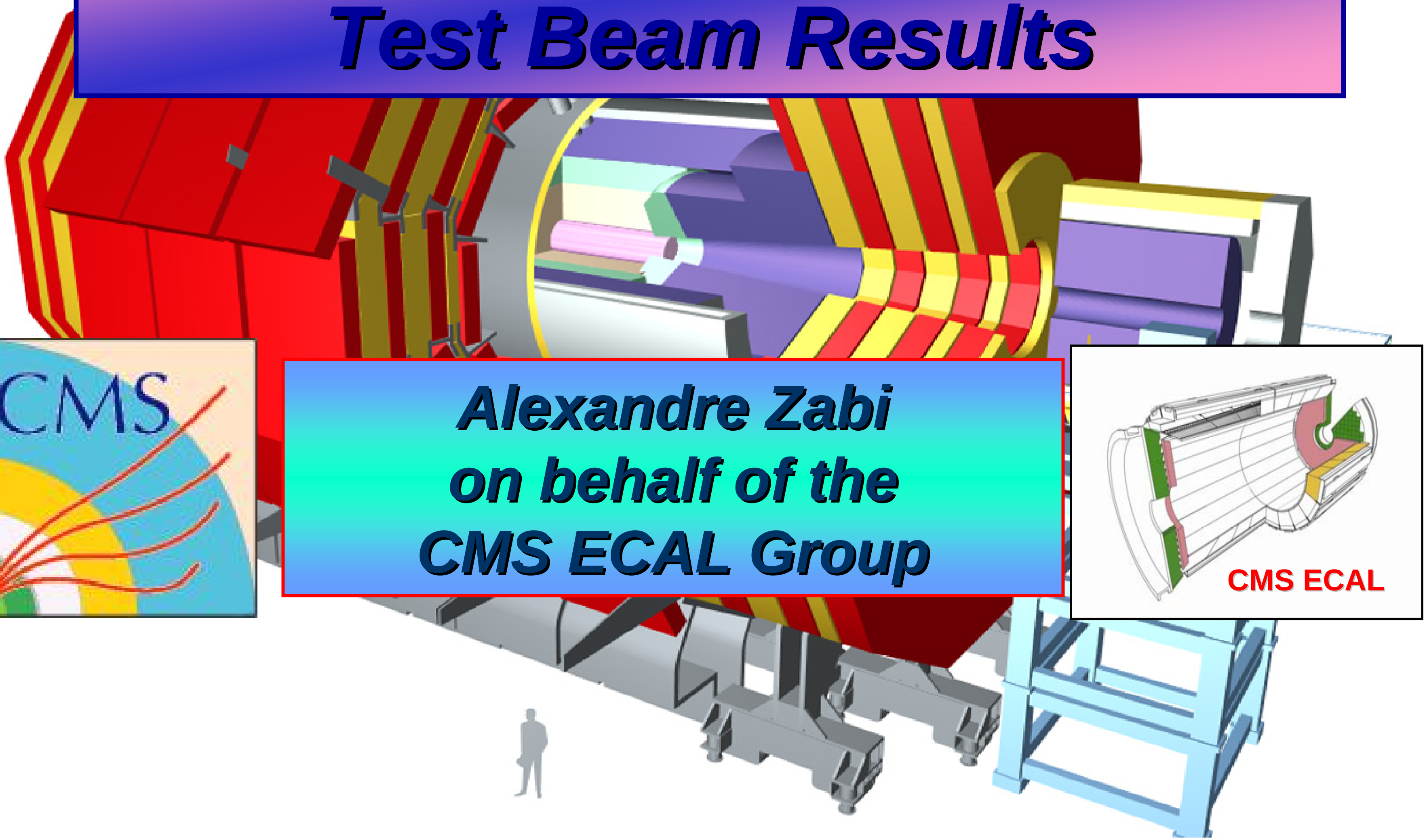
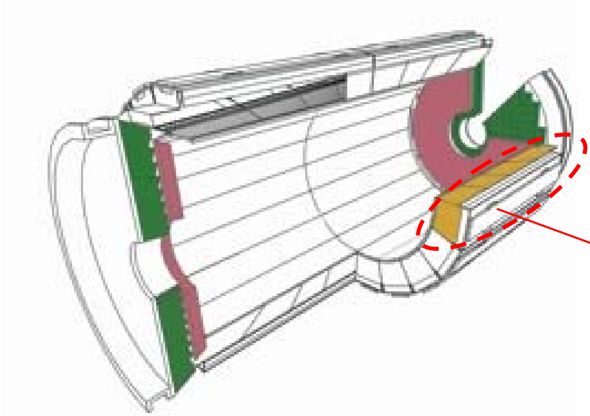
CMS ECAL Performance: Test Beam Results



Alexandre Zabi
on behalf of the
CMS ECAL Group

OVERVIEW



October-November 2004: TEST BEAM

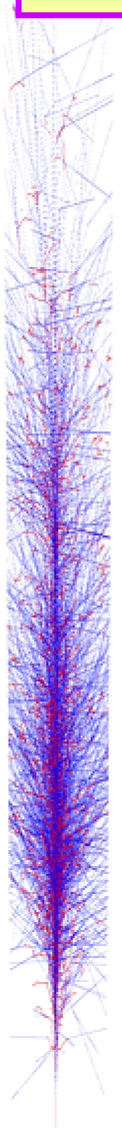
→ 1^{st} supermodule (SM10) fully equipped with final electronics

ECAL = Barrel: 36 supermodule (1700 crystals)
End caps: 4 dees (3662) R. Paramatti's talk

Test Beam objectives: verify the performance of the ECAL

→ Reconstruction of the signal amplitude
→ Noise
→ Energy resolution
→ Position dependence of the response
→ checking laser monitoring system see A. Bornheim's talk
→ intercalibration procedure see G. Daskalakis' talk w/ cosmics see G. Franzoni's talk.

OUTLINE



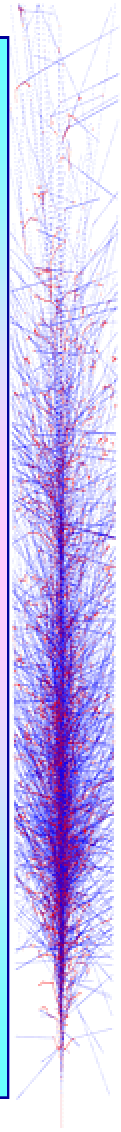
- ***The 2004 Test Beam set-up:***
  - → Description of the Test Beam experimental set-up
  - → ECAL readout electronics

- ***Reconstruction of the signal amplitude:***
  - → Weights method: principle and performance
  - → Implementation for CMS and Test Beam analyses

- ***Noise measurements***
  - → Noise level in 1 channel and crystal arrays

- ***Intrinsic resolution:***
  - → Resolution for central impact at 120 GeV
  - → Resolution as a function of energy

- ***Position dependence of the reconstructed energy***:
  - → Correction Method: Cluster containment corrections
  - → Performance on Test Beam data

