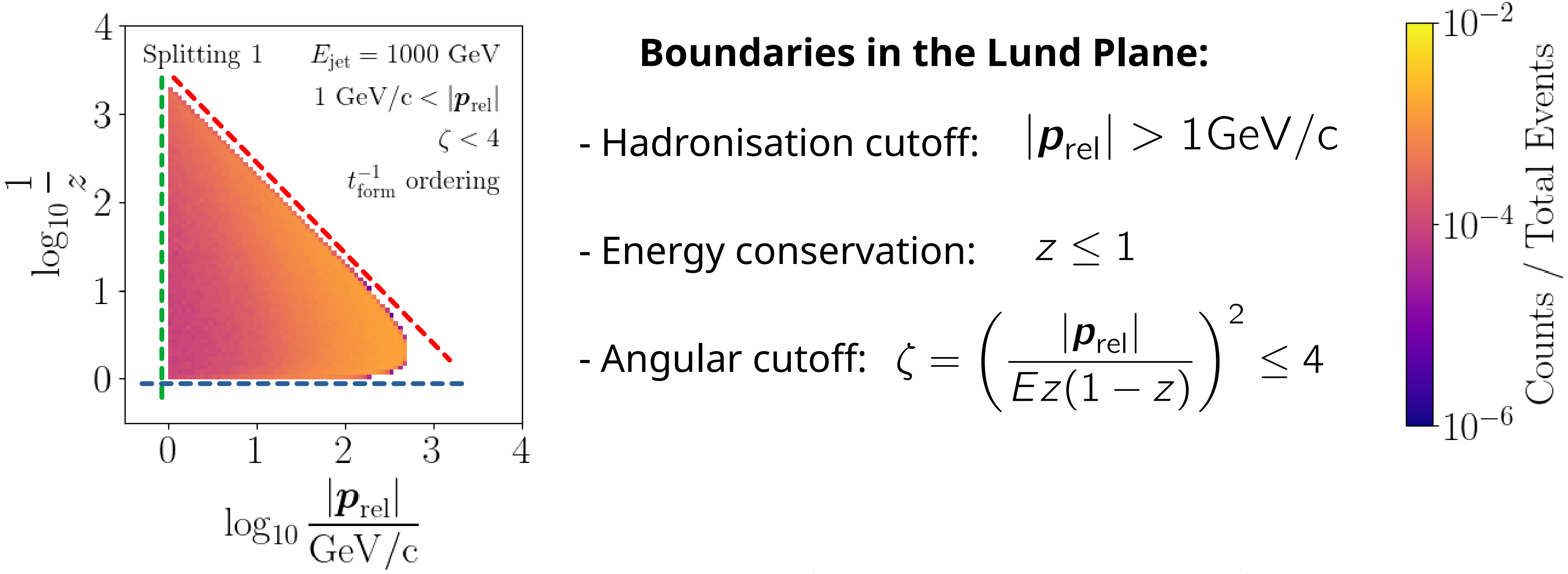

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- Angular cutoff: $\zeta = \left(\frac{|\boldsymbol{p}_{\mathrm{rel}}|}{Ez(1-z)} \right)^2 \leq 4$

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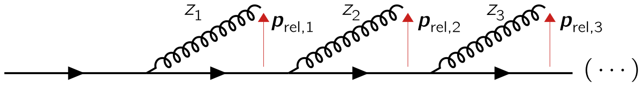

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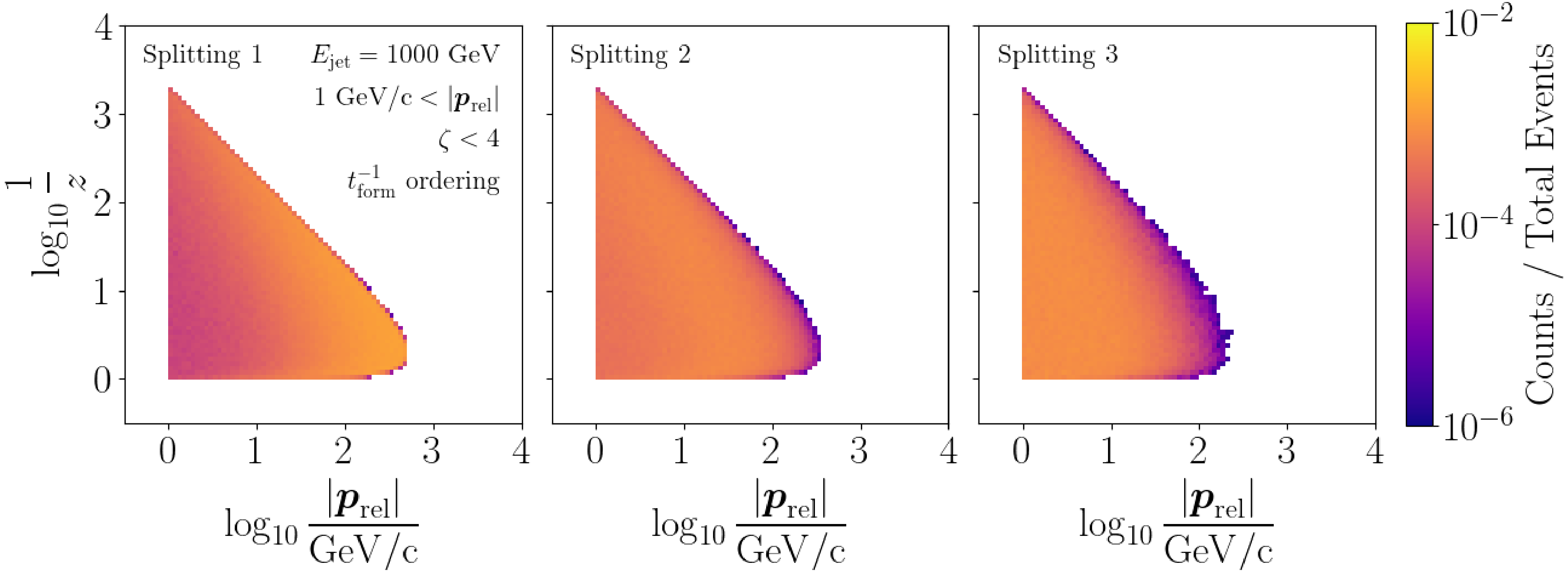
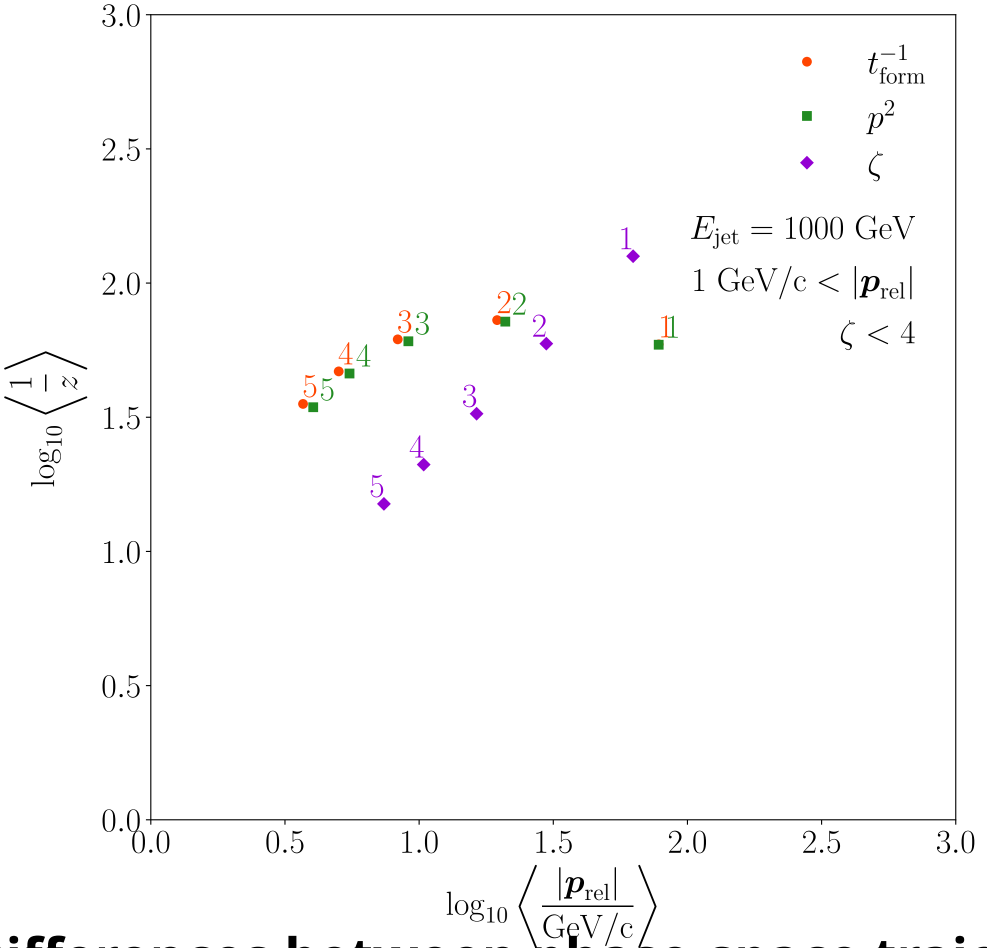
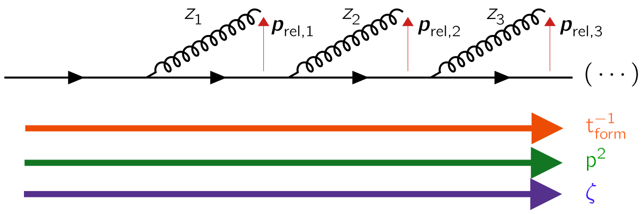


Shower evolution: Transverse momentum <u>decreases</u>, momentum fraction <u>increases</u>.

Lund Plane Trajectories

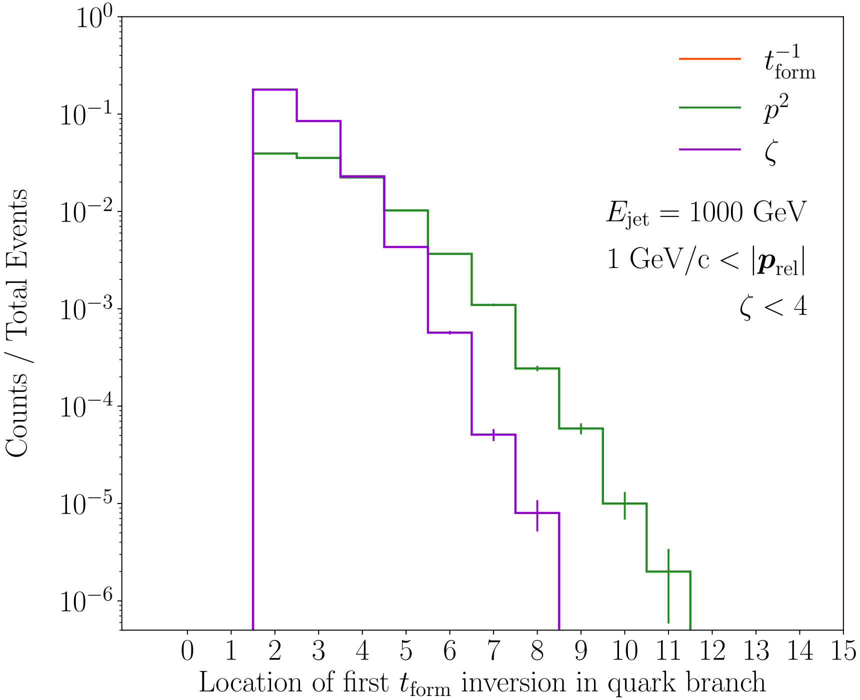




Differences between phase-space trajectories

Inversions in Kinematic Variables

(~ 30% Events with time inversions)



Formation Time Inversions:

Splittings with a formation time shorter that their immediate predecessor.

