ECAL ("all options")

Status of the ILD simulation

Daniel Jeans (The University of Tokyo)
for the ECAL groups

@ ILD meeting, ALCW2015, KEK
April 2015

FR LAL
LLR
LPC
LPNHE
LPSC
OMEGA

JP U. Kyushu
Niigata D.U.
U. Shinshu
U. Tokyo
U. Tsukuba

KR KNU
SKKU

UK U. Birmingham
U. Sussex

DE DESY

ECAL (“all options” *)

Status of the ILD simulation

* I will cover only the “baseline”
si- and sc-ECAL technologies in any detail

“alternative” technologies e.g. MAPS and gas-based readout
are not currently implemented in ILD simulation

there are plans to implement a
MAPS-based ECAL model into ILD

ECAL ("all options")

Status of the ILD simulation *

* I will discuss Mokka simulation used
for and since the DBD

I do not yet know enough about the status of the
new DD4HEP-based simulation to comment

For this meeting we like to ask you to discuss the state of the simulation of the different calorimeter components in ILD.

We like to understand better where the different technologies stand in terms of simulating the system, in terms of modelling the reality, checking against test beam data, we like to understand better to what extend your system is understood and has been validated.

We like to also ask you to point out what is missing to arrive at an well understood and validated simulation, what experiments are needed, and roughly, on what time scale this could happen.

Contents

Geometry, materials

- mechanical structure; services; supports

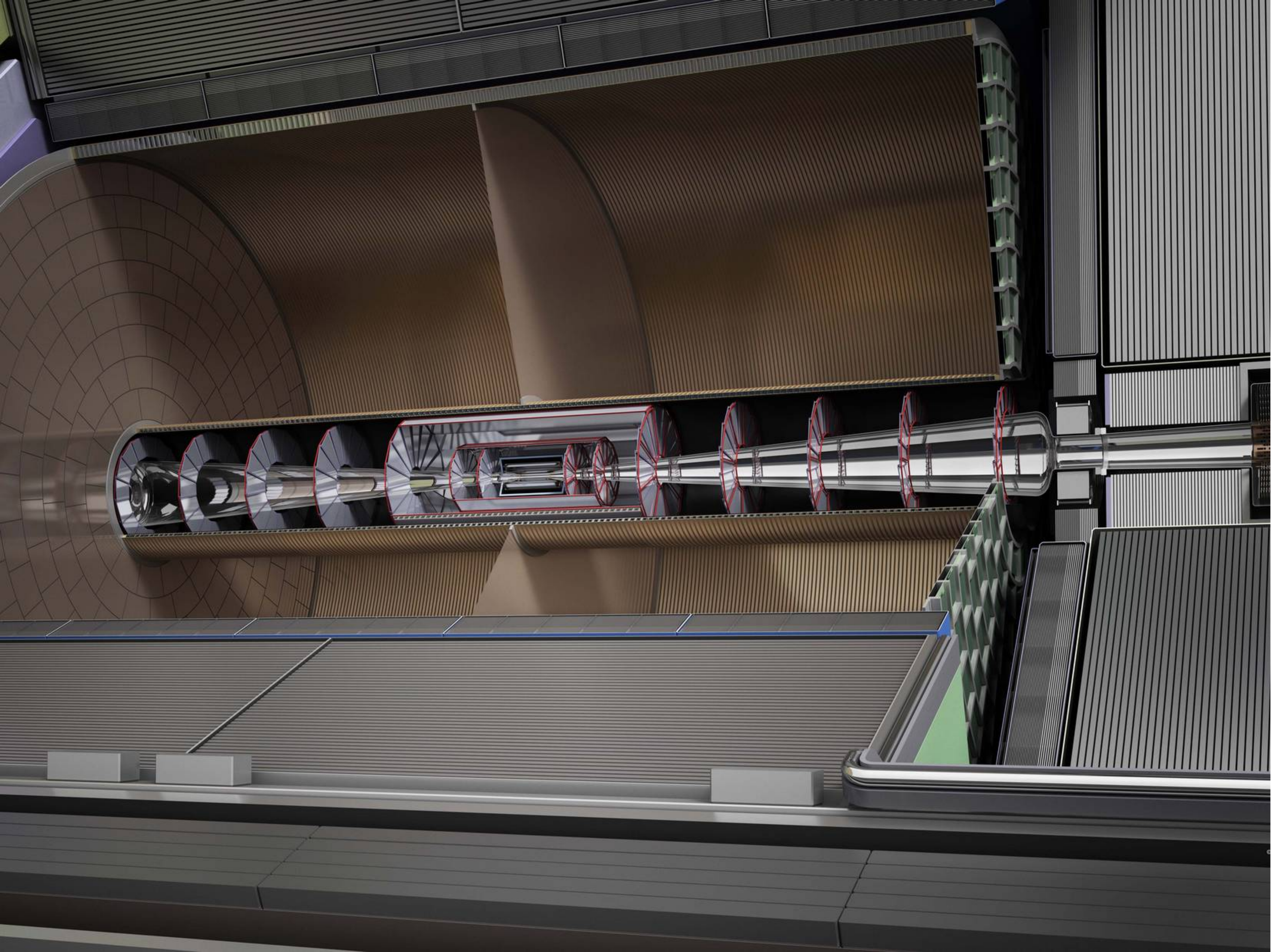
- active layers: silicon, scintillator

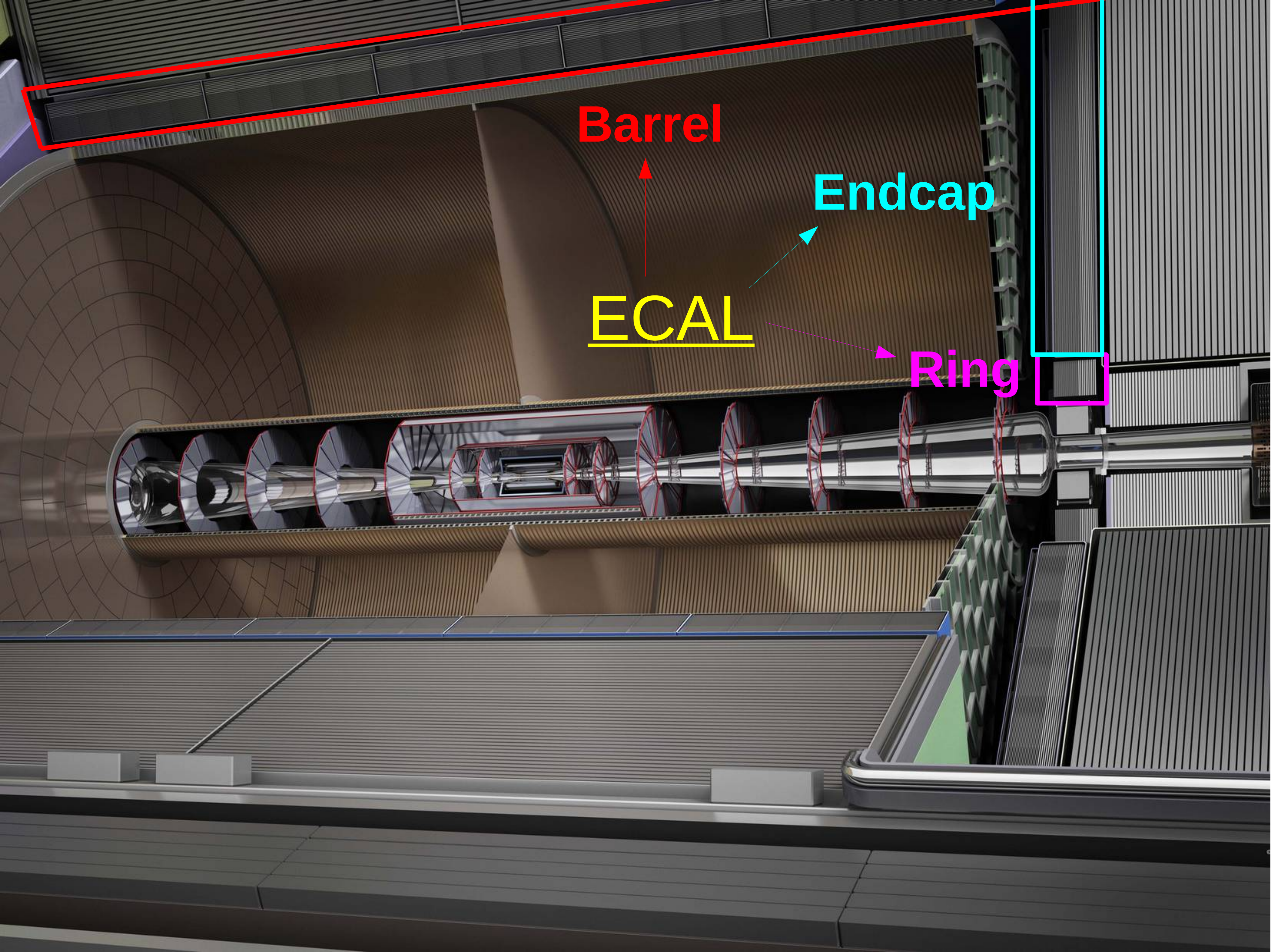
Hit digitisation

Description of test beam performance

- “Physics” prototypes

- “Technological” prototypes

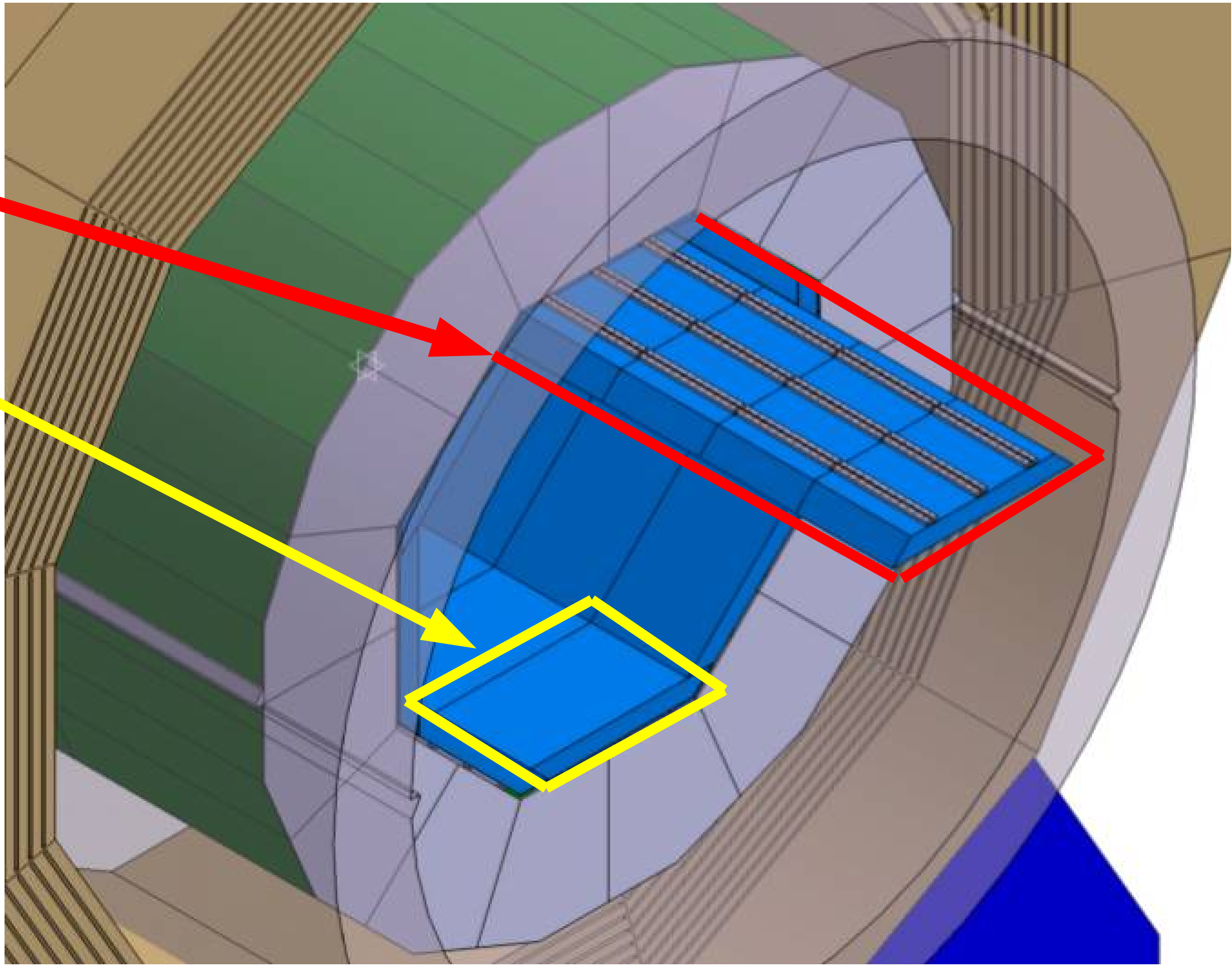



Barrel
Endcap
ECAL
Ring

Mechanical structure
~ independent of readout technology

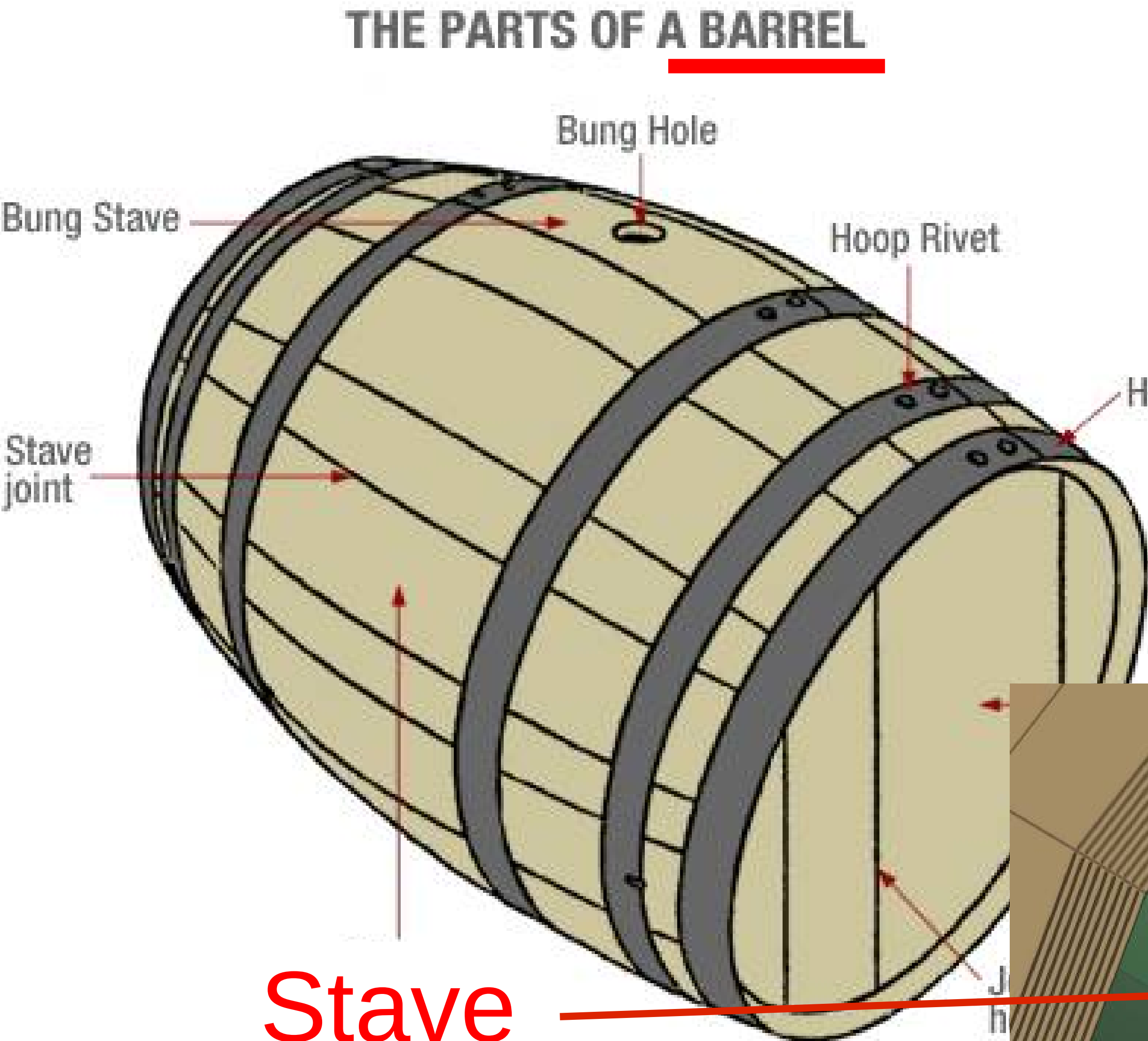
Barrel:

8 staves in azimuth
each with
5 modules in z

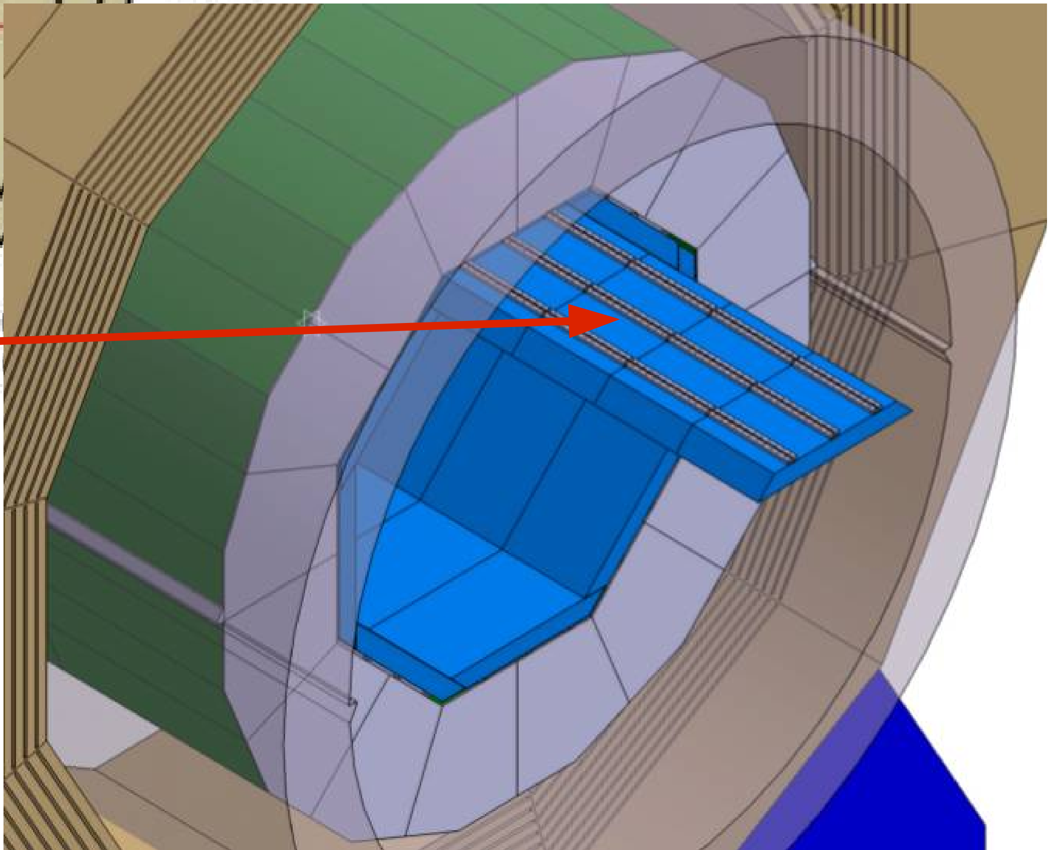


All 40 modules are usually chosen to be identical

Since silicon wafers are available in only a few sizes (4”, 6”, 9”), cost-efficiency imposes a quantisation of the module dimension along z for siECAL