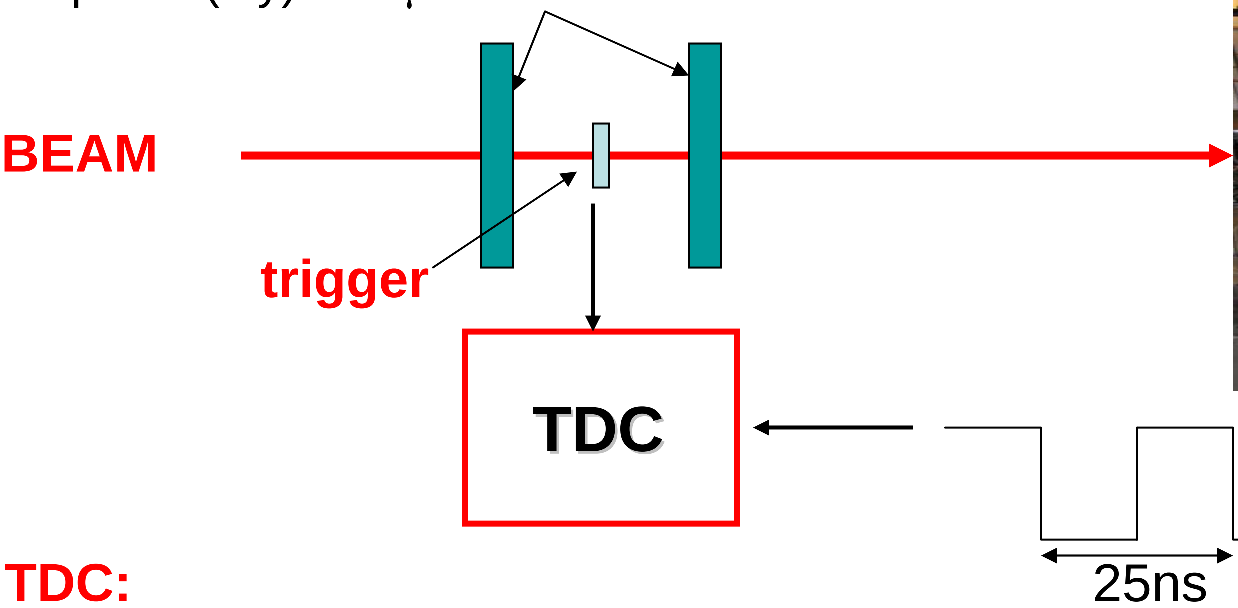


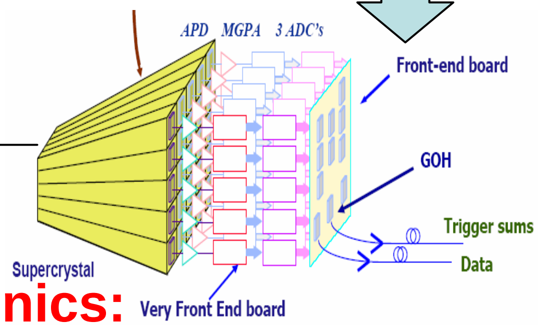
TEST BEAM EXPERIMENTAL SET-UP

Electron beam 20 to 250 GeV range (H4 secondary Line)

Hodoscope: Scintillating fibers

→ Beam position in the transverse plan $\sigma(x/y)=150\mu m$





TDC:

→ Phase between the trigger signal and the readout clock

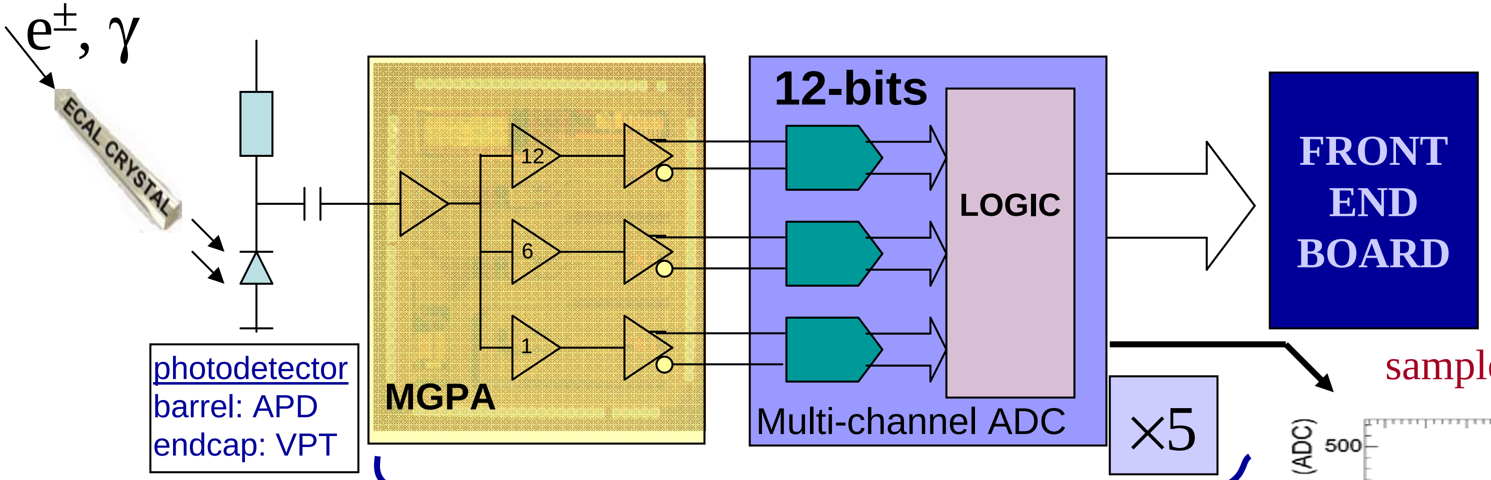
random 25ns (~ 1 ns uncertainty)

Readout Electronics:

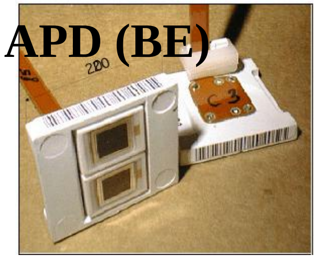
MGPA (multi gain pre-amplifier)

Final electronics

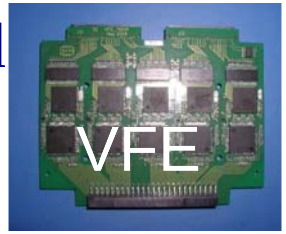
READ OUT ELECTRONICS



ADC Samples the signal every 25ns

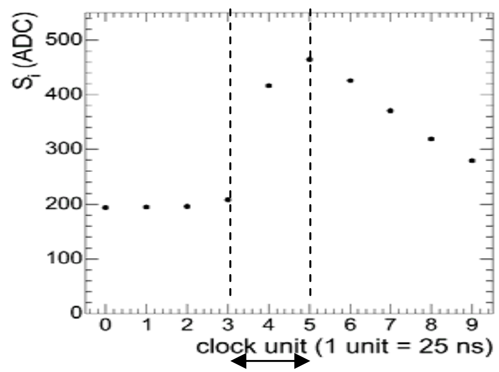


Very Front End Board



See P. Rumerio's talk

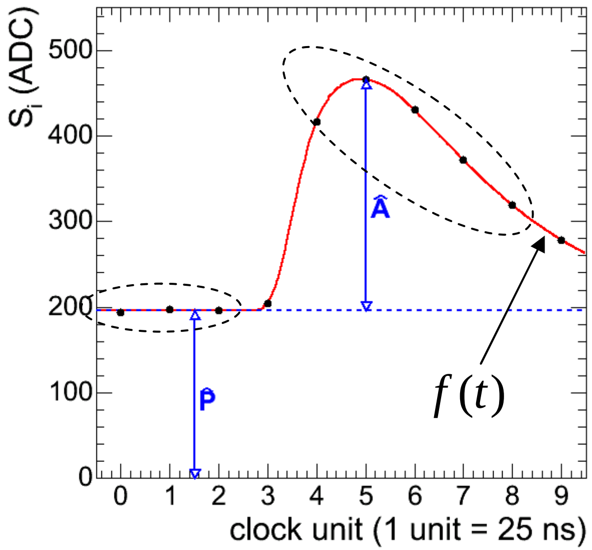
samples



40ns shaping time

⇒ After pre-amplification, the signal is sampled every 25 ns by the ADCs
⇒ samples → reconstruct the signal amplitude
⇒ proportional to the energy deposited by the particle in the crystal

RECONSTRUCTION OF SIGNAL AMPLITUDE



⇒ **Digital filtering**:

$$A = \sum_i w_i \cdot S_i$$

- **S_i** : time sample #i (in ADC counts)
- **W_i** : weight #i (from signal representation f(t))

⇒ Using weights that give the best signal/noise ratio

$$\sigma_{weight} = \sqrt{\sum_i W_i^2} \times \sigma_{sample}$$

< 1

Different implementations:

- "5-weights" on the peak: measure the Amplitude **A** after subtracting average pedestal
- "3+5 weights": measure **A,** using the pre-samples in the reconstruction $\rightarrow$ this method subtracts the pedestal **P** event/event

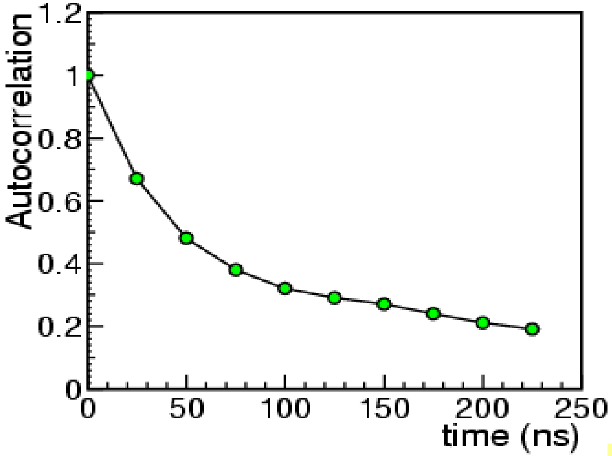
RECONSTRUCTION OF SIGNAL AMPLITUDE

Noise measurements from data with no beam

Method	1x1 (MeV)	3x3 (MeV)	5x5 (MeV)
1 sample	44±0.4	137±2	241±3
5-weights	41±0.7	141±4	248±4
8-weights	40±0.7	118±3	200±4

