Title: Jets Without Jets

Date: Dec 04, 2013 01:00 PM

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Abstract: Jets are key tools for physics at the LHC. Usually, jets are identified through a jet algorithm. In this talk, I will present an alternative way of thinking about jets, by showing how a broad class of inclusive jet-based observables can be replaced by event shapes. These event shapes do not require any jet clustering, but they still implement a jet-like pT cut on "jets" with an R-like radius. I will discuss various applications, including event selection at trigger-level, event-wide trimming, and alternative definitions for boosted objects identifiers.

Mirror Screens

Jets Without Jets

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Perimeter Institute, 12-04-2013

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

Preparing for next LHC run

Where do we stand after the first LHC run?

- Need to pin down Higgs properties
- Need to fully explore EW scale: non-minimal Higgs sectors? New dynamics?

Jets are clusters of hadrons used as proxy for partons and **crucially enter almost every LHC analysis**

- Higgs hadronic decays
- Multijet final states (e.g. SUSY)
- Heavy resonances decays (e.g. heavy Higgses, top partners)
- Missing energy tags (e.g. SUSY, dark matter searches)
- Removing contamination from soft hadronic activity (pileup)
- ...

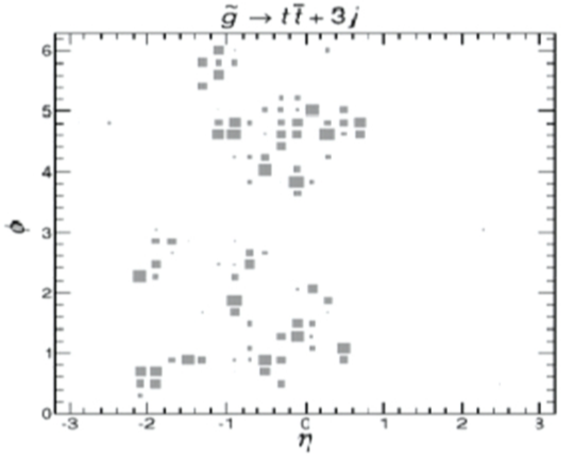
This talk: **new approach to study jets**

Do we need a new approach?

Standard approach:

- jet = cluster of particles
- jet algorithms provide clustering rules

A physics case for the need of a better approach: overlapping jets in multijet events, e.g. how many jets in this event?



[from H.K. Lou, BOOST 2013]

Outline

- Counting jets without clustering
- A general strategy for any inclusive jet-like event shape
- Trimming with event shapes
- Individual jets
- Summary and remarks

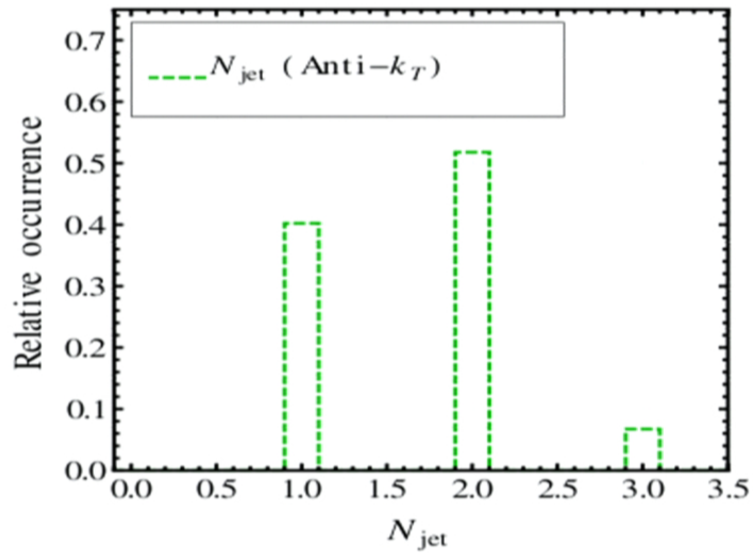
Counting jets with event shapes

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

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

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

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



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Counting jets with event shapes

