The CMS Crystal Calorimeter

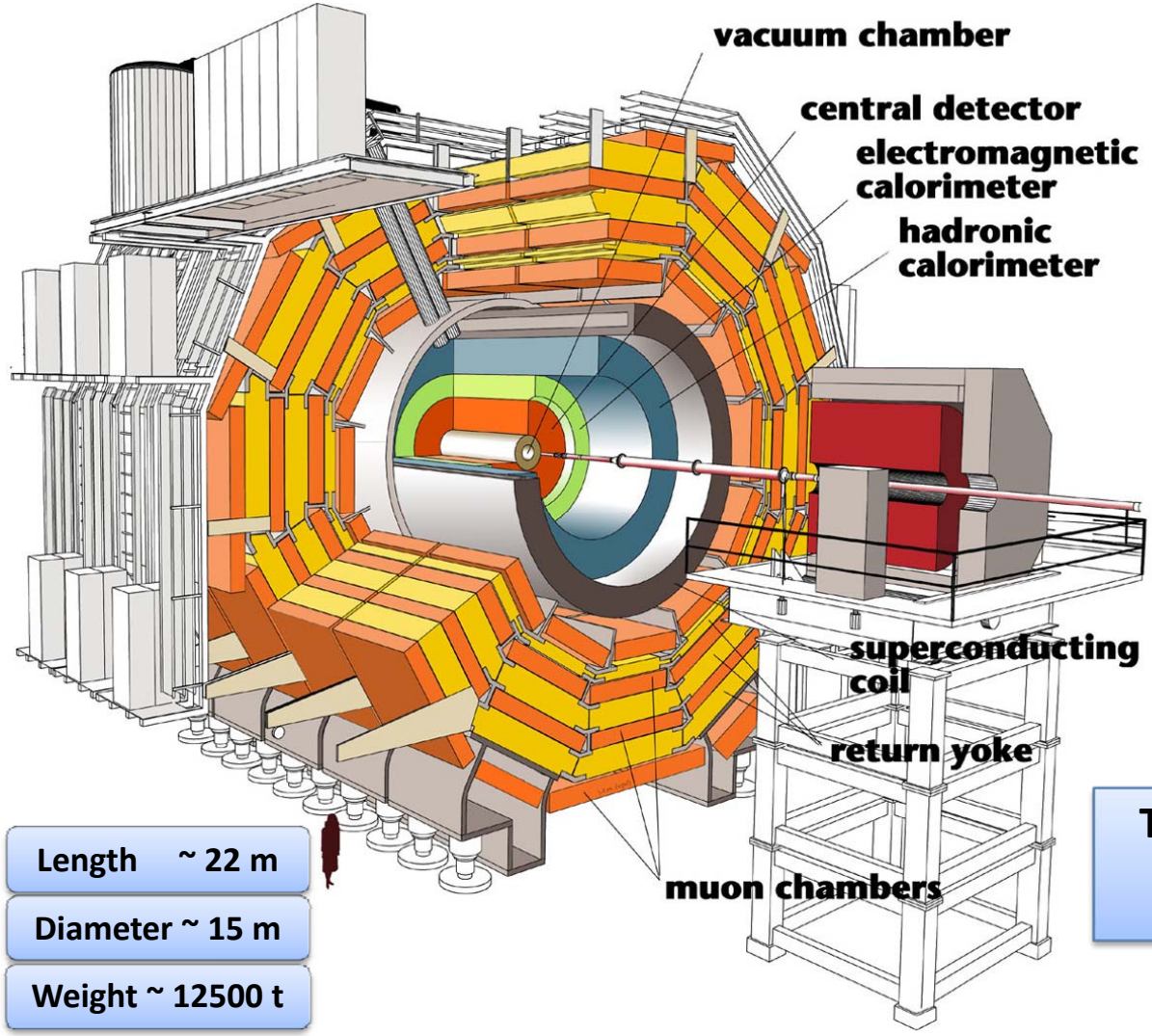
XIII International Conference on Calorimetry in High Energy Physics

Pavia, May 26-30, 2008

W. Lustermann on behalf of the CMS ECAL group

- Introduction
- Calorimeter Design
- Construction and Installation
- Calibration
- Summary

Compact Muon Solenoid



Length ~ 22 m

Diameter ~ 15 m

Weight ~ 12500 t

CMS Objectives:

- Higgs discovery
- Physics beyond the Standard Model

Search for the Higgs

Benchmark:

$H \Rightarrow \gamma\gamma$ ($m_H < 140$ GeV / c^2)

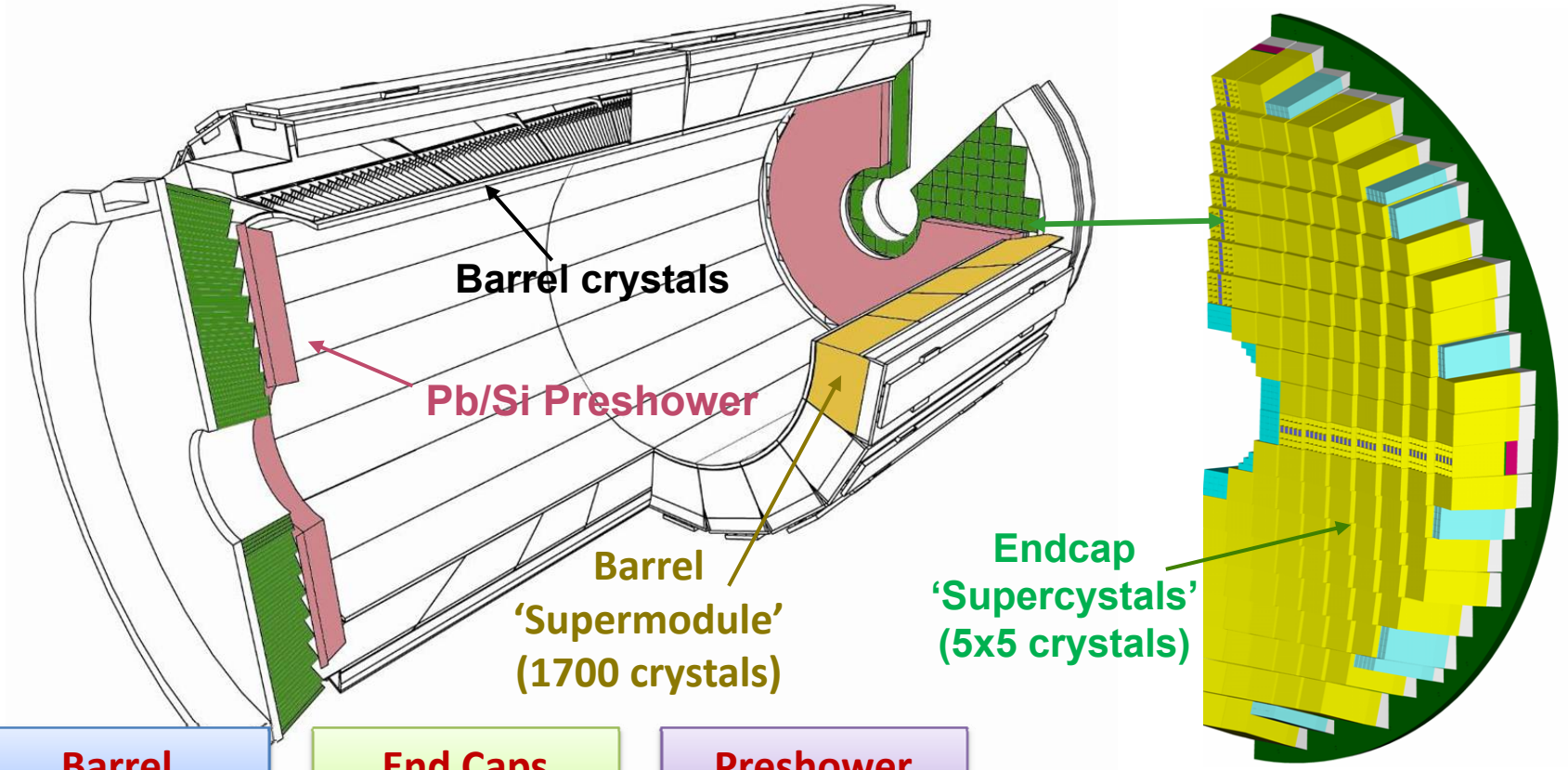
Also:

$H \Rightarrow ZZ$ and $H \Rightarrow WW$

Target ➔ high resolution ECAL

$\Delta E/E$ ~ 0.5% for E > 100 GeV

Calorimeter Construction



Barrel	End Caps	Preshower
• 61200 crystals • 36 super modules • $\|\eta\| < 1.48$ • ~ 26 X_0	• 14648 crystals • 4 Dees • $1.48 < \|\eta\| < 3$ • ~ 25 X_0	• Pb/Si • $1.65 < \|\eta\| < 2.6$ • 3 X_0

