The R&D progress of CEPC PFA HCAL

Boxiang Yu

On behalf of the CEPC Calorimeter working Group

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

Outline

—CEPC Detector Concept(s)

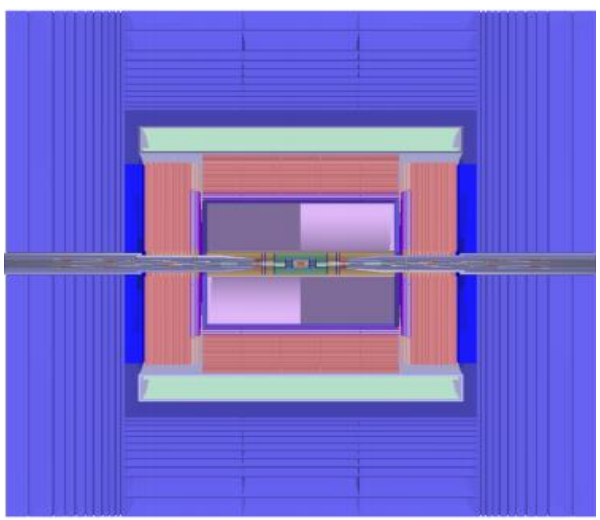
—The options of CEPC-PFA-HCAL;

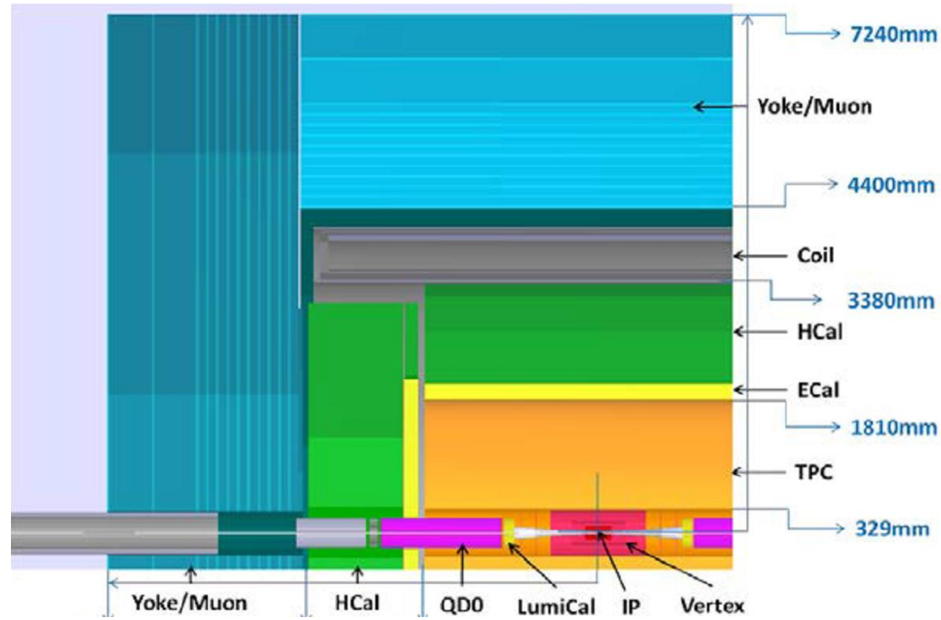
—The progress of two option of PFA-HCAL
- DHCAL based on RPC and MPGD(THGEM/GEM);
- AHCAL based on scintillator;

