Electron and Photon Energy Measurement Calibration with the ATLAS Detector

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on behalf of the ATLAS Collaboration

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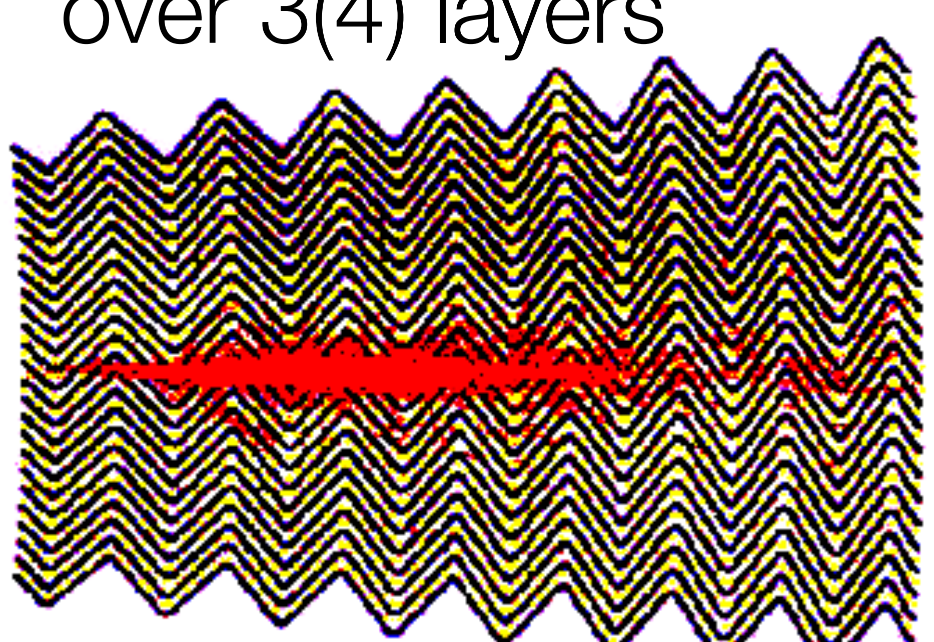
Overview of calibration procedure

- 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



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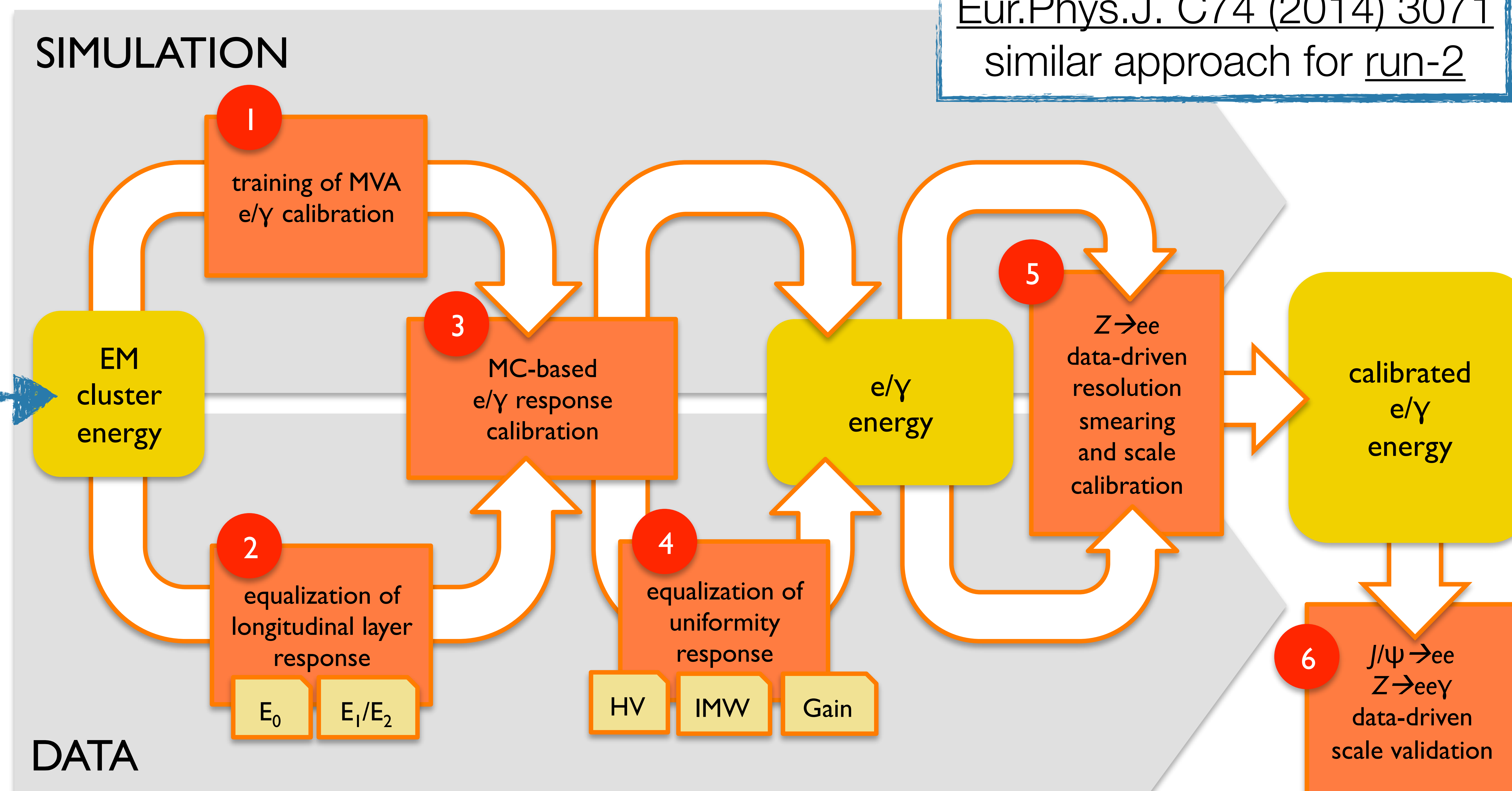
similar approach for run-2



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, η, cell index, η & ϕ positions wrt to cell edge

converted γ:
- fractions of conversion p_T, conversion radius

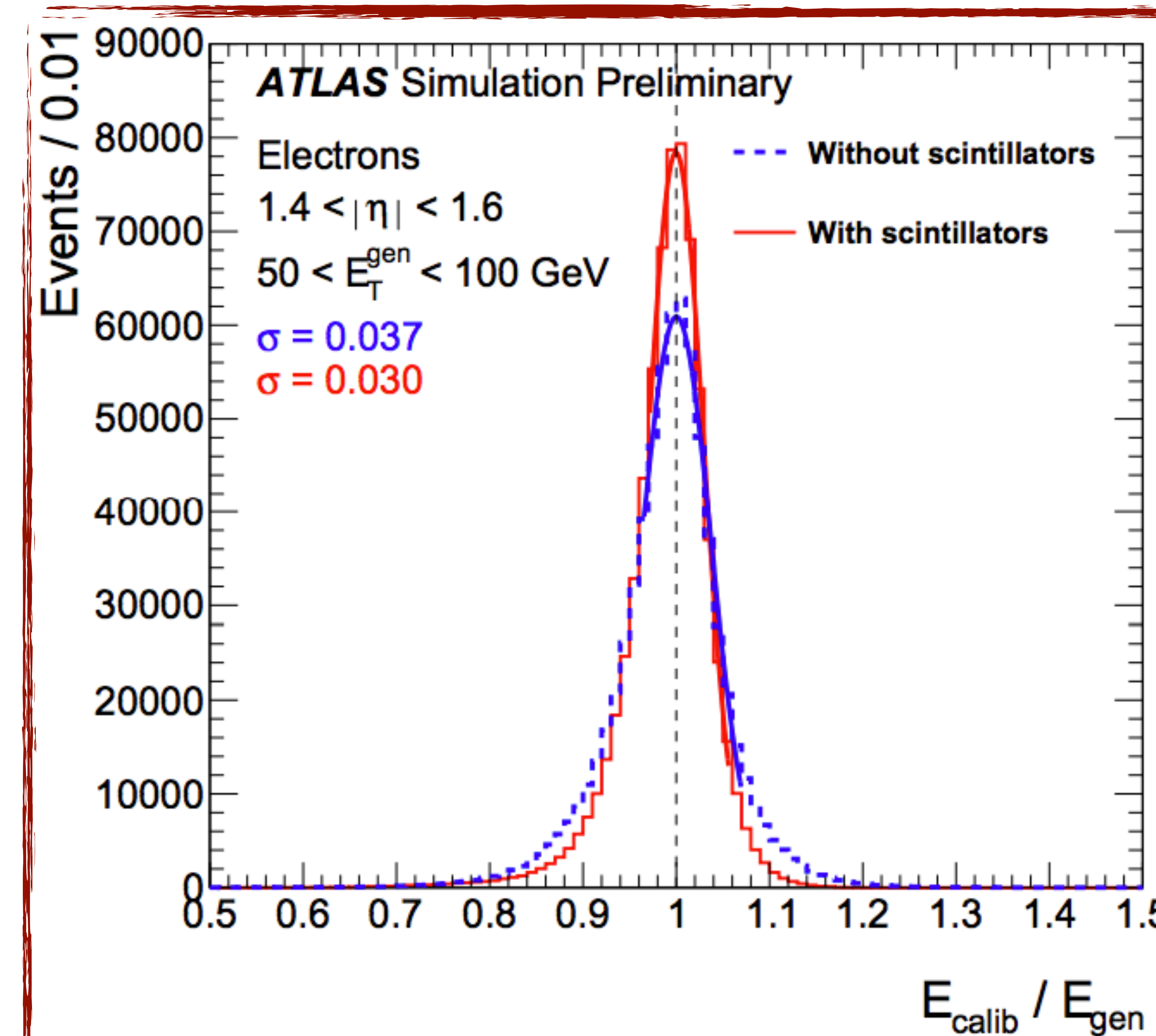
transition region (1.4<|η|<1.6):
- fraction of energy deposits in scintillators of Tile calorimeter, relative ϕ positions

Input samples
- Simulated single electrons and converted & unconverted photons

Boosted regression tree with gradient boosting on cluster energy in 111 |η| × E_T bins