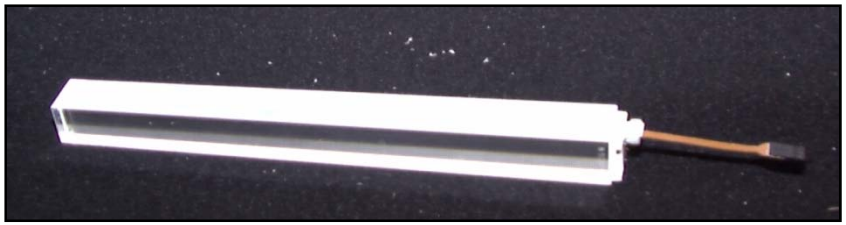
Life time:	• ~10 years
Maintenance:	• zero

Crystals

- Crystals: Lead Tungstate: $PbWO_4$
- Fast scintillation: 80% of the light collected in 25ns
- Radiation length: 0.89 cm
- Moliere radius: 2.2 cm

$\Rightarrow$ Compact calorimeter design

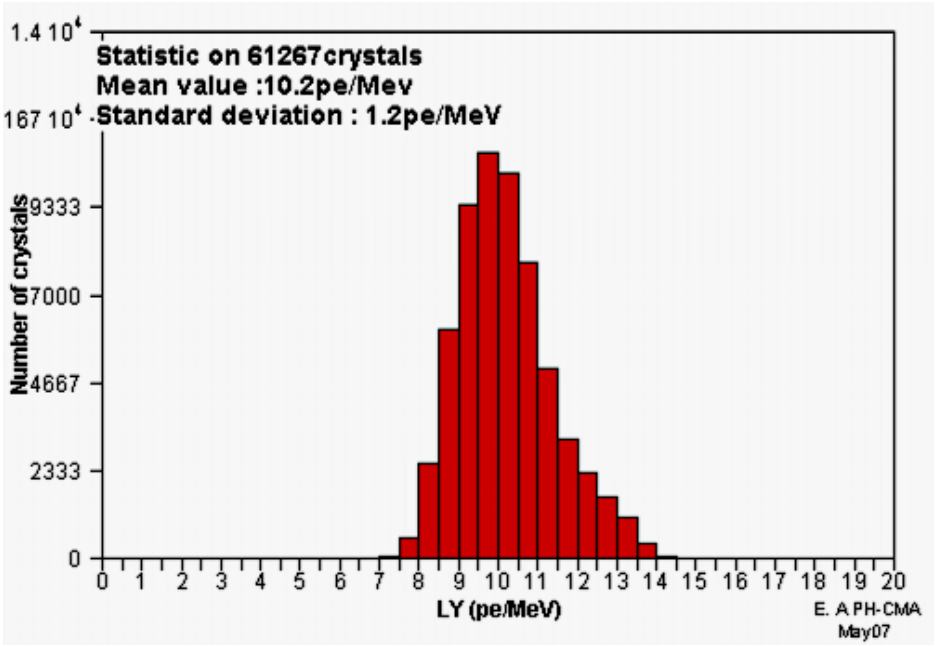
$\Rightarrow$ fine segmentation



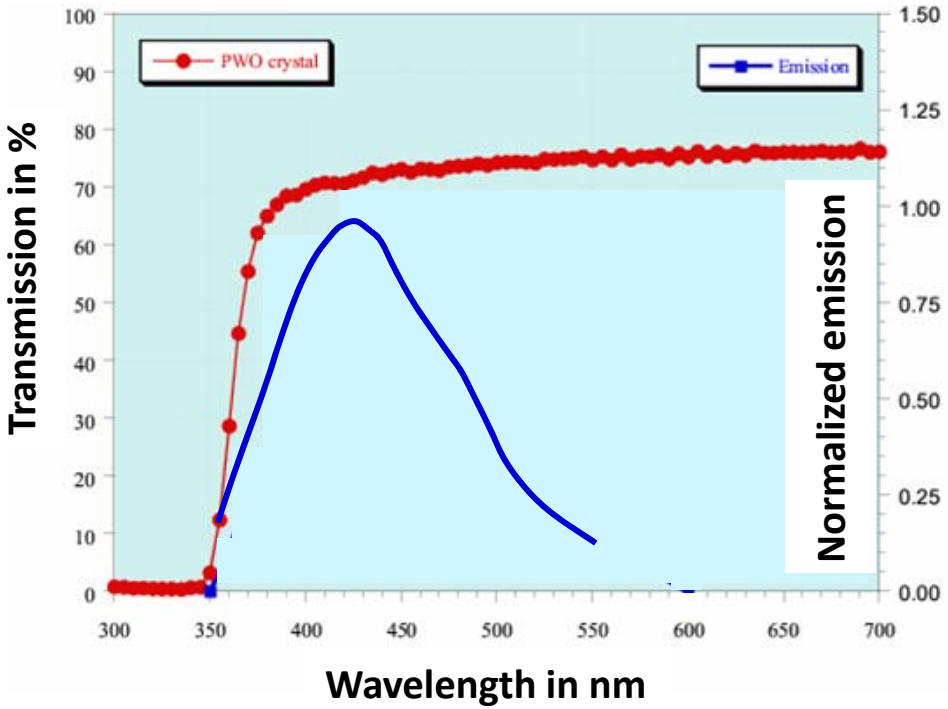
- Low light yield: >8 pe / MeV
- Light yield change: -2% / °C

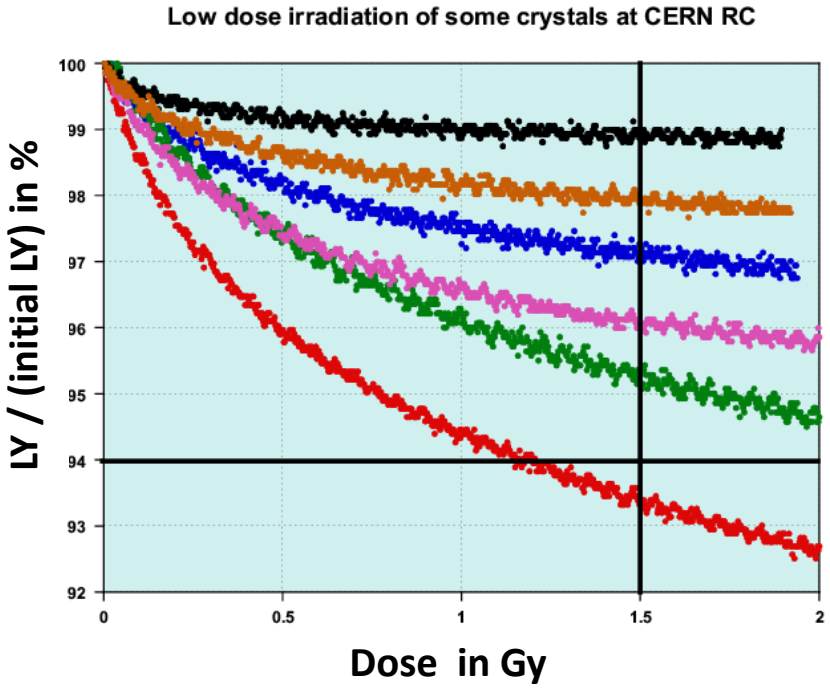
$\Rightarrow$ requires: T = (18 ± 0.05) °C

- Front non uniformity of the light yield: |FNUF| < 0.35 % / X_0 (de-polish one face of the crystals to 0.35 μm for the barrel crystals)



Crystals Radiation Hardness





Radiation:

affects only the light transmission

Low dose rate (0.15Gy/h) irradiation only on sample basis

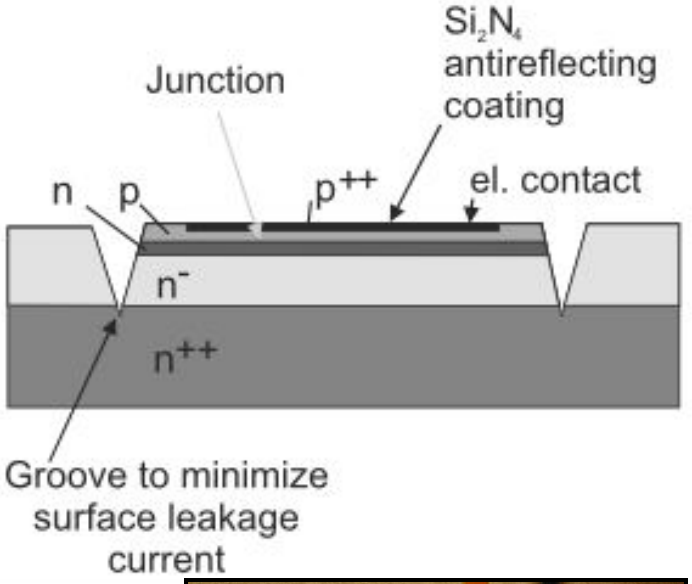
Light yield loss correlates with slope of transmission spectrum

all crystals are tested by an automatic crystal control system (ACCOS),

APD: Barrel Photodetector

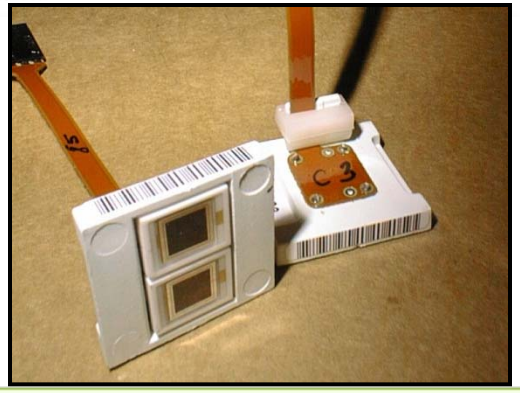
APD type S8141 from Hamatsu:

- Two APDs per crystal
- Active area: (5 x 5) mm2
- Capacitance: 80 pF
- Reversed bias: (340 - 440) V
- Quantum efficiency: 75% at 430 nm
- Gain variation: -2.4 % / °C
- Nominal gain: 50 changes 3.1 %/V
- ⇒ Bias voltage stable to ± 20 mV



Require 99.9% reliability

- Radiation tests: Co^{60} to 5 kGy
- Gain, dark current, noise spectrum measurement
- Annealed under bias at 80°C, 4 weeks
- ⇒ 95% of the APD's passed selection



Capsule directly glued on the crystal rear face

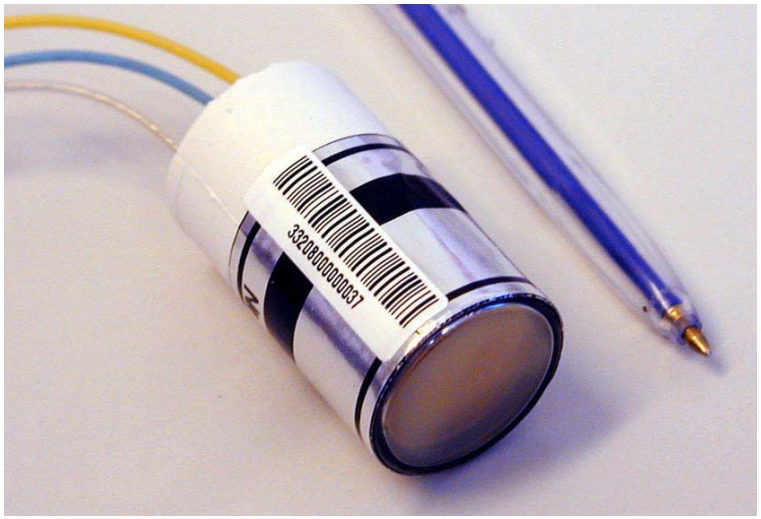
VPT: End Caps Photodetector

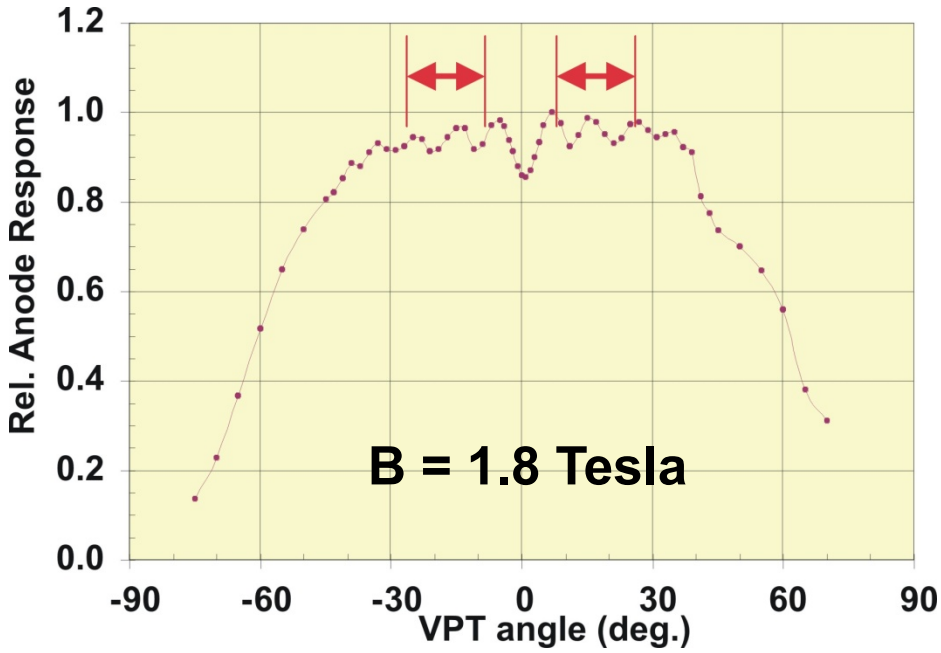
Vacuum Photo Triodes (VPT): single stage photo-multiplier

- Total: ~15000 pcs
- Active area: 280 mm2
- Quantum efficiency: 20% at 430 nm
- Nominal gain: 10
- Excess noise factor: 3

> All pcs delivered and tested

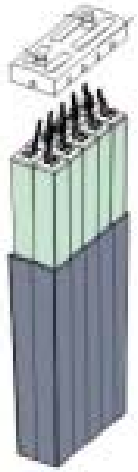
- All VPT's tested up to B = 1.8 T for angles $|\theta| < 30°$
- Sample testing up to B = 4 T
- Radiation effects < 10%



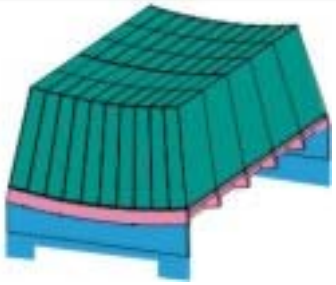


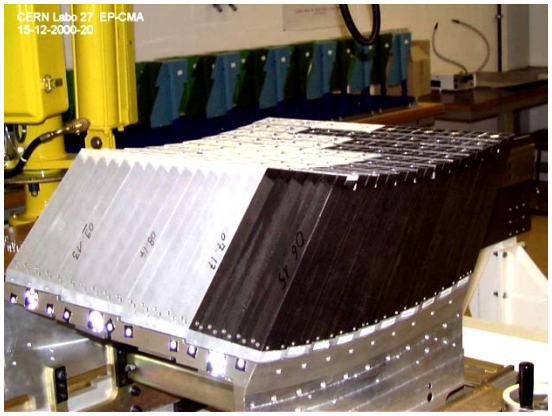
Barrel Calorimeter Construction

Sub-module assembly (10 crystals)

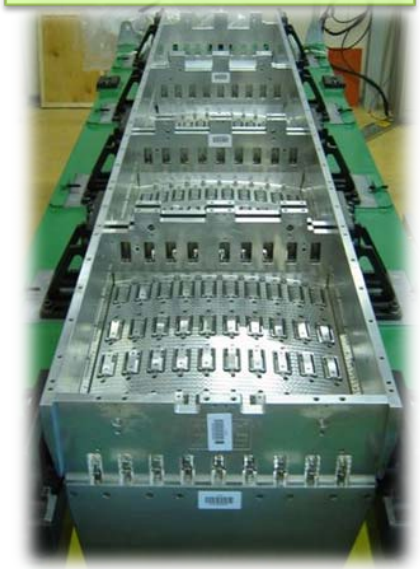


Module
400 (500) crystals



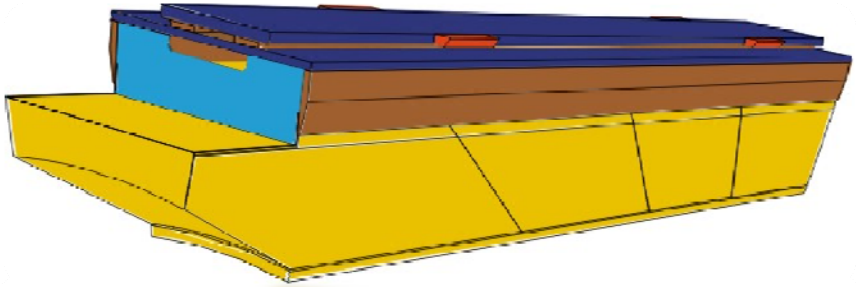


bare supermodule



Cooling circuits installed

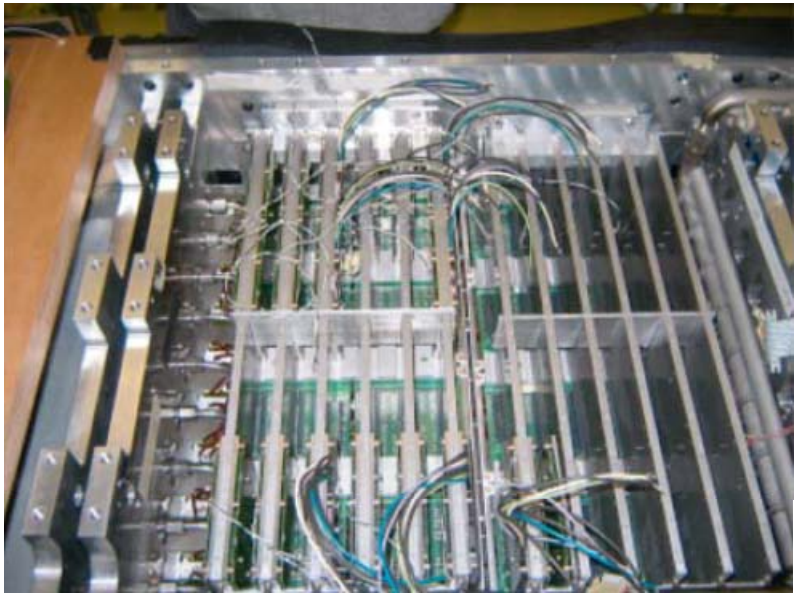
Super module (4 modules, 1700 crystal)

