The R&D progress of CEPC HCAL

Yu Boxiang

On behalf of the CEPC Calorimeter working Group

State Key Laboratory of Particle Detection and Electronics, China
Institute of High Energy Physics, CAS

CEPC Workshop,25 May 2018, Rome

Outline

— Requirements of CEPC Calorimeter

— The options of CEPC-HCAL;

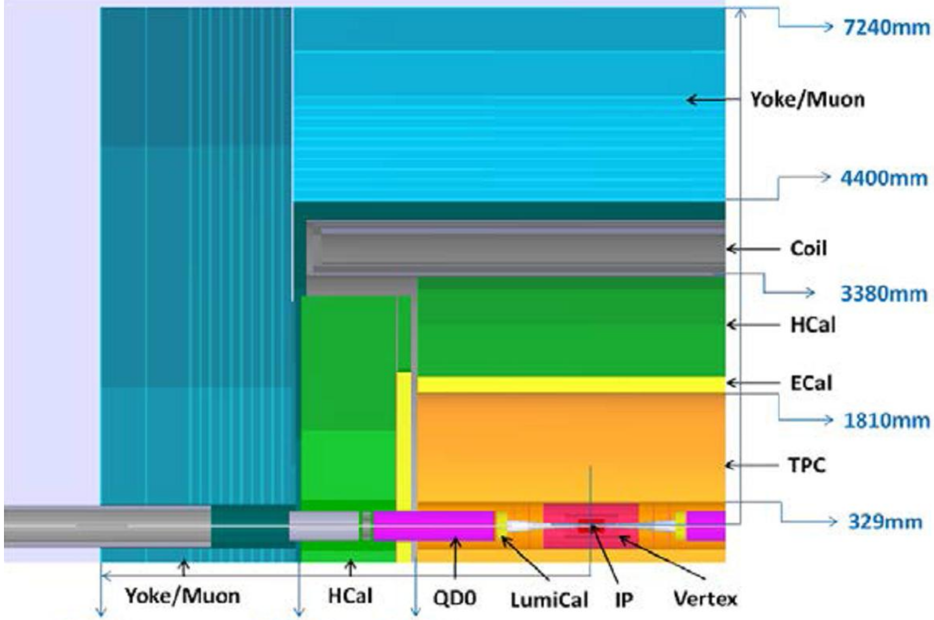
— The progress of two option of HCAL
  - DHCAL based on RPC and MPGD(THGEM/GEM);
  - AHCAL based on scintillator;

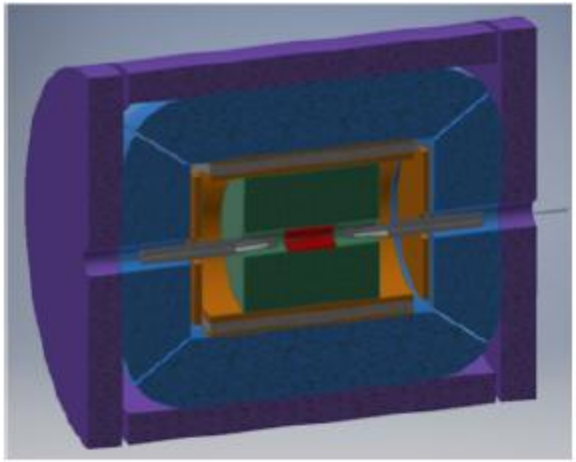
— Summary

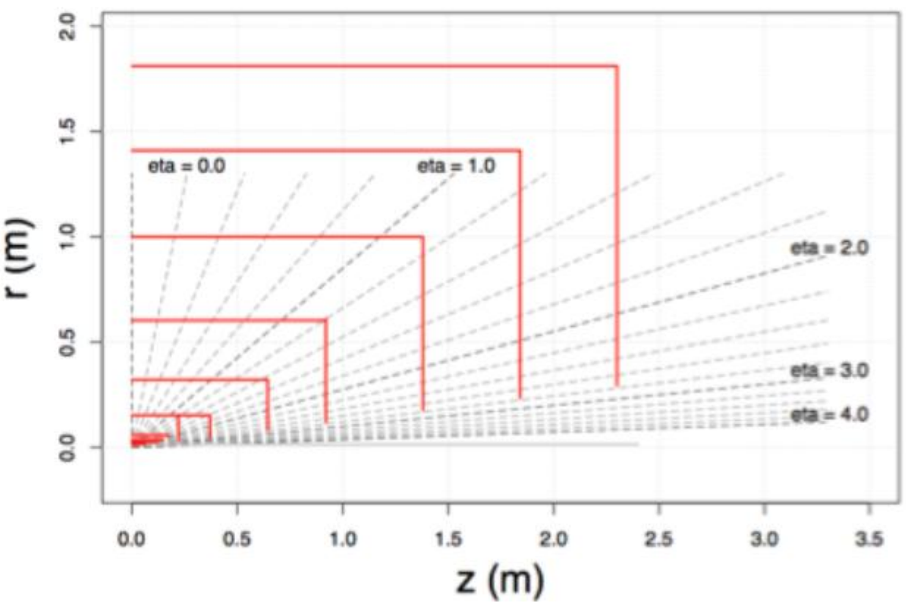
Requirements of CEPC Calorimeter

- Jet energy resolution (HCAL combined with ECAL and tracker):
  $\sigma_E/E \approx (3\% - 4\%)$ @100GeV

- High granularity, Compact showers(small radiation length X_0, and small Moliere radius R_M),
  Minimum dead materials



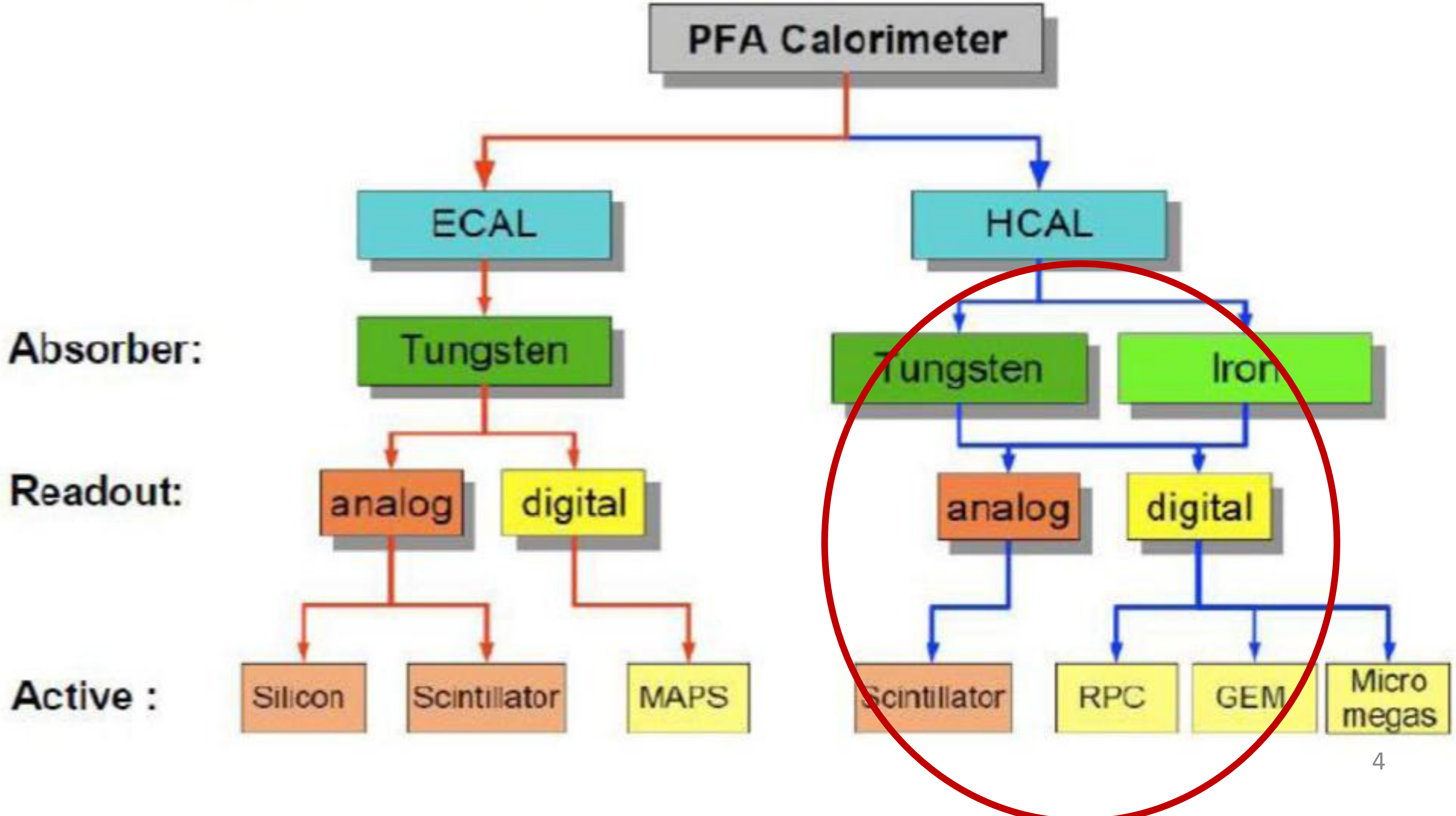




The options of CEPC-HCAL;

Two options:

1. Digital HCAL (DHCAL): Gas detector, RPC & MPGD(THGEM/GEM)
2. Analog HCAl (AHCAL): Plastic scintillator



CEPC high granularly calorimeter study

— Hardware
- CEPC-ECAL (Mingyi‘s talk)
  - ➢ 3 Institutions: USTC+IHEP+LLR
- CEPC-HCAL
  - ➢ 4 Institutions: USTC+IHEP+SJTU+IPNL

— Simulation & Optimization(Bing‘s talk and Hang‘s talk)
- PFA
  - ➢ 3 Institutions: IHEP+LLR+IPNL
- Geometry optimization
  - ➢ 2 Institutions: IHEP+SJTU

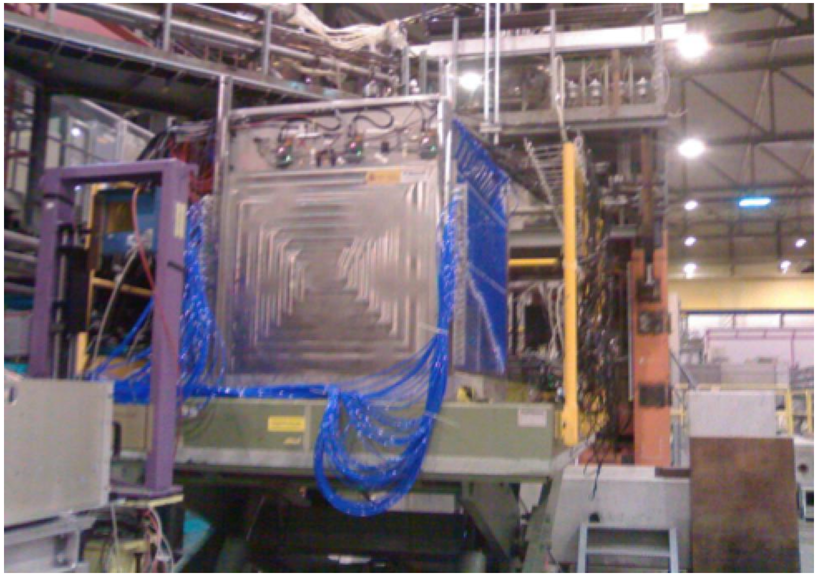
SDHCAL Based on RPC（IPNL+SJTU within CALICE）