Target: E_{true}/E_{reco}

Energy shift to optimise peak position closer to unity in several |η| × E_T bins



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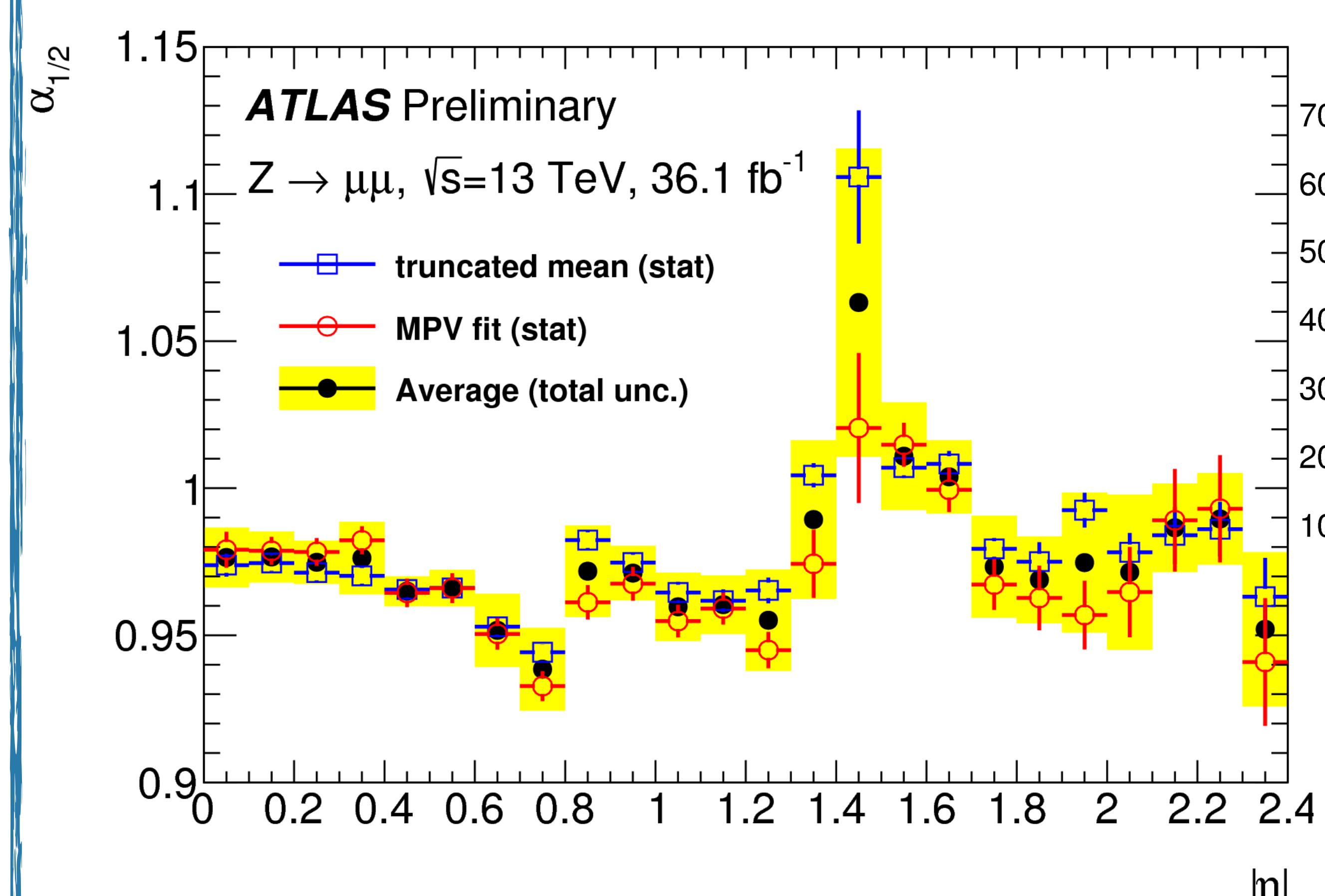
Corrections applied on data

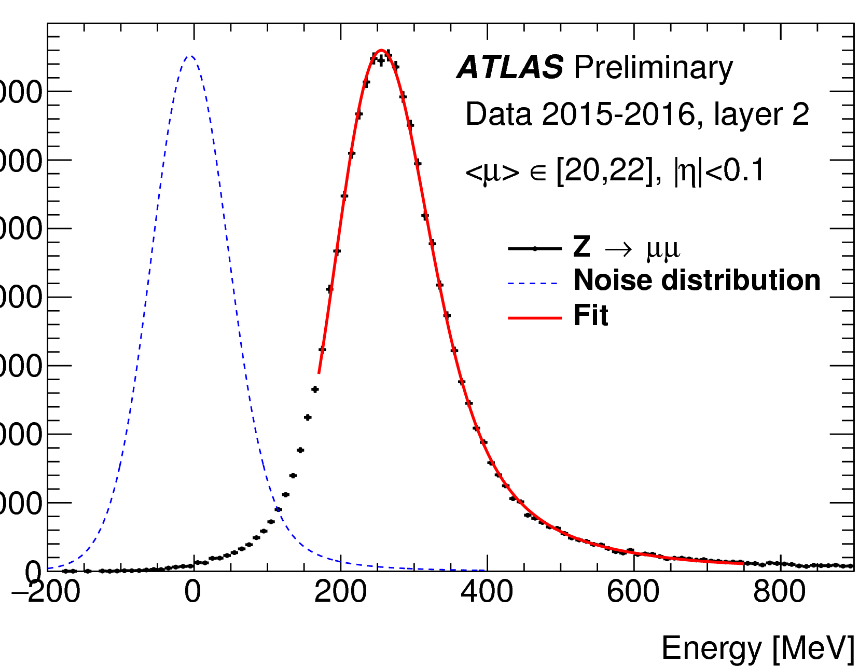
Residual mis-calibration of layer response due to mis-calibration of cell electronics response or cross talk

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: $$\alpha_{1/2} = \left(\frac{E_{1/2}^{\text{data}}}{E_{1/2}^{\text{MC}}}\right)$$

$$\left(E_{1/2} = \frac{E_{layer1}}{E_{layer2}}\right)$$



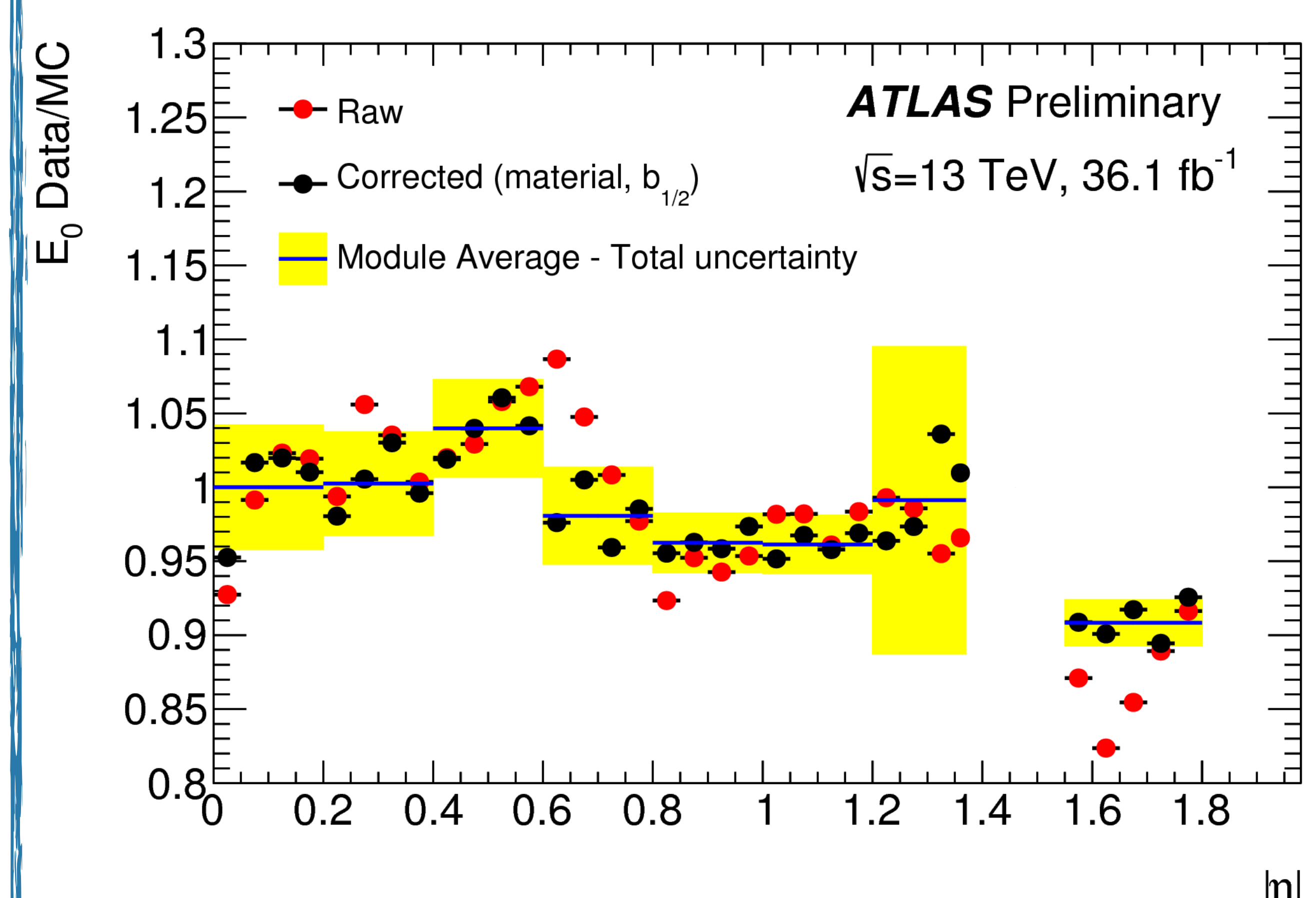


→ uncertainty < 3%

Presampler correction

- Estimated from measured and simulated $Z \rightarrow ee$ events
- Recalibrate PS with: $$\alpha_{PS} = \frac{E_0^{\text{data}}}{E_0^{\text{MC,corr}}}$$

$$\rightarrow \frac{E_0^{\text{MC,corr}}}{E_0^{\text{MC}}} = 1 + A \cdot \left(\frac{E_{1/2}^{\text{data}}}{E_{1/2}^{\text{MC}} \cdot b_{1/2}} - 1\right)$$



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 γ)

