Reconstruction of Electrons and Photons in the ATLAS Detector

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On behalf of the ATLAS collaboration

Joint Meeting of Pacific Region Particle Physics Communities
University of Hawaii

Physics requirements

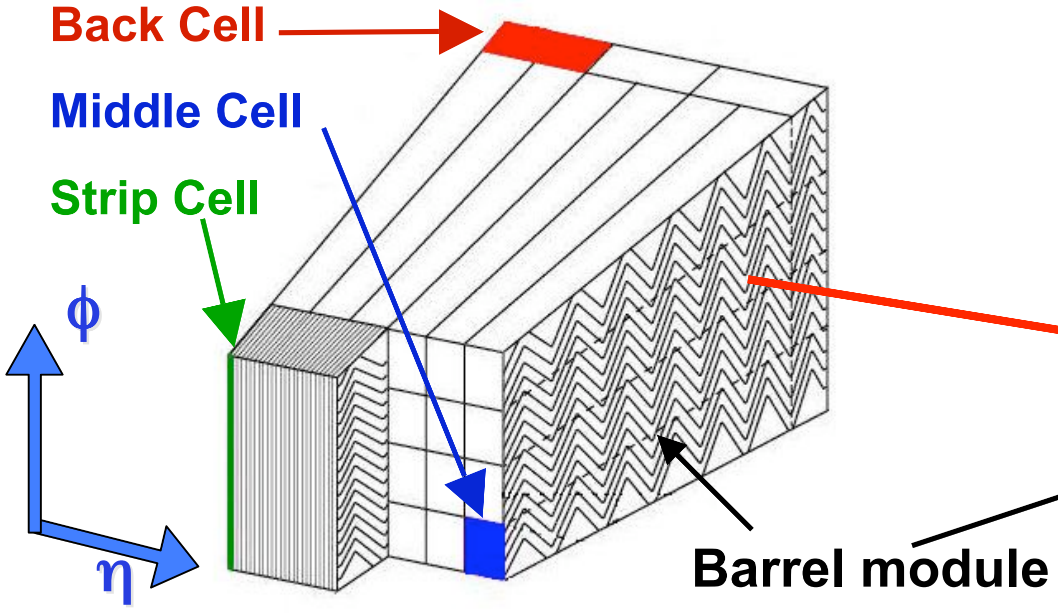
- Discovery potential of Higgs (into $\gamma\gamma$ or 4e for what concerns e/γ reconstruction) determines most of the performance requirements.
- Largest possible EM calorimeter acceptance and uniformity.
- Large dynamic range : 20 MeV…2TeV.
- Energy resolution ($e^{\pm}$,γ): $\sigma_E/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
  - → precise EM calorimeter mechanics & electronics calibration (<0.25%)…
- Linearity : < 0.5% for energies above 10 GeV.
  - → presampler (correct for dead material), layer weighting, electronics calibration
- Position and angular measurements: 50 mrad/$\sqrt{E}$ ($H \rightarrow \gamma\gamma$ mass reconstruction).
  - → Fine strips, lateral/longitudinal segmentation of EM calorimeter
- Particle id (e/jet separation): $R_{jet} \sim 10^6$ for a pure inclusive electron sample.
  - → fine calorimeter granularity.
  - → TR information from Inner Detector.
- Particle id (γ/jet separation): $R_{jet} \sim 5000$ for $E_T > 25$ GeV.
  - → fine calorimeter granularity.
  - $R(\gamma/\pi^0) > 3$ for 50 GeV p_T.

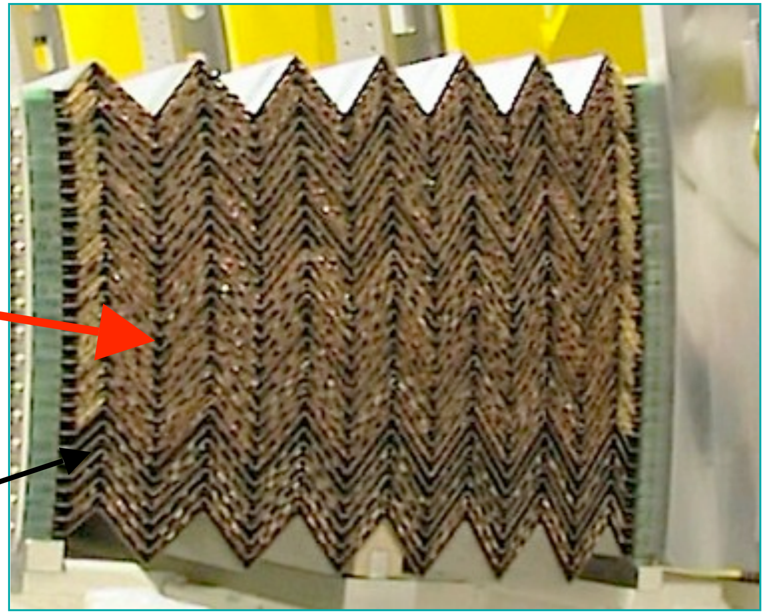
⇒ Choose LAr accordion technology.

- Photon conversion recovery efficiency > 80%.
  - → ID tracking/vertexing.
  - → E/p to separate from low multiplicity high-p_T π^0 converted γ.
- Inner detector p_T resolution of O(1%)
  - → Local ID alignment at ~1μm
  - → ID magnetic field known to 0.05% (10G). W-mass precision measurement.
  - → ID material understood to ~1% (for $W \rightarrow e\,\nu$ mostly).

⇒ Choose mixture of pixels, Si μ-strips and straw tubes for Inner Detector.

LAr EM Calorimeter description





EM Calo (Presampler + 3 layers):

- **Presampler** 0.025x0.1 (ηxϕ)
  ⇒ *Energy lost in upstream material*
- **Strips** 0.003x0.1 (ηxϕ)
  ⇒ *optimal separation of showers in non-bending plane, pointing*
- **Middle** 0.025x0.025 (ηxϕ)
  ⇒ *Cluster seeds*
- **Back** 0.05x0.025 (ηxϕ)
  ⇒ *Longitudinal leakage*

•LAr-Pb sampling calorimeter (barrel)
•Accordion shaped electrodes
•Fine longitudinal and transverse segmentation
•EM showers (for $e^{\pm}$ and photons) are reconstructed using calorimeter cell-clustering

The ATLAS Tracker

The Inner Detector (ID) is organized into four sub-systems:

Pixels

- 1 removable barrel layer
- 2 barrel layers
- 4 end-cap disks on each side
- ($0.8\ 10^{8}$ channels)

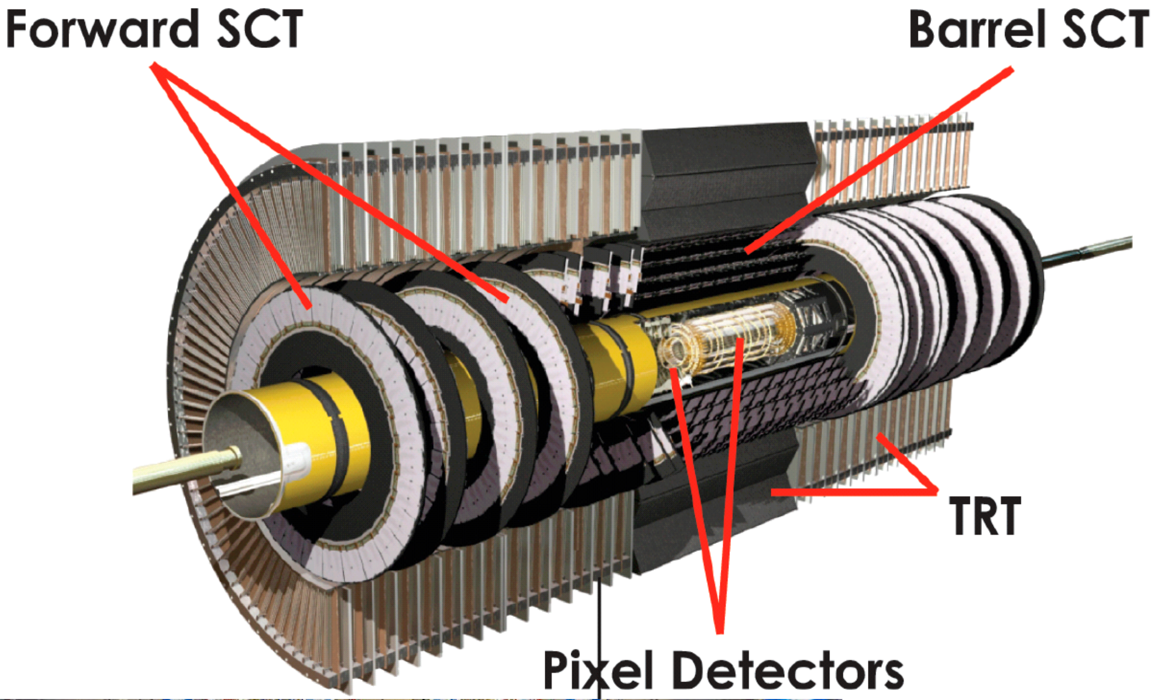
Silicon Tracker (SCT)

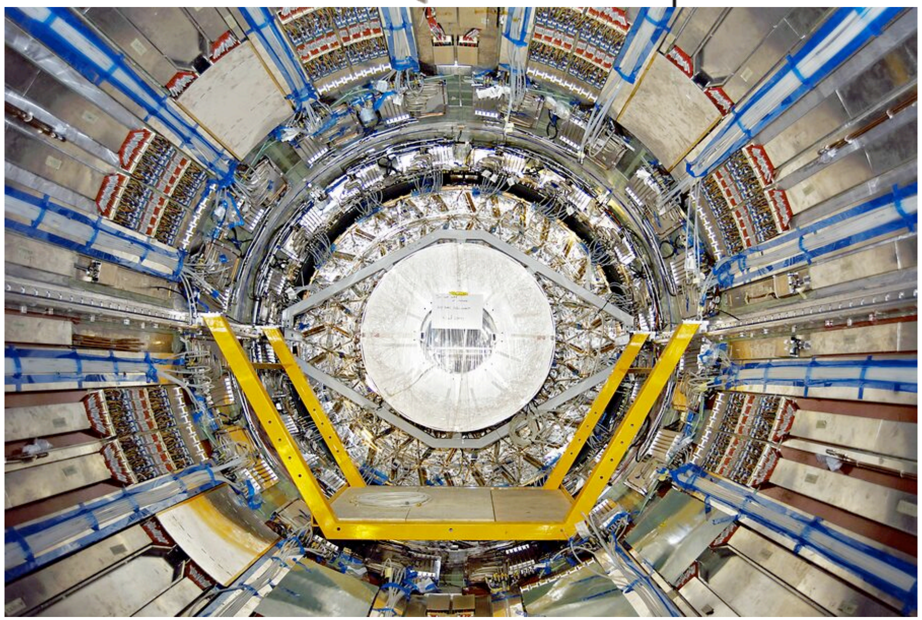
- 4 barrel layers
- 9 end-cap wheels on each side
- ($6\ 10^{6}$ channels)