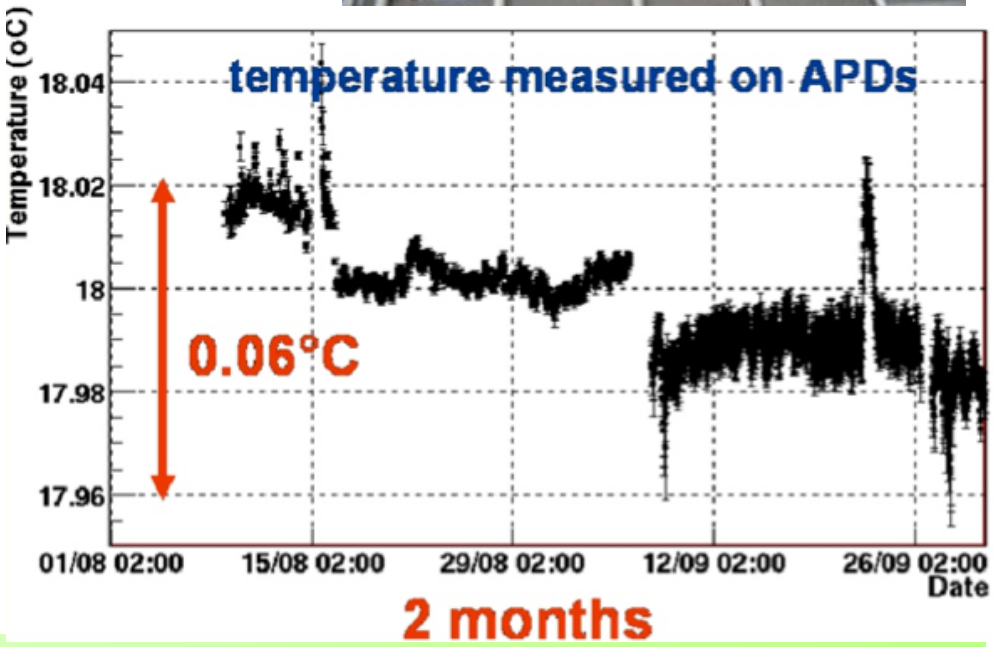


Cooling

Excellent thermal stability of crystals and APD's:

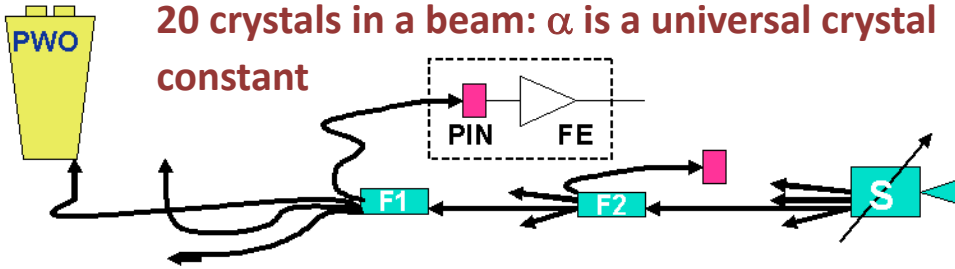
- APD/crystal Stability < 0.1 ºC
- Remove ~4.5 kW heat per super module
- Electronics connected to cooling bars using thermal interface materials
- Total water flow 50 l / s (barrel)

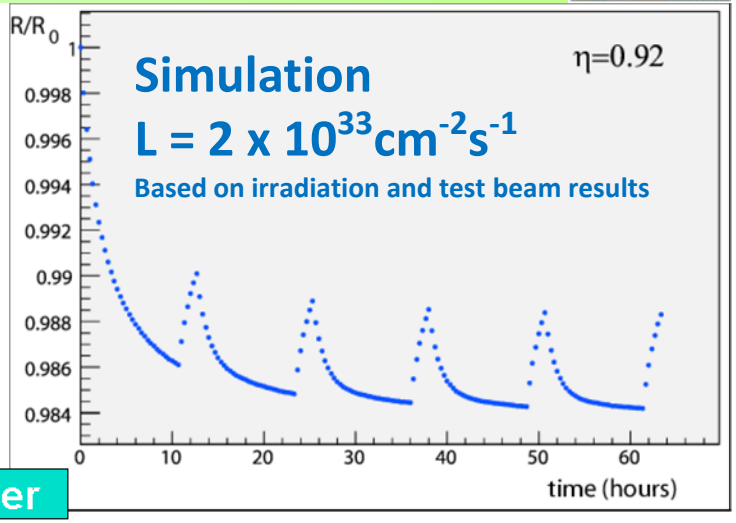


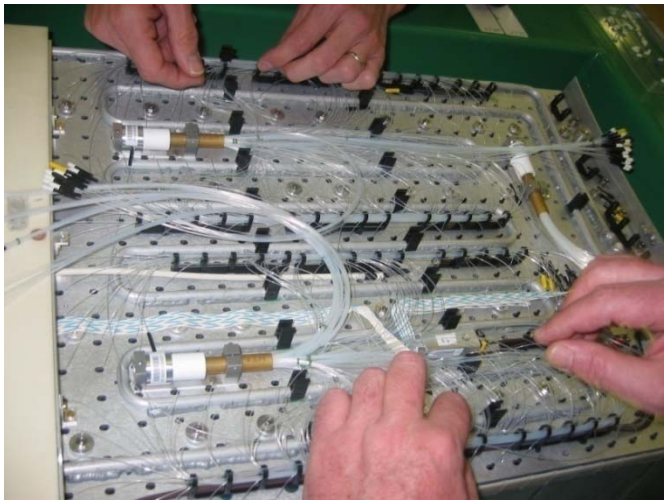


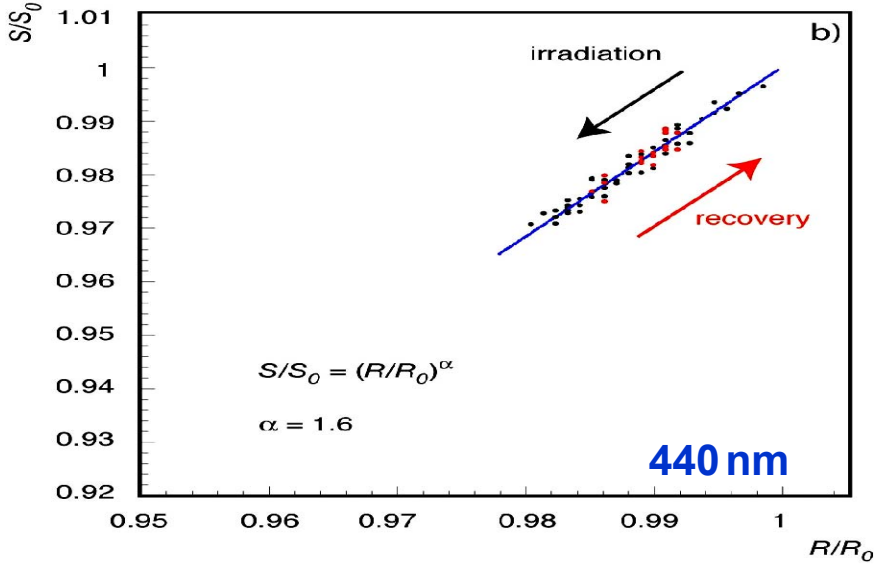
Light Monitoring System

- Crystals light yield changes due to irradiation ==> Monitor response to laser light of 440nm, and 796nm
- Relative response to electrons and laser light characterized by a single constant α ==>Test with 20 crystals in a beam: α is a universal crystal constant



