THE UNIVERSITY OF CHICAGO

Jet Timing

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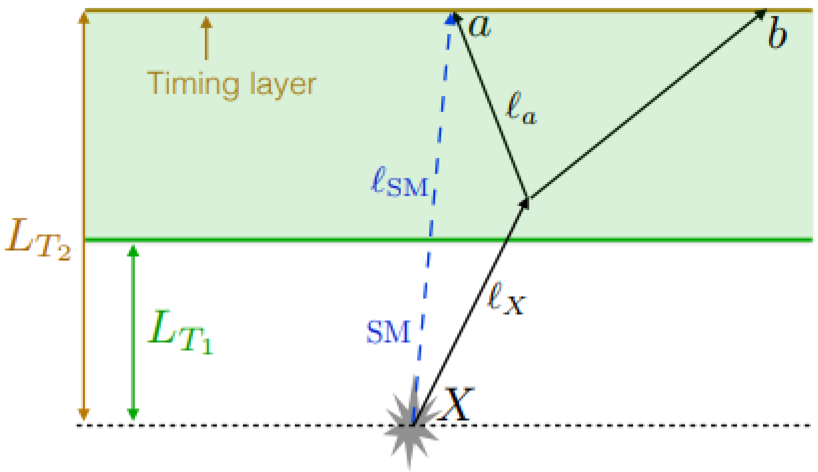
Based on arXiv:2109.01682

Why timing matters?

- LLPs always have a delay in arrival time:
  1. Longer path
  2. Massive parent particle



1.

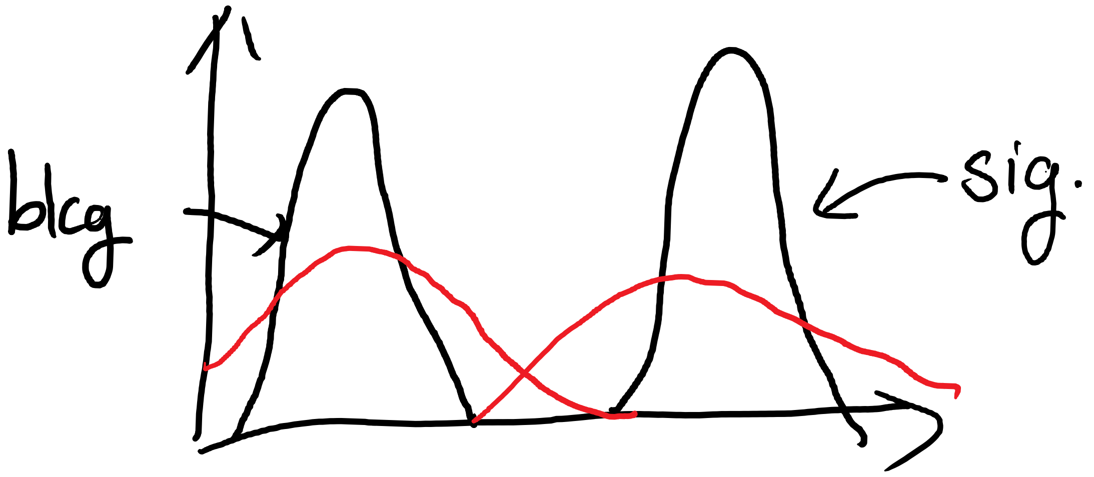
1. Image from 1805.05957

Timing a jet

- Possible definitions: A jet is a set of particles, $\{i\}$
  - Random: Set t_J to be a random element from the set $\{t_i\}$
  - Median: Set t_J to be the median from the set $\{t_i\}$
  - Hardest: Label the particle with the highest p_T with the index i_h. Set $t_J = t_{i_h}$
  - Average: Set t_J to be the arithmetic mean of the set $\{t_i\}$
  - p_T-weighted: Set t_J to be the following:

$$t_J^{p_T} = \frac{1}{H_{T,J}} \sum_i p_{T,i} t_i \,, \qquad H_{T,J} = \sum_i p_{T,i}$$

Why study multiple definitions?



