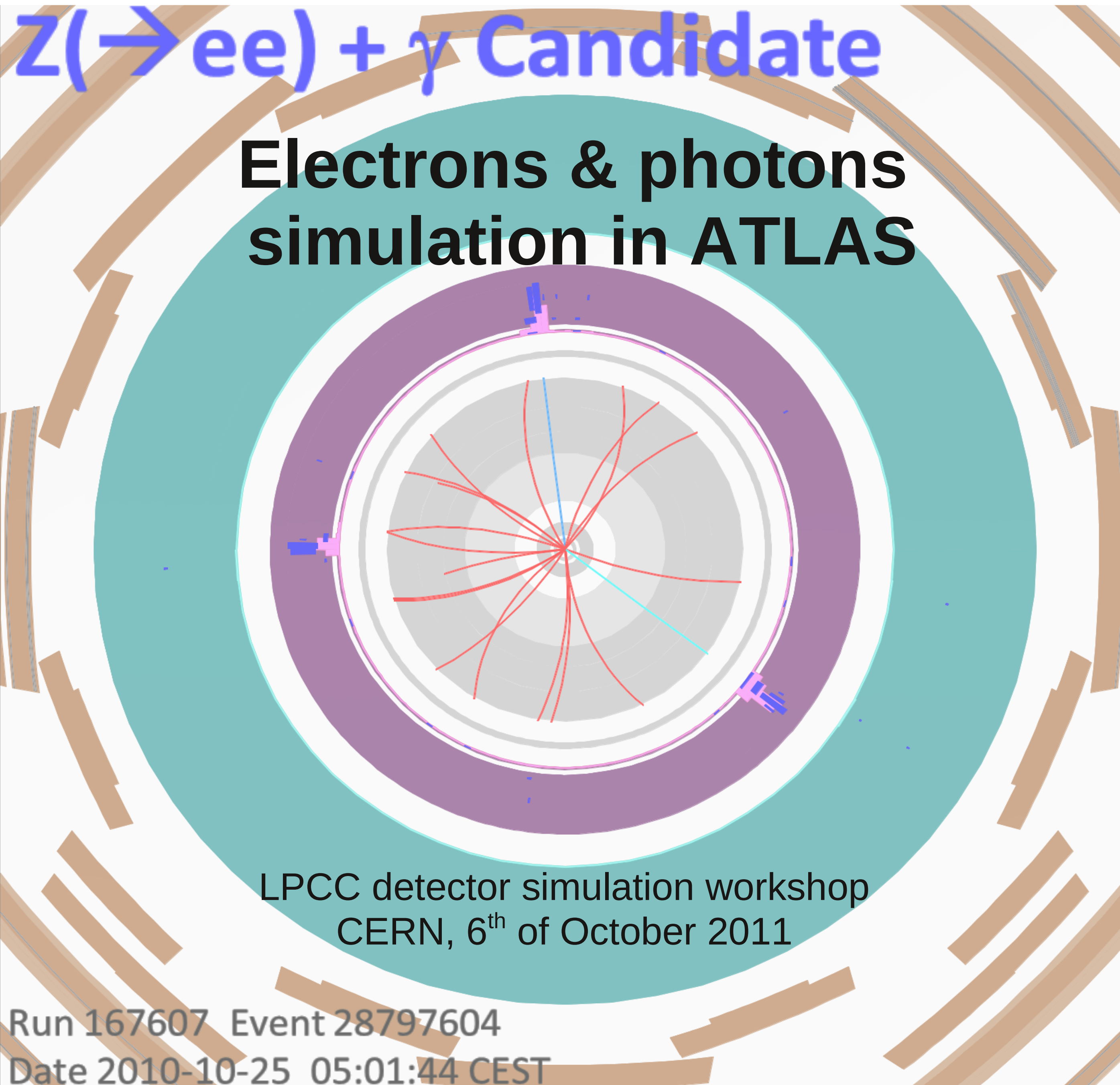
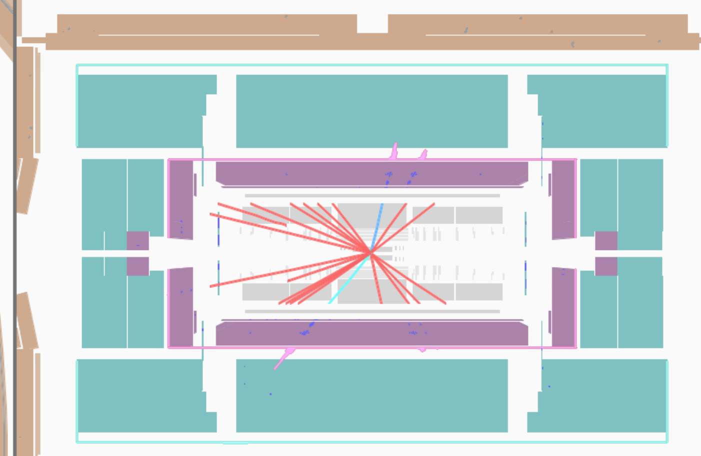


