SiW ECAL Technological Prototype
Test beam results

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2nd AIDA Annual Meeting INFN Frascati

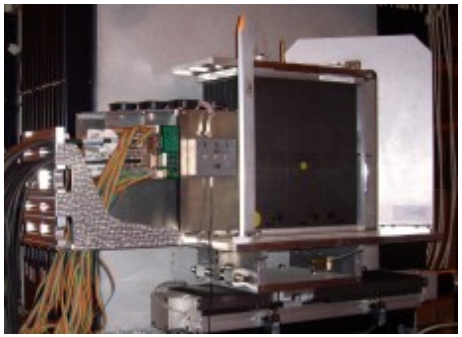
CALIIMAX-HEP
2010 BLANC 0429 01

SiW ECAL R&D

Physics Prototype

Proof of principle

2003 - 2011



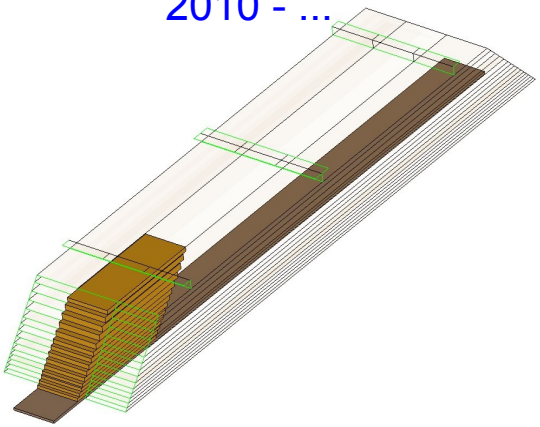
Number of channels : 9720

Weight : ~ 200 Kg

Technological Prototype

Engineering challenges

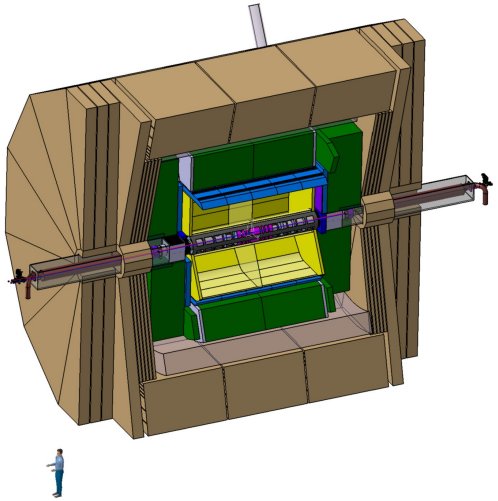
2010 - ...



Number of channels : 45360

Weight : ~ 700 Kg

LC detector



ECAL :

Channels : ~100 10^6

Total Weight : ~130 t

SiW Ecal within AIDA


Silicon sensors (51 kEuro+18 kEuro)

Mechanical aspects – Cooling (27 kEuro)


Ecal Front End Electronics (31 kEuro)

Former EUDET partners

- Project description: ECAL extension of the EUDET Module

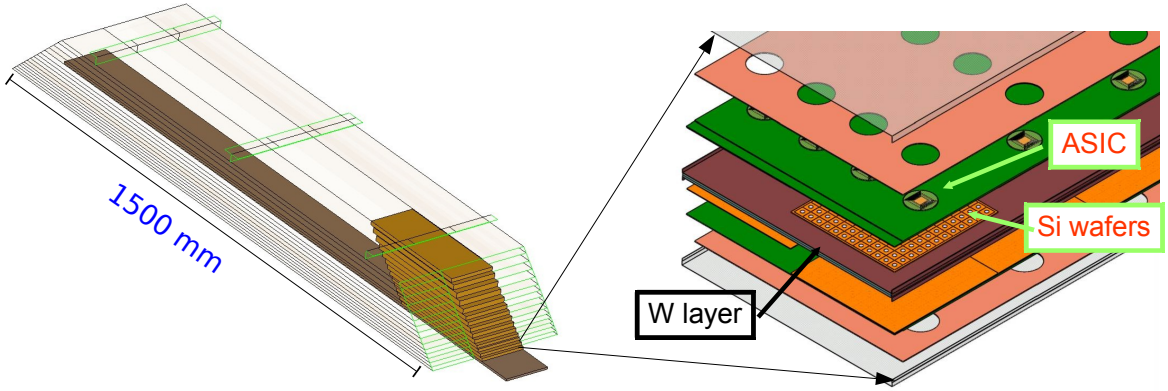
- Project task: Electromagnetic calorimeter of at least 18x18 cm^2 area
  i.e. several short ASUs assembled in vertical direction
  MS 46 to be delivered in month 36

Technological prototype

Technological solutions for the final detector

Construction start: 2010

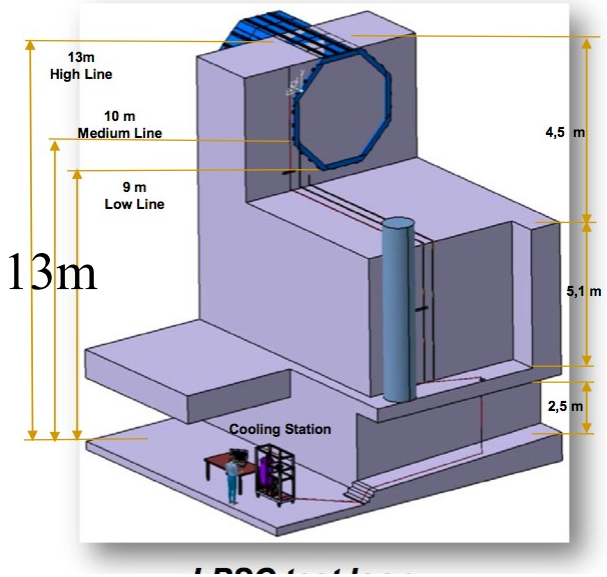
Test beam: 2012



- Realistic dimensions
- Integrated front end electronic
- Small power consumption (Power pulsed electronics)

Large components – Alveolar structure and cooling

1.5 m long alveolar structure to house Ecal layers
3/5 of a barrel module of the ILD concept
Tungsten plates wrapped into Prepreg
Planar within 5mm
Work on longer structures are ongoing



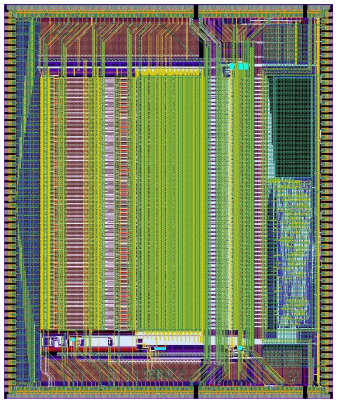
Reminder EUDET studies:
Evacuation of (residual) power of 0.2-0.35 W/layer

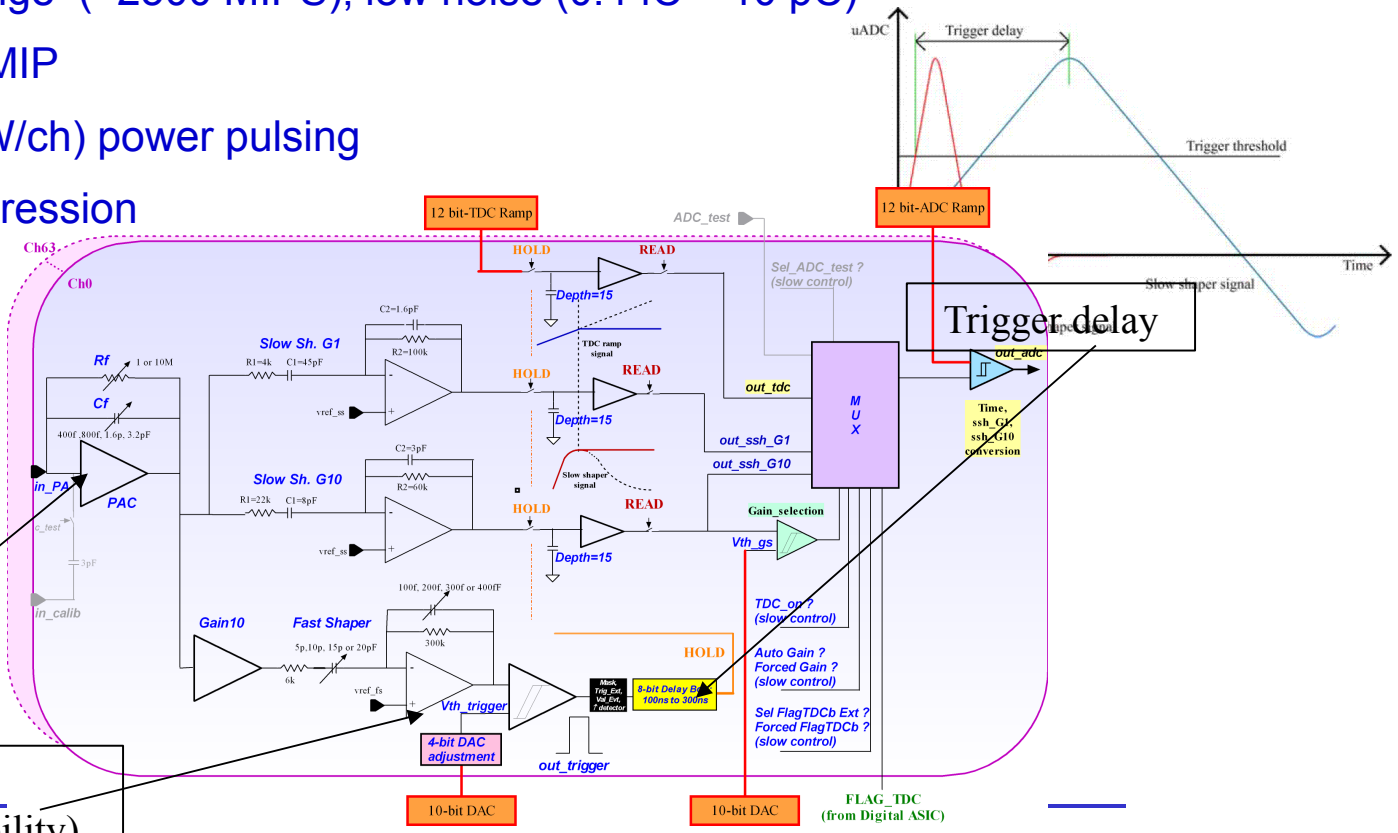
Development of a leak less cooling system
for a full detector

Front end electronics: SKIROC

SKIROC (Silicon Kalorimeter Integrated Read Out Chip)

- SiGe 0.35µm AMS
- 7.5 mm x 8.7 mm
- High integration level (variable gain charge amp, 12-bit ADC, digital logic)
- 64 channels
- Large dynamic range (~2500 MIPS), low noise (0.4 fC – 10 pC)
- Auto-trigger at ½ MIP
- Low Power: (25µW/ch) power pulsing
- On chip zero suppression





Preamplifier (adjustable gain)

Internal trigger (self-triggering capability)