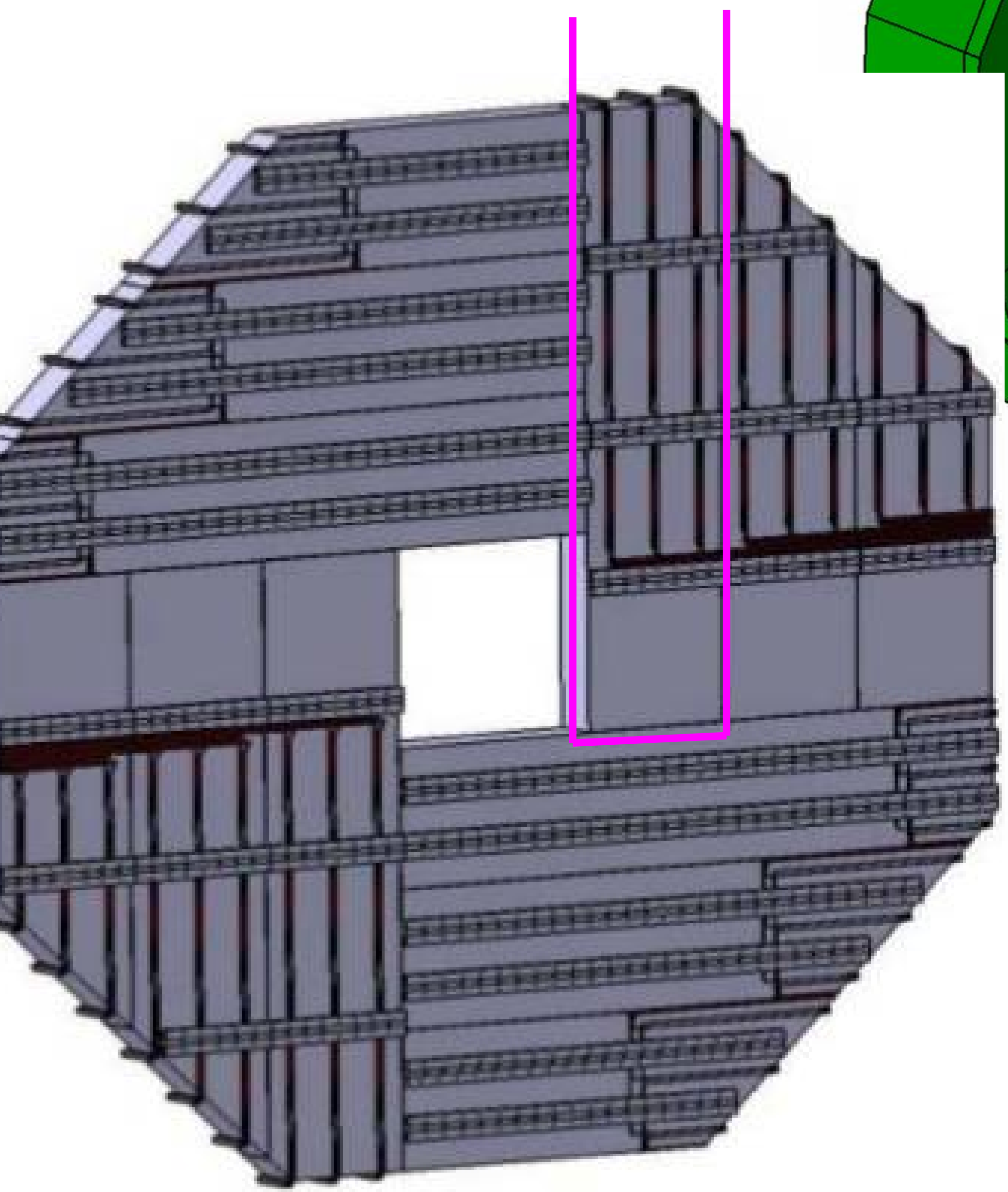


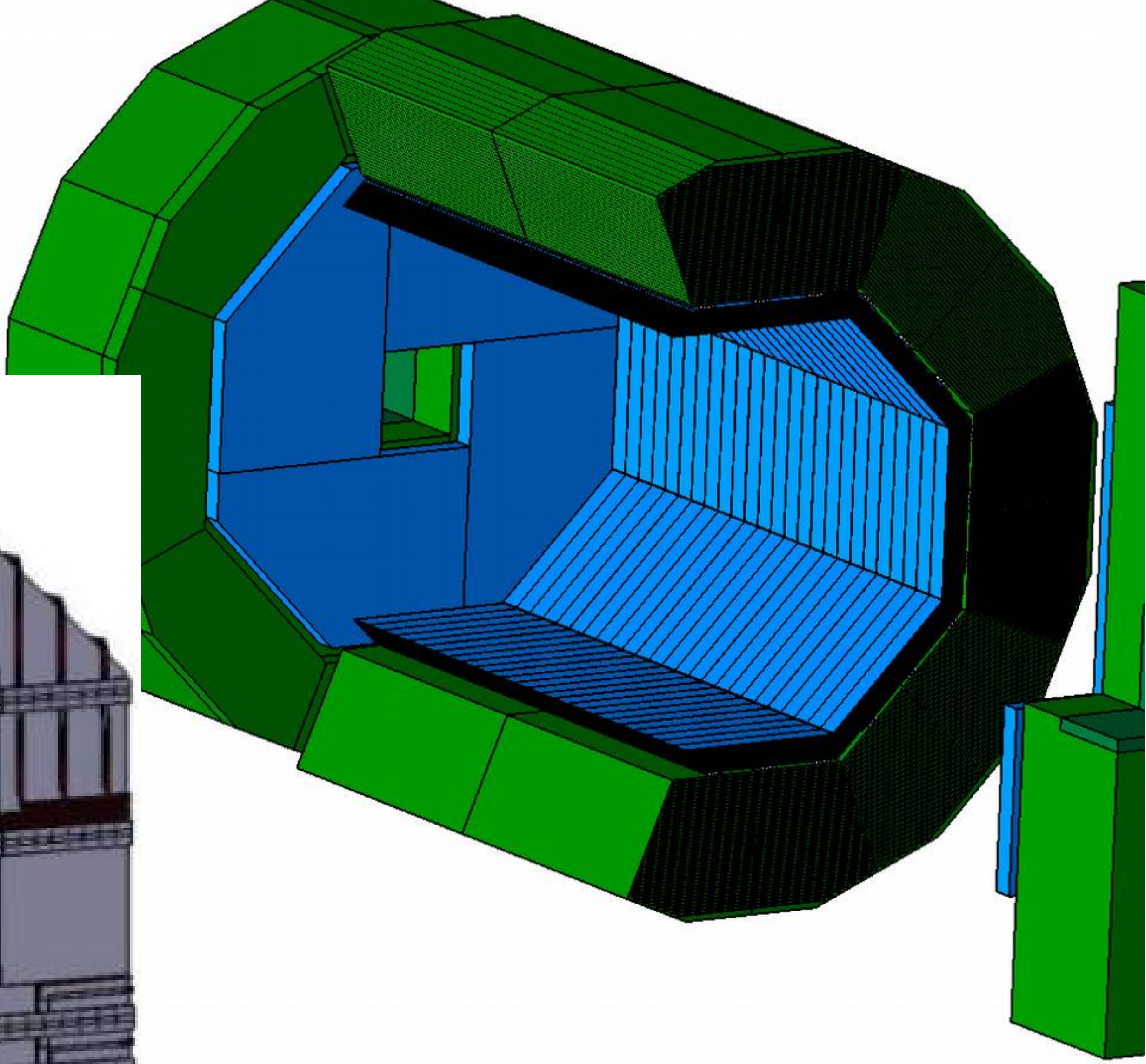
Stave



You may find the contents of one rather more intoxicating than that of the other...

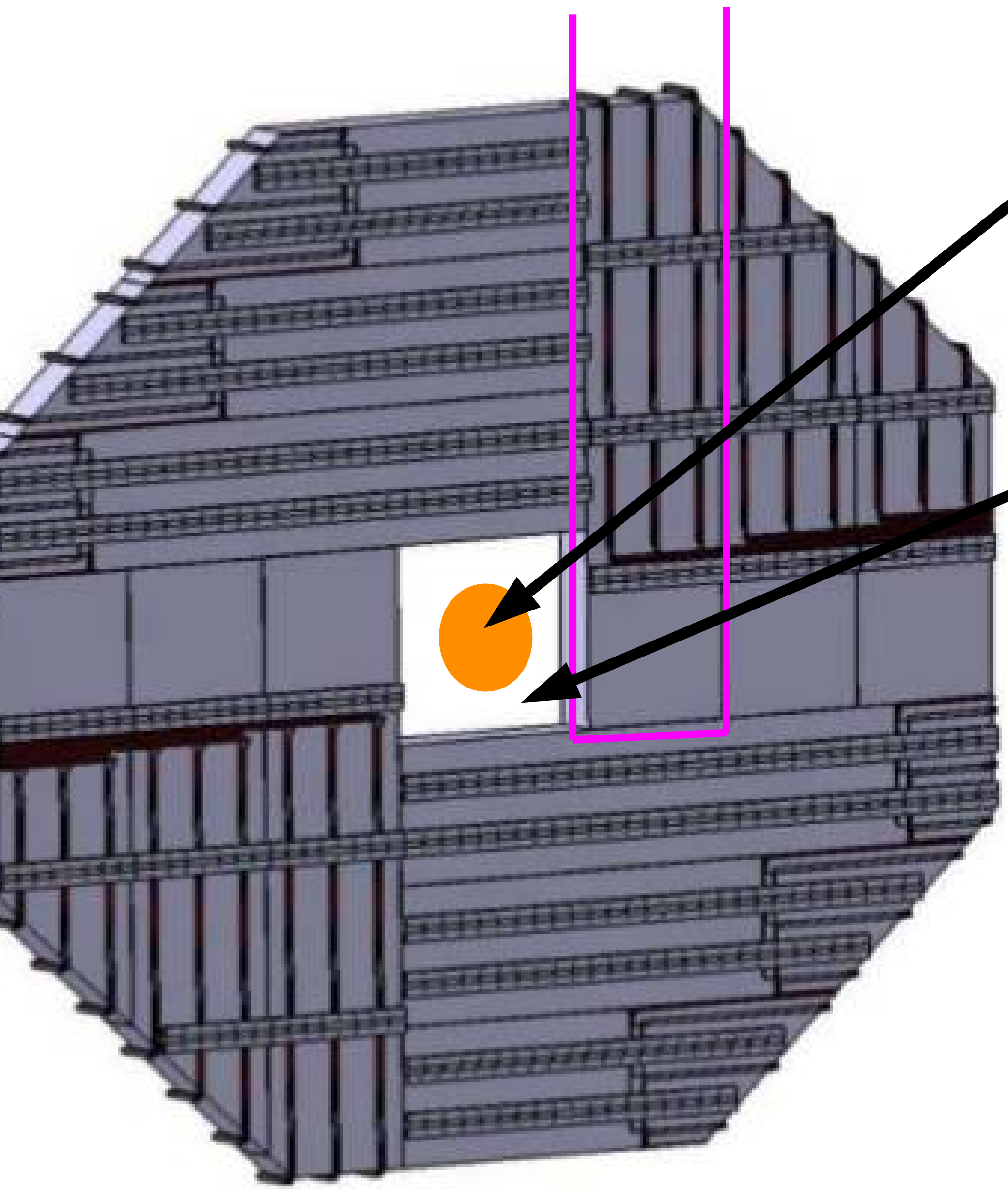
2 endcaps,
4 quadrants,
3 modules





ECAL endcap

2 endcaps,
4 quadrants,
3 modules



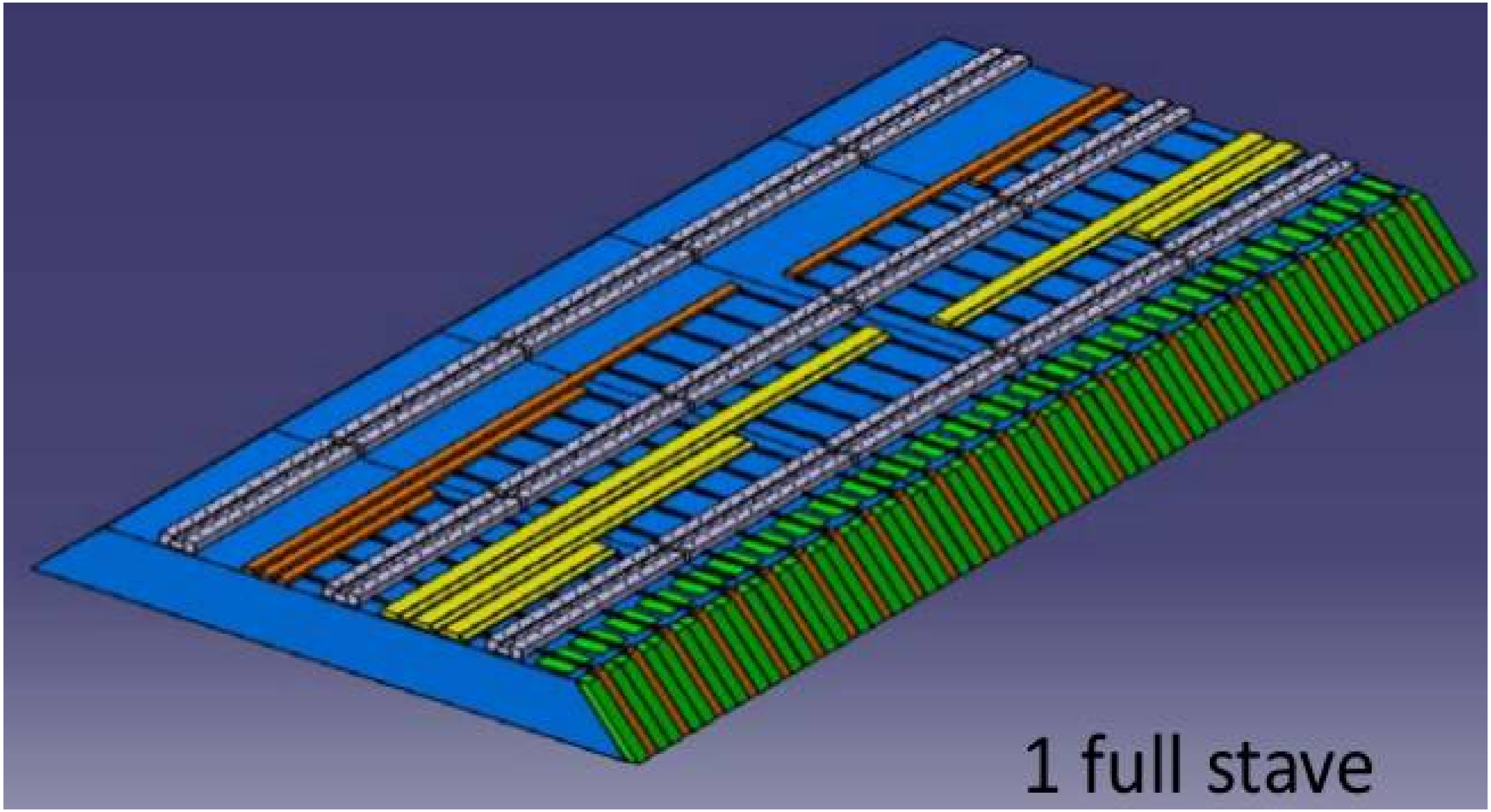
LumiCal
- belongs to FCAL

ECAL ring

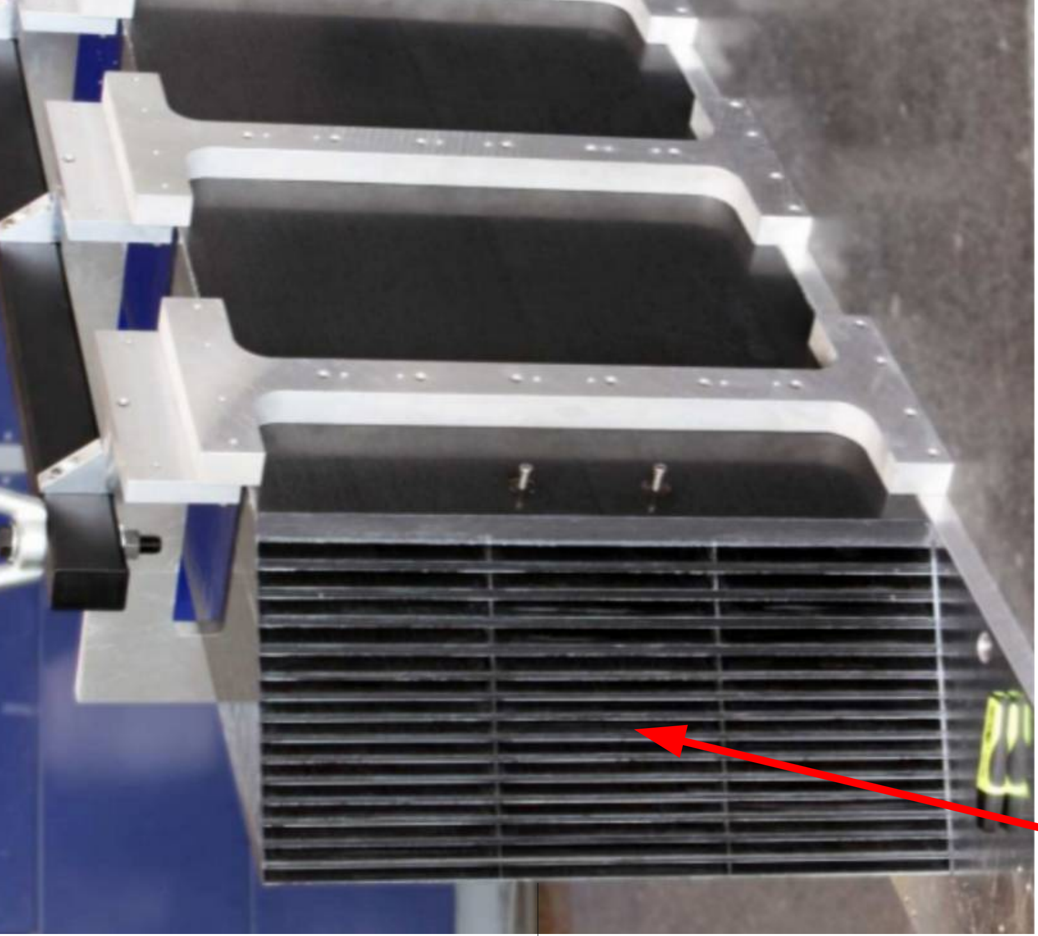
No detailed mechanical design exists

→ geometrically simplistic simulation based on si-ECAL

Services (cooling water, HV, DAQ) run in ~3cm gap between ECAL & HCAL



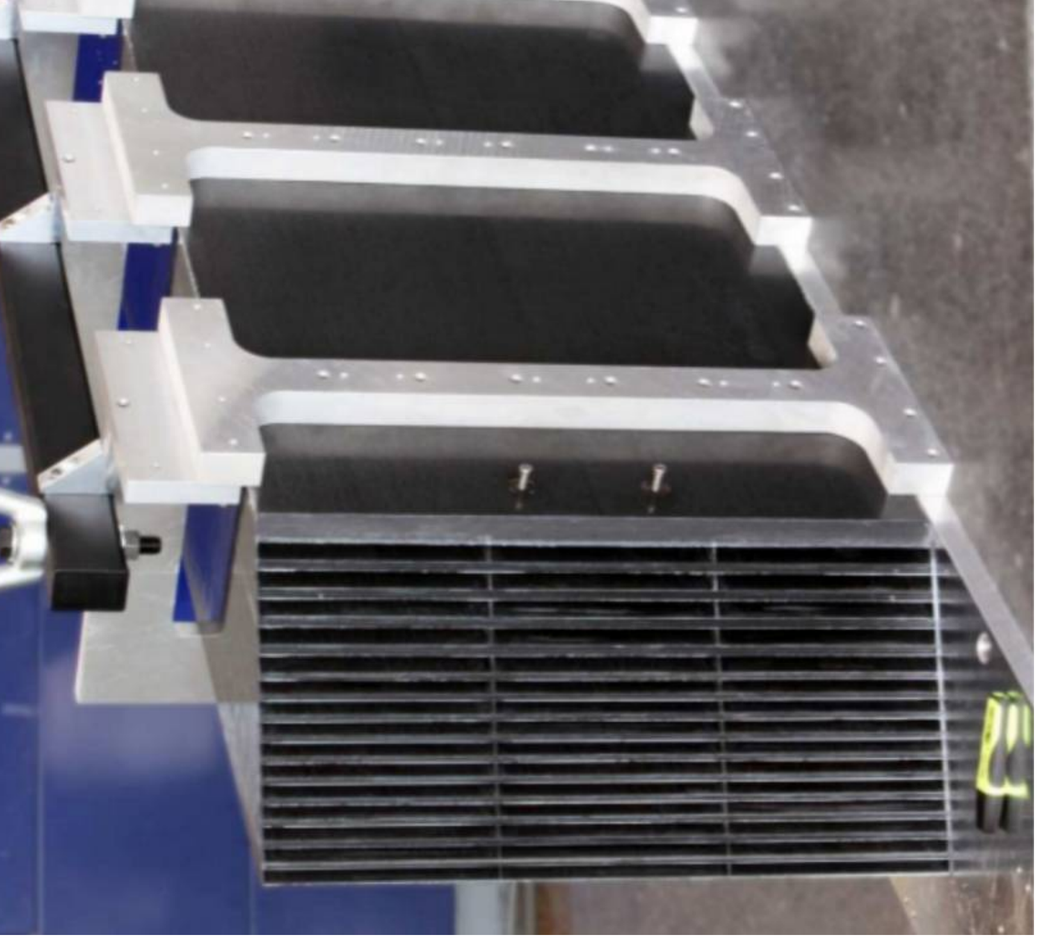
An averaged layer of this service material is implemented in the simulation



Barrel and Endcap modules have similar “alveolar” structure

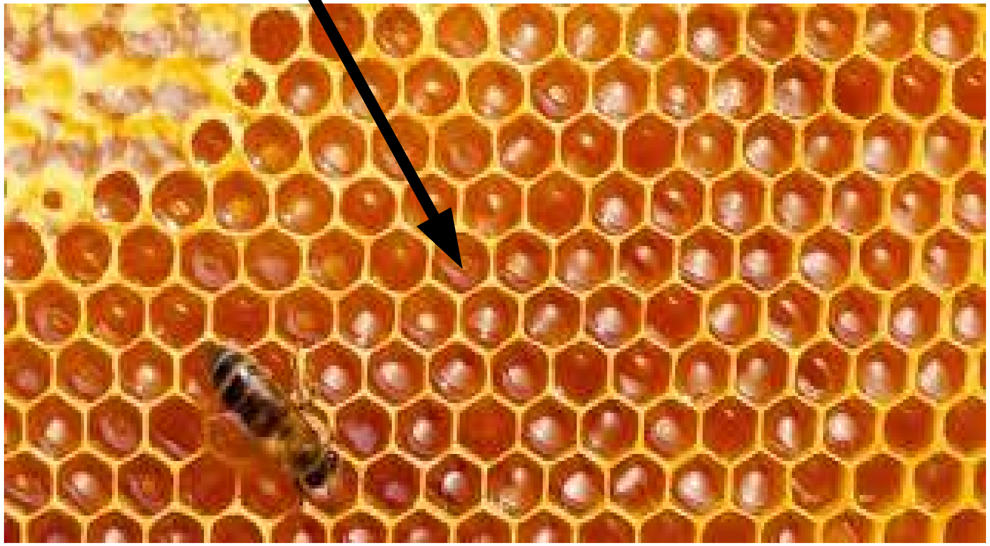
Sensitive layers
“slabs”
are housed within this structure

