Status of CEPC Calorimeter R&D

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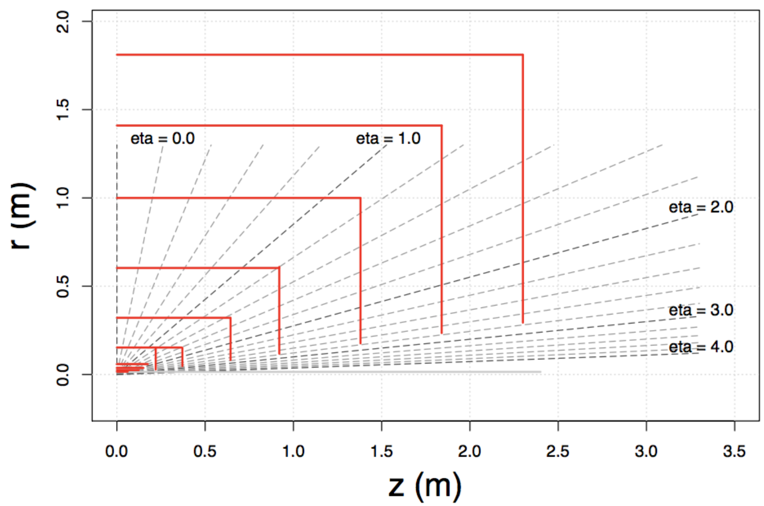
CEPC Detector Overview

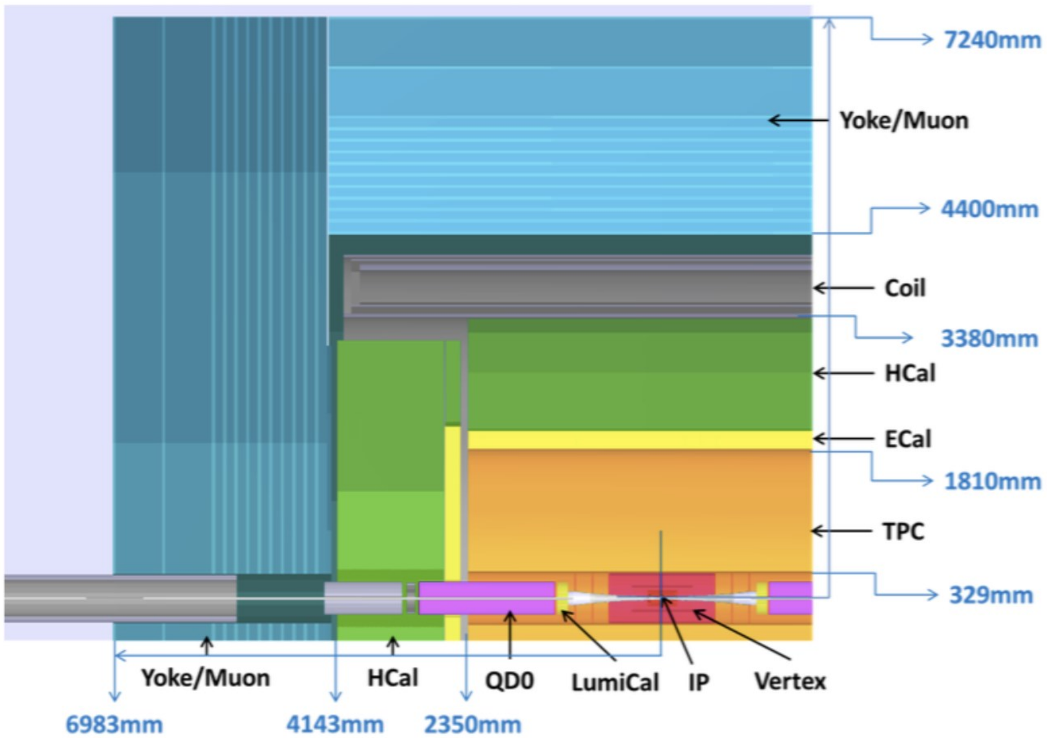
Baseline: ILD-like

- TPC tracking + Imaging calorimetry (ECAL+HCAL)
- PFA-oriented

Alternatives

- Low-field concept
- Full-silicon concept

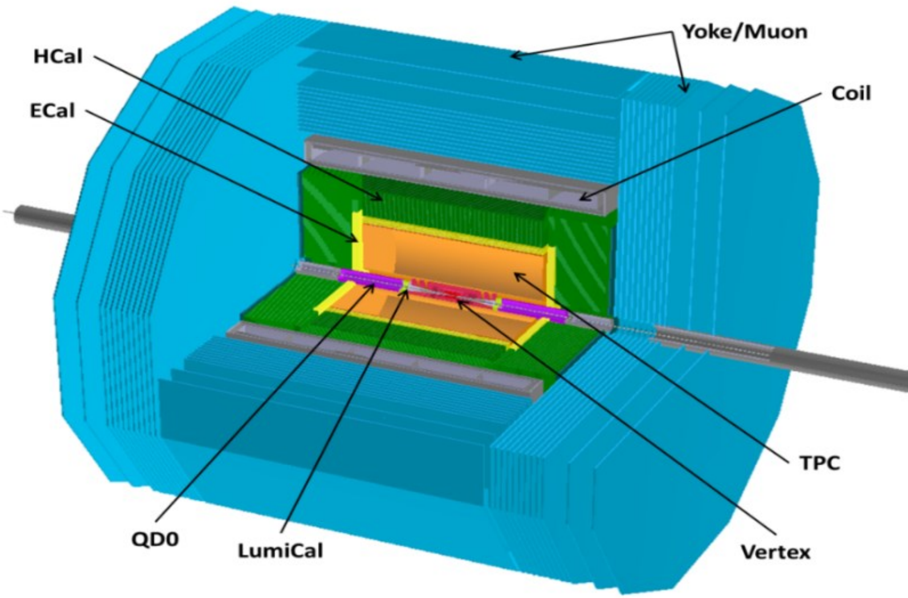




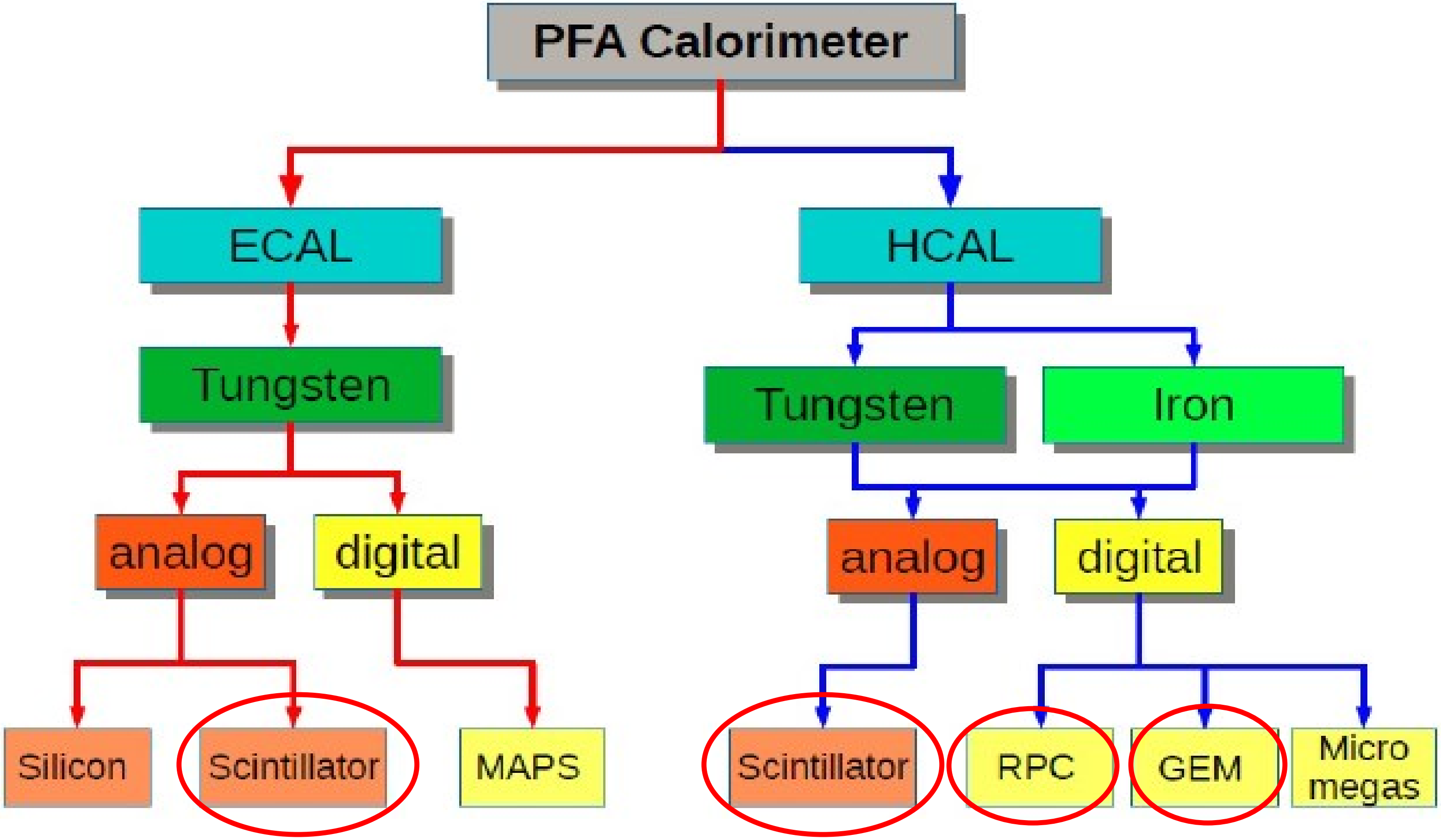
CEPC Detector Overview

Calorimeter Requirements

- **Precise measurements of electrons and photons:**
- $\sigma_E/E \approx 16\%/\sqrt{E} \oplus 1\,\%$
- **Jet energy resolution (ECAL combined with HCAL and tracker):**
- $\sigma_E/E \approx (3\% - 4\%)$
- **Imaging detector with high granularity**
  - **Detailed information of showers**
  - **Compact showers (small X_0, and small R_M)**
  - **Minimum dead materials**



CEPC Calorimeter Options



ECAL Option Covered

- **Scintillator**

HCAL Option Covered

- **Analog: Scintillator**
- **Digital: RPC, GEM/THGEM**

CEPC Calorimeter R&D

China MOST CEPC R&D Phase-I project

- Proposed and approved in 2016
  - Studies on physics and key technologies of a high-energy circular electron-positron collider
- Phase-II project also just approved (2018)

HCAL R&D efforts

- Digital
  - RPC: SJTU & IPNL, Tsinghua …
  - GEM/THGEM: USTC, IHEP, UCAS …
- Analog
  - Scintillator: IHEP, USTC, BNU, SJTU …

ECAL R&D efforts

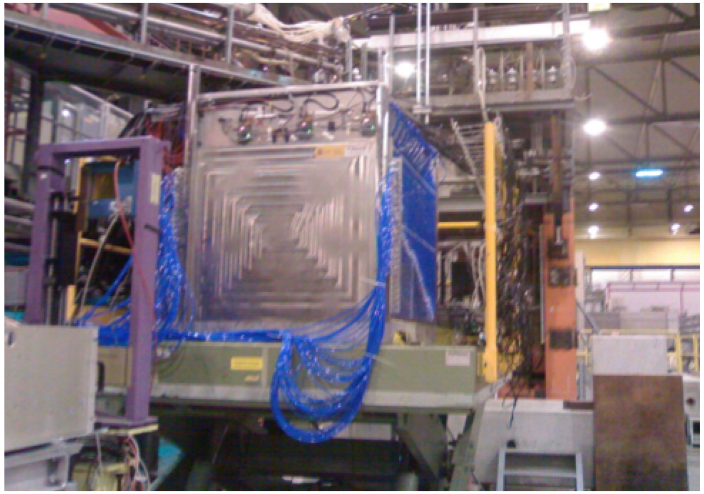
- Analog
  - Scintillator: IHEP, USTC, BNU …

