CALICE

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for the CALICE Collaboration

68. DESY PRC, November 2009

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

CALICE
Calorimeter for ILC

TUM
LMU
Excellence Cluster
Universe

CALICE: Mission and Philosophy

- Development of highly granular "imaging" calorimeters for detectors at a future Linear Collider
  - Evaluate different technologies to find the best solution for a future experiment
- The physics benefit: Unprecedented 3D resolution of hadronic showers, will help to improve hadronic shower models in simulations

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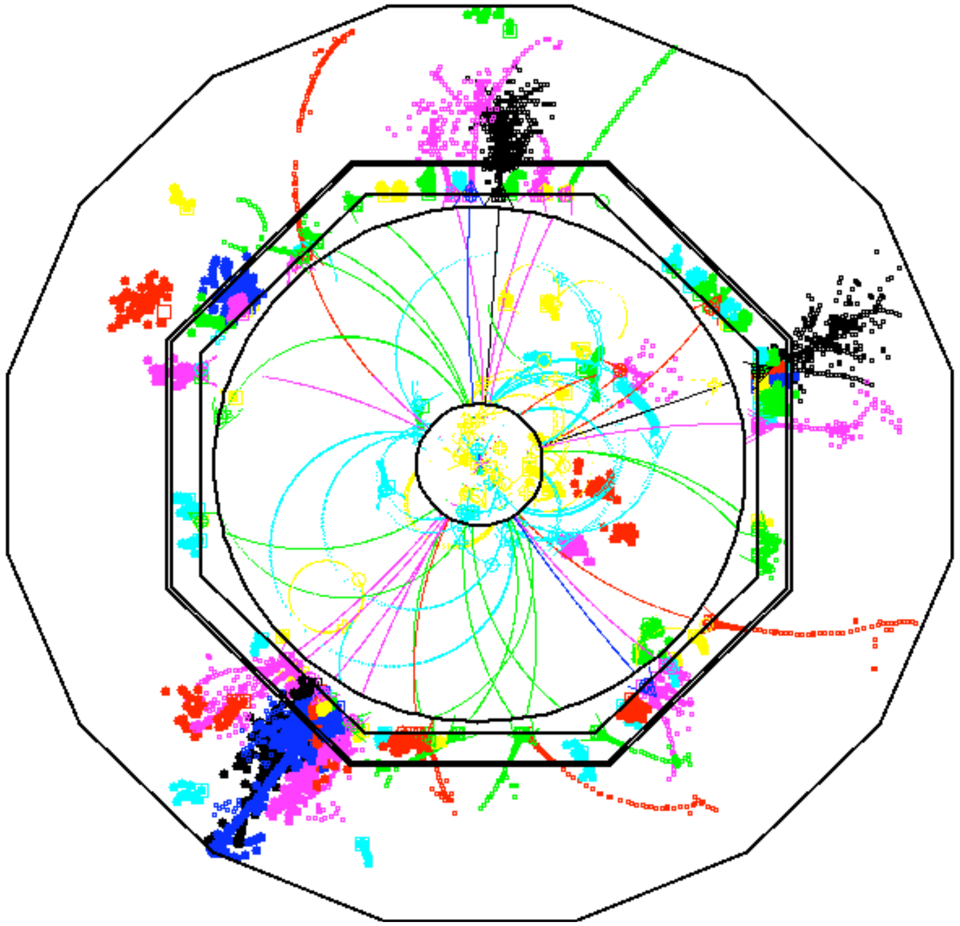
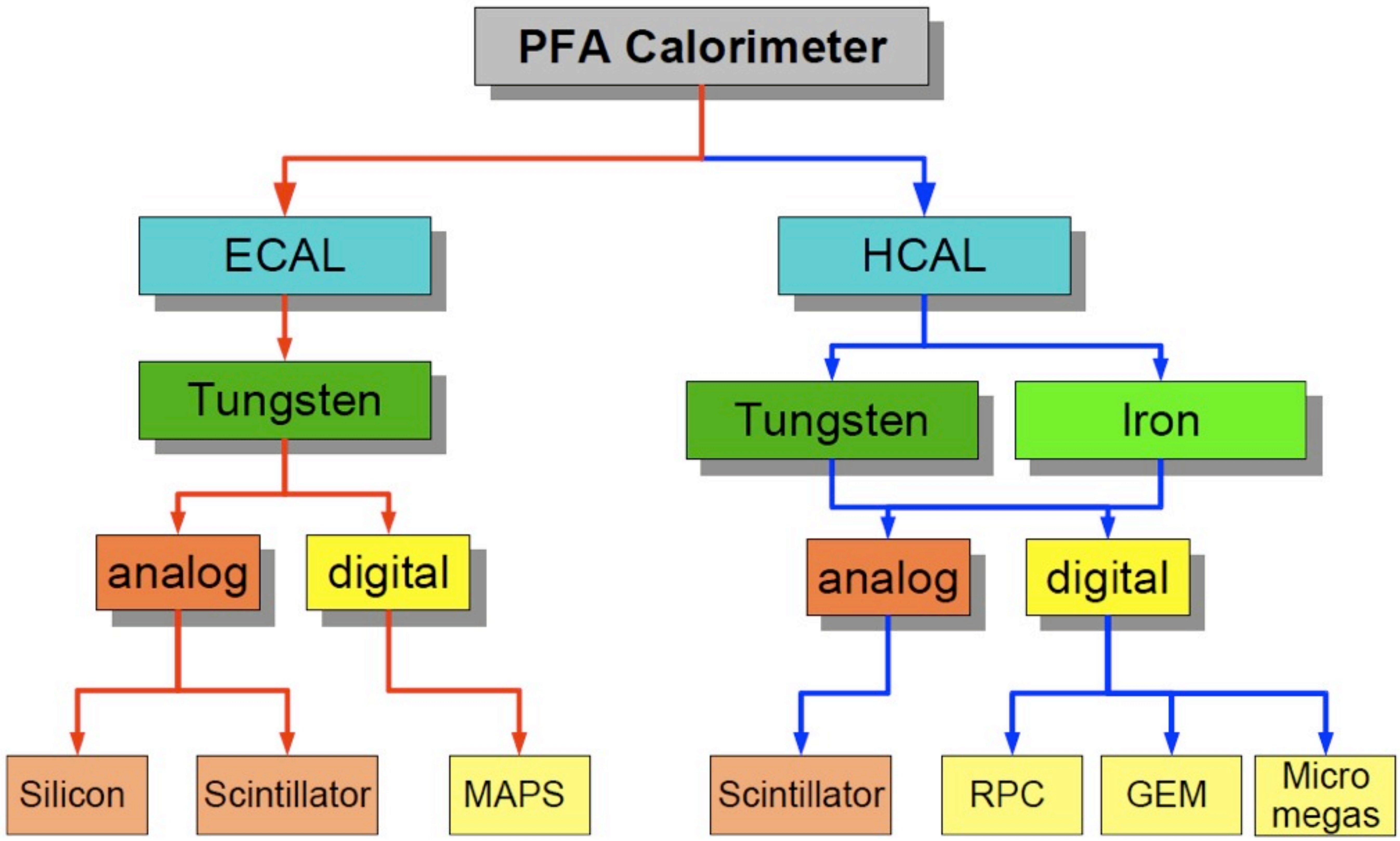
The basis of it all: The Particle Flow Concept

- Four vector reconstruction for each particle in a jet, with the best possible resolution
- ~ 65% of jet energy best measured in tracker!
- Particle separation (granularity) in the calorimeters more important than resolution!



The Technology Tree



CALICE: The Collaboration

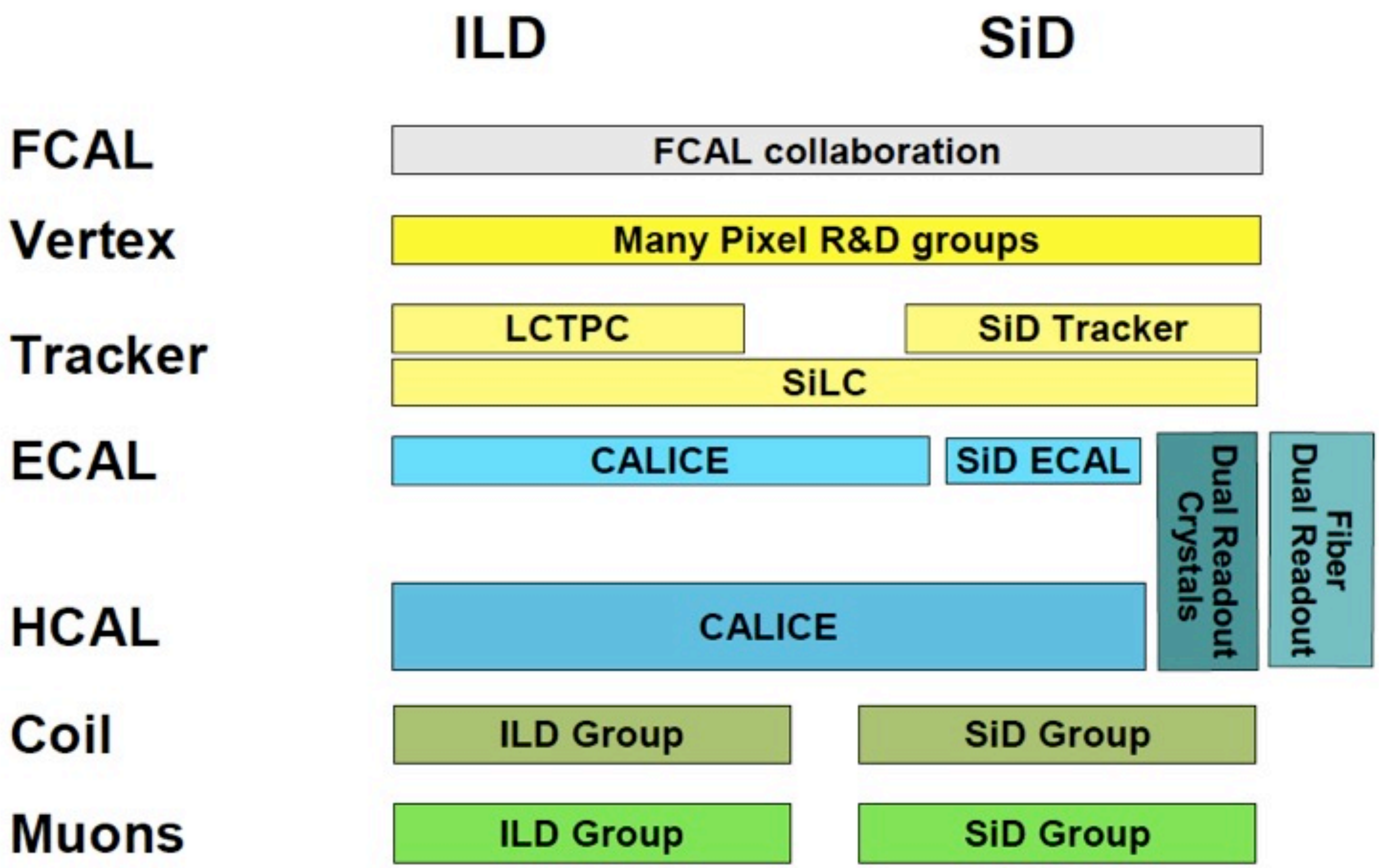
- A very dynamic, steadily growing collaboration

Approximately 330 scientists and engineers from 57 institutes in 17 countries
Truly global: 4 regions (Africa, Americas, Asia, Europe)

- Last collaboration meeting: Lyon, September 2009
  - the best-attended CALICE meeting so far (91 Participants)!
    ... and new institutes joining!

Embedding into ILC Community

- R&D for Calorimetry across detector concepts



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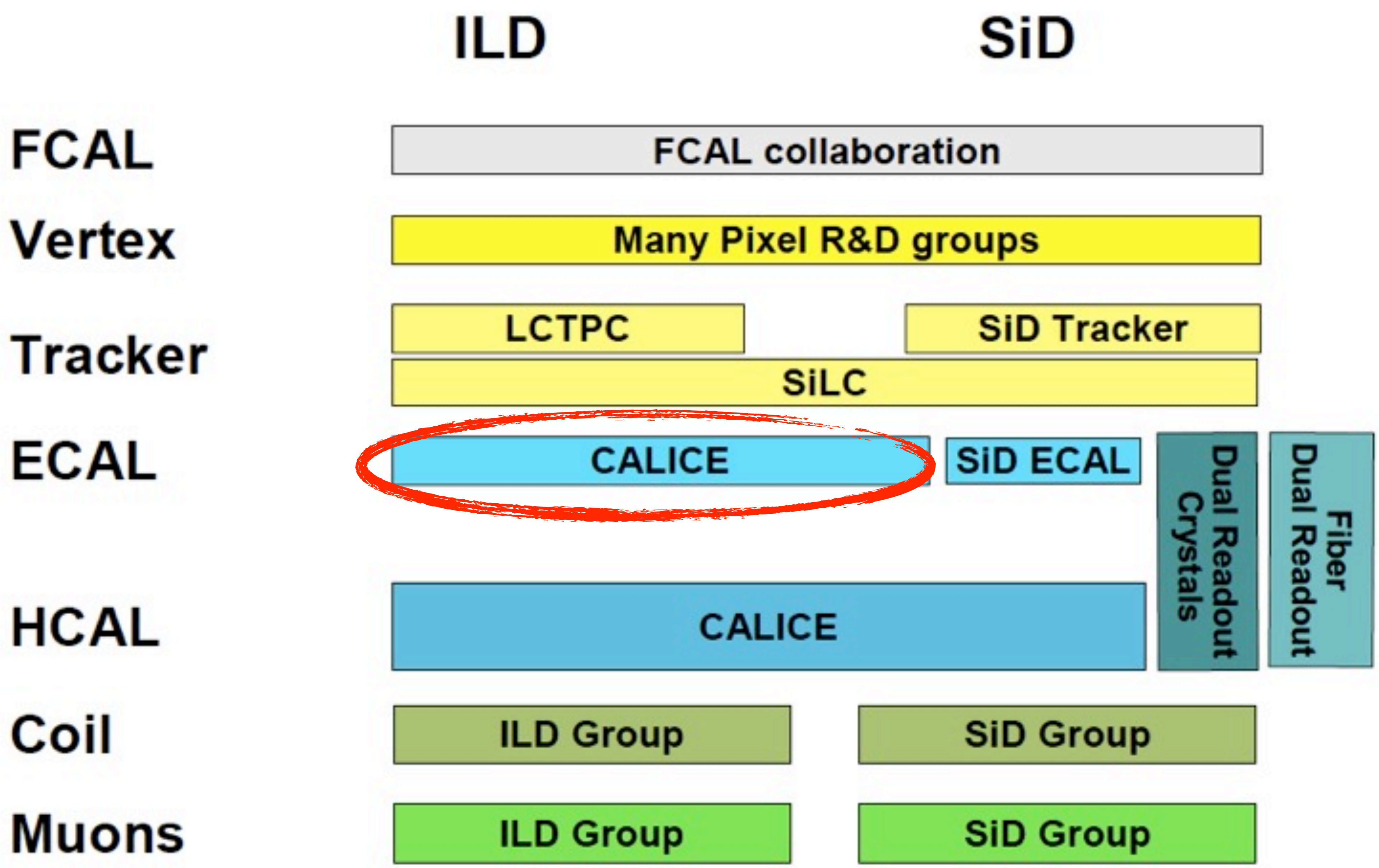

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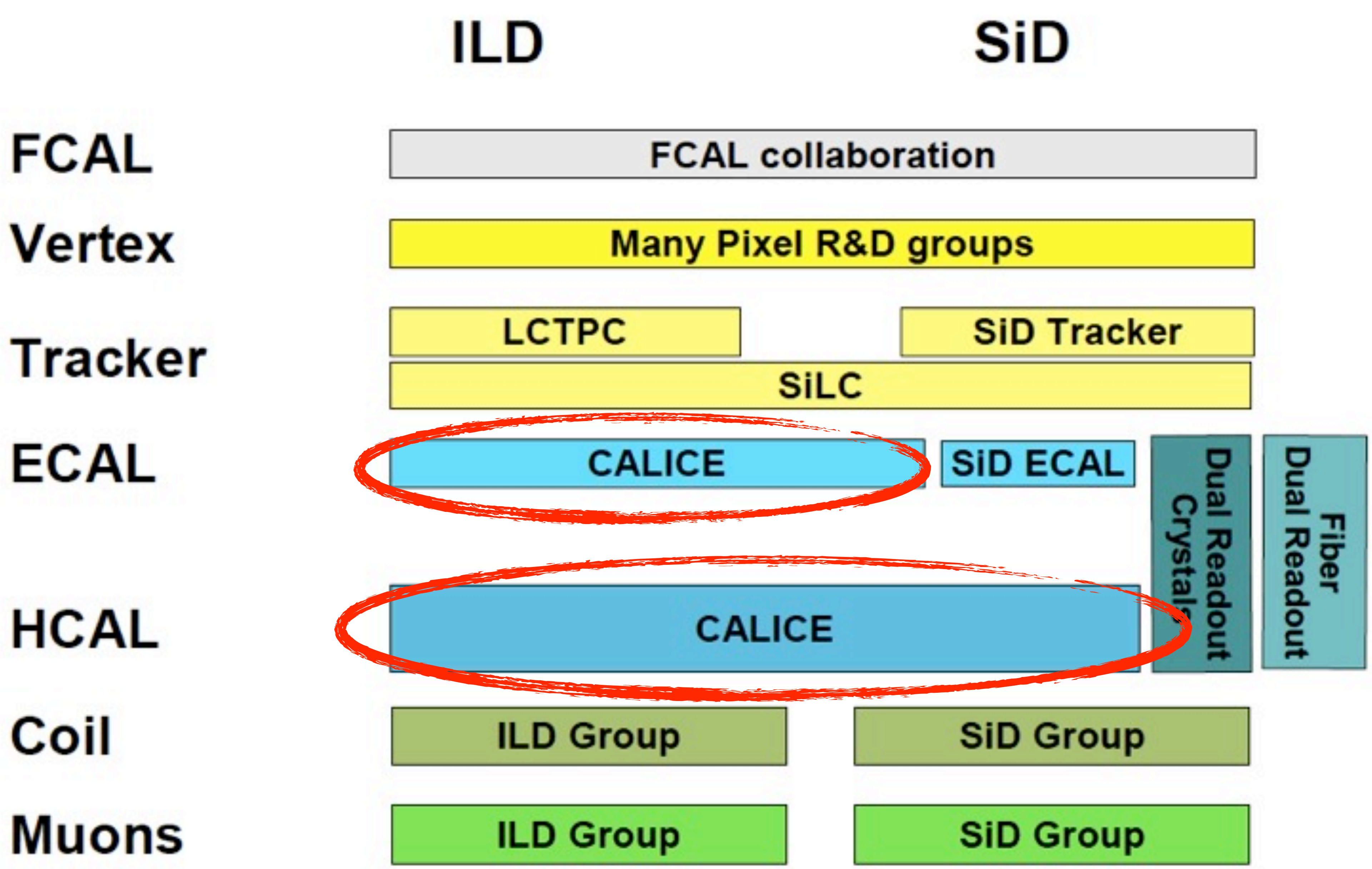


Embedding into ILC Community

- R&D for Calorimetry across detector concepts

ILD **SiD**

5. EVALUATION OF THE THREE CONCEPTS

5.1 ILD

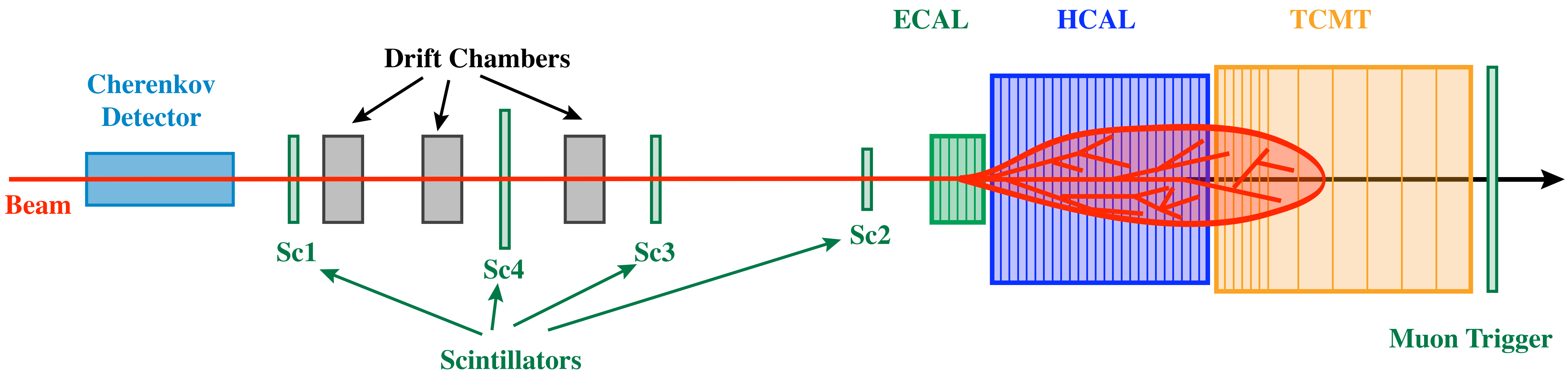
The ILD Collaboration has presented a LOI which documents the impressive quantity and quality of work performed. A particular strength of the LOI is the very extensive R&D effort made in test beams with full-size prototypes of the calorimeter having been constructed and operated at DESY, CERN and Fermilab. Indeed, alternative technologies for the calorimetry are also being explored in the test beam program. Integrated with these calorimeter tests their data have been taken with a "tail catcher" for one of the possible muon system options. This large data set will allow ILD to validate the PF strategy which is central to their design. The data will also enable ILD to revisit some of their parameter choices, for example the total depth of their calorimeter.

In future, tests in a full strength magnetic field will be made. Initial layout of power and other components in the high field can be studied. Prototyping of the TPC is ongoing in other tests.

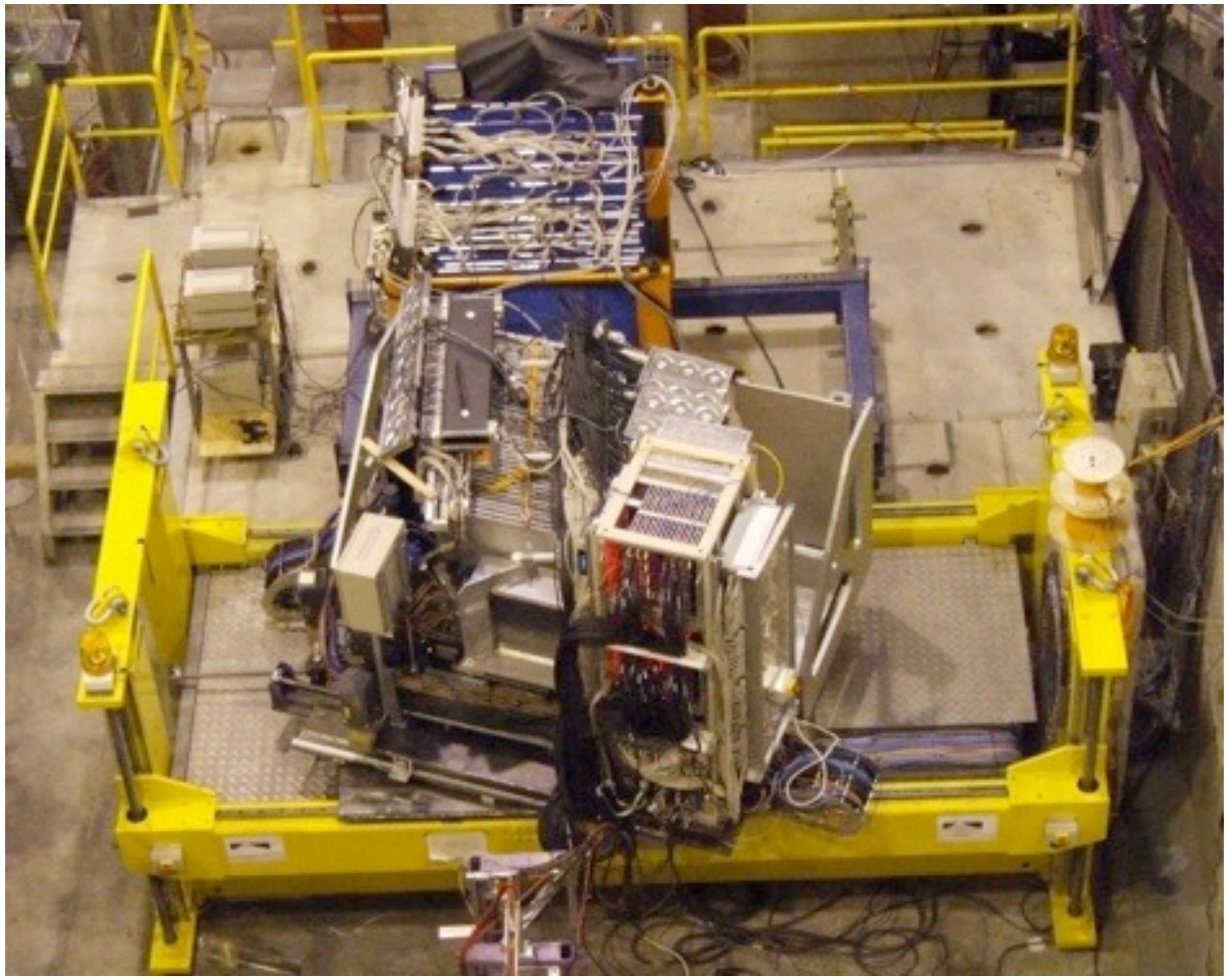
... a crucial role in the validation of ILD!

Test Beam Program: Highlights

Extensive Test Beam Program

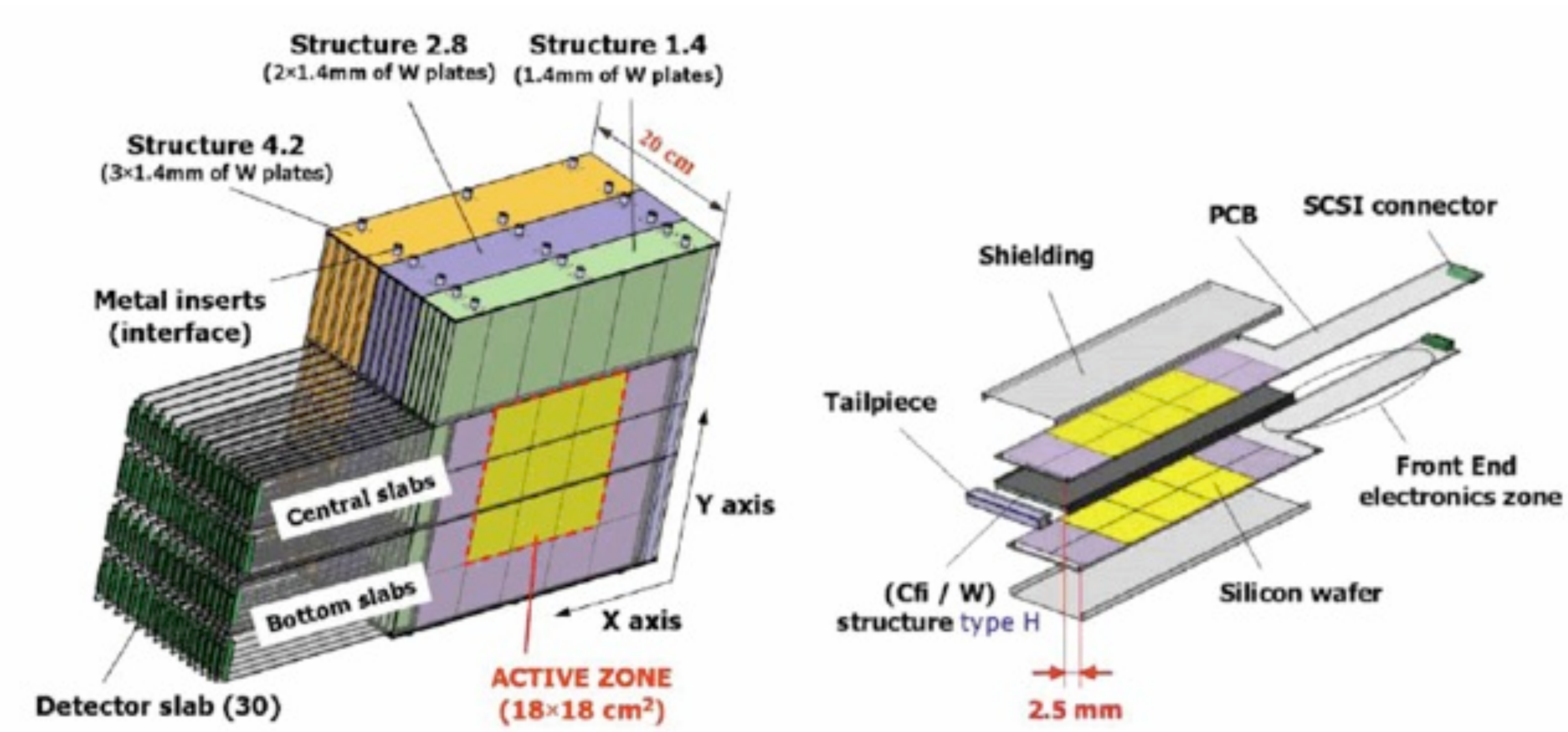


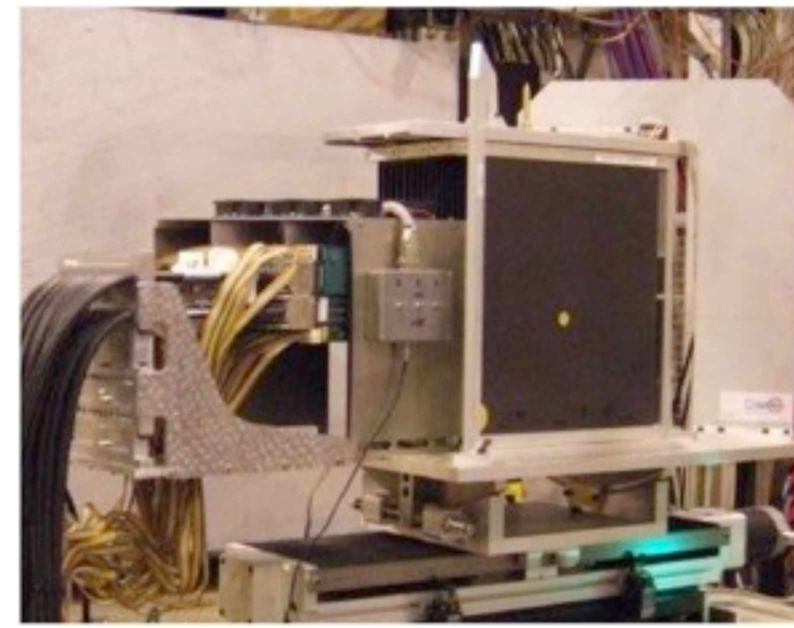
- Extensive test beam campaign
  - DESY: 2006
  - CERN: 2006, 2007
  - FNAL: 2008, ...
- Wide variety of beam energies and particle species
  - 2 GeV to 80 GeV
  - muons, $e^{\pm}$, $\pi^{\pm}$, unseparated hadrons
- 1 HCAL, 1 TCMT, 2 ECAL Technologies



The Physics Prototypes

- Testing of first generation of prototypes finished in May 2009





SiW ECAL (2006-2008)

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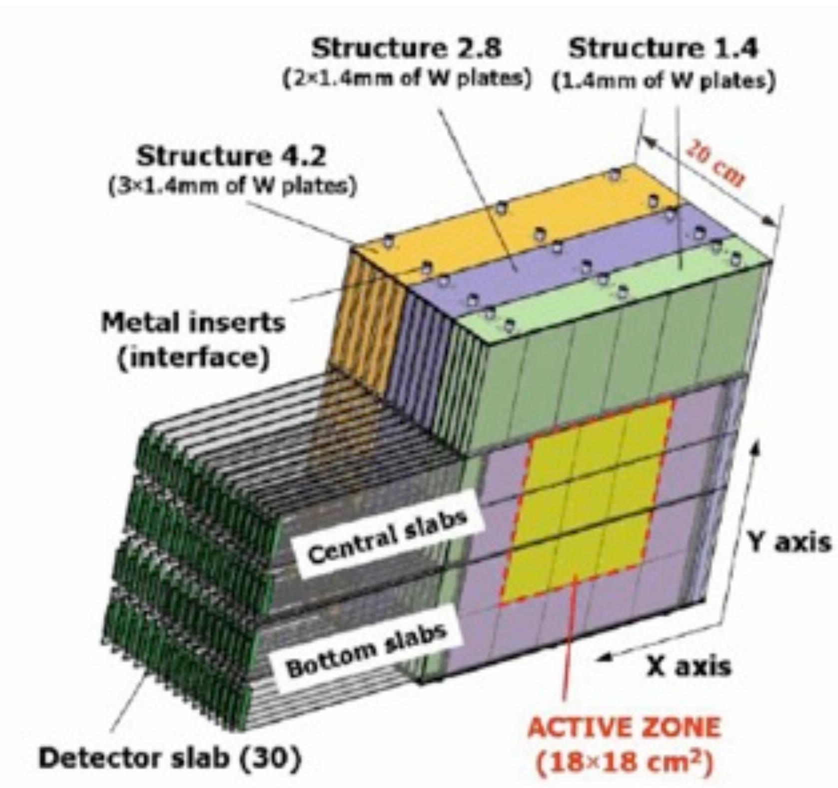

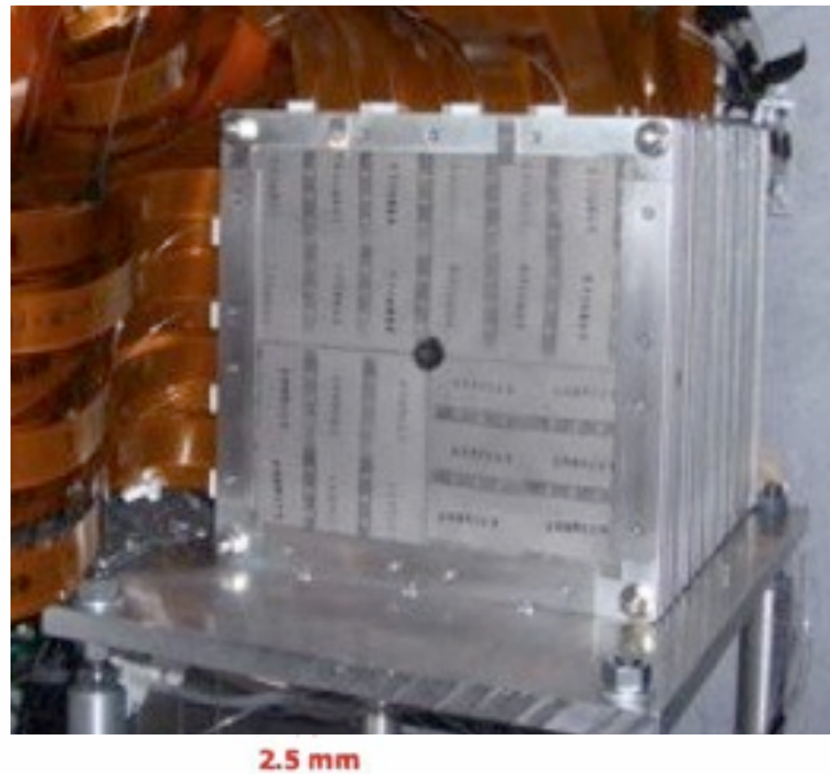

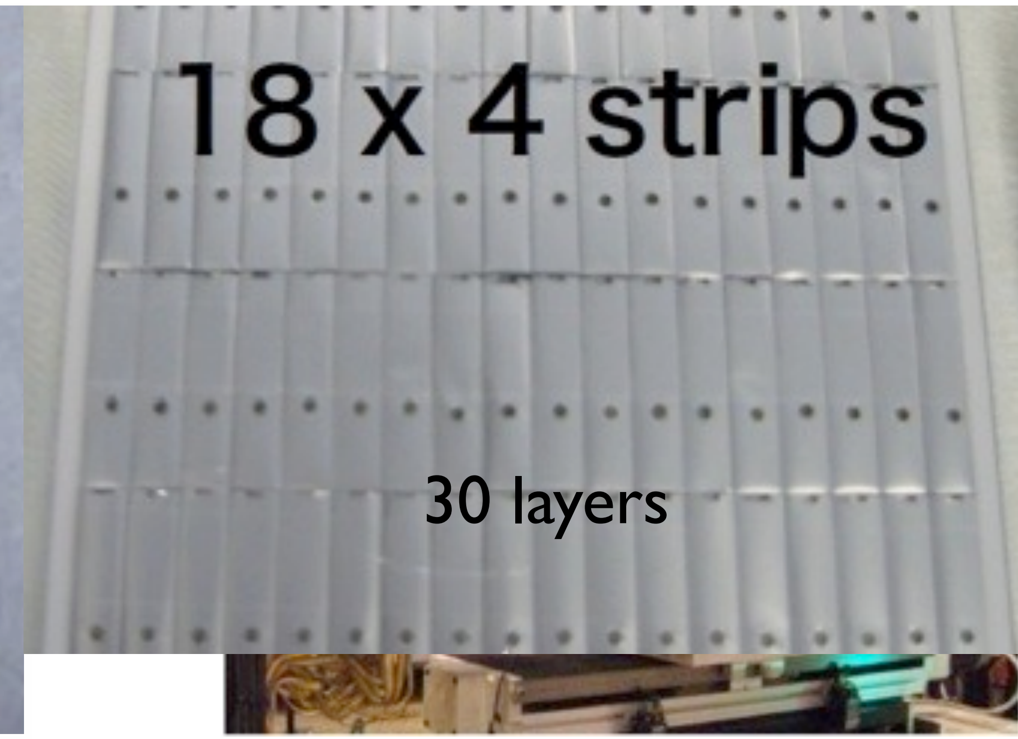

SiW ECAL (2006-2008)

Scintillator-W ECAL (2008-2009)

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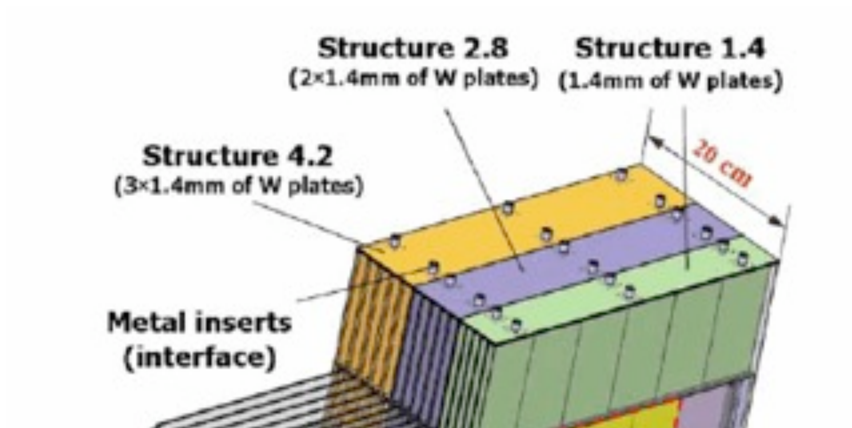
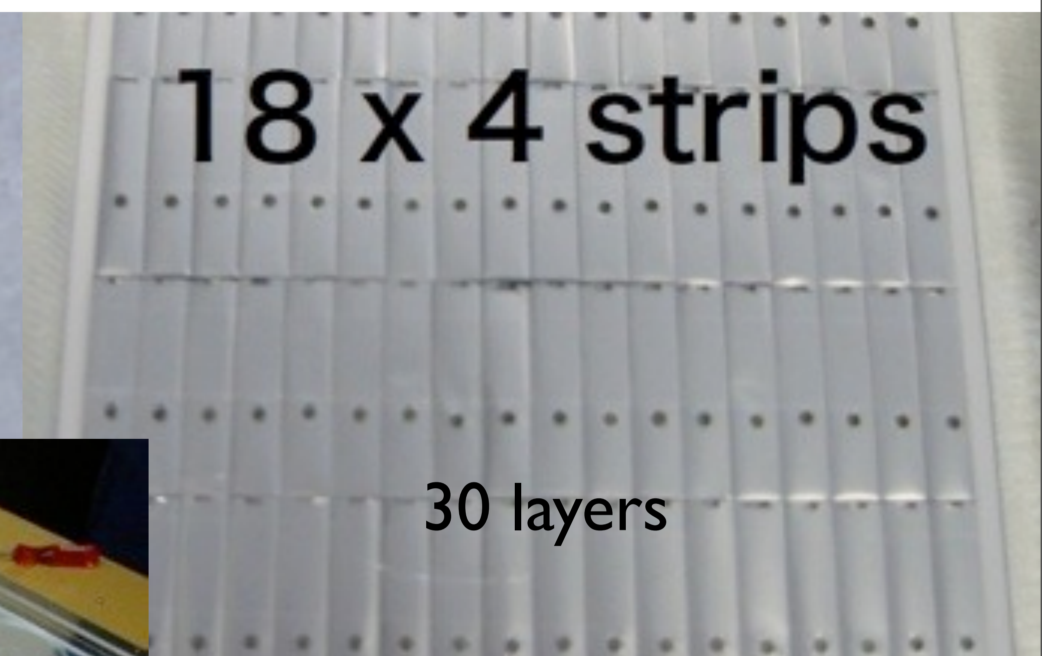
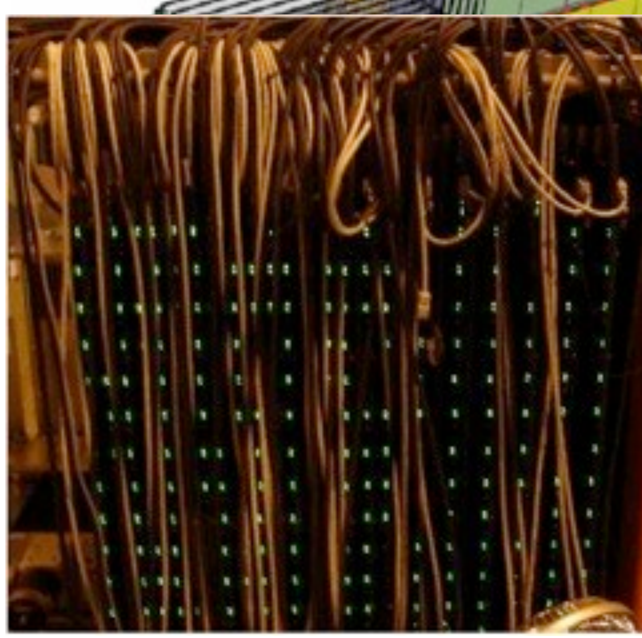
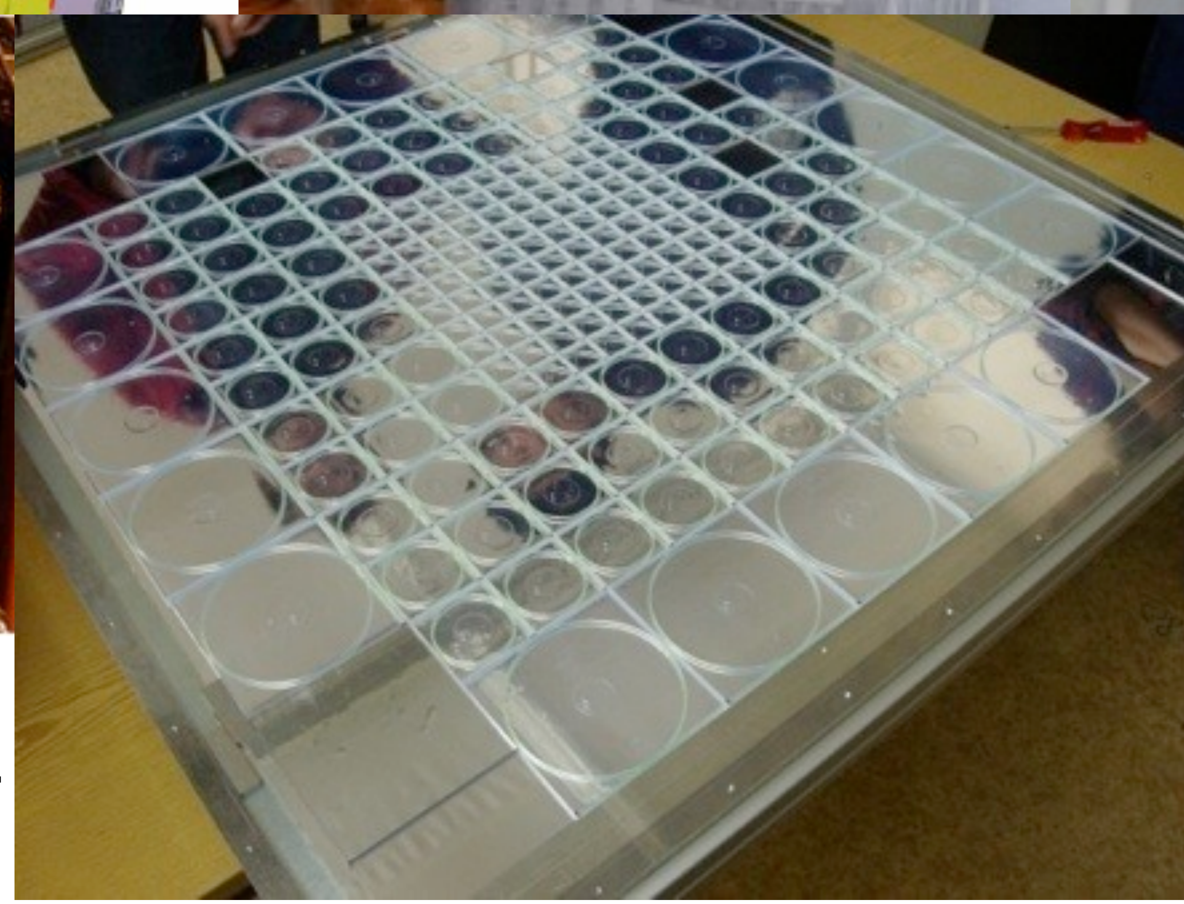




