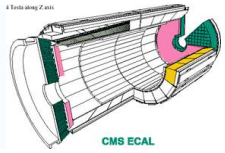


Studies of the CMS Electromagnetic Calorimeter performance in the electron test beam

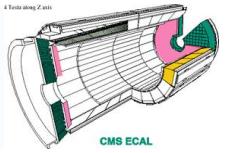
Roberta Arcidiacono

Universita' degli Studi di Torino & INFN

on behalf of the CMS-ECAL Group

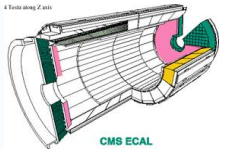
CALOR 2008 - Pavia - 26,30 May

Outline



- **CMS ECAL in short**
- **Test Beam data taking & setup (Barrel)**
- **Test Beam 2006 goals**
- **Performance studies:** noise, position and energy resolution, detector response linearity, inter-calibration
- **Conclusions**

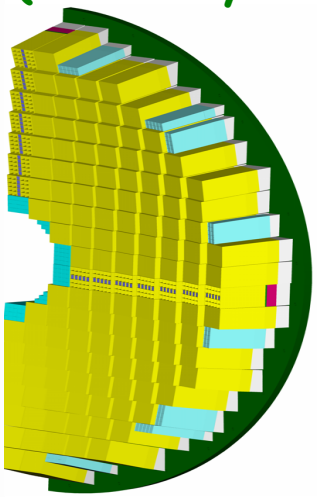
ECAL Layout



Pb/Si Preshower

Barrel crystals

Endcap 'Dee'
(3662 crystals)



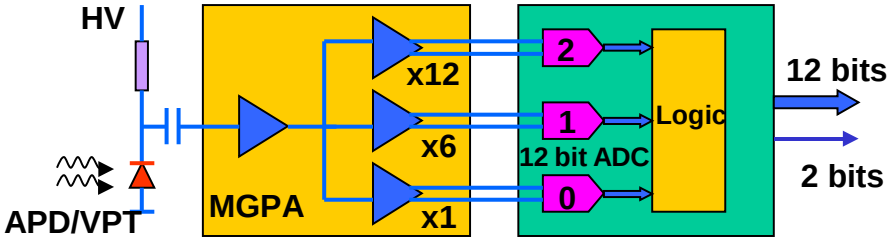
Barrel
'Super Module'
(1700 crystals)

Lead tungstate crystals $PbWO_4$
Avalanche photodiodes (Barrel)
Vacuum phototriodes (Endcaps)

Barrel: $|\eta| < 1.48$
36 Super Modules
61200 crystals (2 x 2 x 23 cm^3)

Endcaps: $1.48 < |\eta| < 3.0$
4 Dees
14648 crystals (3 x 3 x 22 cm^3)

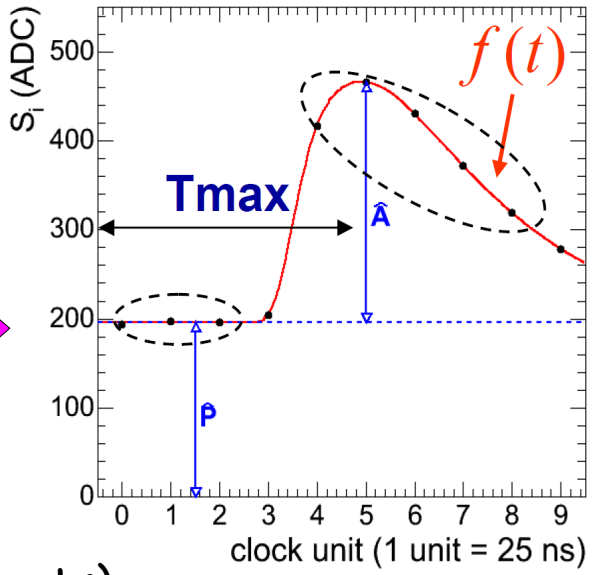
Pulse Shape Reconstruction



VFE architecture for single channel

in VFE: 3-gain amplification
shaping, digitization & sampling every 25 ns

1 ADC= 37 MeV



from samples → reconstruct the signal amplitude using digital filtering technique

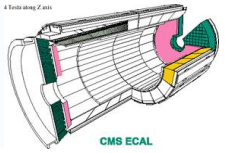
$$\hat{A} = \sum_{i=0}^{i=N} w_i \times S_i$$

Si : time sample #i (ADC counts)

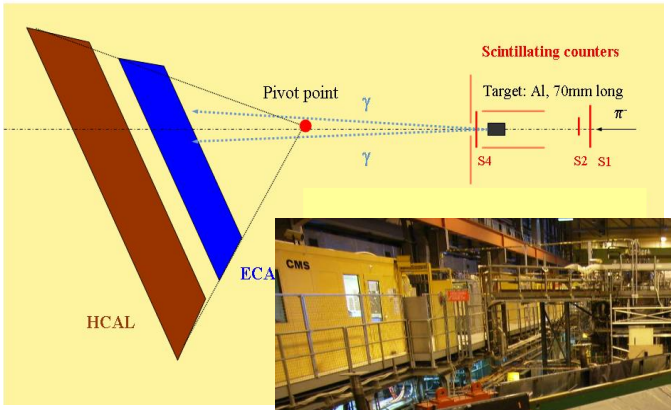
wi : weight #i (from f(t))

3+5 weights: measure A, using the pre-samples in the reconstruction
-> this method subtracts the pedestal P on event-to-event