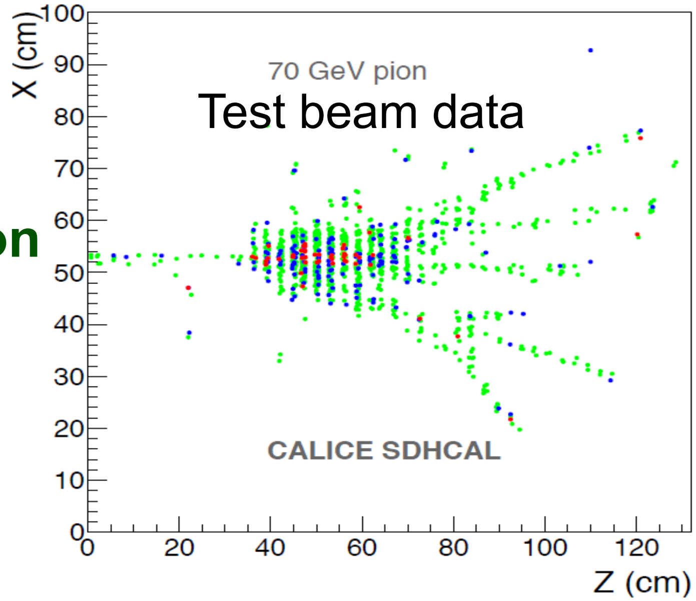
SDHCAL Option: RPC

RPC-SDHCAL R&D

Details @I. LAKTINEH's talk

- IRPC-SDHCAL prototype (IPNL): first technological prototype of high-granularity calorimeters
- SJTU in close collaboration with IPNL, Tsinghua and several other groups within CALICE collaboration to work on RPC-SDHCAL R&D:
  - Particle ID
  - Energy reconstruction
  - Structure & geometry optimization

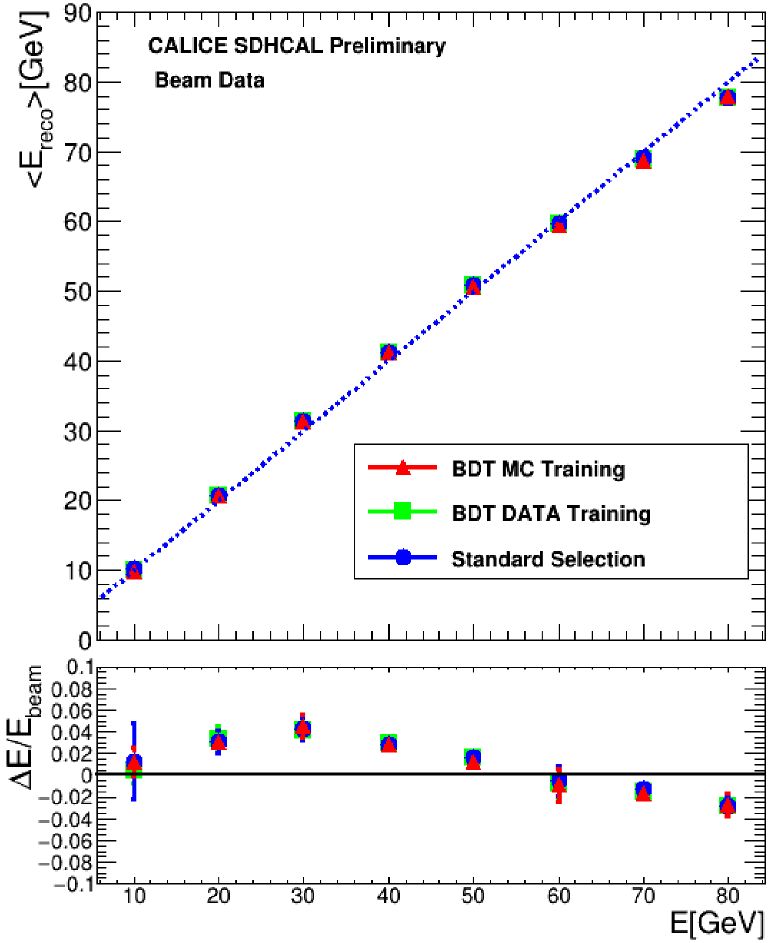


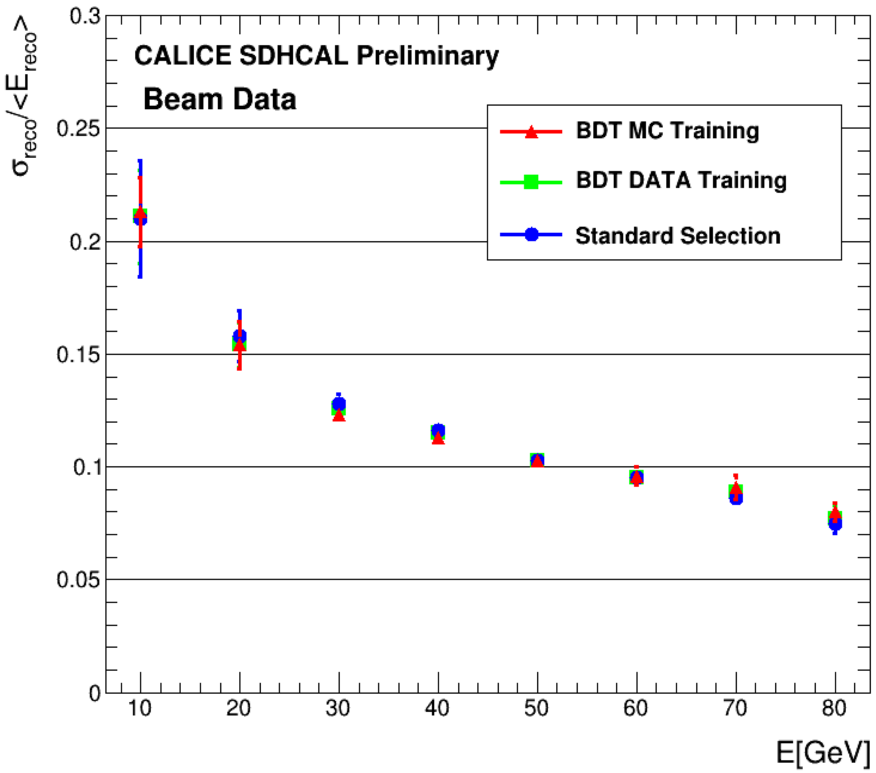


- Total Size:1.0x1.0x1.3 m^3
- Total Layers: 48
- # of Channels(pads): 440000

SDHCAL Option: RPC

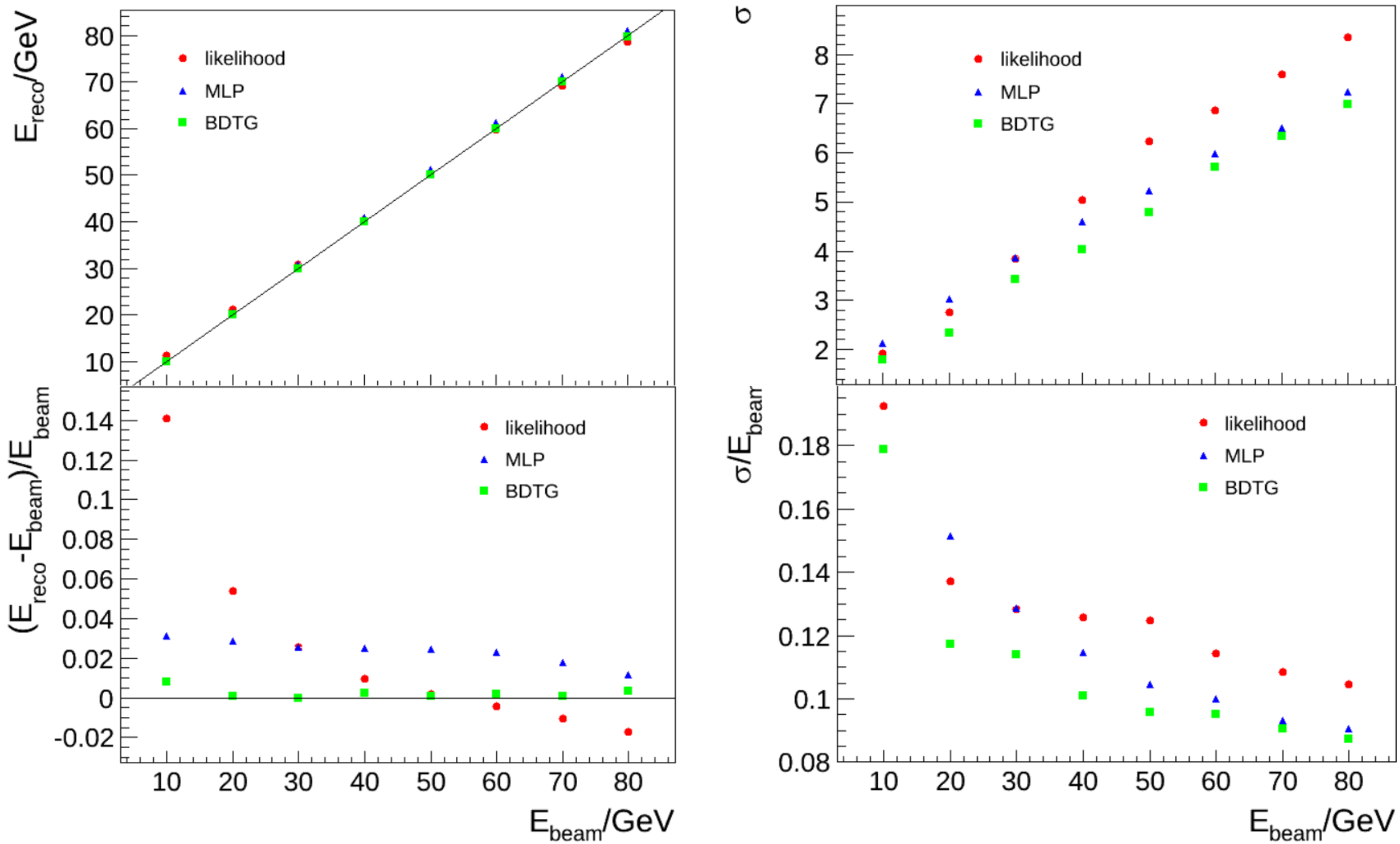
Details @I. LAKTINEH's talk





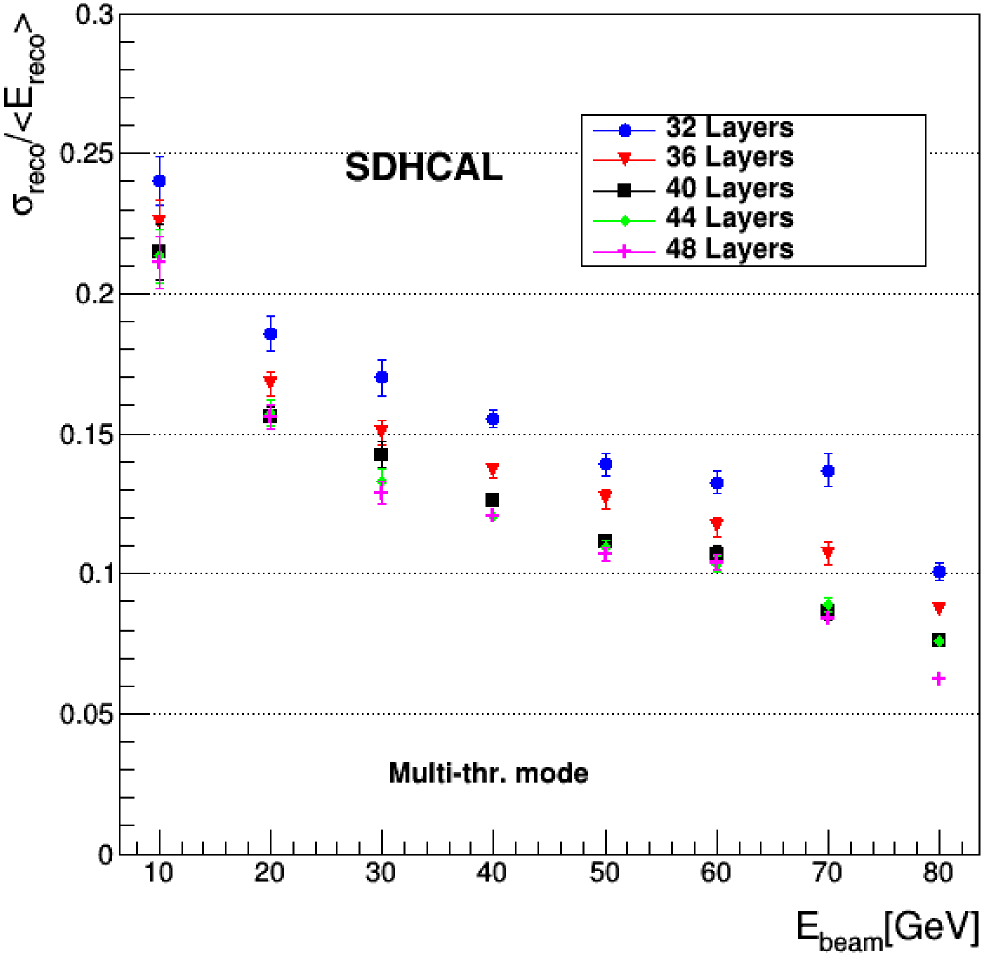
Particle identification using BDT in SDHCAL

SDHCAL Option: RPC



Under development: comparison of different MVA reconstruction methods using simulated π^- samples

