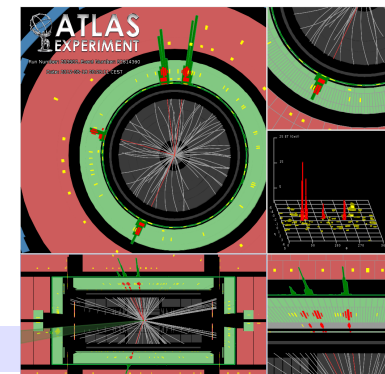# Electrons in ATLAS and CMS
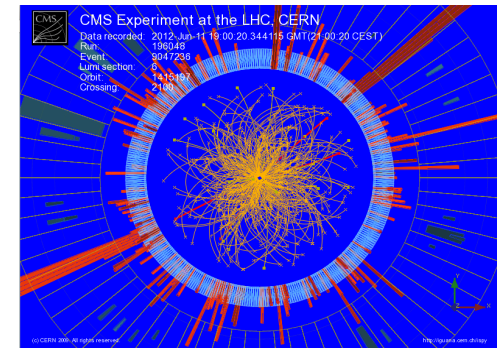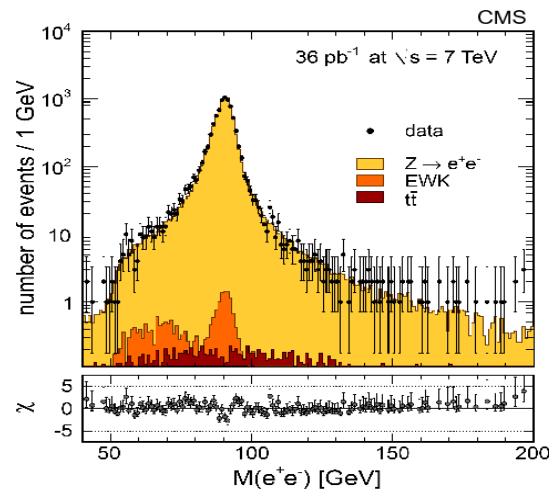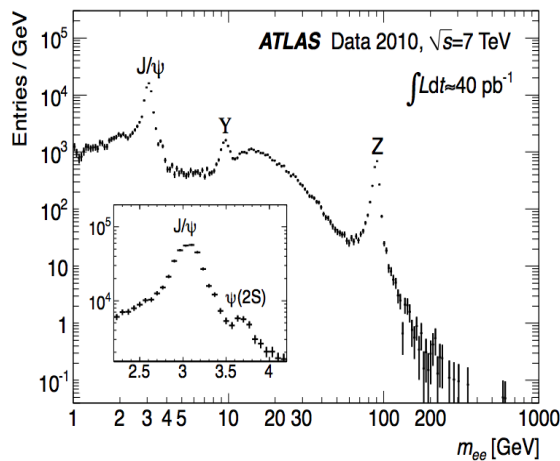
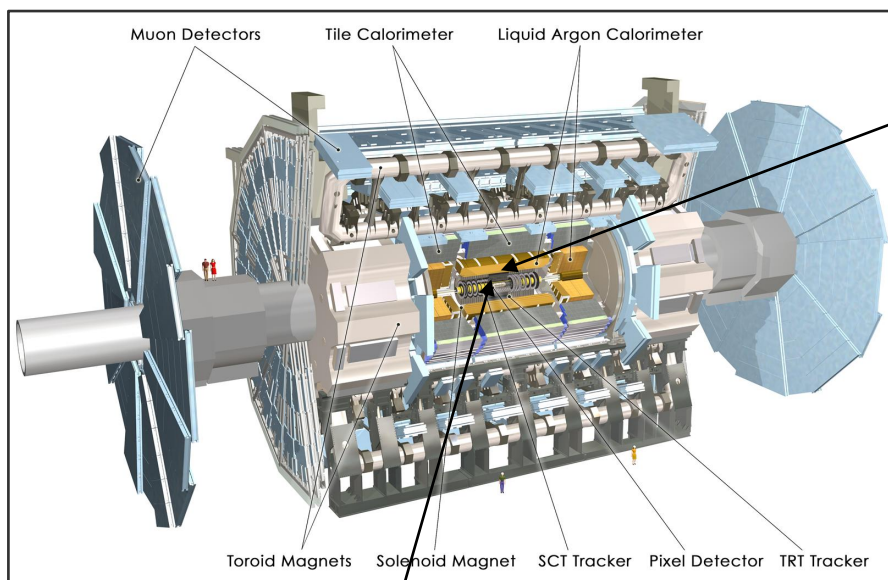C. Charlot / LLR-École Polytechnique

LHC-France, Annecy, apr. 2013

Physics with electrons

❏ Electrons are essential tools in many physics areas

    ❏ EWK (W, Z bosons), top decays

    ❏ Higgs search (diboson decay modes)

    ❏ BSM (SUSY charginos and neutralinos decays, TeV resonances)

❏ Need to cover a wide p_T range from few GeV to few TeV

    ❏ also non isolated electrons

❏ Higgs search in H→ZZ*→4e has been the driving case for low p_T electron reconstruction and ID

ATLAS EM Calorimeter and Tracker

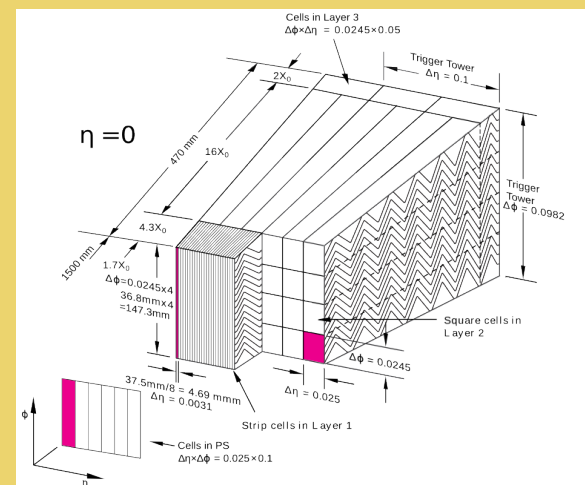Muon Detectors — Tile Calorimeter — Liquid Argon Calorimeter

