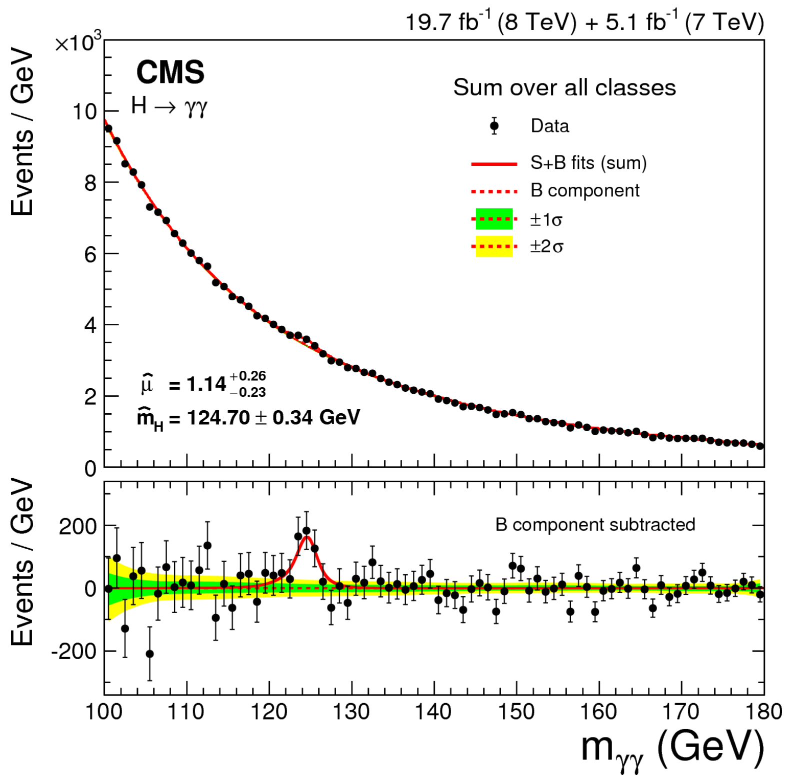
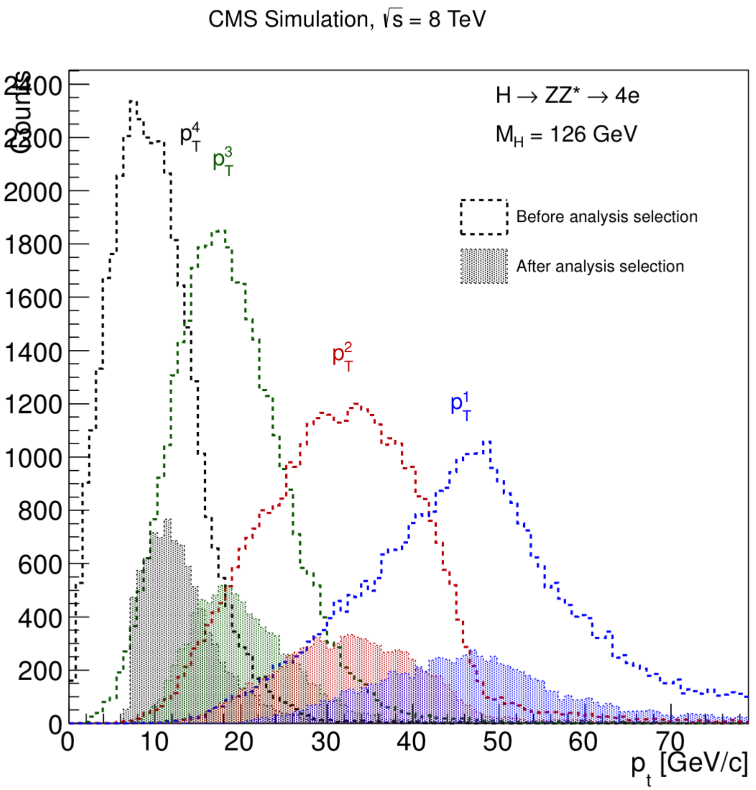
Run 1 legacy performance: electrons/photons.

The challenge:



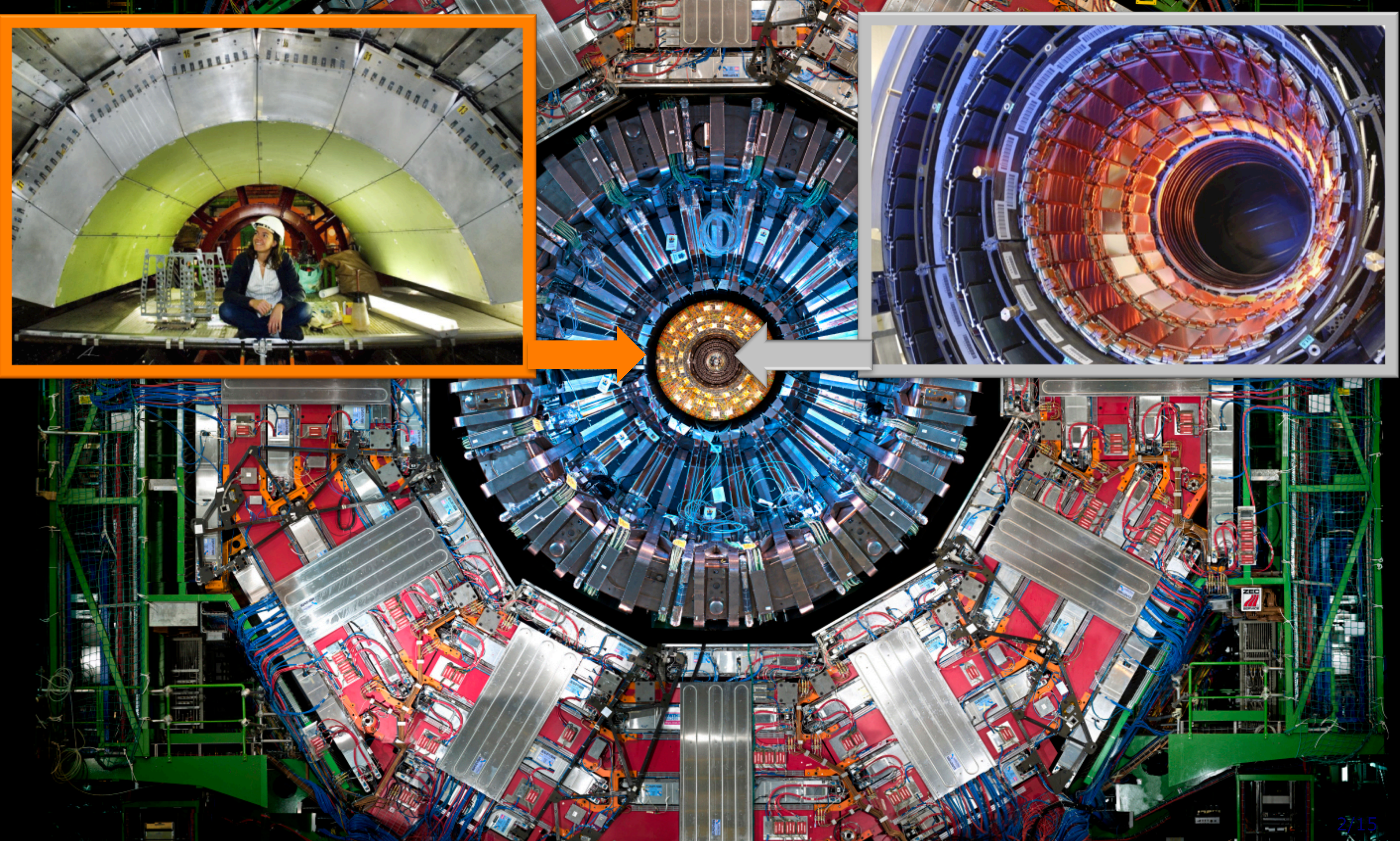


Daniele Benedetti (Purdue University)