Transition Radiation Tracker (TRT)

- Axial barrel straws
- Radial end-cap straws
- 36 straws per track
- ($4\ 10^{5}$ channels)

Common ID items



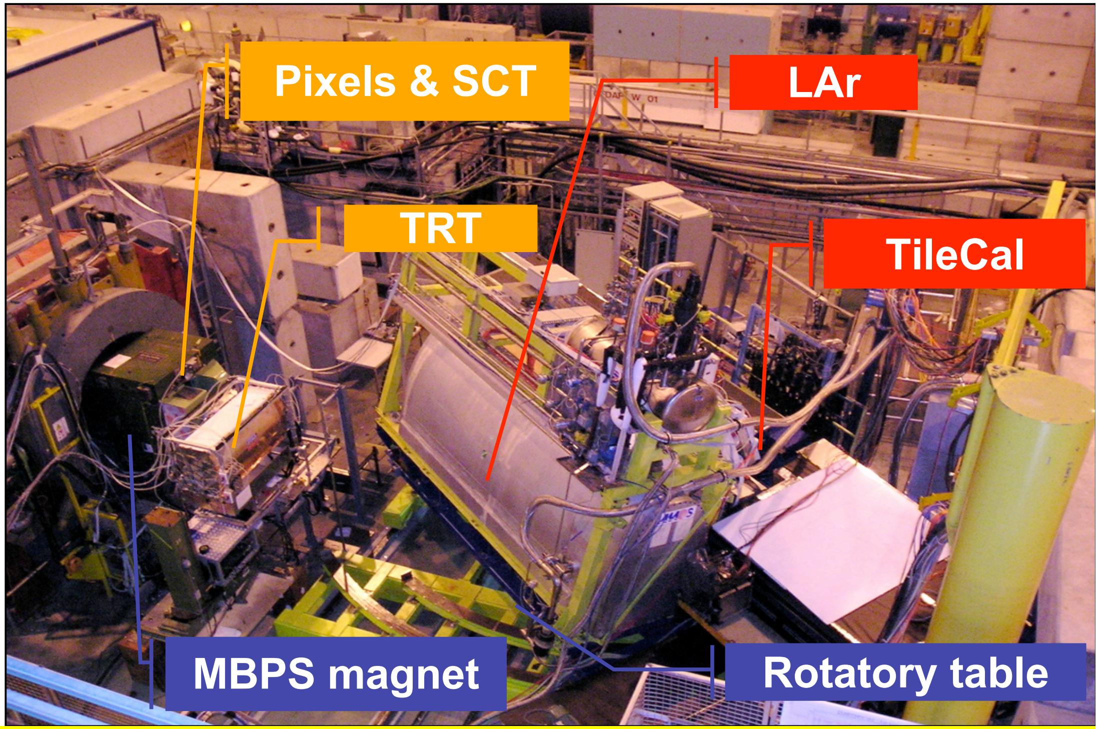


Barrel
TRT+SCT

Detector Performance:Combined Test Beam

22M events taken with the full ID/Calorimeter and validated by the offline monitoring;

- e^{+-}, π^{+-}, μ, γ
- E scan: 1 - 350 GeV
- B scan: 0 - 1.4 T
- Additional material (η = 1.6):
    - Pixel/SCT 12% X/X_0
    - SCT/TRT 24% X/X_0



CTB provides the means for studying detector performance.
Experience gained has had major impact on ATLAS-wide studies:

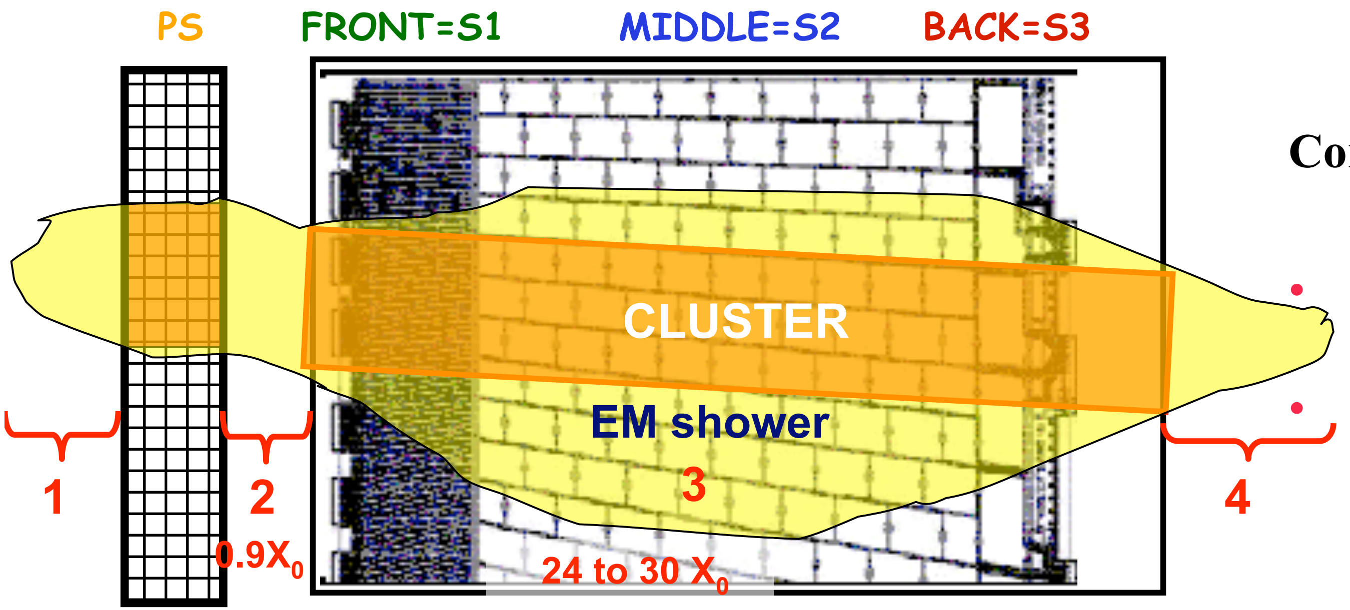
…besides the magnitude of the effort on the HW and SW integration…

1. Development of reconstruction/alignment/calibration for real detector;
2. Study of individual detector performance (efficiency, resolutions, noise);
3. Improving the simulation/digitization;

Good understanding of the above is necessary for moving towards…

4. Combined performance (material effects, particle ID, photon conversions)

EM Calorimeter energy reconstruction



Corrections due to cluster position:

- $\Delta\eta$ (S-shape modulation) ± 0.005
- $\Delta\phi$ (offset in accordion) ± 0.001

Two main clusterization methods:

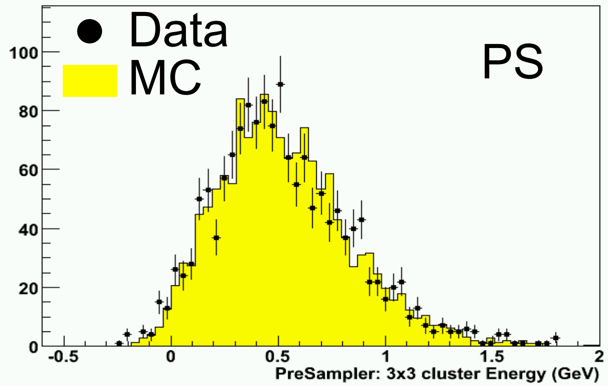
- Fixed size sliding window:
  - 3×3, 3×7… cells, 2nd sampling $\eta \times \phi$;
  - Some energy left out, especially for small sizes.
- Topological clusters:
  - Variable size cluster, minimize noise impact;
  - Additional splitting algorithm is also provided.

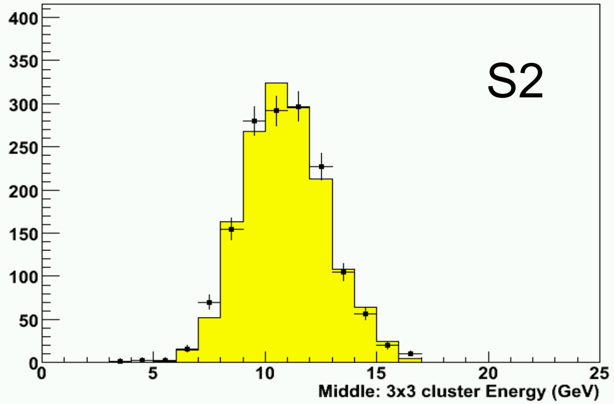
Corrections for energy losses:

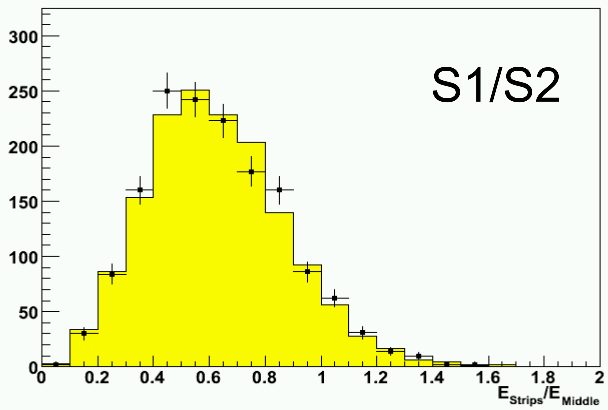
1. Before PS
2. Between PS & Calo
3. Outside cluster: depends on clustering method
4. After calorimeter: ~ Energy in BACK

