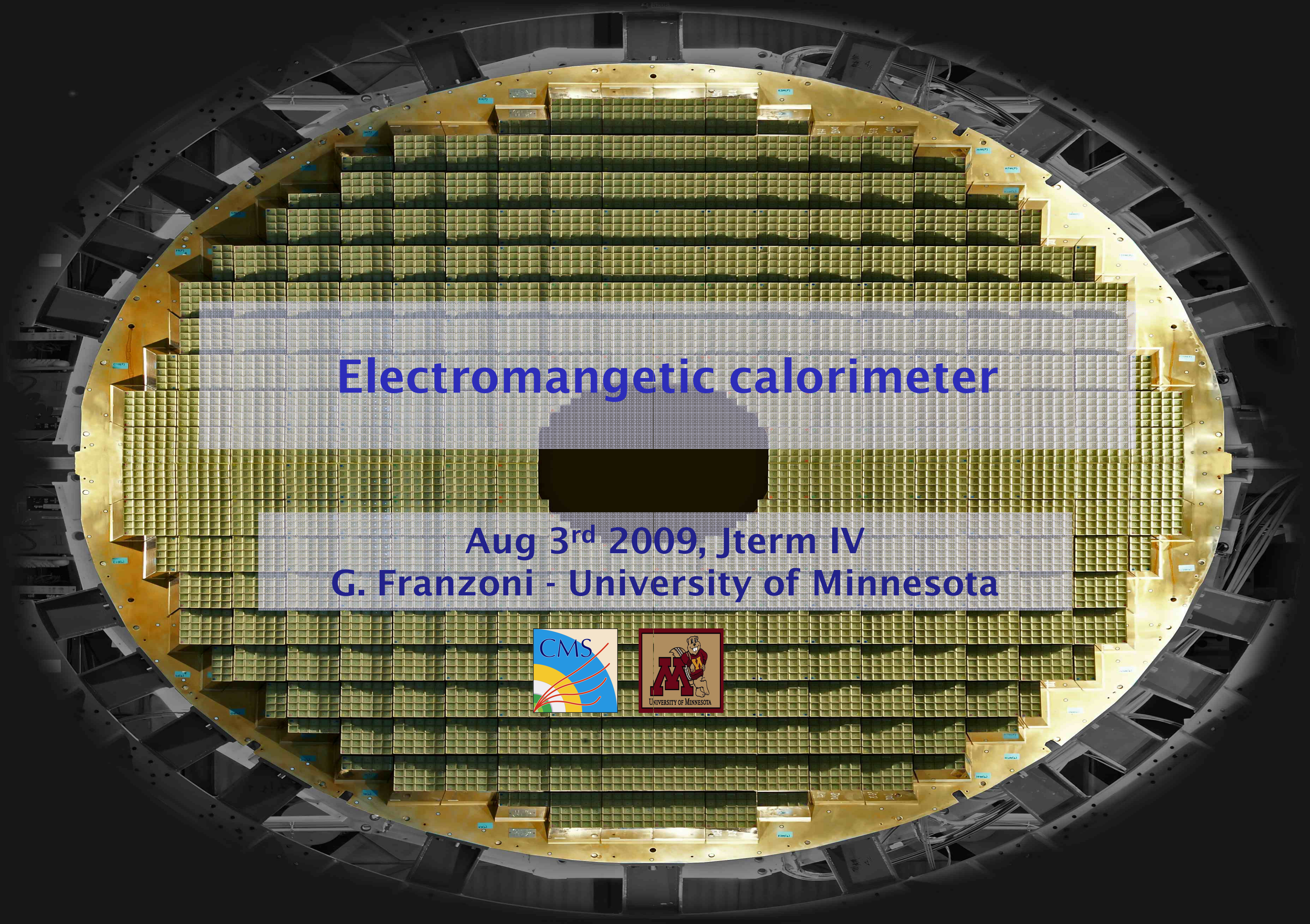


Electromangetic calorimeter

Aug 3rd 2009, Jterm IV

G. Franzoni - University of Minnesota

Outline

- Requirements and target for the Electromagnetic calorimeter at CMS
- Technology choices
  - Layout/Crystals/photo-detectors
  - L1 trigger
  - Data reduction
- Performances highlights
  - Calibration
  - CRAFOT08 results (3 papers in preparation)
- Conclusions: ***many chances to join ECAL effort***!

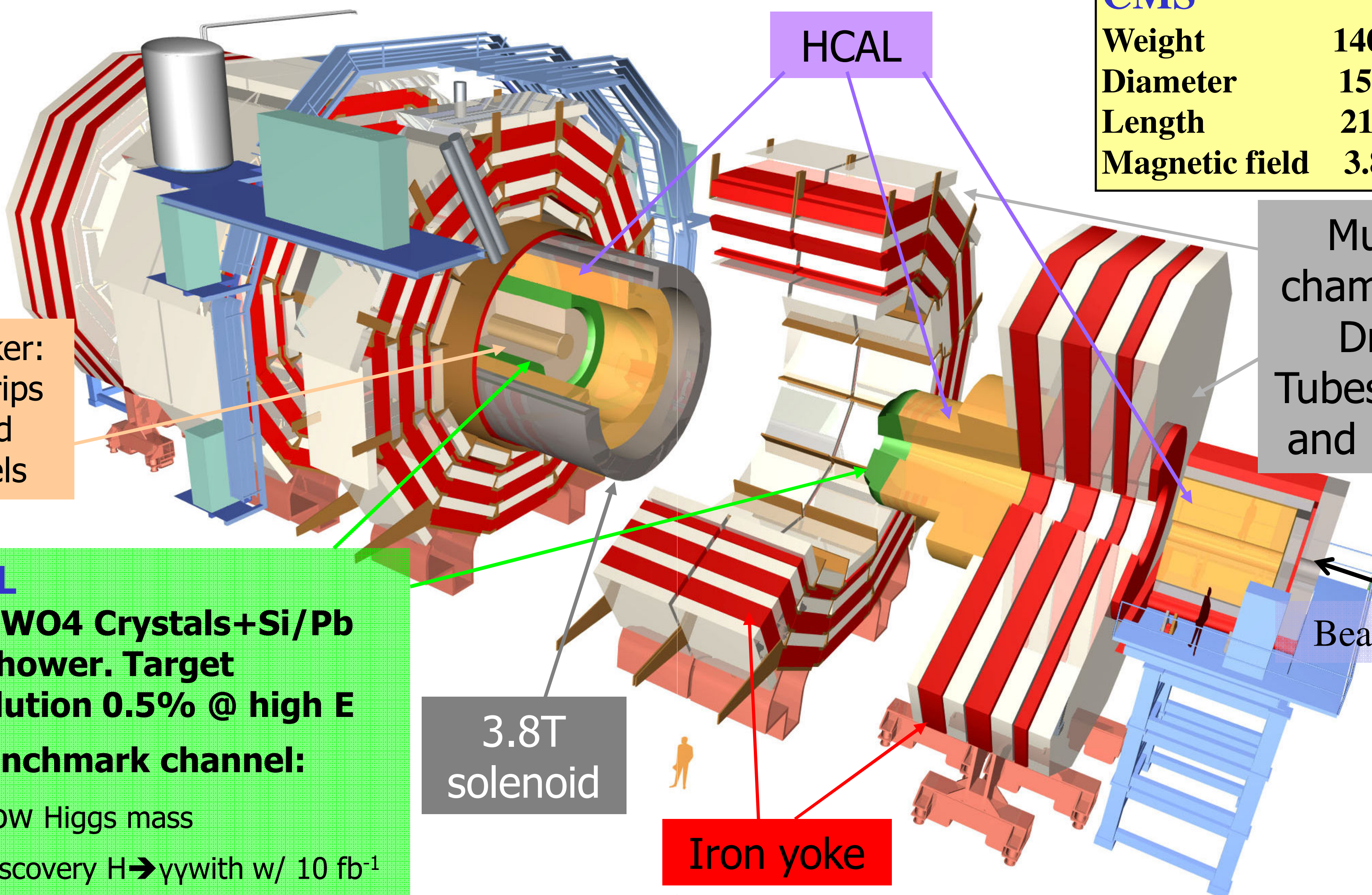
Disclaimer

+ Many topics not covered (ECAL&ES local reconstruction, clustering, in situ calibration, time measurement *et cetera*)

