CALICE Prototype Calorimeters
for linear collider detectors

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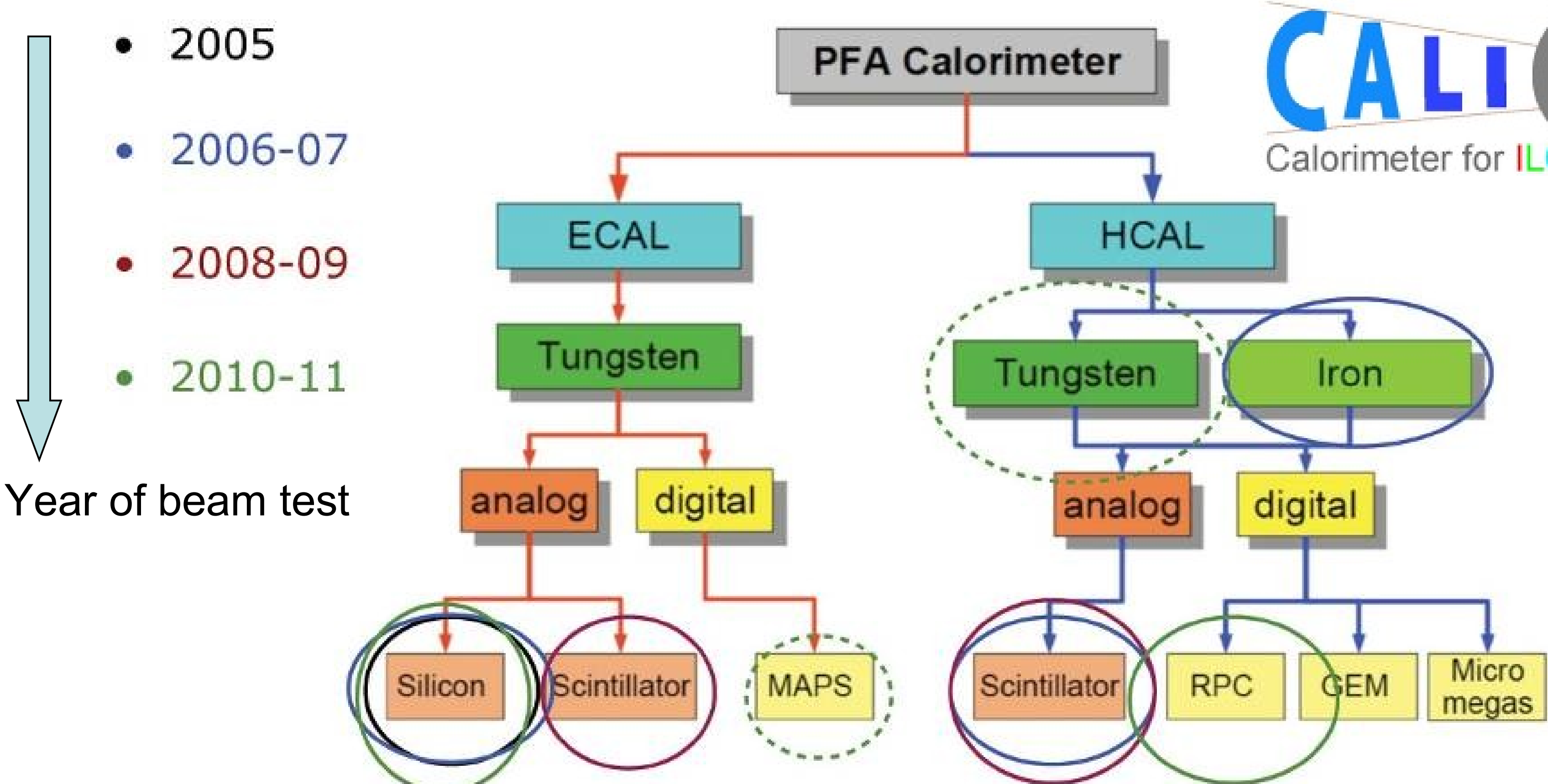
CALICE
Calorimeter for ILC

EPS - HEP2011, Grenoble

CALICE leads R&D effort for Imaging Calorimetry

- The next lepton collider detector will be optimized for Particle Flow Algorithms (PFA's)
  → calls for Imaging Calorimetry
- CALICE collaboration developed new concepts and technologies for such kind of devices
- Many 1st generation prototypes have been tested in beam



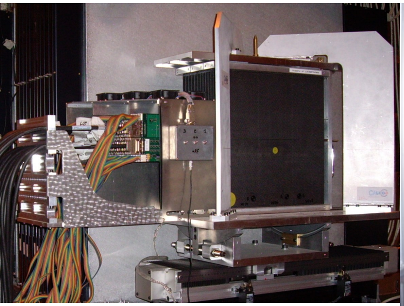
Readout cell size: 144 - 9 cm^2 → 4.5 cm^2 → 1 cm^2 → 0.25 cm^2 → 2.5×10^{-5} cm^2

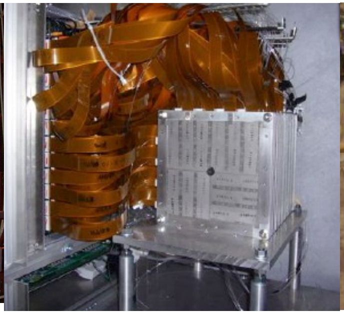
Technology: Scintillator + SiPM/MPPC | Scintillator + SiPM/MPPC | Gas detectors Silicon | Silicon | Silicon (MAPS)

CALICE 1^{st} generation calorimeter prototypes

- **These prototypes address 'proof of principle' for detector concept**
  - Some technical issues for a real detector are left out, to get physics results in early stage
- **The analog prototypes have successfully completed their test beam program**
  - Analog: measuring energy in each cell, with Silicon, or Scintillator+SiPM
  - The beam data produced excellent physics results, please see Misha's talk
- **The digital[1]/semi-digital[2] prototypes using gas detector as active medium are being tested now / will be tested soon**
  - Using gas detector for calorimetry is a NOT a new idea (L3, CDF, etc.)
  - Digital readout: count particles in shower → perfect match for gas detectors
  - Current status
    - RPC DHCAL: has been in test beam for ~ 1 year, data analysis started
    - RPC sDHCAL: started test beam this summer, 1^{st} physics data expected this fall
    - Micromegas, GEM based (s)DHCAL: preparing for test beam

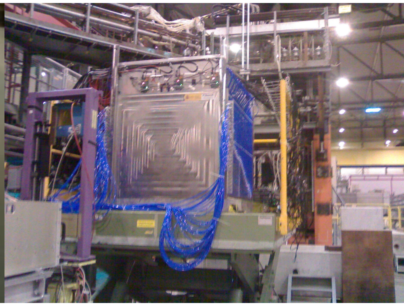
1: Digital readout: signal is compared to a single threshold → above threshold (hit) or below (no hit)
2: Semi-digital readout: signal is compared to a few thresholds, instead of 1 in digital readout


Si-W ECAL


Sci-W ECAL

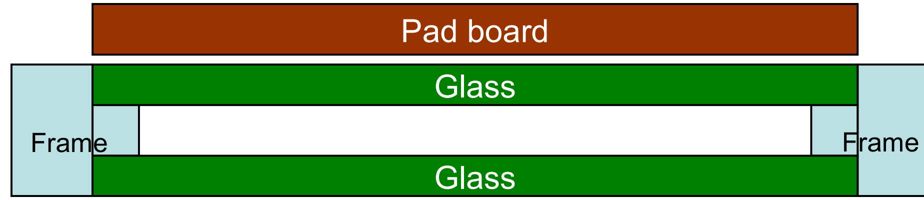

Sci-Fe AHCAL

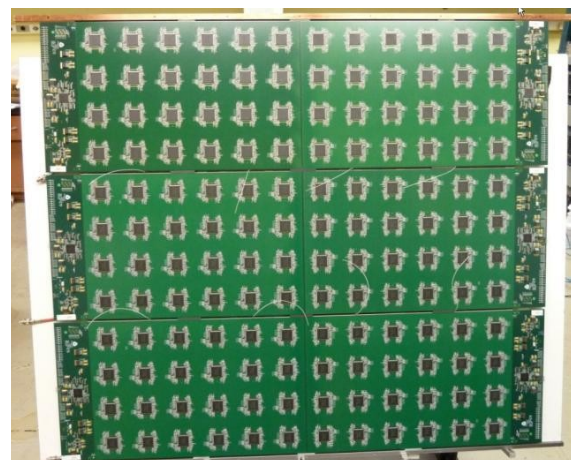

RPC-Fe DHCAL

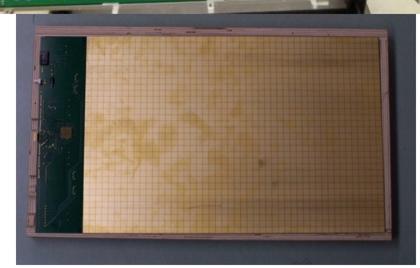

RPC-Fe SDHCAL

RPC DHCal prototype

- **Main features**
  - $1cm^2$ readout pads
  - Digital readout (1 threshold, yes or no)
  - $\sim 1m^2$ for each layer (cassette)
  - 52 (38 + 14) layers in total
  - ~2cm Fe absorber for each first 38 layers, thicker Fe absorber for last 14
  - Total CH. count: ~500,000
- **RPC's**
  - Glass electrodes
  - 32 x 96 cm^2 in size, readout by 2 FEB's
  - 3 RPC's for each layer/cassette
- **Readout system: very challenging**
  - Embedded FE readout (2nd gen. feature)
  - Signal ~100fC to ~1pC
  - Built around a 64-ch asic (DCAL)
  - FEB host 24 asic's + data concentrator
  - FEB & pad board glued together with conductive epoxy
  - 2 levels of data concentration (data concentrator[x24] + collector[x12])
  - VME readout at the end
  - Triggered & Trigger-less readout
- **Construction**
  - Started 2008, ended 2/2011
  - 1st beam test 10/2010

