The Detector at the CEPC: Calorimeters

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（on behalf of the CEPC-SppC Study Group）

IHEP, Beijing, March 11, 2015

Outline

- Introduction
- Calorimeters
  - ECAL with Silicon and Tungsten
  - ECAL with Scintillator and Tungsten
  - HCAL with RPC and Stainless Steel
  - HCAL with Thick GEM and Stainless Steel
- Future R&D Plan
- Summary

Requirements for CEPC Detector Design

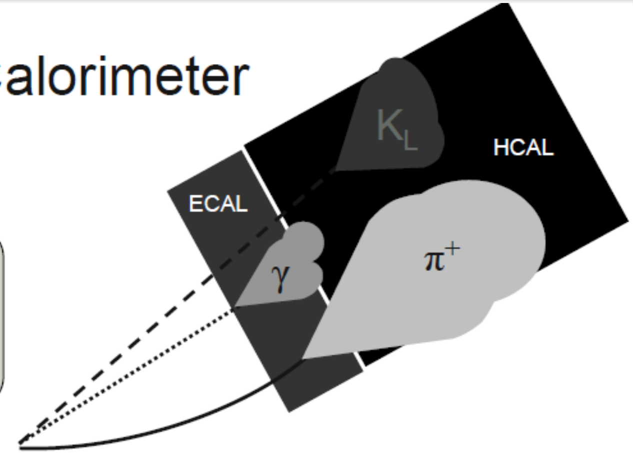
Critical Physics Benchmarks for CEPC Detectors design.

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$BR(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$BR(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu m$
$H \to q\bar{q},\ V^+V^-$	$BR(H \to q\bar{q},\ V^+V^-)$	ECAL, HCAL	$\sigma_E^{jet}/E \sim 3-4\%$
$H \to \gamma\gamma$	$BR(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

Goal: Jet Energy Resolution 3 – 4 % or 30% / √E @ 100GeV

PFA and Imaging Calorimeter

Particle Flow Algorithms and Imaging Calorimeter



The idea…

Charged particles	measured with the	**Tracker**
Neutral particles	measured with the	**Calorimeter**

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/$\sqrt{E}$	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/$\sqrt{E}$	$0.16^2\ E_{jet}$
Confusion	Required for 30%/$\sqrt{E}$		$\leq 0.24^2\ E_{jet}$

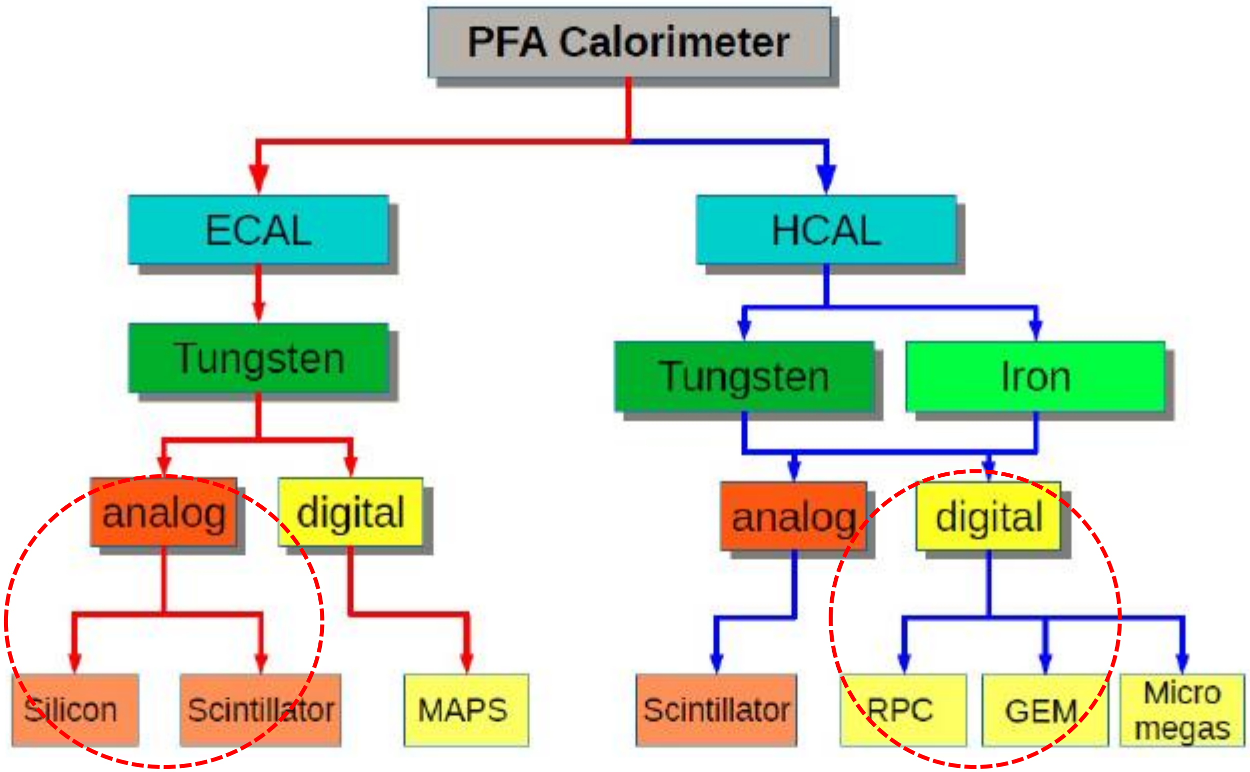
(Charged + Photons + Neutral Hadrons: 18%/$\sqrt{E}$)

Requirements for detector system

→ Need excellent tracker and high B – field
→ Large R_I of calorimeter
→ Calorimeter inside coil
→ Calorimeter as dense as possible (short X_0, λ_I)
(Calorimeter inside coil; Calorimeter as dense as possible: **thin active medium**)
→ Calorimeter with **extremely fine segmentation**

Global R&D of Imaging Calorimeters

https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers



Absorber :

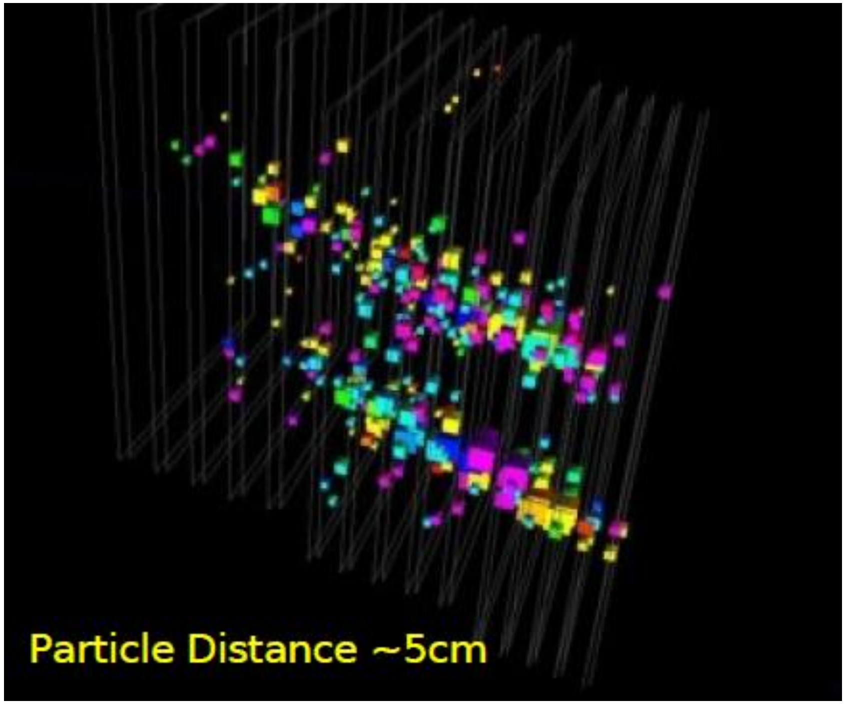
Readout:

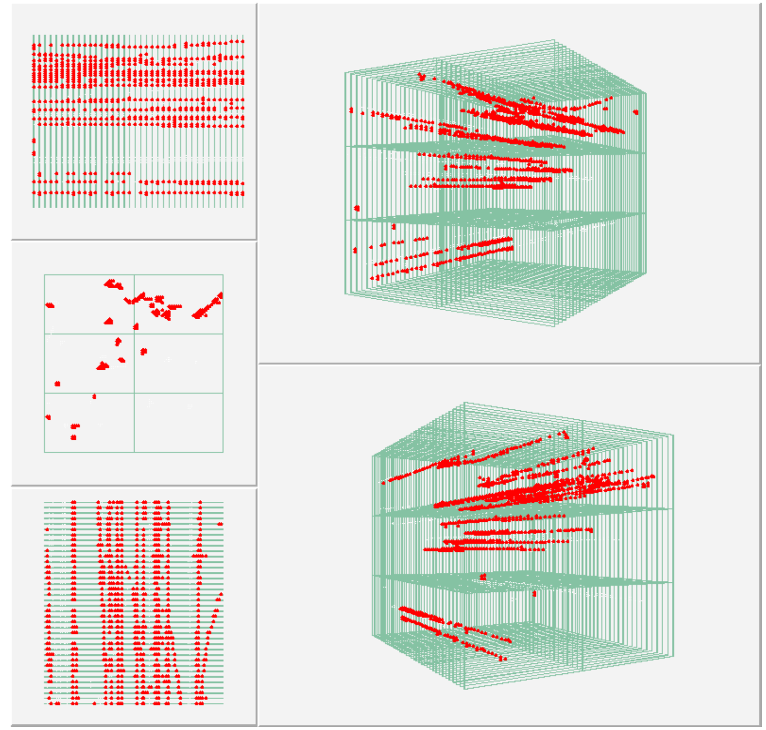
Active:

Readout cell size: 144 - 9 cm² → 4.5 cm² → 1 cm² → 0.25 cm² → 0.13 cm² → 2.5x10⁻⁵ cm²