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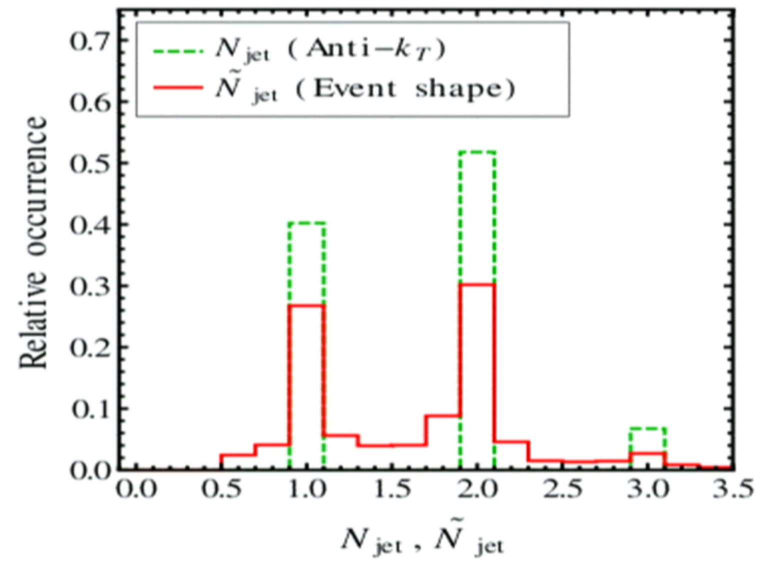

A physical picture

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

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

For infinitely narrow jets separated by more than R:

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

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The general strategy

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

inclusive jet variable

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

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

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event shape

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event shape

The general strategy

Any inclusive (i.e. summed over all jets) jet observable

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

can be turned into a jet-like event shape

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

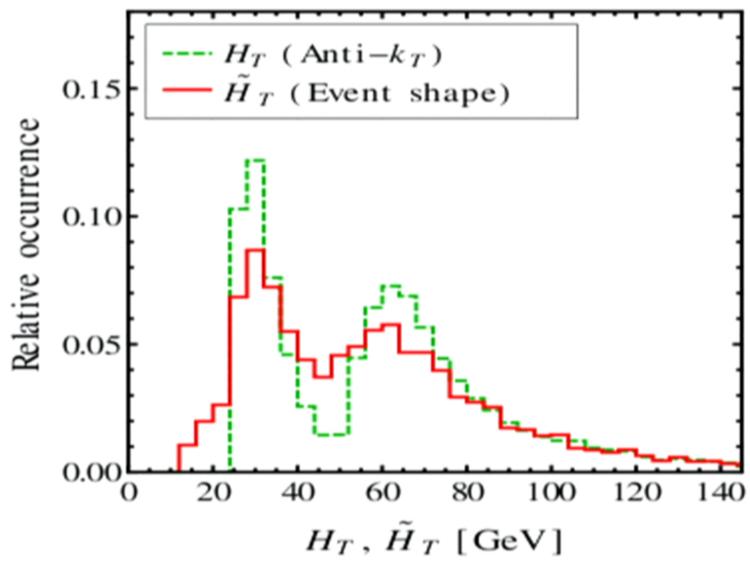
Transverse energy & missing transverse momentum

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

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

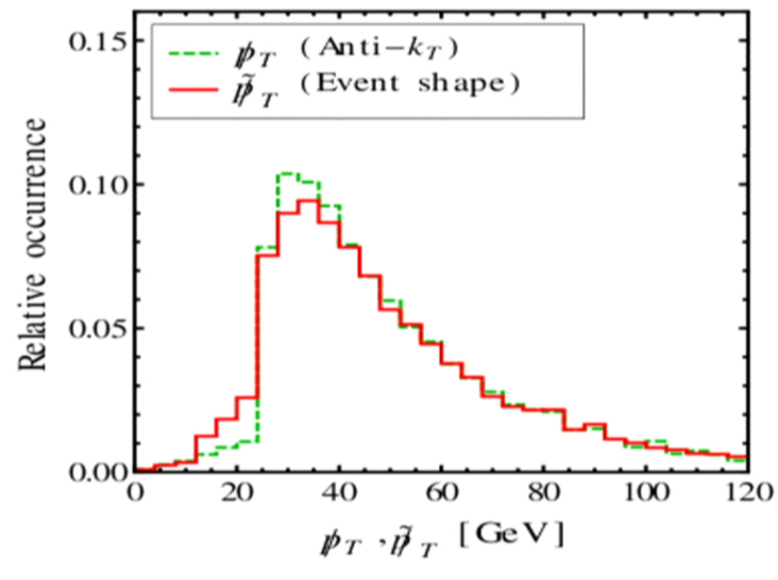
$\mathrm{pp} \to \mathrm{jj}$

$\mathrm{R} = 0.6, \mathrm{p}_{\mathrm{Tcut}} = 25$ GeV



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

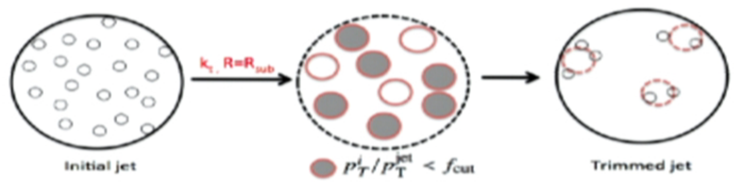
$\mathrm{R} = 0.6, \mathrm{p}_{\mathrm{Tcut}} = 25$ GeV