on behalf of the CMS collaboration

The CMS detector:
the electromagnetic calorimeter

… and the tracker



The CMS detector:
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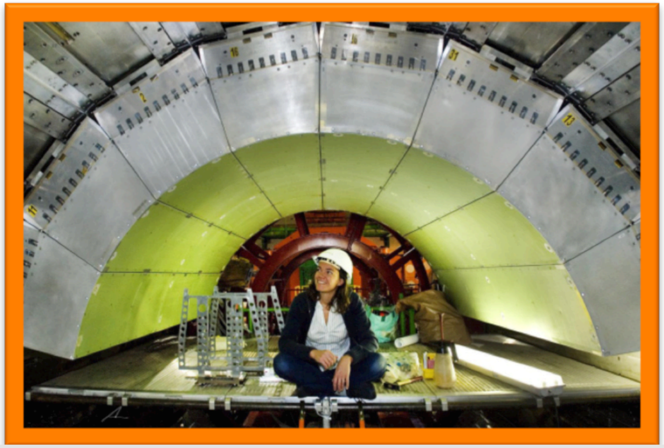
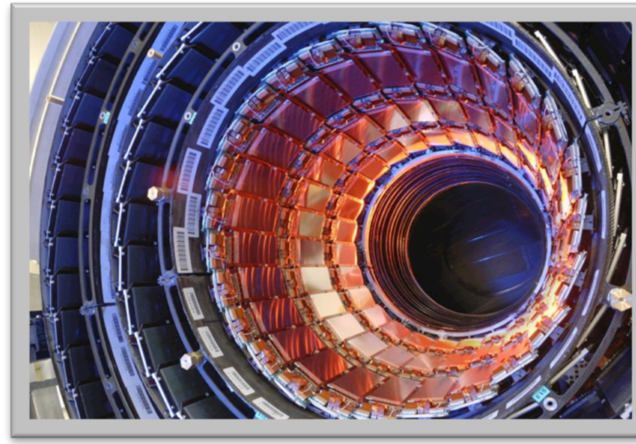




Homogeneous, hermetic, high granularity $PbWO_4$ crystal calorimeter

Density of 8.3 g/cm^3, radiation length 0.89 cm, Molière radius 2.2 cm.

Barrel: 61200 crystals in 36 super-modules, Avalanche Photo-Diode (APD) readout

Endcaps: 14648 crystals in 4-Dees, Vacuum Photo-Triode (VPT) readout + Preshower.

ECAL performance from test beam:

$$\frac{\sigma(E)}{E} = \frac{2.8\%}{\sqrt{E}} \oplus \frac{0.128}{E} \oplus 0.3\%$$

- constant term to be kept $\ll$ 1%
- stochastic term also affected by the material upstream

Pixels and Silicon Strip detectors

Pixels: (100x150μm^2) ~1 m^2 for 66M of channels

Si Strips: (80-180μm^2) ~200m^2 for ~ 9.6M of channels

Electron track reconstruction efficiency > 98% in the barrel for p_T > 10 GeV.

Electron track resolution ~4% in the barrel for p_T ~ 10 GeV.

ECAL calibration

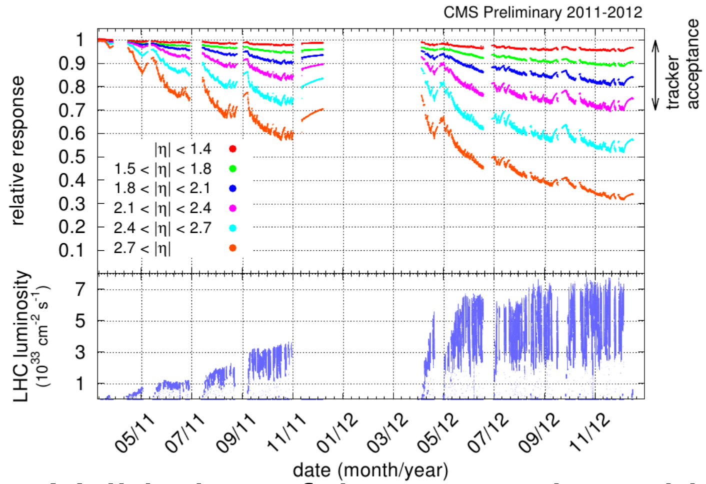
75848 crystals to calibrate in situ during operations.

Light yield variations:

crystal transparency → radiation dose-rate dependence

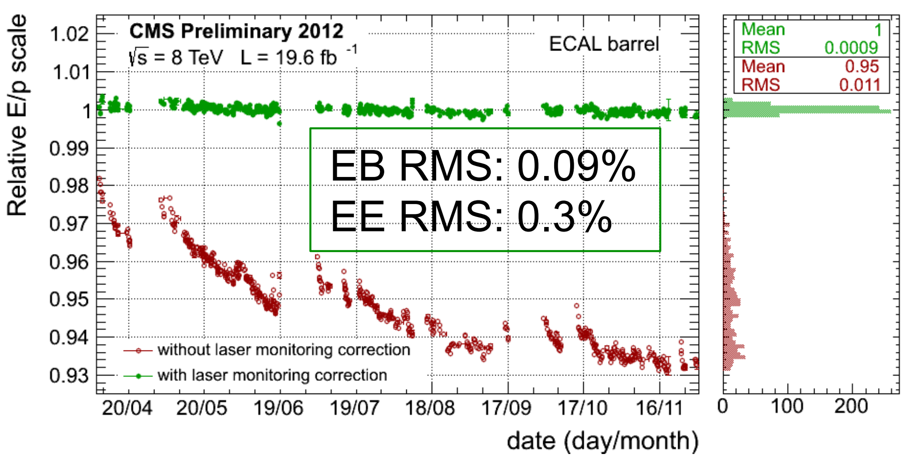
Electronics stability:

