Optimal Jet Finder
work in progress

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Jets: from partons to detector signatures

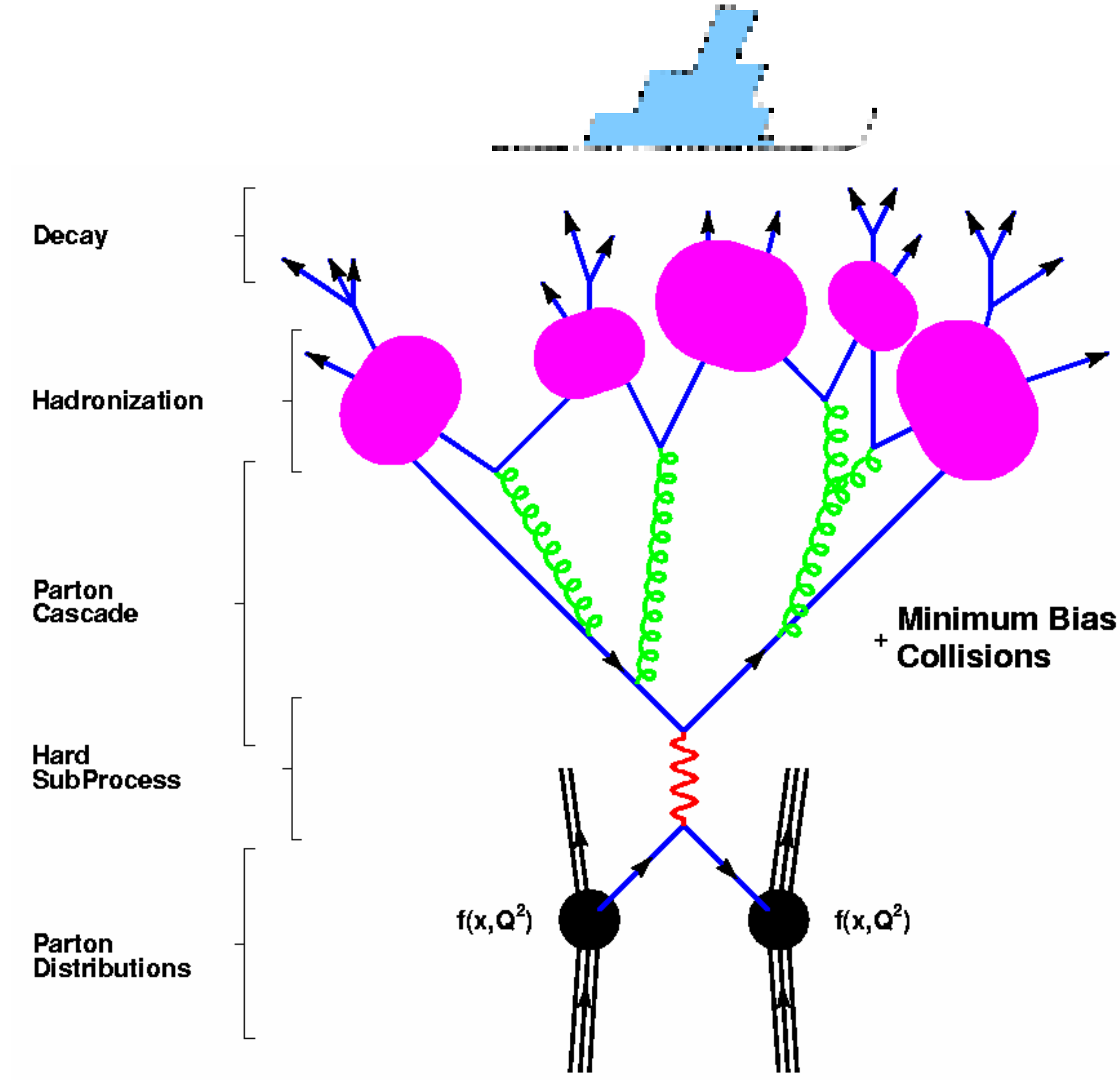
Detector signals

⇑

Jets of hadons

⇑

QCD partons



M. Dobbs and J.B. Hansen, Comput. Phys. Commun. 134 (2001) 41.

Infrared and collinear safety

Quark and gluon jets (identified to partons) can be compared to detector jets, if jet algorithms respect collinear and infrared safety
(Sterman & Weinberg, 1977)

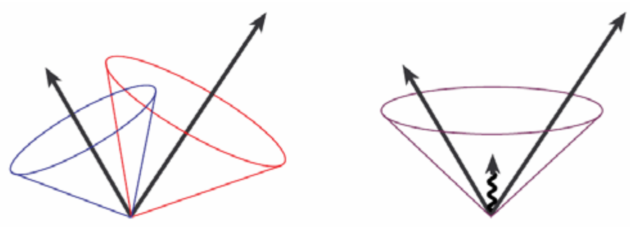


Figure 1. An illustration of infrared sensitivity in cone jet clustering. In this example, jet clustering begins around seed particles, shown here as arrows with length proportional to energy. We illustrate how the presence of soft radiation between two jets may cause a merging of the jets that would not occur in the absence of the soft radiation.

hep-ex/0005012

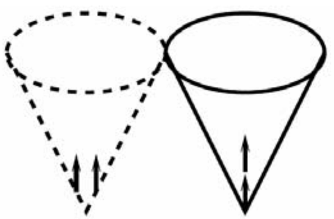


Figure 2. An illustration of collinear sensitivity in jet reconstruction. In this example, the configuration on the left fails to produce a seed because its energy is split among several detector towers. The configuration on the right produces a seed because its energy is more narrowly distributed.

