CMS - ECAL
Test beam results

QuickTime™ and a
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Outline

- Introduction
- Monitoring
  - T° stability
  - Monitoring of Crystal Light Transmission
- Performance
  - APD Pulse Reconstruction
  - Crystal Intercalibration
  - Energy Resolution
  - Impact Point Reconstruction
  - Trigger Primitives
- Monte-Carlo Simulation
- Conclusion

CMS-ECAL
Design criteria - Constraints - Challenges

ECAL was optimized to favour the Higgs Discovery at the LHC

with $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^* \rightarrow 4e$ channels

Design Criteria:

- **Homogeneous calorimetry** (with fine **transversal segmentation**) for best measured Higgs mass resolution ($\Delta M / M < 1\%$) in $\gamma\gamma$ channel;
- Lead tungstate (**$PbWO_4$**) crystals for a **fast** *(25 ns bunch crossings)* and **compact** calorimeter
- Energy resolution goal: $\boldsymbol{\sigma_E / E = 2.7\% / \sqrt{E} \oplus 0.15 / E \oplus 0.5\%}$ with E in GeV)

Main Constraints:

- Low $PbWO_4$ scintillation yield at room-temperature,
- Very hostile radiation environment of LHC
- 4T solenoidal magnetic field of CMS

Major Challenges:

- Photo-detection with gain amplification (APDs = *Avalanche Photodiodes* for central barrel and VPTs for the Endcaps)
- Radiation hard Very-front end (VFE) and front-end (FE) electronics
- Wide range dynamics for the energy measurement (-> 1.5 TeV in Barrel, -> 3TeV in Endcap)
- Establish and maintain inter-calibration at better than 1% level (T° stability, monitor rad. damage/recovery, …)

Test Beam: Objectives

- **Evaluation of detector performance**
  - **Check Inter-calibration stability and transferability to CMS in situe …**
  - **Measure Noise, E linearity and resolution, position resolution, …**

- **Real-life test of a complete integrated systems**
  - **Full detector readout electronics**
    ($PbWO_4$ crystal ⇒ twin-APDs, VFE, FE,…)
  - **Final CMS Laser Light Monitoring system (4 λ's)**
  - **CMS prototype Slow Control and Security systems (DCS)**
    for LV, HV, T°, …
  - **Develop reconstruction algorithms**
  - **Complete on-line/off-line chain of RooT-based software**

Test Beam setup

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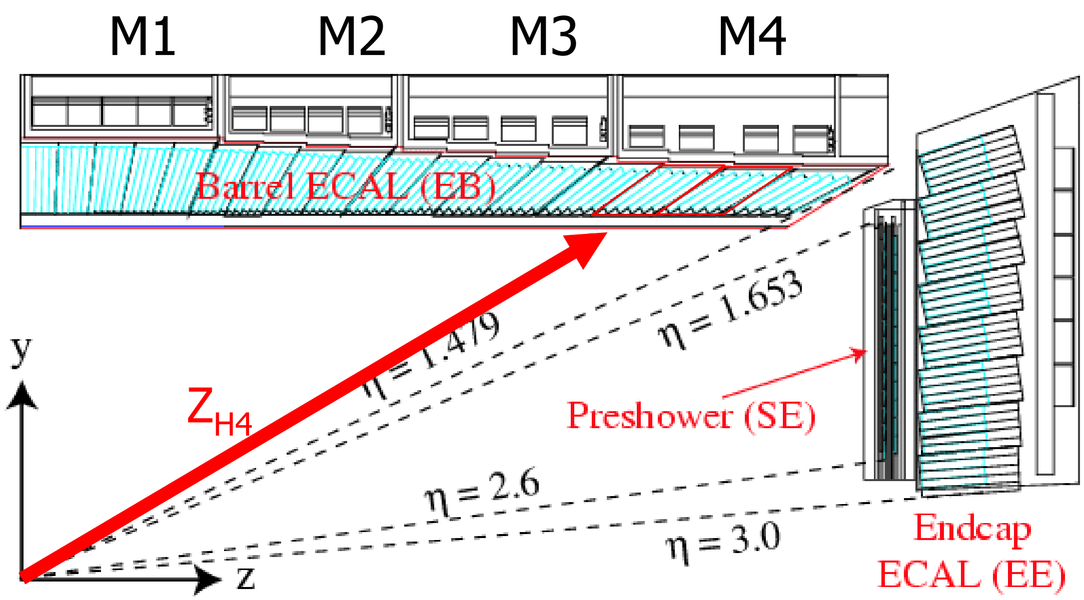
Beam hodoscope



e.g. Datasets:

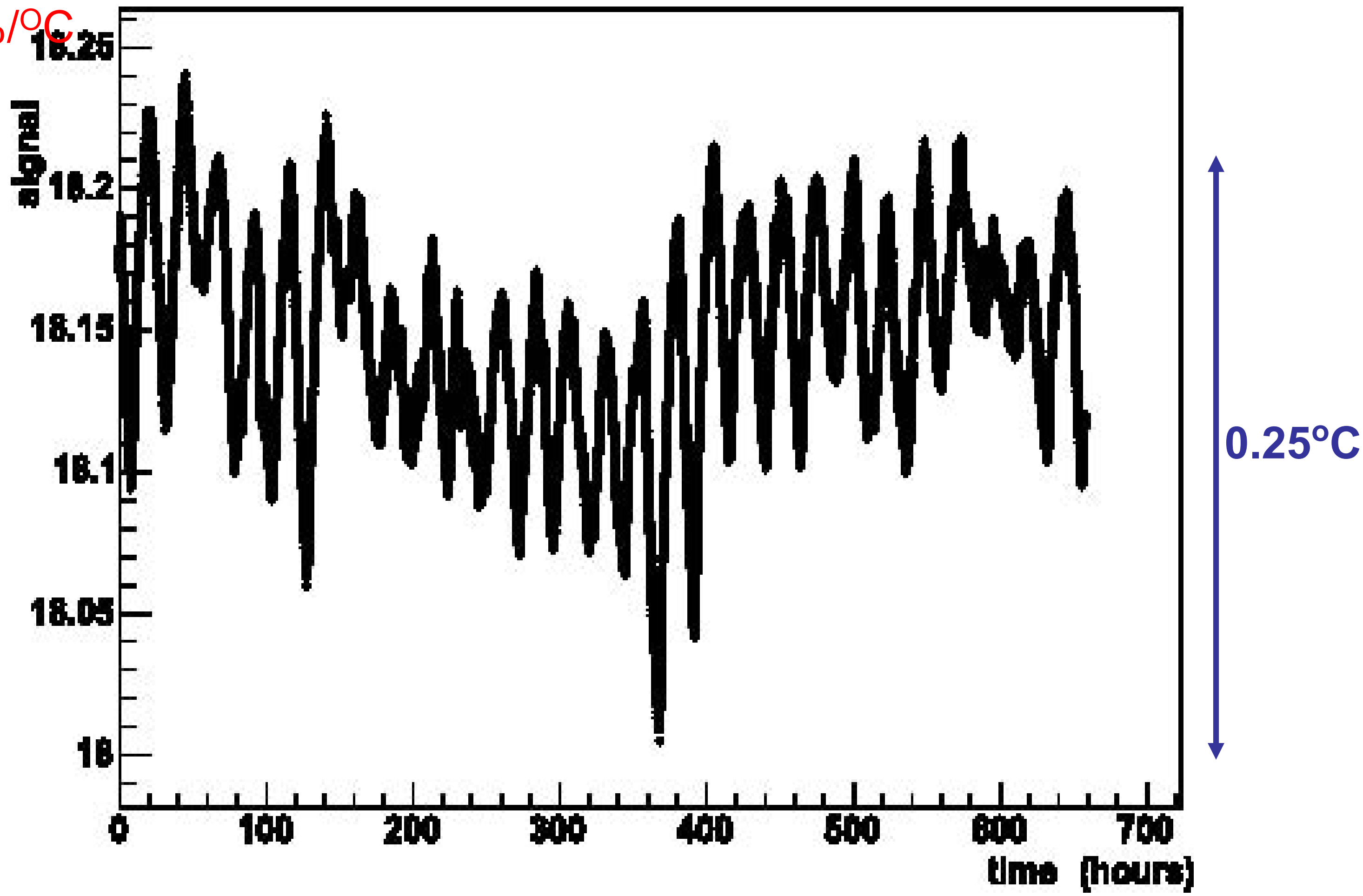
- Intercalibrations 50, 120 GeV
- E scans (20, …, 200 GeV)
- Uniform impact on crystal surface
- e/π irradiation runs
- Laser mon. runs,
- pedestal runs, HV scan/dark current
- Ecal trigger tests
- Temperature Steps