SDHCAL Prototype

- **Total Size:1.0x1.0x1.4m^3**
- **Total Layers: 48**
- **Total Channel(pads):440000**
- **Power consumption:$10\mu W/channel$**

(Power pulsing)

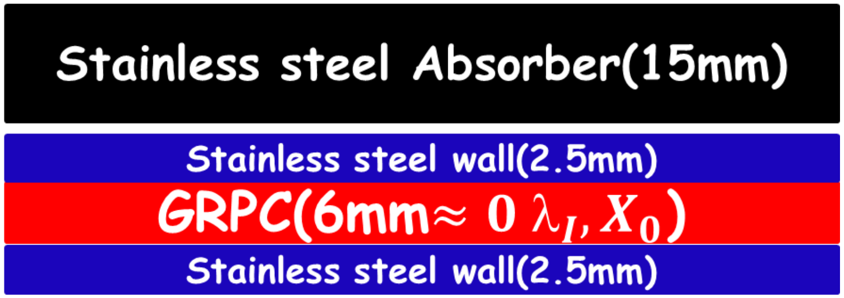
the first technological prototype among a family of prototypes of high-granularity calorimeters

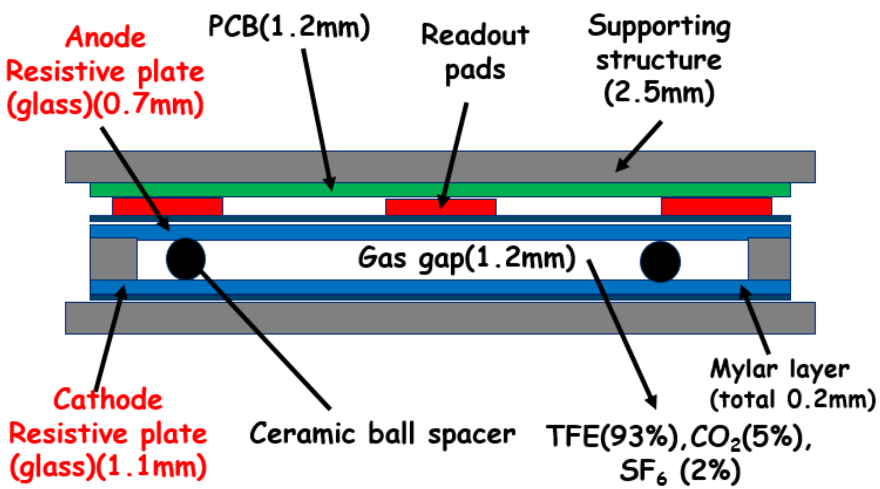


Developed by the CALICE collaboration

Structure of sampling layer

$(0.12\lambda_I, 1.14X_0)$



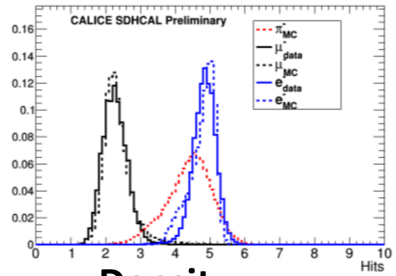


ASIC HARDROC(64 channel)
three-threshold (Semi-digital)
110fC,5pC,15pC

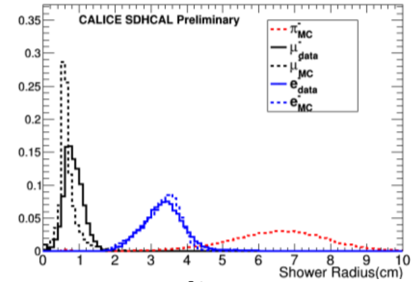
Analysis of test beam data： Particle identification using BDT in SDHCAL

◆ **BDT 6 var Input:**

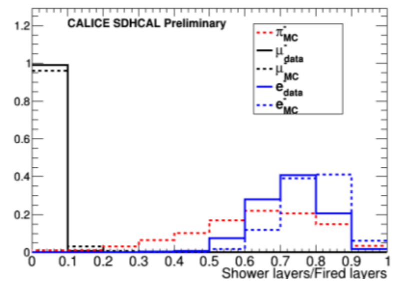
1. First layer of the shower(Begin)
2. Number of tracks in the shower (TrackMultiplicity)
3. Ratio of shower layers over total fired layers(NInteractinglayer/Nlayers)
4. Shower density(Density)
5. Shower radius(Radius)
6. Maximum shower position(Length)