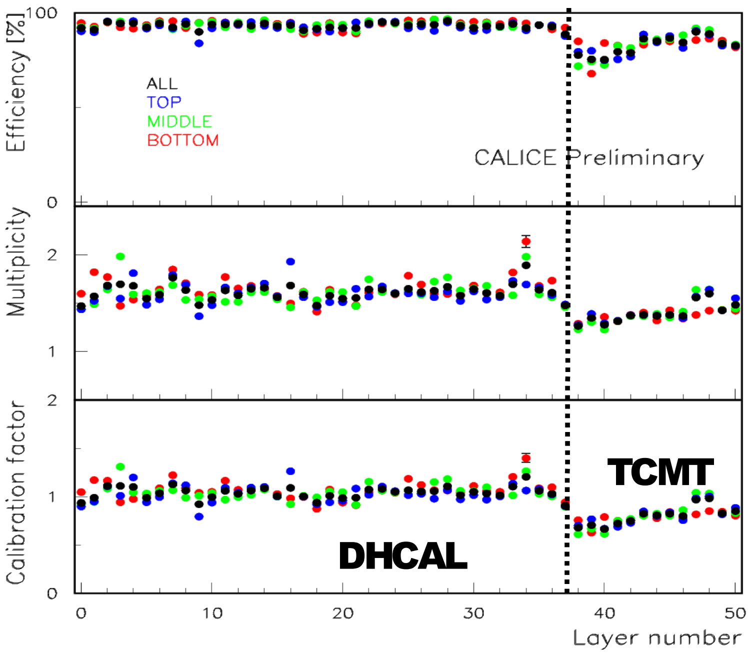






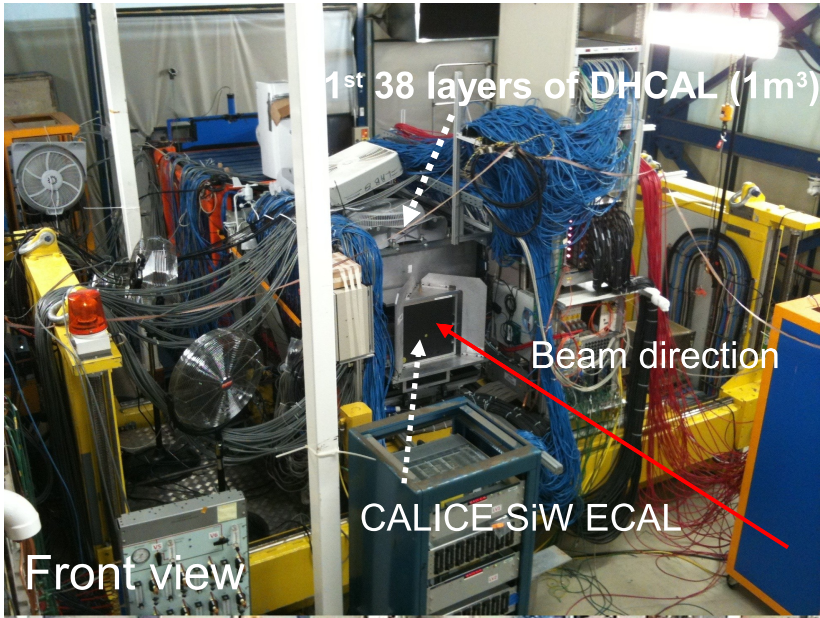
RPC DHCAL test beam at Fermilab

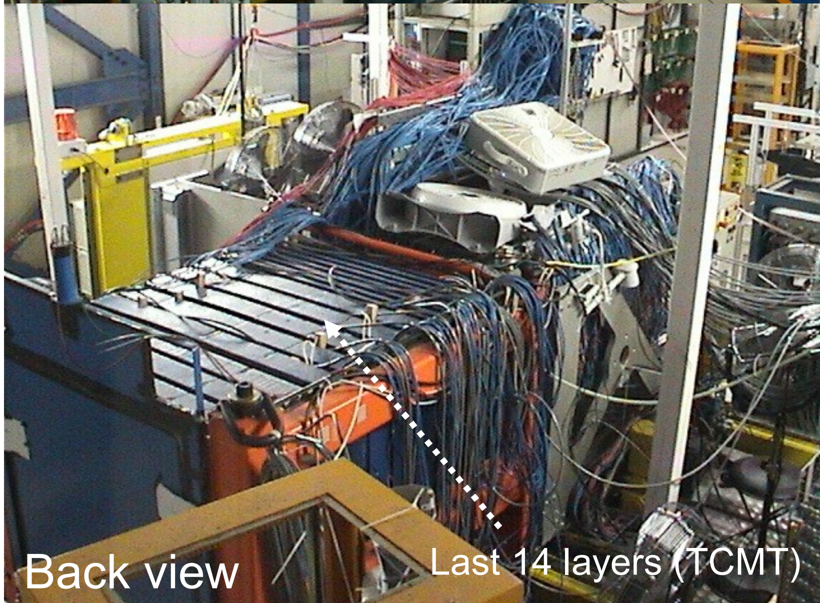
- **Had 4 test beam runs so far**
  - 10/2010: 38 layers
  - 2/2011: completed 38 + 14 during run
  - 4/2011: SiW ECAL + RPC DHCAL
  - 6/2011: RPC DHCAL alone
  - More test beam in 2011 - 2013
- **Both RPC's and readout system worked amazingly well**



Tail catcher (TCMT) is cooler
→ lower efficiency, multiplicity

DHCAL: first 38 layers with 2cm absorbers
TCMT: last 14 layers with thicker absorbers





RPC DHCAL: 1st look at data

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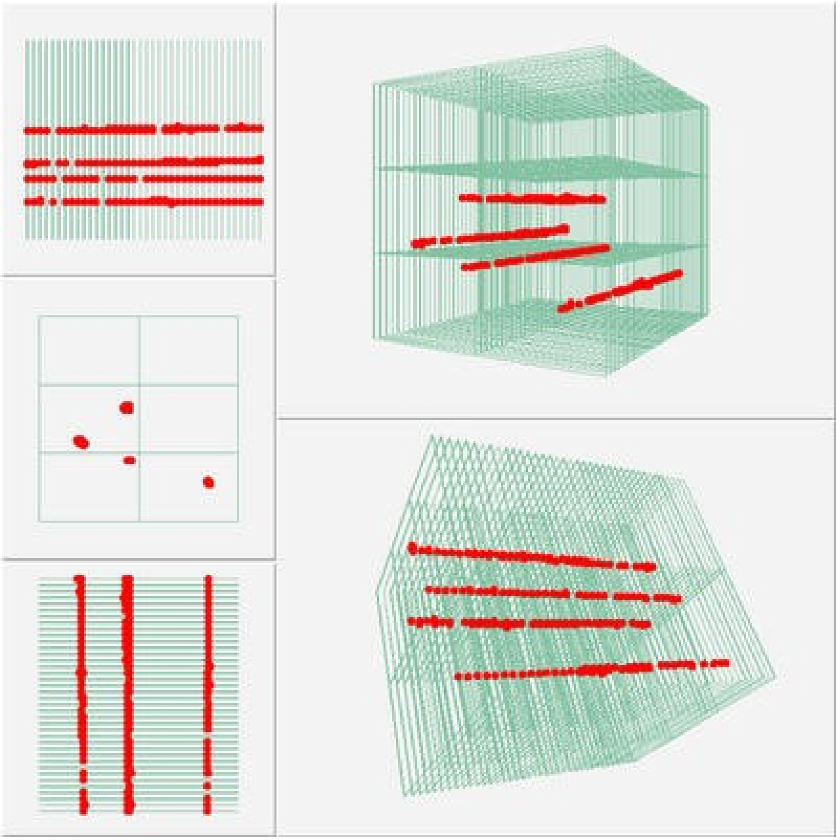
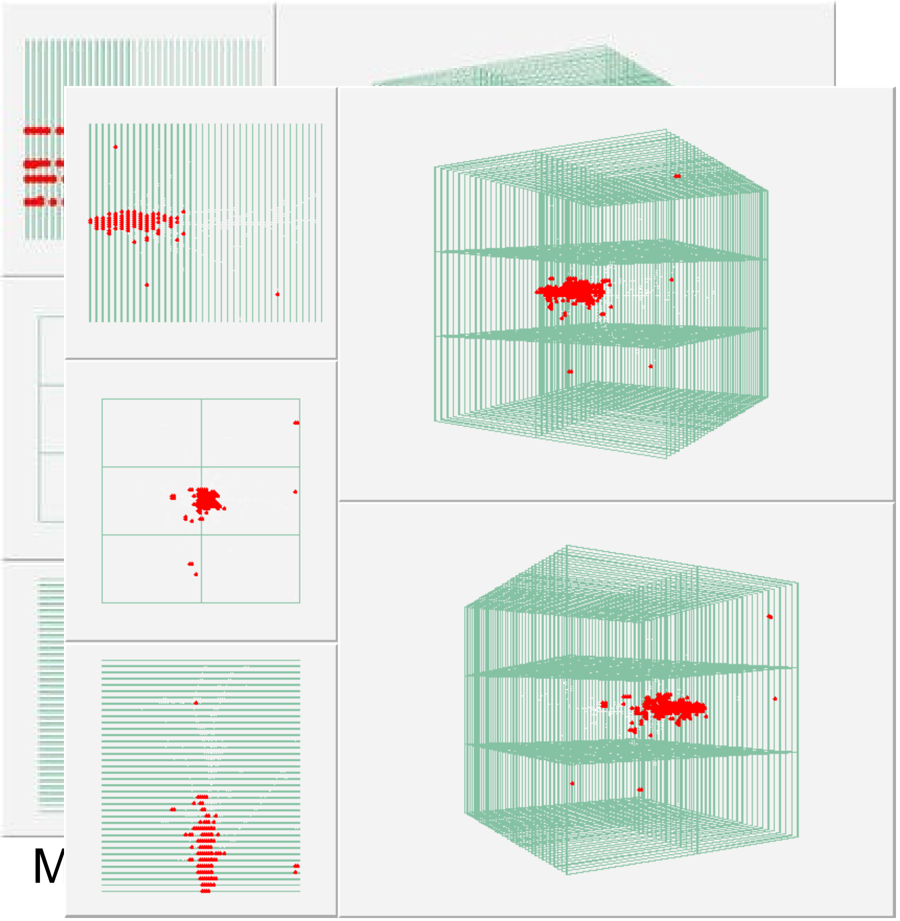


