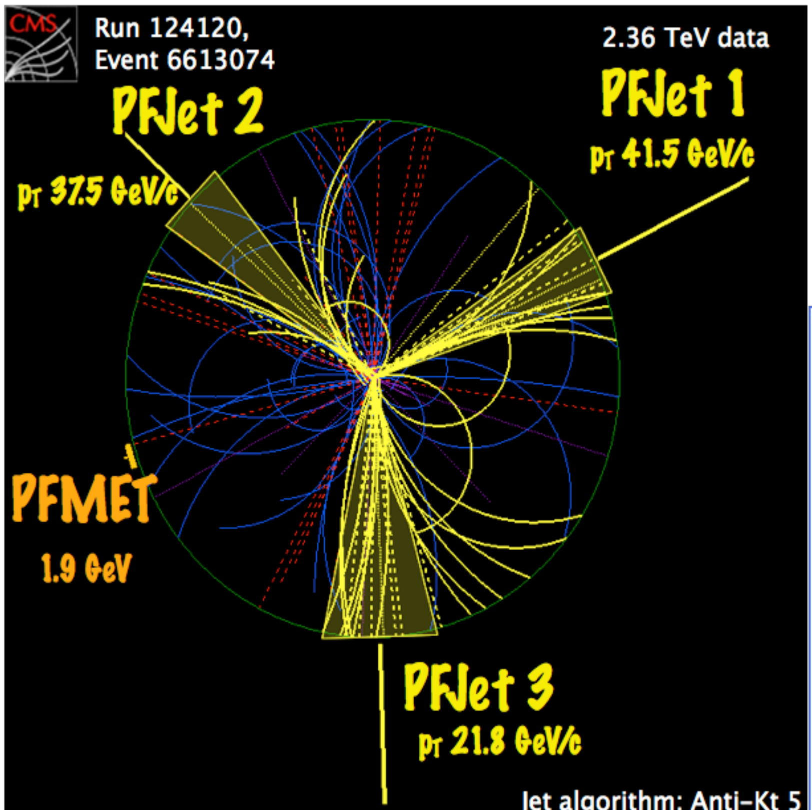
Particle Flow technique (in ALEPH, CMS,…, R&D)

Use the best system you have to measure particles in the event

Typical jet composition:
- charged hadrons (~ 60%)
- neutral hadrons (~ 10%)
- photons (~ 30%)

Cluster single particles in Jets



Multijet @ 2.36 TeV

PFJets with (uncorrected) pT > 20 GeV/c

Particle inside the jet:
- Charged hadrons
- Photons
- Neutral hadrons

Particles outside the jet:
- Charged hadrons
- Photons
- Neutral hadrons

PFMET (1.9 GeV)

CMS:
- high B
- excellent TK
- granular ECAL

Strong improvement in JET/MET resolution

Electrons and photons in CMS

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5th School on LHC Physics

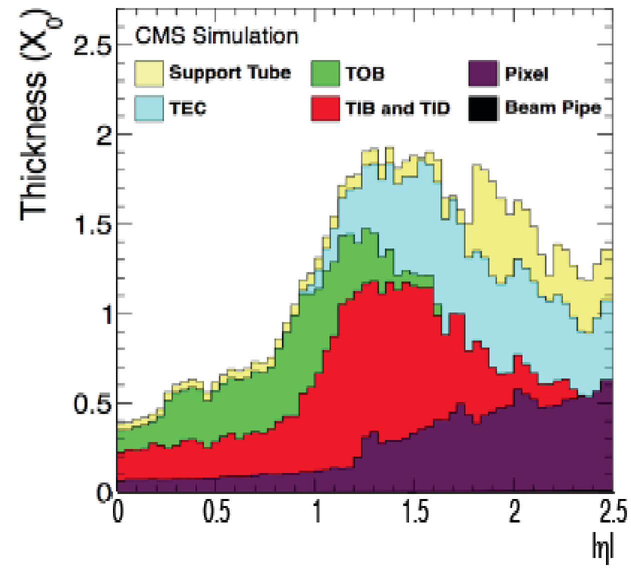
National Centre for Physics
Islamabad – August 2016

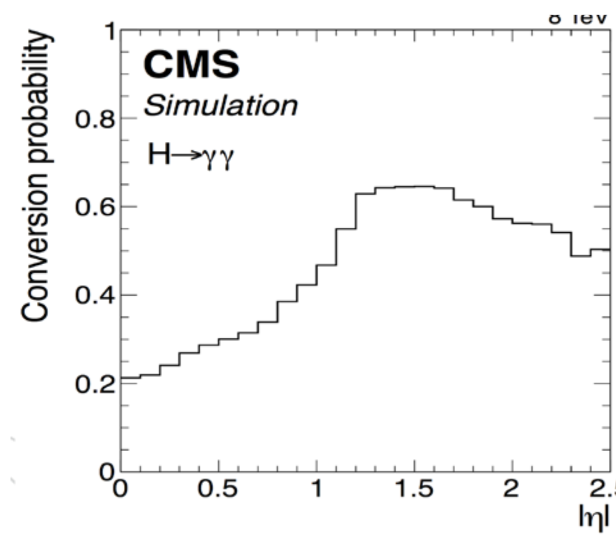
Outline

- Electron and photon reconstruction
  - ECAL super-clusters
  - GFS tracks (only electrons)
  - Energy-momentum combination (only electrons)
  - Higgs $\rightarrow\gamma\gamma$ mass resolution
- Electron and photon selection
  - MVA vs cut based identification
  - Isolation
  - Efficiency measurements with Tag & Probe

e/γ reconstruction: tracker material

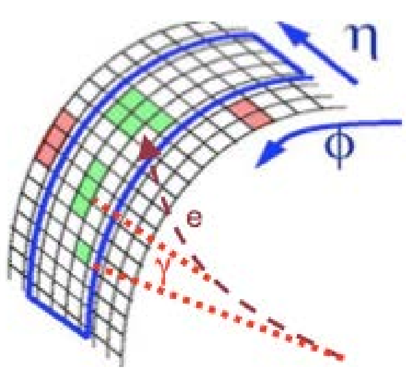
- Complex tracking system + frames + cooling + cables and services.
- Up to two radiation lengths between the interaction point and the electromagnetic calorimeter !
- Bremsstrahlung and photon conversions (fraction of the e/γ energy not reaching the calorimeter).
- At the end of the barrel, electrons radiate on average more than 50% of their energy.

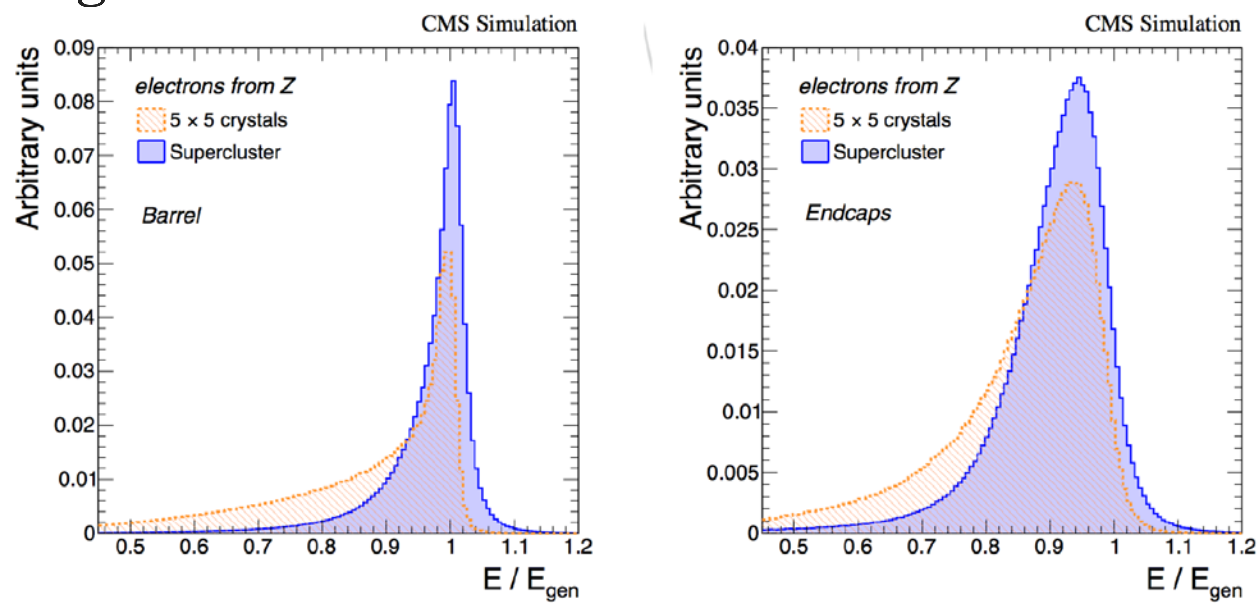




e/γ reconstruction: superclusters

- **Supercluster: dynamic clustering algorithm that works both for (un)converted photons & electrons**
  - Energy spread almost only in magnetic bending direction φ direction
  - Asymmetric search window η x φ to recover energy from bremsstrahlung or conversions





