# A look at Seedless Infrared Safe Cone Algorithm

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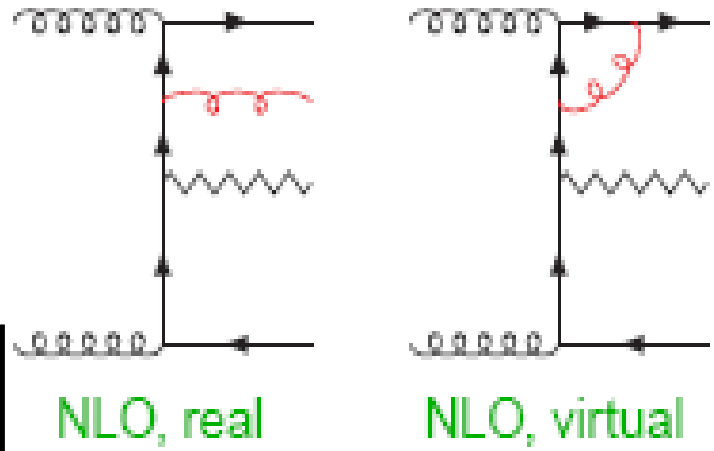
# Clustering Algorithms

- Cone Clustering Algorithms
  - Fixed Cone Algorithm
  - Iterative Cone
  - MidPoint Algorithm
  - Seedless Infrared-Safe Cone jet algorithm
- Sequential Re combination Algorithms
  - kT clustering
  - Cambridge

# Infrared (IR) Safety

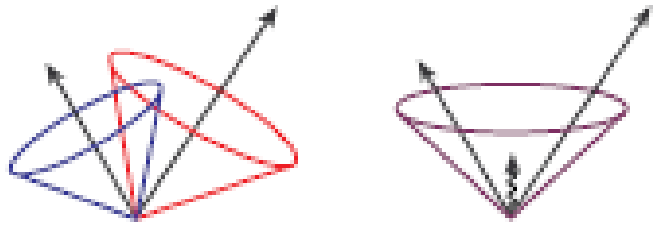
Stability up emission of soft particles is required for perturbative computing to make sense.




- In the iterative cone algorithms used in Tevatron Run I is not IR safe.
- Additional seed at *MidPoint* between two stable cones are added to make the algorithm safe to only NLO for inclusive jet cross section.

(Run II jet physics hep-ex/0005012)

- ***Midpoint*** algorithm is un-safe at NNLO for inclusive jet cross section (3 partons + 1 to balance pt $(\mathcal{O}(\alpha_s^4))$).
- Some process are un-safe even at LO/NLO.



# SisCone Algorithm

- No seed, use all input objects
  - GenJets: All stable Gen Particles
  - CaloJets: CaloTowers Et>0.5 GeV, noise suppression thresholds

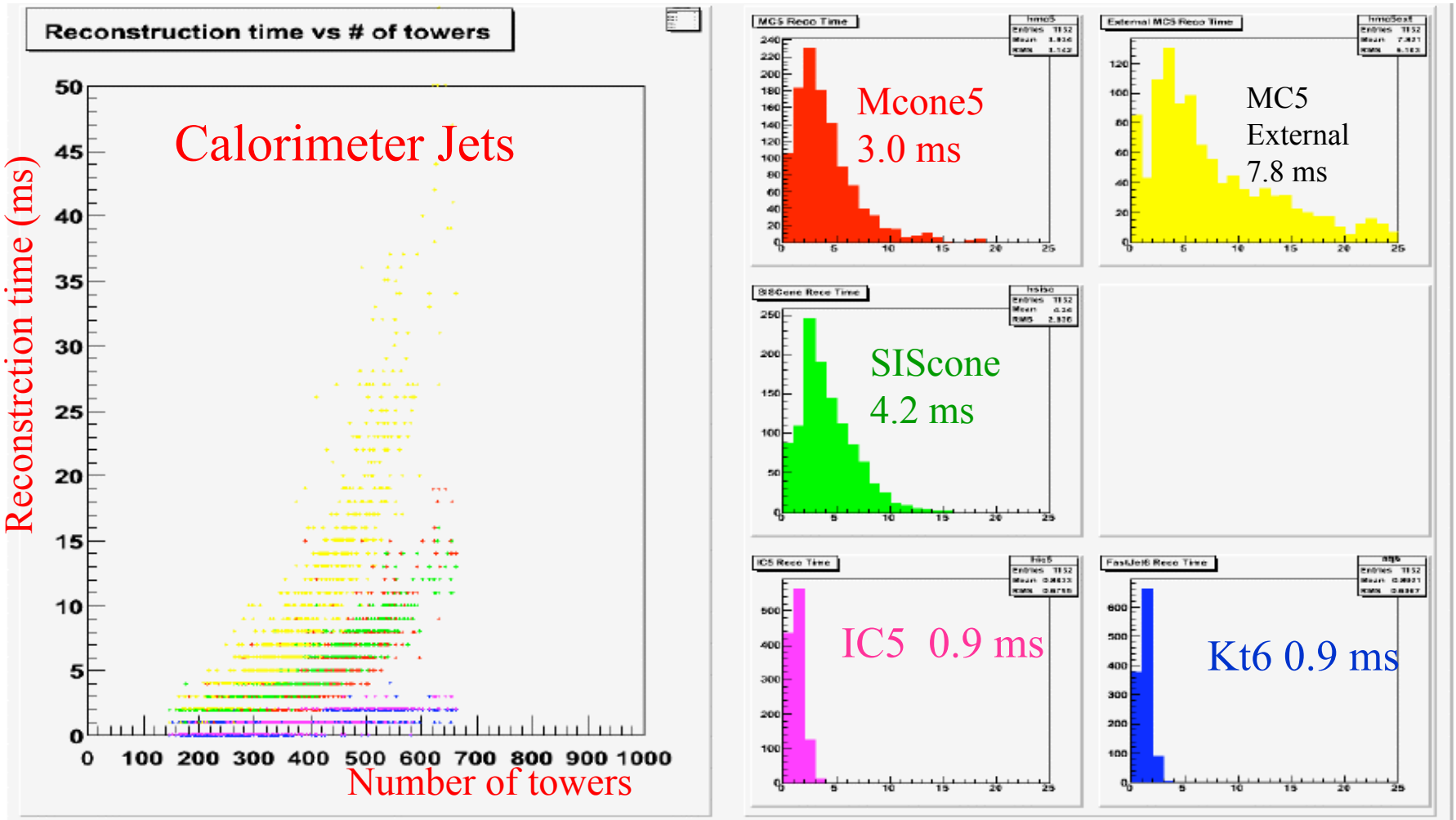
1. Use all particles (current particles)
2. repeat
   - Find *all* stable cones of radius R from the current set of particles.
   - For each stable cone, create a protojet from current particles contained in the cone, and add it to the list of protojets
   - Remove all particles that are in stable cones from the list of current particles.
3. until no new stable cones are found or one has gone around the loop Npass times.
4. Run a Tevatron Run II type split-merge procedure on full list of protojets with overlap parameter f (=0.75) and transverse momentum threshold pt,min (=0)

# SISCone Stable Cones

- Check stability for each and every subset of particles.
- Brute force approach, manageable for small number (N)of particle but unrealistic for large *N*. It is used in MCFM (N ≤4).
  - ( Complexity $O(N2^N)$ **$10^{17}$ years for N = 100)**
- A circle enclosing a set of particles can be moved around such that two of the particles lie on it circumference and it still encloses the same set of particles.
- For given particle ***i,***
  - find all circles with ***i, j*** *(j=1,N Rij<2R)* on the circumference.
  - Calculate Pt-weighted centroid of all the particles in this circle.
  - This subset of particles is stable if the cone centered on this centroid (y,φ) contains all the initial particles and no additional particle.
  - Complexity is ***O****(Nn ln n),* *n* is number of particles in cone *R*.

