In-situ Calibration of the ATLAS Electromagnetic Calorimeter with Z $\rightarrow$ee Events

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On behalf of the ATLAS collaboration

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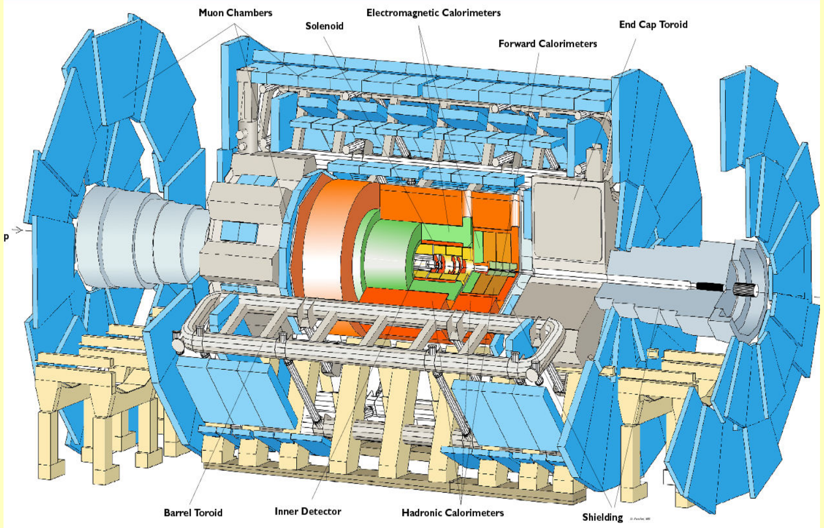
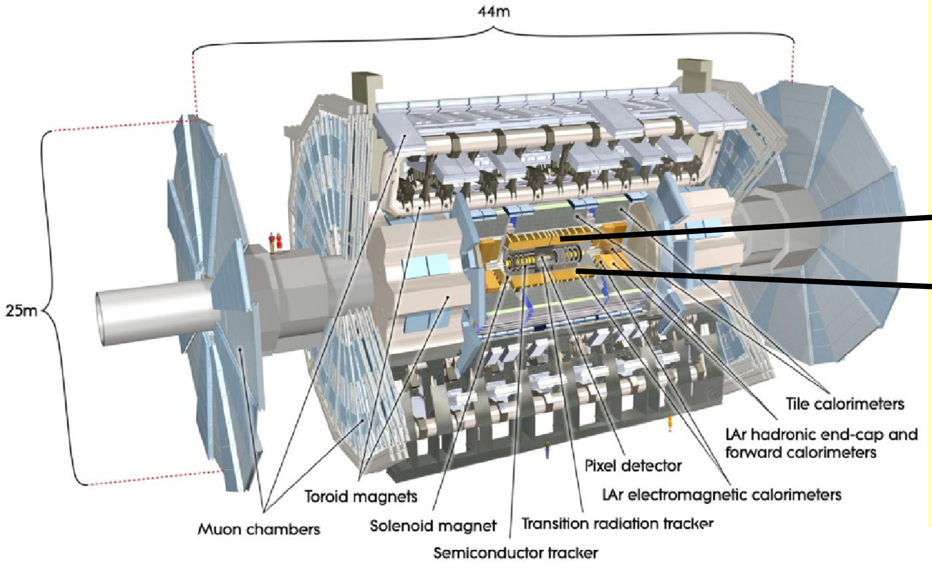
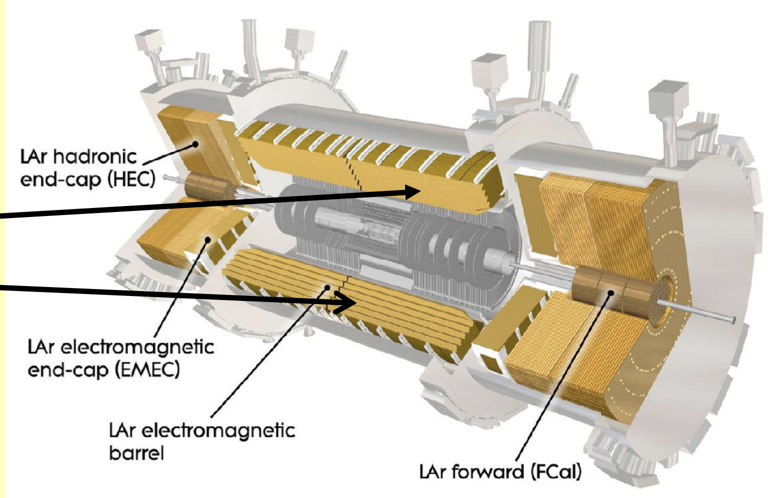


Outline

- Introduction and Motivation
- Calibration method
- Results from Monte Carlo data
  - Assessment of in-situ performance with initial data
  - systematics
- Conclusions and outlook