→ uncertainty < 5%

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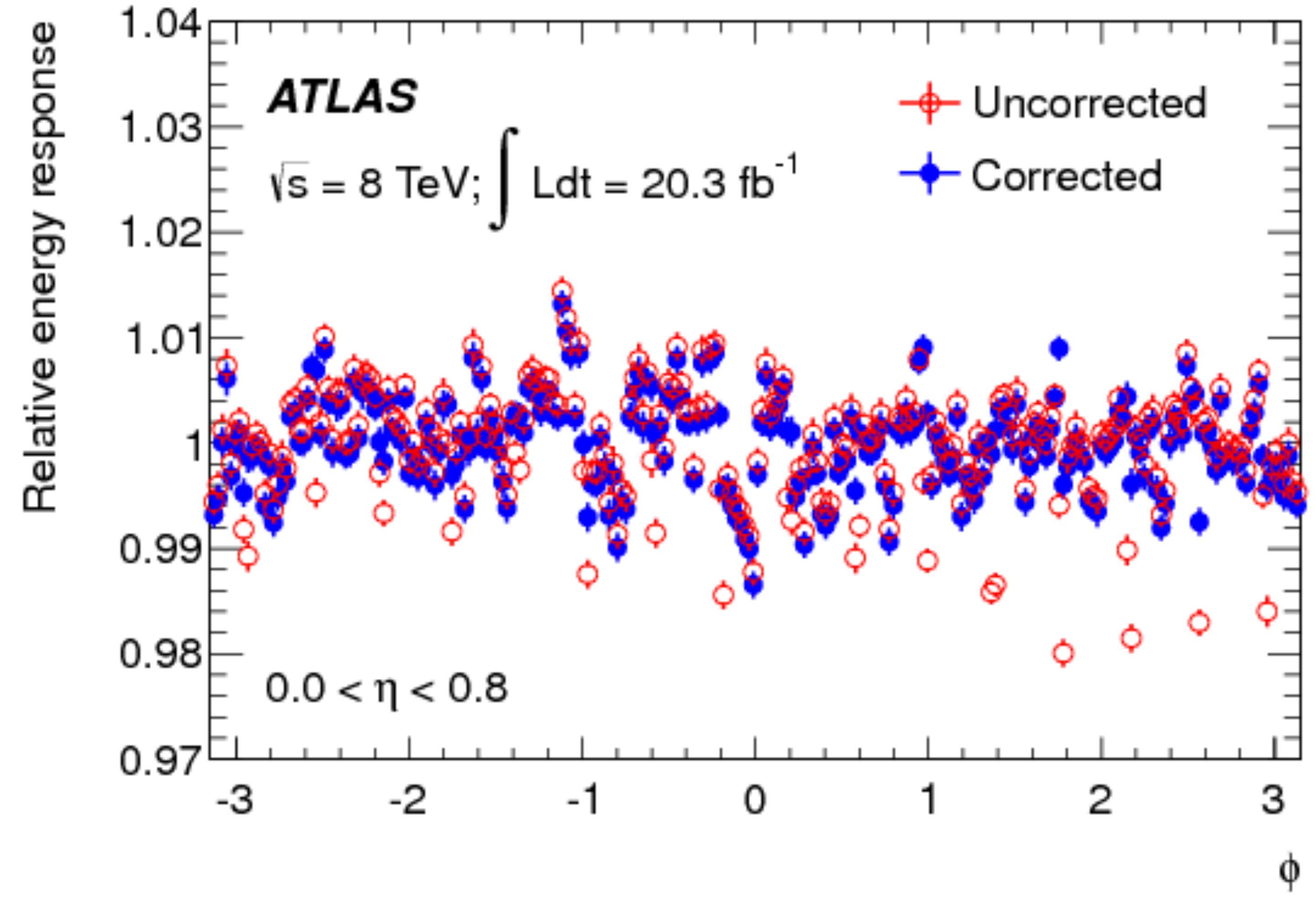
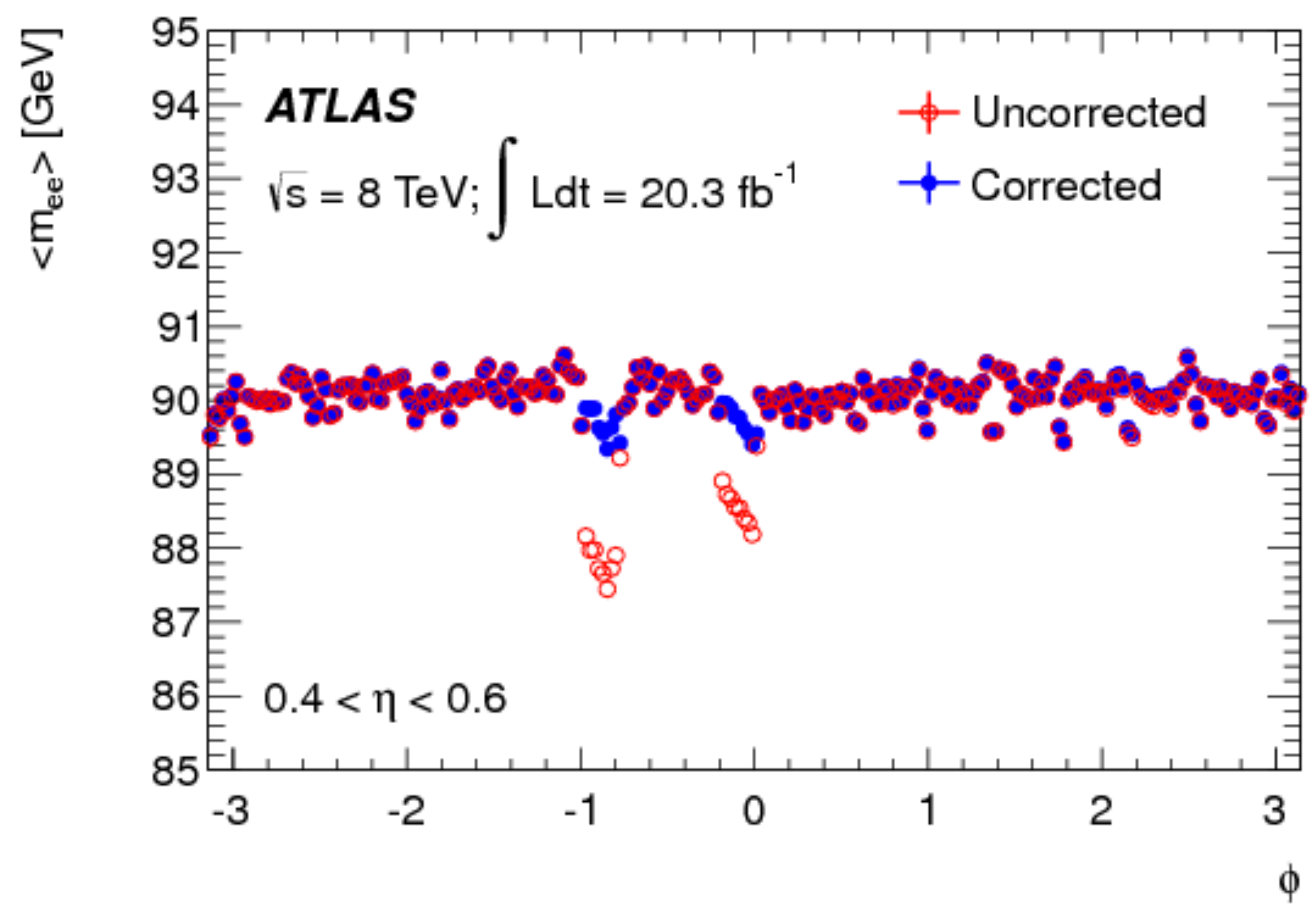
Corrections applied on data

Uniformity correction

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



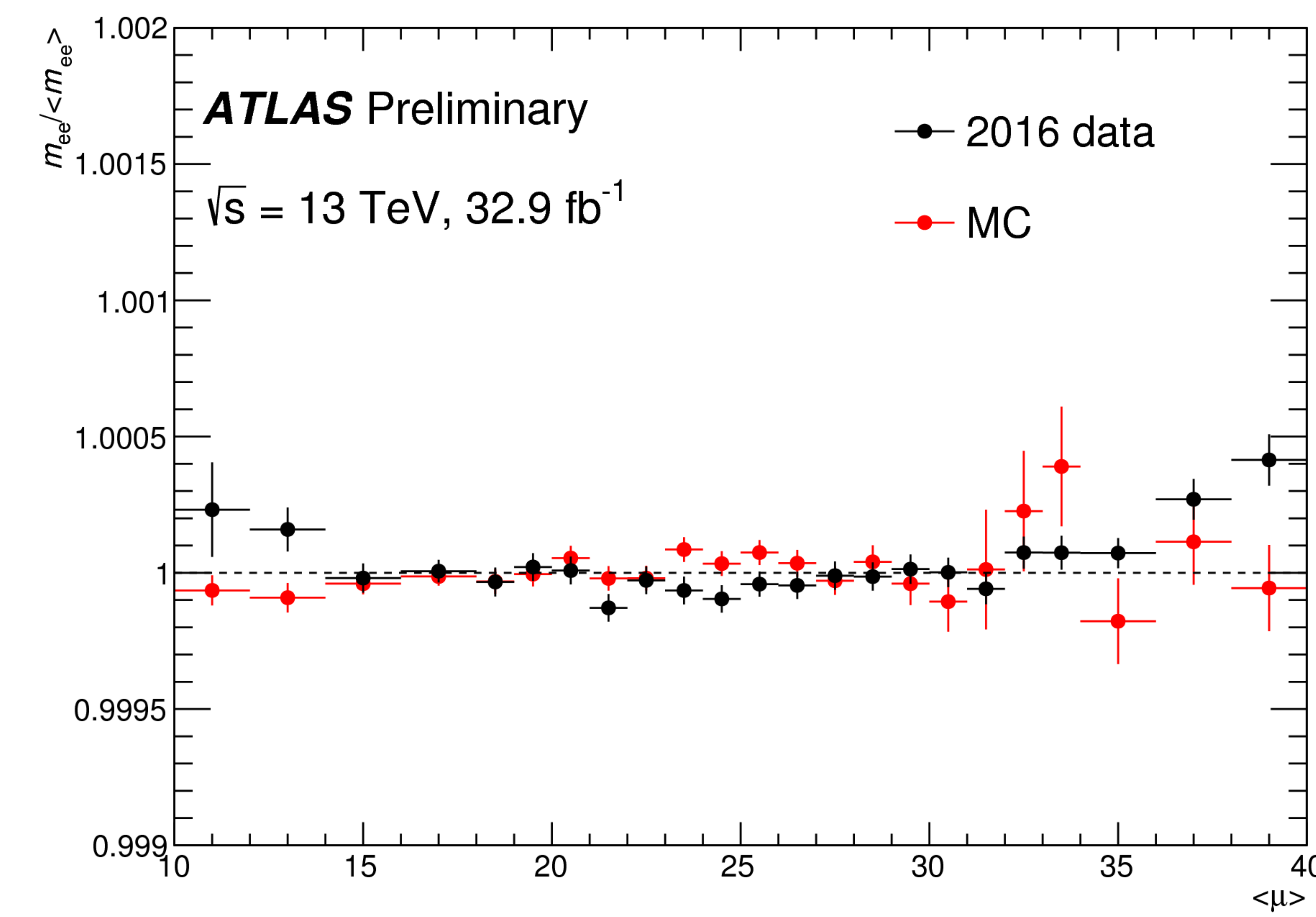
- Several HV sectors in the LAr calorimeter at non-nominal HV
- Partially corrected on reconstruction level
- Derived from $Z \to ee$



→ ~ 1% effect on resolution

Pile-up energy shift

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



- Worse energy scale & resolution at high pile-up → covered by uncertainties

→ Stability < 0.05% integrated over η

Energy scale & resolution

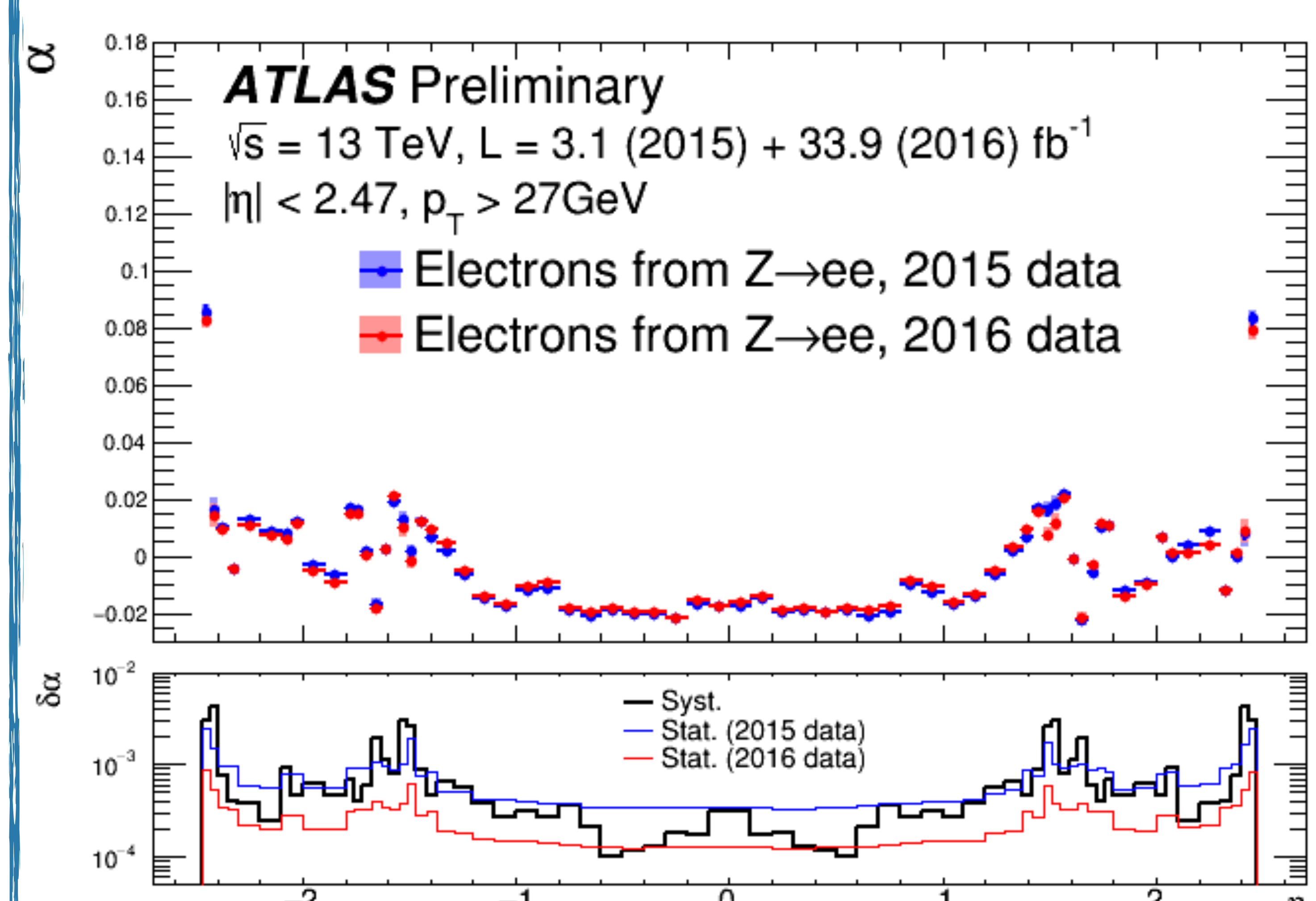
Energy scale calibration derived from data/MC comparison with $Z \rightarrow ee$ → residual mismatch