Toroid Magnets — Solenoid Magnet — SCT Tracker — Pixel Detector — TRT Tracker

LAr EM $|\eta|<3.2$

Pb/LAr sampling calorimeter

Accordion geometry, outside the coil
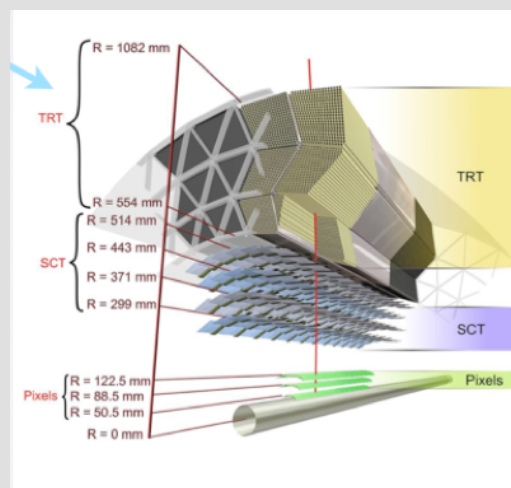
- Barrel ($|\eta|<1.475$)
- Endcaps ($|\eta|>1.375$)

- 22-30 X_0 length
- 3 longitudinal samplings (strip, middle, back) + presampler
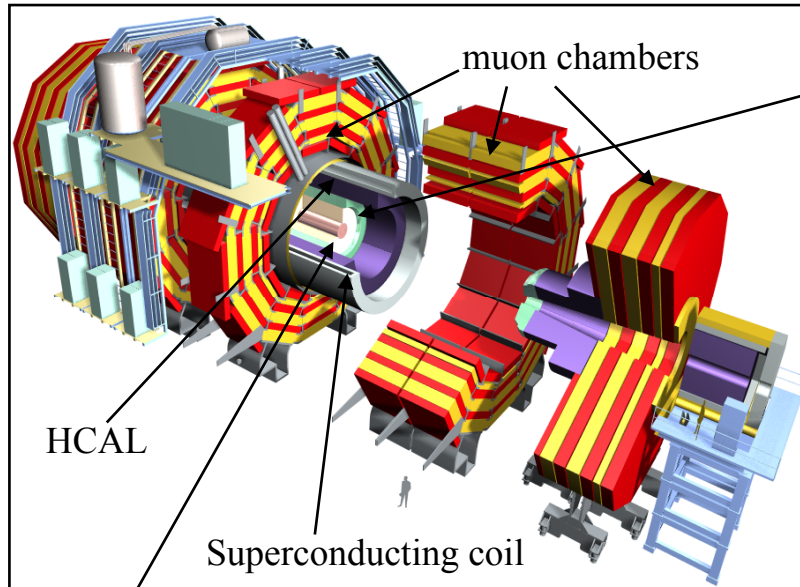   - 0.025x0.025 (middle sampling)

TRACKER $|\eta|<2.5$

- **Pixels** (3 layers)
- **SCT** (8 hits/track)
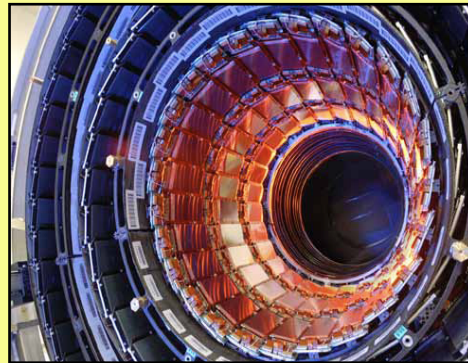- **TRT** (straw tubes, ~30 hits/track, $|\eta|<2$)

2T solenoidal field
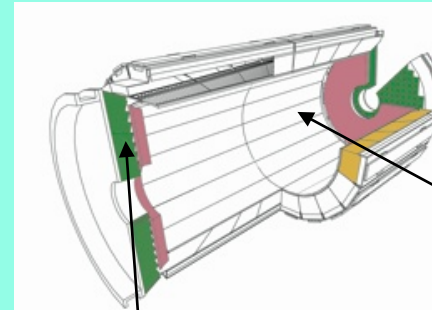
CMS EM Calorimeter and Tracker

muon chambers

HCAL

Superconducting coil

ECAL

~76000 **scintillating PbWO4 crystals**
quasi-projective geometry, inside the coil

$|\eta|<3.0$

- $25X_0$ length
- 0.0175 in $\eta - \phi$

Barrel ($|\eta|<1.5$**)**
- 36 supermodules

Endcaps ($|\eta|>1.5$)
- 4 dees
- 3X0 lead preshower
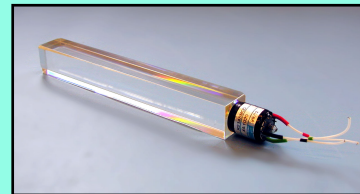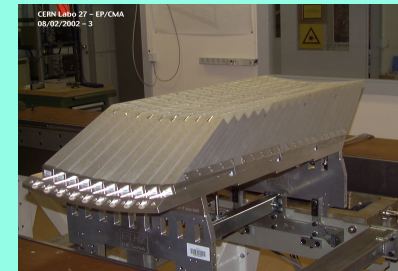
- dense: ~80% in 1 Xtal
- fast: 80% in 25ns

TRACKER

All silicon tracker

$|\eta|<2.5$

- **Pixels (100x150μm2)**
  3 layers (barrel)
  2x2disks (forward)

- **Strips (10cmx80μm)**
  >14 hits/track (depending
  on η)

4T solenoidal field

Challenges in electron reconstruction

❑ Electrons characterized by a high E_T cluster in ECAL matched in position and momentum with a track

  ❑ In principle straightforward but..

❑ .. discrete Si trackers bring up to ~$2X_0$ material (electronics, cables, cooling, support) upstream the calorimeters

  ❑ Electrons showering in the tracker material get their energy spread in ϕ by the magnetic field

  ❑ The energy spread is more important at low p_T

❑ .. physics imposes excellent reconstruction and ID efficiency at low p_T

  ❑ Especially in H→ZZ*→4e where the signal yield goes ~ ε^4

  ❑ Background is also more important at low p_T

❑ Finally, electron selections need to cover a various range of working points

  ❑ Loose (multiletpons), medium (Z), tight (W)

ATLAS electron reconstruction

- Starts by seed clusters in ECAL
    - 3x5 in $\eta \times \phi$ units (0.025x0.025), sliding window
    - $E_T > 2.5$ GeV to seed an electron
- Match the seed cluster to a (KF) track
    - Based on outer track parameters
    - Looser selection in bending plane, known charge: $|\Delta\eta| < 0.05$, $-0.05 < q*\Delta\phi < 0.1$
- Attempt to match the track to a secondary vertex
    - Converted photon disambiguation
- Rebuild clusters in optimized sizes
    - 3x7 (5x5) in central (forward)
- Matched tracks are refit with GSF
    - To improve parameters for final ID (next slides)

one cell
In the middle
Layer
(0.025x0.025)

