Electromangetic calorimeter of CMS: status and performances

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On behalf of the CMS ECAL group

Outline

- Electromagnetic calorimeter at CMS
  - System description
  - Current status
- Results from LHC beams
- Results from cosmic rays running
  - Cosmic rays signal
  - Response stability
- Conclusions

Several CMS ECAL speakers at this conference:

+ The ECAL online software in the commissioning of the CMS detector (poster), Pasquale Musella (LIP)

+ Quality assurance issues of the CMS Preshower (poster), Anna Elliott-Peisert (CERN)

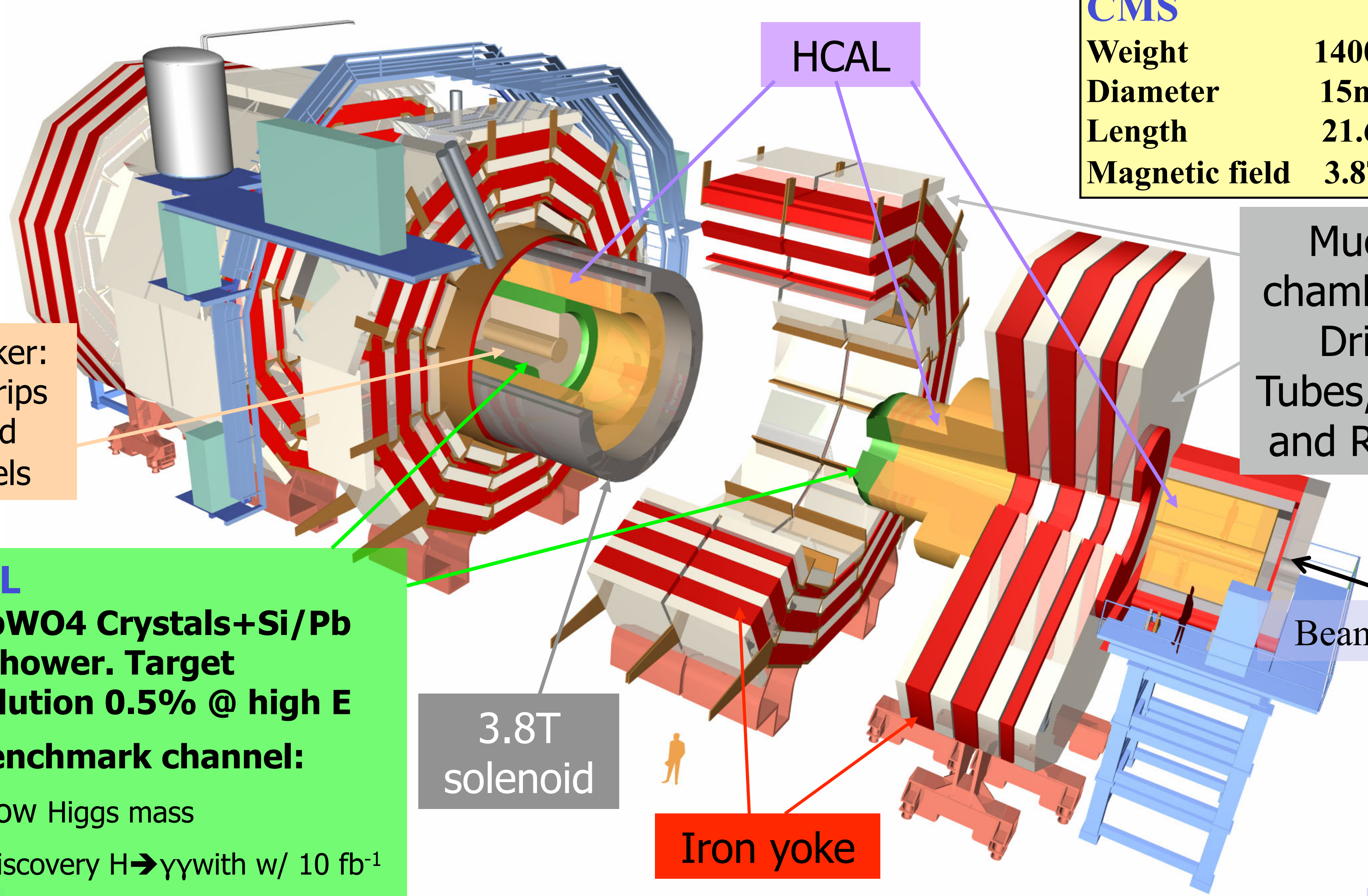
+ Status of the calibration of the CMS electromagnetic calorimeter after the commissioning (poster), Alessio Ghezzi (Milano Bicocca Uni and INFN)

+The CMS preshower construction and commissioning (poster), Rong-Shyang Lu (National Taiwan University - NTU)

+ The CMS ECAL detector control and monitoring system (poster), Wieland Hintz (ETH Zürich)