Small correlated noise between channels

Noise characterization:



- Correlation within 1 channel: sample close in time
  → use of the samples in the peak is less important
- Low frequency noise ~ 0.3
  → Use of pre-samples in the reconstruction method
  → determine **P** event/event

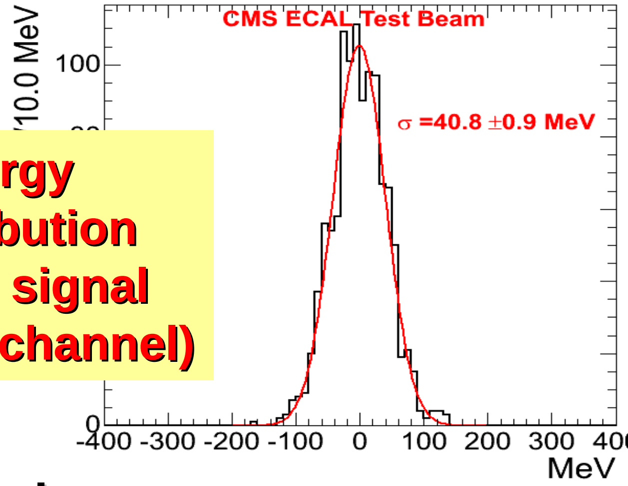
Signal amplitude reconstruction ⇒ 3+5 pedestal subtracting weights
→ removes efficiently all correlated noise between channels

NOISE MEASUREMENTS

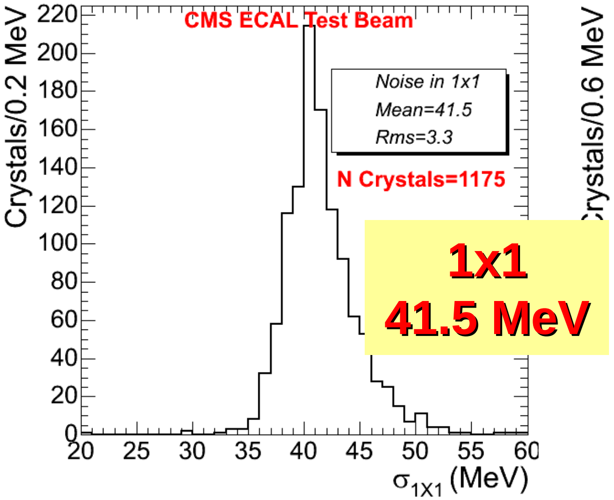
Noise measurements from data with no beam

Noise in 1 channel ~ 40 MeV

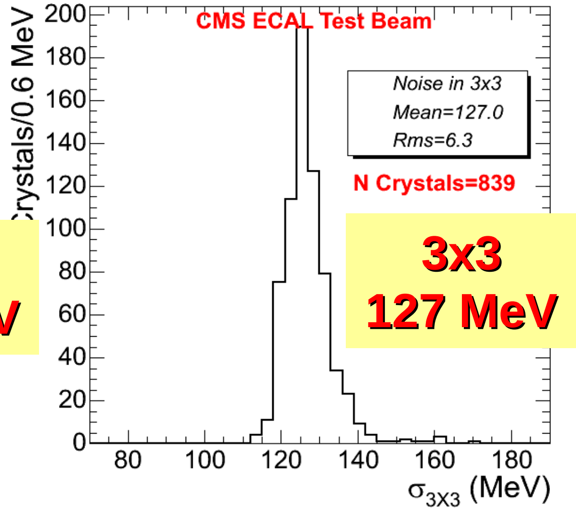
Energy distribution for no signal (typical channel)



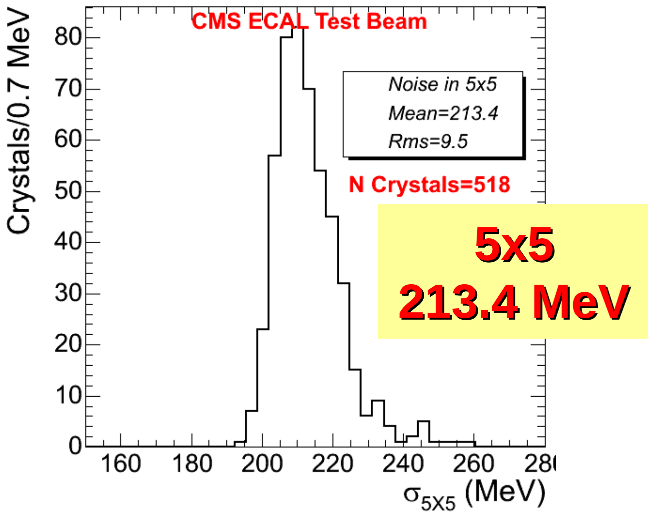
Histogramming the fitted noise σ for many channels:



1x1
41.5 MeV



3x3
127 MeV



5x5
213.4 MeV

IMPLEMENTING RECONSTRUCTION METHOD

⇒ **TEST BEAM ≠ CMS**

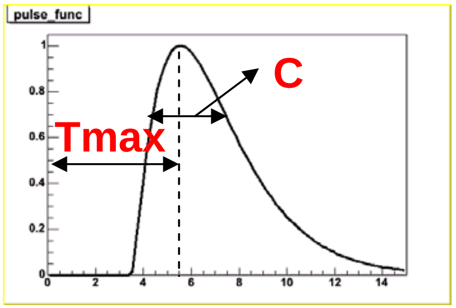
→ **CMS**: electrons arrive in coincidence w/ the clock → **PHASE FIXED**

→ **TEST BEAM**: electrons arrive randomly → **RANDOM PHASE (0→25ns)**

→ **1 set of weights for each bin in phase**

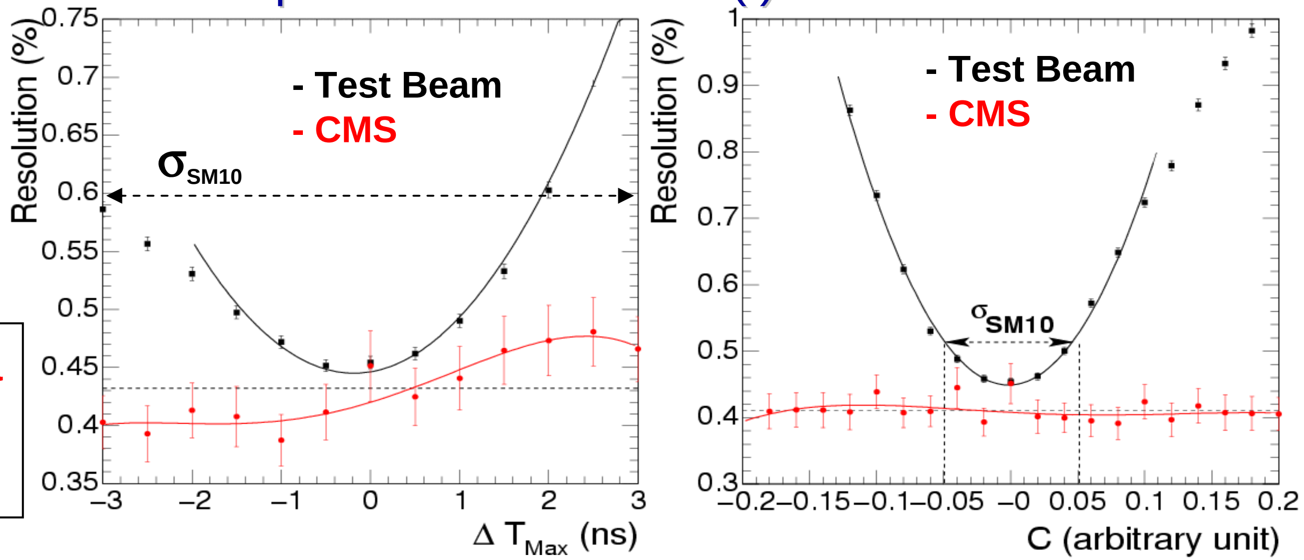
Weights calculated from a signal representation f(t): 2 parameters

