Performance of the CMS Electromagnetic Calorimeter and first results on electromagnetic physics objects

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Physics with e and γ at LHC

Much of the LHC Physics will be done using electrons and photons:

Examples:

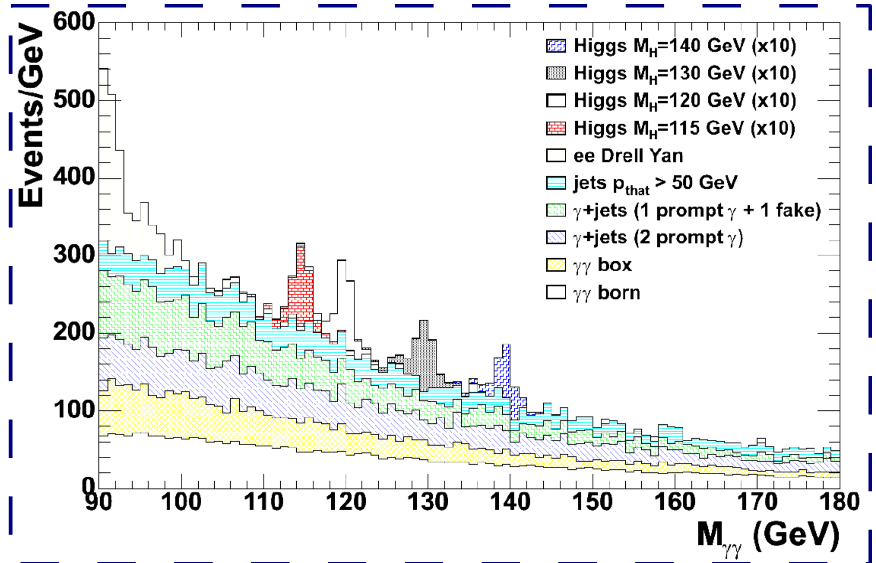
- **EWK and QCD (W,Z,t,γ+jet..)**
- **SUSY (e/γ+MET,..)**
- **Higgs (H→γγ,H→ZZ,H→WW,..)**
- **New resonances (Z'→ee,W'→en,G→γγ,..)**

Benchmark physics channel for the CMS ECAL design: H → γγ

Target energy resolution for unconverted γ: 0.5% @100GeV

Primary instrument to detect electrons and photons: Electromagnetic Calorimeter (ECAL)

The quality of the detector determines the ability to efficiently reconstruct the signal, reject background and clearly observe signatures of new Physics



The CMS Electromagnetic Calorimeter

Crystal calorimeter

75848 $PbWO_4$ crystal

$0<|\eta|<3$

$\Delta\eta \times \Delta\varphi = 0.0175 \times 0.0175 - 0.05 \times 0.05$

24.7-25.8X_0

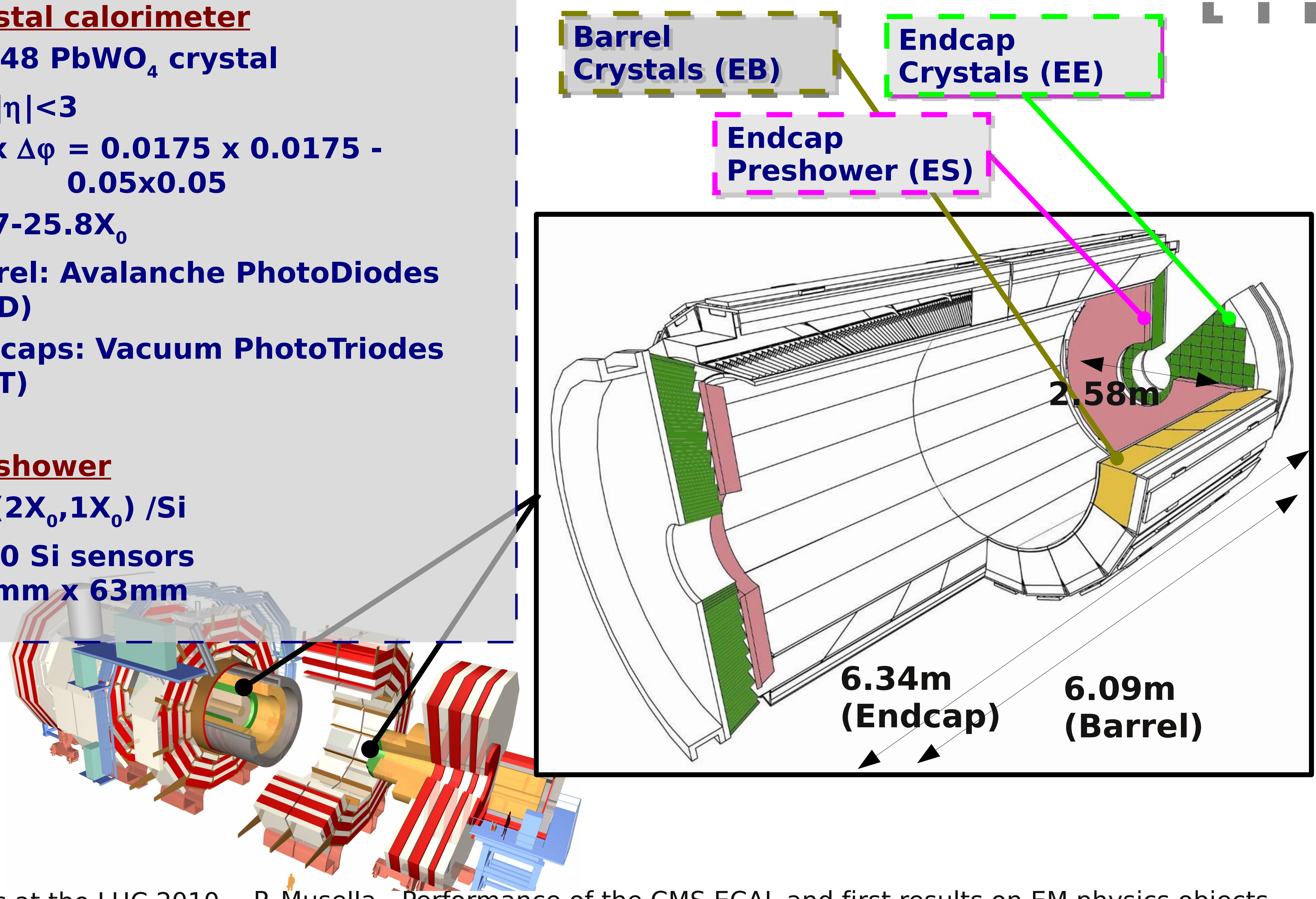
Barrel: Avalanche PhotoDiodes (APD)

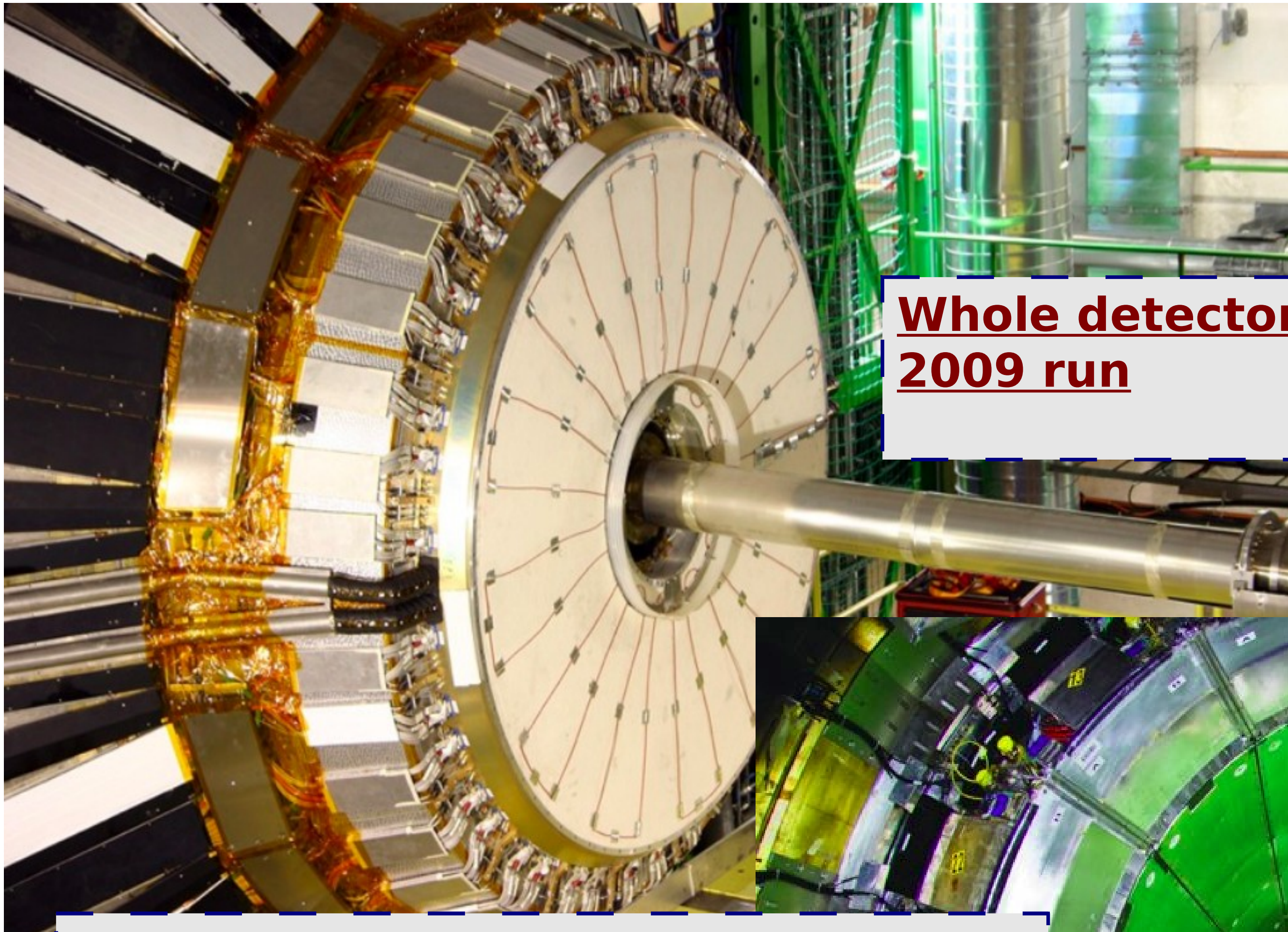
Endcaps: Vacuum PhotoTriodes (VPT)