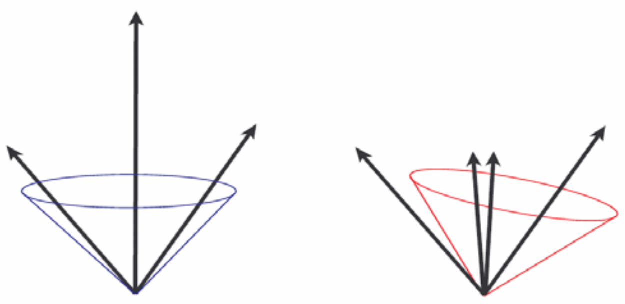


Figure 3. Another collinear problem. In this case we illustrate possible sensitivity to E_T ordering of the particles that act as seeds.

Optimal Jet Finder (OJF)

- Documentation
  - proposed by Fyodor Tkachov
  - short introduction: Phys. Rev. Lett. 91, 061801 (2003)
  - authors webpage (with links to source code, etc.)
    - http://www.inr.ac.ru/~ftkachov/projects/jets/welcome.html

- Implementation in Athena in progress
  - Rolf Seuster, Damir Lelas
  - Discussions with Peter Loch and others ongoing

Optimal Jet Finder (OJF)

HEP event: list of **particles** $p_a, \quad a = 1, 2, \ldots, n_{\text{parts}}$
(partons • hadrons • calorimeter cells • towers • preclusters)

recombination matrix $\{z_{aj}\}_{n_{\text{parts}} \times n_{\text{jets}}}$

$$q_j = \sum_{a=1}^{n_{\text{parts}}} z_{aj} \, p_a$$

the 4-momentum q_j of the j-th jet expressed by 4-momenta p_a of the particles

result: list of **jets** $q_j, \quad j = 1, 2, \ldots, n_{\text{jets}}$

E. Jankowski

Recombination matrix

- Fixes the jet configuration

$$q_j = \sum_{a=1}^{n_{\text{parts}}} z_{aj} p_a$$

the 4-momentum q_j of the j-th jet expressed by 4-momenta p_a of the particles (a=1,2,...,n_{parts})

$$z_{aj} \geq 0$$

the fraction of the energy of the a-th particle can be positive only

$$\bar{z}_a \equiv 1 - \sum_{j=1}^{n_{\text{jets}}} z_{aj}$$

the fraction of the energy of the a-th particle that does not go into any jet

$$\bar{z}_a \geq 0$$

i.e. no more than 100% of each particle is assigned to jets

E. Jankowski

Soft energy and fuzzyness

Cylindrical kinematics

$$E_{\text{soft}} \equiv \sum_{a=1}^{n_{\text{parts}}} \overline{z}_a E_a^{\perp}$$

transverse energy left outside the jets

$$Y \equiv 2 \sum_{j=1}^{n_{\text{jets}}} q_j \cdot \tilde{q}_j$$

fuzziness

$$p_a = E_a^{\perp} \left(\cosh \eta_a, \cos \varphi_a, \sin \varphi_a, \sinh \eta_a \right) \qquad p_a^2 = 0$$

$$E_a^{\perp} \equiv \sqrt{\left(p_a^{\text{x}}\right)^2 + \left(p_a^{\text{y}}\right)^2}$$

$$q_j \equiv \left(E_j, \mathbf{q}_j \right) \equiv \sum_{a=1}^{n_{\text{parts}}} z_{aj} p_a \qquad \eta_j \equiv \frac{\sum_{a=1}^{n_{\text{parts}}} z_{aj} E_a^{\perp} \eta_a}{\sum_{a=1}^{n_{\text{parts}}} z_{aj} E_a^{\perp}} \qquad \frac{\mathbf{q}_j^{\perp}}{\left|\mathbf{q}_j^{\perp}\right|} \equiv \left(\cos \varphi_j, \sin \varphi_j \right)$$

$$\tilde{q}_j \equiv \left(\cosh \eta_j, \cos \varphi_j, \sin \varphi_j, \sinh \eta_j \right) \qquad \tilde{q}_j^2 = 0$$

Final jet configuration

- The recombination matrix is found by minimizing

$$\Omega\left[\{z_{aj}\},\{p_a\}\right] \equiv \frac{1}{R^2} Y + E_{\text{soft}}$$

R weights the relative contributions

- For cylindrical kinematics

$$\Omega = \frac{4}{R^2} \sum_{j=1}^{n_{\text{jets}}} \sum_{a=1}^{n_{\text{parts}}} z_{aj} E_a^{\perp} \left(\sinh^2 \frac{\eta_a - \eta_j}{2} + \sin^2 \frac{\varphi_a - \varphi_j}{2} \right) + \sum_{a=1}^{n_{\text{parts}}} \bar{z}_a E_a^{\perp}$$