Electromagnetic calorimeter in CMS

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

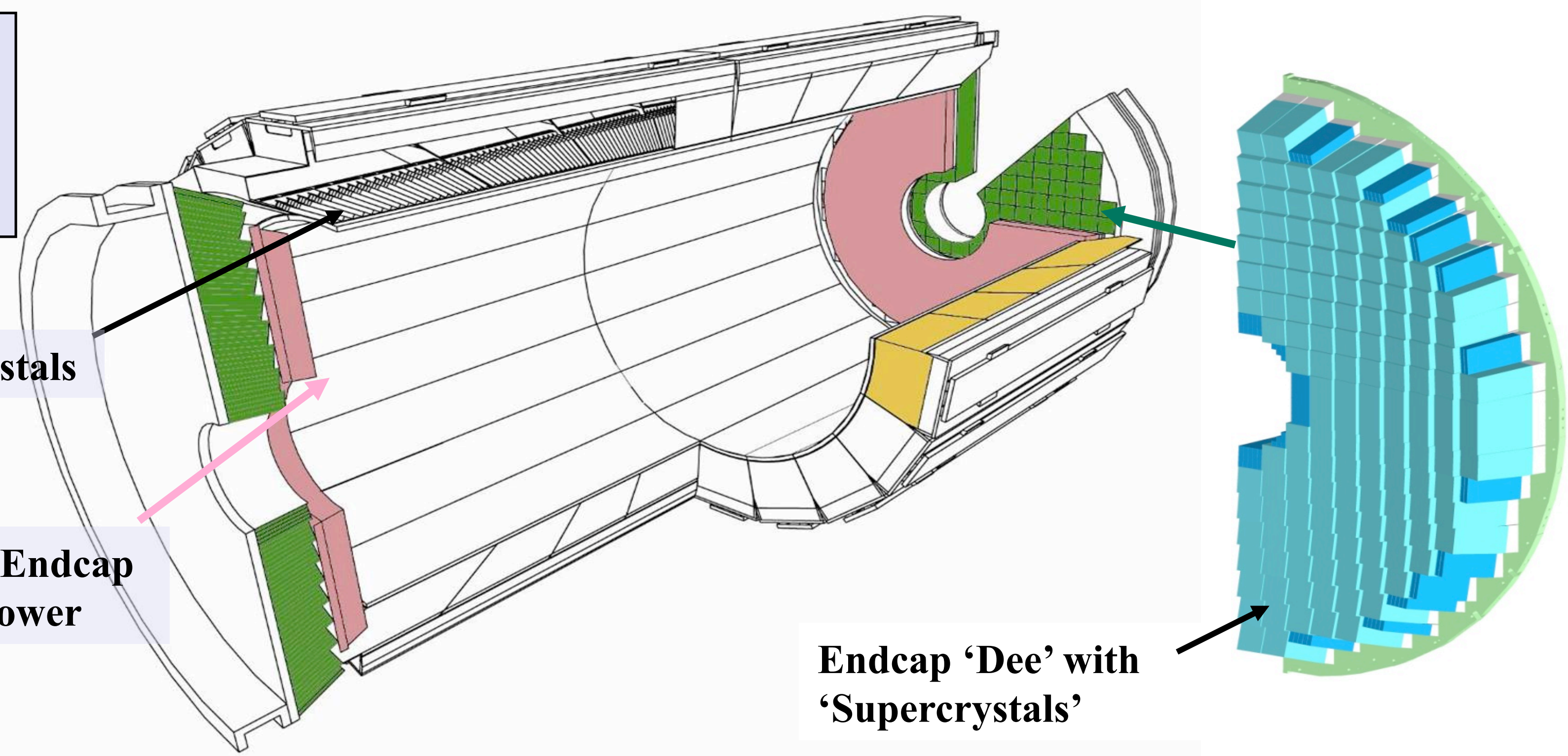


ECAL

- **PbWO4 Crystals+Si/Pb Preshower. Target resolution 0.5% @ high E**
- **Benchmark channel:**
  - Low Higgs mass
  - discovery H➔γγwith w/ 10 fb^{-1}

ECAL layout

PbWO crystals: tapered to provide off-pointing of ~ 3° from vertex

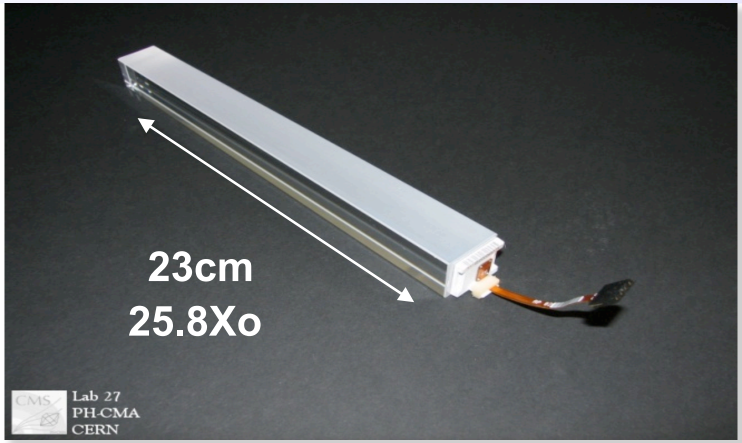


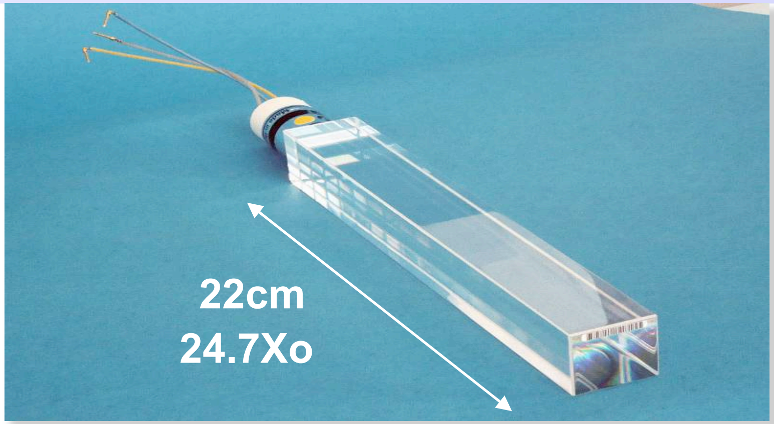
Barrel (EB)
36 Supermodules (18 per half barrel)
61200 crystals
Total crystal mass 67.4t
$|\eta| < 1.48$
$\Delta\eta \times \Delta\varphi = 0.0175 \times 0.0175$

Endcaps (EE)
4 Dees (2 per endcap)
14648 crystals
Total crystal mass 22.9t
$1.48 < |\eta| < 3$
$\Delta\eta \times \Delta\varphi = 0.0175^2 \leftrightarrow 0.05^2$

Endcap Preshower (ES)
Pb ($2X_o$,$1X_o$) / Si
4 Dees (2 per endcap)
4300 Si strips
1.8mm x 63mm
$1.65 < |\eta| < 2.6$

PbWO4 crystals and photodetectors





+ EB crystal, tapered
34 types, ~2.6x2.6 cm^2 at rear

+ Two avalanche photodiodes (APD), 5x5 mm2 each, QE ~75%, Temperature coeff.: -2.4%/°C

+ EE crystal, tapered 1 type, 3x3 cm^2 at rear
+ Vacuum phototriodes (VPT), more rad hard than diodes; gain 8 -10 (B=3.8T), Q.E. ~20% at 420nm

Reasons for choice:

Homogeneous medium
Fast light emission ~80% in 25 ns
Short radiation length X_0 = 0.89 cm
Small Molière radius R_M = 2.10 cm
Emission peak 425nm
Reasonable radiation resistance to very high doses

Challenges:

Crystal LY temperature dependence -2.2%/^{O}C
Need excellent thermal stability

Formation/decay of colour centres
Need precise light monitoring system

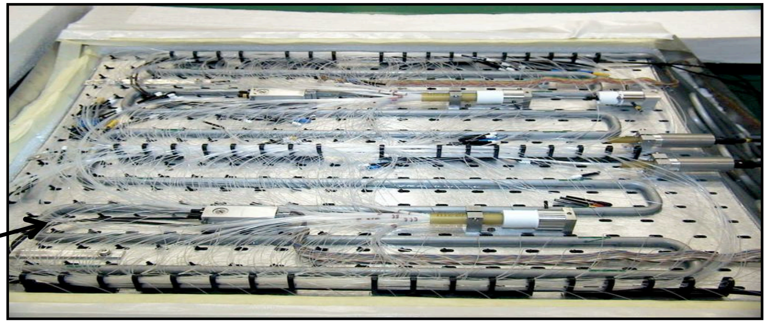
Low light yield (1.3% NaI)
Need photodetectors with gain in magnetic field

