ATLAS and Geant4 EM simulation

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on behalf of the ATLAS Collaboration

LHC detector simulation workshop
26/06/2017

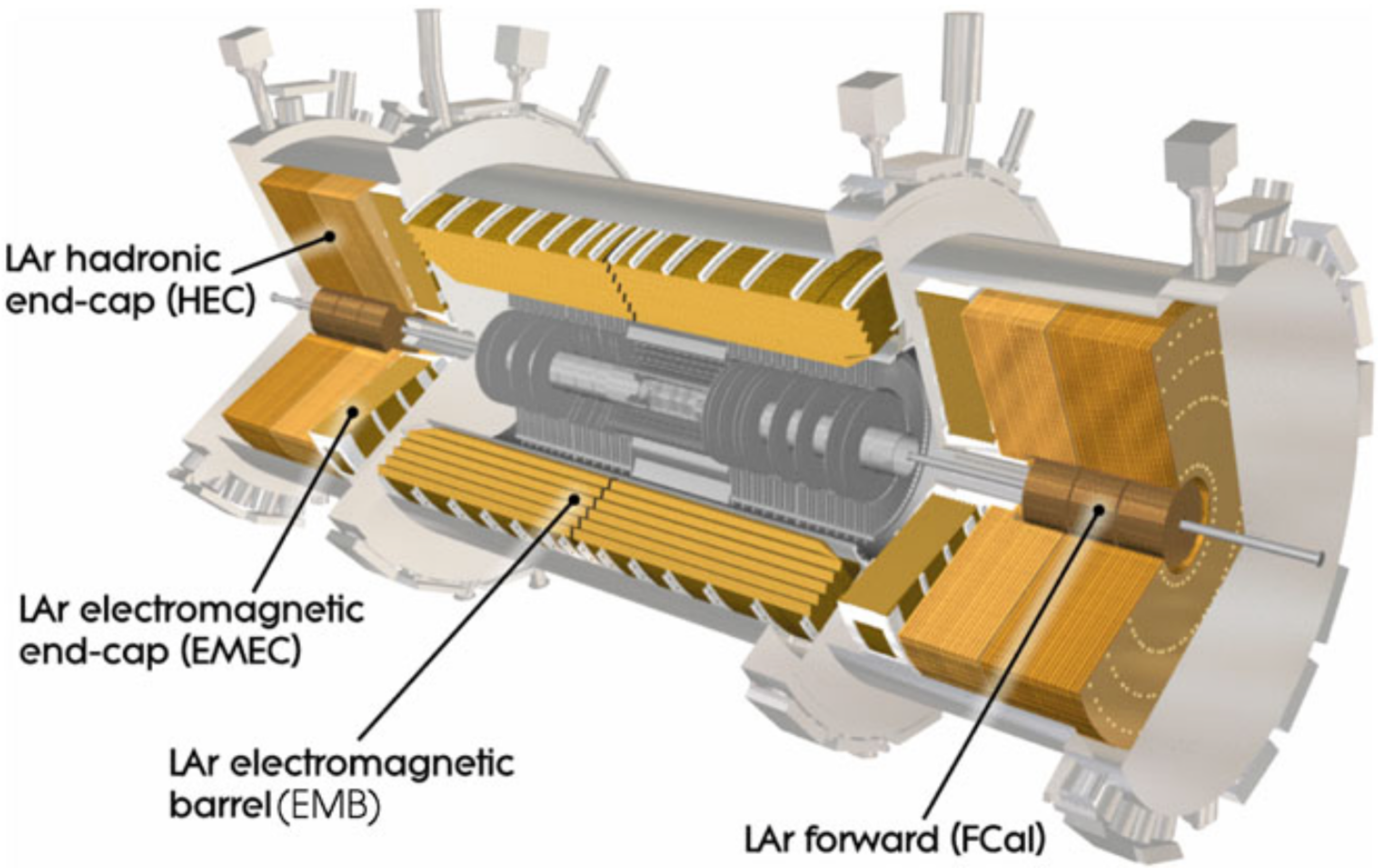
Outline

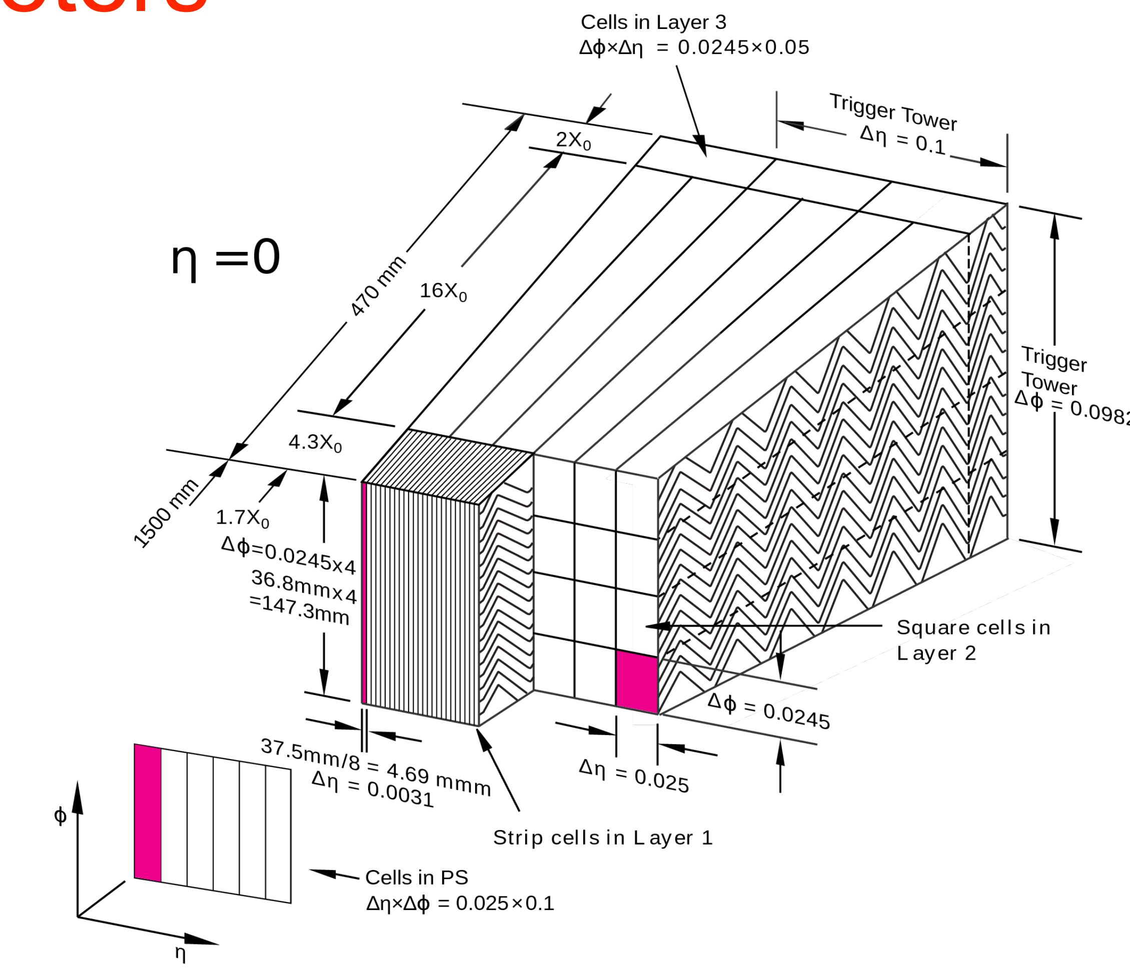
- ATLAS detector and how its calorimeter is simulated in Geant4
- Longitudinal EM shower profiles and material before the calorimeter
- Energy resolution
- Lateral EM shower profiles and modeling of electron and photon identification efficiencies

not covered here (but also relevant to EM physics):

- fast simulation aspects of EM showers => talks by Petr and Federica
- specificities of pileup simulation => talk by Tadej
- simulation of the inner detector => talk by Nora

ATLAS calorimeters



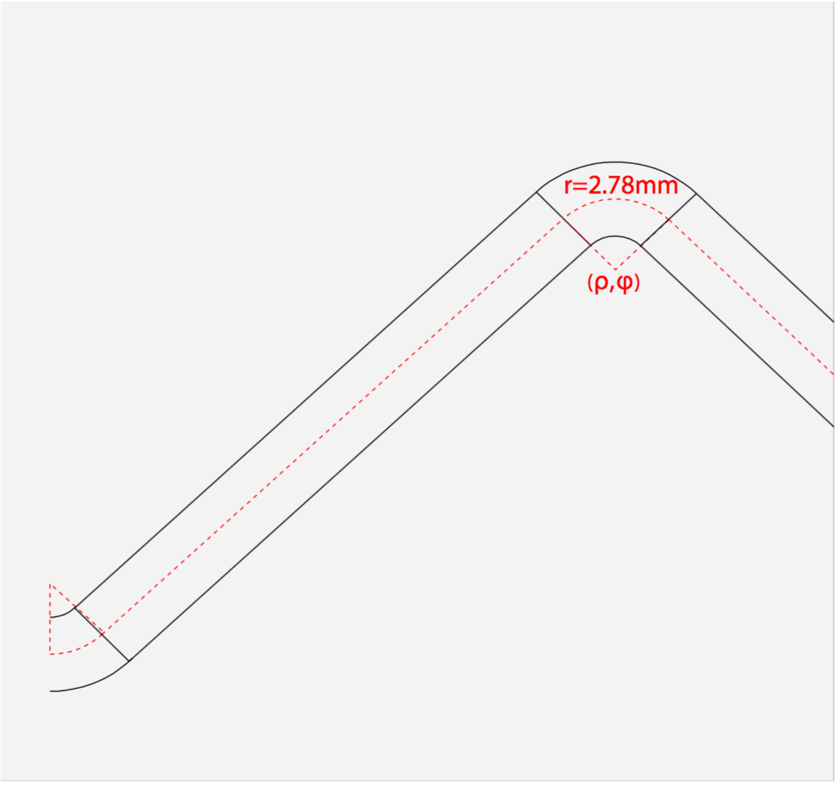


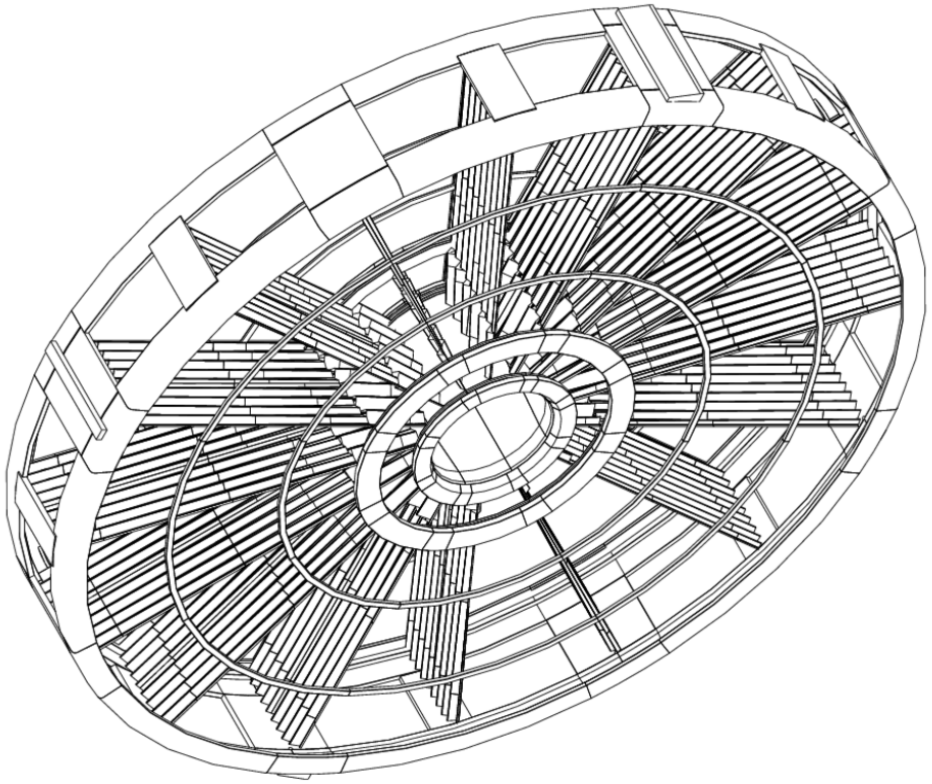
Concentrate on the EM barrel and end-cap calorimeters
Pb-LAr sampling calorimeter with accordion geometry and high transverse and longitudinal granularity

Sampling fraction ~ 15-20%
Intrinsic energy resolution ~ 10%/sqrt(E) (barrel)
"intrinsic" sampling fraction and energy resolutions quite stable with G4 version
(except few per mill not understood change in EMB sampling fraction seen in 4.10)

3 cryostats (one barrel including solenoid , two end-caps)
Tracking (Si pixel and strips, TRT) before the calorimeter
Typically 2-3 X0 before the active part of the calorimeter

G4 simulation ingredients (i)





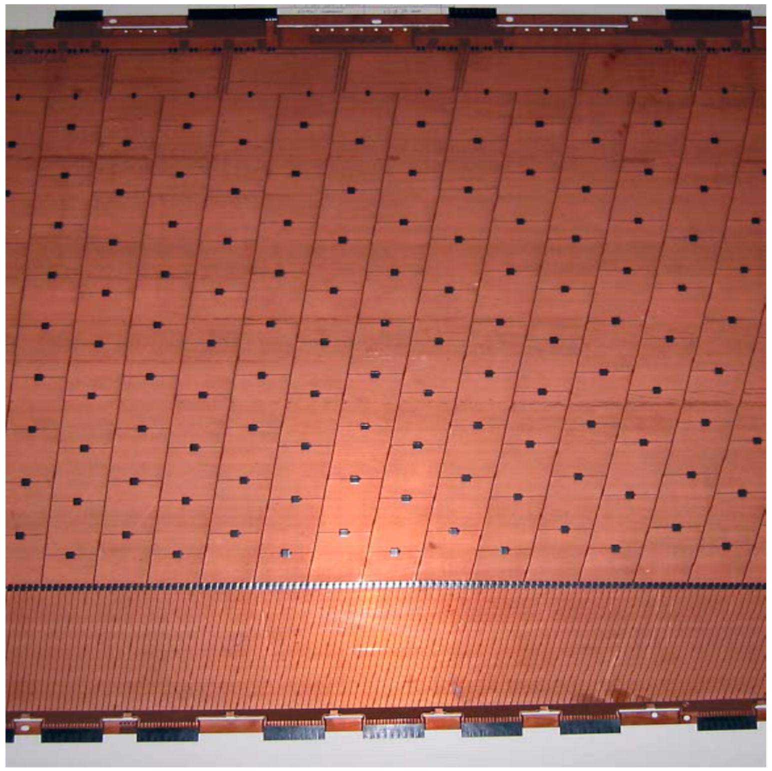
Detailed description of the volumes inside the cryostat including all materials (like cables related to first layer readout, support rings, cryostat, etc..) .

In the active part of the calorimeter: Absorbers (Steel-Glue-Lead-Glue-Steel) and electrodes (Cu), accordion shape, inside LAr bath.