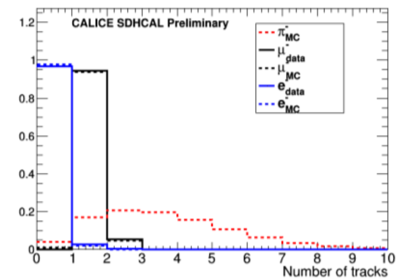


Density



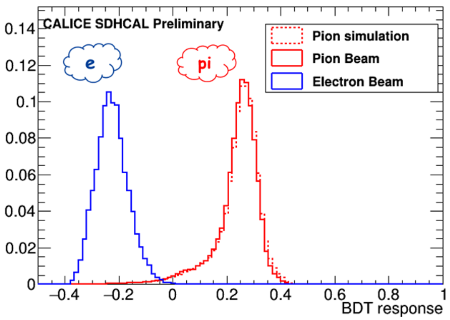
Radius

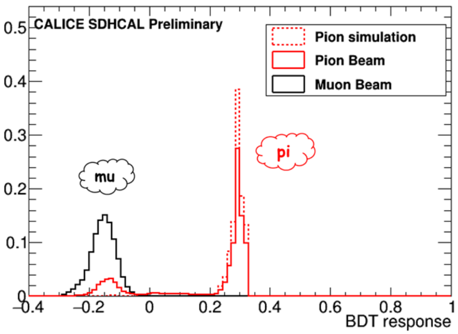




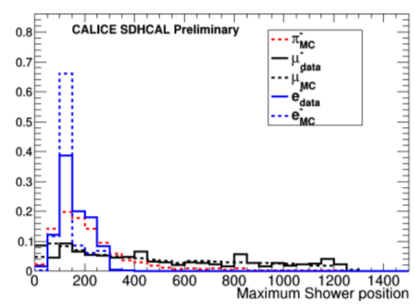
Track multiplicty

Shower layers / fired layers

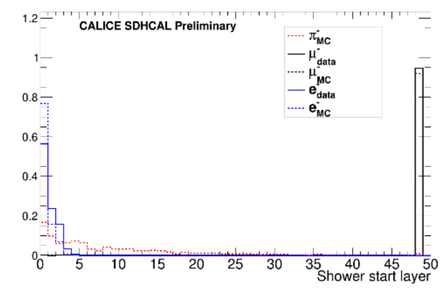




BDT responce



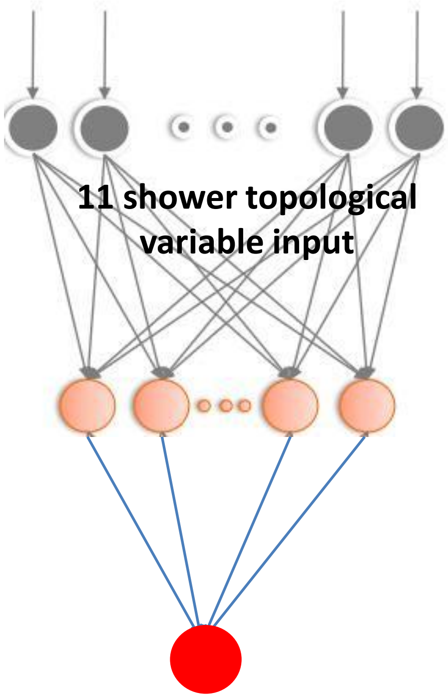
Shower Length



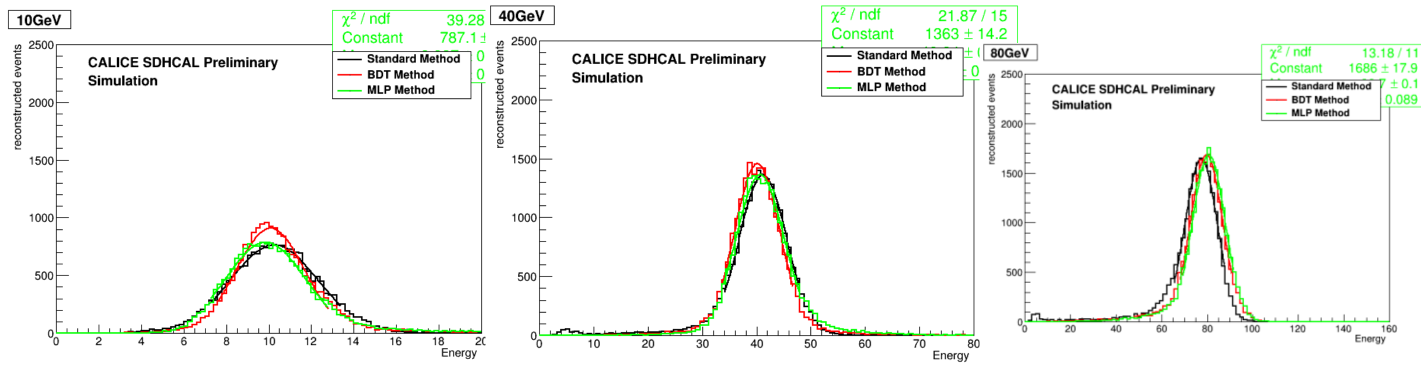
Begin

Analysis of test beam data： Energy reconstruction using MLP and BDT

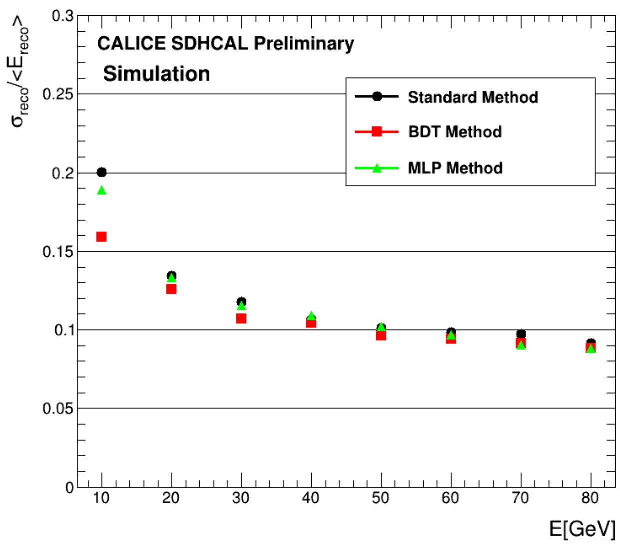
MLP Structure

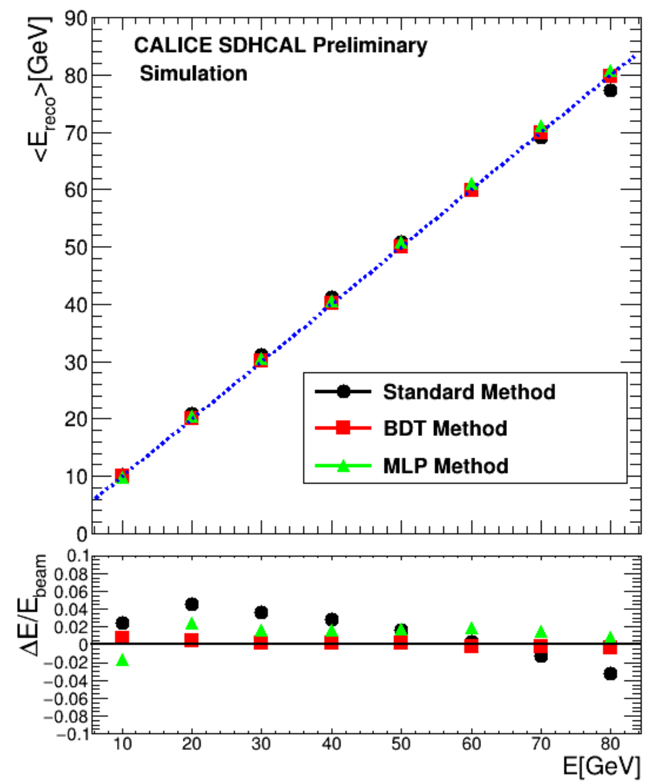


Energy reconstruction

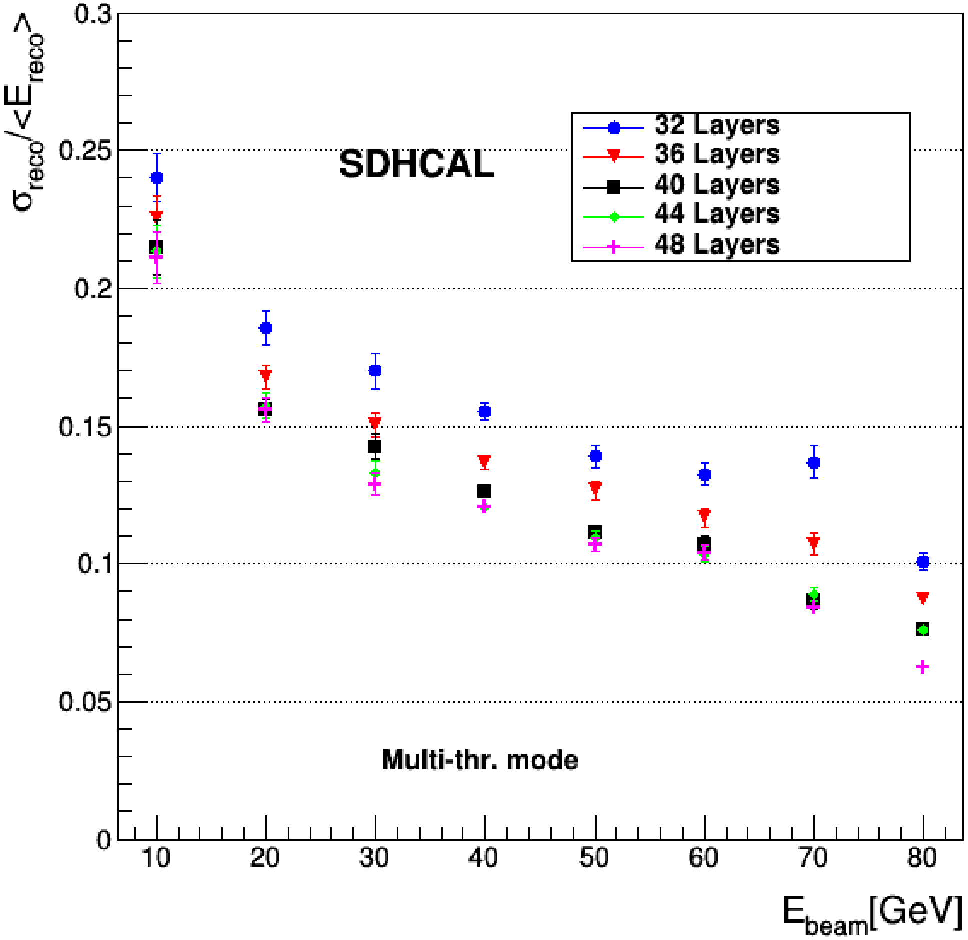


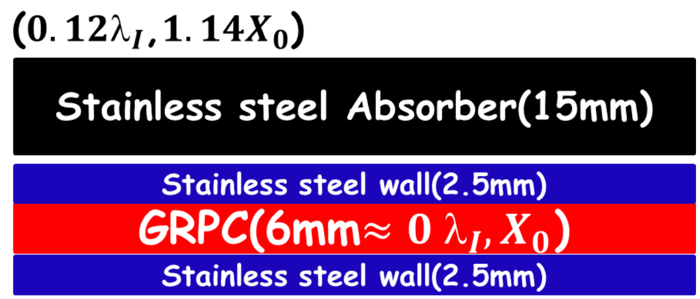
One hidden layer





Optimization of SDHCAL Layers



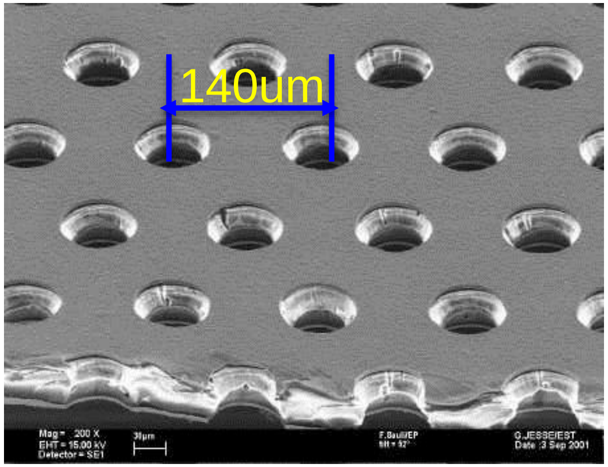


➔SDHCAL has 48 layers which aims for ILC Detector
- 6mm RPC+20mm absorber

➔Optimization no. of layers for CEPC at 240GeV

➔40-layer SDHCAL yields decent energy resolution.

DHCAL based on GEM



Typical parameters

Cu : t = 5µm

Kapton: T = 50µm

Diameter: d = 60µm

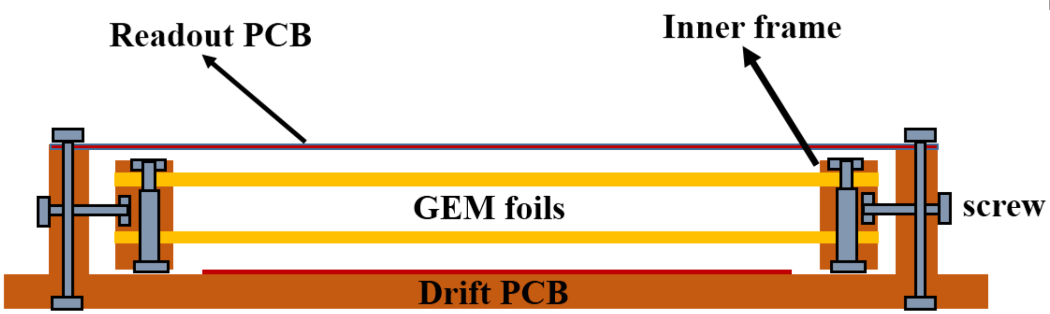
D = 80µm

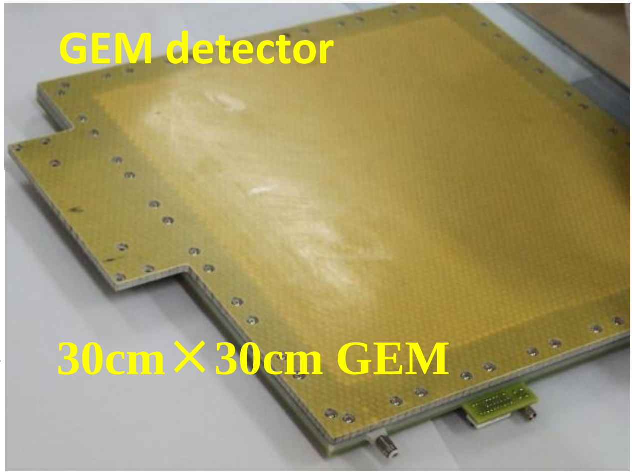
pitch: 140µm

- **Advantages:**

1. assembling process is easy and fast
2. no dead area inside the active area
3. uniform gas flow
4. detachable

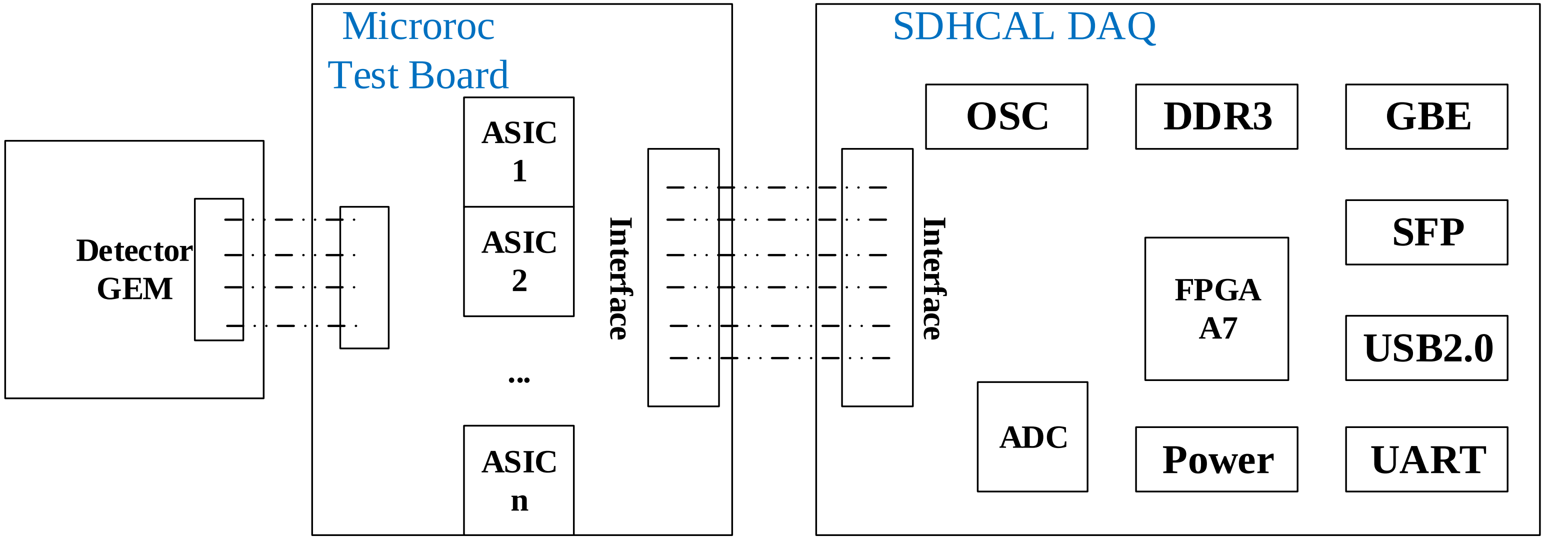
Self-stretching technique (from CERN)