30 layers





-W ECAL (2008-2009)

38 layer analog HCAL
Scintillator-Steel
(2006-2009)

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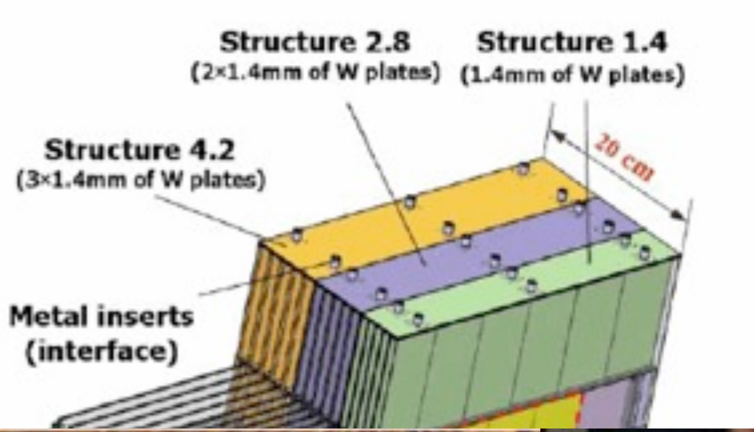

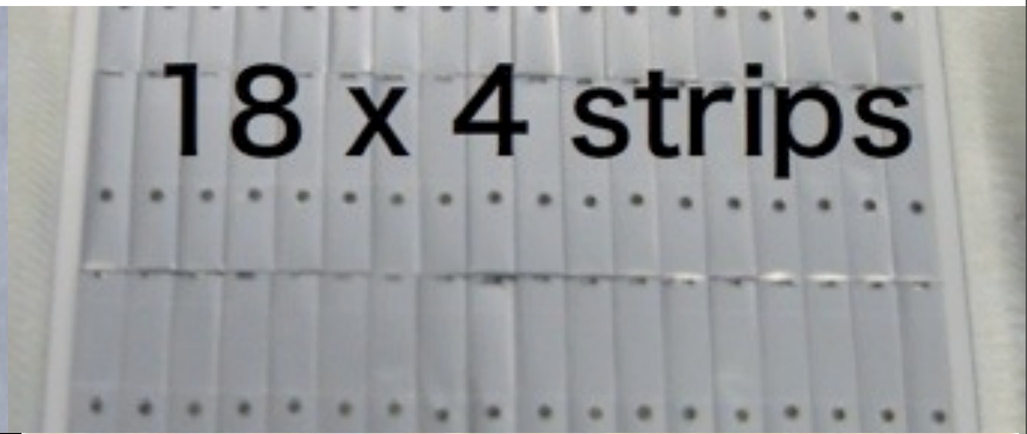

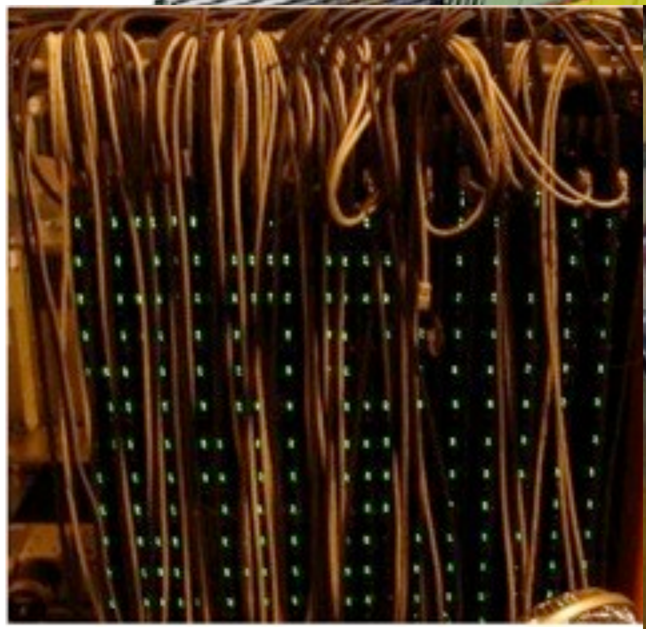

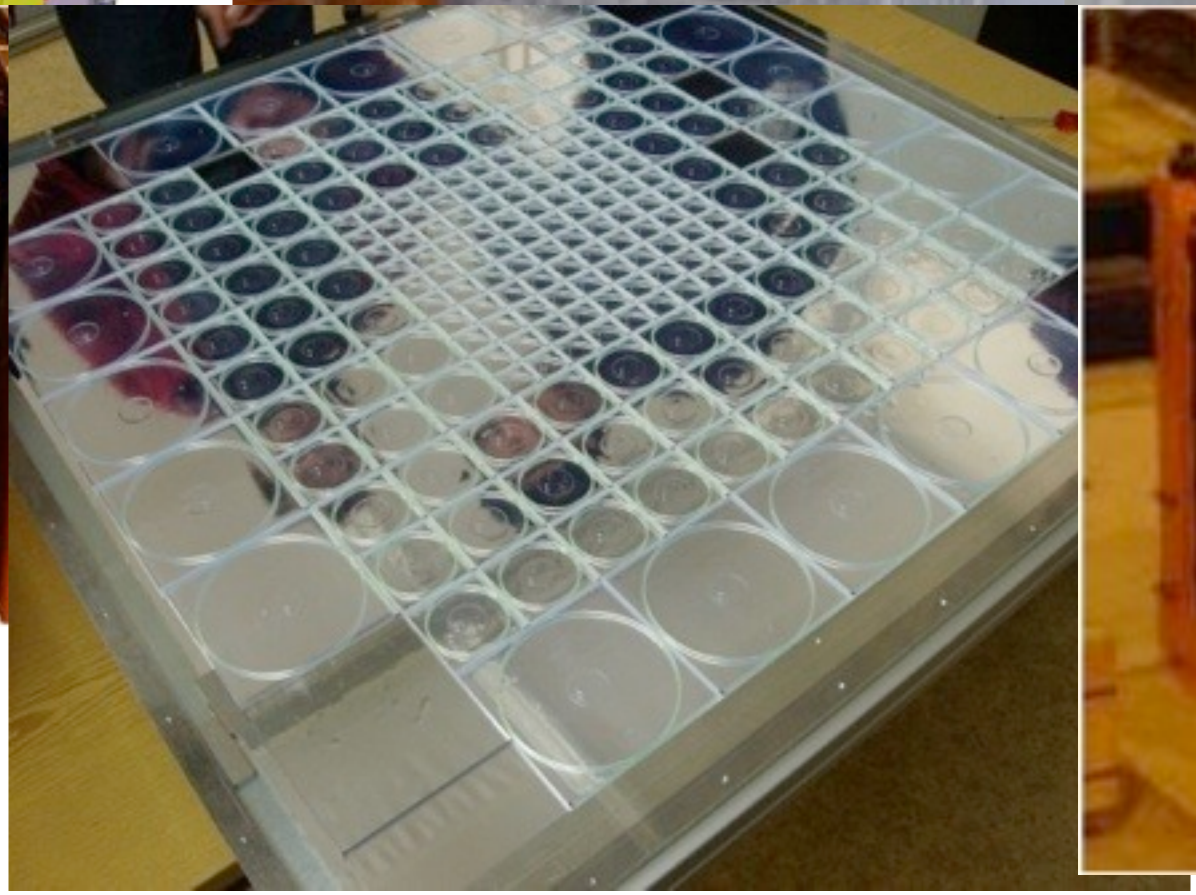

38 layer analog HCAL
Scintillator-Steel
(2006-2009)

Tail Catcher Scintillator Steel
(2006-2009)

The Data Set

- Successful data taking in several run periods on two continents
- ~ 15 TB of raw data taken, close to 500 million events recorded
- hadron and electron/positron data, muons, calibration events w/o beam, in a variety of different detector configurations

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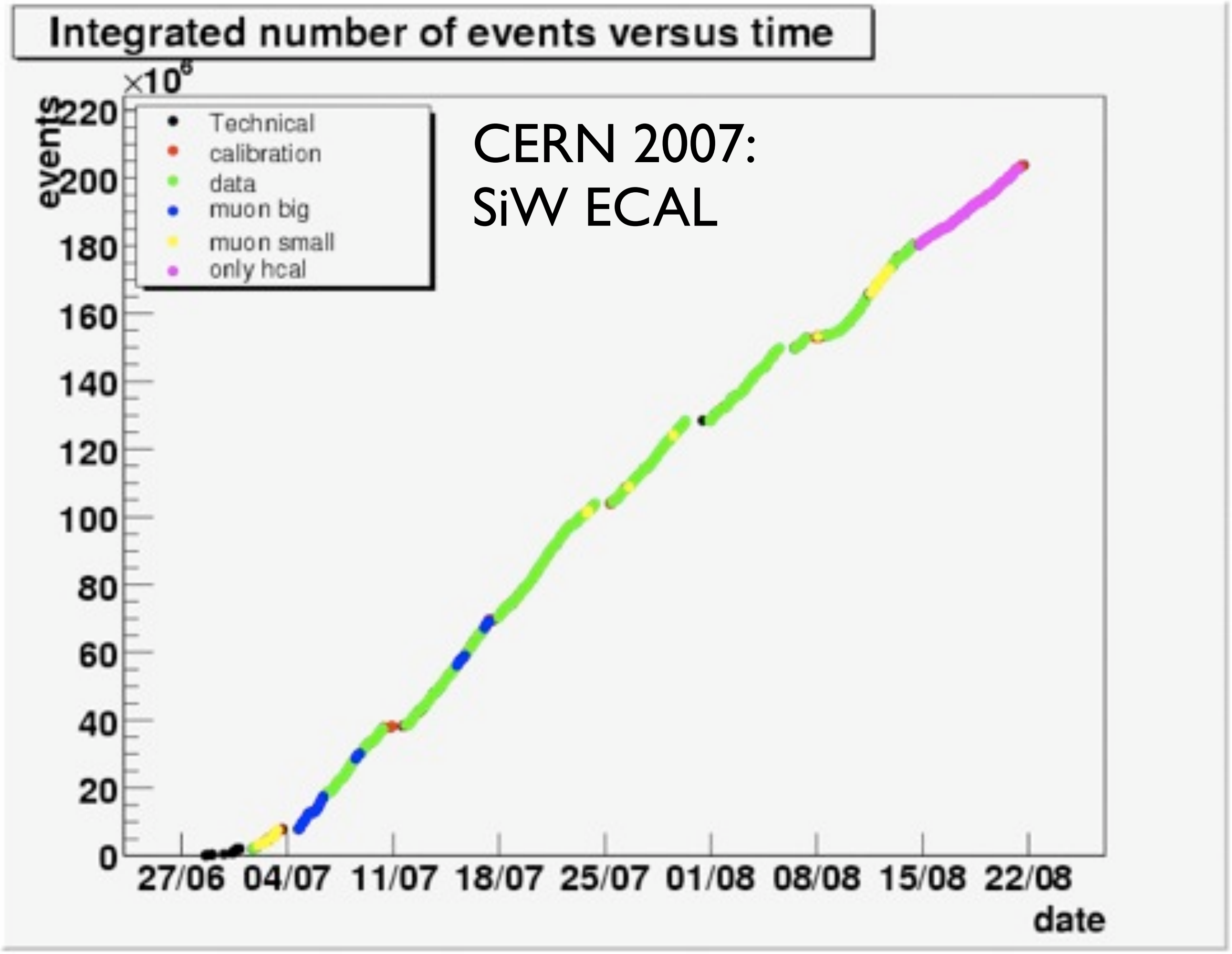

CERN 2007:
SiW ECAL

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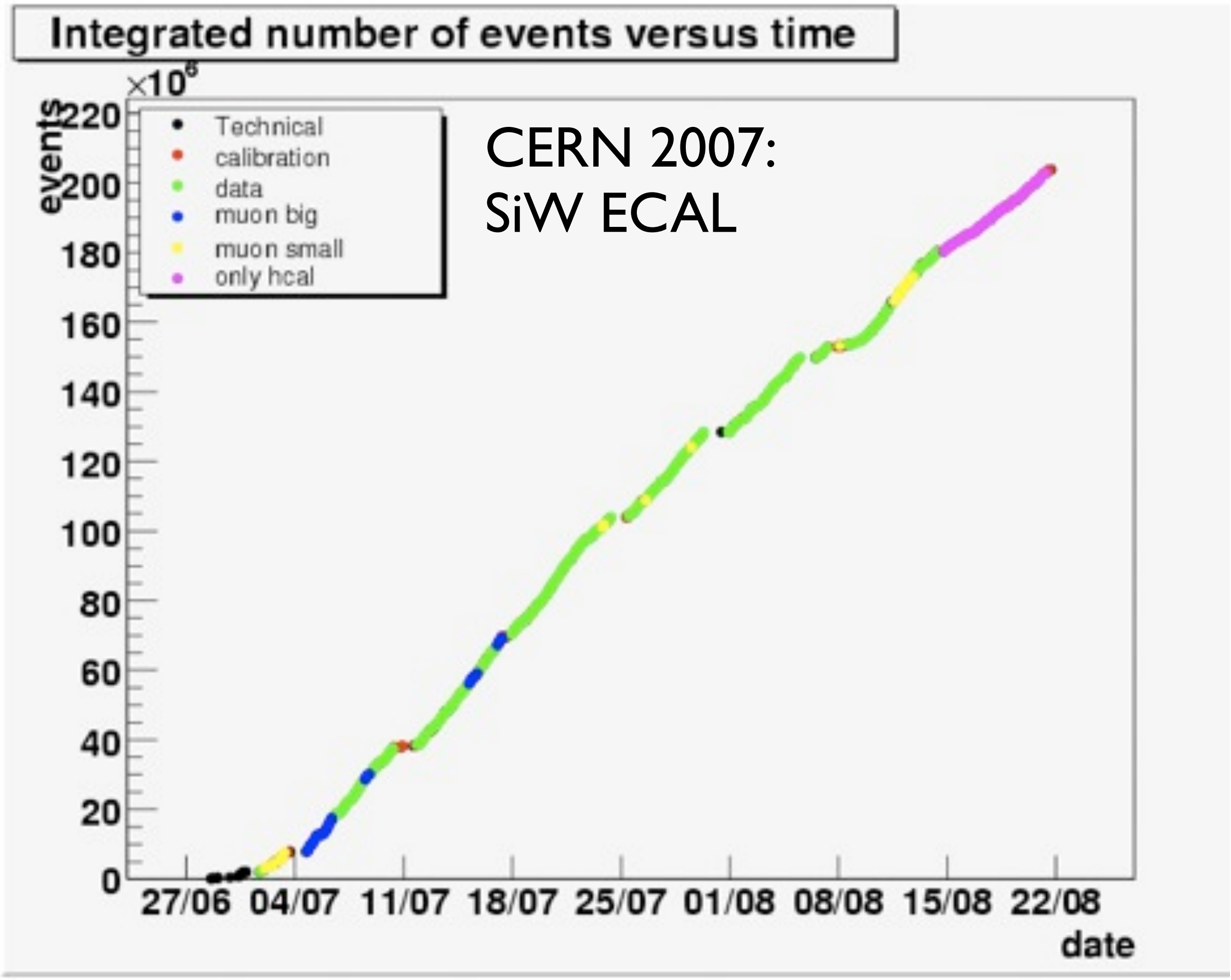
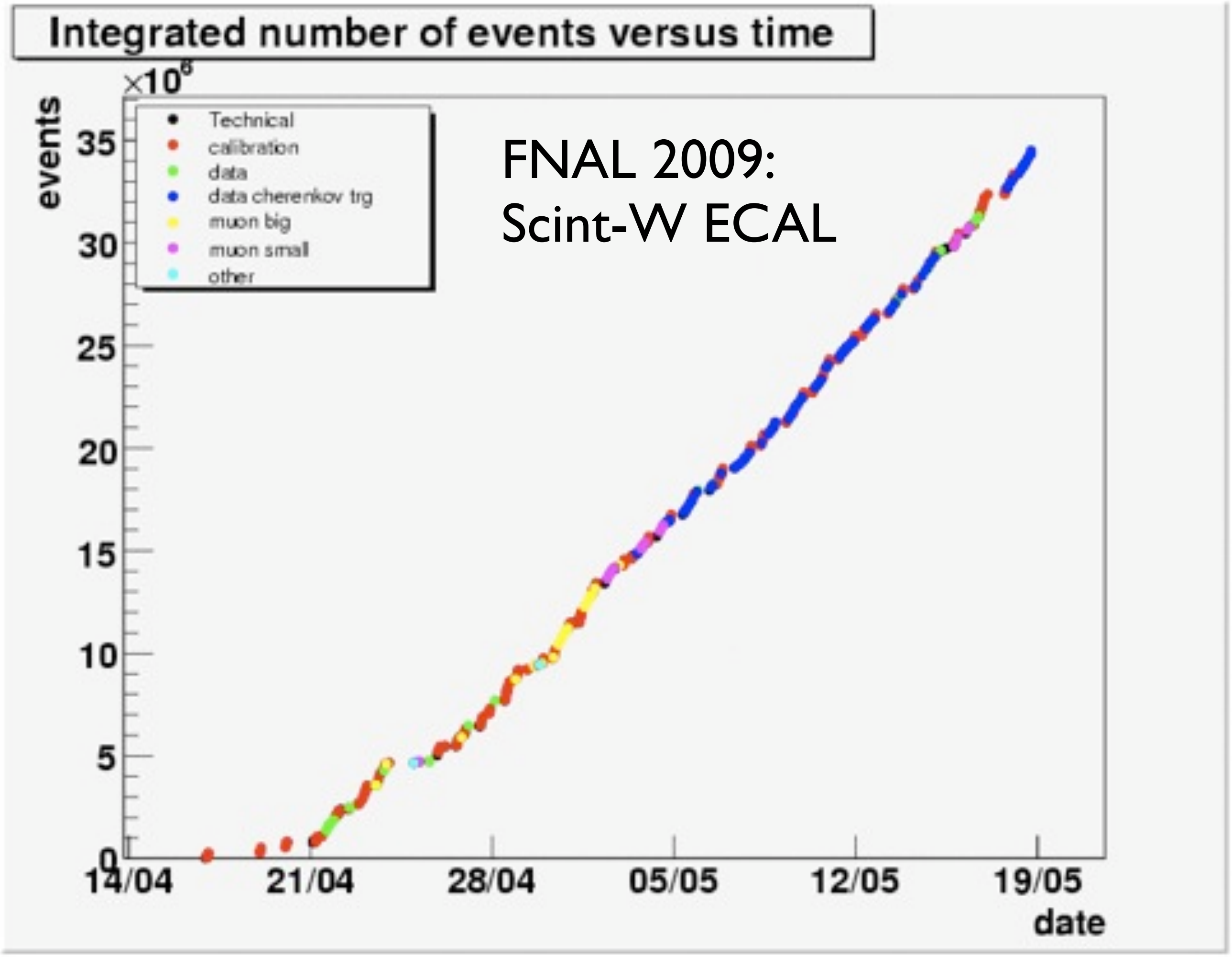
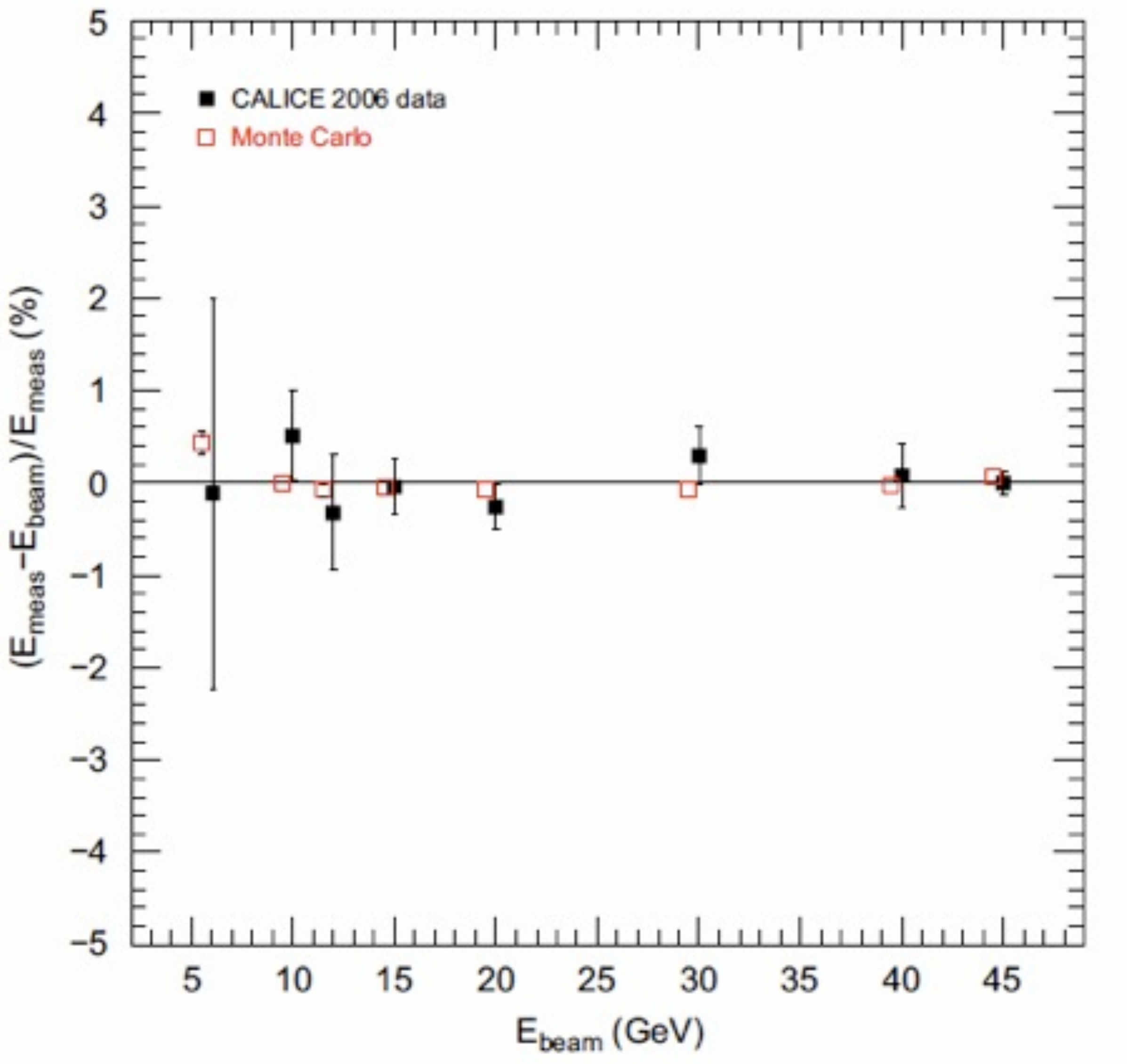
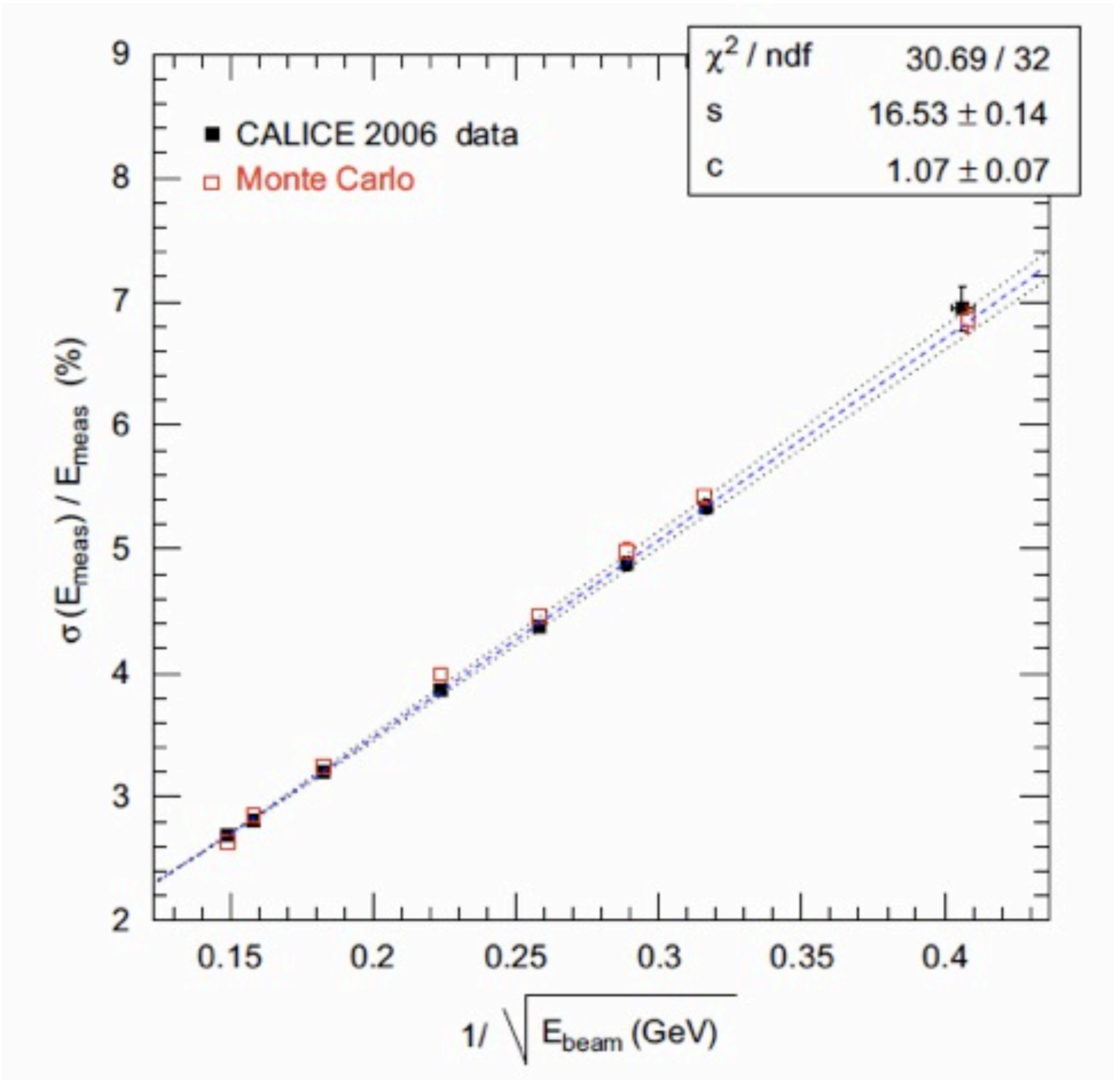




Selected Results: Si-W ECAL



- Good linearity: within 1%
- Resolution:
  16.5% stochastic term, 1% constant term



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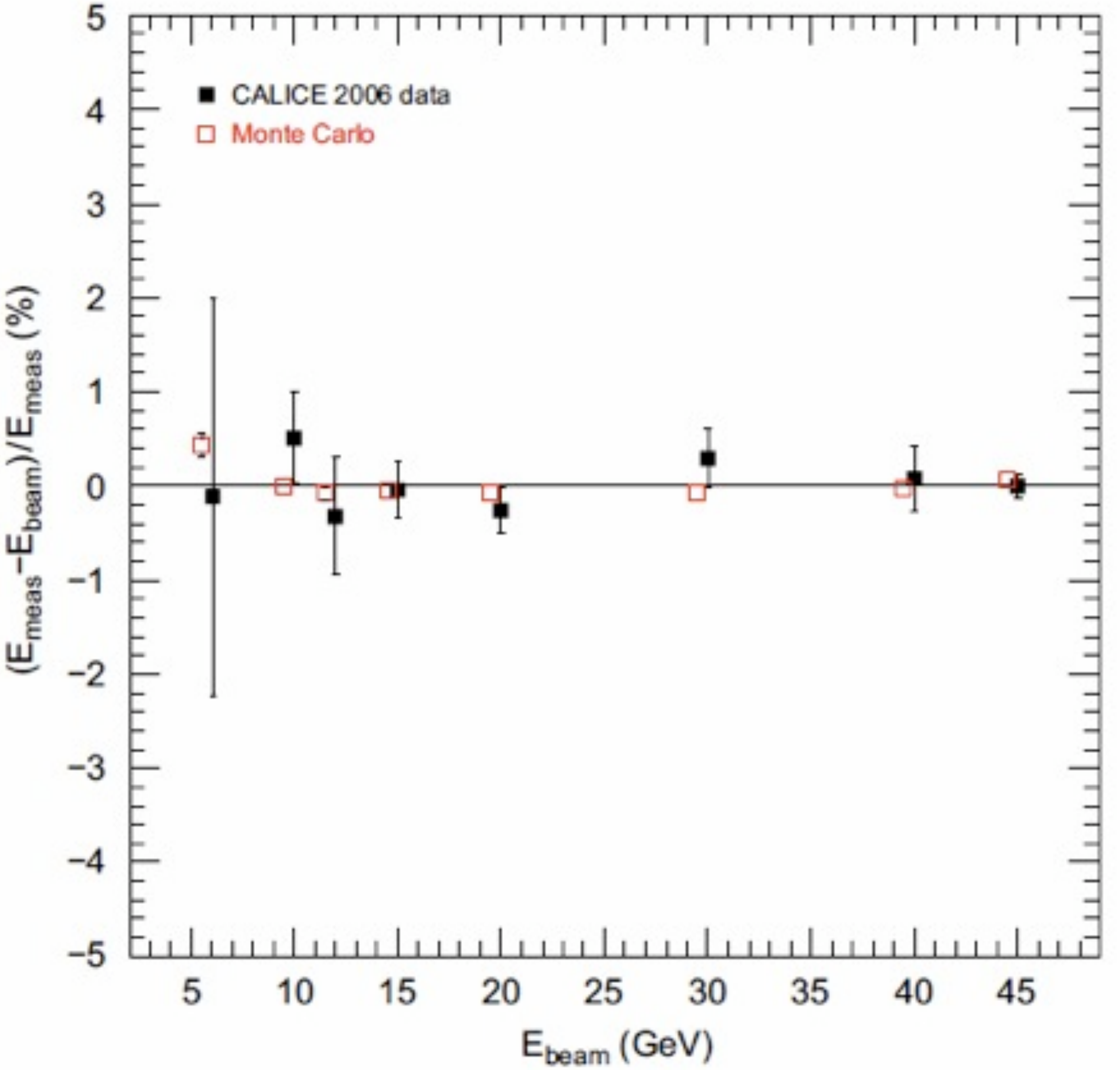

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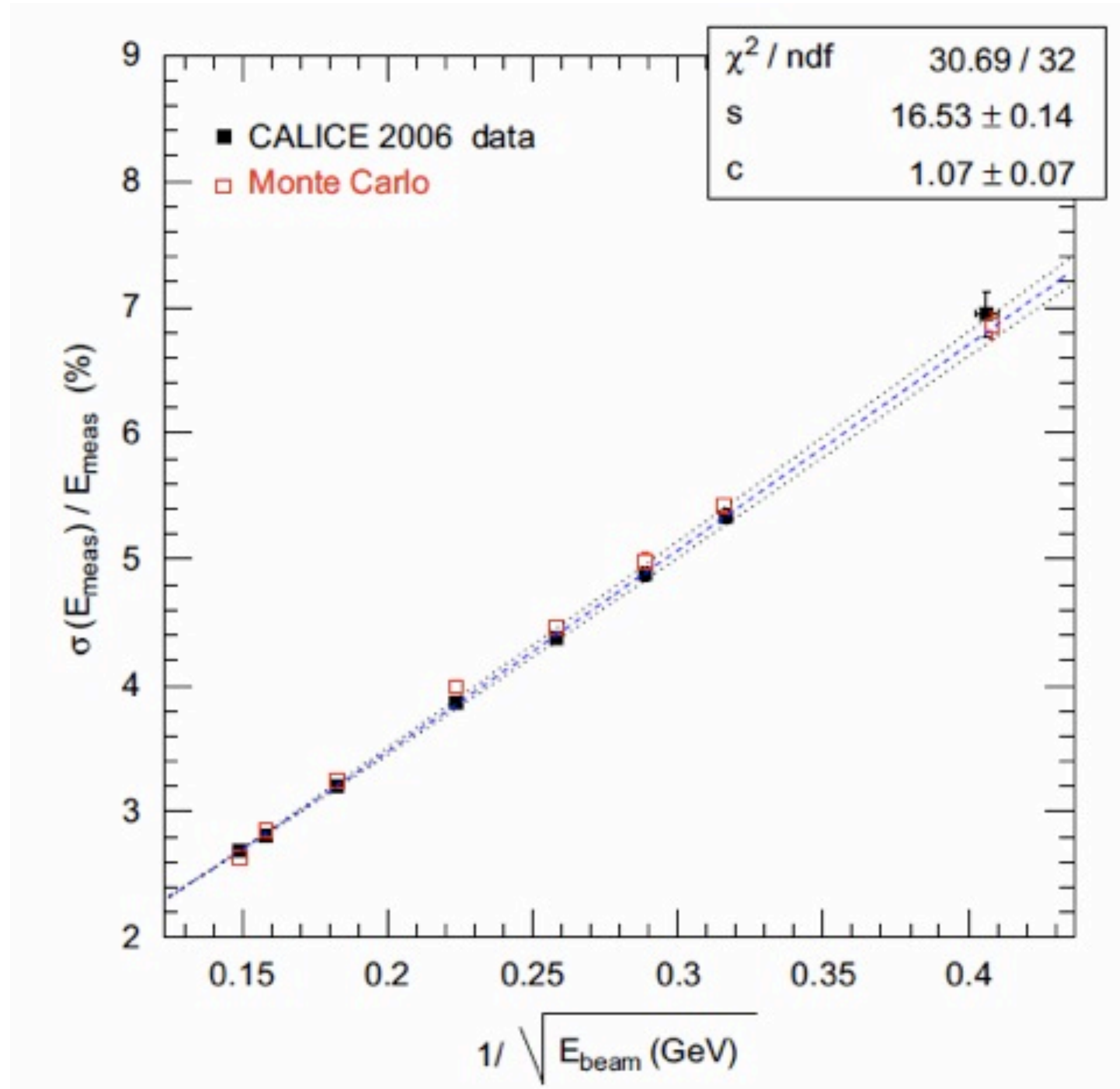
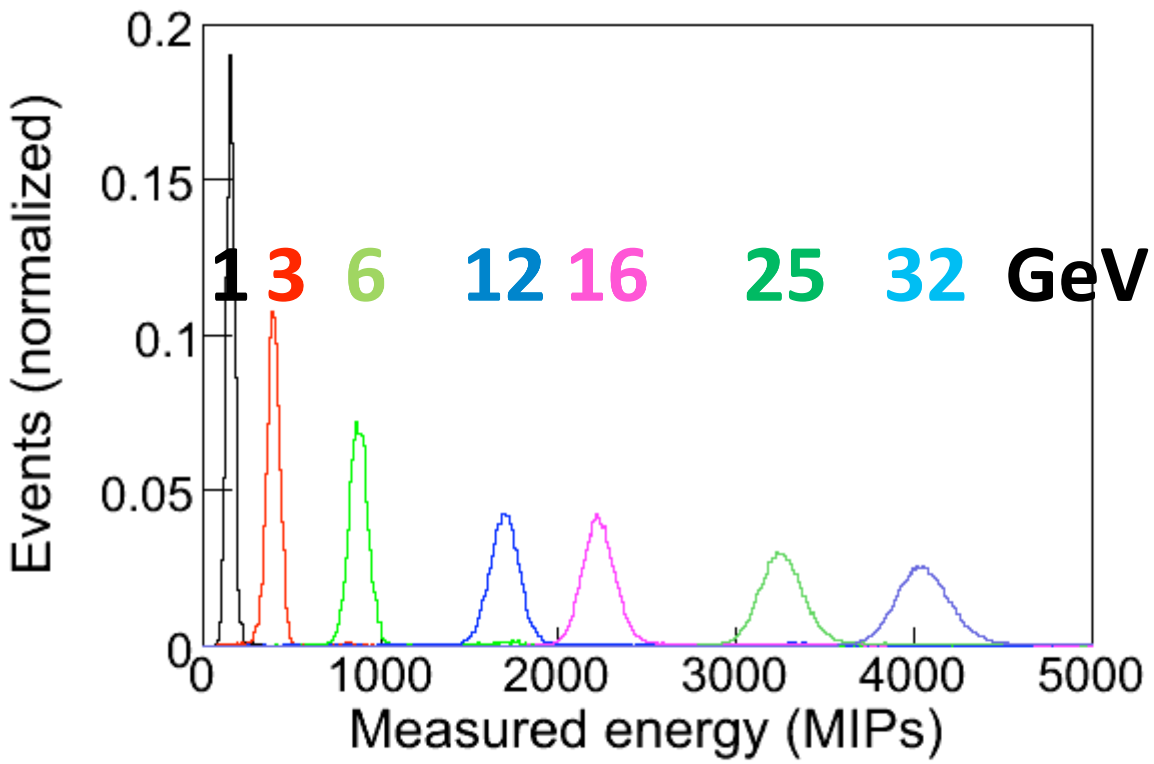


Remember: Optimized for 3D resolution and PFA, not energy resolution!

Selected Results: Scintillator-W ECAL



- Energy reconstruction with electrons: Good linearity of response!

