

The R&D progress of CEPC PFA HCAL

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Outline

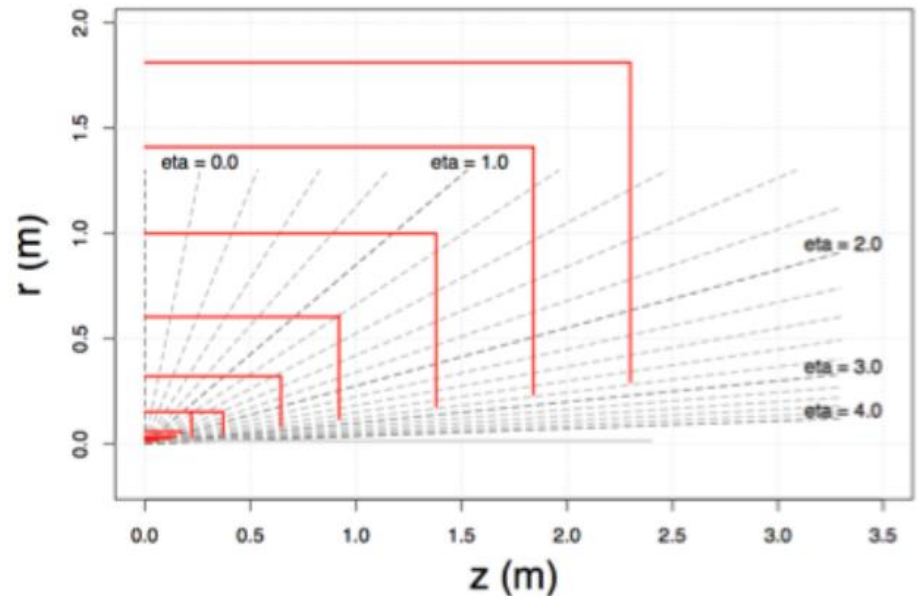
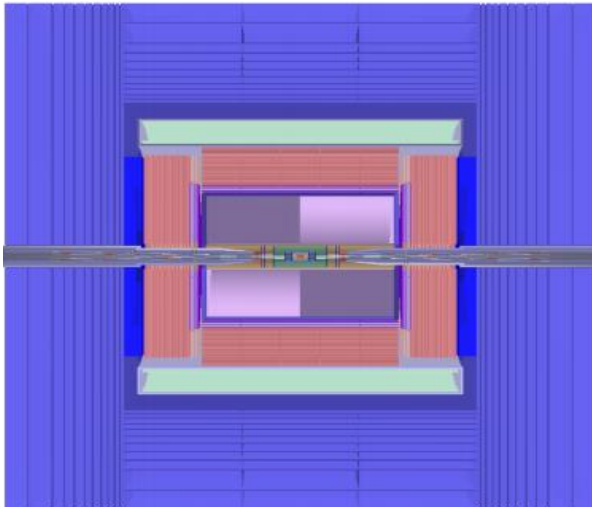
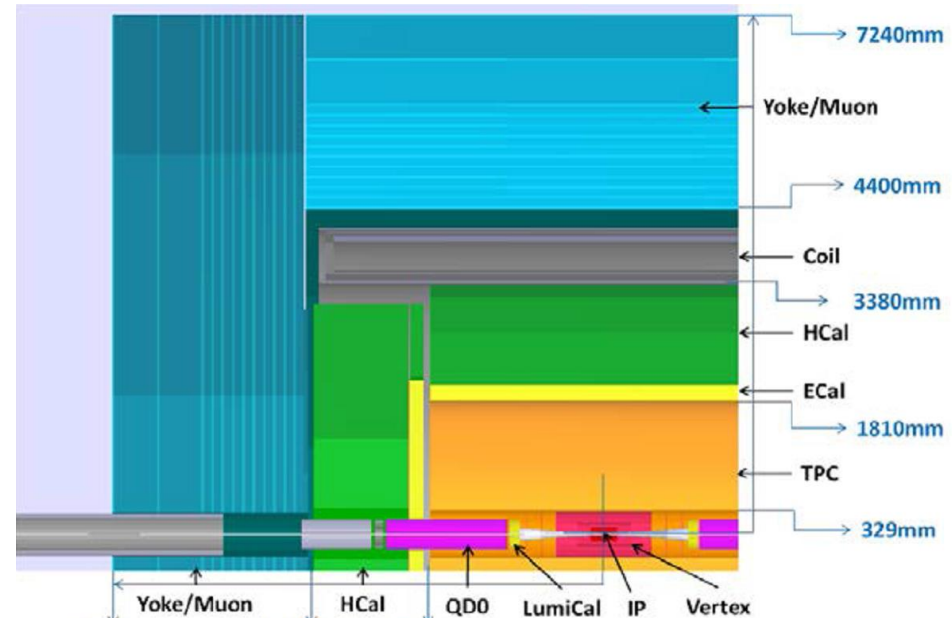


- CEPC Detector Concept(s)
- The options of CEPC-PFA-HCAL;
- The progress of two option of PFA-HCAL
 - DHCAL based on RPC and MPGD(THGEM/GEM);
 - AHCAL based on scintillator;
- Summary

CEPC Detector Concept(s)



- Baseline: ILD-like
 - TPC tracking + Imaging calorimetry (ECAL+HCAL)
 - PFA-oriented
- Alternatives
 - Low-field concept
 - Full-silicon concept



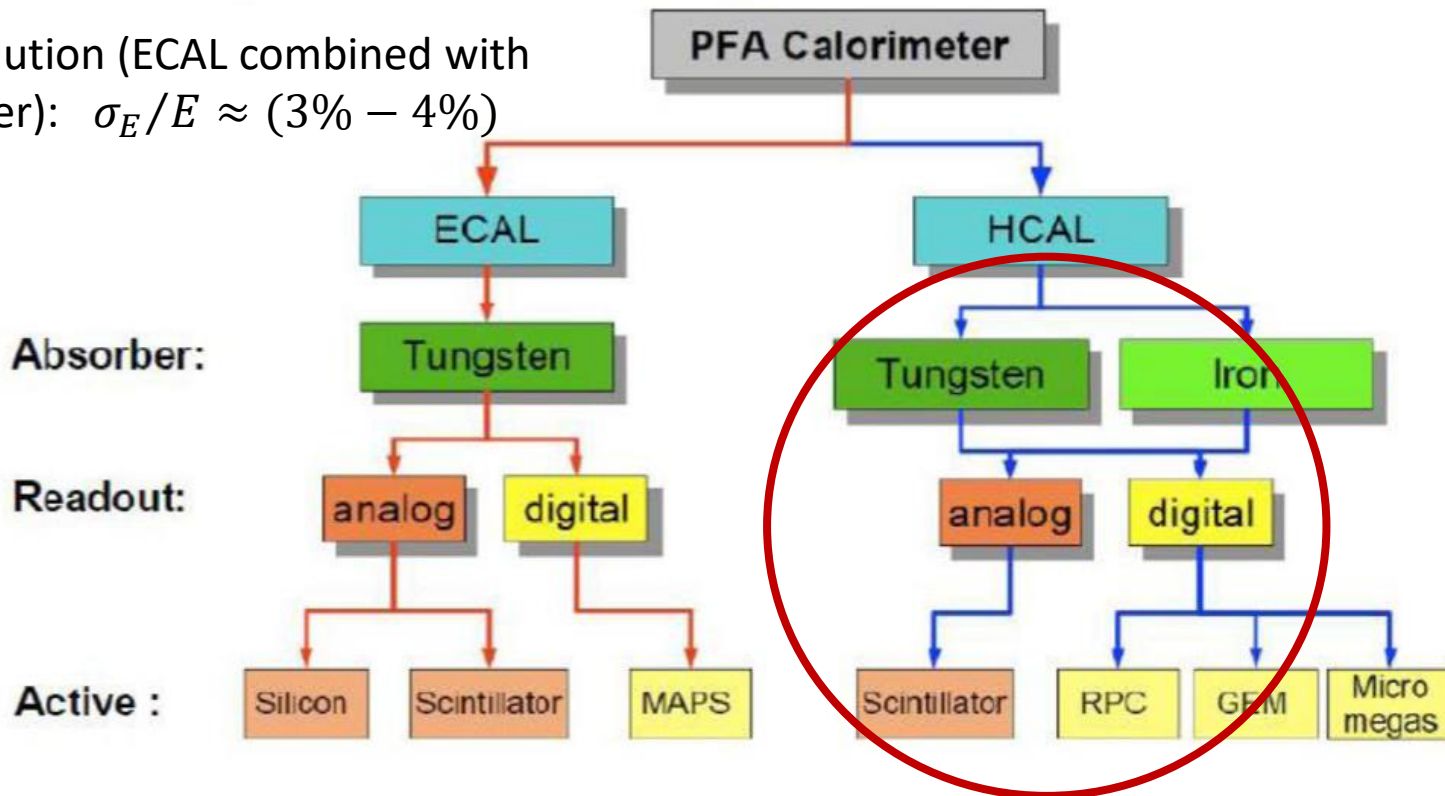
The options of CEPC-PFA-HCAL;



Two options:

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

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





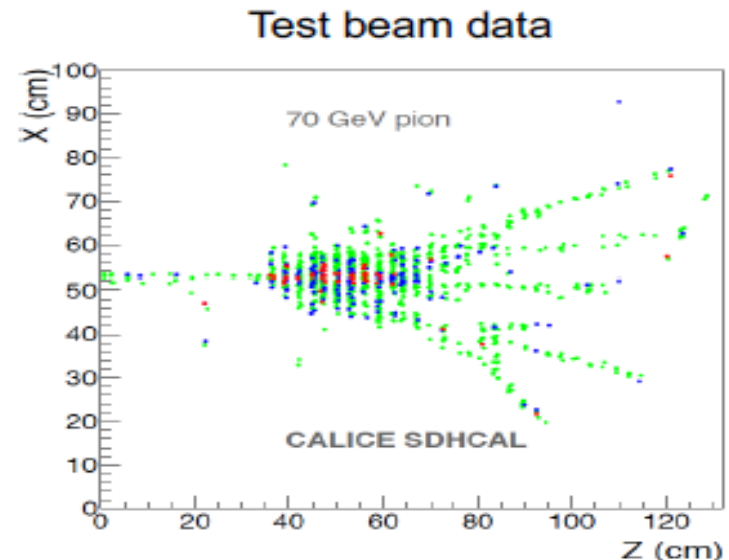
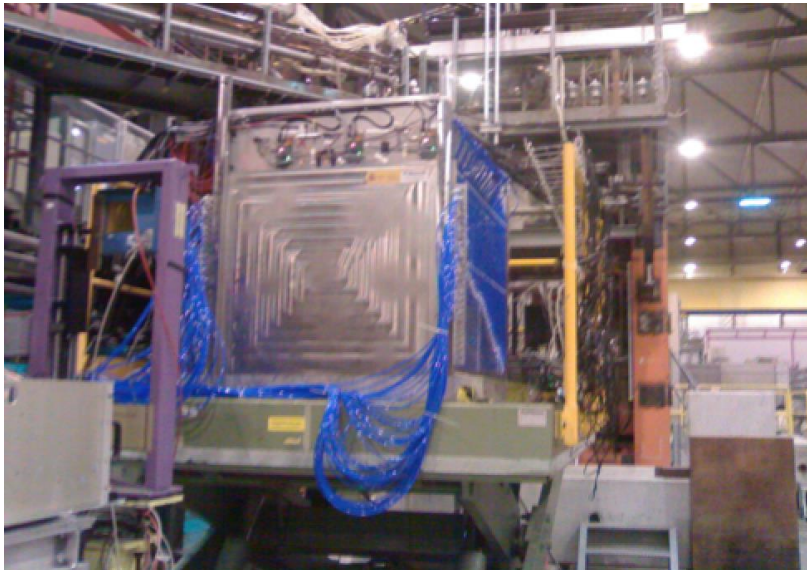
- PFA HCAL R&D topics that started initially from 2016
 - RPC technology
 - MPGD (GEM/THGEM) technology
- Analog option of scintillator was started from 2018;
- Now R&D ongoing for the two options
- IHEP, USTC and SJTU join the CALICE collaboration



SDHCAL Based on RPC (IPNL+SJTU within CALICE)

SDHCAL Prototype

- SJTU is working with IPNL, Tsinghua and several other groups within CALICE on RPC-SDHCAL as part of CEPC detector R&D effort
- Total Size: $1.0 \times 1.0 \times 1.4 \text{ m}^3$
- Total Layers: 48
- Total Channel(pads): 440000
- Power consumption: $10 \mu\text{W}/\text{channel}$
(Power pulsing)



Developed by the CALICE collaboration

Structure of sampling layer



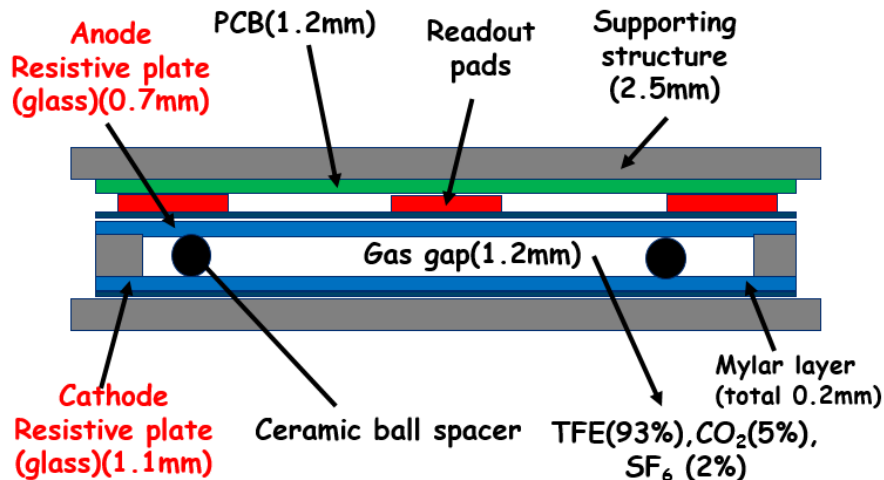
$(0.12\lambda_I, 1.14X_0)$

Stainless steel Absorber(15mm)

Stainless steel wall(2.5mm)

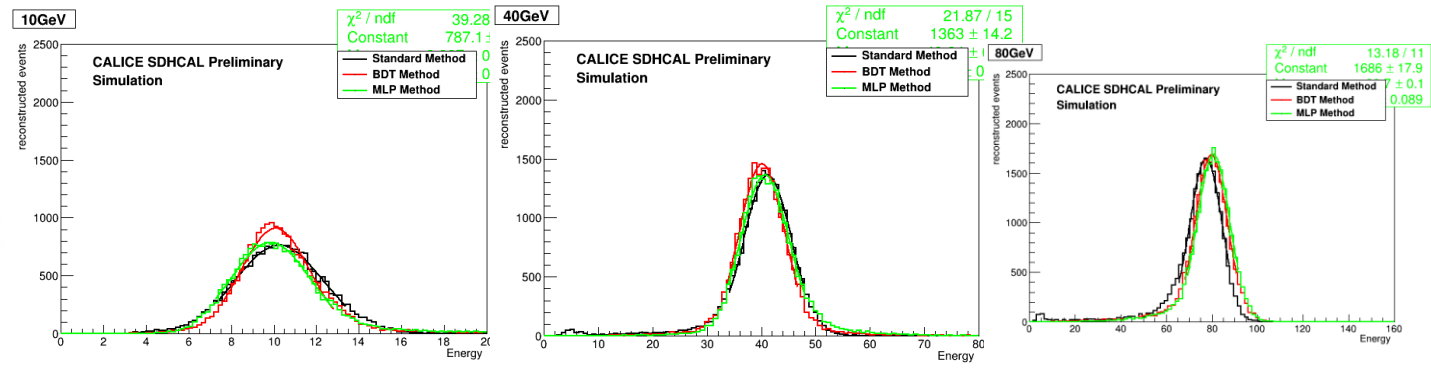
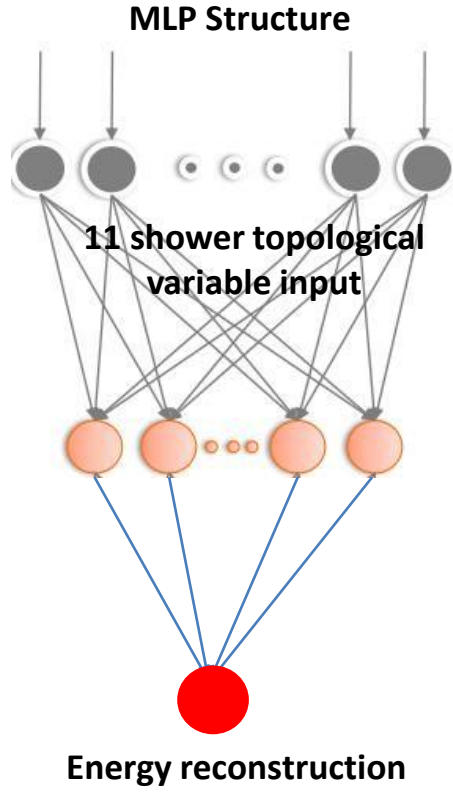
GRPC(6mm $\approx 0.12\lambda_I, X_0$)

Stainless steel wall(2.5mm)

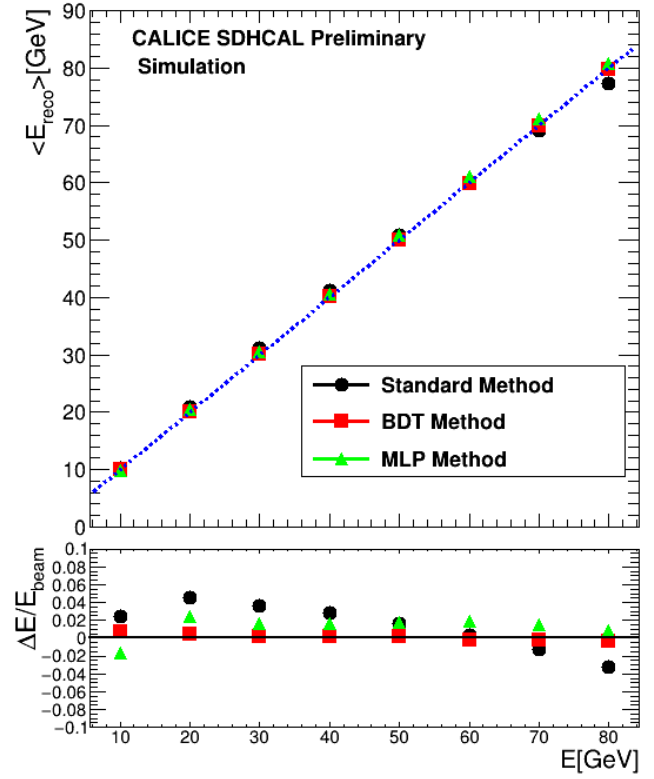
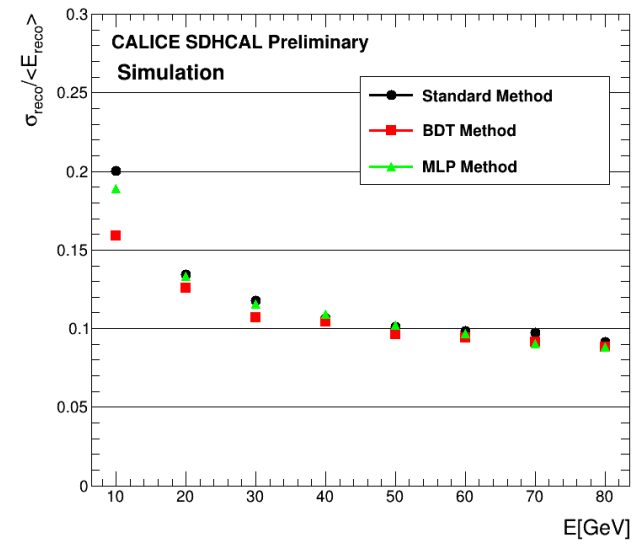