Readout Scheme

- Schematic of the System



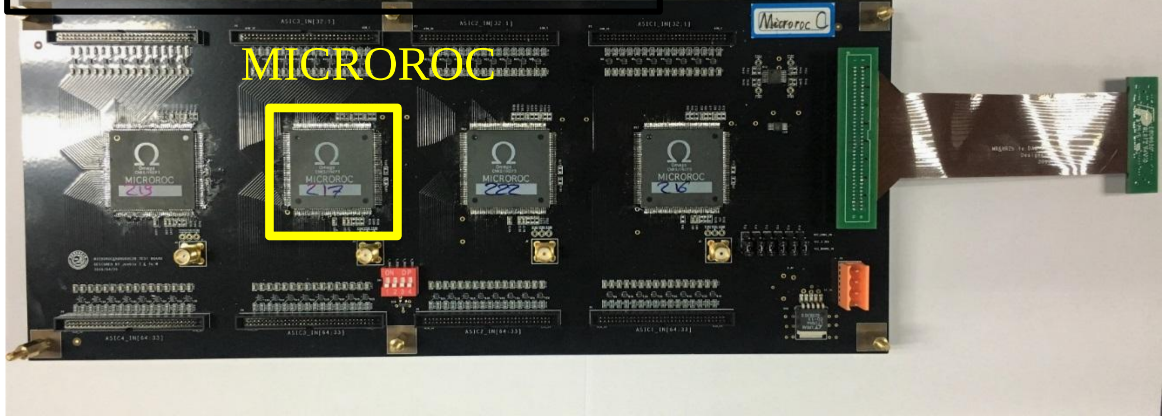
- Readout Board: GEM detector Readout composed by 900 $1cm^2$ pads.
- MICROROC Test Board: Mounted 4 Microroc ASICs, controlled by daisy chain.
- DIF Board: Microroc control, test and data acquisition

Readout ASIC

Readout ASIC	Channels	Dynamic Range	Threshold	Consumption
GASTONE	64	200fC	Single	2.4mW/ch
VFAT2	128	18.5fC	Single	1.5mW/ch
DIRAC	64	200fC for MPGD	Multiple	1mW/ch, 10μW/ch(ILC)
DCAL	64	20fC~200fC	Single	——
HARDROC2	64	10fC~10pC	Multiple	1.42mW/ch,10μW/ch(ILC)
MICROROC	64	1fC~500fC	Multiple	335μW/ch, 10μW/ch (ILC)

Considered the multi-thresholds readout, dynamic range and power consumption, MICROROC is an appropriate readout ASIC

Microroc Test Board

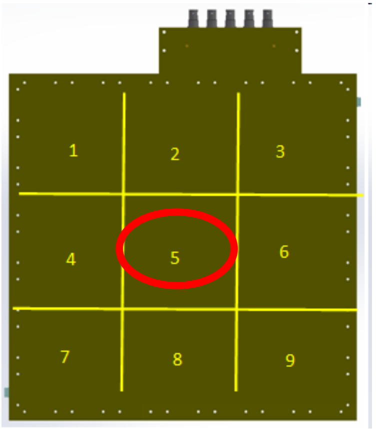


MICROROC Parameters

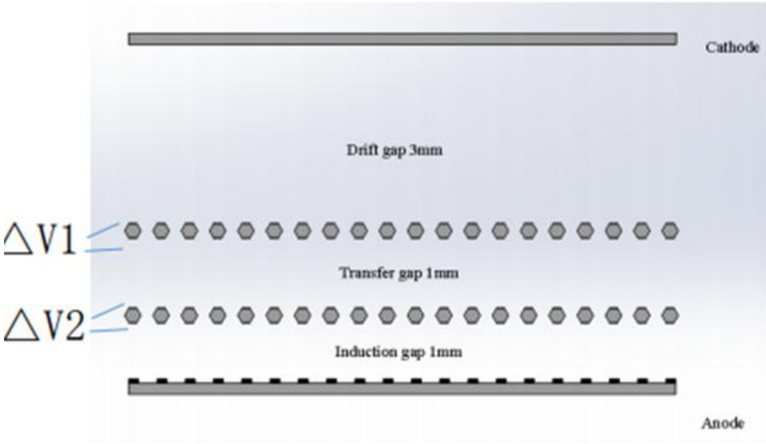
- Thickness: 1.4mm
- 64 Channels
- 3 threshold per channel
- 128 hit storage depth
- Minimum distinguishable charge:2fC

Structure and gain of GEM detector

Division of the 30cmX30cm double GEM detector



Structure of GEM detector

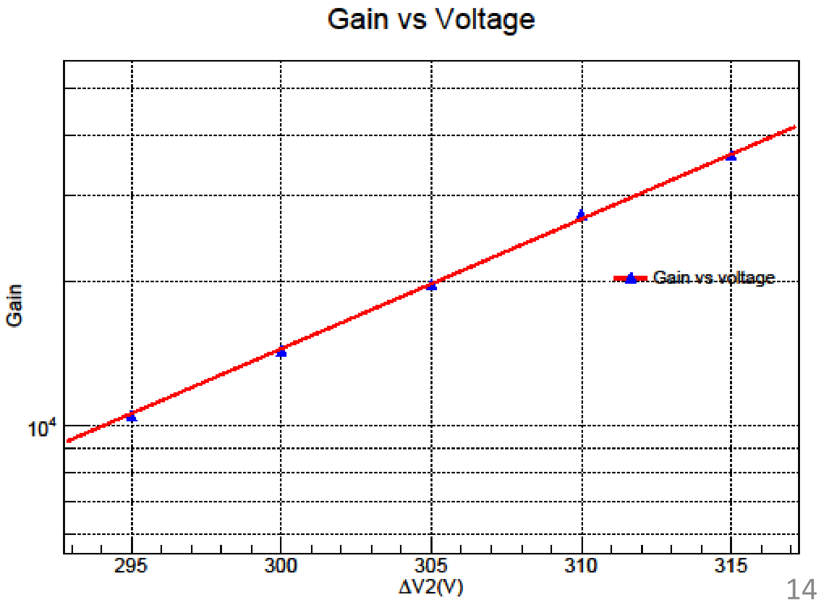


Initial voltage of GEM foil:

△V1: 285 V; △V2: 295 V

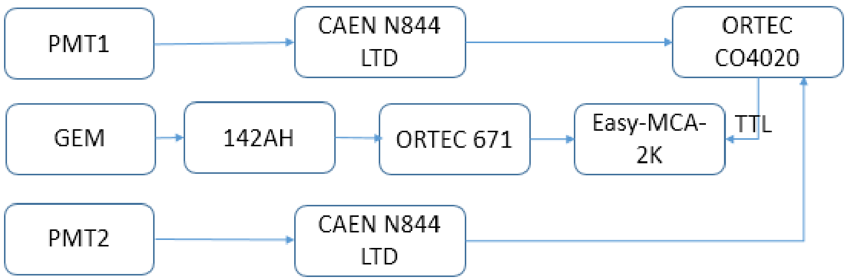
- Edrift: 1.45 kV/cm;
- Etrans: 2.95 kV/cm ;
- Eind: 3 kV/cm