temperature and voltage dependence



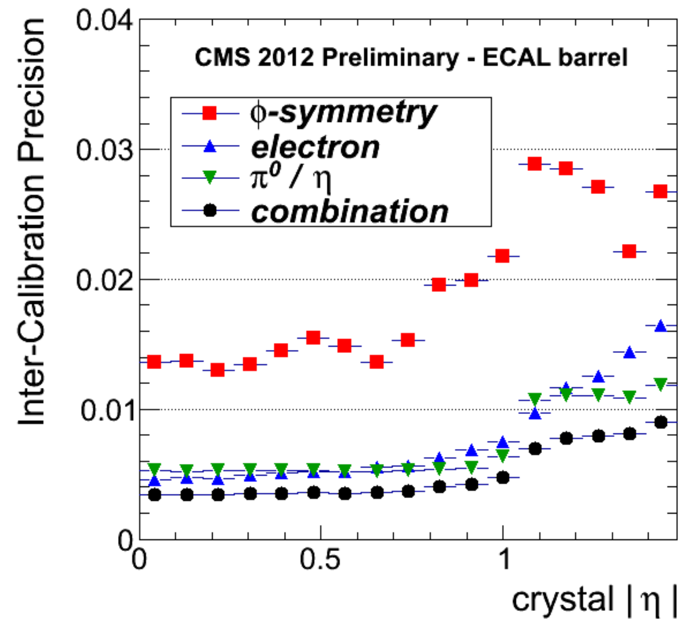
~30%

Validation of the correction with E/p



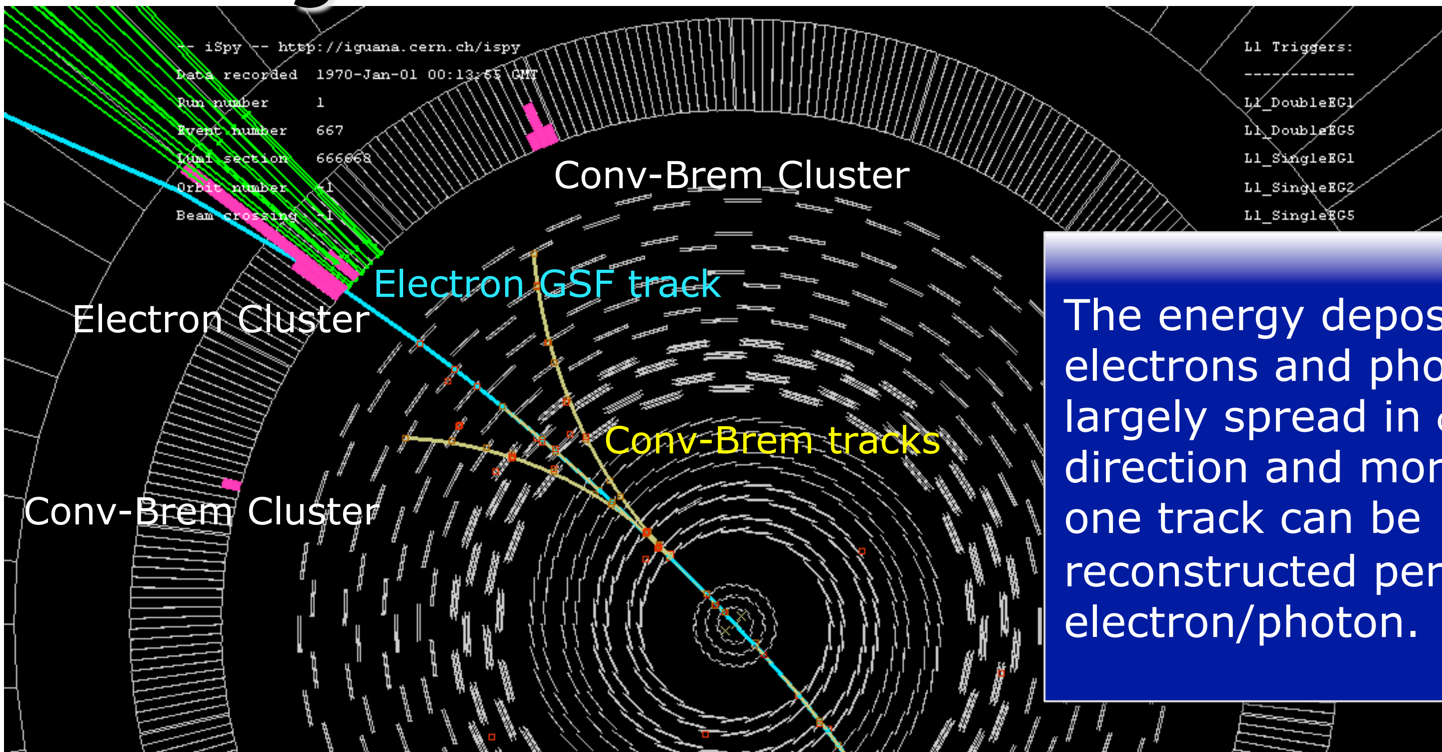
Inter-calibration

1. φ-symmetry of energy flow in crystals at given η
2. $\pi^0/\eta \rightarrow \gamma\gamma$ invariant mass
3. $Z \rightarrow e^+e^-$ invariant mass and E/p with electrons from $W \rightarrow e\nu$

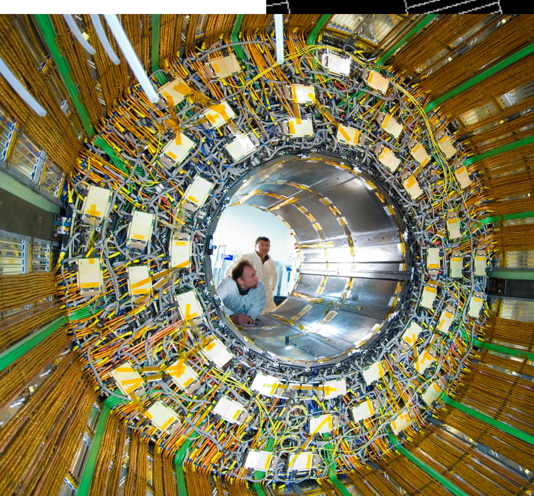


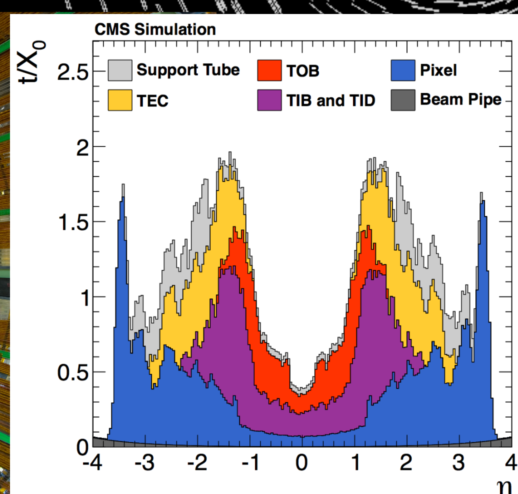
Barrel: <1% (~0.4% for |η|<1)
Endcaps: ~2% (almost everywhere)

Electron/photon reconstruction and material budget

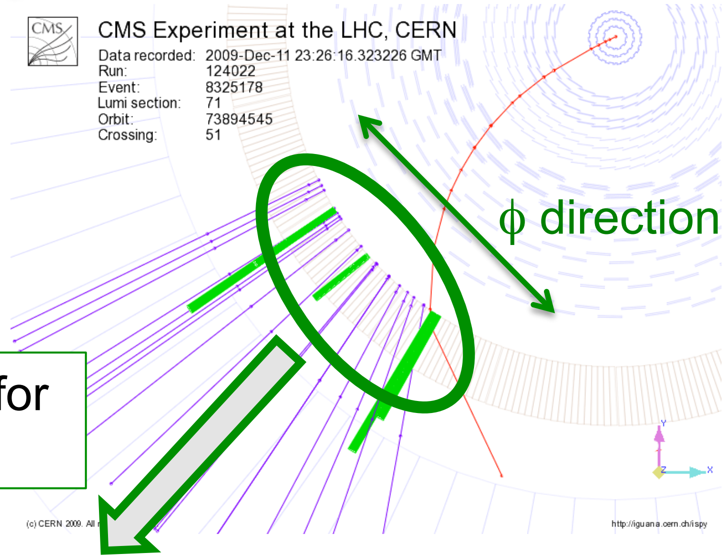


The energy deposits from electrons and photons are largely spread in ϕ direction and more than one track can be reconstructed per electron/photon.

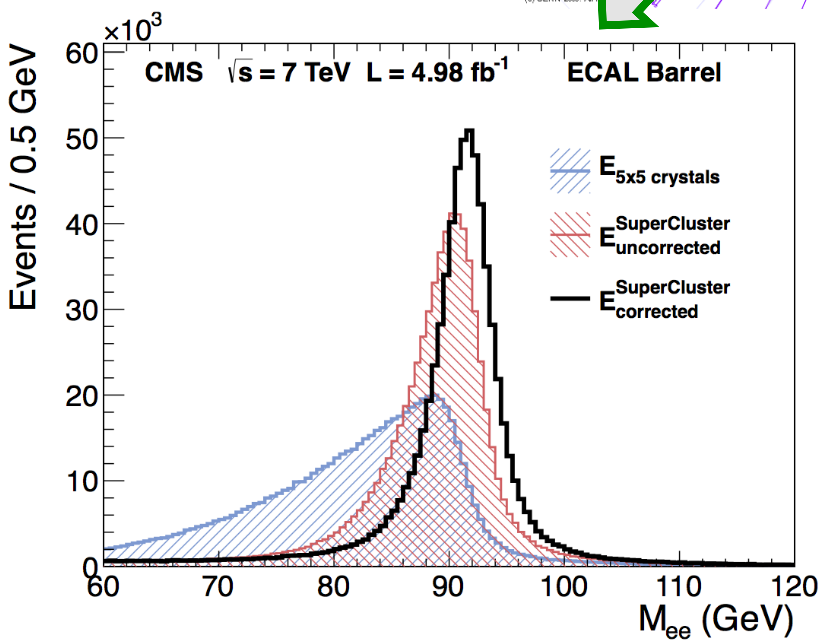




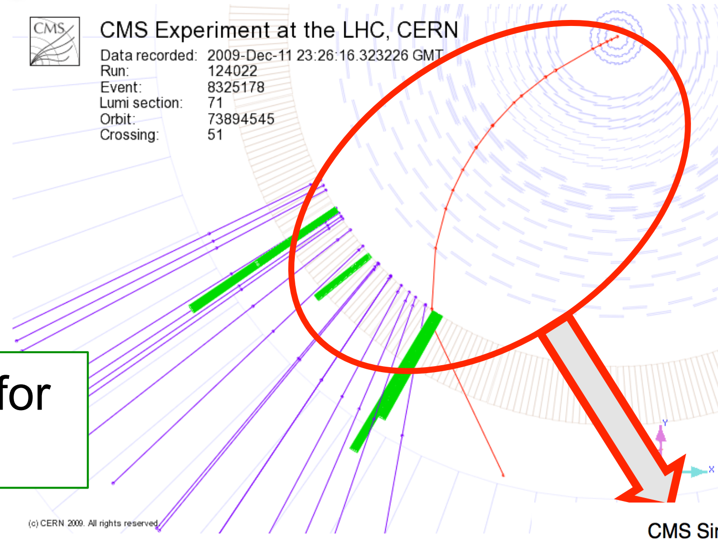
Electron/Photon reconstruction and energy correction