Towards IP

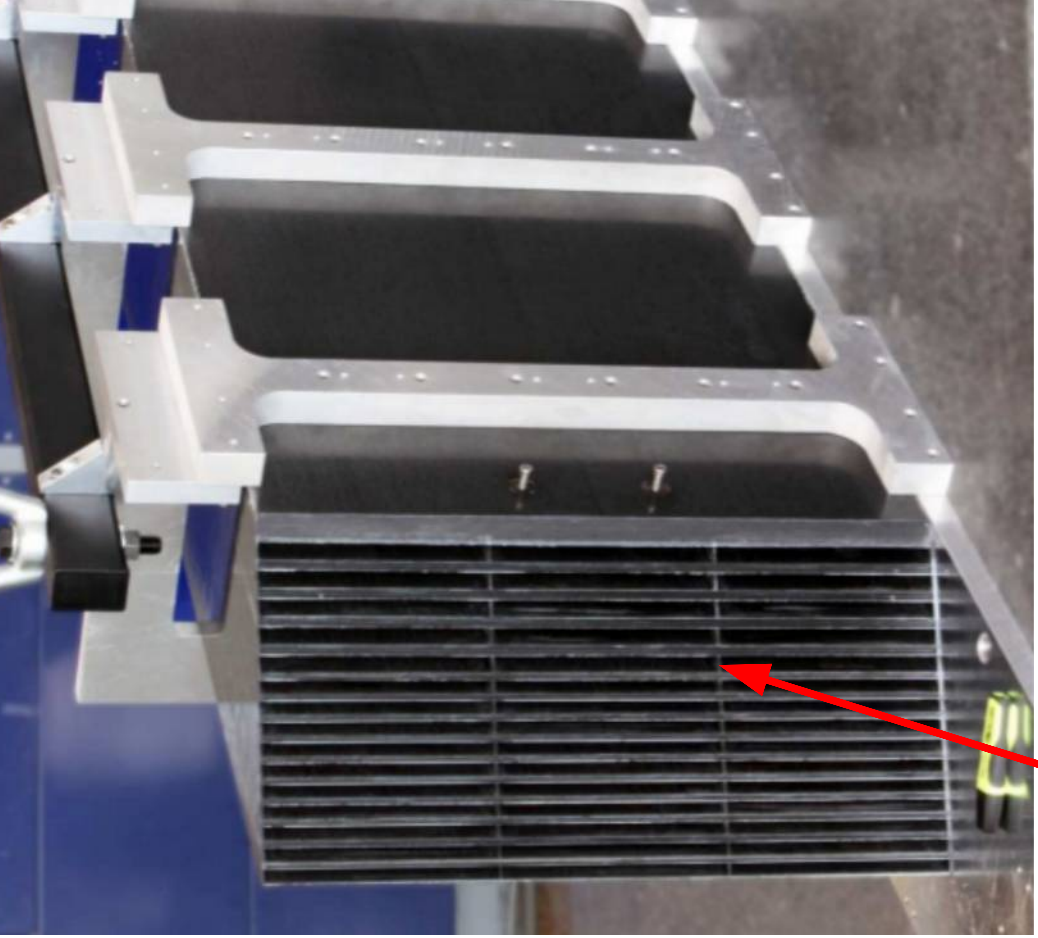


Barrel and Endcap modules have similar "alveolar" structure

In French, alvéole can refer to a cell of a honeycomb



In English, alveolus usually refers to an airsac within the lung.
I could not find an attractive photo to illustrate this.

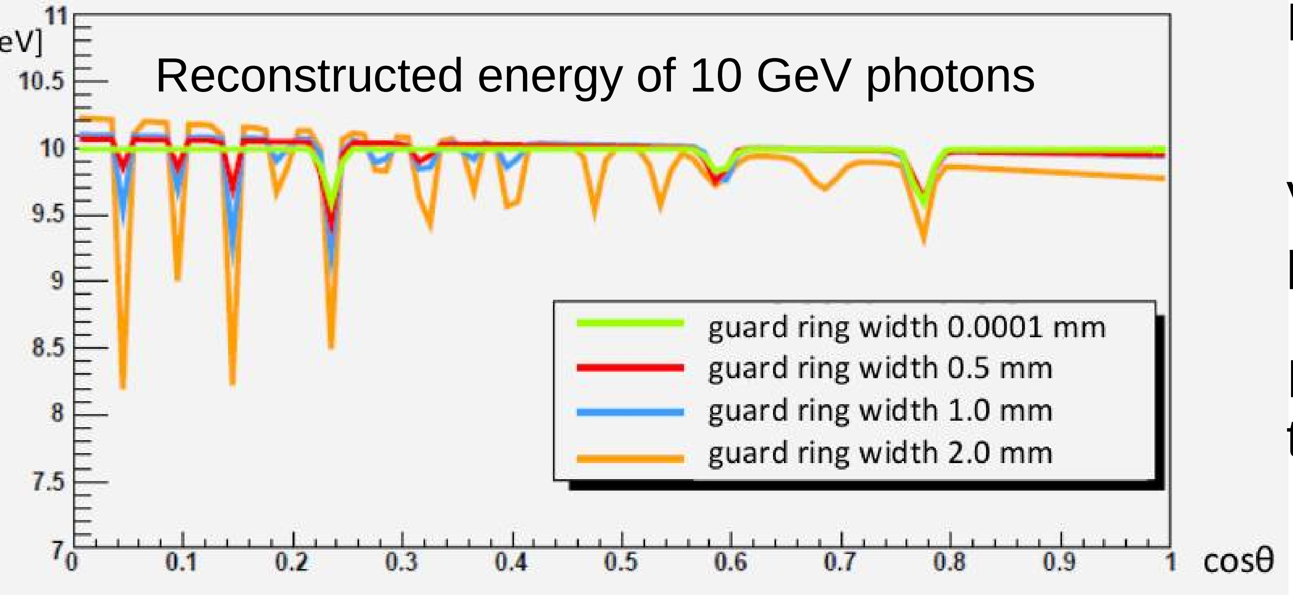


Barrel and Endcap modules have similar “alveolar” structure

Carbon fibre composite

Tungsten absorber to induce EM showers

Structural supports thin,
but so is the core of EM showers

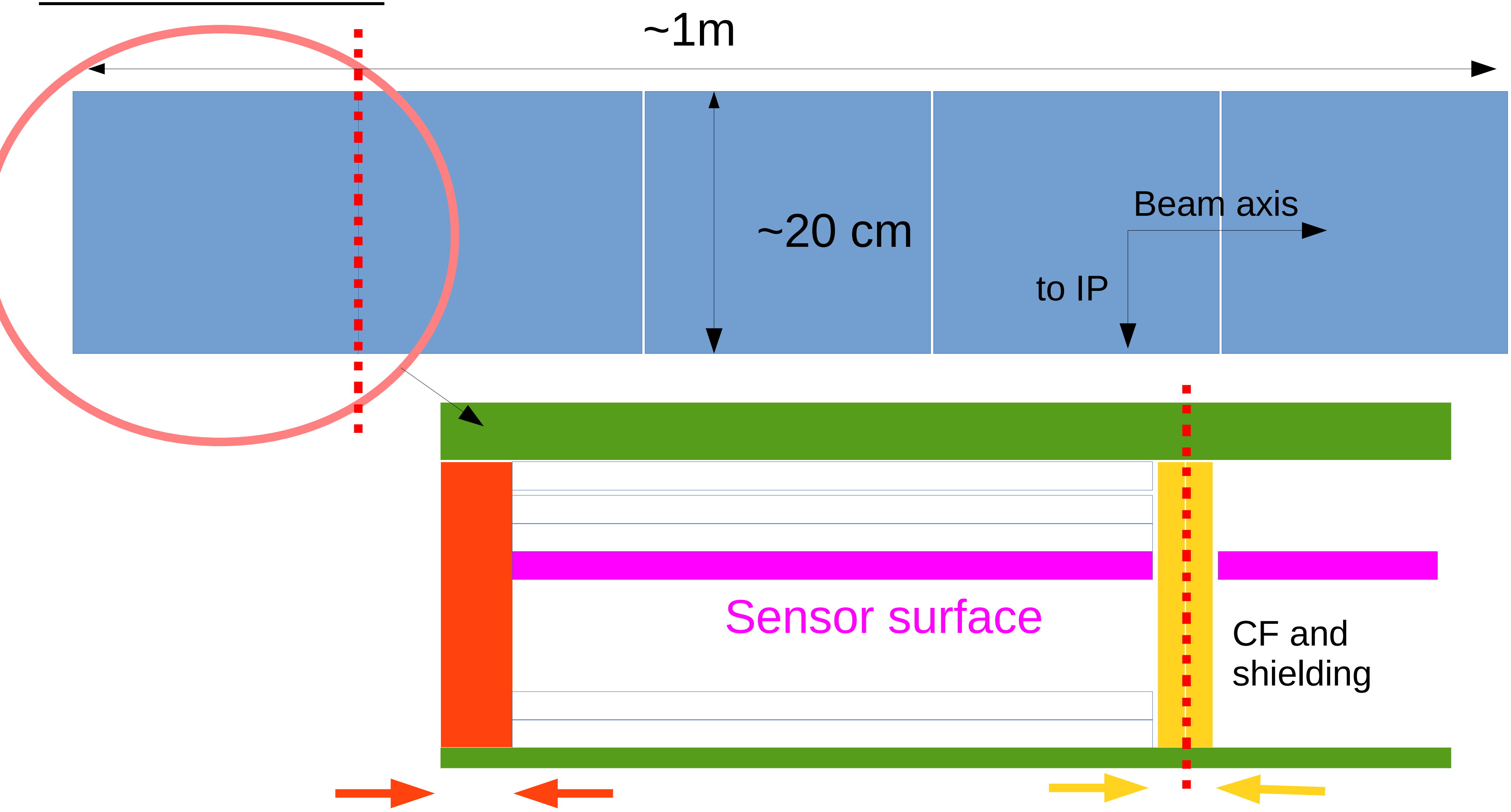


No projective cracks,
but not far off at cos θ ~ 0

Visible effect on reconstructed photon energies

Important to reasonably describe these cracks in simulation

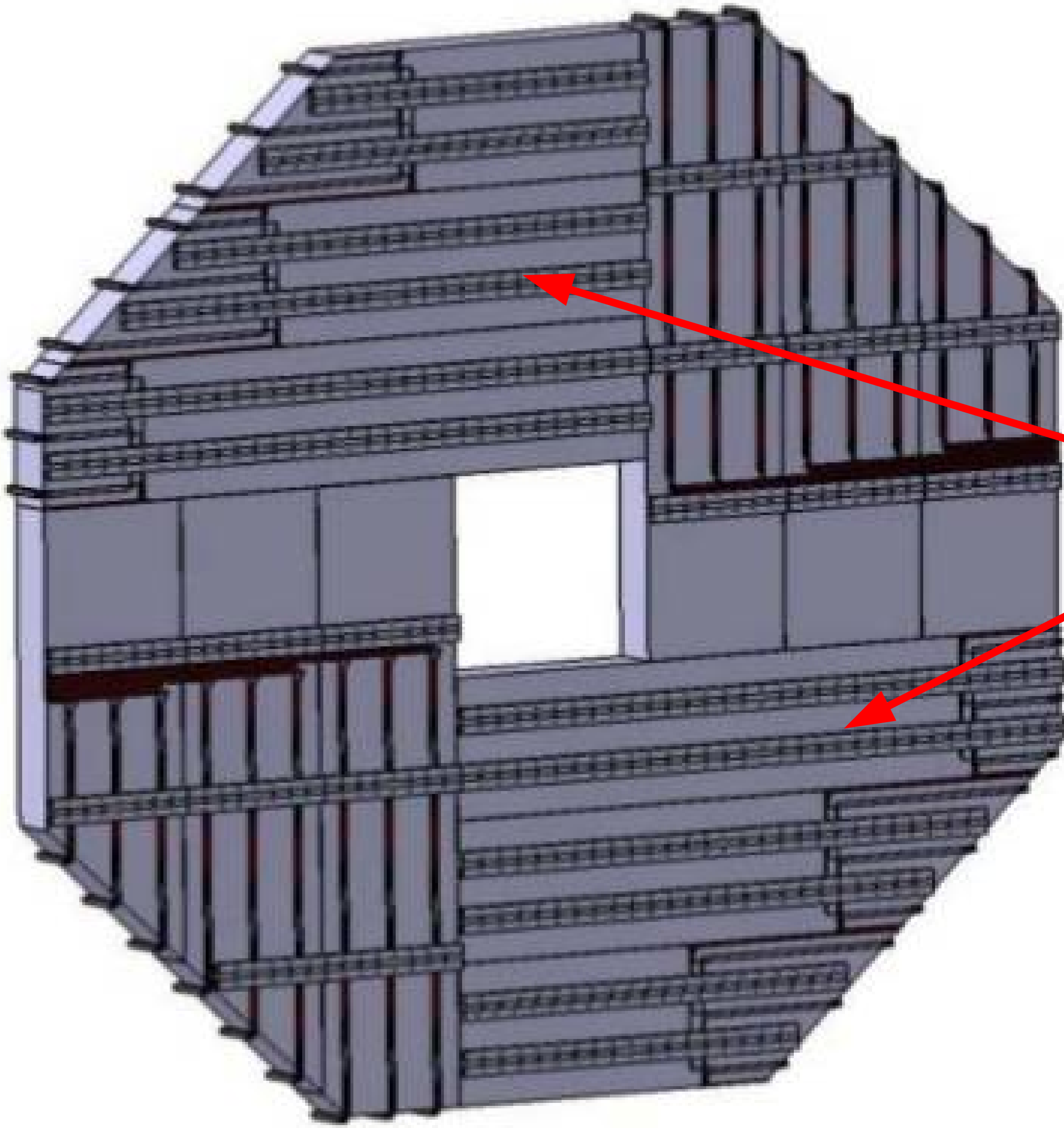
Barrel module



Mechanical design (from engineers via H. Videau)

	2.61	2.58 mm
Mokka model:	3.10	2.20 mm

Rather good description: within reasonable uncertainties

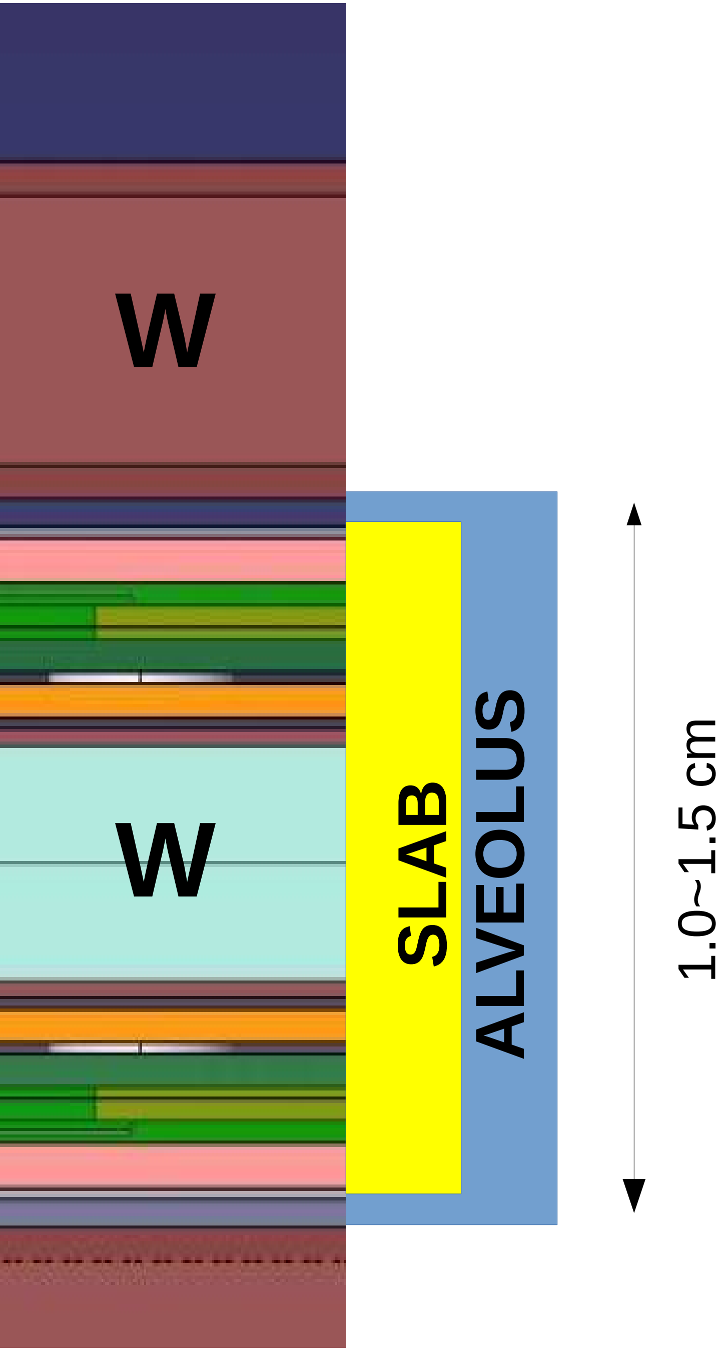


<u>Endcap mechanics</u>

Alveolar structure is intrinsically less rigid when in horizontal configuration: detector mass tends to shear the structure

Thicker supporting walls may be required, especially with seismic issues: mechanical tests and simulations are continuing

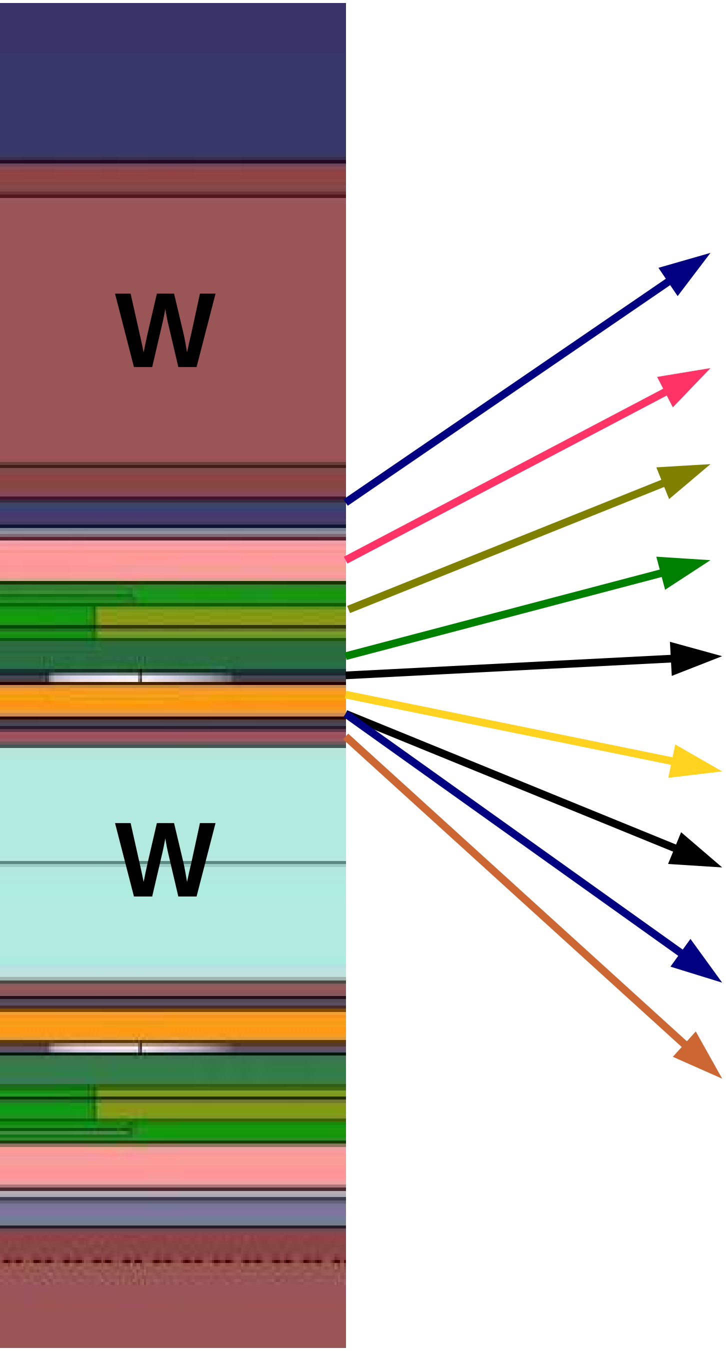
Materials within the SiECAL slab



A good description of the materials within the slab is needed to successfully model the shower shape:

average
Radiation Length - longitudinal
and
Molière Radius - transverse
of the ECAL

Materials within the SiECAL slab



Thickness (microns)	Mechanical	Simulation
air	150	250
Shield (~Cu)	600	500
ASIC	1200	0
PCB	1600	800
glue	100	100
silicon	300~725	500
glue	100	0
HV kapton	100	100
Carbon Fiber	150	150

SiECAL slab

Thickness (microns)	Mechanical	DBD Simulation
air	150	250
Shield (~Cu)	600	500
ASIC	1200	0
PCB	1600	800
glue	100	100
silicon	300~725	500
glue	100	0
HV kapton	100	100
Carbon Fiber	150	150

Significant thickness taken by BGA-packaged ASIC: more robust for mass production.

