CMS ECAL Calibration and Test Beam Results

- Goals for ECAL
- Final calibration with LHC
- Light monitoring system for short term variations
- Initial calibration in lab and with cosmics
- Calibration with test beam
- Noise, time- and energy resolution
- Shower containment correction
- Conclusion

Goals for ECAL:

Main goal: precise energy and position measurement of e, γ

Benchmark for $m_H < 150$ GeV / c^2: $H \Rightarrow \gamma\gamma$ (Γ_H/m_H small and large background)
for higher m_H : $H \Rightarrow ZZ, WW \Rightarrow X$+leptons

Energy resolution for calorimeter:

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

a: Stochastic term: shower fluctuations, photo-statistics, fluctuations of transverse leakage

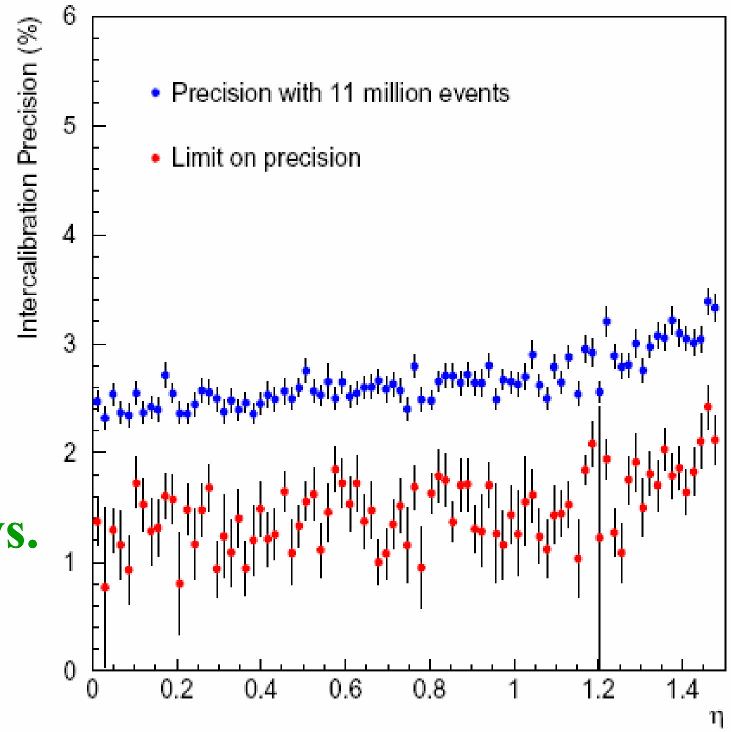
b: Noise term (5x5): electronics noise, dark current, pile-up

c: Constant term: calibration, non-uniformities, fluctuations due to T, HV, longitudinal leakage

Final calibration with LHC:

Φ symmetry calibration with minimum bias events and Jet triggers:

- Intercalibration of rings of Xtals at equal η, with min. bias. events or with Jet triggers and the energy flow from opposite (2^{nd}) jet, to avoid trigger bias.
- Use $Z \rightarrow e^+e^-$ events to intercalibrate rings.
- Precision of better than 2% within a few days.
- Energy in Xtals up to 6 GeV.