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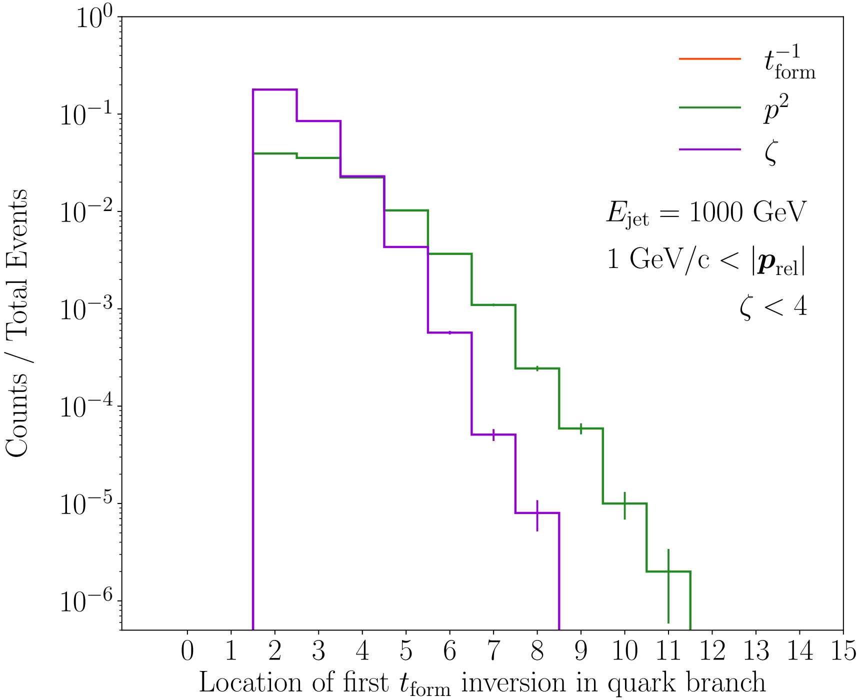

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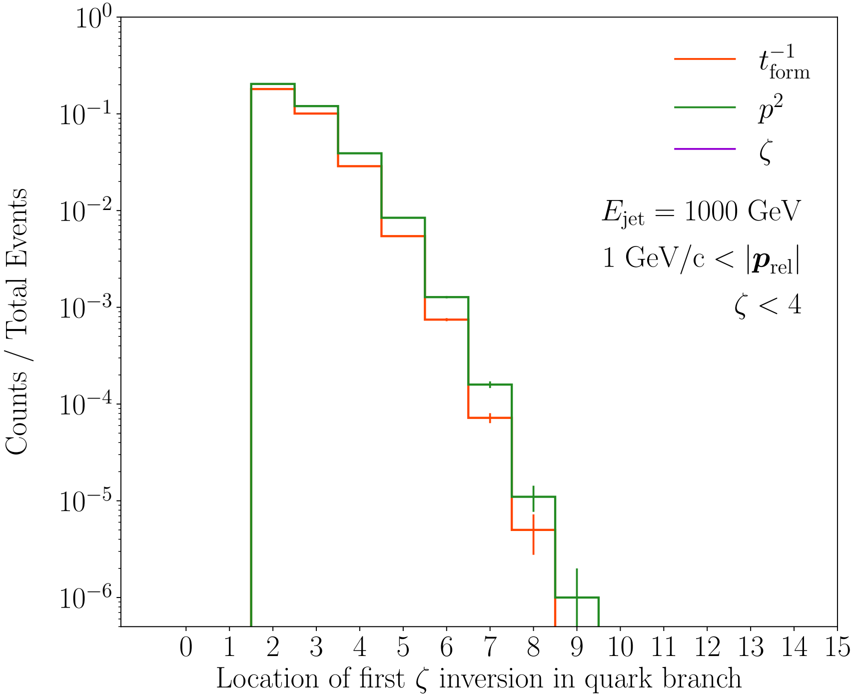

Angular inversions

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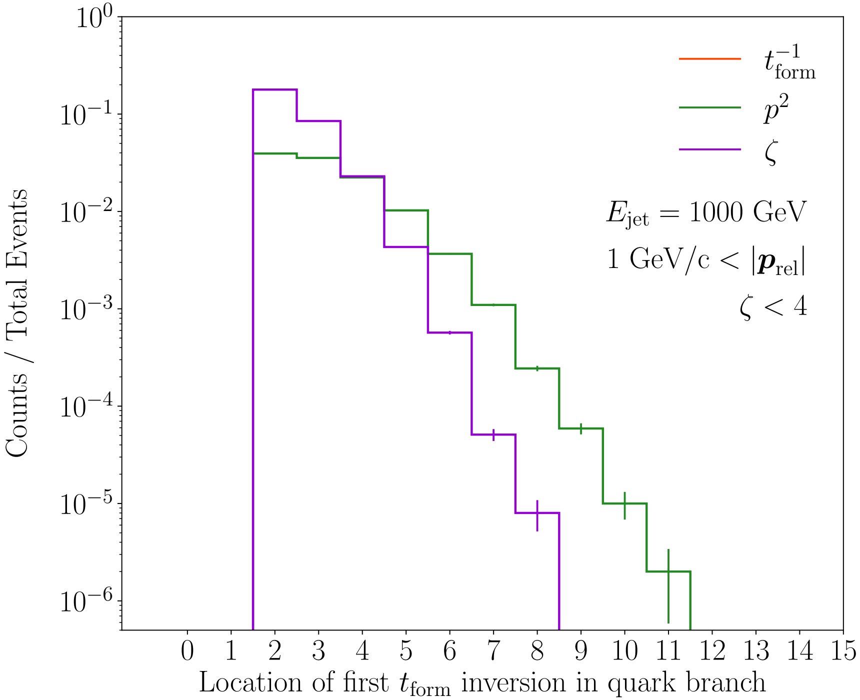

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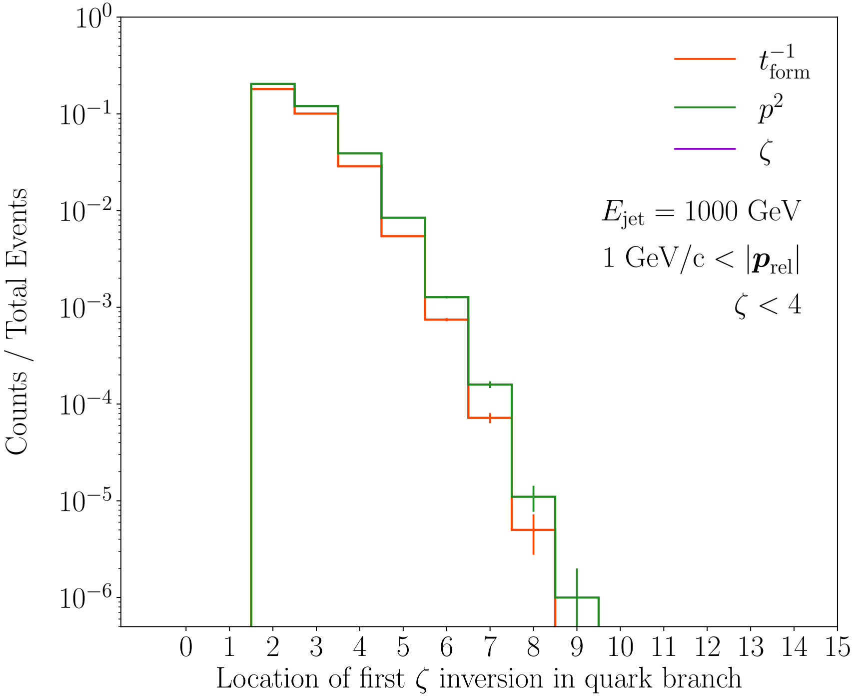
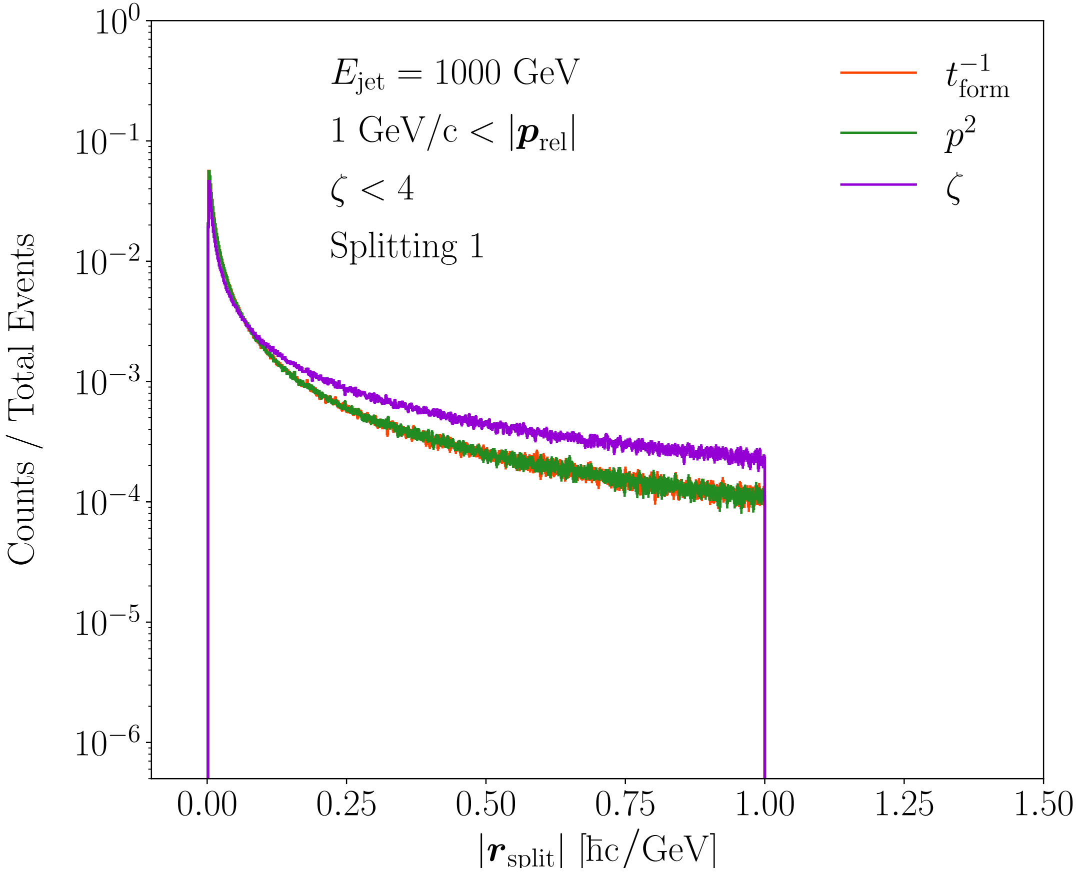


Angular inversions

Can this discrepancy translate into differences in quenching magnitude?

Now, a simple quenching model!

Choosing a quenching condition



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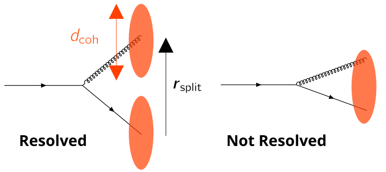

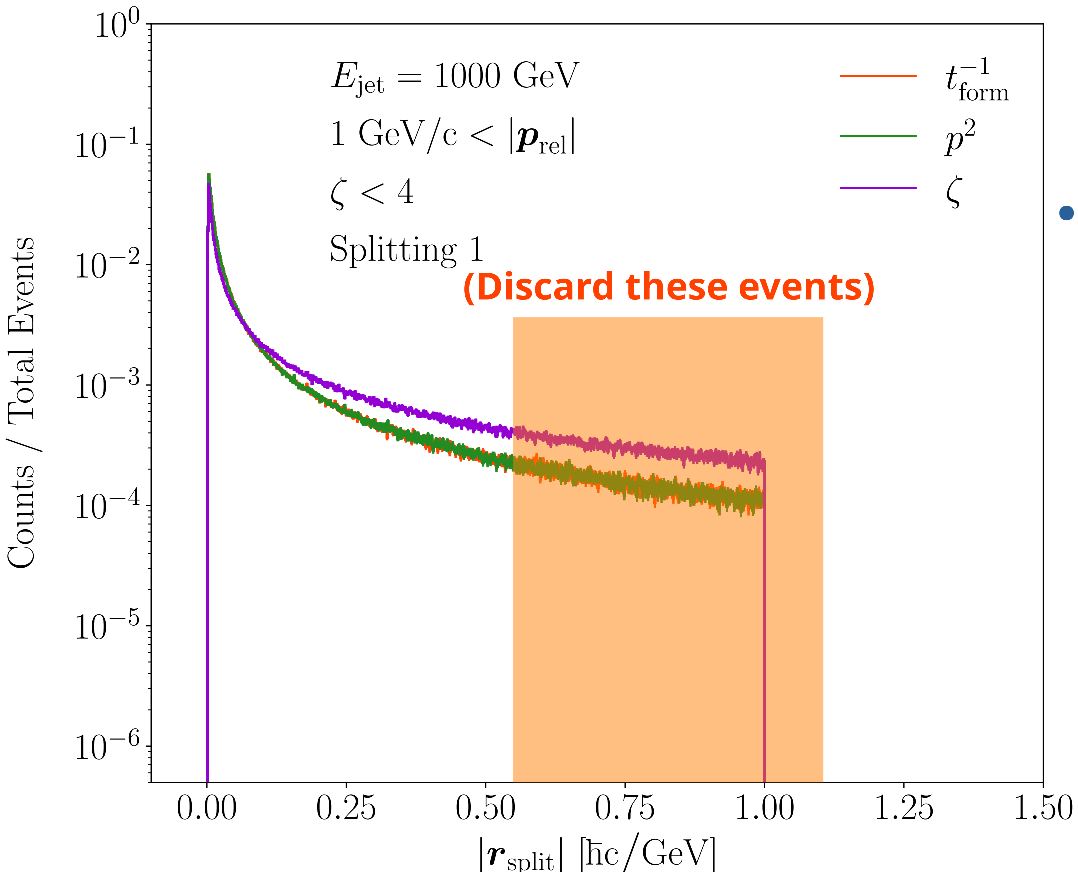

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(Decoherence)