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

Imaging Calorimeters





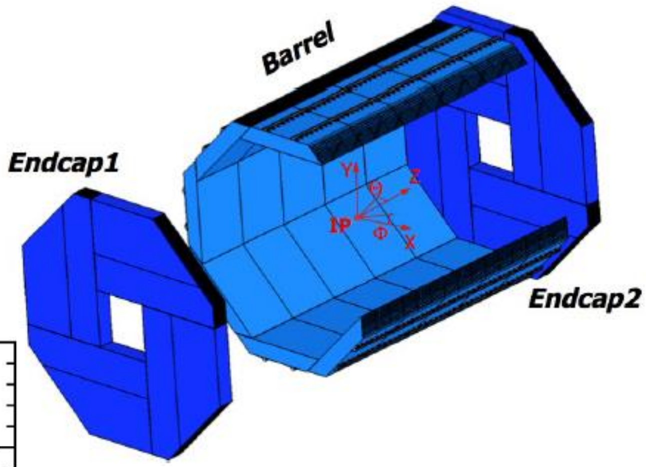
Two electrons ~ 5cm apart
CALICE SiW ECAL

~20 muons in 1m^2 area
CALICE RPC DHCAL

This is exactly what PFA needs: distinguishing individual showers within jet environment, in order to get excellent jet energy/mass resolution

CEPC ECAL: Silicon-W

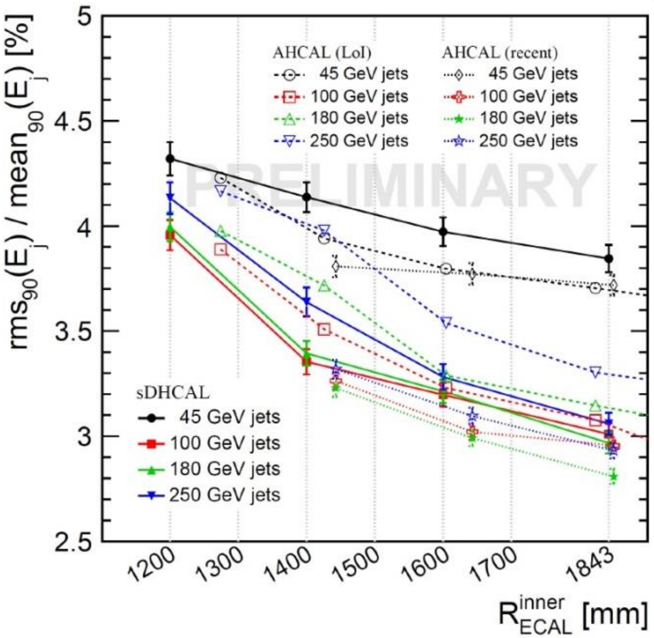
- **The ECAL consists of a cylindrical barrel system and two large end caps.**
  - One Barrel: 5 octant wheels
  - Two Endcaps: 4 quarters each
- **2 active sensors interleaved with tungsten absorber**
  - silicon pixel 5 x 5 mm^2
  - PCB with Very Front-End ASIC

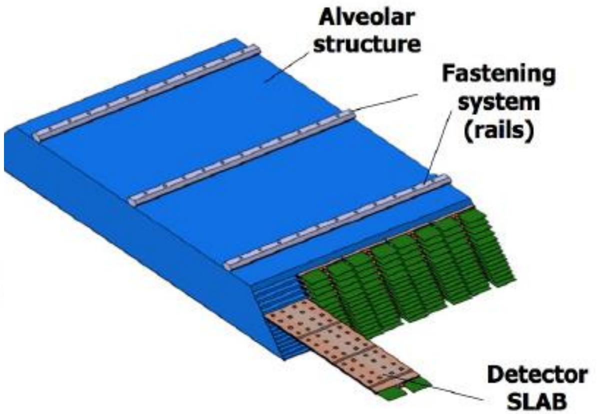


→JER is determined using Z→qqbar decay at rest

→ Based on PandoraPFA

→ SiW ECAL: 5×5 mm^2
with AHCAL: 3×3 cm^2
with sDHCAL: 1×1 cm^2



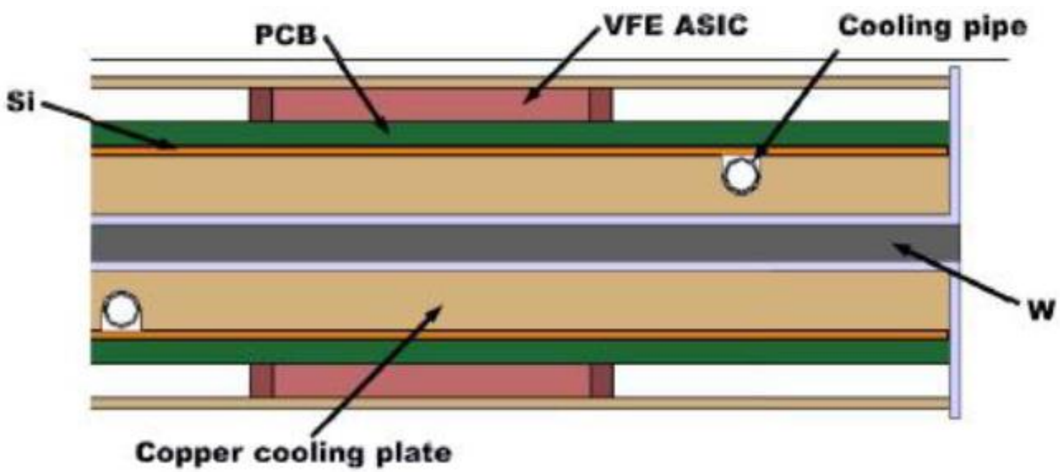


Active Cooling System

- CEPC is designed to operate at continuous mode with beam crossing rate: 2.8×10^5 Hz. Power pulsing will not work at CEPC.
- Compare to ILD, the power consumption of VFE readout electronics at CEPC is about two orders of magnitude higher, hence it requires an active cooling
  - Evaporative CO_2 cooling in thin pipes embedded in Copper exchange plate.
  - For CMS-HGCAL design: heat extraction of 33 mW/cm^2, allows operation with 6×6 mm^2 pixels with a safety margin of 2
- To be modelled for Mokka simulation

➔ Transverse view of the slab with one absorber and two active layers.

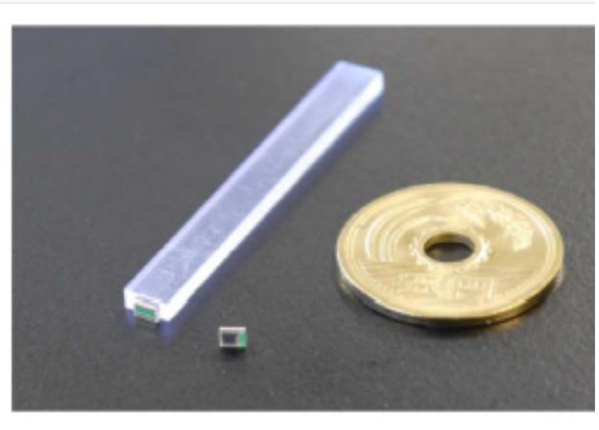
➔ The silicon sensors are glued to PCB with VFE chips, cooled by the copper plates with CO_2 cooling pipes.



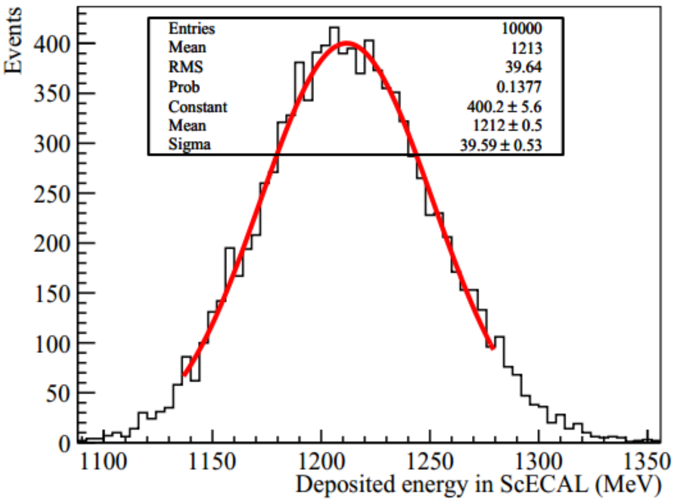
ECAL with Scintillator-W option

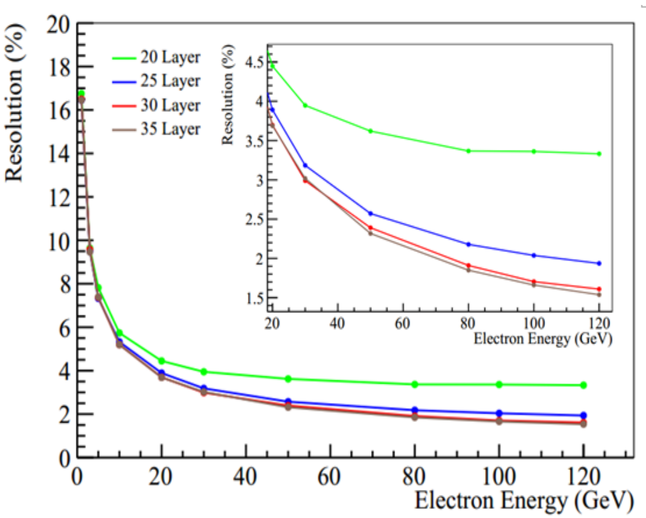
- **A super-layer (7mm) is made of**
  - tungsten plate (3 mm thick)
  - 5 x 45 mm^2 plastic scintillator strips (2 mm thick)
  - a readout/service layer (2 mm thick)

- **The energy resolution of 25 GeV electron is about 3.3% (cf. CALICE TB results)**
- **To achieve required energy resolution, the number of layers should be ~ 25.**



