R&D for SiW ECAL

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Conseil Scientifique IN2P3

Advanced European Infrastructures for Detectors at Accelerators

CALIIMAX-HEP
2010 BLANC 0429 01

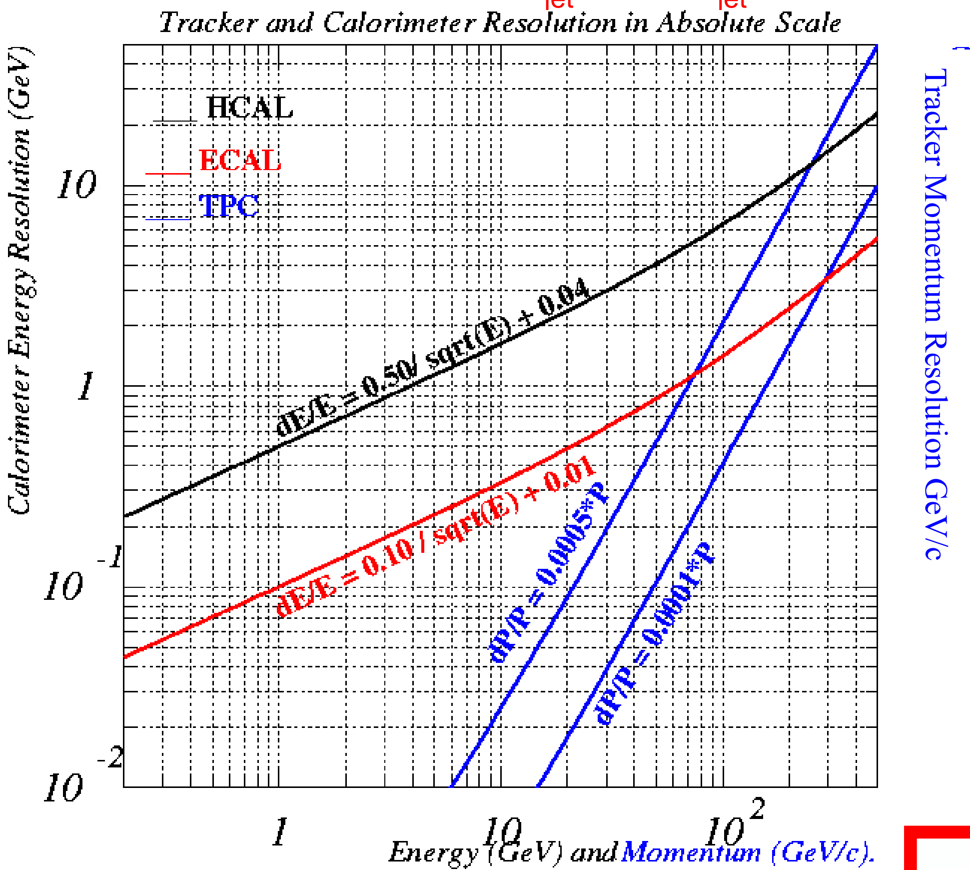
EU-FP7 Grant Agreement 262025

Jet energy resolution

Final state contains high energetic jets from e.g. Z,W decays

Need to reconstruct the jet energy to the utmost precision !

Goal is around 3%/E_{jet} - 4%/E_{jet}



Jet energy carried by …

- Charged particles ($e^{\pm}$, $h^{\pm}$,$\mu^{\pm}$)): 65%

  Most precise measurement by Tracker

  Up to 100 GeV

- Photons: 25%

  Measurement by Electromagnetic Calorimeter (ECAL)

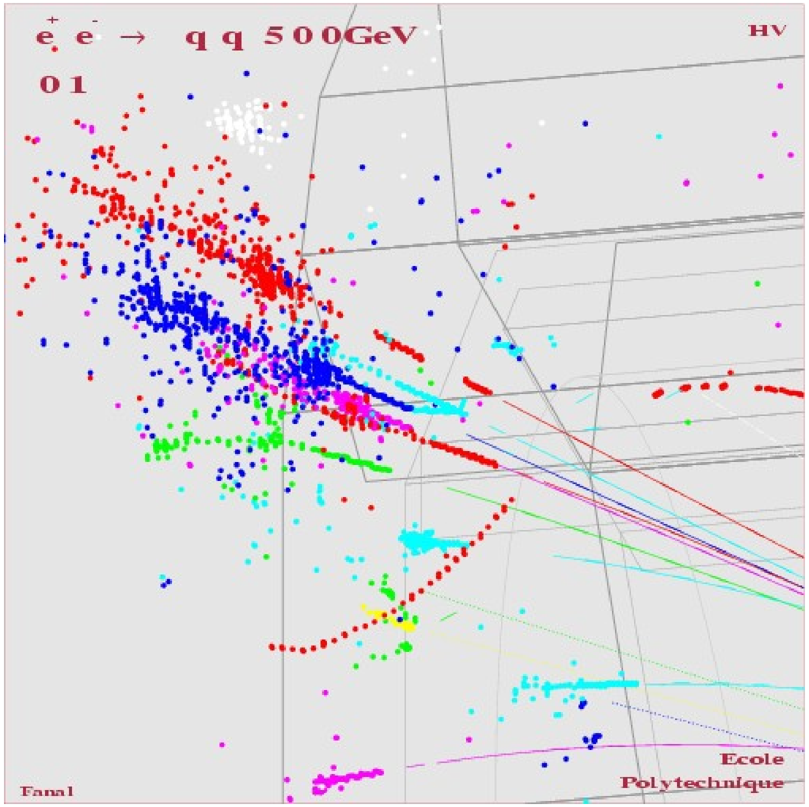
- Neutral Hadrons: 10%

  Measurement by Hadronic Calorimeter (HCAL) and ECAL

$$\sigma_{Jet} = \sqrt{\sigma^2_{Track} + \sigma^2_{Had.} + \sigma^2_{elm.} + \sigma^2_{Confusion}}$$

Confusion term

- Base measurement as much as possible on measurement of charged particles in tracking devices
- Separate of signals by charged and neutral particles in calorimeter



- Complicated topology by (hadronic) showers
- Correct assignment of energy nearly impossible

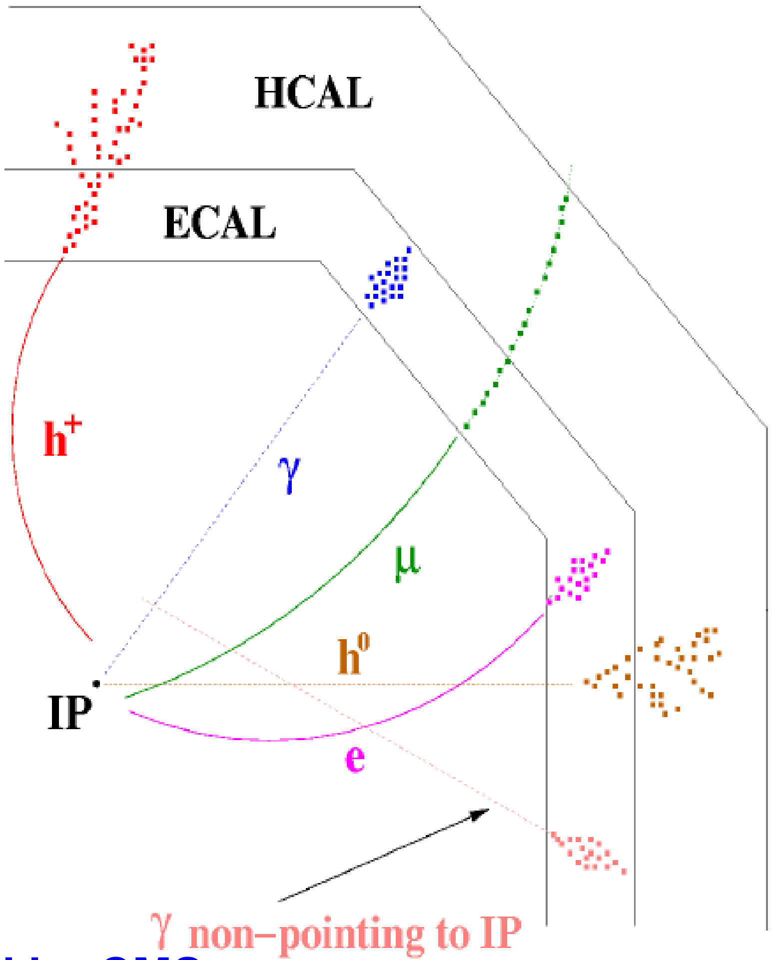
⇒ Confusion Term

Need to minimize the confusion term as much as possible !!!

Particle flow detector

Jet energy measurement by measurement of **individual particles**
Maximal exploitation of precise tracking measurement

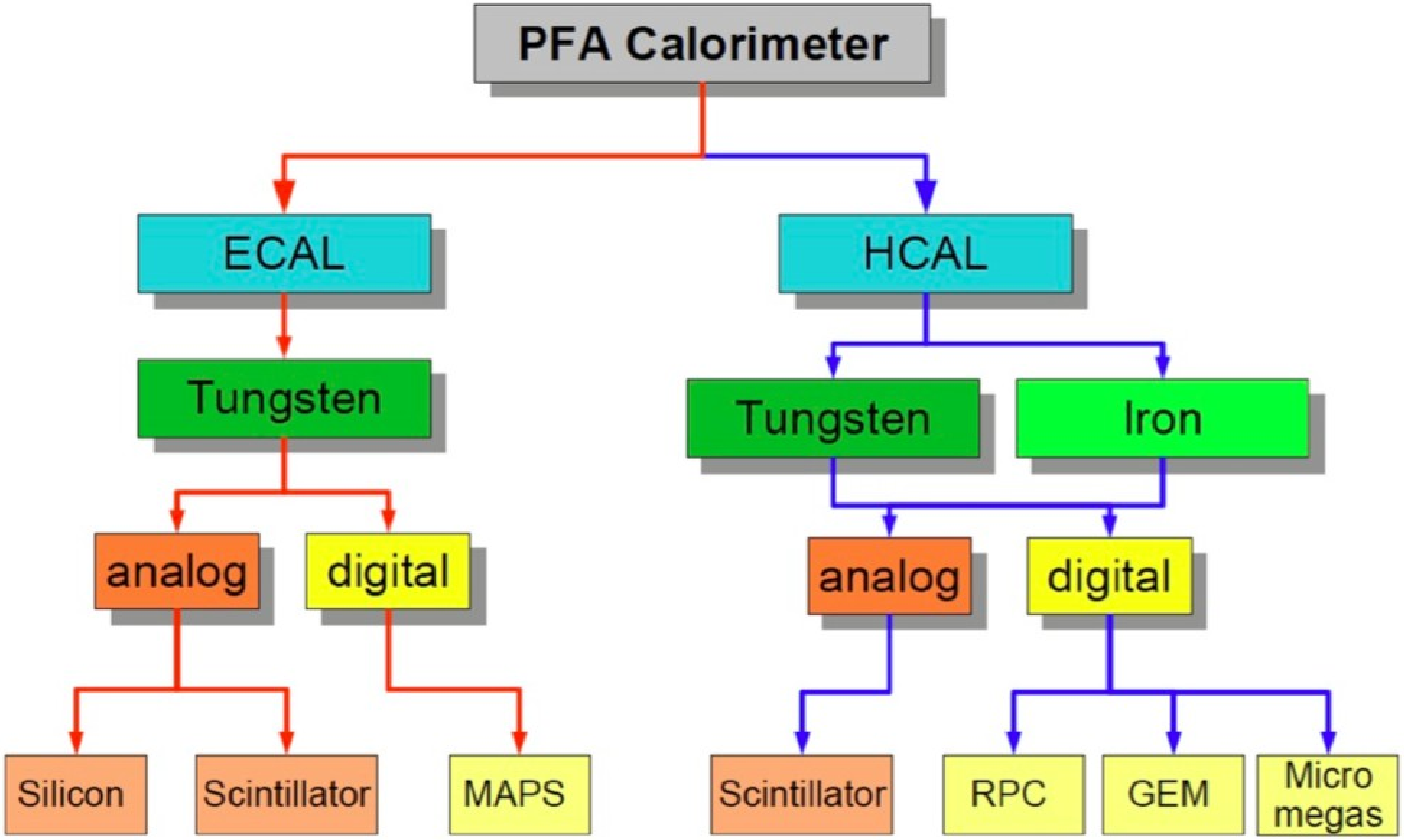
- large radius and length
  - to separate the particles
- large magnetic field
  - to sweep out charged tracks
- "no" material in front of calorimeters
  - stay inside coil
- small Molière radius of calorimeters
  - to minimize shower overlap
- **high granularity of calorimeters**
  - to separate overlapping showers



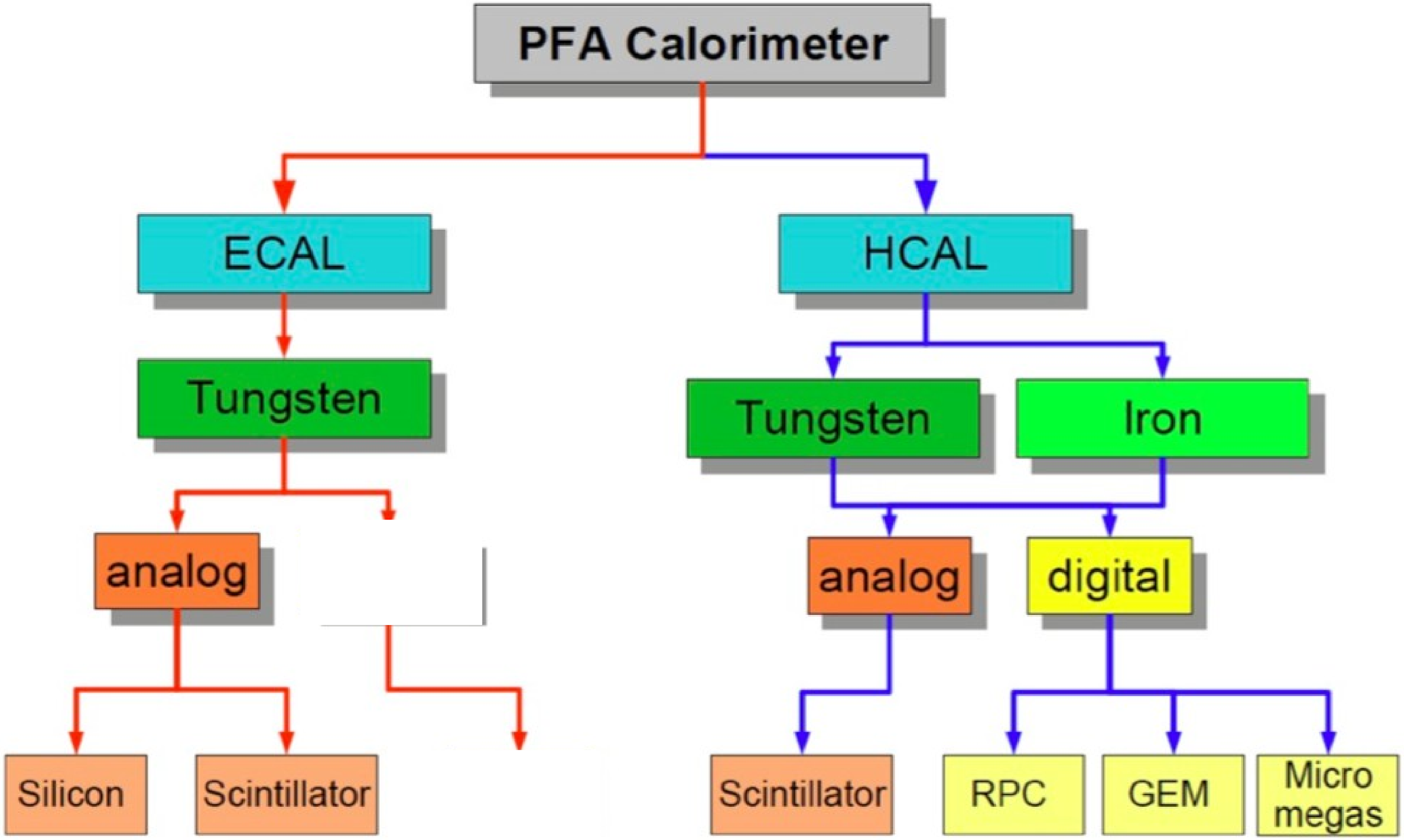
Physics goals at the ILC demand the construction of highly granular calorimeters!!!
Emphasis on tracking capabilities of calorimeters

