The CMS Electromagnetic Calorimeter: Construction, Commissioning and Calibration

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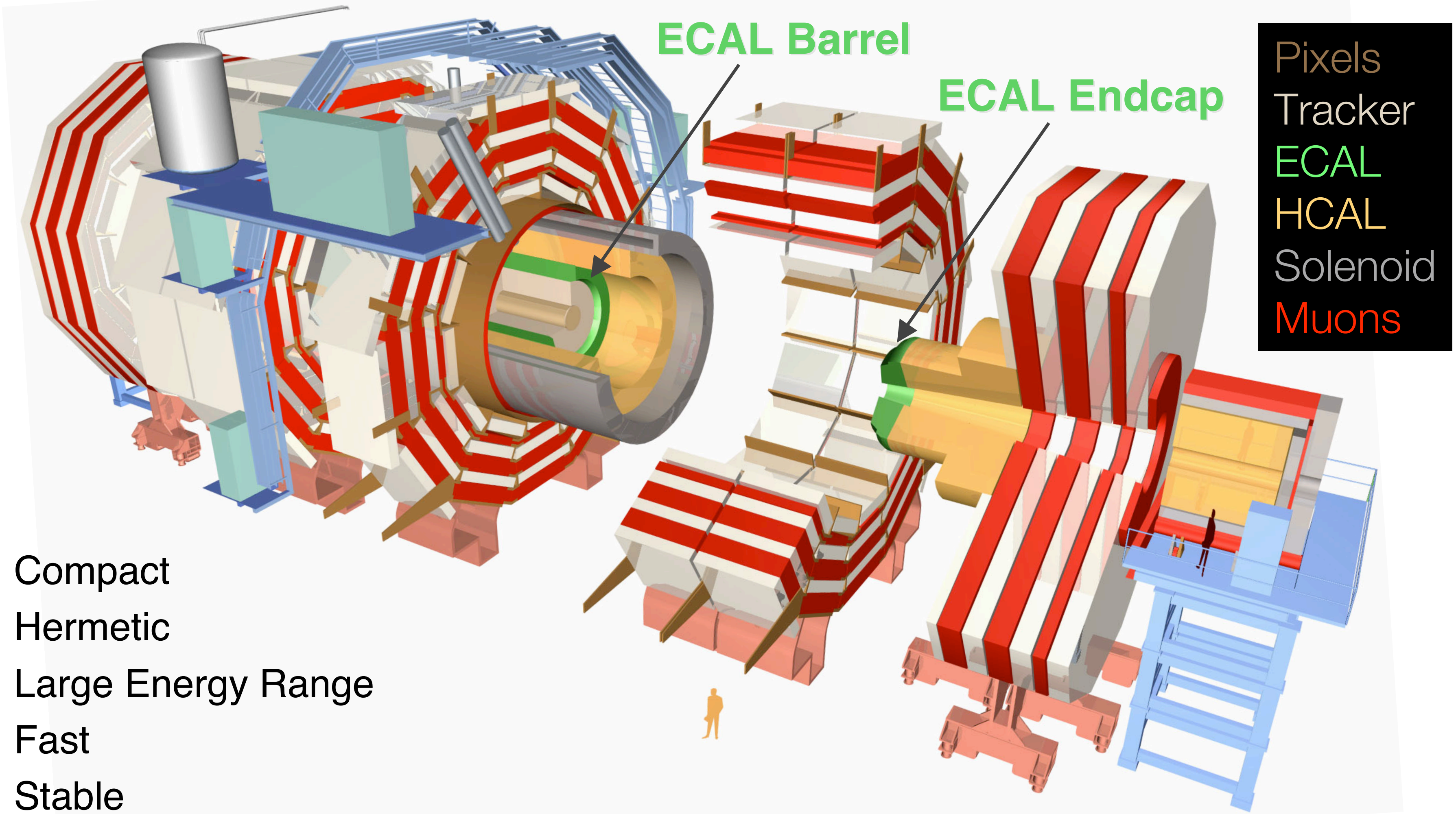
CMS ECAL Requirements