Temperature control

Temperature dependance:

- **APD** => -2.4%/°C
- **$PbWO_4$** => ~2.2%/°C

DCS

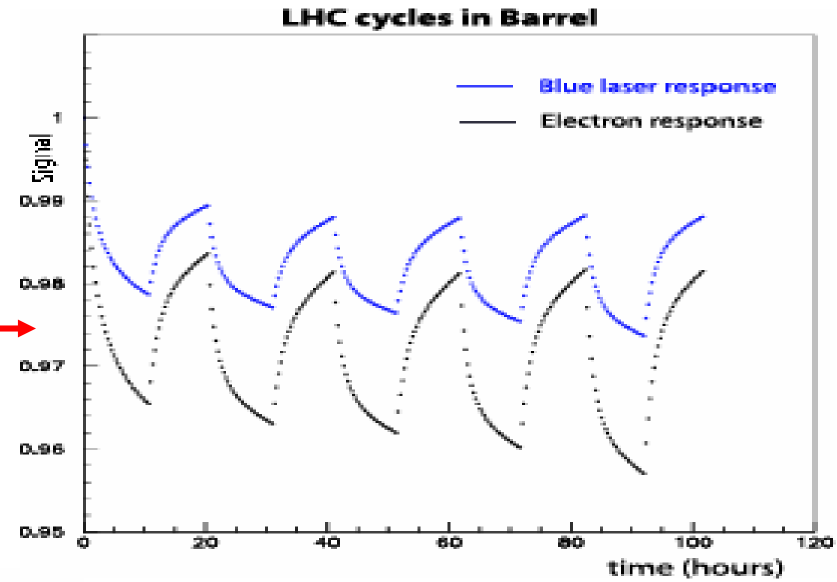


Laser Monitoring 1/3

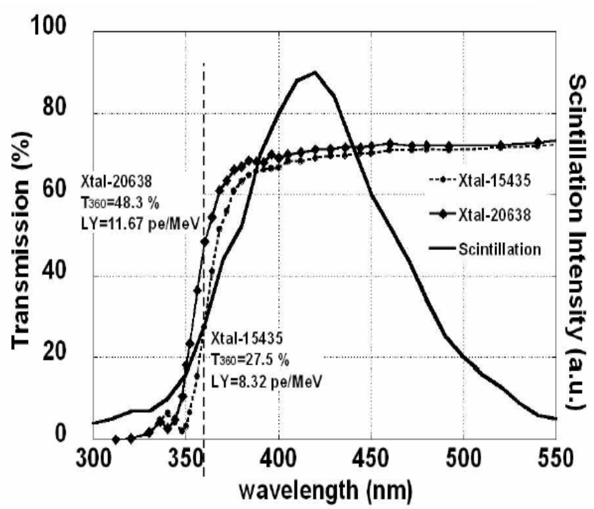
- Loss in extracted light up to ~ 3-5% for expected 0.15 Gy/h
- Transmittance reduced in blue and green where emission spectrum peaks
- Irradiation affects only transmission

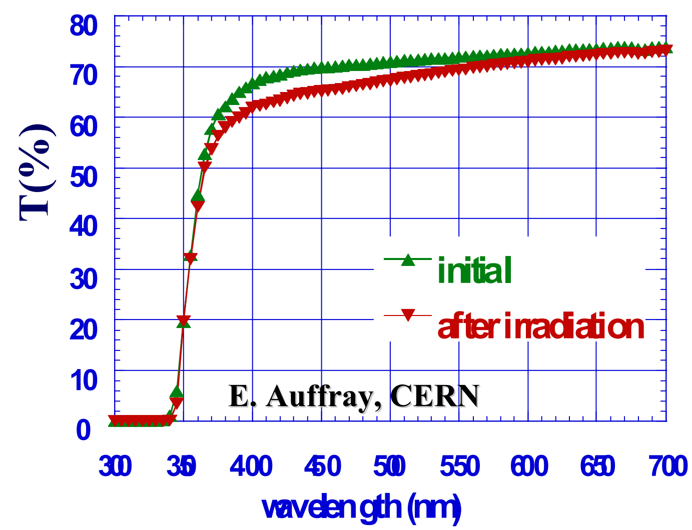
can be monitored and corrected for →

⇒ Use laser light (2 lasers; 4 wavelengths 440/495 nm and 700/800 nm

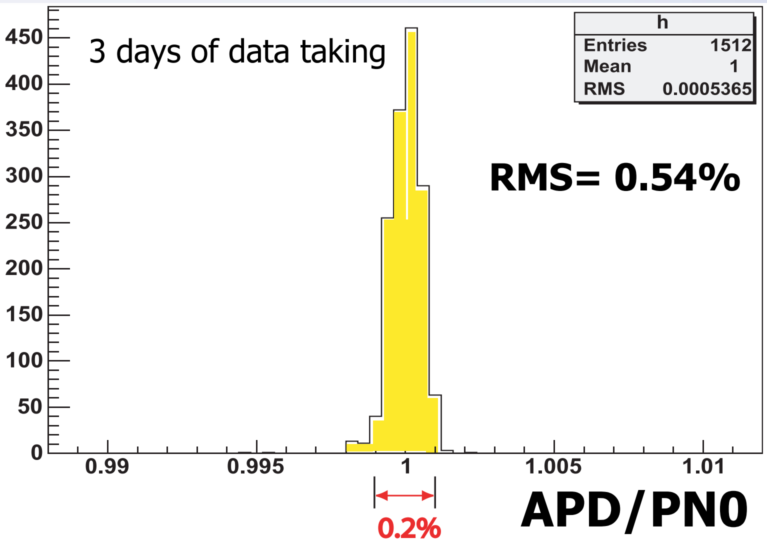


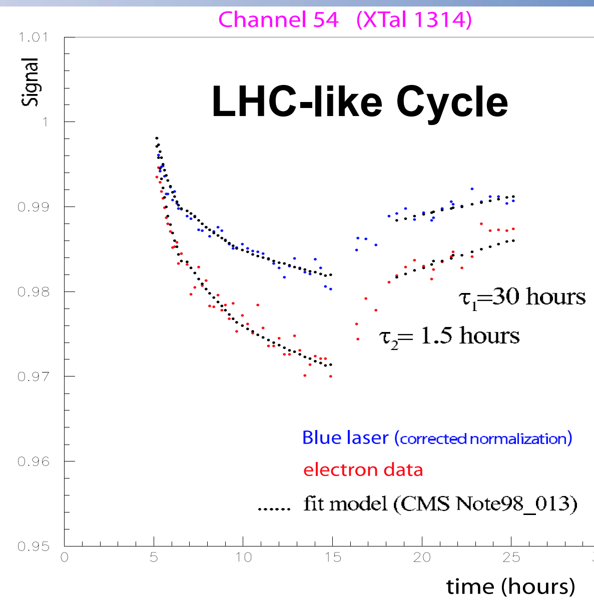
Almost no effect in red/infrared
⇒ used as ref. to disantangle other possible effects

