Jets without jets

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BOOST 2013 WORKSHOP

D.B., Tucker Chan, Jesse Thaler "Jet Observables Without Jet Algorithms" (in preparation)

Outline

- Introduction
- Jet-like event shapes
- Trimming with event shapes
- Motivations
- Summary and future directions

Introduction

- Two ways of characterizing a hadronic final state:
  1. Run a jet algorithm → "standard jets", jet-based observables
     [Jet multiplicity, H_T, p_T^{miss}, jet mass, etc. . .]
  2. Event shape observables
     [N-jettiness, energy correlation functions (see Andrew Larkoski's talk), etc. . .]
- This talk: systematic way to turn (a certain class of) jet-based observables into event shapes

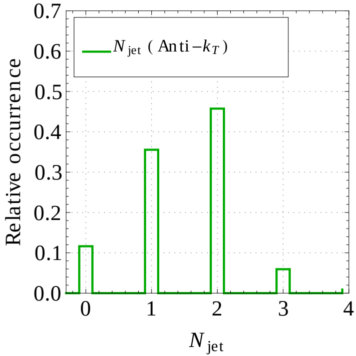
Counting jets with event shapes

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

Count jets with $R = 0.6$ and min transverse momentum $p_{T0} = 25$ GeV

$$\widetilde{N}_{\text{jet}}(p_{T0}, R) = \sum_{i \in \text{event}} \frac{p_{Ti}}{p_{Ti,R}} \Theta(p_{Ti,R} - p_{T0})$$

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



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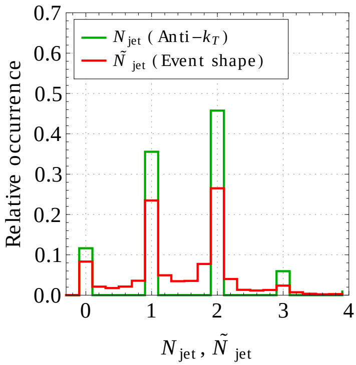

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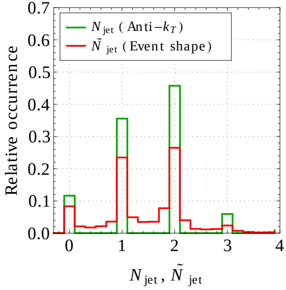
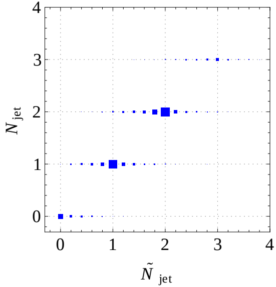
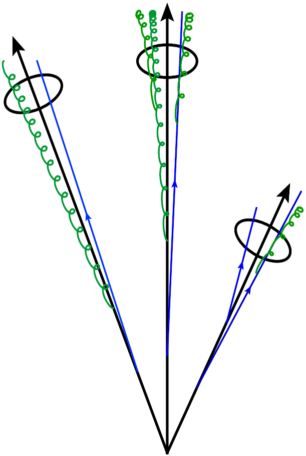




A physical picture



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For infinitely narrow jets separated by more than R:

$$\widetilde{N}_{\text{jet}}(p_{T0}, R) = \sum_{\text{jets}} \Theta(p_{T\text{jet}} - p_{T0})$$

This is exactly the number of jets!

Deduce a general strategy

1. $N_{\text{jet}}(p_{T0}, R) = \sum_{\text{jets}} \Theta(p_{T\text{jet}} - p_{T0})$ ⟵ inclusive jet observable

2. $N_{\text{jet}}(p_{T0}, R) = \sum_{\text{jets}} \underbrace{\sum_{i \in \text{jet}} \frac{p_{Ti}}{p_{T\text{jet}}}}_{\simeq 1} \Theta(p_{T\text{jet}} - p_{T0})$

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

4. $\widetilde{N}_{\text{jet}}(p_{T0}, R) = \sum_{i \in \text{event}} \frac{p_{Ti}}{p_{Ti,R}} \Theta(p_{Ti,R} - p_{T0})$ ⟶ event shape

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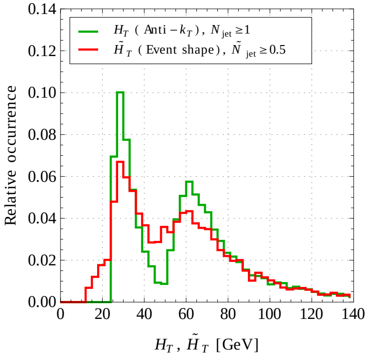
Transverse & missing transverse momentum

$$\widetilde{H}_T = \sum_{i \in \text{event}} p_{Ti}\, \Theta(p_{Ti,R} - p_{T0})$$

$$\widetilde{p}_T^{\text{miss}} = \left| \sum_{i \in \text{event}} \vec{p}_{Ti}\, \Theta(p_{Ti,R} - p_{T0}) \right|$$