Preshower

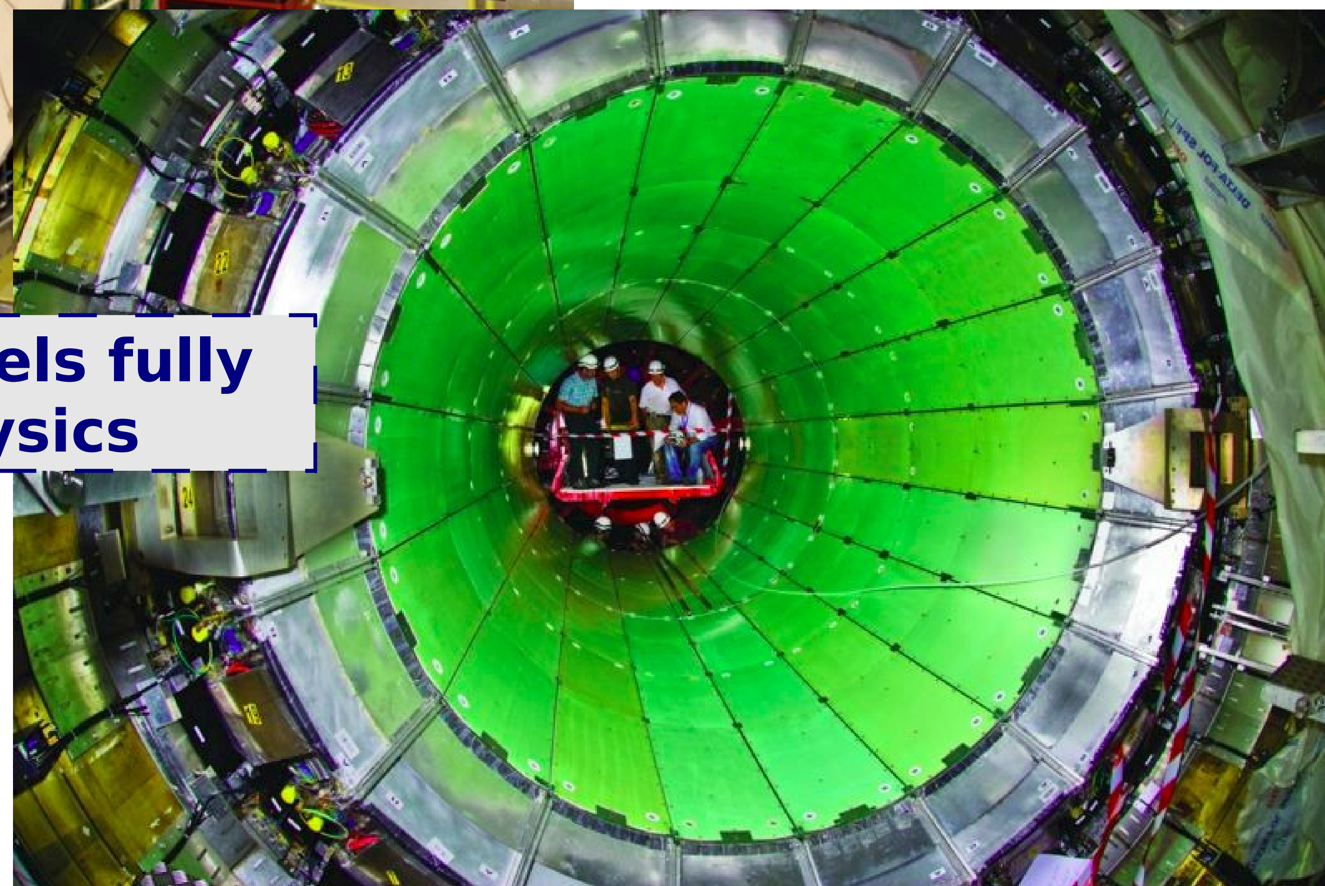
Pb ($2X_0$,$1X_0$) /Si

4300 Si sensors
1.8mm x 63mm



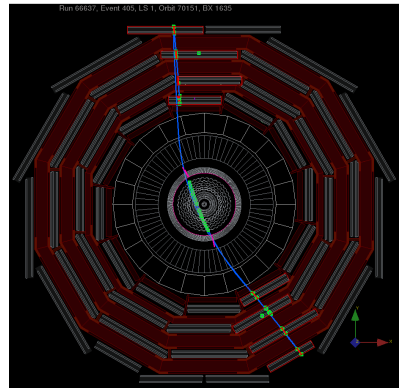


Whole detector commissioned before LHC 2009 run



>99.2% of the channels fully operational for Physics

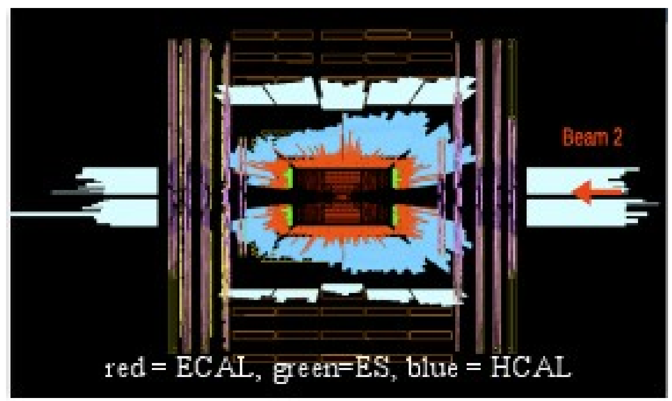
From Commissioning to Physics



Cosmic rays runs

Extended data taking with 3.8T solenoidal field

- measurement of the muon stopping power in $PbWO_4$
- validation of EB energy scale to <2%
- validation of EB regional intercalibration to 1%



Beam splashes

450 GeV LHC beam dumped on collimators 150m from CMS

- improvement of EE intercalibration precision
- time alignment

We are here

LHC Collisions

$\sqrt{s}$=900GeV,2.36TeV 2009 collisions and $\sqrt{s}$=7TeV 2010 collisions

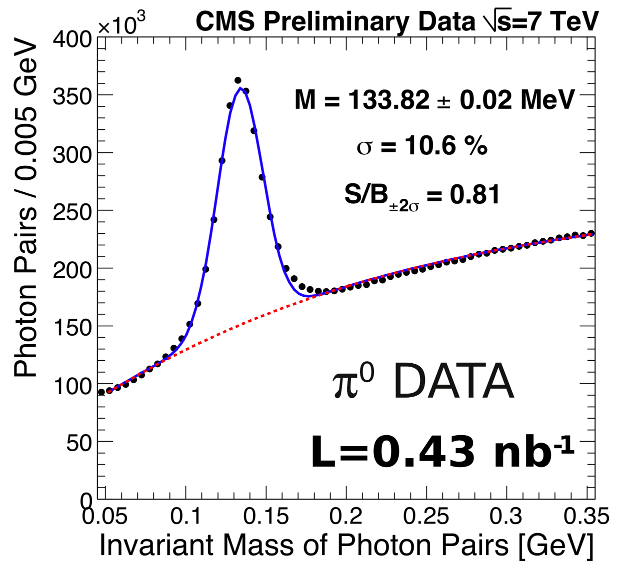
- observation of η and π^0 peaks
- preliminary results on in-situ calibration
- commissioning of E.M. Physics objects in pp collisions

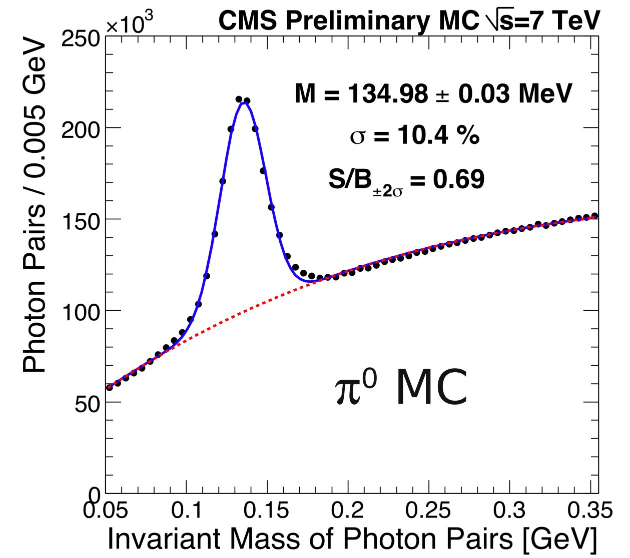
First signals

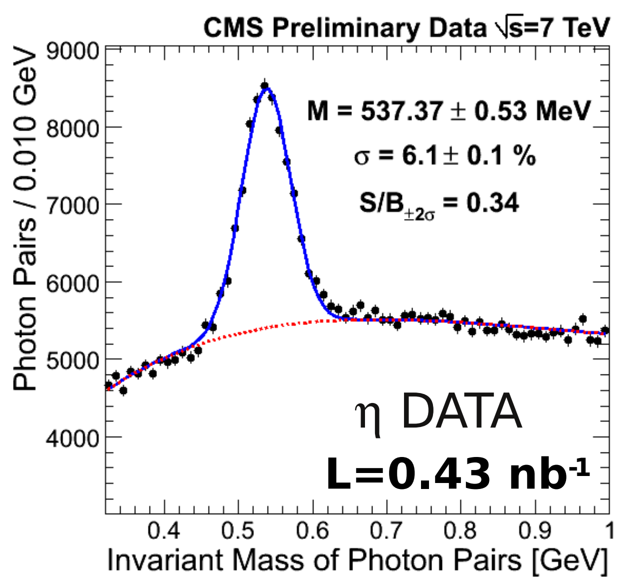
π^0 peak plot produced in <1d at $\sqrt{s}$=900GeV and in <1h at $\sqrt{s}$=7TeV

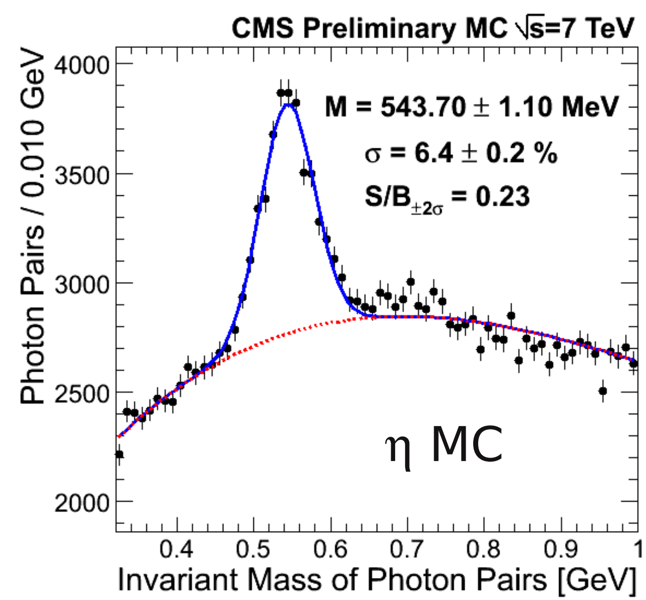
$\pi^0(\eta)$ selection:
E_T^{γ}>400MeV,
$p_T^{\gamma\gamma}$>1(2.5)GeV/c
(in a detector made for 100GeVs signals)

Peak positions agree with MC expectations within 1%.
⇓
Very good understanding of energy scale.









Detector calibration

Channel-to-channel calibration gives the biggest contribution to energy resolution at high energies

Energy resolution

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

Test-beam measurement (e on crystals centre): a=2.8% GeV$^{1/2}$, b=127 MeV, c=0.3%

Extensive precalibration campaing (lab. measurements, cosmic rays, testbeams)

Several methods to calibrate in-situ:

- φ-symmetry calibration: invariance of energy flow around the beam axis in minimum bias events. Intercalibrate crystals at the same pseudorapidity, other methods are needed to intercalibrate regions at different pseudorapidity.

- π^0 and η calibration: mass constraint on photon energy, use unconverted γ's reconstructed in 3x3 matrices of crystals.

- High energy electron from W and Z decays (E/p with single electrons and invariant mass with double electrons). High luminosity required. Helpful at the startup only for energy scale. Testing also J/ψ.