Cluster

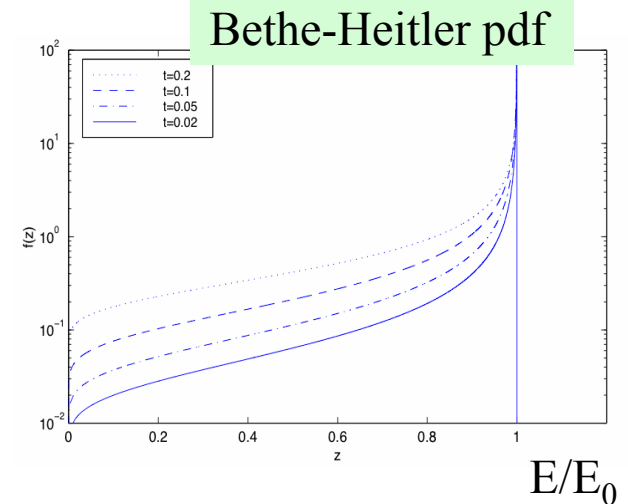vertex in ID
the conversion happens
on the 1st SCT layer
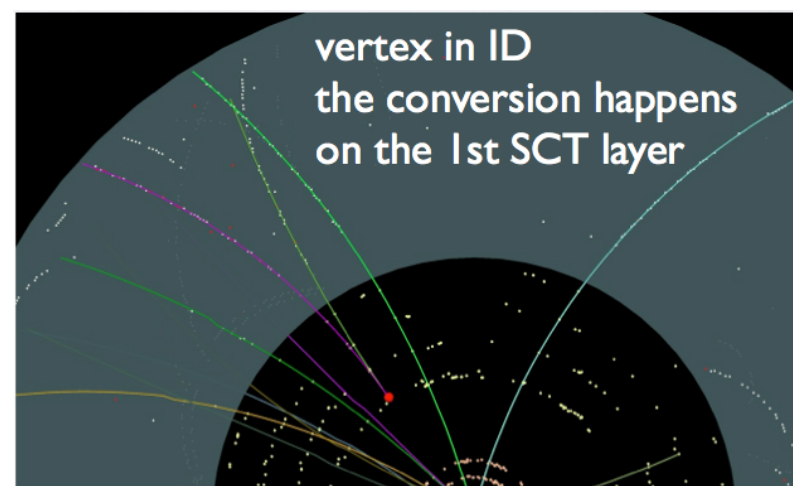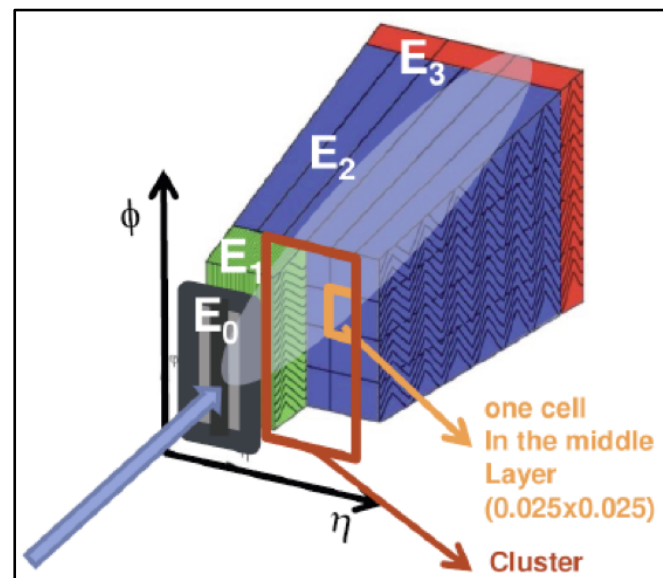
CMS electron reconstruction

- Starts by clusters of clusters in ECAL
  - Collect bremsstrahlung photons and converted bremsstrahlung photons
  - Fixed in η, dynamical in ϕ (extension<±0.3rad)
- Match superclusters with hits in the pixel layers
  - Before bremsstrahlung has occurred
- Matched pixel hits initiate dedicated electron tracking
  - Loose pattern recognition, GSF fit
- Electron candidates finally defined by loose track–superclusters matching criteria
  - $|\Delta\eta|$<0.02, $|\Delta\phi|$<0.15

- ECAL-driven strategy complemented by an in-out approach more efficient at low p_T, starting with KF tracks
  - Match standard (KF) tracks to clusters (mva discriminant)
  - Electron GSF tracking from matched KF track seeds
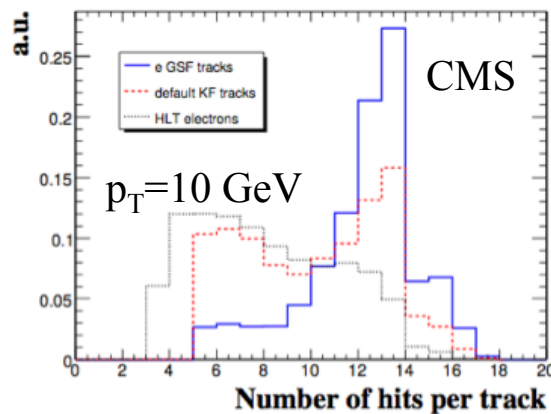 - Track tangents matched to clusters to form super-clusters

