Performance of Jet Algorithms in CMS

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- Introduction of four algorithms
- Performance comparison
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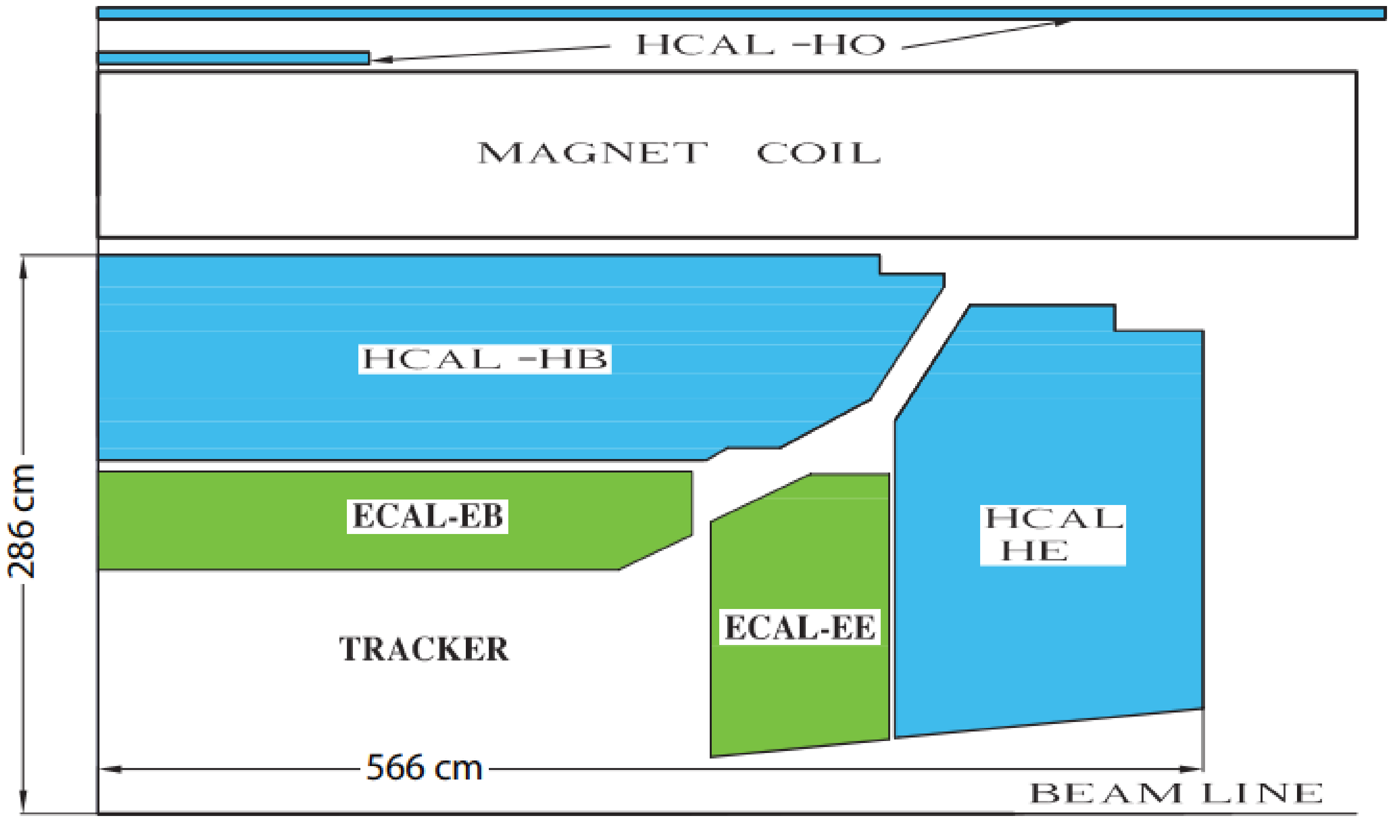
CMS Calorimeter



~4200 Calorimeter Towers

ECAL: Lead Tungstate Crystals
HCAL: Copper-Scintillator Sampling Calorimeter

Barrel Coverage: $|\eta| < 1.4$
Endcaps Coverage: $1.4 < |\eta| < 3$
Forward Coverage: $3 < |\eta| < 5$

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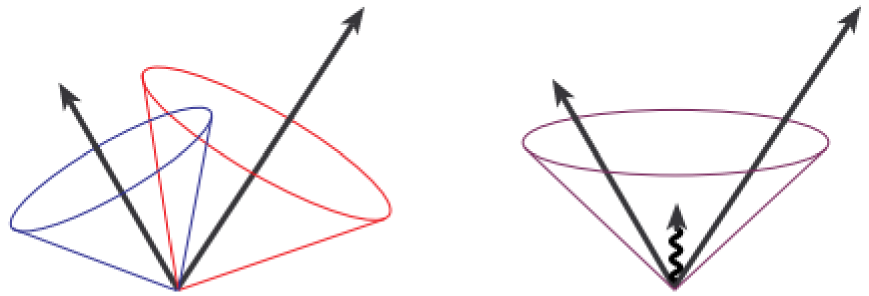
Review of algorithm requirements

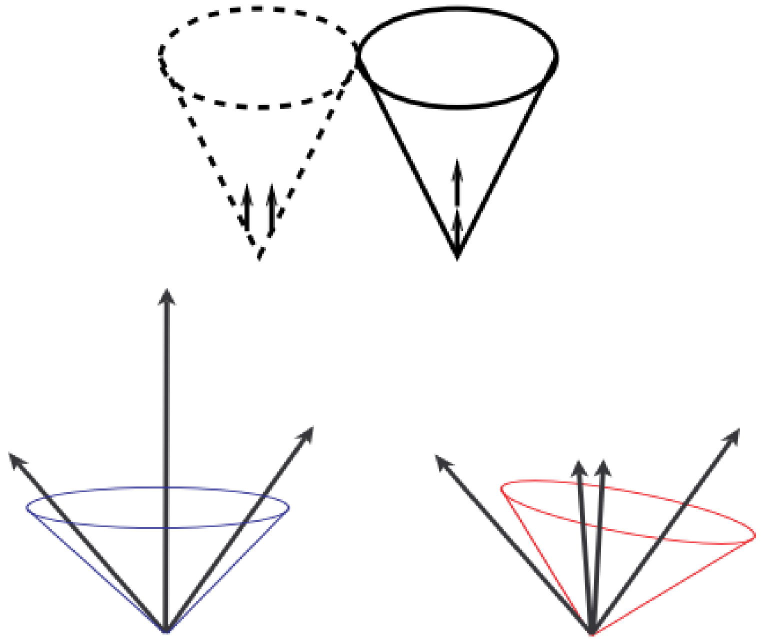
- Infrared safety:

The result of the jet finding is stable against the addition of soft particles.

