SiW Ecal physics prototype
Six years of running experience

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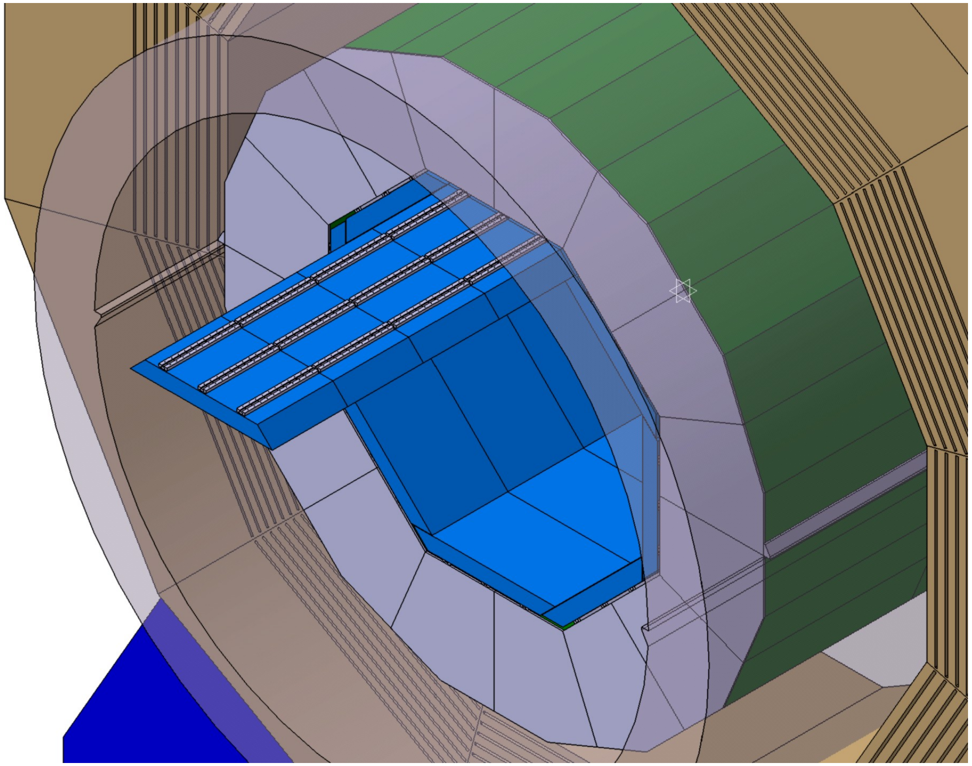
SiW Ecal - Basics

The SiW Ecal in the ILD Detector



Basic requirements

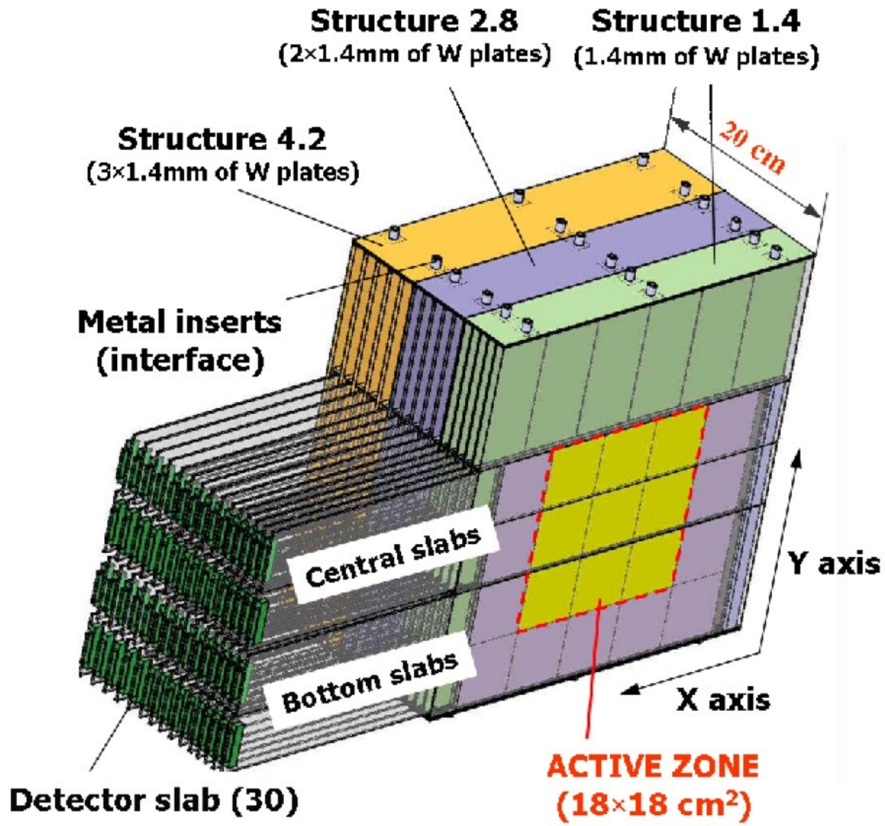
- Extreme high granularity
- Compact and hermetic

Basic choices

- Tungsten as absorber material
  - X_0=3.5mm, R_M=9mm, λ_I=96mm
  - Narrow showers
  - Assures compact design
- Silicon as active material
  - Support compact design
  - Allows for pixelisation
  - Large signal/noise ratio

SiW Ecal designed as particle flow calorimeter

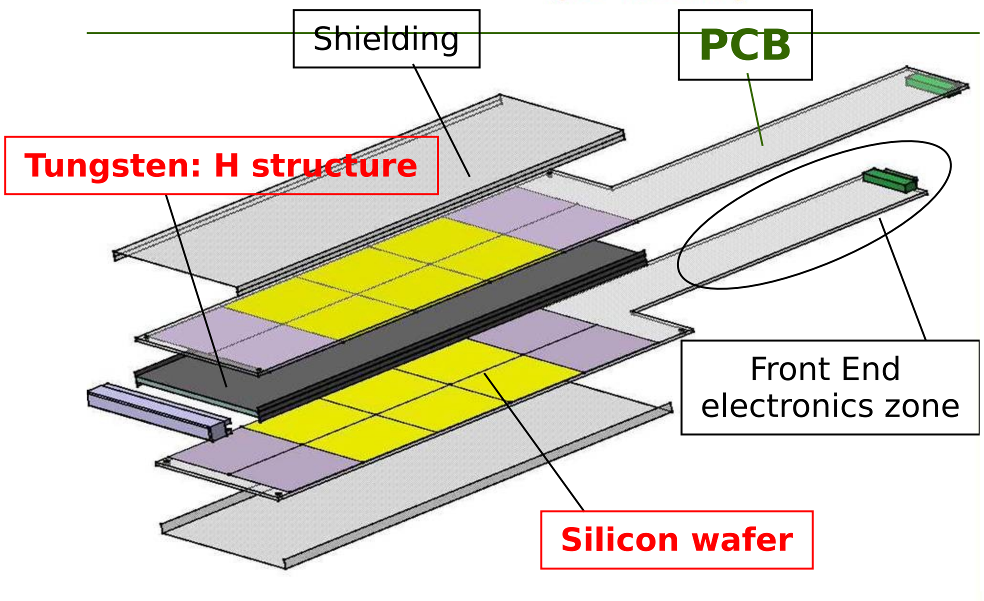
SiW Ecal Physics Prototype



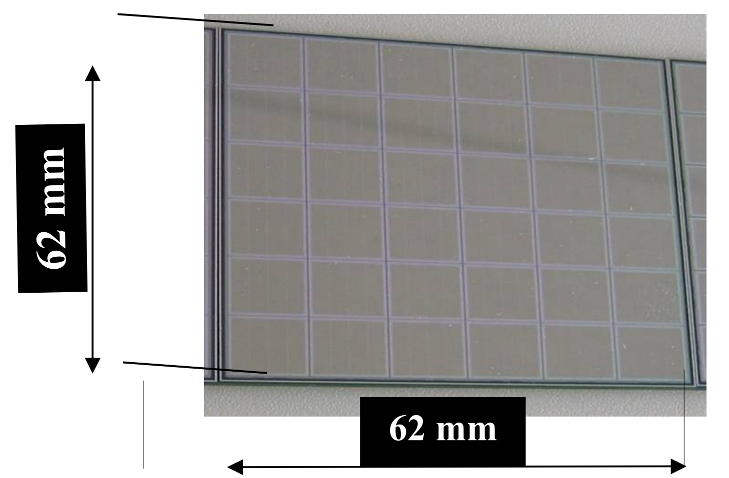
30 layers of tungsten:

- 10 x 1.4 mm (0.4 X_0)
- 10 x 2.8 mm (0.8 X_0)
- 10 x 4.2 mm (1.2 X_0)
  - 24 X_0 total, 1 λ_I