# Timing Issue

Fedor Ratnikov (Maryland)

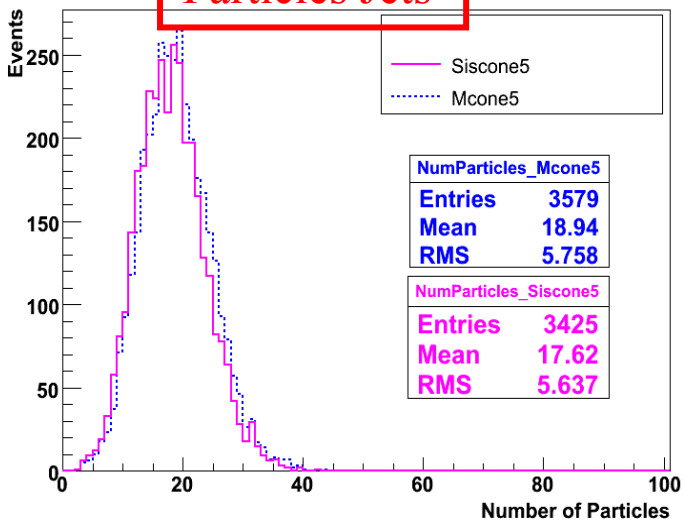



July 26, 2007 F.Ratnikov. CMS Jet/MET Meeting. Jet SW Status and Plans 5 of 11

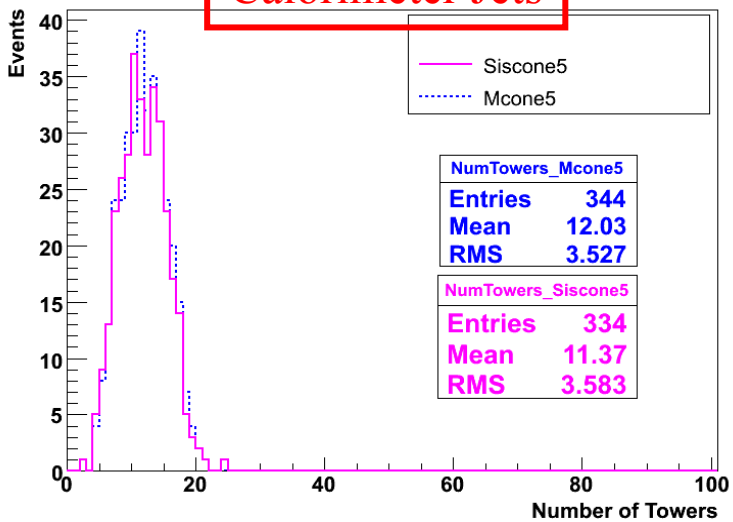
# Energy distribution in a jet

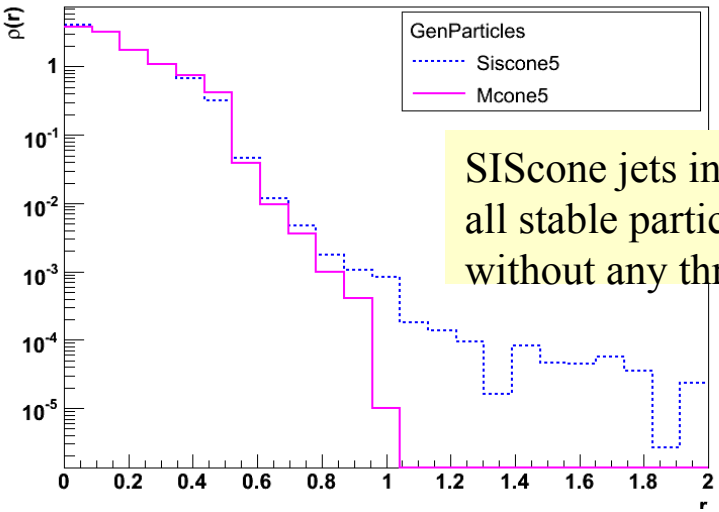
Pelin Kurt (Cukurova)

Particles Jets



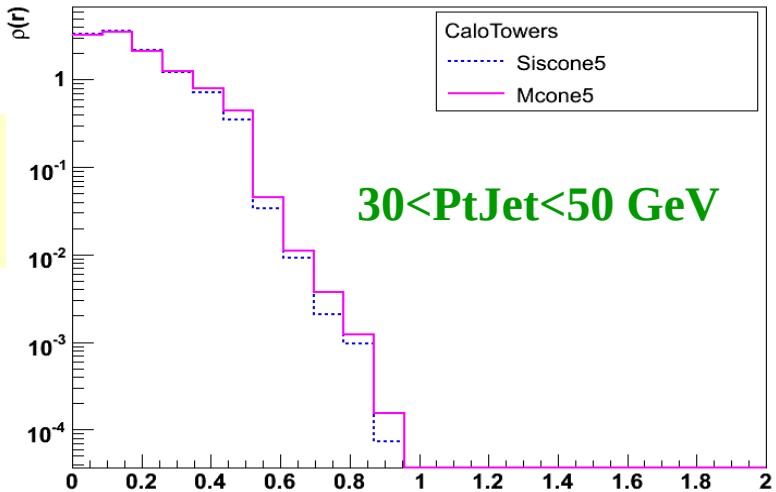

Calorimeter Jets




SIScone jets include all stable particles without any threshold.