Muons

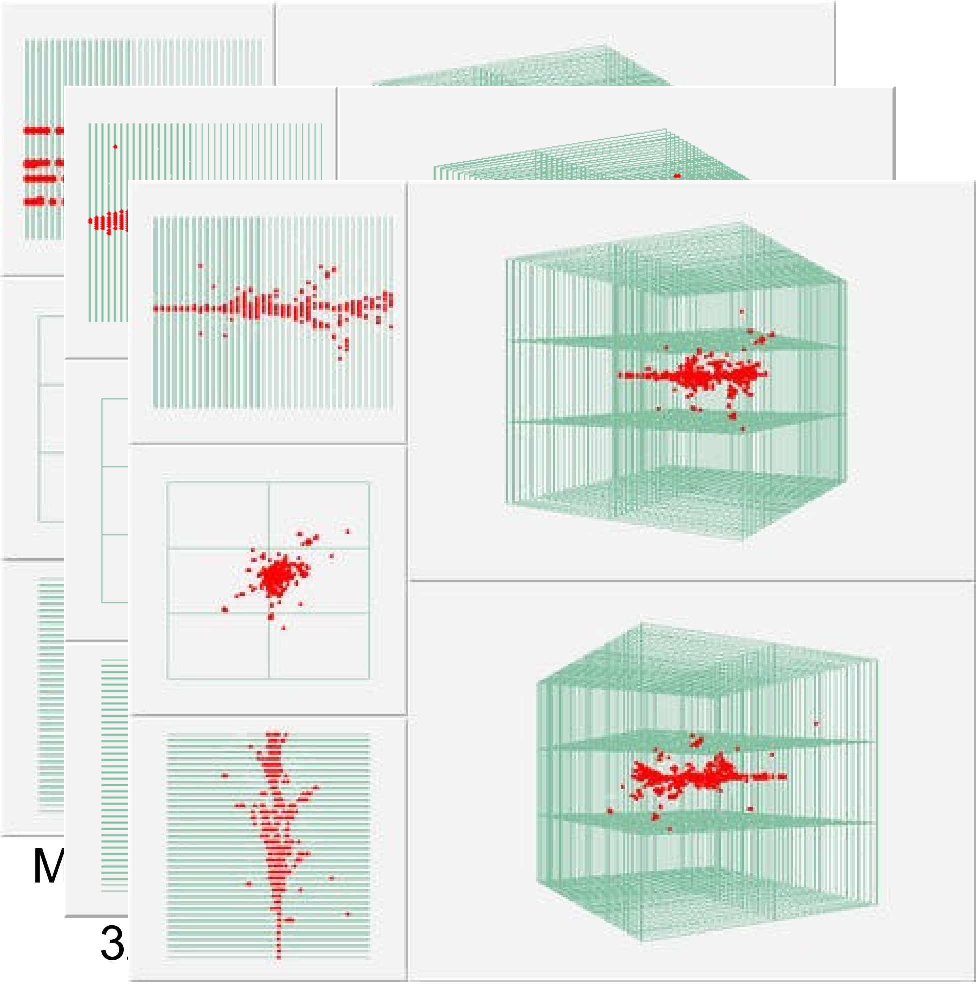
RPC DHCAL: 1st look at data



M

32 GeV Positron

RPC DHCAL: 1st look at data



32 GeV Pion

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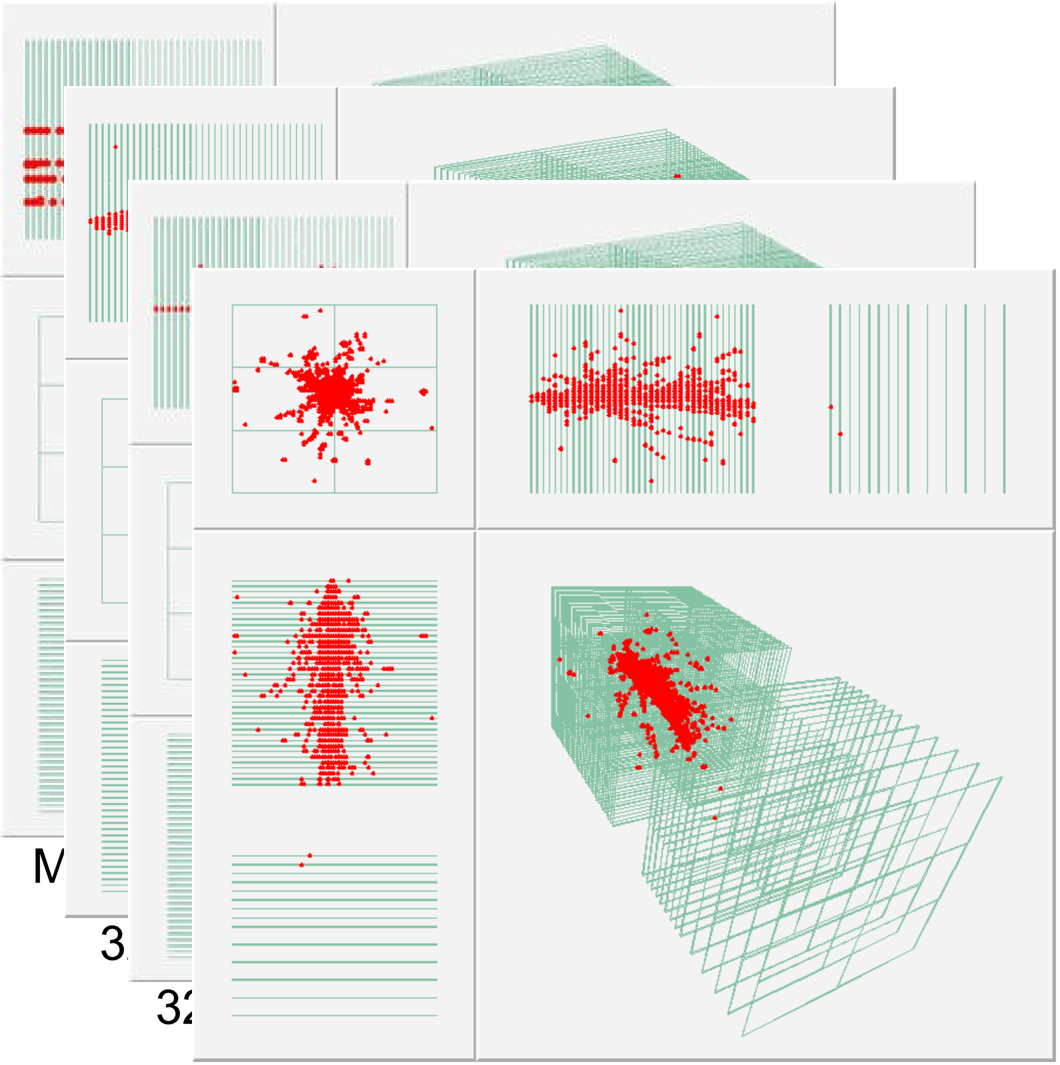
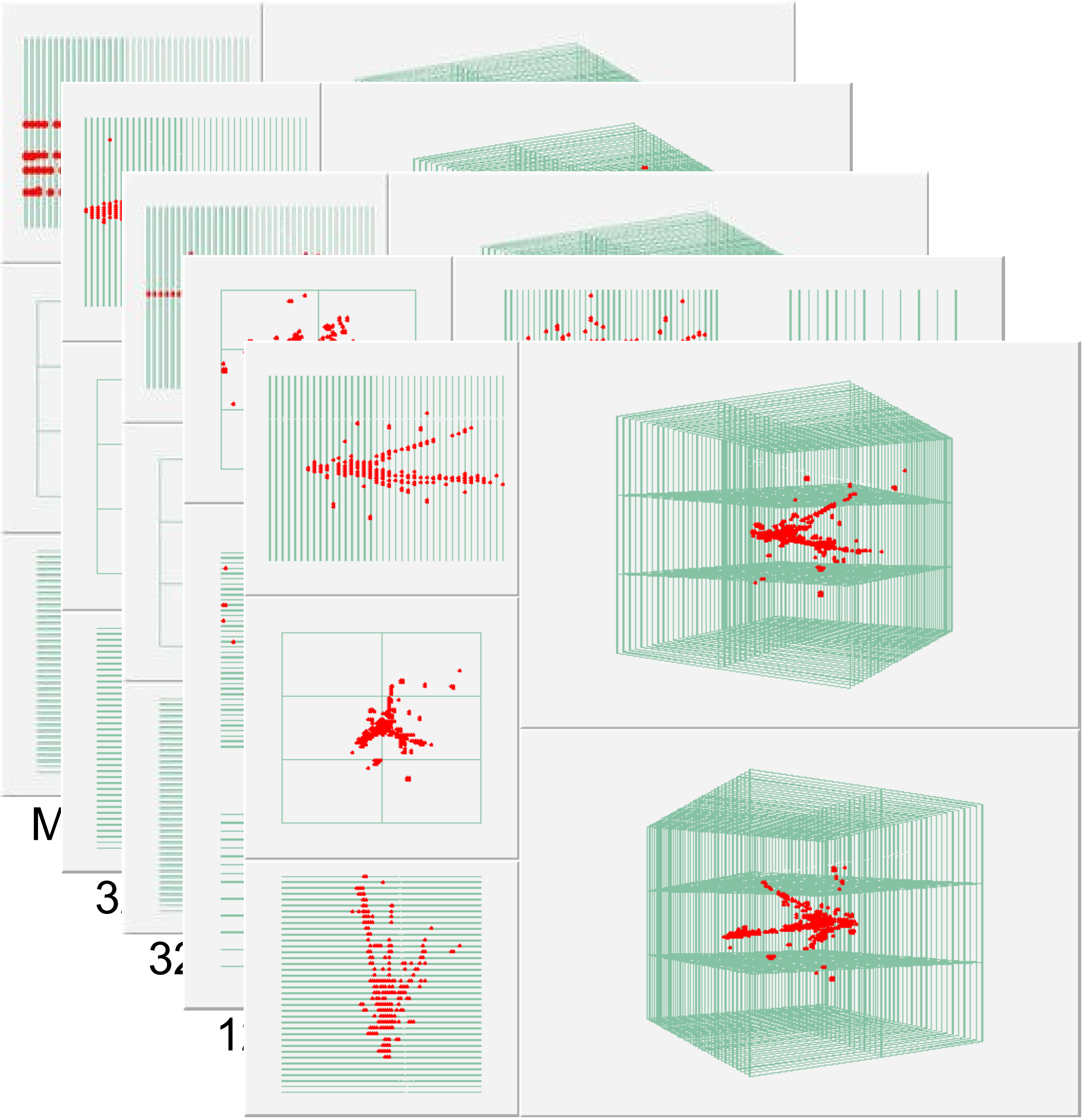