Electrons & photons simulation in ATLAS

ATLAS EXPERIMENT

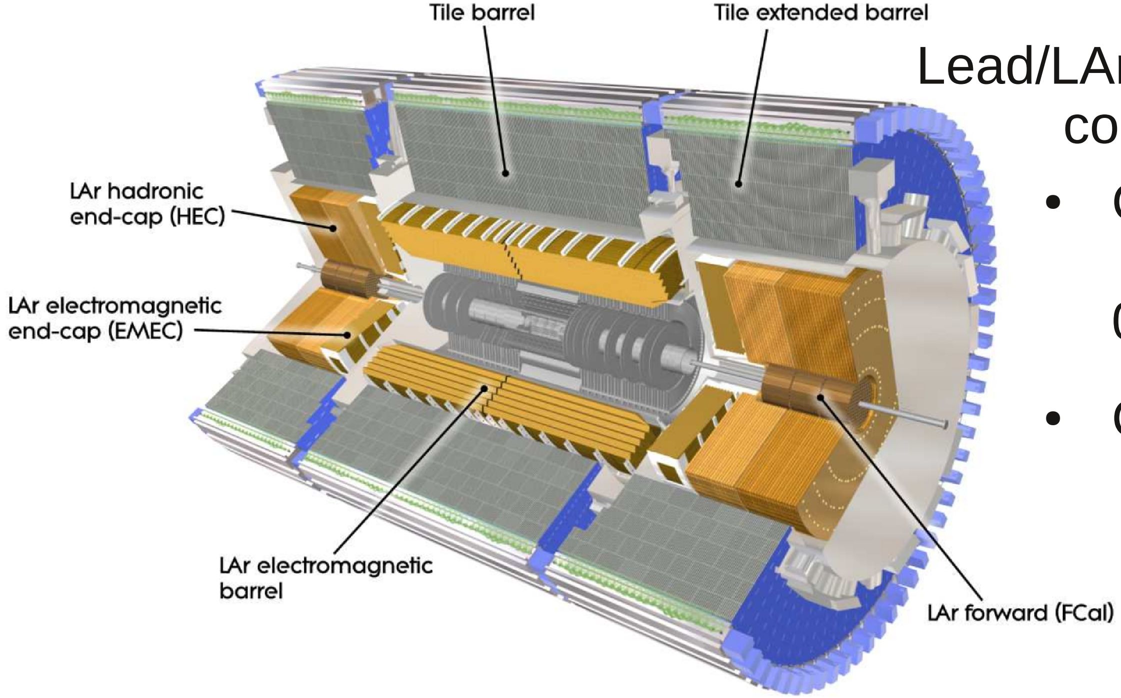


Olivier Arnaez
Mainz University

On behalf of the ATLAS collaboration

LPCC detector simulation workshop
CERN, 6th of October 2011

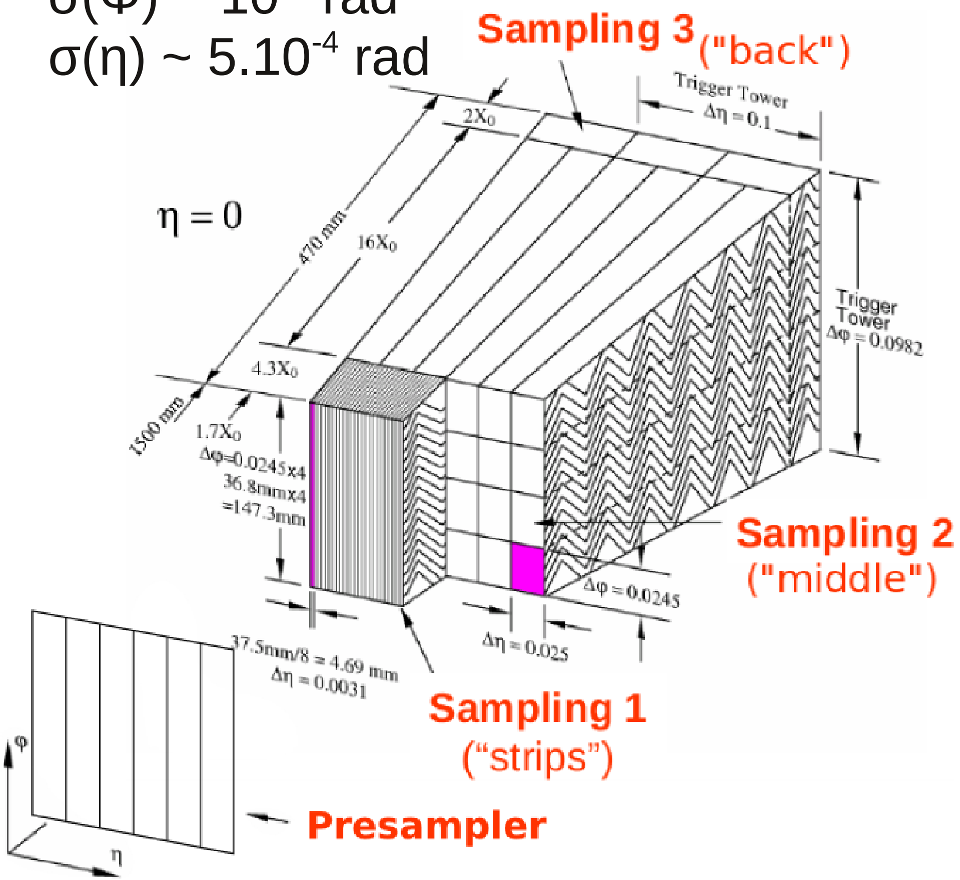
The ATLAS electromagnetic calorimeter



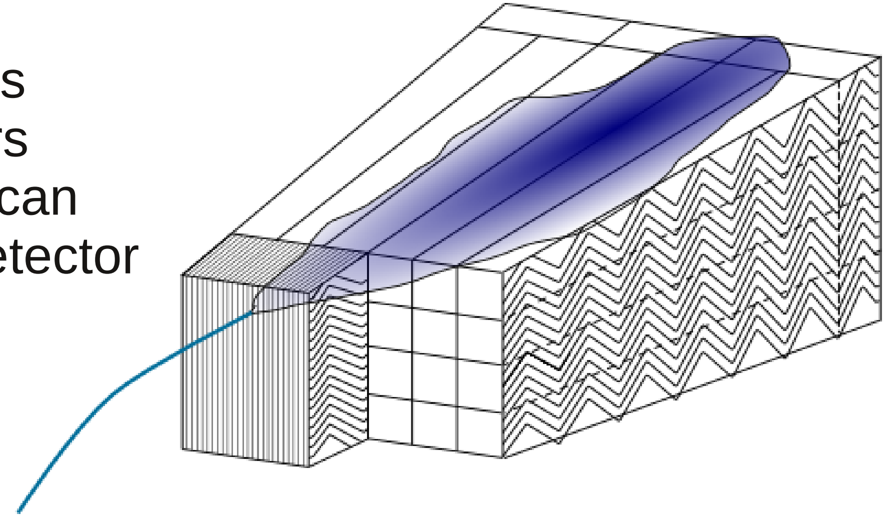
Lead/LAr EM calorimeter divided in 3 longitudinal compartments + Pre-sampler in front

- Good energy resolution :
  $\sigma(E)/E = a/E \oplus b/\sqrt{E} \oplus c$ (with a ~ 0.3 GeV, b ~ 10%, c ~ 0.7%)
- Good angular resolution :
  $\sigma(\Phi) \sim 10^{-3}$ rad
  $\sigma(\eta) \sim 5.10^{-4}$ rad

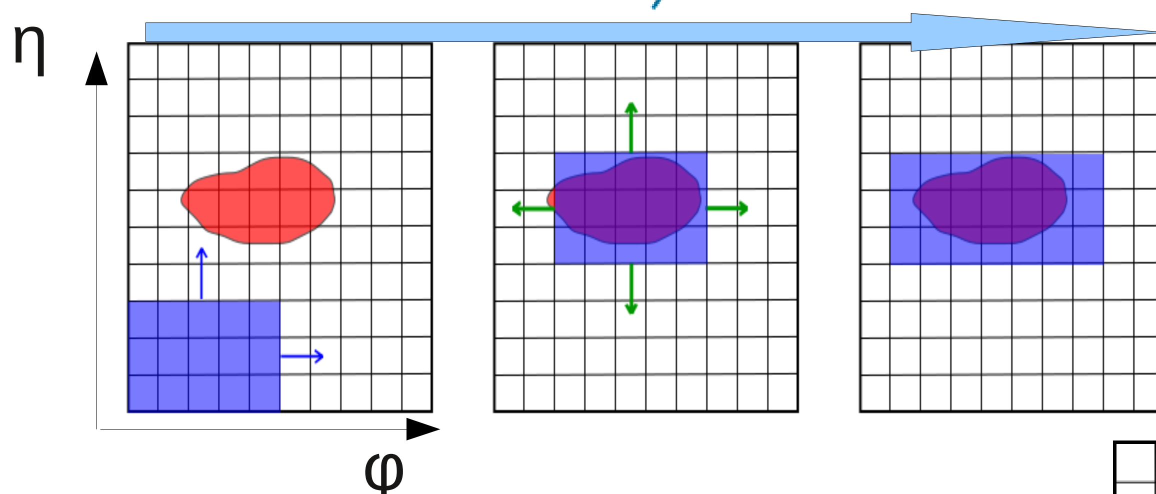
Layer	Granularity $\Delta\eta \times \Delta\varphi$	Radiation length
Pre-sampler	0.025 x 0.1	
Strips	0.003 x 0.1	4.3 X_0
Middle	0.025 x 0.025	16 X_0
Back	0.05 x 0.025	2 X_0



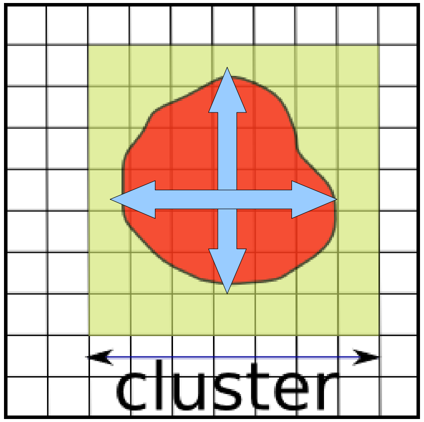
Electromagnetic objects in ATLAS



- In ATLAS an electron or a photon candidate is defined as a cluster of cells in the calorimeters representing the energy deposit to which we can associate tracks reconstructed in the inner detector
- Sliding window algorithm to reconstruct the energy deposits :

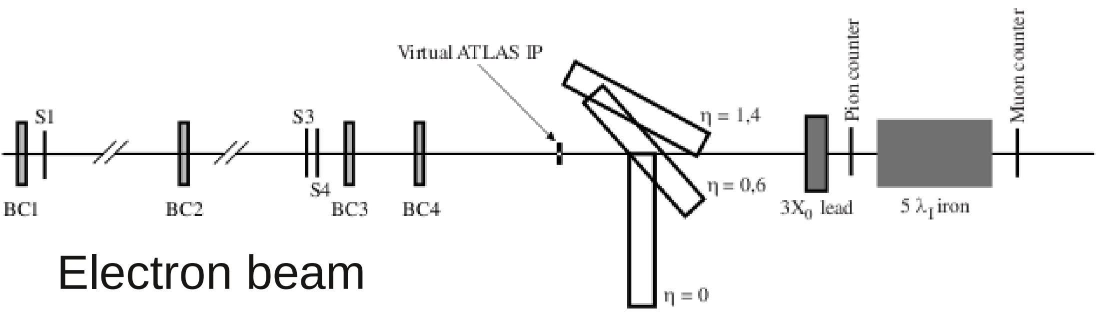


- The identification of such objects is then based on :
  - The shower shape in the calorimeter
  - Track quality (number of hits, direction wrt the cluster,...)
  - Transition radiation (TRT “high threshold hits”)
  - E/p

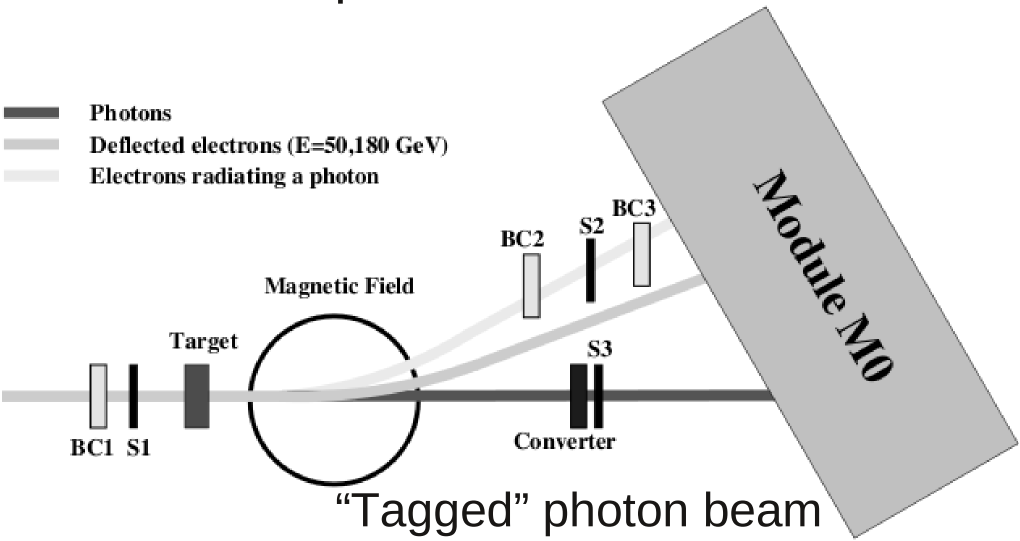


Reminder: test beam tests

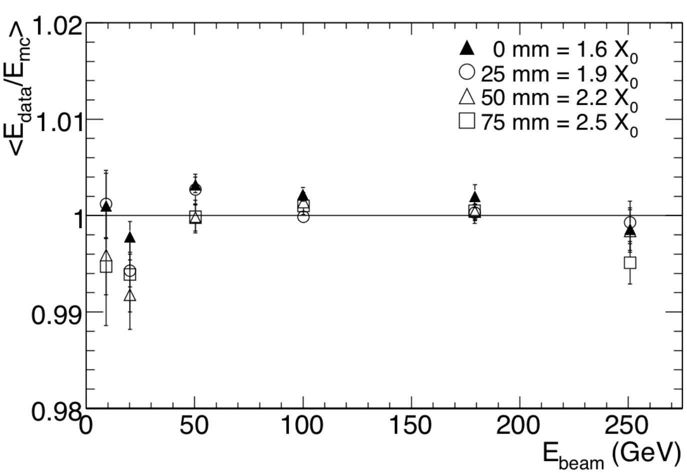
- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to
  - Test beam

