CALICE RESULTS & FUTURE PLANS

Imad Laktineh

For the calice collaboration

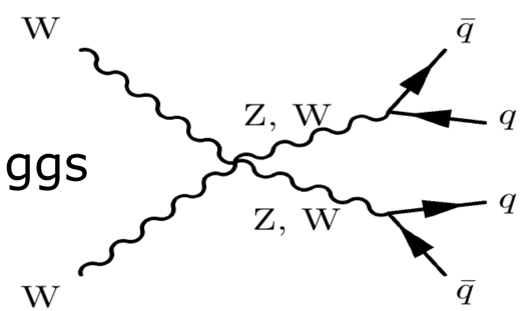
OUTLINE

- Introduction
- Calice physics prototypes performances
- Testbeam results
- Calice technological prototypes for ILC
- Conclusion

Jet Energy Resolution

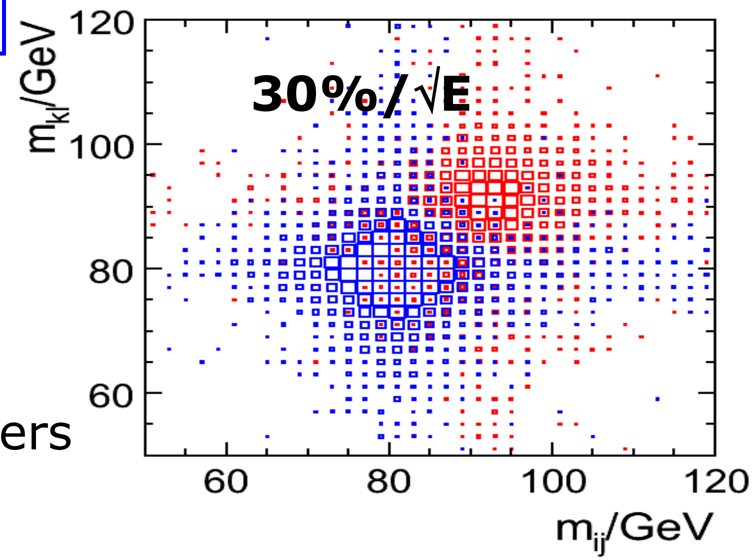
For future colliders, jet energy resolution will be a determinant factor of understanding high energy physics.

Exemples:
→Trilinear Higgs self coupling measurement
→WW scattering measurement in absence of Higgs

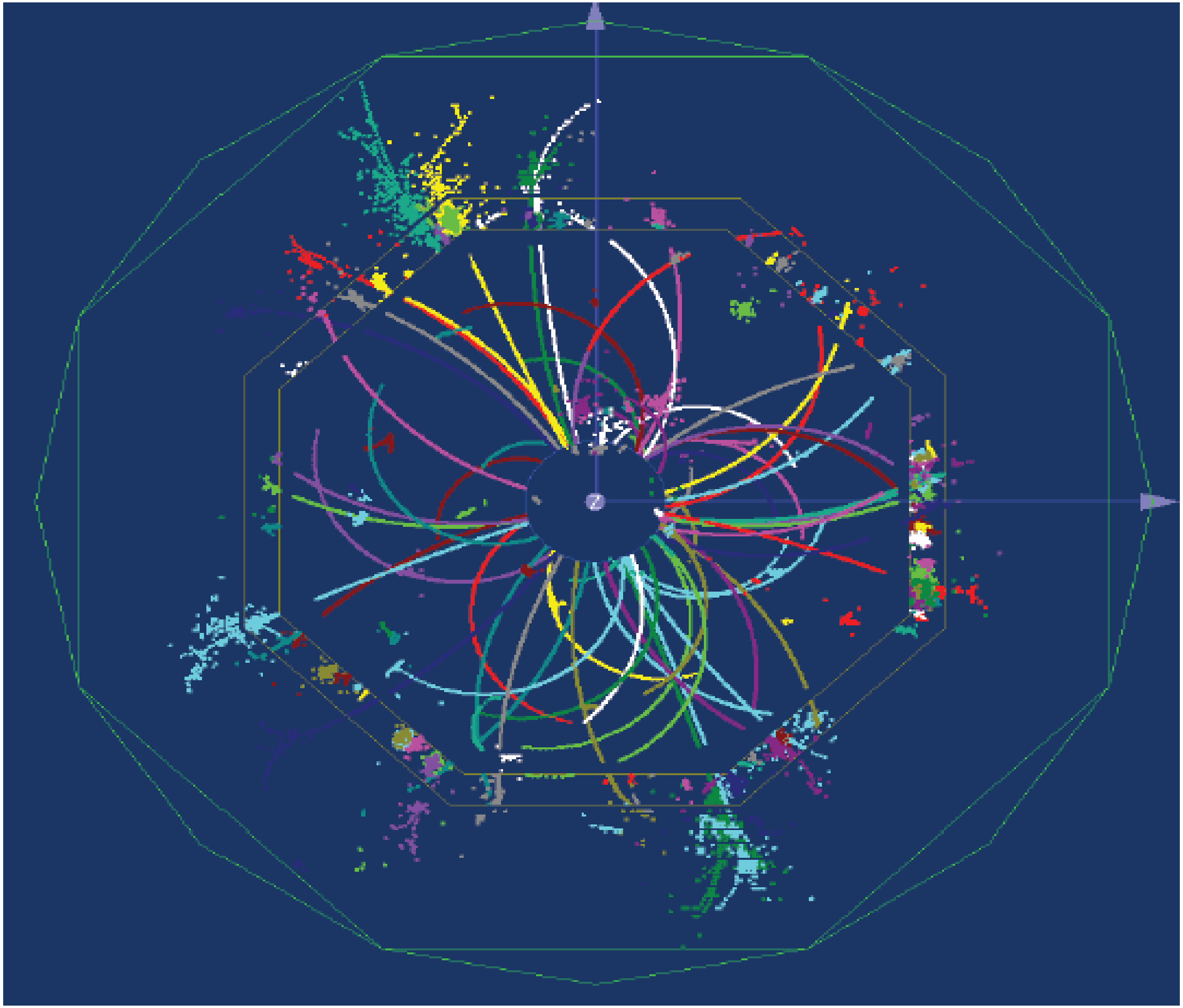


$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{E}{100}\right)^{+0.3} \%$$

Resolution | Tracking | Leakage | Confusion



To improve on the jet energy resolution
PFA is a promising solution to reduce the confusion term → high granularity Calorimeters

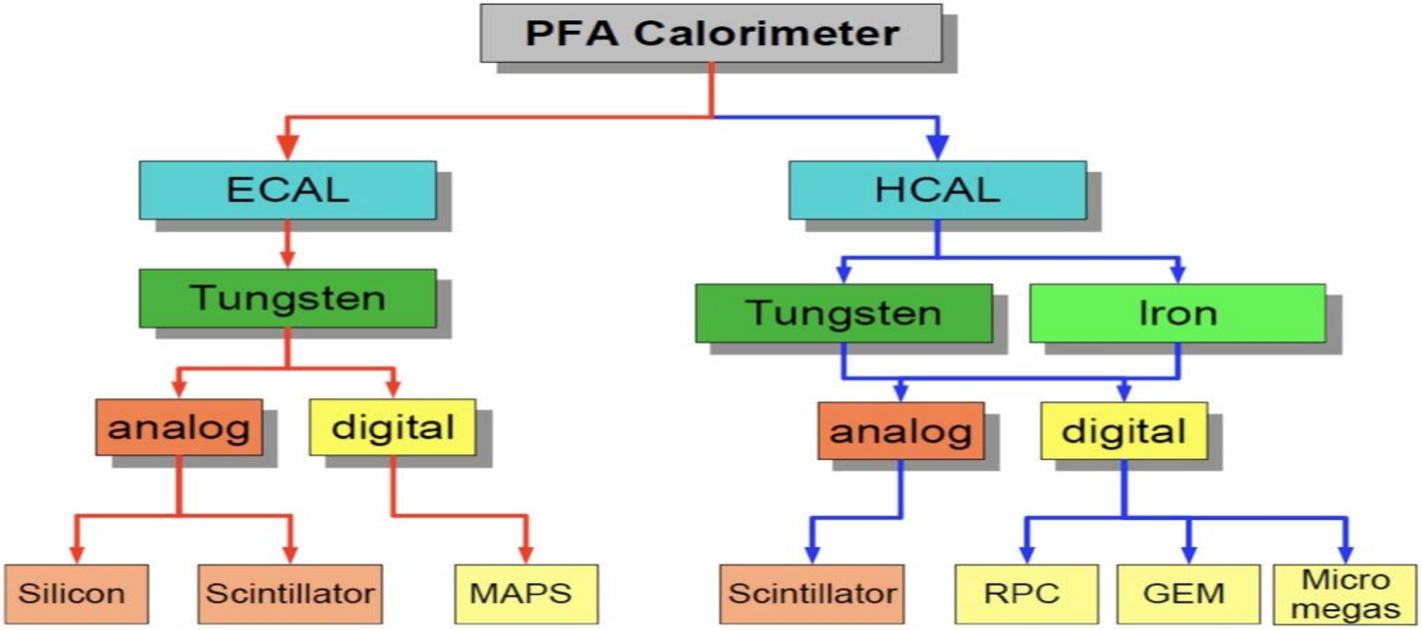


Collaboration is :

More than **337** physicists/engineers from 17 countries working on different technologies of electromagnetic and hadronic calorimeters.

It aims at developing high granular calorimeter to be used for future linear colliders but not only.

Activities :


PFA Calorimeter
ECAL
HCAL
Tungsten
Tungsten
Iron
analog
digital
analog
digital
Silicon
Scintillator
MAPS
Scintillator
RPC
GEM
Micro megas

Testbeams

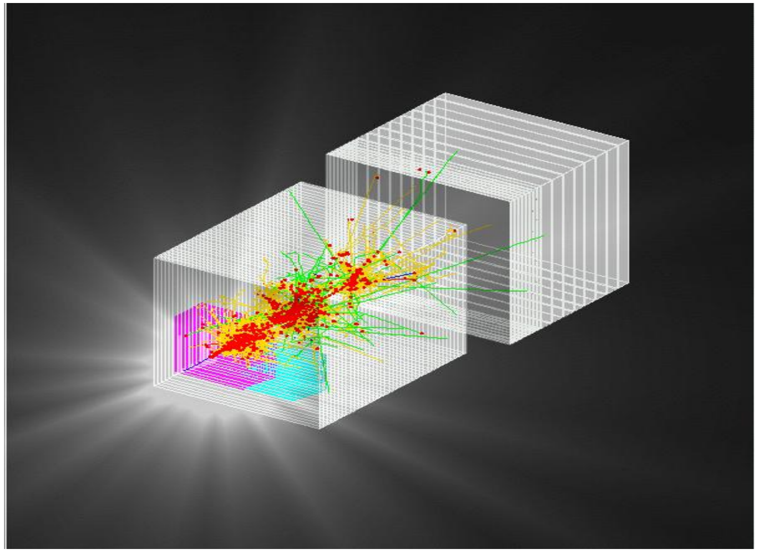
Testbeams campaigns at DESY, CERN and Fermilab using 1st generation "physics" prototype:

Si-W ECAL 2005-08
Scint-W ECAL 2007-09
Scint-Fe HCAL 2006-09

Different kinds of particles: electrons, pions, muons and protons
Different energies : Few GeVs -120 GeVs
Mostly combined tests: ECAL+HCAL with a common DAQ

Goals:

- Validate the detectors concepts
- Understand EM and Hadronic showers (collaboration with GEANT4 group)



Electromagnetic Calorimeters : Si-W

Tungsten absorber

small Moliere Radius (9mm)

small X0 (3.5mm)

small $X0/\lambda_{INT}$ (0.03)

Silicon active sensors

high resistivity silicon (5 kΩ cm)

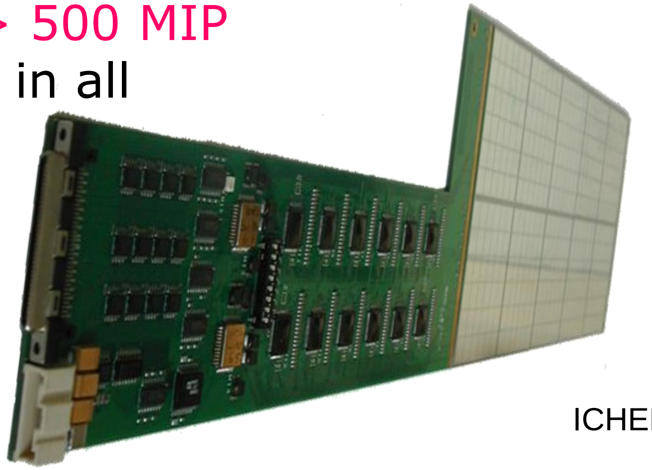
500 micron thickness -> S/N 7.5 @ MIP

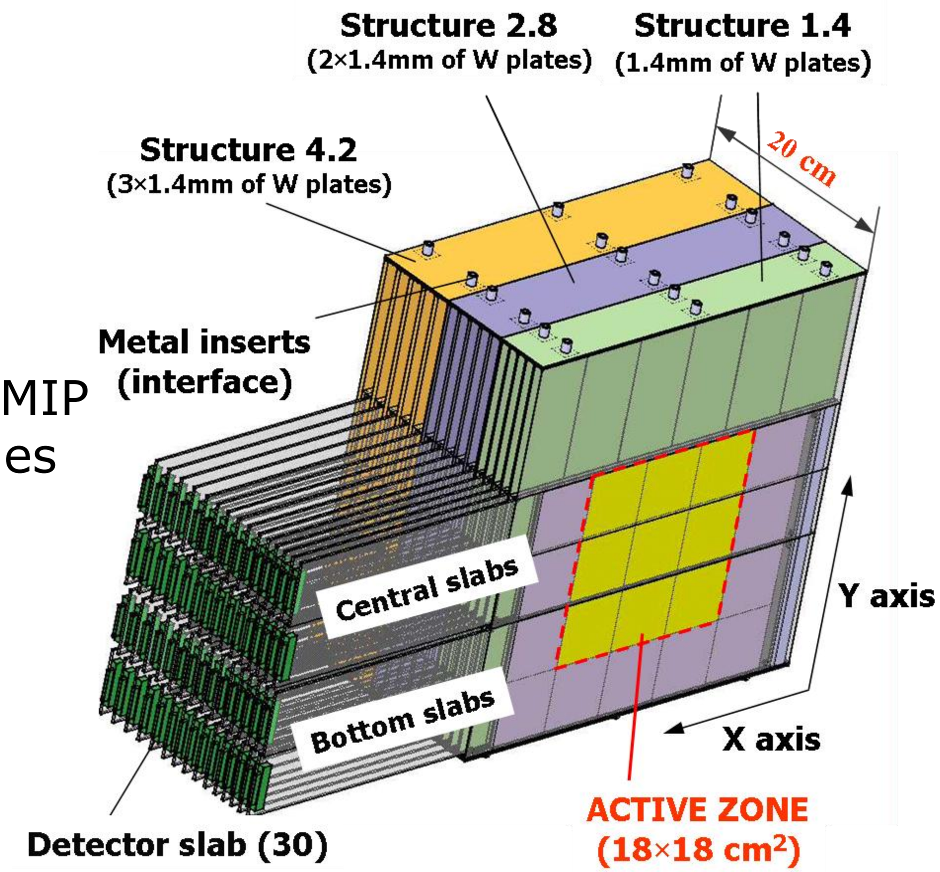
10x10 mm2 reverse biased PIN diodes (~200 V)