Distance from jet center



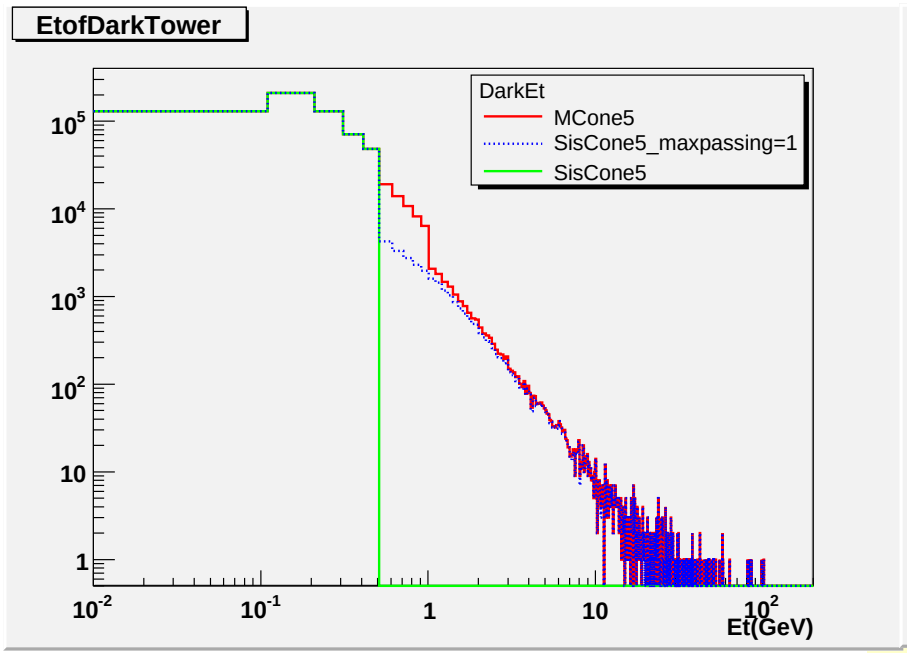

**30<PtJet<50 GeV**

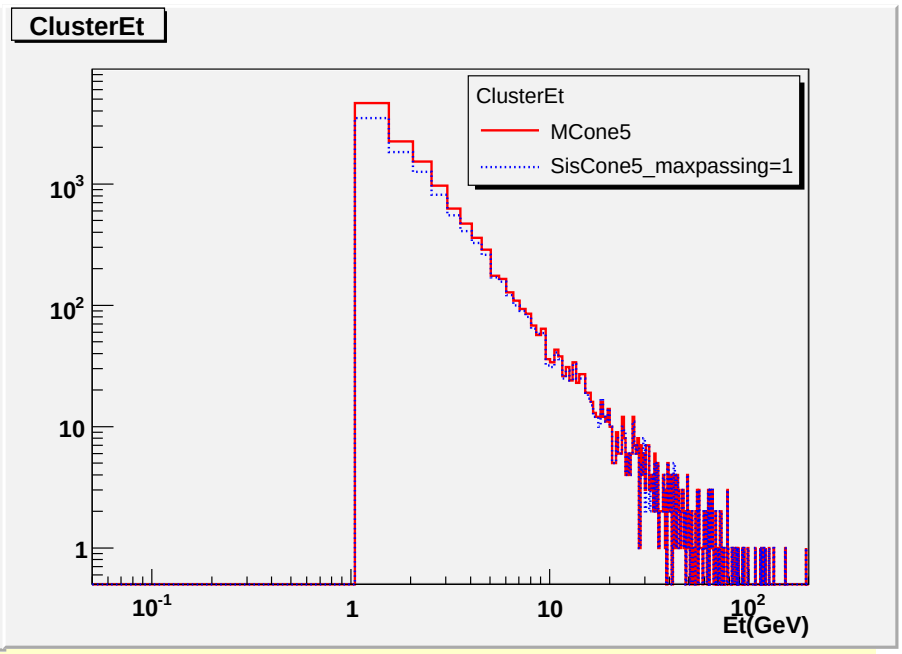
Distance from jet center

# Unclustered Energy

Huseyin Topakli (Cukurova)

- MCone does not cluster all the energy in an event (dark towers/jets)
- In SIScone, multi-pass scheme, all towers are clustered.
- SIScone with single pass behaves like MCone.
- QCD dijet 2000 events, 1.0 TeV <pt-hat <1.4 TeV.



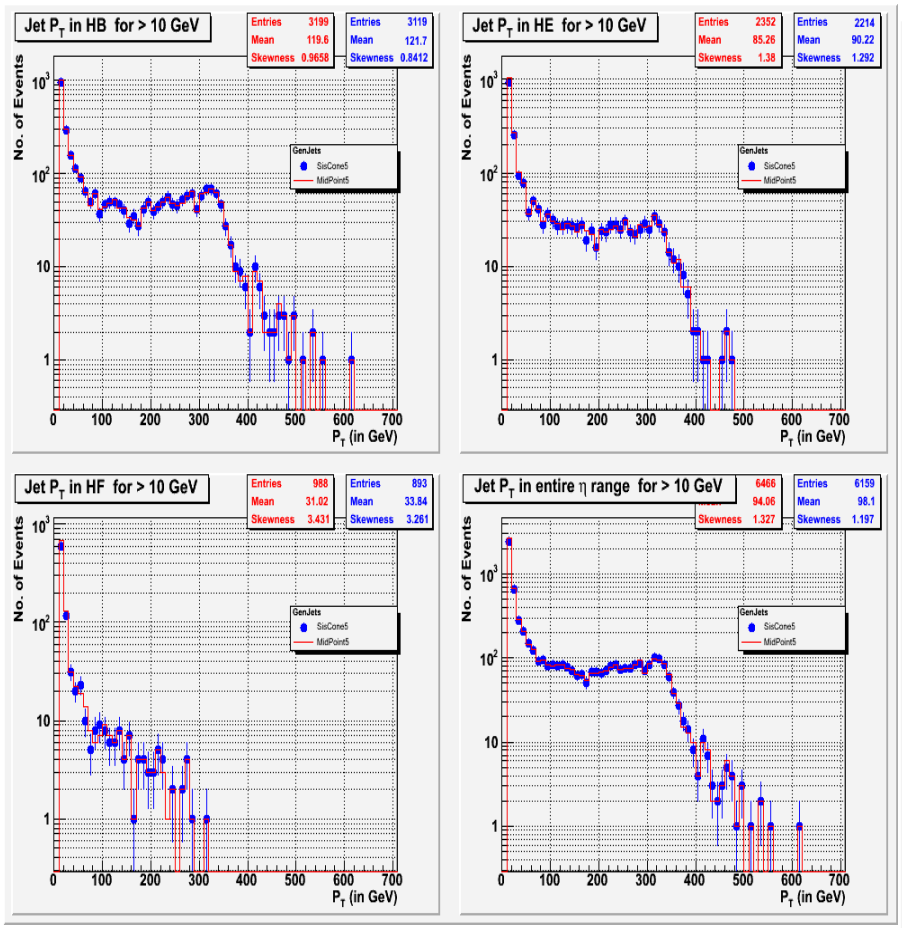




Dark towers clustered with simple cone algorithm.

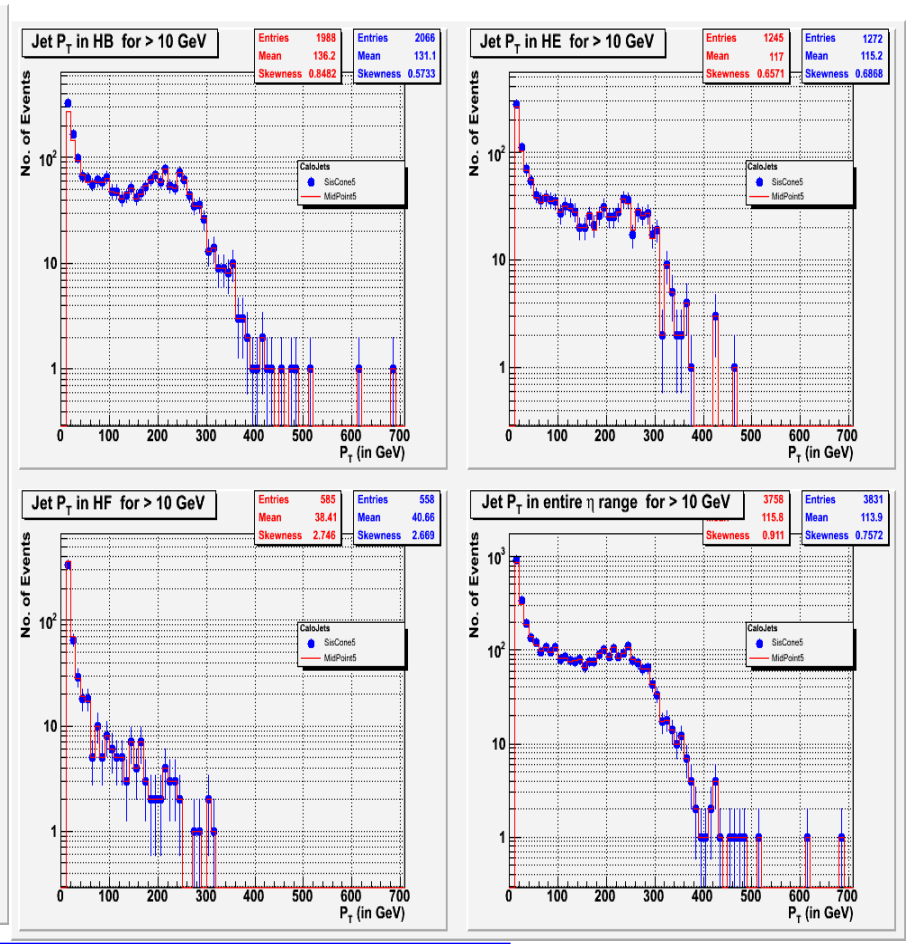
# Z' (700 GeV) Events

Manoj Jha (Delhi)