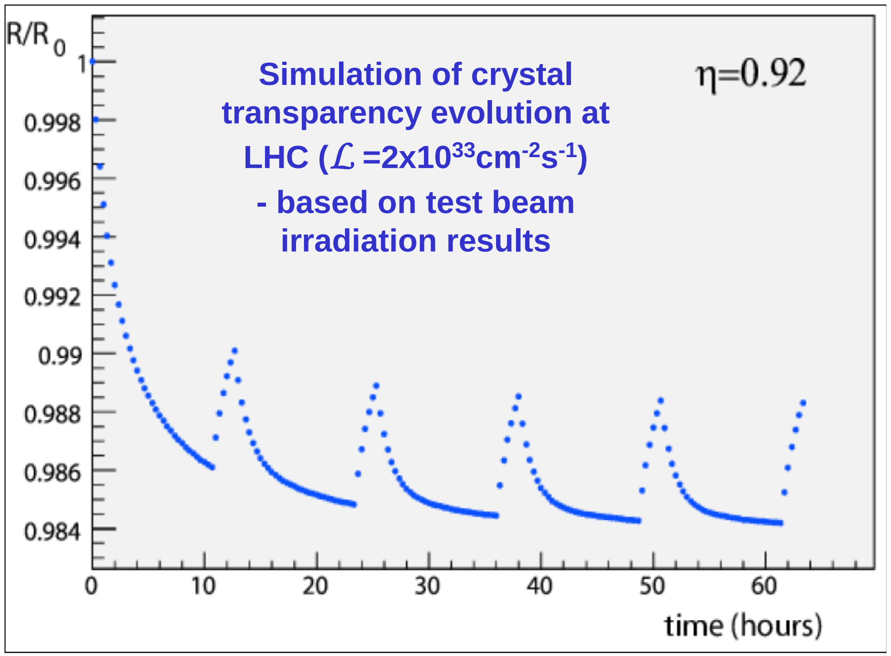


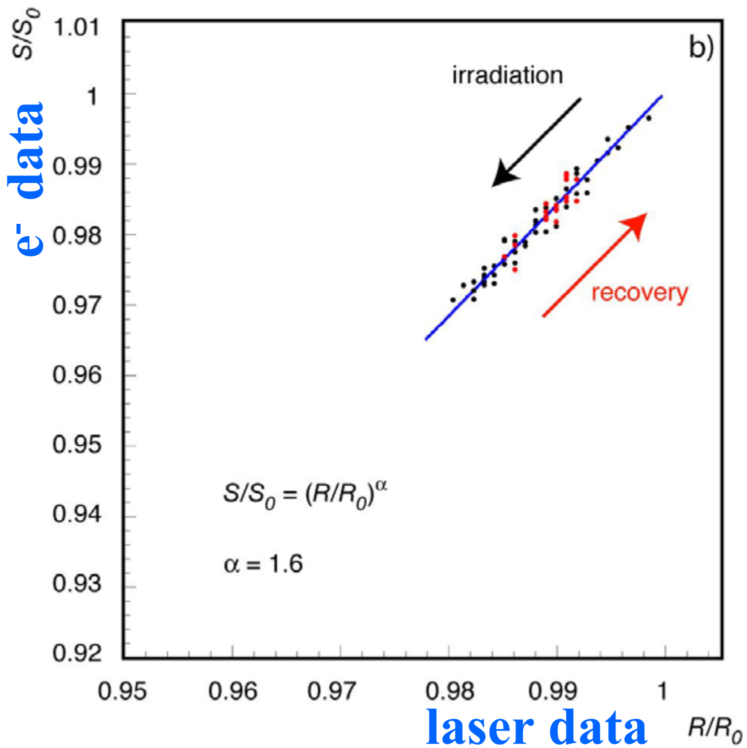
Ultimate calibration with W → e ν using E/p:

- Depends weakly on starting calibration constants.
- Accuracy of 0.5% within 6 months at $L=10^{33}$ (5-7 fb^{-1} needed).
- Need Tracker operational and aligned.

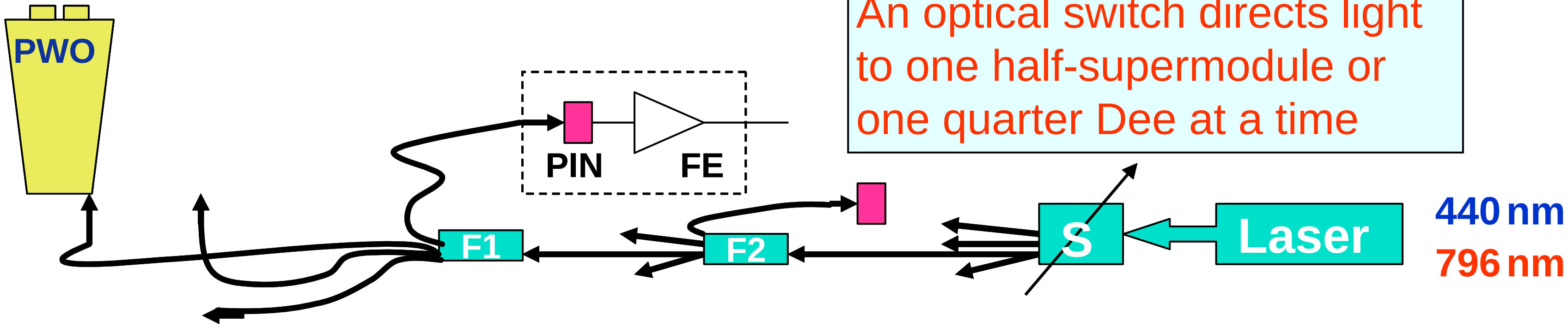
Light monitoring system:

- Short term variations of calibration constants monitored with laser system.
- Light transmission of Xtals changes with radiation.
- Change depends on dose rate and on individual crystal.
- Difference of variation after irradiation between electrons and laser can be described by a universal α for a given producer (tested in beam).