ASIC HARDROC(64 channel)
three-threshold (Semi-digital)
110fC, 5pC, 15pC

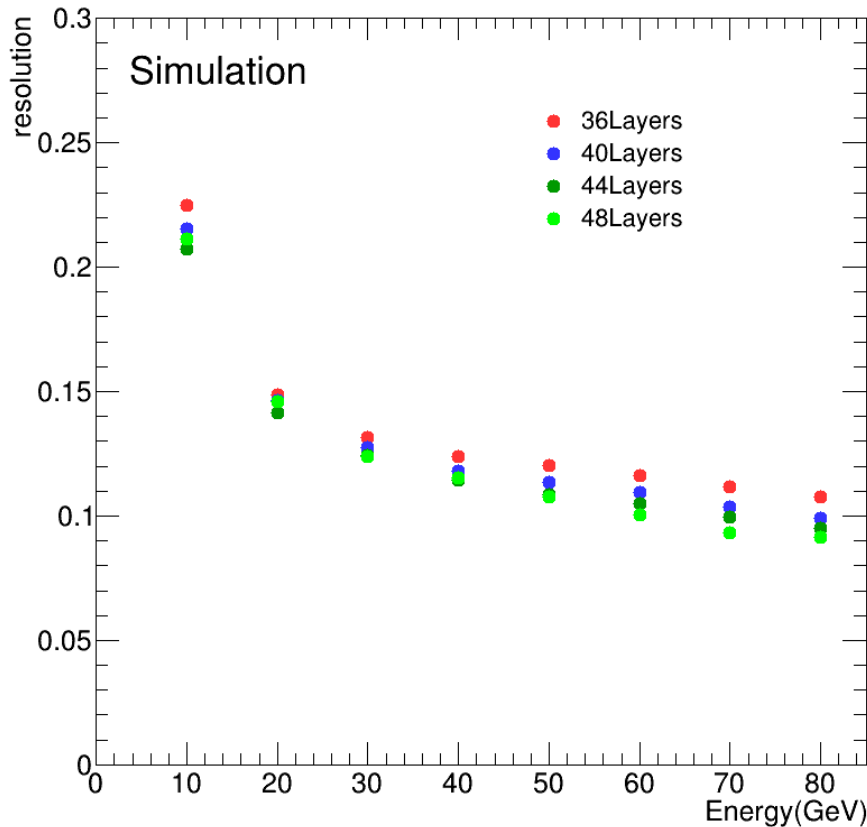
Analysis of test beam data: Energy reconstruction using MLP and BDT



One hidden layer



Optimization of SDHCAL Layers



$(0.12\lambda_I, 1.14X_0)$

Stainless steel Absorber(15mm)

Stainless steel wall(2.5mm)

GRPC(6mm $\approx 0.12\lambda_I, X_0$)

Stainless steel wall(2.5mm)

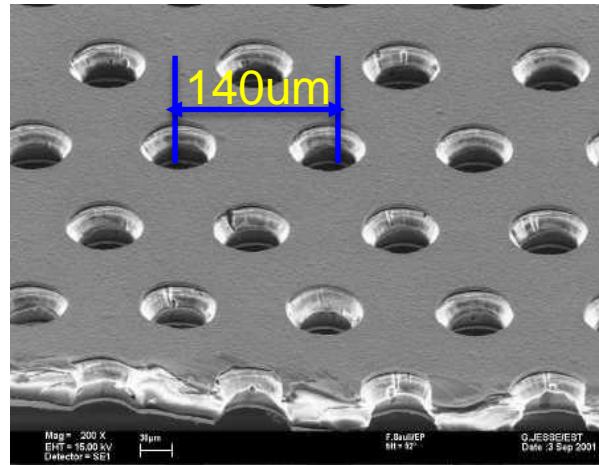
→ SDHCAL has 48 layers which aims for ILC Detector

- 6mm RPC+20mm absorber

→ Optimization no. of layers for CEPC at 240GeV

→ 40-layer SDHCAL yields decent energy resolution.

DHCAL based on MPGD(GEM)



Typical parameters

Cu : $t = 5\mu\text{m}$

Kapton: $T = 50\mu\text{m}$

Diameter: $d = 60\mu\text{m}$

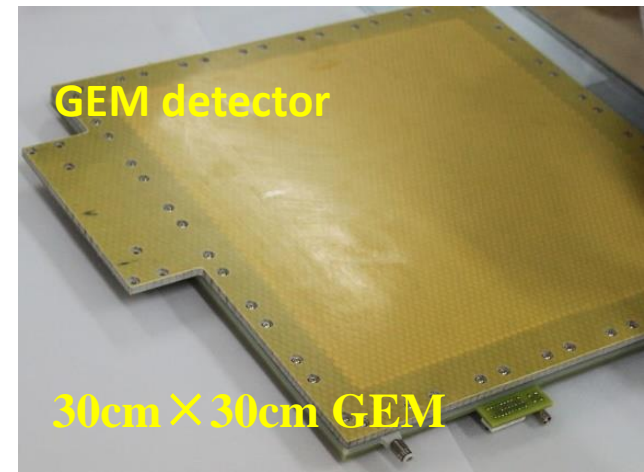
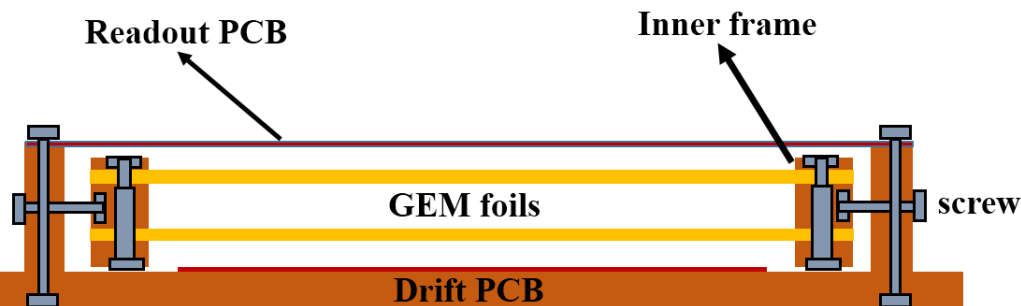
$D = 80\mu\text{m}$

pitch: $140\mu\text{m}$

Advantages:

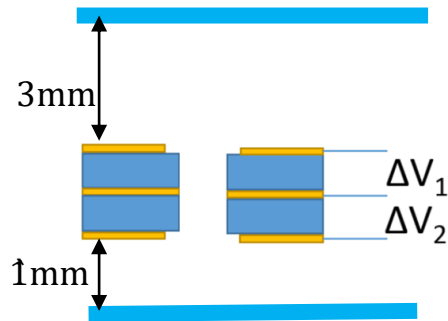
1. assembling process is easy and fast
2. no dead area inside the active area
3. uniform gas flow
4. detachable

Self-stretching technique (from CERN)