½ integrated in detector housing
⇒ Compact and self-supporting detector design



6x6 PIN diode matrix
Resistivity: 5kΩcm - 80 (e/hole pairs)/µm



Thickness:
525µm

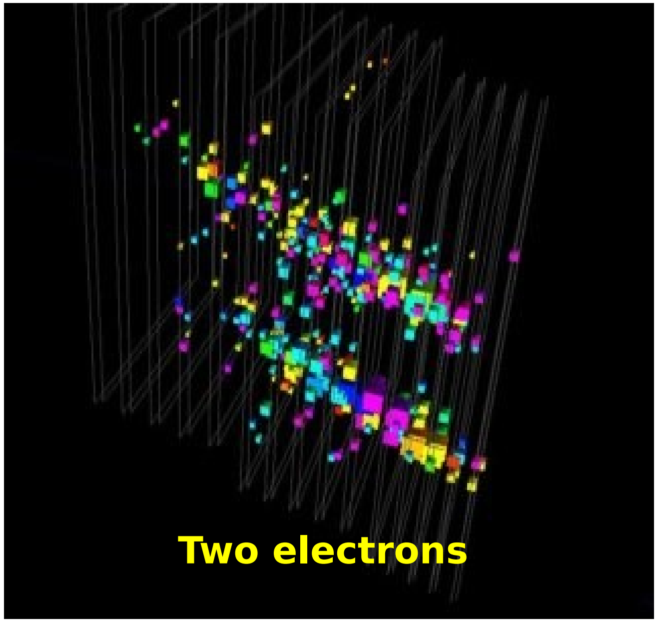
Total: 9720 Pixels/Channels

Large scale beam tests

Experimental setup

Zoom into Ecal

Particle distance~ 5 cm
→ No confusion !!!



- 2005 Ecal 2 / 3 equipped

- 2006, Ecal 2 / 3 equipped
  Low energy electrons (1-6 GeV at DESY), high energy electrons (6-50 GeV at CERN)

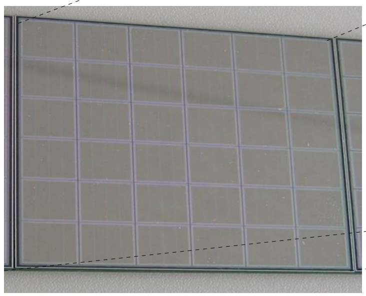
- 2007, Ecal nearly completely equipped
  High energy pions (6-120 GeV CERN), Tests of embedded electronics

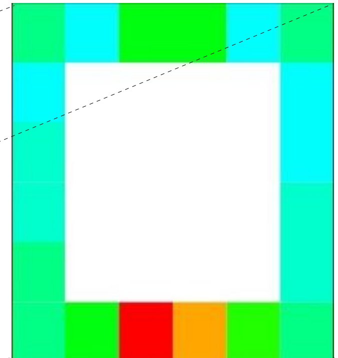
- 2008 FNAL, Ecal completely equipped
  Pions at low energy,

- 2011 FNAL, Ecal completely equipped

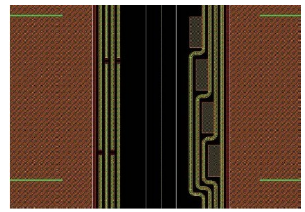
R&D for silicon wafers

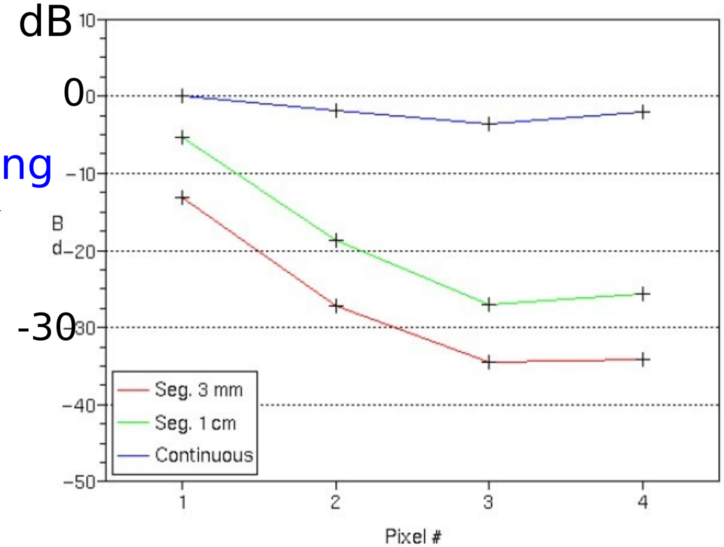
Square pattern in wafer response





Segmented guardring



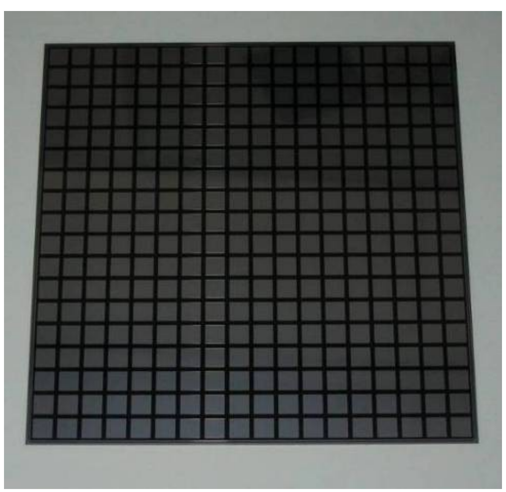


Xtalk continous guardring <-> Pixel

Attenuation of Xtalk

Beyond the physics prototype

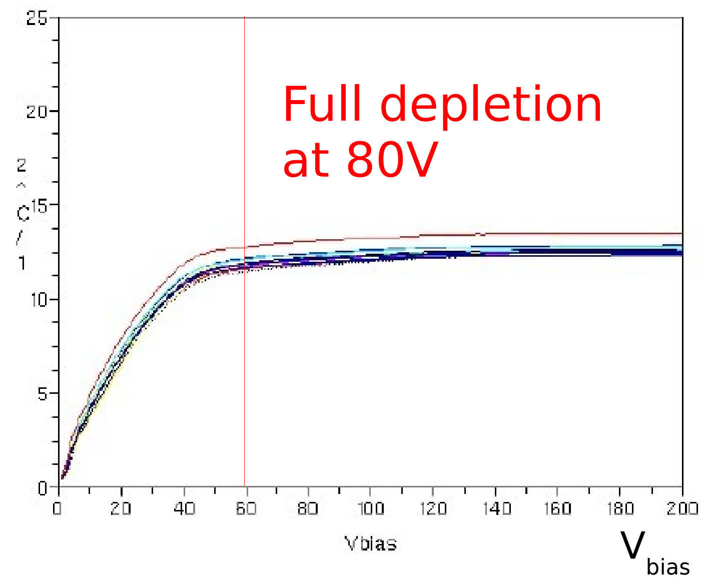
Wafers with smaller pixels



5x5 mm² pixels
~optimal "ILD width"