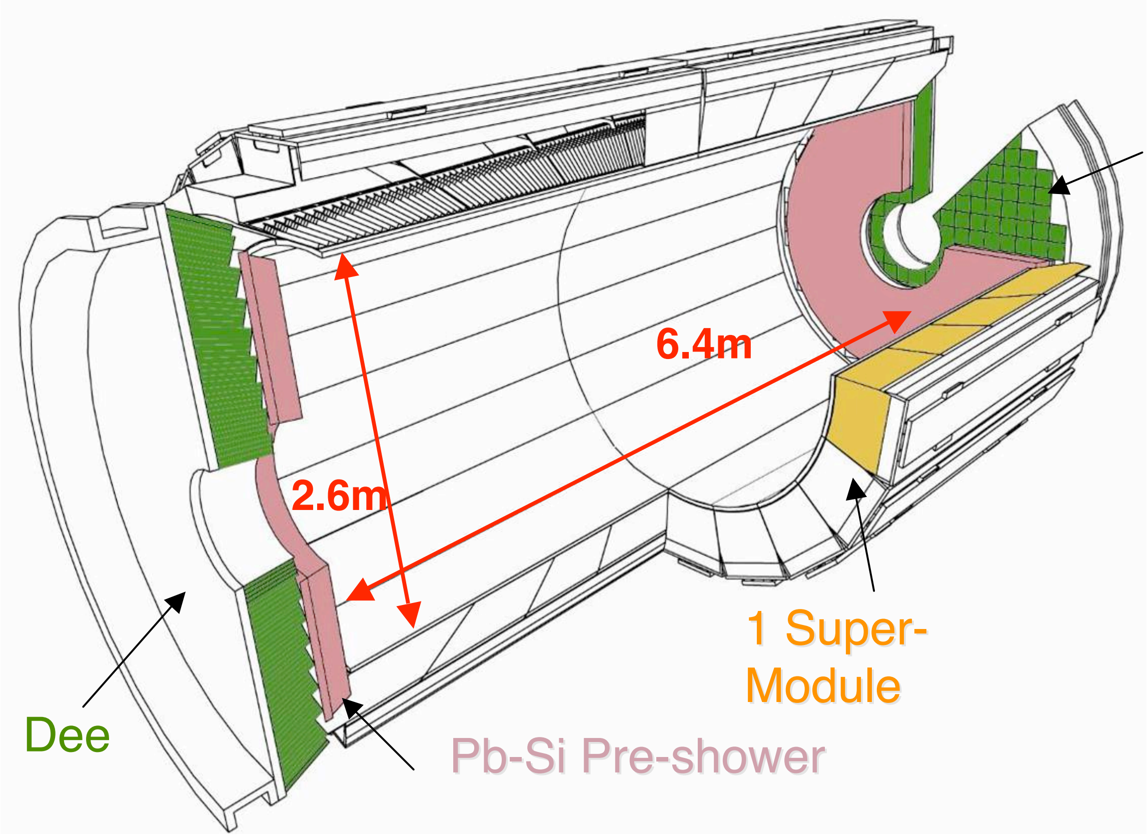
- Compact
- Hermetic
- Large Energy Range
- Fast
- Stable
- Radiation Resistant
- Excellent Energy Resolution

- Benchmark channel: Discovery of low mass Higgs in H→γγ channel

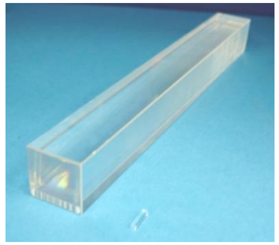
- Target energy resolution 0.5% at high energy

CMS ECAL Design

Homogenous Lead Tungstate ($PbWO_4$) Crystal Calorimeter + Pb-Si Preshower



Crystals are projective and positioned pointing slightly off the IP to avoid cracks.

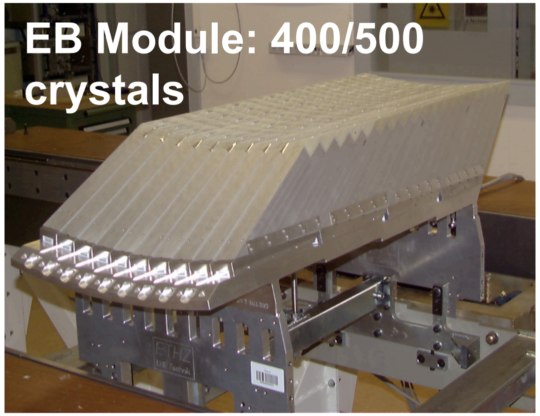


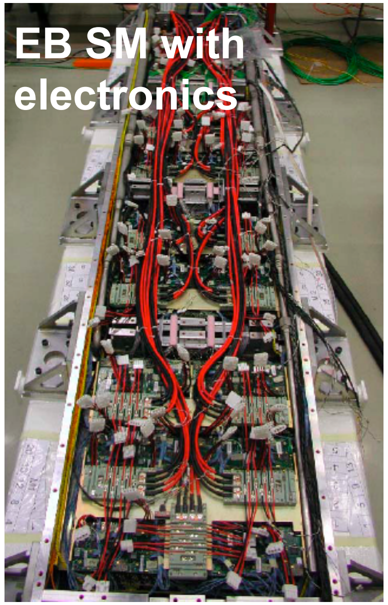
Barrel (EB):
- 61200 crystals
- 36 Supermodules (SM), each 1700 crystals
- $|\eta| < 1.48$

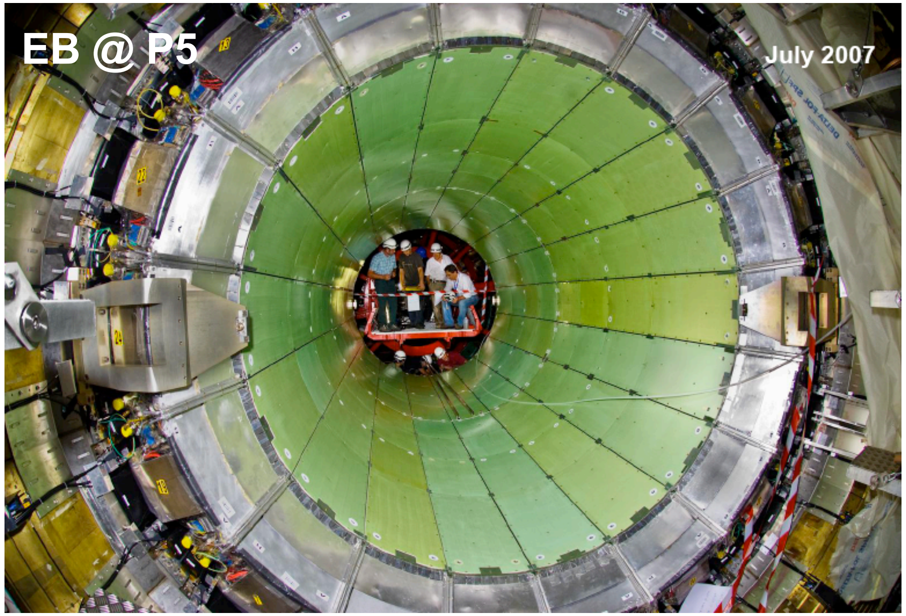
Endcap (EE):
- 14648 crystals
- 4 Dees, SuperCrystals of 5x5 xtals
- $1.48 < |\eta| < 3.0$