- Collinear safety:

1. E_T splitting between towers does not affect jet finding
2. E_T ordering of particles does not affect jet finding





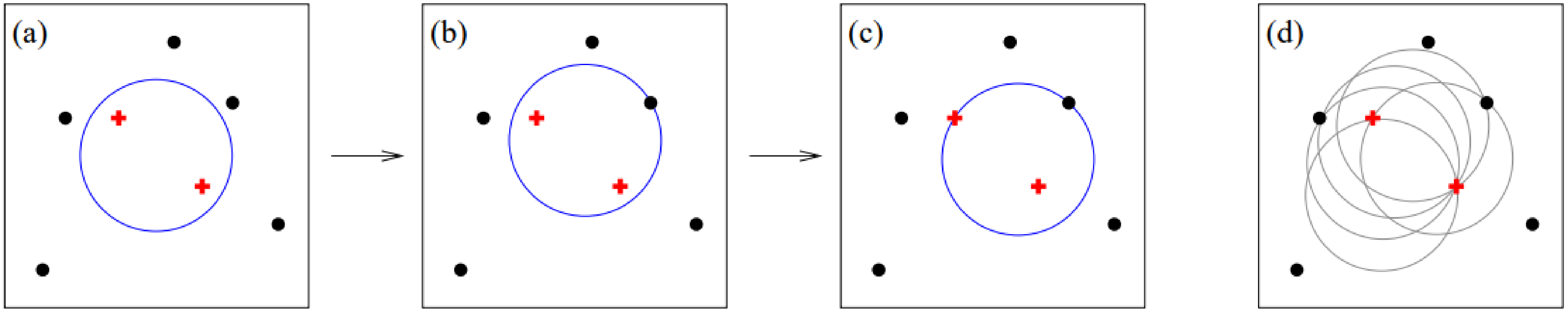
Iterative Cone & Midpoint Cone

- Iterative Cone Algorithm:
  - Find seeds (towers or particles with $E_T > 1\text{GeV}$) and arrange them in descending order.
  - Search inputs in range $\sqrt{\eta^2 + \phi\text{^}2} \leq R$ （R is a free parameter of cone size).
  - Declare a jet and remove its constituents if cone is stable.
  - Very simple, fast
  - Not infrared safe, not collinear safe.

- Midpoint Cone Algorithm:
  - Similar with Iterative Cone, but add mid points between jets within a distance $\Delta R < 2R$ as seed.
  - Allow input presents in different proto jets, apply splitting and merging algorithm to solve overlap.
    - Arrange proto jets in descending order, find highest E_T neighbor
    - If $\frac{E_T^{shared}}{E_T^{neighbor}} > f$, Merge; otherwise, Split
  - Collinear safe, not infrared safe for pQCD orders beyond NLO

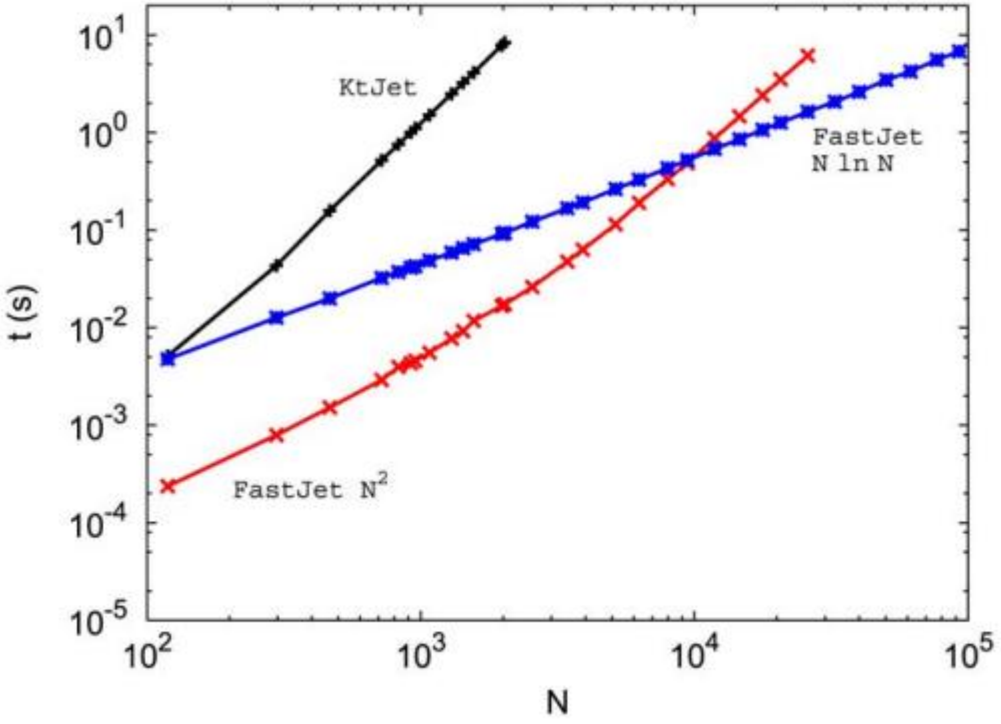
SISCone

- Seedless Infrared-Safe Cone Algorithm
  - For each particle i, find all particles j within 2R distance, Get circles that i and j are on the circumference, sort the circles.
  - Consider 4 cones that i and j are in/out the cone, fast exclude unstable cones, add other cones into list.
  - Explicitly check the stability of cones in the list, get proto jets.
  - Modified split-merge algorithm(use p_T instead of E_T, set p_T threshold).
  - Reduce time complexity from $\mathcal{O}(N2^N)$ to $\mathcal{O}(Nn \ln n)$
  - Collinear safe, infrared safe to all orders of pQCD



Fast kT

- Fast k_T Algorithm
  - A new implementation of the k_T algorithm.
    - For each particle pair i j, $d_{ij} = \min\left(k_{ti}^2, k_{tj}^2\right) R_{ij}^2$
    - For each particle i, $d_{iB} = k_T^2 D^2$
    - If $d_{ij} < d_{iB}$, Merge two particles; otherwise, declare a jet
  - Reduce time complexity from $\mathcal{O}(N^3)$ to $\mathcal{O}(N \ln N)$ by computer science method
  - Collinear safe, infrared safe



