R&D for a highly granular SiW ECAL and analysis of beam test data

Thibault Frisson (LAL, Orsay)

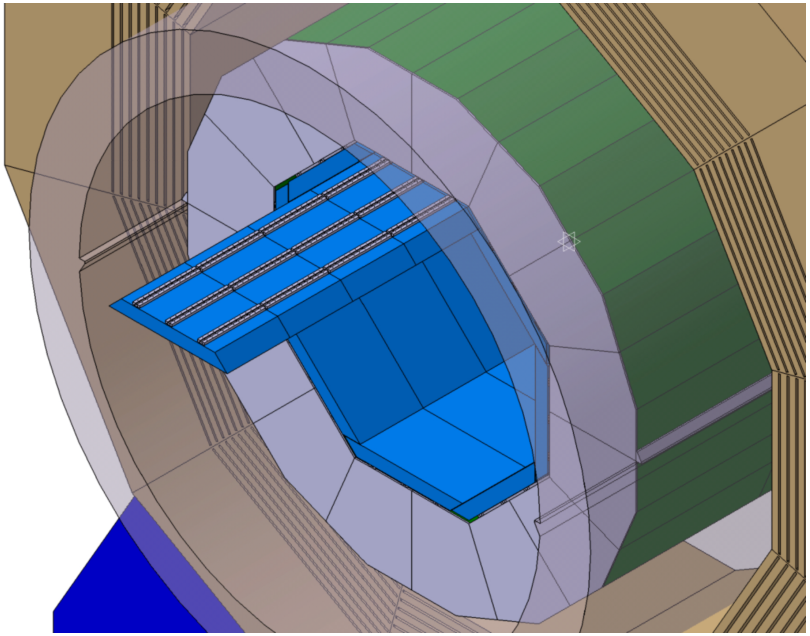
on behalf of the CALICE collaboration

CALIIMAX-HEP
2010 BLANC
0429 01

SiW ECAL for a future LC detector

SiW ECAL is one of the proposal for future LC detectors

→ Optimized for Particle Flow Algorithm



The SiW ECAL in the ILD Detector
(presented by Daniel Jeans)

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

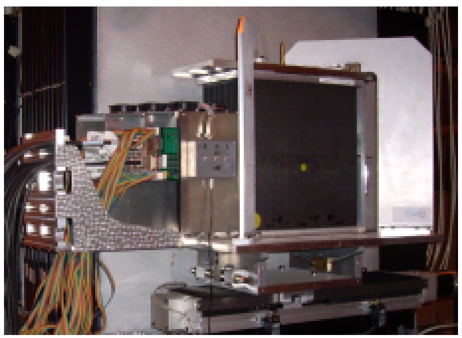
- Silicon as active material
    - Support compact design
    - Allows for pixelisation
    - Large signal/noise ratio

SiW ECAL R&D

Physics Prototype

Proof of principle

2003 - 2011



JINST 3, 2008

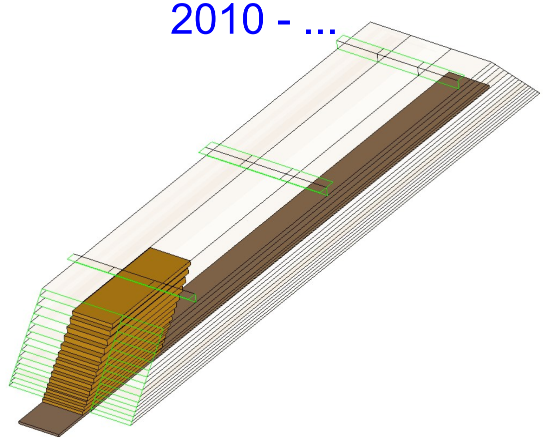
Number of channels : 9720

Weight : ~ 200 Kg

Technological Prototype

Engineering challenges

2010 - ...

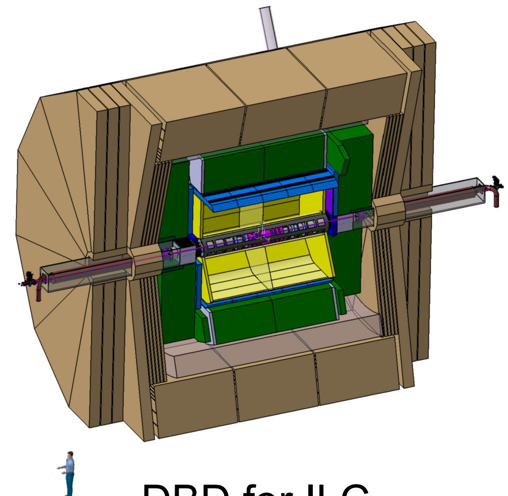


TDR EUDET-Report-2009-01

Number of channels : 45360

Weight : ~ 700 Kg

LC detector



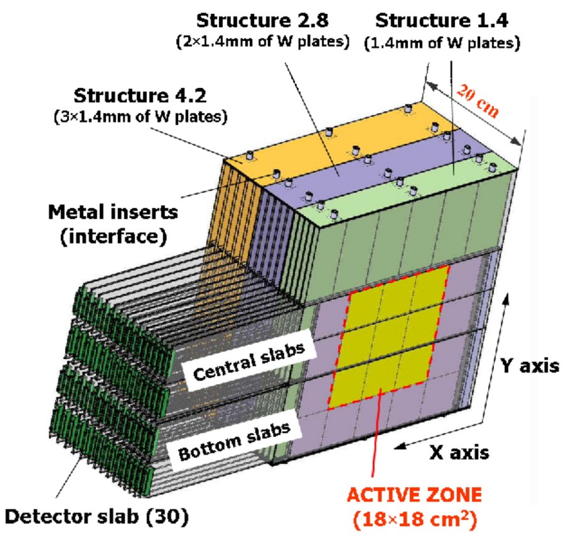
DBD for ILC
CDR for CLIC

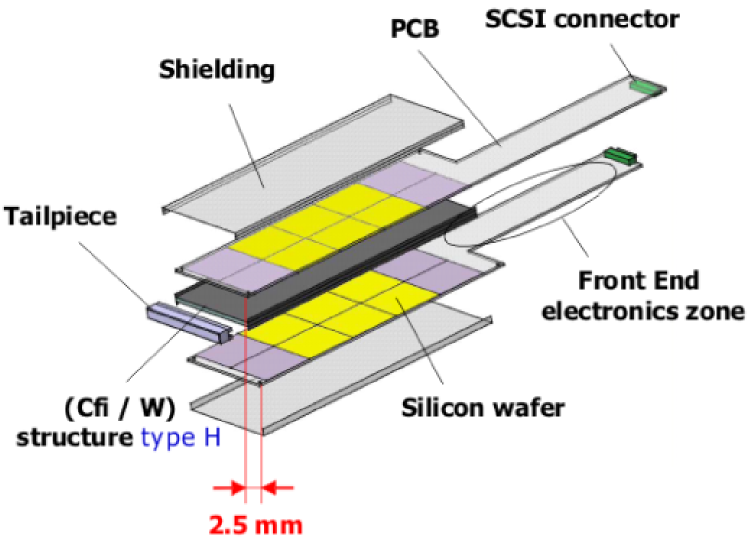
ECAL :

Channels : ~ $100\ 10^6$

Total Weight : ~ 130 t

Physics prototype





Carbon-fibre mechanical structure

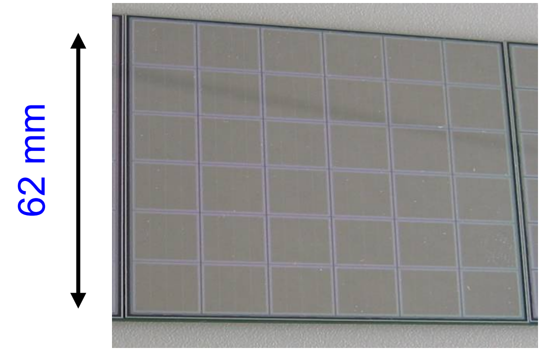
30 layers of tungsten: 24 X_0, 1 λ_I

10k channels

S/N ~ 8

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

6x6 PIN Diode Matrix – **1 x 1 cm²**



Thickness:

525µm

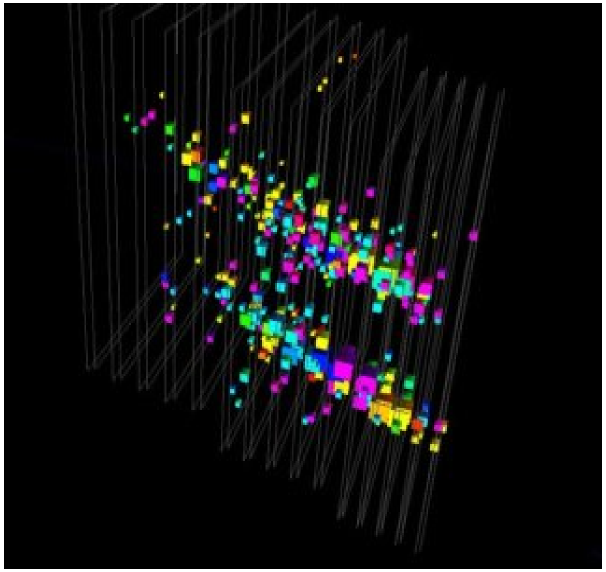
Resistivity: 5kΩcm

80 (pairs e/hole)/µm

Beam tests

2006-2011: DESY, CERN, FNAL

e-, π, μ, p (1 - 180 GeV)



Proof of principle for high granularity calorimeter

Improve our understanding of the detector prototype

- noise, calibration, performances
- validation of simulations

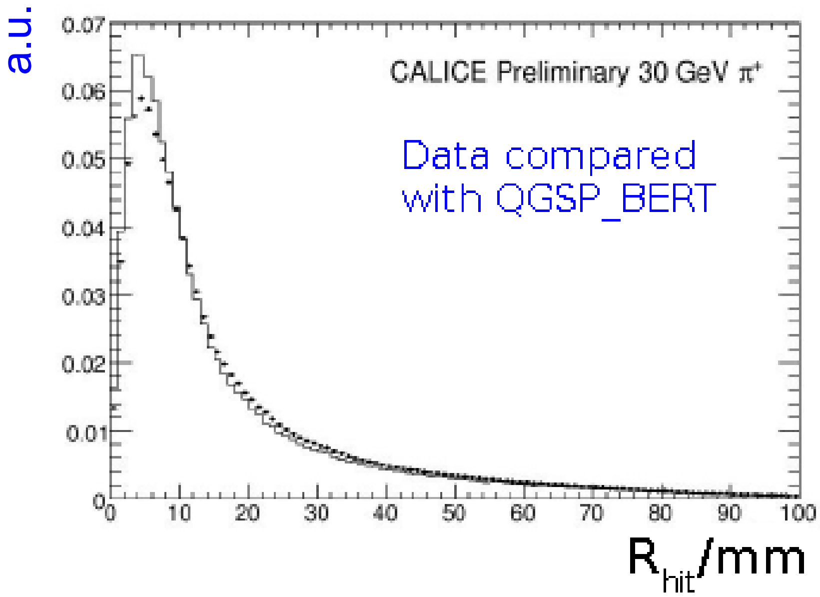
} Development of methods, algorithms...

Unprecedented granularity

- detailed testing of G4 simulations
- better understanding of hadronic interactions

Hadronic shower profiles

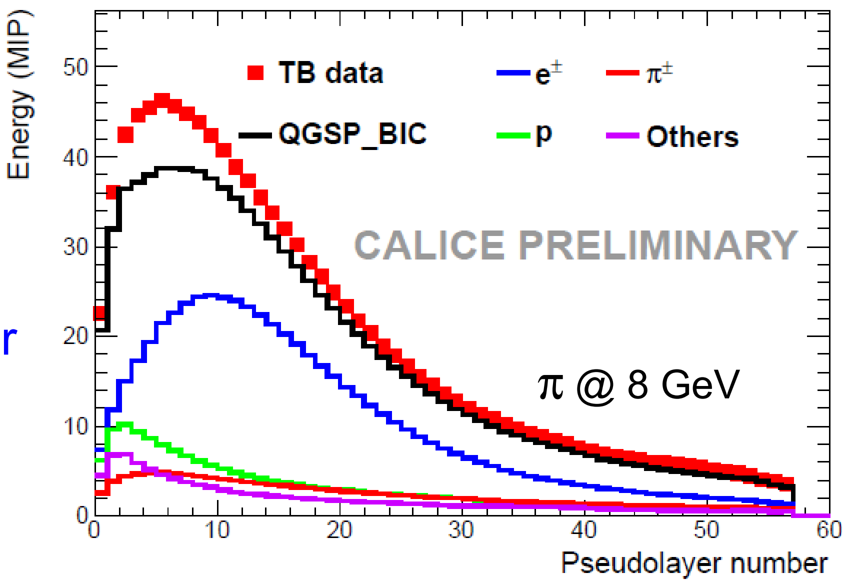
Major study for PFA: affects overlap of showers



high transverse and longitudinal granularity
→ unprecedented details of the showers

Not easy to select a model (depends on observable, energy…)…
…but relatively small difference between models (~20%)

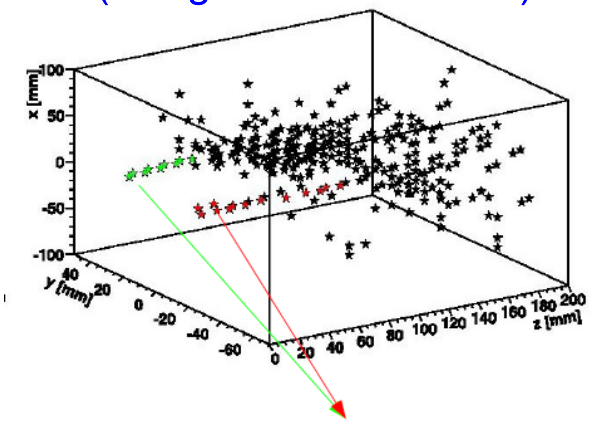
Small X_0 / λ_I
→ study the components of the shower



Imaging interactions

High granularity allows particle tracking through detector

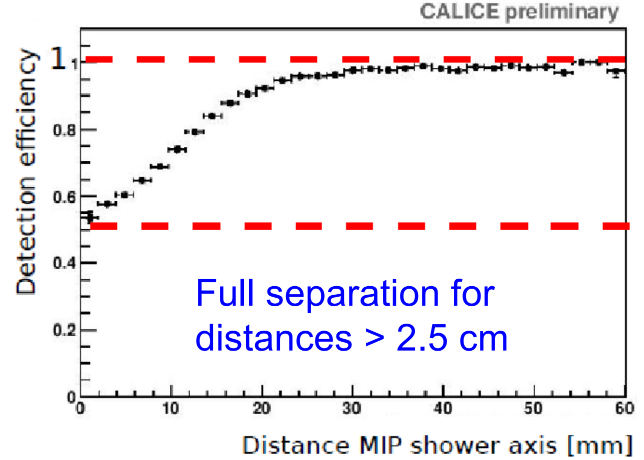
Imaging processing techniques
(Hough transformation)



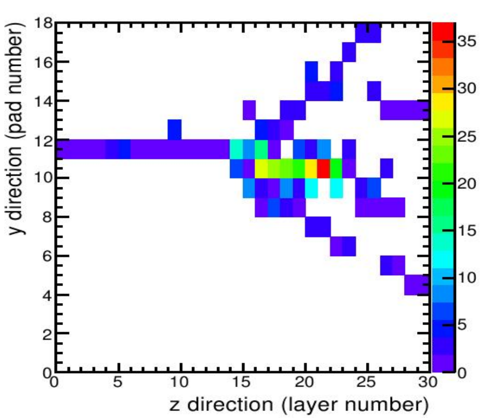
Two pions entering
the SiW Ecal

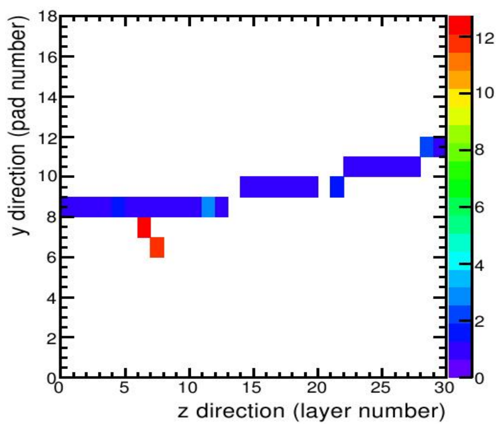
Essential for PFA
(especially for
neutral / charged
particle separation)