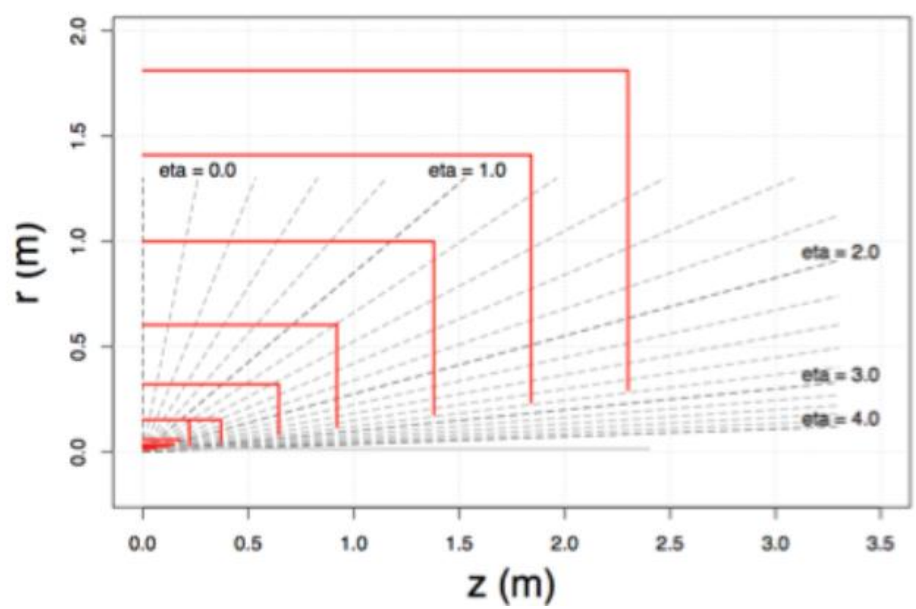
—Summary

CEPC Detector Concept(s)