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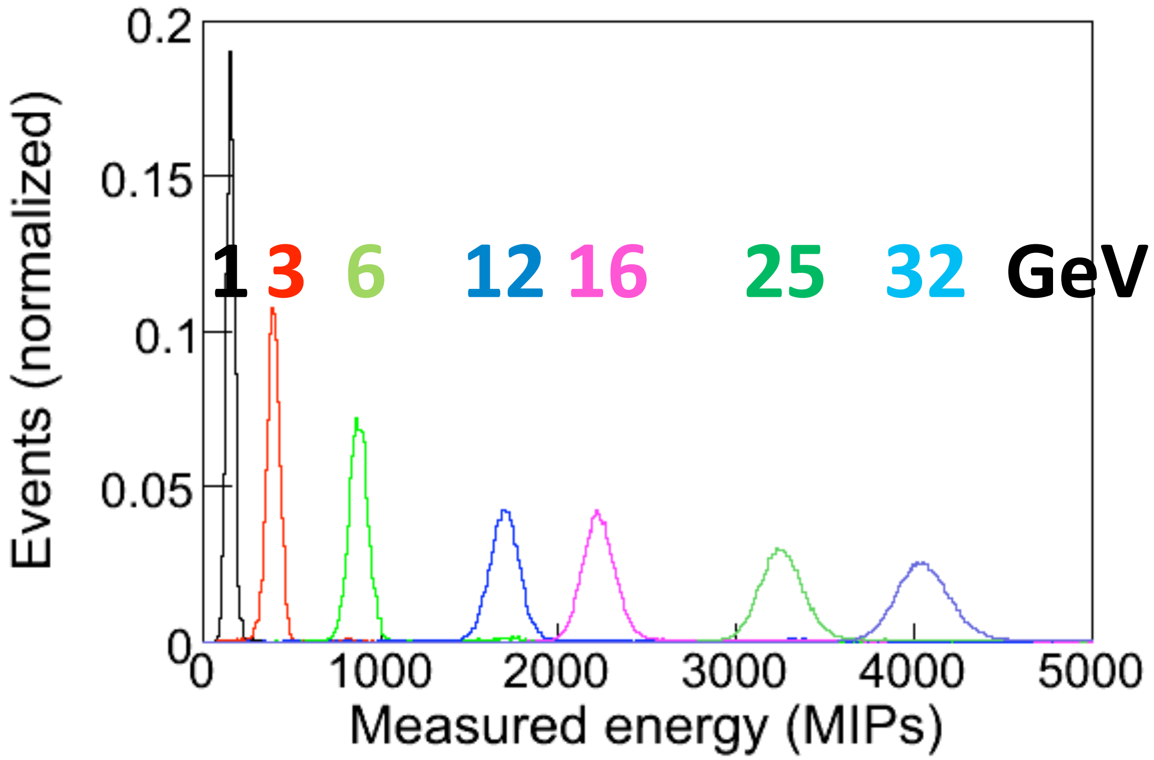
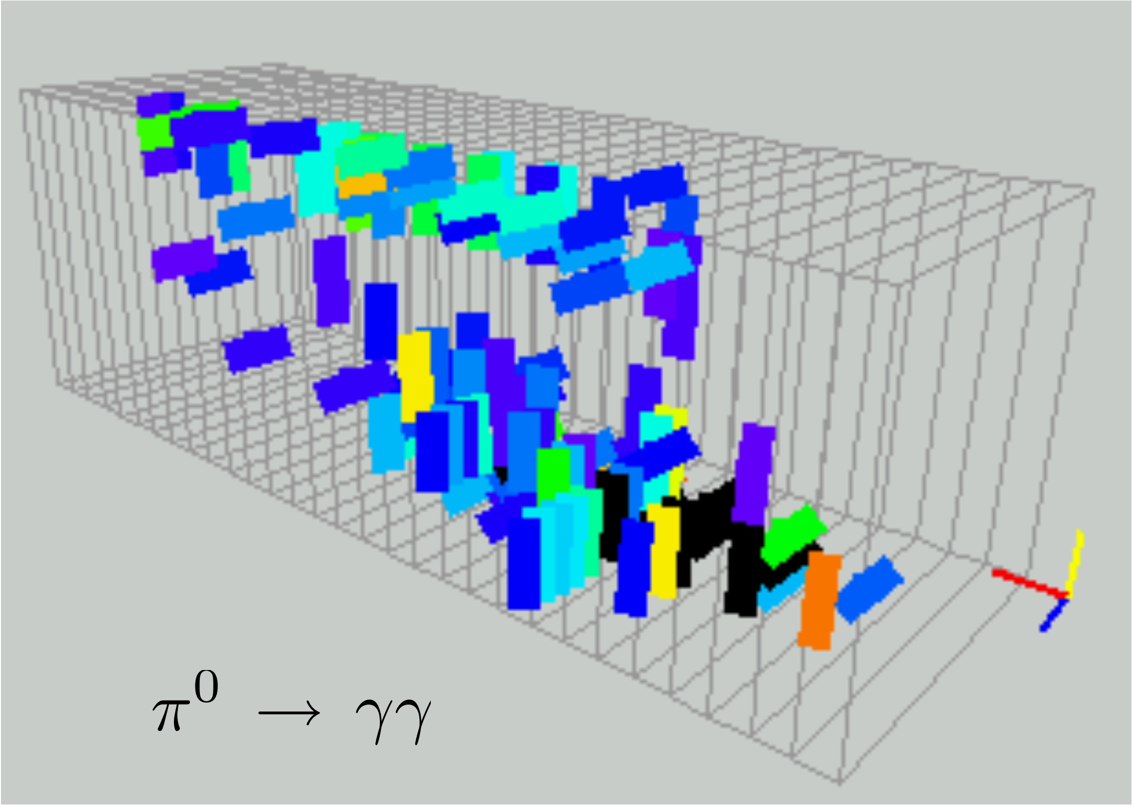
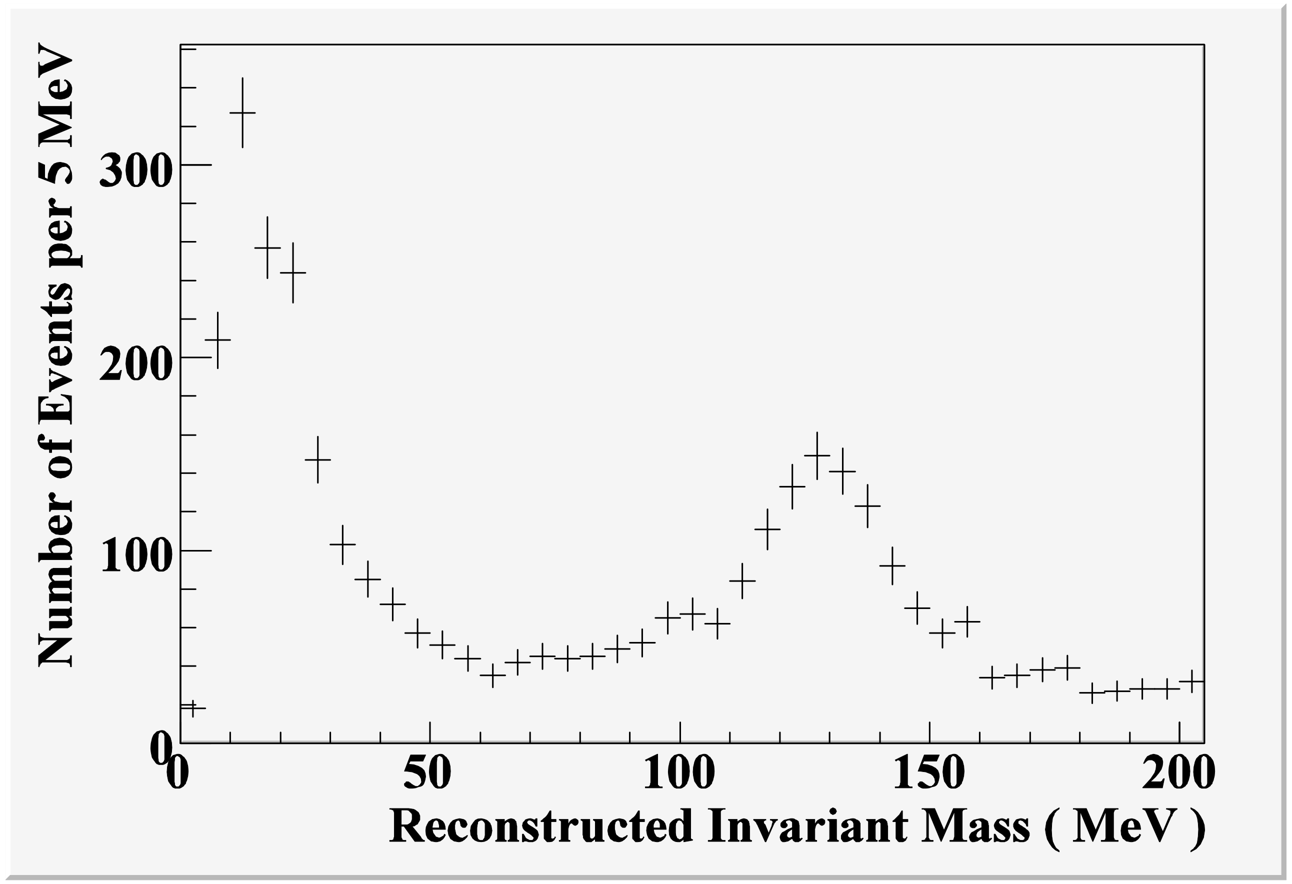
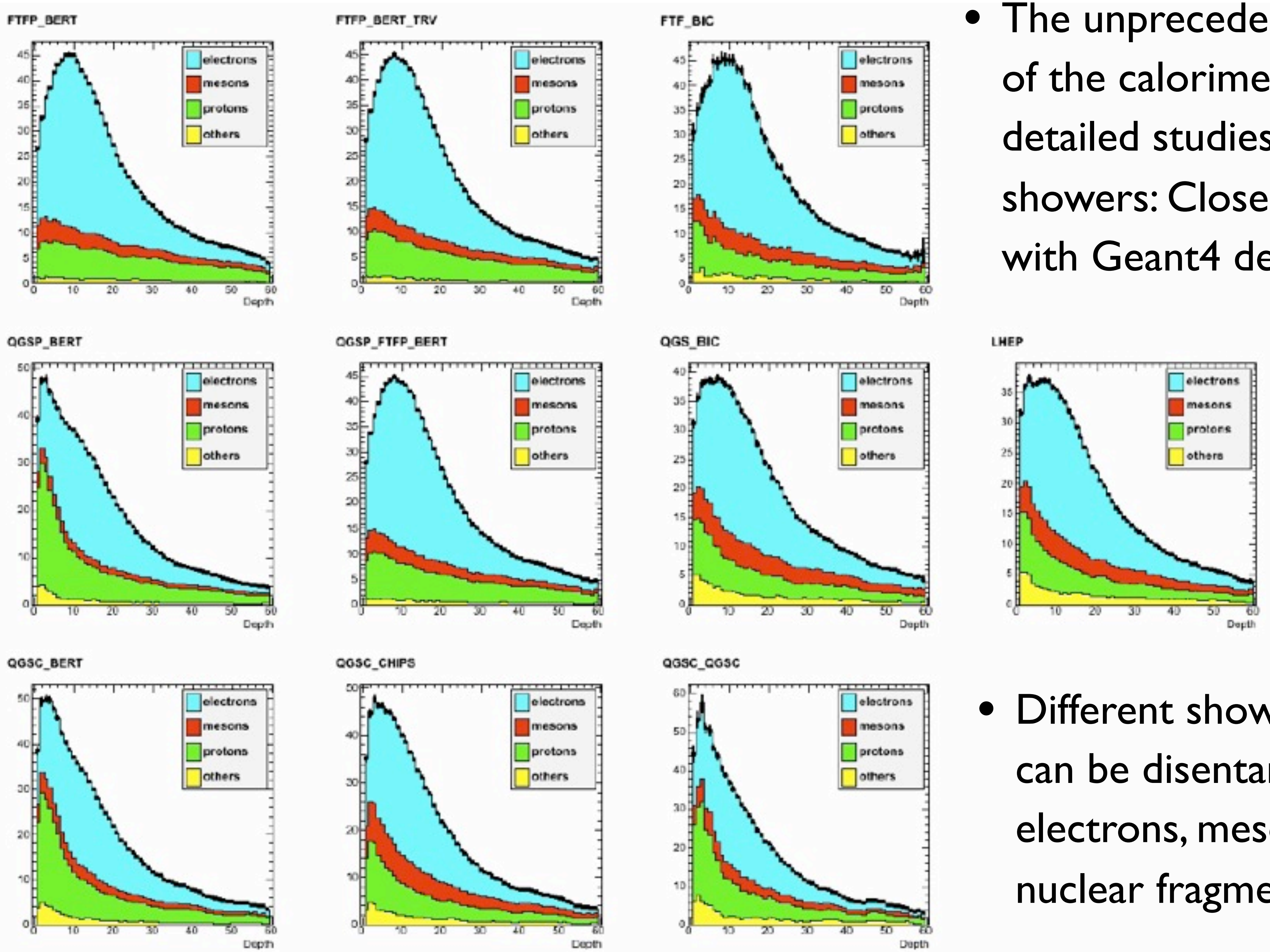


- Energy reconstruction with electrons: Good linearity of response!
- Demonstrated capability of π^0 detection:
  Production target 1.8 m upstream of ECAL





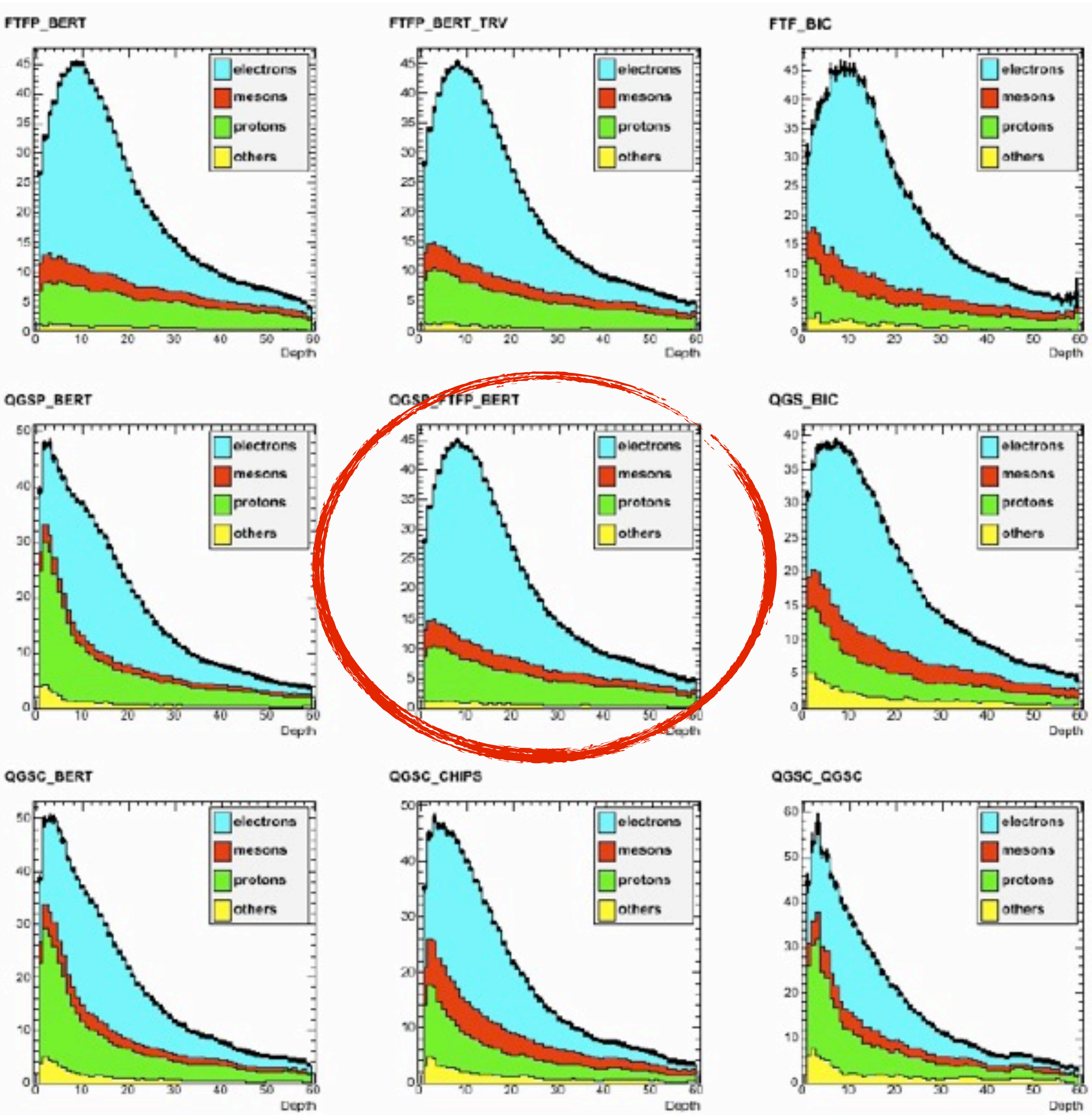
Understanding Hadronic Showers



- The unprecedented granularity of the calorimeters allows detailed studies of hadronic showers: Close collaboration with Geant4 developers

- Different shower components can be disentangled: electrons, mesons, protons, nuclear fragments

Understanding Hadronic Showers



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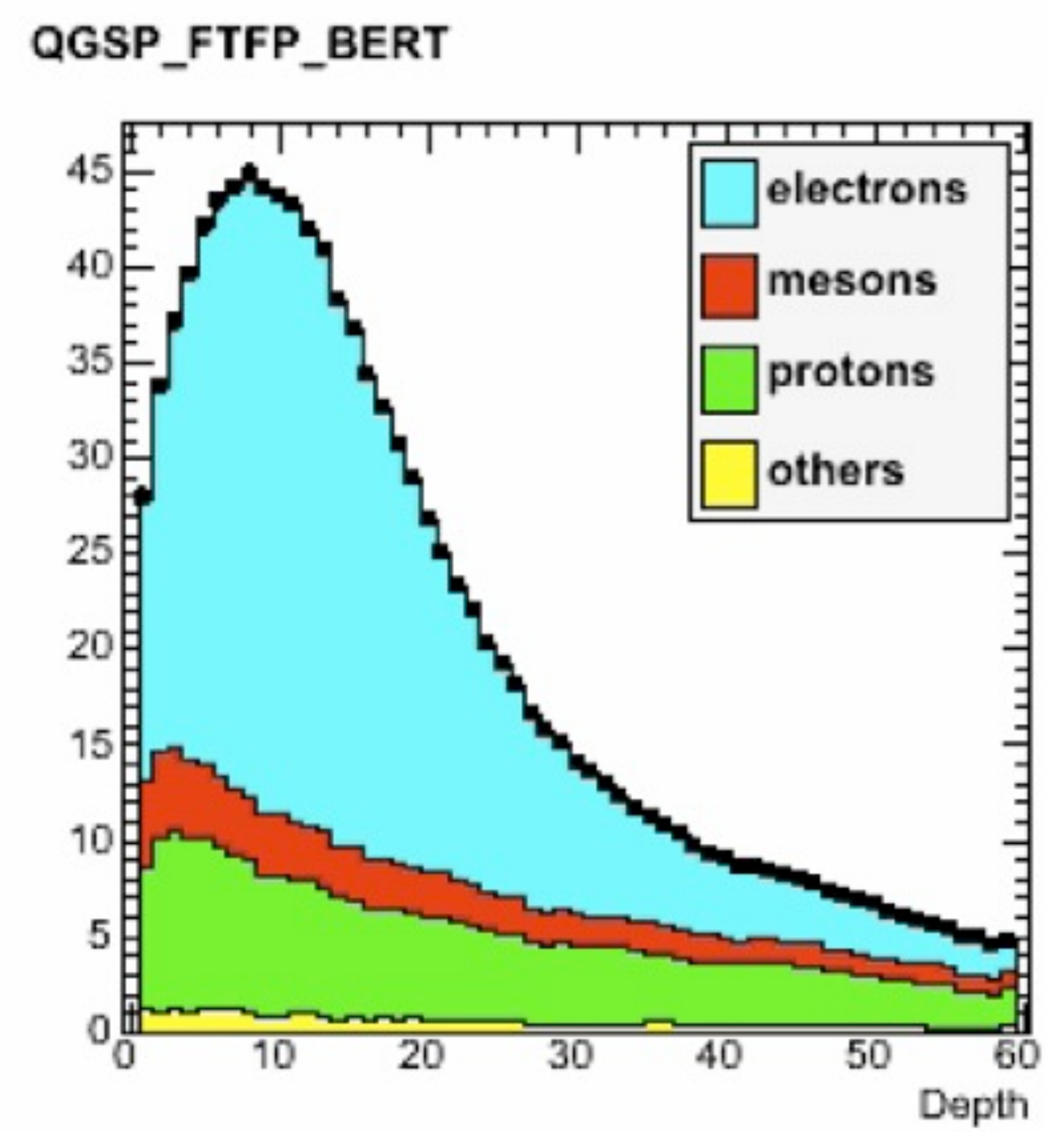
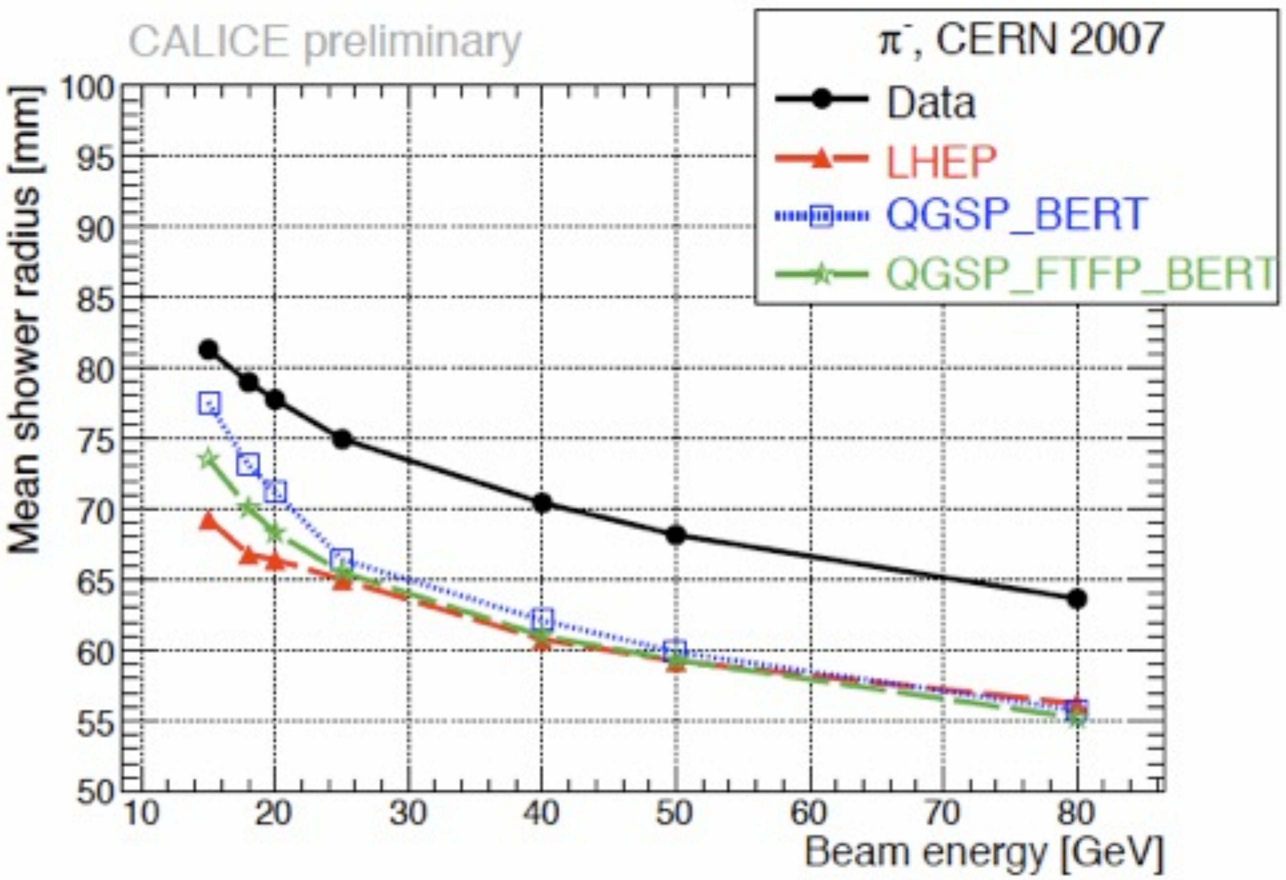
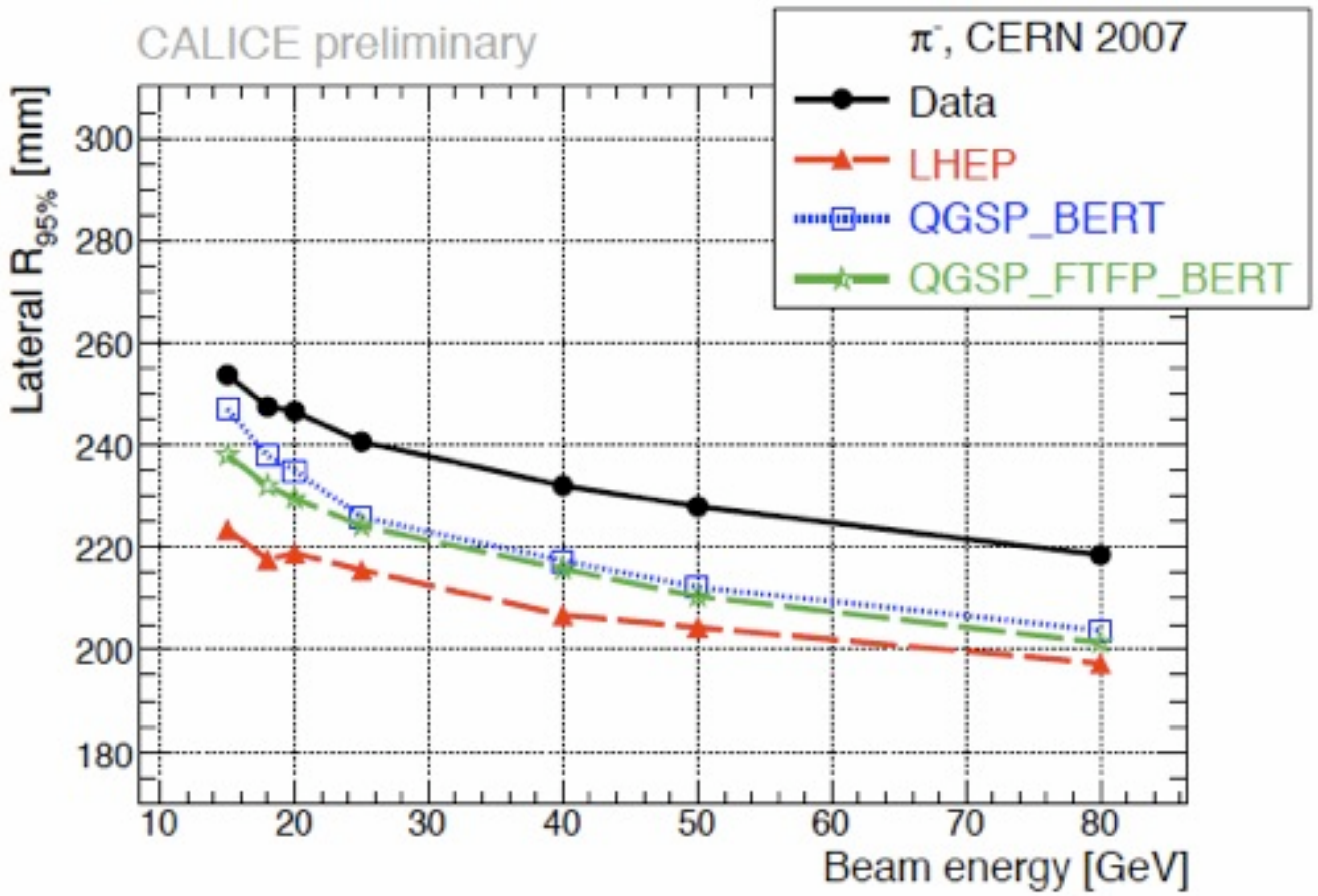


Selected Results: Pions in the Analog HCAL





- Mean shower radius, radius needed for 95% containment

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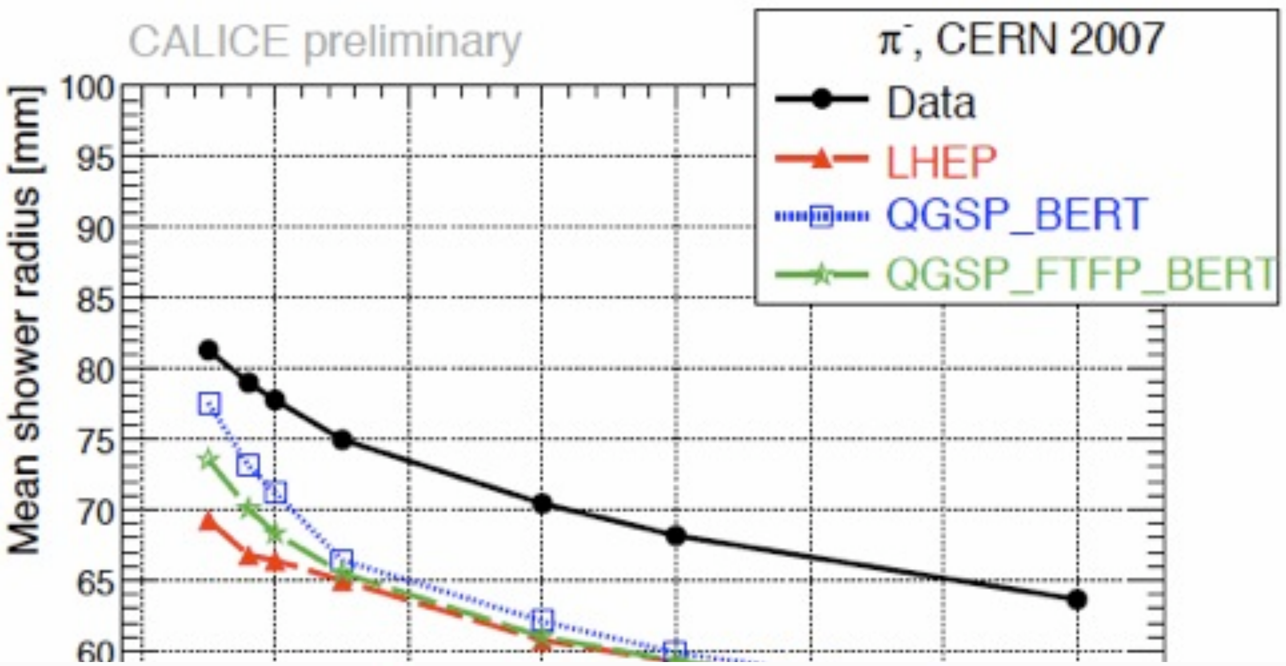
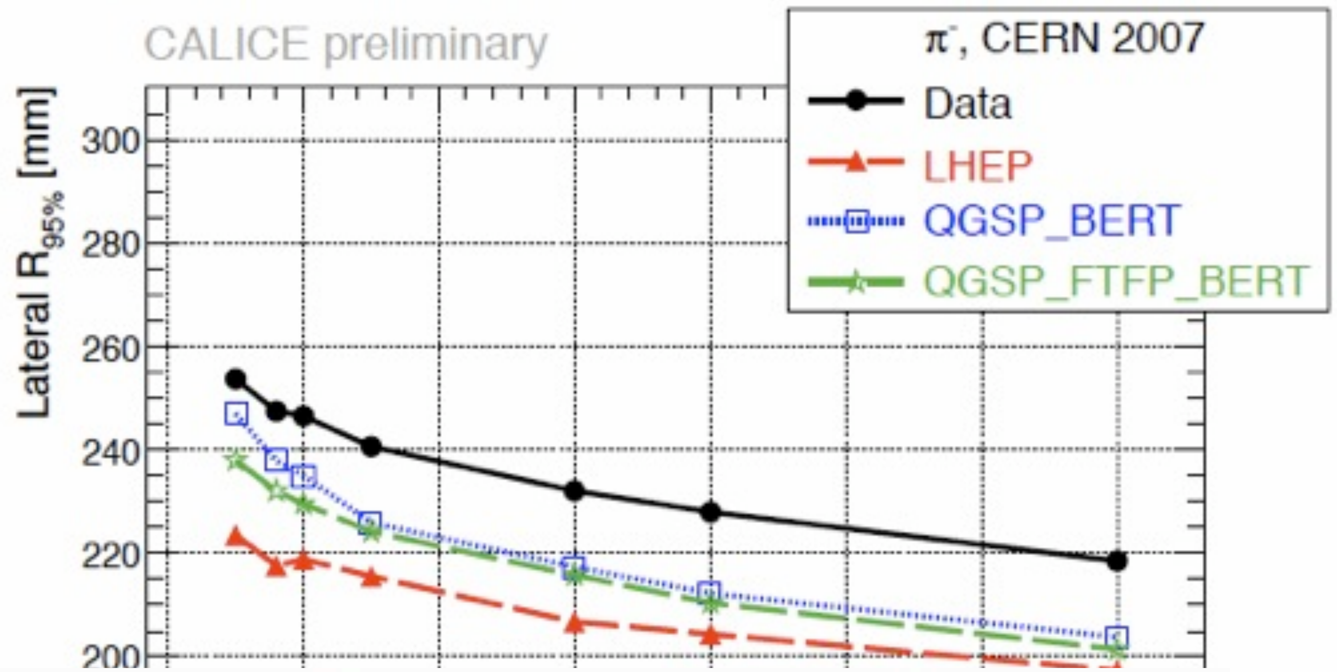
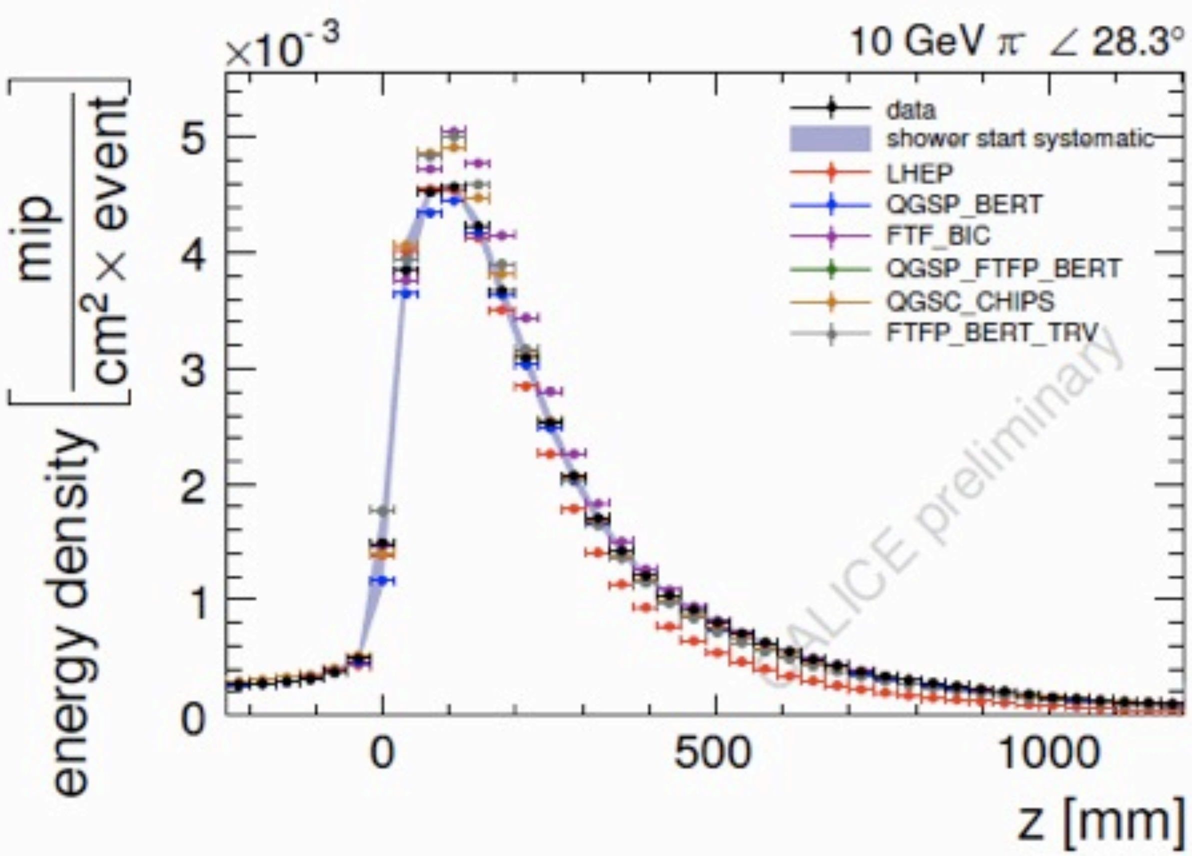
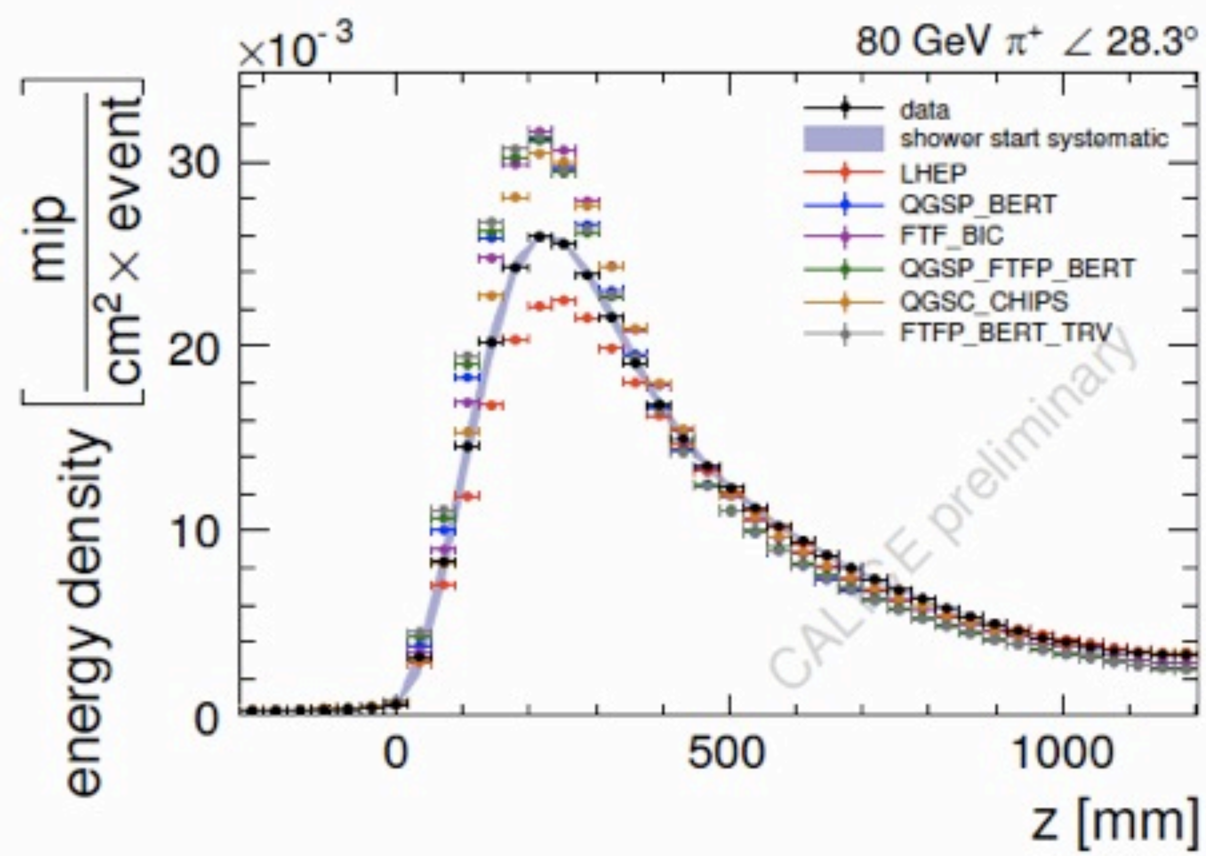




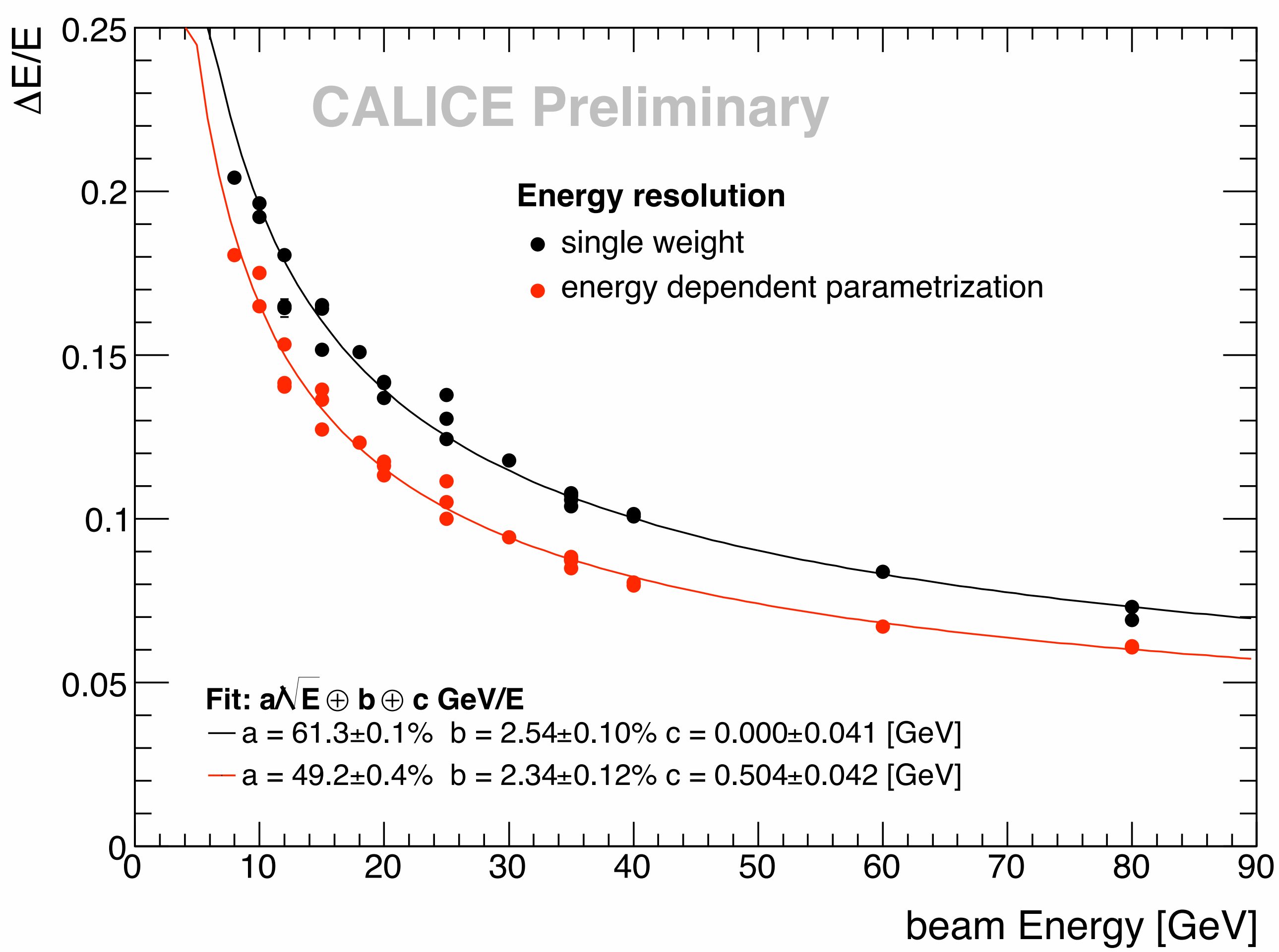


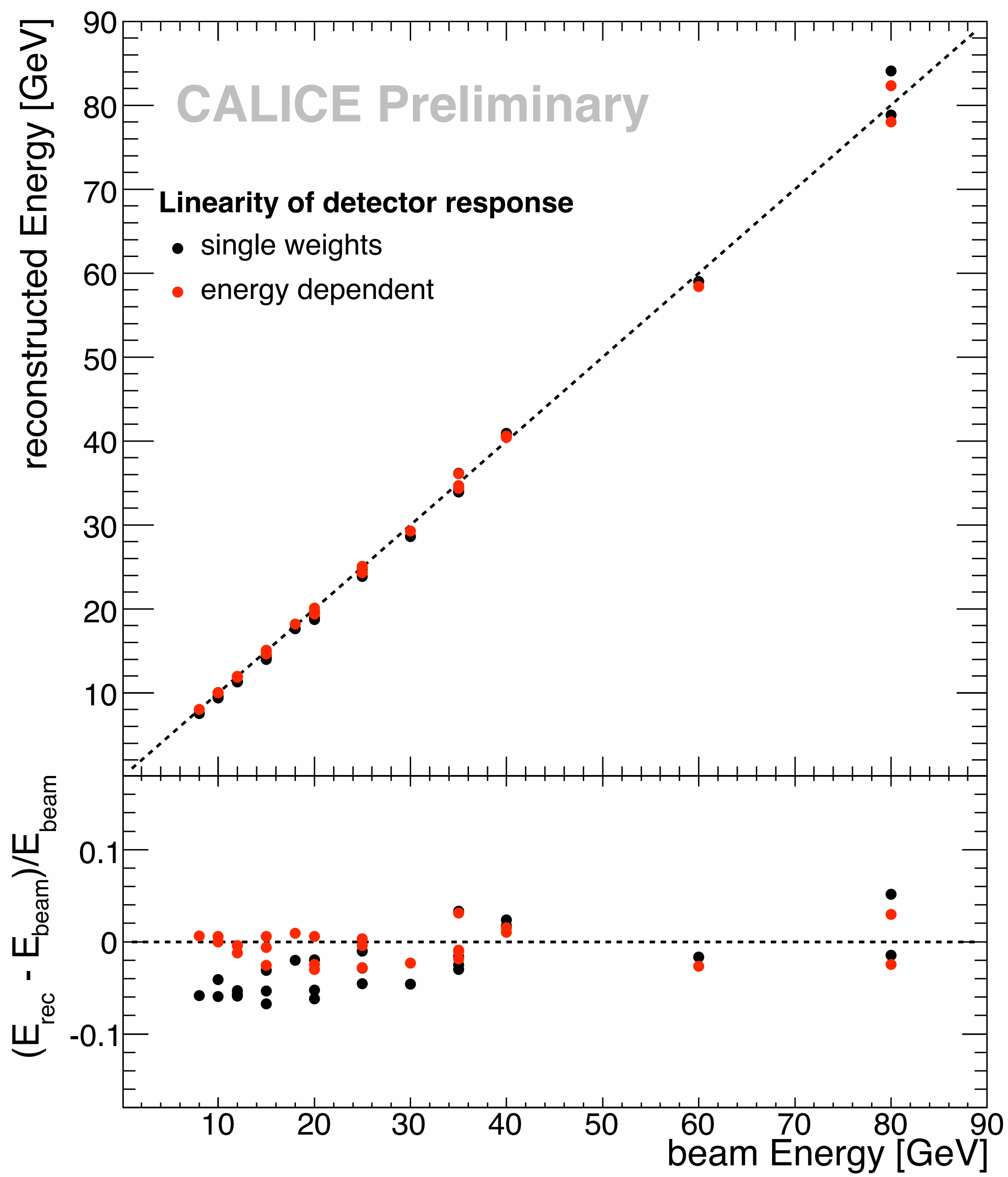


- Longitudinal profile, measured from shower start point

Selected Results: Combined Setup with Pions

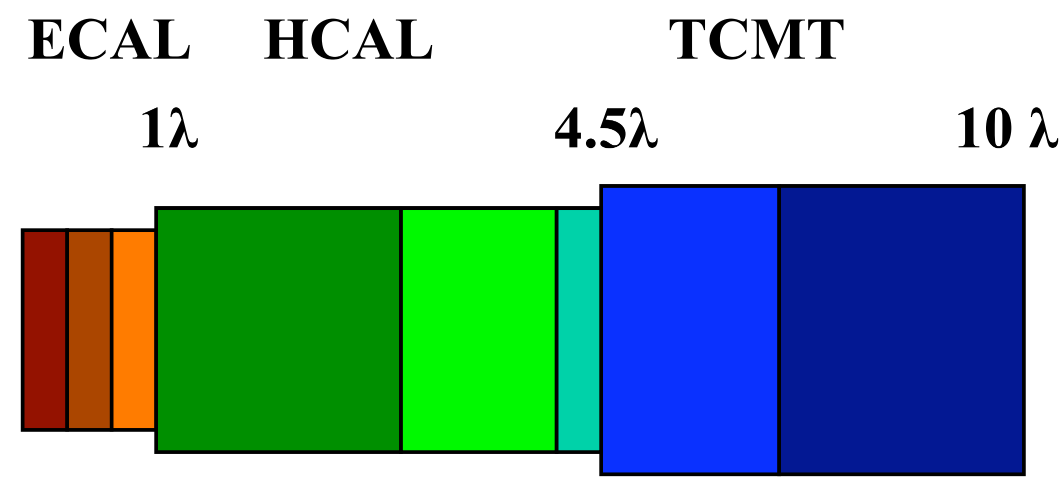
- With a simple energy density based weighting (“Software Compensation”) very good linearity over large energy range
- 20% improvement in resolution with simple weighting:
  ~ 50% stochastic term, 2.5% constant term



