CMS ECAL performance

Testbeam results

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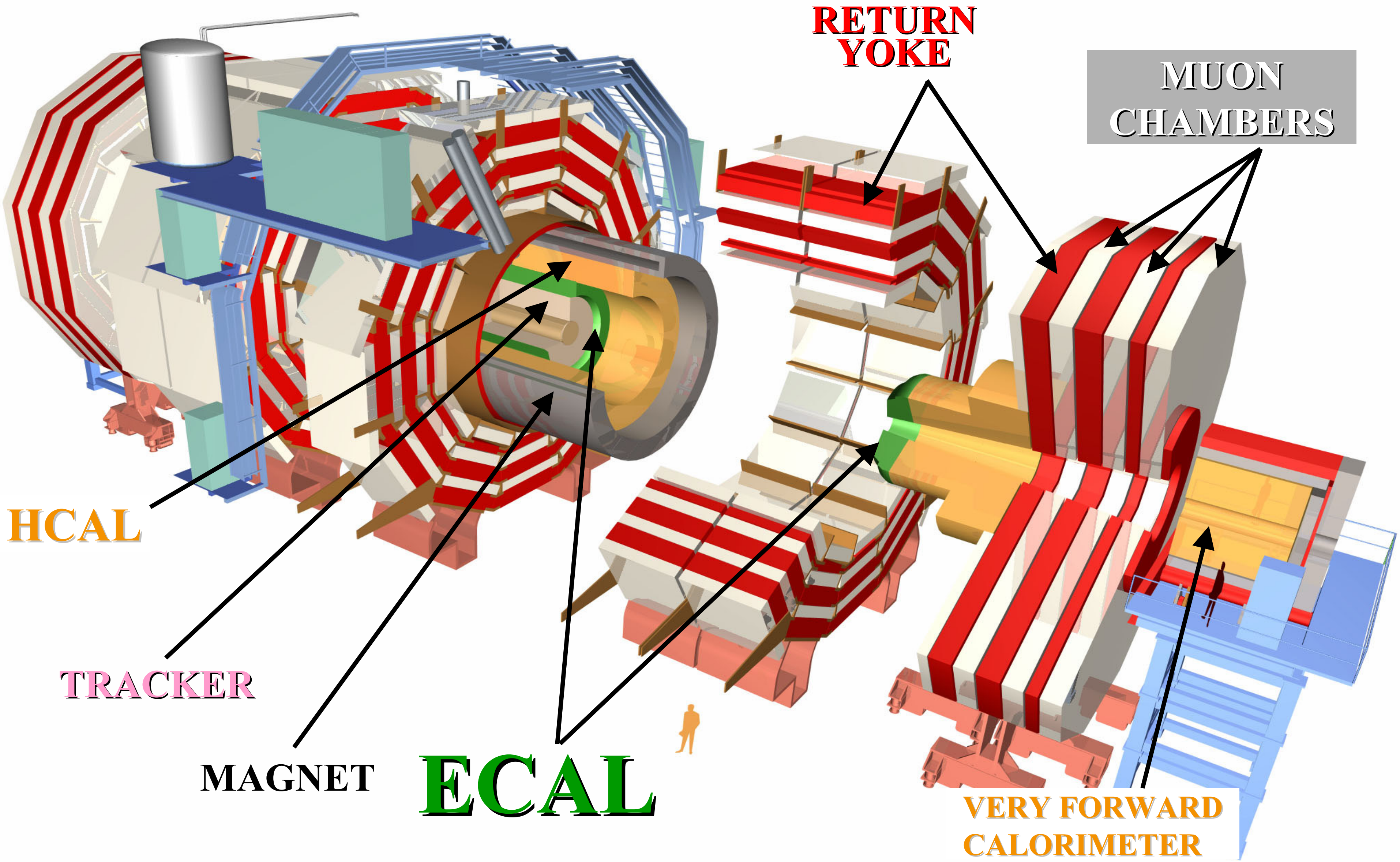
On behalf of the CMS/ECAL Collaboration

DPF 2004 – Riverside, California,USA

August 26-31, 2004

Compact Muon Solenoid



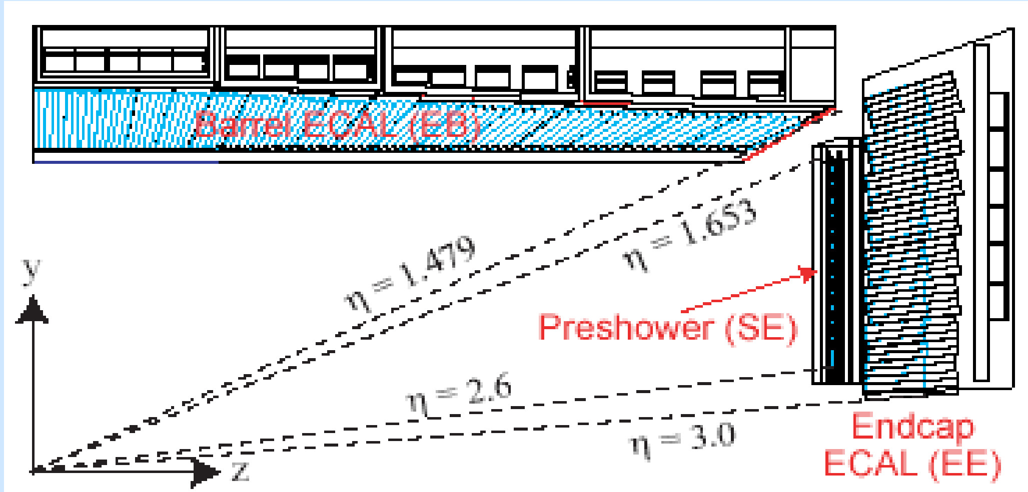
Electromagnetic Crystal ($PbWO_4$) Calorimeter

Barrel:

61200 crystals

~ 22×23×230 mm^3

25.8 X_0



Endcap:

14648 crystals

30×30×220 mm^3

25.0 X_0

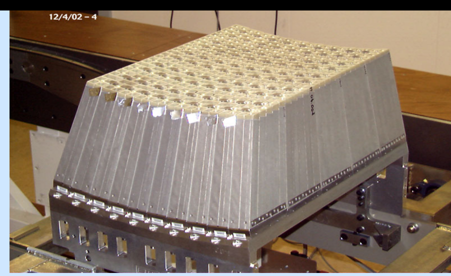
Preshower:

Pb conv. / Si det.

3 X_0

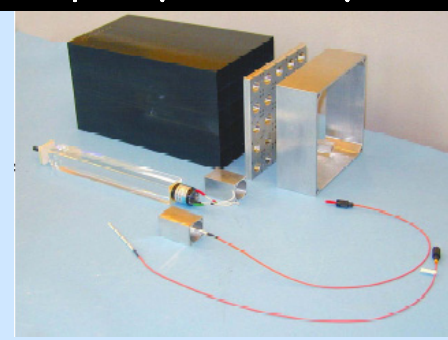
Submodule (10 crystals)

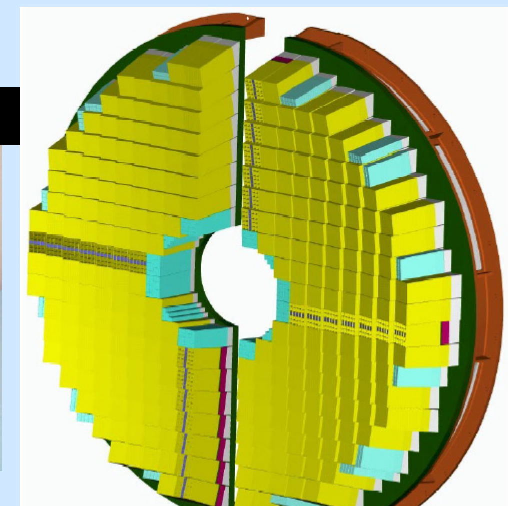
Module (40/50 Submodules)



