



Calorimetry for a Linear Collider

Silicon-Tungsten EM calorimeter

Daniel Jeans

Laboratoire Leprince Ringuet, Ecole polytechnique
for the CALICE collaboration

VCI 2010

Un



In2p3

Linear Collider goals

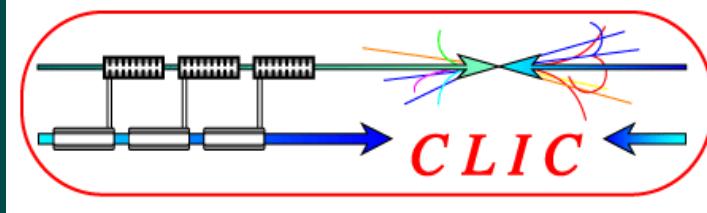
Detector requirements

Overview of CALICE activities

Silicon-W ECAL

Conclusions

Linear Collider goals



Precisely measure TeV-scale physics

Higgs boson physics - quantum numbers, couplings, rare decays

Threshold scans of new particle production

Loop effects of particles beyond kinematic reach

e+ e- linear colliders under study:

ILC: $90 \rightarrow 500$ GeV, Super Conducting RF acceleration

Relatively mature technology

CLIC: $\rightarrow 3$ TeV, two beam acceleration

Polarised beams – e.g. at ILC $e^- \sim 80\%$, $e^+ \sim 30\%$

Well defined initial state: energy, angular momentum

Clean, fully reconstructed final state

High precision measurements

LC detector

Massive new particles will often decay via W/Z/H bosons

Need to efficiently tag these bosons

leptonic decays ~ easy

hadronic decays → excellent jet energy resolution

3% resolution to distinguish W and Z, jet energies $\sim 40 \rightarrow \sim 100$ GeV
 $> \sim 2 \times$ better than current performances

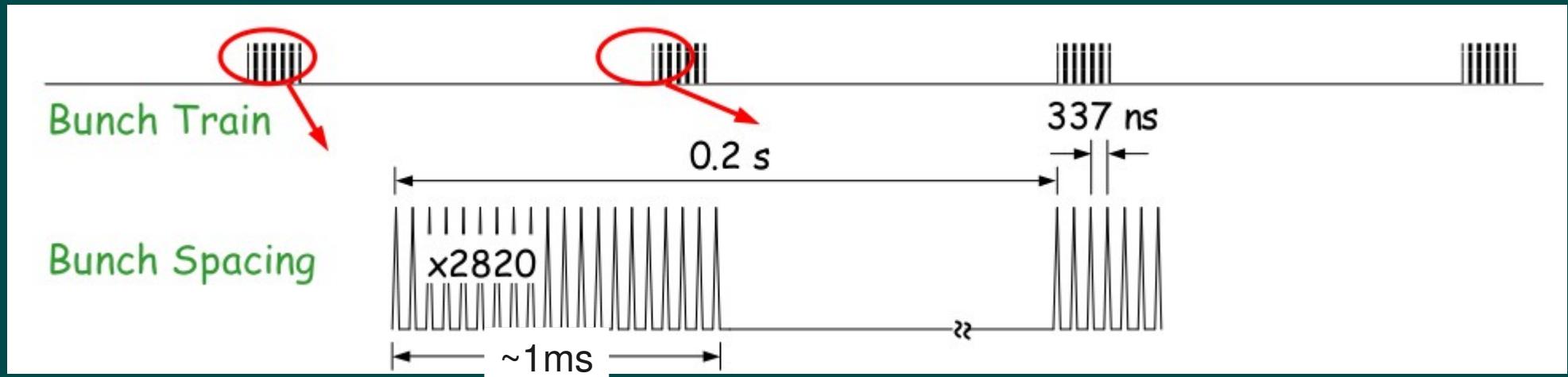
Also require excellent

track impact parameter resolution; secondary vertices - b, c, tau

lepton identification (including tau), hermiticity

Work with specific beam structure

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



Particle Flow leading proposal to achieve 3% jet energy resolution

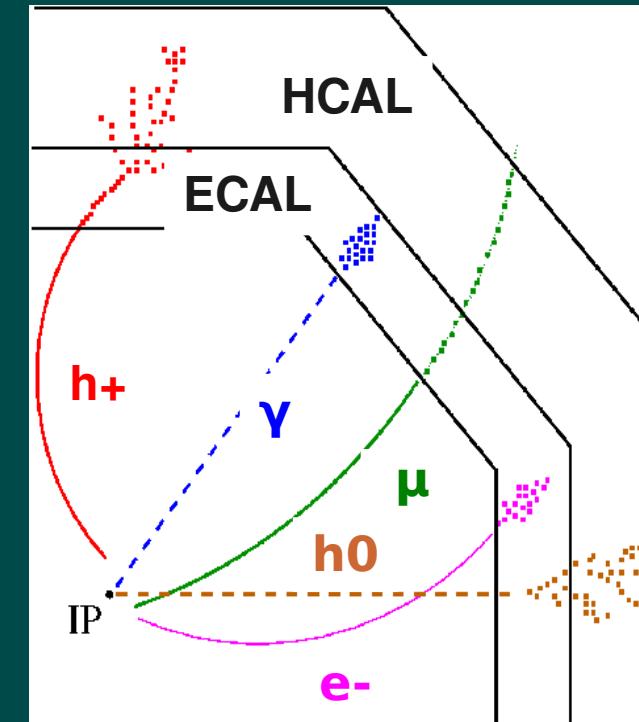
Hadronic jet energy traditionally measured in calorimeters

Large fluctuations in hadron showers limit energy resolution

Jet energy typically ~65% charged (mostly hadrons)
25% photons, 10% neutral hadrons

Particle flow proposes to measure:

charged energy with tracker ~ perfect precision
photons in EM calorimeter
neutral hadrons in HCAL
→ greatly reduce impact of
hadron shower fluctuations



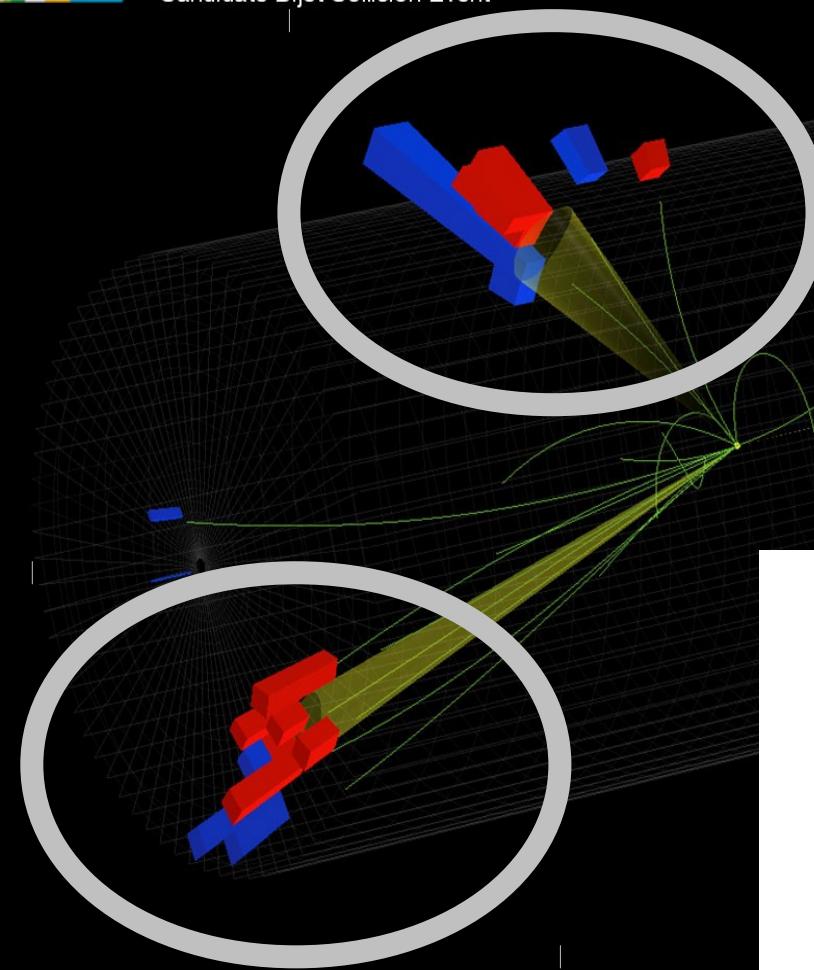
Requires identification of each particle's energy deposition

→ highly granular calorimeter

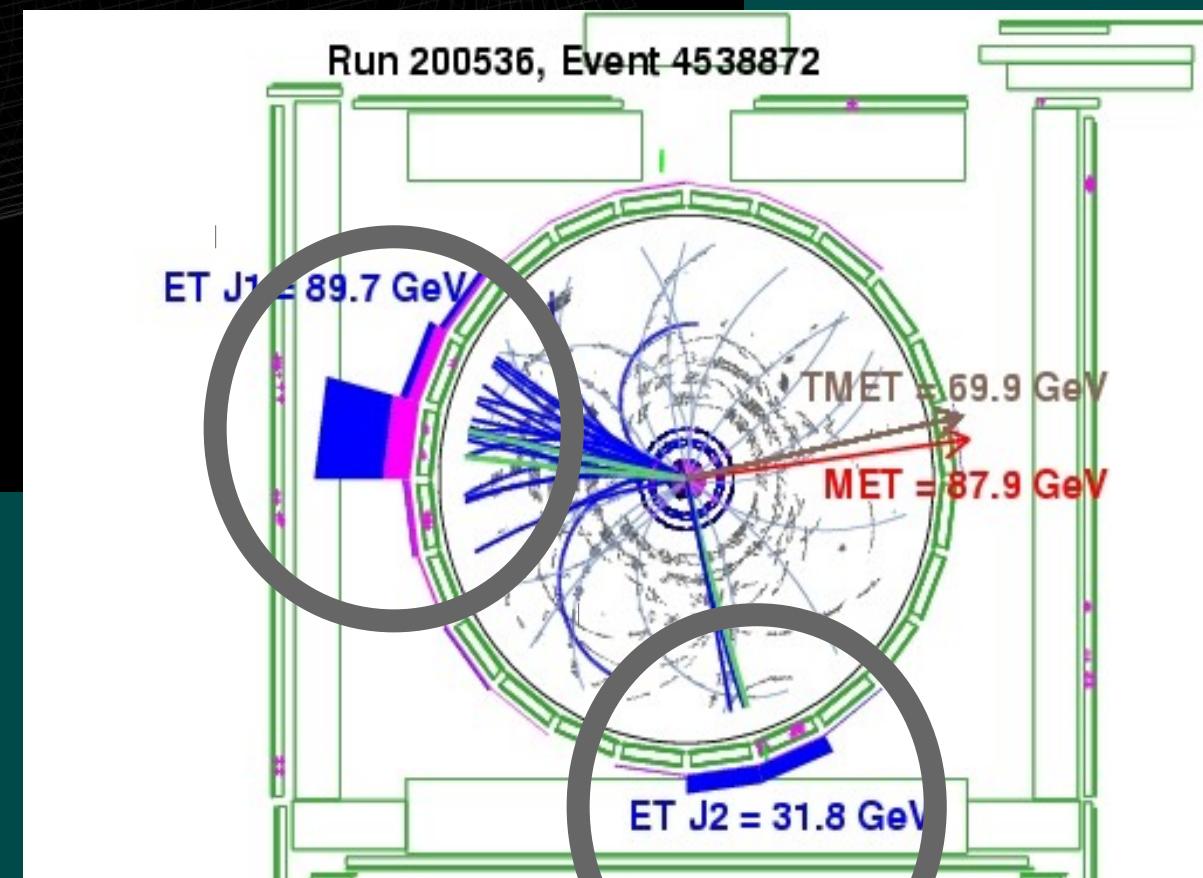
Single particle energy resolution secondary importance



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



From this...

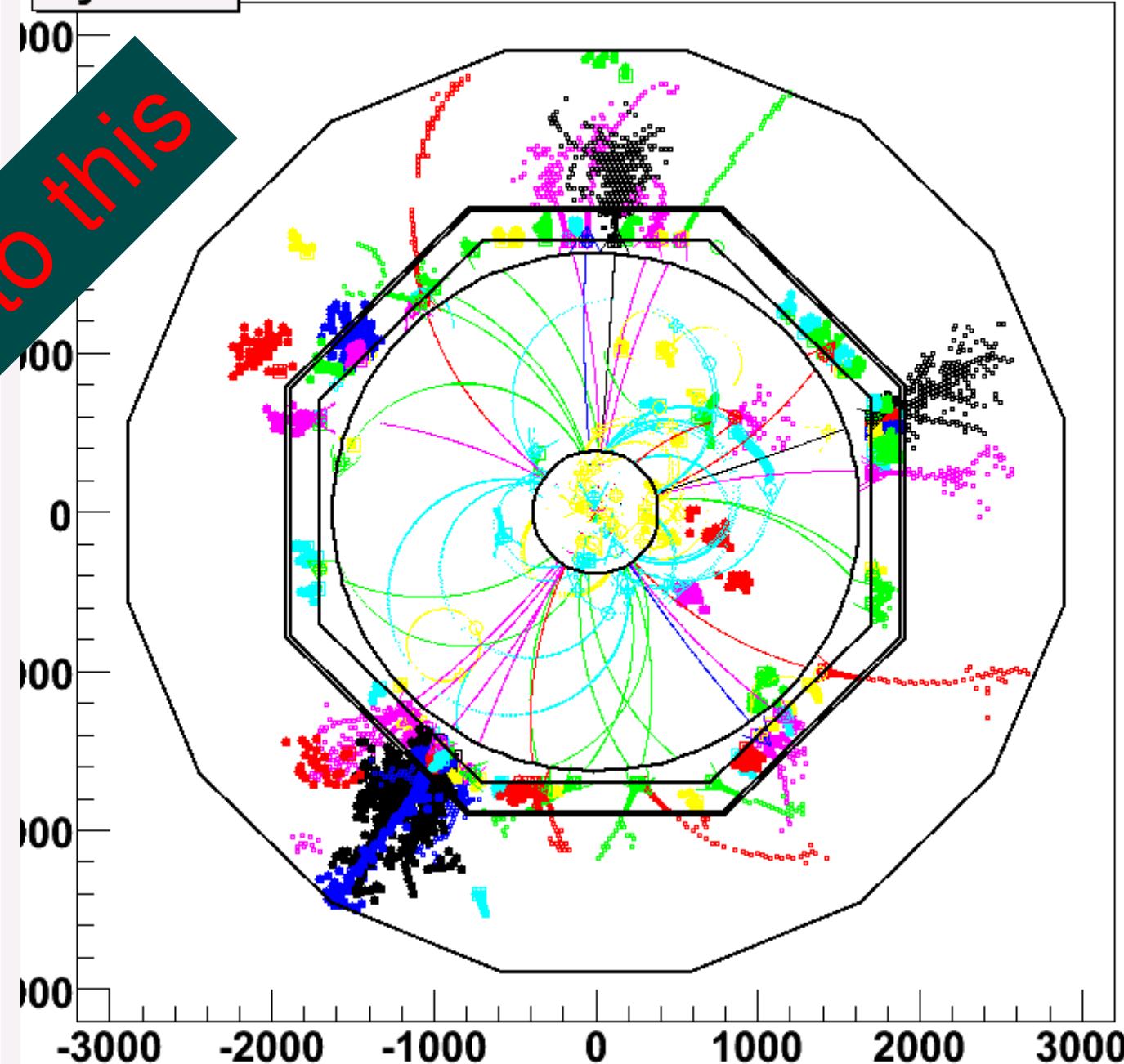




CMS Experiment
Date Recorded
Run/Event: 123
Candidate Dijet

xy view

...to this



ET J2 = 31.8 GeV

LC Calorimeters

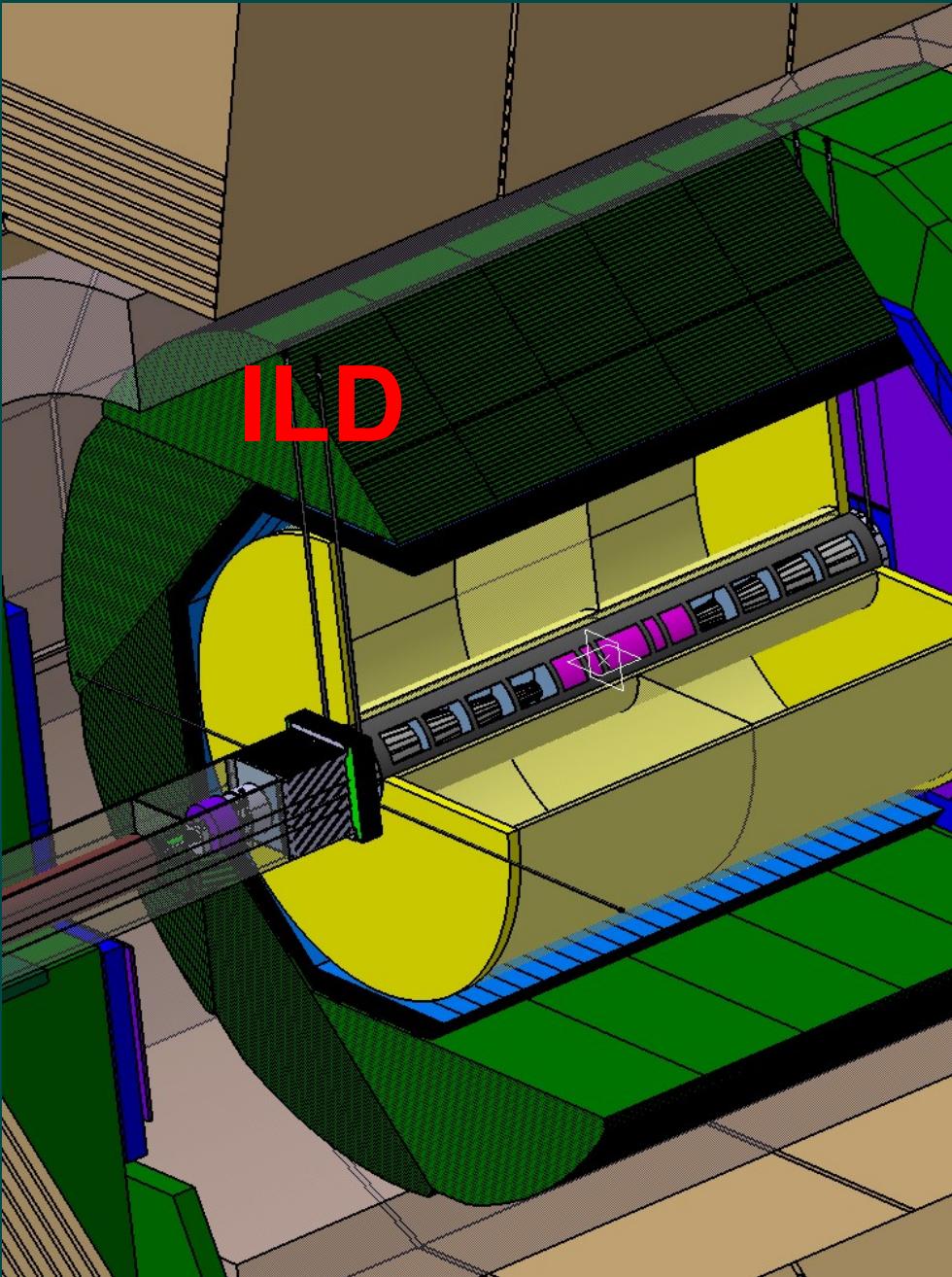
reduce dead material,
calorimeters inside coil
→ compact readout technology
insensitive to ~4T field
- large area sensitive material,
large number of channels