e/γ reconstruction: superclusters

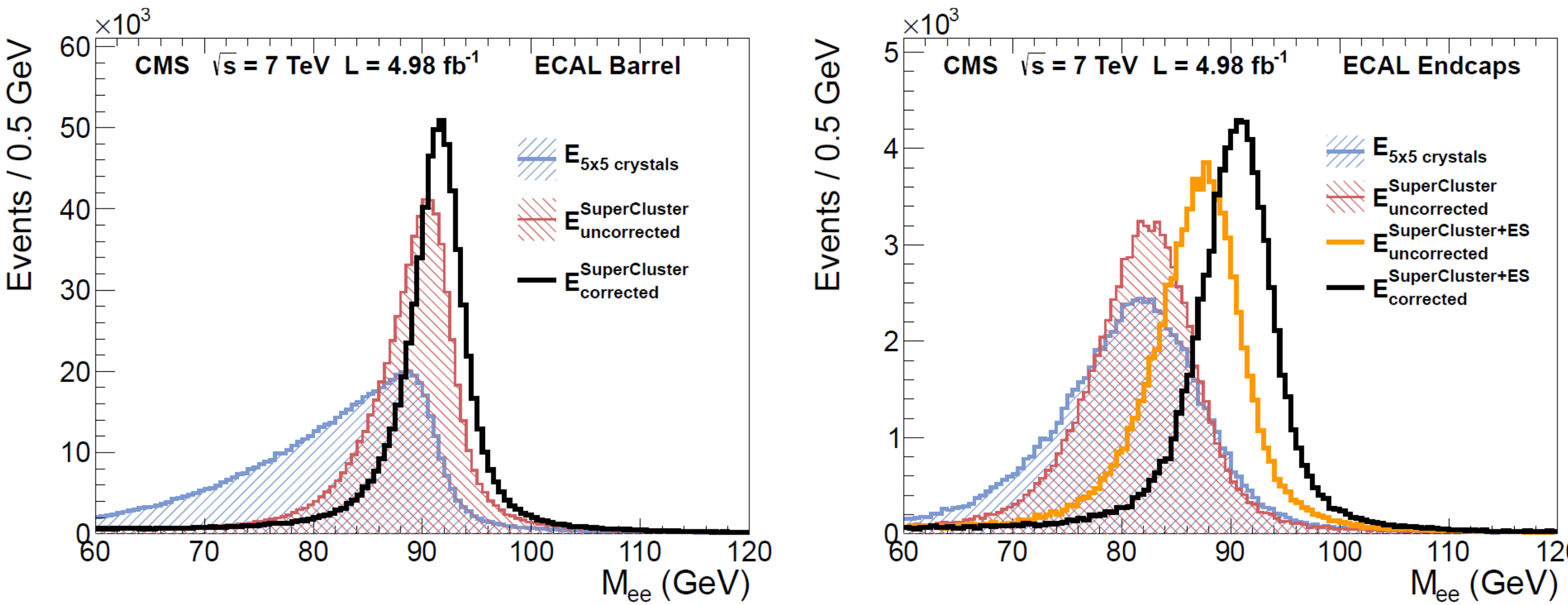
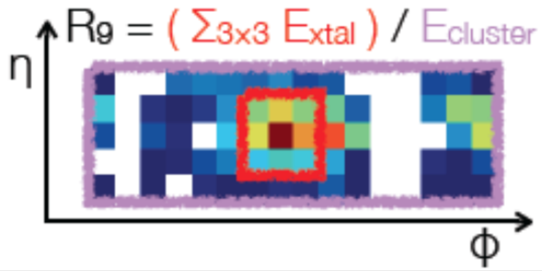


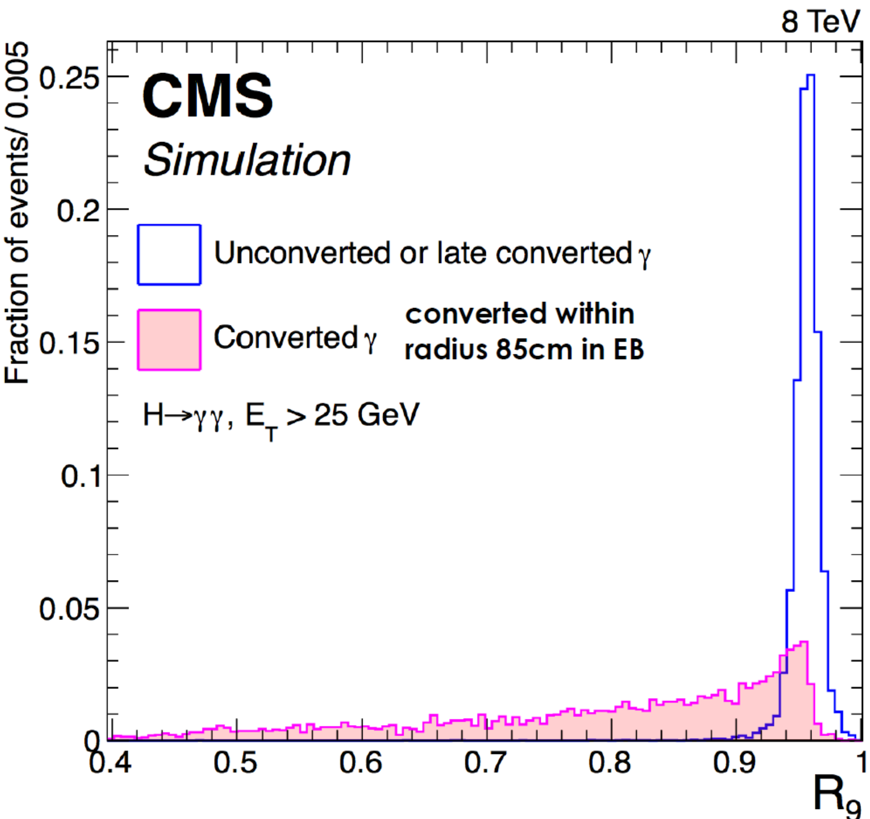
Figure 10. Reconstructed dielectron invariant mass for electrons from $Z \to e^+e^-$ events, applying a fixed-matrix clustering of 5x5 crystals, applying the supercluster reconstruction to recover radiated energy, and applying the supercluster energy corrections. For the EE the effect of adding the preshower detector energy is shown.

e/γ reconstruction: superclusters

EM objects which have irradiated can be identified already at SC level

Use R_9 shower-shape variable to discriminate:
- low / high bremsstrahlung electrons
- unconverted / converted photons

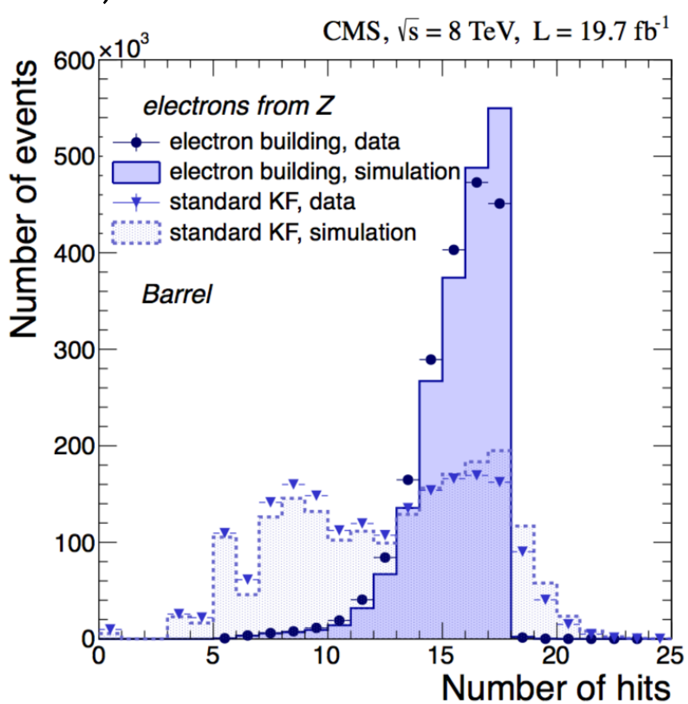


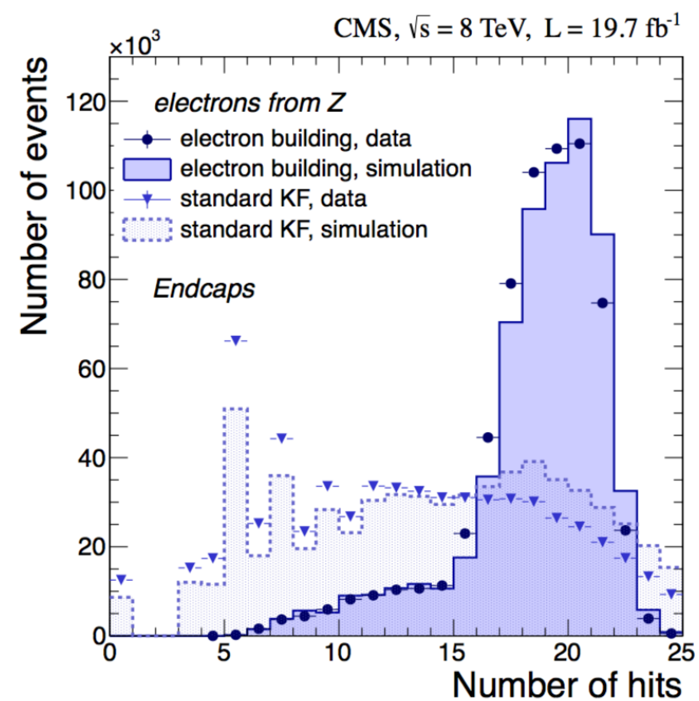


electron reconstruction: GFS tracking

Specific track algorithm for electron:

Seed algorithm: ECAL driven (pixel matching) + track driven
Building: iterative combinatorial KF with loose X^2 cuts (to build longer tracks)
Fit: model Bethe-Heitler energy loss at each layer with linear combinations gaussians (GSF).