2-7% overall energy correction
>7% at low energy, high η

Description of the electrons in the detector: Data *v.s.* MC





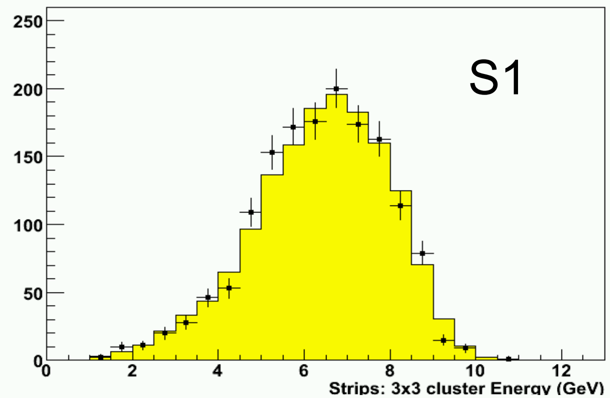


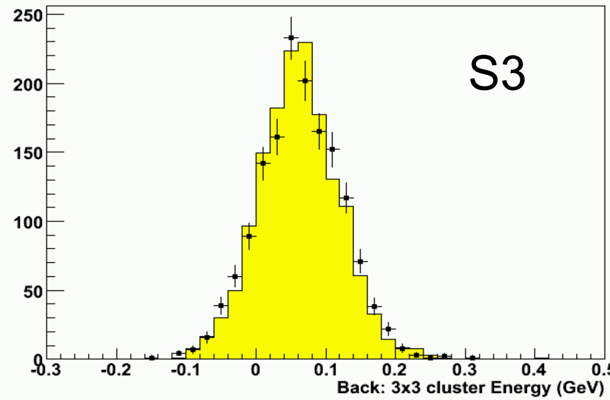
RATIOS
Data/MC

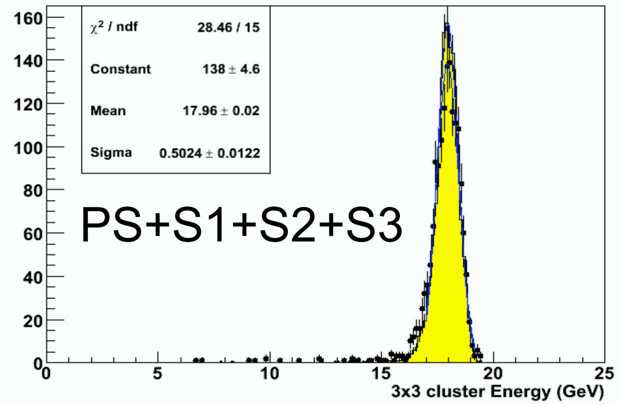
E=20GeV

E	1.0 (0.001)
PS	0.993(0.018)
S1	0.992(0.007)
S2	0.995(0.005)
S3	1.014(0.030)
S1/S2	**0.997(0.012)**

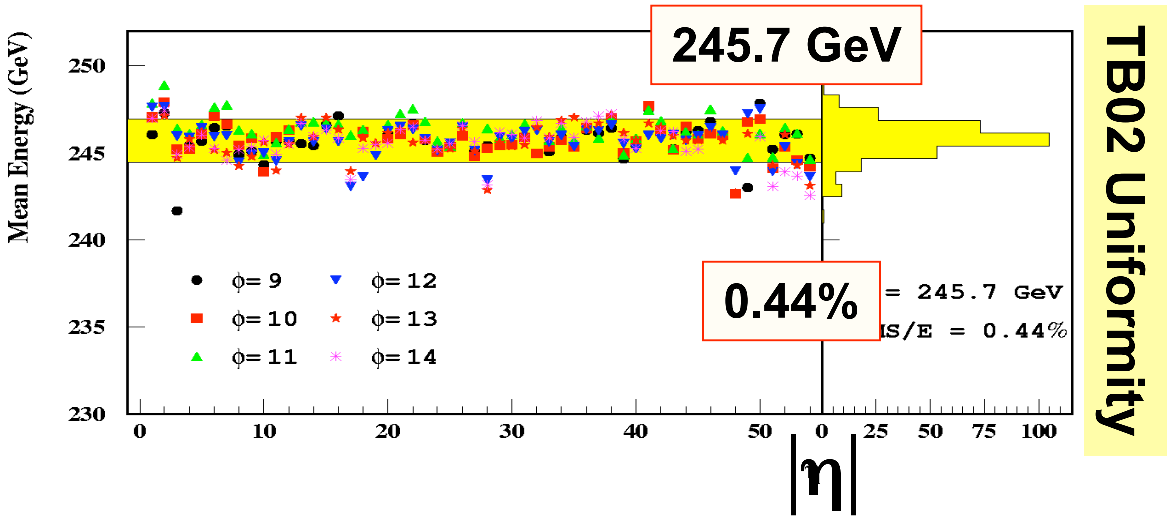
Good agreement
Up to E = 250 GeV



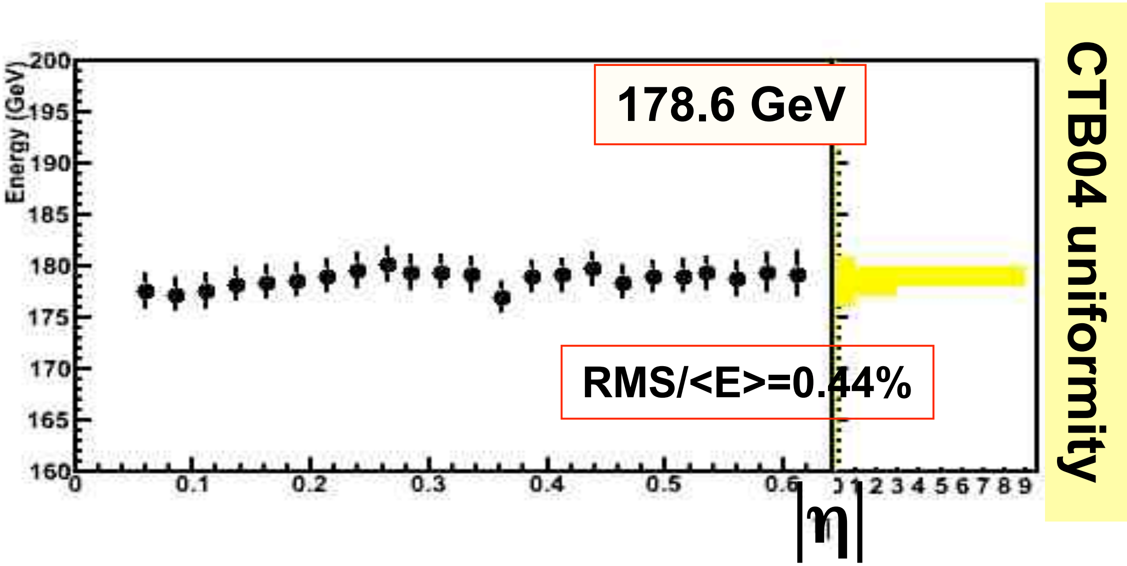




Reconstructed electron uniformity



Standalone, LAr Calorimeter test.



Combined LAr Calorimeter and Inner Detector test.

Including the whole Inner Detector in front of the LAr calorimeter results in no degradation of the reconstructed electron uniformity.

Energy Calibration

$$E_{rec} = \lambda\left(off + w_0 E_0 + E_1 + E_2 + w_3 E_3\right)$$

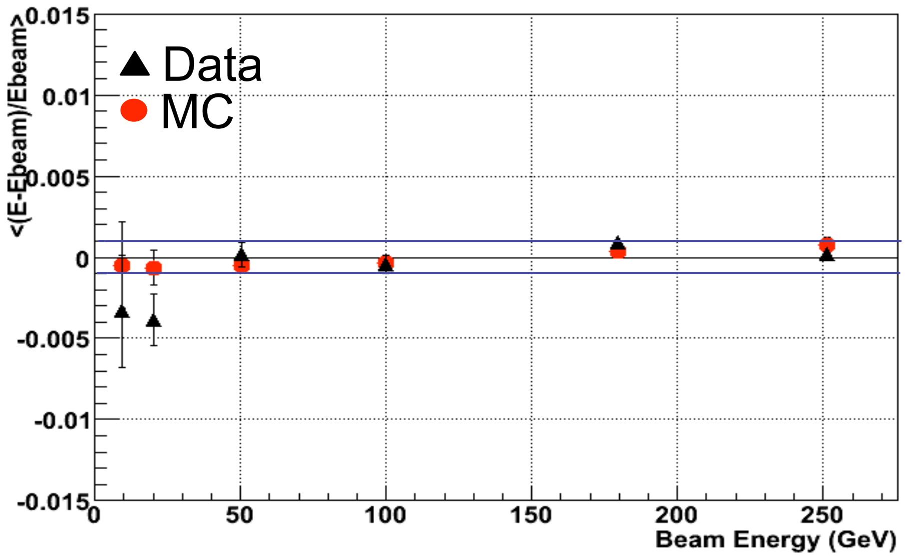
The 4 coefficients are reconstructed via χ^2 fit on a sample of single electrons in a [-2σ,+3σ] range around the most probable value of the reconstructed energy distribution:

$$\chi^2 = \sum_i^N \frac{\left(E_{rec}^i - E_{true}^i\right)^2}{\sigma_E^2}$$

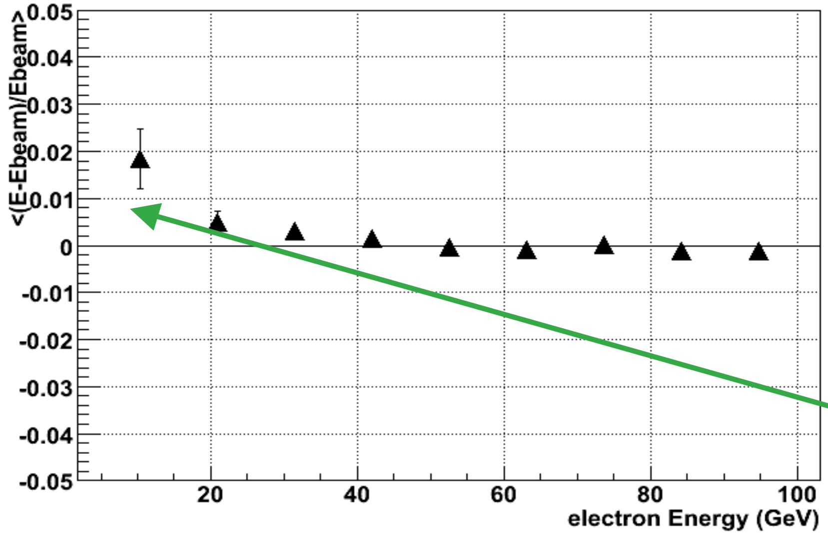
- **Simple method.**
- **4-parameters, η-dependent, energy-independent.**
- **Weights absorb different effects and their energy dependence (offset and w_0 absorb energy loss upstream the calorimeter, and between the presampler and the strips).**
- **It is not possible to unfold these effects. More complex approach relying on detailed understanding of MC under study.**

Linearity-electrons

Combined Inner Detector LAr Calorimeter test.