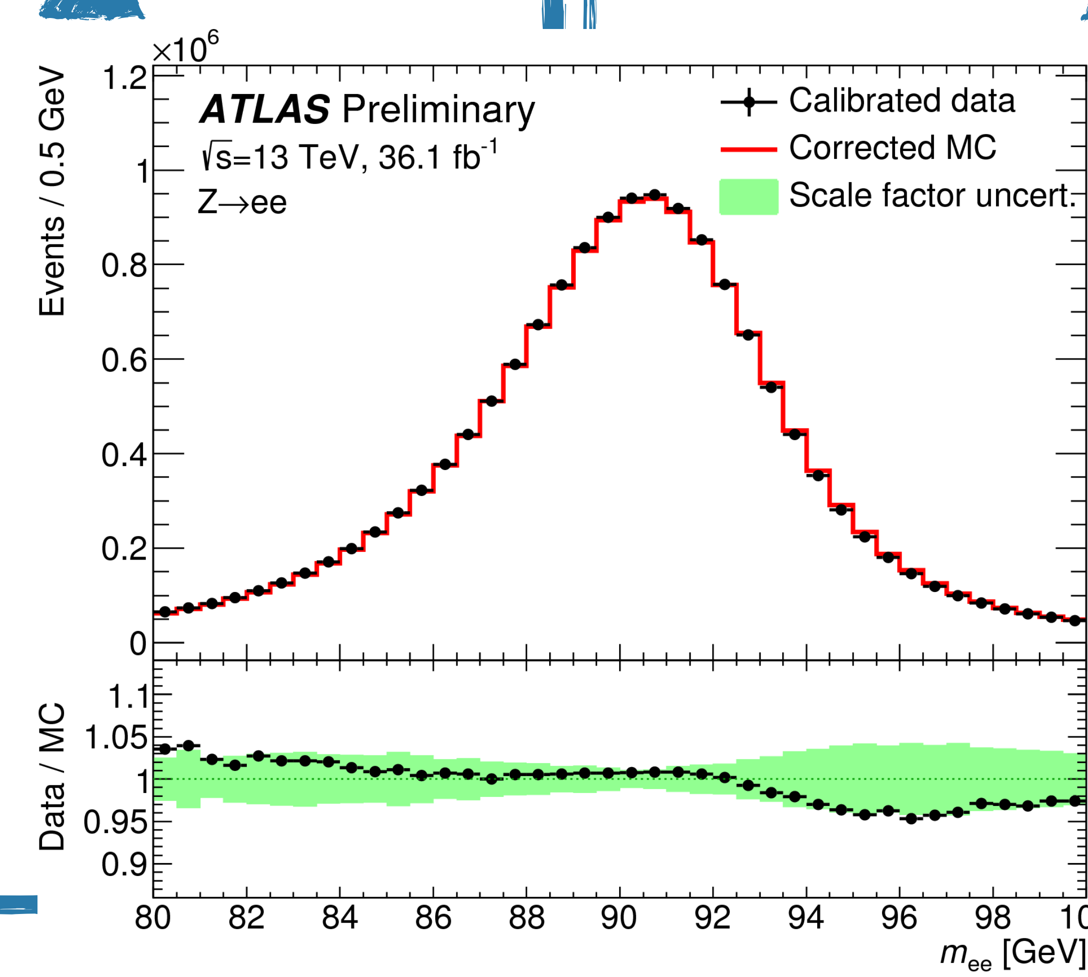
Energy scale

$$E_{\mathrm{i}}^{\mathrm{Data}} = E_{\mathrm{i}}^{\mathrm{MC}}(1+\alpha_{\mathrm{i}})$$

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

→ Applied on data





Energy resolution

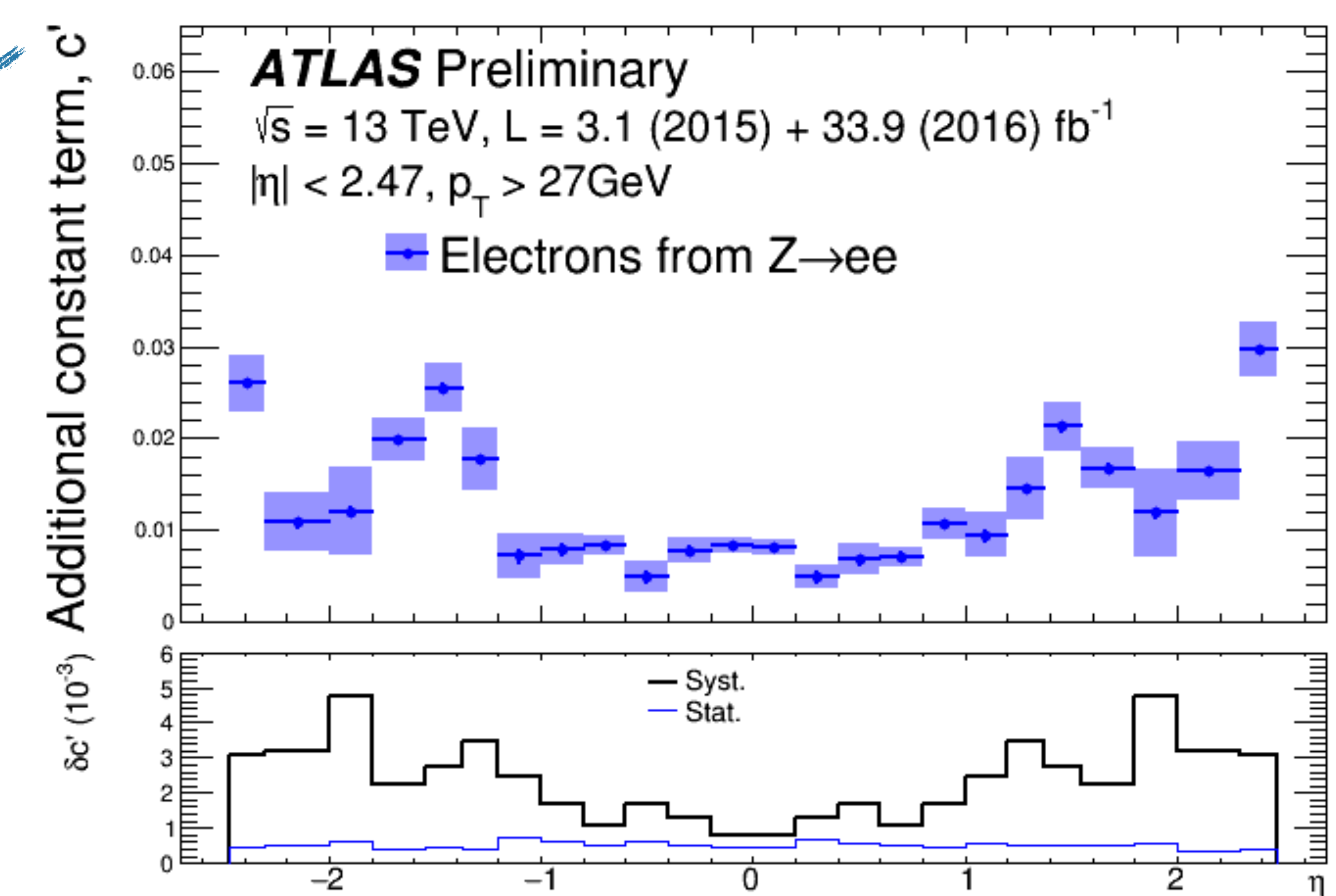
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

sampling, noise, constant term

$$\rightarrow \left(\frac{\sigma_E}{E}\right)^{\mathrm{data}} = \left(\frac{\sigma_E}{E}\right)^{\mathrm{MC}} \oplus c'$$

simulation models data well up to constant term c'

→ Applied on simulation



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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 η regions, energy ranges)

→ Layer inter-calibration

→ Non-linearity of cell energy measurement

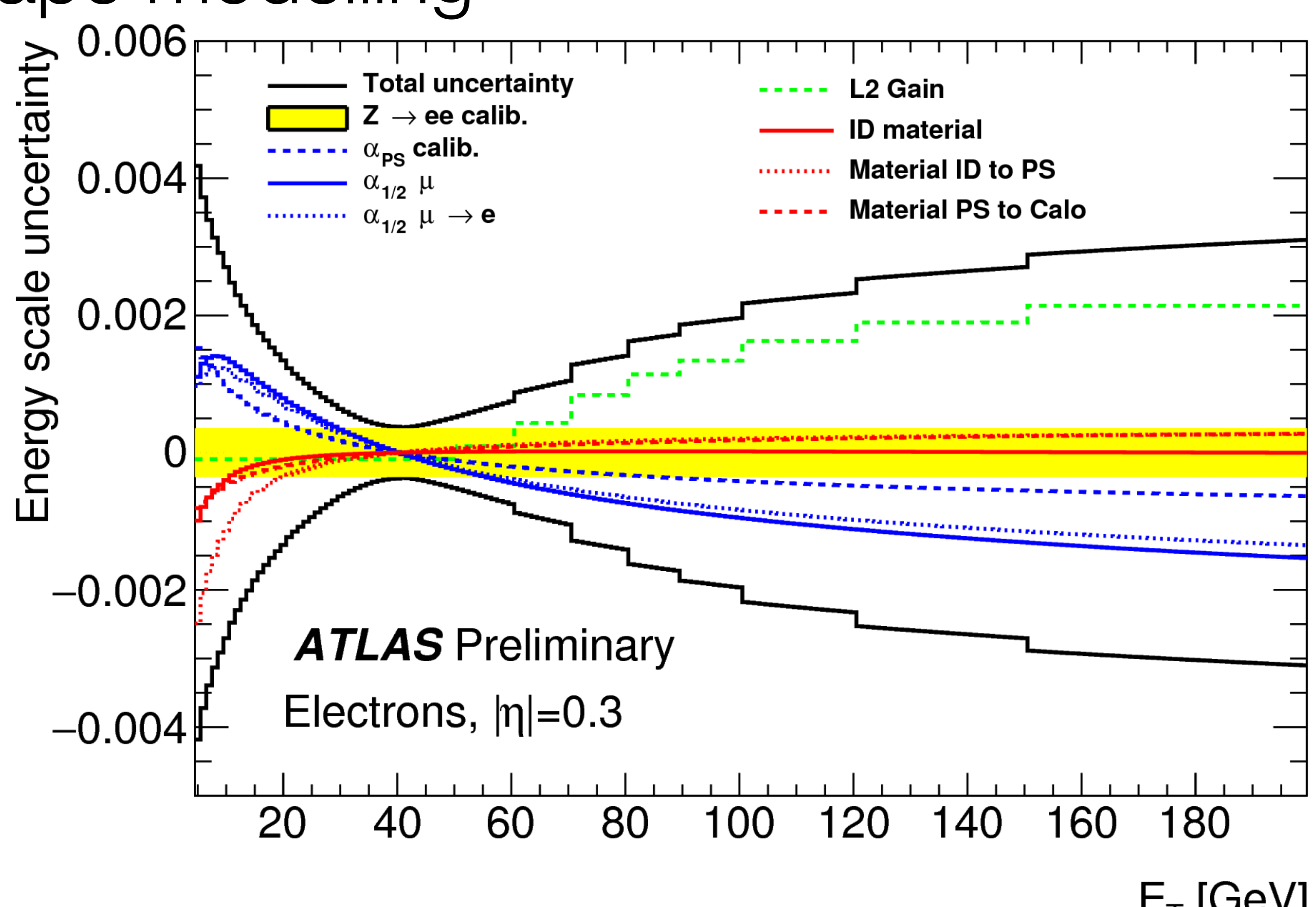
→ Material in front of calorimeter

→ Lateral shower shape modelling

→ Tile scintillator calibration ($1.4 < |\eta| < 1.6$)