NB.: Potential of particle flow well demonstrated by CMS

Calorimeter Technologies for LC detectors



Calorimeter Technologies for LC detectors



The IN2P3 contributes strongly to all these technologies

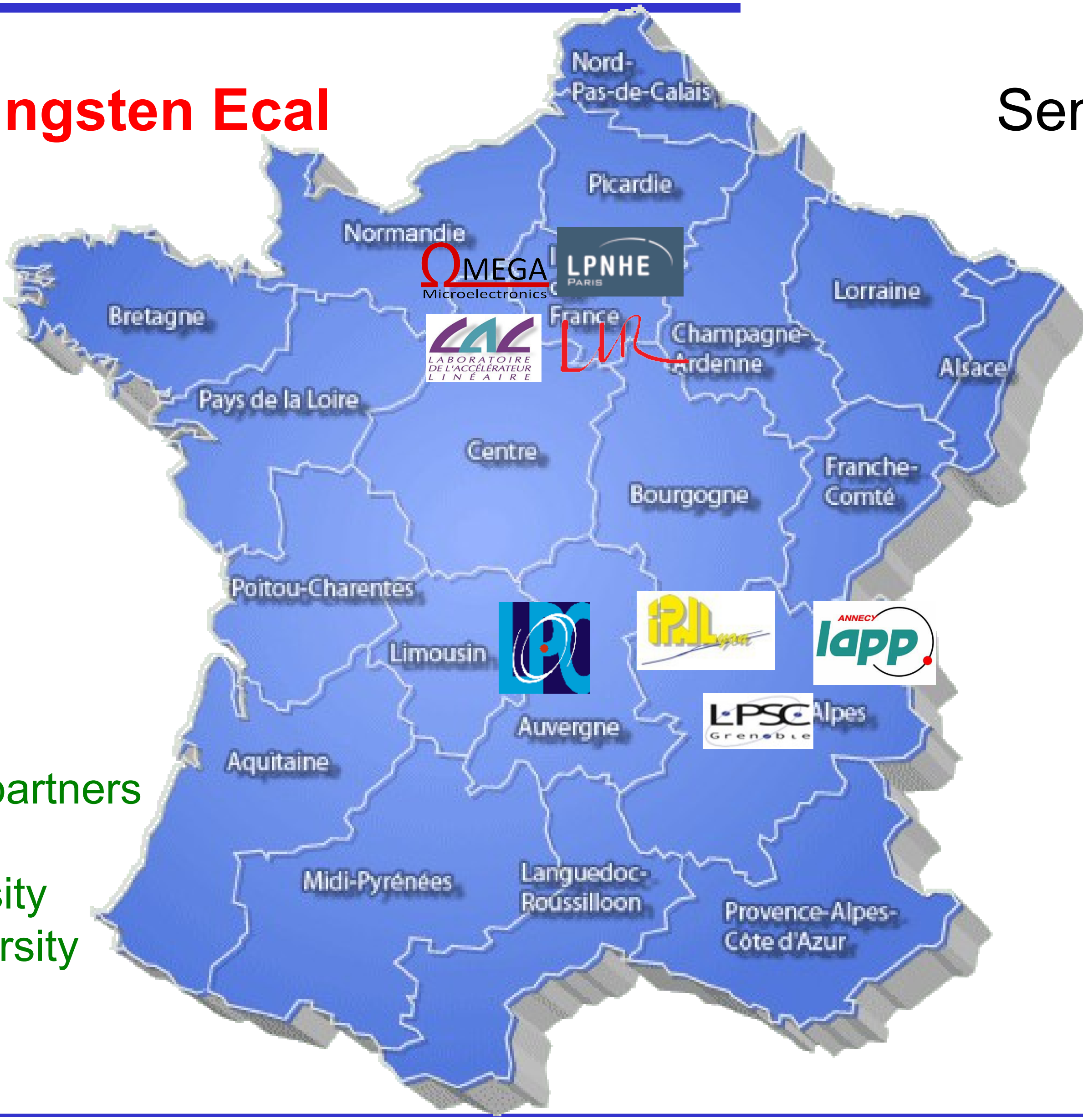
IN2P3 groups working on highly granular calorimeters

Silicon Tungsten Ecal
(This talk)

LAL
LLR
LPC
LPNHE
LPSC
OMEGA

International partners

Tokyo University
Kyushu University
SKKU
FZU

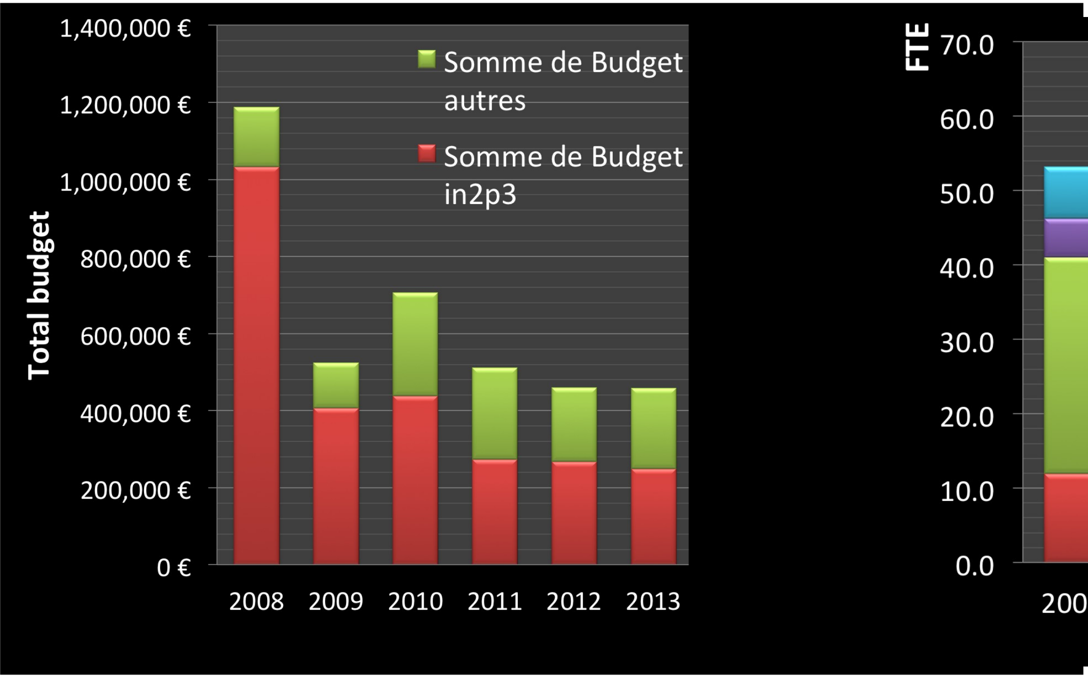


Semi digital Hcal

IPNL
LAPP
LLR
OMEGA

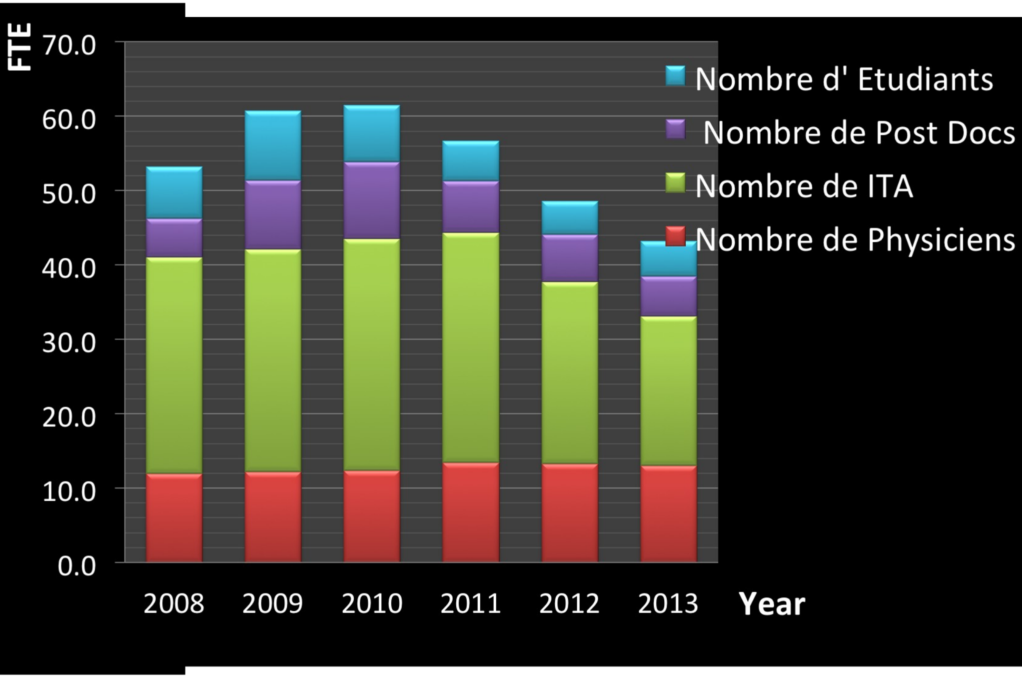
Devlopment of budget for calorimeter R&D since 2008

Budget



Total: ~ 3.85 MEUR
(~30% from 2008)

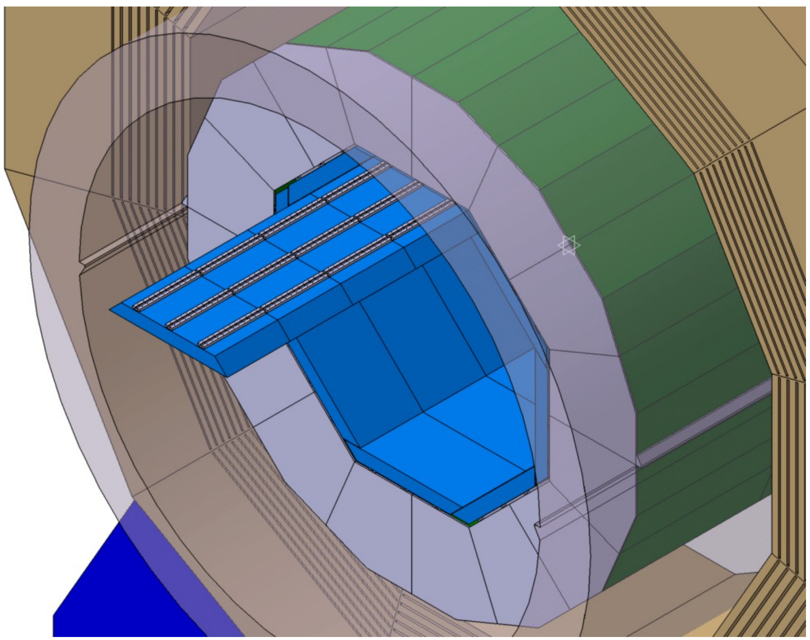
Staff



Total: 324

SiW ECAL is one of the proposals for future LC detectors

➡ Optimized for Particle Flow Algorithm:



The SiW ECAL in the ILD Detector

Basic Requirements:

- Extreme high granularity
- Compact and hermetic

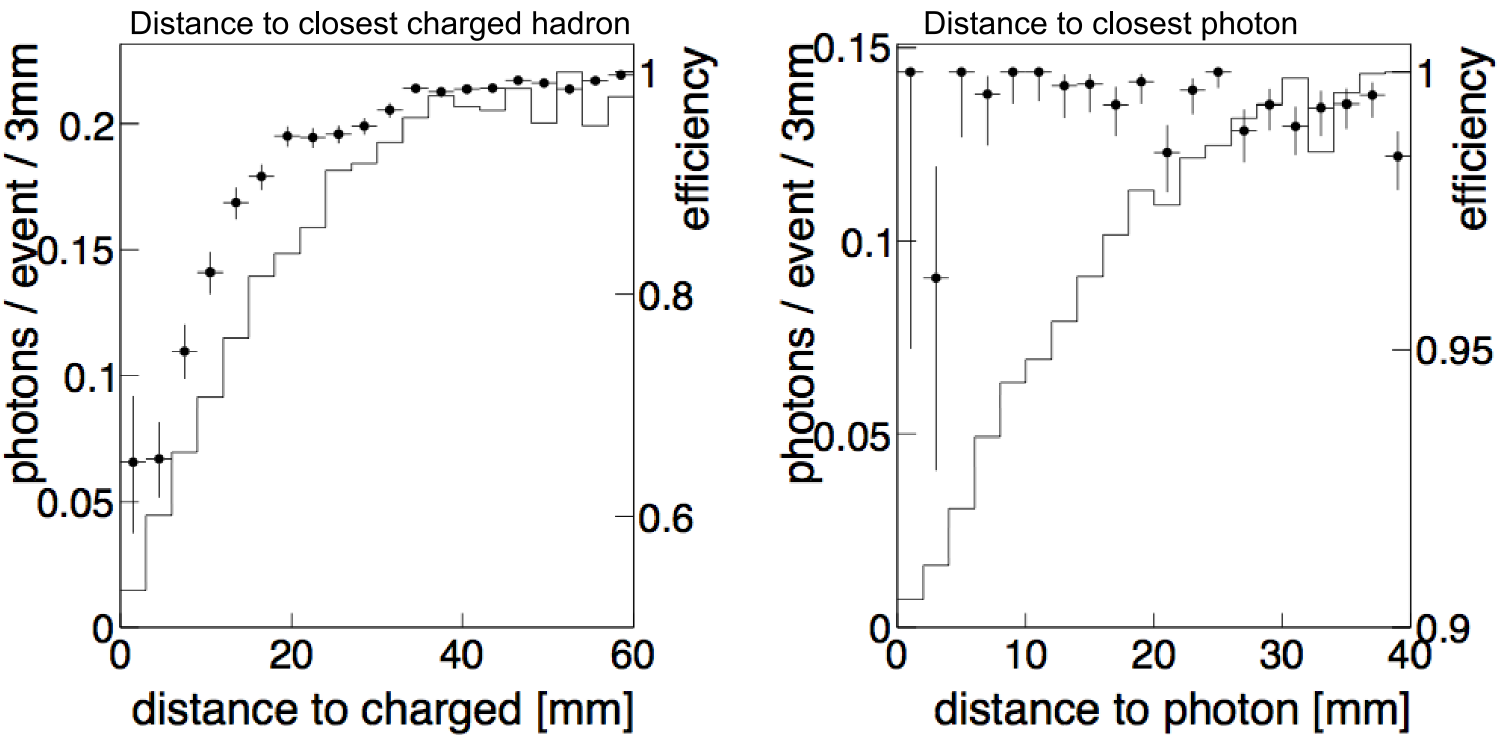
Basic Choices:

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

Example GARLIC algorithm

Gamma Reconstruction algorithm for LInear Collider

Simulation study in ILD for 500 MeV photons



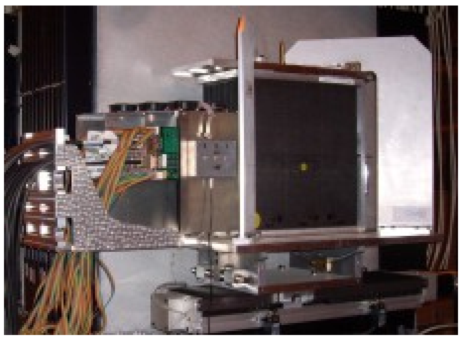
Very promising separation power due to high granularity

SiW ECAL R&D

Physics Prototype

Proof of principle

2003 - 2011



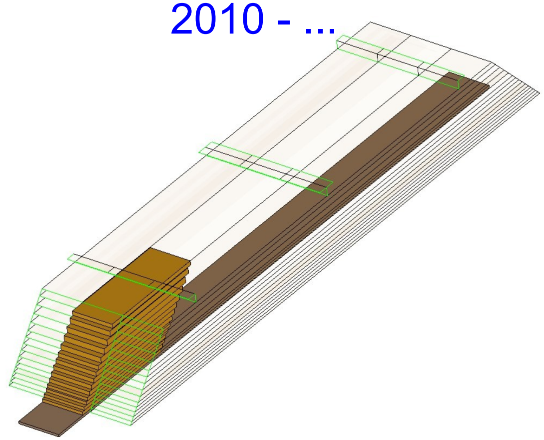
Number of channels : 9720

Weight : ~ 200 Kg

Technological Prototype

Engineering challenges

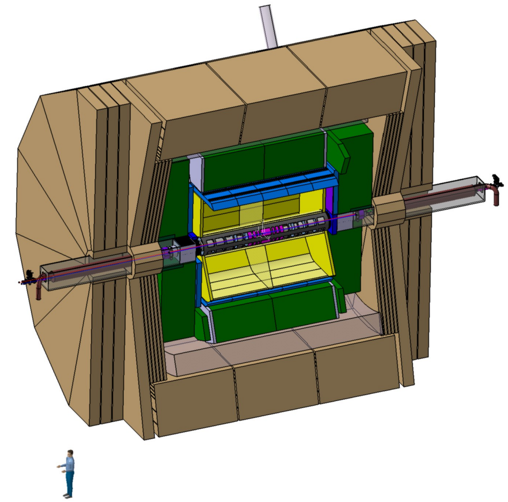
2010 - ...