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





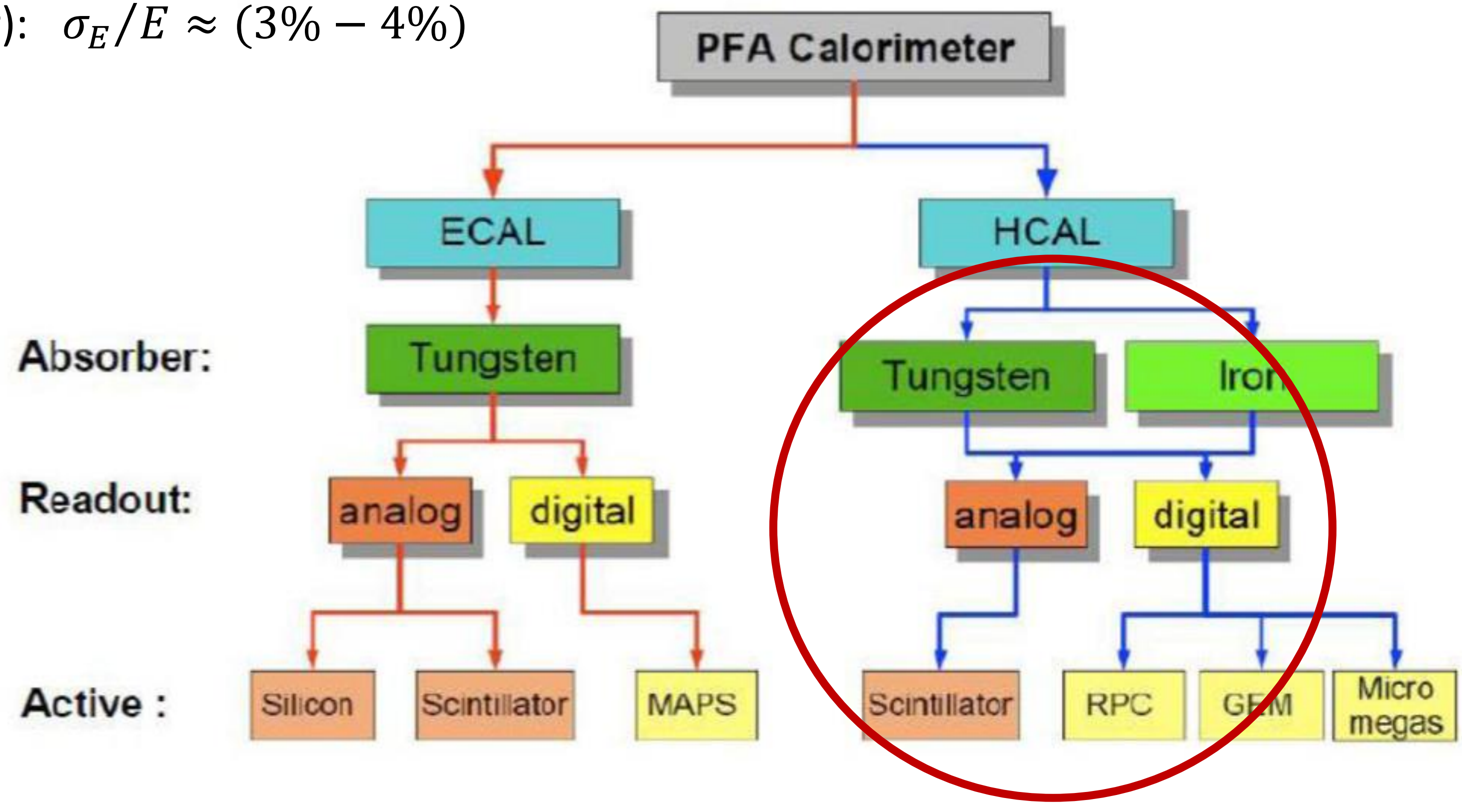


The options of CEPC-PFA-HCAL;

Two options:

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

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



PFA HCAL R&D for CEPC

- 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

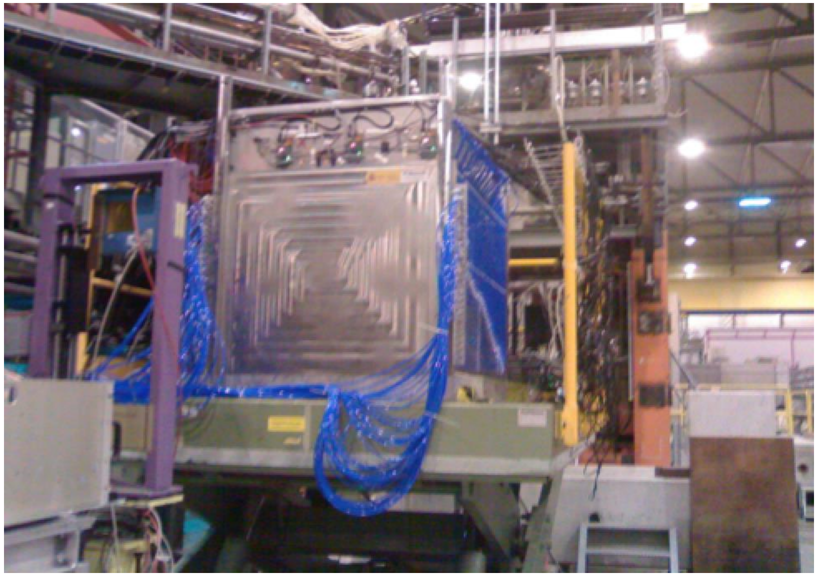
SDHCAL Based on RPC（IPNL+SJTU within CALICE）

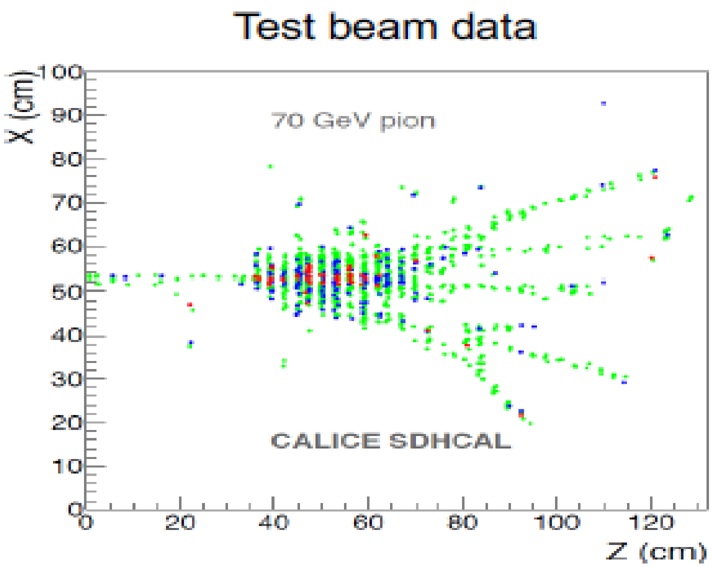
SDHCAL Prototype

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

(Power pulsing)