Evaluating performance

- Reference time: Treat the jet J as a massless particle with three-momentum $\vec{p}_J$ and known production vertex and calculate the crossing time.
  - For prompt jets, in a cylindrical detector with radius r_T,

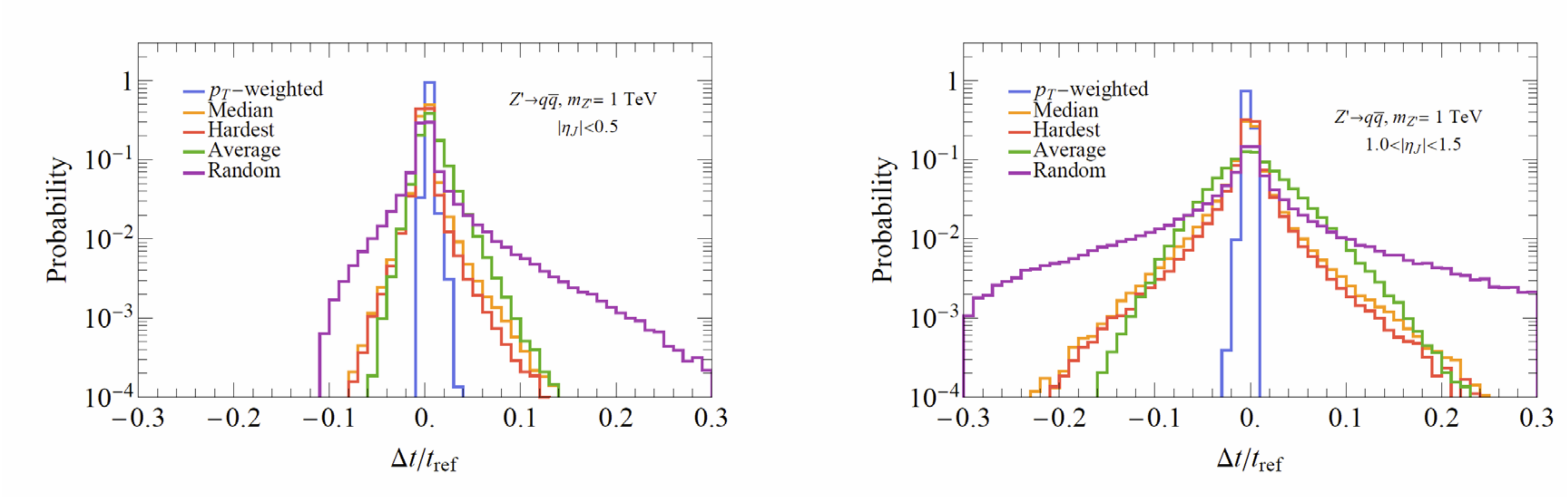
$$t_{\mathrm{ref}} = \frac{r_T}{c}\frac{|\vec{p}_J|}{p_{T,J}} = \frac{r_T}{c}\cosh\eta_J$$

- Metric:

$$\frac{\Delta t}{t_{\mathrm{ref}}} \equiv \frac{t_J - t_{\mathrm{ref}}}{t_{\mathrm{ref}}}$$

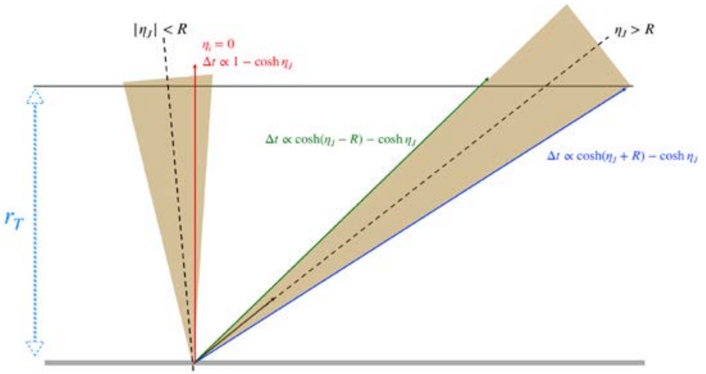
- Narrower distribution ⇒ More stable definition

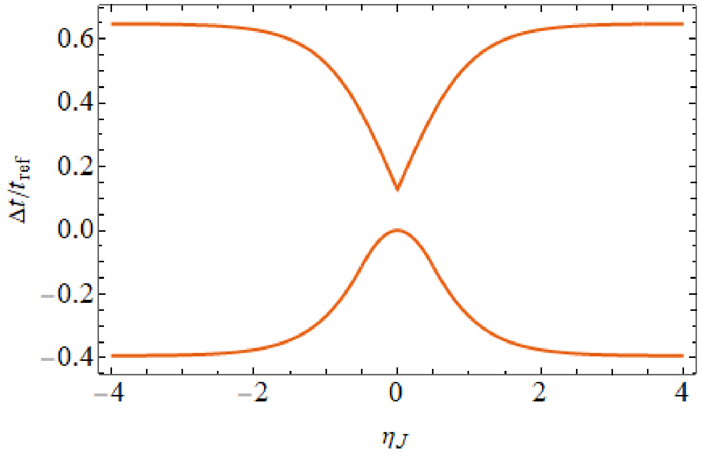
Timing distribution (prompt jets)

