Les Houches, 18/06/2007
Physics at TeV Colliders Workshop

Jets in CMS

Mónica L. Vázquez Acosta (CERN)
Dorian Kcira (University of Louvain)
Joanna Weng (ETH)
Jet Algorithms implemented in CMS:
- $k_T$ clustering algorithms
  - KtJet
  - FastKt
- Cone algorithms
  - Iterative Cone
  - Midpoint

Recombination Scheme
momentum addition rule of particles in a jet

- **E-scheme:**
  \[ E_{ij} = E_i + E_j \]
  \[ P_{ij} = P_i + P_j \]
External implementation of the algorithms

- **KtJet** (Butterworth, Cox, Waugh): *v1.06*
- **FastJet** (Cacciari, Salam): *v2.1.0b1*

**Parameters**

**FastKt**
- D parameter: 1.0 or 0.6

**KtJet**
- D parameter: 1.0

FastJet package is validated in CMS. 
KtJet will be dropped from standard reconstruction.
Iterative Cone

- Towers are assigned to a jet that is found first and then constituents are excluded from the input list
- No dedicated jet merging/splitting step
- Seed threshold is applied
- Fast algorithm used in the High Level Trigger

**Parameters**

- **Cone Size:** 0.5 or 0.7
- **Seed:** $E_T > 1$ GeV
Midpoint

- Internal implementation of the Midpoint algorithm
  http://www.pa.msu.edu/~huston/tev4lhc/JetClu+Midpoint-StandAlone.tgz

- Plan to move to external implementation of the FastJet package

**Parameters**

- Cone Size: 0.5 or 0.7
- Seed: $E_T > 1$ GeV
- overlapThreshold: 0.75 (controls splitting-merging)
- maxPairSize: 2
- maxIterations: 100
Input to jet algorithms
CaloTower

Cells in the ECAL are merged to make up for the size of one HCAL cell (HCAL barrel cell: $\Delta\eta \Delta\phi = 0.087 \times 0.087$).

Energy of tower: sum of all readout cells which pass zero-suppression. Towers are treated as massless particles and the direction is defined by the nominal interaction point and the center of the tower.

Cell Thresholds to form a CaloTower: Scheme B

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Thresholds</th>
<th>NIC $\eta \approx 0$</th>
<th>JEL $\eta \approx 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HB</td>
<td>HO</td>
<td>HE</td>
</tr>
<tr>
<td>A</td>
<td>0.7</td>
<td>0.85</td>
<td>0.9</td>
</tr>
<tr>
<td>B</td>
<td>0.9</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>C</td>
<td>1.2</td>
<td>1.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

NIC = Noise In Cone (GeV)
JEL = Jet Energy Loss (GeV)

Calotowers are used as input to all jet algorithms:
Tower Thresholds: $E_T > 0.5$ GeV (reduce the effects of Pileup)
Tracking better than calorimetry up to 200 GeV
Combine Tracker/Calorimeter information
to improve reconstruction
Only particles before the beampipe are considered.

- **Lifetime > 10 mm** set stable
- **Lifetime < 10 mm** set unstable: decayed in Pythia

**Hadron Level jets** two collections with input:
- `genParticlesAllStable`: all stable particles
- `genParticlesAllStableNoNu`: exclude neutrinos and non-interacting BSM particles

**Hadron Level MET** two collection with input:
- `genParticlesAllStableNoNu`: exclude neutrinos and non-interacting BSM particles
- `genCandidatesForMET`: exclude neutrinos, muons and non-interacting BSM particles
Inputs to jet algorithms

Collections of

- CaloTowers
- Particle Flow objects
- Generator level particles

available in Analysis Object Data (AOD, Tier2)

Possibility to redo jet finding at the analysis level with different jet algorithms/parameters.
Jet Algorithm Parameter Optimization
Three different jet algorithms considered

Cone, MidPoint, $k_T$

Low luminosity sample of events

$tt\bar{b}$ (fully/semileptonic) and $tt\bar{b}H$ (fully/semileptonic)

PU, UE, radiation (no hard gluon radiation)

Quality criteria define

$\mathcal{E}_s$: event selection efficiency

Angular distance between jet and parton

Energy difference between jet and parton

FracReco: combined angular/energy variable, fraction of well reconstructed event

FracGood: fraction of selected & well reconstructed jets

FracGood = $\mathcal{E}_s \times$ FracReco

Study performance of algorithms versus their parameters using the quality criteria at hadron level

Not studied: detector effects, magnetic field
- Optimal value of R/D-parameter depends on event topology
- As expected higher multiplicities would require smaller radia of jets
- No apriori “natural” parameter values, optimizations are specific to the final state topology