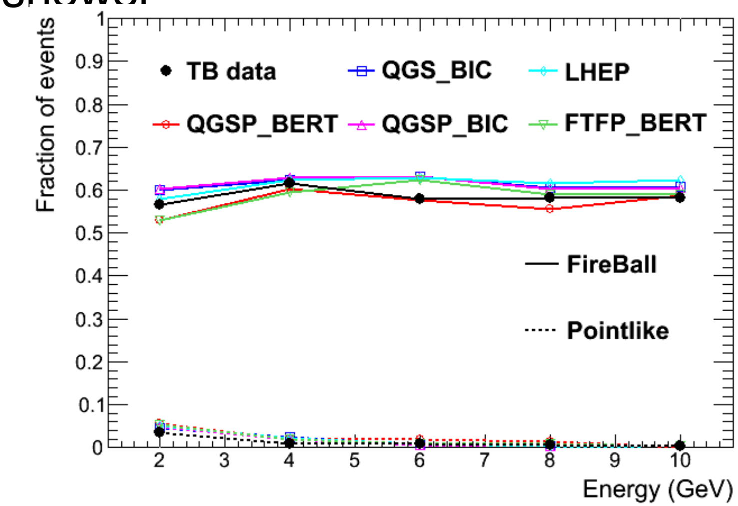
Efficiency to separate
MIP - electron



High granularity permits detailed view into hadronic shower



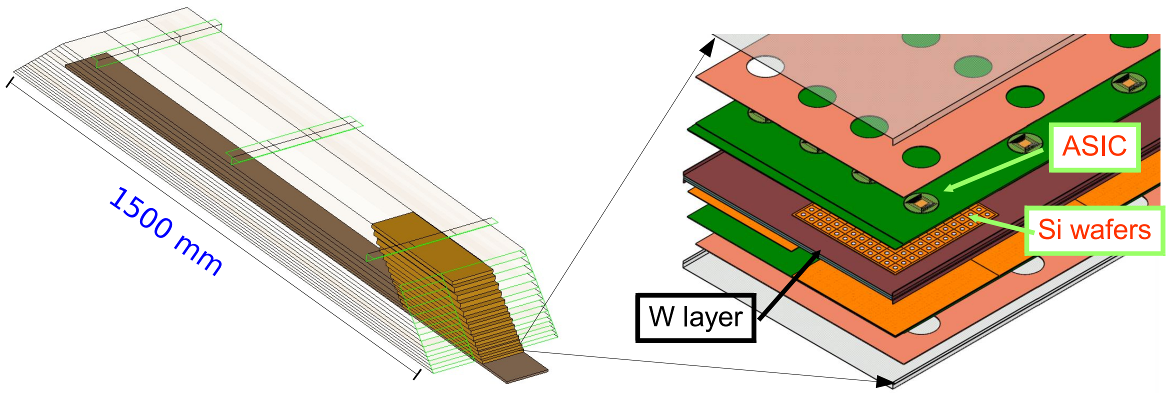




Technological prototype

Technological solutions for the final detector

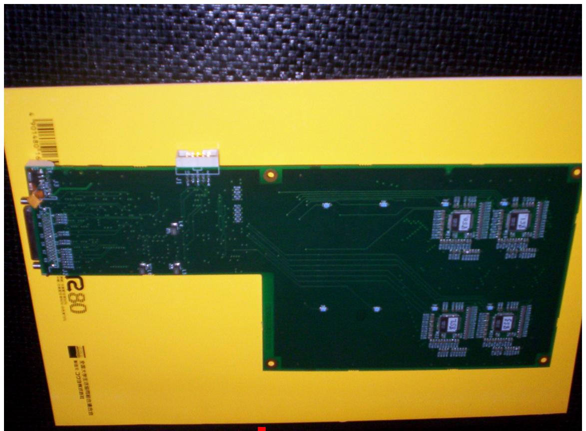
Construction start: 2010



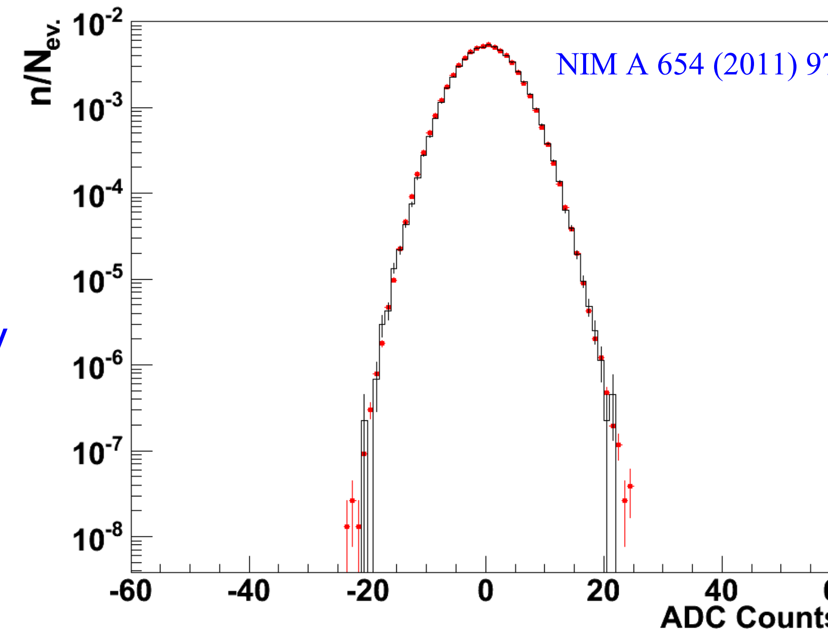
- Realistic dimensions (3/5 of a barrel module of the ILD concept)
- Integrated front end electronic
- Small power consumption (Power pulsed electronics)

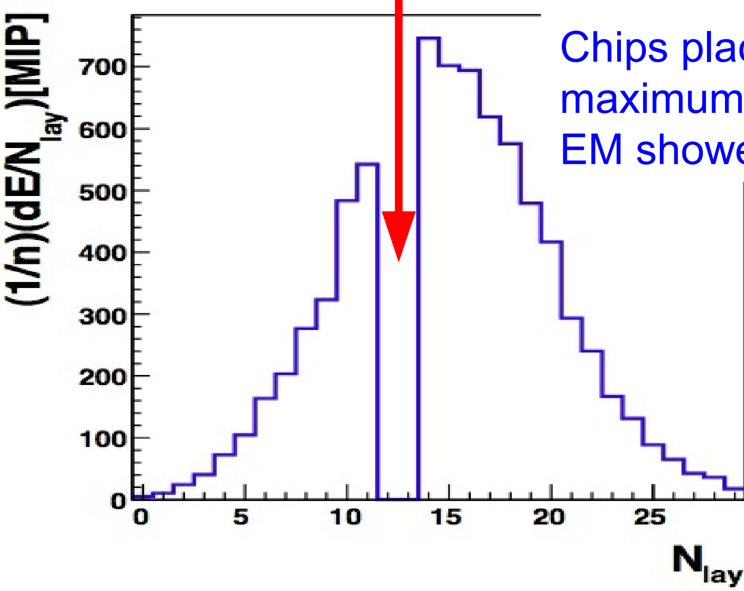
Embedded electronics - Parasitic effects?

Exposure of front end electronics to electromagnetic showers



Comparison: Beam events
(Interleaved) Pedestal events



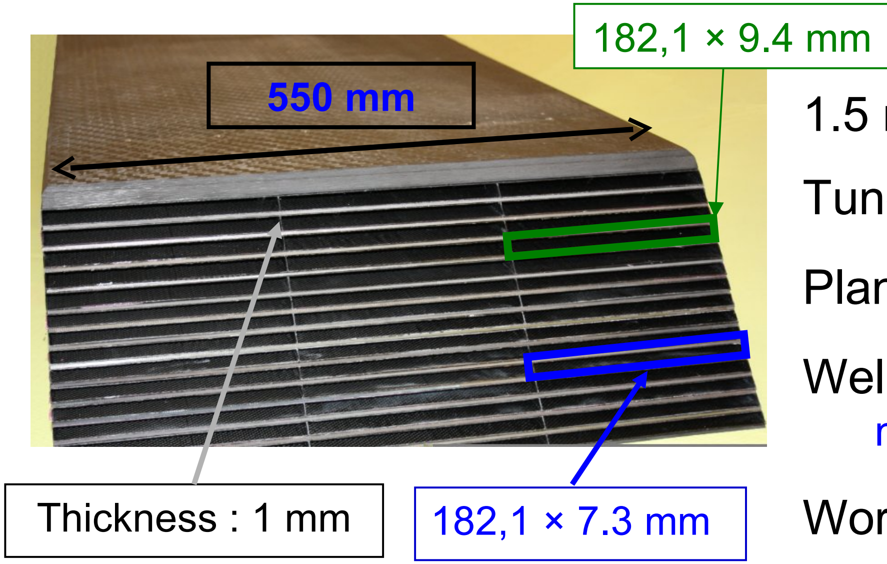


Chips placed in shower maximum of 70-90 GeV EM showers

- No sizable influence on noise spectra by beam exposure
  ΔMean < 0.01% of MIP ΔRMS < 0.01% of MIP
- No hit above 1 MIP observed
  => Upper Limit on rate of faked MIPs: ~7×10^{-7}