+ Take a look at references, join discussions

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

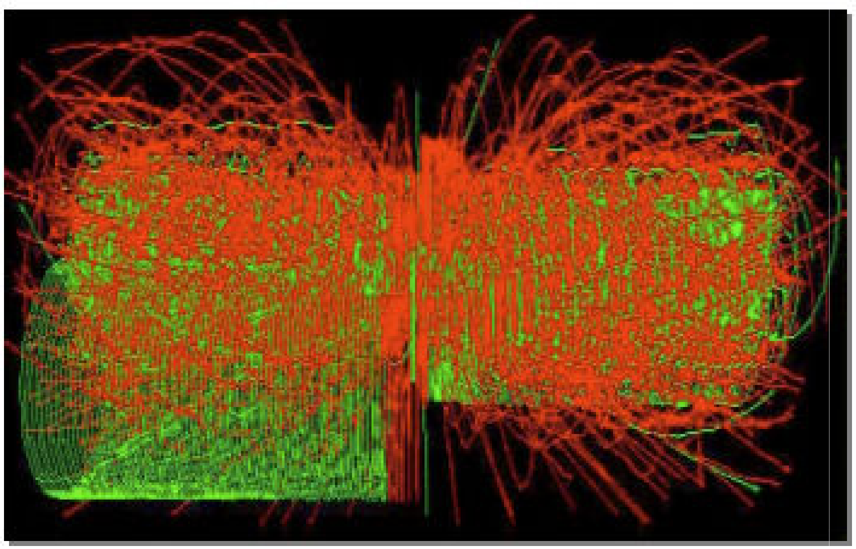
  discovery $H \rightarrow \gamma\gamma$with w/ 10 fb^{-1}

Target and goals

- CMS and LHC-environment requirements:
  - Fast (40 MHz)
  - Highly granular and compact
  - Radiation resistant
- Physics requirement:

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

  - **a**: stochastic
  - **b**: noise
  - **c**: narrow resonances require constant term 0.5%



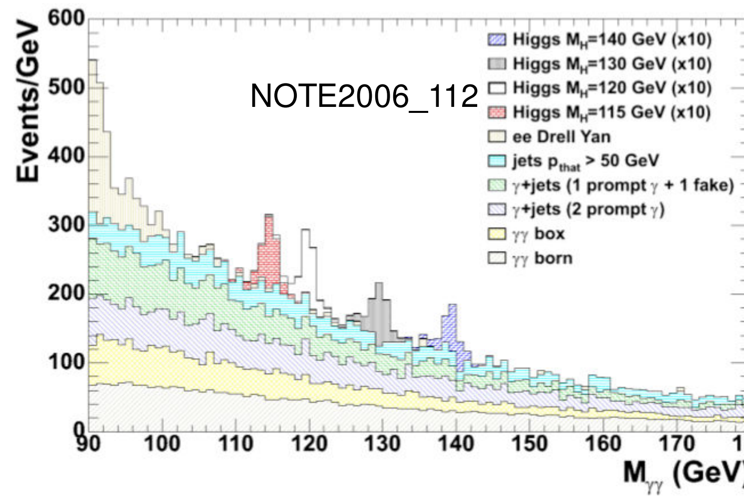


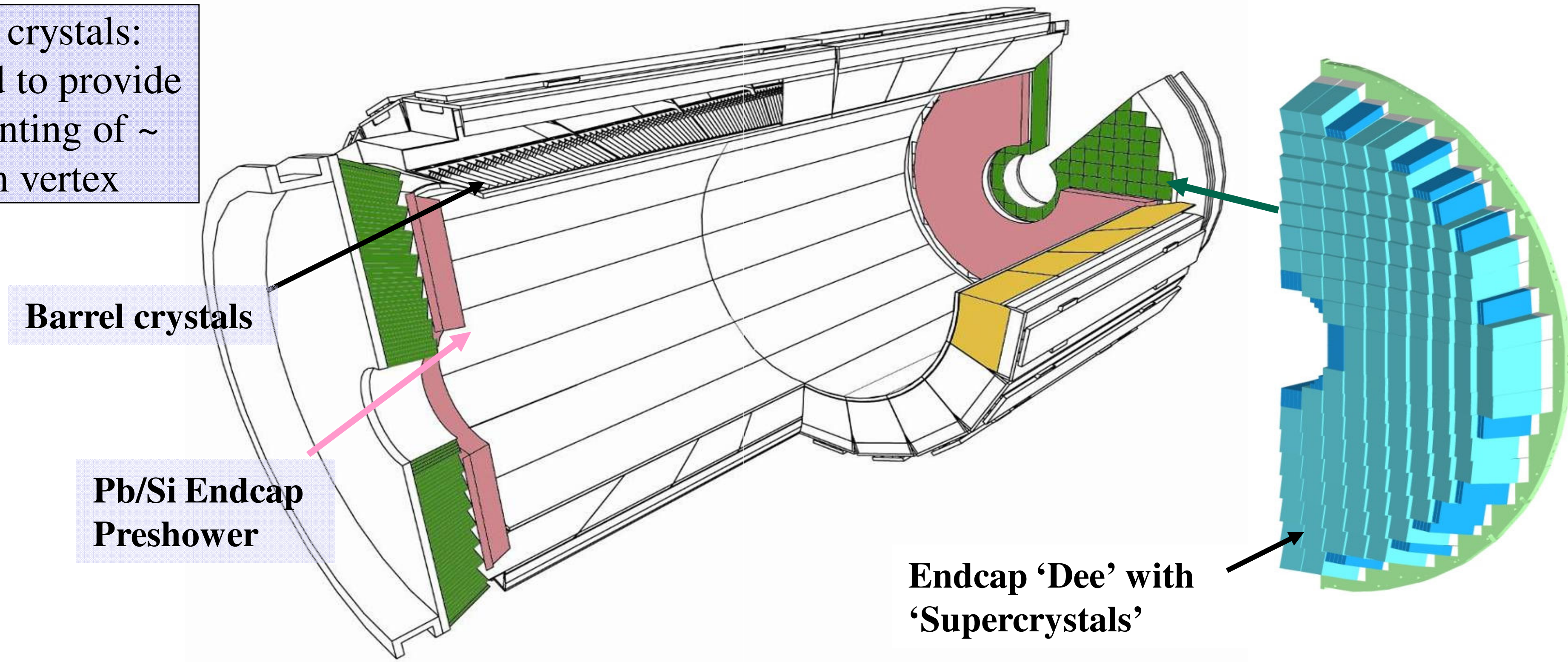
Figure 3: Di-photon invariant mass spectrum after the selection for the cut-based analysis. Events are normalized to an integrated luminosity of 1 fb^{-1} and the Higgs signal, shown for different masses, is scaled by a factor 10.

ECAL:

The detector

ECAL layout

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

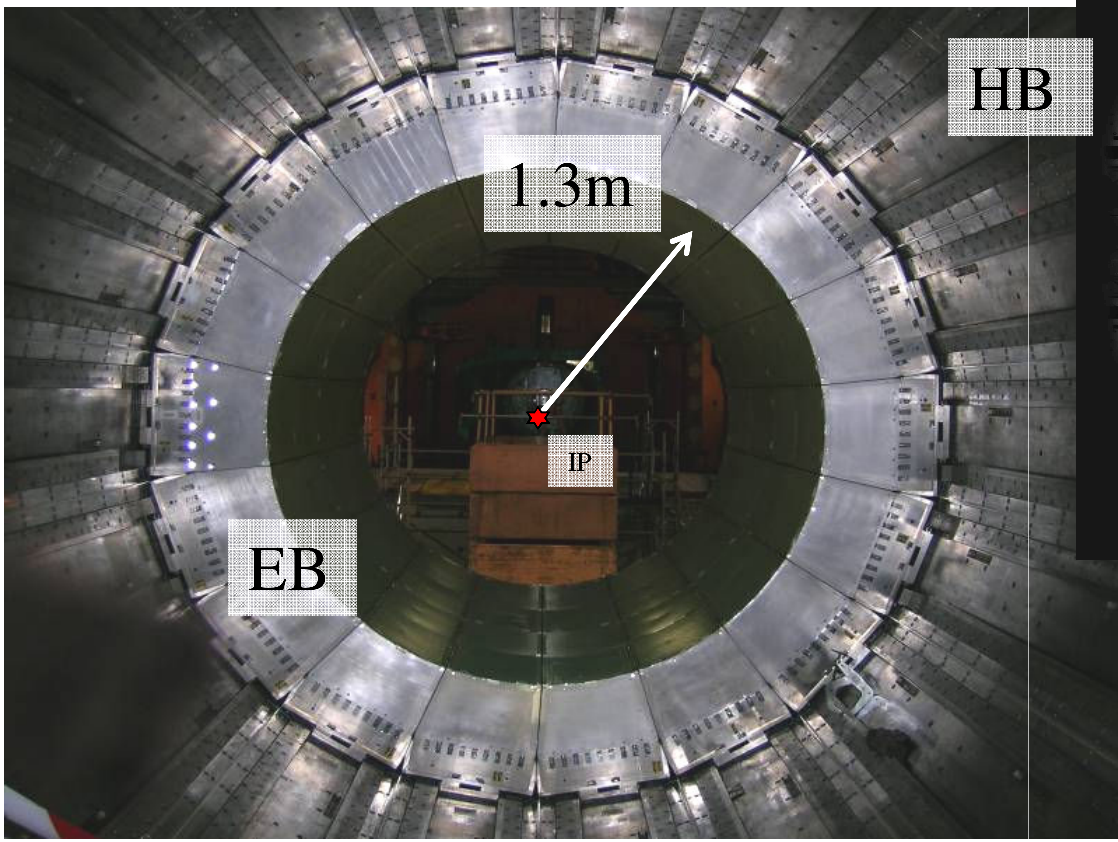


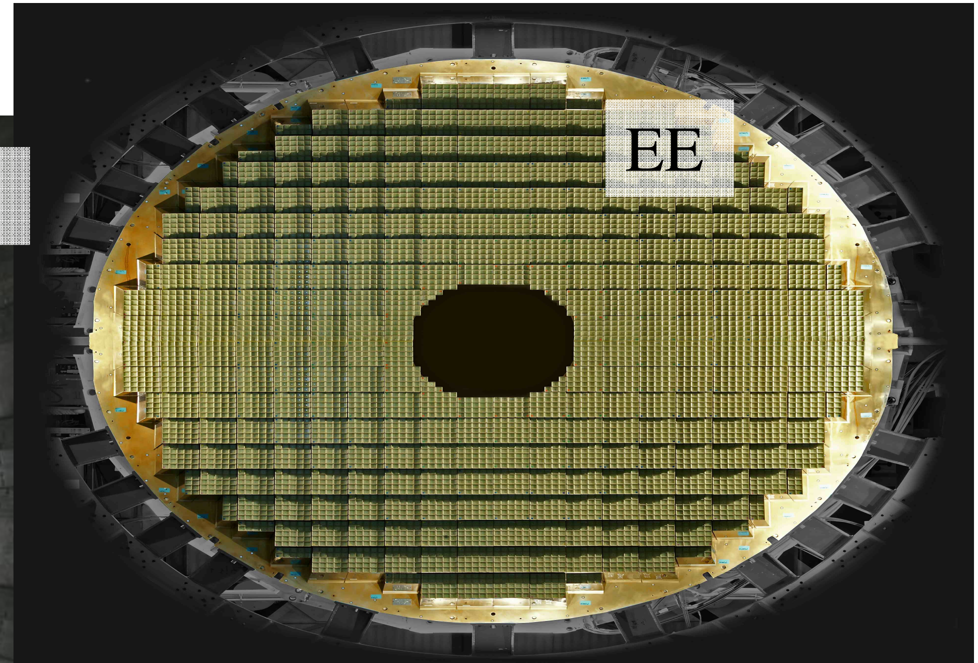
Barrel (EB)
36 Supermodules (18 per half barrel)
61200 crystals
Total crystal mass 67.4t
$|\eta| < 1.48$
$\Delta\eta \times \Delta\varphi = 0.0175 \times 0.0175$

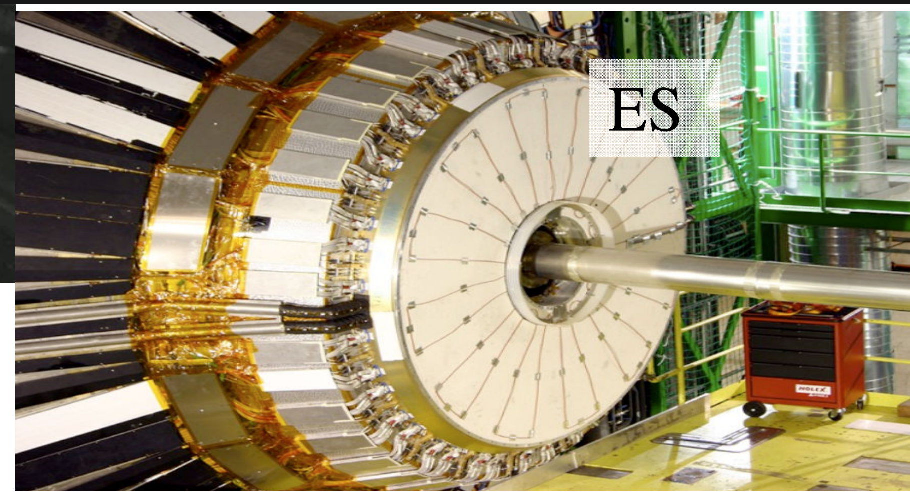
Endcaps (EE)
4 Dees (2 per endcap)
14648 crystals
Total crystal mass 22.9t
$1.48 < |\eta| < 3$
$\Delta\eta \times \Delta\varphi = 0.0175^2 \leftrightarrow 0.05^2$

Endcap Preshower (ES)
Pb ($2X_0$,$1X_0$) / Si
4 Dees (2 per endcap)
4300 Si strips
1.8mm x 63mm
$1.65 < |\eta| < 2.6$

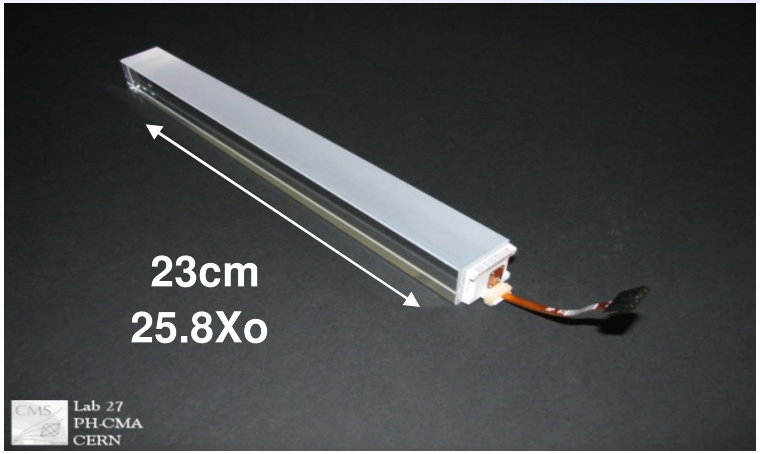
ECAL : the true thing in Cessy

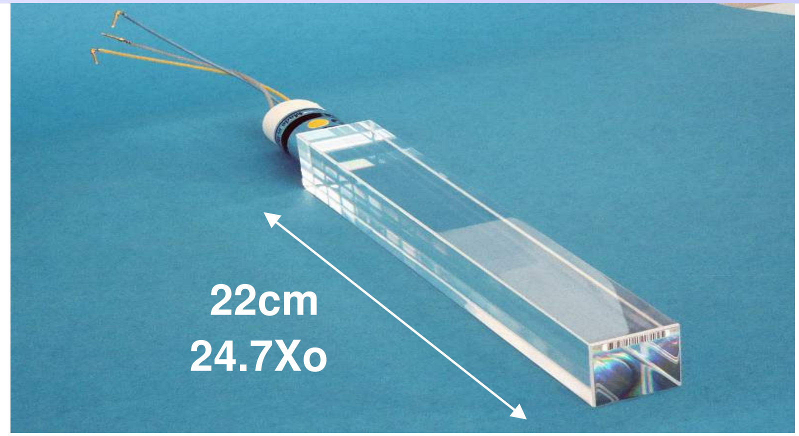






PbWO4 crystals and photodetectors





+ 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

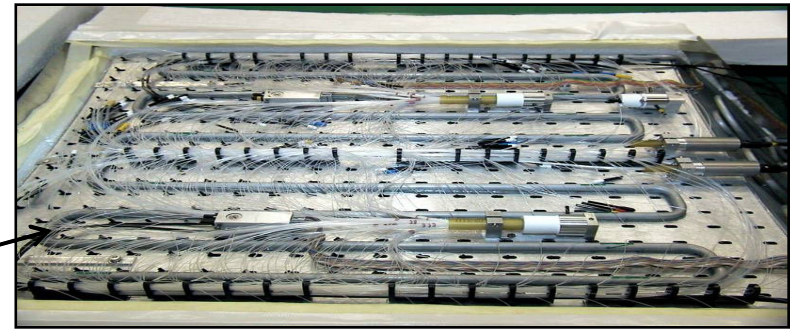
Low light yield (1.3% NaI)
Need photodetectors with gain in magnetic field