Tmax (signal timing) and **C** (width)



CMS = Test Beam data within 1 ns interval in phase

Impact of the choice of f(t) on the resolution



⇒ **CMS: synchronous mode → 1 set of weights can be used for the whole ECAL**

⇒ **Test Beam: more sensitive to individual channel pulse shape**

→ **1 set of weights/channel is needed**

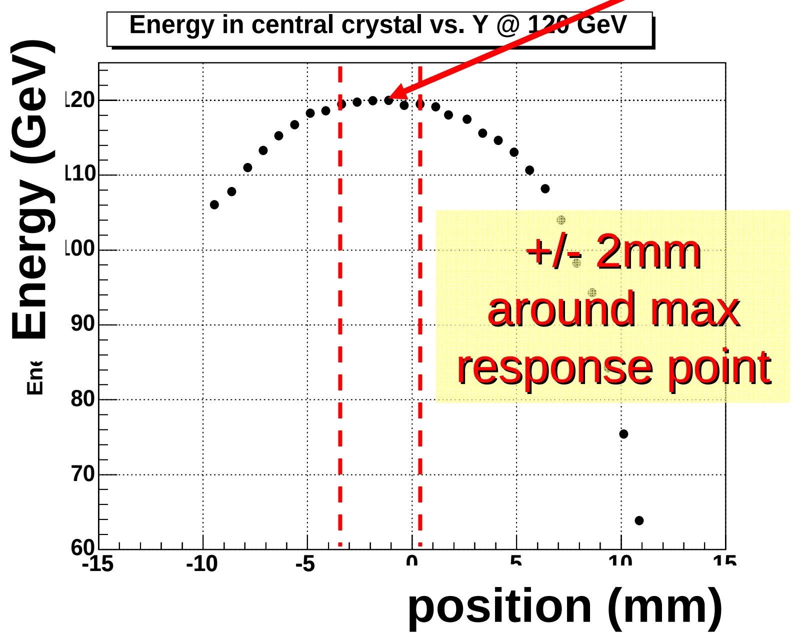
ECAL INTRINSIC ENERGY RESOLUTION

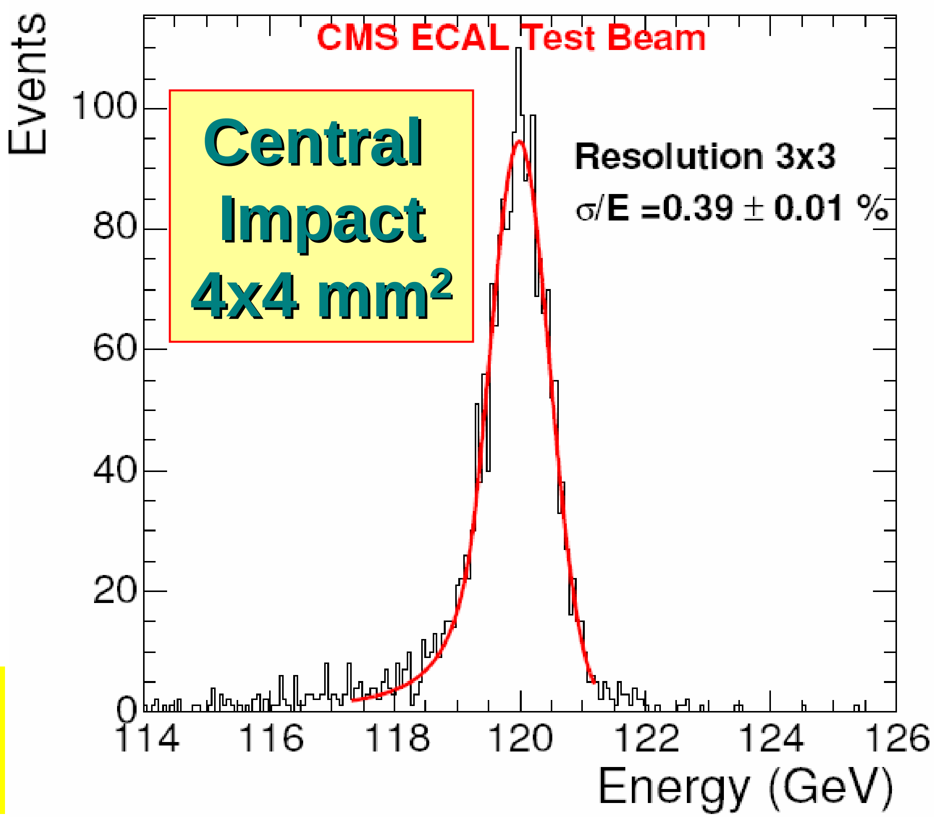
⇒ **Resolution in the 3x3 matrix of crystals**:

→ **30k events** with electron beam of **120 GeV**

→ **Intrinsic resolution of ECAL**: Impact electron is restricted to a **4x4 mm^2 region**

→ small variation of the energy contained in the matrix and small effect from crystal intercalibration



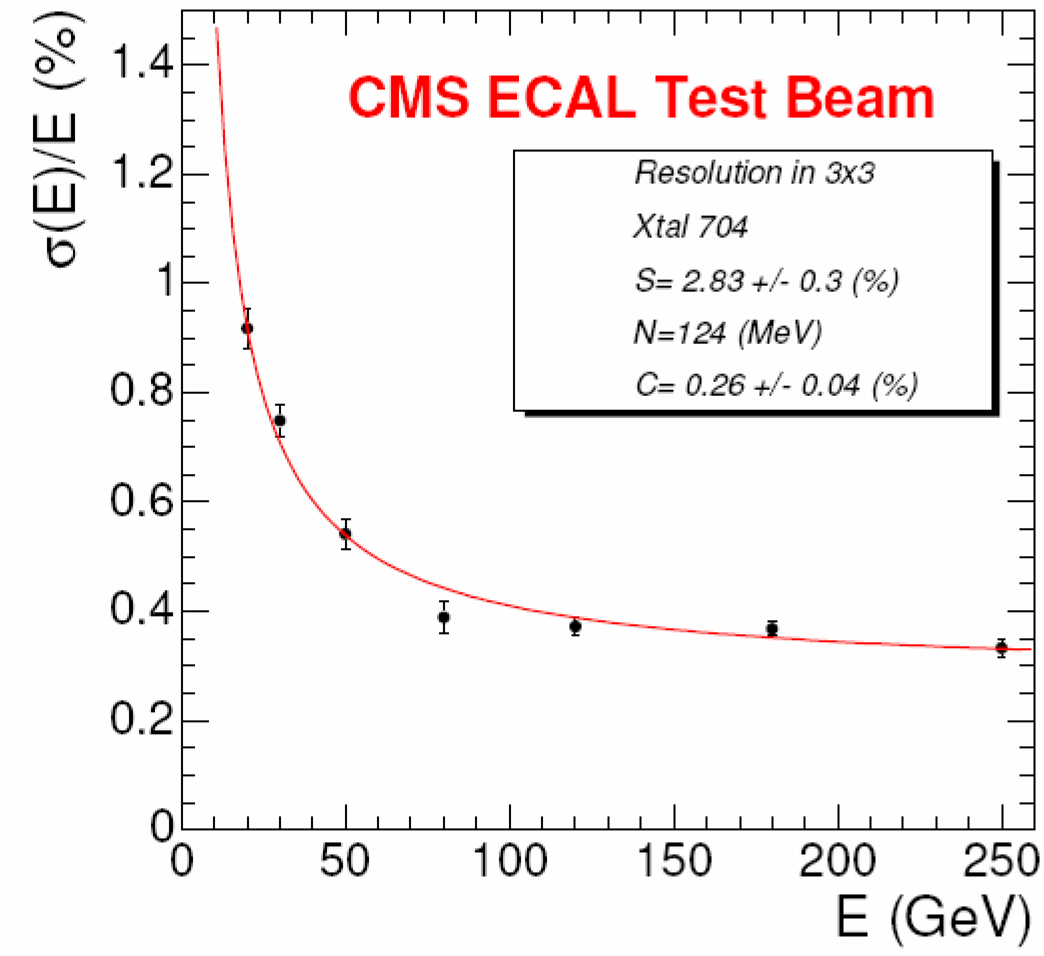


⇒ Excellent resolution of 0.4% at 120 GeV.