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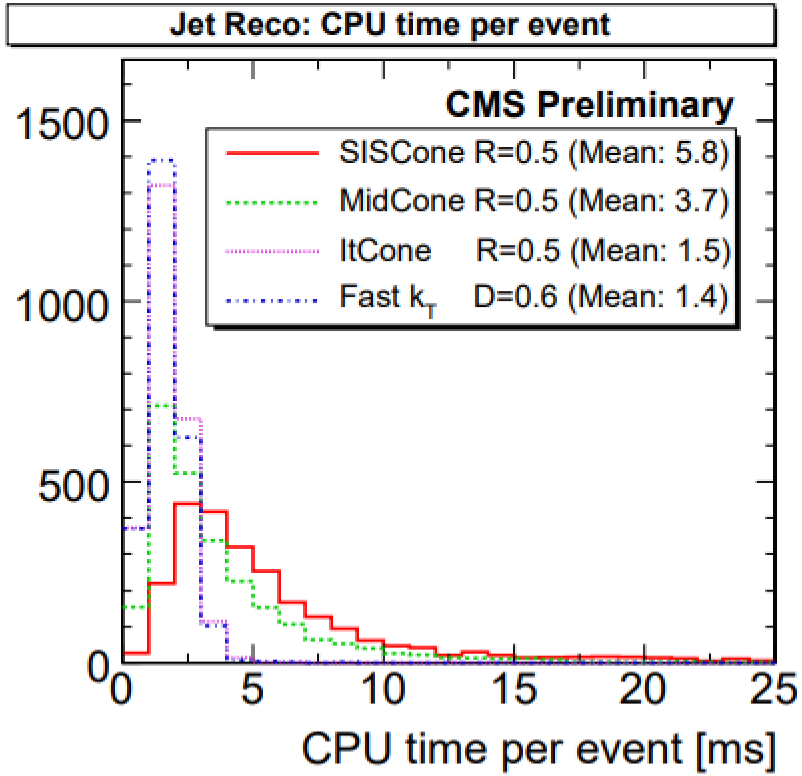
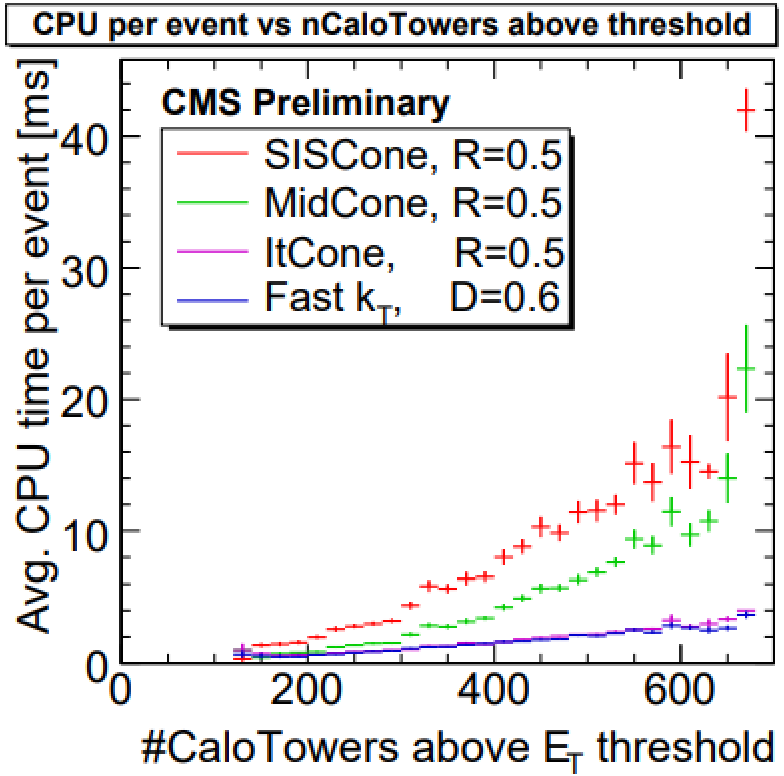
Performance of the algorithms

- Use QCD dijet and $t\bar{t}$ Monte Carlo samples without pileup to test the performance of algorithms.
- Study how well the calorimeter-level reconstruction represents the hadron-level of the process.
- Mostly concerned with the relative performance between different algorithms and different radius parameters(R/D).
- Most performance are consistence across different region, so only show the result for barrel region.
- Result is derived using MC truth information if not specified

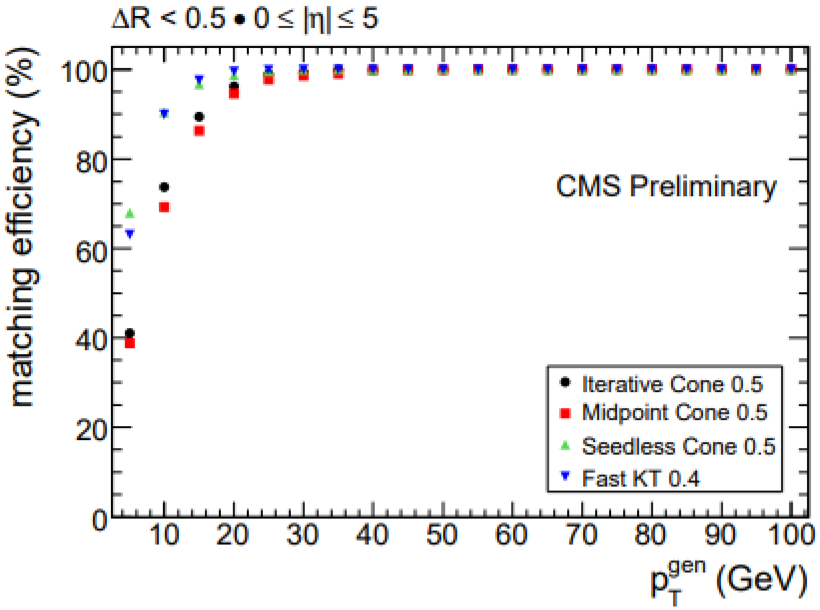
CPU Time Requirements

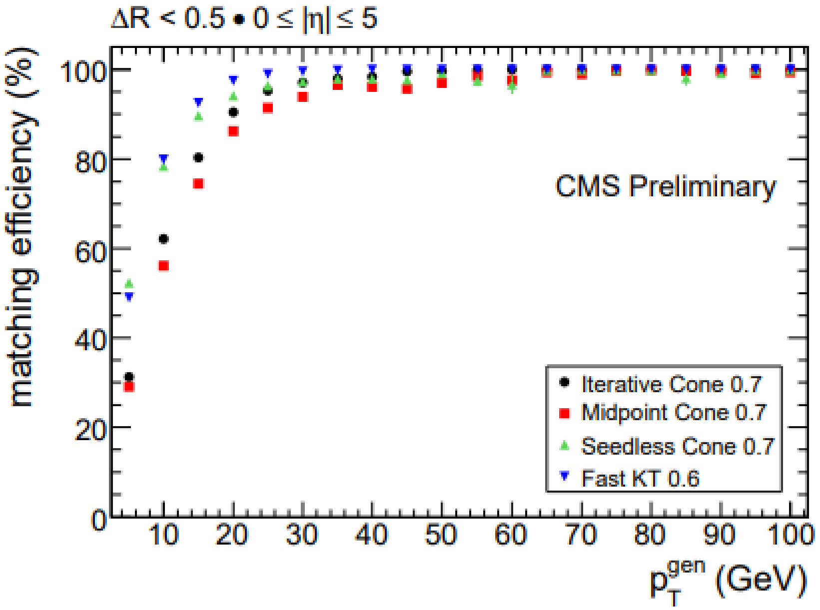




Fast kT is as fast as Iterative cone, though SISCone is slower, its time spent is much shorter than event reconstruction($\approx$ 10s), so is acceptable.

