Pulse (Energy) & Position Reconstruction in the CMS ECAL

(Testbeam Results from 2003)

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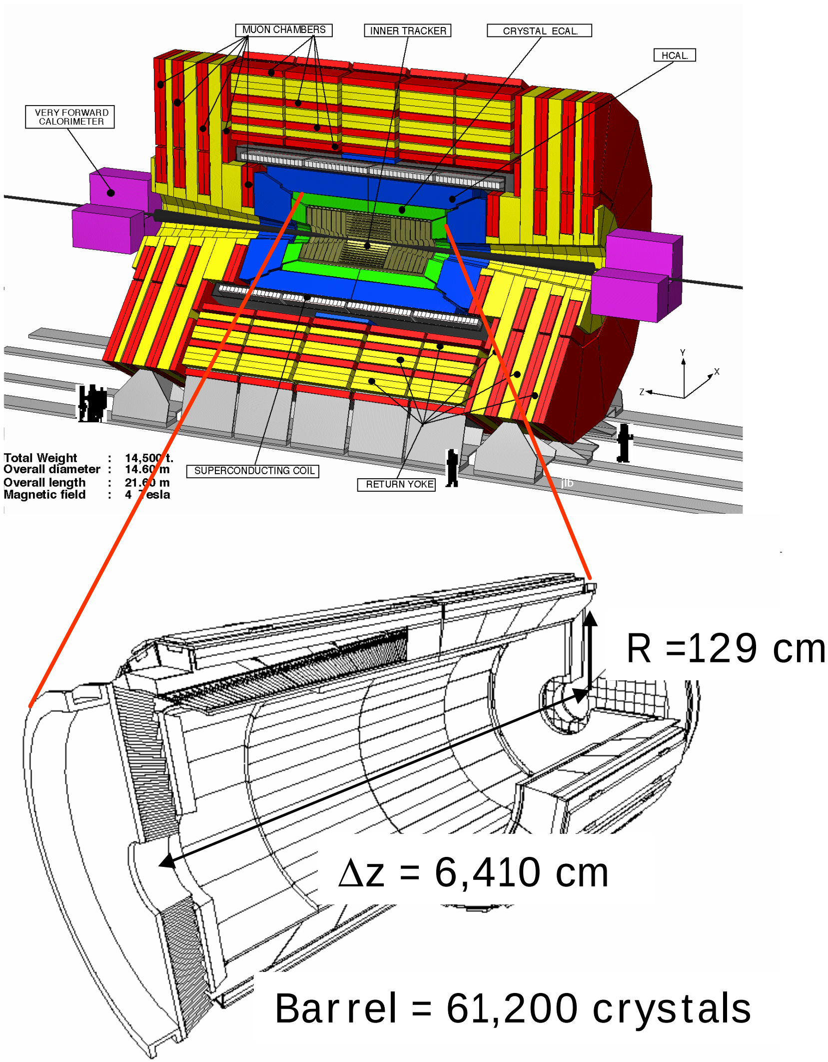
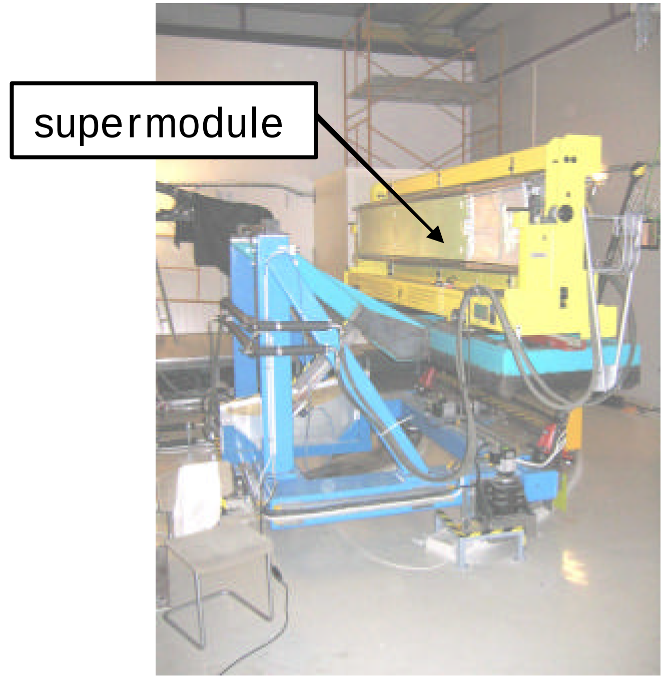
On behalf of the CMS ECAL community

The Compact Muon Solenoid dectector



The H4 Testbeam at CERN



Testbeam set-up in 2003:

- 2 supermodules (SM0/SM1) have been placed in the beam (electrons)
- Front-end electronics:

  FPPA(100) /MGPA(50) crystals equippe

Two testbeam periods in 2003

Two sets of front-end electronics used: FPPA and MGPA

the new 0.25 mm front-end electronics ← (MGPA)

	FPPA	**MGPA**
# gains	4	3
SM (# equip. crys.)	SM0 (100)	SM1 (50)
period	long	short
Electron energies (GeV)	20, 35, 50, 80, 120, 150, 180, 200	25, 50, 70, 100 (using PS heavy ion run)

Pulse (Energy) Reconstruction

Part 1

- **A single pulse … and how to reconstruct it**
  (some testbeam specifics & evaluate universalities in the ECAL)
- **Optimizing the algorithm**
- **Results**