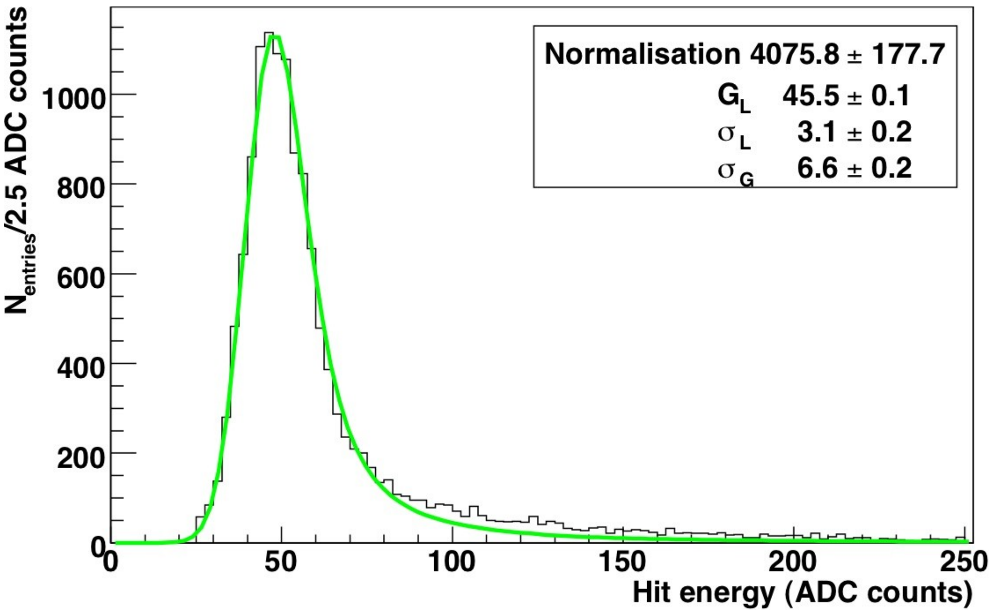
Thickness: 325 µm

Characterisation



Breakdown at ~500 V

Calibration – Uniformity of response



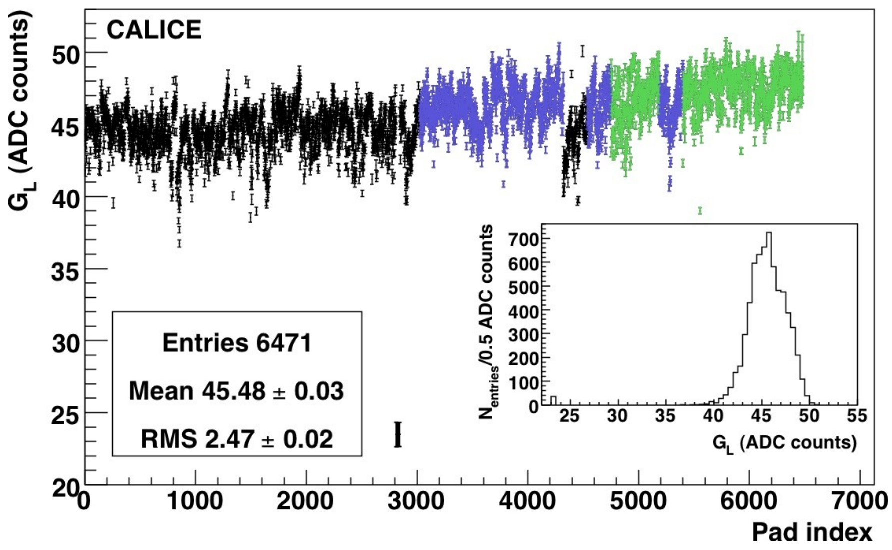
Calibration with with wide spread μ-beam

18 Mio. Events
Uniform response of all cells
only 1.4‰ dead cells

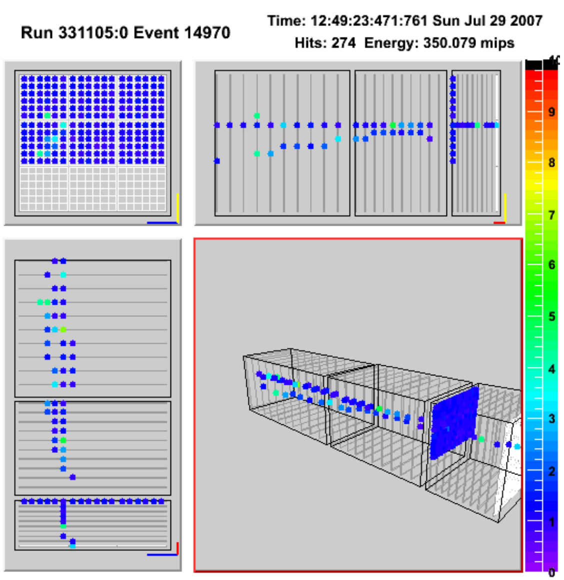
Differences in response can attributed to different

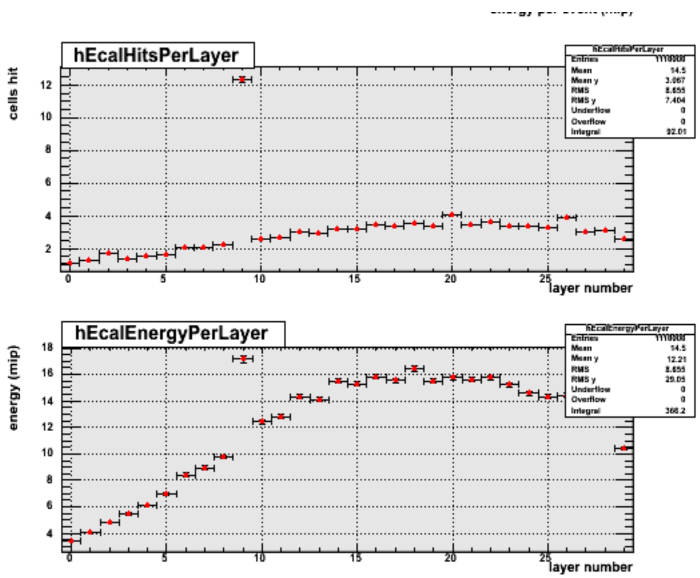
- Manufacturers
- Production series

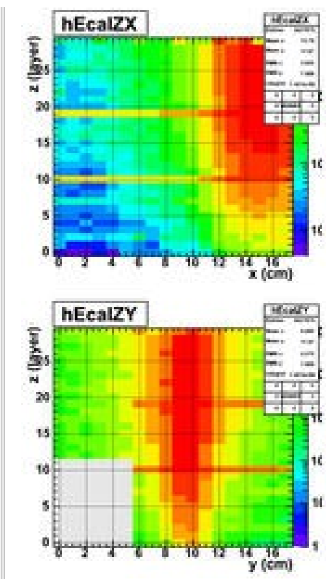
Experience to deal with different manufacturers and production series
Essential for final detector
~3000m^2 of Silicon needed



- Fake differential in chip PHY3 makes pedestals strongly dependend on exterior effects
- Baseline of a whole PCB is changing dynamically
- Pedestal calculated in the pedestal events is no longer valid
- Calculation wrt to this pedestal may cause much too high values of energy deposit