→ Photon reco classification

→ Pile-up related residual energy shift ~ 10 MeV



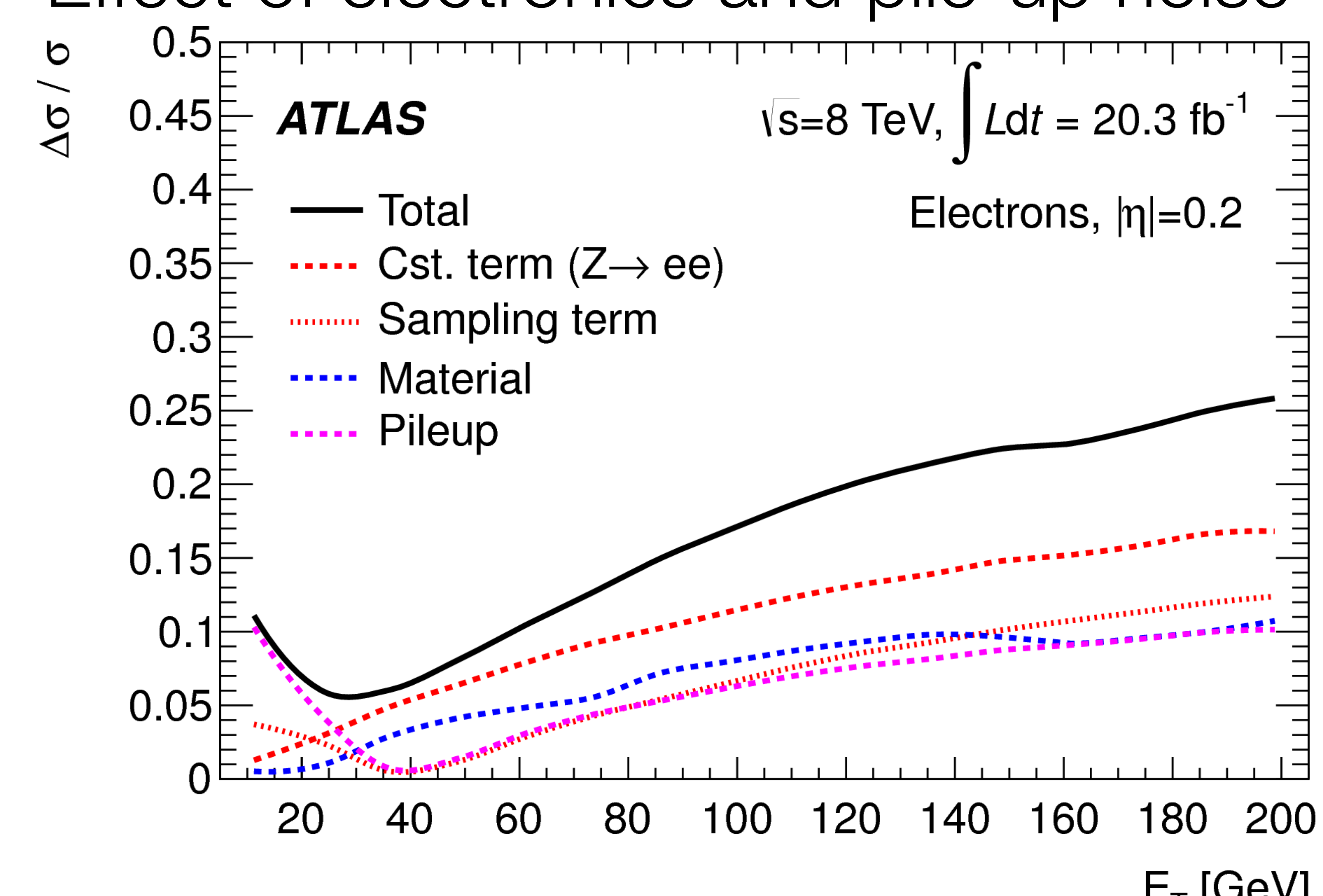
Resolution uncertainties

→ 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



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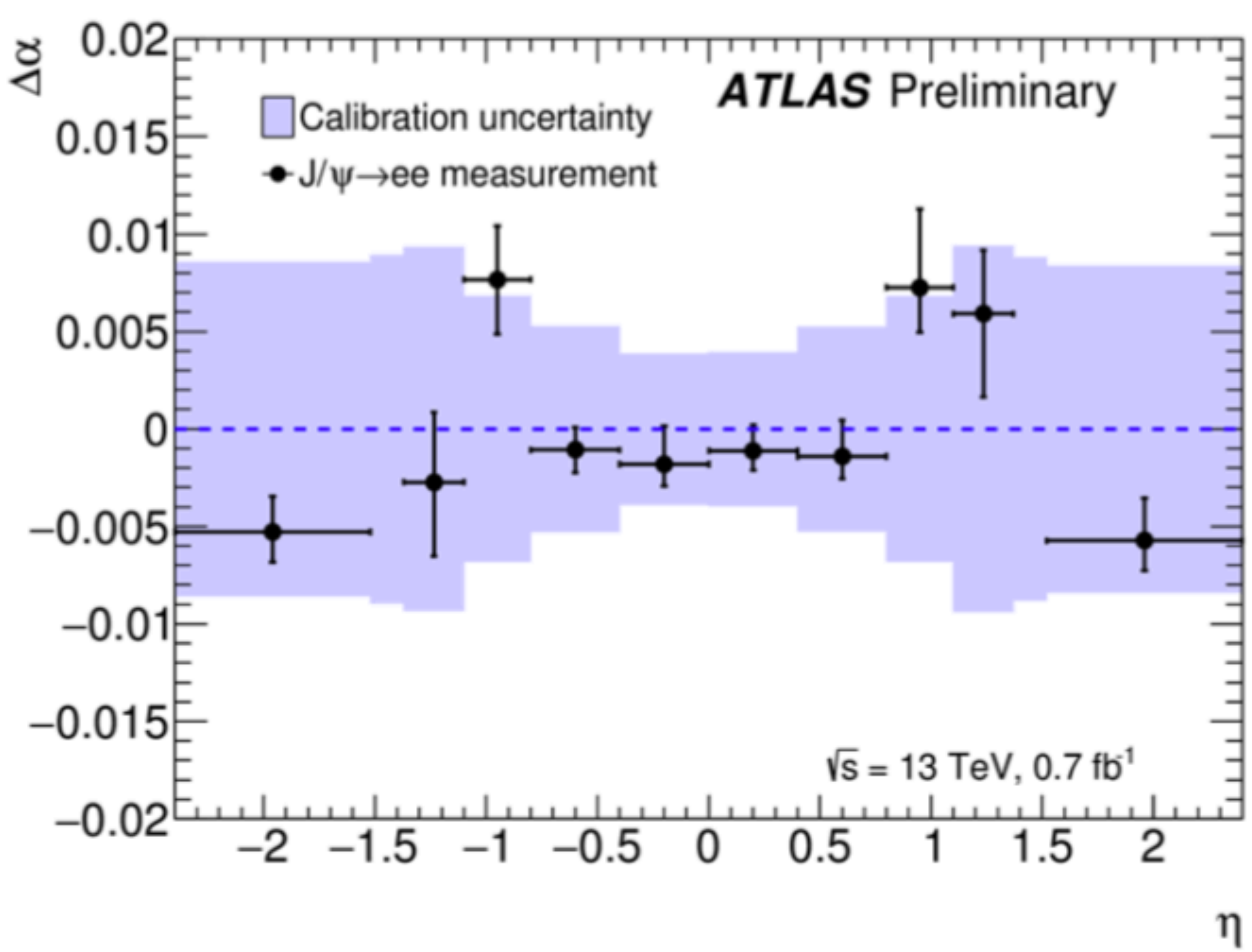
Cross checks

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

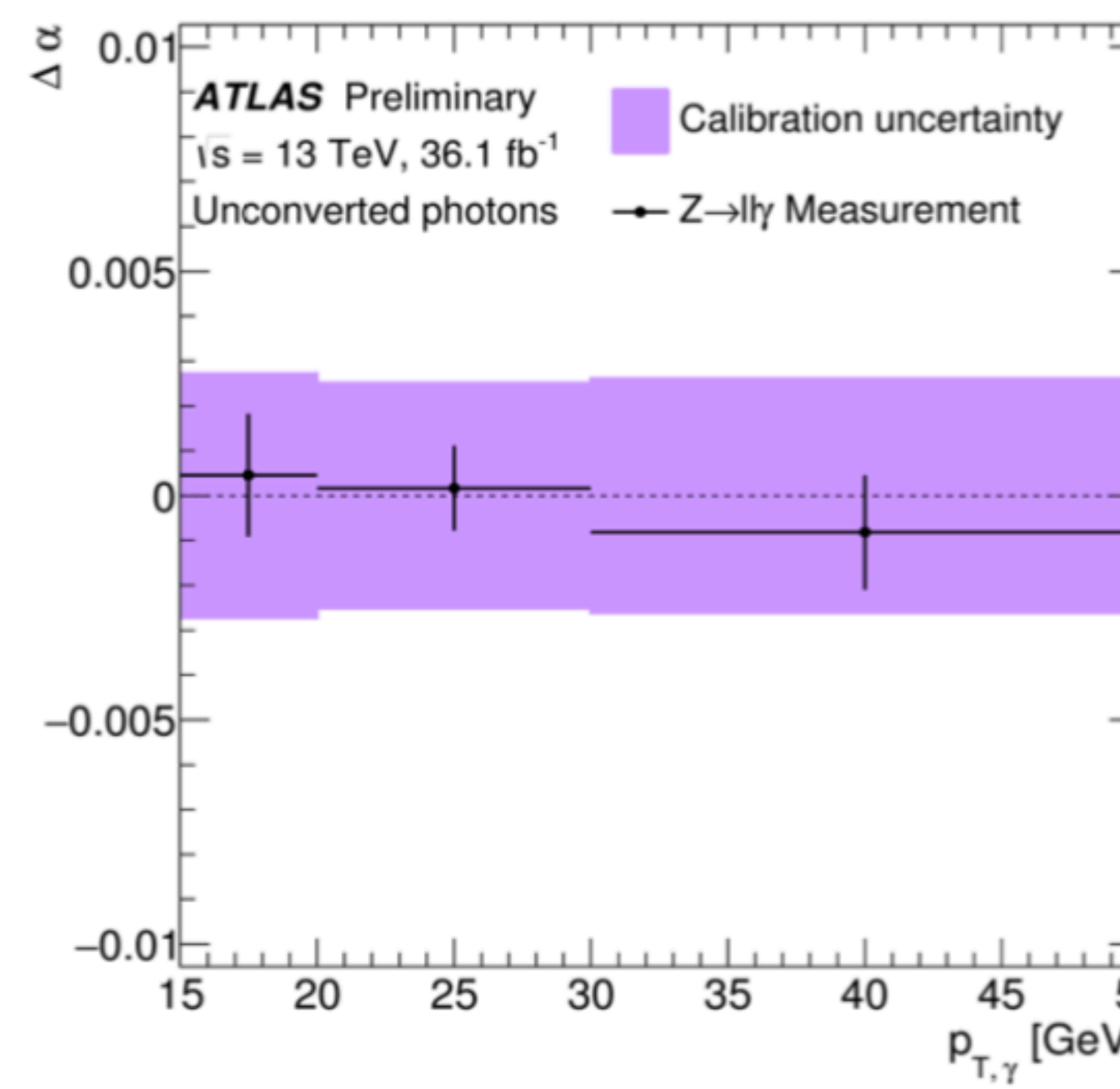
$J/\Psi \to ee$:

- Probe extrapolation to low energies
- Overall agreement within 1%



$Z \to ee\gamma$ & $Z \to \mu\mu\gamma$:

- Probe photon energy scale
- Overall agreement within 0.3%

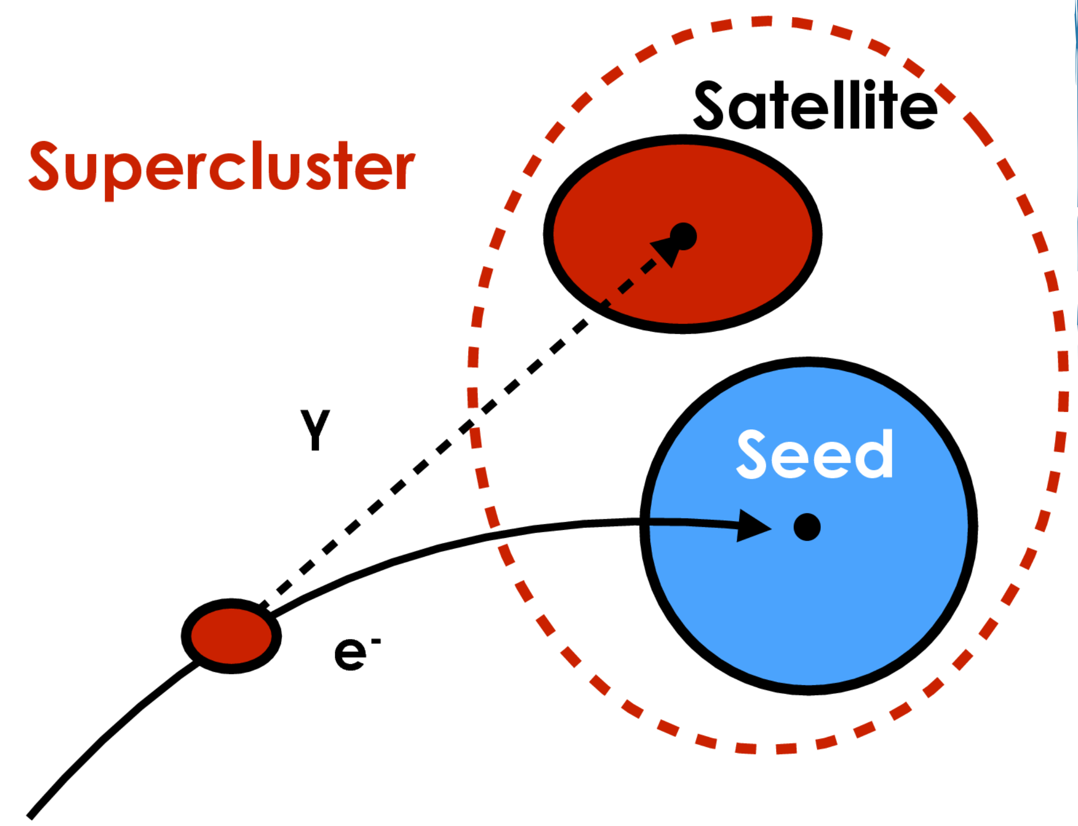


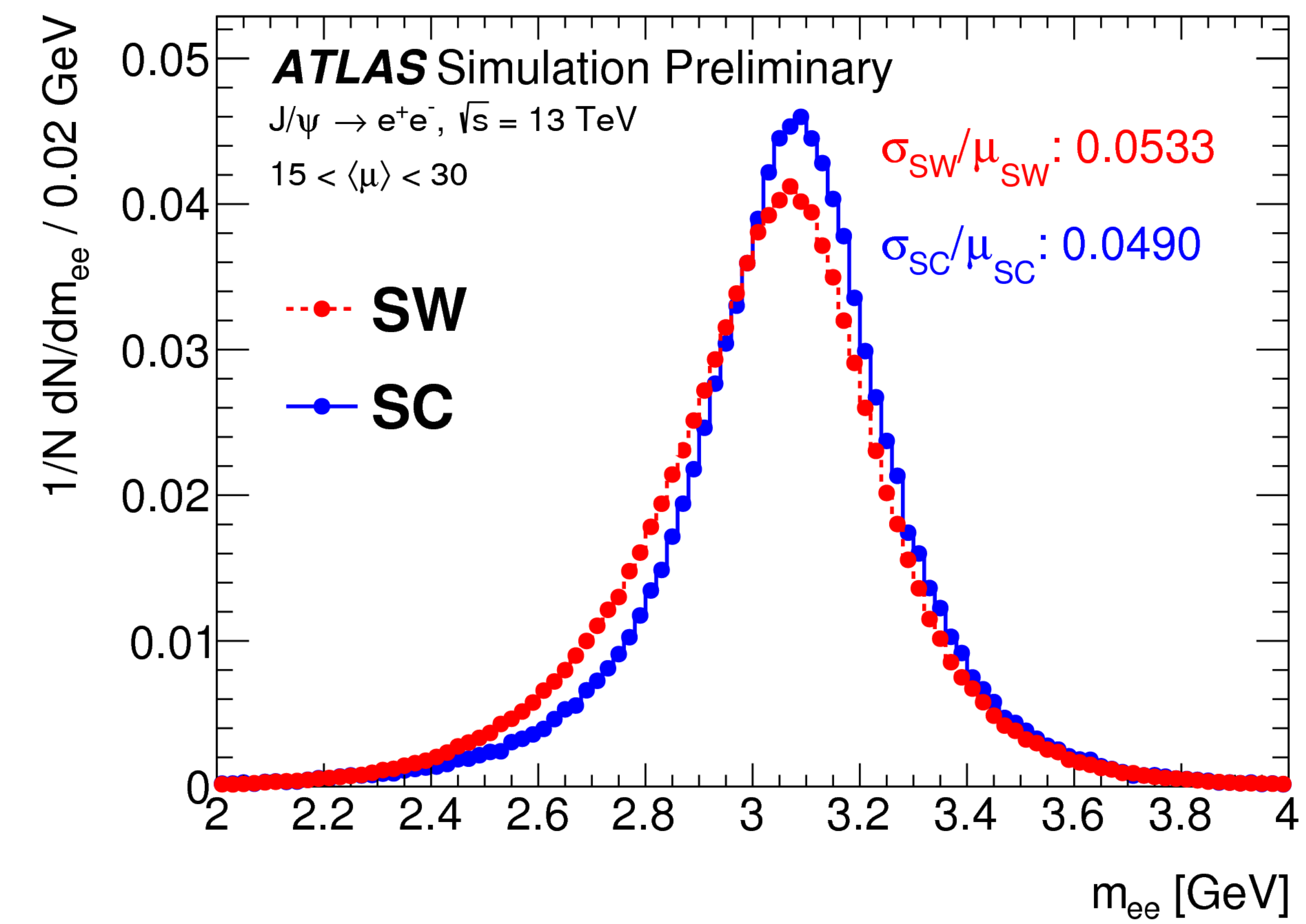
New developments: Super-Cluster reconstruction

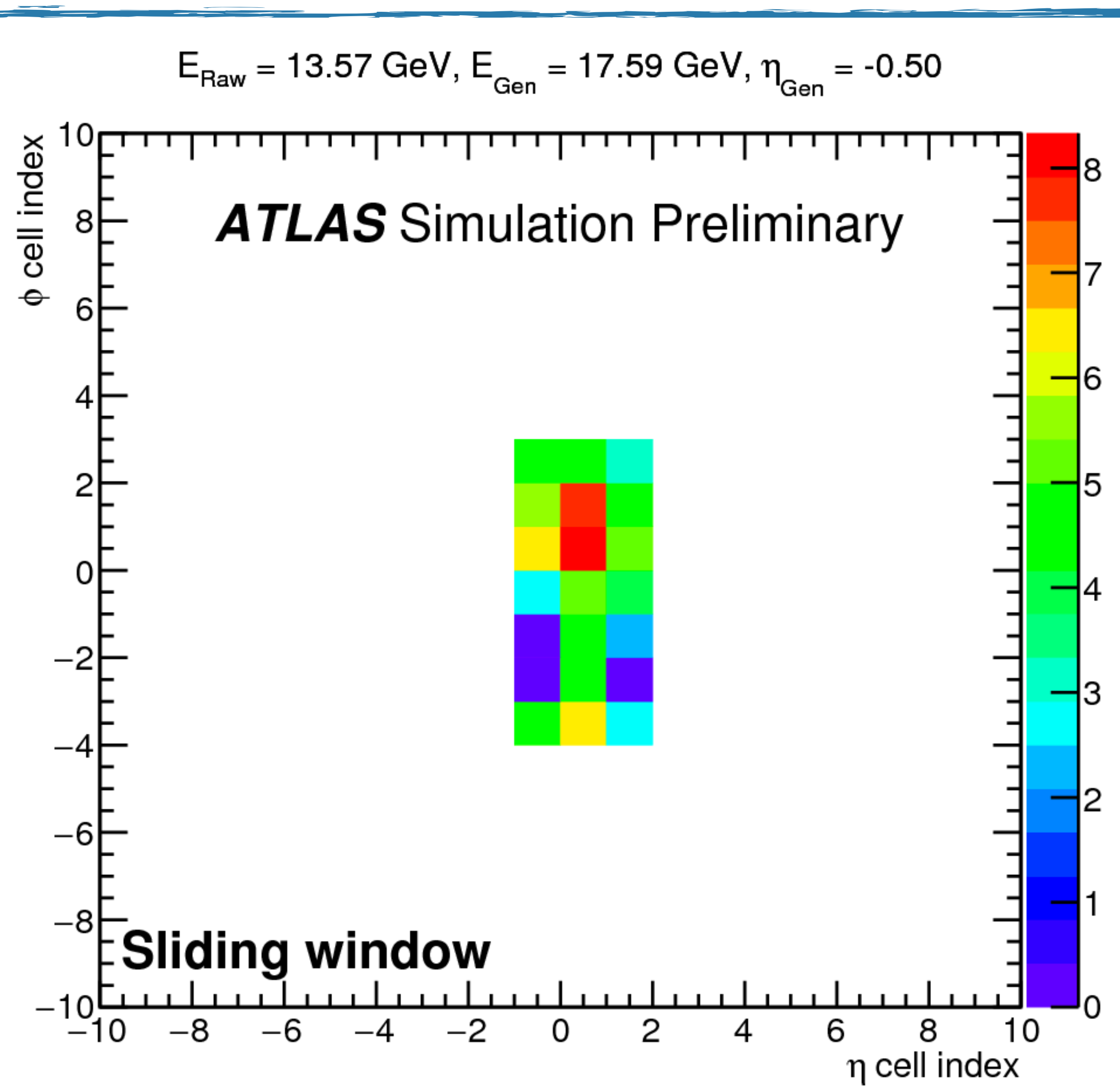
- Previous reconstruction approach: fixed size clusters ($\Delta\eta \times \Delta\phi = 3\times7$ (5×5) barrel (endcap))
- New approach: Super-Clusters
  → Dynamical, topological cell clustering
  → Recovery of Bremsstrahlung loss