120 GeV Proton ~1400 hits!

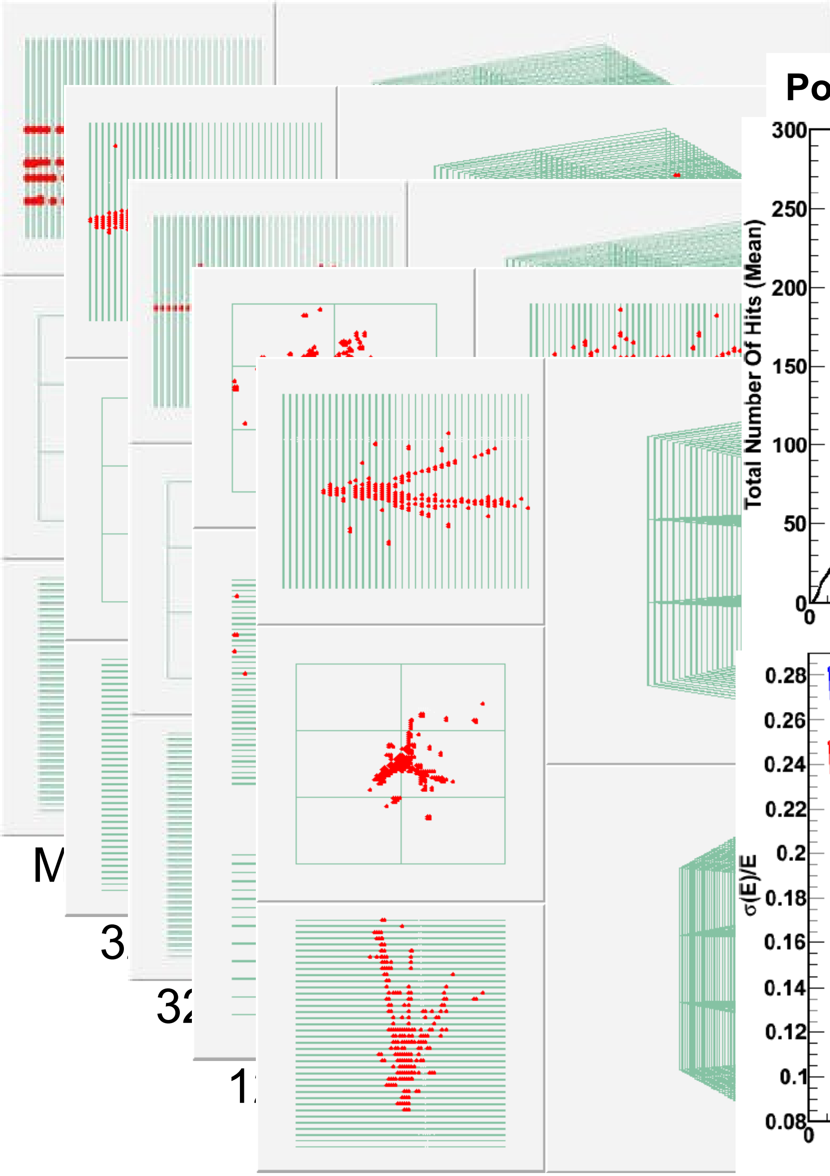
RPC DHCAL: 1st look at data



Neutral hadron!

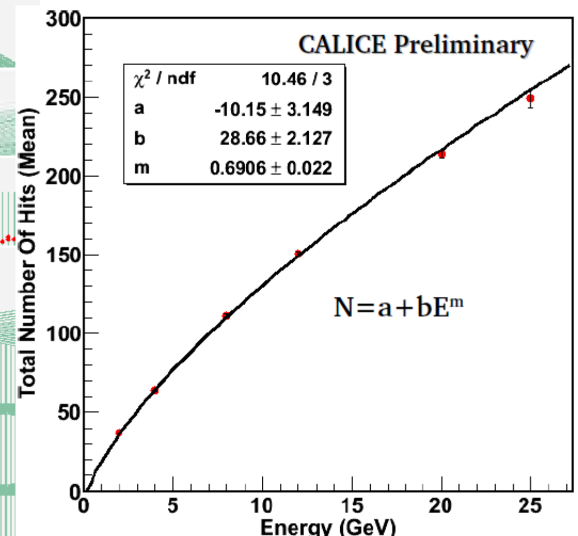
RPC DHCAL: 1st look at data

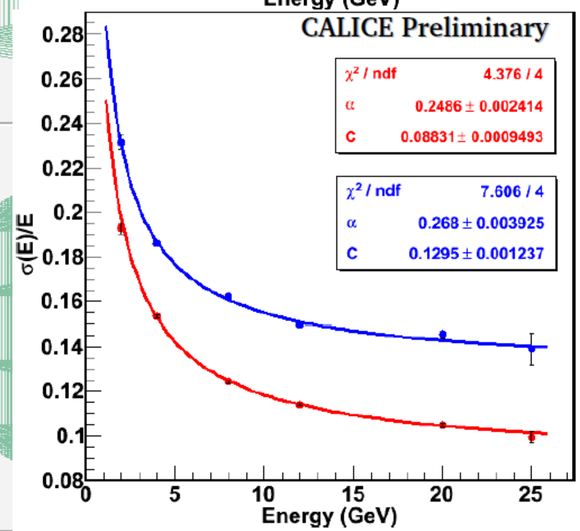
Preliminary results: no calibration yet!



Neutral hadron!