PS and SiPM

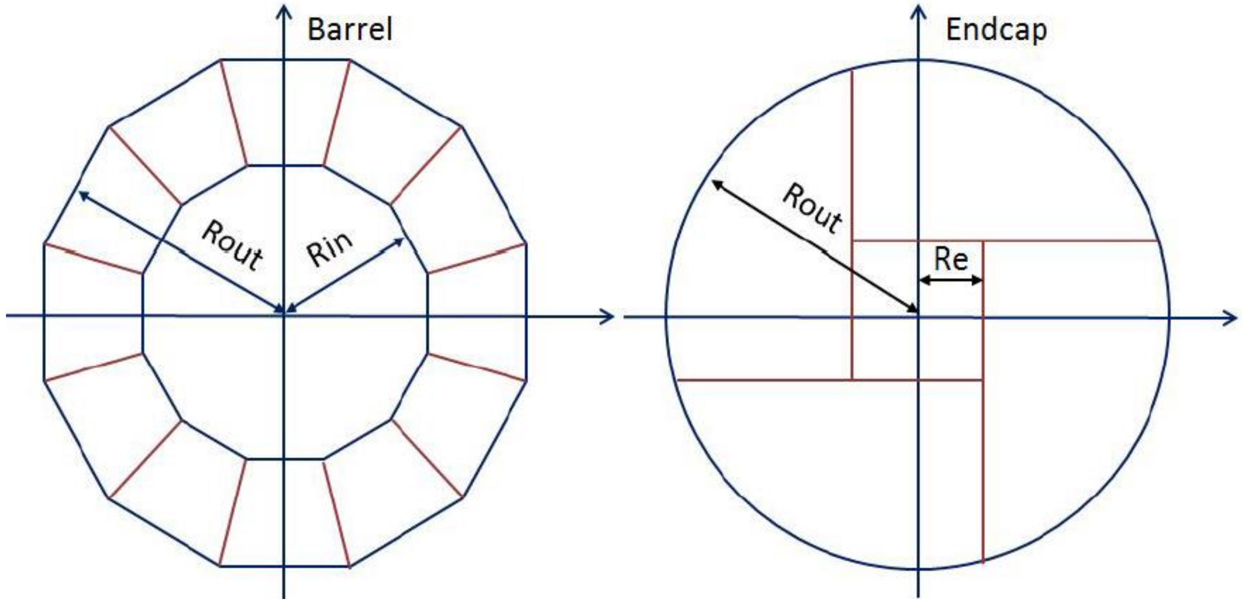




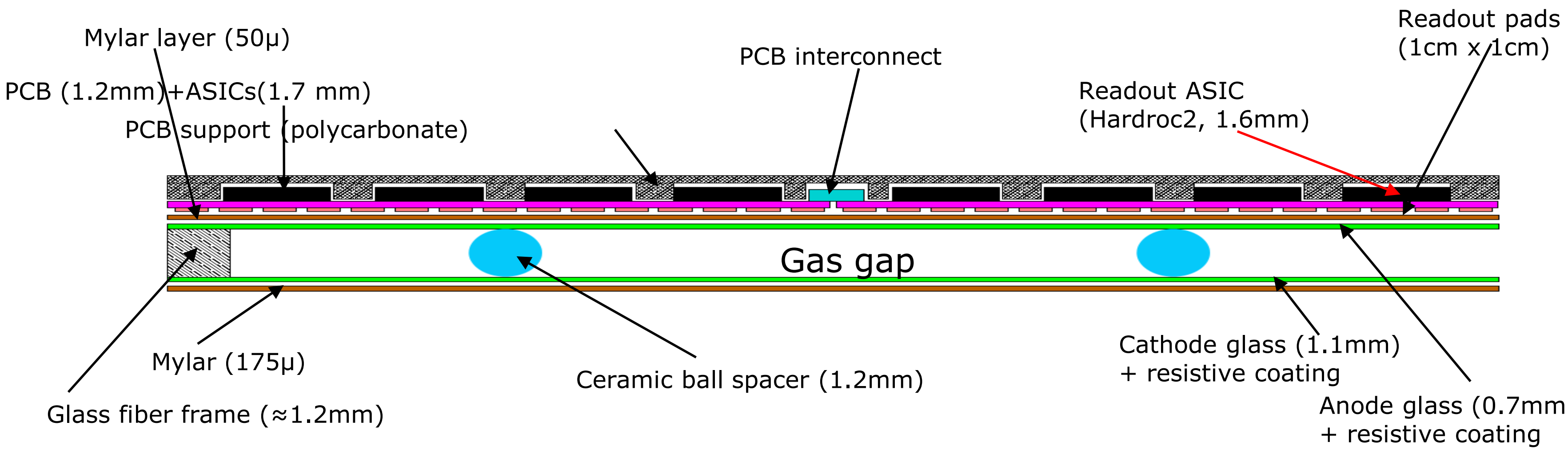
Hadron Calorimeter

- The HCAL consists of
  - a cylindrical barrel system: 12 modules
  - two endcaps: 4 quarters
- Absorber: Stainless steel

- **Active sensor**
  - Glass RPC
  - Thick GEM
- **Readout (1×1 cm^2)**
  - Digital (1 threshold)
  - Semi-digital (3 thresholds)

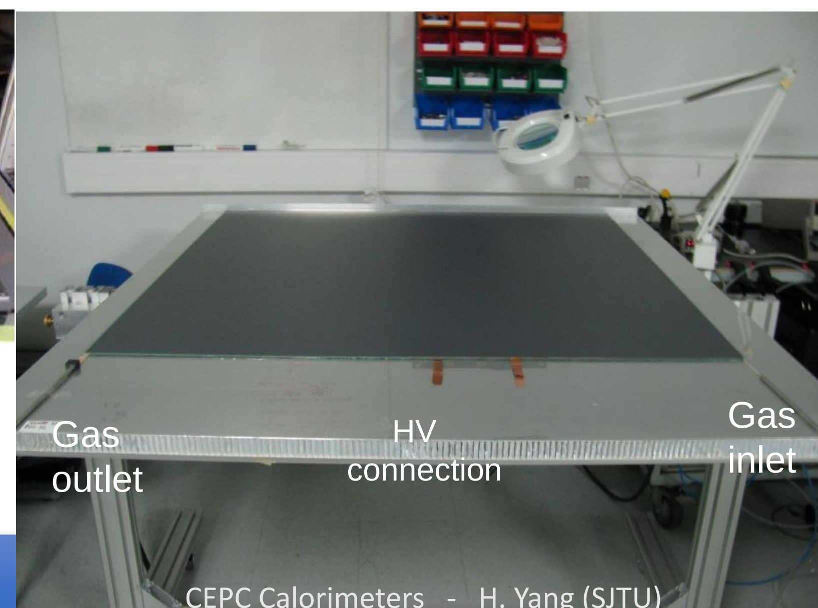


DHCAL with RPC



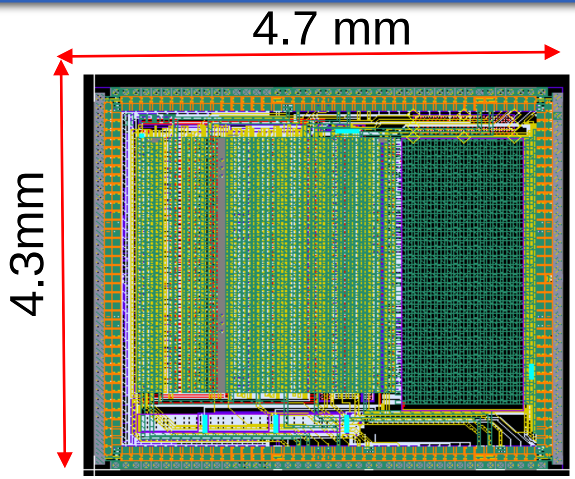
Large GRPC R&D

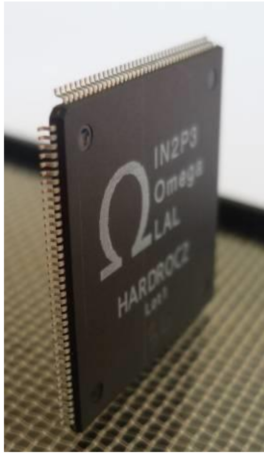
- ✓ Negligible dead zone (tiny ceramic spacers)
- ✓ Large size: 1 × 1 m^2
- ✓ Cost effective
- ✓ Efficient gas distribution system
- ✓ Homogenous resistive coating



Electronics Readout System R&D

ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity

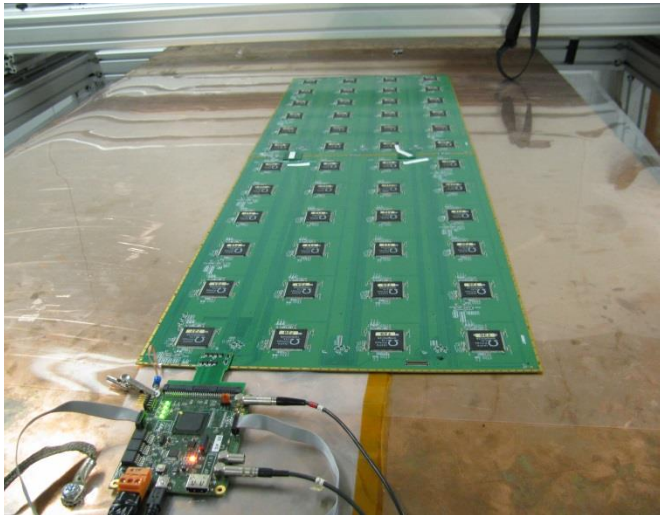




Printed Circuit Boards (PCB) were designed to reduce the cross-talk with 8-layer structure and buried vias.

Tiny connectors were used to connect the PCB two by two so the 24X2 ASICs are daisy-chained. $1\times1m^2$ has 6 PCBs and 9216 pads.