Multivariate technique for energy correction

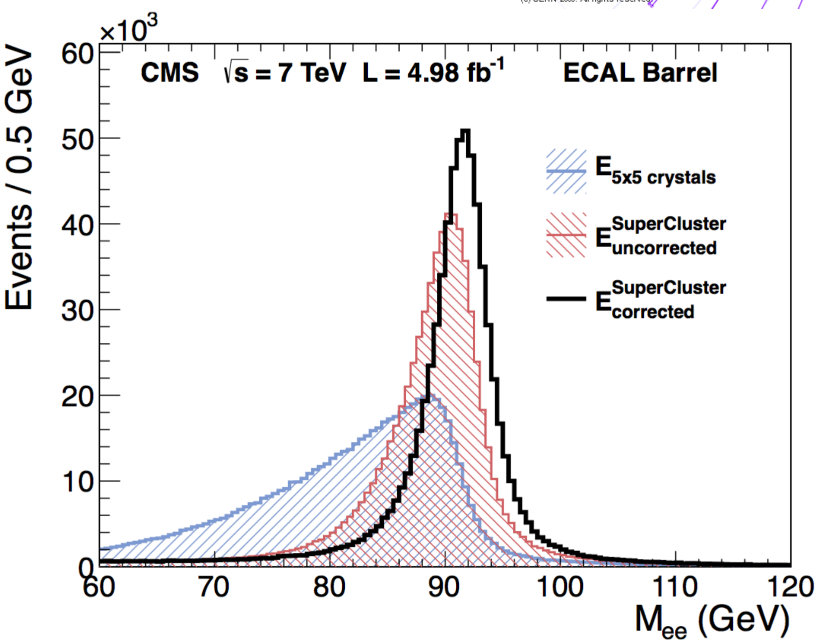


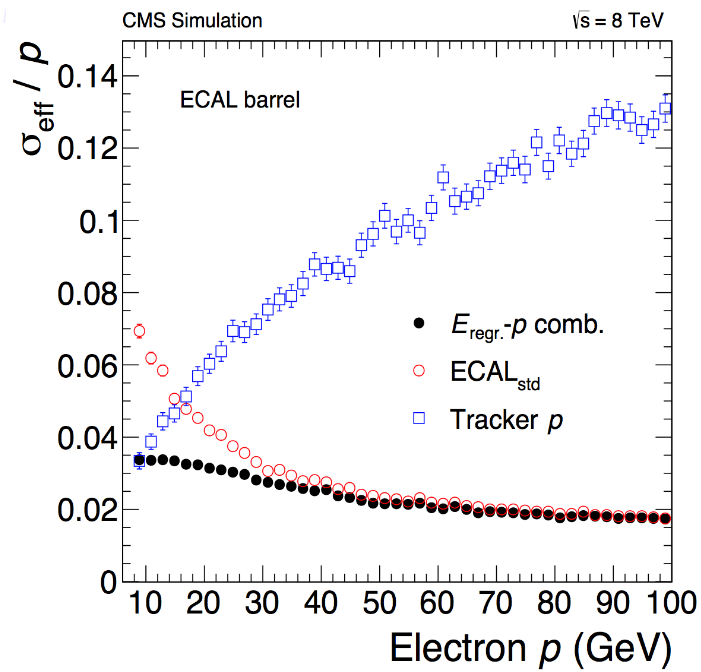
Electron/Photon reconstruction and energy correction



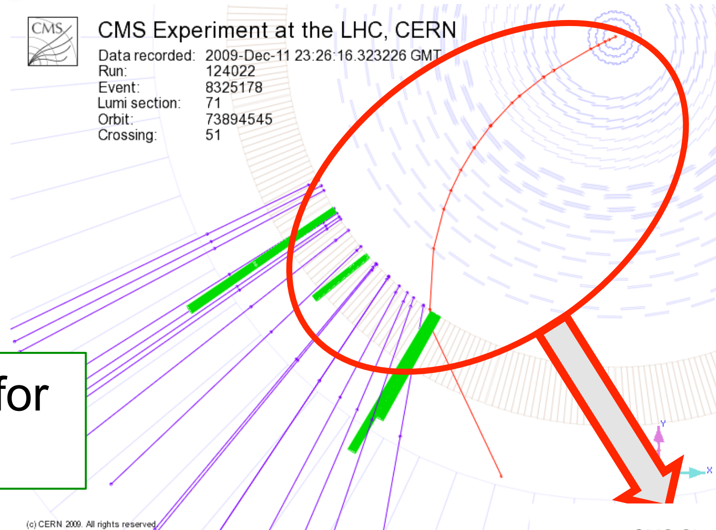
Dedicated electron track reconstruction and fitting (Gaussian Sum Filter)

Multivariate technique for energy correction





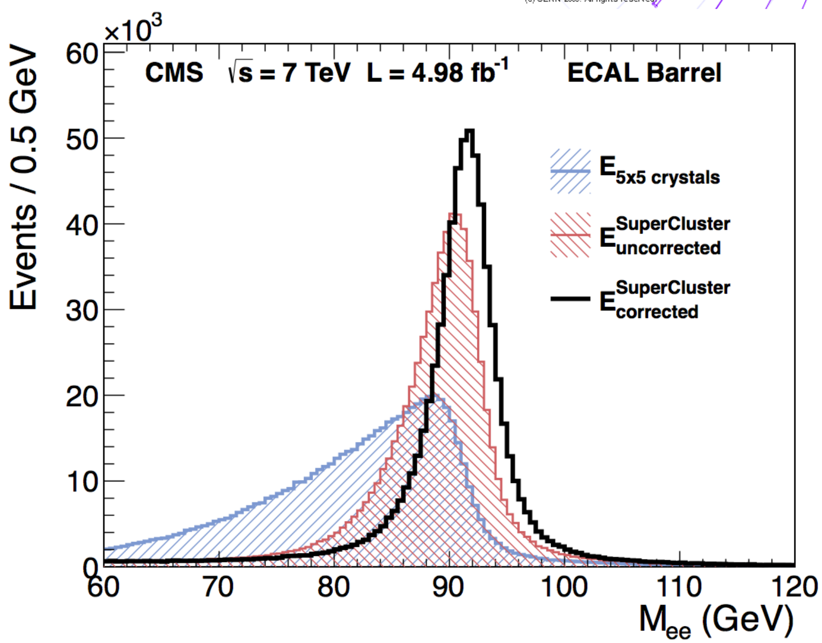
Electron/Photon reconstruction and energy correction

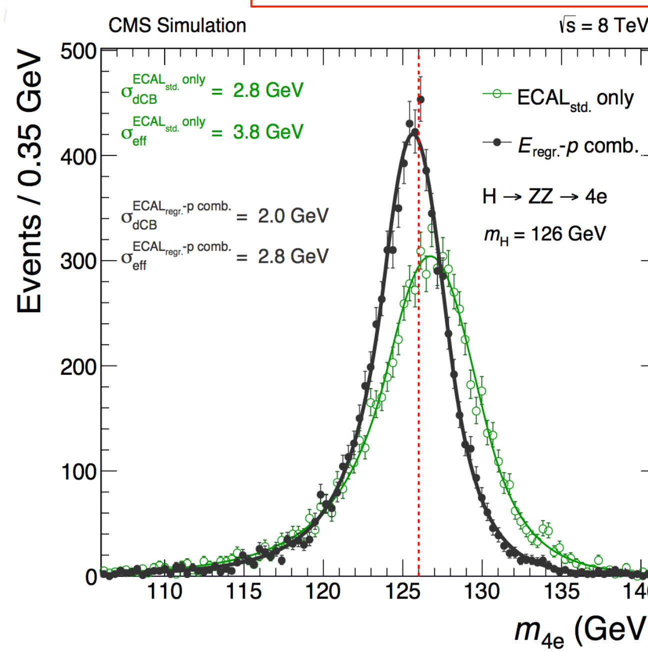


Dedicated electron track reconstruction and fitting (Gaussian Sum Filter)