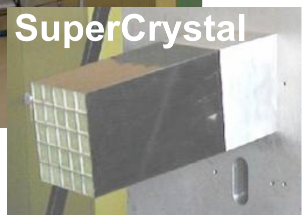
Preshower (ES):
- Pb-Si
- 4 Dees
- 4300 Si strips
- $1.65 < |\eta| < 2.6$

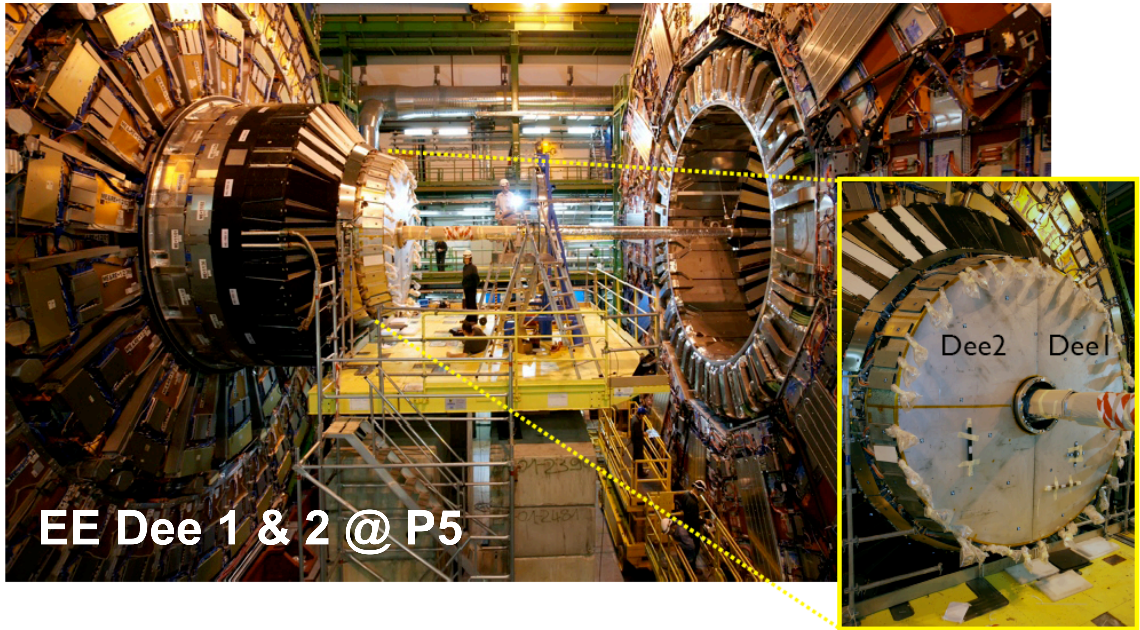
ECAL Construction





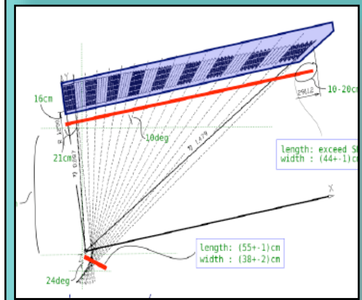




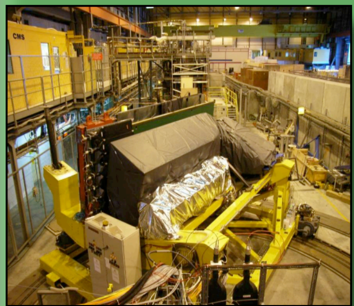


Highlights from the CMS ECAL Timeline

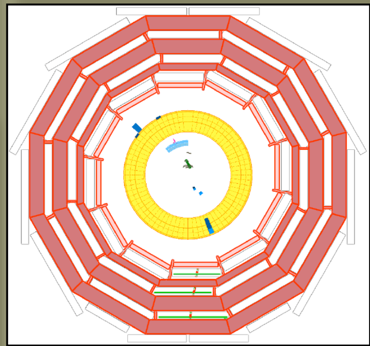
2006-2007:
Commissioning & calibration of each SM with cosmics on surface



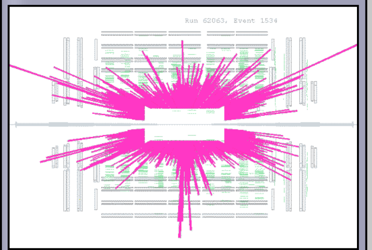
2006:
H4 Test Beam: 9 SM calibrated; H2 Combined Test Beam: ECAL+HCAL



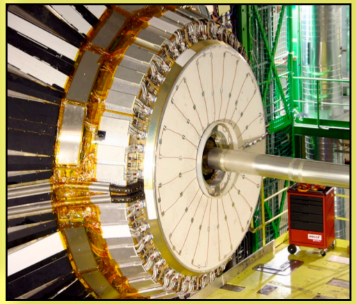
2006:
2 SM tested with B-field on surface (MTCC)