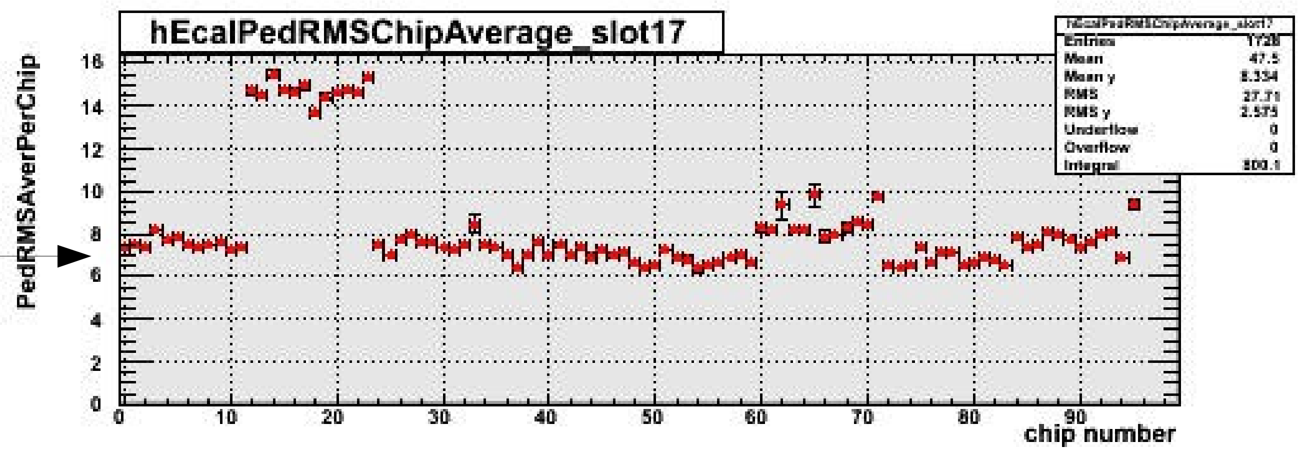




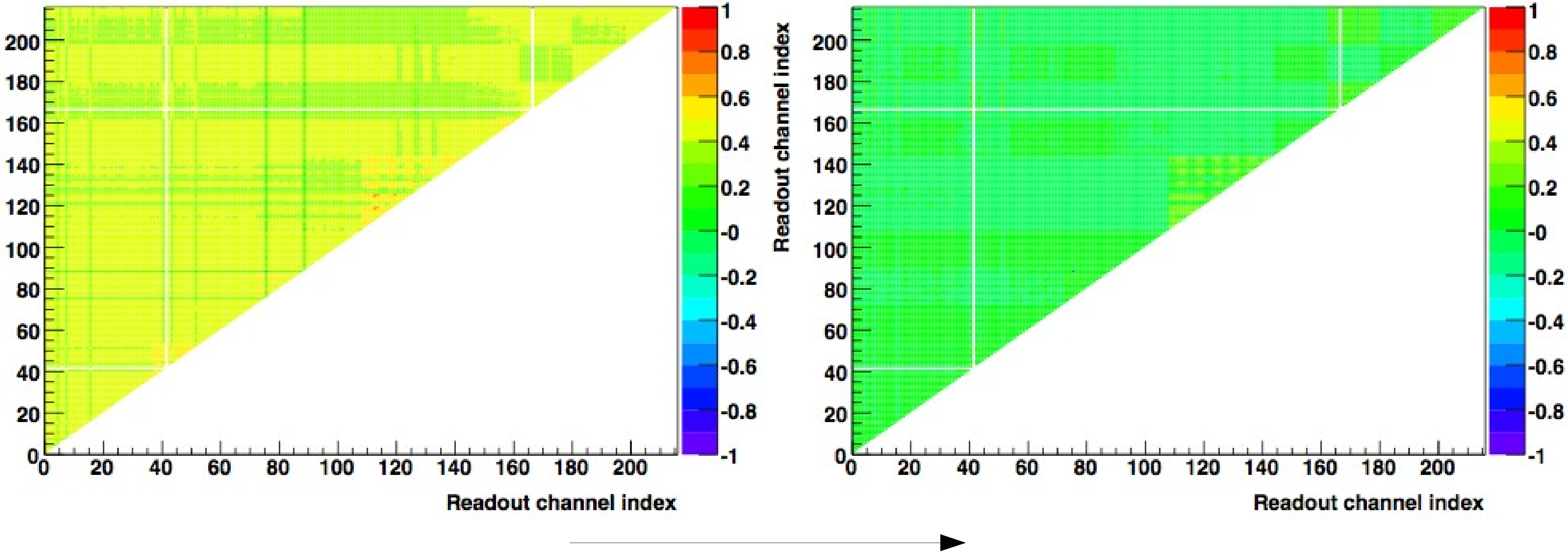
Further noise problems

- All noise values for the cells on a PCB are too high
- Very sensitive to the delivered power, thus to the power supplies and/or the power cables
- Changing of power cable can solve the problem
- Several cables marked as „problematic“ – need replacements
- Access difficult in many cases (danger to do more harm than good)

Typical noise value



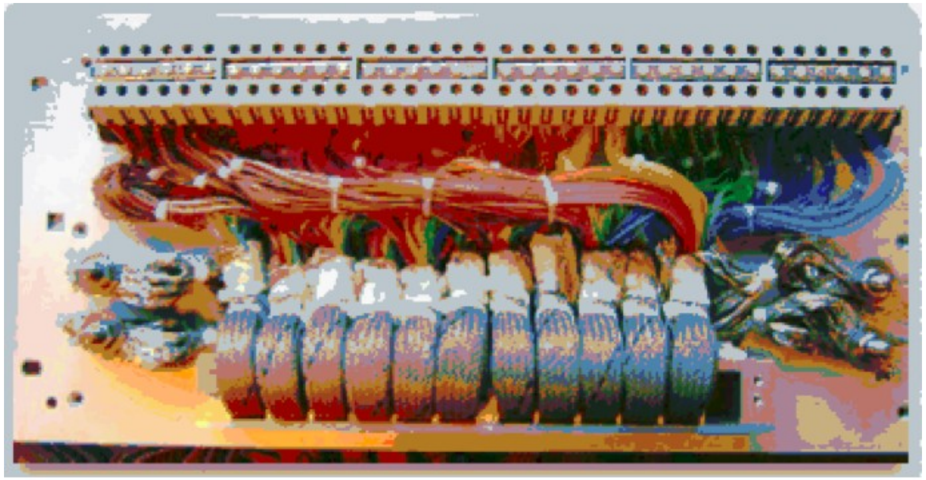
Offline correction of correlated noise



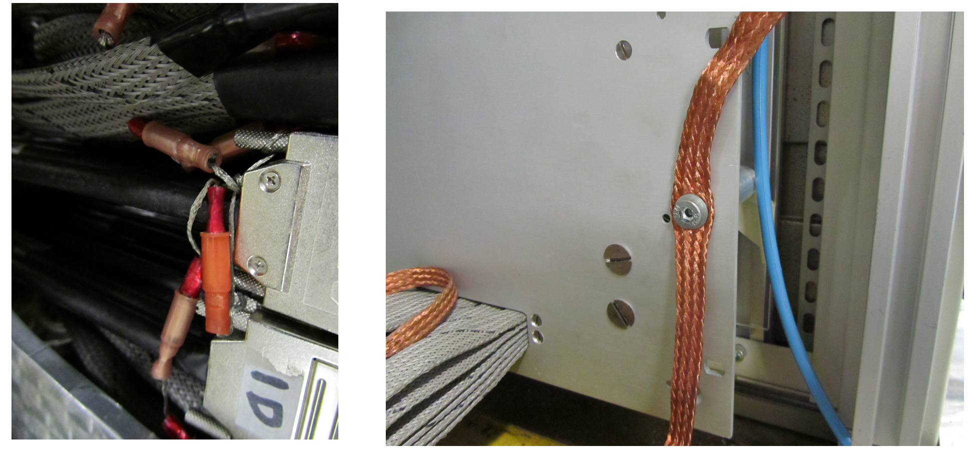
Application of offline correction

Noise problems annoyed shift crews but **don't** compromise data analysis

Fighting the correlated noise



New patch panel (2008)



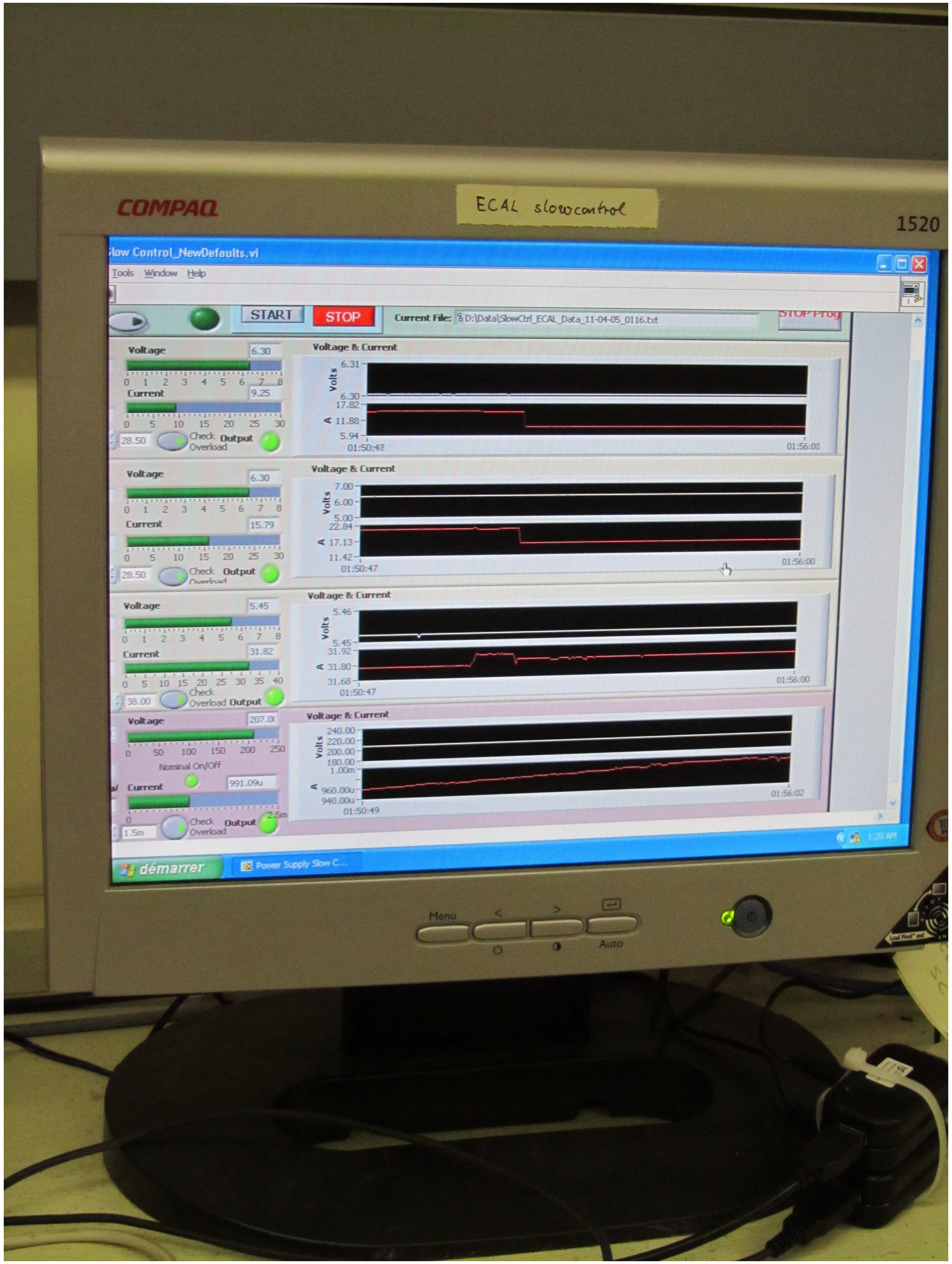
Proper grounding of Ecall layers and DAQ