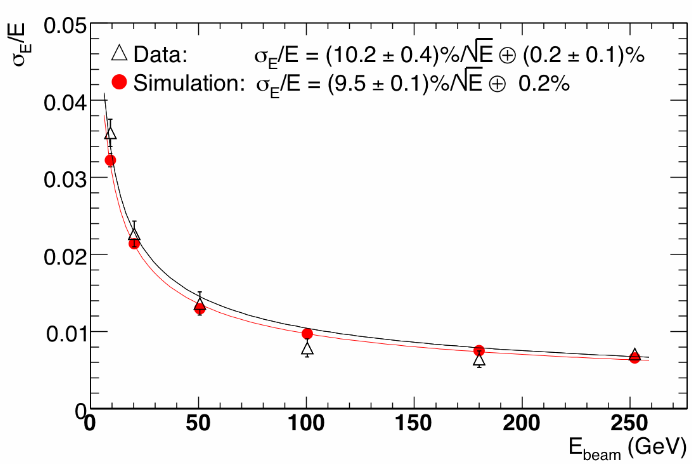


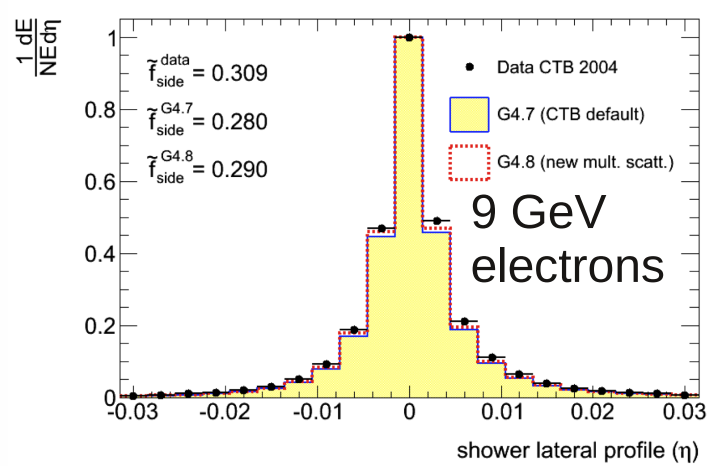
Electron beam



“Tagged” photon beam

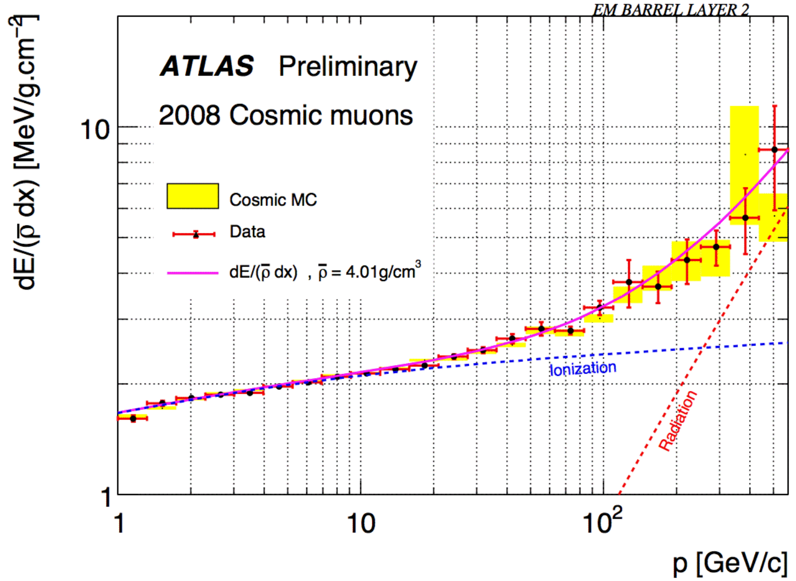




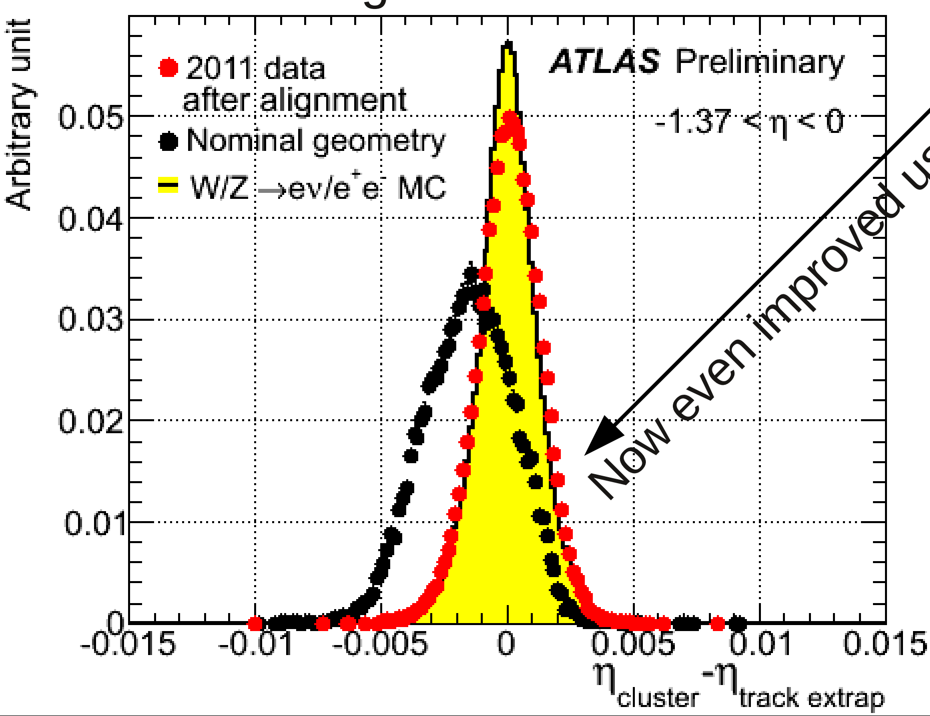


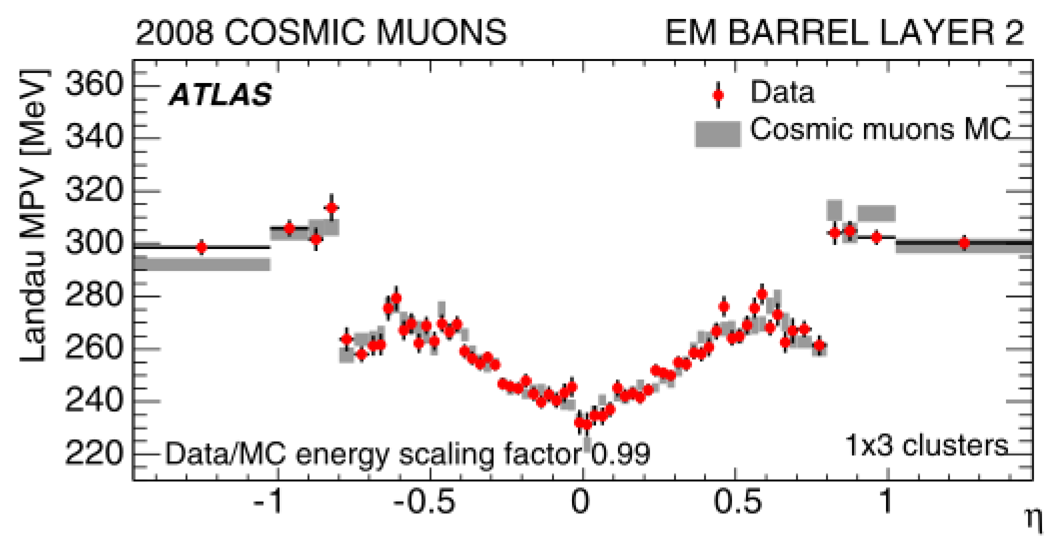
Reminder: cosmic data (muons)

- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to
  - Test beam
  - Cosmics : selection of muons
    - Check of the visible energy in the calo
    - Adjustment of the calorimeter response
    - Improvement of the inner detector-calo alignment