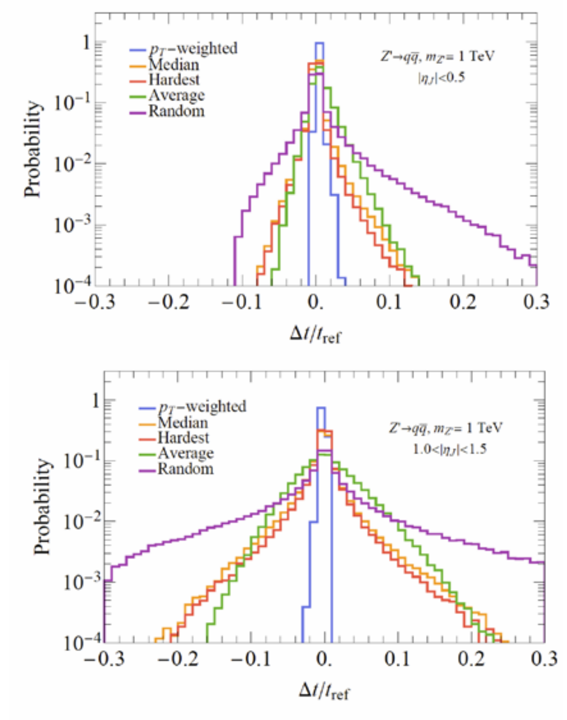


Analytic behavior of prompt jets

- Model detector as cylinder with radius: r_T
- Imagine a jet as object with hard boundaries at $\eta_J \pm R$. For any massless, prompt particle in the jet, we have

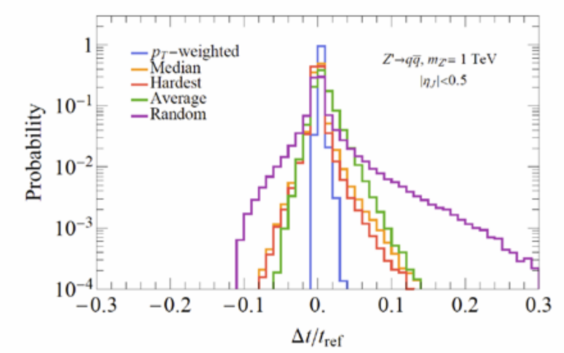


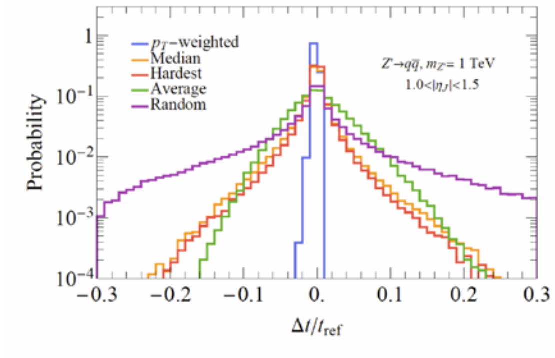




Analytic behavior of prompt jets (cont.)

- For ideal prompt jets

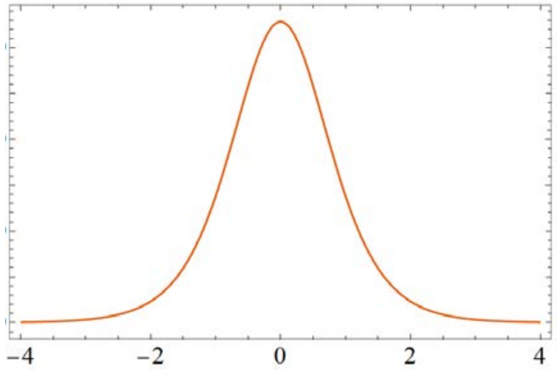




$$\frac{\Delta t_{p_T}}{t_{\text{ref}}} = \frac{p_{T,J}}{H_{T,J}} \frac{E_J}{|\vec{p}_J|} - 1$$