ECAL RESOLUTION vs ENERGY: central impact

⇒ RESOLUTION vs Energy for XTAL 704 3x3

⇒ Intercalibration constants from beam data (120 GeV)



XTAL 704
3x3

S (stochastic) ~ 3%

C (constant) ~ 0.3%

⇒ beam $\sigma_P/P \sim 0.1\%$

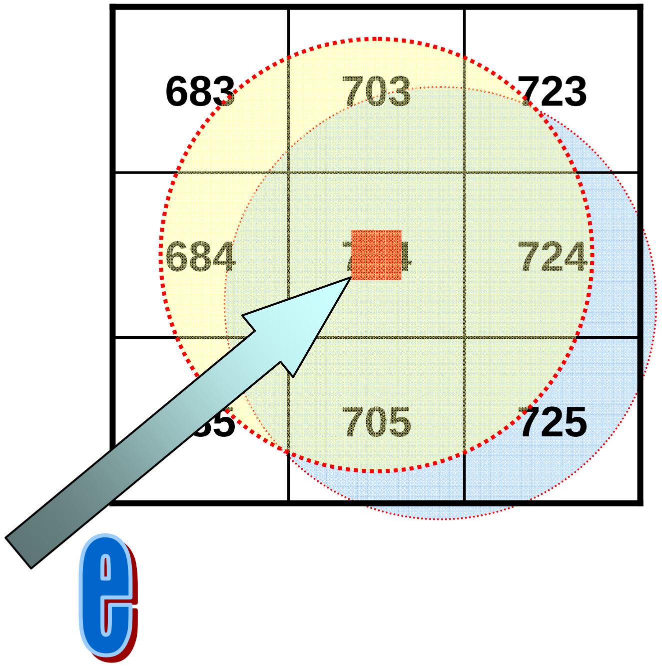
⇒ Synchrotron radiation:

Energy (GeV)	$\sigma_p/p(\%)$
50	~ 0
120	~ 0
150	0.05
180	0.11
250	0.23

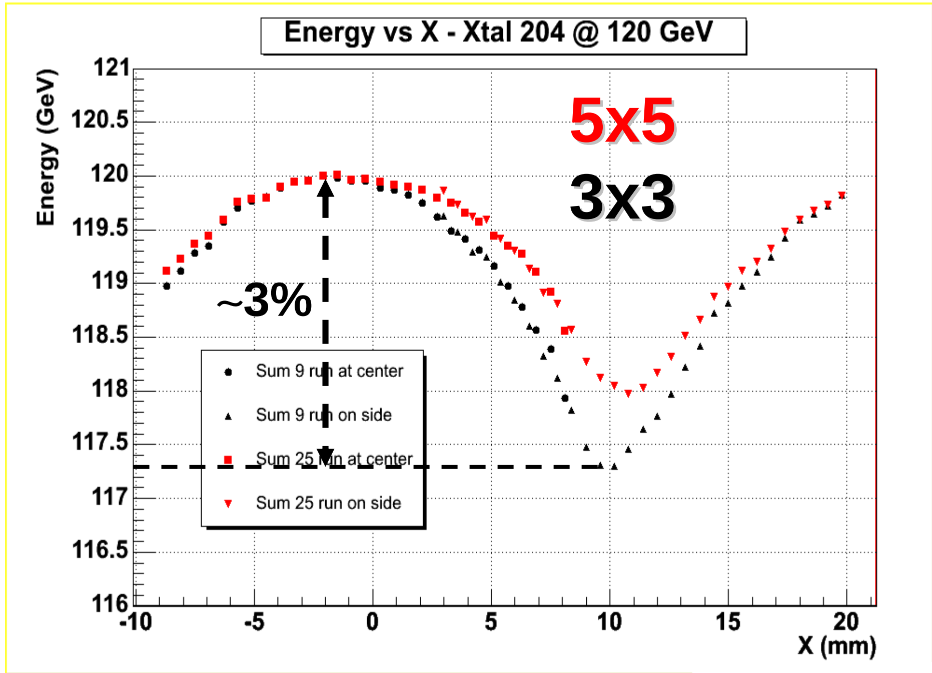
POSITION DEPENDENCE OF THE RESPONSE

⇒ Energy contained in an array of crystals depends on the position the shower

Example: 3x3 matrix



Containment effect decreases with the matrix size



Hodoscope

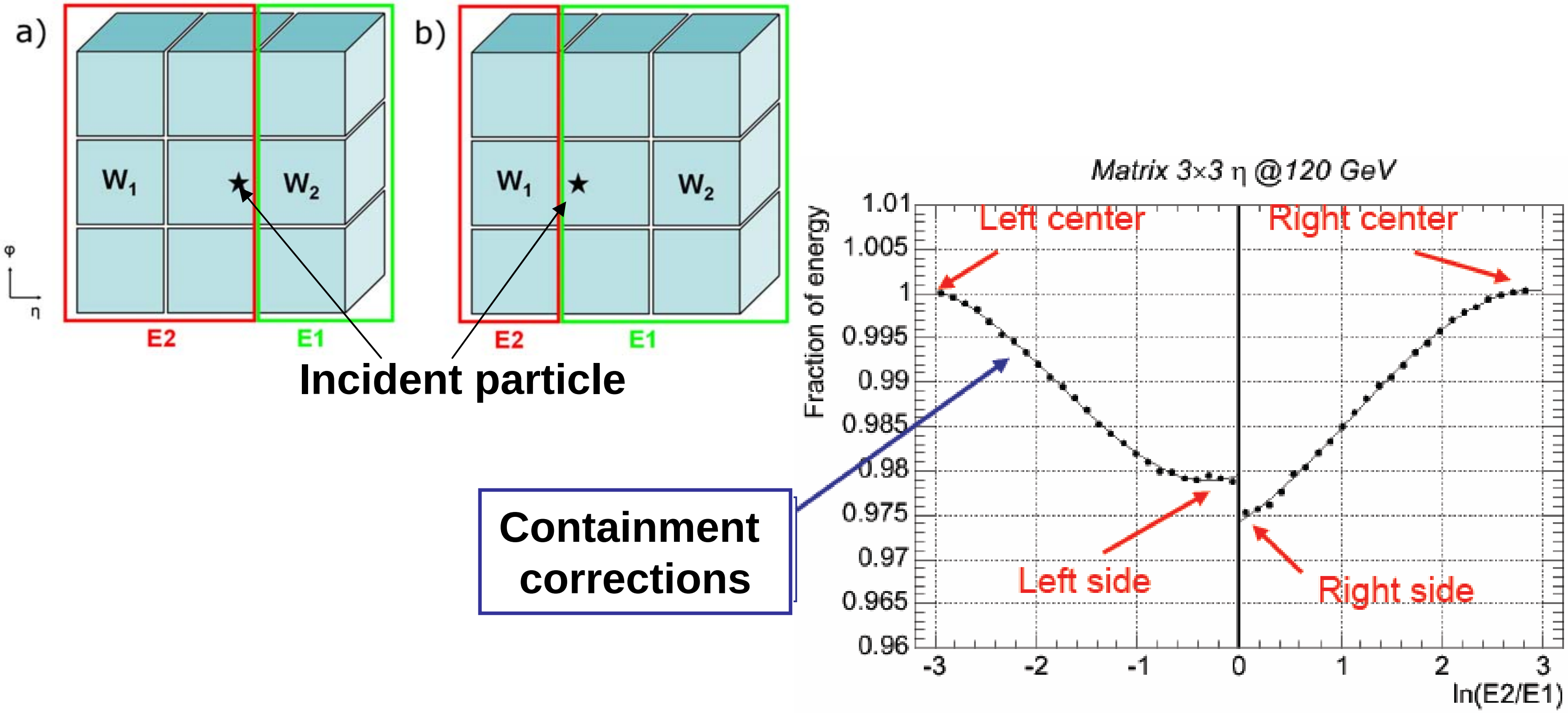
Resolution:

⇒ Uniform impact → containment corrections needed

POSITION DEPENDENCE OF THE RESPONSE

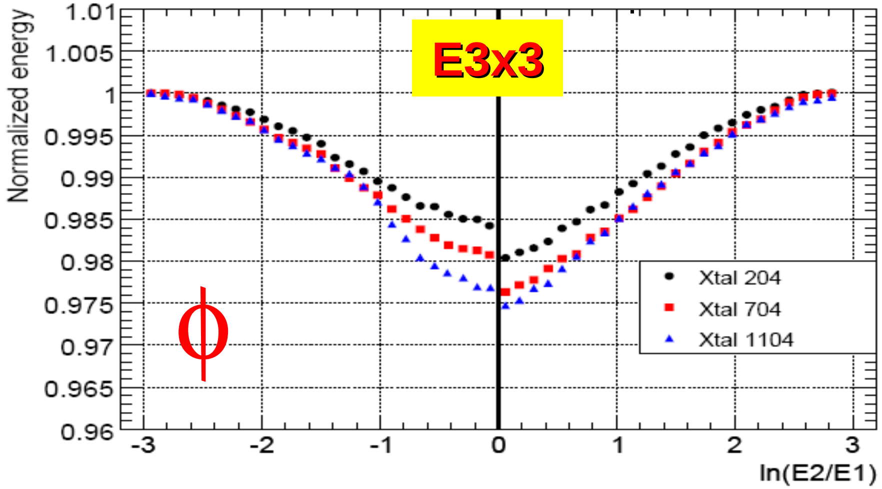
→ ***Containment Corrections***:
Parameterization of the response as a function of the position.