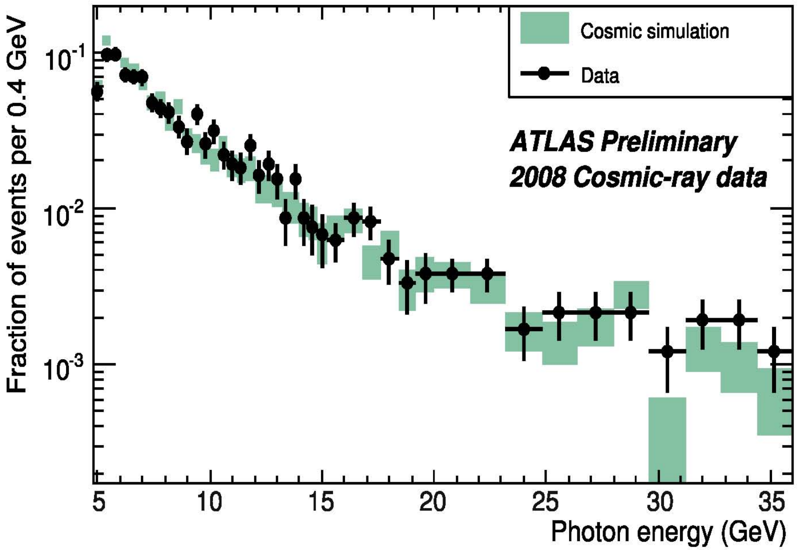
Now even improved using collisions

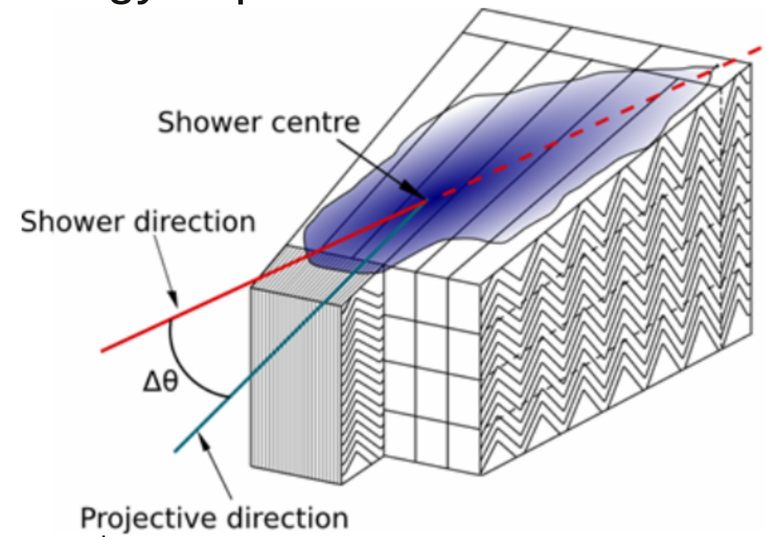




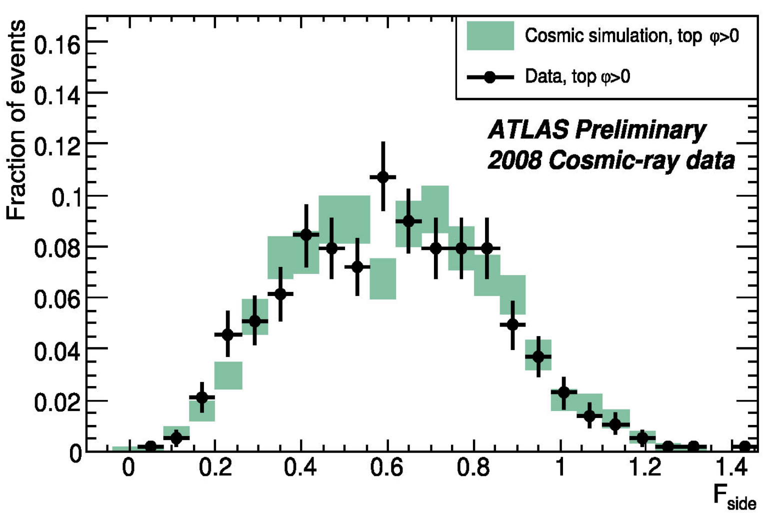
Reminder: cosmic data (photons)

- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to
  - Test beam
  - Cosmics : selection of muon large brems-strahlung energy deposit in the calorimeter

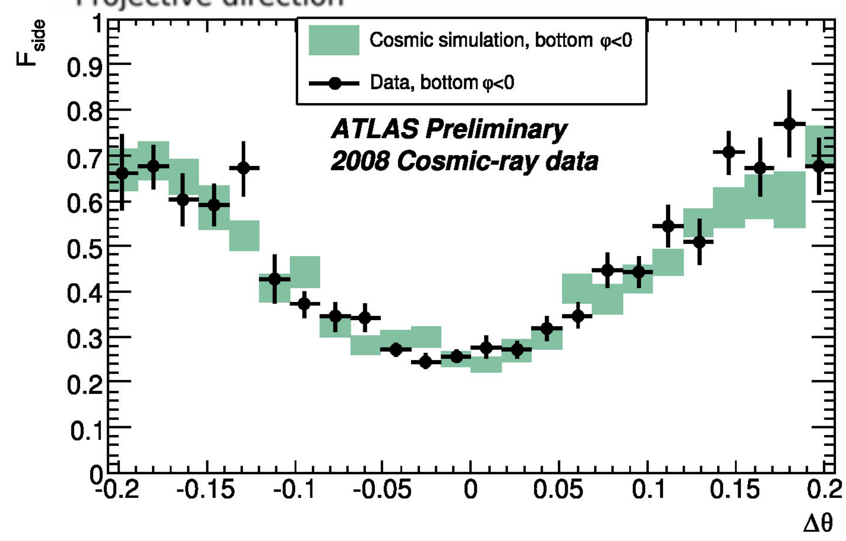




Very good agreement in energy, direction, energy loss of the cosmic muons (even below ~100 meters of rock) and energy deposits

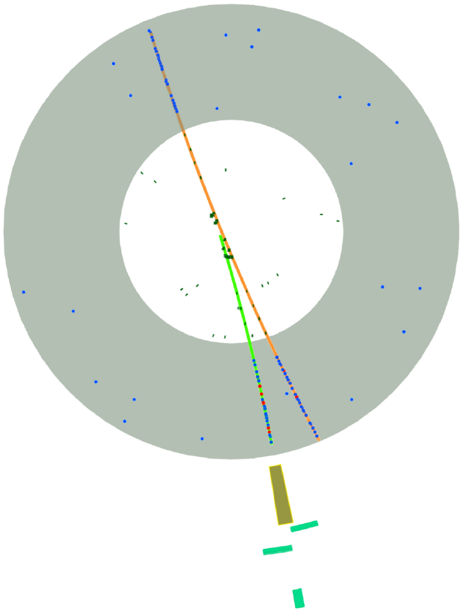


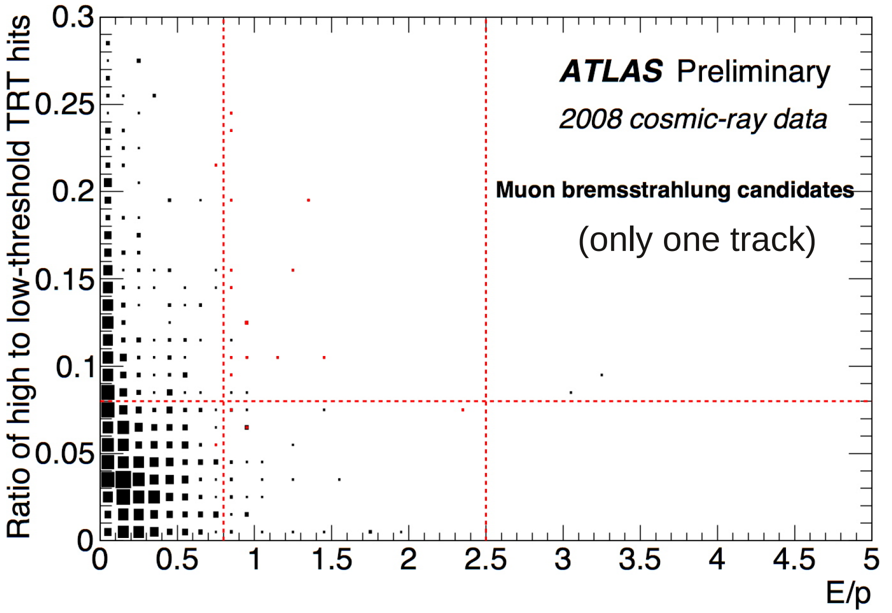
Shower width in the first compartment

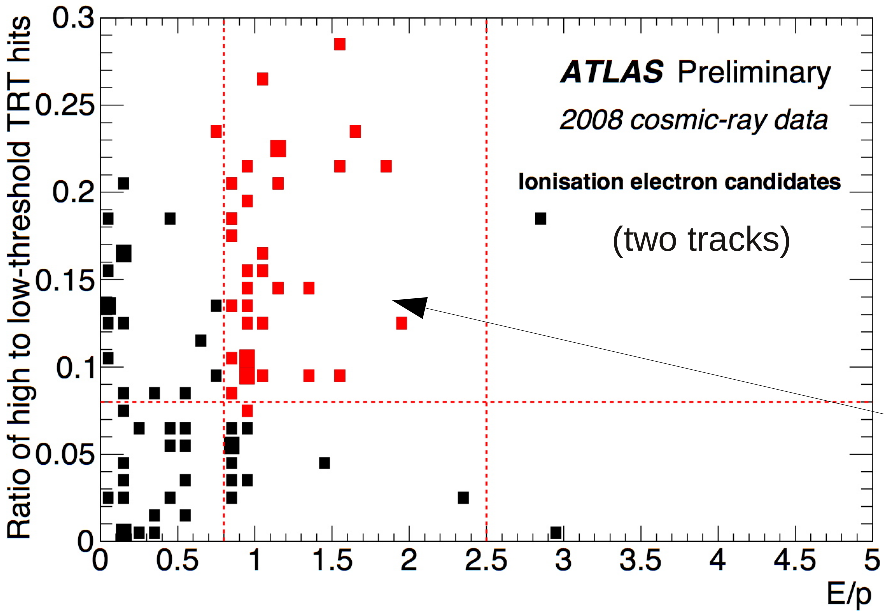


Reminder: cosmic data (electrons)

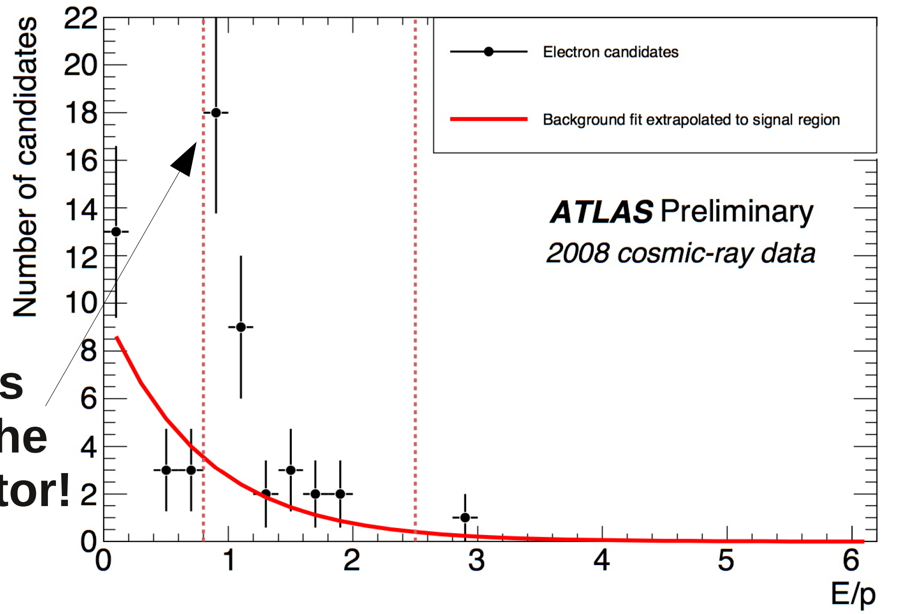
- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to
  - Test beam
  - Cosmics : selection of muon large bremsstrahlung energy deposit in the calorimeter and ionisation electron candidates but also high energy δ-rays







First electrons observed in the ATLAS detector!