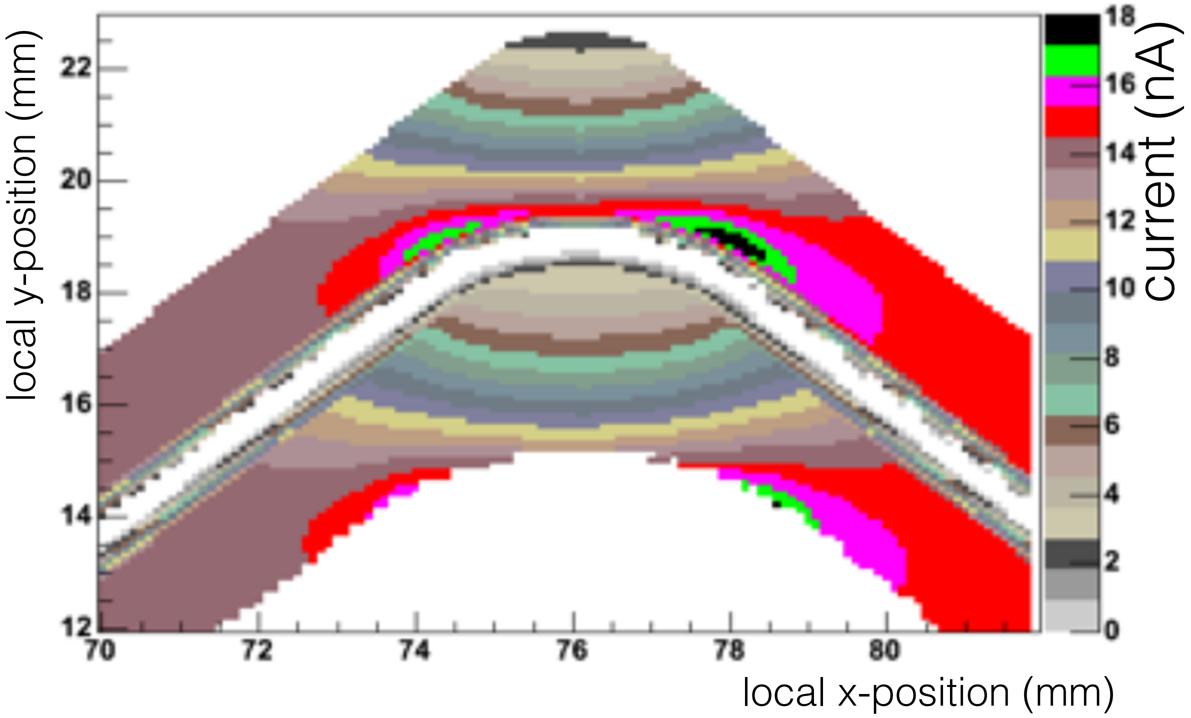
More complicated end-cap geometry implemented using the custom solid approach

Detailed properties coming from detector construction papers.

G4 simulation ingredients (ii)



Current / MeV deposit
in absorber fold



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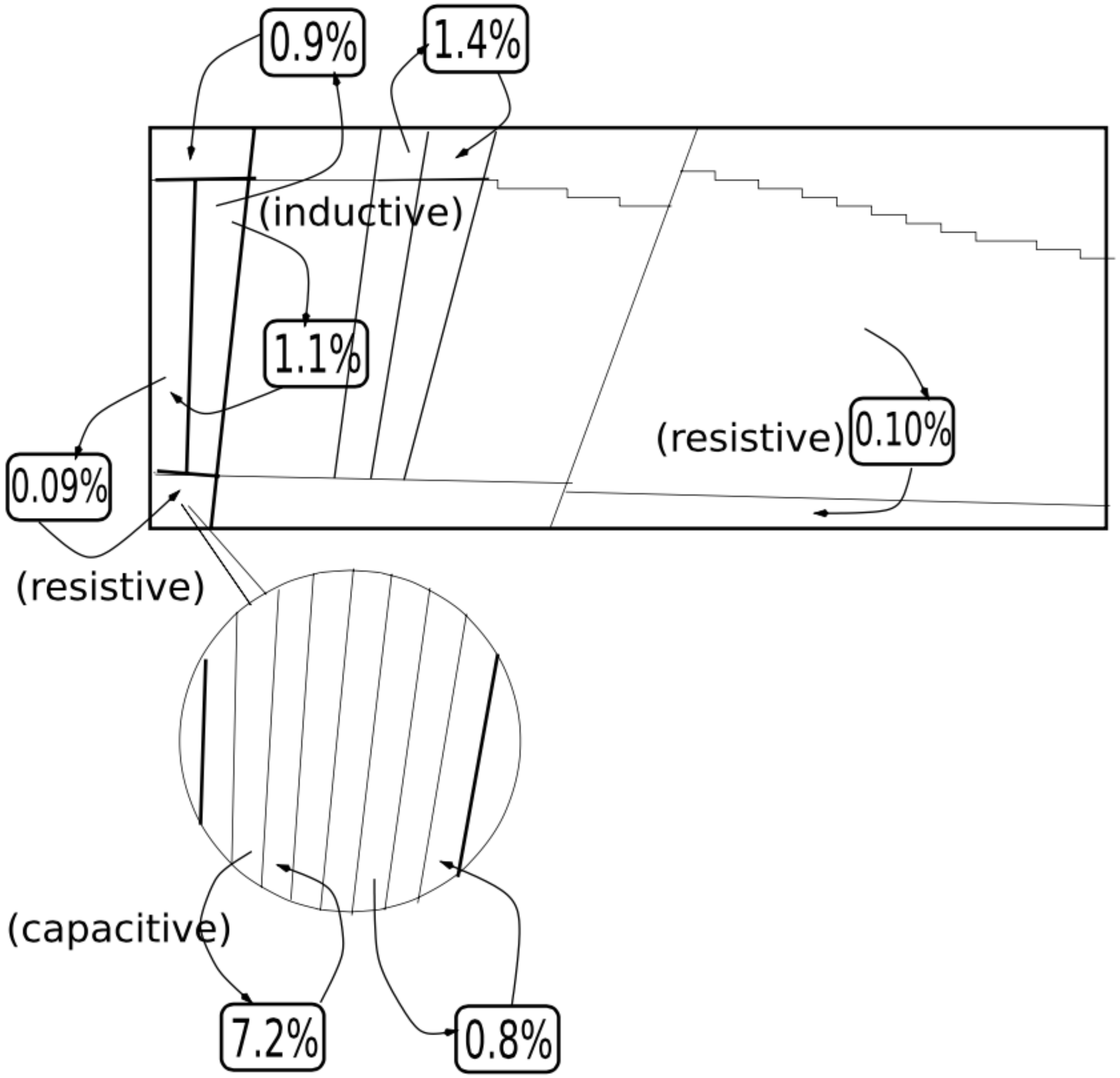
Implementation of the readout structure of the electrodes

Variations in electric field taken into account to compute ionization current for the energy lost in each G4 step.

Cross-talk effects between different calorimeter cells also included, mostly using predictions from electronics calibration measurements

Typical cross-talk values in EM barrel



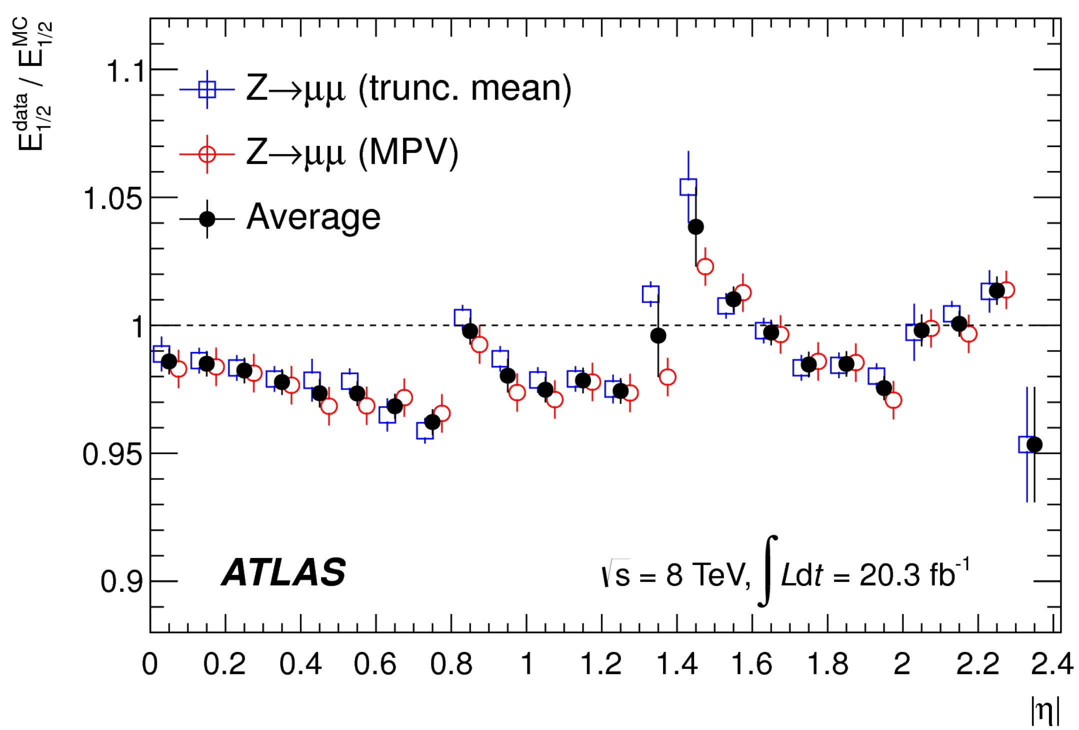
Main effects

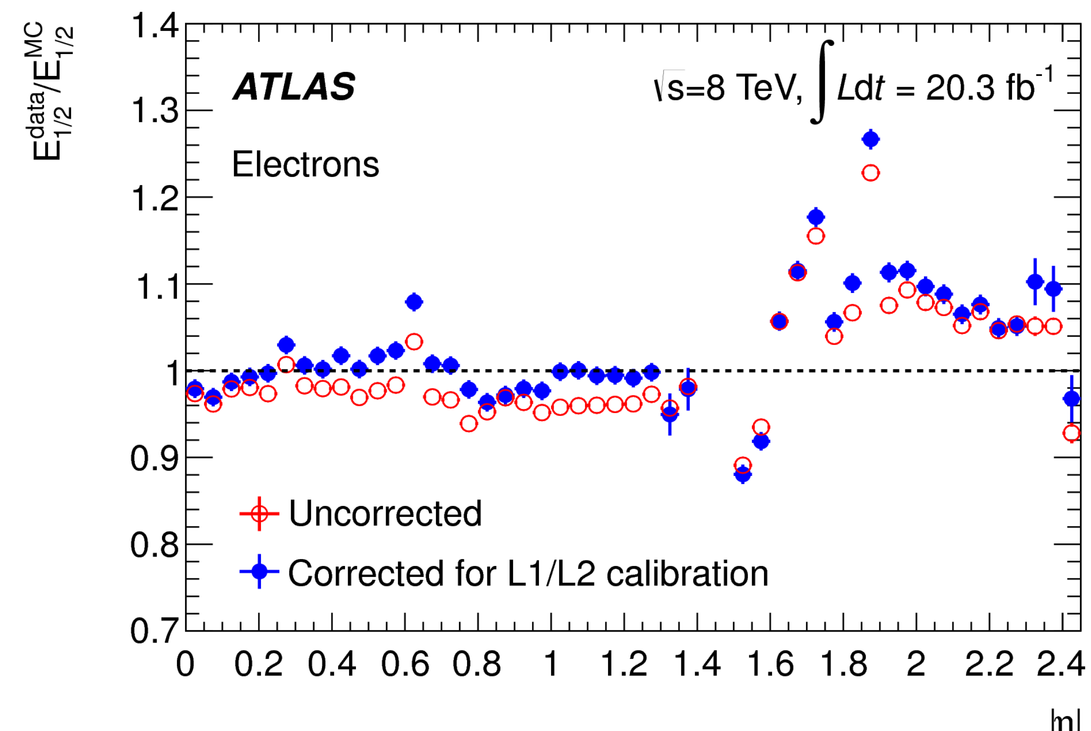
- longitudinal shower shape
  - ~1% migration between first and 2nd layer
  - most energy in E3 from cross-talk from 2nd layer for low/medium energy EM showers
- Widen lateral shower shape in eta-direction in layer 1
  - Also some impact on lateral shower shape in layer 2

Longitudinal EM shower profile

Use first two layers of the EM calorimeter
Pre-requisite: proper inter calibration
Done comparing data/MC for muons (from W,Z decays)
- Small signal (~50 MeV layer 1, 250 MeV layer 2) but clean from upstream material systematics
- ~1-2% systematics when extrapolating muon measurement to electrons

Once done can look at E1/E2 of electrons and compare to MC predictions





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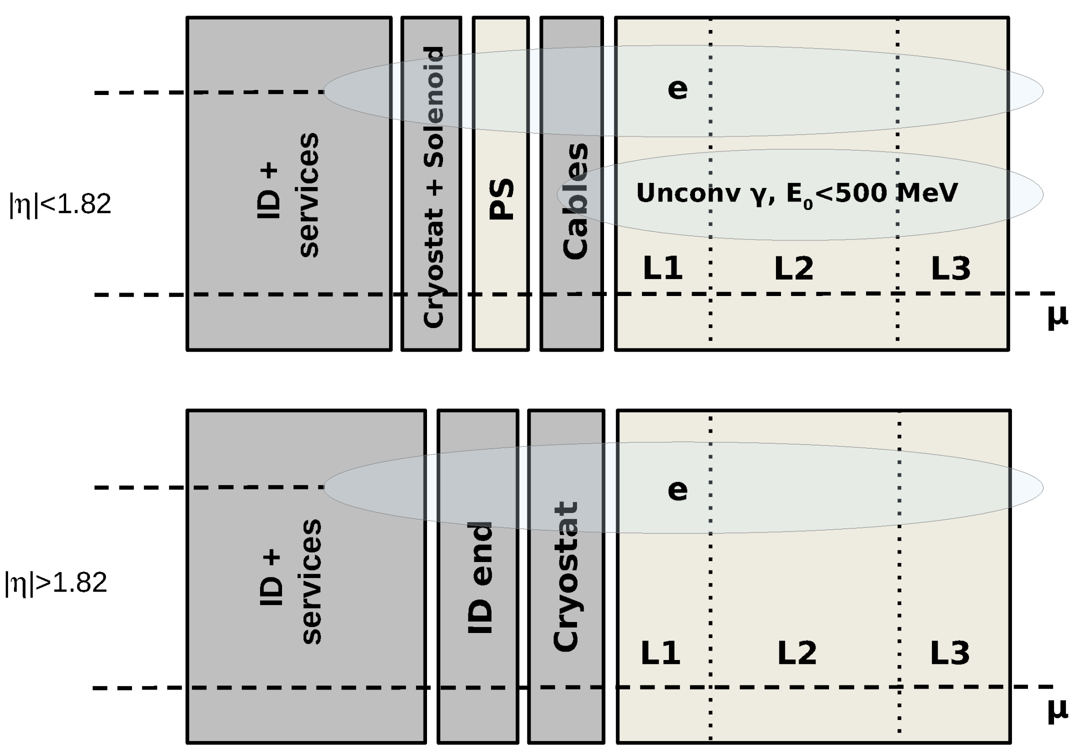
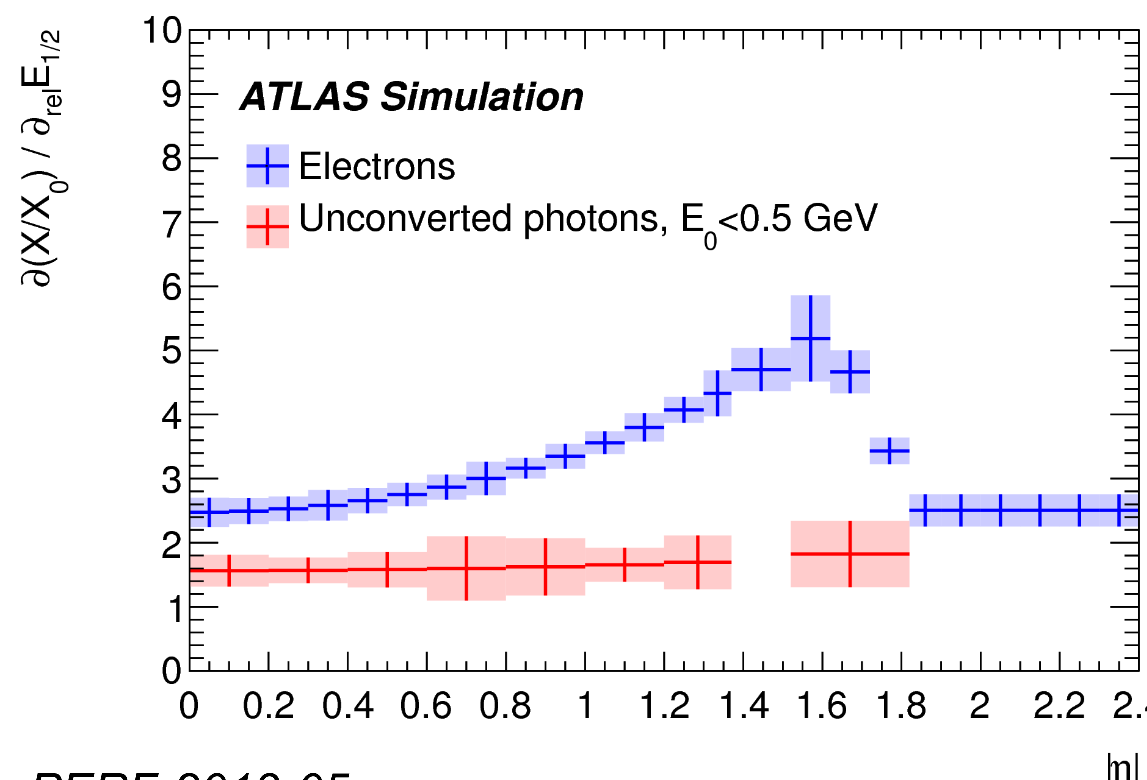
Material before the EM calorimeter