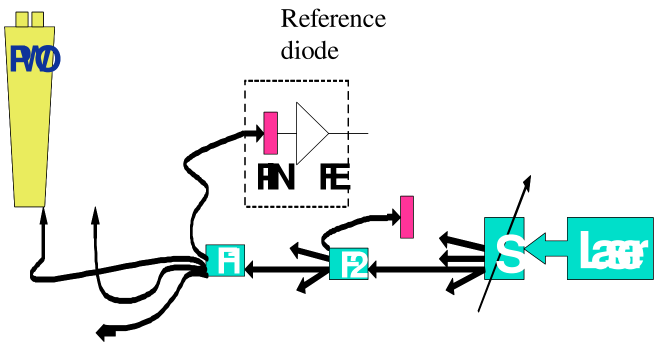
Crystal transparency monitoring

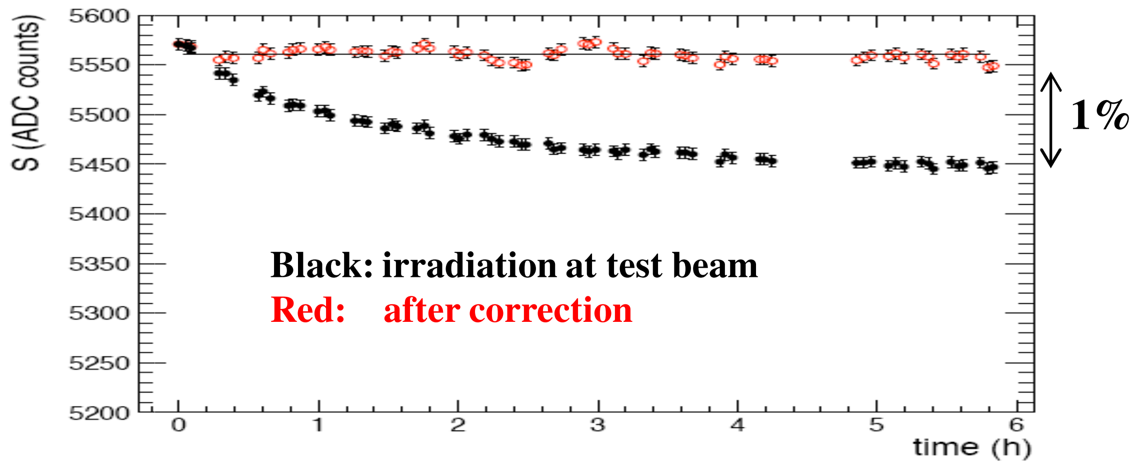
Transparency and colour centres:

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:

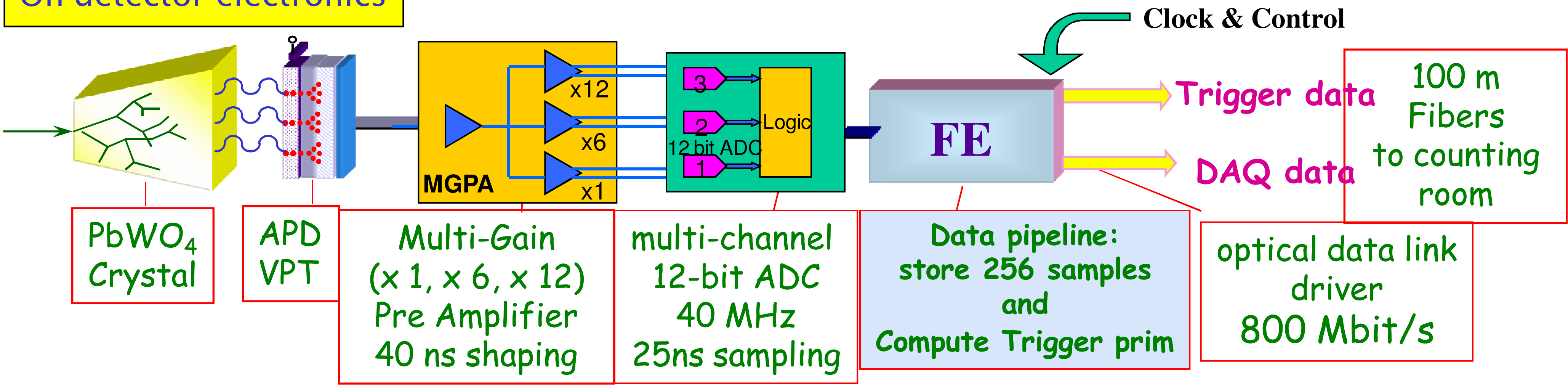
Response to laser pulses relative to initial response provides correction for loss of light yield loss $PbWO_4$

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

CMS DN-2008/004 , CMS NOTE-2006/038

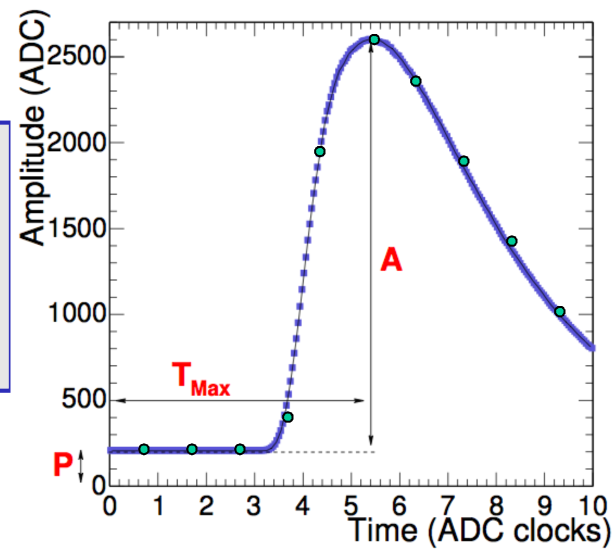
ECAL on detector electronics

On detector electronics

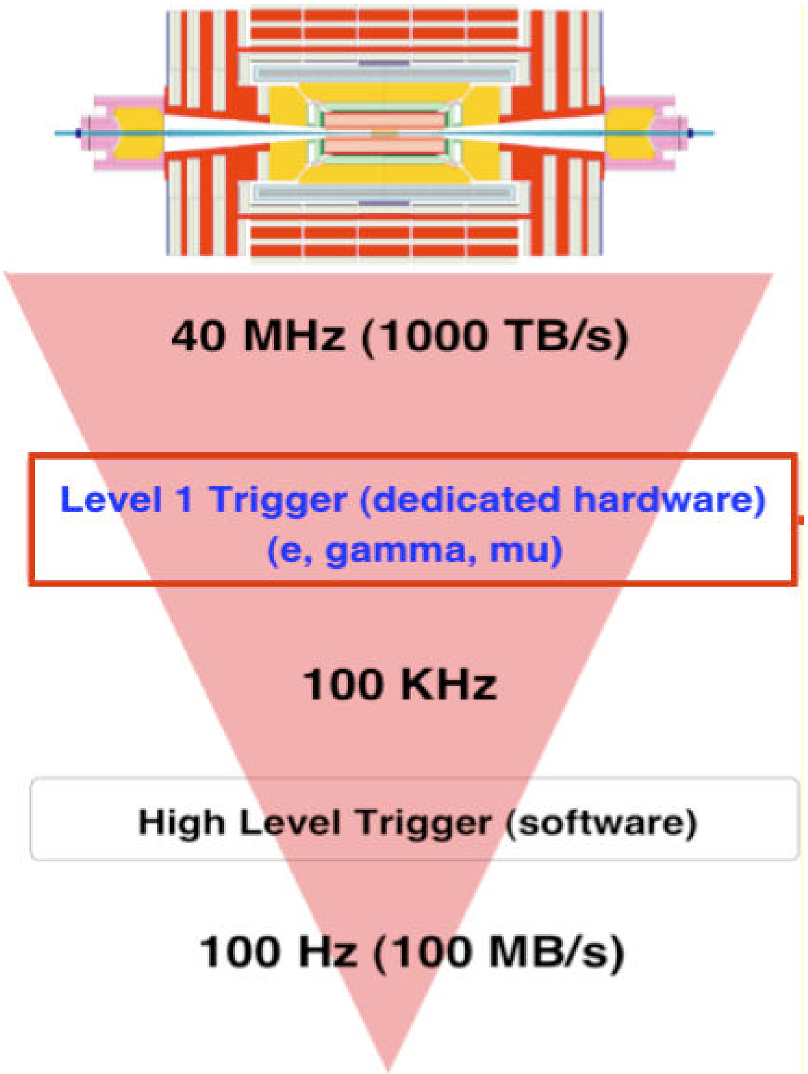


Off detector electronics

- 10 digitized values for each crystal which is read out
- digitized sample are a pair: (gain, amplitude)
- one ADC counts corresponds on average to 35/64 MeV in EB/EE
- dynamic range of single channel extends up to 1.6/2.9 TeV