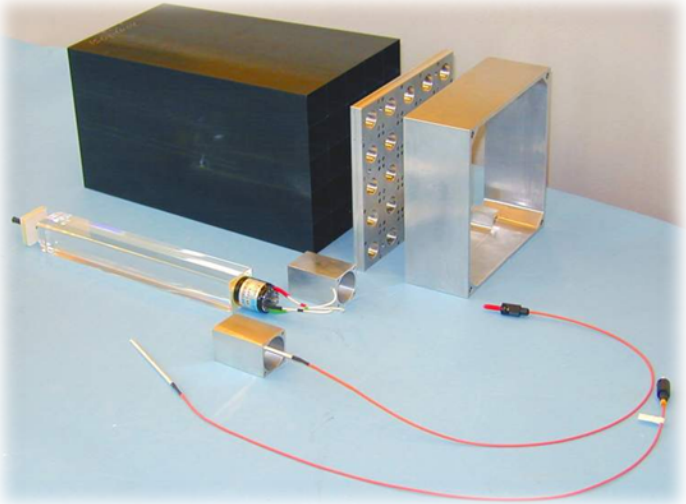


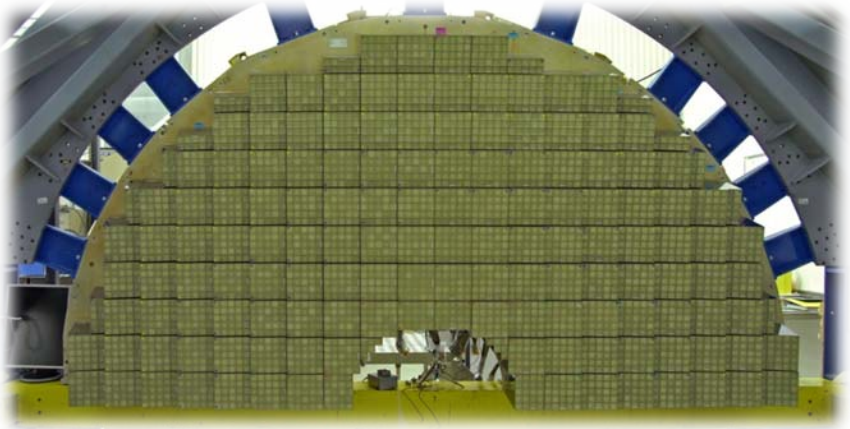




ECAL End Caps

Supercrystal (SC): 5x5 crystals





4 "Dees" of 156 SCs each

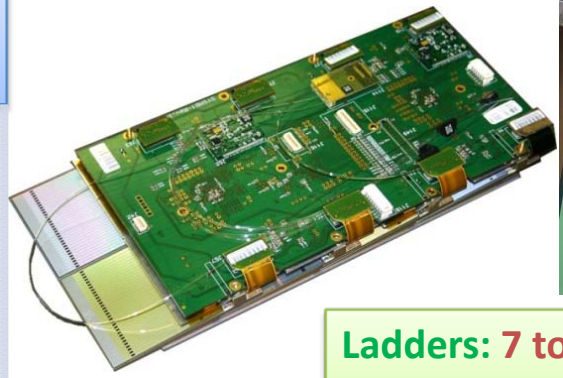
- Installation of SCs completed
- Installation and commissioning of electronics ongoing
- First end cap expected for June 08
- Second end cap expected for July 08

Pre-Shower Detector

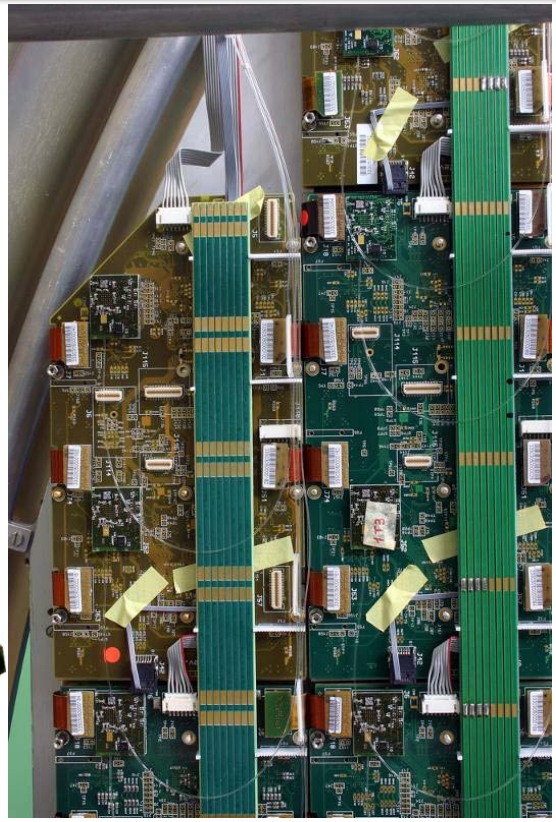
Rapidity	• 1.65 < |η| < 2.6 (End caps)
Motivation	• Improved π^0/γ discrimination
Layout	• 2 orthogonal planes of Si strip detectors behind 2 X_0 and 1 X_0 Pb respectively
Strip pitch	• 1.9 mm (63 mm long)
Area	• 16.5 m^2, 4300 detectors

4 "Dees" of 126 ladders each

- all mechanics at hand
- 60% of Si modules and 30% of ladders tested
- Assembly of first Dee started
- ➔ 1 end cap ready in July 08

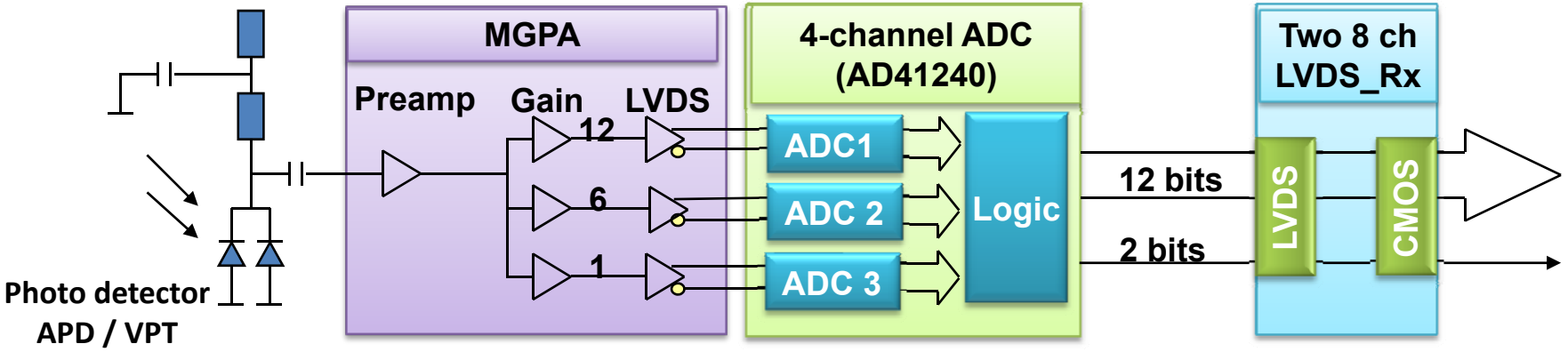


Trial Mounting on first plane)



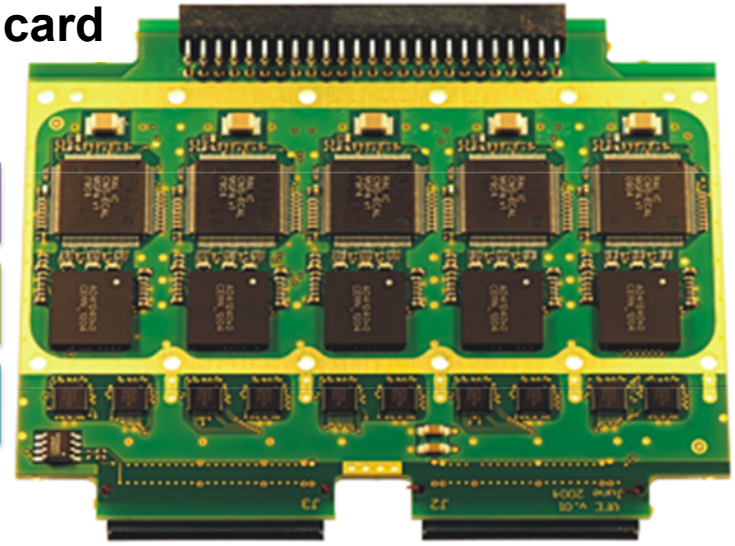
Ladders: 7 to 10 Si detectors integrated with FE elecronics