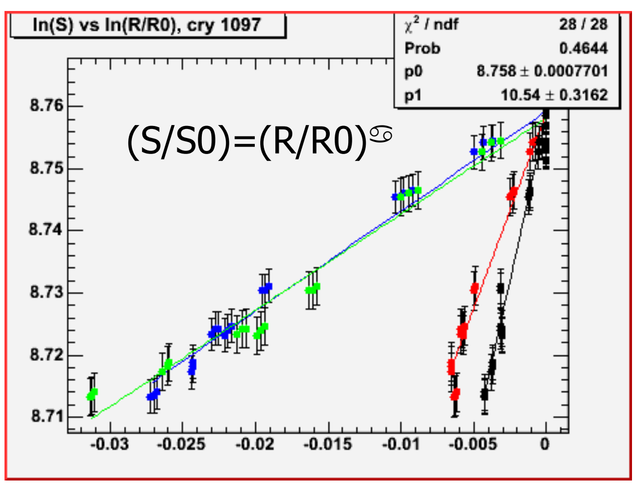


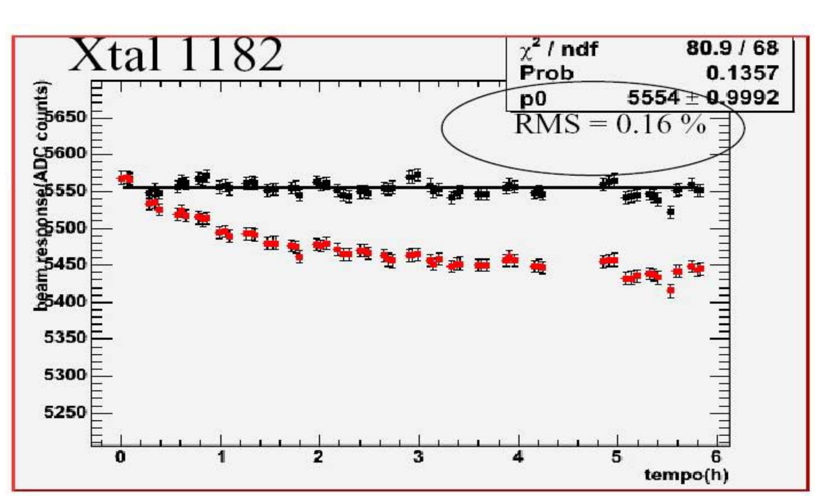


Laser Monitoring 2/3





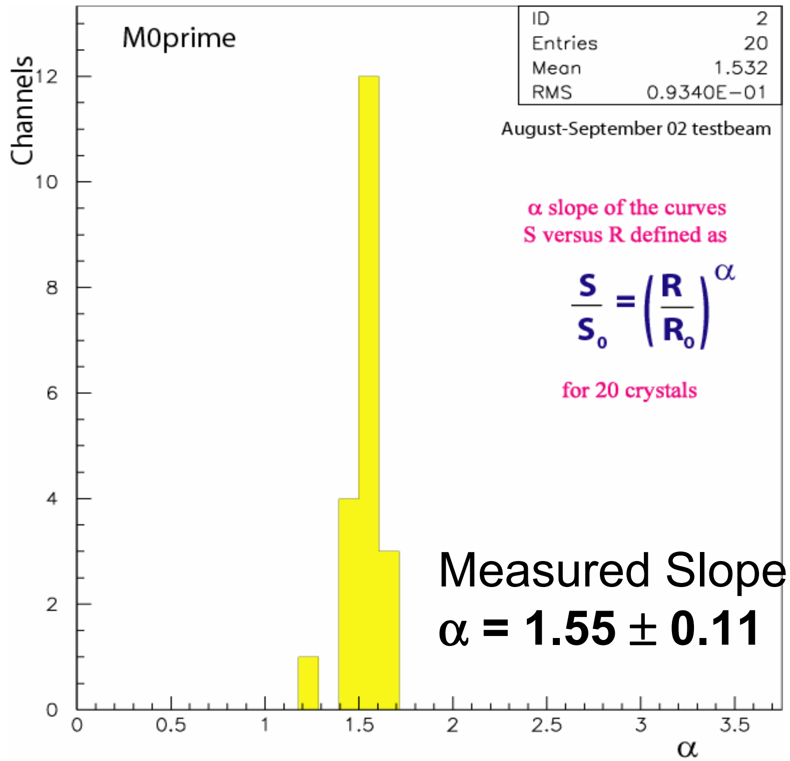




Laser Monitoring 3/3

Dispersion of α (120 GeV electron irradiation)