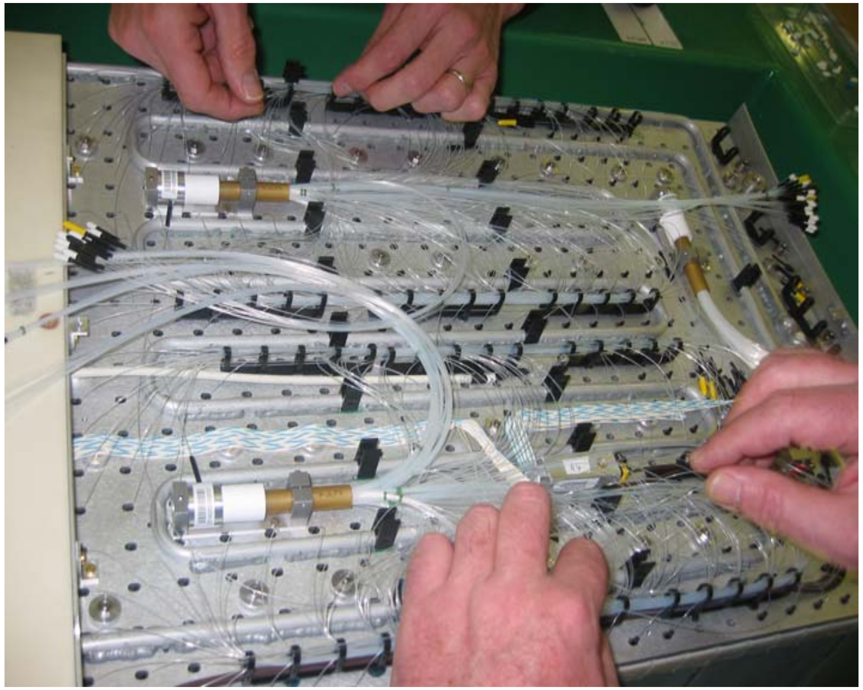




Light monitoring system (2):



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



- Transmission in CMS frequently monitored (every 20min entire ECAL) with laser light (440nm,796nm) injected through fibers into the front (Barrel) or rear (Endcap) of each Xtal.
- Blue laser monitors radiation effect at emission peak.
- Infrared laser monitors light distribution system and read-out chain.
- Stability of system monitored with PN diodes (0.1%).

Initial calibration in Lab and with cosmics:

Intercalibration with light yield measurement in the Lab:

- Light yield measured with radioactive source for each Xtal.
- By comparison to test beam data of same Xtals, 4.6% precision achieved.
- Since light yield and longitudinal transmission at 360nm are correlated, combination of both measurements improves intercalibration (4.1%).

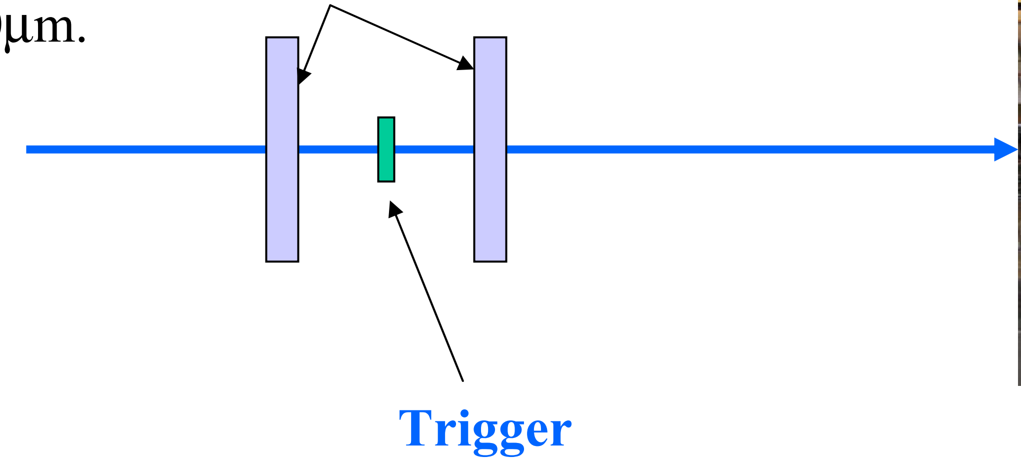
Calibration with cosmic muons :

- Each SM passes cosmic muon stand before final installation in CMS.
- During 1-2 weeks up to 600k useful events.
- Cosmic muons aligned to Xtal axis deposit 250 MeV in Xtal.
- APD gain increased from 50 to 200.
- Signal to noise ratio: 30.
- Precision on inter-calibration ~2% (depending on η).
- ~22 SM already calibrated.

Calibration with test beam:

only for a few SMs possible:

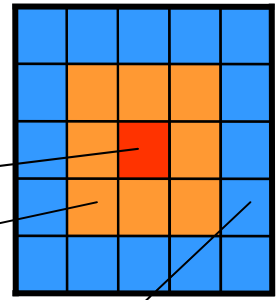
Hodoscope: Scintillating fibers.
For beam position in the transverse plan.
$\sigma(x/y)=150\mu m$.