Test beams with technological prototype

DESY – April, July 2012 and February 2013

TA: AIDA-DESY-2012-003, AIDA-DESY-2012-007, AIDA-DESY-2013-001

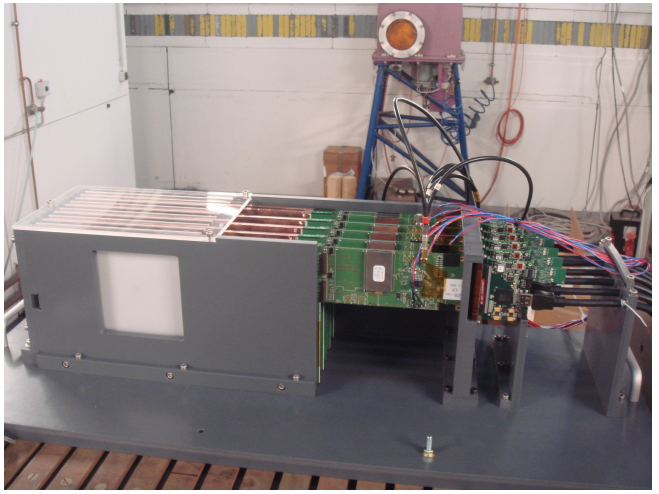
- Up to 10 layers (FEV8)
  - Internal trigger

Total = 1536 channels

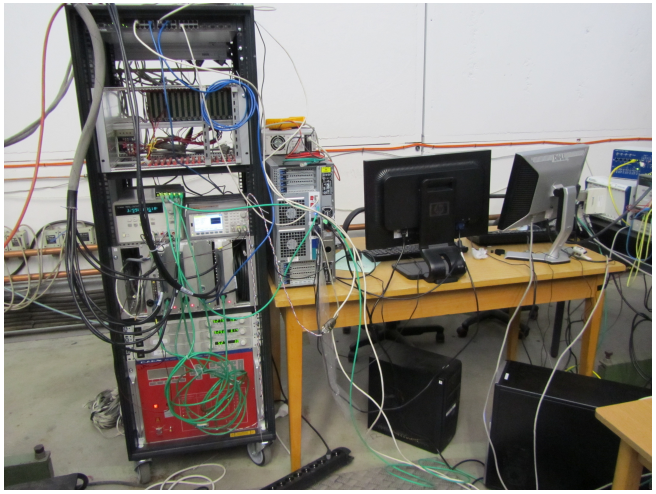
PreAmplifiers of noisy channels are switched off

total active channels = 1278

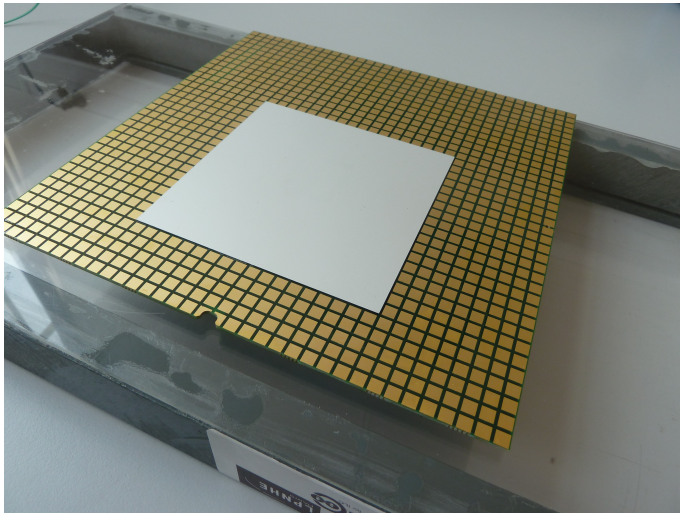
Detector read out by CALICE DAQ2
(continuation of EUDET DAQ)
+ Software (CALICOES) to operate detector
→ Details on DAQ tomorrow

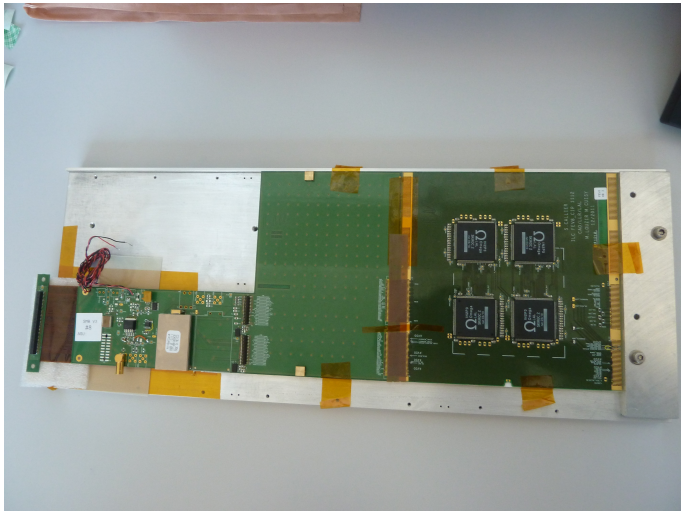


- Test program
  - 2012: Commissioning
    Test of highly integrated electronics
    in conservative mode
  - 2013 Test of power pulsing
    Tests in magnetic field



Layer design for beam tests





ASU is the entity of
Si Wafer, ASICs and PCB

Conservative ASU design for beam tests

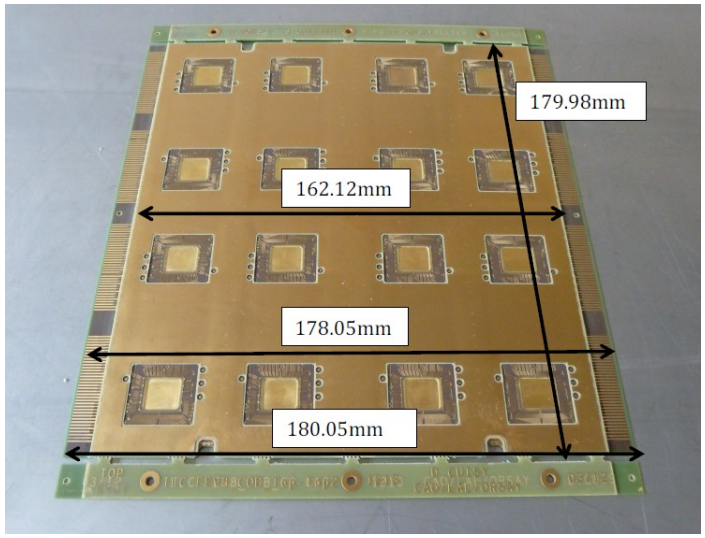
- 1 Si Wafer with 256 pixels of 5X5 mm2 and thickness of 325 mum
  compare with 4 wafers for final design

- Wafer glued onto PCB
  EPOTEK-4110, development of automatised procedure

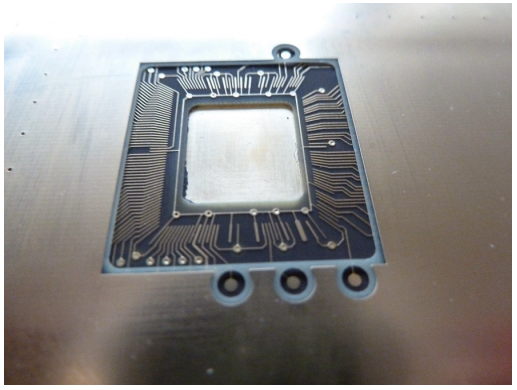
- 4 ASICs in PQFP package
  Compare with 16 ASICs wire bonded (→ later) or in very thin BGA package

PCB R&D – FEV_COB et al.

PCB is critical → Goal :1 mm thick, 8 layers, 1% flatness , ASICs bounded into



- Available since december 2012
  (Boards from Exception and Protecno)
- **First board for 16 ASICs = 4 wafers**
  (btw. Several proposal to assure planarity exist)
- Now equipped with 8 SKIROC ASICs
  (Bonding by CERN) → Needs testing
  Bonding was not straightfoward,
  thin bonding pads to be improved



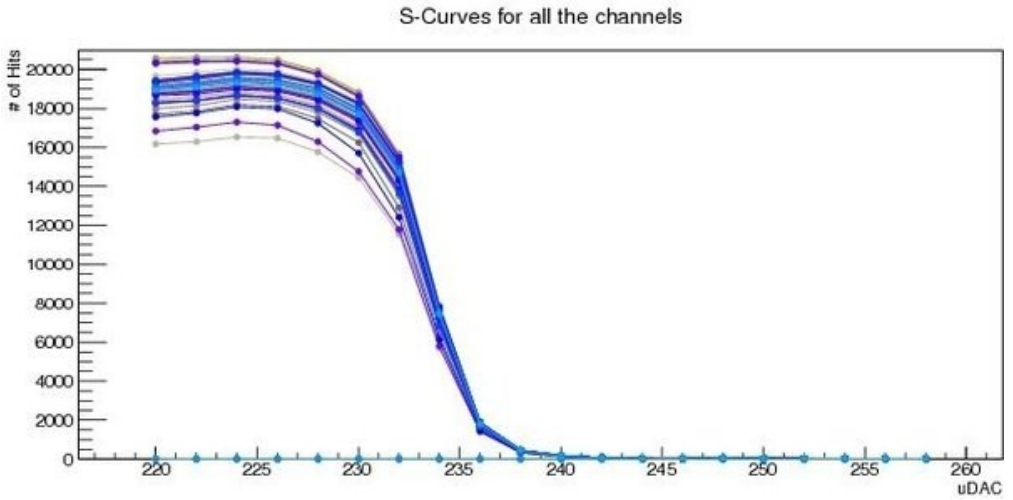
FEV_COB is aggressive solution
Alternatives with ASICs in package
e.g. BGAs will be studied as well

Calibration of ASICs

Establishment of calibration procedure for a larger number of cells

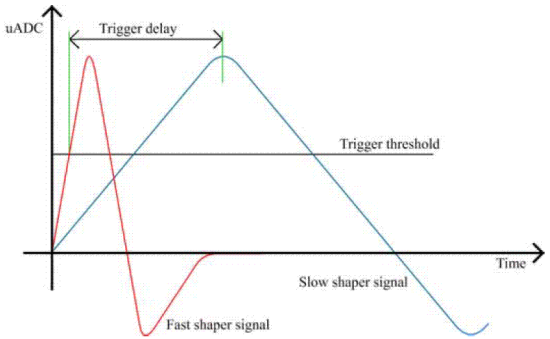
Trigger threshold

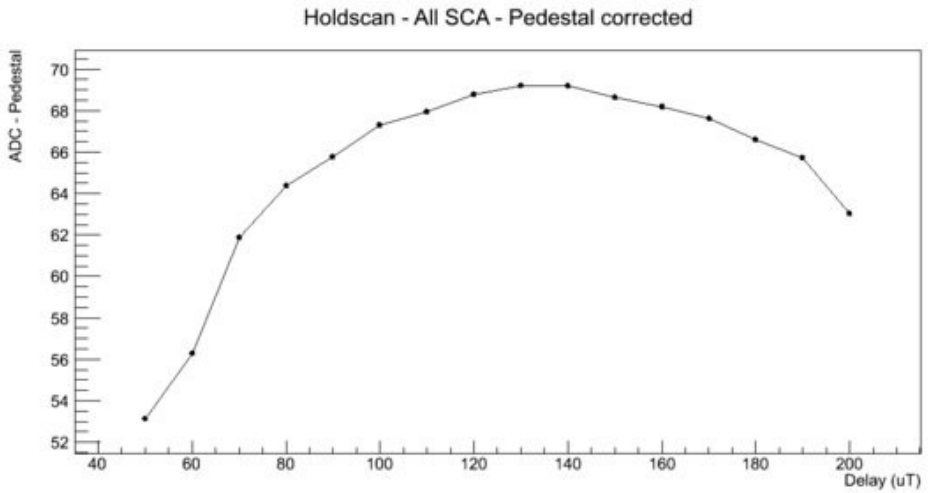
- depends on the gain
- Needs to be adjusted for each channel
- Done by 'hand' in 2012/13
- Development and test of an automatic procedure for and during first test beam in 2013