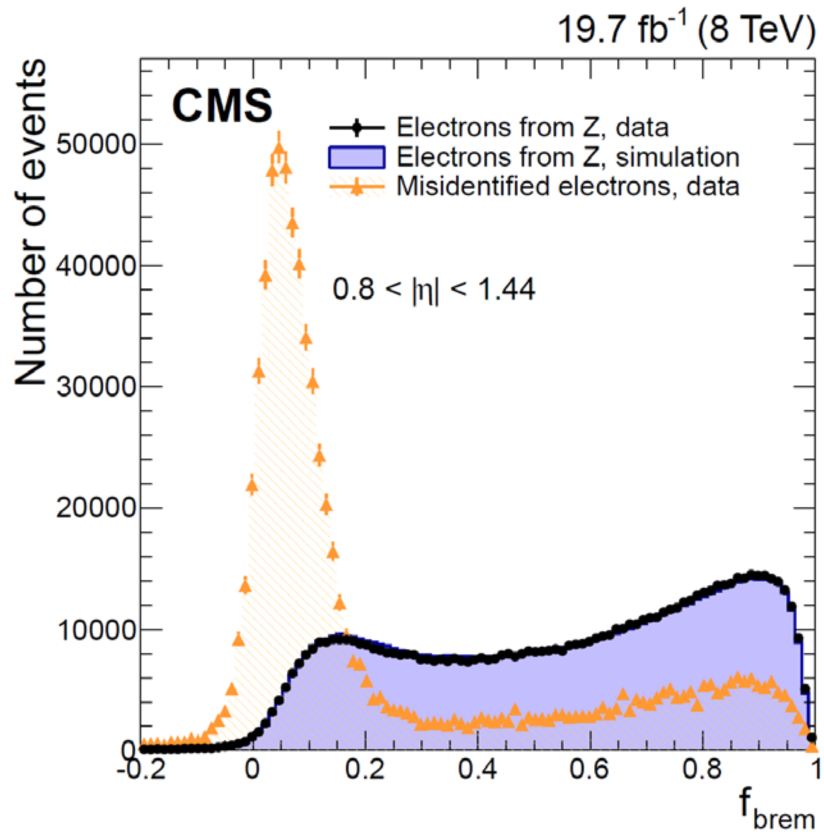


electron reconstruction: bremsstrahlung

GSF fit allows to measure bremsstrahlung fraction comparing momentum at begin/end of the track

$$f_{\mathrm{brem}} = [p_{\mathrm{in}} - p_{\mathrm{out}}]/p_{\mathrm{in}}$$

brem fraction can be used also to discriminate fake electrons (pions do not radiate)

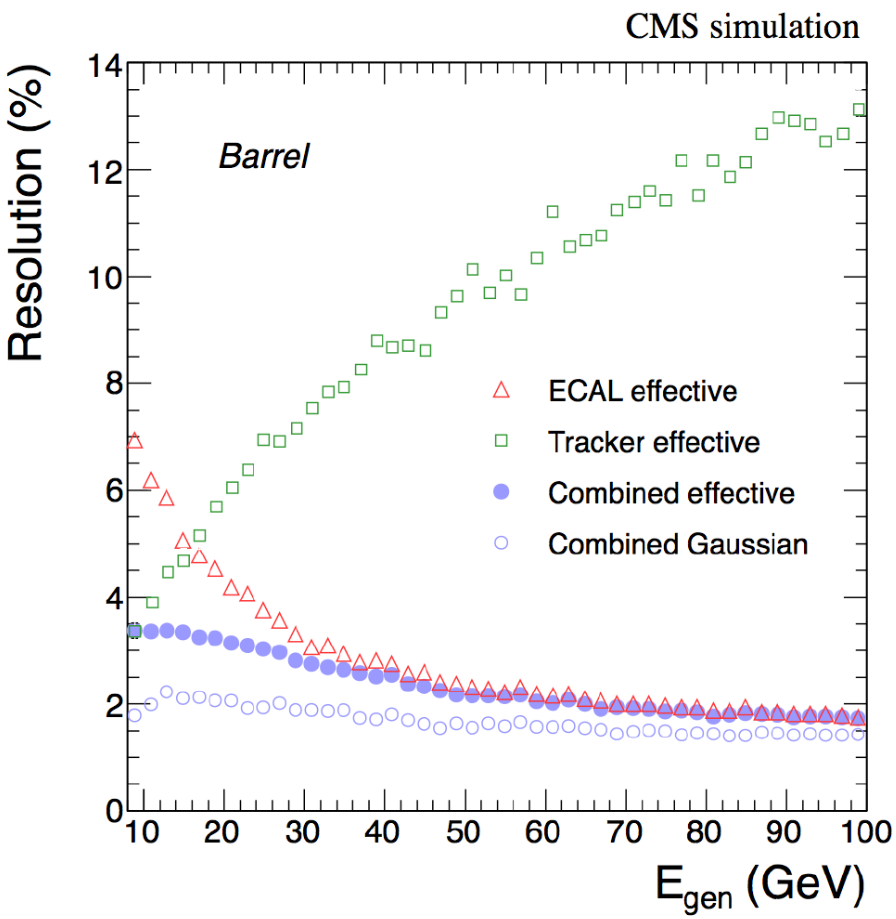


electron reconstruction: e/p combination

Electron momentum/energy measurement:

E>20 GeV ECAL dominates energy resolution

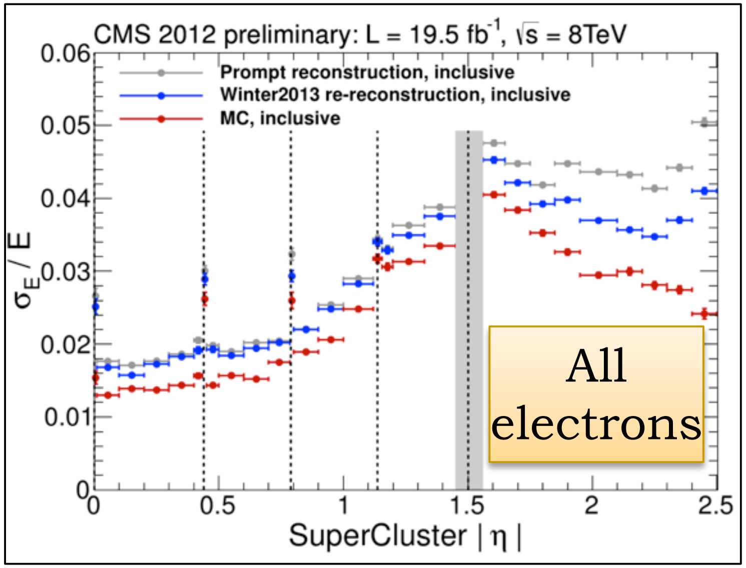
Optimal momentum estimate for electrons from combination of ECAL energy and track momentum



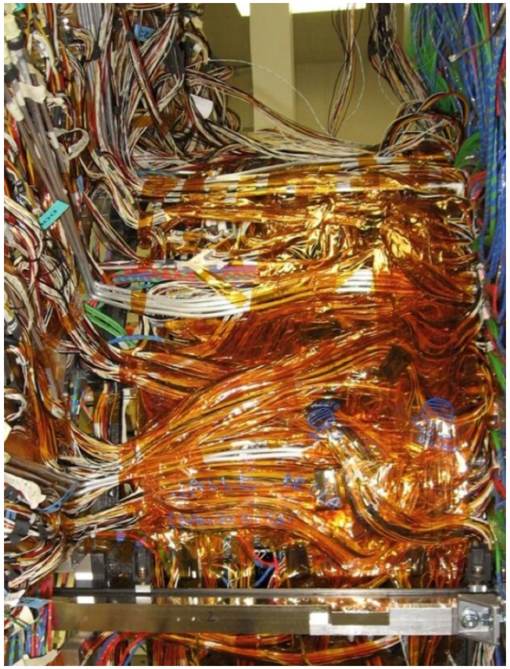
Data – MC comparison of energy resolution

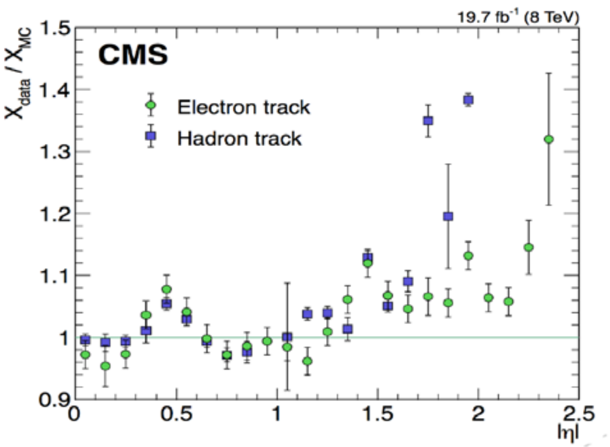
Double effort continuously ongoing to:

1. Improve the energy resolution both in Data and MC: inter-calibration precision, optimization of cluster corrections.
2. Reduce the difference between data and MC due to contributions possibly not fully simulated (laser correction stability, tuning of the material simulation, etc).