SDHCAL Option: RPC

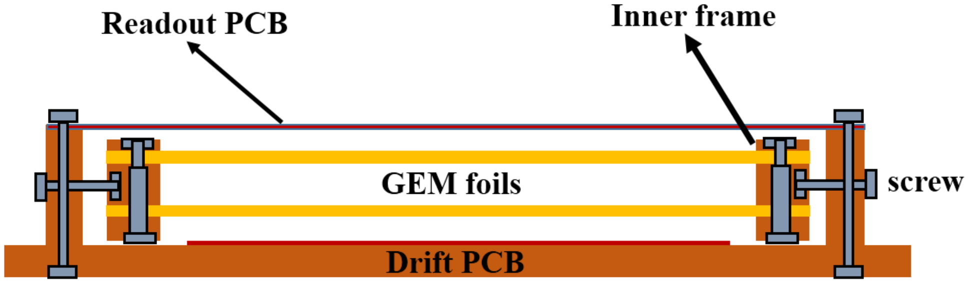


- RPC-SDHCAL has 48 layers, initially aims for ILC experiment
- Optimizing number of HCAL layers for CEPC at 240GeV
- 40 layers already yields decent energy resolution in CEPC regime

RPC-SDHCAL structure and geometry optimization

SDHCAL Option: GEM

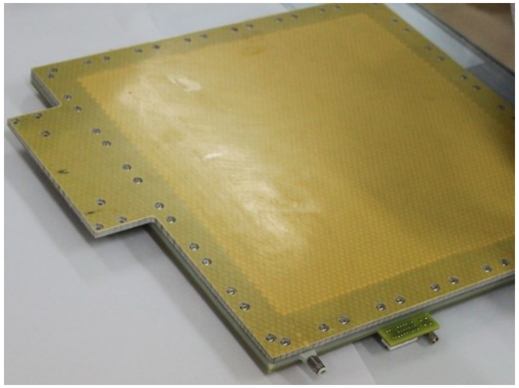
- More compact GEM detector
  - triple-GEM → double-GEM
- Exploring double-GEM with self-stretching technique
  - A purely mechanical method to assemble GEM detectors
  - Self-stretching technique very suitable for large-size GEM fabrication
    - No gluing, easy and fast assembly and labor saving
    - No inner spacers, no dead areas, smooth gas flow
    - Complete re-opening possible, highly replaceable and repairable
    - R&D ongoing



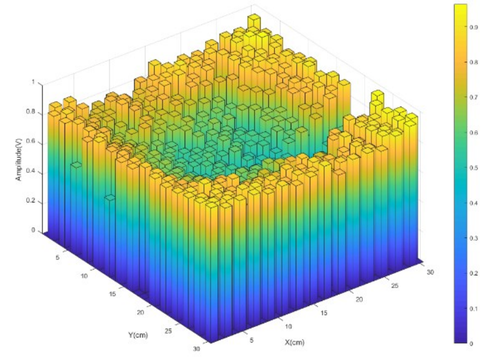
DHCAL: GEM Option

- Built a 30cm*30cm double-GEM prototype
- Tested the prototype with radiation source and cosmic-rays

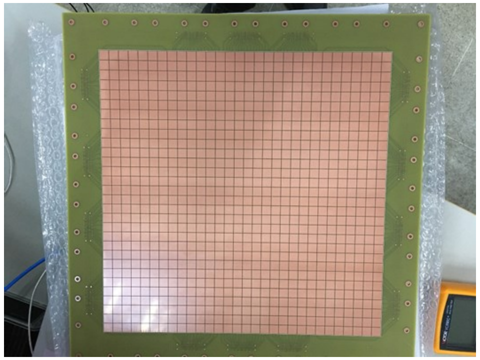
Double-GEM prototype



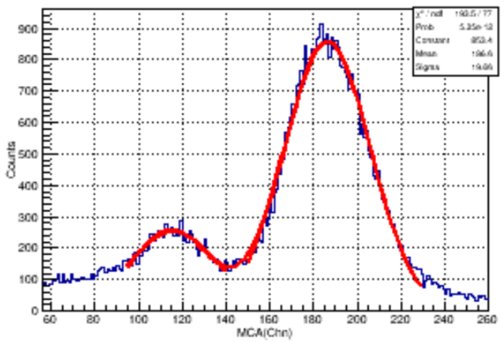
Gain uniformity: ~19%



Pad readout:1cm*1cm



Typical X-ray energy spectrum

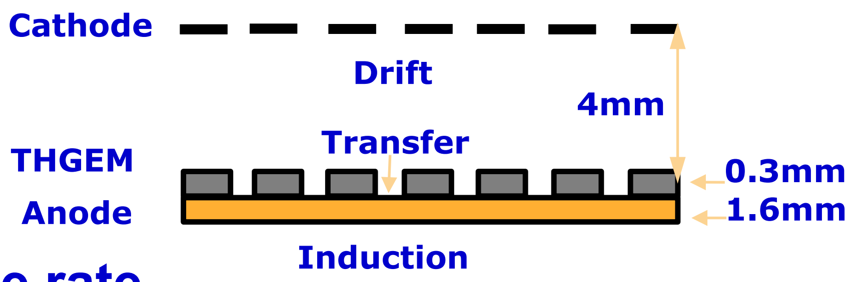


- Cross-talk between neighboring channels: 1.5%
- MIP efficiency with Ar+CO2 too low: 85% with HV on GEM foil @ 400V already
- High Ar percentage with a powerful quenching ingredient required: Ar/iC4H10(95/5) gives 99% efficiency

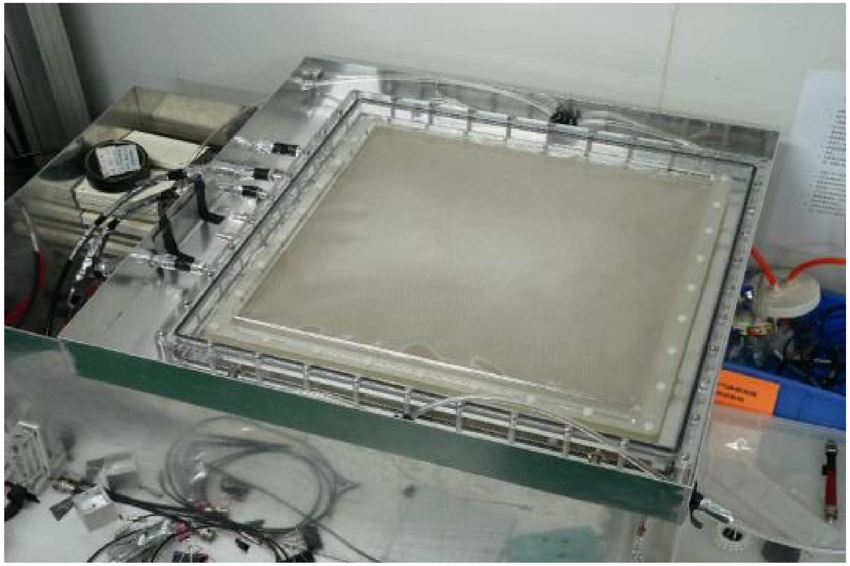
DHCAL: THGEM Option

- Three detector structures with THGEM
  - Double THGEM
  - Single THGEM
  - WELL-THGEM
    - Ideal option for HCAL
    - Thinner, high gain, lower discharge rate
    - R&D ongoing

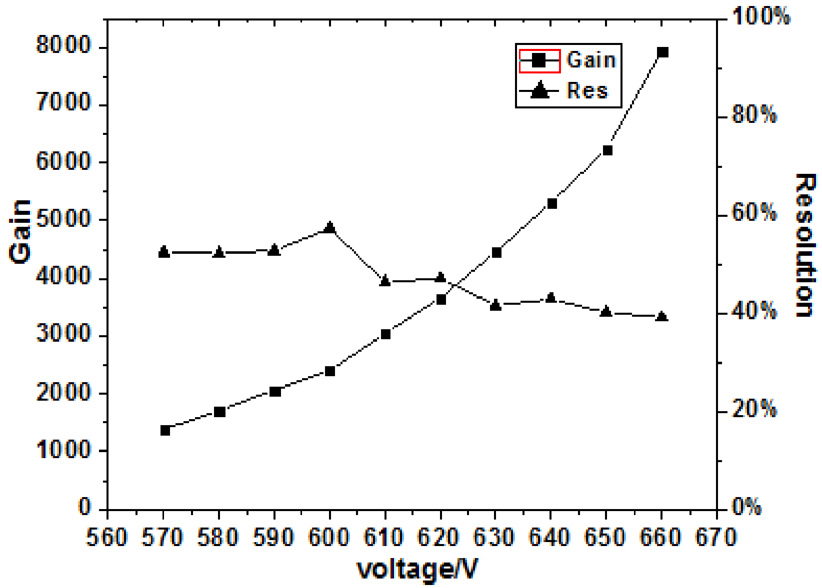
Thickness of WELL-THGEM < 6mm



40cm×40cm THGEM

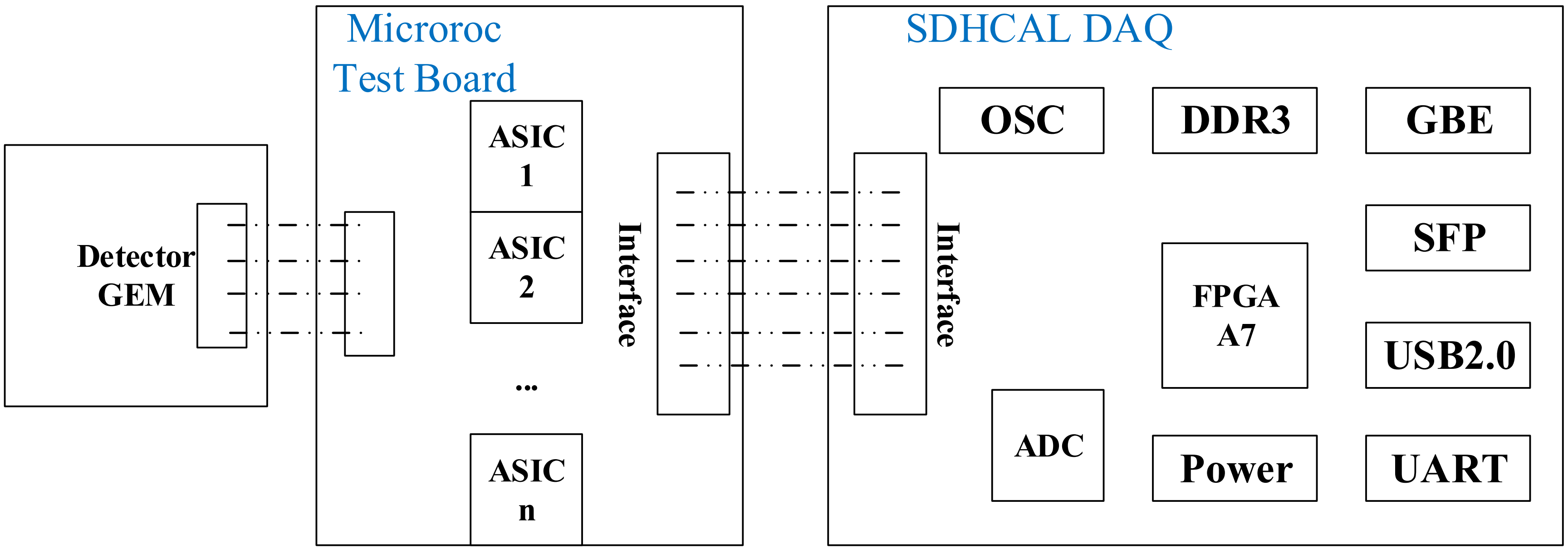


Gain measured of WELL-THGEM



DHCAL: GEM Option – Readout System R&D

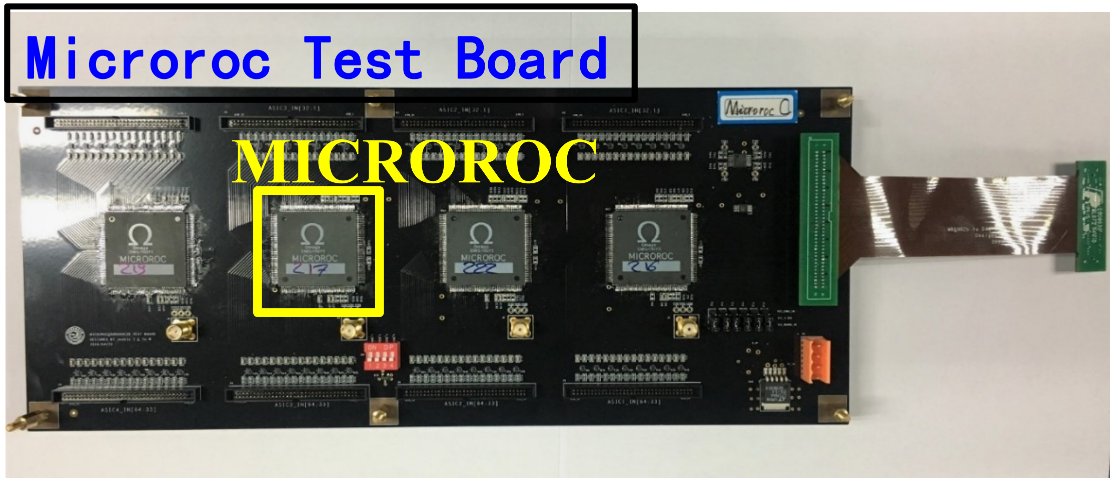
Digital readout system schematic :