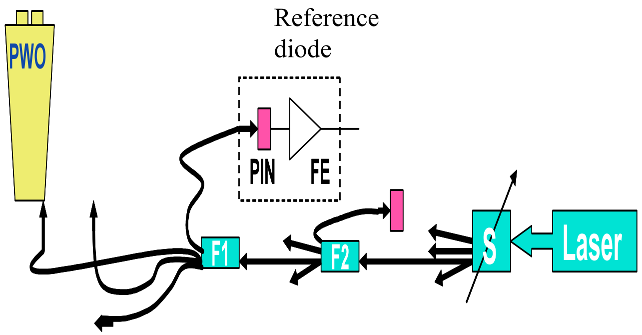
Crystal transparency monitoring

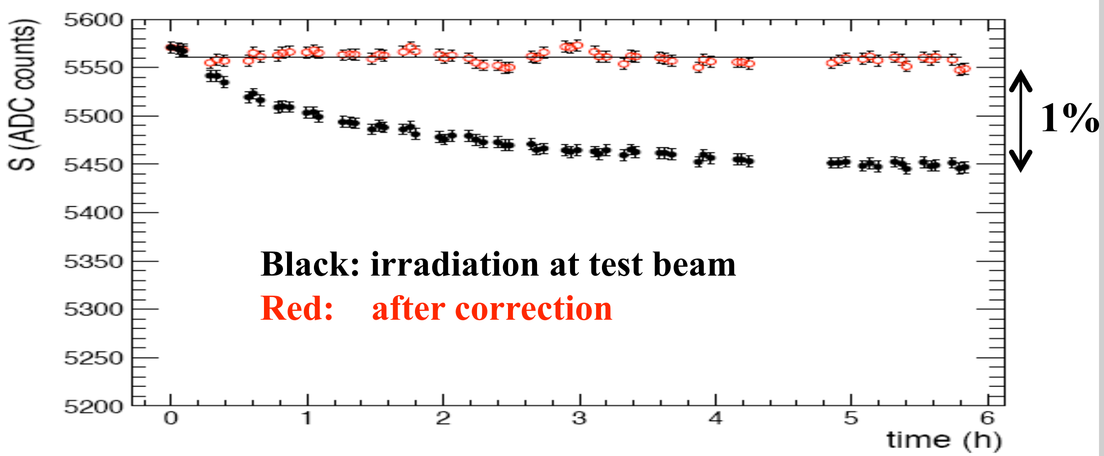
Transparency and colour centres:

These form in $PbWO_4$ under irradiation
Partial recovery occurs in a few hours

Damage and recovery during LHC cycles tracked with a laser monitoring system; 2 wavelengths: 440 nm and 796 nm







Light injected into each crystal using quartz fibres, via the front (Barrel) or rear (Endcap)

Laser pulse to pulse variations followed with pn diodes to 0.1%

Normalise calorimeter data to the measured changes in transparency

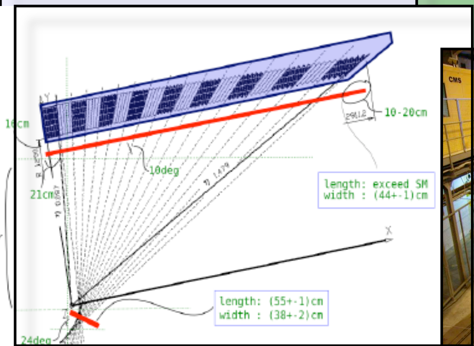
Transparency correction:

Response to laser pulses relative to initial response provides correction for loss of light yield loss $PbWO_4$

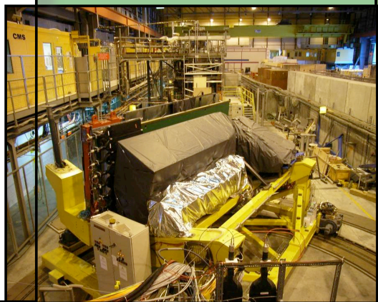
Test beam irradiation exercises showed precision of correction of 0.15% on several channels

Time line of the CMS ECAL project

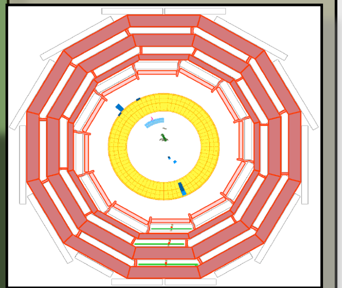
Commissioning / calibration of each SM with cosmics on surface



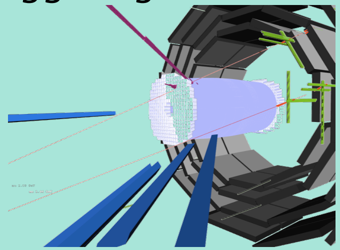
Test Beam: calibration of 9 supermodules Combined Test beam @ H2: ECAL+HCAL



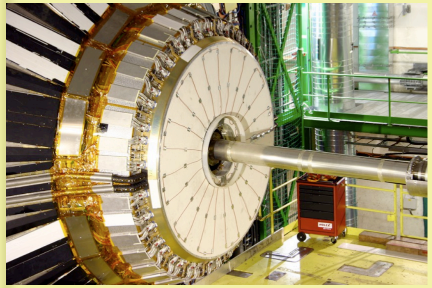
2 SM tested with magnetic field in surface (MTCC)



Endcaps Installation. Commissioning with cosmics and beam splases at P5; 1 month continuous data taking self-triggering