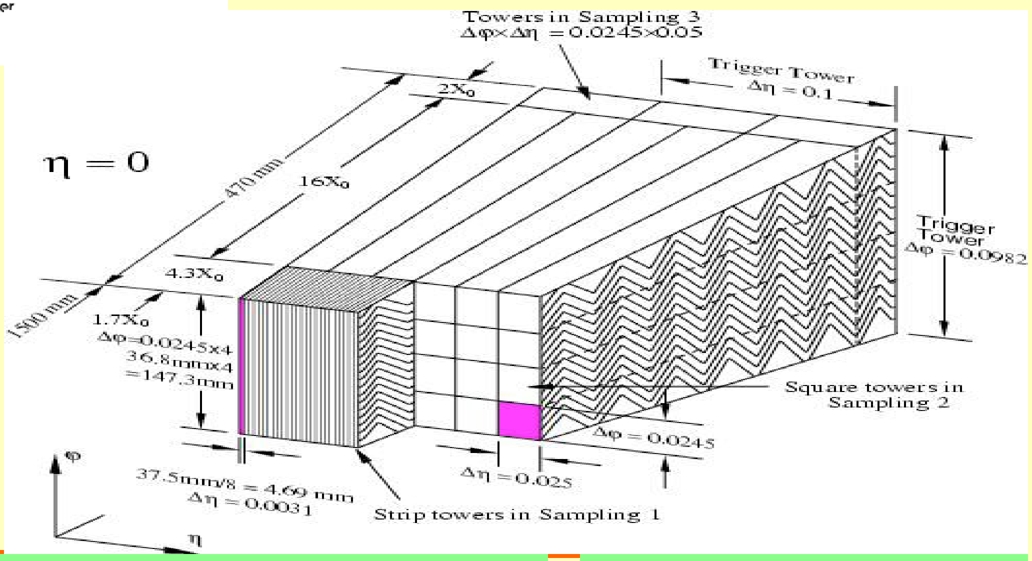
Liquid Argon(LAr) Calorimeter





$$\eta = -\ln \tan\left(\frac{\theta}{2}\right)$$

Cell/Cluster size in middle layer:
Cell size (Δη x Δϕ)=0.025x0.025
Electron cluser (Δη x Δϕ)=0.075x0.175
Photon cluser (Δη x Δϕ)=0.075x0.125



Motivation

- H→ γγ : to observe signal peak on top of huge γγ background
  - places severe requirements on the performance of the EM Calo.
  - need mass resolution of ~ 1.2%
    - response uniformity (i.e. total constant term of energy resolution) ≤ 0.7% over |η| < 2.4
- Energy resolution is parameterized as

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

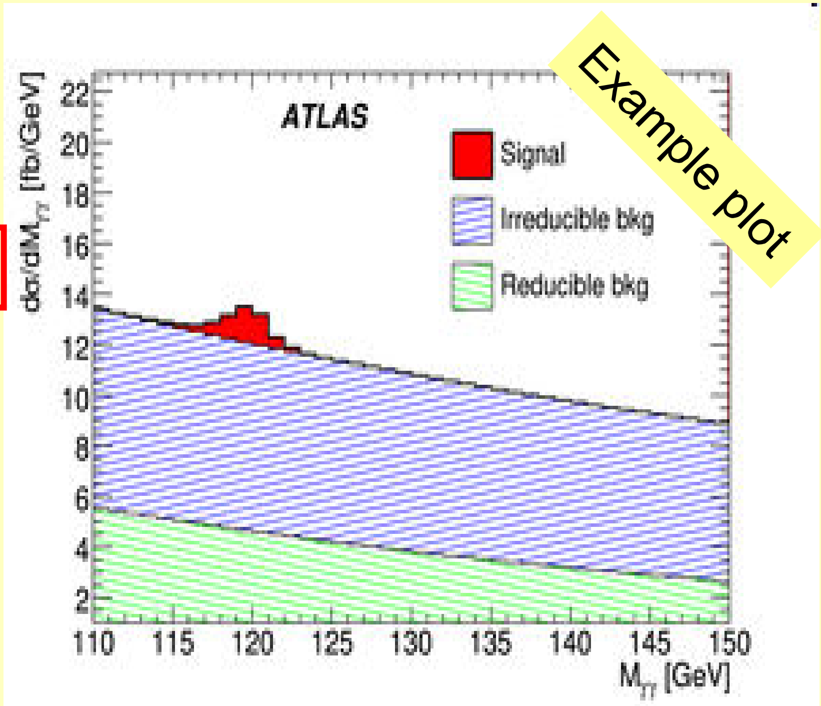
where $c_{tot} = c_L \oplus c_{LR} \leq 0.7$

- From the test beam the local constant(c_L) term ~0.5%

⇒ the "long range" zone to zone non-uniformity(c_{LR}) must be ≤ 0.5%

⇒ zone is $\Delta\eta\times\Delta\phi$=0.2×0.4

- Long range non-uniformities can be corrected using electrons from Z boson decays

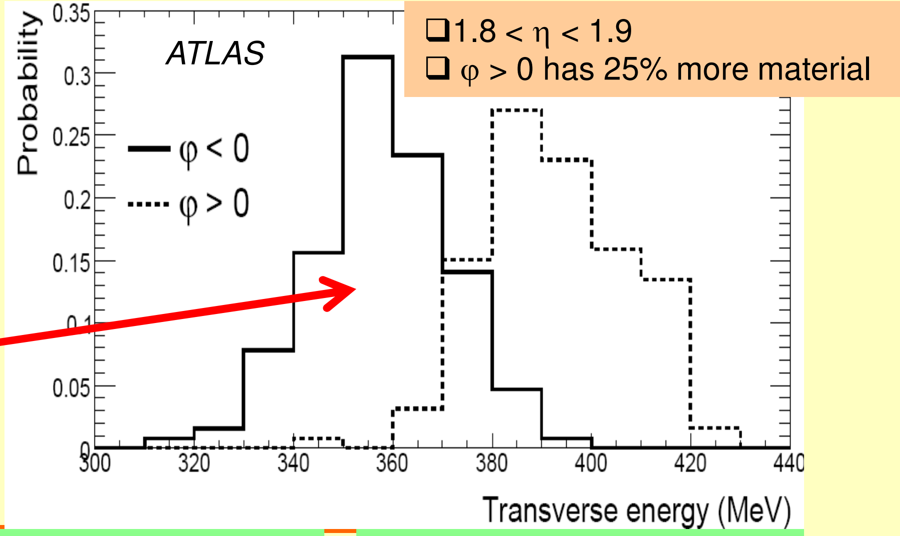


Not using sophisticated methods developed by Higgs group for background subtraction