**Generated Jets**




**Calorimetry Jets**

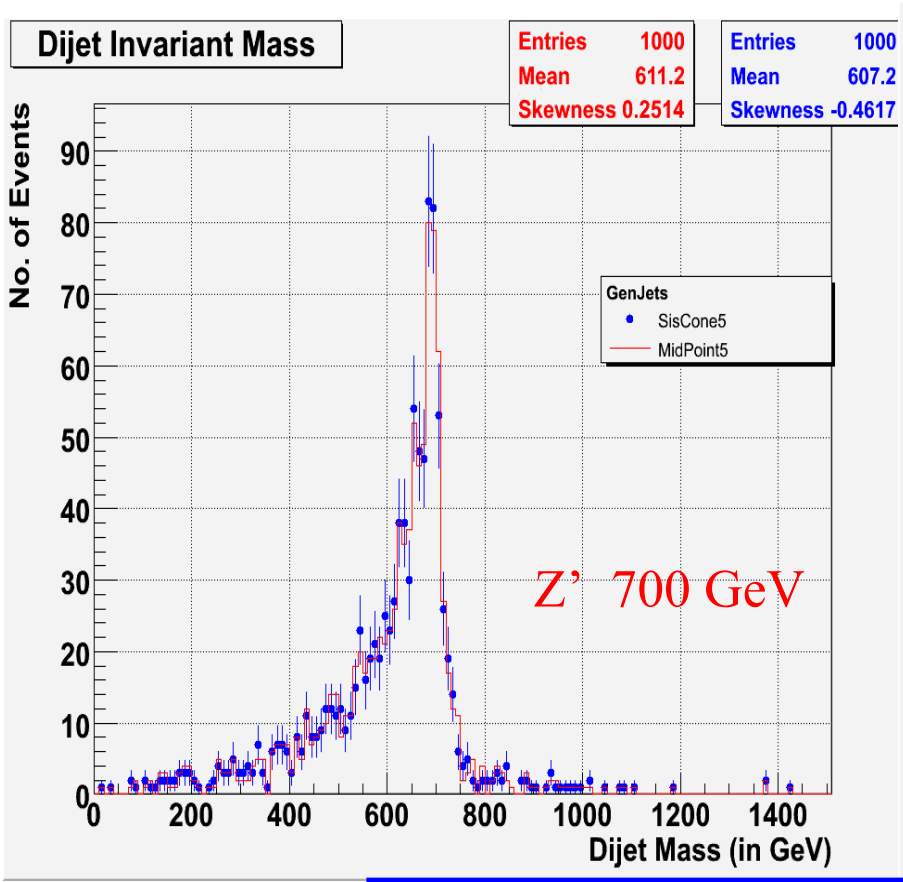



Similar behaviour is observed.

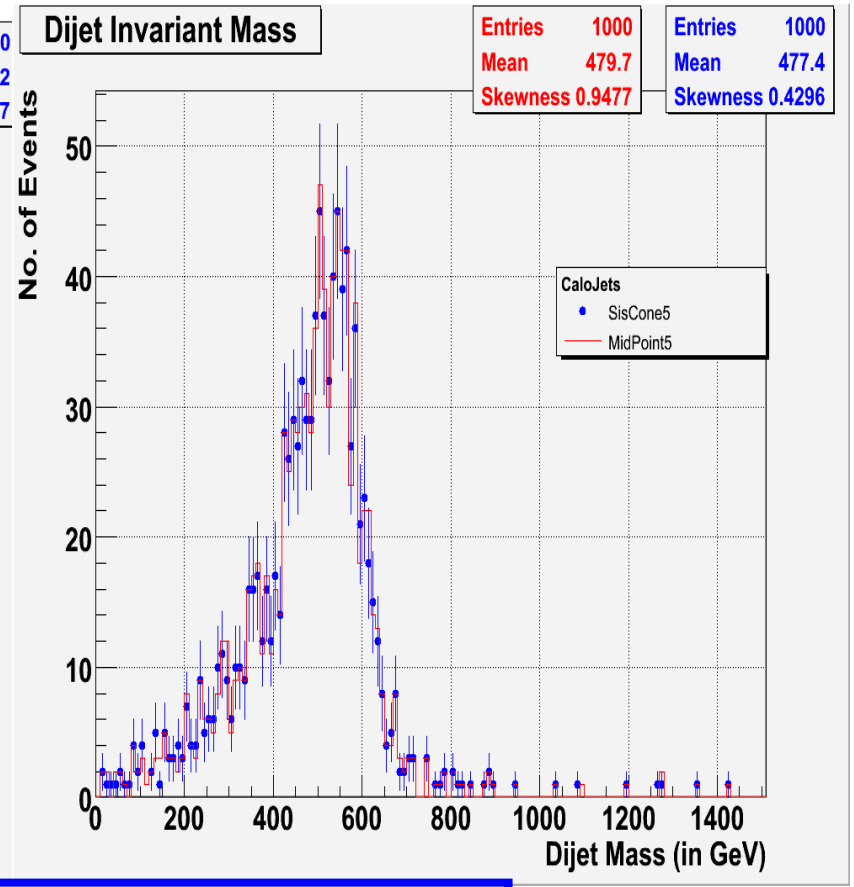
# Dijet Invariant Mass

Manoj Jha (Delhi)