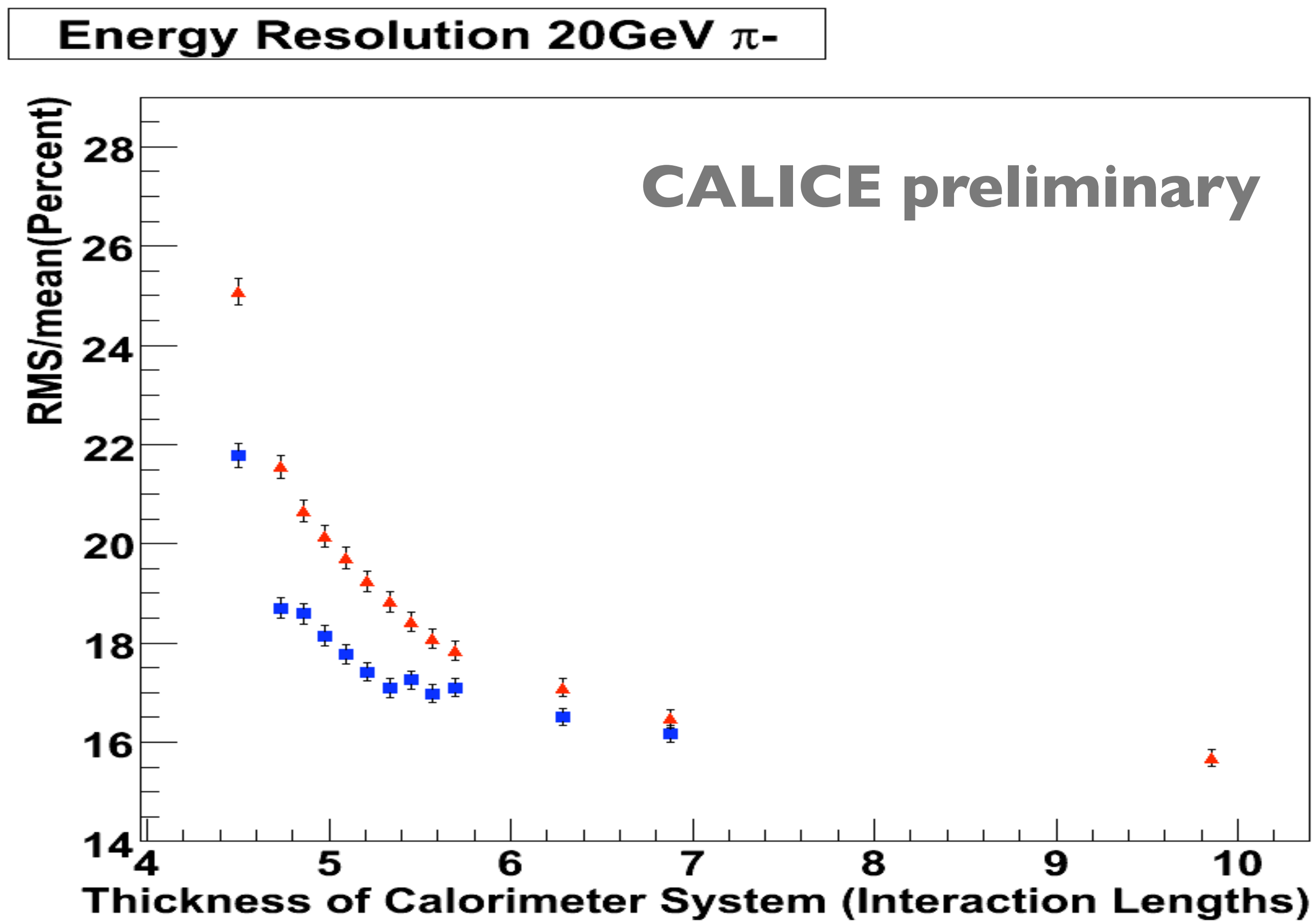


Selected Results: Combined Setup, Calorimeter Depth

- A first study of the impact of
  - Calorimeter depth
  - post-sampling behind magnet coil



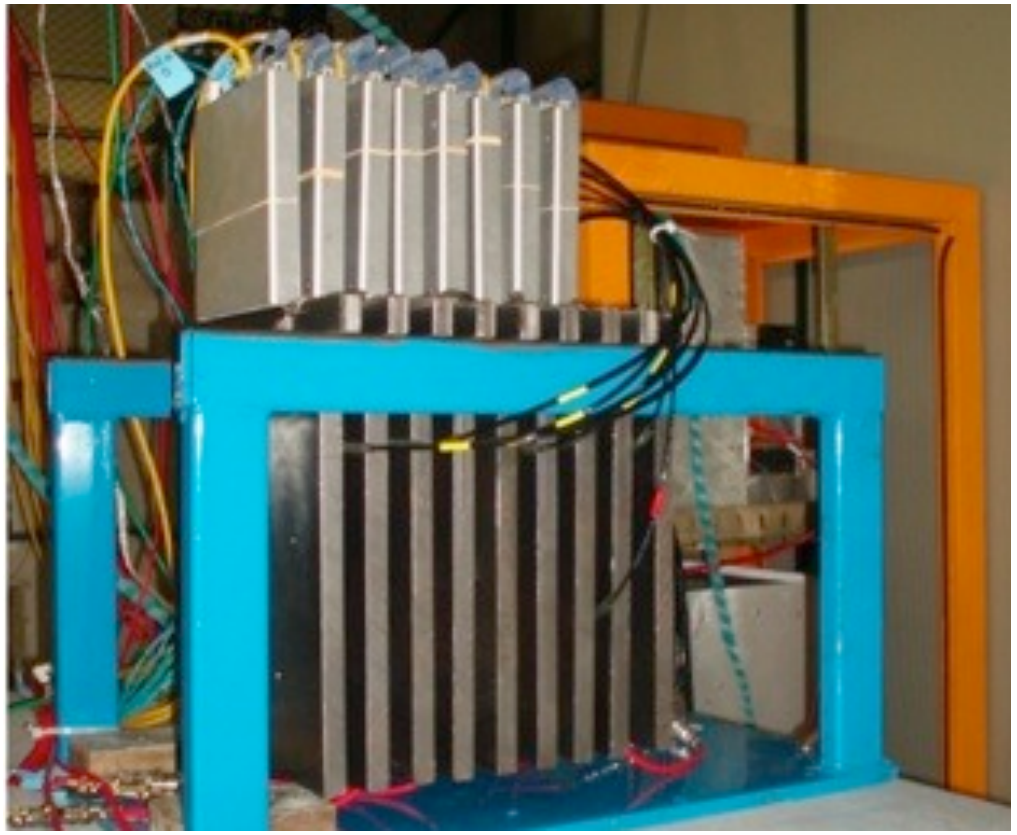
Assume a 1.8 λ thick magnet coil behind calorimeter system, then a possible post-sampler

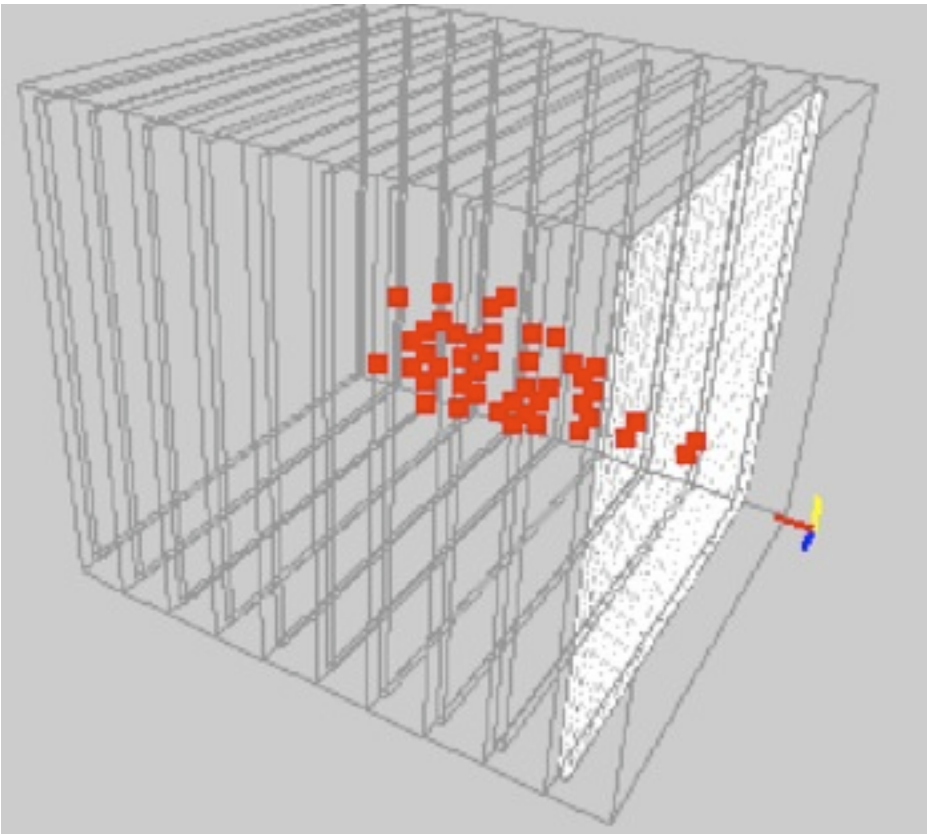


The Road Ahead

A Digital HCAL Physics Prototype

- The concept: Active layers of glass RPCs with 1 cm^2 pads, one bit readout per channel
- Proof of principle measurement at Fermilab:
  - small prototype: 20 x 20 cm^2 active area, 8 layers (6 read out)
  - 1.2 X_0 Steel/Cu absorber per layer





positron shower in the prototype

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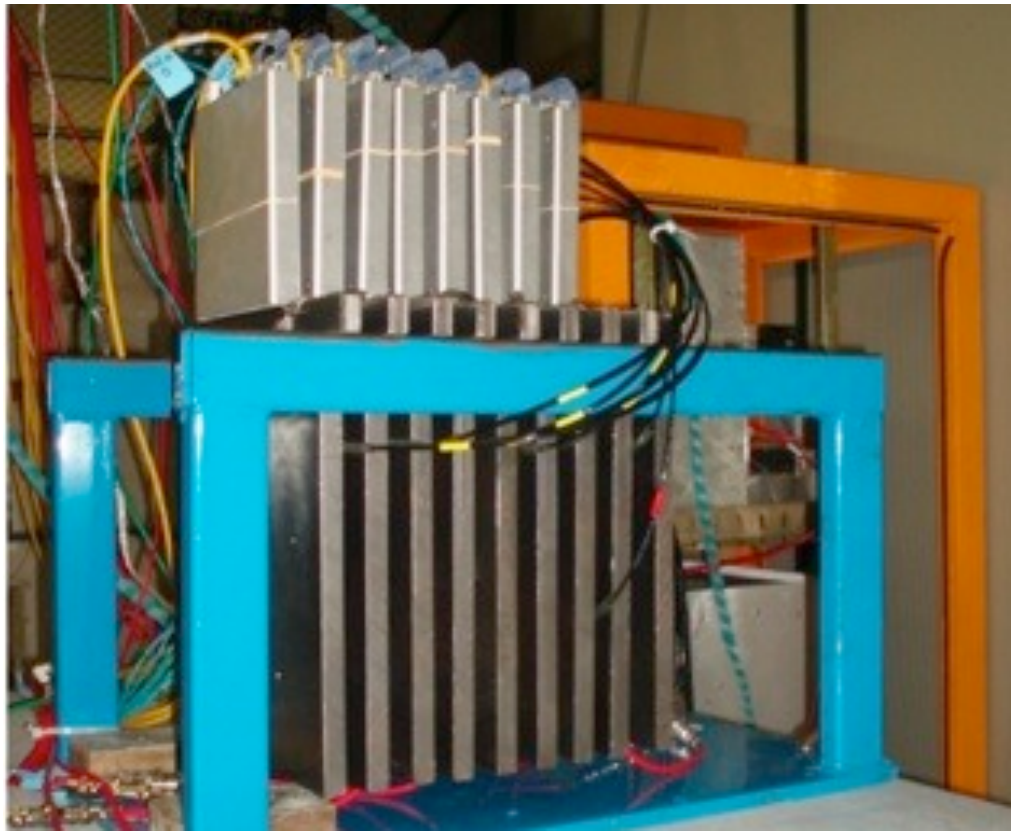

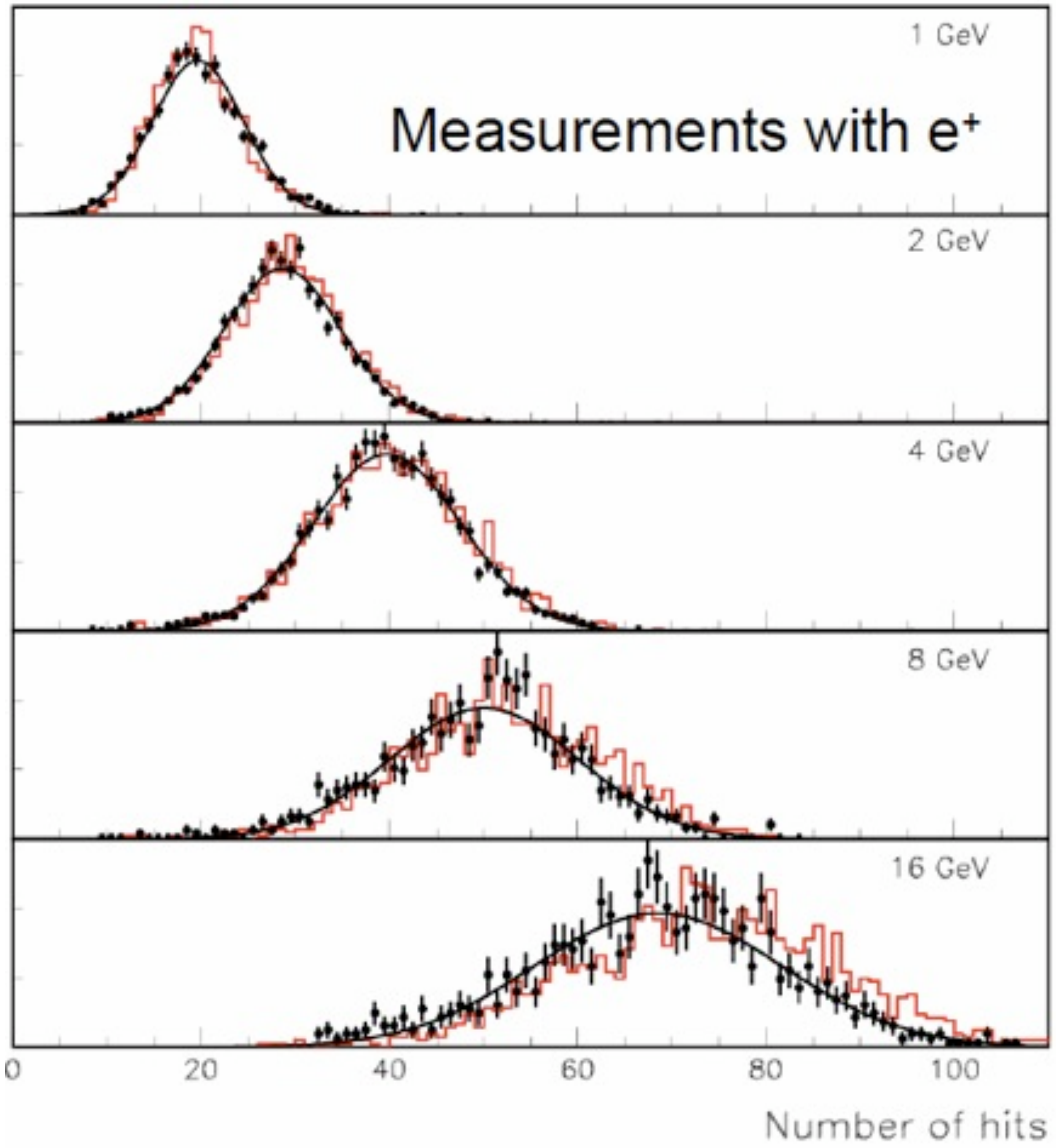

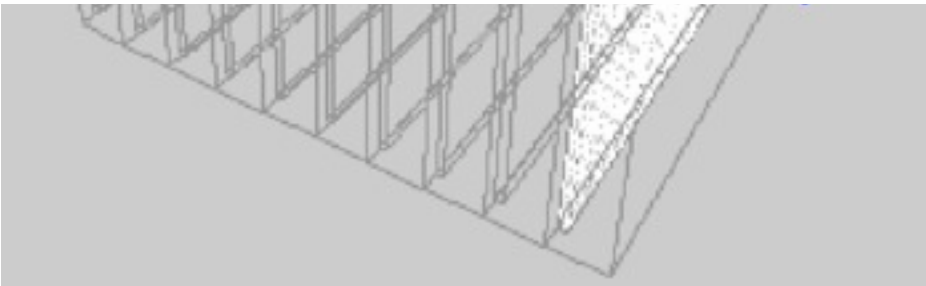

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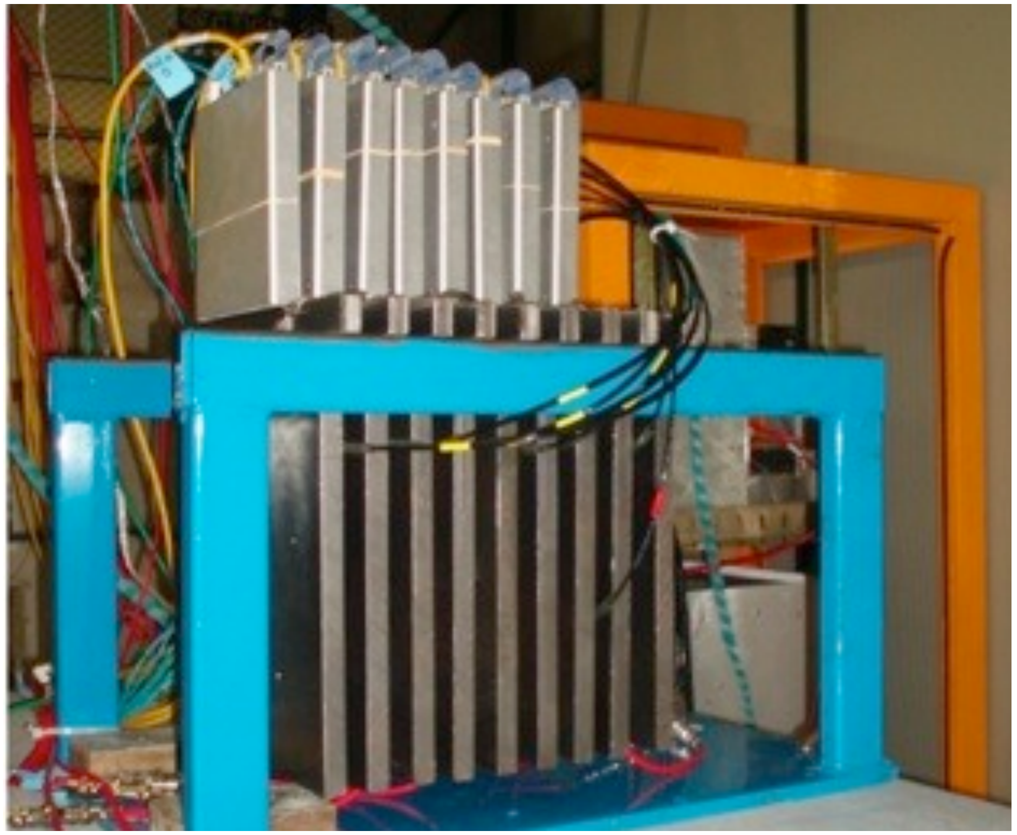
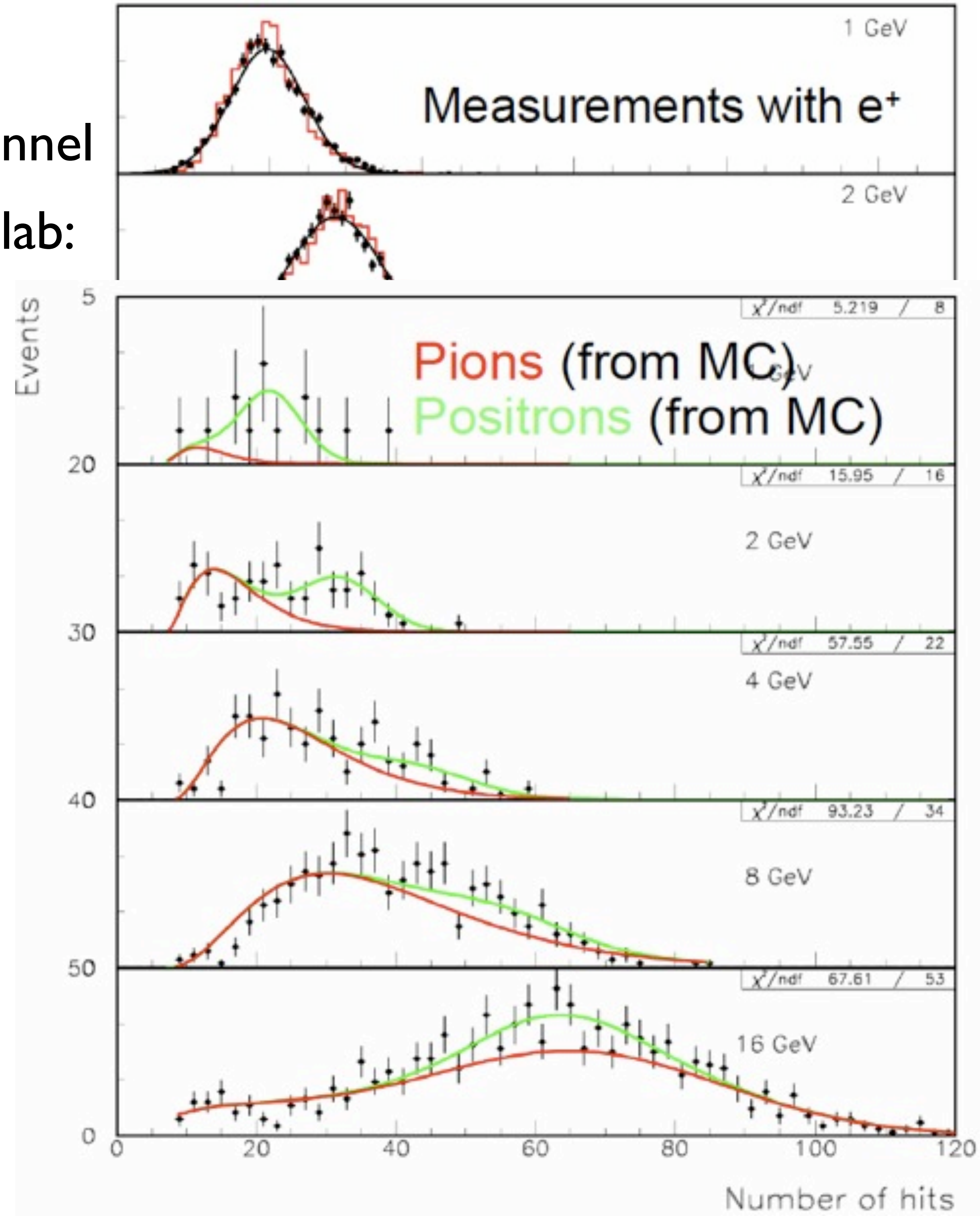
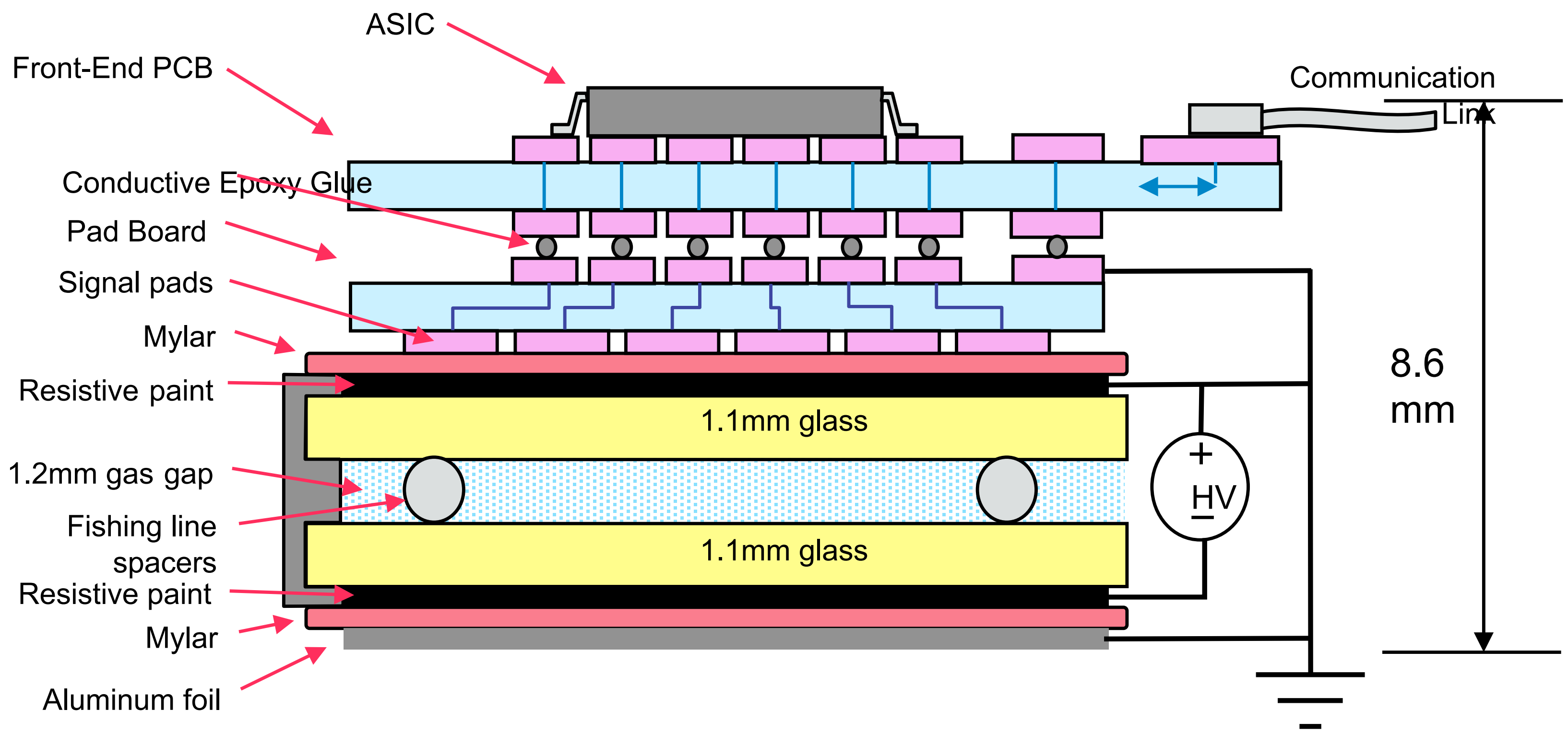




Under Construction: 1 m^3 Physics Prototype

- 40 layers with ~ 1 x 1 m^2 size: To be used in existing HCAL absorber structure
- Build up out of 3 RPCs per layer, 32 x 96 cm^2
- 1 cm^2 readout pads: a total of ~ 400 000 channels



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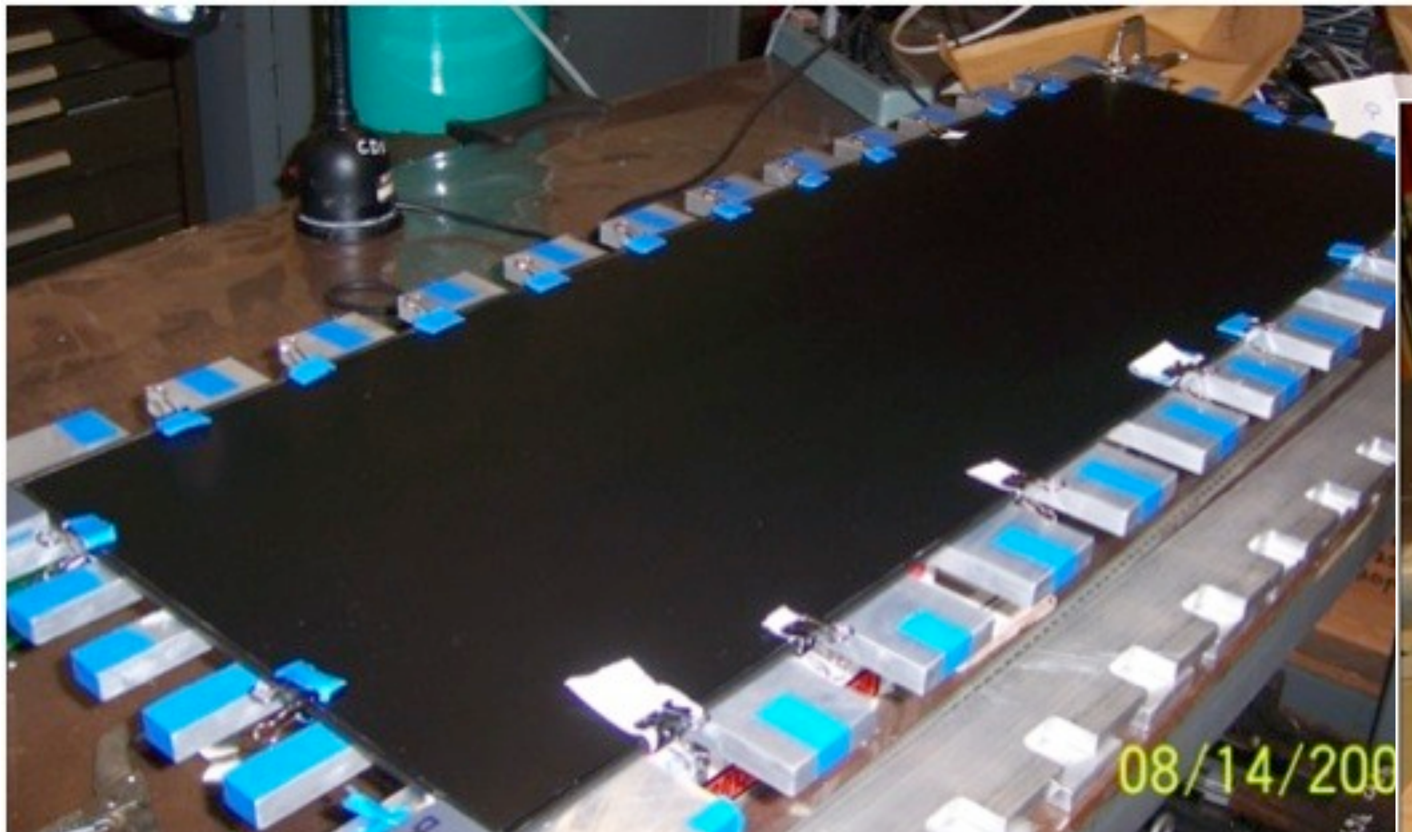

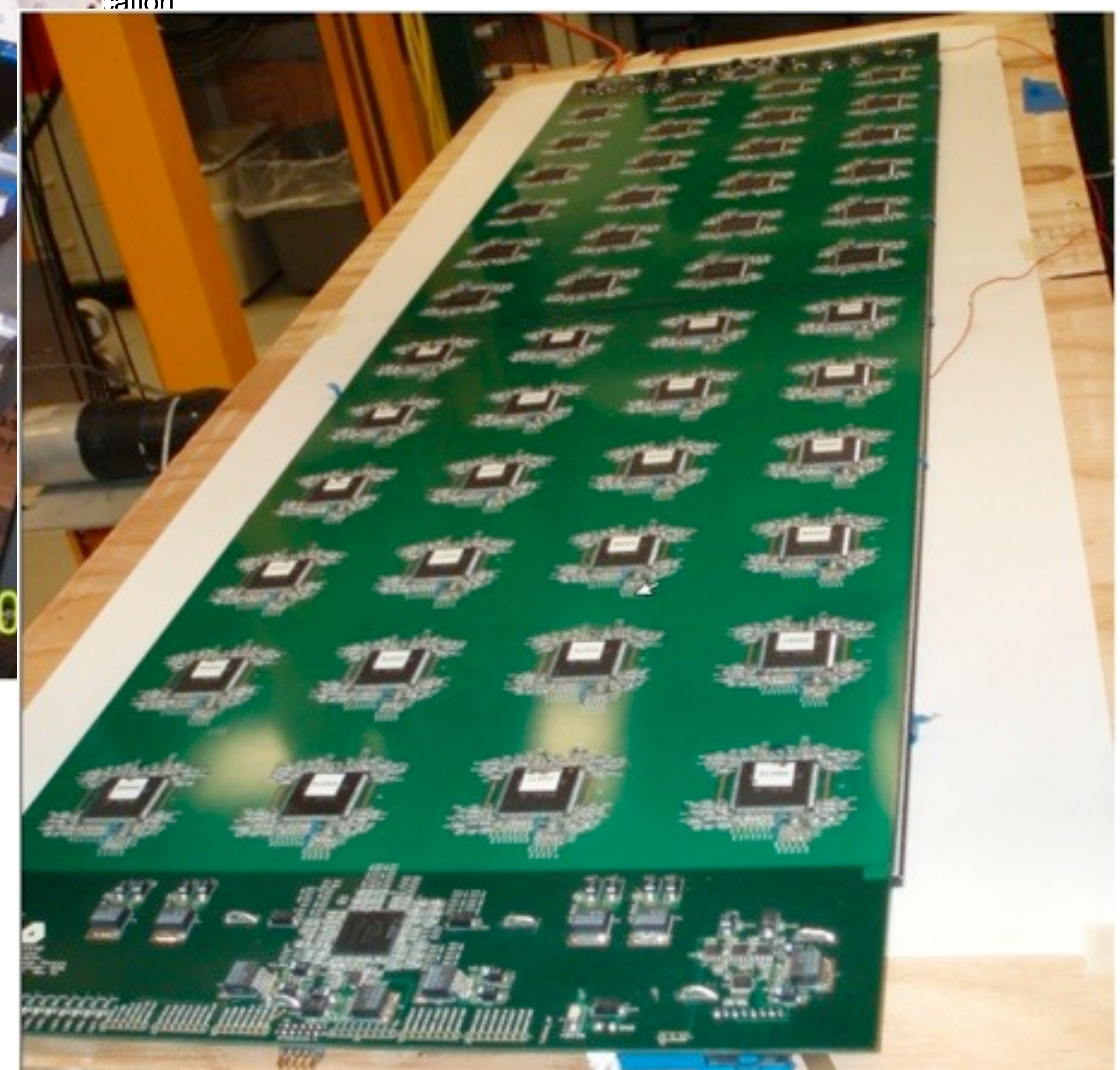

RPCs and electronics (using DCAL III chip) under construction at ANL

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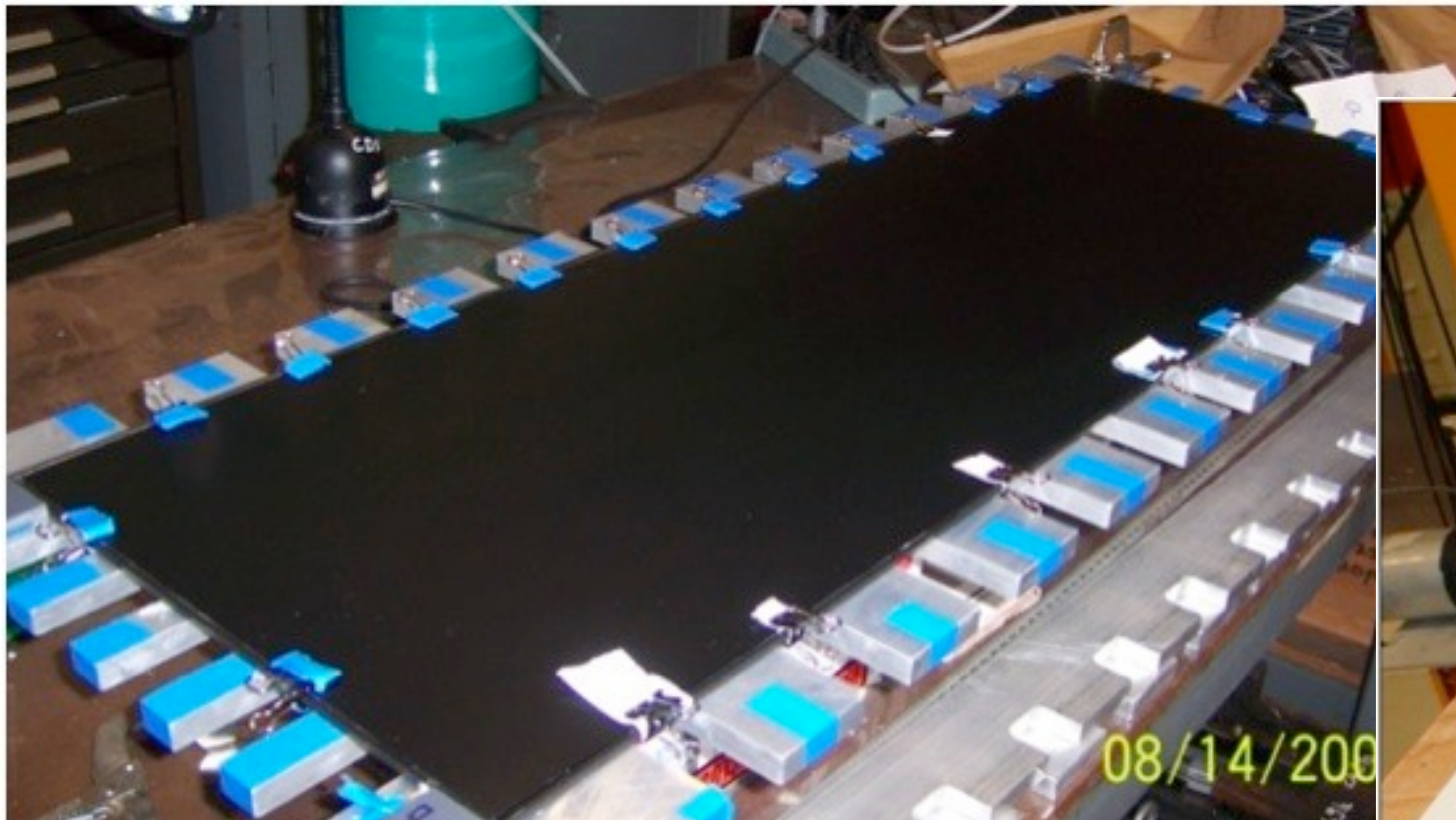
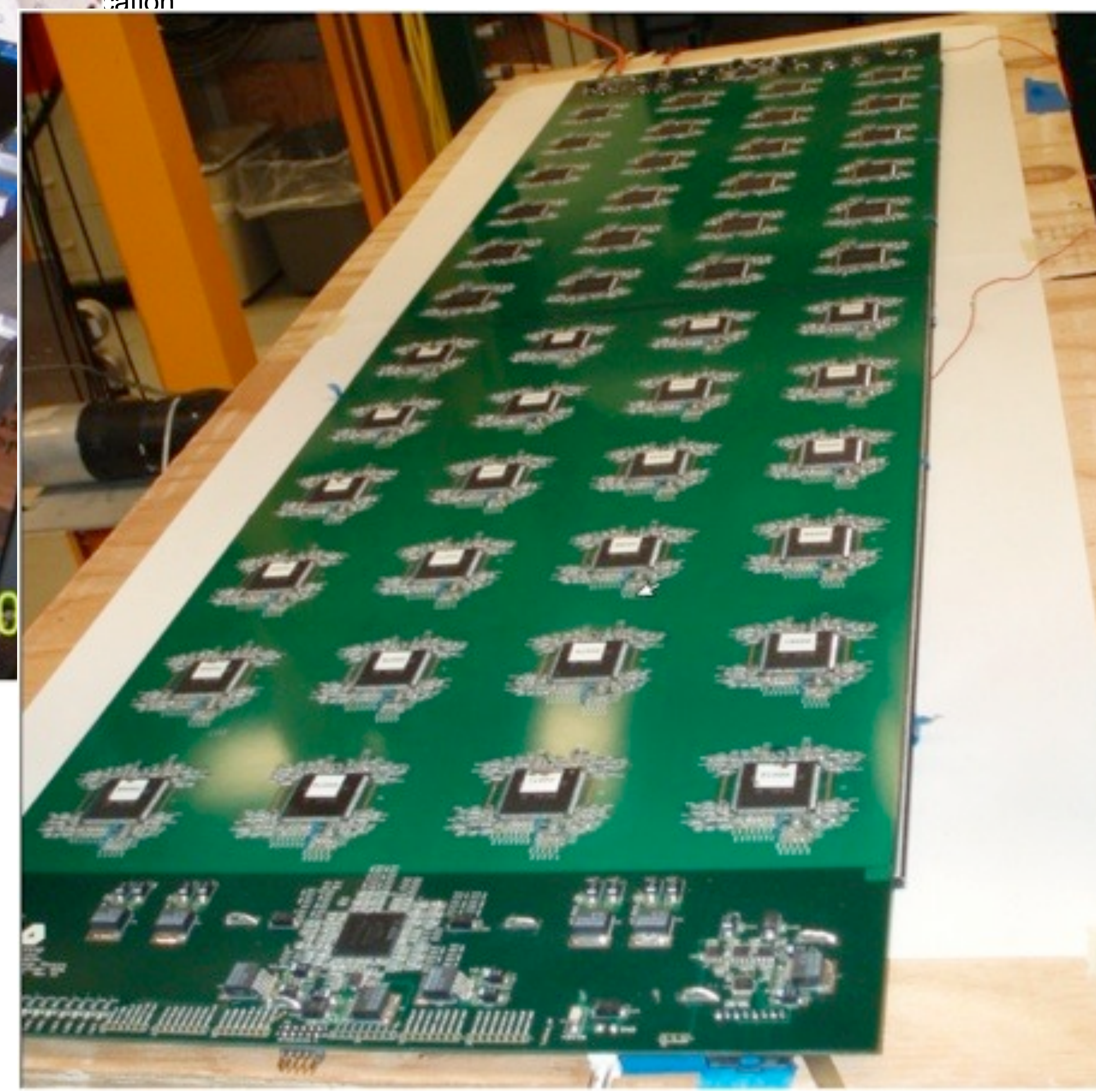