ECAL

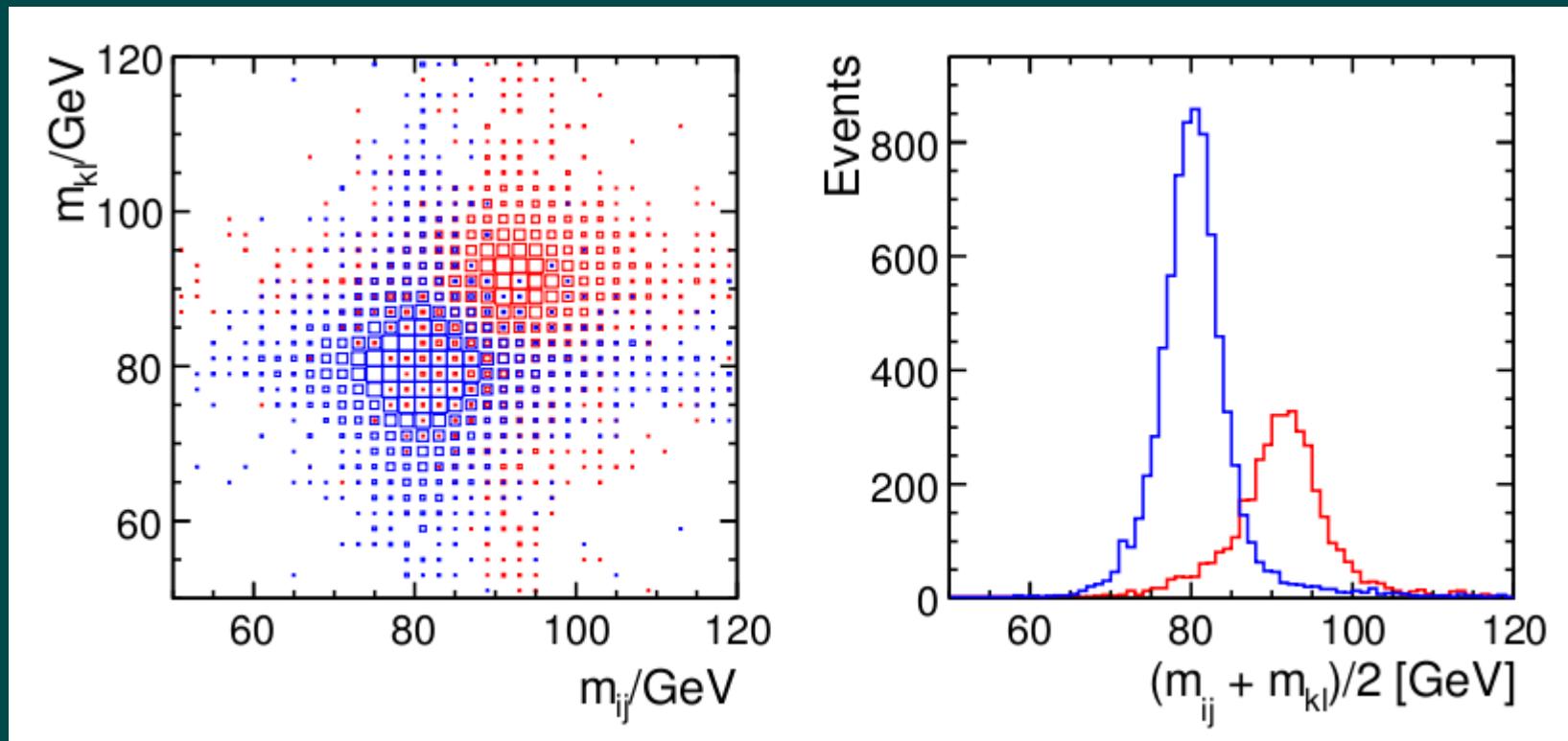
~24 X0, 20 cm thick
~2500 m² active detectors
~80M readout channels

HCAL

~5 lambda
~7000 m² detection area
~8M readout channels
+ Muon system/Tail-catcher



$e^+e^- \rightarrow WWvv / ZZvv \rightarrow qqqqvv$
jet-jet masses (particle flow)



ILD full simulation

Linear Collider goals

Detector requirements

Overview of CALICE activities

Silicon-W ECAL

Conclusions

CALICE collaboration

Particle Flow Calorimetry for a future Linear Collider

336 physicists/engineers

57 institutes

17 countries

4 regions (Africa, America, Asia and Europe)

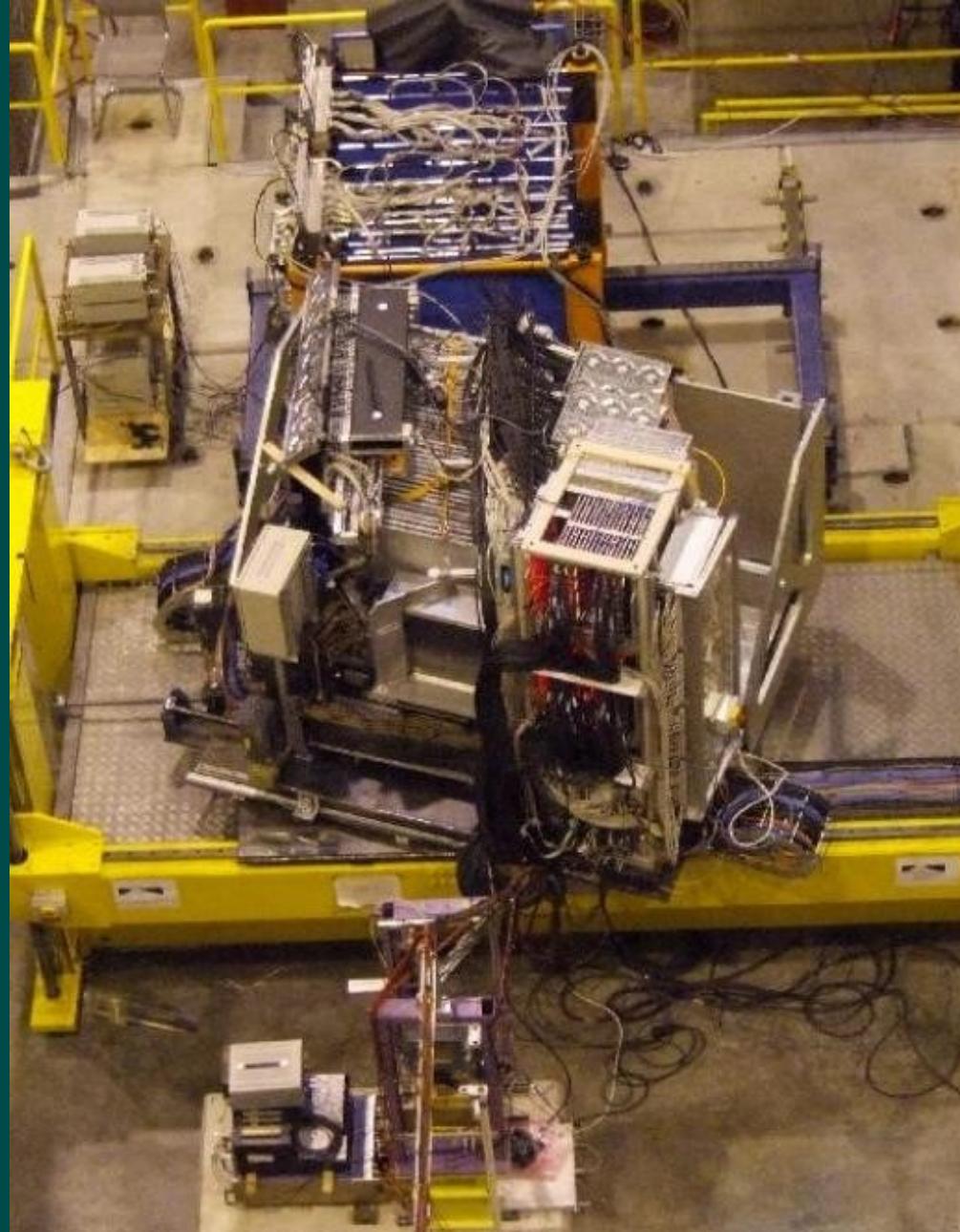
Groups study different technologies

Collaborate on:

Technical issues

Combined test beams

Data analysis



CALICE collaboration

Particle Flow Calorimetry
for a future Linear Collider

336 physicists/engineers

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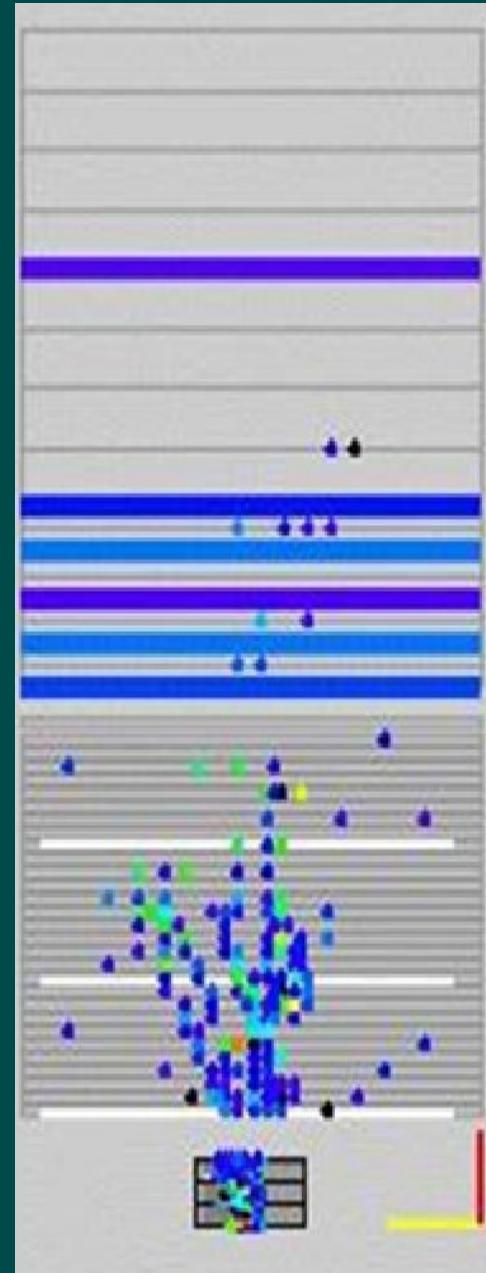
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Technical issues
Combined test beams
Data analysis



CALICE
Calorimeter for ILC

CALICE calorimeter technologies

Sampling calorimeters → intrinsic longitudinal granularity
~ 20-30 layers for ECAL, 40-50 for HCAL

Absorber material:

ECAL

- Tungsten:
 - small Molière Radius (10mm),
 - small X_0 (3.5mm), small X_0/λ_{INT}
 - compact showers,
 - thin ECAL, good hadron-electron separation

HCAL

- (non-magnetic) stainless steel
 - structural strength, λ/X_0
- Tungsten considered for high energy > 1 TeV
 - more compact showers, reduce leakage

Active layer technologies

High granularity → PFA performance

Robust and stable → low maintenance

Thin → limit calorimeter thickness

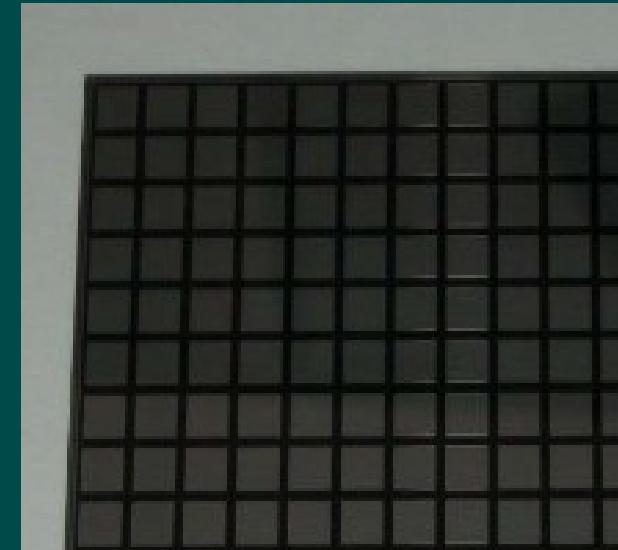
Silicon - ECAL

Analogue readout:

High resistivity Silicon, reverse biased PIN diodes

5x5 mm² cells

12-bit readout



Digital readout:

CMOS Monolithic Active Pixel Sensors (0.18 μ)

On-pixel data processing

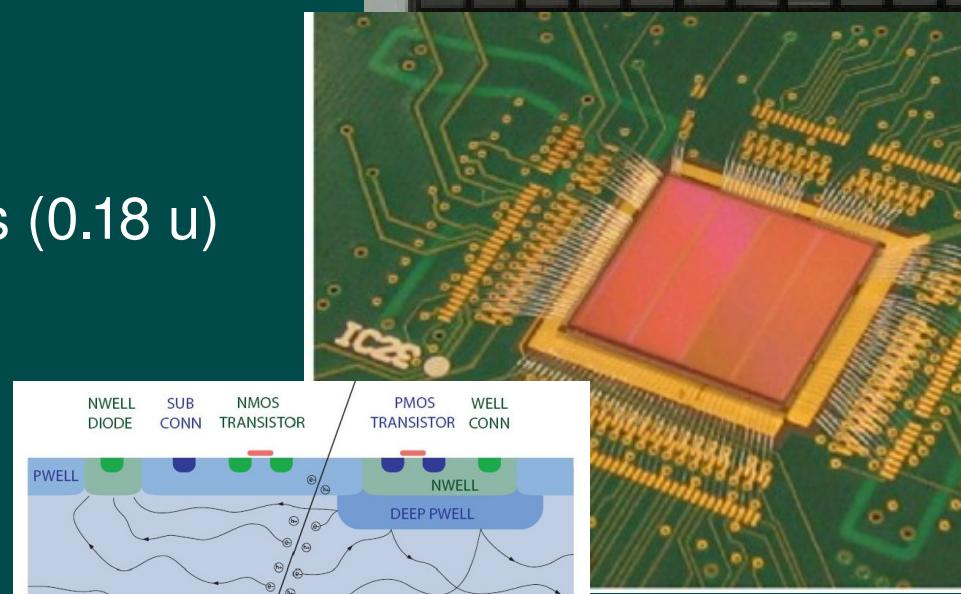
1-bit readout

→ suppress Landau fluctuations

50x50 micron pixels

→ avoid saturation

9X9 mm², 28k pixel prototypes tested



Active layer technologies

High granularity → PFA performance

Robust and stable → low maintenance

Thin → limit calorimeter thickness

Silicon - ECAL

Analogue readout

High resistivity

5x5 mm² cells

12-bit readout

more details later

Digital readout:

CMOS Monolithic Active Pixel Sensors (0.18 μ)