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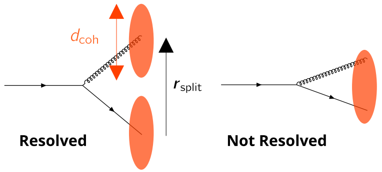
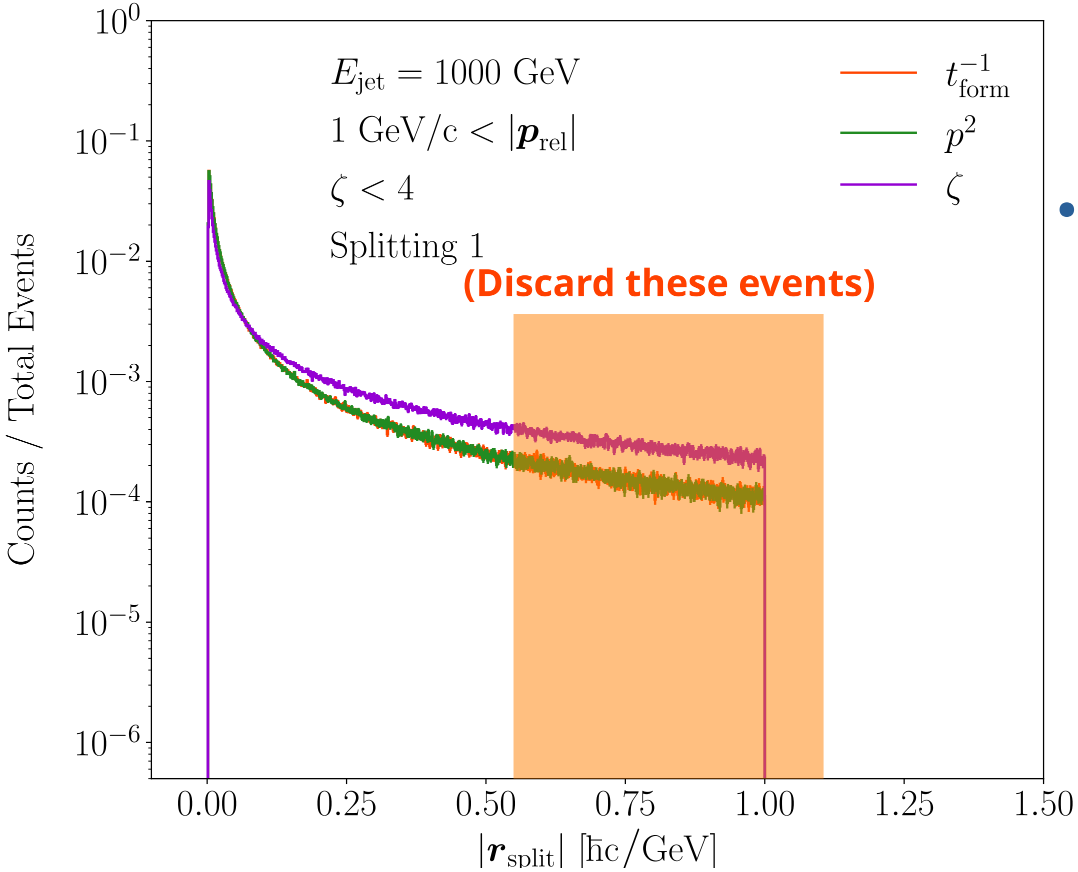
Mehtar-Tani, Salgado, Tywoniuk :: Phys.Rev.Lett. 106 (2011)
Casalderrey-Solana, Iancu :: JHEP 08 (2011) 015

Choosing a quenching condition





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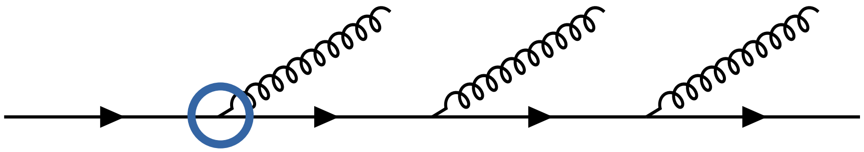

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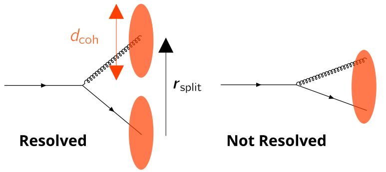

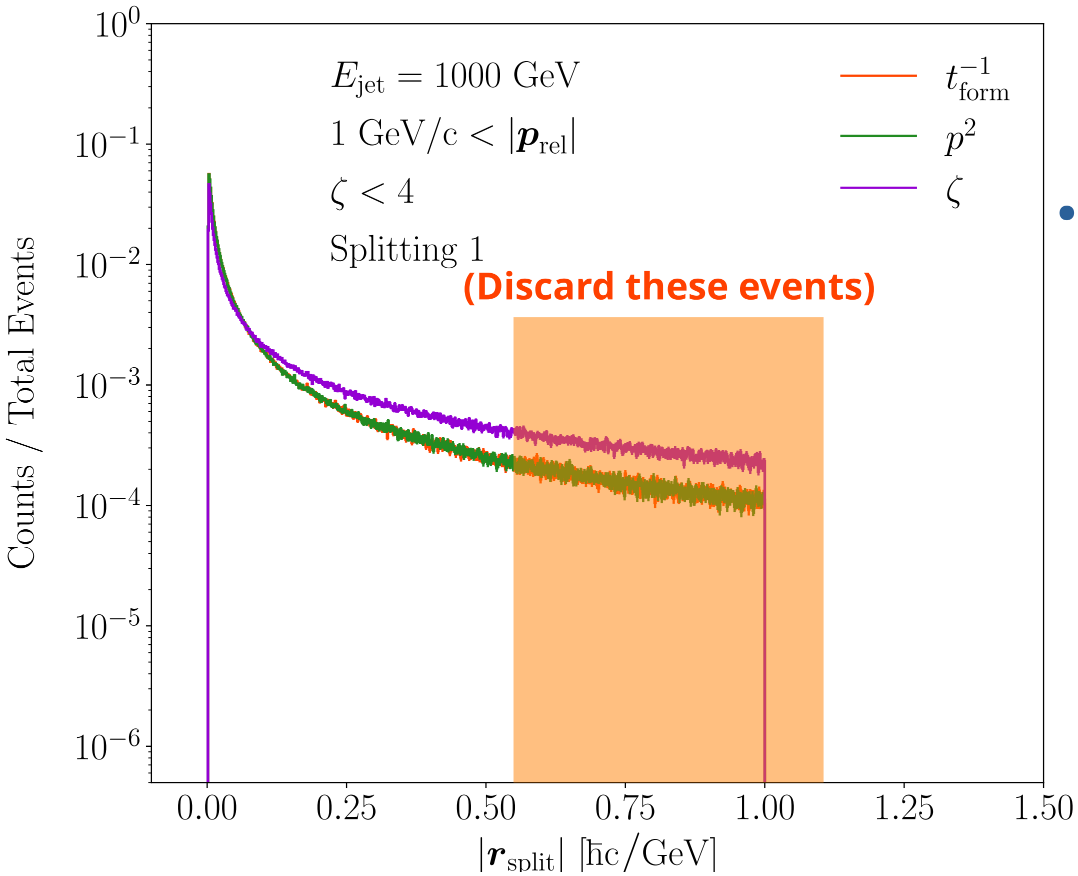

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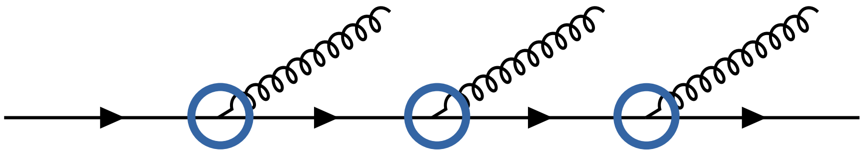

- Option 1: Apply only to first splitting
- Option 2: Apply to whole quark branch

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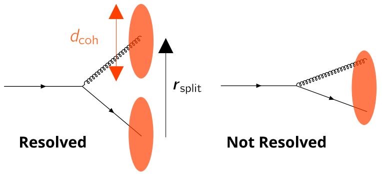
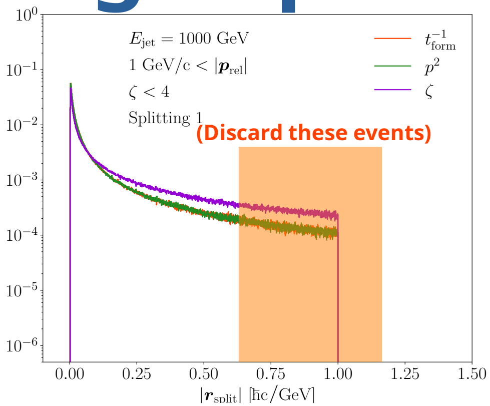
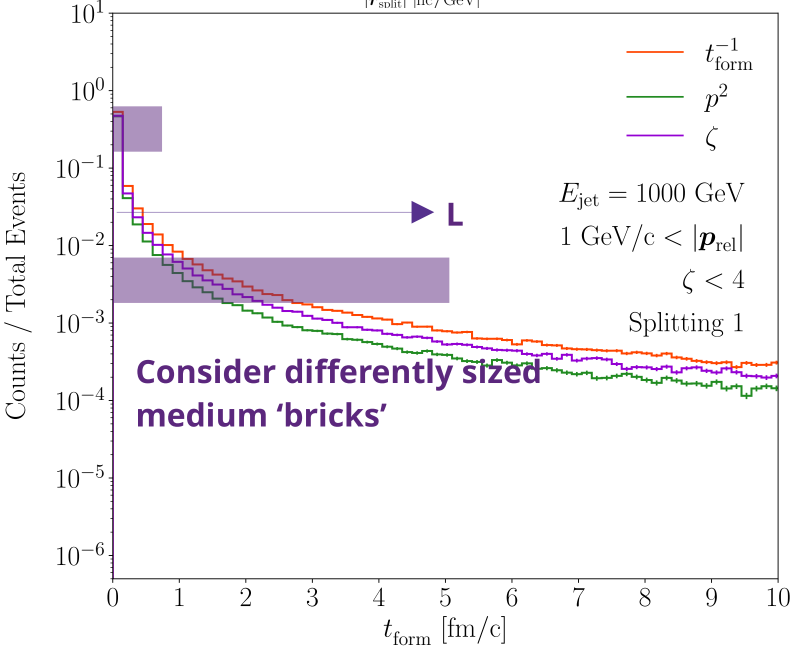






Transverse distance between daughters:

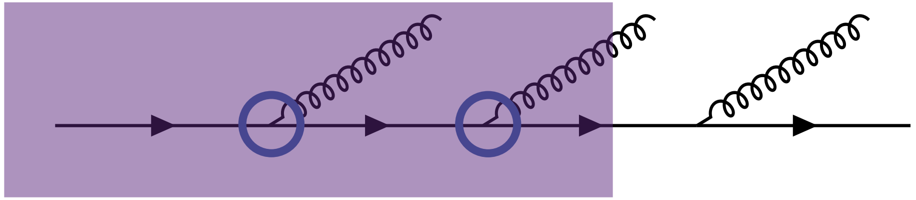
$$|\boldsymbol{r}_{split}| = \frac{1}{|\boldsymbol{p}_{rel}|} = \sqrt{\zeta}\; t_{form}$$

- A simplistic model: eliminate event if

(Decoherence)

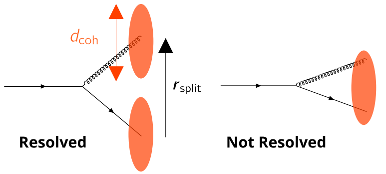
$$|\boldsymbol{r}_{split}| > \frac{1}{\sqrt{\hat{q}L}} = d_{coh} \text{ and } t_{form} < L$$

Two implementations:

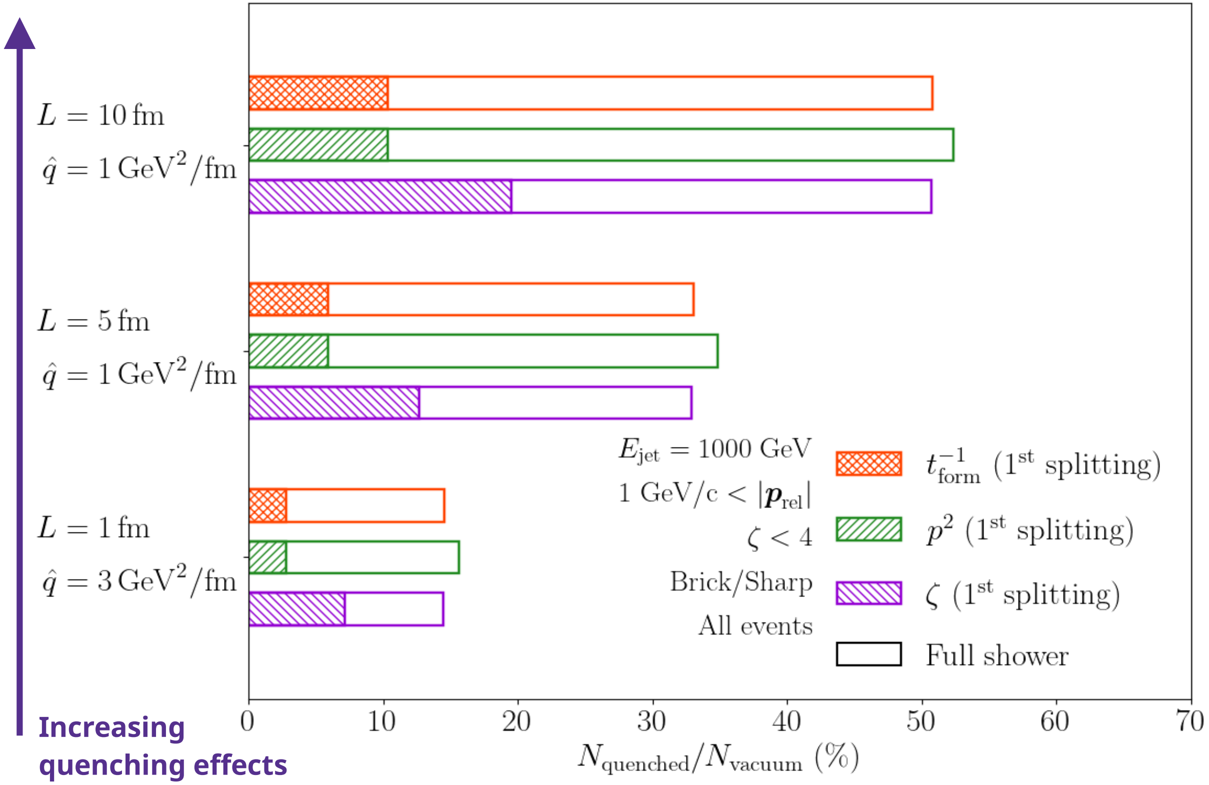


- Option 1: Apply only to first splitting
- Option 2: Apply to whole quark branch

Fraction of Quenched Events



Percentage of events eliminated by the quenching condition



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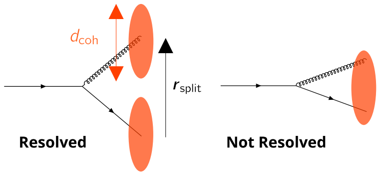

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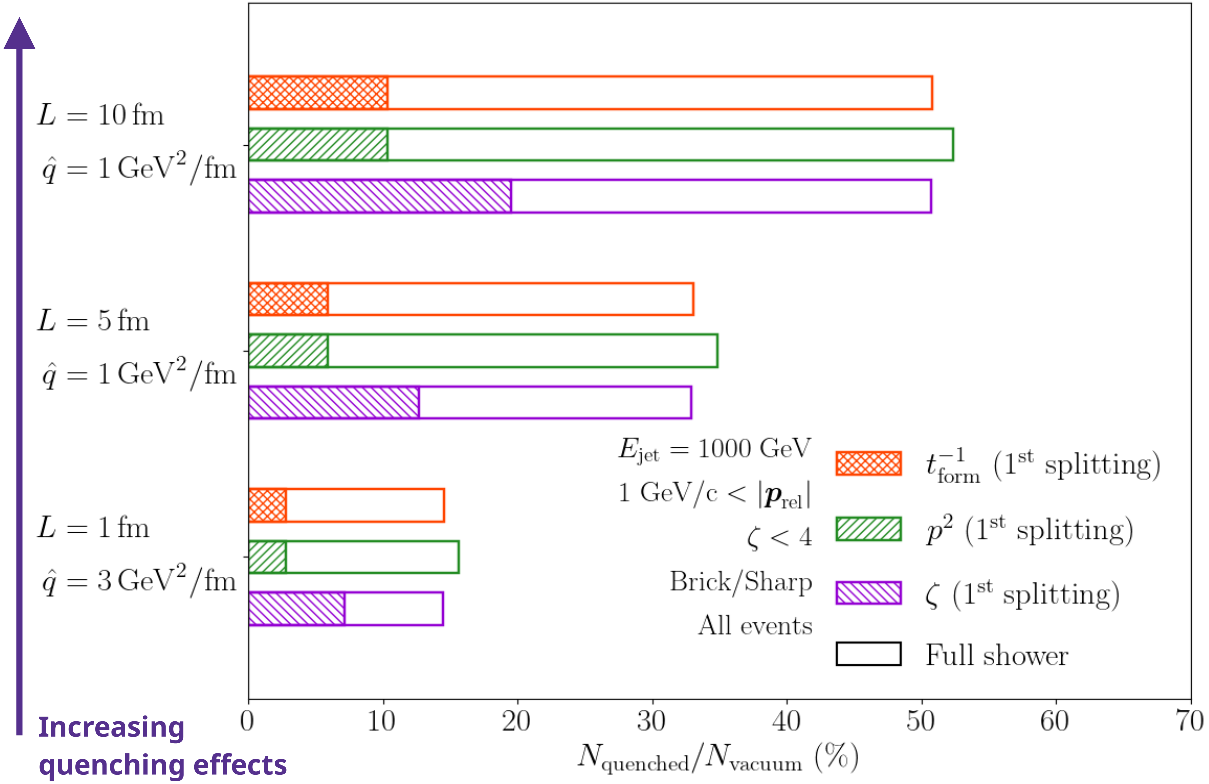

Applying conditon to the first splitting → Significant differences in quenching between algorithms

Differences are **washed out** when applying the condition to the full quark branch.

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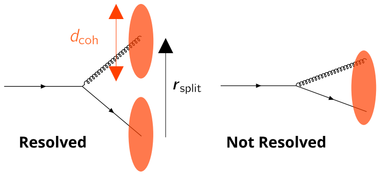

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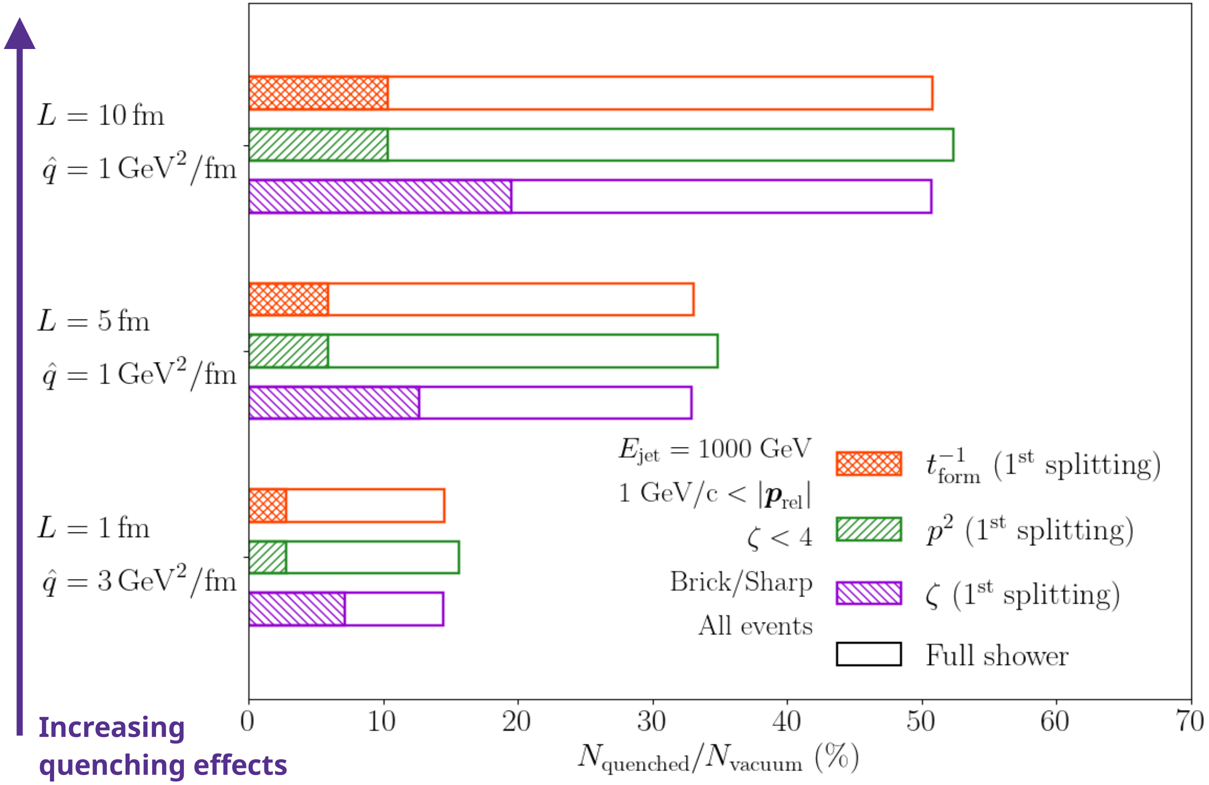

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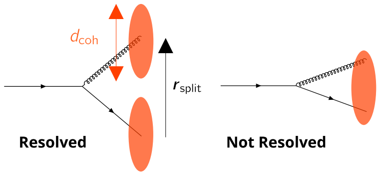
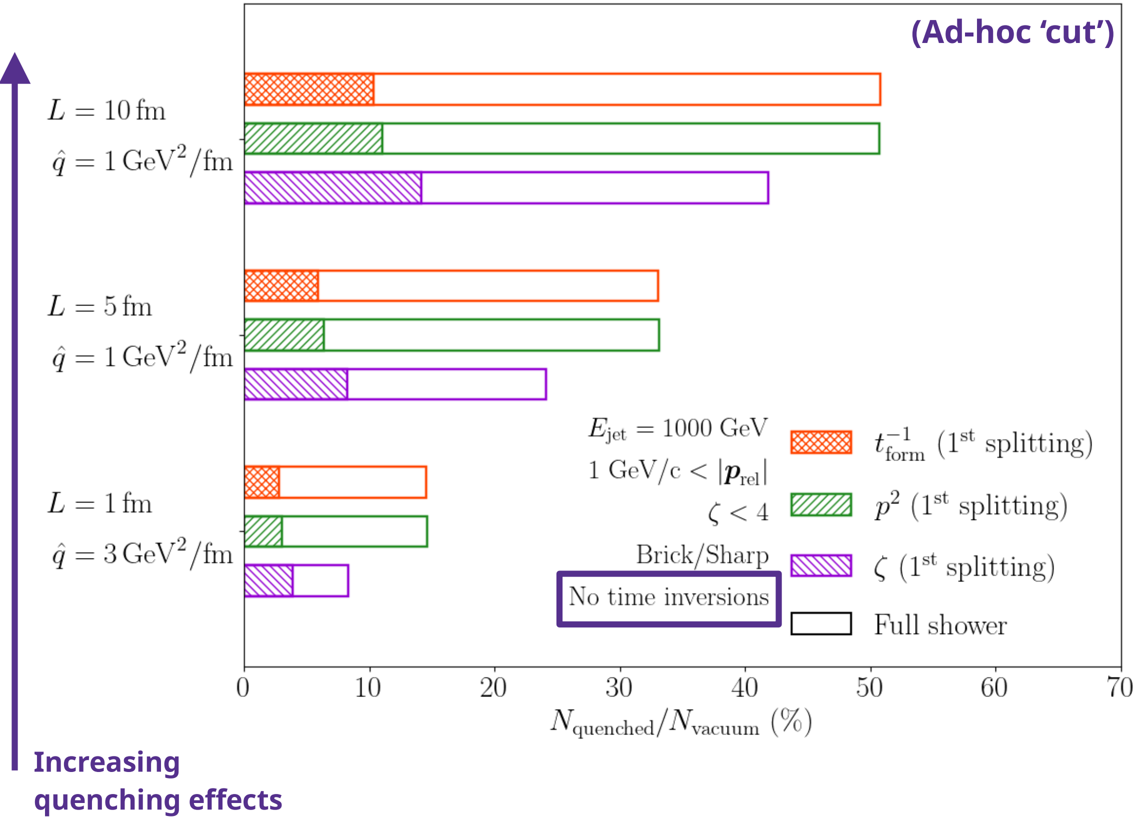
<u>What role do time-inversions play in these quenching differences?</u>

Fraction of Quenched Events

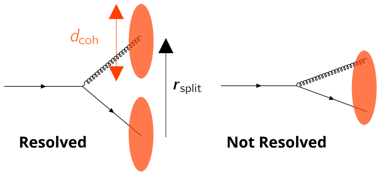


Discarding time-inverted events from the samples:



*** All events with at least one time-inverted splitting are removed before applying the quenching model

Fraction of Quenched Events



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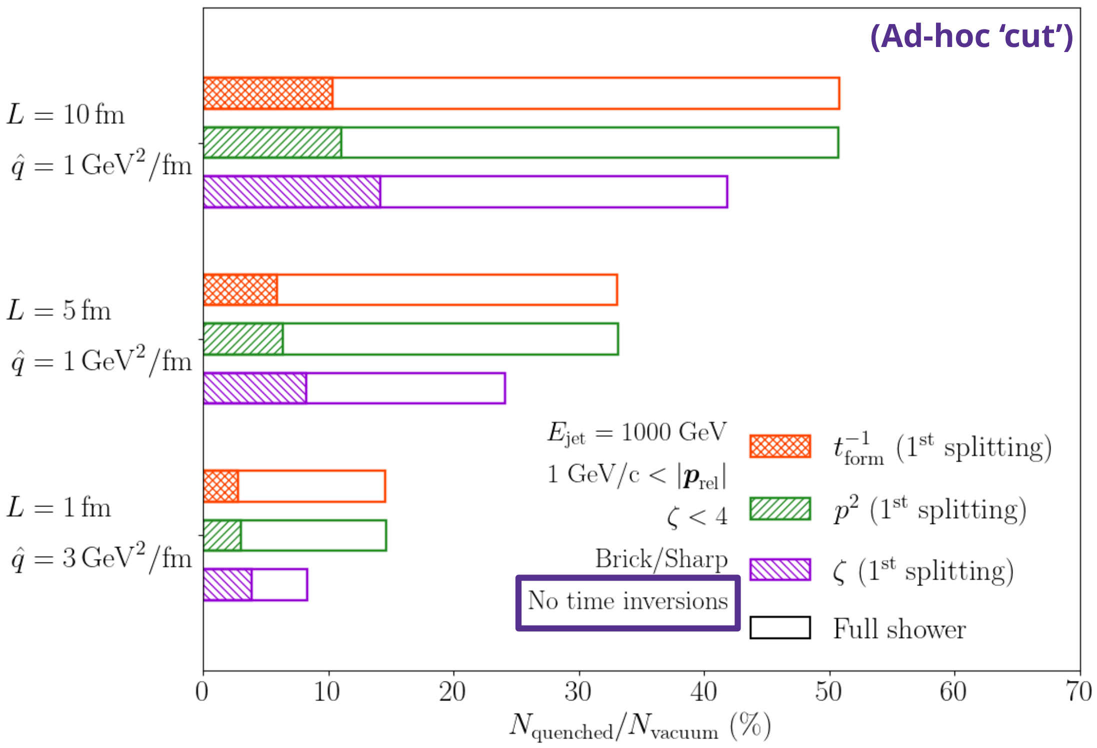

Increasing quenching effects

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For angular ordered showers:

$\Rightarrow \zeta$ decreases faster than t_{form}^{-1}

$\Rightarrow |\boldsymbol{r}_{\mathrm{split}}|$ can increase

$\Rightarrow$ Sample more resilient to quenching

$$|\boldsymbol{r}_{\mathrm{split}}| = \frac{1}{|\boldsymbol{p}_{\mathrm{rel}}|} = \frac{\sqrt{\zeta}}{t_{\mathrm{form}}^{-1}}$$

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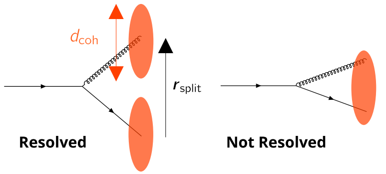

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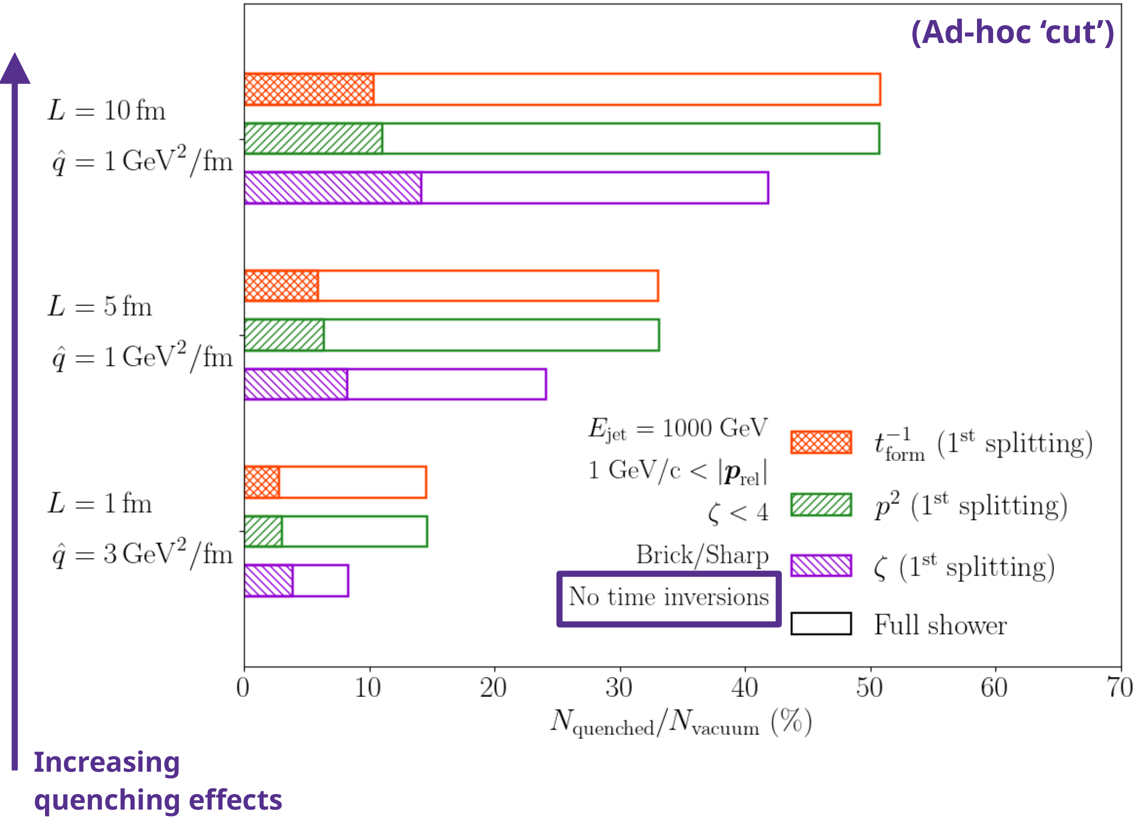

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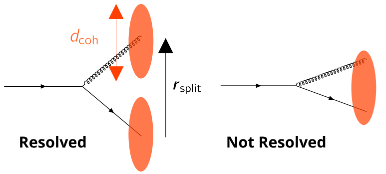
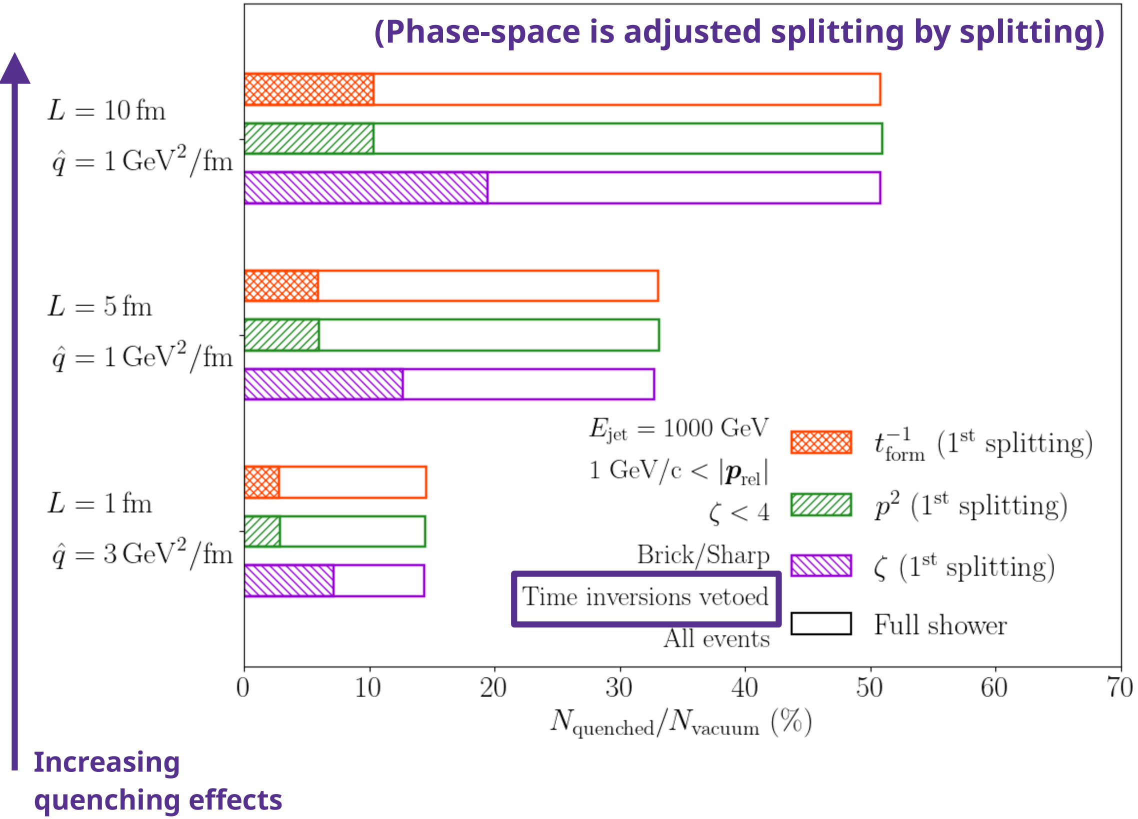
This is only one way of preventing inversions!

Fraction of Quenched Events



Vetoing the time-inversions by retrial:



*** Time-inverted splittings are re-tried while generating the shower

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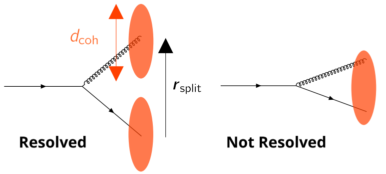

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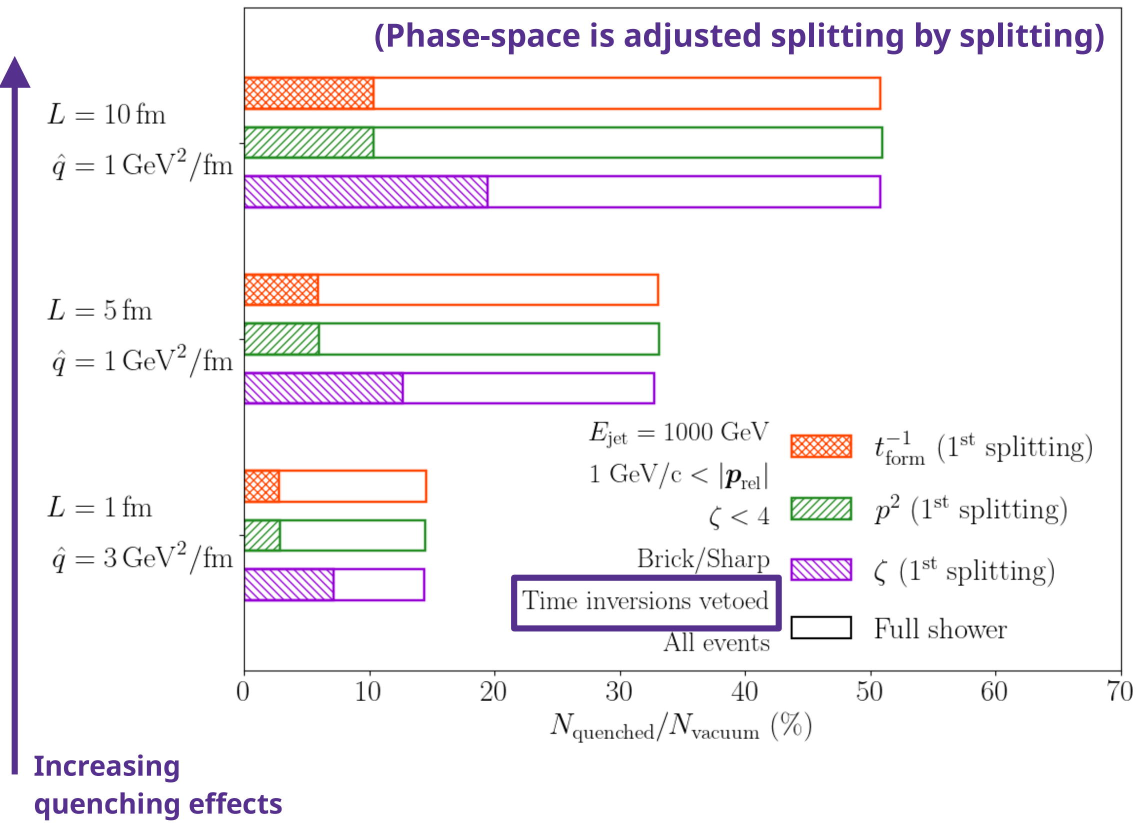