Multivariate technique for energy correction

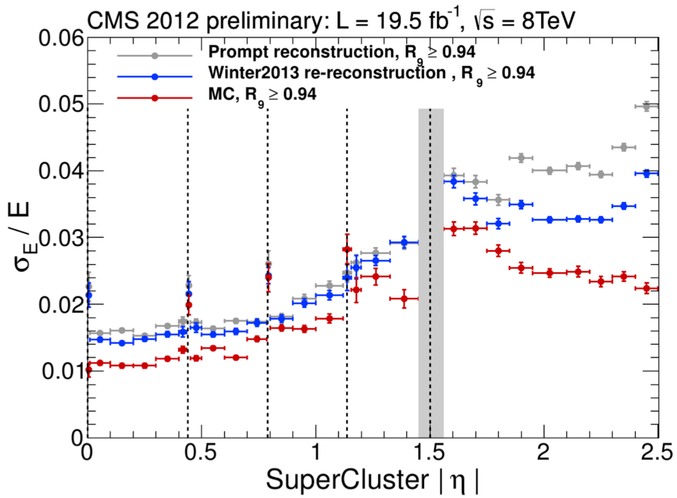
From ECAL only parametric correction to multivariate technique for energy correction and for ECAL-track combination



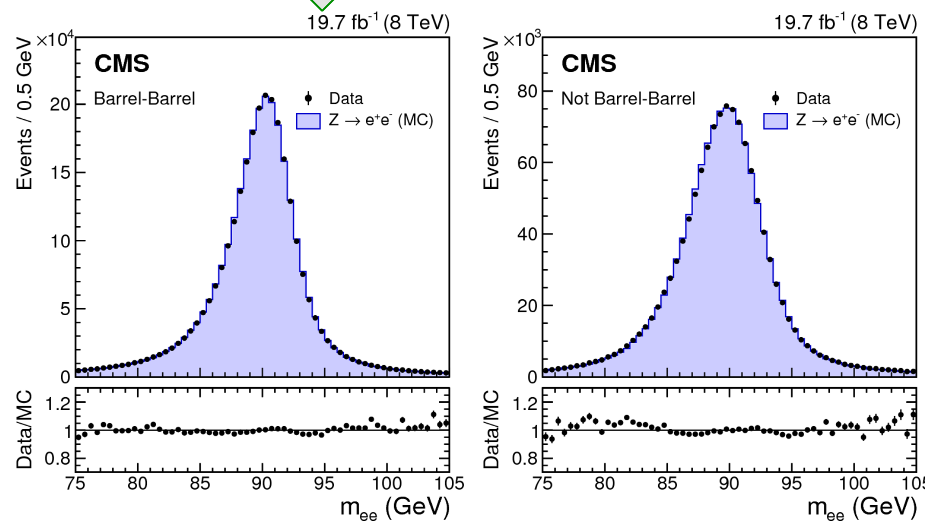


Performance: energy resolution

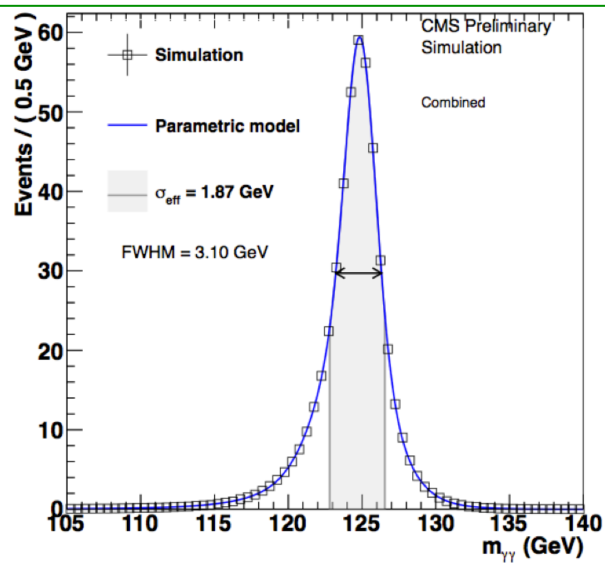
With electron from Z: DATA and simulation



Tune the simulation to match the performance observed in DATA

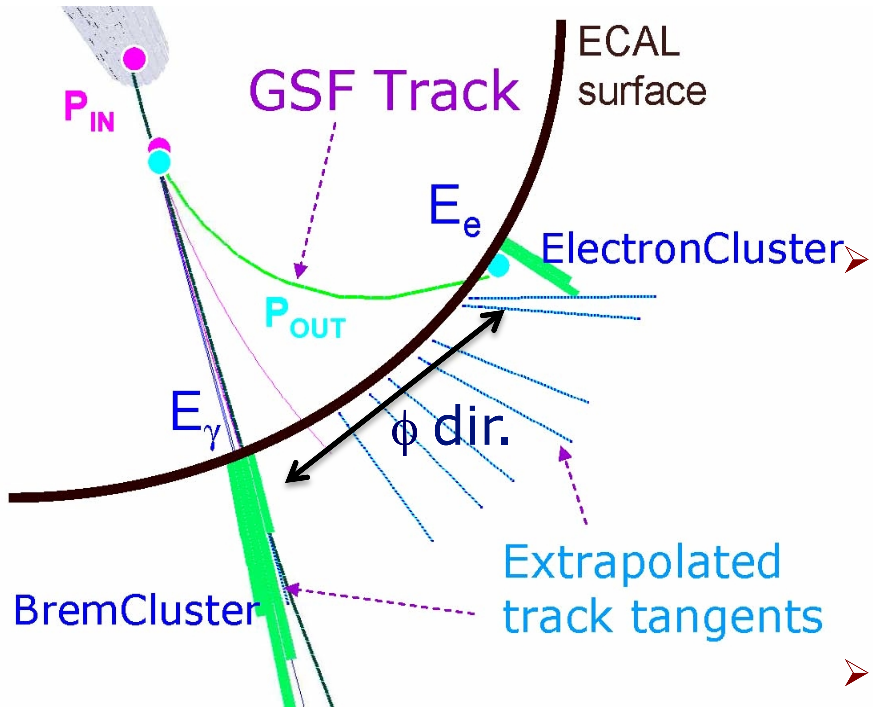


H (m_H = 125 GeV/c^2) ->γγ from simulation



Photon resolution predicted with fine-tuned simulation. Electron and photon differences treated as systematics.

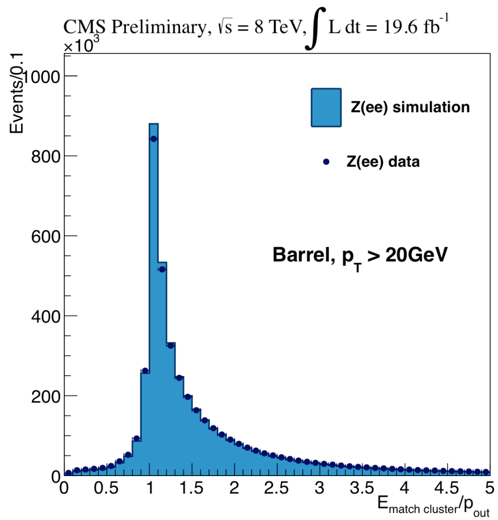
Main electron/photon identification variables