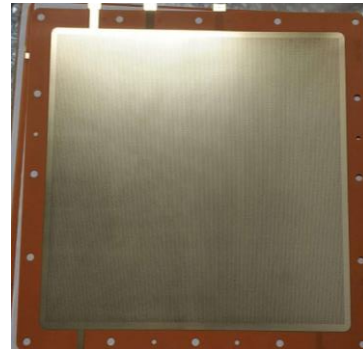
M-THGEM detector

- Structure

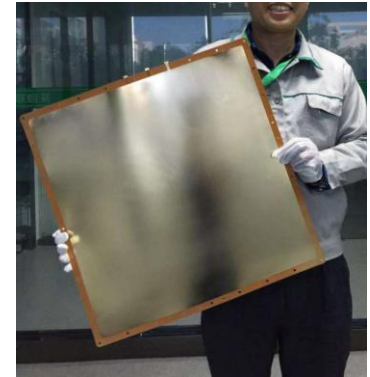


- Performance

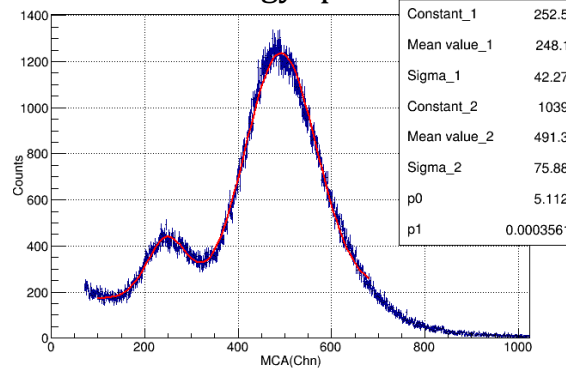
200mm × 200mm M-THGEM foil



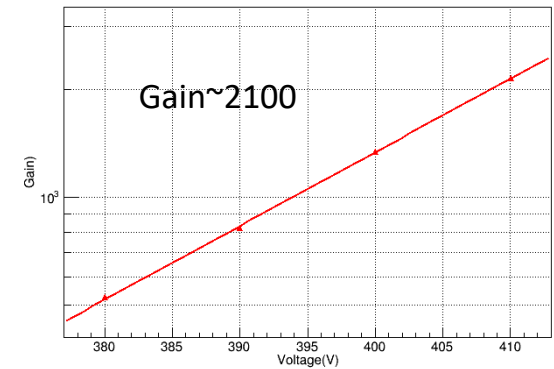
500mm × 500mm M-THGEM detector



⁵⁵Fe Energy spectrum



Gain VS voltage



50cm*50cm detector result

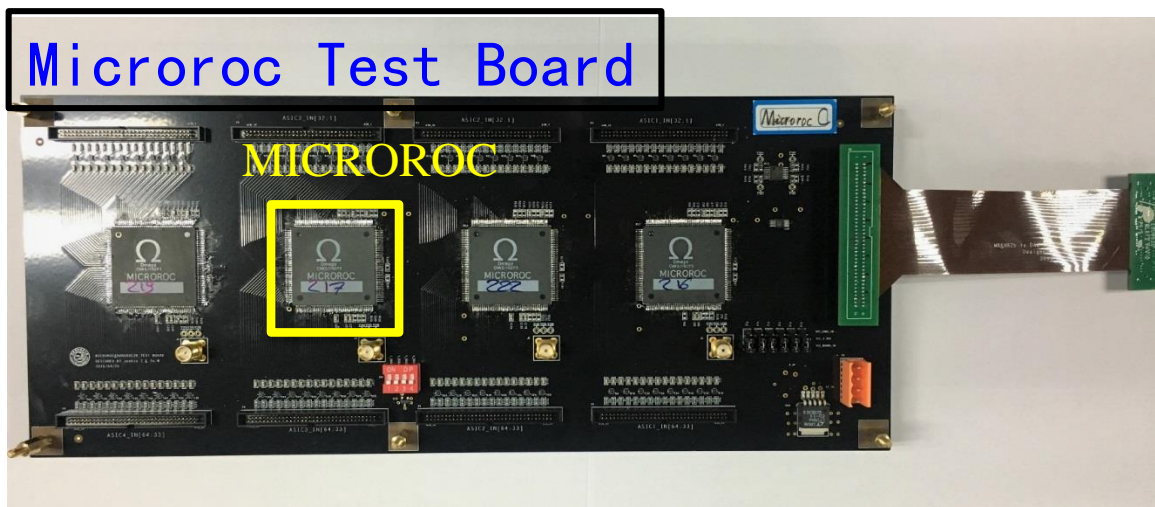
THGEM detector is also a option of MPGD-DHCAL, 50cm*50cm detector is under develop.

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, 10 μ W/ch(ILC)
DCAL	64	20fC~200fC	Single	—
HARDROC2	64	10fC~10pC	Multiple	1.42mW/ch, 10 μ W/ch(ILC)
MICROROC	64	1fC~500fC	Multiple	335 μ W/ch, 10 μ W/ch (ILC)

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



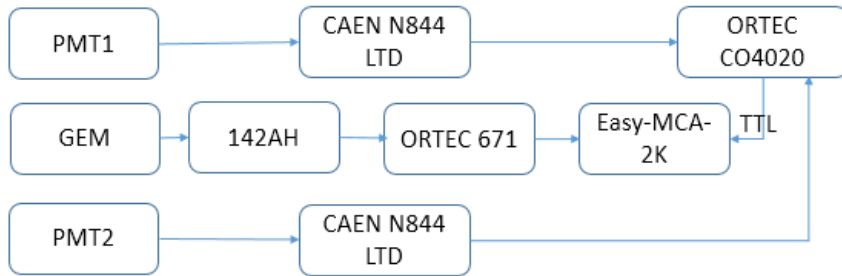
MICROROC Parameters

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

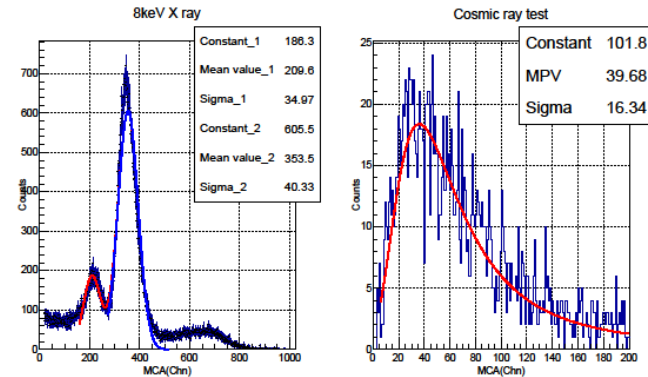
Detection efficiency for MIPs of GEM detector



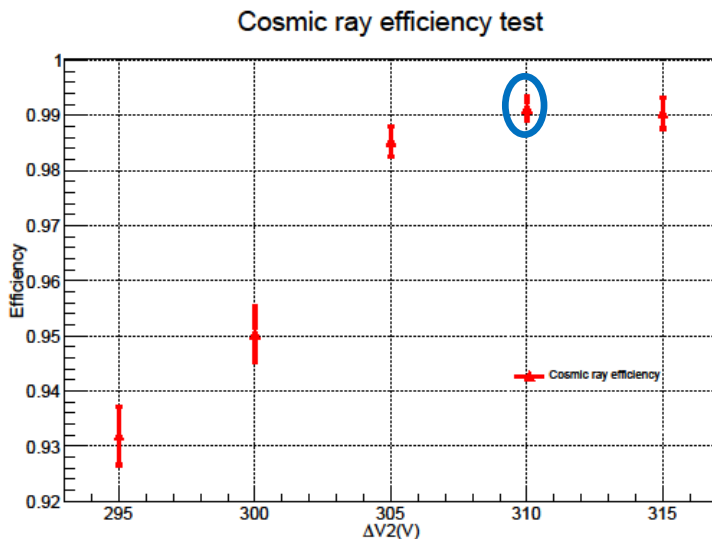
Electronic system



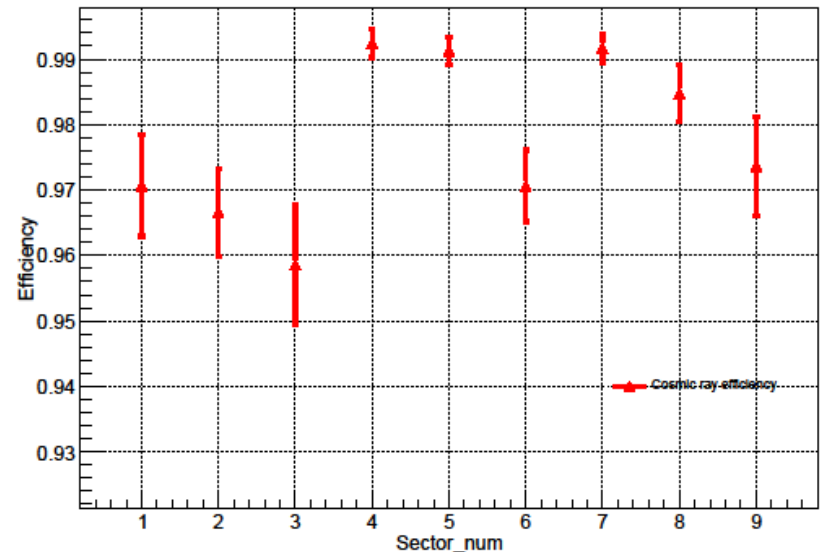
Spectra of X ray and cosmic ray



Detection efficiency vary with voltage



cosmic ray efficiency test



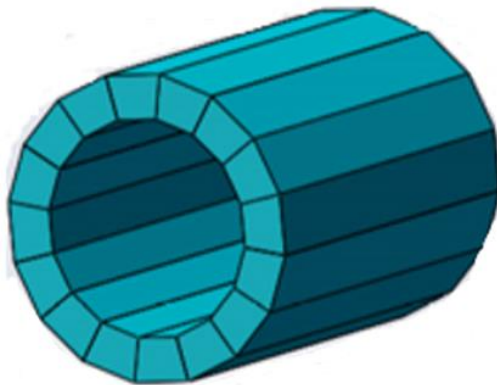
Detection efficiency in different area of GEM detector



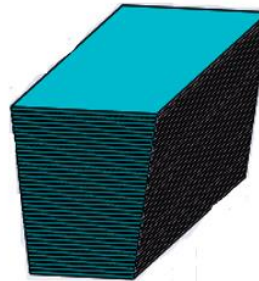
— Analog hadron calorimeter for CEPC:

- The absorber: 2cm Stainless steel ($0.12\lambda_p$, $1.14X_0$);
- Detector cell size: $3\text{cm} \times 3\text{cm}$ or $4\text{cm} \times 4\text{cm}$;
- ASIC Readout chip: KLauS (KIP, Uni-Heidelberg) SPIROC2E, etc.
- The sensitive detector : Scintillator(organic scintillator);
- About 40 sensitive layers, total readout channel: ≈ 6 Million ($3\text{cm} \times 3\text{cm}$)