Very Front End Electronics



digitize once every 25 ns the energy in all crystals

VFE card



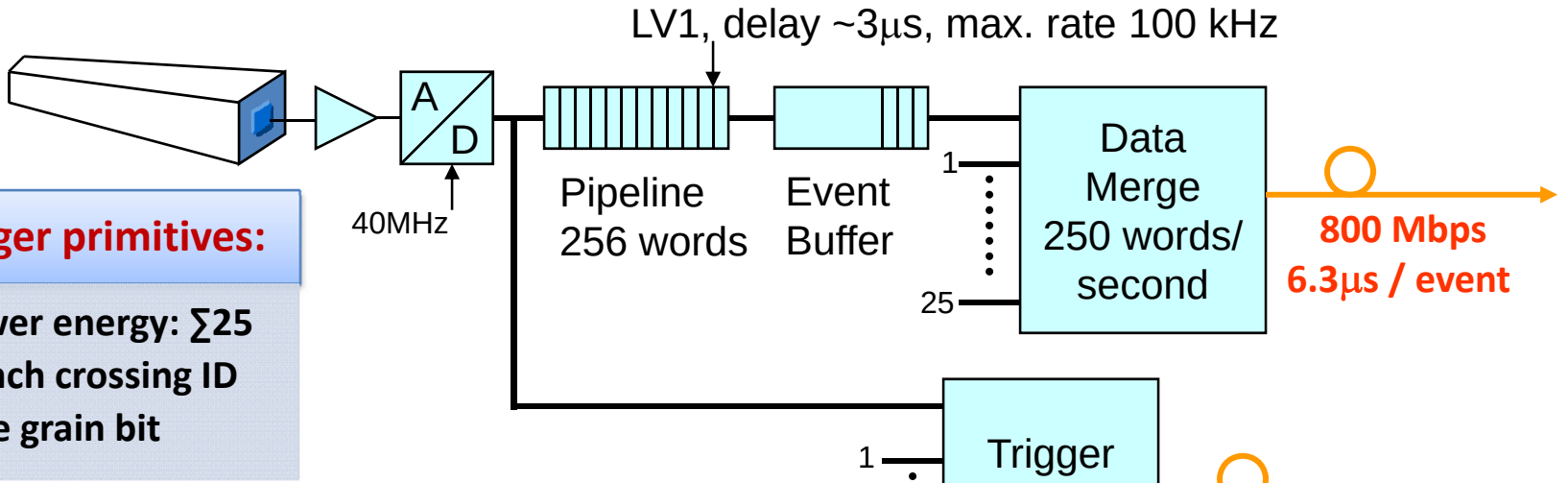
MGPA

ADC

LVDS_Rx

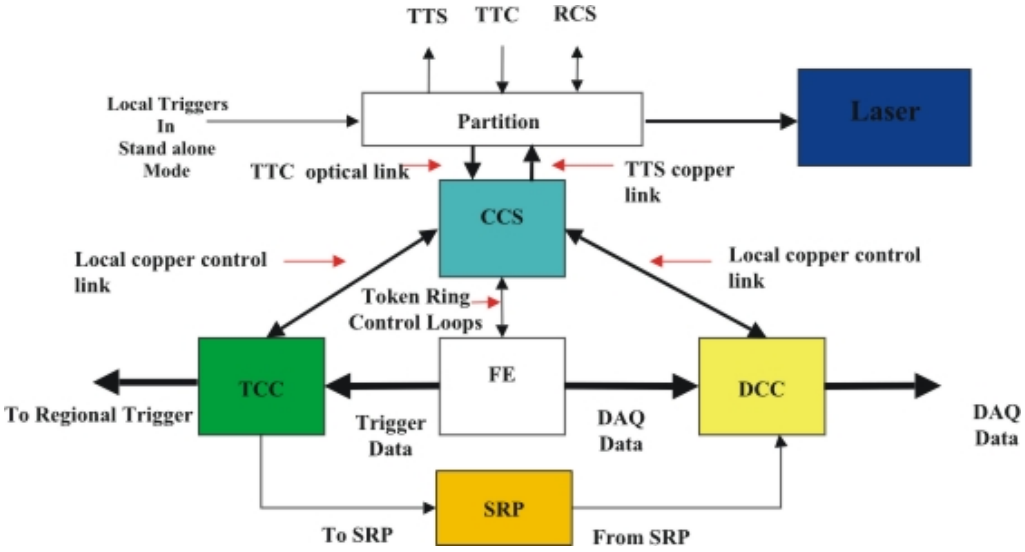
- ENC: 8000e- gain 6, 12
- ENC: 28000e- gain 1
- Noise: ~40 MeV (g12)
- ADC: 12 bit (ENOB 10.9), 40 MHz

Front End Electronics



Trigger primitives:

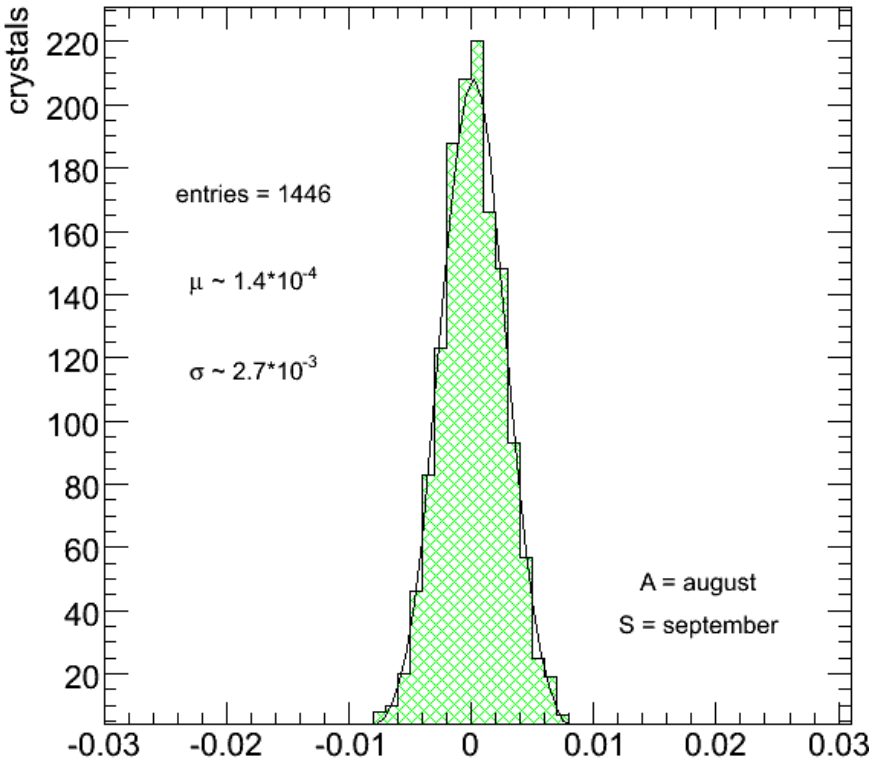
- **Tower energy: ∑25**
- **Bunch crossing ID**
- **Fine grain bit**

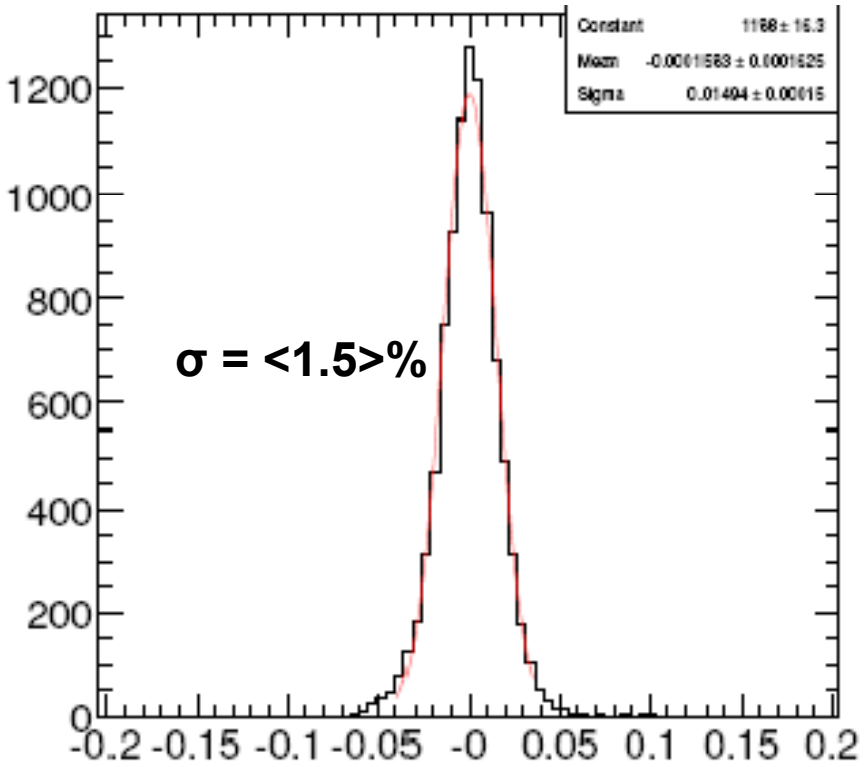


Crystals Intercalibration

9 super modules (25%) inter-calibrated with electron beam
σ / √2 = 0.2%
Electron beam reproducibility