Gain of the detector in 95%Ar-5% iC4H10 mixture

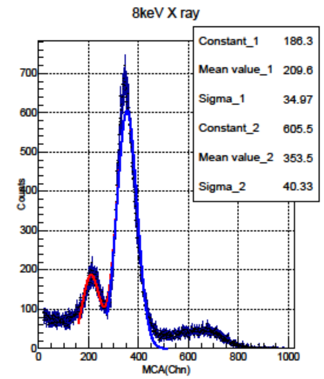


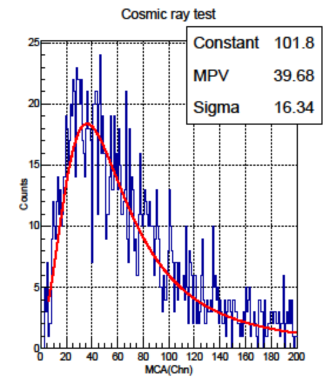
Detection efficiency for MIPs

Electronic system

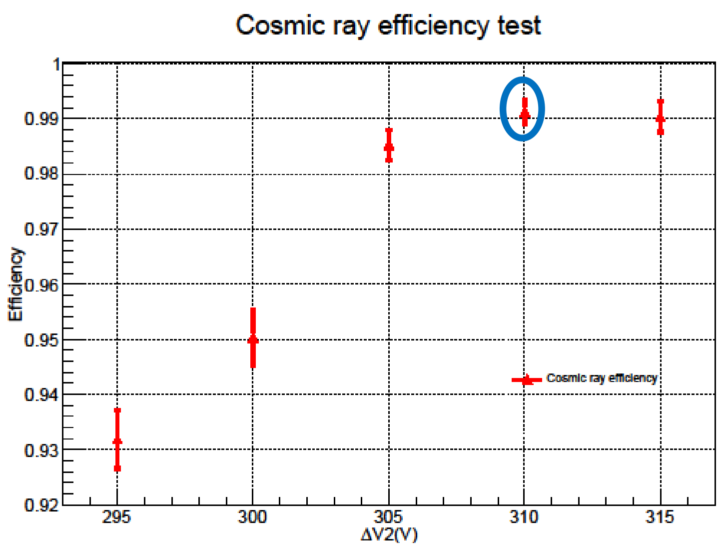


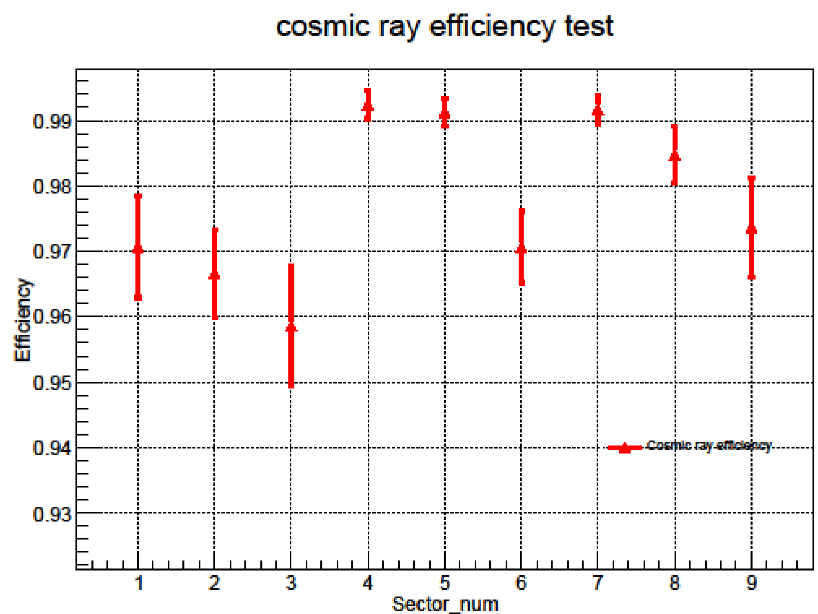
Spectra of X ray and cosmic ray





Detection efficiency vary with voltage

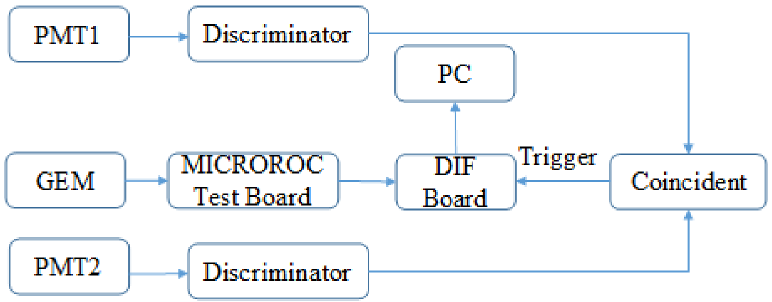




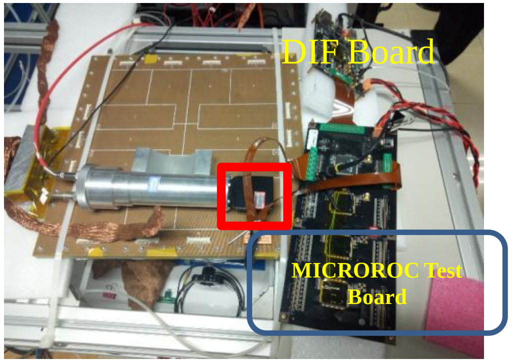
Detection efficiency in different area of GEM detector

Detection efficiency and multiplicity test_1

Electronic system based on Microroc chip



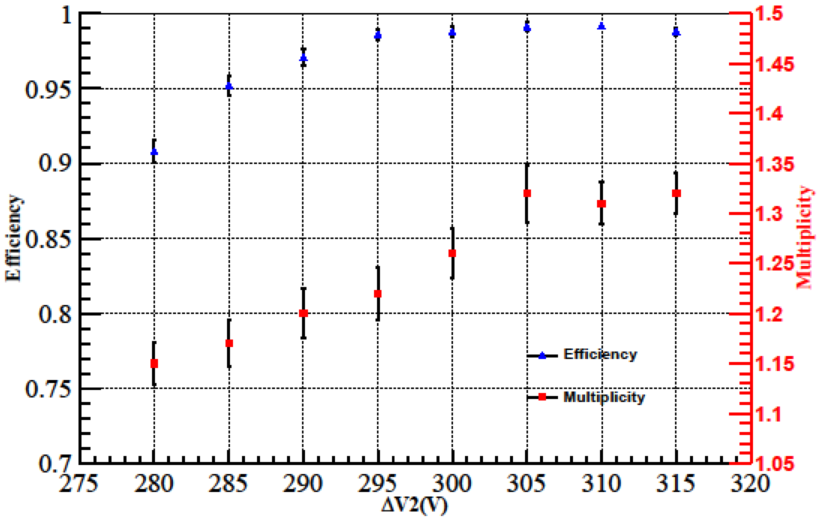
Photograph of the test system



Initial voltage of GEM foil:

△V1: 285 V; △V2: 295 V

- Edrift: 1.45 kV/cm;
- Etrans: 2.95 kV/cm ;
- Eind: 3 kV/cm

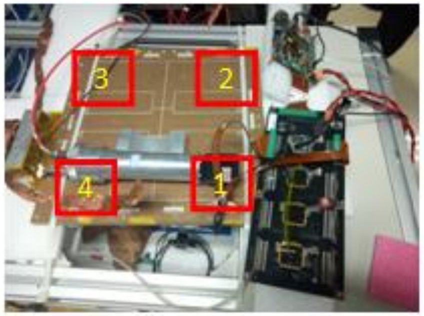


Detection efficiency and multiplicity vary with high voltage

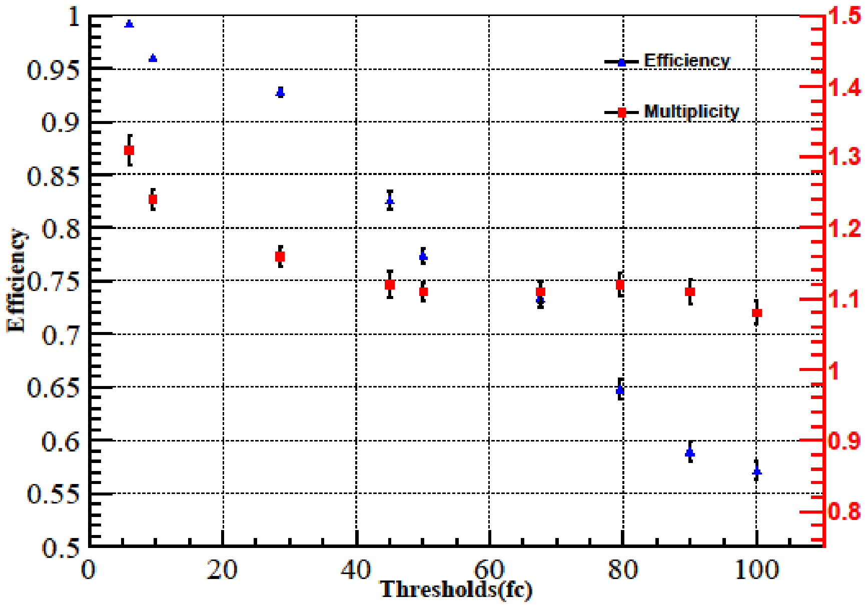
Detection efficiency and multiplicity test_2

- Edrift: 1.45 kV/cm;
- Etrans: 2.95 kV/cm ;
- Eind: 3 kV/cm
- △V1:300 V
- △V2: 310 V

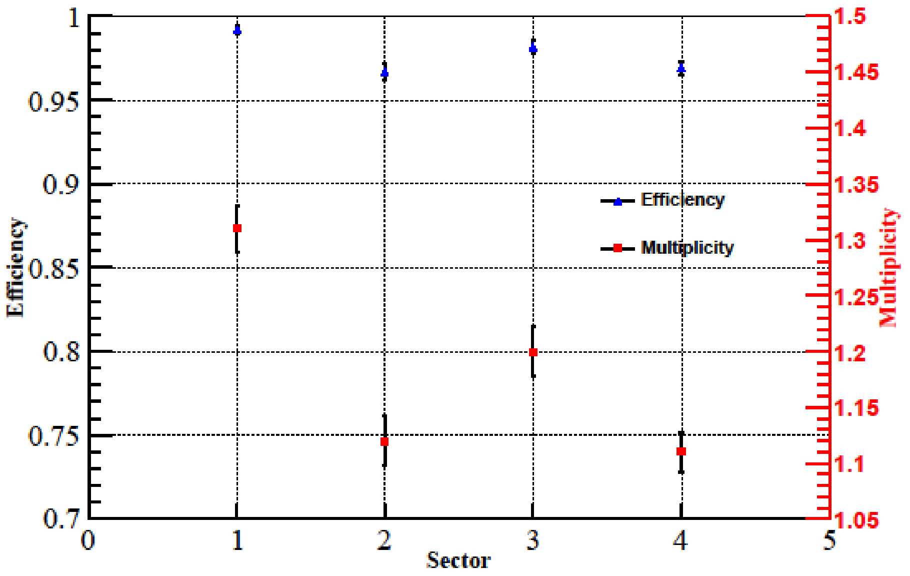
Division of the GEM detector



Detection efficiency and multiplicity vary with thresholds

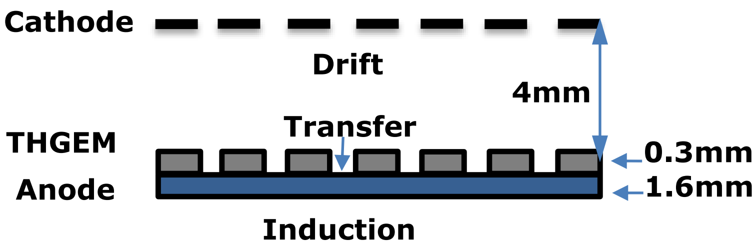


Detection efficiency and multiplicity in different area of GEM detector

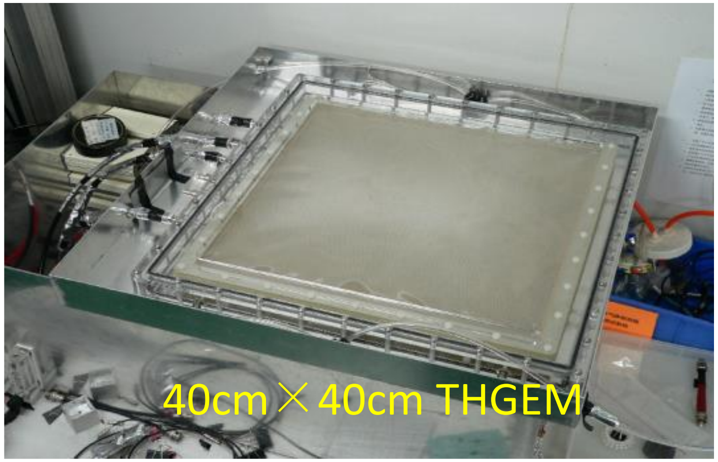


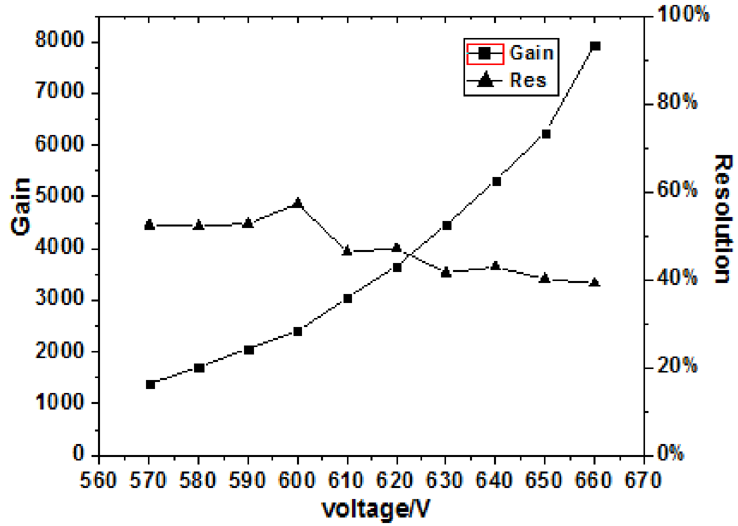
Preliminary study on THGEM-DHCAL

- three structure can be selected;
  - THGEM;
  - WELL-THGEM;
- WELL-THGEM is the-best selection.
  - thinner, high gain, lower discharge