CMS trigger and ECAL L1

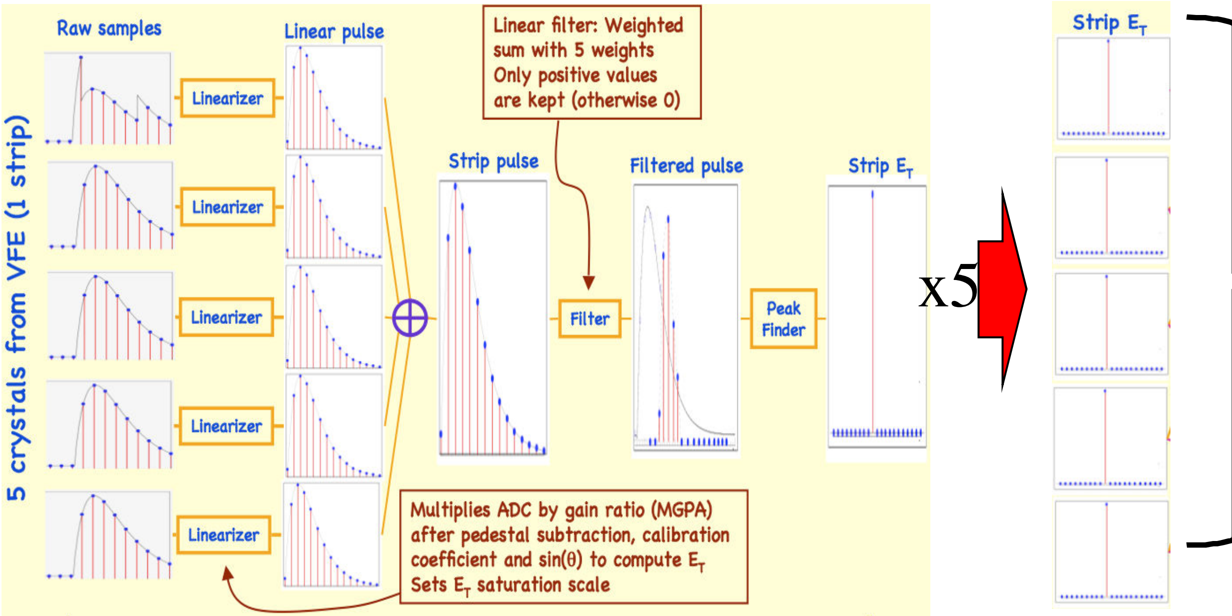


- Reduction from 40 MHz to ~100 Hz
  - L1 trigger (40 MHz -> 100 kHz)
  - High Level trigger (-> ~100Hz)
- Calorimeters and muon detectors participate to L1. All to HLT
- ECAL, @each bunch crossing and for each trigger tower (5x5channels in EB; <= in EE):
  - Trigger Tower transverse energy
  - Bunch crossing assignment
  - Compactness bit (e.m. VS hadronic deposition): ECAL Fine Grain
- delivered to Regional Calorimeter Trigger Used for E.M streams and total ET + missing ET streams

ECAL trigger primitive generation

- For each strip (5 channels):

- For each trigger tower (5 strips):

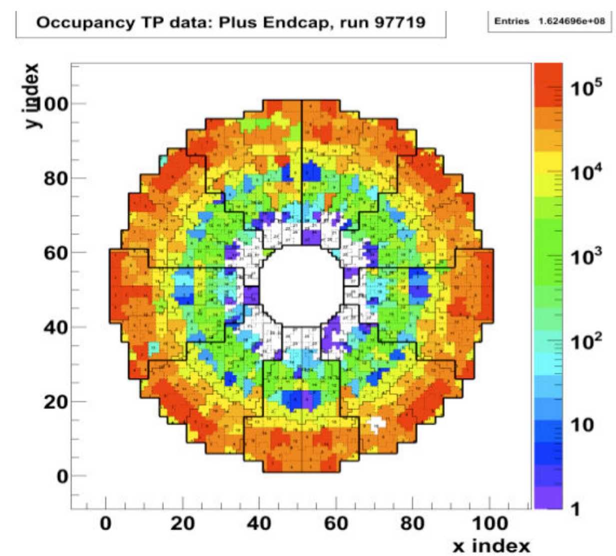


- Transverse energy of tower:

$$E_t^{tower} = \sum_1^5 E_t^{strip}$$

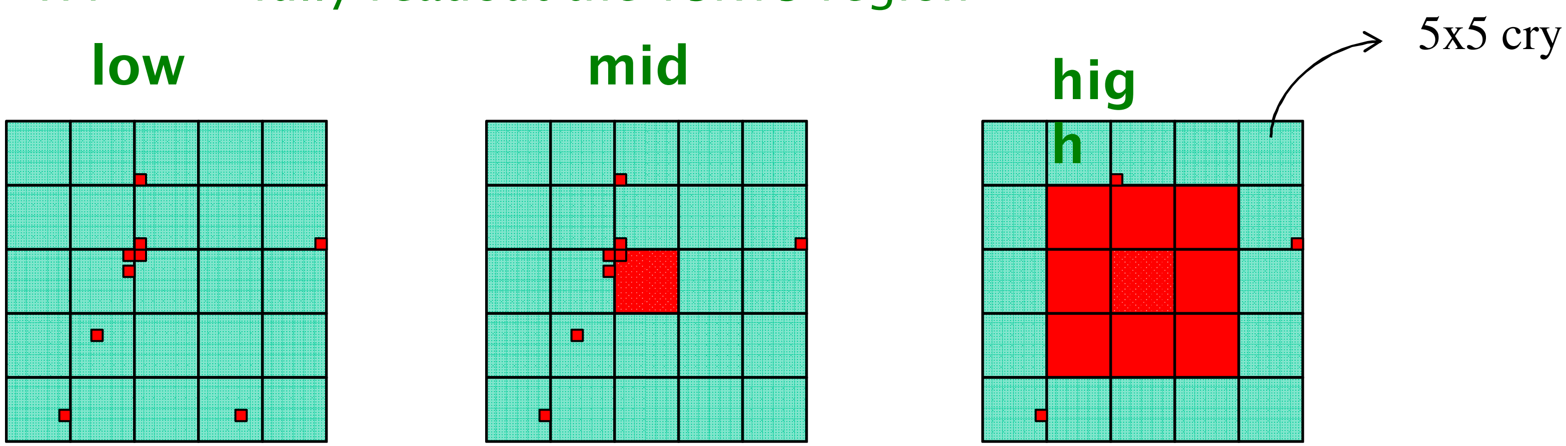
- Fine grain bit: e.m. if pair of adjacent strips w/ SumEt >90% E_t^{tower}

- EE trigger commissioning ongoing, EB since 08
- Understand a calorimeter and its stability/noise only after commissioning in self-trigger mode: when triggered externally (e.g. O(1kHz) @test beams) sampling 2.5E-4 of live time



ECAL data reduction: 0suppression and Selective Readout

- Only active part of the calorimeter can be readout (full: 2MB/event)
- Use trigger primitives amplitude to identify 5x5 **regions of interest**:
  - TP<thr1: single-channel amplitude cut (ZeroSuppression)
  - thr1<TP<thr2 : fully readout the 5x5 region
  - thr2<TP: fully readout the 15x15 region



- Thresholds:
  - For cosmics EB/EE: ZS 105/195 MeV, thr1=thr2=312.5 MeV
    - Much work in this area during CRAFT09
  - Due to evolve with luminosity: thr1=thr2=1 GeV at startup
- **One of the most active areas of commissioning during CRAFT09**

ECAL: highlights

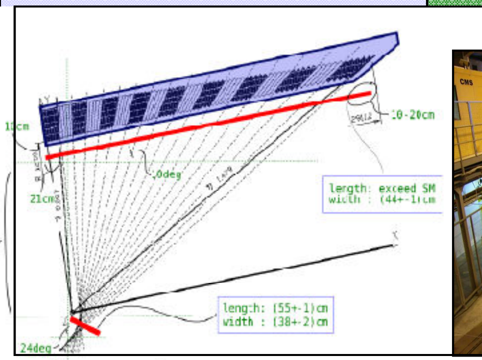
- **resolution at test beam**
- **pre-calibration**
- **stability**

} Constant term in situ

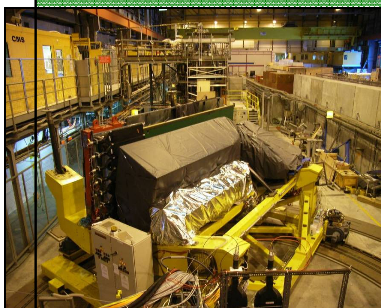
Much gone into CRAFT papers: CFT-09-004, CFT-09-005, CFT-09-006

Time line of the CMS ECAL project

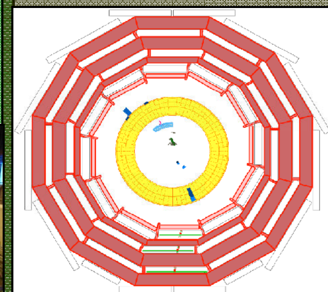
Commissioning /calibration of each SM with cosmics on surface



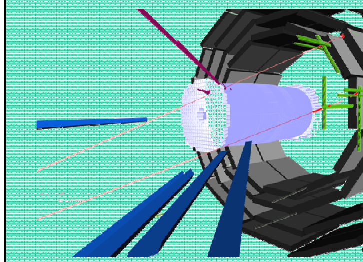
Test Beam: calibration of 9 supermodules
Combined Test beam @ H2: ECAL+HCAL



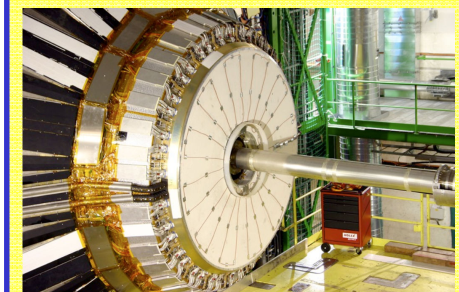
2 SM tested with magnetic field in surface (MTCC)



Endcaps Installation.
Commissioning with cosmics and beam splases at P5
CRAFO08; 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