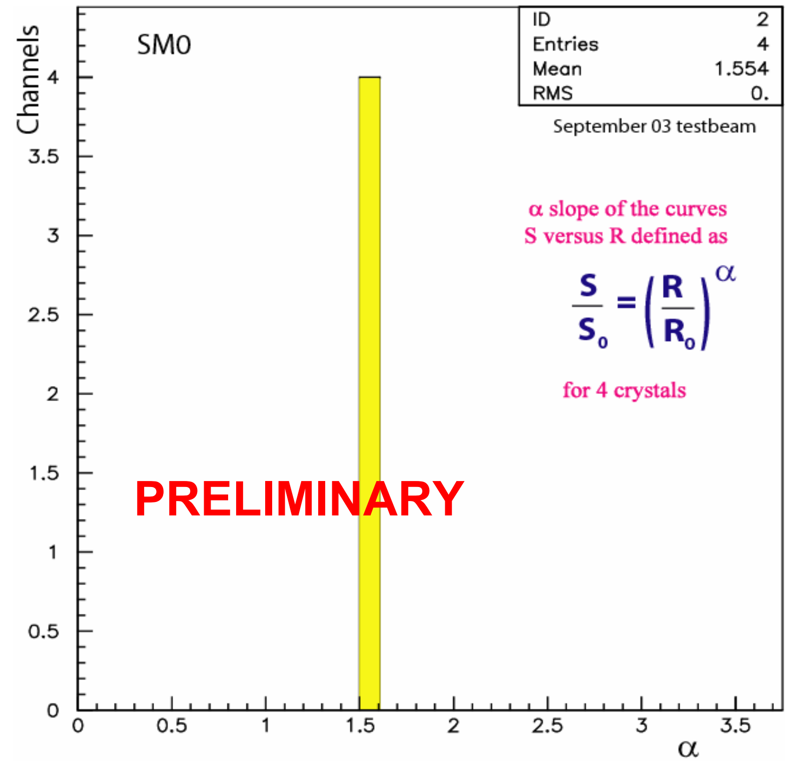
XLs geometry type 8



Measured Slope

α **= 1.55 ± 0.11**

XLs geometry type 16

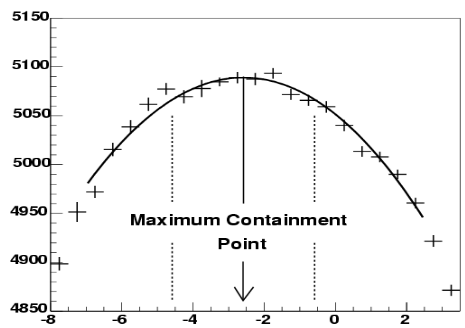


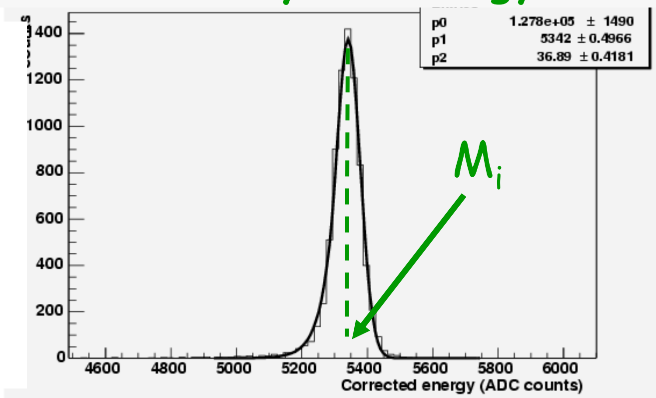
Same slope α for XLs geometry type 8 &16

→ σ/μ = **7%** (type 16) compare to **6.3%** (type 8)

Electron intercalibration at H4

In Testbeam:





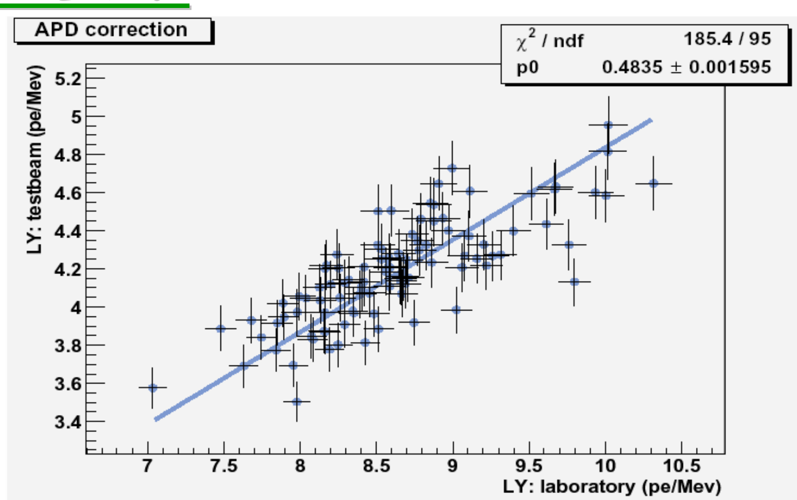
Relative calibration:

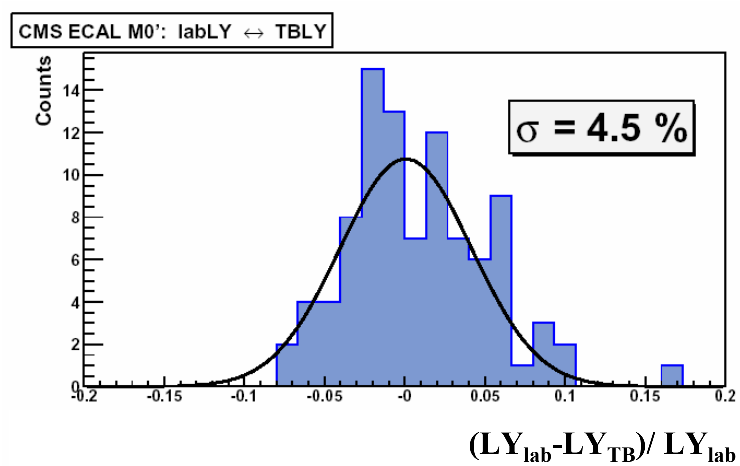
$$\alpha = M_i/M_{ref}$$

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

In the Lab.:

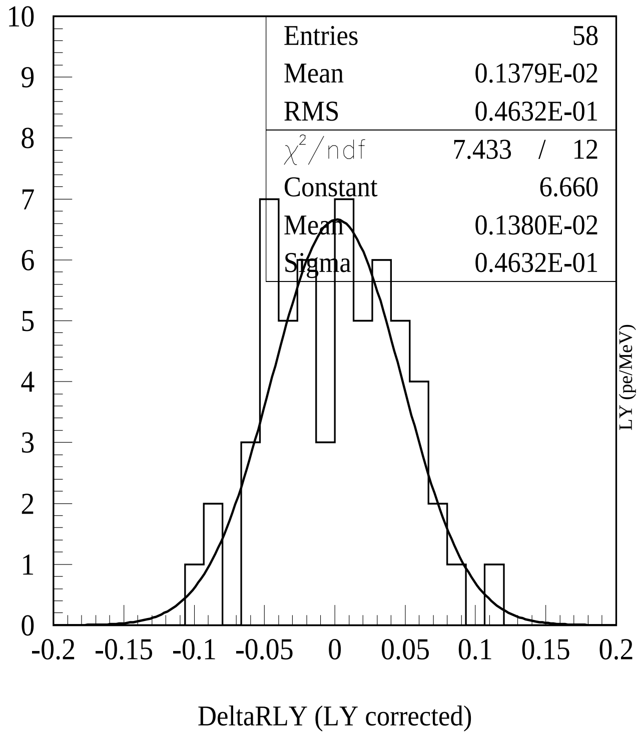
L.Y. measurement using ^{60}Co source 1.2 MeV