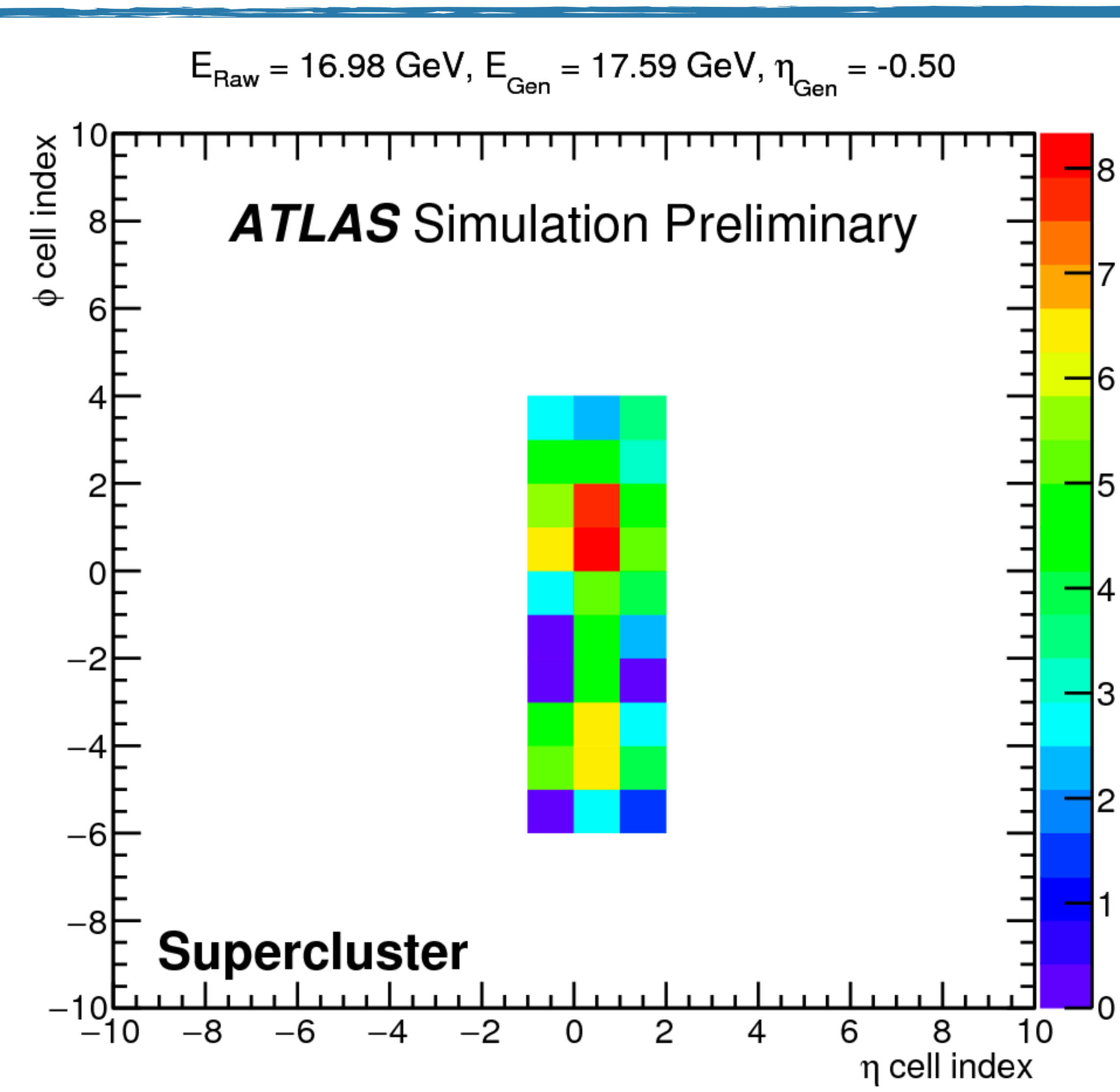
→ Energy resolution improved by up to 30%

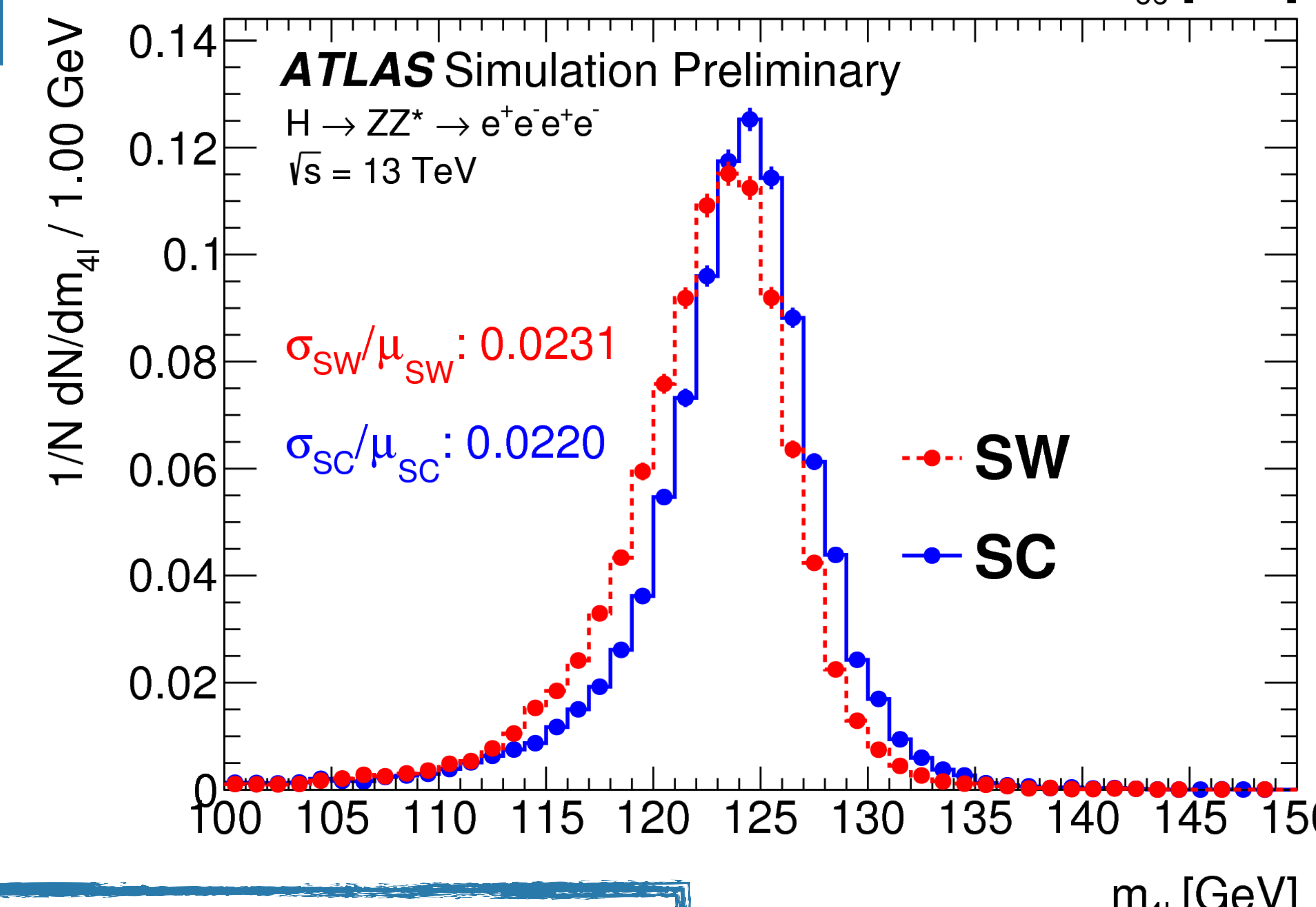
→ Mass resolution (*J/Ψ, Z, H*) improved by 5-10%