SuperModule (4 Modules)

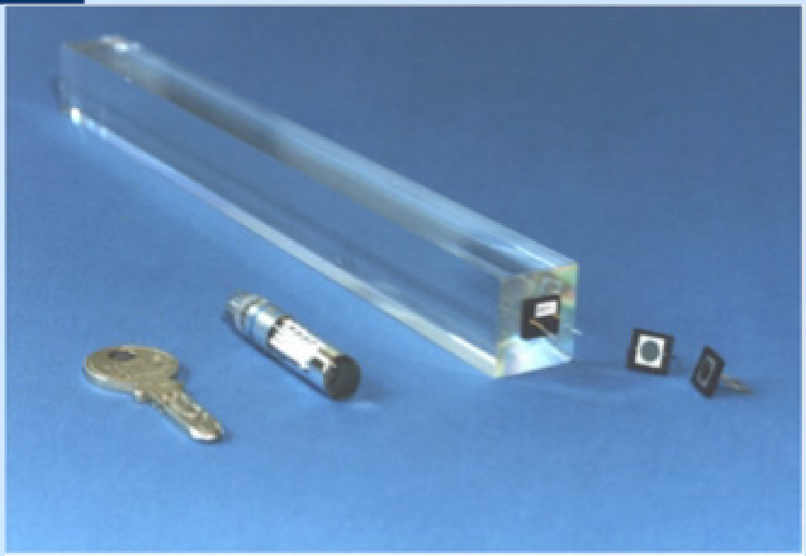
SuperCrystal (25 crystals)





Two Endcap Dees
(2 × 138 SuperCrystals)

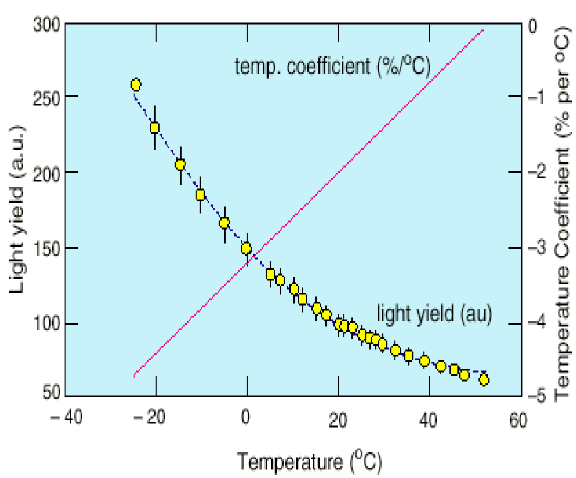
$PbWO_4$ Crystals



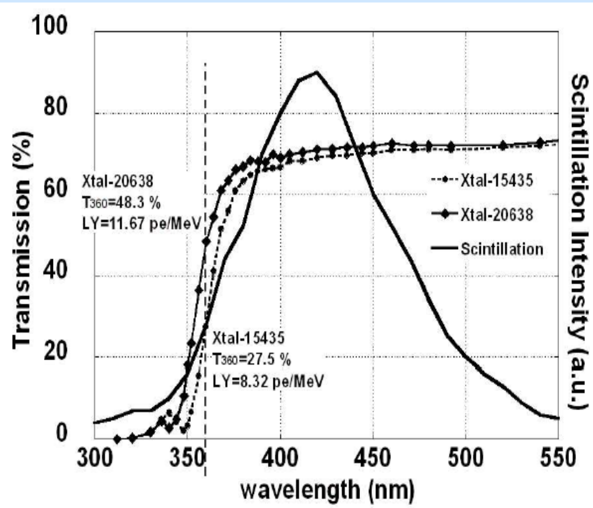
Conditions:
- 4T magnetic field
- 25 ns between bunch crossings
- radiation dose of ~ 1-2 kGy/year at $10^{34} cm^{-2} s^{-1}$

$PbWO_4$ Characteristics		
Radiation length	8.9	mm
Moliere radius	22	mm
Hardness	4	Moh
Peak emission	440	nm
Emitted light in 25 ns	80%	
Refractive index	2.3	
Light yield (23 cm)	100	γ/MeV

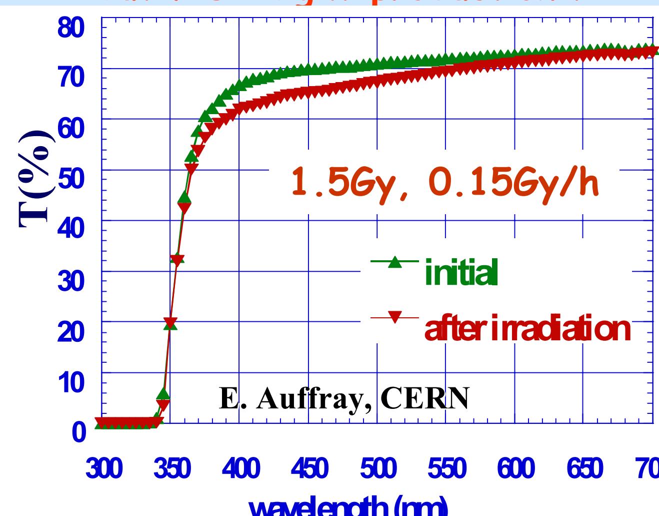
L.Y. dependence on T



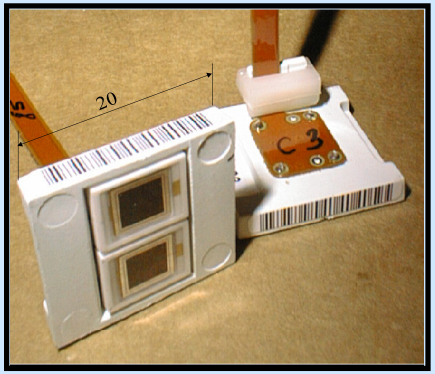
Transmission variations



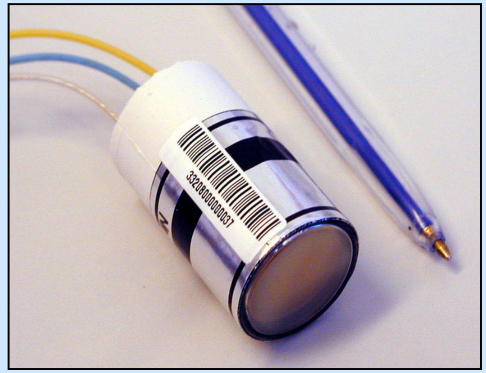
Radiation affects transmission but NOT light production !



