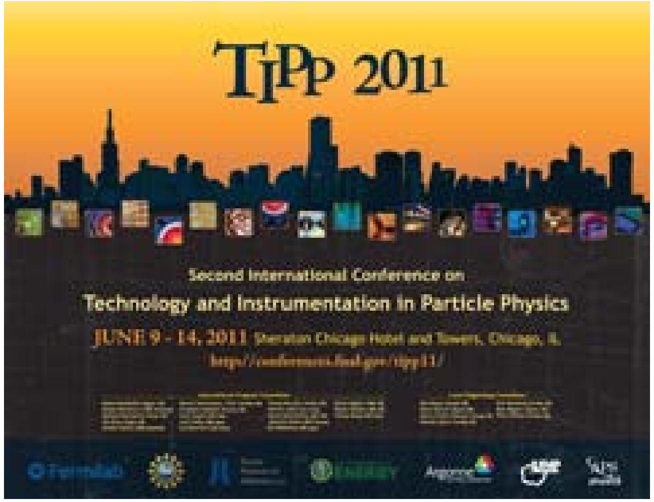
Silicon-Tungsten EM calorimeter

Daniel Jeans - Rémi Cornat
Laboratoire Leprince-Ringuet
Ecole Polytechnique – IN2P3/CNRS

On behalf of the CALICE collaboration



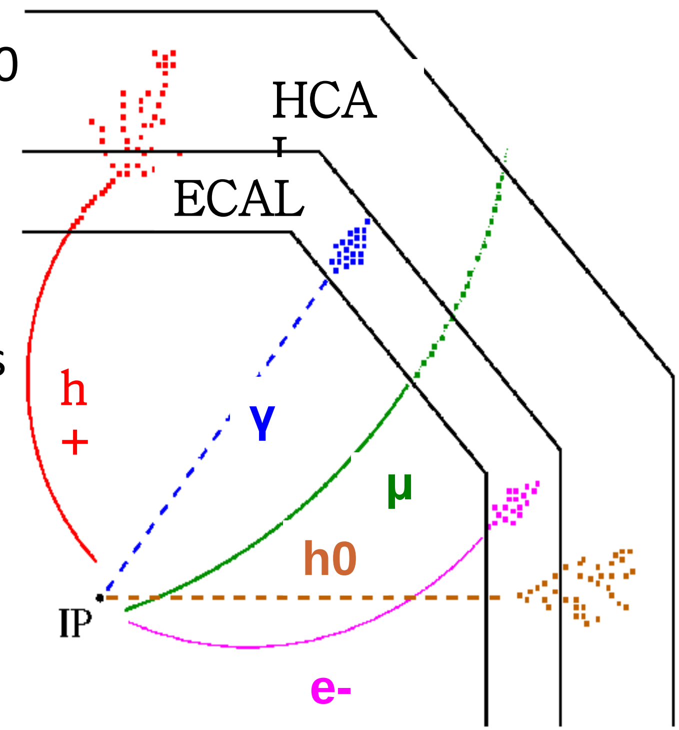
Detectors for a future linear collider

Precisely measure TeV-scale physics

e+ e- linear colliders under study

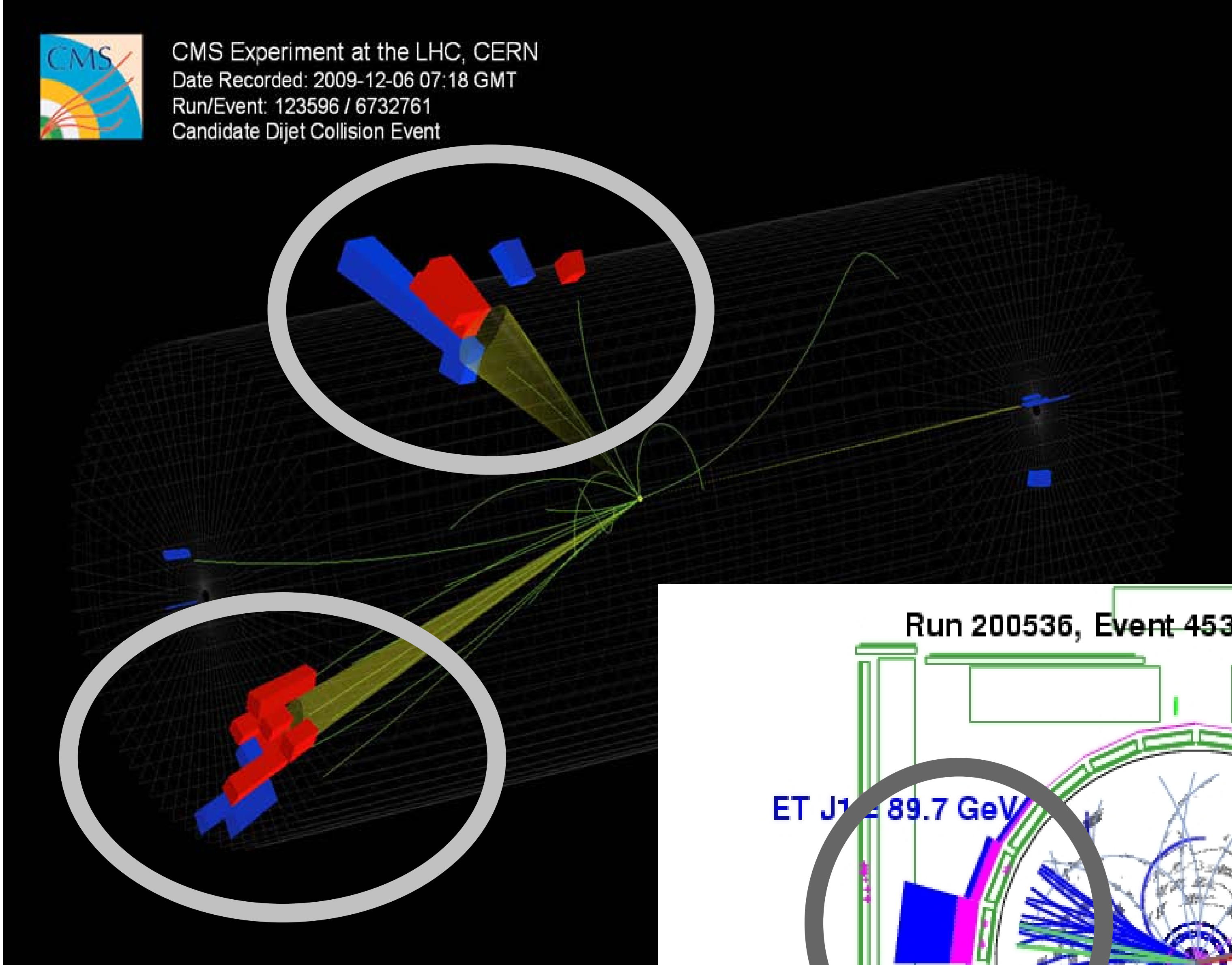
Particle flow proposal

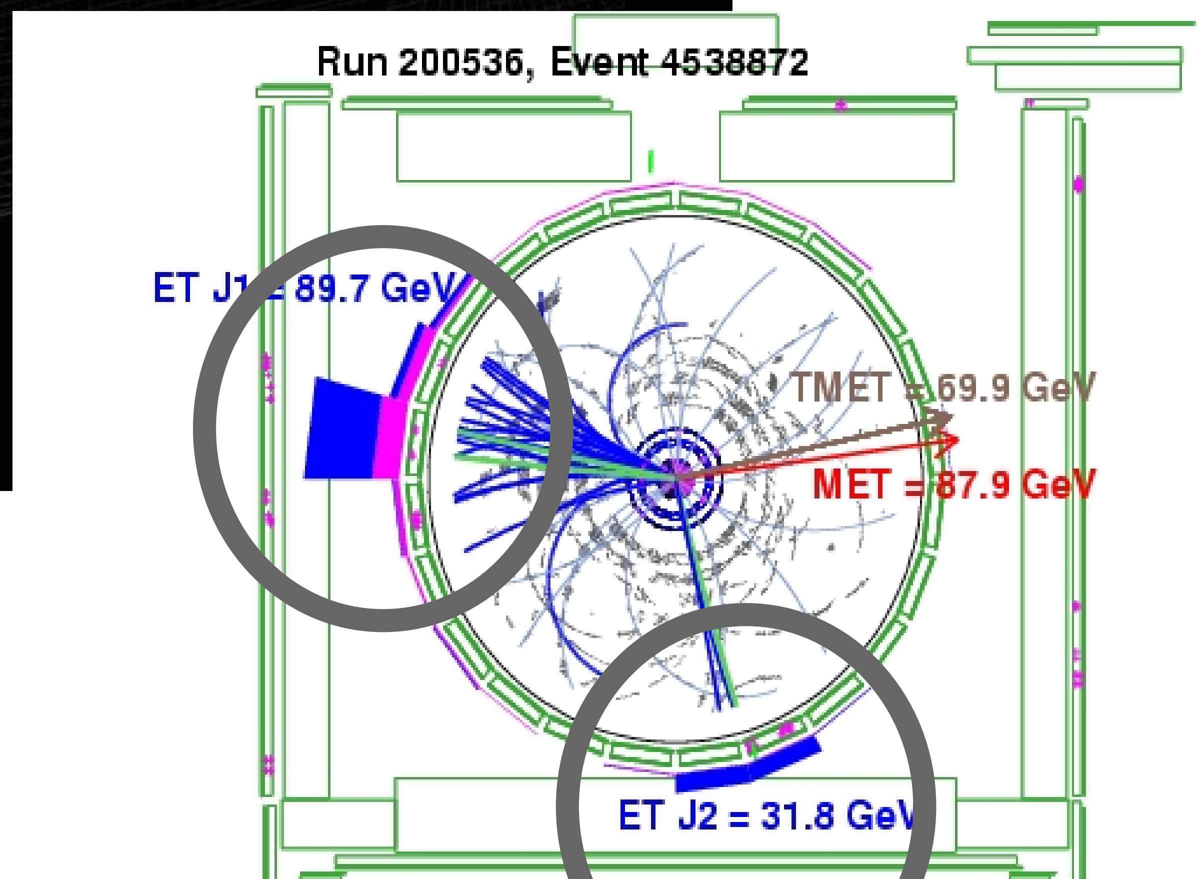
- Boson hadronic decays needs excellent jet energy resolution
- 3% resolution to distinguish W and Z, jet energies ~20 to ~250 GeV
- ~2 x better than current performances
- charged energy with tracker ~ perfect precision, photons in EM calorimeter, neutral hadrons in HCAL
- greatly reduce impact of hadron shower fluctuations