On-pixel data processing

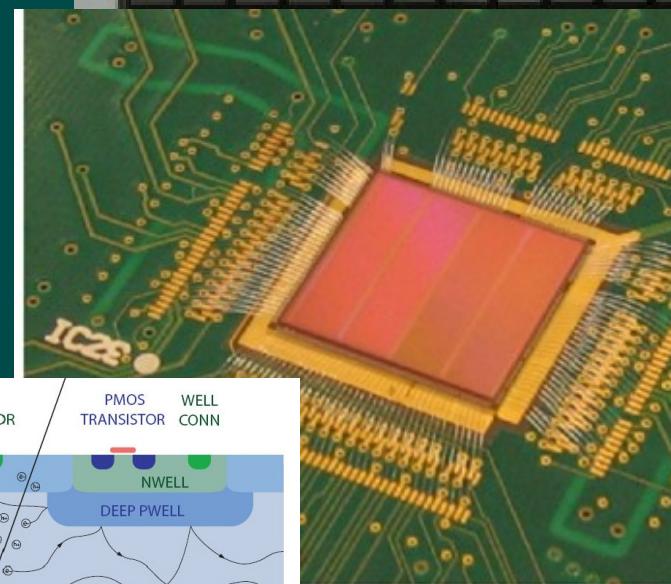
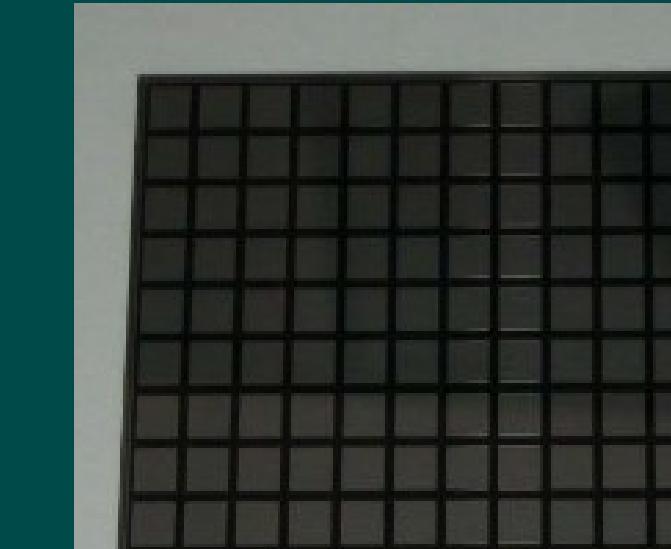
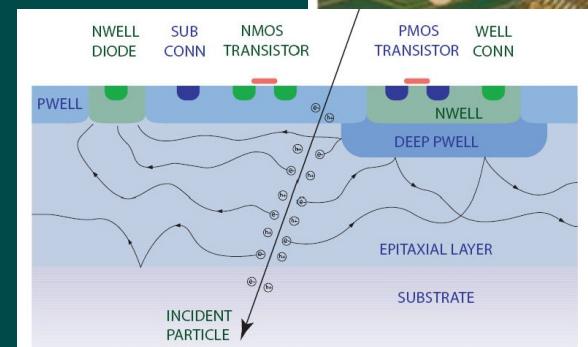
1-bit readout

→ suppress Landau fluctuations

50x50 micron pixels

→ avoid saturation

9X9 mm², 28k pixel prototypes tested



Scintillator with SiPM/MPPC readout

SiPM/MPPC device suitable for calorimeter use

Small size, Insensitivity to magnetic fields

Low cost, High gain $\sim 10^5 \rightarrow 10^6$

Auto-calibration (single photon peaks)

Coupled to scintillator either directly or via WLSF

ECAL: 4.5x1 cm² scintillator strips

Tested different scintillators & coupling schemes
effective granularity via dedicated strip reconstruction
~2K channel prototype tested in beam

HCAL: 3x3cm² scintillator tiles

1M3, 4.5 lambda, 8k channel prototype tested in beam

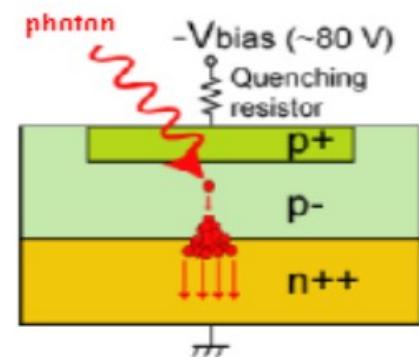
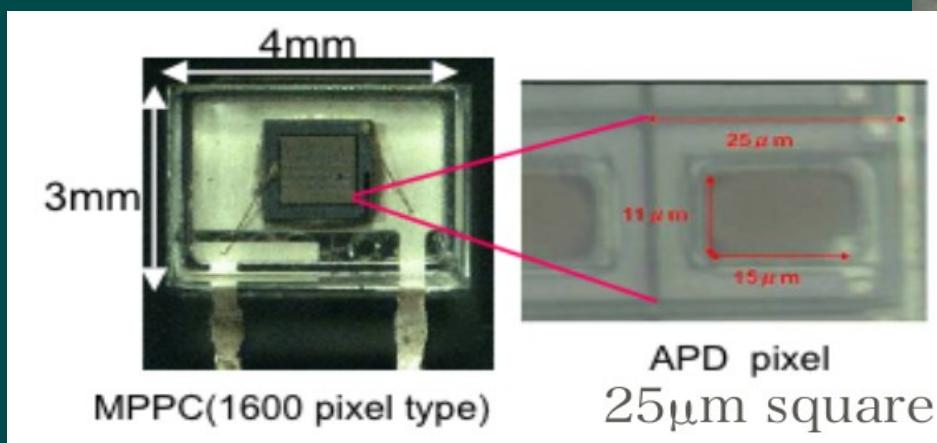
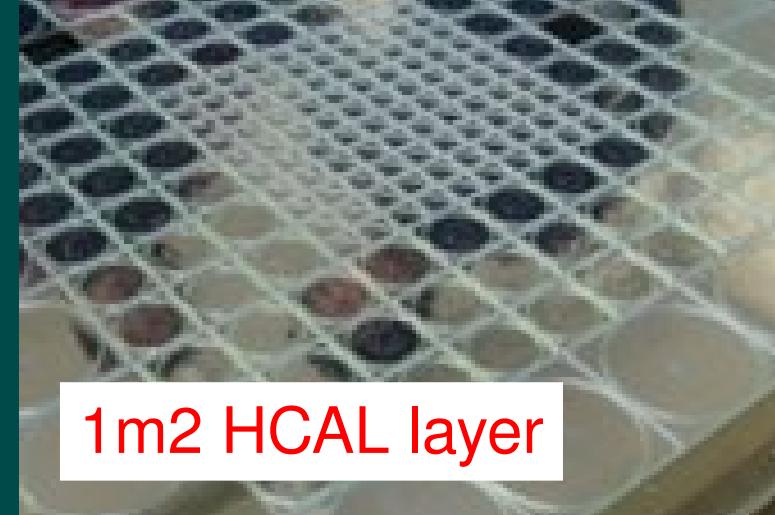
Light calibration system

Identify EM component

→ software compensation

Test hadron shower
simulations

Muon detector/tail catcher
5x100 cm² strips



Scintillator with SiPM/MPPC readout

SiPM/MPPC device suitable for calorimeter use



posters

KOTERA, Katsuhige

Study of granular electromagnetic calorimeter with PPDs
and the scintillator strips for ILC

SIMON, Frank SEIDEL, Katja

Particle Showers in a Highly Granular Hadron Calorimeter

Muon detector/tail catcher
5x100 cm² strips



Glass Resistive Plate Chambers for HCAL

Pair of thin glass plates,
resistive paint, 7→8kV

Thin, high efficiency,
inexpensive

Readout in 1cm² pads

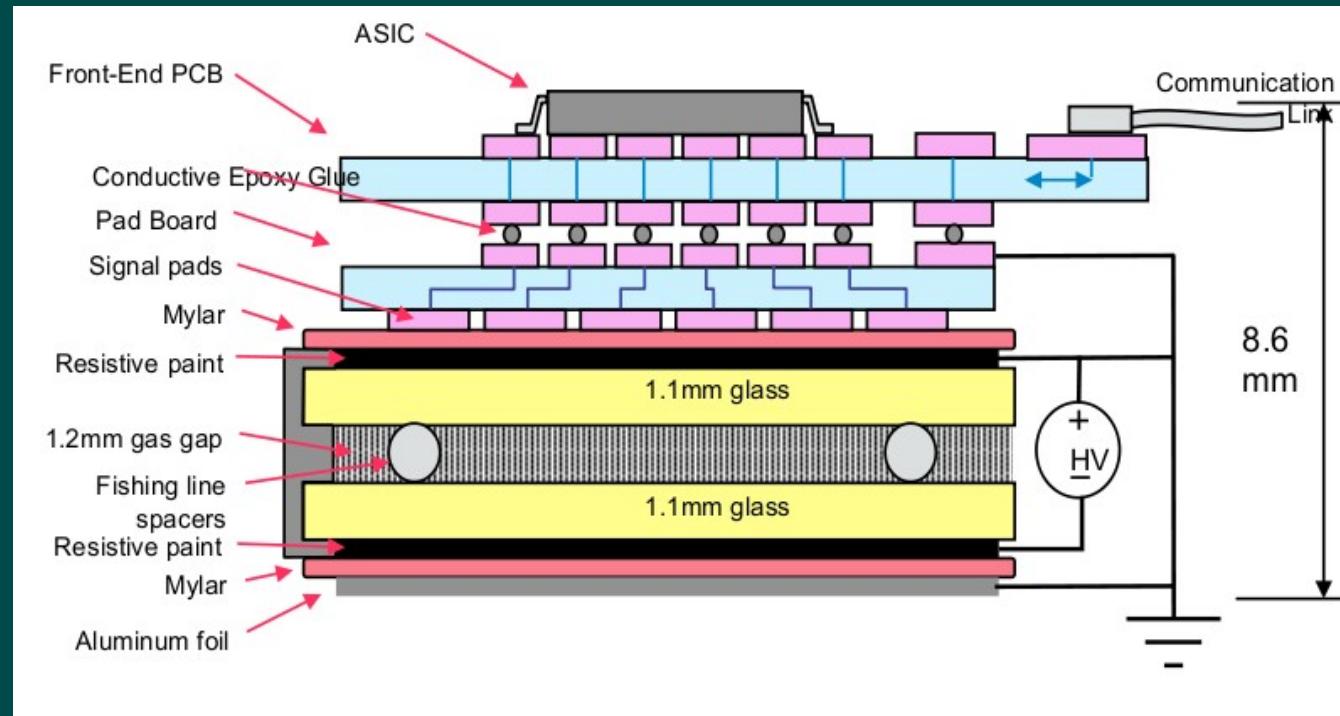
Two readout versions:

Purely digital readout

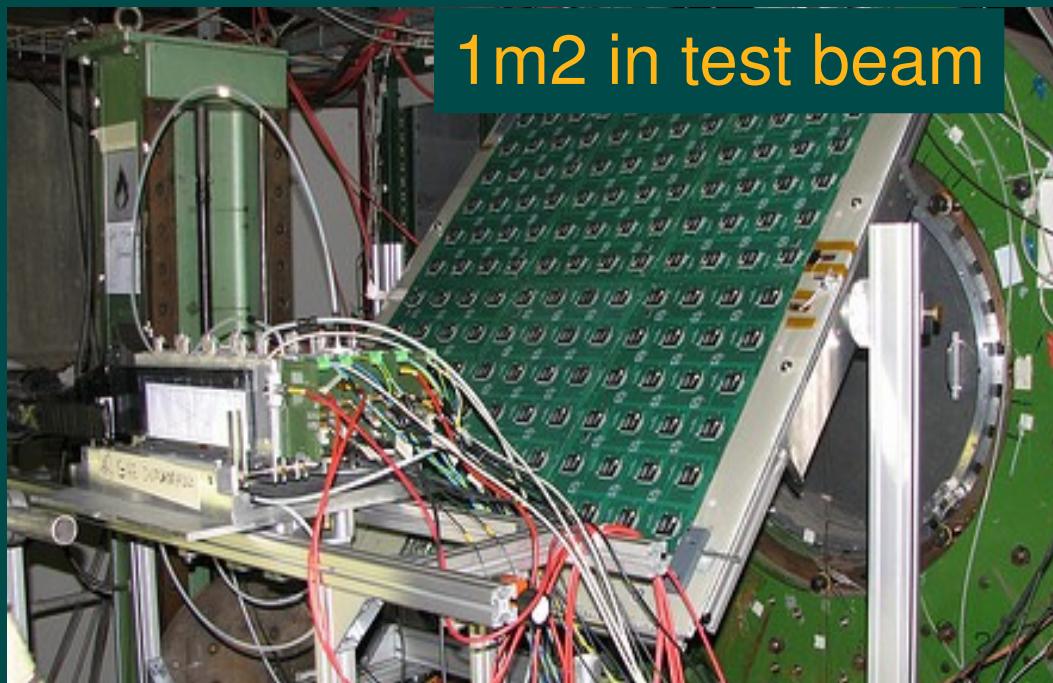
- suppress Landau tails
- reasonable data volume

Semi-digital 2-bit readout

- three energy thresholds
- identify electromagnetic parts
of hadronic shower
- software compensation



m2 planes constructed and tested
m3 prototypes under preparation



Glass Resistive Plate Chambers for HCAL

Pair of thin glass plates

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Thin

ine

Rea

REPOND, Jose

Digital Hadron Calorimeter: a novel approach to
calorimetry

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LAKTINEH, Imad KIEFFER, Robert

Semi-Digital Hadronic Calorimeter Using GRPCs for
Future Linear Collider Experiments

m2

m3 prototypes under preparation



Communication

Link

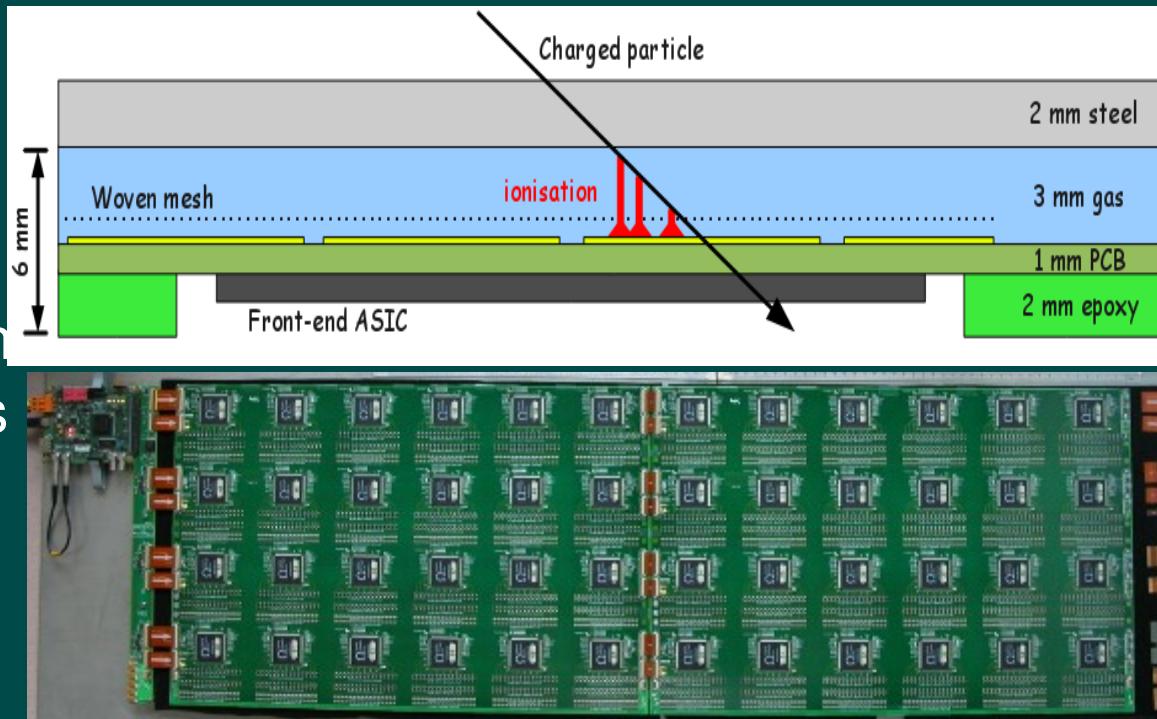
8.6
mm



MPGD Micro Pattern Gaseous Detectors (HCAL)

MicroMegas

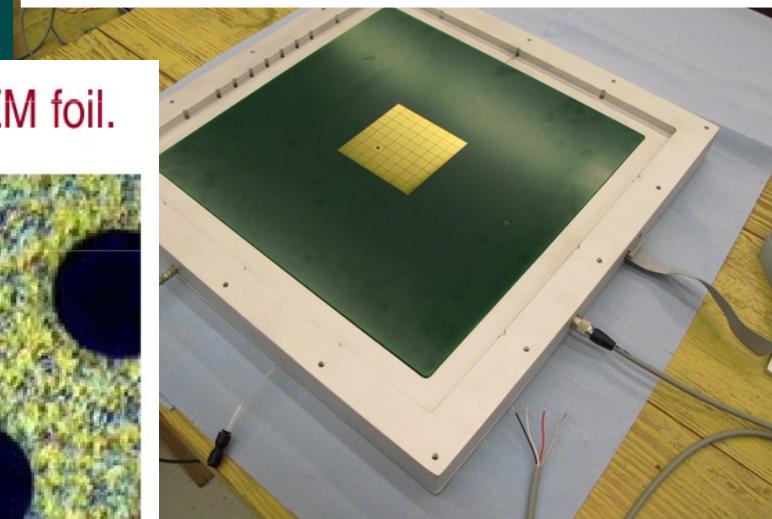
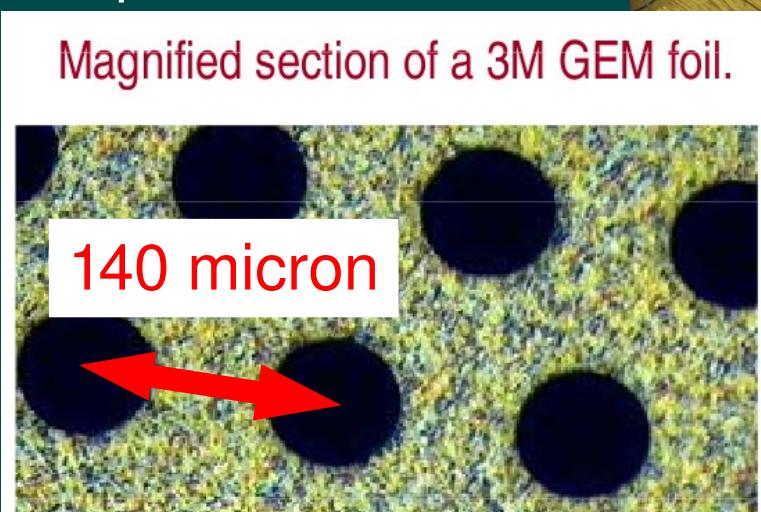
Stainless Steel mesh,
30 micron wires, 80 micron pitch
3mm drift, 128 micron amplification
Semi-digital readout, 1x1cm² pads
12X32 cm² chamber tested
1m² planes in preparation