In-situ calibration also has to establish absolute EM scale to an accuracy~0.1%

A bit of details

- Some sources of long-range non-uniformities:
  - High voltage variation due to localized calorimeter defects
  - Liquid Argon (LAr) temperature variations
  - Impurities
  - Mechanical deformation
  - Material in front of the calorimeter
- By construction the response uniformity is within~1-2% assuming perfect knowledge of the material in front of calorimeter
- Material could be mapped out using different methods:
  - photon conversions, energy flow measured in layers of EM calorimeter
- Transverse energy accumulated in $\Delta\eta \times \Delta\phi = 0.1 \times 0.025$ middle-layer



Description of the Intercalibration Method

- The basic idea is to constrain the measured di-electron invariant mass to the Z boson line shape
- Method:
  - Divide EM Calorimeter into 384 regions (zones) of $\Delta\eta \mathrm{x} \Delta\phi = 0.2 \mathrm{x} 0.4$
  - For region "i", the long range constant term " α" in terms of reco. energy

$$E_i^{reco} = E_i^{true}(1+\alpha_i)$$

di-electron mass in pair of region (i,j):

$$M_{ij}^{reco} \approx M_{ij}^{true}\left(1+\frac{\alpha_i+\alpha_j}{2}\right) = M_{ij}^{true}\left(1+\frac{\beta_{ij}}{2}\right)$$

$$\beta_{ij} \equiv \alpha_i + \alpha_j$$

- Solve for β's by minimizing the log-likelihood,

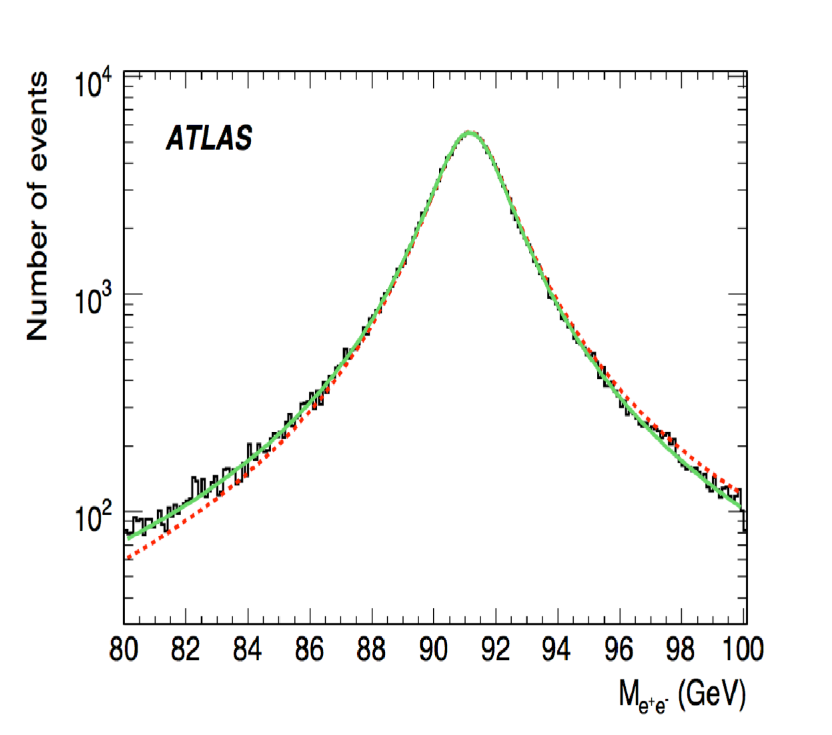
$$-\ln L = \sum_{k=1}^{N_{ij}} -\ln L_k\left(\frac{M_k}{1+\frac{\beta_{ij}}{2}}\right)$$

- Where L_k quantifies the compatibility of di-electron mass M_k in event "k" with the Z boson line shape

Solve for α's with least squares method

Z boson line shape

- Using Z boson line shape as a reference
  - Line shape is modeled with relativistic Breit-Wigner
  - Corrected with parton luminosity factor to best describe the Z line shape in pp collision
  - Convolution with a gaussian to take into account finite resolution of the calorimeter
- Can also use Z mass distribution using ideal data (understood material, aligned detector)



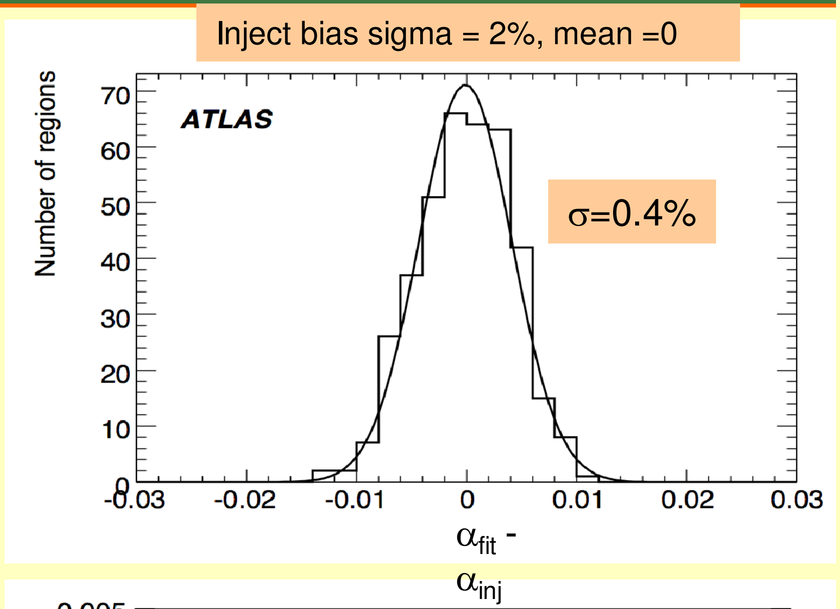
In the following slides "α" means long range calibration constants

