Jets Without Jets

Daniele Bertolini
Massachusetts Institute of Technology

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D.B., Tucker Chan, Jesse Thaler
"Jet Observables Without Jet Algorithms"
arXiv:1310.7584

Preparing for next LHC run

- Jets are clusters of hadrons used as proxy for partons and **crucially enter almost every LHC analysis** (Higgs, SUSY multijet signals, missing energy tags, boosted objects and jet substructure, pileup reduction, etc . . .)

- **This talk**: **new approach to study jets**
  - Some of these results shown at Boost 2013, will focus on new developments since then

Outline

- Counting jets without clustering
- Jets at the trigger level
- Trimming as a local weight
- Summary

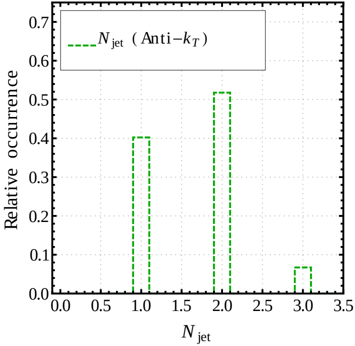
Counting jets with event shapes

$$pp \to jj \text{ @ } \sqrt{s} = 8 \text{ TeV}$$

$$R = 0.6 \text{ and } p_{\mathrm{T}} \geq p_{T\mathrm{cut}} = 25 \text{ GeV}$$

$$\widetilde{N}_{\mathrm{jet}}(p_{T\mathrm{cut}}, R) = \sum_{i \in \mathrm{event}} \frac{p_{Ti}}{p_{Ti,R}} \Theta(p_{Ti,R} - p_{T\mathrm{cut}})$$

$$p_{Ti,R} = \sum_{j \in \mathrm{event}} p_{Tj} \, \Theta(R - \Delta R_{ij})$$



[DB, Boost 2013]

Counting jets with event shapes

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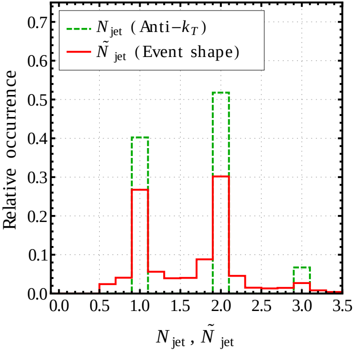
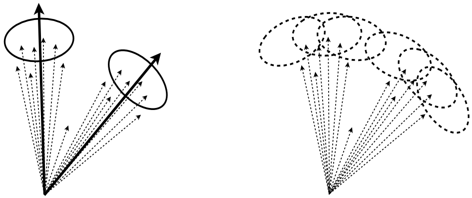


[DB, Boost 2013]

A physical picture



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For infinitely narrow jets separated by more than R:

$$\widetilde{N}_{\text{jet}}(p_{T\text{cut}}, R) \longrightarrow N_{\text{jet}}(p_{T\text{cut}}, R) = \sum_{\text{jets}} \Theta(p_{T\text{jet}} - p_{T\text{cut}})$$

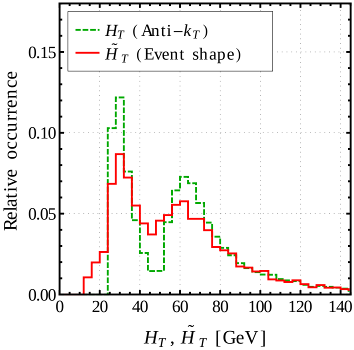
Transverse energy & missing transverse momentum

$$\widetilde{H}_T = \sum_{i\in\text{event}} p_{Ti}\,\Theta(p_{Ti,R} - p_{T\text{cut}})$$

$$\widetilde{\not{p}}_T = \left|\sum_{i\in\text{event}} \vec{p}_{Ti}\,\Theta(p_{Ti,R} - p_{T\text{cut}})\right|$$