GEM

Studying single, double and triple GEMs
Gain ~ 3500 (double)
Readout pads 1x1 cm²
Readout with KpiX chip
30x30 cm² chamber
preparing 1m² planes

30x30 cm² GEM chamber



MPGD Micro Pattern Gaseous Detectors (HCAL)

Mic
Stain
30
3mm
Sem
12x3
1m2

posters



CHEFDEVILLE, Maximilien

Application of Micromegas in hadronic calorimetry



GEM

Studying single, double and triple GEMs

Gain ~ 3500 (double)

Readout pads 1x1 cm²

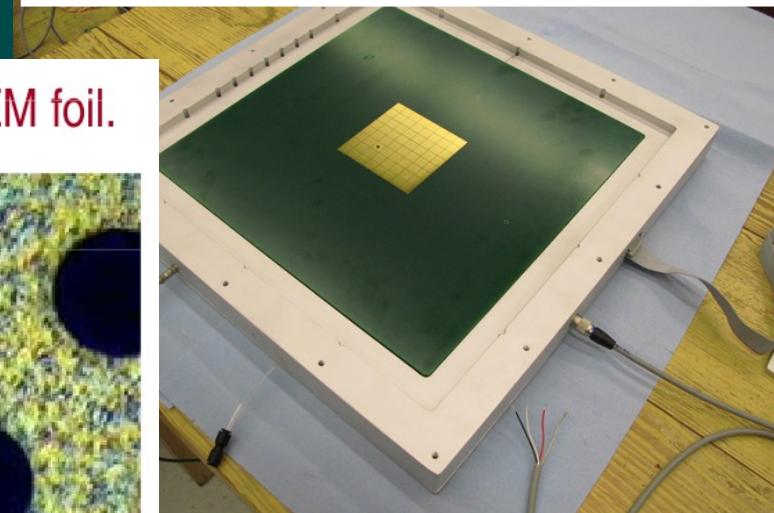
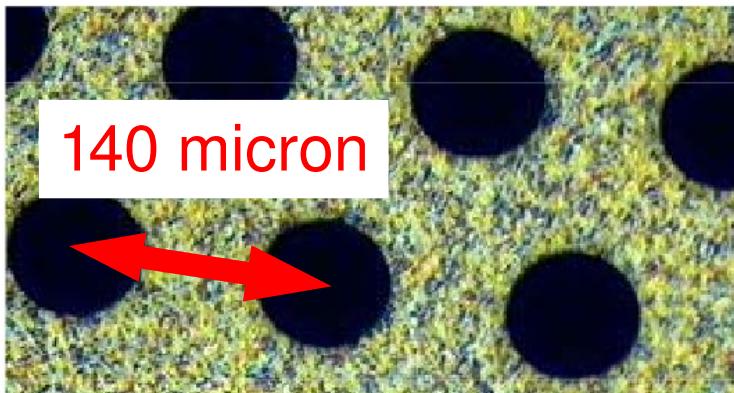
Readout with KpiX chip

30x30 cm² chamber

preparing 1m² planes

30x30 cm² GEM chamber

Magnified section of a 3M GEM foil.



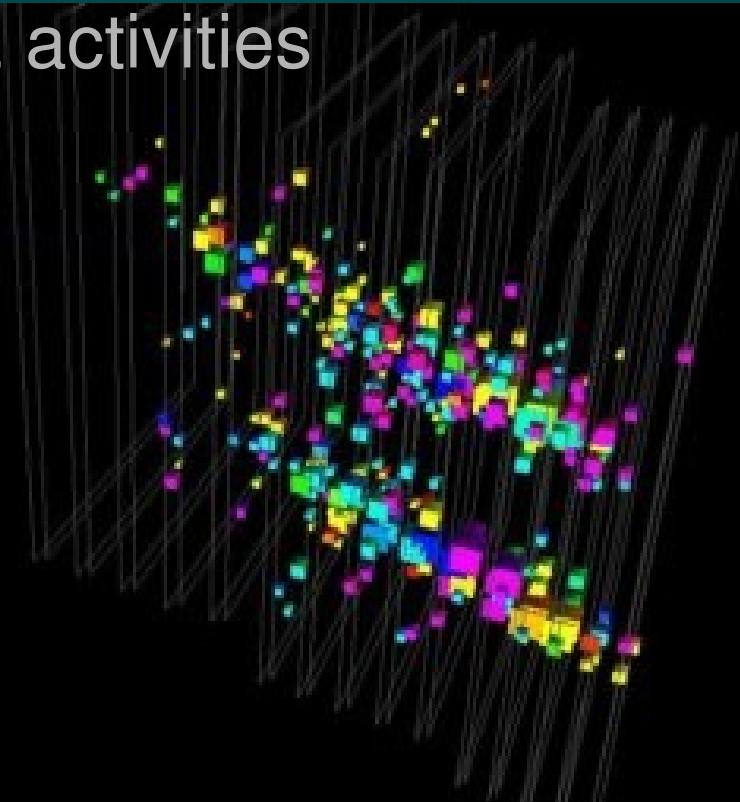
Linear Collider goals

Detector requirements

Overview of CALICE activities

Silicon-W ECAL

Conclusions



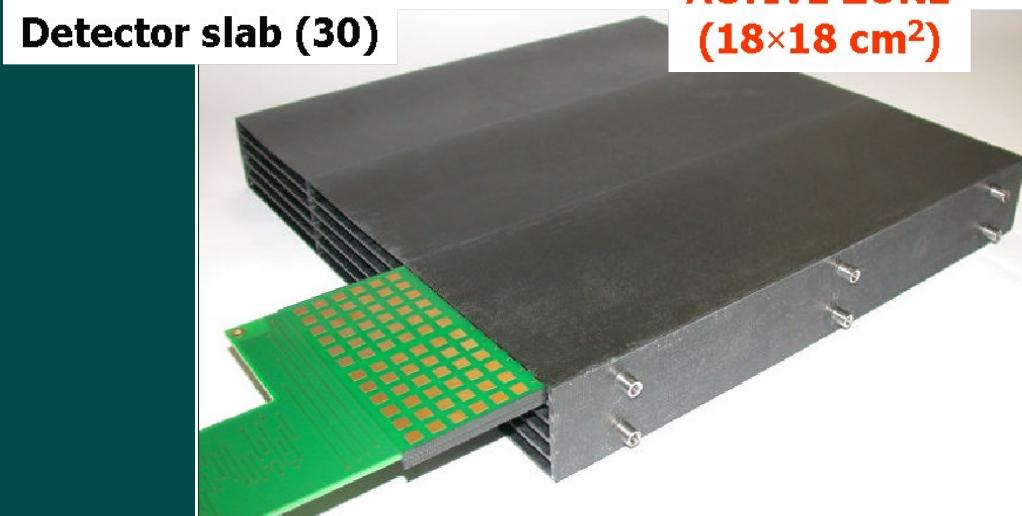
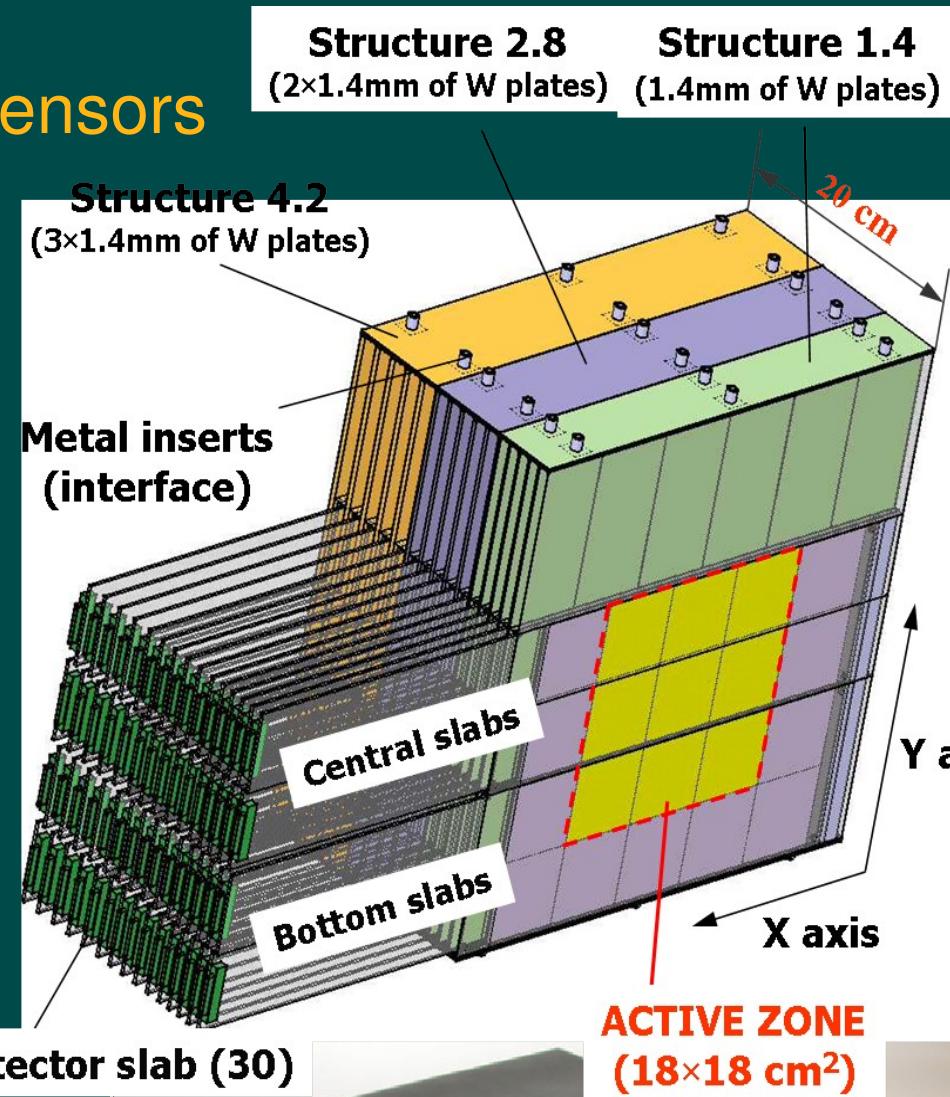
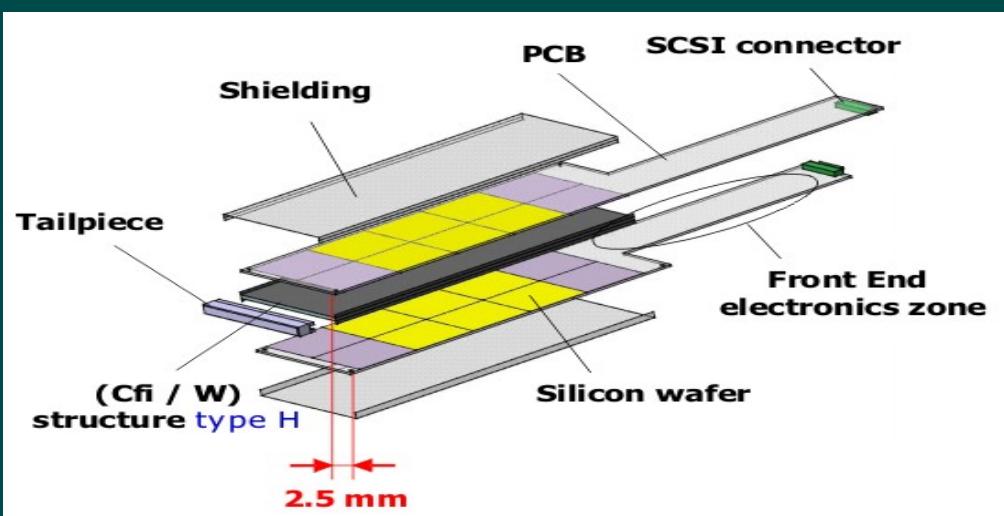
Sampling calorimeter based on Tungsten absorber and Silicon sensors

First generation prototype constructed and beam tested 2006-2008

30 layers - granularity, energy resolution
3 sampling fractions – low en efficiency

Mechanical structure: carbon fibre composite, incorporating tungsten layers

Carbon Fibre detector slabs hold silicon sensors, mounted on PCBs



Silicon sensors

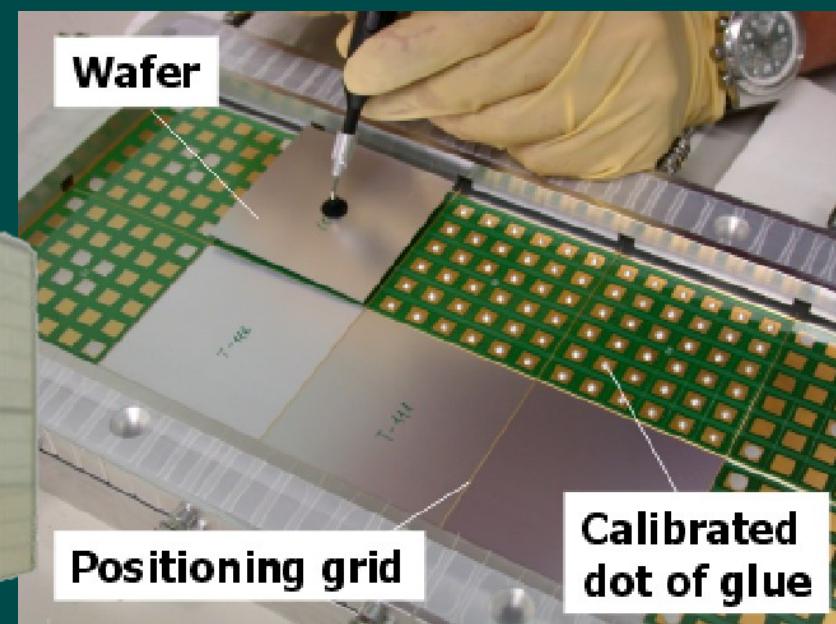
500 micron thick high-res Si $5 \text{ k}\Omega \text{ cm}$
6x6cm² sensor from 4" wafers

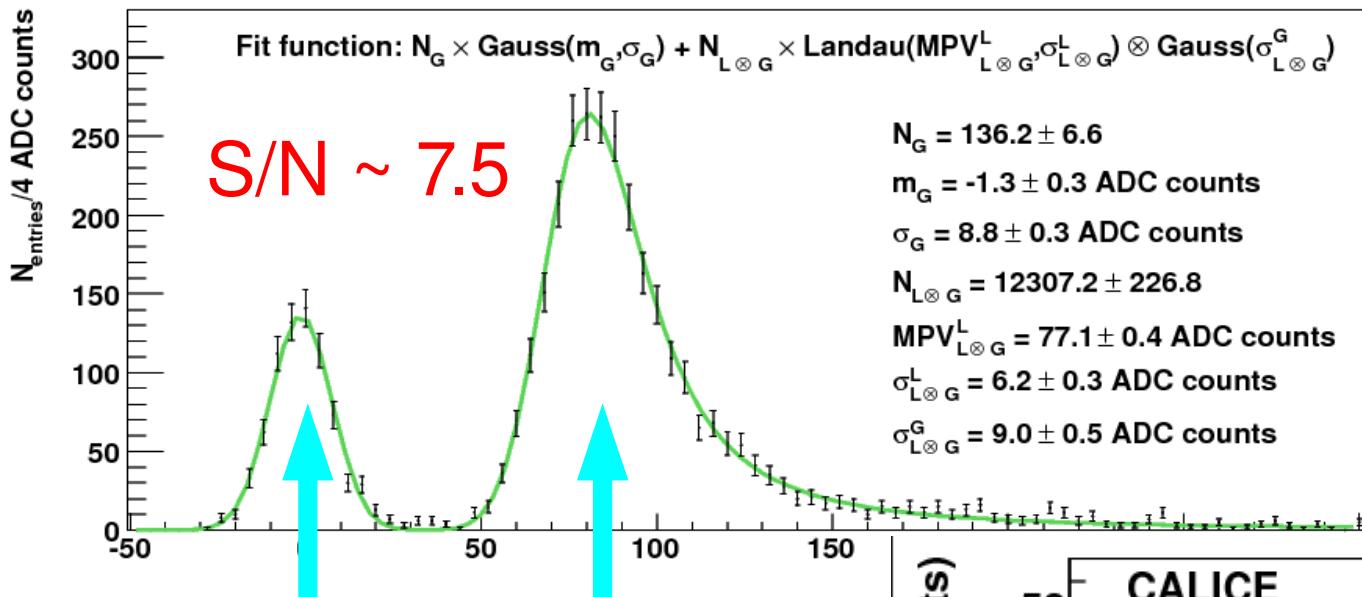
Segmented into 10x10 mm² P-I-N diodes
fully depleted by 200V reverse bias