Possible Effects: Transient effects
Single event upsets

Mechanical structure



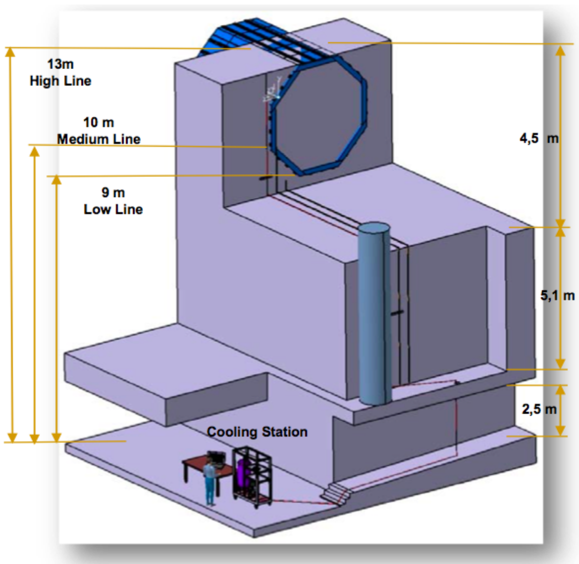
1.5 m long alveolar structure to house ECAL layers

Tungsten plates wrapped into Prepreg

Planar within 5 mm

Well understood
mechanical constraints, thermal behavior

Work on longer structures are ongoing



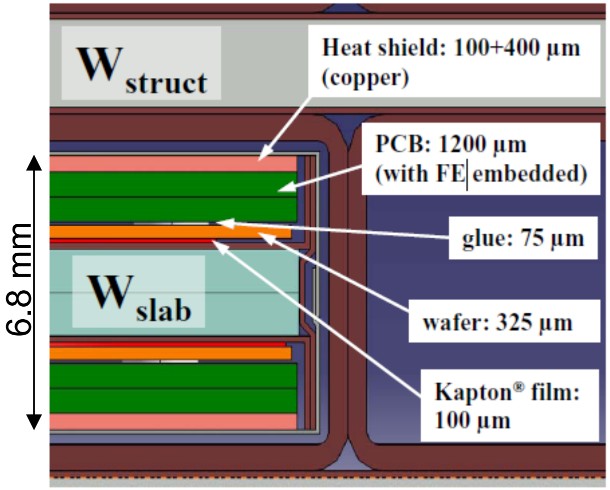
Evacuation of (residual) power of 0.2-0.35 W / layer

Development of a leak less cooling system for a full detector

ECAL layer

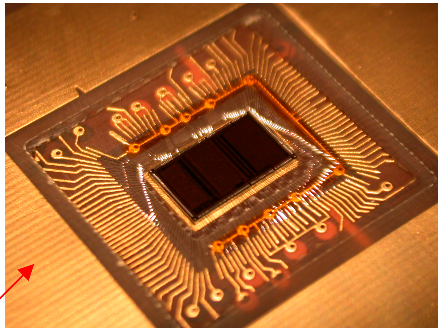
1 Active Sensor Units (ASU)

- 1 kapton (HV for PIN diodes)
- 1 layer PIN diodes
- 1 PCB with microchips embeded
- 1 thermal drain (copper)



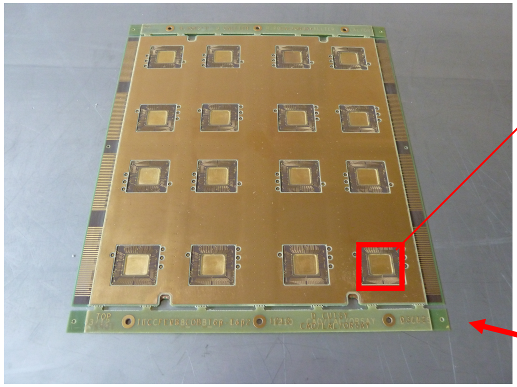
W thickness:

- 2.1 mm (20 layers)
- 4.2 mm (9 layers)

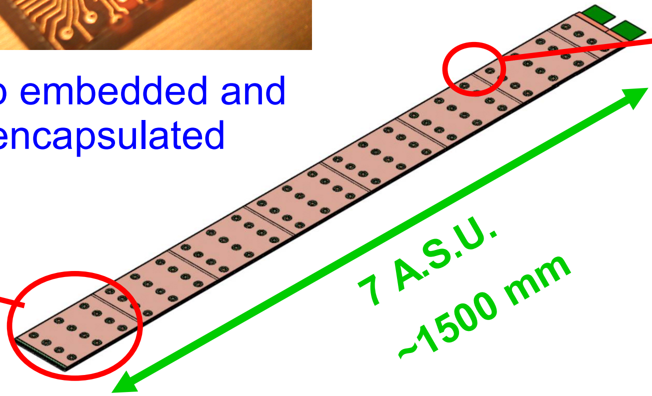


Chip embedded and encapsulated

Interconnection studies

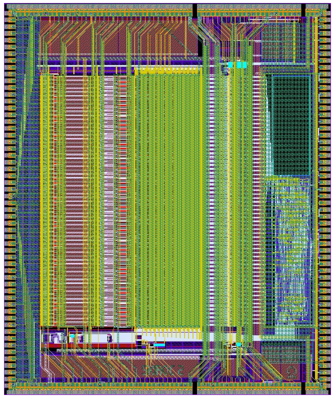


PCB prototype



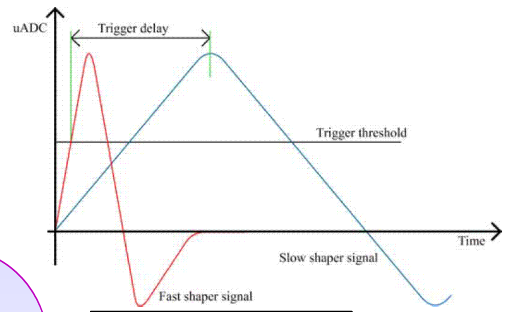
Front end electronics: SKIROC

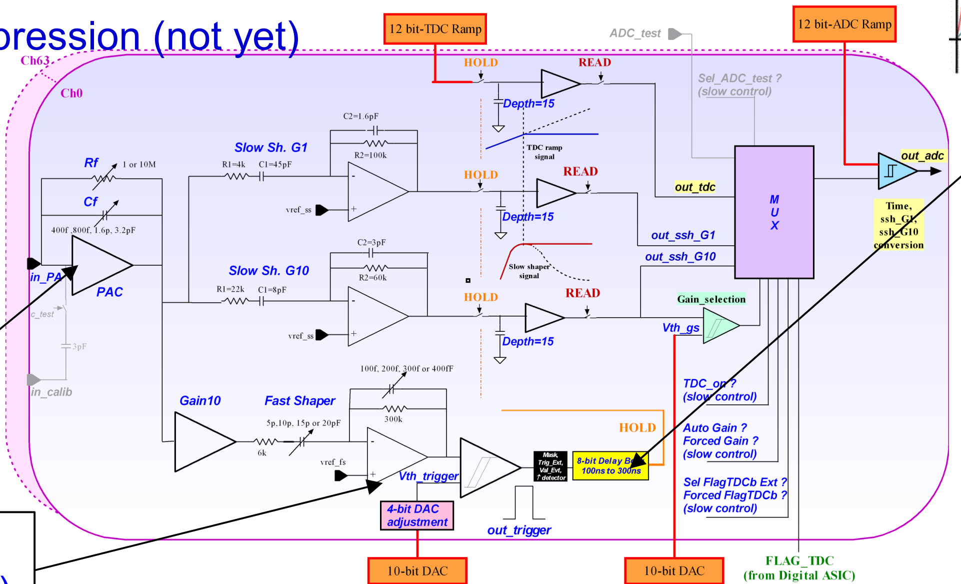
See Nathalie's talk



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 (not yet)



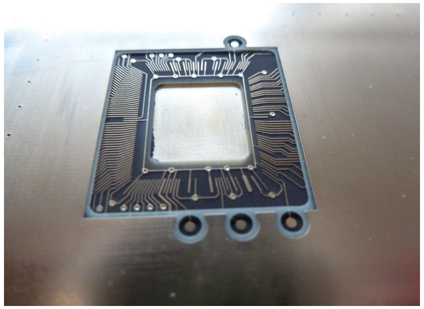


Trigger delay

Preamplifier
(adjustable gain)

Internal trigger
(self-triggering capability)

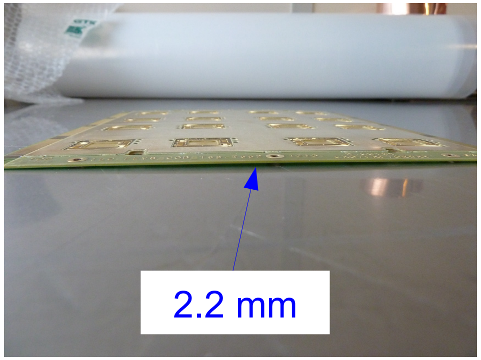
PCB – Embedded electronics



PCB prototype for embedding the chips: aggressive design

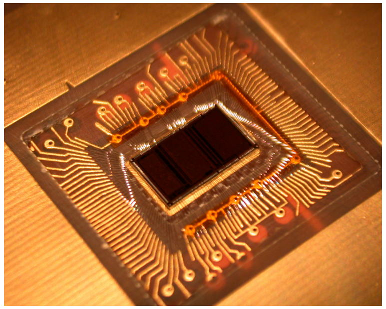
1.2 mm height for a board of 18 x 18 cm^2 and 9 layers