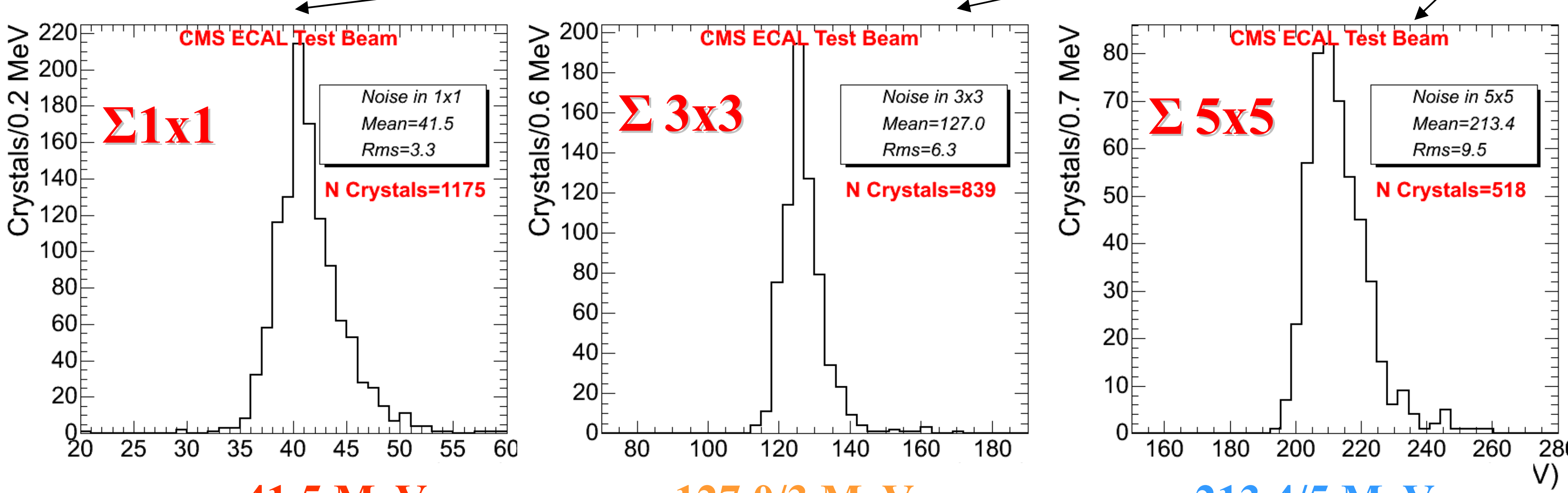


- **Goal is to have a < 2% accuracy for initial inter-calibration in CMS.**
- **Electrons of 120 GeV.**
- **Goal is to calibrate ≥ 10 SMs (1 twice).**

Noise:

With random events applying amplitude reconstruction:





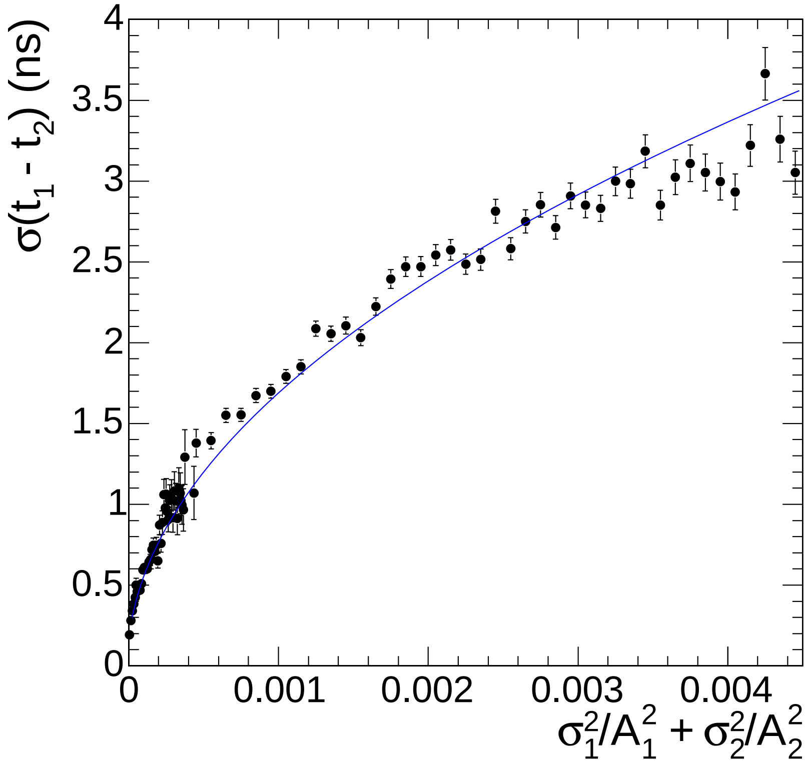
41.5 MeV ≈ 127.0/3 MeV ≈ 213.4/5 MeV

- Noise of ~ 40 MeV/Xtal.
- No coherent noise, if pedestal is subtracted event by event.

Time resolution:

Time difference between 2 Xtals hit by same shower

Resolution on time difference

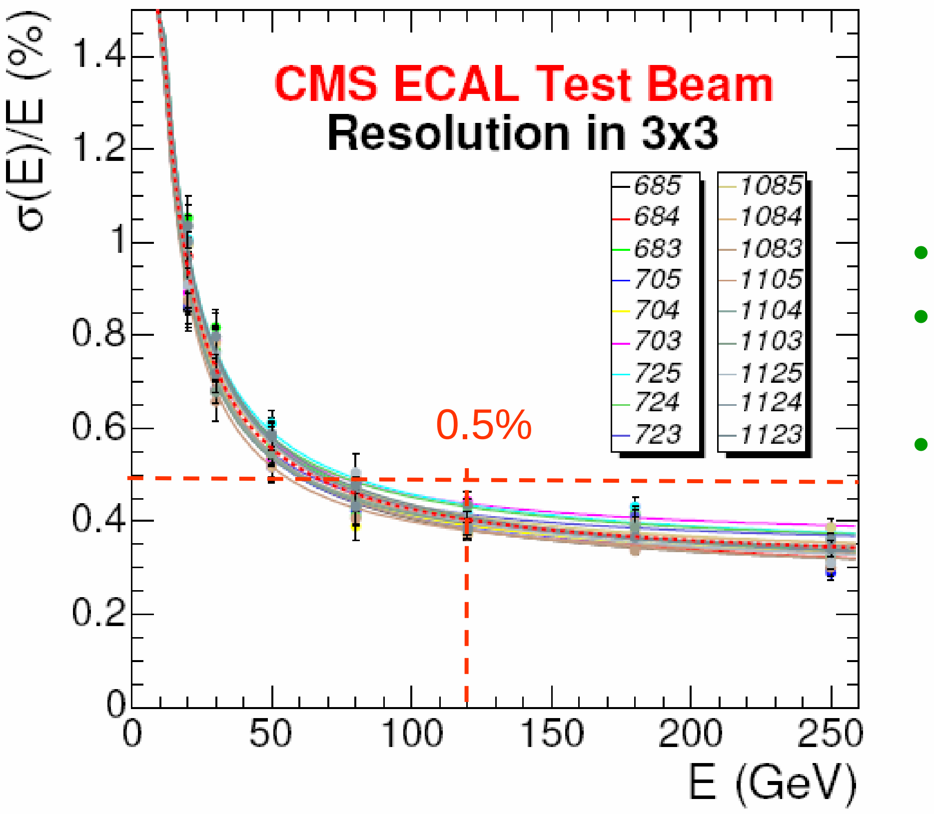


$(\text{Noise/Signal})^2$

- **Signal timing must be stable in CMS.**
- **If E > 2 GeV, σ(δt) < 1 ns.**
- **If E > 40 GeV, σ(δt) ≈ 0.11 ns.**

Energy resolution:

Central impact (4×4 mm2)



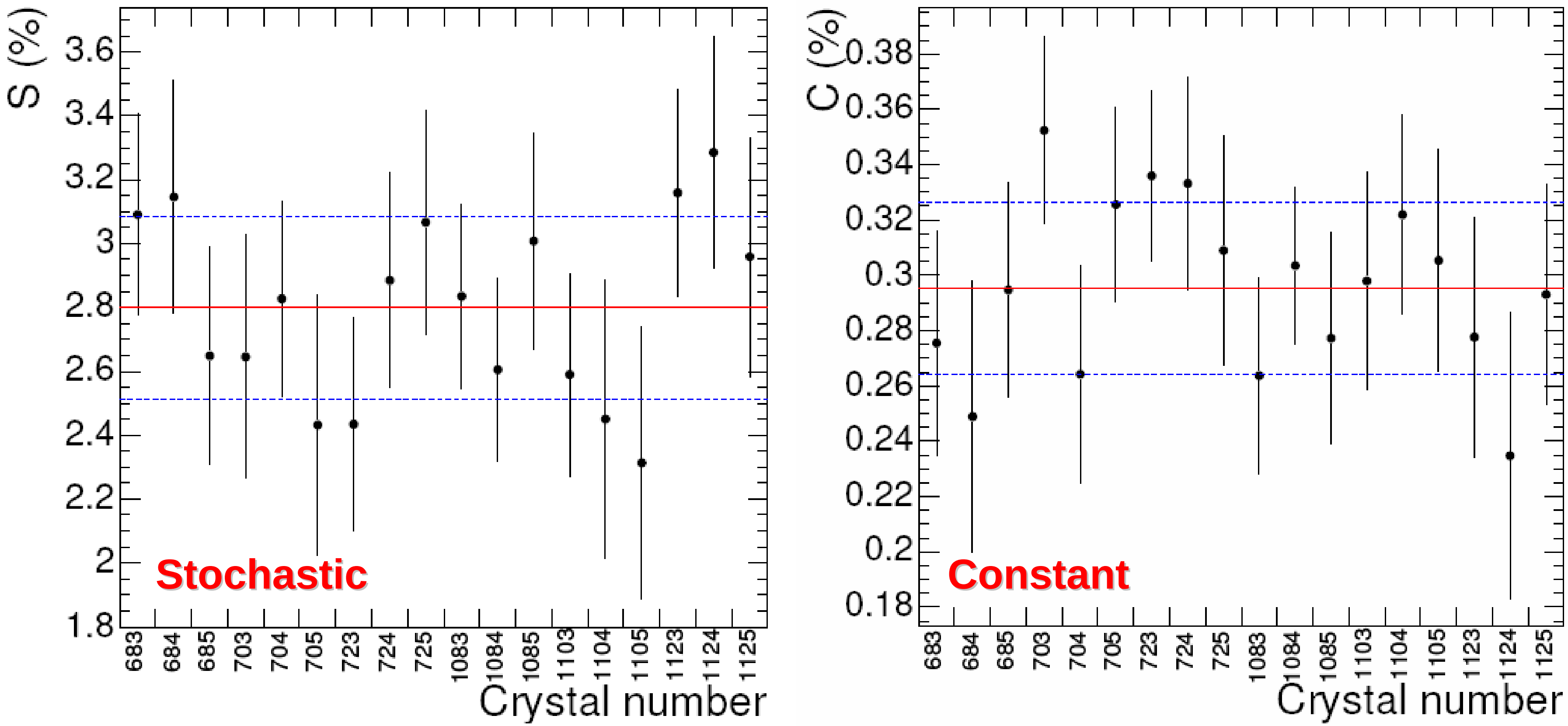
- Subtraction of pedestal event by event.
- Reconstruction of signal amplitude with digital filtering (at low energy).
- Result as expected by MC studies + photostatistics + longitudinal non-uniformity.