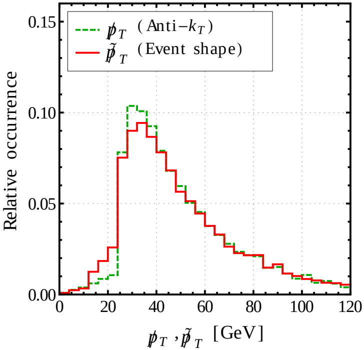
$pp \to jj$

$R = 0.6,\ p_{T\text{cut}} = 25$ GeV



$pp \to Z(\nu\bar{\nu})j$

$R = 0.6,\ p_{T\text{cut}} = 25$ GeV



Jets Without Jets

$$\mathcal{F} = \sum_{\text{jets}} \underbrace{\mathcal{F}_{\text{jet}}}_{f(\{p_j^\mu\}_{j\in\text{jet}})} \Theta(p_{T\text{jet}} - p_{T\text{cut}})$$

$$\widetilde{\mathcal{F}} = \sum_{i\in\text{event}} \frac{p_{Ti}}{p_{Ti,R}} \underbrace{\mathcal{F}_{i,R}}_{f(\{p_j^\mu \Theta(R-\Delta R_{ij})\}_{j\in\text{event}})} \Theta(p_{Ti,R} - p_{T\text{cut}})$$

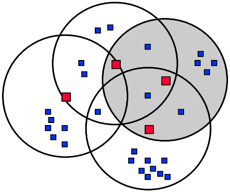
- **Locality** $\rightarrow$ need only information in the neighborhood of each particle
- **Alternative characterization of an event**
- **New calculable properties**

Locality

Jets at trigger level

Event shapes allow to calculate jet properties locally = only information in the neighborhood of each particle is needed

Neighborhood = circle of radius R around the particle



Easily parallelizable, can use for low-level trigger

- Inclusive observables: $\widetilde{N}_{\text{jet}}$, $\widetilde{H}_T$, $\widetilde{\not{p}}_T$ ✓
- More exclusive information, individual jets p_T and axis?

Locality

Jets at trigger level

Get jet axis and p_T from probability densities

(see also jet energy flow project [Berger,Berger,Bhat,Butterworth,Ellis, et. al. 2001])

$$\rho_{N_{\rm jet}}(\hat{n}) = \sum_{\rm jets} \delta(\hat{n} - \hat{n}^r_{\rm jet}) \quad \rightarrow \quad \widetilde{\rho}_{N_{\rm jet}}(\hat{n}) = \sum_{i \in \rm event} \frac{p_{Ti}}{p_{Ti,R}} \delta(\hat{n} - \hat{n}^r_{i,R})$$

$$\rho_{H_T}(\hat{n}) = \sum_{\rm jets} p_{T\rm jet}\, \delta(\hat{n} - \hat{n}^r_{\rm jet}) \quad \rightarrow \quad \widetilde{\rho}_{H_T}(\hat{n}) = \sum_{i \in \rm event} p_{Ti}\, \delta(\hat{n} - \hat{n}^r_{i,R})$$

r=recombination scheme, $p_{T\rm cut} = 0$

Locality

Jets at trigger level

- $\widetilde{\rho}_X(\hat{n}) = \sum_j \omega_{X_j} \delta(\hat{n} - \hat{m}_j^r)$, want $\mathcal{O}(n)$ distinct directions $\hat{m}_j^r$ for an n-jet event
- Use a winner-take-all recombination scheme

  (see [Larkoski,Neill,Thaler, 2014] for theoretical aspects of wta axis)

$$p_{Tr} = p_{T1} + p_{T2}, \qquad \hat{n}_r = \begin{cases} \hat{n}_1 & \text{if } p_{T1} > p_{T2} \\ \hat{n}_2 & \text{if } p_{T2} > p_{T1} \end{cases}$$

Locality

Jets at trigger level

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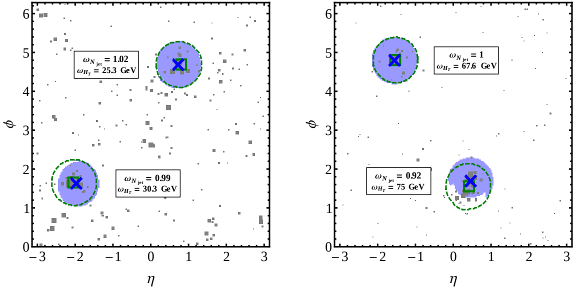
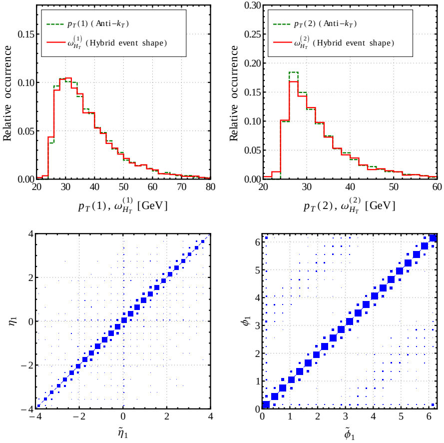