Requires identification of each particle's energy deposition

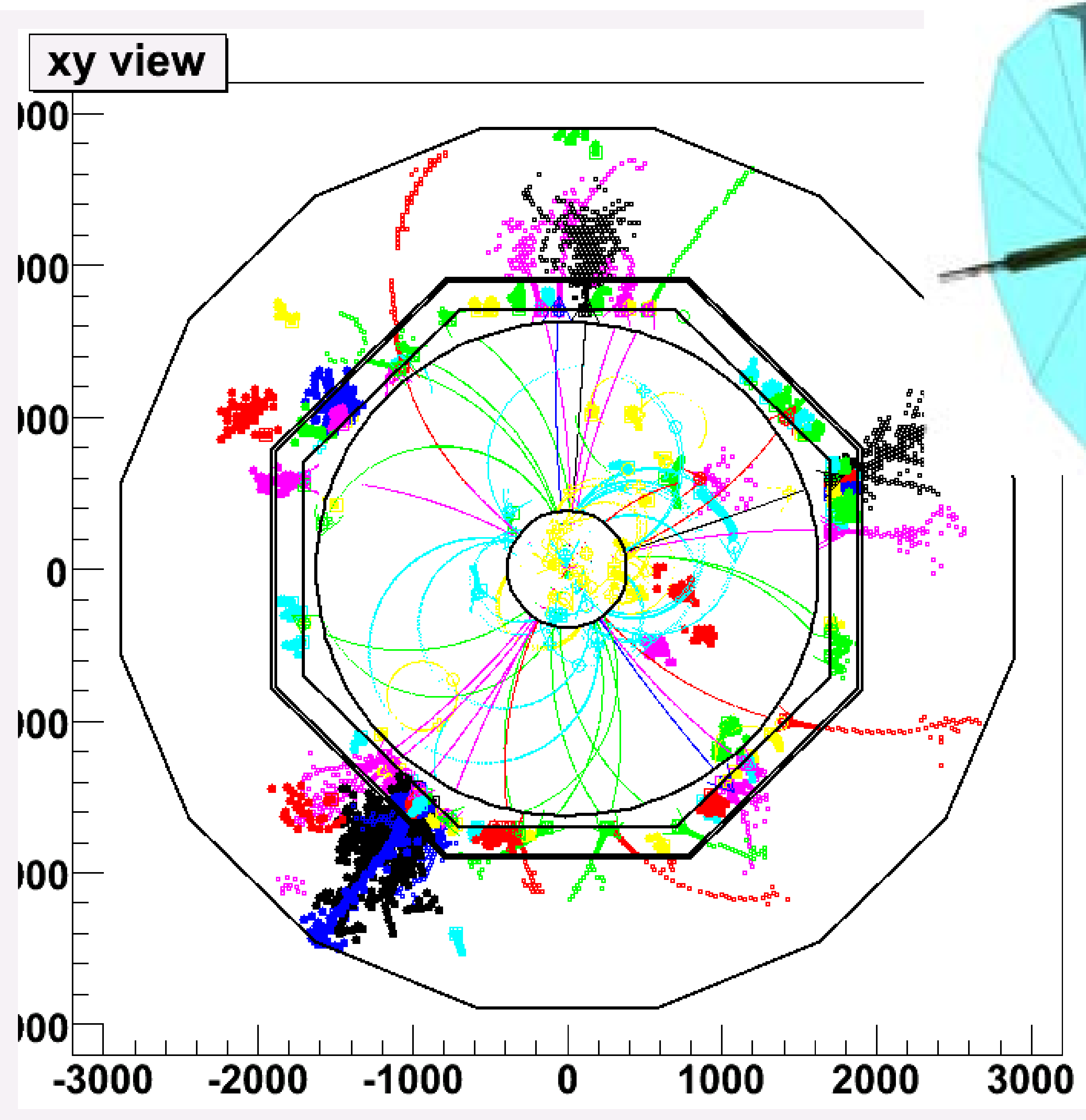
- highly granular calorimeter : 10 k channels/dm^3
- Single particle energy resolution secondary importance

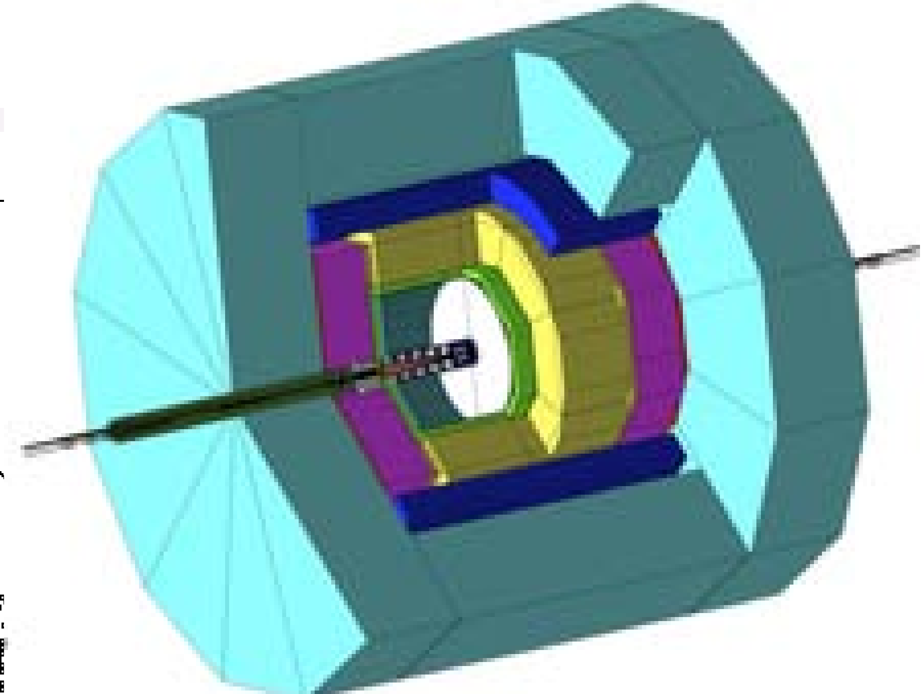

CMS Experiment at the LHC, CERN
Date Recorded: 2009-12-06 07:18 GMT
Run/Event: 123596 / 6732761
Candidate Dijet Collision Event

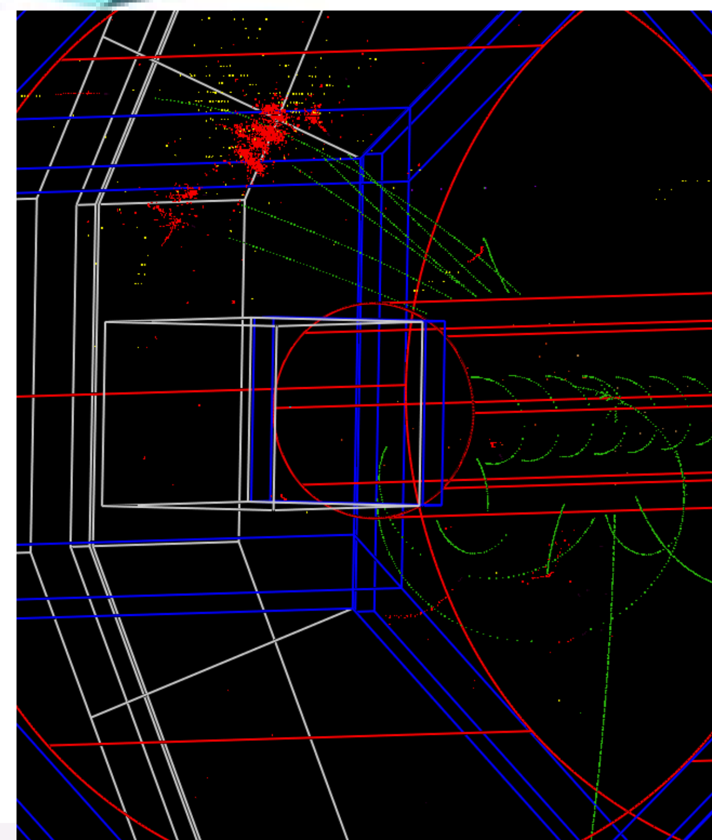

Run 200536, Event 4538872
ET J1 = 89.7 GeV
TMET = 69.9 GeV
MET = 87.9 GeV
ET J2 = 31.8 GeV

From this...

To this...







Calorimeters for ILC

Reduce dead material, calorimeters inside coil

→ readout technology insensitive to ~4T field

large area sensitive material, large number of channels

ECAL :

~24 X0, 20 cm thick

~2500 m^2 active detectors

~100M readout channels

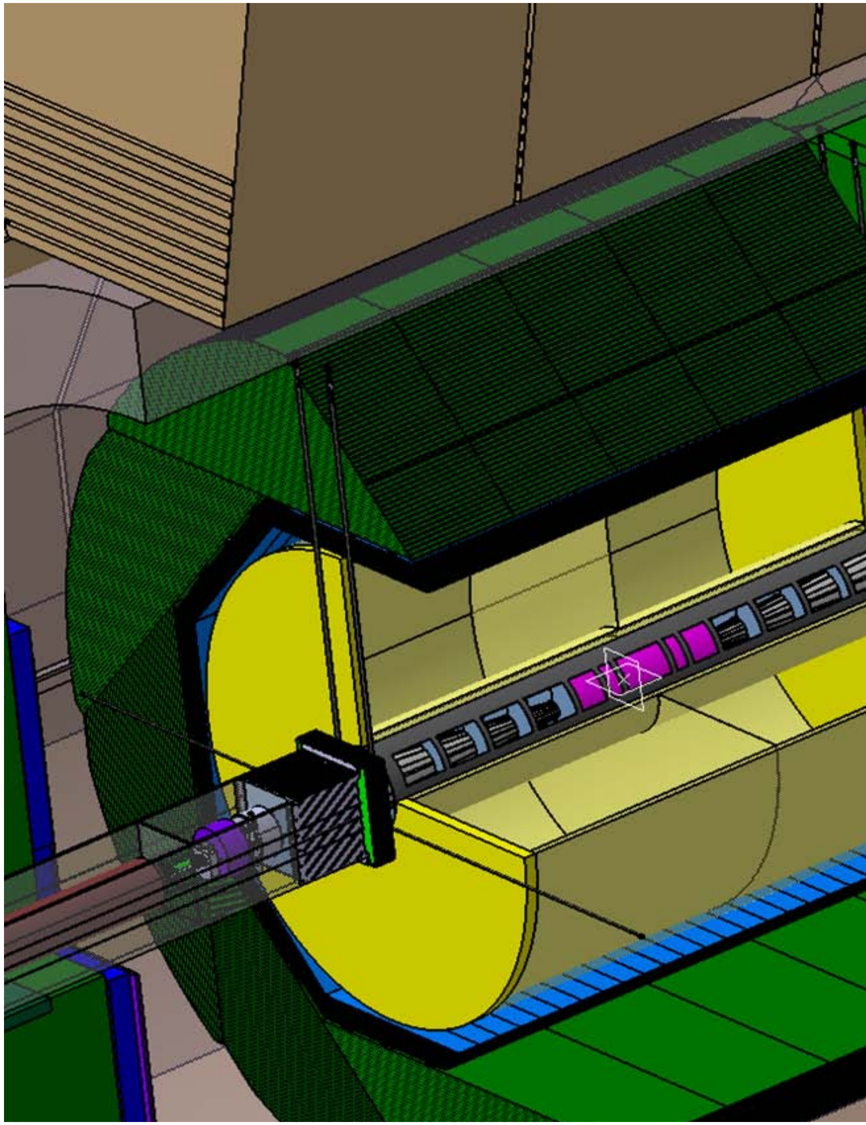
HCAL :