Number of channels : 45360

Weight : ~ 700 Kg

LC detector



ECAL :

Channels : ~100 10^6

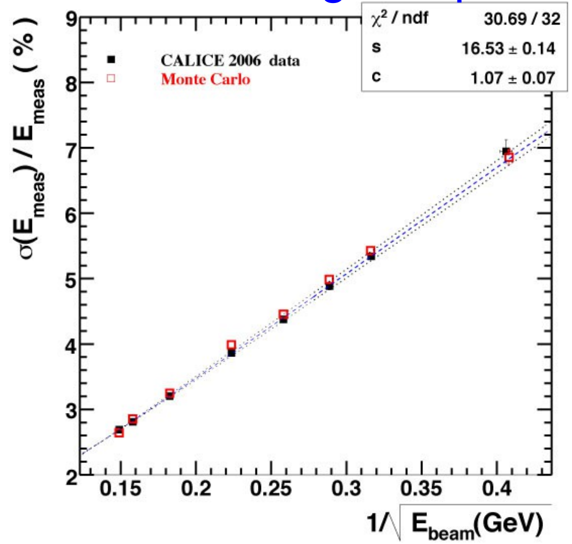
Total Weight : ~130 t

Studies are well integrated in international collaboration CALICE and ILD detector concept

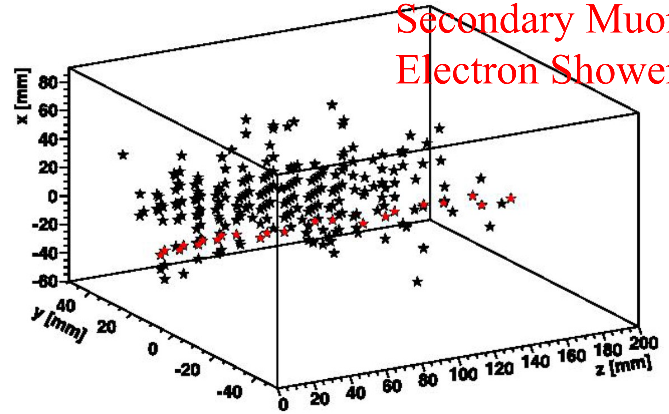
Physics prototype – Brief summary of results I

Calorimeter for Particle Flow

Design emphasises spatial granularity over energy resolution

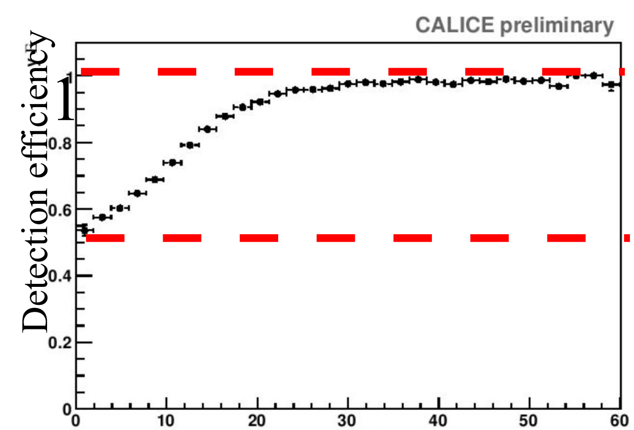


Secondary Muon within Electron Shower



Resolution curve shows typical
√E dependency

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

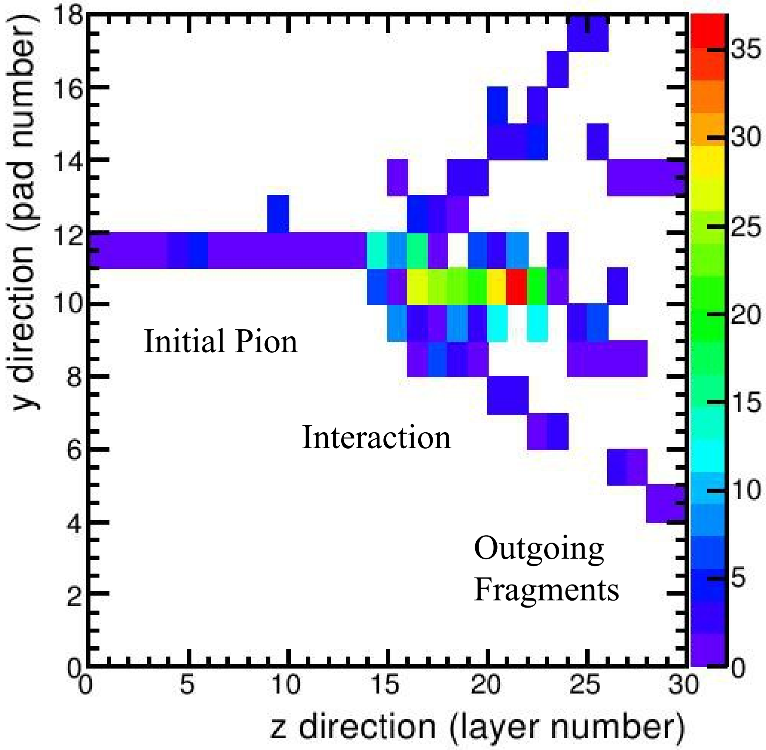


- Resolution well described by MC
- Confirms value used in detailed simulation studies

Granularity and hadronic cascades

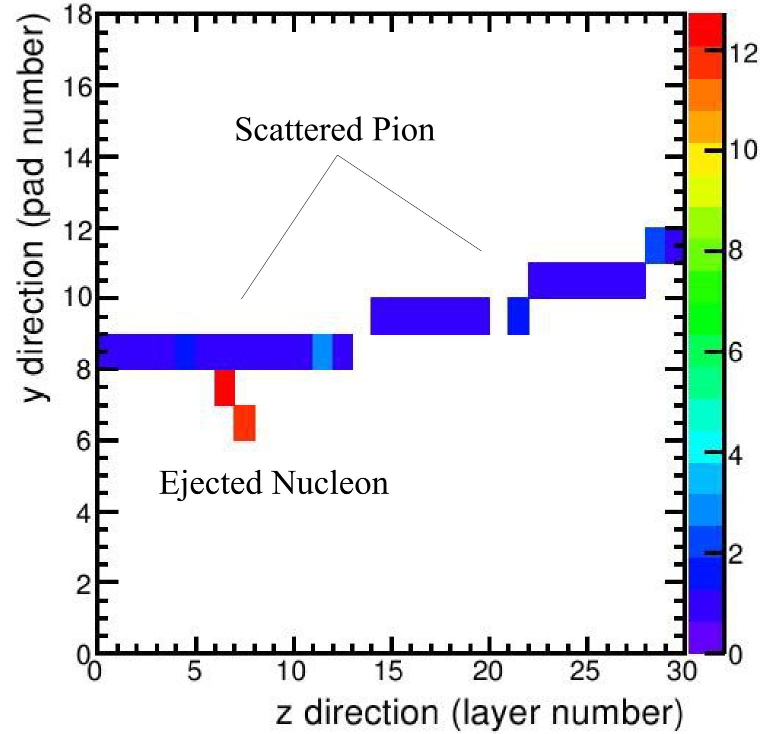
(Start of) Hadronic Showers in the SiW Ecal

Complex and Impressive



Inelastic Reaction in SiW Ecal

Simple but Nice



Nucleon Ejection in SiW Ecal

High granularity permits detailed view into hadronic shower

SiW Ecal phys prototype (still) one of the best calorimeters worldwide to study interaction region

Technological prototype

Technological and industrial solutions for the final detector

Construction start: 2010

First beam tests : 2012 - 2013

Total height few mm

- Realistic dimensions
- Integrated front end electronic

  No drawback for precision measurements

- Small power consumption (Power pulsed electronics)

ECAL layer

A layer is composed of several short ASUs:

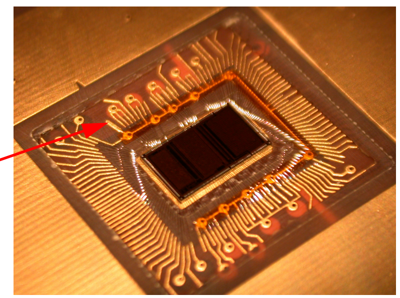
- A.S.U. : Active Sensors Units

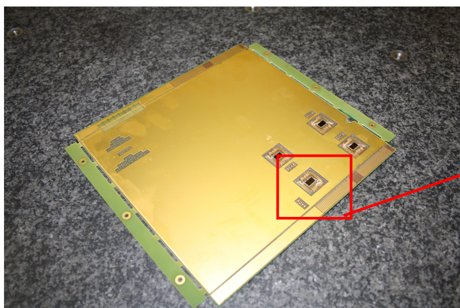
Interconnection work

Dedicated mechanical 'scaffolding' will be constructed

ASIC+PCB+SiWafer =ASU

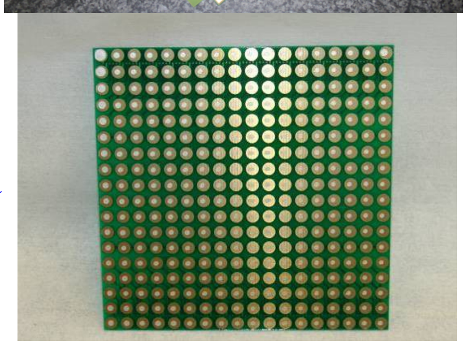
Wire Bonding or BGA

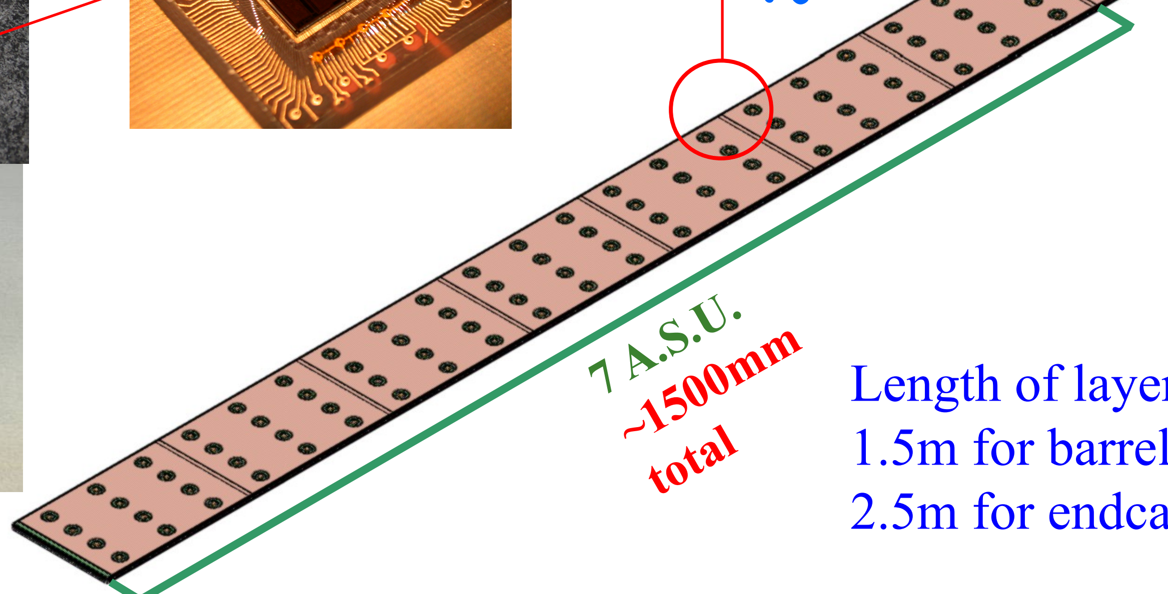




PCB is glued onto SiWafers

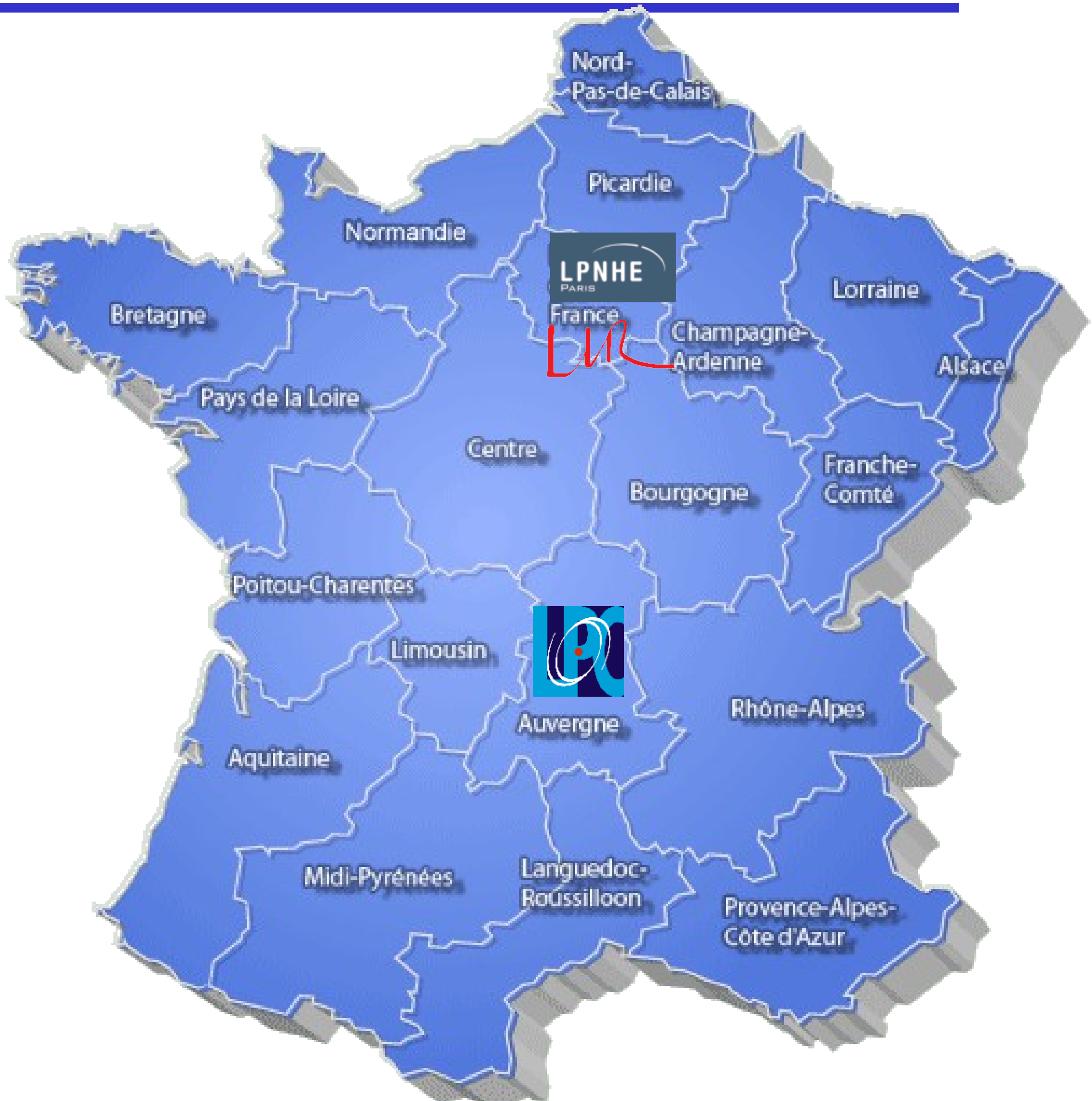
Gluing robot about to be commissioned





Length of layer:
1.5m for barrel
2.5m for endcaps

Si Wafer R&D

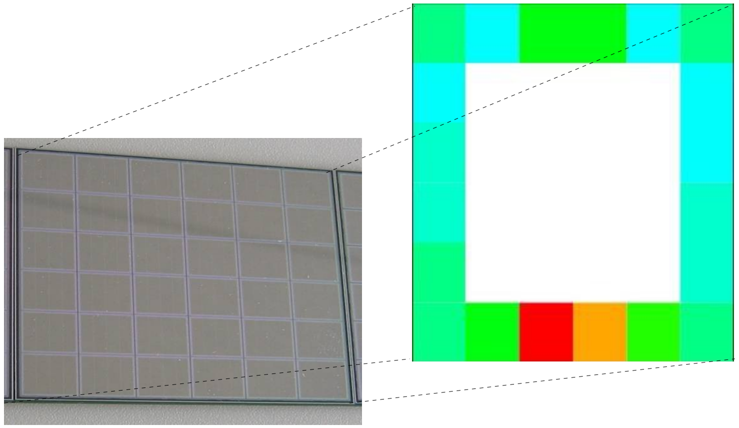


Guard rings studies
SiWafer simulation
SiWafer costing
LLR, LPNHE

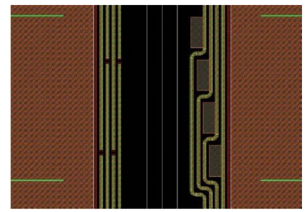
Guard ring studies
LPC

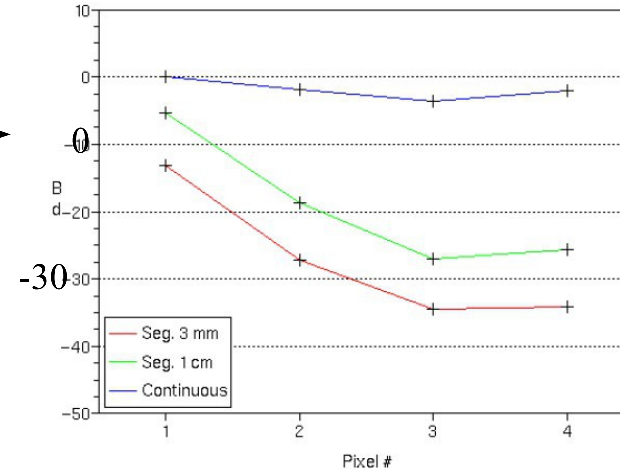
Si Wafer R&D

Square Pattern in Wafer Response



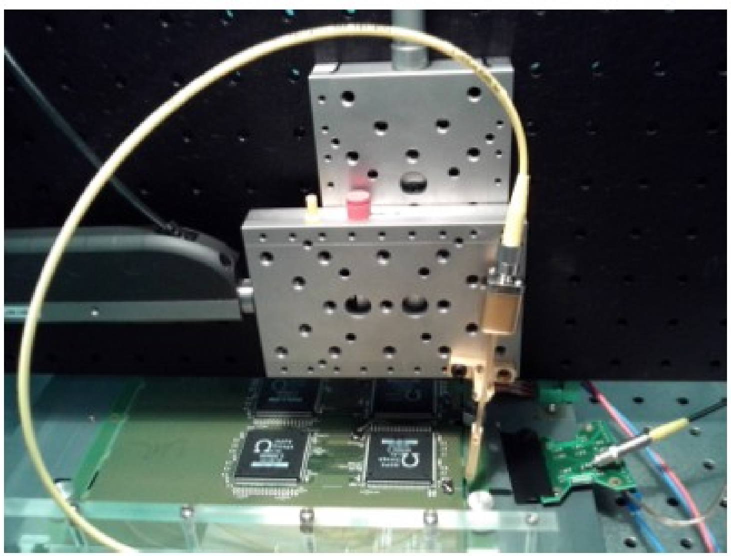
Segmented Guardring





Xtalk Continous Guardring <-> Pixel

Attenuation of Xtalk



Systematic studies with laser system
Accompanied by simulation of Si diodes

Plan to use PHIL at LAL for Si studies

Further Aspects of Si Wafer R&D

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

  Resistivity: 5 kOhmxcm, 325 mum thick, 324 pixels

  These wafers show excellent behaviour!!!

  => Si technology at hand however it comes at a 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 Japanese groups and Hamamatsu photonics

  NDA between CNRS and LFoundry under edition

Microelectronics and beam tests

SKIROC ASIC,
PCB,
(Beam) Tests of FEE

OMEGA, LAL, LLR

CALORIC ASIC

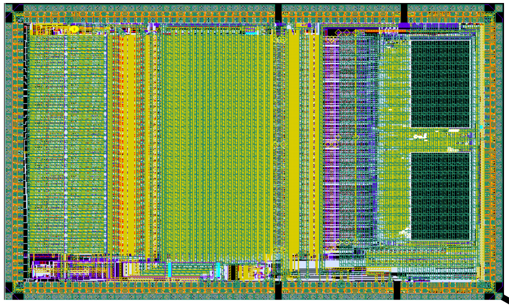
LPC

DAC, ADC Designs

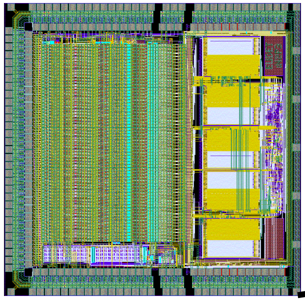
LPSC

Microelectronics – ASIC development

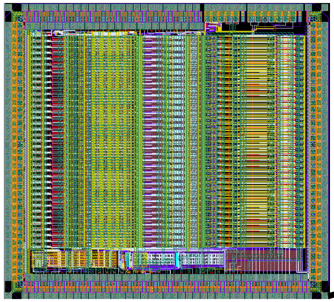
- Large scale modules (~2m)
- Partially funded by EU
- ECAL, AHCAL, SDHCAL



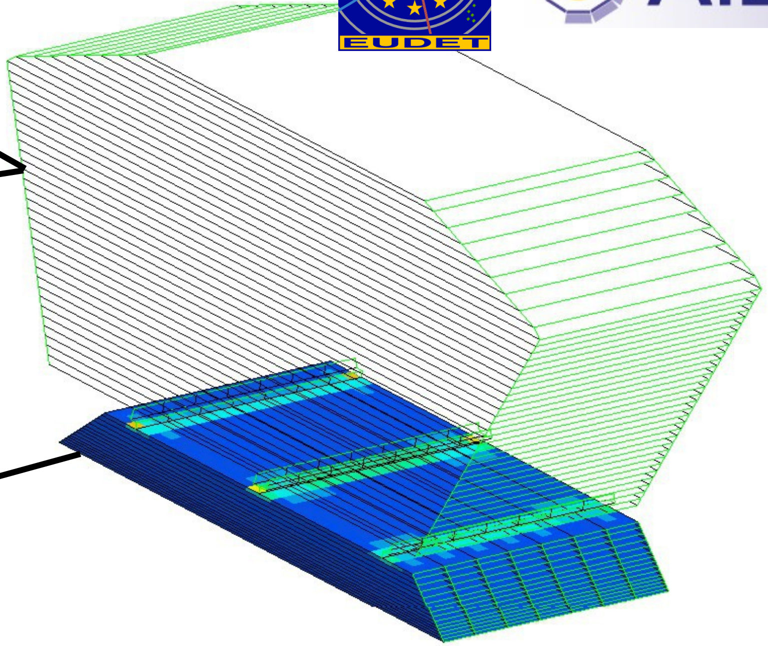
SPIROC
Analog HCAL/ECAL
(SiPM)
36 ch. 32mm²



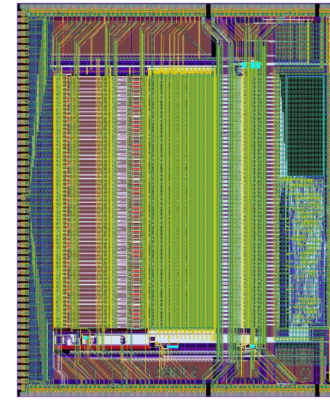
HARDROC
MICROROC
Semi digital HCAL
(RPC, µmegas)
64 ch. 16mm²



SKIROC
ECAL
(Si PIN diode)
64 ch. 20mm²

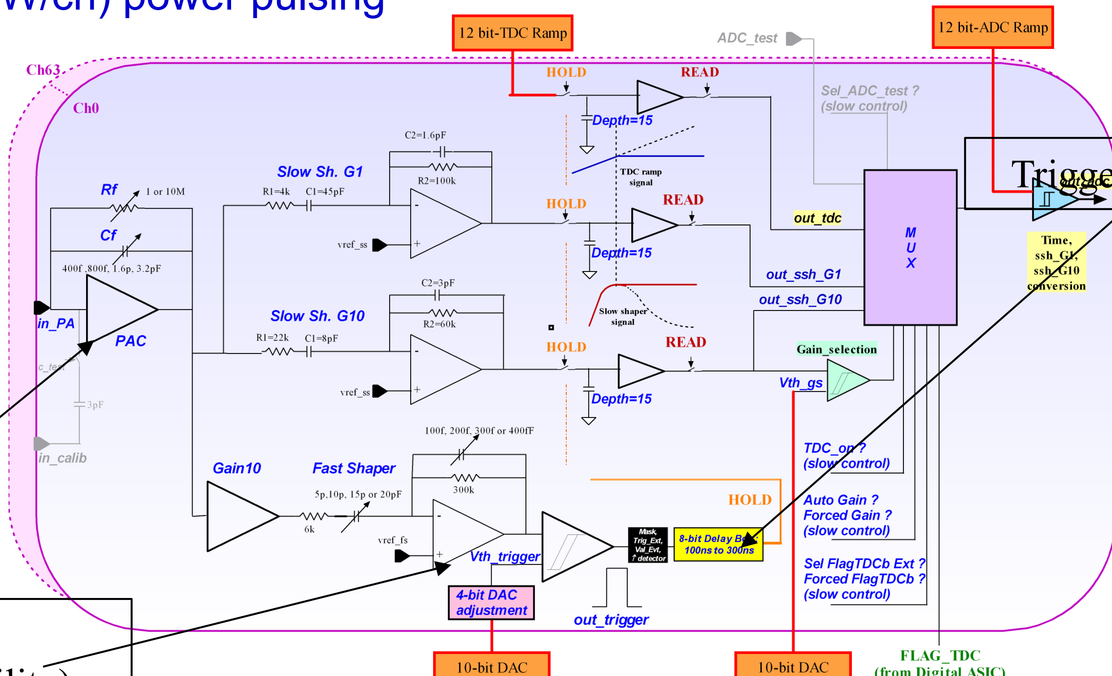


Front end electronics: SKIROC



SKIROC (Silicon Kalorimeter Integrated Read Out Chip)

- SiGe 0.35µm AMS, Size 7.5 mm x 8.7 mm, 64 channels
- High integration level (variable gain charge amp, 12-bit Wilkinson ADC, digital logic)
- Large dynamic range (~2500 MIPS), low noise (~1/10 of a MIP)
- Auto-trigger at ½ MIP, on chip zero suppression
- Low Power: (25µW/ch) power pulsing



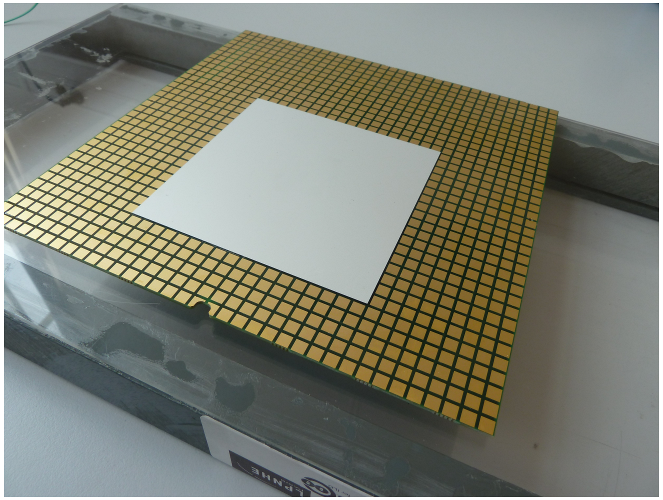
Trigger delay

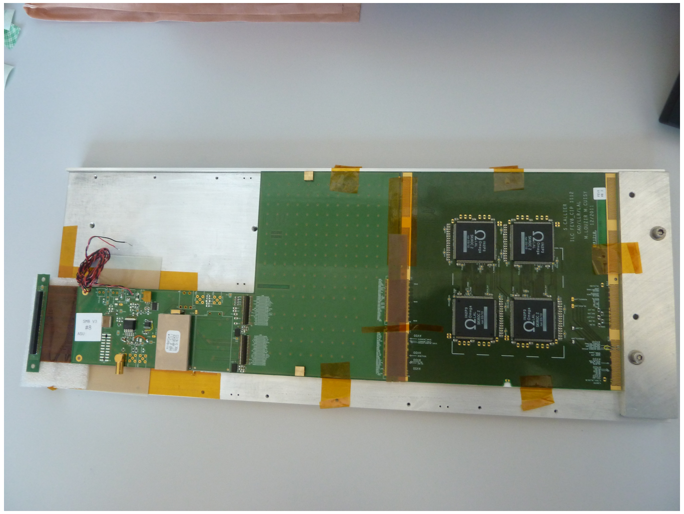
Preamplifier
(adjustable gain)

Internal trigger
(self-triggering capability)

Beam tests

Layer design





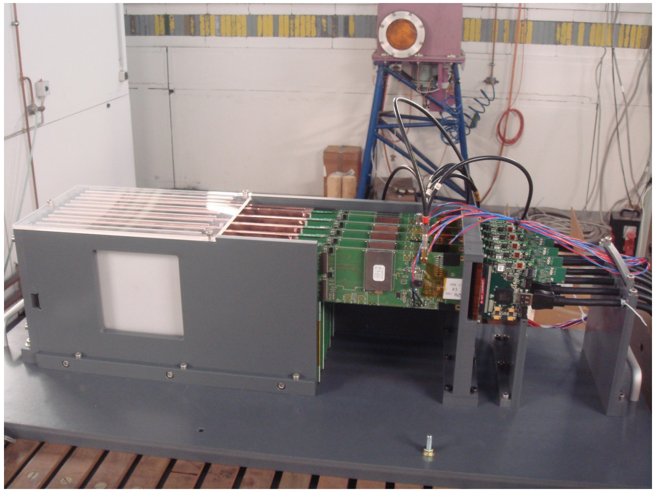
- 1 Si Wafer with 256 pixels of 5x5 mm^2 and thickness of 325 mum

  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 or in very thin BGA package

Beam test setup @ DESY

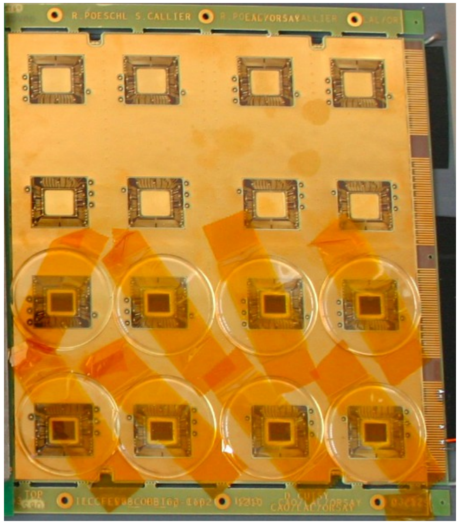


Up to 10 layers with
total number of active channels = 1278

- Test program
  - 2012: Commissioning
    - Test of front end electronics
  - 2013 Test of power pulsing, Tests in magnetic field

R&D on interface cards - PCBs

Two major options:



- BGA packaged chips (better testability).

