Electron and Photon Energy Measurement Calibration with the ATLAS Detector

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Overview of calibration procedure

- Electron/Photon passes through absorber of the Liquid-argon calorimeter → Electromagnetic shower
- Shower particles ionise LAr
- Ionisation electrons drift to electrode due to HV applied in LAr gap → Current collected by read-out electrodes → Signal amplified, shaped and digitised
- Cells combined to clusters over 3(4) layers

SIMULATION

1. training of MVA e/γ calibration
2. equalization of longitudinal layer response
   - $E_0$, $E_1/E_2$
3. MC-based e/γ response calibration
4. equalization of uniformity response
   - HV, IMW, Gain
5. $Z\rightarrow ee$ data-driven resolution smearing and scale calibration
6. $J/\psi \rightarrow ee$ $Z\rightarrow eee\gamma$ data-driven scale validation

DATA


You want to know more about the ATLAS LAr Calorimeter? → Steffen Stärz’s talk

Or more about the identification of electrons and photons in ATLAS? → Nadezda Proklova’s talk

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Simulation based calibration

Energy measured in cluster of given size in each layer
→ Energy loss out of cluster and in passive material needs to be recovered by multivariate approach

Input variables
- reconstructed energy, fractions of energy deposits in calorimeter layers, \( \eta \), cell index, \( \eta \) & \( \phi \) positions wrt to cell edge
- converted \( \gamma \):
  - fractions of conversion \( p_T \), conversion radius
  - transition region \( (1.4<|\eta|<1.6) \):
    - fraction of energy deposits in scintillators of Tile calorimeter, relative \( \phi \) positions

Boosted regression tree with gradient boosting on cluster energy in 111 \( |\eta| \times E_T \) bins

Target: \( E_{\text{true}}/E_{\text{reco}} \)

Energy shift to optimise peak position closer to unity in several \( |\eta| \times E_T \) bins

Input samples
- Simulated single electrons and converted & unconverted photons

ATLAS Simulation Preliminary
- Electronic
  - \( 1.4<|\eta|<1.6 \)
  - \( 50 < E_T^{\text{gen}} < 100 \text{ GeV} \)
  - \( \sigma = 0.037 \)
  - \( \sigma = 0.030 \)
Corrections applied on data

Residual mis-calibration of layer response due to mis-calibration of cell electronics response or cross talk

Inter-layer calibration of first & second layer

- Estimated from measured and simulated $Z \rightarrow \mu\mu$ events
  → Muons insensitive to upstream material and energy deposits ~ layer depth

- Recalibrate layer 2 with:
  \[
  \alpha_{1/2} = \left( \frac{E_{1/2}^{\text{data}}}{E_{1/2}^{\text{MC}}} \right) \\
  \left( \frac{E_{1/2}}{E_{\text{layer1}}} = \frac{E_{\text{layer2}}}{E_{\text{layer2}}} \right)
  \]

  → uncertainty < 3%

Presampler correction

- Estimated from measured and simulated $Z \rightarrow ee$ events

- Recalibrate PS with:
  \[
  \alpha_{PS} = \frac{E_{0}^{\text{data}}}{E_{0}^{\text{MC,corr}}}
  \]

  \[
  \left( \frac{E_{0}^{MC,corr}}{E_{0}^{MC}} = 1 + A \times \left( \frac{E_{1/2}^{\text{data}}}{E_{1/2}^{MC} \cdot b_{1/2}} - 1 \right) \right)
  \]

A : correlation between $E_{1/2}$ and $E_0$ under material variations in front of PS (estimated from MC)

$b_{1/2}$ : correction on $E_{1/2}$ for imperfect modelling of passive material between PS and L1 (estimated from unconverted $\gamma$)

→ uncertainty < 5%
**Corrections applied on data**

**Uniformity correction**
- Slightly larger gaps in-between LAr calorimeter modules
- Further gravity induced widening of intermodule-gaps
- Derived from $Z \rightarrow ee$

- Several HV sectors in the LAr calorimeter at non-nominal HV
- Partially corrected on reconstruction level
- Derived from $Z \rightarrow ee$

$\rightarrow \sim 1\%$ effect on resolution

**Pile-up energy shift**
- Bi-polar pulse shape
  $\rightarrow$ Ideally: energy deposits from pile-up average to zero
  $\rightarrow$ Reality: residual energy shift (up to 500 MeV) $\rightarrow$ Pedestal correction
- Probed with $Z \rightarrow ee$

