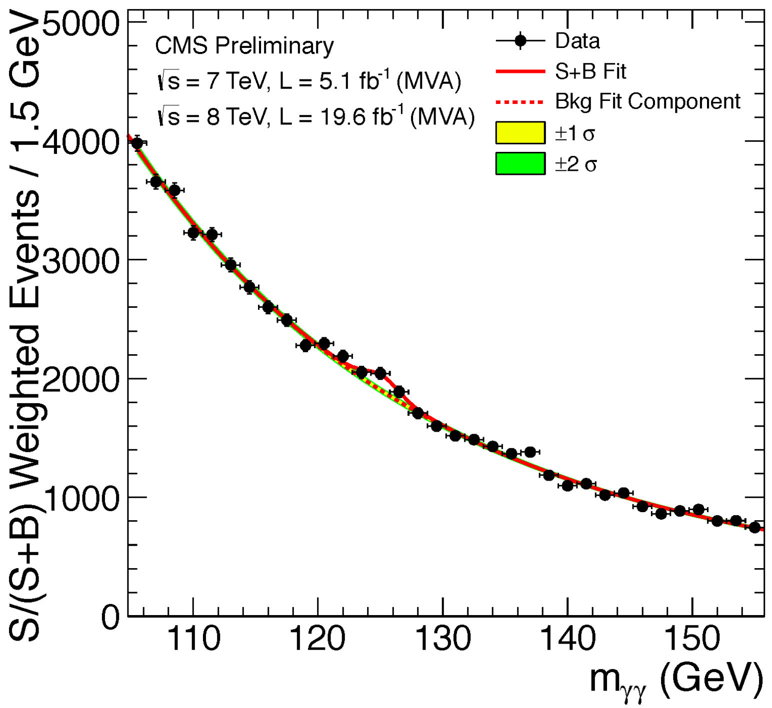
Photon reconstruction and performance in ATLAS and CMS

Elisabeth Petit
LAPP

LHC France 2013, Annecy
4th of April 2013

Introduction

- Photon performance of utmost importance for:
  - $H \rightarrow \gamma\gamma$
  - SM prompt photon
  - SUSY
  - exotics



- Higgs-oriented talk

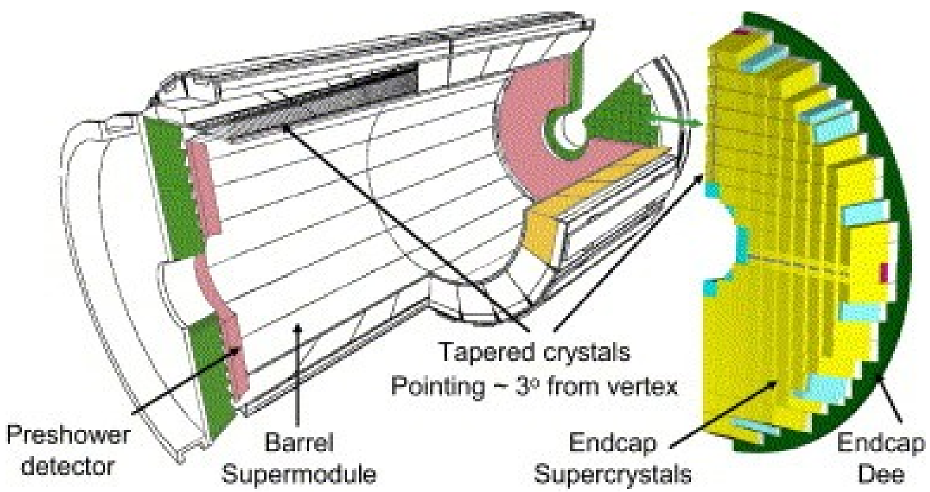
- Di-photon invariant mass:

$$m_{\gamma\gamma}^2 = 2\, E_1\, E_2\, (1-\cos\Delta\alpha(\gamma_1;\gamma_2))$$

Electromagnetic calorimeters

CMS:

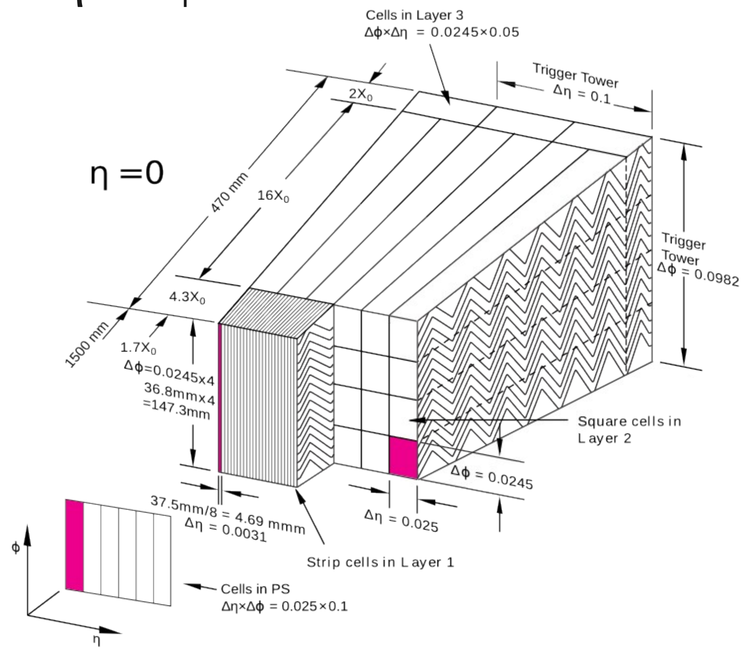
- Homogeneous $PbWO_4$ crystal calorimeter
  - $\Delta\eta \times \Delta\varphi = 0.0174 \times 0.0174$



$$\frac{\sigma_E}{E} = \frac{2.8\,\%}{\sqrt{E}} \oplus \frac{12\,\%}{E} \oplus 0.3\,\%$$

ATLAS:

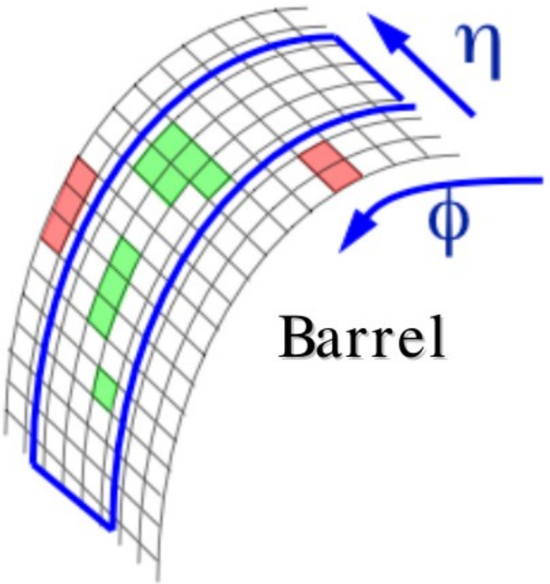
- Lead-LAr sampling calorimeter
  - accordion geometry
  - $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$



$$\frac{\sigma_E}{E} = \frac{10\,\%}{\sqrt{E}} \oplus 0.7\,\%$$

Photon reconstruction, CMS

- in 5x5 crystal clusters and 50 GeV photons:
  - ~97% of unconverted photon energy
- >50% probability to convert into e^+e^- pair
  ⇒ spreads in φ due to B-field
  ⇒ super-clusters (SC)
- Barrel:
  - narrow in η: 5 crystals
  - long in φ: ±10-15 crystals
- Endcap:
  - from 5x5 crystal around most energetic + pre-shower



- Conversion: use of R_9 variable (E_{3x3}/E_{SC})
  - unconverted: E_{5x5} energy
  - converted: E_{SC} energy

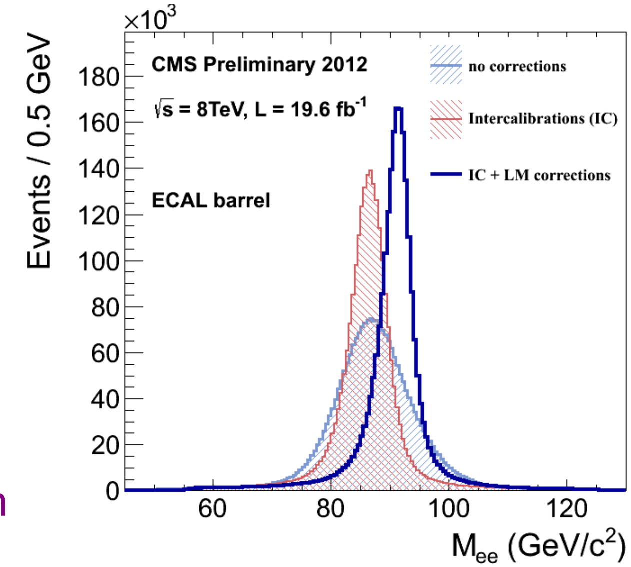
Photon energy, CMS

- Photon energy: $E_\gamma \propto F(\eta) \sum_{\text{clusters}} c_i \cdot L_i \cdot E_i$

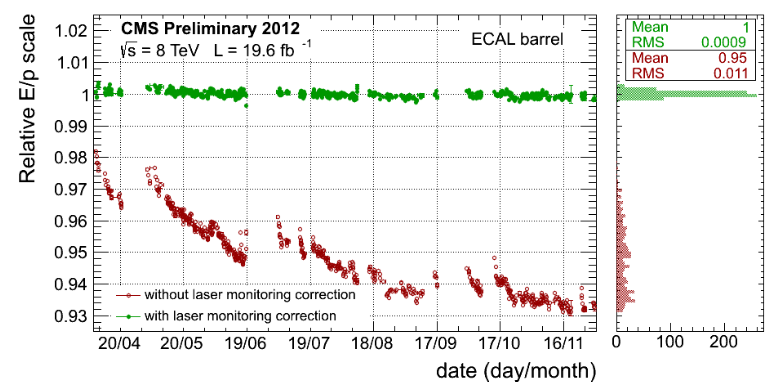
corrections (losses, containment)

intercalibration (φ symmetry, π0, E/p, ...)

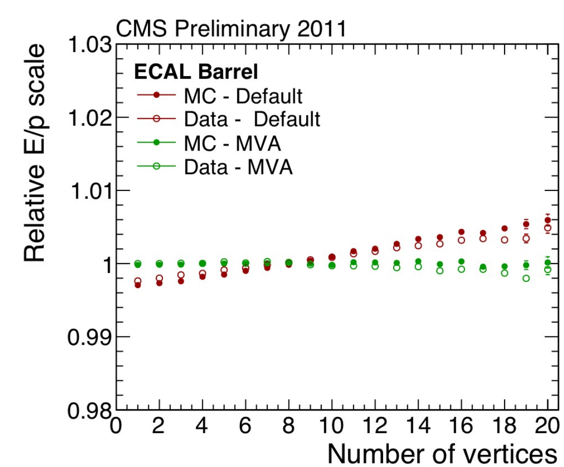
laser response correction



- Corrections with MC or BDT
  - pile-up independent
- Even-by-event estimate of energy uncertainty

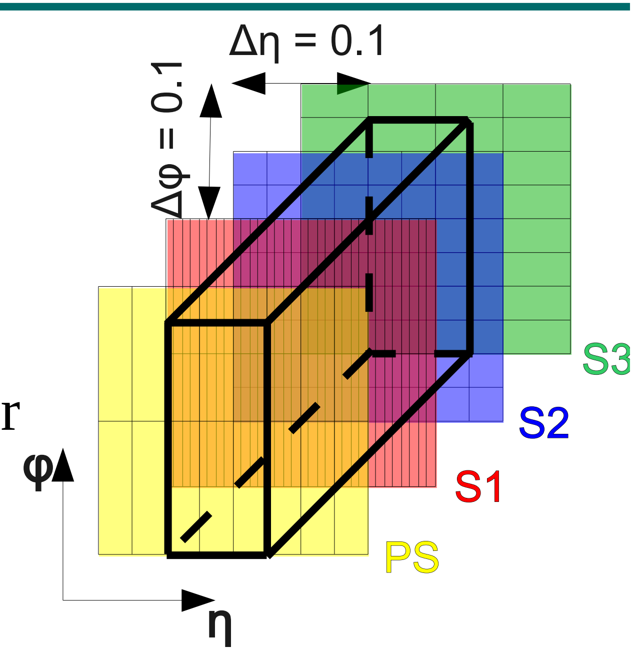


- Absolute energy scale: $Z \to ee$
- Energy resolution: $Z \to ee$ line-shape
  - in η, R_9, run period bins
- Energy scale stable at per mill level



CMS-DP-2013-007

Photon reconstruction, ATLAS

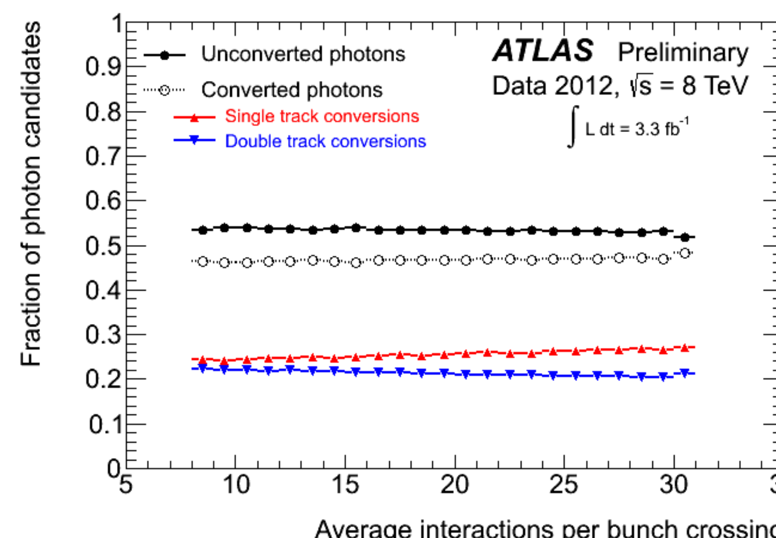


- Cluster reconstruction
  - $\Delta\eta\mathrm{x}\Delta\varphi = 0.075\mathrm{x}0.175 = 3\mathrm{x}5/3\mathrm{x}7$ cells, in barrel
  - $\Delta\eta\mathrm{x}\Delta\varphi = 0.125\mathrm{x}0.125 = 5\mathrm{x}5$ cells, in end-caps
- Conversion: matched track from vertex in inner detector
  - stable with pile-up
- Photon energy: $E_\gamma = E_{\mathrm{front}} + E_{\mathrm{calo}} + E_{\mathrm{back}}$

loss before calo ($\propto$ E_{PS})