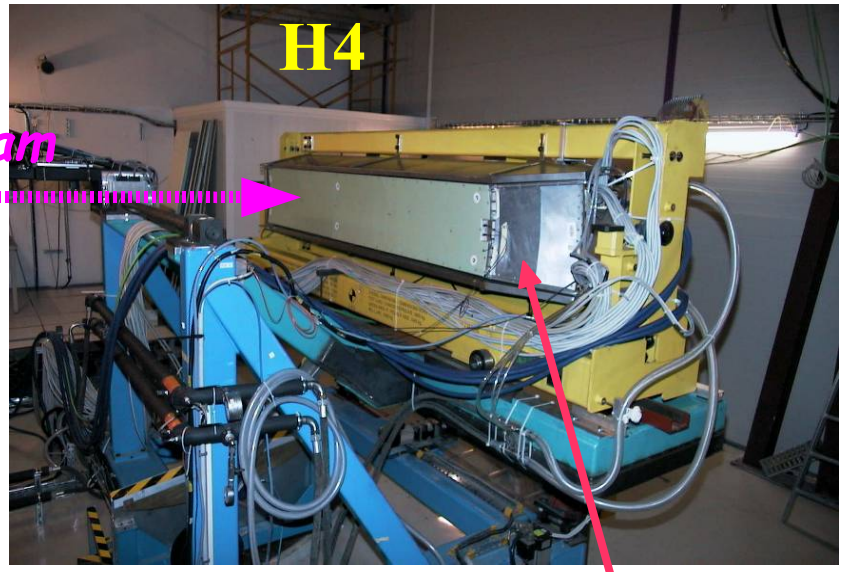
Test Beam Data Taking



- **2004** Test-beam: 1 Super Module with e-, detailed system test @CERN
- **2006** Test-beam(s)
  - 9 SM calibrated/studied in H4 with electron beam
  - Combined test with HCAL in H2 (1 SM) with pion/electron beam
  - Cosmic test bed for inter-calibration (all 36 SMs)

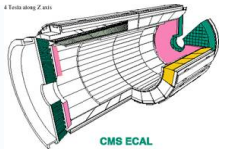


e- beam



Super Module

Test Beam Scope in 2006



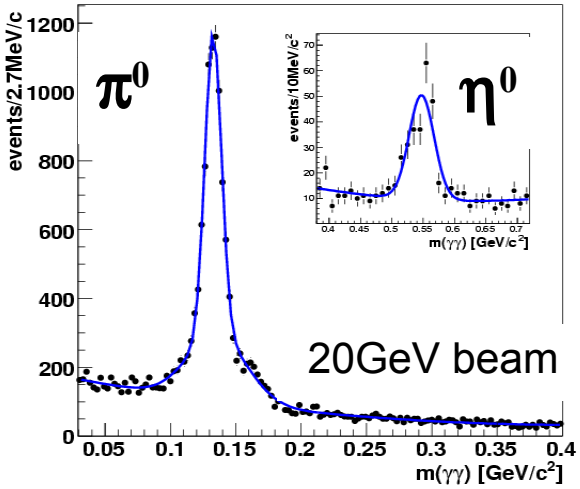
H4 beam line:
electrons 15-250 GeV

Inter-calibration (9 SM)
Shower containment
Noise
Position Resolution
Irradiation (6 xtals)
Response Linearity
Energy Resolution
Gain Ratio
Synchronous Running
Xtals Laser Monitoring

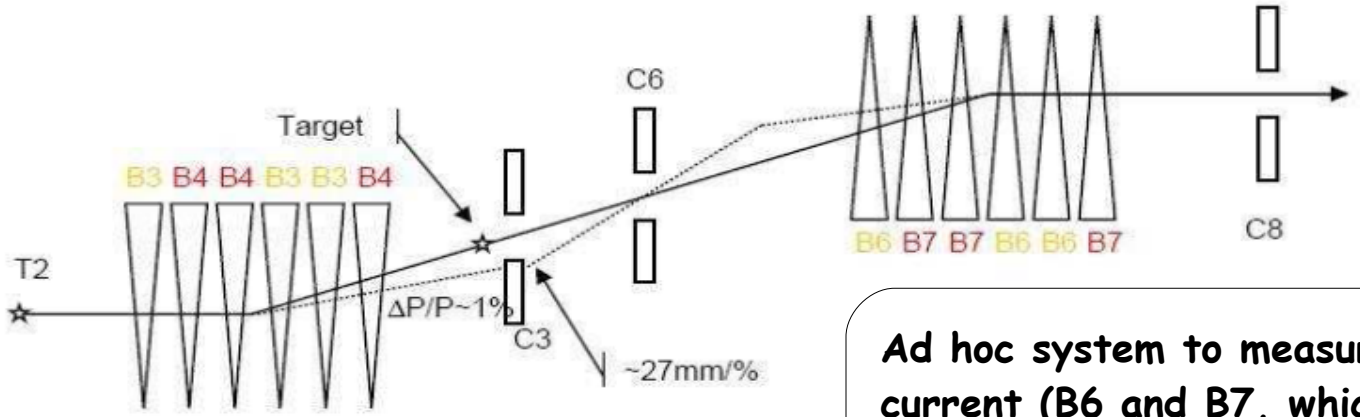
70 days of data taking
~ 2 billions electrons collected

H2 beam line:
e+- 1-100 GeV, Pions

Combined Calorimeters Test
ECAL performance @ low energies
Collect π^0 data sample