Good S/N for MIP detection ~ 7.5

Response intrinsically insensitive to
temperature, voltage

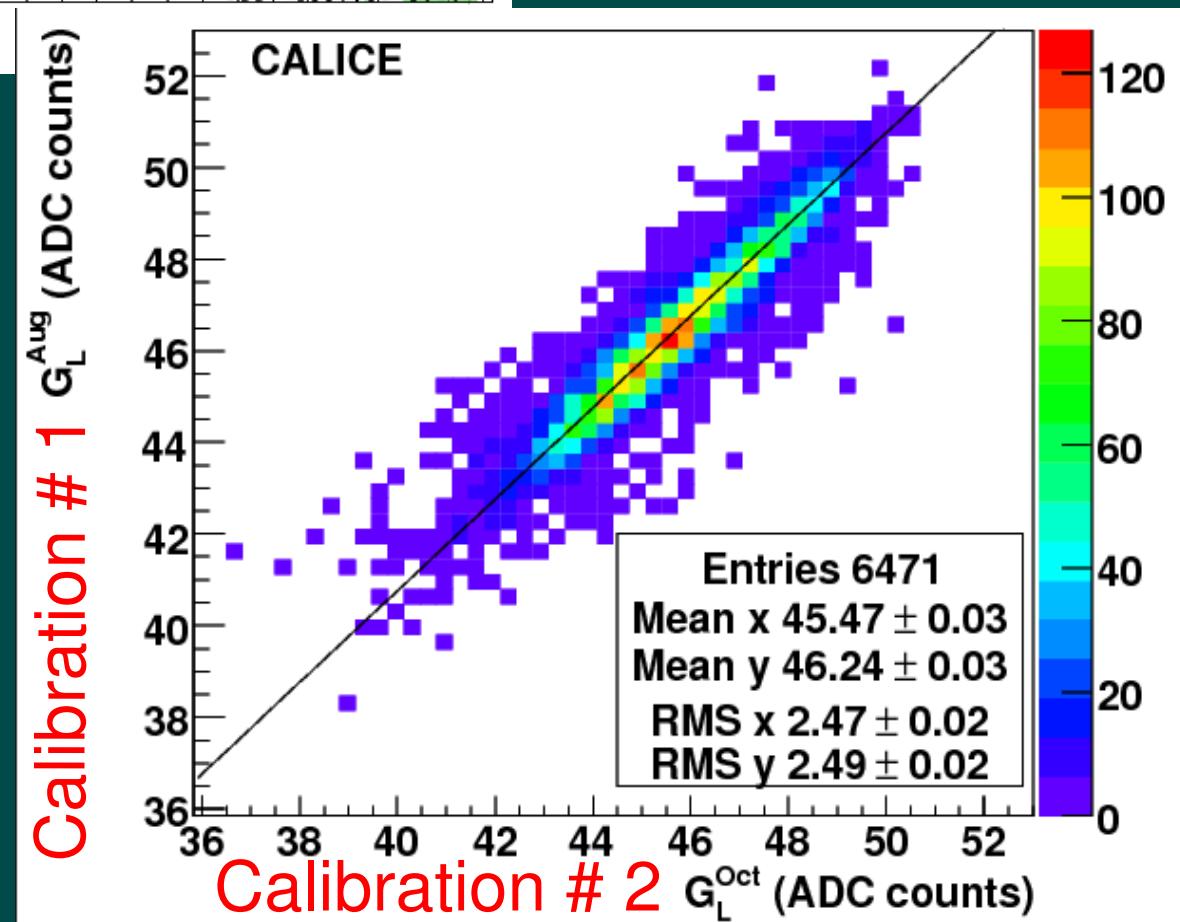
Front-end electronics mounted
outside detector





ECAL calibrated
with cosmics and
muon beams

Shows very stable
behaviour



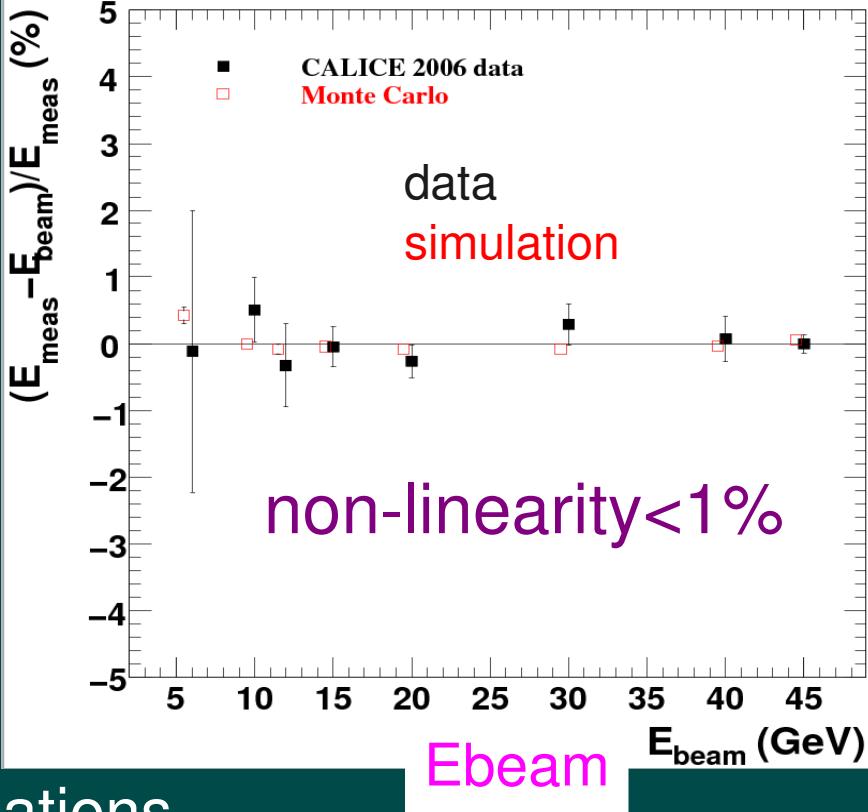
Calibration stability

Combined test beams with
scintillator HCAL and tail catcher
2006 → 2008 DESY, CERN, FNAL

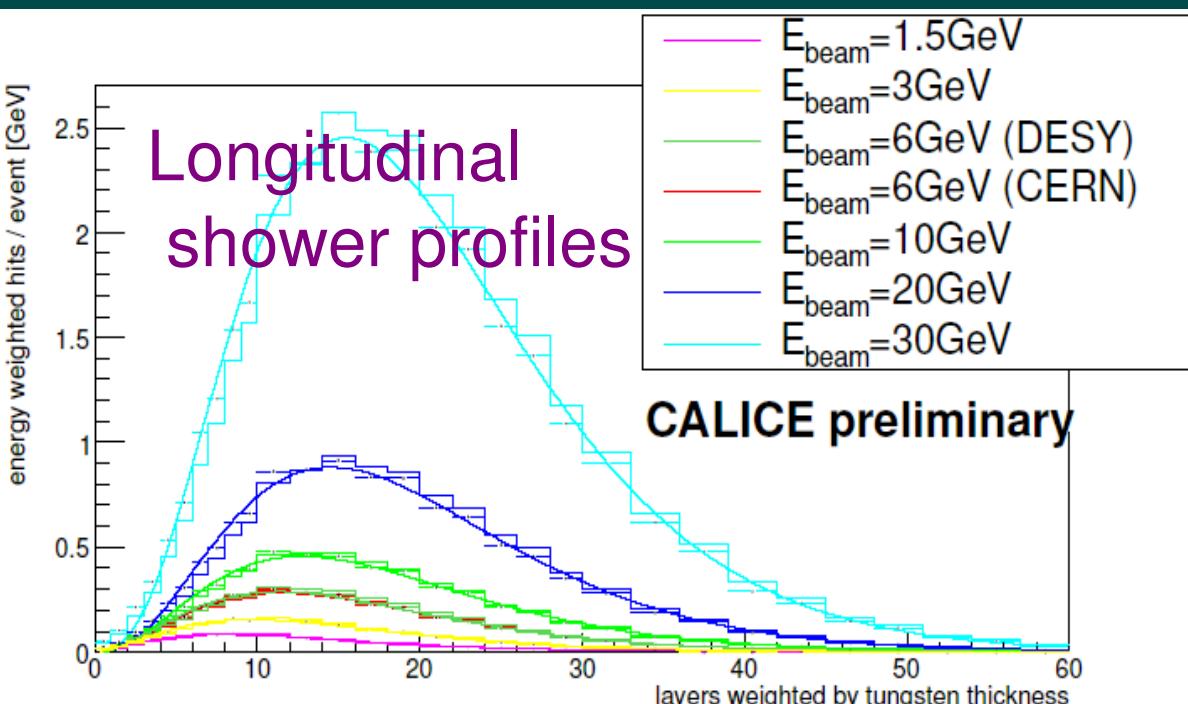
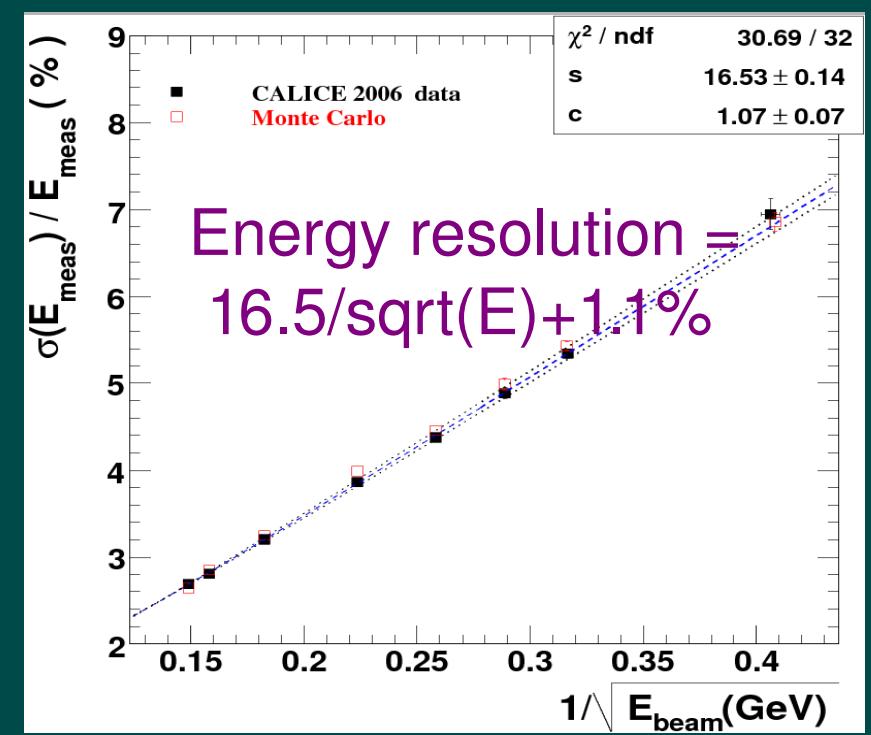
e⁺-, pions, muons, protons, 2-80GeV

Measured linearity and resolution of
energy response to electrons

Detector performs as expected from simulations

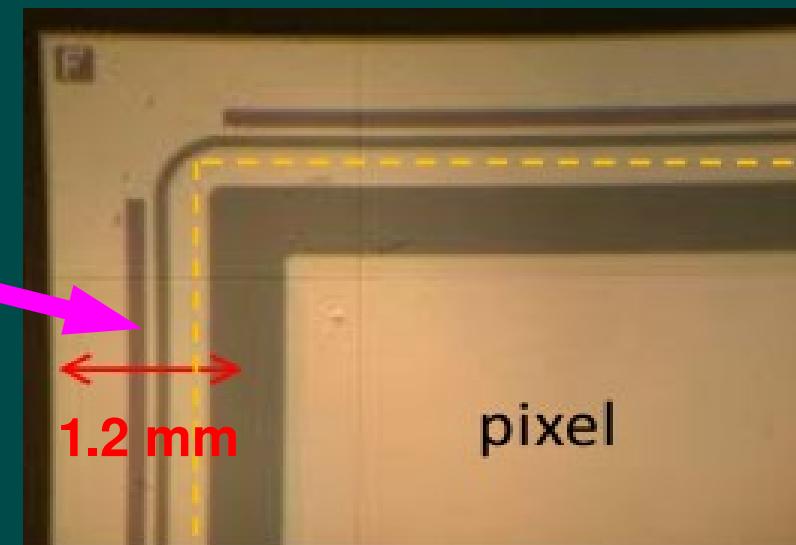


Ebeam



Guard rings protect Silicon sensors
against breakdown

- insensitive area
- produced interesting effects...



Guard rings protect Silicon sensors

against breakdown

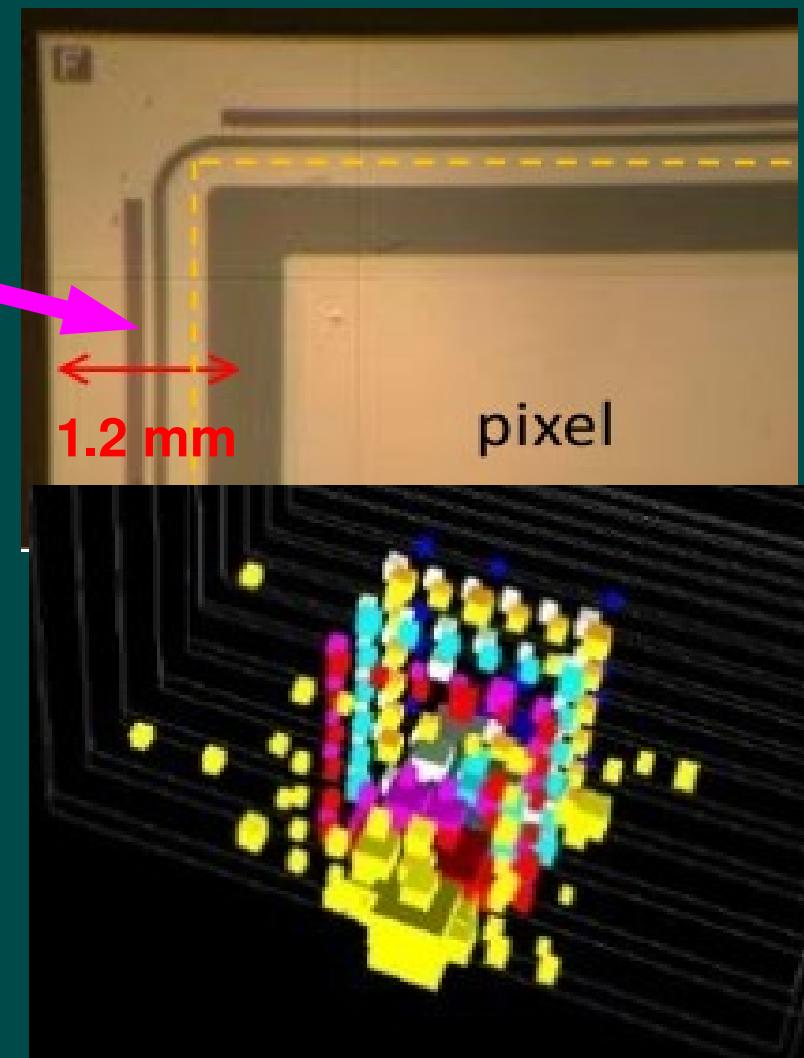
- insensitive area
- produced interesting effects...