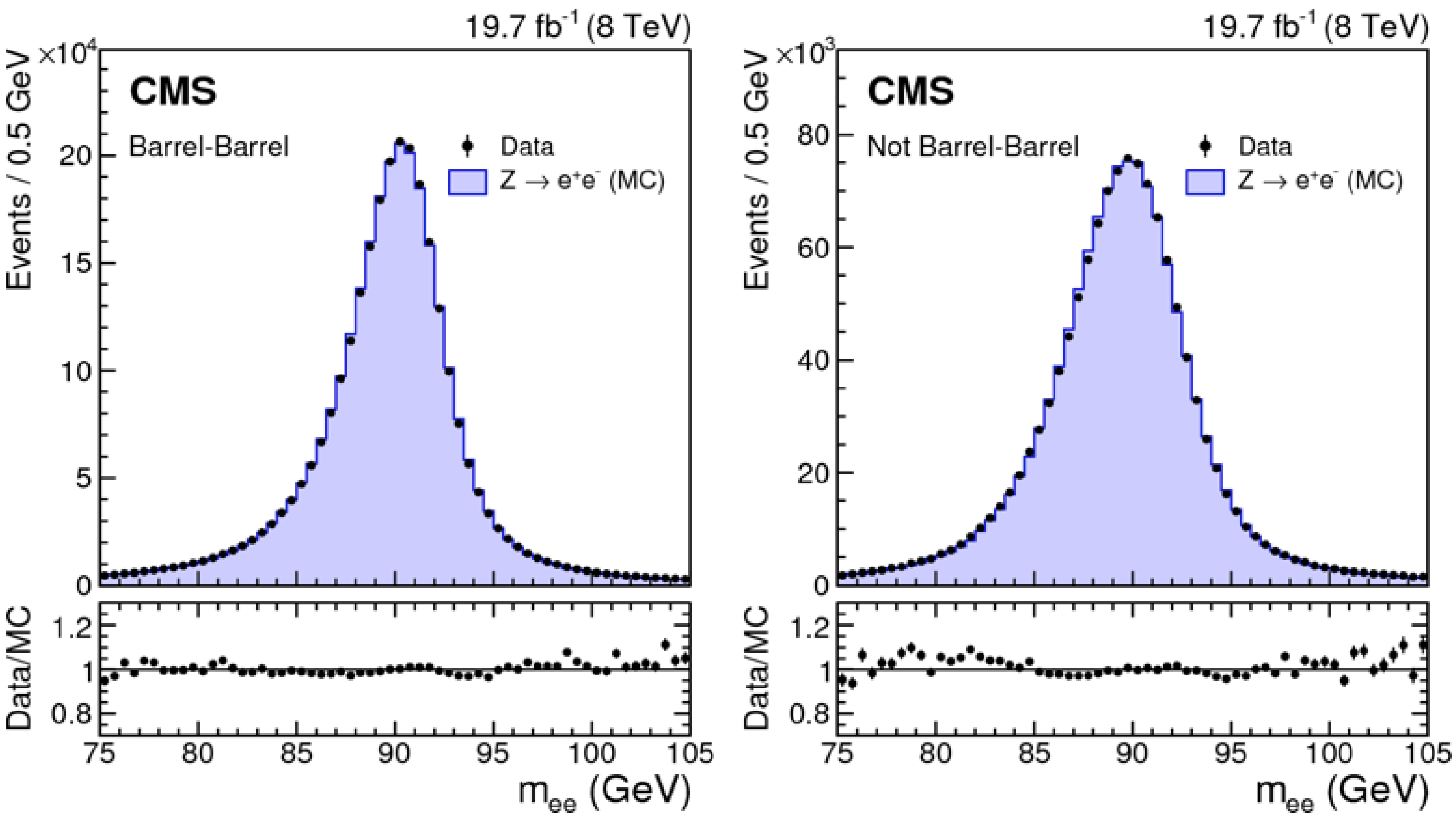
A perfect simulation of all the cables and services is a mission impossible !



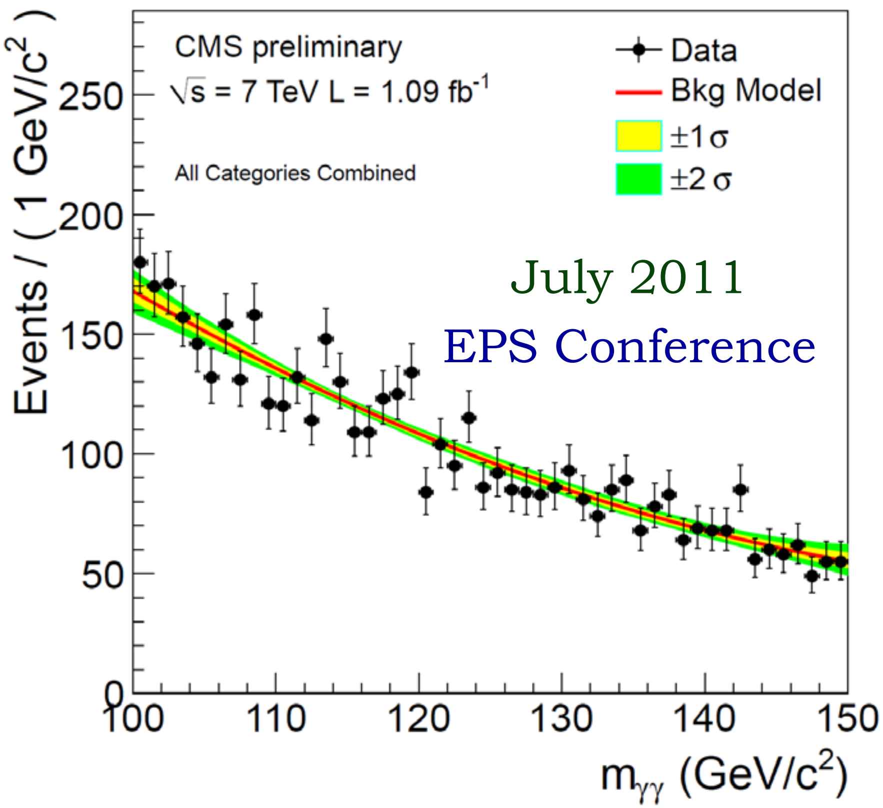


Ultimate tuning of energy resolution in simulation

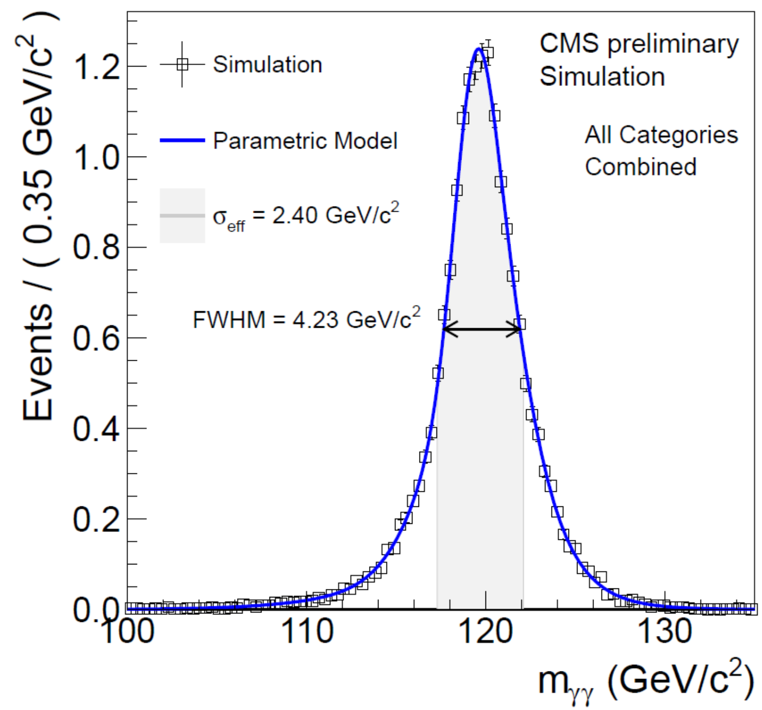
- Simulation adapted by adding an extra smearing term (as a function of pseudo-rapidity, shower shape and transverse momentum)
- After this final correction, the agreement is excellent.



Evolution of CMS H→γγ mass resolution (2011 – first data)



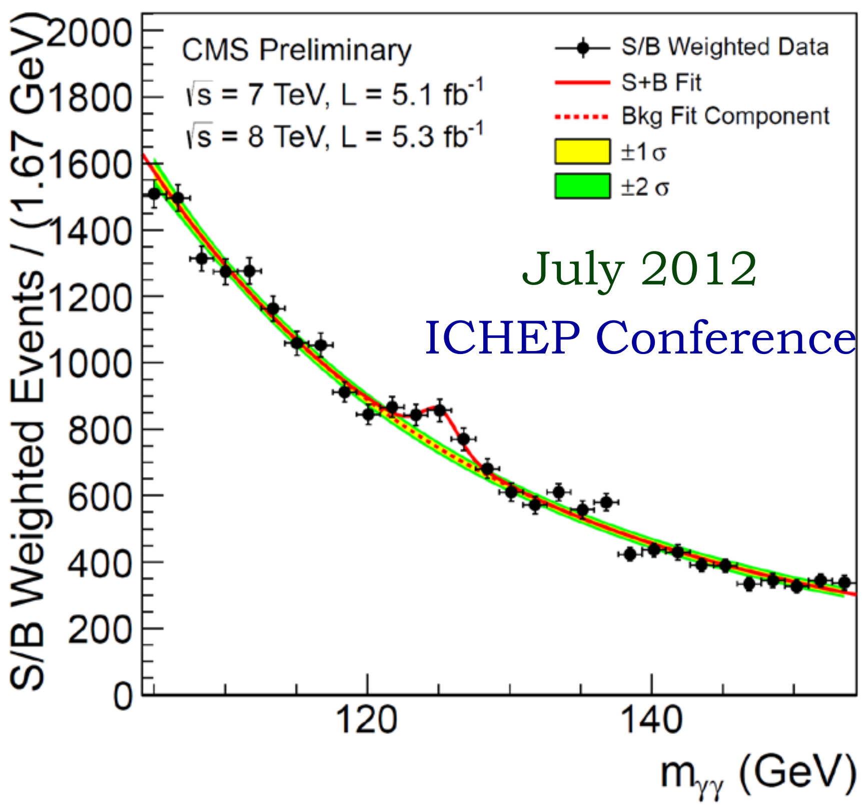
Hγγ invariant mass distribution.
Energy resolution from data.