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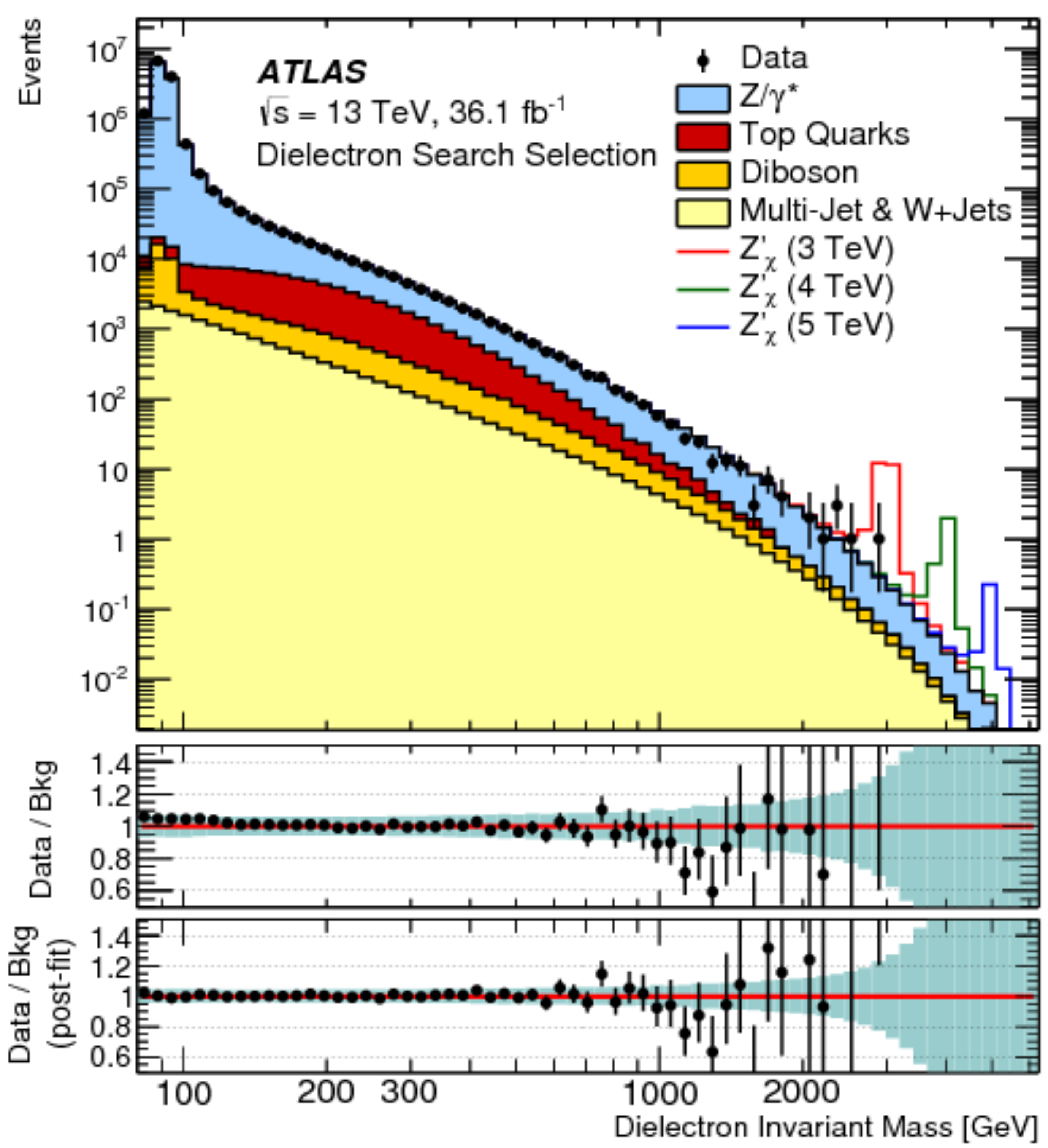
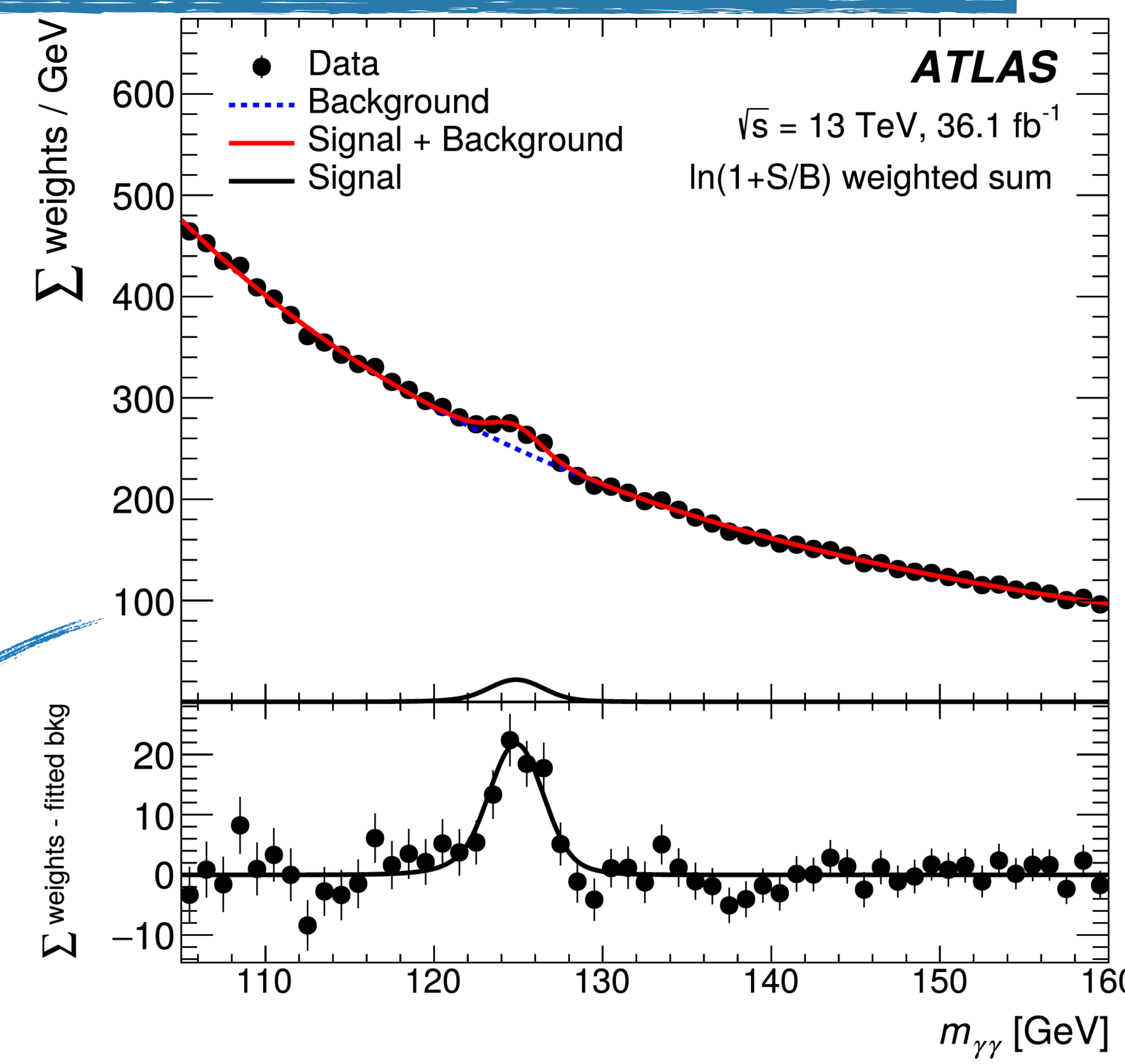
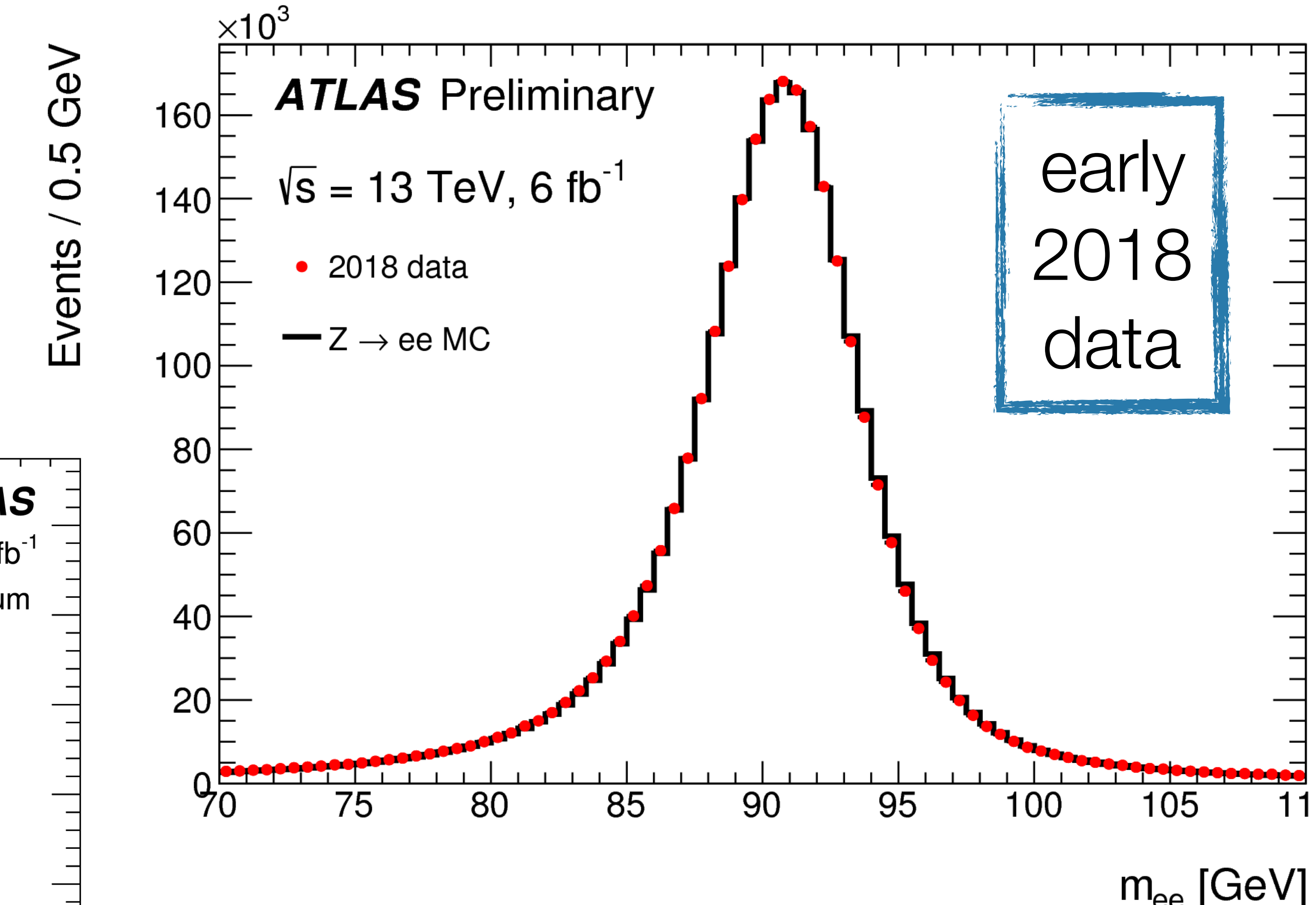
Impact on physics analyses & first look into 2018 data

- 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





Source	Systematic uncertainty in m_H [MeV]
EM calorimeter response linearity	60
Non-ID material	55
EM calorimeter layer intercalibration	55
$Z \to ee$ calibration	45
ID material	45
Lateral shower shape	40
Muon momentum scale	20
Conversion reconstruction	20
$H \to \gamma\gamma$ background modelling	20
$H \to \gamma\gamma$ vertex reconstruction	15
e/γ 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, …

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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 $Z \to ee$ & $H \to \gamma\gamma$ have different fractions of objects in MG

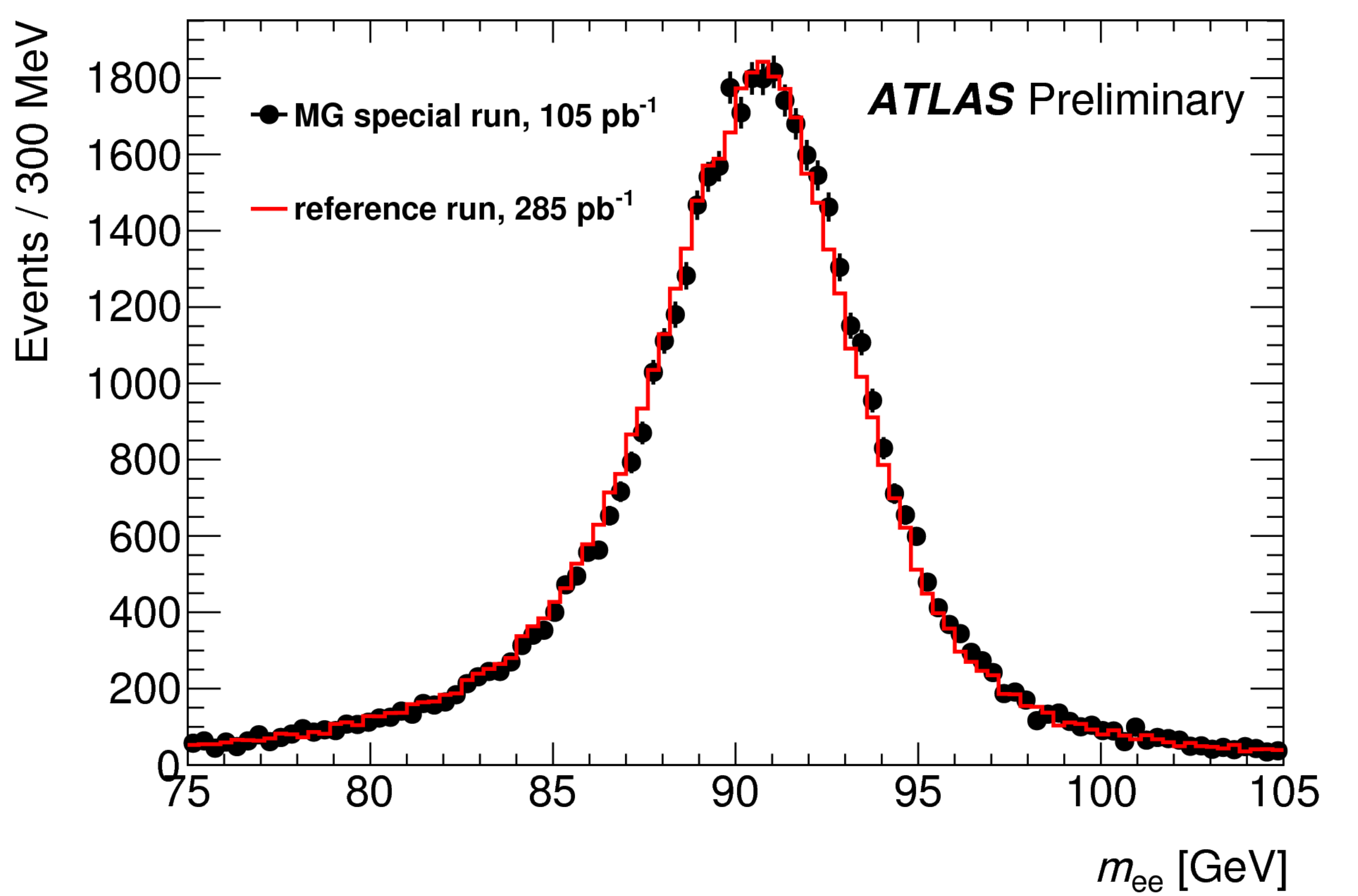
- Linearity of read-out electronics in each gain better than 0.1% but relative inter-calibration of different read-out gains can have large impact

→ Measuring $Z \to ee$ 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