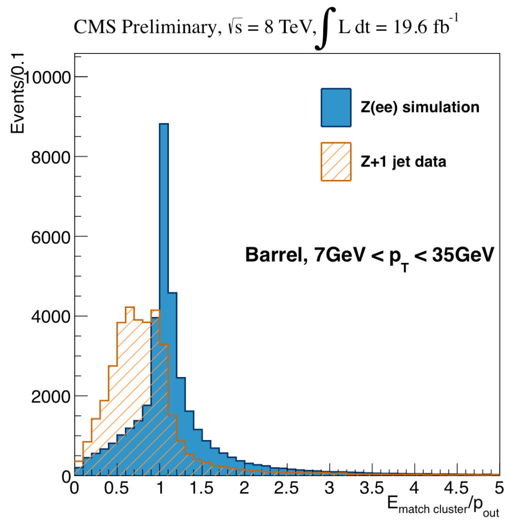


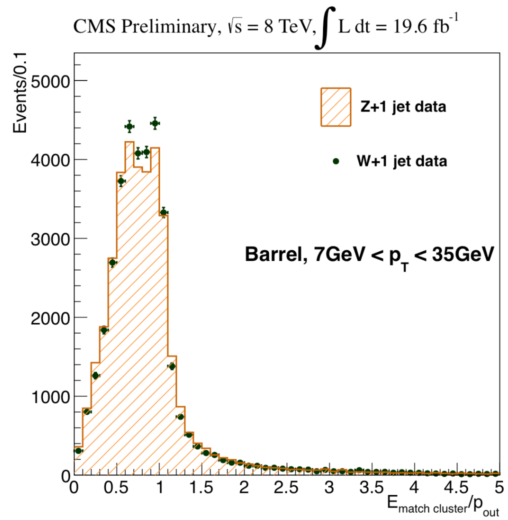
- Track-ECAL-HCAL-Preshower matching observables
  - ✓ Energy matching (eg. E/P, Hcal/Ecal …)
  - ✓ Geometrical matching in η and ϕ directions and at vertex or calorimeter surface
- Pure ECAL observables
  - ✓ Cluster shapes:
    - ✓ in η-direction, more effective for signal-background separation.
    - ✓ in ϕ-direction, helpful to categorize correctly bremming and not-bremming electrons.
- Pure tracking observables
  - ✓ p_{in}-p_{out}/p_{in} (Electron-Track) = bremsstrahlung emission seen by the tracker

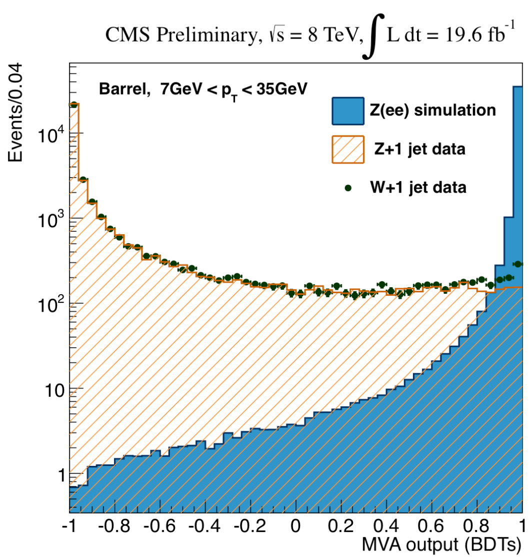
- Combining several variables is the typical optimization to be performed with a multivariate analysis (MVAs).
- With MVAs the background that model the fakes needs to be carefully chosen, taken from data control samples.