Photodetectors / Read out chain

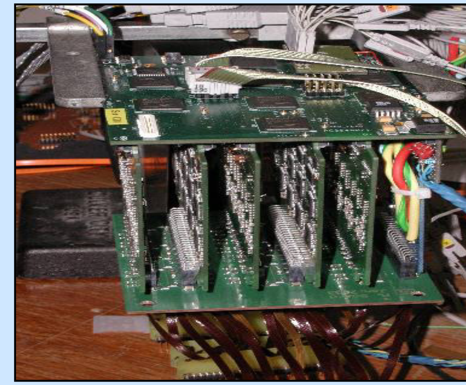


APD (Barrel)



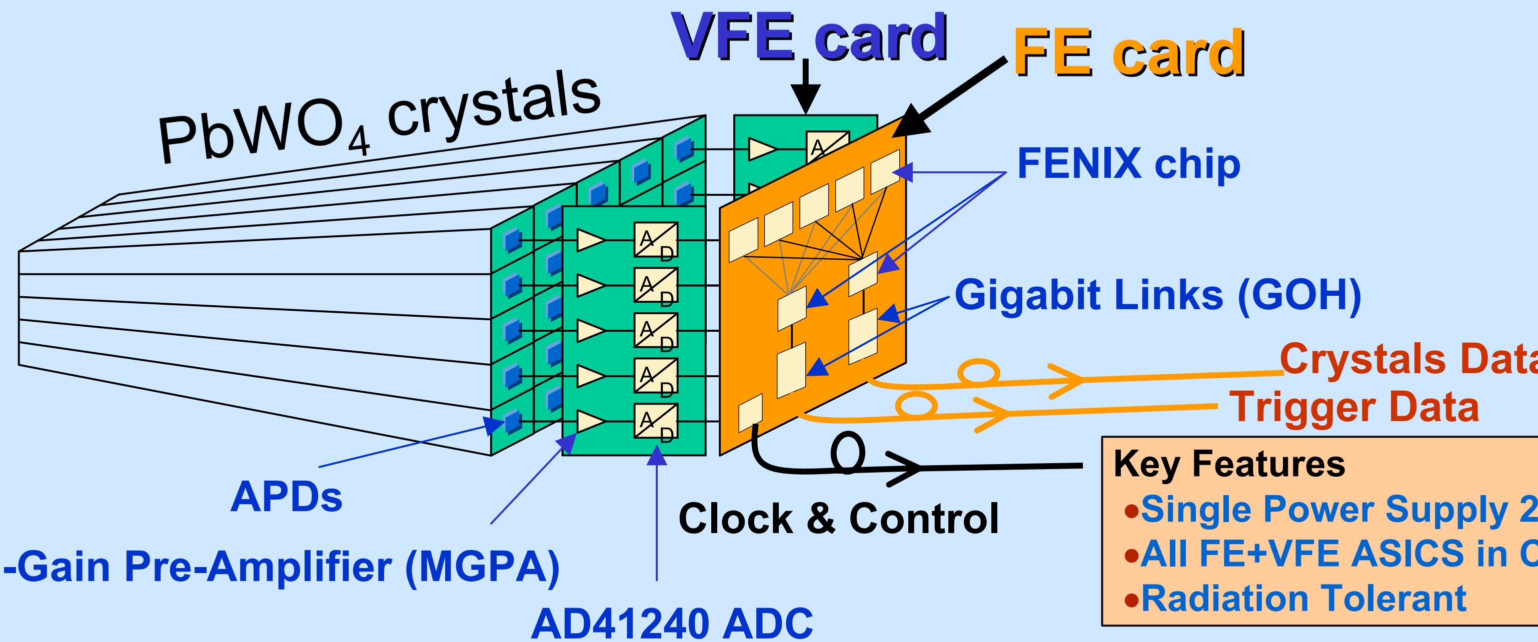
VPT (Endcap)

- Radiation resistant
- B-field insensitive



Trigger Tower

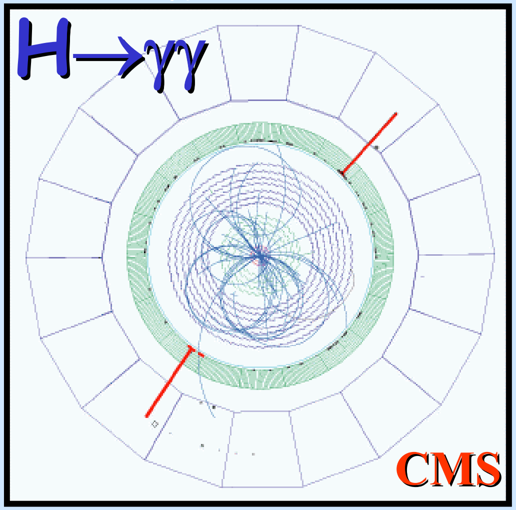
- Radiation Tolerant

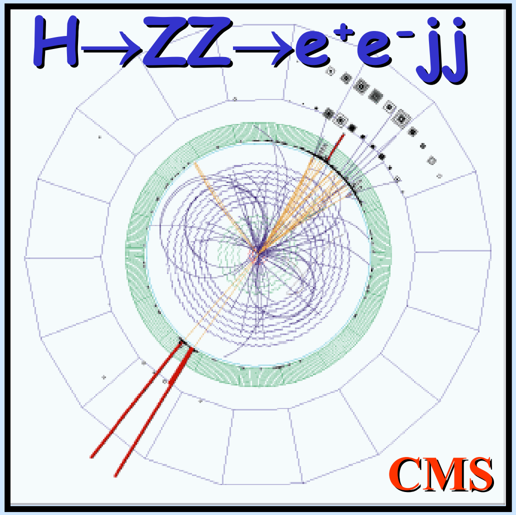


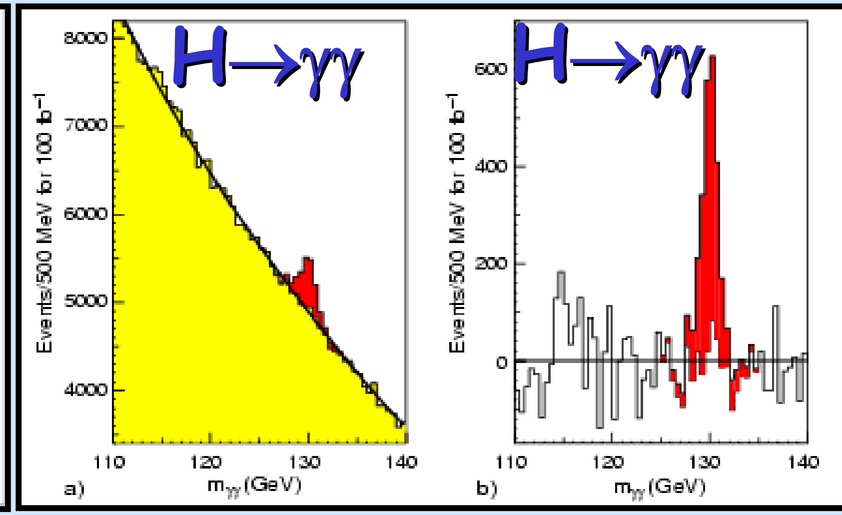
Key Features
- Single Power Supply 2.5V
- All FE+VFE ASICS in CMOS 0.25 µm
- Radiation Tolerant

Physics Motivation

The golden channel if $M_H < 150\ GeV/c^2$	Very important if $M_H > 150\ GeV/c^2$	Signal & background for $M_H = 130\ GeV/c^2$







- The $H \rightarrow \gamma\gamma$ mass resolution is a benchmark for the LHC e/m calorimetry.
- Excellent energy and position resolution in the detection of $e^{\pm}$, γ is mandatory.

We need an extremely high-precision electromagnetic calorimeter !!!