Locality

Jets at trigger level

Event shape + local winner-take-all recombination (hybrid event shape) gives individual jets p_T and axis



pp → jj

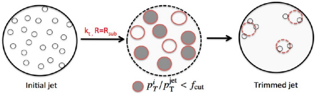
hardest and next-to-hardest jet p_T

pp → jj

hardest jet axis

Locality

Trimming as a local weight



Traditional trimming:

- Recluster jet's constituents with $\mathbf{R_{sub}} < R$ and remove subjets whose $p_{T\text{sub}}/p_{T\text{jet}} < \mathbf{f_{cut}}$

Shape trimming:

$$\tilde{t}^{\mu}_{\text{event}} = \sum_{i \in \text{event}} p_i^{\mu} \underbrace{\Theta\left(\frac{p_{Ti,R_{\text{sub}}}}{p_{Ti,R}} - f_{\text{cut}}\right) \Theta(p_{Ti,R} - p_{T\text{cut}})}_{\mathbf{w_i}}$$

- Trim by assigning a binary weight $\mathbf{w_i} = 0$ or 1 to each particle
- Can trim in "parallel" while computing an event shape

$\mathcal{S} = \sum_{i \in \text{event}} s(p_i^{\mu}) \Longrightarrow \mathcal{S}^{\text{trim}} = \sum_{i \in \text{event}} s(p_i^{\mu})\, \mathbf{w_i}$

Summary

Take home message: inclusive jet-based observables $\rightarrow$ event shapes

- **Locality**
  - Only need information in the neighborhood of each particle, easily parallelizable
  - Hybrid event shapes give information about individual jets
  - Viable way to define jets at trigger level?

  - Trimming can also be recast as a local weight and used at trigger level for pileup reduction
  - This *per particle* approach to pileup reduction can be generalized to include additional information (e.g. charged tracks, local area subtraction) and used both at trigger and analysis level

Summary

- **Alternative characterization of an event**
  - Keep more information (overlapping jets) and algorithm independent
  - Design new analyses, e.g. multijets with fractional $\widetilde{N}_{\text{jet}}$
  - Jet substructure
- **New calculable properties**
  - Recast jet-based observables in a closed form
  - Infrared and collinear safe
  - Jet-based observables $\rightarrow$ event shapes for infinitely narrow jets
    Expect similar factorization and resummation properties
  - Fractional $\widetilde{N}_{\text{jet}}$ sensitive to soft radiation only, calculate in QCD

*All jets without jets functions soon available as part of FastJet contrib project

Backup, the general strategy

$$N_{\text{jet}}(p_{T\text{cut}}, R) = \sum_{\text{jets}} \Theta(p_{T\text{jet}} - p_{T\text{cut}})$$

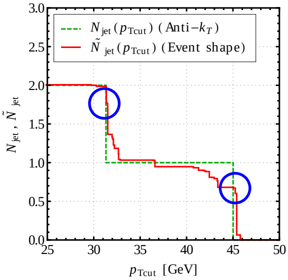
$$N_{\text{jet}}(p_{T\text{cut}}, R) = \sum_{\text{jets}} \underbrace{\sum_{i \in \text{jet}} \frac{p_{Ti}}{p_{T\text{jet}}}}_{\simeq 1} \Theta(p_{T\text{jet}} - p_{T\text{cut}})$$

$\sum_{\text{jets}} \sum_{i \in \text{jet}} \to \sum_{i \in \text{event}}$ and $p_{T\text{jet}} \to p_{Ti,R}$

$$\widetilde{N}_{\text{jet}}(p_{T\text{cut}}, R) = \sum_{i \in \text{event}} \frac{p_{Ti}}{p_{Ti,R}} \Theta(p_{Ti,R} - p_{T\text{cut}})$$