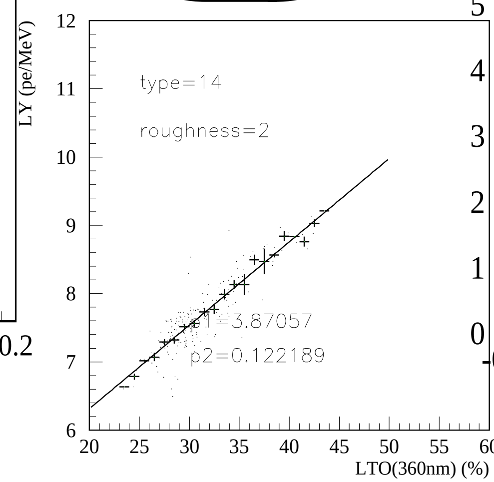
Pre-calibration from laboratory data

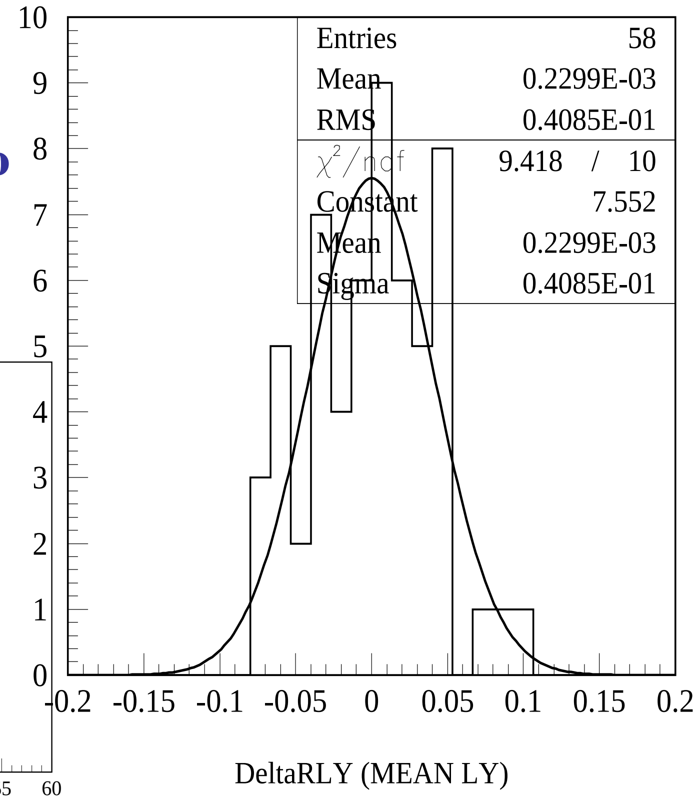
LY corrected for Reference crystal (R.P.)



MEAN LY=(LY_cor+LY_LTO)/2

4.6% **4.1%**





An improvement has been obtained by using the correlation between LY and transmission at 360 nm (here for SM0 in 2003)

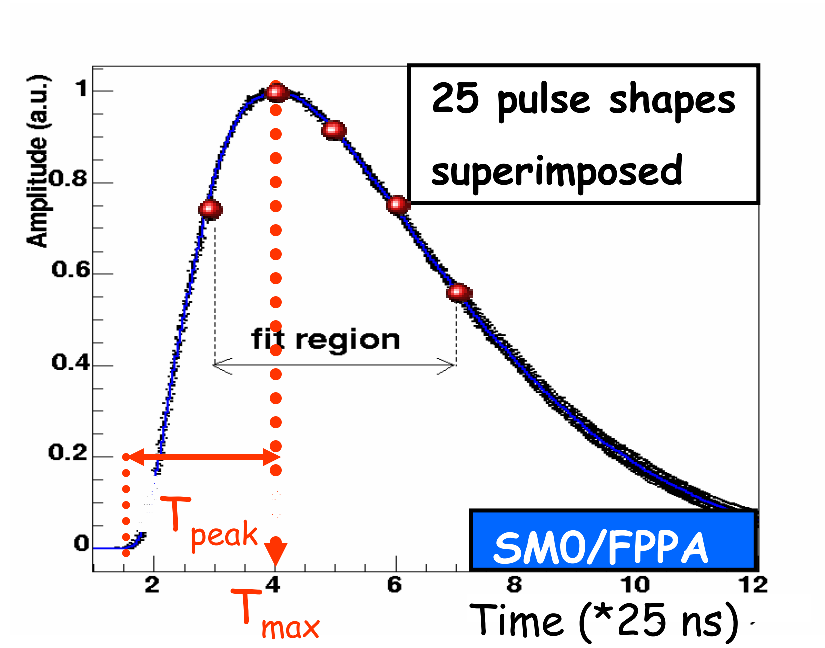
Pulse Shapes Reconstruction-Weight Method(1/5)

Analytic description of pulse shape:

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

- Shifts the peak
- 2 ns spread in T*max* among crystals

- « Universal » shape parameters



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

Sample heights | Amplitude | Pedestal | Covariance Matrix

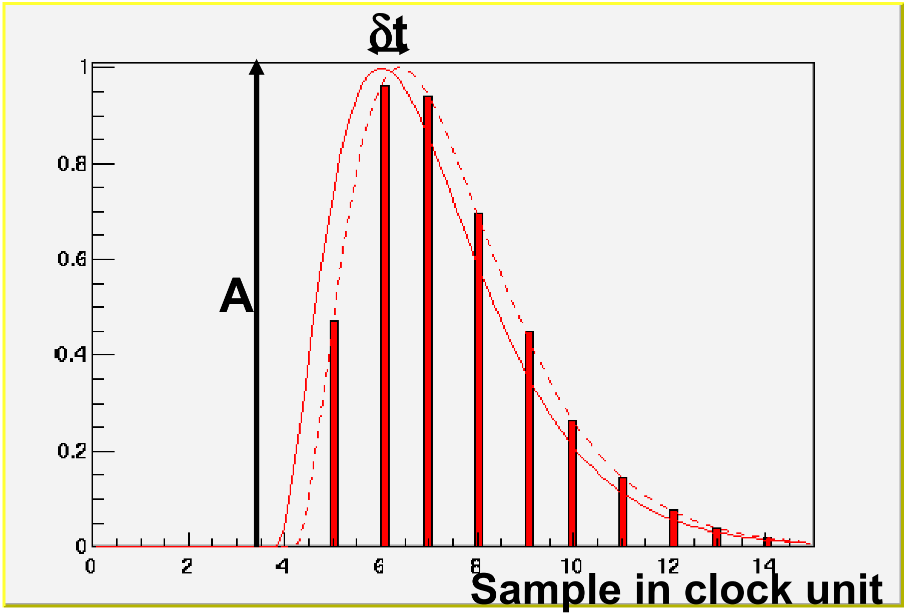
Expected sample heights : *f(t)*

Pulse Shapes Reconstruction (2/5)

Pulse Shapes

Aim: **Sampling ADC** ⇒ **Amplitude of the pulse shape** ⇒ **Energy in the crystal**

Testbeam specificity:
random phase
i.e. $\sigma(\delta t)$ = 25 ns
(<1 ns in CMS)



Methods: **Weights Methods** $\tilde{A} = \sum w_i S_i$

1) « General Weights » = w_i rely on specific shape for each crystal

2) « Light Weights » = w_i assume universal shape (e.g. nanogreen laser)

Fit Method

3) Iterative fit of an analytic function to data

Timing optimisation (3/5)

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Parameters optimisation (4/5)