$\propto E_1 + E_2 + E_3$

loss after calo



ElectronGammaPublicCollisionResults

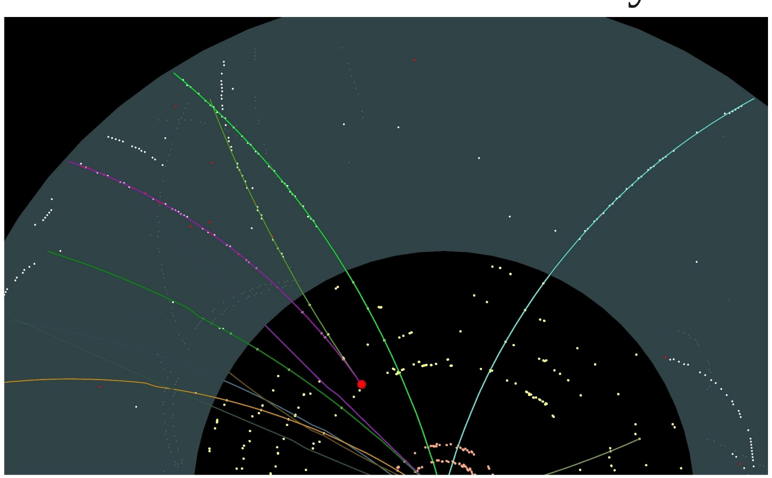
- Corrections from MC
- Absolute energy scale: corrected from $Z \to ee$ events
- Energy resolution: $Z \to ee$ line-shape

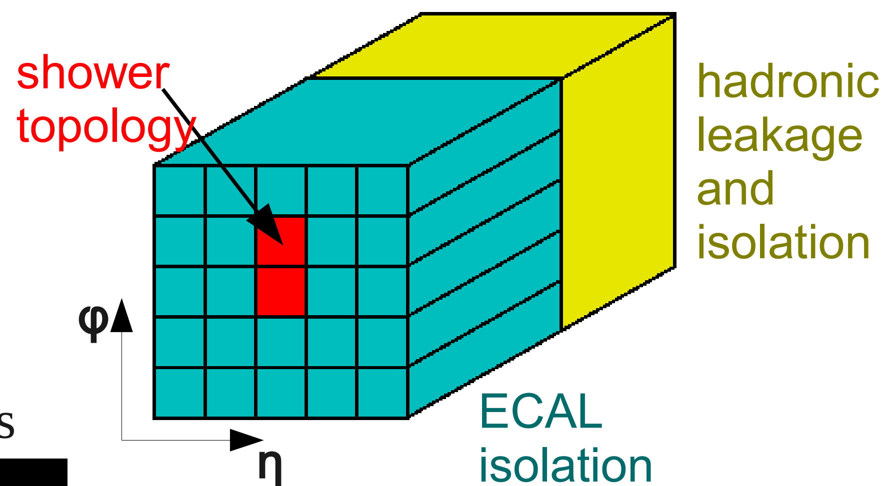
Photon identification

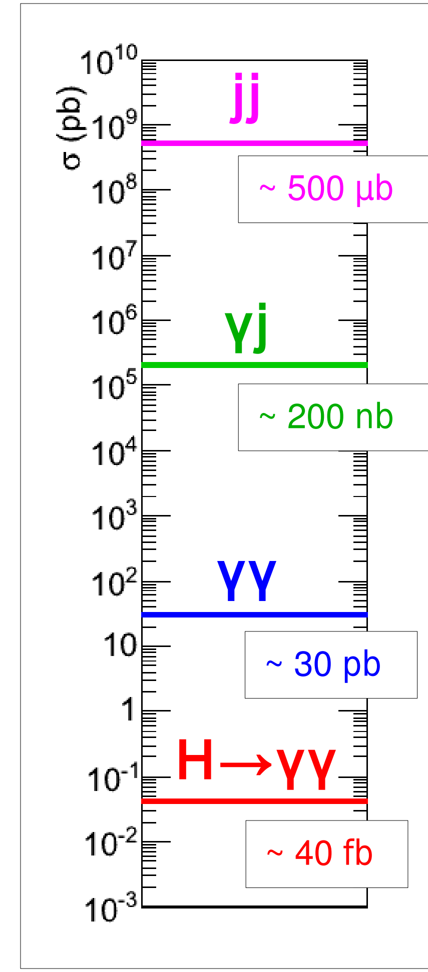
- High photon efficiency vs high jet rejection
  - hadronic leakage
  - main background: $\pi^0 \rightarrow \gamma\gamma$
    $\Rightarrow$ shower topology
  - photon isolation

    (cluster + track)

- Electron veto
  - no hits in inner layers





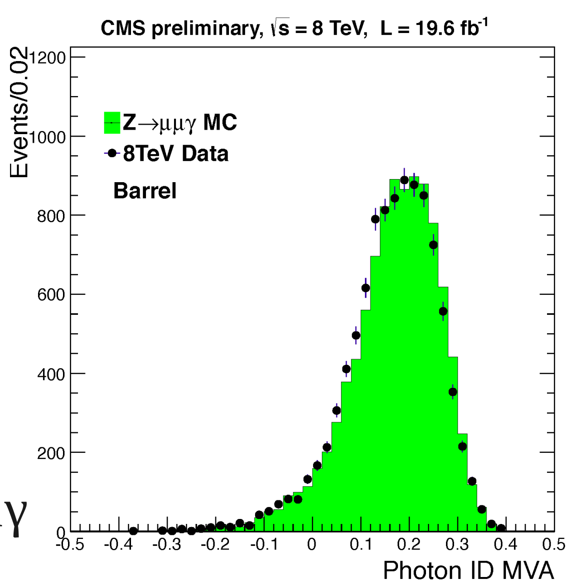


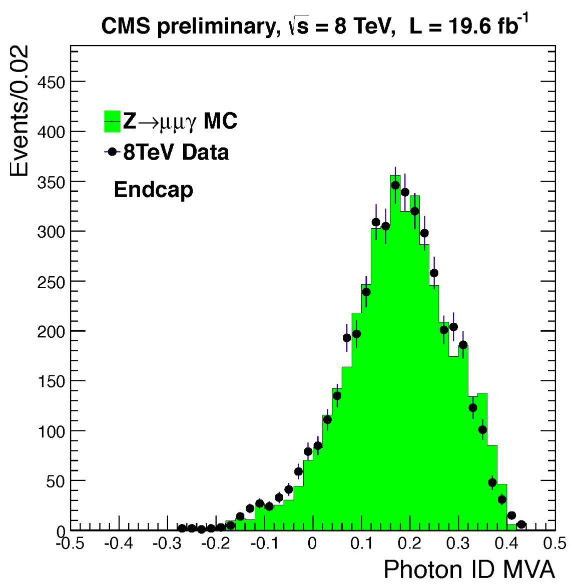
Identification, CMS (1)

- Preselection
  - electron veto
  - hadronic leakage (E_{had}/E_{γ})
  - isolation (PF) +shape
  - efficiency: 92-99%
  - good data-MC agreement: 1.0-2.6% uncerainty

- Cut-based identification
  - separated for barrel/endcap and converted/unconverted
  - lateral shower shape
  - isolation (3 variables)
  - uncertainty:
    1% (barrel)
    1.6% (end-cap)

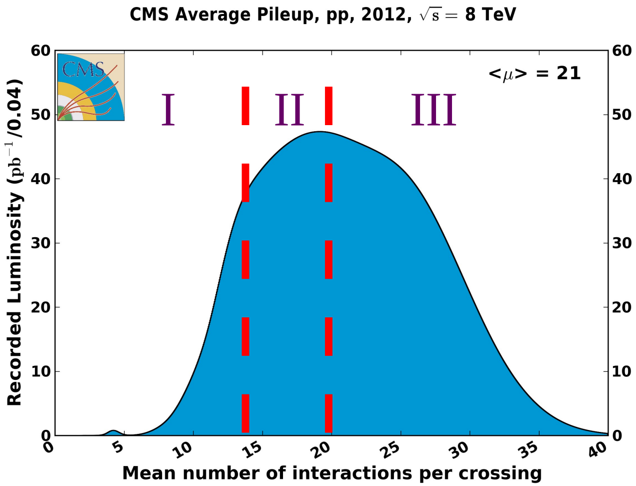
- MVA identification
  - shower topology (7 variables)
  - isolation (3 variables)
  - energy density per unit area (pile-up)
  - checked with $Z \to ee$ and $Z \to \mu\mu\gamma$ good data-MC agreement
  - a few % uncertainty



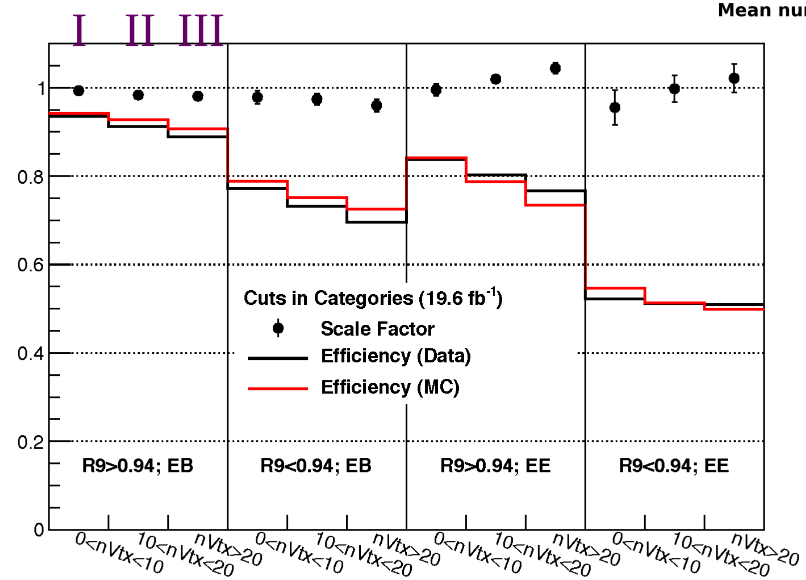


CMS-PAS-HIG-13-001

Identification, CMS (2)

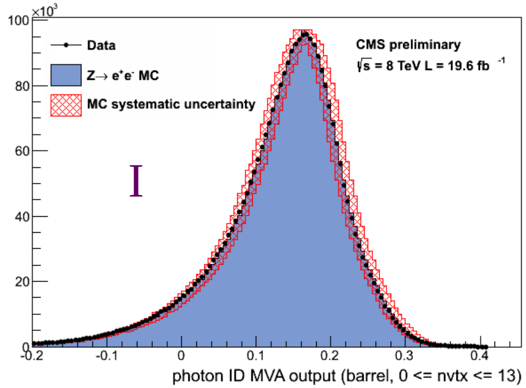


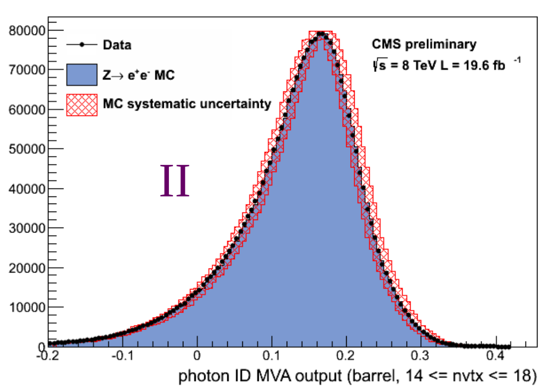
- Cut-based:
  - slight dependence on pile-up
  - good agreement data-MC

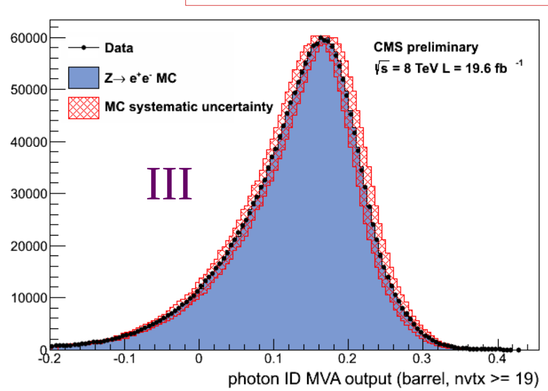


- MVA:
  - pile-up independent

CMS-PAS-HIG-13-001

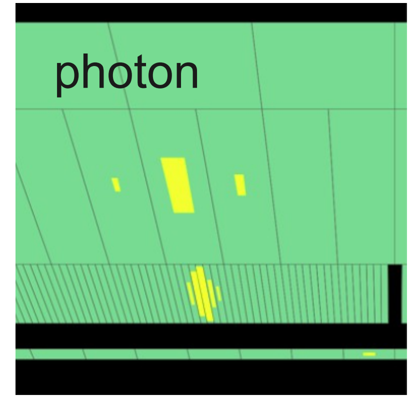


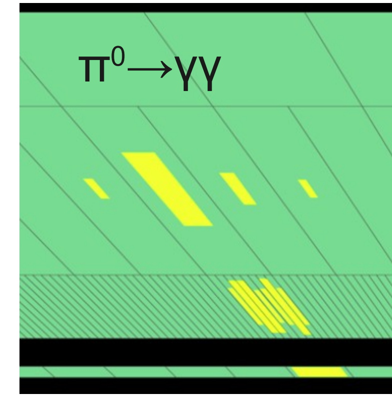


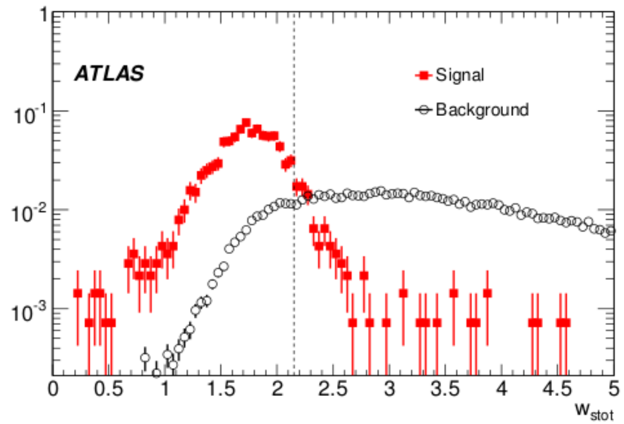


Identification, ATLAS (1)