~5 lambda

~7000 m^2 detection area

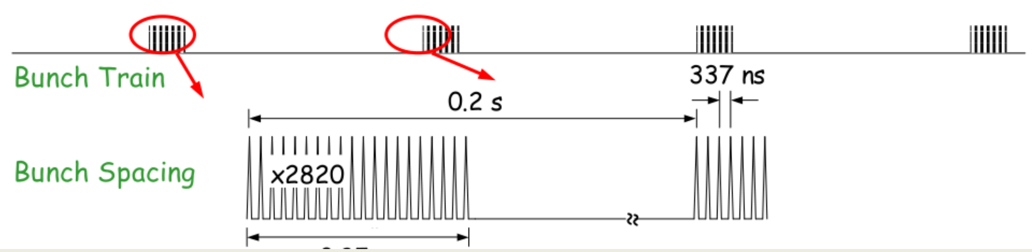
~8M readout channels

\+ Muon system/Tail-catcher



Work with specific beam structure

ILC: 5Hz trains each of 3k bunches @ 340 ns



CALICE collaboration

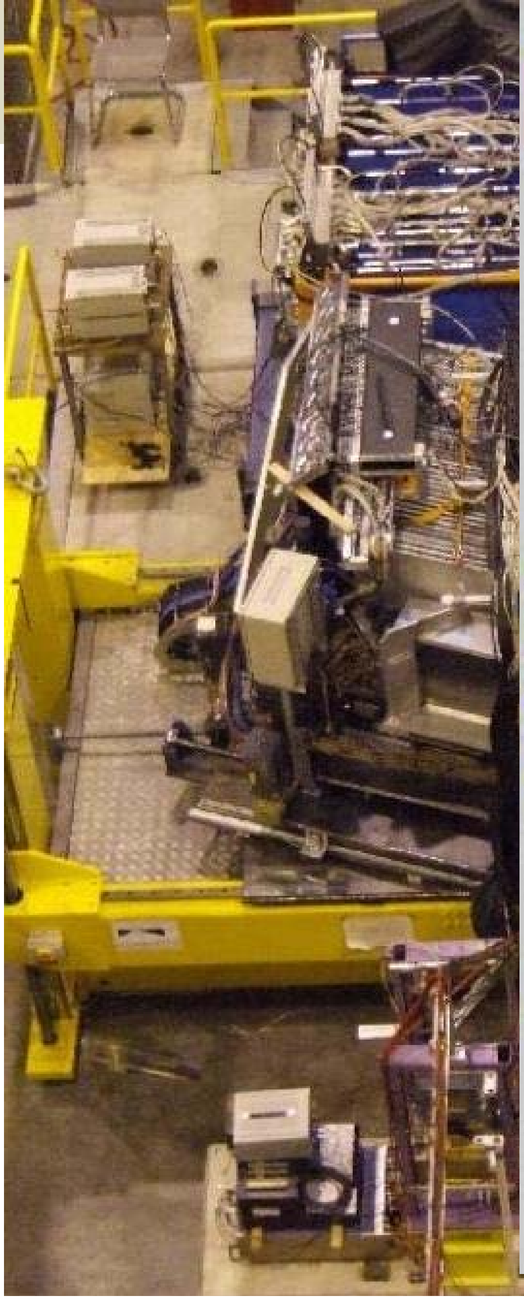
Particle Flow Calorimetry
for a future Linear Collider

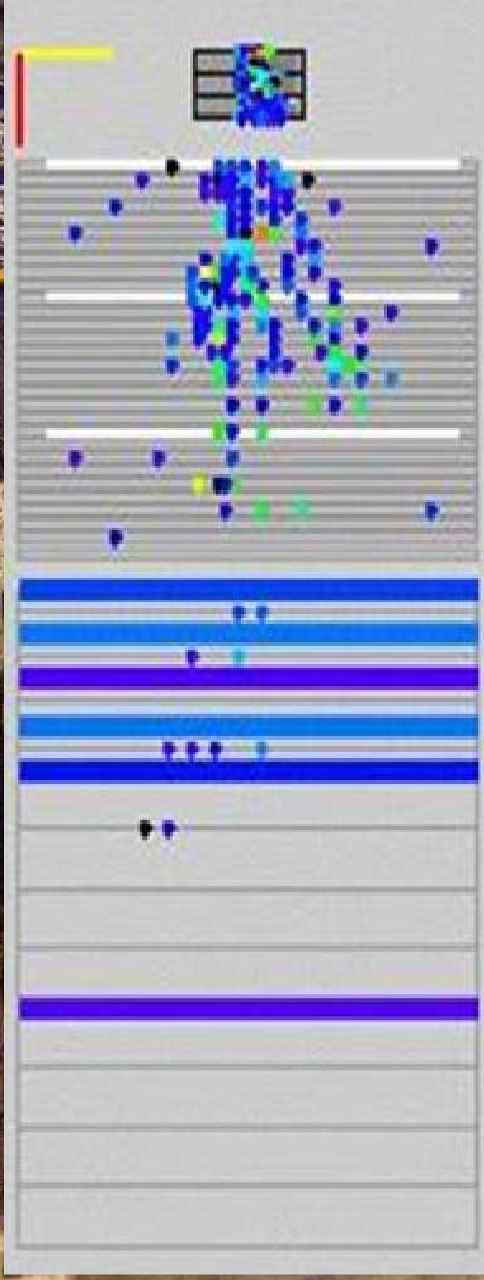
336 physicists/engineers
57 institutes
17 countries
4 regions (Africa, America, Asia and Europe)

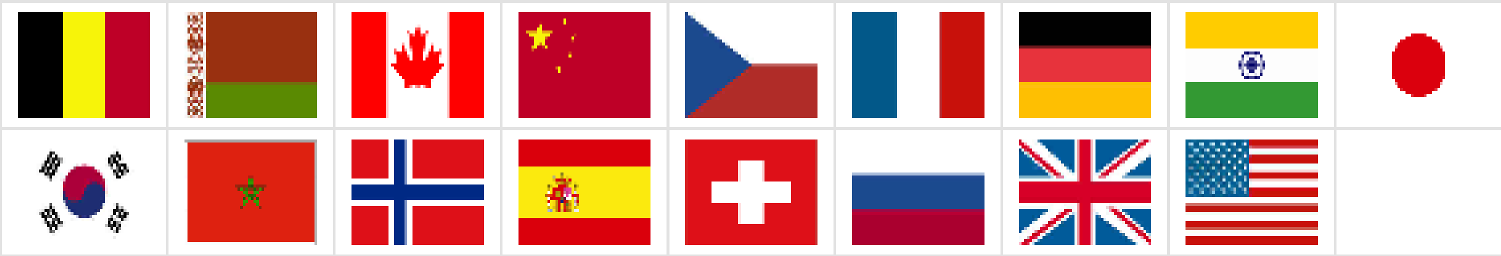
Groups study different technologies

Collaborate on:

Technical issues
Combined test beams
Data analysis







Calorimeter for ILC

Proof of concept

- Physics prototype (2006)

Proof of feasibility

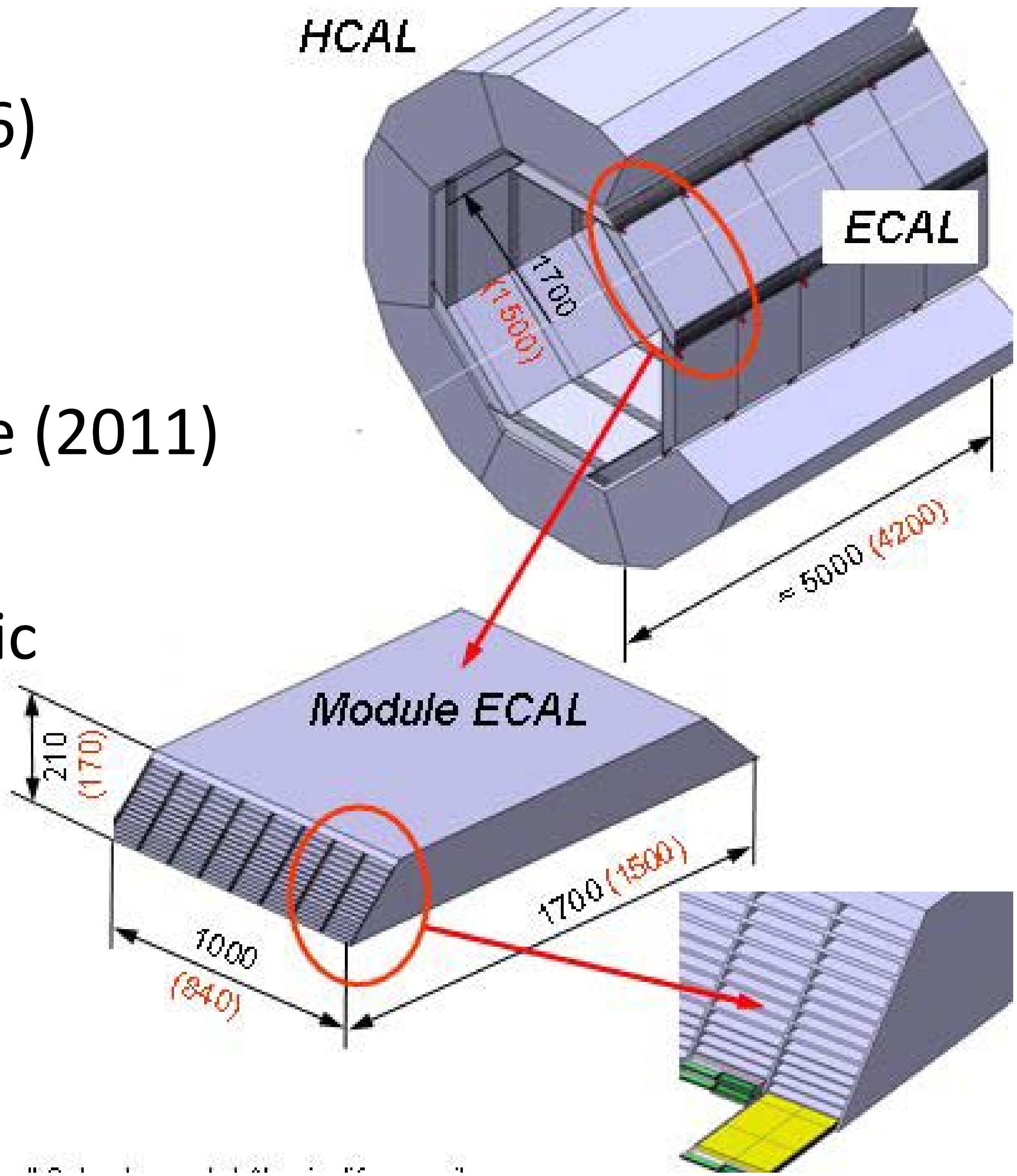
- Technological prototype (2011)

Sampling calorimeter: intrinsic longitudinal granularity

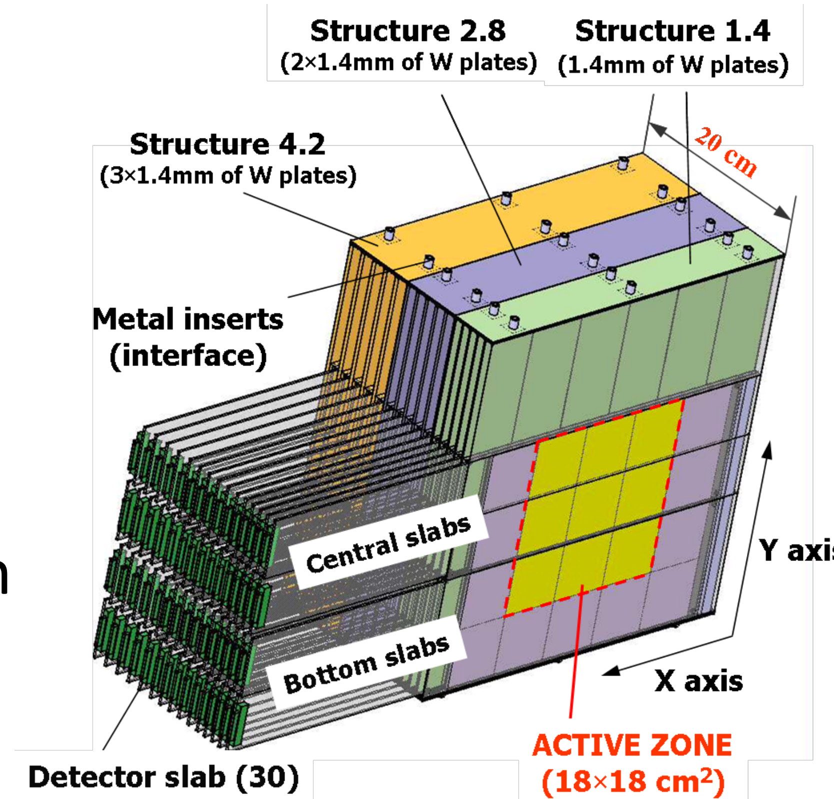
~30 layers for ECAL

1 tower instrumented

(40k channels, 20 cm^2 crosssection)



CALICE : SI-W ECALorimeter



Tungsten absorber material:
- small Molière Radius (10mm),
- small X0 (3.5mm), small X0/λINT
  - → compact EM showers,
  - thin ECAL,
  - good hadron-electron separation

Silicon sensor readout layers
- High resistivity Silicon, reverse biased PIN diodes
  - 5x5 mm2 readout granularity, 12-bit dynamic range

- High granularity → PFA performance
  - Thin → limit calorimeter thickness
  - Robust and stable → low maintenance

Moscaw State Univ.