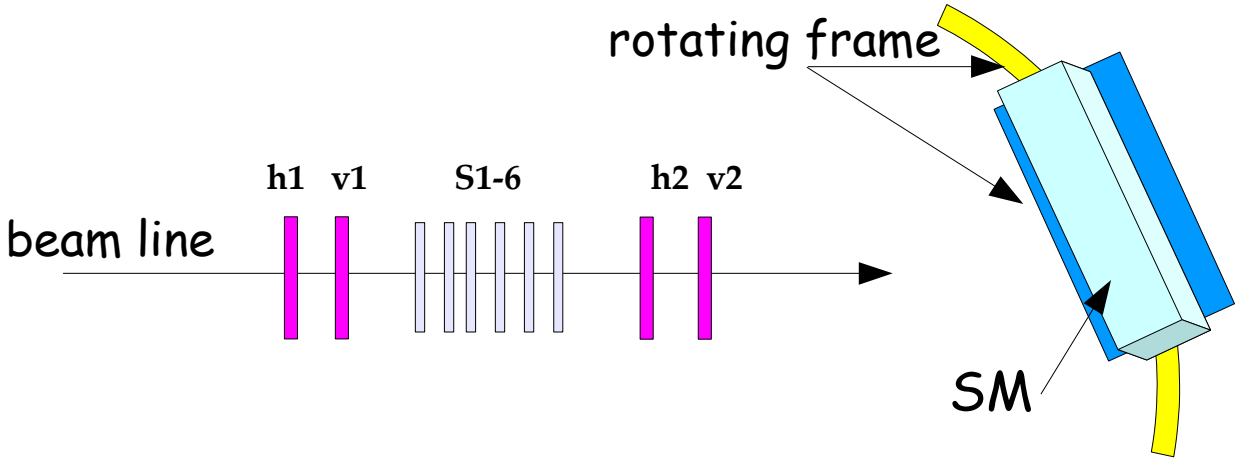


H4 Setup

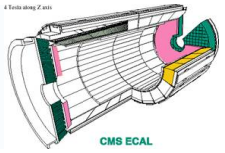


Ad hoc system to measure bending magnets current (B6 and B7, which select the beam momentum) with < 10-3 precision.
Precision achieved on Beam Energy ~2 ‰

- 4 planes of scintillating fibers Hodoscopes (1mm Ø fibers). Position resolution = 150 μm .
- ~ CMS pointing geometry reproduced.



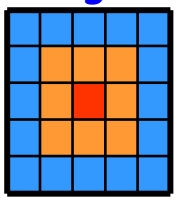
Noise



Studied applying amplitude reconstruction to Pedestal events (random triggers)

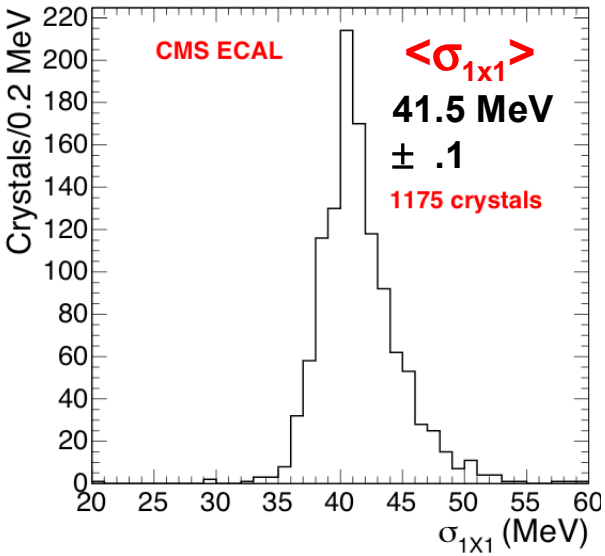
- Low frequency (pick-up) noise taken away by pre-sample measurements.
- Small high frequency noise observed with negligible effect on amplitude reconstruction
- NB: test of 2 SM in 3.8T solenoid magnetic field (MTCC) demonstrated the same performance

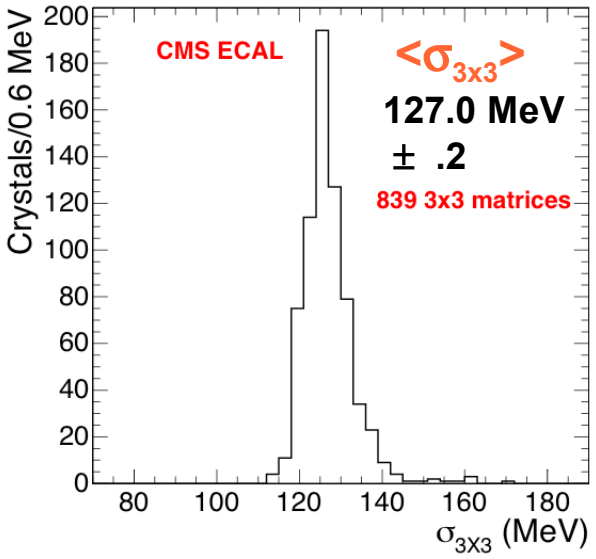
clustering matrix

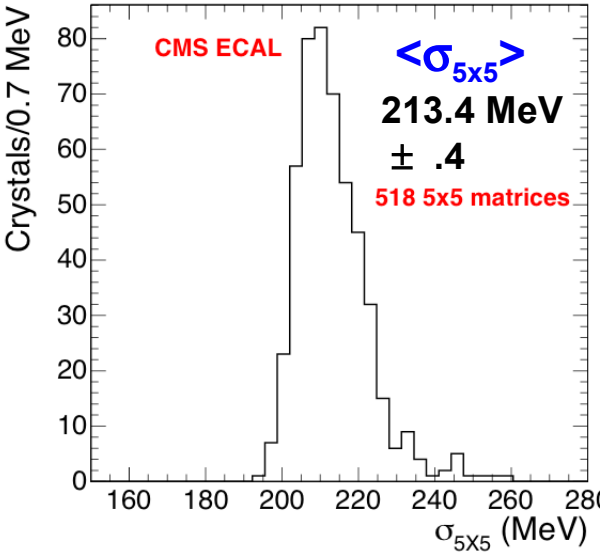


no coherent noise

Histogramming the fitted noise σ for many channels:







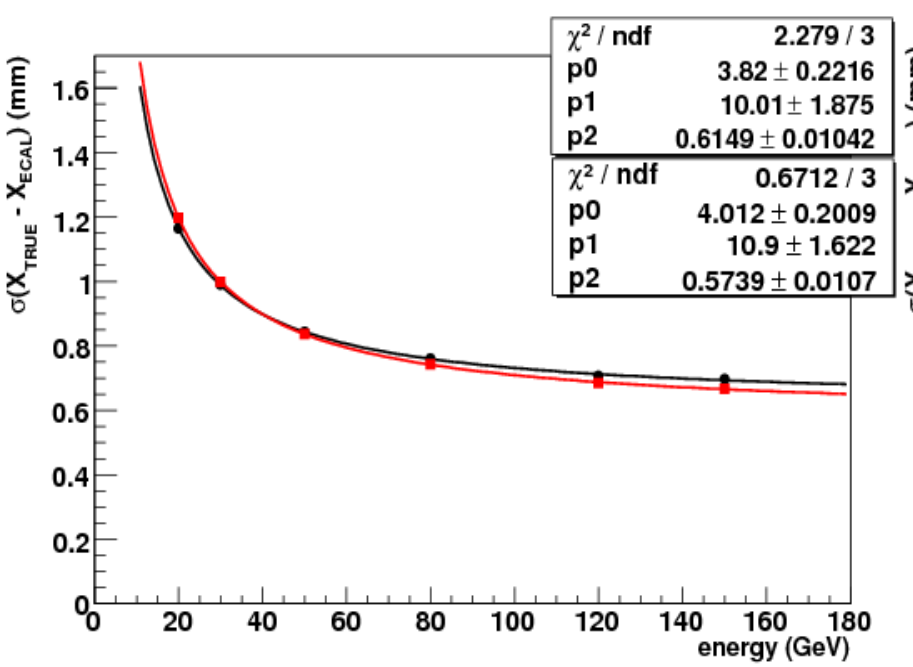
Position Resolution

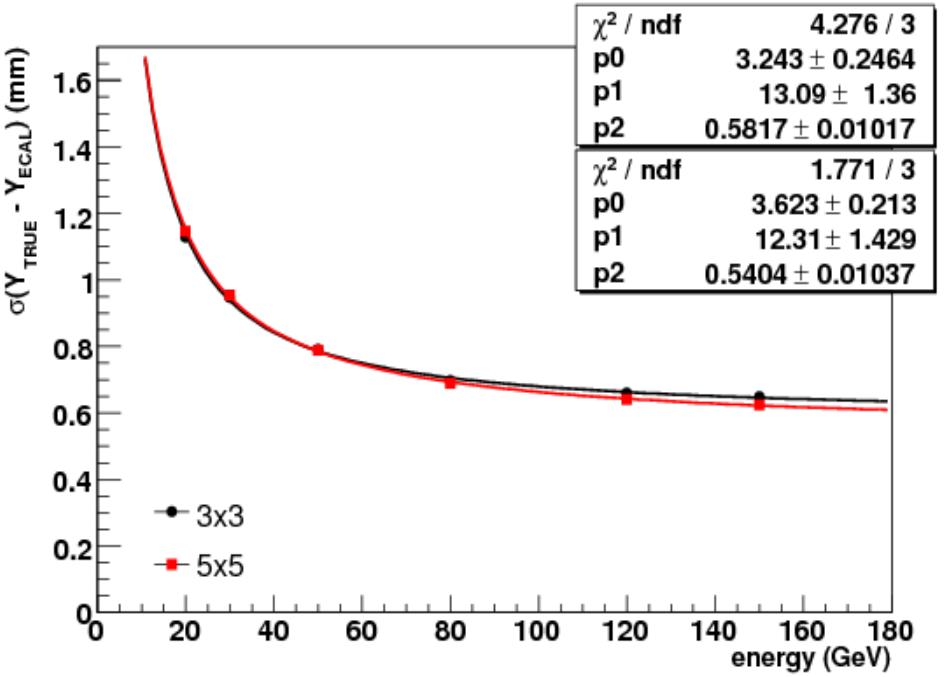
$X_{ECAL} = \sum w_i x_i / \sum w_i$ sum on 3x3 or 5x5 matrix