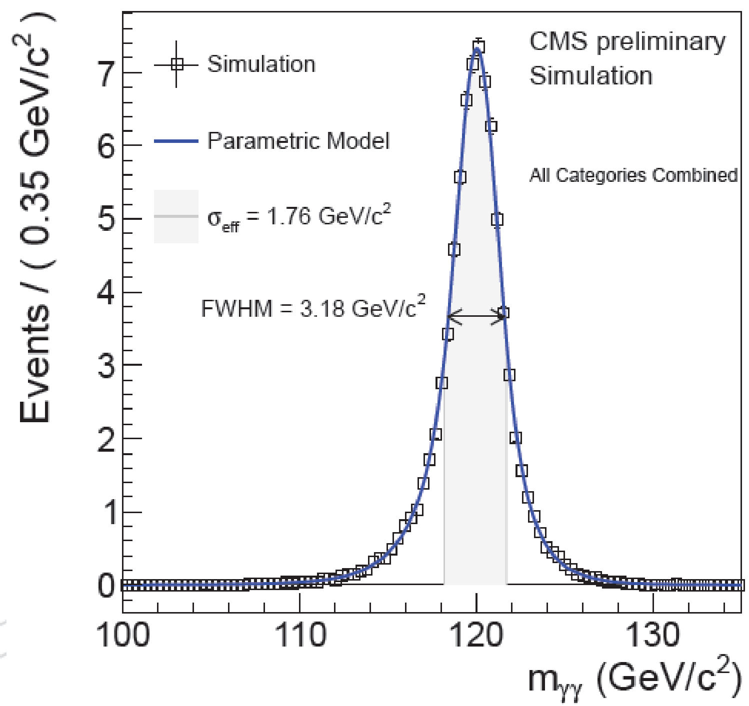
$\sigma_{eff}/M_H = 2.0\%$

$FWHM/2.35 = 1.5\%$

Evolution of CMS H→γγ mass resolution (2012 – the discovery)



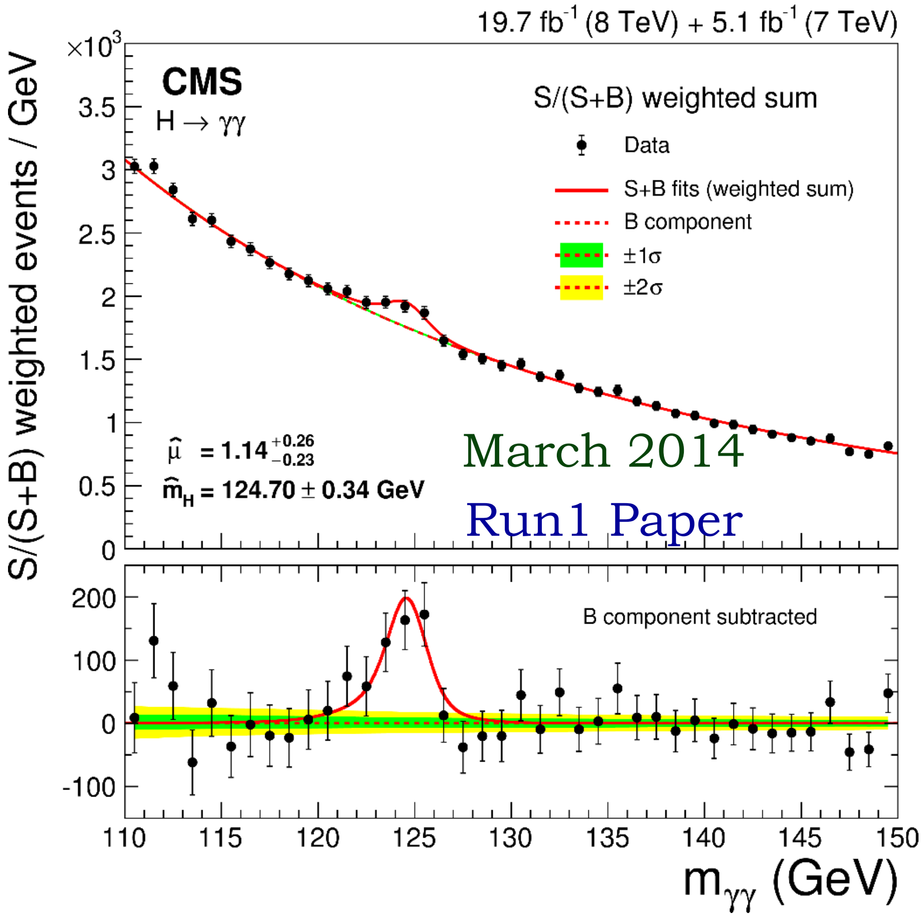
Hγγ invariant mass distribution.
Energy resolution from data.



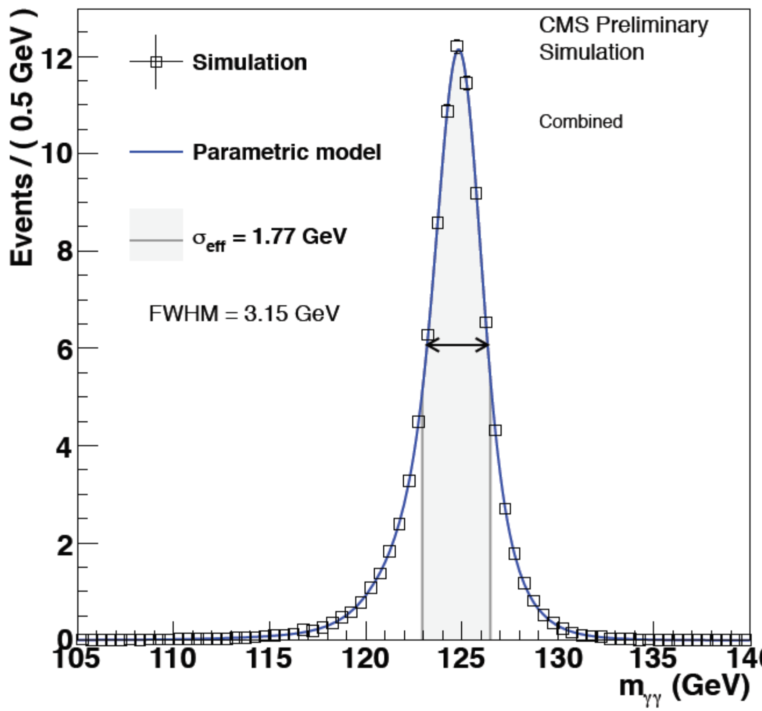
σ_{eff}/M_H = 1.47% (was 2.0%)

FWHM/2.35 = 1.13% (was 1.5%)

Evolution of CMS H→γγ mass resolution (full Run1 statistics)



Hγγ invariant mass distribution.
Energy resolution from data.



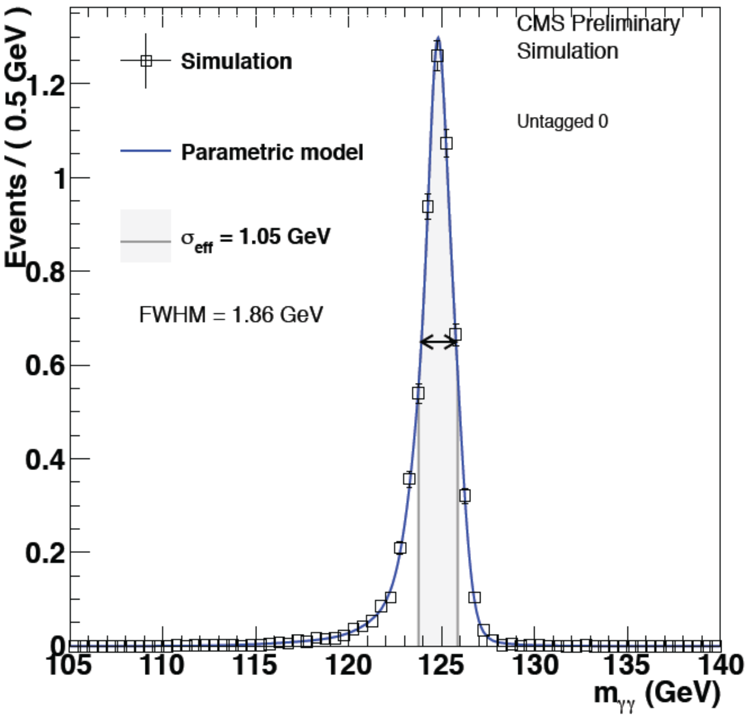
σ_{eff}/M_H = 1.42% (was 2.0%)

FWHM/2.35 = 1.07% (was 1.5%)

Evolution of CMS H→γγ mass resolution (full Run1 statistics)