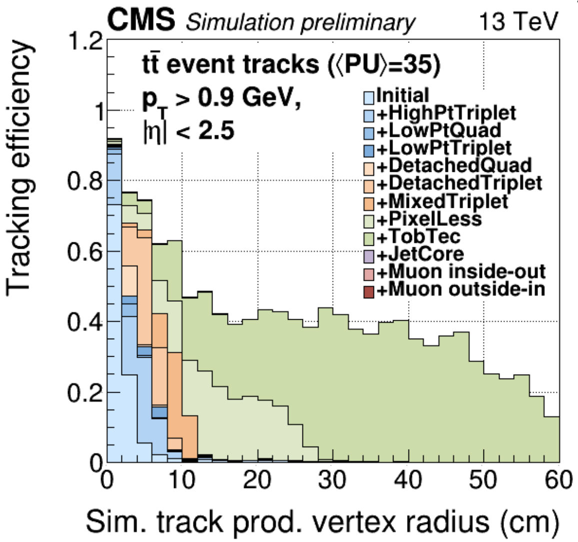
≤ 1

$\sim 1 + \frac{m_J^2}{|\vec{p}_J|^2} \sim 1 + \#\,\text{sech}^2\,\eta_J$



Analytic behavior of delayed jets

- Tracking performance for large $x_{T,M}$ is poor
- Kinematics reconstructed from IP not DV
- Broadens p_T-weighted time and biases hardest time



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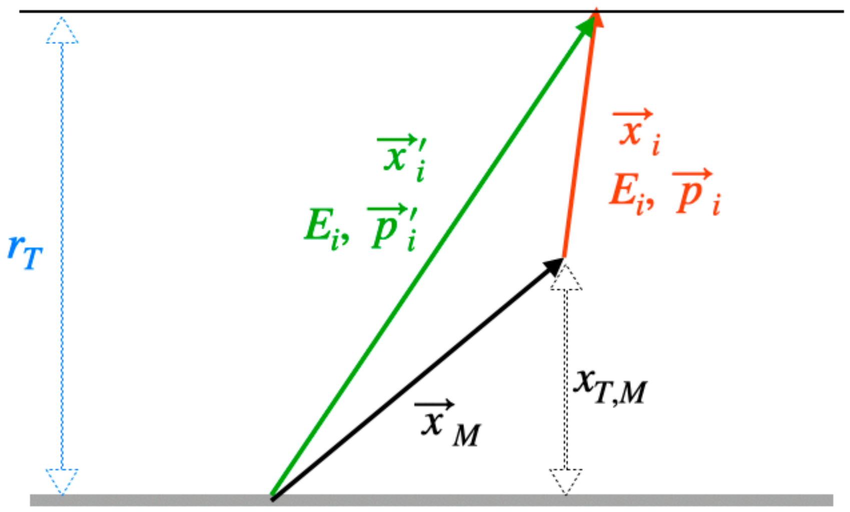
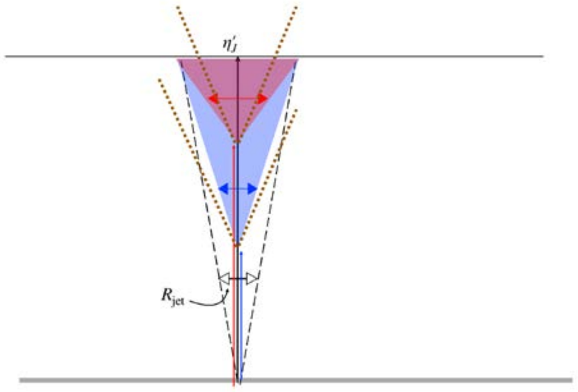
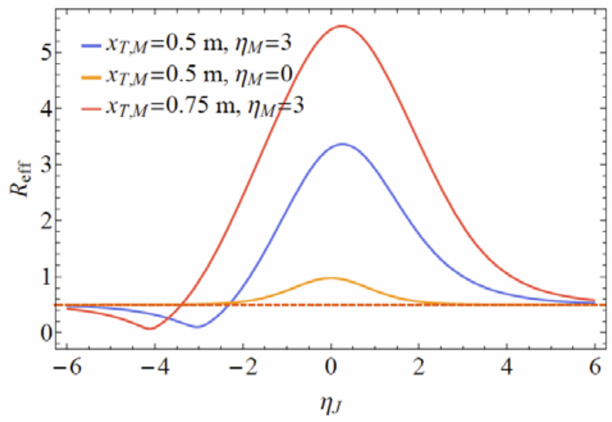