Default CMS settings:
- Iterative Cone: R=0.5
- Midpoint: R=0.5
- k_T: D=0.6

<table>
<thead>
<tr>
<th>IC jet radius</th>
<th>$k_T$ R-parameter</th>
<th>jet radius</th>
<th>MC Overlap Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>FracGood</td>
<td>Value</td>
<td>FracGood</td>
</tr>
<tr>
<td>2 quarks</td>
<td>0.5</td>
<td>53.9</td>
<td>0.6</td>
</tr>
<tr>
<td>4 quarks</td>
<td>0.5</td>
<td>22.3</td>
<td>0.5</td>
</tr>
<tr>
<td>6 quarks</td>
<td>0.3</td>
<td>11.2</td>
<td>0.4</td>
</tr>
<tr>
<td>8 quarks</td>
<td>0.3</td>
<td>4.85</td>
<td>0.3</td>
</tr>
</tbody>
</table>
- Reconstruct W from the decay into quarks
- mass, width extracted from Breit-Wigner fit
  \[ \text{width/mass} = 2.35\% \]
- MadGraph values
  \[ W_{\text{mass}} = 80.42 \text{ GeV} \]
  \[ W_{\text{width}} = 2.04 \text{ GeV} \]

W mass from partons

W mass from hadrons

\[ W_{\text{mass}} = 79.4556 \text{ GeV} \]
\[ W_{\text{width}} = 10.6995 \text{ GeV} \]
Hadron level jets:
hadronic W decay in semileptonic ttbar

Increasing D/R parameters:
hadron level jets gather extra energy (UE) and overestimate W mass
Detector level jets (CaloTowers): hadronic W decay in semileptonic ttbar

Uncorrected jets

Less sensitivity to algorithm parameters compared to hadron level jets
Particles with $<0.7$ GeV do not reach the Ecal due to high magnetic field
Detector level jets (ParticleFlow):
hadronic W decay in semileptonic ttbar

FastJet results seem more stable
ParticleFlow: less sensitive to JES (tracks well calibrated)
FastJet Studies
Jet Reconstruction Time

Reconstruction time vs # of towers

- KT
- Fast KT
- Midpoint Cone 0.5
- Iterative Cone 0.5
Estimation of Area

- Estimate area of each jet using “ghost” particles
- Fill event with very soft particles
- Recluster and count how many “ghost” particles fall in each jet

Subtraction of background

- Except for hard jets, pt/area is uniform
- Use median to estimate background
- Subtract from each jet depending on surface
- FastJet provides standard methods for doing the above

- Generate MC sample with full CMS simulation
- Add pileup (low lumi) to same events
- Run FastJet on both samples with and without subtraction in case of PU
Pileup subtraction

- Recovered mass peak with event-by-event subtraction
- Detailed studies of subtraction parameters have started
FastKT Pileup Subtraction
Detector Level Jets (CaloTowers)

W hadronic decay
$tt\bar{t}$ semileptonic events

Full CMS simulation
Uncorrected jets
Jet Energy Scale in CMS

Factorized multi-level corrections

Offset: removal of pile-up and residual electronic noise
Relative ($\eta$): variations in jet response with $\eta$ relative to control region
Absolute ($p_T$): correction to particle level versus jet $p_T$ in control region
Flavor: correction to hadron level for different types of jet (b, tau, etc.)
Underlying Event: luminosity independent spectator energy in jet removed
Parton: correction to parton level

- Default Corrections are to the hadron level
- Flavour, parton level and underlying event corrections are optional
### Comparison of Jet Reconstruction with ATLAS

<table>
<thead>
<tr>
<th>Method</th>
<th>CMS</th>
<th>ATLAS</th>
<th>Discussions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iterative Cone</td>
<td>R=0.5 R=0.7 Seed: $E_T &gt; 1,\text{GeV}$</td>
<td>R=0.4 R=0.7 Seed: $E_T &gt; 1,\text{GeV}$ overlap: 0.5</td>
<td>Peter Loch</td>
</tr>
<tr>
<td>SeedCone with Split/Merge</td>
<td></td>
<td></td>
<td>Chiara Roda</td>
</tr>
<tr>
<td>FastKt</td>
<td>D=0.6</td>
<td>D=0.4 D=0.6</td>
<td>Joey Huston</td>
</tr>
<tr>
<td>Midpoint</td>
<td>R=0.5 R=0.7 overlap: 0.75</td>
<td>R=0.4 R=0.7 overlap: 0.5</td>
<td>(March 07)</td>
</tr>
</tbody>
</table>

Both experiments use E-Recombination Scheme

Run in default reconstruction