Positron response/resolution



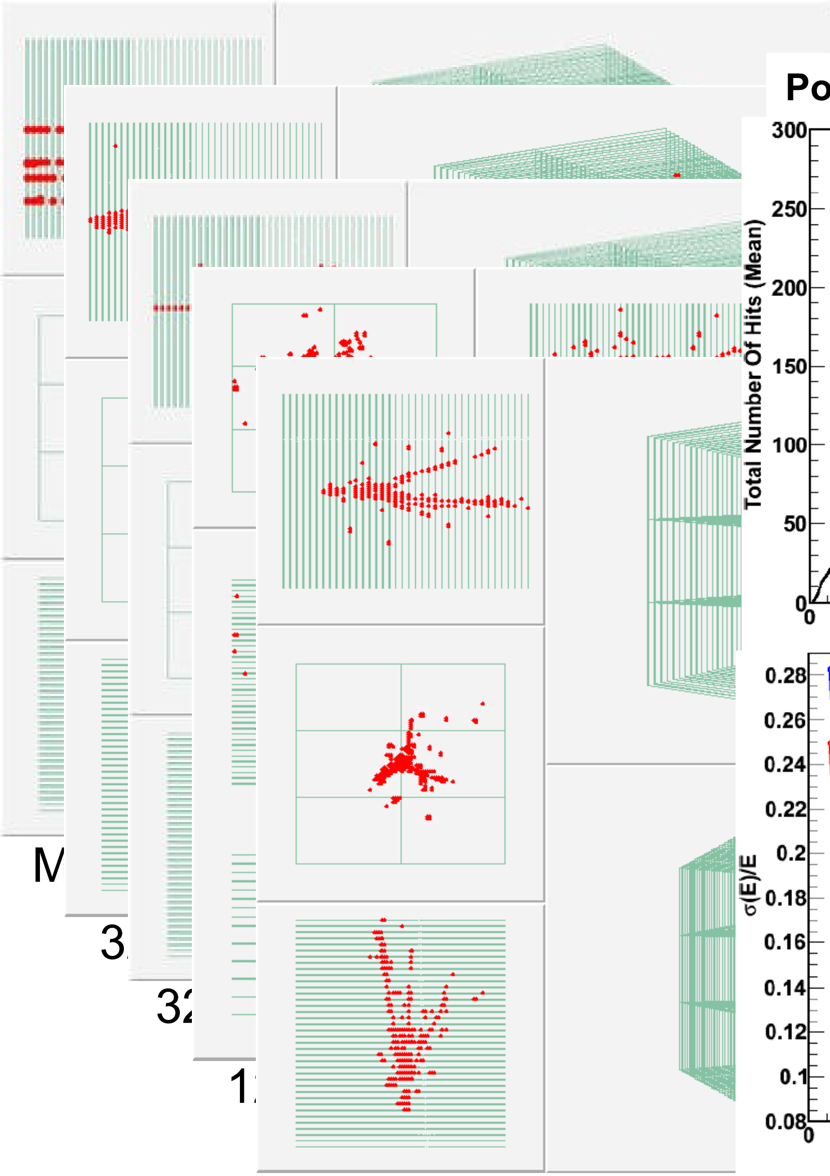


Uncorrected for non-linearity

Corrected for non-linearity

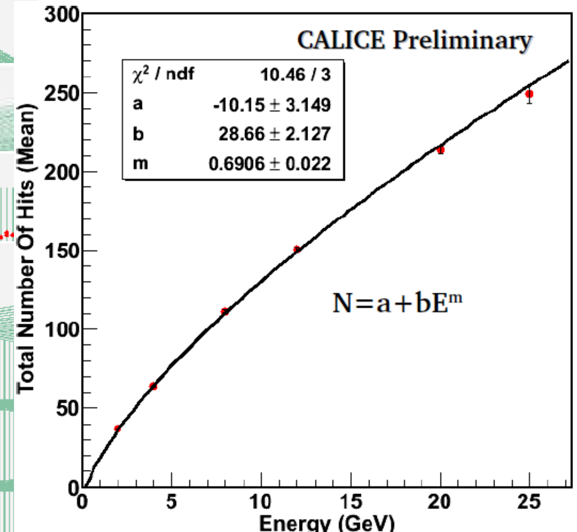
RPC DHCAL: 1st look at data

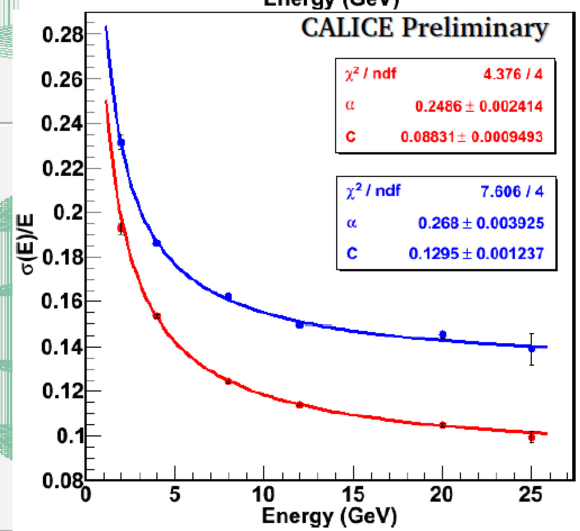
Preliminary results: no calibration yet!



Neutral hadron!

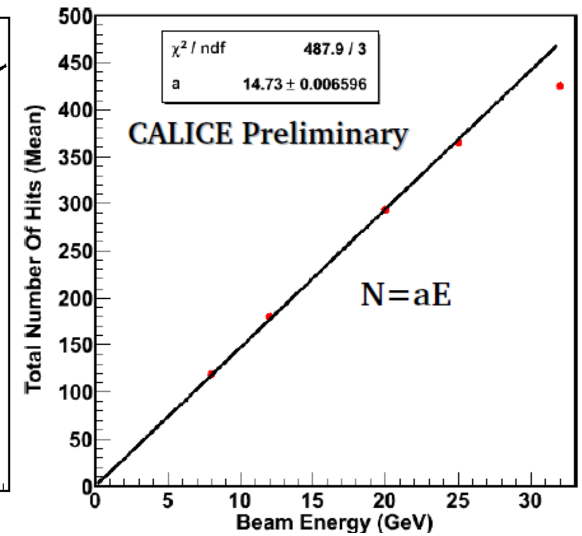
Positron response/resolution

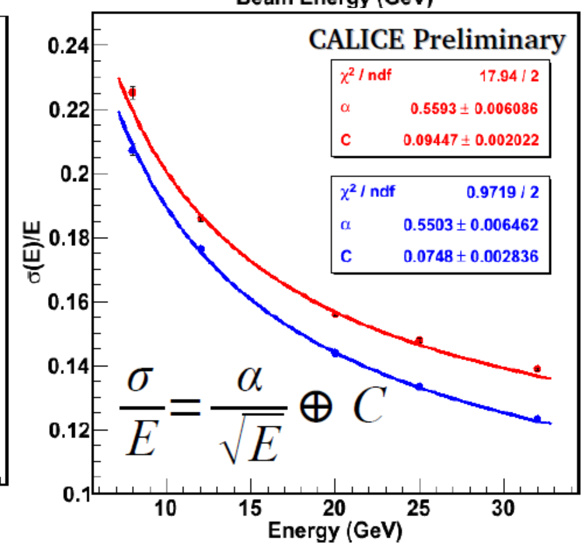




Uncorrected for non-linearity
Corrected for non-linearity

Pion response/resolution





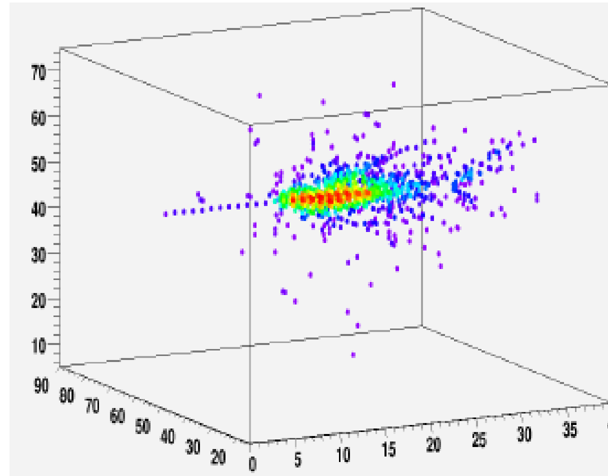
$$\frac{\sigma}{E} = \frac{\alpha}{\sqrt{E}} \oplus C$$

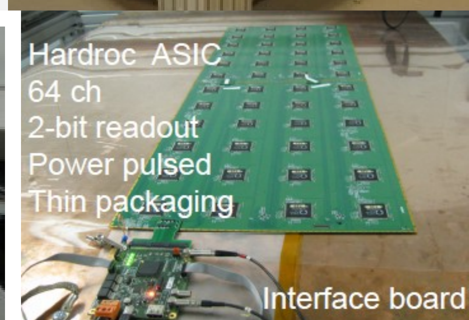
Standard pion selection
+ No hits in last two layers

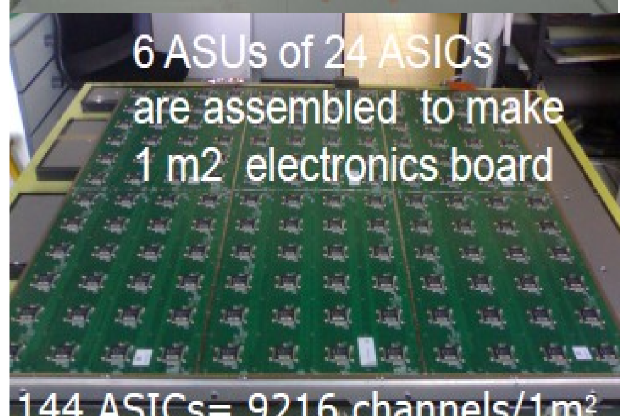
RPC semi-DHCAL prototype

- **Semi-digital approach**
  - 2-bit / 3-threshold readout to improve particle counting
    - Thresholds at 0.2, 5, 10 MIP
    - Distinguishing 0, 1, several and a lot of particle on one pad
  - Have the potential to improve
    - Linearity
    - Energy resolution at high E
- **Main features**
  - 1cm² pad / 1m² cassette
  - 1m² RPC's
  - 2-bit, embedded readout
  - FE asic power pulsed
  - 2 FEB chained together and readout from one side
  - Thin active element (~6mm)
  - Self-supporting structure
- Construction status
  - Finished ~40 layers by 6/2011
  - First beam run 6-7/2011
  - Next beam run 9-10/2011