E1/E2 for electrons very sensitive to material before the calorimeter
Use a mixture of electrons and unconverted photons to constrain the material in different areas
Material in the active part of the ID detector constrained by construction surveys

Translate the measurement of E1/E2 from electrons to a measurement of the amount of material before the calorimeter

~1.8X0 ~0.6X0 at eta ~0





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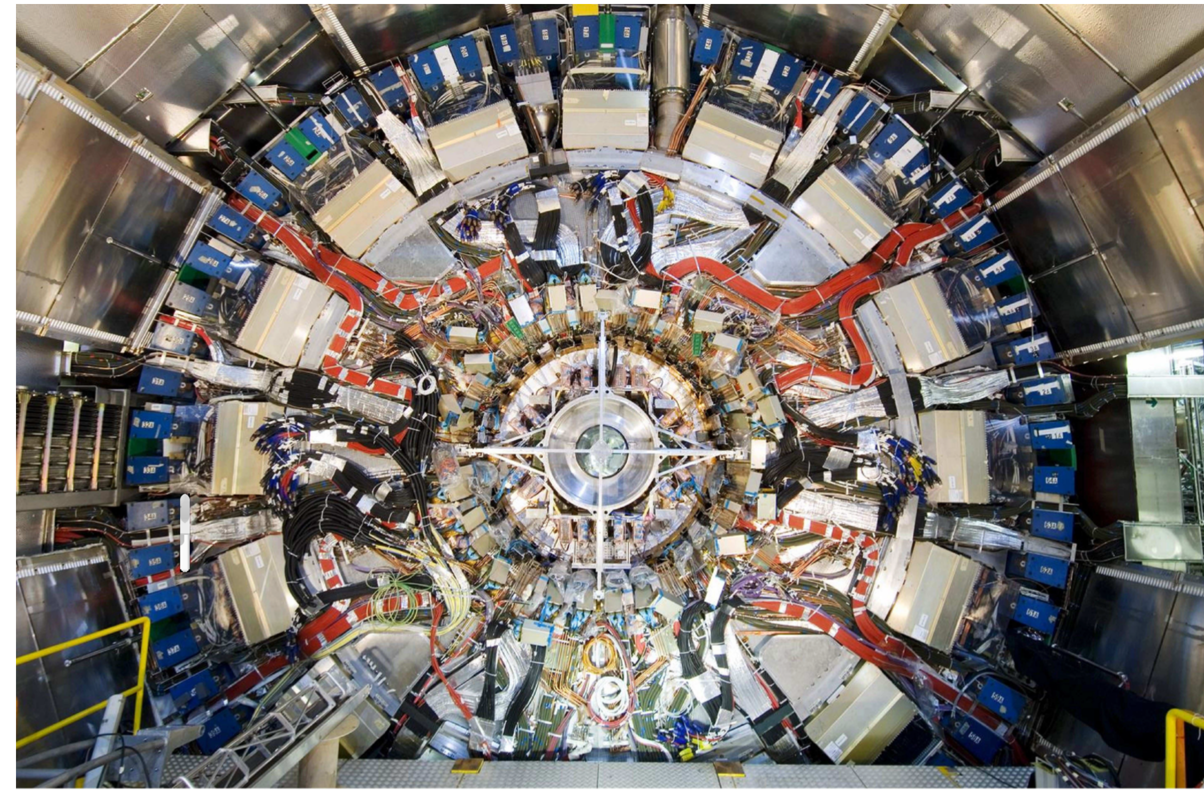
Some deviations observed from the original run 1 detector description.

Mostly in the area with large amount of services before the calorimeter cryostat.

Most of the deviations understood after checking detailed drawings



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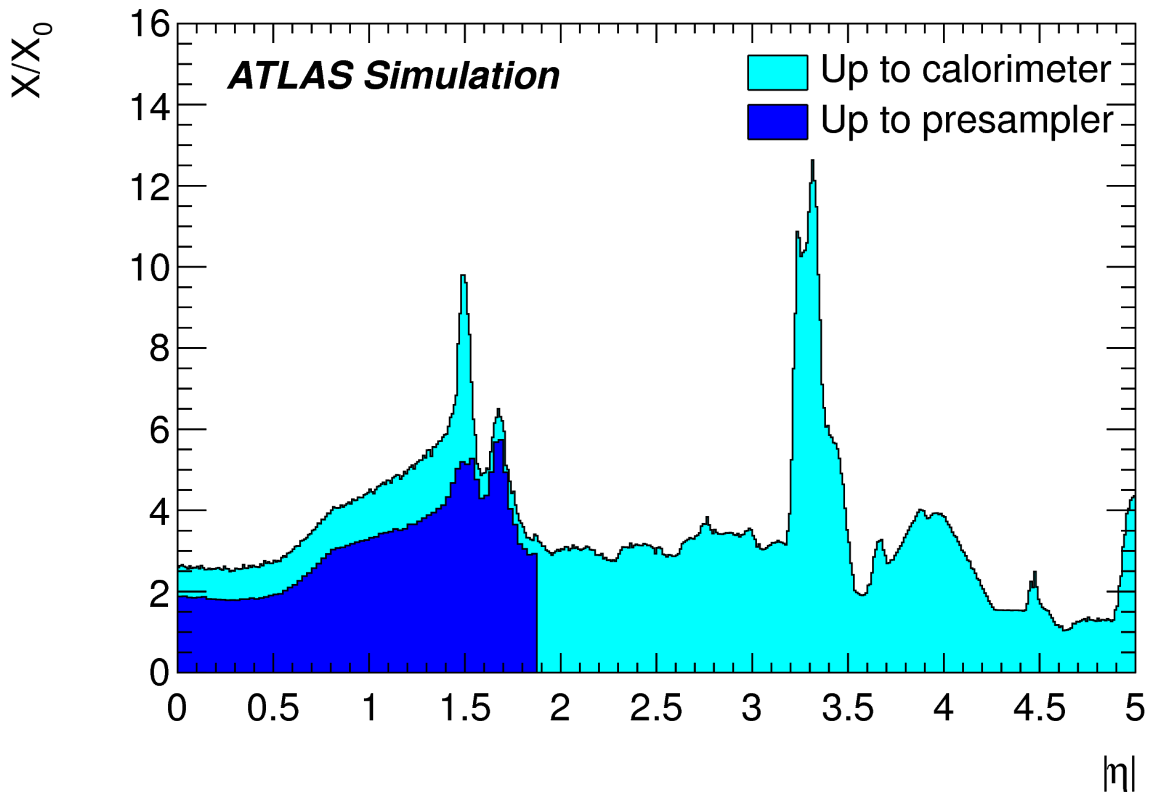
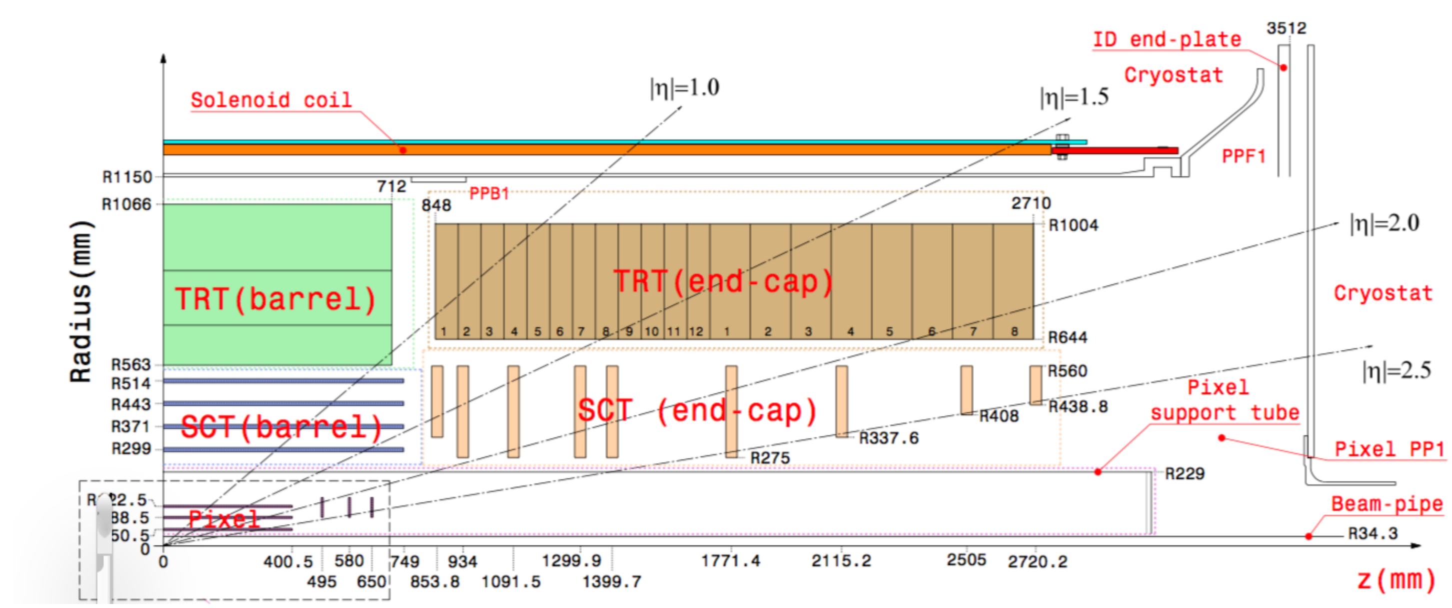


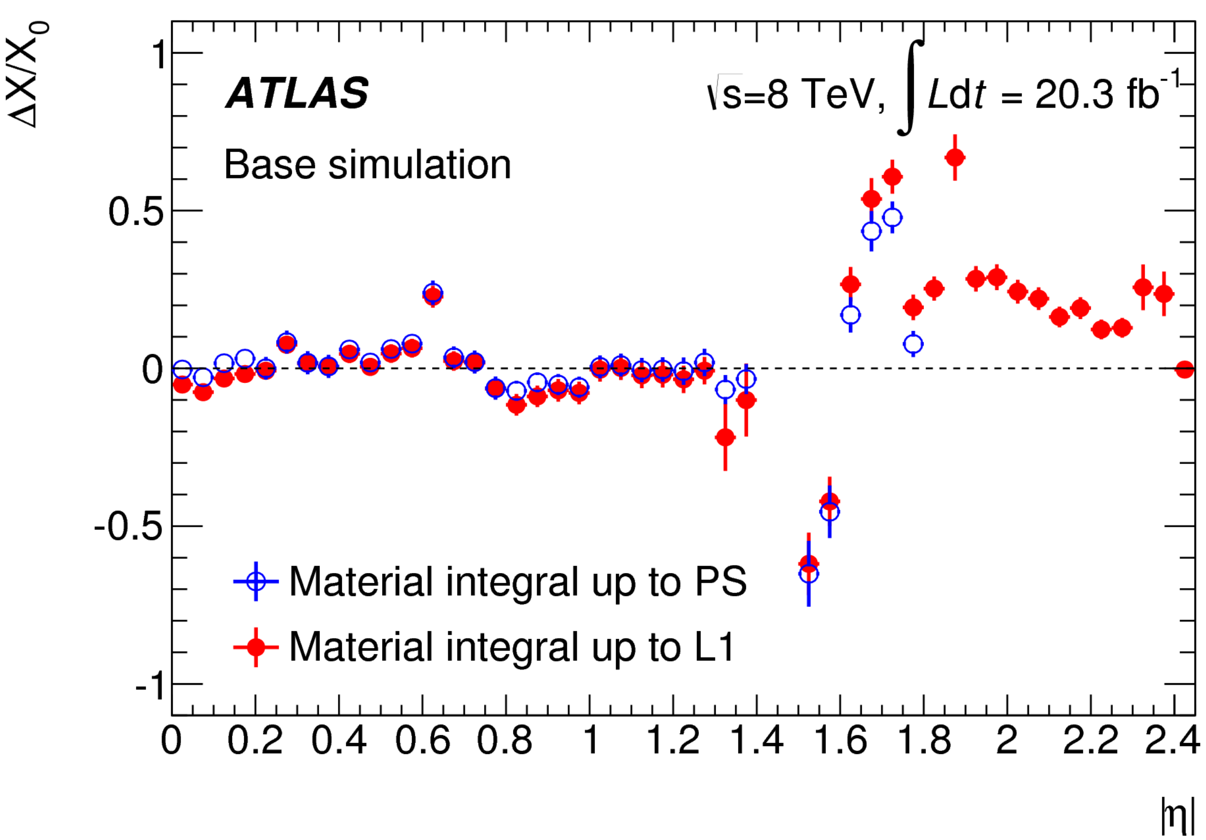


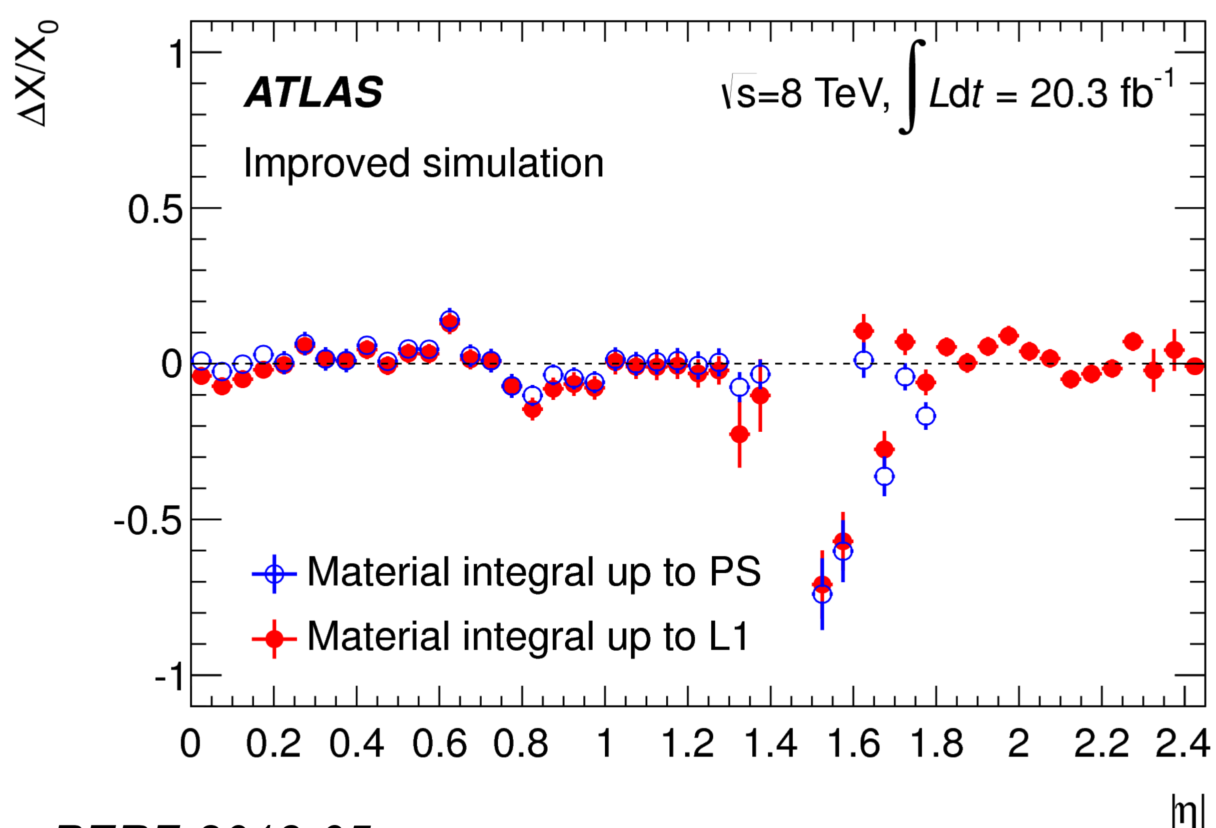
Material before the EM calorimeter

A new geometry was developed to incorporate these improvements from the data-driven studies of material before the calorimeter