- Use of fine segmentation of calo
  - 8 shower shape variables
  - 2 hadronic leakage variables
  - in η bins



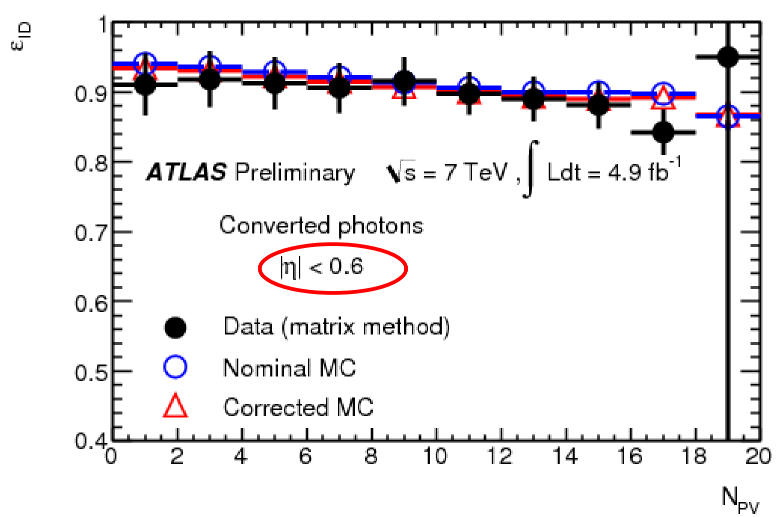


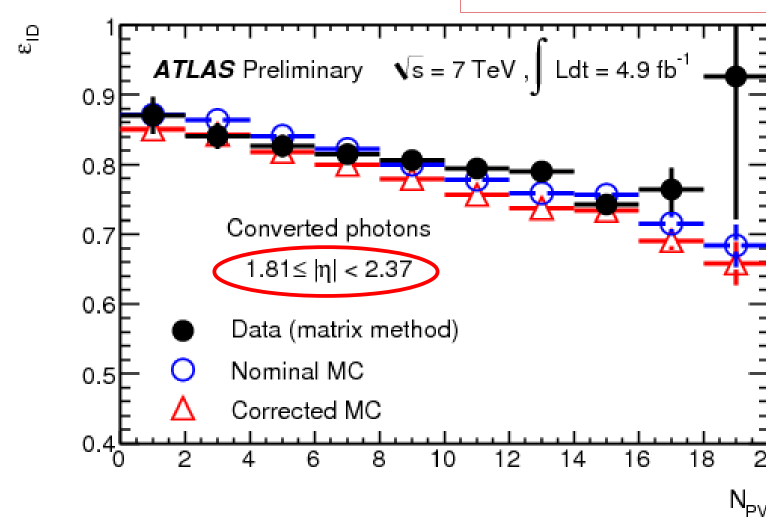


CERN-OPEN-2008-020

- Optimised to be ~pile-up independent

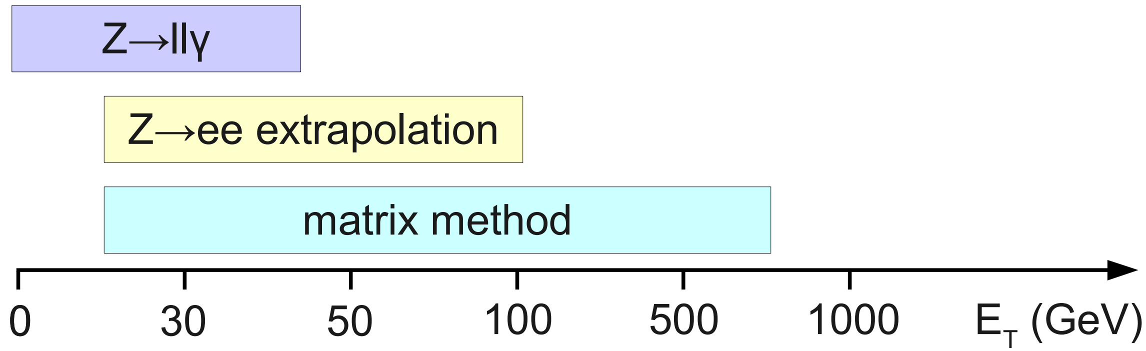
ATLAS-CONF-2012-123

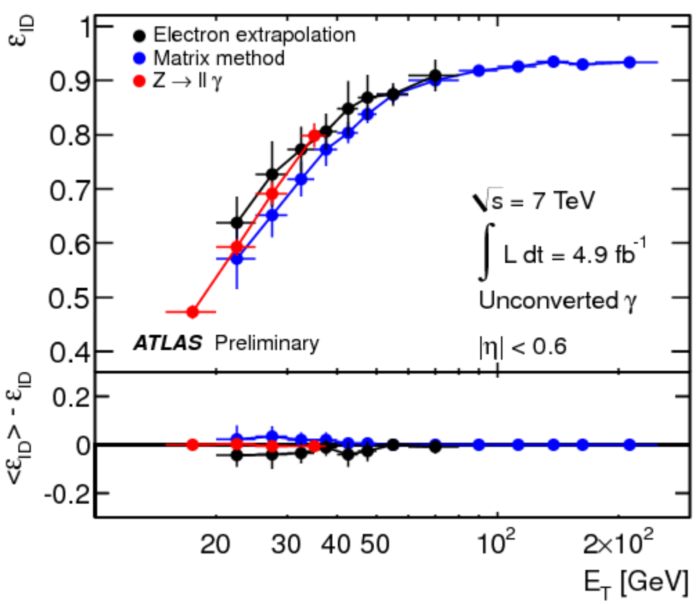


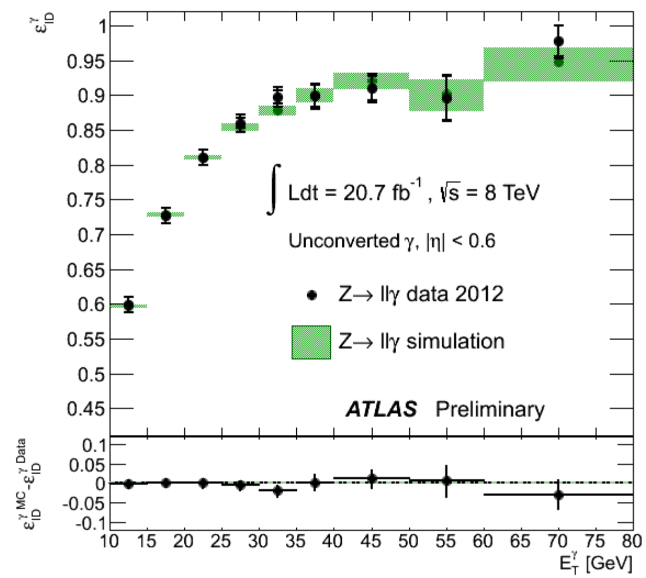


Identification, ATLAS (2)

- Efficiency measured with 3 data-driven measurements
  - Z radiative decay (see talk by C. Rangel)
  - Extrapolation from Z → ee
  - Matrix method isolation-identification







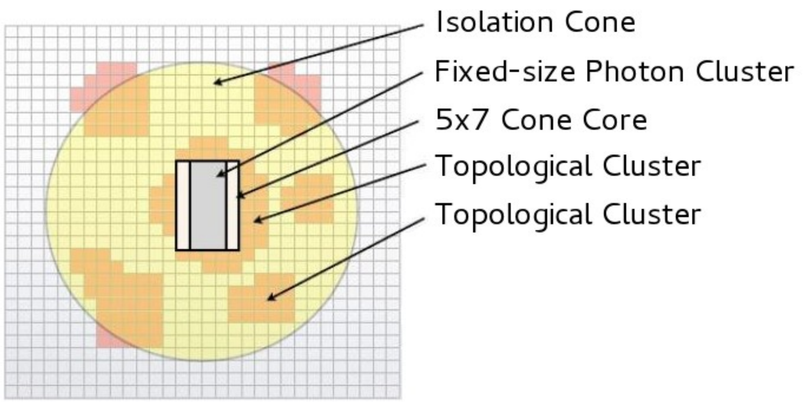
- Efficiency > 85% for E_T > 40 GeV
- Uncertainty: 2.5-1.5%

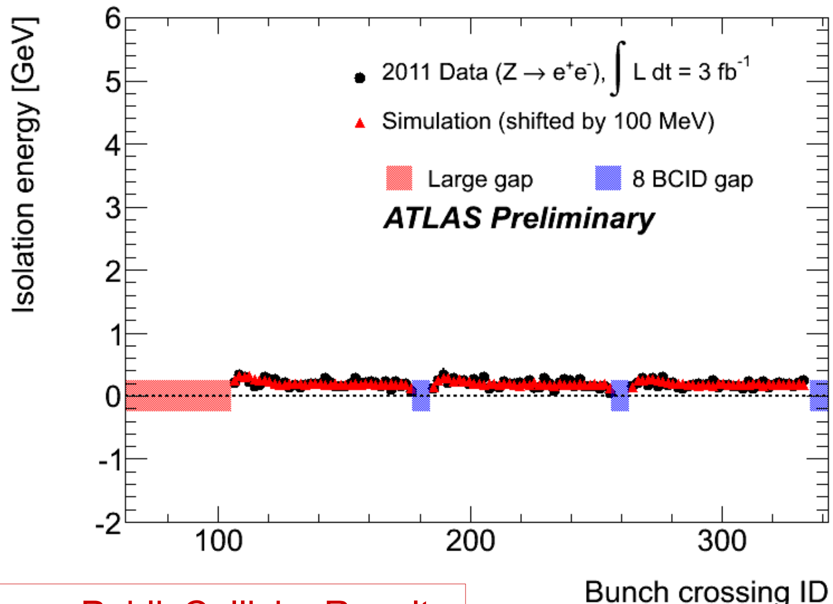
ATLAS-CONF-2012-123

EgammaPublicPlots

Isolation, ATLAS

- Computed from topological clusters in calorimeter with $\Delta R < 0.4$
- Corrected for pileup and underlying event by subtracting ambient energy density event-by-event





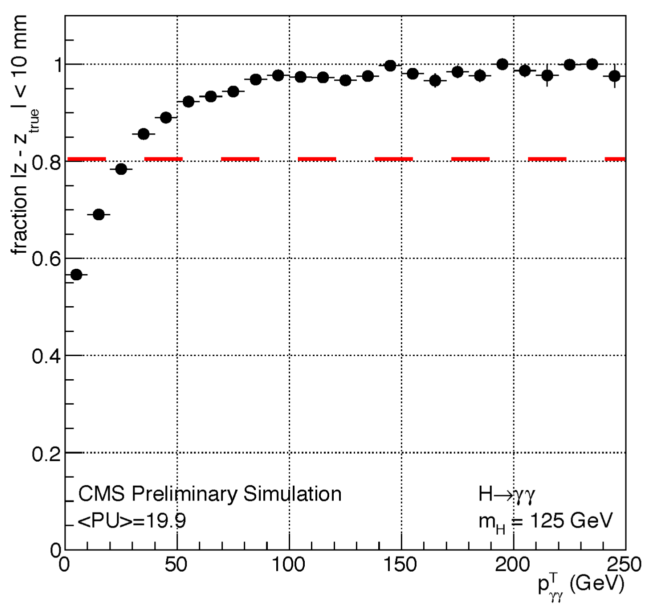
ElectronGammaPublicCollisionResults

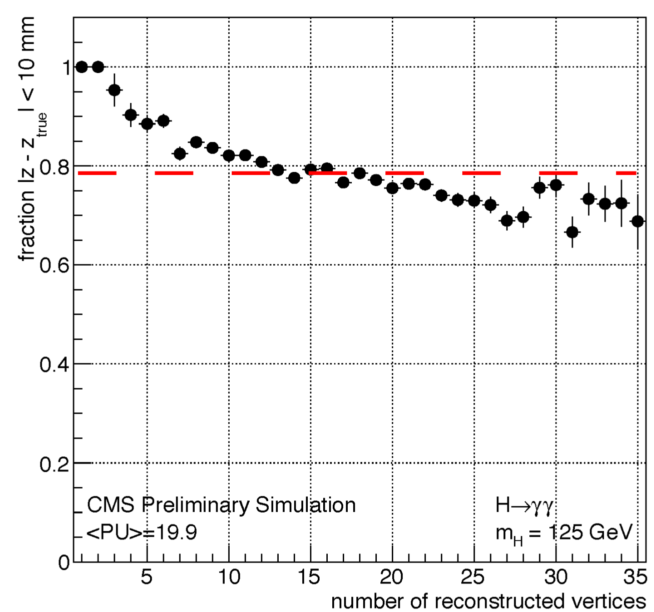
- E_T^{iso} independent from E_T, pile-up, Underlying Event
- Uncertainty on data/MC comparison ($Z \to ee$): 1%