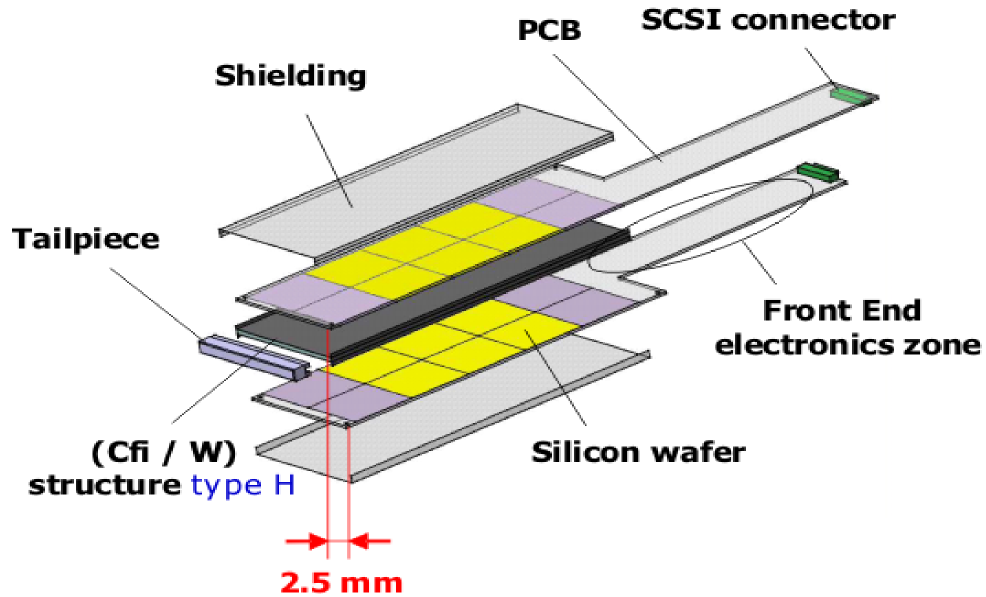
First prototype (2006)

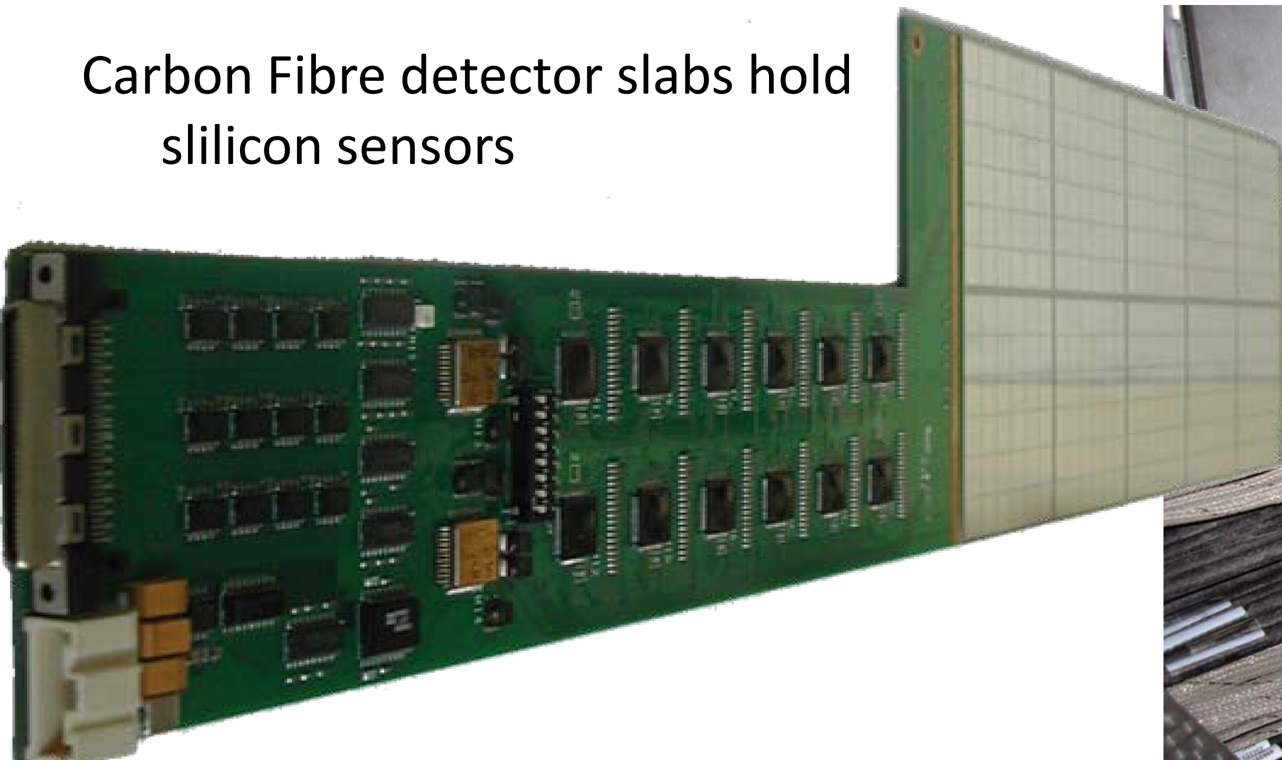
First generation prototype constructed
and beam tested 2006-2008

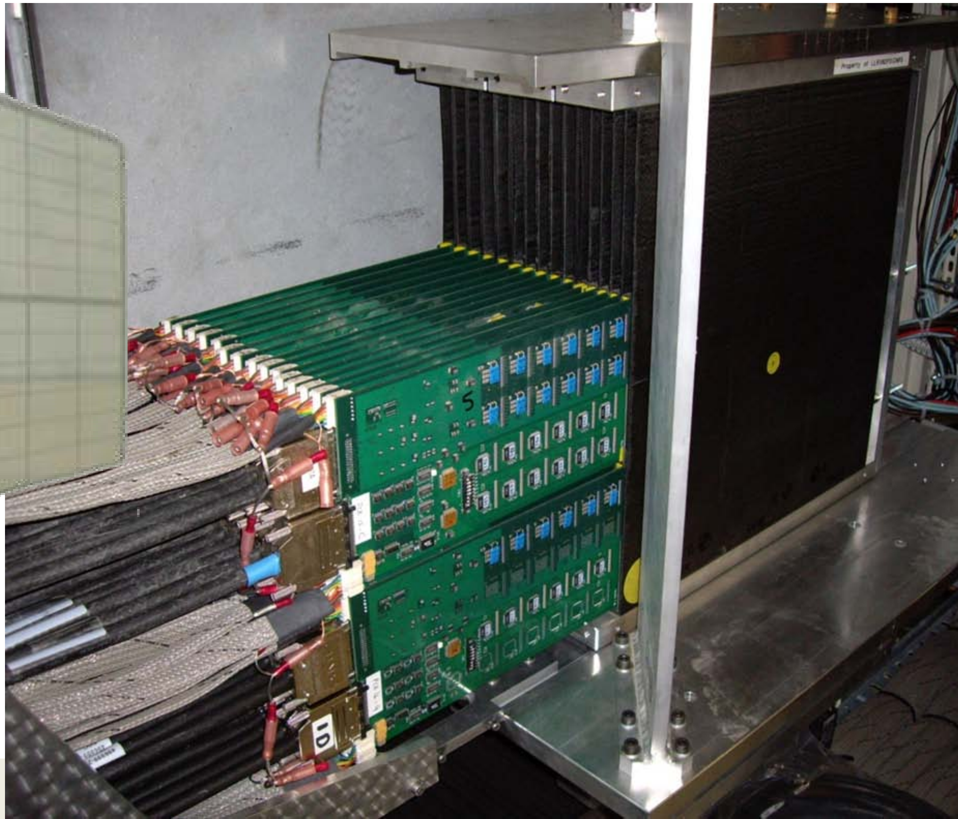
30 layers - granularity, energy resolution
3 sampling fractions

Mechanical structure: carbon fibre composite, incorporating tungsten layers

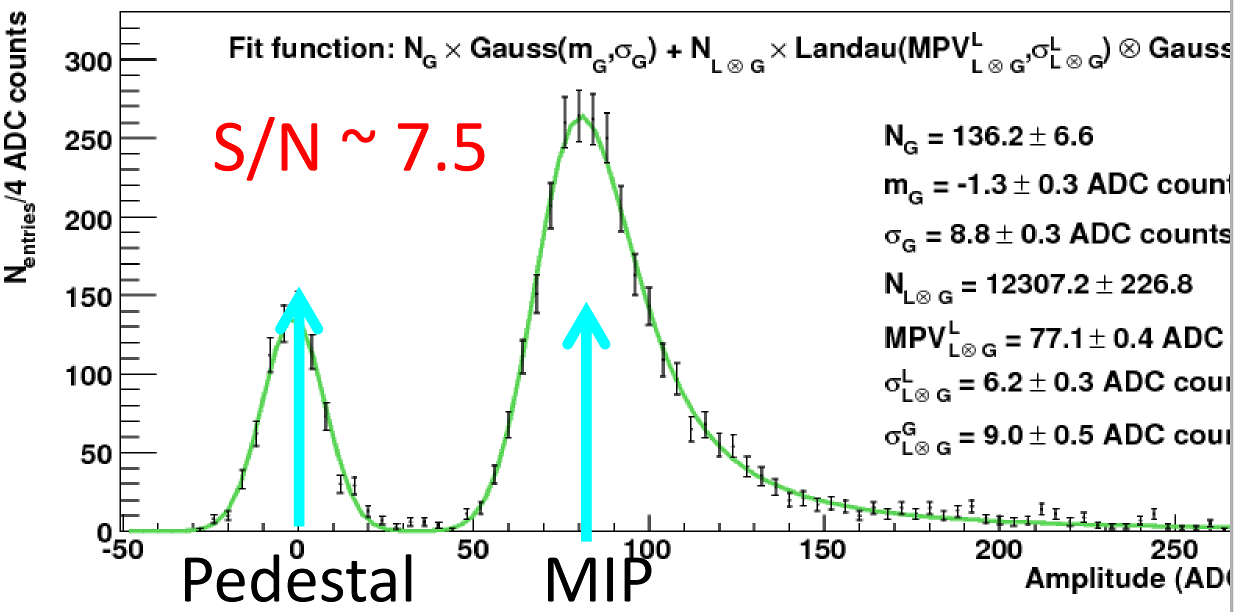
Carbon Fibre detector slabs hold
slilicon sensors