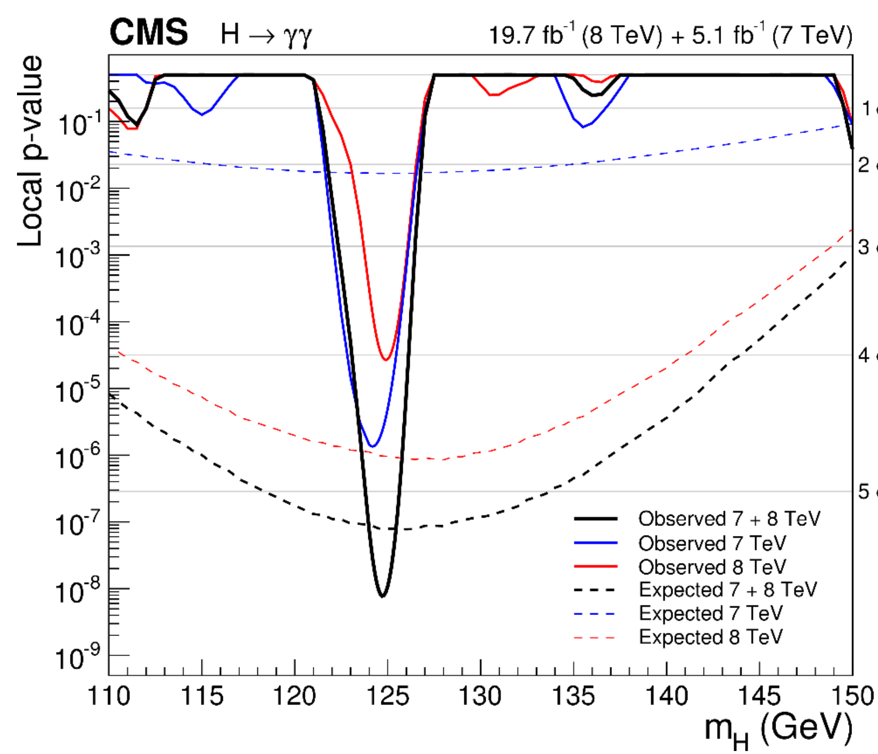
March 2014 - Run1 Paper

Best H→γγ category



σ_{eff}/M_H = 0.84%
FWHM/2.35 = 0.63%

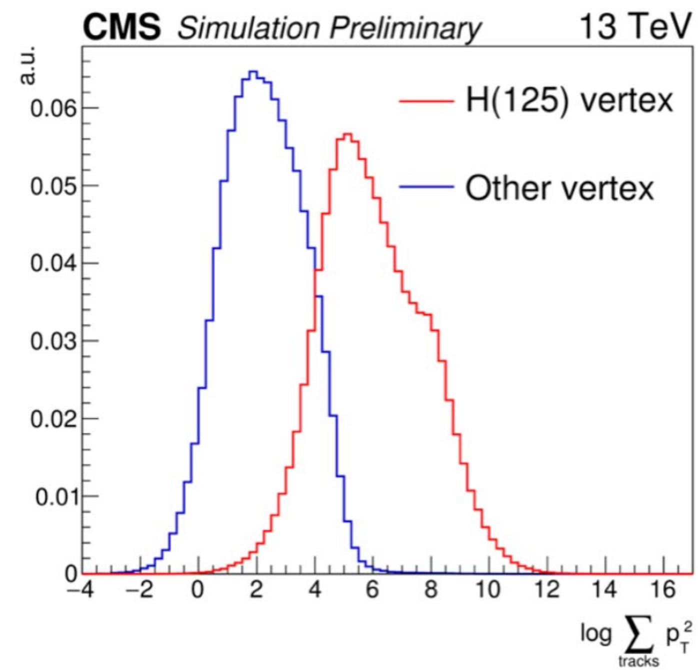
- Observation in the γγ decay channel alone
- 5.7 σ significance with Run1 data

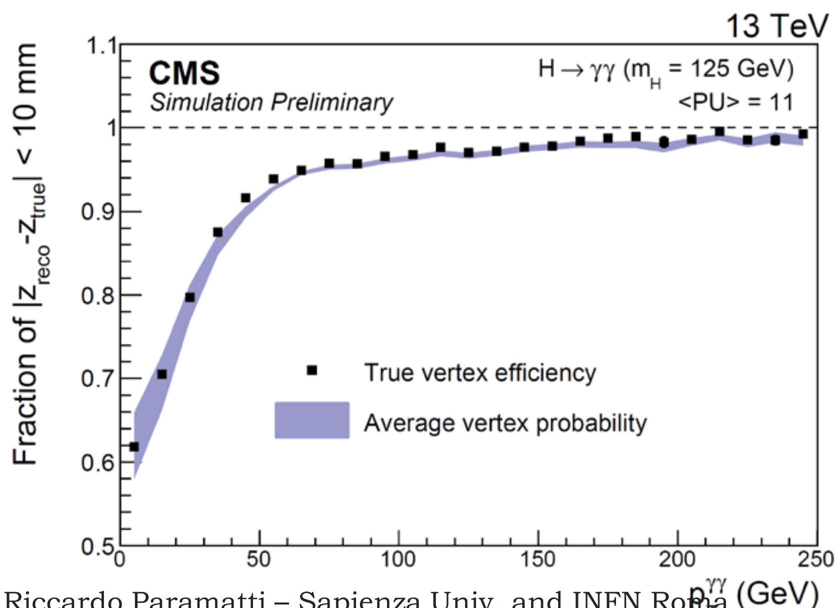


Diphoton vertex identification

- Spread of primary vertex position is ~ 5 cm in z
- If vertex is located within 1 cm, contribution to the mass resolution from angle negligible
- The vertex is selected using recoiling tracks (and reconstructed conversion when present)
- Multivariate approach for optimal performance

Σp_T^2, $p_T(\gamma\gamma)$ vs $p_T(\text{tracks})$, z_{conv}





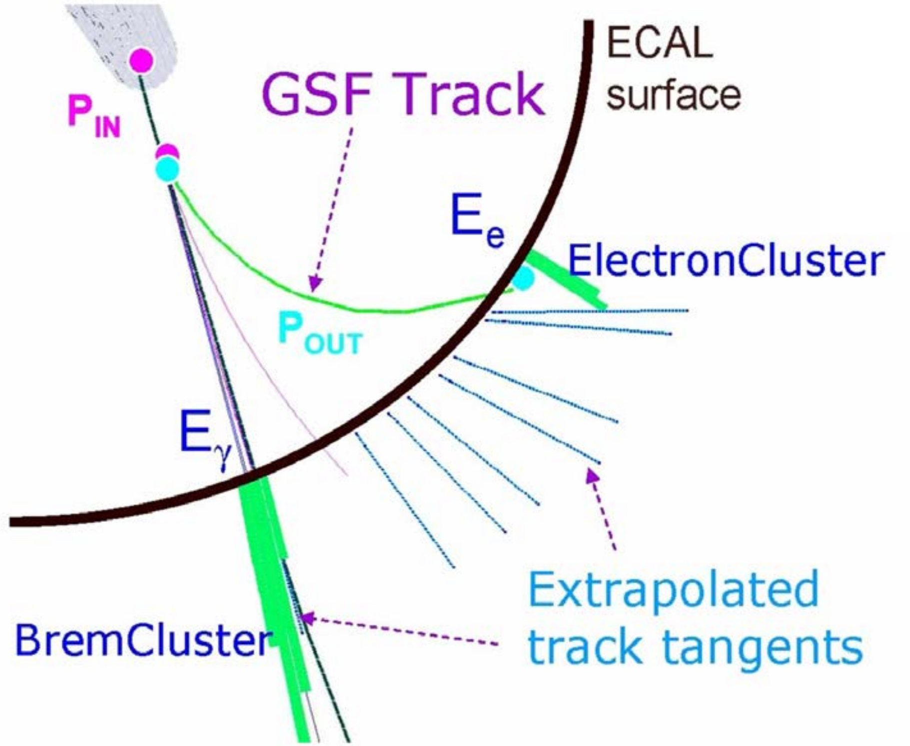
- Probability to assign the correct vertex depends on the pT(γγ).
- Average probability is ~ **90%**.
- Performance validated in data with Z→μμ events

Electron and photon selection

Identification

- Electrons: aim to select prompt isolated electrons. Rejection of fakes from jets.
  - misidentified pions (also $\pi_0 \rightarrow \gamma\gamma$ with early conversion)
  - non-isolated electrons (e.g. from b decays)
- Photons: selection of prompt isolated photons. Rejection of fakes from jets.
  - mostly fakes come from π_0, $\eta \rightarrow \gamma\gamma$

Electron identification

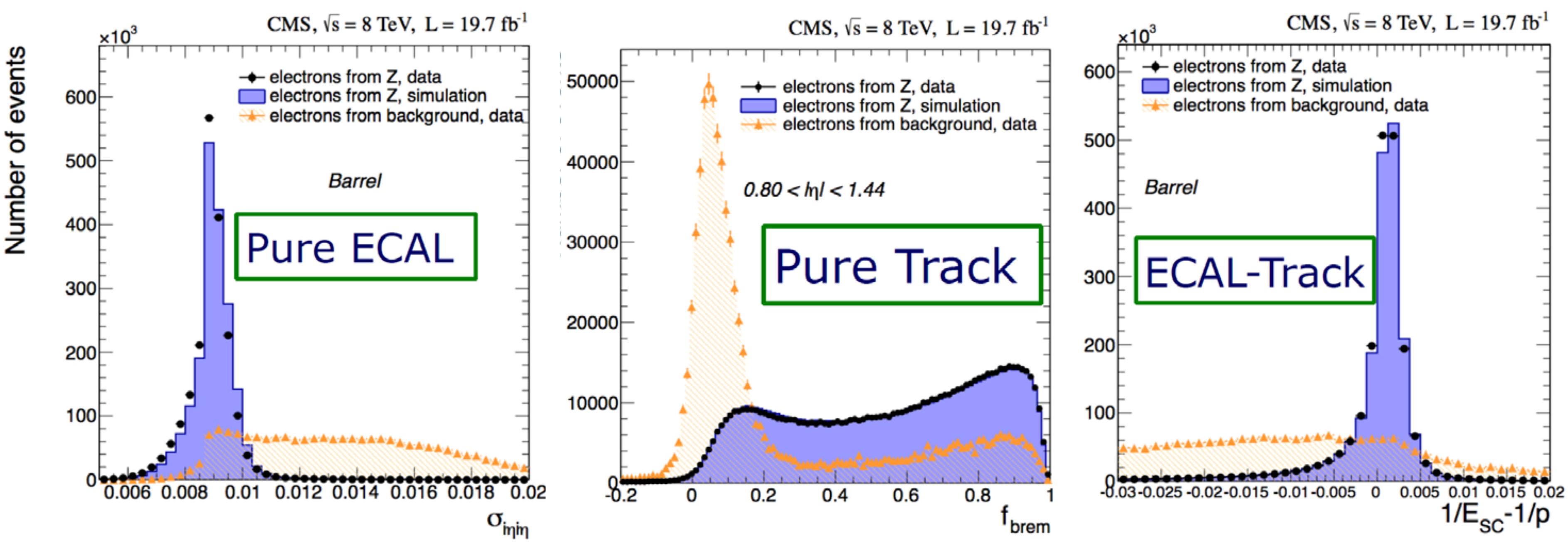


Combining several variables is the typical optimization to be performed with a multivariate analysis (MVA).