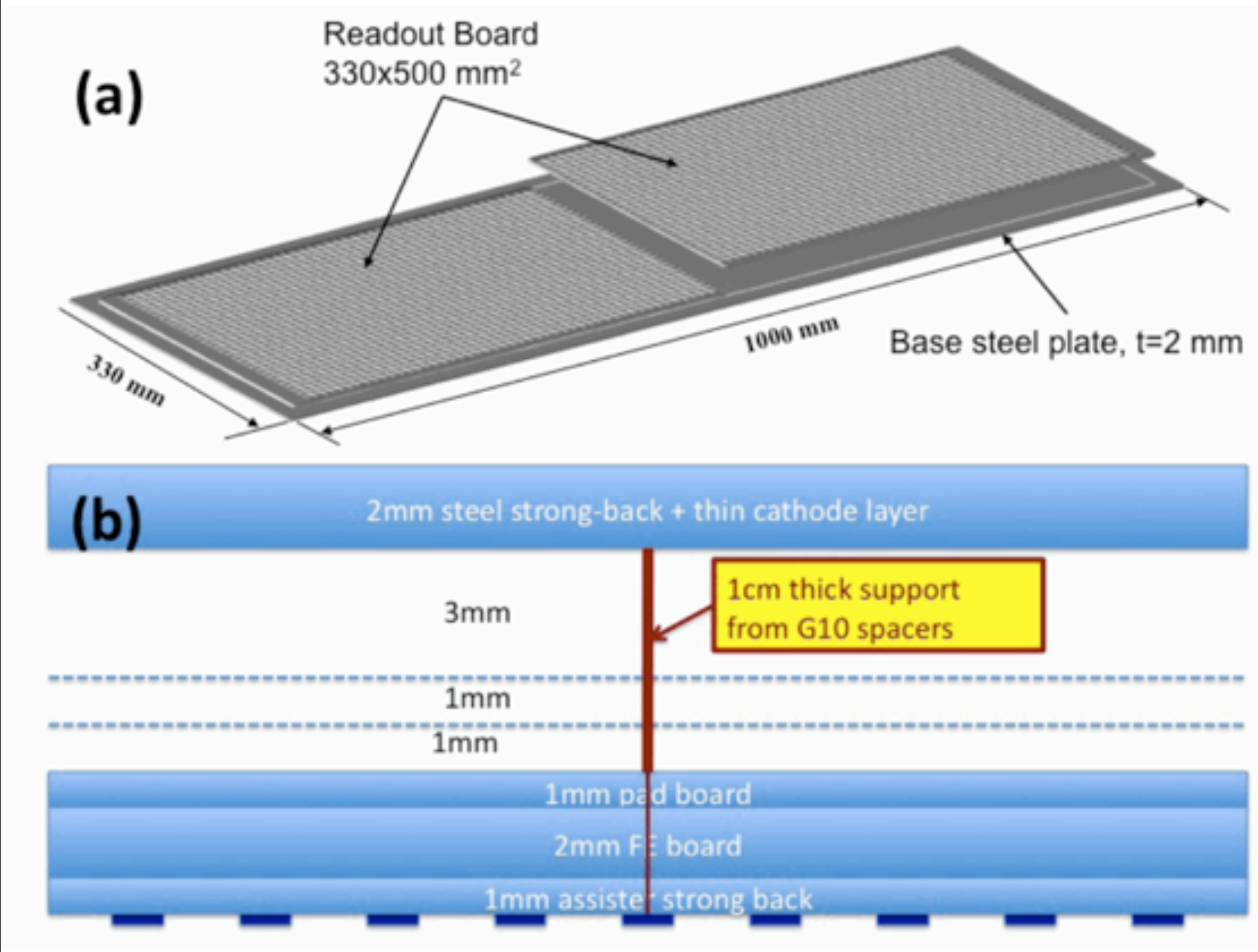


RPCs and electronics (using DCAL III chip) under construction at ANL

Beam test at FNAL planned for Spring 2010

Alternative Technology: GEM Readout

- Robust, high-rate capable detectors
- Prototypes under construction, lead by UTA

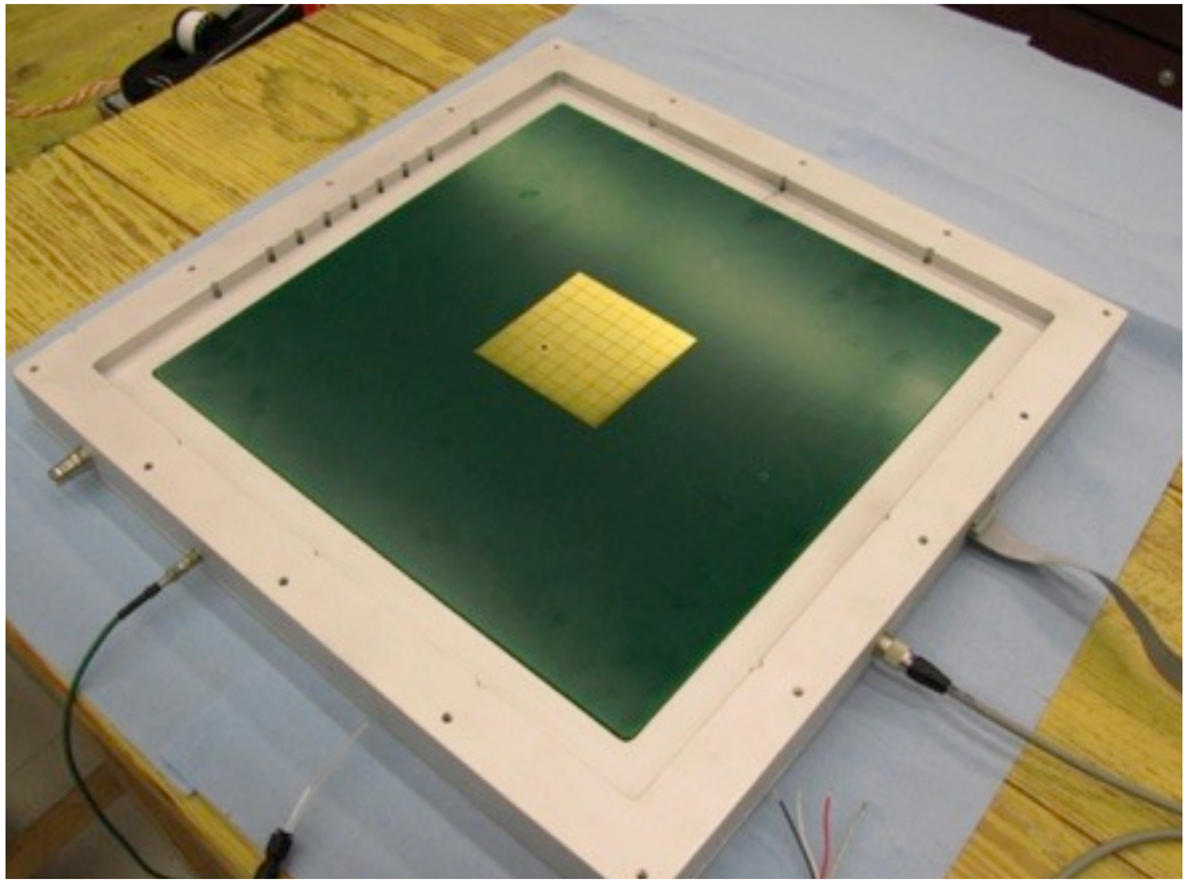


Double-GEM design

1 cm^2 readout pads, read out with KPix chip

Goal: Use 100 x 33 cm^2 large GEM foils for unit chamber, currently being optimized & produced at CERN

GEM Tests: First Results



- 30 x 30 cm^2 double GEM detector
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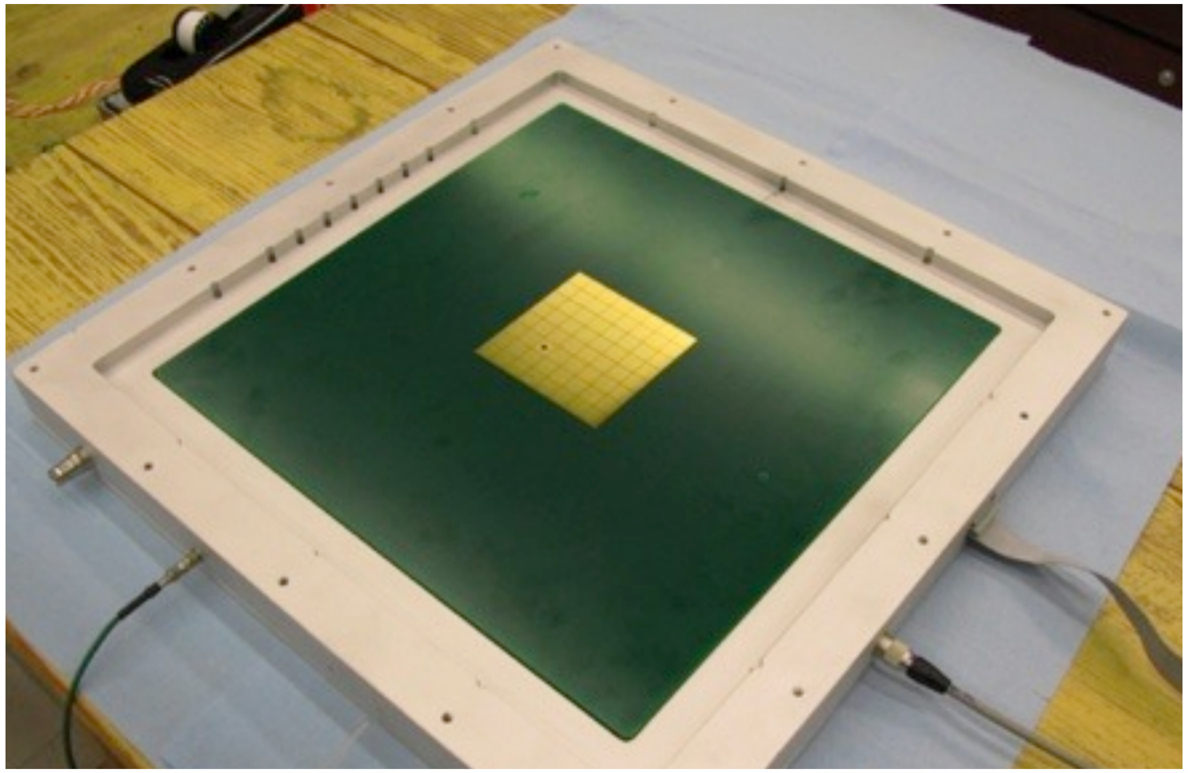

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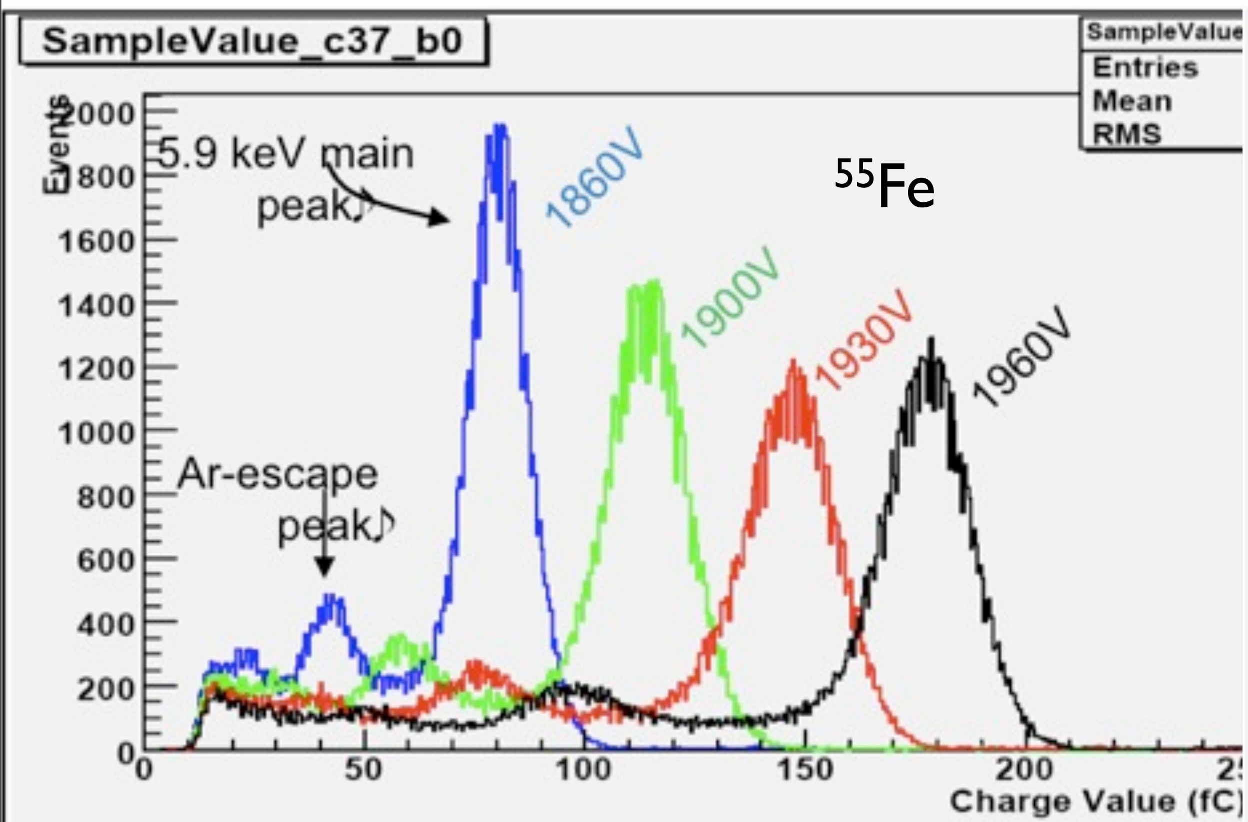

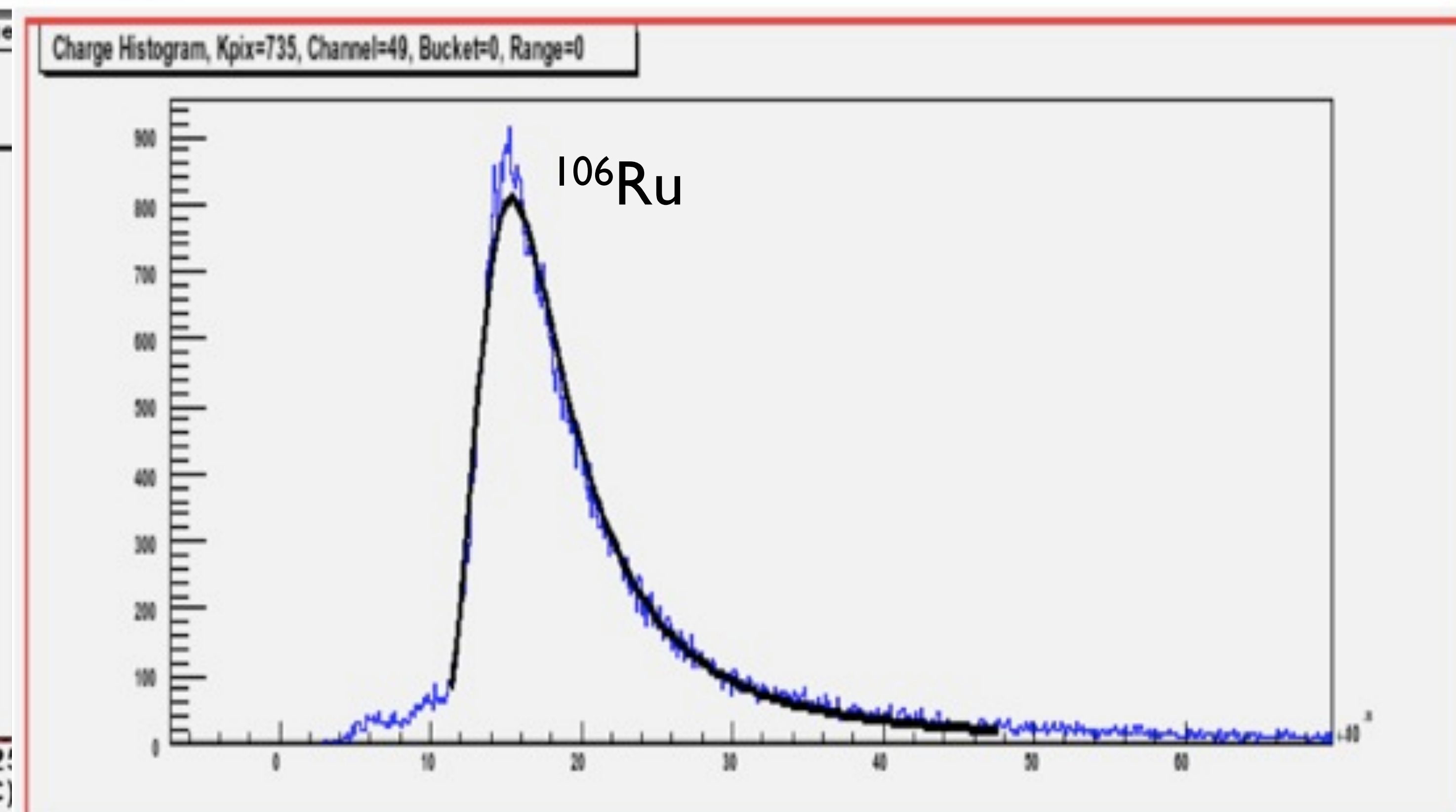

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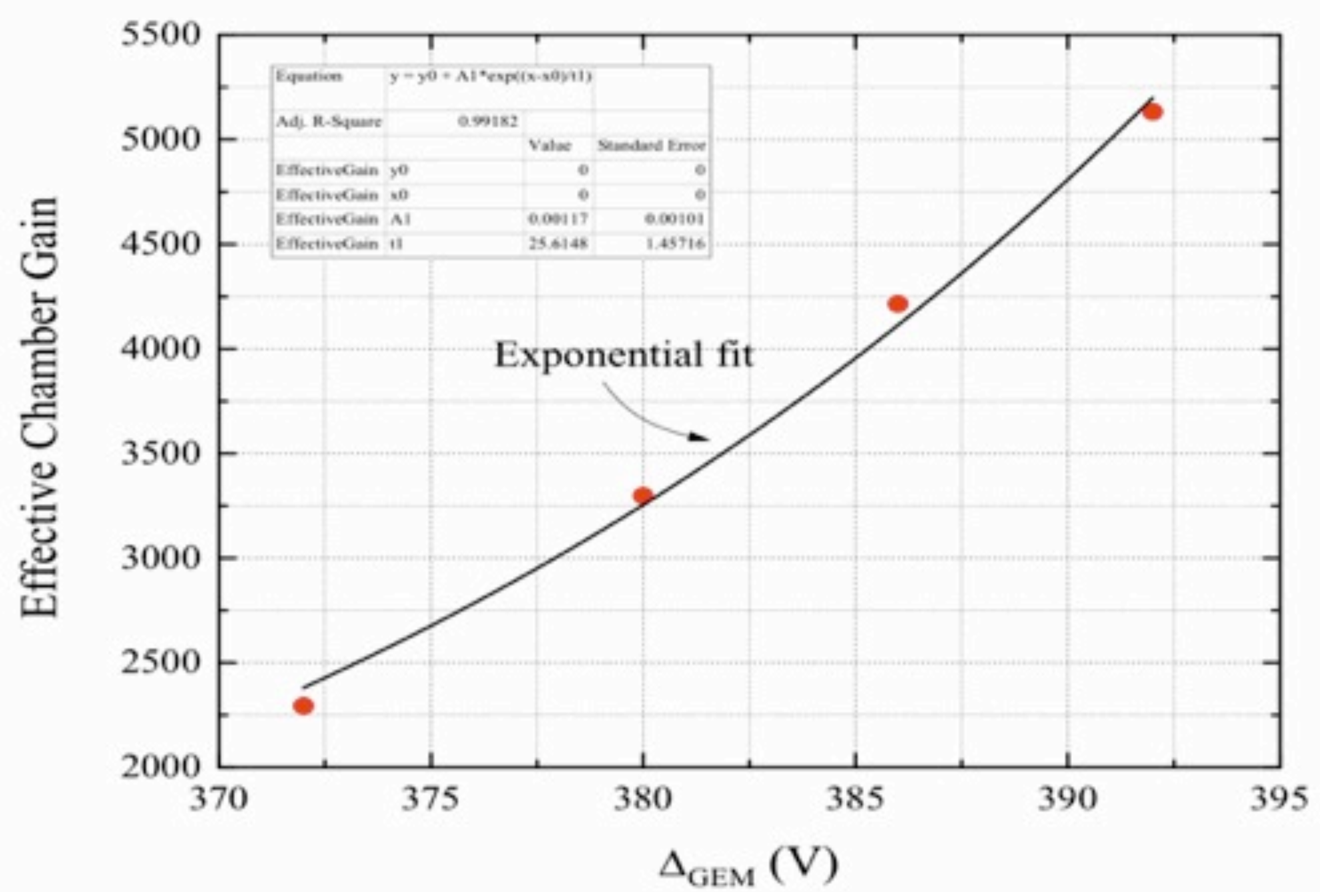
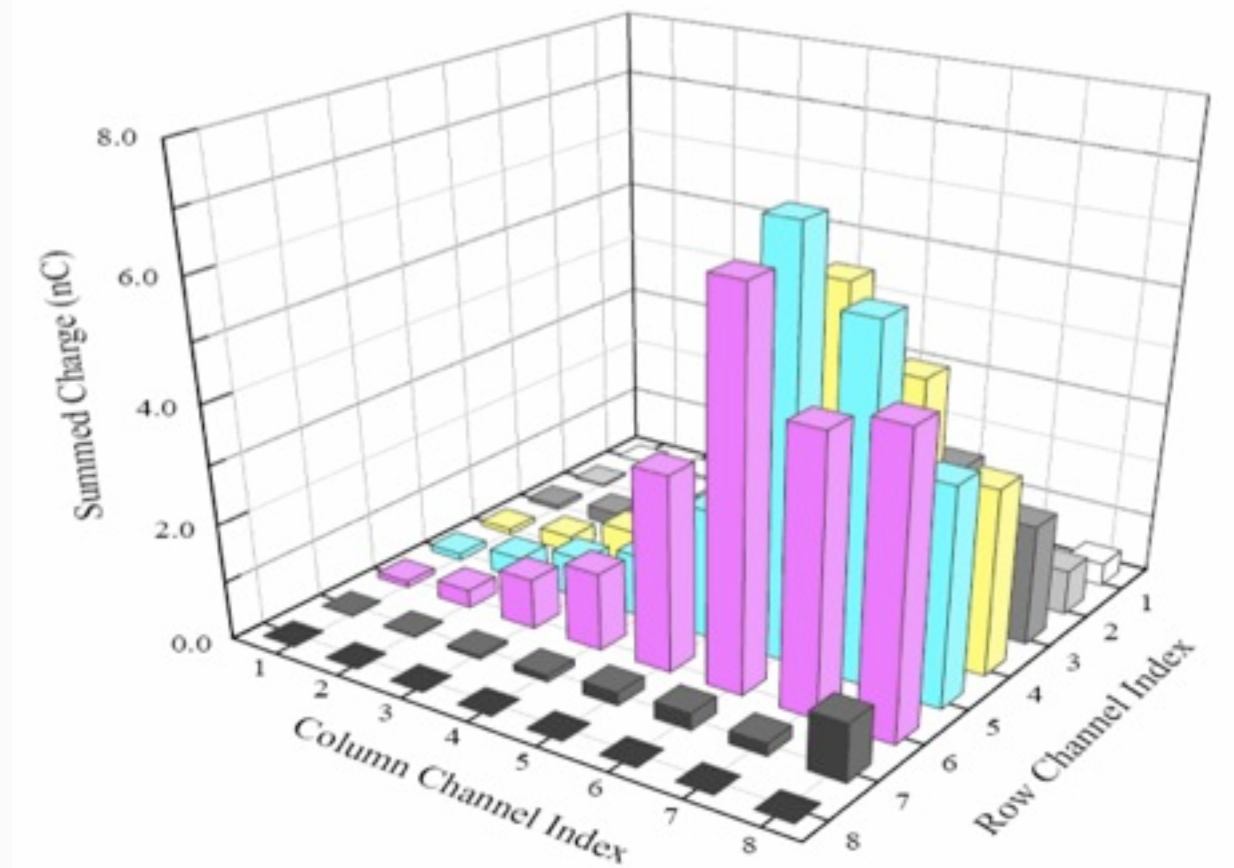
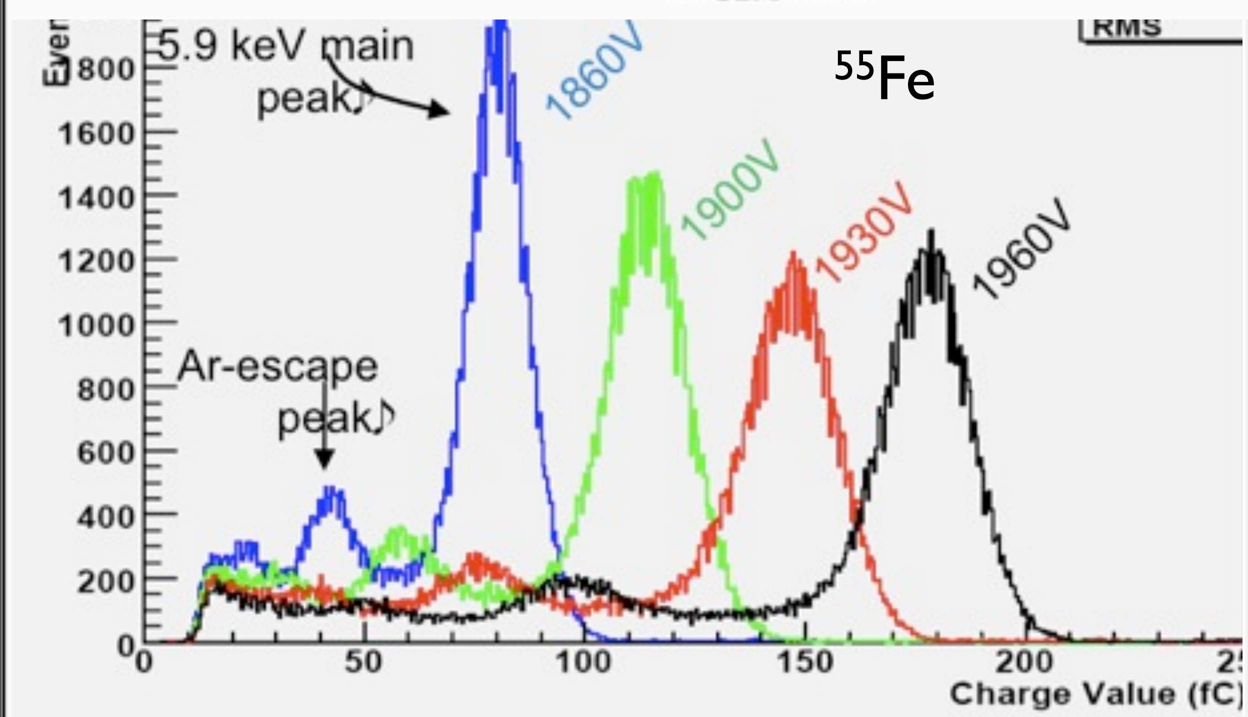
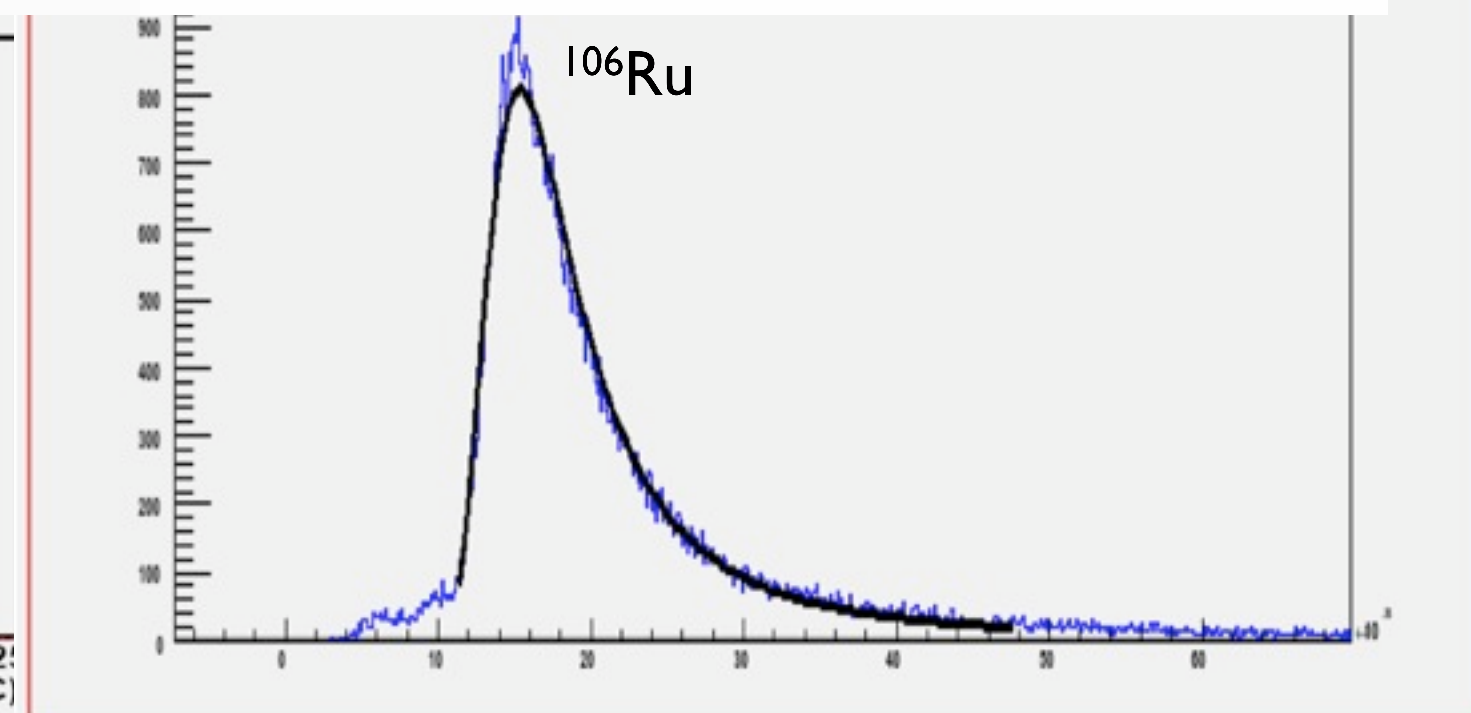


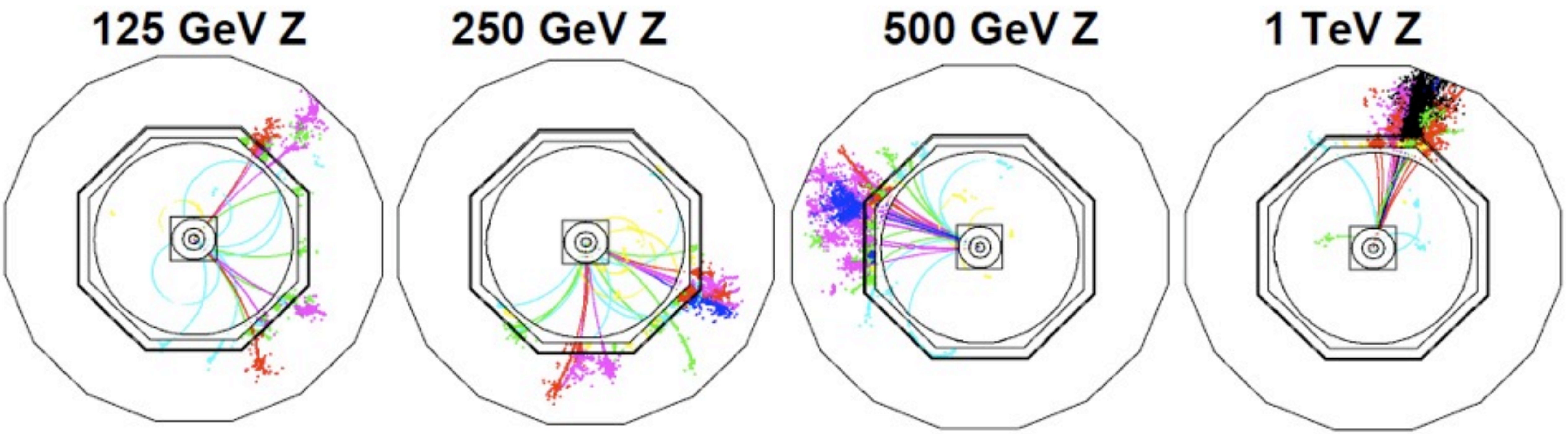






Being Prepared: Studies for Higher Energies

- LHC might tell us we need higher energy: A multi-TeV Linear Collider, CLIC
- Calorimetry necessarily is a bit different at those energies: More depth required to fully contain hadronic showers



ILD-like detector, with 8 λ deep HCAL (M.Thomson, ALCPG09)

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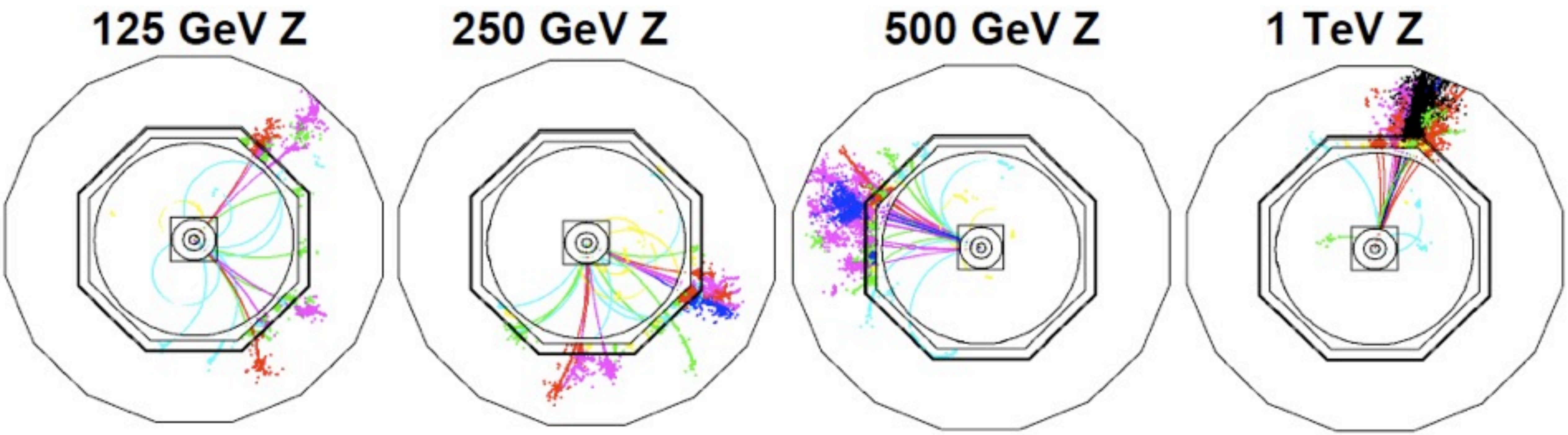

ILD-like detector, with 8 λ deep HCAL (M.Thomson, ALCPG09)

A key consideration: The cost of the magnet depends strongly on the radius
A compact calorimeter, meaning a dense absorber, is needed!
The obvious choice: Tungsten

Investigating the Tungsten Option

- Tungsten is very different from Steel:
  - very different λ/X_0 ratio: em subshowers very short
  - heavier nucleus: More neutrons in the shower

Material	Fe	W
λ_I [cm]	16.77	9.95
X_0 [cm]	1.76	0.35
dE/dx [MeV/cm]	11.4	22.1
R_M[cm]	1.72	0.93

Simulation studies indicate that a W HCAL is possible, with slight deterioration of the performance compared to steel

➩ Experimental verification indispensable!

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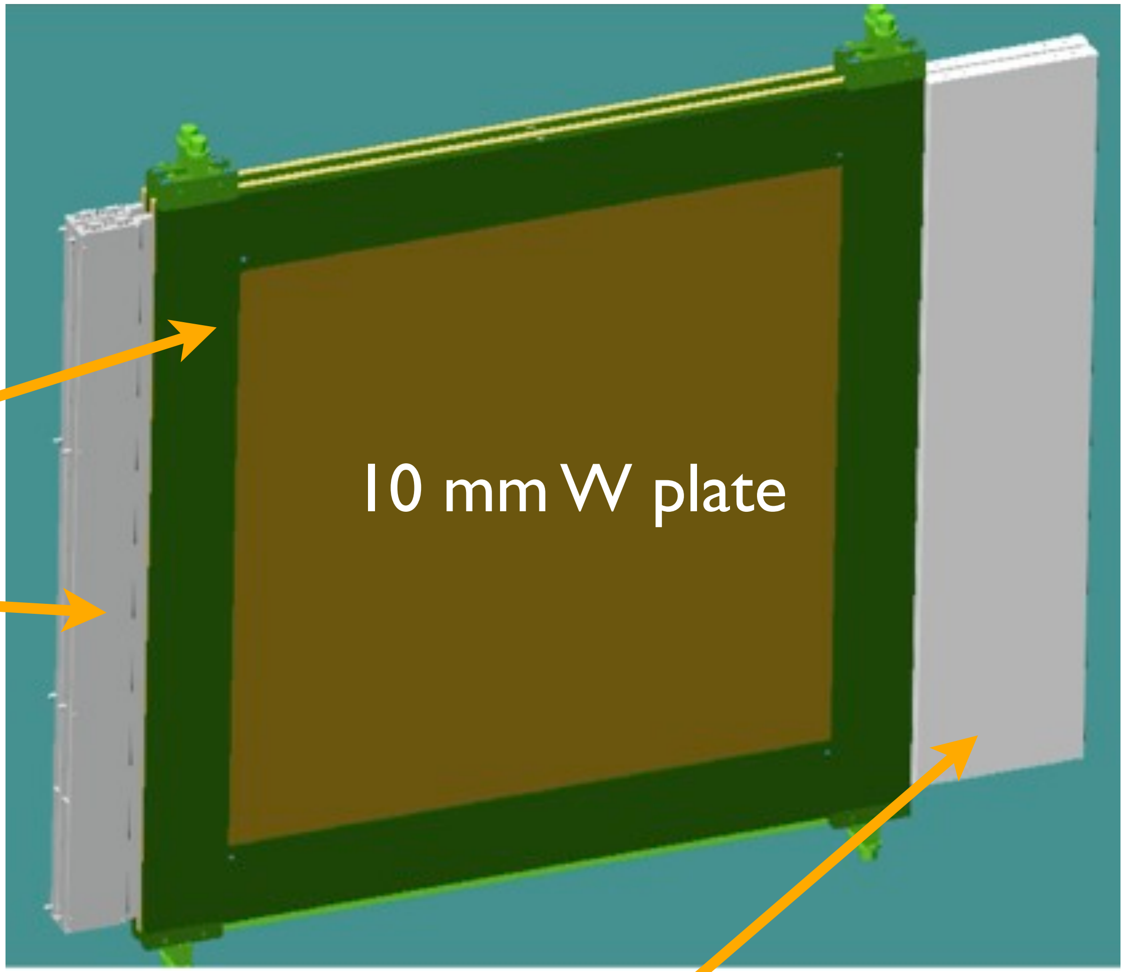
The strategy: Modify the existing absorber structure to hold W plates, test with AHCAL prototype active layers



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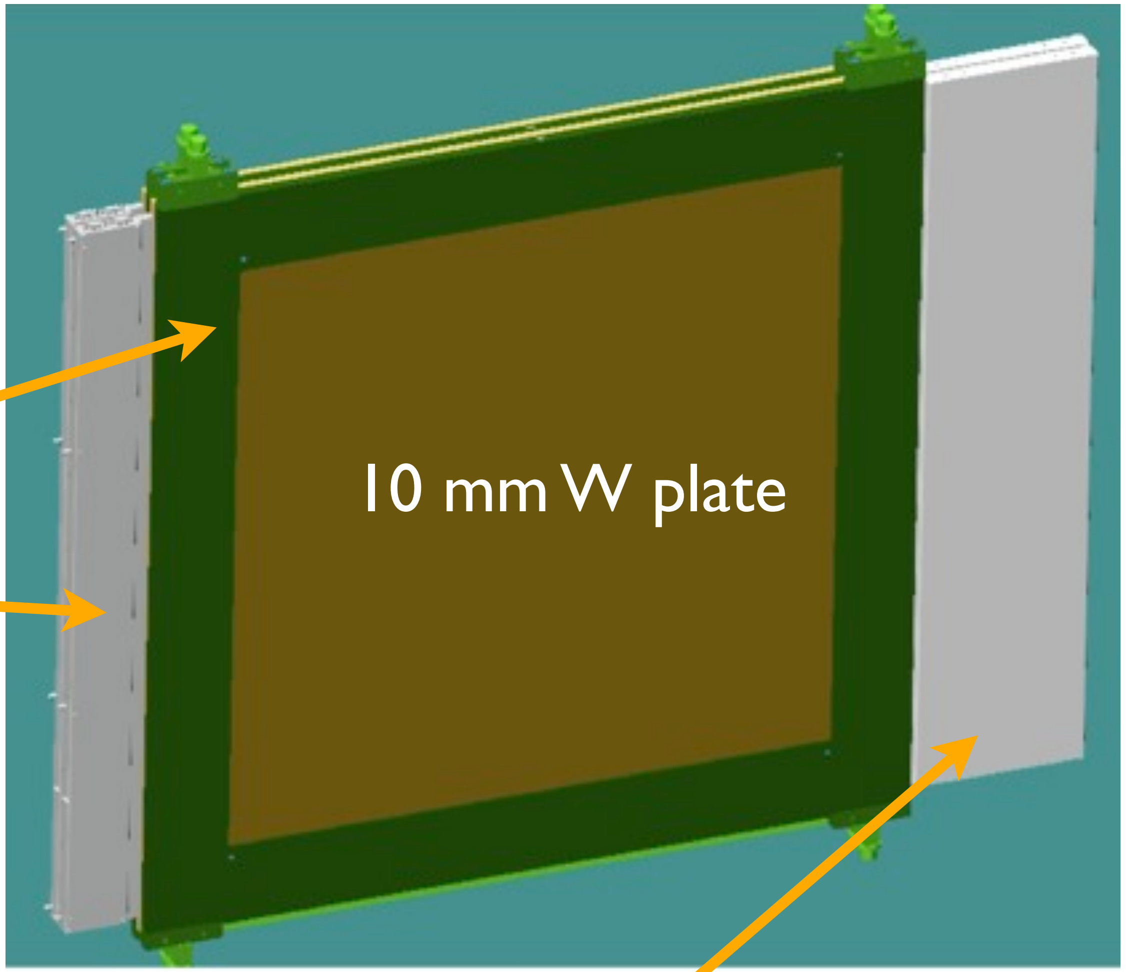
16 mm Al frame

calibration boards



front-end electronics

In later tests: 2nd generation electronics that provide time stamping and auto-triggering
Crucial to study the shower time structure!
Use MicroMegas to evaluate digital performance.

The 2nd Generation Prototypes

- Under construction: The next generation of prototypes
  - Main goal: Demonstrate the possibility to build imaging calorimeters with fully integrated electronics
  - Meet the space constraints in a real collider detector!