2008:
Endcap Installation. Commissioning with cosmics and first beam in-situ



2009:
Installation of preshower and commissioning of Endcap trigger



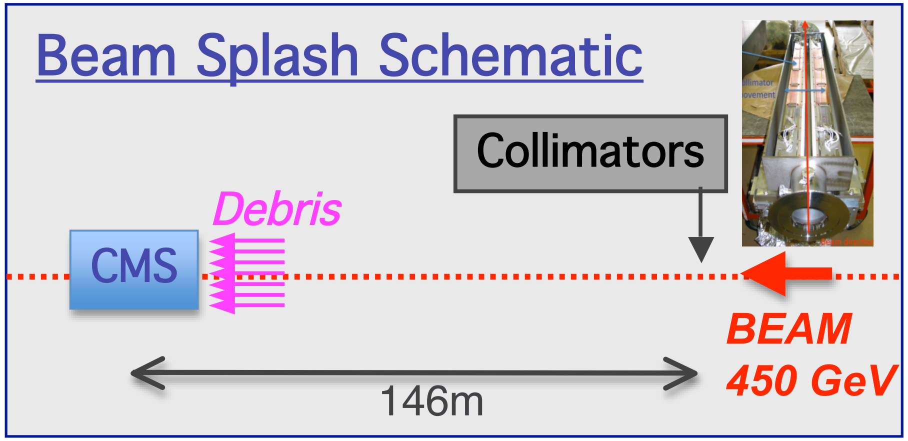
2007:
H4 EE Test Beam; Individual signoff of each SM during installation

2006 **2007** **2008** **2009**

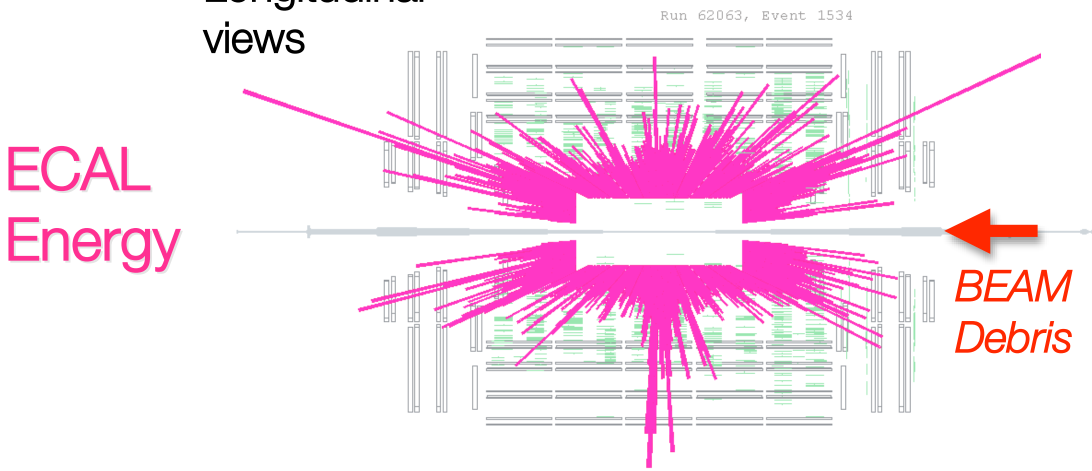
Commissioning ECAL with First Beam

Beam Splash Events: Single beam shots of 2×10^9 protons onto closed collimators 150m upstream of CMS

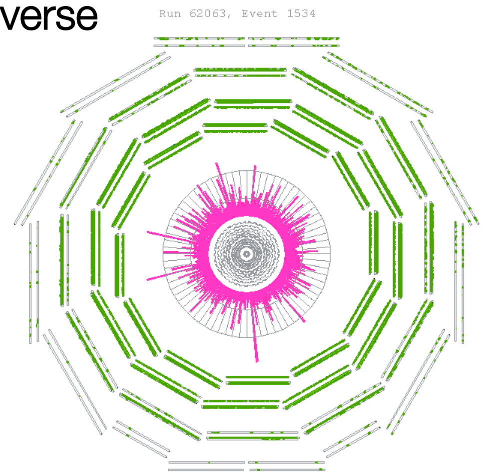
A “wave” or “splash” of secondary particles passed through CMS, depositing a huge amount of energy