BGA version is considered as save incremental step:

test of chips before soldering ;

Space for external decoupling capacitors

Symmetric stacking will improve flatness,

good for wafer gluing

Optimal shielding of signal traces

- PCB with naked die
- Available since december 2012
- Thin board (~1.2mm)
  - Planarity is an issue
  - Challenging for PCB producers
- First functional tests in summer 2013
- Collaboration with SKKU/Korea
  - New production during 2014

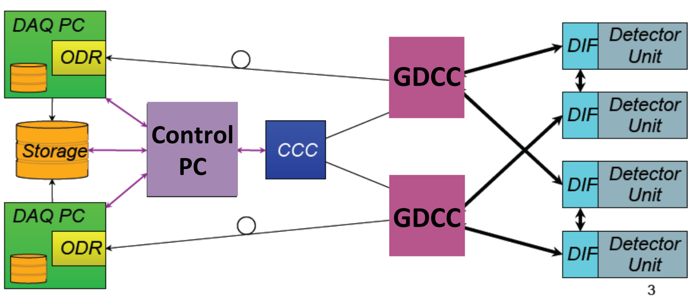
Si-W ECAL DAQ system

Standard: Giga-ethernet, 8b10b encoded local link, diff. pairs lvds signals over HDMI

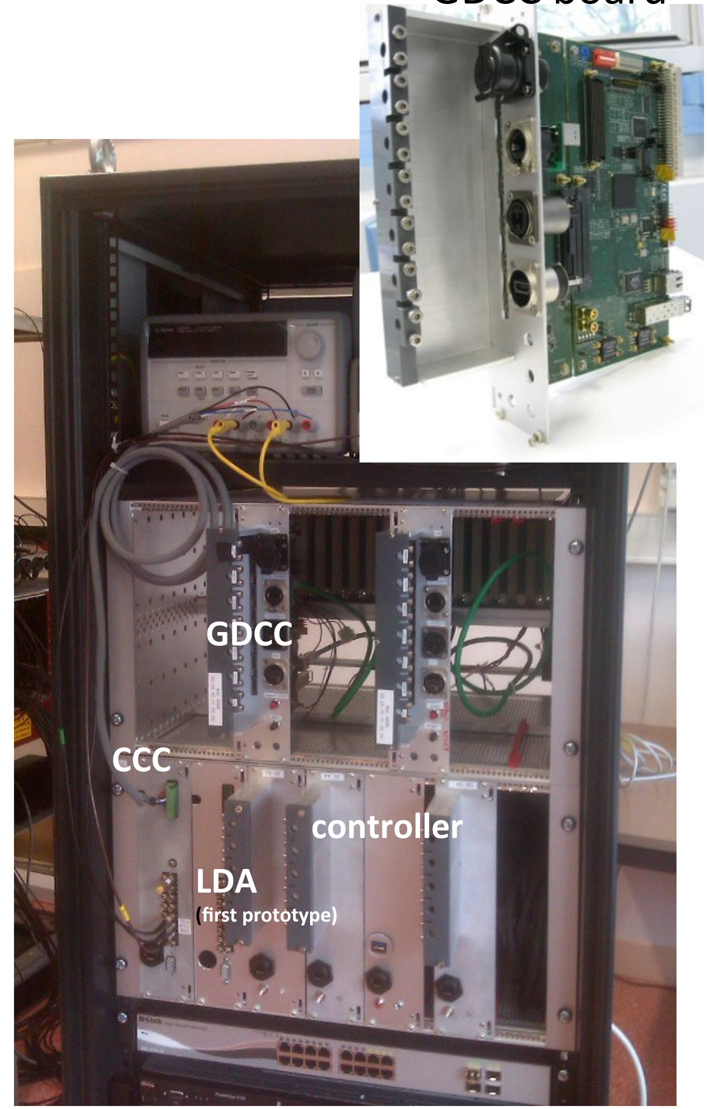
Scalable: architecture of a computing network w/o routing, modular software configured using XML, scripted using python.

Compact: one cable for slow control, data acquisition, fast signals and possibly power

(**Detector Unit** : ASICs)
DIF : Detector InterFace connects generic DAQ and services
GDCC : GigaEthernet Data Concentrator Card
ODR : Off-Detector Receiver is PC interface
CCC : Clock and Control Card fans out to ODRs (or LDAs)



GDCC board



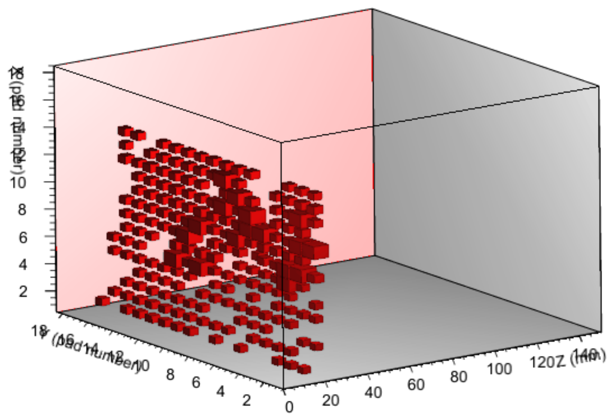
Scaled for low occupancy, low noise detectors featuring **auto-trigger & zero suppression at read-out chip level**. 40 Mbit/s link at detector interface allow to control & read 10k channels.

Central clock and control board (CCC) for overall synchronisation

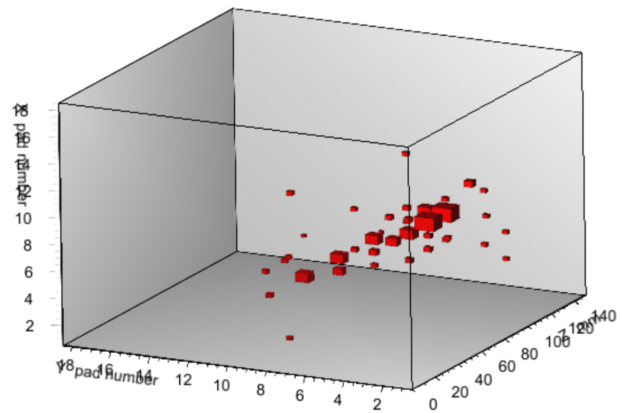
Modular integration of components into 6U modules for use in test beams.

Quick review on results

Event filtering 'Plane events???'

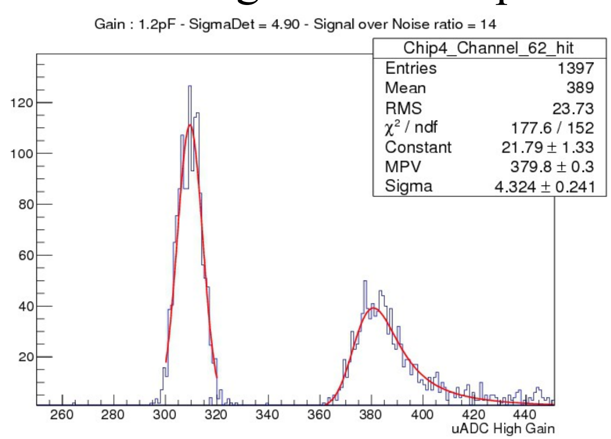


1 e- (5 GeV)
5 W plates between layers



Observed in 2012 with significant frequency
Can be remedied by correct PreAmplifier reference

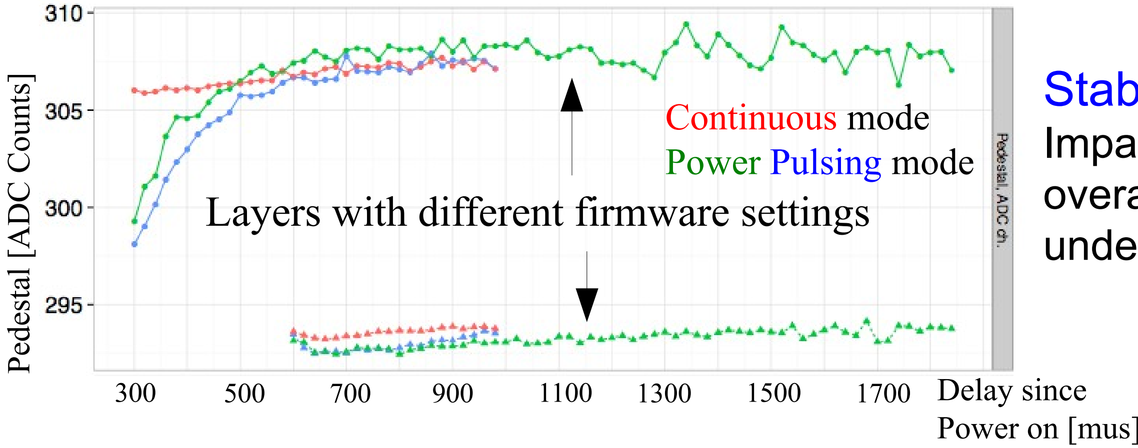
Excellent Signal/Noise separation



2012/13 data taking allowed
For thorough examination/validation
of SKIROC ASIC
SKIROC2 → SKIROC3
Still some way to go

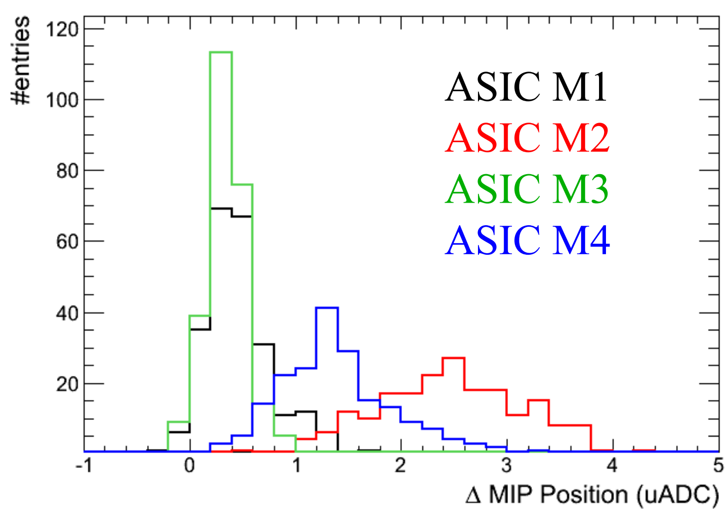
Power pulsing

Operation comparable to ILC mode, 1ms data taking and 99ms idle



Stable pedestal after around 600mus

Impact of ramp up time on overall consumption needs to be understood



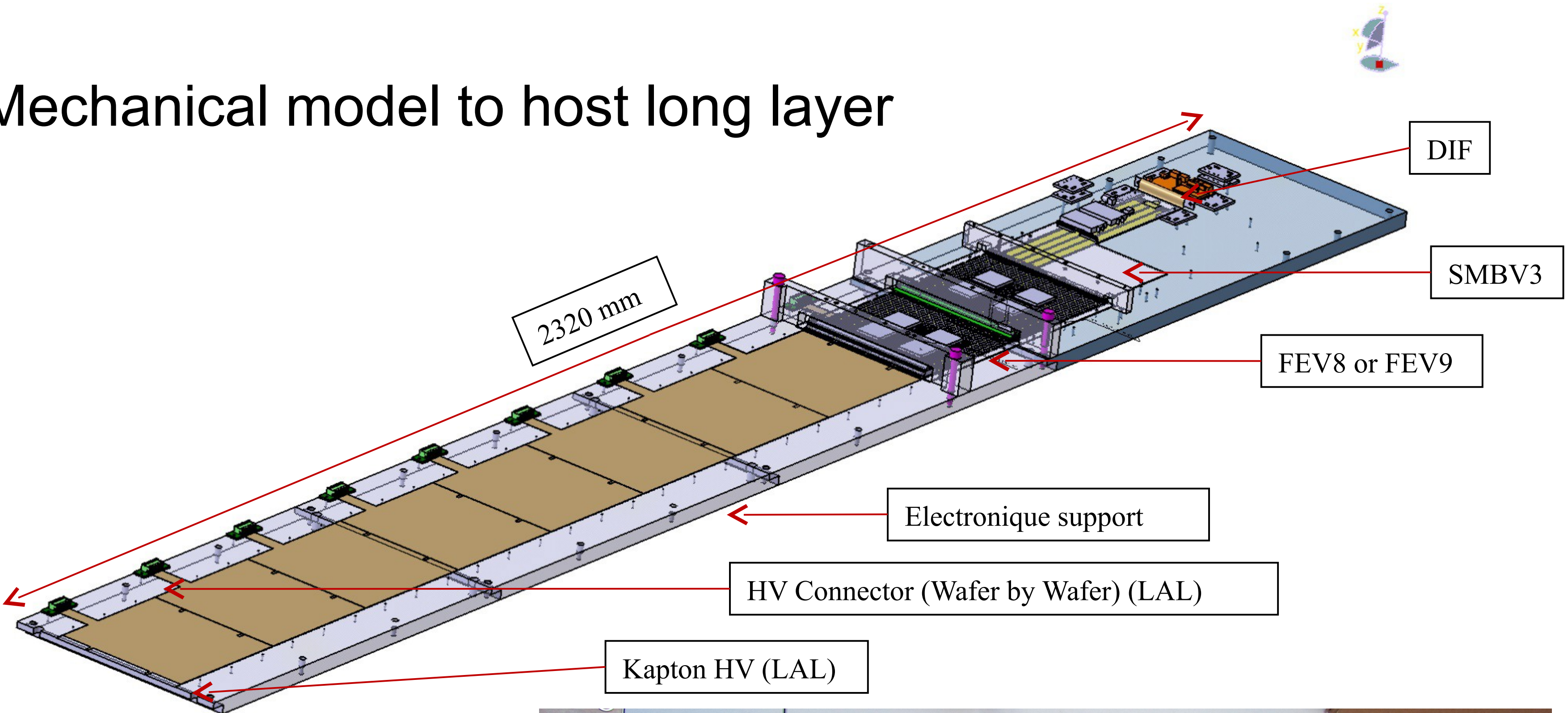
Measurement ok for power pulsing for “properly” connected ASICs

Encouraging results for SKIROC operation in power pulsed mode

- Full system issue
- Still more studies needed

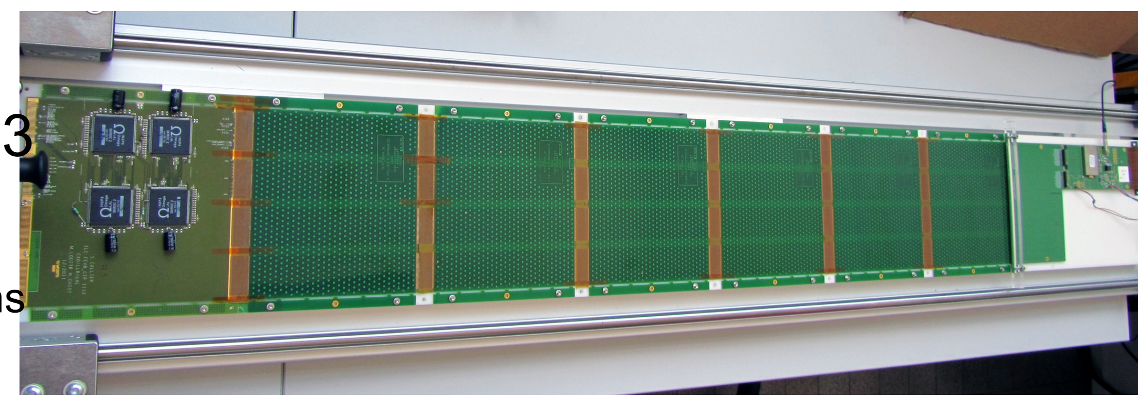
Towards long layer

Mechanical model to host long layer

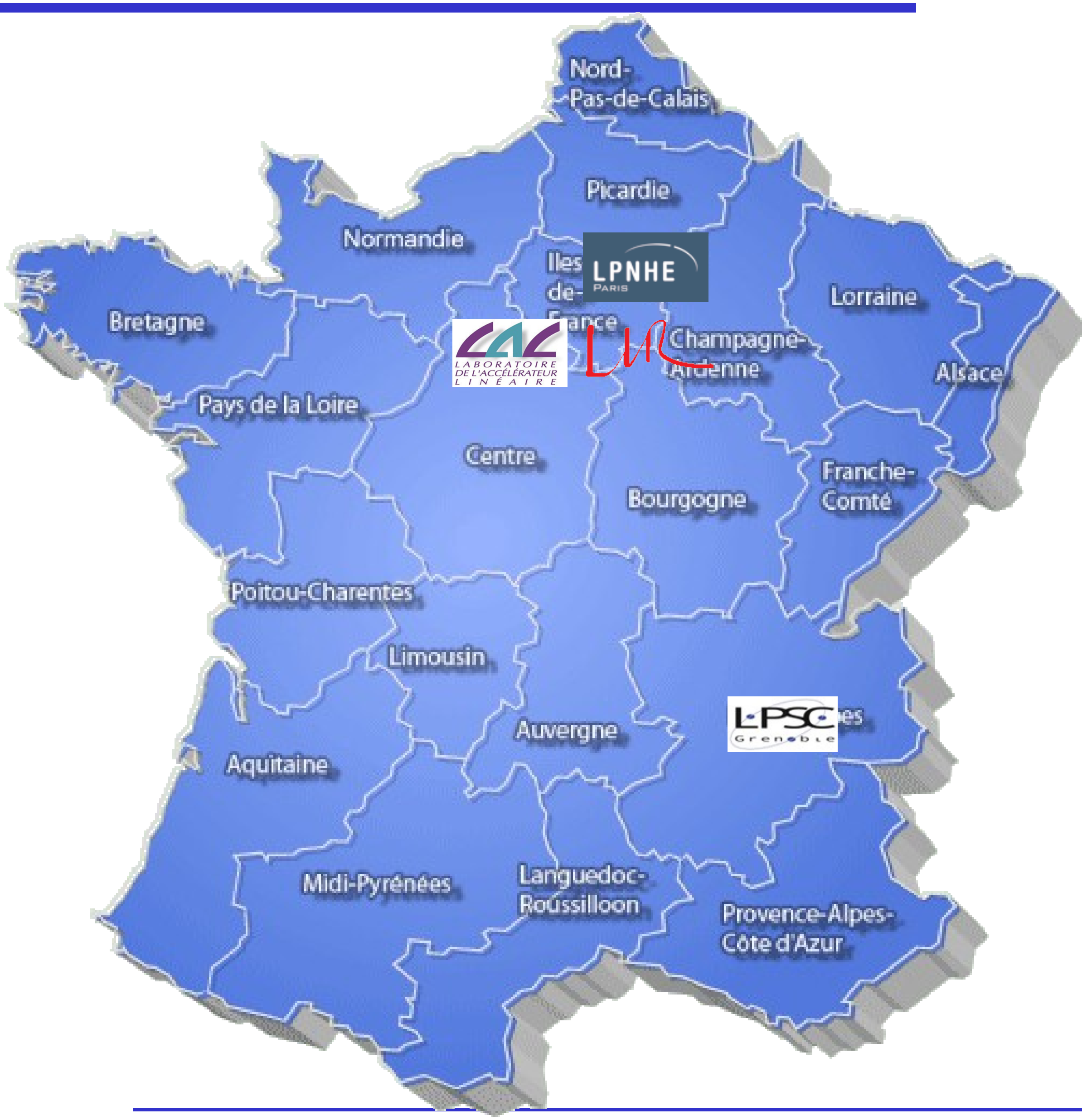


First steps in summer 2013

- Clock transmission on simplified setup with straight lines
- System test with next PCB versions