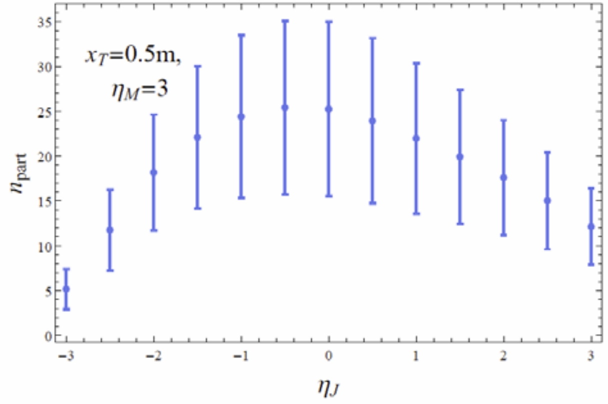
1. Image from https://twiki.cern.ch/twiki/bin/view/CMSPublic/TrackingPOGPerformance2017MC

Analytic behavior of delayed jets (cont.)

- Jets clustered with η' rather than η
- Effective cone size using η can be different from R_{jet}
- Two effects:
  1. n_{part} increases with R_{eff}
  2. Spread in absolute time increases with R_{eff}





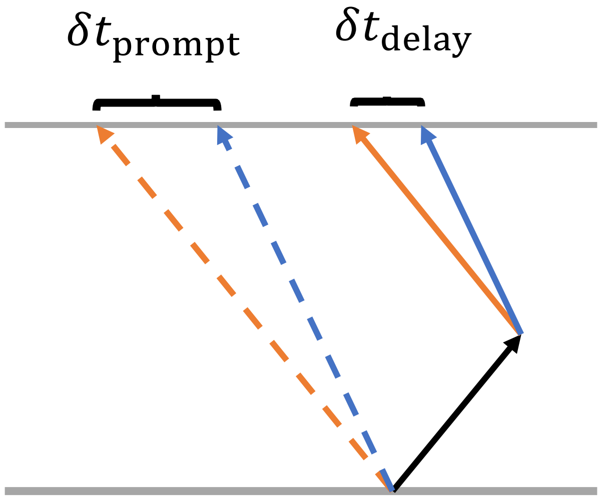


Analytic behavior of delayed jets (cont.)

- On average, particles travel a shorter distance from production vertex

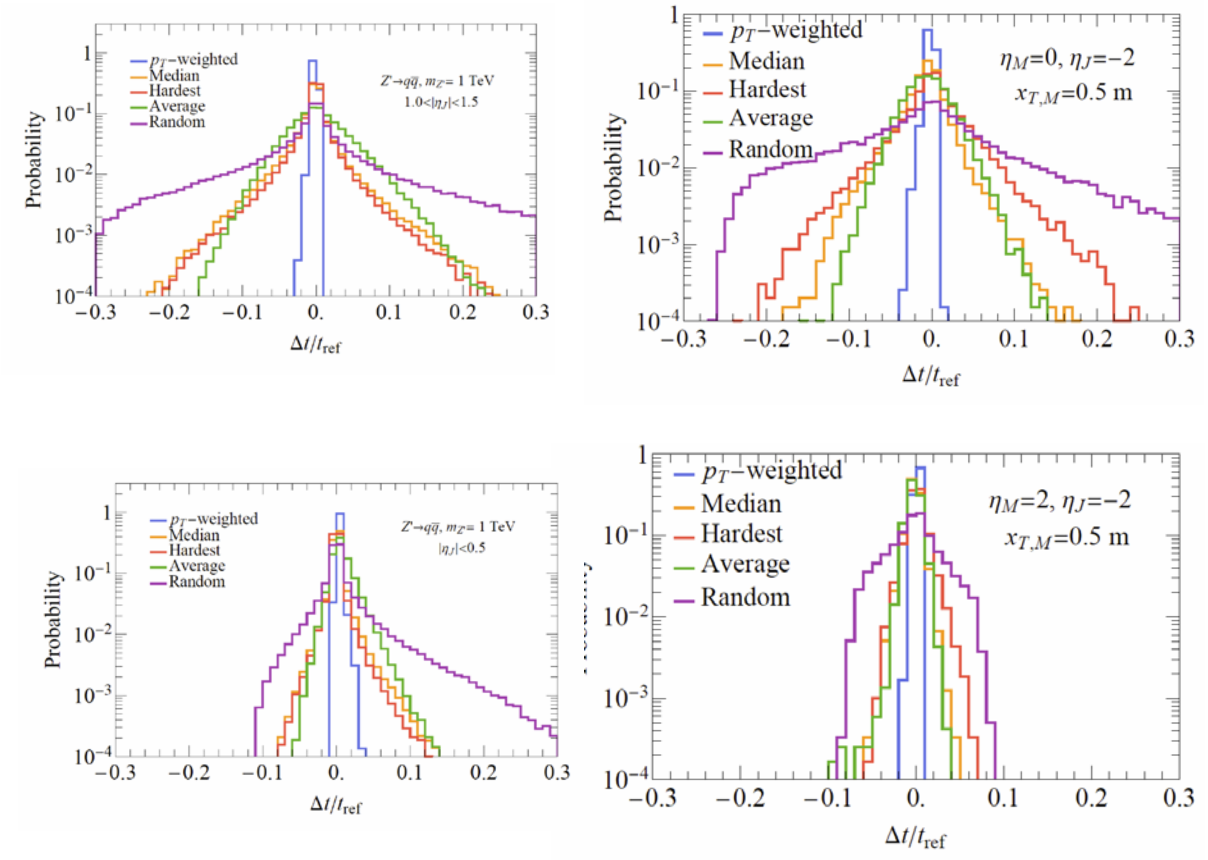
$$\Rightarrow \langle \delta t_{\mathrm{prompt}} \rangle > \langle \delta t_{\mathrm{delay}} \rangle$$

