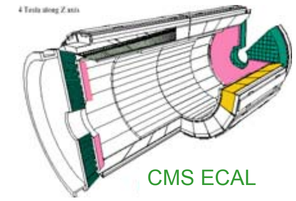
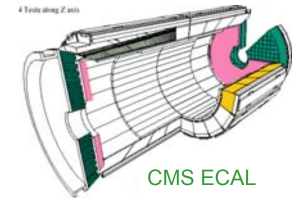


The Status of the CMS Electromagnetic Calorimeter

R M Brown
On behalf of the CMS ECAL Community

Rutherford Appleton Laboratory

Overview



- Introduction
- Design objectives and technology choices
- Description and status:
  - Crystals
  - Photo-detectors
  - On-detector electronics
  - Off-detector electronics
  - Laser monitoring system
  - Mechanical construction and assembly
- Pre-shower
- Test beam results
- Calibration strategy
- Construction and installation schedule
- Summary

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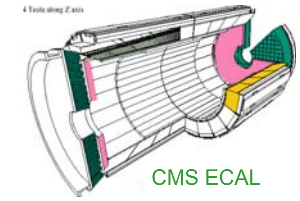
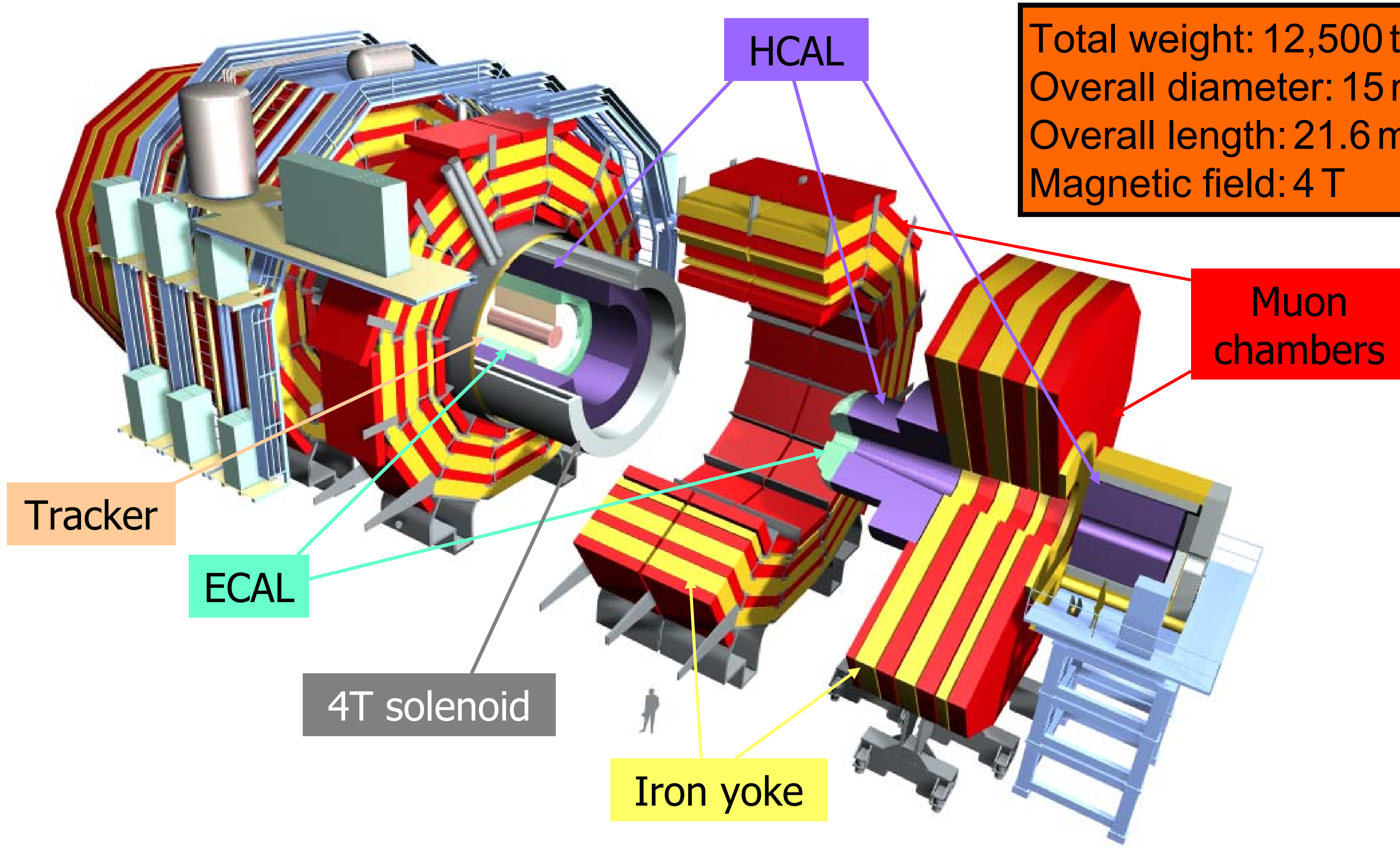
Compact Muon Solenoid



Total weight: 12,500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 T



ECAL design objectives

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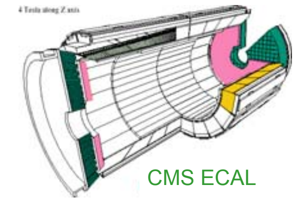


High resolution electromagnetic calorimetry is a central design feature of CMS

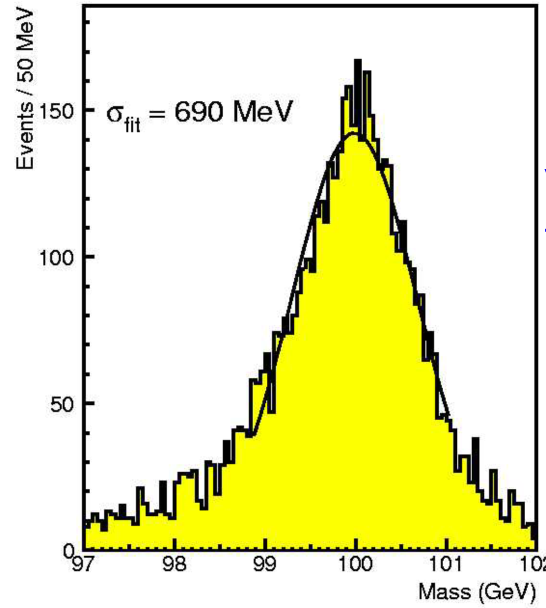
Benchmark process: $H \to \gamma\gamma$

$$\sigma_m / m = 0.5\left[\sigma_{E_1}/E_1 \oplus \sigma_{E_2}/E_2 \oplus \sigma_\theta / \tan(\theta/2)\right]$$

Where: $\sigma_E/E = a/\sqrt{E} \oplus b \oplus c/E$

Aim:		Barrel	End cap
Stochastic term:	$a =$	2.7%	5.7%
(p.e. stat, shower fluct, photo-detector, lateral leakage)			
Constant term:	$b =$	0.55%	0.55%
(non-uniformities, inter-calibration, longitudinal leakage)			
Noise: (electronic, pile-up)	Low $\mathcal{L}$ $c =$	155 MeV	770 MeV
	High $\mathcal{L}$	210 MeV	915 MeV

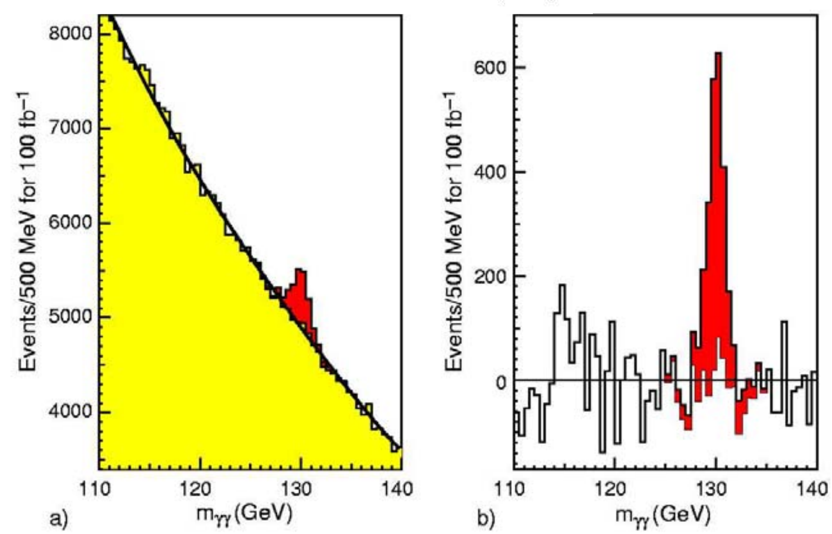
($\delta\theta$ limited by interaction vertex measurement)



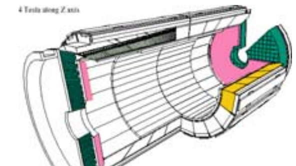
$\mathcal{L} = 10^{34}\,cm^2 s^{-1}$

Vertex by track finding

$m_H = 100$ GeV



Challenges & Choices


CMS ECAL

Challenges:

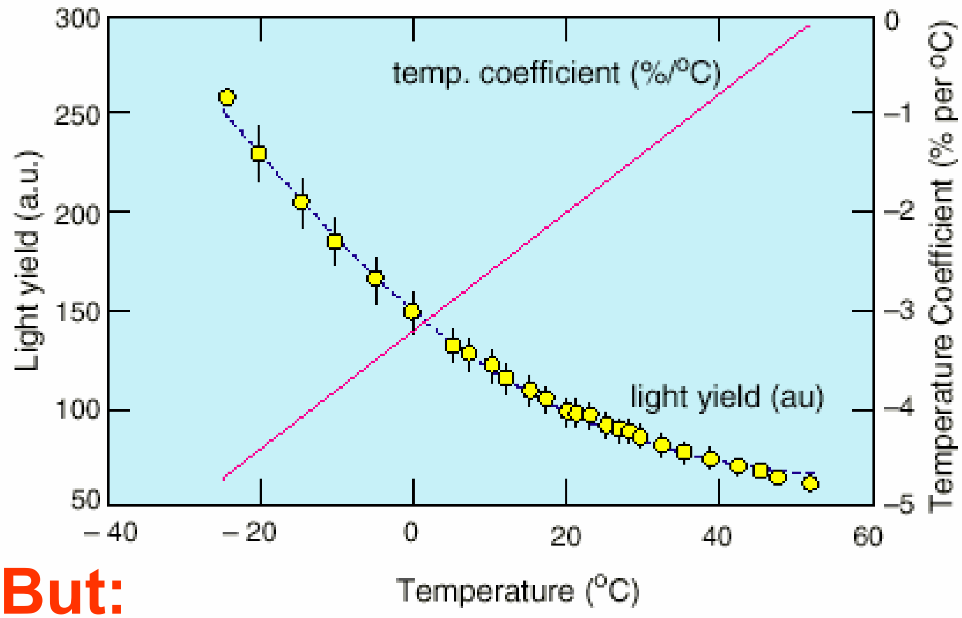
- Fast response (25ns between bunch crossings)
- High radiation doses and neutron fluences
  (10 year doses: 10^{13} n/cm^2, 1kGy at η=0   2x10^{14} n/cm^2, 50kGy at η =2.6)
- Strong magnetic field (4 Tesla)
- On-detector signal processing
- π^0/γ discrimination
- Long term reproducibility