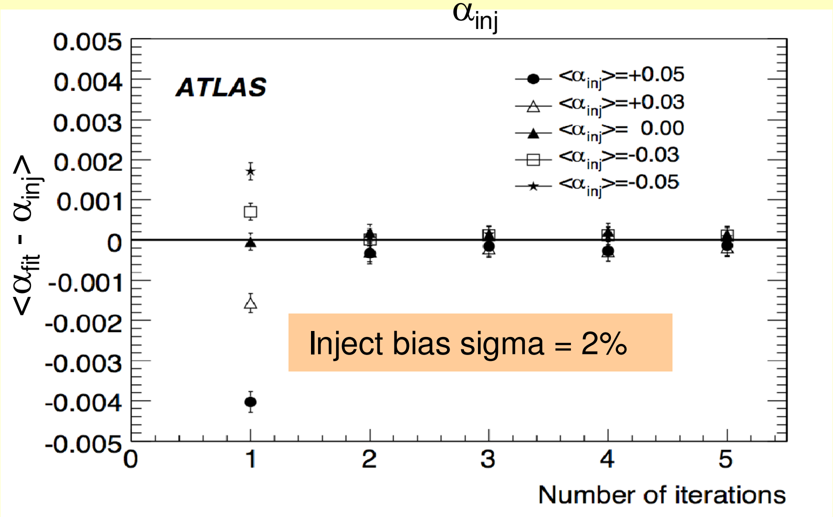
Monte Carlo Generator Level Tests

- Events generated with Pythia 6.403
  - Tested the method with 50K events
  - Smear electron energy as

$$\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}}$$

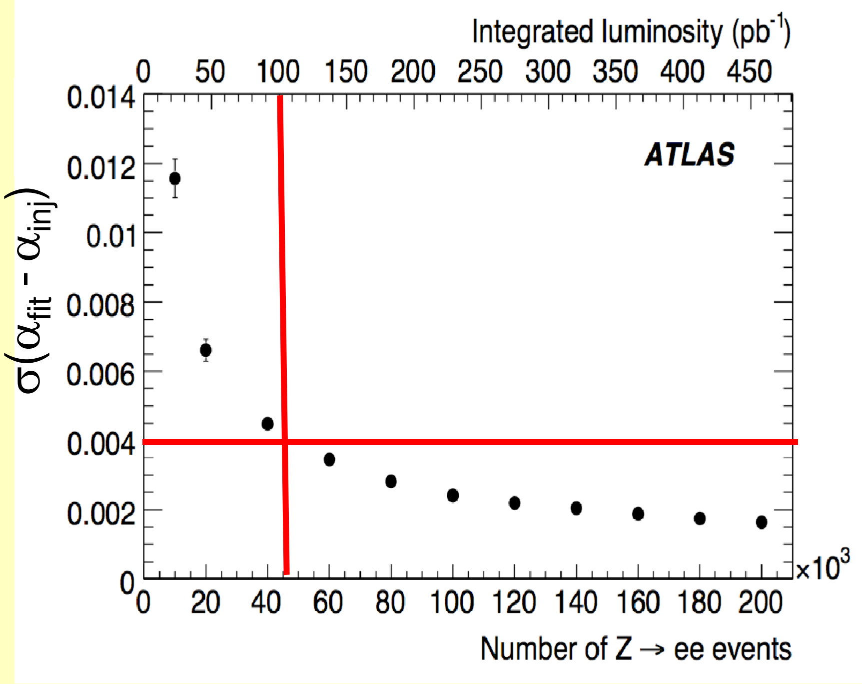
  - Selection cuts:
    - at least one electron with $p_T > 10$GeV, $|\eta| < 2.4$
    - di-electron mass > 60 GeV
  - Fit gives an unbiased estimator of the injected "α's" for injected bias of mean=0, sigma=2%
  - For inject bias of mean=-3%, bias on energy scale 0.1%
  - Performing a second iteration gives unbiased estimator of "α"





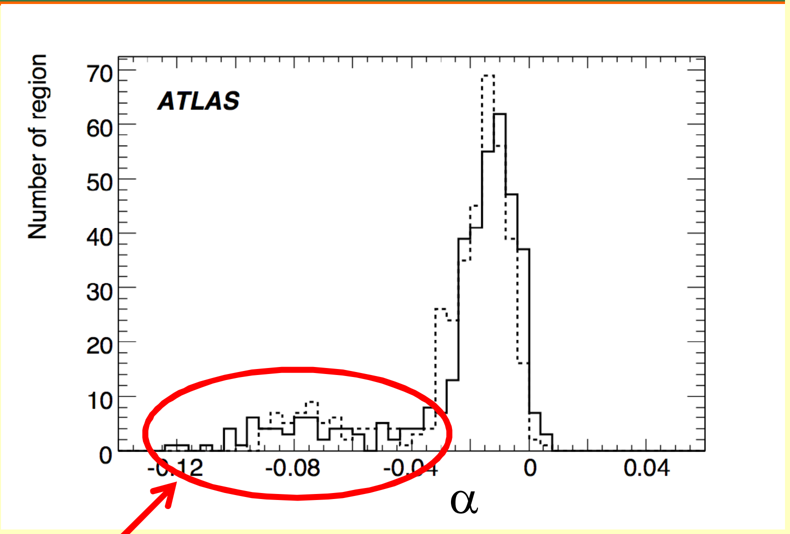
Constant term as a function of luminosity