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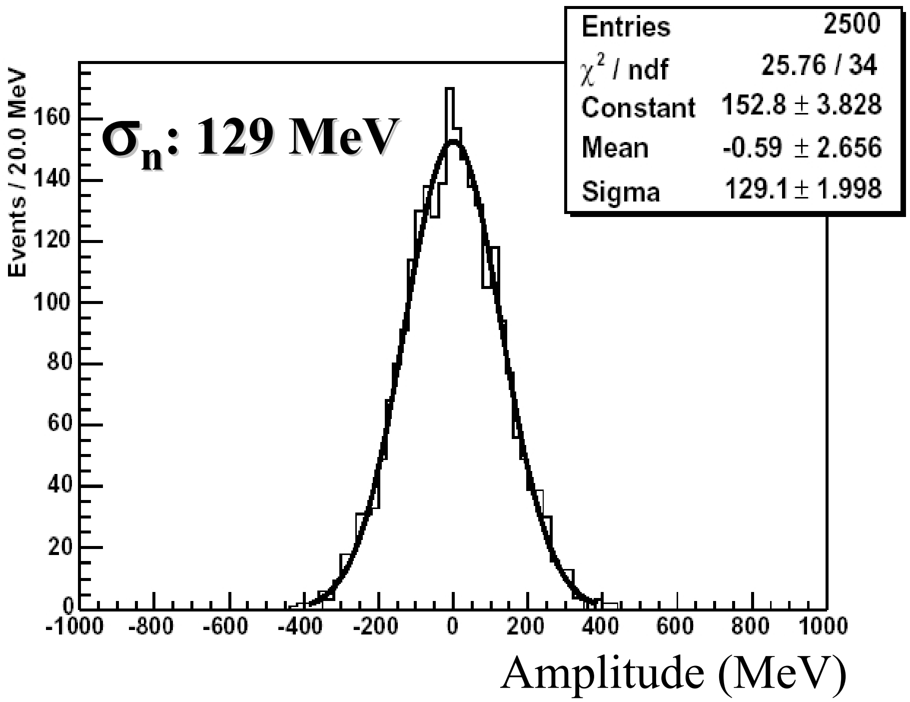
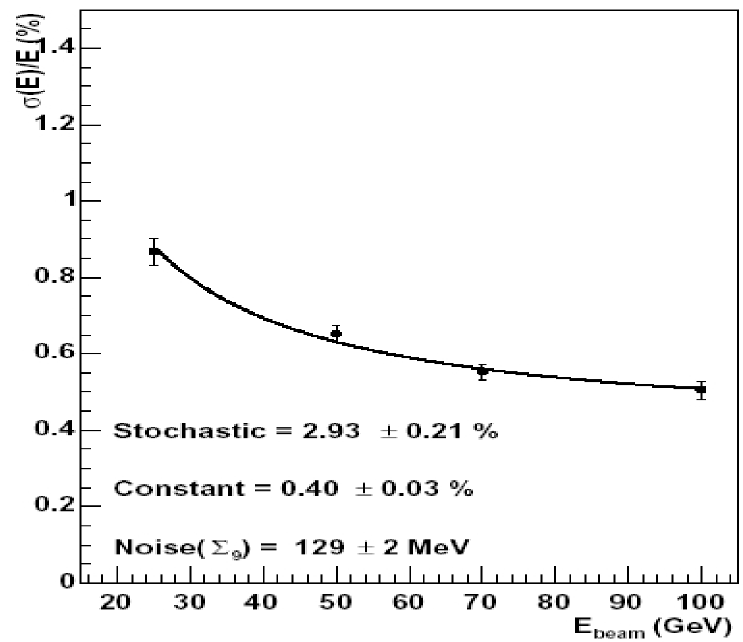
Noise - Energy resolution (5/5)





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

⇒ **Very good resolution specially at low energy**

Beam position (1/3)

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Position reconstruction from crystal's energy measurements (2/3)

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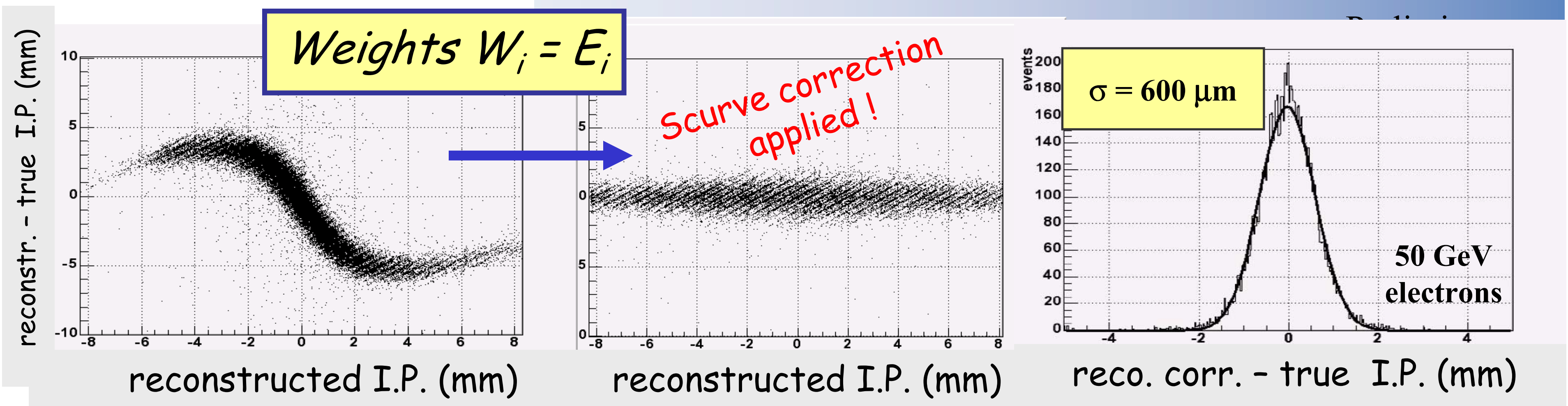
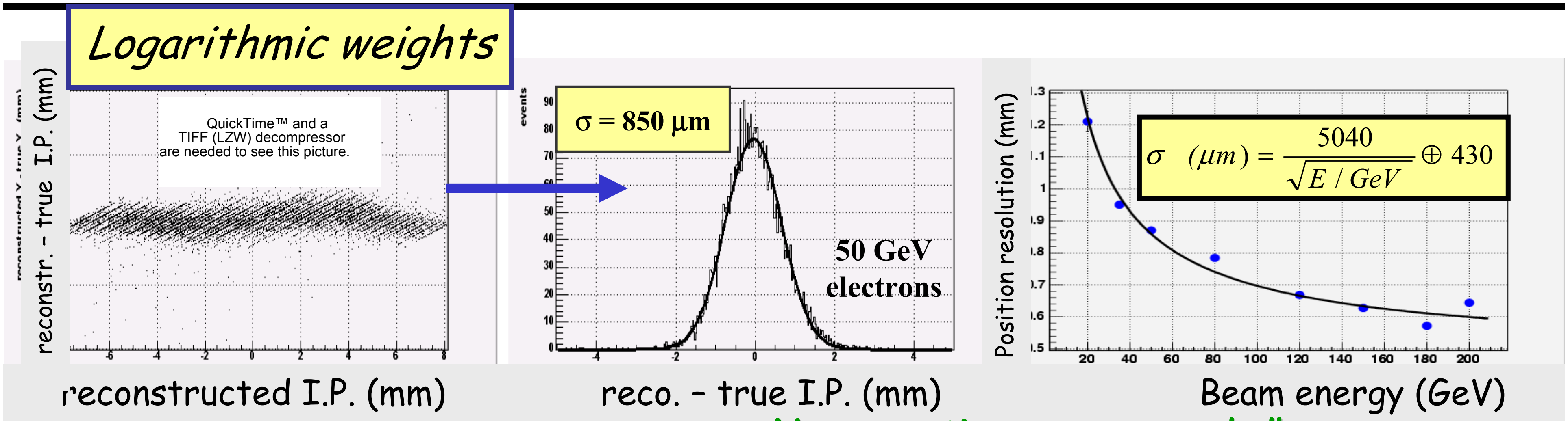
Position Reconstruction (3/3)



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



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

Ecal Data Flow (1/6)

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TPG from test beam (2/6)

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Reconstructed TPG output (3/6)

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TPG linearity (4/6)

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

TPG Energy resolution (6/6)

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Bunch crossing assignment efficiency (5/6)