New power connectors

Net effect:

< 2008 Daily error bursts
2008 long periods w/o noise problems
2011 Only very occasional noise problems

Ecal slow control and diagnostics



- Ecal SC was easy to operate and Sufficient for 99% of the running time

... the remaining 1%

- Only monitoring of entire system

- No access/monitoring of individual Components

=> Occuring problems required Always manual intervention

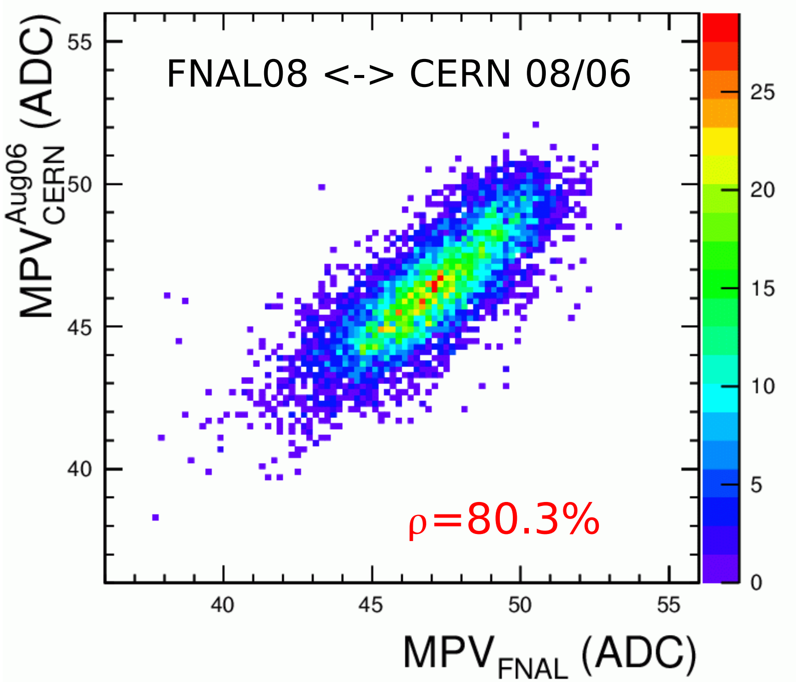
=> Time consuming and accident prone

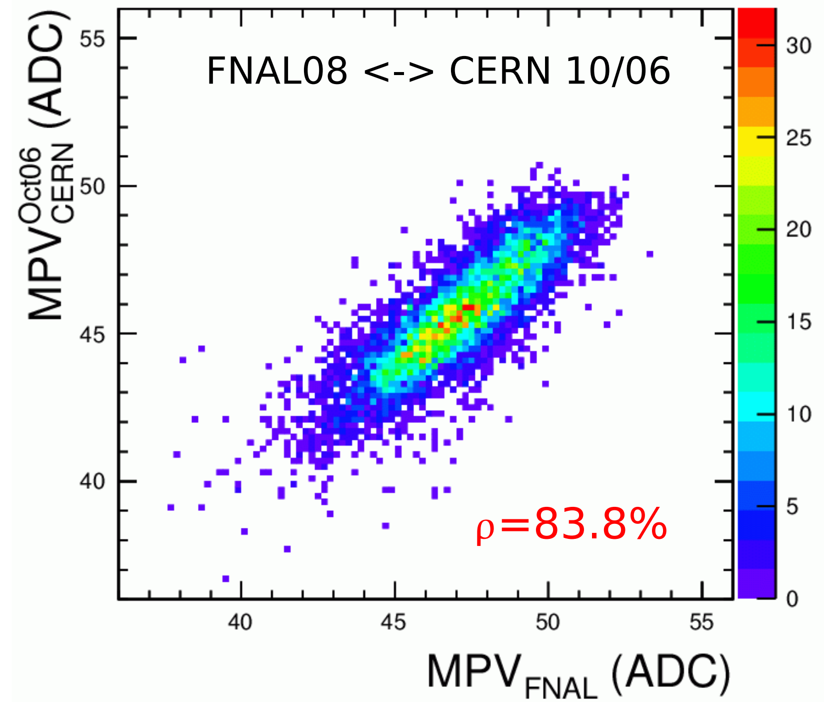
Example: Wafer break through (?) in 2011
Could only be diagnosed upon disassembly of the detector

Stability of detector – Example calibration

Calibration constants in different beam test campaigns

PhD Thesis H. Li, LAL





High correlation between calibration constants

Constants obtained in 2007 were still applied for 2011 online monitor

No sign of ageing

Wafer Breakthrough in 2011?

Summary and conclusion

- Successful running of SiW Ecal between 2005 and 2011

- Quick installation and easy operation

- Stable response over 6 years

- Occurring noise problems could be largely remedied by careful revision of detector grounding
  Offline corrections

- Calibration procedure fairly simple

- Slow control and diagnostics to be improved for next prototype

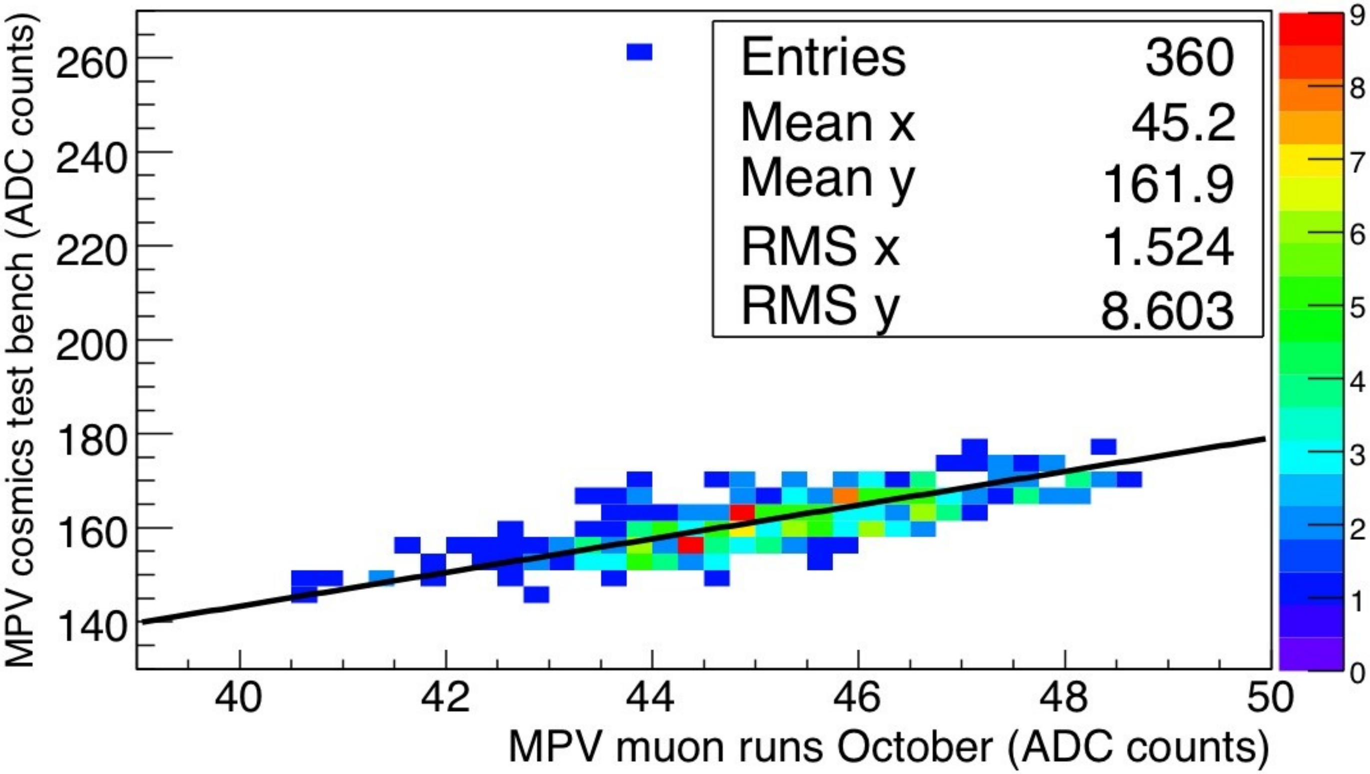
Backup Slides

Stability of calibration?