Points of interest for simulation

- Even if well-probed on the test beam and cosmic data, the simulation is still a crucial element in ATLAS physics analyses since not all electron and photon performance can be measured on collisions data

- Key points for the simulation of electron and photon shower shapes
  - Geant4 physics/tracking
  - Geometry description of the sub-detectors
  - Conversion of energy loss in calorimeters to visible energy
  - Upstream material
  - Cross-talk (not part of the actual "simulation" process)

- Identification also strongly relies on inner detector
  - Amount of transition radiation
  - Track extrapolation (ID alignment, calo-ID alignment, scattering,...)

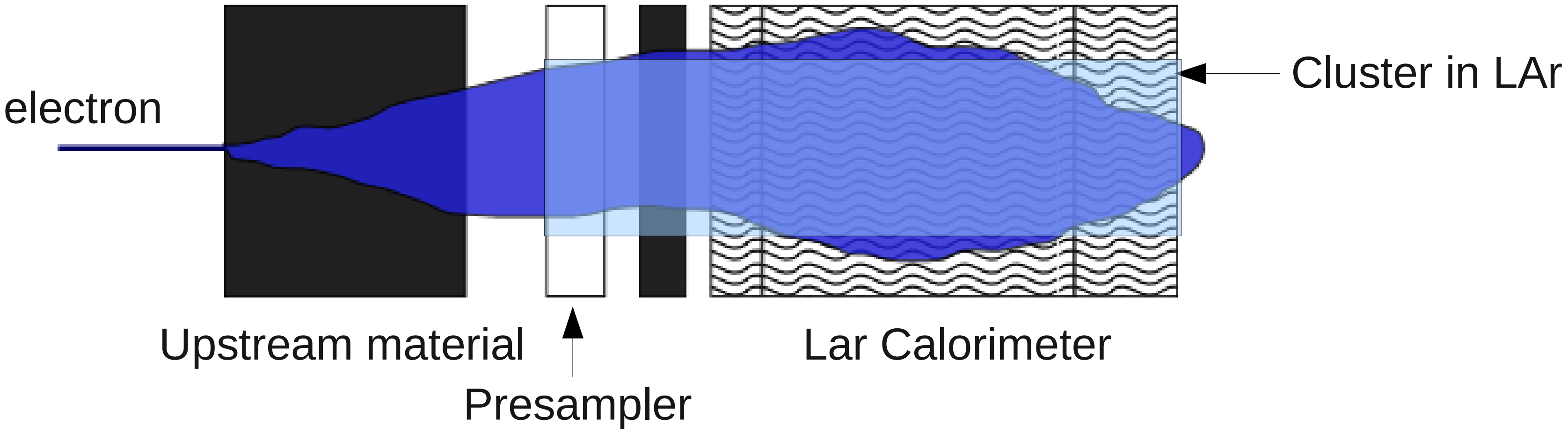
see Markus Jungst's talk

Energy calibration

- One reason why the simulation is sensitive to the knowledge of material is the energy calibration scheme

- As the initial energy does not fully deposit within the electron/photon cluster, it is important to correct the cells energy sum to improve the energy scale and resolution

- Our calibration procedure is based on calibration hits
  - Store all GEANT4 energy deposits (in active, inactive material or escaping)
  - Parametrize the energy leaks (ouside the cluster, in the dead material,...) in function of the position, the energy and the shower depth using this simulation



- Of course this calibration is strongly dependent on the knowledge of the upstream material, this is why we need to map it

Upstream material using conversions (1)

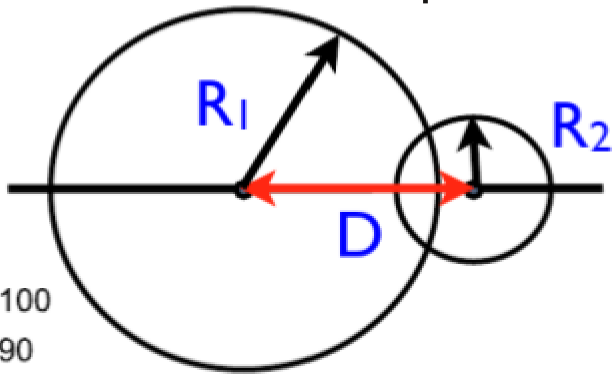
- The fraction of photons which convert being related to the radiation length through the formula

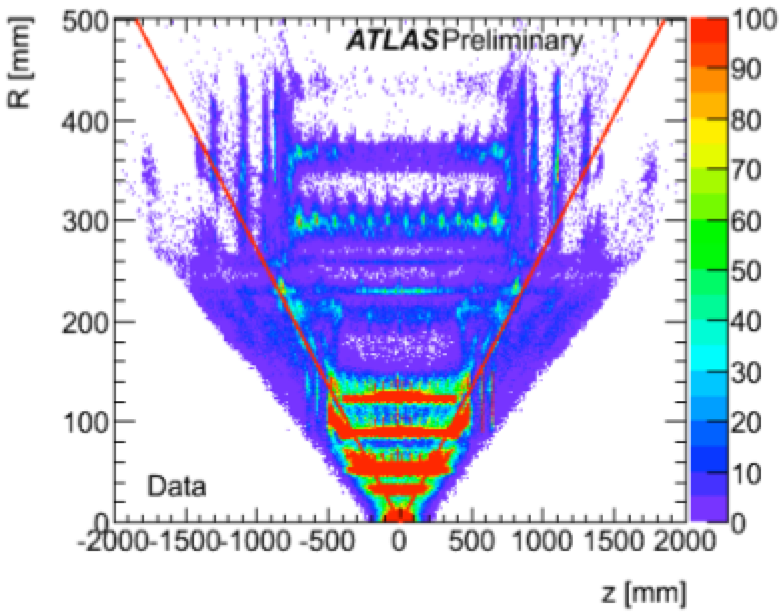
$$\frac{X}{X_0} = -\frac{9}{7}\ln(1 - F_{\mathrm{conv}})$$

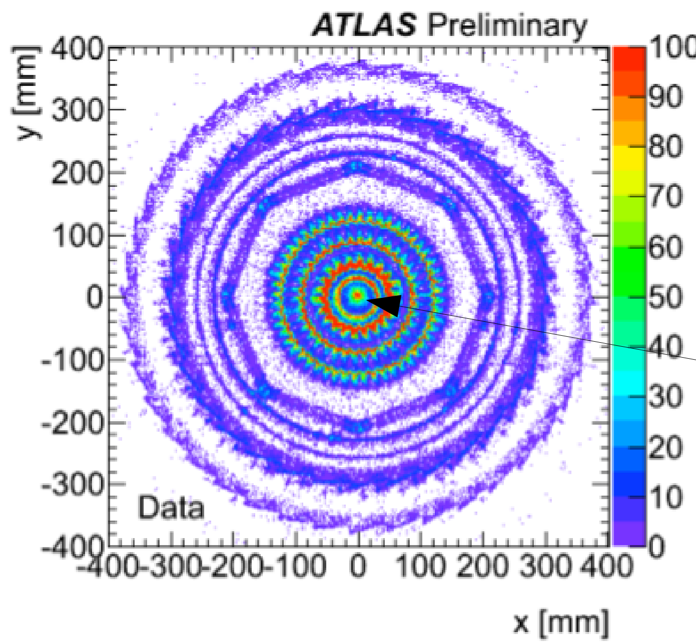
  The radiation length (and thus the amount of material at a given distance) can be measured in collision data using the conversions

- Those are selected by reconstructing conversion vertices associated to two tracks pointing to the interaction point (|z| < 20 mm) passing some identification requirements from the TRT (high transition radiation)

- The quality of the vertexing is insured by requiring
  $D - R_1 - R_2 > 0$ and $\chi^2 < 2.5$