Jet Matching Efficiency



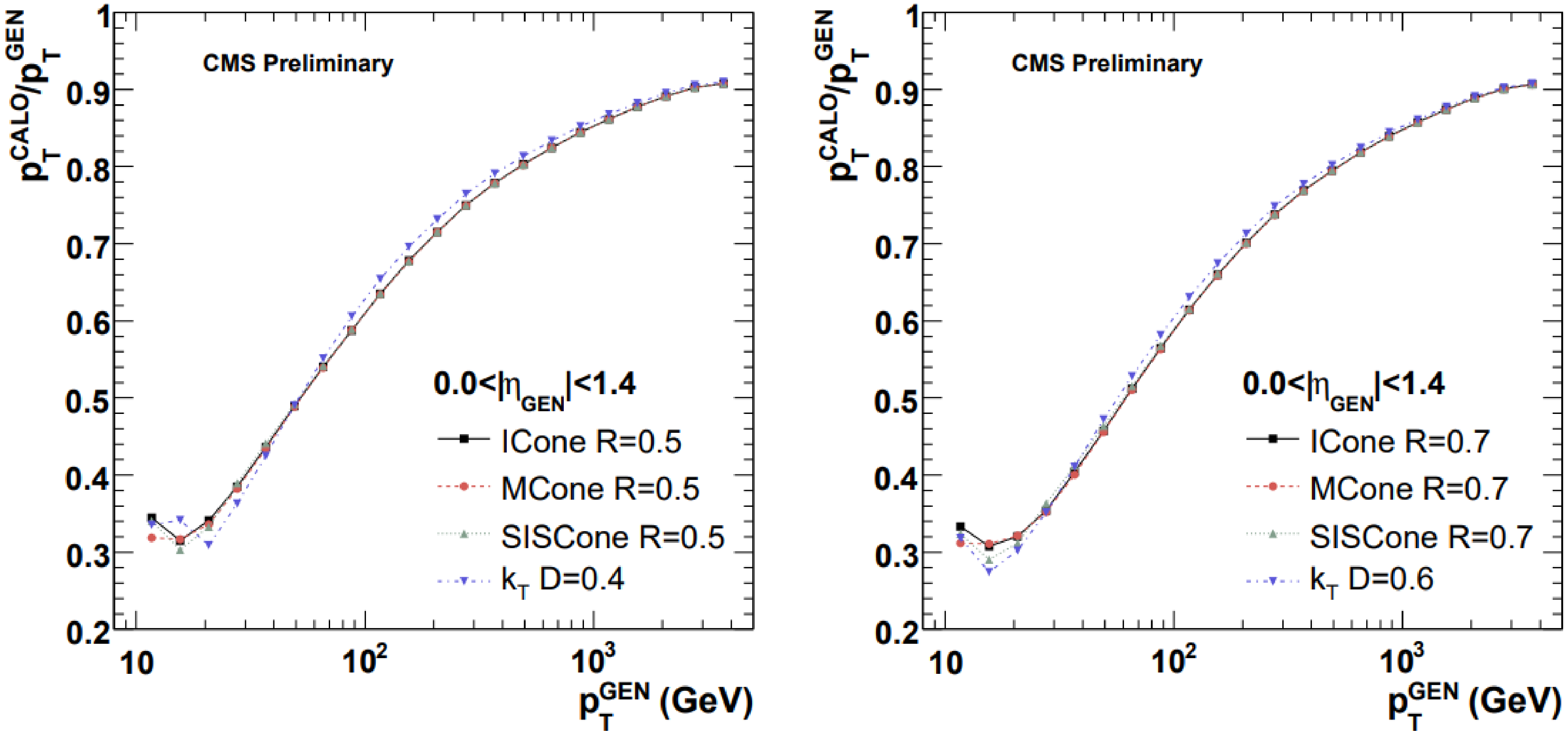


The jet matching efficiency is defined as the ratio of the number of particle jets matched to a calorimeter jet within $\Delta R < 0.5$ and the total number of particle jets.

With same ΔR cut, we can compare the efficiency between algorithms.

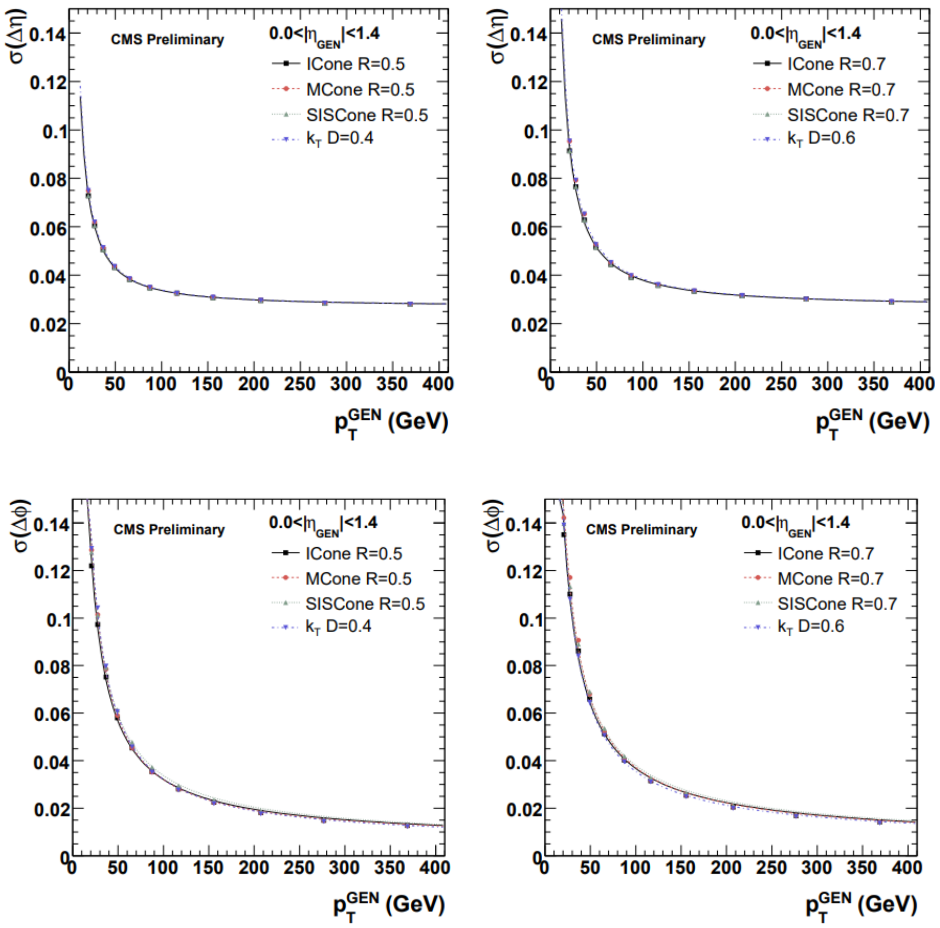
Fast kT and SISCone has much better performance in both small and large radius parameters.