E_T=51.7 GeV

ϕ_{SC}=-2.2rad

PXL

beam spot
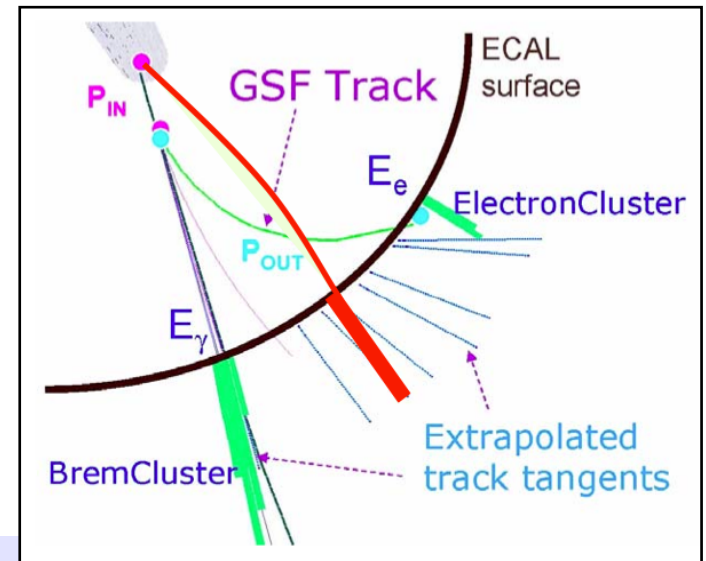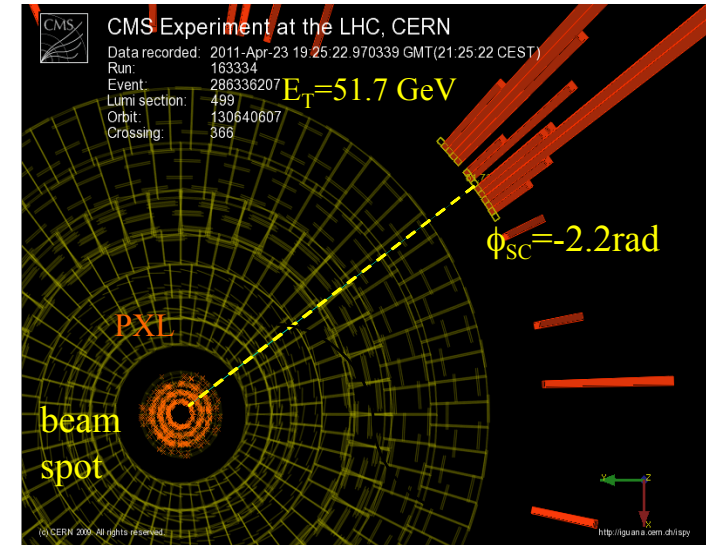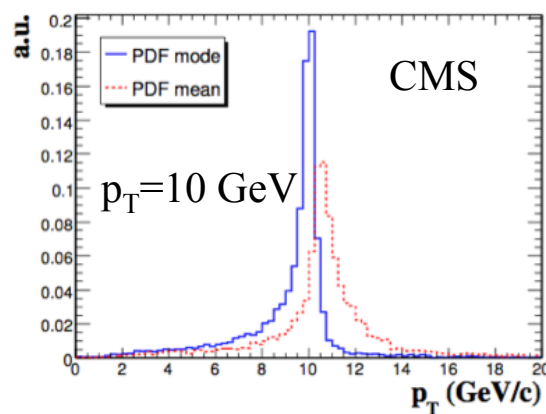
Electron tracking

- ❏ Electron tracking is peculiar, large amount of radiative loss by electrons
  - ❏ Affects the track direction in the the bending plane
- ❏ Radiative energy loss highly non-gaussian
  - ❏ Bad χ^2 compatibility and in the end hit collection efficiency loss if using KF
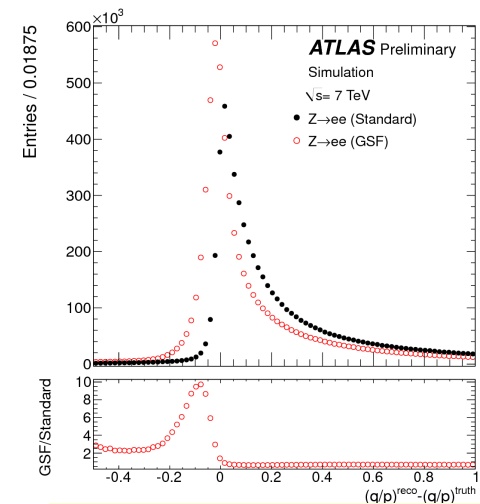 - ❏ CMS and (more recently) ATLAS use the GSF

Bethe-Heitler pdf

E/E_0

"Electron reconstruction in CMS", Eur. Phys. J. C 49 (2007) 1099

CMS

p_T=10 GeV

CMS

p_T=10 GeV

ATLAS Preliminary
Simulation
√s= 7 TeV
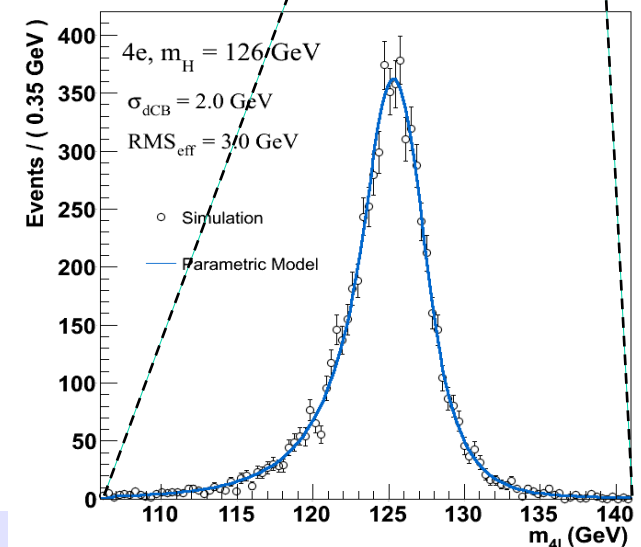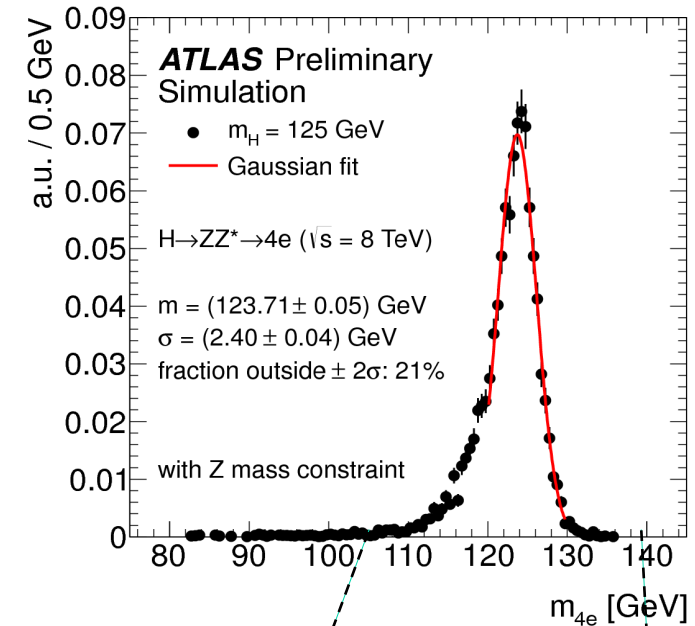• Z→ee (Standard)
○ Z→ee (GSF)