Results on in-situ calibration

ϕ-symmetry

Comparison of 2009 and 2010 calibrations show nice reproducibility

Regional relative scales in barrel with 0.43nb^{-1}

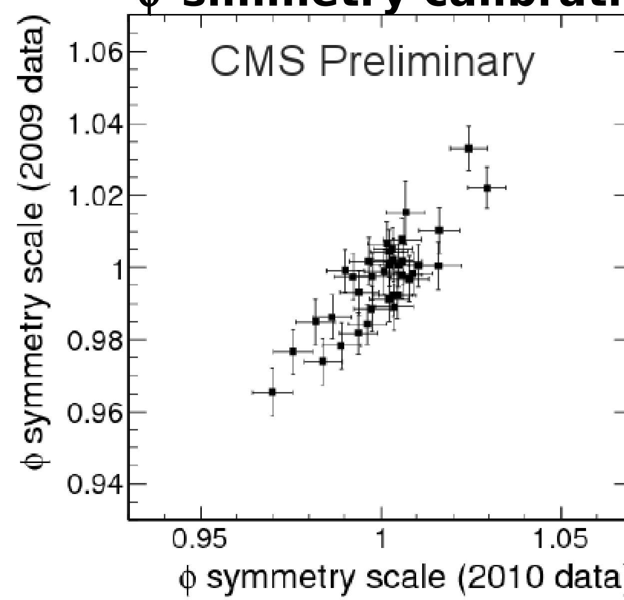
ϕ-symmetry and π^0 calibrations compared and combined

Statistical errors already negligible

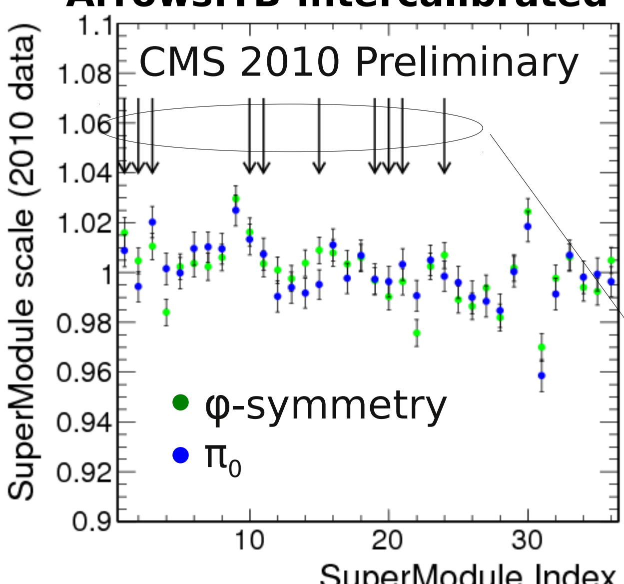
Comparison to test-beam scales estimates a 0.5% precision on regional relative scales

Expect to achieve design 0.5% precision in channel-to-channel in EB with 10pb^{-1}

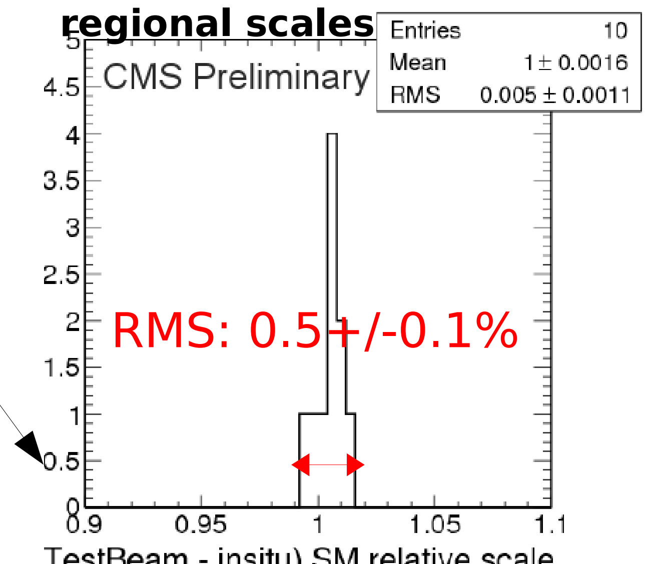
ϕ-simmetry calibration

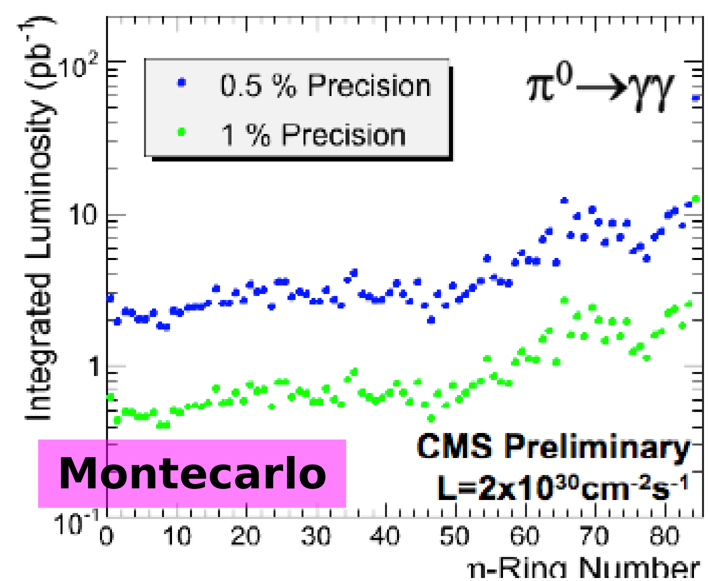


Arrows:TB-intercalibrated



In-situ vs testbeam regional scales



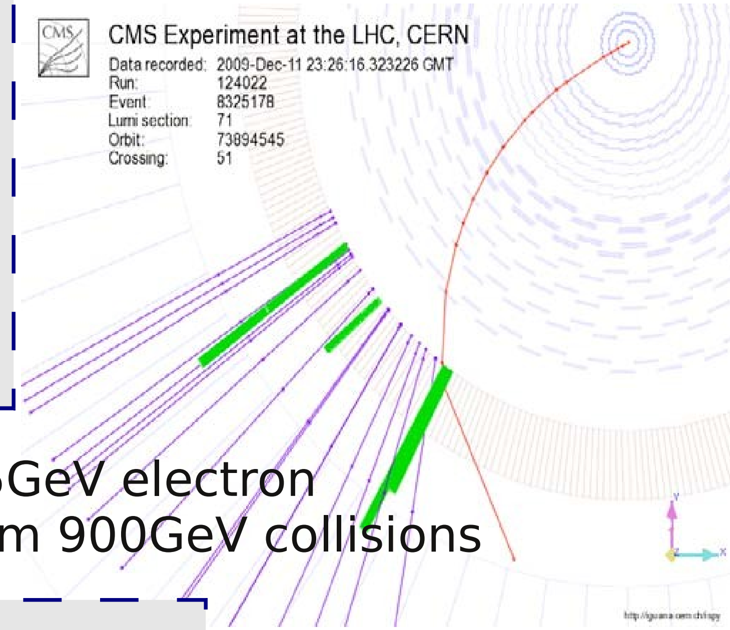


From detector to e/γ: clustering

Energy needs to be clustered in order to reconstruct e and γ:

5x5 crystal matrix contains ~97% of the energy for unconverted γ

Electron bremsstrahlung and photon conversions cause spread of energy in ϕ



2.5GeV electron
from 900GeV collisions

Superclusters to collect bremsstrahlung and conversion energies

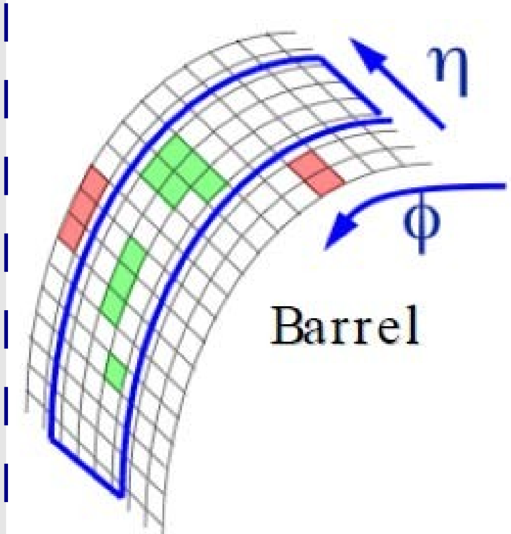
Barrel:

Start from highest energy deposits and search for deposits in ϕ in a narrow η window

Endcaps:

Use 5x5 crystal windows

Add preshower deposits



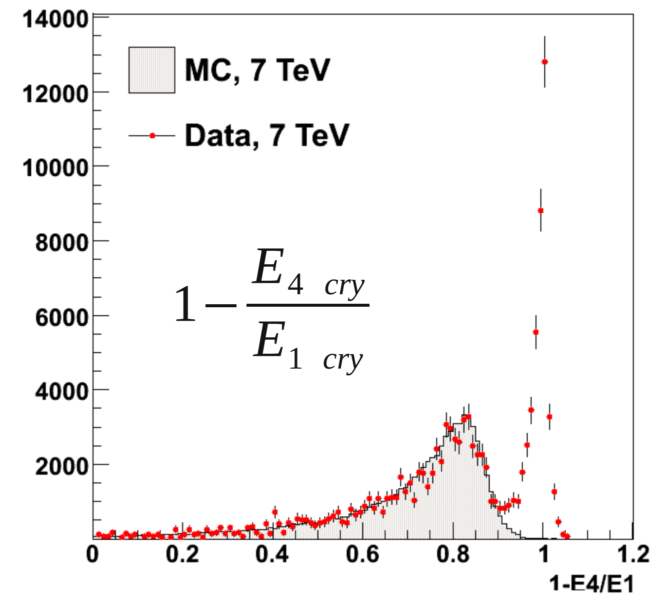
Anomalous signals

We observe anomalous signals in collision events: apparent large energy deposition in a single crystal

Signals uniformly distributed in barrel (APD readout)

Origin: deposits by heavily ionizing particles in APDs

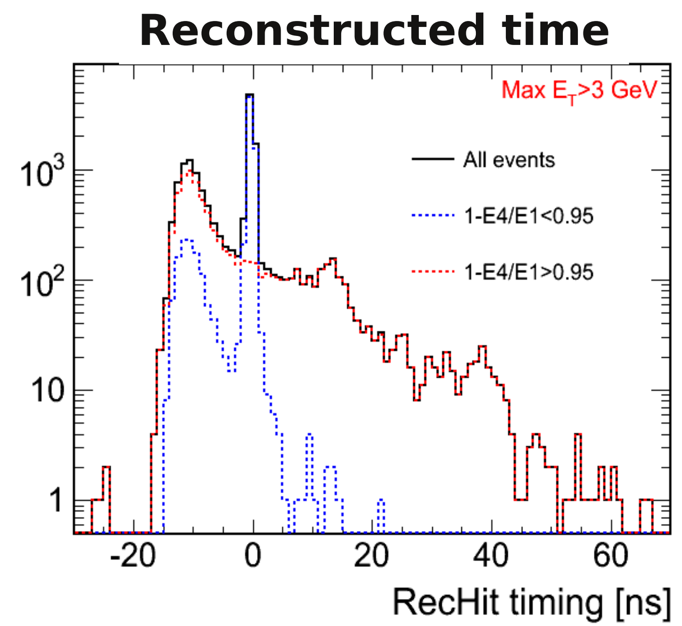
Rate at $\sqrt{s}$=900GeV: 1 event per 10^3 minimum bias collisions



Topological and timing informations are used to tag such events.

At cluster level, anomalous signal appear as energy in a single crystal, while normal e.m. showers are typically shared among several crystals.