Di-photon vertex, CMS

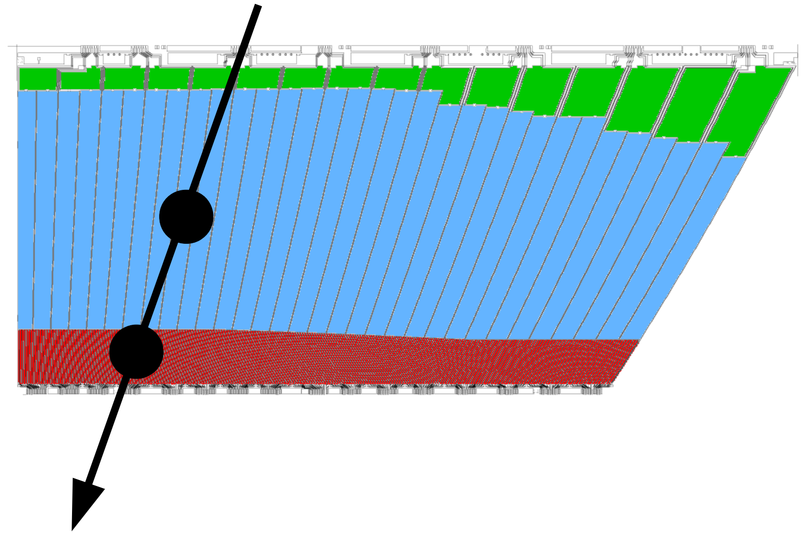
- Correlations between di-photon system and recoiling tracks
  - unconverted photons
- Conversion vertex
  - converted photons
- Information in BDT
- Efficiency of finding vertex 10 mm from true one: > 80%
- Slight dependence on pile-up

CMS-PAS-HIG-13-001

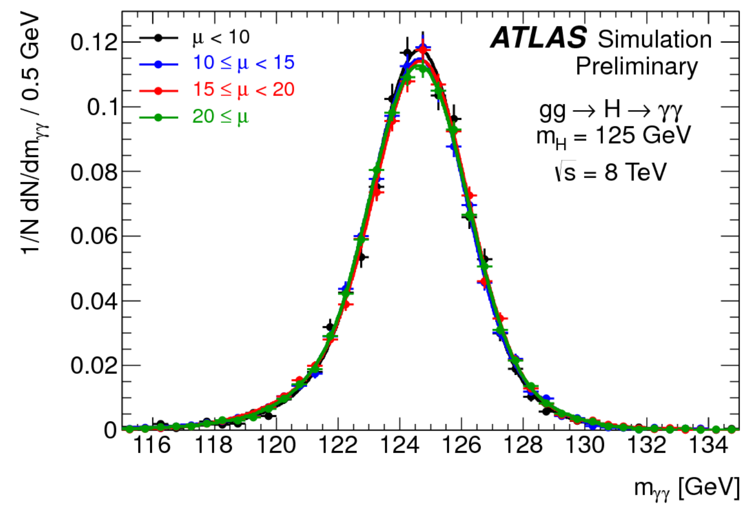




Di-photon vertex, ATLAS



- Use of longitudinal segmentation of calo
  - unconverted photons
  - *"calo pointing"*
- Conversion vertex
  - converted photons
- NN algorithm
  - calo pointing
  - Σp_T and Σp_T^2 of tracks
  - conversion info
  - $\Delta\varphi$(all tracks, di-photon)



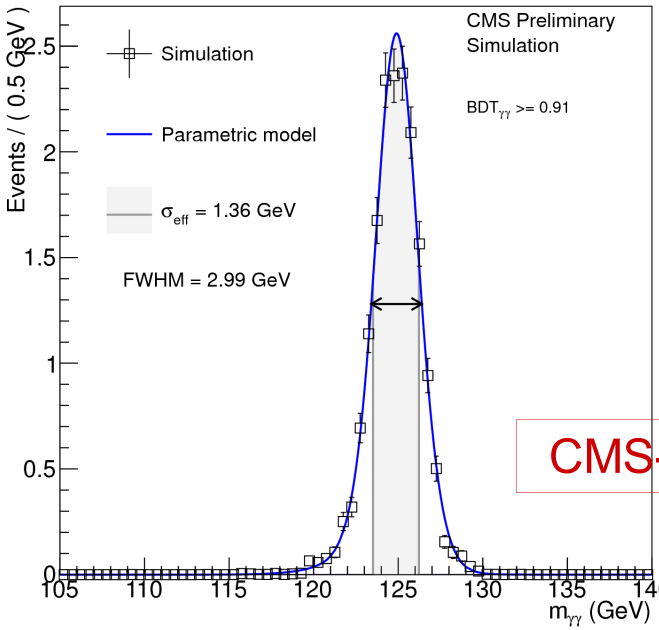
- Efficiency of finding vertex 10 mm from true one: ~ 100%
- Slight dependence on pile-up

ATLAS-CONF-2011-161

ATLAS-CONF-2013-012

Conclusions

- Photon energy reconstruction, identification, pointing essential for $H \to \gamma\gamma$ reconstruction
- Different strategies for ATLAS-CMS for different calorimeters and tracking
  - but overall similar performance!
- $m_{\gamma\gamma}$ resolution < 1.8 GeV
- Pile-up robust reconstruction

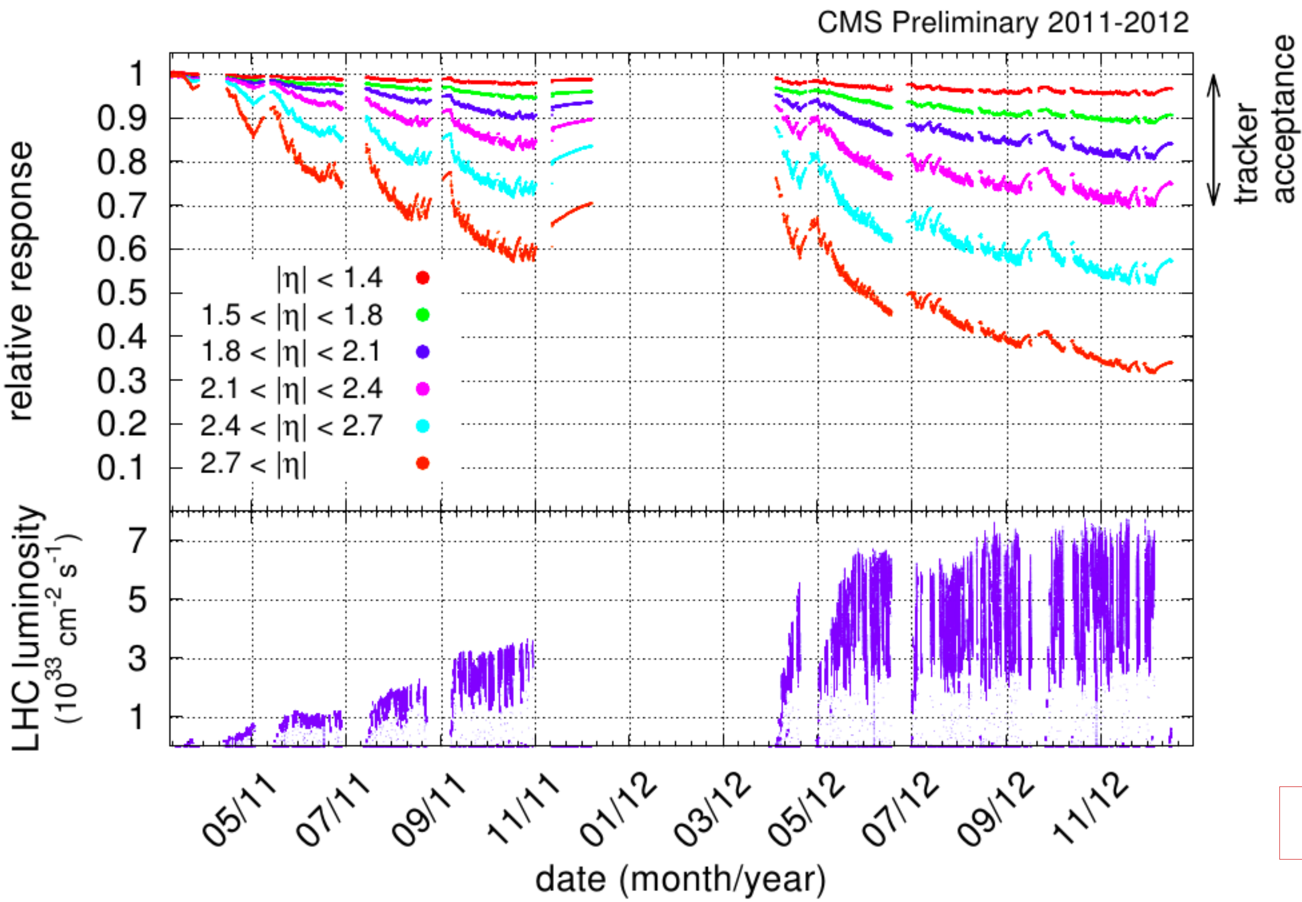


CMS-PAS-HIG-13-001

- Now more information on $H \to \gamma\gamma$ physics in O.Davignon and F.Couderc talks

Back-up slides

CMS ECAL relative response

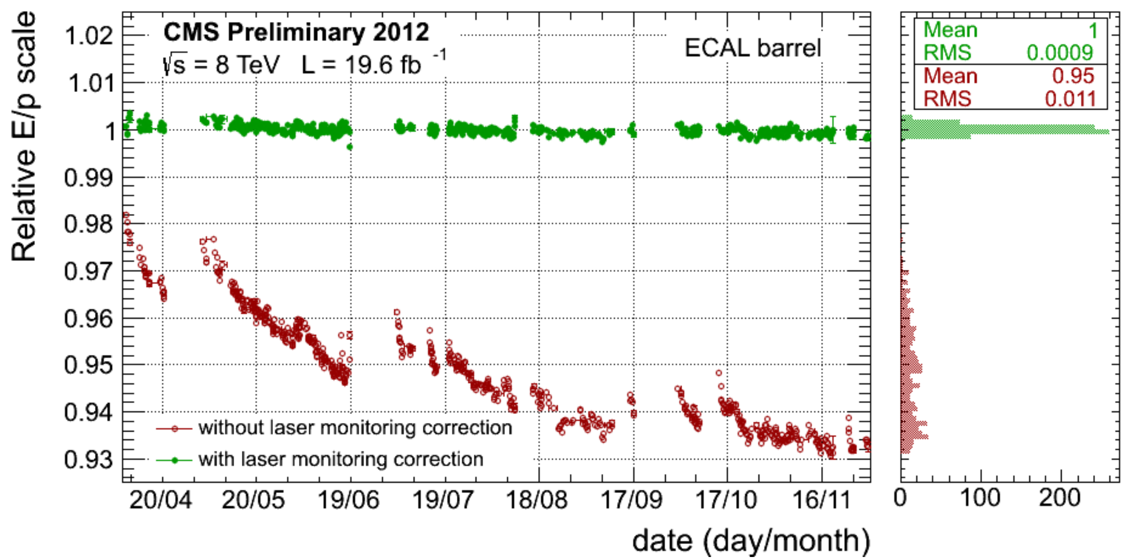


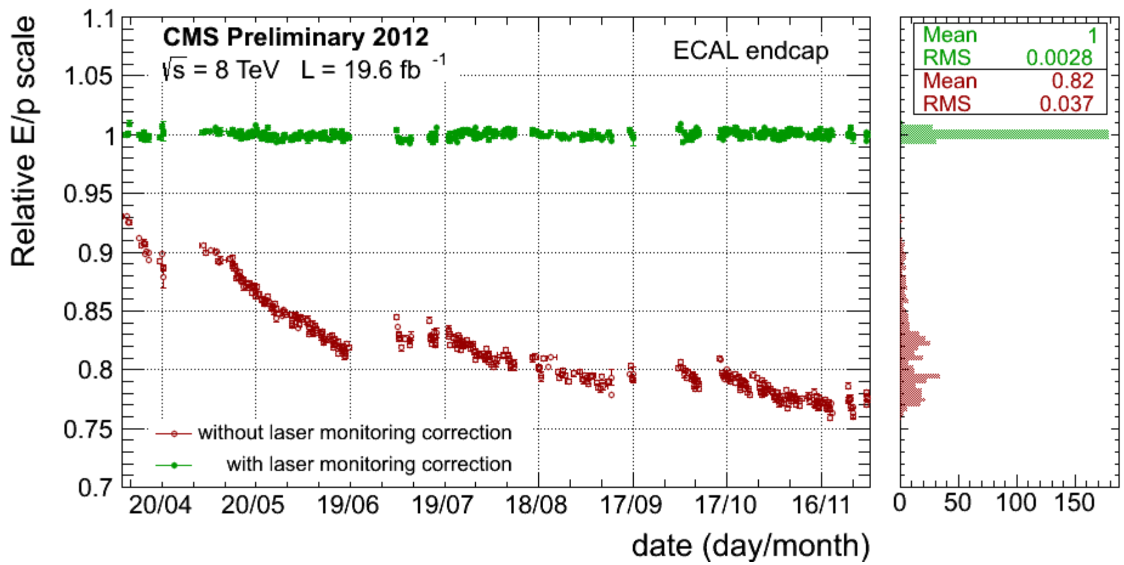
CMS-DP-2013-007

- Relative response to laser light measured by the ECAL laser monitoring system, averaged over all crystals in bins of η
- Response change in ECAL channels:a few % in barrel, up to 25% in most forward endcap regions used for electron and photon reconstruction. Response change observed in ECAL channels: up to 6% in barrel, up to 30% at η ~ 2.5 (limit of tracker acceptance). Response change up to 70% in region closest to beam pipe. Measurements are used to correct physics data