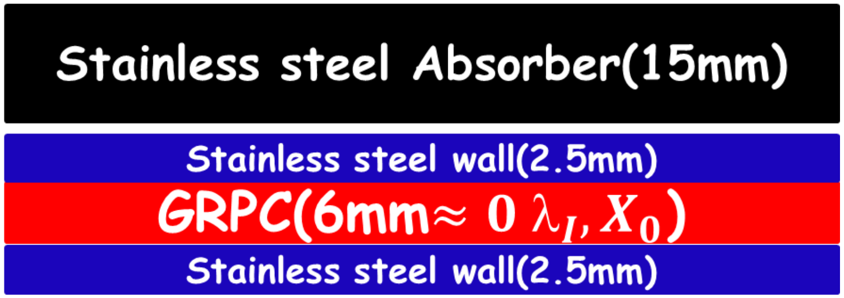


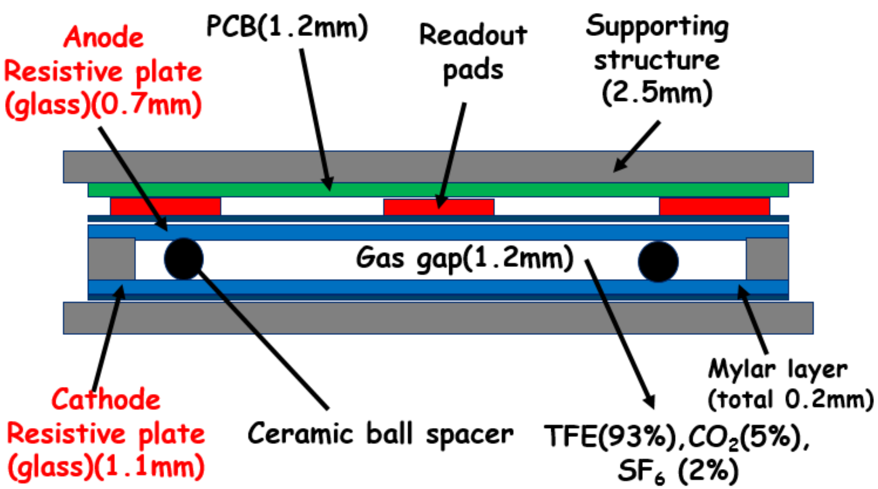


Developed by the CALICE collaboration

Structure of sampling layer

$(0.12\lambda_I, 1.14X_0)$





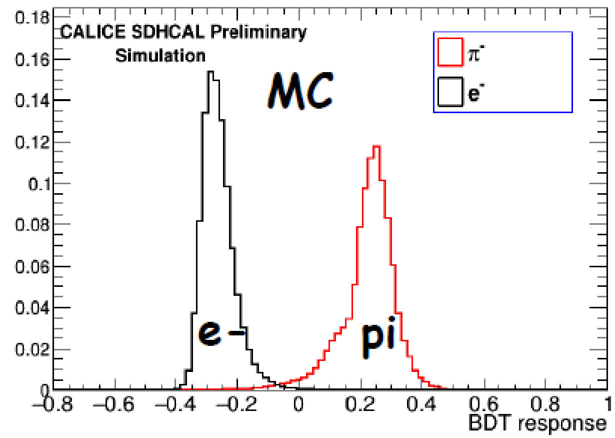
ASIC HARDROC(64 channel)
three-threshold (Semi-digital)
110fC,5pC,15pC