Jet Response



The jet response is defined as $R_{jet} = p_T^{CALO}/p_T^{GEN}$.
Different algorithms show good agreement, indicate chosen D and R correspondence are good.

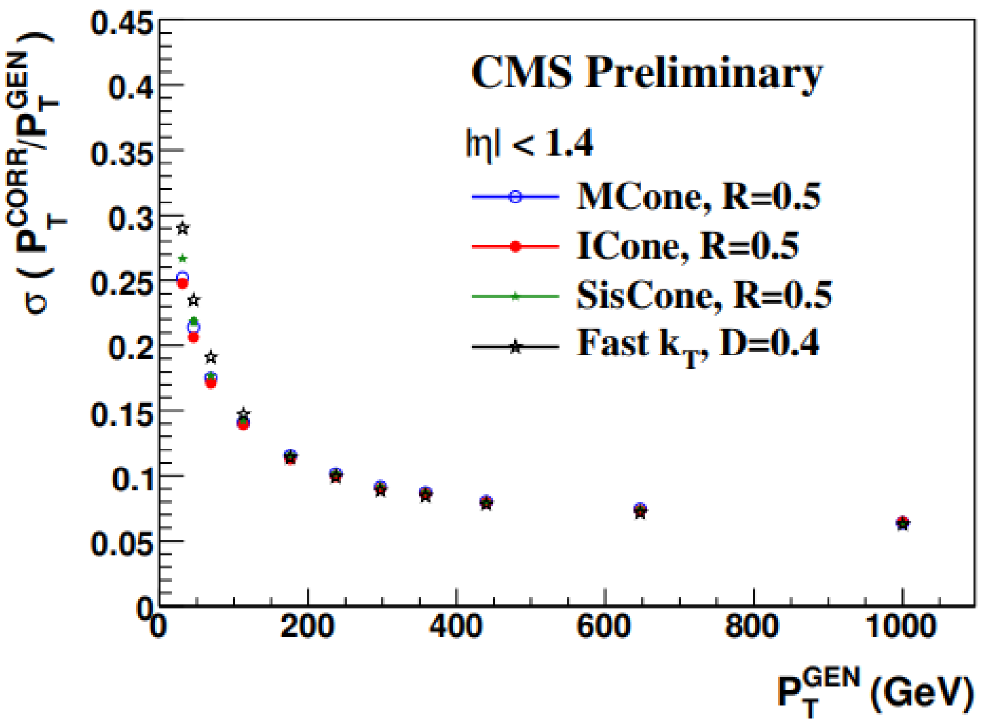
η And ϕ Resolution

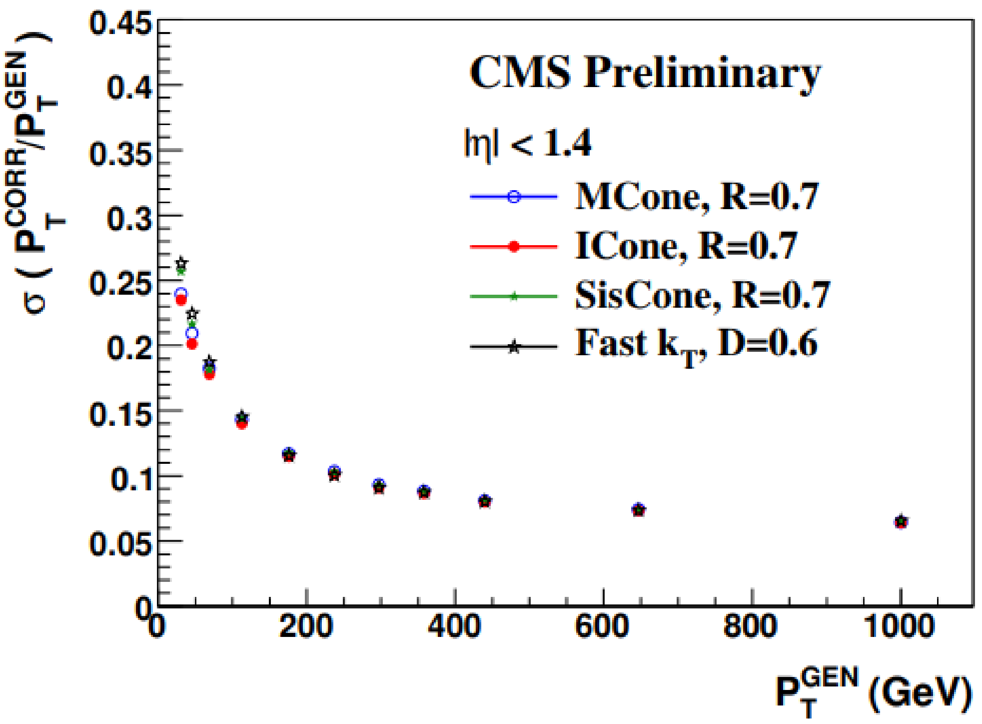


Good agreements found in different algorithms and different radius parameter.