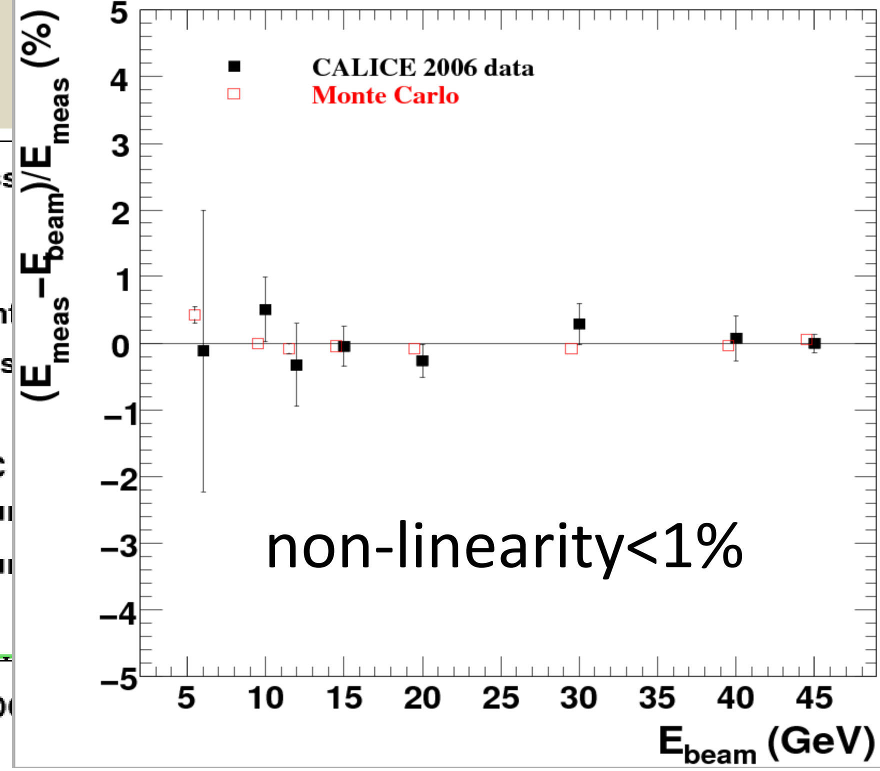


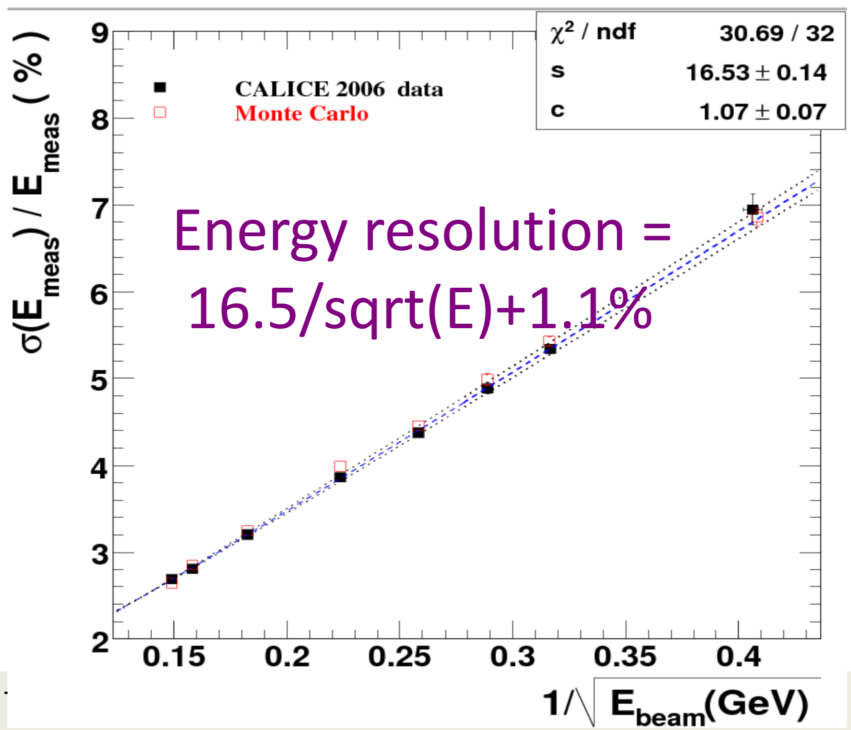


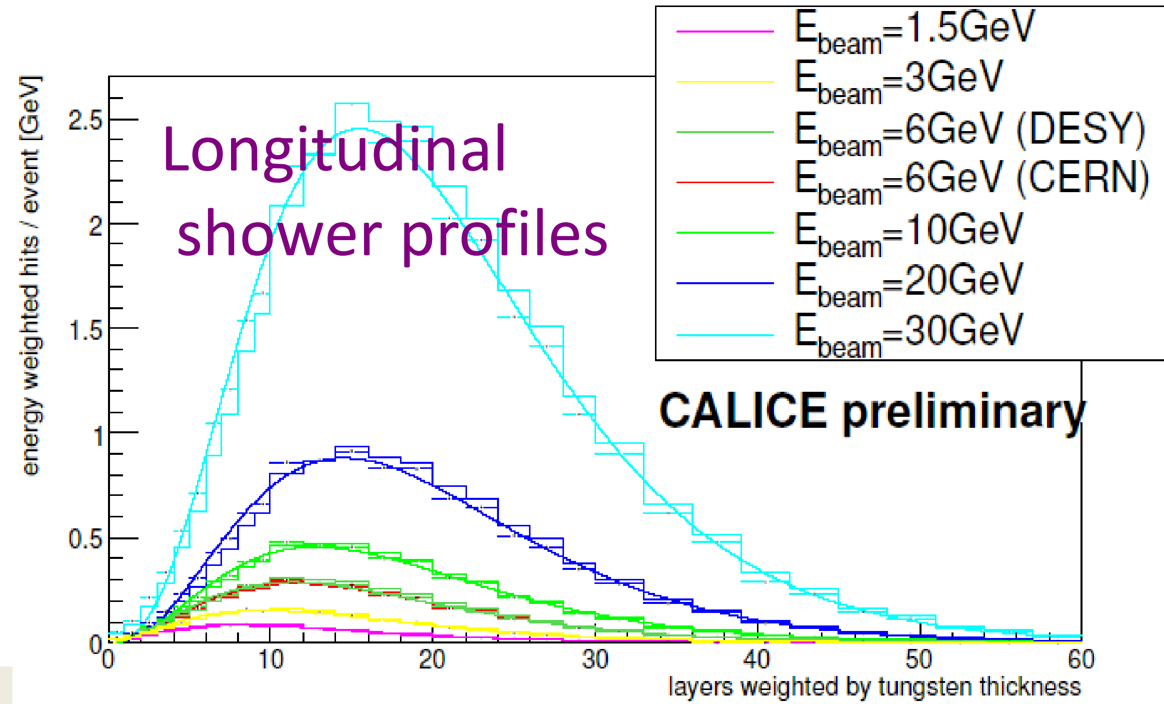


Performance





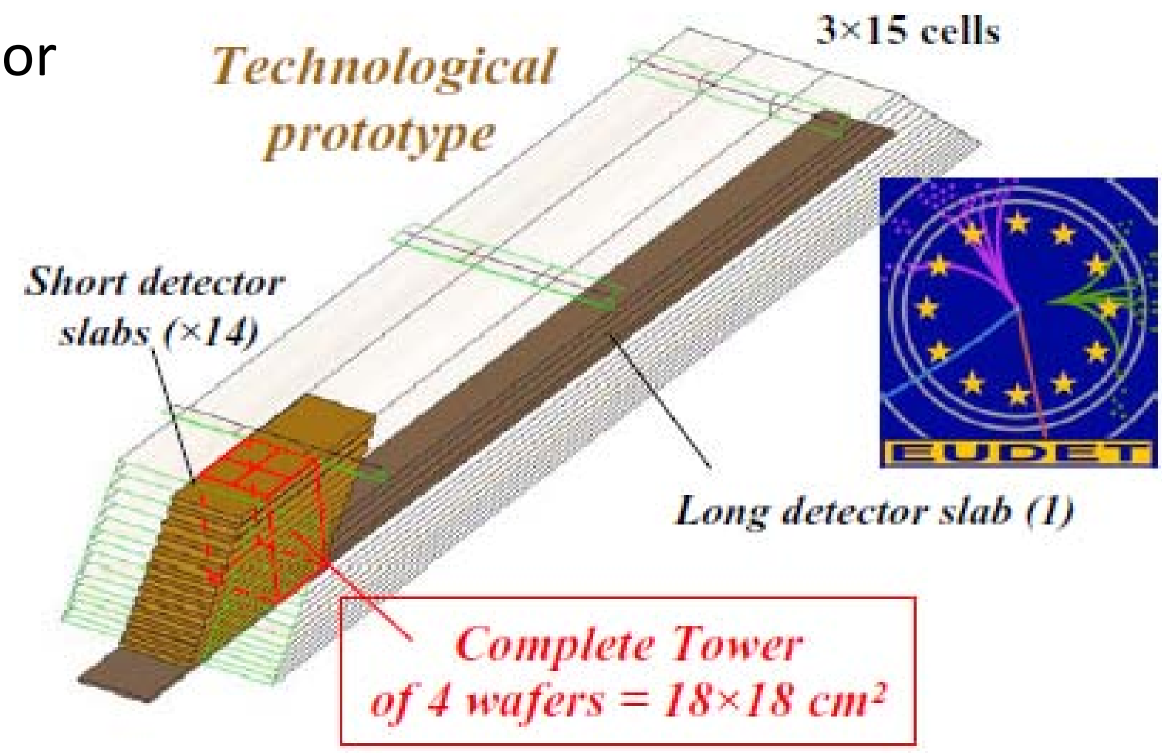


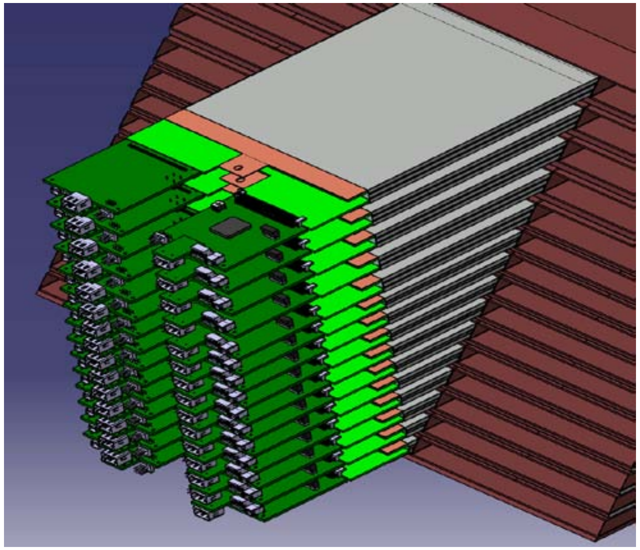


Technological Prototype (2011)

Next steps: towards a LC detector module → ~2014

~ 2/3 final module size
(partially instrumented)
9 cm large sensors
→ less edge effects
Smaller pixels
→ granularity
Power-pulsed, embedded
FE electronics
→ low power 25 µW/ch





Mechanical structure

Tungsten plates wrapped into carbon fibre: 15 layers

7 mm tick detector slab slided into alveola

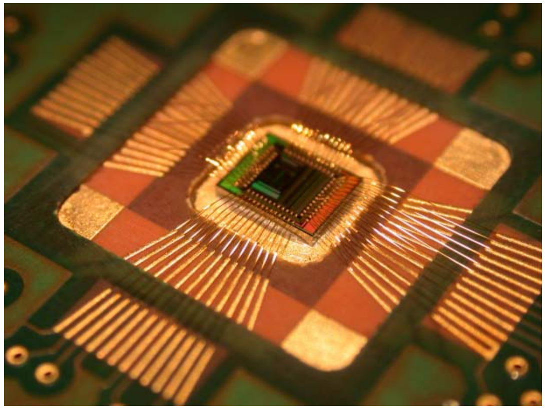
= 1 tungsten core, 2 layers of detectors + electronics on PCB