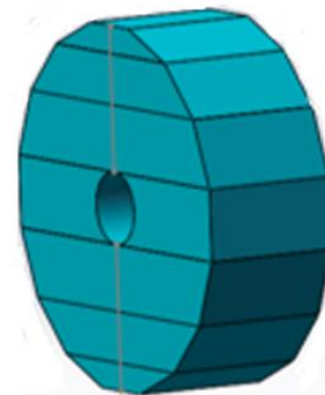
AHCAL barrel



AHCAL super module



AHCAL endcap

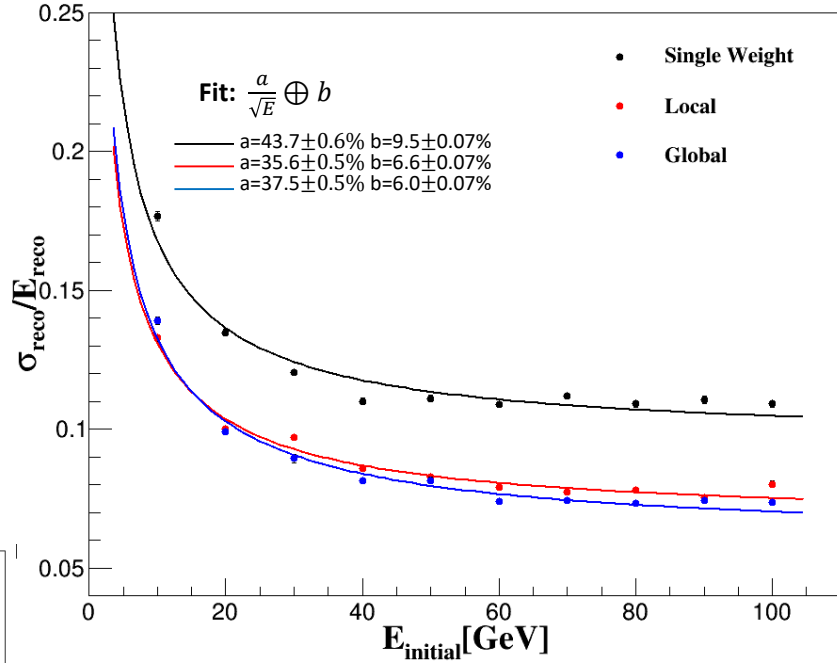
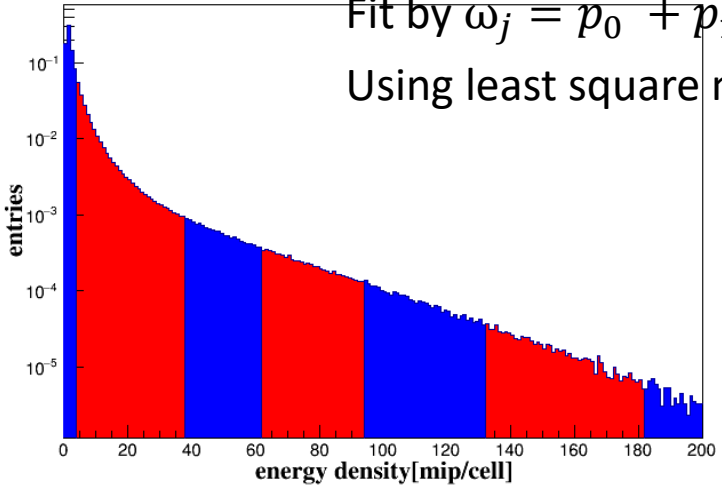


Software compensation for Energy reconstruction at AHCAL

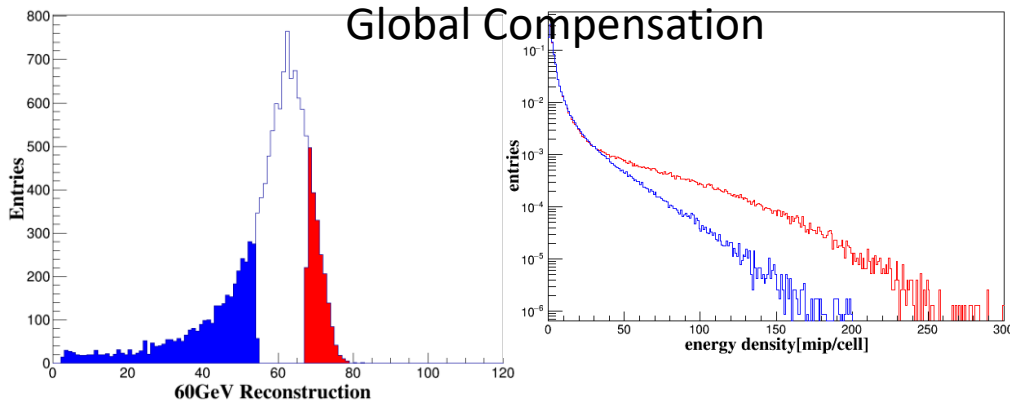
Local Compensation

Fit by $\omega_j = p_0 + p_1 e^{(p_2 * e_j)}$

Using least square method



Global Compensation



Local Compensation improves by ~18%
Global Compensation improves by ~15%

$$C_{global} = n_{e < e_{lim}} / N_{e < e_{mean}}$$

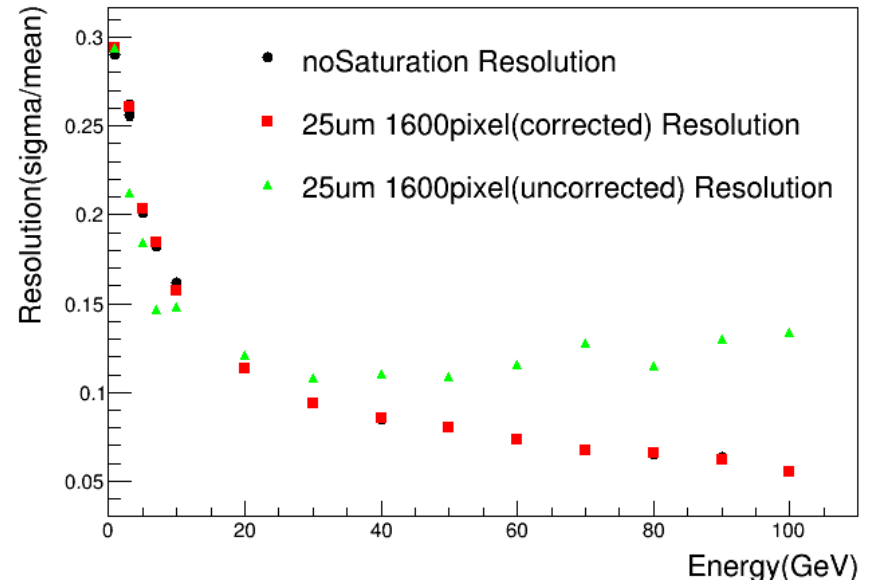
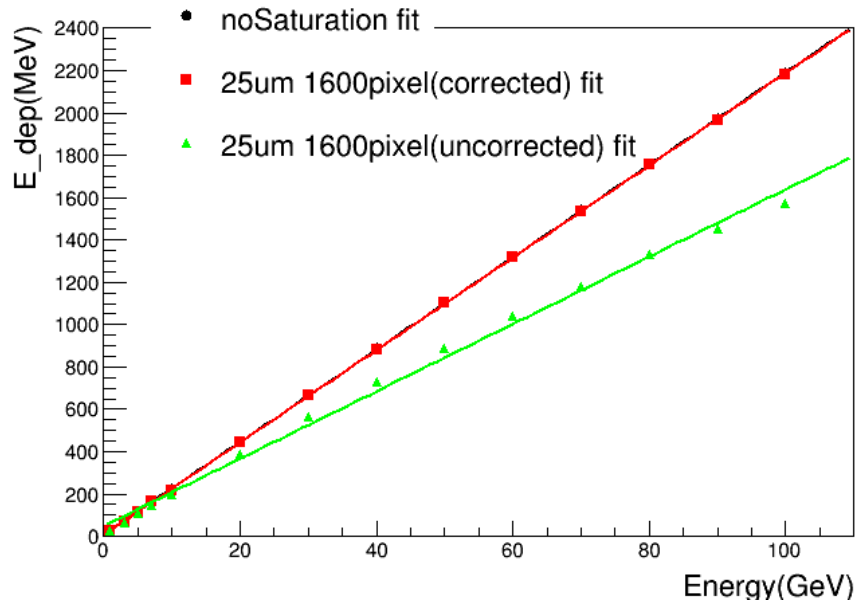
$$E_{rec} = \sum_i (E_{HCAL,i} \times C_{global})$$

SiPM saturation effect on AHCAL dynamic range

Scintillator: $30 \times 30 \times 3\text{mm}^3$

SiPM: 1mm^2 with 1600 Pixels

- SiPM Saturation will influence the AHCAL energy reconstruction.
- The digitization method has combined the simulation hits (deposit energy) and test results to calculate the fired pixel number for each SiPM by Monte Calo.



$$\text{Corrected by } N_{\text{fire}} = N_{\text{pix}} (1 - e^{-\epsilon N_{\text{in}} / N_{\text{pix}}})$$

After correction, the dynamic range of 1600 pixels SiPM is enough!

AHCAL prototype Plan

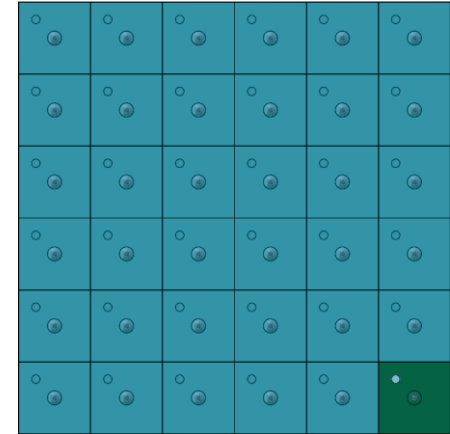


Motivation:

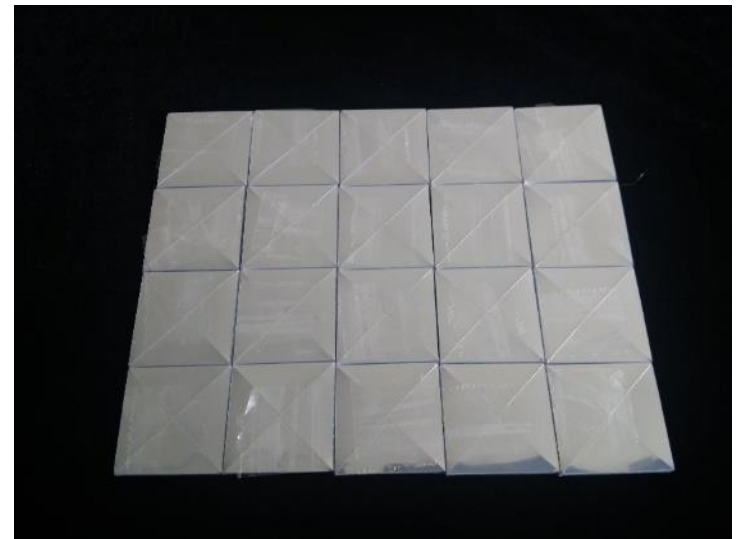
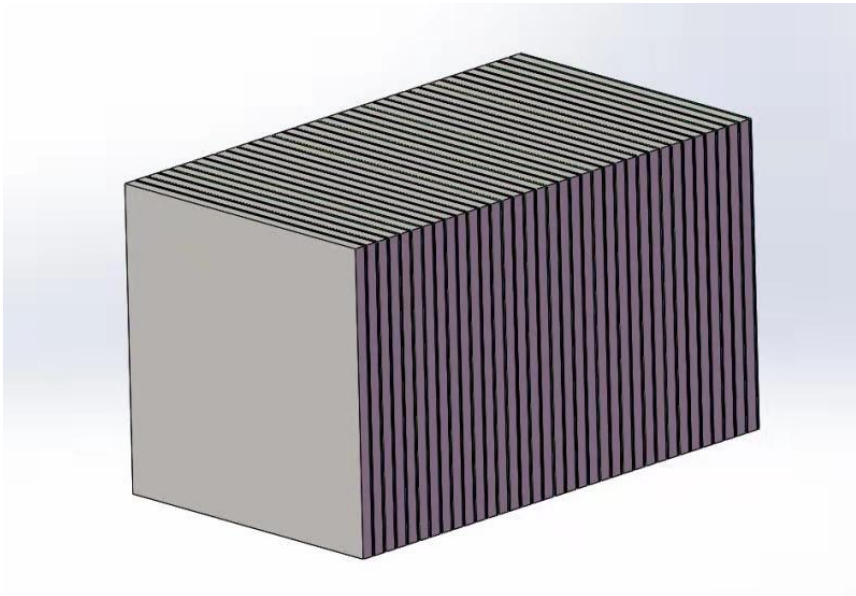
- A AHCAL prototype fit the CEPC requirement.

Specification:

- Active layers: under optimization (≈ 35);
- Detector cell: under optimization ($30 \times 30 \times 3 \text{ mm}^3$);
- Absorber: stainless steel;
- Readout: SiPM+ASIC



Ability of cell mass production

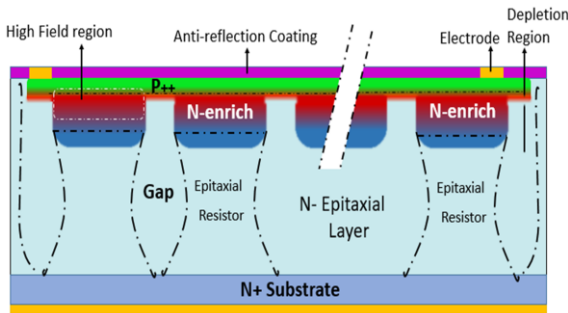


Chinese NDL-SiPM Test-1 (**1mmx1mm 10umSiPM**)

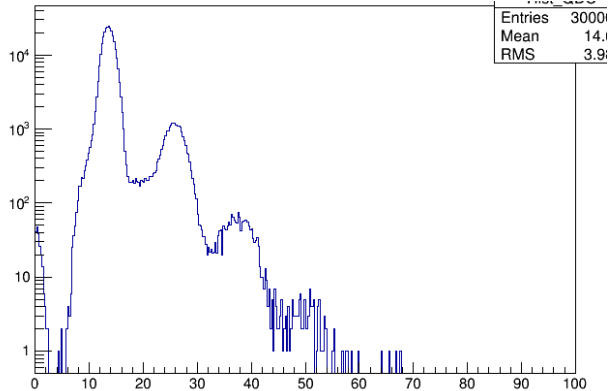


Six NDL-SiPMs was tested (electron-Sr90): 30mmx30mmx3mm with PL Scintillator

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



Structure of EQR SiPM



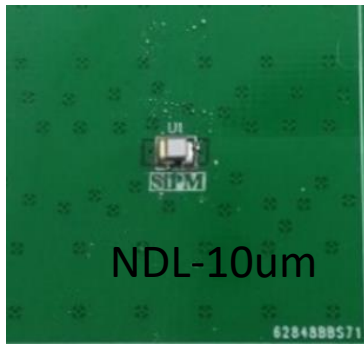
Crosstalk spectrum

NDL-SiPM 11-1010C specification

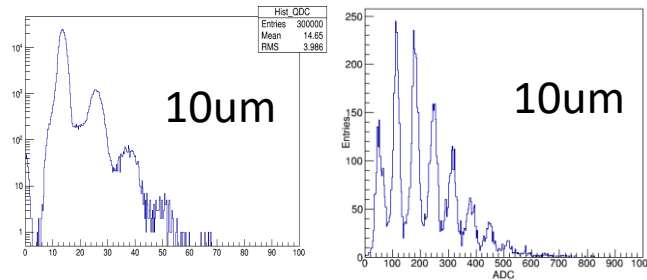
Parameter	Value	Parameter	Value
Effective Active Area	1 × 1mm ²	Peak PDE@420nm*	39%
Effective Pitch	10 μm	Dark Count Rate*	~500 kHz
Micro-cell Number	~10000	1 p.e. Pulse Width	5 ns
Operating Temperature	-196°C - +40°C	Temperature Coefficient For V _b	25 mV/C
Breakdown Voltage (V _b)	25.5 ± 0.2 V	Gain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

NDL SiPM website => <http://www.ndl-sipm.net/>

NDL-SiPM + ASIC Test-2

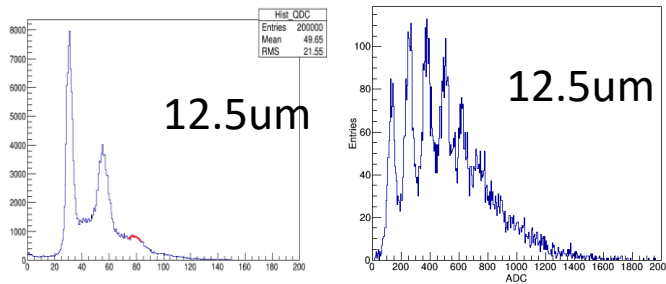


Calibration by their **NDL preamplifier**



Self-trigger

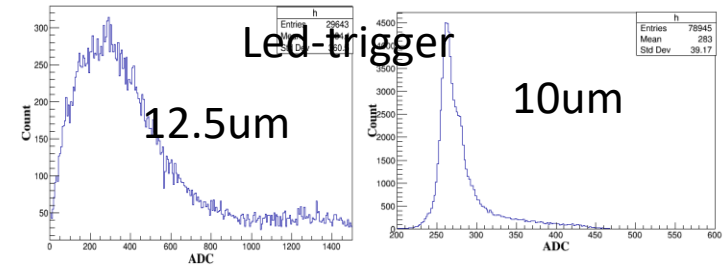
Led-trigger



12.5um

12.5um

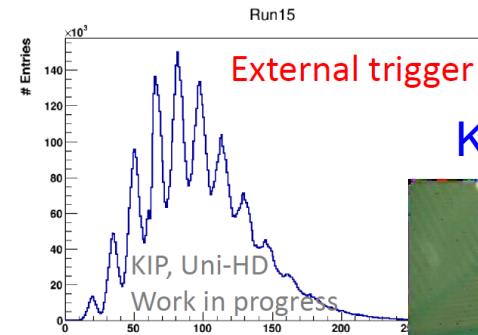
Read-out and Calibration by **Spiroc2b**



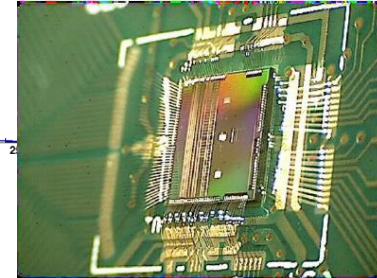
Led-trigger

12.5um

10um



KLaUS Chip



Pitch	10um	12.5um	15um (under developing)
Peak PDE @420nm	31%	32%	35%
Gain	$2 \cdot 10^5$	$3.5 \cdot 10^5$	$5 \cdot 10^5$
Breakdown Voltage(V)	27.5	21.5	

KLaUS ASIC (KIP, Uni-HB)