$w_i = w_o + \log(E_i/E_{TOT})$ $w_o = 5$

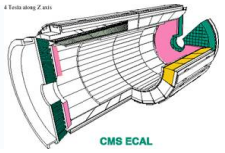
X_{TRUE} measured with hodoscopes

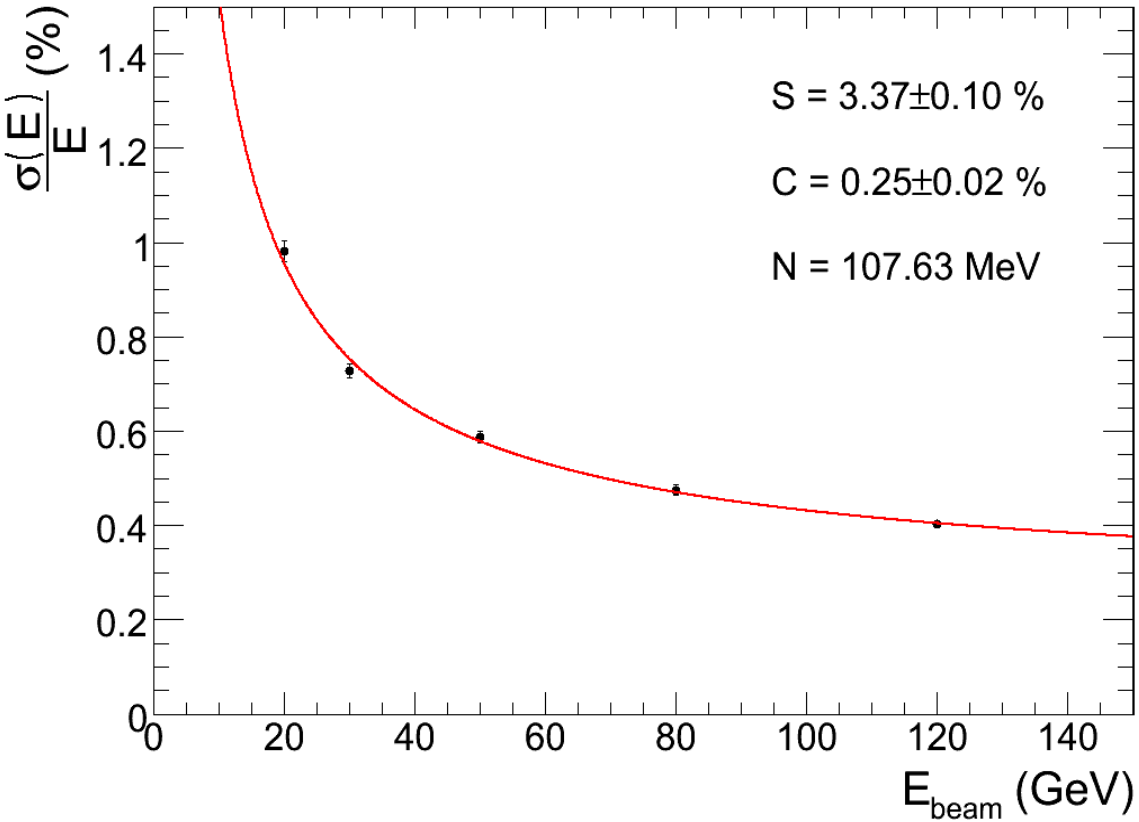
- 25 xtals studied
- reproducibility of results demonstrated on different SM





Energy Resolution





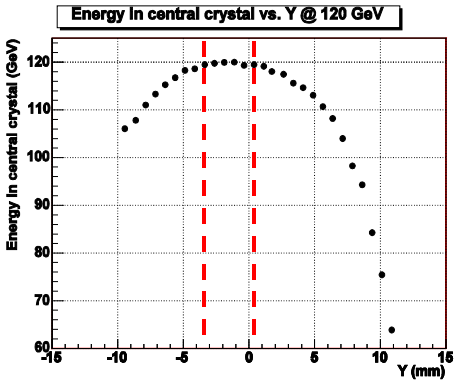
Energy summed in a 3x3 matrix for 25 Xtals of SM16

- Optimized weight
- Impact point restricted to 4 x 4 mm^2
- 30000 events in each crystal
- Inter-calibration (measured using beam data @ 120 GeV) accuracy convoluted into resolution

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{3.37\%}{\sqrt{E}}\right)^2 + \left(\frac{0.107}{E}\right)^2 + (0.25\%)^2$$

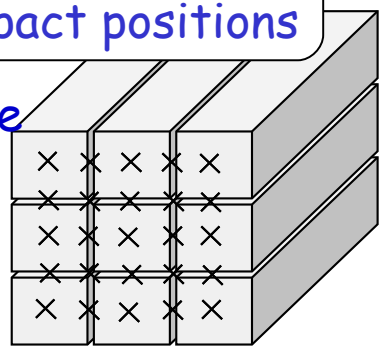
Stochastic Noise Constant

E in GeV



Shower Containment

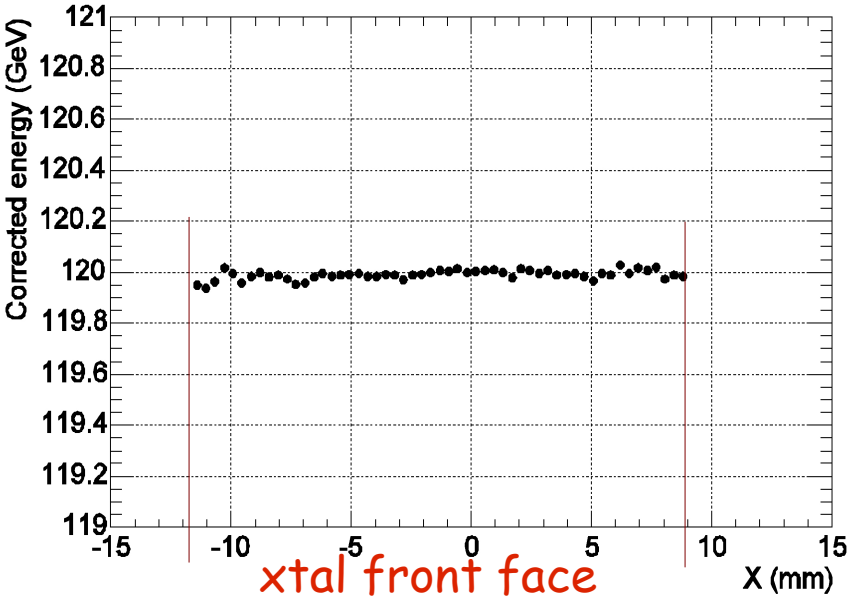
Series of runs at 120 GeV centred on many points within matrix 3x3
Results averaged to simulate the effect of random impact positions