$pp \to jj$

$R = 0.6,\, p_{T0} = 25$ GeV



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

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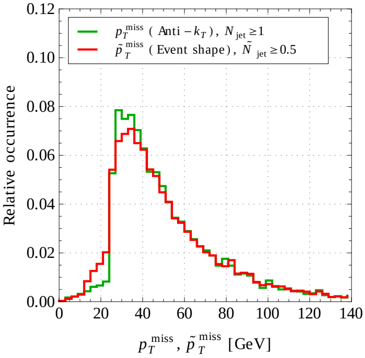


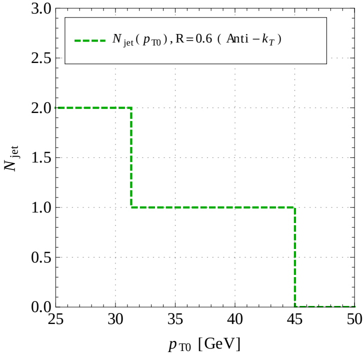
Shapes can tell you the p_T of the n^{th} hardest jet

Standard Jets:

Consider $N_{\text{jet}}(p_{T0})$ for fixed R

Let $p_{T0}(N_{\text{jet}})$ be the pseudo-inverse

$p_{T0}(n) = p_T(n)$ of n^{th} hardest jet



Event shape:

$\widetilde{N}_{\text{jet}}(p_{T0}) = \sum_{i \in \text{event}} \frac{p_{Ti}}{p_{Ti,R}} \Theta(p_{Ti,R} - p_{T0})$

Find functional dependence on p_{T0} by ordering $\{p_{Ti,R}\}$ vector

Define $\widetilde{p}_T(n)$ of n^{th} hardest jet from pseudo-inverse:
$\widetilde{p}_T(n) = p_{T0}(n - 0.5)$

[Note: in a similar way can get $\widetilde{N}_{\text{jet}}(R)$ for fixed p_{T0}]

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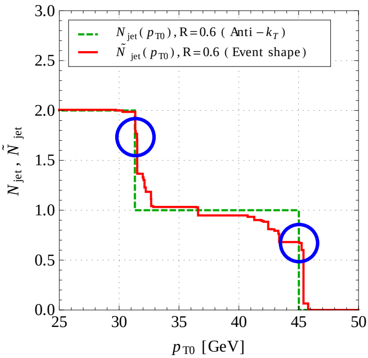

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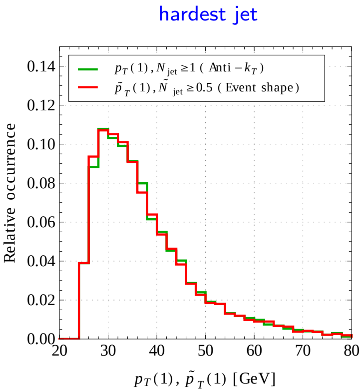
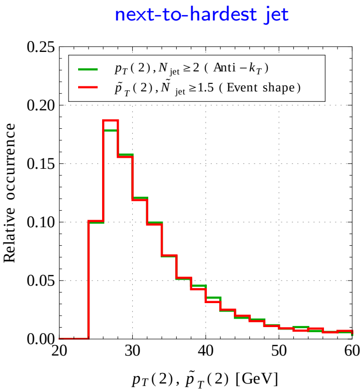
Shapes can tell you the p_T of the n^{th} hardest jet

$pp \to jj$, $R = 0.6$, $p_{T0} = 25$ GeV





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Trimming with event shapes

Trimming removes soft wide-angle radiation from a jet.
It can be used for:

- improving mass resolution for boosted objects
- reducing jet contamination from ISR, UE, pileup

Traditional "tree trimming":

- recluster jet's constituents with $R_{\text{sub}} < R$ via C/A or k_T
- remove subjets whose $p_{T\text{sub}}/p_{T\text{jet}} < f_{\text{cut}}$

Trimming with event shapes

4-mom of a trimmed jet: $t^\mu_{\text{jet}} = \sum_{\text{subjets}} p^\mu_{\text{sub}} \Theta\left(\frac{p_{T\text{sub}}}{p_{T\text{jet}}} - f_{\text{cut}}\right)$

Need an inclusive jet/subjet observable: 4-mom of the event

$t^\mu_{\text{event}} = \sum_{\text{jets}} \sum_{\text{subjets}} p^\mu_{\text{sub}} \Theta\left(\frac{p_{T\text{sub}}}{p_{T\text{jet}}} - f_{\text{cut}}\right) \Theta(p_{T\text{jet}} - p_{T0})$

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":

$$\widetilde{t}^\mu_{\text{event}} = \sum_{i \in \text{event}} p^\mu_i \Theta\left(\frac{p_{Ti,R_{\text{sub}}}}{p_{Ti,R}} - f_{\text{cut}}\right) \Theta(p_{Ti,R} - p_{T0})$$