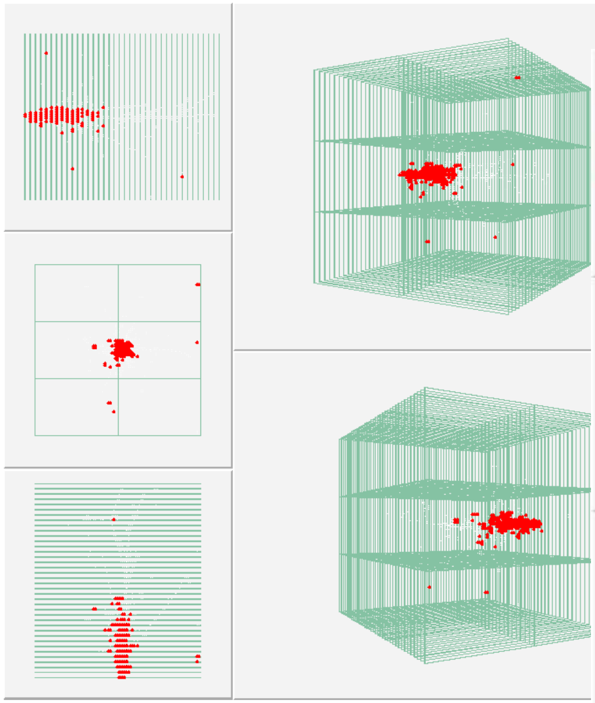
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.



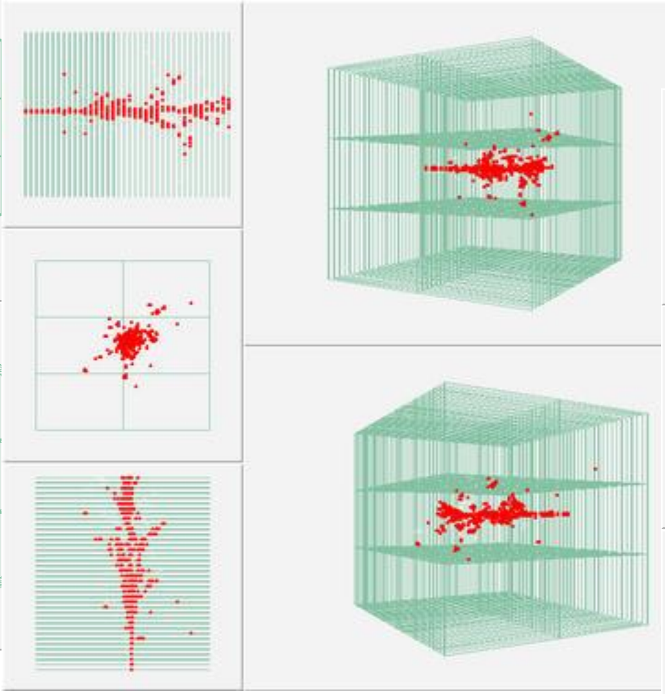
Prototype of DHCAL with RPC

Prototype of DHCAL based on RPC

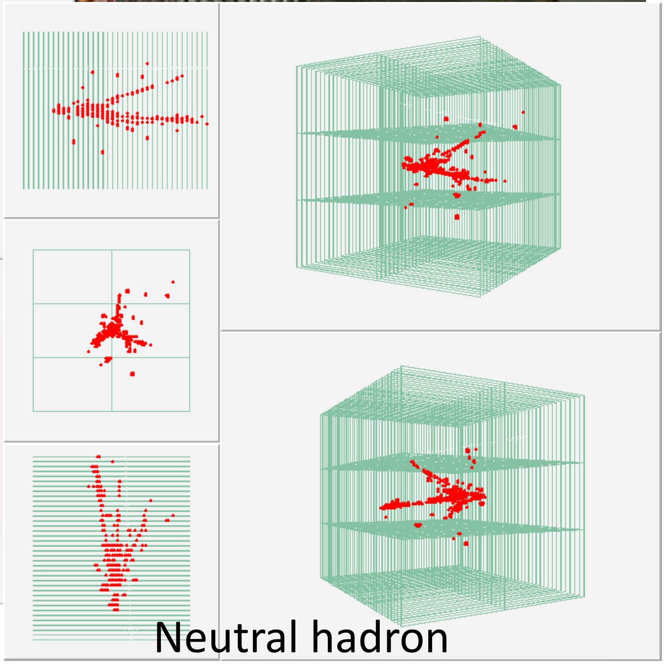
- **ANL (J. Repond, L. Xia et.al.)**
  1m³, 1 threshold, TB at CERN/Fermilab



Positron



High Energy Pion

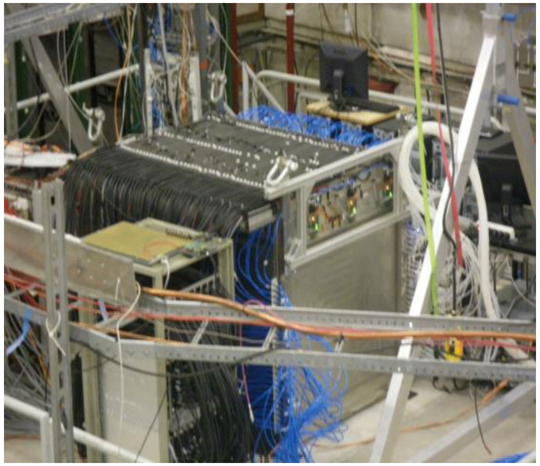


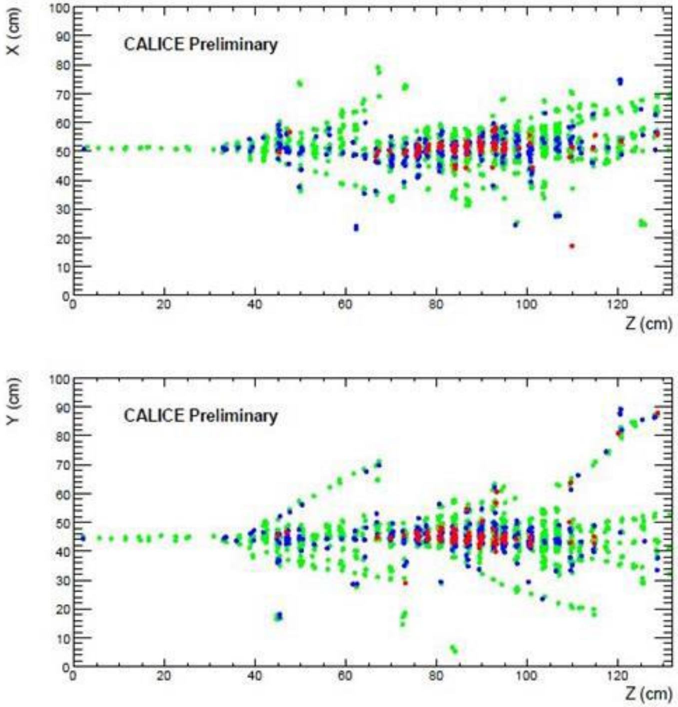
Neutral hadron

Prototype of SDHCAL with RPC

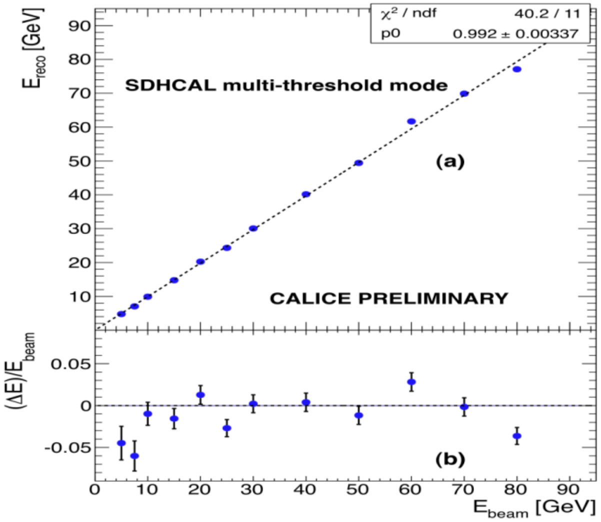
Prototype of SDHCAL based on RPC

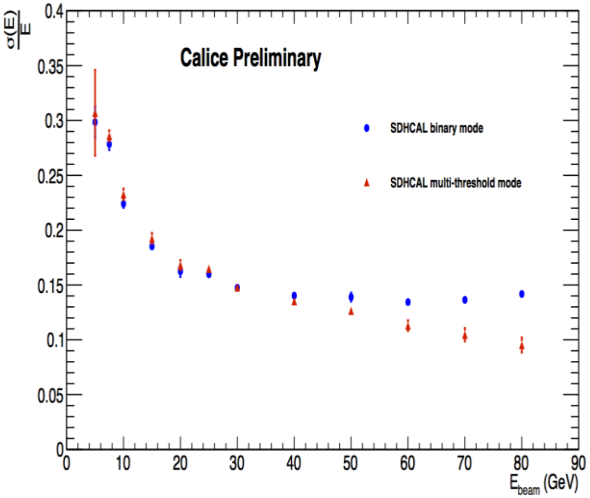
- IPNL (I. Laktineh, R. Han et.al.)
  1m^3, 3 thresholds, Test Beam at CERN