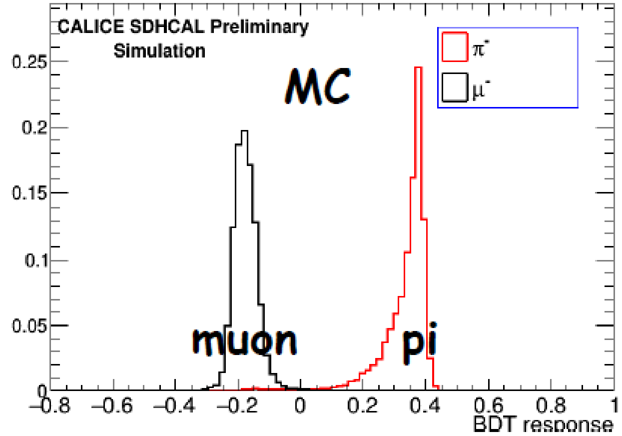
SDHCAL TestBeam Data Analysis: PID using BDT

- TMVA of root, Methods: BDT 6var
- Training and Test
  - Signal: 160000 pion events with energy 10,20,30,40,50,60,70 and 80GeV
  - Background:160000 electron events with energy 10,20,30,40,50,60,70 and 80GeV
  - Background: ≈120000 muon events with energy 10,20,30,40,50,60,70 and 80GeV

  Mixed Background

  - Ntraining : Ntest=1 : 1



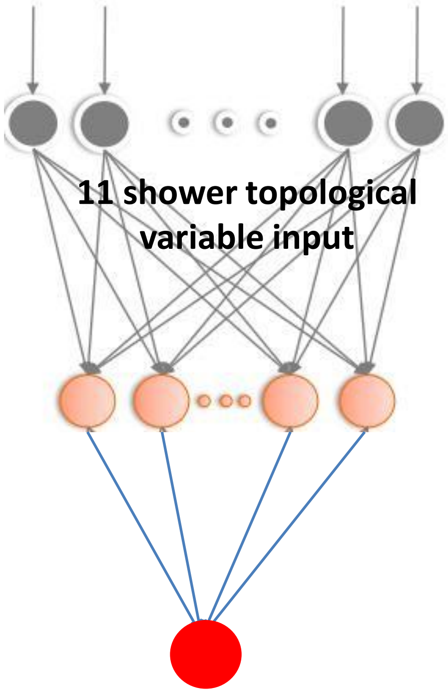


Strong separation power in pi/e and pi/muon

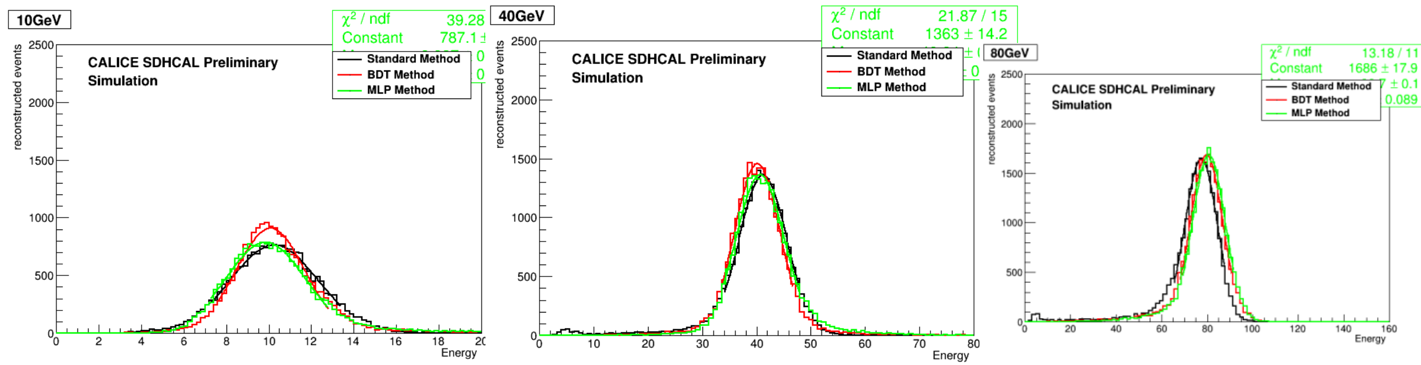
"Hadron selection using Boosted Decision Trees in the semi-digitial hadronic calorimeter", CALICE-CAN-2019-001