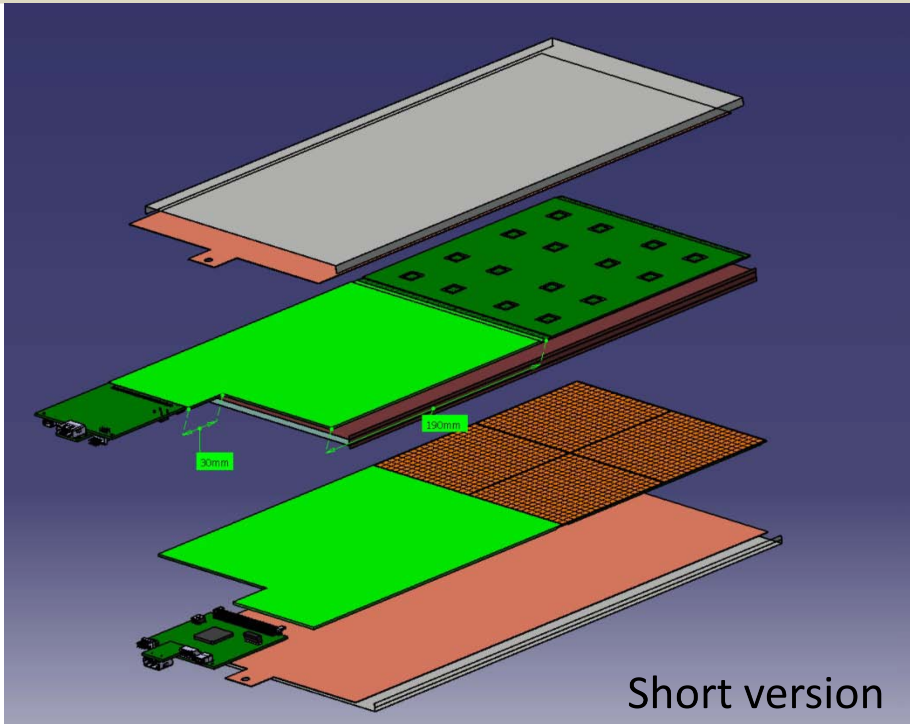
Detector slab

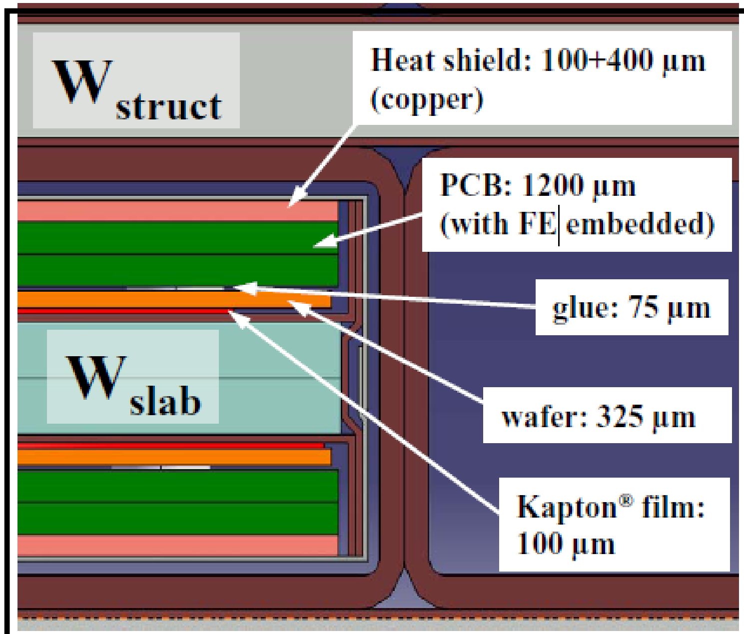
Compact assembly of 2 layers of 1 to 8 Active Sensor Units (ASU)

1 ASU = 1 kapton (HV bias for PIN diodes)
+ 1 layer PIN diodes
+ 1 PCB with microchips embeded
+ 1 thermal drain (copper)

PCB is critical : 1 mm tick, 8 layers, 1% flatness , chips bounded *into*



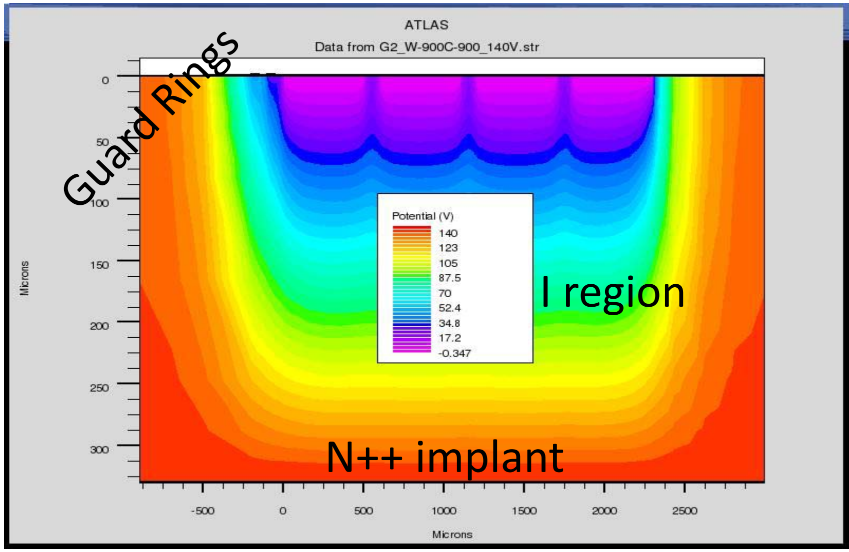




PIN diode matrices design

- The simplest design to control the cost
  - Few thousands of m^2 needed for ILD
  - Minimize the number of steps of the processing procedure
  - Guard rings = same as pixels
    prevent breakdown
  - Glued on PCB : Floating GR
- Drawbacks :
  - Large dead zone at the edges (>1 mm)
  - Crosstalk (Square Events)
- Cost is to be optimized by a factor 3 compared to R&D batches

P++ implants (pixels)



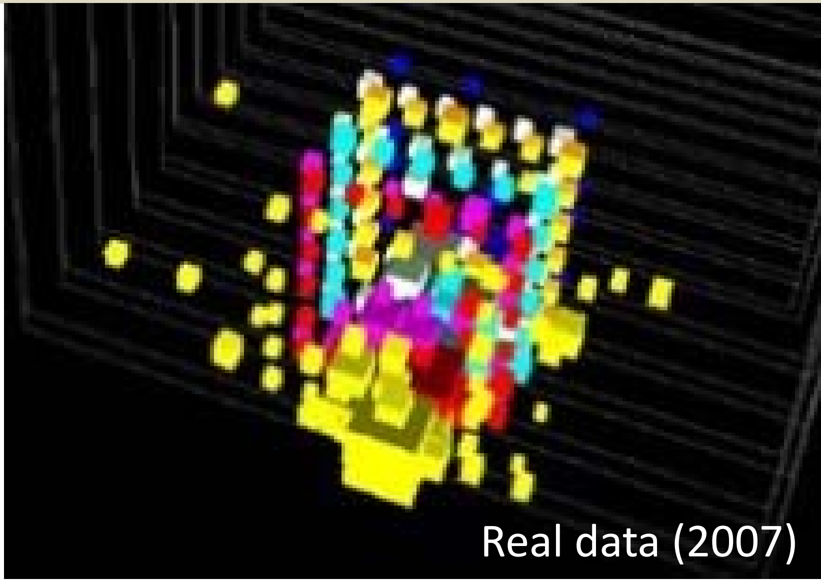
9x9 cm^2, 256 pixels

PIN diodes : square events

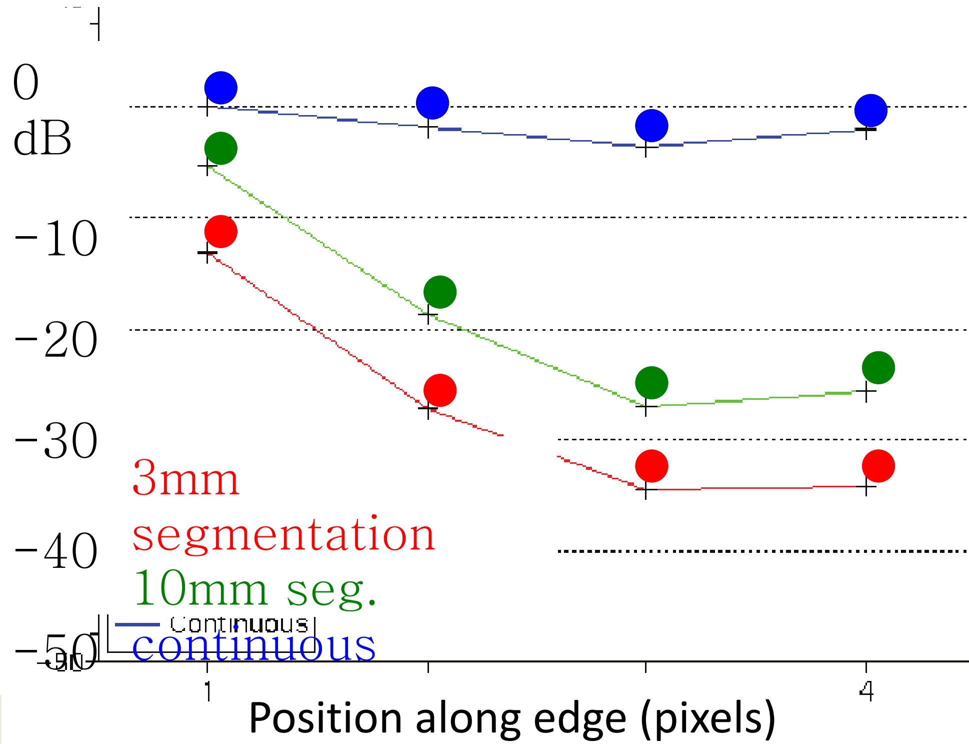
"Square events" when shower energy deposited in guard ring

Capacitive coupling between continuous and *unbiased* ring and edge pixels

Studies underway to reduce effect
- segmented guard rings
- promising results



Signal attenuation along sensor edge



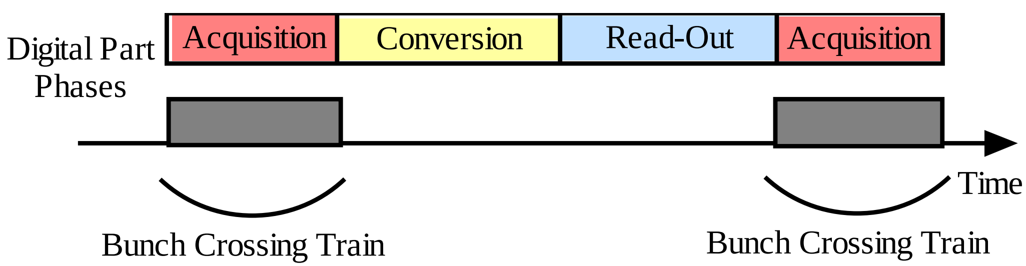
SKIROC chip

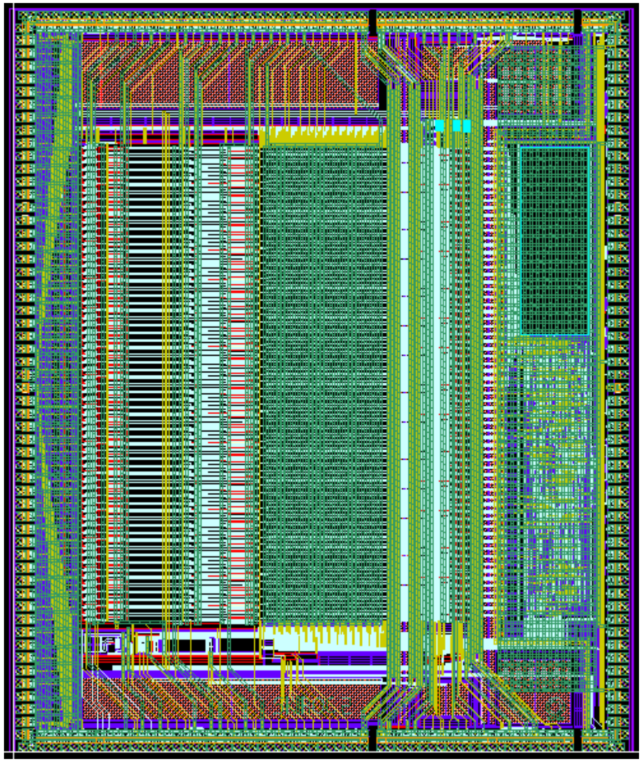
Silicon Kalorimeter Integrated Read Out Chip