Longitudinal views

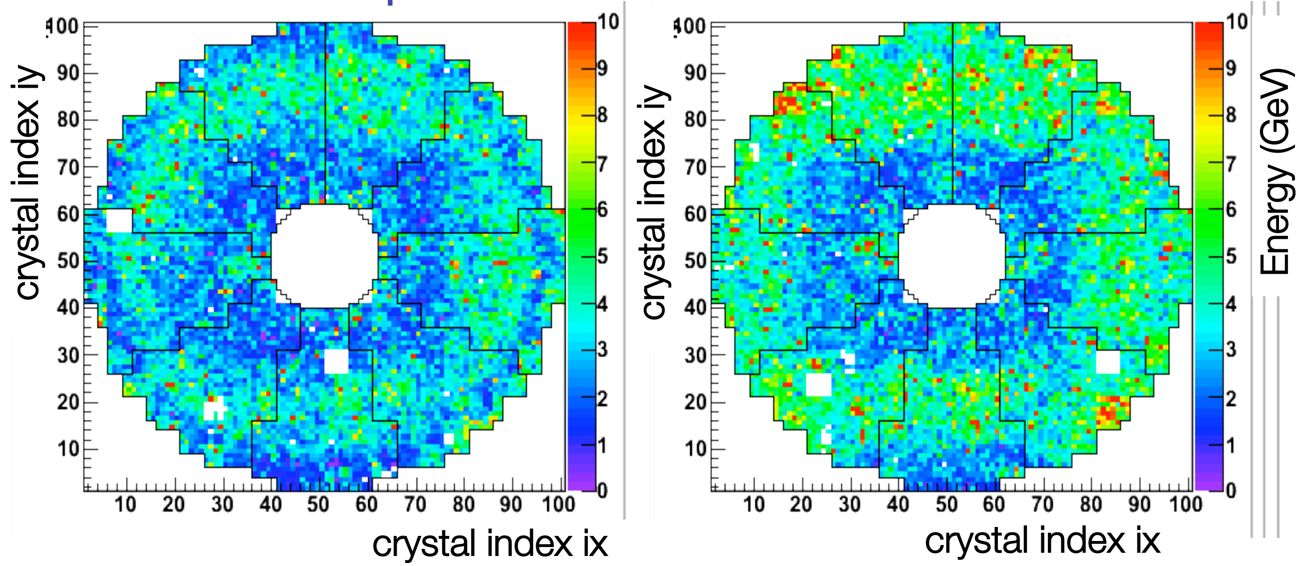


Transverse views

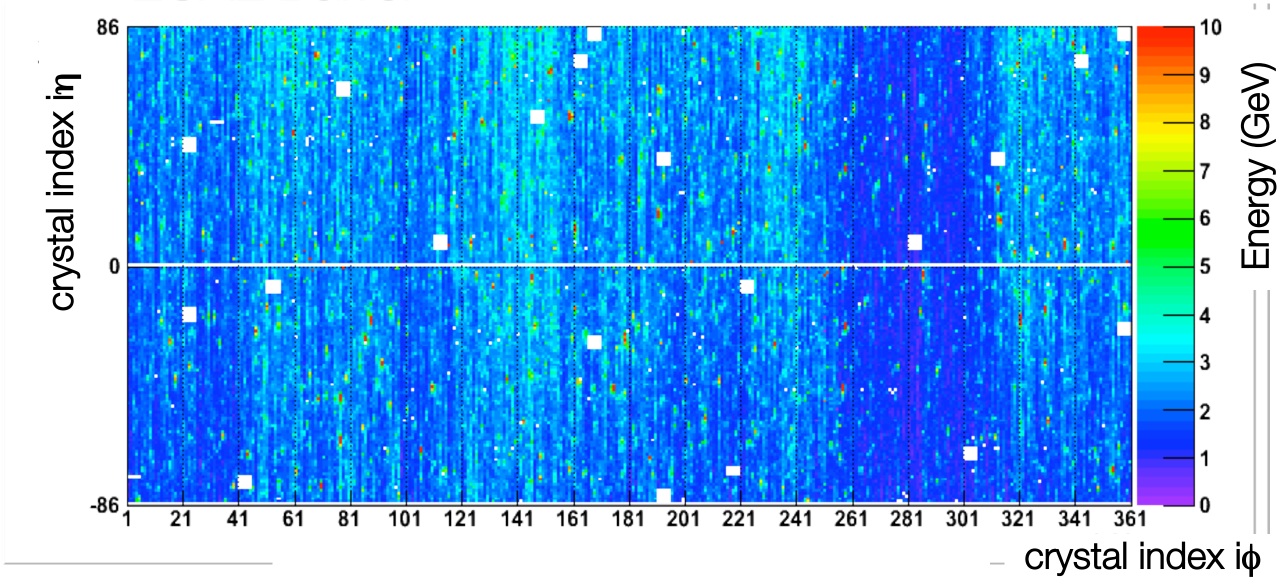


Beam Splash: ECAL Energy

ECAL Endcaps



ECAL Barrel

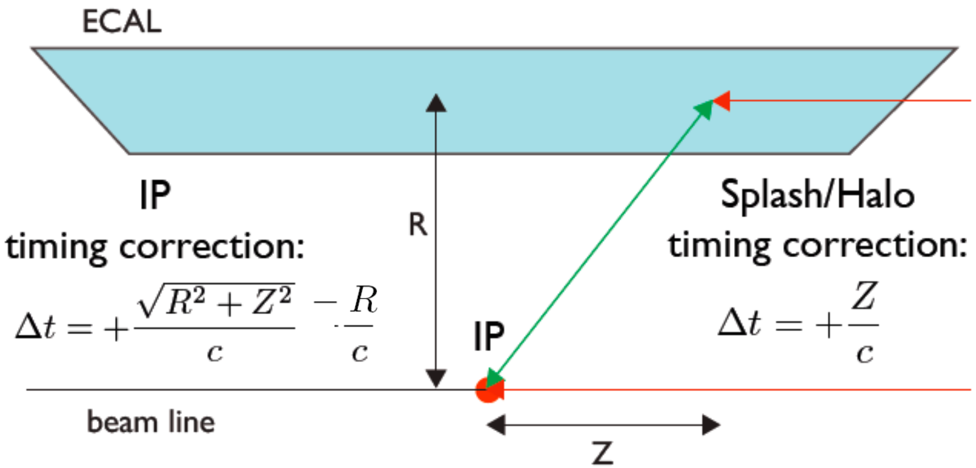


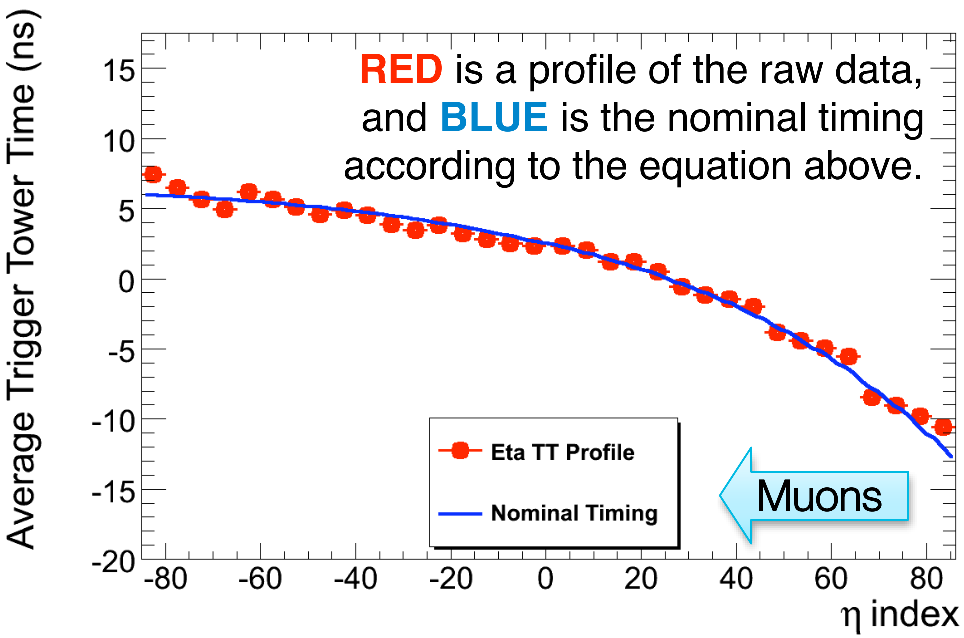
- More than 99% of ECAL channels fired
- Enormous amount of energy deposited in calorimeters!
- ~200 TeV energy deposited in EB+EE
- Estimated hundreds of thousands of muons passing through CMS per event
- White areas: channels masked from readout

Beam Splash: ECAL Timing

Beam splash events provide a source of synchronous hits throughout detector, allowing to internally synchronize ECAL

$$\Delta t = \Delta t_{Readout} + \Delta t_{PlaneWave}$$
$$= (\sqrt{x^2 + y^2 + z^2} - R \pm z)/c$$





- **Hardware** allows steps of **1ns** steps
- Further synchronization applied in **offline** reconstruction, **better than 1 ns**
- Synchronization prior was done with laser light; Latency then adjusted w/ splashes
- Synchronization from beam splashes will be start-up condition; better precision w/ LHC data