Linearity at the 0.2% level 10 GeV < E < 250 GeV.
Rises to ~1% when the full Inner Detector is placed in front.



Atlas study:

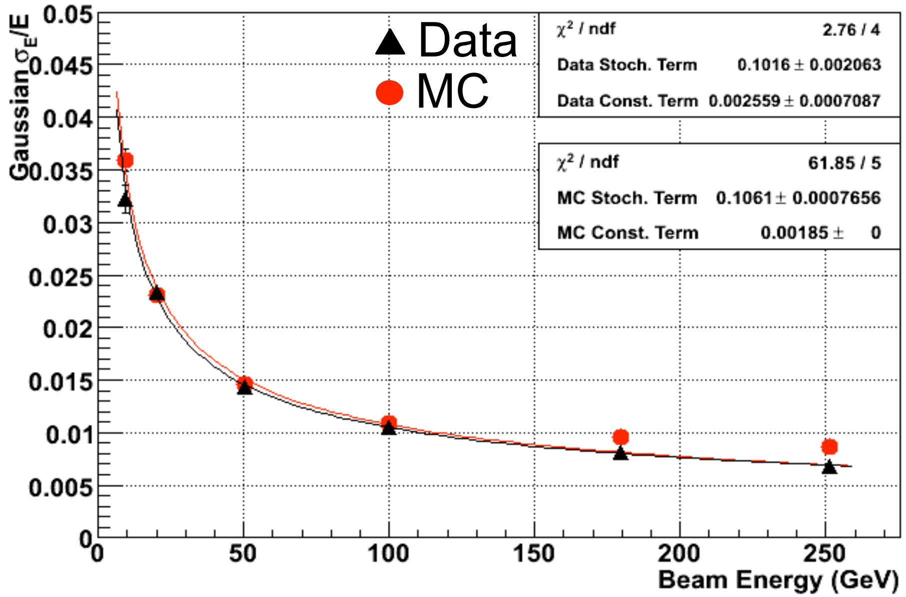
Linearity at the 0.3% level >20 GeV.
Full η-range except barrel end-cap crack

Low energy bias will be reduced when larger statistics will be used during weight evaluation

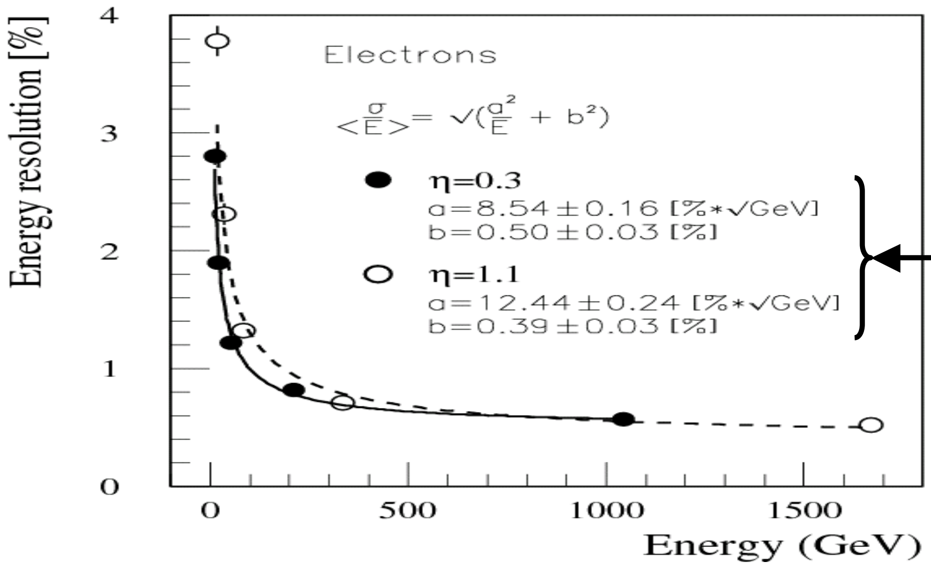
Resolution-electrons

Combined Inner Detector LAr Calorimeter test:

Stochastic Term: 10.2±0.2%
Constant Term: 0.25±0.07%



ATLAS TDR study, barrel EM

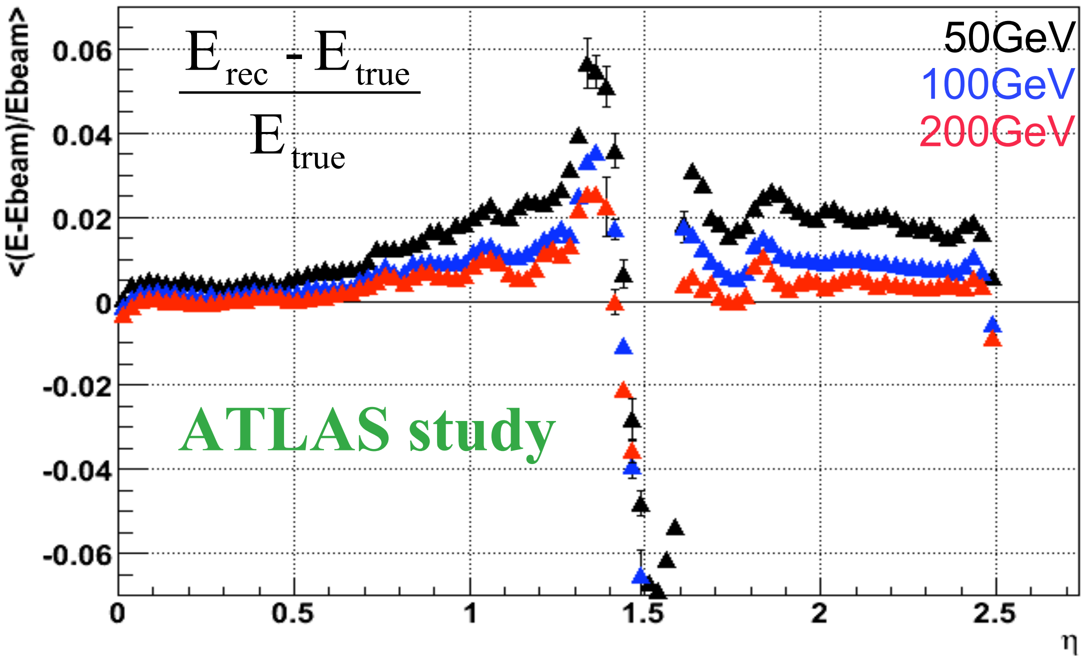


At larger η in barrel, material in front of EM Calorimeter, increases from $0.4X_0$ to $1.1X_0$

$\Downarrow$

Stochastic term in resolution increases significantly.

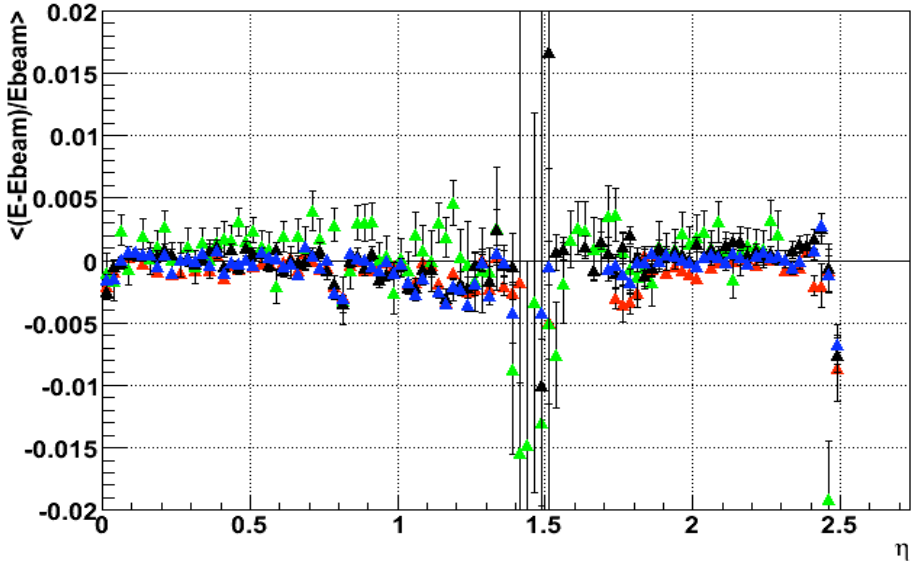
Electrons *v.s.* Photons



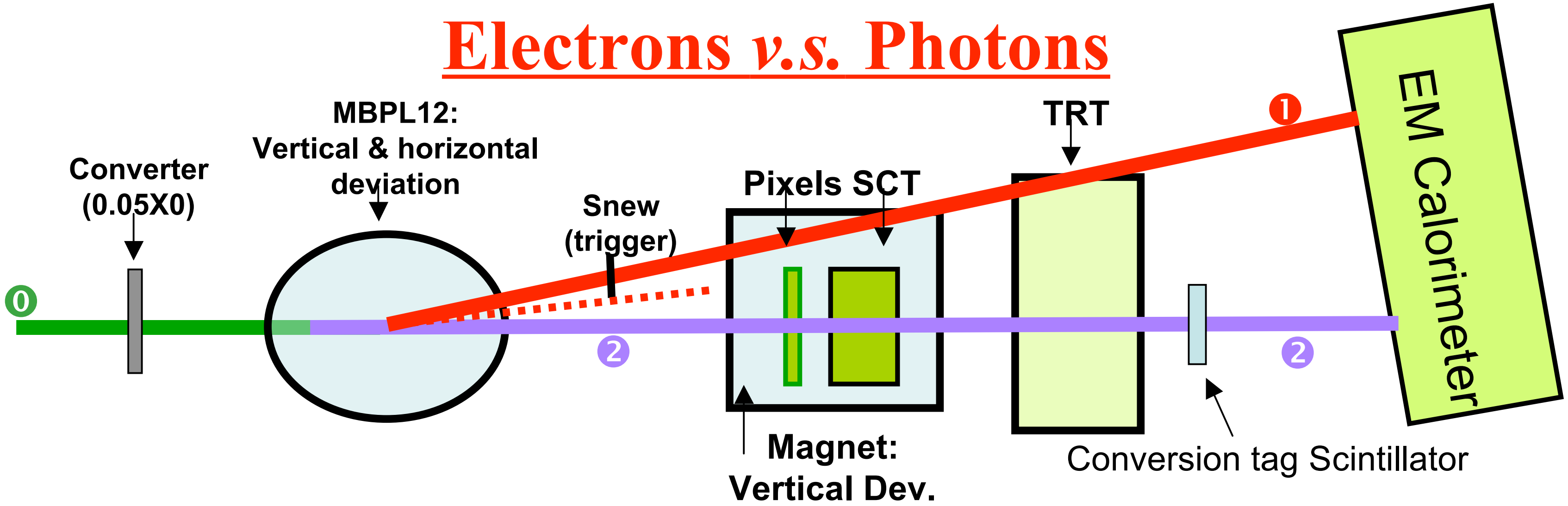
- When photons are calibrated as electrons, significant non-linearity is observed.
- At η=0.3, a O(1%) effect.
- Can be checked using test beam data.