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.8\%}{\sqrt{E}}\right)^2 + \left(\frac{125(\text{MeV})}{E}\right)^2 + (0.30\%)^2$$

Stochastic **Noise** **Constant**

Energy resolution (2):

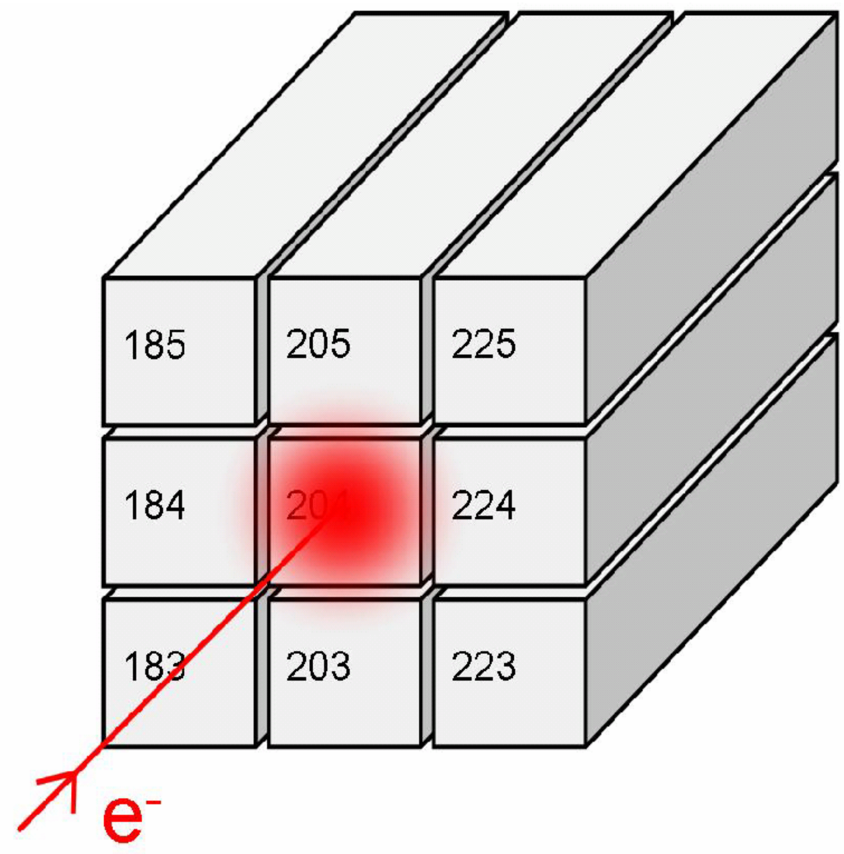
Central impact (4×4 mm2) :

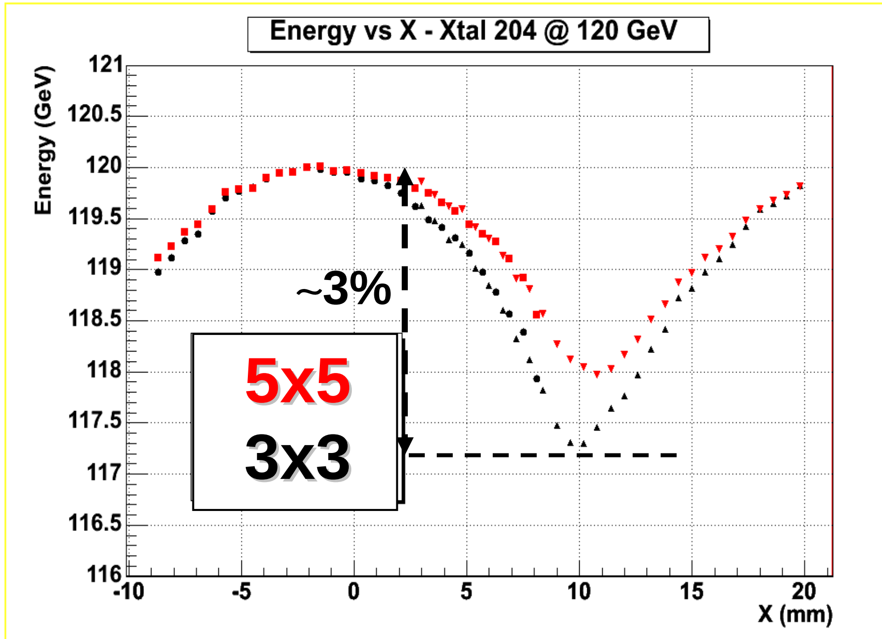


Shower containment correction:

- Energy in a 3x3 cluster varies of ~3% with position of cluster in central Xtal.
- Containment effect decreases with matrix size.
- Correction developed using the energy distribution deposit in this 3X3 array.