For anomalous signals the time reconstruction is biased, due to difference in pulse shape. This makes apparent timing of anomalous signal earlier

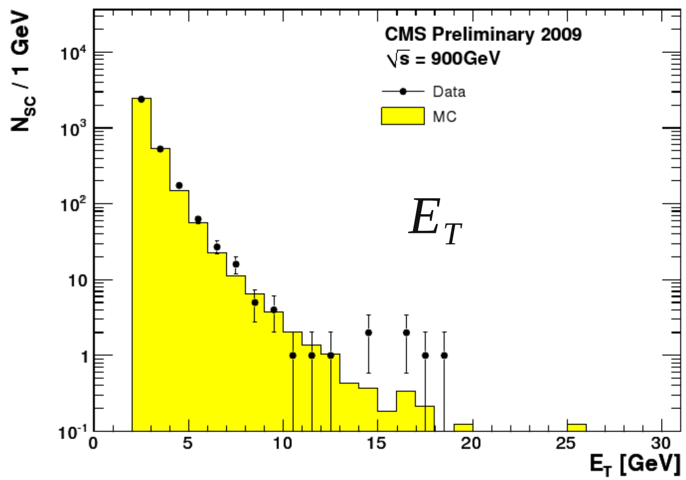


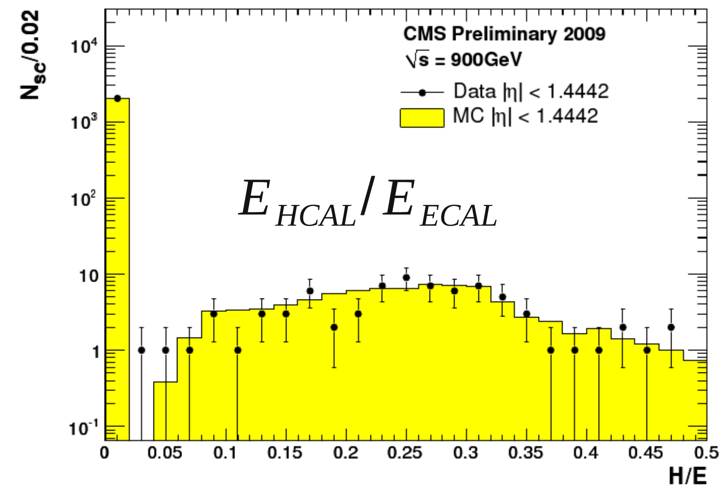
Superclusters in 900GeV collisions

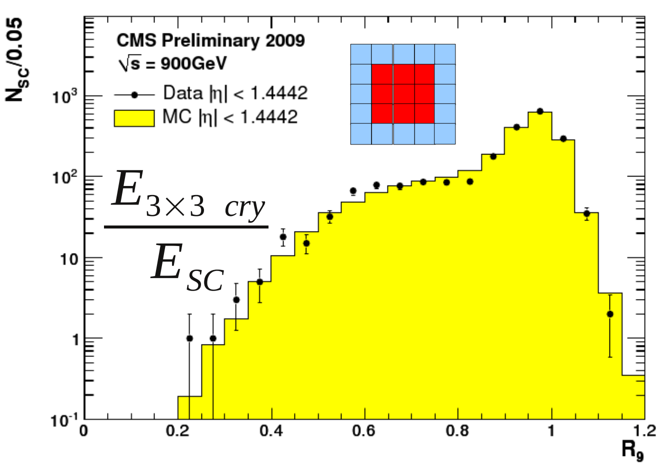
Superclusters from 1.8M minimum bias events at √s=900GeV compared to realistic MC simulation

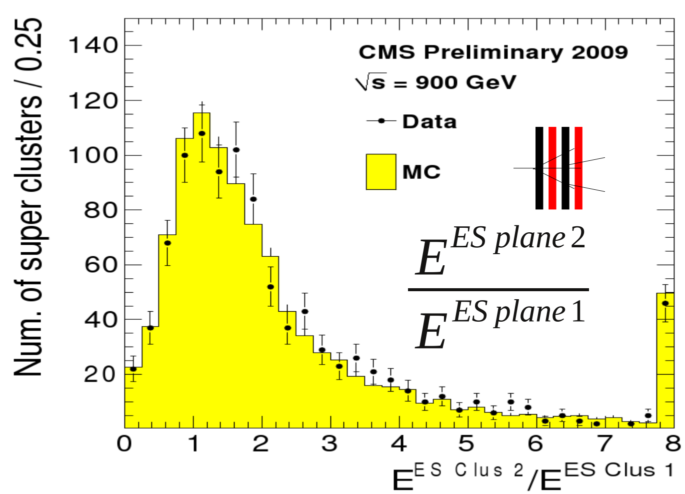
Sample is background-dominated

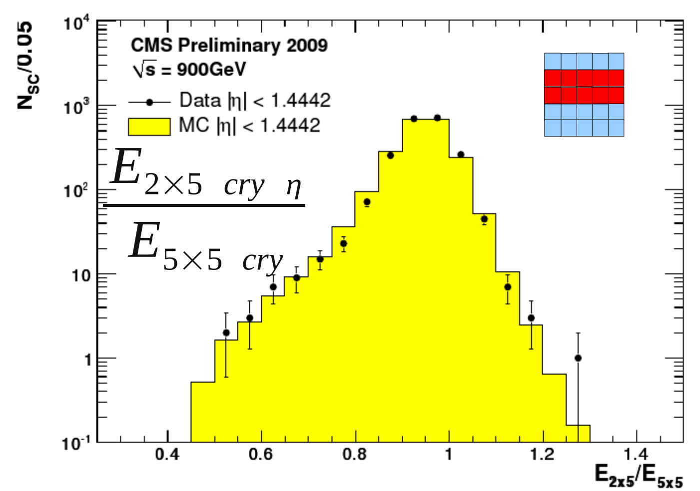
Globally good agreement in kinematic and cluster shape distributions











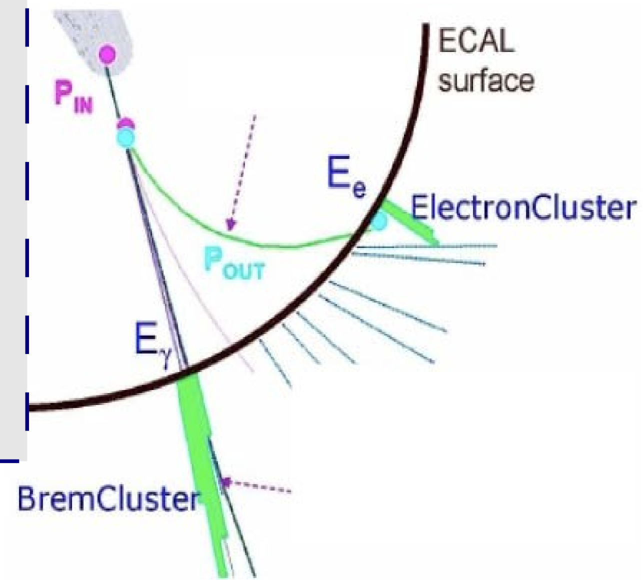
Electron reconstruction at CMS

Electron reconstruction has to take into account material in front of ECAL ($\sim 1X_0$)

Combine Si Tracker and ECAL informations.
Two complementary approaches:
- tracks as starting point ("tracker seeding")
- Supercluster as starting point ("ECAL seeding")

Bremsstrahlung recovery in ECAL: Superclusters

Bremsstrahlung modelling in tracking:
Dedicated algorithm for electron tracking
Propagation model takes into account of bremsstrahlung emission probability.
Amount of radiation estimated from difference between inner and outer momenta



Final energy-momentum combination combining Si tracker and ECAL information

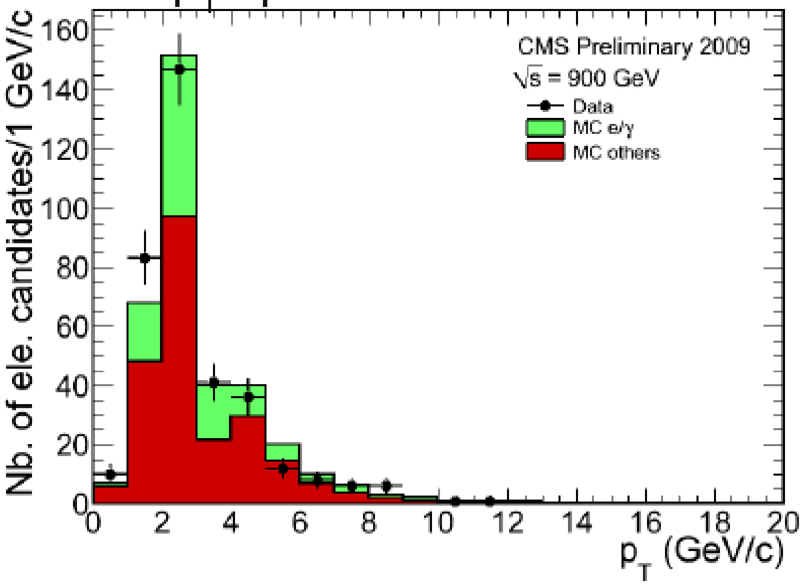
Electrons in 900GeV collisions

Electron candidates in $\sqrt{s}$=900GeV collisions compared to MC simulation

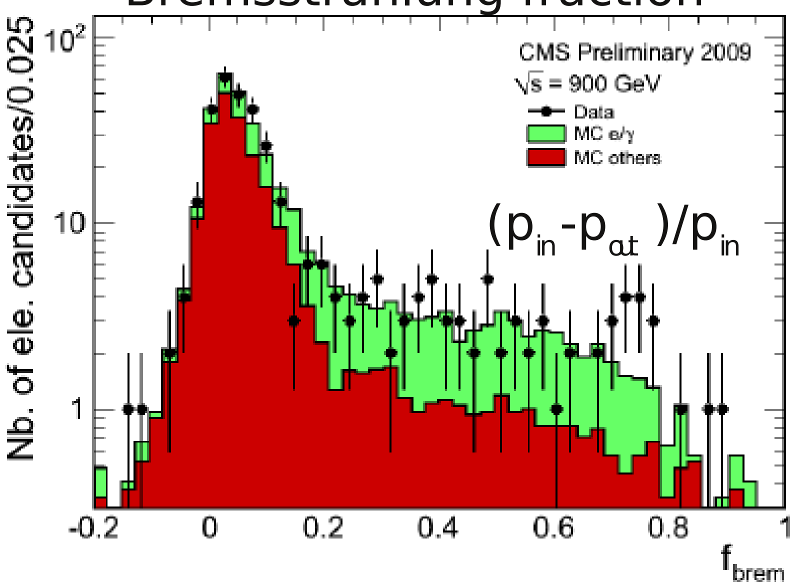
Selected 351 electron candidates, loosening standard preselection cuts

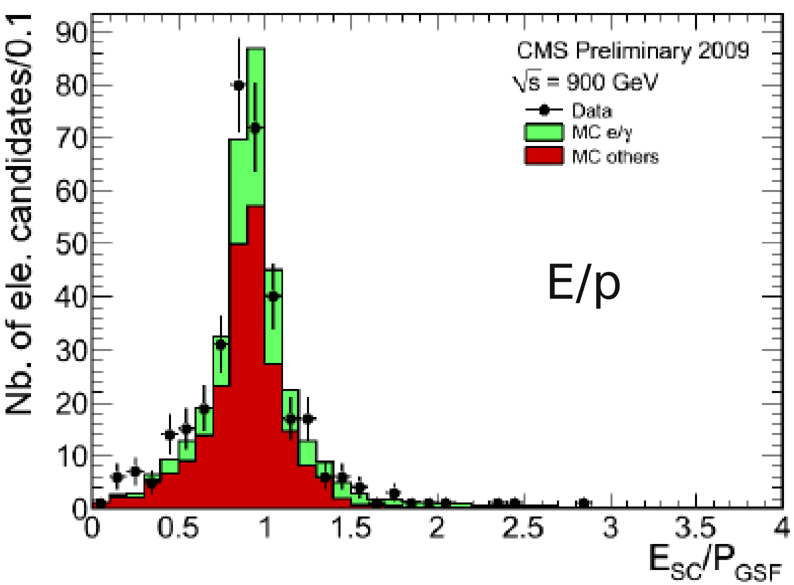
Comparison carried out on background: from MC expect 40% of real electrons, from γ conversion or $\pi^0 \rightarrow ee\gamma$

p_T spectrum



Bremsstrahlung fraction





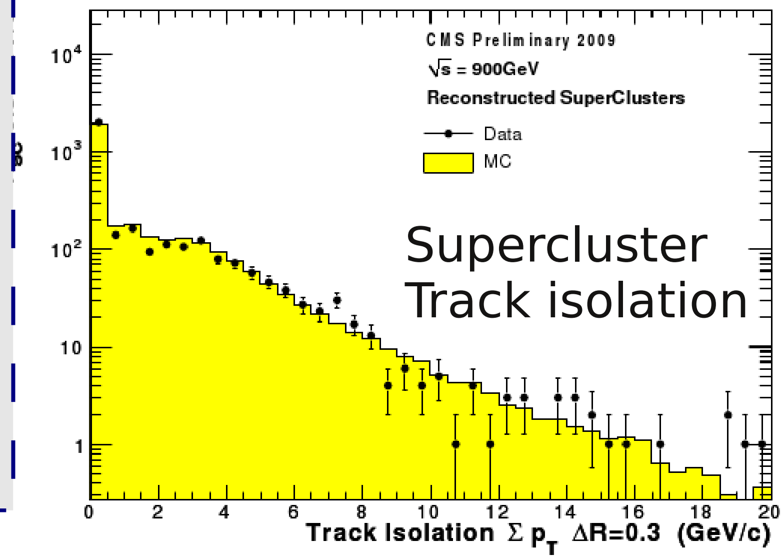
Particle identification and isolation

Reconstruction algorithms tuned for high efficiency
Background rejection factor of 10^4-10^5 required