CMS: E/p response

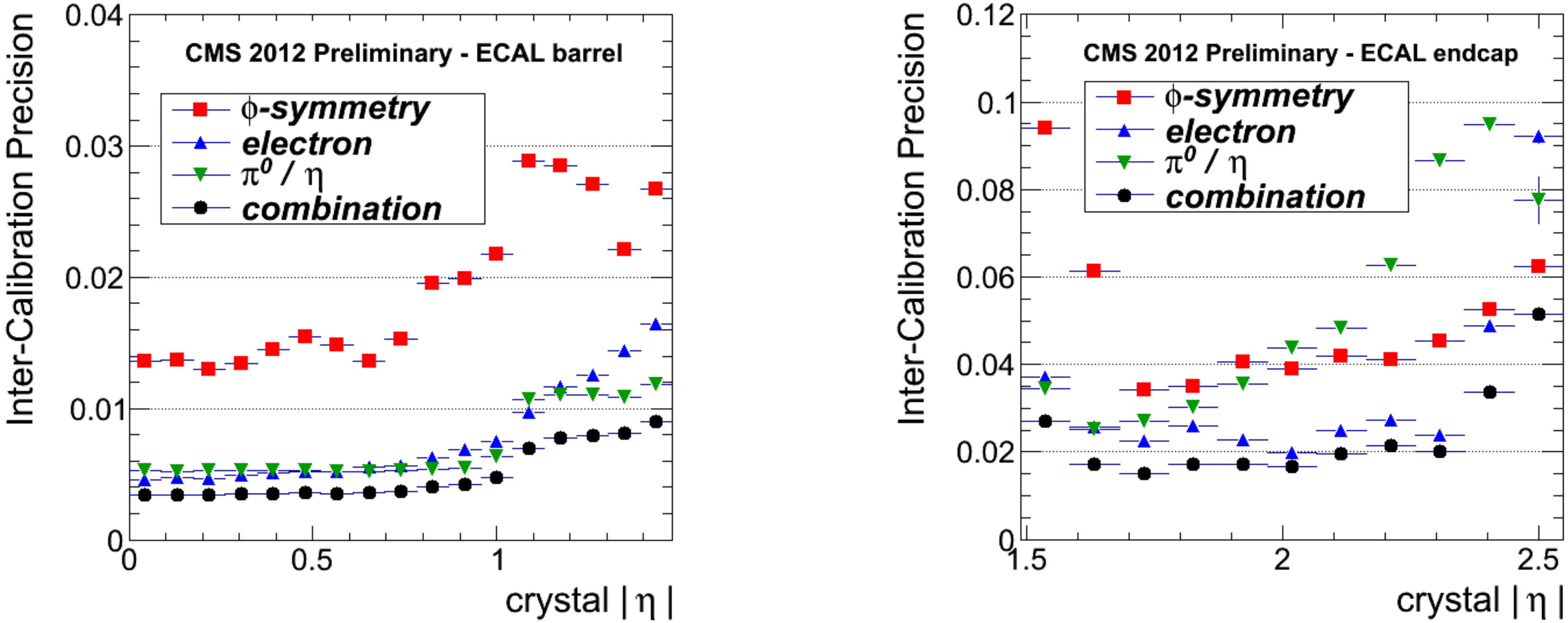
- Reconstruction with latest calibration and alignment conditions (Winter2013 re-reconstruction);
- $W \rightarrow e\nu$ decays
- Before (red points) and after (green points) corrections to ECAL crystal response variations due to transparency loss
- ECAL Barrel: average signal loss ~5%, RMS stability after corrections 0.09%
- ECAL Endcap: average signal loss ~18%, RMS stability after corrections 0.28%





CMS-DP-2013-007

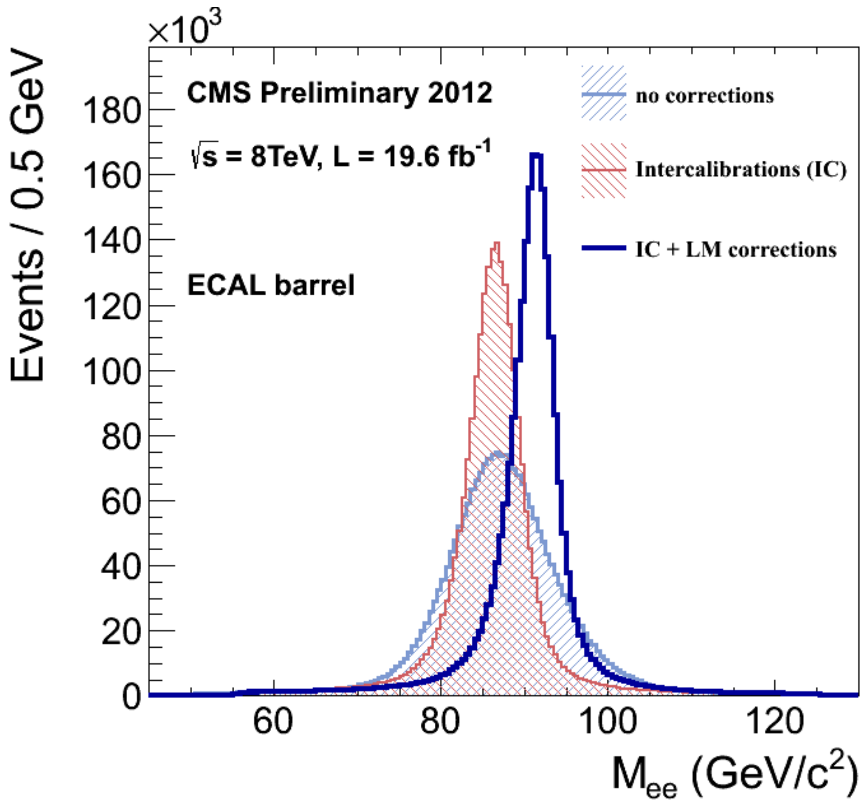
CMS: intercalibration

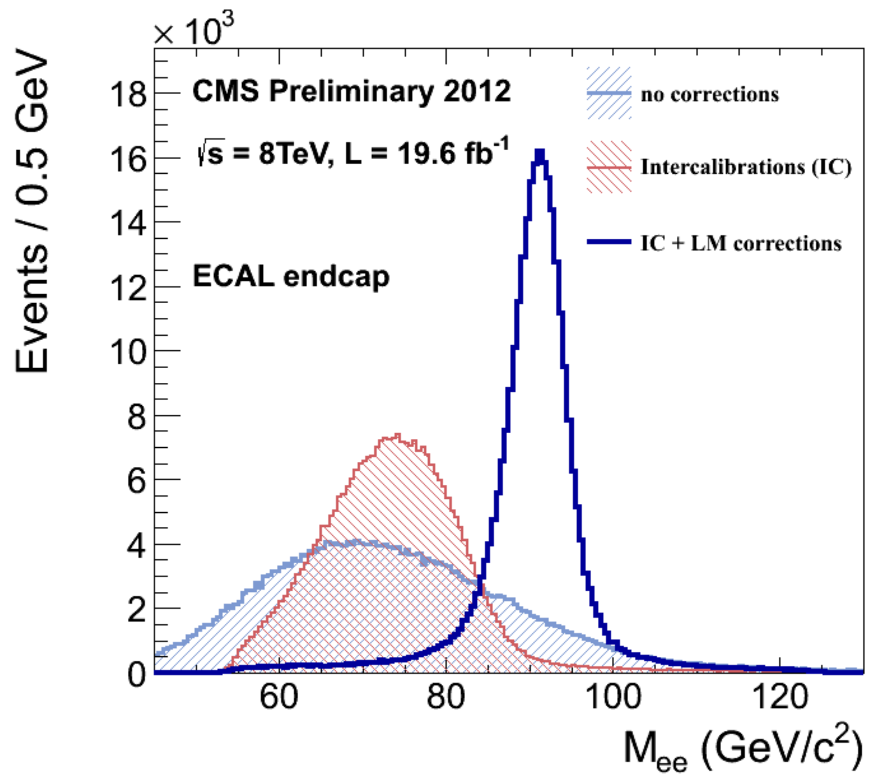


- 2012 inter-calibration
- φ-symmetry, π0 → γγ and η → γγ decays, W and Z decay electrons
- Precision of the phi-symmetry and photon calibrations at the level of the systematic errors. Precision of the electron calibration is still dominated by the statistical errors for η > 1.

CMS-DP-2013-007

CMS: ECAL energy calibration

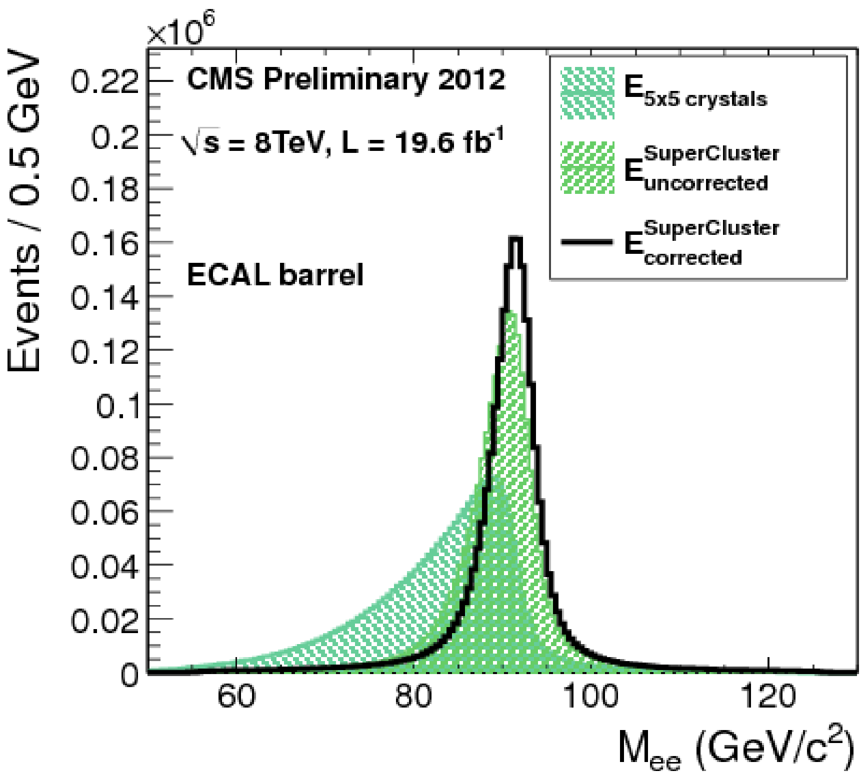


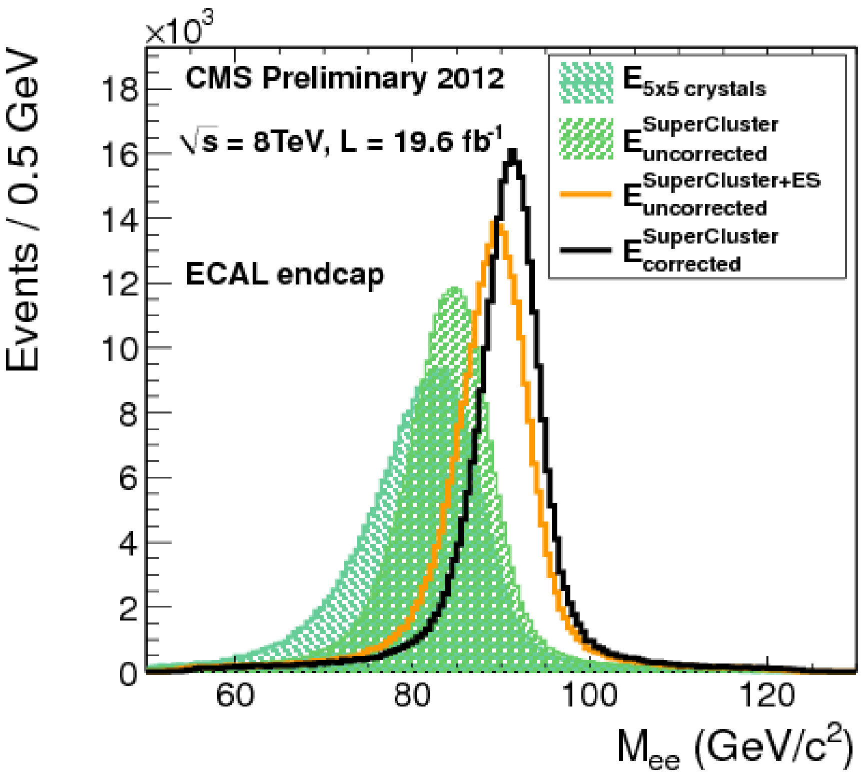


- Impact on the $Z \rightarrow ee$ energy scale and resolution obtained from applying energy scale corrections to account for the intrinsic spread in crystal and photo-detector response, and time-dependent corrections to compensate for channel response loss.