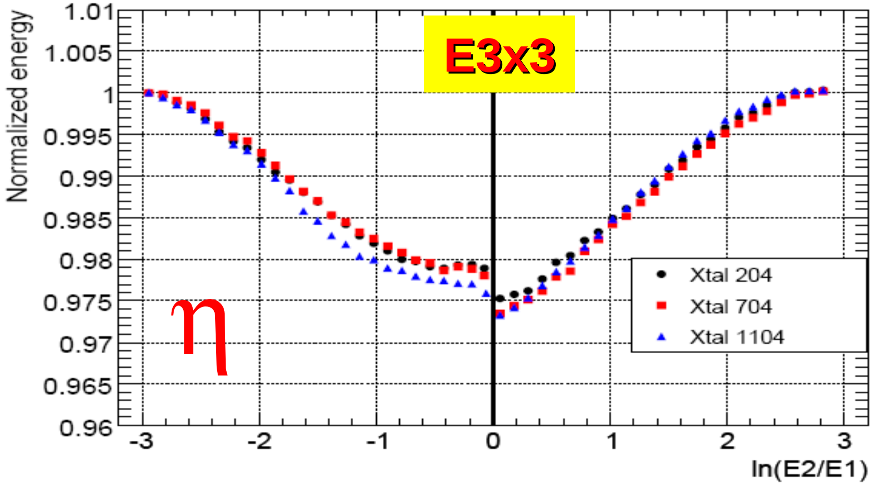
⇒ Position is determined by looking at energy deposition in the crystals
→ **log(E2/E1)** as a measurement of the position on the crystal.
where E2 and E1 are the energy in rows of crystals:

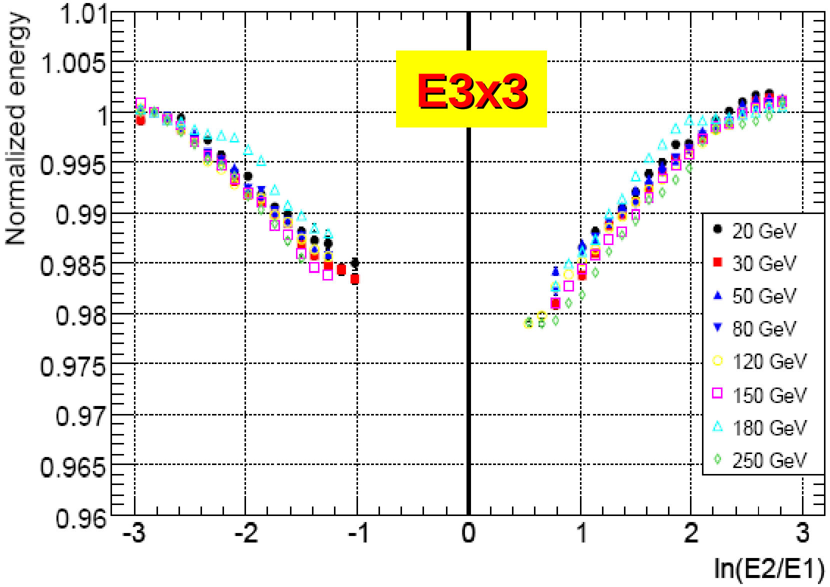


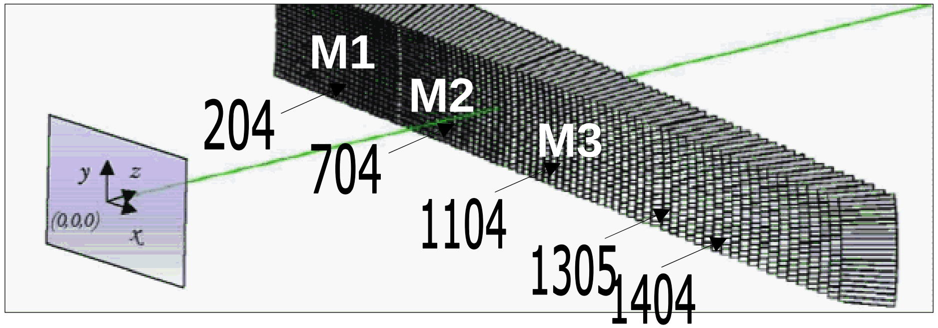
CONTAINMENT CORRECTIONS

⇒ **Dependence of the fitted correction functions on location and on beam energy has been investigated**









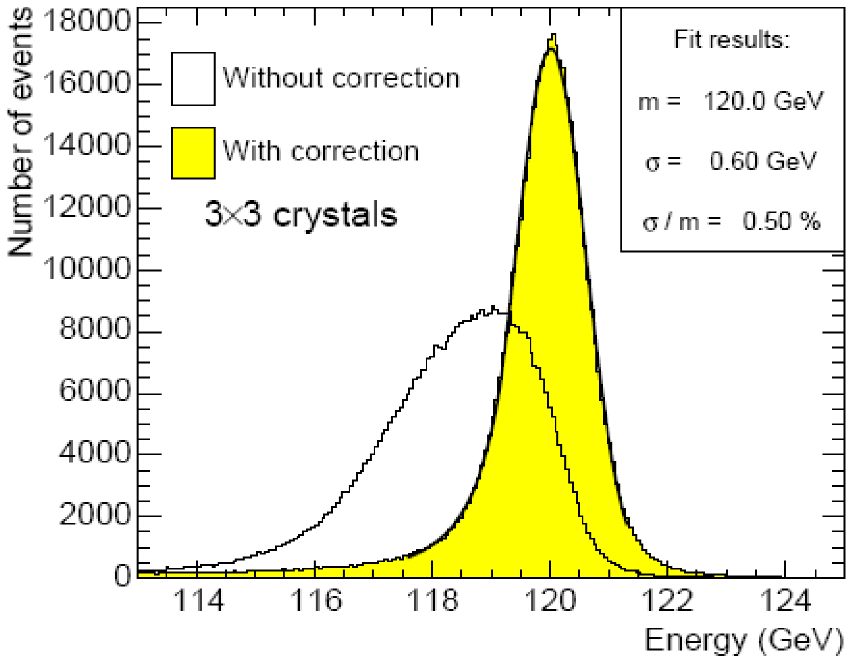
⇒ **Small differences not predicted in MC:**
→ **to investigate in Test Beam 2006**

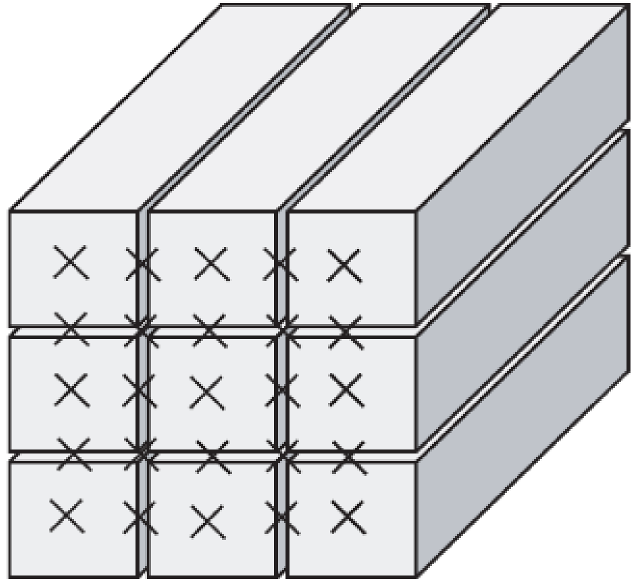
⇒ **Corrections independent of energy**

⇒ **a single parameterization was used**

ECAL ENERGY RESOLUTION: uniform impact

⇒ **Study of containment corrections performance: Energy resolution 3x3**
→ 30k events runs @ 120 GeV
→ Beam directed in many positions → combining data sets