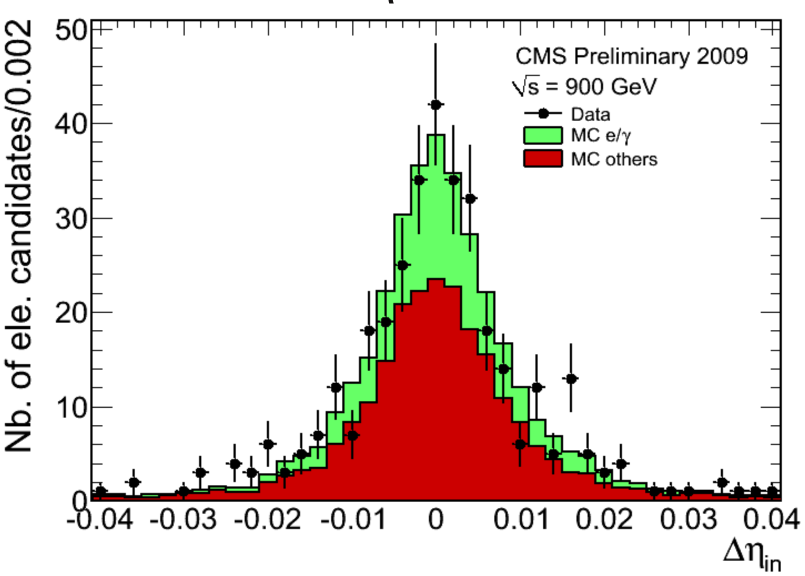
Tools for background rejection:
- **geometrical ECAL/tracker matching**
- **E/p**
- **HCAL/ECAL deposits**
- **cluster shape**
- **candidates isolation**

e

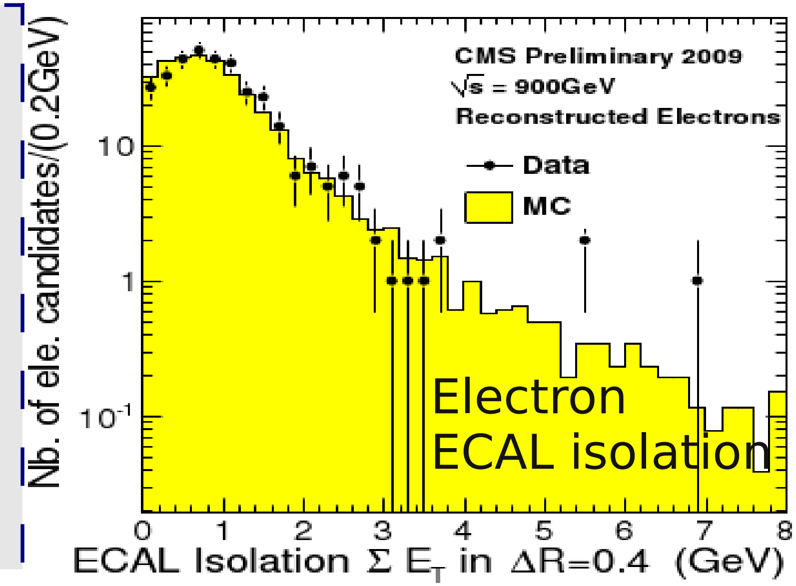
γ



Electrons $\Delta\eta$(SC-Track)



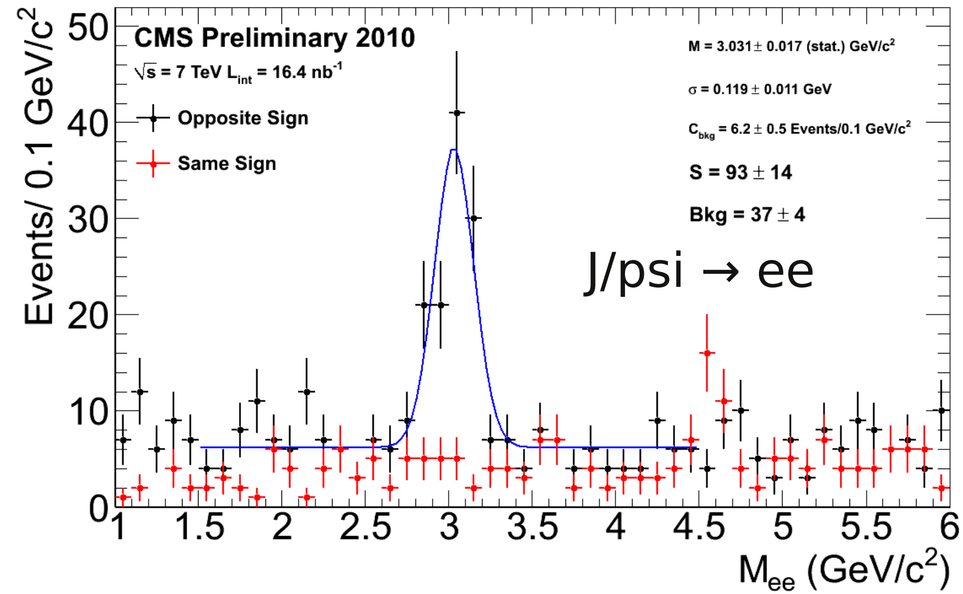
Isolation sums calculated adding calorimetric deposits or track momenta around candidates

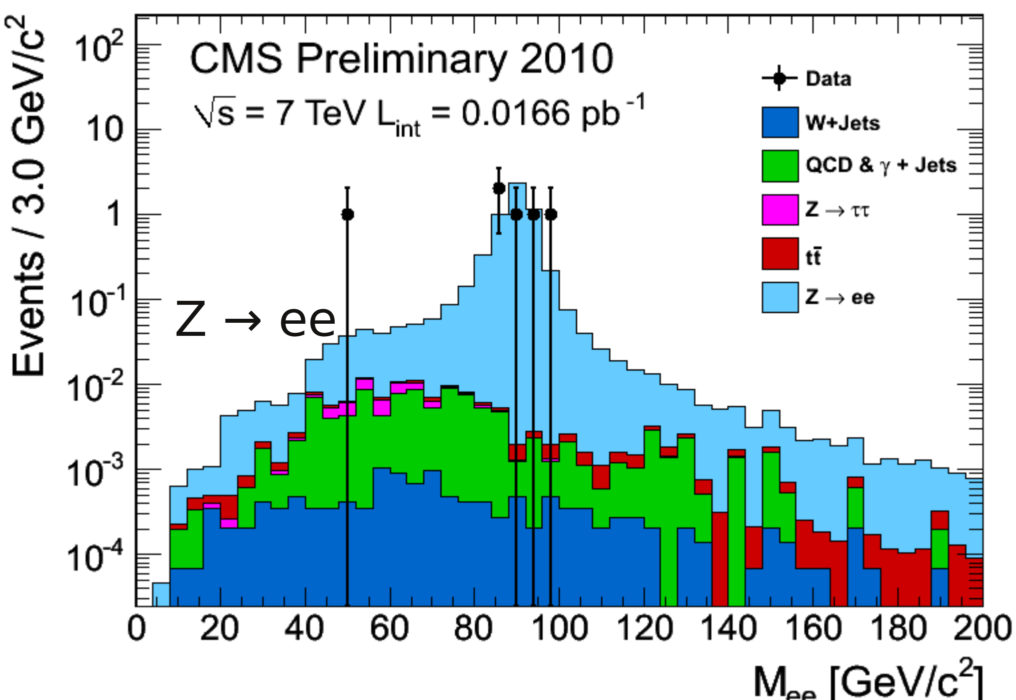


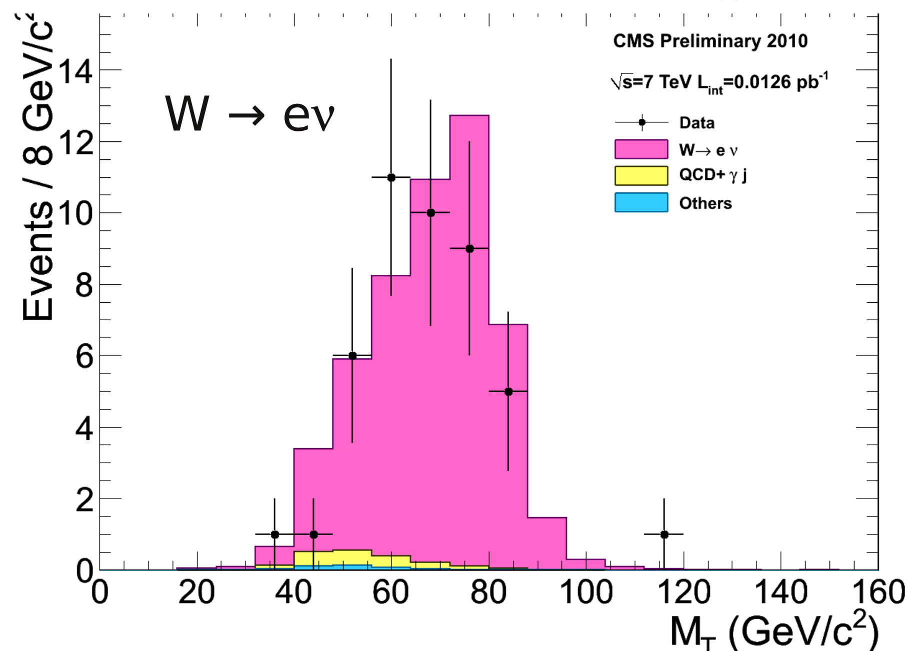
From objects to Physics processes

Using particle identification tools, resonances decaying in electrons can be selected.