Trimming with event shapes

Grooming methods aim to remove soft wide-angle radiation from a jet:

- Improve mass resolution for boosted objects
- Reduce jet contamination from ISR, UE, pileup
- On the market:
  - Filtering and mass drop [Butterworth,Davison,Rubin,Salam 2008]
  - Pruning [Ellis,Vermilion,Walsh 2009]
  - Trimming [Krohn,Thaler,Wang 2010]



Traditional "tree trimming":

- Recluster jet's constituents with $\mathbf{R}_{\text{sub}} < R$
- Remove subjets whose $p_{T\text{sub}}/p_{T\text{jet}} < \mathbf{f}_{\text{cut}}$

Trimming with event shapes

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:

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

Shape trimming as weight assignement

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

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

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

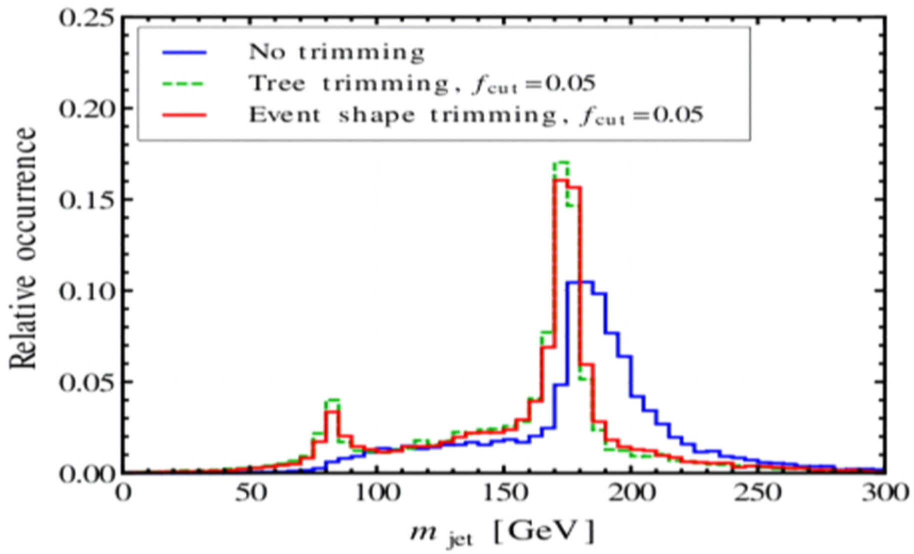
- Can generalize binary case and combine with other theoretical/experimental weights

Shape trimming

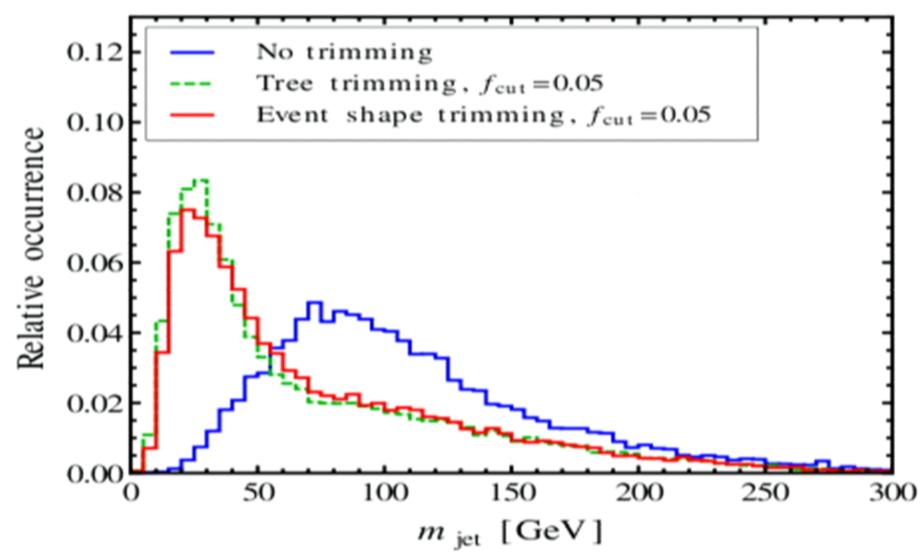
Test mass resolution on boosted top sample + QCD background (BOOST 2010 samples)