Thicker PCB to ensure flatness

PCB/ASIC thickness should be increased in next simulation model : non-negligible effect on Moliere radius.

Studies of thinner PCB+ASIC assemblies are underway, but are not yet demonstrated

SiECAL slab

Thickness (microns)	Mechanical	DBD Simulation
air	150	250
Shield (~Cu)	600	500
ASIC	1200	0
PCB	1600	800
glue	100	100
silicon	300~725	500
glue	100	0
HV kapton	100	100
Carbon Fiber	150	150

Current protoypes:
320 um thick silicon

Previous prototypes:
525 um

725 um yet to be tested

Thicker sensors give some improvement of EM energy resolution, but take more space and (I guess) cost more

Scintillator ECAL

Thickness (microns)	Mechanical	DBD Simulation
air	150	250
Shield (~Cu)	500	500
PCB+ASIC	1300	800
reflector	57	57
scintillator	1500 (?)	2000
reflector	57	57
Carbon Fiber	150	150

Scintillator ECAL

Thickness (microns)	Mechanical	DBD Simulation
air	150	250
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reflector	57	57
scintillator	1500 (?)	2000
reflector	57	57
Carbon Fiber	150	150

1.3mm thickness assumes QFP ASIC package in cavity: may not be suitable for mass production (*c.f.* AHCAL)

Scintillator ECAL

Thickness (microns)	Mechanical	DBD Simulation
air	150	250
Shield (~Cu)	500	500
PCB+ASIC	1300	800
reflector	57	57
scintillator	1500 (?)	2000
reflector	57	57
Carbon Fiber	150	150

Thinner scintillator attractive for compactness

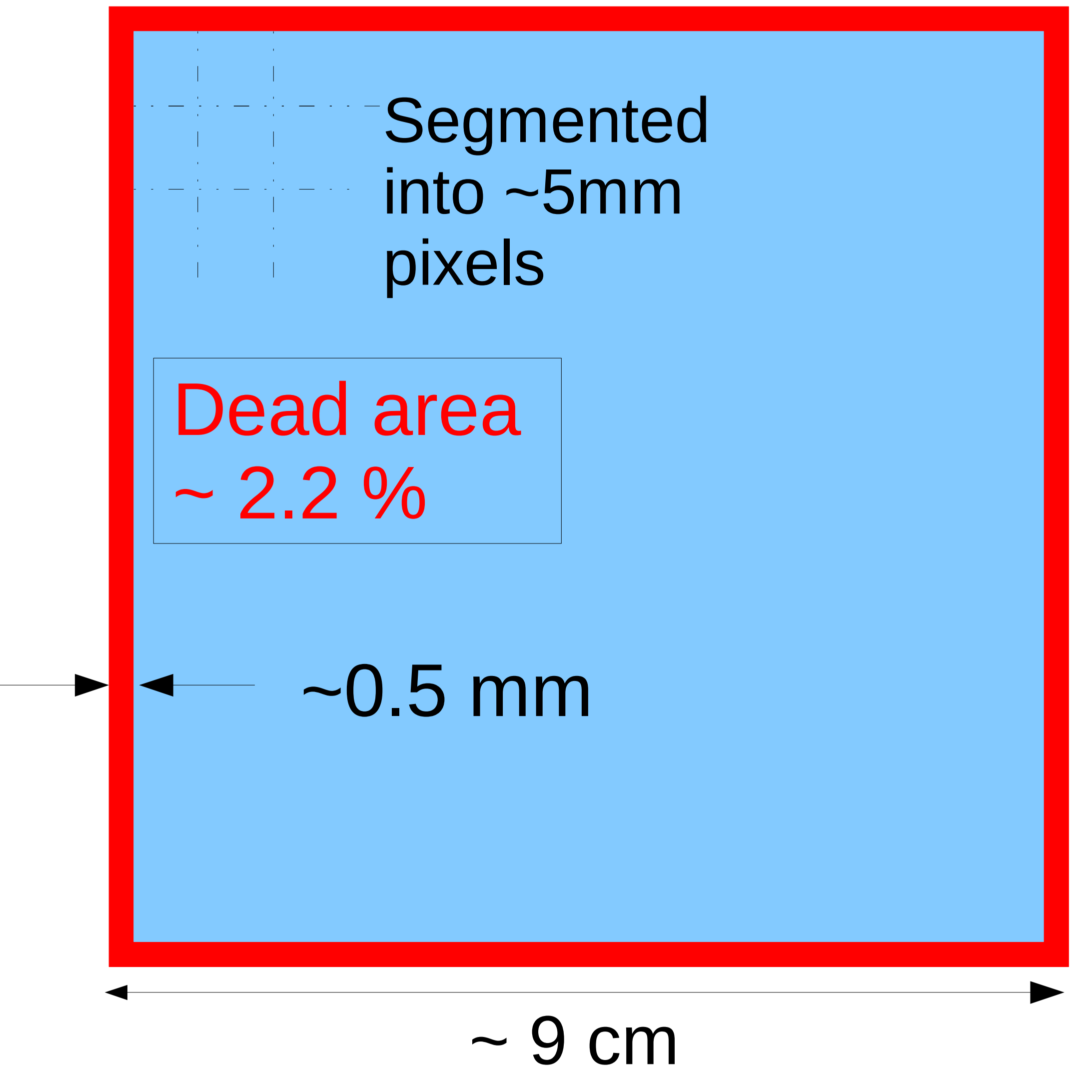
Past and present prototypes have thickness 2~3 mm

Sufficient light yield and uniformity of <2mmscintillator has not yet been demonstrated (simulations suggest it should be OK)

<u>Sensitive surface within slab is tiled with sensors</u>

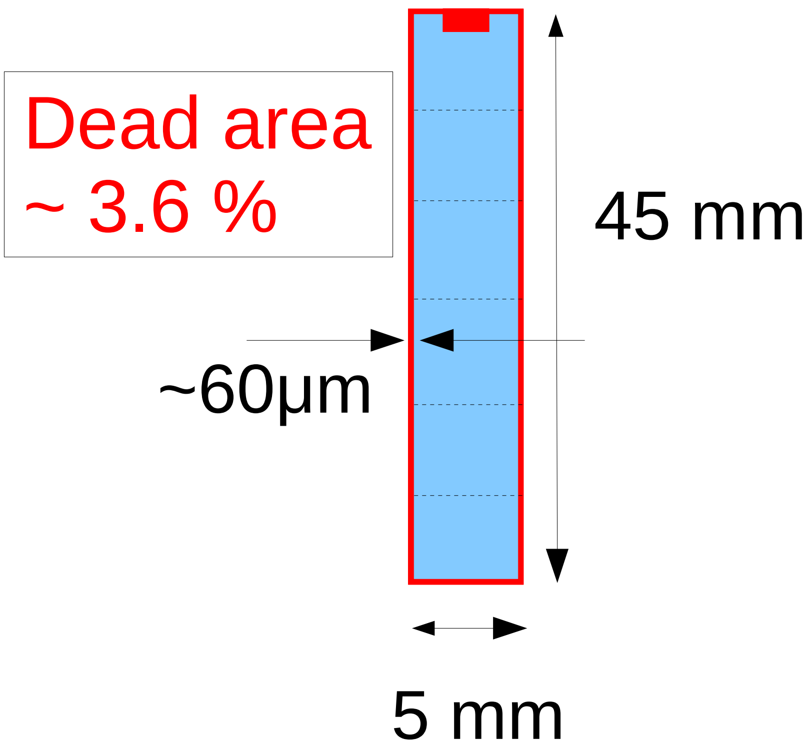
Silicon

Guard ring of silicon sensor



Scintillator

MPPC volume and
reflecting foil around strip

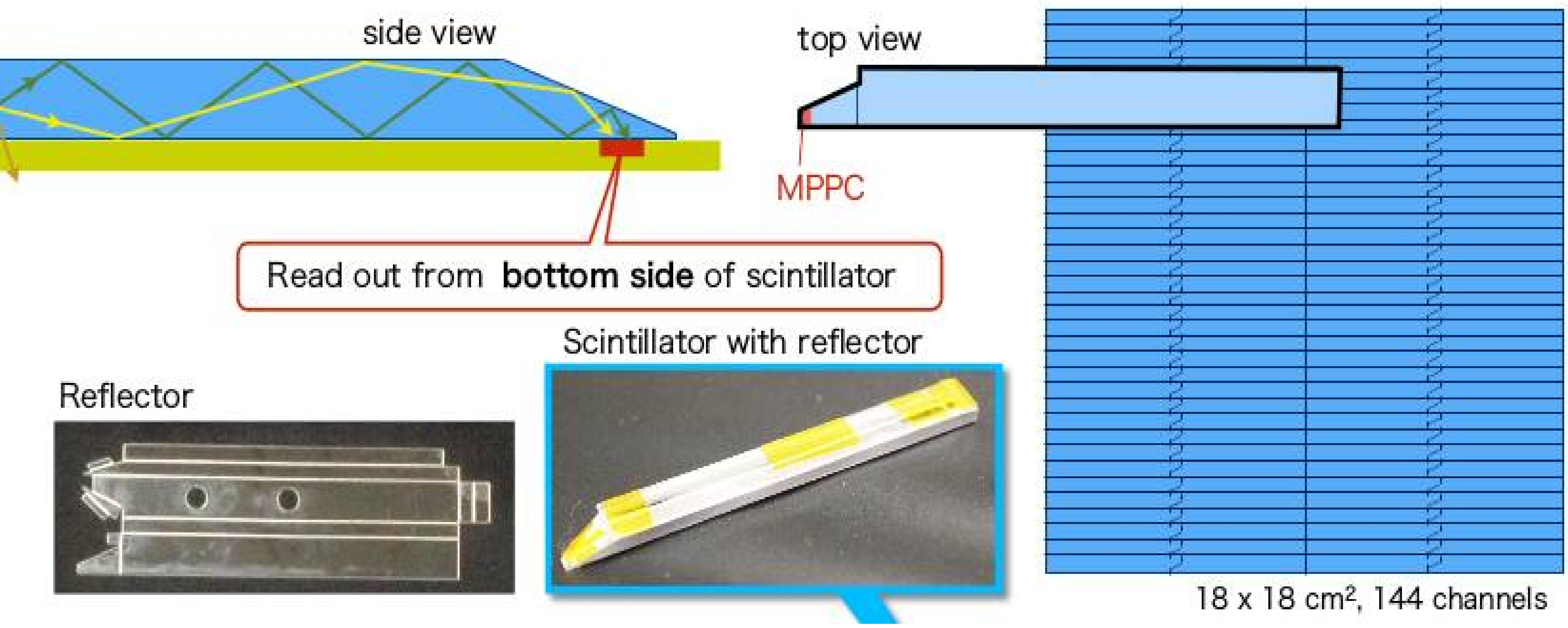


Strip can be segmented into
“virtual cells” along its length
to simulate non-uniformity

These dead area fractions are both reasonable estimates

Bottom-side readout of scintilator strips

Relatively new proposal
Better for mass production: MPPCs integrated in PCB
Reduction of dead area due to MPPC package



This geometry not yet implemented into ILD

Contents

Geometry, materials

- mechanical structure; services; supports
- active layers: silicon, scintillator

Hit digitisation

Description of test beam performance

- “Physics” prototypes
- “Technological” prototypes

Digitisation of hit energies

For DBD: Apply threshold at ~½ MIP
Convert deposited energy to EM-shower energy

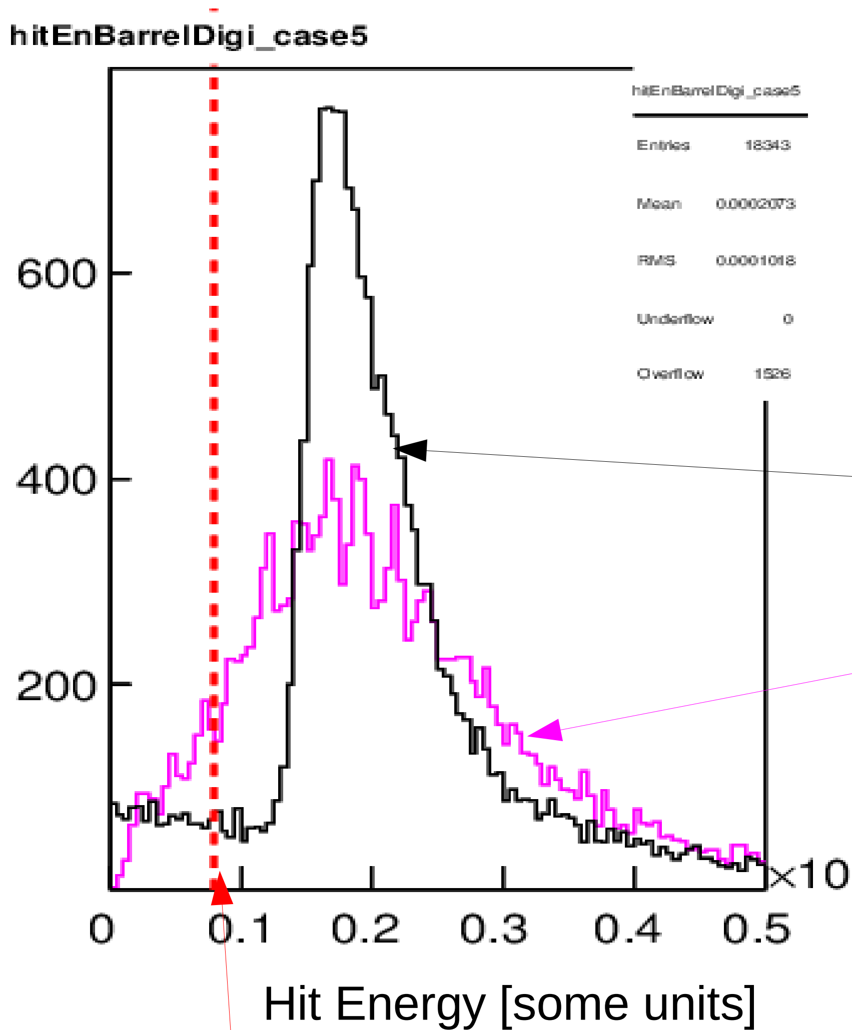
Since the DBD, several possibilities for more realism have been implemented into the ILDCaloDigi digitisation processor

- Random noise (gaussian)
- Saturation of electronics
- Random mis-calibrations (both fully- and un-correlated)
- Random dead channels
- MPPC characteristics: saturation, fluctuations and calibration
- Non-uniformity of strip response

This allows us to better describe both the
mean and fluctuations of signals

These effects are significant for MPPC readout
particularly for small signals (~MIP) and
large signals (high energy EM shower core)

~ negligible for si-ECAL, where fluctuations dominated by Landau



ILD simulation: ECAL hits for
10 GeV muon

Energy deposited in scintillator

Digitised energy (ILDCaloDigi)
with my educated guesses for
non-uniformity,
MPPC statistics
noise

Typical threshold @ ~0.5 MIP

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Description of test beam performance

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Physics prototypes

Granularity a little less than present design

~ longitudinally: similar

~ laterally: 2 times coarser laterally

Previous generation of sensors and electronics

e.g. no power pulsing

SiECAL

525 um thick sensors

Continuous guard ring

ScECAL

Early generation 1600 pixel MPPC

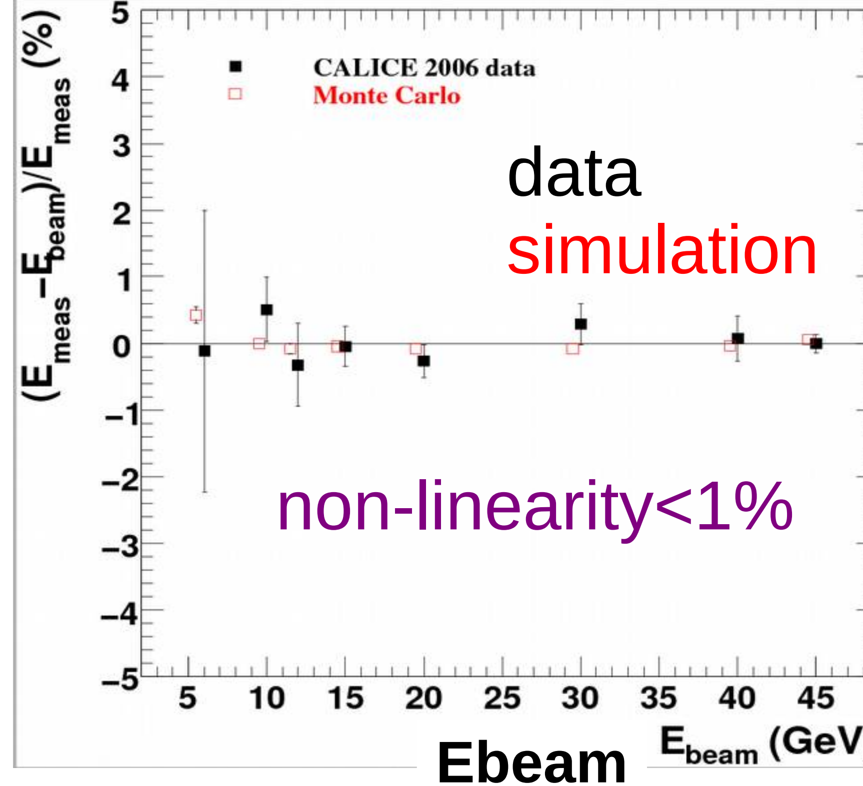
Not enough pixels for ILD ECAL dynamic range (up to 250 GeV)

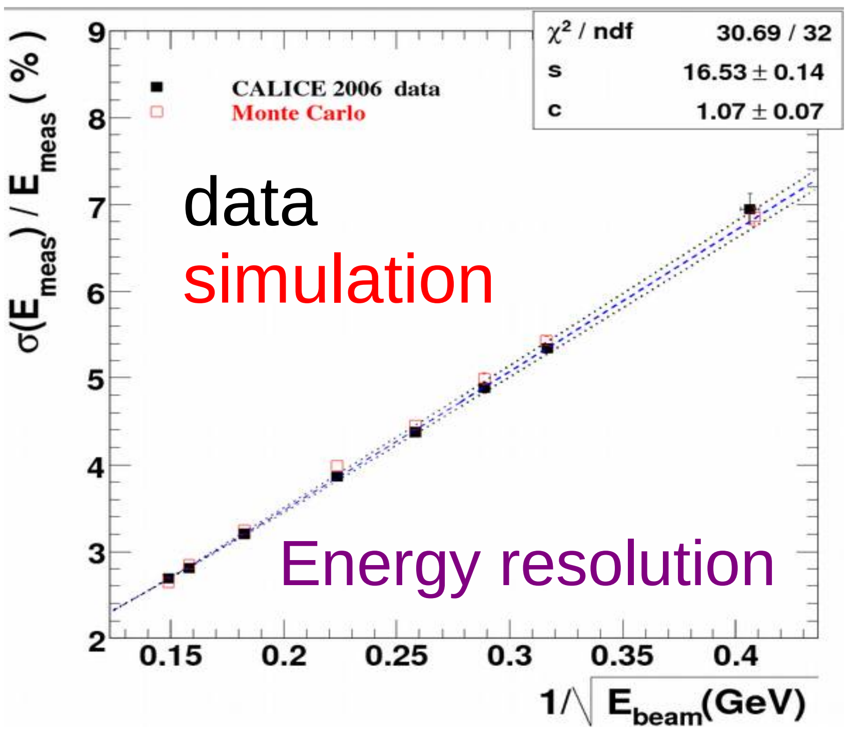
Sufficient for test beams (up to 32 GeV)