Algorithm: fixed n_{jets} case

1. Start with some (random) value of the recombination matrix z_{aj} and minimize Ω with respect to z_{aj} for some given p_a

2. Repeat this a few times, each time starting with a different (random) z_{aj}

3. The value of z_{aj} that corresponds to the smallest of the minima of Ω is the final jet configuration for the required (fixed) number of jets

Algorithm: general case

- If the number of jets is to be determined

1. Start with $n_{jets} = 1$
2. Find the corresponding n_{jets} configuration
3. Check if $\Omega < \omega_{cut}$ is fulfilled; if yes stop here
4. If not, increase n_{jets} by one and repeat at 2

- The parameter ω_{cut} is some small positive number, analogous to the jet resolution parameter of conventional recombination algorithms

A few comments

- OJF is infrared and collinear safe
- the authors claim it is based on an optimal jet definition that solves the problem of jet definition in general
- conventional jet algorithms have z_{aj} equal to 0 or 1, i.e. a particle either entirely belongs to some jet or does not belong to that jet at all
  - Hadronization is always effect of interaction of at least two hard partons evolving into two jets, so some hadrons that emerge in this process can belong partially to both jets (continuous z_{aj} for OJF)
- need to assess the robustness of the algorithm
  - small changes in input particle kinematics
  - pileup

Optimal Jet Finder (OJF)

- OJF evaluation ongoing
  - comparison with other jet algorithms
    - speed issues
  - observables
    - number of jets
    - kinematics distributions
    - event shape variables
  - robustness
- In the following slides, some results I have recently obtained looking at fully hadronic ttbar events
  - an “excuse” to play with OJF

Samples

- Generated by Damir Lelas
- Sample 5204
  - MC@NLO ttbar→6jets, full simulation, Athena 11.0.42
- AOD produced using Athena 12.0.5
  - 1050 events, E_T > 7 GeV filter on jets
  - ParticleJetContainer
    - each produced which its own H1 weights
      - Cone4TowerParticleJets   Cone4TopoParticleJets
      - ConeTowerParticleJets   ConeTopoParticleJets
      - Kt4TowerParticleJets   Kt4TopoParticleJets
      - Kt6TowerParticleJets   Kt6TopoParticleJets
  - JetCollection using OJF
    - no proper H1 weights available: use Cone weights
    - number of jets fixed to 6
    - R parameter set to 0.7
      - FuzzyTowerJets   FuzzyClusterJets

Jet-parton matching

- Study events with “true” jet hypothesis
- Matching criteria
  - For each parton, look for a matching jet
    - restrict search in a region limited by $\Delta R_{max} = 0.2$
    - keep the closest jet in this region
  - Demand that a jet be matched only once
    - matching efficiencies depends on interparton distances
      - same top combinations

$\langle \Delta R(\text{u-b}) \rangle$	$= 2.220 \pm 0.002$	$\langle \Delta R(\text{ubar-bbar}) \rangle$	$= 2.219 \pm 0.002$
$\langle \Delta R(\text{u-dbar}) \rangle$	$= 2.008 \pm 0.002$	$\langle \Delta R(\text{ubar-d}) \rangle$	$= 2.010 \pm 0.002$
$\langle \Delta R(\text{dbar-b}) \rangle$	$= 2.037 \pm 0.002$	$\langle \Delta R(\text{d-bbar}) \rangle$	$= 2.036 \pm 0.002$