Important Criterium during evaluation process of detector concepts

Affects both: precision and operability of detector: ~10^8 calo cells in LC Detector

Calibration Constants on testbench and in beam test campaign

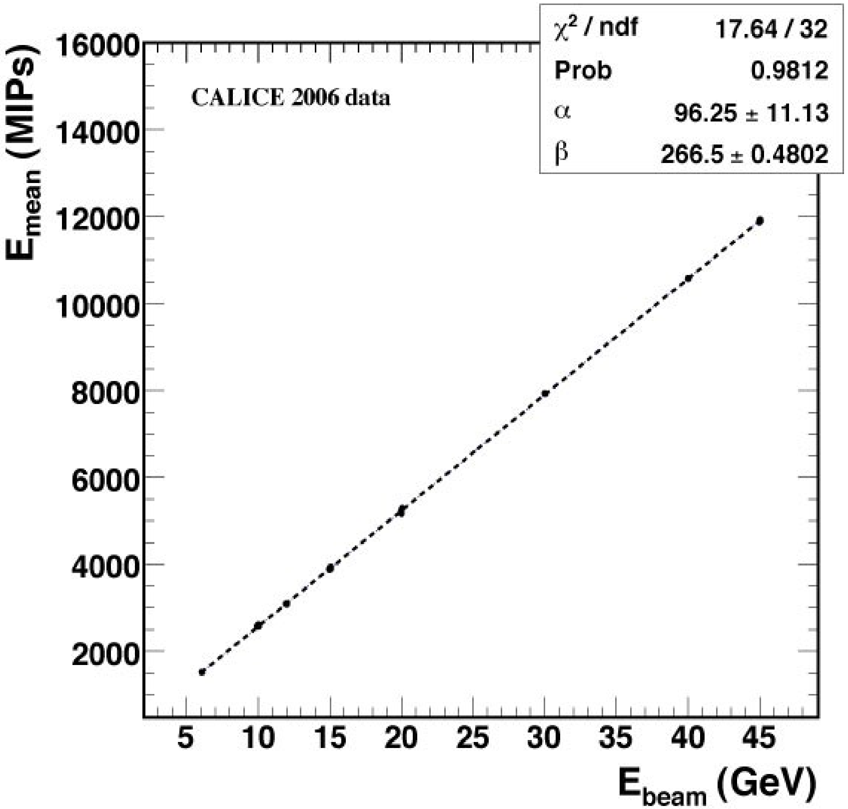


High Correlation between calibration constants

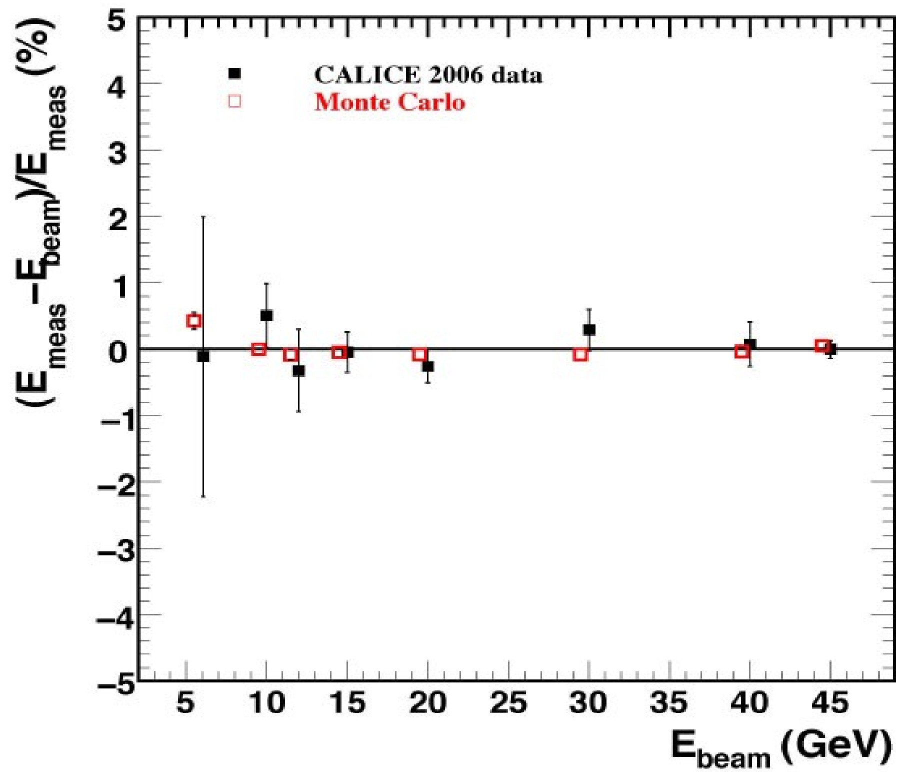
For “final” detector:
Detector modules can be calibrated in beam test prior to installation

Linearity of response

Overview



Residuals

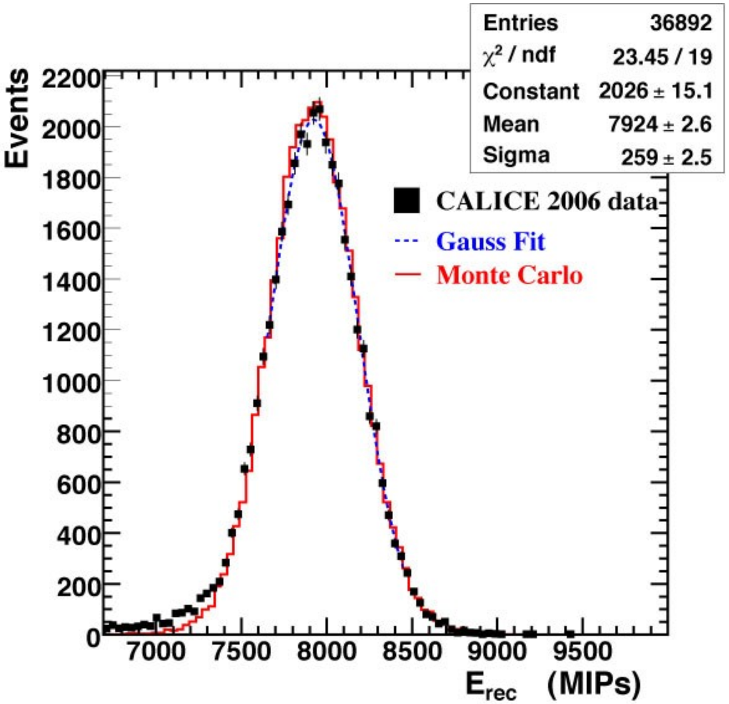


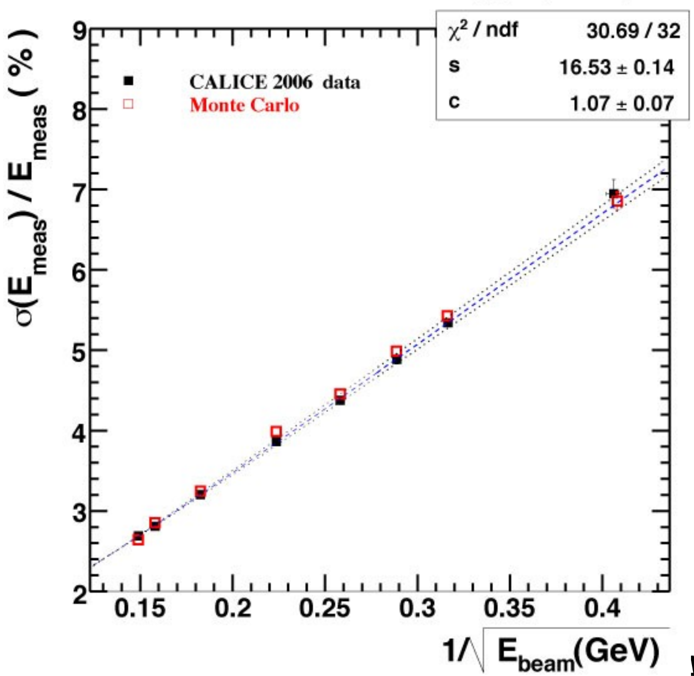
- Highly linear response over large energy range

- Linearity well reproduced by MC
  MIP/GeV ~ 266.5 [1/GeV]

- Non-linearity O(1%)

Energy resolution





Example 30 GeV electron beam:

Gaussian like calorimeter response

Resolution curve shows typical √E dependency

$$\frac{\Delta E_{meas.}}{E_{meas.}} = \left[\frac{16.6 \pm 0.1\,(stat.)}{\sqrt{E\,[\mathrm{GeV}]}} \oplus (1.1 \pm 0.1) \right] \%$$