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

$pp \to t\bar{t} \to$ hadrons



$pp \to jj$



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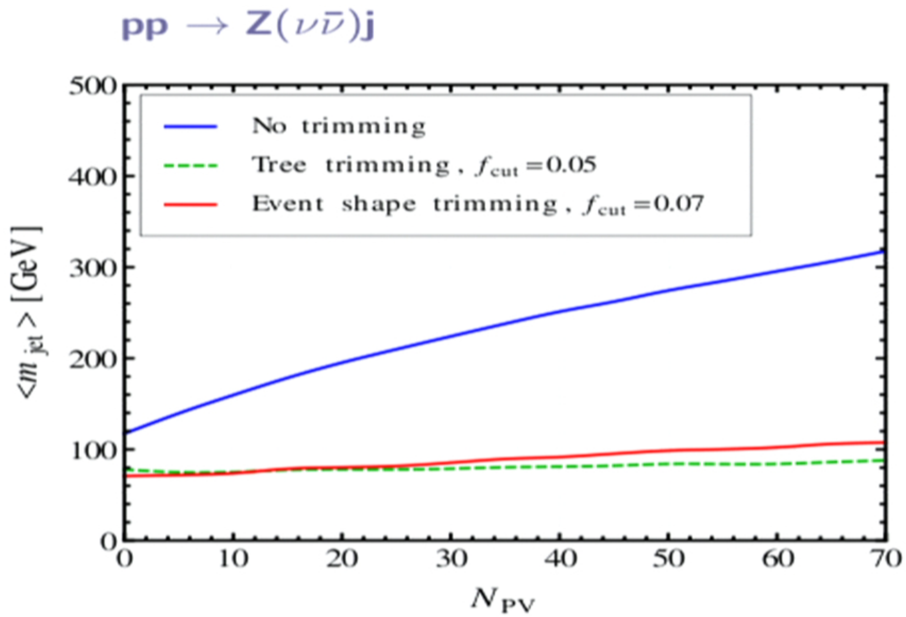
Shape trimming

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

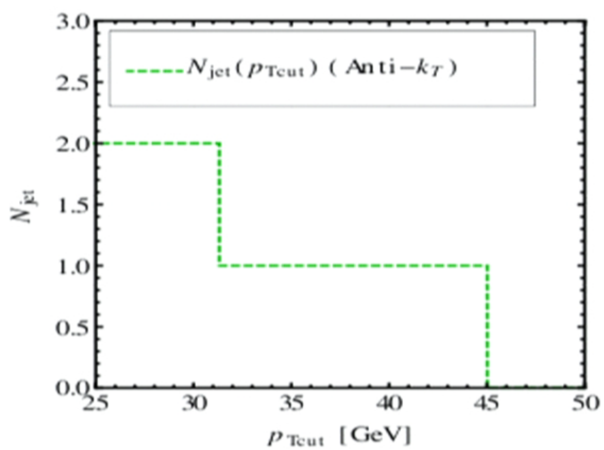
- $R = 1$, $p_{T\text{cut}} = 500$ GeV, $R_{\text{sub}} = 0.2$
- Test different values of f_{cut}



Individual jets

Despite this framework is designed for inclusive observables, we can still get information about individual jets

- **Jet $\mathbf{p_T}$**: define p_T from the (pseudo)inverse of $\widetilde{N}_{\text{jet}}(p_{T\text{cut}})$



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

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

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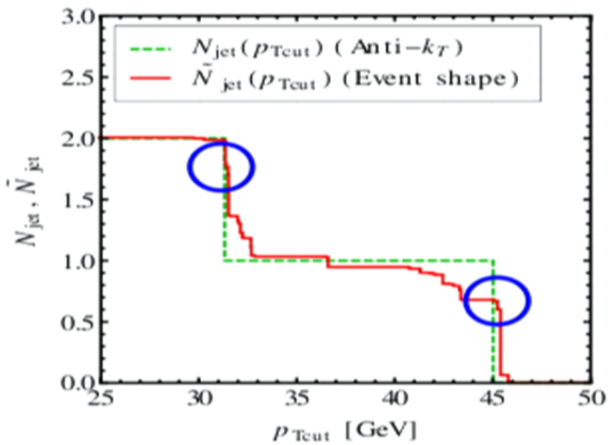