Uncertainties:
- stat. uncertainty from data
- uncertainties from the E1/E2 calibration and the impact on electrons E1/E2
- change in G4 physics list => much smaller uncertainty than the one above

Reducing the uncertainty on the material before the calorimeter allowed for instance a smaller uncertainty in the electron -> photon energy calibration extrapolation





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Energy deposit in presampler layer

Checked with electrons
Very sensitive to material upstream the presampler => Use E1/E2 studies to constrain it
Data/MC <E(presampler)> ratio actually used to correct energy scale of presampler
very close to 1 in barrel region

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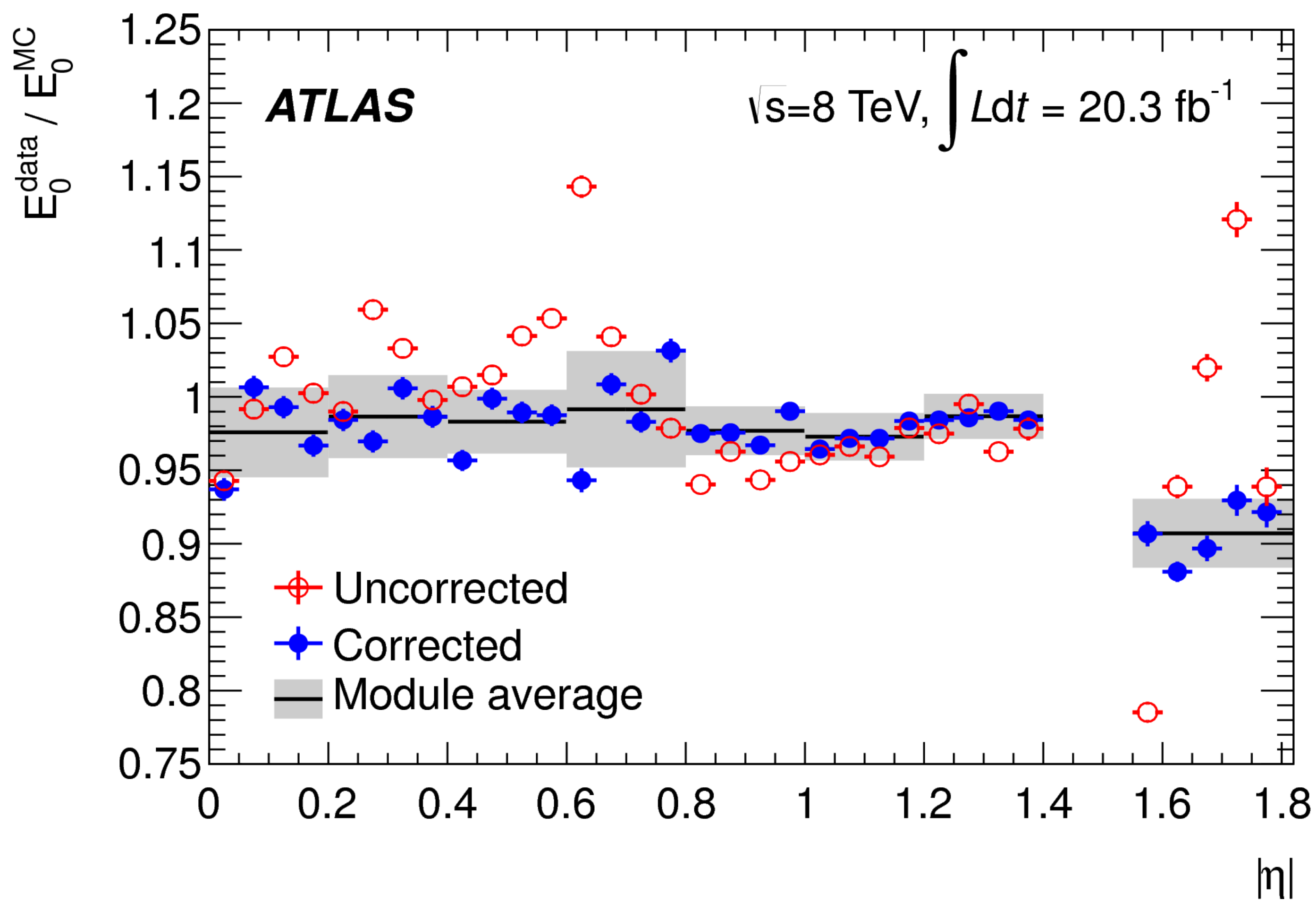


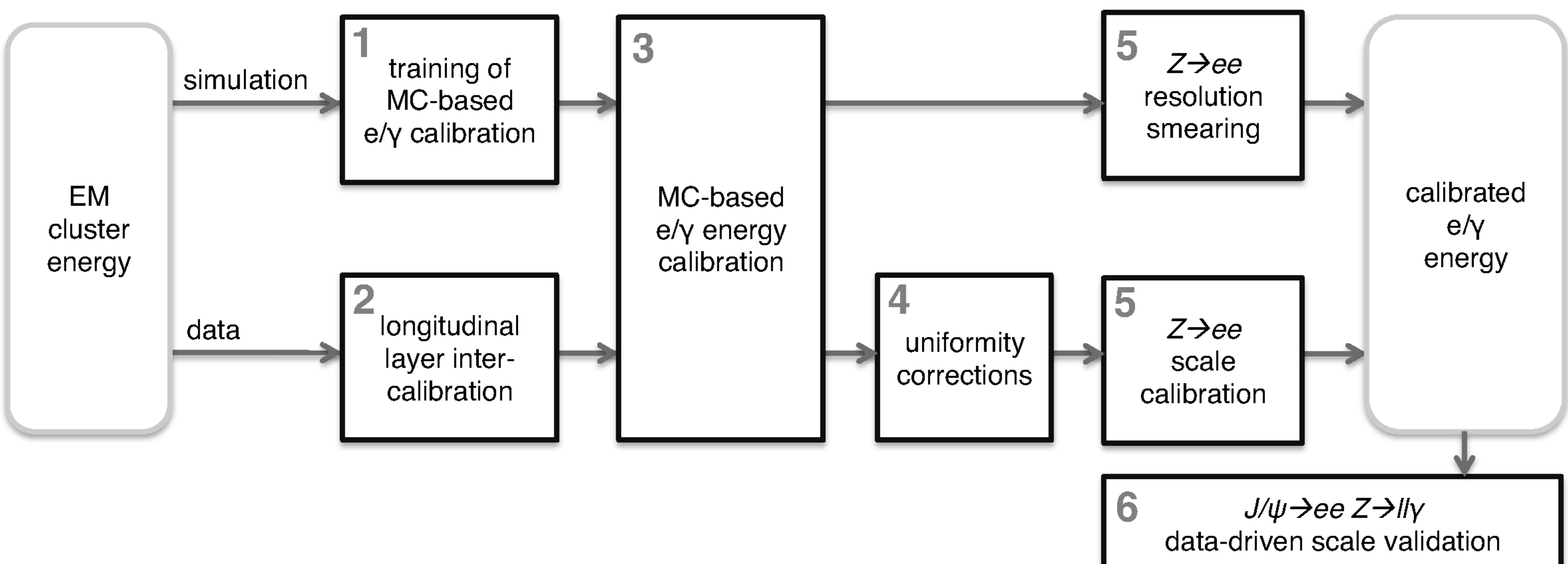
Energy calibration and resolution

e/photon energy estimate from calorimeter layer energies optimized using a BDT regression algorithm, this corrects for upstream energy loss and cluster containment effects => need accurate MC description

Layer energies are calibrated in data to match MC

Small local variations corrected in data

Then one is left with eta-dependent overall data/MC energy scale adjustments and data-MC resolution difference from the energy resolution constant term (=f(eta))
These factors are determined from Z->ee events



Energy calibration and resolution

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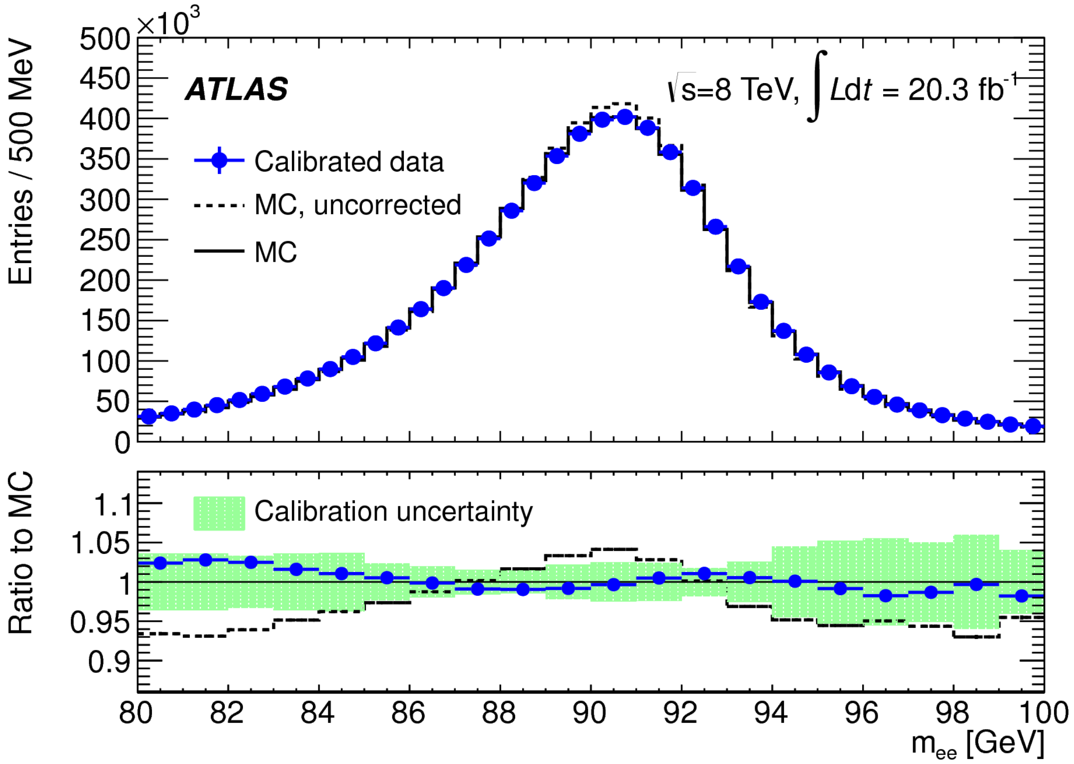
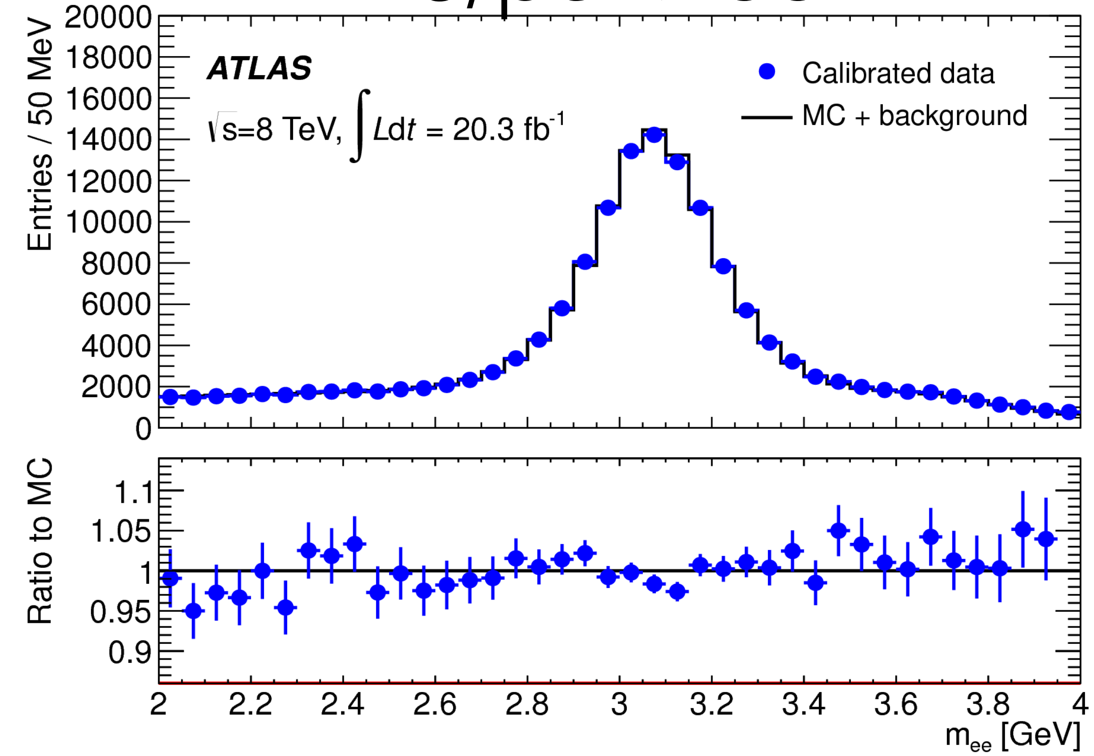
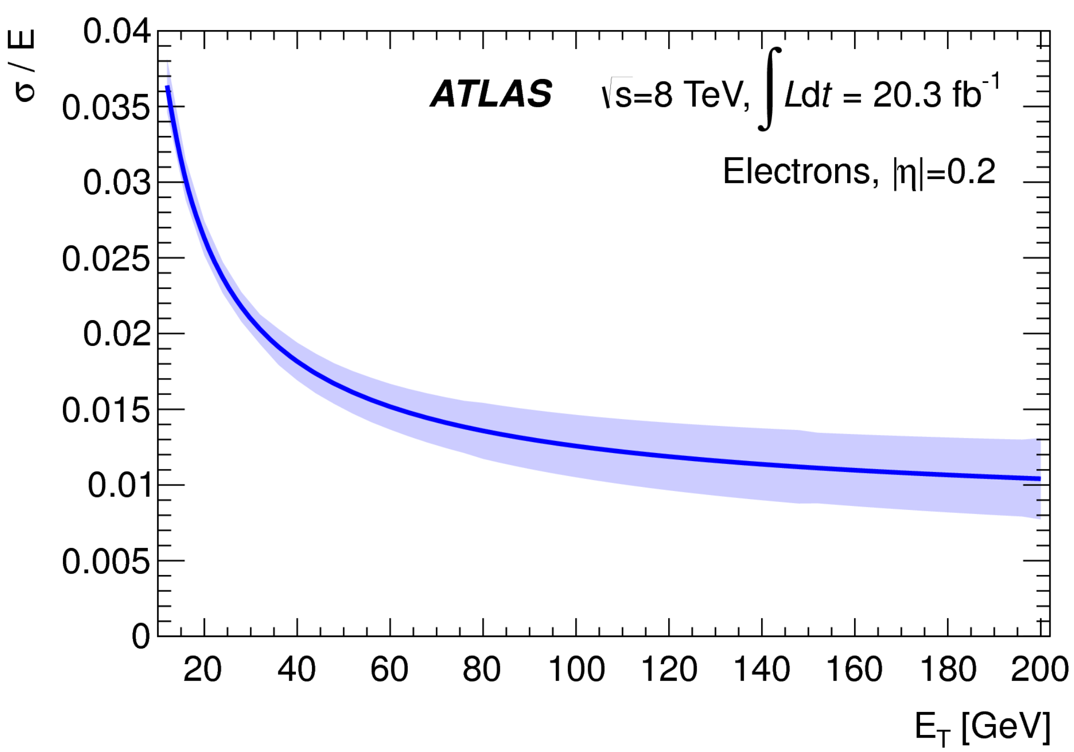
Z->ee

