Electron and Photon Energy Measurement Calibration with the ATLAS Detector

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• 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

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
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

- Electrons
  - $1.4 < |\eta| < 1.6$
  - $50 < E_T^{\text{gen}} < 100$ GeV
  - $\sigma = 0.037$
  - $\sigma = 0.030$

$E_{\text{calib}} / E_{\text{gen}}$
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:
  - $\alpha_{1/2} = \left( \frac{E_{1/2}^{\text{data}}}{E_{1/2}^{\text{MC}}} \right)$
  - $E_{1/2} = \frac{E_{\text{layer1}}}{E_{\text{layer2}}}$
  - $\rightarrow$ uncertainty < 3%

Presampler correction

- Estimated from measured and simulated $Z \rightarrow ee$ events
- Recalibrate PS with:
  - $\alpha_{PS} = \frac{E_{0,\text{data}}}{E_{0,\text{MC,corr}}}$
  - $\rightarrow$ uncertainty < 5%

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

$A$ : 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 $\gamma$)

$\rightarrow$ uncertainty < 5%
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 $Z \rightarrow ee$

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

Energy scale calibration derived from data/MC comparison with $Z \rightarrow ee \rightarrow$ residual mismatch

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

Energy resolution

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

simulation models data well up to constant term $c'$

→ Applied on simulation

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

\[ \frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c \]

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

![Graphs showing energy scale uncertainty and resolution uncertainties](image-url)
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 \((\Delta \eta \times \Delta \phi = 3 \times 7 \ (5 \times 5) \) 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%

ATLAS Simulation Preliminary

\[
\frac{1}{N} \frac{dN}{dE}\text{ (0.02 GeV)}
\]

\[
E_{\text{Raw}} = 13.57 \text{ GeV}, \ E_{\text{Gen}} = 17.59 \text{ GeV}, \ \eta_{\text{Gen}} = -0.50
\]

\[
E_{\text{Raw}} = 16.98 \text{ GeV}, \ E_{\text{Gen}} = 17.59 \text{ GeV}, \ \eta_{\text{Gen}} = -0.50
\]
Impact on physics analyses & first look into 2018 data

- 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
\( \sqrt{s} = 13 \) TeV, 36.1 fb\(^{-1}\)

Dielectron Search Selection

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

\( Z \rightarrow \ell^+\ell^- \) MC

ATLAS

Source

Systematic uncertainty in \( m_H \) [MeV]

- EM calorimeter response linearity
- Non-ID material
- EM calorimeter layer intercalibration
- \( Z \rightarrow \ell^+\ell^- \) calibration
- ID material
- Lateral shower shape
- Muon momentum scale
- Conversion reconstruction
- \( H \rightarrow \gamma\gamma \) background modelling
- \( H \rightarrow \gamma\gamma \) vertex reconstruction
- \( e/\gamma \) energy resolution
- All other systematic uncertainties

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