Photon-specific calibrations applied after particle ID, result in improved linearity.

Different calibrations for converted and unconverted photons necessary.



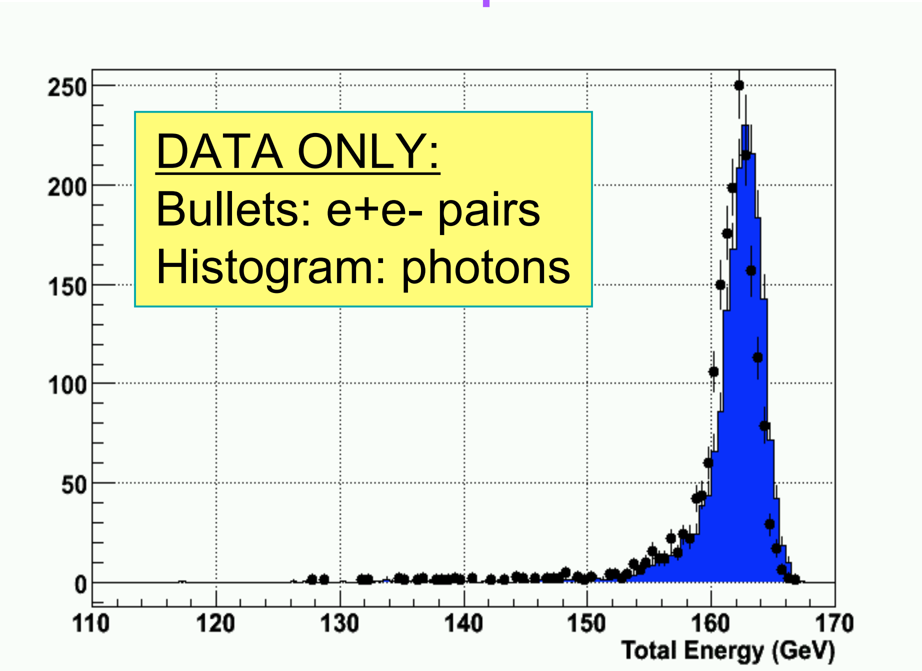
Electrons *v.s.* Photons



⓪ Initial Positron 180GeV

❶ Positron after Bremsstrahlung

❷ 60GeV photon



- Combined Test Beam photon runs could be used to check the photon-specific calibration (equivalent to ATLAS η=0.3).
  - Establish the O(1%) effect when using the electron calibration.
  - Use electrons from converted photons during the same photon run to reduce systematic errors.
  - Compare the photon/electron reconstructed energy.
  - Apply the photon-specific calibration weights and re-evaluate.
- Requires that indeed electron linearity is <0.2% (as shown by the electron data)

$E(\gamma)-E(e^+e^-)=0.6$ GeV @ 60 GeV

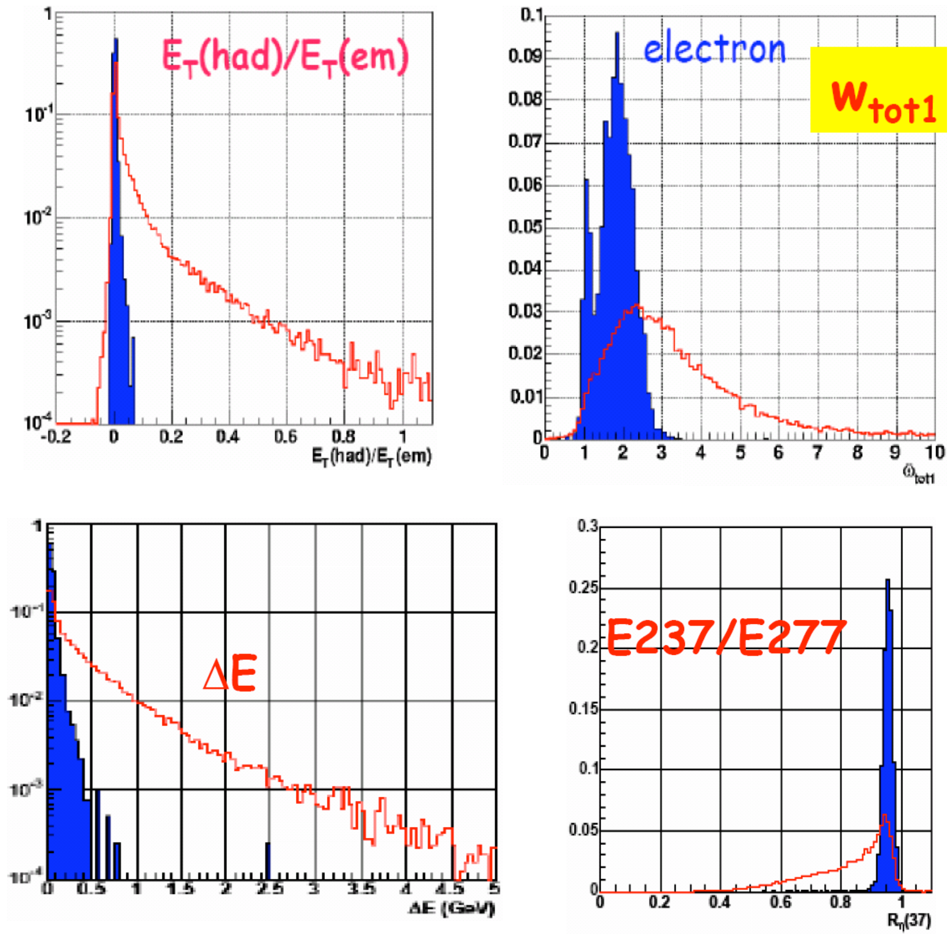
e/jet Separation

Shower shapes:

- **Hadronic leakage**
- **Width of second sampling**
- **E37/E77 in middle sampling**
- **Width in 40 strips**

Secondary maxima in strips:

- $\Delta E = E_{2^{nd}max} - E_{min}$
- **ShowerCore**

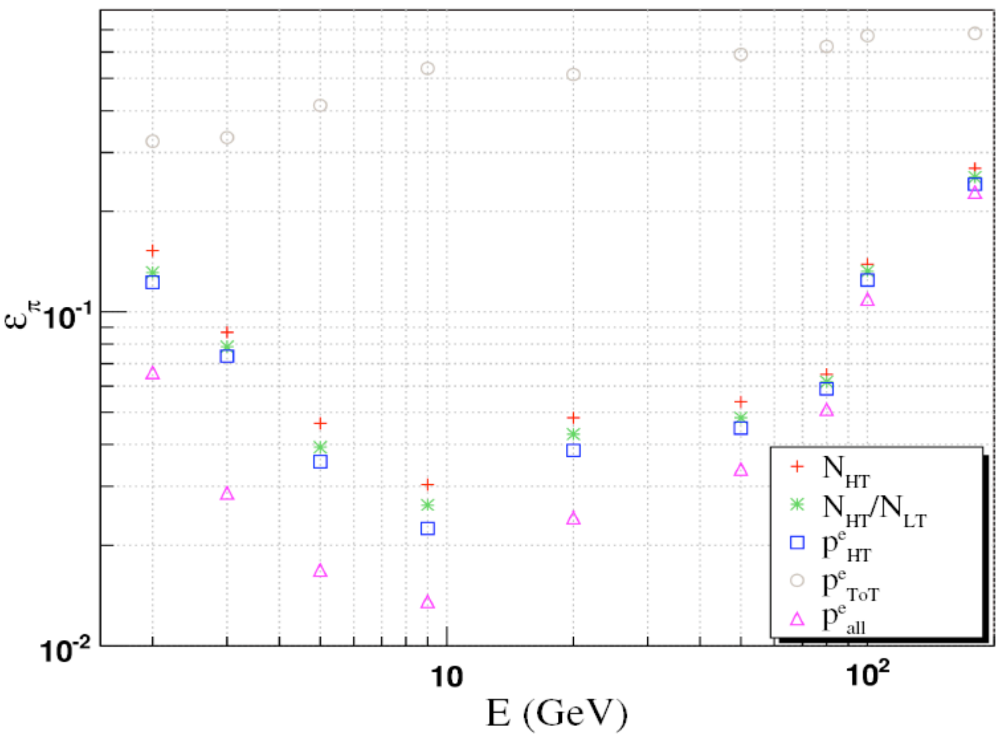


Adding tracking info: For 75-80% efficiency, ~10^5 rejection,
to reject photon conversions and charged pions with EM interaction in Calo.

e/π separation using the Transition Radiation Tracker

- TRT high threshold hits must be due to x-rays from electrons:
  - Use N_{HT}/N_{LT} (normalize to number of straws);
  - Likelihood variable (deal with different HT probability): $$p^e_{HT} = \frac{\prod_i p^e_{HT\ i}}{\sum_{j=e,\pi} \prod_i p^j_{HT\ i}}$$
- Add the time over threshold (ToT) information:
  - Depends on track-to-anode distance;
  - Remove HT hits to avoid possible correlations: $$p^e_{ToT} = \frac{\prod_{i\ noHT} p^e_{ToT\ i}}{\sum_{j=e,\pi} \prod_{i\ noHT} p^j_{ToT\ i}}$$
- Combine the two likelihoods to obtain optimal e/π separation: $$p^e_{all} = \frac{p^e_{HT}\, p^e_{ToT}}{\sum_{j=e,\pi} p^j_{HT}\, p^j_{ToT}}$$

CTB-04 Data



- Use Test Beam data to extract the necessary probabilities per straw for e/π beams.
- Overall e/π separation yield depends on p. Best results at ~10 GeV.
- For 5 GeV < E < 50 GeV, R_π>30 and $\varepsilon_e \sim 90\%$.