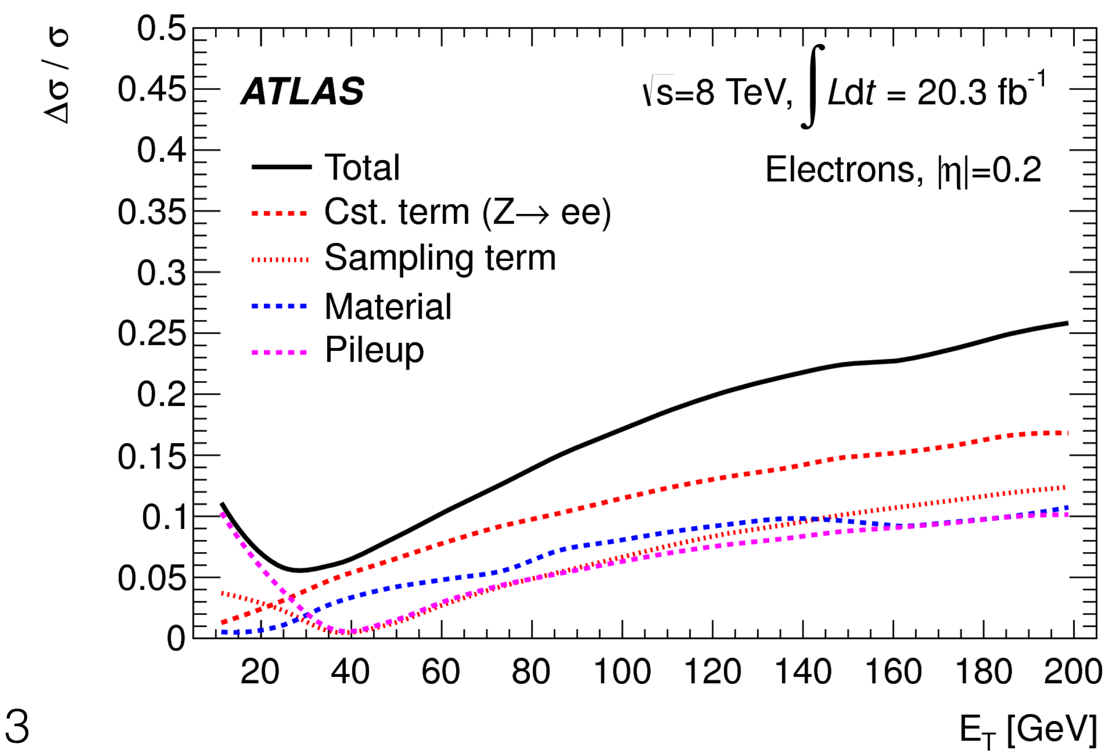


J/psi->ee



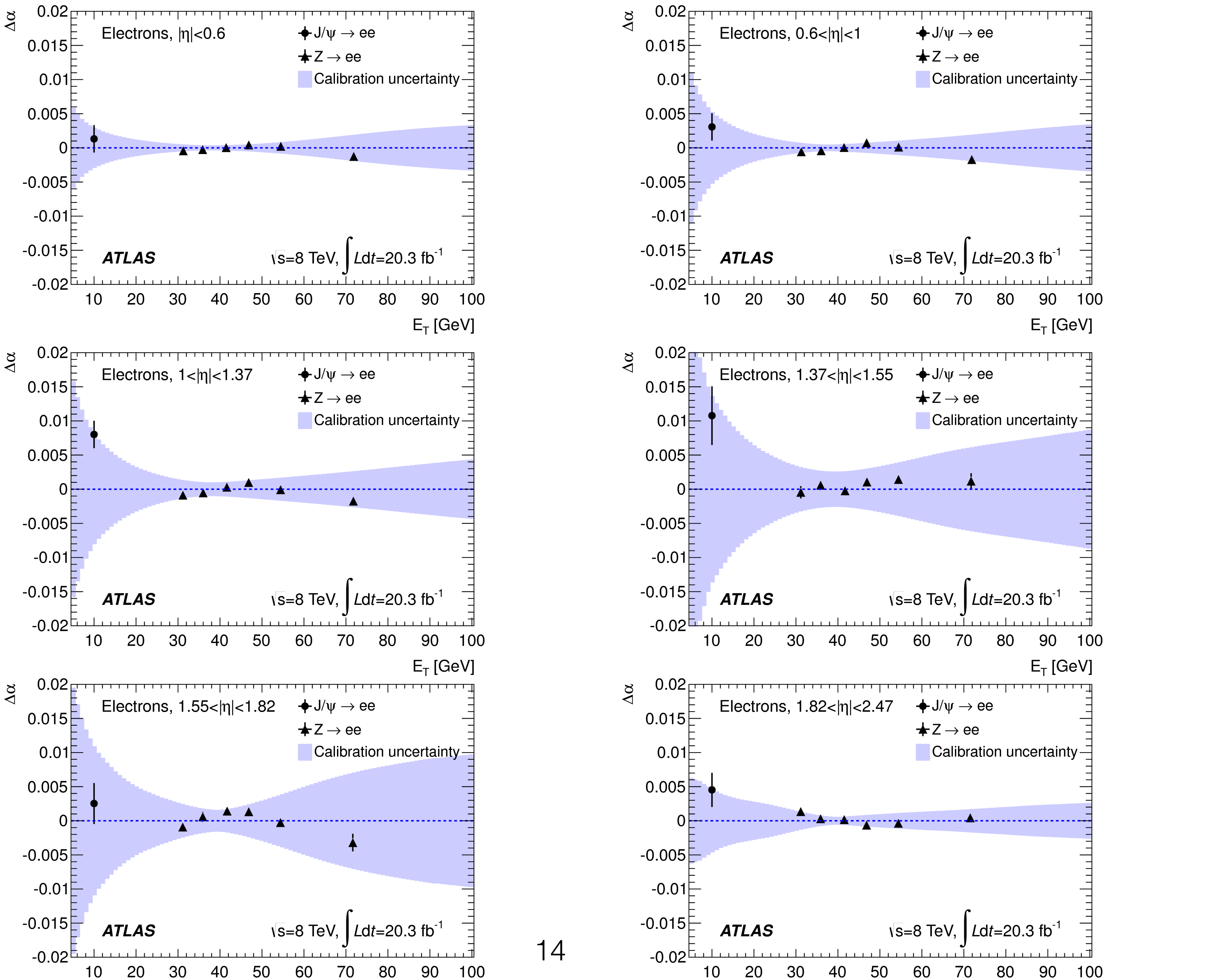
Sampling term uncertainty: assumes 10% uncertainty (conservative, from TB studies)





Electron energy scale accuracy (run 1)

Low Et : material and layer calibration uncertainties ~ comparable
High Et : uncertainty on possible non-linearity in readout electronics



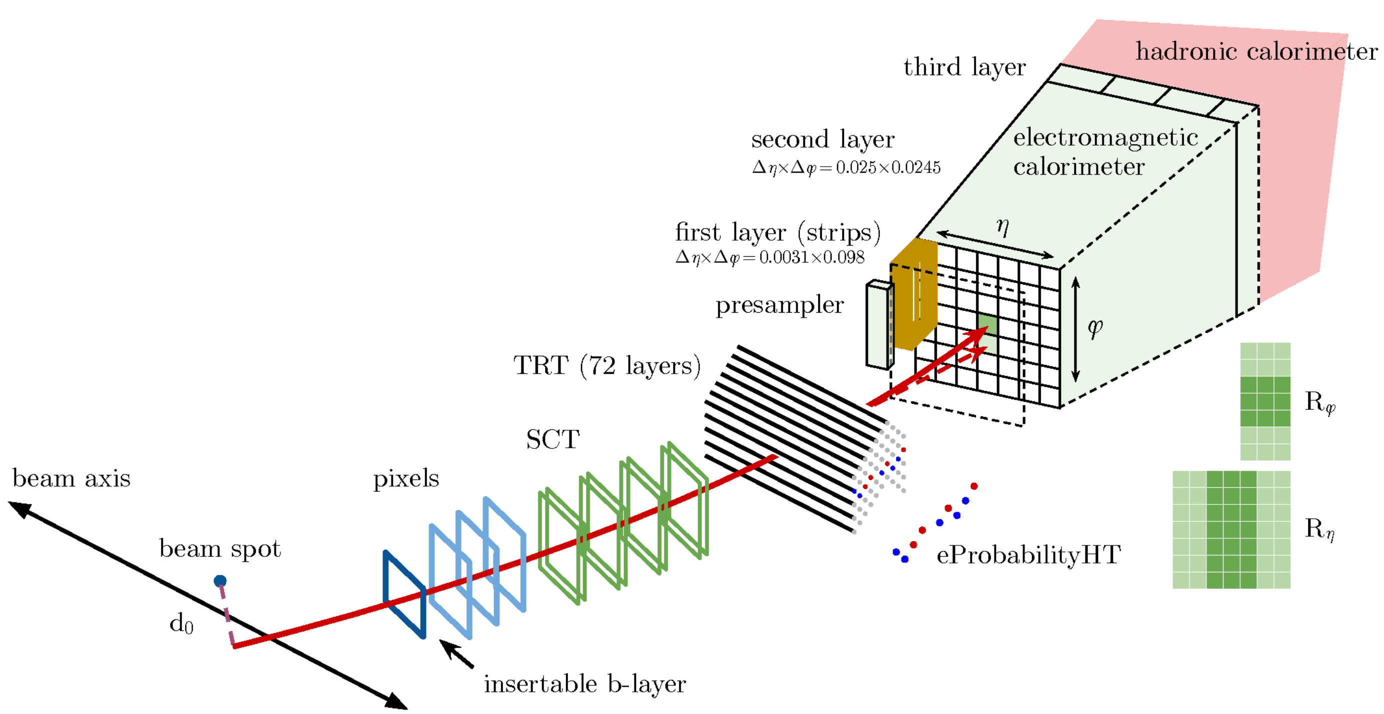
Lateral EM shower shapes

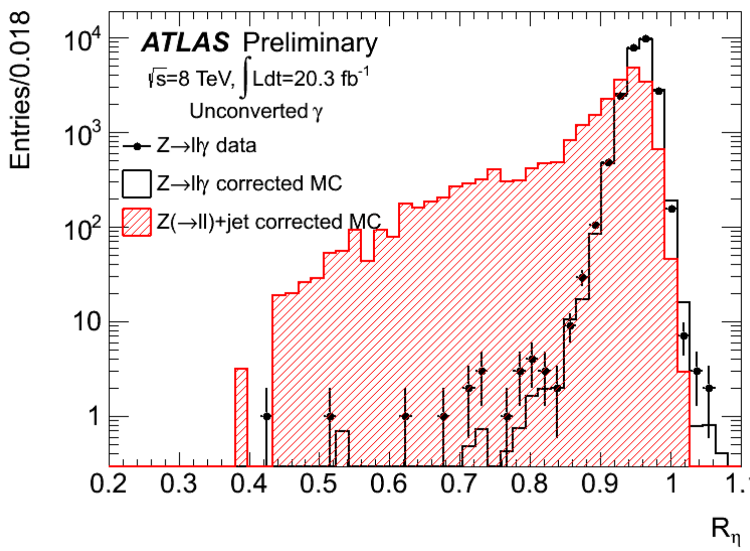
Lateral EM shower shapes are key input variables to separate "isolated" electron and photons from background sources (produced from jets).

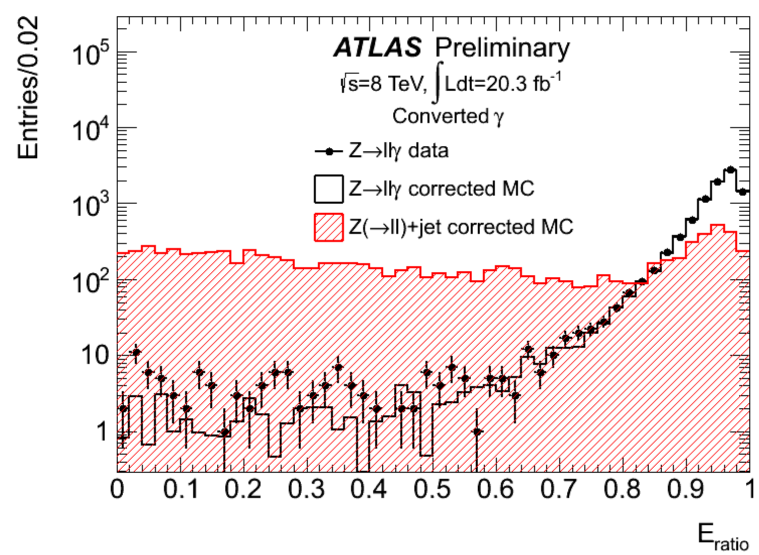
For instance the finely segmented first layer allows photon/pi0 discrimination.

Longitudinal shower shapes and tracking variables are also used for electron identification.

Photon identification uses a set of cuts on various shower shape variables.
Electron identification combines the different variable in a likelihood.
Data-MC difference in shower shapes included in identification optimization.