Mechanics and detector integration

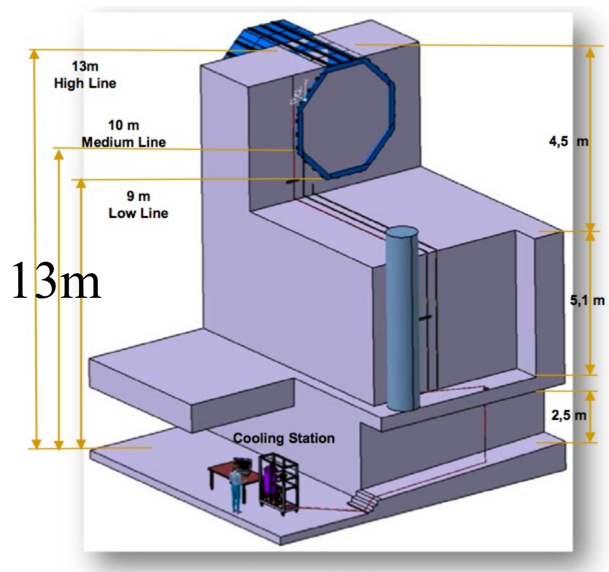


Alveolar structures
Integration concept
Detector assembly
LAL, LLR, LPNHE

Alveolar structures,
Cooling,
Hardware studies
LPSC

Infrastructure – Alveolar structure and cooling

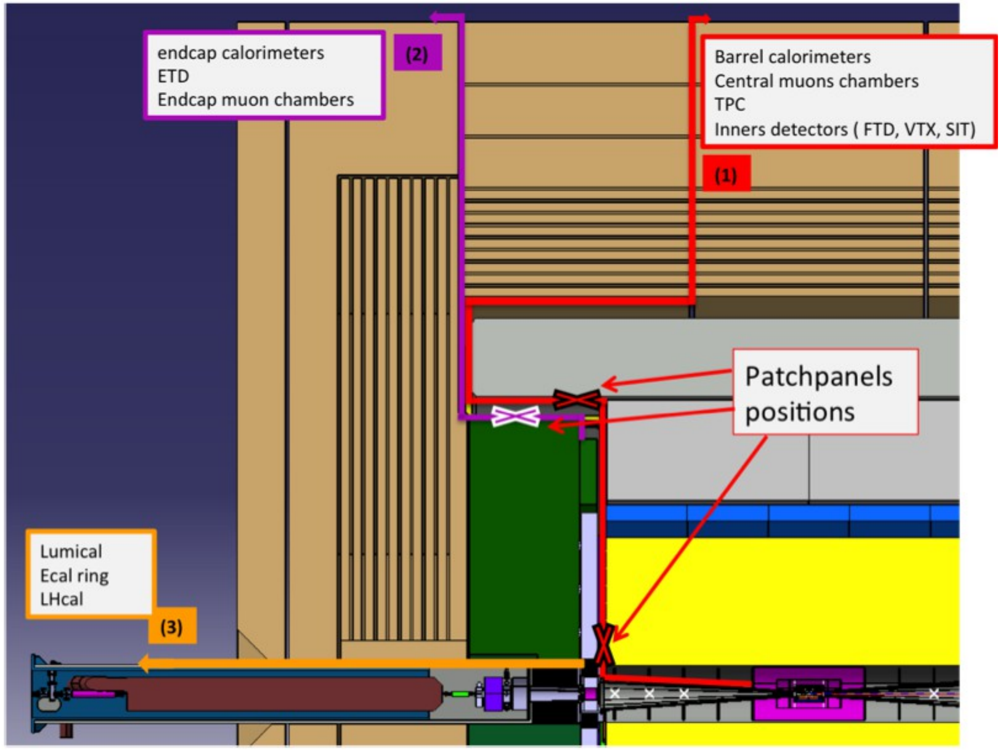
1.5 m long alveolar structure to house Ecal layers
3/5 of a barrel module of the ILD concept
Tungsten plates wrapped into prepreg
Planar within 5mm
Work on longer structures for detector endcaps is ongoing

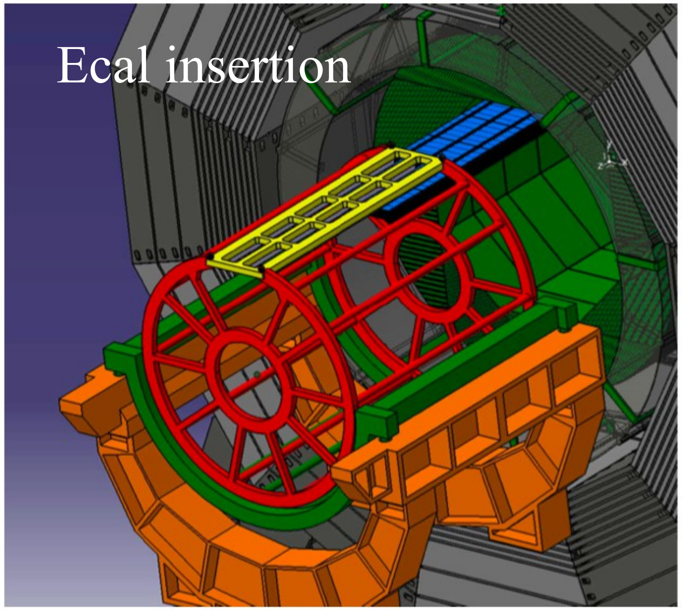


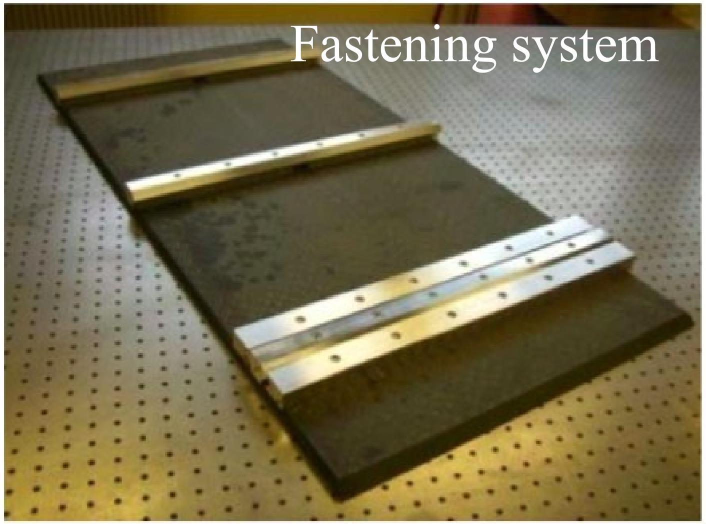
Evacuation of (residual) power of 0.2-0.35 W/layer
Development of a leak less cooling system for a full detector

(Ecal) Integration

Quadrant of ILD detector with services





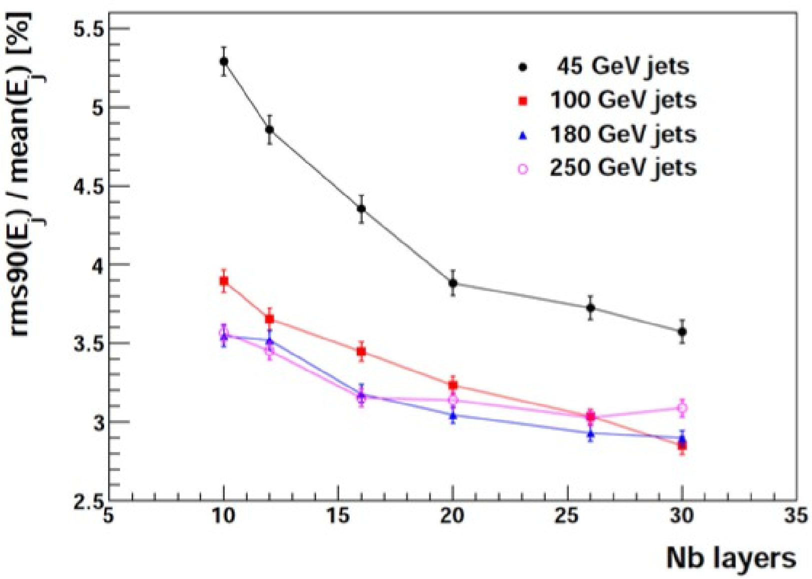


Detector optimisation

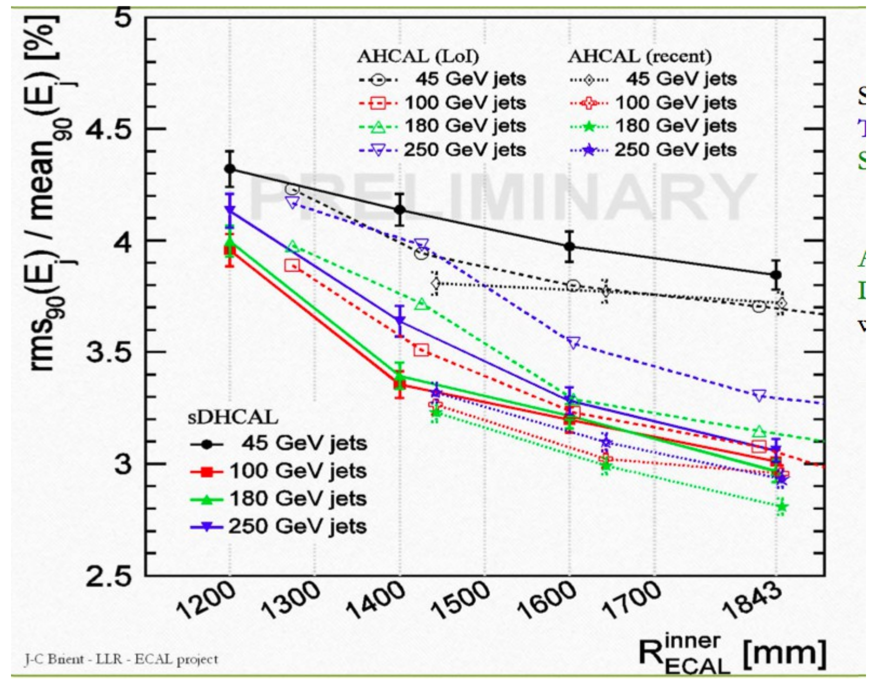
SiEcal is cost intensive sub detector
Large radius of ILD is compromise between LDC and GDL and amplifies cost

Two main questions

Less layers?



Smaller inner Ecal radius?



Need to have:
Proper set of parameters but also appropriate benchmarks
A good crystal bowl (What we decide "now" may be with us until ~2045)

Conclusion and outlook

- Successful operation of physics prototype (2004-2011)

Proof-of-principle of highly granular Ecal
Highly performant on particle separation
Unprecedented views into hadronic cascades (Still a lot of things to explore)

- Ongoing work on technological prototype (since ~2010)

Alveolar structures have been constructed
Four beam tests with small and conservative but yet progressively complicated setup
Development of DAQ system
Thorough examination of SKIROC2 ASIC, including power pulsing

- Towards a 'real' calorimeter system (2014-2016)

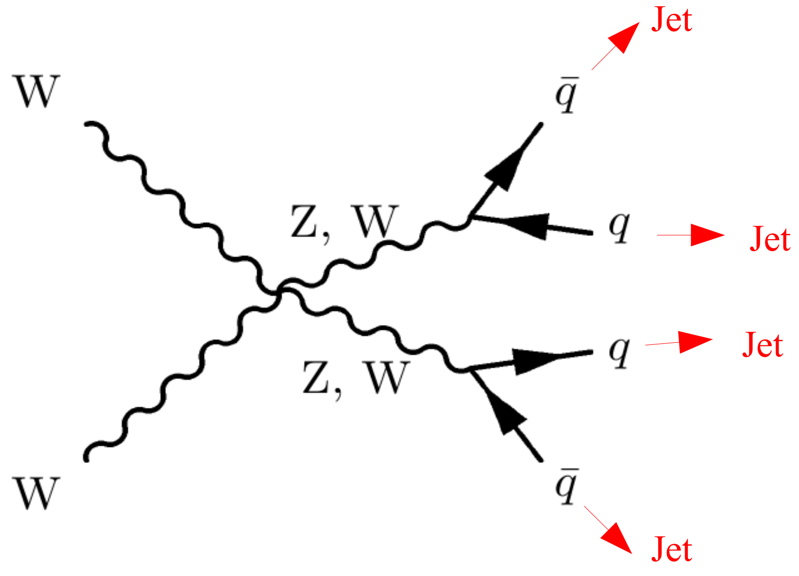
16 ASICs per ASU, Up to 160 ASICs per layer
Next ASIC version (SKIROC2b)
Long layer
Si Wafer design
Cooling
Detector integration
First ideas on industrialisation