- Injected gaussian bias of mean=0., sigma=2%
- At 100pb^{-1} long range constant term~0.4%
- Combining with local term 0.5% gives total constant term ~0.6%
- assume perfect knowledge of material in front of calorimeter

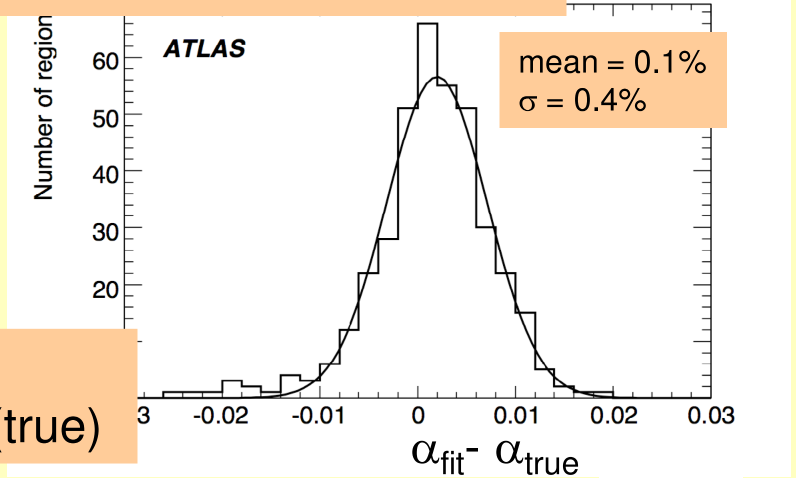


Results from realistic MC simulation

- Results reported for ~200pb^{-1} pseudo-data
  - Events were simulated/reconstructed with Atlas misaligned geometry
  - Added extra material in the Inner Detector and Calorimeter
  - Realistic misalignment
- Selection criteria:
  - Two medium electrons
  - Opposite sign
  - p_T>20 GeV, $|\eta|$ <2.4
  - Mass window, 80< M_{ee}<100 GeV
    - Selection efficiency~21.5%



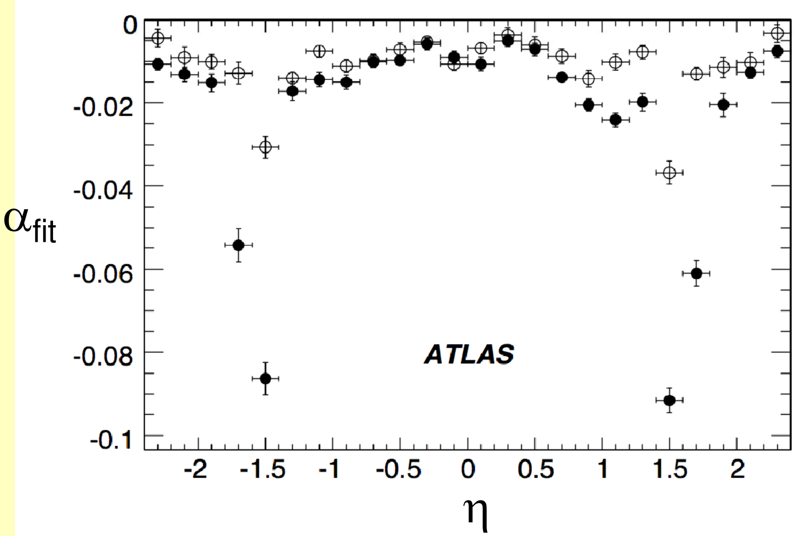
due to extra material added in simulation

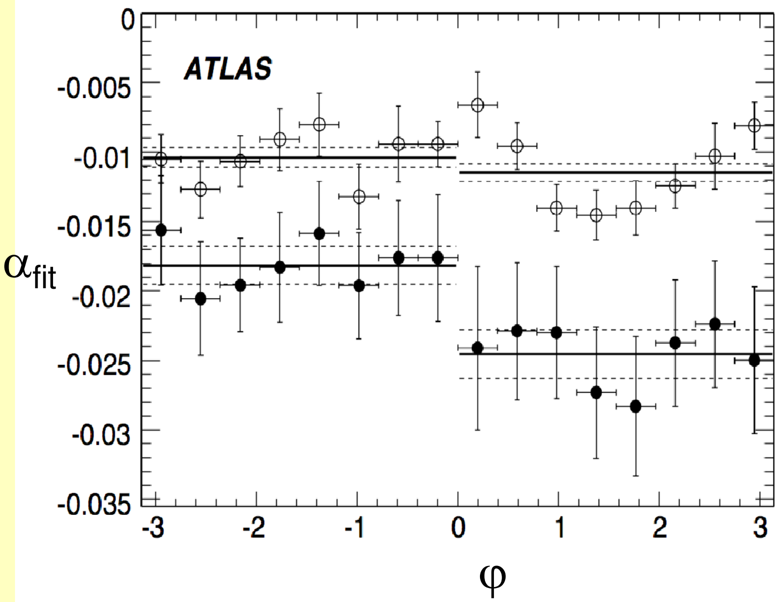


intrinsic true "α's" are derived by fitting
the peak position of (p_T(reco)-p_T(true)) /p_T(true)