Red: 2nd generation features

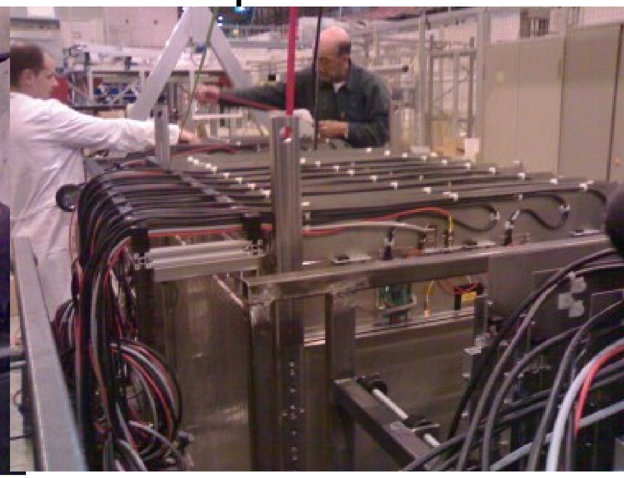


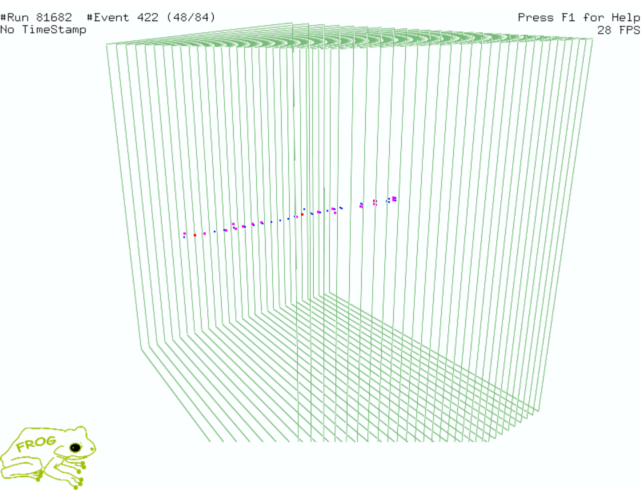


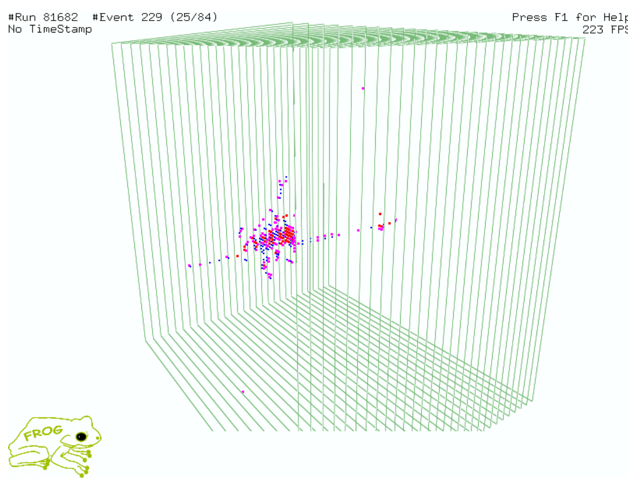


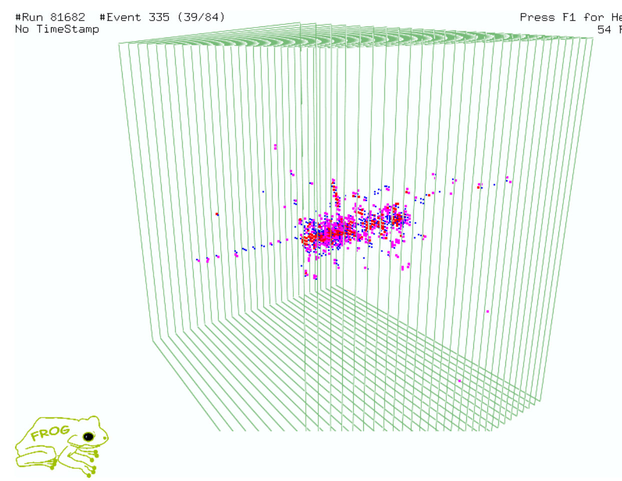
RPC semi-DHCAL test beam at CERN

- The prototype successfully assembled at CERN
- Tested front end readout and detector behavior with beam
- More beam test / physics run expected in 9-10/2011

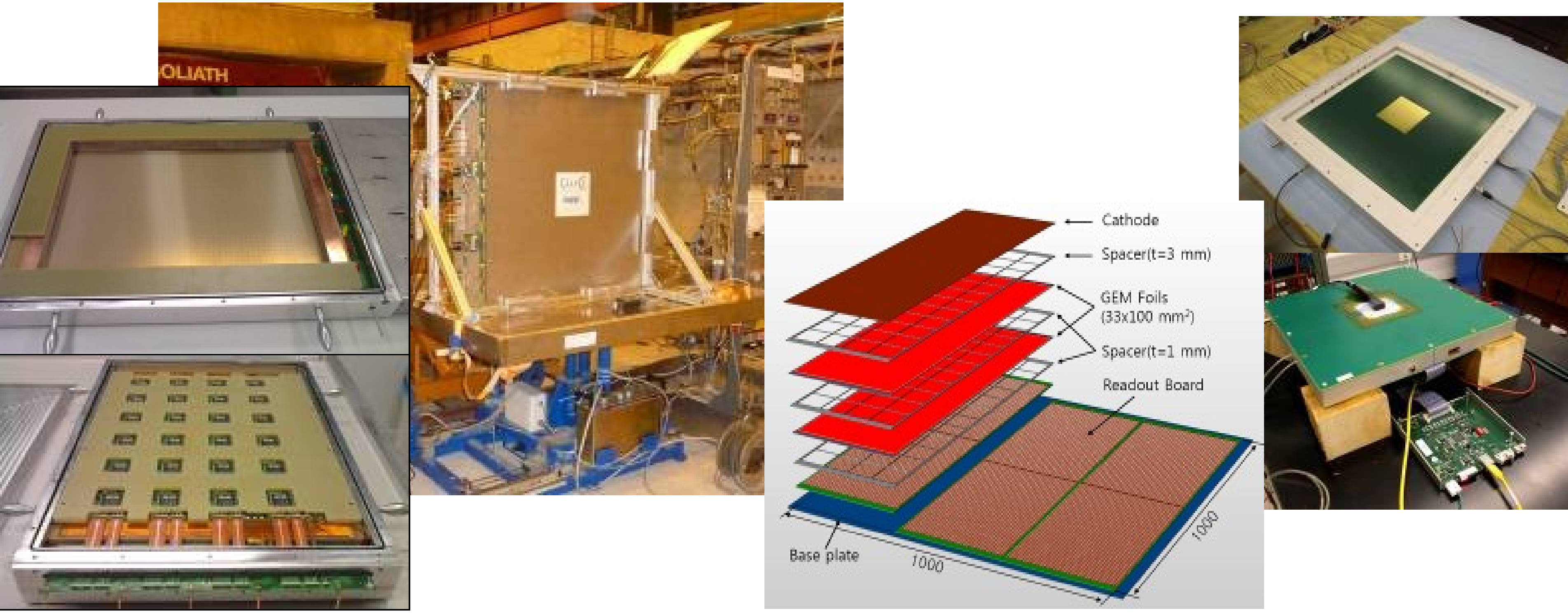









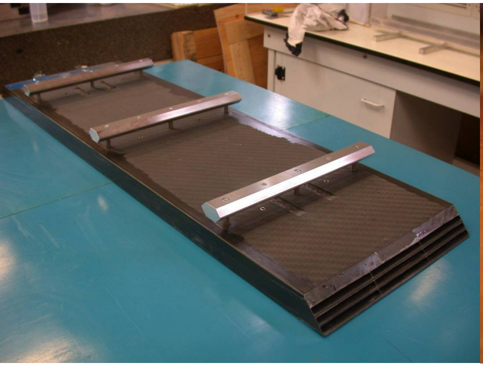
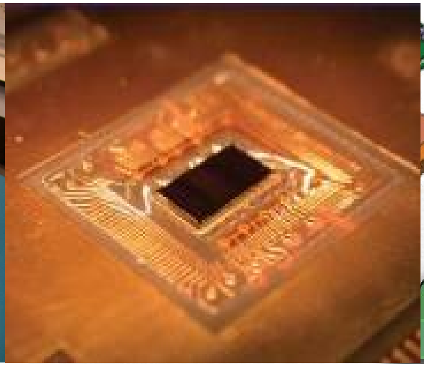
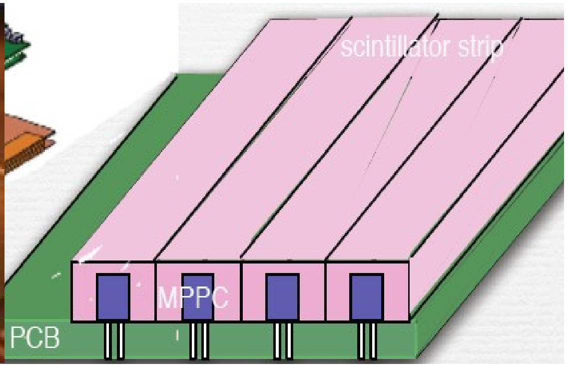
Micromegas and GEM (s)DHCAL prototypes

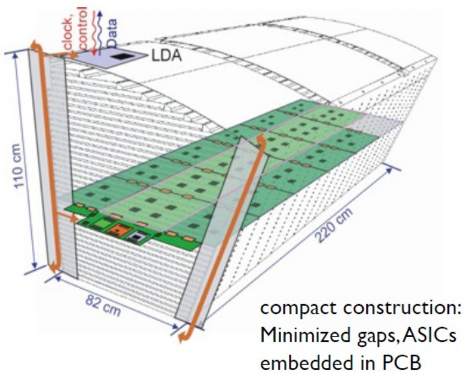


- **CALICE collaboration is also developing (s)DHCAL with Micromegas and GEM detectors**
  - Both detectors can handle very high rate
  - Prototype layers has been constructed / expected (1cm^2 pad, 1m^2 layer)
  - Beam test of prototype layer is done / expected

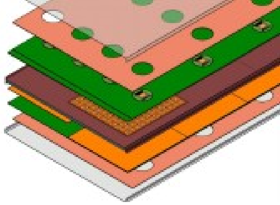
Calice 2nd generation calorimeter prototype

- **These prototypes address all issues in building a 'real detector'**
  - **Embedded** readout
  - Embedded calibration system
  - **Power reduction** / heat dissipation / cooling
  - Cables / connections / service / supplies
  - **Realistic geometry:** compact, with minimum dead space
  - Self-support mechanical structure
  - Industrialize detector building when possible
- **Several such prototypes are being developed/constructed, or planned**

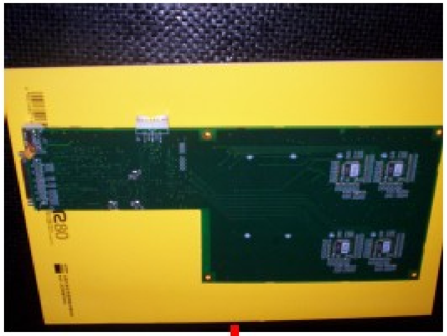


compact construction:
Minimized gaps, ASICs
embedded in PCB

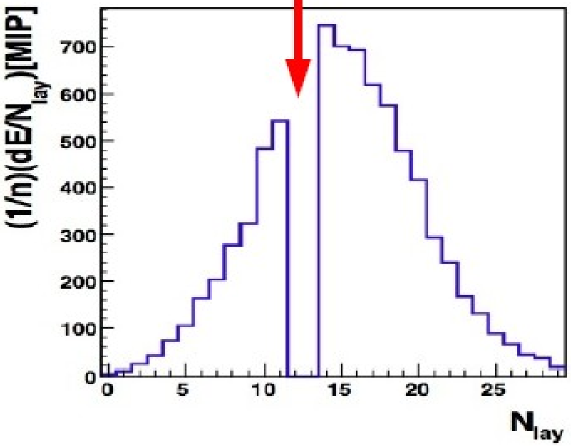


Embedded electronics – parasitic effects?