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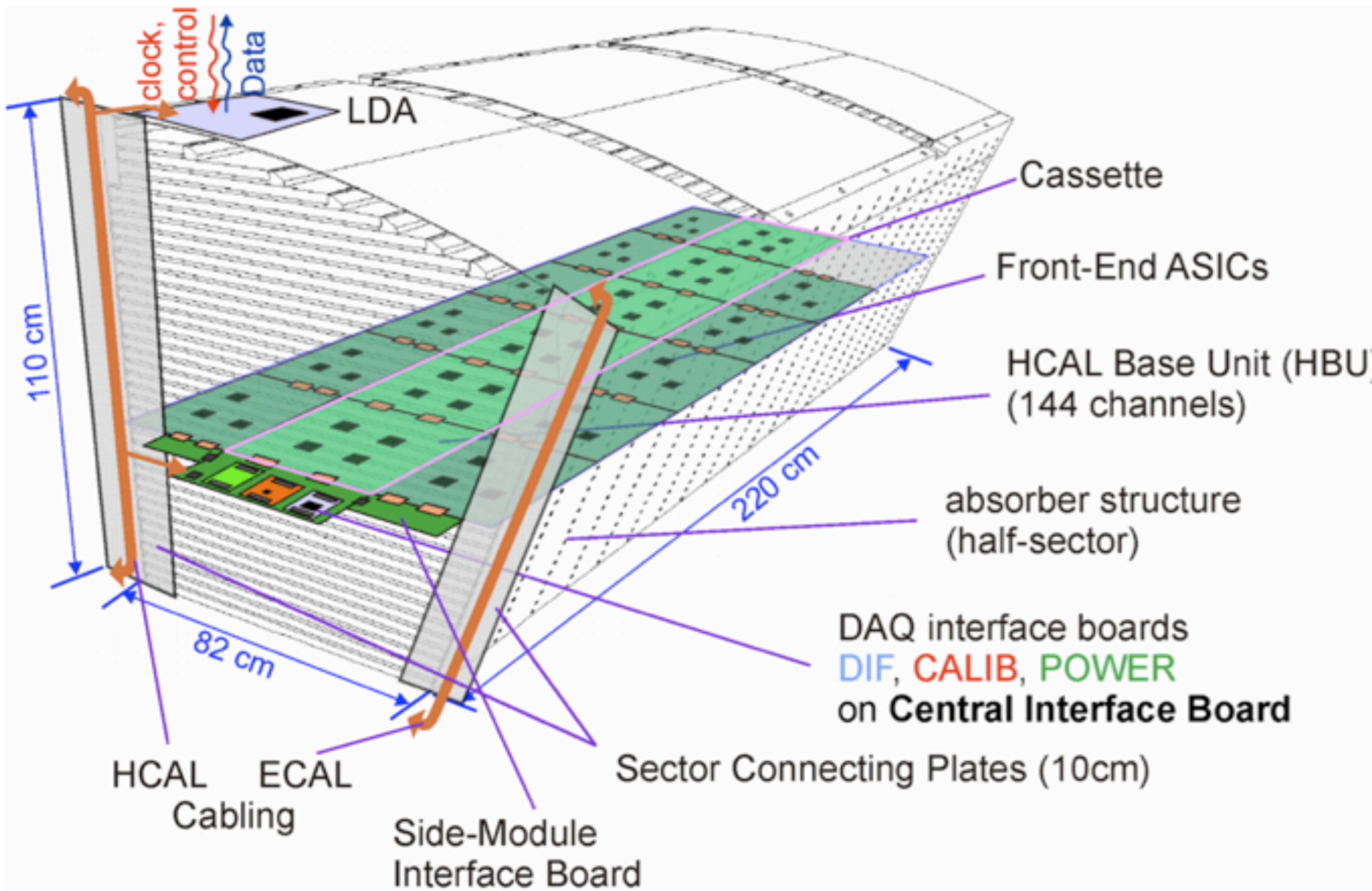
The Analog HCAL:

design of a complete module: 48 layers deep



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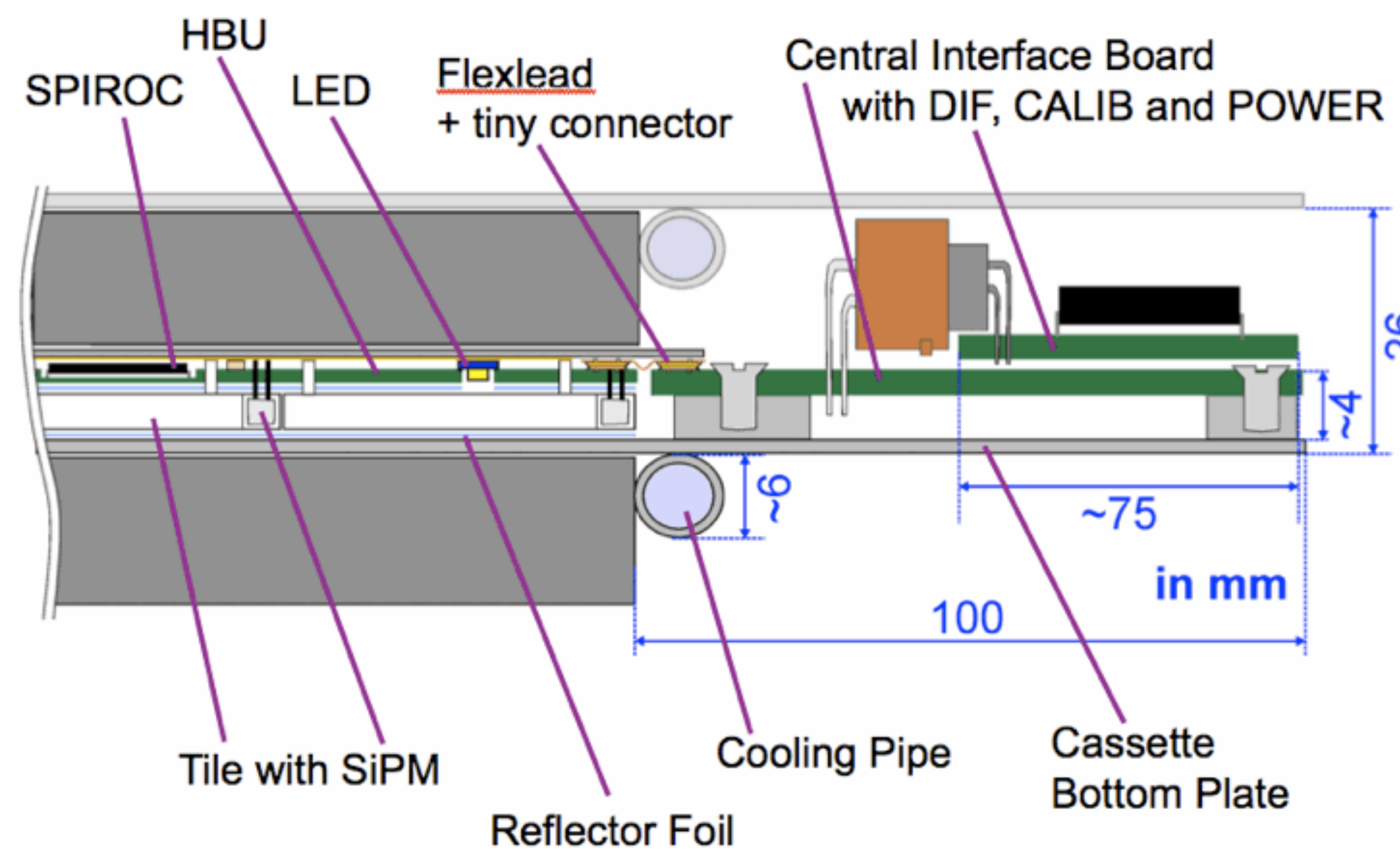
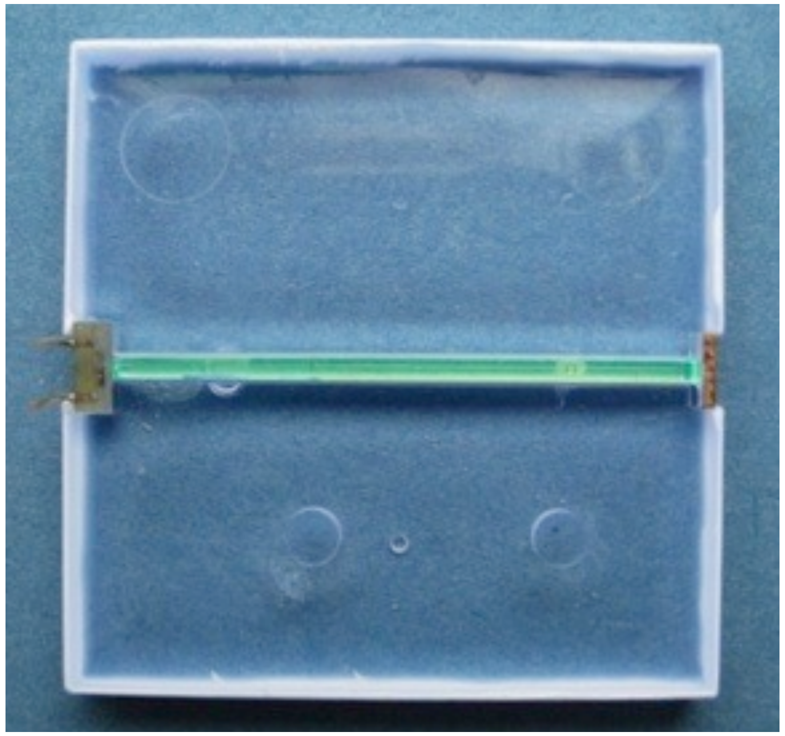
compact layers: 3 mm thick tiles + electronics in a cassette

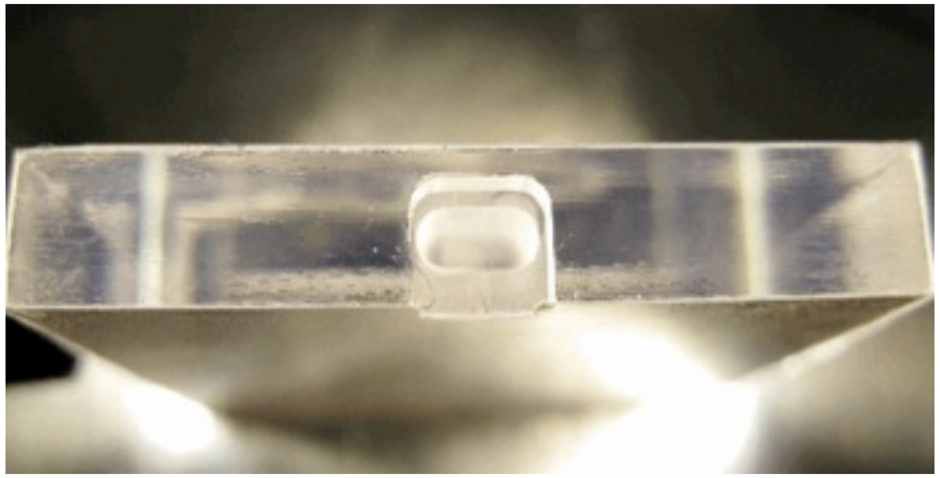


2nd Generation AHCAL

- Scintillator cells: 3 x 3 cm^2, 3 mm thick



- Use improved ITEP MRS APD and WLS fiber
- Also under investigation: fiberless readout with blue sensitive SiPMs and specially shaped tiles



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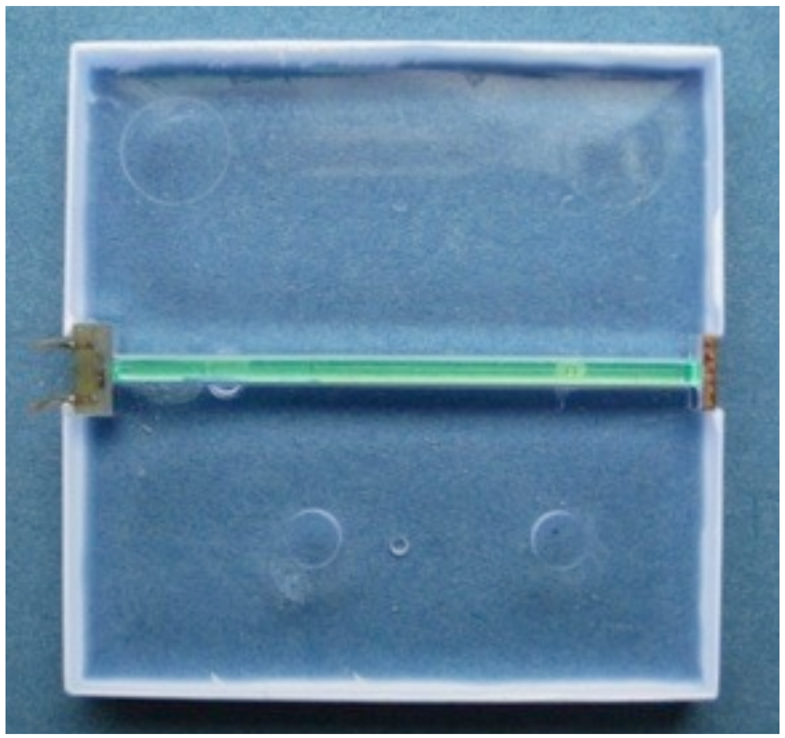
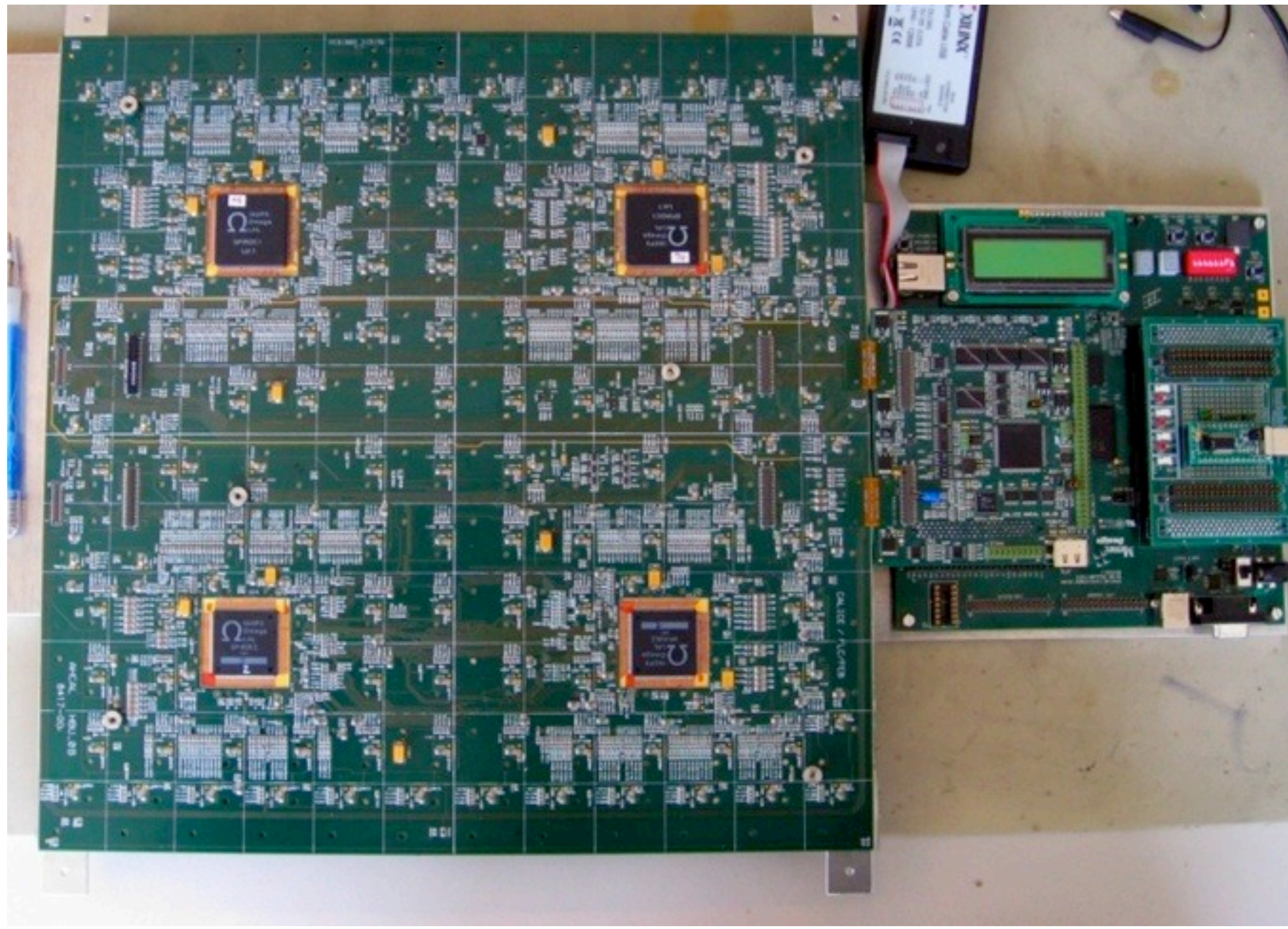


- HBU Board,
  4 SPIROC chips
  - Built-in LED calibration system



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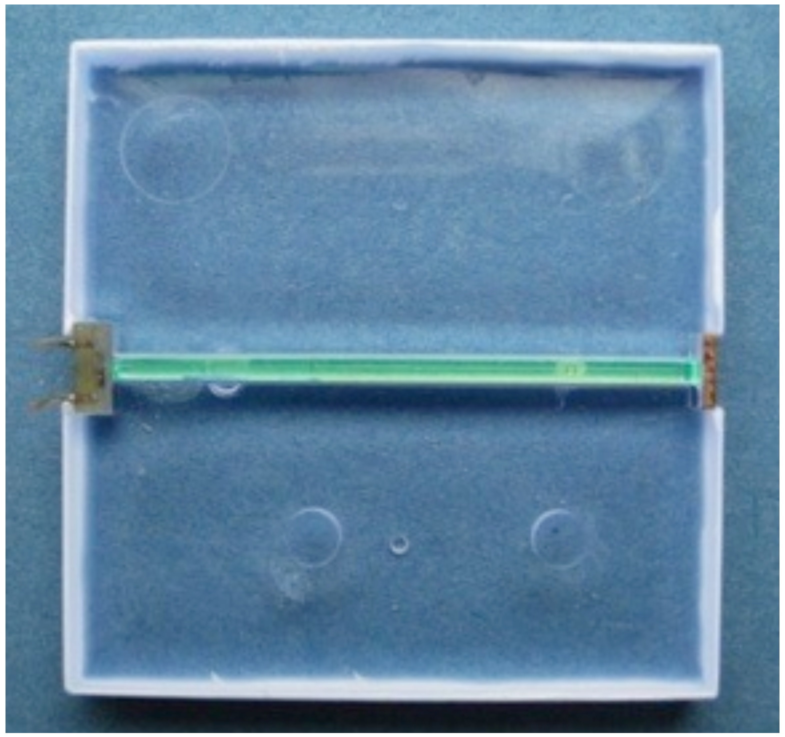

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  - assembly with tiles

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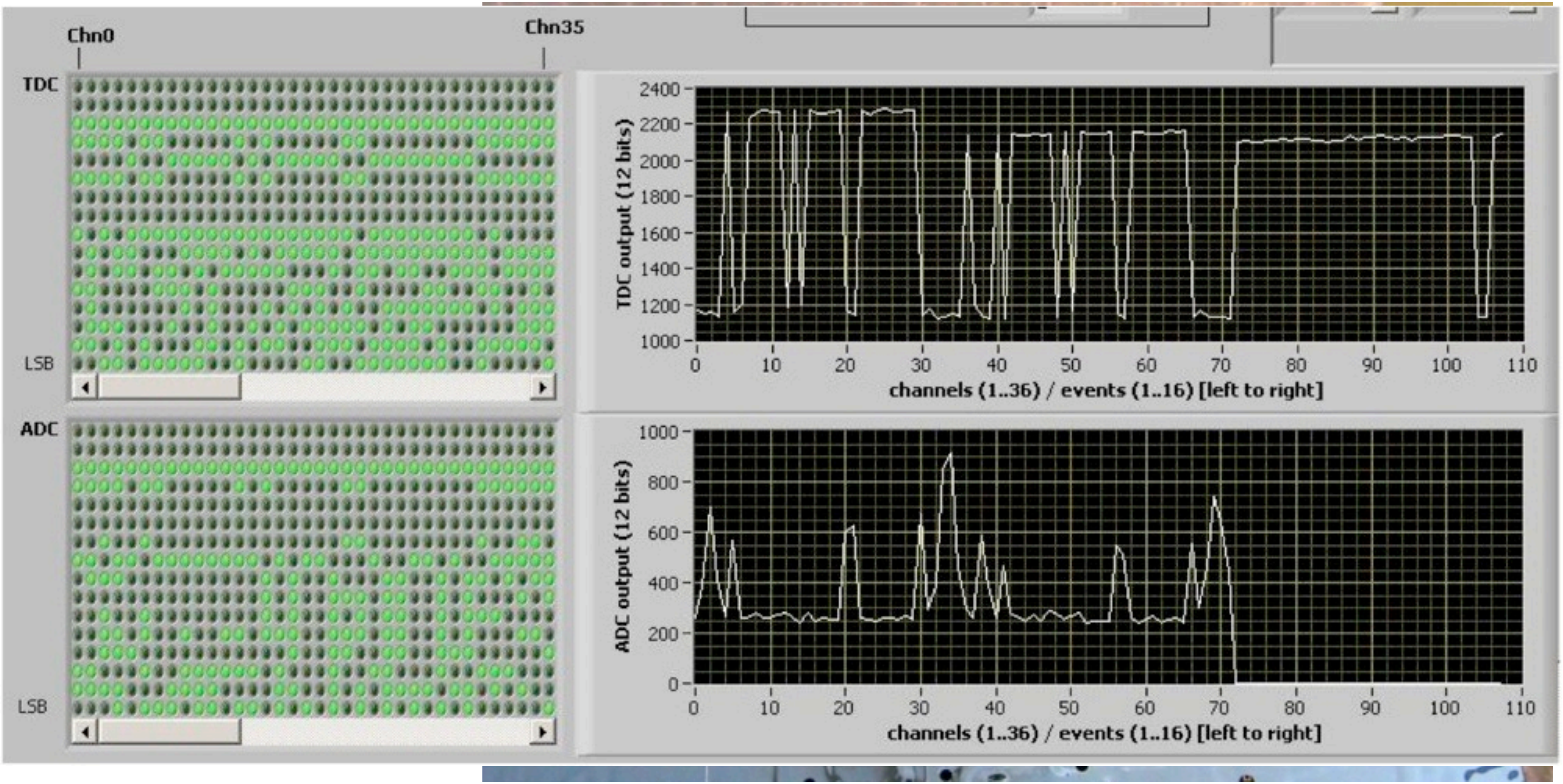
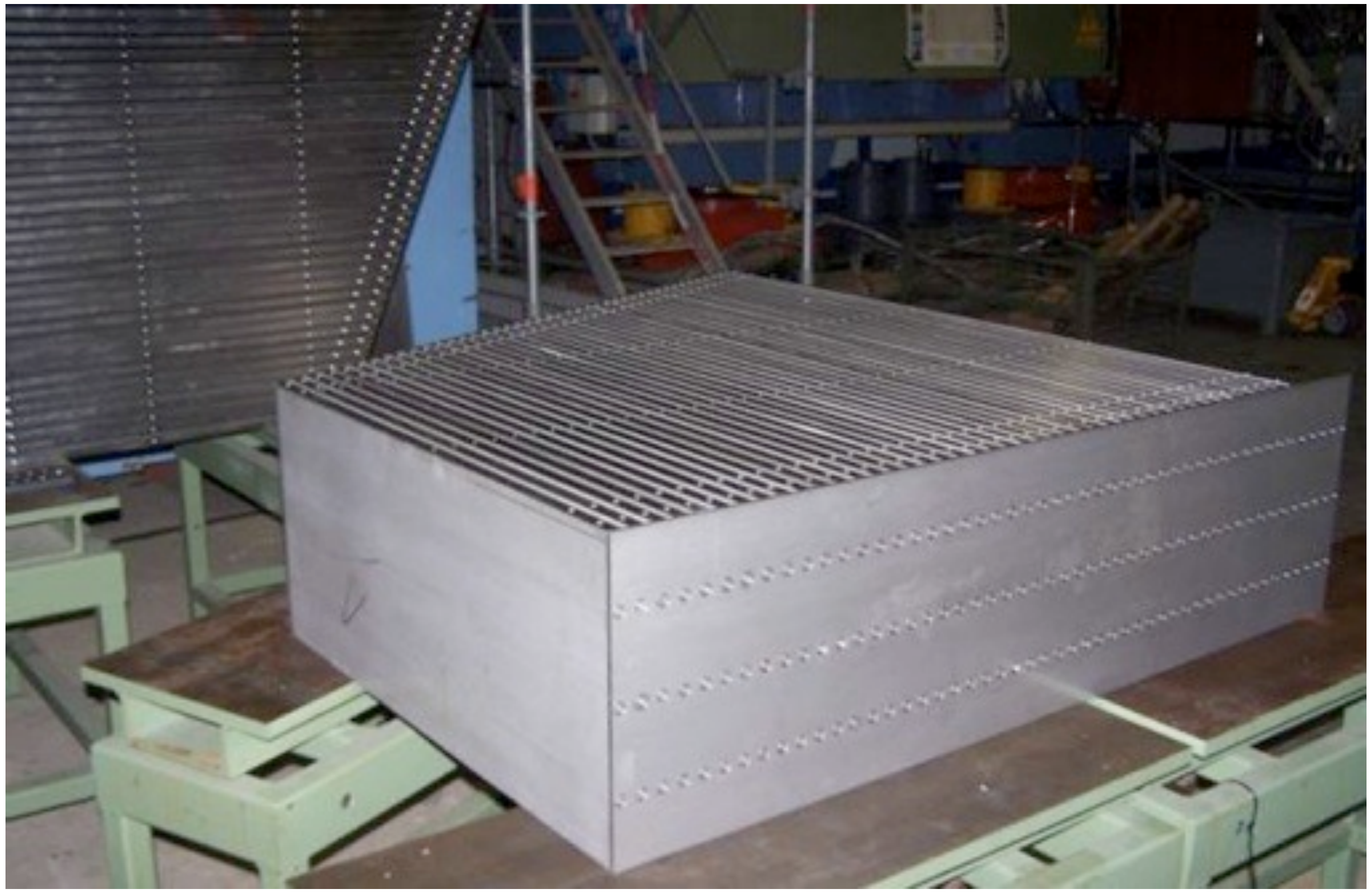


- First signals with LEDs seen, standalone beam test coming up

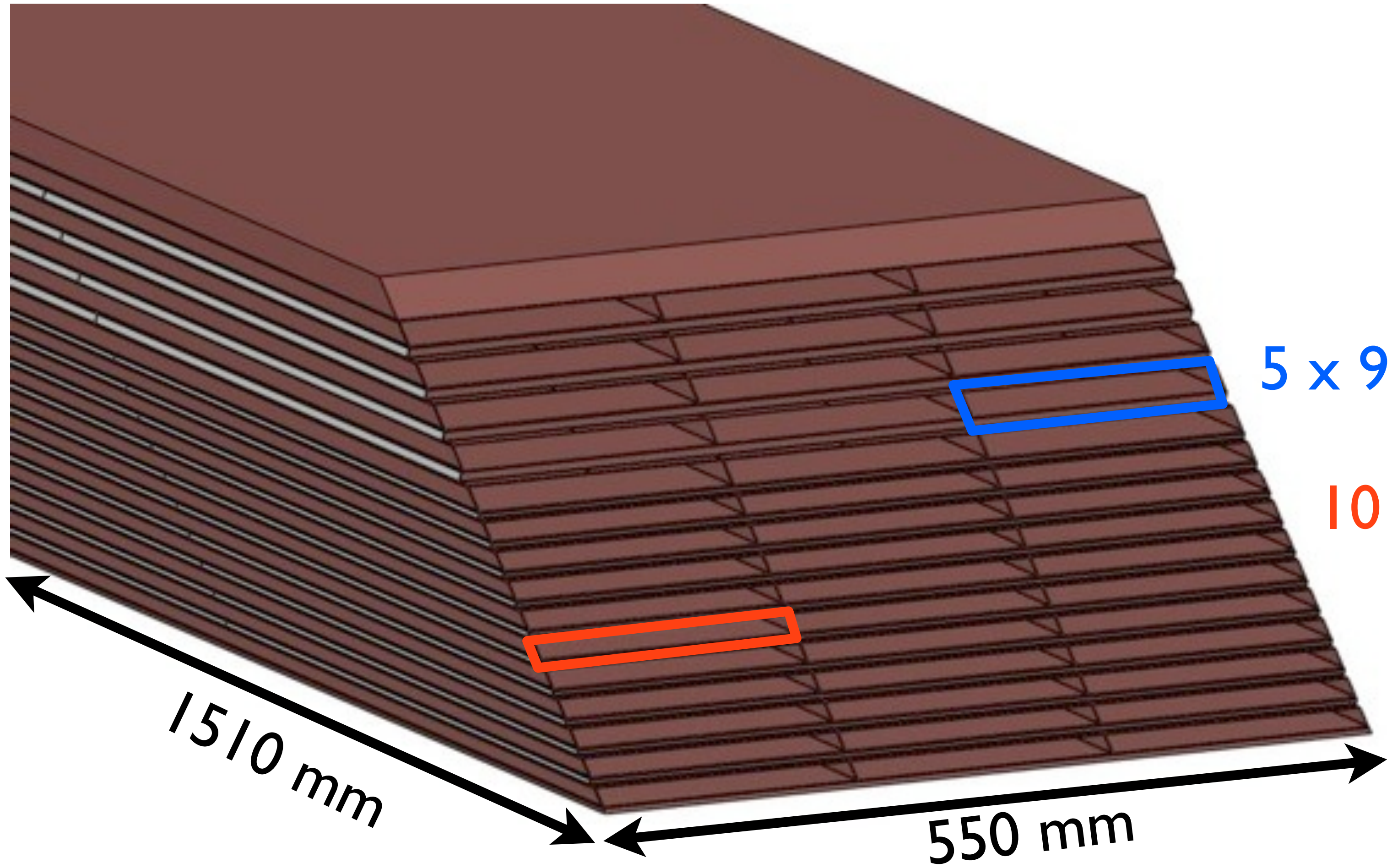
Mechanical Structures for the 2nd Generation AHCAL

- Two vertical and one horizontal structure
  - Test of tolerances, signal transmission, thermal issues, ...
  - Beam tests with instrumented vertical structures:
    - Small scale (2 k channels) instrumentation for electrons
    - Large scale (40 k channels) for hadrons



2nd Generation SiW ECAL

- Realistic W mechanical absorber structure



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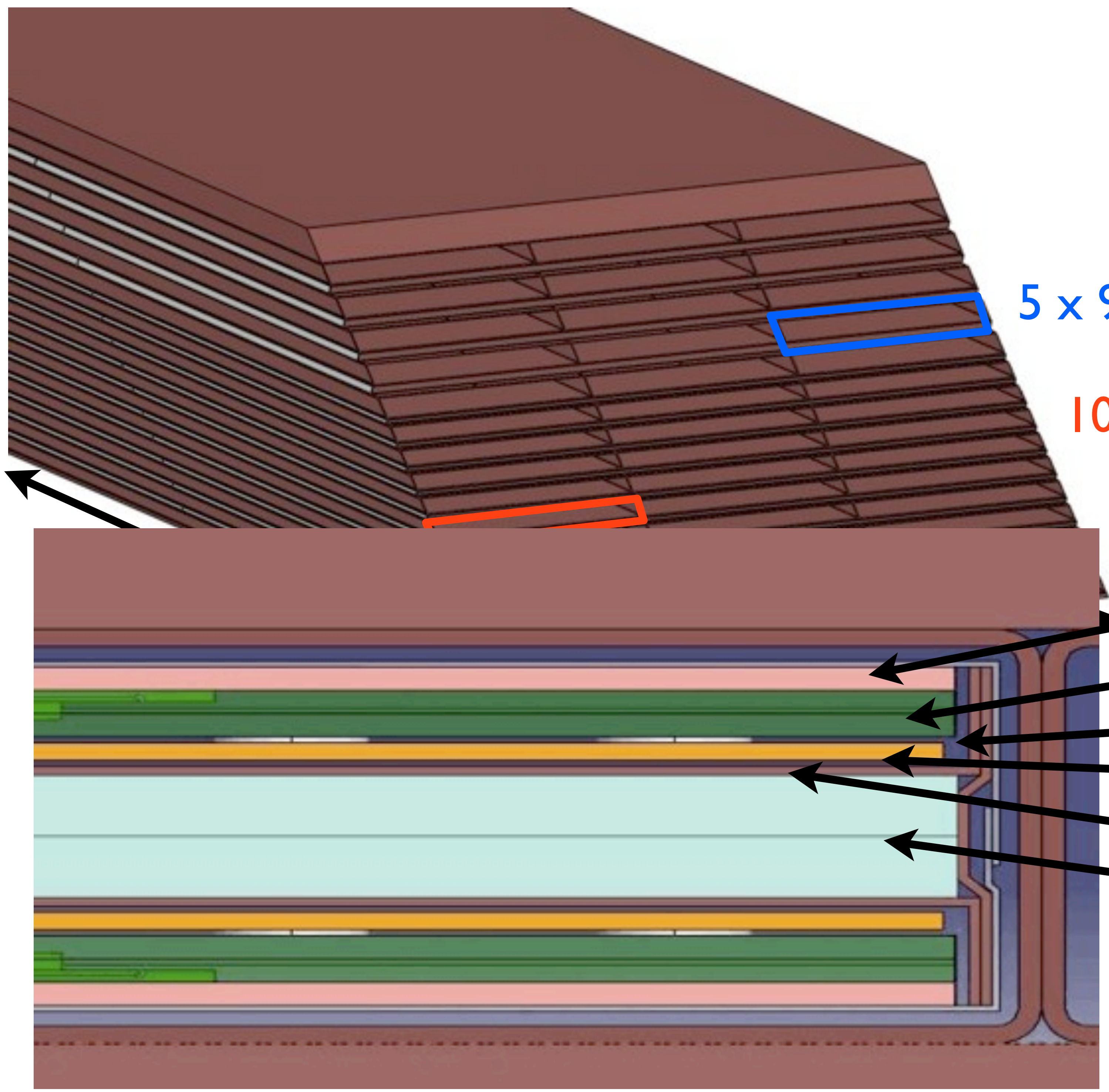

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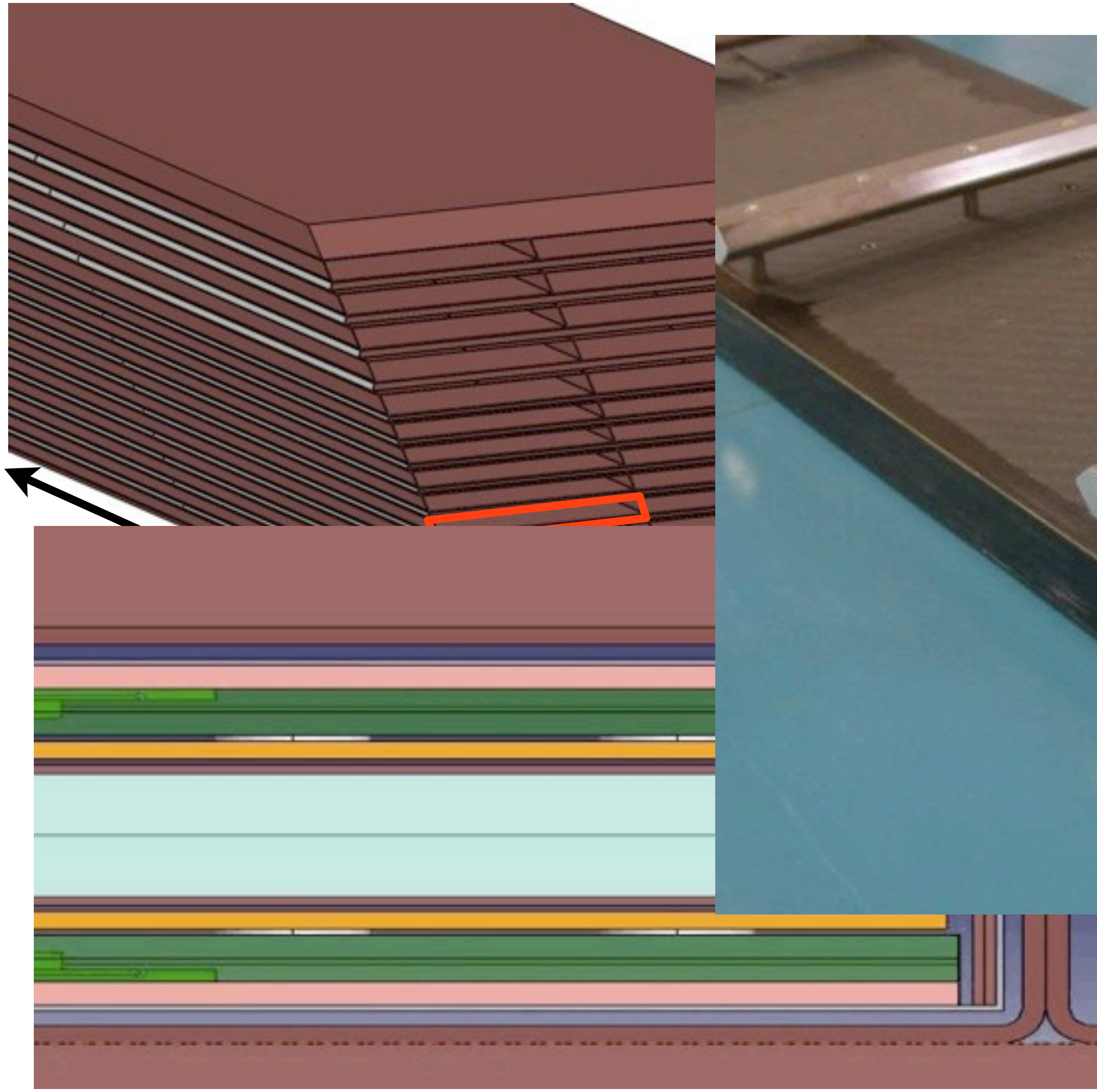
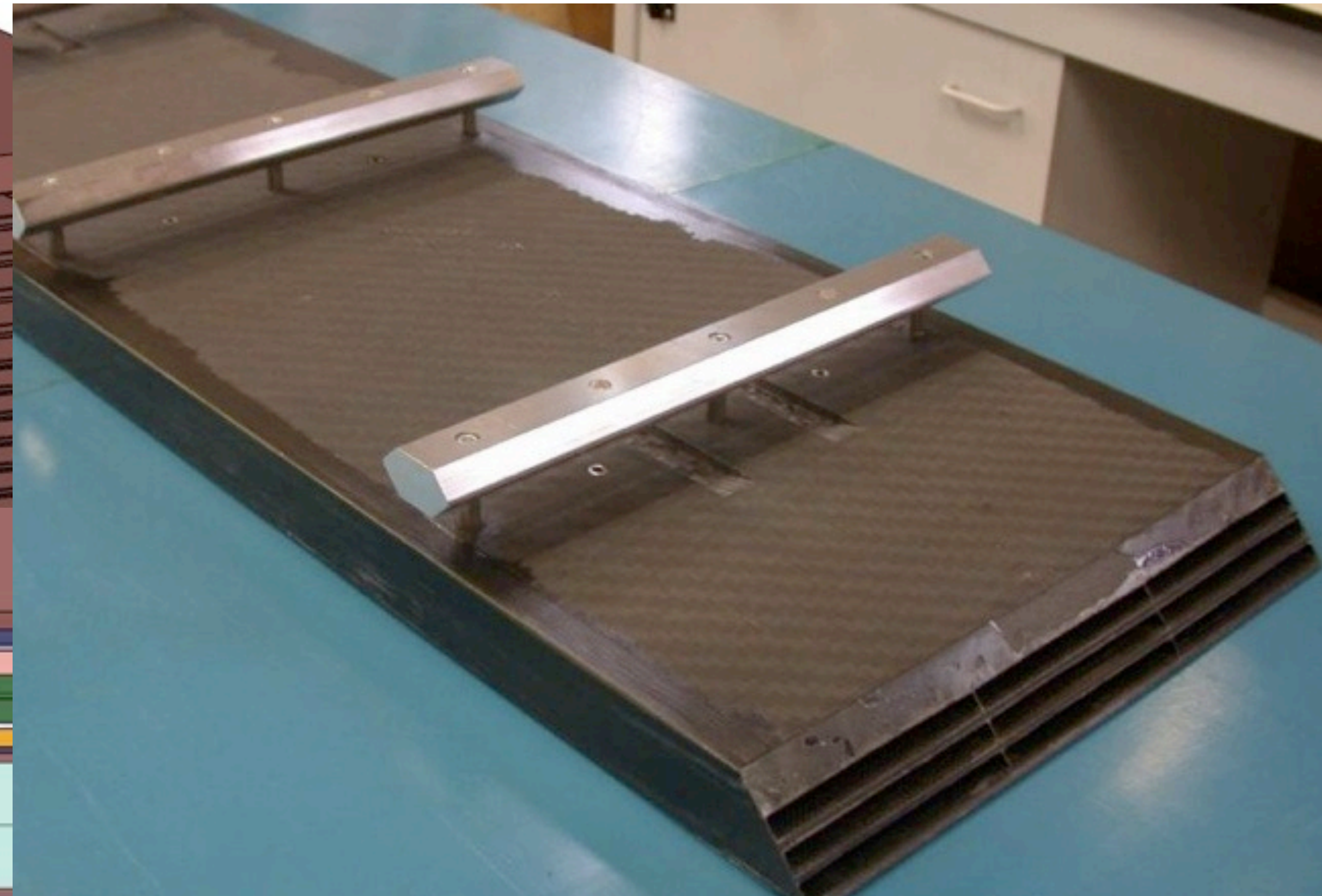
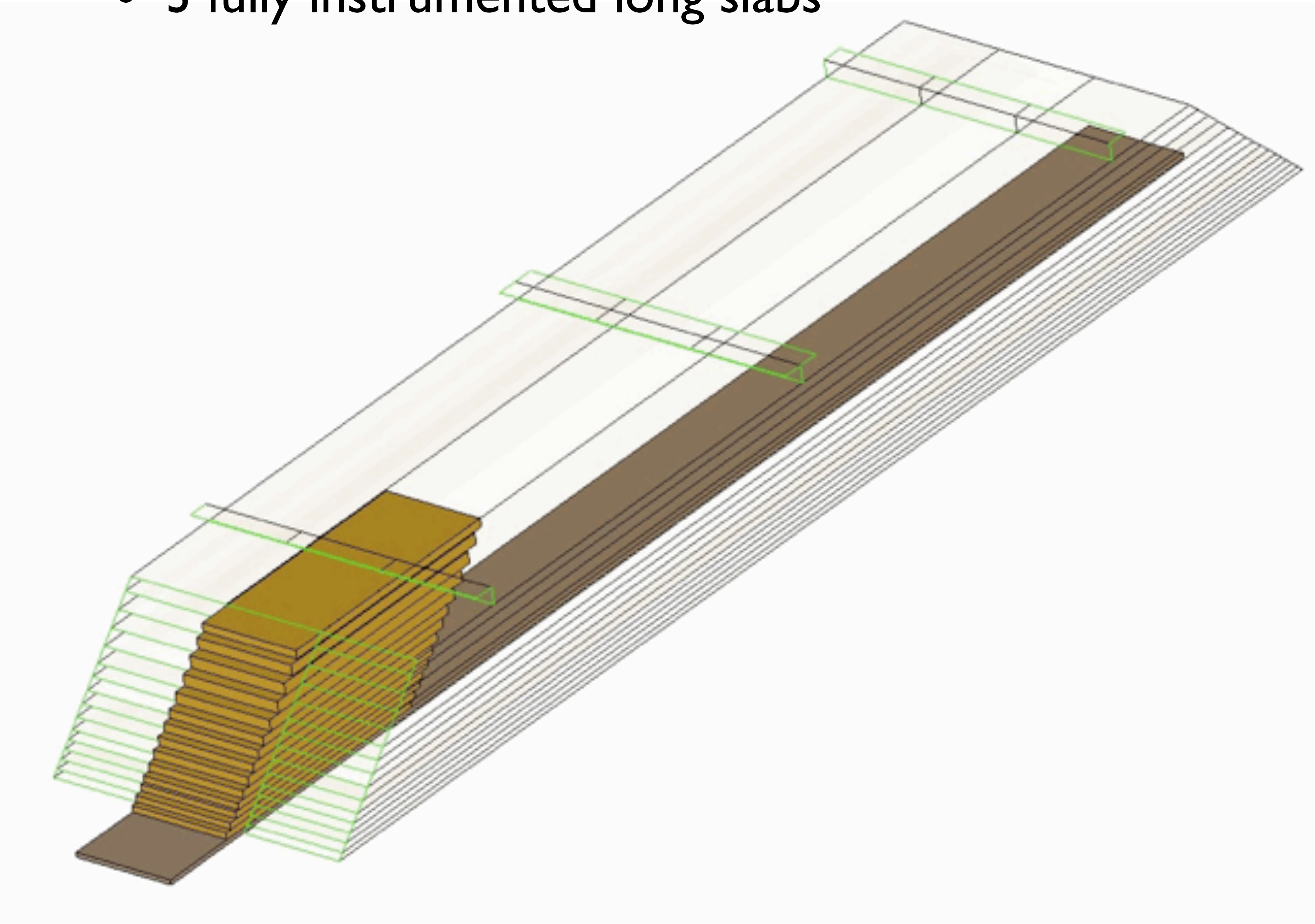




2nd Generation SiW and Scint-W ECAL

- Construction Plan for SiW(within EUDET Framework):
  - 1 completely instrumented tower (18 x 18 cm^2, 15 short slabs, 30 layers)
  - 3 fully instrumented long slabs