Commissioning at MWGR and CRAFT09

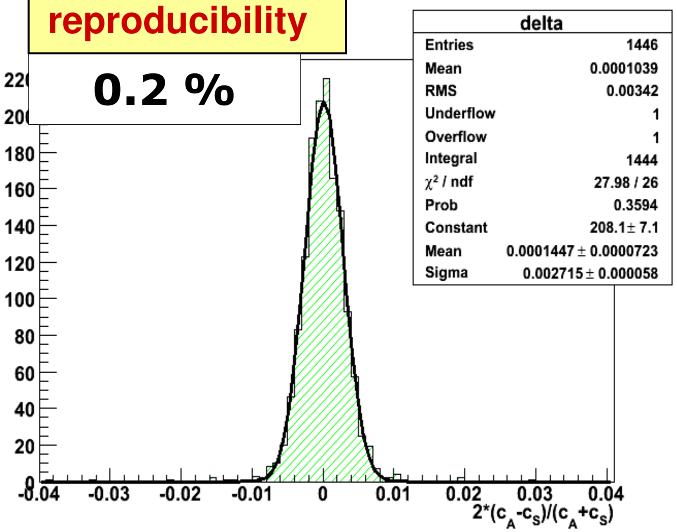
Performance in EB test beam 2006

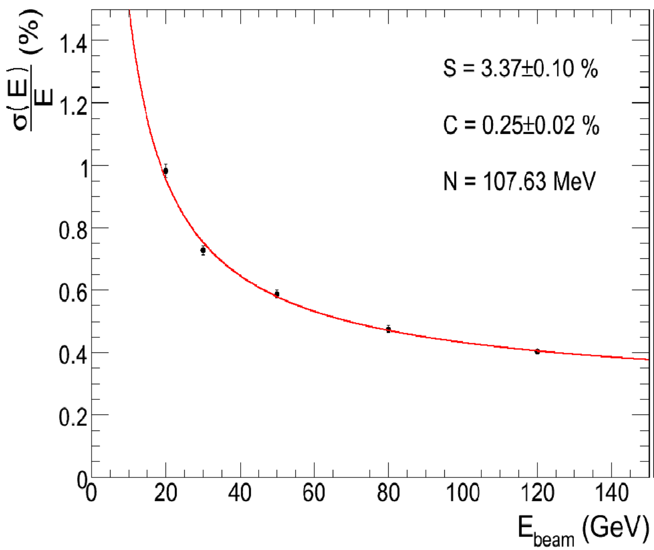
Intercalibration with electron beam

- 9 Supermodules intercalibrated with electrons @ 120 GeV H4
- 1 Supermodule partially calibrated with electrons @ 50 GeV H2

Intercalibration reproducibility

0.2 %





Optimized the amplitude reconstruction method

Achieved constant energy resolution term (local) better than 0.5%

Noise at expected level (~40 MeV x channel) without evidence for spatially correlated noise

$$\frac{\sigma}{E} = \frac{3.37\%}{\sqrt{E}} \oplus \frac{108}{E} \oplus 0.25\%$$

Precalibration with cosmic rays

Whole of EB precalibrated 1.5%

Each supermodule exposed to cosmics for at least 1 week

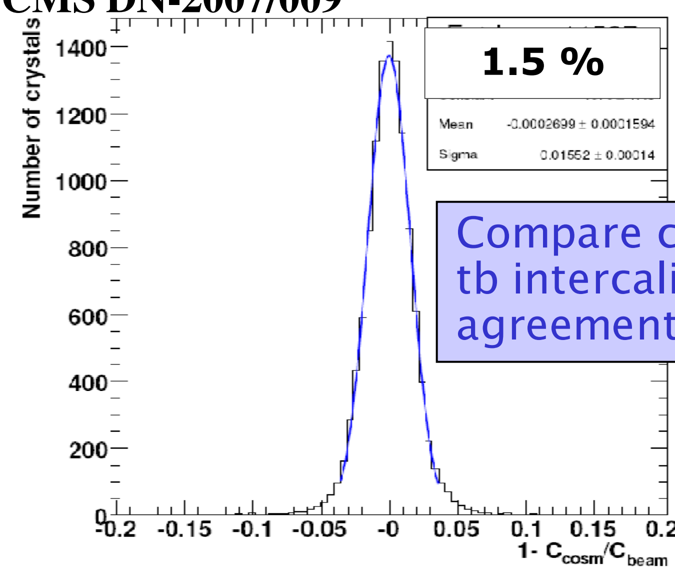
- Supermodule inclined 10°
- Increased APD gain (x4)
- ~ 5 million triggers/SM
- ~ 500 <selected events/ crystal>

Whole of EE precalibrated 7.5%

Splash events and combining with laboratory measurements

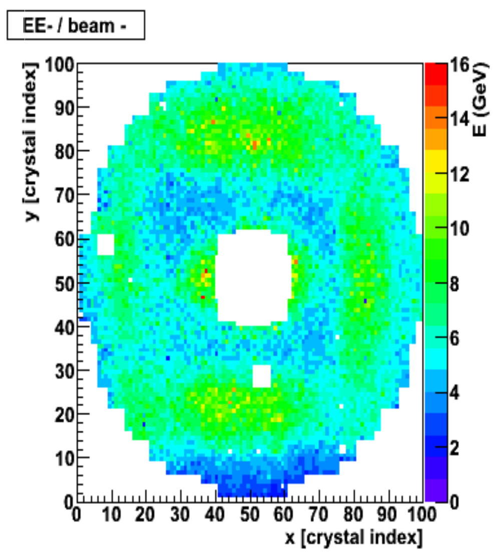
- Assume local uniformity of splashes on 5x5 regions
- Equalize 25 channels within
- Inter-calibrated 5x5 regions using lab pre-calibrations

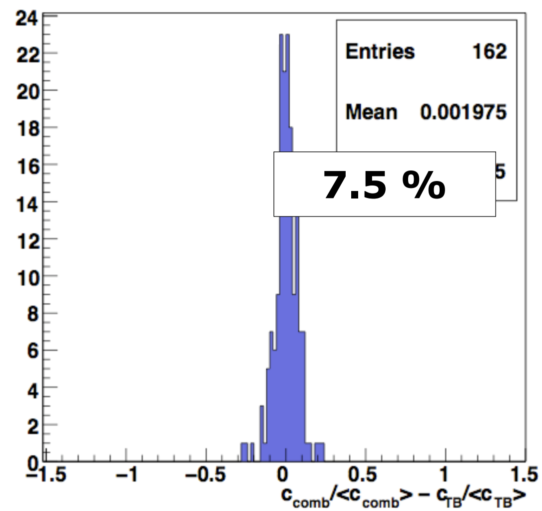
CMS DN-2007/009



Compare cosmic & tb intercalibration: agreement: 1.5%

CMSDN-2009/008



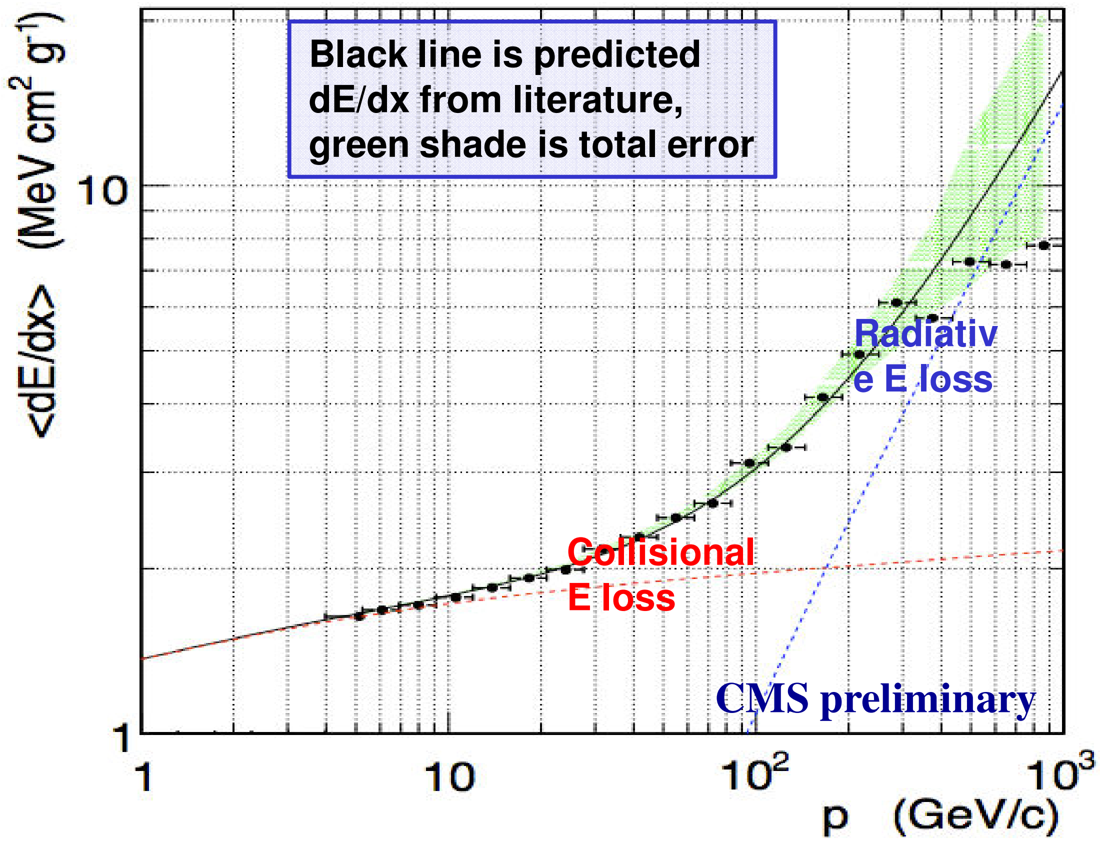


Stopping power (CFRAFT08): dE/ρdx

- 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 consistency of the tracker momentum scale and of the energy scale in ECAL**