Exposure of front end electronics to electromagnetic showers

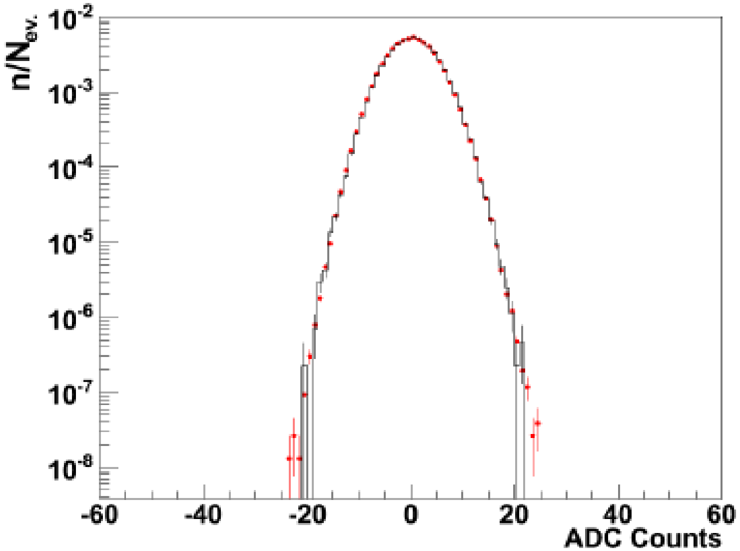


Chips placed in shower maximum of 70-90 GeV elm. showers



Possible Effects: Transient effects
Single event upsets

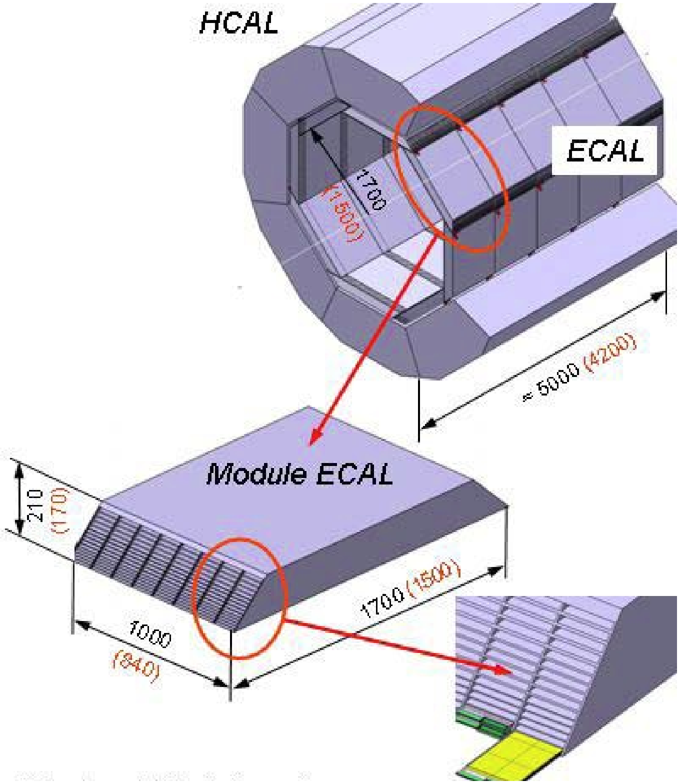
Comparison: Beam events
(Interleaved) Pedestal events

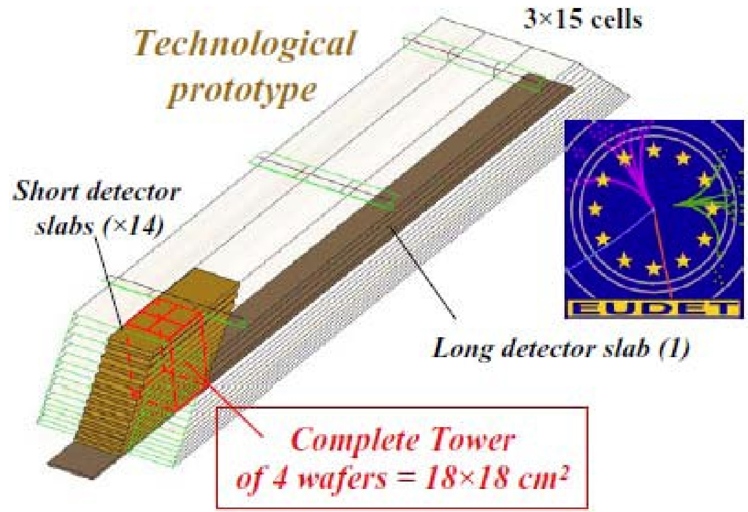


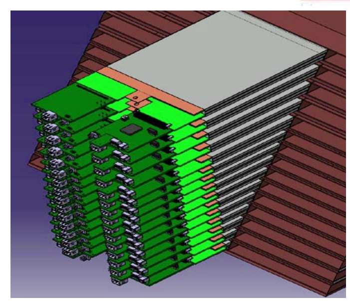
- No sizable influence on noise spectra by beam exposure
  ΔMean < 0.01% of MIP ΔRMS < 0.01% of MIP
- No hit above 1 MIP observed
  => Upper Limit on rate of faked MIPs: ~7×10^{-7}

Also RPC/DHCAL test beam: embedded electronics subjected to EM/hadronic showers
no 'side effect' ever seen

Si-W ECAL 2nd gen. prototype

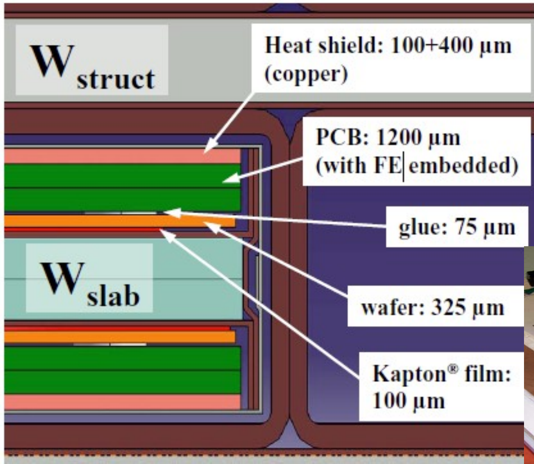


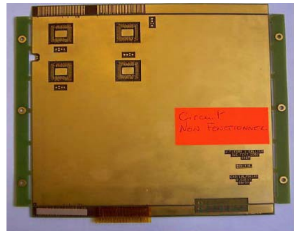


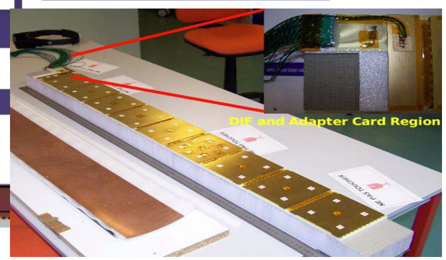


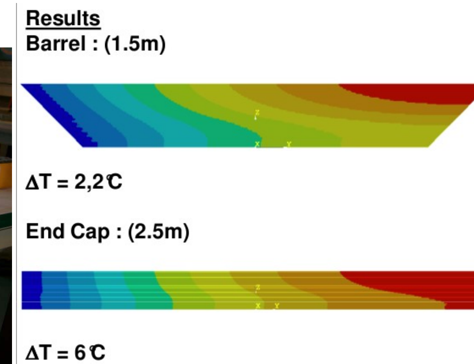
- ~2/3 of final module size (partially instrumented, 18 x 18 cm^2 tower)
- 9x9 cm^2 sensors, with 0.5 x 0.5 cm^2 cell size (factor of 4 smaller than 1st gen.)
- FE power pulsed (0.25 µw / ch), FE readout embedded
- FEB's chained together, extremely compact design
- Realistic cooling scheme (leak less water cooling)