=> better hit collection

=> precise estimate from mode

=> reduced bias in q/p

Electron momentum

- ❏ ECAL clusterized energy needs to be corrected for numerous effects:
  - ❏ Lateral leakage, rear leakage, loss upstream the ECAL, transparency loss (CMS)
- ❏ Each term parametrized as function of the measured energy in all 3 long. segments + pre-sampler (ATLAS)
- ❏ Multivariate energy regression using as input cluster position, shape variables, preshower energy for endcaps (CMS)
- ❏ Energy measurement combined with the track p using a weighted mean (in progress in ATLAS)
- ❏ Assign errors to individual electron momentum
  - ❏ Large variations of resolution depending on η, showering pattern

ATLAS Preliminary Simulation

- ● m_H = 125 GeV
- — Gaussian fit

$H \rightarrow ZZ^* \rightarrow 4e$ ($\sqrt{s}$ = 8 TeV)

m = (123.71 ± 0.05) GeV
σ = (2.40 ± 0.04) GeV
fraction outside ± 2σ: 21%

with Z mass constraint

m_{4e} [GeV]

4e, m_H = 126 GeV
σ_{dCB} = 2.0 GeV
RMS_{eff} = 3.0 GeV

- ○ Simulation
- — Parametric Model
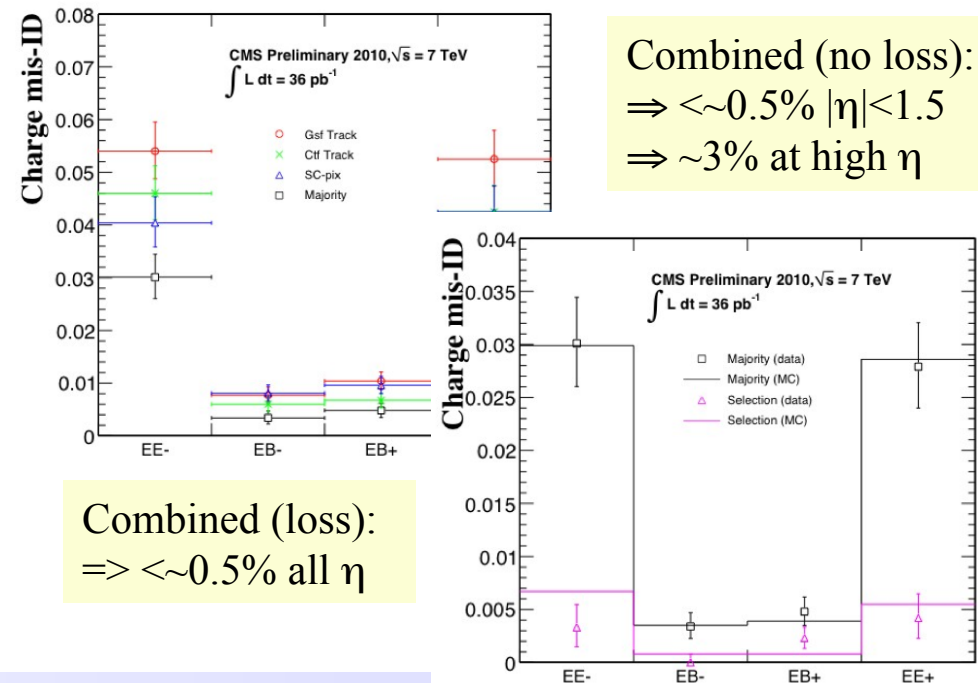
m_{4l} (GeV)

See also talks in Higgs session

Charge mis-ID

❏ Electron showering in the tracker material also induces important charge mis-ID

  ❏ Track from a bremstralhung converted leg taken as the electron track

  ❏ Up to 6% in the forward region @RECO level

❏ Charge mis-ID is reduced by applying electron selection

❏ Can also combine several charge estimates (no loss or with loss)

Combined (no loss):
⇒ <~0.5% |η|<1.5
⇒ ~3% at high η
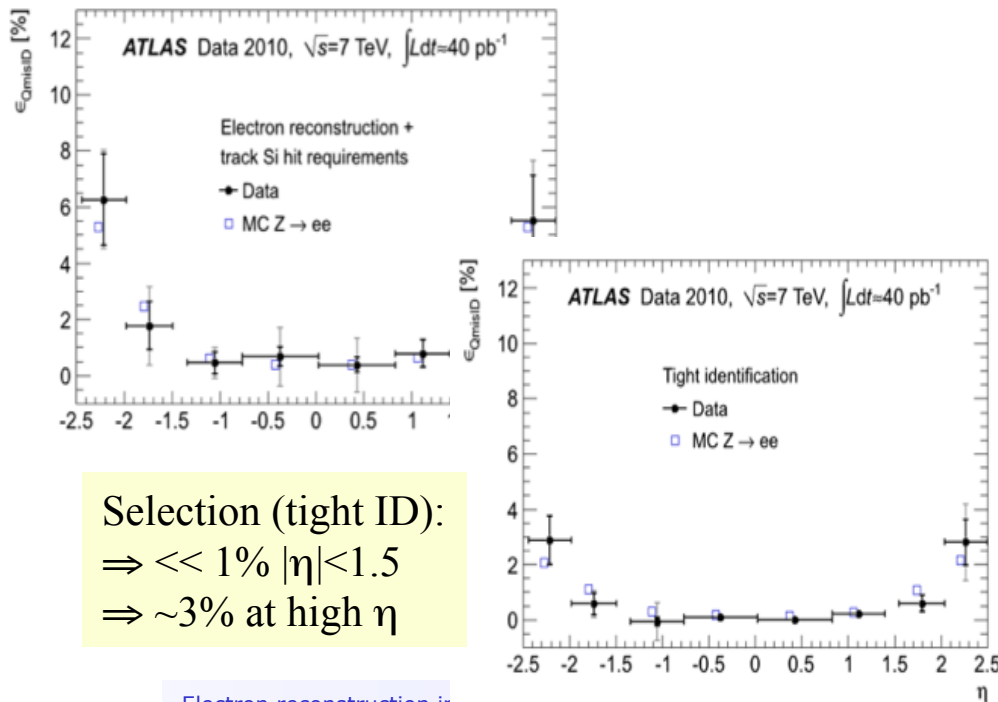
Selection (tight ID):
⇒ << 1% |η|<1.5
⇒ ~3% at high η