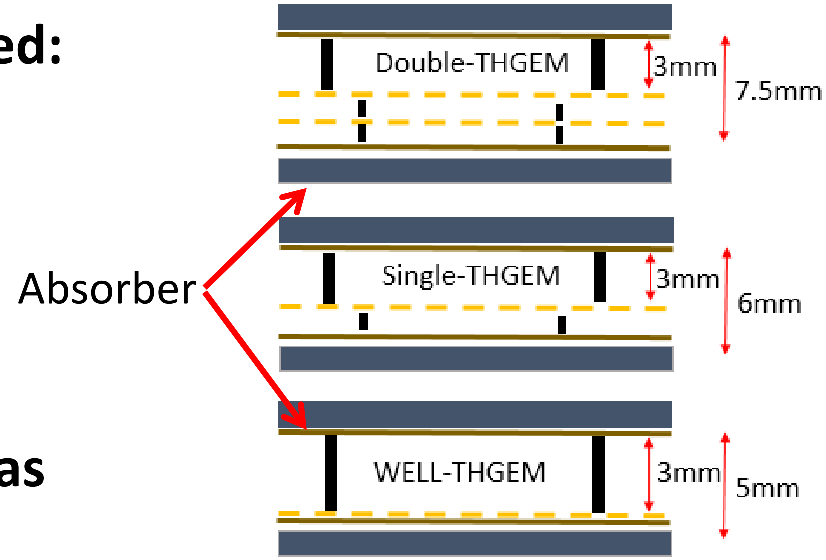
80 GeV Pion

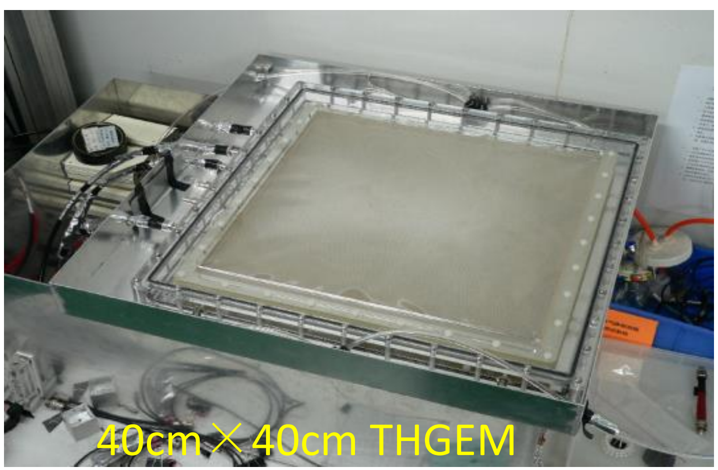


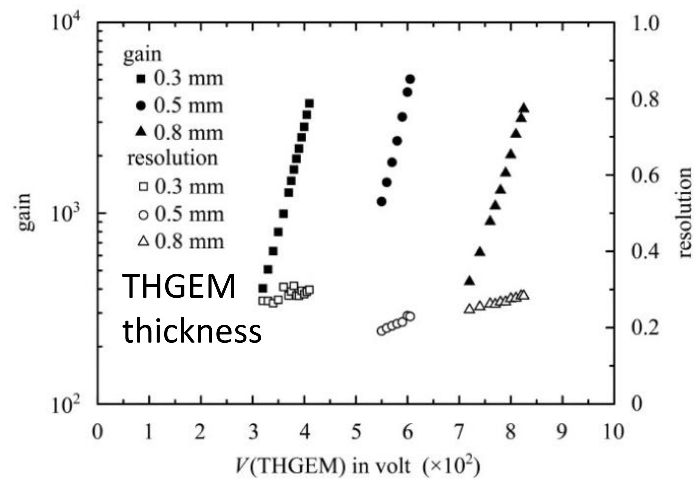


DHCAL based on THGEM

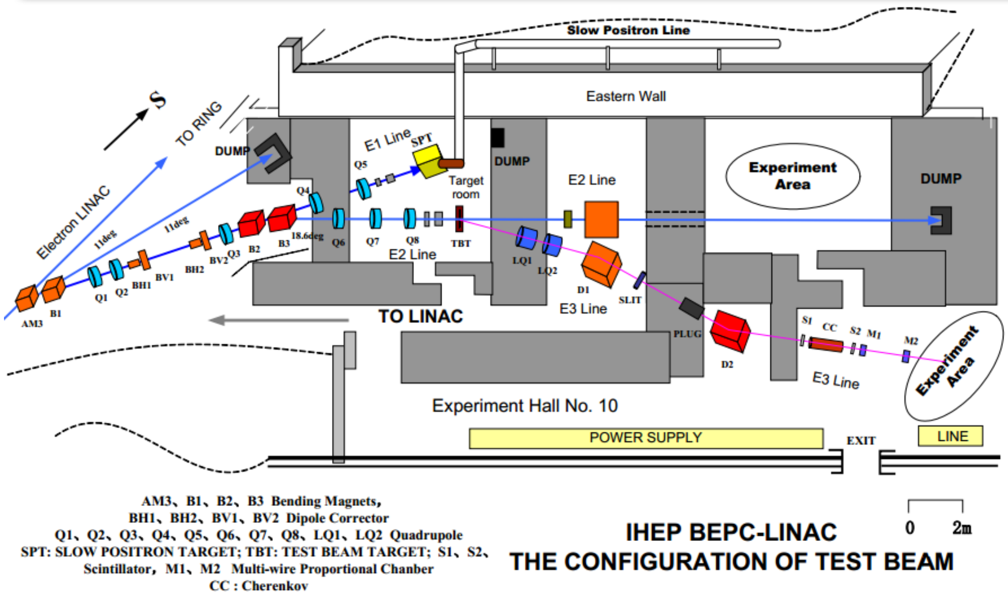
- **Three THGEM options are explored:**
  - **Double - THGEM**
  - **Single - THGEM**
  - **WELL - THGEM**
- **WELL-THGEM is optimal choice**
  Thinner, lower discharge
- **40 × 40 cm^2 of THGEM (below) was produced in China**