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Monte Carlo Simulation 1/2

- Geant4 simulation of an entire ECAL supermodule in the H4 test beam

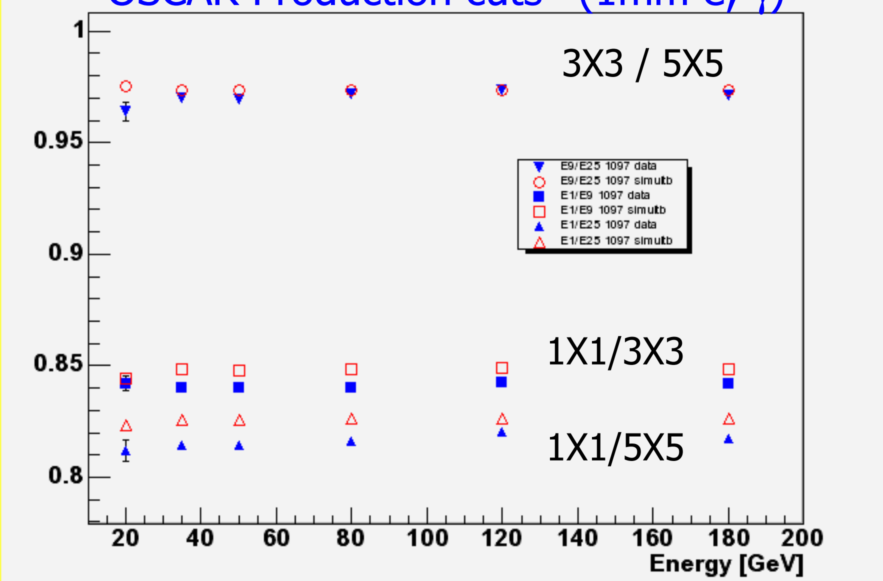
  Based on Geant 4.5.0

  Supermodule geometry read from standard geometry (XML) files

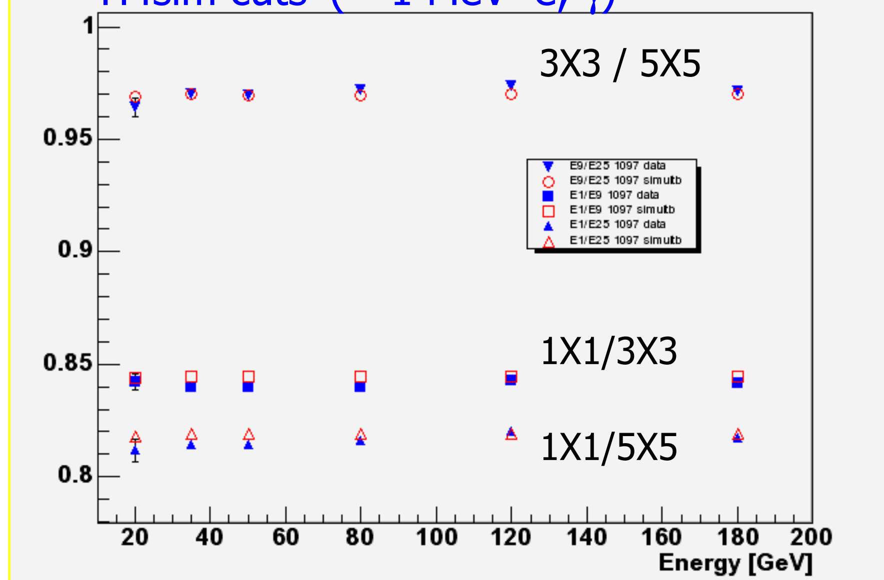
  Simulates longitudinal non-uniformity of light collection (construction DB)

e.g. Containment vs Energy

'OSCAR Production cuts' (1mm e, γ)

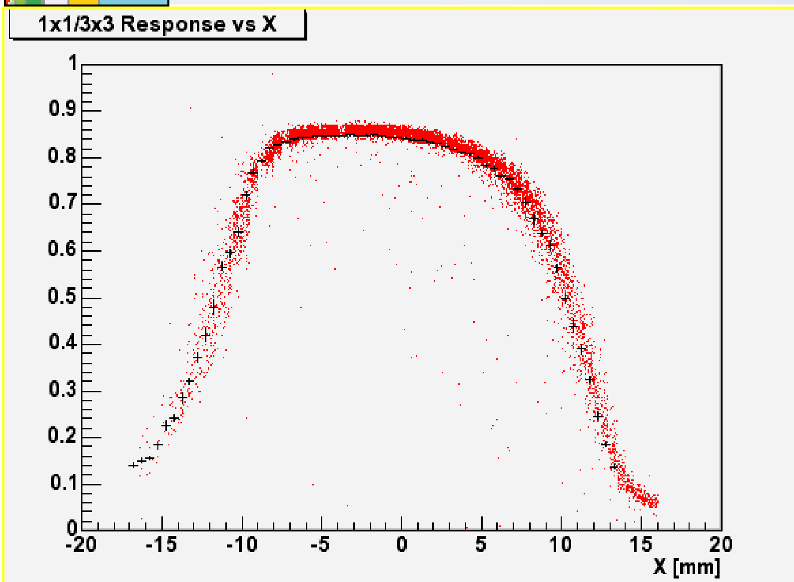


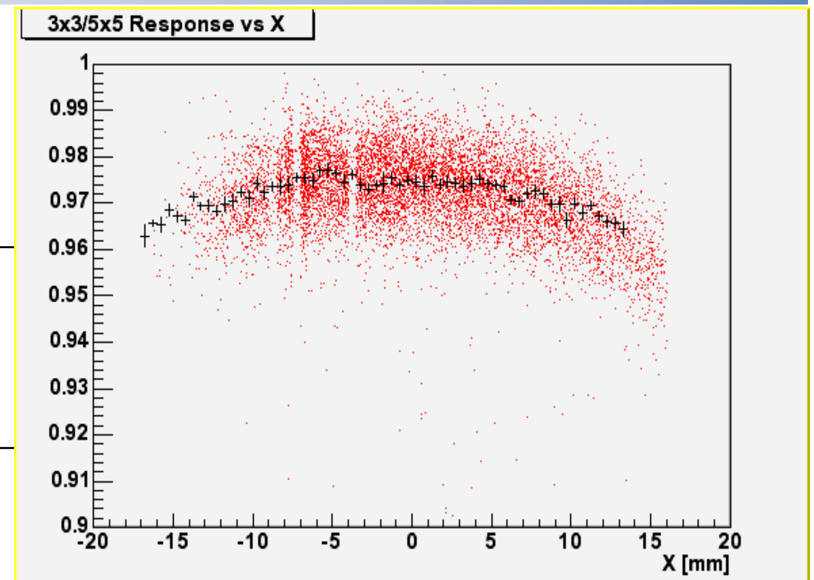
'H4sim cuts' (~ 1 MeV e, γ)



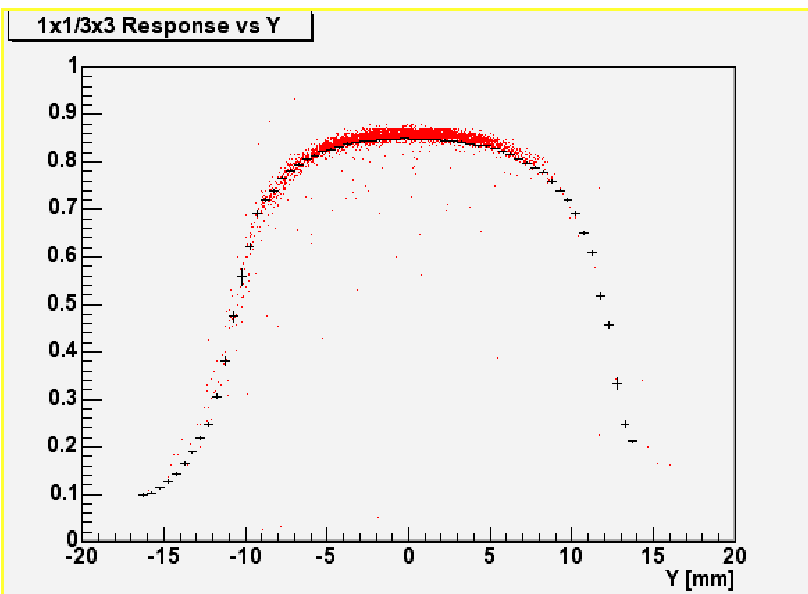
$\rightarrow$ *Geant 4 shower narrower than data (better agreement with H4sim-like cuts)*