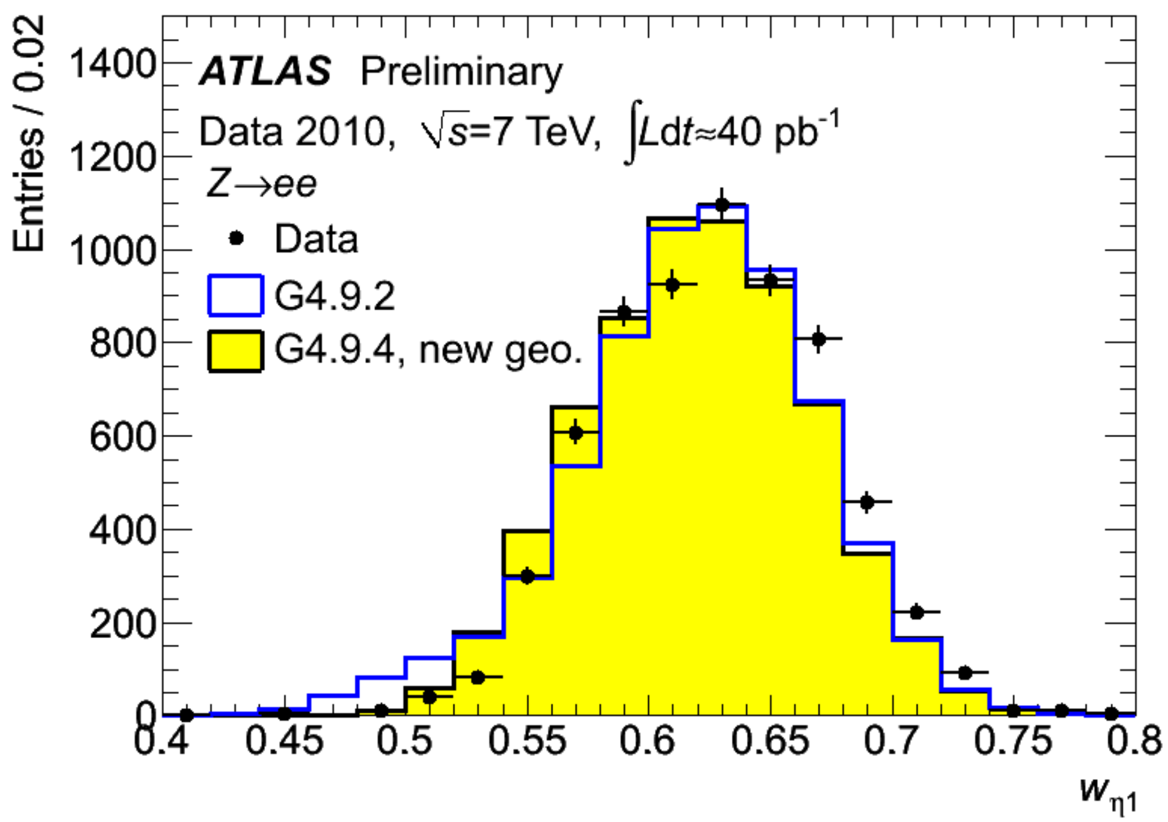


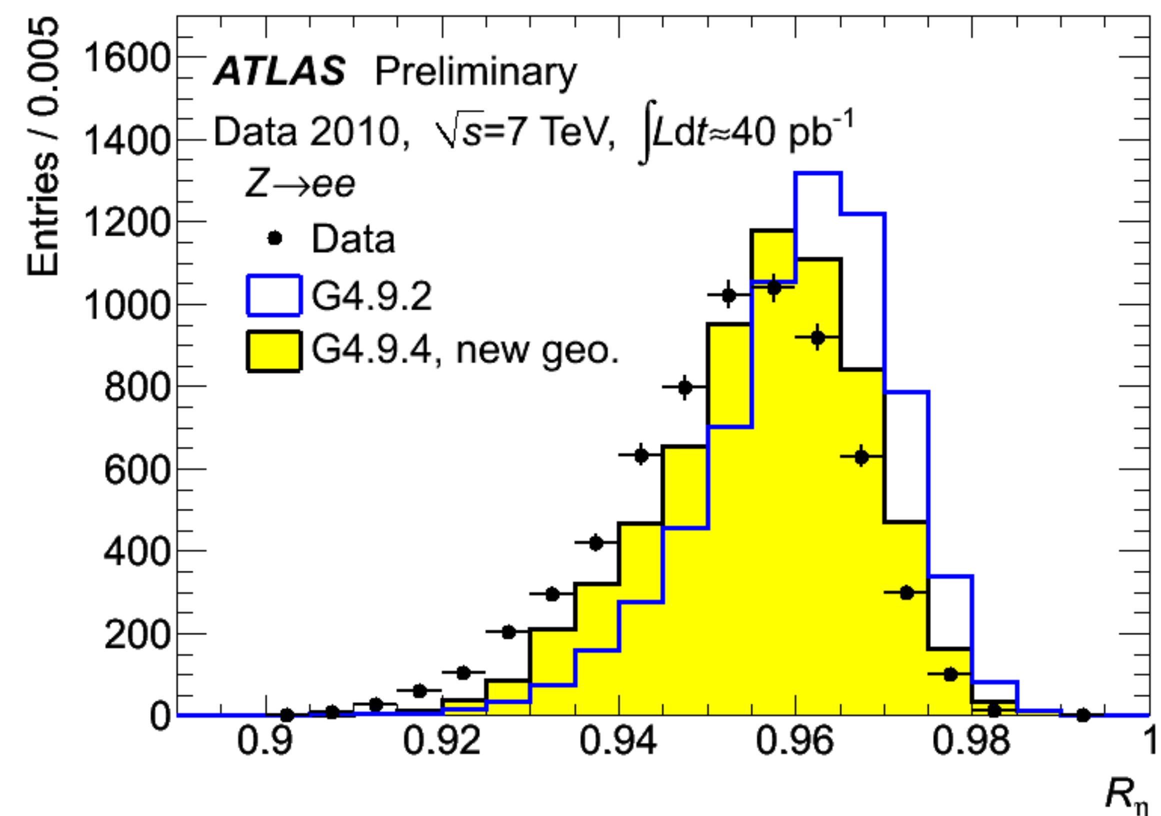


(link)

Lateral EM shower shapes

(link)





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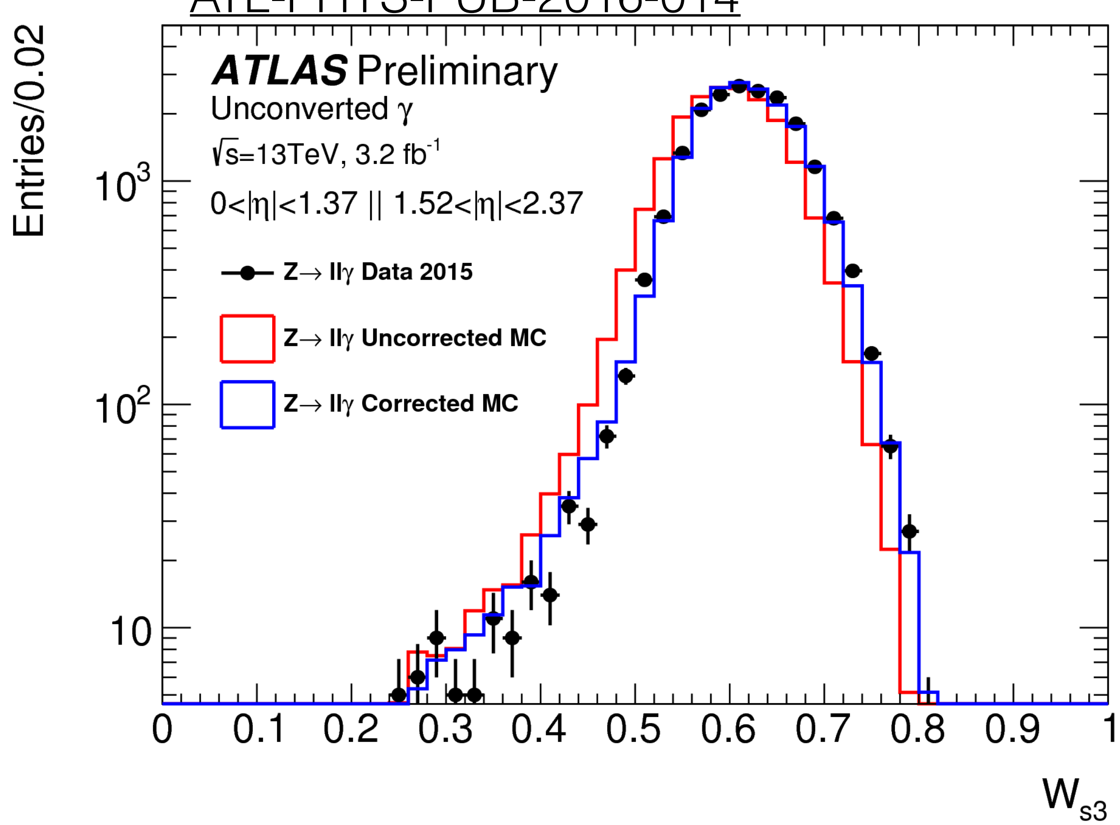

Shower shapes in eta-direction consistently wider in data than simulation both for electrons and photons

Original discrepancy observed beginning of run 1 was reduced using G4.9.4 instead of G4.9.2 (problem with blended material).

Keep using more detailed absorber geometry description

Lateral EM shower shapes (ii)

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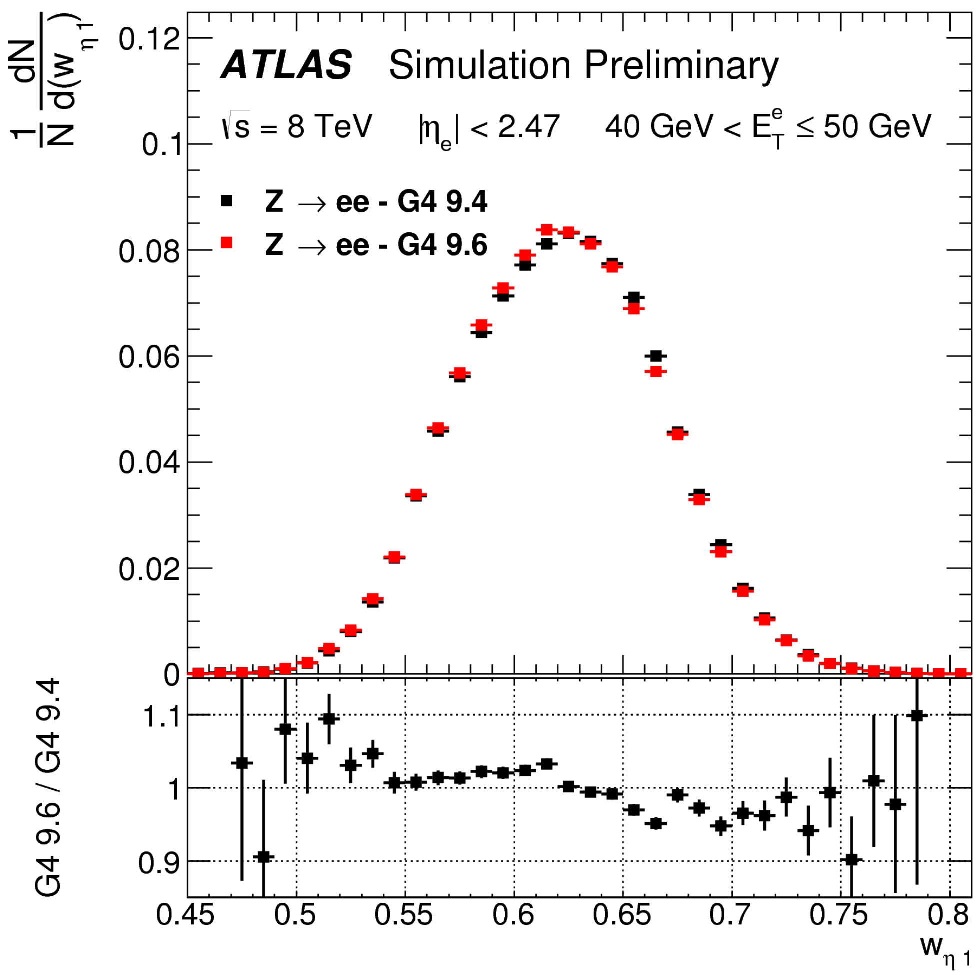

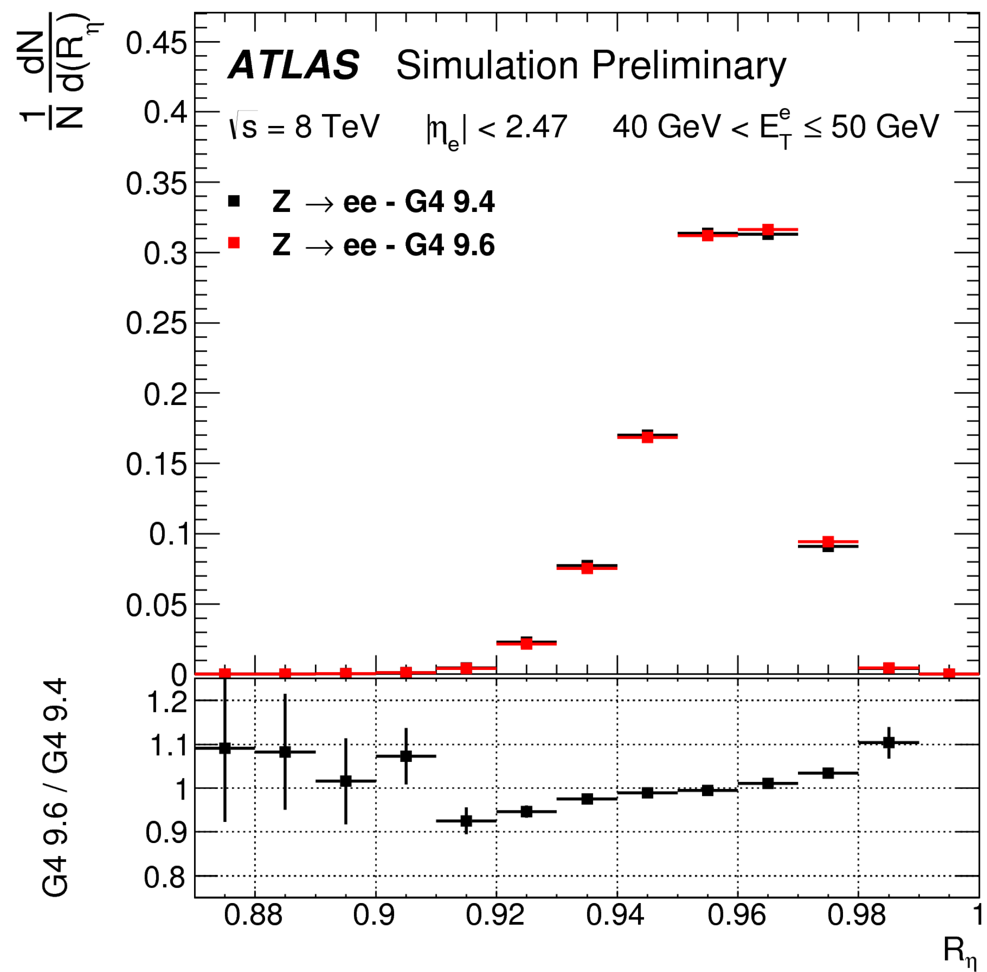

Shower shapes in G4.9.6 slightly narrower than in G4.9.4
G4.10 slightly wider than G4.9.6

These differences as well as changing G4 physics list (using for instance EMY or EMZ physics list) and changing range cuts are significantly smaller than the remaining data-MC differences

=> apply shifts to MC shower shape variables to correct for the average data-MC differences

Electron Identification

Very accurate measurements from Z->ee samples (and J/psi->ee)
(~0.1-0.2% accuracy for Et~45 GeV from 2015 data)