Calibration constants vs eta/phi

- Comparison between nominal (open circles) and realistic (full circles) simulation
- Effect of extra material visible between positive and negative ϕ
  - Difference~0.6%

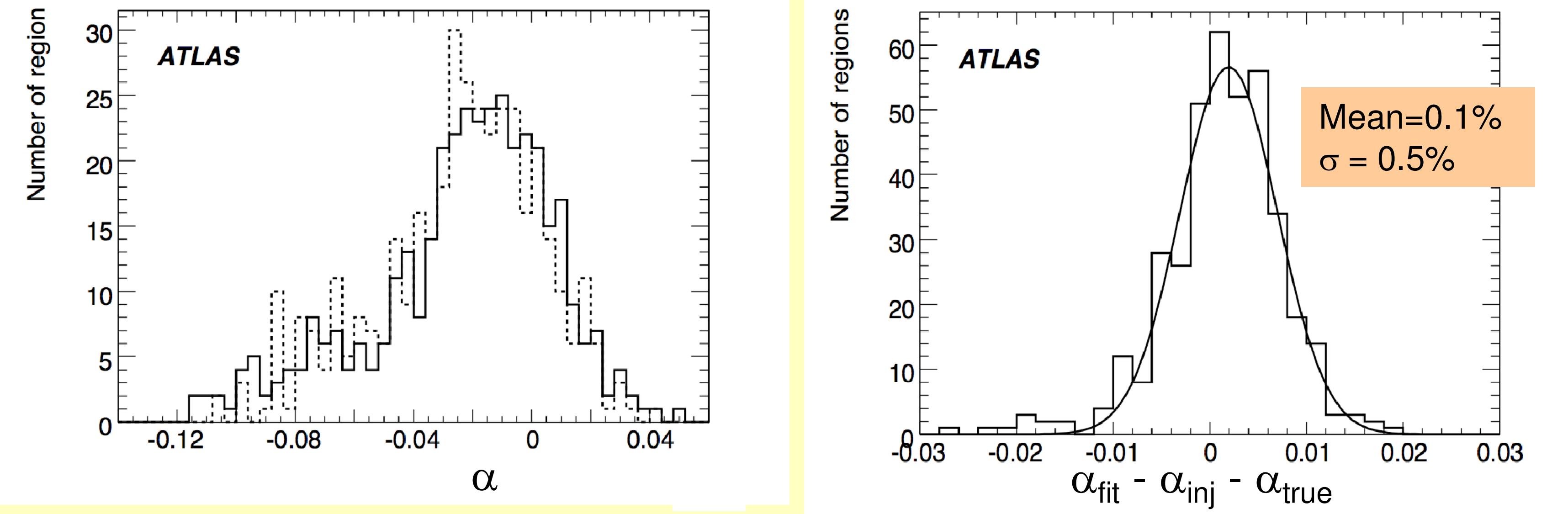




Realistic simulation plus injected bias

- Injecting bias from a gaussian distribution of mean=0., sigma=2%
- Estimating true "α's" as before using truth information
- Good agreement between data driven fitted "α's" and true alpha's
- Could recover constant term~0.5%
- Absolute energy scale accuracy~0.1%

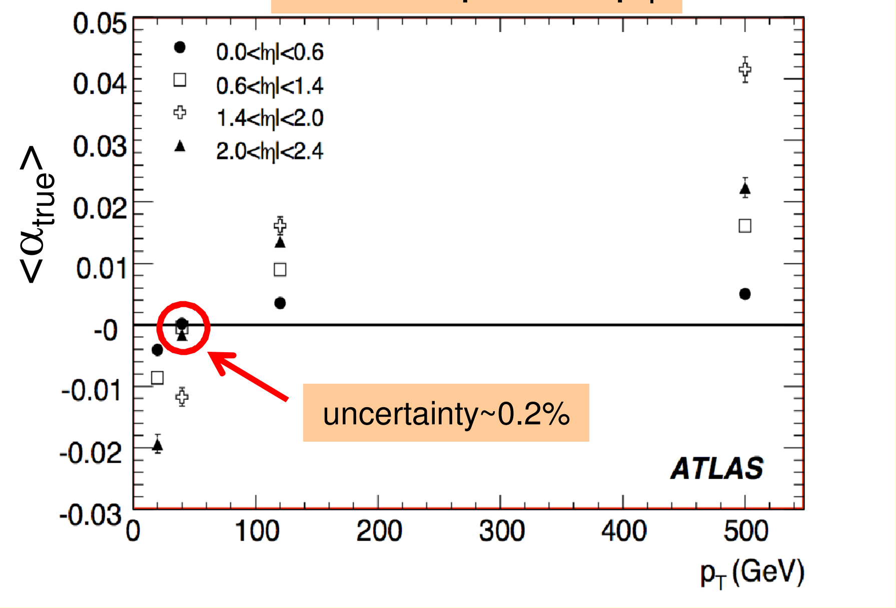
- With 200 pb^{-1} and initial non-uniformity of 2% the long range constant term is within~0.5%
- Repeating the same exercise at 100 pb^{-1} give constant term~0.8%, bias on absolute scale~0.1%



A word about systematics

- Bias due to QCD background
  - Contribution from QCD background with two jets faking electrons is small
  - Negligible effect on determination of energy scale
- Extrapolation to low or high p_T
  - Electron p_T from Z boson has peak~45 GeV
  - For electron in $|\eta|$ <0.6, p_T dependence is within ~0.5%
  - Effect is worse for non central electrons
  - Non-linearity is due to the presence of extra material
  - Study has been ongoing to cross check calibration constants in the low p_T region with J/psi→ee
- At Z boson scale uncertainty~0.2% for central electron
- For non central electron~1%