      - other 9 combinations

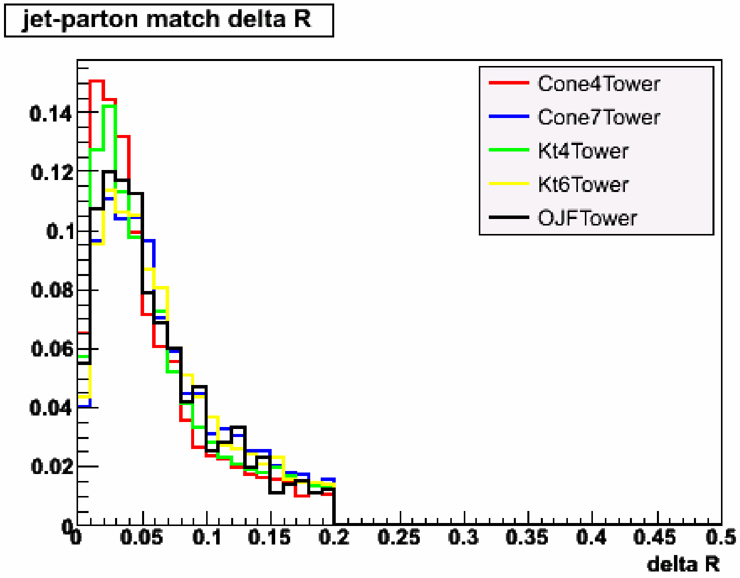
$\langle \Delta R \rangle \approx 2.40$

Parton matching efficiencies

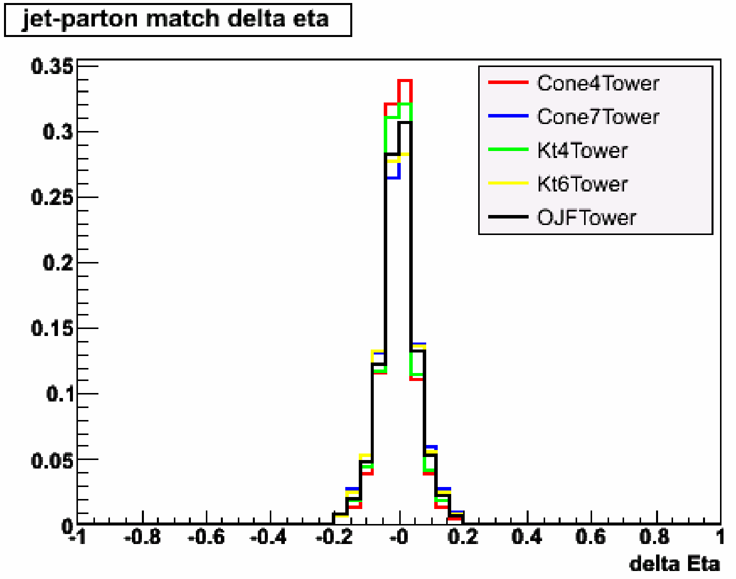
- no p_T jet cuts applied

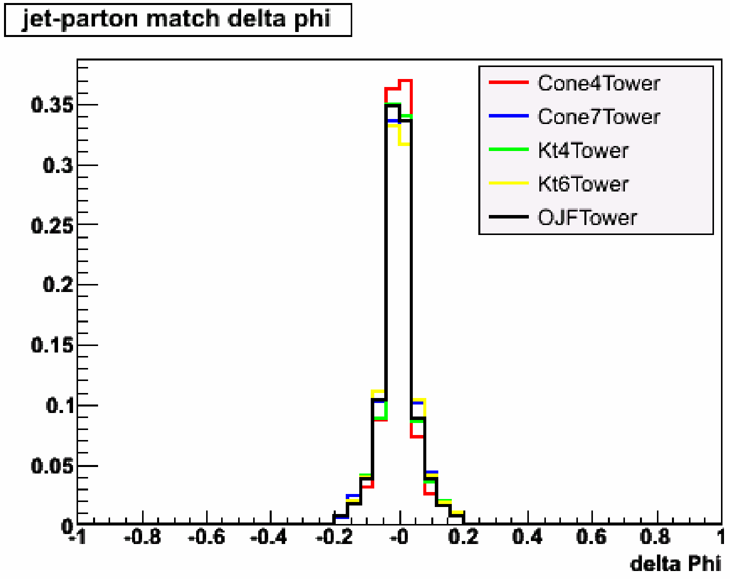
5204 sample ttbar->6jets Athena 12.0.5	Cone4TowerParticleJets	Cone4TopoParticleJets	ConeTowerParticleJets	ConeTopoParticleJets	Kt4TowerParticleJets	Kt4TopoParticleJets	Kt6TowerParticleJets	Kt6TopoParticleJets	**FuzzyTowerJets**	**FuzzyClusterJets**
number of events	1049	1049	1049	1049	1049	1049	1049	1049	1049	1049
at least 6 jets in |eta| < 3	870	967	847	929	1039	1024	1043	1024	675	564
all matched partons 1 to 1	153	162	52	48	205	202	153	151	11	14
matching efficiency	**17.6%**	**16.8%**	**6.1%**	**5.2%**	**19.7%**	**19.7%**	**14.7%**	**14.7%**	**1.6%**	**2.5%**
u	73.6%	73.7%	58.7%	57.5%	74.8%	74.6%	70.0%	71.3%	59.3%	60.8%
dbar	69.5%	68.4%	51.8%	49.8%	71.5%	72.2%	65.8%	66.3%	51.0%	52.1%
b	78.4%	78.8%	68.6%	64.8%	79.0%	79.8%	76.8%	76.8%	68.7%	69.0%
ubar	72.6%	75.2%	60.9%	59.0%	78.3%	78.0%	72.8%	74.7%	61.1%	64.5%
d	69.4%	69.3%	52.8%	51.2%	72.2%	72.5%	68.1%	68.7%	51.6%	52.7%
bbar	77.0%	76.9%	65.6%	62.1%	77.9%	78.6%	74.5%	75.3%	68.9%	66.1%
at least 6 jets in |eta| < 3	870	967	847	929	1039	1024	1043	1024	675	564
all matched partons 1 to 1	153	162	52	48	205	202	153	151	11	14
assume 6 highest pt jets	53	57	25	21	57	56	47	47	11	14
matching efficiency	**6.1%**	**5.9%**	**3.0%**	**2.3%**	**5.5%**	**5.5%**	**4.5%**	**4.6%**	**1.6%**	**2.5%**
at least 6 jets in |eta| < 3	870	967	847	929	1039	1024	1043	1024	675	564
exactly 6 jets	250	127	222	142	19	41	23	50	675	564
all matched partons 1 to 1	22	12	6	3	1	3	4	5	11	14
matching efficiency	**2.5%**	**1.2%**	**0.7%**	**0.3%**	**0.1%**	**0.3%**	**0.4%**	**0.5%**	**1.6%**	**2.5%**