**Generated Jets**



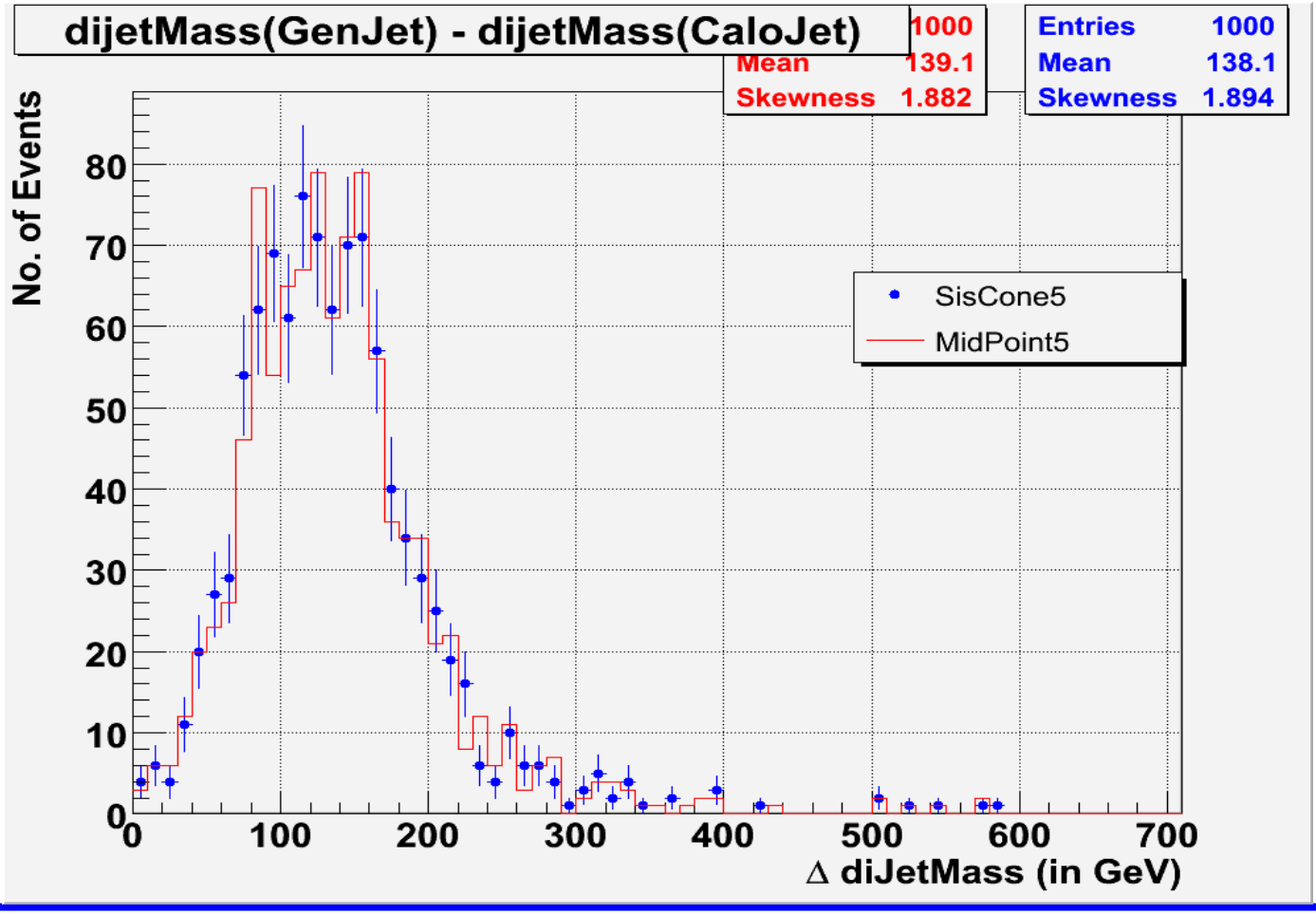

**Calorimetry Jets**




Similar behaviour is observed.

# Diff. in Invariant Mass at GenJet & CaloJet

Manoj Jha (Delhi)