Energy Reconstruction using MLP and BDT

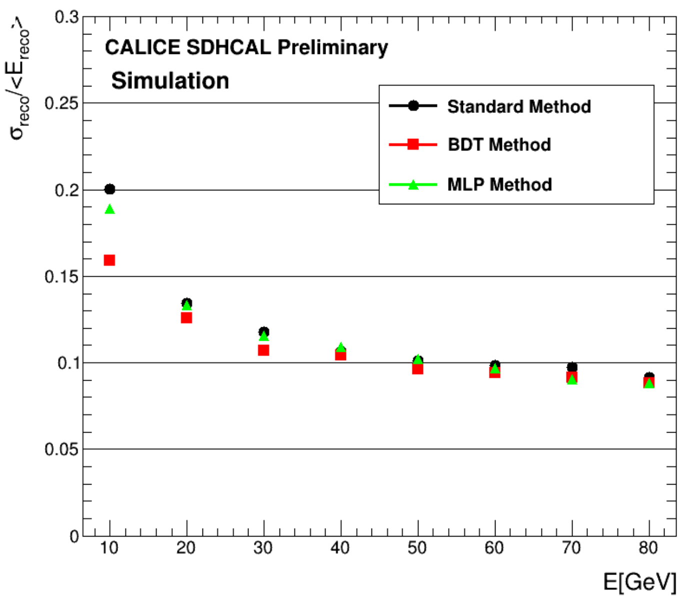
MLP Structure

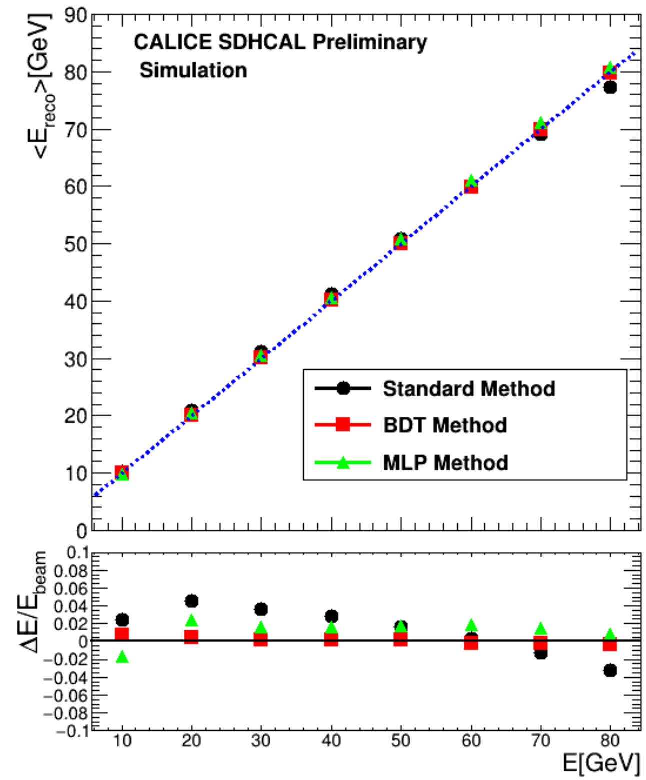


Energy reconstruction



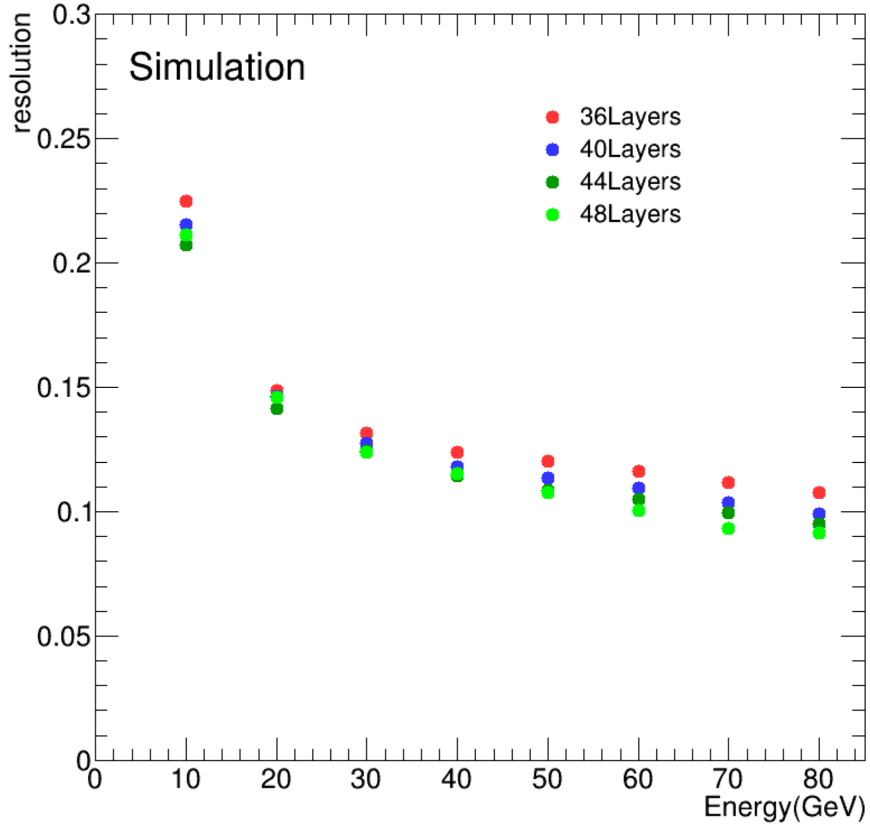
One hidden layer