- Technology SiGe 0.35µm AMS.
- Production batch received Q3'10
- 64 channels, variable gain charge amp, 12-bit ADC, digital logic
- Power-pulsed → 25 µW/channel

Power pulsing

- Variable current consumtion according to state
- 1 slab : 0 to 10 Amps pulses of 1 ms at 5 Hz



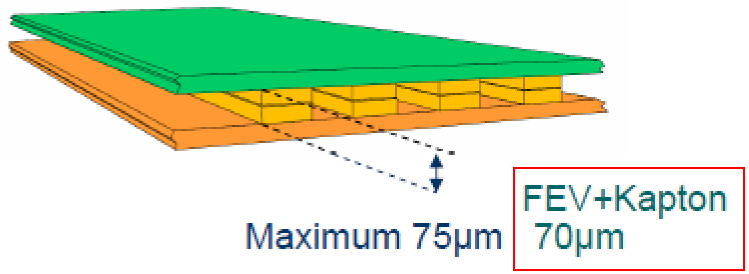


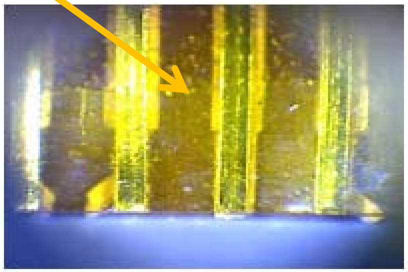
SLAB assembly

Up to 9 equipped PCBs interconnected to make detector slab

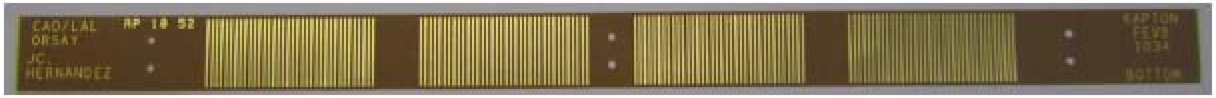
Electrical and mechanical connection made thanks to Kapton connecting cable

2 techniques under investigation
- Soldering or
- Adhesive & Anisotropic Conductive Film





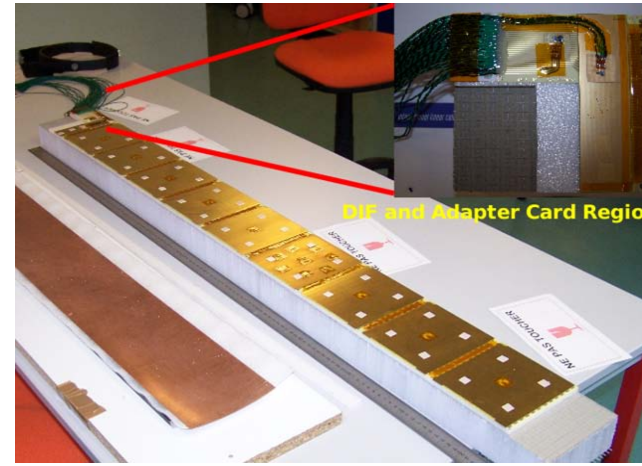
Full size kapton for interconnects

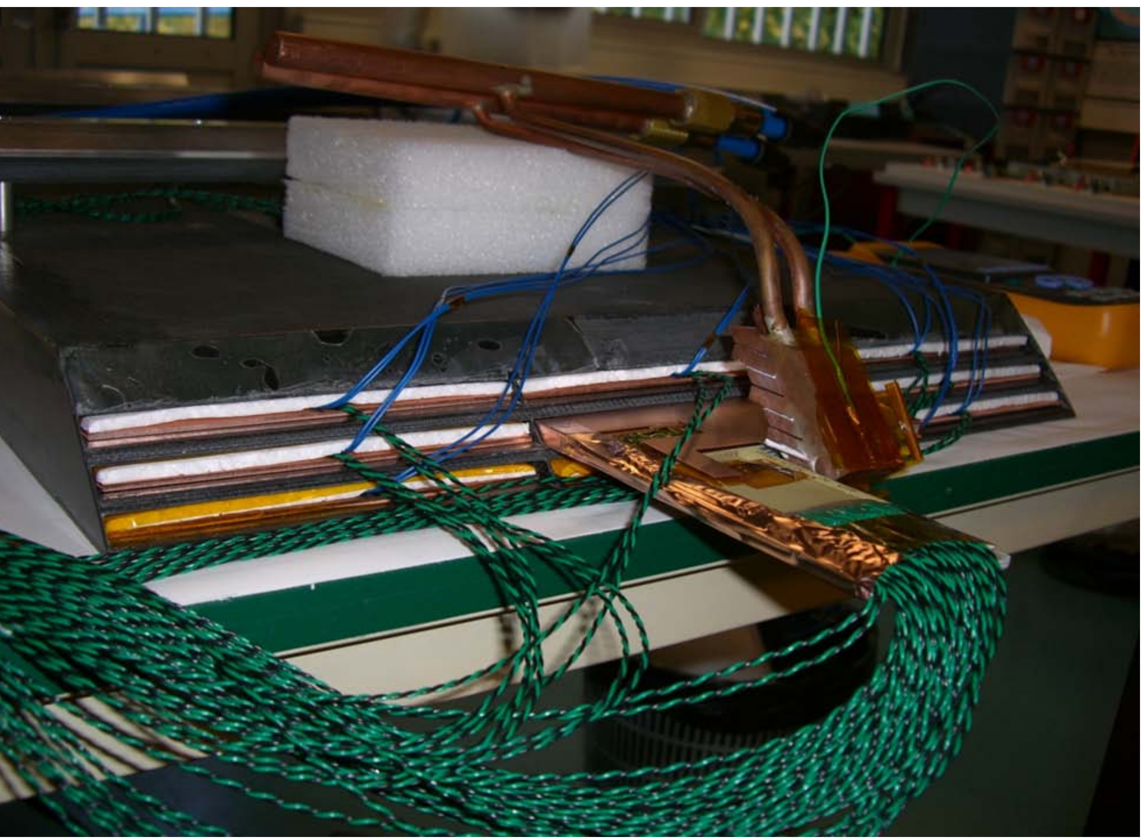


18 cm, 4 slots of 36 pins each

Developing a leakless water cooling system

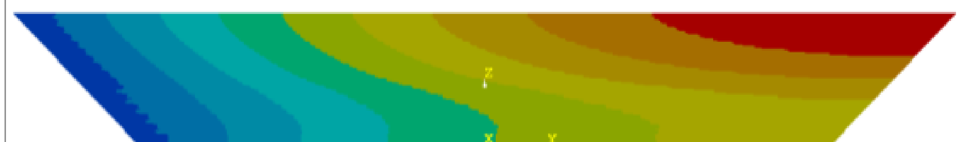
Total ECAL power dissipation O(10 kW)
even at 25 μW/ch
Need active cooling system (cold water pipe + radiator)
Limit : temperature differences within ECAL
heat transfer to neighbouring detectors





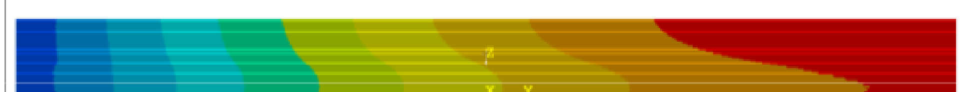
Cooling tests in demonstrator module

Results
Barrel : (1.5m)



ΔT = 2,2℃

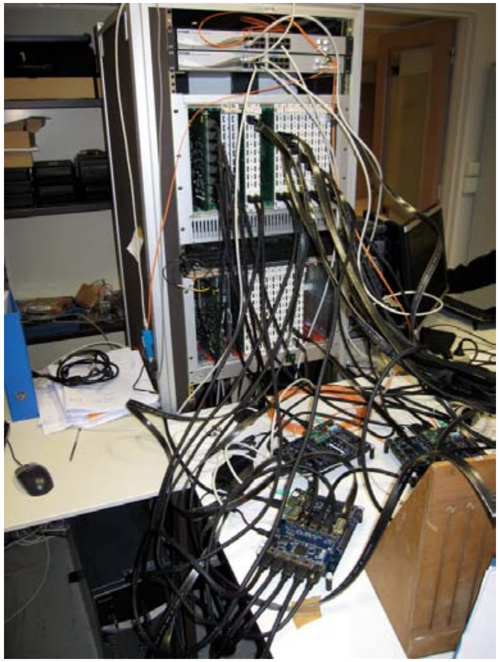
End Cap : (2.5m)