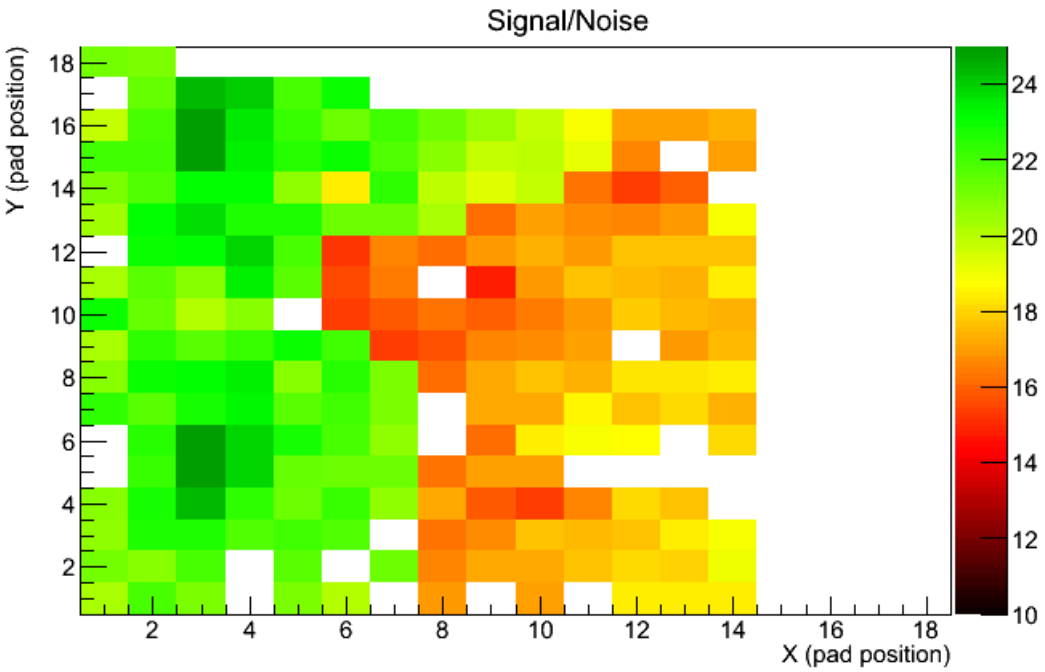
Trigger delay

- depends on the trigger threshold



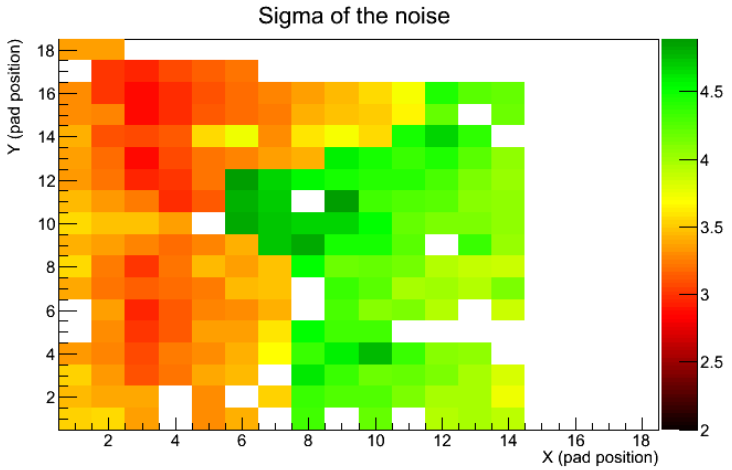


Data Analysis 2012 – Signal over noise ratio

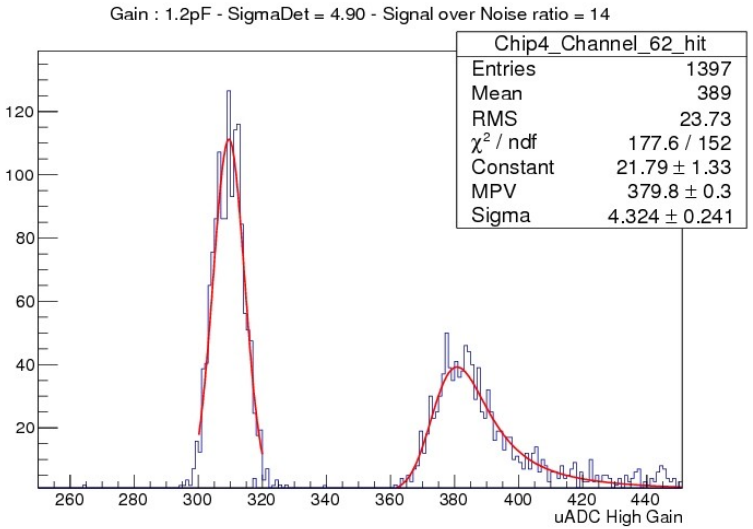


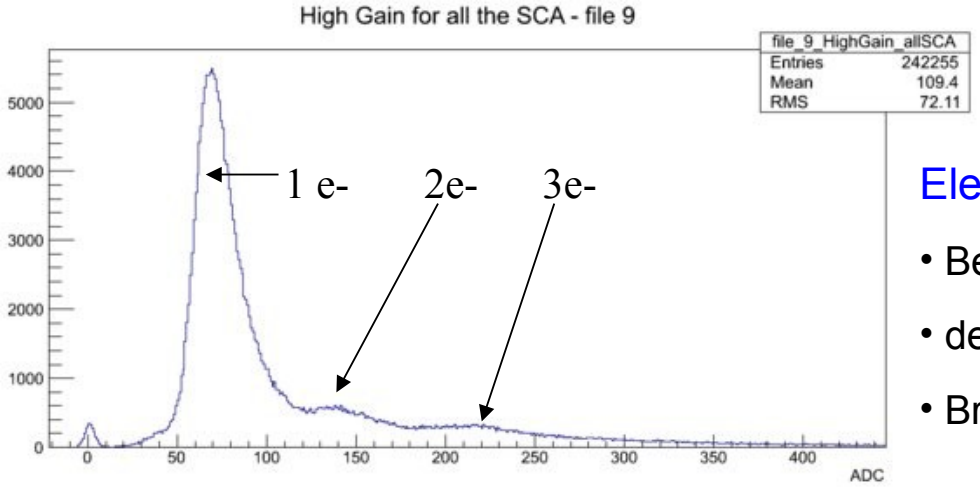
Results after setting of trigger thresholds and event filtering (see backup slides)
White spots = Noisy cells
noice induced by PCB routing

S/N > 10
(for all gains available with SKIROC2)
R&D target is 10:1



2012 Data - Energy measurement



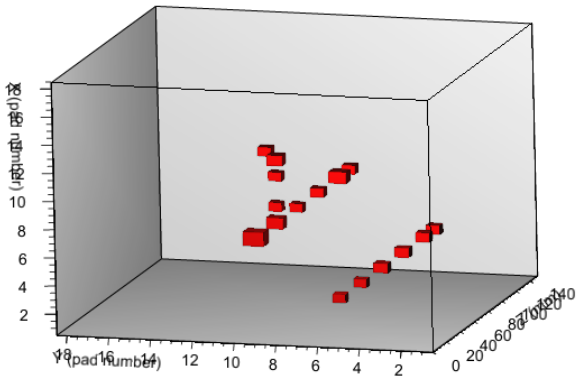


Electron sources:

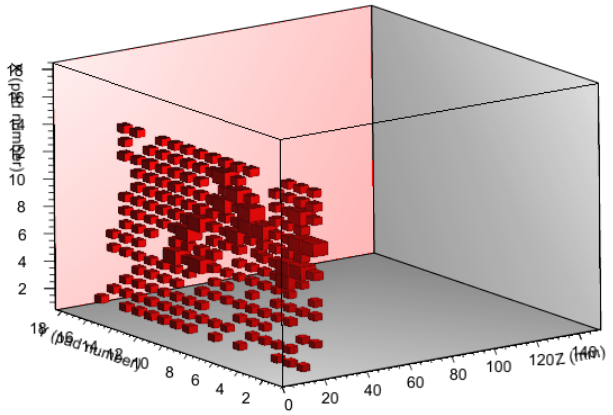
- Beam
- delta rays
- Bremsstrahlung + gamma conversion (2e-)
  + Compton

Event displays (Search the error ;-))

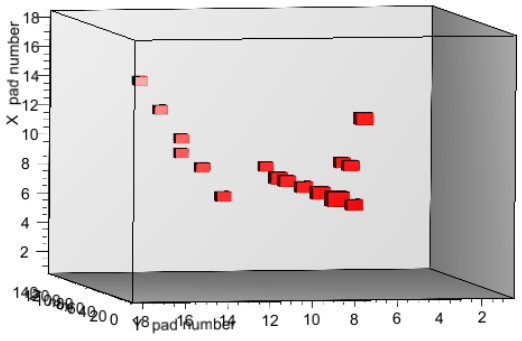
2 e- (3 GeV, no tungsten)



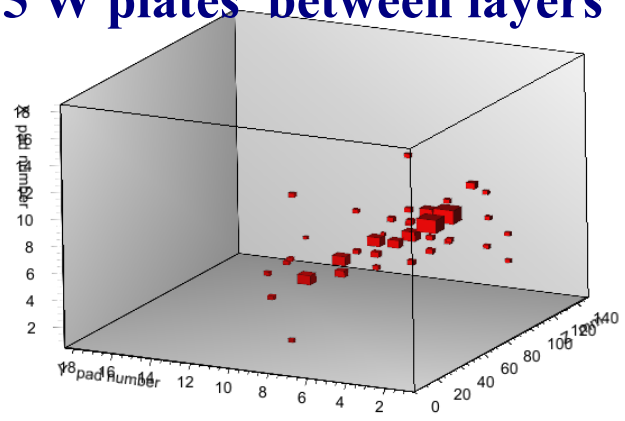
'Plane events???'



1 cosmic + 1 e-
(3 GeV, no tungsten)



1 e- (5 GeV)
5 W plates between layers



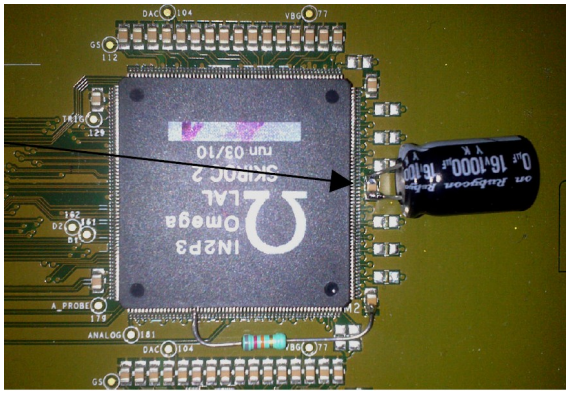
SKROC debugging

PA is referenced to the analog power supply level

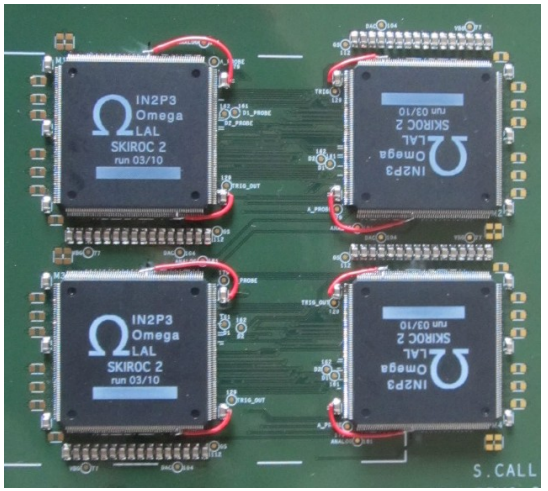
Instabilities of power supply level → fake events