Backup

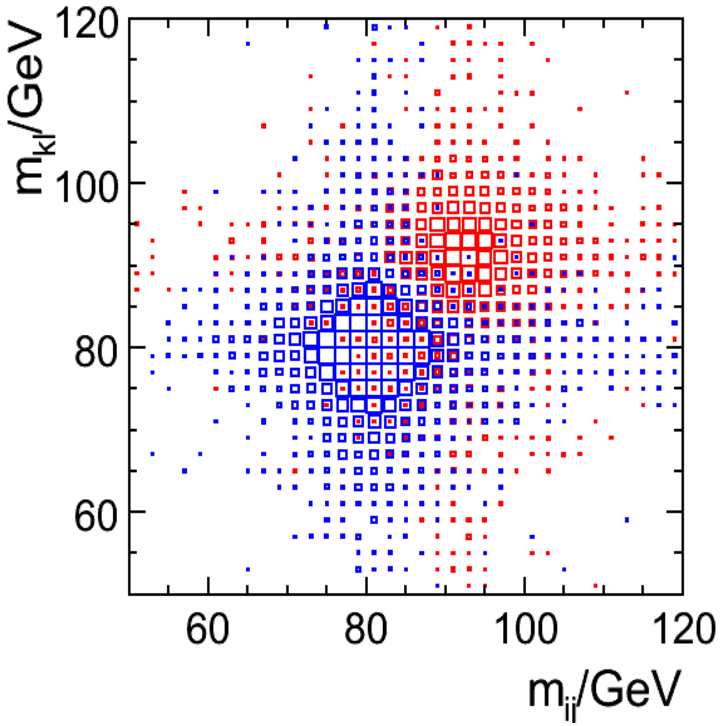
Multijet final states in e+e-

e.g. Boson Boson Scattering

Manifestation of new physics
Strong Electroweak Symmetry Breaking



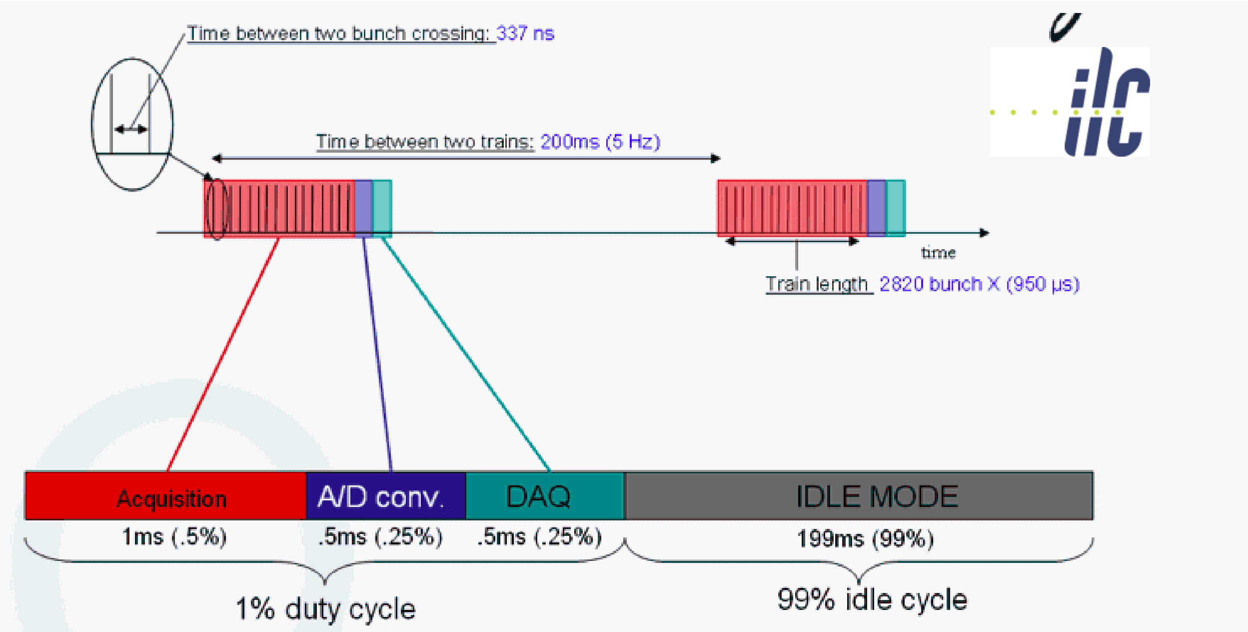
W, Z separation in the ILD Concept



Remember: M_Z-m_W ≈ 10 GeV

- Need excellent jet energy resolution to separate e.g. W and Z bosons in their hadronic decays
  Goal is around $3\%/E_{jet}$ - $4\%/E_{jet}$

Power pulsing



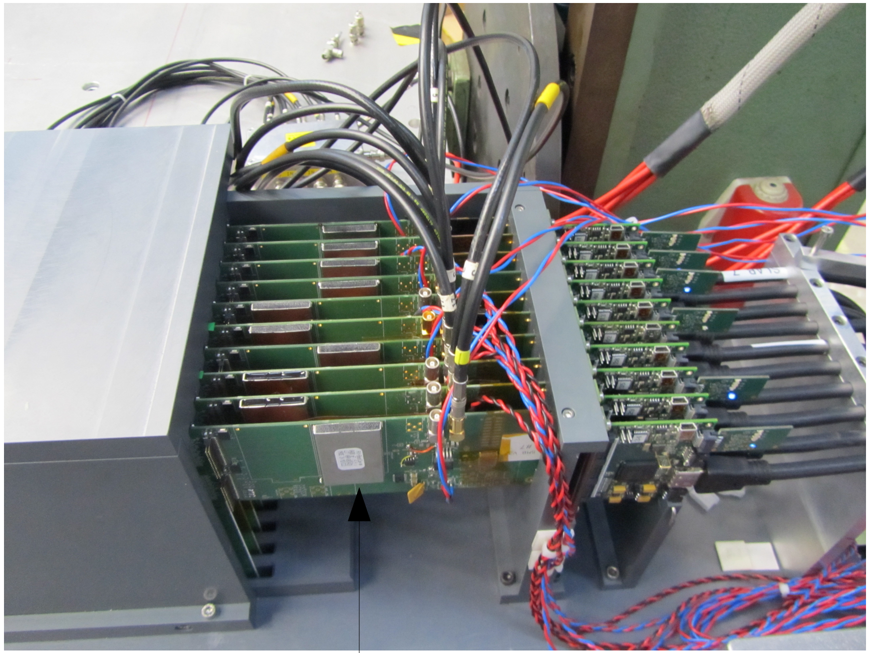
N.B. Final numbers may vary

- Electronics switched on during > ~1ms of ILC bunch train and data acquisition

- Bias currents shut down between bunch trains

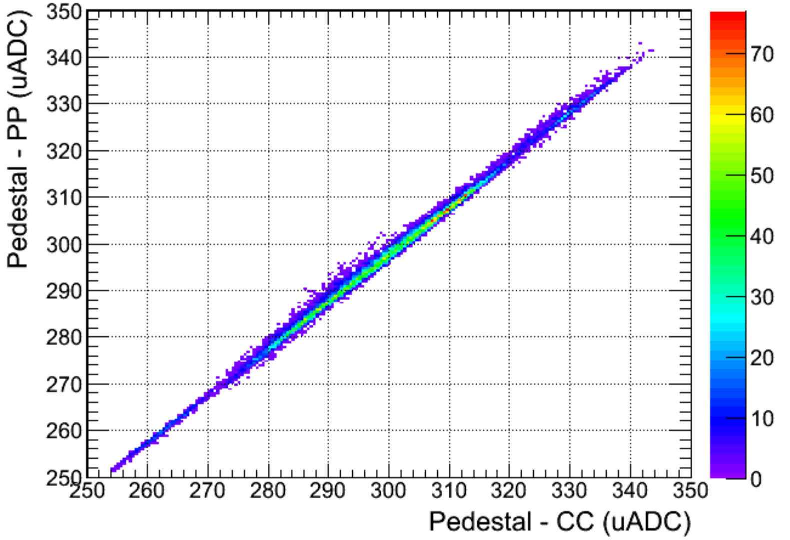
Mastering of technology is essential for operation of ILC detectors

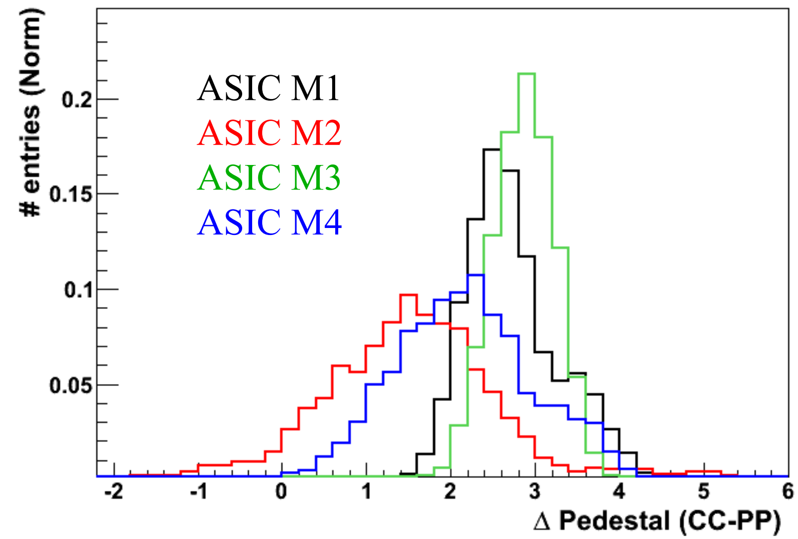
2013 beam tests



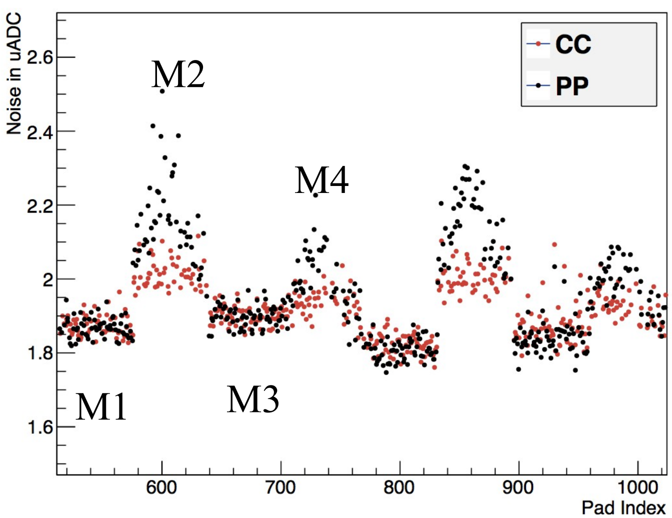
Battery charger application
AVX BestCap BZ01
After regulator

Power pulsing – Pedestal analysis





Noise for all the Pad of the detector



Clear pattern for ASICs M1, M3

Pedestal shift of ~1% in PP mode

Pedestal width constant

Less clear situation for M2, M4

PCB routing seems to distort

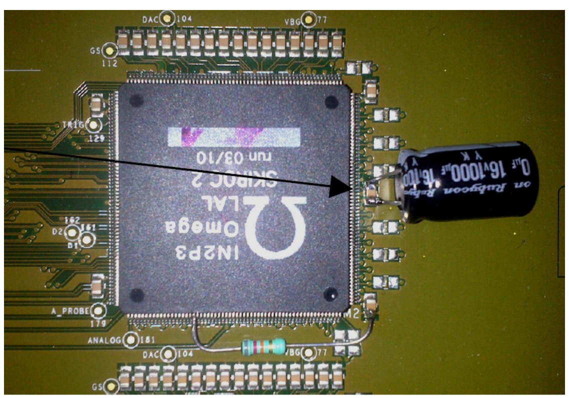
Pedestal spectra

SKIROC integration defaults

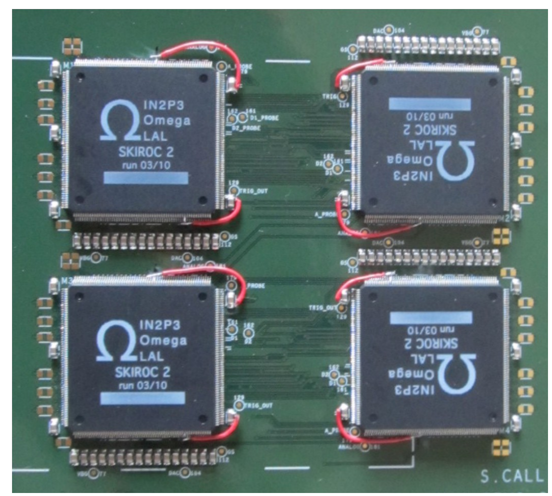
Pre Amplifier is referenced to the analog power supply level
Instabilities of power supply level → fake events

- Some analogue signals plugged on digital power supply → Noise at ASIC inputs
- 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

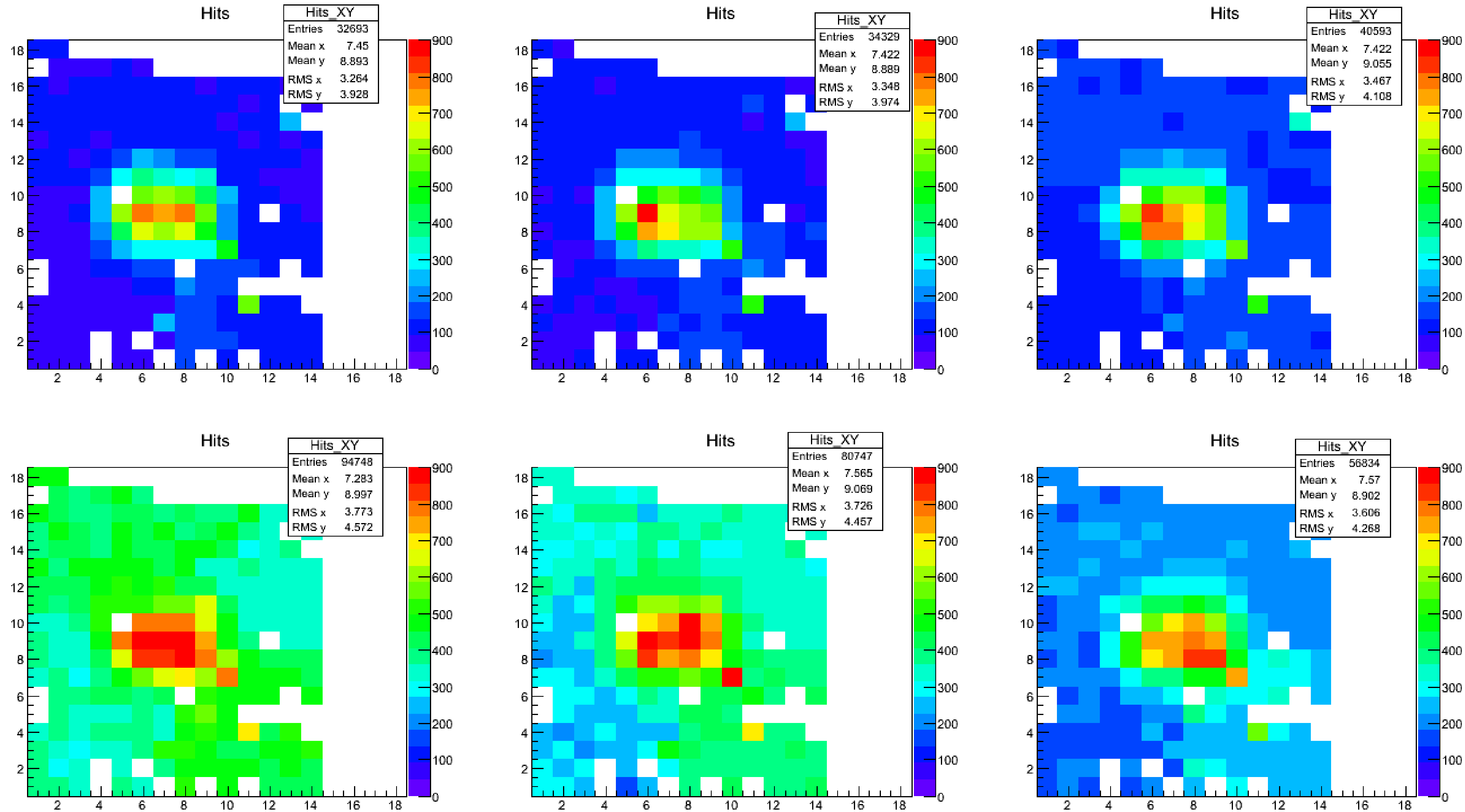


Big capacitance to stabilise power supply



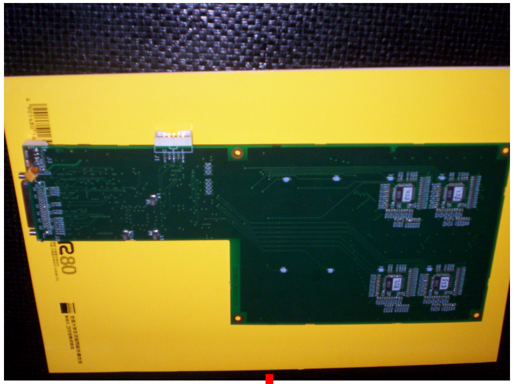
Re-routing of analog and digital power supply

Beam spot

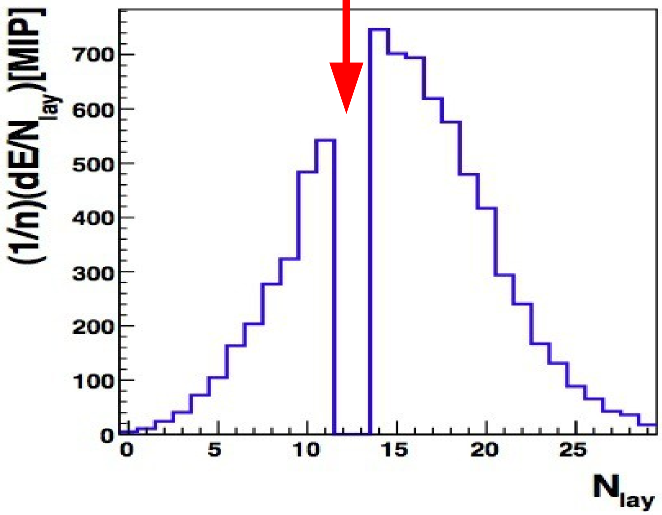

Hits
Hits_XY
Entries 32693
Mean x 7.45
Mean y 8.893
RMS x 3.264
RMS y 3.928
Hits
Hits_XY
Entries 34329
Mean x 7.422
Mean y 8.889
RMS x 3.348
RMS y 3.974
Hits
Hits_XY
Entries 40593
Mean x 7.422
Mean y 9.055
RMS x 3.467
RMS y 4.108
Hits
Hits_XY
Entries 94748
Mean x 7.283
Mean y 8.997
RMS x 3.773
RMS y 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

Embedded electronics – Parasitic effects?