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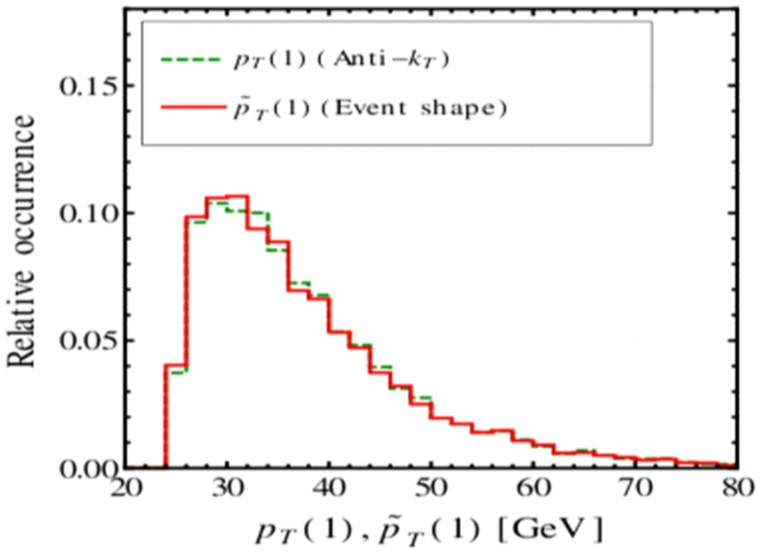
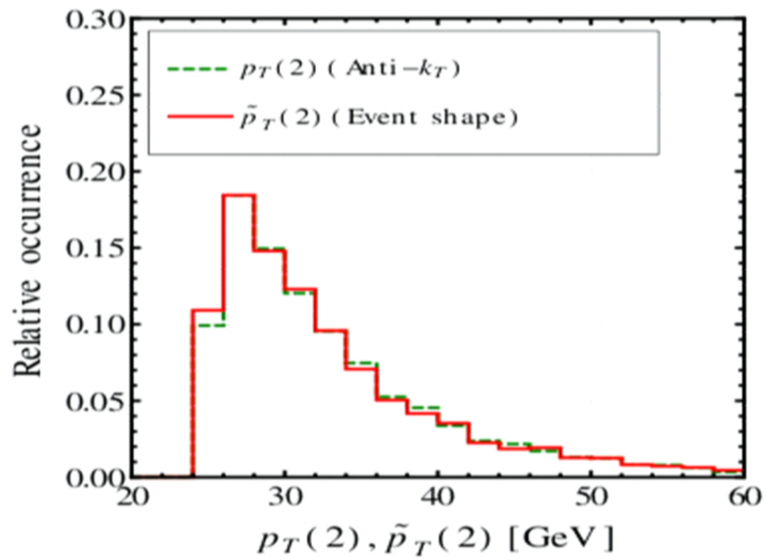
Individual jets

p_T distribution of the two hardest jets in $pp \to jj$
$R = 0.6, p_{T\text{cut}} = 25$ GeV