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Fraction of quenched events remains levelled across algorithms for the ‘Full Branch’ condition

Warning: Phase-space altered splitting-by-splitting

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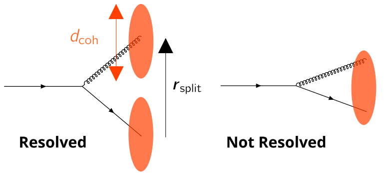

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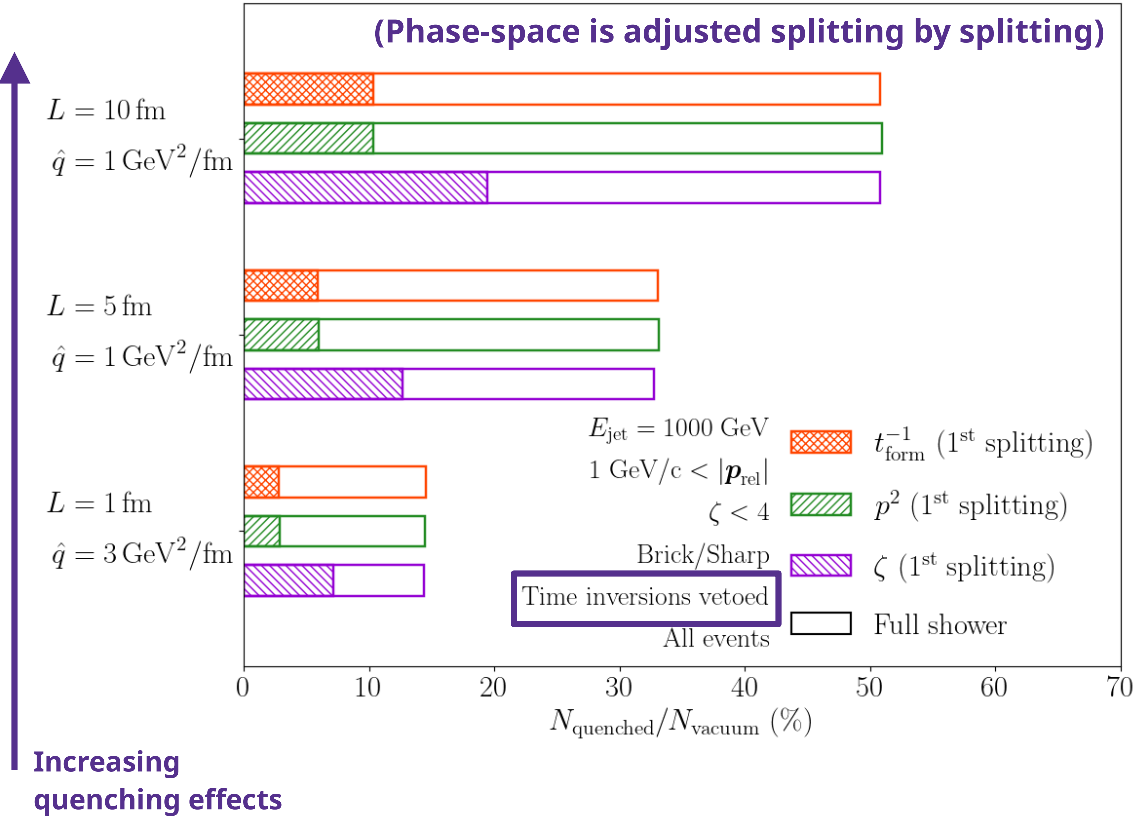

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The implementation details of the jet interface with a time-evolving medium are crucial!

Summary

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Thanks!

Acknowledgements

LIP

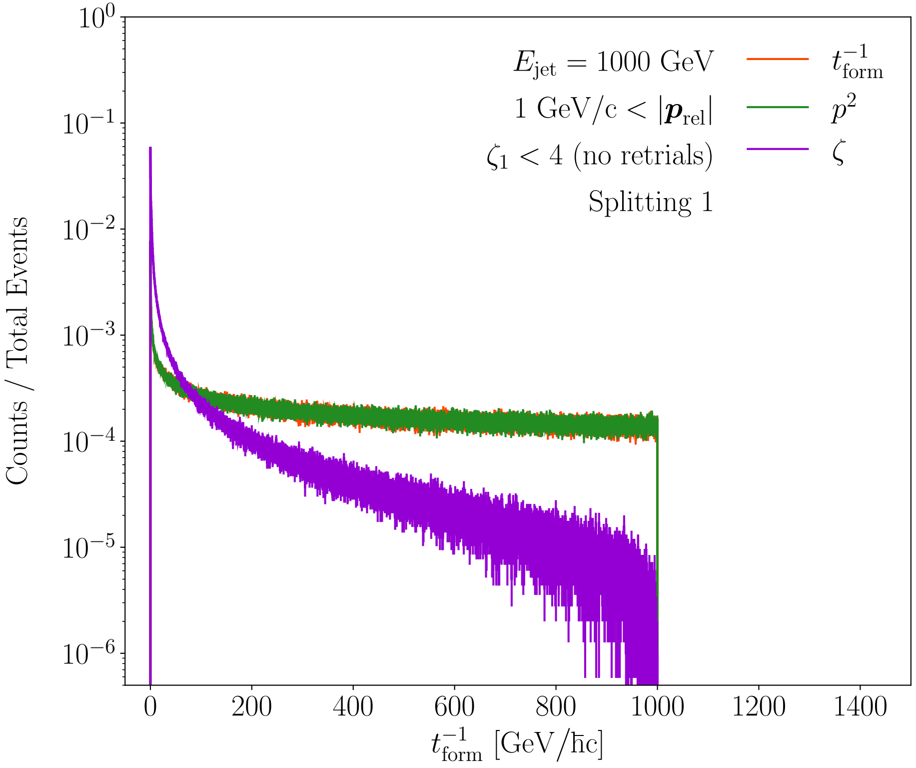
Fundação
para a Ciência
e a Tecnologia

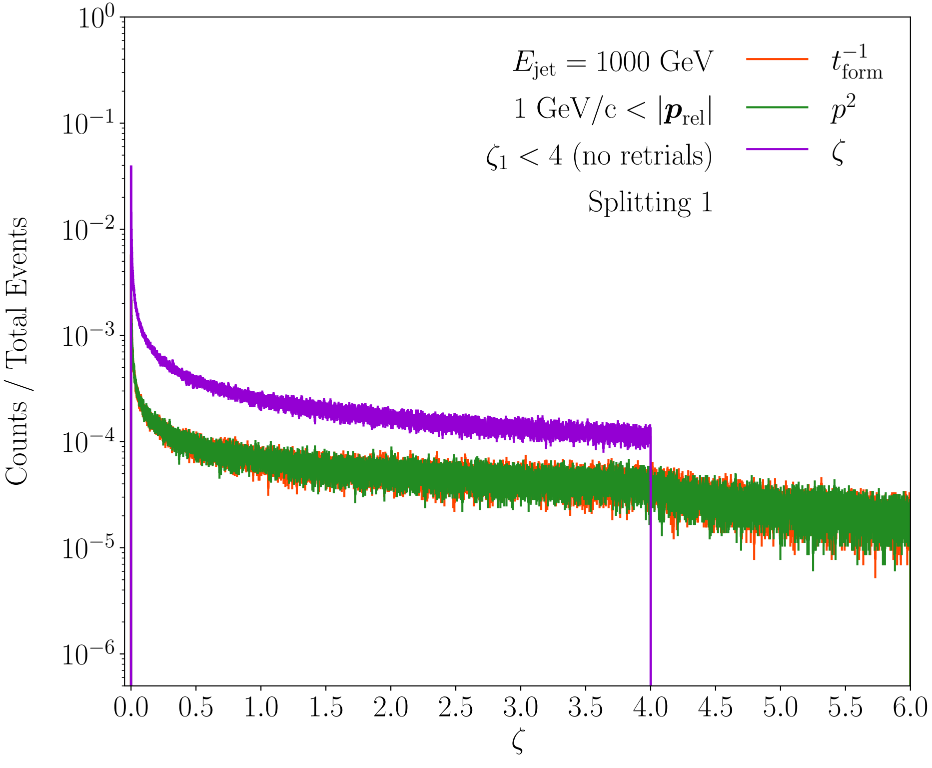
TÉCNICO
LISBOA

REPÚBLICA
PORTUGUESA

Backup Slides

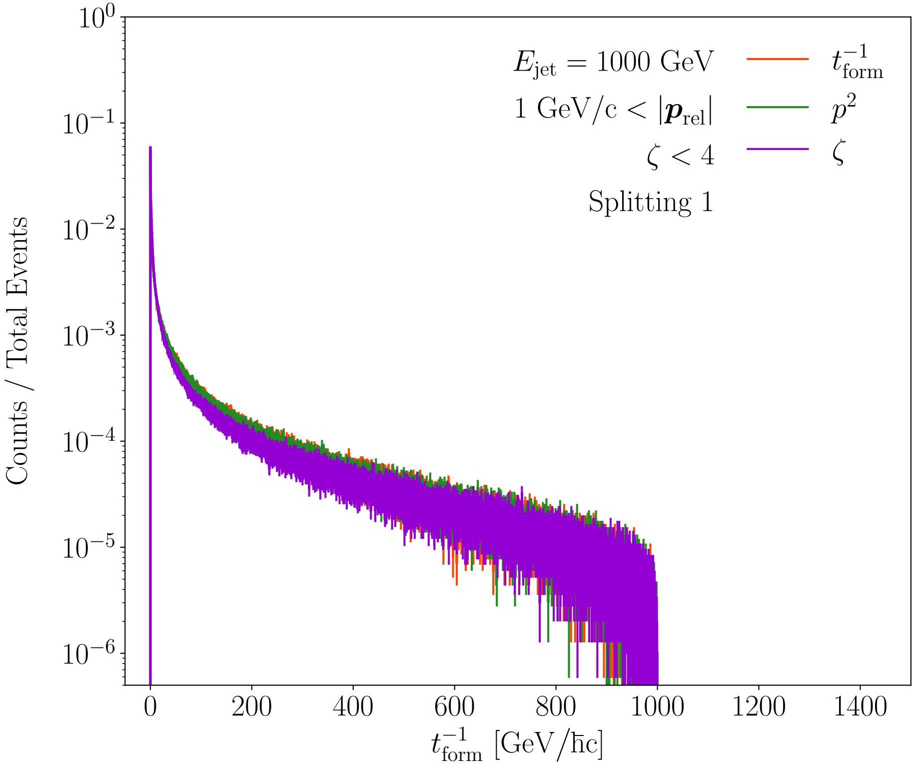
Without the consistency condition

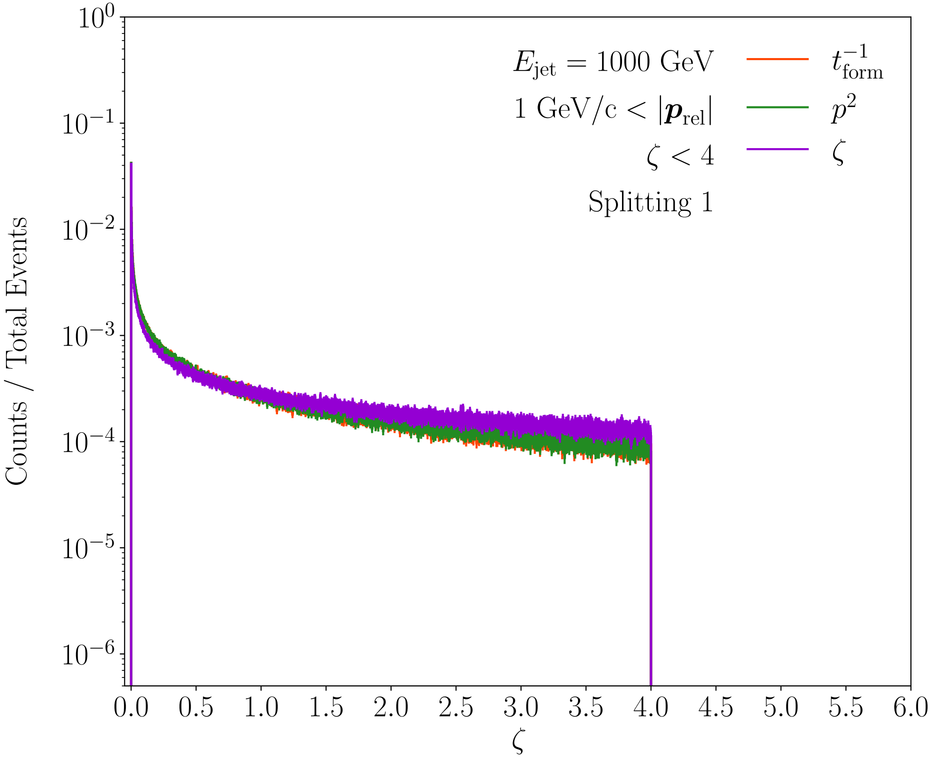




If the condition $\zeta < 4$ is used simply to initialise the angular shower, the time and angle distributions do not behave consistently across algorithms