Deviation from total flatness max: 0.5 mm



- First board for 16 ASICs (4 wafers) available
- Now equipped with 8 SKIROC ASICs (Bonding by CERN)

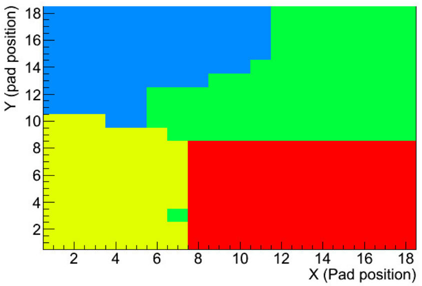
→ Needs testing (Bonding was not straightforward, thin bonding pads to be improved)

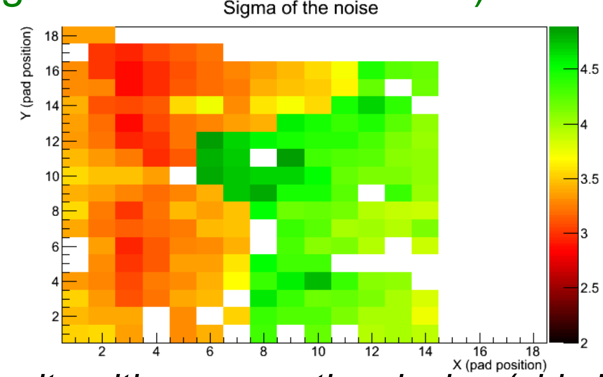


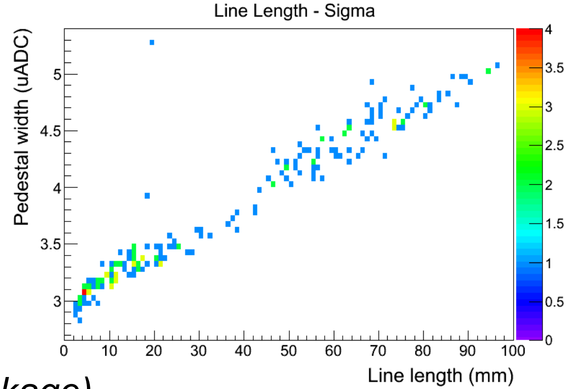
Line density in PCB → routing is crucial

Critical points are :

- Noise ∝ line length
- Cross talk (Digital → readout channels)





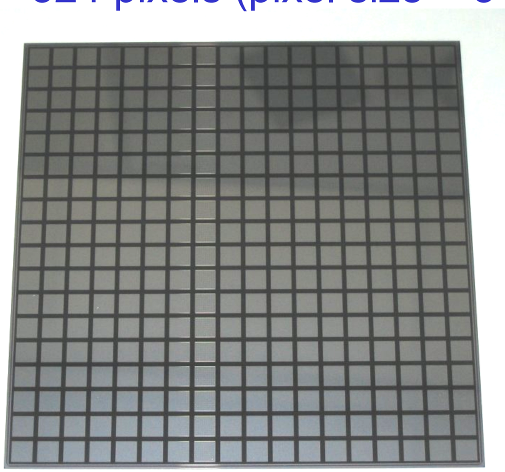


Results with conservative design (chip in package)

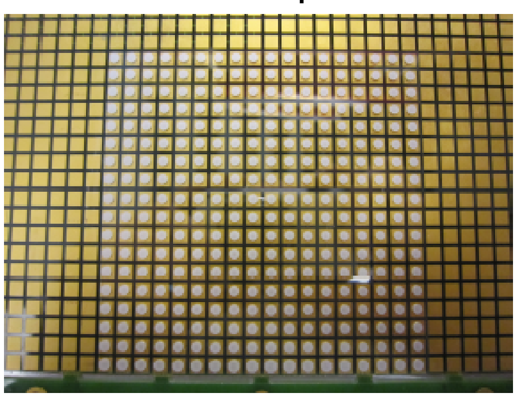
Silicon wafers

Si wafer (HPK):

- 9x9 cm²
- Thickness = 320 μm
- 324 pixels (pixel size = 5 x 5 mm²) → lateral granularity = 4 x better than physics prototype



Gluing onto PCB and development of automatised procedure

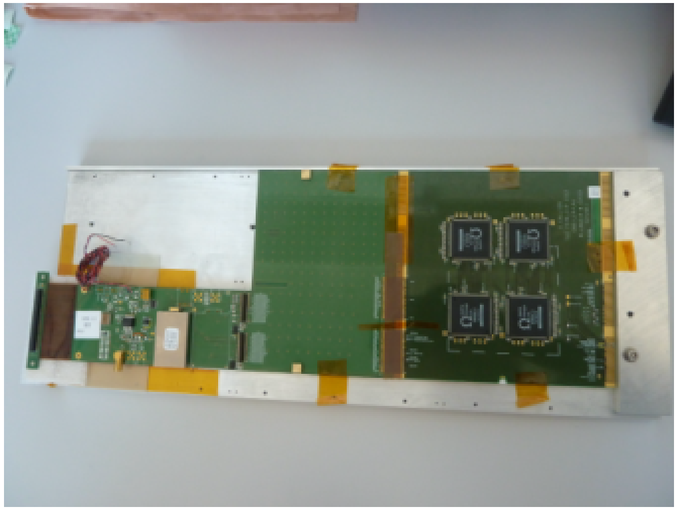


- Optimization studies on guard rings and characterization.
- Guard ring around the wafer to control the leakage currents
- Different technologies are tested

The road to the technological prototype

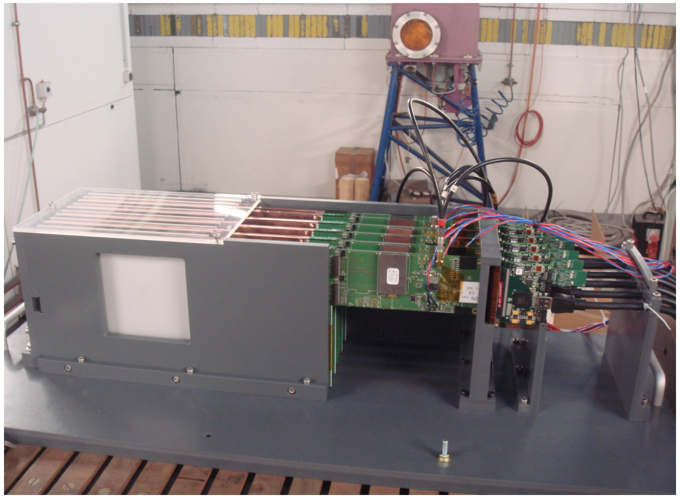
Intermediate step: Conservative layer design for beam tests

- First test in beam
- Benchmark to go further



Test beam @ DESY : e- (1 - 5 GeV)

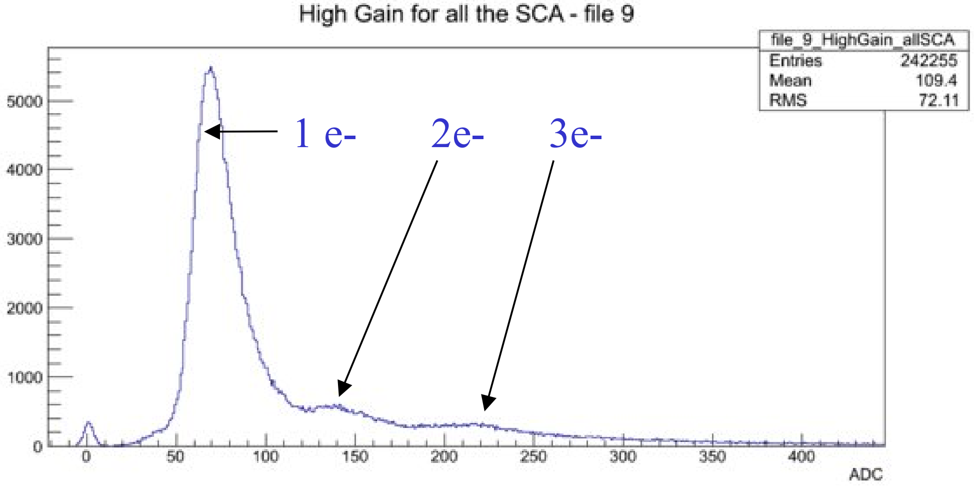
- Single detection layer
- 4 ASICs per slab (1⁄4 final design) – conservative design (chip in package)
  - 4 SKIROCs x 64 channels = 256 channels/slab