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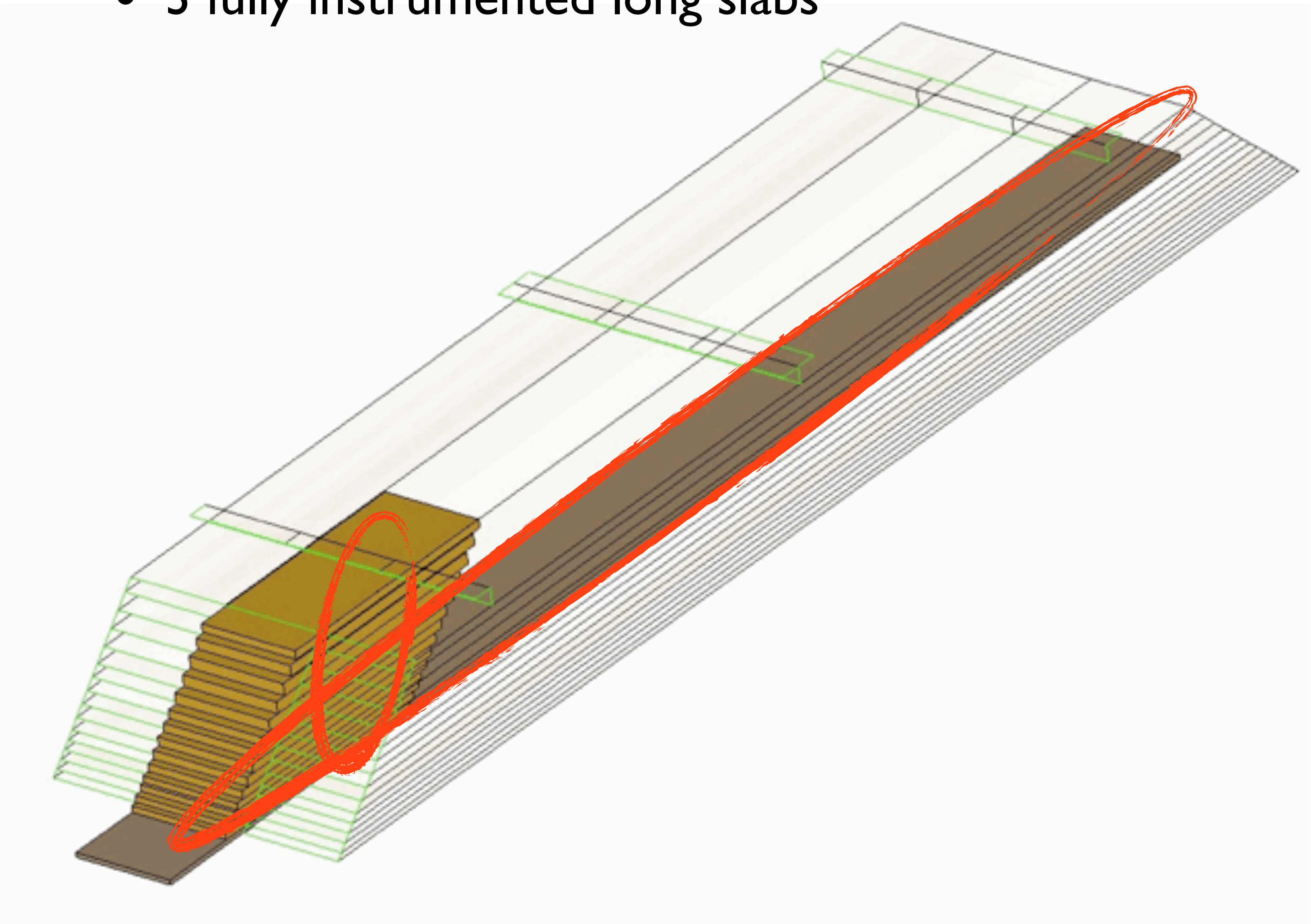

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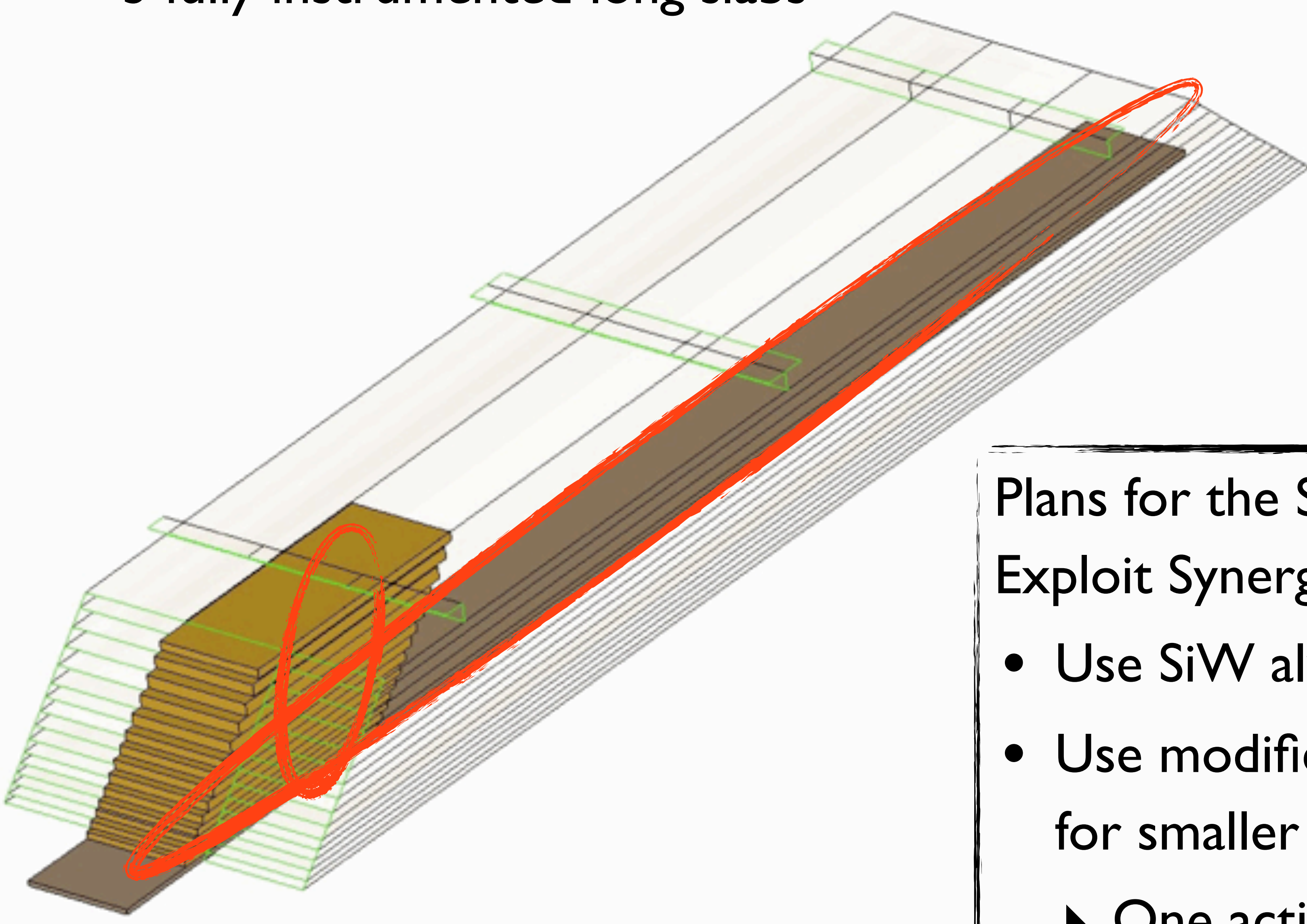

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Plans for the Scint-W ECAL 2G Prototype: Exploit Synergies within CALICE

- Use SiW alveolar structure
- Use modified AHCAL HBU boards: adapted for smaller cells
  - One active layer per slab (instead of 2 for SiW)

Pushing the Limits of Granularity: A Digital ECAL

- Extreme resolution needed to resolve every single particle within an electromagnetic shower: Densities of up to 100 particles / mm^2 expected
  - Readout granularity of 50 x 50 μm^2 required

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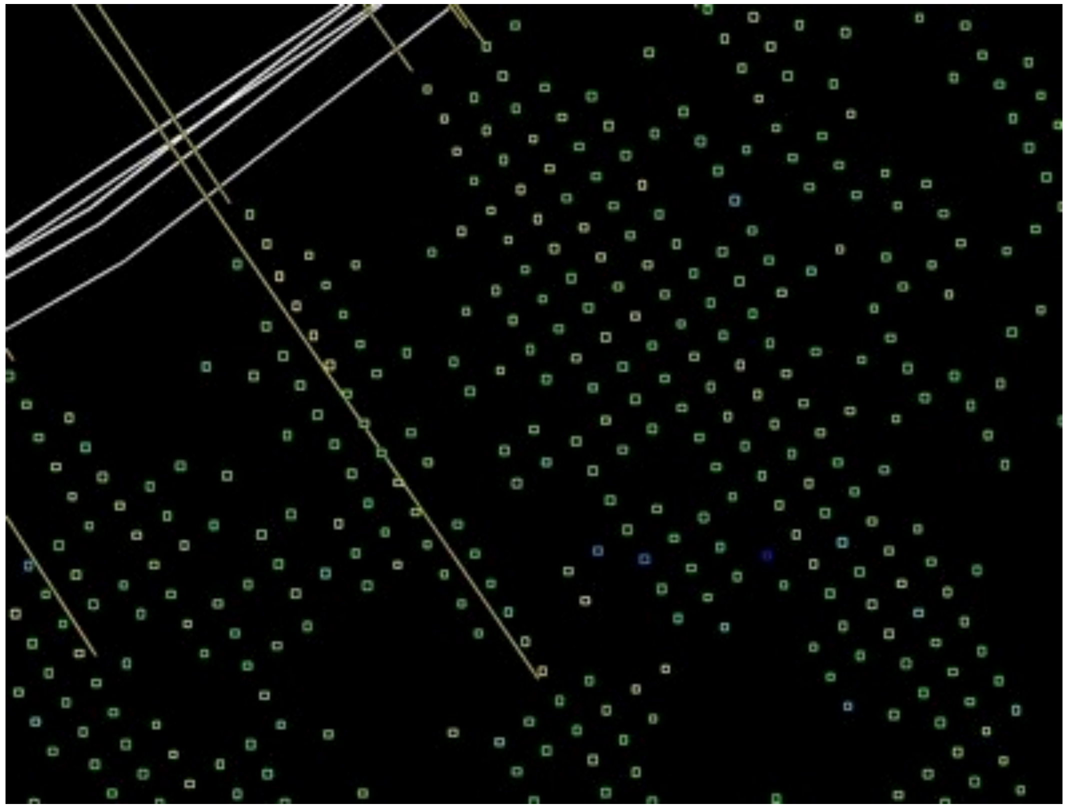

go from here...

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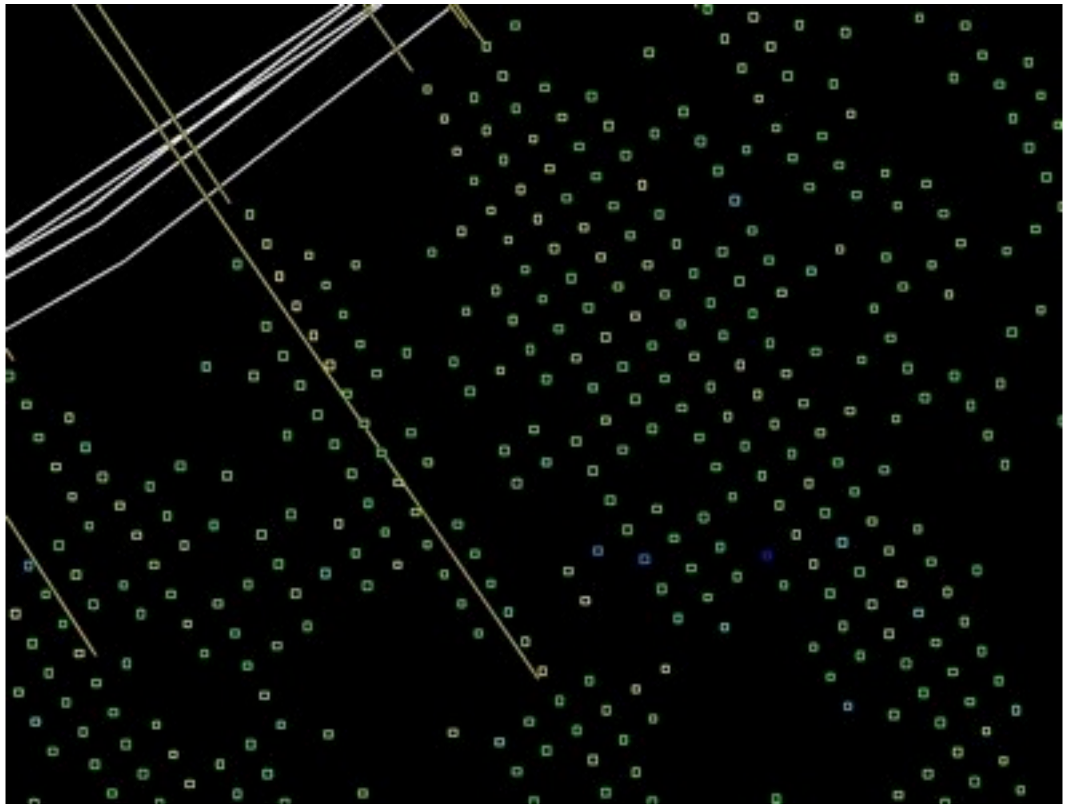
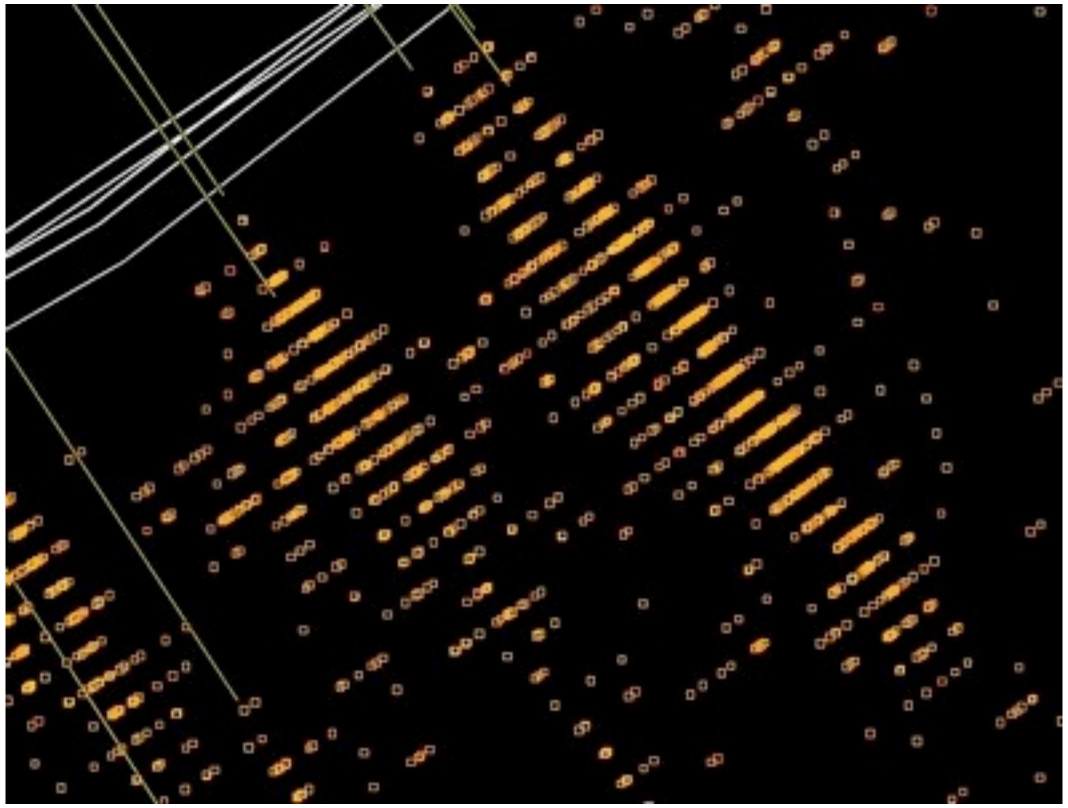


go from here...

to there...



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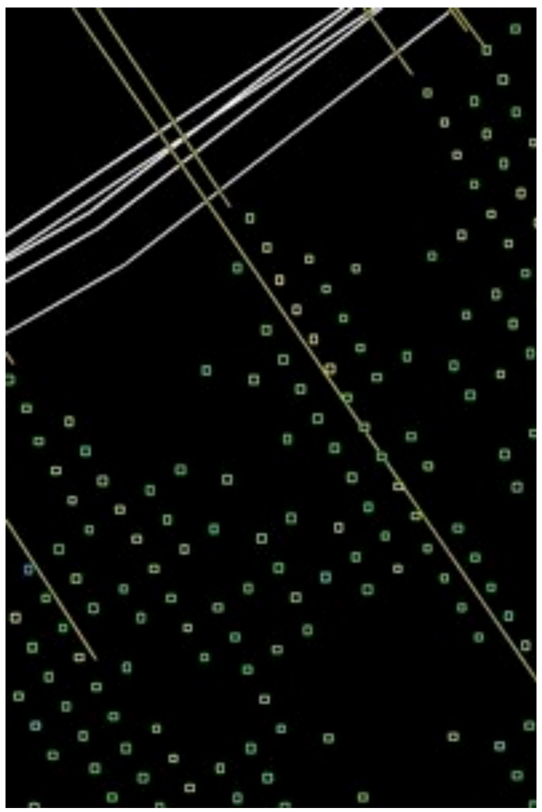
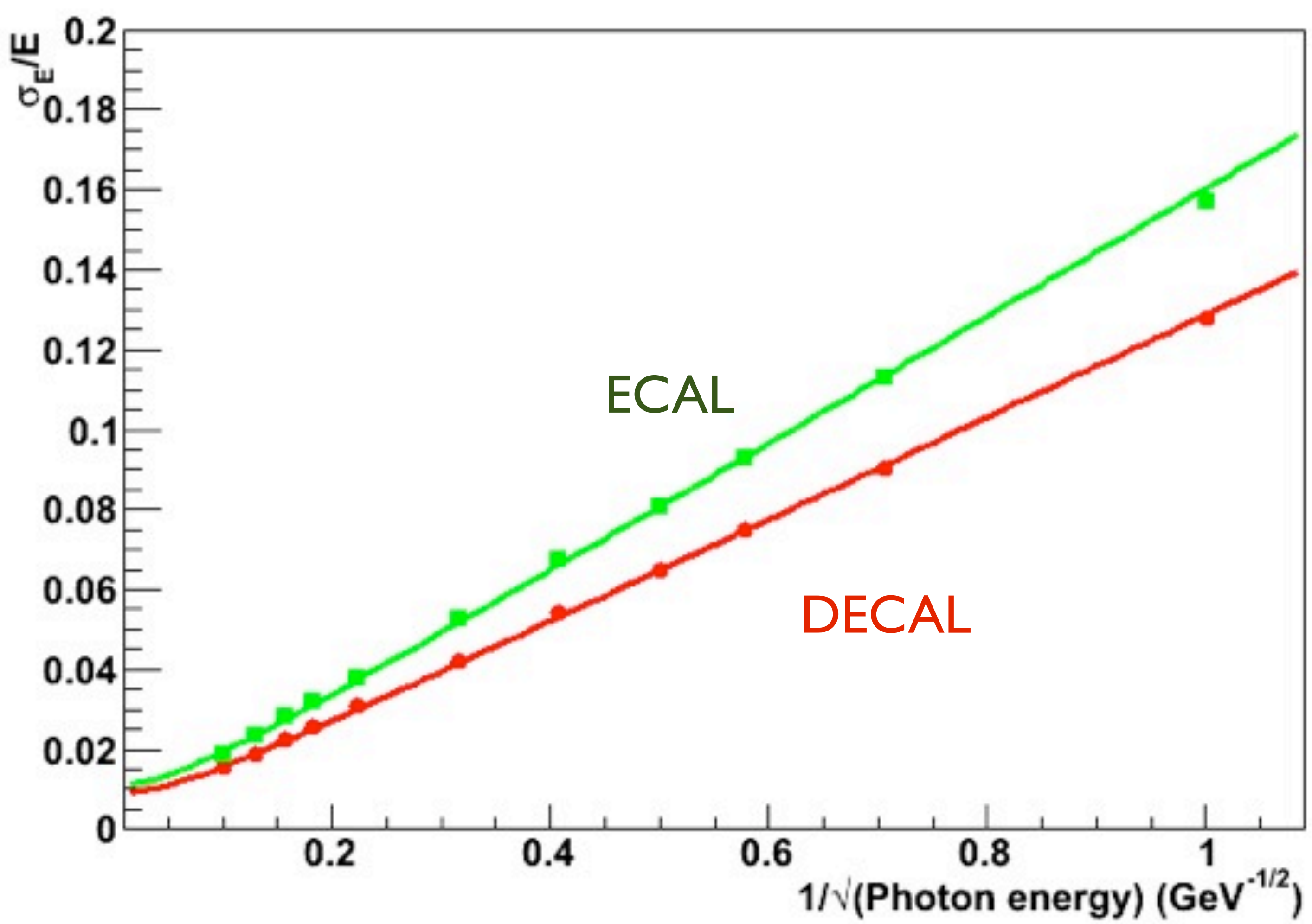
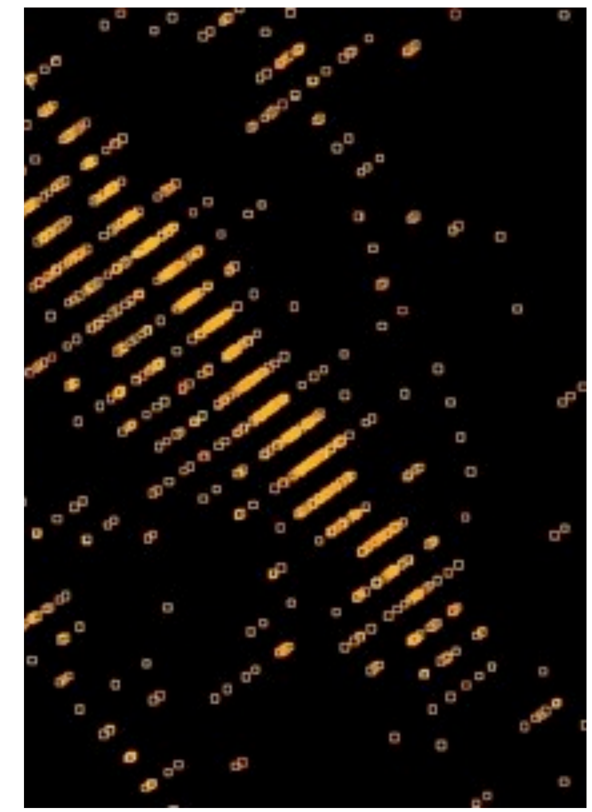


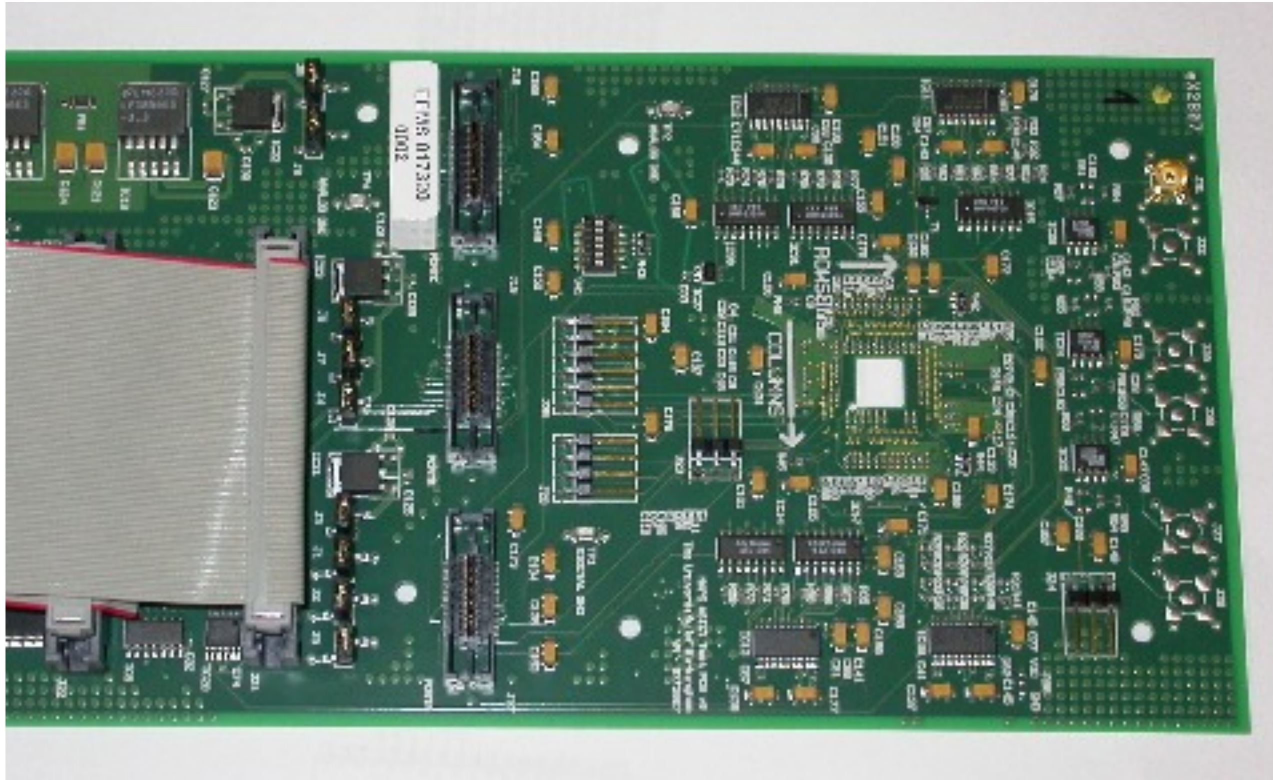




improvement in resolution: particle counting beats energy measurement: less fluctuations!

DECAL Technology

- A challenging idea: A complete ILC detector would be a Tera-pixel Calorimeter!
- The technology: MAPS - A standard CMOS product
  - Potentially significant price advantage over high resistivity Si diodes
- Tests of sensor prototypes at CERN in 2009: 8.4 x 8.4 mm^2 sensitive area



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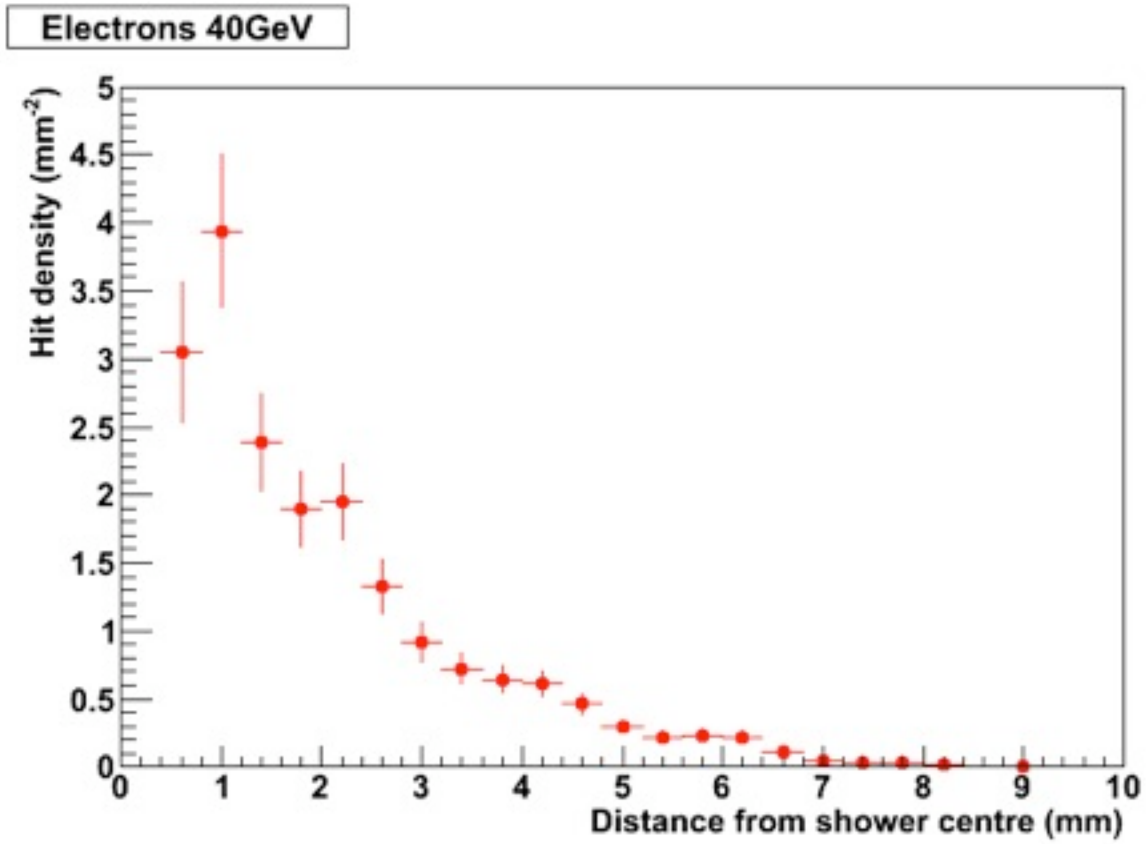

First measurements of hit density near the shower maximum of em shower

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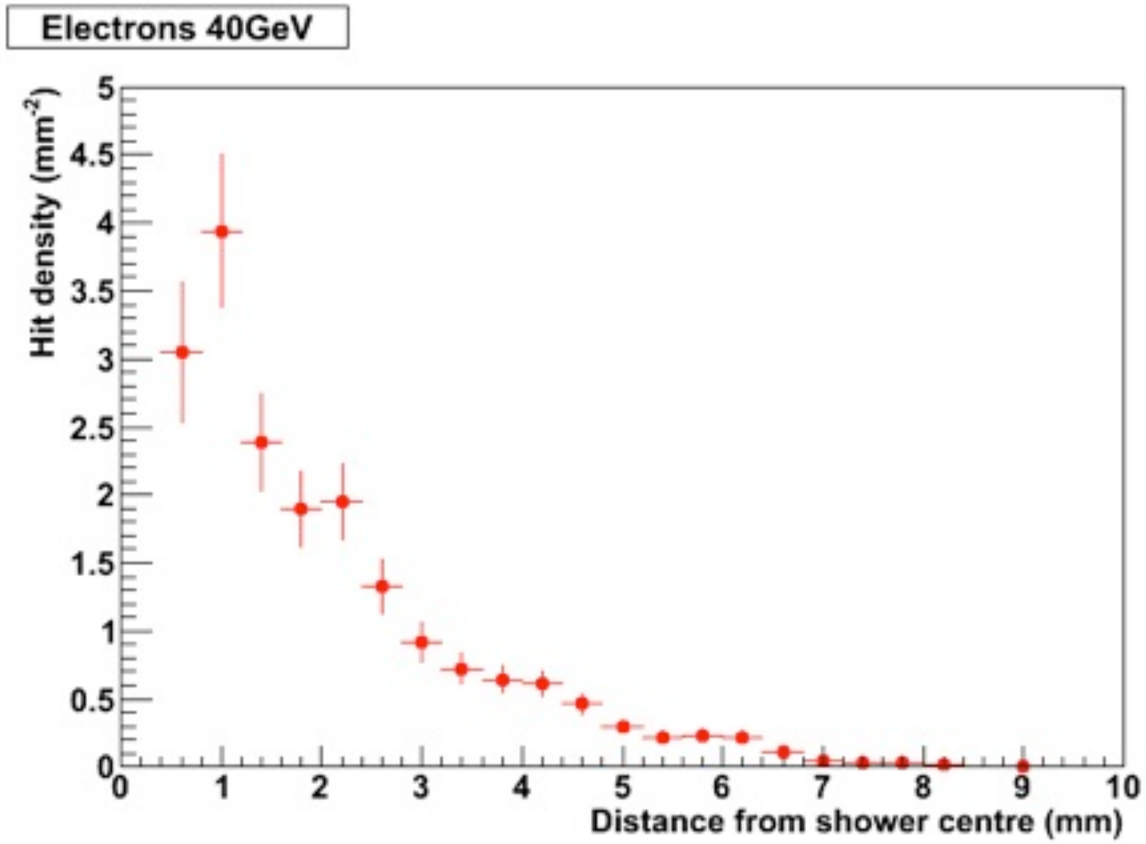

First measurements of hit density near the shower maximum of em shower

Funding for further developments in the UK still unclear...

A Semi-Digital HCAL

- The motivation: Avoid the limited dynamic range of a digital HCAL, keep the simplicity of a gas detector readout
  - 2 bit per cells: 3 thresholds

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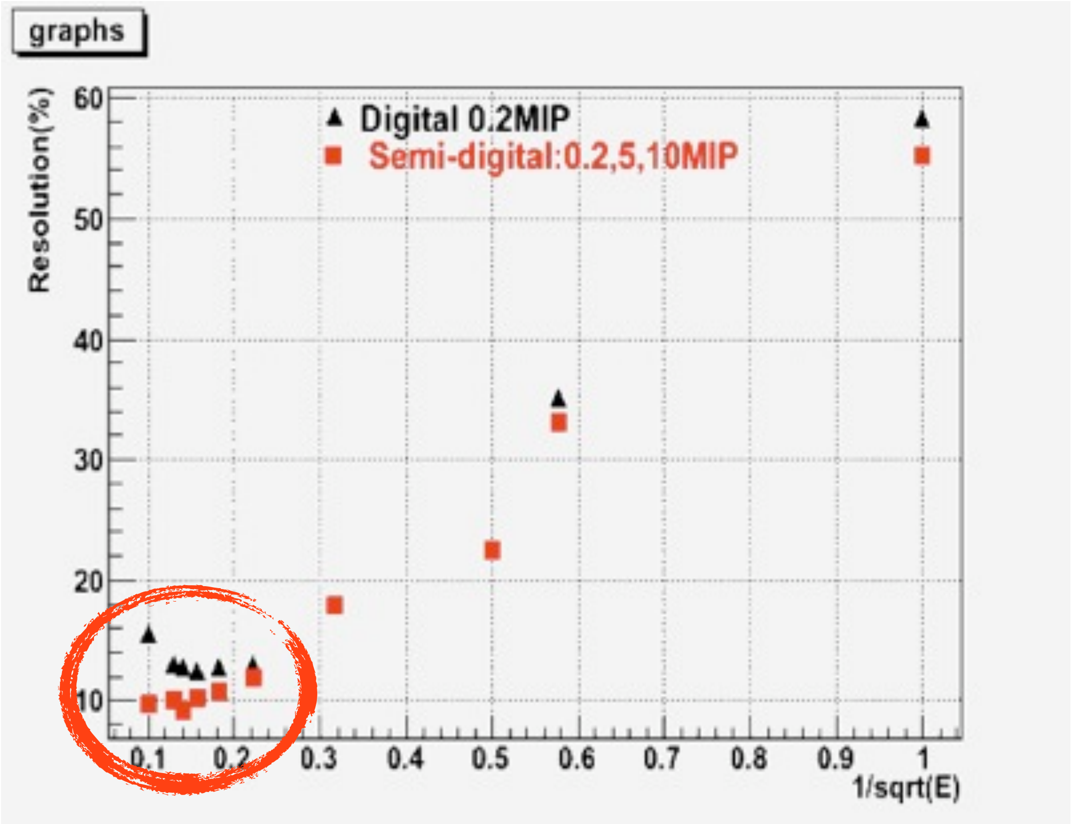

Simulations show the potential for significant improvement of resolution at high energies

A Semi-Digital HCAL

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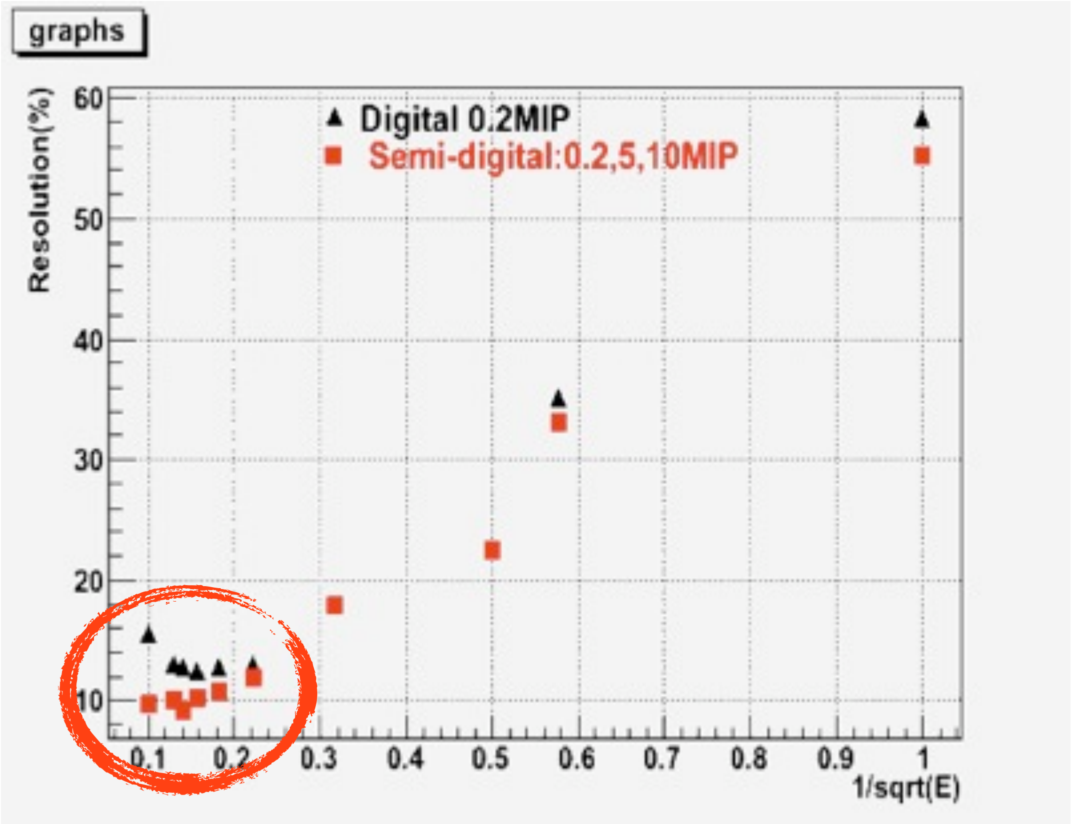
  - 2 bit per cells: 3 thresholds

Concept so far unproven, depends on detailed response characteristics of the detectors: Test required!



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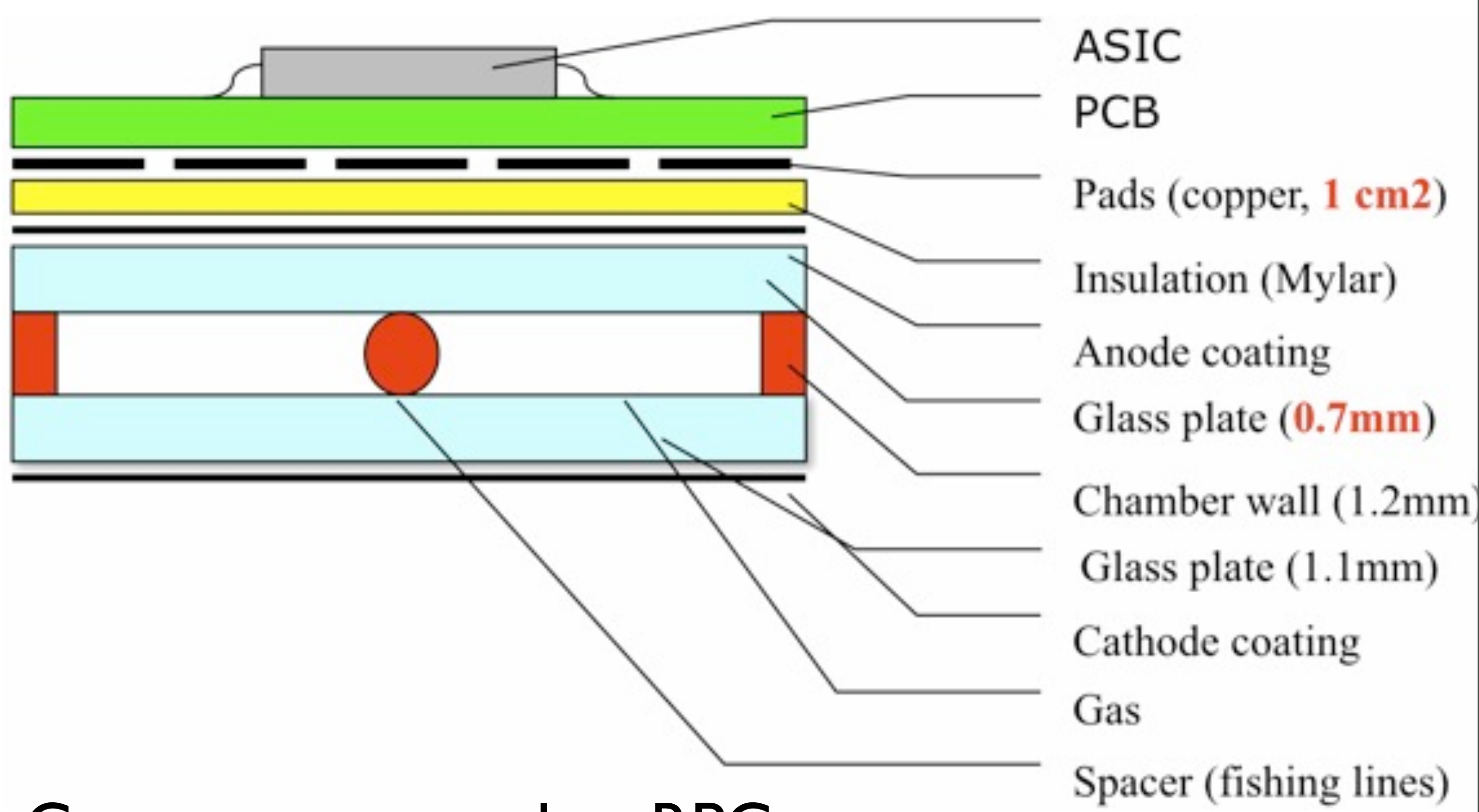
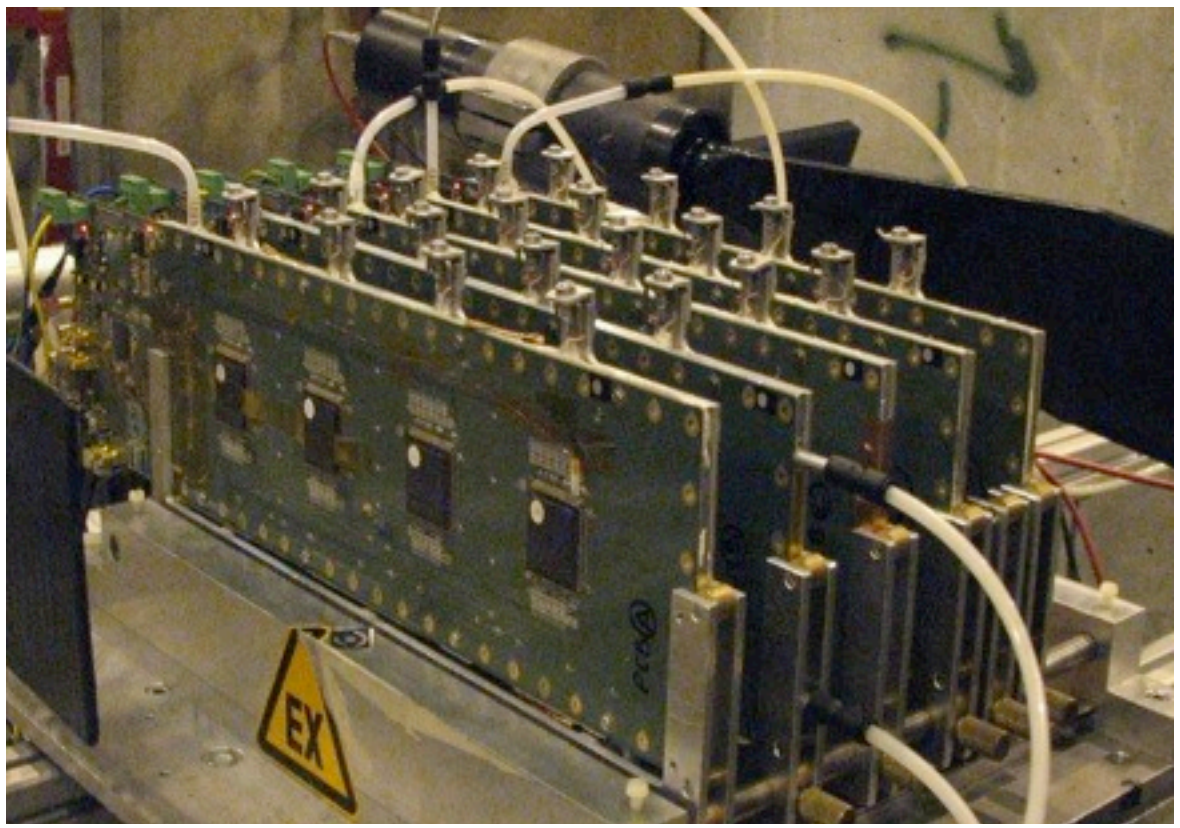