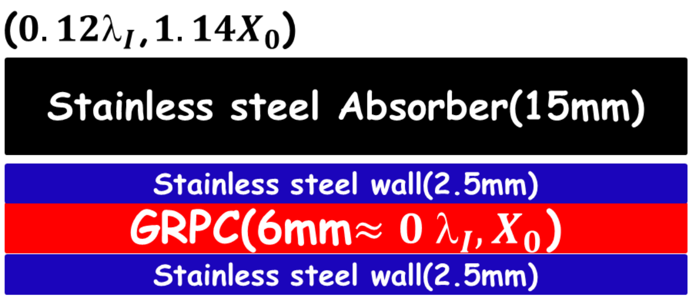




Analysis Note is under preparation

Optimization of SDHCAL Layers





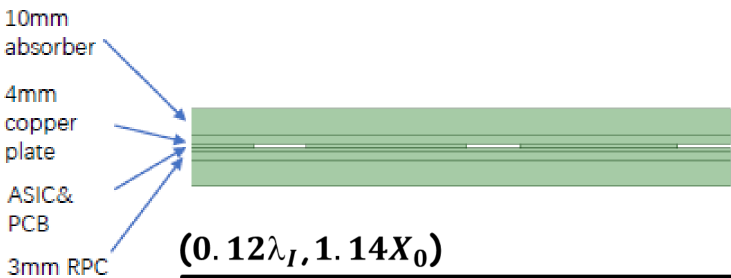
➔SDHCAL has 48 layers which aims for ILC Detector
- 6mm RPC+20mm absorber