- Both algorithms have similar calorimeter dijet mass resolution

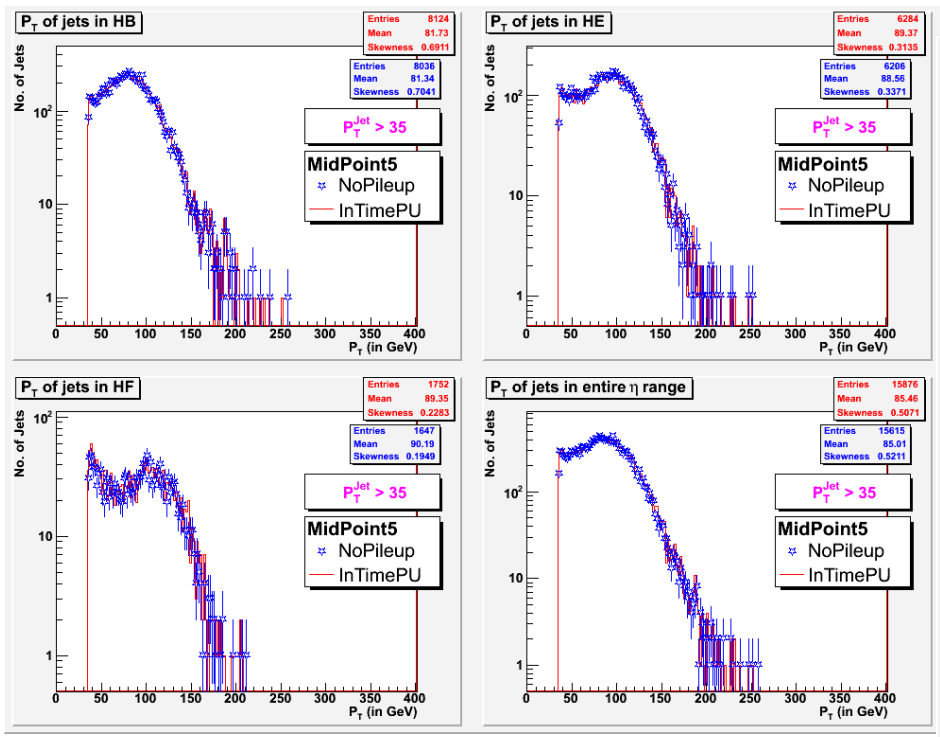
# QCD Jets with/without pile-up

Manoj

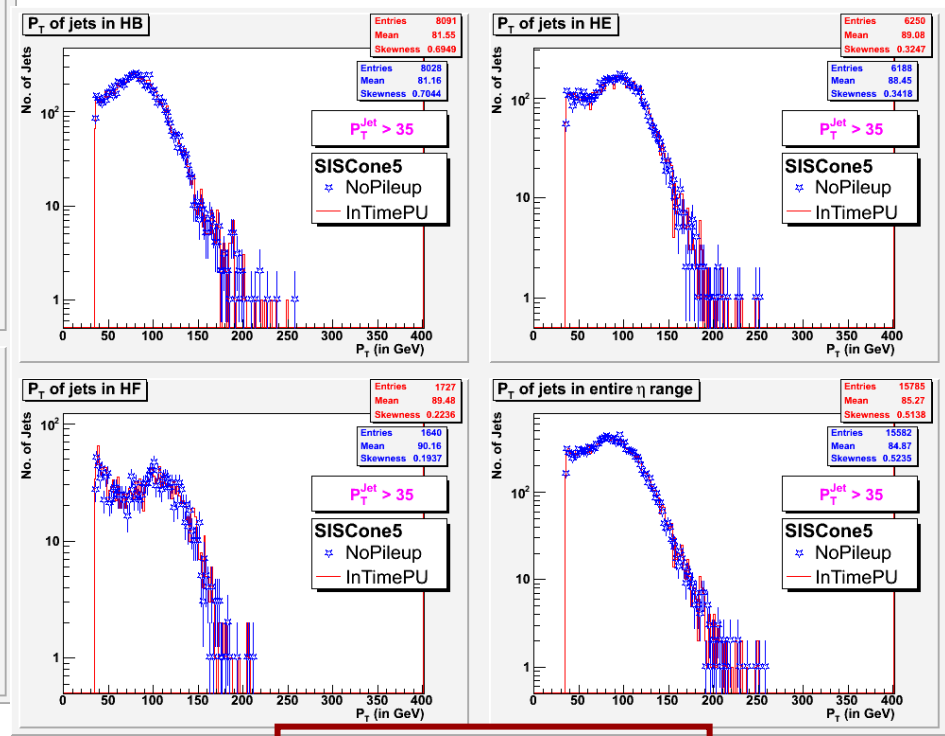
Pt of Jets for Pt > 35 GeV

Private sample Pt-hat 120-135 GeV

**MidPoint5**




**SISCone5**



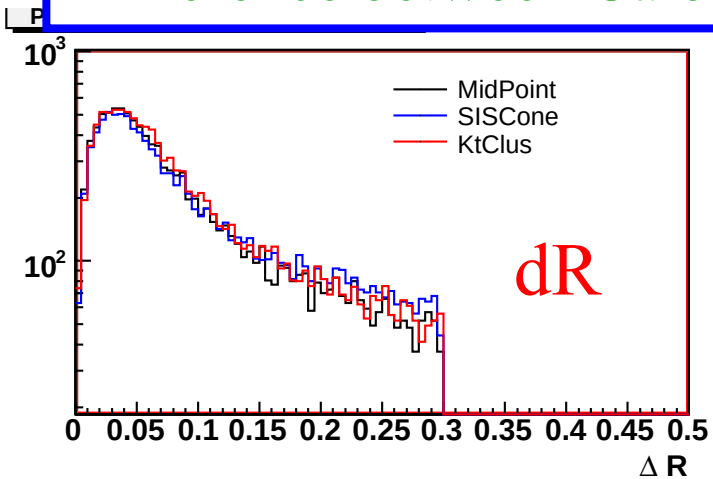

**Mean ~ 85.46**

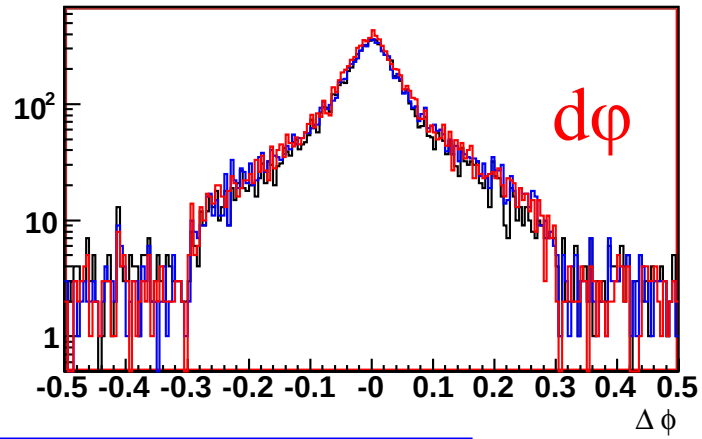
**Mean ~ 85.27**

# Hadronic Top Events

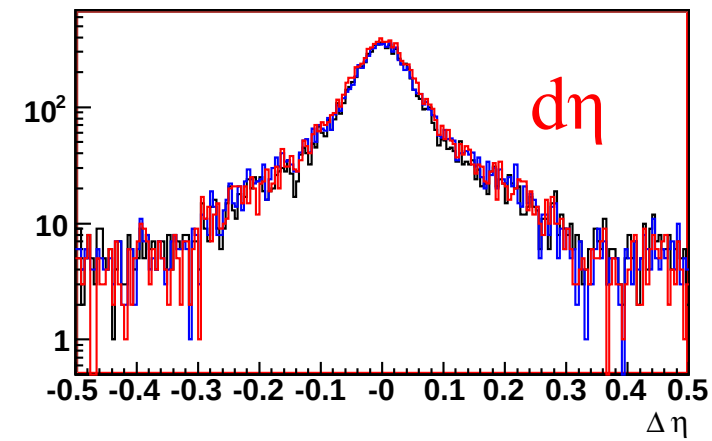
Frank Chlebana (Fermi lab)

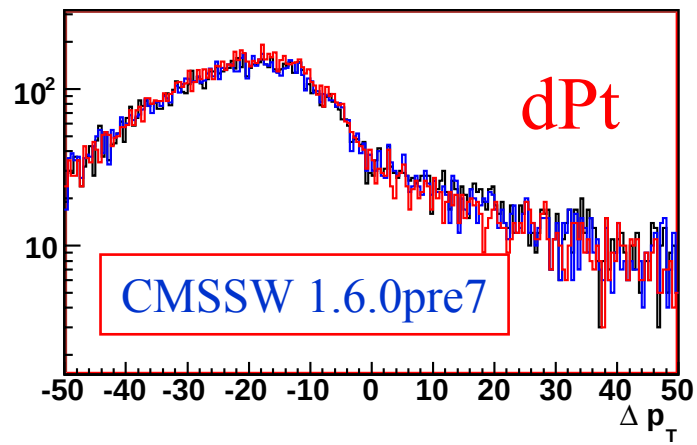
## Difference between CaloJet and the matching parton




Similar behaviour is observed.

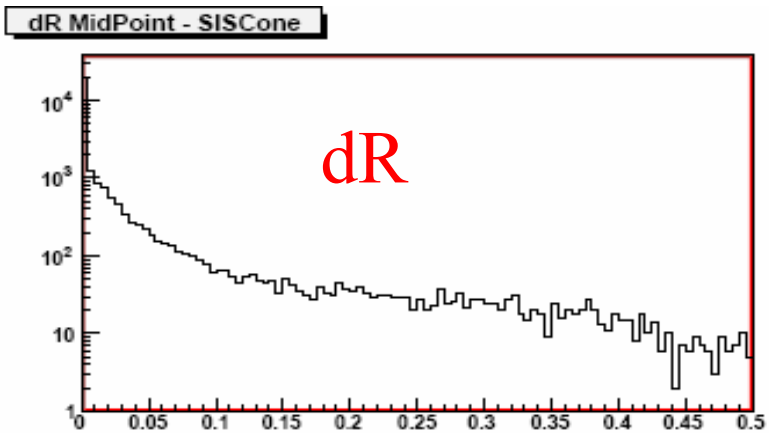


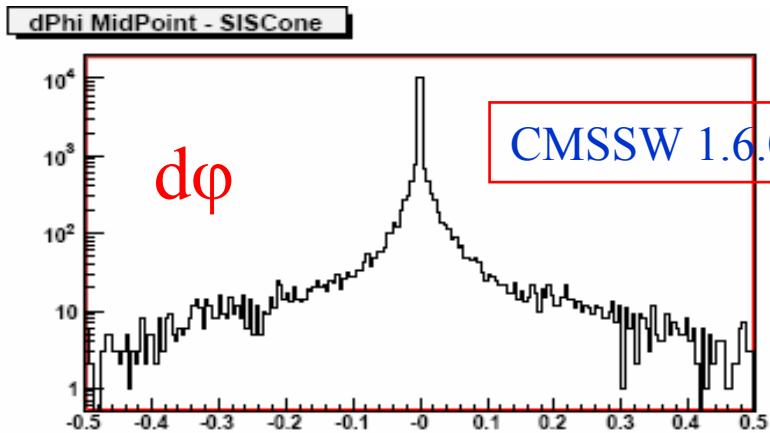



# Hadronic Top Events

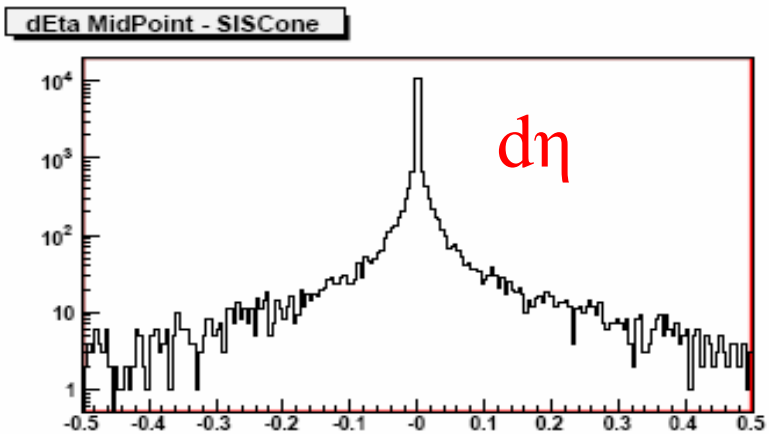
Frank Chlebana (Fermi lab)