CMS target: $\sigma(E_\gamma)/E_\gamma < 1\%$ for $E_\gamma = 50$ GeV

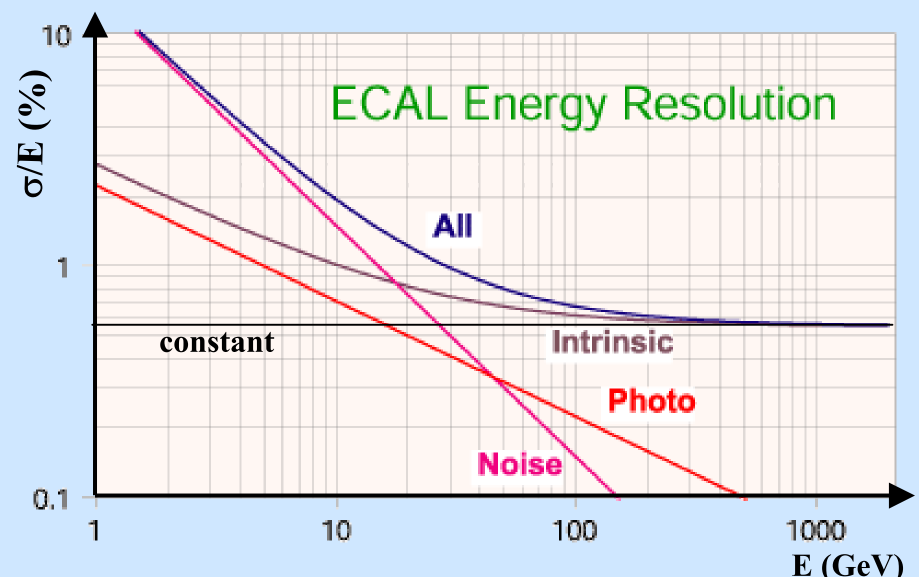
Energy resolution parameterization

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus \frac{\sigma_n}{E} \oplus c \qquad \text{(E in GeV)}$$

a **'Stochastic term':** Shower fluctuations, transverse leakage, photostatistics

σ_n **'Noise term':** Electronic noise, radiation induced I_{dark} , pileup

c **'Constant term':** Calibration, LY non uniformity, rear leakage



Target Performance		
Contribution	*Barrel*	*Endcap*
Stochastic term	2.7%	5.7%
Constant term	0.55%	0.55%
Noise term (MeV)	155 (210)	770 (915)

For a 5×5 Crystal array

Testbeam set-up

Trigger Scintillators (20x20 mm^2)
&
Fiber Hodoscopes
(Impact point resolution: 190μm)

Moving Table (η, φ)

Testbeam periods

2002

100 channels with "old" electronic (FPPA)
cooling and monitoring systems not final

- Test of APDs, HV, LV, VFE electronics
- Universality of irradiation behaviour
- Pre-calibration from LAB measurements

2003

100 channels with "old" electronics (FPPA)
50 channels with "new" final electronics (MGPA)
cooling and monitoring systems finalised

- Noise levels, preamplifier auto-gain switching
- Stability of cooling & monitoring systems
- Behaviour of new electronics

2004

1 supermodule (MGPA-1700 channels)

- Final system test
- Inter-calibration, energy and position scans

Important aspects

Energy reconstruction per channel (Noise & pedestal)

↓

Intercalibration (in Testbeam / in Lab)

⇓

Energy and **impact point** reconstruction/resolution

↓

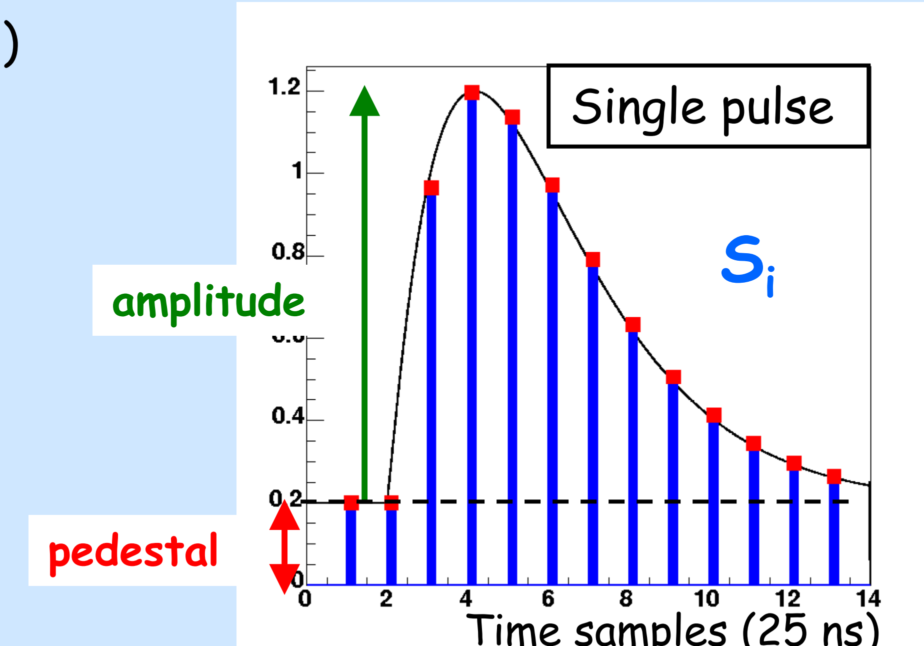
Affected by:

- Radiation
- Temperature variations
- HV variations

} Should be monitored & controlled

Single pulse reconstruction

- Digitization at 40 MHz (each 25 ns)
- 3 gain ranges (MGPA)
- Energies up to 1.3 TeV
- 14 time samples available offline



$$\tilde{A} = \sum_i w_i \bullet S_i$$

Amplitude — weights — signal+noise

Optimal weights extraction

$$\chi^2 = (\vec{S} - A \times \vec{F} - P)^T \, Cov^{-1} \, (\vec{S} - A \times \vec{F} - P)$$

Sample heights | Amplitude | Pedestal | Covariance Matrix

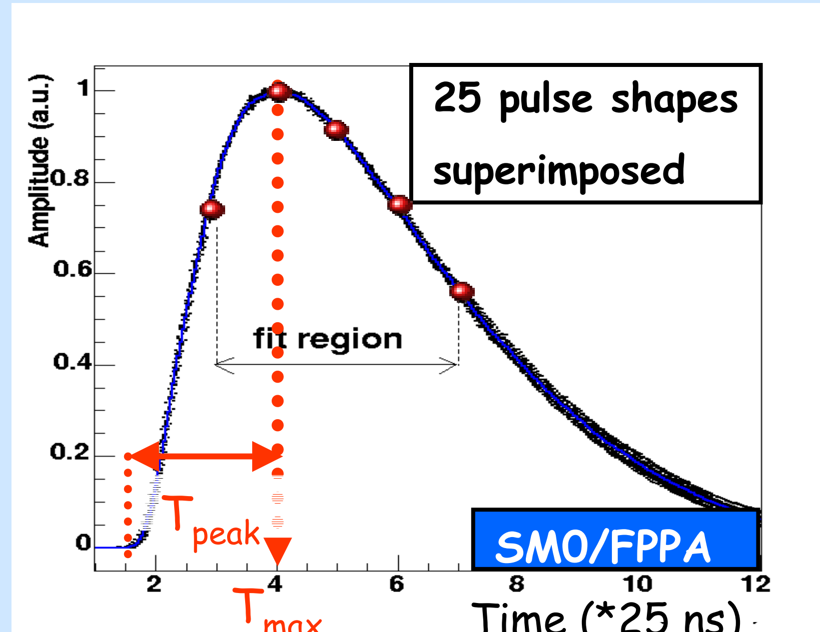
Expected sample heights : *f(t)*

Analytic description of pulse shape:

$$f(t) = \left[\frac{t - (T_{max} - T_{peak})}{T_{peak}} \right]^{\alpha} e^{-\alpha \left(\frac{t - T_{max}}{T_{peak}} \right)}$$