- GEM detector readout composed of 900 $1cm^2$ pads
- MICROROC Test Board: 4 MICROROC ASICs Mounted, controlled by daisy chain
- DIF Board: Microroc control, test and data acquisition

DHCAL: GEM Option – PCB Board R&D

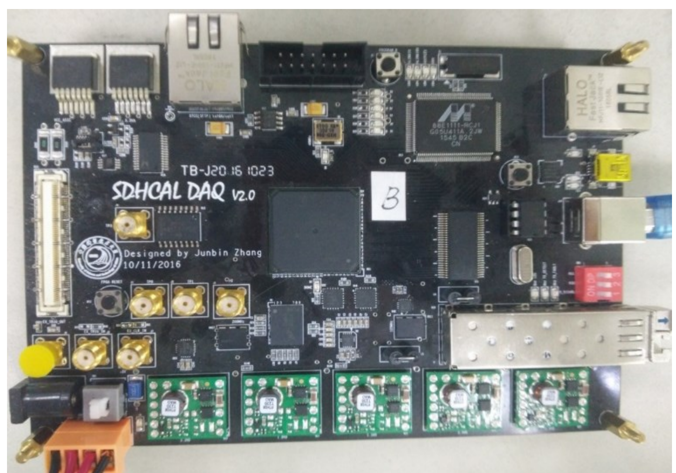
Microroc Test Board



MICROROC Parameters

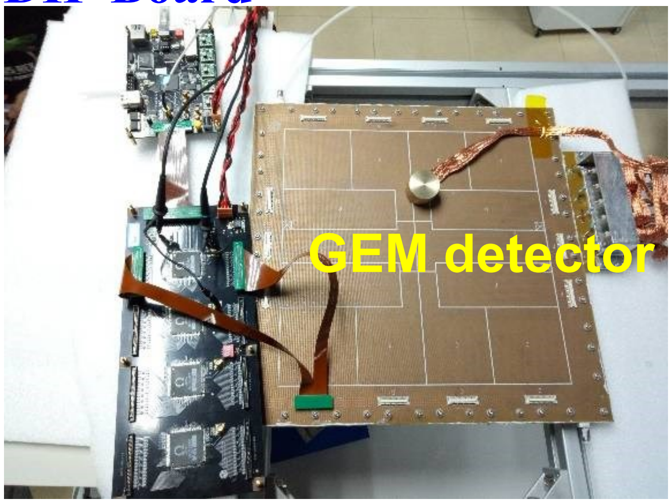
- ✓ Thickness: 1.4mm
- ✓ 64 Channels
- ✓ 3 threshold per channel
- ✓ 128 hit storage depth
- ✓ Minimum distinguishable charge: 2fC

DAQ Board

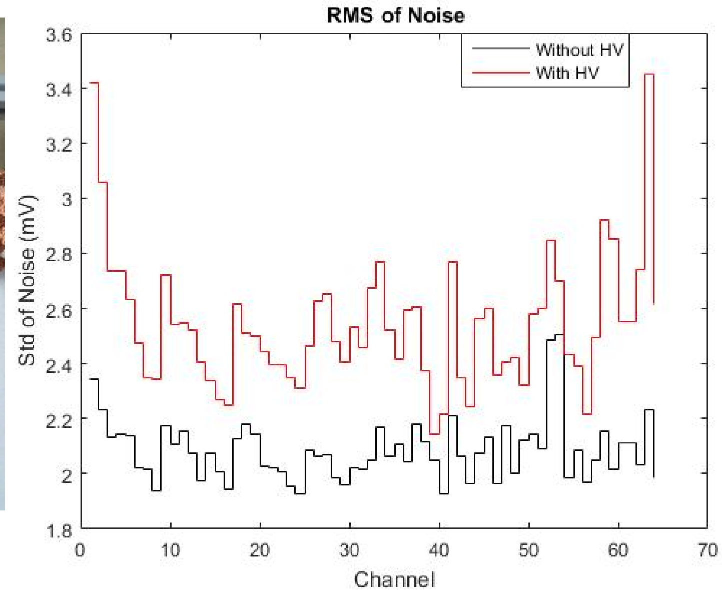


DHCAL: GEM Option – Test of Readout System

DIF Board

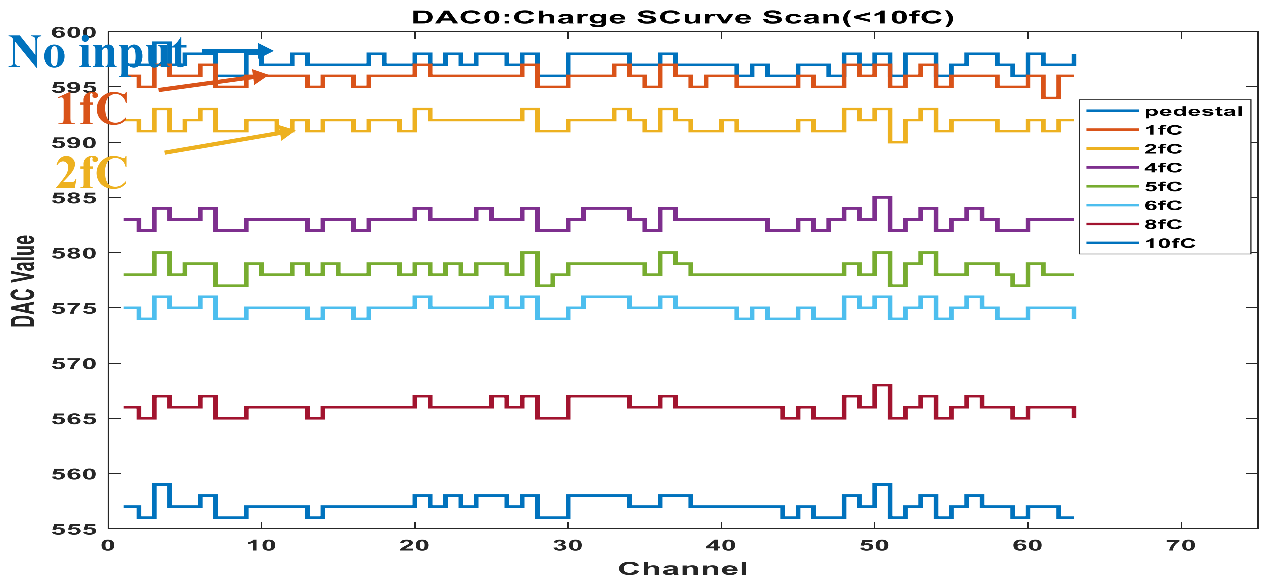


MICROROC Test Board



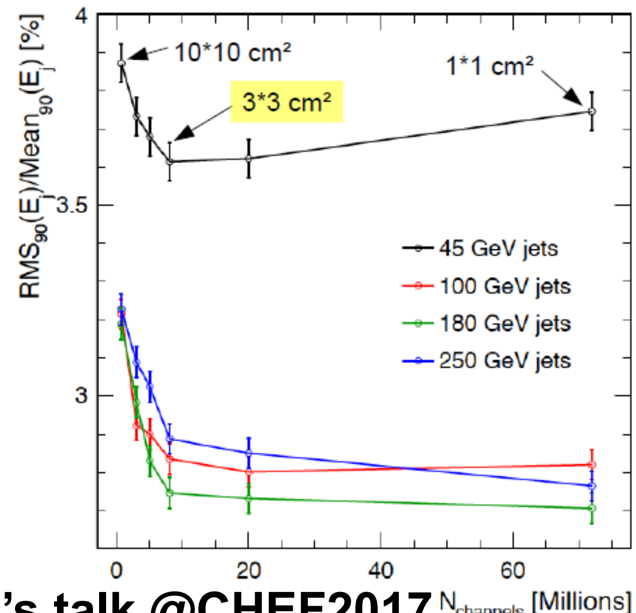
- Noise level without GEM detector ~0.25fC
- Noise level with GEM detector ~0.35fC

Uniformity check



AHCAL: Scintillator Option

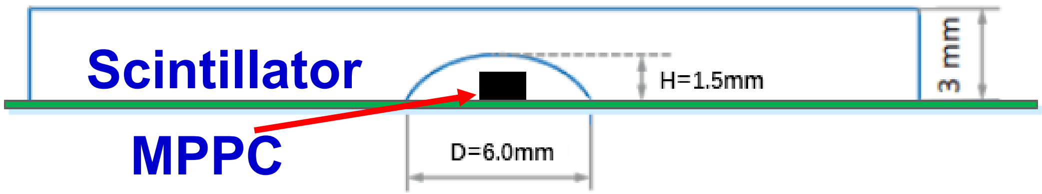
- Analog HCAL based on scintillator
  - The absorber: 2cm stainless steel
  - Base readout cell size: 3cm*3cm
    Readout chip: ASIC SPIROC2E
  - Sensitive detector : scintillator
  - Total number of readout channels of HCAL with 40 layers:
    - ~ 5 M (3cm*3cm)
    - ~ 3 M (4cm*4cm)



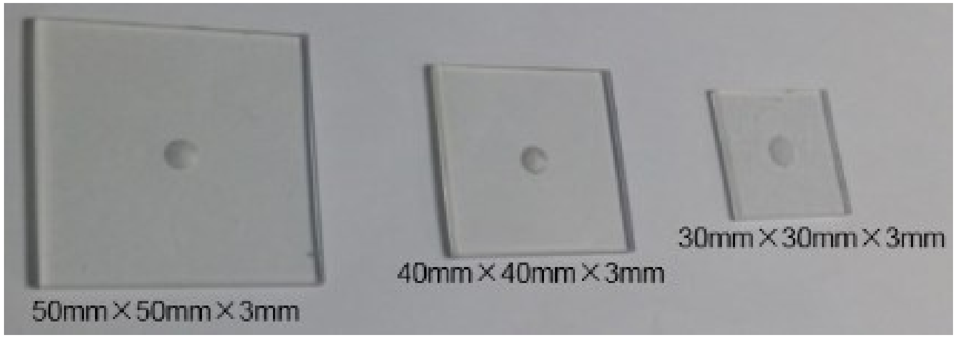
Katja's talk @CHEF2017

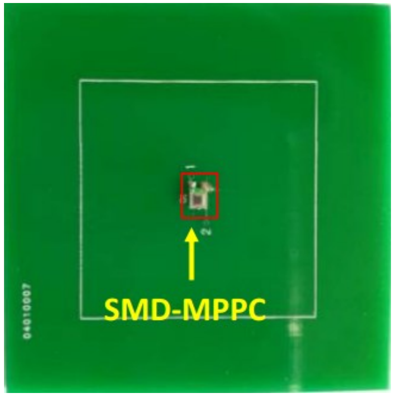
AHCAL: Scintillator Option – Detector Cell

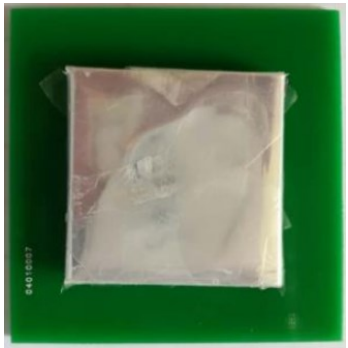
- A dome-shaped cavity is made at the center of plastic scintillator tile via mechanical drilling and polishing
- Surface-mounted SiPM for light readout
- Scintillator(BC408) tile wrapped by ESR foil
- Tile sizes variation: $30\times30\times3mm^3$, $30\times30\times2mm^3$, $40\times40\times3mm^3$, $50\times50\times3\ mm^3$