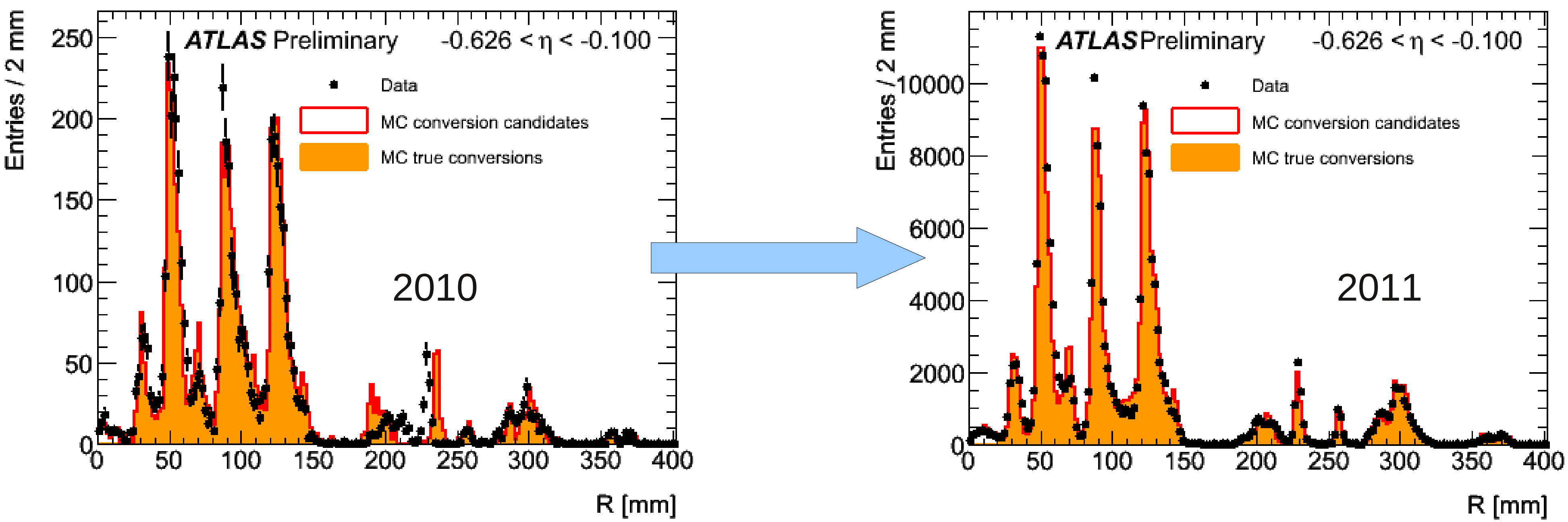




Little bit not-centered beam pipe

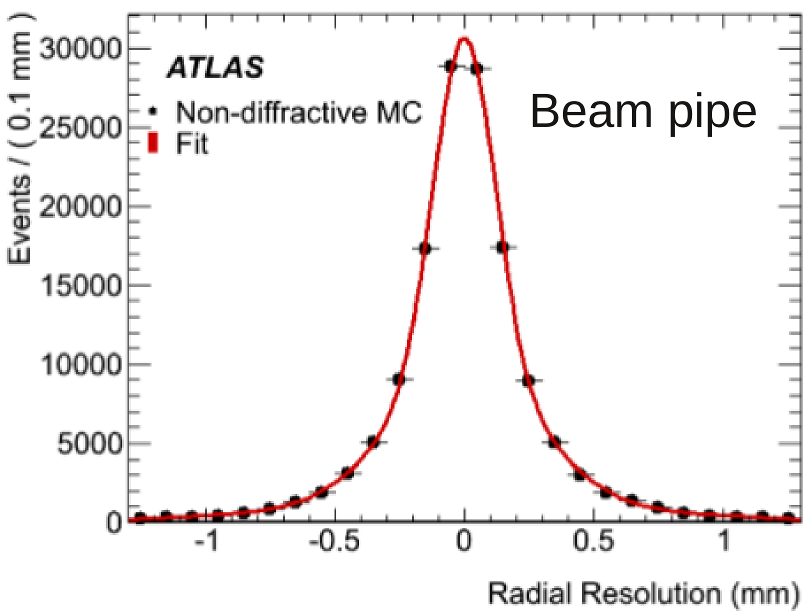
Upstream material using conversions (2)

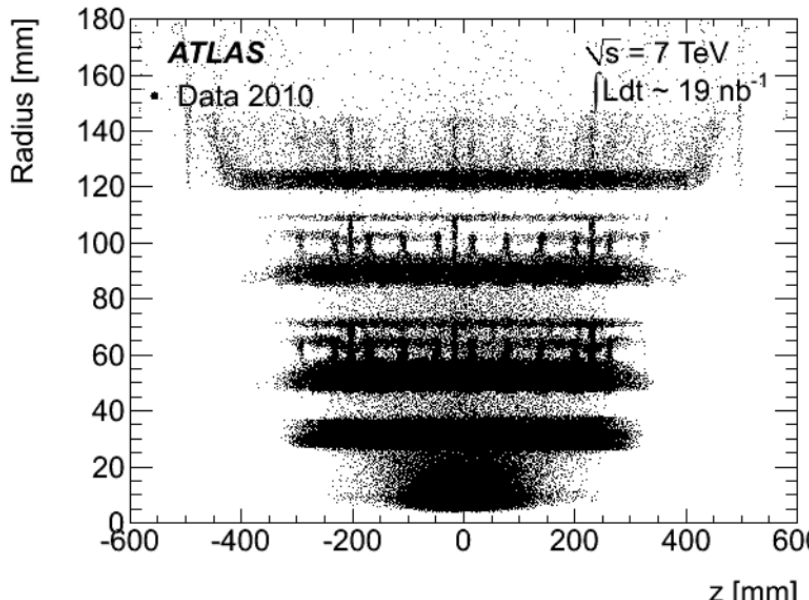
- The three pixel and the first two SCT layers are clearly visible.
- Overall there is a good agreement between the data and the simulation.
- However, some improvements on the geometry were required
- Radial resolution in photon conversions is approximately 5 mm (opening angle between outgoing electron-positron pair close to zero)



Upstream material using hadronic interactions (1)

- While conversions measure the radiation length, the interaction length can be probed using secondary hadronic interactions
- Low energy primary hadrons (<p>~4 GeV) interact with material → large opening angles
  → excellent spatial resolution (200-300 μm in R and z for radii < 100mm
  ~1 mm at larger radii)
- Selection based on non diffractive events with large track multiplicity at primary vertices, but using only those not pointing to them (secondaries)
- Data are compared to PYTHIA6 (AMBT1 tune) simulated through GEANT4, corrected for a slight difference (~5-7%) in number of primary tracks.
  MC is needed for taking into account the strong R- and z-dependences of the secondary track reconstruction efficiency

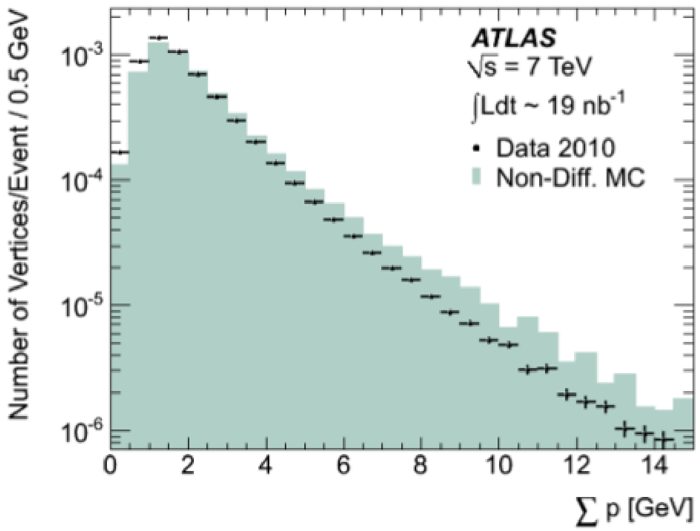




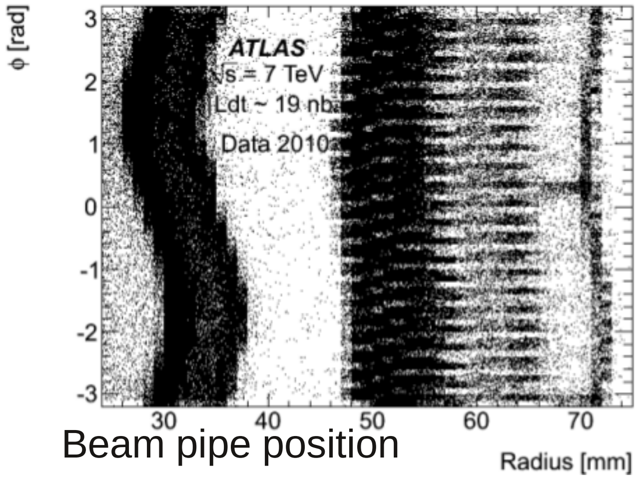
Upstream material using hadronic interactions (2)

- Uncertainty on modelling of hadronic interactions in GEANT4 controlled by studying the vertex yield in a control region
  - Using the Be part of the beam pipe (well-known composition, size and location)

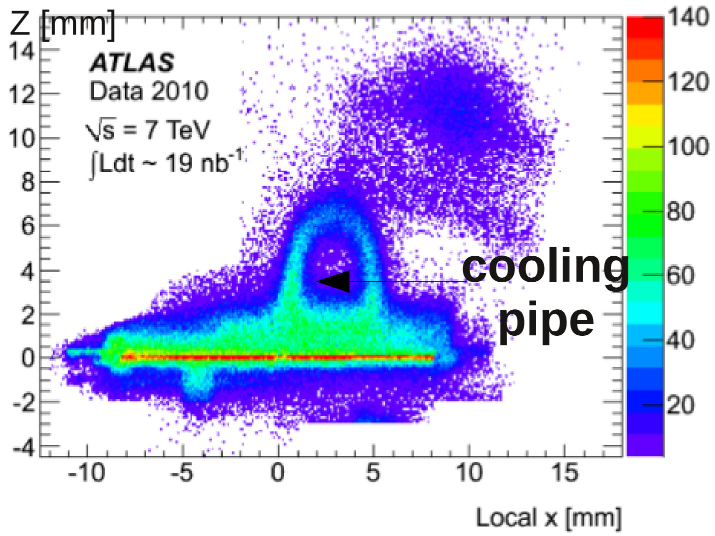
⟶ reasonable agreement

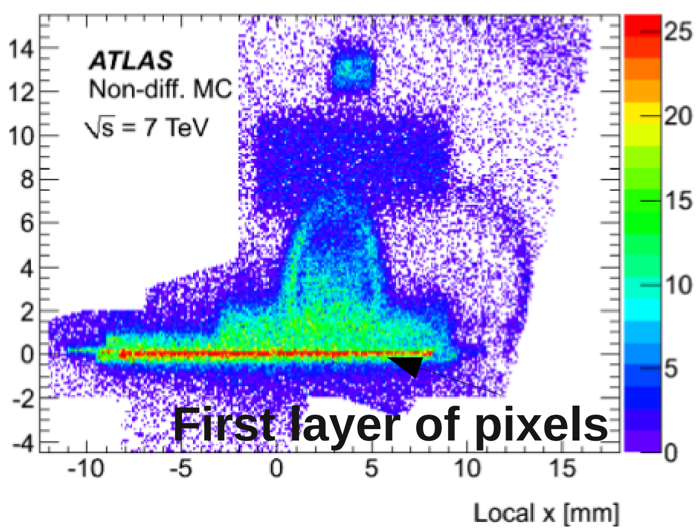


- New versions of the simulation have incorporated these results on the material mapping