- VDD_delay/sca plugged on analog power supply → increase instabilities of power supply level
- Analog power supply common to the 4 ASIC
- Self-sustained → sometimes filled all the 15 ASIC memories
- Highly dependant of the number of ASIC with hits, dependant of the number of triggered channels

Patches



Big capacitance to stabilise power supply



Re-routing of analog and digital power supply

Complete understanding of ASICs vital for 3rd generation (AIDA)

2013 beam tests

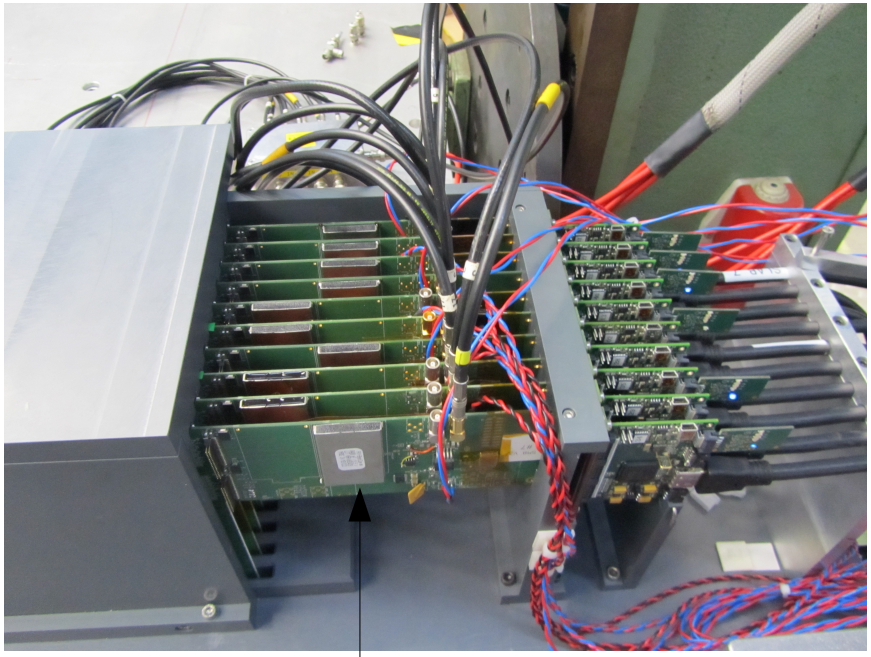
Alltogether 10 layers

- 4 continous operation
- 4 power pulsed
  Including h/w modifications see above
- 2 could not be reliably operated

DAQ: Readout by 2 LDAs

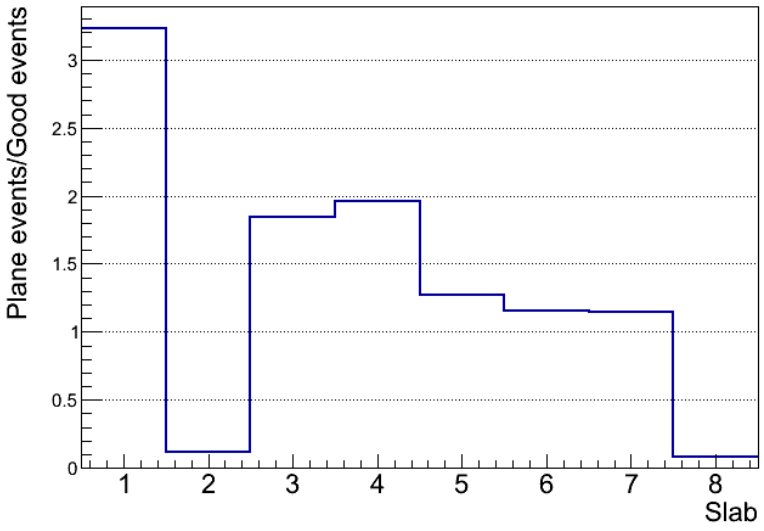
Power pulsing
Duty cycle 99%, 10Hz

Operation in power pulsing
Mode requires removal of
Decoupling capacitances
=> Do not expect as stable
performance as in continuous mode



Battery charger application
AVX BestCap BZ01
After regulator

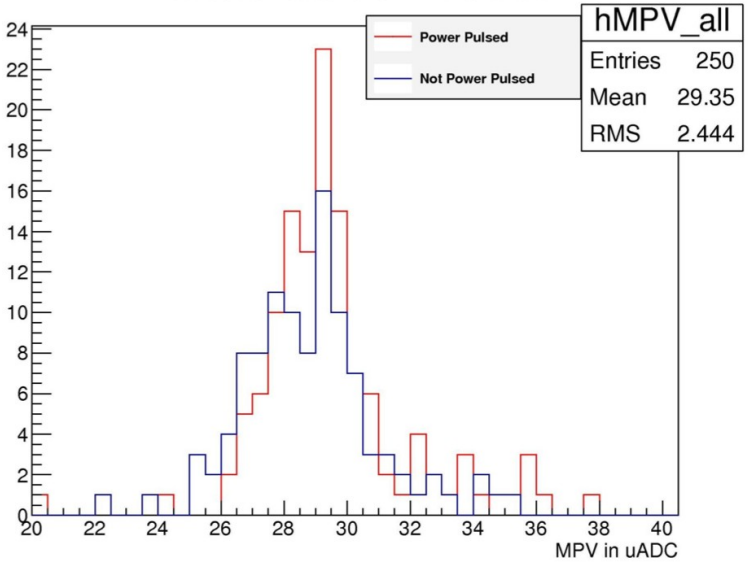
2013 beam tests first results



Frequency of plane events

- Slab 2 and 8 were subject to patches
- Smaller frequency of plane events observed
- However effects of retriggering are still under investigation

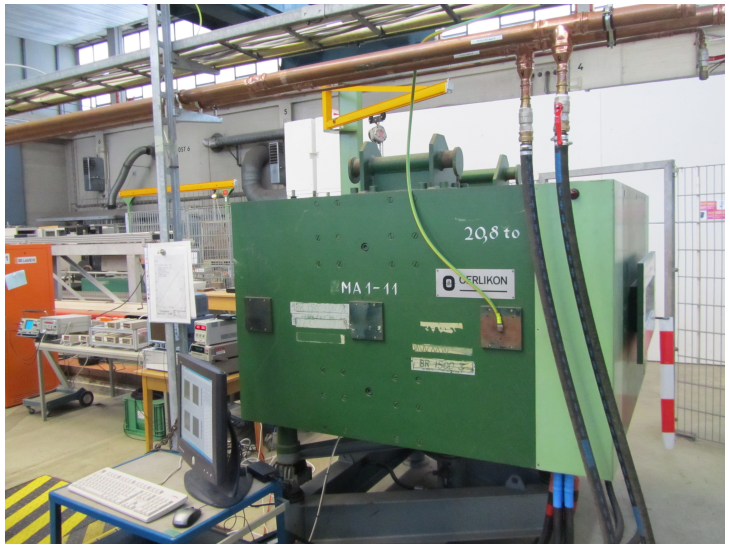
→ Stay tuned

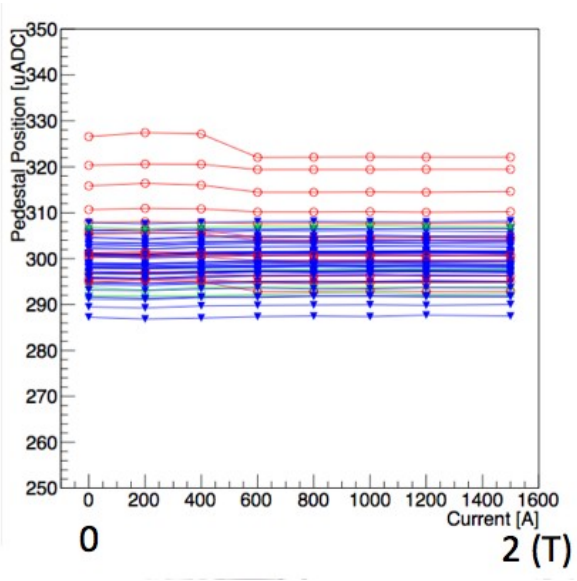


Comparison Power pulsing No power pulsing

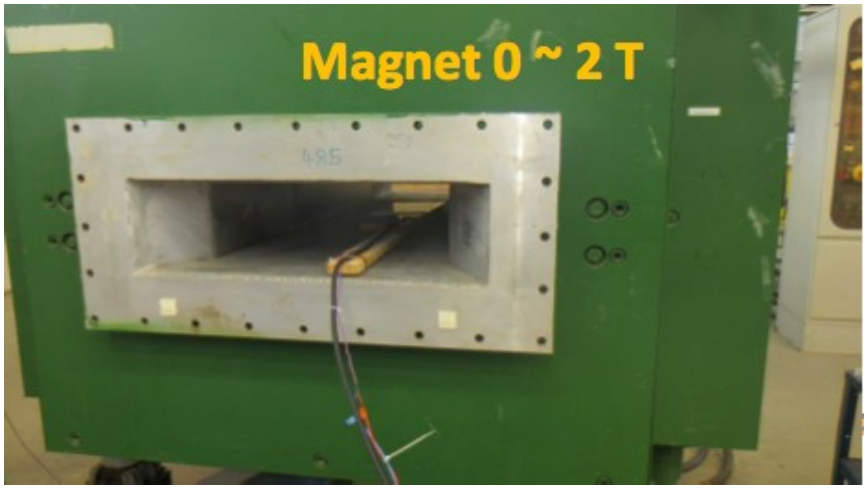
- For good layer 2 same quality of MIP spectra
  Ongoing analysis but result is encouraging