Scintillator tile wrapped by ESR foil was glued on the PCB

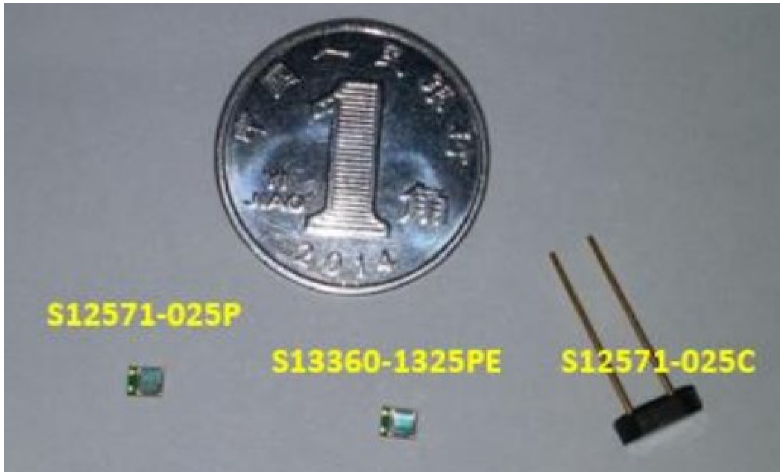


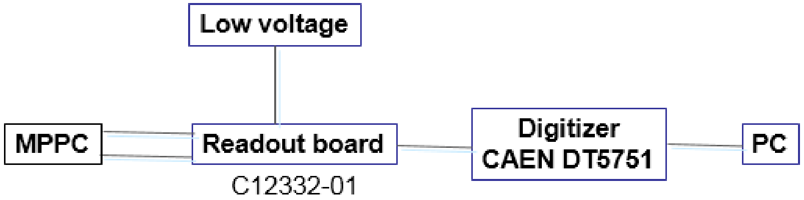




AHCAL: Scintillator Option - Readout Test

- Hamamatsu C12332-01 readout board
- Built-in temperature compensation keeps SiPM response stable

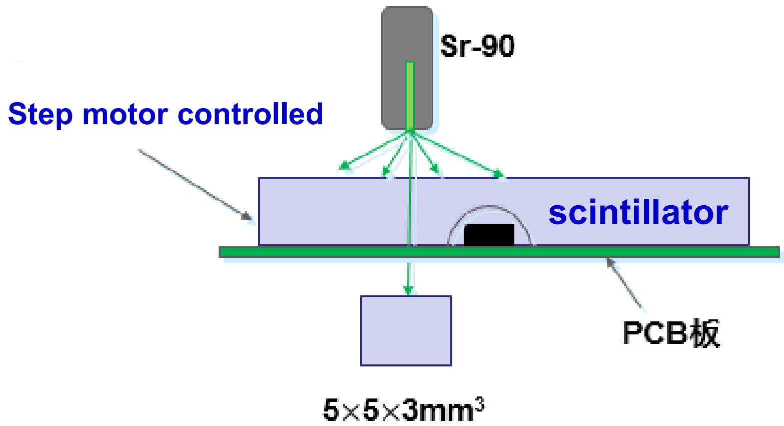




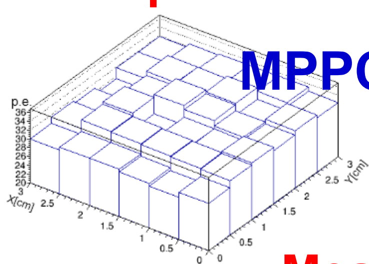
S12571-025P specs
Sensitive area :1×1mm^2
Pixel size :25×25μm^2
Pixel number:1600
Gain: 5.15E+05

S13360-1325PE specs:
Sensitive area :1.3×1.3mm^2
Pixel size :25×25μm^2
Pixel number:2668
Gain: 1.1E+06

AHCAL: Scintillator Option – Cell Response Uniformity



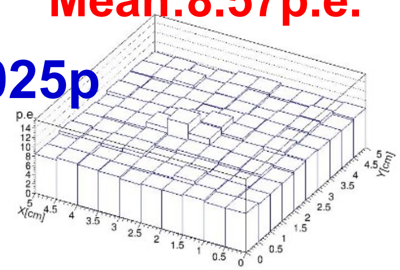
Mean:32.2p.e.



MPPC S12571-025p

30x30x3mm^3

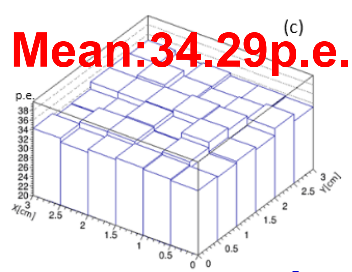
Mean:8.57p.e.



50x50x3mm^3

Uniformity ~ 10%

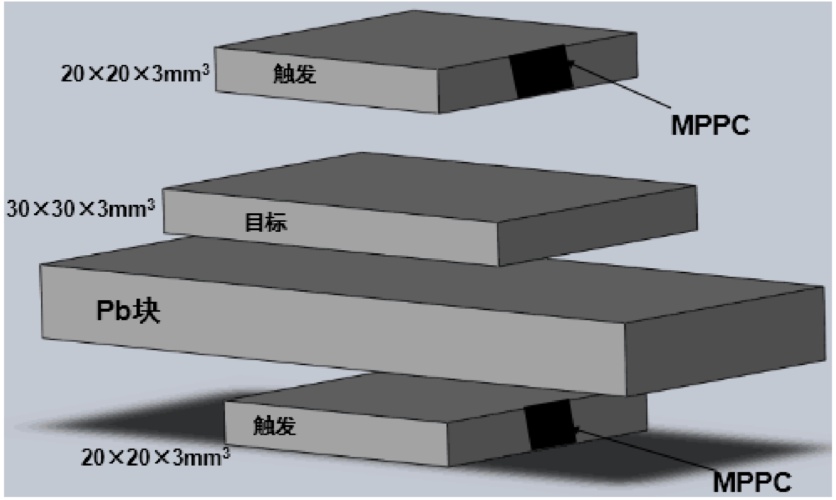
Mean:34.29p.e.



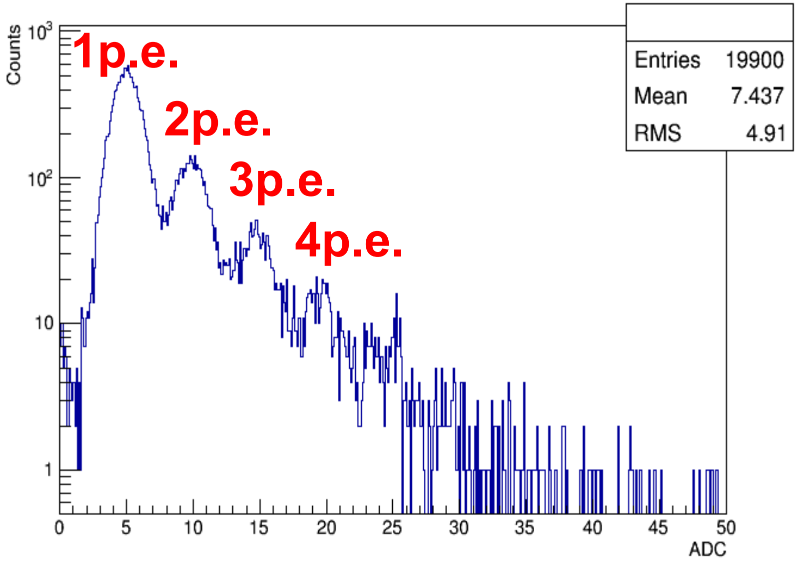
30x30x2mm^3

MPPC S13360- 1325PE

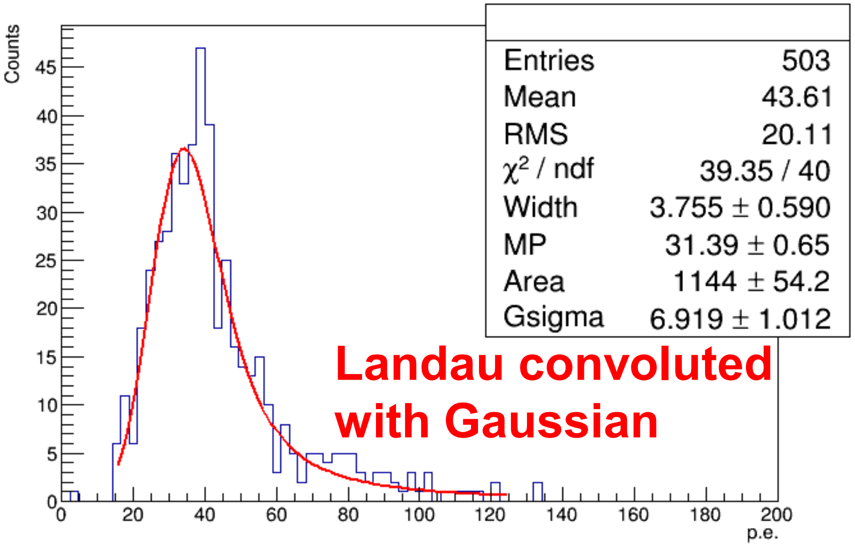
AHCAL: Scintillator Option – Cosmic-ray Test



- $30x30x3mm^3$, $30x30x2mm^3$, $40x40x3mm^3$, $50x50x3mm^3$
- SiPM type: S12571-025p, S13360-1325PE



SiPM dark count spectrum



Cosmic-ray energy spectrum

AHCAL: Scintillator Option - Test Results

Table 1 Cosmic-ray measurement results of detector cells with different sizes

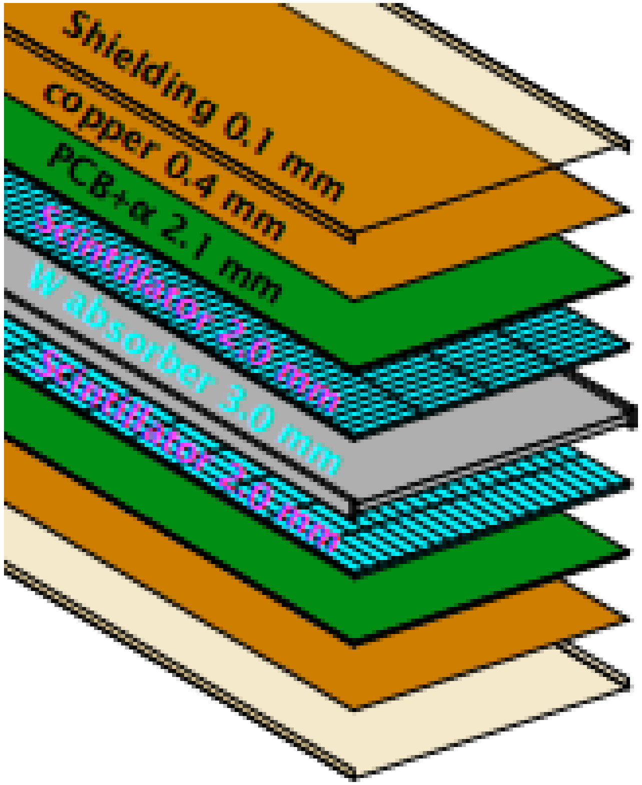
No.	Detector Cell	MPPC Type	Reflective Foil Type	Mean $N_{p.e.}$	Polishing Methods
1	$30\times30\times3mm^3$	S12571-025P	ESR	31.39±0.65	Ultra Precise Polishing
2	$30\times30\times3mm^3$	S12571-025P	ESR	22.55±0.7	Precise Polishing
3	$30\times30\times3mm^3$	S12571-025P	ESR	18.92±0.39	Rough Polishing
4	$30\times30\times3mm^3$	S12571-025P	TYVEK	13.63±0.33	Precise Polishing
5	$40\times40\times3mm^3$	S12571-025P	ESR	14.89±0.73	Precise Polishing
6	$50\times50\times3mm^3$	S12571-025P	ESR	9.87±0.43	Precise Polishing
7	$30\times30\times2mm^3$	S13360-1325PE	ESR	33.89±0.49	Precise Polishing

- **MIP responses in most of the above cell configurations are rather efficient**
- **Optimized detector cell size: 30*30*2mm^3**

ECAL: Scintillator Option

ECAL with scintillator option

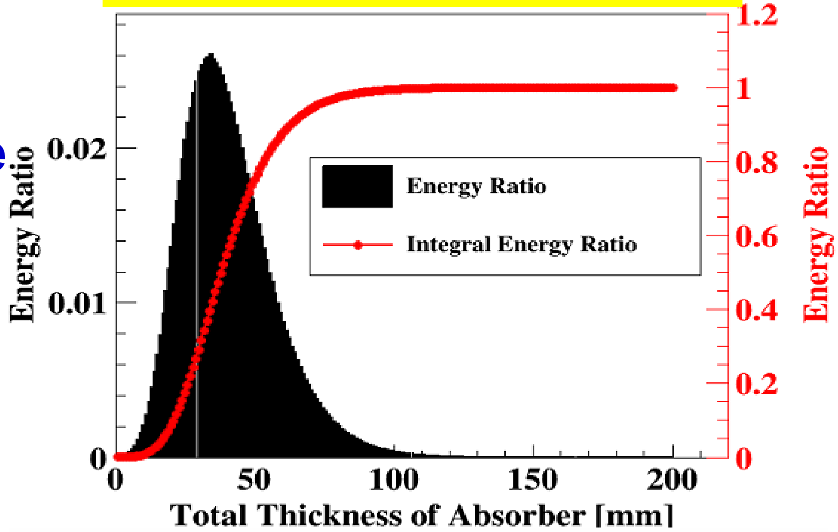
- A sampling calorimeter with scintillator-tungsten sandwich structure (ScW)
  - Sandwich structure: absorber + scintillator readout module + PCB
  - Scintillator readout module: Scintillator + SiPM
  - Absorber: Tungsten