Some of the challenges







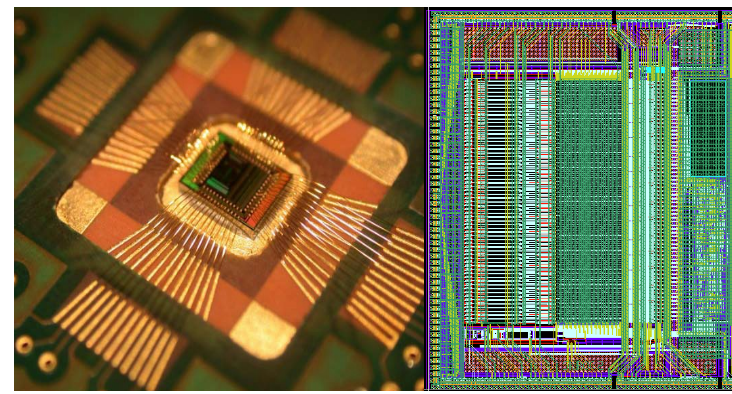


Thermal simulation

Leak less water cooling

Detector slab

- Compact assembly of 2 layers of 1 to 8 ASU's + W core
  - ASU = 1 Kapton cable + Si wafer + PCB + thermal drain (copper)
- PCB is critical: 1mm thick, 8 layers
  - 1% flatness
  - chips bounded into the board



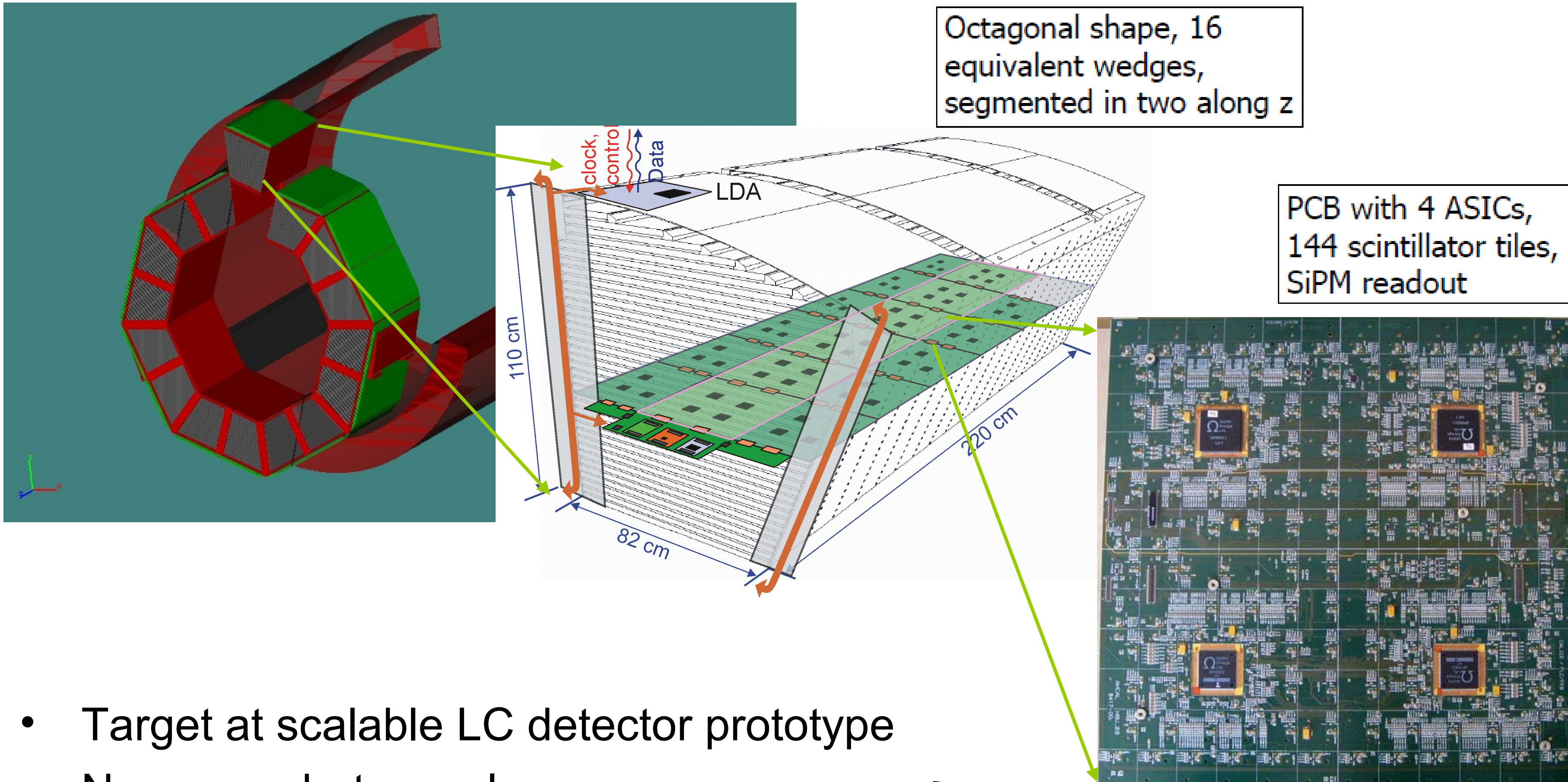
SKIROC chip

(Silicon Kalorimeter Integrated ReadOut Chip)

- Technology: SiGe 0.35 µm AMS
- 64-ch, variable gain charge amp
- 12-bit ADC, digital logic
- Power pulsed → 25 µw / ch

- Smaller cells: 5 x 5 mm²
- 325 µm thick
- Improved guard ring
- working with industry to understand and reduce cost

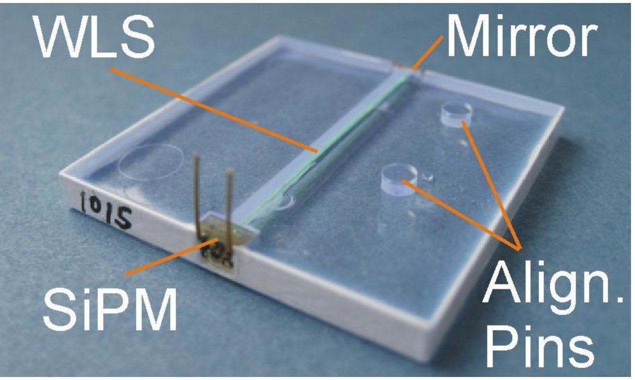
Scintillator AHCAL 2nd generation prototype

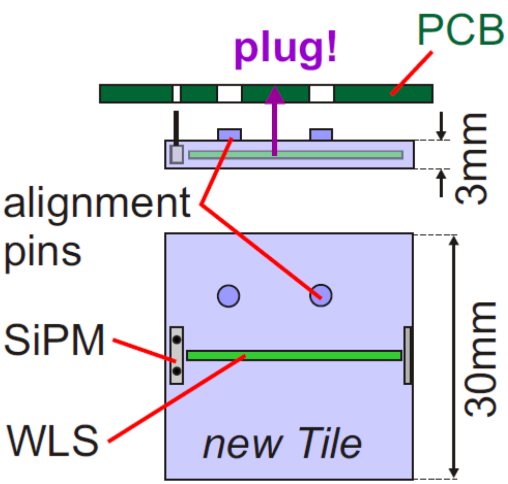


- Target at scalable LC detector prototype
- No spacer between layers
- Minimize dead space between wedges
- Minimize gap between barrel and endcap

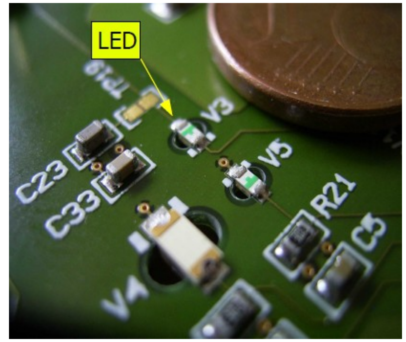
} Integrated readout electronics

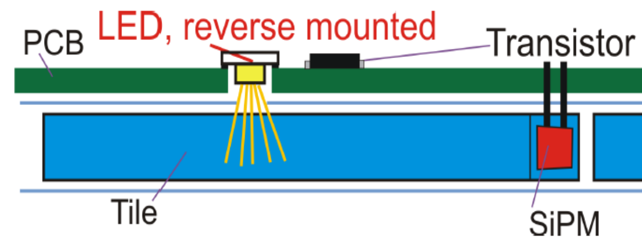
Some of the challenges





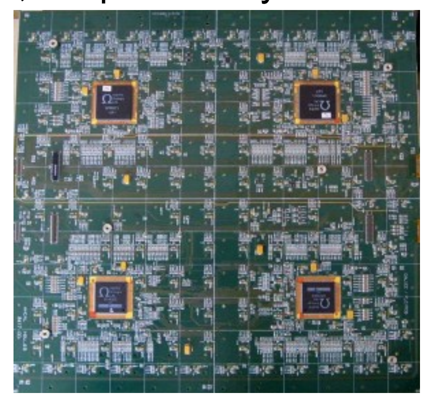
- Active elements are scintillator tiles of 3 x 3 x 0.3 cm^3
- Wavelength shifting fiber embedded into tile, and coupled to SiPM
- Tiles plugged into PCB with ‘lego’ like pins: nominal tile distance 100μm





Embedded LED calibration system

- Provide Gain / saturation calibration for SiPM
- LED mounted on PCB, couple directly to tile



SPIROC2: specific chip for SiPM readout

- Input DAC for channel-wise bias adjustment (36-ch)
- Power pulsing → 25 μw / ch
- (Auto) dual-gain setup per channel
- Auto-trigger mode
- Timestamp (300ns ramp, 12-bit TDC)
- PCB hosts 4 asics (144 ch), 6 PCB’s are chained together in a row

Summary

- Imaging calorimeter is a key ingredient of a detector system optimized for PFA

- CALICE collaboration devoted the last ~10 years into the R&D and developed 2 generations of prototypes
  - The 1st generations provide ‘proof of principle’
    - SiW, SciW ECal and Sci AHCAL achieved the goal
    - Gaseous DHCAL, sDHCAL are almost there
  - The 2nd generations provide scalable prototypes for a real detector system
    - Several prototypes are being developed / planned