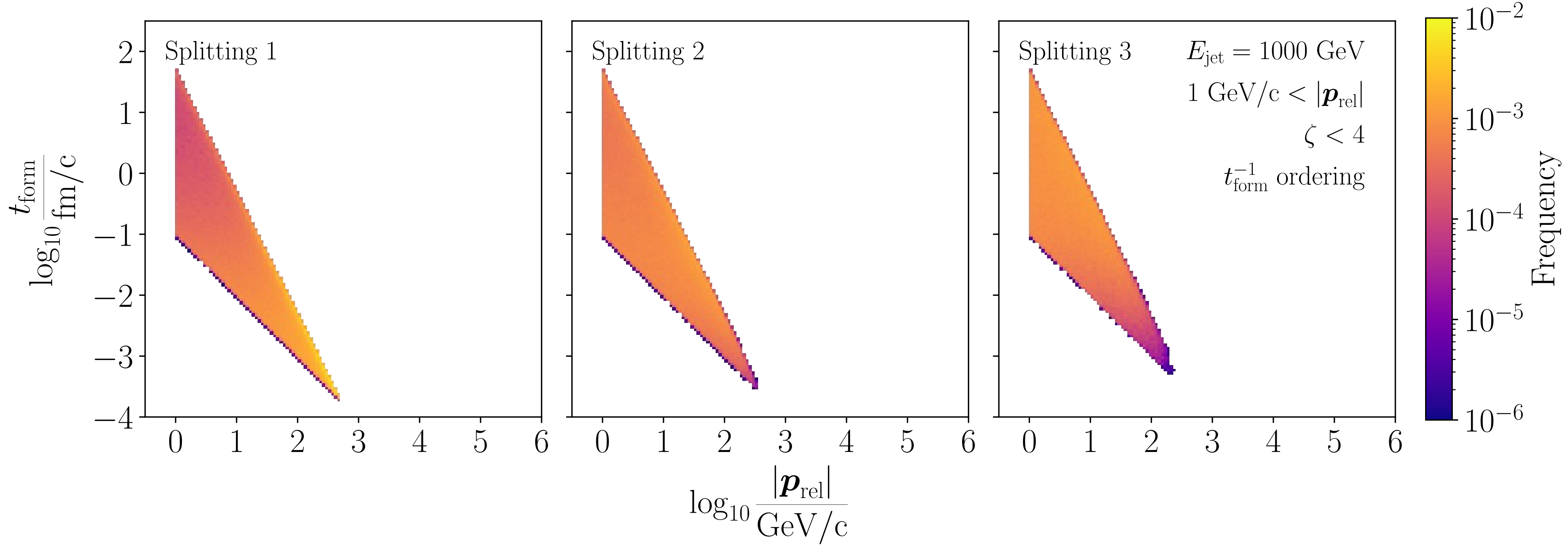
With the consistency condition





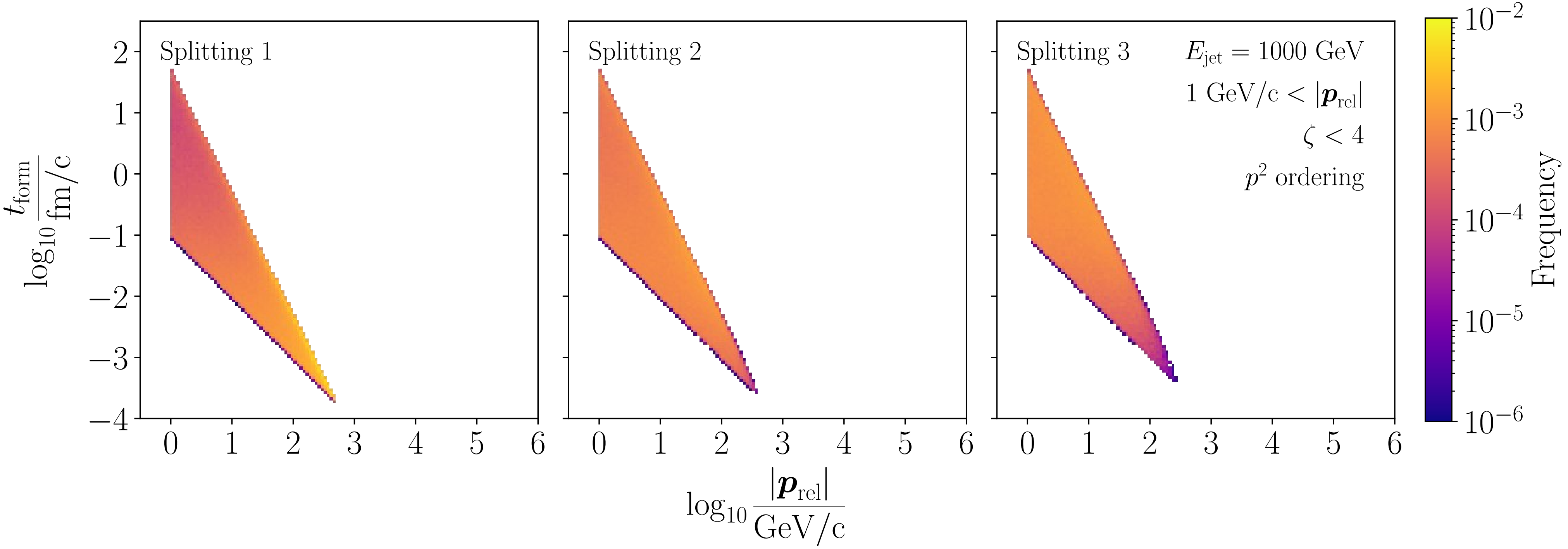
When the condition ζ < 4 is used as a veto for all emissions, the distributions become consistent.

Impact on Lund Plane Densities



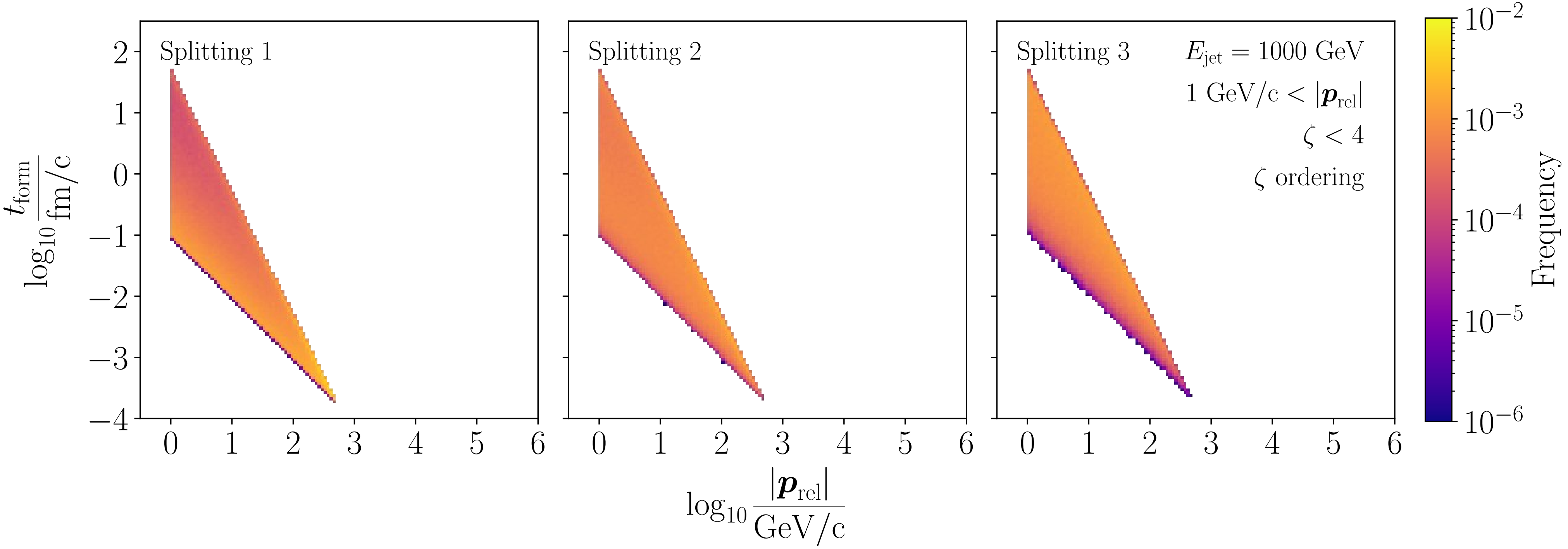
Time ordered shower – Vacuum

Impact on Lund Plane Densities



Mass ordered shower – Vacuum

Impact on Lund Plane Densities



Angular ordered shower – Vacuum

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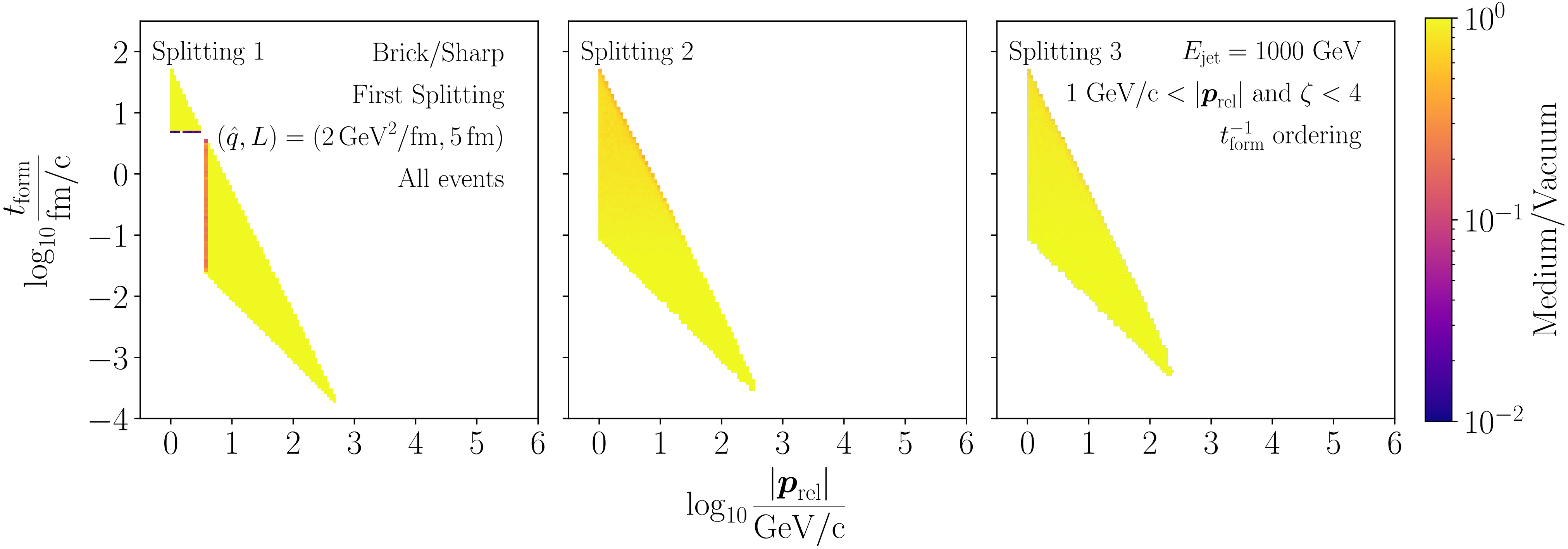
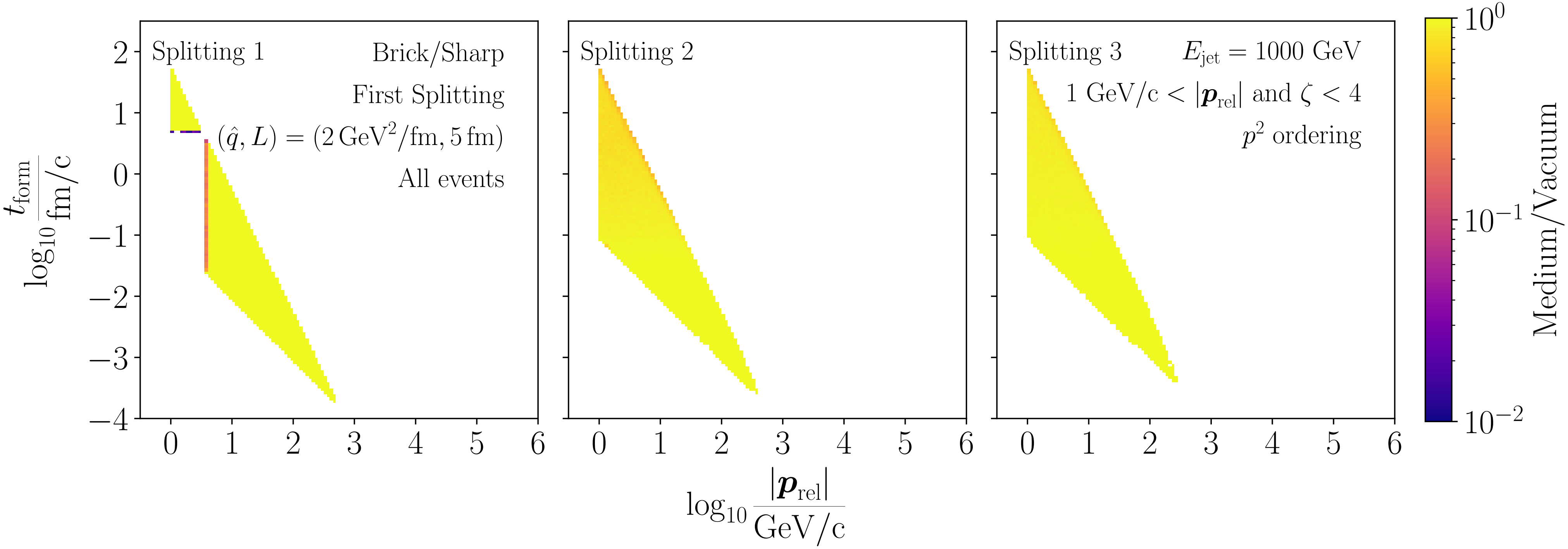