12-bit ADC: dynamic range

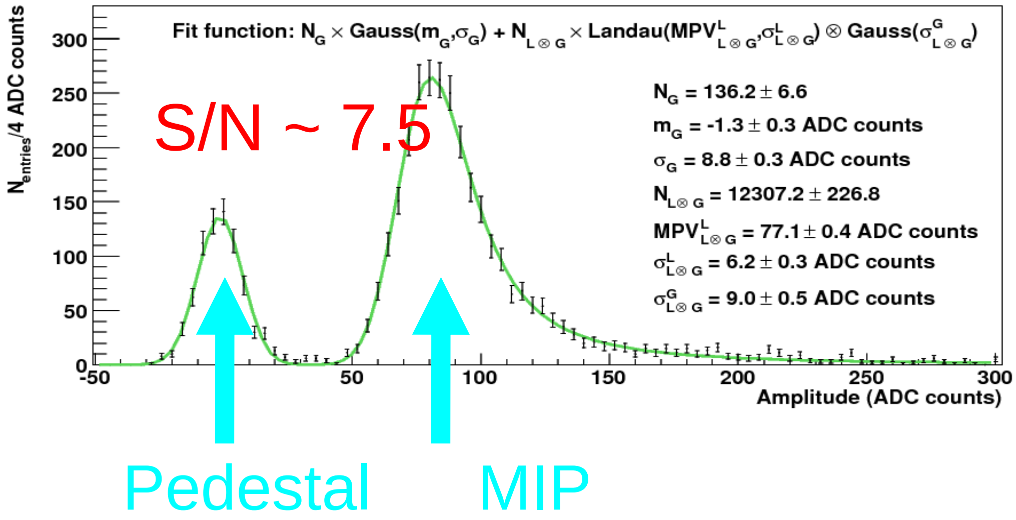
0.5 -> 500 MIP

24 X0 in all

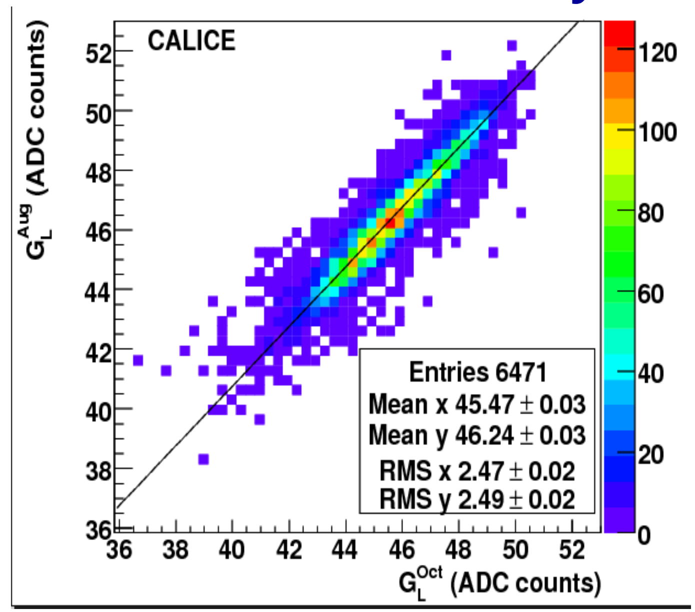


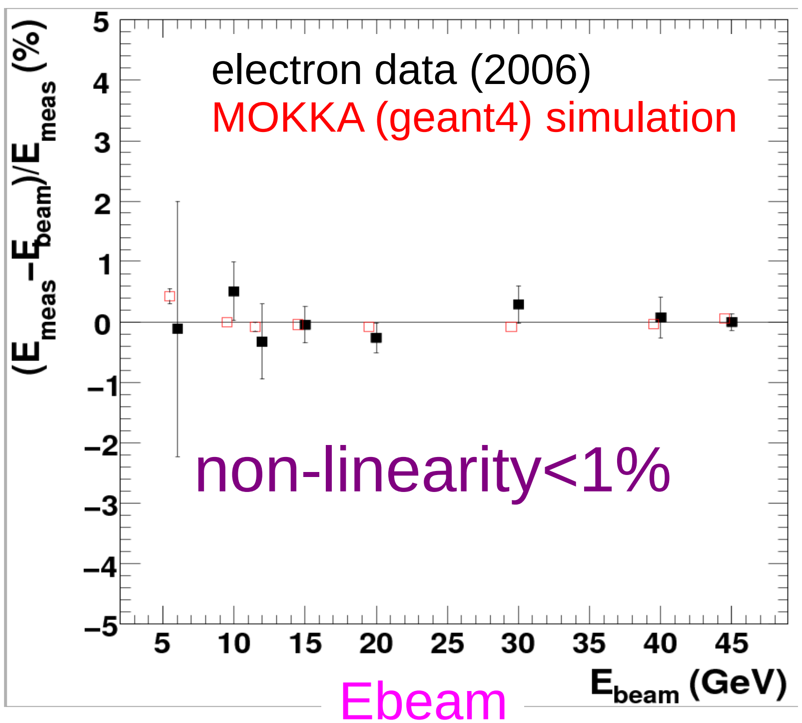


Calibration stability

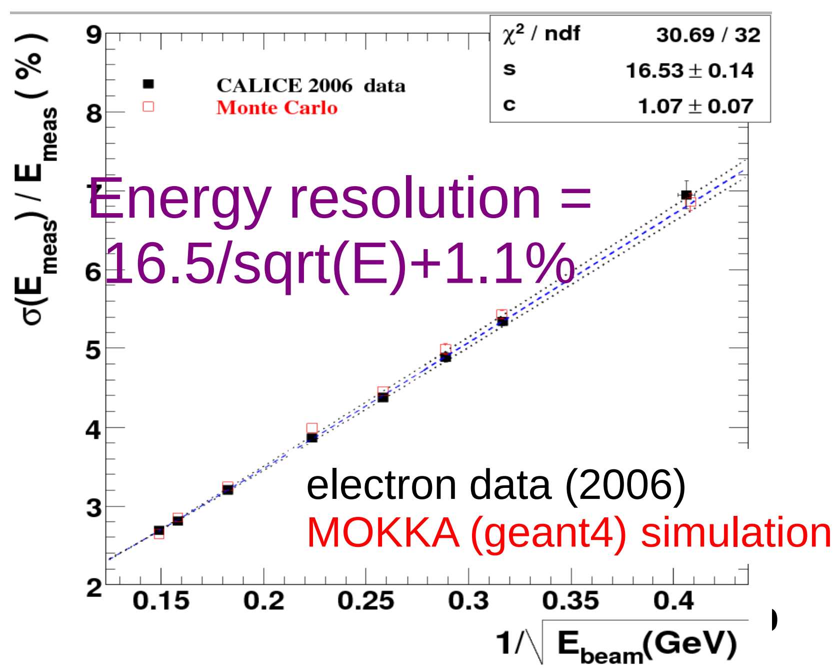


Calibration # 1



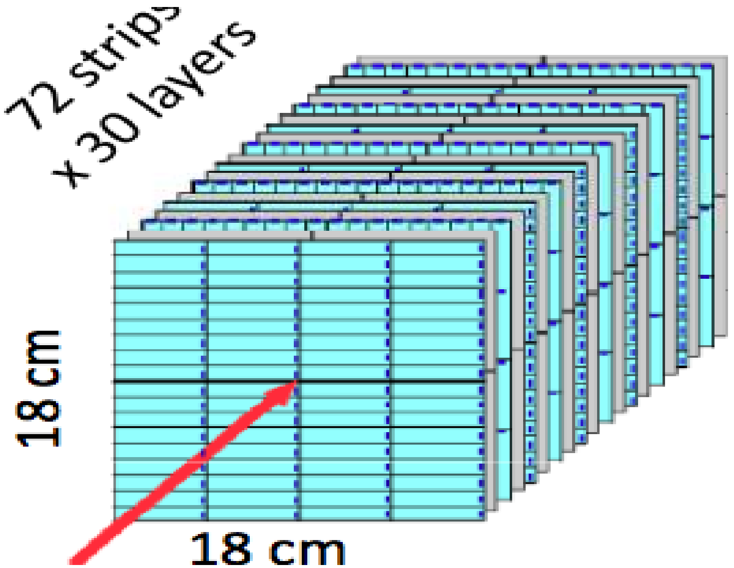


Calibration # 2

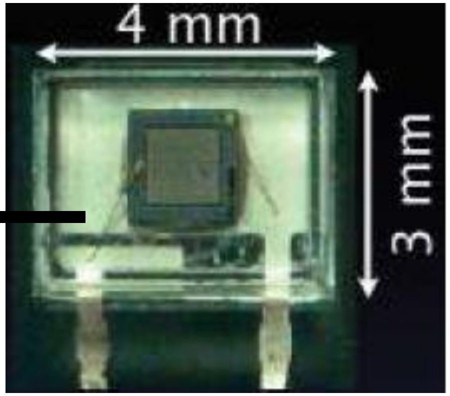


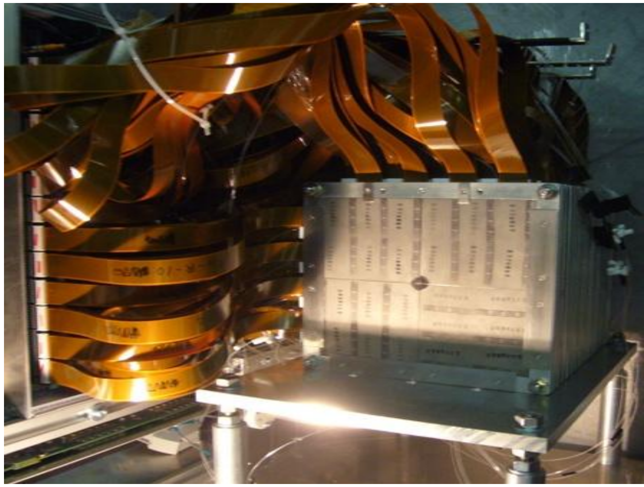
Electromagnetic Calorimeters : Scint-W

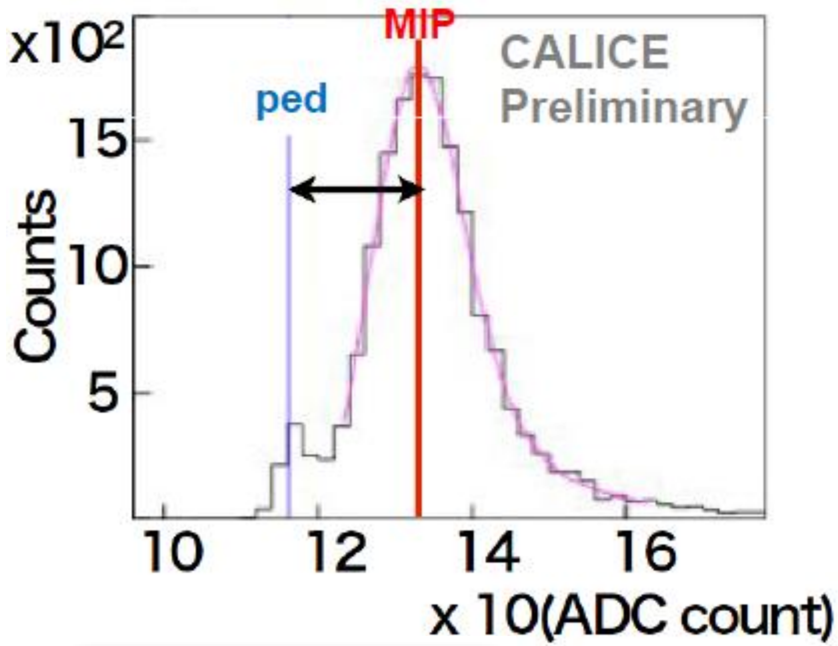
- Sandwich structure with scintillator-strips (3 mm) and tungsten layers (3.5 mm).
- Extruded scintillator with WLS fibers read with the MPPC.
- Strips are orthogonal in alternate layers (X-Y layers).
- 72 strips x 30 layers = 2160 channels