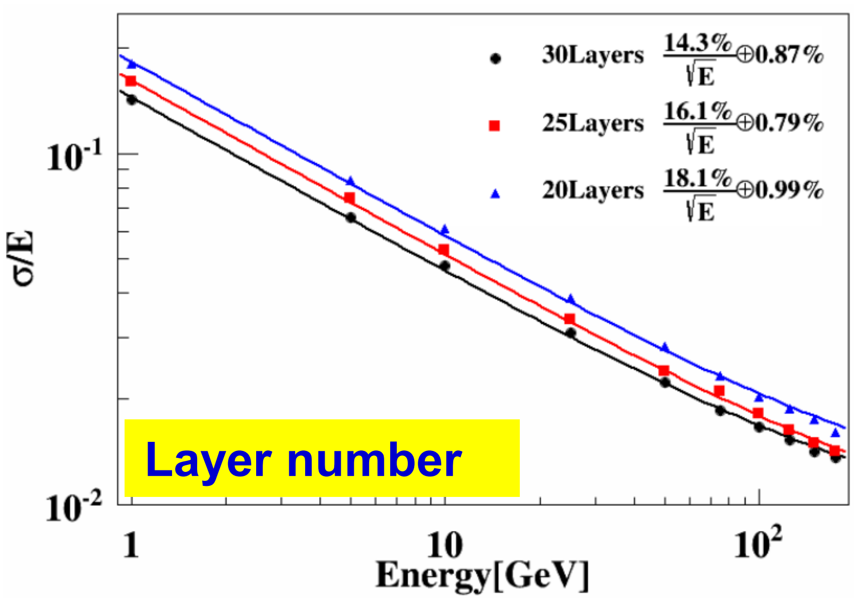


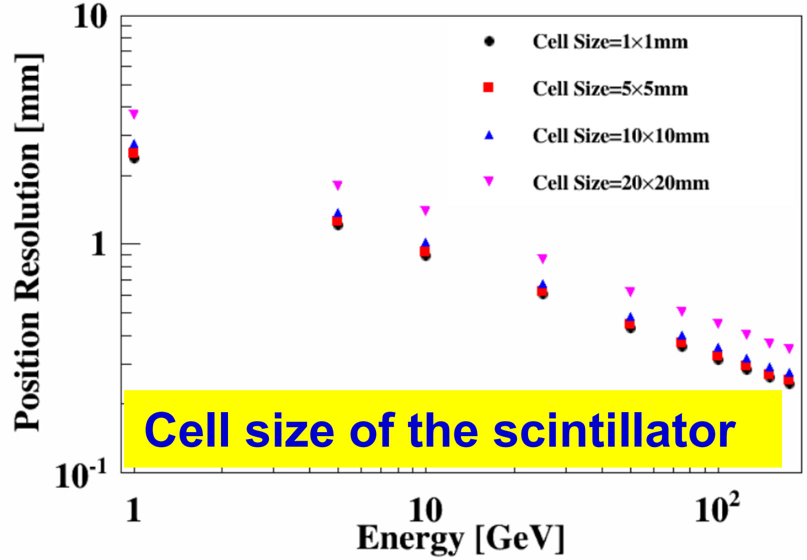
ECAL: Scintillator Option – Design Optimization

- Structure and geometry optimization done using simulation samples
- Thickness of the absorber, layer number, cell size and thickness of the scintillator
  - Thickness: 80~90mm
  - Layer number: 30

Thickness of the absorber



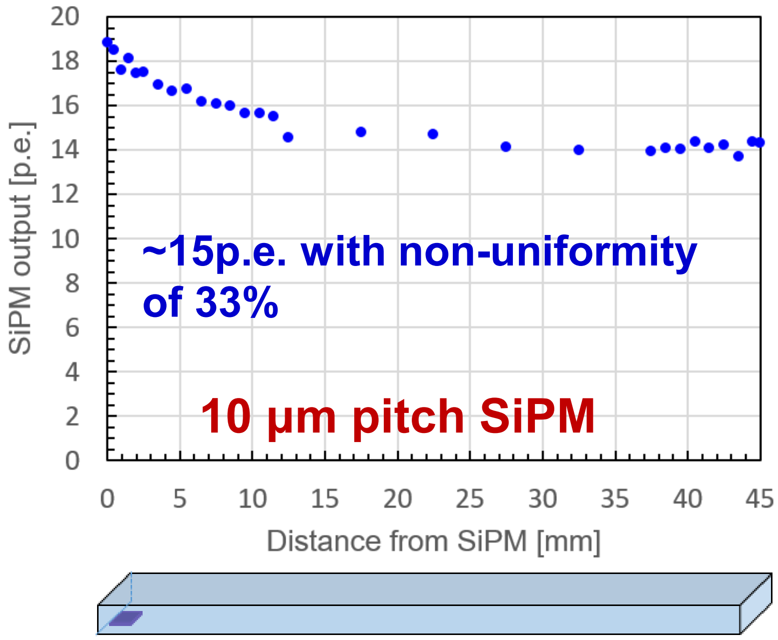


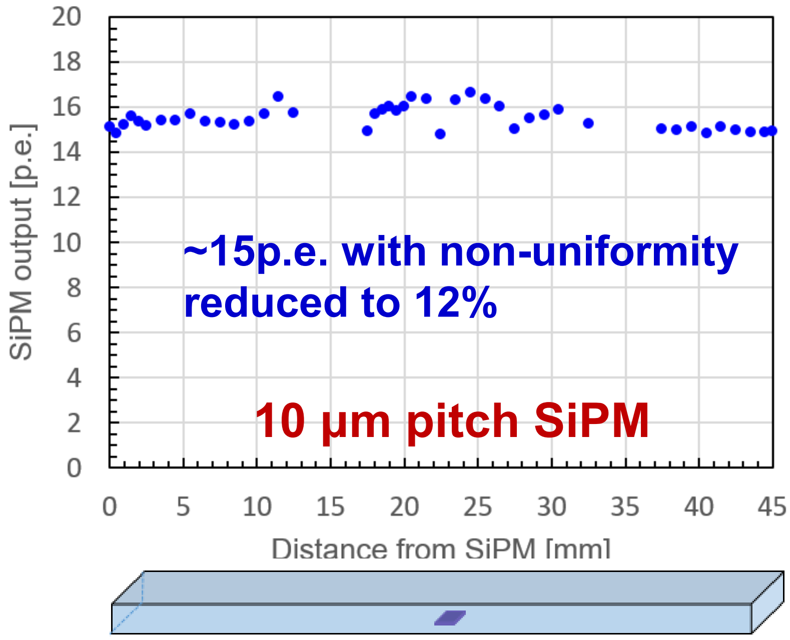


ECAL: Scintillator Option – Module Simulation

Standalone Geant4 simulation is used to optimize scintillator module

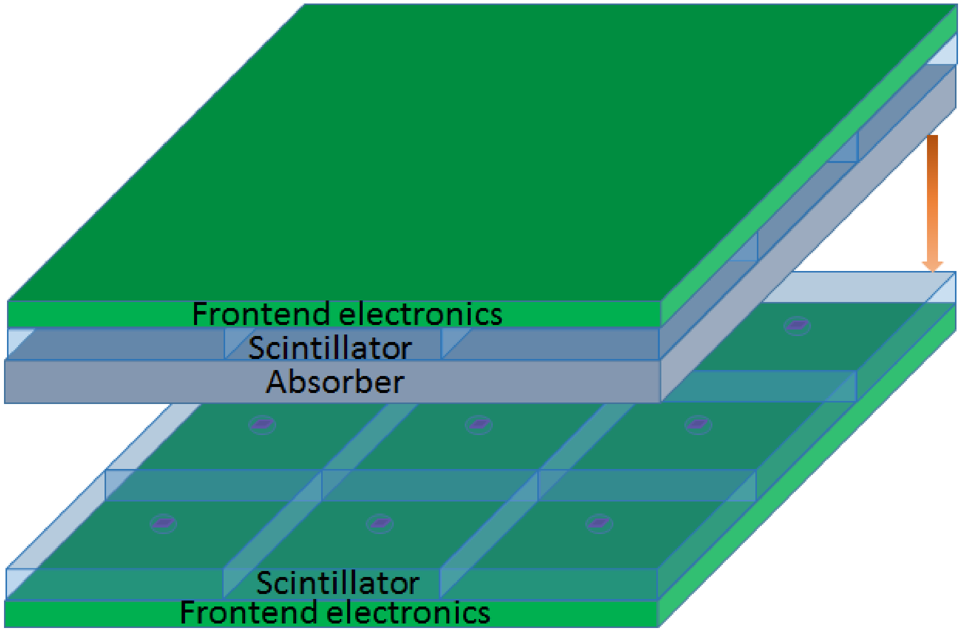
- PhysicsList: QGSP_INCLXX + Standard Geant4 Optical Physics (Version: Geant 4.10.3)
- Scintillator Strip: BC408, dimension: 45×5×2mm³
- SiPM: 1×1×0.1mm3 , Pitch size 25µm, 1600pixel
- Cladding: ESR, Tyvek
- Particle source: Sr-90, Center of the Strip, Vertical incidence

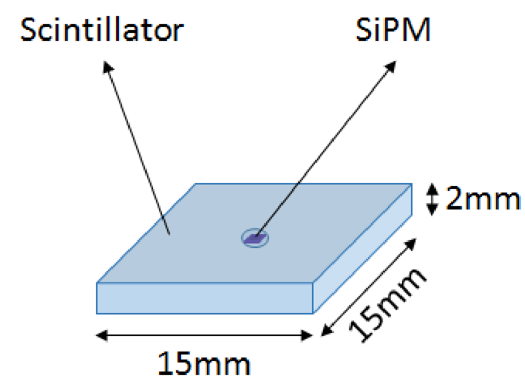




The bottom-center coupled mode is chosen for the prototype

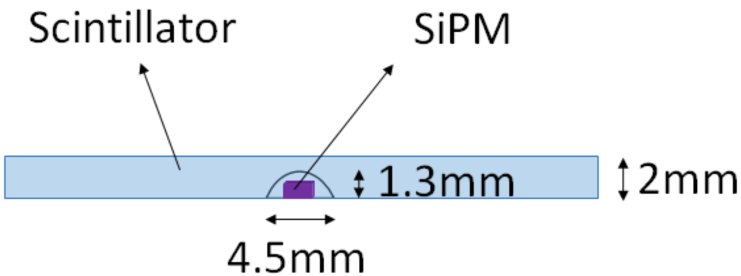
ECAL: Scintillator Option – Module Optimization

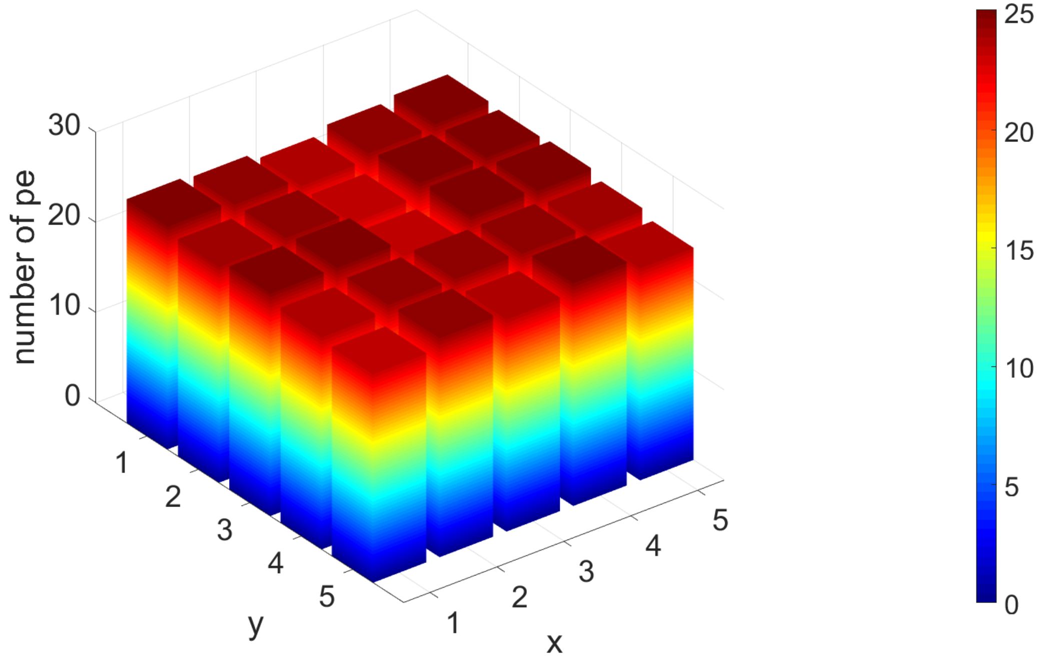




- Both strip and square scintillator modules tested and compared
  - Total number of the modules the same
- Geant4 simulation results suggest the cell size of square module could be enlarged to 15mm×15mm
- SiPM embedded into the dome-shaped cavity of the scintillator
- Relative simple reconstruction algorithm
- No dead area