η Resolution may be diluted since primary vertex is assumed to be at z = 0

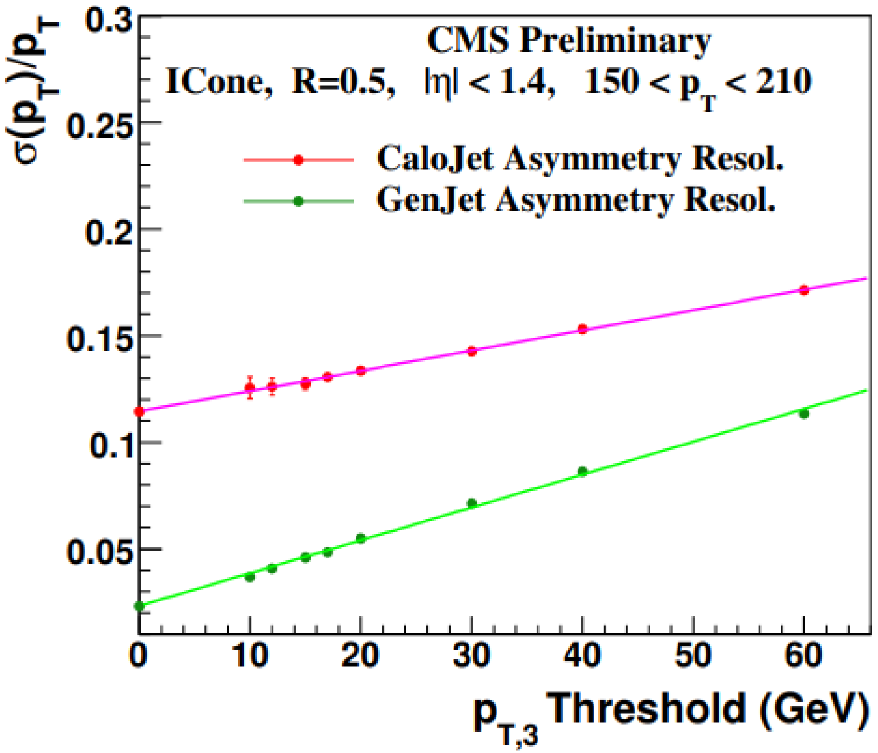
Jet Energy Resolution

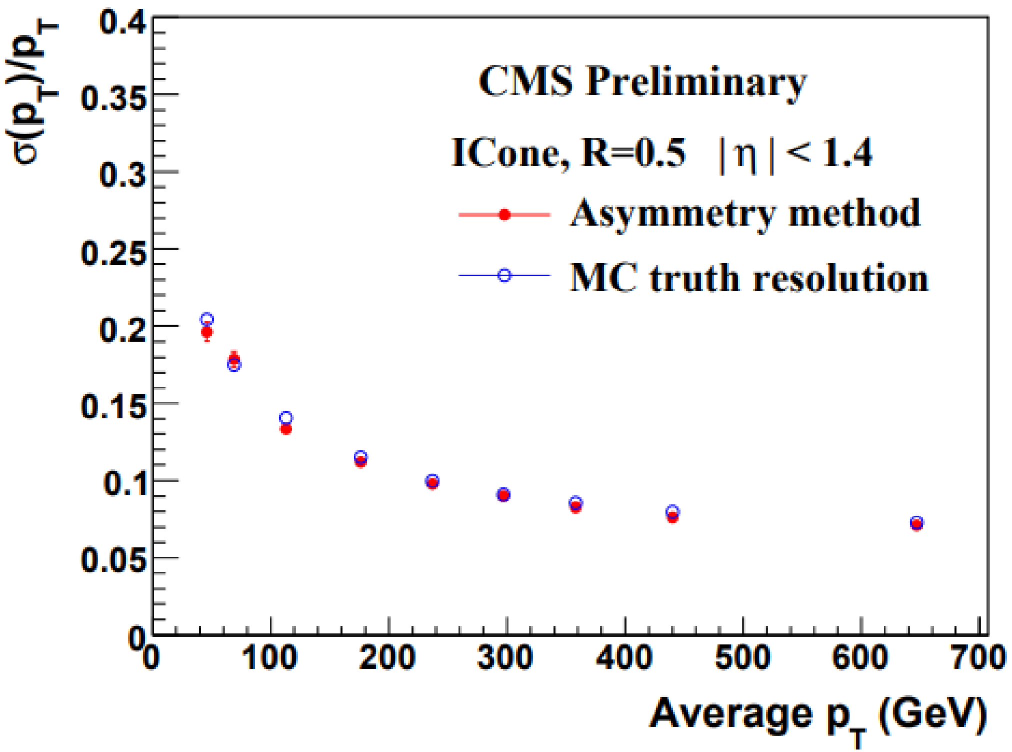




Jets reconstructed with Fast kT show slightly worse resolution at low p_T^{GEN}, while no significant impact of the radius parameter choice is observed.

Jet Energy Resolution



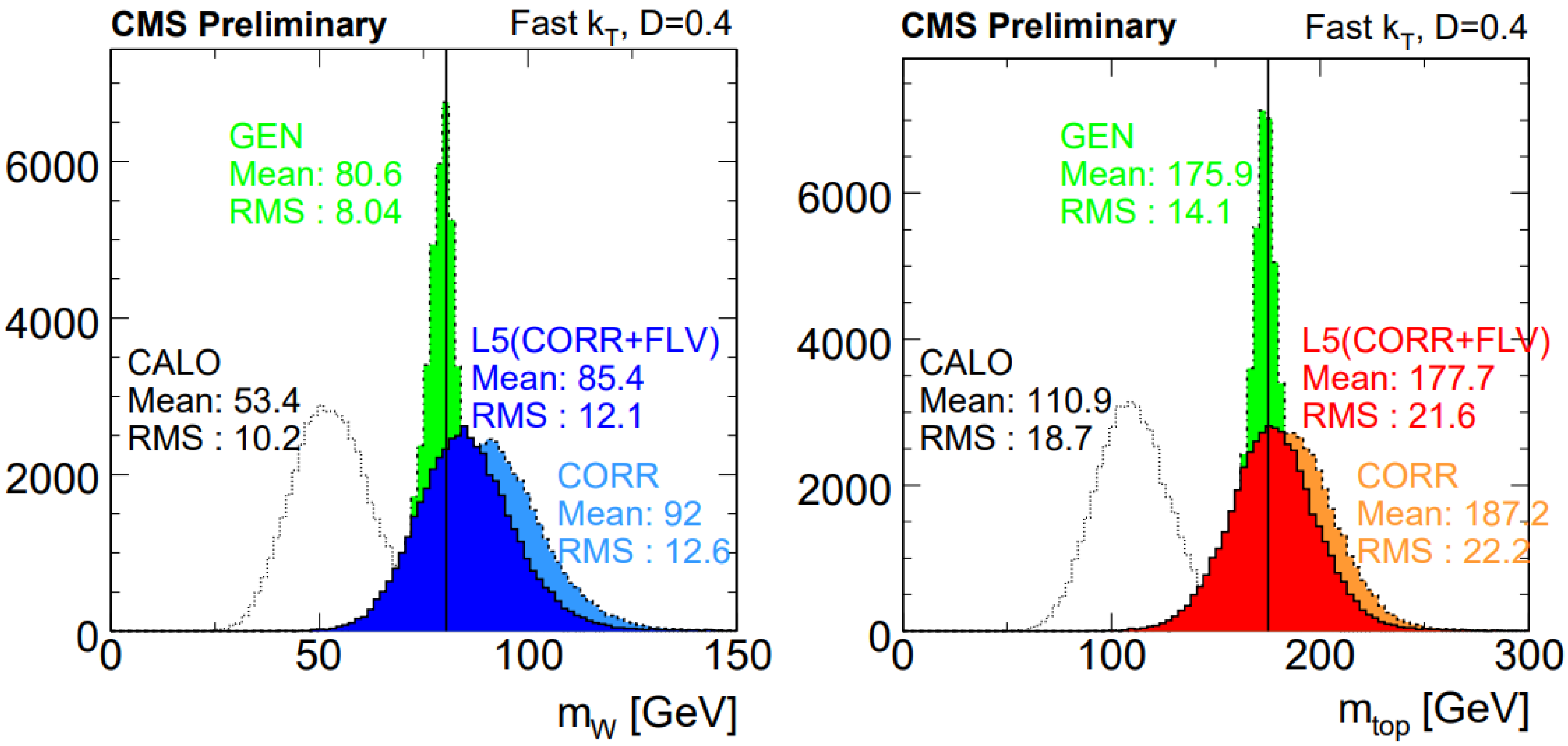


Resolution is also obtained by using the data-driven Asymmetry Method.