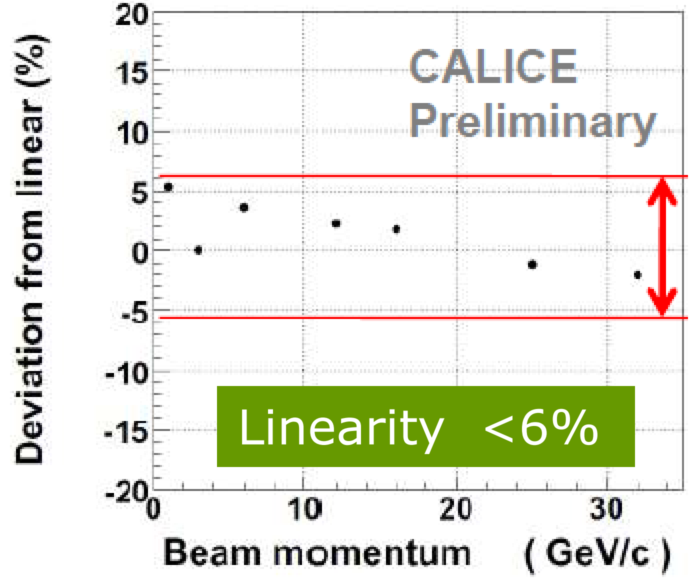


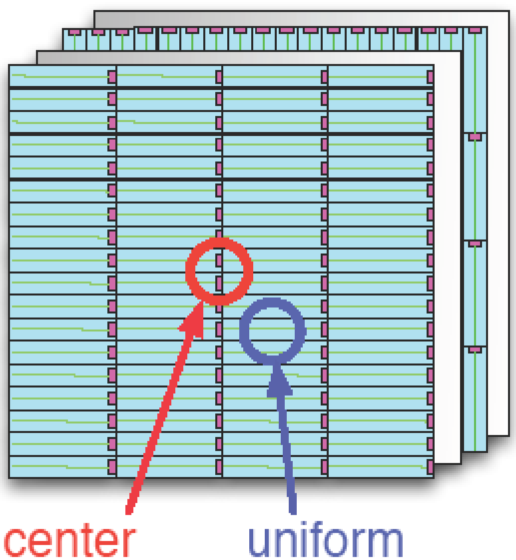
4.5 x 1 x 0.2 cm

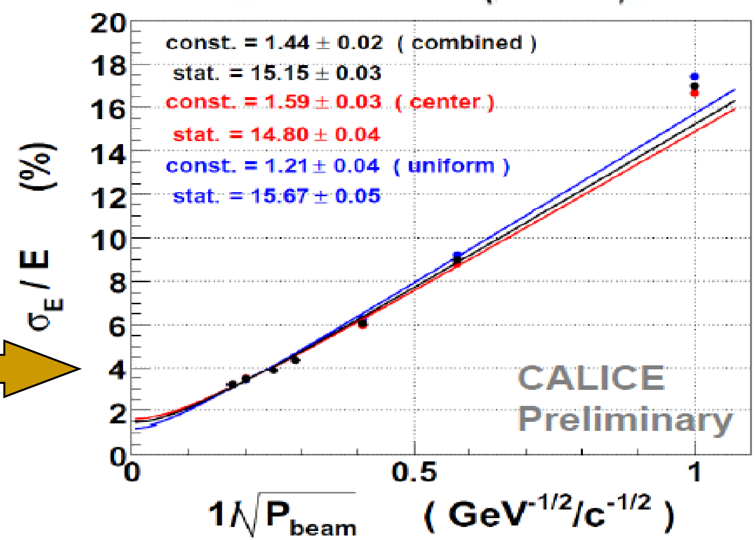








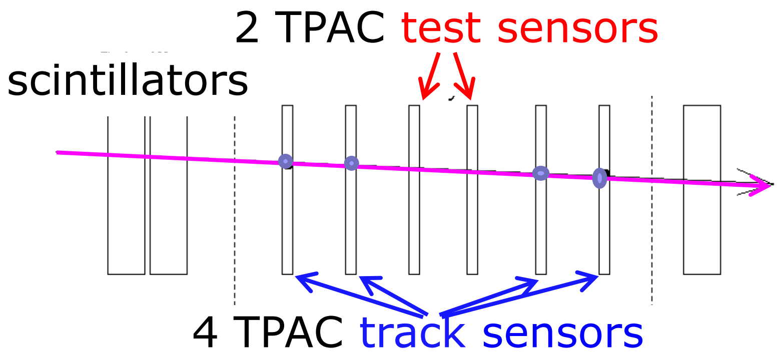




$$\frac{\sigma}{E} = \frac{(15.15 \pm 0.03)\%}{\sqrt{E}} \oplus (1.44 \pm 0.02)\%$$

Electromagnetic Calorimeters : DCAL

Aim : Substential cost reduction by using
Monolithic Active Pixel Sensors

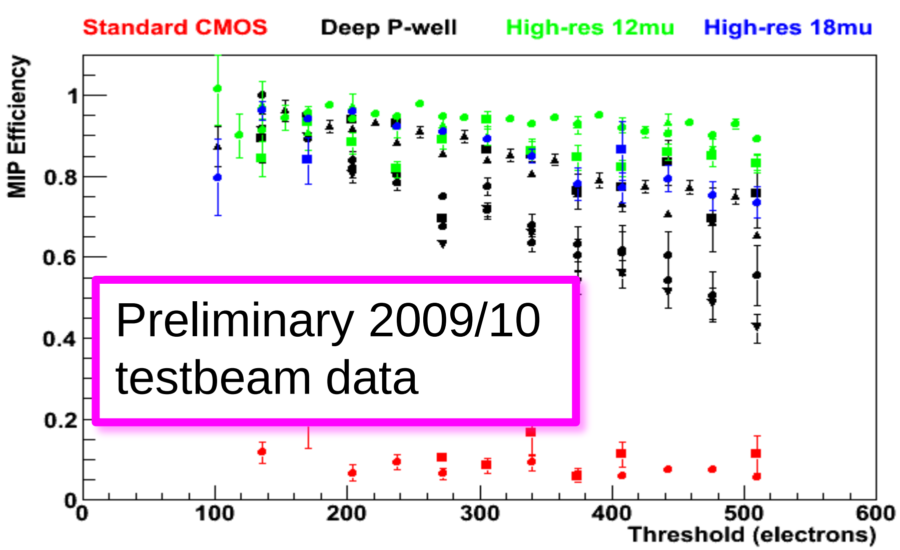


Project tracks to individual test sensors

Check for sensor hits as function of track (x,y) position relative to pixel centre

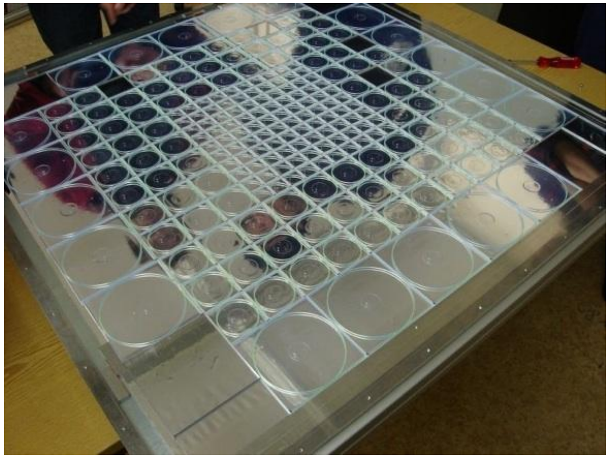
Determine efficiency by fitting distribution

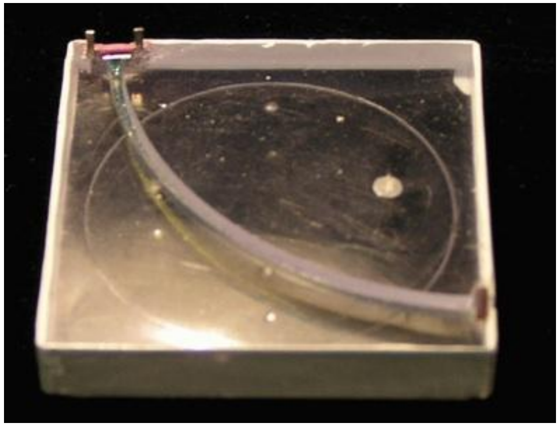
- Efficiency for 4 sensor variants, from CERN (Aug.'09, 120 GeV p) and DESY (Mar.'10, 1-5 GeV e^-) testbeams
- Standard CMOS sensors have low efficiency due to signal absorption by circuit elements
- Deep p-well (INMAPS) reduces signal absorption, raises efficiency by factor ~5
- (12mm) high-resistivity epitaxial layer raises efficiency by *further* factor ~2

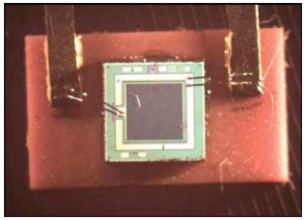


Hadronic Calorimeters : Scint-Fe

- 38 steel layers of 2cm each, 5.3 λ_{int}
- 7608 tiles with **SiPM**s ➔ Analogue readout
- 100 3x3 cm^2 tiles, then 6x6 cm^2 and 12 x12 cm^2
- Light collection via WLS fiber
- Followed by a Tail Catcher 5x100 cm^2 strips 6 λ_{int} in 16 layers

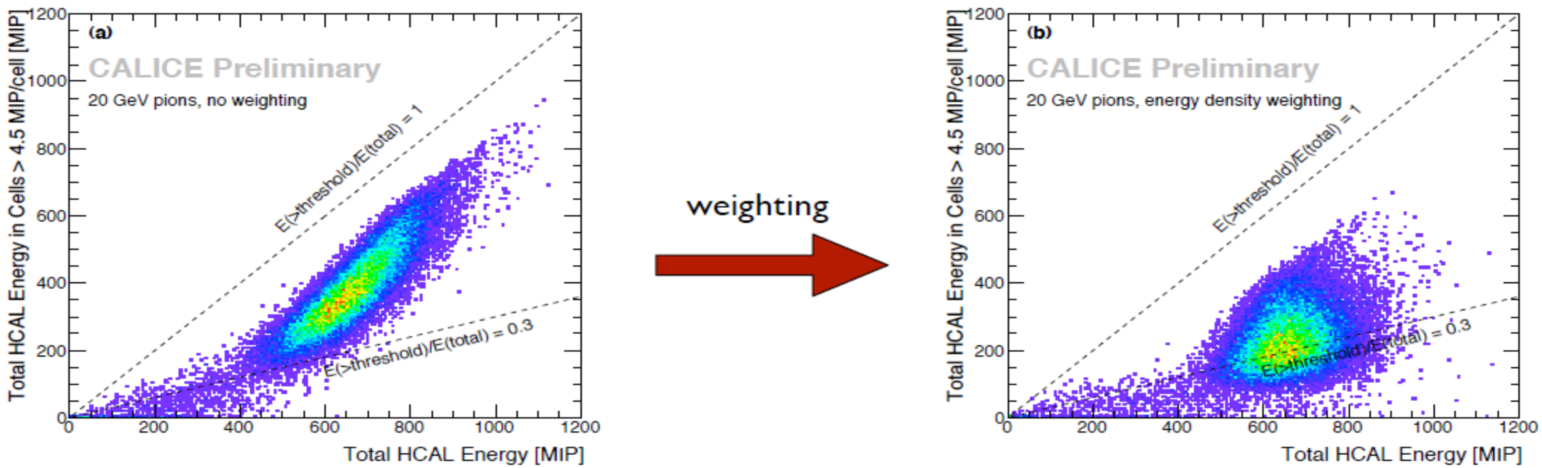


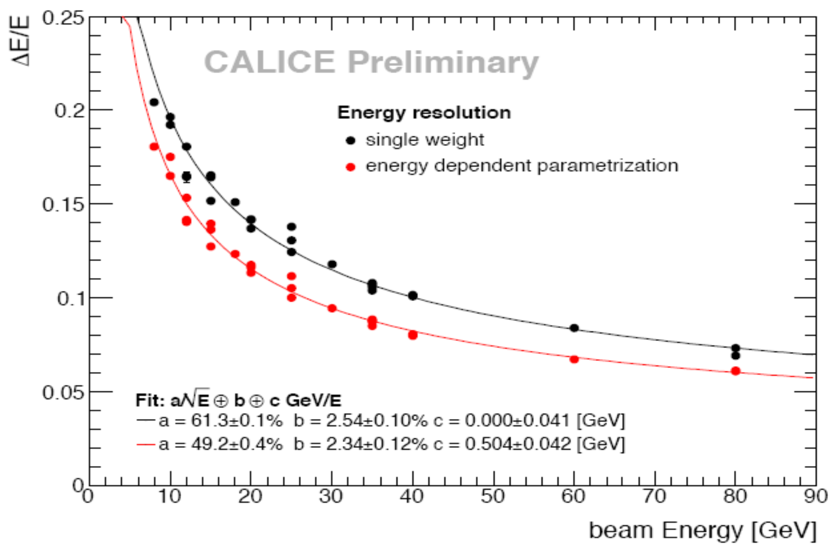


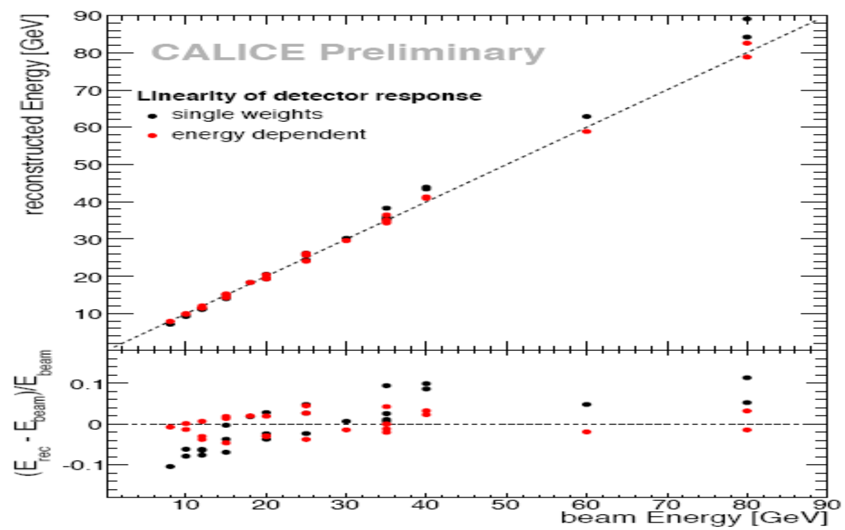


SiPM

High granularity of AHCAL allows for software compensation
Ex: EM part of the shower is more dense →cells with higher energy are associated to lower weight (e/$\pi \cong 1.3$ in AHCAL).