J/psi, Z and W peaks becoming visible with ~15nb^{-1} of $\sqrt{s}$=7TeV data







(More on W's and Z's E.Di Marco's talk)

Summary

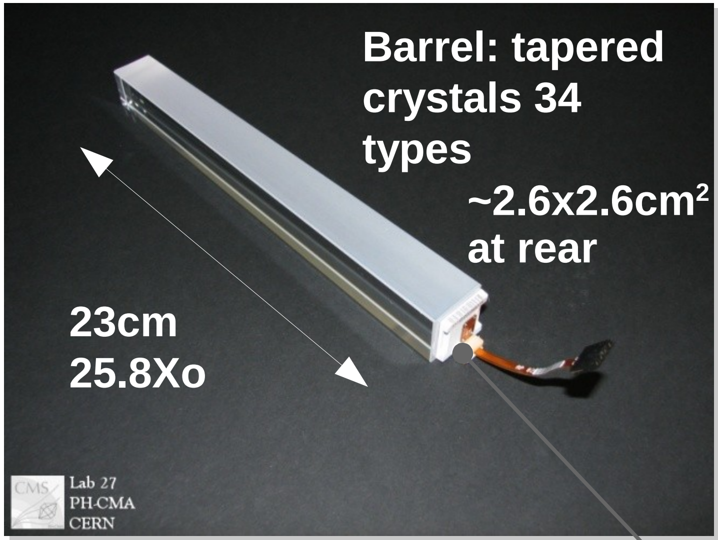
- Crystal and preshower CMS Electromagnetic Calorimeter are fully operational at CERN LHC
- Successful beam data taking in 2009 and 2010
  - Low energy resonances important for detector commissioning
  - Good detector calibration already achieved. Excellent perspectives for 2010
- Electromagnetic physics objects commissioned with 900GeV data
  - Allowed commissioning of reconstruction algorithms
- First resonances observed at $\sqrt{s}$=7TeV
  - Excellent perspectives for physics with e/γ in 2010-2011

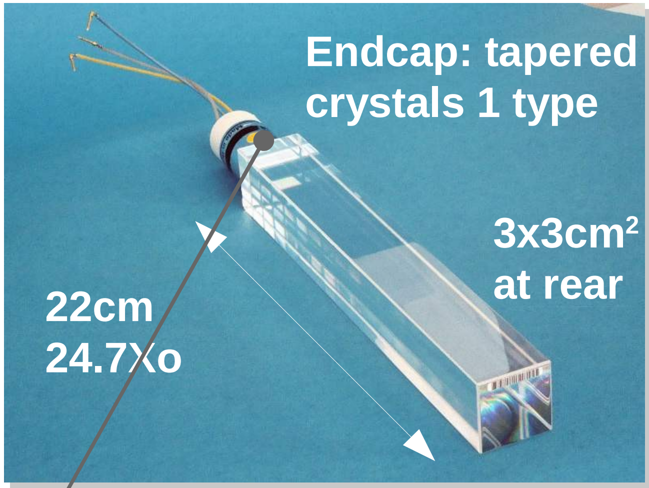
Backup

Crystals and photodetectors

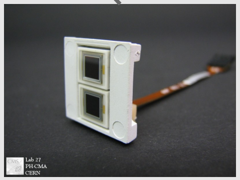
$PbWO_4$
- Homogeneous medium
- Fast light emission ~80% in 25ns
- Short radiation length Xo = 0.89cm
- Small Moliere radius Rm = 2.20cm
- Emission peak 425nm
- Good radiation hardness

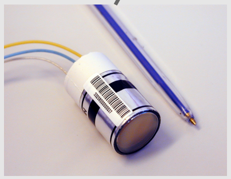
Challenges
- Low light yield
Need highly efficient photodetectors
- L.Y. temperature dependent: -2%/C
Need excellent thermal stability
- Formation and decay colour centres:
Need precise light monitoring system





Avalanche Photo Diodes
(2x 5x5mm^2)
Q.E.: ~75%
Temp. coeff: -2.4%/C





Vacuum Photo Triodes
More rad. hard
Q.E.: ~20%

Results from cosmic ray runs

Muon stopping power in PbWO

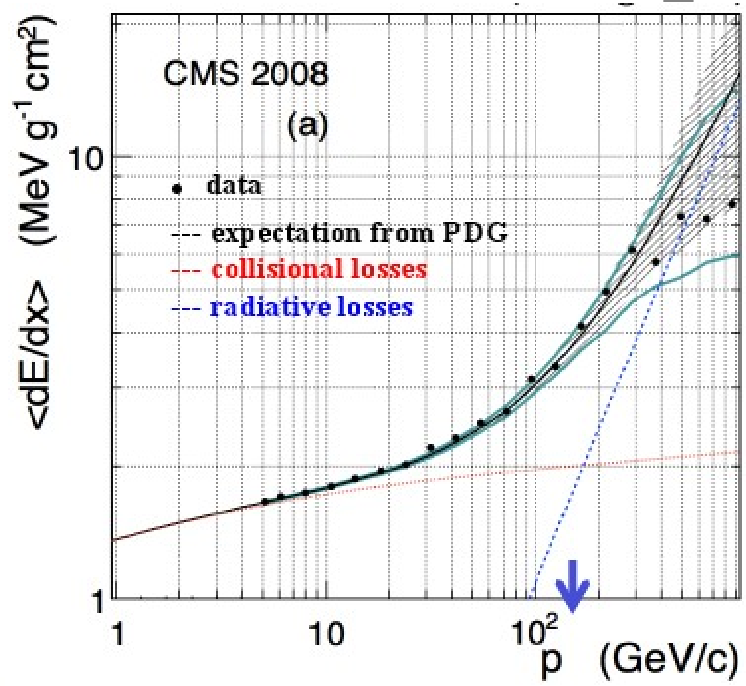
- dE/dx as a function of muon p 2GeV:1TeV
- dE from ECAL cluster
- p from Si Tracker measurement

Energy scale from test-beam validated with an overall <2% precision

Measured PbWO critical energy:

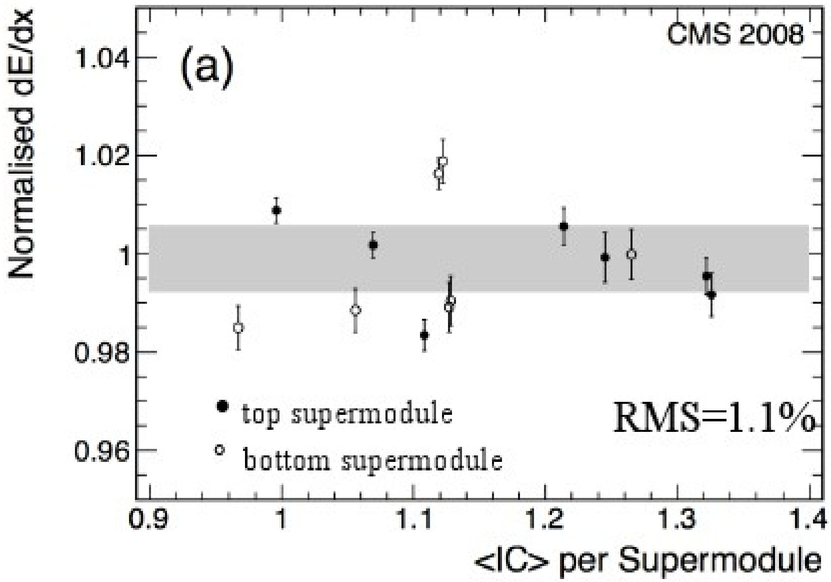
$$160^{+5}_{-6}\,(\text{stat.}) \pm 8\,(\text{syst.})\ \text{GeV}$$

PDG prediction: 169.5GeV



EB local energy scale validation

- use dE/dx from coll. losses (p_μ 5:10GeV/c)
- used vertical SM
- stat. uncertainty: 0.4%
- syst. uncertainty:
  - 0.5% from muon/crystal angle
  - <0.5% from muon spectrum variations



Response uniformity verified with 1% precision

Beam splashes in the crystals

Beam splashes from 2009 run as seen by the crystals

Average energy deposited per crystal in 800 consecutive splashes ~12GeV

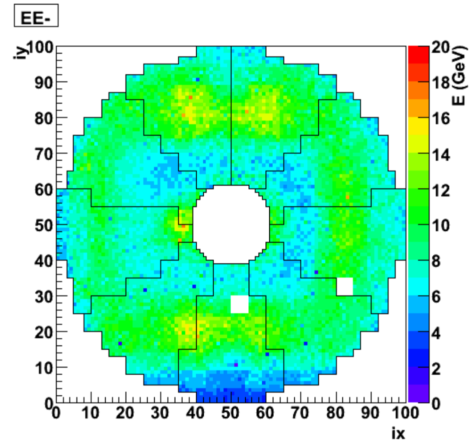
White regions correspond to crystal masked from the readout

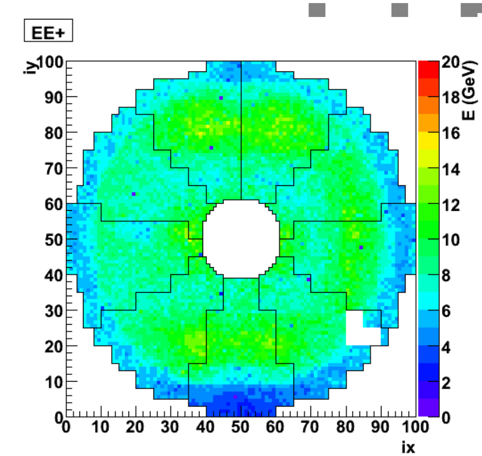
Beam splash events for detector calibration

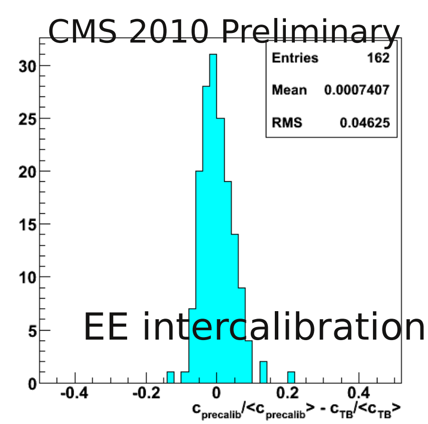
Local deposit uniformity used to extract EE intercalibration constants.

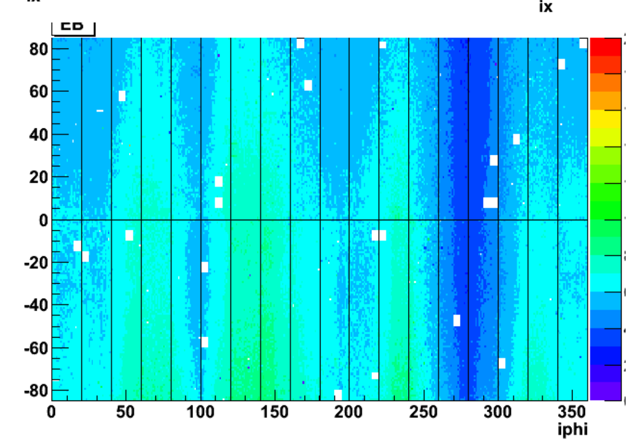
Precision improved from 7.4% to 4.3%

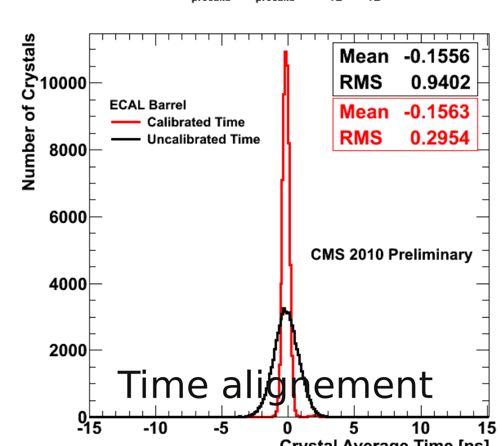
Extracted time alignment constants for sub-ns time precision at high energy