- Worse energy scale & resolution at high pile-up $\rightarrow$ covered by uncertainties
  $\rightarrow$ Stability $< 0.05\%$ integrated over $\eta$
Energy scale

\[ E_{i}^{\text{Data}} = E_{i}^{\text{MC}} (1 + \alpha_i) \]

- \( \Delta \alpha(2015-16) < 0.2\% \) caused by luminosity related heating of LAr and HV currents

→ Applied on data

\[ E = a \sqrt{E} + b + c \]

Energy resolution

\[ \sigma_E = \left( \sigma_E \right)^{\text{MC}} \oplus c' \]

- simulation models data well up to constant term \( c' \)

→ Applied on simulation
Systematic uncertainties

- Uncertainties originate from data/MC disagreements and energy dependence of calibration
- Separate treatment of electrons, converted and unconverted photons

Scale uncertainties
- Set of 64 independent uncertainty sources (e.g. for different $\eta$ regions, energy ranges)
  - Layer inter-calibration
  - Non-linearity of cell energy measurement
  - Material in front of calorimeter
  - Lateral shower shape modelling
  - Tile scintillator calibration
    $(1.4 < |\eta| < 1.6)$
  - Photon reco classification
  - Pile-up related residual energy shift $\sim 10$ MeV

Resolution uncertainties
- Impact of residual non-uniformities affecting energy measurement
- Fluctuations in energy loss before calorimeter
- Shower and sampling fluctuations in calorimeter
- Effect of electronics and pile-up noise
Cross checks

Extrapolation of energy scale from $Z \rightarrow ee$ to different energies and to photons
→ Tested by extracting residual scales from other reference processes after applying full calibration procedure

$J/\Psi \rightarrow ee$:
• Probe extrapolation to low energies
• Overall agreement within 1%

$Z \rightarrow e\gamma$ & $Z \rightarrow \mu\mu\gamma$:
• Probe photon energy scale
• Overall agreement within 0.3%
New developments: Super-Cluster reconstruction

- Previous reconstruction approach: fixed size clusters ($\Delta \eta \times \Delta \phi = 3 \times 7$ (5×5) barrel (endcap))
- New approach: Super-Clusters
  → Dynamical, topological cell clustering
  → Recovery of Bremsstrahlung loss
  → Energy resolution improved by up to 30%
  → Mass resolution ($J/\Psi$, $Z$, $H$) improved by 5-10%
• Precise knowledge of energy scale and resolution crucial for many physics analyses, both precision measurements and searches
• 13 TeV data reveals excellent performance in wide energy range
• Continuous effort to improve performance

ATLAS Preliminary
\( \sqrt{s} = 13 \text{ TeV}, 6 \text{ fb}^{-1} \)

\( Z \rightarrow ee \) MC

Data

Source: Systematic uncertainty in \( m_H \) [MeV]

- EM calorimeter response linearity: 60
- Non-ID material: 55
- EM calorimeter layer intercalibration: 55
- \( Z \rightarrow ee \) calibration: 45
- ID material: 45
- Lateral shower shape: 40
- Muon momentum scale: 20
- Conversion reconstruction: 20
- \( H \rightarrow \gamma\gamma \) background modelling: 20
- \( H \rightarrow \gamma\gamma \) vertex reconstruction: 15
- \( Z/\gamma \) energy resolution: 15
- All other systematic uncertainties: 10

Thanks for your attention!

Questions?

You want to see more related physics results?
→ Talks by Liza Mijovic, Oliver Kortner, …
Backup
LAr cell non-linearity

- Dependence of energy response with particle energy
  - Difference of energy response between electron clusters with all cells in high gain (HG) or at least one in medium gain (MG) observed
  - Not reproduced by MC
  - Problematic as $Z \rightarrow ee$ & $H \rightarrow \gamma\gamma$ have different fractions of objects in MG

- Linearity of read-out electronics in each gain better than 0.1% but relative inter-calibration of different read-out gains can have large impact
  - Measuring $Z \rightarrow ee$ events in special runs with lowered thresholds to study gain inter-calibration
    - Highest energy cells in layer 2 are read out in MG (instead of HG)
  - Effective energy scale shows small difference, most significantly in $0.8 < |\eta| < 1.37$
  - Origin still under investigation
  - Related uncertainty up to 1% for high energy electrons
Material determination

- Calibration relies strongly on MC → accurate detector simulation crucial
- More material in-front of calorimeter → earlier shower development
- Exploit $E_{1/2}$ from unconverted photons and electrons to estimate material before calorimeter and between PS and accordion
- Method sensitivity estimated from MC with distorted geometries