Stability of response: overview

LY: crystal light yield
M: APD gain

ECAL response sensitive to variations of:

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

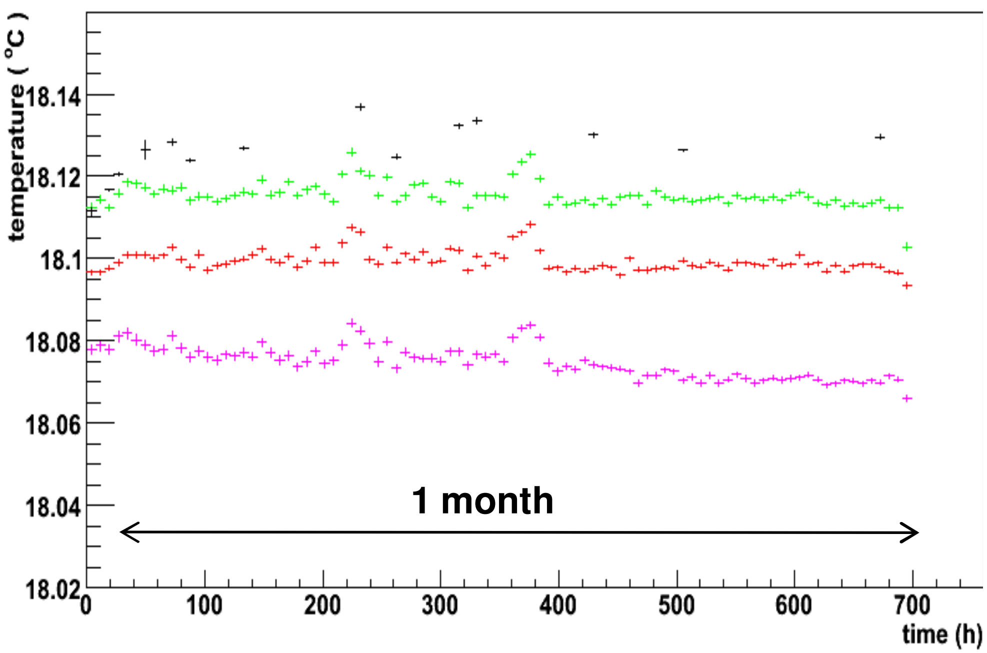
Controls and monitoring:

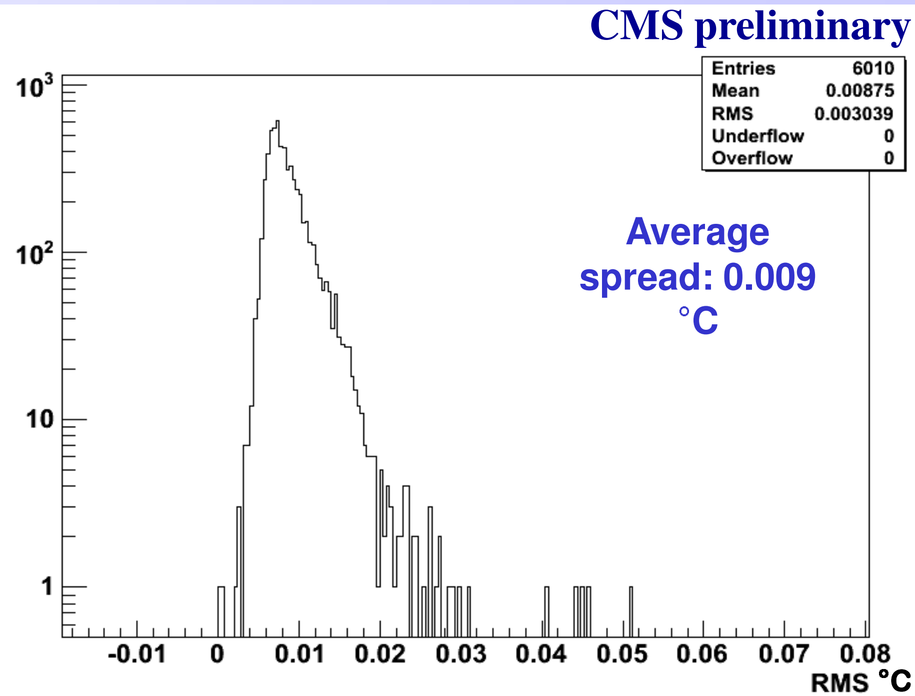
- Controlled (temperature, high voltage, dark current measurements)
- **ECAL response monitored and corrected with laser data**

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

Stability: temperature during CRAFT08

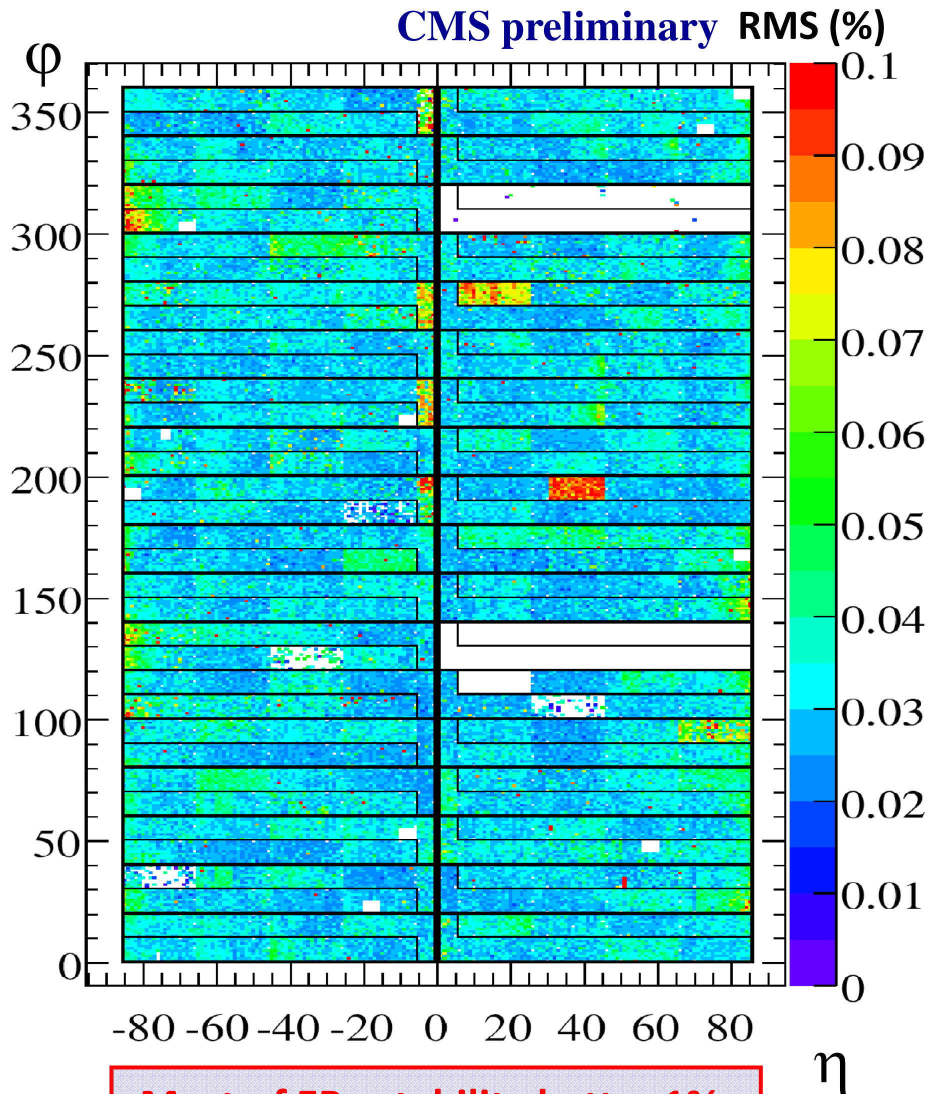




- EB equipped with one precision temperature sensor every 10 channels, in good thermal contact with APD and crystal
- For each sensor, thermal stability is quantified with the RMS of the temperature measurements over one month of data taking
- The observed stability is 0.009 °C on average and better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