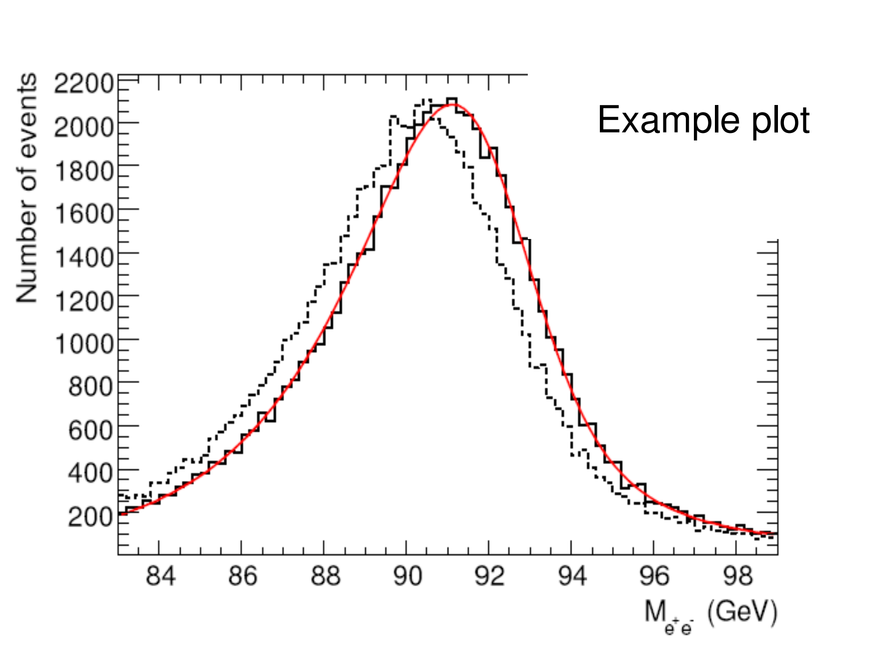
mean alpha vs p_T



Corrections derived with Z→ee were applied to single electron samples in different p_T range

Z boson mass

- The data driven way to check the performance of the calibration machinery is to compare the di-electron invariant mass before and after corrections



Conclusions

- Methods to calibrate ATLAS Electromagnetic calorimeter are in in place
- Performance studied on realistic Monte Carlo data
  - With 200pb^{-1} the long range constant term is ~0.5%
    - hence the total constant term~0.7%
  - Absolute energy scale accuracy ~0.1%
  - For central electron corrections can be extrapolated to full p_T spectrum within 0.5%
  - For non-central electrons linearity is degraded due to extra material
- Studies are in progress to improve/cross check $Z \rightarrow ee$ calibration by using isolated electrons from W boson and in the low p_T region using electrons from J/psi

Backup Slides

Backup

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

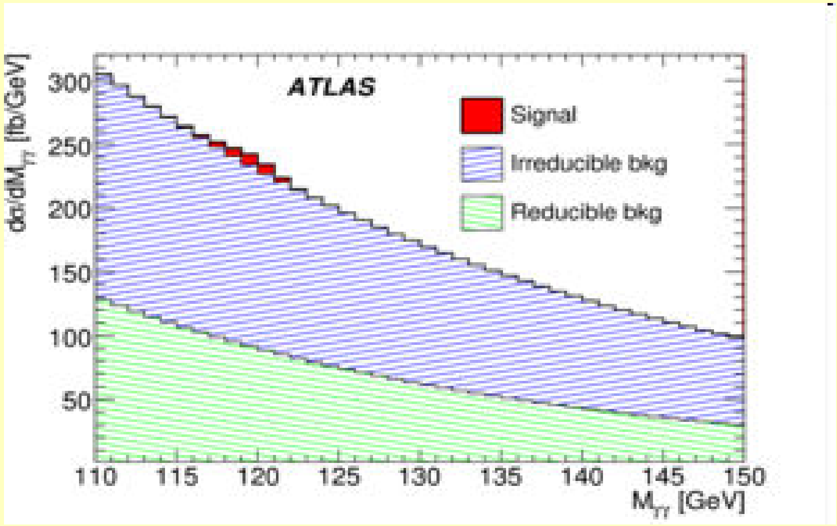
$$c_{tot} = c_L \oplus c_{LR}$$

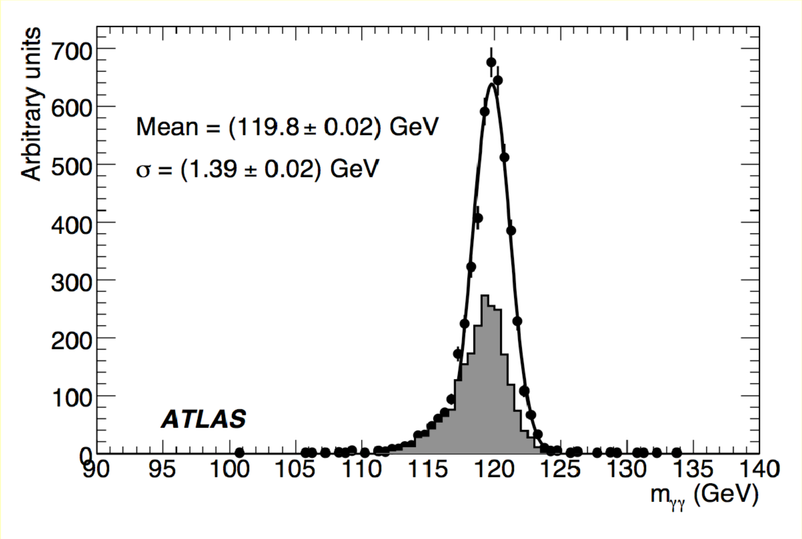
- a = stochastic term (sampling fluctuation)
- b = noise term (electronic, pile-up)
- c = constant term (non-uniformities, inter-channel calibration)