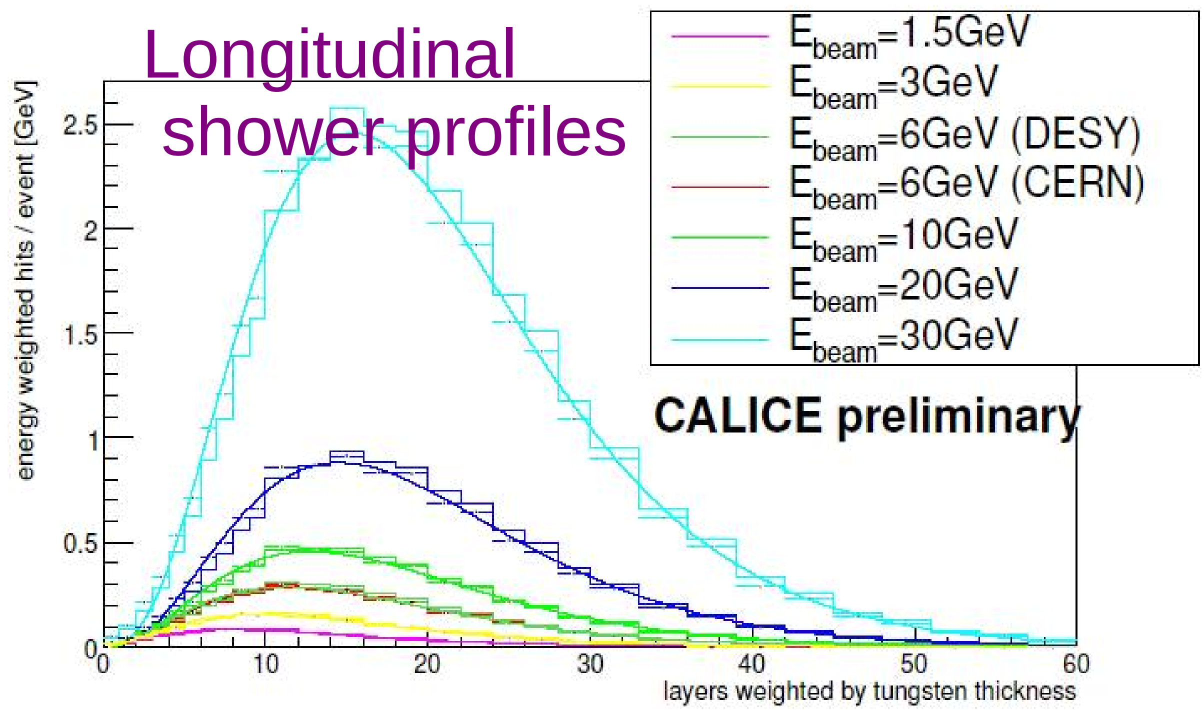
SiECAL: physics prototype

Linearity and resolution of energy response to electrons

Detector performs as expected from simulations





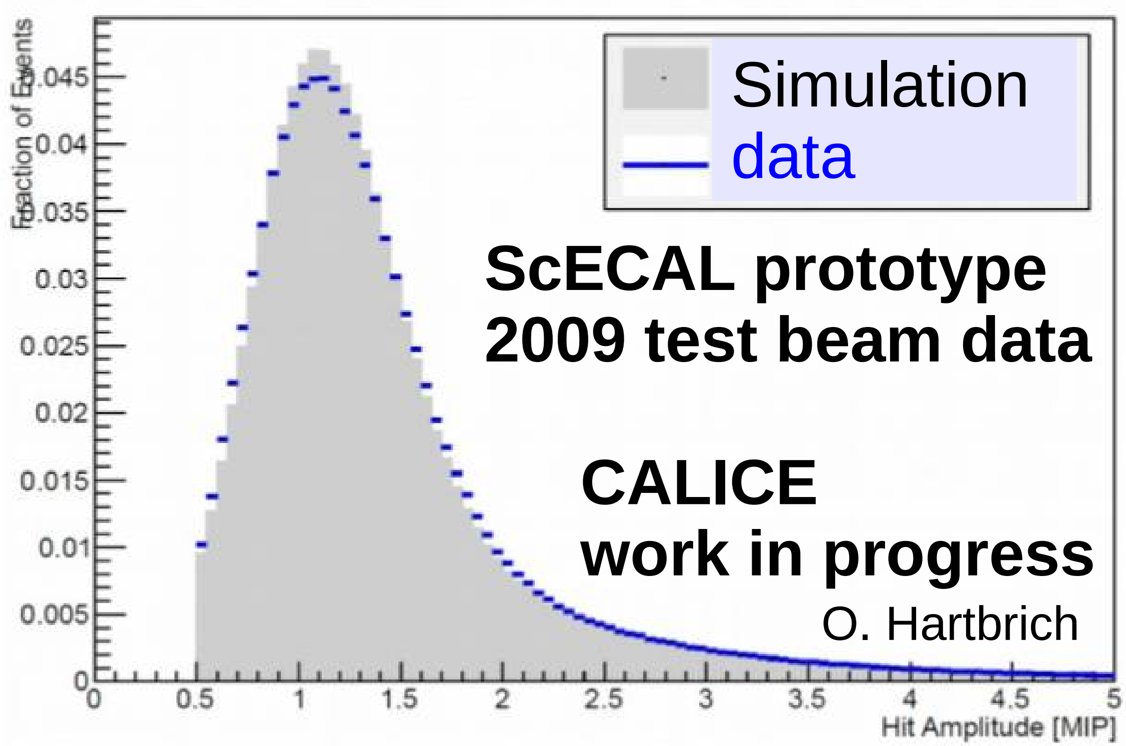


Apply realistic digitisation model to description of ScECAL prototype

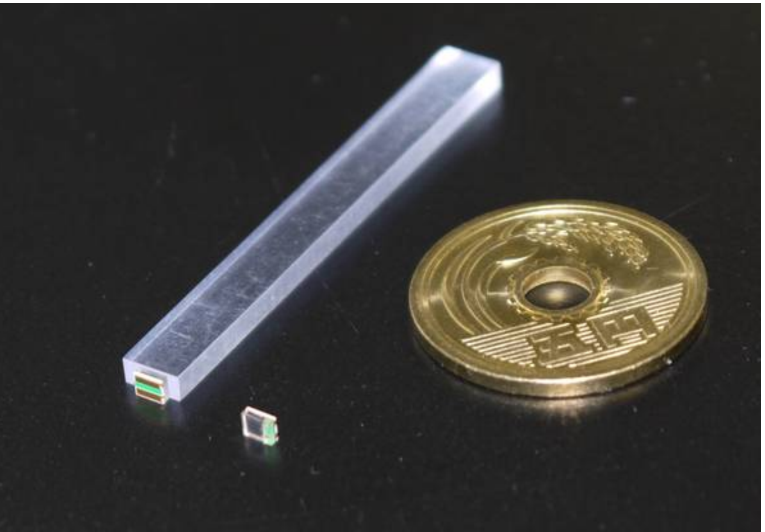
Simulation includes
- MPPC statistics,
- noise,
- perfectly uniform strips

Small data-MC difference may be due to strip non-uniformities

rather minor effect,
even @ MIP level

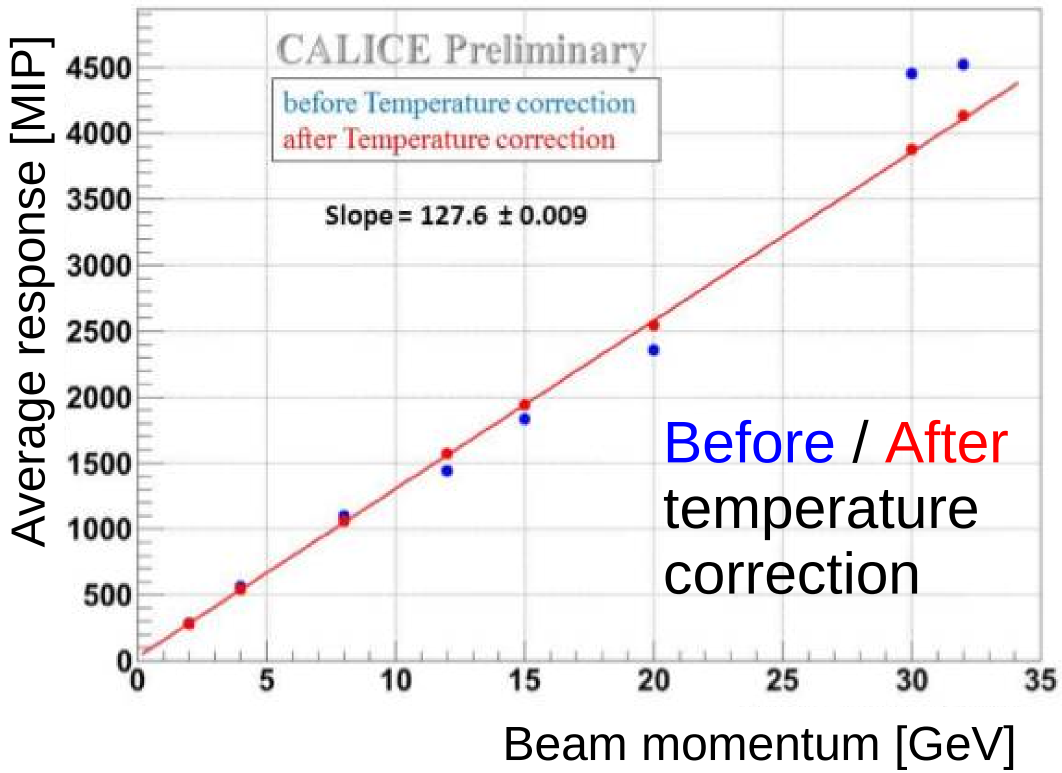


Energy of selected MIP hits



Temperature dependence of SiPM/MPPC response

e.g. 2009 ScECAL test beam campaign:
temperature variations between 19 and 27 degrees
(due to faulty A/C...)



As expected, temperature affects the calorimeter response
Even rather extreme temperature variations can be corrected for,
recovering a linearity better than 2%

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- mechanical structure; services; supports
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- “Technological” prototypes

Technical prototypes

Develop and test techniques needed for real detector construction

Small element of module -N

- On-board electronics
  - (with power-pulsing, zero suppression, ...)

Move towards mass production techniques

Technical prototypes

Silicon ECAL

Sensors

Cross-talk effects due to (floating) guard ring
were observed in physics prototype

Two technologies developed to address this problem:

Segmented GR	(LLR design)
No guard-ring	(proprietary HPK design)

These ideas have both been tested
and work well

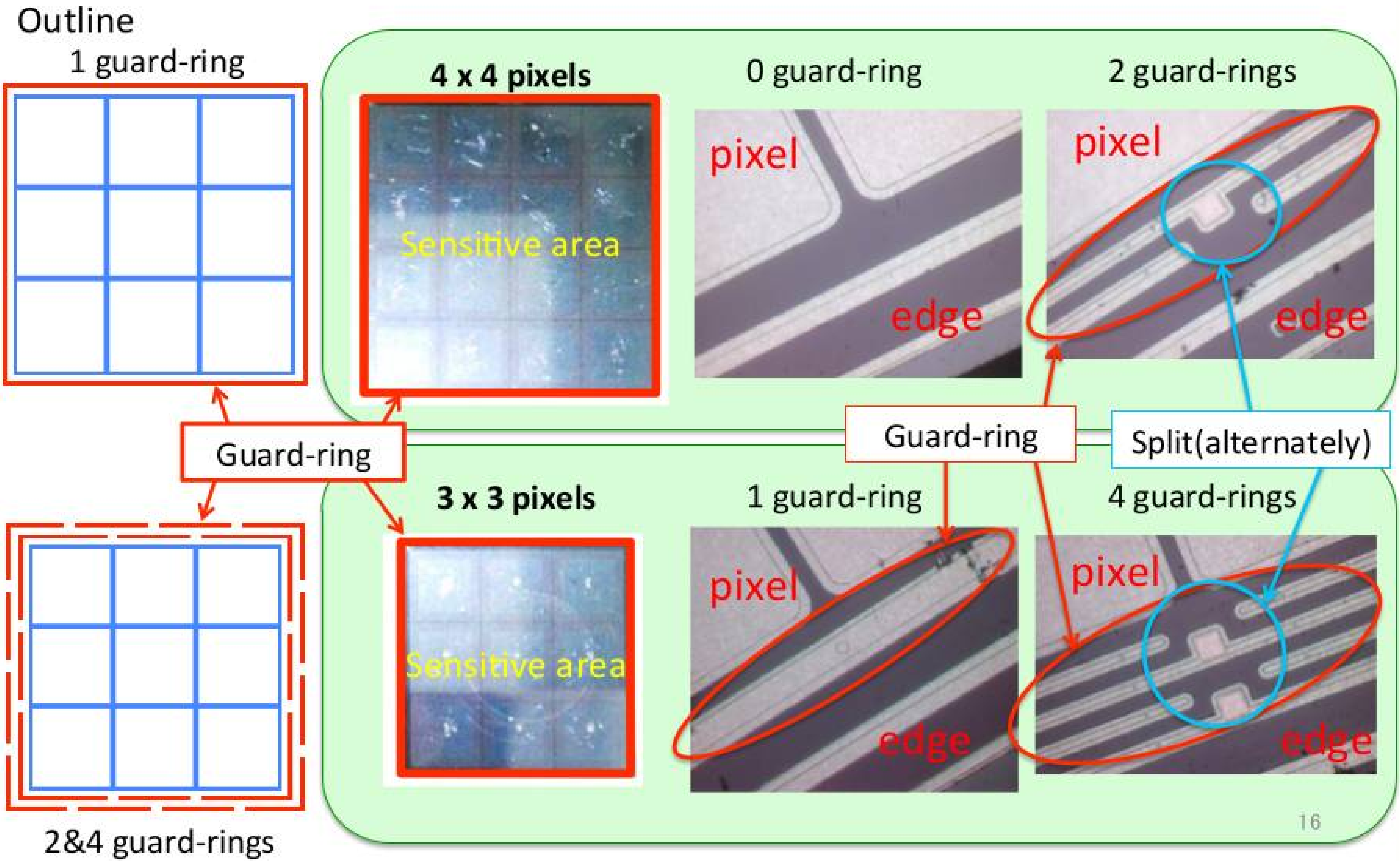
Additional sensor samples will soon be ordered from
both HPK and LFOUNDRY

Larger sensors, thicker sensors, different resistivities, ...

Baby chip(to compare guard rings)

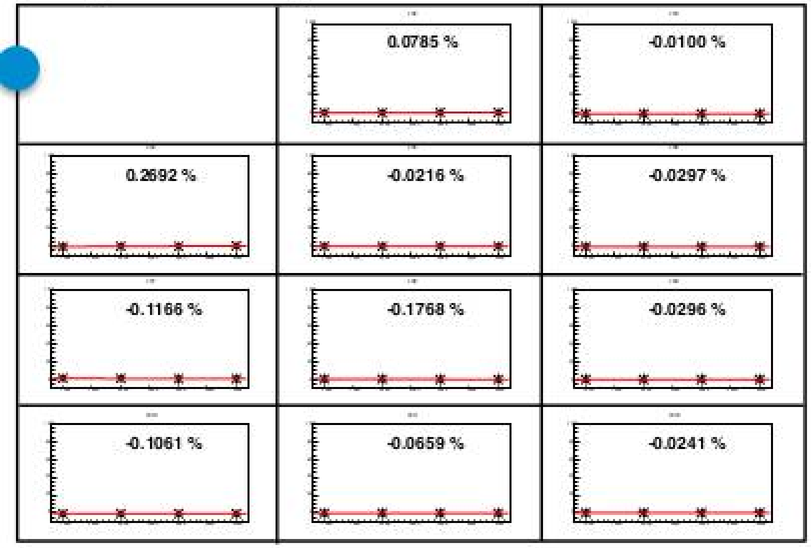
These chips are made to compare the effect of different guard ring structures.