"Uniform" impact

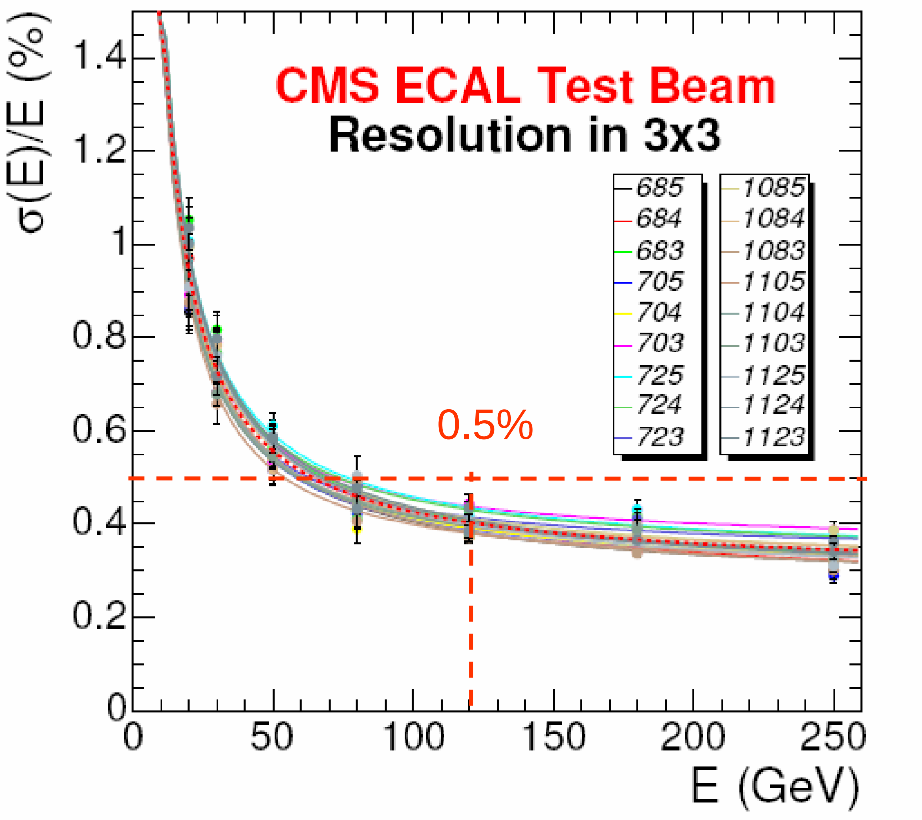




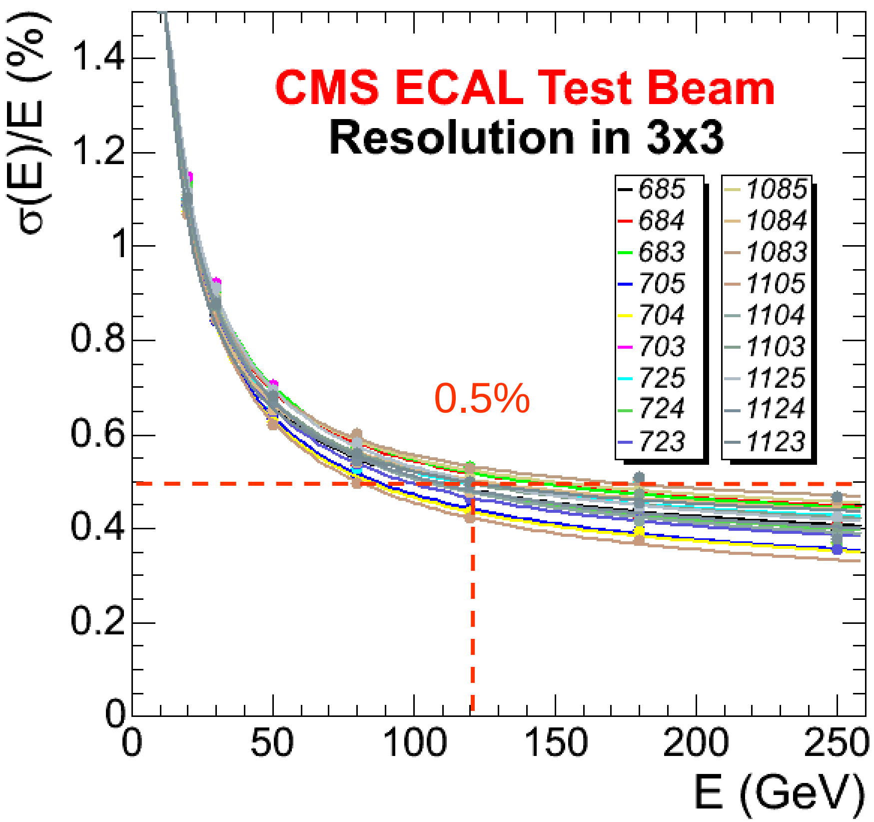
Hodoscope

Energy resolution (3):