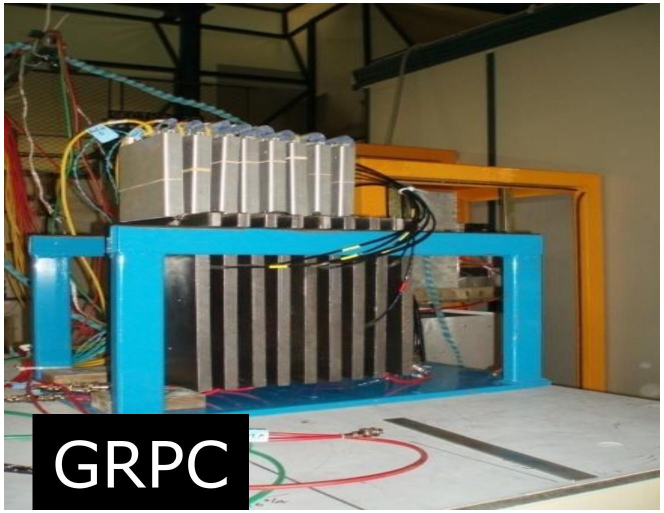




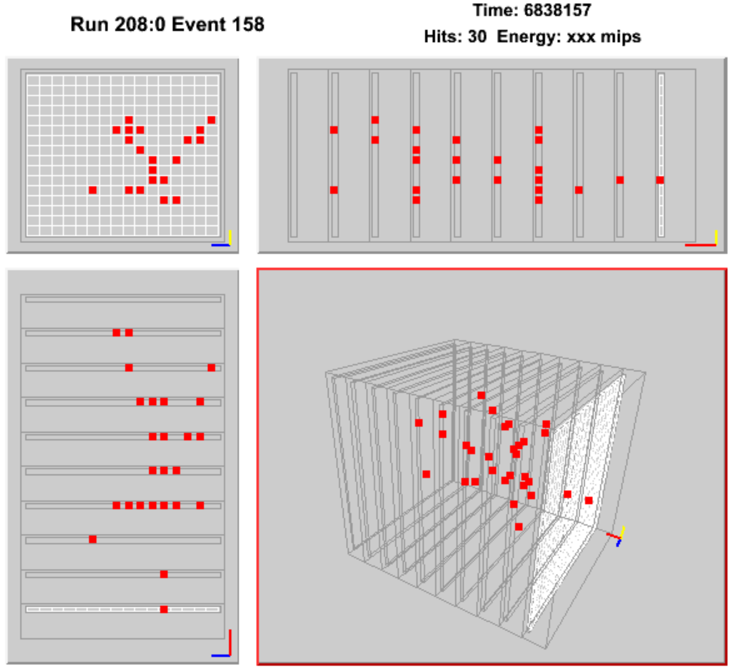


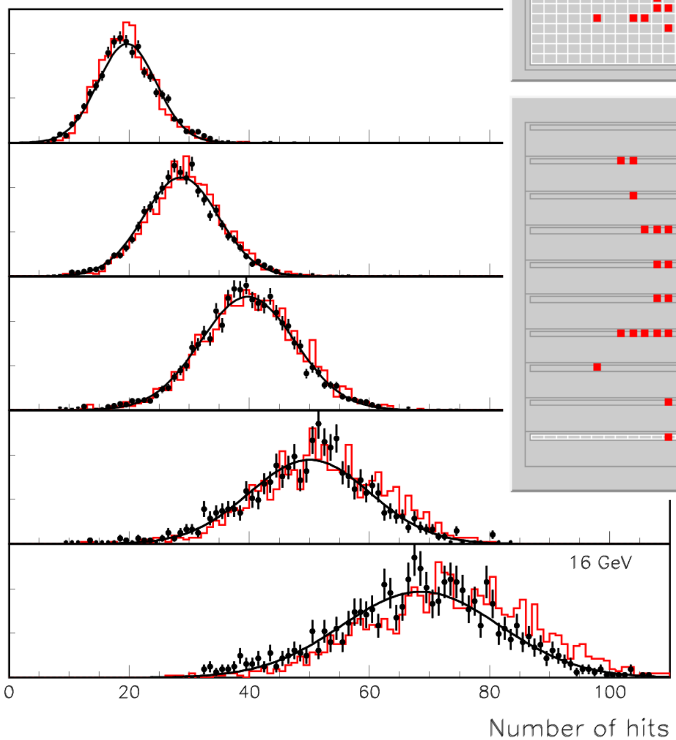
Hadronic Calorimeters : gas-Fe

Gas detectors provide excellent homogeneity
They allow higher granularity and reduced neutron sensitivity
Equipped with digital or semi-digital they are less affected by dE/dX fluctuations. They allow higher granularity.
Small prototypes with different sensitive media: GRPC, GEM, Micromegas as sensitive medium were successfully built and operated

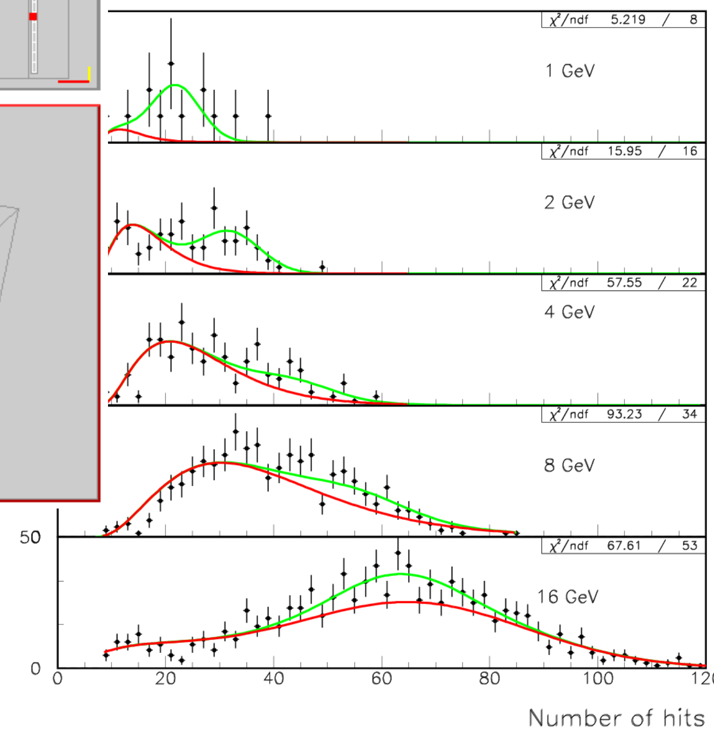


Results obtained with small digital HCAL testbeam confirm expectation from simulation





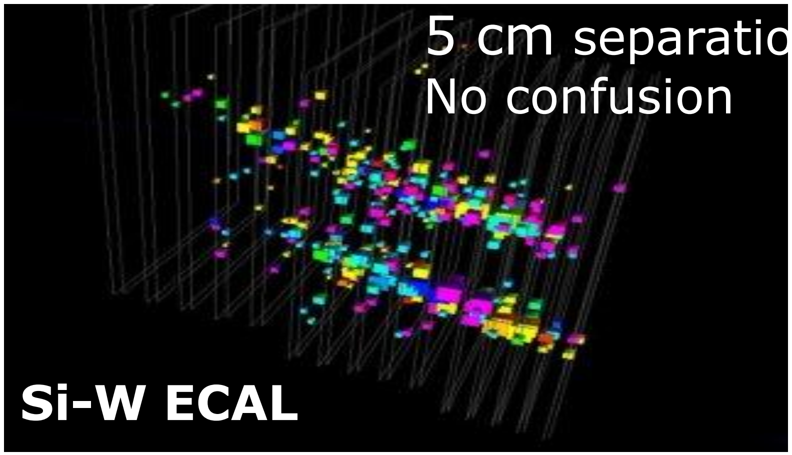
Response to positrons

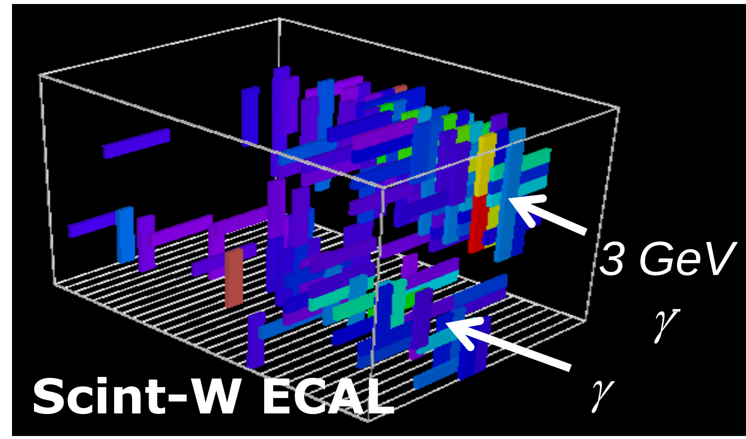


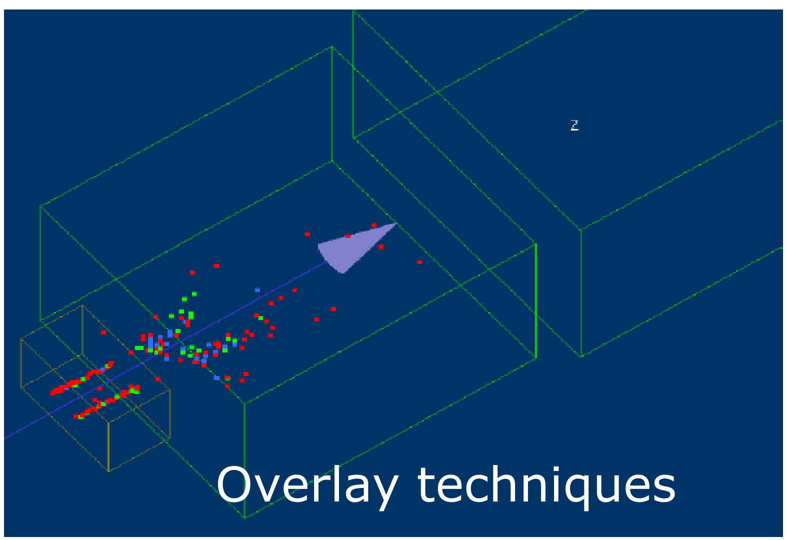
Response to pions
Fit to 2 components
- Pions (from MC)
- Positrons (from MC)