Exposure of front end electronics to electromagnetic showers



ASICs placed in shower maximum
of 70-90 GeV elm. showers

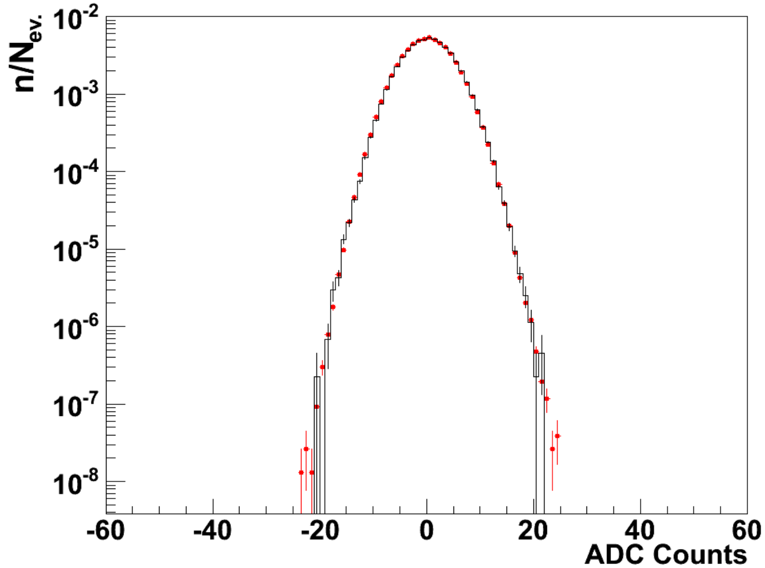


Possible Effects: Transient effects

Single event upsets

Comparison: Beam events

(Interleaved) Pedestal events

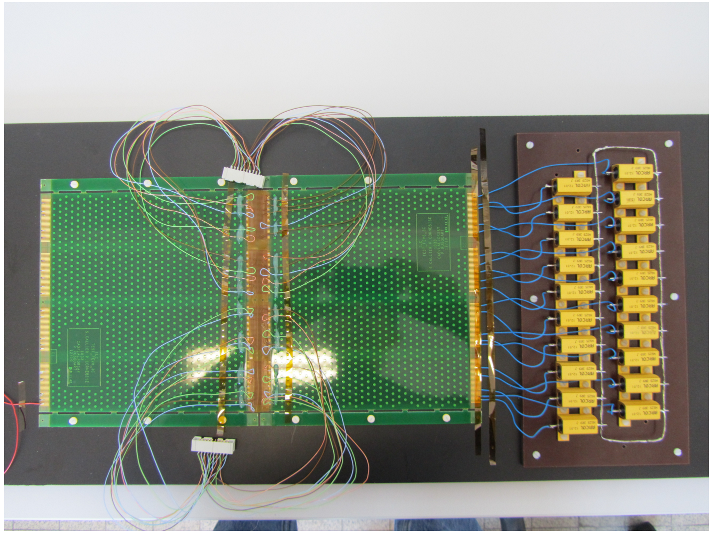


- No sizable influence on noise spectra by beam exposure

  ΔMean < 0.01% of MIP ΔRMS < 0.01% of MIP
- No hit above 1 MIP observed

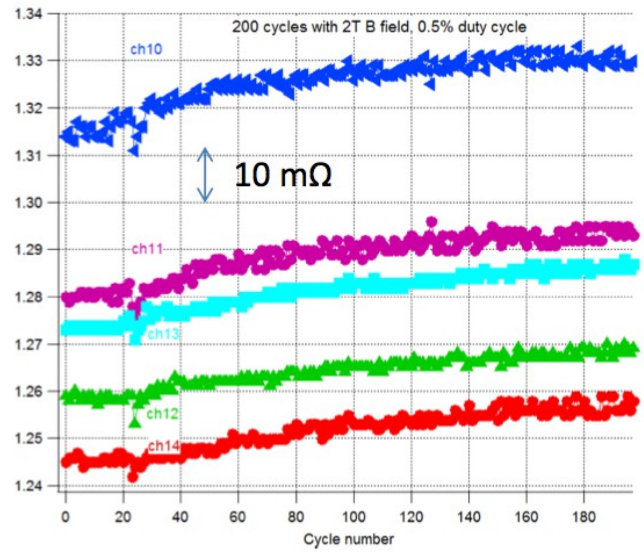
  => Upper Limit on rate of faked MIPs: ~7×10^{-7}

Tests in magnetic field II



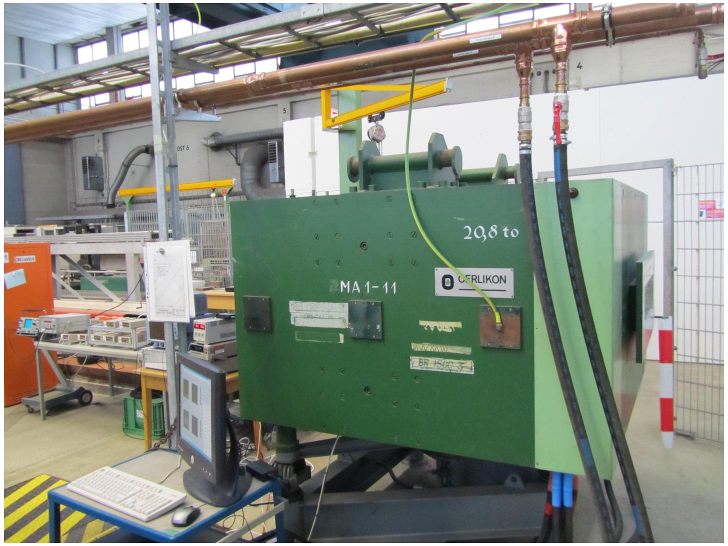
Measurement of the ohmic resistance across the interconnection between two ASUs

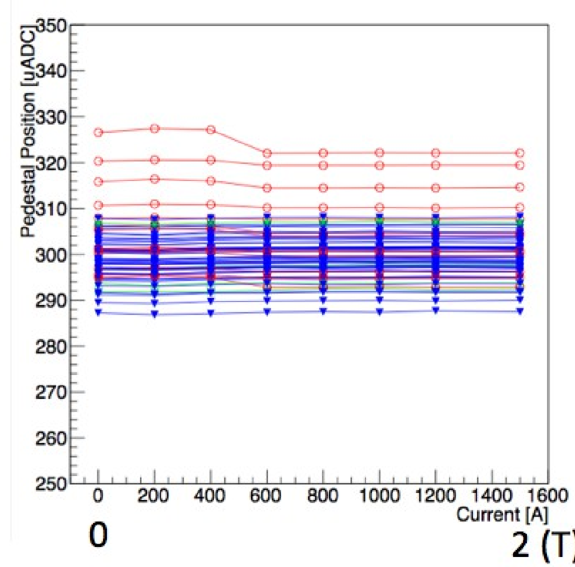
With and w/o B-Field, various duty cycles and frequencies



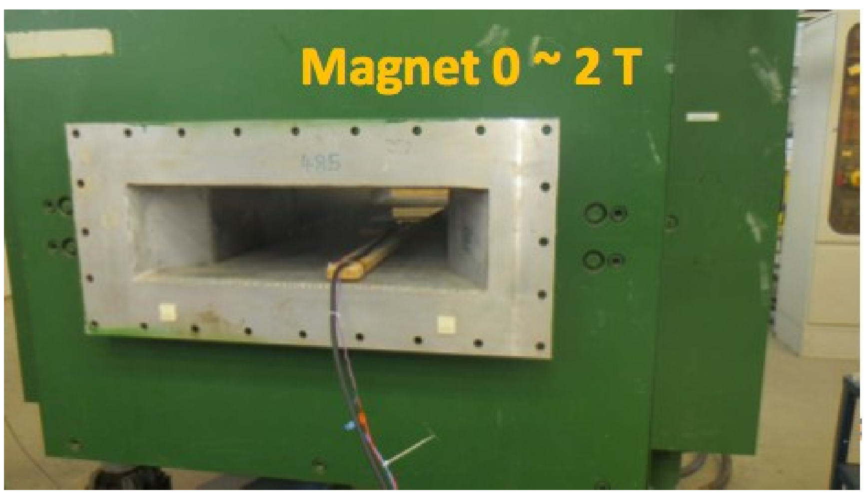
Conclusion: The ohmic resistance
Varies by about 20 mOhm (thermal effect)

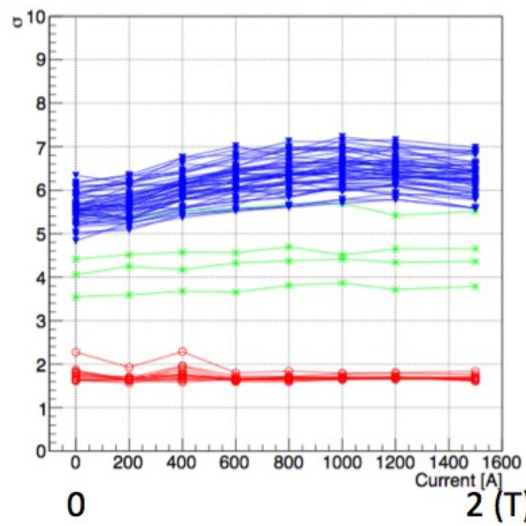
Power pulsing tests in magnetic field I





Pedestal position



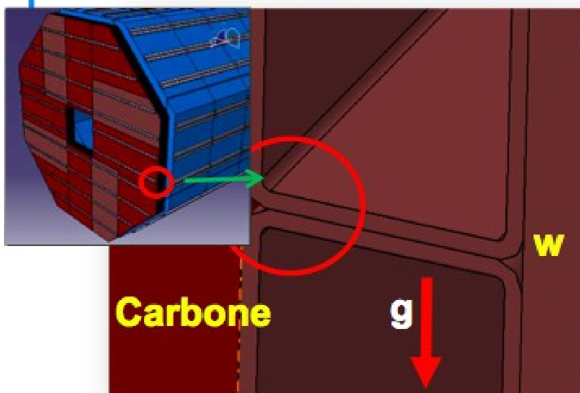


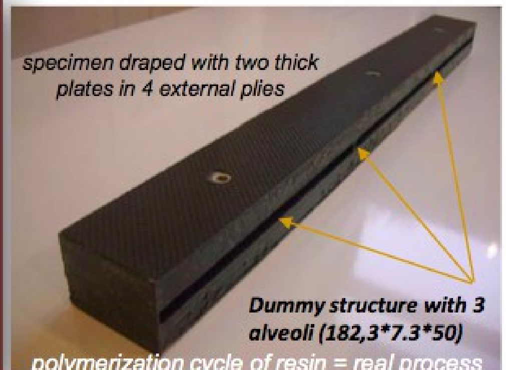
Pedestal width

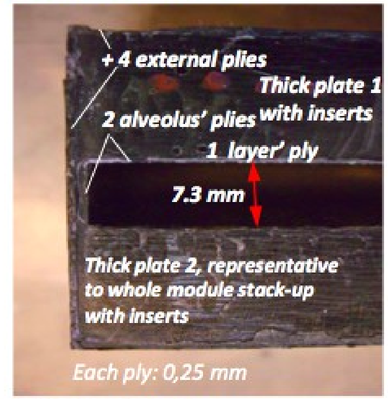
Alveolar structures – Shearing tests

ECAL End-Caps: shearing tests

Problem of bending stress of alveoli skins / evolution of external plies

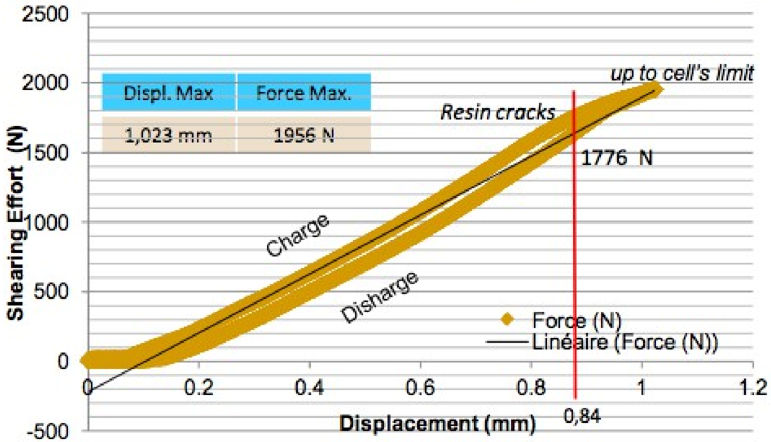






Influence of modification of external ply thickness on the first main constraint of external and internal walls

If external plies thickness increases => **Impact on ECAL dead zone** => **Optimization of deflection values**



- 2 tests performed on dummy structures with no rupture !
- The charge & discharge cycle thus shows an hysteresis in specimens' behaviour which certainly evolves towards a progressive decrease in the force / displacement with the gradual breakdown of the resin before destruction of the composite.
- Shearing allowable stress / tests: **6,6 MPa** before first crack
- safety factor: 2,9 to 3.7 (correct for normal operating conditions) with respect to the stress induced / largest module (2,5m–25,5 kN)

Ongoing developments 2013-2014

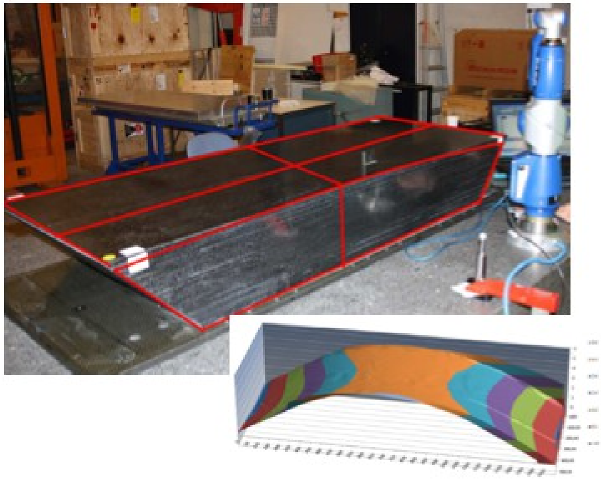
- -2 dummy structures moulding / shearing tests / **strain**
- -Destructive tests (up to 1st resin cracks) / **verification**
- -FE simulations / (0°- 90°) load cases & correlation /tests
- -**Draping** optimization

Alveolar structures – Mechanical tests

Mechanical structures

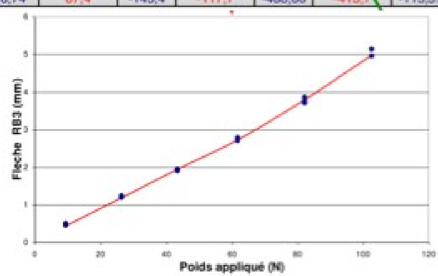
Prototype: 3/5 of one module, ~ 600 kg.
Separately built layers "cooked" together.
Simulated mechanically & thermally.

Another prototype with molded Bragg grating fibers. Detailed verification of simulated elongations under loads (by monitoring frequency shift of light reflected by fiber).



Correlation with the experimental data (FBGs):

	Load (N)	ε_{yy} FBG1 (µm/m)		ε_{yy} FBG2 (µm/m)		ε_{yy} FBG3 (µm/m)		ε_{yy} FBG4 (µm/m)		ε_{yy} FBG5 (µm/m)	
		Exp.	Simu.	Exp.	Simu.	Exp.	Simu.	Exp.	Simu.	Exp.	Simu.
M1	9,38	-2,52	14	-12,6	-12,2	-29,86	-36,8	-7,41	-8,1	4,91	29
M2	26,35	0,84	27,8	-32,77	-30,6	-92,9	-100,7	-24,72	-26,5	15,55	42,51
M3	43,32	10,92	41,1	-53,78	-49,1	-156,77	-165,6	-39,55	-44,9	26,2	55,8
M4	61,64	21,01	55,4	-78,16	-69	-235,57	-237	-59,33	-64,8	31,11	70
M5	82,08	33,61	71,5	-109,26	-91,4	-336,77	-319,6	-79,93	-87,1	44,21	86,2
M6	102,53	48,74	87,4	-145,4	-117,7	-468,66	-413,7	-115,37	-112,8	58,13	102,2



Vérification des paramètres du modèle en comparant la flèche FBG3 mesurée et simulée