Installation of the preshower and commissioning of of trigger in Endcaps

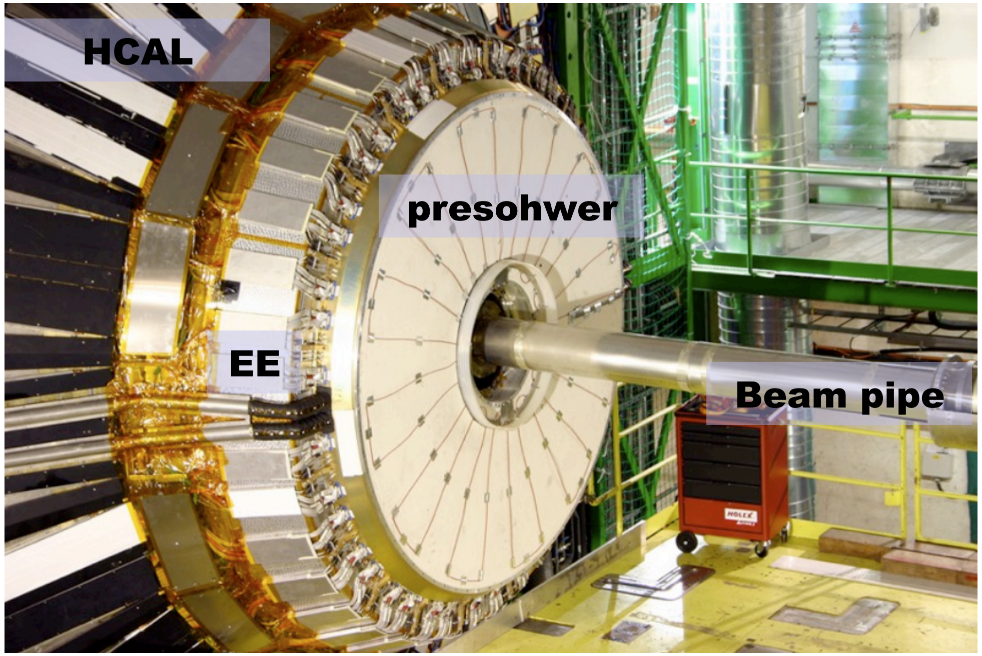


Signoff each supermodule during installation P5. EE test beam

2005 2006 2007 2008 2009

Status of the calorimeter

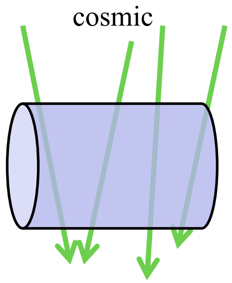
- Preshower:
  - Installed in the months of February-March 2009
  - First data collected to check out components and connections ➔ same status of health as in the laboratory, prior to installation:
    - 99.88% good channels (tot 137k)
    - MIP Signal/noise: 3.6 in low gain (physics) and 9 in high gain (calib)



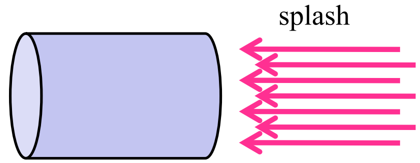
- Cristal calorimeter:
  - EB and EE active through LHC beams and extended cosmic rays run in 2008
  - More than 99.5% of the channels are in good health for physics
  - System routinely operated in CMS global exercises, collecting data to monitor the detector and consolidate data acquisition and procedures
  - Trigger commissioning in the endcaps: first data collected, being finalized

Last year of commissioning: three phases

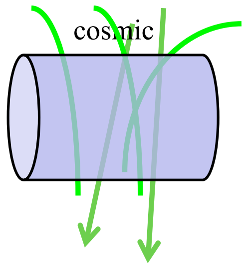
- Cosmic rays runs at **zer**o **T**esla magnetic field (**CRUZET**), march september 08
  - Collection of cosmic rays, mip and showers
  - Exercise and consolidate data acquisition and trigger
  - Test and improve procedures, services, reliability



- LHC circulating beams and beam splash events, sept 08
  - Beam splash events: internal synchronization and calibration
  - About 40 hrs in total of halo muons



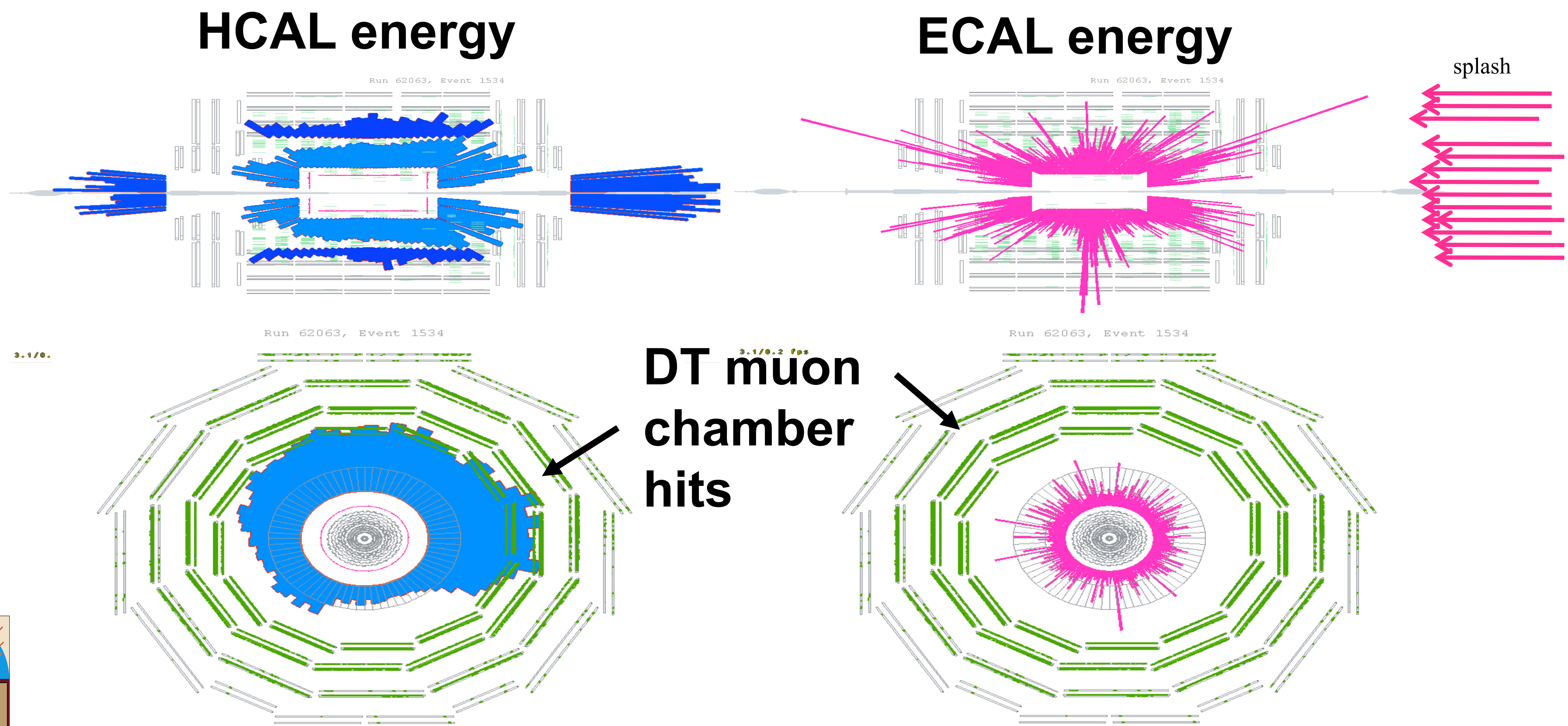
- Cosmic rays runs **at fo**ur **T**esla magnetic field (**CRAFT**), oct-nov 08
  - Steady running for ~1 month, test of response stability