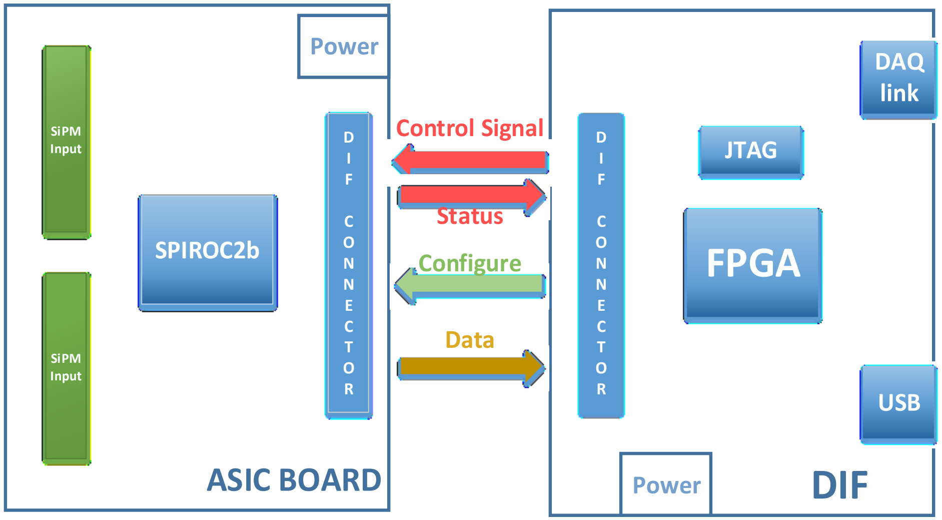
ECAL: Scintillator Option – Square Module Test





- Module output: 22 p.e. for MIP, slightly higher than strip module
- Better output uniformity (<10%) than strip module
- Further tests are needed

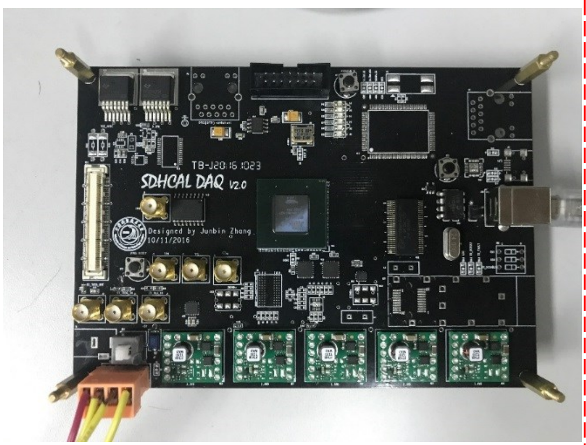
ECAL: Scintillator Option – Readout System R&D



Readout System Schematic

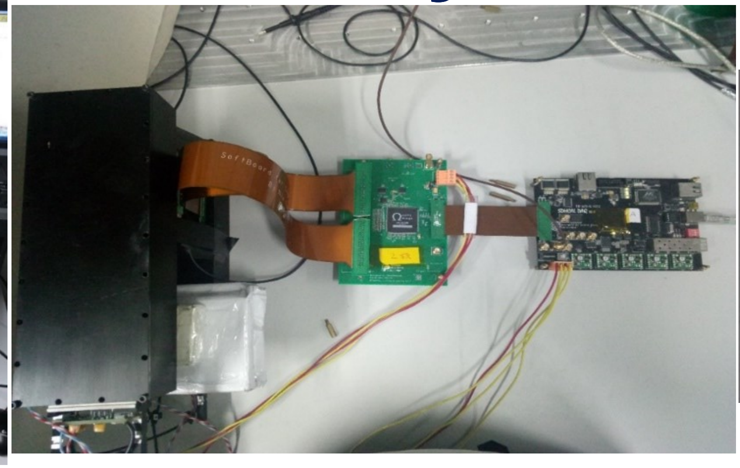
- ASIC board is developed with **SPIROC2b** chip, which performs amplification, auto-triggering, digitization and zero-suppression
- DIF plays the role of collecting data and configuring chip before system running
- USB for data upload & commands sending
- USB for single DIF, and serial port for DAQ when using multiple DIF

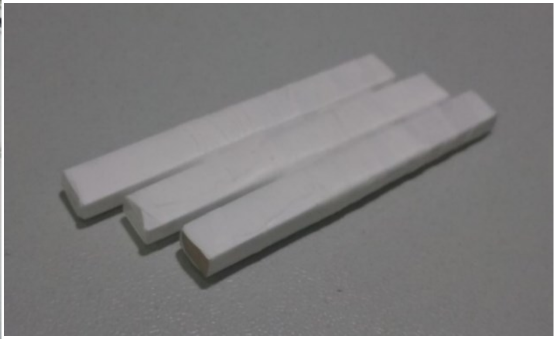
FEB



DIF

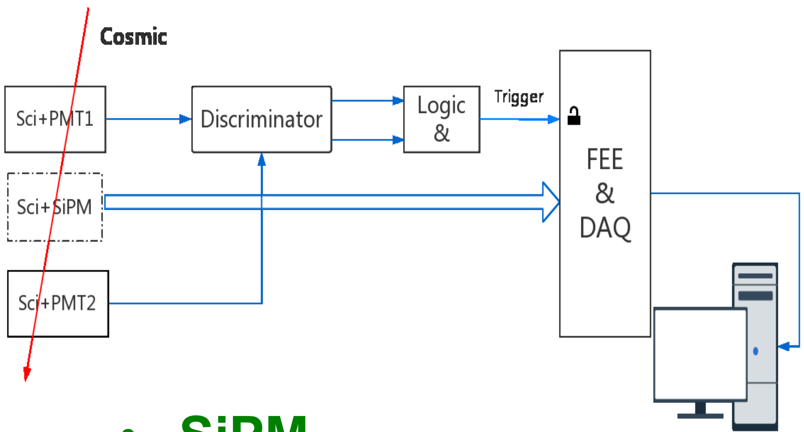
ECAL: Scintillator Option – Cosmic-ray Test





Test Platform

Cosmic ray test

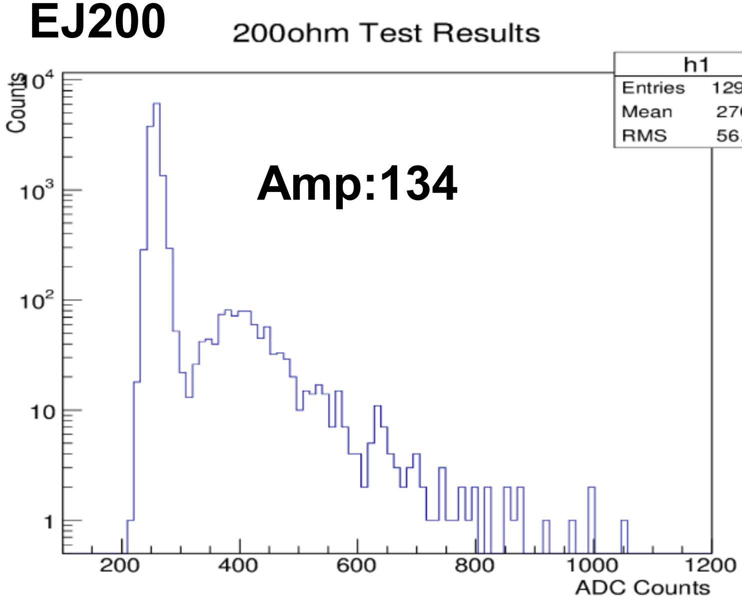


- **SiPM**
  - **S12571-010P**
  - **1mm×1mm**
  - **10k pixels**

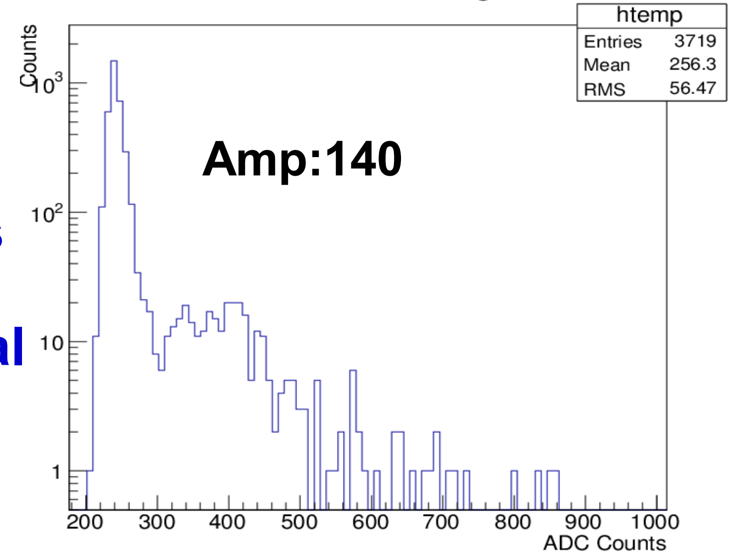
- **Three different scintillator materials were tested using cosmic rays**
  - **Plastic scintillator**
    - **BC408**
    - **EJ200**
  - **Crystal**
    - **BGO crystal**

ECAL: Scintillator Option – Cosmic-ray Test

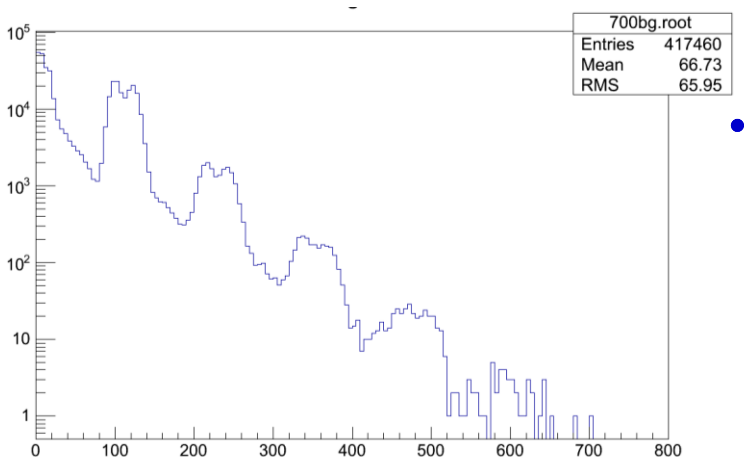
EJ200



BC408



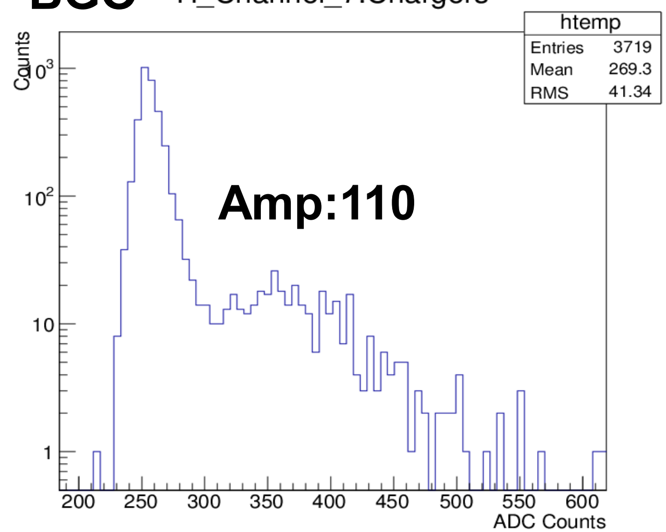
- **Peak of MIPs separated from pedestal clearly**



Spectrum of SiPM dark noise

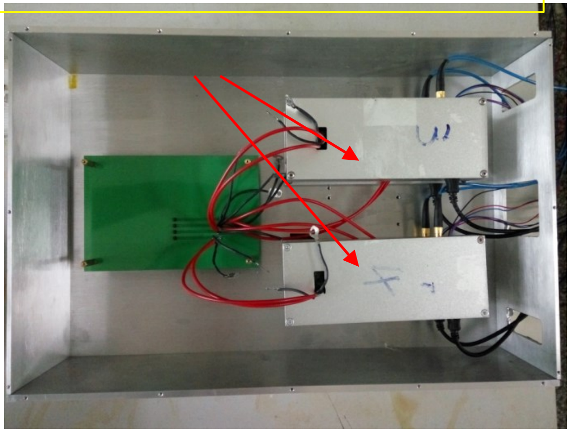
- **Electronics working with good performance**