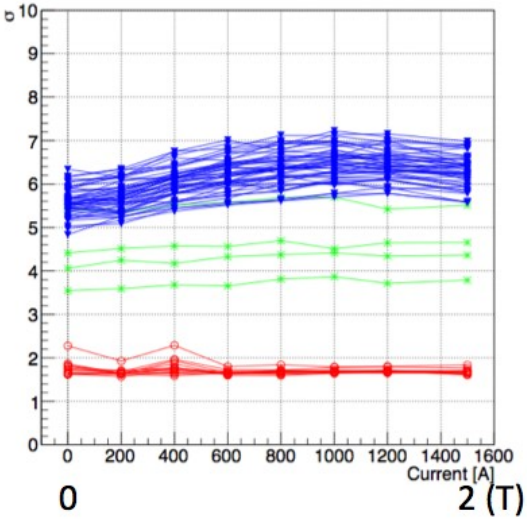
Power pulsing tests in magnetic field I





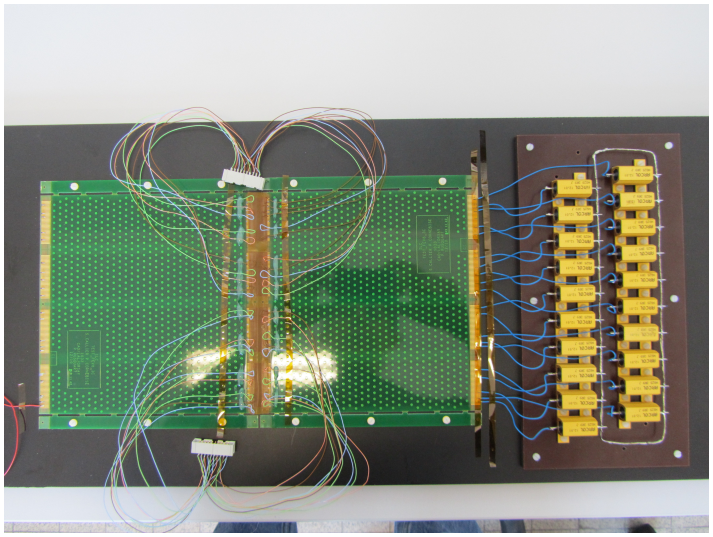
Pedestal position

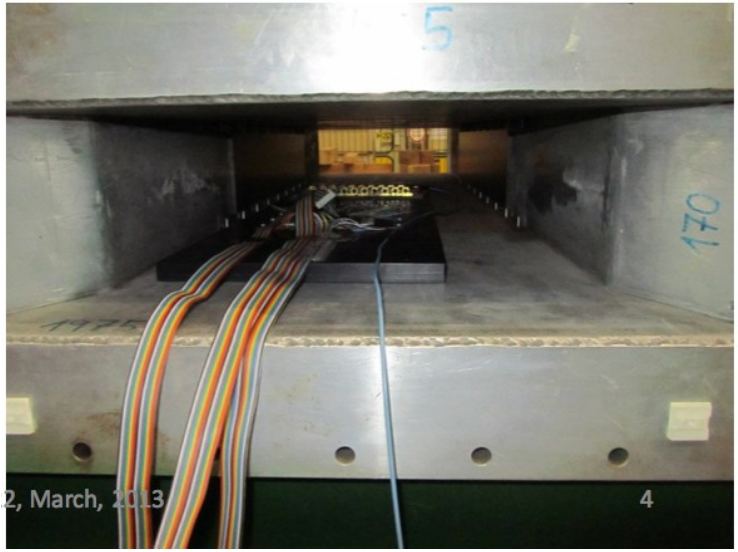




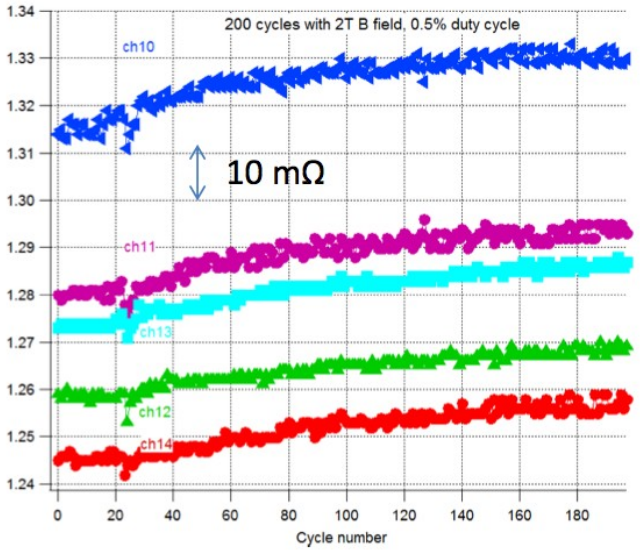
Pedestal width

Tests in magnetic field II





Measurement of the ohmic resistance across the interconnection between two ASUs
With and w/o B-Field, various duty cycles and frequencies

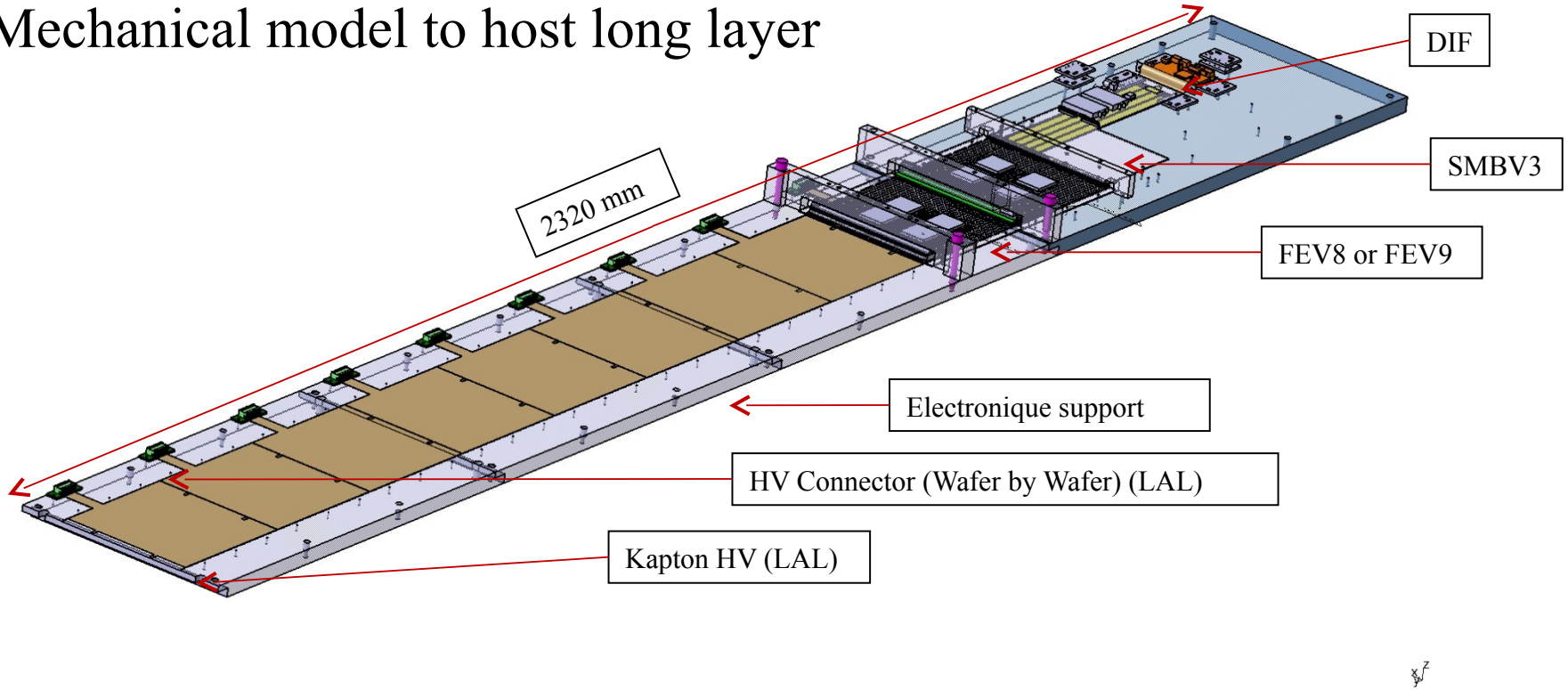


Conclusion: The ohmic resistance
Varies by about 20 mOhm (thermal effect)

Towards long layer

1.1 – inter-connection of 10 FEV8 or FEV9

- At the eve of tests long layer
→ Realised in coming weeks
Mechanical model to host long layer



Elements of Si Wafer R&D

- Wafers used in beam test are from Hamamatsu ordered in 2007

  Resisitivity: 5 kOhmxcm, 325 mum thick, 324 pixels

  These wafers show excellent behaviour!!!

  => Si technology at hand however it has its price!!!

- R&D focused on optimisation of wafer design

  Guard ring or no guard ring, dead zones at wafer edges

  Width and thickness of silicon wafers

  Tolerances in leakage current

- Intensive contacts with Japanes groups and Hamamatsu photonics

  Forging contacts with other partners

- Setting up of Laser Systems for wafer characterisation

  Non trivial task, issue is getting right laser power and guidance of laser light

- Optimisation of existing simulation programs for details of Si response

Conclusion and outlook

- Since beginning of 2012 SiEcal R&D is (again) running at full speed

  Benefits decisively from excellent progress on DAQ

- Three testbeams with conservative but yet progressively complicated setup

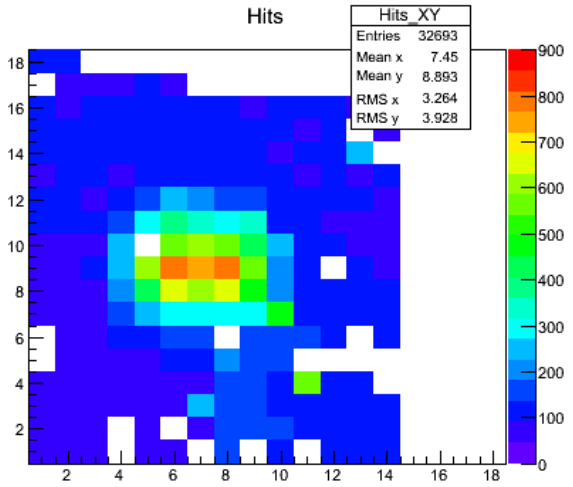
  Allow for identifying step-by-step goods and bads of the system
  Self-triggering ASICs require very careful power management
  A number of observed odds were actually related to peripheral devices or non optimal power supply
  Debugging of Front End Electronics is ongoing

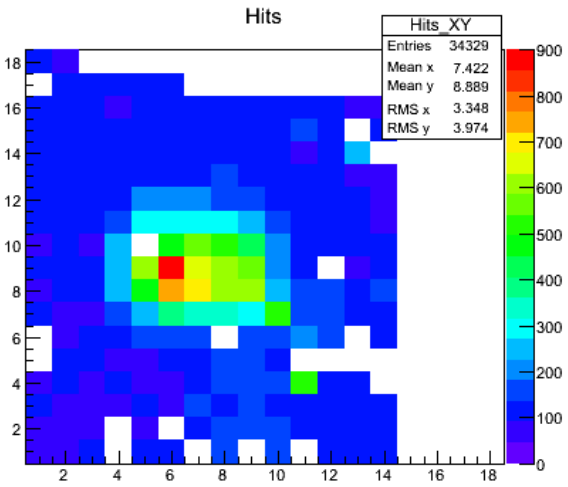
Deliverable: An electromagnetic calorimeter with 18x18cm2
In extension of the EUDET Module

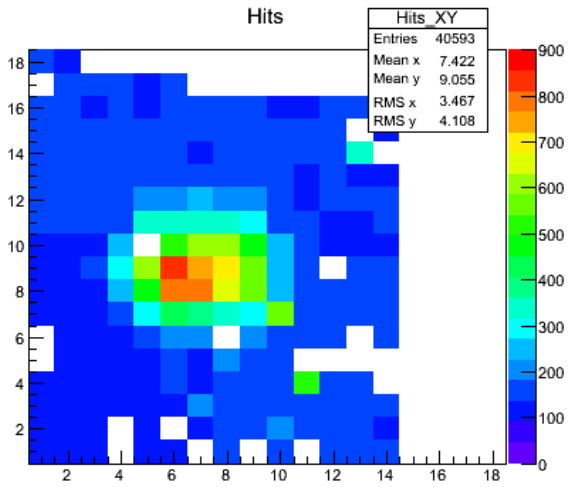
- Addressing now issues of a 'real' calorimeter system

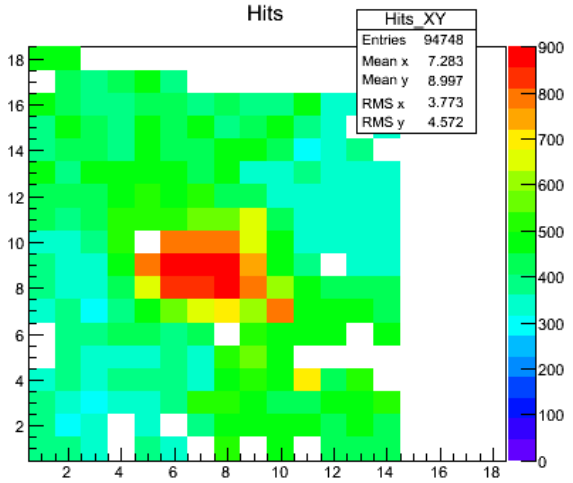
  16 chips per ASU (needed for deliverable), needs also further DAQ development
  Si Wafer optimisation (standing item)
  Long layer, cooling
  First ideas on industrialisation