CMS-DP-2013-007

CMS: ECAL supercluster energy

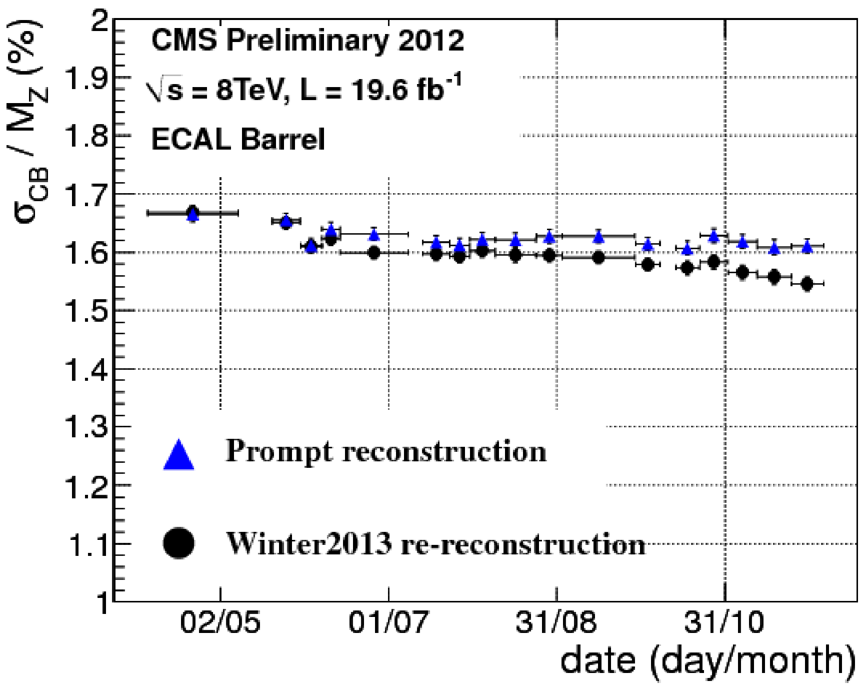


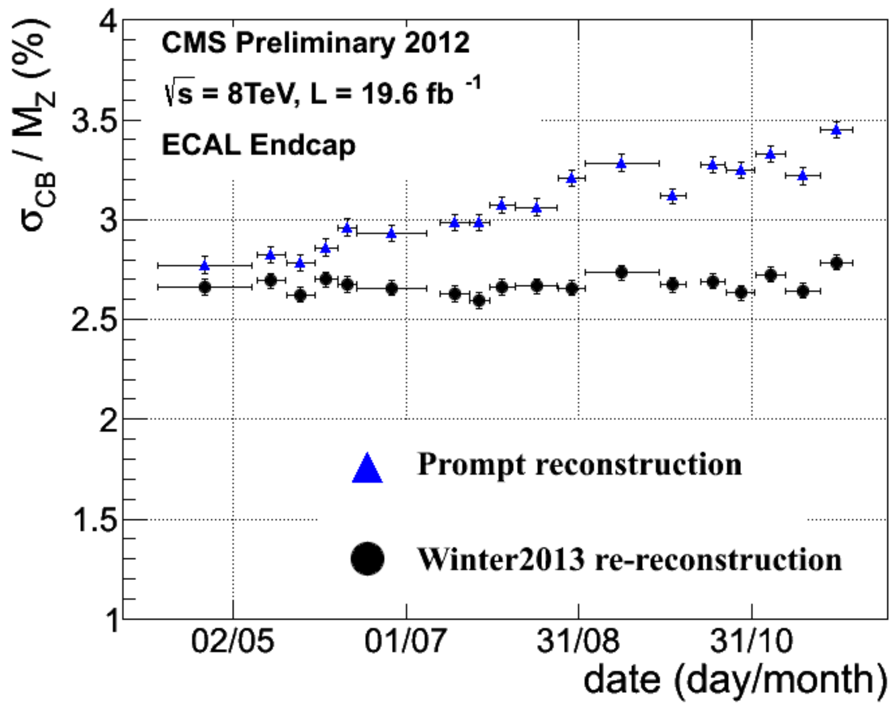


- Impact on the $Z \rightarrow e^+e^-$ energy scale and resolution from the incorporation of more sophisticated clustering and cluster correction algorithms.

CMS-DP-2013-007

CMS: Zee invariant mass

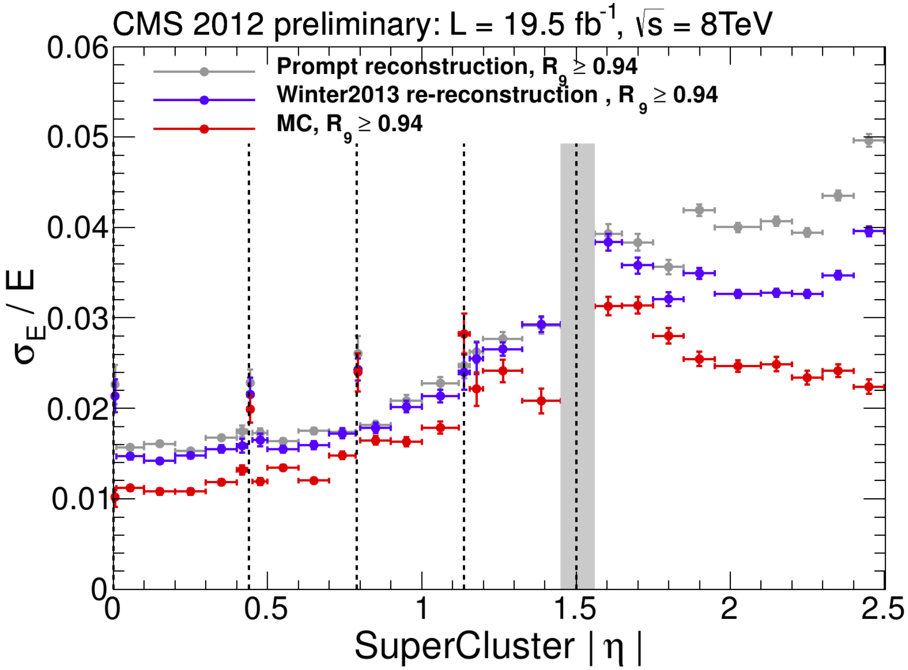


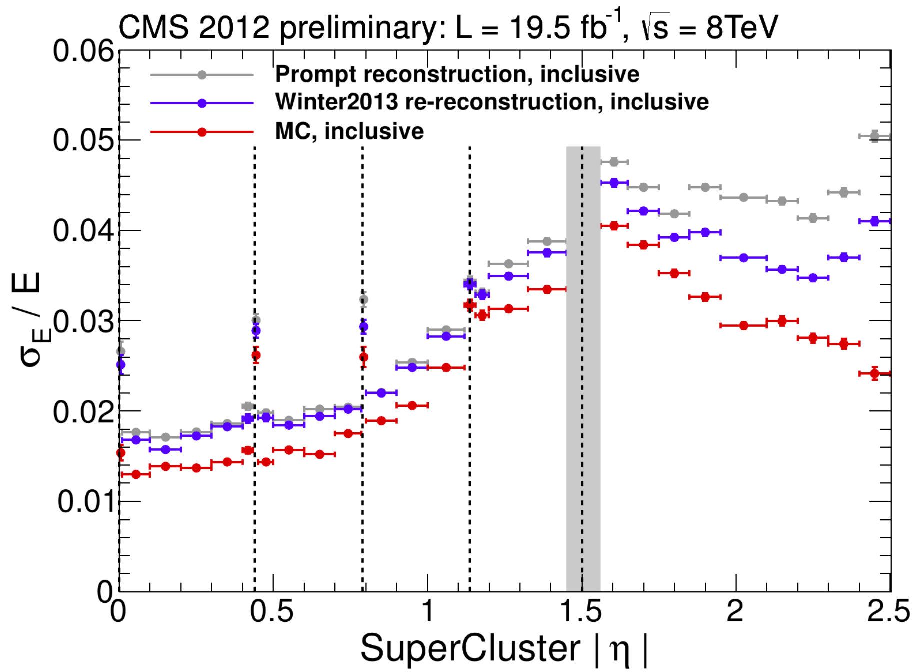


- Mass resolution of the Z peak, reconstructed from ee decay mode
- Width of the Z peak is fitted with a convolution of a Crystal Ball with a Breit-Wigner line shape. The Gaussian width parameter of the Crystal Ball function is taken as a measure of the mass resolution.

CMS-DP-2013-007

CMS: ECAL energy resolution (Zee)

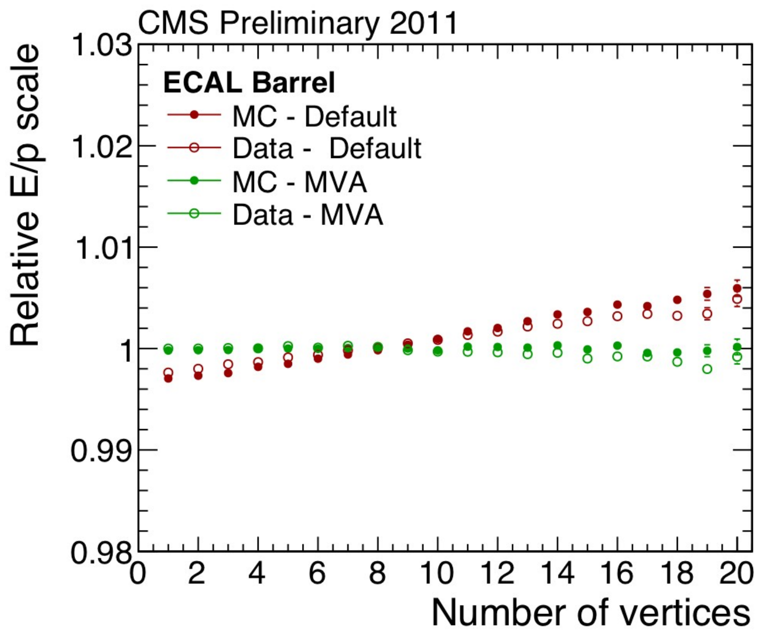


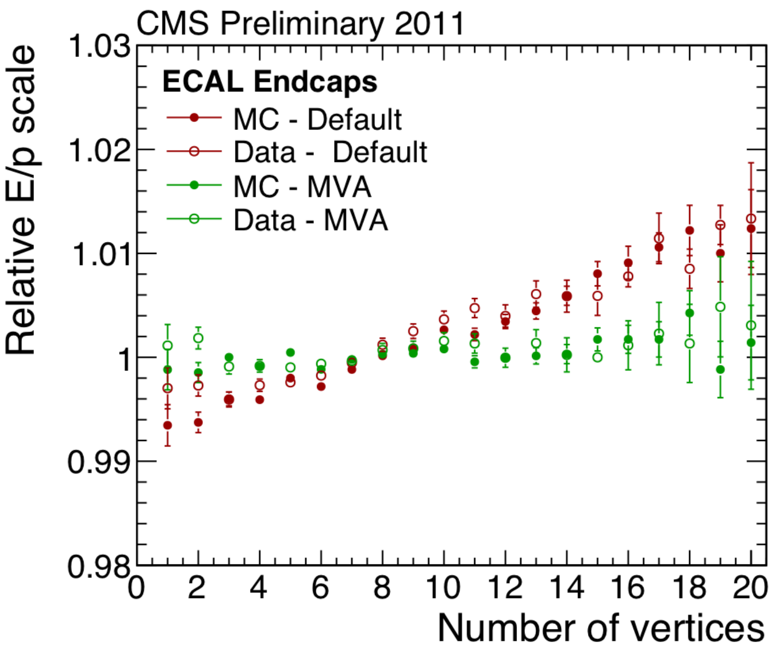


- Relative electron (ECAL) energy resolution unfolded in bins of η (electrons from $Z \rightarrow ee$)R
- Resolution extracted from an unbinned likelihood fit to $Z \rightarrow ee$ events, using a Voigtian (Landau convoluted with Gaussian) as the signal model.
- Resolution affected by the amount of material in front of the ECAL and is degraded in the vicinity of the eta cracks between ECAL modules
- Resolution, especially in the endcaps, improves significantly after a dedicated calibration using the full 2012 CMS dataset (blue points) with respect to the prompt calibration from early 2012 CMS data (gray points).

CMS-DP-2013-007

CMS: Response dependence on pileup



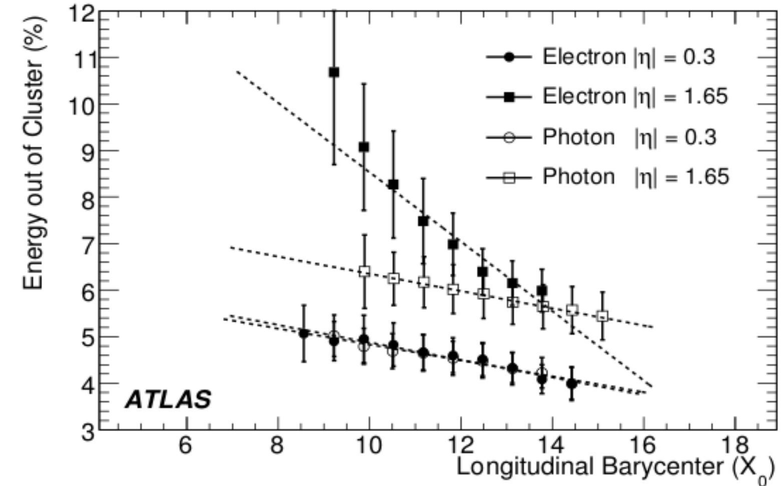


- Dependence of the reconstructed energy on the number of reconstructed vertices in the event.
- The default reconstruction of the data (open red circles) and MC (filled red circles) is compared to MC-driven corrections to the energy based on a multivariate analysis (MVA) of the energy response which includes pileup sensitive global event variables, for the data (open green circles) and MC (filled green circles) .