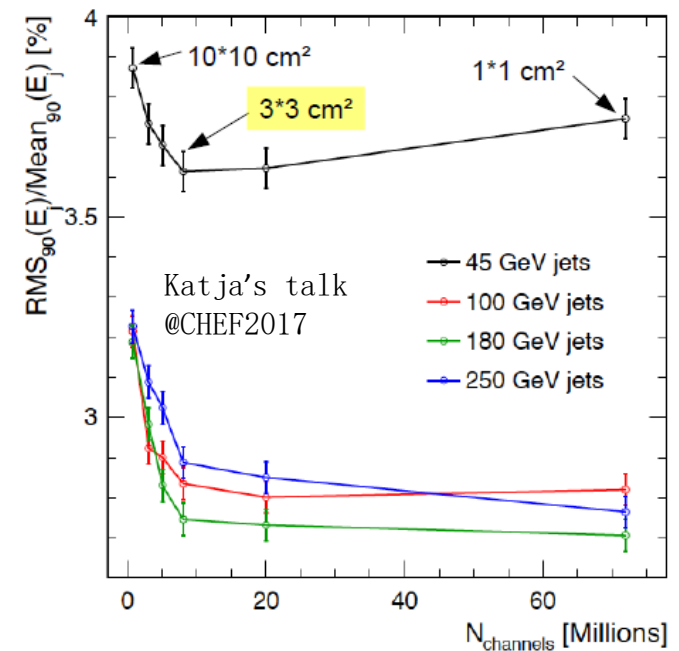
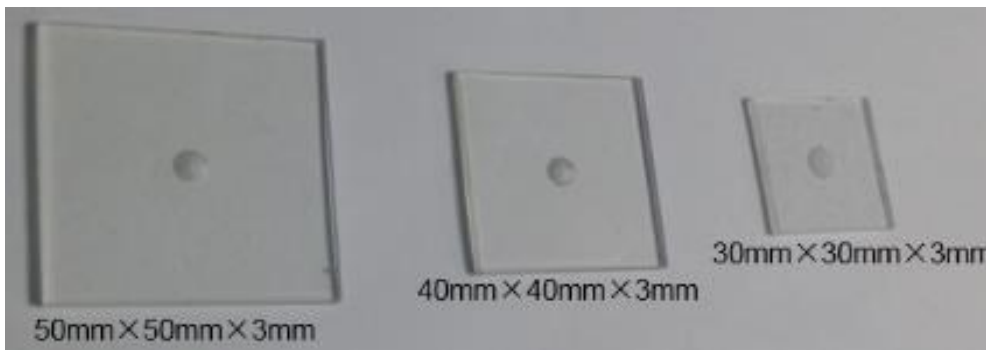
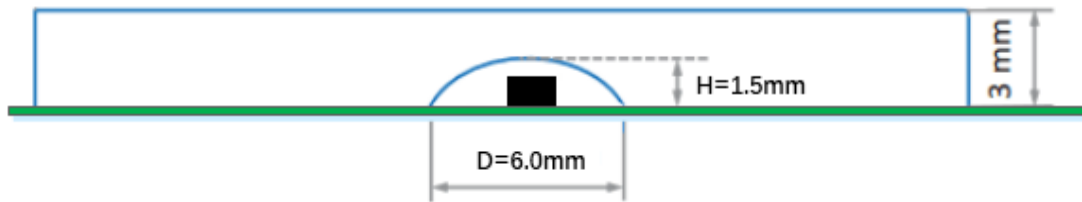
- Low noise, low power dissipation
- Continuous readout without dead time

25 uW / channel @ duty cycle 0.5%

Scintillator Detector Cells study



- The four sizes of $30 \times 30 \times 3 \text{mm}^3$, $40 \times 40 \times 3 \text{mm}^3$ and $50 \times 50 \times 3 \text{mm}^3$ were studied.
- SiPM or MPPC(surface-mounted)
- PS were wrapped by ESR foil



Detector cell size VS jet energy resolution

Cosmic-rays Mips measurement results



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

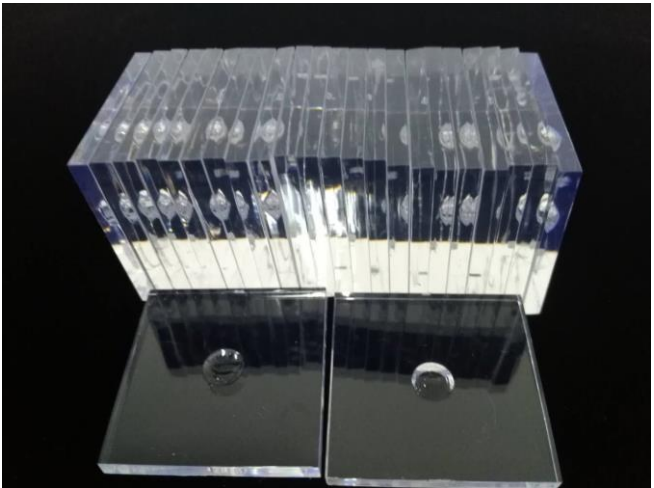
No. [↵]	Detector Cell [↵]	MPPC Type [↵]	Reflective Foil Type [↵]	Mean $N_{p.e.}$ [↵]	Polishing Methods [↵]
1 [↵]	30×30×3mm ³ [↵]	S12571-025P [↵]	ESR [↵]	31.39±0.65 [↵]	Ultra Precise Polishing [↵]
2 [↵]	30×30×3mm ³ [↵]	S12571-025P [↵]	ESR [↵]	22.55±0.7 [↵]	Precise Polishing [↵]
3 [↵]	30×30×3mm ³ [↵]	S12571-025P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

- The light output result show the 30mm × 30mm and 40mm × 40mm is acceptable, light output of 50mm × 50mm is not enough for ASIC readout.

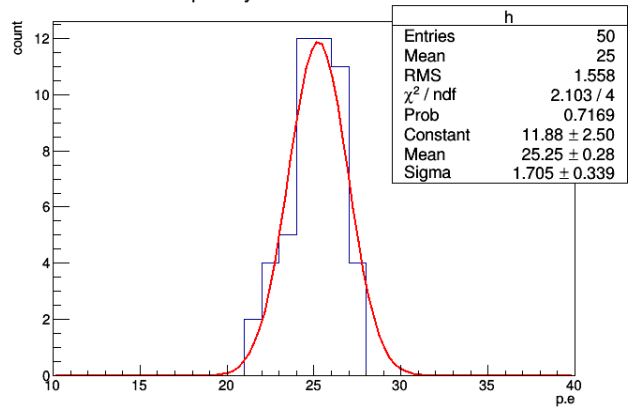


Injection moulded Scintillator tiles

- 300 tiles polystyrene, BisMSB
 - injection moulded at Beijing
 - incl. dimple, no further surface treatment;
- Mechanical tolerances is fine for assembly, the size error less than 50um;
- Scintillators Light output fluctuation is $\sigma < 7\%$;



photoyield of the scintillant



Size uniformity

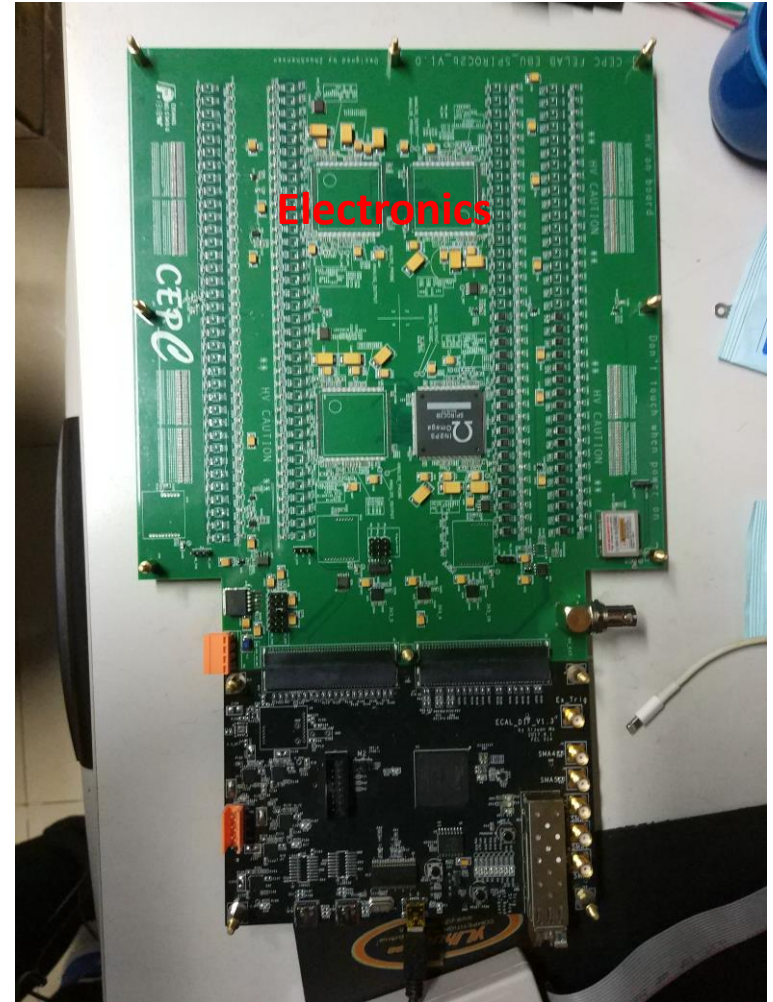
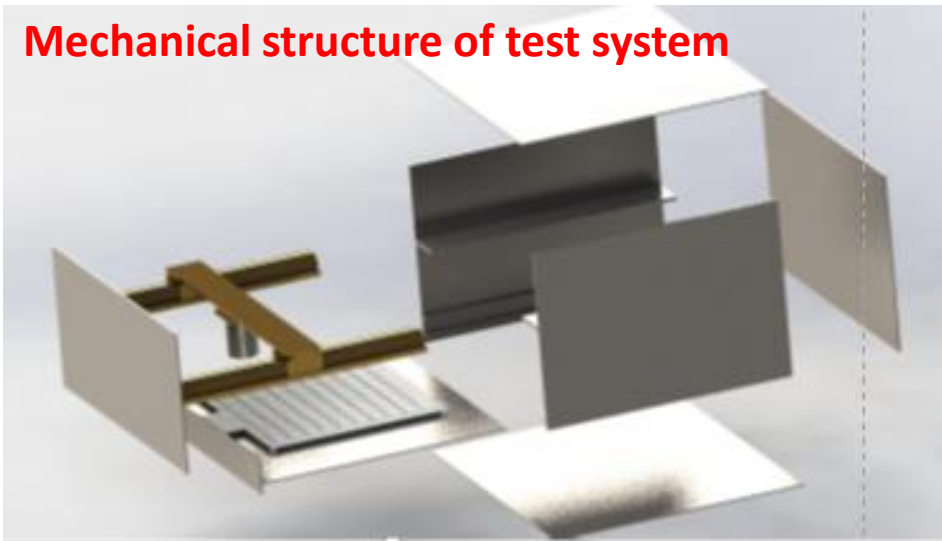
Tiles size(mm)	30.08x30.01 x3.08	30.07x30.04 x3.09	30.04x30.02 x3.09	30.09x30.09 x3.09	30.05x30.03 x3.09
Light output(p.e.)	23.5	22.78	22.86	25.02	23.54