“Square events” when shower energy

deposited in guard ring

Coupling between continuous ring

and edge pixels



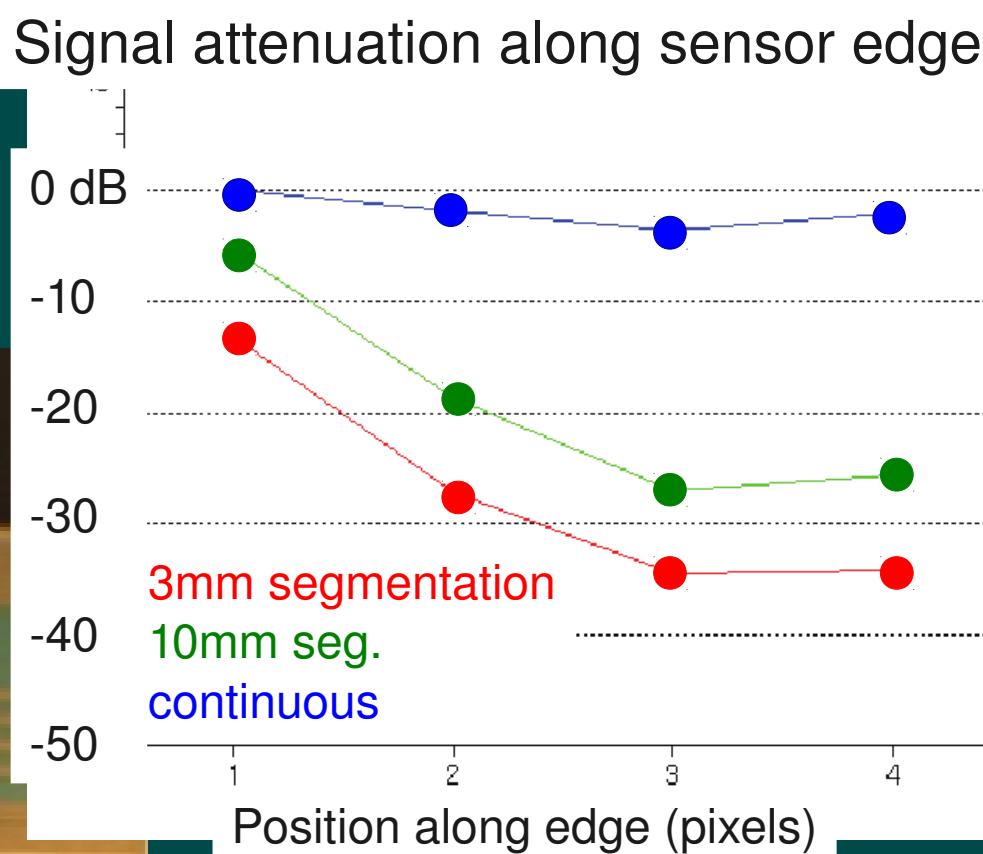
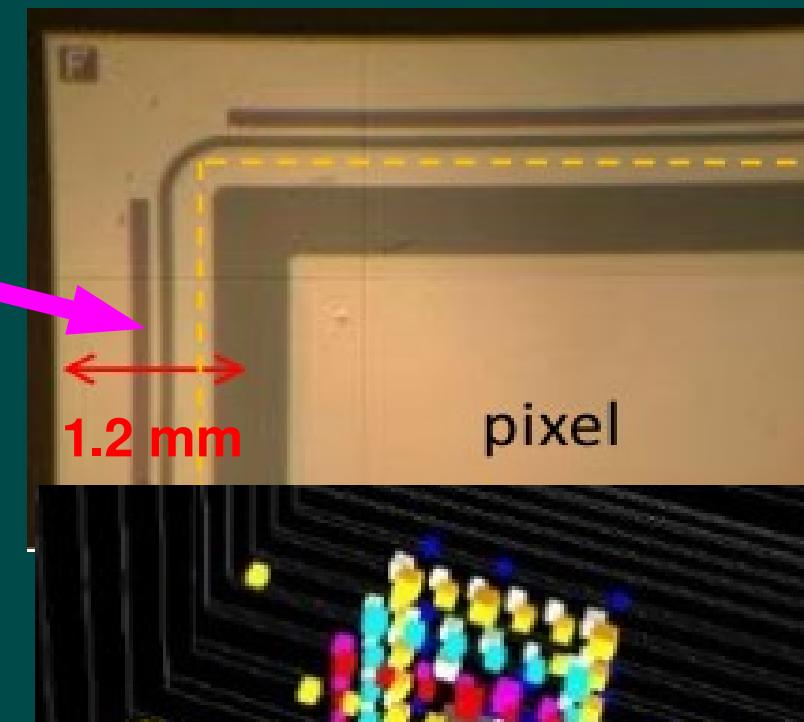
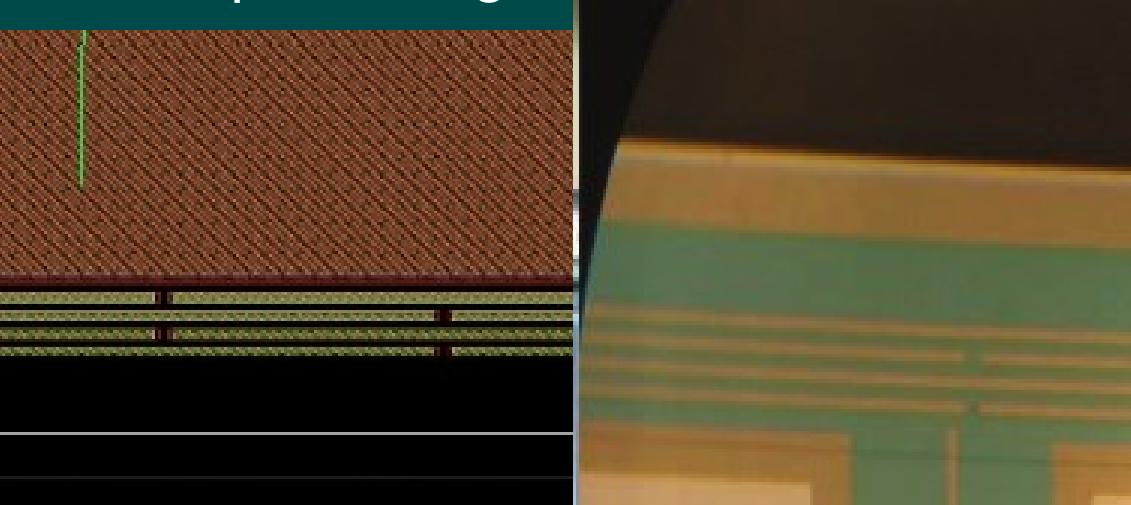
Guard rings protect Silicon sensors
against breakdown

- insensitive area
- produced interesting effects...

“Square events” when shower energy
deposited in guard ring

Coupling between continuous ring
and edge pixels

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



Next steps: towards a LC detector module → ~2014

~ 2/3 final module size
(partially instrumented)

Larger sensors

→ less edge effects

Smaller pixels

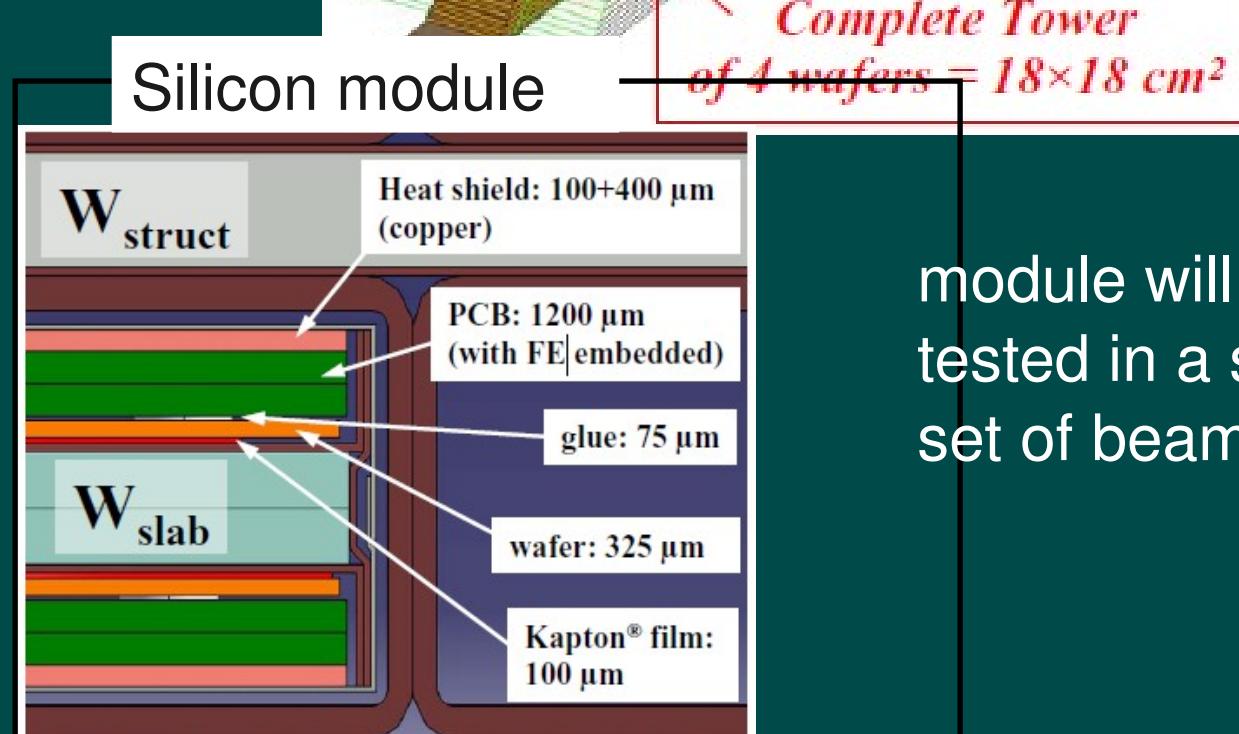
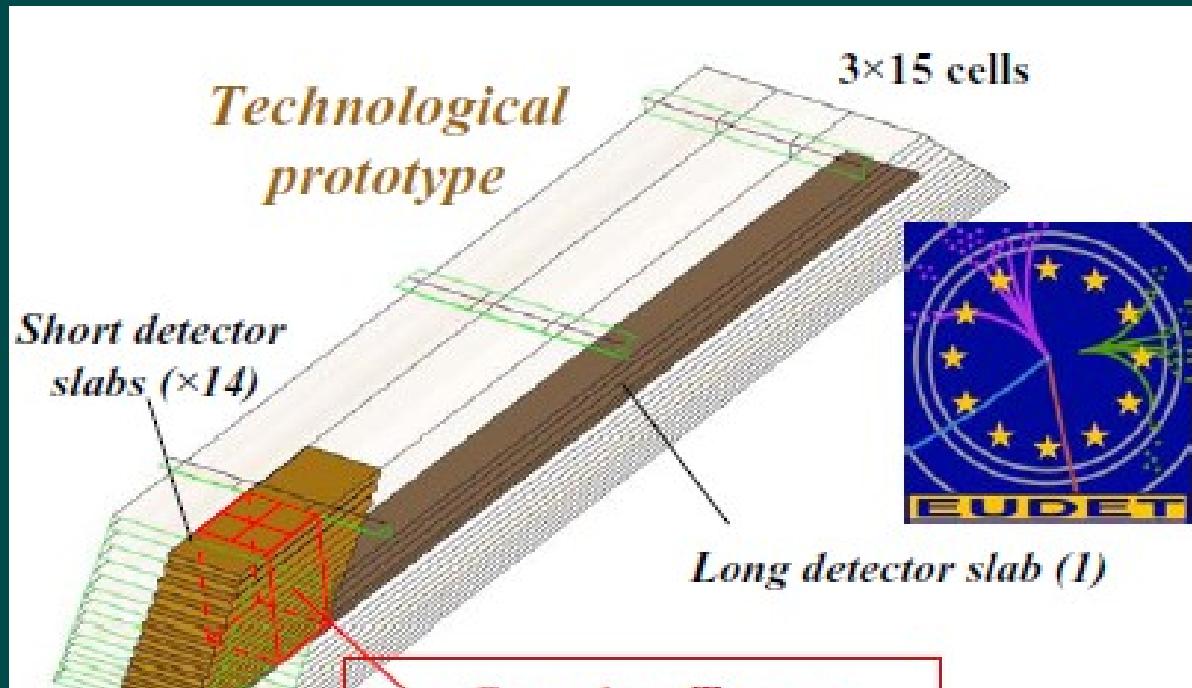
→ granularity