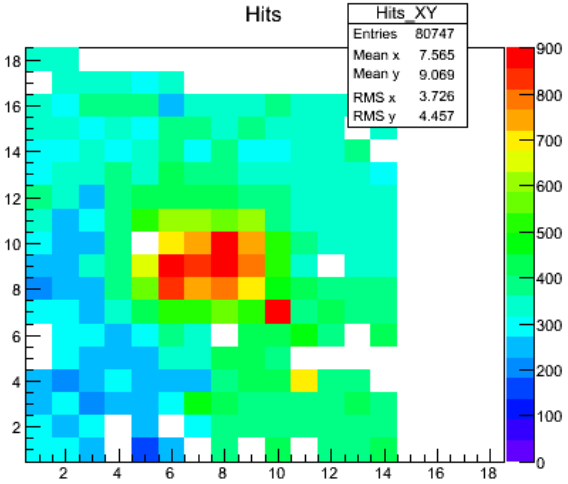
Beam spot

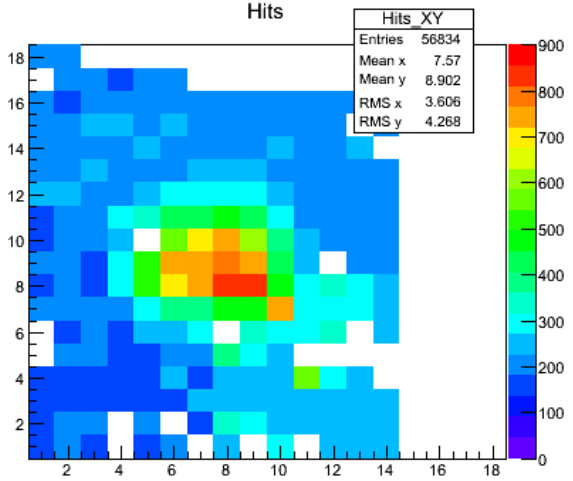

Hits
Hits_XY
Entries 32693
Mean x 7.45
Mean y 8.893
RMS x 3.264
RMS y 3.928


Hits
Hits_XY
Entries 34329
Mean x 7.422
Mean y 8.889
RMS x 3.348
RMS y 3.974


Hits
Hits_XY
Entries 40593
Mean x 7.422
Mean y 9.055
RMS x 3.467
RMS y 4.108


Hits
Hits_XY
Entries 94748
Mean x 7.283
Mean y 8.997
RMS x 3.773
RMS y 4.572


Hits
Hits_XY
Entries 80747
Mean x 7.565
Mean y 9.069
RMS x 3.726
RMS y 4.457


Hits
Hits_XY
Entries 56834
Mean x 7.57
Mean y 8.902
RMS x 3.606
RMS y 4.268

Detection efficiency

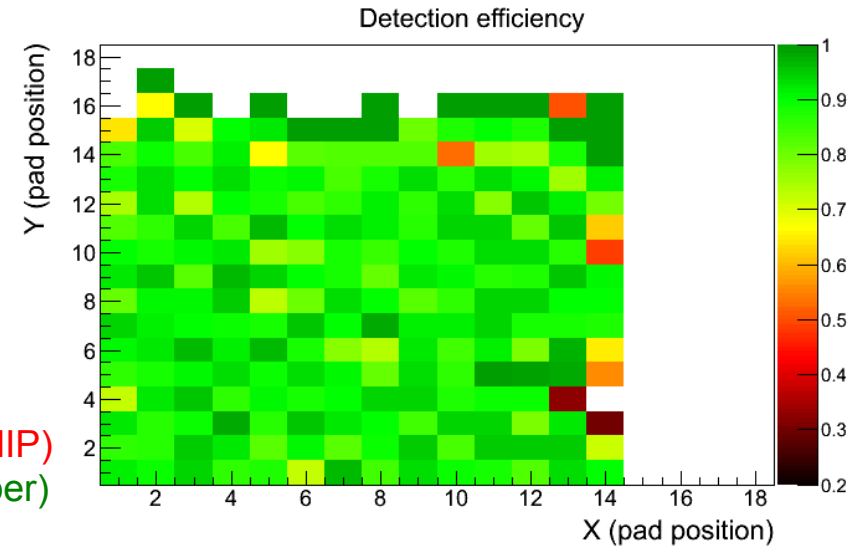
Data: 3GeV – No W – XY scan
Total number of events: 2,3.10^6
Track selection:

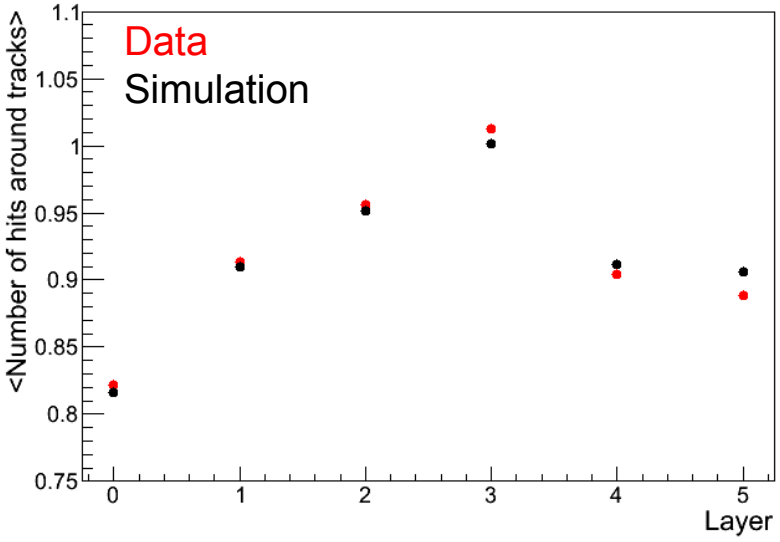
At least 3 layers with hits
Linear fit of the e- track
Nhits<10

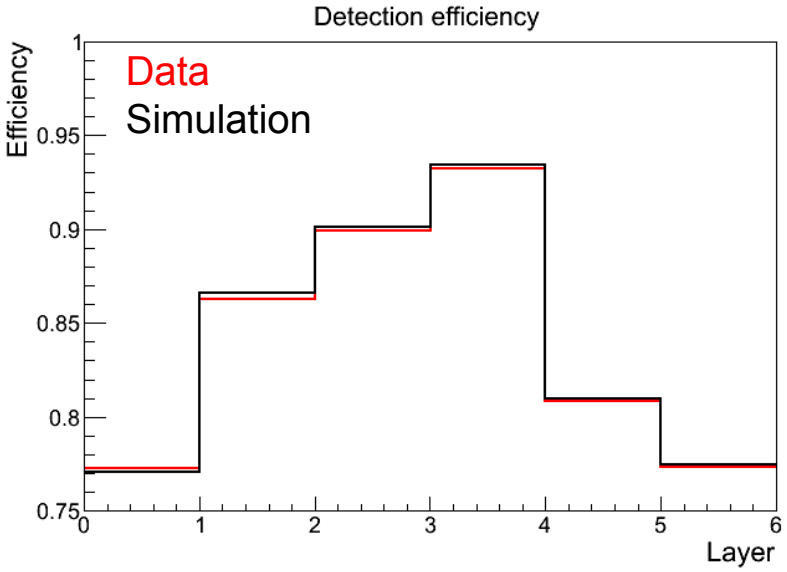
Inefficiencies due to:

Switched off channels
Too high trigger thresholds (80%-95% of the MIP)

➡ Should be improved with the next test beam (December)

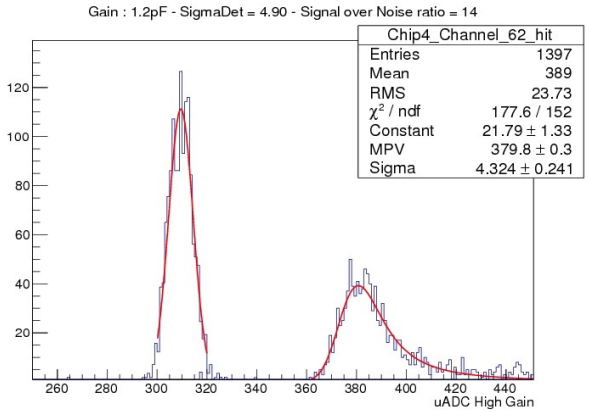


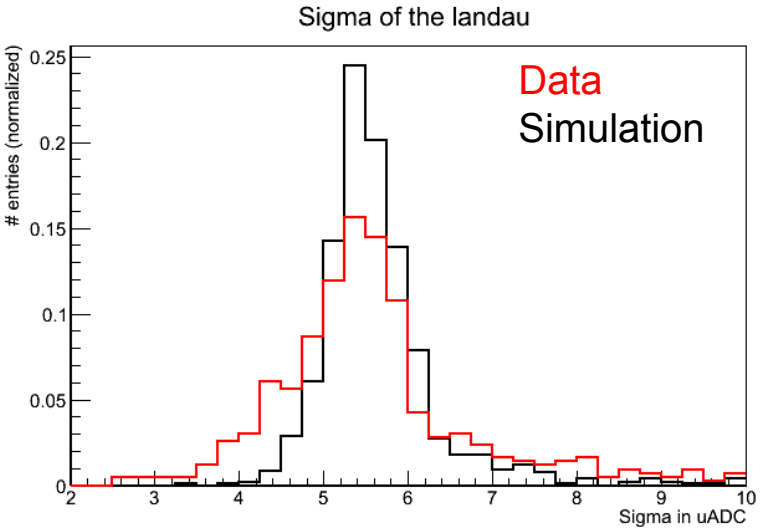


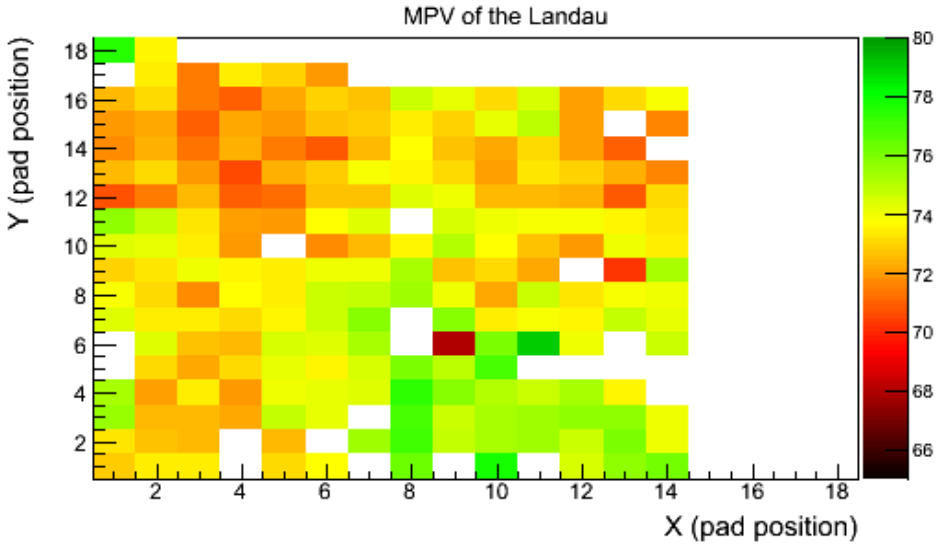


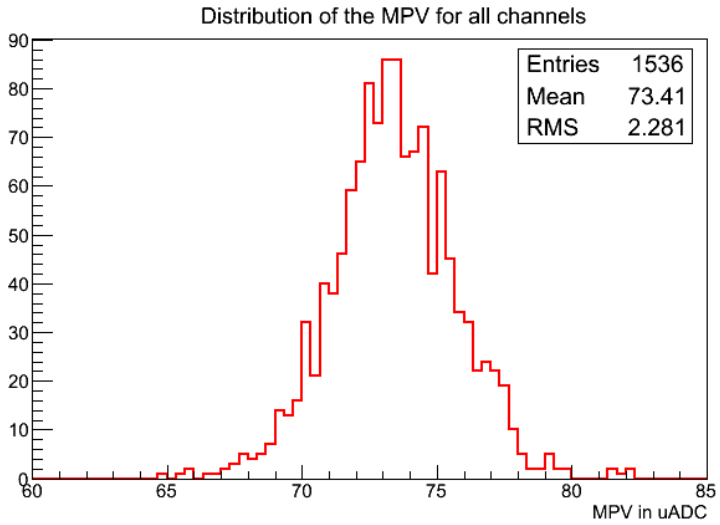
Energy calibration

Establishment of calibration procedure for a larger number of cells
Homogeneity of response (x,y scan of detector)