Combined (loss):
=> <~0.5% all η

Electron reconstruction in

Electron Identification

- Jet background rejection achieved using track-cluster matching variables, shower shape variables and pure tracker variables

- E/p, $\Delta\phi$, shower shape along ϕ affected by bremsstrahlung
  - Concentrate on shape along η

- Bremsstrahlung also sign electrons (pions do not radiate)
  - $f_{brem} = (p_{in}-p_{out})/p_{in}$

- Cut based methods (ATLAS & CMS)

- CMS also uses multivariate methods
  - ~30% gain at $p_T<10$ w.r.t. cut based with same backgd rejection
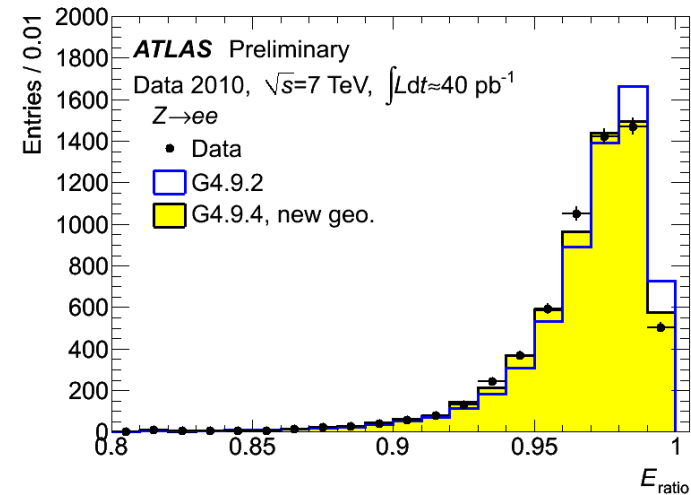
Good description with MC is crucial
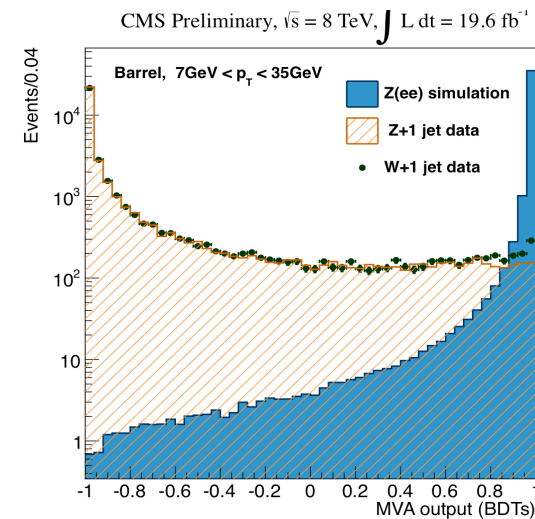
Data samples used for backgd training and testing

Input variables: shower shape, electron class, η, n_{vtx}..

Electron Isolation

❏ Combines information from the calorimeters and from the tracker ("detector based") or from reconstructed particles ("particle flow" approach, see Colin's talk)

   ❏ no energy double counting, natural removal of overlapping leptons in the cone

❏ Also here bremsstrahlung and bremsstrahlung conversion limit the performances

   ❏ Need to remove regions associated with the entire electron footprint

❏ Calo-based isolation is PU sensitive

   ❏ Corrections based on the average event density (ρ)
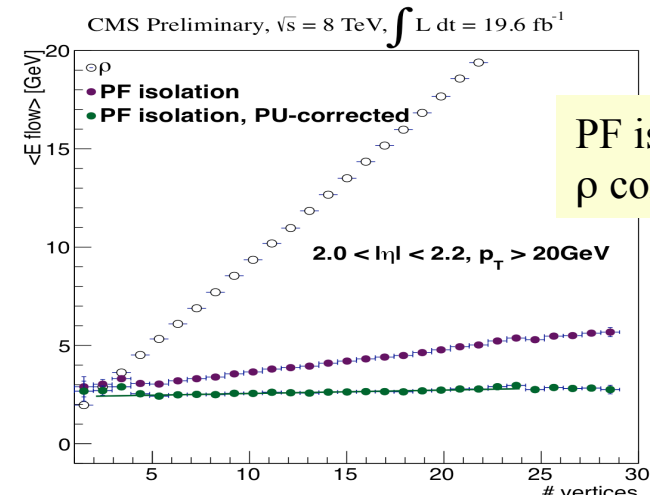
PF iso, ρ correction
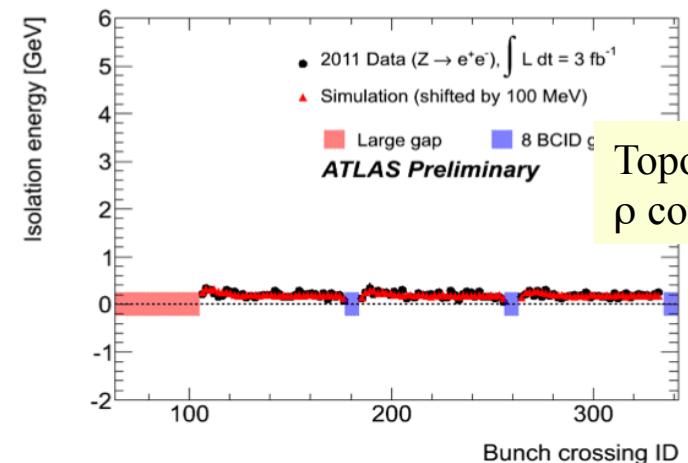
Topo. clusters, ρ correction