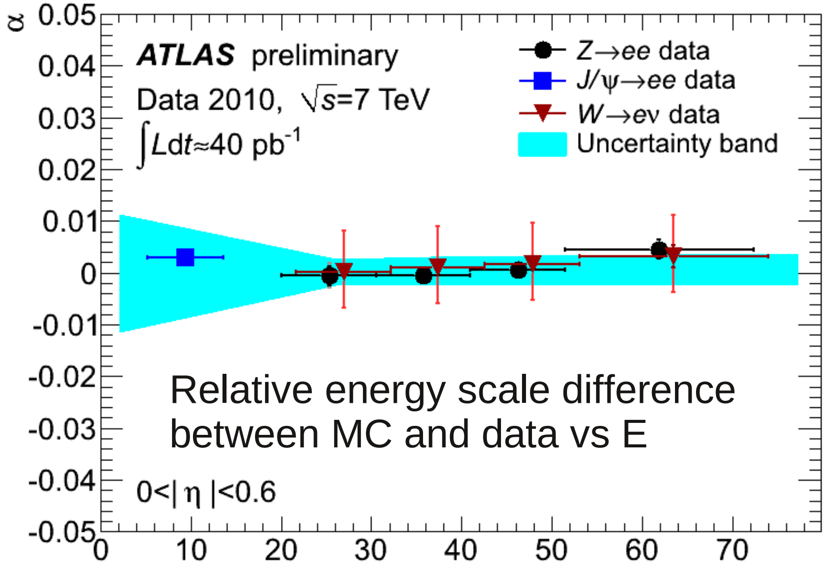
Beam pipe position

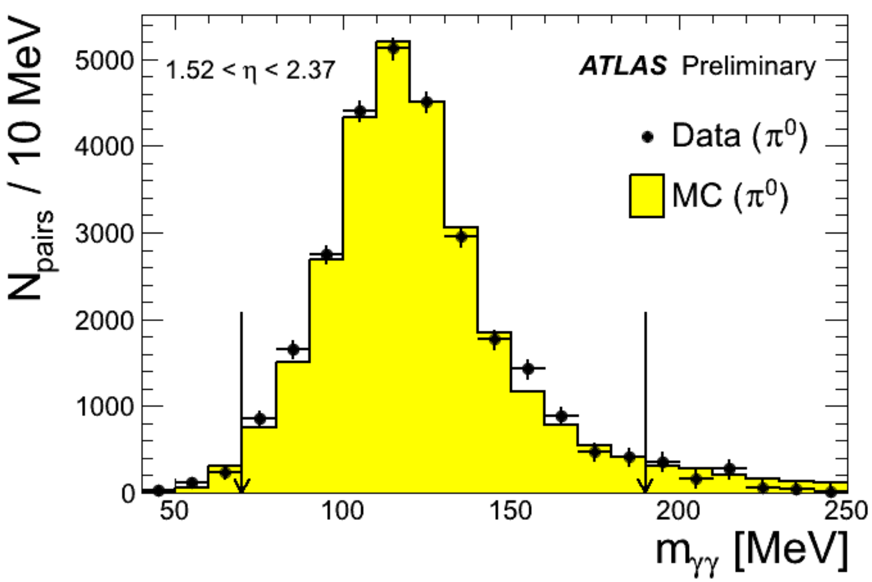


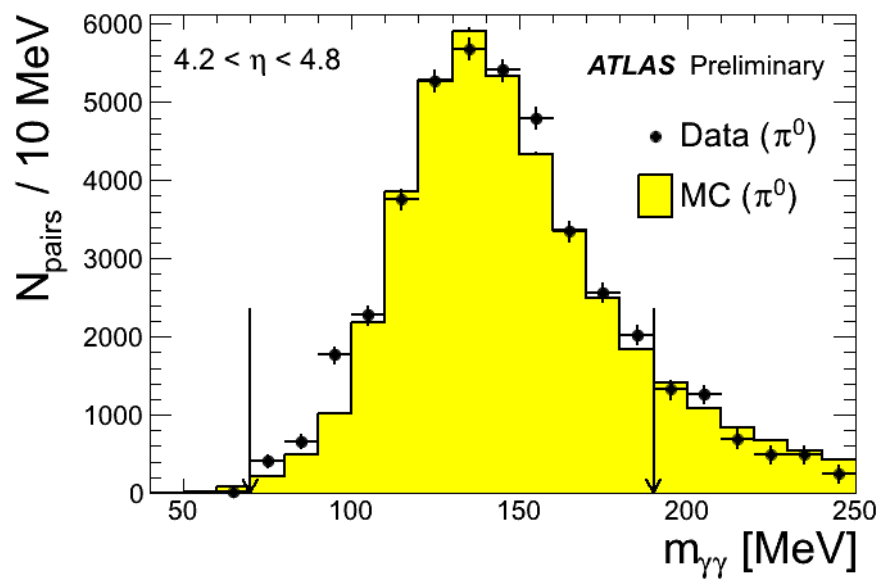


Impact on energy scale and resolution

- Precision on material mapping good enough for the calibration aspects (energy scale and resolution) but could also have some impacts on the identification discriminant distributions

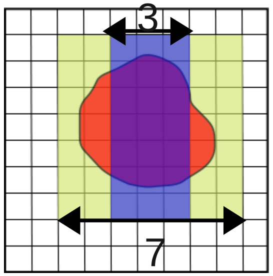




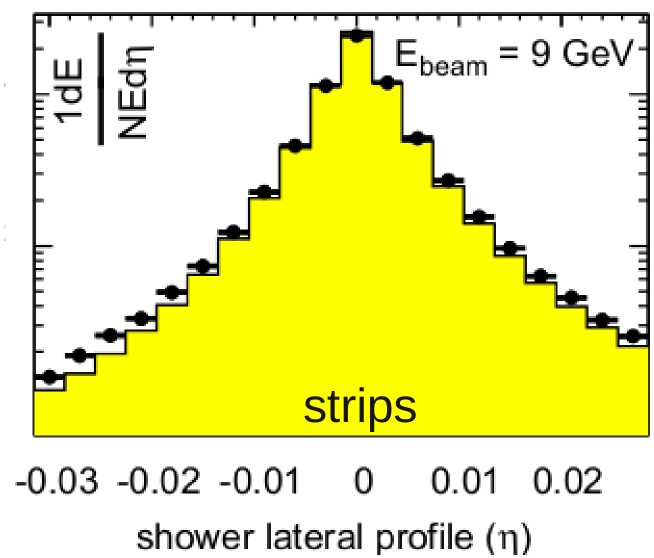


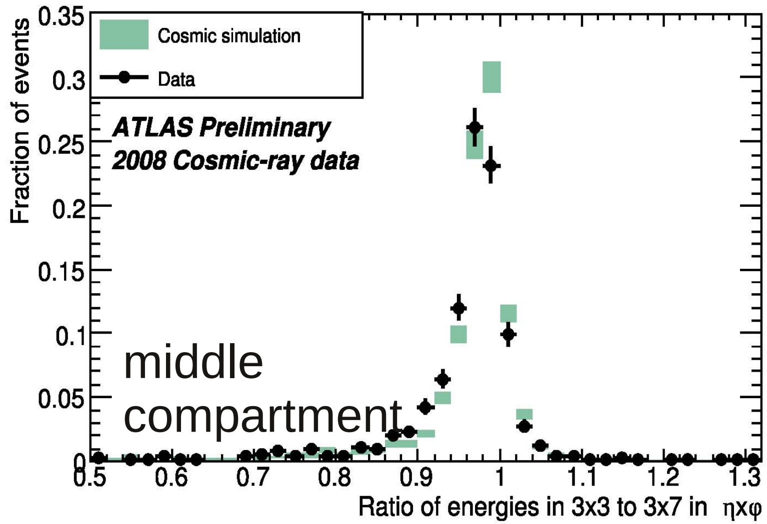
Shower shape discriminant variables

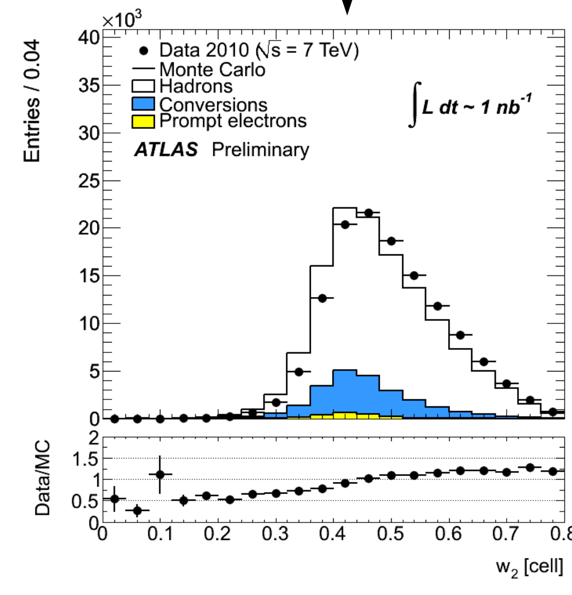
- The shower shape in the calorimeter allows for the rejection of a large fraction of background (O(1000))



- Benefiting from the thin granularity and the segmentation of the calorimeter, ATLAS defined a few variables illustrating the shower width in eta/phi and its longitudinal extension
- Even if the agreement is fairly good, the simulation does not perfectly predict the key distributions for the lateral development
- This has been observed during the test beam, the cosmics, and the collisions data-taking