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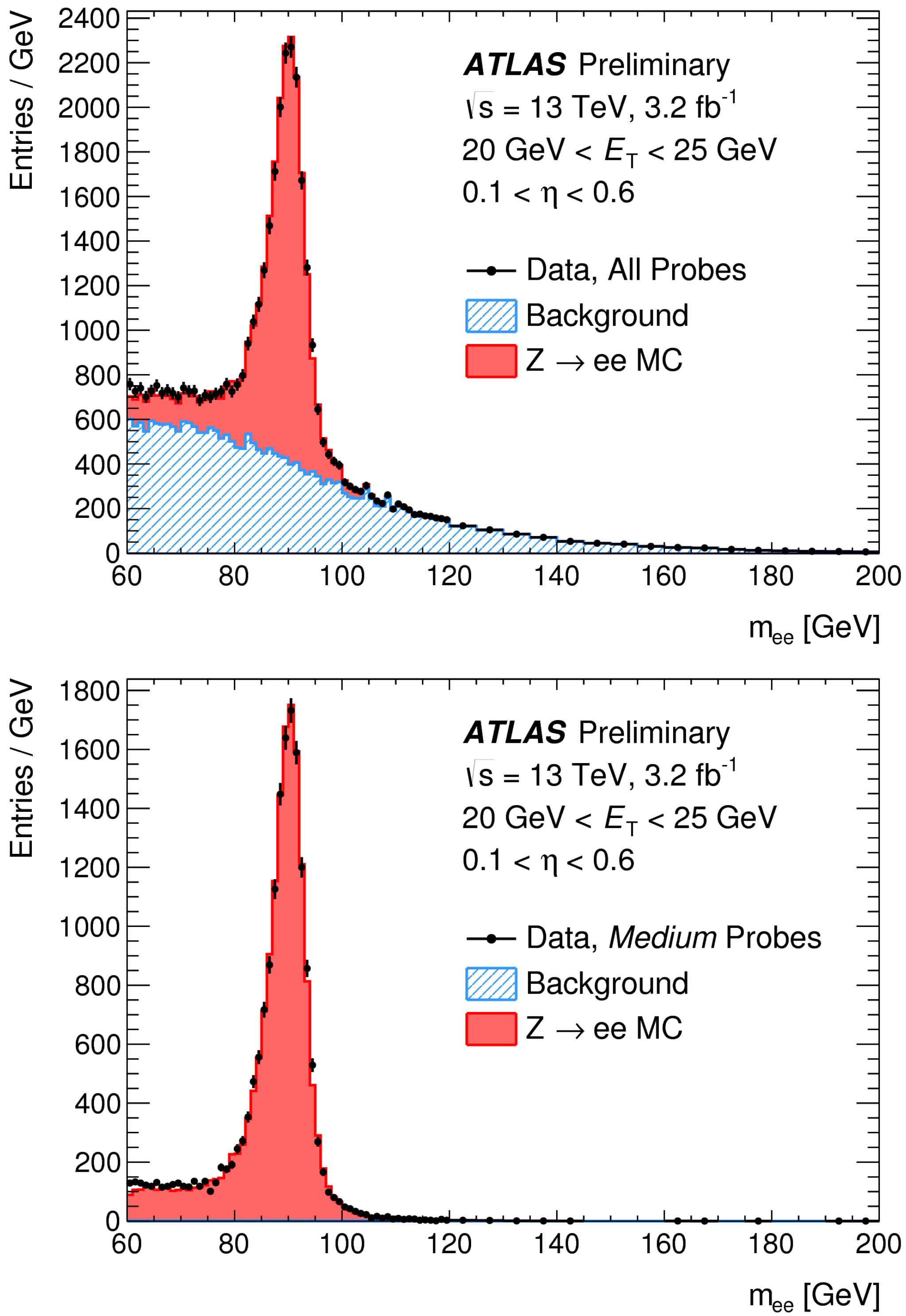
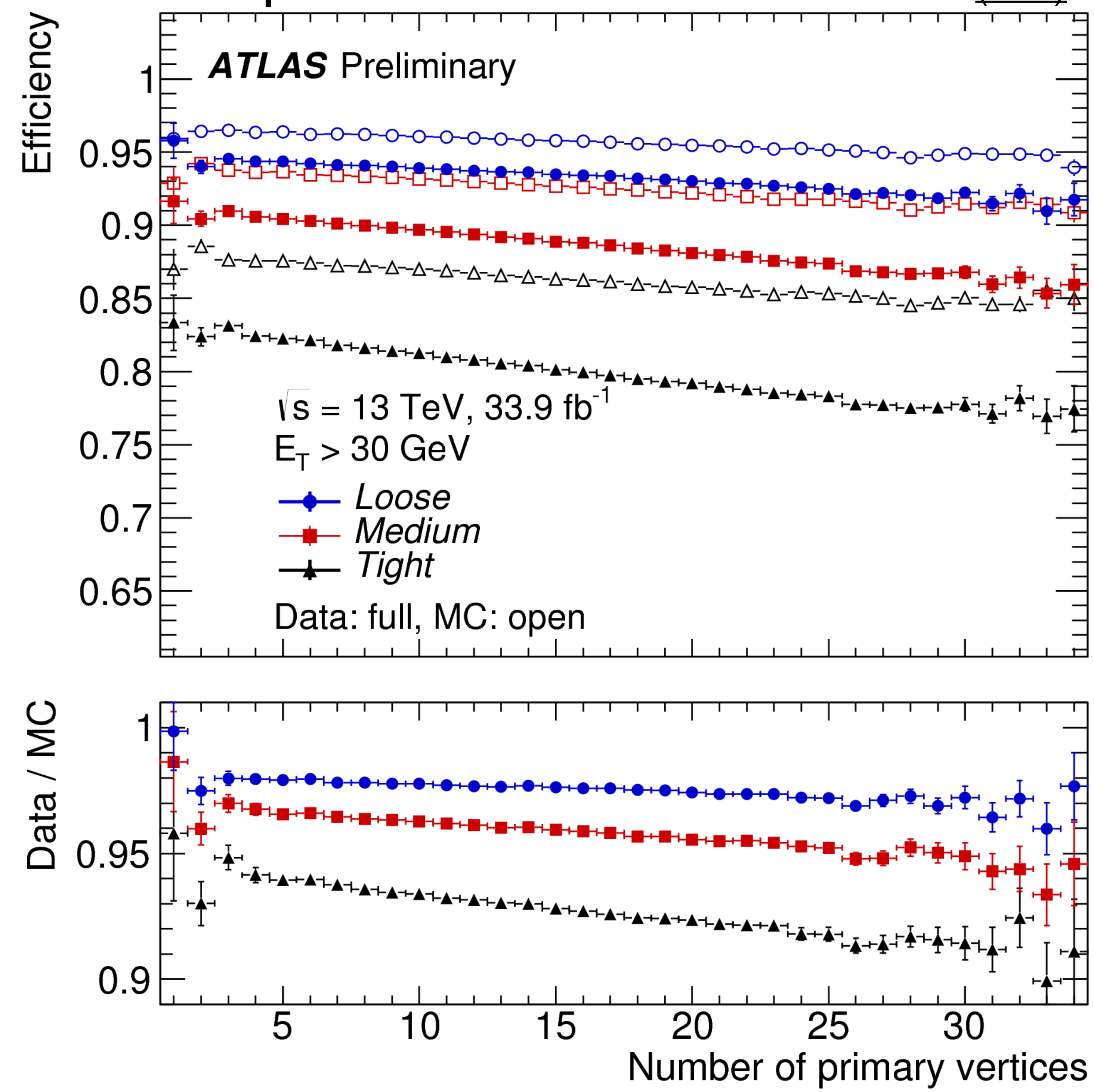


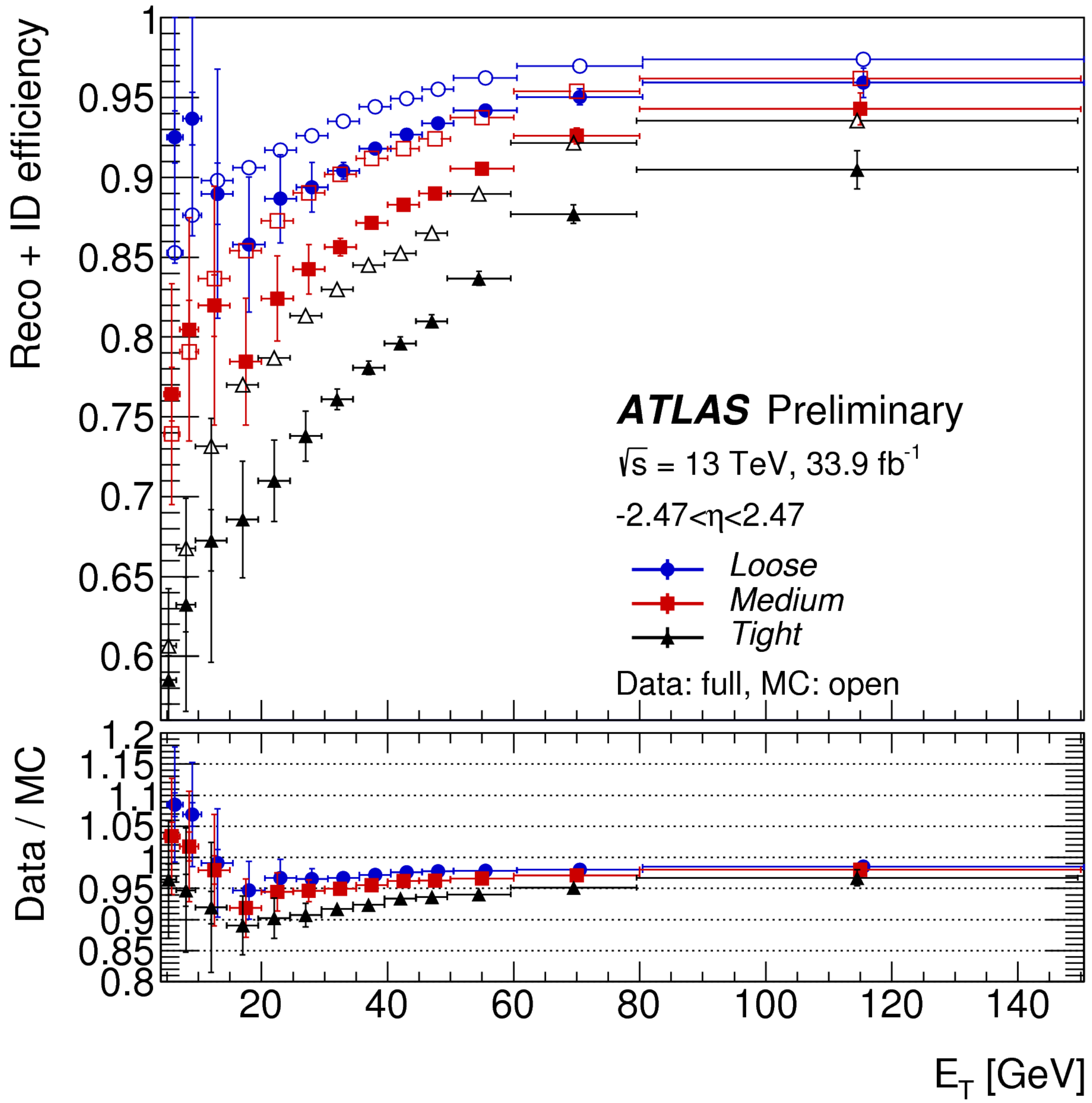
pileup dependence of efficiency reproduced within 2-3% (link)

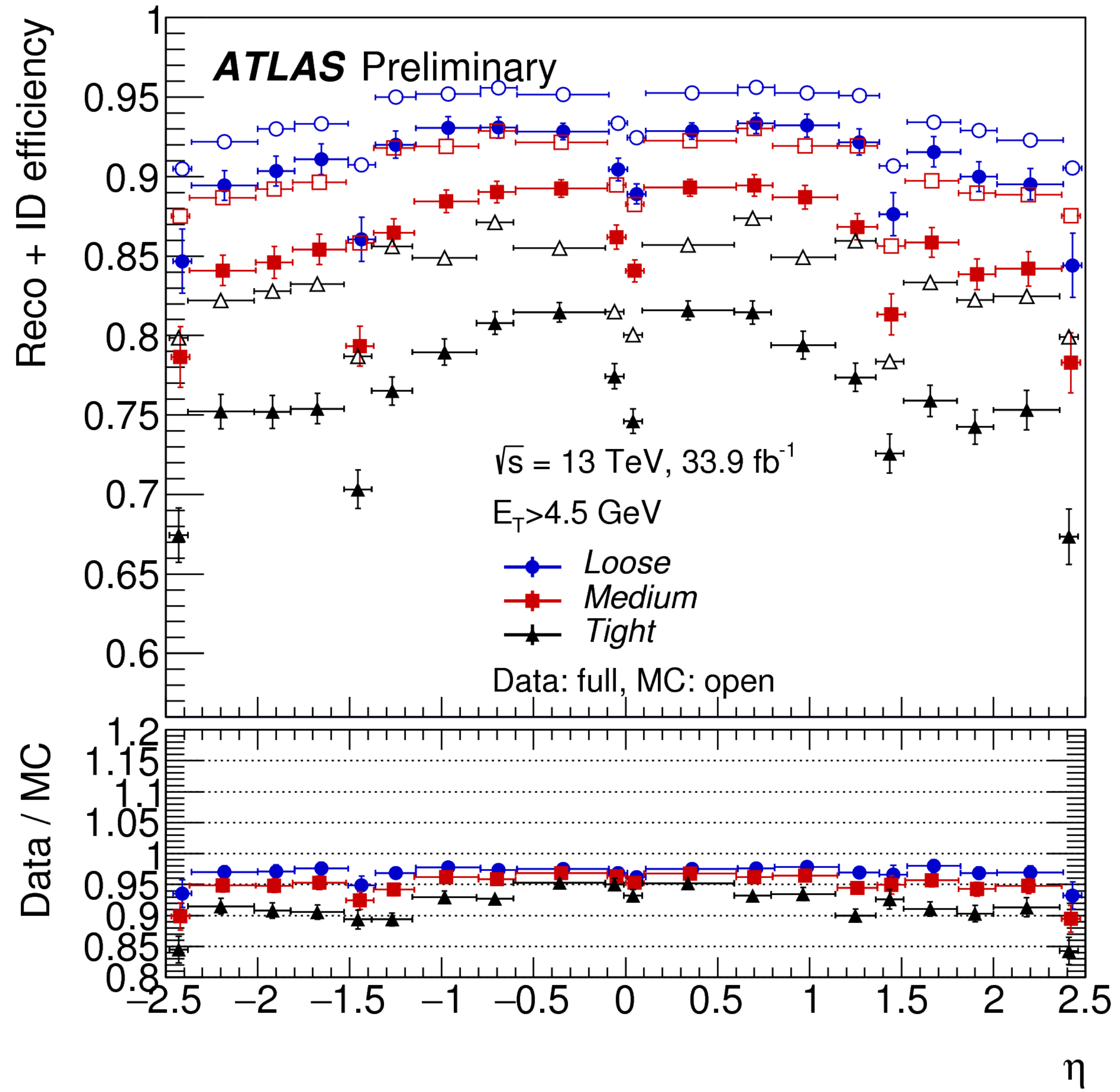


Electron Identification

Most of data/MC efficiency difference comes from lateral shower shape difference.
Also some effect from TRT MC description (different amount of Xe/Ar in MC than data)
MC here is "out of the box" Geant4 prediction for the shower shapes

link





Photon identification

Several techniques to measure identification efficiency of isolated photon

- Z->ll gamma (mostly low E)
- Z->ee with e->photon extrapolation (intermediate Et) (Smirnov transform applied to electron shower shape variables)
- high Et direct photons (measure tight/loose efficiency after bkg subtraction)

Good agreement with "corrected" MC predictions

Small drop at high Et for unconverted photons related to layer1 <-> layer 2 cross-talk effects

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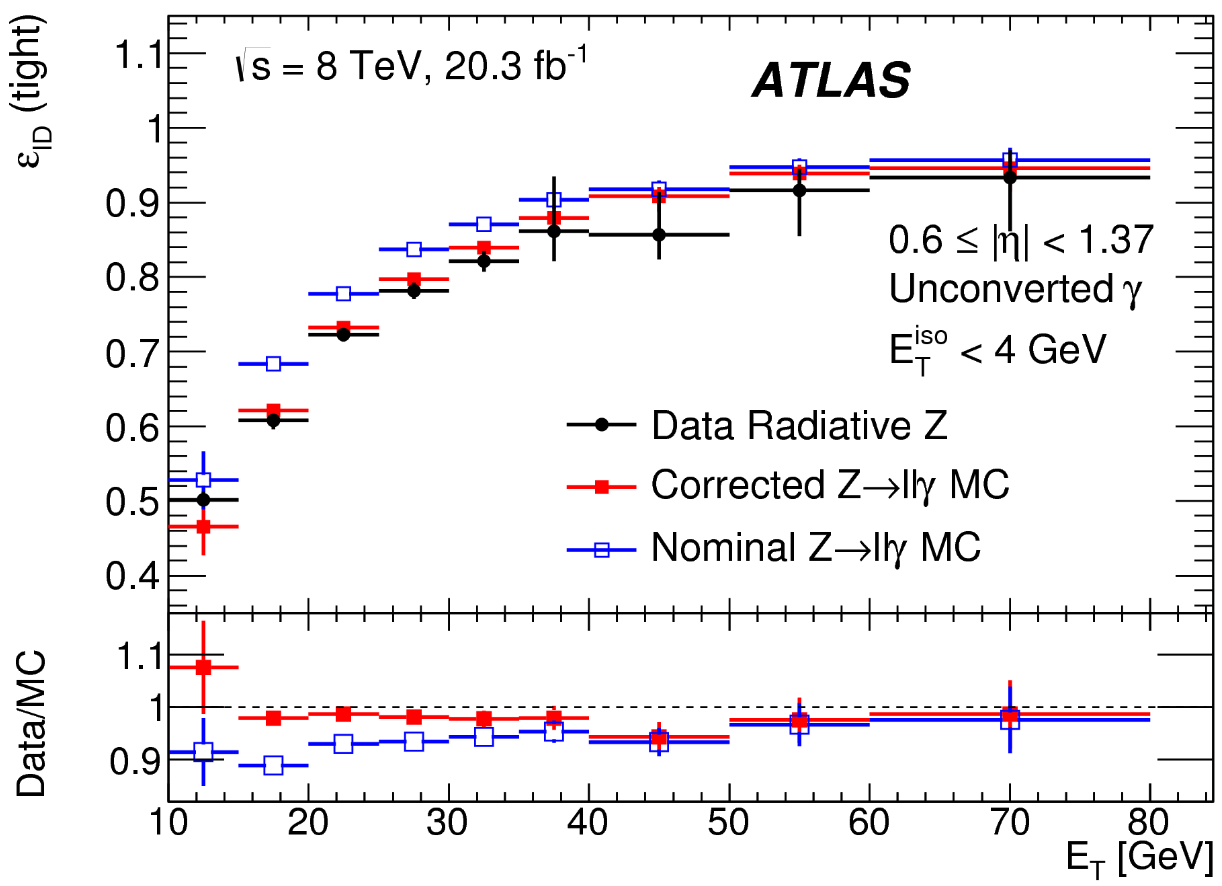