Normalized distributions: towers

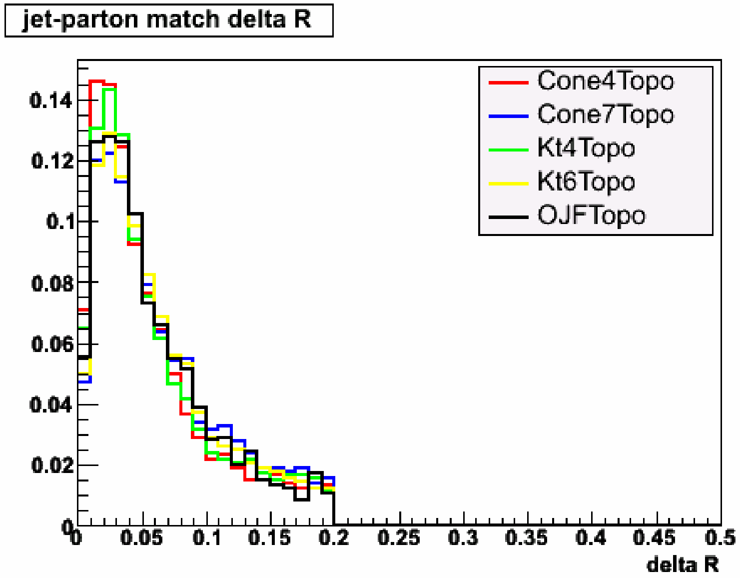


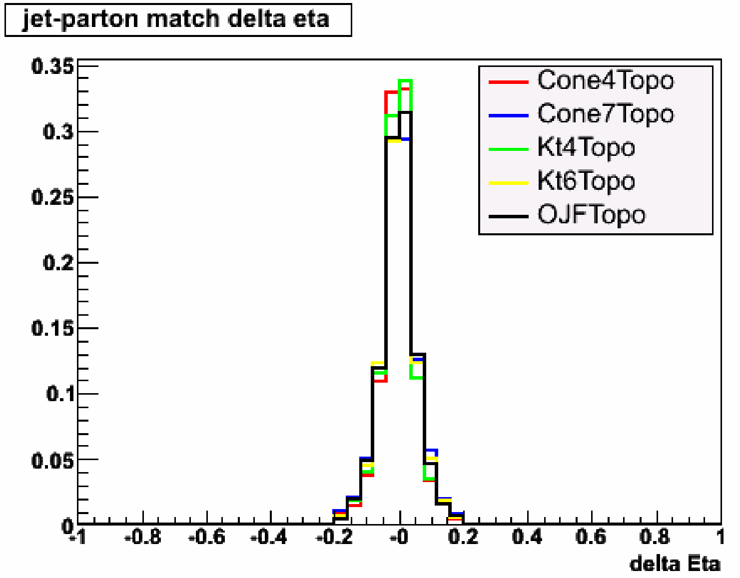
corresponds to events after requiring at least 6 jets in |eta| < 3