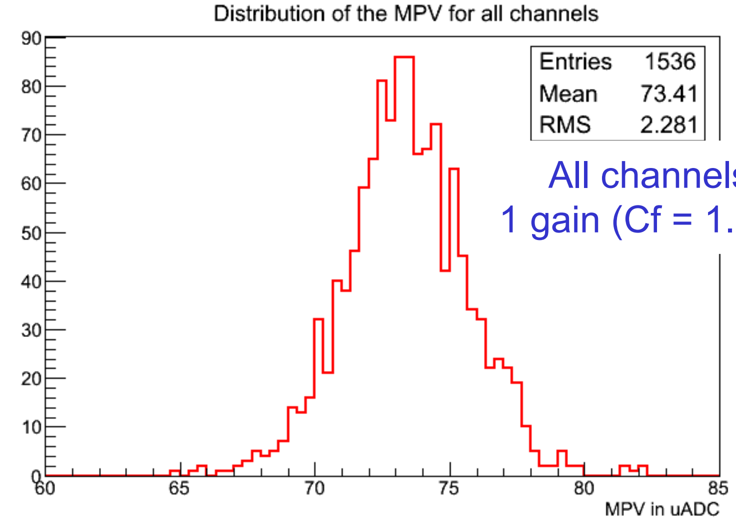


- 6 layers (July 2012) → 1536 channels
- 8 layers (February 2013) → 2048 channels
  - 4 layers in power pulsing

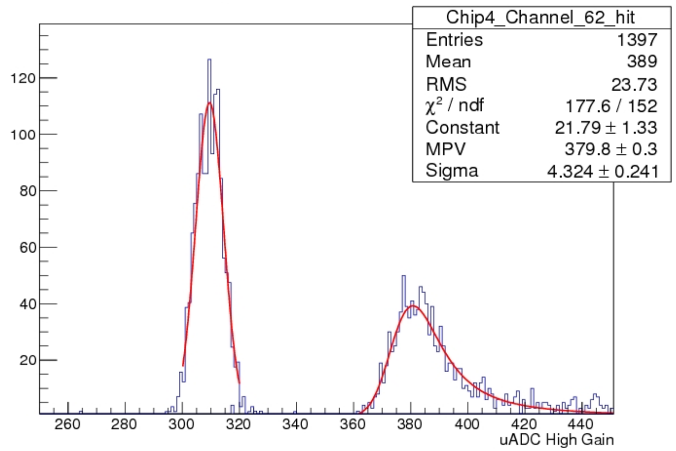
Selection of results

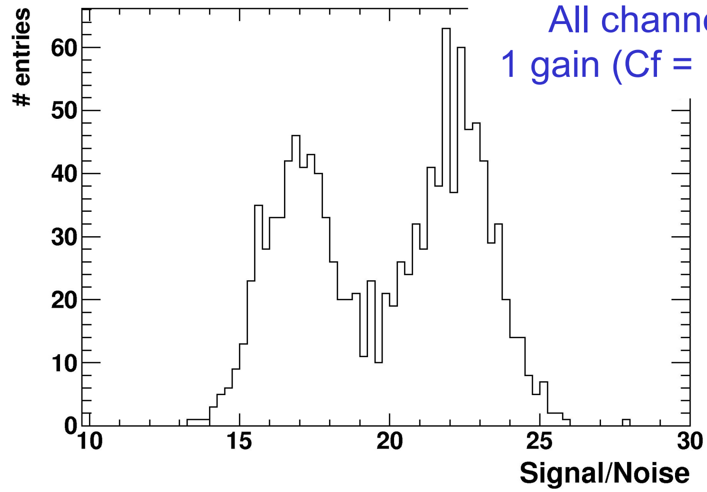
Complete understanding of electronics → Filtering of non-physic events
Establishment of calibration procedure for a larger number of cells
Homogeneity of response (x,y scan of detector)





All channels
1 gain (Cf = 1.2 pf)

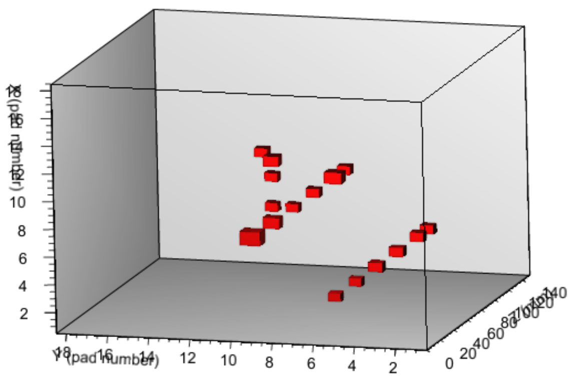




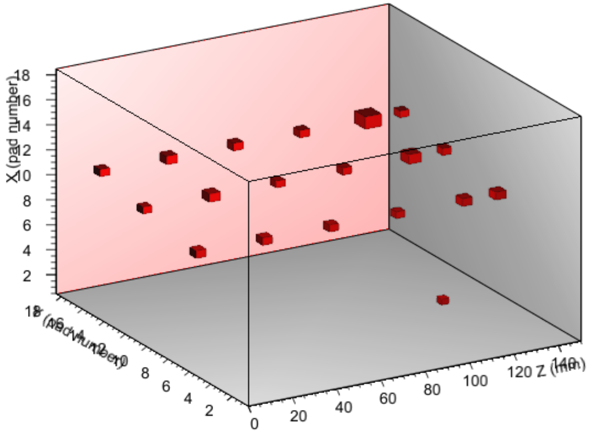
All channels
1 gain (Cf = 1.2 pf)

Event display

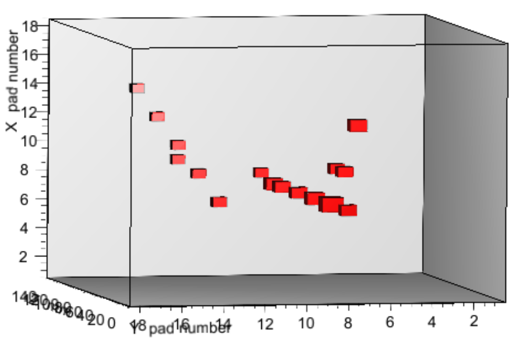
2 e- (3 GeV, no tungsten)



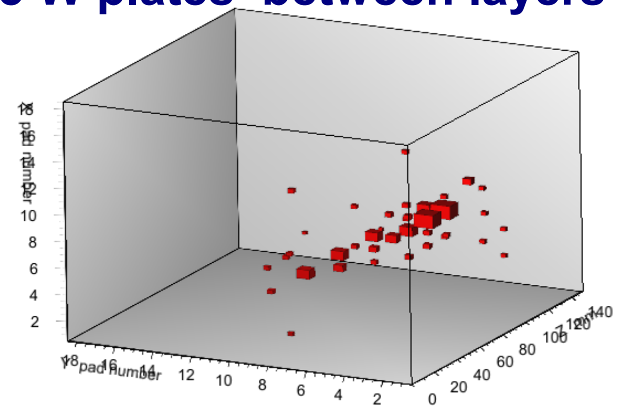
3 e- (3 GeV, no tungsten)



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



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



R&D in progress… first test beams show promising results

Summary and outlook

Successful R&D for a highly granular SiW ECAL physics prototype

Operated over several years
Exposed to several particle beam types and energies
Capacity of separating particles impressively demonstrated

The R&D for technological prototype is ongoing

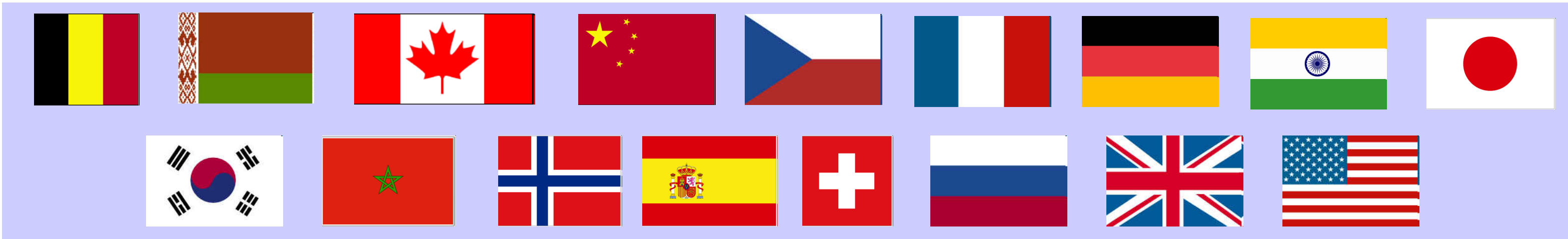
A lot of work on different aspects to prove the engineering feasibility of the project
- long layers
- power consumption (power pulsing) → critical point
- ...