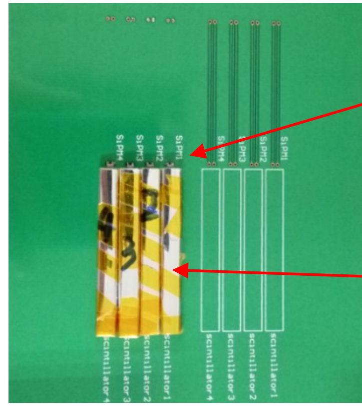
BGO



ECAL: Scintillator Option – Beam Test

Driver circuit: C12332-01

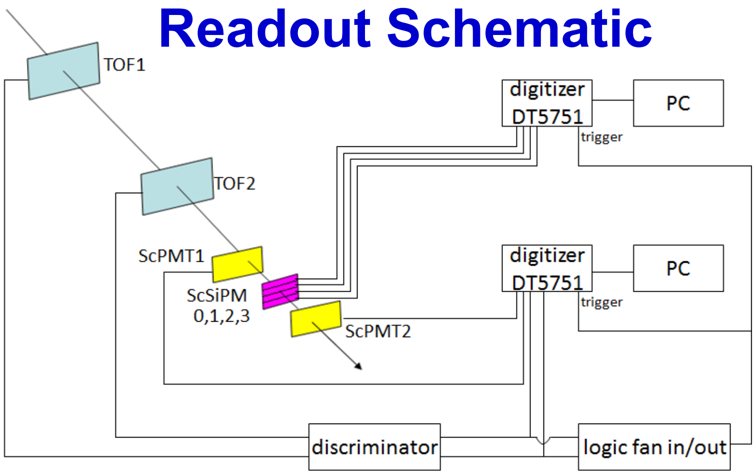




S12571-025P (Hamamatsu)

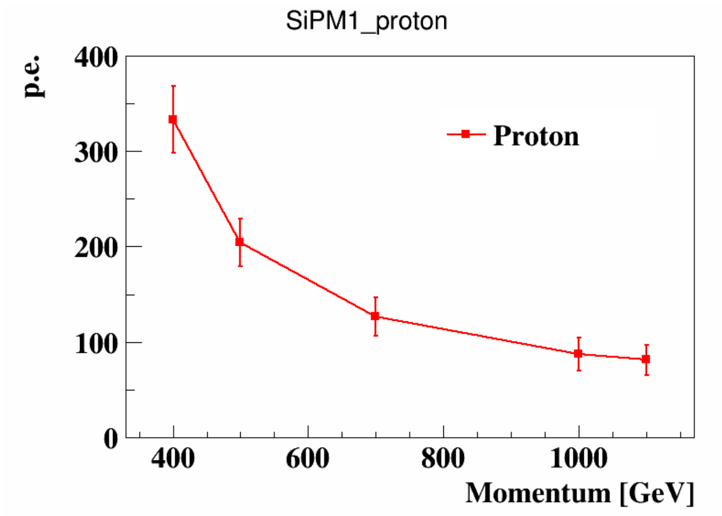
BC408 with dimension of 45mm×5mm×2mm

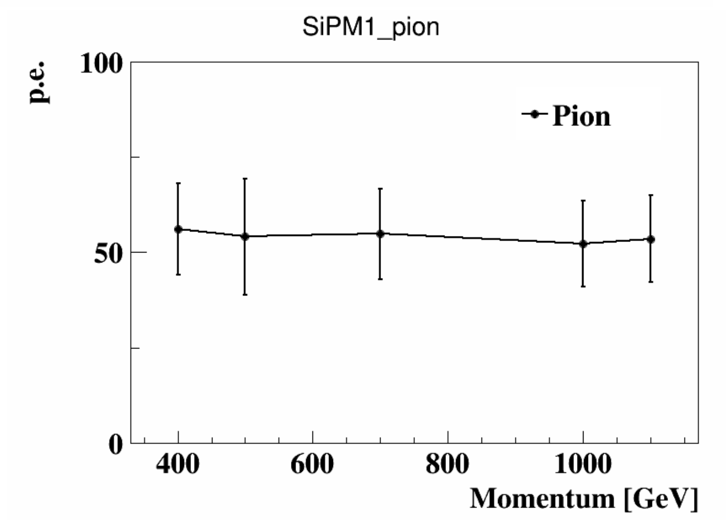
Readout Schematic



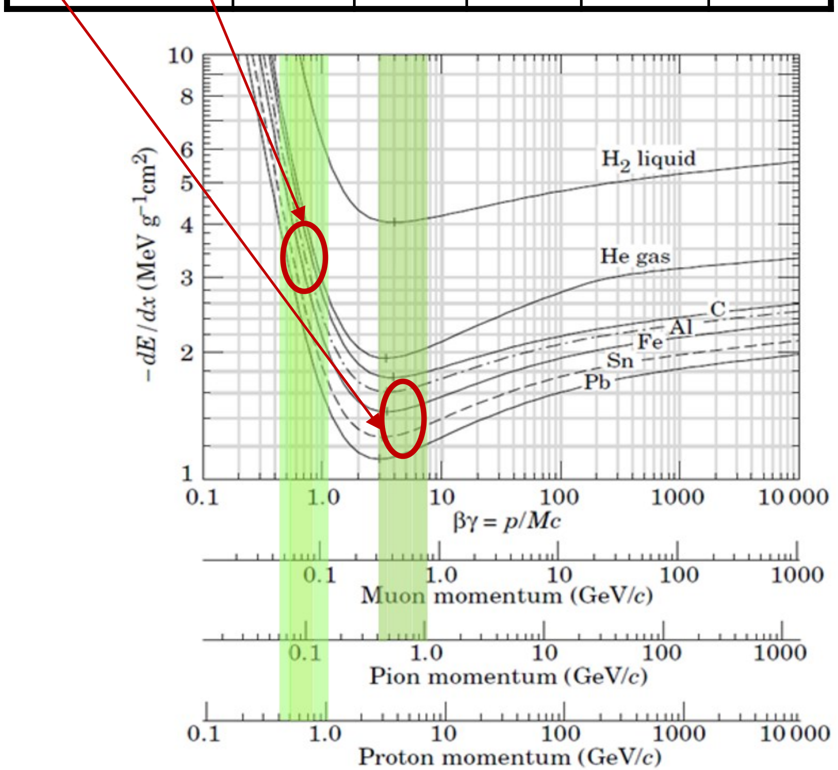
- Mini prototype was constructed and tested by test beam to study layout and coupling mode of the scintillator and SiPM
- Performed at E3 beam at IHEP, proton and pion mixed irradiation, momentum of the particles range from 400MeV to 1.1GeV

ECAL: Scintillator Option – Energy deposition and momentum





Momentum (MeV/c)	400	500	700	1000	1100
βγ(proton)	0.43	0.53	0.75	1.07	1.17
βγ(pion)	2.87	3.59	5.02	7.17	7.89



- **dE/dx (proton and pion) consistent with expectation**

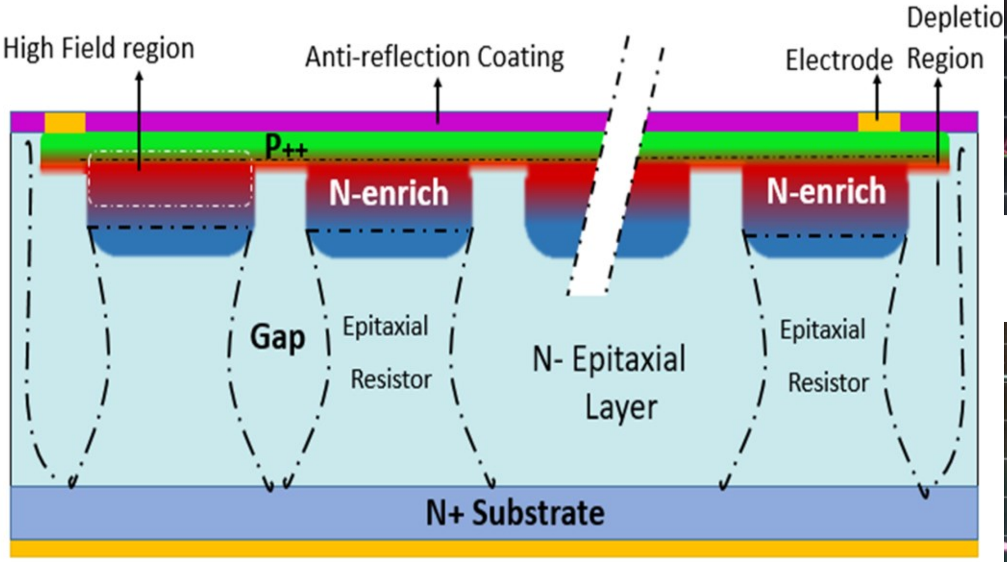
Summary and Outlook

- ✓ CEPC calorimeter R&D well underway
  - ✓ HCAL & ECAL
  - ✓ Aiming for PFA calorimeter with high granularity
- ✓ Lots of R&D to be done
  - ✓ Build a sizable HCAL/ECAL prototype
  - ✓ Beam test
  - ✓ Other critical R&D items
- ✓ Welcome worldwide collaboration
  - ✓ Close collaboration with IPNL already fruitful
  - ✓ Joined efforts within CALICE collaboration
  - ✓ Become more integrated into global PFA calorimeter R&D activities in the future

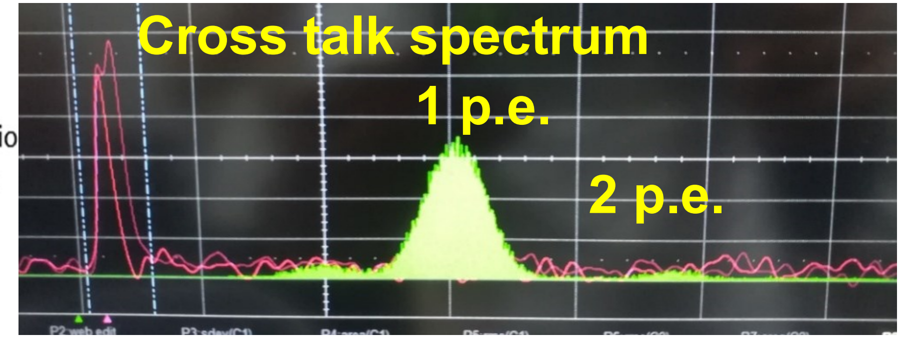
Backup

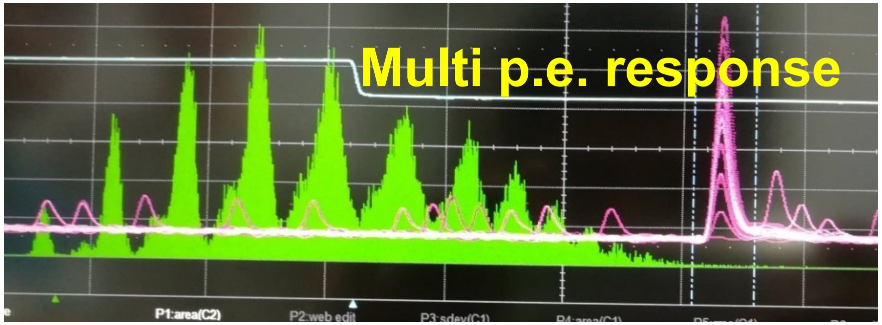
Chinese NDL SiPM

- Chinese Beijing Normal University (BNU) has developed silicon photomultiplier (SiPM) technology with epitaxial quenching resistors (EQR).
- NDL EQR-SiPM is easy to implement owning to its unique structure featuring intrinsic continuous and uniform cap resistor layer, hence reducing the cost of the fabrication.



Schematic structure of EQR SiPM





Parameters and performance of NDL SiPM

	NDL SiPM	
Effective Active Area	11-3030 B-S	22-1414 B-S
	3.0×3.0 mm^2	1.4×1.4 mm^2 (2×2 Array)
Effective Pitch	10 μm	10 μm
Micro-cell Number	90000	19600
Fill Factor	40%	40%
Breakdown Voltage (V_b)	23.7±0.1V	23.7±0.1V
Measurement Overvoltage (V)	3.3	3.3
Peak PDE	27%@420nm	35%@420nm
Max. Dark Count (kcps)	< 7000	<1500
Gain	2×10^5	2×10^5
Temp. Coef. For V_b	17mV/° C	17mV/° C

Good performance,
Room for improvement

Higher dynamic range
Higher fill-factor

High Dark count rate

Slightly low gain