Pixel size : 5.5 mm x 5.5 mm   Thickness: 320µm

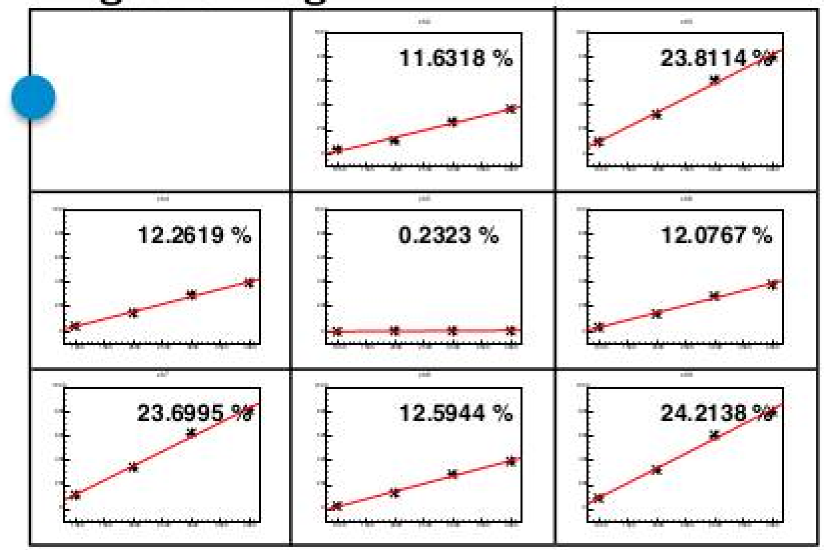


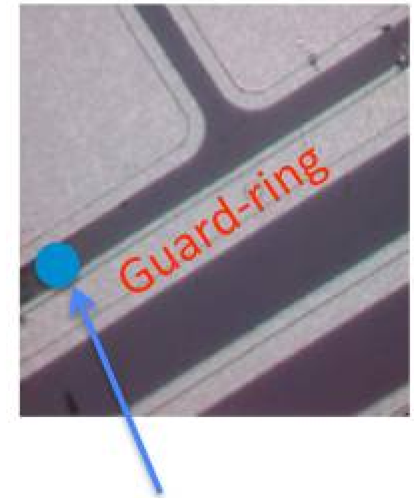
GR-induced cross-talk: laser injection

0 guard-ring



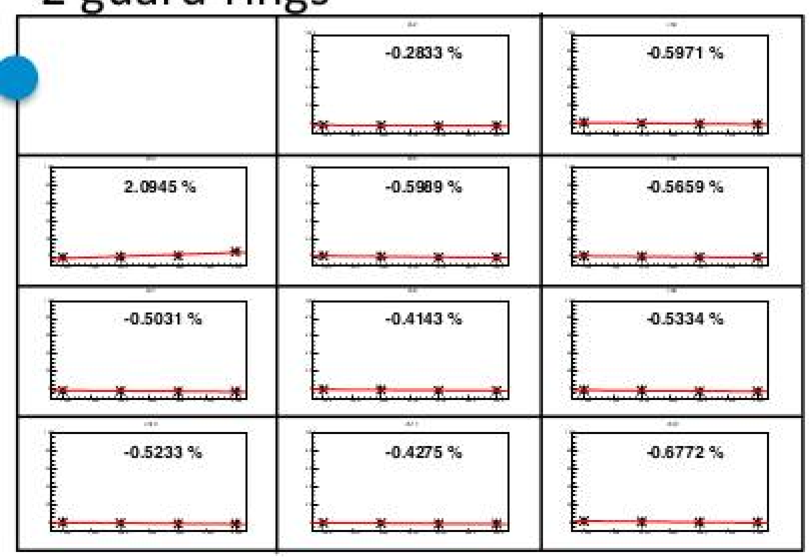
1 guard-ring



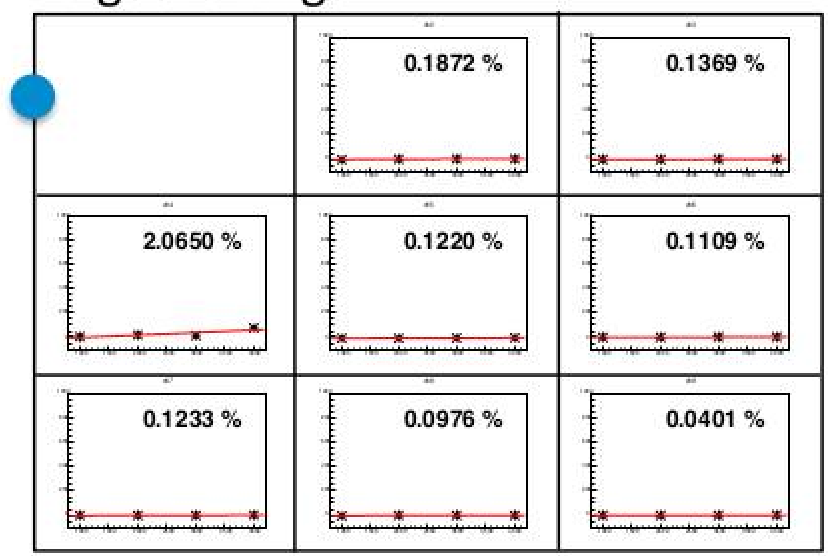


Laser point
（Most inner gap）

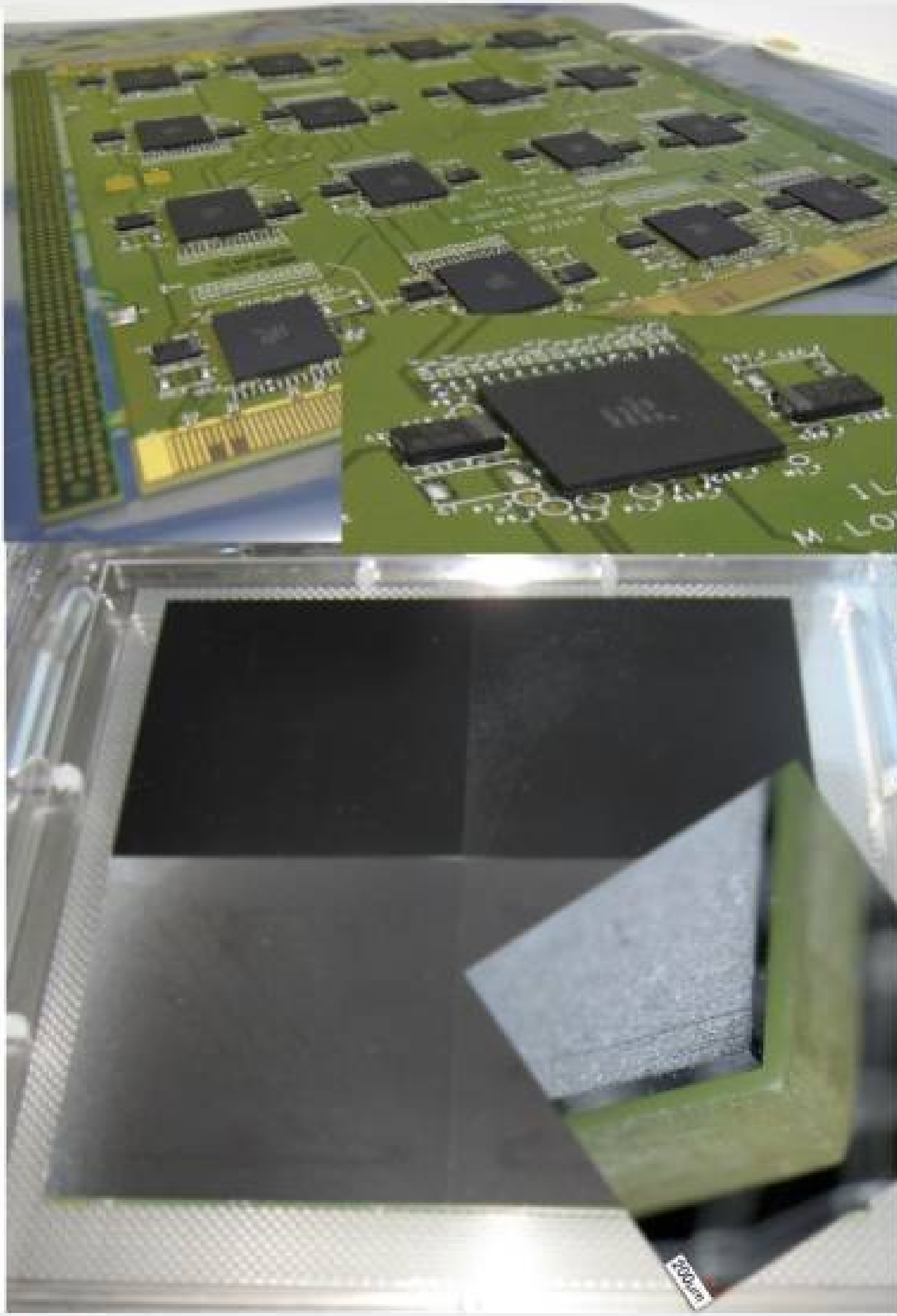
2 guard-rings



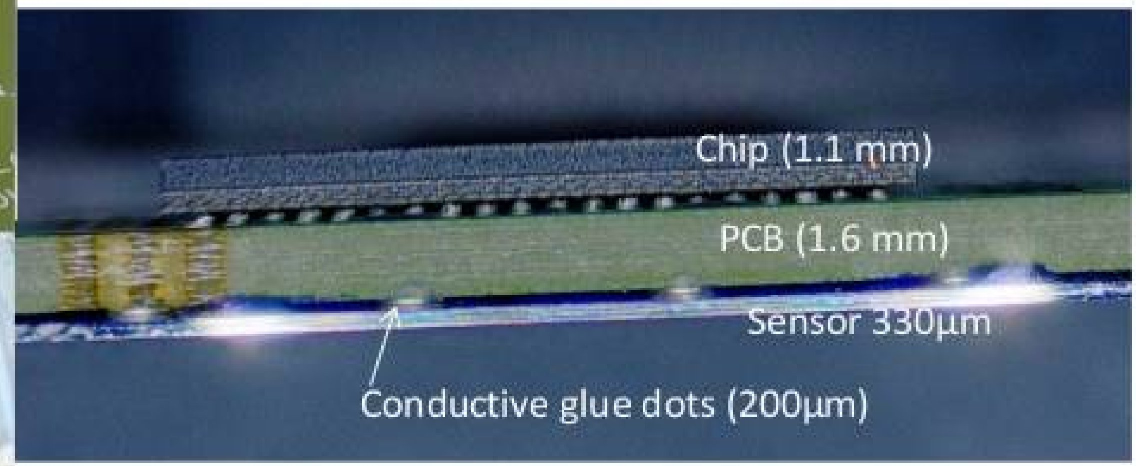
4 guard-rings



Detector module assembly

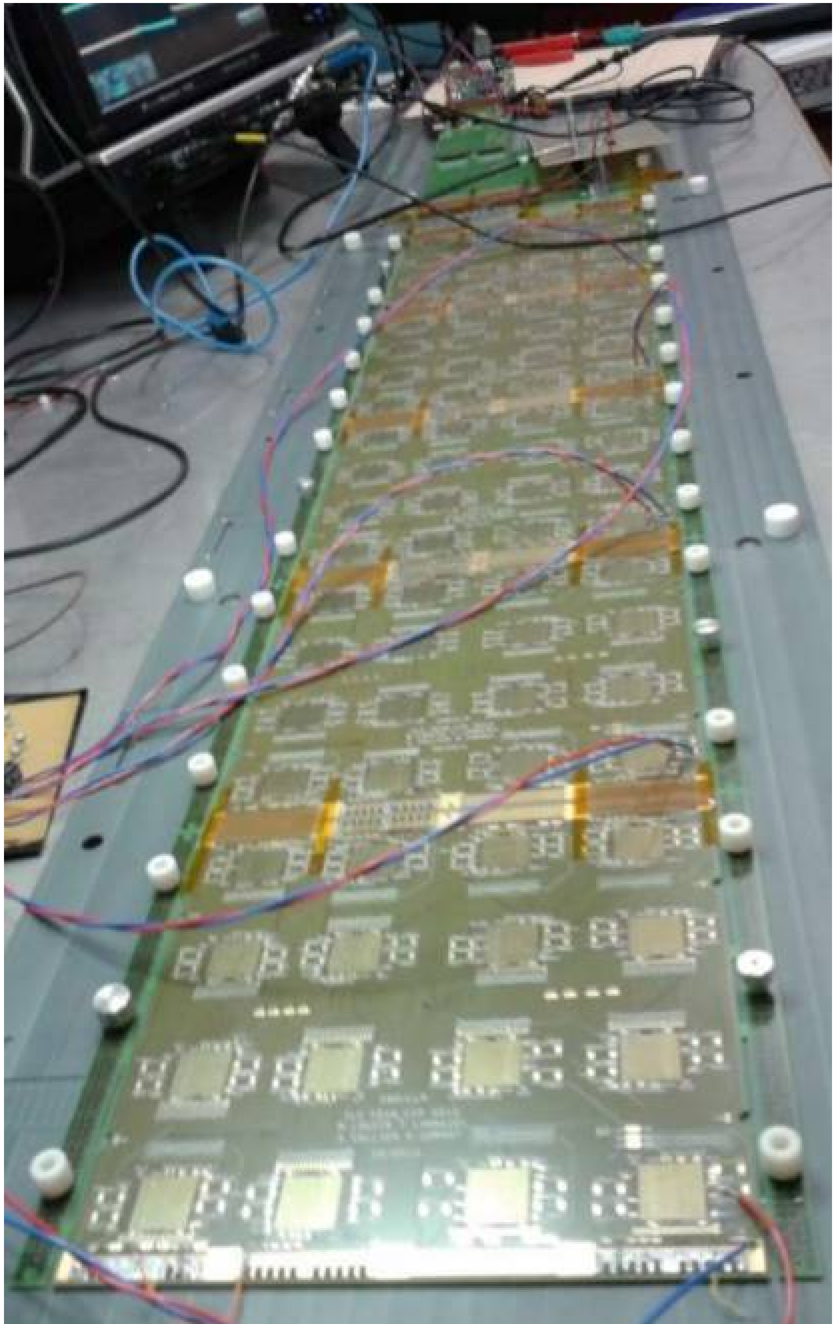


Robots for gluing sensors are developed (LPNHE)
⇨ First step towards industrialization



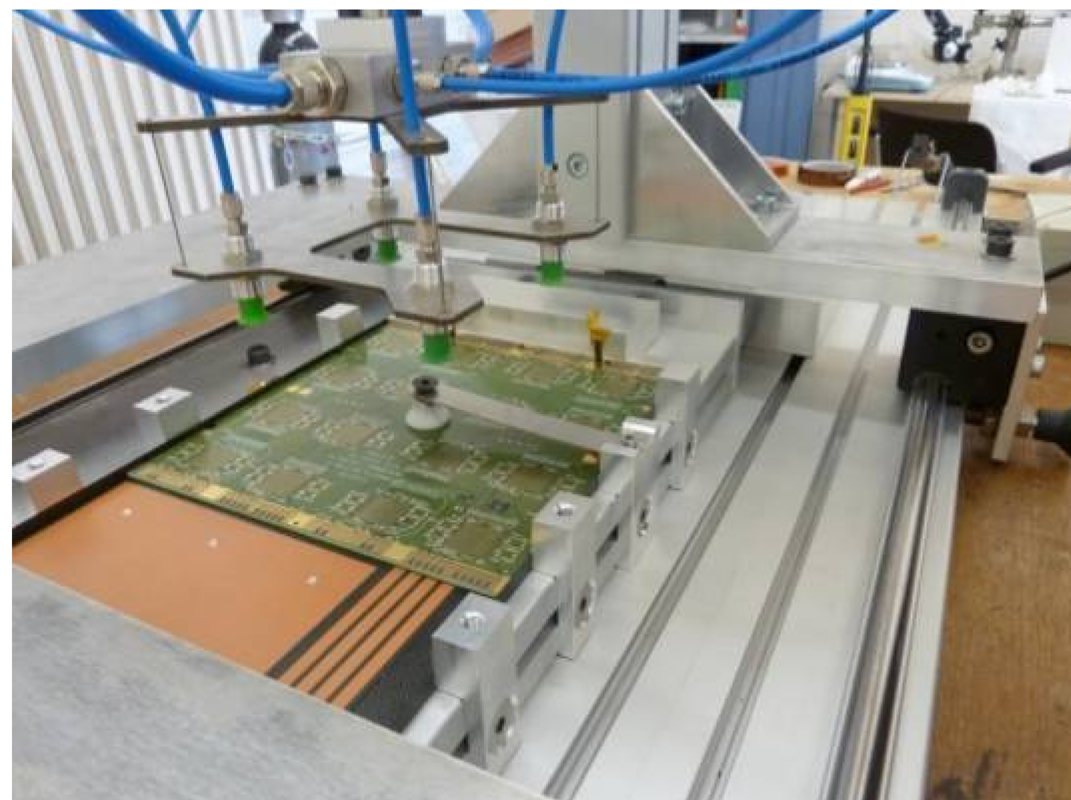
4 wafers 9cm x 9 cm wide can be glued with a 20 µm precision and a reproducible process. Glue is dispensed then pressed in order to form 200 µm thick dots

"Active Sensor Unit" (ASU)



Semi-automated assembly bench
being commissioned @ LAL

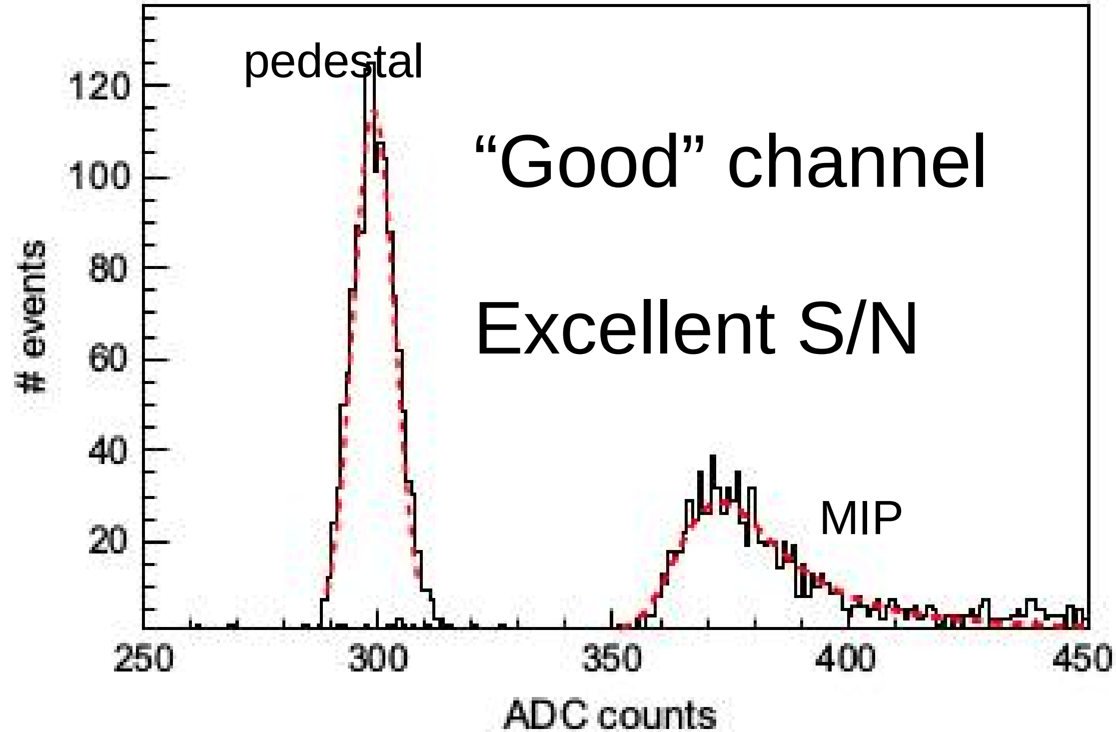
Interconnect chain of ASUs ;
Assemble detector slab
- W core,
- HV supply,
- cooling plate



SiECAL technical prototype

first generation
1 sensor / ASU
(2012 beam test @ DESY)

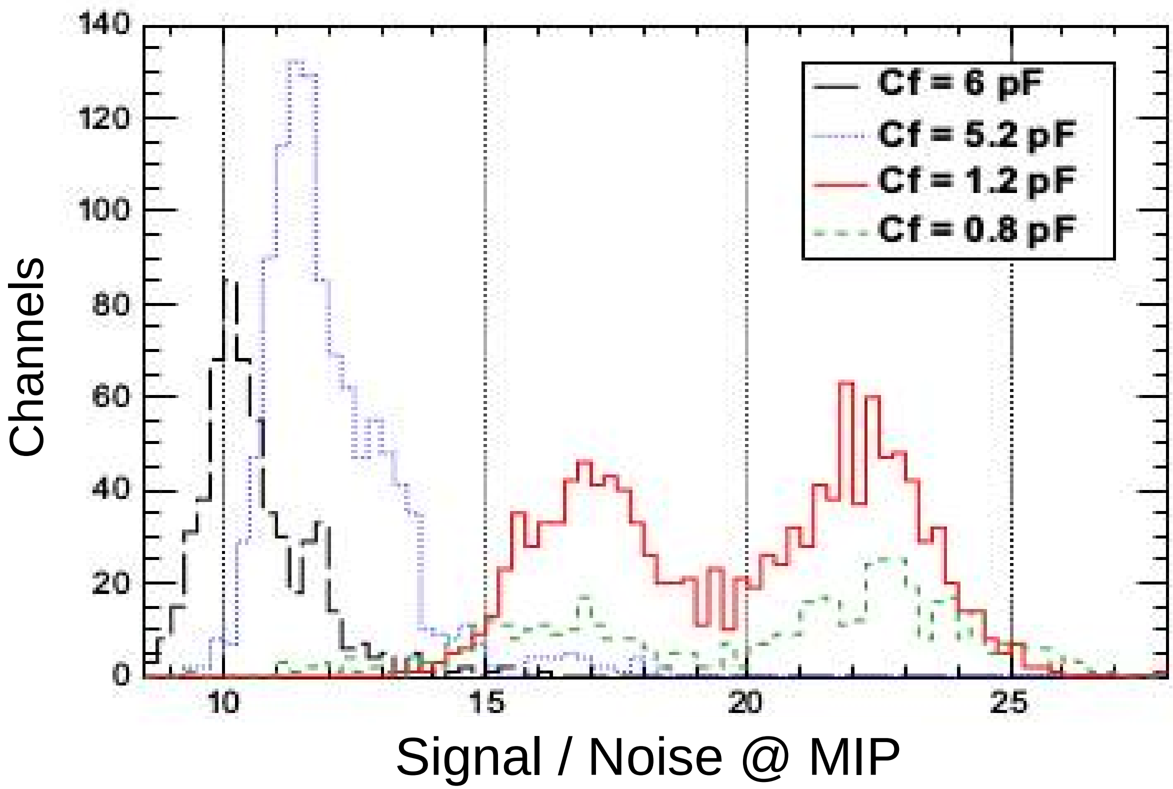
No power-pulsing



"Good" channel

Excellent S/N

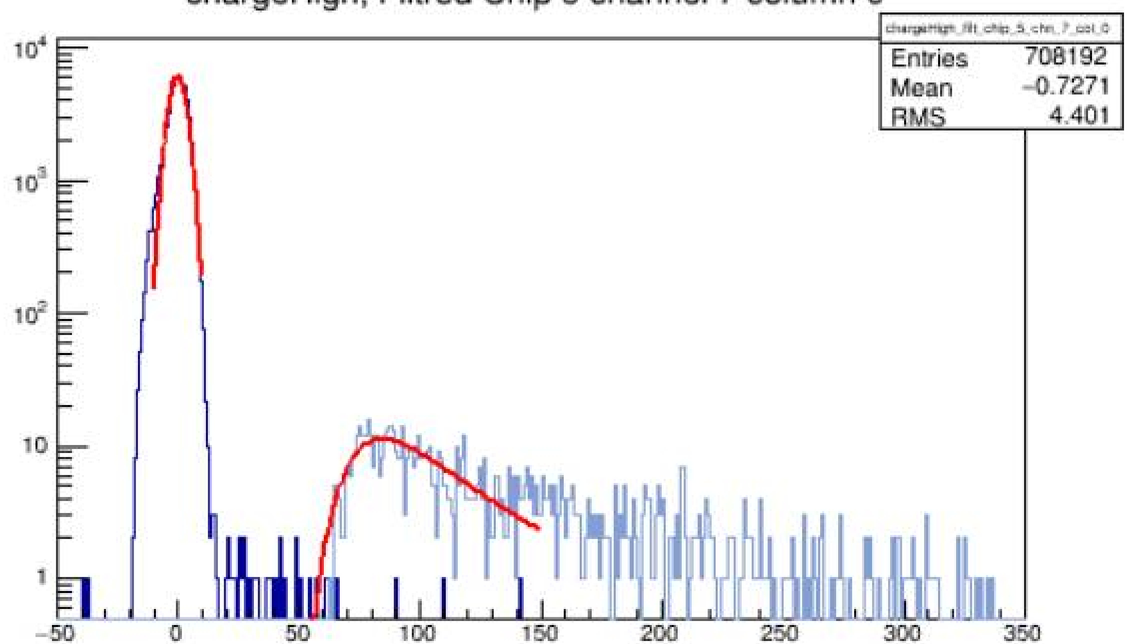
tion for one channel. The feedback capacitance is 1.2 pF.



Large dispersion:
traced to non-uniform PCB routing

Gain : 1.2 pF (high)

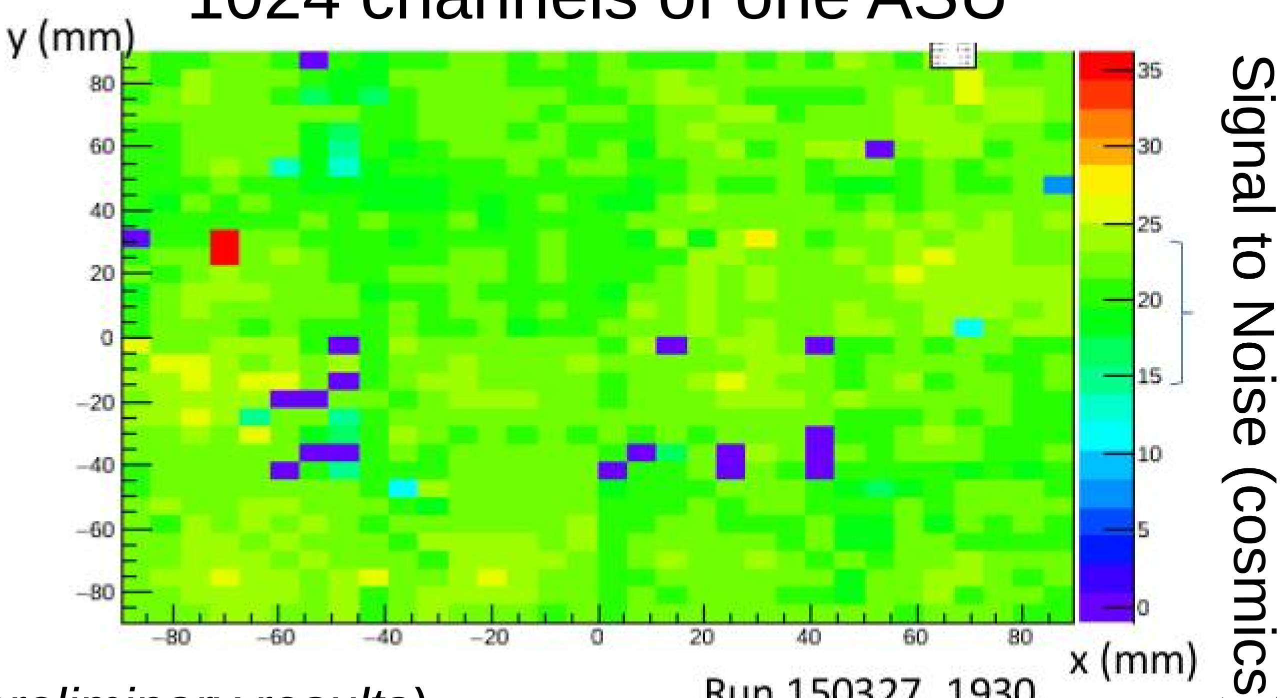
Typical channel



Latest generation (2014/15):

- new PCB layout
- 4 sensors / ASU
- Cosmics
- Power pulsing

1024 channels of one ASU



Run 150327_1930

(preliminary results)