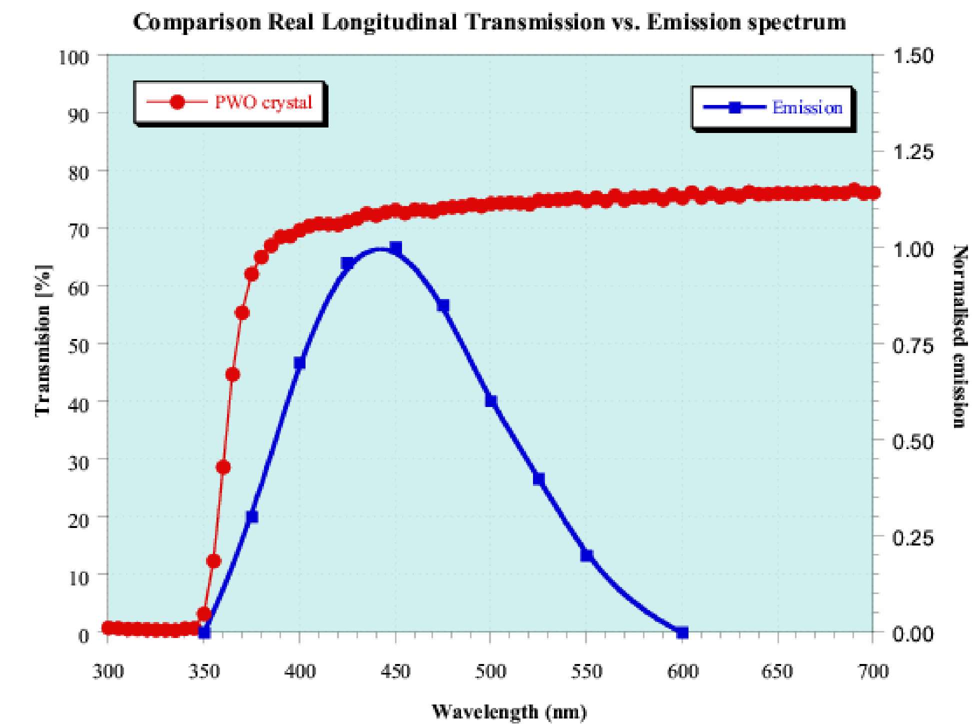
Choices:

- Lead tungstate crystals
- Avalanche photodiodes (Barrel), Vacuum phototriodes (Endcaps)
- Electronics in 0.25 μm CMOS
- Pb/Si Preshower detector in Endcap region
- Laser light monitoring system

Lead tungstate properties

Fast light emission: ~80% in 25 ns
Peak emission ~425 nm (visible region)
Short radiation length: X_0 = 0.89 cm
Small Molière radius: R_M = 2.10 cm
Radiation resistant to very high doses





But:

Temperature dependence ~2.2%/°C
→ Stabilise to ≤ 0.1°C

Formation and decay of colour centres in dynamic equilibrium under irradiation
→ Precise light monitoring system

Low light yield (1.3% NaI)
→ Photodetectors with gain in mag field

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Crystal production

CMS ECAL

Crystals are supplied by the Bogoroditsk Techno-chemical Plant (BTCP) in Russia

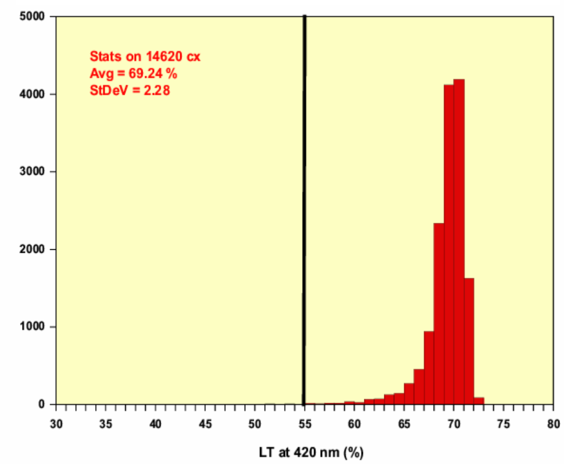
All crystals are tested for:

- Radiation Hardness
- Light Yield
- Physical Dimensions
- Light yield uniformity

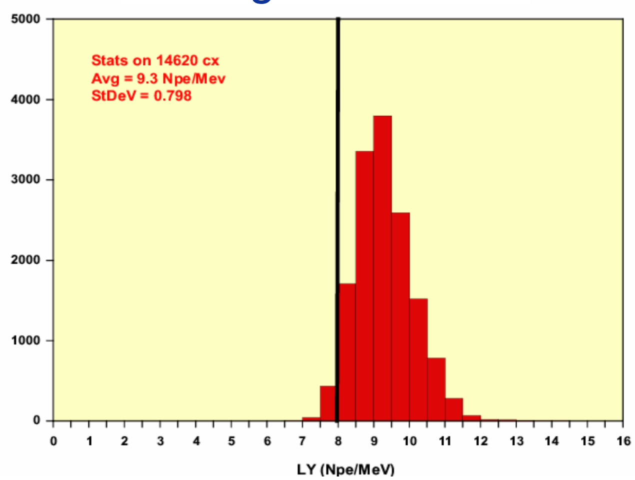
Delivered quality uniformly high

So far 28800 Barrel crystals delivered (47%).

Transmission at 420nm



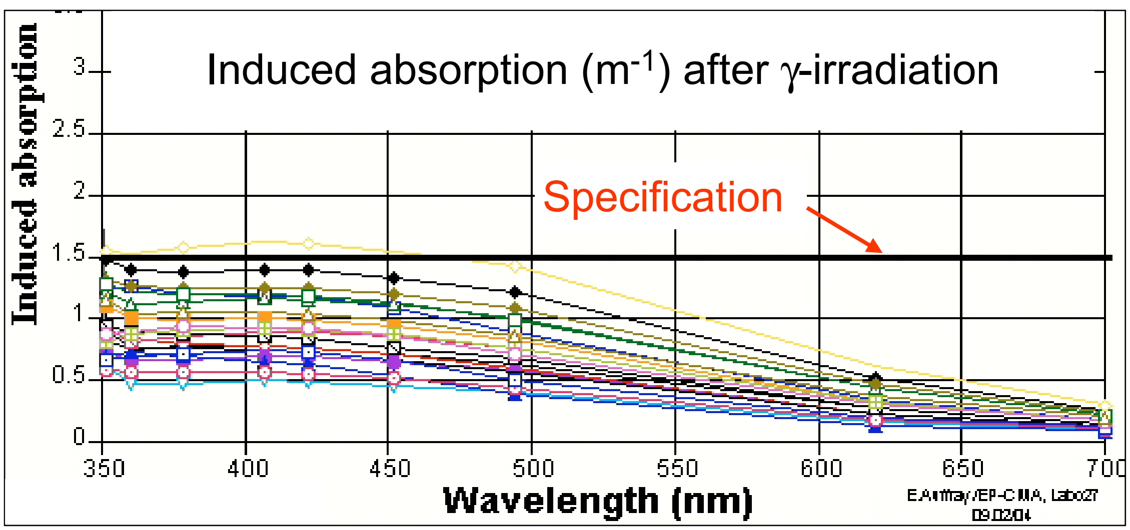
Light Yield

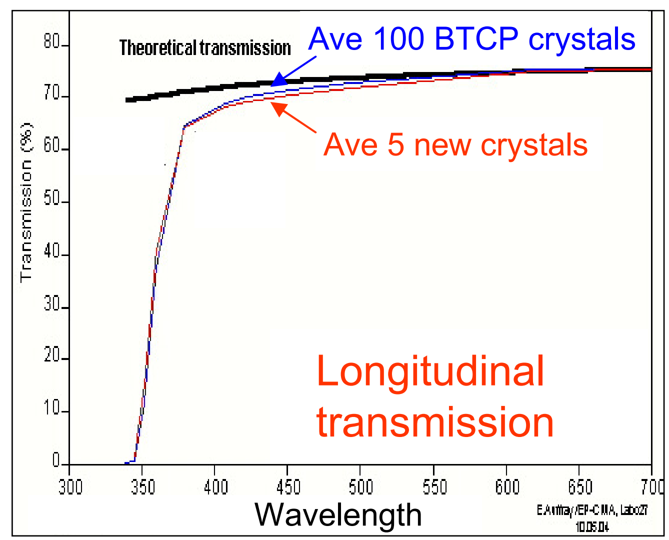


Increasing crystal production

However: problems have been encountered with production costs & schedule
(For example: planned change to 2 crystals/ingot could not be implemented)
➔Not possible to meet the CMS schedule with BTCP alone

- **Action underway to engage additional suppliers**
  Potential producers asked to propose a minimal quantity (2 SM + ½ Dee) plus optional additional quantities.
- Tenders opened on August 17th
  - All potential producers responded and submitted conforming bids
  - Sum of offers exceeds delivery rate needed to meet CMS schedule.
- Crystals from potential new producers under evaluation



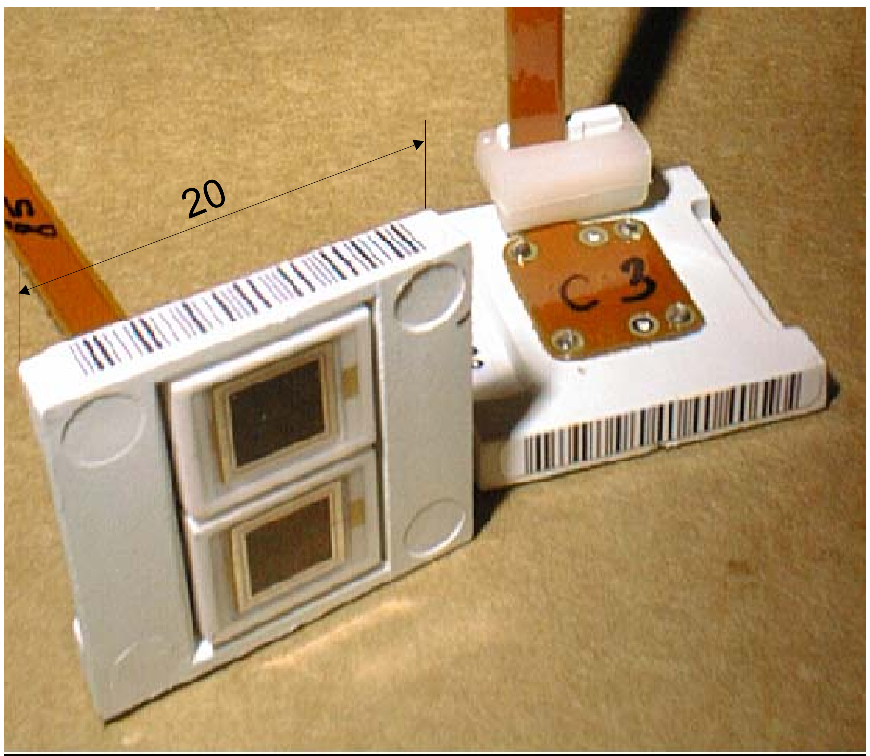


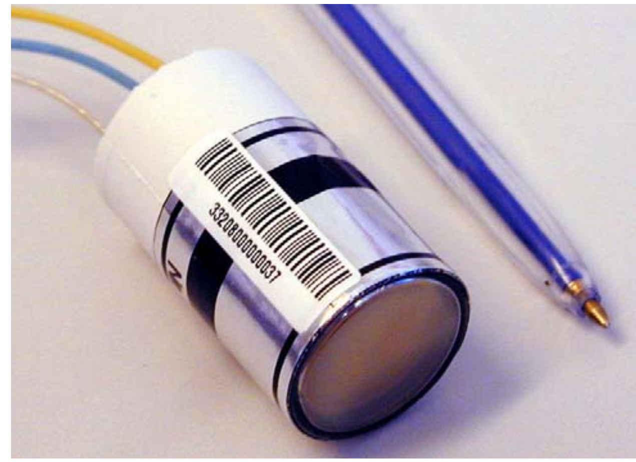
Photodetectors

Barrel - Avalanche photodiodes:

Two 5x5 mm^2 APDs/crystal

- Gain: 50
- QE: ~75%
- Temperature dependence: $-2.4\%/^{O}C$





Endcaps: - Vacuum phototriodes:

B-field orientation favourable for VPTs
(Axes: $8.5^{O} < |\theta| < 25.5^{O}$ wrt to field)

More radiation resistant than Si diodes
(with UV glass window)

- Active area ~ 280 mm^2/crystal
- Gain 8 -10 at B = 4 T
- Q.E. ~ 20% at 420 nm
- Temperature dependence small

Photodetector status

Barrel - Avalanche photodiodes:

Delivery complete

Testing almost complete

Endcaps: - Vacuum phototriodes:

4 - year production schedule

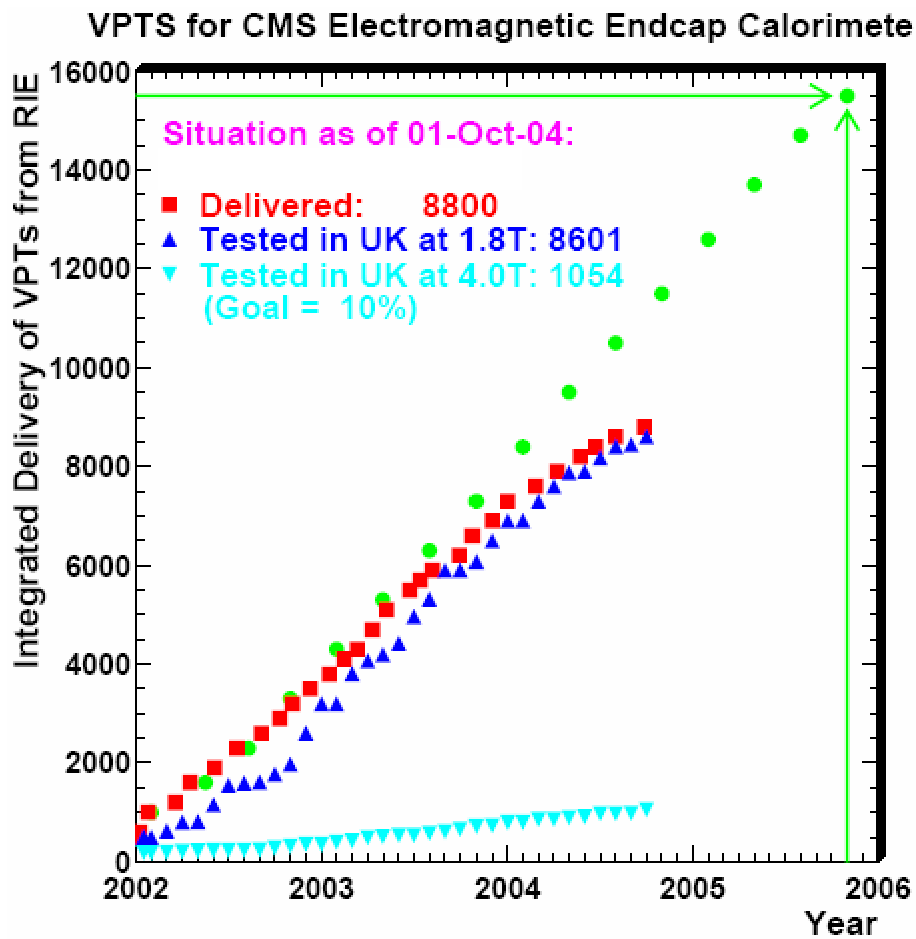
Test 100% at 1.8 T, $-30^{O} < \theta < +30^{O}$

Test 10% at 4.0 T, 15^{O}

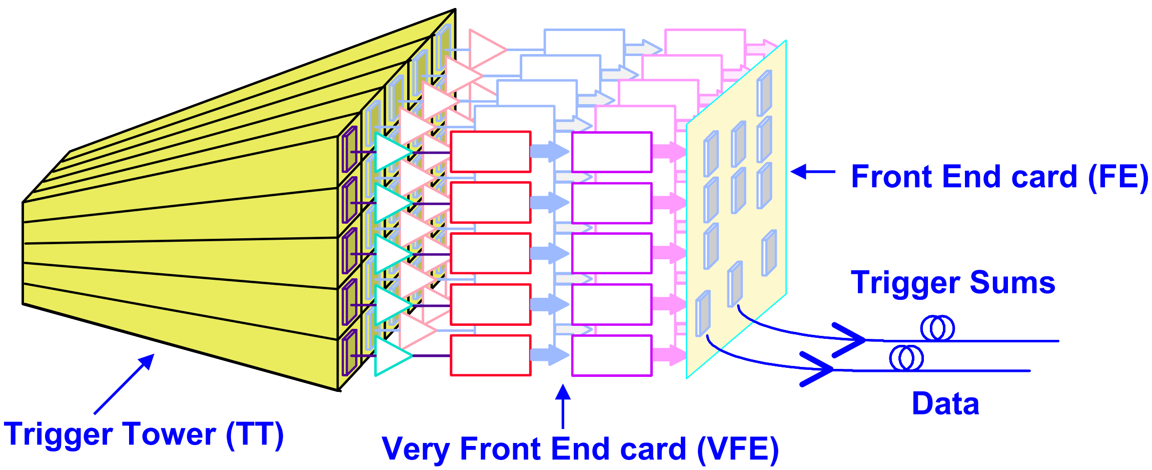
8800 (57% of total) delivered

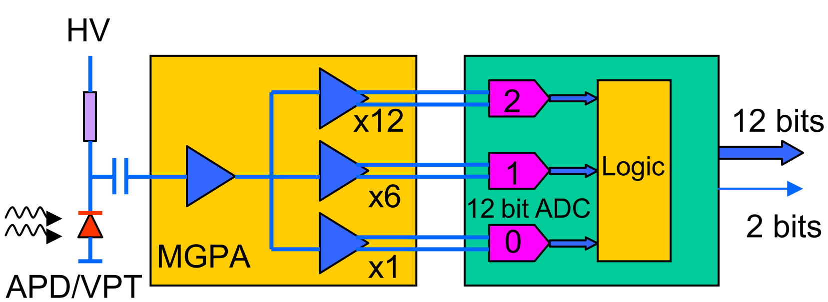
8601 (98% of delivery) tested at 1.8 T

1054 (12% of delivery) tested at 4.0 T



On-detector electronics





VFE architecture for single channel
0.25 μm IBM CMOS process

Trigger primitives computed on the detector
Command & control via token ring (à la CMS Tracker)
Modularity: Trigger Tower (25 channels in Barrel)
- 5 VFE Boards (5 channels each)
- 1 FE Board
- 1 Fibre sending trig primitives (every bunch Xing)
- 1 Fibre sending data (on Level1 accept)

On-detector electronics: status

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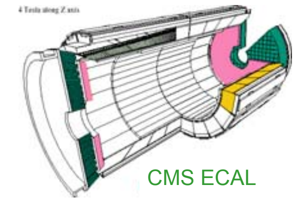


CMS ECAL

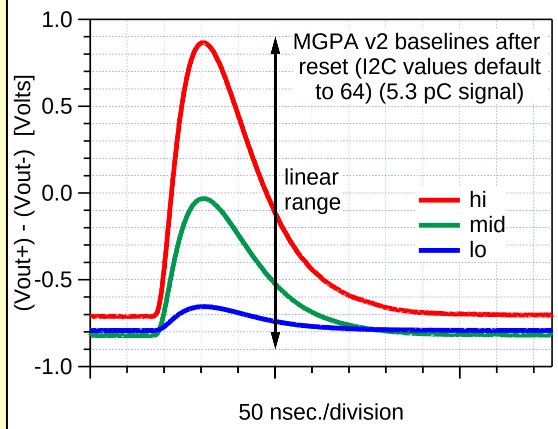
2002 & 2003: readout architecture changed → 4 new chips in 0.25 μm

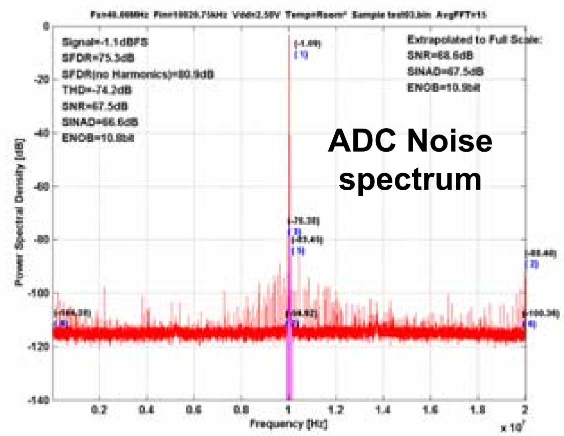
MGPA (Multi-gain preamplifier):
Successful engineering run - 48 wafers being packaged (enough for full ECAL)

AD41240 (Custom designed 12-bit ADC):
10.9 bit ENOB achieved (meets specification)
17 wafers packaged, remaining 31 wafers due in October

FENIX (2 functions - generate trigger primitives
- read out data on level 1 accept)
21 wafers being packaged, remaining 27 due in October

Buffer chip (LVDS/LVCMOS between ADC/FENIX):
'Pacing item': 48 wafers in October - enough for Barrel



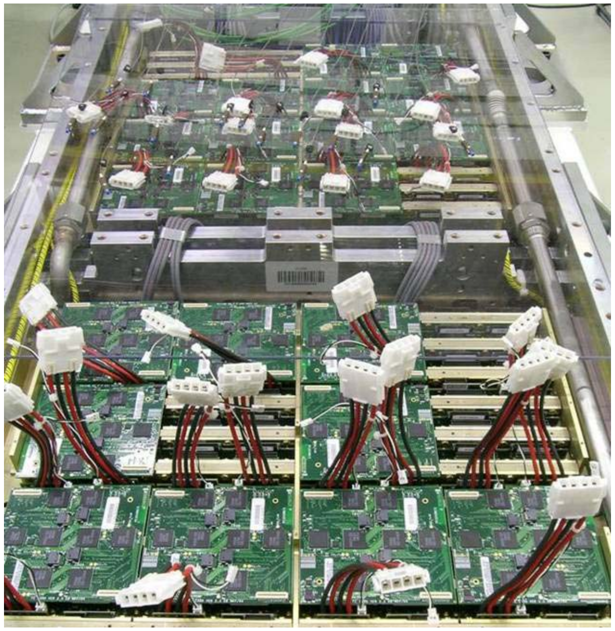


- Chip yields (80-95)% in engineering runs

- Successful pre-series of all on-detector electronics (enough for 3 'Supermodules')

- Full production in progress

Electronic noise



400 Channels powered

~ 40 – 45 MeV/Channel

System noise measured on Supermodule10

Off-Detector electronics

Prototypes produced for:
Data Concentrator Card (DCC)
Clock & Control System (CCS)
Half Trigger Concentrator Card (TCC)

On target to use DCC/CCS in test beam

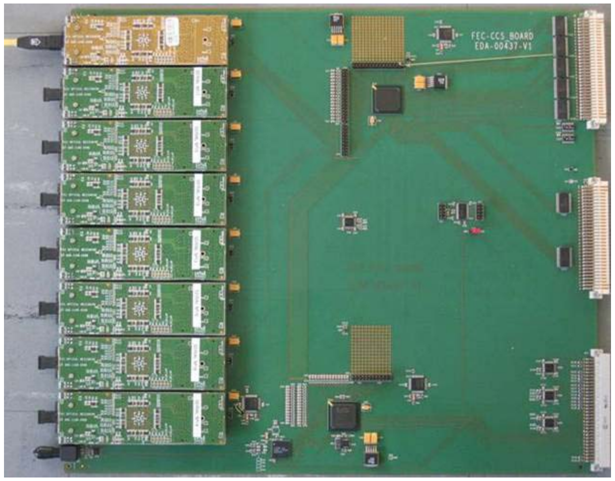
CCS preproduction launched

Selective Readout Processor (SRP)
 - design now well advanced

Off-Detector electronics production in 2005

DCC and Tester

TCC24



CCS

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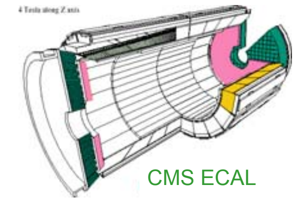
Laser light monitoring (1)