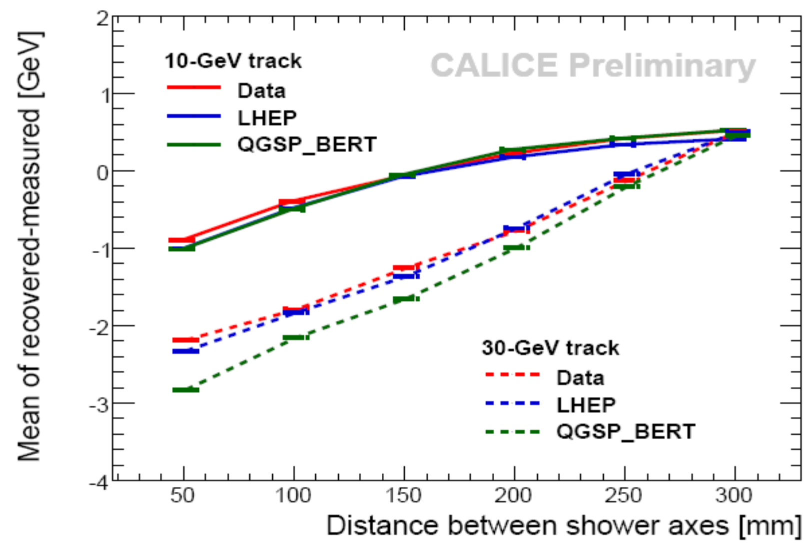
Lessons from Calice Testbeams

High granularity allows for particles separation and PFA application

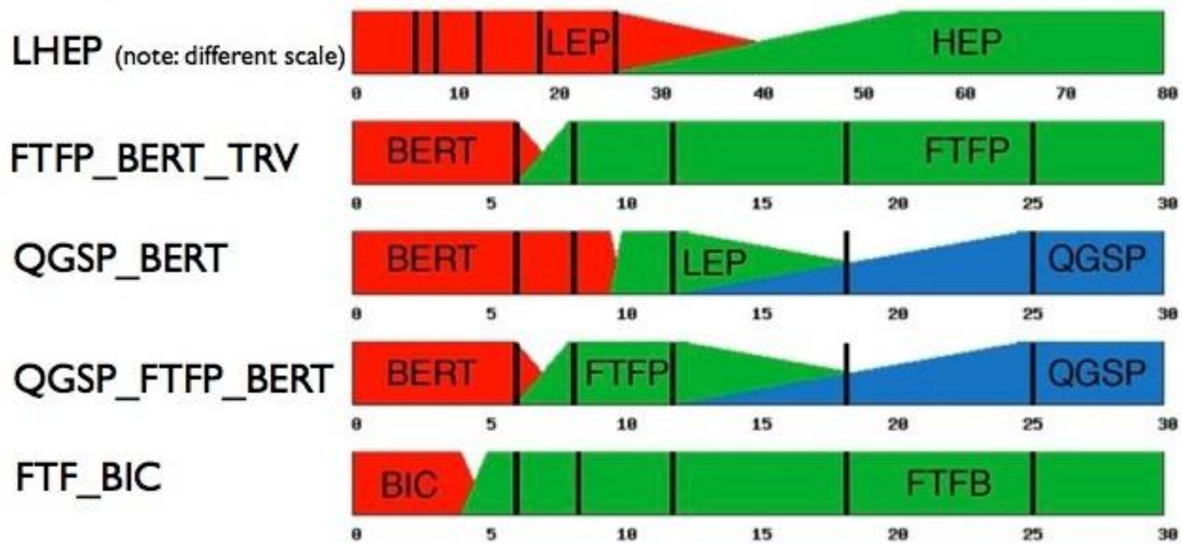








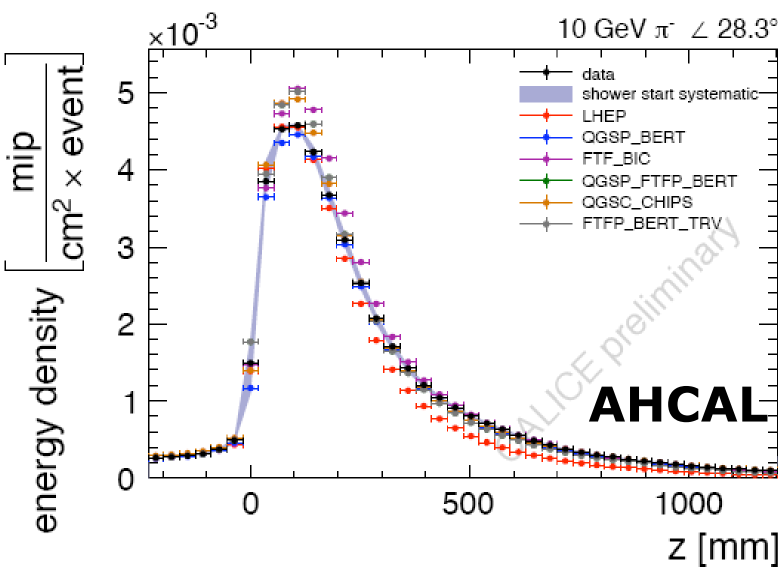
Two charged pions separation

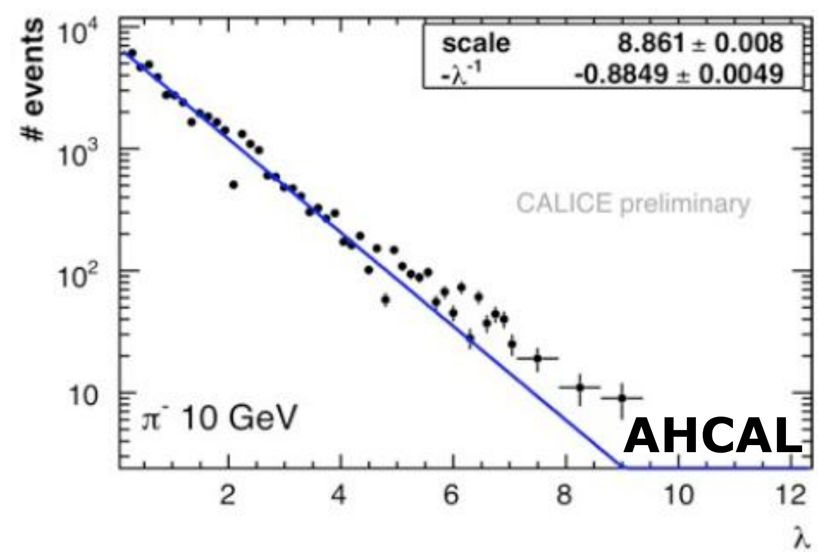


between models for certain

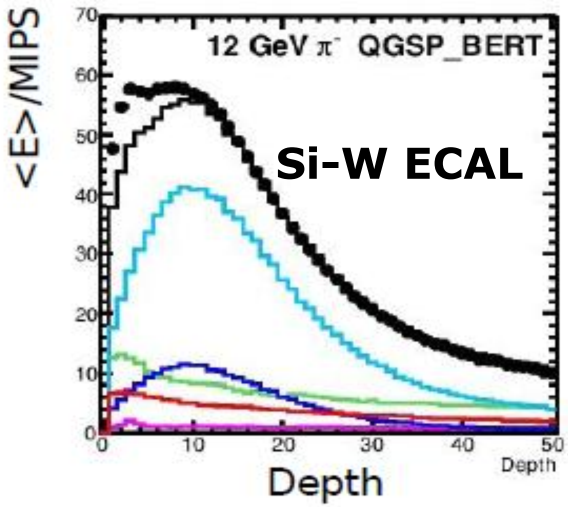
E [GeV]

Hadronic shower longitudinal profile: Important for containment



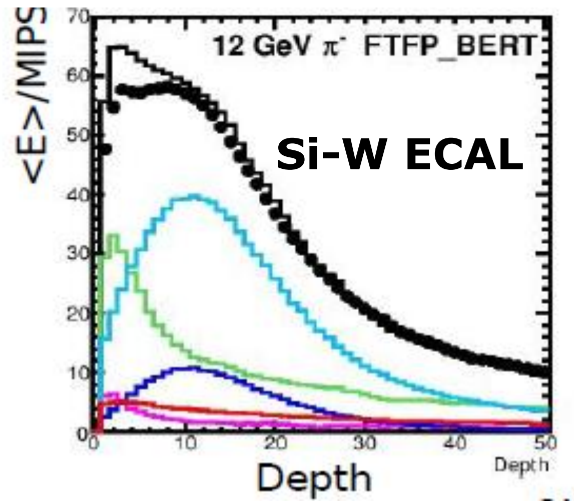


Hadronic shower transverse profile: Important for PFA

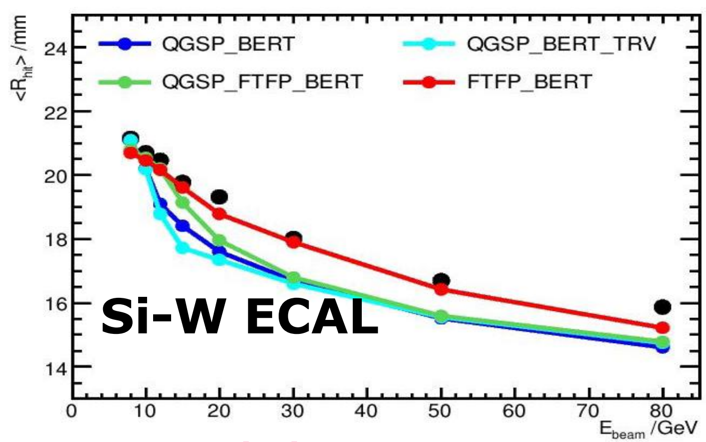


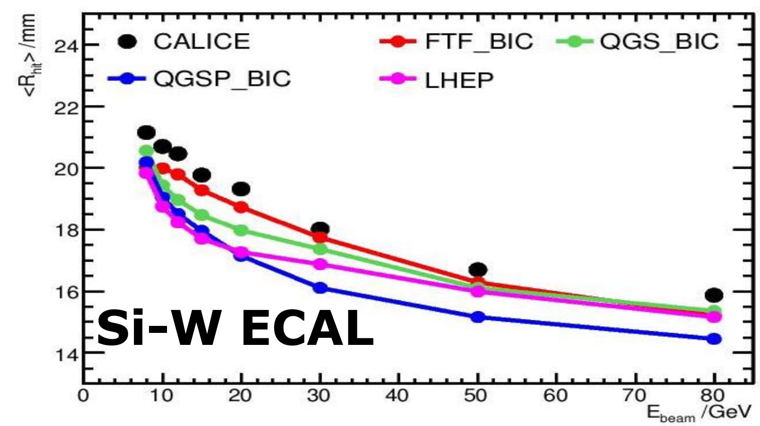
Shower Components:

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



Granularity allows more sensitivity to different shower components

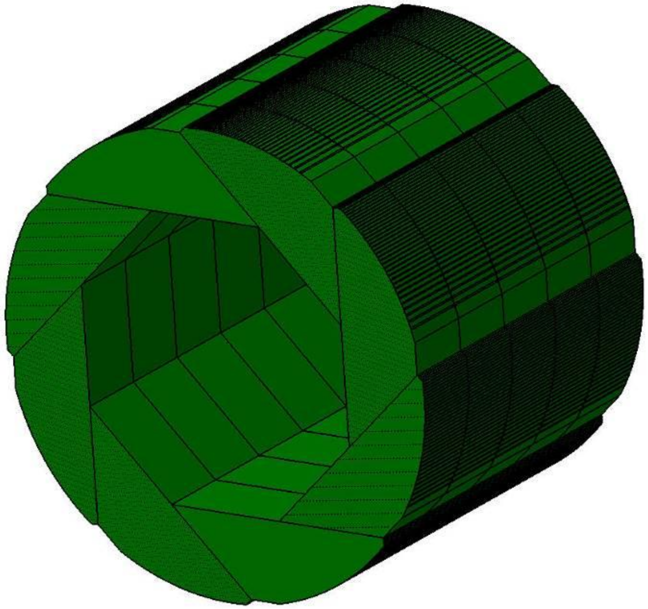


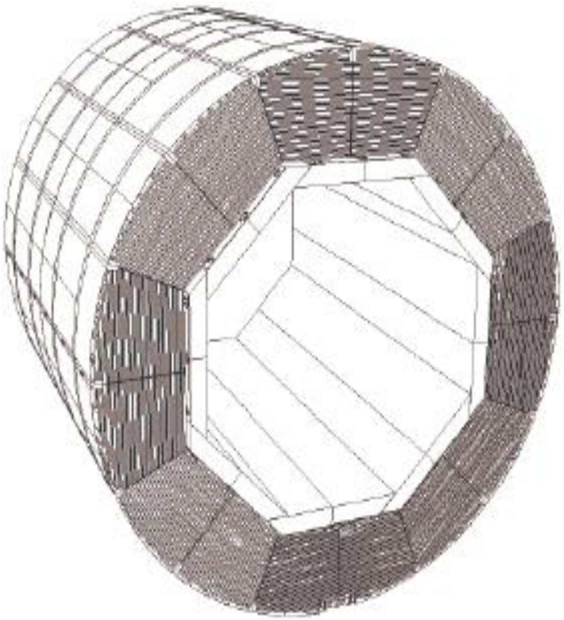


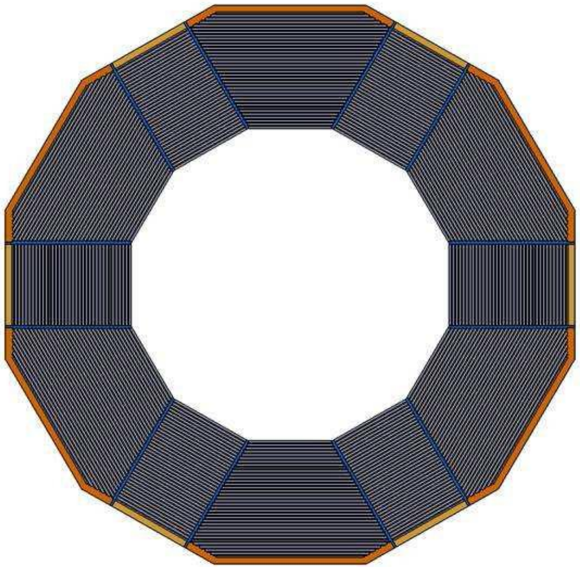
Bertini model seems the most adequate at low energies
While at high energy data favour Fritiof model.

Towards Technological prototypes for future Linear Colliders

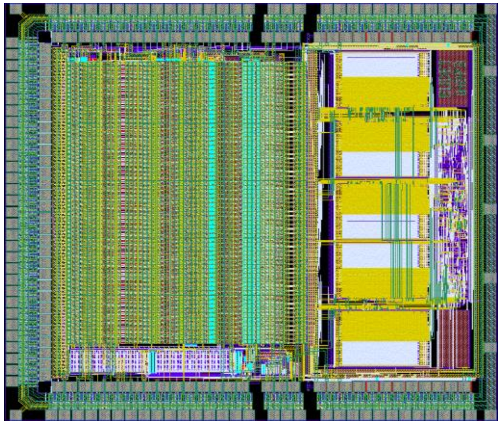
Goals: To prove the capability to build large, efficient and hermetic calorimeters with low consumption readout electronics and robust mechanical structure. New prototypes are being conceived and built





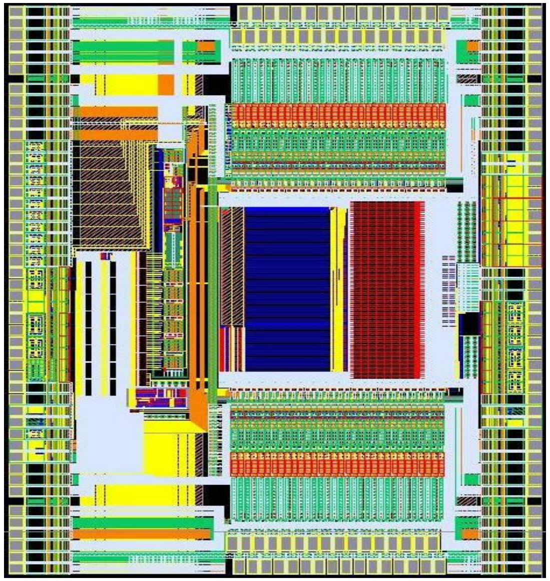


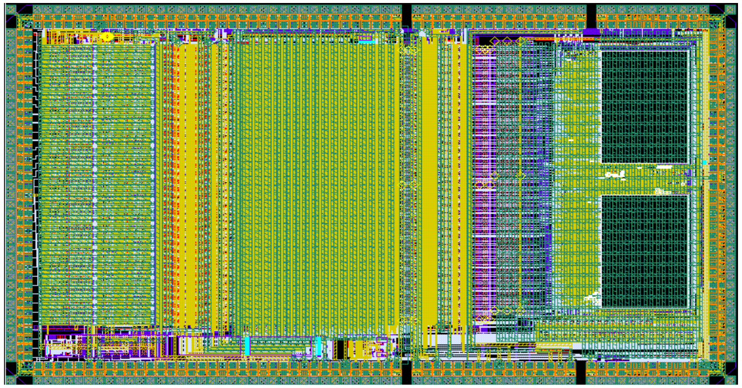
ASICs are developed within the CALICE collaboration for the technological different technologies.
Some of them are already produced to equip the first technological Prototypes.