First test beams with conservative design:
- encouraging results
- identification of open issues

Analysis of power pulsing data is on-going (February 2013 test beam)

Back up

The CALICE collaboration



+300 people, +50 institutes, 17 countries

R&D detector for futur linear e+/e- collider

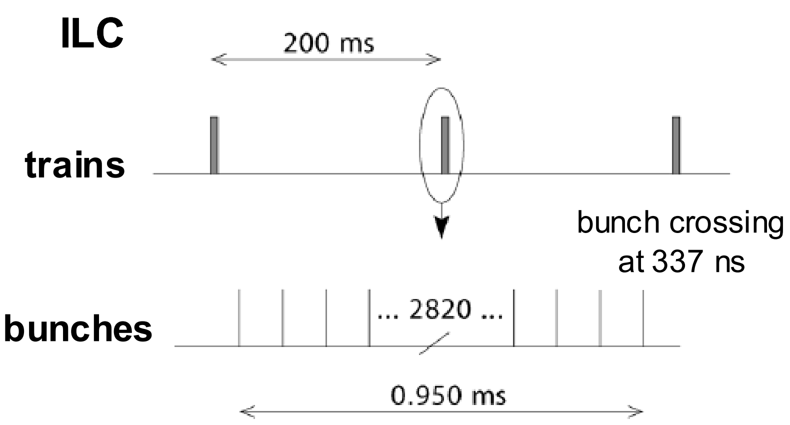
(ECAL, HCAL, muon detectors, tail catchers…)

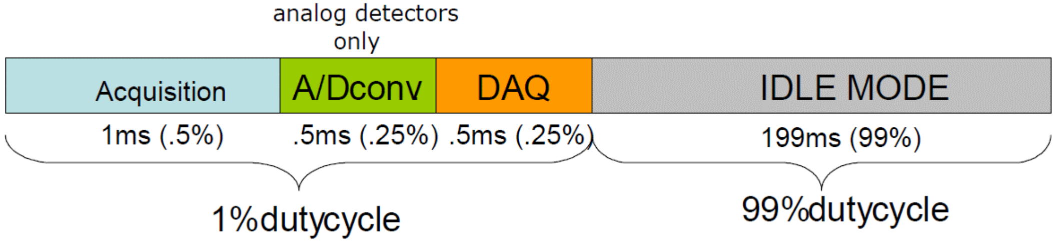
➔ Common approach:

Ultra-granular "imaging" calorimetry → particle flow algorithm

- Physics Prototypes
  - Small prototypes. Proof of principle of technologies.
- Technological prototypes
  - Testing more realistic hardware designs which could be scaled up to full detector
- Combined beam tests
  - Reconstruction algorithms
  - Validate MC simulations

Power pulsing





Long idle time between trains:

- Power intensive fast analog only for <1% of the time
- Long breaks for data handling

Power Pulsing

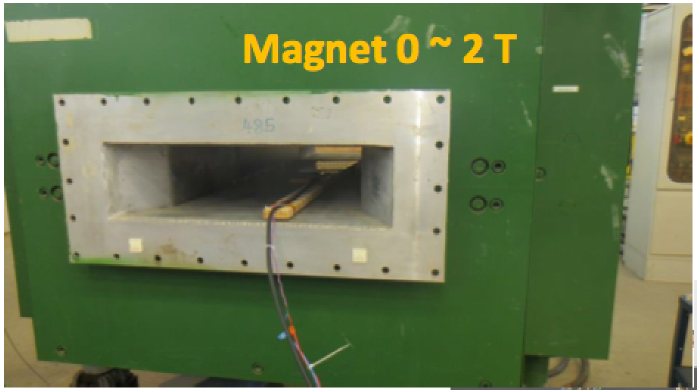
0 to 10 Amps pulses of 1 ms at 5 Hz

Power pulsing (it may be included in the talk)

Power pulsing (PP): duty cycle 99% , 10Hz

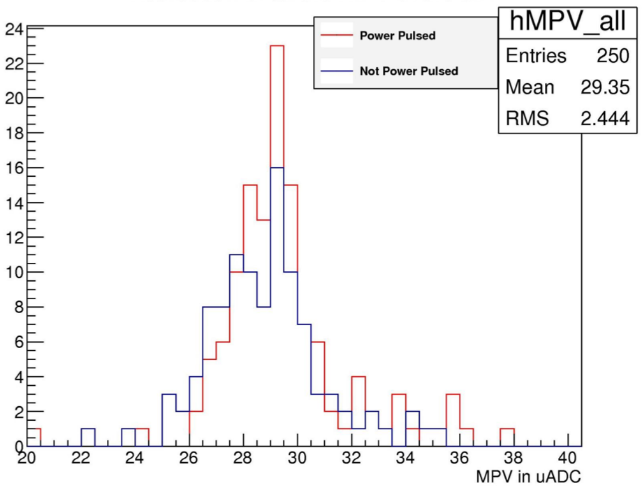
Operation in power pulsing mode requires removal of decoupling capacitances
→ Do not expect as stable performance as in continuous mode

Tests in magnetic field



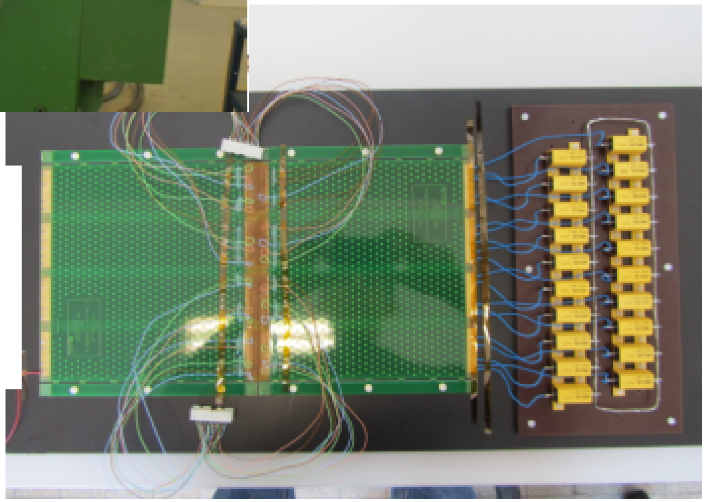
Measurement of the pedestal in 1 layer

Tests in beam



MPV of the landau distribution
Comparison PP - No PP (same layer)

Interconnection (2 ASUs):
Measurement of the ohmic resistance

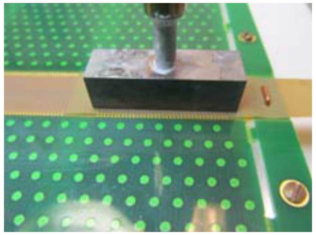


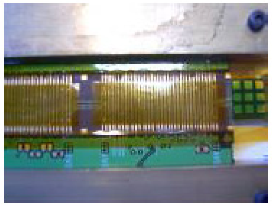
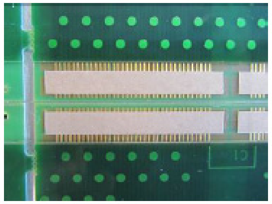
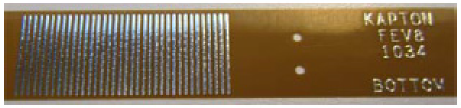
Ongoing analysis but first results are encouraging

Interconnexions

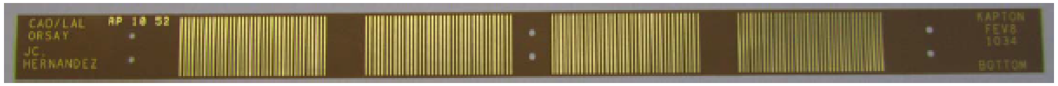
Up to 9 equipped PCBs interconnected to make detector slab

→ Electrical and mechanical connection made thanks to Kapton connecting cable



Technology	Advantages	Disadvantages
N°1 Solder 	-Proven technology -Possible to repair -~3 euros/connector	-Difficult procedure -Too much heat for the glue of wafers -Cannot be industrialized
N°2 ACF 	-Easy to install -Easy to remove -Easy to industrialize	-Needs to have a perfect planarity -Needs to have a thermode ~15Keuros -10mA maximum per wire -~30 euros/connector -Too much pressure =mechanical stress for the wafers
N°3 Spécial Kapton 	-Easy to install -Good reliability -Possible to repair -Easy to industrialize -Good strength -~4 euros/connector	-I don't know yet