Time ordered shower – Medium/Vacuum (First Splitting)

Impact on Lund Plane Densities



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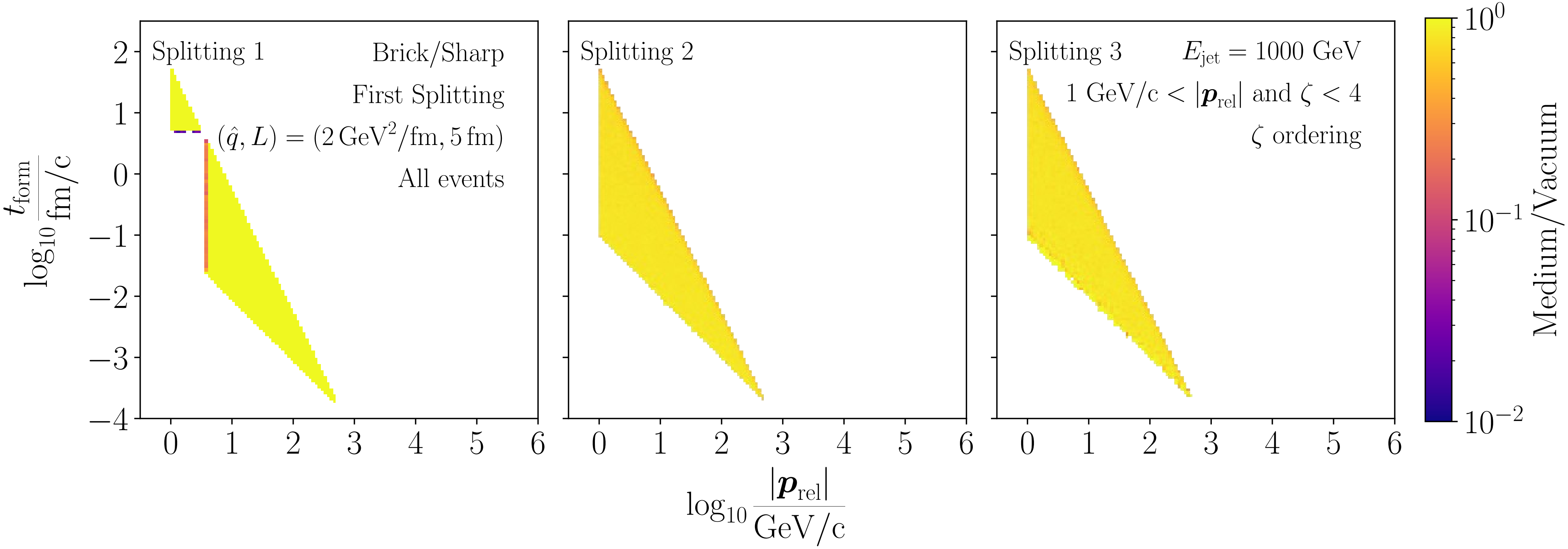

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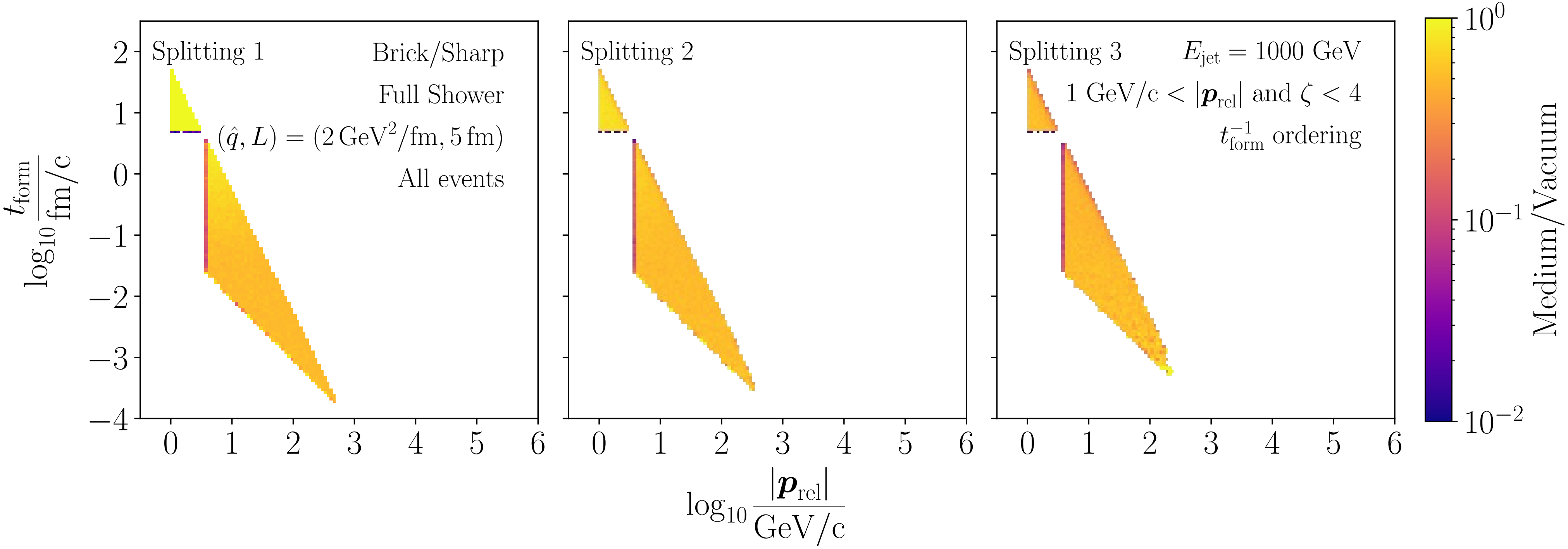

Time ordered shower – Medium/Vacuum (Full Branch)

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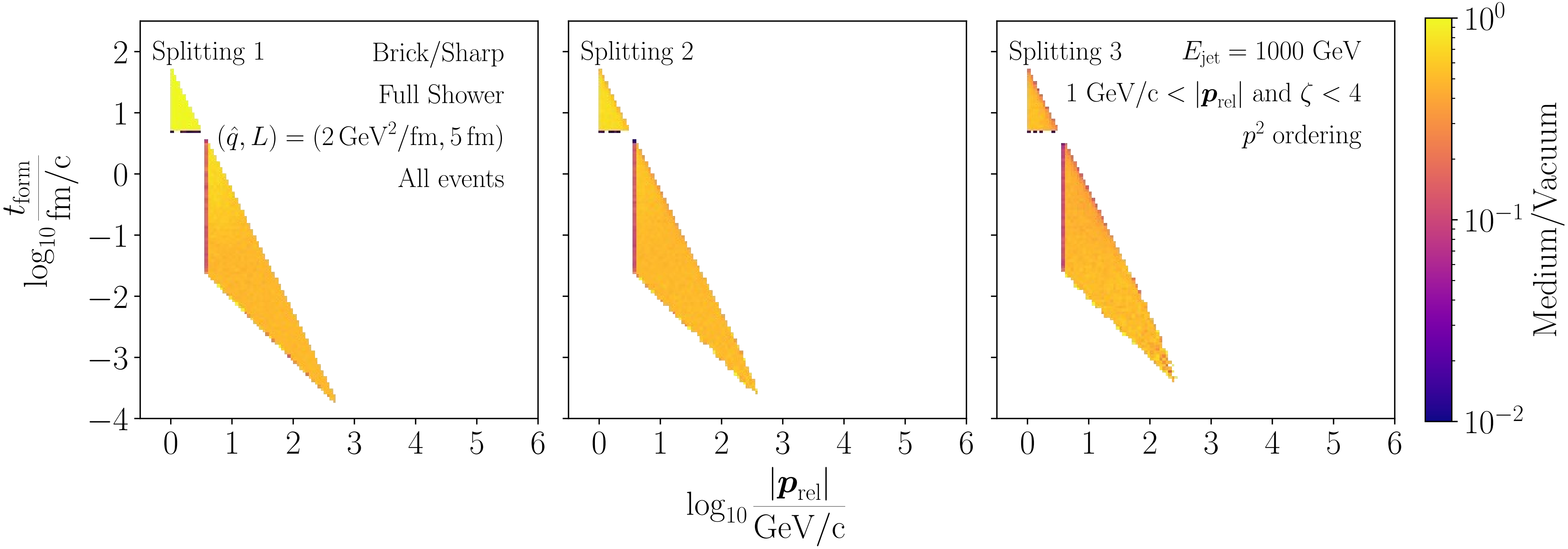

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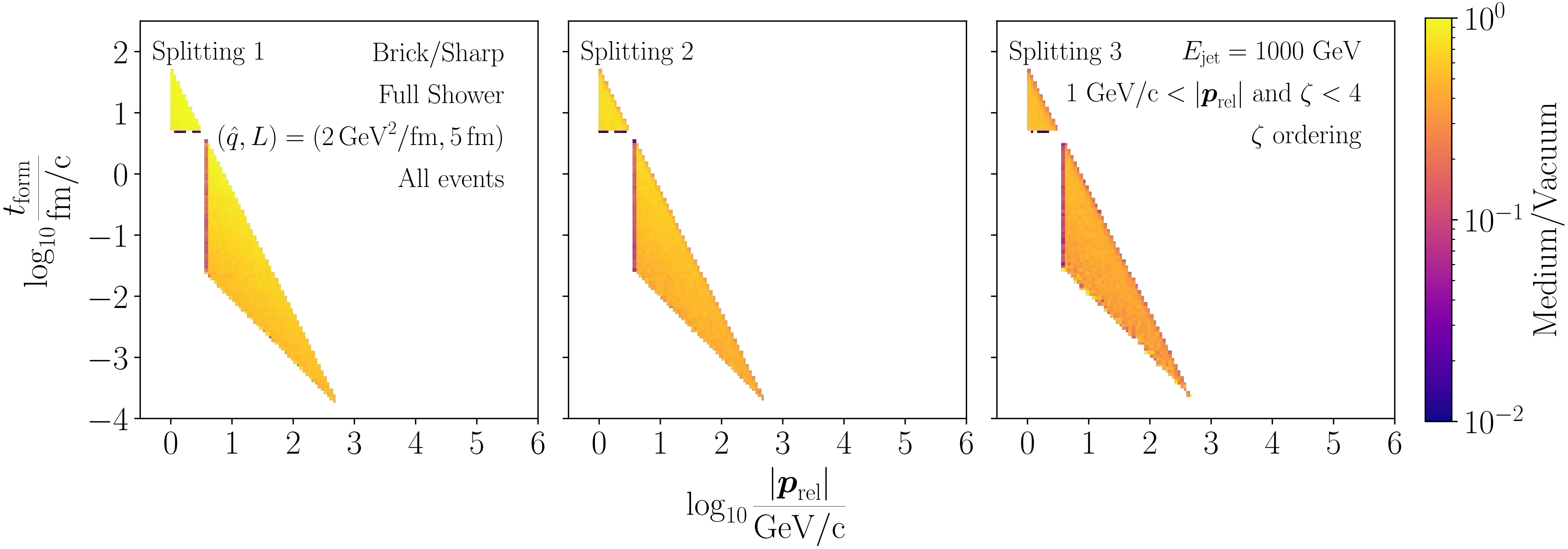

Angular ordered shower – Medium/Vacuum (Full Branch)