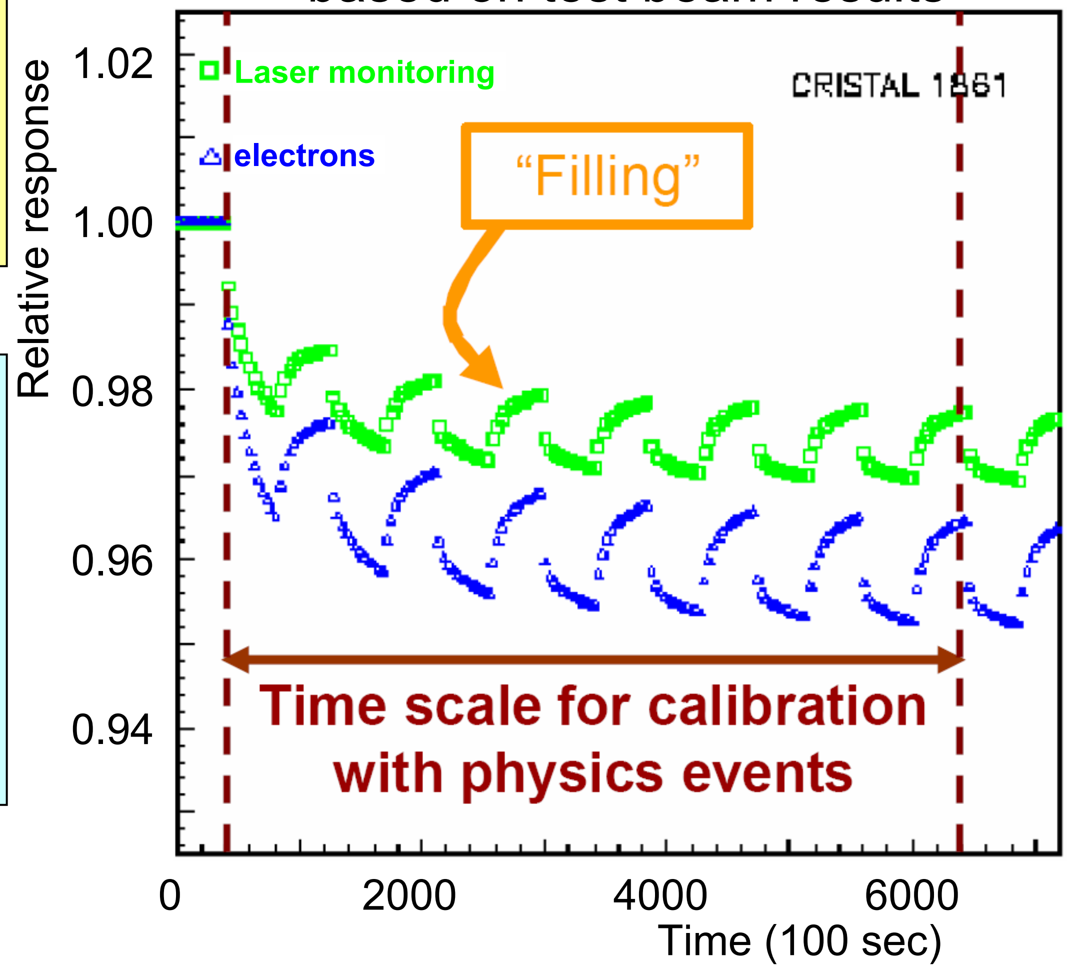


CMS ECAL

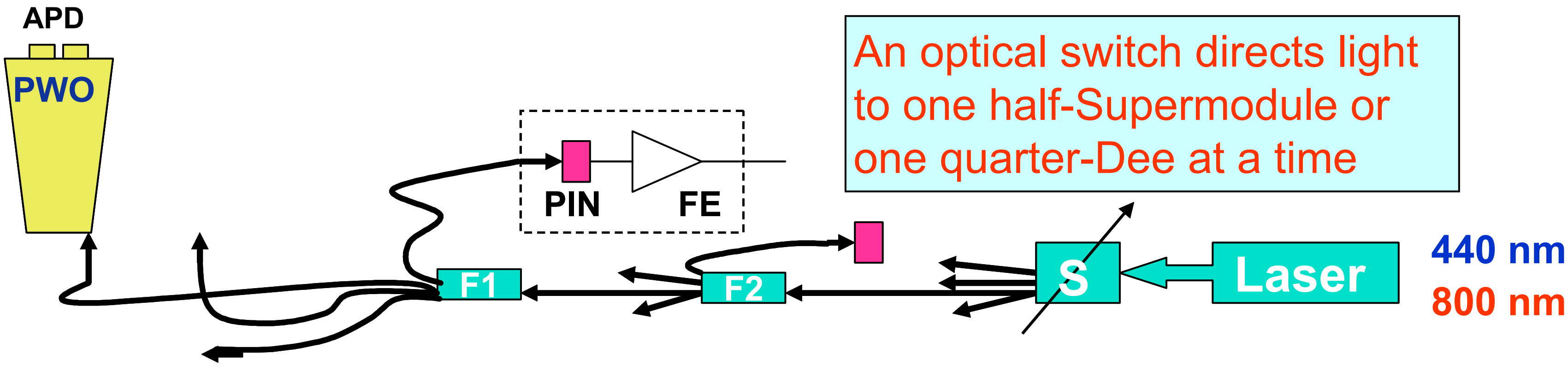
- Colour centres form in PWO under irrad^{n}
- Transparency loss depends on dose rate
- Equilibrium is reached after a low dose
- Partial recovery occurs in a few hours

- Damage and recovery during LHC cycles tracked with a laser monitoring system
- 2 lasers provide 4 wavelengths: 440/495 nm and 700/800 nm
- Light is injected into each crystal
- Stability monitored with PN diodes (0.1%)

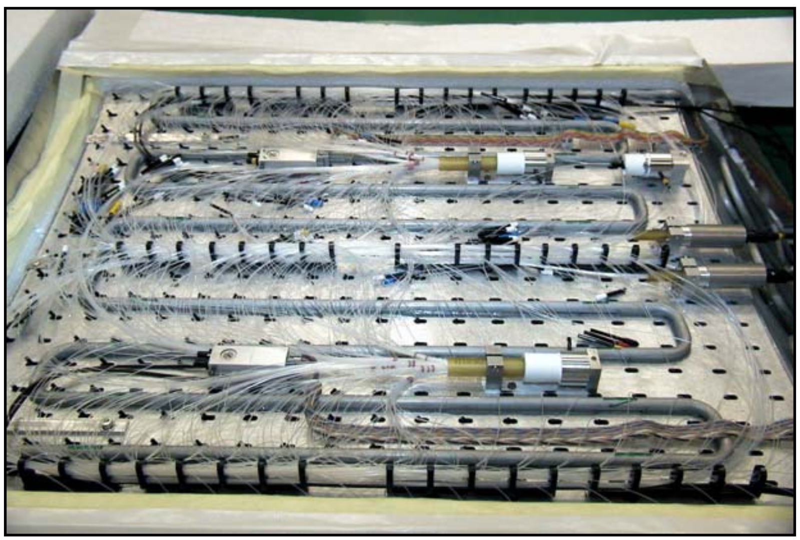
Simulation for high luminosity at η = 0 based on test beam results



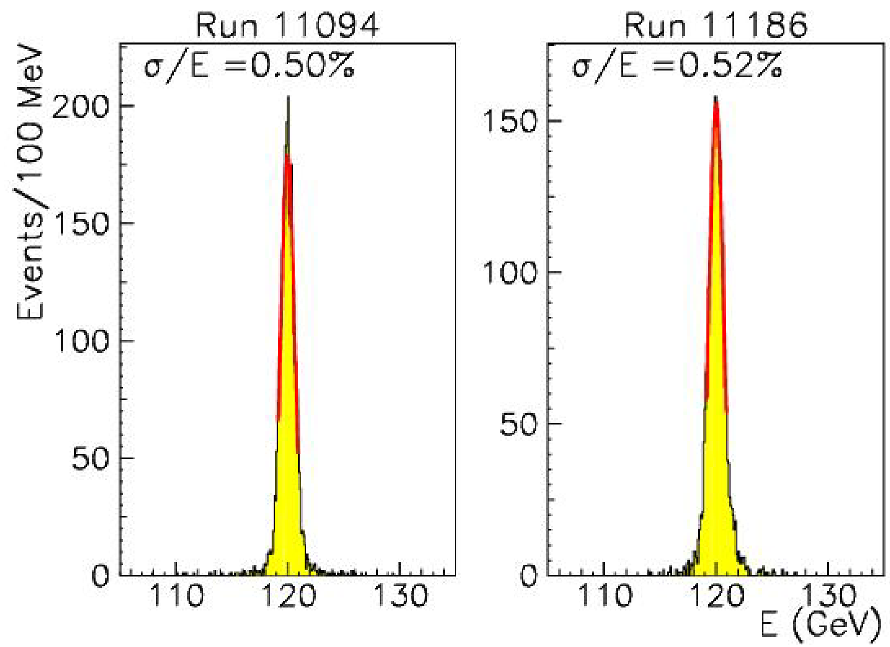
Laser light monitoring (2)



An optical switch directs light to one half-Supermodule or one quarter-Dee at a time



Light is injected through fibres into the front (Barrel) or rear (Endcap) of each crystal



Resolution before irrad$^{\underline{n}}$ / after irrad$^{\underline{n}}$ and correction