A soft radiation correction is derived by selecting events with an additional 3rd jet and studying the measured resolution with p_T cut of 3rd jet.

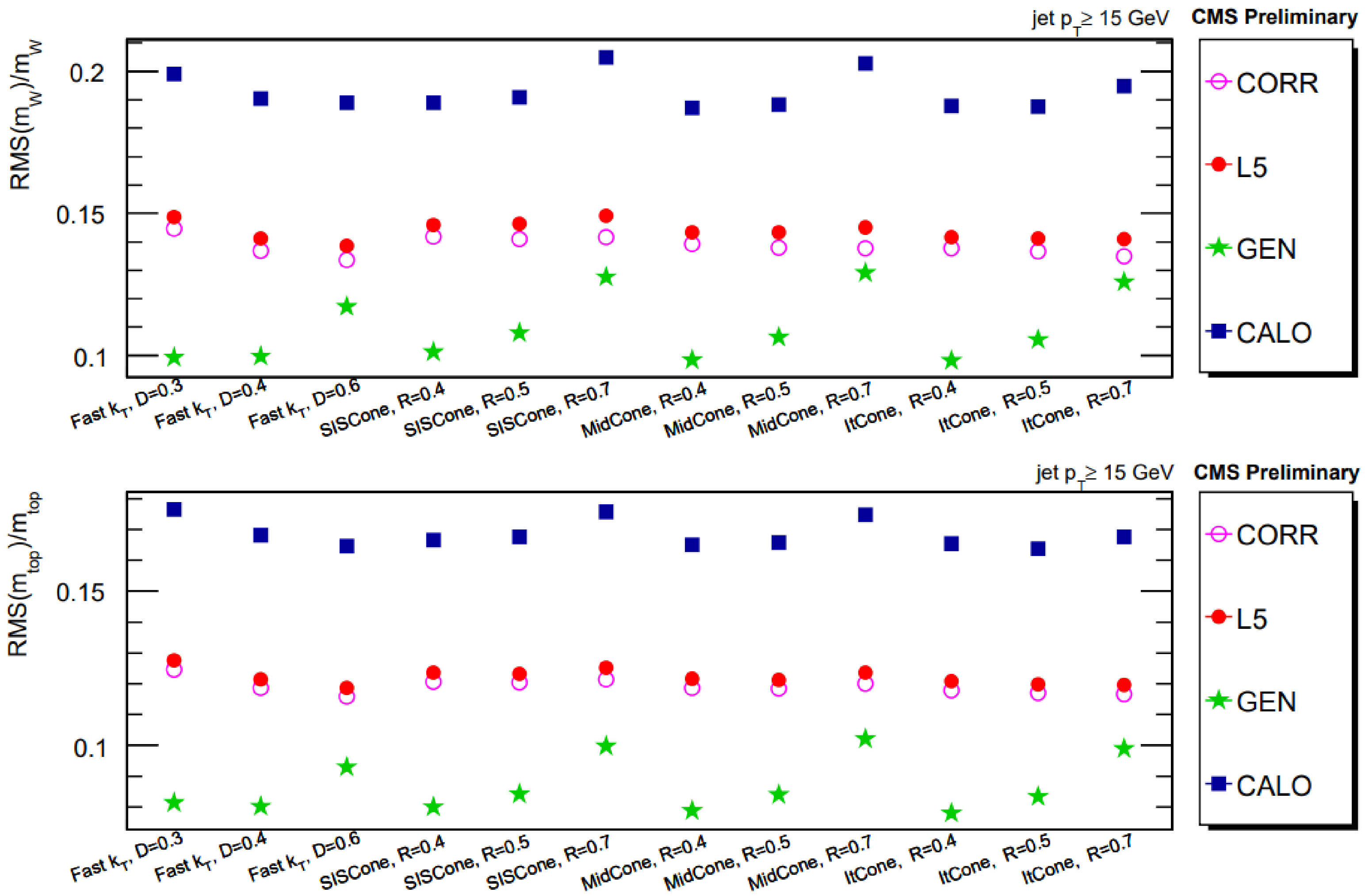
The result derived from MC truth and asymmetry method shows good agreement

Jet Reconstruction In $t\bar{t}$ Events

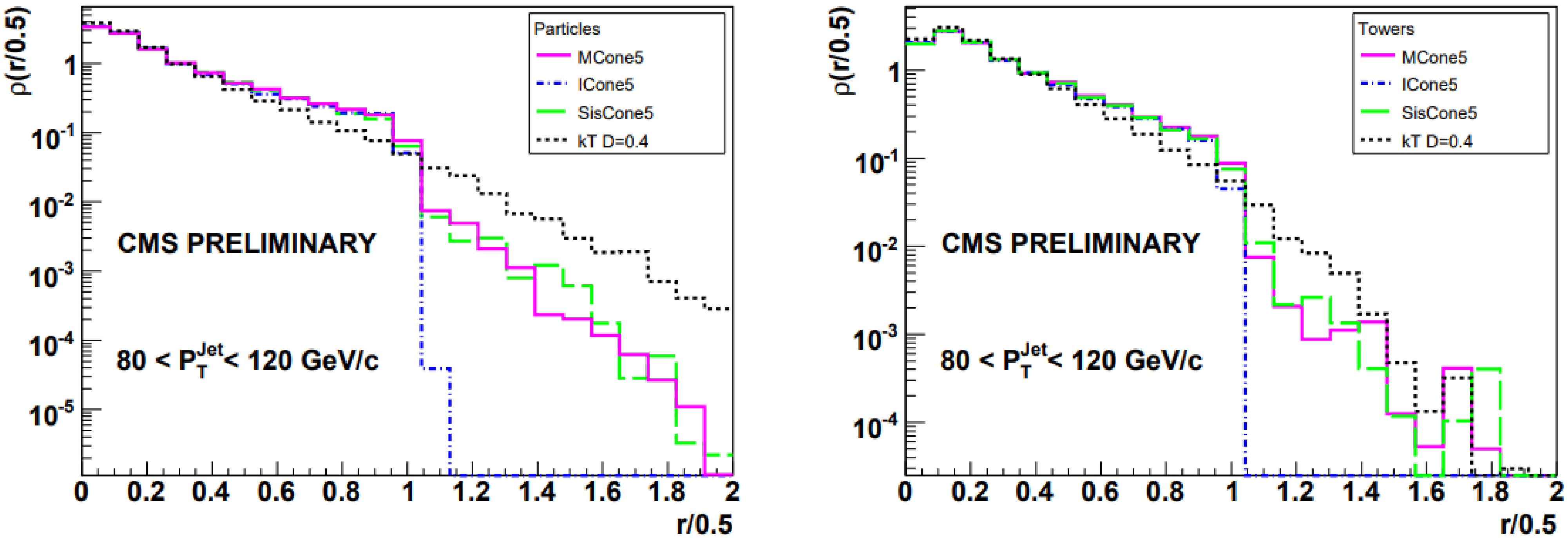


Events with one or zero lepton in final state are selected, the Fast kT algorithm is found more efficiently in fully resolve hadronic than any cone-based algorithm.
Two-jet(W boson) and three-jet(top quark) masses are compared on four levels.
Relative width $\mathrm{RMS}(m)/m$ of all the four algorithm is also showed in next page.