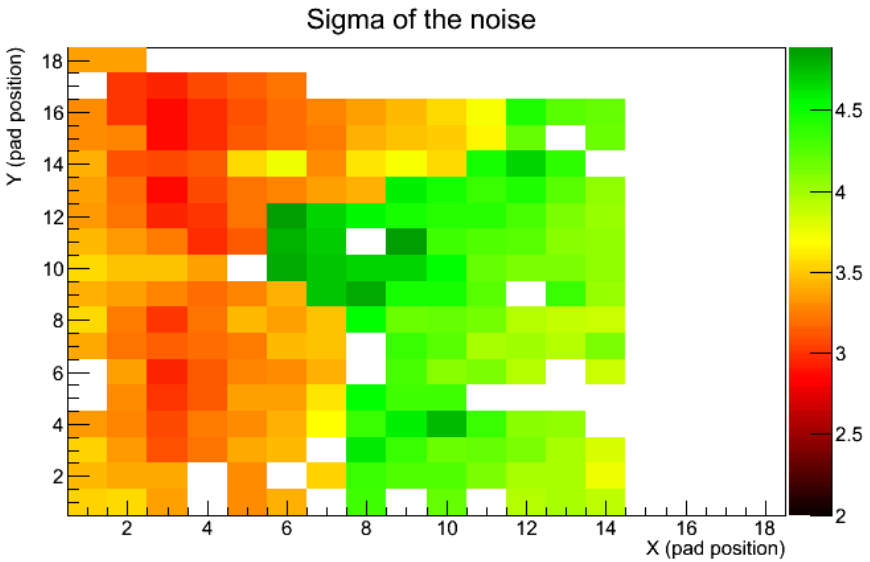








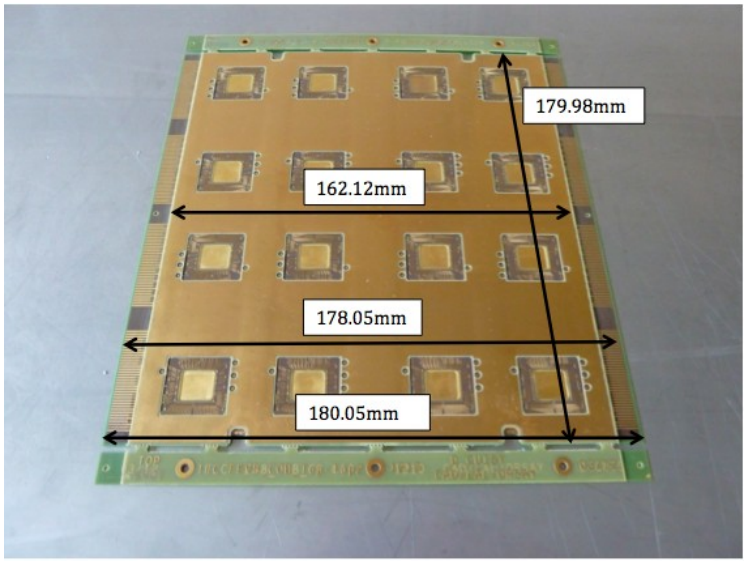
Noise width

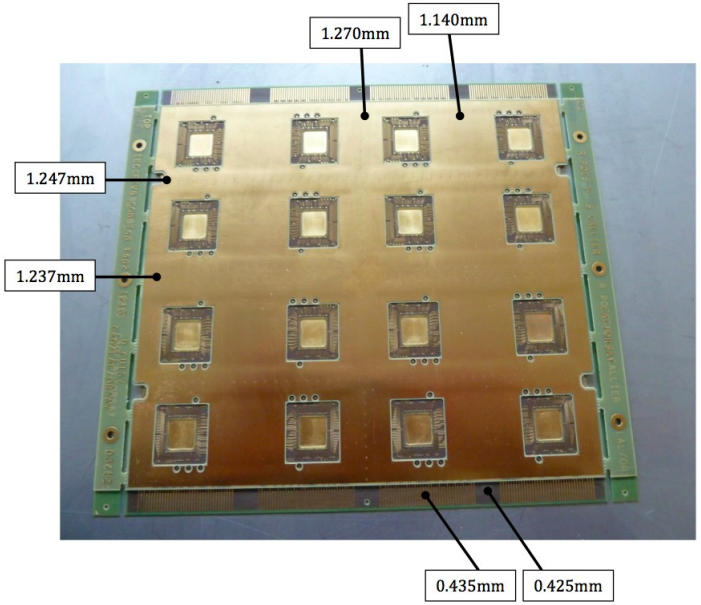

Sigma of the noise
Y (pad position)
X (pad position)
18
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18
4.5
4
3.5
3
2.5
2

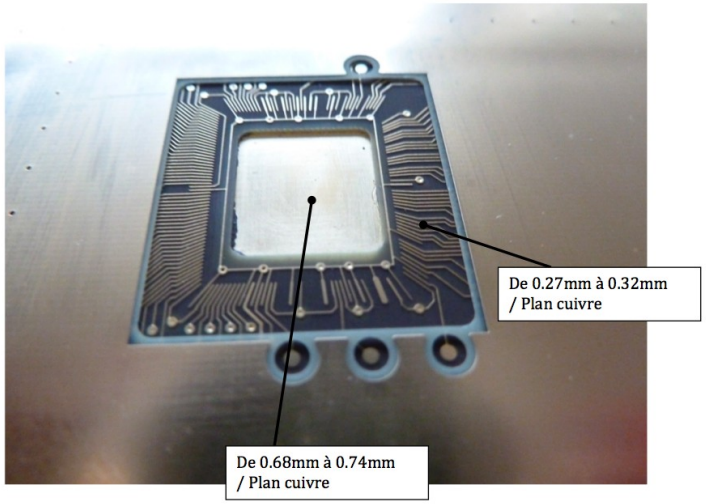
What's next

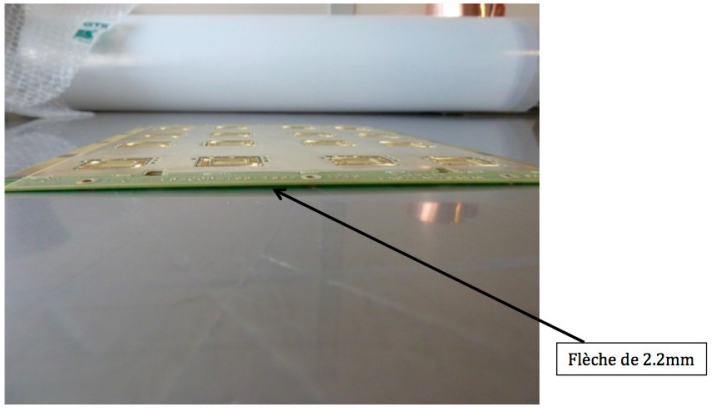
- Beam tests in 2012 were extremely useful for 'team formation' and to obtain experience with new hardware
- Need to understand shortcomings of e.g. SKIROC2 to go to SKIROC3
  - SKIROC3 not before beginning of 2014
- Scrutinising of slab production
  - some wafers got broken during production
  - Revision of tools
  - Make use of small production to establish procedure/specs for mass production (where possible)
- Address power pulsing
  - Hardware understood well enough to address this important step (need for proof was highlighted many times during PAC meeting)
  - Have already beam test slots at DESY → DESY Planning 2013

FEV_COB – Engineering highlight









Thanks

Special thanks to our experts:

Frédéric, Mickael, Patrick, Rémi and Stéphane

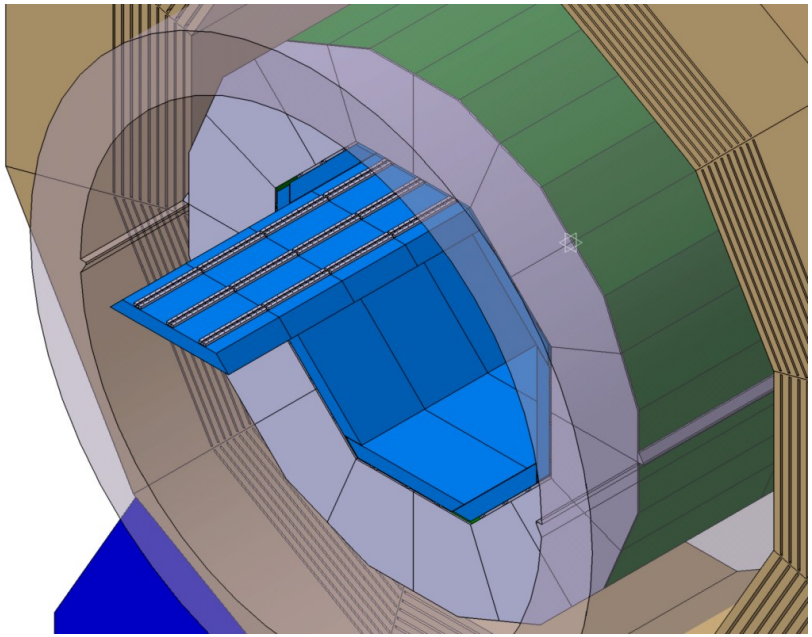
And to everyone who took part in the preparation of the test beam:

- LLR, LAL+OMEGA, LPNHE
- Kyushu University, Tokyo University, Nippon Dental University
- SKKU

SiW ECAL for a future LC

SiW ECAL is one of the prototypes for future LC detectors

➡ Optimized for Particle Flow Algorithm:



The SiW ECAL in the ILD Detector

Basic Requirements:

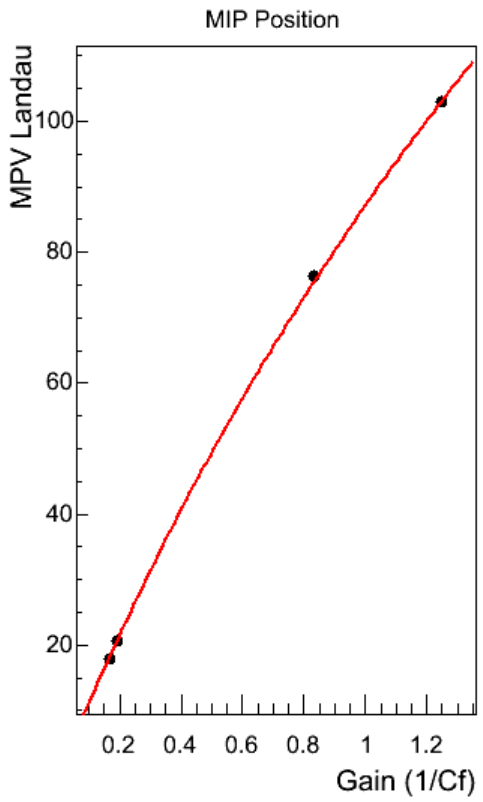
- Extreme high granularity
- Compact and hermetic