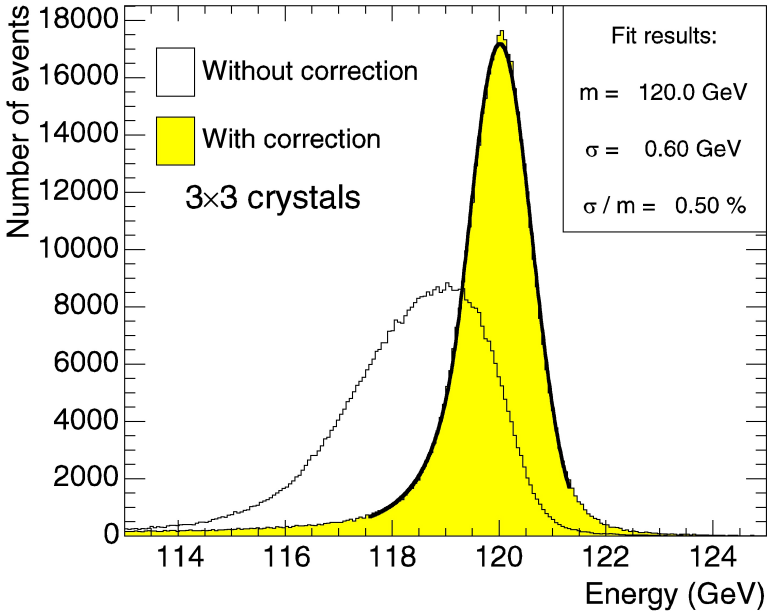


Impact point correction is based on energy deposits in the crystals matrix (should be usable for photons!)

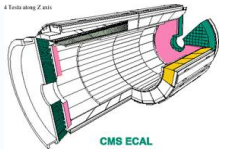
Correct by a function of log ratios of energies in Σ 3x3

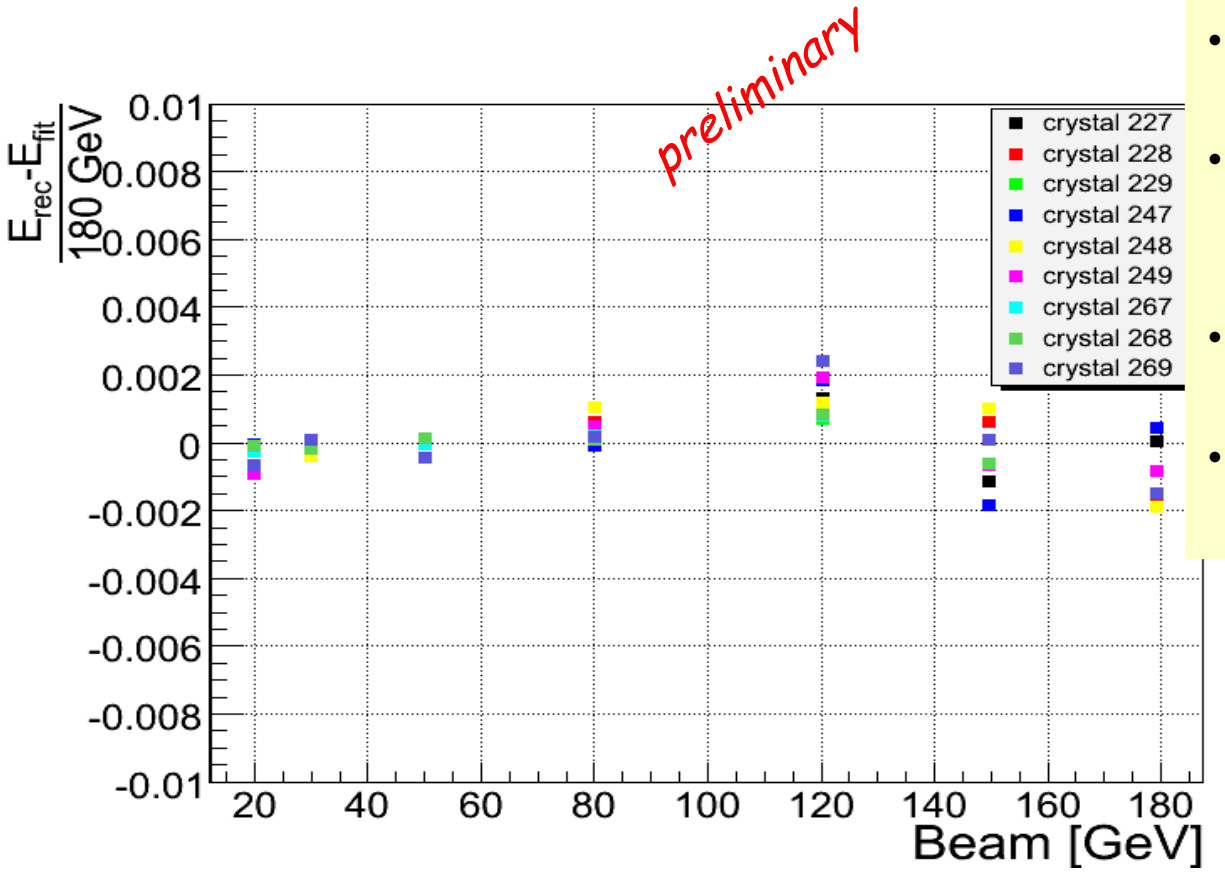
- universal in η (and ϕ)
- energy independent





Energy Linearity @H4



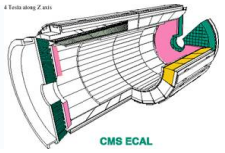


- 9 xtals response (5x5 matrix) studied in [20-180] GeV
- only central events (cut ±1 mm around max cont. point)
- include beam & inter-calibration uncertainty
- VFE electronics linearity measured to be ~ 0.1 %