Jet Reconstruction In $t\bar{t}$ Events



Energy Distribution Within A Jet

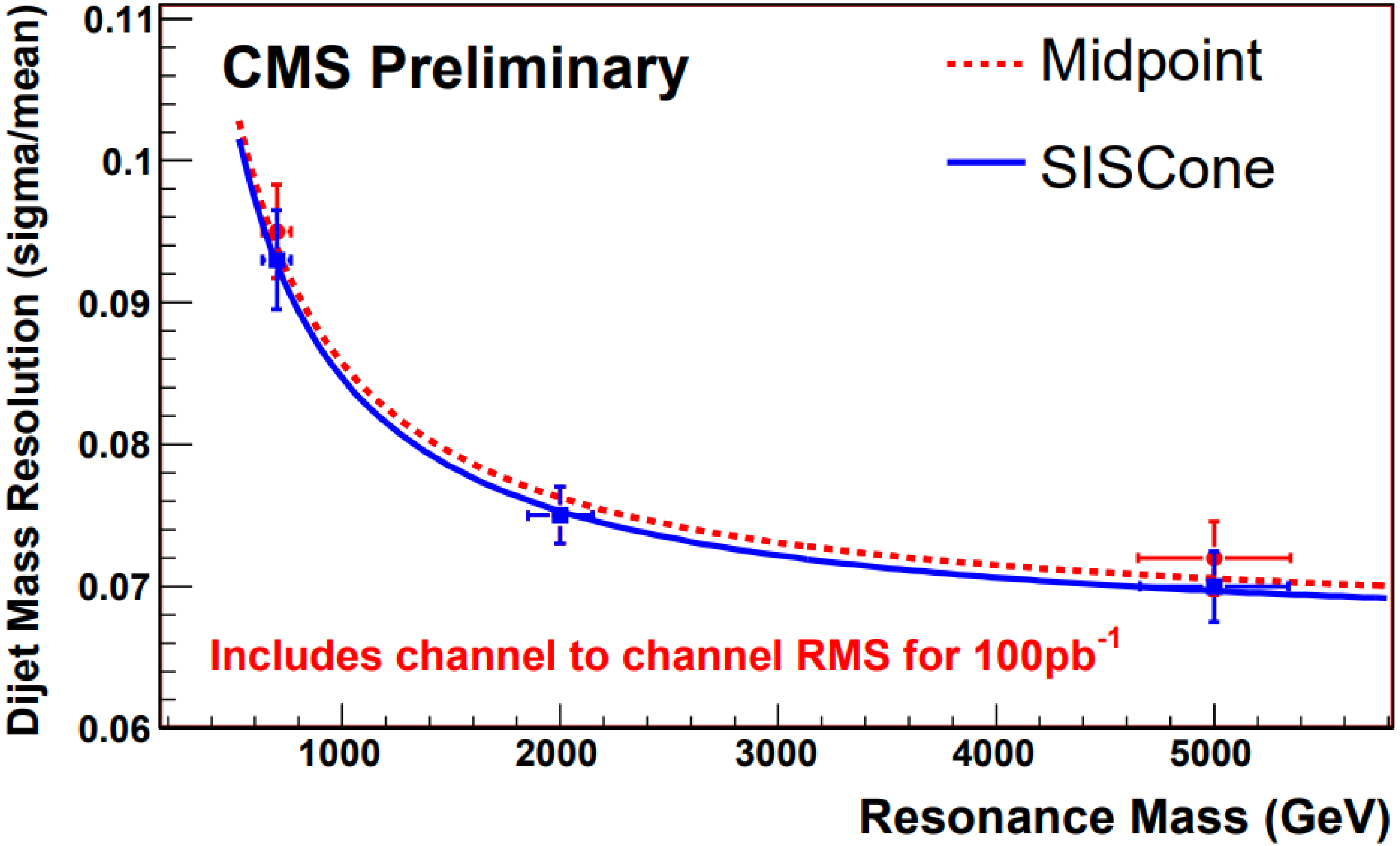


To study the internal property of jet, define differential jet shape $\rho(r)$ as

$$\rho(r) = \frac{\sum p_T(r - \Delta r/2, r + \Delta r/2)}{\Delta r \sum p_T^{jet}}$$

Both particle-level and calorimeter-level distributions are in good agreement for all algorithms.

Dijet Mass Resolution



Study dijet mass resolution of Z' boson (resonance mass up to several TeV).
Result from two algorithms shows good agreement over entire studied range of resonance mass.

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Summary & Outlook

- Summary:
  - Four algorithms performance are compared over different radius parameters. The performance comparison include jet energy response, position resolutions, energy resolutions, efficiencies in QCD dijet samples, reconstruction of the more complex $t\bar{t}$ signal, jet composition and shape distributions, and dijet mass resolution in Z' events.
  - Performance on calorimeter-level is similar between algorithms with same radius parameter, while SISCone is as good as or even better than Midpoint Cone algorithm.
  - Execution time of Fast kT is shorter than most cone-based algorithm, well suited for high multiplicity environment of LHC pp Collisions. Its performance is also very well.
- Outlook:
  - Further studies will be conducted regarding the performance of all algorithms in events with high pileup and more realistic calorimeter noise.

Referance

[1] CMS Collaboration, Performance of jet algorithms in CMS (2007), CMS Physics Analysis Summary JME-07-003.

[2] G. C. Blazey et al., “Run II jet physics: Proceedings of the Run II QCD and Weak Boson Physics Workshop”, hep-ex 0005012 (2000).

[3] G. P. Salam and G. Soyez, “A practical seedless infrared-safe cone jet algorithm”, JHEP05(2007)086 (2007).

[4] M. Cacciari and G. P. Salam, “Dispelling the N3 myth for the Kt jet-finder”, Phys.Lett. B641 57-61 (2006).

[5] S. Catani, Y. L. Dokshitzer, M. H. Seymour and B. R. Webber, “Longitudinally invariant Kt clustering algorithms for hadron hadron collisions”, Nucl.Phys.B406:187-224 (1993).

[6] Abdullin, S. & Abramov et al. Design, performance, and calibration of CMS hadron-barrel calorimeter wedges(2008). European Physical Journal C. 55. 159-171. 10.1140/epjc/s10052-008-0573-y.

Thanks