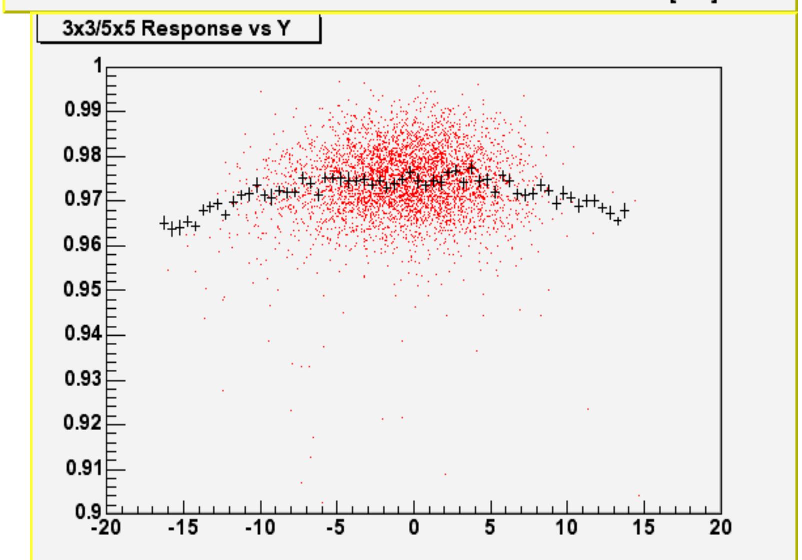
E1/E9 - E9/E25 @ 120 GeV 2/2





- Data
- MC



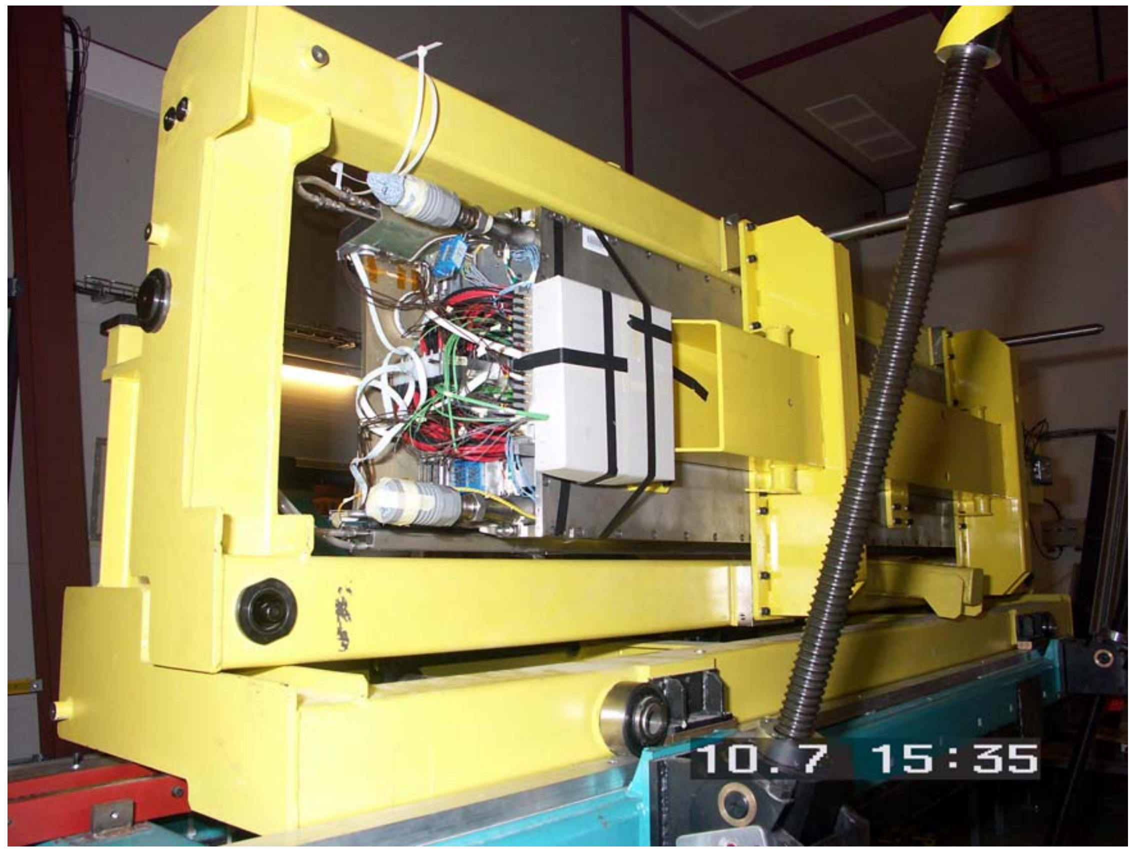


Prospects

- A first complete ECAL Supermodule (1700 channels = 1/18th of 1/2 Barrel) **is in the beam and will be fully tested and calibrated at H4**

•**Thu 7 Oct, 17.00**
• **SM10 transported to H4 and mounted on turntable.**

• **Well done to all concerned!**
Services/readout being installed and connected



Prospects

- ***Main emphasis on:***
- Final validation of control and monitoring systems
- Stability of inter- and absolute calibration
- Detector performances (noise, E resolution, linearity)

First test beam data with final VFE (MGPA …) / FE (Fenix, TPG …) / DCC … and final readout system

- Inter-calibration systematics versus η and ϕ

Comparison with LAB Measurements and MC model

- Full TPG validation
- Extensive MC tuning and comparisons

Transport of knowledge to CMS in situe

Schedule:

- SM is at H4 for 6 weeks

Conclusions

- Major control systems (security, T° stability) adequate

note: **stability in time $\Delta T \sim \pm 0.05\ ^0C$**

uniformity within ‘ SM ’ $\Delta T \sim \pm 0.2\ ^0C$

• Light transmission losses from irradiation (annealing/recovery phases) properly monitored/corrected with Laser monitoring system

• Inter-calibration (maximal containment point) stable against pulse shape reconstruction method, E calibration point, noise …

note: The crystal inter-calibration for CMS in situe will come from

- *LAB. predictions at ~ 4% level for startup*
- *Event properties (ϕ-symmetry/η rings; π^0, $\eta^0 \rightarrow \gamma\gamma$, …) at few %*
- *Physics events ($W \rightarrow e\nu$, $Z \rightarrow e^+e^-$) to reach 0.5% and determiine*
- *an absolute E scale for e and γ*

- Energy resolution is reaching design goal *(proven for fixed impact)*
- Impact point (position) resolution as required for all physics purposes
- Full simulation tools available
- TPG validated for the 1st time in 2003, more this Year.