Trimming with event shapes

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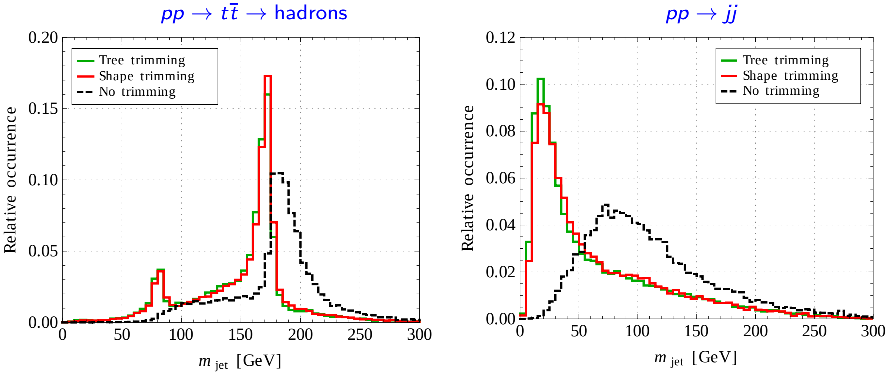
Trimming with event shapes

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

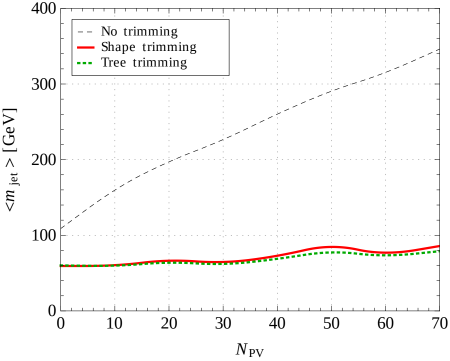
- $R = 1,\ p_{T0} = 200$ GeV, $R_{\rm sub} = 0.2,\ f_{\rm cut} = 0.05$



Trimming with event shapes

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

- $R = 1$, $p_{T0} = 500$ GeV
  $R_{\text{sub}} = 0.2$, $f_{\text{cut}} = 0.05$ (as in ATLAS study)



⟨ jet mass ⟩ versus number of soft events overlaid

Trimming with event shapes

"Shape trimming":

$$\widetilde{t}^{\mu}_{\text{event}} = \sum_{i \in \text{event}} p^{\mu}_i \underbrace{\Theta\left(\frac{p_{Ti,R_{\text{sub}}}}{p_{Ti,R}} - f_{\text{cut}}\right)\Theta(p_{Ti,R} - p_{T0})}_{\mathbf{w_i}}$$

- event-wide trimming with no jet/subjet clustering
- equivalent performances on mass resolution and pileup mitigation
- assign a weight $\mathbf{w_i}$ to each particle: can trim in "parallel" while computing an event shape

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

Motivations

We defined event shapes for N_{jet}, H_T, and p_T^{miss}
We recast trimming as an event shape

Use such jet-like event shapes:

1. at trigger level
   - "local" characterization of the gross properties of the event + milder turn-on behavior of event shapes
   - "local" pileup suppression through shape trimming
2. at analysis level
   - remove algorithm dependence
   - use when standard jets overlap

Summary

1. For any inclusive additive jet observable

$$\mathcal{F} = \sum_{\text{jets}} \sum_{i \in \text{jet}} f(p_i^\mu; p_{\text{jet}}^\mu)$$

can define a jet-like event shape

$$\widetilde{\mathcal{F}} = \sum_{i \in \text{event}} f(p_i^\mu; p_{i,R}^\mu)$$

e.g. $\widetilde{N}_{\text{jet}}$, $\widetilde{H}_T$, $\widetilde{p}_t^{\text{miss}}$

- can include multiple sums $\sum_{\text{jets}} \sum_{i,j \cdots \in \text{jet}} \to \sum_{i,j \cdots \in \text{event}}$
- similarly can define subjet-like event shapes, e.g. shape trimming
- similarly can define subjet-like jet shapes, e.g. subjet multiplicity

Summary

2. Provide an alternative/complementary characterization of the event, to be used both at trigger and analysis level
    - $\widetilde{N}_{\rm jet}$, $\widetilde{H}_T$, $\widetilde{p}_t^{\rm miss}$ and shape trimming will be available as FastJet contrib add-on

3. Jet-based observables $\equiv$ event shapes for infinitely narrow jets. Expect the same factorization and resummation properties

Future directions

1. Explore the full potential of jet-like event shapes, e.g. how to use information of continuous $\widetilde{N}_{\text{jet}}$ distribution
2. Explore similar techniques to study jet substructure
   - Preliminary results on subjet counting in boosted top samples
3. Can you recast intrinsically recursive algorithms (e.g. pruning, mass-drop, exclusive k_T) as event shapes ?

Work in progress  ...