Commissioning ECAL with Cosmics

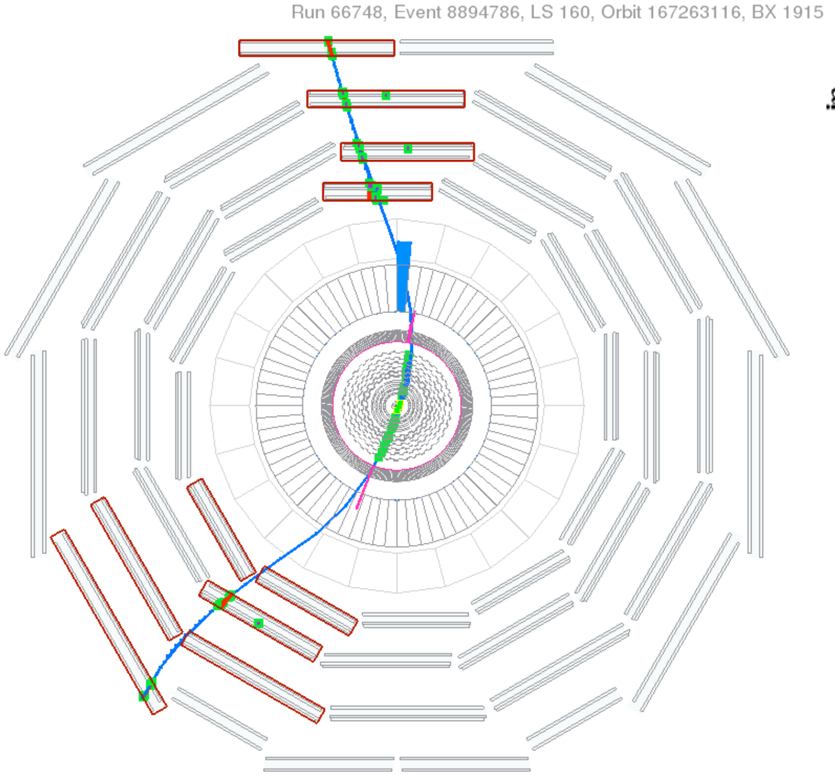
CRAFT: Cosmic Run At Full Tesla

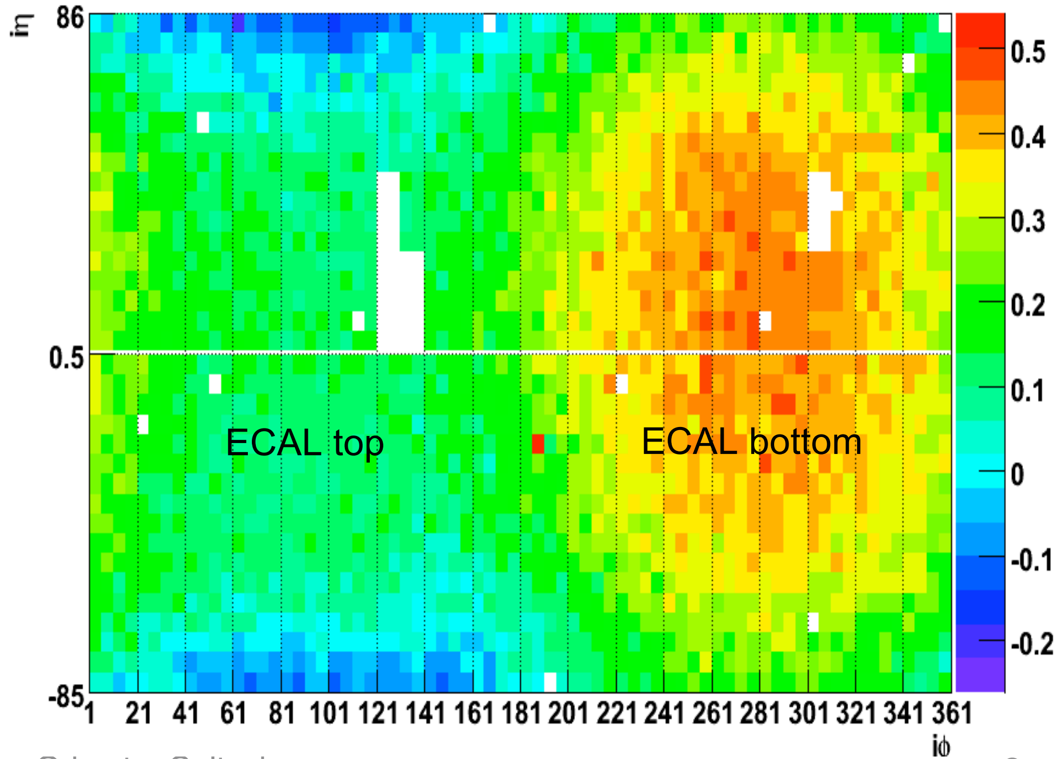
- > 300 M cosmic events collected
- 3.8T field operated for ~1 month
- All CMS subsystems participated

ECAL Timing

- Average timing of cosmic signal
- Top-bottom difference (t.o.f.)

$$t_{top} - t_{bottom} = c \cdot t_{flight}$$

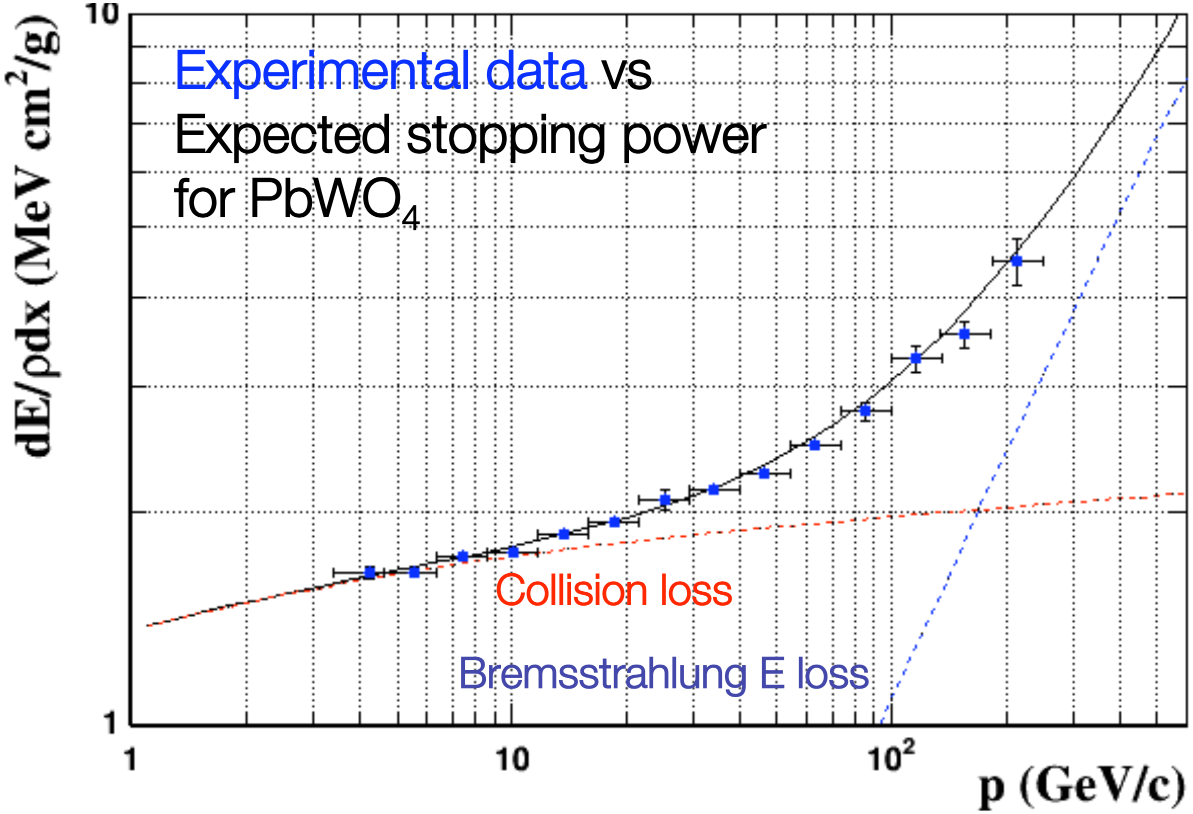




Stopping Power dE/dx with Cosmics

dE/ρdx of cosmic muons traversing ECAL vs muon momentum

- Events for dE/dx selected to be loosely pointing: d0<1m, |dz|<1m
- dE: energy from ECAL clusters
- dx: length traversed in ECAL crystals
- Momentum measured by silicon tracker



Results indicate the correctness of the tracker momentum scale and ECAL energy scale.