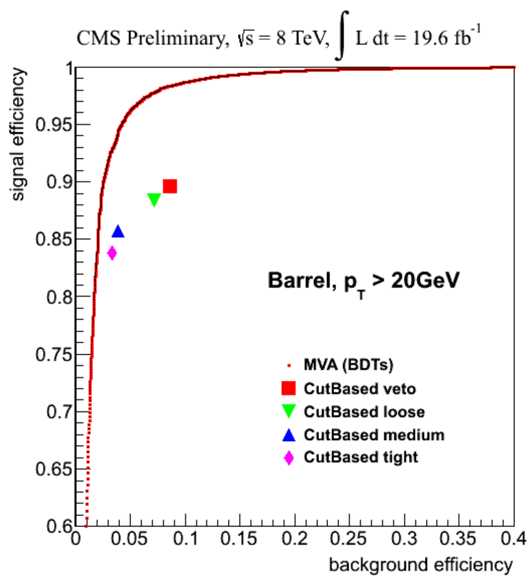
Training and MVAs output



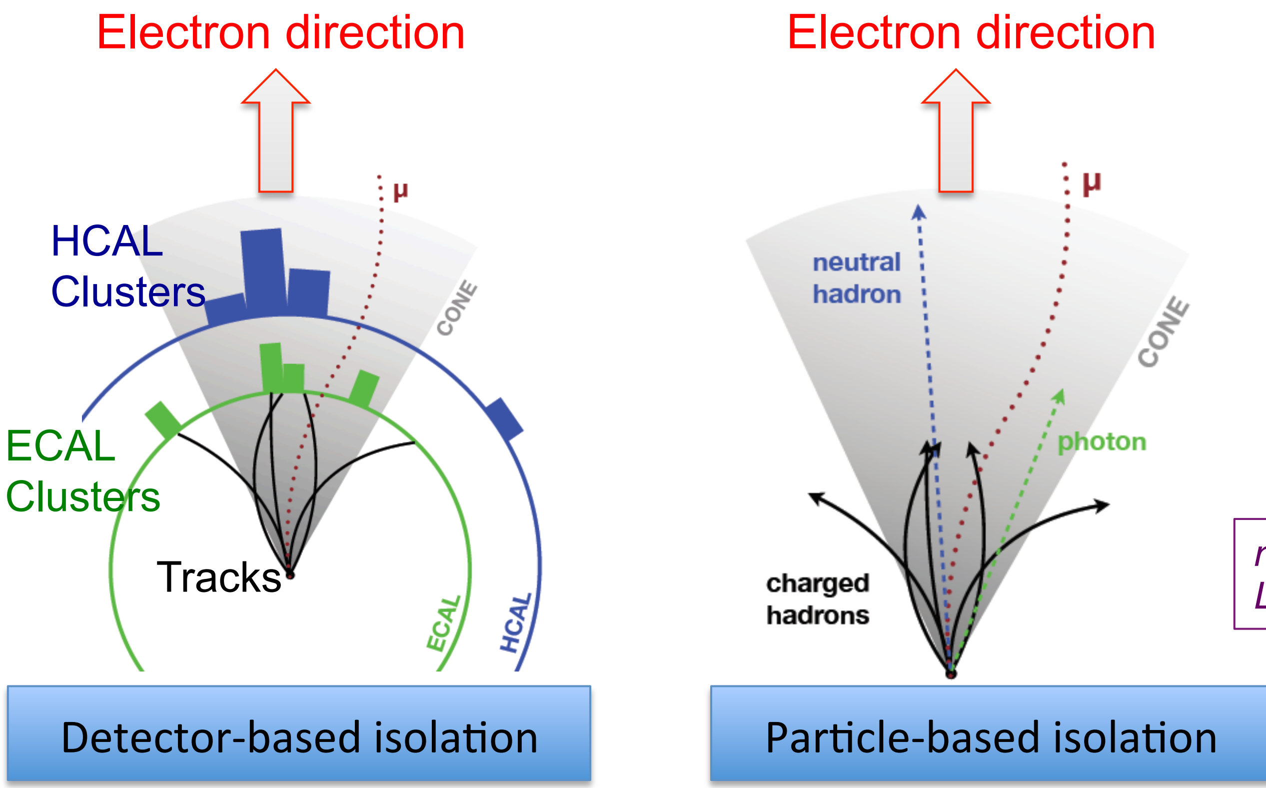








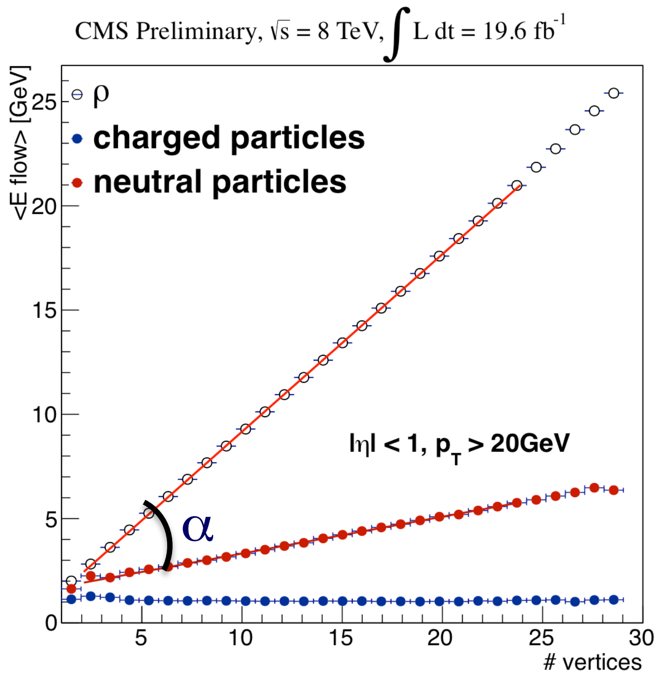
The particle-based isolation

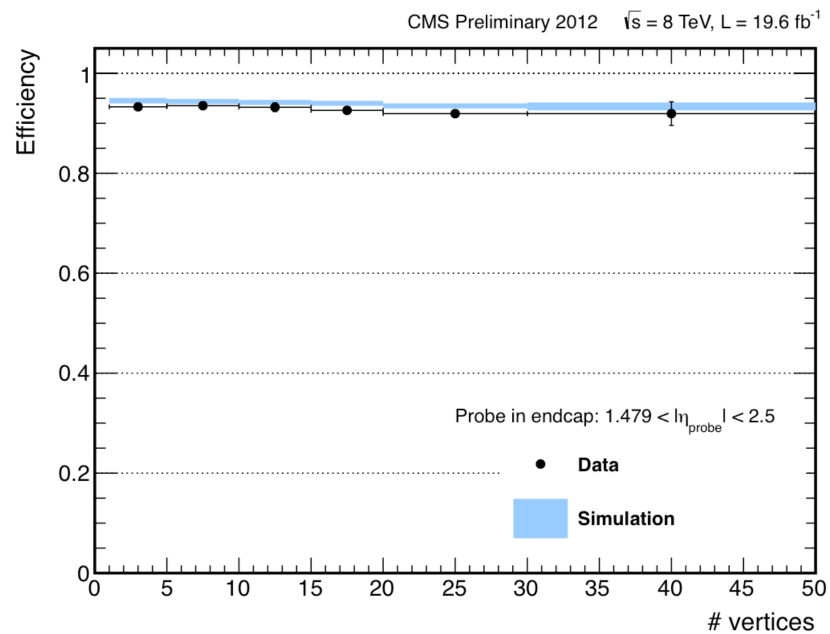


more details in L. Gray talk

- Particle-flow resolve the correlations among track and cluster energy measurements
- Charged hadrons can be fully matched to the primary vertex.

Correction of isolation for PU



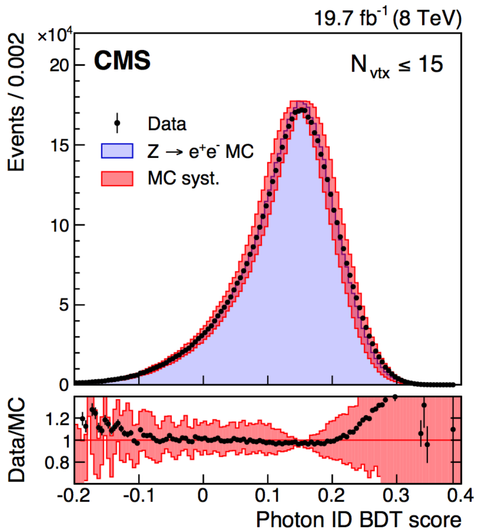


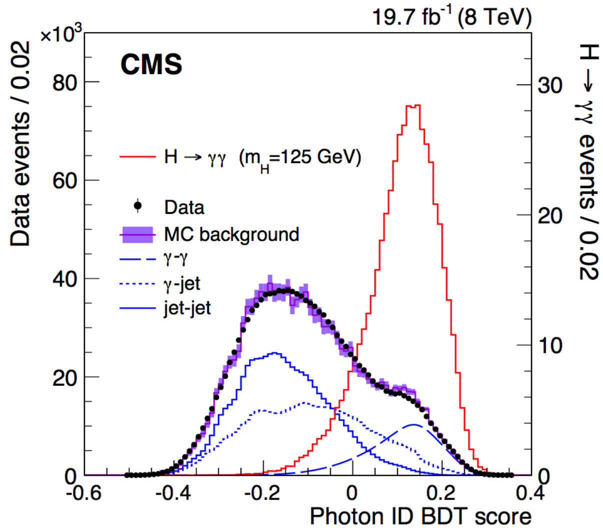
ρ = energy density estimate in the event

α = effective correction needed to neutral particles in the isolation cone

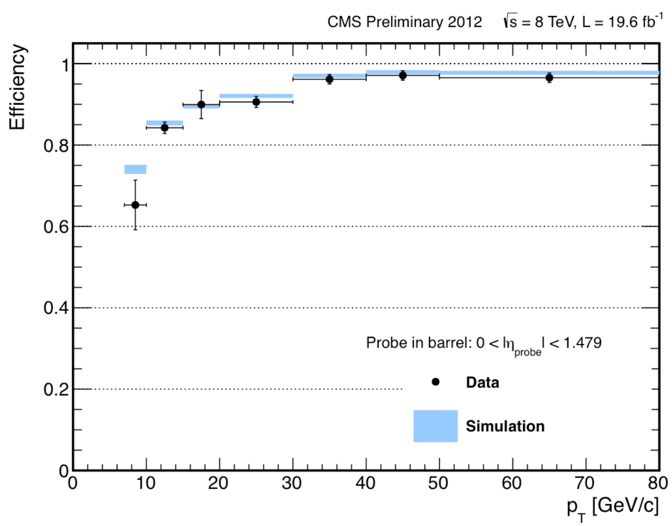
→ flat efficiency

Data and Simulation comparison & efficiency



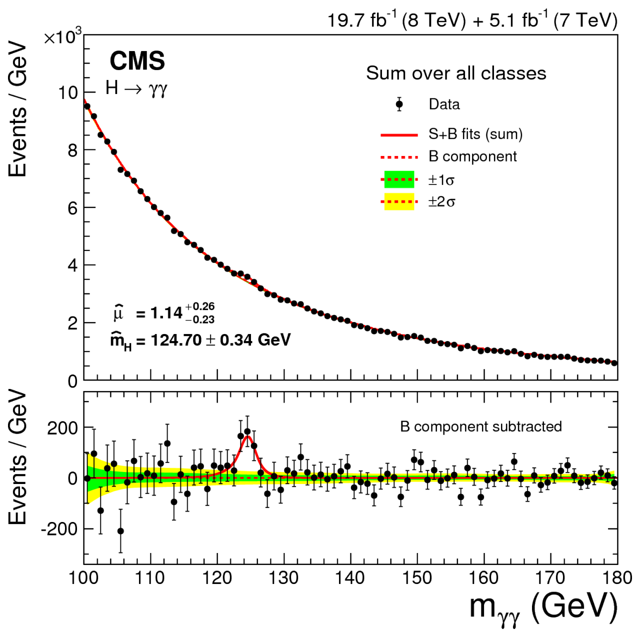


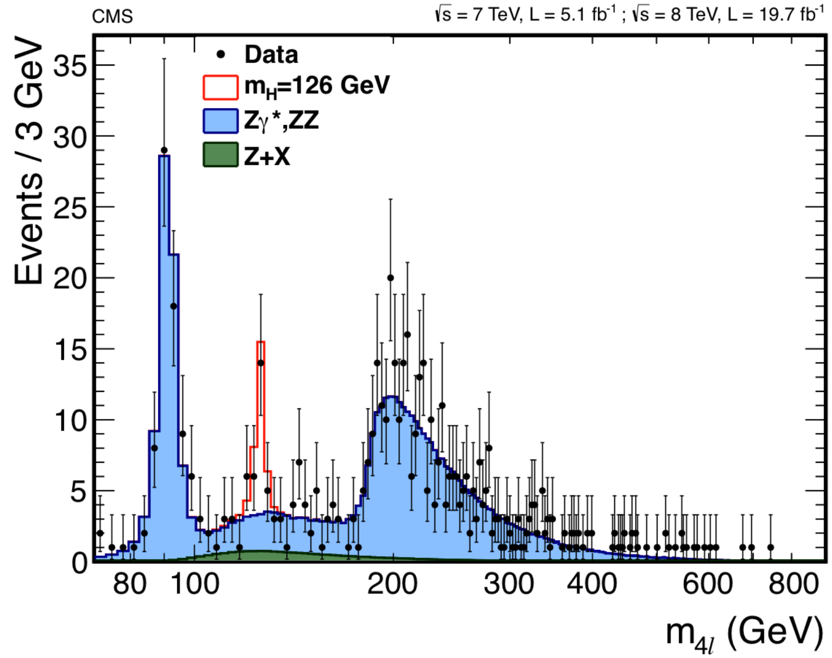
Photons:
good agreement for both signal and background for the multivariate estimator.