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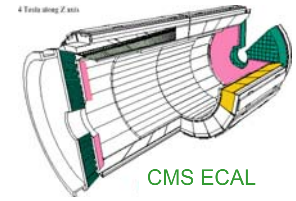
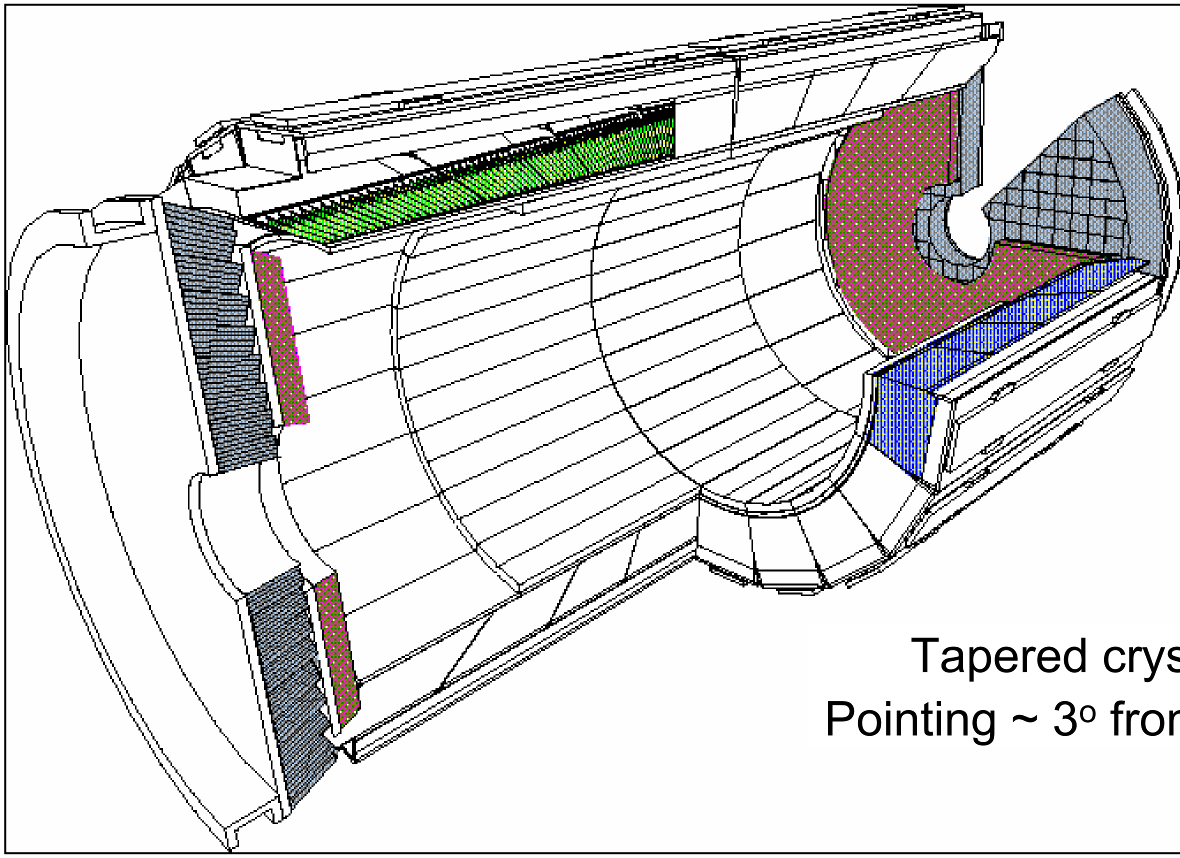
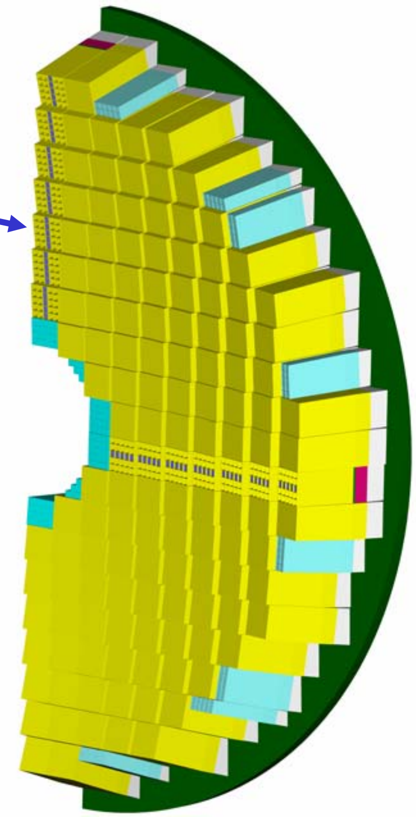
Construction



CMS ECAL



Tapered crystals
Pointing ~ 3° from vertex



Barrel: 36 Supermodules (18 per half-barrel)
61200 Crystals (34 types) – total mass 67.4 t
Dimensions: ~ 25 x 25 x 230 mm^3 (25.8 X^0)
$\Delta\eta \times \Delta\varphi$ = 0.0175 x 0.0175

Endcaps: 4 Dees (2 per endcap)
14648 Crystals (1 type) – total mass 22.9 t
Dimensions: ~ 30 x 30 x 220 mm^3 (24.7 X^0)
$\Delta\eta \times \Delta\varphi$ = 0.0175 x 0.0175 - 0.05 x 0.05

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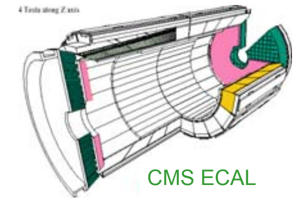
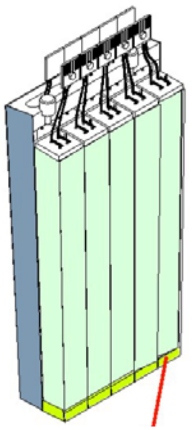
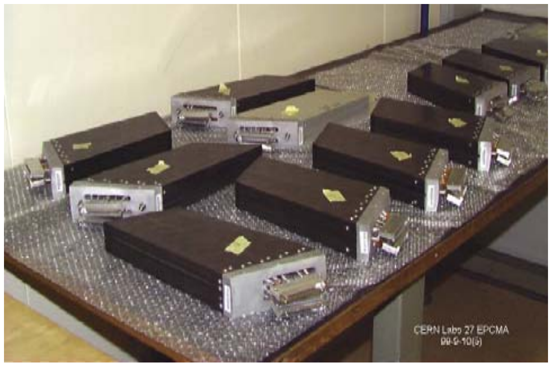
Construction: barrel



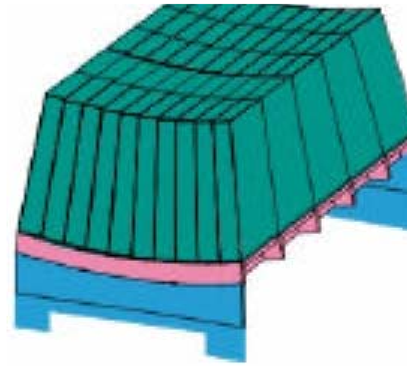
CMS ECAL

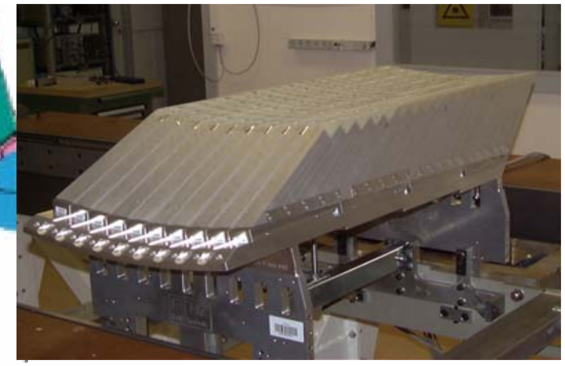
2 Regional Centres: CERN and Rome



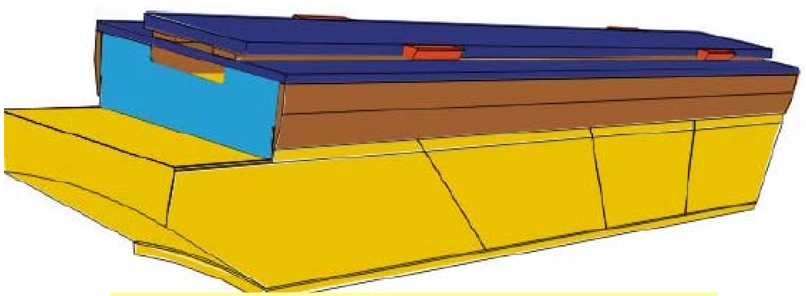


Sub-module: 10 crystals





Module: 400/500 crystals



Super-module: 1700 crystals

Assembly status

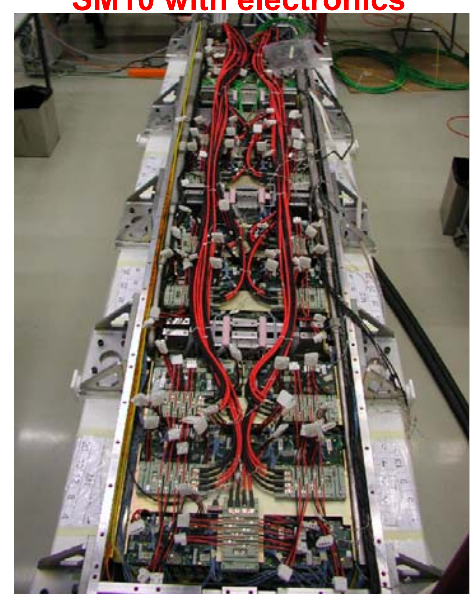
55 Modules (38%)

13 Bare Supermodules (36%)

1 Supermodule + electronics

($\Rightarrow$ test beam ~7/10/04)

SM10 with electronics



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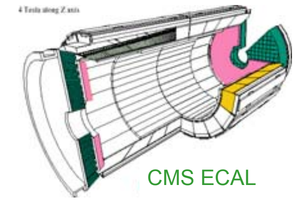
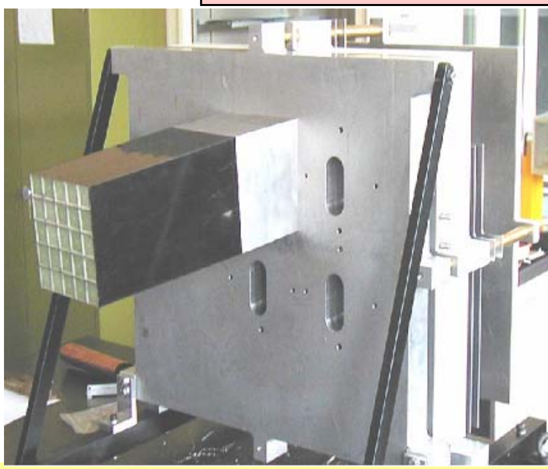
Construction: Endcaps

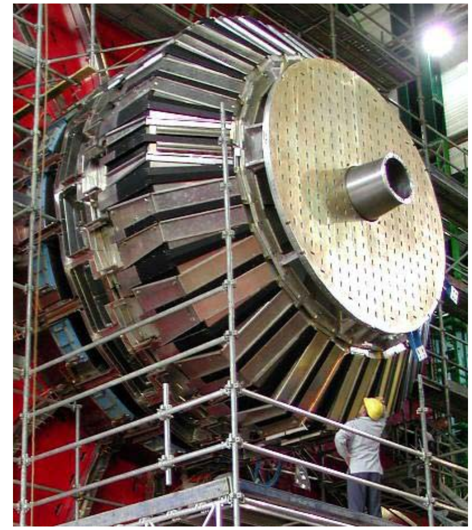


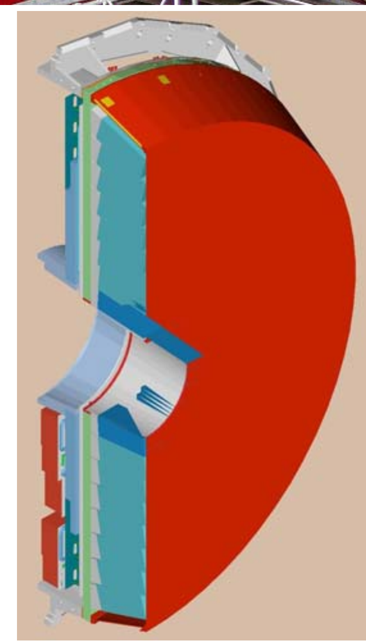
Regional Centres: CERN and RAL



Supercrystal: 25 crystals

Dee (½ endcap): 3662 crystals





Production status

Backplates:	4 completed (100%) 2 delivered to CERN
'Alveolas':	450 completed (80%)
Environment screen:	Being ordered
Crystals:	~300 Preproduction crystals delivered

Supercrystals: 3 prototypes built

- performance confirmed in test beam

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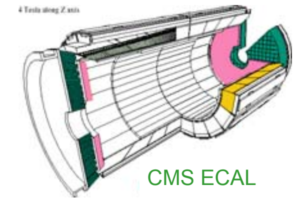
Preshower detector