HARDROC
64-ch
Power-Pulsed
SDHCAL

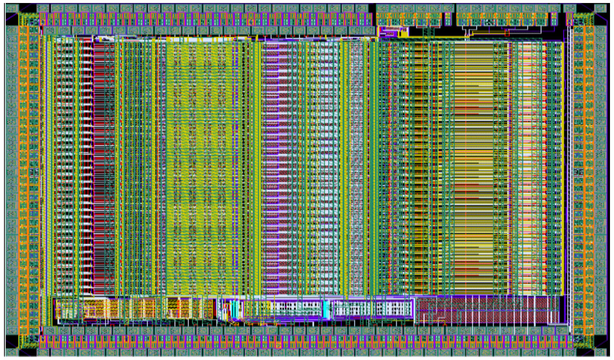
DCAL
64-ch
DHCAL





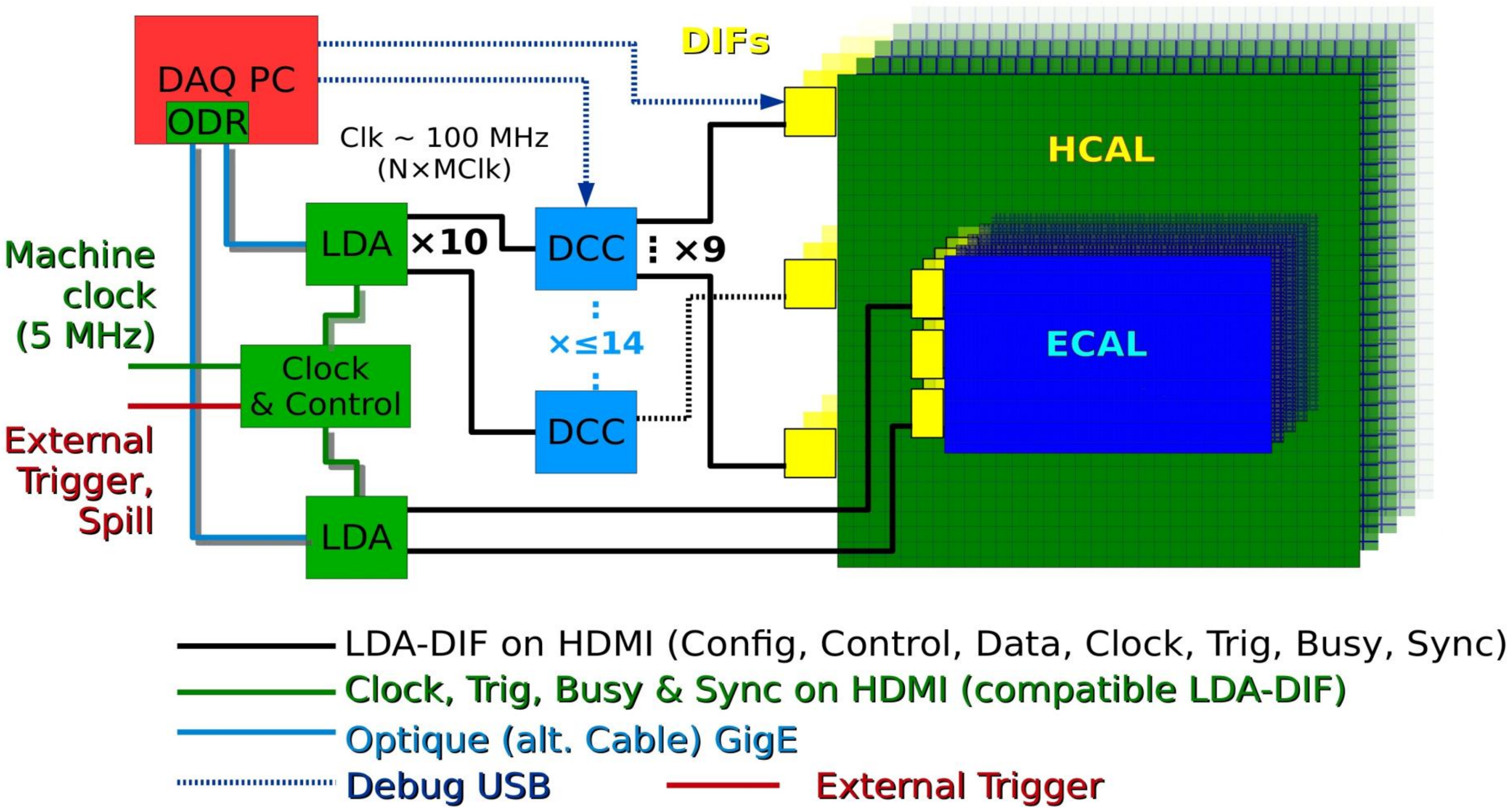
SPIROC
36-ch
PP
AHCAL

SKIROC
36-ch
PP
ECAL



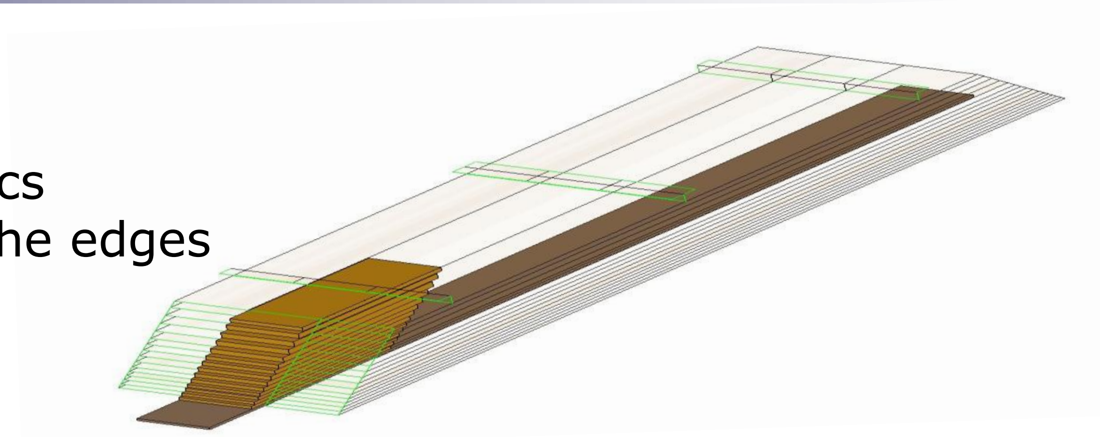
But also others to come soon: MICROROC (micromegas)

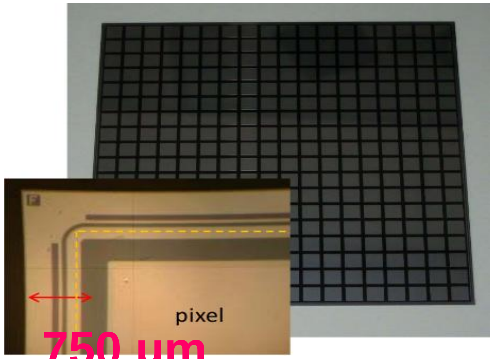
An **acquisition system** is being developed and will be used by all the technological prototypes. Cards are developed and currently tested



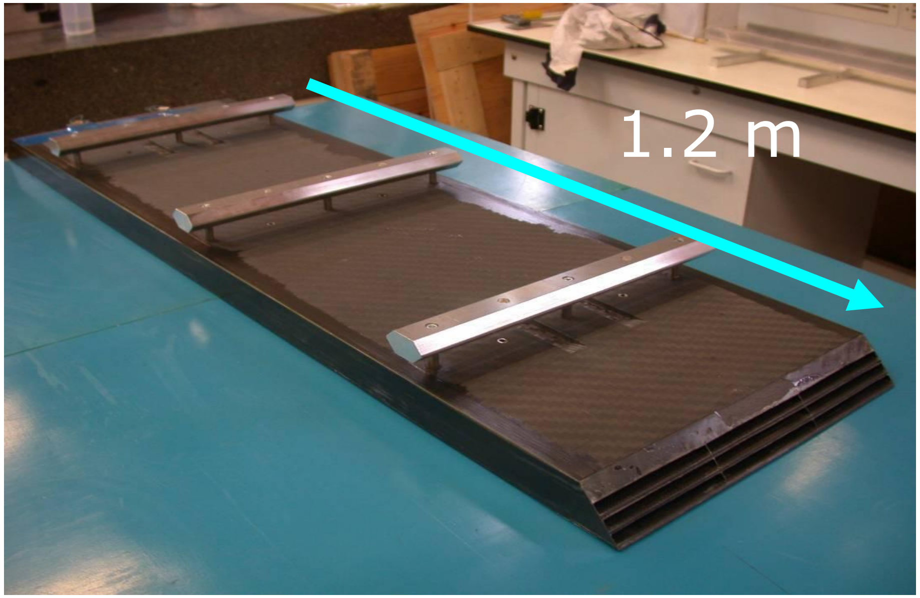
ECAL PROTOTYPE

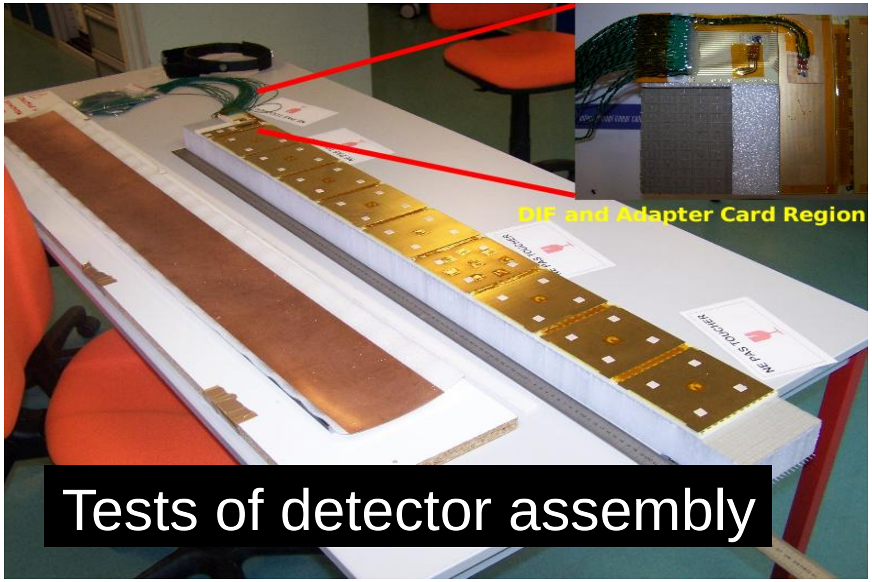
Embedded Front End electronics
Power and cooling system at the edges



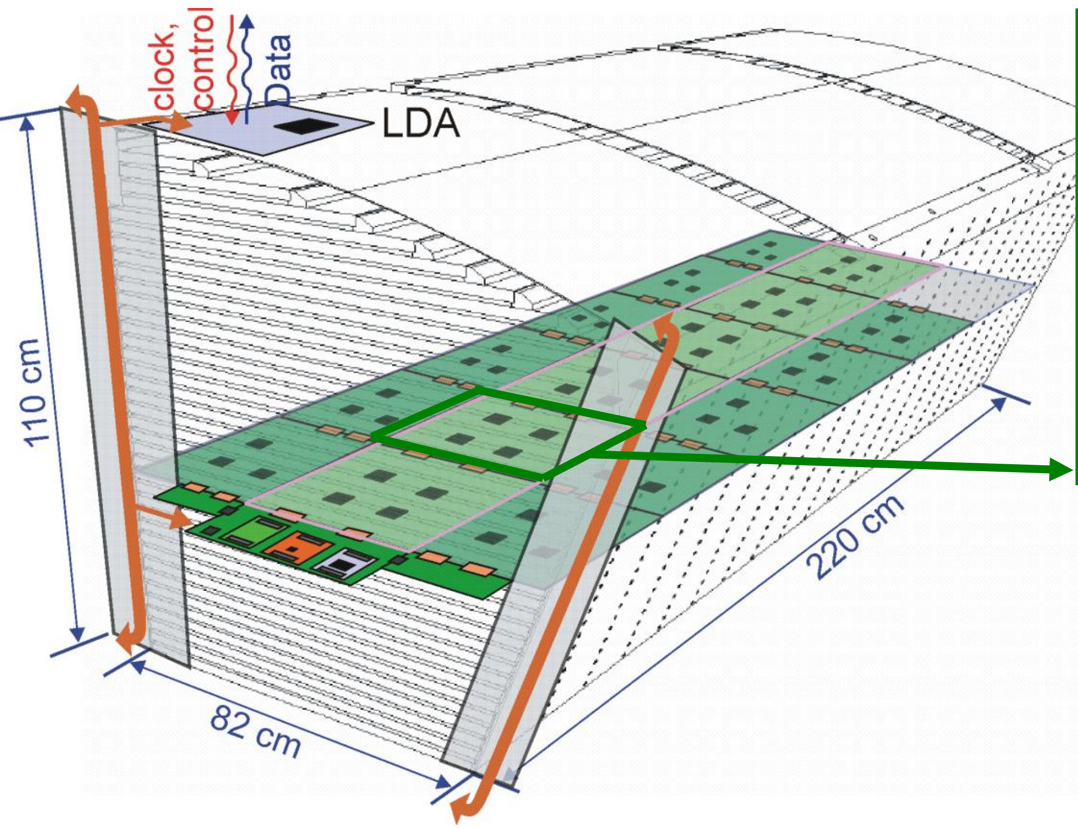


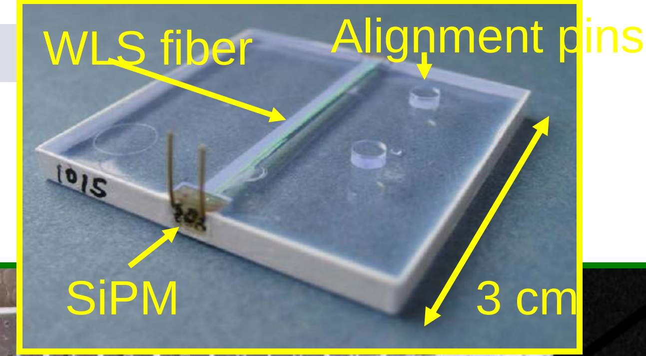
New sensor design
Segmented guarding rings
300 micron thickness
Dynamic range :0.5 -> 2500 MIP