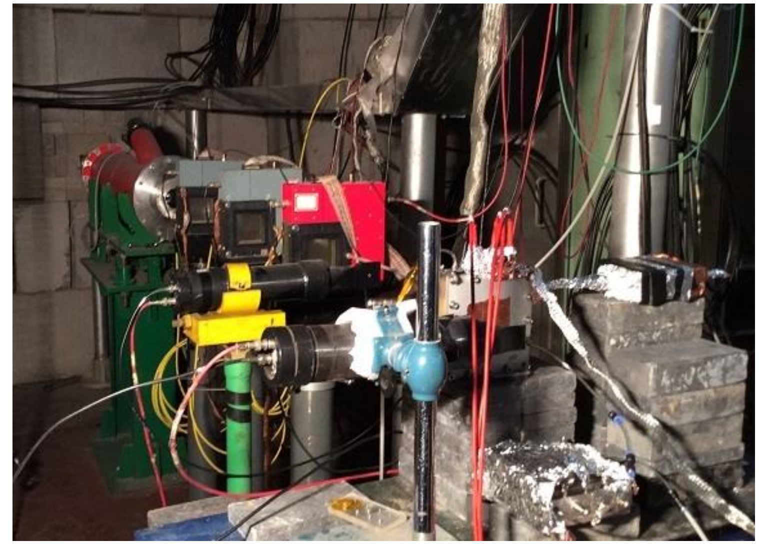


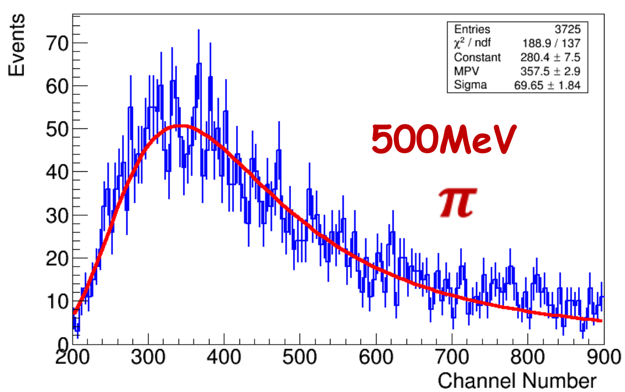


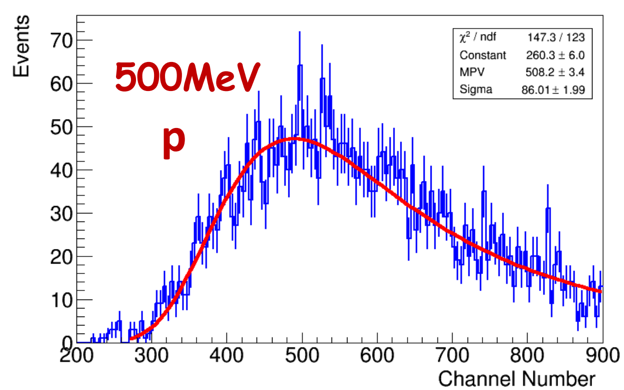


WELL-THGEM Test Beam at IHEP





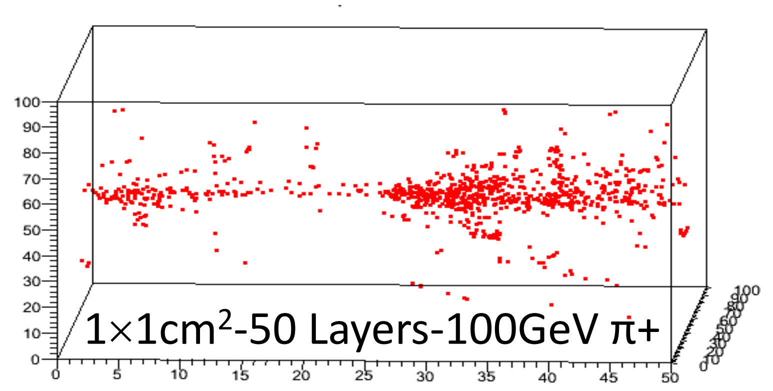


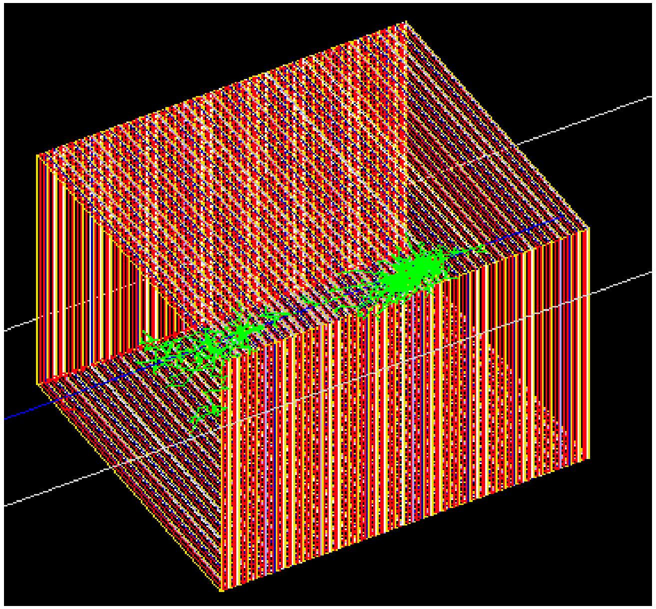


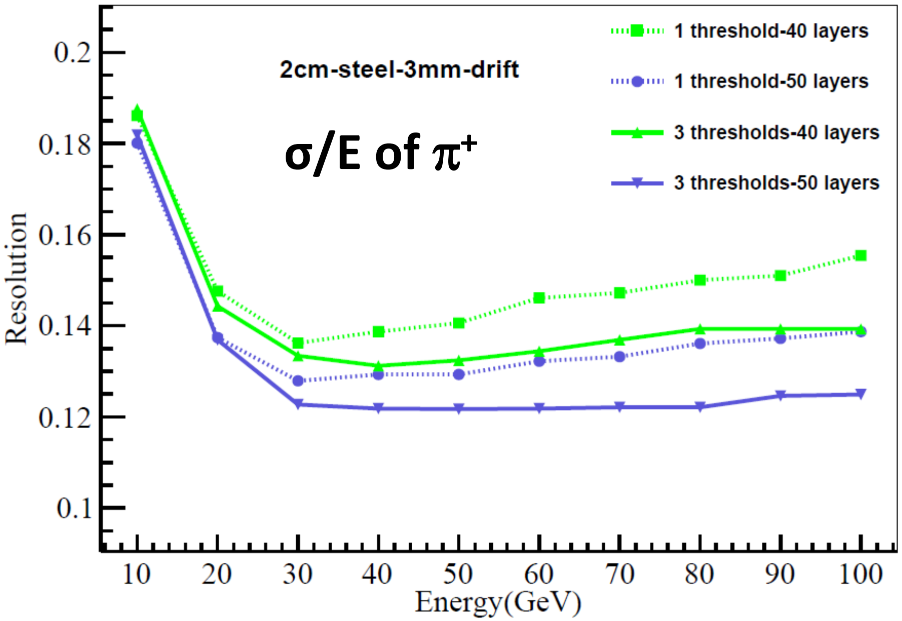
Well-THGEM, Ar/3%iC_4H_{10};

Simulation of DHCAL

- Absorber: 2cm stainless steel
- Drift gap: 3mm
- Number of layers: 40, 50
- Ecell = 1, 5 and 10 MIPs if the charge is above the thresholds typically placed at 0.1, 1.5 and 2.5 MIPs







Future Plan: Critical R&D

- **Detector optimization**
  - Granularity of calorimeters
  - Number of layers of calorimeters
- **Readout Electronics (PCB, low power VFE ASIC)**
- **Cooling system**
  - Power pulsing will NOT work at the CEPC, effective cooling and power saving strategy need to be developed and tested
- **Gas recirculation system**
- **High voltage distribution system**
- **Calibration system**
  - Energy, position and density calibration etc.
- **Mechanical: self-support and compact module**

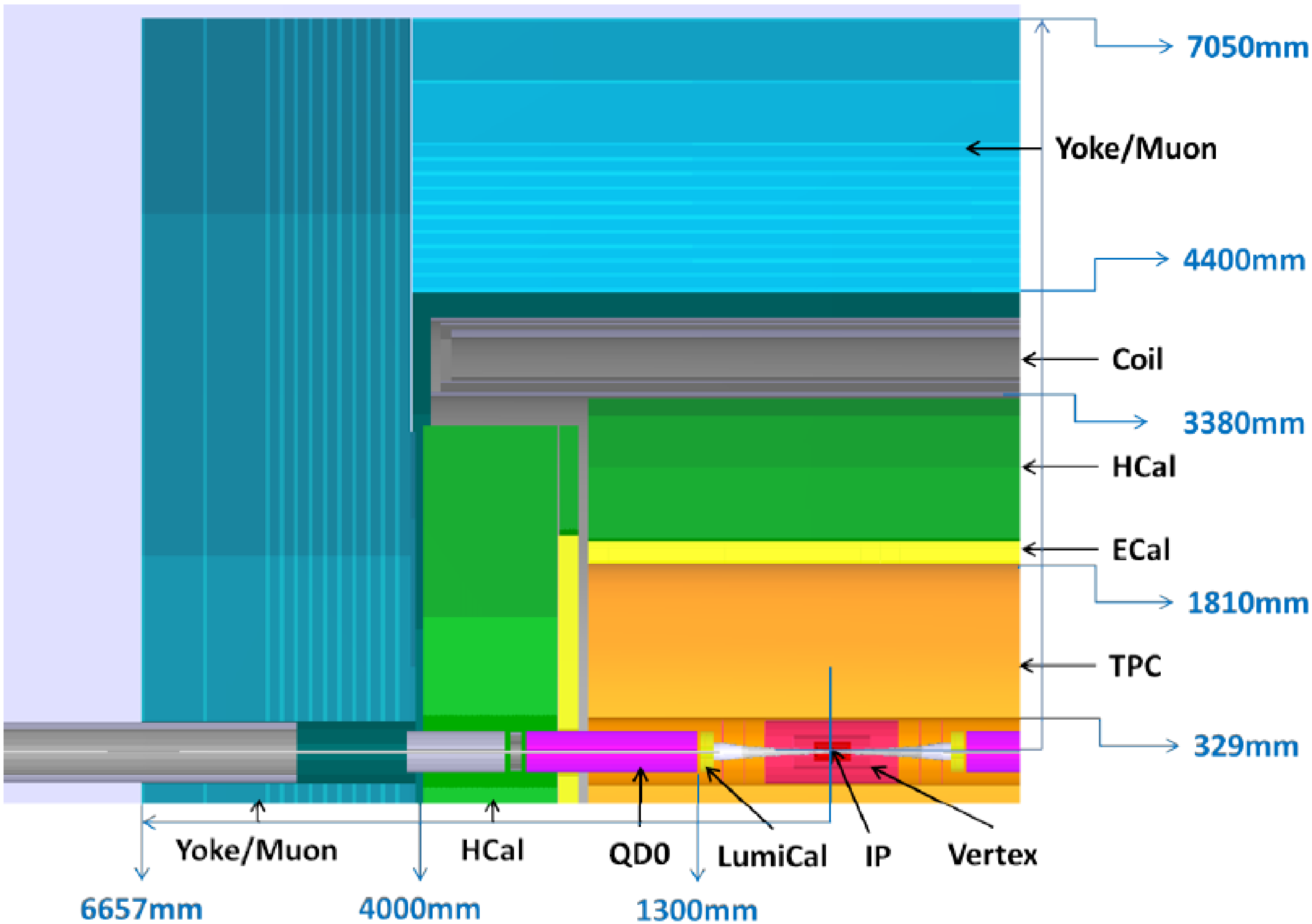
Summary

- As a starting point, two alternative technology options are explored for both ECAL and HCAL in preCDR based on CALICE and ILD R&D efforts.
    - ECAL (Silicon-W and Scintillator-W)
    - HCAL (RPC-Steel and THGEM-Steel)
- Identify some critical R&D plans which is best fit for CEPC calorimeters.
- Calorimeters detector design and optimization are onging and more international collaboration are needed. Other technology options are welcome for the design of CEPC calorimeters in CDR phase.

Many thanks to all members of CEPC Physics and Detector working group who made significant efforts to prepare the CEPC-SPPC preCDR ！

Backup Slides

Overview of the CEPC Detector



Si-W ECAL: Physics & Technological prototype

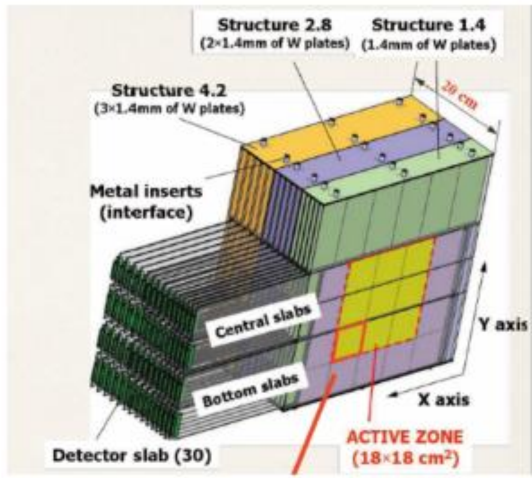
Physics prototype: 2005-2011

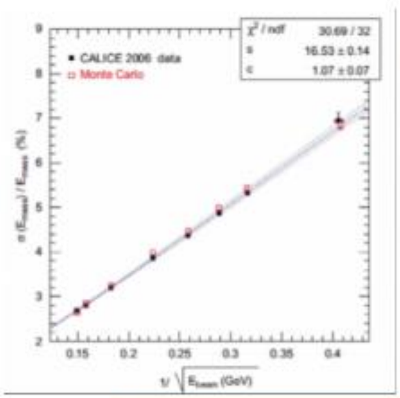
PFA proof of concept with comparison to MC (PandoraPFA etc.)

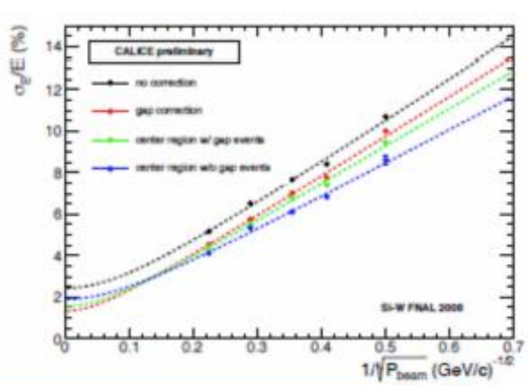
Electronics outside

– 1cm x 1cm pixels
– full 30 layers

(used for PAMELA sat.)