universal

- Shifts the peak
- Control the Shape
- Similar for large sets of crystals

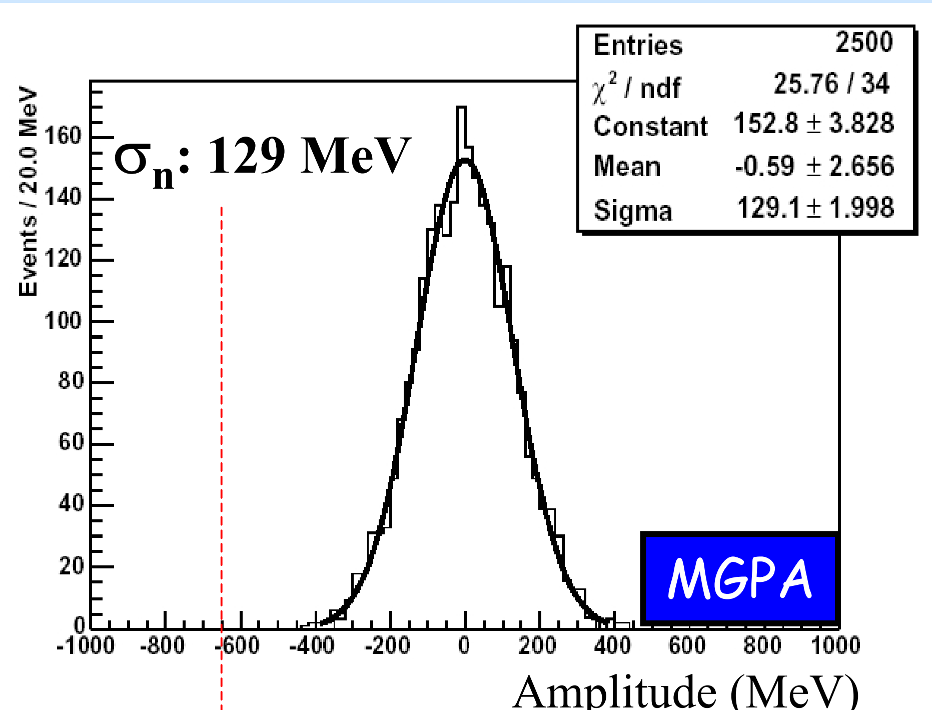


Energy Resolution

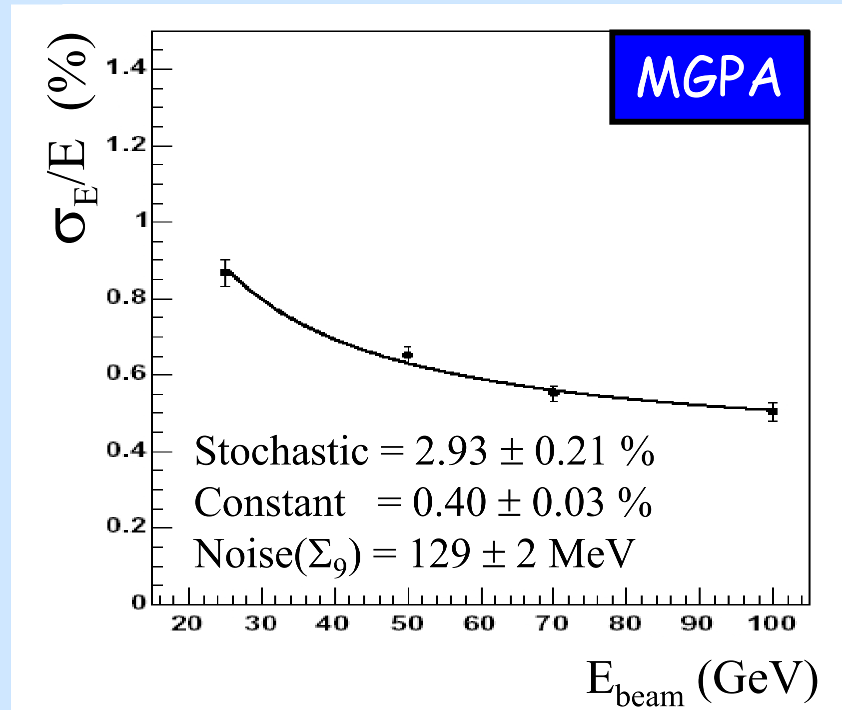
The intercalibration step is first…but it will be discussed later…

- Noise is estimated from pedestal runs
- Sum over a 3×3 crystal matrix

- Energy is the sum of a 3×3 crystal matrix around the most energetic crystal

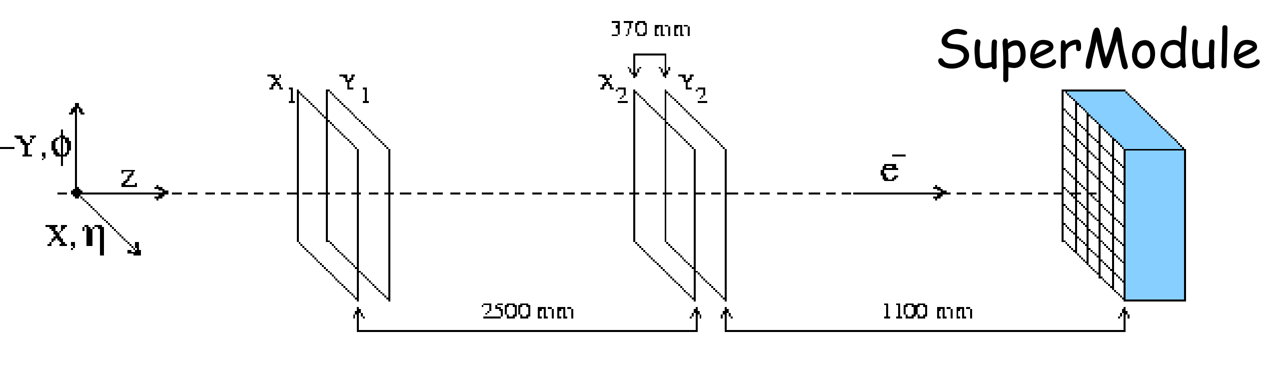


45 MeV per channel

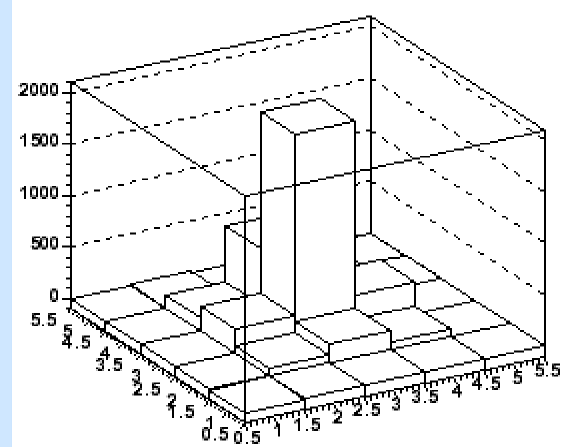


$$\frac{\sigma_E}{E} = \frac{(2.9 \pm 0.2)\%}{\sqrt{E/GeV}} \oplus \frac{(129 \pm 2)MeV}{E} \oplus (0.4 \pm 0.03)\%$$

Impact point reconstruction



Fiber Hodoscopes
(σ ~ 190 μm)



Energy deposition in a 5x5 crystal matrix

Purpose:
Reconstruct the impact position using only the energy depositions in the crystals.