In general, more uniform behaviour

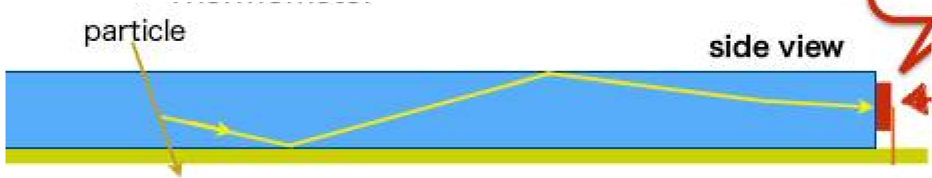
~2% outlying cells
...to be understood

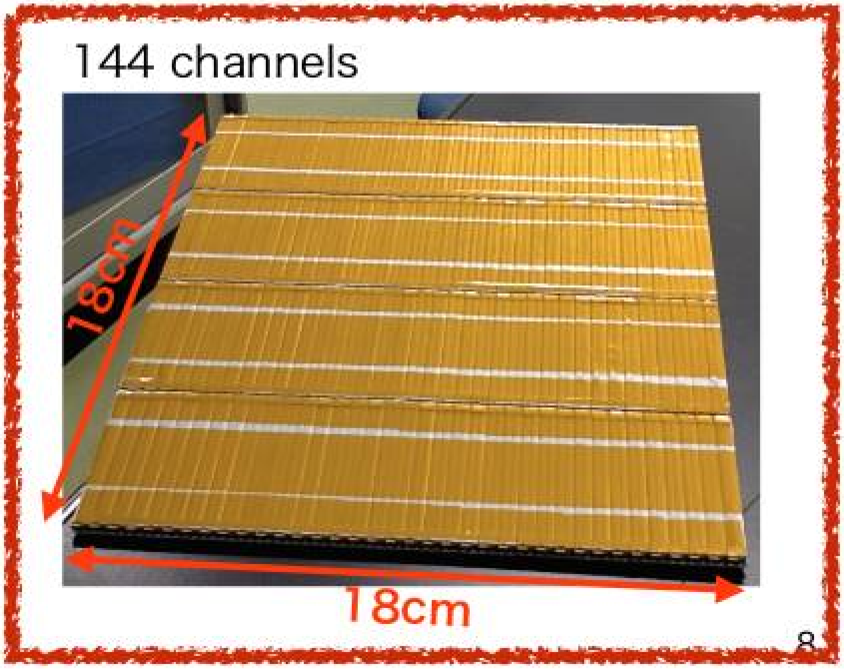
Technical prototypes

Scintillator ECAL

“traditional” side readout

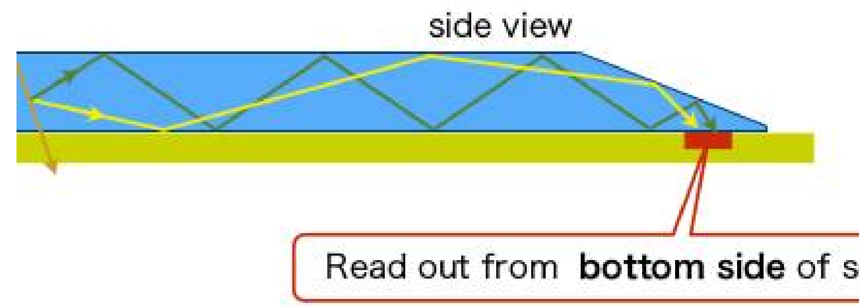
Pixel size
layer2 : 10um
layer3 : 25um



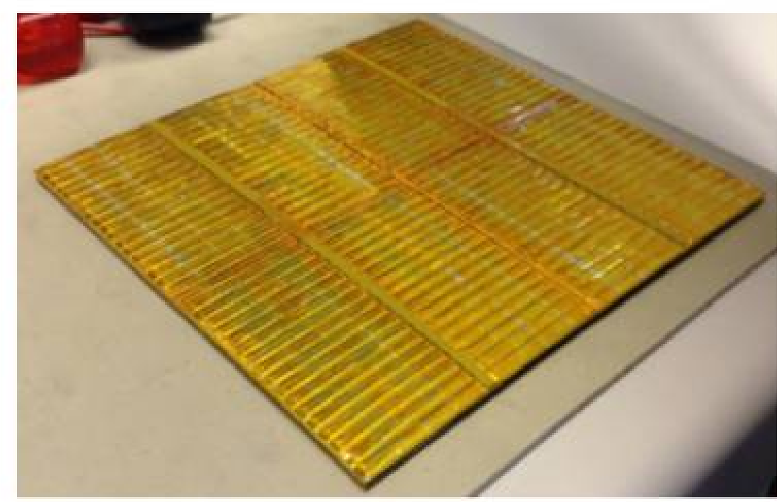


3 layers exposed to test beams in 2014

bottom side readout



MPPC: 10 um pixel size



In two layers, the number of dead channels was small : 1~3 / 144 channels

<u>ScECAL technical prototype</u>

45 x 5 mm^2 strips, 144 per EBU

Now using Hamamatsu MPPCs with
- 10000 pixels, size 10x10 um^2 ←needed for ECAL dynamic range
- 1600 pixels, 25x25 um^2
  - Not the latest models, a few years old
  - MPPC/SiPM development is now very active:
    - the devices available in a few years
      - will almost certainly have significantly better properties

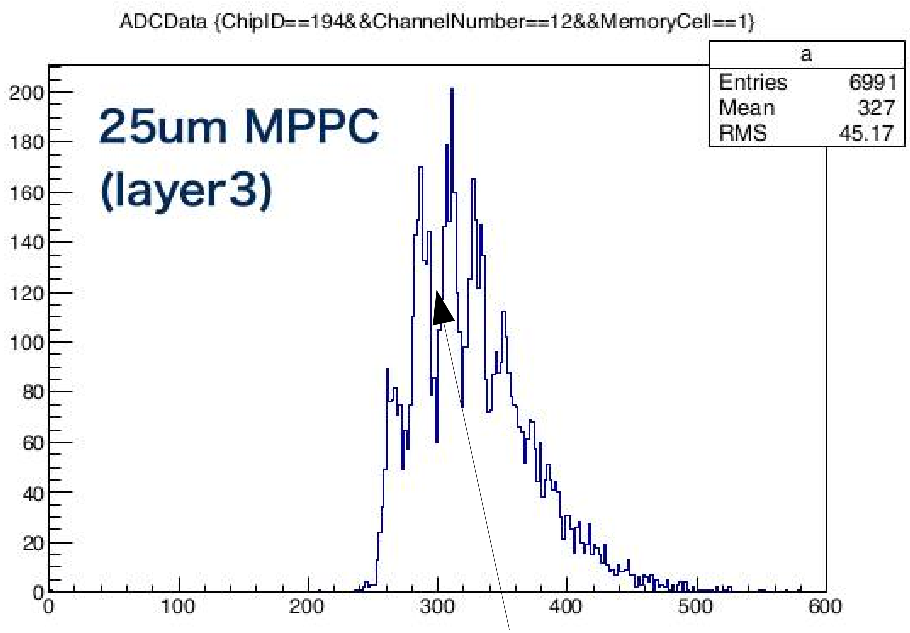
Typically 7 p.e. per MIP
- Larger would give better S/N & hit energy resolution
  - but earlier saturation

Working closely with DESY AHCAL group
- Same SKIROC2 ASIC ←is dynamic range sufficient for ECAL?
- Front end PCB “EBU”
- Identical DAQ, power, etc
- Mechanics

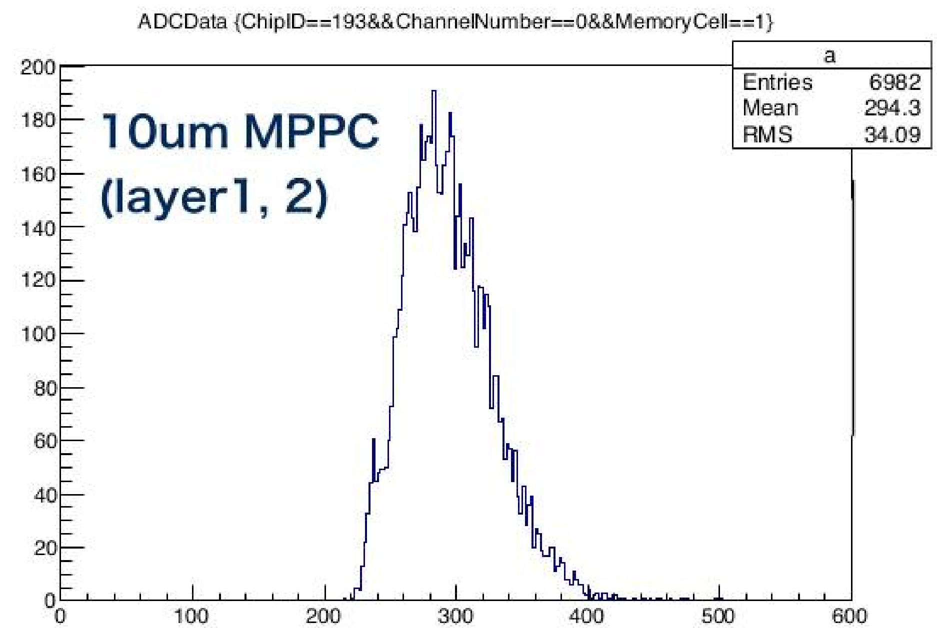
MPPC needs calibration of:

ADC per MIP ← equalise response among channels : MIP-like particles
ADC per pixel ← used to correct for MPPC saturation : LED light

ADC per pixel requires low light
and higher gain electronics readout that what is used in real events
It proved to be difficult to measure # ADC / pixel for the 10 um pixel MPPCs:



These fringes used to
calibrate ADC/pixel



Not clearly seen when using 10um pixels:
Smaller signal per pixel,
Swamped by “electronics” noise

Further tuning of readout ASIC required for
10 um pixel MPPC
More appropriate configuration?
ASIC reoptimisation? I am not an expert...

Other problem was MPPC noise:

Dark firing of pixels,

in conjunction with

large inter-pixel cross-talk, hit threshold @ a few p.e.

Gives rather large number of noise hits,

necessitating the setting of a high threshold

which tends to cut into the MIP distribution

MIP calibration not really successful

In the near term,

attempts to solve, or at least improve, the calibration are underway

Identify external noise sources

Fine-tune MPPC operating voltage and ASIC settings

In the farther term,

Trenched MPPCs with much lower cross-talk are coming onto the market

reduce multi-pixel noise to negligible levels

not yet available for 10 um pixels favoured by ScECAL

Summary I

<u>Mechanical structures</u>

In general well understood and simulated
    Specific questions:
        ECAL ring ←not covered in detail   uncertain time estimate
        endcap wall thickness, under study,   1+ years

    Adjustment of some component thicknesses in simulation ←can do now
        Learning from technical prototypes

<u>ECAL physics prototypes have been accurately simulated</u>

Calibrations procedures work for both options
    Including e.g. extreme temperature variations for MPPCs

EM resolution & linearity in range O(1) → 10s of GeV
    well simulated

cont.inued...

Summary II

Additional realism in ILDCaloDigi ← ready, need to fix parameters

Gives improved description of single hit energies
Brings realism of two options to a similar level

Development of technical prototypes underway

SiECAL
Basic technology rather stable
working well at single board level with power-pulsing
Next step is to test chain of boards

ScECAL
learning to calibrate with small pixel MPPCs
still to be demonstrated ← maybe O(1) year
but no fundamental showstopper expected

MPPC/SiPM devices still developing fast

MAPS
Effort is restarting
ILD simulation planned

FINE

Figures taken from many sources:

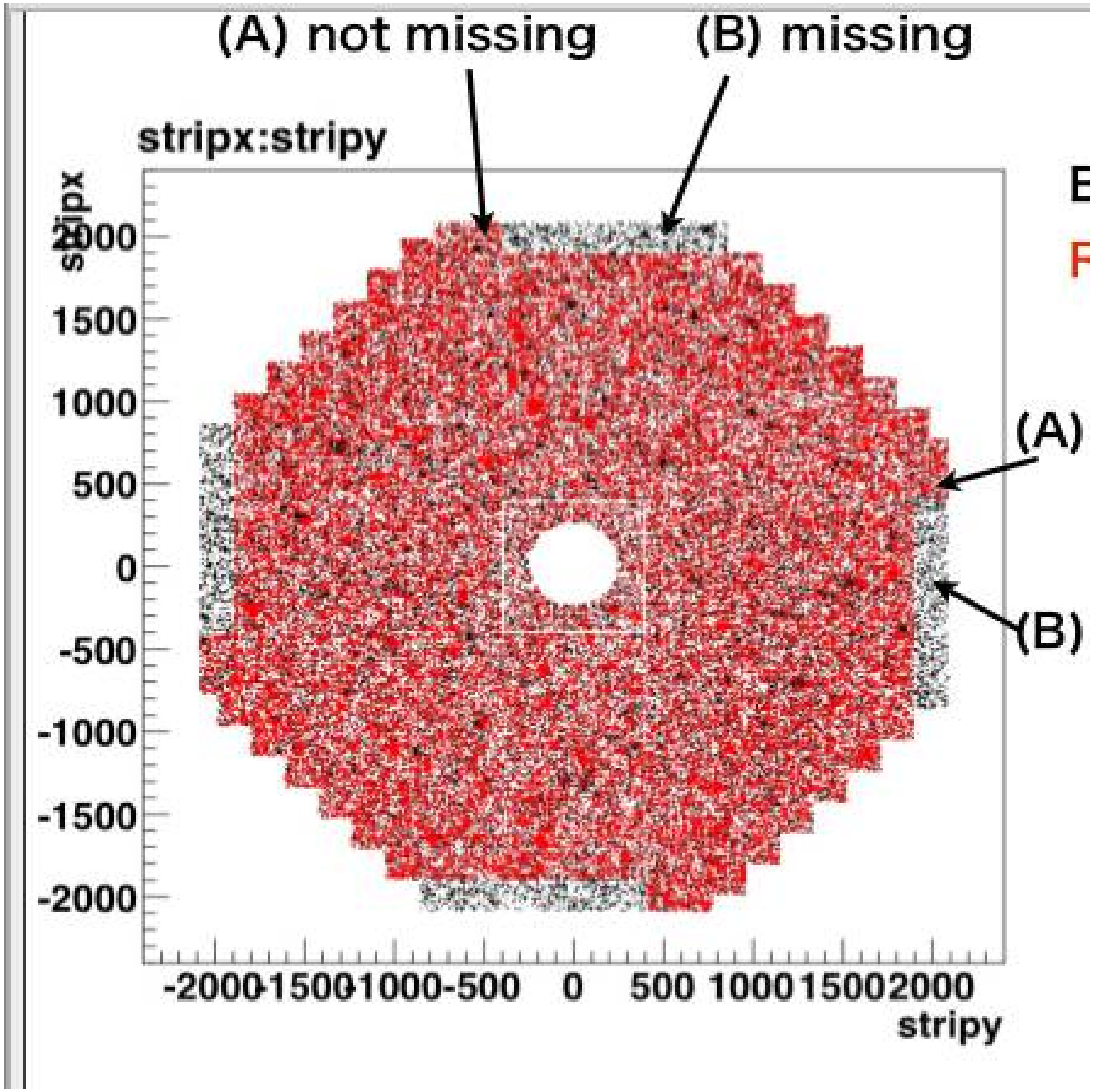
Takada, Cornat, Ieki, Kotera, Poeschl, and several others

The first hand-made production of strip “ladders”

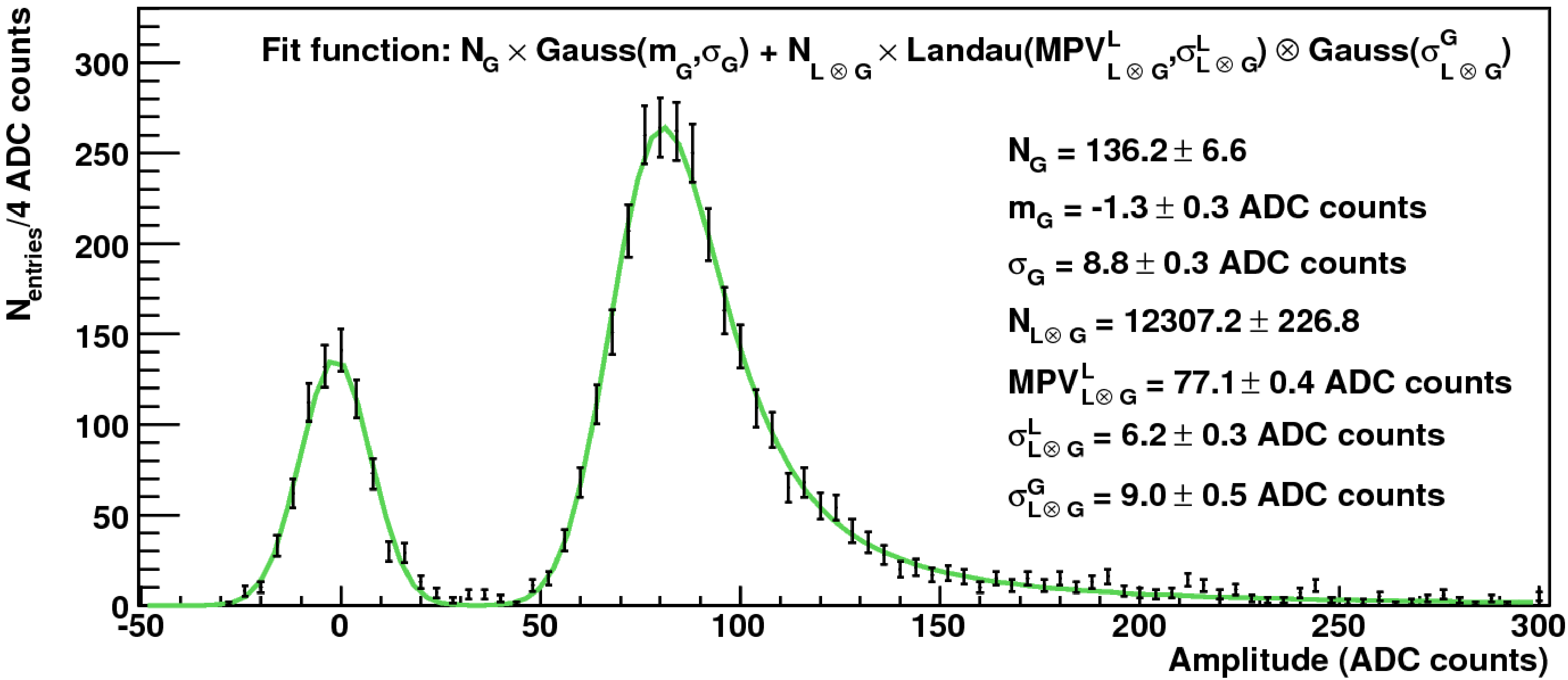
I measured the lengths of four 36-strip ladders by using a vernier caliper at their top, middle and bottom. (bottom means farthermost position from MPPC).