ECAL Calibration & Monitoring

Calibration of ECAL crucial to maintain high energy resolution

- Without inter-calibration, same signal would produce different outputs in different crystals.
- Also need overall energy scale

$$E_{\mathrm{e},\gamma} = G \times \mathcal{F} \times \sum_{i}^{\text{Cluster}} c_i \times A_i,$$

absolute energy scale

algorithmic corrections

inter-calibration constants

amplitudes

Uncalibrated Supermodule:
6%-10% spread in response among channels

→

Lab Pre-Calibration:
4% EB, 9% EE (all crystals)

Cosmic Pre-Calibration:
1.5-2.5% (all EB)

TestBeam Pre-Calibration:
<1% (1/4 of EB & 400 EE xtals)

→

In-Situ Physics Calibration:
0.5% resolution

ECAL Monitoring (Monitor Stability and Measure Radiation Effects):

ECAL Stability (<< 0.5%):
Monitored with Laser System

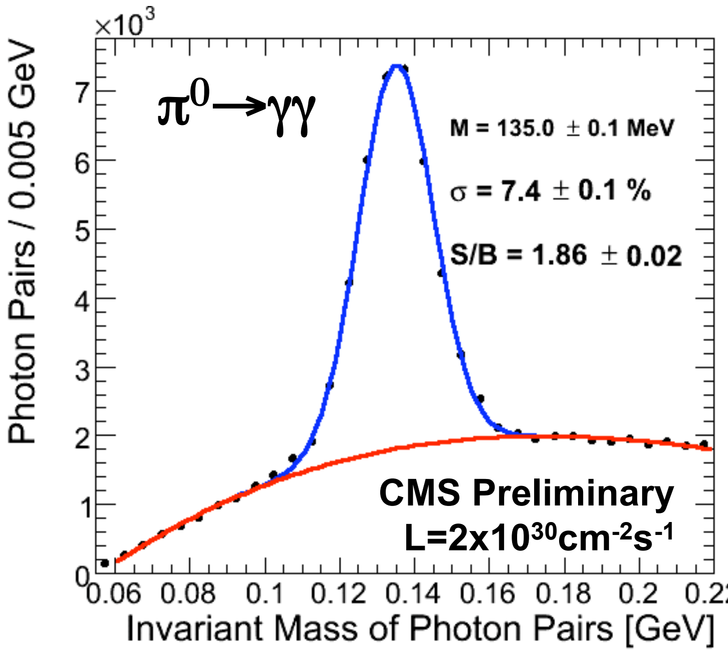
→

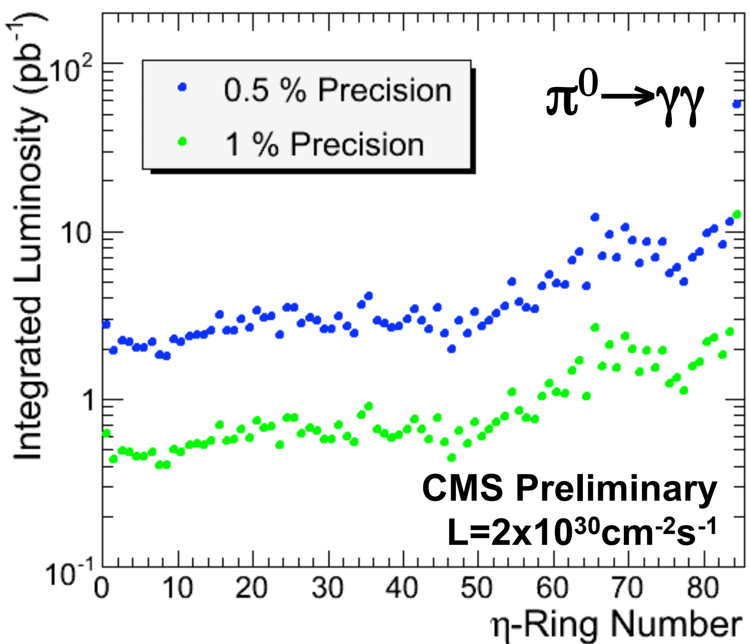
Transparency Change Correction:
Signal Change under Irradiation,
Measured with Laser Monitoring System

ECAL In-Situ Calibration

Goal: improve startup calibration as quickly as possible in-situ

Strategy	Time	Precision
ϕ symmetry: use invariance of mean energy deposited by jets at fixed η	Few hours	~ 2-3%
$\pi^0 \to \gamma\gamma$: mass peak @ low luminosity	Few weeks	<= 1%
$Z \to ee$: absolute energy calibration	100 pb^{-1}	< 1%
$W \to e\nu$: E/p measurement	5-10 fb^{-1}	0.5%





Conclusions

- **Crystal ECAL has been integrated and commissioned in situ, and has been collecting data since 2008**
  - Performance has been proven with first LHC circulating beams
  - In addition, more than 300M cosmic ray events collected during CRAFT
- **Preshower detector installed in Feb-March 09**
  - Being commissioned and has joined CMS global data taking
- **CMS ECAL on track for first LHC collision data**
  - Ready to improve pre-calibration with in-situ physics calibration
  - Expect results not just with cosmics or single beam, but with collisions soon!