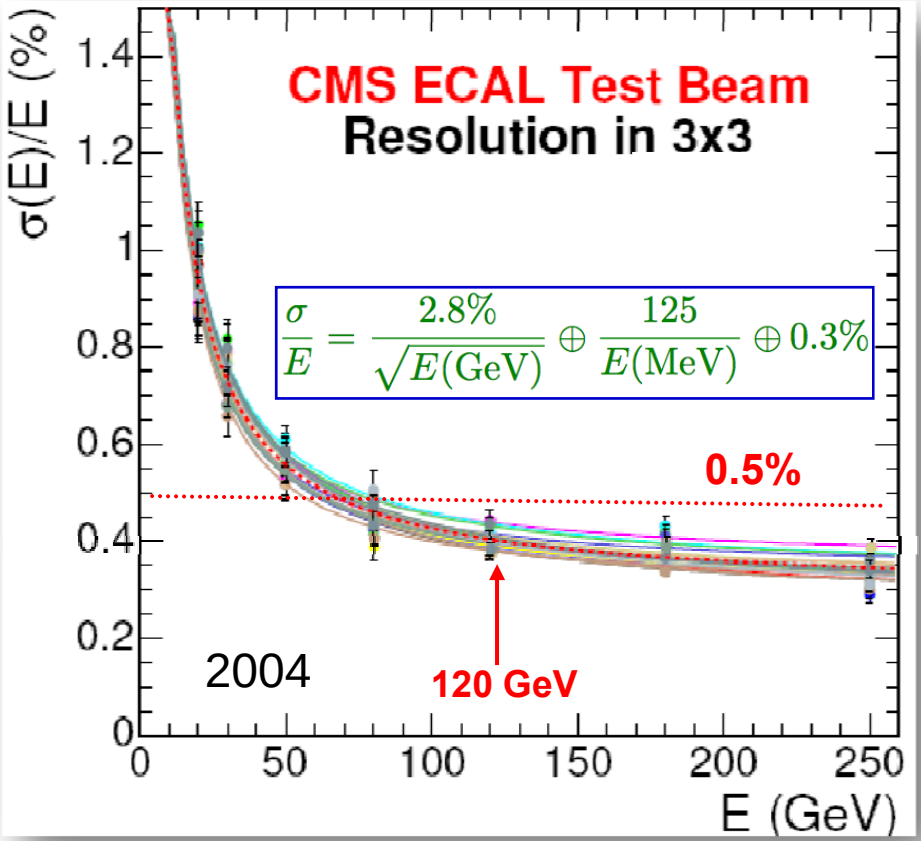
36 super modules (100%) inter-calibrated with cosmics
Electron beam cosmic muons comparision





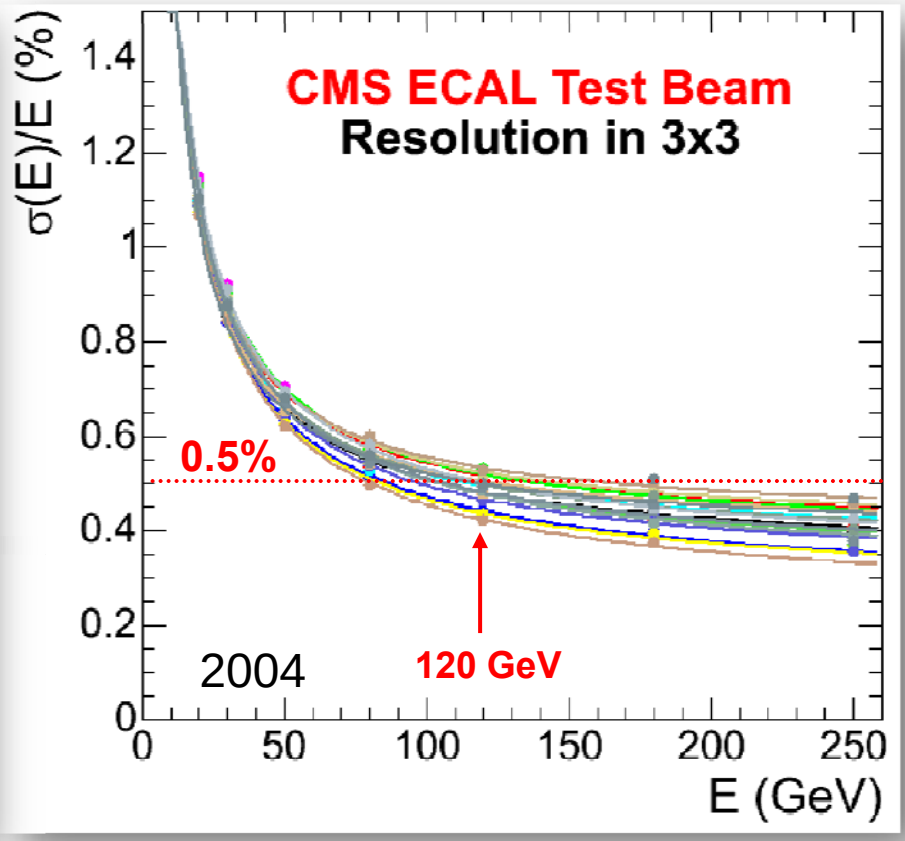
Energy Resolution

Central impact (4x4 mm^2)



Uniform impact (20x20 mm^2)

After impact position corrections



see talk of R. Arcidiacono

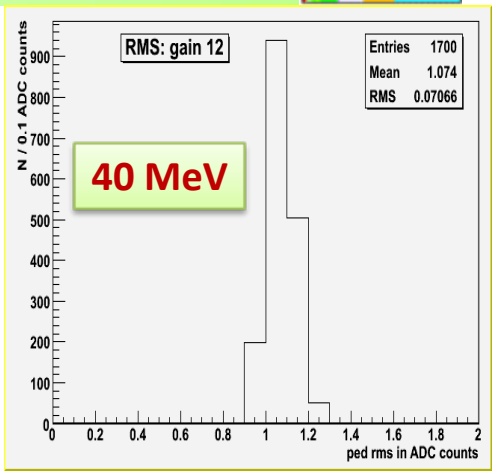
EB Integration and Installation

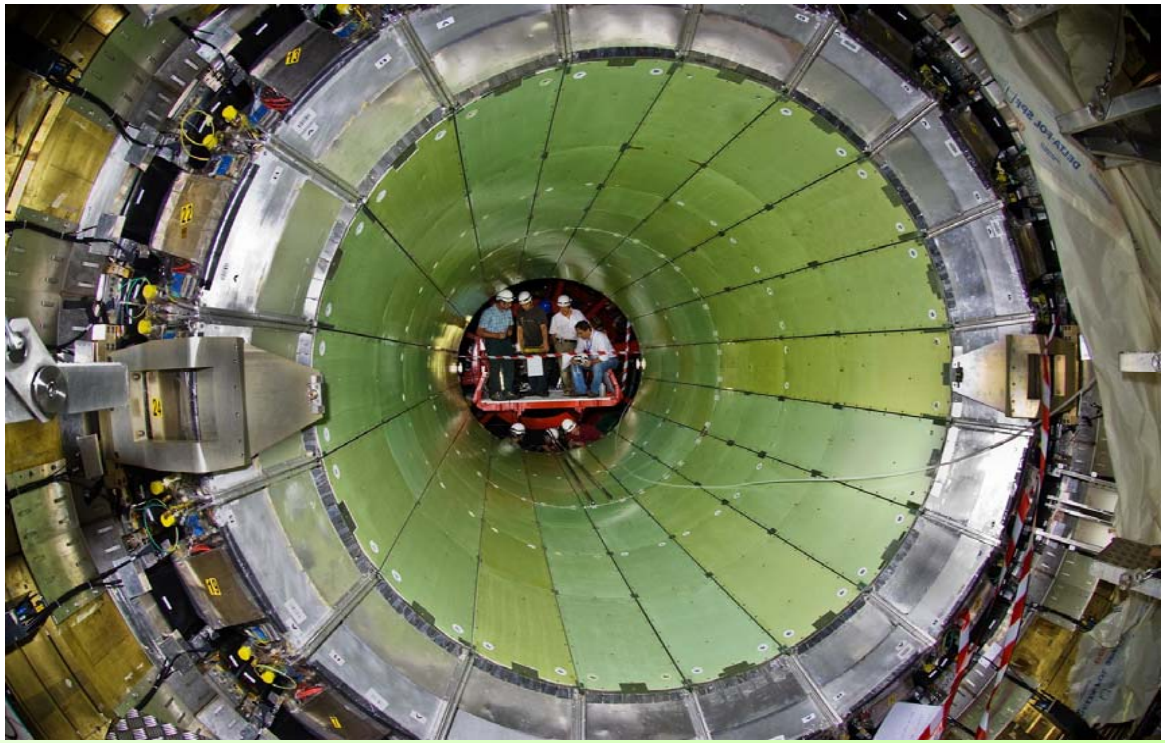
Barrel Construction and Installation completed