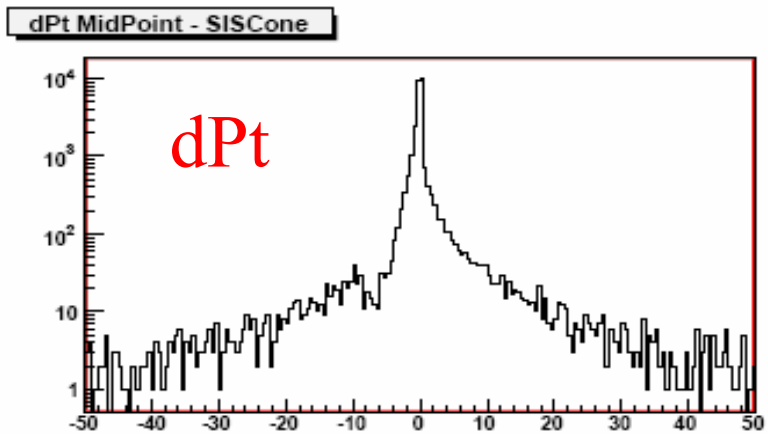
## Jet by jet difference between MCone and SISCone




CMSSW 1.6.0pre7



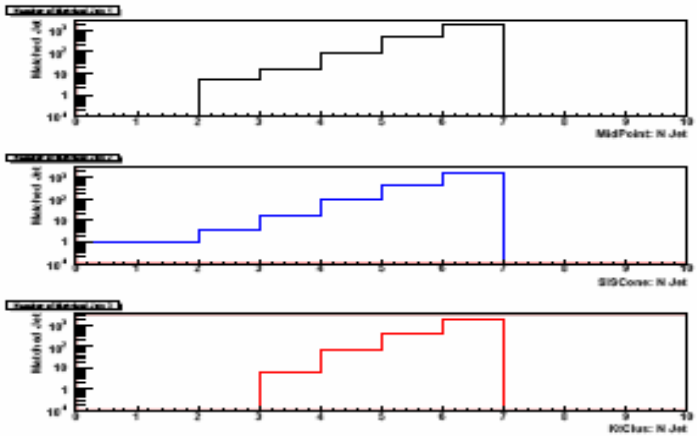
# Hadronic top events

Frank Chlebana (Fermilab)

Number of jets reconstructed for $t\bar{t} \rightarrow$ 6jets

Start with 5050 $t\bar{t}$ events
2280 ($\sim$ 45%) fully hadronic decay

dR(parton-CaloJet)<0.3




| | MidPoint | / | SISCone | / | KtClus |
|---|---|---|---|---|---|
| Jets 0 = | 0 | / | 1 | / | 0 |
| Jets 1 = | 0 | / | 1 | / | 0 |
| Jets 2 = | 5 | / | 4 | / | 0 |
| Jets 3 = | 15 | / | 18 | / | 6 |
| Jets 4 = | 89 | / | 100 | / | 72 |
| Jets 5 = | 477 | / | 442 | / | 399 |
| Jets 6 = | 1694 | / | 1714 | / | 1803 |
| Eff. | 74% | / | 75% | / | 79% |

Similar performance for MCone5 and SISCone algorithms.

# Summary

- MidPoint Algorithm is not infrared safe and the QCD measurements performed using this algorithms will introduce unnecessary uncertainty when comparing to theory calculation.
- Seedless-Infrared-safe Cone (SISCone) clustering algorithm is theoretically better behaved and thus preferred.
- SISCone algorithms has similar CPU cost as MidPoint.
- MCone and SISCone perform similarly (see Marek's talk).
- Using SISCone algorithm *may* make comparison with ATLAS easier.

# References:

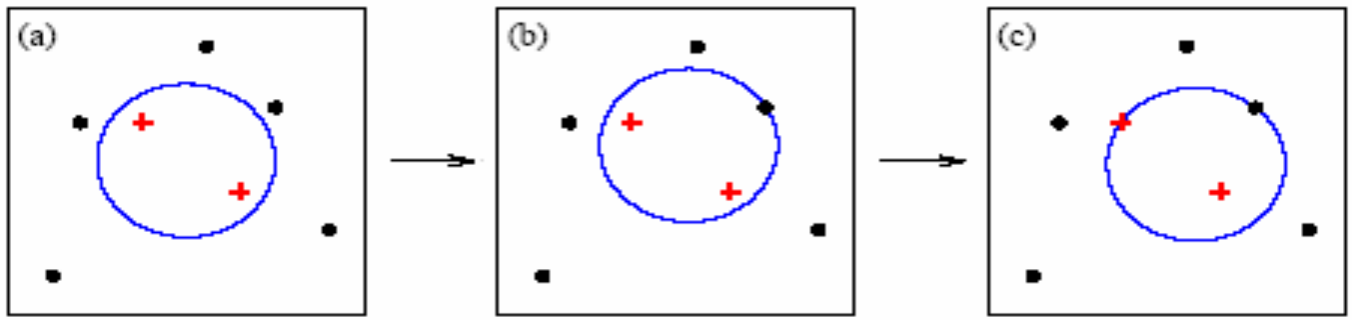

- **Gavin Salam,** *A practical Seedless Infrared Safe Come Algorithm,* XLII Rencontres de Moriod, 17-24 March, 2007.
- **Manoj Jha (Delhi) et al**, *Study of SISCone A Seedless Infrared-Safe Cone jet algorithm*, July 9, 2007.
- **Manoj Jha (Delhi) et al,** *Study of SISCone A Seedless Infrared-Safe Cone jet algorithm*, July 23, 2007.
- **Frank Chlebana**, A look at top Events using SIScone, Sept 4, 2007.
- JHEP 05 (2007) 086 [arXiv:0704.0292 [hep-ph]].

# Transform into a geometrical problem

Cones are just *circles* in the $y - \phi$ plane. To find all stable cones:

1. Find all distinct ways of enclosing a subset of particles in a $y - \phi$ circle
2. Check, for each enclosure, if it corresponds to a stable cone

Finding all distinct circular enclosures of a set of points is *geometry:*




*Any enclosure can be moved until a pair of points lies on its edge.*

Polynomial time recipe for finding all distinct enclosures:

- For each *pair* of points in the plane, draw the two circles that have those two points on their edge.

# Midpoint IR unsafety? Who cares?

Midpoint was supposed to solve *just this type of problem.* But worked only at lowest order.

IR/Collinear unsafety is a serious problem!

- Invalidates theorems that ensure finiteness of perturbative QCD
  Cancellation of real & virtual divergences
- Destroys usefulness of (intuitive) partonic picture
  you cannot think in terms of hard partons if adding a 1 GeV gluon changes 100 GeV jets
- 'Pragmatically:' limits accuracy to which it makes sense to calculate

| Process | 1st miss cones @ | Last meaningful order |
|---|---|---|
| Inclusive jets | NNLO | NLO [NNLO being worked on] |
| $W/Z + 1$ jet | NNLO | NLO |
| 3 jets | NLO | LO [NLO in `nlojet++`] |
| $W/Z + 2$ jets | NLO | LO [NLO in `MCFM`] |
| jet masses in $2j + X$ | LO | **none** |

## Algorithm 1: SISCone as a whole

1: Put the set of current particles equal to the set of all particles in the event.
2: **repeat**
3: Find *all* stable cones of radius $R$ for the current set of particles, e.g. using algorithm 2.
4: For each stable cone, create a protojet from the current particles contained in the cone, and add it to the list of protojets.
5: Remove all particles that are in stable cones from the list of current particles.
6: **until** No new stable cones are found, or one has gone around the loop $N_{\text{pass}}$ times.
7: Run a Tevatron Run-II type split–merge procedure, algorithm 3, on the full list of protojets, with overlap parameter $f$ and transverse momentum threshold $p_{t,\text{min}}$.