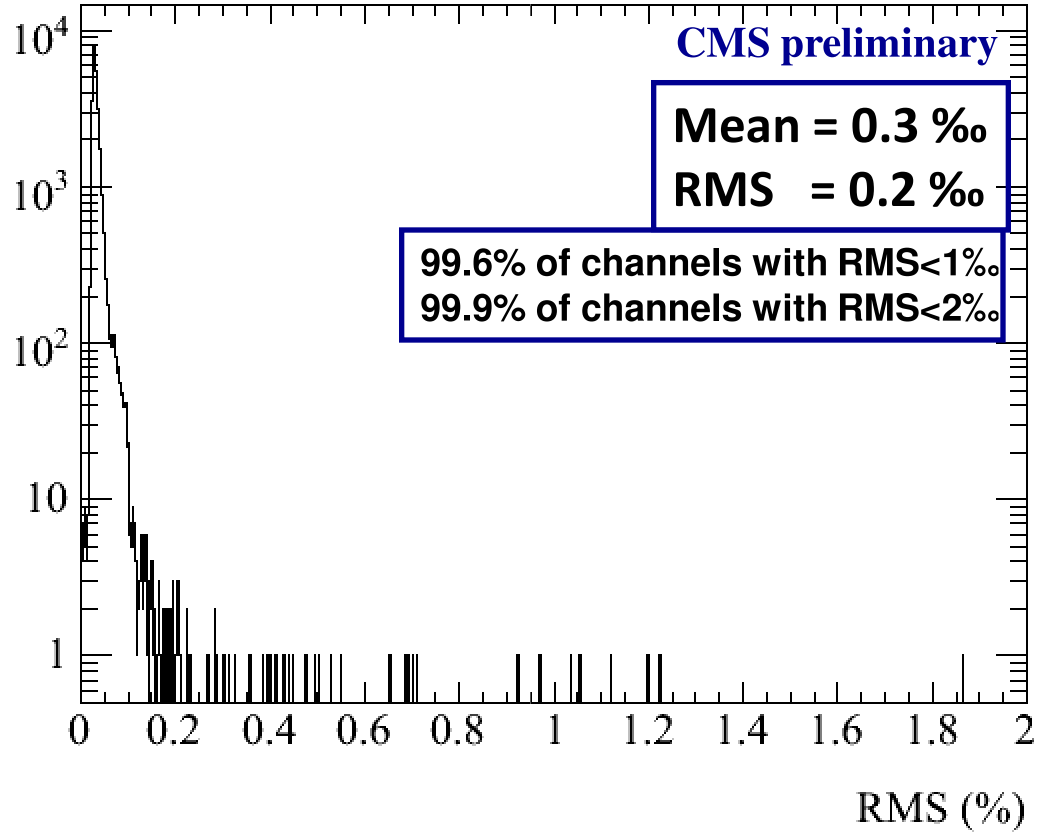
Transparency monitoring stability in EB

- 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**
- Comparable results for EE

CONCLUDING 1: CRAFT 09 analysis challenges

- Seven offline analysis challenges for CRAFT 09: here
- One working group for each challenge, with a contact person to steer the progress and welcome new comers.

- **Cosmic in ECAL endcaps** (C.M. Kuo and P. Govoni)

  reconstruction and study of m.i.p.'s and high energy deposits from cosmic rays in the ECAL endcap (EE crystals and ES preshower) and assessment its performance. Matching between silicon tracker, preshower and ECAL crystals.

- **Transparency Monitoring** (J. Malcles and M. Gataullin)

  end-to-end test, from laser raw data to application of transparency correction in offline reconstruction: work flow exercise of the laser monitoring. Study of ECAL stability, re-doing analysis 2008 with available PN.

- **VPT stability** (A. Ledovskoy)

  load tests and monitoring with LED of the VPT response with orange and blue light.

- **L1 Trigger** (to be discussed with P. Paganini et al.)

  validation of the ECAL L1 trigger primitives with emulation and study of trigger efficiency on the EE. Repeat emulation and efficiency stuty in EB, with TP produced using intercalibrations.

- **Interplay of ECAL stability with trigger** (D. Konstantinov)

  understanding of fake triggers due to pedestal instabilities and study of trigger configurations to mask or reduce the effects. Conclusion on influence on trigger of test pulse and laser in the LHC gap. Study of rates and ECAL trigger instability.

- **ECAL Noise and impact physics objects** (E. Di Marco)

  study of ECAL noise and its impact on fake physics objects and on isolation in standard reconstruction for e/gamma and jetMet. Foresees contacts to POG's.

- **Ecal data reduction** (Ph. Gras)

  validation of EE Selective Readout Processor, threshold for data reduction (Zero Suppression, SRP), and check consistency with simulation.

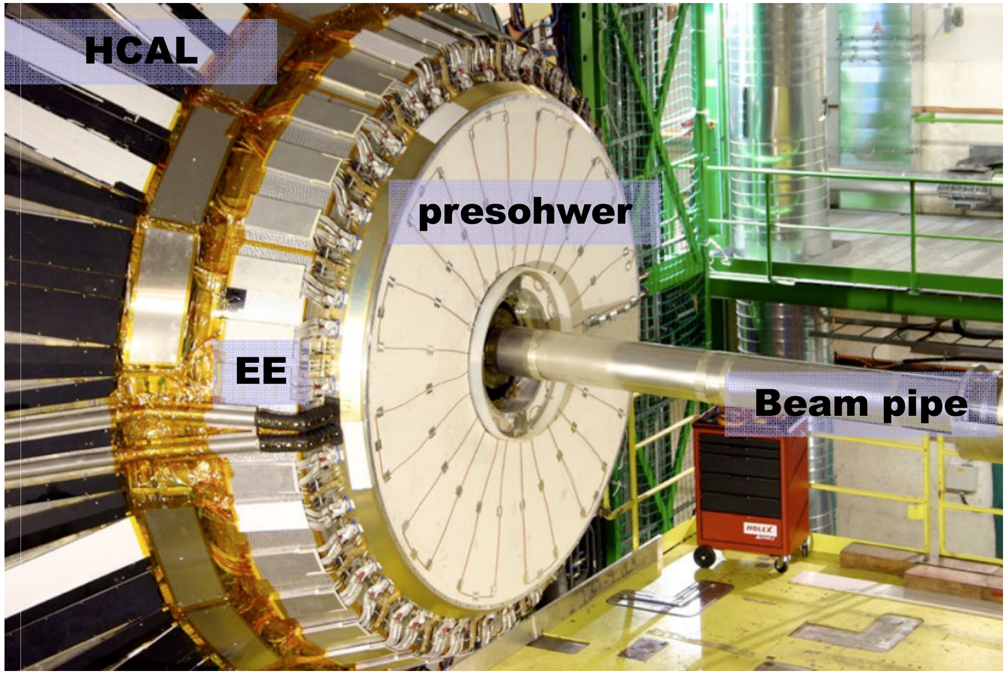
CONCLUDING 2:
CMS ECAL: running if you get involved

- 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
- Getting ready and in shape for run 2009

- **Help is needed in many critical areas of the ECAL project**. A lot to learn, a lot still to do and to follow up.
- Among those, ECAL DPG (main page):
  - "ECAL opportunities": list of uncovered tasks here
  - Recent workshop on software (one of the emergencies): here
- **Get involved!**

Status of the calorimeter July 09

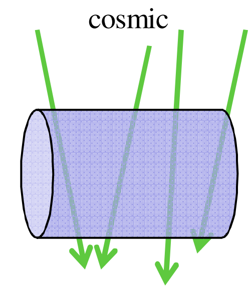
- Preshower:
  - Installed in the months of February-March 2009
  - First data collected to check out components and connections ➔ same status of health as in the laboratory, prior to installation:
    - 99.88% good channels (tot 137k)
    - MIP Signal/noise: 3.6 in low gain (physics) and 9 in high gain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



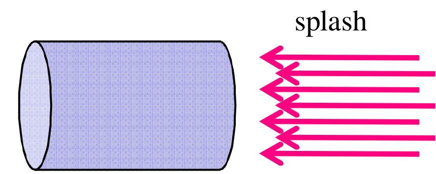
- Cristal calorimeter:
  - EB and EE active through LHC beams and extended cosmic rays run in 2008
  - More than 99.5% of the channels are in good health for physics
  - System routinely operated in CMS global exercises, collecting data to monitor the detector and consolidate data acquisition and procedures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

Last year of commissioning 2008: three phases

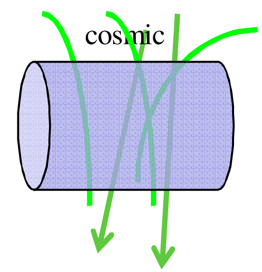
- Cosmic rays **ru**ns at **ze**ro Tesla magnetic field (**CRUZET**), march september 08
  - Collection of cosmic rays, mip and showers
  - Exercise and consolidate data acquisition and trigger
  - Test and improve procedures, services, reliability



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



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