- Results from beam splashes

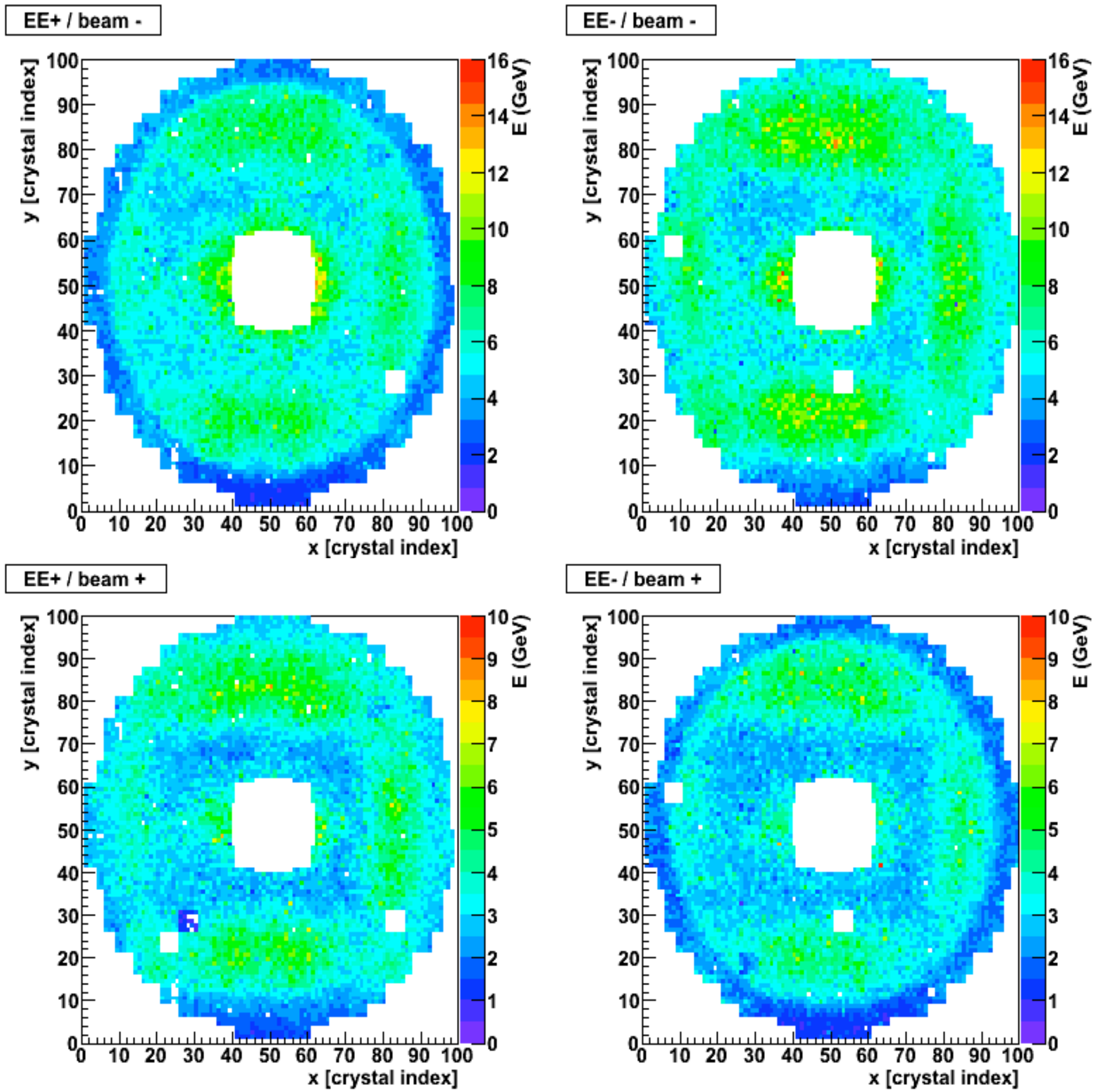
Beam splashes at CMS

- 10^9 protons at 450 GeV dumped on collimator 150 m upstream of the CMS experiment. ECAL total energy: 150-250 TeV



ECAL and beam splashes

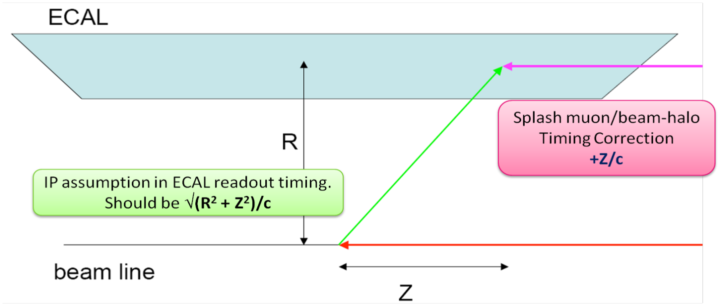
- Average energy per crystal over 50 splashes: 5-8 GeV
- Patterns:
  - shielding structures (square) and floor of the LHC tunnel (bottom)
  - Lower energy at large radius of downstream EE, due to shielding effect of barrel
- EE pre-calibrations (spread 25%):
  - Measurements from laboratory applied (precision of 9%): smoother and enhanced patterns
  - New set *being* derived assuming local uniformity, to be combined with lab measurements for better startup values



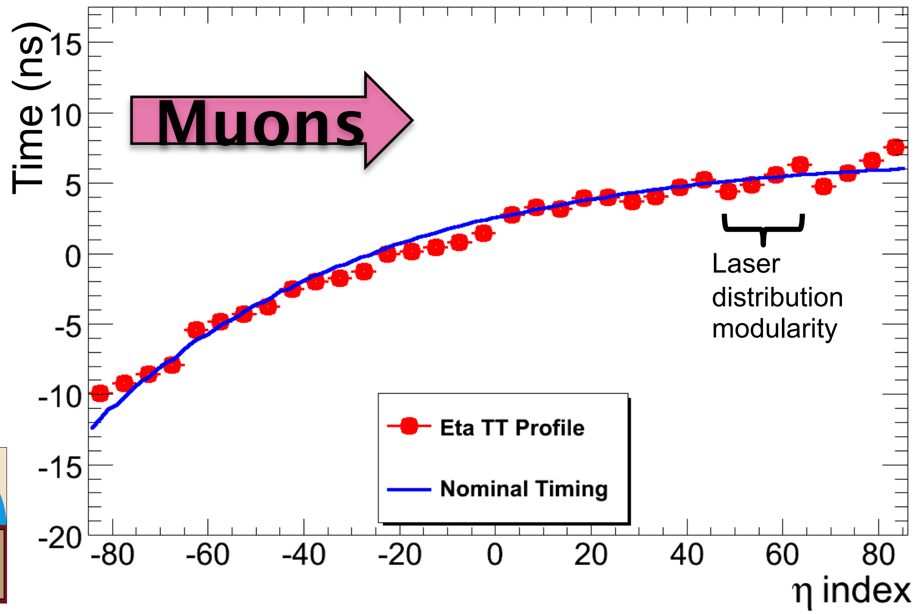
Beam splashes and synchronization

ECAL synchronization schema for collisions:

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



- Physics case: time measurement from ECAL to be employed for background rejection (halo, cosmics) and searches of delayed particles (HSCP, GMSB)
- For high energy clusters, precision of time measurement limited by synchronization of ECAL channels