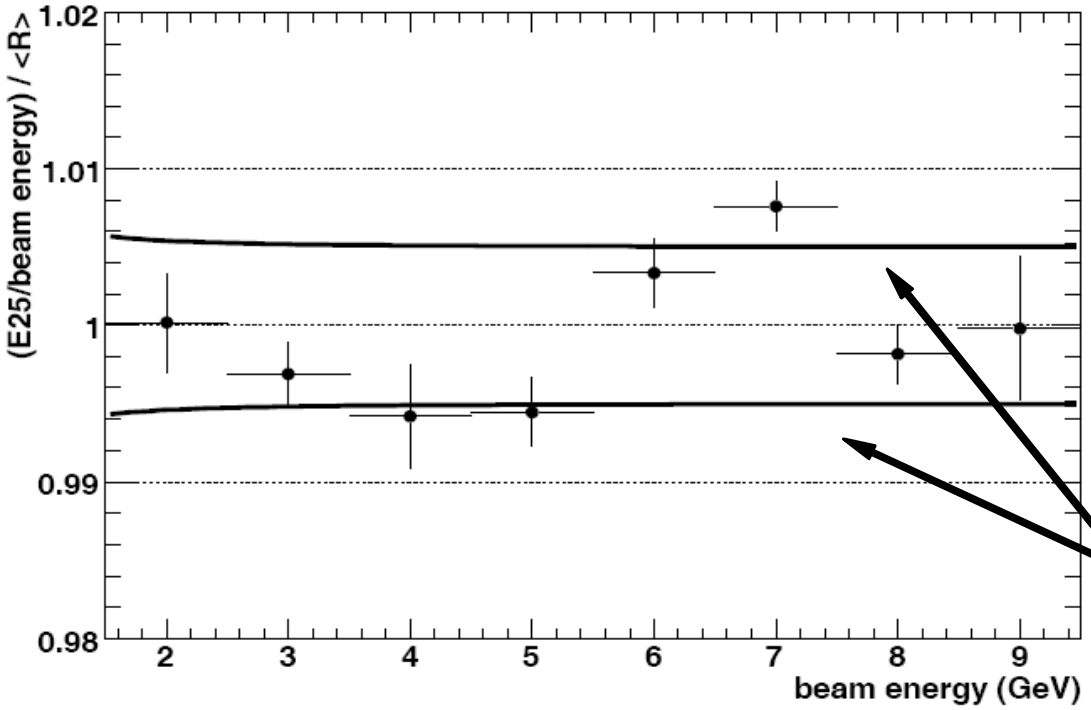
- no systematics studied
- gain switch occurs @ 150 GeV

Differential Linearity in [20-180] GeV **< 0.2 %**

Energy Linearity @H2



Linearity investigated with e- 2-9 GeV
e+ 9-100 GeV



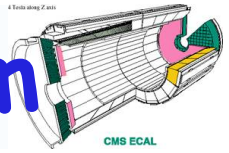
16 Xtals selected along SM
energy summed in 5x5 matrix

E25 = Crystal Ball fit peak
R = weighted average of
Rj (E25/Ebeam @ energy j)

beam energy uncertainty

Linearity in [2-9] GeV < **0.5 %**

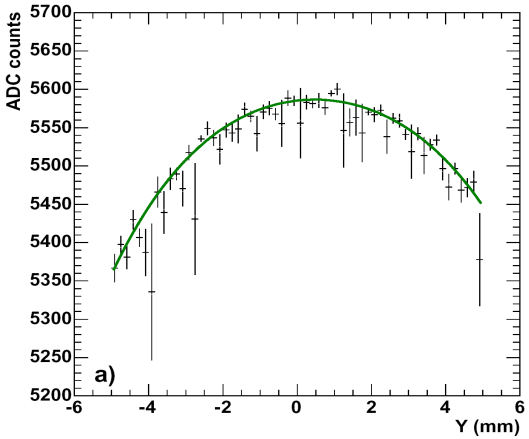
Inter-calibration @ Test Beam



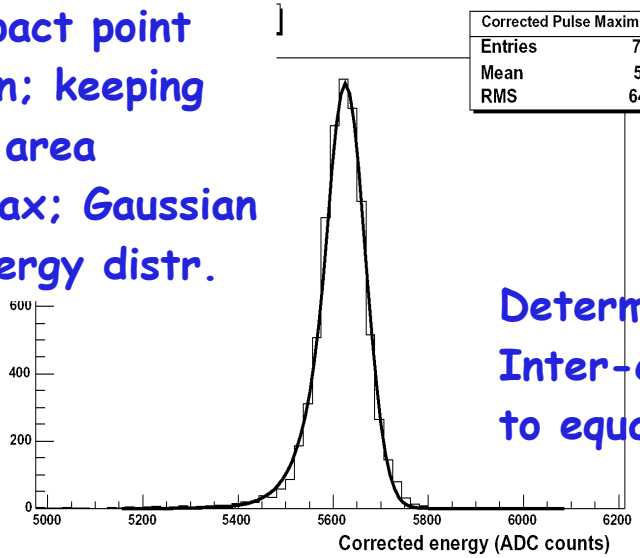
e- beam @ 90 / 120 GeV on 9 SM

$$E_{e,\gamma} = G \times \mathcal{F} \times \sum_i c_i \times A_i$$

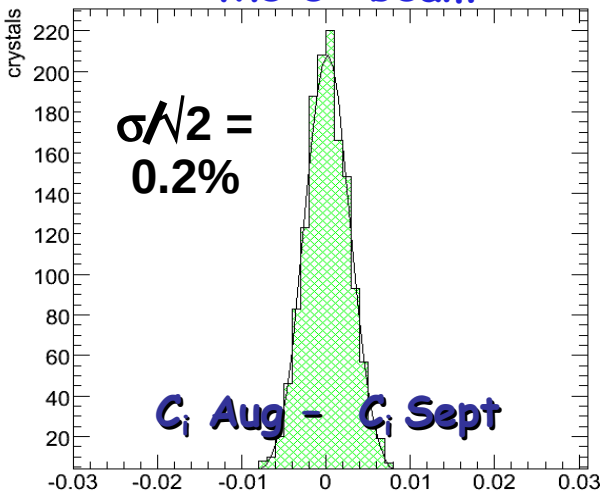
Fit X-Y coordinate of E deposition in single crystal to find maximal containment point



Apply impact point correction; keeping 6x6 mm^2 area around max; Gaussian fit of Energy distr.