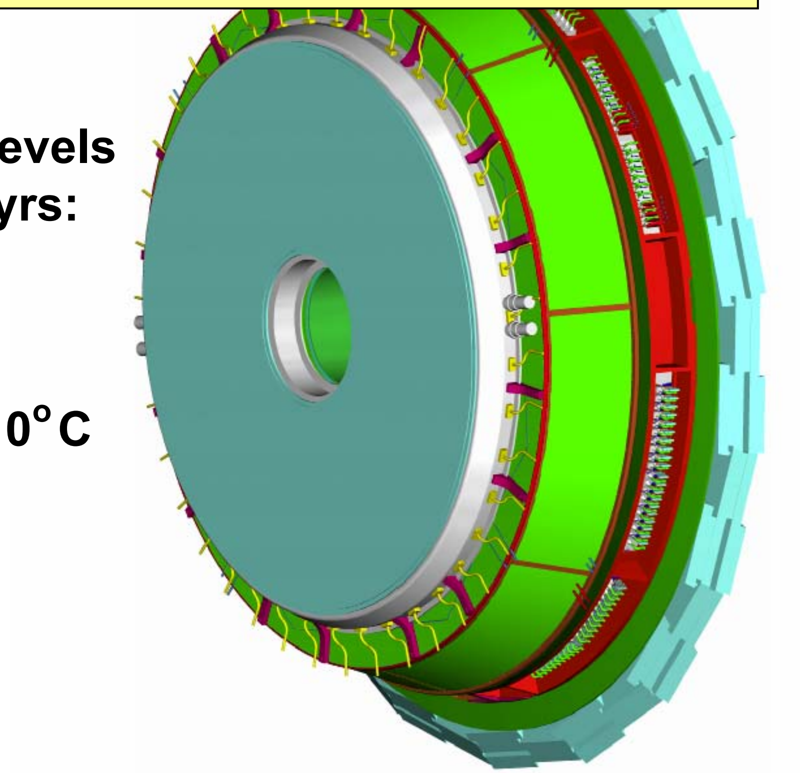
Rapidity coverage: 1.65 < |η| < 2.6 (End caps)
Motivation: Improved π^0/γ discrimination

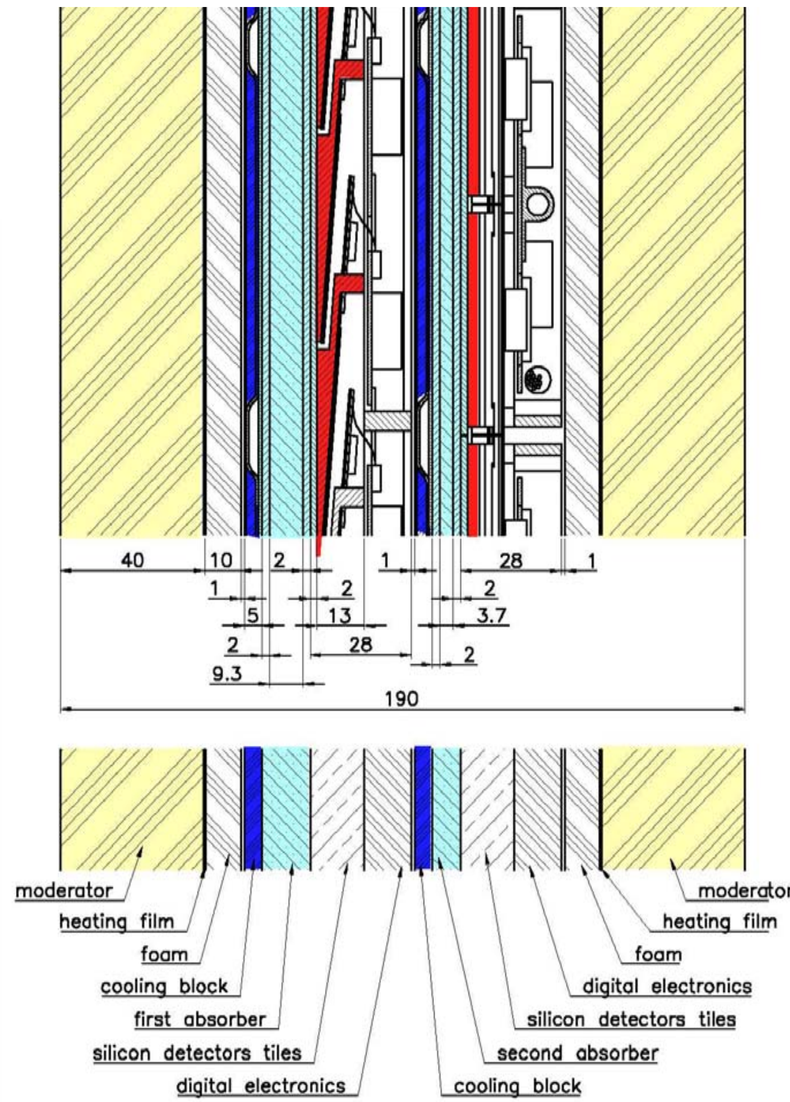
- 2 orthogonal planes of Si strip detectors behind 2 X_0 and 1 X_0 Pb respectively
- Strip pitch: 1.9 mm (60 mm long)
- Area: 16.5 m^2 (4300 detectors, 1.4×10^5 channels)

High radiation levels
- Dose after 10 yrs:

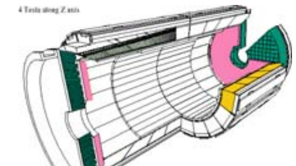
- ~ 2×10^{14} n/cm^2
- ~ 60 kGy

➔ **Operate at -10°C**

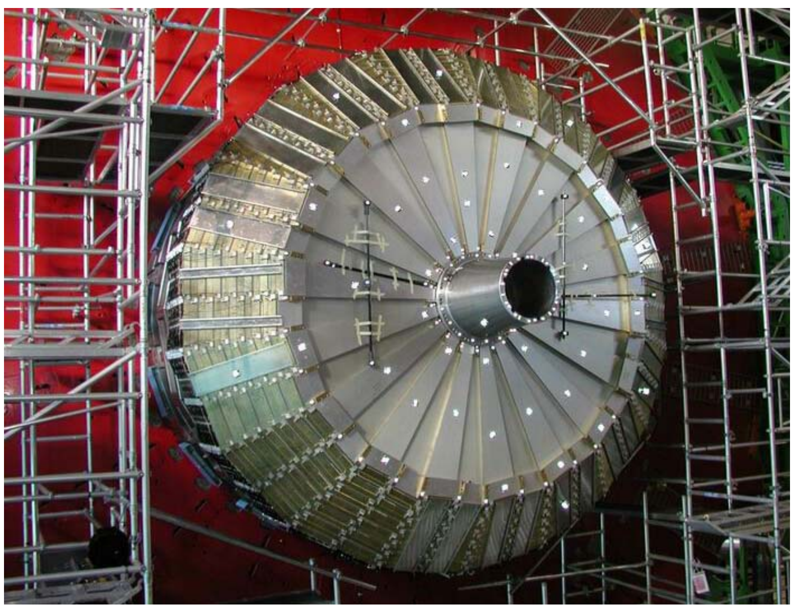




Construction: Preshower



CMS ECAL



Assembly status

Delivery of sensors:

ELMA (Russia) - 1446/1800
BEL (India) – 500/1000
ERSO (Taiwan) – 436/1200
Hamamatsu/Greece – 1170/1000
→3552/5000 (71%) good sensors

VFE Electronics:

PACE-3 (preamp/shaper + memory) & K-chip (data concentrator) in 0.25 μm CMOS:
Prototypes work well before / after irradiation

Support cones:

Successful trial installation on HCAL Endcap

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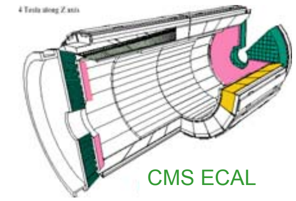
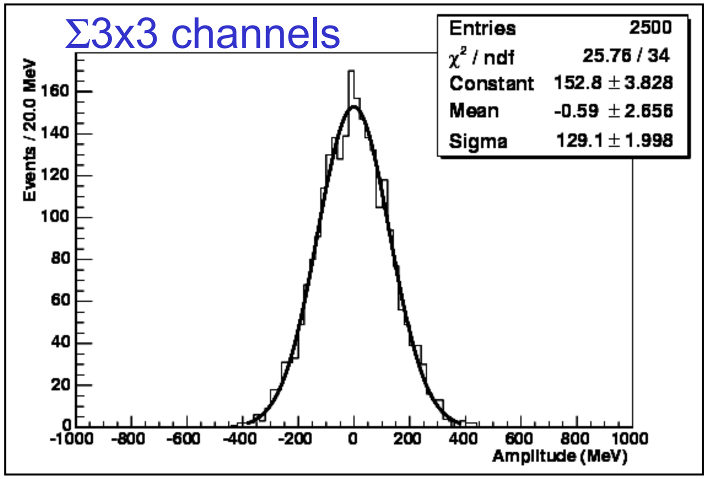
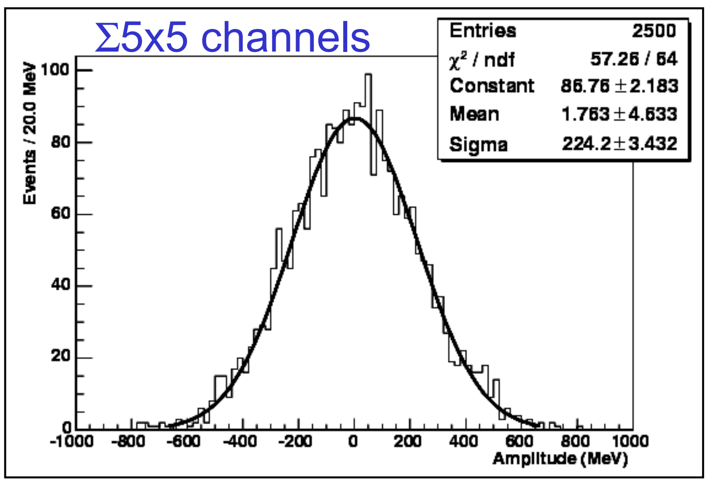
Test beam results



Final electronics

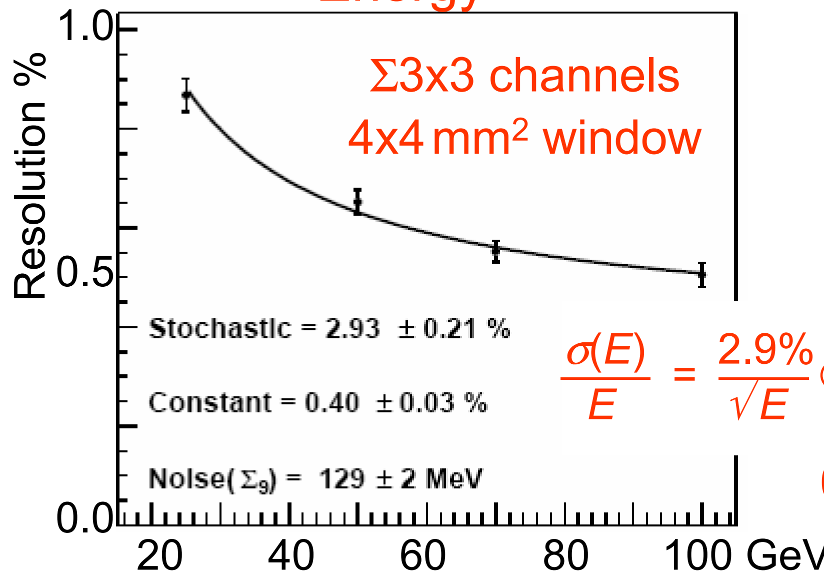


Noise / channel ≈ 43 MeV



Noise / channel ≈ 45 MeV

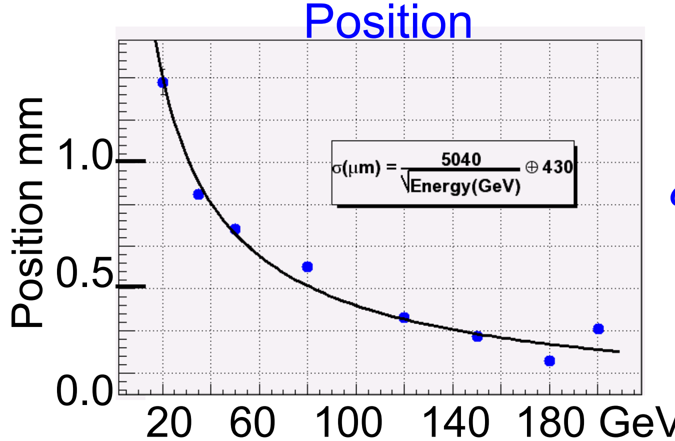
Energy



$$\frac{\sigma(E)}{E} = \frac{2.9\%}{\sqrt{E}} \oplus \frac{129\text{ MeV}}{E} \oplus 0.40\%$$