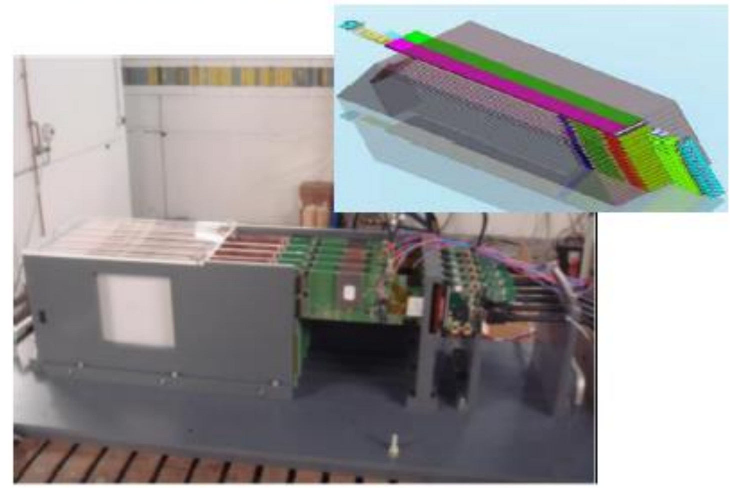






16.5%(stochastic) 1–2% (constant) obtained with 1–45 GeV e^-/e^+ at 2006/2008 BT

Technological prototype



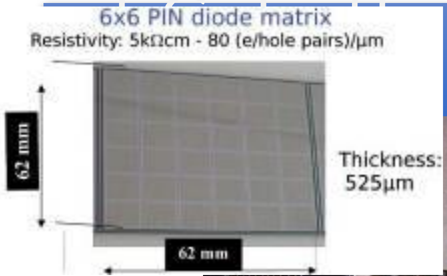
Embedded electronics

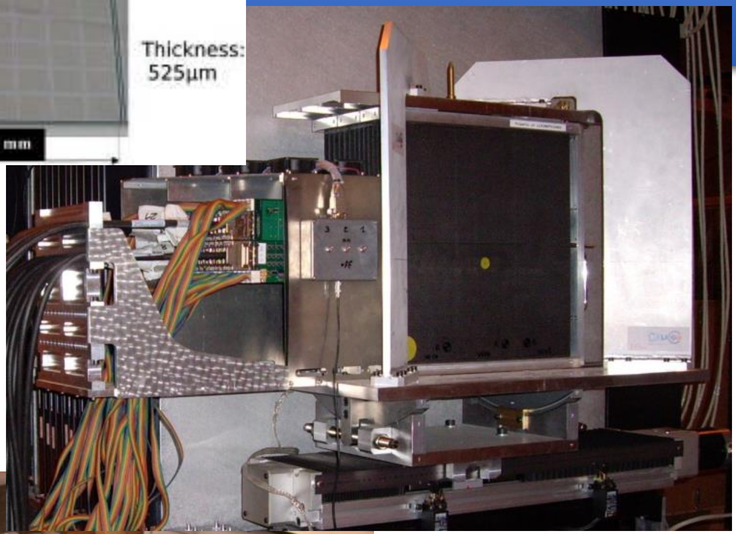
– SKIROC2 analog/digital ASICs
  - auto-triggered, zero suppr., PP
– pixels 5×5mm²

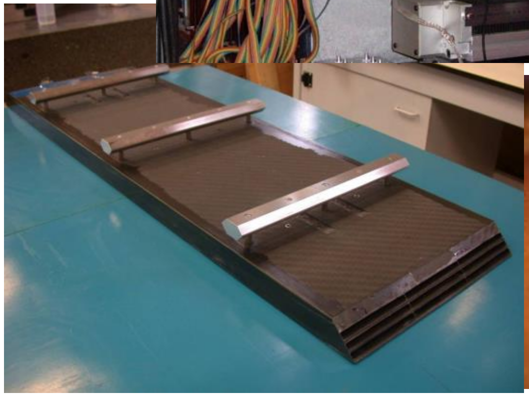
Assess the feasibility

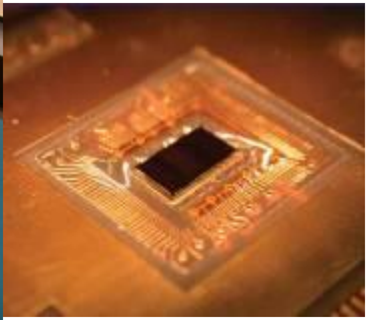
Establish procedures and develop test benches for mass production

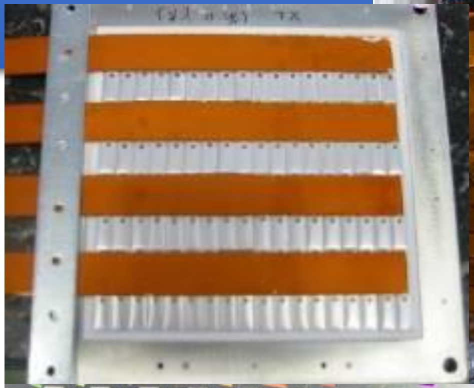
rts

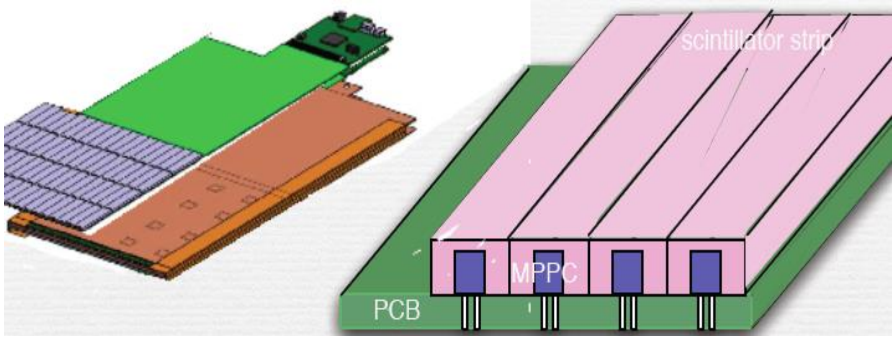












CALICE Si/W ECal:

- Physics prototype* tested in beam (1x1cm^2)
- R&D/construction for Technical prototype**
- Readout cell reduced to 0.25cm^2 for 2nd prototype
- First test beams of new prototype soon

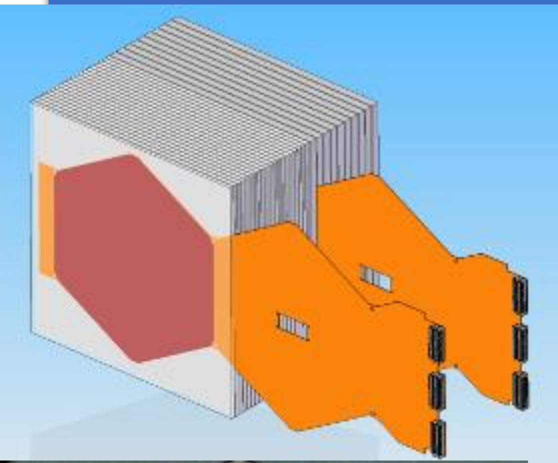
CALICE Sci/W ECal:

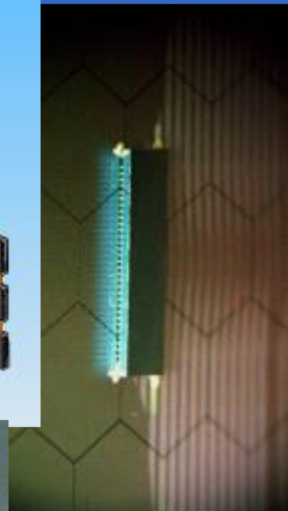
- Physics prototype tested in beam (1x4.5cm^2)
- Technical prototype R&D/construction
- Started first beam tests

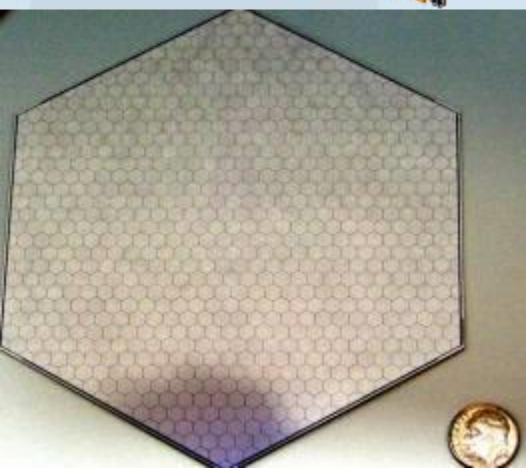
*** Physics prototype: proof of principle device***

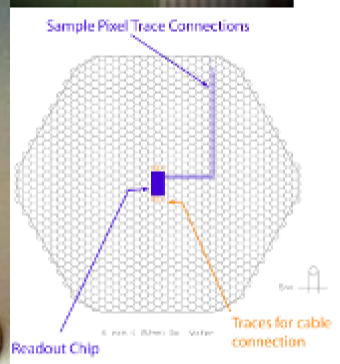
***** Technical prototype: prototype close to a real detector***