SM22 was exposed twice to the e- beam

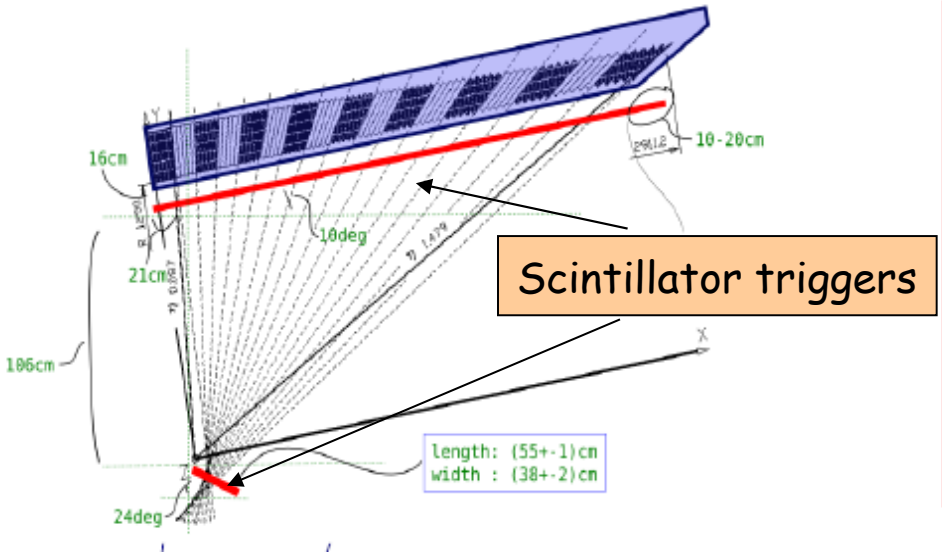


Determine relative Inter-calibration to equalize response

$$c_i = \frac{M_{ref}}{M_i}$$

precision achieved ~ 0.3 %

Inter-calibration with Cosmics



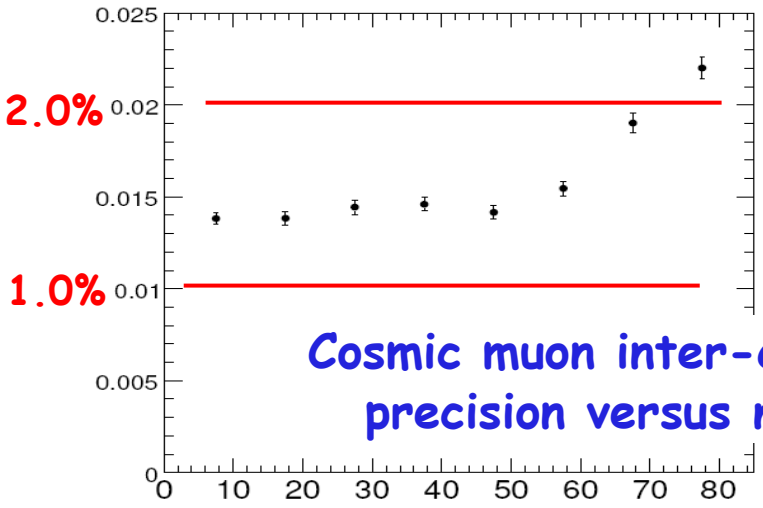
Scintillator triggers

1 week of cosmics data taking for each SM

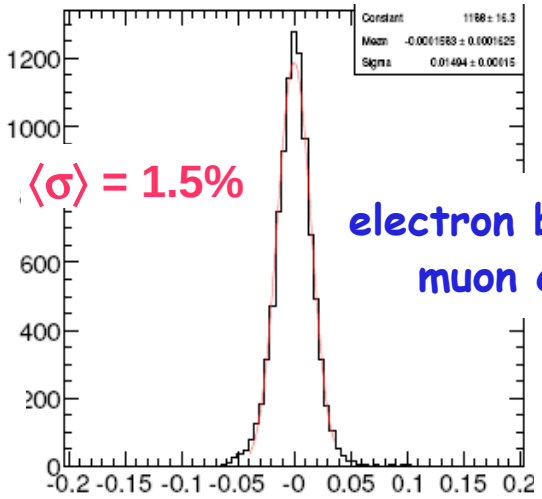
- SM inclined of 10 degree
- APD gain increased to 200 (x4)

S/N for aligned muons ~ 25

- 5 million triggers x SM
- 500 <selected events x crystals>



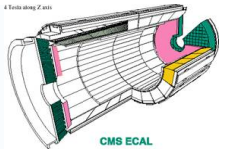
Cosmic muon inter-calibration precision versus η 'index'



electron beam – cosmic muon comparison

precision achieved ~ 1.5 %

Conclusions



- Electron Test Beam studies demonstrate that CMS ECAL will meet its ambitious design goals
- Intrinsic ECAL resolution has been measured in large arrays of crystals, at a range of energies

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{3.37\%}{\sqrt{E}}\right)^2 + \left(\frac{0.107}{E}\right)^2 + (0.25\%)^2$$

- Linearity in the range [2-180] better than 0.5%
- ECAL is pre-calibrated, installed, commissioned and ready to be calibrated 'in situ'