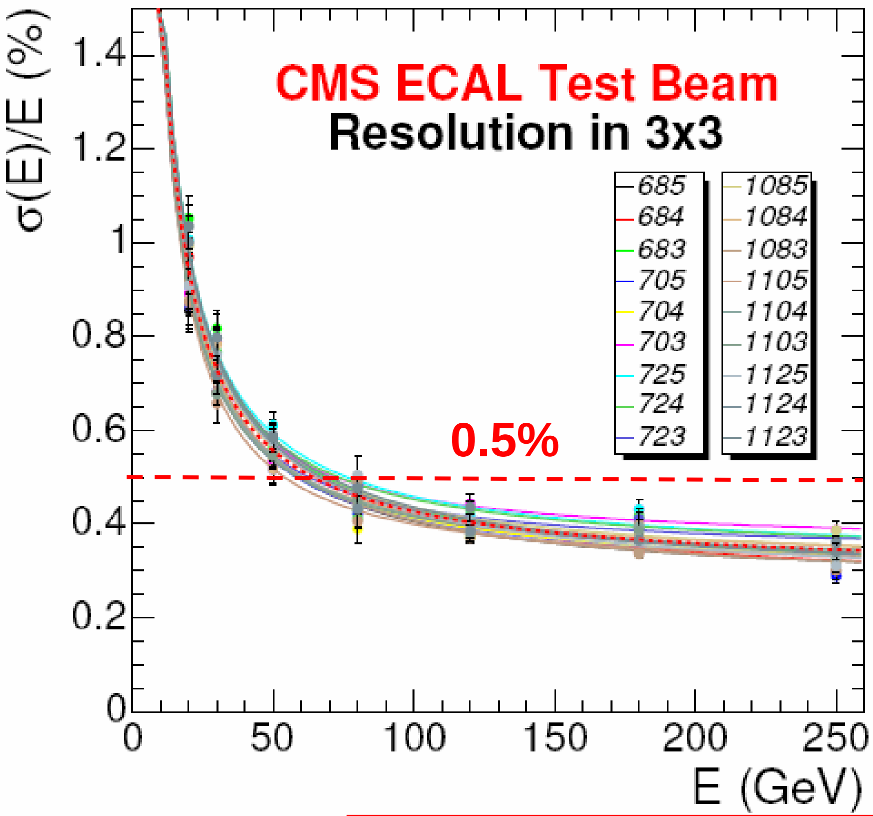




⇒ **Good performance of the containment corrections:**
→ **0.50% energy resolution at 120 GeV**

ECAL INTRINSIC RESOLUTION vs ENERGY

Central impact: 18 3x3 matrices



Average resolution at each energy point:

Energy (GeV)	Resolution (%)
20	0.94 ± 0.05
30	0.74 ± 0.04
50	0.56 ± 0.03
80	0.45 ± 0.02
120	0.40 ± 0.01
180	0.38 ± 0.01
250	0.34 ± 0.01

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.9\%}{\sqrt{E}}\right)^2 + \left(\frac{125(MeV)}{E}\right)^2 + (0.30\%)^2$$

Stochastic **Noise** **Constant**

CONCLUSIONS

Test beam studies:

- ♦ Determine a signal amplitude reconstruction giving best performance
  - → implementation for Test Beam asynchronous
  - → conclusion for CMS (1 set of weights)
- ♦ Corrections for containment effect

ECAL performance:

⇒ Noise in 1 channel ~ 40 MeV

→ reconstruction method eliminates coherent noise

⇒ **Energy Resolution: 3x3 matrix**

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.9\%}{\sqrt{E}}\right)^2 + \left(\frac{125(MeV)}{E}\right)^2 + (0.30\%)^2$$

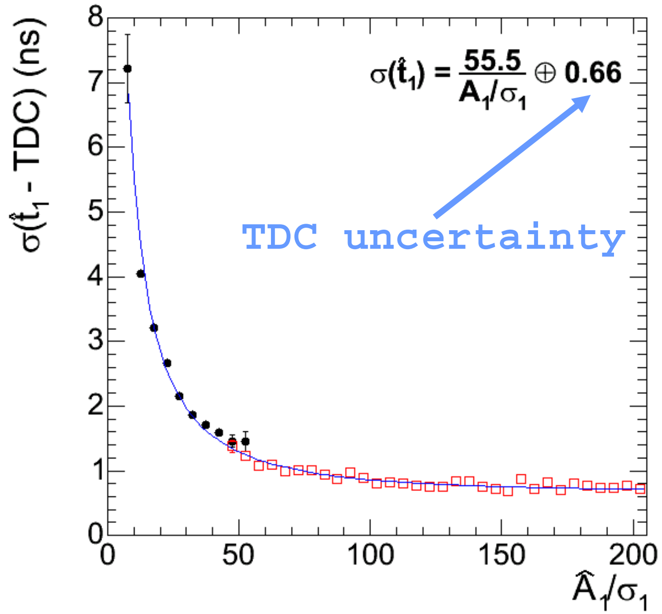
⇒ **Excellent performance of the ECAL**

BACK-UP SLIDES

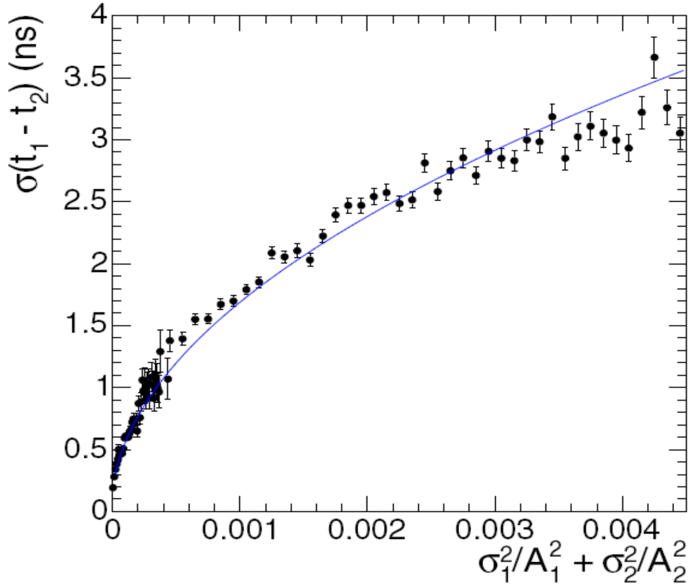
TIMING MEASUREMENT

⇒ **Filtering technique**: determine an additional set of weights to measure the signal timing.

Time resolution Test Beam 2004



Time resolution: time difference between 2 channels hit by the same electron shower



$$\left(\frac{noise}{signal}\right)^2$$

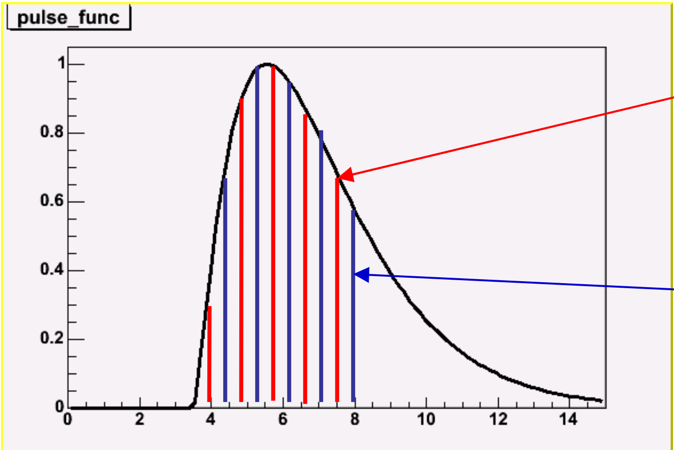
Excellent time resolution: → **E > 2 GeV → σ(δt) < 1 ns**
→ **E > 40 GeV → σ(δt) ~ 0.11ns**

- ♦ **Check signal timing:** must remain stable → variation of the response with time → important for CMS running
- ♦ **Time of flight of high energy particles**

AMPLITUDE RECONTRUCTION: TEST BEAM

⇒ **Asynchronous case**: *TDC (phase) is random between 0 and 25 ns.*
→ *we consider 25 bins of 1ns*

⇒ **In order to use the weights method in the asynchronous case we need to determine a set of weights for each TDC bins:**