A single pulse

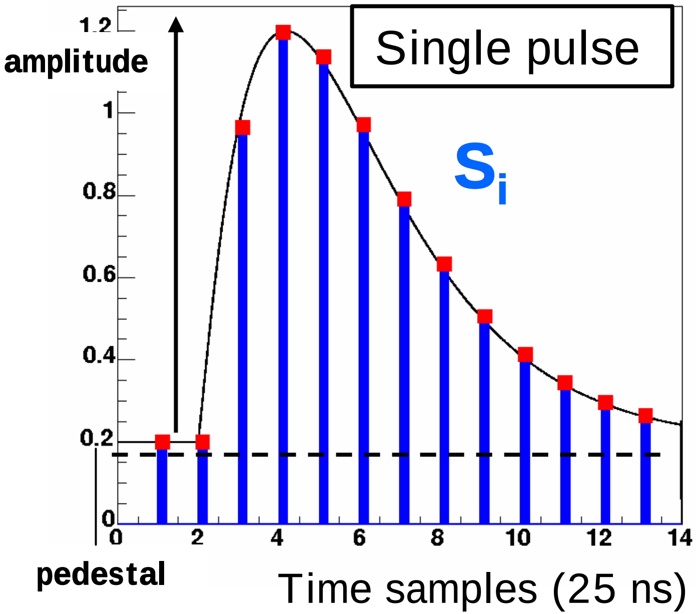
1) Photons detected using an APD

2) Signal is amplified

3) Digitization at 40 MHz (each 25 ns)

3(4) gain ranges (Energies up to 2 TeV)

4) 14 time samples available offline



How to reconstruct the amplitude:

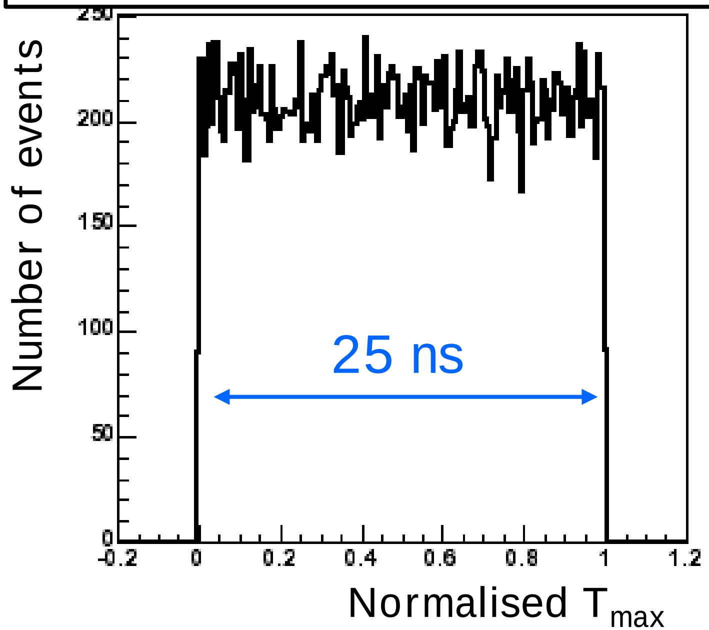
- Analytic fit: In case of large noise -> biases for small pulses
- Digital filtering technique: Fast, possibility to treat correlated noise

Timing information

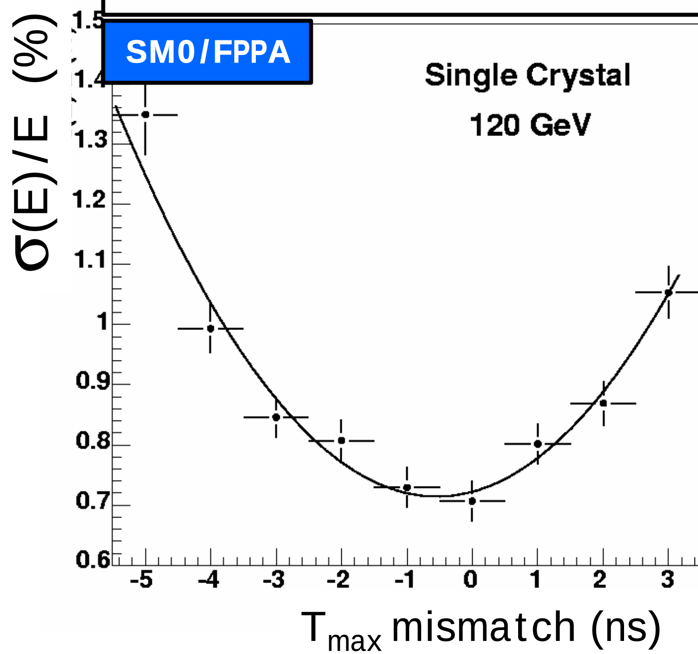
CMS: Electronics synchronous w.r.t LHC bunch crossings

Testbeam: A 25 ns random offset/phase w.r.t the trigger

Spread in Time of maximum response



Resolution versus mismatch



- Precision on Tmax: CMS: jitter < 1 ns Testbeam: < 1 ns (use 1 ns bins)

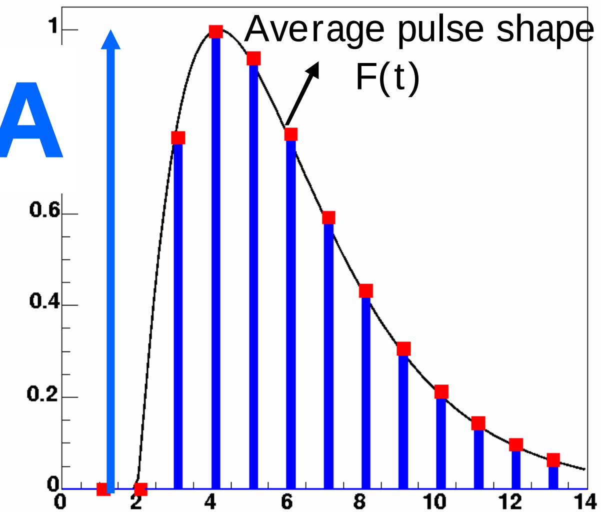
Pulse Reconstruction Method

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

Amplitude — weights — signal+noise

- Weights computation requires knowledge of the average pulse shape
- Optimal weights depend on assumptions on S_i