The methods:

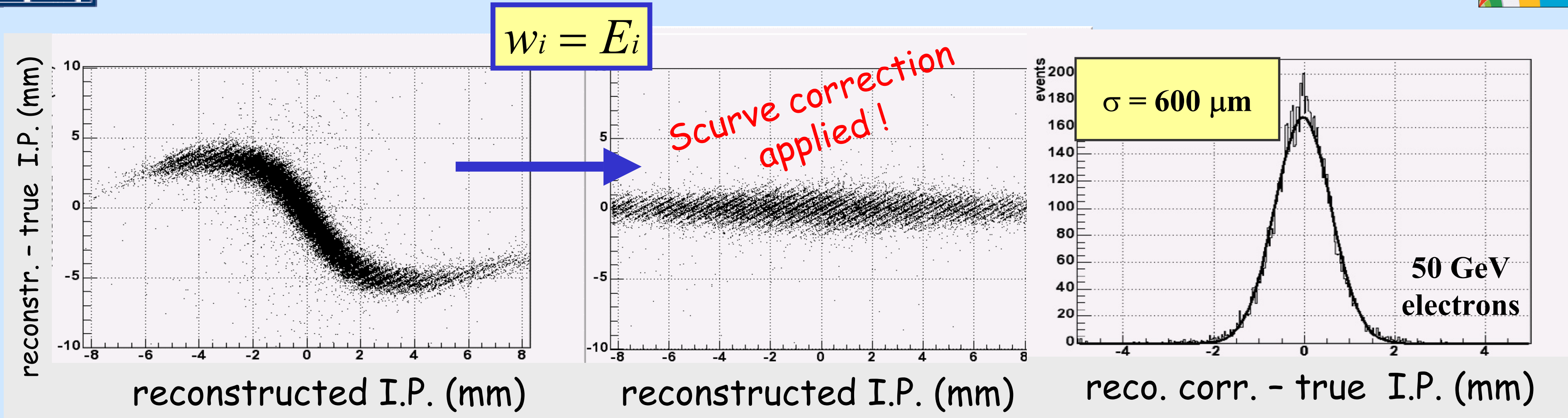
$$\langle x \rangle = \frac{\sum_i w_i \bullet x_i}{\sum_i w_i}$$

x_i: position of the *i-th* crystal

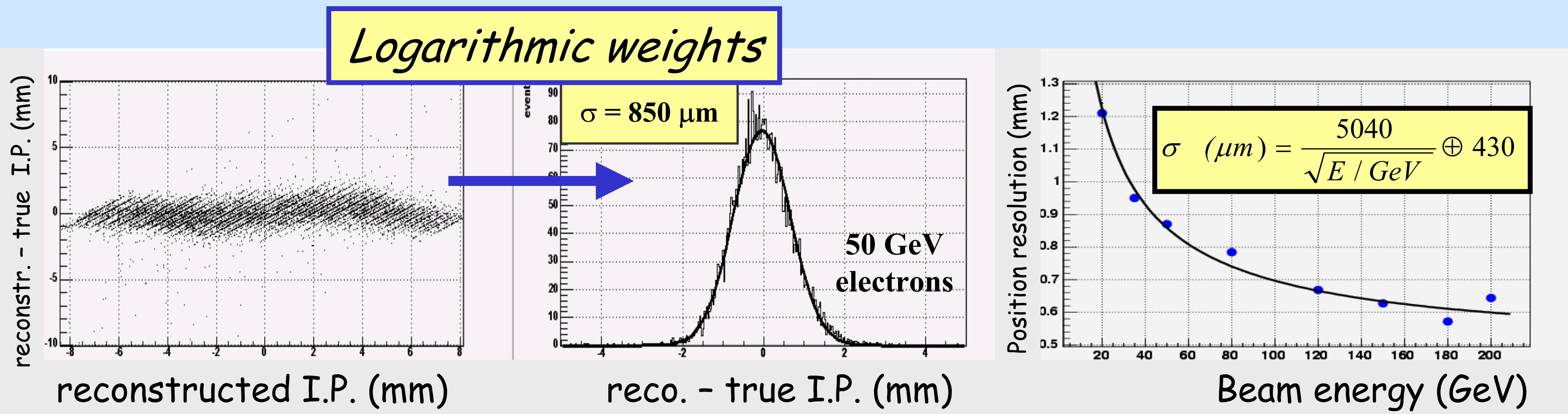
- $w_i = E_i$
- $w_i = w_0 + \log\left(\frac{E_i}{\sum_j E_j}\right) \quad w_i > 0$

E_i: energy in the *i-th* crystal

Impact point reconstruction



Main disadvantage : S curve corrections are E, η dependent !



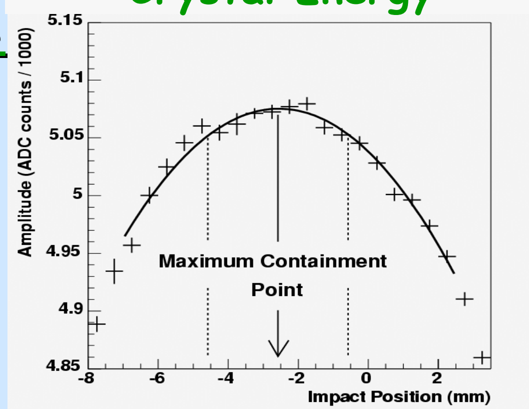
Main advantages :
- **No corrections curves needed!**
- **Adequate position resolution!**

Intercalibration

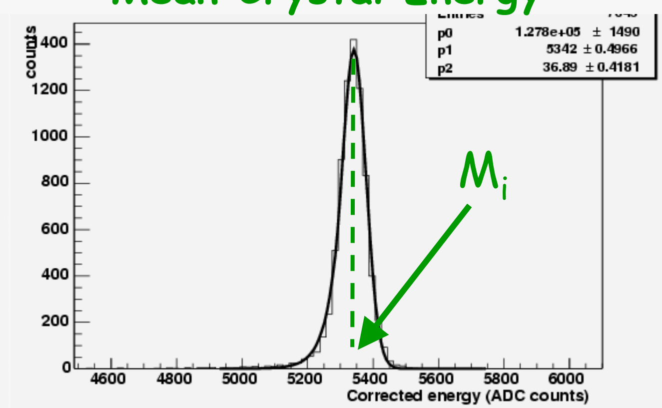
Intercalibration of channel-to-channel responses

In Testbeam:

Crystal Energy



Mean Crystal Energy

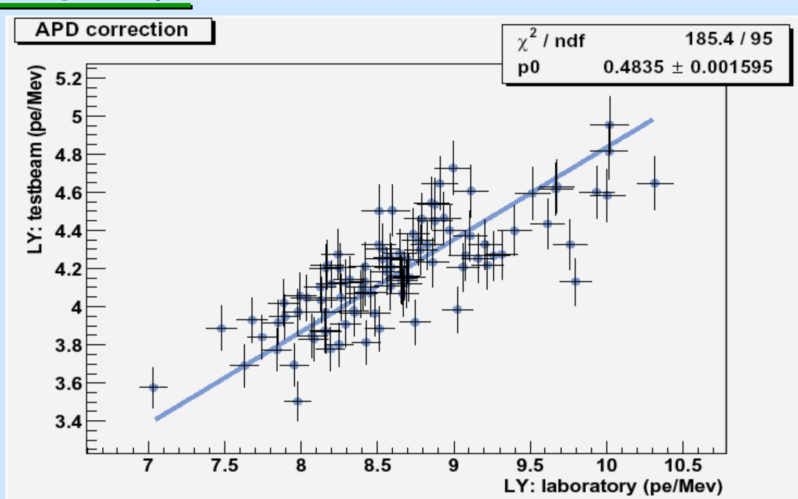


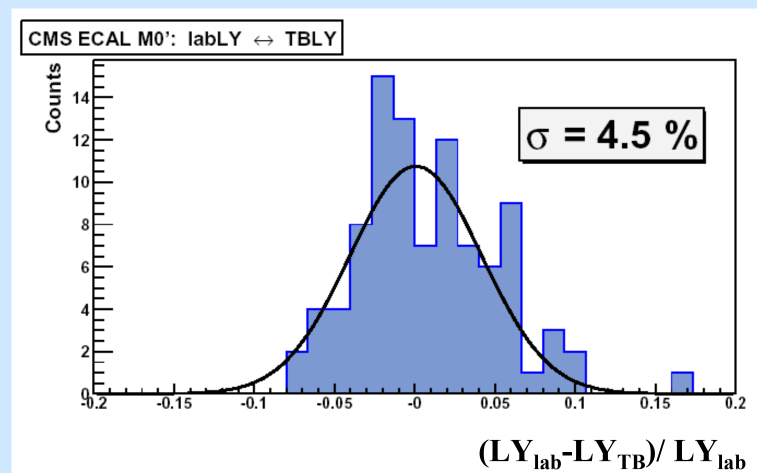
Relative calibration:

$$\alpha_i = \frac{M_i}{M_{\mathrm{Ref}}}$$

Improves energy resolution (necessary for constant term < 0.5%)

In the Lab.: L.Y. measurement using ^{60}Co source 1.2 MeV





Cooling – Temperature stability

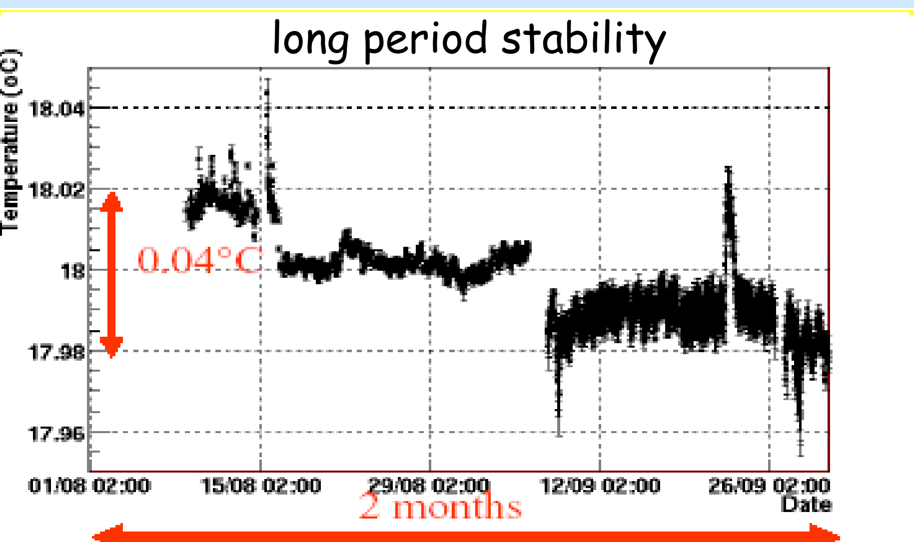
Both APDs and $PbWO_4$ are sensitive to temperature variations

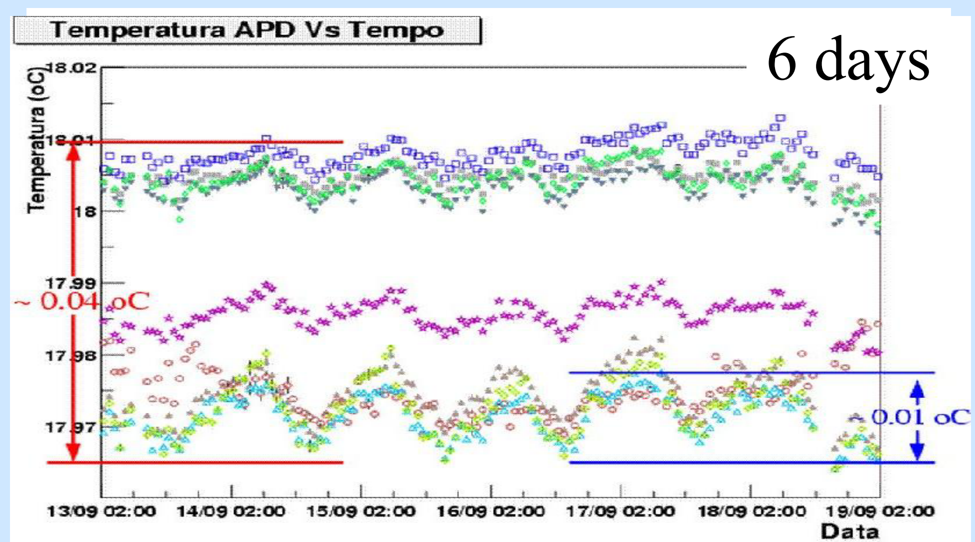
APD gain (M) T dependence : $\alpha_T\ (\%/{}^0C) = \frac{1}{M}\frac{dM}{dT}$ = -2.11 ± 0.04 % / °C (laser runs)

(APD + crystal) LY T dependence : $\beta_T\ (\%/{}^0C) = \frac{1}{R}\frac{dR}{dT}$ = -3.75 ± 0.07 % / °C (electron runs)

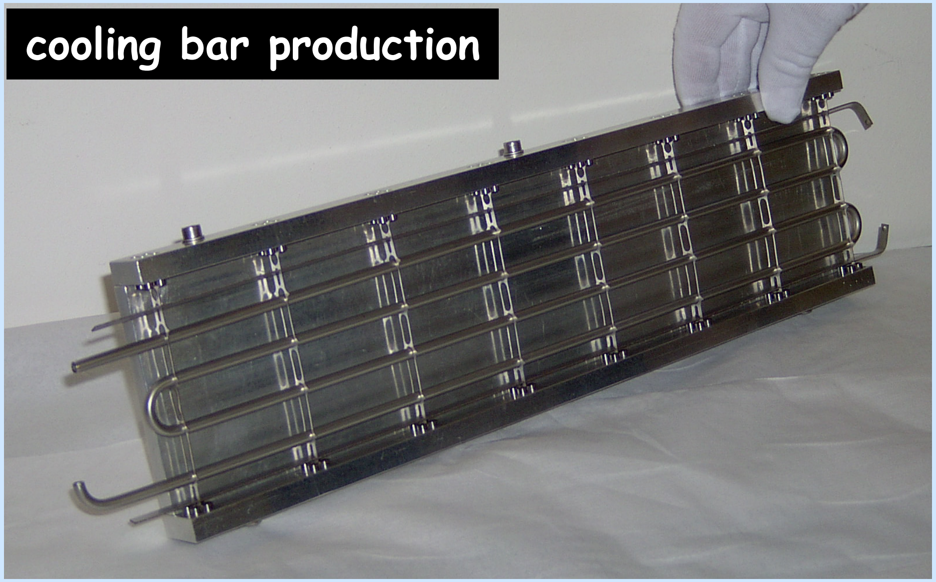
System requirements in the APD/crystal region:

- **stability in time: ΔT ~ ± 0.05 ⁰C**
- **uniformity : ΔT ~ 0.2 ⁰C within a Supermodule**