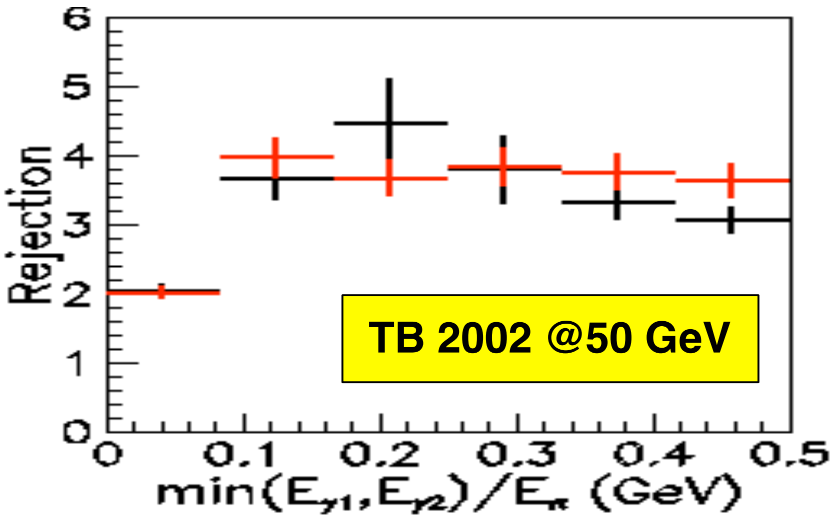
γ/π^0 Separation

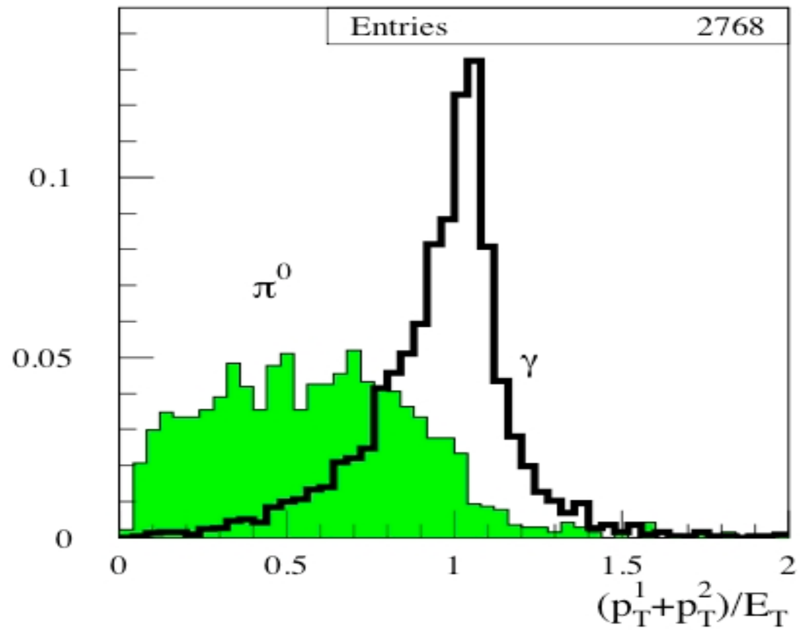
- After application of hadronic leakage and 2nd EM sampling criteria, ~80% of the remaining background is composed of isolated π^0 from jet fragmentation.

- The high granularity of the first sampling provides the required rejection.

- Eff: 90%; $R(\pi^0) = 3.2 \pm 0.2$

- Consistent with TB-2002

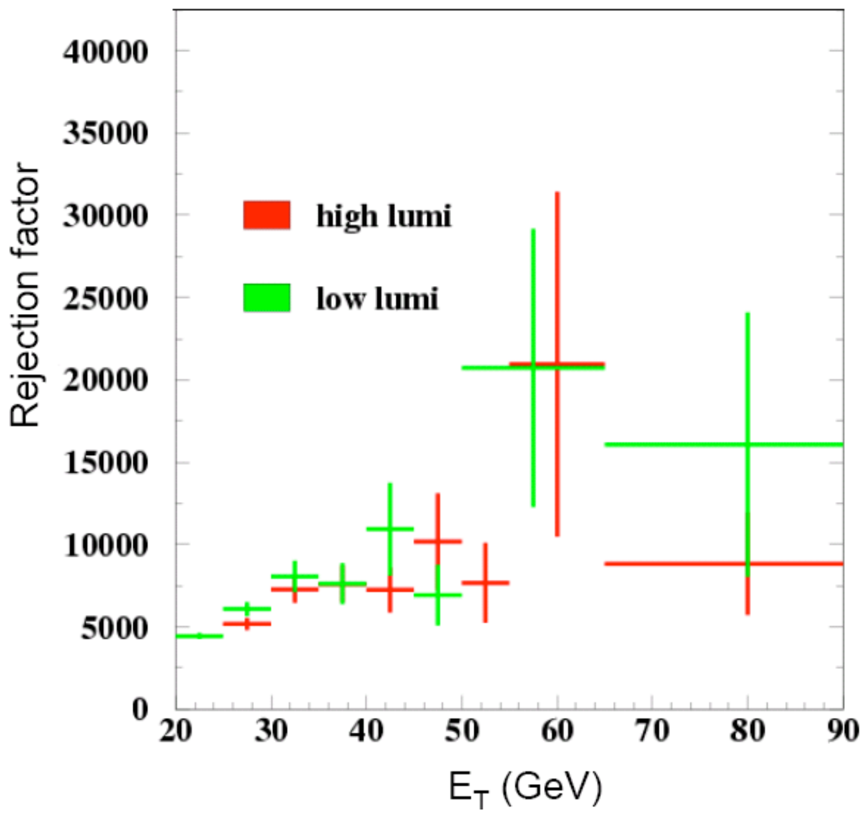




The tracker is necessary to keep $R(\pi^0)>3$ in the case of converted photons. Use a cut on E/p after converted photon recovery

γ/jet Separation

Evaluating with single γ of different energies or from $H \rightarrow \gamma\gamma$



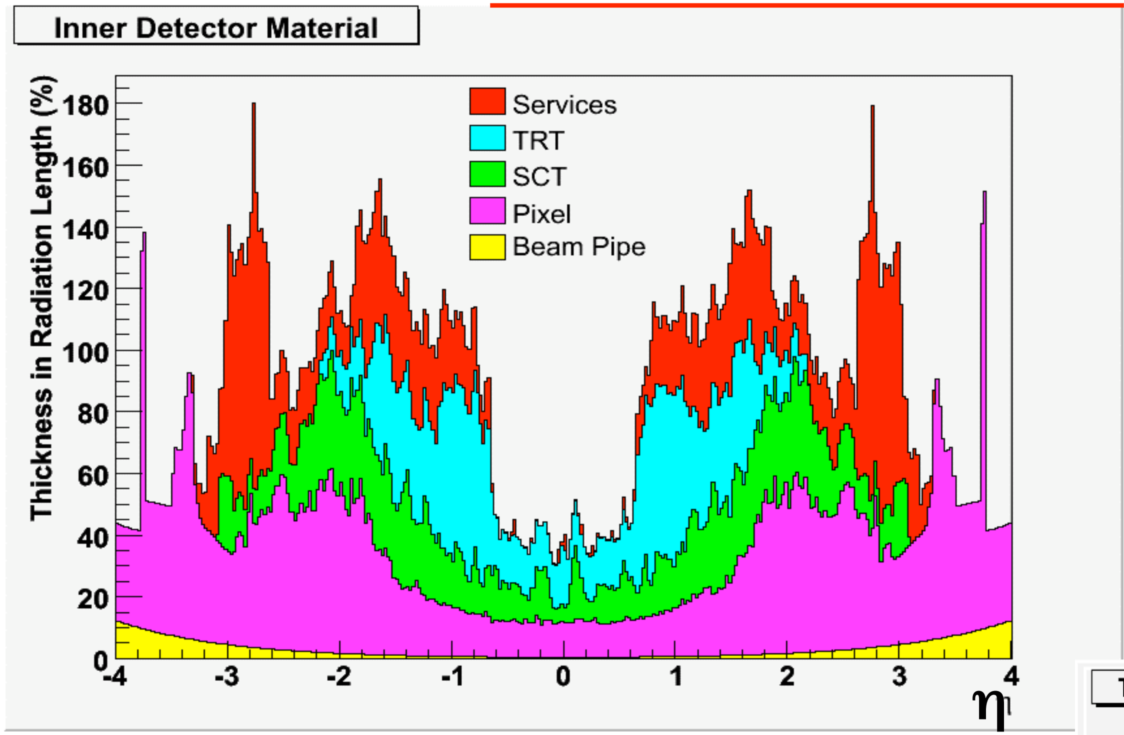
- $R_{jet} \sim 7000$ @ 80% efficiency and $p_T > 25$ GeV
  - –3000 on quark jets
  - –21000 on gluon jets

→ Difference due to softer fragmentation function of gluon jets.