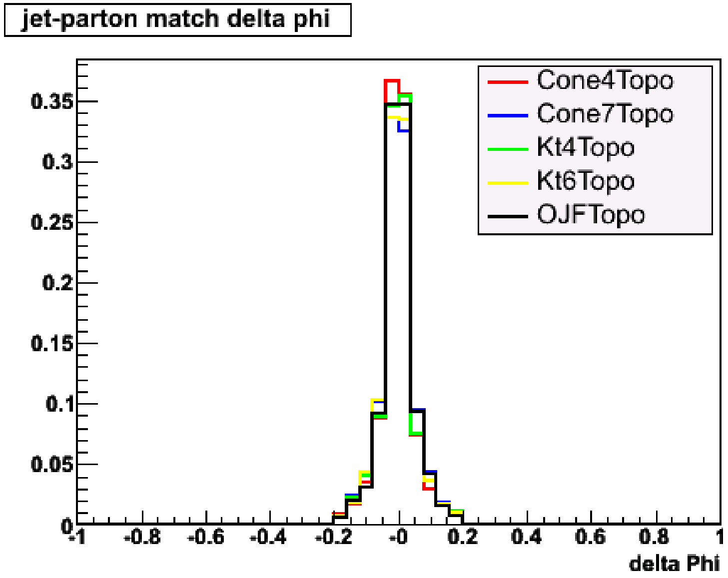




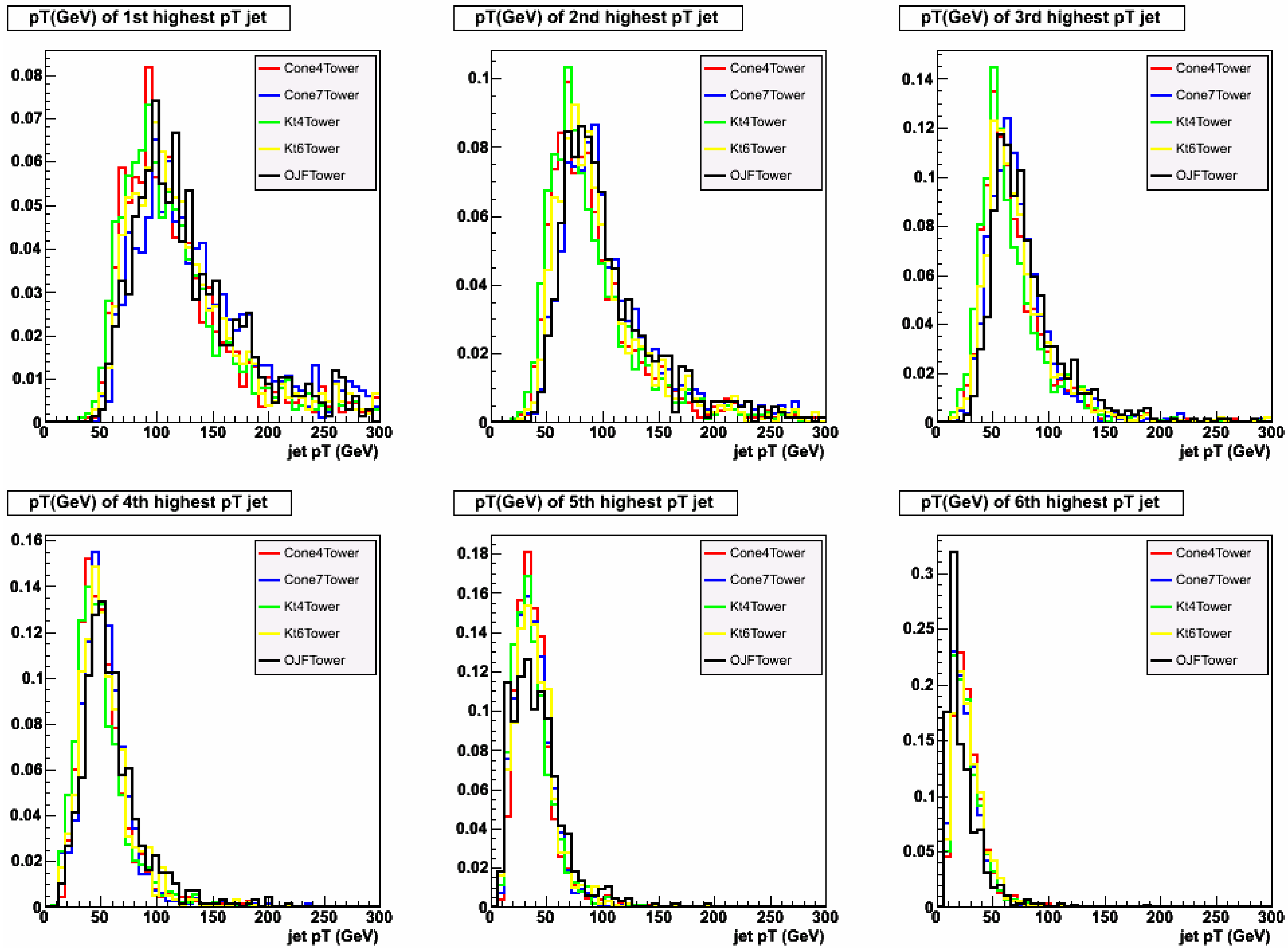
Normalized distributions: topo clusters



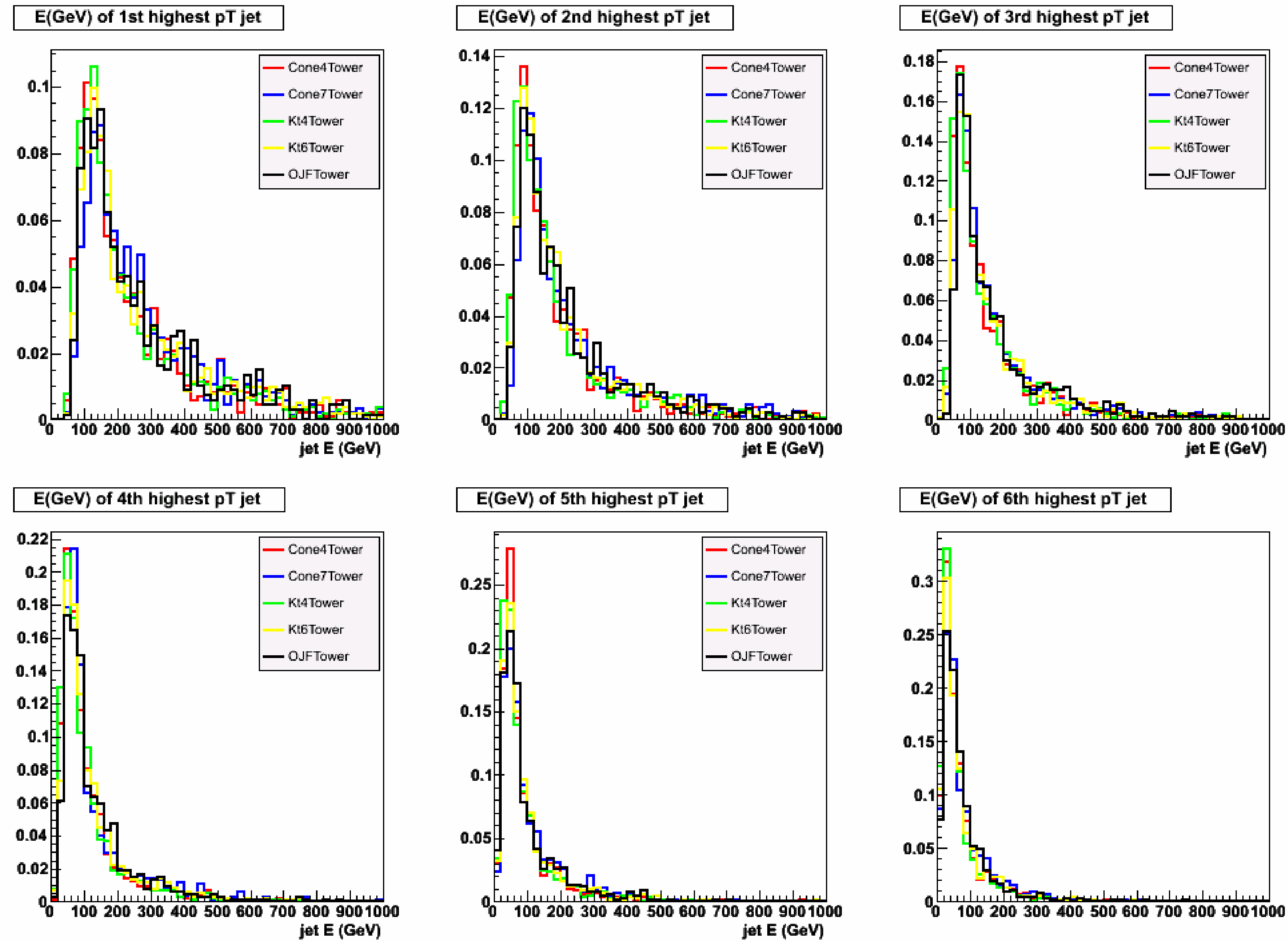




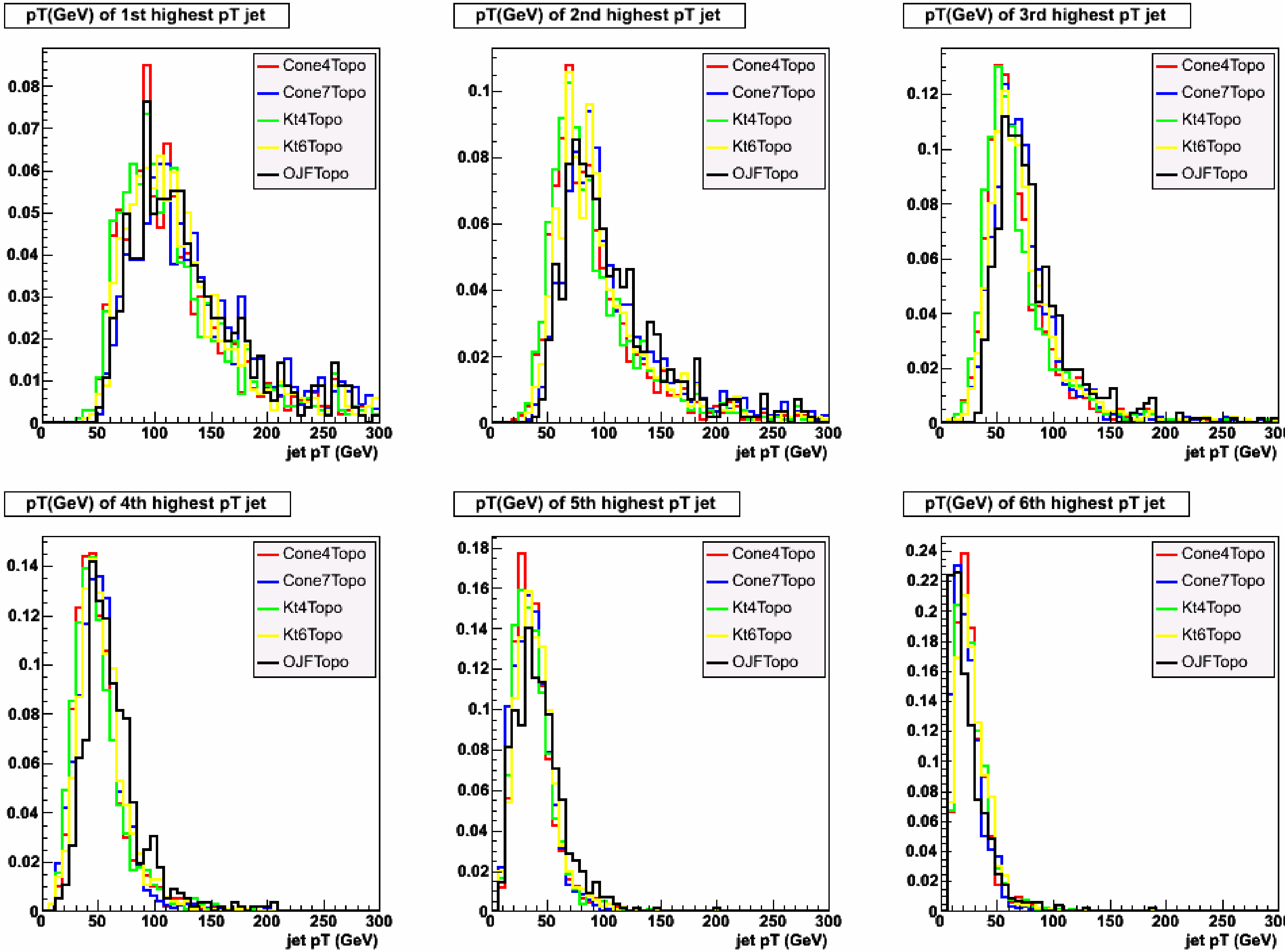
Normalized p_T distributions: towers