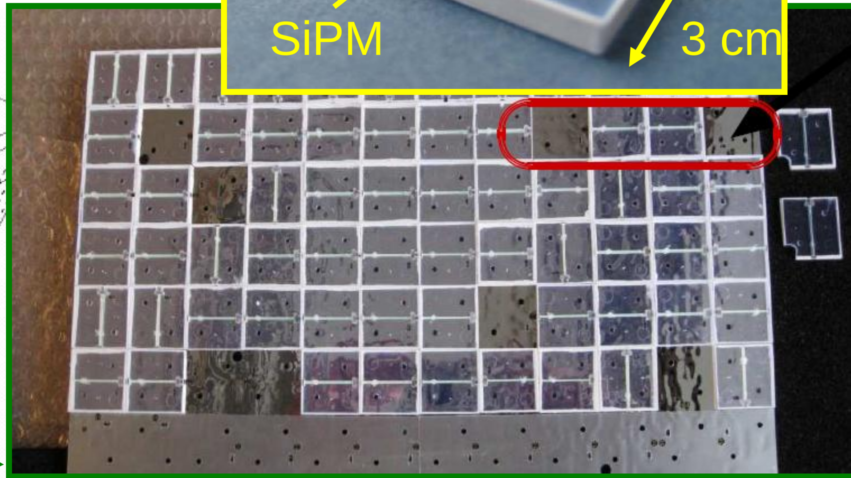


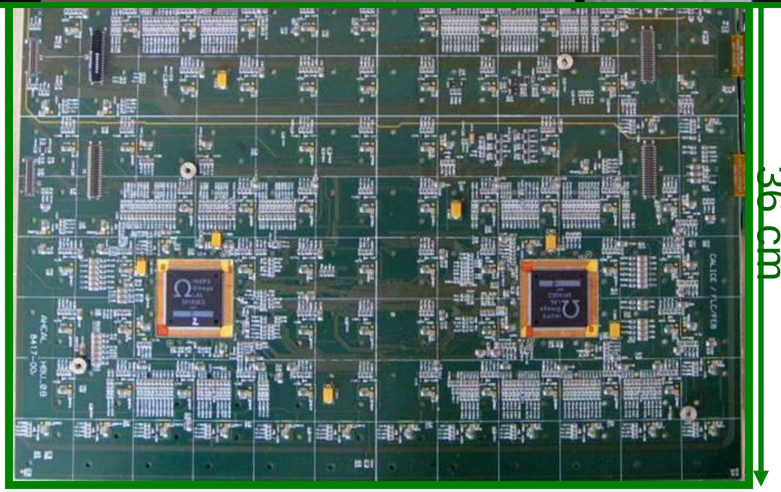


AHCAL PROTOTYPE









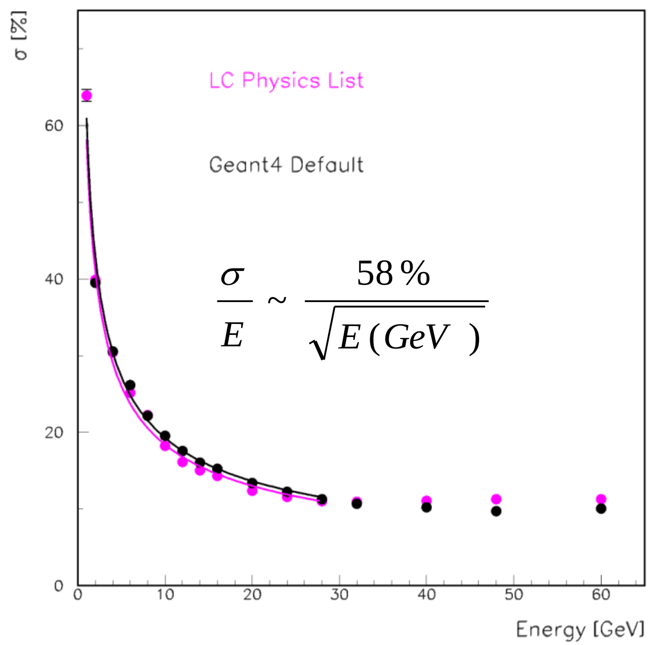
- Front End electronics integrated in active layer
- made of interconnected cassettes (36x36 cm)
- power and calibration modules at barrel edge
- 2.2m long communication lines in the layer

PCB board with 4 SPIROC chips connected to 144 scintillator tiles with SiPM readout

DHCAL PROTOTYPE

38 active layers each 1 x 1 m^2
~10,000 1 x 1 cm^2 readout pads per layer
Embedded electronics
~350,000 readout channels in total

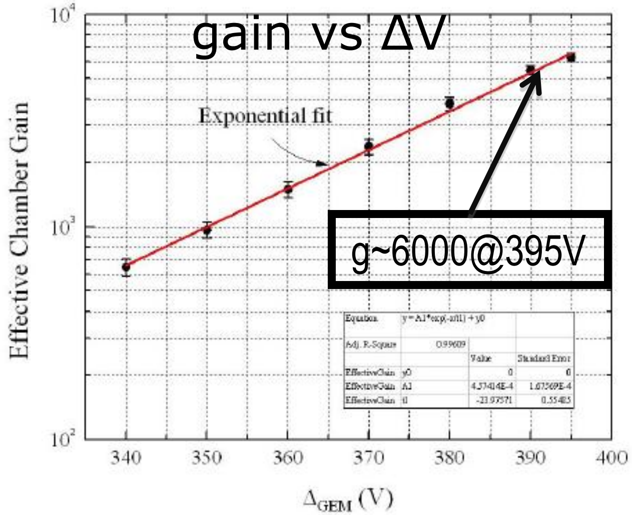
1st cassette undergoing tests

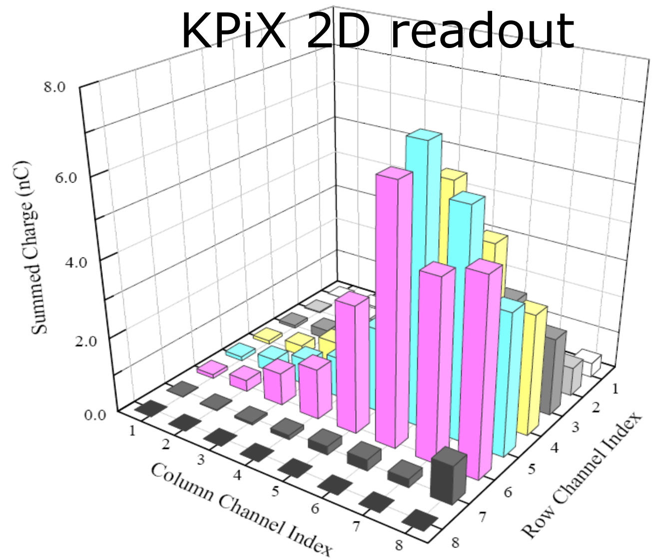


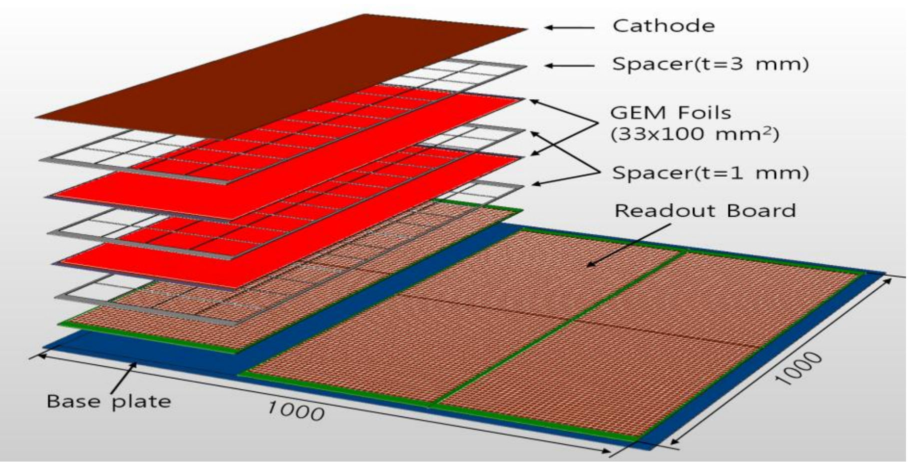
$1m^3$ Prototype is being Built. Testbeam in fall 2010 using the mechanical structure of the physics AHCAL prototype

The DHCAL prototype will also include few layers with the GEM Technology and both KPiX analog and DCAL digital readout chips

30cmx30cm chamber characteristics understood with KPiX.
The first 1m² GEM detector is designed and being built.





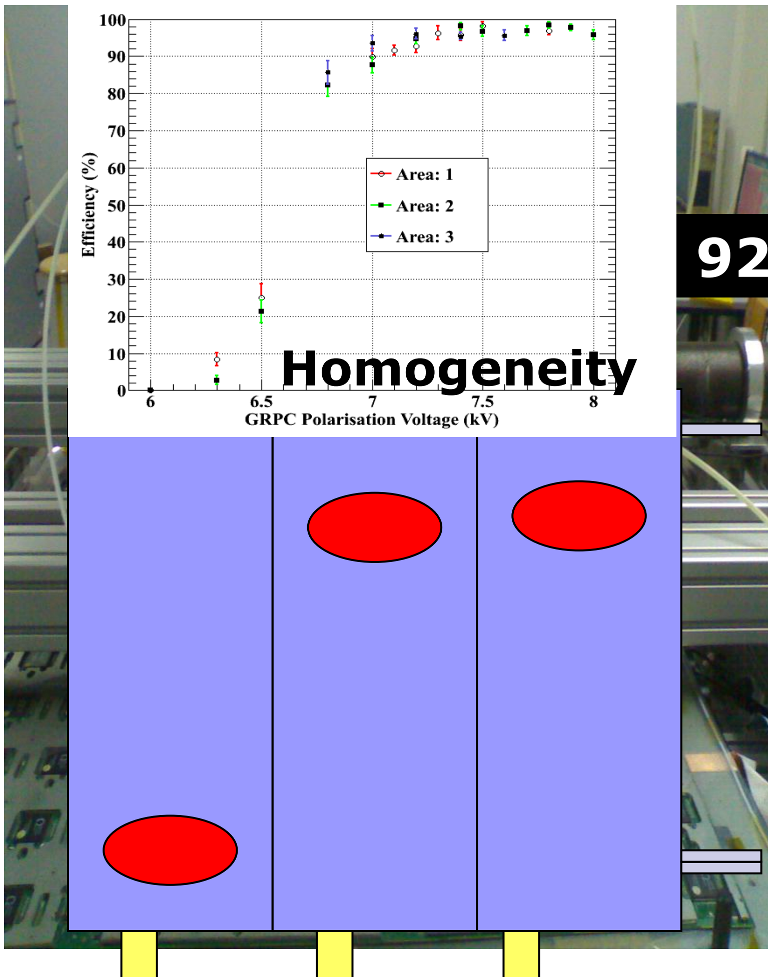


Design for Large Area GEM detector frames

SDHCAL PROTOTYPE

Aim: replacing the digital by semi-digital readout to improve on energy resolution at high energy and coming as close as possible to ILC requirement

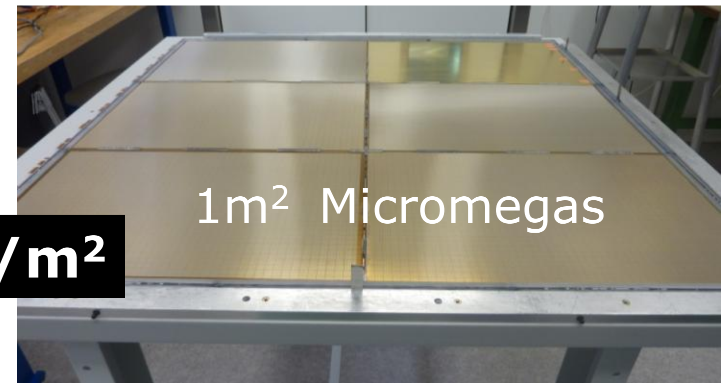
Two technologies are followed: GRPC and Micromegas