- Pure tracking observables
  1. P_{IN}-P_{OUT}/P_{IN} (GSF) = fbrem
  2. # hits KF
  3. χ^2 KF & GSF
- Pure ECAL observables
  1. Cluster shape in η direction $\sigma_{i\eta i\eta}$
  2. Cluster shape in ϕ direction $\sigma_{i\phi i\phi}$
  3. Cluster shape for circularity $(E_{5x5}-E_{5x1})/E_{5x5}$
  4. Cluster width in η
  5. Cluster width in ϕ
  6. R9
- Track-ECAL-HCAL-ES matching observables
  1. E_{Tot}/ P_{IN}
  2. E_{Ele}/ P_{OUT}
  3. $\Delta\eta_{OUT}$ (GsfTrackAtECAL-EleClus)
  4. $\Delta\eta_{IN}$ (GsfTrackAtVertex-Superclus)
  5. $\Delta\phi_{IN}$ (GsfTrackAtVertex-Superclus)
  6. H/E
  7. ES/E(Raw)
  8. 1/E – 1/p (p combination of gsfmean
- Isolation

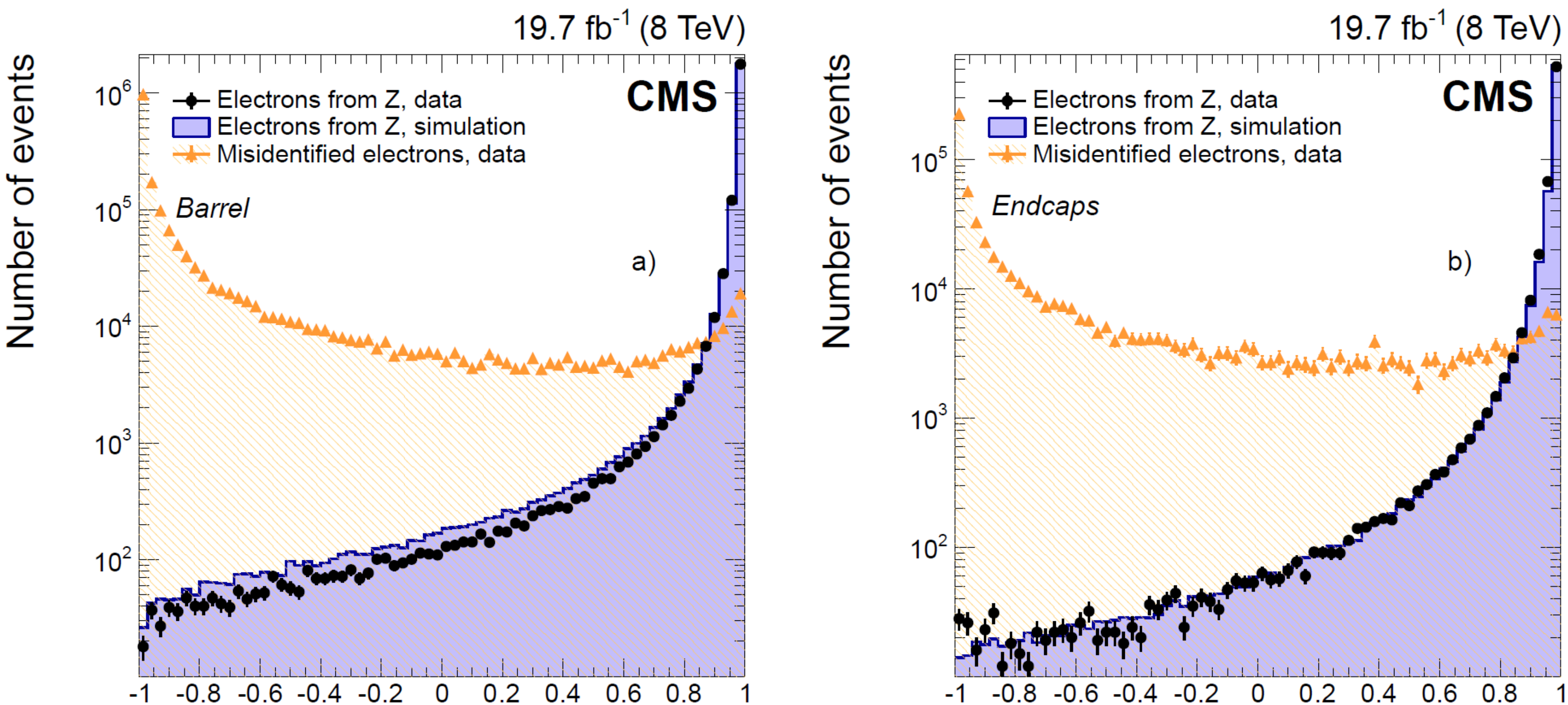
Electron identification

Excellent data/MC agreement of MVA input variable is needed.



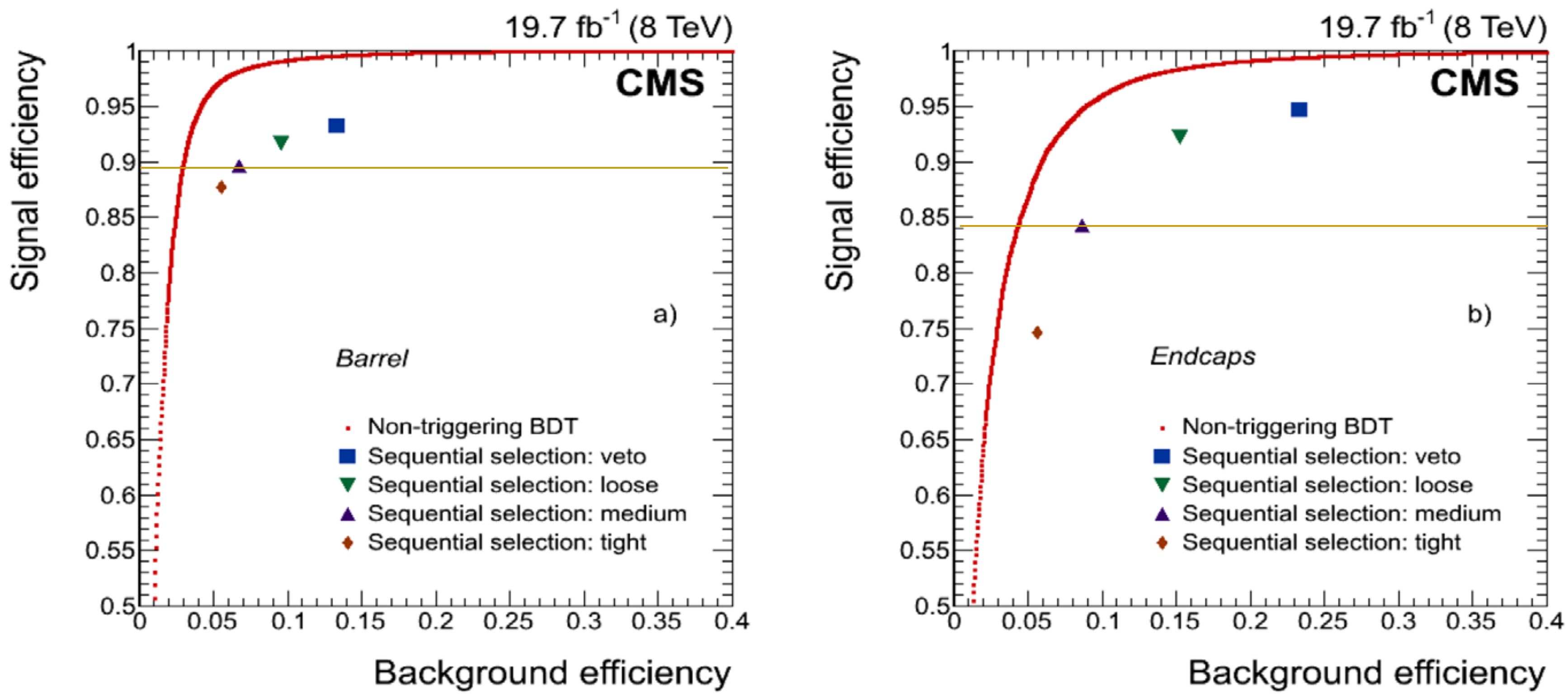
Electron identification

- Output of the electron-identification BDT for Z electrons in data and simulation.



Electron identification

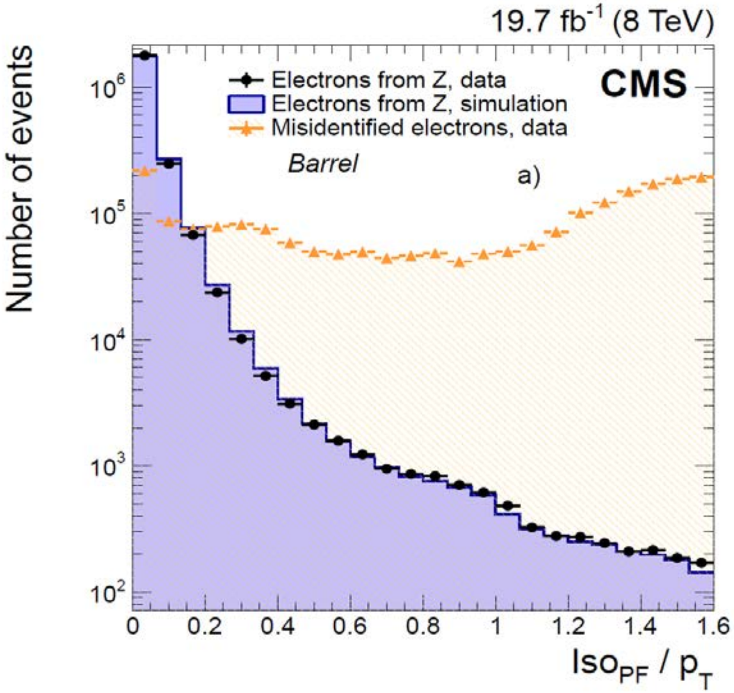
MVA brings about x2 background rejection for the same signal efficiency

