In-situ jet energy calibration methods in ATLAS at the CERN LHC

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APS meeting

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✧ Goal ans systematics effects
✧ ATLAS calorimetry
✧ Overall strategy
✧ In-situ methods
✧ Conclusion
Goal and systematics effects

Goal on the absolute jet energy scale ⇒ \( \sim 1\% \)
\( (M_{\text{top}}, M_{\text{sparticles}}) \)

Detector effects
- Non compensating calorimeter
- Distribution of dead material
- Electronic noise

Jet energy reconstruction
- Jet definition
- Energy reconstruction method

Physics effects
- Fragmentation
- ISR & FSR
- Underlying event
- Pile-up of minimum bias events
jet $\rightarrow$ fixed cone algorithm

sampling method

weight to compartment

$$\frac{\sigma(E)}{E} = \frac{52.3\%}{\sqrt{E}} \oplus 1.7\% \ (\eta=0.3)$$

noise term: $\oplus \frac{2 \text{ GeV}}{E}$

$$\frac{\sigma(E)}{E} = \frac{64.2\%}{\sqrt{E}} \oplus 3.6\% \ (\eta=2.45)$$

"H1" method

weight to individual cells

<table>
<thead>
<tr>
<th>Type</th>
<th></th>
<th>$\eta$</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM</td>
<td>LAr</td>
<td>$</td>
<td>\eta</td>
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<tr>
<td>HAD</td>
<td>Scintillator</td>
<td>$</td>
<td>\eta</td>
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<tr>
<td>LAr</td>
<td></td>
<td>$1.5 &lt;</td>
<td>\eta</td>
</tr>
<tr>
<td>Forward LAr</td>
<td></td>
<td>$3.1 &lt;</td>
<td>\eta</td>
</tr>
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Overall calibration strategy

Before LHC starts

✦ Modules of each calorimeter calibrated in beam (∼1/8)
✦ Transport the calibration constants inside each calorimeter technology
✦ Extend to jets via Monte-Carlo

⇒ Jet energy scale known at ∼ 5-10%

LHC starts

✦ Absolute hadron energy scale
  E/p method
✦ Absolute jet energy scale (goal ∼1%)
  W mass reconstruction
  Z+jet balance
✦ Energy regions not covered by in-situ samples → MC

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E/p method

Charged isolated energetic hadrons ($E/p=1$) produced in $\tau^\pm \rightarrow h^\pm \nu_\tau$ from direct $W^\pm (+jet) \rightarrow \tau^\pm \nu_\tau$ and $Z^0/\gamma^* \rightarrow \tau^+\tau^-$

Low luminosity case, trigger available

Multi-tracks bck rejection

QCD & $\tau \rightarrow 3$-prongs
(matching + isolation)
Bias=0.2%

additionnal neutral energy

$\tau^\pm \rightarrow \pi^\pm \pi^0 \nu_\tau$
(fine $\eta$ strips & longitudinal segmentation)
Bias<0.6% over full INDET range

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Main source of E/p bias under control (QCD and $\tau^\pm$ decay): overall bias < 0.8%

Available statistic: ∼320k events/year (low luminosity)

Energy covered: from 20 GeV (trigger)
  upto 250 GeV at $|\eta| = 2.5$ (LAr had)

✦ relative method to the inner detector
  (absolute momentum scale known at 0.5% before LHC starts)
✦ inter-calibration of subdetectors of different technologies
✦ results directly comparable to those obtained in beam ($\pi^\pm$)
  ⇒ check and tune Monte-Carlo
    (hadronic shower and description of dead material)
Jet energy scale for light quark

High statistics \((80 \times 10^3 \text{ event/day low lum.})\)

1 isolated lepton + >4 jets (within 2 b-jets)

- low bck rate \((W + \text{jets and WW}) \Rightarrow \text{jet-jet combinatory from } t\bar{t} \text{ events}
- \(45 \times 10^3 \text{ event/year low luminosity}

\[ \begin{align*}
\Delta R &= 0.4 \\
M_W - 15 < M_{jj} < M_W + 15 \text{ GeV} \\
\bullet \ p_T(jet) &\sim 50 \text{ GeV} \Rightarrow \text{energy loss outside cone (FSR)} \\
\bullet \ p_T(jet) > 200 \text{ GeV} \Rightarrow \text{jets overlap (recovered with additionnal criteria } \Delta R > 0.8) \\
\bullet \text{ISR and underlying events} \Rightarrow \text{small effects}
\end{align*} \]
W mass reconstruction

✧ low $p_T(jet)$ range $\Rightarrow \sim 3\%$
$(p_T \sim 50 \text{ GeV})$
residual systematics effects from FSR
energy loss out of cone should be reduce
using a larger cone $\Delta R = 0.7$

✧ mid $p_T(jet)$ range $\Rightarrow \sim 1\%$
$(p_T \sim 50\text{-}200 \text{ GeV})$
the 1% precision is achievable

✧ high $p_T(jet)$ range
$(p_T > 200 \text{ GeV})$
residual effects from overlap of the two jets
lack of statistics (criteria on well seperated jets)

$4 \bar{\nu} \, j$ jets calibration:
$M_{jj} = M_W$
Balance Z+jet

Jet energy scale for light parton & b quark
Large statistics
direct Z+jets
with Z → ee, μμ

Balance in $p_T$ between Z and highest-$p_T$ jet in event
fixed cone $\Delta R=0.7$

Fractional imbalance:
$$FrI = \frac{p_T^Z - p_T^\text{jet}}{p_T^Z}$$
not perfect
(ISR+FSR)

Back-to-back topology selection
✦ [20- 60] GeV: 10% → 4%
✦ [60-120] GeV: 7% → 3%

enlarging cone → ~1% achievable ($p_T > 20$ GeV)
Balance Z+jet

Accuracy of the calibration:
\[ p_{T}^{\text{reco}}(\text{jet}) \] rescaled to the \( p_{T}(Z) \)
compared to the \( p_{T}(\text{parton}) \)

\[ \Rightarrow 1\% \text{ achievable for } p_{T} > 60 \text{ GeV} \]

- wide energy and \( \eta \) ranges covered
- inter-calibration inside overall calorimetry
- high statistics
  (barrel: [60-120] GeV 100k/year low lum.)
- Z+b-jet events \( \rightarrow \) separate calibration for b-jet with 1% precision
  (6% of b-quark - sample of 90% purity)
Conclusion

3 methods under study to constrain the precision on the absolute jet energy scale to 1% difficult but should be possible

✦ E/p method
  inter-calibration
  check Monte-Carlo (beam comparison)

✦ W mass reconstruction
  1% jet energy scale at mid-$p_T$ range

✦ Z+jet balance
  $p_T > 60$ GeV 1% possible
  high energy and full calorimetry covered
  independant b-jet energy scale