0.6% at 50 GeV

Position



$$\sigma_x(E) = \frac{5040}{\sqrt{E}} \oplus 430 \quad (\mu m)$$

0.85 mm at 50 GeV

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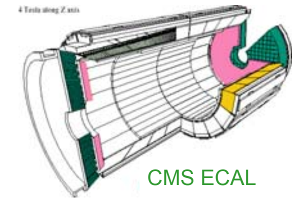
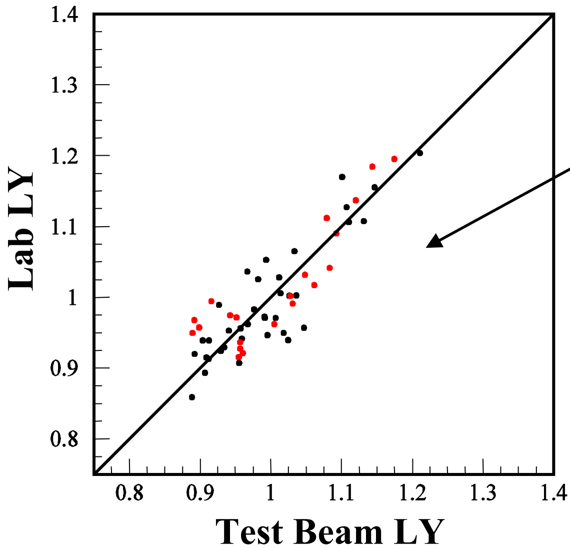
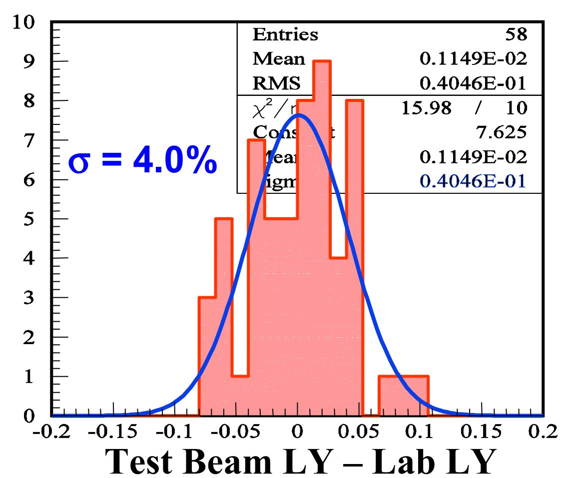
Calibration strategy



Lab measurements → Pre-calibration → In-situ calibration





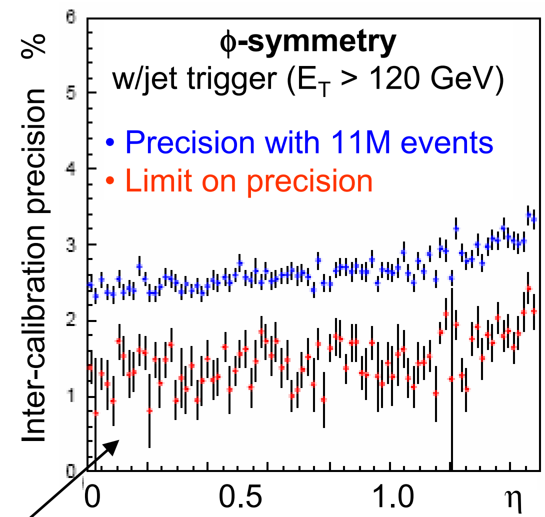
Initial pre-calibration by 'dead reckoning' based on lab measurements (~4%)

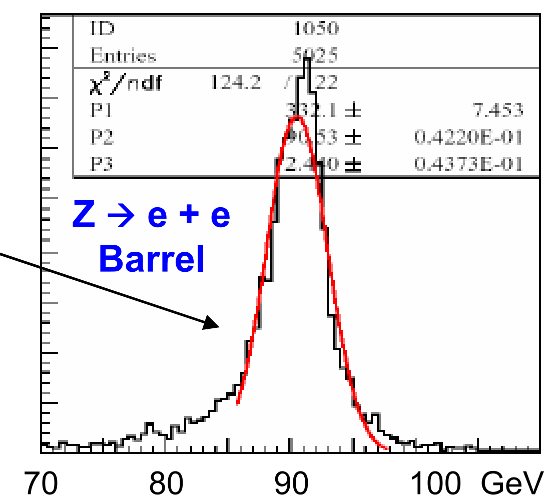
Reference pre-calibration of few SM with 50/120 GeV electrons in test beam (<2%)

Fast in-situ calibration based on principle that mean energy deposited by jet triggers is independent of ϕ at fixed η (after correction for Tracker material) (~2-3% in few hours)

ϕ-ring inter-calibration and $Z \rightarrow e + e$ cross-calibration (~1% in 1 day)

Finally: calibration to < 0.5% with $W \rightarrow \nu + e$ in ~2 months





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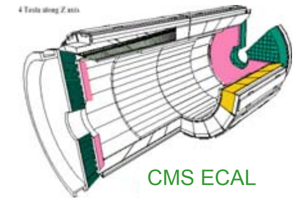
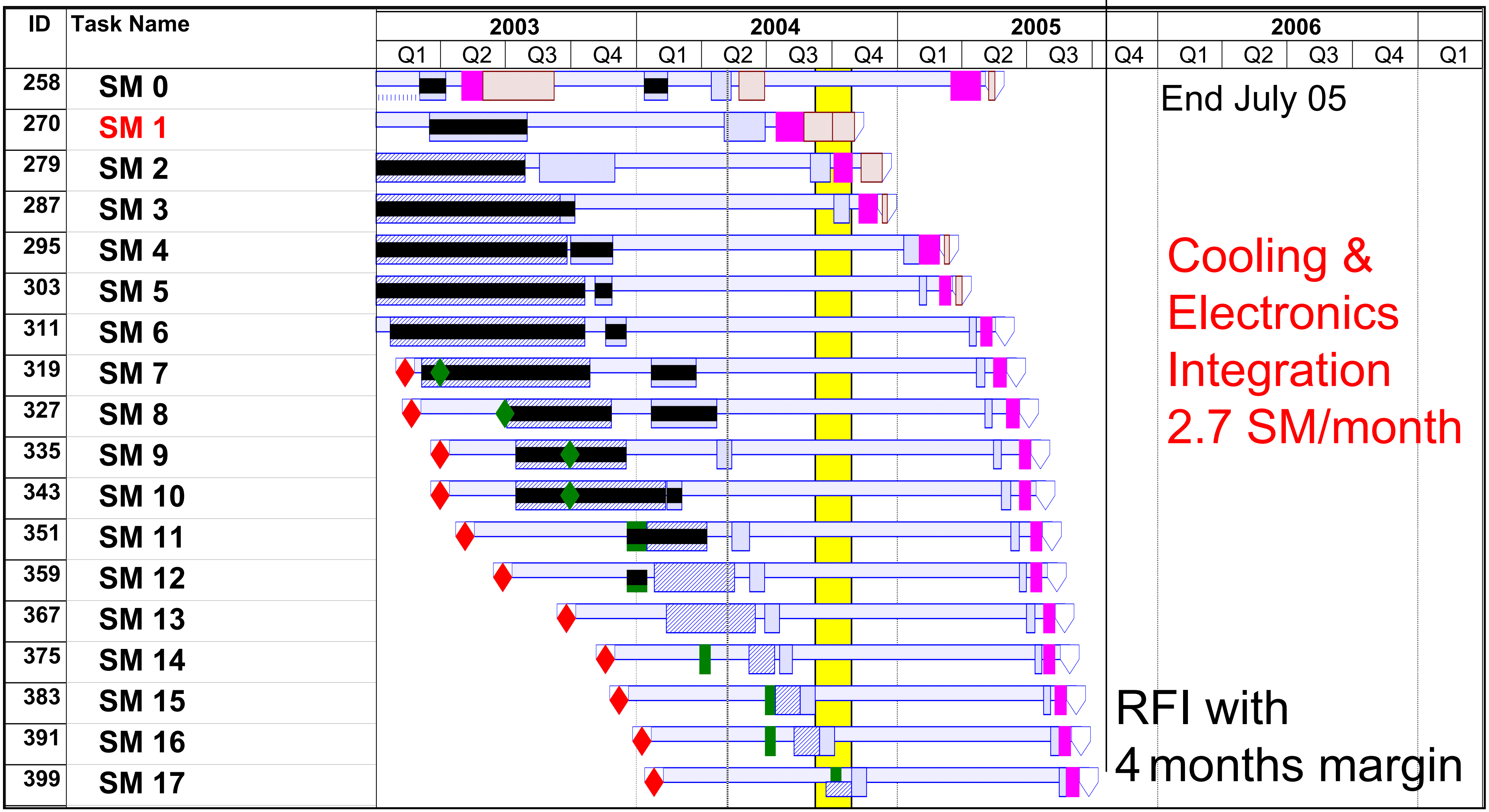
Barrel Construction Schedule (1)





CCLRC

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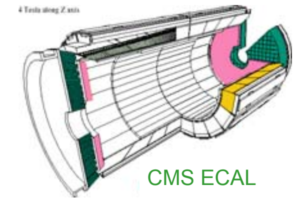
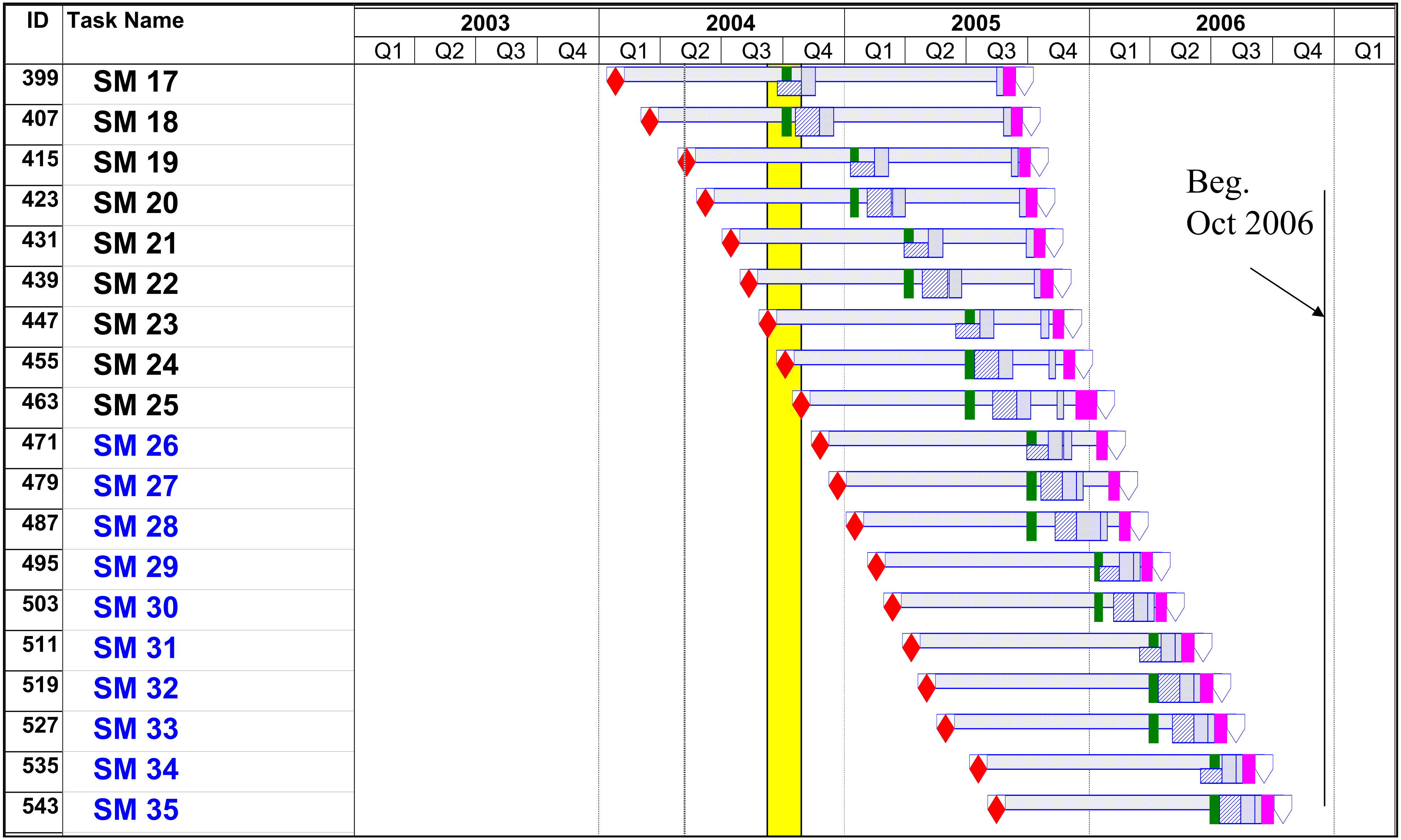
Barrel Construction Schedule (2)