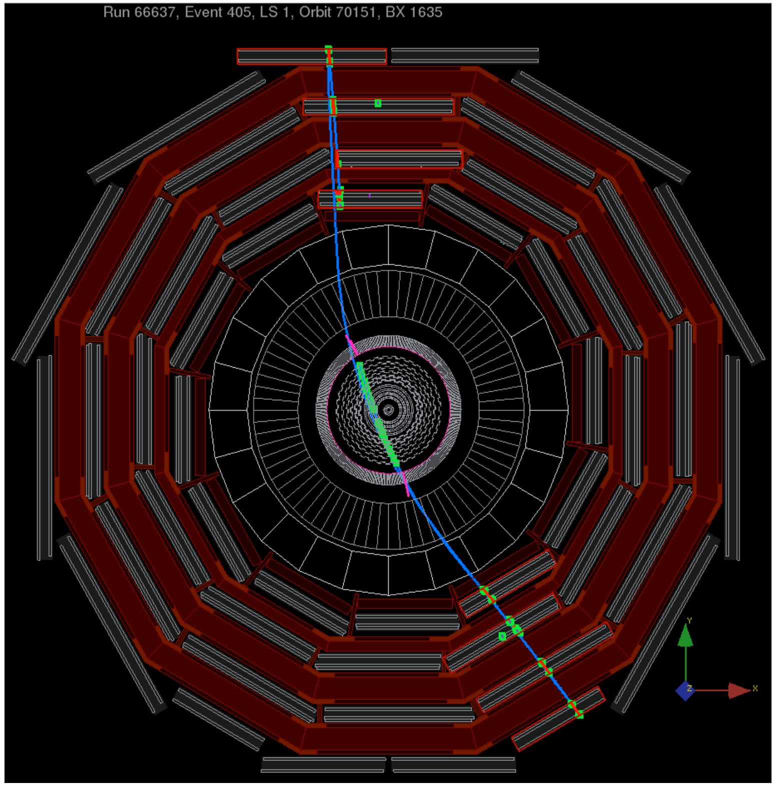


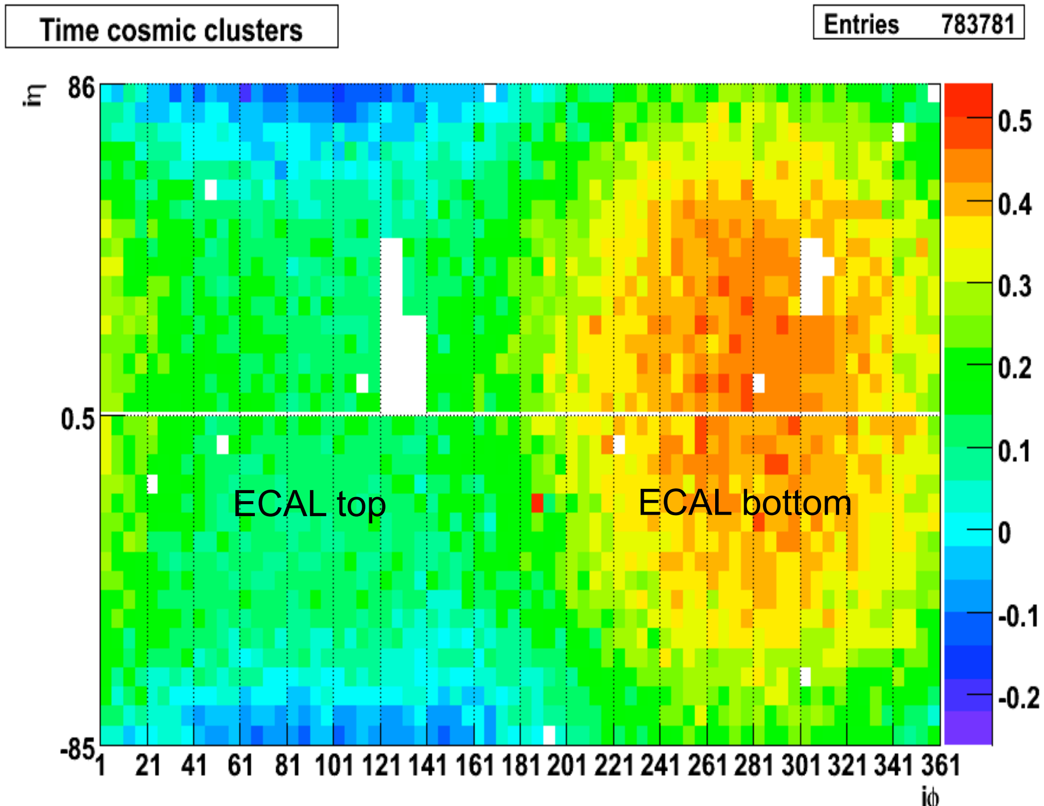
- Splashes provide reference for synchronization of whole ECAL:
  - Observed pattern due to pre-synchronization obtained using laser events
  - Readout latency adjusted w/ splashes: **hardware** allows steps of **1ns** steps
  - Further synchronization applied in **offline** reconstruction, **better than 1 ns**
  - Synchronization from splashes will be start-up condition; better precision w/ LHC data

- Results from cosmic ray runs

Cosmic rays signal in ECAL

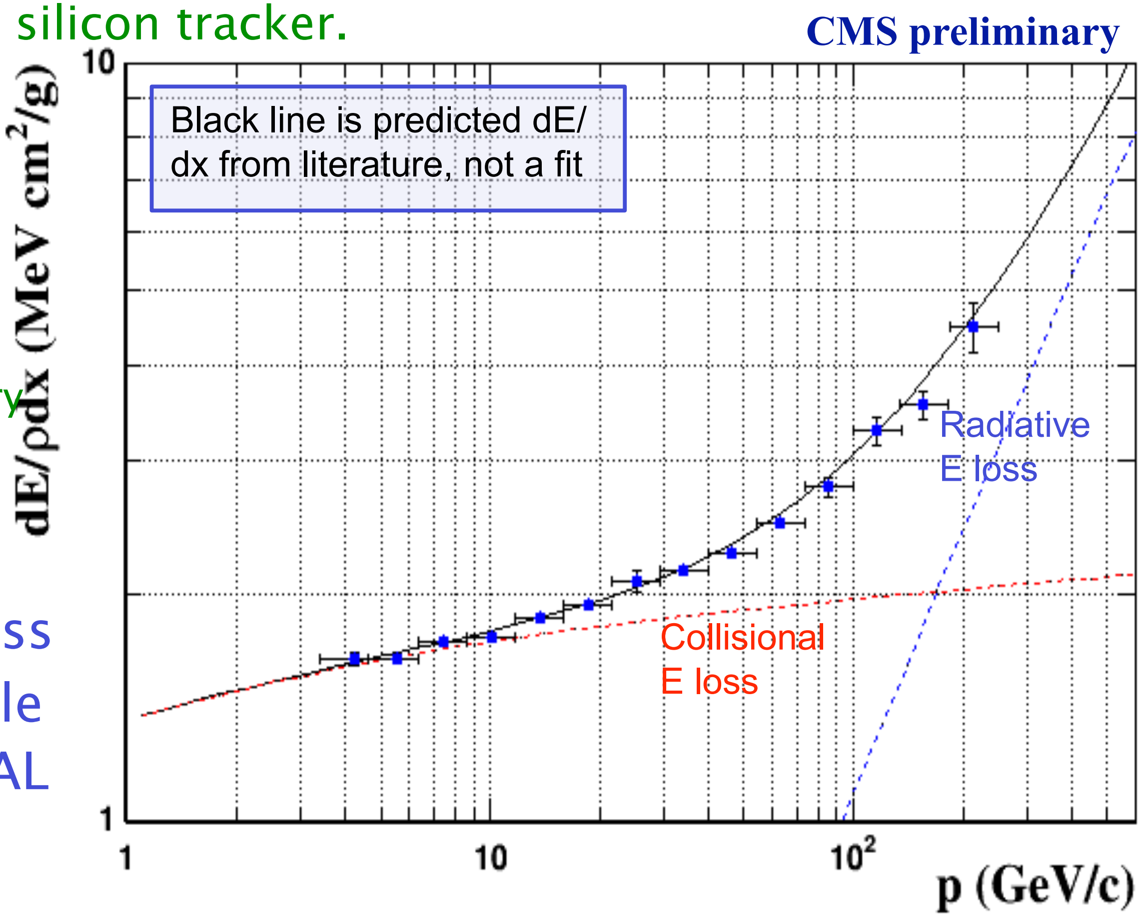
- Minimum ionizing particles deposit 250 MeV in ECAL. Increase efficiency: signal/noise enhanced (x4) in EB to the value of 20, by increasing the gain of the APD.
- Pattern in reconstructed time: time of flight top➔bottom and internal synchronization schema for collision events