Central impact



"Uniform" impact

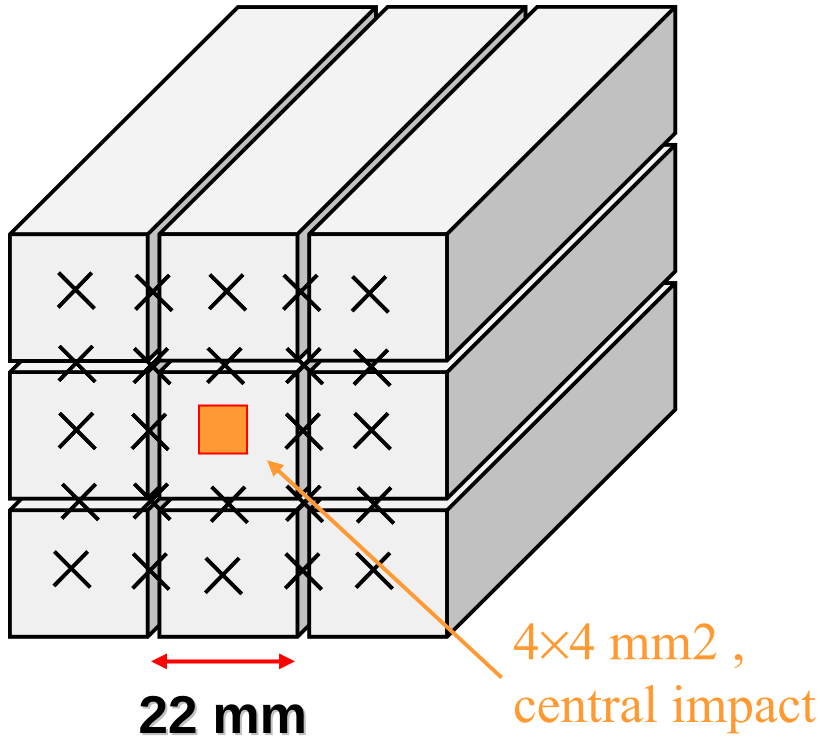


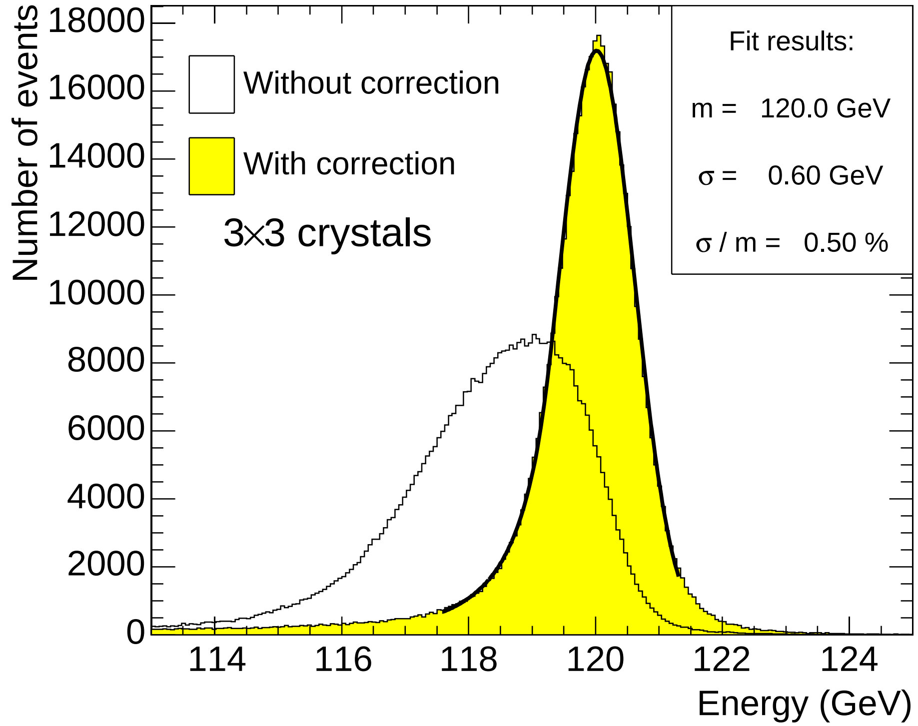
- Energy resolution ≤ 0.5% at 120 GeV for any electron impact.
- Same shower containment correction applied (for all E and all Xtals).

Energy resolution (4):

- Beam position centered at many locations of a 3x3 matrix .
- Uniform impact, best simulation of situation in CMS.
- Resolution of 0.5% achieved at 120 GeV.
- Same shower containment correction applied (for all E and all Xtals).

Uniform impact





Conclusions:

- Electromagnetic calorimetry with high resolution is central design feature of CMS.
- Final calibration in LHC with data and laser system.
- Light monitoring system is working as expected.
- Inter-calibration constants predetermined in lab, with cosmics and with test beam.
- Test beam results for noise, time and energy resolution confirm the ambitious design goals of ECAL.

References:

- E resolution: CMS Note 2006/140
- Cluster containment: CMS Note 2006/045