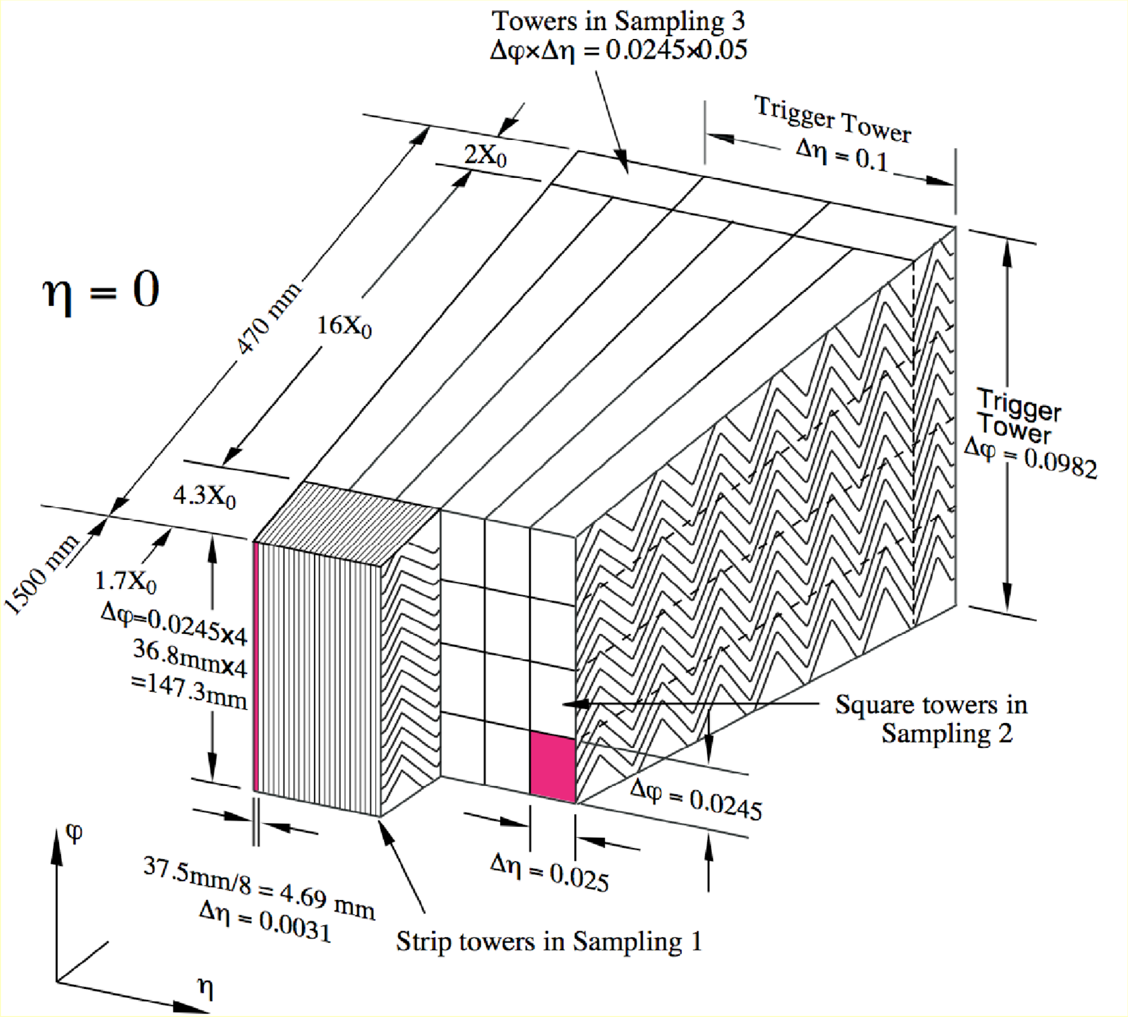
backup

Table 1.1: General performance goals of the ATLAS detector. Note that, for high-p_T muons, the muon-spectrometer performance is independent of the inner-detector system. The units for E and p_T are in GeV.

Detector component	Required resolution	η coverage	
		Measurement	Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\%\ p_T \oplus 1\%$	±2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	±3.2	±2.5
Hadronic calorimetry (jets)			
barrel and end-cap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	±3.2	±3.2
forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 < \lvert\eta\rvert < 4.9$	$3.1 < \lvert\eta\rvert < 4.9$
Muon spectrometer	σ_{p_T}/p_T=10% at $p_T = 1$ TeV	±2.7	±2.4







Towers in Sampling 3
Δφ×Δη = 0.0245×0.05
Trigger Tower
Δη = 0.1
2X0
η = 0
470 mm
16X0
Trigger Tower
Δφ = 0.0982
4.3X0
1500 mm
1.7X0
Δφ=0.0245x4
36.8mmx4
=147.3mm
Square towers in
Sampling 2
Δφ = 0.0245
φ
37.5mm/8 = 4.69 mm
Δη = 0.0031
Δη = 0.025
Strip towers in Sampling 1
η