Electron data/simulation efficiency are compared down to 7 GeV: good agreement is observed

Conclusions





From H → γγ:

m_H = 124.70 ± 0.31(stat) ± 0.15(syst) GeV

Excellent results on mass resolution thanks to a deep understanding of the ECAL performance with careful scrutiny of all the details and to the use of energy correction with multivariate techniques.

From H → ZZ → 4l:

~30% improvements

on the H->ZZ->4e channel object selection from first publication to analysis for discovery, thanks to a multivariate identification and particle-based isolation

Questions?

daniele.benedetti@cern.ch

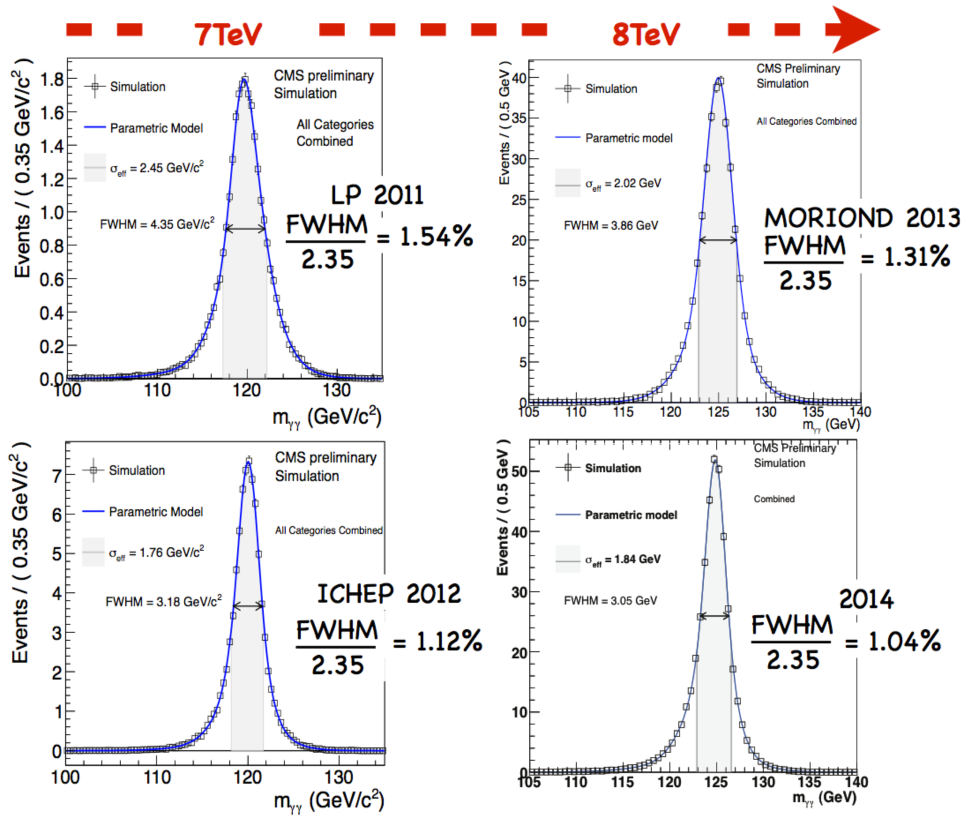
Lessons learned: resolution

- **Long journey to improve the energy resolution:**
  - ✓ **improved calibration of the ECAL detector**
  - ✓ **improved description of the ECAL simulation with a run-dependent Monte Carlo description of the detector that follows the evolving conditions during data taking in 2012, and includes the simulation of out of time pileup over the time windows [-300 ns, +50 ns]**
  - ✓ **improved multivariate energy correction using a semi-parametric likelihood technique in order to construct a prediction for the full distribution of E-True/E-Raw.**

PROMPT reconstruction within 48h from data taking

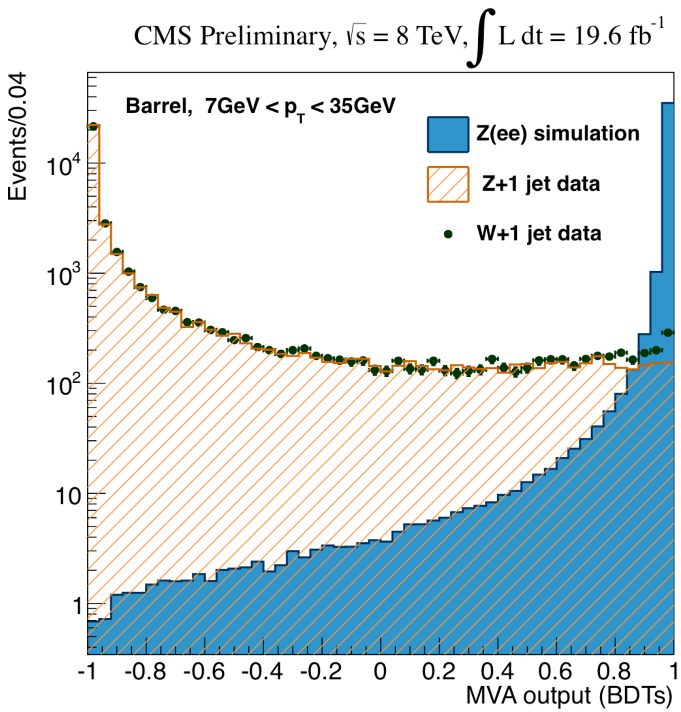
↓

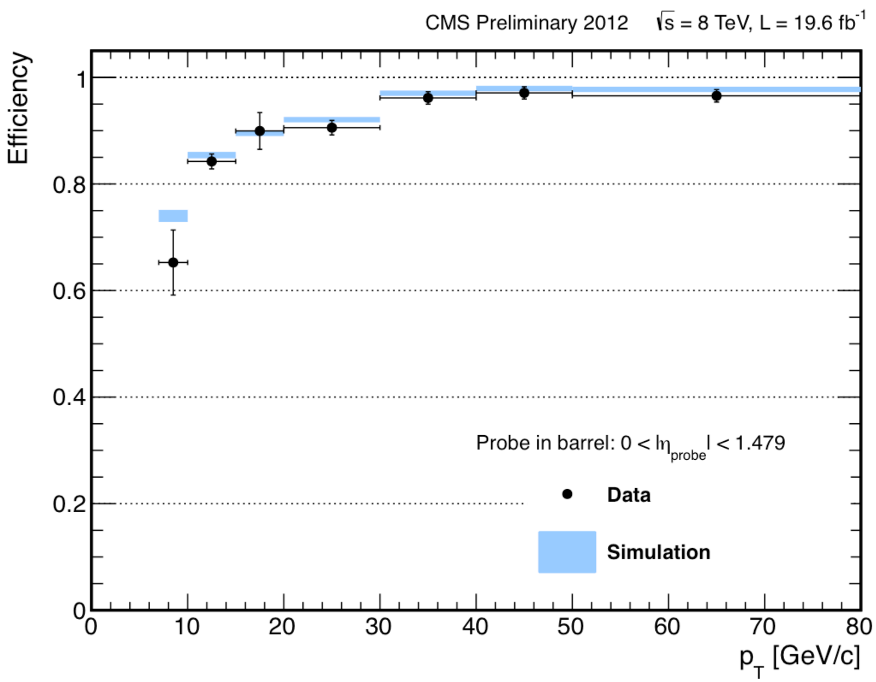
RECONSTRUCTION with improved conditions



Lessons learned: identification

- **Multivariate techniques fully exploited during Run1**
  - ✓ **The choice of the background training/testing samples plays a crucial role in final performance.**
    - **CMS choice is to get the background directly from DATA**
  - ✓ **Test the efficiency differences between DATA and simulation is very challenging for low-pt electrons due to the high background.**





Backup

ECAL-related systematic uncertainties on m_H

From $H \to \gamma\gamma$:

$m_H = 124.70 \pm 0.31(stat) \pm 0.15(syst)$ GeV

- Electron/photon differences in the simulation .... 0.10 GeV
  - ✓ material distribution .... 0.07 GeV
  - ✓ longitudinal light-yield non-uniformity .... 0.02 GeV
  - ✓ Geant4 .... 0.06 GeV
- Residual non-linearity in scale .... 0.10 GeV
- Photon energy scale corrections .... 0.05 GeV
- Z line shape .... 0.01 GeV