The thickness of WELL-THGEM<6mm





Gain result of 20cmX20cm THGEM

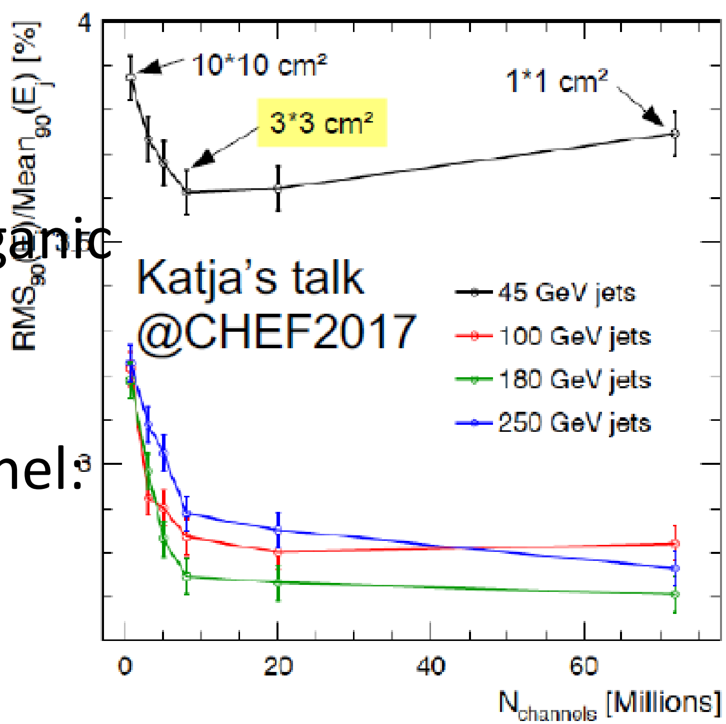
DHCAL Next Step

- More analysis of RPC-DHCAL will be done;
- Based on study status, THGEM&GEM will be merged to THGEM detector
- Integrate ASIC readout with THGEM Detector;
- Design and Test 50cm×100cm THGEM detector in 6mm.

The R&D progress of scintillator AHCAL

— Analog hadron calorimeter for CEPC:

- The absorber: 2cm Stainless steel;
- Detector cell size: 3cm×3cm (baseline) , 4cm× 4cm, 5cm× 5cm ;
- Readout chip: ASIC SPIROC2E
- The sensitive detector : Scintillator(organic scintillator);
- 40 sensitive layers, total readout channel: ≈6 Million (3cm× 3cm)

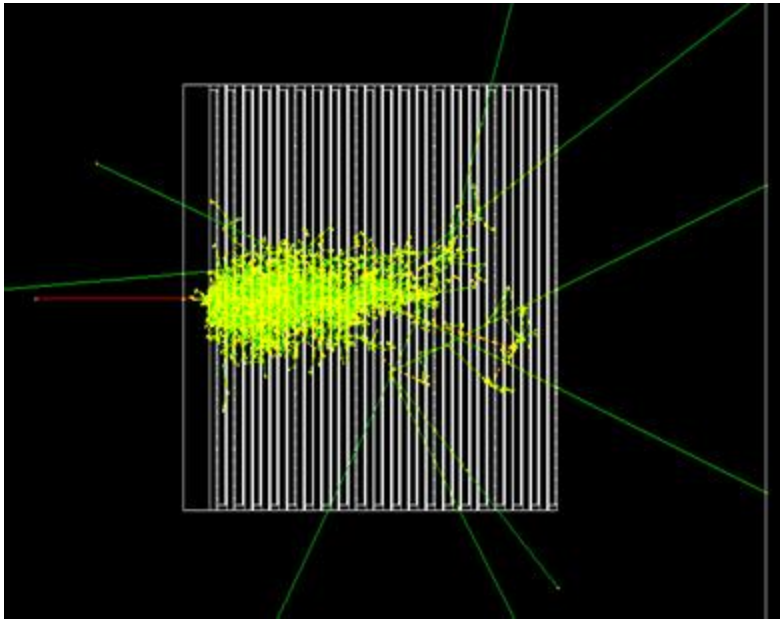


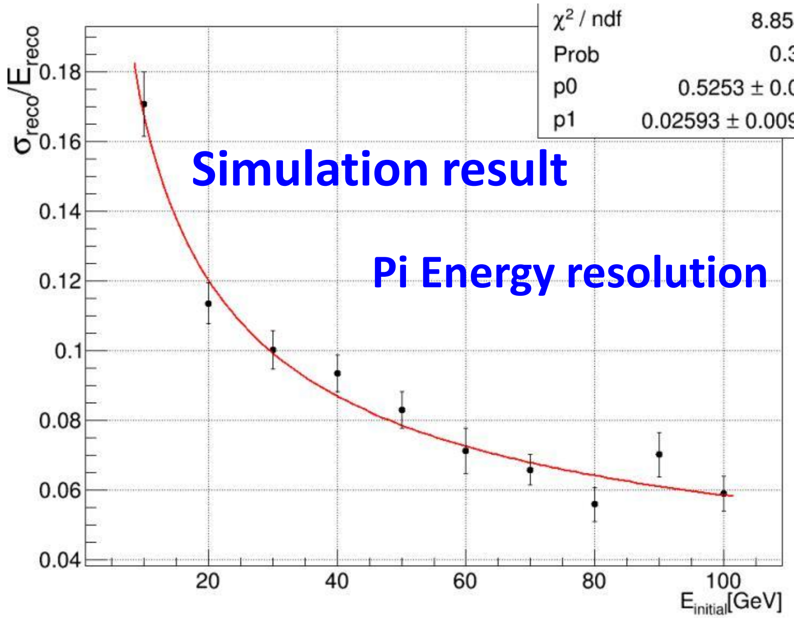
AHCAL prototype Plan

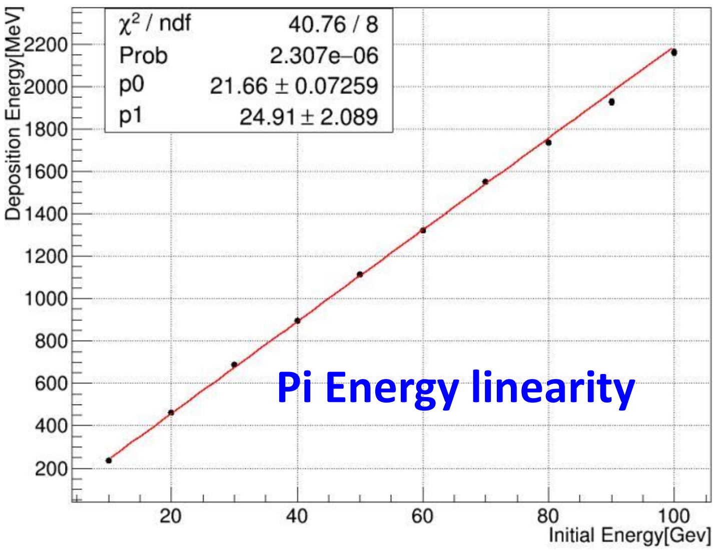
Get about 10M RMB funds

Specification:

- 35 active layers;
- Detector cell:17*17*35=10115;
- Absorber: stainless steel;
- ASIC Chip： SPIROC-2E；
- Prototype size:51*51*87.5cm^3

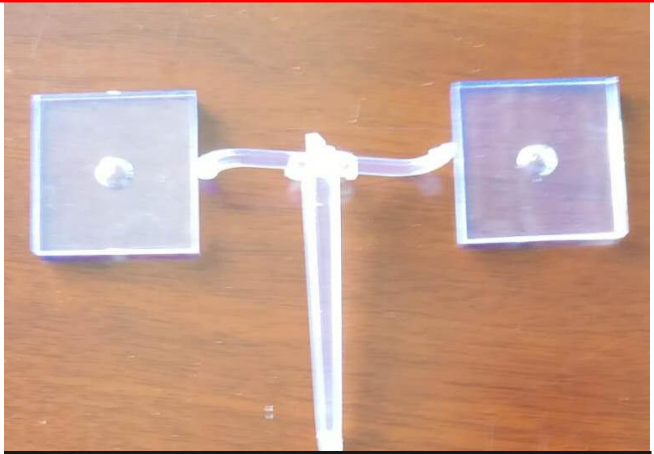


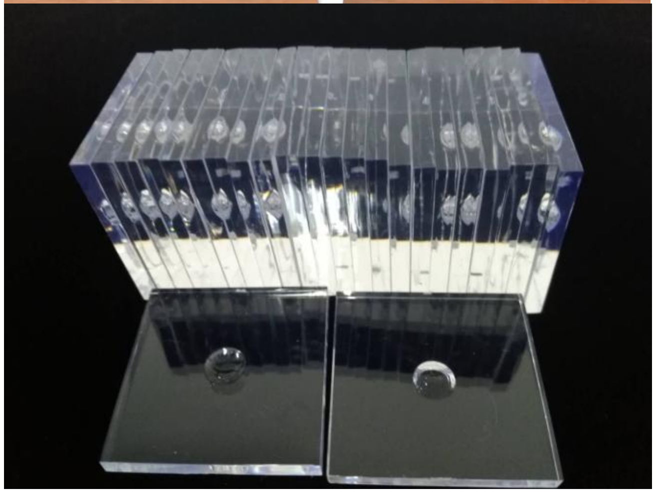




Injection moulded Scintillator tiles

- 4000 tiles polystyrene, POPOP
  - injection moulded at Beijing
  - incl. dimple, no further surface treatment;
- Mechanical tolerances OK for assembly, the size error less than 50um;
- One batch scintillators Light yield is not very uniform, but the problem has been found, caused by material mixer, new batch scintillator under production;

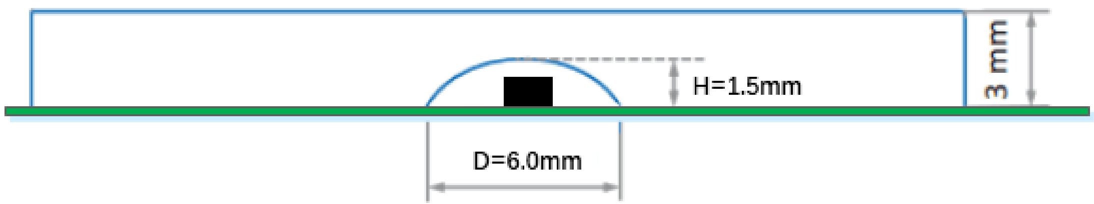




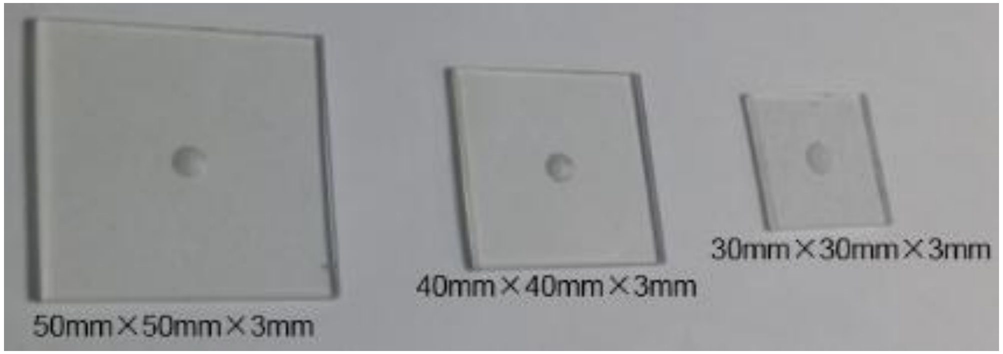
Tiles size(mm)	30.08x30.01 x3.08	30.07x30.04 x3.09	30.04x30.02 x3.09	30.09x30.09 x3.09	30.05x30.03 x3.09
Light yield(p.e.)	23.5	22.78	22.86	25.02	23.54