CMS-DP-2012-024

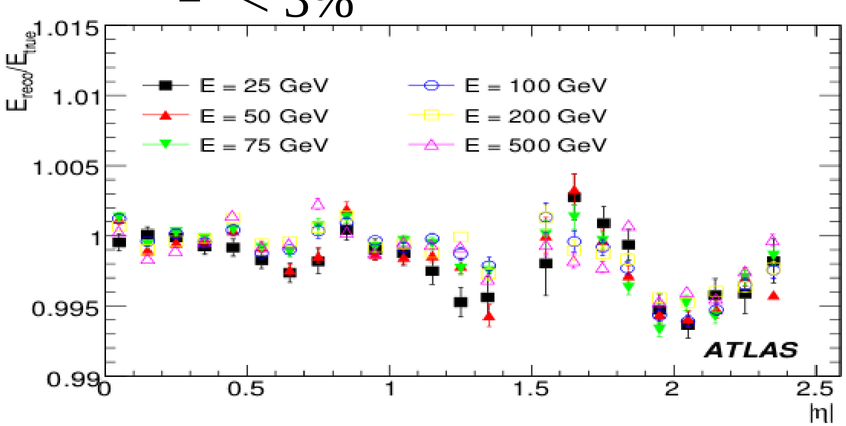
Photon energy reconstruction, ATLAS

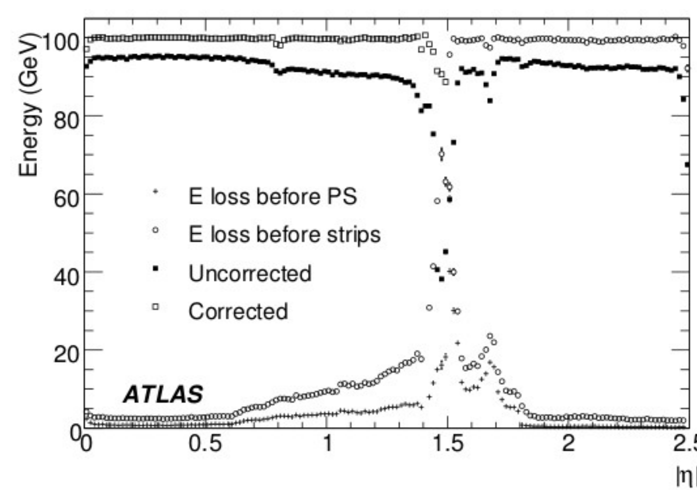
- $E_\gamma = E_{front} + E_{calo} + E_{back}$
- $E_{calo} = C_{cal}(X,\eta)(1+f_{out}(X,\eta))\sum_{i=1}^{3} E_i$
  - X: longitudinal barycentre
  - η: cluster barycenter
  - f_{out}: fraction of energy deposited outside cluster (<7%)
  - C_{cal}: calibration factor (0.98-1)



$$X = \frac{\sum_{i=1}^{3} E_i X_i + E_{PS} X\,PS}{\sum_{i=1}^{3} E_i + E_{PS}}$$

- $E_{front} = a(E_{cal},\eta) + b(E_{cal},\eta)E_{PS} + c(E_{cal},\eta)E_{PS}^2$
- $f_{leak} = E_{back}/E_{cal} = f_0^{leak}(\eta)X + f_1^{leak}(\eta)e^X$
  - < 3%



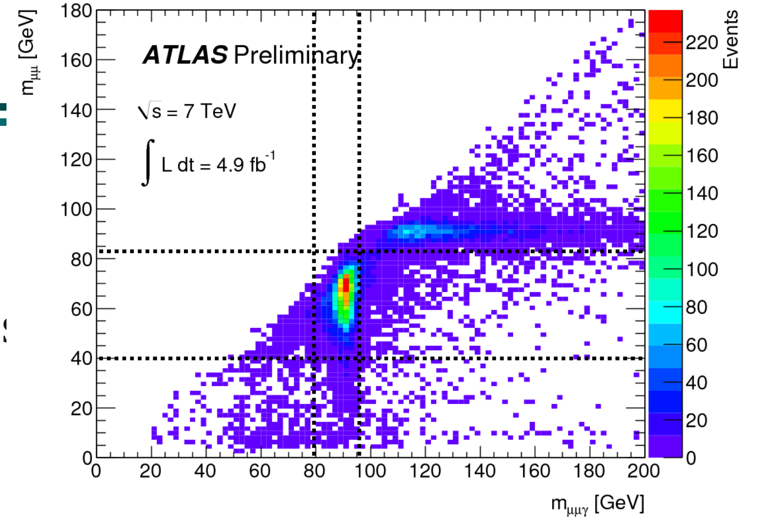


ATLAS identification (1)

- Radiative Z decay
  - signal extraction with signal+background templates: 96-98% purity

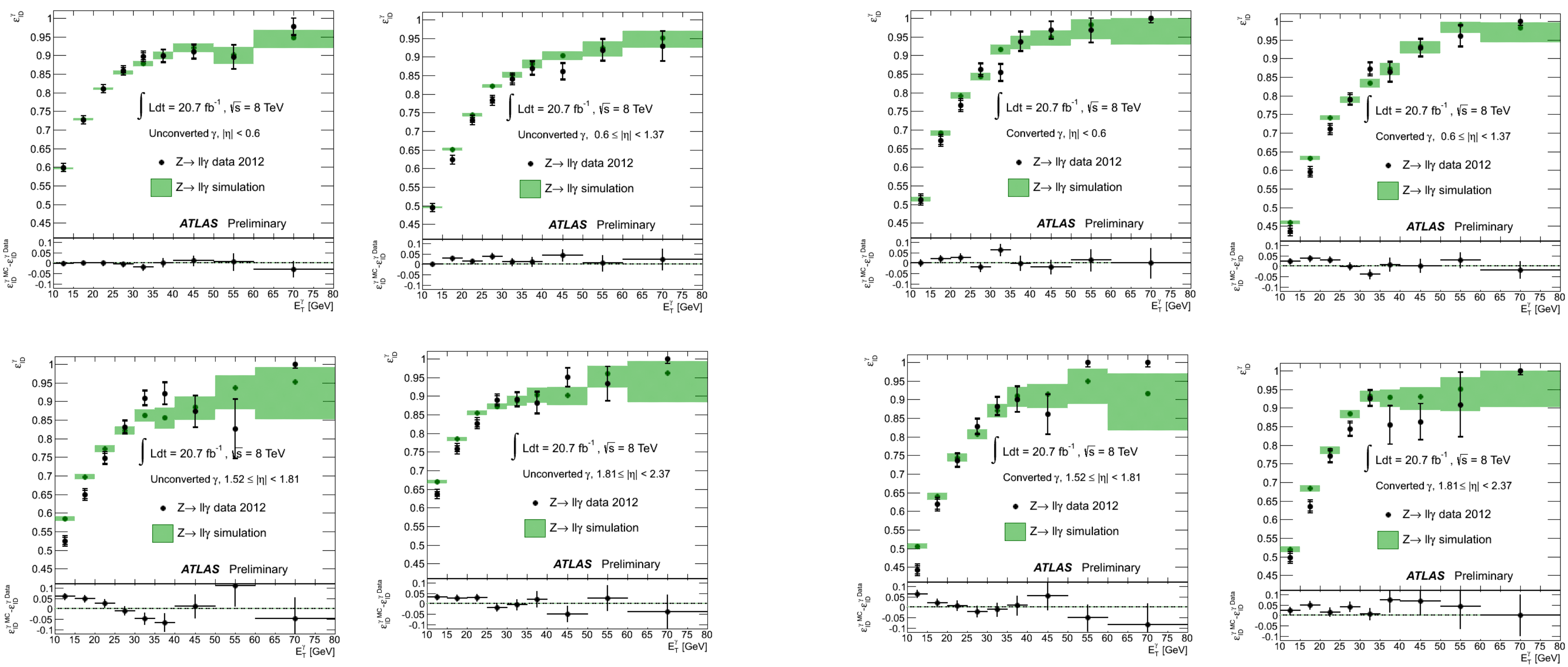
ATLAS-CONF-2012-123

EgammaPublicPlots



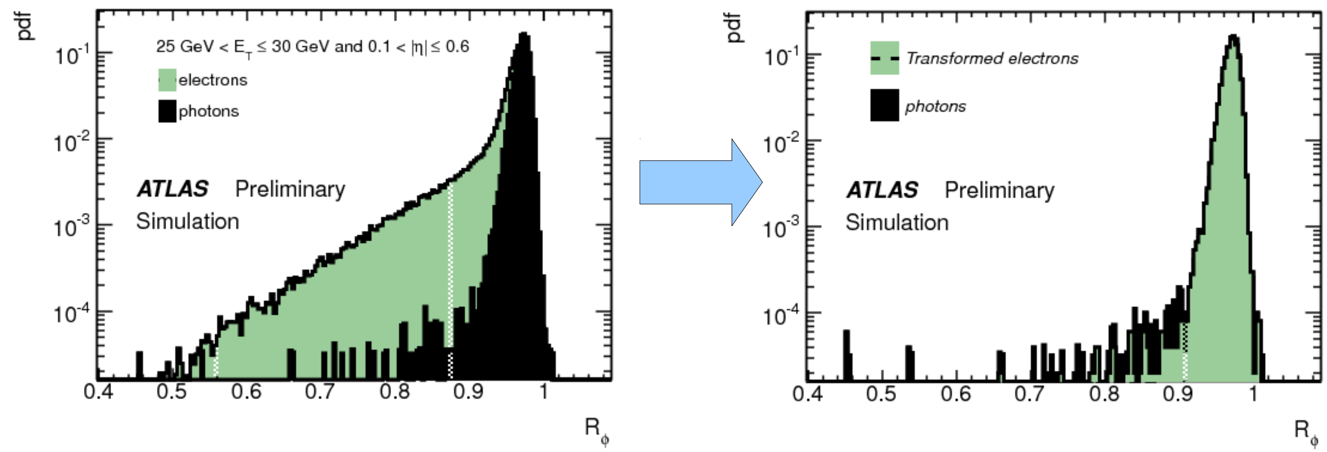
unconverted

converted

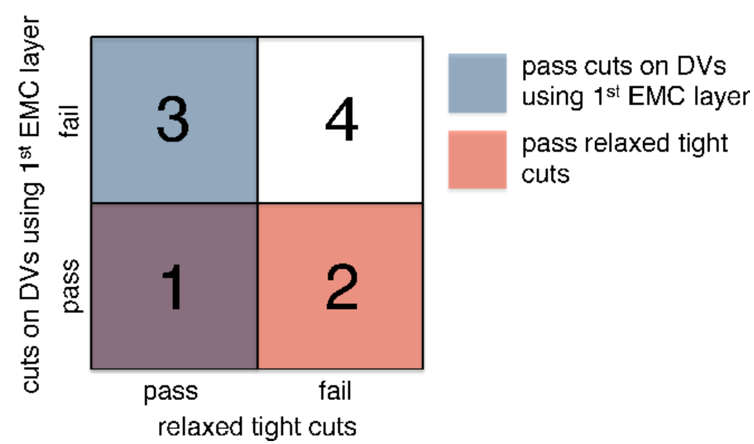


ATLAS identification (2)

- Extrapolation from $Z \rightarrow ee$ tag-and-probe
  - transformation to match electron to photon shower-shapes



- Matrix method
  - $N_{pass} = \varepsilon_S .\, N^S_{pass} + \varepsilon_B .\, N^B_{pass}$
  - isolation efficiencies estimated from data

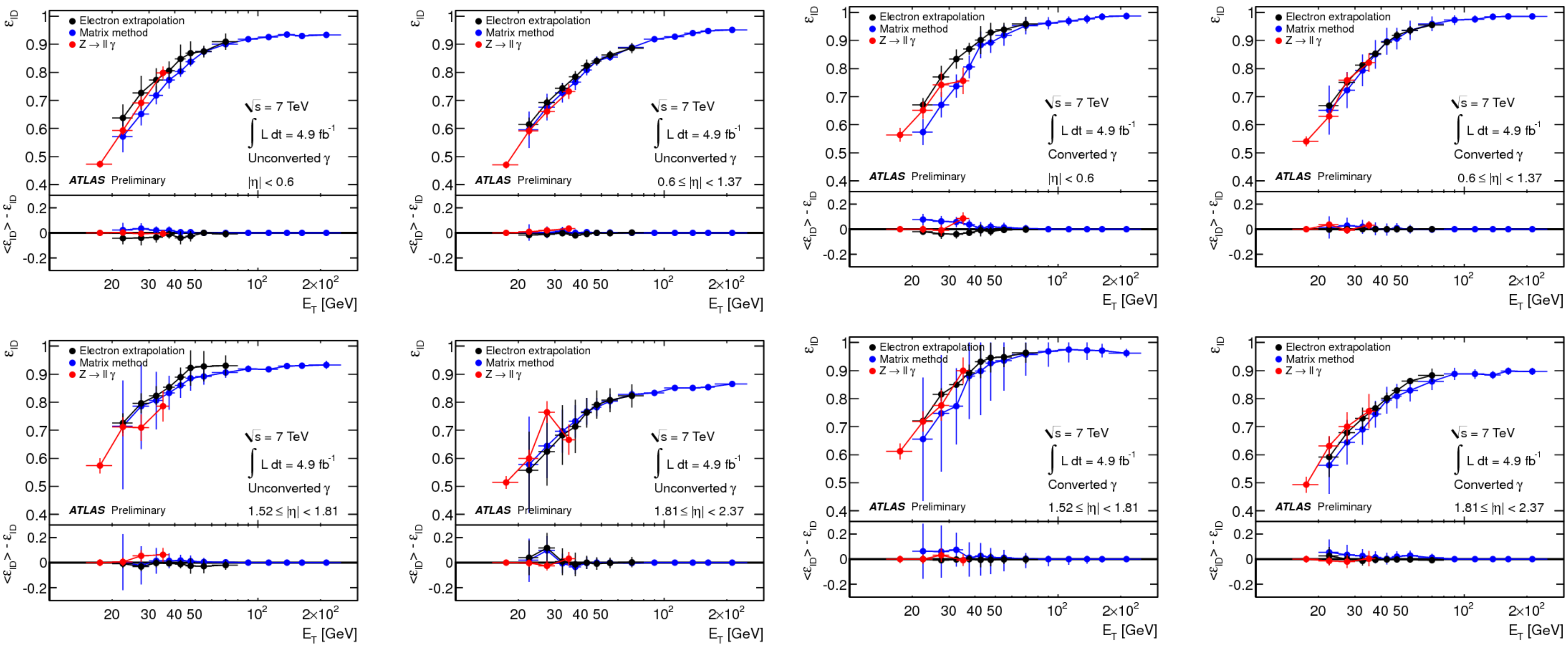


ATLAS-CONF-2012-123

ATLAS identification (3)