Detector cell test system design



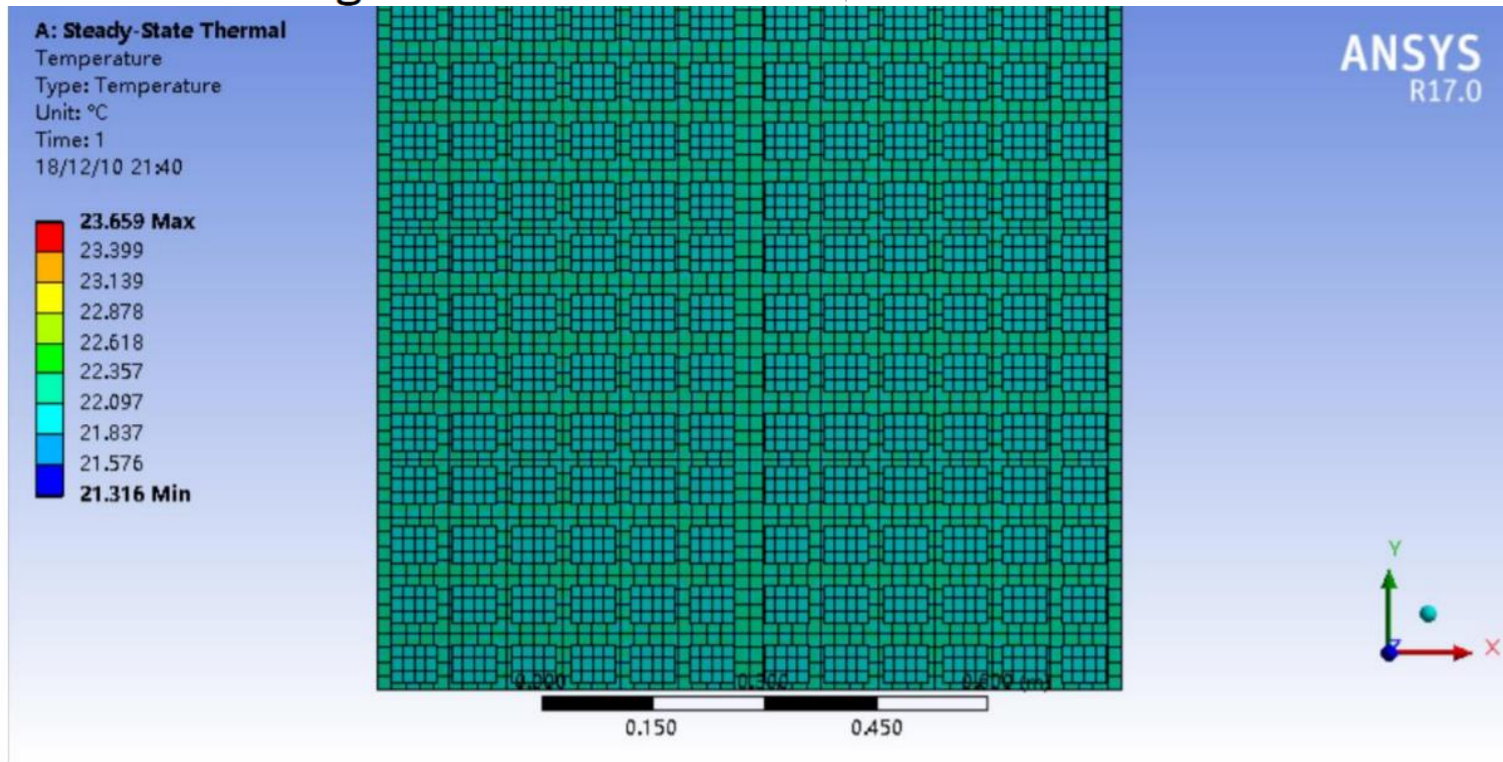
- About 100 detector cells one batch;
- Electronics under design;
- Mechanical structure under design;

Mechanical structure of test system



Cooling is under study

- 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



Rectangle pipe, water temperature: 22°C



Summary and next

- The construction of CEPC-HCAL prototype based on scintillator is started, the direction is NDL SiPM+ new ASIC;
- Some critical R&D items identified, which will be followed up.
- We have joined in the CALICE group last year;

CALICE Collaboration Meeting 2018 量能器国际合作组会议

Shanghai Jiao Tong University and Tsung-Dao Lee Institute

上海交通大学和李政道研究所, September 19-21, 2018



Thanks for your attention!

Backup

Detector cell assembly gluing experiment

motivation:

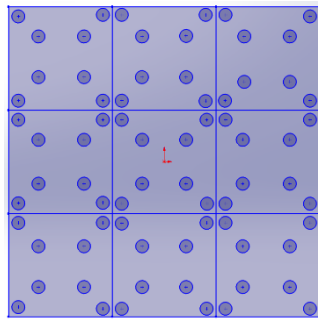
In order to quickly and effectively realize the integration of large area AHCAL detection unit.

Materials:

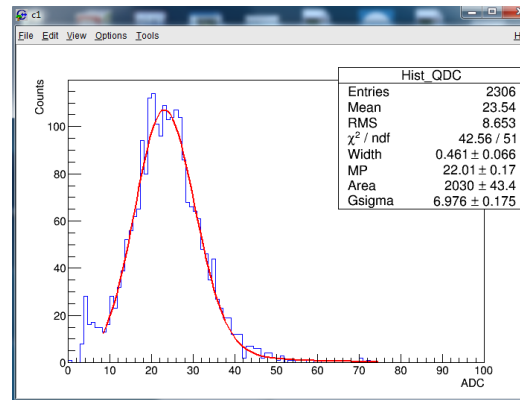
1. Araldite 2011 epoxy glue
2. 3×3 PCB board
3. Detector cell;
4. A film used to brush glue

Result:

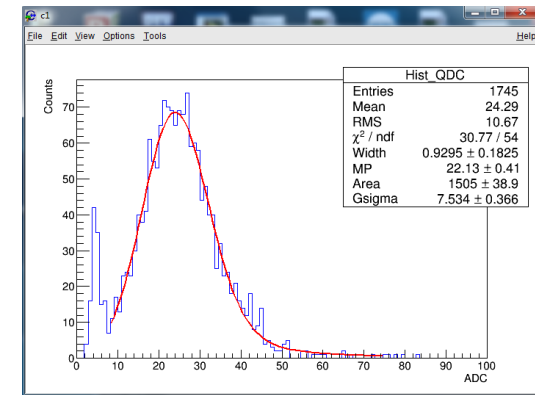
1. This way is working;
2. The detector cell was glued on PCB board fasten;
3. Maybe reduce to 4 glue hole;
4. Plan to test crosstalk and prototype.



Light output

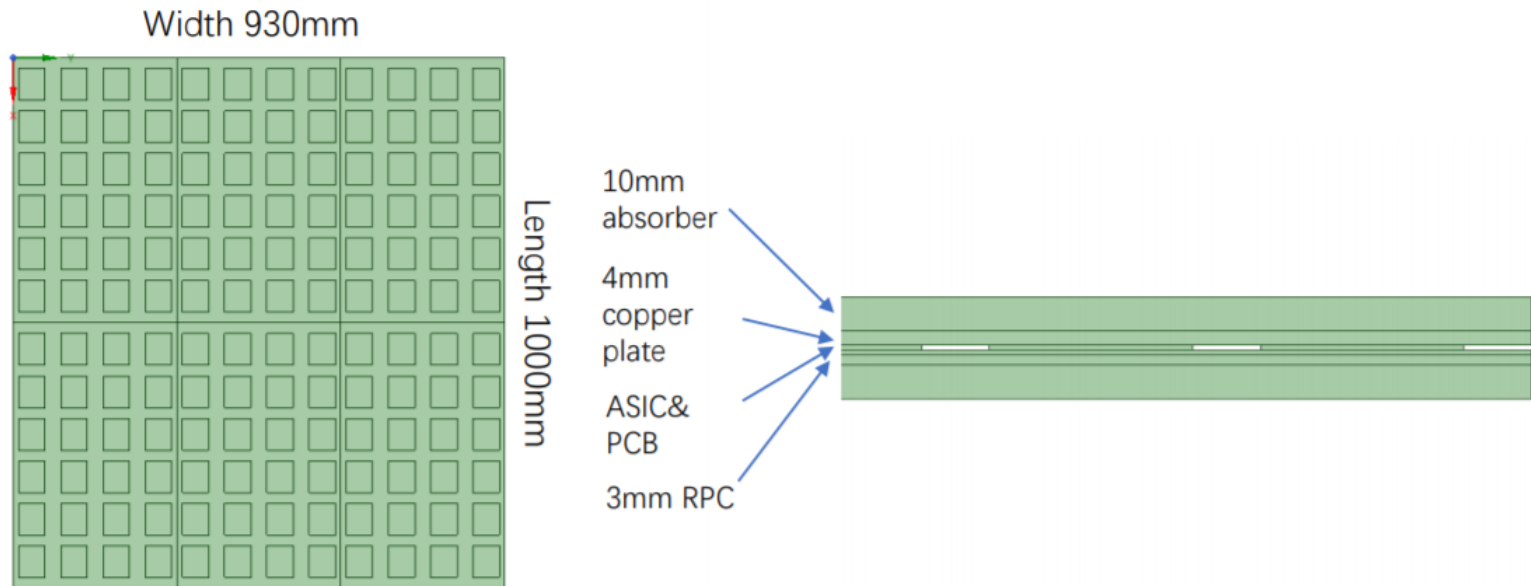


Before glued



After glued

Model



Active Cooling

- 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 $6 \times 6 \text{ mm}^2$ 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.