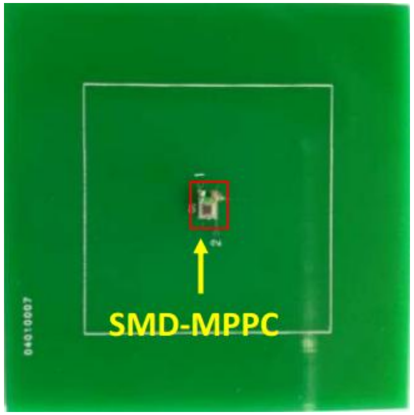
Detector Cells study

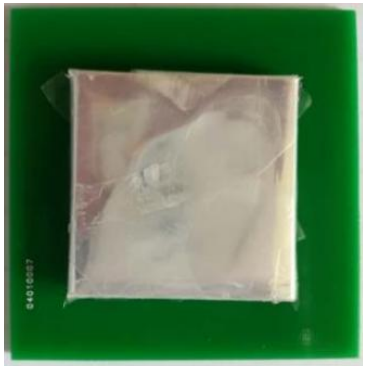
– Via mechanical drilling and polishing, detector cell was made
– The four sizes of $30\times30\times3\text{mm}^3$,$30\times30\times2\text{mm}^3$, $40\times40\times3\text{mm}^3$and $50\times50\times3\text{mm}^3$ were made.
– SiPM or MPPC(surface-mounted)
– Scintillator(BC408) were wrapped by ESR foil



Scintillator tile wrapped by ESR foil was glued on the PCB

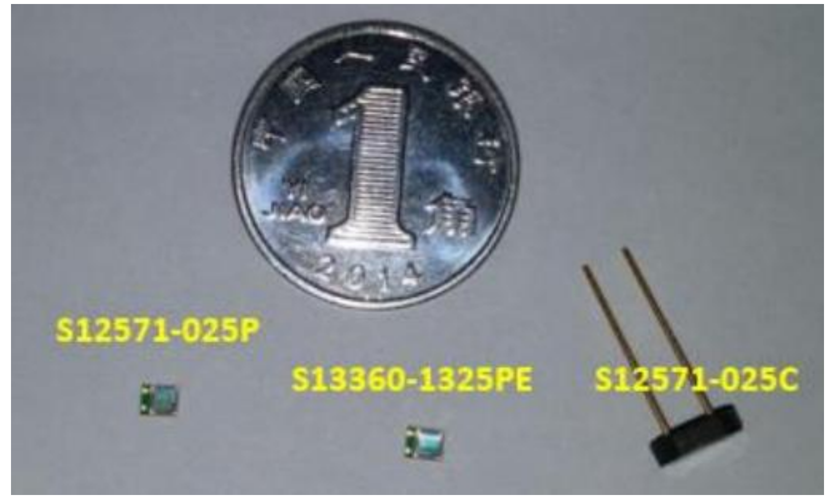


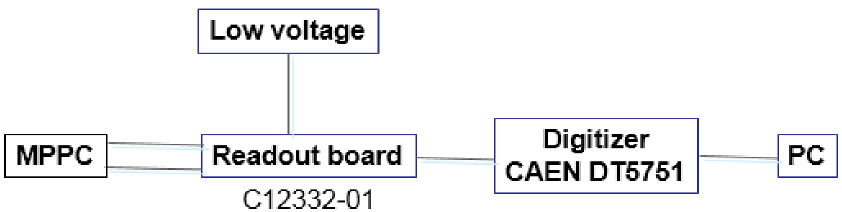




Readout electronics

- Electronic readout board is Hamamatsu C12332-01
- Temperature compensation keep amplitude of the SiPM stable

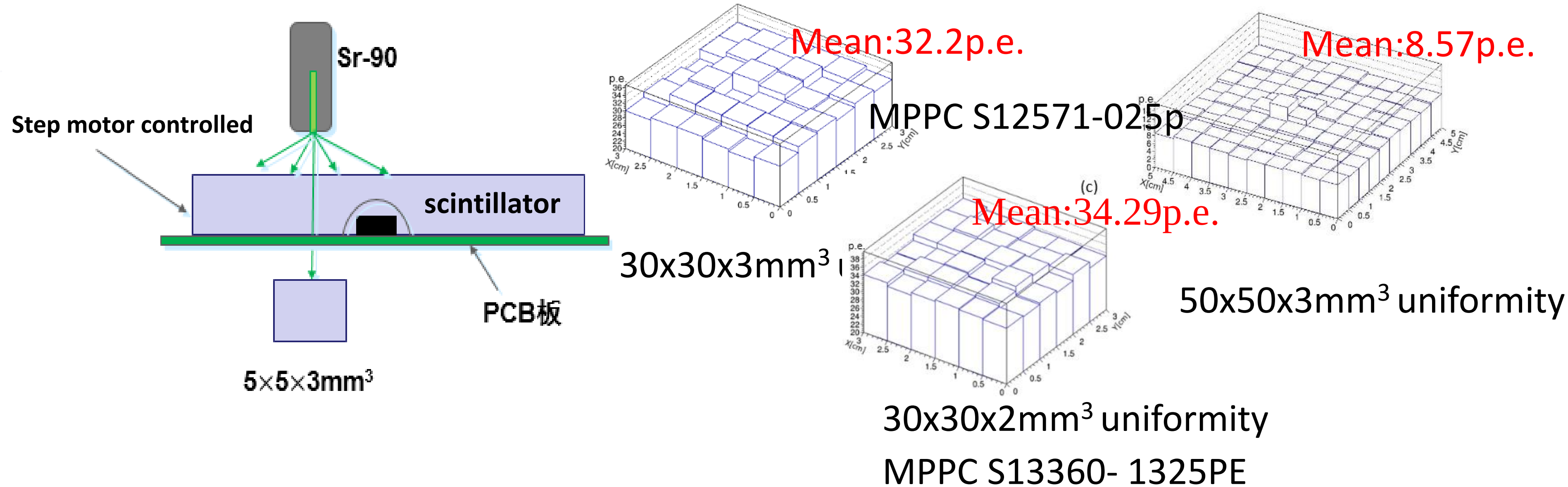




S12571-025P parameter :
Sensitive area :1 × $1mm^2$
Pixel size :25 × $25\mu m^2$
Pixel number:1600
Gain: 5.15E+05

S13360-1325PE parameter :
Sensitive area :1.3 × $1.3mm^2$
Pixel size :25 × $25\mu m^2$
Pixel number:2668
Gain: 1.1E+06

Uniformity measurement



- Uniformity scans (MPPC: S12571-025P and)
- Scintillator tile under study can be moved in a step size of 5 × 5 mm^2
- 30x30x3mm^3, 30x30x2$mm^3$and 50x50x3mm^3 were measured .

- The mean response can reach 100%,94% within 10% deviation from the mean value, respectively.

Cosmic-rays measurement results

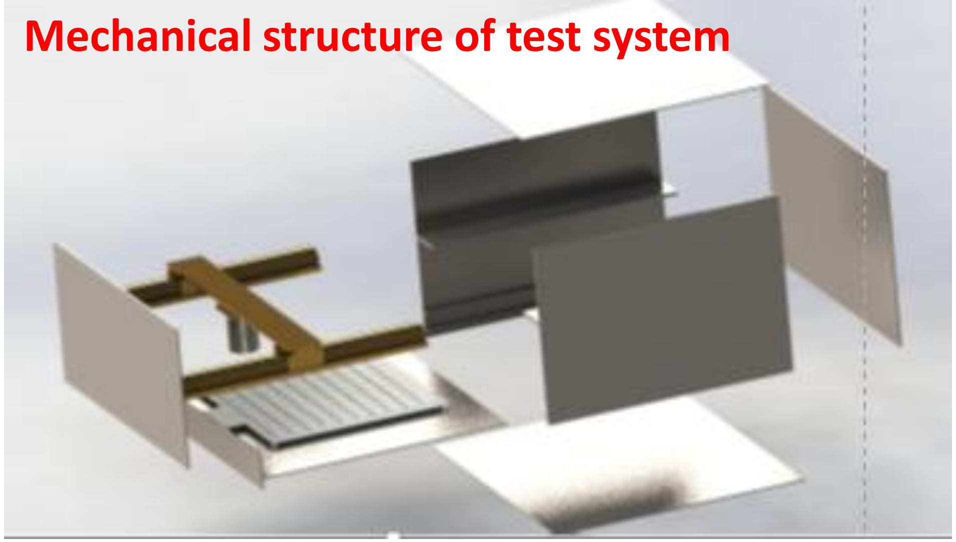
Table 1 Cosmic-ray measurement results of detector cells with different sizes

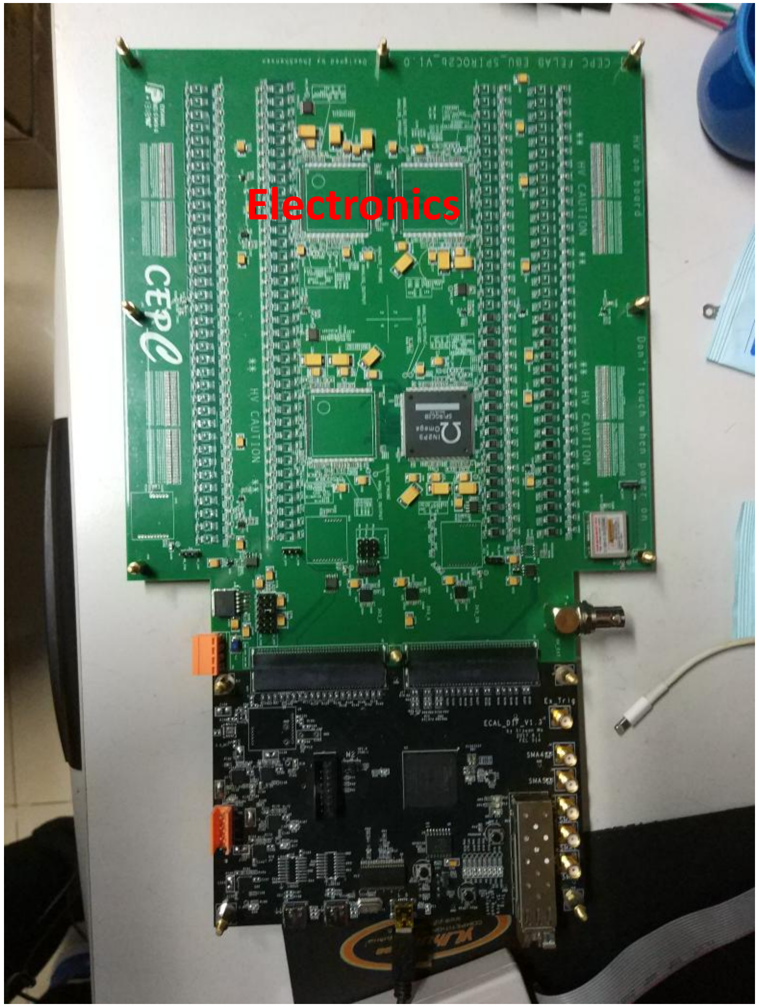
No.	Detector Cell	MPPC Type	Reflective Foil Type	Mean $N_{p.e.}$	Polishing Methods
1	$30\times30\times3mm^3$	S12571-025P	ESR	31.39±0.65	Ultra Precise Polishing
2	$30\times30\times3mm^3$	S12571-025P	ESR	22.55±0.7	Precise Polishing
3	$30\times30\times3mm^3$	S12571-025P	ESR	18.92±0.39	Rough Polishing
4	$30\times30\times3mm^3$	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