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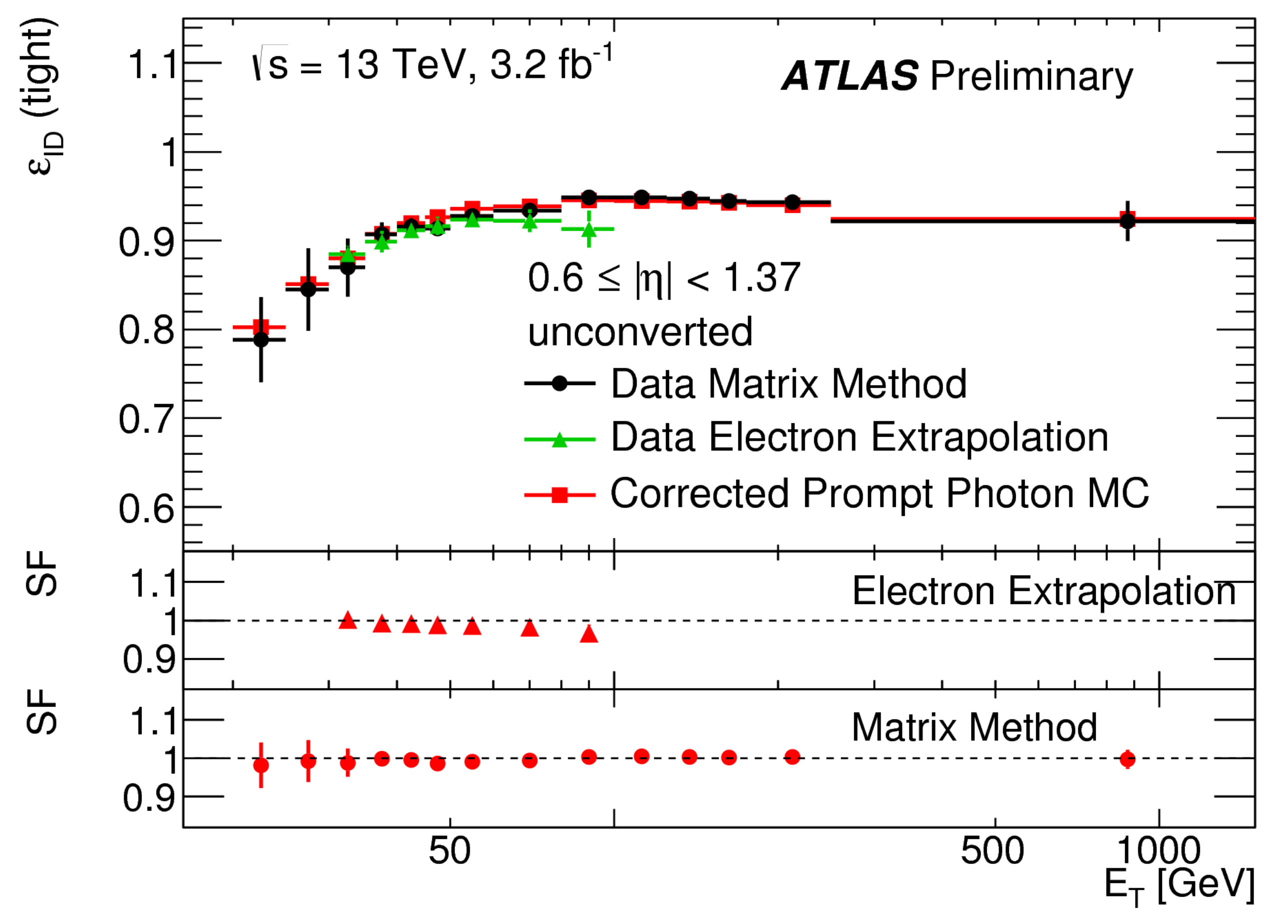

Side impact of EM lateral shower shapes on energy calibration

Lateral cluster containment different data-MC
Absorbed in energy scale calibration with Z->ee but implicitly assumed to be energy and e/photon independent
Check with Z->ll gamma events in run1 measuring directly cluster lateral leakage.
Limited by data stat.
Taken as extra uncertainty on photon energy scale

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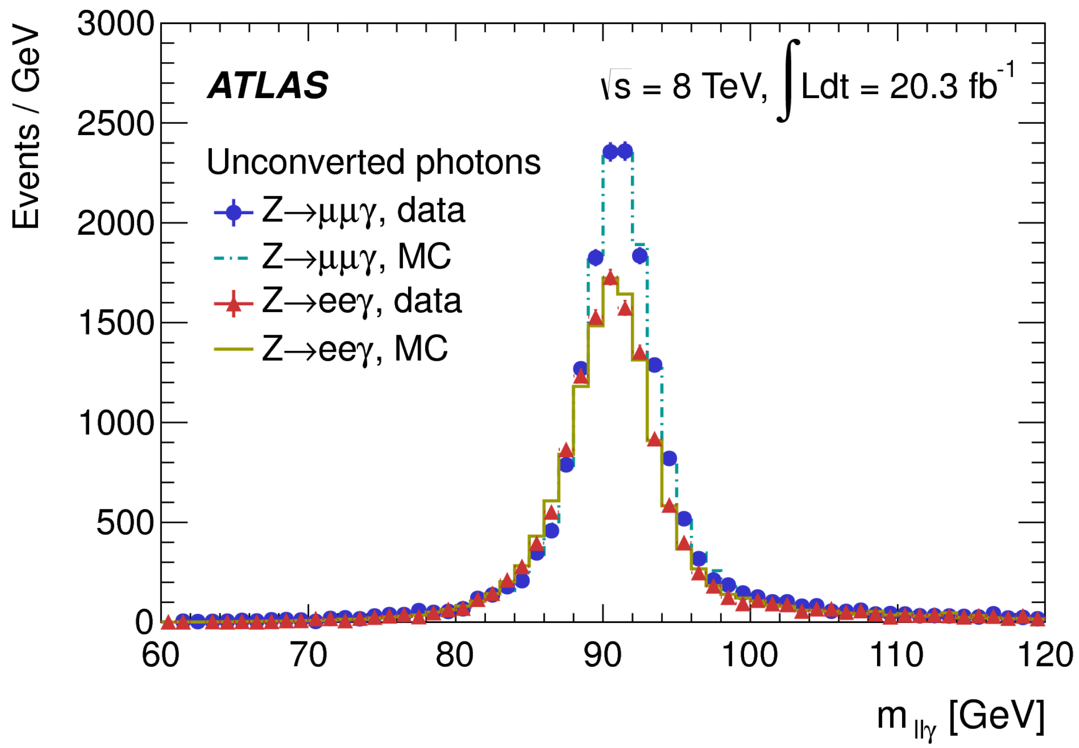
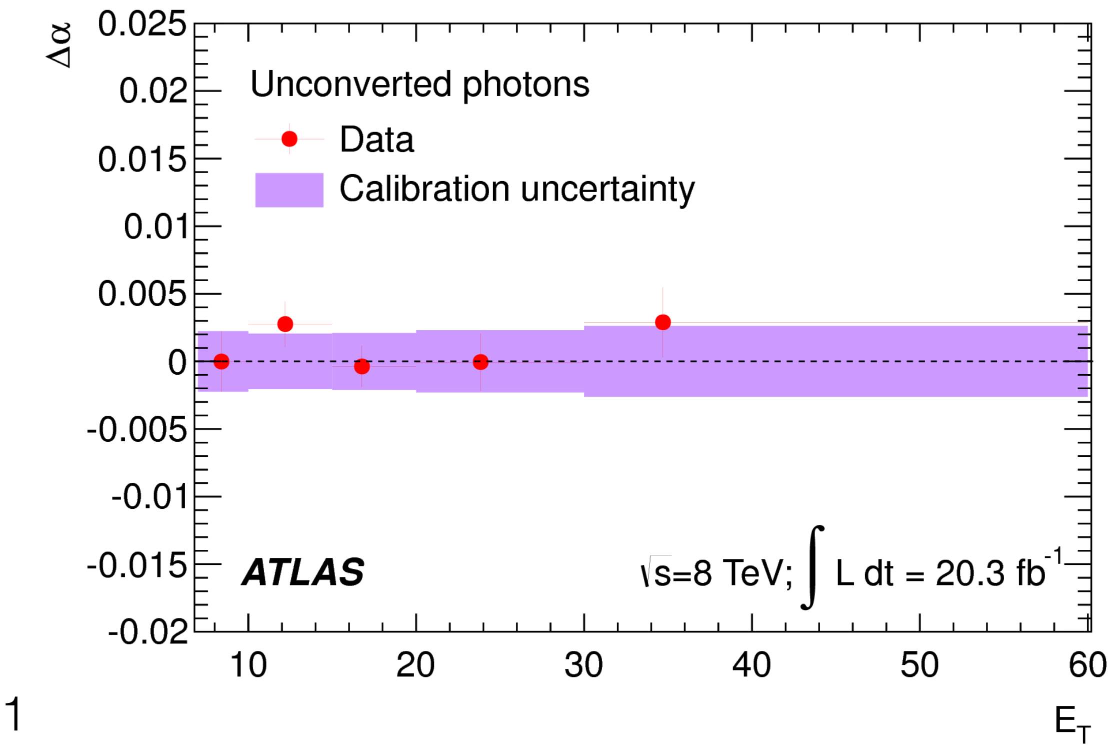
Particle type	$\|\eta\| < 0.8$	$0.8 \leq \|\eta\| < 1.37$	$1.52 \leq \|\eta\| < 2.37$
$\Delta(\gamma - e)$, converted	0.16 ± 0.11	0.46 ± 0.10	0.19 ± 0.10
$\Delta(\gamma - e)$, unconverted	0.03 ± 0.04	0.10 ± 0.06	0.05 ± 0.04

(%)

Photon energy scale check with Z->llgamma mass peak
=> consistent within uncertainties from electron calibration extrapolation





Conclusions

- The main difference between data and simulation for EM showers in ATLAS is related to the modeling of the lateral shower shapes
  - mostly in the eta direction
  - affects in a very similar way electrons and photons
  - material before the calorimeter ruled out as the main cause of this difference
  - Small differences seen between G4 versions and physics lists but these differences are significantly smaller than the data-Geant4 difference
  - At this stage, no clear proof if this difference is related to Geant4 physics or to small inaccuracies the ATLAS simulation (either affecting the simulation or the modeling of the readout)
- Given the large statistics of data available to perform data-driven measurement of identification efficiencies and of energy calibration, these differences don't impact significantly the accuracy of electron and photon objects reconstruction and identification efficiency
- Still, a good G4 simulation is important for the proper optimization of the energy corrections and to be able to extrapolate the measurements performed for instance with Z->ee events to different kinematic regime with minimal systematic uncertainties

backup

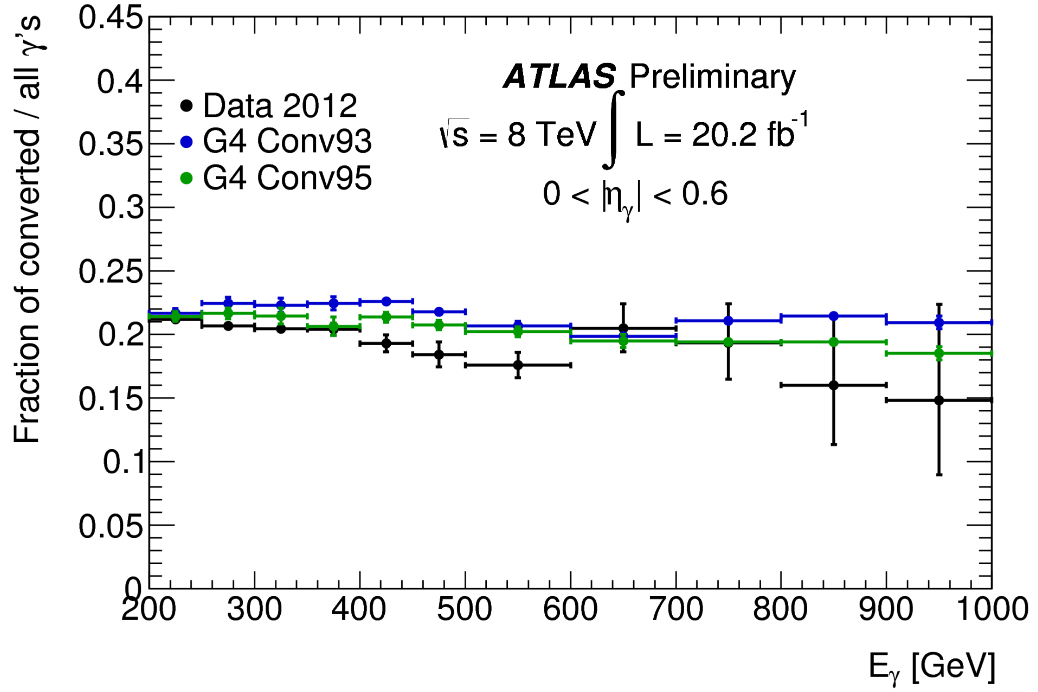
Versions of G4 used recently in ATLAS

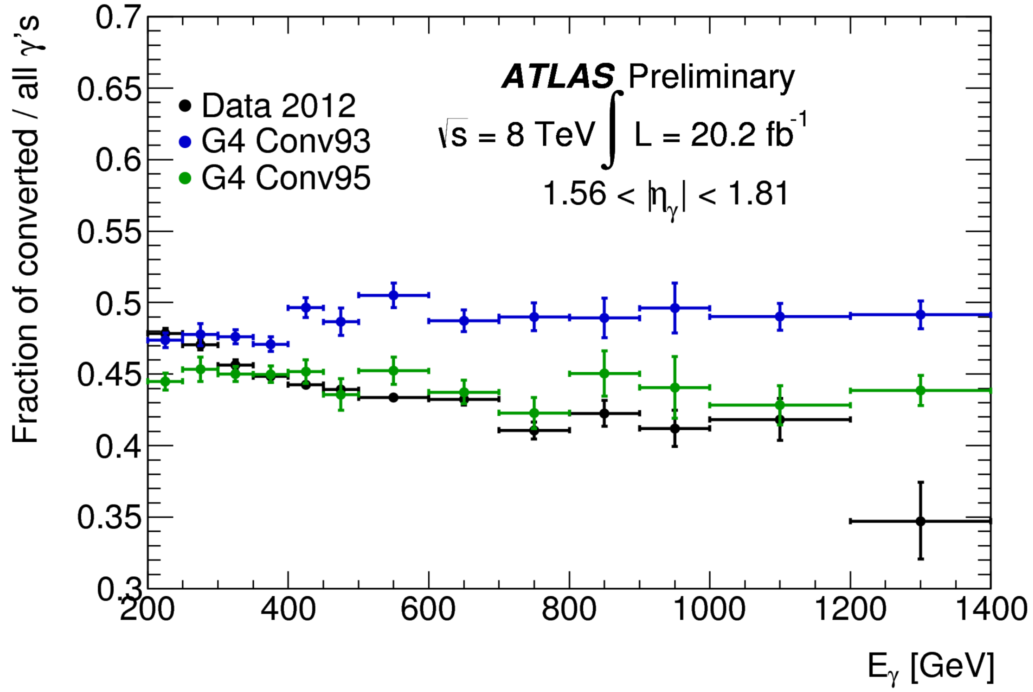
- Final run 1 simulation: Geant 4.9.4 patch04 atlas07 QGSP_BERT, bug fix Urban93, Conv93 models
- Current run 2 simulation: Geant 4.9.6 patch03 atlas04 FTFP_BERT, Urban96 and Conv95
- Next (ongoing) run 2 simulation campaign: Geant 4.10.1 patch01 atlas02 FTFP_BERT
- All with 0.1mm range cut in EM calorimeters

Conv93 vs Conv95 in G4.9.4 simulation

Conv 95 takes into account the Landau-Pomeranchuk-Migdal effect which reduces the cross-section for pair production at high energy

Preferred by data (caveat: no systematics on the data points)





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