Pulse Reconstruction Method



How to extract the optimal weights:

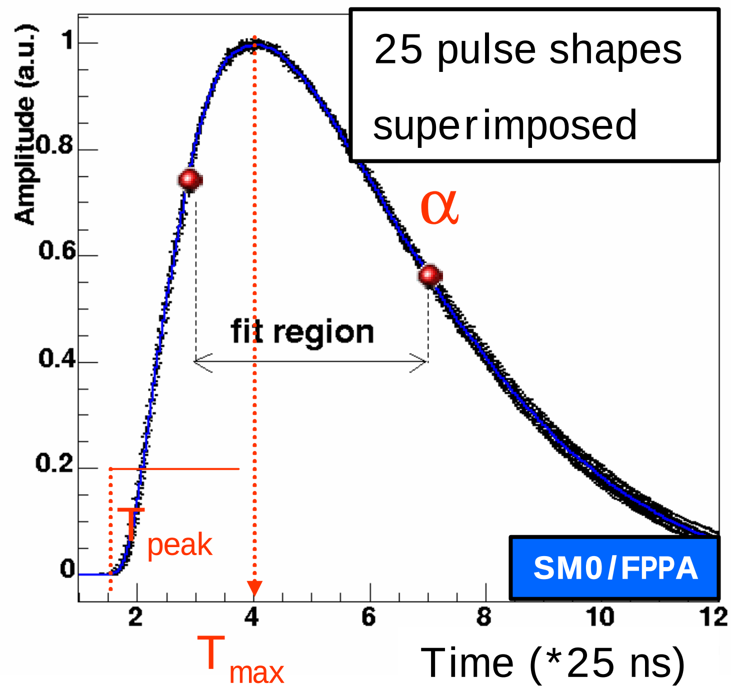
$$\chi^2 = (\vec{S} - A\times\vec{F})^T\, Cov^{-1}\, (\vec{S} - A\times\vec{F})$$

- $\vec{S}$: Sample heights
- A: Amplitude
- Cov^{-1}: Covariance Matrix
- $\vec{F}$: Expected sample heights: F(t)

Minimize χ^2 w.r.t A → assuming { No pedestal, No correlations } →

$$w_i = \frac{f_i}{\sum_i (f_i^2)}$$

- Timing: Define a set of weights for each 1 ns bin of the TDC offset
- Knowledge of expected shape required: shape itself, timing info and gain rati



- Analytic description of pulse shape:

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

Could also use digital representation

universal

Note:
- Shapes (T_{peak}, α) are similar for large sets of (all) crystals
- T_{max}: 2 ns spread in the T_{max} for all crystals (we account for it)

Optimization of parameters

- Optimization depends on particular set-up.

  For the testbeam:
  - How many samples
  - Which samples

- Treatment of (correlated) noise

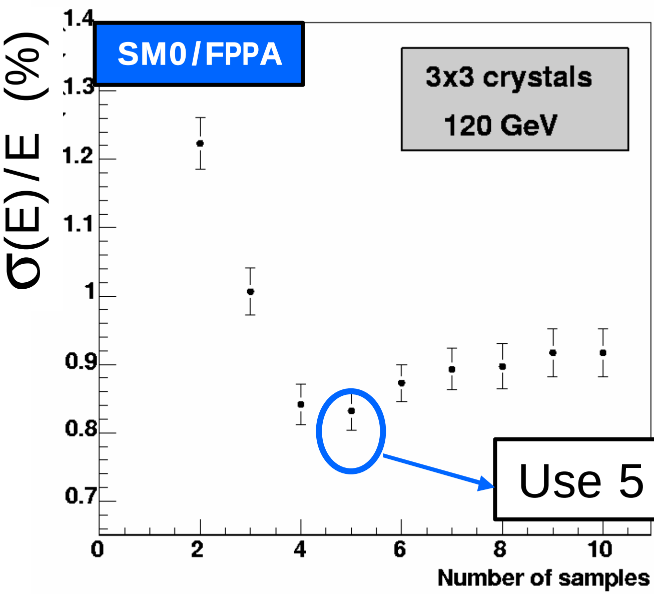
total # samples

More samples:

- Precision (depends on noise and a correct pulse shape description)

Less samples:

- Faster & smaller data volume
- Reduce effects from pile-up & noise

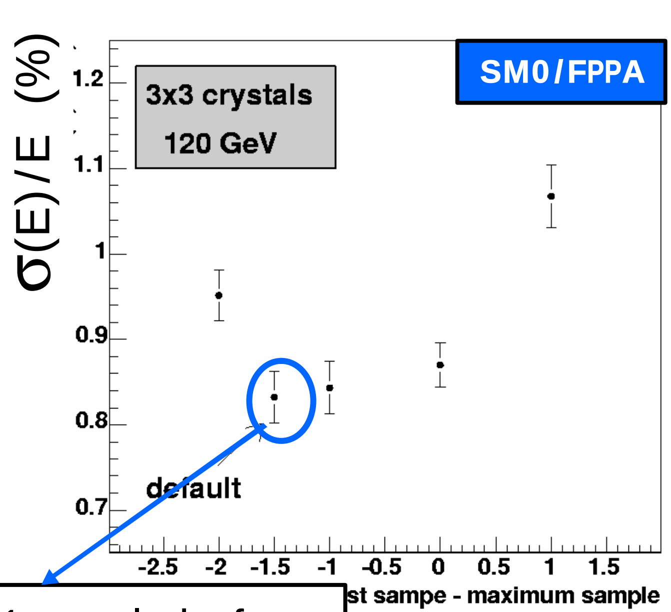


Use 5 samples

which samples

- Variance on <Ã> scales like sample heights ⟶ Use largest samples

Depend on TDC offset (decided per event)