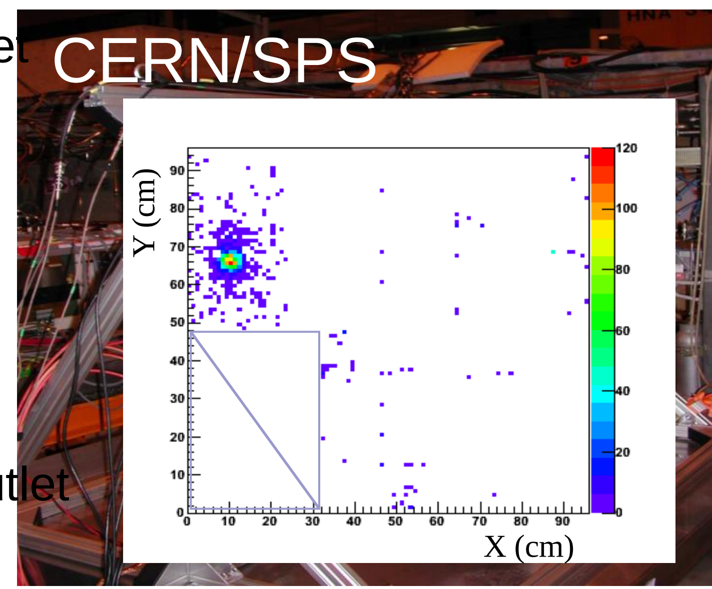


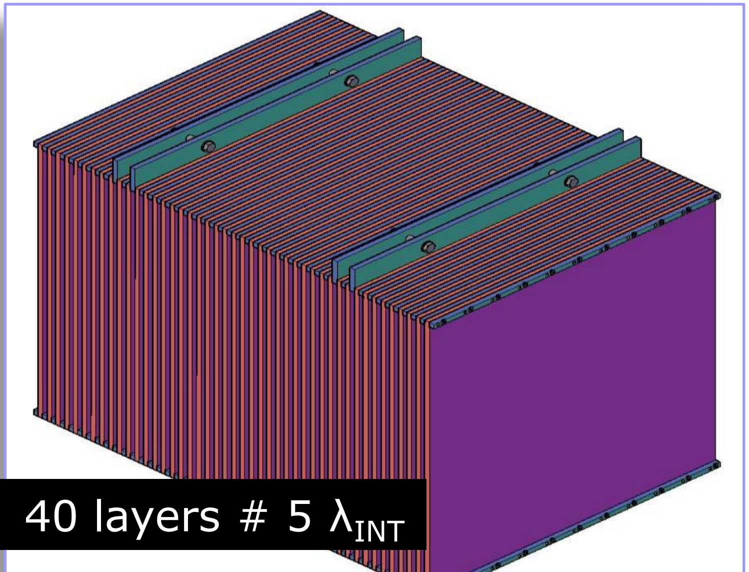
9216 ch/m²

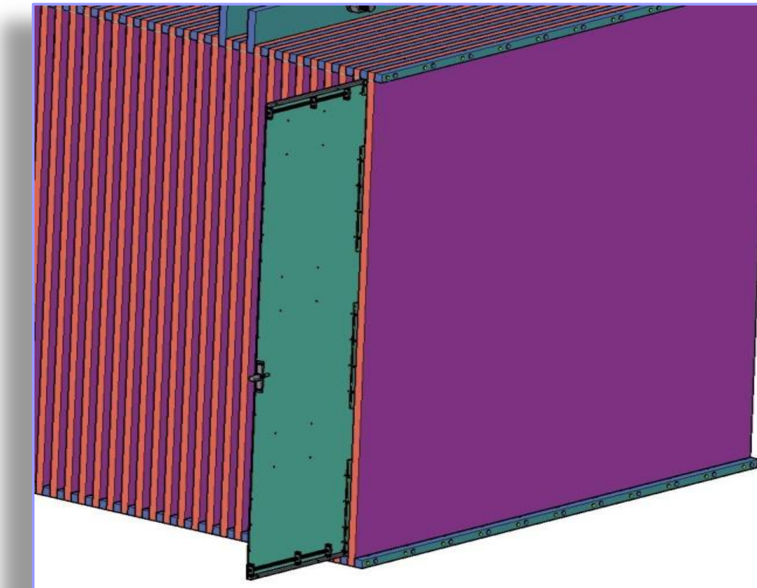
Gas inlet

Gas outlet



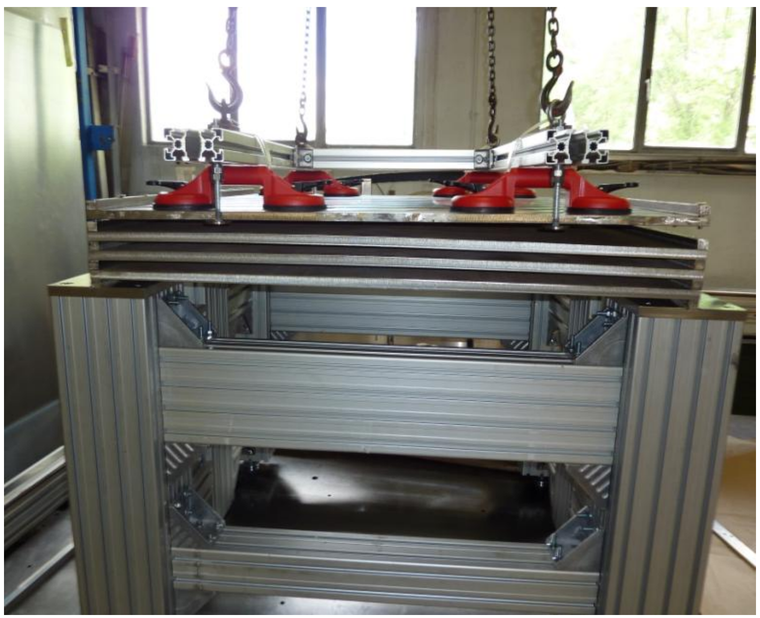


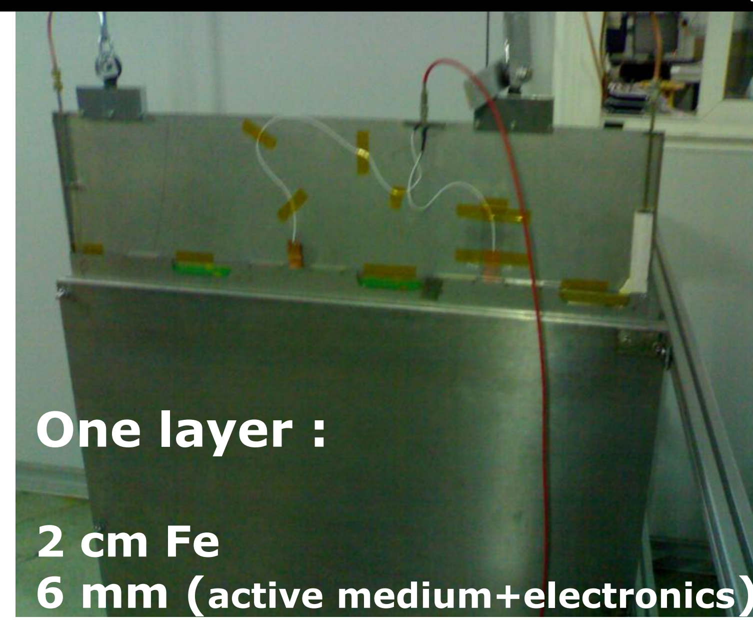




40 layers # 5 λ_{INT}

Self-supporting structure as the one expected in ILC is conceived and being built





One layer :

2 cm Fe
6 mm (active medium+electronics)

Tungsten option

Particle flow can also be a promising option at CLIC energies(0.5-3 TeV).

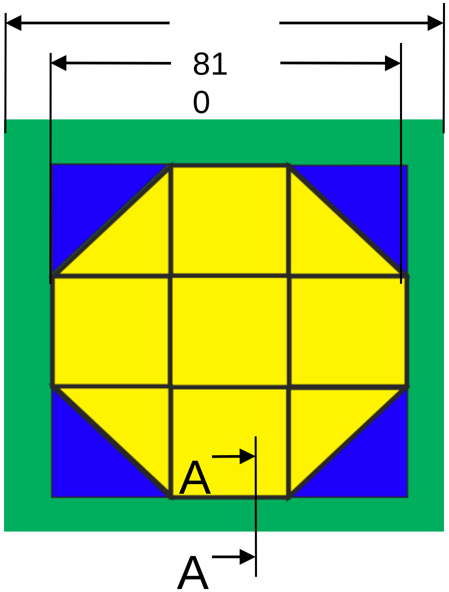
Performance limitation due to leakage
→ HCAL with > 7 λ_{INT} needed

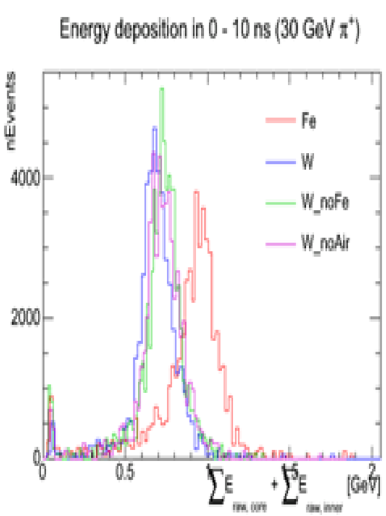
Tungsten absorber can be the solution

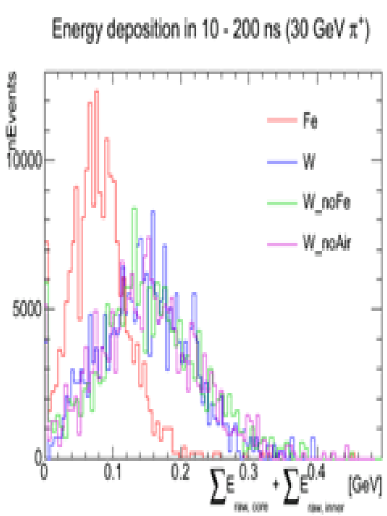
- Cost-competitive with larger coil
- More neutrons→ Timing is an issue

A mechanical structure of 32 tungsten plates is being built at CERN.

Test beam validation with **scintillator** and **gaseous detectors** to start in fall 2010

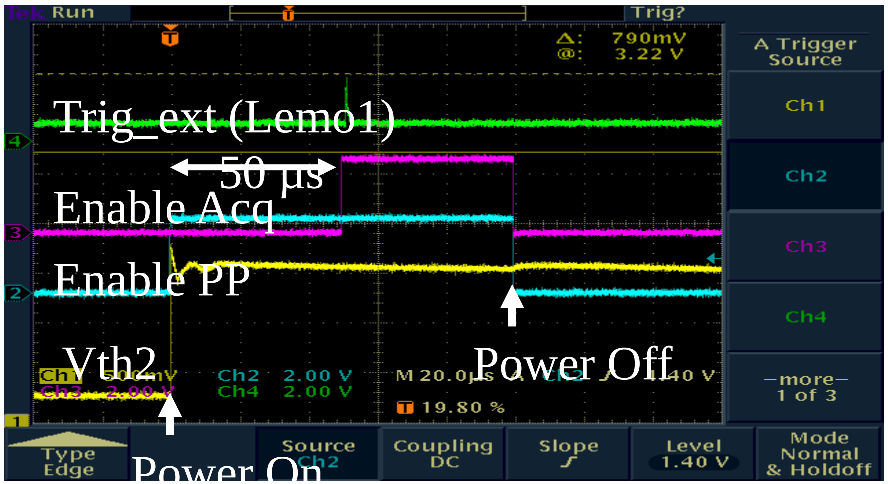


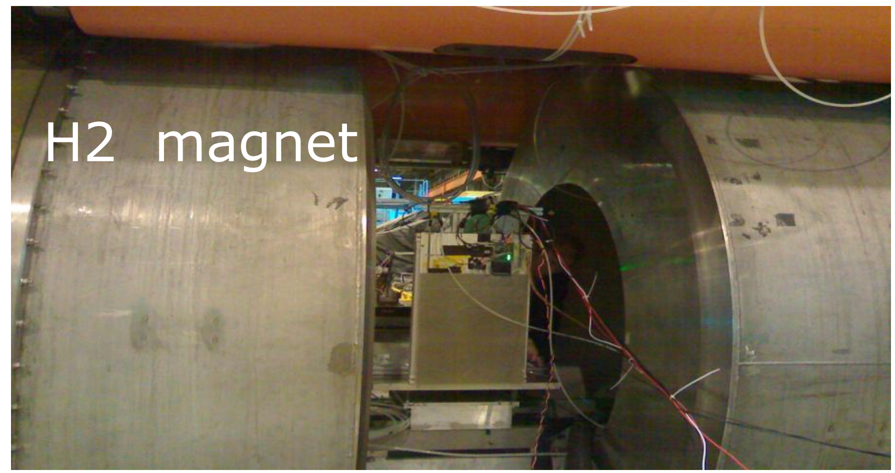


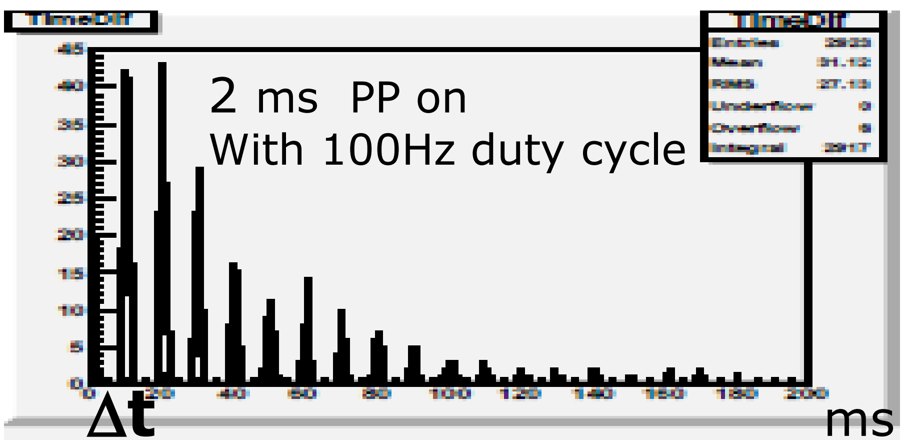


Technological concepts are becoming reality :

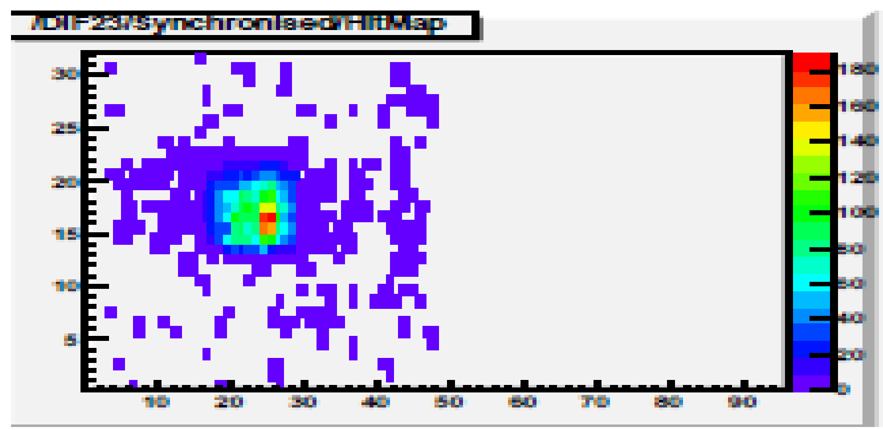
Power Pulsing was tested with a magnetic field of 3 Tesla and detector performance remains identical







Time difference of 2 consecutive evts



Beam shape in presence of the 3 Tesla field

Conclusion

- Calice prototypes were extremely useful to validate the concept of PFA-based high granularity calorimeters
- They provide an excellent tool to test the different hadronic shower models and sort them out
- Some PFA techniques have been successfully applied to separate showers created by closed-by particles
- Technological prototypes using different technologies are being conceived and built
- Next years will witness exciting studies of hadronic showers and development of PFA-related techniques