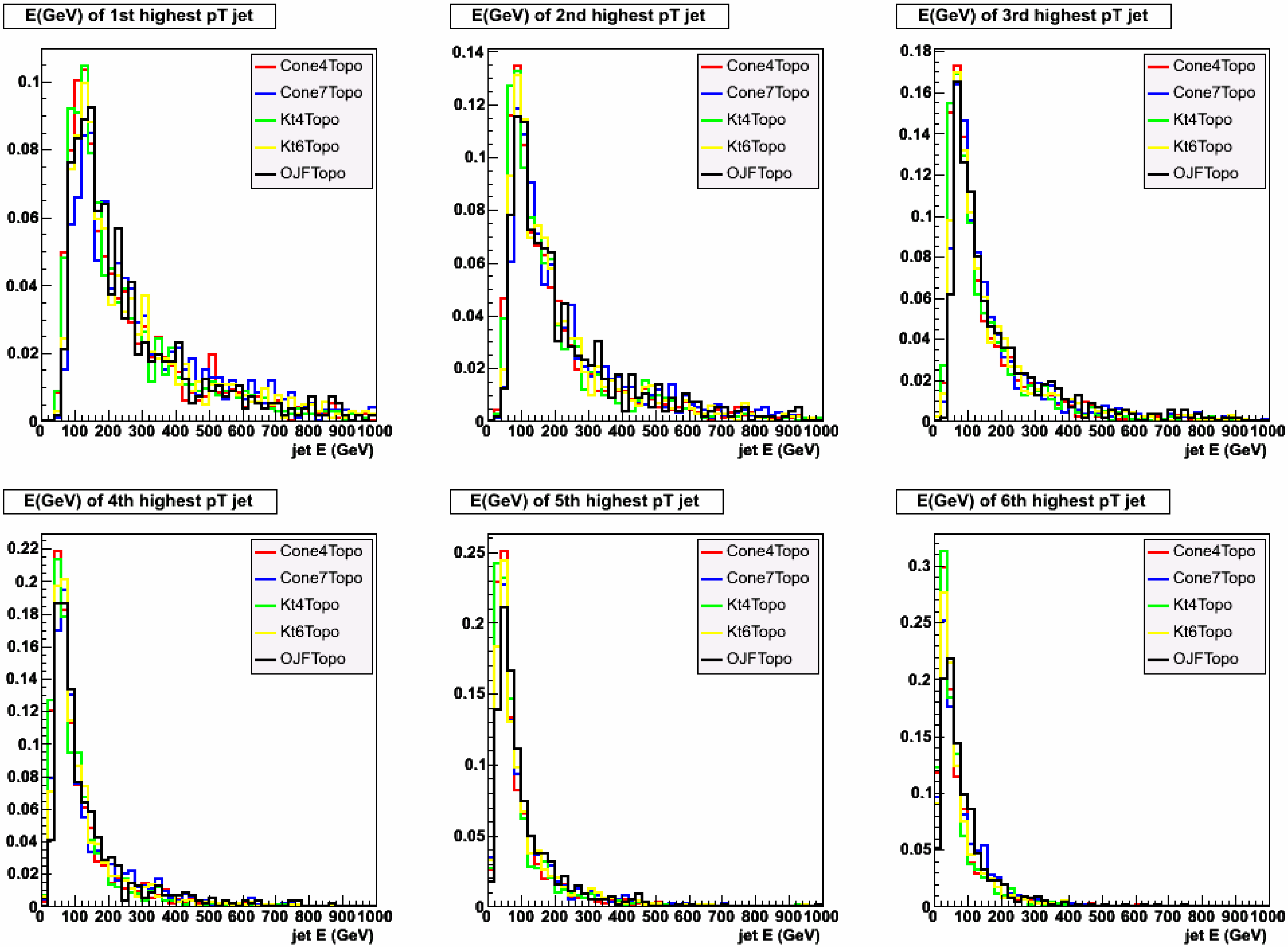
Normalized E distributions: towers



Normalized p_T distributions: topo clusters



Normalized E distributions: topo clusters



Comments

- Very encouraging results for OFJ
  - here fixed number of jet mode!
  - should try with number of jets not fixed
    - adjust ω parameter
  - more events would allow mass plots
    - requires 6 matched partons 1 to 1
  - more systematic tests being discussed
    - compare with particle truth
    - need larger samples
    - explore various OJF parameter values