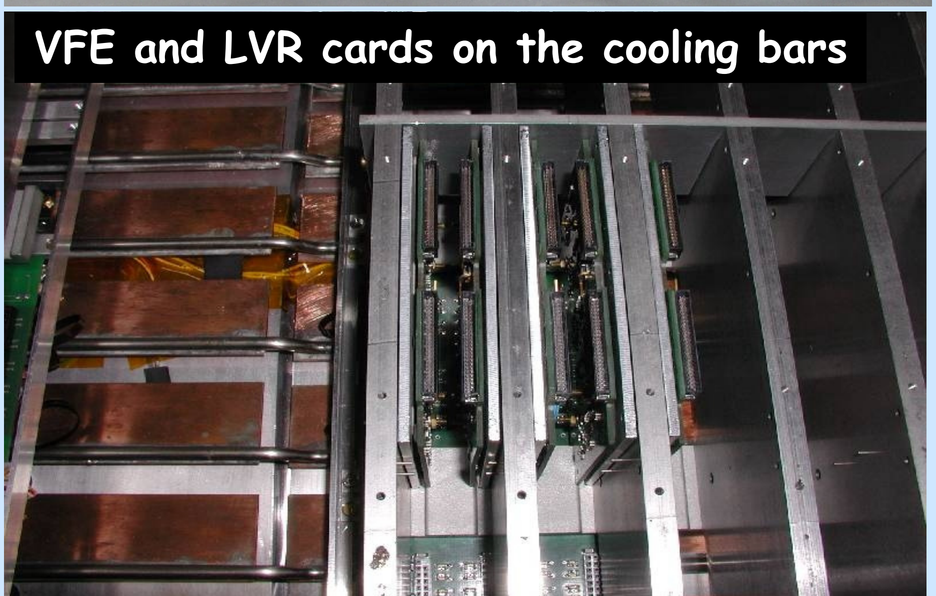


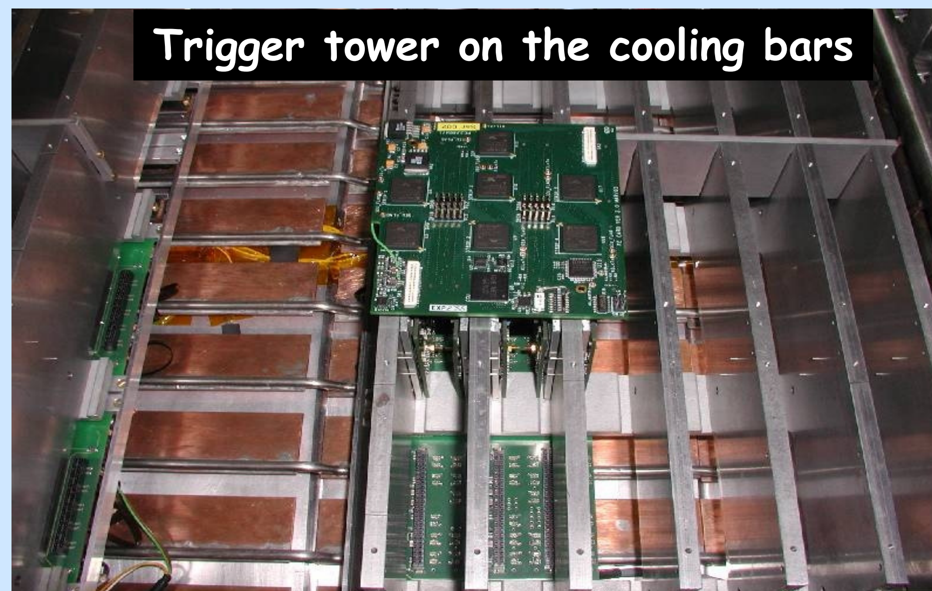


Cooling components



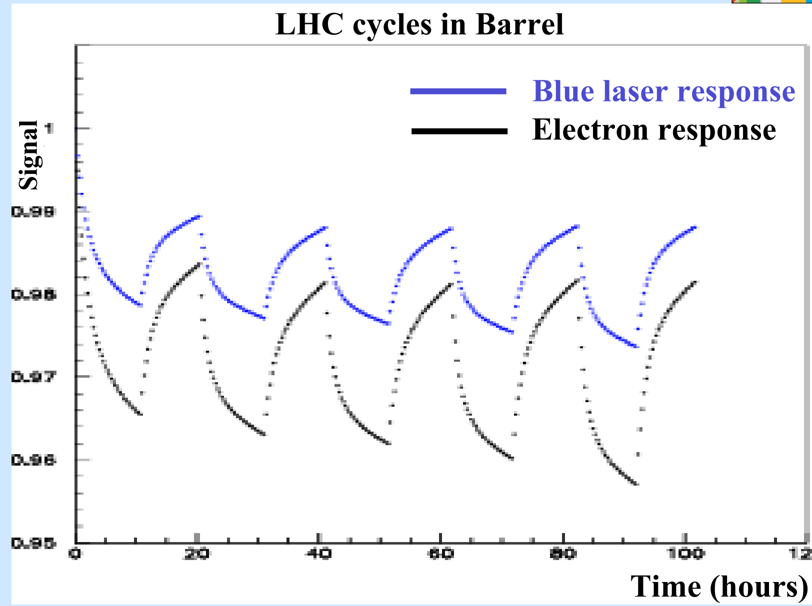
All these components are in production !!!

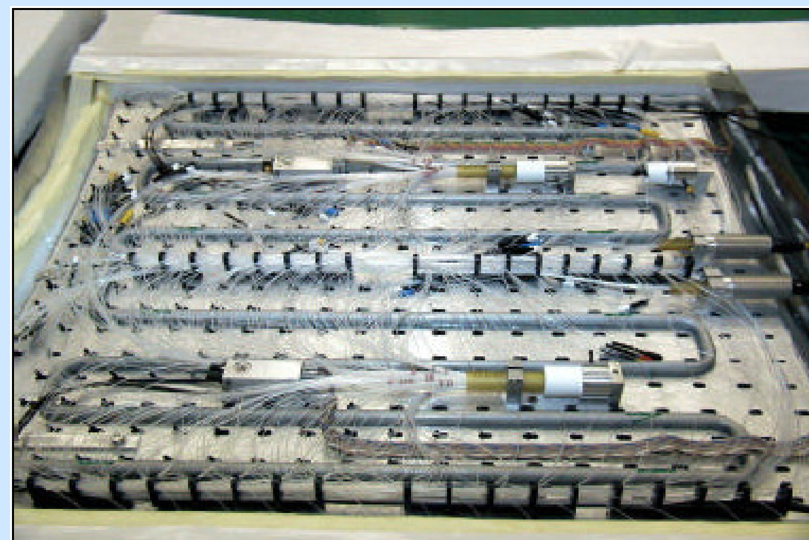




Light monitoring

- Irradiation affects only the light transmission.
- Loss in extracted light (~ 3 % for 0.15 Gy/h) due to reduced transmission can be monitored and corrected by the injection of laser light as reference.
- 2 laser systems with 4 wavelengths : 440/495 nm and 700/800 nm





A dedicated presentation on the laser monitoring system and the Testbeam results will be given by Adolf Bornheim.

Conclusions

- The CMS electromagnetic Calorimeter is well underway.
- The first complete ECAL supermodule (1700 channels, 1/36th of the Barrel) will be fully tested and calibrated in the Testbeam this Autumn.
- The previous years Testbeam campaigns gave encouraging results:

- Energy resolution has reached the CMS/ECAL target.
- Position resolution is adequate for all physics purposes.
- Initial crystal calibration can reach a 4% level in the LAB. In situ calibration with physics events ($W \rightarrow e\nu$, $Z \rightarrow e^+e^-$) will upgrade calibration to 0.5%.
- Cooling guarantees very small temperature variations in time & space.
- Radiation effects are monitored and corrected with the help of a Laser system.