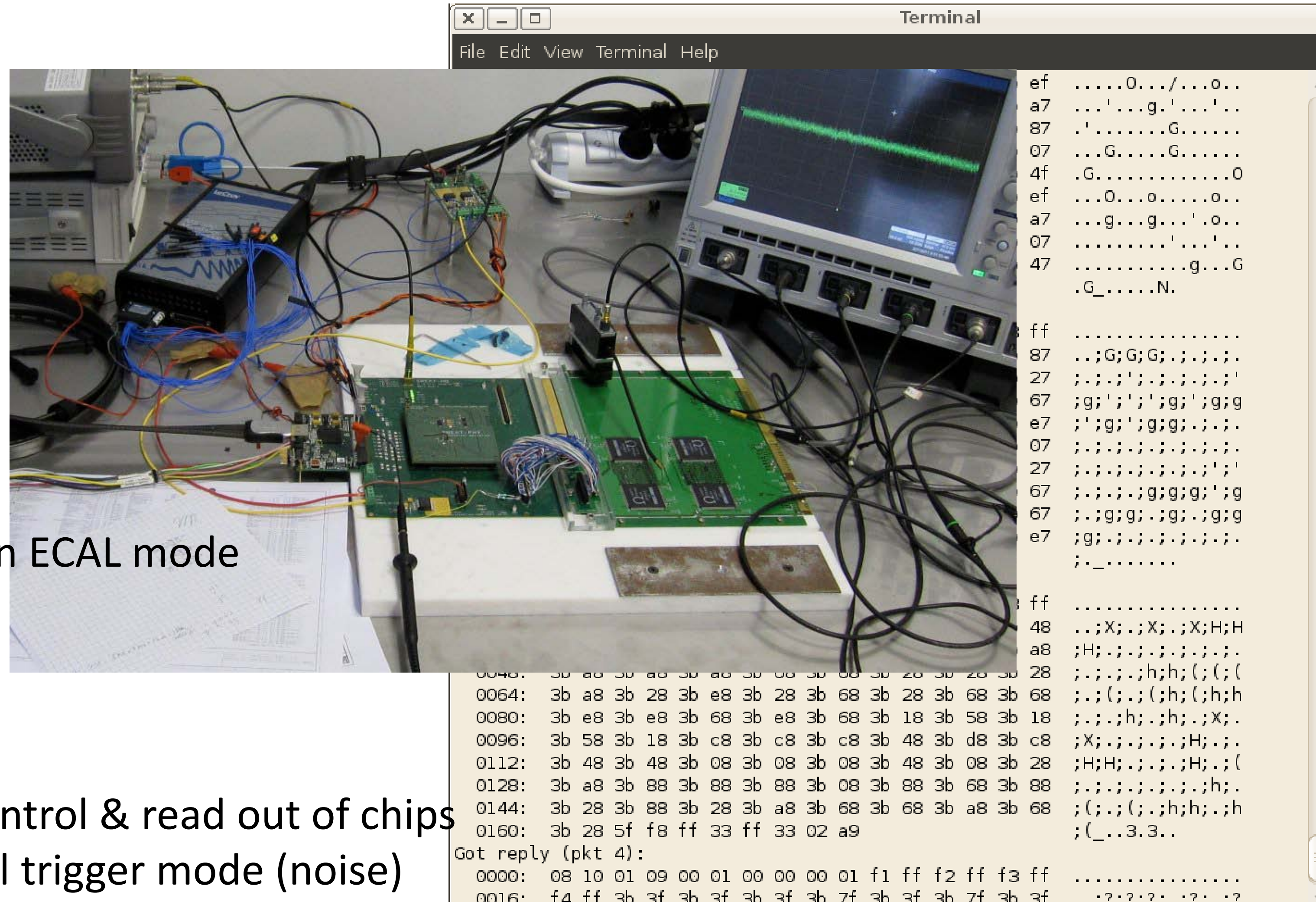
ΔT = 6℃

Thermal simulations of detector

Preliminary tests of the first ASU



Most efforts spend on CALICE new generation DAQ (talk #432)
Standard detector interface, common HDL code to every CALICE det.
Python scripts for testing



1 ASU with 4 SPIROCs in ECAL mode
1 Si Wafer

Slow control & read out of chips
External trigger mode (noise)

Summary

LC calorimeters must have unprecedented jet energy resolution

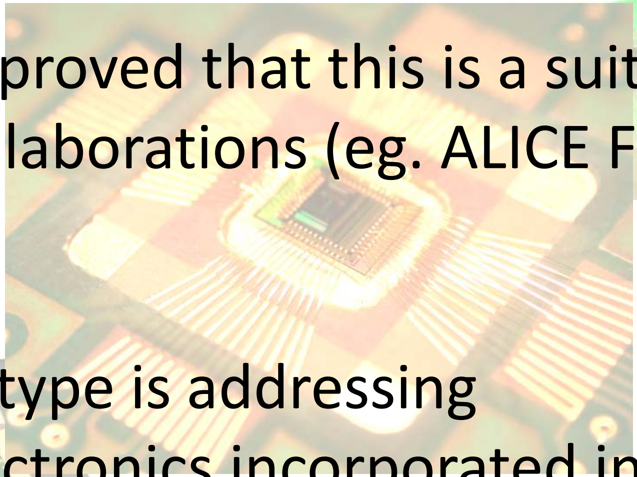
Particle flow technique

with highly granular calorimeter can achieve this

CALICE Si-W ECAL

Physics prototype has proved that this is a suitable technology

May interest other collaborations (eg. ALICE FO-CAL)

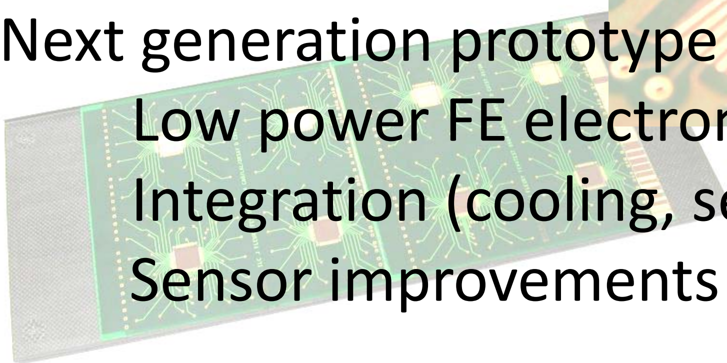


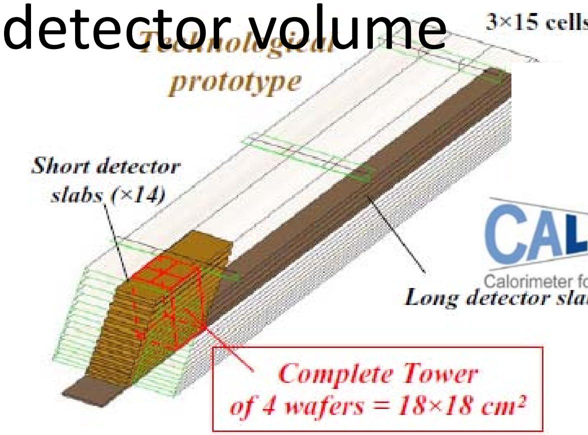
Next generation prototype is addressing

Low power FE electronics incorporated in detector volume

Integration (cooling, services)

Sensor improvements & industrialisation

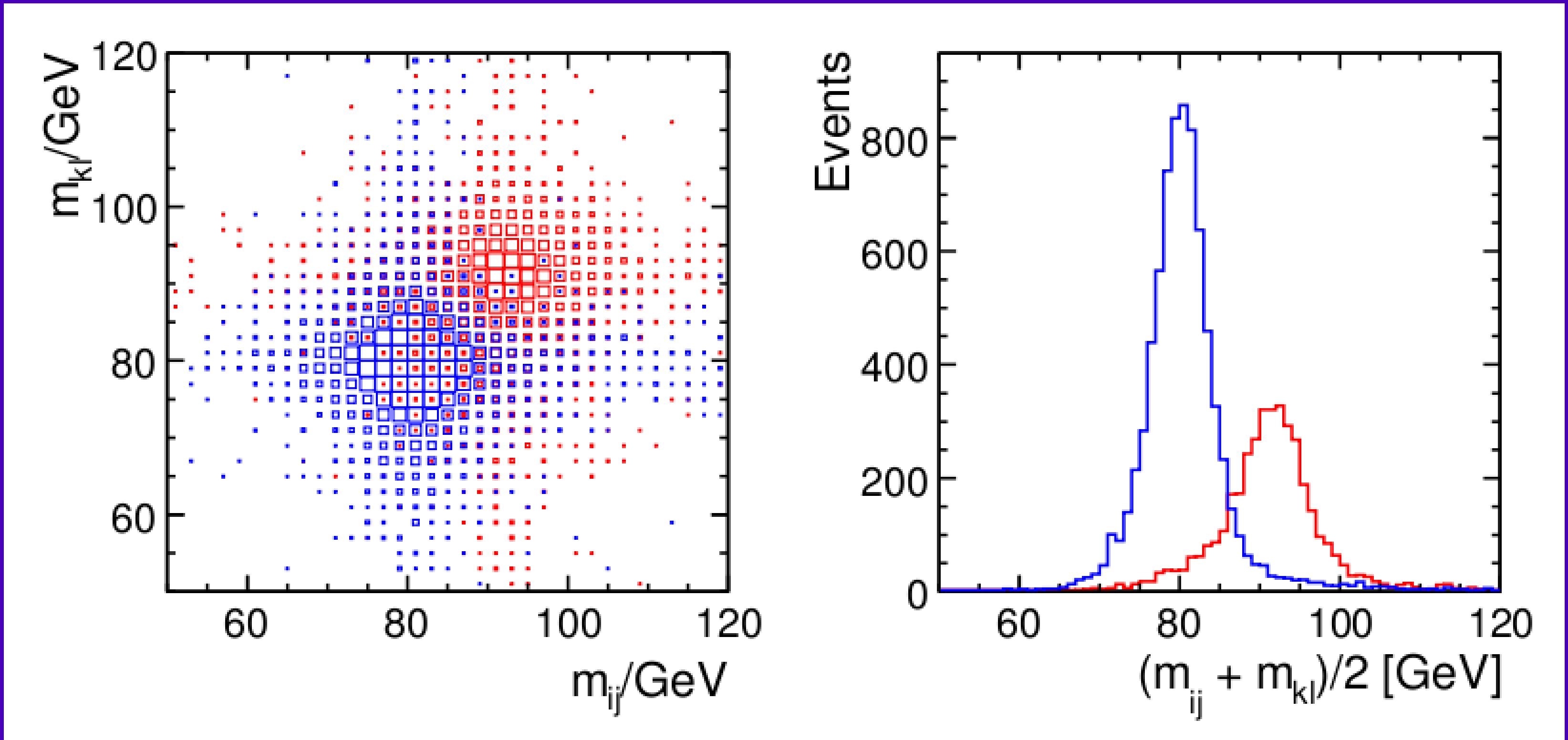




Good understanding of how to build ECAL

Backup slides

e+ e- → WWvv / ZZvv → qqqqvv jet-jet masses (particle flow)



ILD full simulation

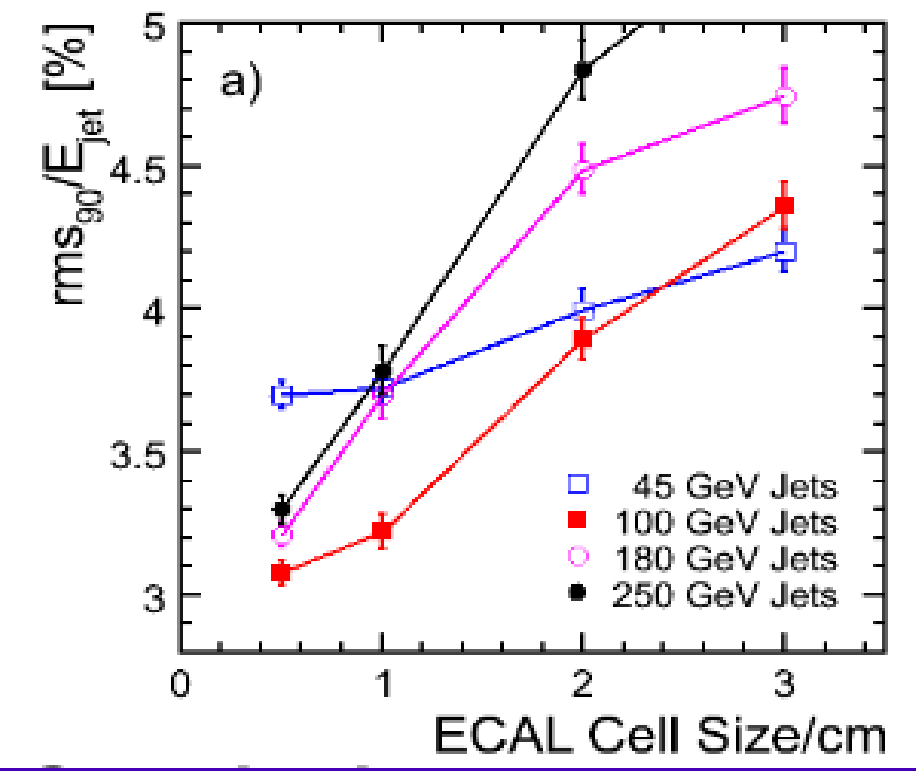
Detector optimisation

- essentially optimised for particle flow

- not single particle performance

- requires complex sophisticated event reconstruction

- PandoraPFA program has demonstrated the required ~3% jet energy resolution over a wide range of jet energies.



Used to decide overall detector dimensions and required calorimeter segmentation.