=> very small dependency with PU after corrections, good description with MC

Efficiency measurements

- A lot of Z→ee decays, allow for pure sample of electrons via tag-and-probe
- Data/MC scale factors O(%) for p_T>20, uncertainties dominated by systematic effects
- Larger SF at p_T<~ 20 GeV, up to ~10%
  - More background
  - Difficulty to separate the signal in the tail
  - Some discrepancies between Z→ee and J/ψ→ee expected efficiency
- Good stability with PU
  - After using PU-robust variables in the ID and event density corrections for isolation
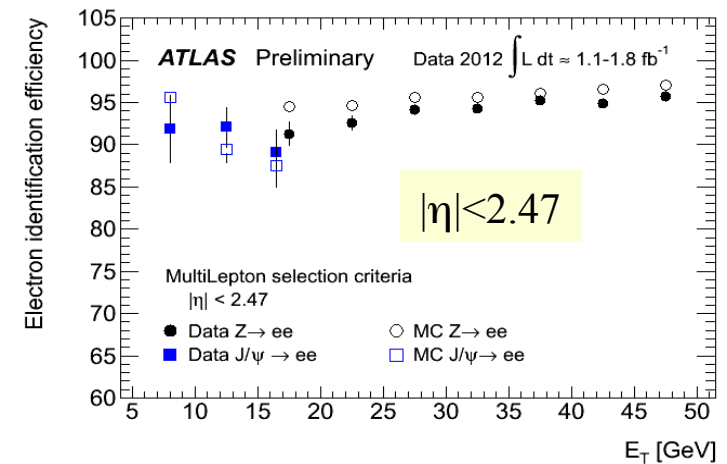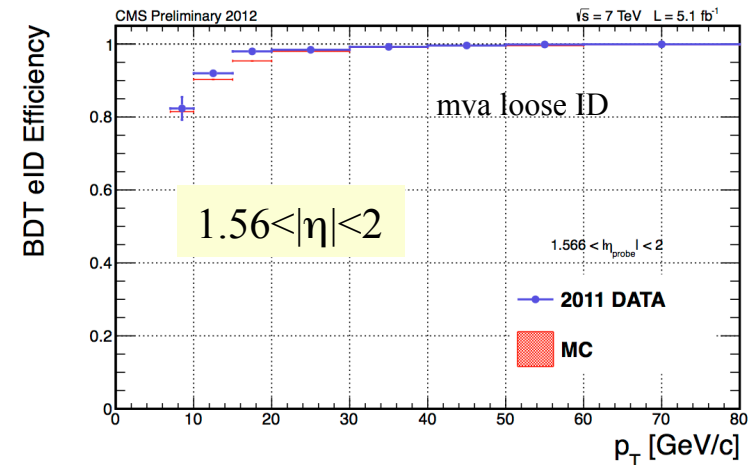
Momentum scale

- ❏ Momentum scale controled from Z→ee, J/ψ→ee and Y→ee, W→eν (ATLAS)

- ❏ Small variations with PU, well reproduced in MC

- ❏ After calibration with Z→ee, momentum scale is:
  - ❏ within ~0.2% @ 35-50 GeV
 - ❏ up to ~1.5% @ low p_T

See also talks in Higgs session
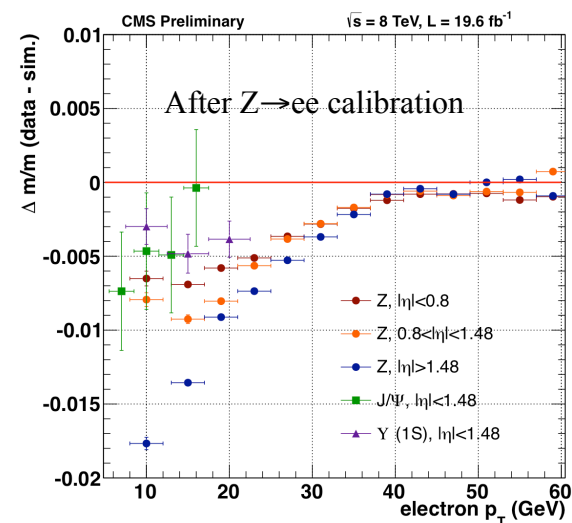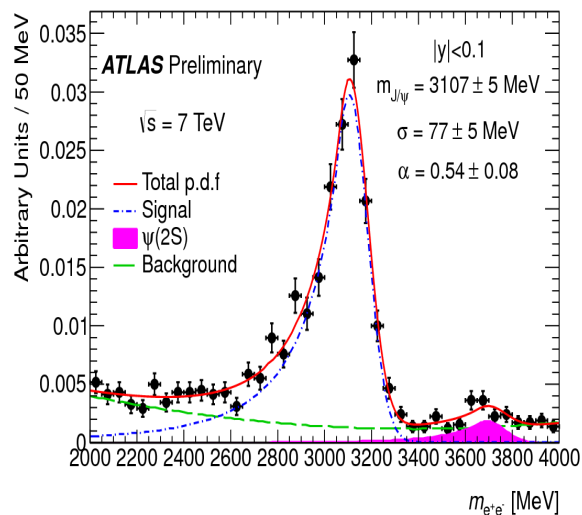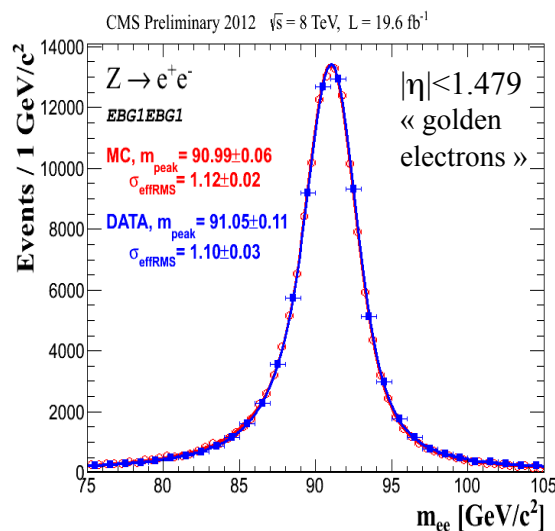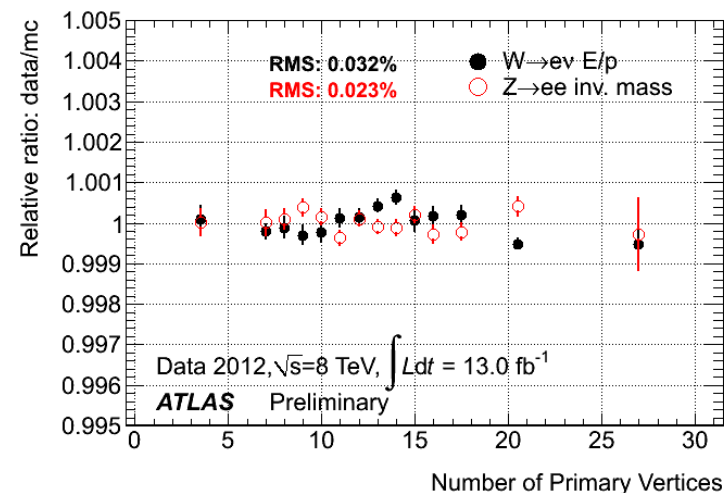
Conclusions