- Resolution well described by MC
- Confirms value used in LOI

Design emphasises spatial granularity over energy resolution

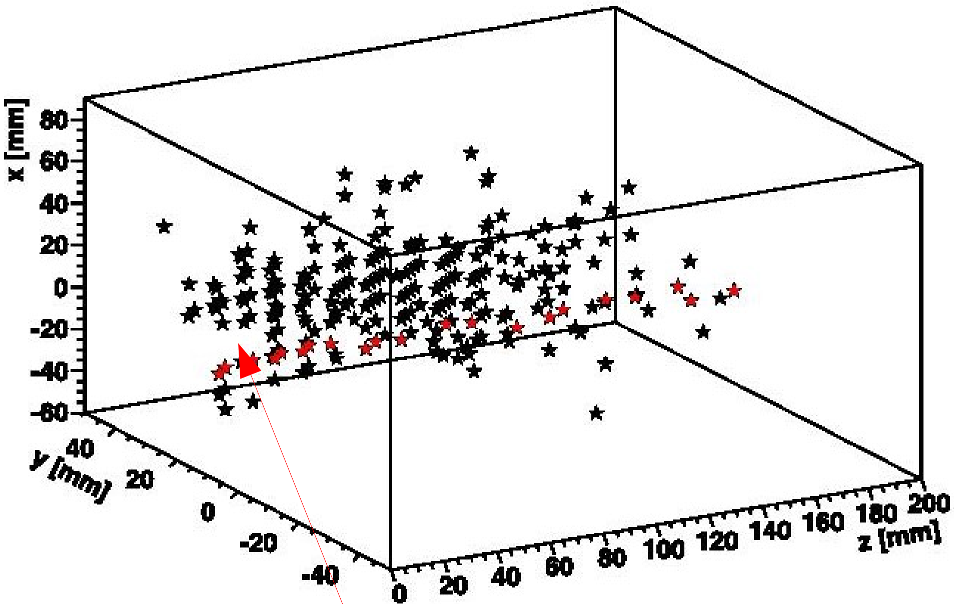
Calorimeter for Particle Flow

Exploiting the high granularity – Particle separation

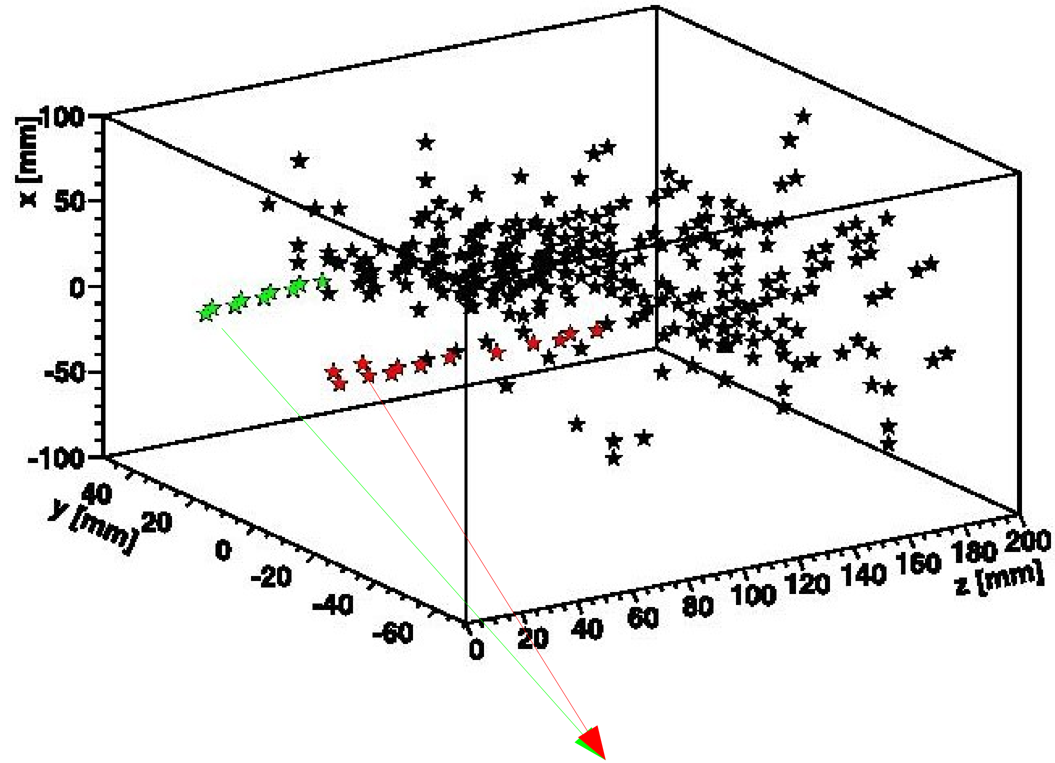
High granularity allows for application of advanced imaging processing techniques

E.g. Hough transformation

Events recorded in test beam



Secondary muon within electron shower

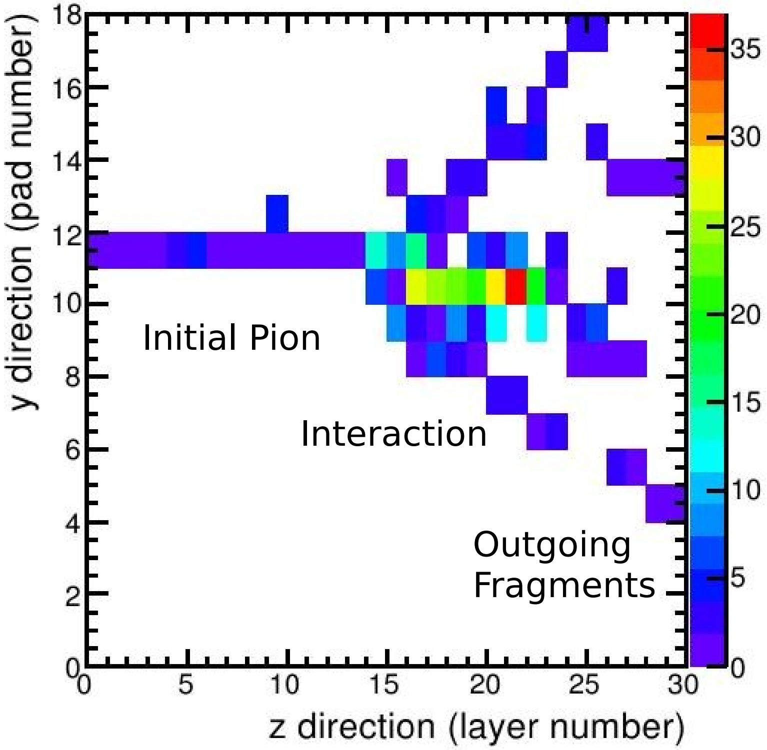


Two pions entering the SiW Ecal

Granularity and hadronic cascades

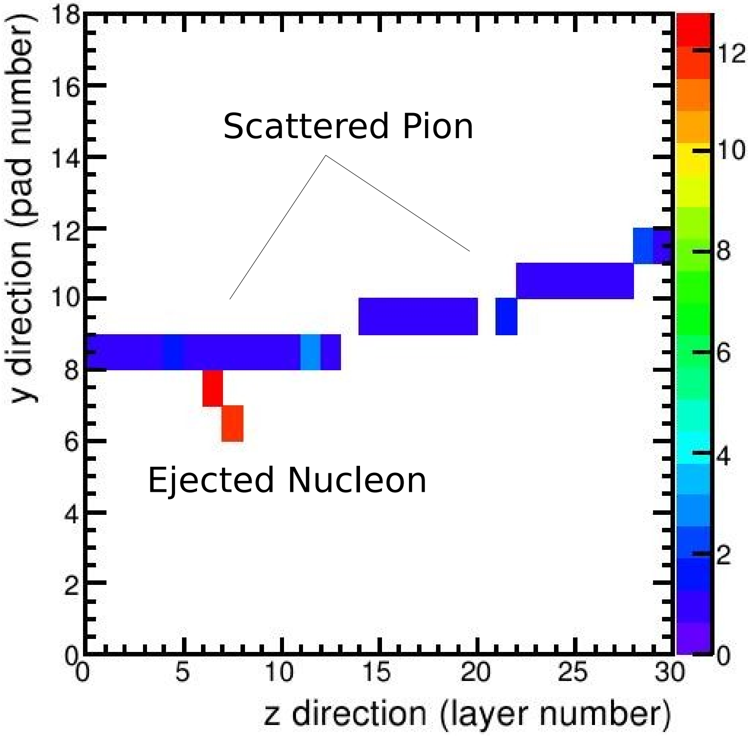
(Start of) Hadronic showers in the SiW Ecal