Power-pulsed, embedded

FE electronics

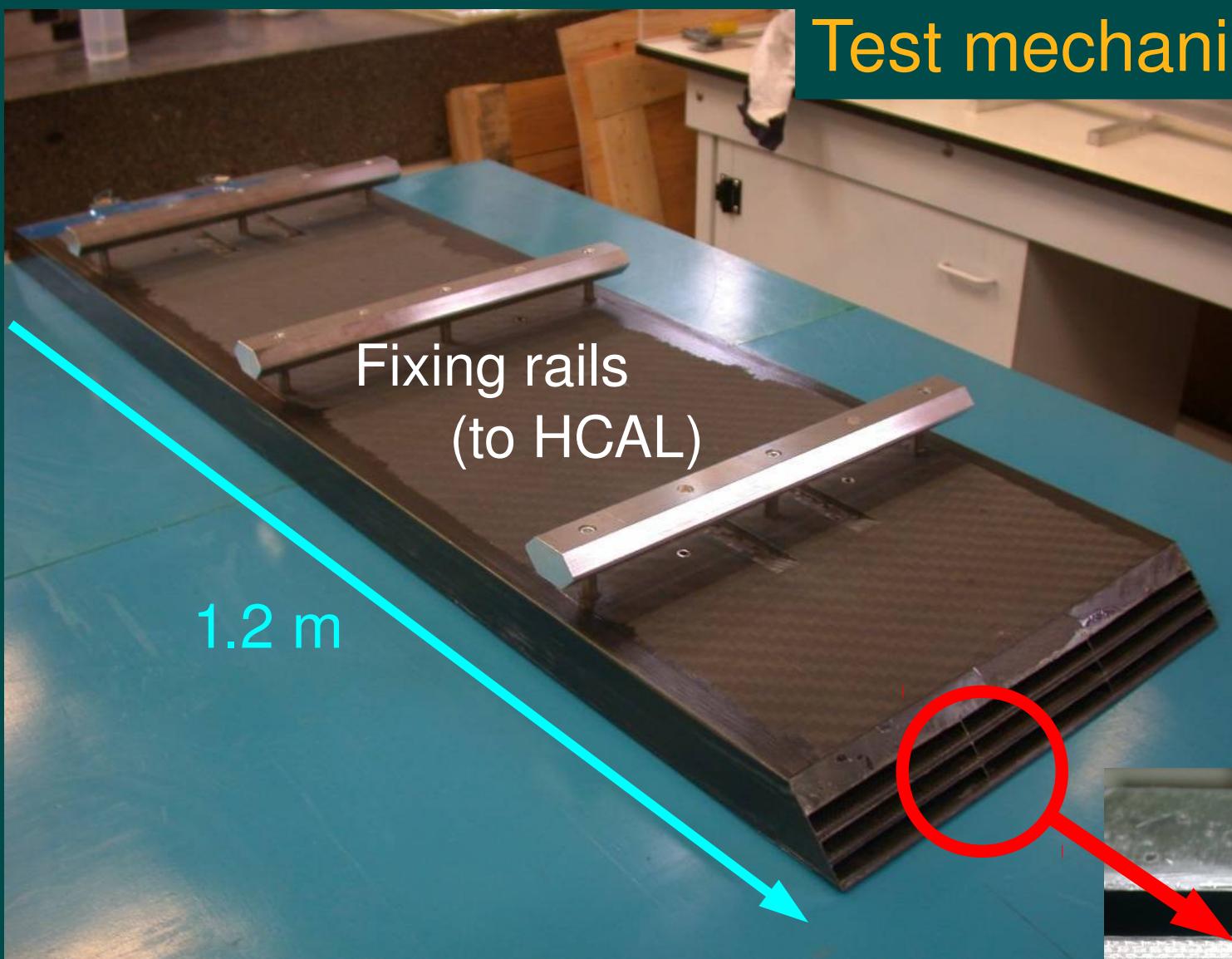
→ low power

Industrialisation
of Si production
→ control cost



module will be
tested in a second
set of beam tests

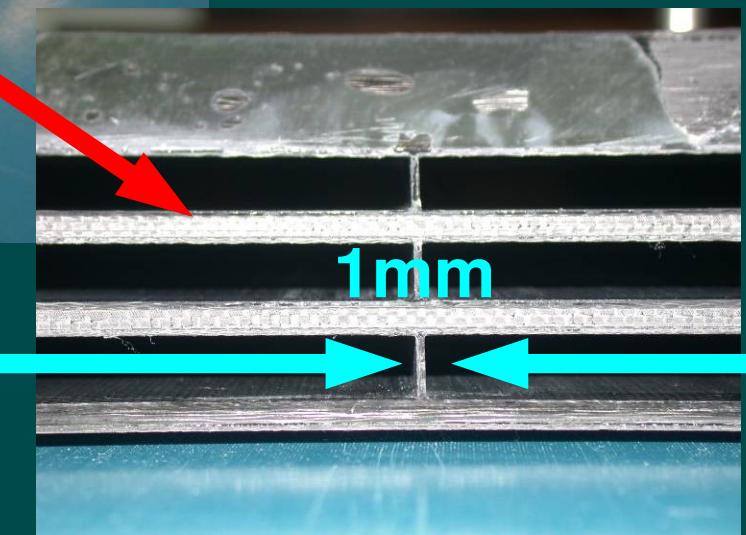
Test mechanical structures



CF-epoxy + W

Check

- assembly
- rigidity
- planarity



Improved Si detectors

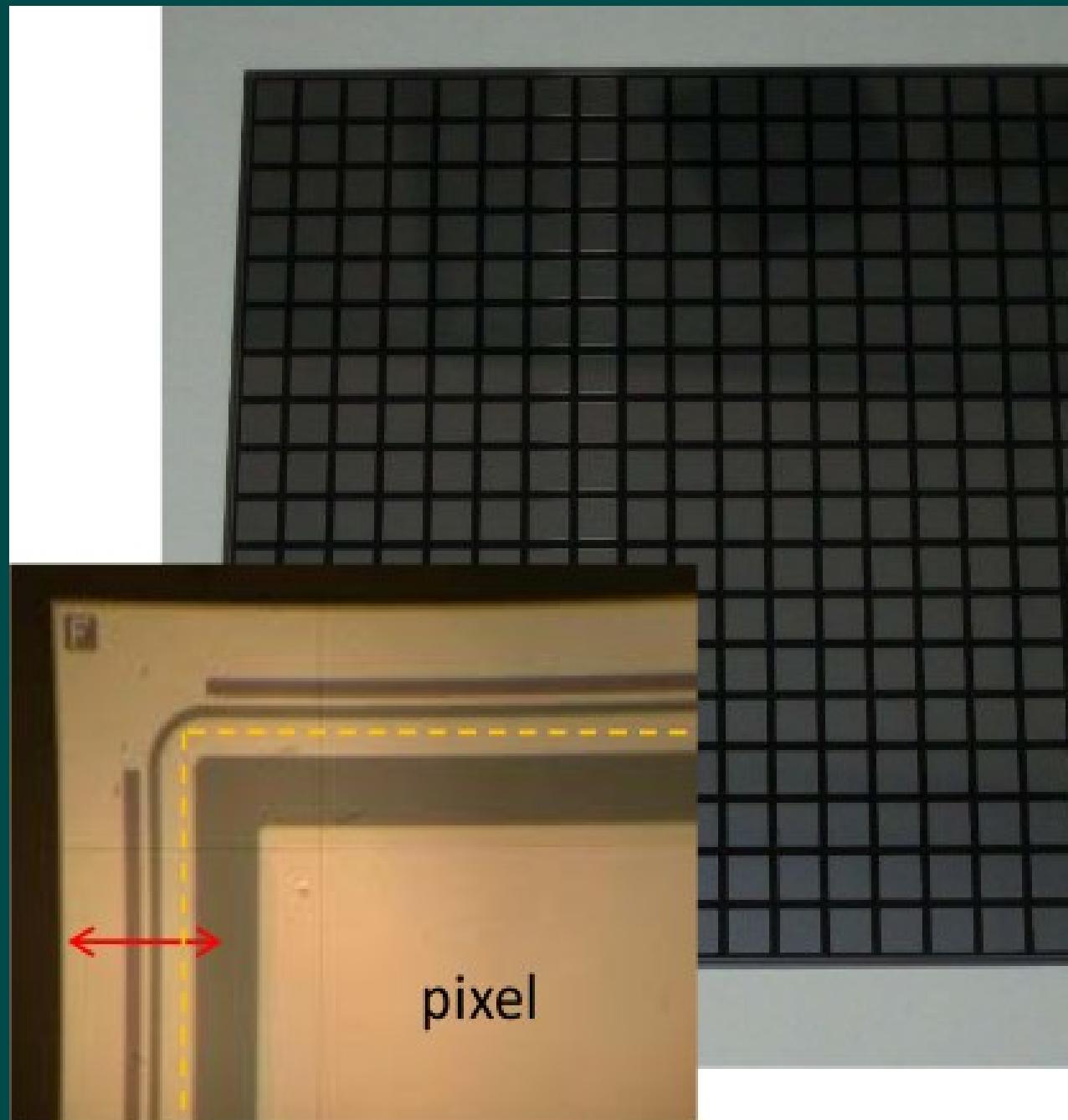
Larger size
9x9 cm²

Smaller cells
5x5mm²

Smaller guard rings
1200 → 750 microns

Guard ring design
Reduce x-talk

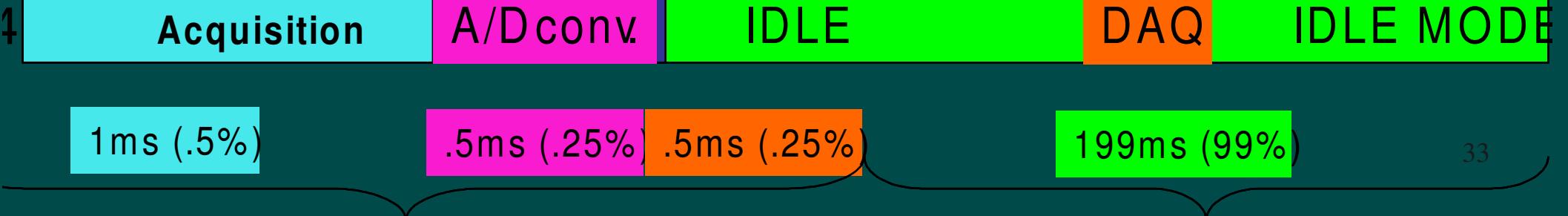
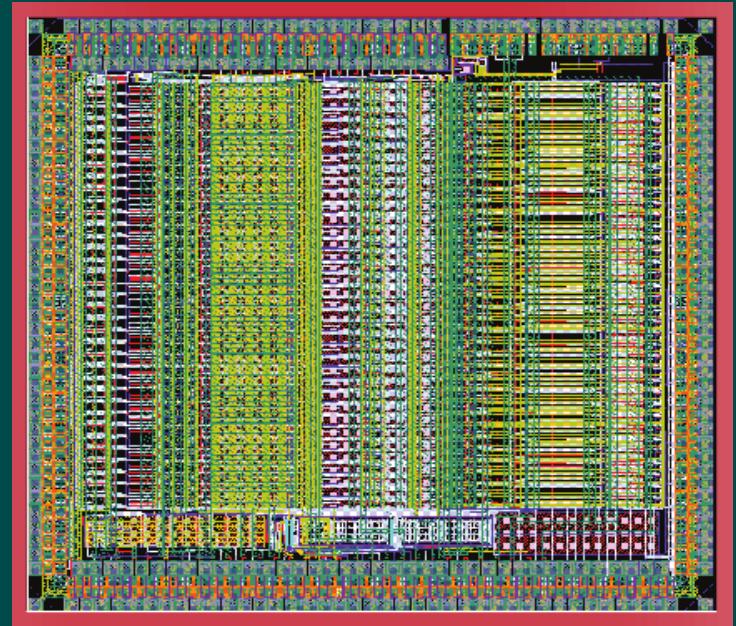
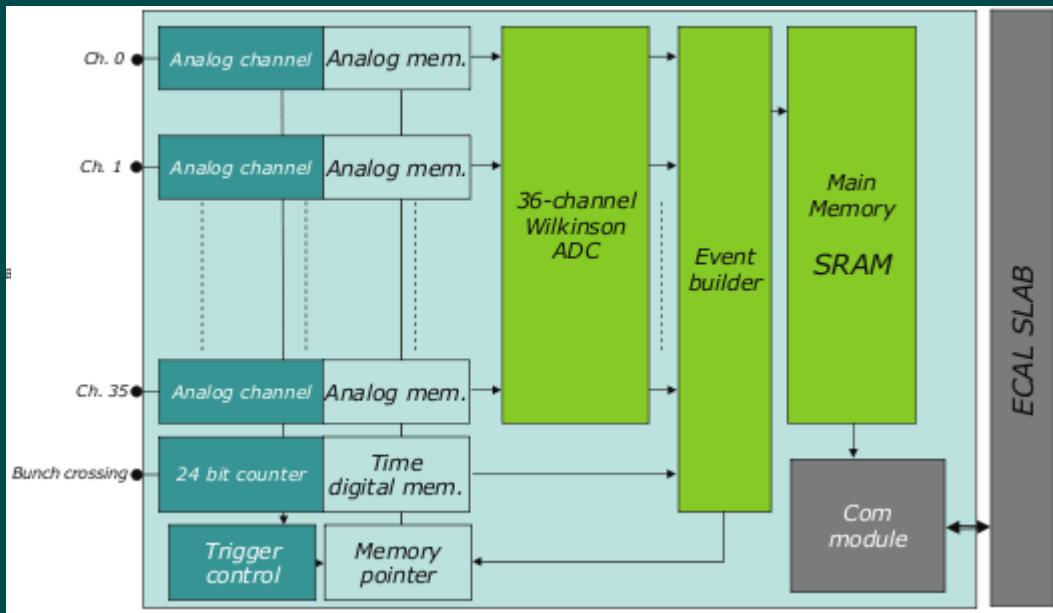
Industrialisation