Individual jets

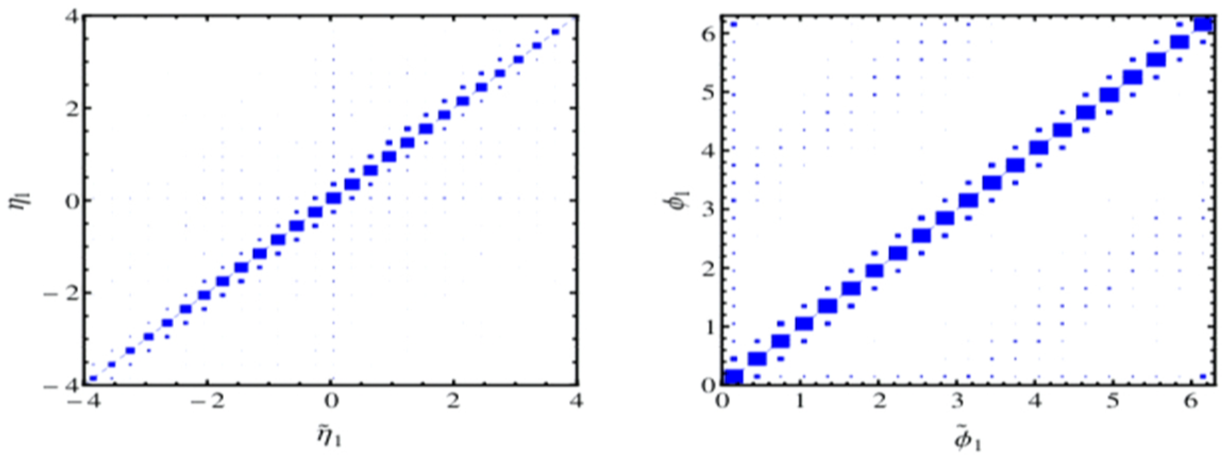
- **Jet axis**: use probability density

$$\rho_{N_{\rm jet}}(\hat{n}) = \sum_{\rm jets} \delta(\hat{n} - \hat{n}^r_{\rm jet})\, \Theta(p_{T\rm jet} - p_{T\rm cut}) \qquad \text{r=recomb. scheme}$$

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

$pp \to jj$, $R = 0.6$, $p_{T\rm cut} = 25$ GeV

hardest jet axis, anti-k_T vs (hybrid) event shape, r=Winner-Take-All



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$pp \rightarrow jj$, $R = 0.6$, $p_{T\rm cut} = 25$ GeV

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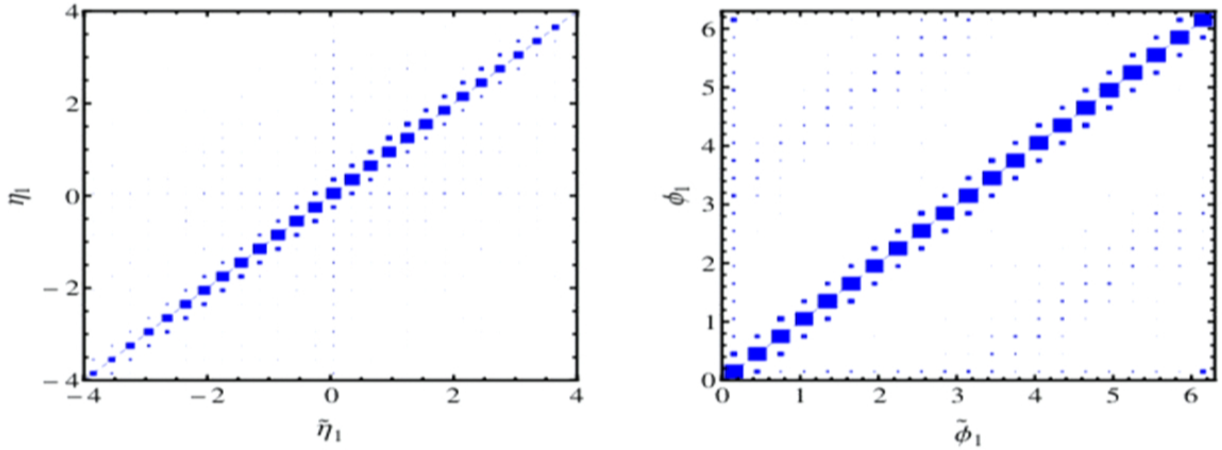

Summary and remarks

Properties and future developments of jets without jets approach

New: alternative characterization of the event

- Any inclusive jet-based observable can be turned into an event shape (N_{jet}, H_T, trimming. . .)
- Keep more information (overlapping jets) and algorithm independent
- Implemented as FASTJET contrib package
- **Design new analyses, e.g. multijets with fractional $\widetilde{N}_{\text{jet}}$**
- **Jet substructure**

Summary and remarks

Properties and future developments of jets without jets approach

Local: Requires only information in the neighborhood of a particle

- Easily parallelizable, can use $\widetilde{N}_{\text{jet}}$, $\widetilde{H}_T$, trimming in low-level trigger
- **Pileup will be critical in next LHC runs, extend shape trimming with area subtraction**
- **Generalize weights to include additional information, e.g. charged tracks**

Summary and remarks

Properties and future developments of jets without jets approach

Analytic: recasts jet-based observables in a closed form

- Can get full functional dependence on R, $p_{T\mathrm{cut}}$.
  Useful to get information about individual jets
- Infrared and collinear safe
- Jet-based observables $\rightarrow$ event shapes for infinitely narrow jets.
  Expect similar factorization and resummation properties
- **Explore variability with R**
- **Explore analytic structure (e.g. non-integer jet multiplicity)**
- **Can recast intrinsically recursive algorithms (e.g. pruning, mass-drop, exclusive k_T) as event shapes?**