- As a fraction of the irreducible $\gamma\gamma$ background:
  - ~ 20% from γ-jet
  - ~ 15% from jet-jet

•Low luminosity: 2×10^{33} cm^{-2} s^{-1}
•High luminosity: 1×10^{34} cm^{-2} s^{-1}

Photon Conversion Recovery

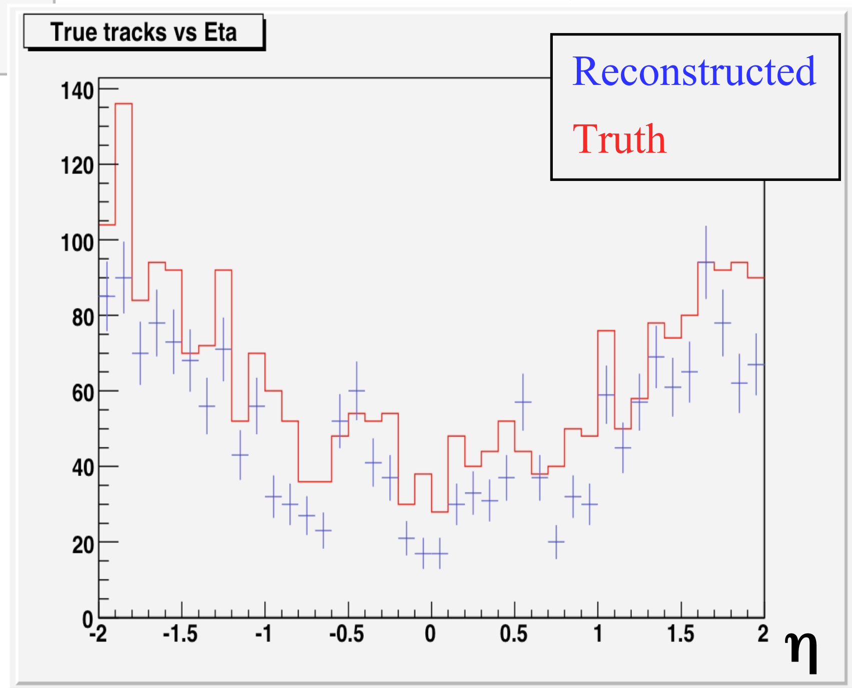


Depending on η, 30-50% of produced photons will convert inside the ID.

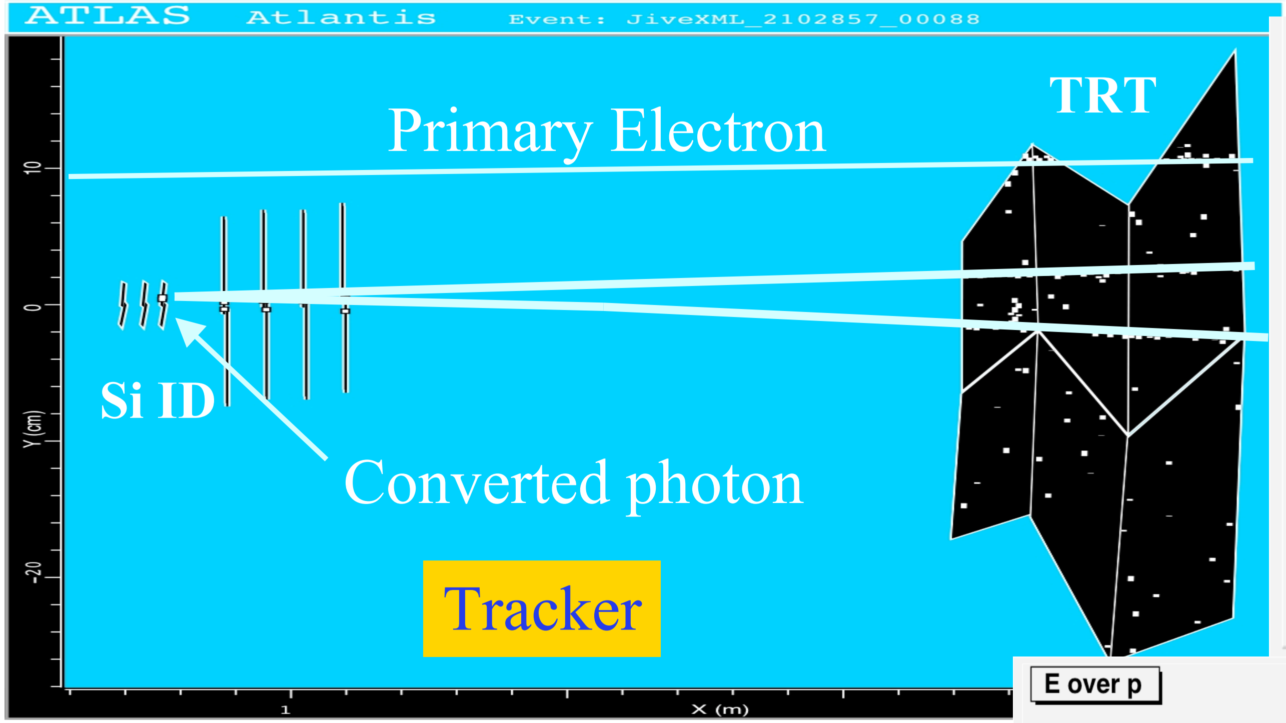
Efficient photon conversion recovery is essential.

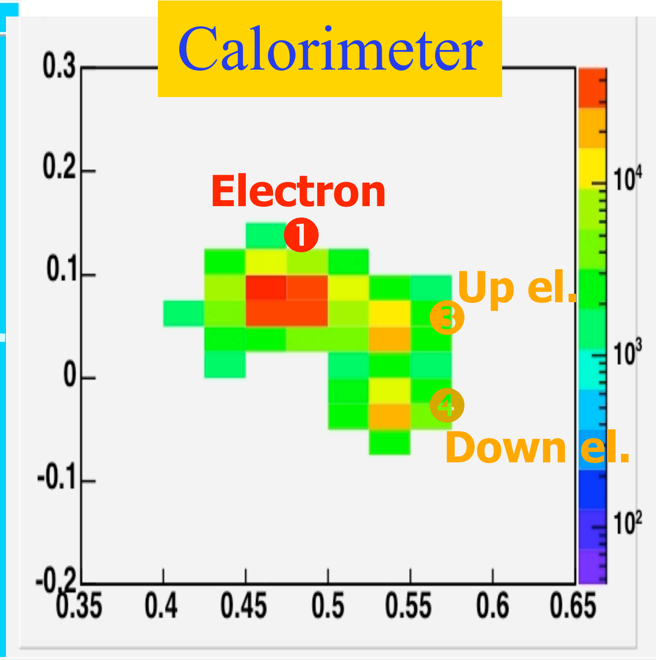
- Start from the TRT reconstructing tracks going backwards into the Si part of ID.
- More efficient recovery of late photon conversions inside the ID.
- Conversion recovery efficiency >80% for R<80cm from beam line, |η|<2.
- Follows well the ID material distribution.