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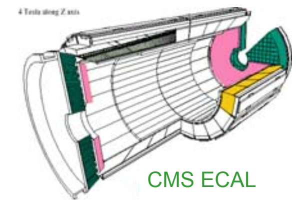
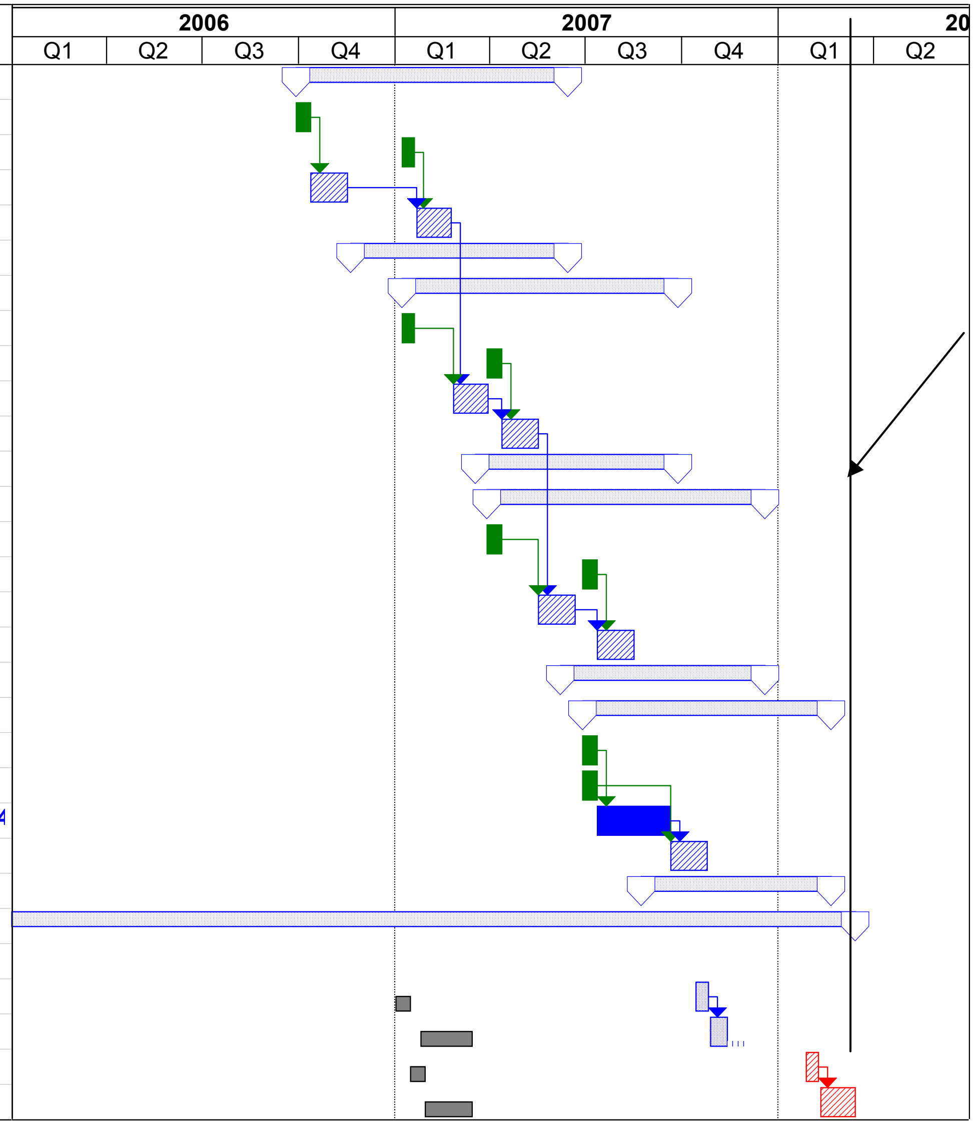
EE Construction Schedule

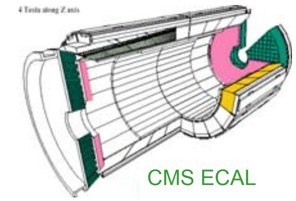


ID	Task Name
610	**Dee 1**
611	Crystals delivery Dee1
612	Crystals delivery Dee1
613	Assembly supercrystals for Dee 1
614	Assembly supercrystals for Dee 1
615	**Dee 1 ass + test**
619	**Dee 2**
620	Crystals delivery Dee 2
621	Crystals delivery Dee 2
622	Assembly supercrystals for Dee 2
623	Assembly supercrystals for Dee 2
624	**Dee 2 ass + test**
628	**Dee 3**
629	Crystals delivery Dee 3
630	Crystals delivery Dee 3
631	Assembly supercrystals for Dee 3
632	Assembly supercrystals for Dee 3
633	**Dee 3 ass + test**
637	**Dee 4**
638	Crystals delivery Dee 4
639	Crystals delivery Dee 4
640	**Assembly supercrystals for Dee 4**
641	Assembly supercrystals for Dee 4
642	**Dee 4 ass + test**
646	**Installation in CMS**
647	Lay EE + ES cables
648	Assemble EE+1 on YE+1
649	Connect, test and debugg EE+1
650	Assemble EE-1 on YE-1
651	Connect, test and debugg EE-1



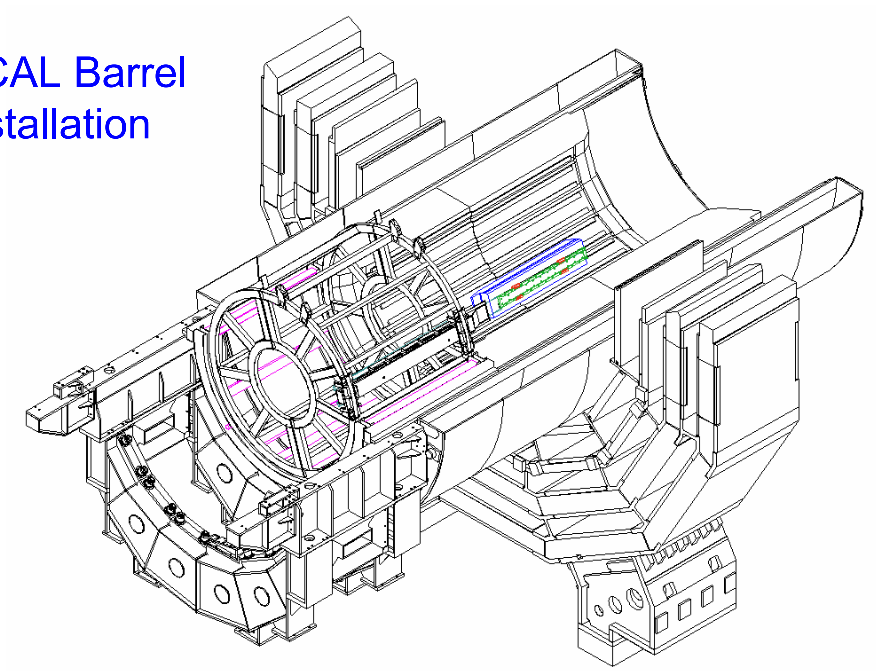
Mid. February 2008

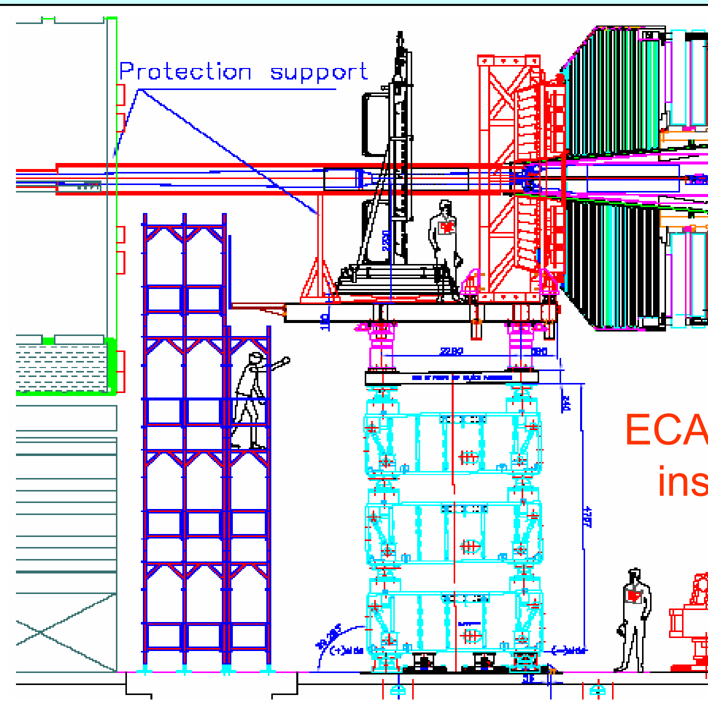
Installation Schedule



May 2005:	Delivery of installation tooling
September 2005:	Installation of 1 or 2 Supermodules for surface magnet test
January 2006:	EB+/- installation on surface
May - October 2006:	EB- Installation in cavern
April 06 - Feb 2007:	Cabling and commissioning of EB+ and EB-
Dec 07 - Feb 2008:	EE+/ES+ Installation and commissioning
Feb - March 2008:	EE-/ES- Installation and commissioning

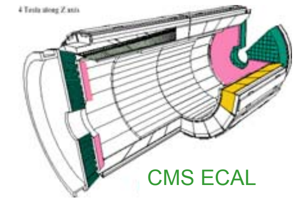
ECAL Barrel installation





ECAL Endcap installation

Summary



- High resolution electromagnetic calorimetry is a central design feature of CMS
- The construction of the Barrel ECAL is proceeding well
- Procurement of all major components is in hand for the Endcap ECAL
- Crystal delivery is limiting the schedule for both Barrel and Endcap
  - Good progress is being made with actions to address this
- The change in readout architecture has been an outstanding success
- The Pre-shower detector is on course for completion as planned
- A calibration strategy has been developed that avoids the requirement of measuring every Supermodule/Dee in an electron beam
- Test beam results confirm the ECAL should meet its ambitious design goals