❑ Electrons are essential ingredients to LHC physics

❑ A lot of work in ATLAS and CMS to optimize the reconstruction and selection performance

❑ Different detectors but similar problems and similar solutions to

   ❑ Mitigate the effects of the tracker material upstream the calorimeters

   ❑ Mitigate the PU effects

❑ The low p_T region which is needed for the Higgs is the most challenging

   ❑ Highest possible efficiency needed for H→ZZ*→4l

   ❑ >~80% selection efficiency achieved @ 10 GeV

❑ Excellent scale determination achieved, thanks to o(10M) Z→ee in each experiment and good understanding with MC

❑ Let's improve further for the new run!
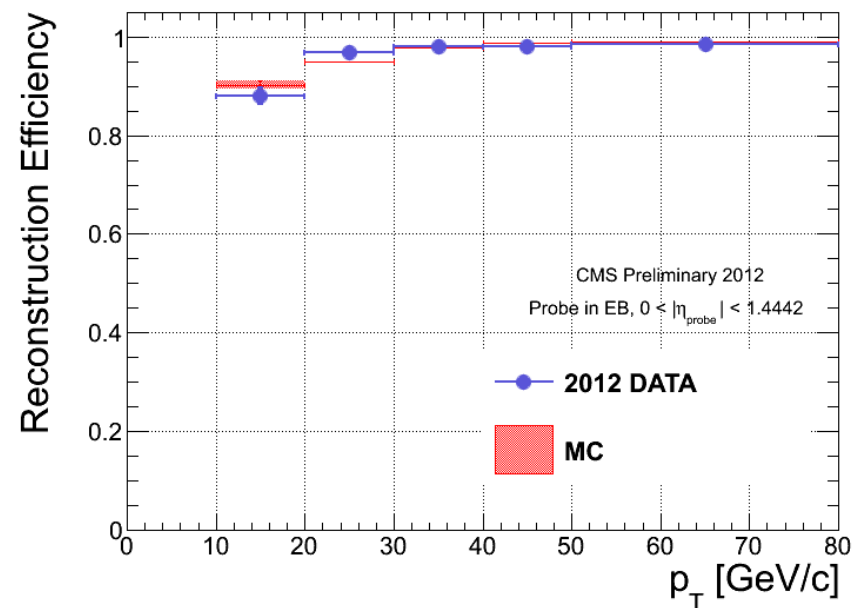
Backup

Reco efficiency ATLAS & CMS
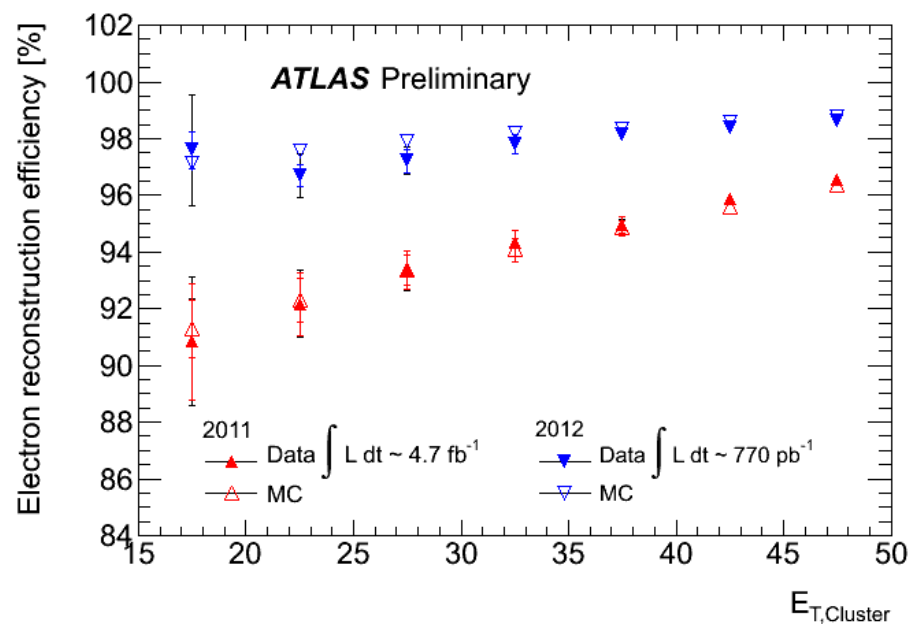
p$_T$>15 GeV
(transition region 1.37<|η|<1.52 excluded)

Seed cluster – track matching
>=1 pixel hit & >=7 silicon hits (pixels+strips)

p$_T$>10 GeV
(transition region 1.44<|η|<1.56 included)
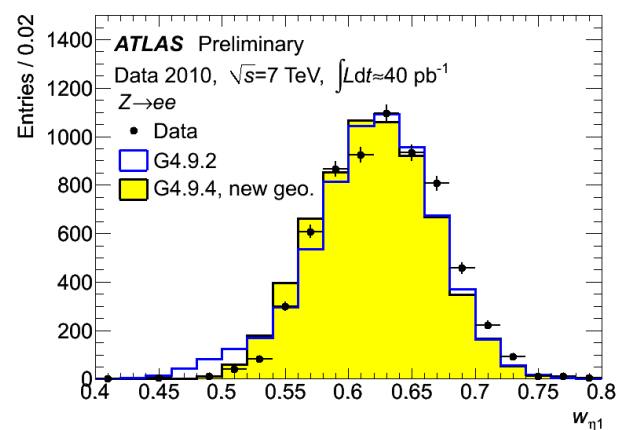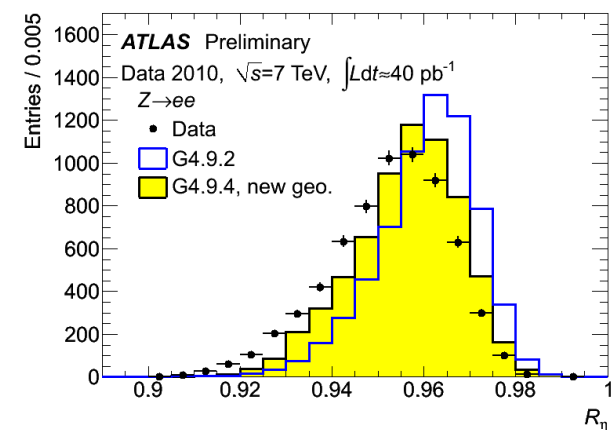
Supercluster – track matching
>=2 pixel hits & >=5 silicon hits (pixels+strips)

ID variables ATLAS

ID variables CMS