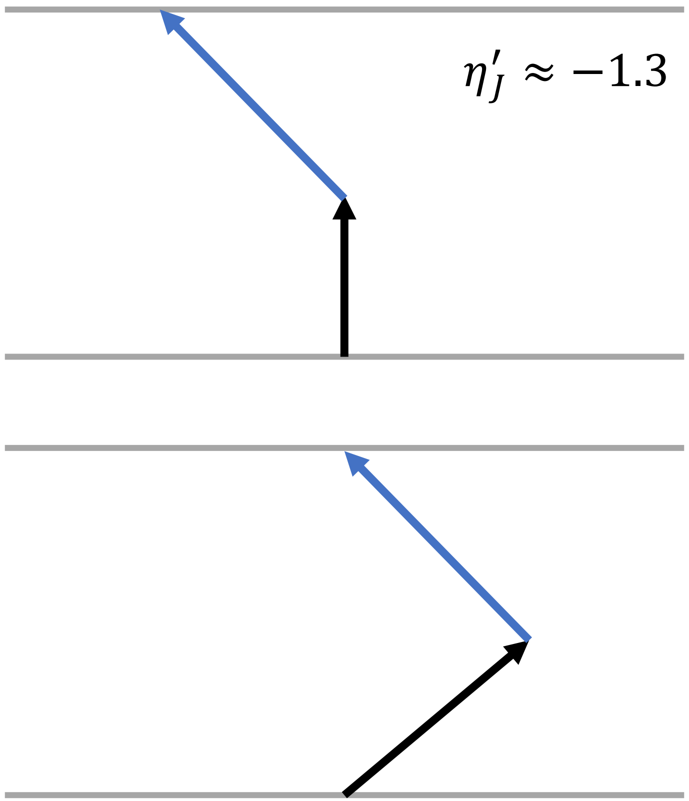
- Final arrival time is always larger vs prompt



$$\left\langle \frac{\Delta t}{t_{\mathrm{ref}}} \right\rangle_{\mathrm{prompt}} > \left\langle \frac{\Delta t}{t_{\mathrm{ref}}} \right\rangle_{\mathrm{delay}}$$

Timing distribution (Delayed jets)





Summary

- A good timing definition is important for background separation
- p_T-weighted time is very robust for ideal prompt jets
- Geometric effects important for displaced jet.
- In many displaced scenarios, p_T-weighted still performs very well

Backup/details

Simulation details of prompt jets

- Generate $Z' \to q\bar{q}$ in Pythia 8.240 with $m_{Z'} = 1\ \mathrm{TeV}$
- MPI, ISR, and hadronization[1] switched off
- FSR switched on
- $r_T = 1\ \mathrm{m}$
- Final state particles produced inside detector with $p_T > 0.5\ \mathrm{GeV}$ and $|\eta| < 4.0$ were clustered into $R = 0.5$ anti-k_T jets using FastJet v3.3.2
- Stored the jet times of the hardest jet