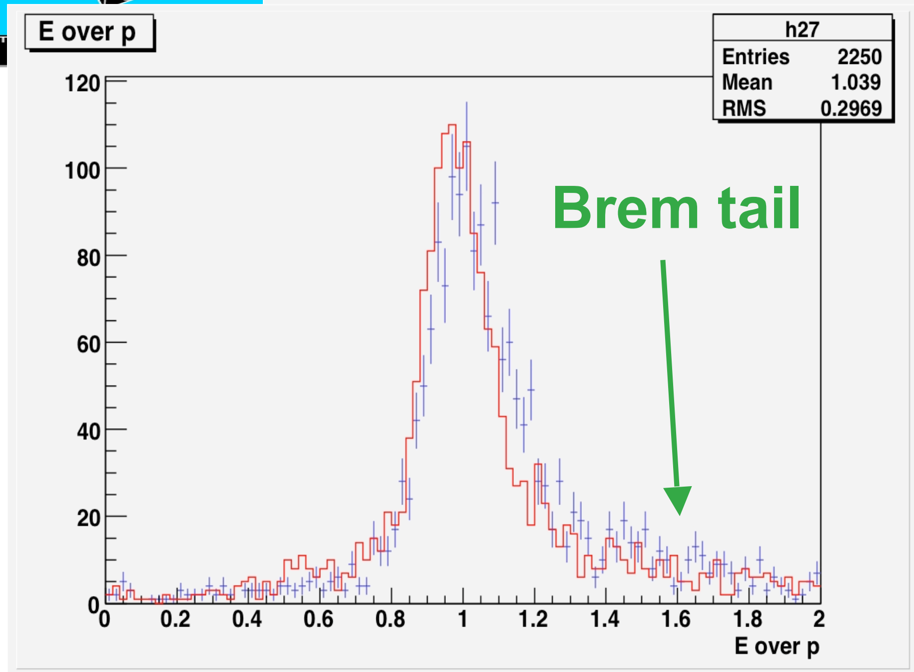
Atlas study



Photon Conversion Recovery in CTB-2004



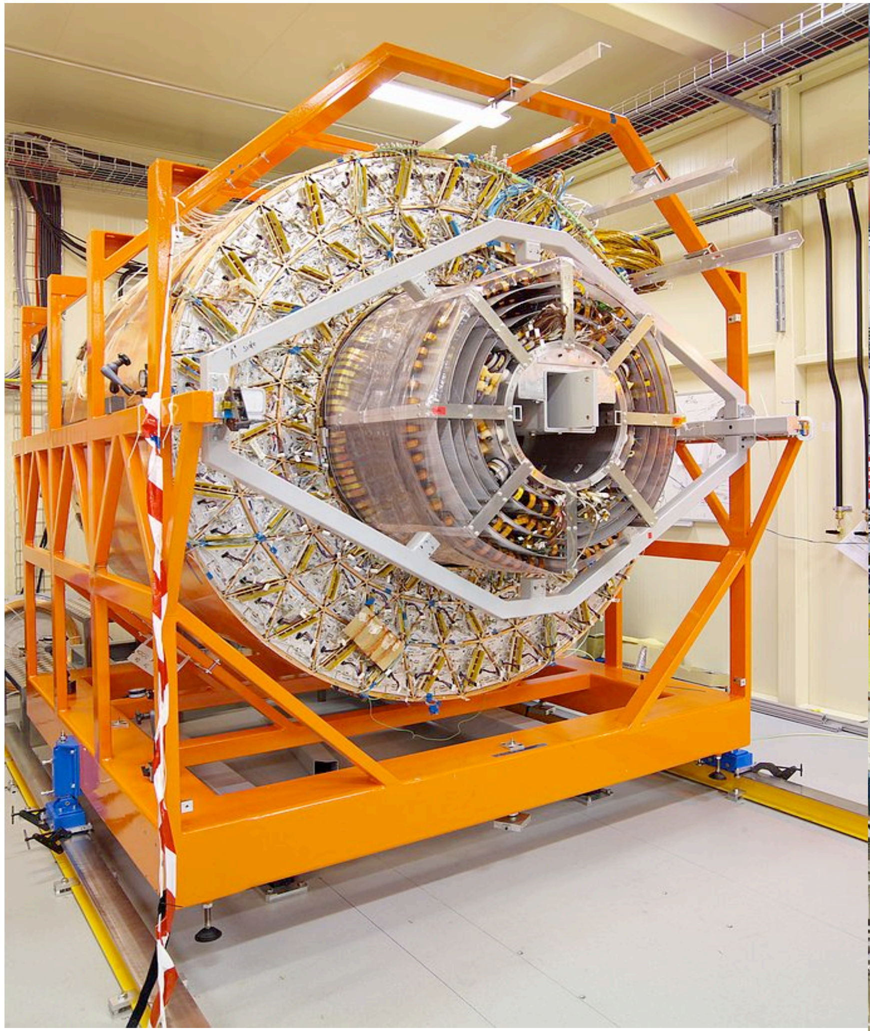


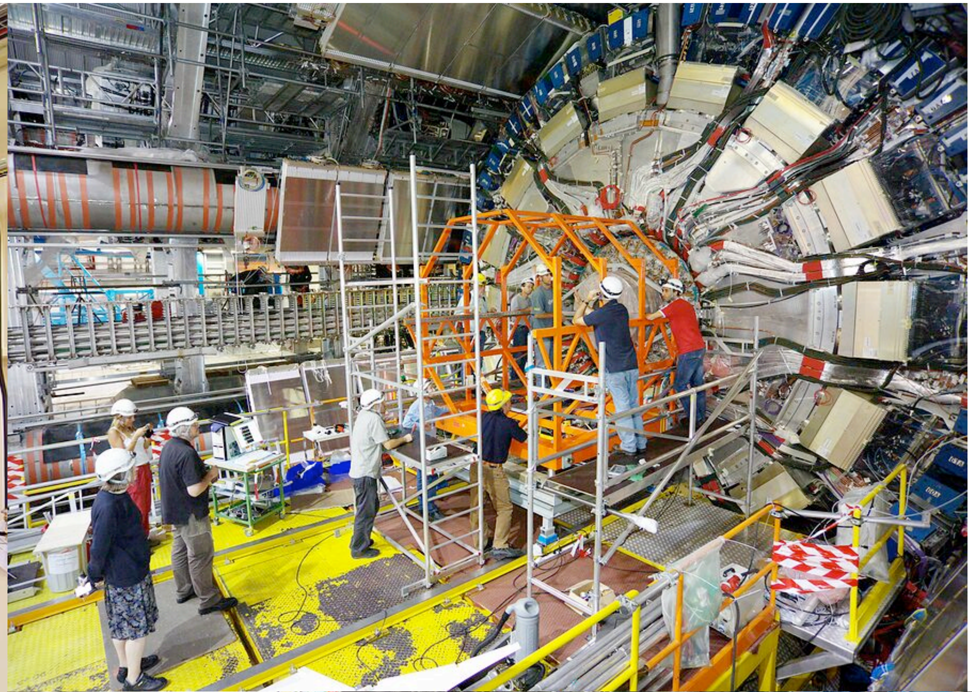


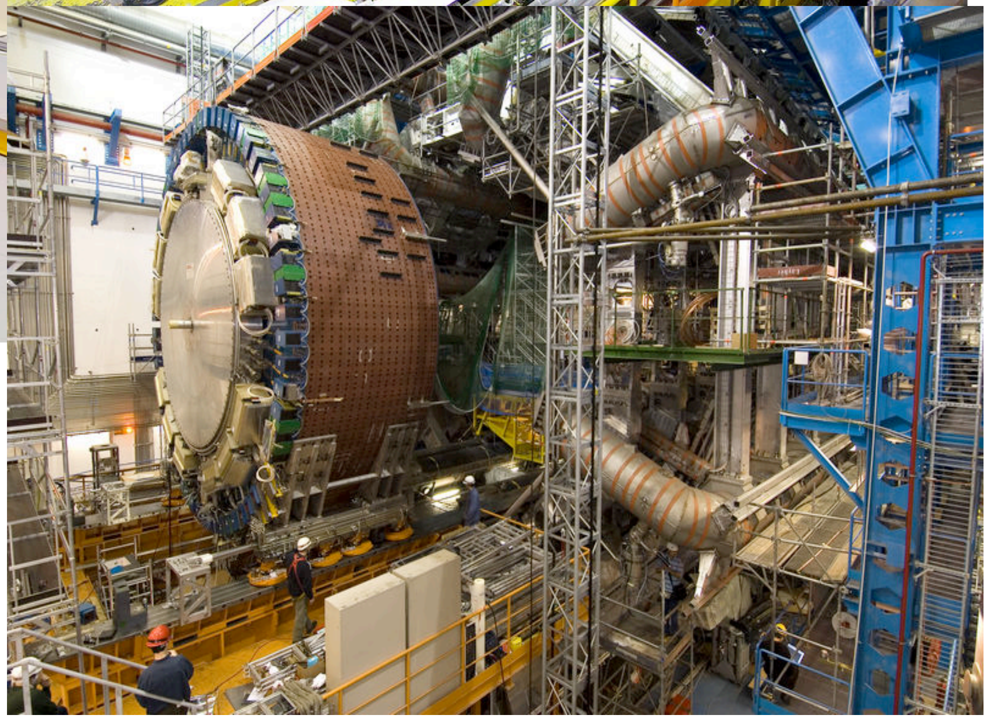
- **Topological clustering used to reconstruct 3 objects in EMC:**
  - primary e^-
  - e^+e^- pair from converted γ
- **Step 1: reconstruct conversion tracks in ID.**
- **Step 2: Combine to EM clusters, compute E/p.**

Conclusions

- Electron and photon ID are essential components of the physics program at LHC.
- Reconstruction procedures and identification methods are established and have been tested in both test beam and full detector MC.
- Different algorithms available for clusterization, identification and calibration.
- Dedicated algorithms for low p_T electrons have also been developed.
- Linearity, resolution and identification capabilities approaching desired specifications.
- Physics with electrons and photons will be ~10 times more challenging at the LHC than in Tevatron $\Rightarrow$ requirements on LHC detectors are more stringent.
- ATLAS barrel Inner Detector and EM Calorimeter are now installed and ready to be commissioned together with cosmics in the coming months.







The ATLAS detector being assembled…

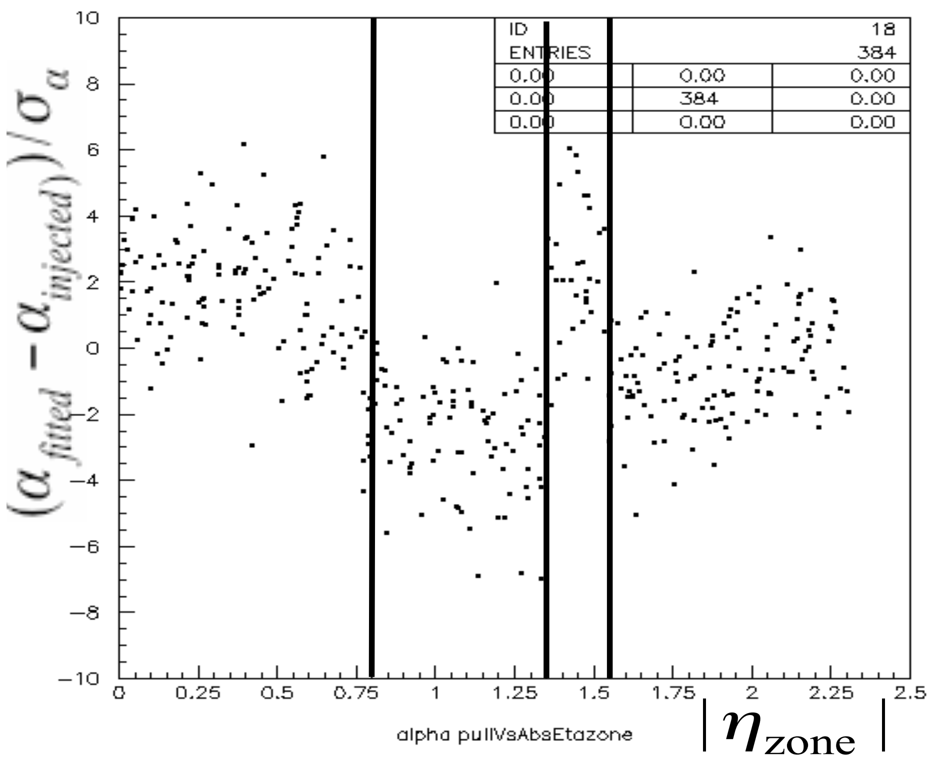
Back-up slides

EM Calorimeter cluster corrections

- η position correction, for layers 1 and 2 ~ 0.4%
- ϕ offset correction, for layer 2 ~ 0.2%
- Energy corrections ~ 2-7%
  - Gap correction
  - Lateral out-of-cone correction
  - Longitudinal corrections
  - Overall energy scale
- Energy modulations, vs η and ϕ ~ 0.2%
- Correct for HV problems and pathological cells

In-situ calibration

- The previous calibration schemes demonstrate a small "local" constant term of $\leq$0.5% over limited regions of the EM calorimeter. There are 384 such regions ($\Delta\eta\times\Delta\phi$=0.2×0.4) in ATLAS.
- Long range calibration non-uniformities to be resolved in-situ using physics samples, such as $Z\rightarrow ee$.
  - **High rate, 1Hz at 10^{33} cm^2 s^{-1};**
  - **Essentially background free;**
  - **Stand alone method using the Z-mass constraint and no tracker information;**
  - **Z-mass close to other particle masses to be precisely measured, such as W-bosons.**



- Inject random mis-calibration coefficients with ~2% rms.
- Recover correction coefficients by a log-likelihood fit of reconstructed Z-mass to the expected Z lineshape.
- From ~70K Z (O(150pb^{-1})), ~0.4% stat. accuracy on intercalibration/region.
- Bias from absorbing wrong dead material correction: ~1% effect.

In addition use $W\rightarrow e\nu$ isolated electrons and reconstruct E/p:

- **Verify material in tracker and in front of Calo.**
- **Improve inter-calibration if needed.**

e/γ measurements using the Inner Detector

- Calo only + tracking (Inner Detector) → isolated e/γ id
  - No track → photon
    - **Include photon conversions in this sample using specific algorithms**
  - Matched track → electron.
    - **Slightly improve resolution by including measured p (brem corrected) in electron final energy estimate.**
    - **Reject photon conversions from this sample.**

- Low p_T electron reconstruction also available for less isolated electrons. Start from tracks, add calorimeter information:
  - Apply track quality cuts
  - Extrapolate to EM calo samplings
  - In each sampling look for cell with max E deposit
  - Create cluster around that cell
  - Estimate discriminating variables
  - Physics: b-tagging, B-physics, initial calibration with J/psi to ee