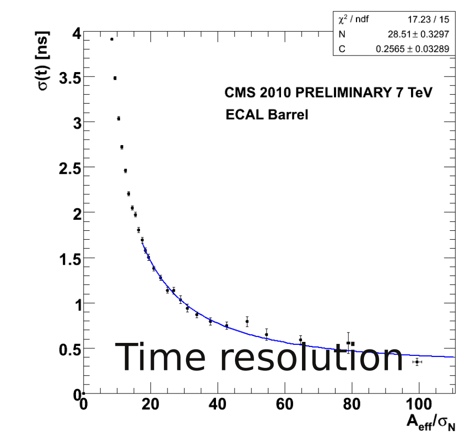




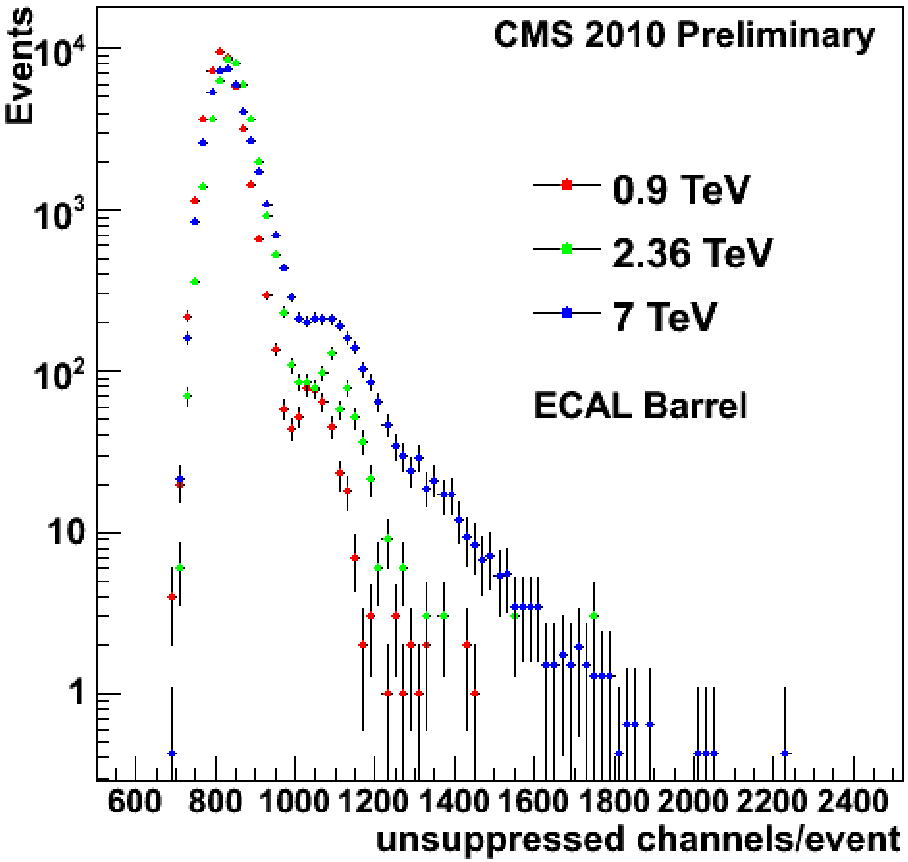


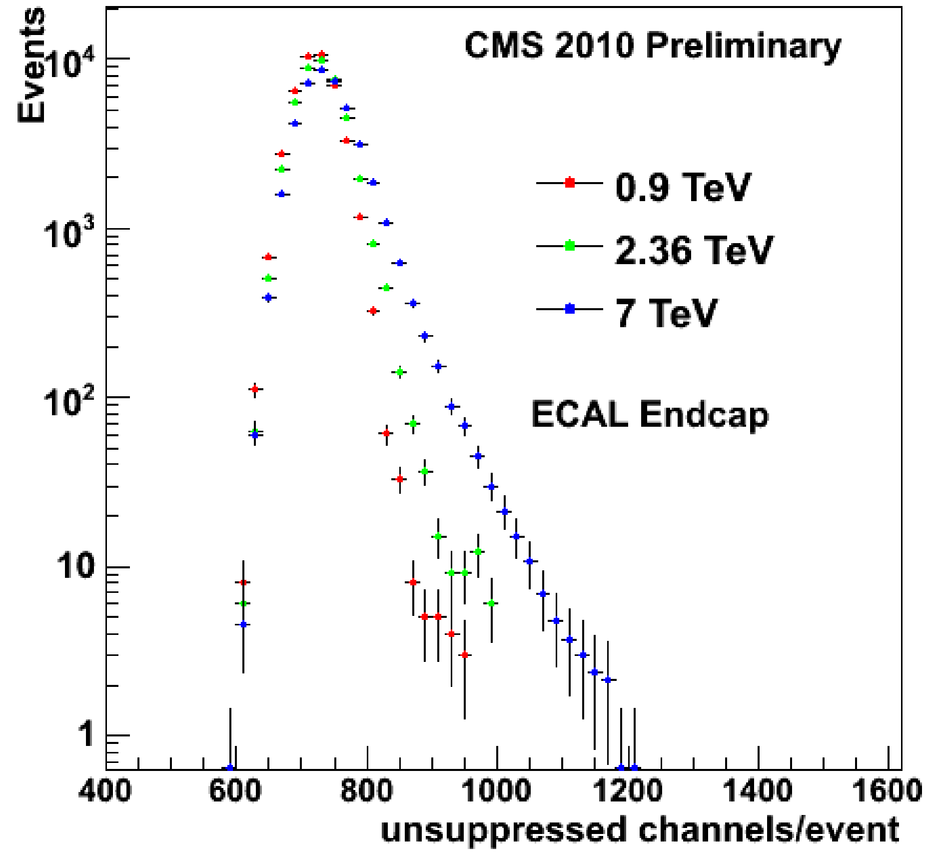






Online data reduction

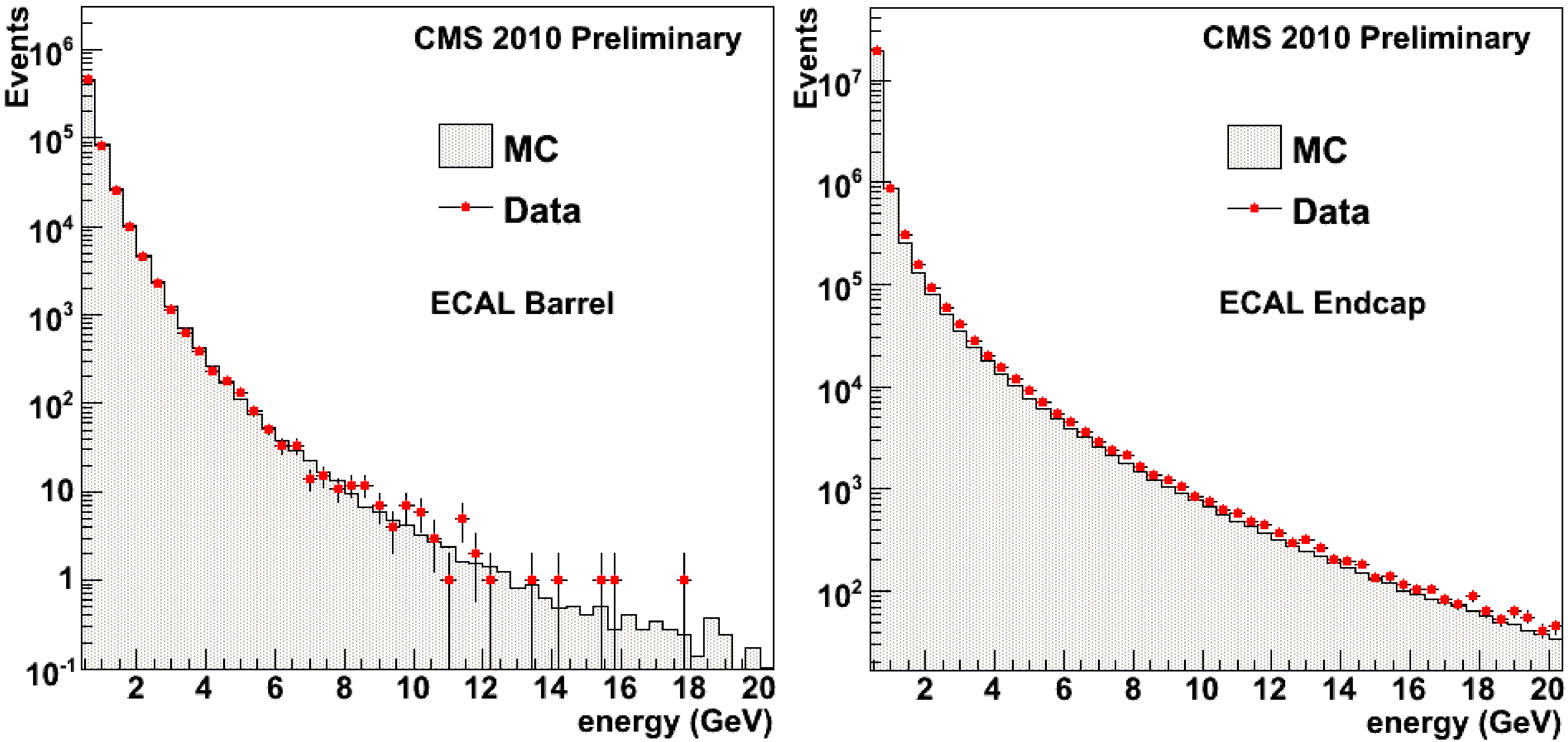




- Number of readout channels per minimum bias event at 0.9-7 TeV cms energy

The readout is controlled by the Selective Readout Processor. The main peak is due to channels in low interest regions and above zero suppression threshold; secondary peaks at larger occupancies are due to high interest regions (E_T>2 GeV) where 225 crystals are readout without zero suppression. The increased number of readout channels per events reflects the hardening of the E_T spectrum with the centre of mass energy

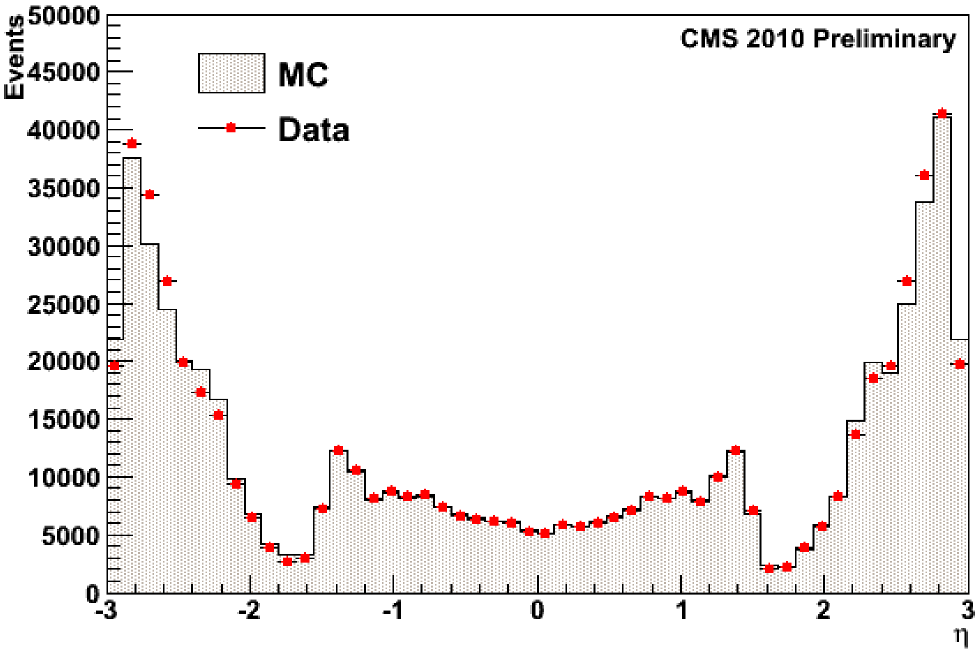
Energy spectra per channel

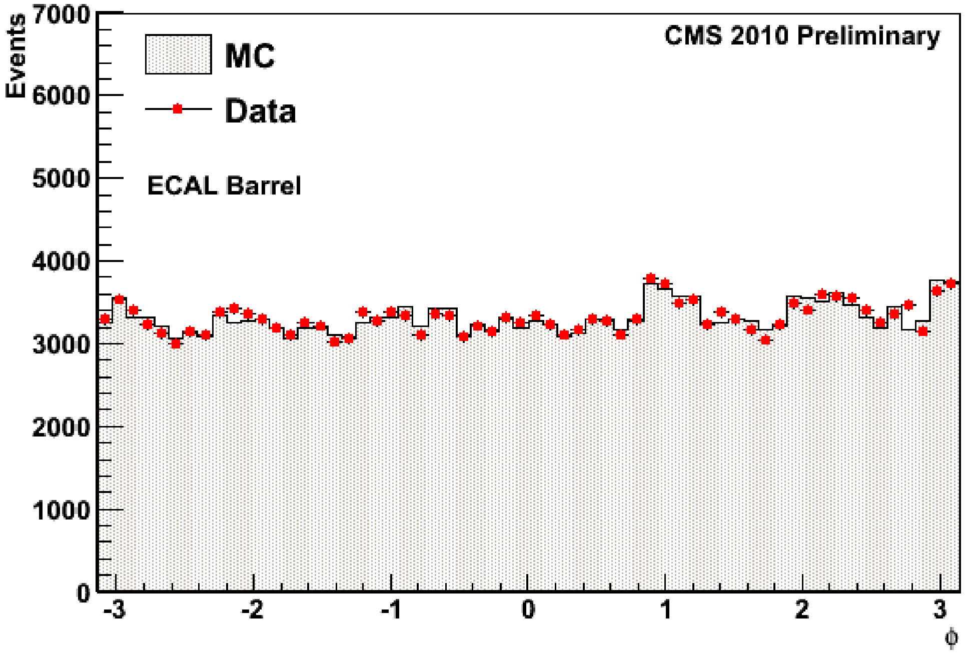


- Energy spectra in the individual channels. Data and MC are for the same luminosity; event quality and signal quality[1] selections are applied