1. Reasoning discussed later

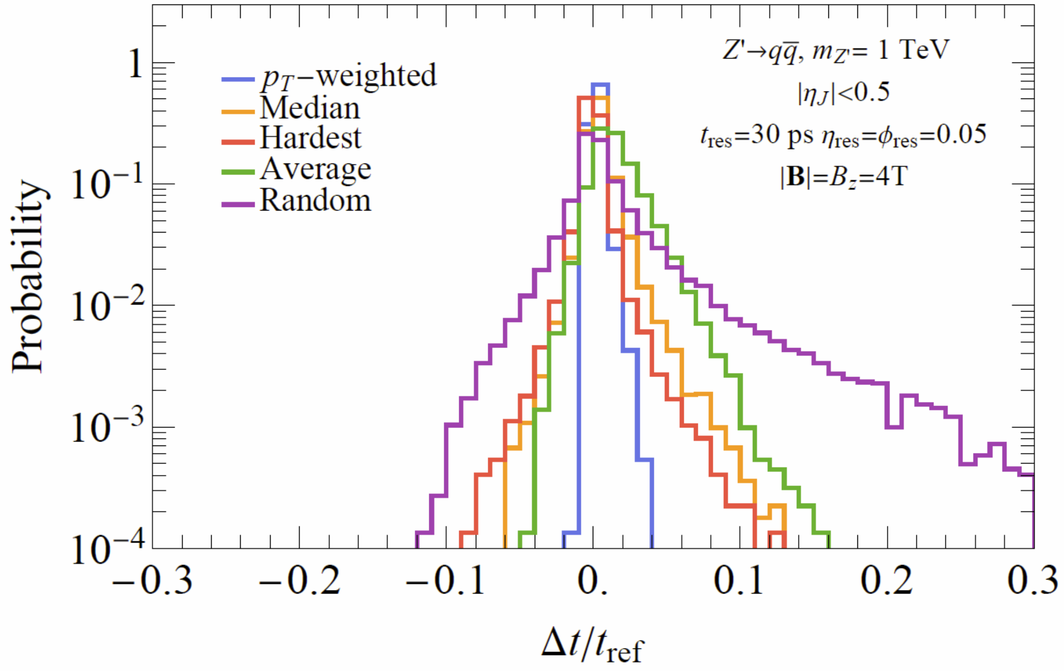
Simulation details (delayed jets)

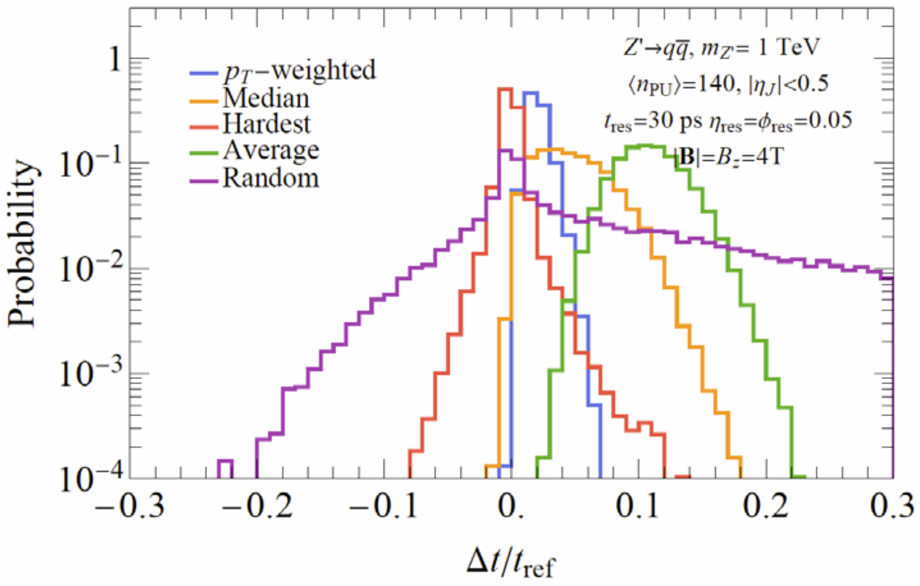
- Used MG5 to generate $pp \to \tilde{g}\tilde{g} \to gg\tilde{G}_0\tilde{G}_0$ events
- Adjusted the kinematics of the LHE file to fix the following:

$$x_{T,M}, \eta_M, \eta_D, \beta_M, \Delta\phi$$

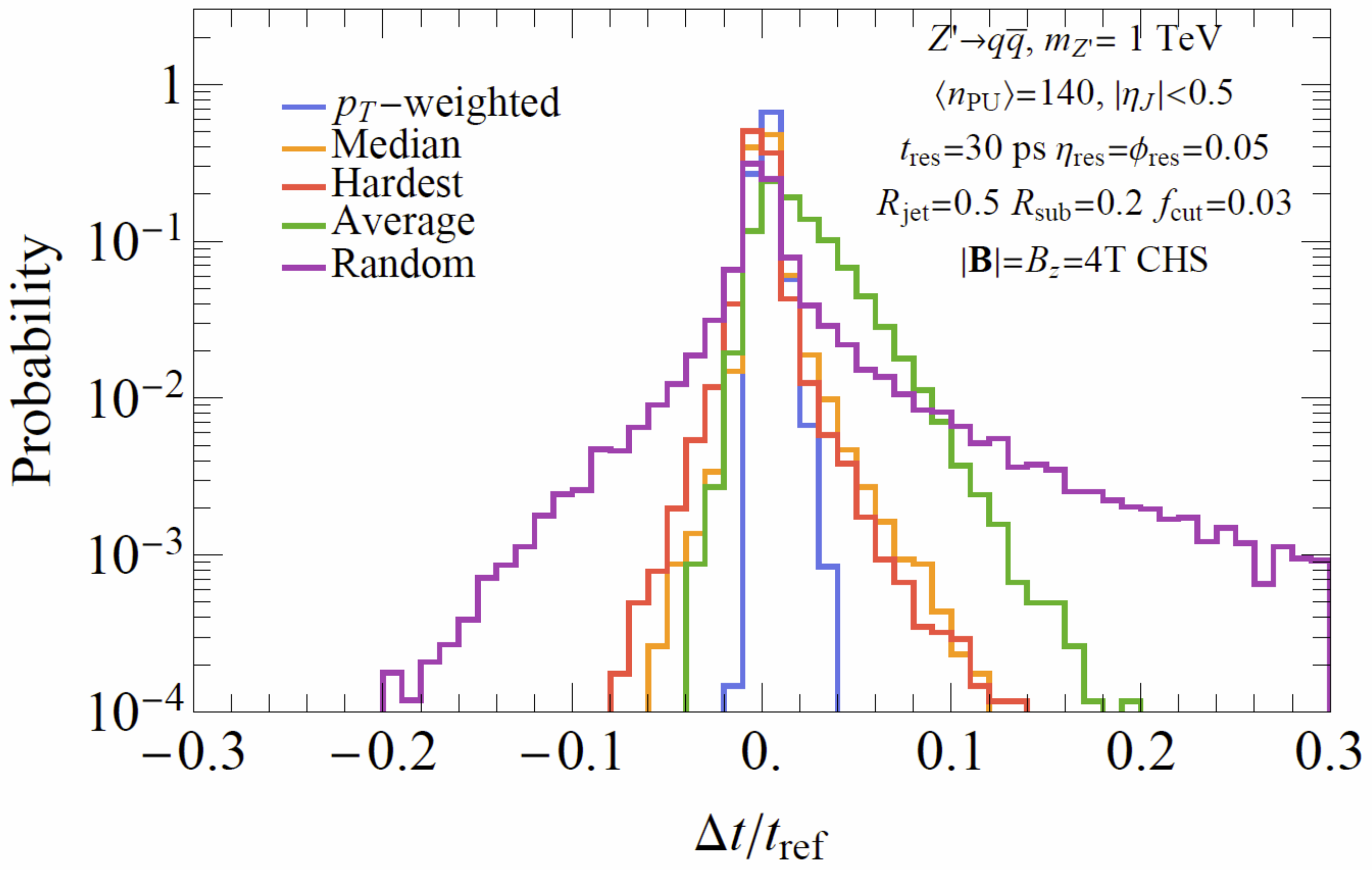
- Events showered in Pythia8 with ISR, MPI, and hadronization disabled
- Final state particles produced inside detector with $p'_T > 0.5$ GeV and $|\eta'| < 4.0$ were clustered into $R = 0.5$ anti-k_T jets using FastJet v3.3.2

Additional prompt effects





Additional prompt effects



Timing distribution (delayed jets)