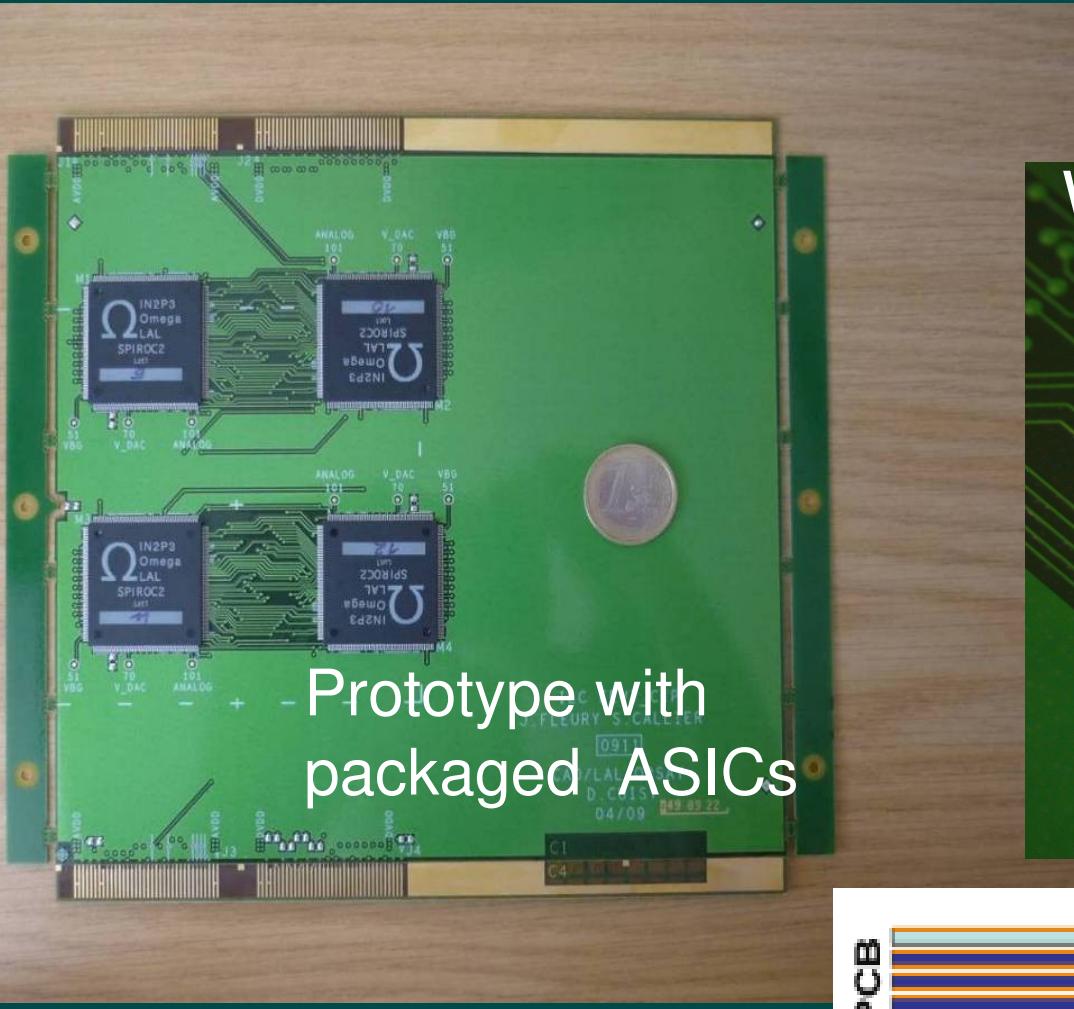
Low power Very Front End ASIC – SKIROC2

64 channels, variable gain charge amp, 12-bit ADC, digital logic

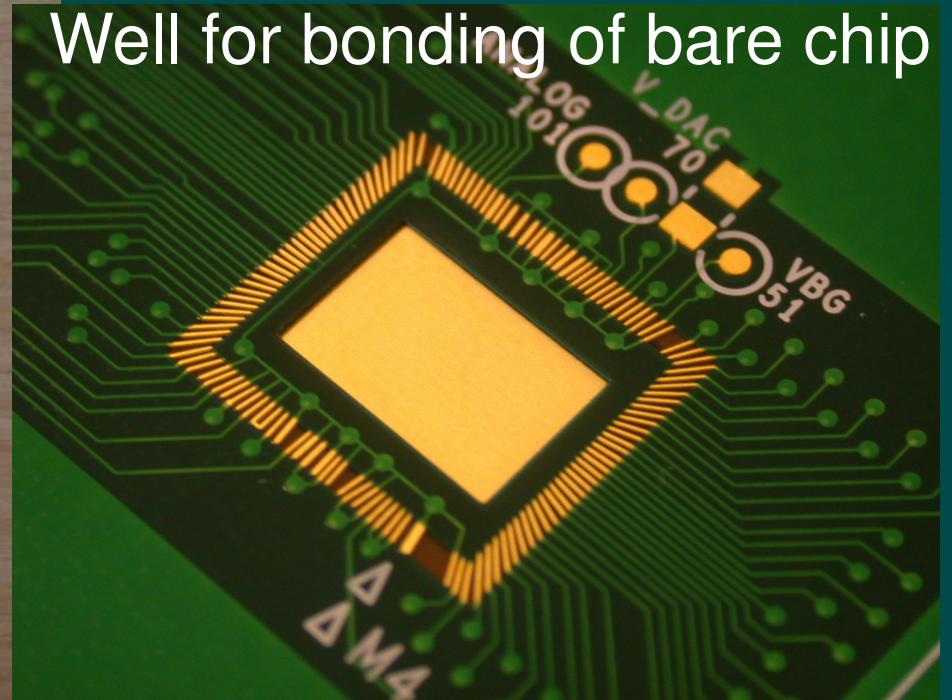
Power-pulsed → 25 µW/channel



Thin PCB with embedded FE electronics thickness ~ 1mm



Prototype with packaged ASICs

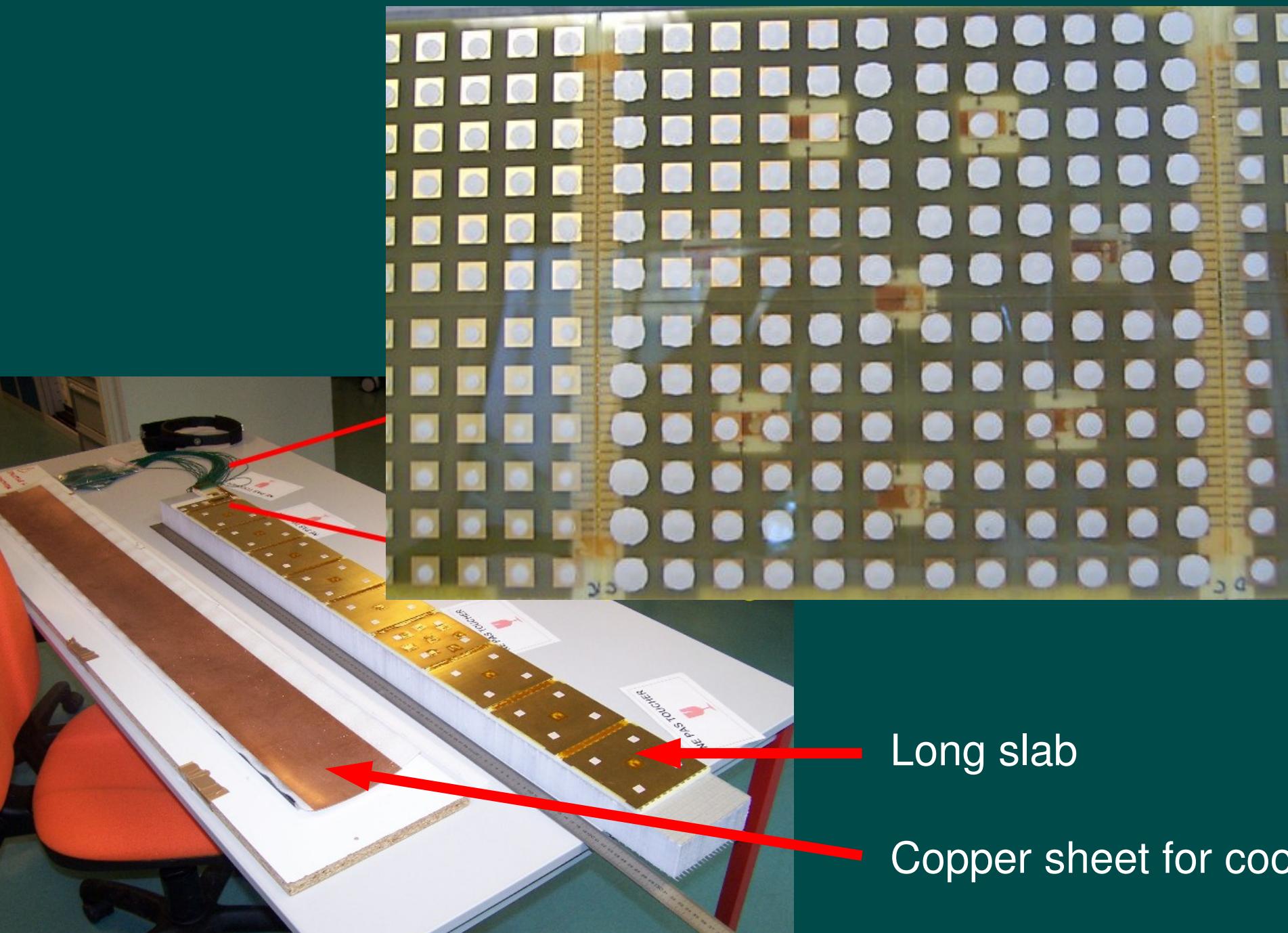


Well for bonding of bare chip



Detector slab construction

PCB stitching Gluing of Silicon sensor

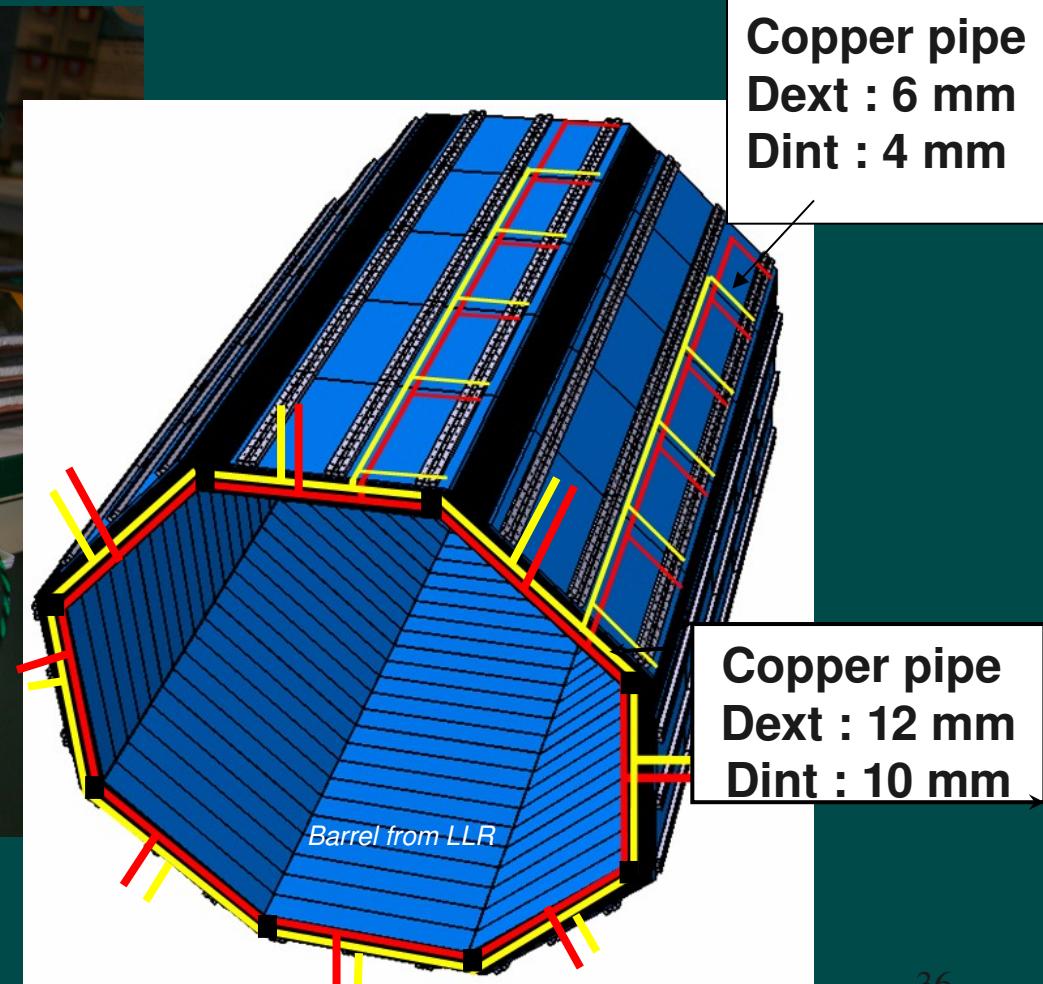


Cooling studies

Total ECAL power dissipation $O(10 \text{ kW})$
Leakless water cooling system



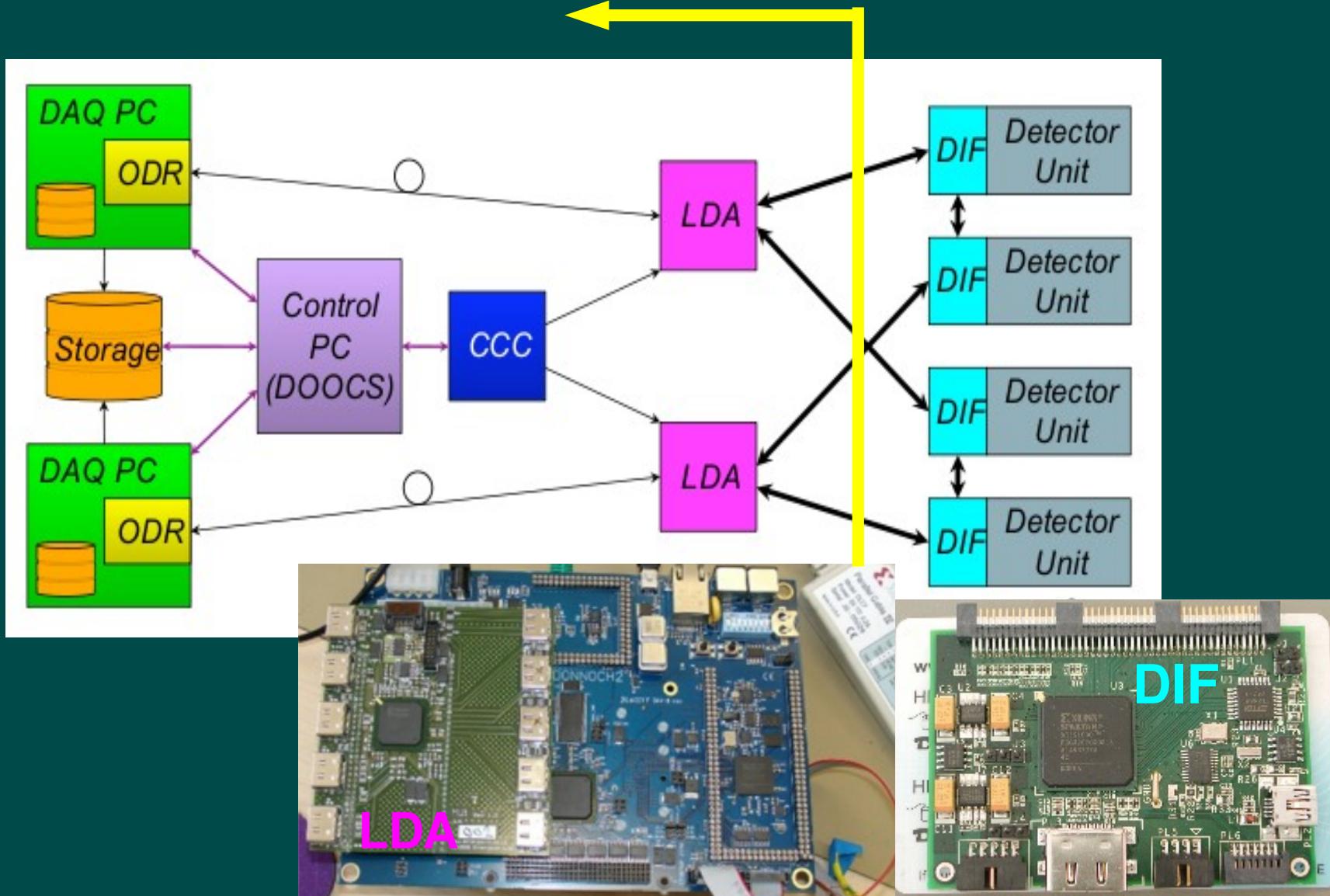
Cooling tests in demonstrator module



DAQ system

Scalable, robust system based on off-the-shelf components

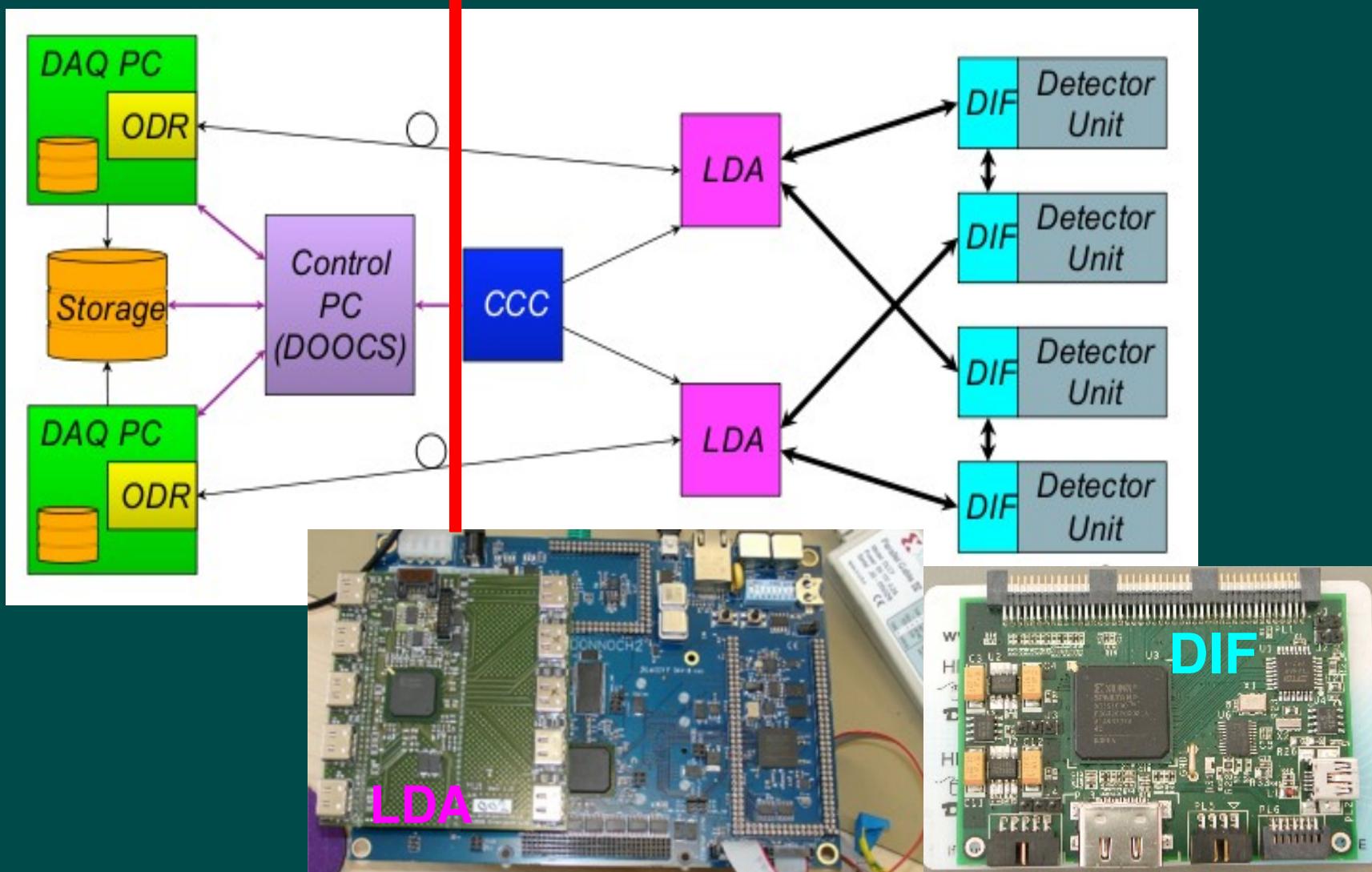
Common to CALICE calos



DAQ system

Scalable, robust system based on off-the-shelf components

Inside detector



Summary

LC calorimeters must have unprecedented jet energy resolution

Particle flow technique with highly granular calorimeter can achieve this

CALICE very active program of LC calorimeter development
- wide range of technologies under study

Si-W ECAL

Physics prototype has proved that this is a suitable technology

Next generation prototype is addressing
Sensor improvements & industrialisation
Low power FE electronics incorporated in detector volume
Integration (cooling, services)

Good understanding of how to build ECAL

POSTERS

* KOTERA, Katsushige

Study of granular electromagnetic calorimeter with PPDs and the scintillator strips for ILC

* REPOND, Jose

Digital Hadron Calorimeter: a novel approach to calorimetry

* LAKTINEH, Imad KIEFFER, Robert

Semi-Digital Hadronic Calorimeter Using GRPCs for Future Linear Collider Experiments

* SIMON, Frank SEIDEL, Katja

Particle Showers in a Highly Granular Hadron Calorimeter

* CHEFDEVILLE, Maximilien

Application of Micromegas in hadronic calorimetry

Backup slides

SKIROC ("Silicon Kalorimeter Integrated Read-Out Chip"):

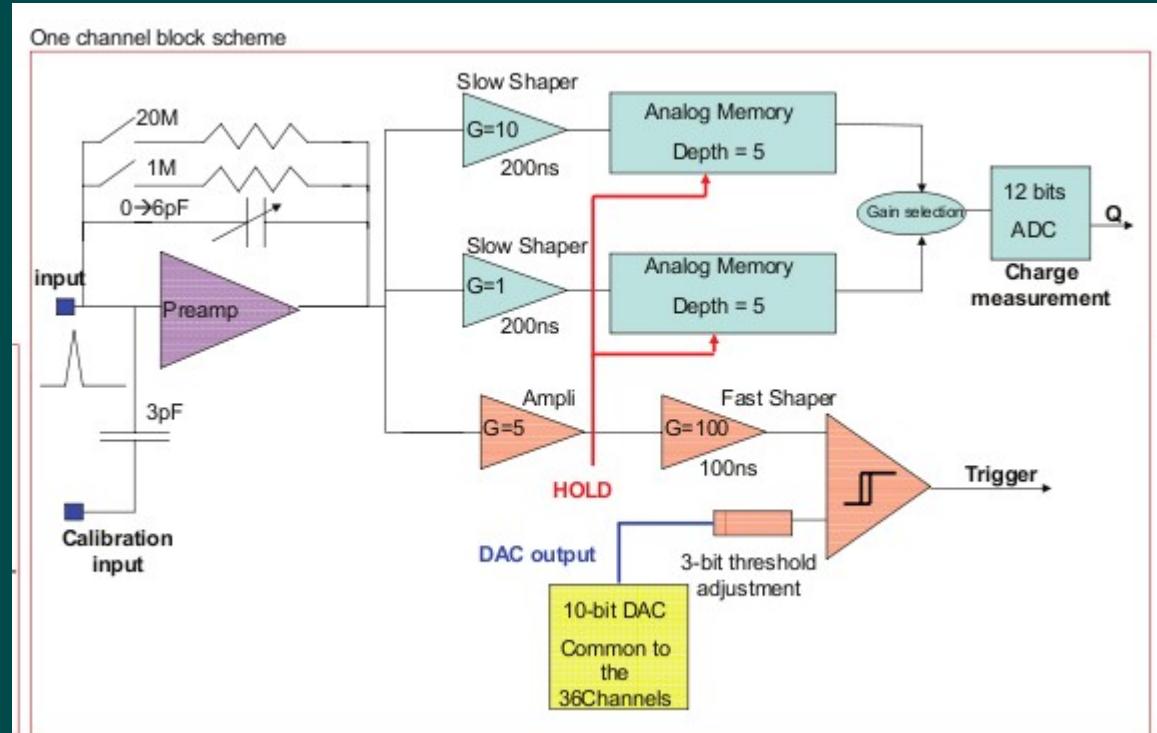
64 channels

charge preamplifier for charge measurement down to the MIP (3.84 fC) to maximum around 2500 MIP.

Dual gain shaping, analog memory, 12 bit-digitisation, self-trigger capability on single MIP.

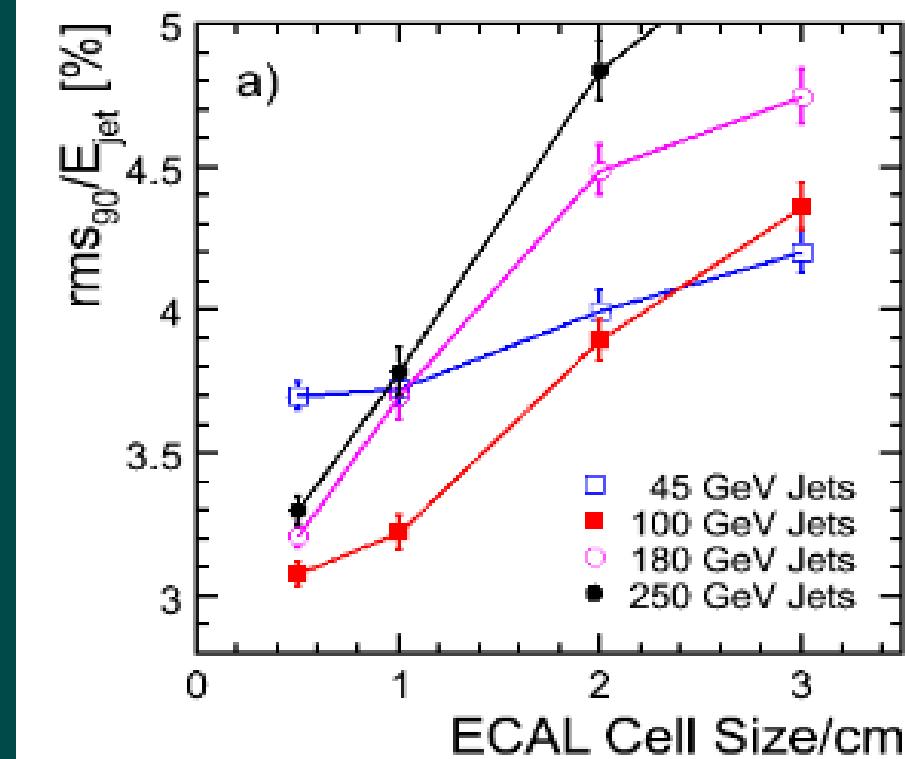
25 μ W/ per channel → no active cooling

Charge injection → in situ calibration



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.

