Calorimeter and jet reconstruction

M. Weber
(knowledgeable... but not expert)

Jet energy measurement with the ATLAS detector in proton-proton collisions at $\sqrt{s} = 7$ TeV, arXiv:1112.6426v1
Temperaturänderung:

\[ \Delta T = \frac{\Delta E}{C} \]

mit \( \Delta E = \) Energieverlust des einfallenden Teilchens
\( C = \) Wärmekapazität von Wasser

Man braucht 1 kCal, um 1 Liter Wasser um 1° zu erhöhen.

1 kCal = \( 1000 \times 2.61 \times 10^{-19} \) eV
= \( 2.61 \times 10^{22} \) eV
= \( 2.61 \times 10^{13} \) GeV = \( 2.61 \times 10^{7} \) TeV
Jet reco basics

• **Jets** used for ATLAS physics analyses are reconstructed by a jet algorithm starting from the energy depositions of **electromagnetic and hadronic showers** in the **calorimeters**.

• The jet Lorentz four-momentum is reconstructed from the corrected energy and angles with respect to the primary event vertex.
EM and Hadronic showers

Detector Effects On Jets

**Change of composition**
- Radiation and decay inside detector volume
- “Randomization” of original particle content

**Defocusing changes shape in lab frame**
- Charged particles bend in solenoid field

**Attenuation changes energy**
- Total loss of soft charged particles in magnetic field
- Partial and total energy loss of charged and neutral particles in inactive upstream material

**Hadronic and electromagnetic cascades in calorimeters**
- Distribute energy spatially
- Lateral particle shower overlap

By P. Loch
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Particle jets

- The **jet** energy calibration relates the jet energy measured with the ATLAS calorimeter to the true energy of the corresponding **jet of stable particles** entering the ATLAS detector.
- “Track jets”: for systematic studies and calibration purposes, built from charged particles using their momenta measured in the inner detector.
– Absorber (passive) and detector (active) layers
– Fluctuations in visible energy: "sampling fluctuations" due to variation of the number of charged particles in the detector
Energy resolution

• Statistical fluctuations
  – In the number of particles in the shower
  – In the number of escaping or undetected particles

• Noise
  – Electronic noise
  – Pile up

• Constant
  – Dead material
  – Calibration errors
  – Mechanical imperfections

\[
\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{\sigma_n}{E} \oplus \text{constant}
\]

• Higher energy -> better resolution
ATLAS jets

• Use **Anti-kt** with R=0.4 or R=0.6

• Jet finding is done in y-phi coordinates
• Corrections are often done in eta-phi coordinates
• Jet $p_T$ reconstruction threshold is $p_T > 7$ GeV
• **Inputs are:** topological clusters or towers (next slide)
• Topological clusters
  – groups of calorimeter cells that are designed to follow the shower development
  – Start from a seed cell with S/N>=4, iteratively add cells with S/N>=2
  – A splitting procedure exists
    – E = Sum(Ecell), M=0 GeV,

• Towers
  – static, eta x phi = 0.1x0.1, grid elements built directly from calorimeter cells
# Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Loose</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HEC spikes</strong></td>
<td>($f_{HEC} &gt; 0.5$ and $</td>
<td>f_{HECquality}</td>
</tr>
<tr>
<td><strong>Coherent EM noise</strong></td>
<td>$f_{EM} &gt; 0.95$ and $f_{quality} &gt; 0.8$ and $</td>
<td>\eta</td>
</tr>
<tr>
<td><strong>Non-collision background</strong></td>
<td>$</td>
<td>t_{jet}</td>
</tr>
<tr>
<td></td>
<td>or ($f_{EM} &lt; 0.05$ and $</td>
<td>\eta</td>
</tr>
</tbody>
</table>

Table 1: Selection criteria used to reject fake jets and non-collision background.

![Graph](image)
Here the ‘fun’ begins...
Calibration

- **Calorimeter non-compensation**
  partial measurement of the energy deposited by hadrons

- **Dead material**
  energy losses in inactive regions of the detector

- **Leakage**
  energy of particles reaching outside the calorimeters

- **Out of calorimeter jet radiation**
  energy deposits of particles inside the truth jet entering the detector that are not included in the reconstructed jet

- **Noise thresholds and particle reconstruction efficiency**
  signal losses in the calorimeter clustering and jet reconstruction
Jet response

- Based ok MC (without MPI, as offset already corrected)
- Lines depicts the eta boundaries for the corrections, which will be averages
ATLAS knows several correction ‘levels’

• Start from ‘EM scale’
  – Apply an absolute calibration derived from test-beam measurements based on EM-showers
    • Test with muons (test-beam, MC, cosmics)
    • Test with Z-> ee

• Apply a ‘simple’ JES
  – Correct for lower detector response to hadrons
  – Cell based

• More ‘realistic’ scales
  – Cluster-by-cluster, jet-by-jet
  – Use in-situ calibrations
• Closure?
• Uncertainties at the level of 0.5%
• -> Systematic

Measure the top quark mass to $m_t = 173.2 \pm 0.9$ GeV (= 0.5%)... (arXiv:1207.1069)
Other Corrections

• *Pile-up correction*: average additional energy due to additional proton-proton interactions (correction from *in situ* measurements)

• *Jet origin correction*: Correct the direction of the jet to originate from the primary vertex, no effect on energy

• *Jet energy and direction correction*: Correction based on constants derived from the comparison of the kinematic observables of reconstructed jets and those from truth jets (MC).
Off-set due to pile-up

- Actually corrected for before the hadronic energy scale is restored, such that the derivation of the jet energy scale does not depend on it

Prog.Part.Nucl.Phys.
60:484-551,2008
DO Jet Energy Scale cake

Essentially valid for ATLAS too
Offset

- Depends on eta, NPV, bunch spacing
- Also depends on the number of towers in a jet (area, but not trivial depending on jet algorithm)
- Shown: jet offset, based on tower offset
Uncertainty

(a) $0.3 \leq |\eta| < 0.8$
Beyond the simplistic EM+JES

• The EM+JES calibration facilitates the evaluation of systematic, but the energy resolution is rather poor and it exhibits a rather high sensitivity of the jet response to the flavour of the parton inducing the jet

• Global calorimeter cell energy density calibration (GCW)
  – jet is calibrated as a whole, longitudinal weights
  – attempts to assign a larger cell level weight to hadronic energy depositions in order to compensate

• Local cluster calibration (LCW)
  – cluster shape variables characterize the topology of the energy deposits of electromagnetic or hadronic showers
  – “Local”, from simulation, without considering the jet context
Next... Split the jet in sub-jets

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