Backup, alternative way of defining jet p_T

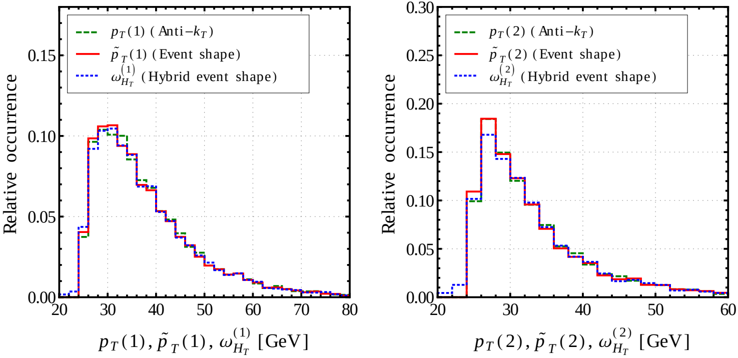
Define p_T from the (pseudo)inverse of $\widetilde{N}_{\rm jet}(p_{T\rm cut})$



$p_T(\text{n}^{\text{th}}\ \text{hardest}) \sim p_{T\rm cut}(N_{\rm jet} = n)$

$\widetilde{p}_T(\text{n}^{\text{th}}\ \text{hardest}) \sim p_{T\rm cut}(\widetilde{N}_{\rm jet} = n - 0.5)$

Backup, alternative way of defining jet p_T



Backup, trimming as a local weight

Tree trimming:

$$t^{\mu}_{\text{event}} = \sum_{\text{jets}} t^{\mu}_{\text{jet}} \Theta(p_{T\text{jet}} - p_{T\text{cut}})$$

$$= \sum_{\text{jets}} \sum_{\text{subjets}} p^{\mu}_{\text{sub}} \Theta\left(\frac{p_{T\text{sub}}}{p_{T\text{jet}}} - f_{\text{cut}}\right) \Theta(p_{T\text{jet}} - p_{T\text{cut}})$$

Make replacements:

- $\sum_{\text{jets}} \sum_{\text{subjets}} p^{\mu}_{\text{sub}} \to \sum_{i \in \text{event}} p^{\mu}_i$
- $p_{T\text{jet}} \to p_{Ti,R}$, $p_{T\text{sub}} \to p_{Ti,R_{\text{sub}}}$

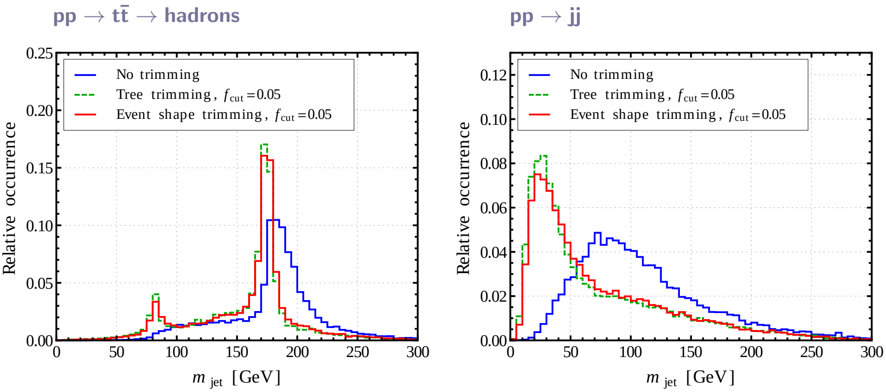
Shape trimming:

$$\widetilde{t}^{\mu}_{\text{event}} = \sum_{i \in \text{event}} p^{\mu}_i \Theta\left(\frac{p_{Ti,R_{\text{sub}}}}{p_{Ti,R}} - f_{\text{cut}}\right) \Theta(p_{Ti,R} - p_{T\text{cut}})$$

Backup, trimming as a local weight

Test mass resolution on boosted top sample + QCD background (BOOST 2010 samples)

- $R = 1$, $p_{T\text{cut}} = 200$ GeV, $R_{\text{sub}} = 0.2$, $f_{\text{cut}} = 0.05$



Backup, trimming as a local weight

Test pileup mitigation on $pp \to Z(\nu\bar{\nu})\,j$ sample

- $R = 1$, $p_{T\text{cut}} = 500$ GeV, $R_{\text{sub}} = 0.2$
- Test different values of f_{cut}