Start at 1 sample before the expected maximum

Treatment of (correlated) Noise

The (correlated) noise that was present in 2003 is under investigation and is treated off-line:

Correlations between samples: Extract Covariance matrix (pedestal run)

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

Covariance Matrix

Pedestals: Use pre-pulse samples and fit Ampl. and Pedestal simultaneously

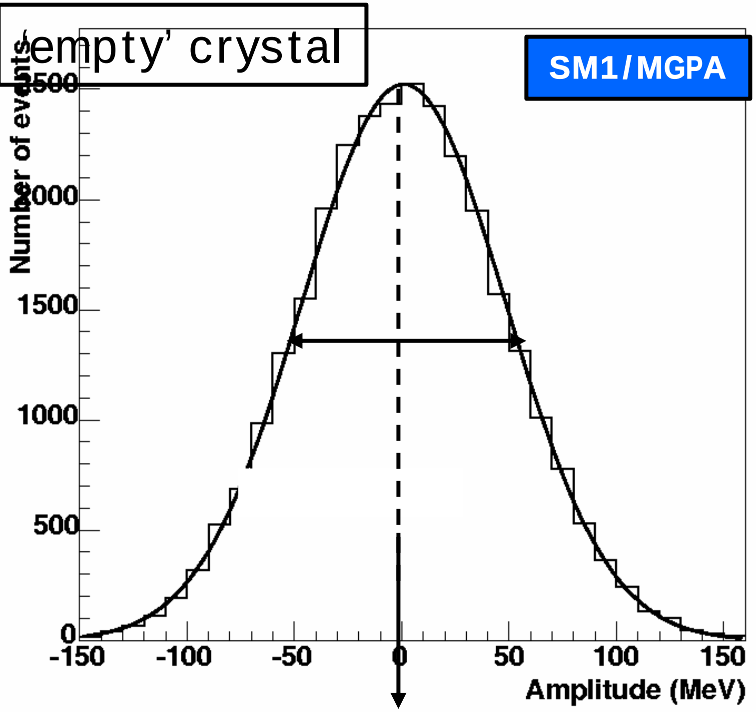
$$c^2 = (\vec{S} - A \times \vec{F} - P)^T \, Cov^{-1} \, (\vec{S} - A \times \vec{F} - P)$$

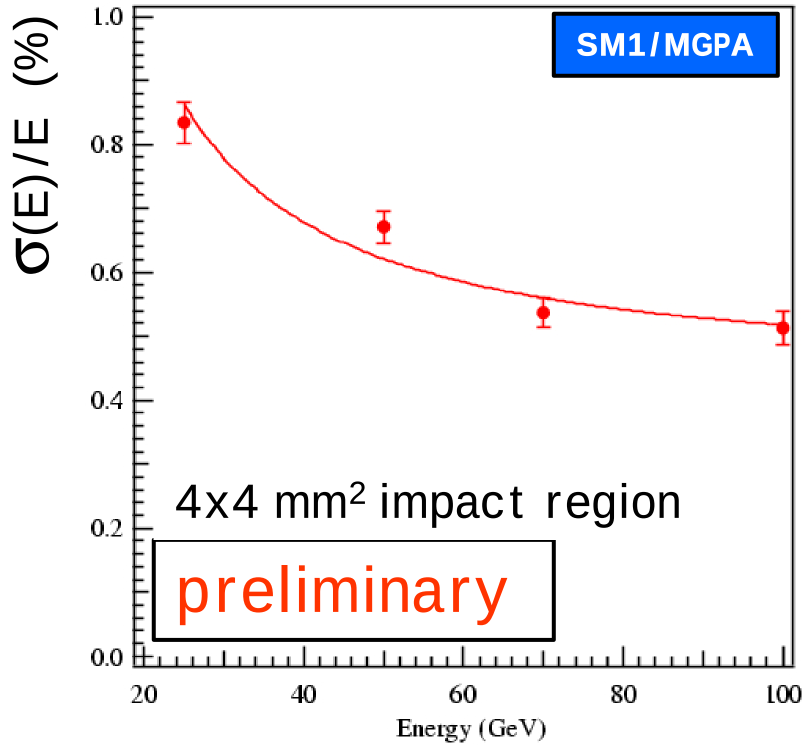
Pedestal

An optimal strategy for this procedure is under investigation

Final design of front-end electronics

Results using **MGPA** electronics





- ‘No bias at small amplitudes
- Noise » 50 MeV (per crystal)

$$\frac{\sigma(E)}{E} = \frac{2.4\,\%}{\sqrt{E}} \oplus \frac{142\ \mathrm{MeV}}{E} \oplus 0.44\ \%$$