Stopping power: dE/ρ dx

- Events selected to be loosely pointing: d0<1m, |dz|<1m
  - dE: ECAL clusters
  - dx is length traversed in ECAL crystals;
  - momentum measured by CMS silicon tracker.
- Clusters built using pre-calibration:
  - From test beam for ¼ of EB (0.3% precision)
  - cosmic rays calibration + laboratory measurements, elsewhere (2%)
  - Energy scale set with test beam
- Results indicate the correctness of the tracker momentum scale and of the energy scale in ECAL



Stability of response: introduction

LY: crystal light yield
M: APD gain

ECAL response sensitive to variations of:

- **Crystal transparency** (under irradiation)
- **Temperature of cry and APD**: $\partial(LY)/\partial T$, $1/M(\partial M/\partial T) \sim -2\%/K$
- **APD biassing high voltage**:
  - $1/M(\partial M/\partial V) \sim 3\%/V$@gain50
  - $1/M(\partial M/\partial V) \sim 7\%/V$@gain200

Controls and monitoring:

- Controlled (temperature, high voltage, dark current measurements)
- **ECAL response monitored and corrected with laser data**

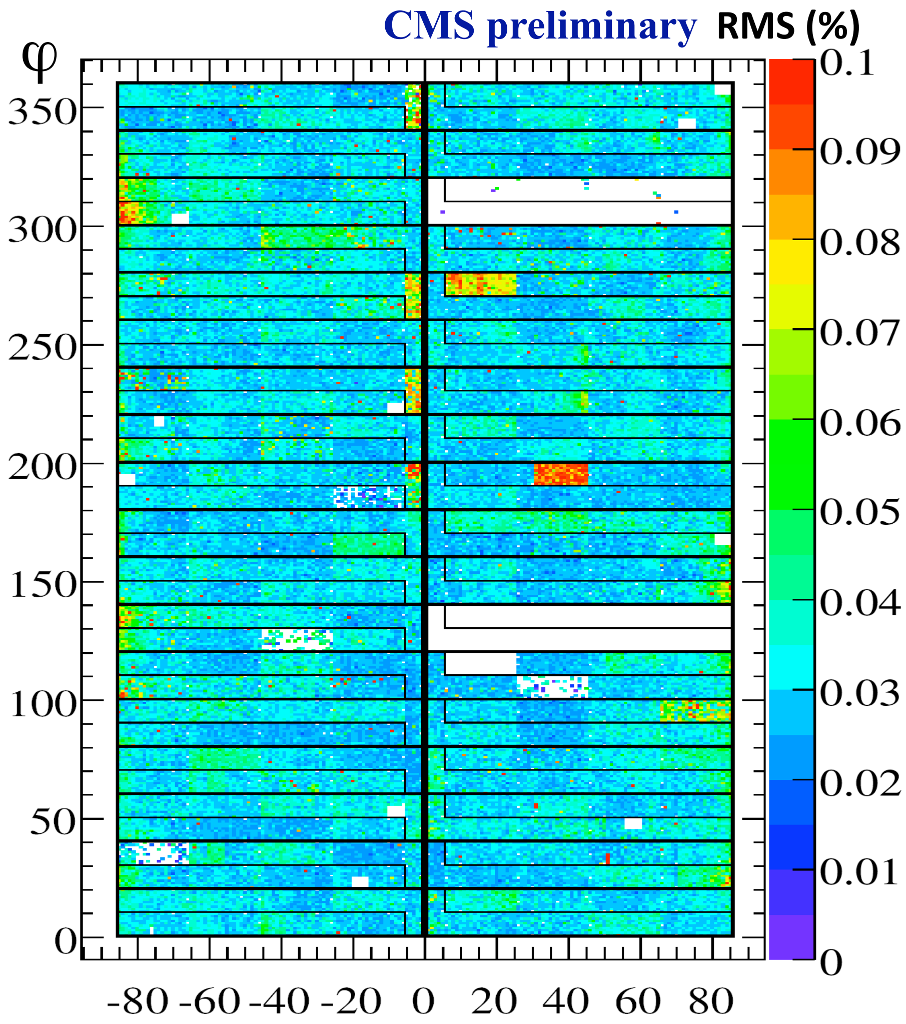
Performances required to keep constant term within specifications:

- Temperature stability at the few 0.01 ˚C level
- HV stability at the 10 mV level
- Laser monitoring of ECAL response at the 2‰ level