An IR safe cone (p. 17)
└ Extras
└ The algorithms

# Algorithm 2: finding stable cones

For any group of collinear particles, merge them into a single particle.
for particle $i = 1 \ldots N$ do
  Find all particles $j$ within a distance $2R$ of $i$. If there are no such particles, $i$ forms a stable cone of its own.
  Otherwise for each $j$ identify the two circles for which $i$ and $j$ lie on the circumference. For each circle, compute the angle of its centre $C$ relative to $i$, $\zeta = \arctan \frac{\Delta\phi_{iC}}{\Delta y_{iC}}$.
  Sort the circles into increasing angle $\zeta$.
  Take the first circle in this order, and call it the current circle. Calculate the total momentum and checkxor for the cones that it defines. Consider all 4 permutations of edge points being included or excluded. Call these the "current cones".
  repeat
    for each of the 4 current cones do
      If this cone has not yet been found, add it to the list of distinct cones.
      If this cone has not yet been labelled as unstable, establish if the in/out status of the edge particles (with respect to the cone momentum axis) is the same as when defining the cone; if it is not, label the cone as unstable.
    end for
    Move to the next circle in order. It differs from the previous one either by a particle entering the circle, or one leaving the circle. Calculate the momentum for the new circle and corresponding new current cones by adding (or removing) the momentum of the particle that has entered (left); the checkxor can be updated by XORing with the label of that particle.
  until all circles considered.
end for
for each of the cones not labelled as unstable do
  Explicitly check its stability, and if it is stable, add it to the list of stable cones (protojets).
end for

An IR safe cone (p. 18)
└ Extras
└ The algorithms

## Algorithm 3: split–merge

1: **repeat**

Remove all protojets with $p_t < p_{t,\min}$.

Identify the protojet ($i$) with the highest $\tilde{p}_t$ ($\tilde{p}_{t,\text{jet}} = \sum_{i \in \text{jet}} |p_{t,i}|$).

Among the remaining protojets identify the one ($j$) with highest $\tilde{p}_t$ that shares particles (overlaps) with $i$.

5: **if** there is such an overlapping jet **then**

6: Determine the total $\tilde{p}_{t,\text{shared}} = \sum_{k \in i\&j} |p_{t,k}|$ of the particles shared between $i$ and $j$.

7: **if** $\tilde{p}_{t,\text{shared}} < f\,\tilde{p}_{t,j}$ **then**

Each particle that is shared between the two protojets is assigned to the one to whose axis it is closest. The protojet momenta are then recalculated.

9: **else**

Merge the two protojets into a single new protojet (added to the list of protojets, while the two original ones are removed).

11: **end if**

12: If steps 7–11 produced a protojet that coincides with an existing one, maintain the new protojet as distinct from the existing copy(ies).

13: **else**

Add $i$ to the list of final jets, and remove it from the list of protojets.

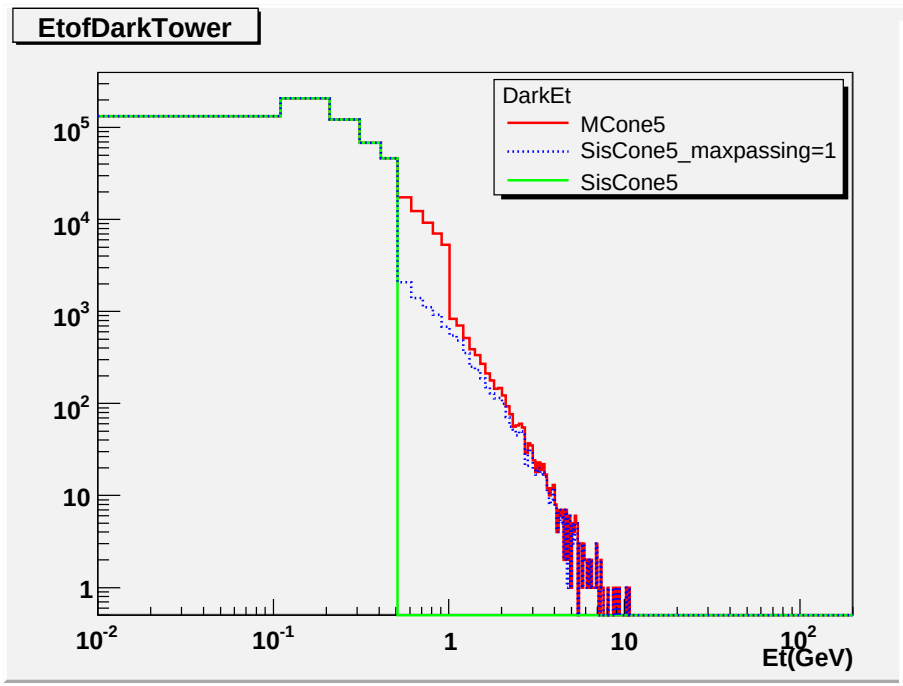
15: **end if**

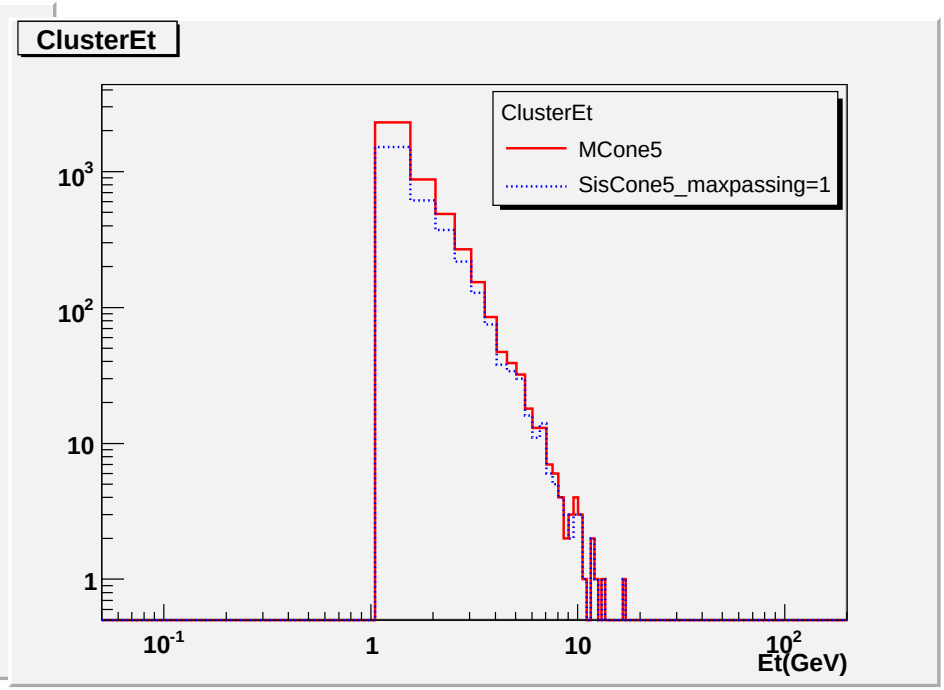
16: **until** no protojets are left.

# Unclustered Energy

Huseyin Topakli (Cukurova)

- MCone does not cluster all the energy in an event (dark towers/jets)
- In Siscone, multi-pass scheme, all towers above threshold are clustered.
- Siscone with single pass behaves like Mcone.
- QCD dijet 2000 events, 80 <pt-hat <120 GeV.




Dark towers clustered with simple cone algorithm.