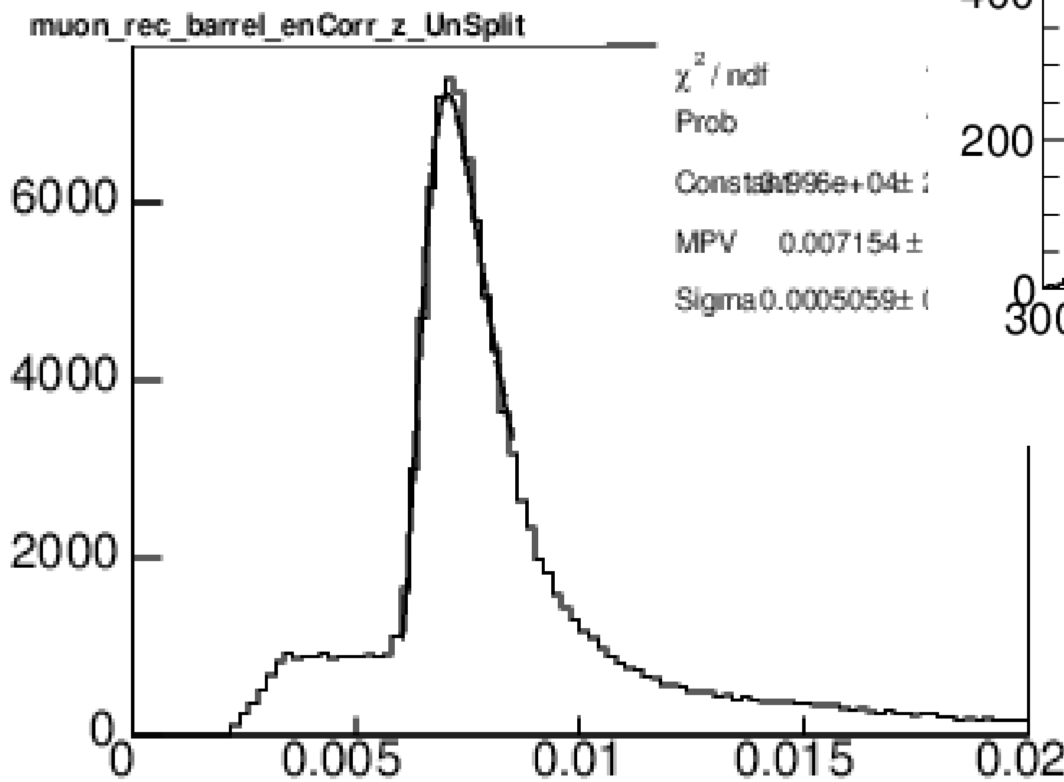
Line	top	middle	bottom	average
1	179.95	179.90	179.90	179.92
2	179.95	180.00	179.95	179.97
3	180.30	180.30	180.20	180.27
4	180.00	180.00	180.00	180.00
			average →	180.04
			stdev →	0.16

(mm)

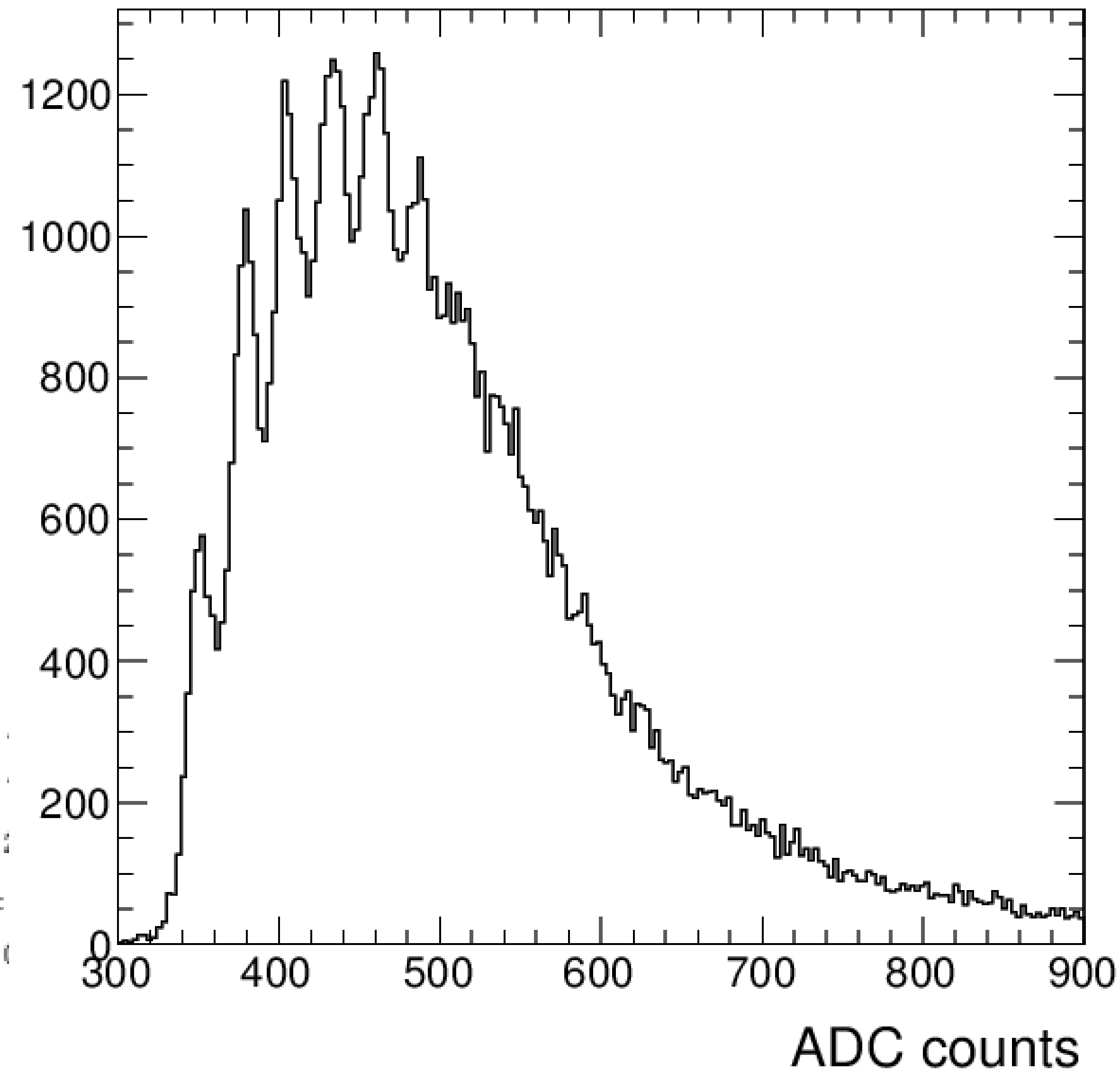

(A) not missing
(B) missing
stripx:stripy
stripx
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2000
-1500
-1000
-500
0
500
1000
1500
2000
stripy
(A)
(B)

SiW physics prototype: cosmics

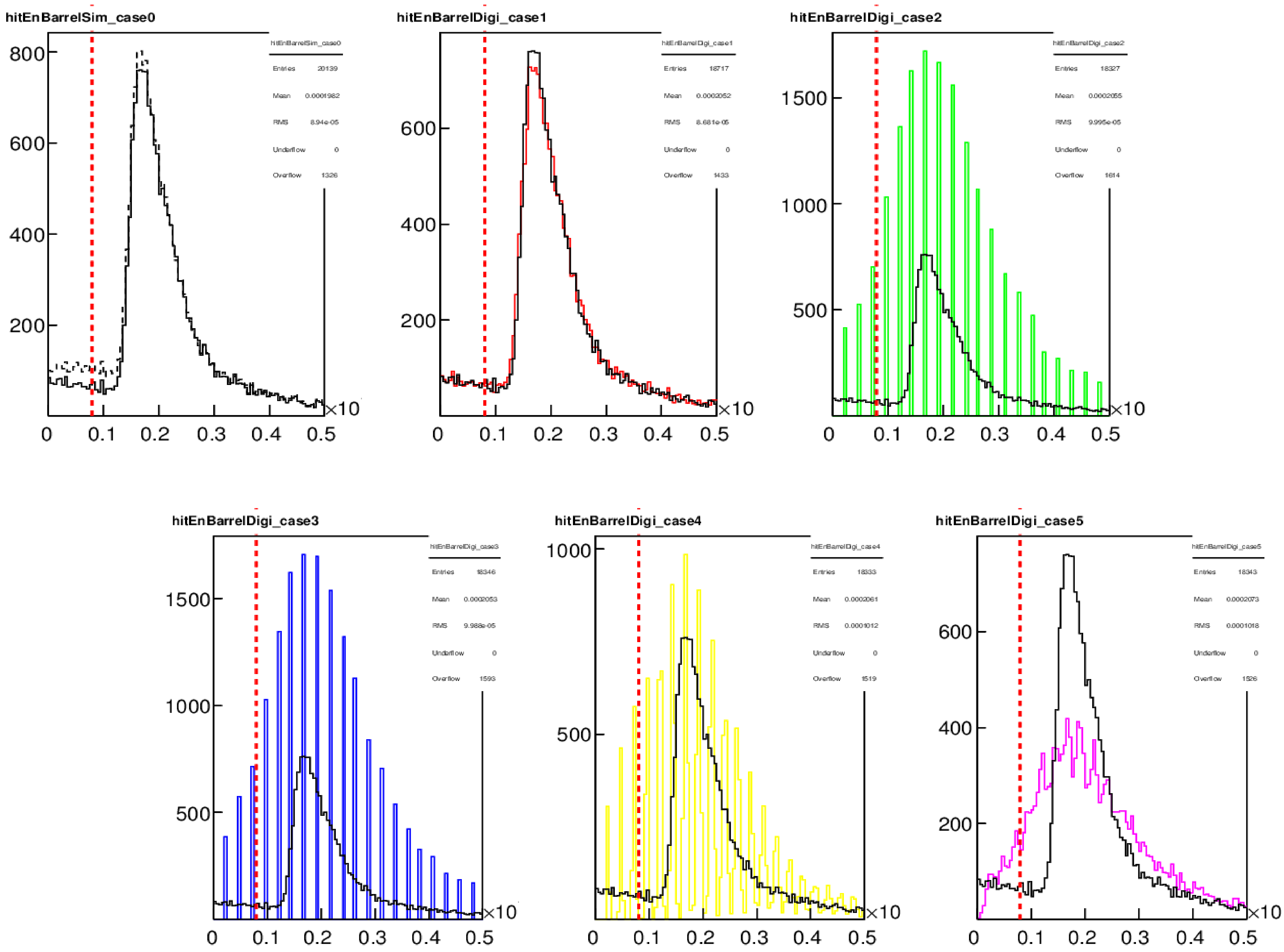


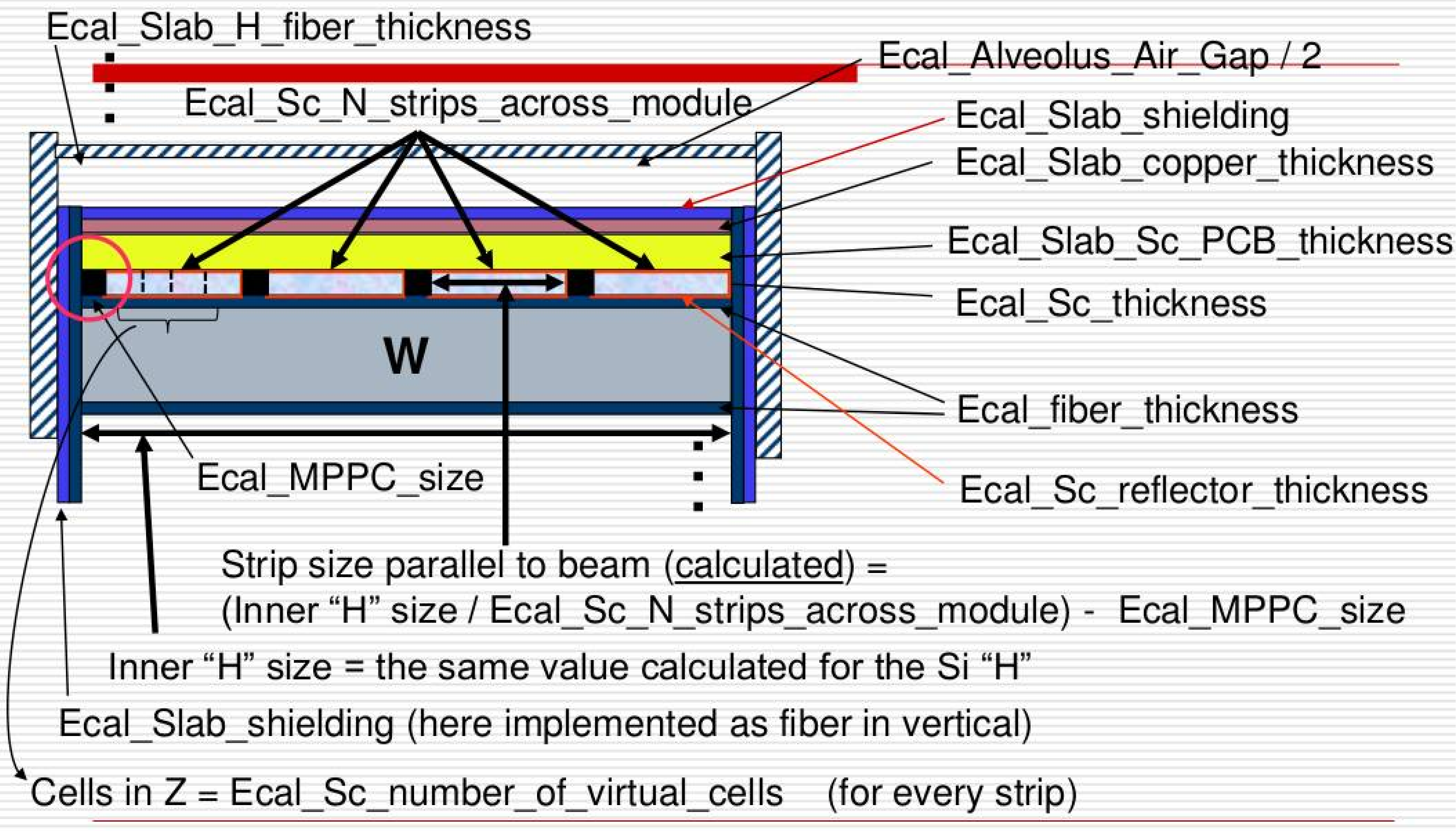


muon_rec_barrel_enCorr_z_UnSplit
χ² / ndf
Prob
MPV 0.007154 ±
Sigma 0.0005059±
0
2000
4000
6000
0
0.005
0.01
0.015
0.02



0
200
400
600
800
1000
1200
300
400
500
600
700
800
900
ADC counts


hitEnBarrelSim_case0
hitEnBarrelSim_case0
Entries 20139
Mean 0.0001982
RMS 8.94e-05
Underflow 0
Overflow 1326
800
600
400
200
0 0.1 0.2 0.3 0.4 0.5
×10
hitEnBarrelDigi_case1
hitEnBarrelDigi_case1
Entries 18717
Mean 0.0002052
RMS 8.681e-05
Underflow 0
Overflow 1433
600
400
200
0 0.1 0.2 0.3 0.4 0.5
×10
hitEnBarrelDigi_case2
hitEnBarrelDigi_case2
Entries 18327
Mean 0.0002055
RMS 9.995e-05
Underflow 0
Overflow 1614
1500
1000
500
0 0.1 0.2 0.3 0.4 0.5
×10
hitEnBarrelDigi_case3
hitEnBarrelDigi_case3
Entries 18346
Mean 0.0002053
RMS 9.988e-05
Underflow 0
Overflow 1593
1500
1000
500
0 0.1 0.2 0.3 0.4 0.5
×10
hitEnBarrelDigi_case4
hitEnBarrelDigi_case4
Entries 18333
Mean 0.0002061
RMS 0.0001012
Underflow 0
Overflow 1519
1000
500
0 0.1 0.2 0.3 0.4 0.5
×10
hitEnBarrelDigi_case5
hitEnBarrelDigi_case5
Entries 18343
Mean 0.0002073
RMS 0.0001018
Underflow 0
Overflow 1526
600
400
200
0 0.1 0.2 0.3 0.4 0.5
×10



Ecal_Slab_H_fiber_thickness
Ecal_Alveolus_Air_Gap / 2
Ecal_Sc_N_strips_across_module
Ecal_Slab_shielding
Ecal_Slab_copper_thickness
Ecal_Slab_Sc_PCB_thickness
Ecal_Sc_thickness
W
Ecal_fiber_thickness
Ecal_MPPC_size
Ecal_Sc_reflector_thickness
Strip size parallel to beam (calculated) =
(Inner "H" size / Ecal_Sc_N_strips_across_module) - Ecal_MPPC_size
Inner "H" size = the same value calculated for the Si "H"
Ecal_Slab_shielding (here implemented as fiber in vertical)
Cells in Z = Ecal_Sc_number_of_virtual_cells (for every strip)

Noise rates with present-day MPPCs:
10 k pixels, “trenched” to reduce cross-talk

SiPM:
Noise rate @0.5px: 20kHz
Pixel crosstalk: 10^-3 (Naomi and Yong independently measured 0.5-0.7*10^-3)

ILC:
Bunchtrain length: 1ms
Bunches in train: 2000

ILD ScECAL:

Lightyield: 10px/MIP
Desired threshold <=0.3MIP -> assume threshold = 2.5px

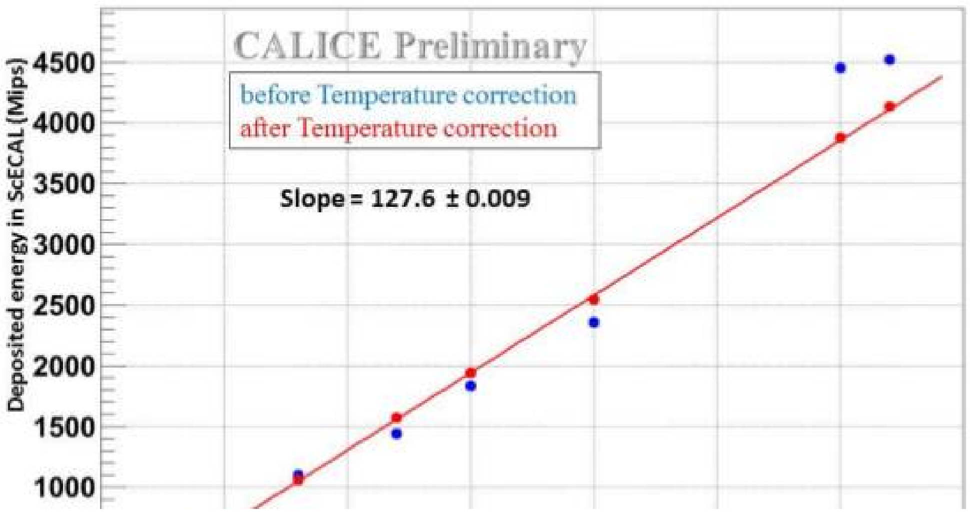
-> Noise rate @2.5px (single channel) = 2*10^-2 Hz

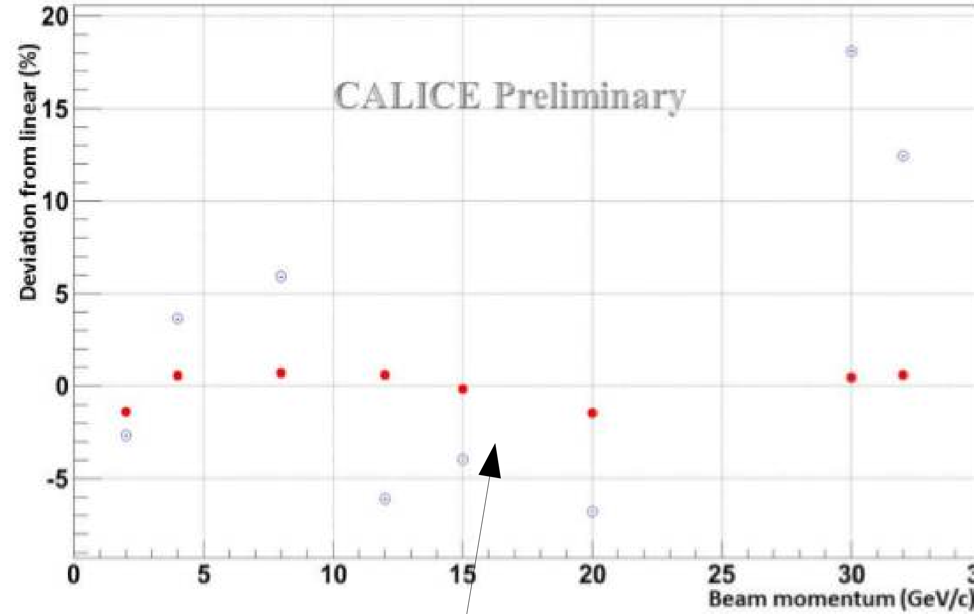
Number of channels = 10^7
Mean number of noise hits per bunchtrain =

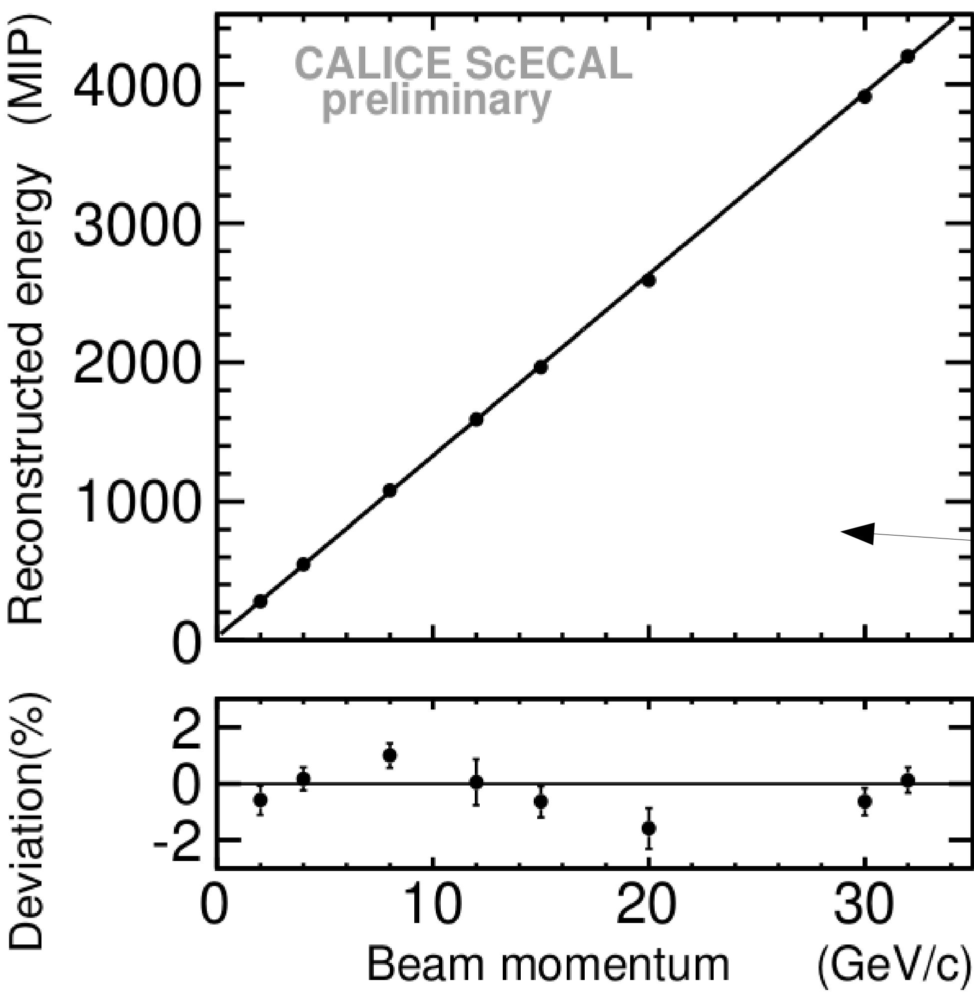
    Noise rate @2.5px * Number of channels * bunchtrain length =
    2*10^-2Hz * 10^7 * 10^-3s = 200

Mean number of noise hits per bunch crossing = 0.1

Oskar Hartbrich







Somewhat outdated

Latest-and-greatest

<u>ScECAL 2009</u>