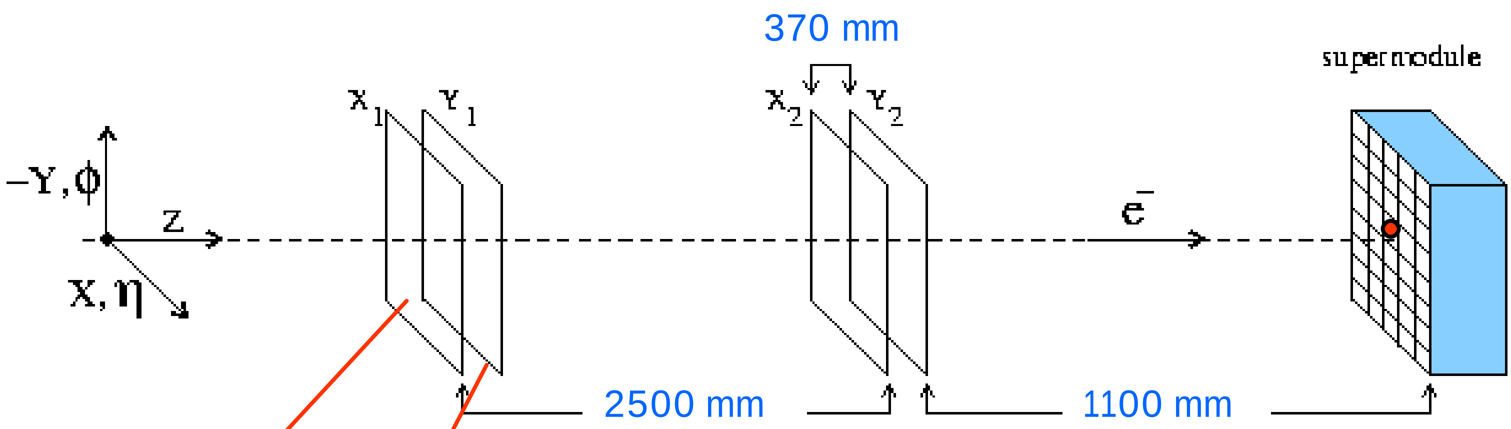
Impact Position Reconstruction

Part 2

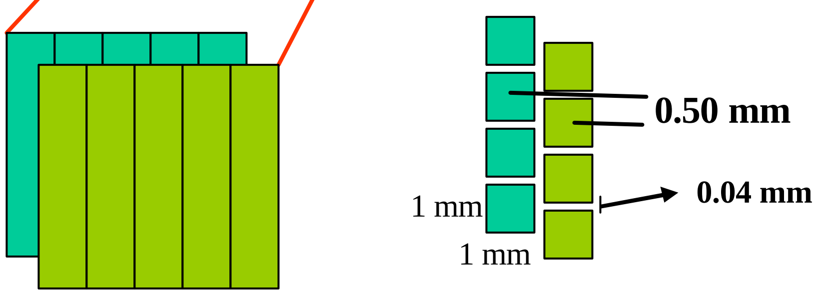
- Determination of the 'true' impact point
- Reconstruction of the impact point (2 methods)
- Conclusions

SM0 / FPPA

- A hodoscope system determines the e-trajectory (and impact point on crystal)

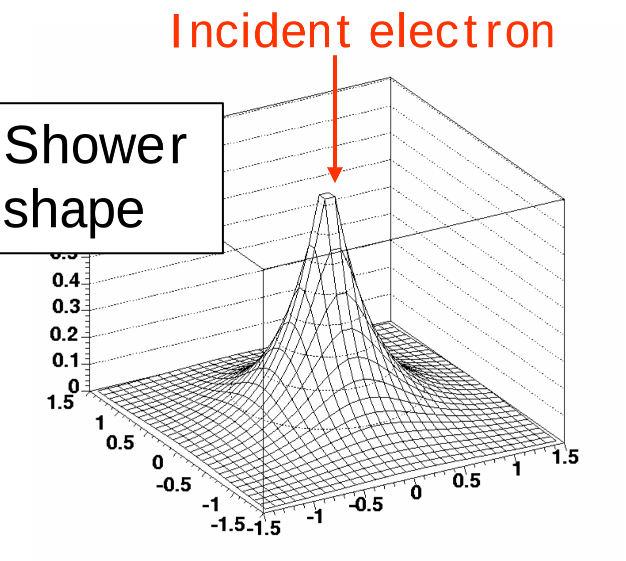


Per plane: 2 staggered layers with 1 mm wide strips

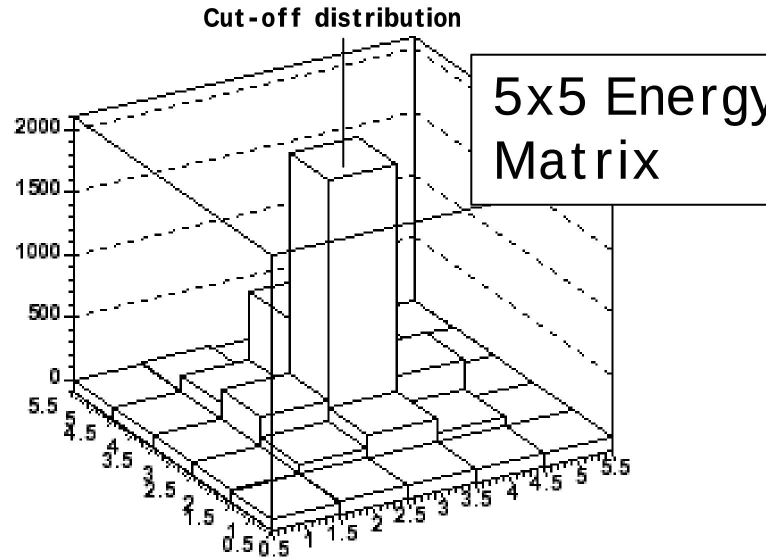


Per orientation 4 points:

$$\sigma(x) = \sigma(y) = 145\ \mu m$$



Crystal size
2.2 x 2.4 cm



Impact on crystal centre: 82% in central crystal and 96% in a 3x3 matrix (use 3x3)

General Idea:

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

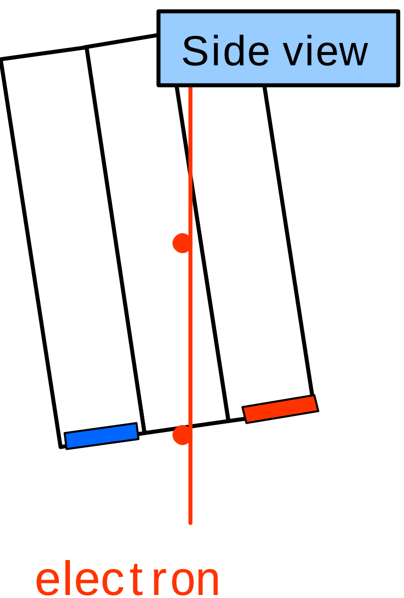
- The position of the crystal (η_i, φ_i) or (x,y)
- Two methods using different weights: $w_i = E_i$ or $w_i = w_0 + \log\left(\frac{E_i}{\sum_j E_j}\right.$

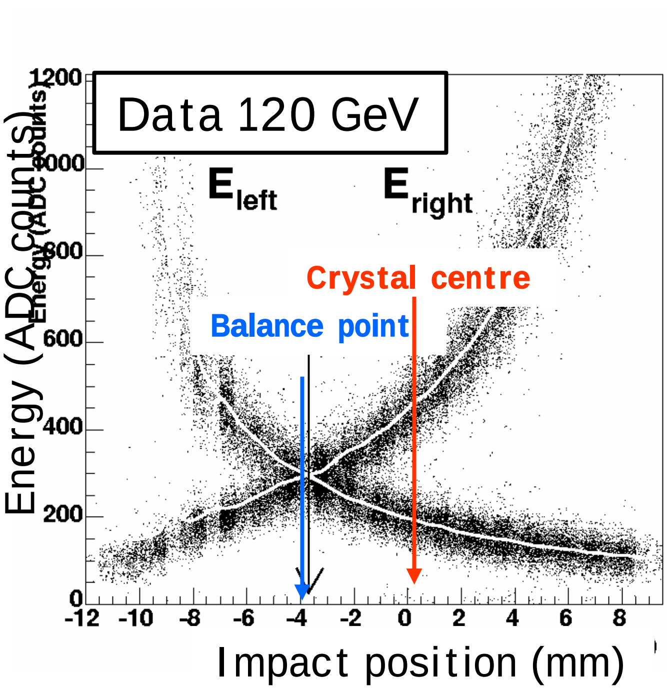
Defining THE position of the crystal:

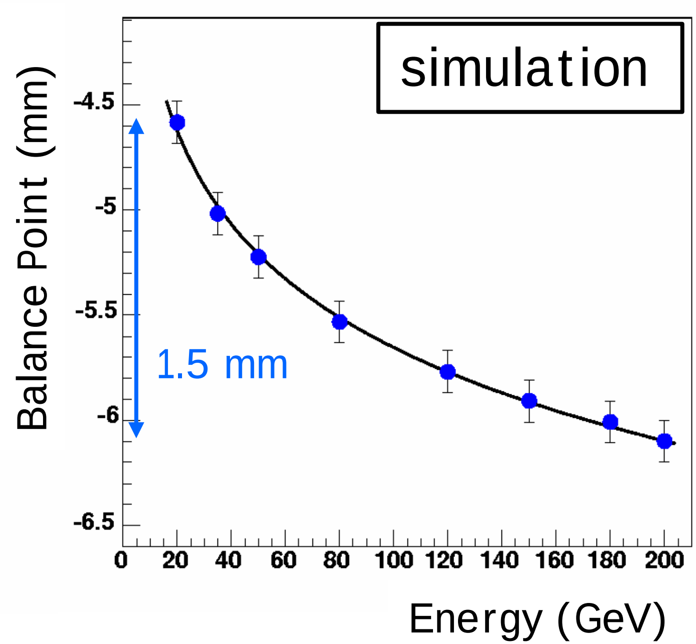
- Crystals are off-pointing and tilted by in h and j
- Depth of shower maximum is energy dependent