Current concept: glass RPCs and/or Micromegas

SDHCAL: First Beam Test Results

- Beam test of a small multi-layer prototype and a 1 m^2 chamber at CERN in 2009



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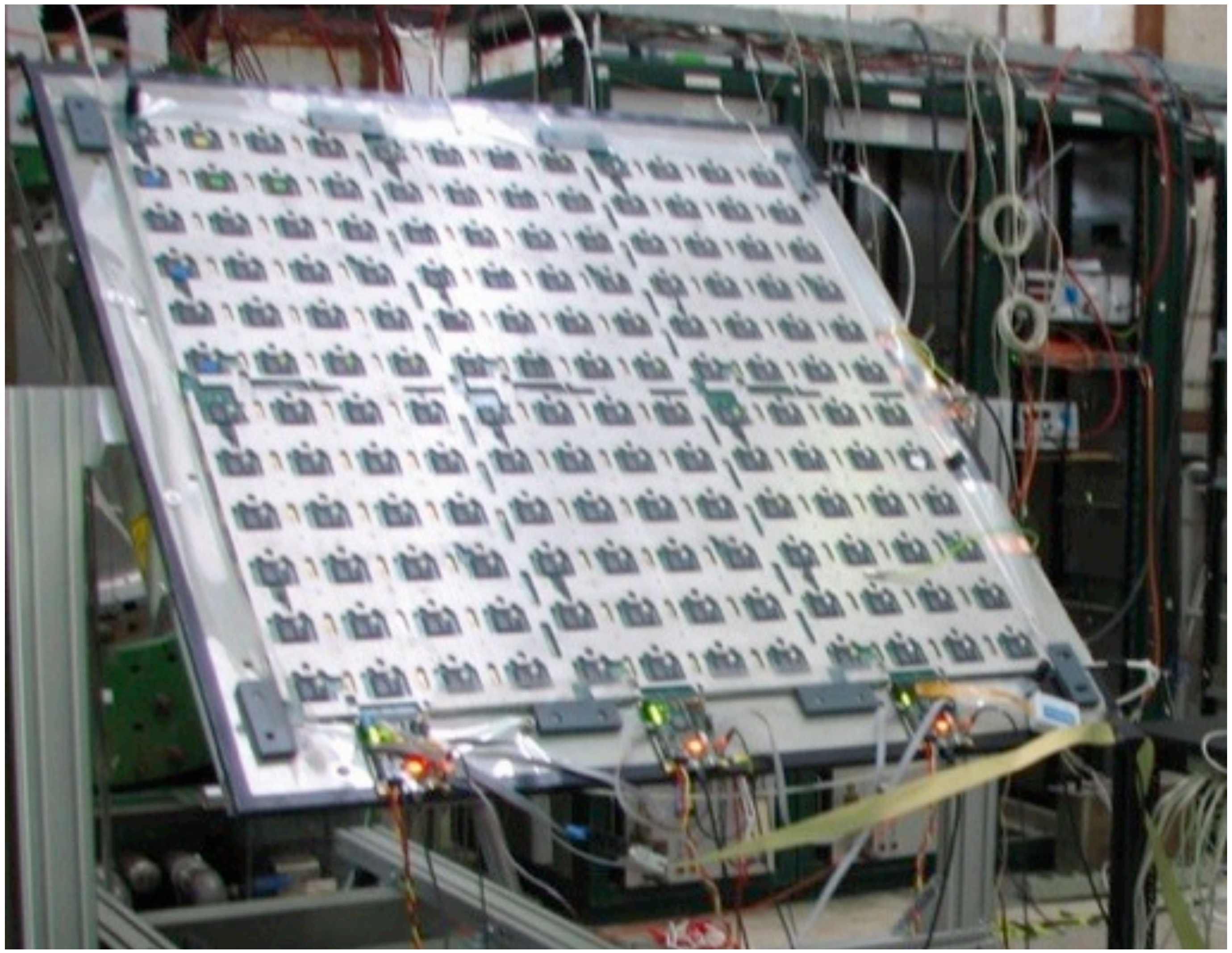
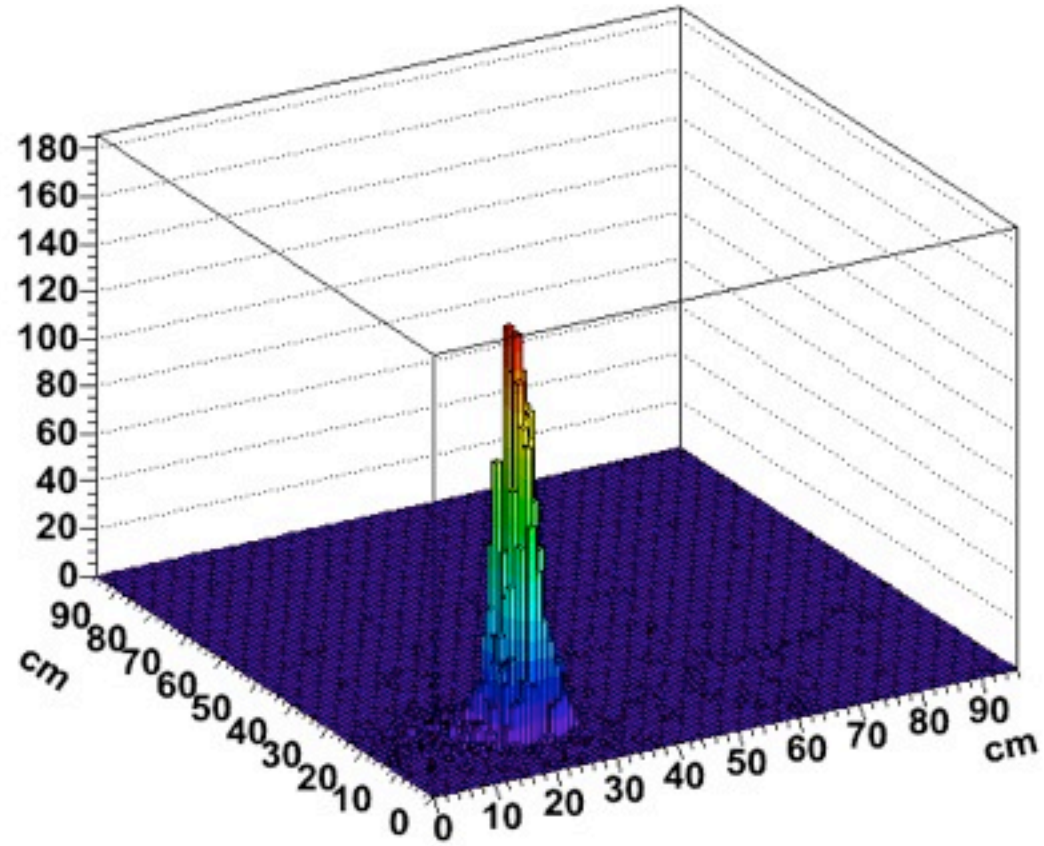
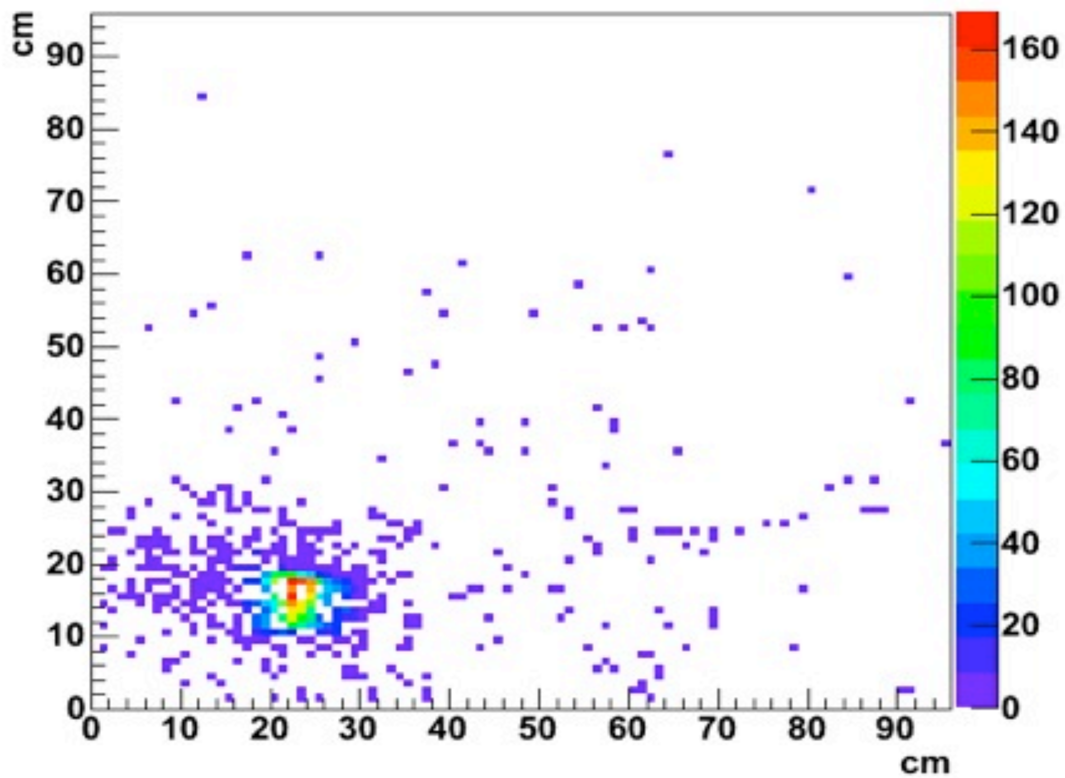
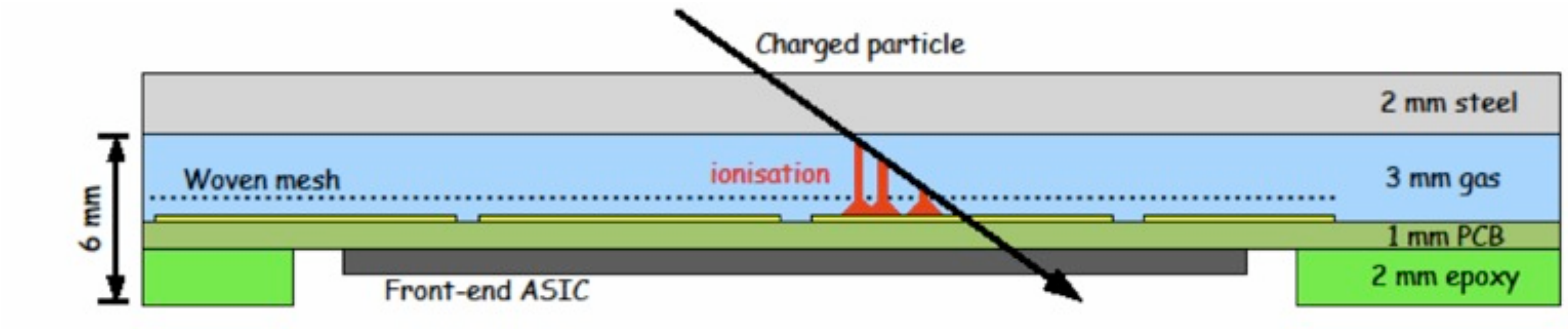


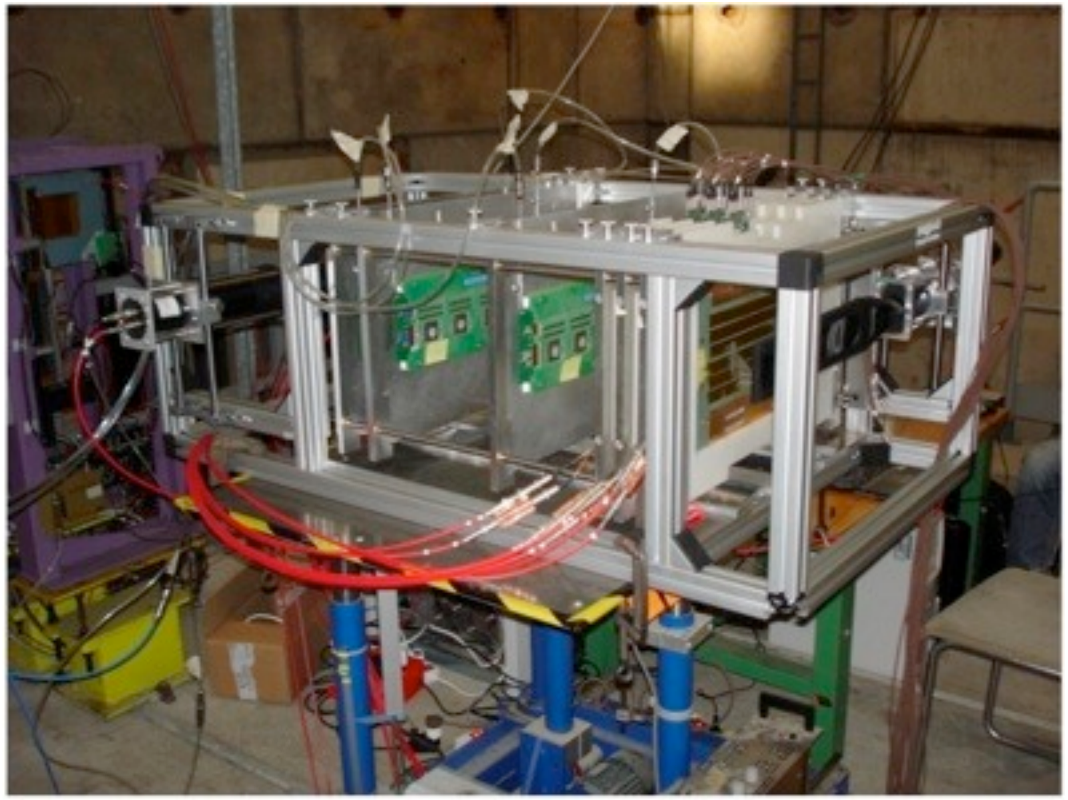


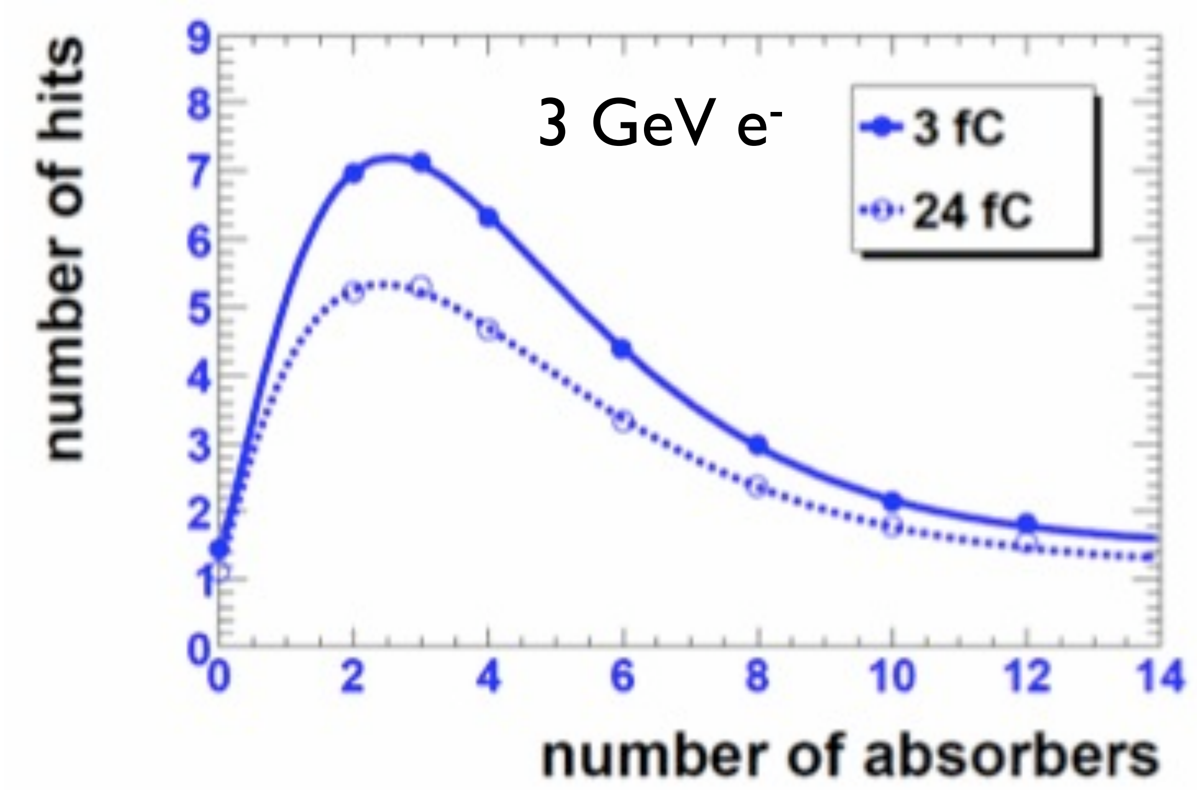


SDHCAL: Micromegas

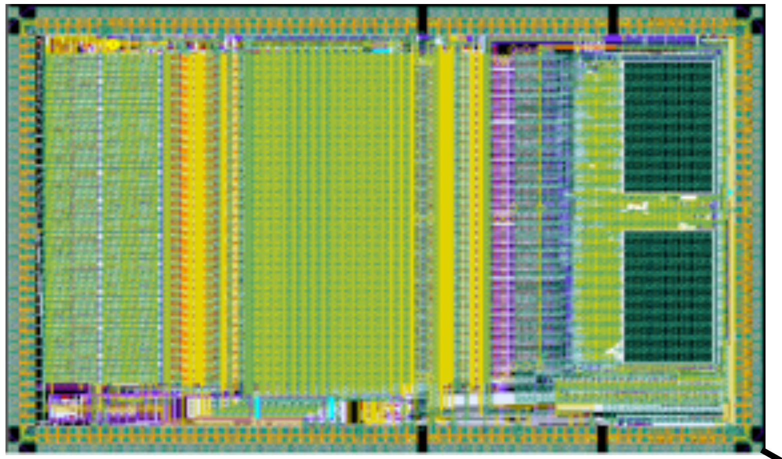


- Successful beam tests at CERN with one detector prototype and varying absorber thickness (2 cm stainless steel plates)
- Also tests with stacks of detectors with different readout electronics (both digital and analog)

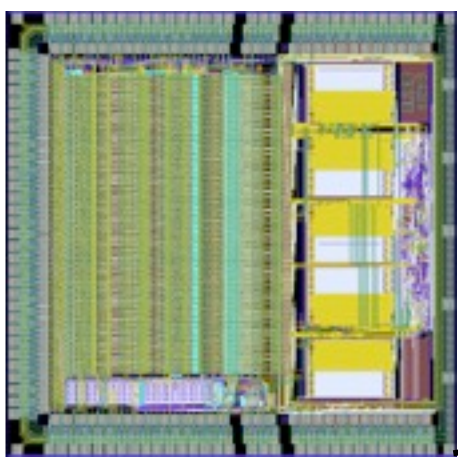




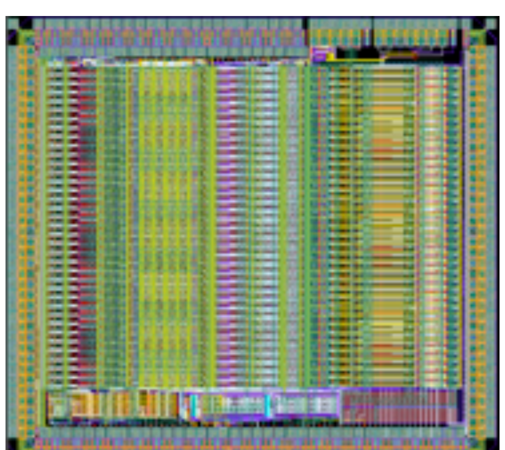
Electronics: Common Development



SPIROC
Analog HCAL
(SiPM)
36 ch. 32mm²
June 07

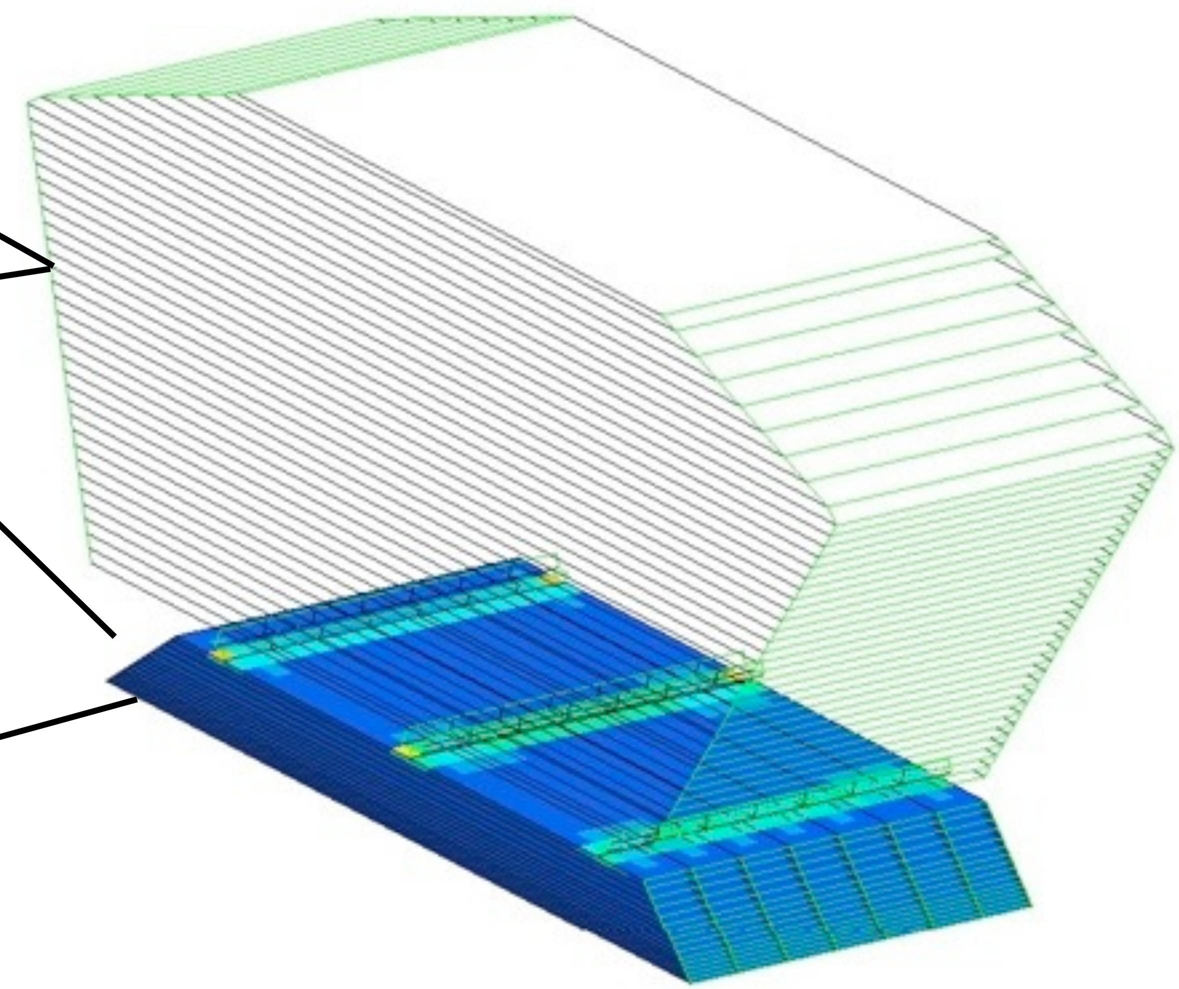


HARDROC
Digital HCAL
(RPC or μmegas)
64 ch. 16mm²
Sept 06



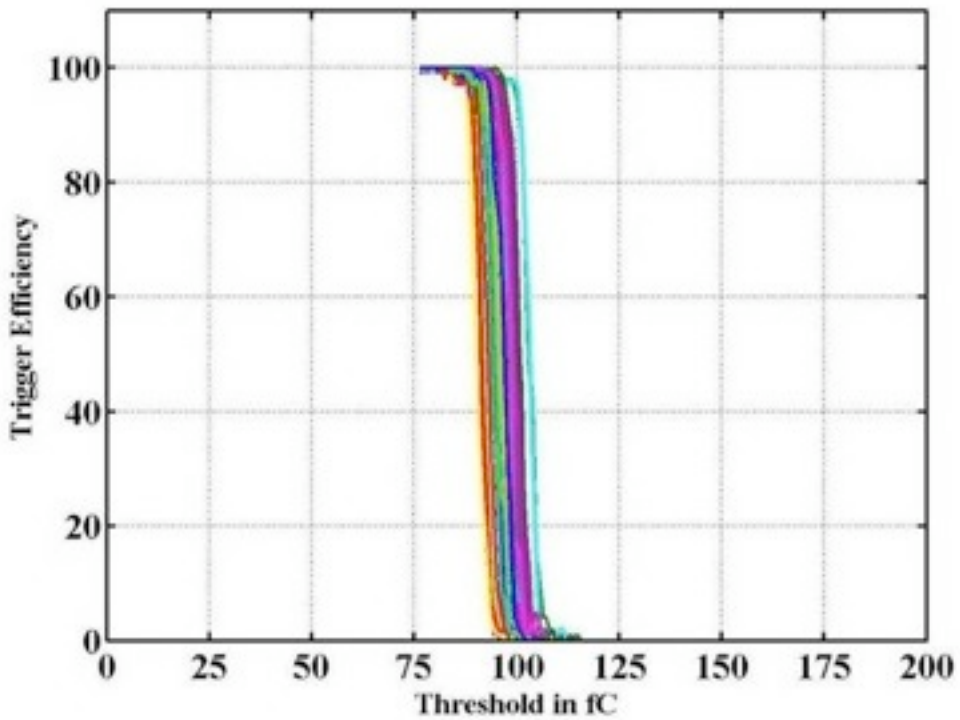
SKIROC
ECAL
(Si PIN diode)
36 ch. 20mm²
Nov 06

- Readout ASICS for all technologies within CALICE
  - Developed at Orsay, supported by EUDET



New Generation of Electronics: First Results

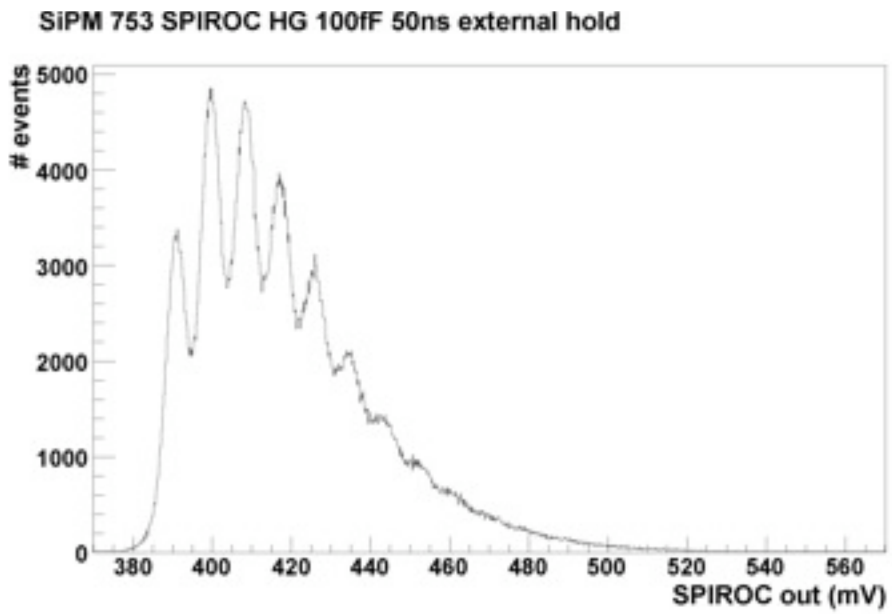
- Successful tests of HARDROC (Digital / Semi-Digital HCAL)



Trigger efficiency for a 100 fC signal as a function of threshold: Very homogeneous performance of all channels in a chip

- used in 1 m^2 beam test at CERN

- Same for SPIROC / SKIROC



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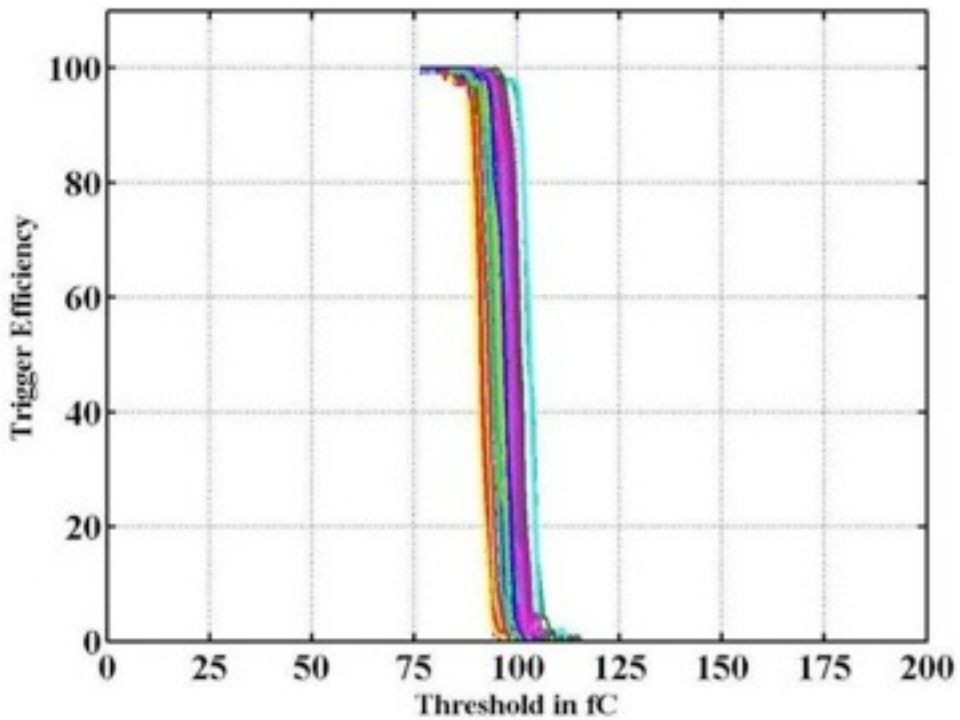

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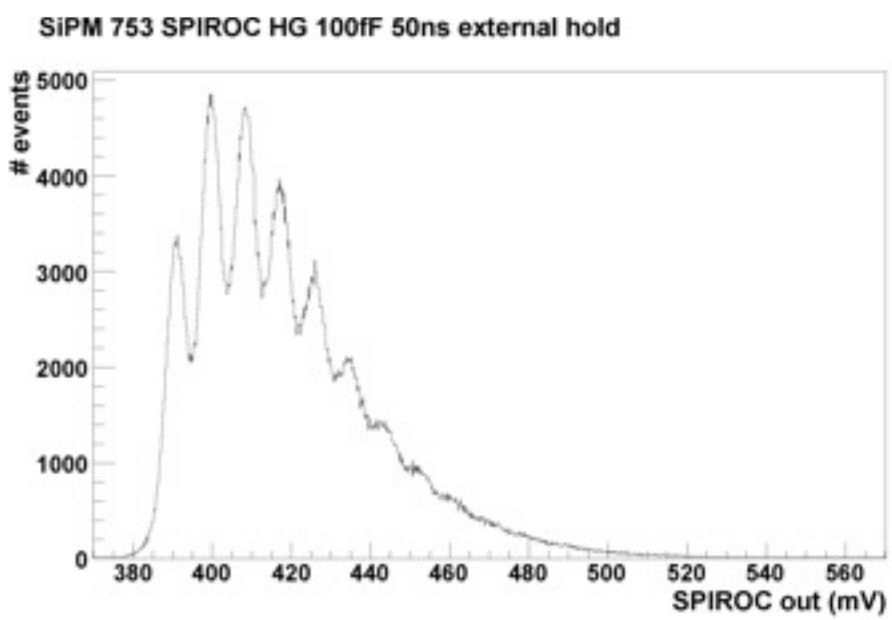
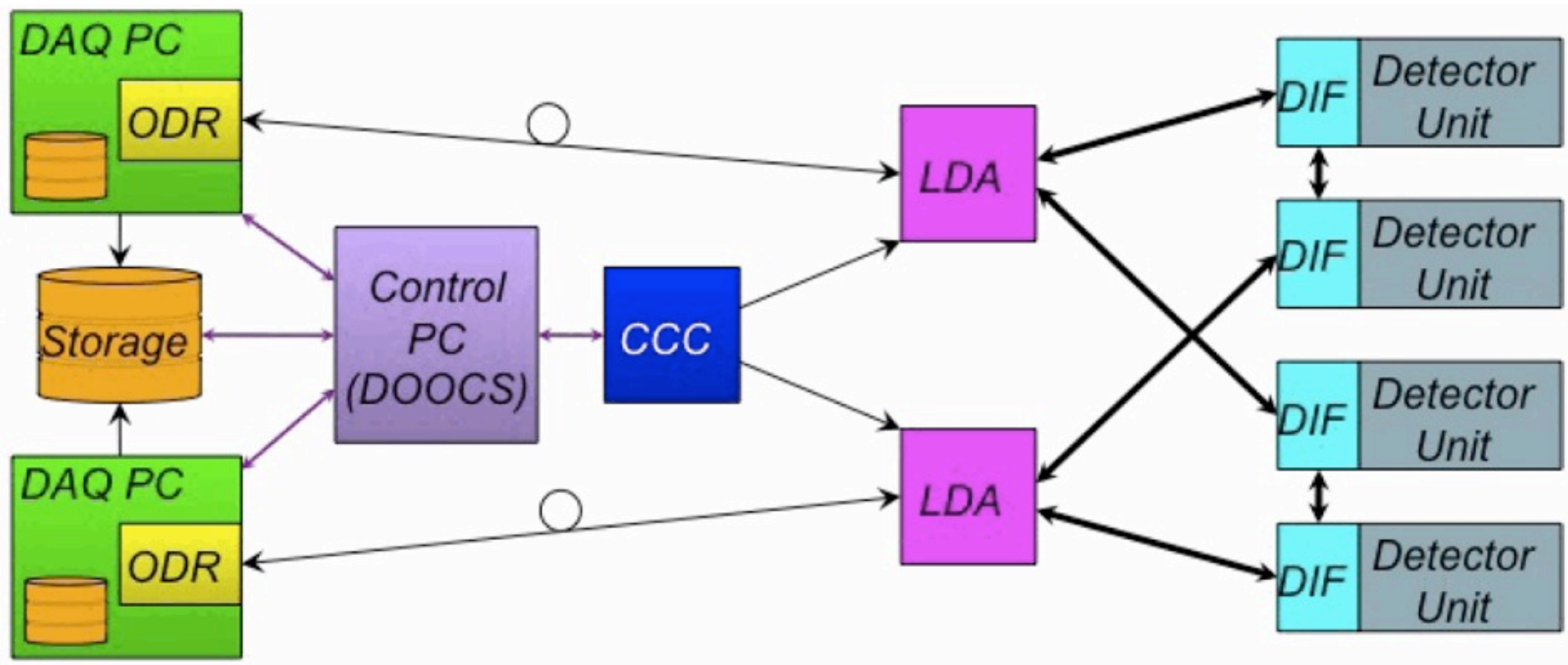


- Auto-trigger, analog storage, 12bit digitization and token-ring readout
- SiGe 0.35μm AMS BiCMOS technology
- Include power pulsing : <1 % duty cycle

Power Consumption:
HARDROC: 7 μW/Ch
SPIROC: 25 μW/Ch

2nd Generation Data Acquisition

- Designed to use commercially available components where possible
- Highly generic: Can incorporate a variety of different subsystems
  - CALICE is an ideal testbed: Different calorimeter technologies, small area tracking



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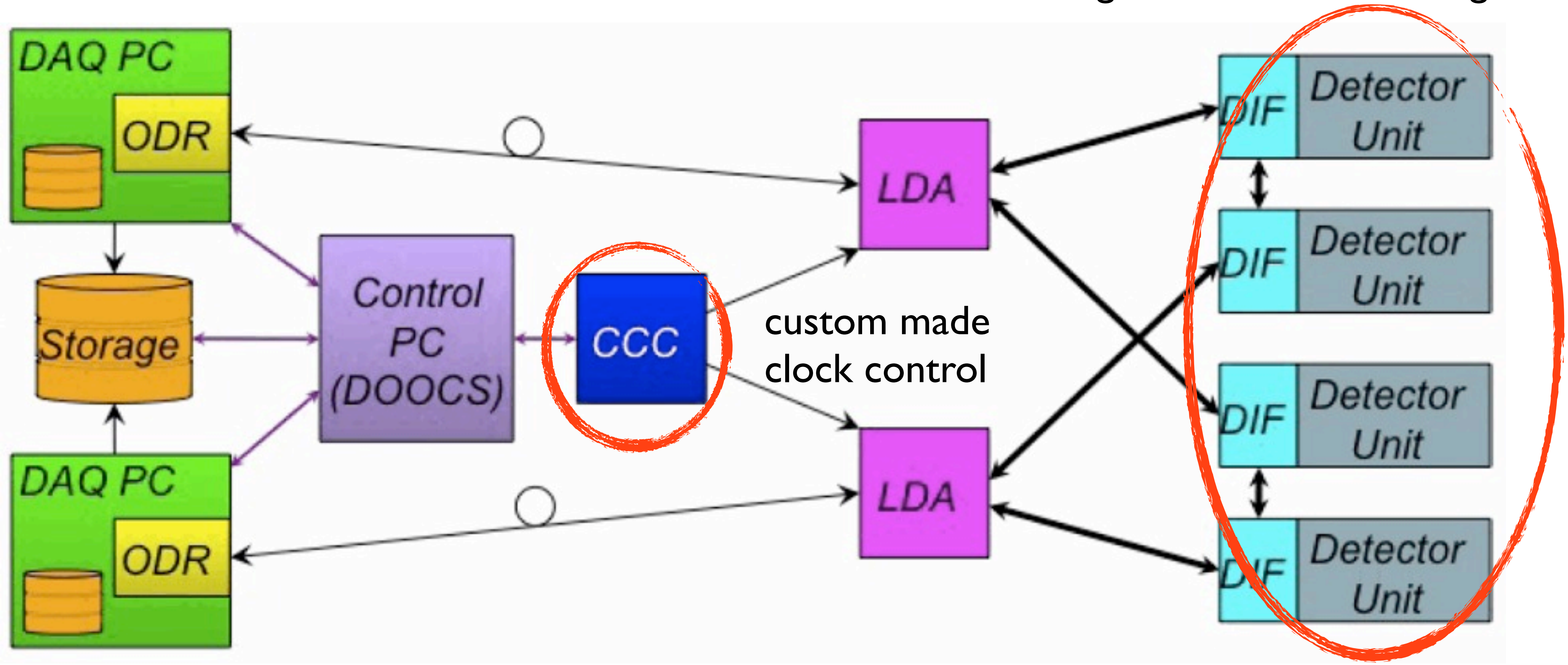

custom made clock control

commercially available components specialized firmware

custom made detector interface: detector specific

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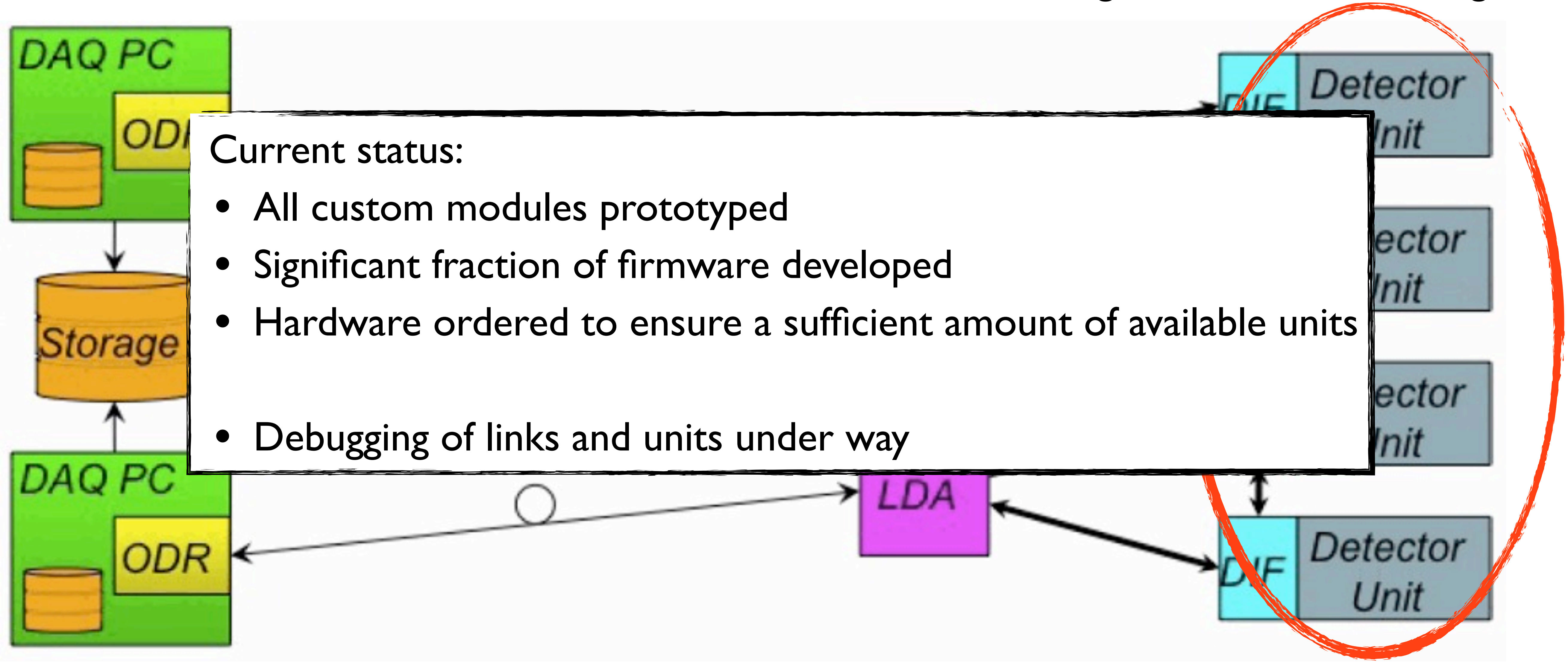

Current status:

- All custom modules prototyped
- Significant fraction of firmware developed
- Hardware ordered to ensure a sufficient amount of available units
- Debugging of links and units under way

commercially available components
specialized firmware

custom made detector
interface: detector specific

Test Beam Roadmap: First Generation

- Completion of the test beam program for the first generation prototypes
  - Digital HCAL with RPC readout: 2010 at FNAL (total of 14 weeks including setup) running with TCMT, potentially also with SiW ECAL (contingent on funding)
  - Digital HCAL with GEM readout: Replace a few RPC layers with GEMs in the prototype: 2011 at FNAL
    - Constraint: AHCAL movable stage has to leave US by 04/2011 for tax reasons
    - ▸ Possible continuation of tests at CERN
  - Analog HCAL with Tungsten absorbers: 2011 at CERN, with existing layers
  - Digital ECAL, test foreseen for 2012 at CERN

Test Beam Roadmap: Second Generation

- Program for the second generation prototypes
  - SiW ECAL:
    - First tests in electron beam with a single ASU expected in 2010
    - Tests of complete prototype in 2011, together with SDHCAL
  - SemiDigital HCAL with RPCs and / or MicroMegas:
    - 1 m^2 layers in 2010 at CERN
    - 1 m^3 physics prototype in 2011 at CERN
  - Analog HCAL
    - First module tests 2009 at DESY
    - Layer test (horizontal test) in 2010
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Special requirements on the time structure of the test beams!

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... and the schedule is contingent on the funding situation.

Conclusion & Request

- CALICE has successfully completed the first round of test beam campaigns at CERN and at Fermilab
  - A rich dataset has been collected, detailed studies of hadronic showers with the potential to constrain shower models are beginning

- A variety of different second generation prototypes are under preparation
  - Fully integrated electronics, power pulsing adapted to the ILC time structure
- A program is now ready to start testing these new prototypes

We ask the PRC for

- Endorsement of this program, in particular of the technological breadth
- Continued support by DESY:
  - for test beam campaigns at Fermilab and at CERN
  - mechanical and electronics engineering support
  - computing resources