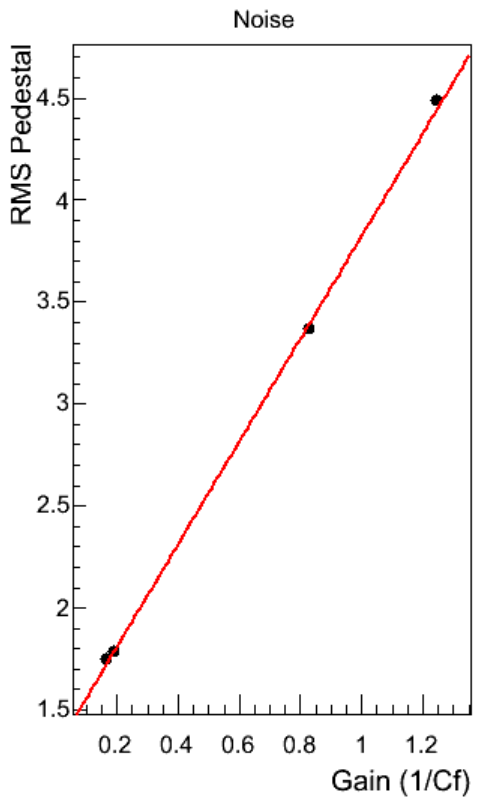
Basic Choices:

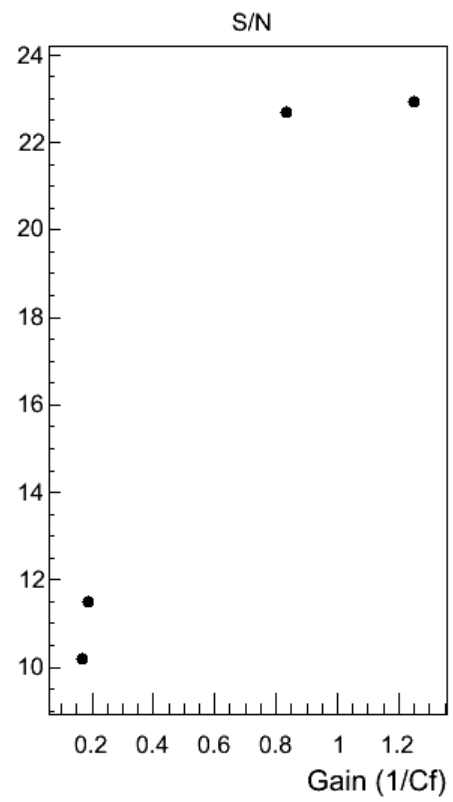
- Tungsten as absorber material
  - X_0=3.5mm, R_M=9mm, λ_I=96mm
  - Narrow showers
  - Assures compact design

- Silicon as active material
  - Support compact design
  - Allows for pixelisation
  - Large signal/noise ratio

Signal sur noise – 'bonne' voie

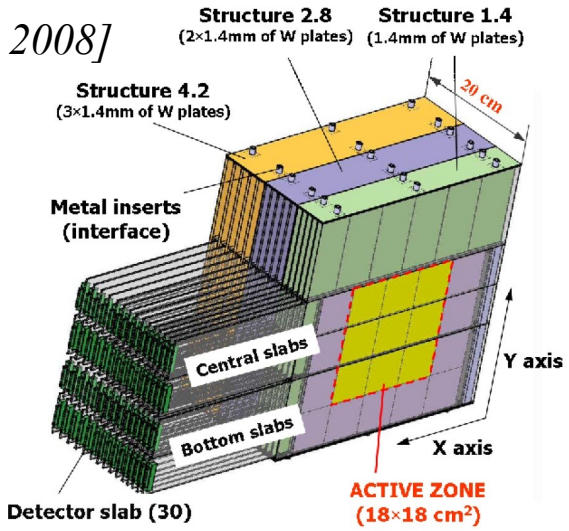


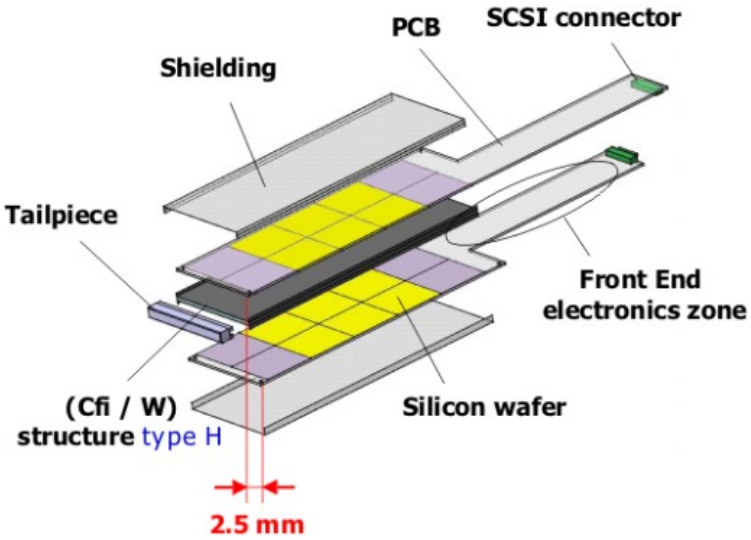




Physics prototype

[JINST 3, 2008]





Carbon-fibre mechanical structure

30 layers of tungsten: 24 X_0, 1 λ_I

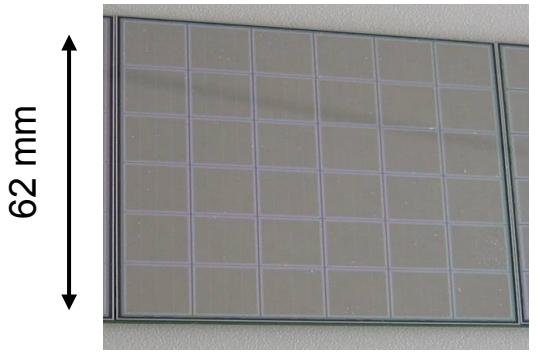
S/N ~ 8

$\sigma_E / E = 16.5/\sqrt{E(GeV)} + 1.1$ %

10k channels

6x6 PIN Diode Matrix – **1 x 1 cm²**

Résistivity: 5kΩcm - 80 (pairs e/hole)/μm



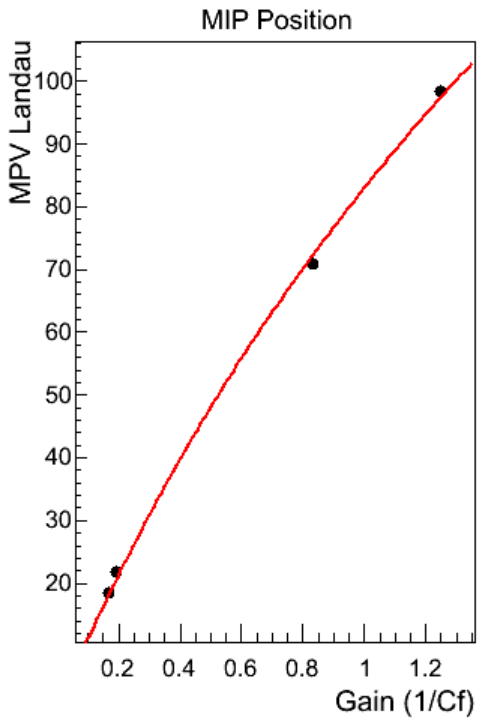
Thickness:

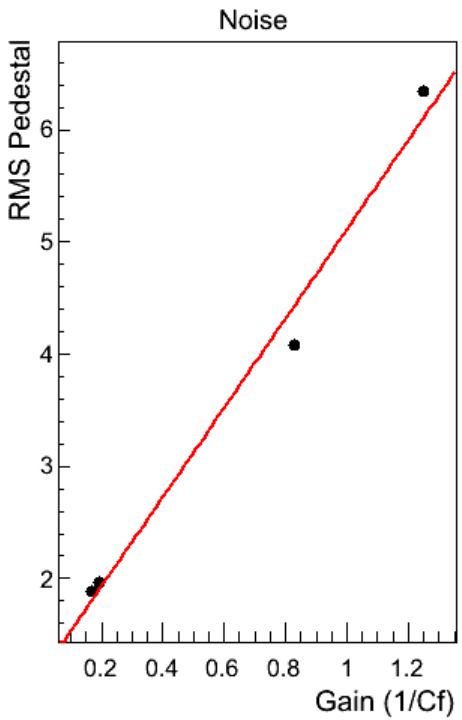
525μm

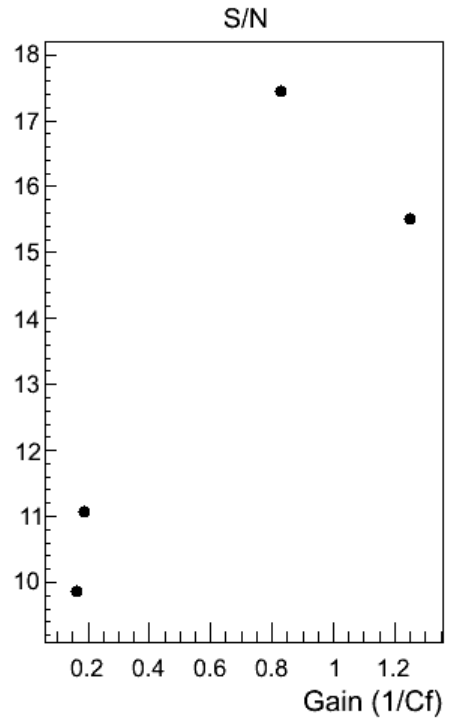
➡ Studied in various test beam facilities

2006-2011: DESY, CERN, FNAL, e-, π, μ, p (1 → 180 GeV)

Signal sur noise – 'moins bonne' voie







Event filtering

- **Ricochet / BCID+1 effect (without hit)**
  - Seen with SKIROC2 test bench and in TB
  - Understood, studied by Romain with test bench (cf Stéphane's talk, Monday)
  - Cut in TB analysis (cut event if delta BCID == 1)
- **BCID +1 +2, +3.... (with hits)**
  - With SKIROC2 test bench: seen for high injected charges (> 50 MIPs)
  - In TB: seen with low injected charges (<10 MIPs), seems to be related to plane events
  - Cut in TB analysis (see planes events)
- **Plane events**
  - Not seen with SKIROC2 test bench → PCB effect?
  - Seems to be correlated with an unstable acquisition (bad pedestal in whole acquisition, BCID +1 +2 +3.....)
  - Cut in TB analysis:
    - MIP data: Number of hits > 10 in one chip AND delta BCID <= 5
    - Showers: Number of hits > 40 in one chip AND delta BCID <= 5 (this cut has not been optimized)
- **Isolated hits**
  - Reconstruction needed to see this effect (not yet well studied: noise, cosmic, related to plane events?)
  - Cut in TB analysis:
    - No cut in layer independent analysis (energy calibration, S/N measurement, pedestal studies....)
    - Cut if we need event reconstruction (MIP detection efficiencies, showers...):
      - we ask at least 3 planes with hits in the same event (after reconstruction)