} the characteristic position is energy dependent

As an example: the balance point in X

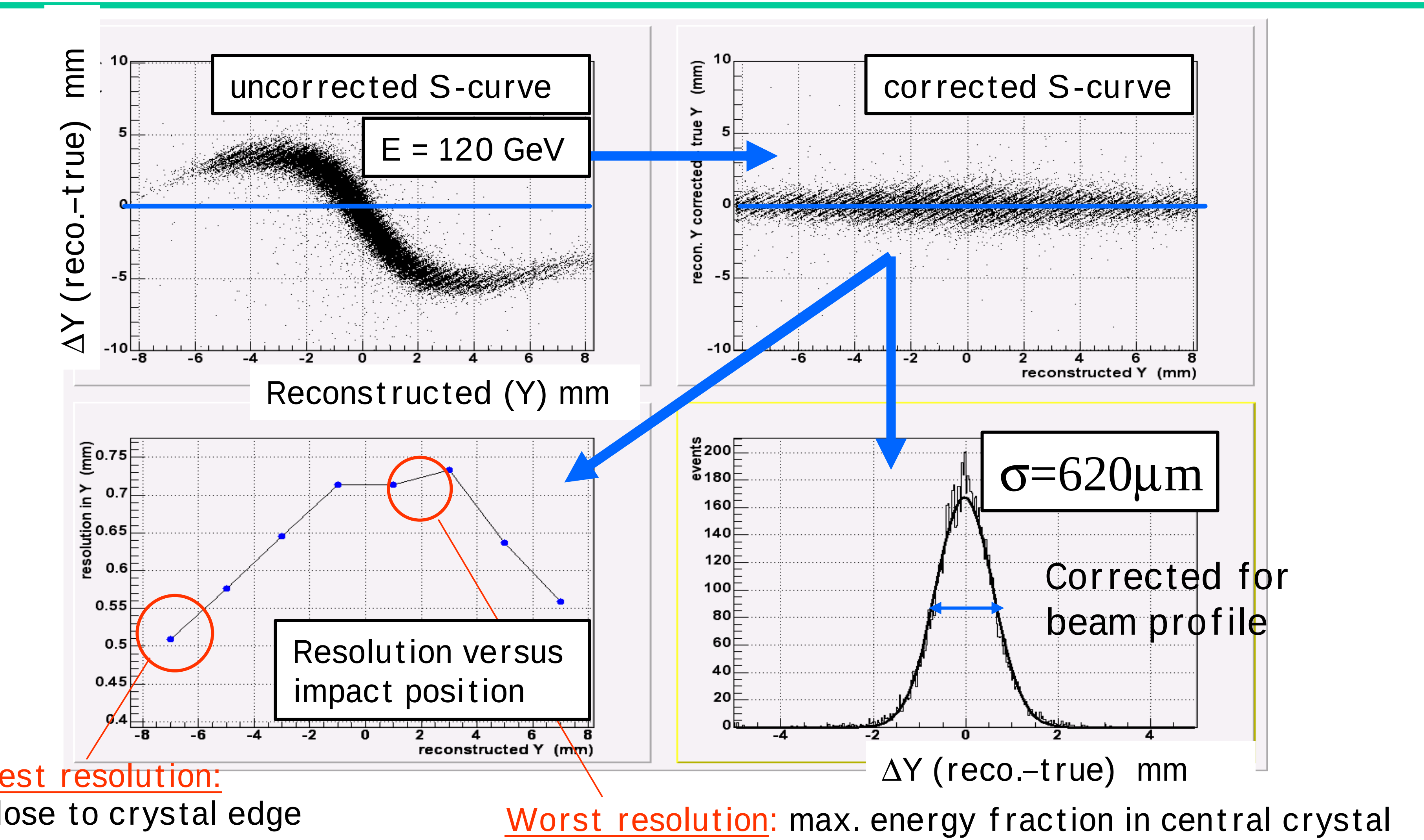






Reconstruction Method 1: Linear weighting

$w_i = E_i$



- Requires a correction that is f(E,η,φ)

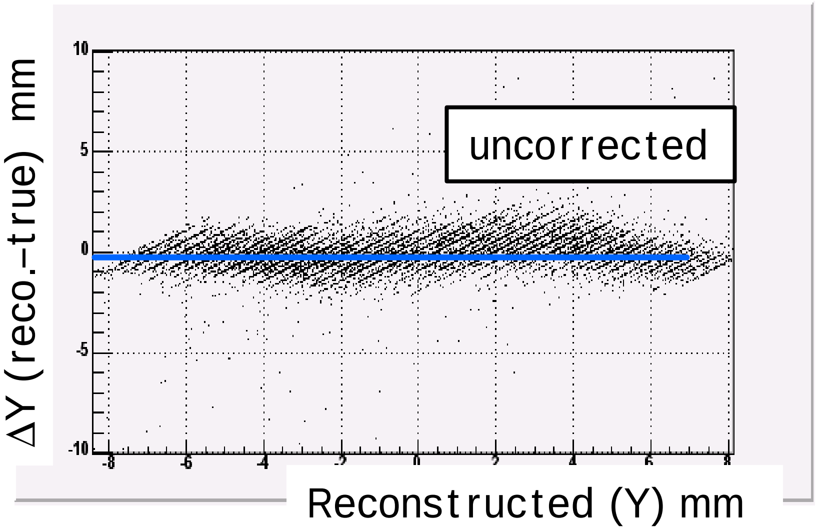
Reconstruction Method 2: Logarithmic weighting

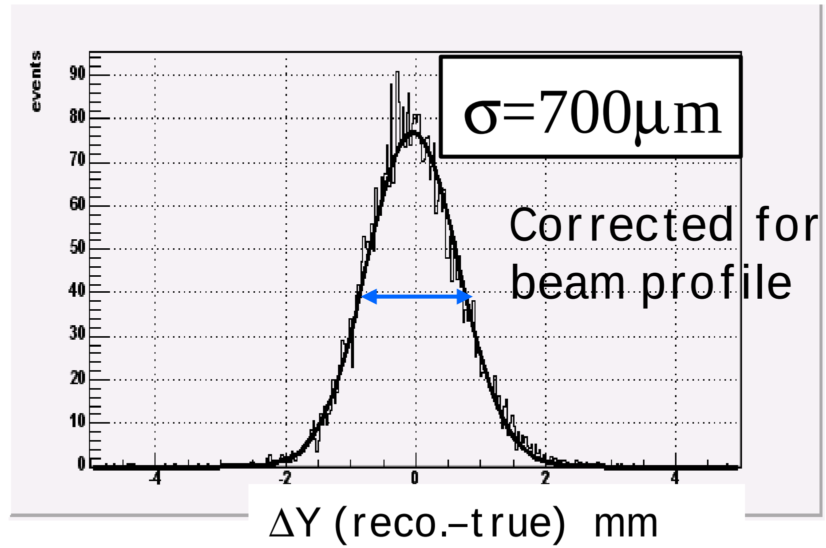
$$w_i = w_0 + \log\left(\frac{E_i}{\sum_j E_j}\right)$$

(all weights should be ³ 0.)