Complex and impressive



Inelastic reaction in SiW Ecal

Simple but nice



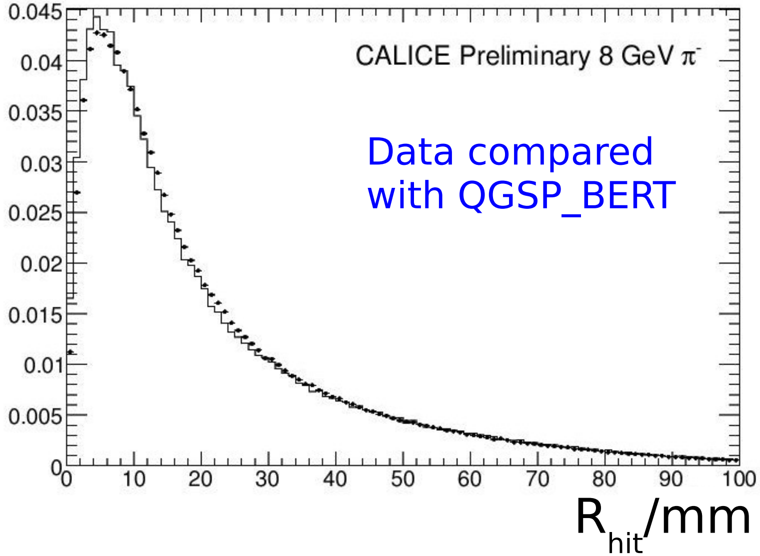
Nucleon ejection in SiW Ecal

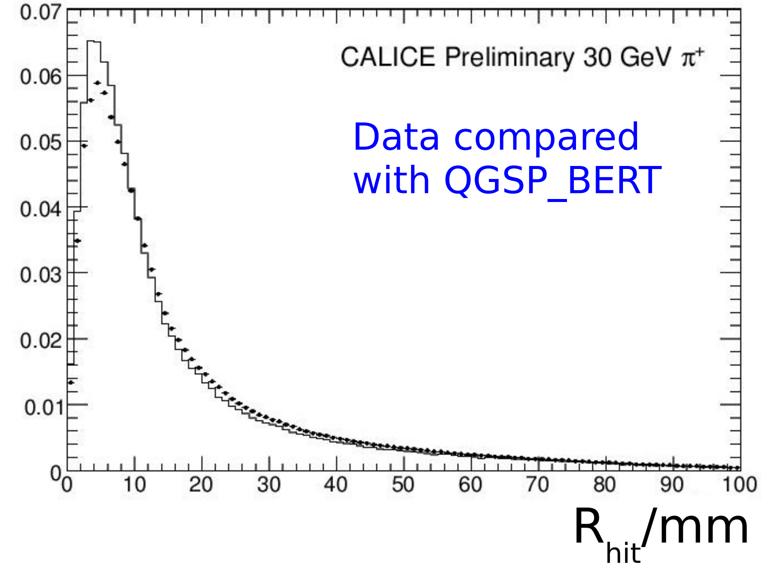
High granularity permits detailed view into hadronic shower

Transversal shower profiles and shower radius

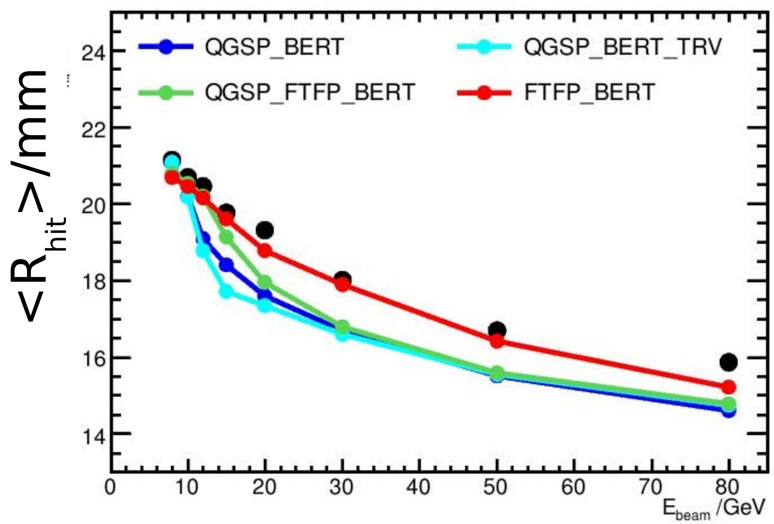
Affects overlap of showers <-> Importance for PFA

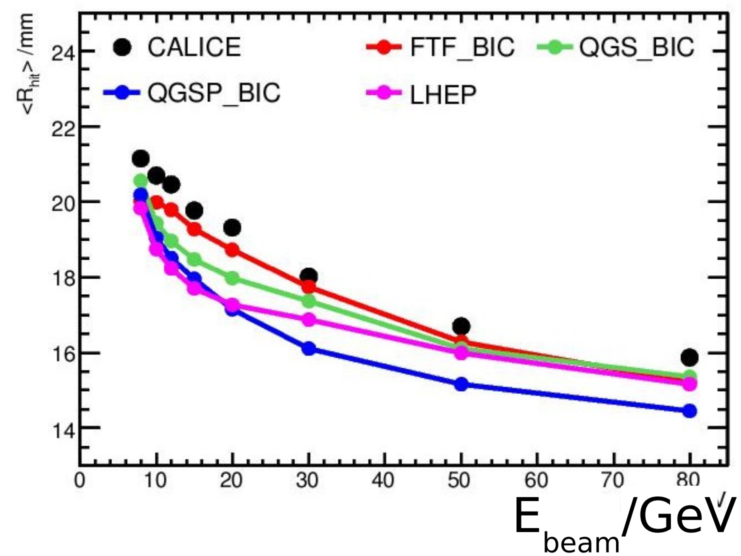
Transverse profiles





Shower radius

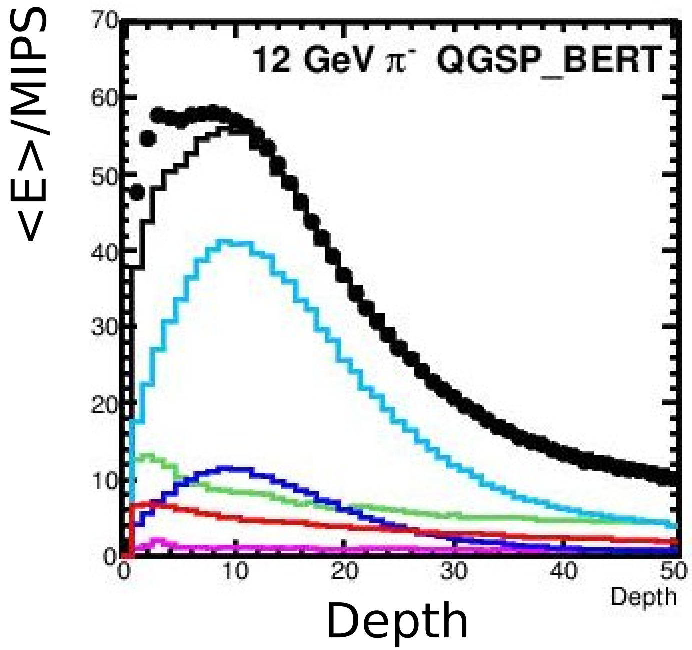




Small energy ok for 'BERT' models
Towards high energy: Underestimation of content in SiW Ecal
Relatively small difference between models (~15%)

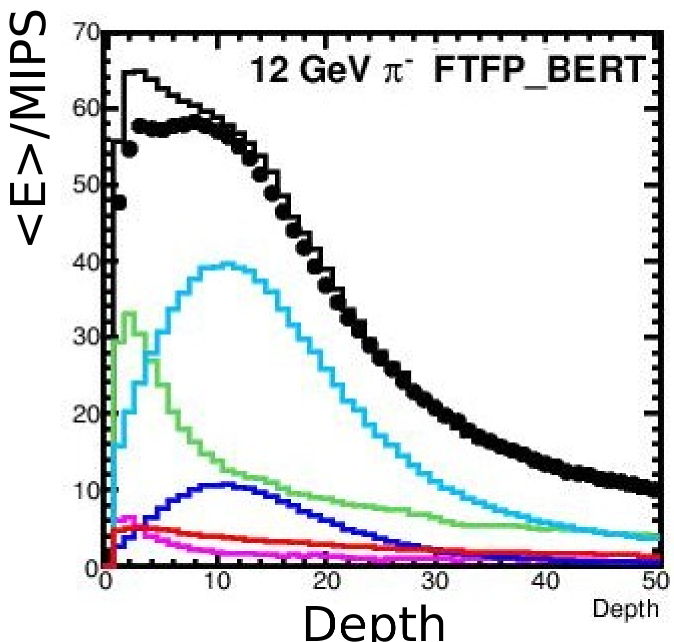
Longitudinal energy profiles

Sensitivity to different shower components



Shower components:

- electrons/positrons
  knock-on, ionisation, etc.
- protons
  from nuclear fragmentation
- mesons
- others
- sum



Significant difference between Models

- Particularly for short range component (protons)

Granularity of SiW Ecal allows (some) disentangling of components

Further studies for shower decomposition are ongoing