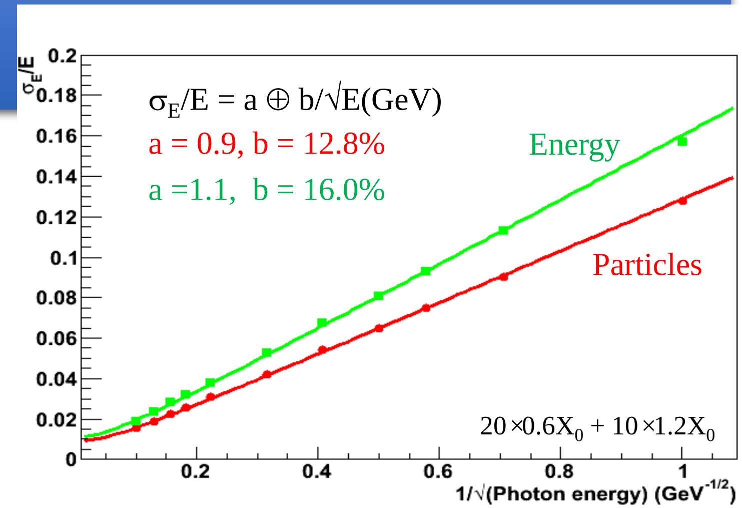
ECal efforts

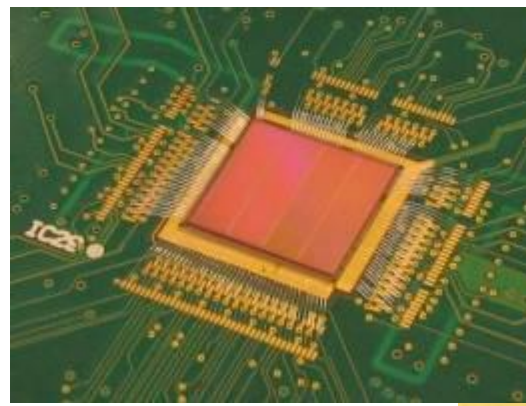


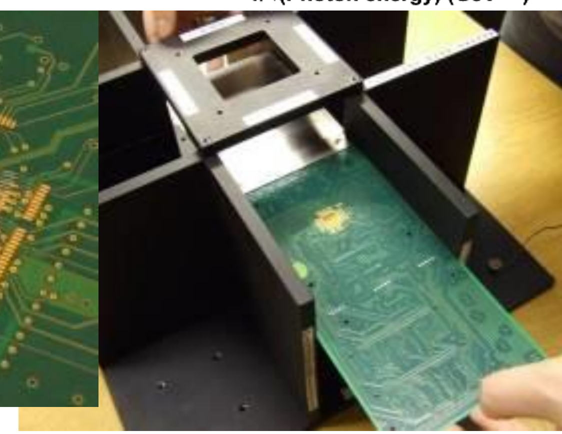












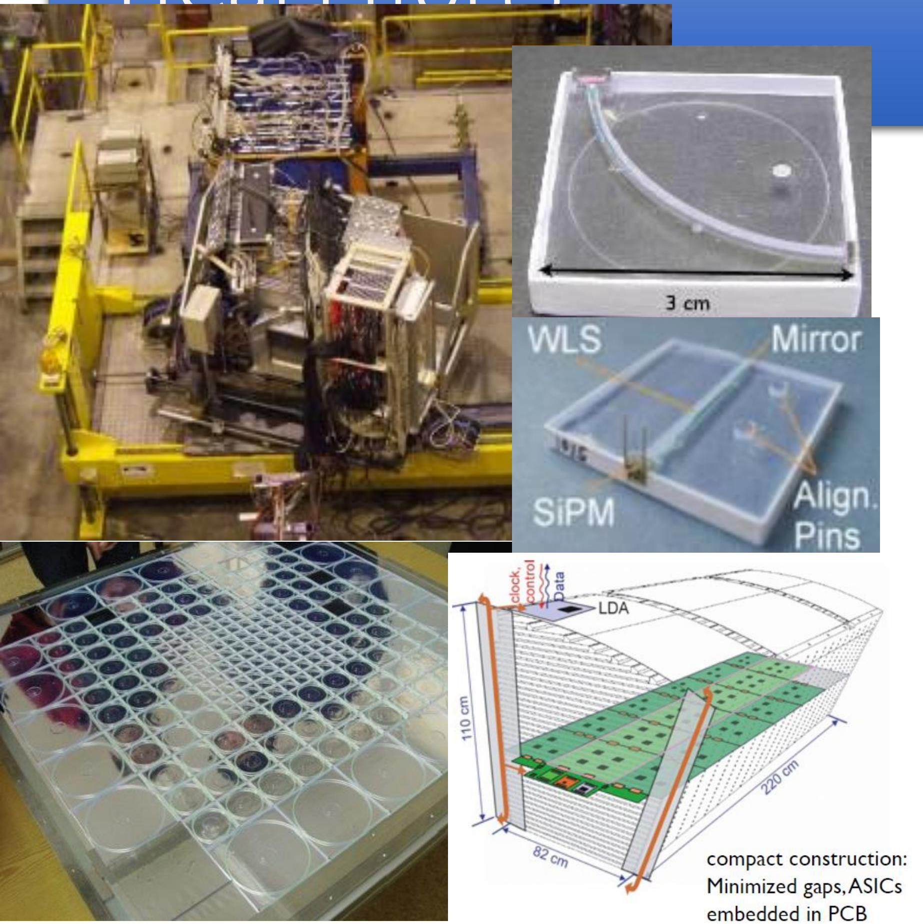
SiD Si/W ECal:

- Target at very compact readout and small cell (~0.13cm^2)
- Address all technical issues from the beginning
- Push technical limits in many aspects
- Total active medium thickness targets at ~1mm
- Test beam module being assembled
- First beam exposures in particle beams

CALICE MEPS Digital ECal:

- Extremely small cell size (0.005x0.005cm^2)
- Working on sensor R&D
- Did sensor test beam

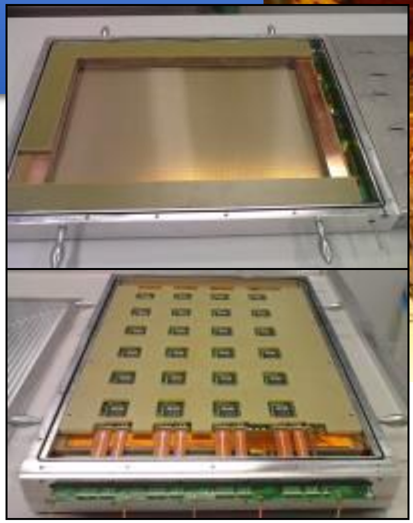
HCal Efforts

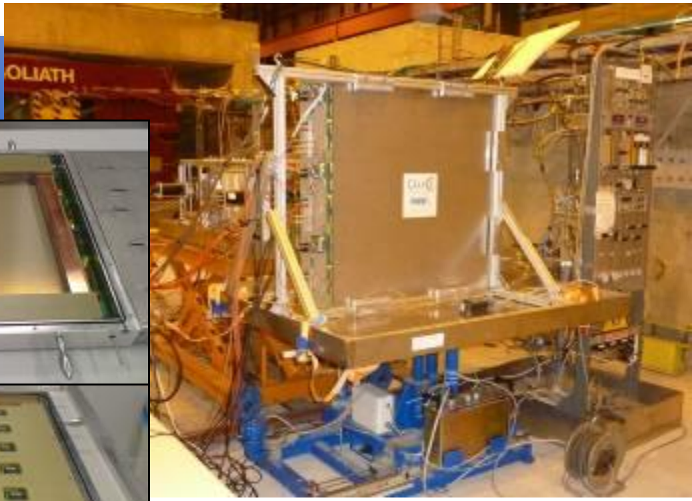


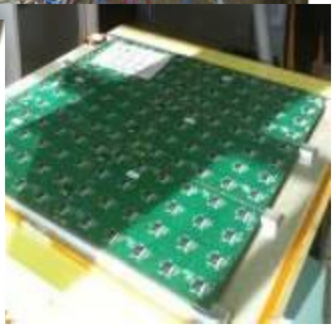
CALICE Sci/SiPM Analog HCal (AHCal):
- Physics prototype (Fe/W) tested in beam
- R&D/construction for Technical prototype
- First test beam of components

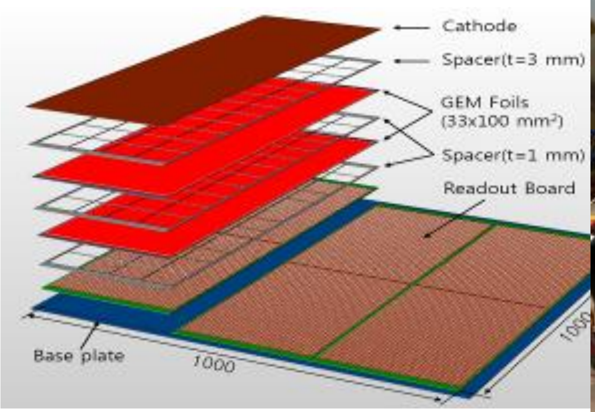
CALICE RPC Digital HCal (DHCal):
- Physics prototype (Fe/W) tested in beam (1cm^{2}pad size)
- Embedded Front End readout, 480K (!) readout channels
- Data analysis on-going
- R&D for Technical prototype started

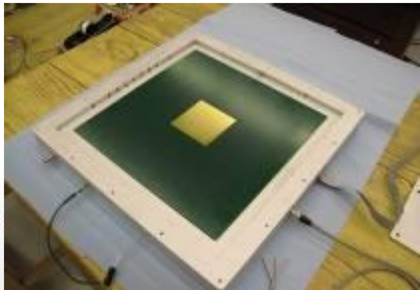
HCal Efforts

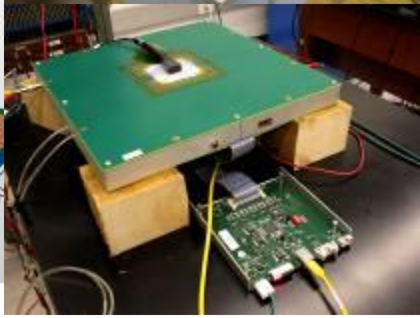












CALICE RPC semi-Digital HCal (sDHCal):

- Large prototype ($1m^3$) constructioned ($1cm^2$pad)
- Beam test at CERN with Fe absorbers
- Addressed several technical issues for real detector
- Explore 3-threshold readout
- R&D towards real detector

CALICE Micromegas/GEM Digital HCal:

- Prototype layer constructed/expected ($1x1cm^2$)
- Prototype layer beam test done/expected
- Both technologies can handle very high rates