Transparency monitoring stability in EB

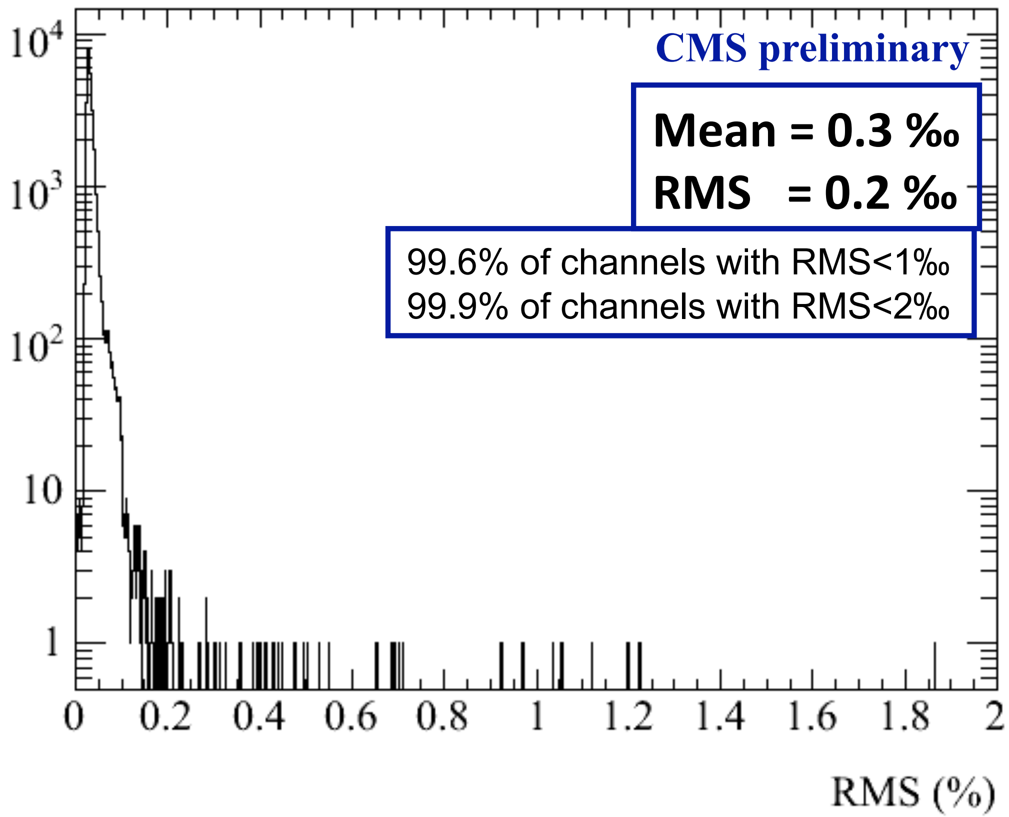
•In absence of transparency variation, the stability of the monitoring system can be assessed

- •Laser data collected throughout CRAFT; laser sequence loops over all ECAL channels every 20 minutes;
- •For each channel and each sequence (600 events), the average <APD/APDref> is employed as monitoring variable
- •"Stability" is defined as the RMS over all laser sequences of normalized <APD/APDref>
- •Stabilities are computed for each channel on a period of 200 hours with stable laser conditions
- •APDref is chosen as a reference because of readout problems with PN reference diodes, which are being fixed
- •White regions lack statistics (2 supermodules were not readout for LV problems, now fixed).



Most of EB: stability better 1‰

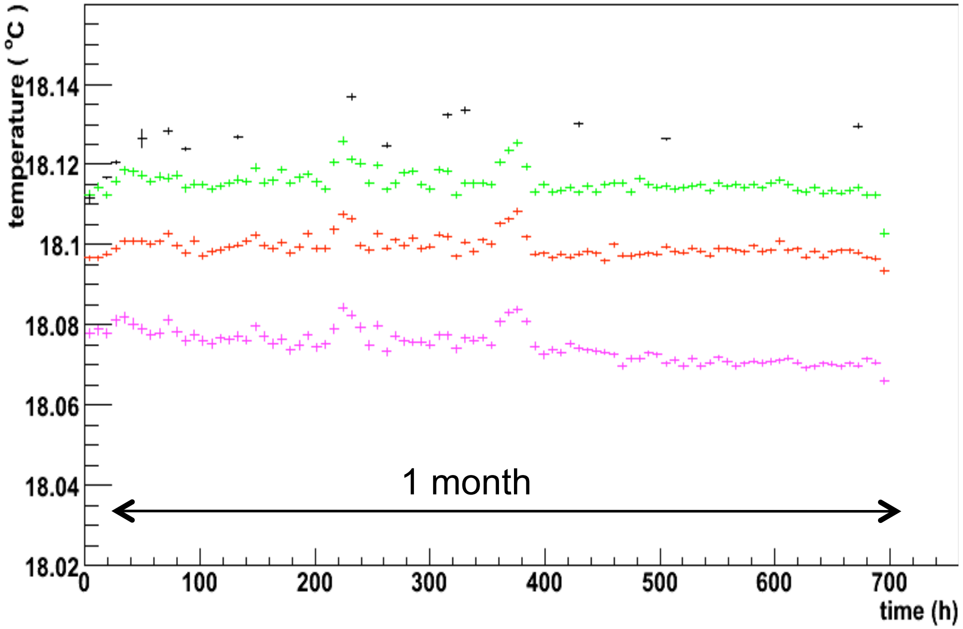
Stability of the transparency monitoring

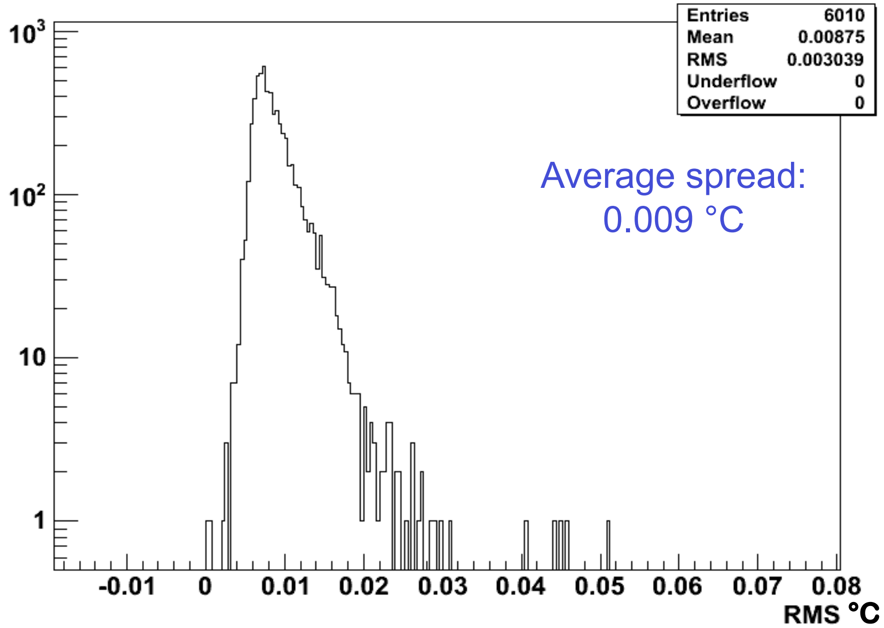


- 1-d projection of map in previous slide
- Transparency monitoring system stable in EB to better than than 2‰ in 99.9% of the channels

Temperature stability during CRAFT

CMS preliminary





- EB equipped with one precision temperature sensor every 10 channels, in good thermal contact with APD and crystal
- For each sensor, thermal stability is quantified with the RMS of the temperature measurements over one month of data taking
- The observed stability is 0.009 ˚C on average and better than 0.05 ˚C in all the channels.

CMS ECAL: conclusions

- Crystal part of CMS Electromagnetic calorimeter has collected data with LHC circulating beams and during cosmic rays test runs
- Preshower detector installed in feb-march 09
  - Optimal health
  - Joined CMS global runs
- Beam splash events allow to validate and improve:
  - Endcap startup calibrations
  - Internal synchronization
- Long cosmic rays run has allowed to validate energy scale in the barrel and assess stability of temperature and transparency monitoring, both matching specifications