Max 600N before destruction



Signal integrity → In progress

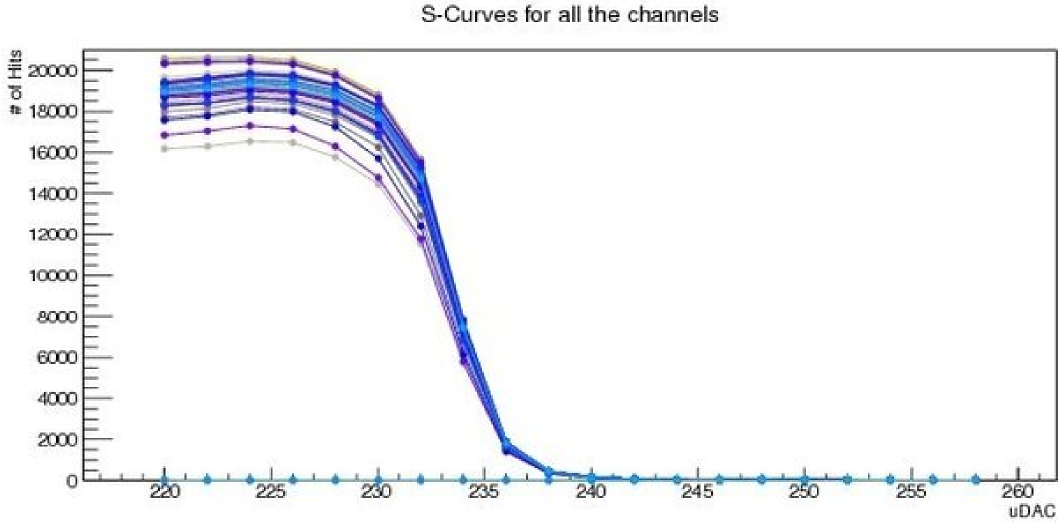
Filtering

- **Ricochet / BCID+1 effect (without hit)**
  - Seen with SKIROC2 test bench and in TB
  - Understood
  - Easy to cut in TB analysis (cut event if delta BCID == 1)
- **Plane events**
  - Instabilities of power supply level → fake events
  - 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
  - Cut in TB analysis:
    - delta BCID <= 5
- **Isolated hits**
  - Reconstruction needed to see this effect (not yet well studied: noise, cosmic, related to plane events?)
  - Cut in TB analysis:
    - we ask at least 3 planes with hits in the same event (after reconstruction)

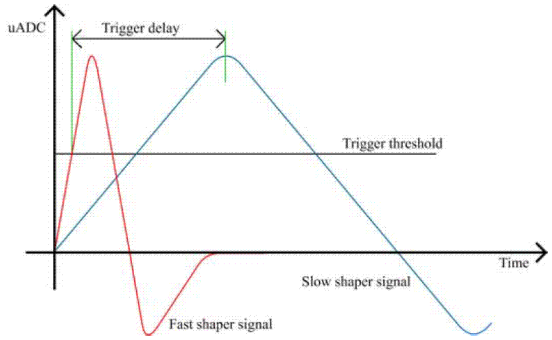
Calibration of ASICs

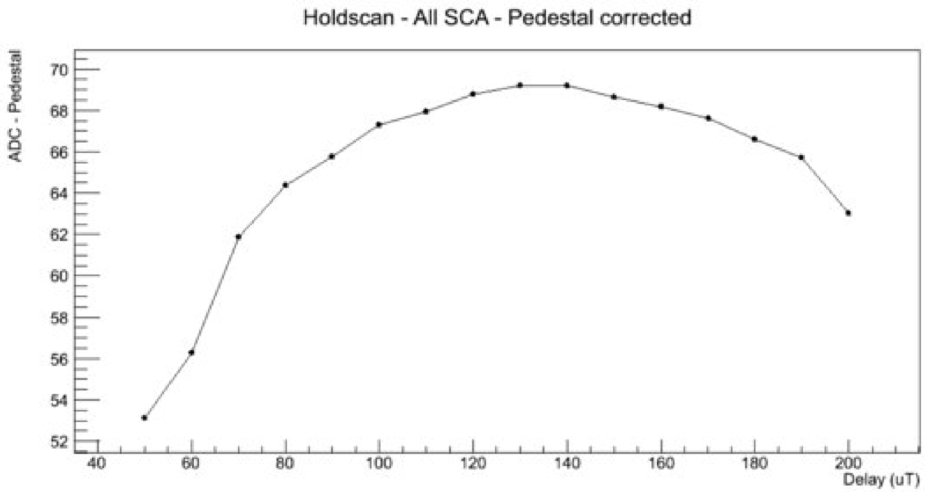
Establishment of calibration procedure for a larger number of cells

Trigger threshold
- depends on the gain

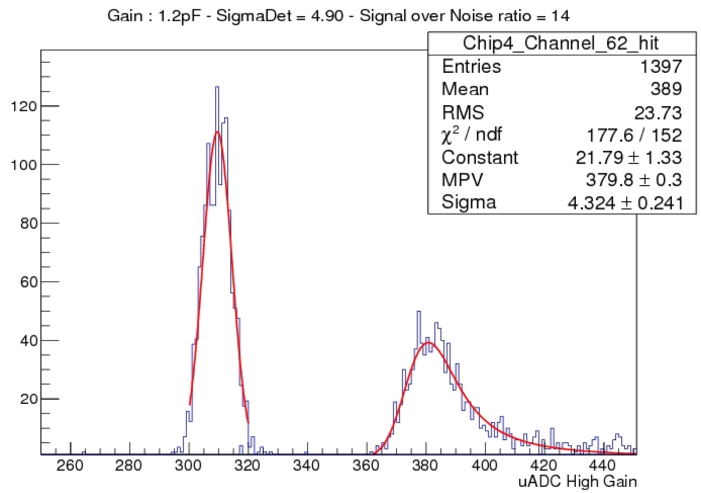


Trigger delay
- depends on the trigger threshold

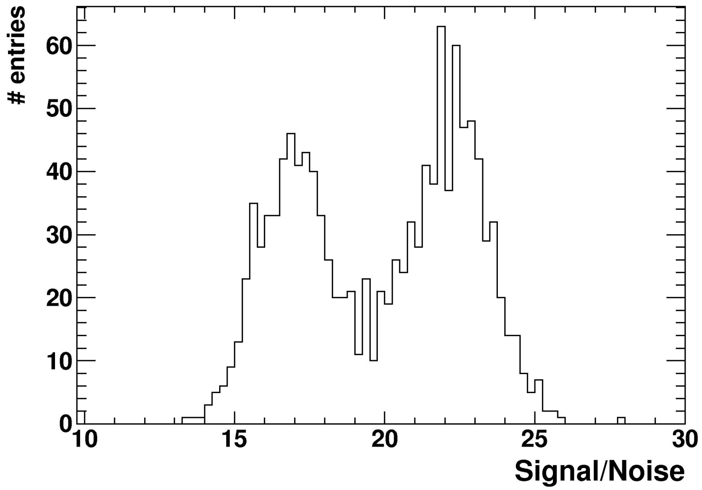




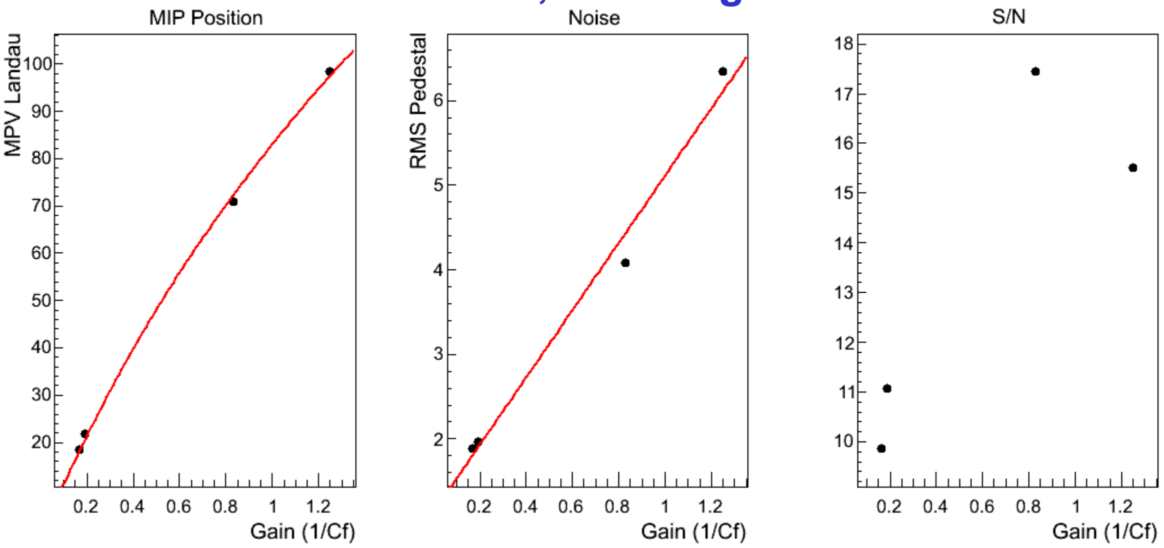
Signal over noise ratio



All channels, 1 gain (Cf = 1.2 pf)



1 channel, several gains



R&D target is 10:1

S/N ≥ 10
(for all gains available with SKIROC2)