- Efficiency measurements comparison:

unconverted converted



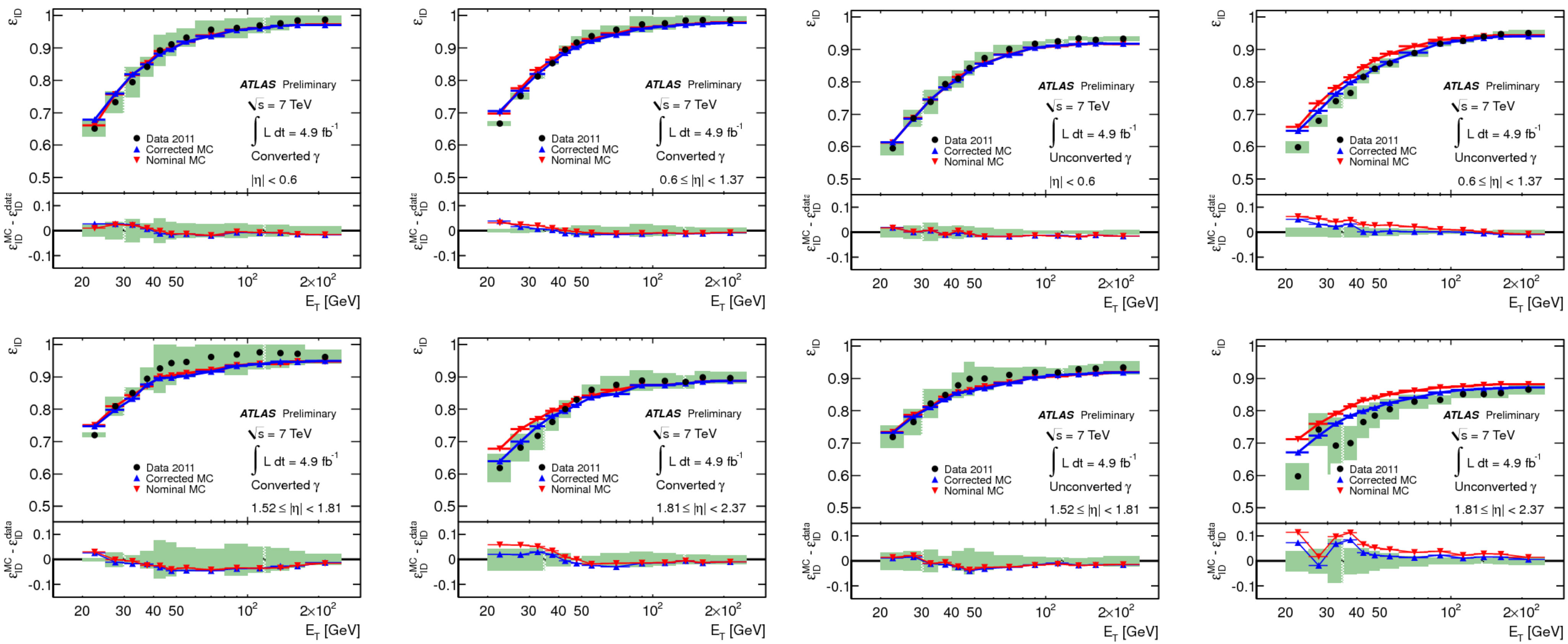
ATLAS-CONF-2012-123

ATLAS identification (4)

- data-MC comparison:

unconverted

converted

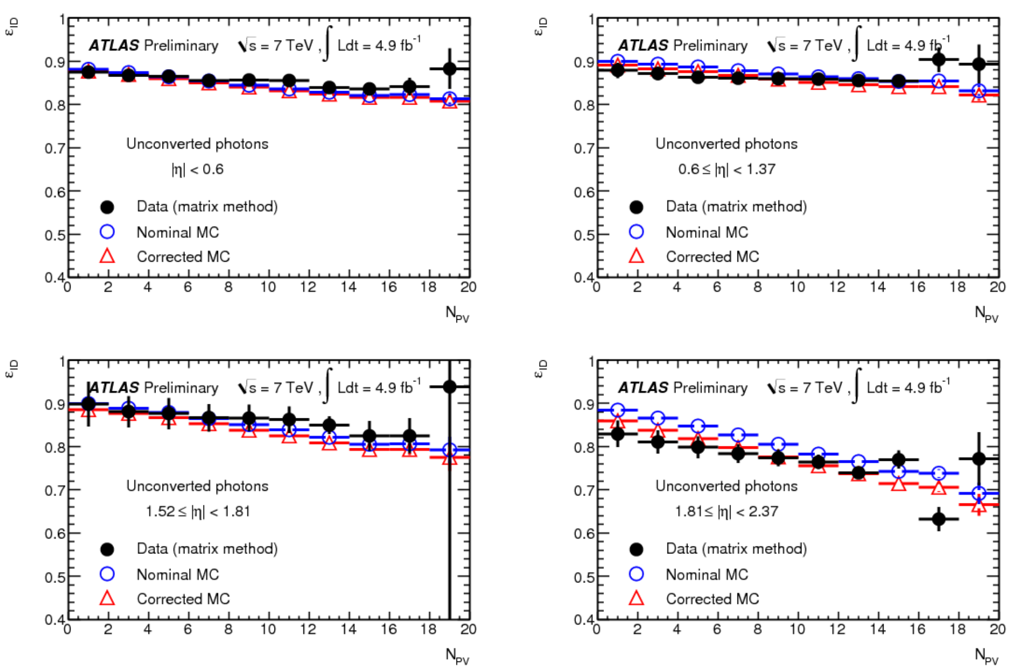


ATLAS-CONF-2012-123

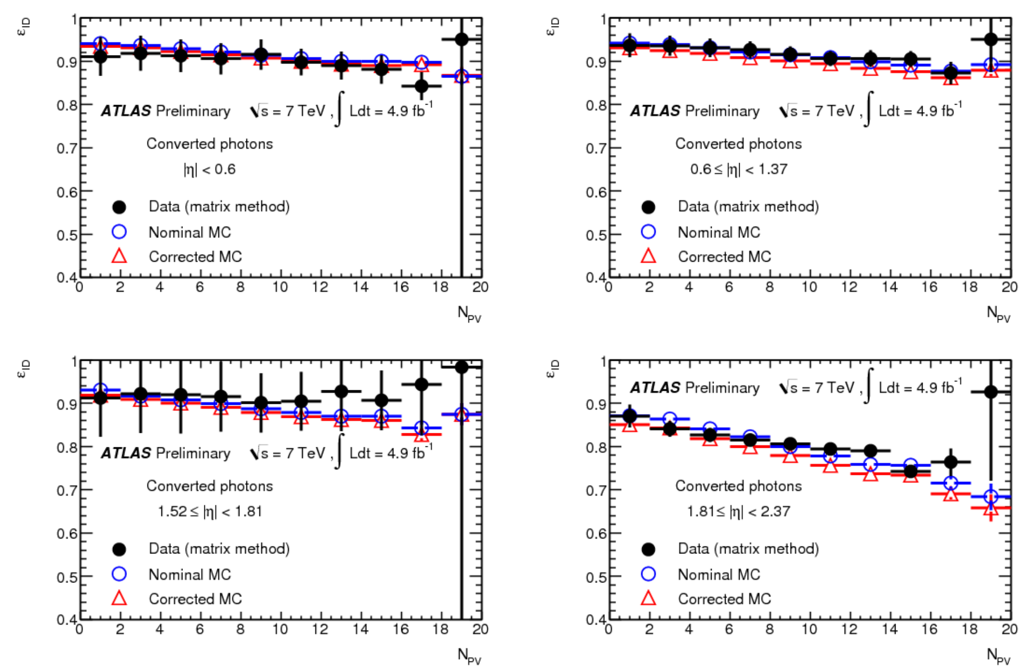
ATLAS identification (5)

- Pile-up dependence:

unconverted

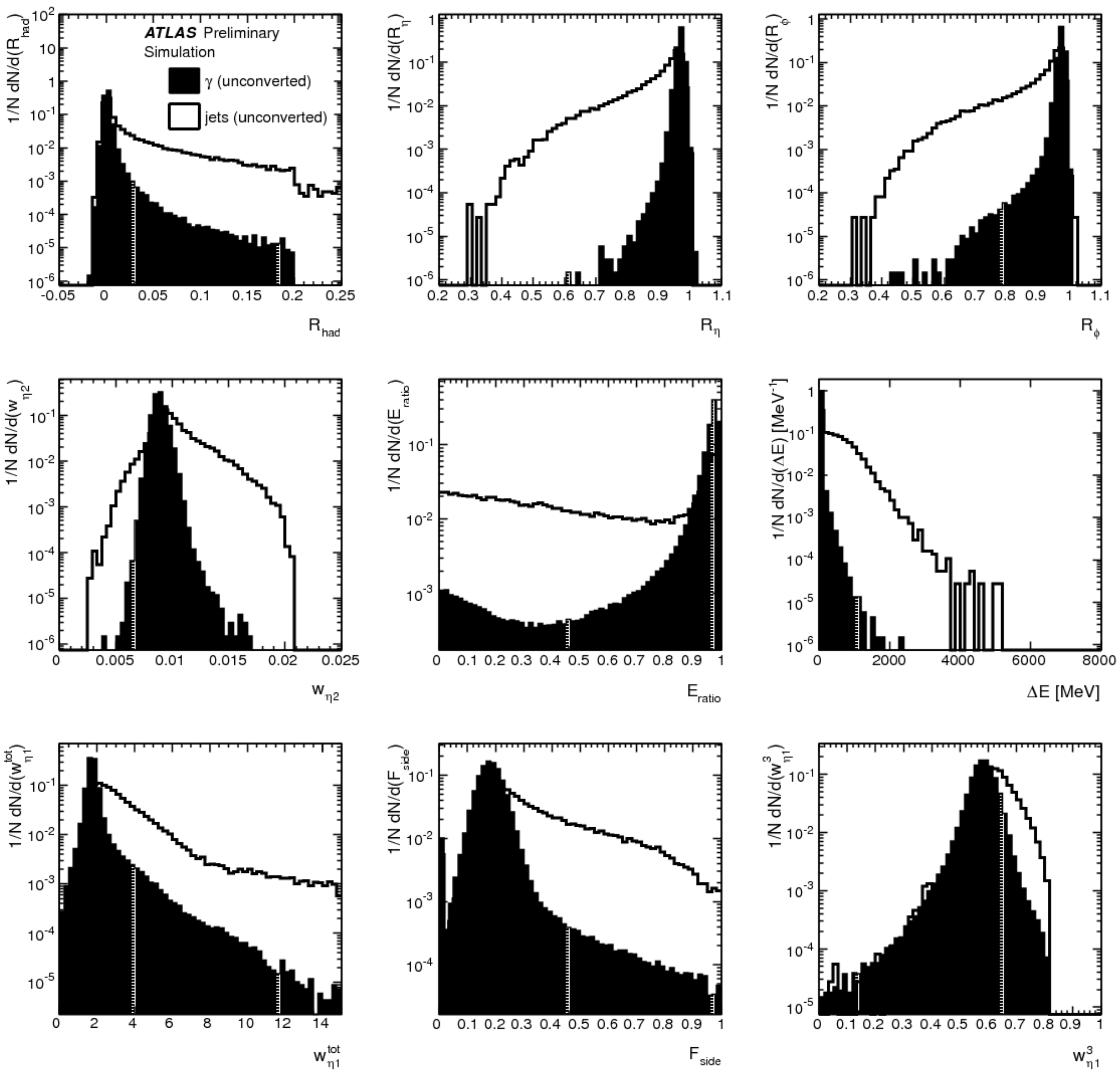


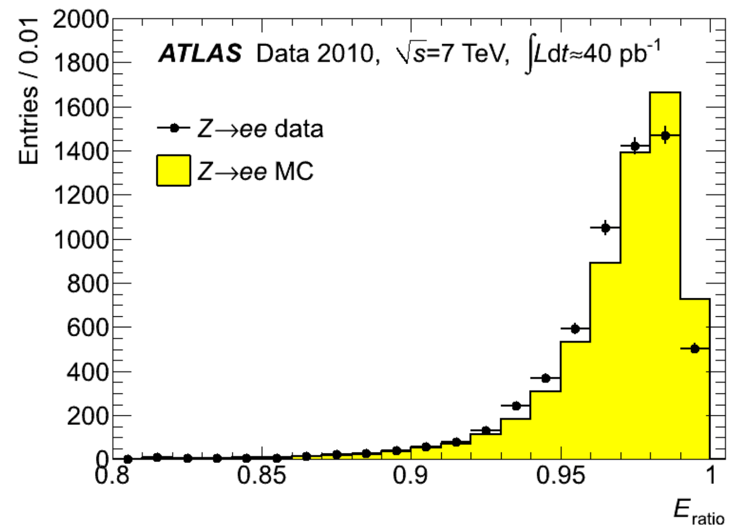
converted

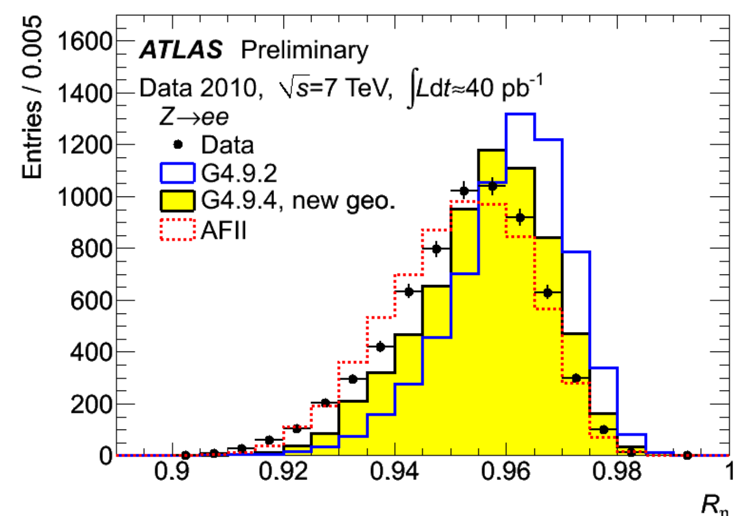


ATLAS-CONF-2012-123

Shower shapes, ATLAS







Eur. Phys. J. C 72 (2012) 1909

ATLAS-PHYS-PUB-2011-007