[1] Removal of signals in Data due to direct deposits in the readout Avalanche Photodiodes (APD), not yet simulated in MC

Rapidity and azimuth distributions





Rapidity and azimuth distributions the channel with highest reconstructed E_T in the ECAL barrel and in the ECAL endcaps (two channels per event) in minimum bias events at 7 TeV

The discontinuity at the transition between ECAL barrel and ECAL encaps ($\eta=\pm1.5$) is an artifact of the selection, to enhance the contribution of ECAL barrel events

Variations as a function of φ, fairly reproduced in MC, reflect modularity and the inhomogeneity of the energy equivalent noise in ECAL

A few channels with noise level higher than the average, not yet simulated in MC, are excluded from the comparison in the endcaps

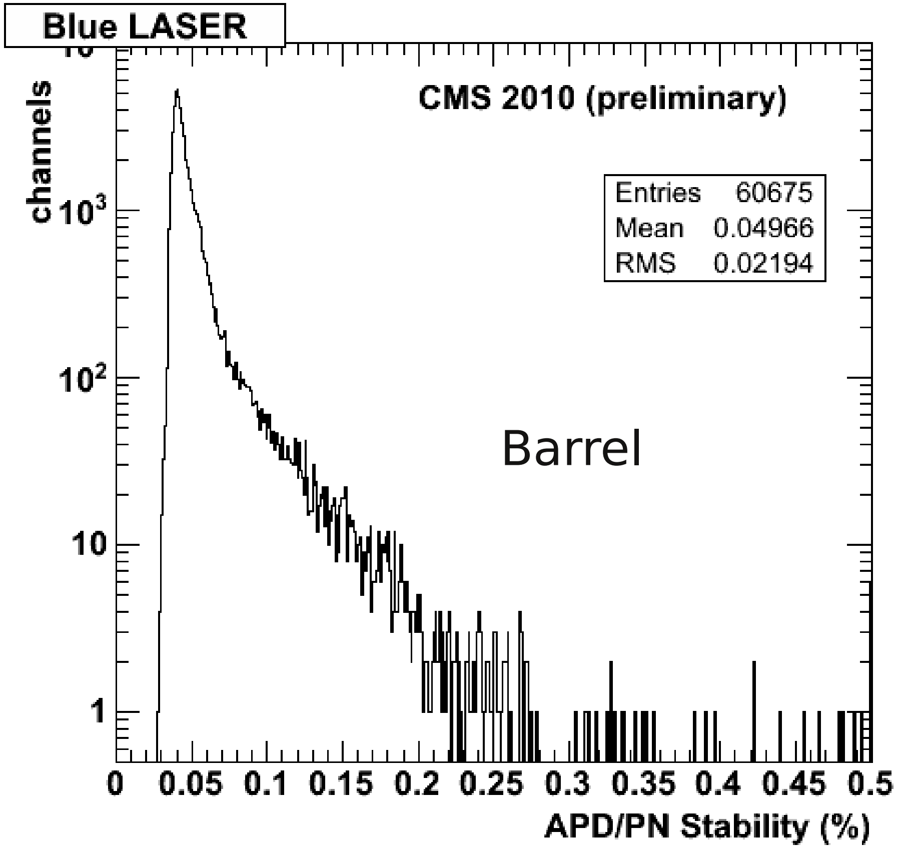
Laser stability

Transparency losses occurs in $PbWO_4$ at high luminosity during LHC fills. Crystals undergo recovery in inter-fill periods

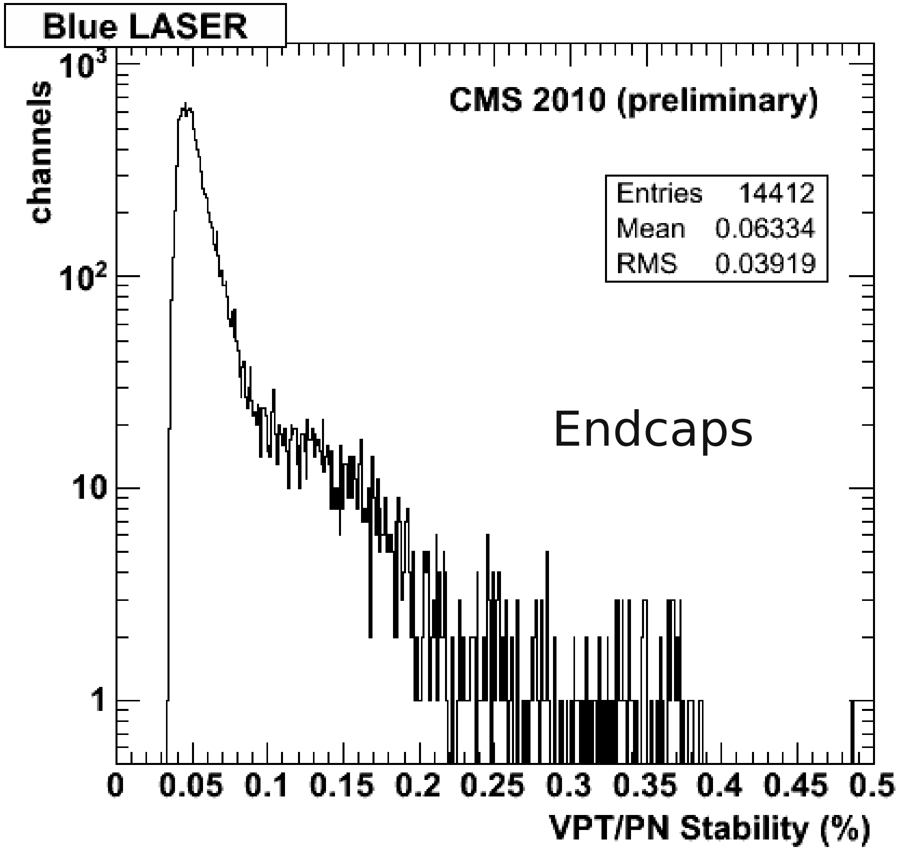
Transparency variations are tracked using a laser monitoring system.

Pulse-to-pulse variations are corrected using reference PNs.

The stability of the monitoring system is estimated from the RMS of the normalized pulse response over a 500h period.



97.5 % of channels below 1 per mil
99% of channels below: 2.4 per mil



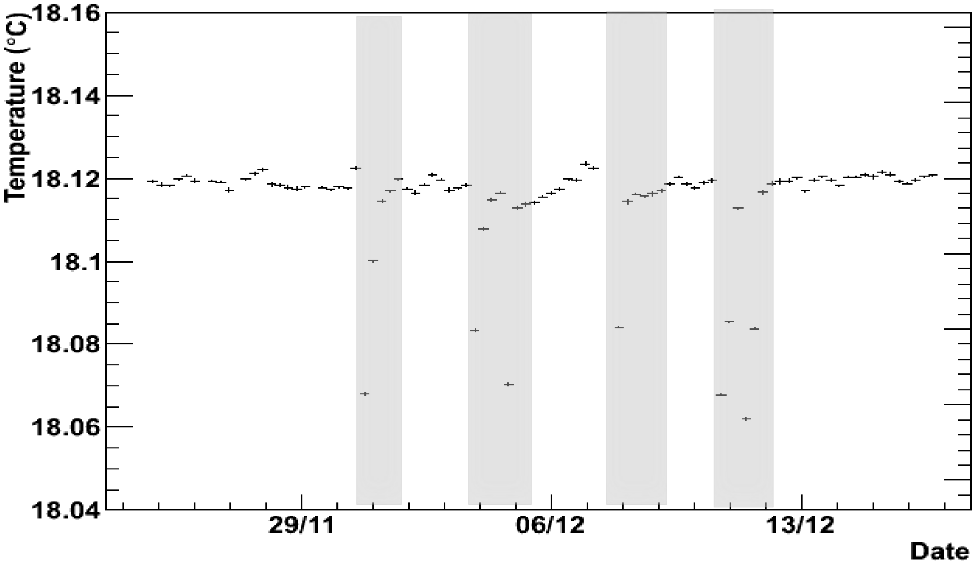
90.5 % of channels below 1 per mil
99% of channels below: 2.5 per mil

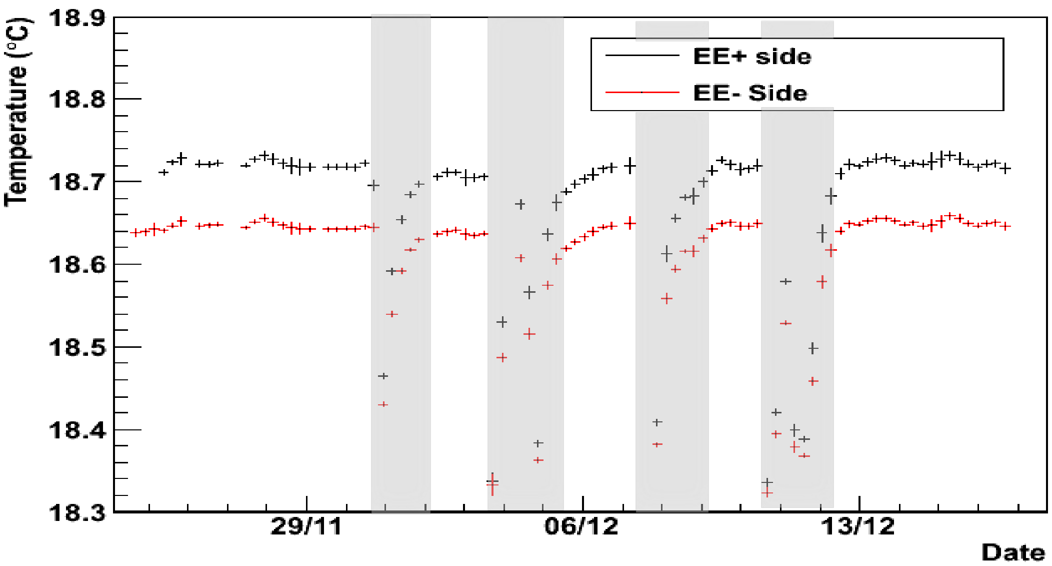
Temperature stability

Temperature in ECAL Barrel (Endcap) need to be stable to better than 0.05 °C (0.1 °C), to keep amplitude response variations below 0.25%

Barrel and Endcap temperature was monitored during the 2009 LHC run.

During beam-on period, the average RMS was found 0.007 ± 0.002 °C for the Barrel and 0.010± 0.008°C for the Endcap





Periods outside data taking are shaded. Instabilities are related to LV off periods.

The CMS detector

CMS

Weight:	**14000t**
Diameter	**15m**
Length	**21.6m**
Magnetic field	**3.8T**