- For same size of detector cell， polishing method is very important;
- Different reflective foil: ESR is better than TYVEK;
- The bigger size detector cell， the less p.e. detected;

Detector cell test system design

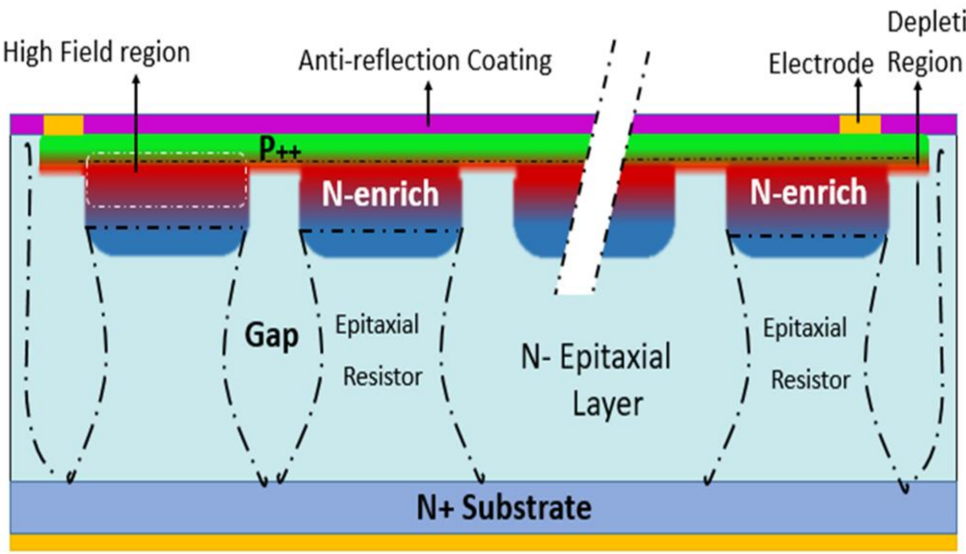
- About 100 detector cells one batch;
- Electronics under design;
- Mechanical structure under design;



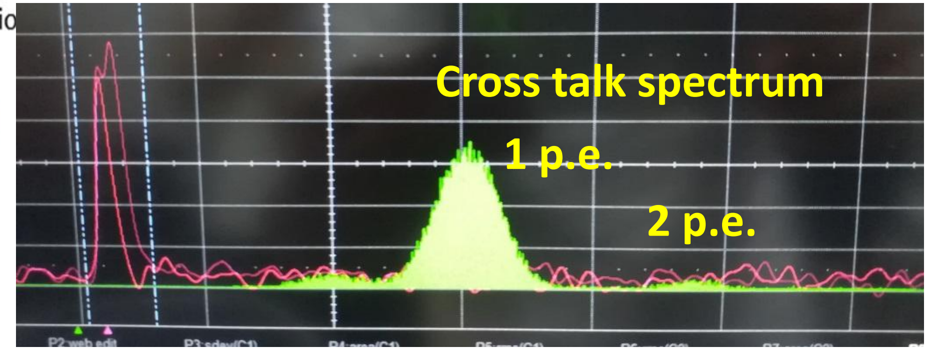


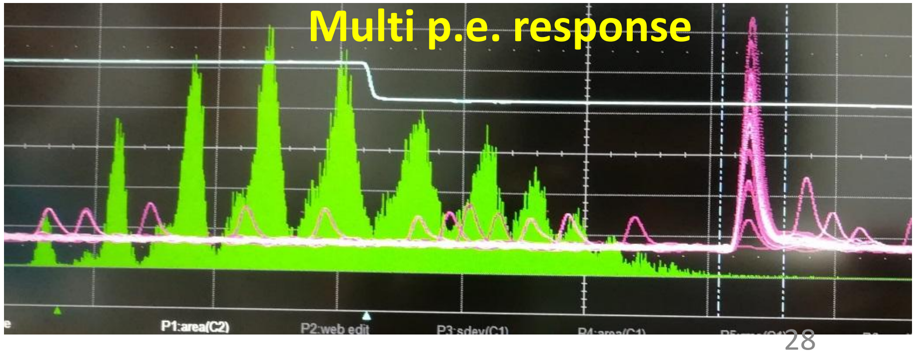
Chinese NDL-SiPMs（Developed by Beijing Normal University）

- Chinese **Beijing Normal University** (BNU) has developed silicon photomultiplier (SiPM) technologies 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, **thus reducing the cost of AHCAL.**



Schematic structure of EQR SiPM

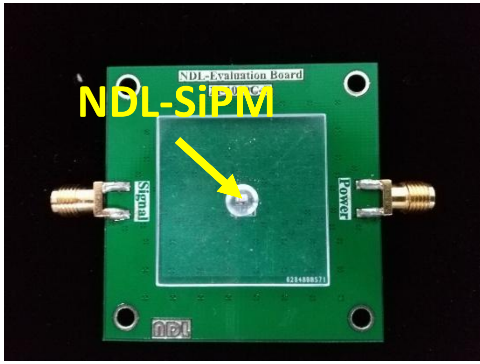




NDL-SiPM Test result (1mmx1mm 10umSiPM new type)

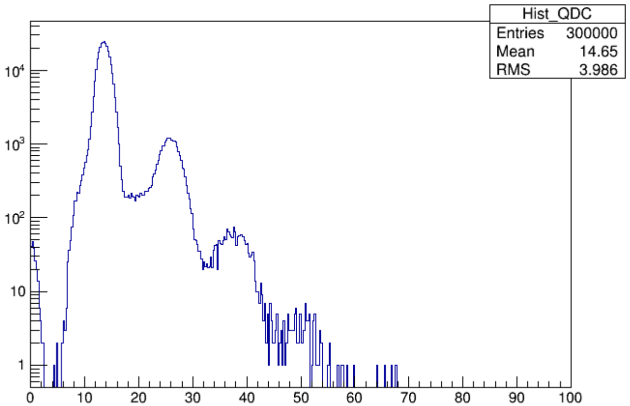
Six NDL-SiPMs was tested: 30mmx30mmx3mm with PL Scintillator

SiPM1	SiPM2	SiPM3	SiPM4	SiPM5	SiPM6
25.43p.e.	25.77p.e.	25.12p.e.	24.06p.e.	23.44p.e.	24.61p.e.



The light yield deviation smaller than 2p.e.

All SiPMs' high Voltage are 35V, each of which is measured after calibration.



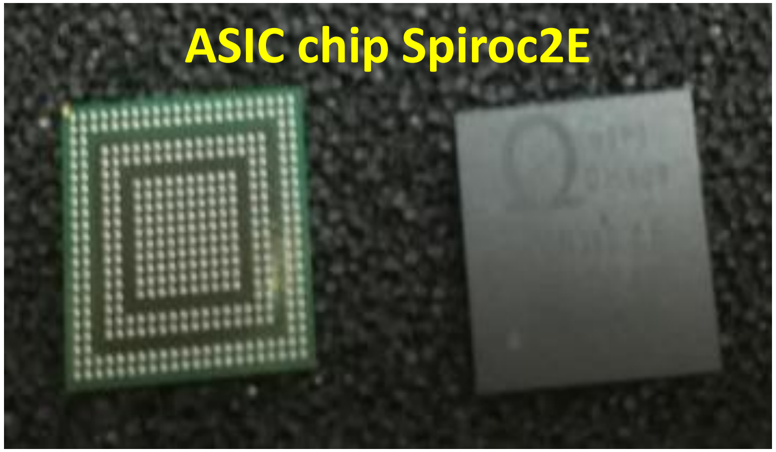
Crosstalk spectrum

NDL-SiPM 11-1010C specification

Parameter	Value	Parameter	Value
Effective Active Area	$1\times 1mm^2$	Peak PDE@420nm*	39%
Effective Pitch	10 μm	Dark Count Rate*	~500 kHz
Micro-cell Number	~10000	1 p.e. Pulse Width	5 ns
Operating Temperature	-196°C - +40°C	Temperature Coefficient For V_b	25 mV/°C
Breakdown Voltage (V_b)	25.5 ± 0.2 V	Gain	$\geqslant 2\times10^5$
Max. Overvoltage (ΔV_{max})	8 V	Single Photon Time Resolution	≤ 70 ps

CEPC-AHCAL Next

- ASCI chip readout study;
- Injection moulded plastic scintillator production;
- Test the Chinese NDL-SiPM;
- Detector cell test system construction;
- Simulation and optimization AHCAL



Summary and next

—The construction of CEPC-HCAL prototype based on scintillator will be started;

—Some critical R&D items identified, which will be followed up.

—Our R&D work would surely be more and more integrated into international PFA calorimeter R&D activities.

Thanks for your attention!

Backup!

NDL EQR-SiPM VS Hamamatsu MPPC

	NDL SiPM		Hamamatsu MPPC	
Effective Active Area	11-3030 B-S	22-1414 B-S	S13360-3025PE	S13360-1325PE
	3.0×3.0 mm^2	1.4×1.4 mm^2 (2×2 Array)	3.0×3.0 mm^2	1.3×1.3 mm^2
Effective Pitch	10 μm	10 μm	25 μm	25μm
Micro-cell Number	90000	19600	14400	2668
Fill Factor	40%	40%	47%	47%
Breakdown Voltage (V_b)	23.7±0.1V	23.7±0.1V	53±5V	53±5V
Measurement Overvoltage (V)	3.3	3.3	5	5
Peak PDE	27%@420nm	35%@420nm	25%@450nm	25%@450nm
Max. Dark Count (kcps)	< 7000	<1500	1200	210
Gain	2×10^5	2×10^5	7.0×10^5	7.0×10^5
Temp. Coef. For V_b	17mV/° C	17mV/° C	54mV/° C	54mV/° C