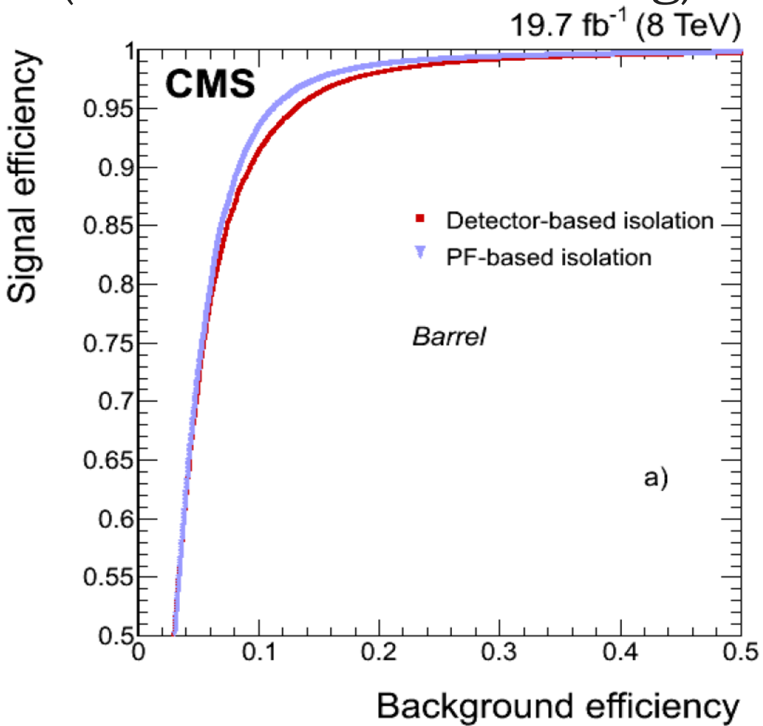


Electron isolation

Isolation powerful to reject electrons (or fakes) inside jets.

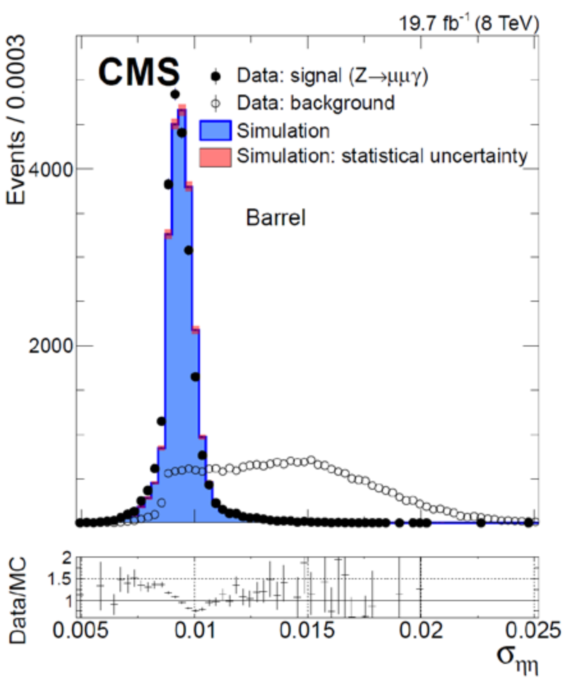
- Isolation defined as the sum of the energy deposits in a cone $\Delta R=\sqrt{(\Delta\eta^2+\Delta\varphi^2)}$ around the electron. $\Delta R=0.3$ or 0.4 are typically used.
- Particle based isolation (based on Particle Flow candidates) is slightly better then detector based (avoids double counting).

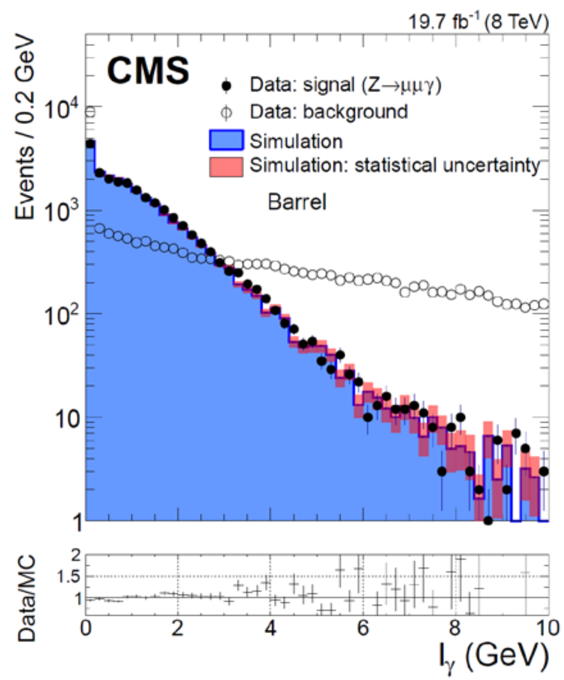


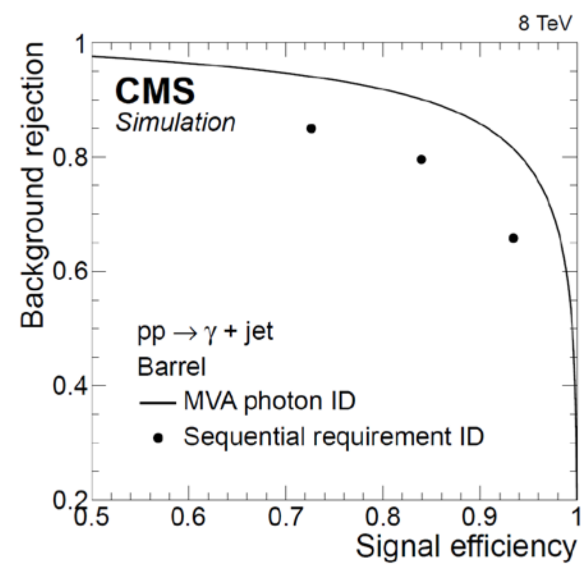


Photon identification

- Lateral shower development
  1. Cluster shape in η direction $\sigma_{i\eta i\eta}$
  2. Cluster shape in ϕ direction $\sigma_{i\phi i\phi}$
  3. Cluster shape for circularity $(E_{5x5}-E_{5x1})/E_{5x5}$
  4. Cluster width in η
  5. Cluster width in ϕ
  6. R9
- Longitudinal shower development
  1. H/E
  2. ES/E(Raw)
- Conversion safe electron veto

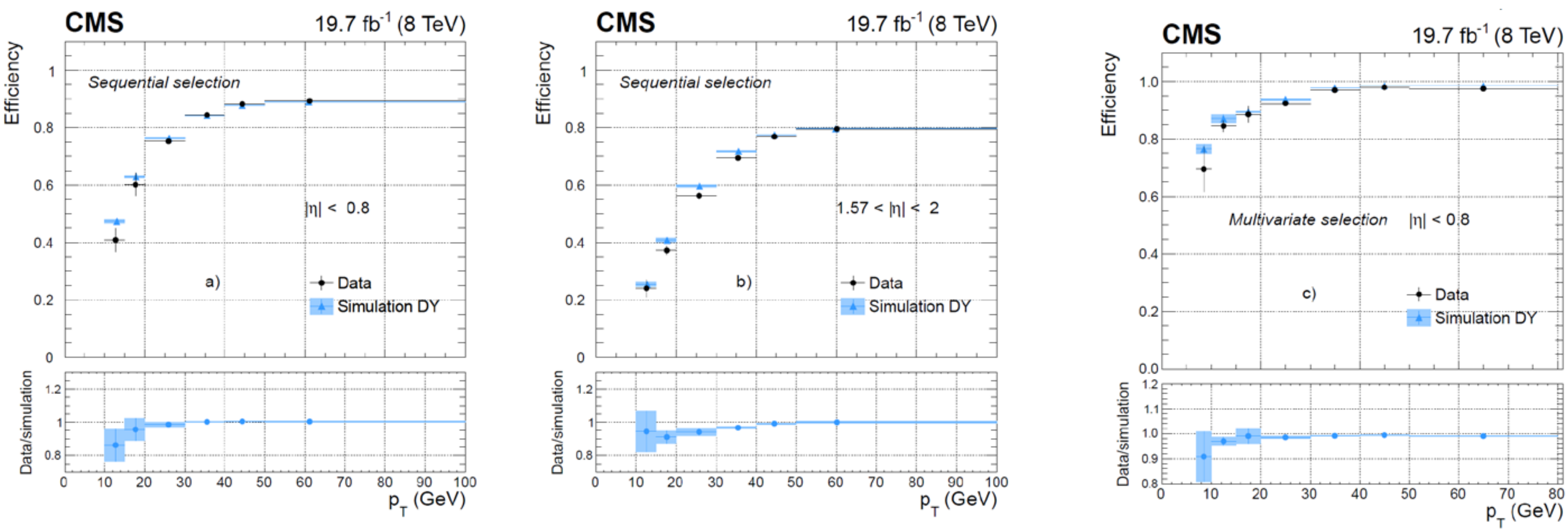






Efficiency with T&P

- A method based on the **Tag and Probe (T&P) technique** [see reference in next slide] exploits Zee events in data to estimate the reconstruction and selection efficiencies for signal electrons.
- Scale factors (Data/MC ratios) if not equal to 1 must be applied at the analysis level.



References

CMS publication web page: http://cms-results.web.cern.ch/cms-results/public-results/publications/

e/gamma CMS performance papers:

- CMS Collaboration, "*Performance of photon reconstruction and identification with the CMS detector in proton-proton collisions at √s = 8 TeV* ", JINST 10 (2015) P08010
- CMS Collaboration, "*Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at √s = 8 TeV* ", JINST 10 (2015) P06005
- CMS Collaboration, "*Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at √s = 7 TeV*", JINST 8 (2013) P09009

Reference for Tag & Probe method:

- CMS Collaboration, "*Measurements of Inclusive W and Z Cross sections in pp Collisions at√s = 7 TeV*", JHEP 01 (2011) 080