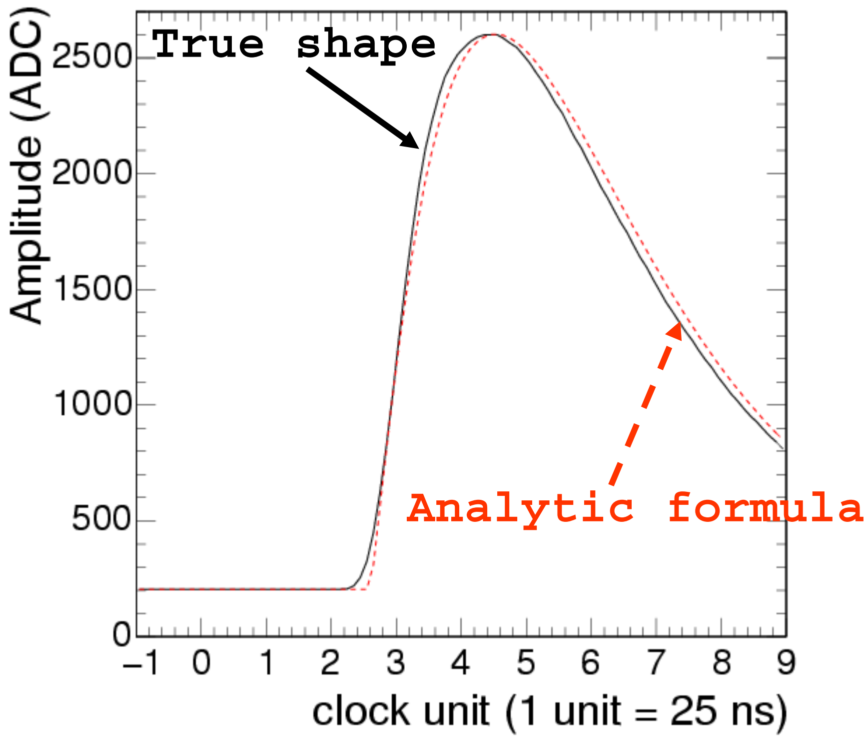


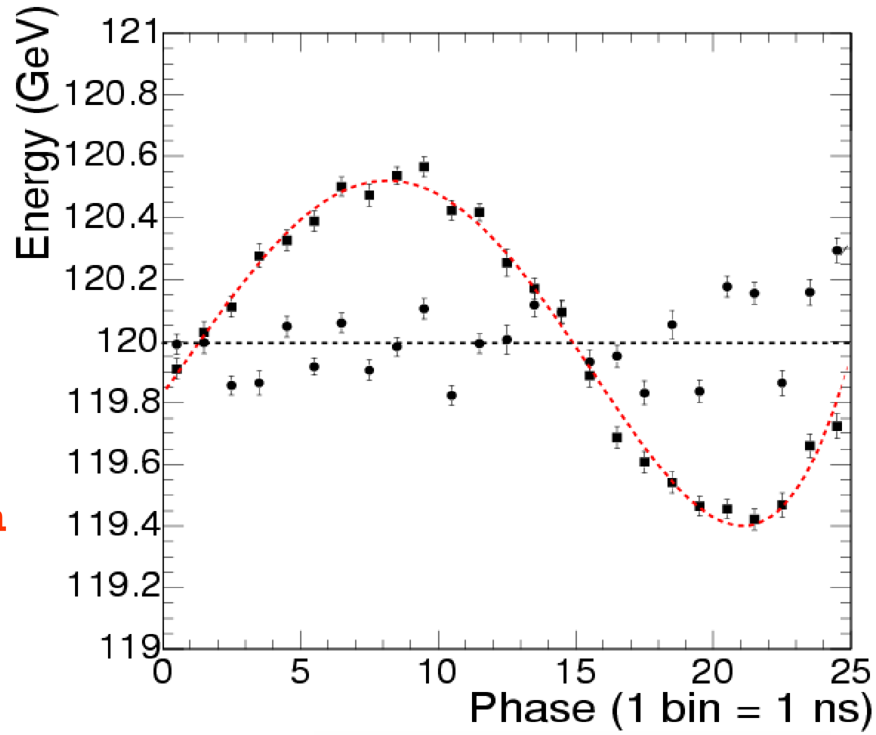
$$W_i = \frac{f(t_i)}{\sum_i f(t_i)}$$

$$W_i = \frac{f(t_i + \Delta t)}{\sum_i f(t_i + \Delta t)}$$

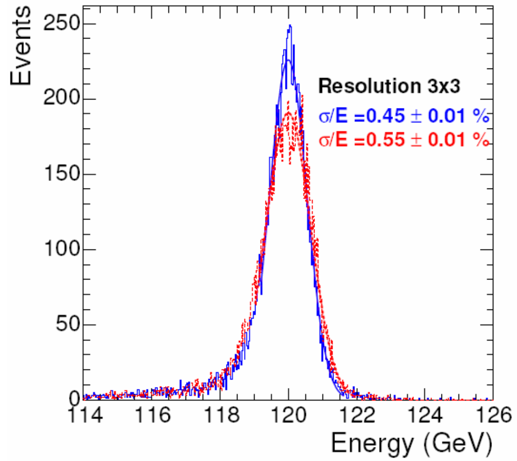
⇒ **Asynchronous case** → severe constraint on amplitude reconstruction:
The weights method must reconstruct to the **same amplitude in all TDC bins**

AMPLITUDE RECONTRUCTION: effect of the shape





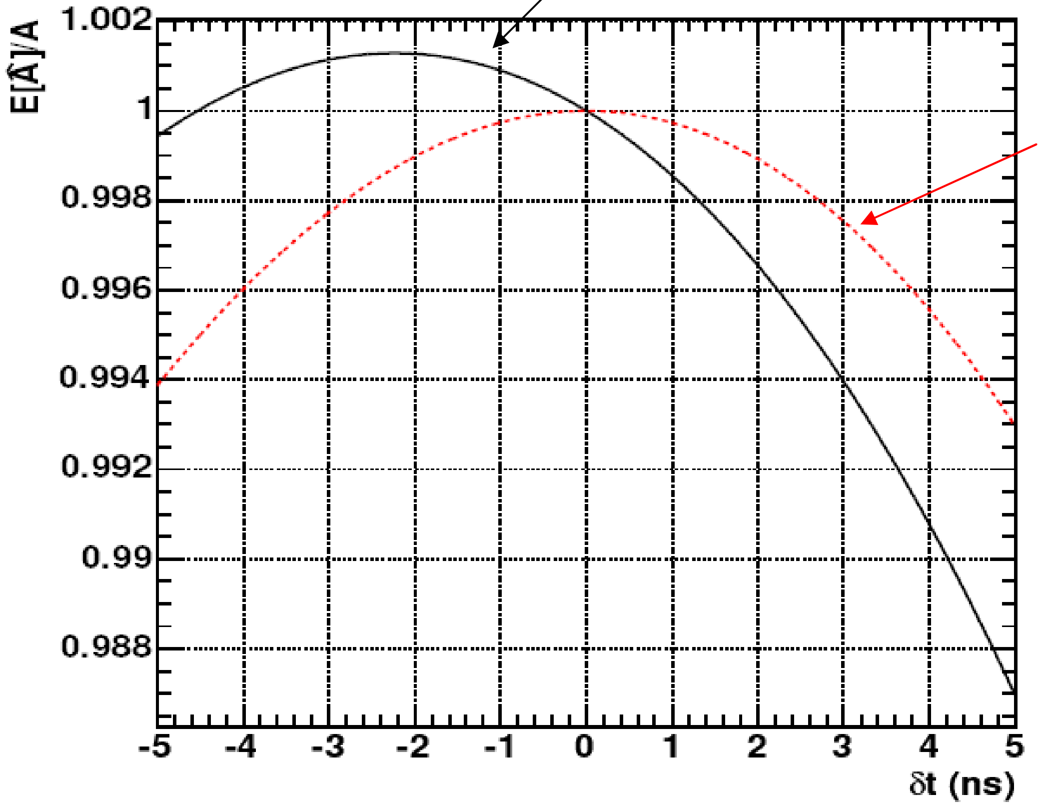
⇒ In asynchronous mode:
shape used ≠ true shape
→ large smearing introduced when combining amplitudes from different phases



AMPLITUDE RECONTRUCTION: bias

Amplitude bias

3+5 pedestal subtracting weights:
Low energy pulse reconstruction



1 weight on peak:
High energy
pulse reconstruction

Signal timing
difference

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