Minimal (relative) crystal energy included in computation

Optimal W_0 = 3.80 (min. crystal energy is 2.24% of the energy contained in the 3x3 matrix

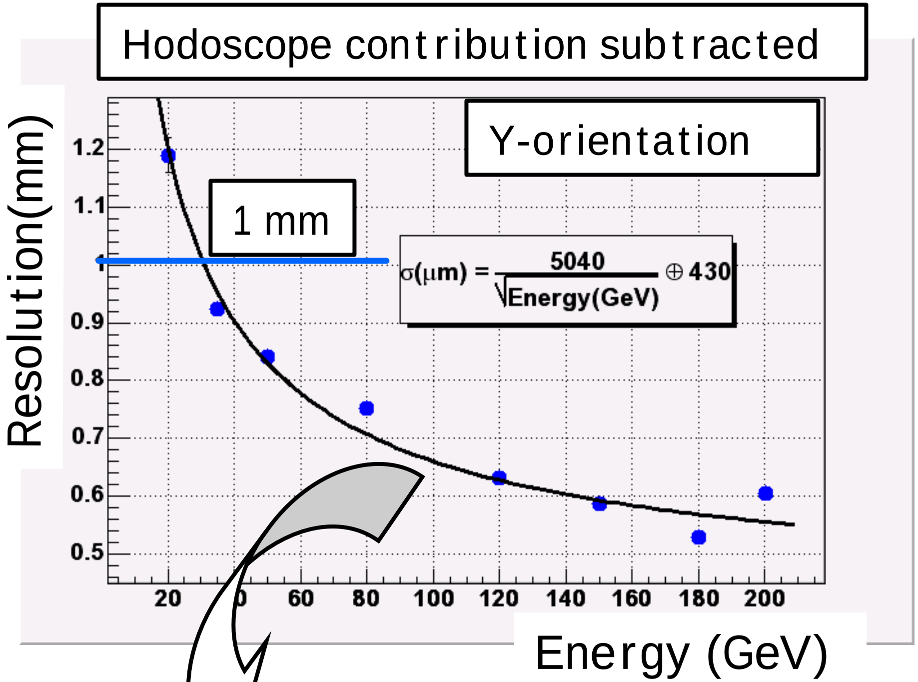




- Resolution is now more flat over the crystal surface
- no correction needed that is f(E,η,φ)

Impact Position Resolution versus energy (x, y)

- Resolution on impact position using the logarithmic weighting method:



$$s_Y (mm) = \frac{5040}{\sqrt{E}} \oplus 430$$

- Resolution in X slightly worse:
  - Different staggering of crystals
  - Different crystal dimensions

    10% larger in X than in Y
  - Different (effective) angle of incidence

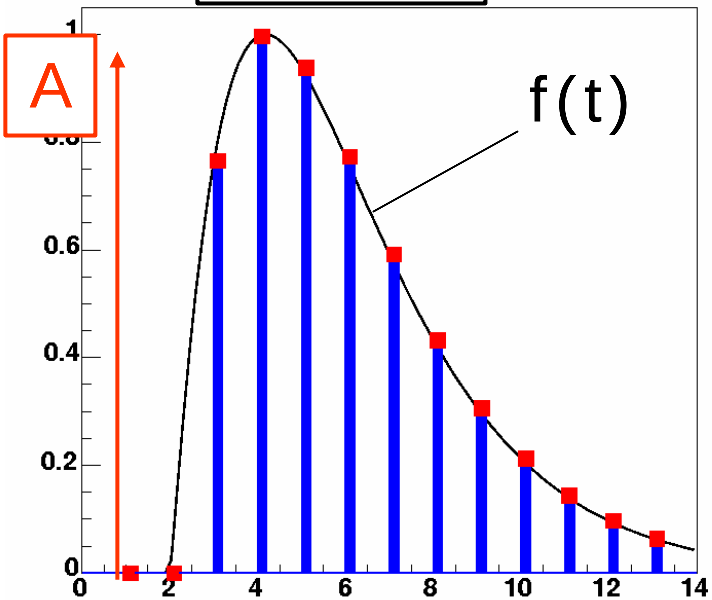
Conclusions

- **Pulse (Energy) reconstruction:**
  - ECAL strategy to reconstruct pulses in the testbeam set-up evaluated
  - Optimized and existing ‘universalities’ are implemented.
  - Energy resolution reaches target precision using the designed 0.25 mm front-end electronics

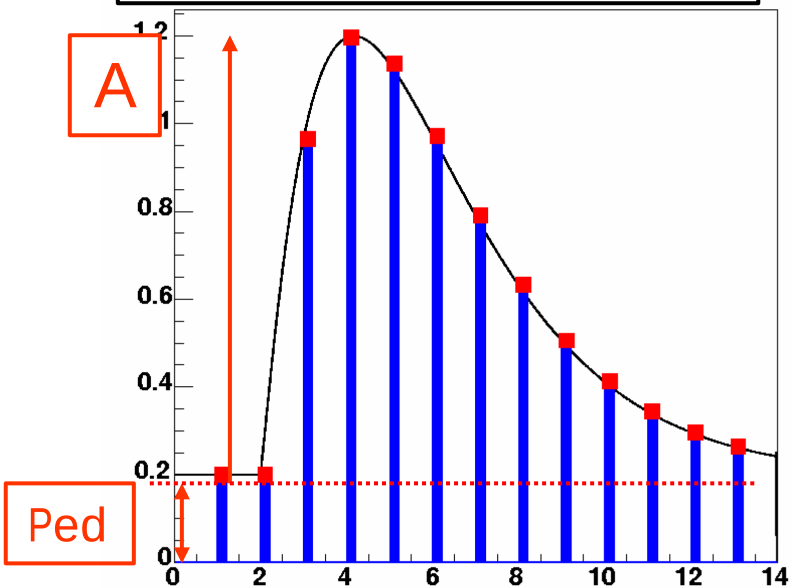
- **Impact point reconstruction:**
  - Evaluated two approaches and extracted resolutions using real data
  - Above 35 GeV: σ_X & σ_Y < 1 mm

Backup slides

pure signal



signal + remaining pedestal



$$w_i = \frac{f_i}{\sum_i (f_i^2)}$$

$$w_i = (l f_i + g)$$

$$l^{-1} = \sum_i (f_i^2) - \left(\sum_i f_i\right)^2 / n$$

$$g = \frac{-l}{n} \sum_i f_i$$

n samples