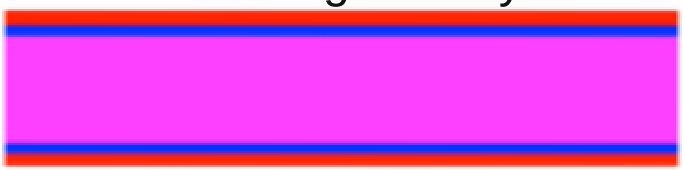




LAr absorber simulation

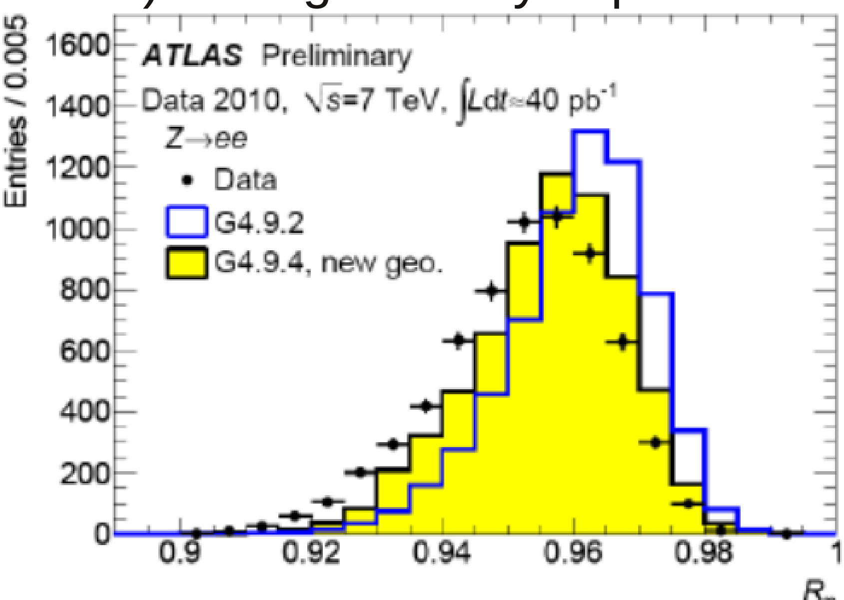
- We have tracked down that a large part of the disagreement was due to an improper simulation of the EM calorimeter absorber
- Real absorber is a sandwich Iron-Glue-Lead-Glue-Iron but it was described as a blended material made of Lead, Iron and Glue

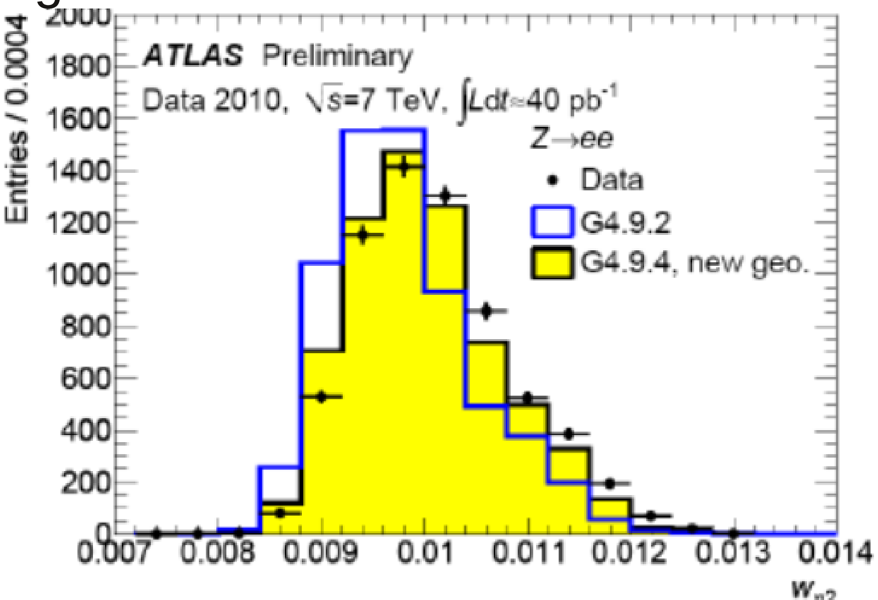
Detailed geometry



Blended geometry

- Running the detailed simulation costs an CPU time increase (30-60% for EM showers) but significantly improved the agreement.

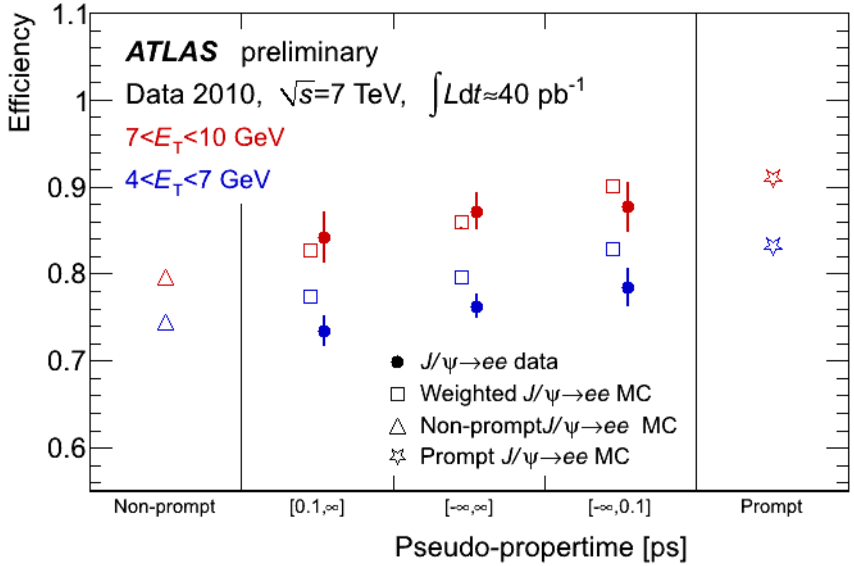


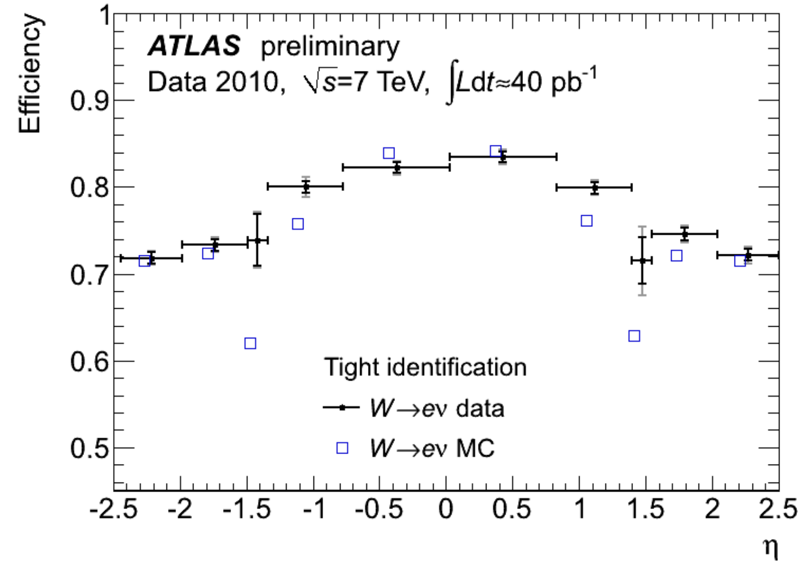


- Have checked impacts of cross-talk, material, geometry (accordion, sagging,...), misalignment,... Unfortunately, yet no good explanation for the remaining discrepancies.

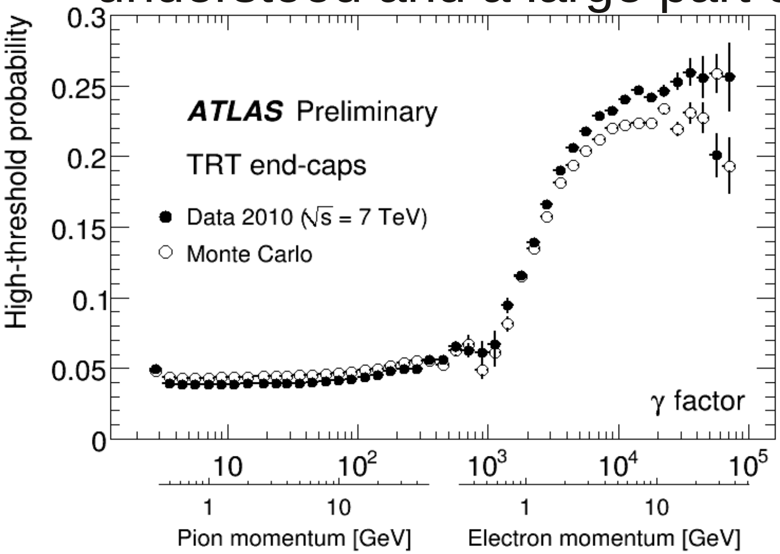
Impact of other aspects of simulation

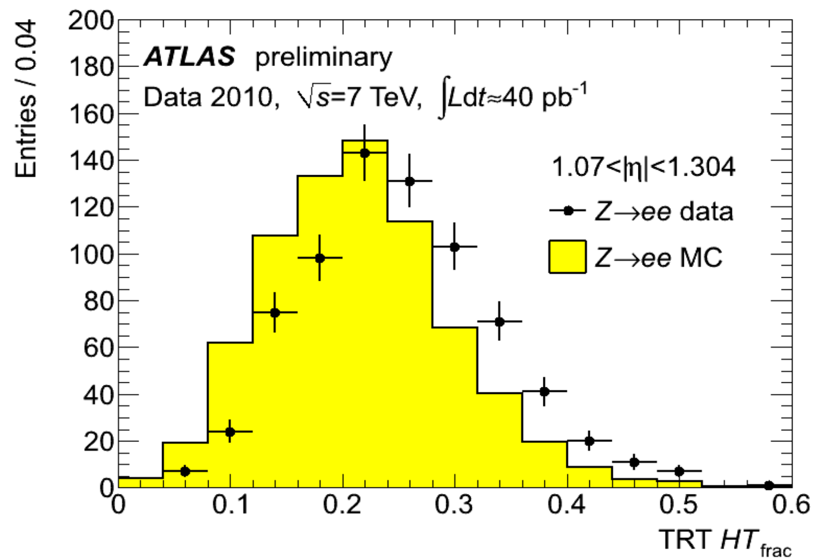
- To select the electrons, we usually cut on many variables and correct the MC predictions by data/MC scale factors measured using T&P-based methods





- Certain regions exhibit higher efficiencies in data than in MC. The reasons are understood and a large part of the effect is due to the transition radiation modelling resulting in a higher probability for an $e^{\pm}$ to have high-energy TRT hits
  - Tuning ongoing





Conclusion

- This talk focused on the slightly imperfect aspects of our Monte Carlo but the ATLAS simulation is actually doing a very good job !
- The few discrepancies we have noticed between Monte Carlo and data have generally been tracked down to simulation imperfections (GEANT4 absorbers modelling, amount of transition radiation,...)
- Other issues are being improved with time and statistics (today using O(4M) W, O(1M) Z and O(70k) J/Psi probes)...