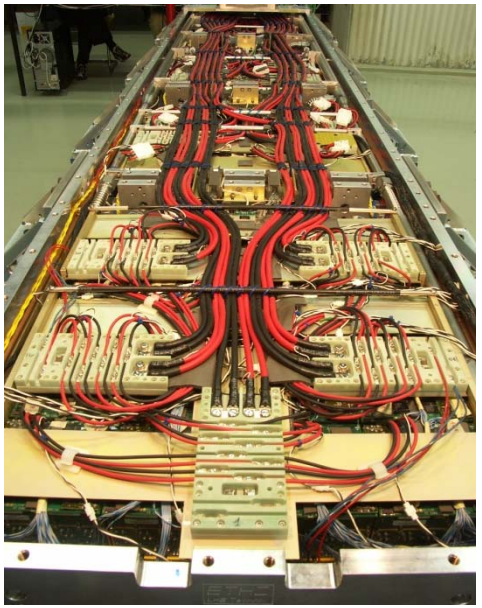
- 61200 channels
- 102 problematic channels (0.17%)
- 21 dead channels (0.034%)

Systematic Testing

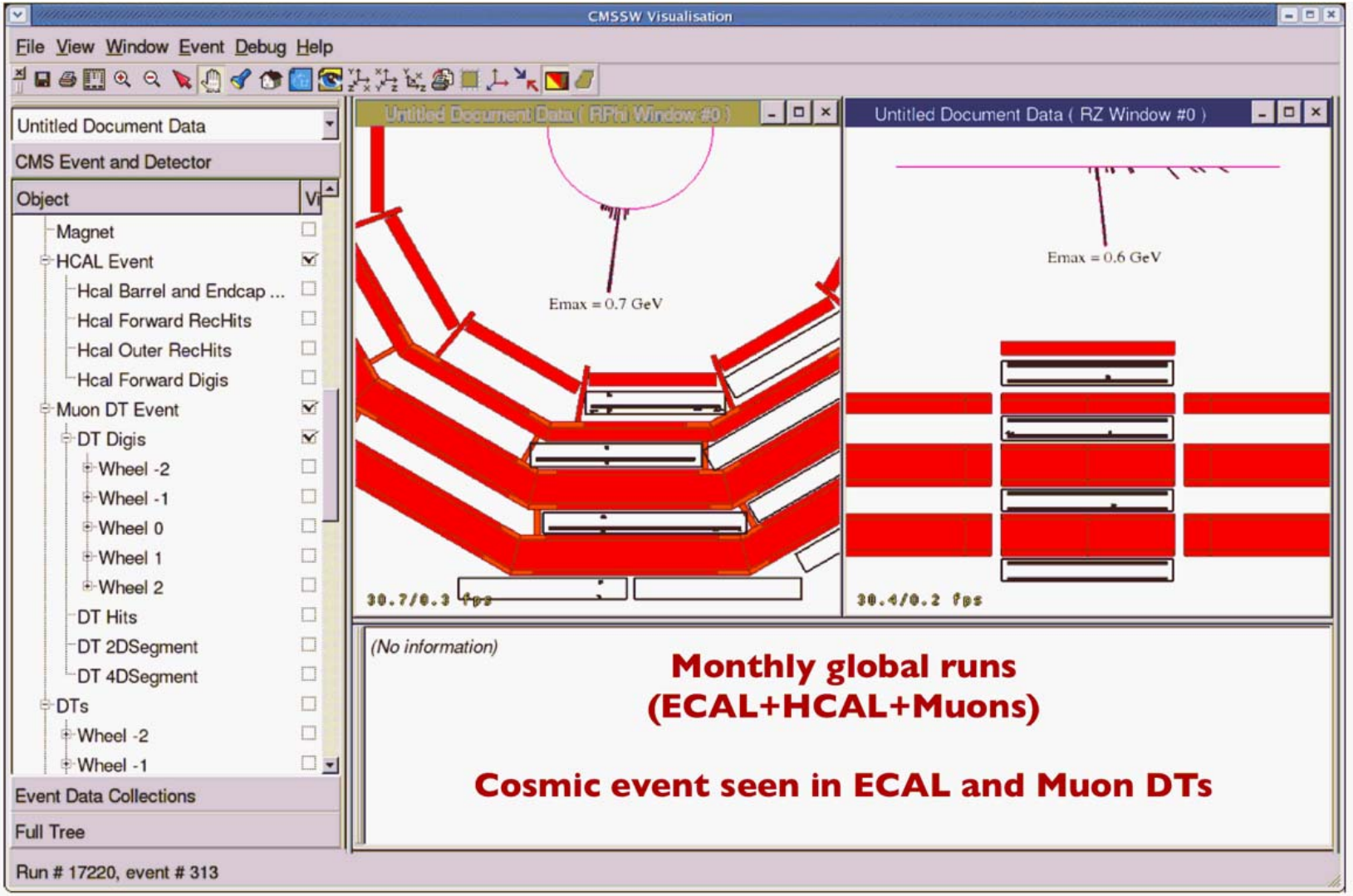
- Pedestal: RMS 1.1 ADC counts ↔ 40 MeV
- Test pulse and Laser



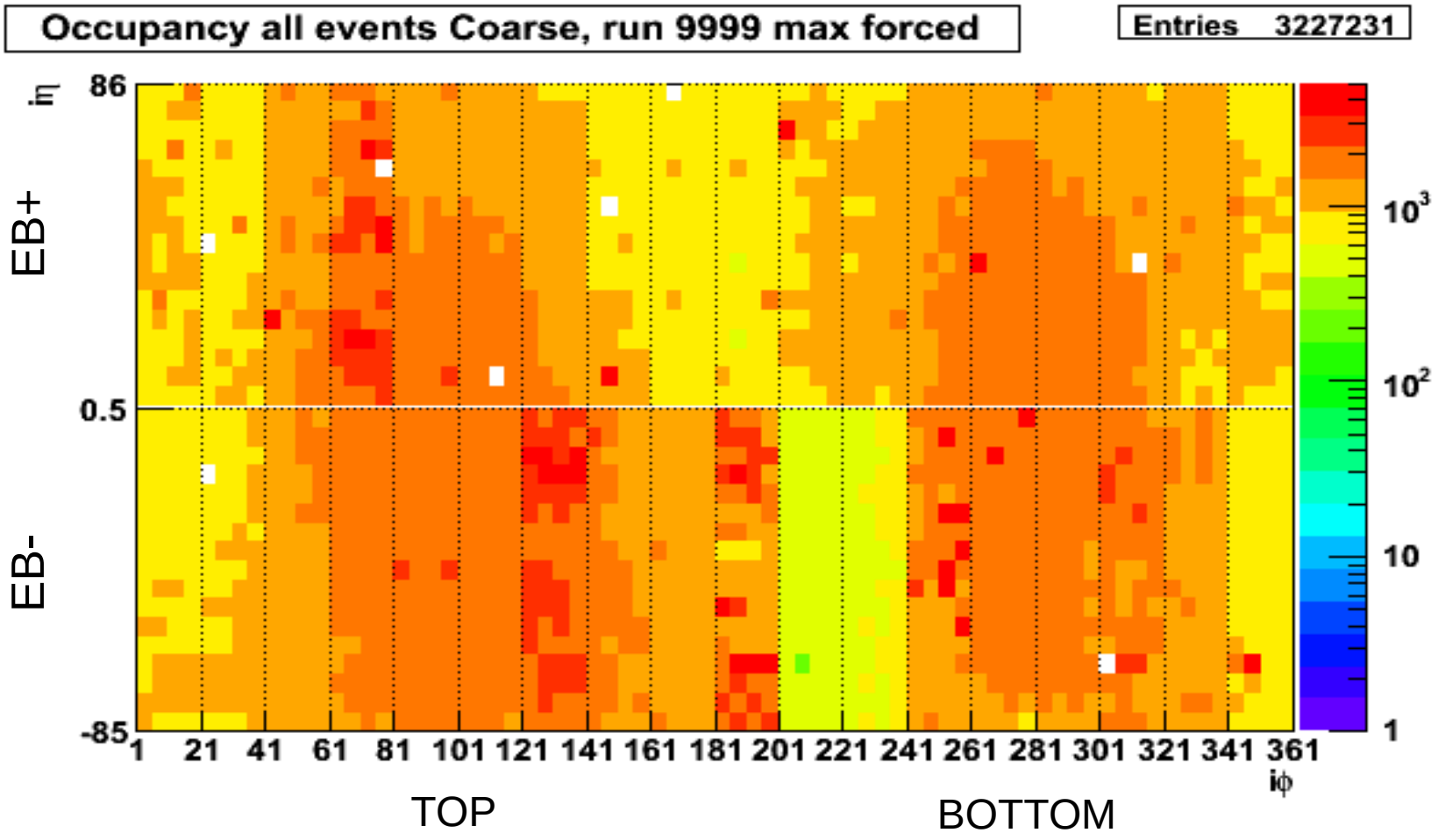




Cosmic Muon Event



ECAL Cosmic Muon Occupancy



Summary

Design	• CMS features a high resolution crystal calorimeter • Pre-shower detector in the end cap region
Construction Installation	• Barrel part is installed and tested • End caps close to completion, installation start June • Pre-shower progressing well , installation start July
Calibration	• All barrel channels intercalibrated to better than 2% • Extensive beam studies of 9 SMs have demonstrated the excellent performance
Operation	• ECAL barrel successfully integrated into CMS and participates to CMS global data taking (cosmic muons)