➔Optimization no. of layers for CEPC at 240GeV

➔**40-layer SDHCAL yields decent energy resolution.**

Simulations of Active Cooling

ANSYS Simulation of RPC+PCB With copper plate & water tubes



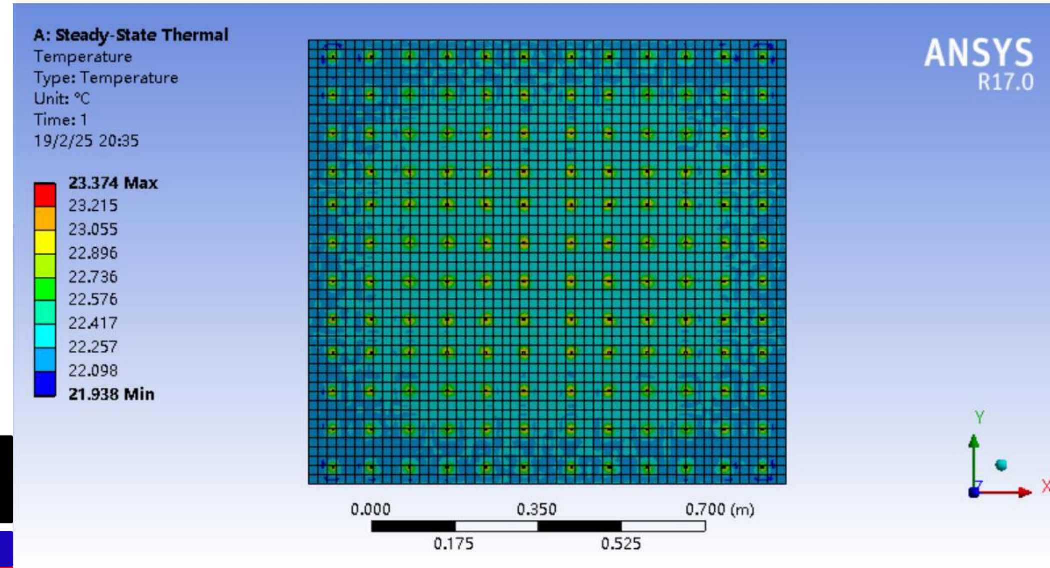
$(0.12\lambda_I, 1.14X_0)$

Stainless steel Absorber(15mm)

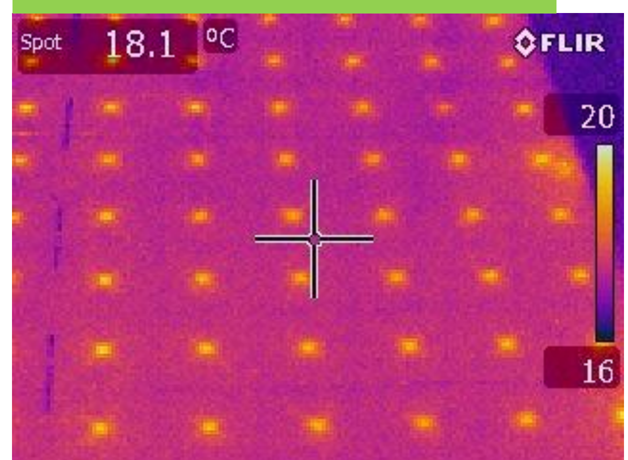
Stainless steel wall(2.5mm)

GRPC(6mm≈ $0\ \lambda_I, X_0$)

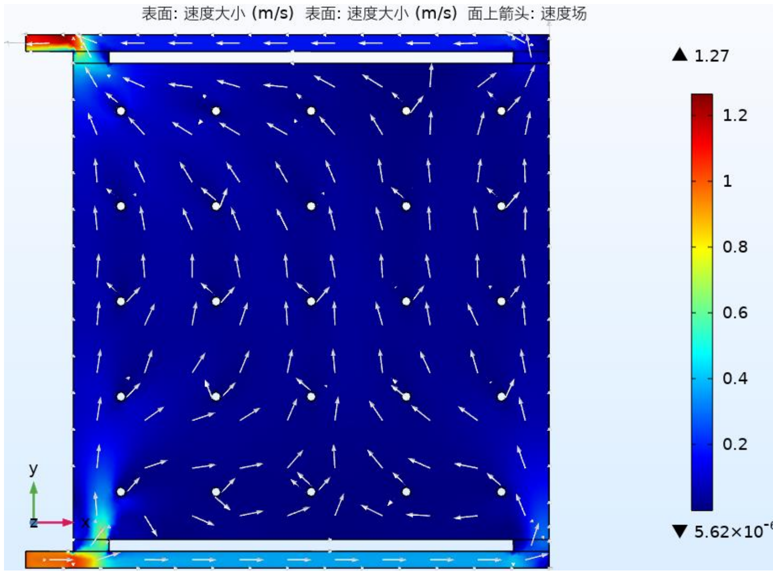
Stainless steel wall(2.5mm)

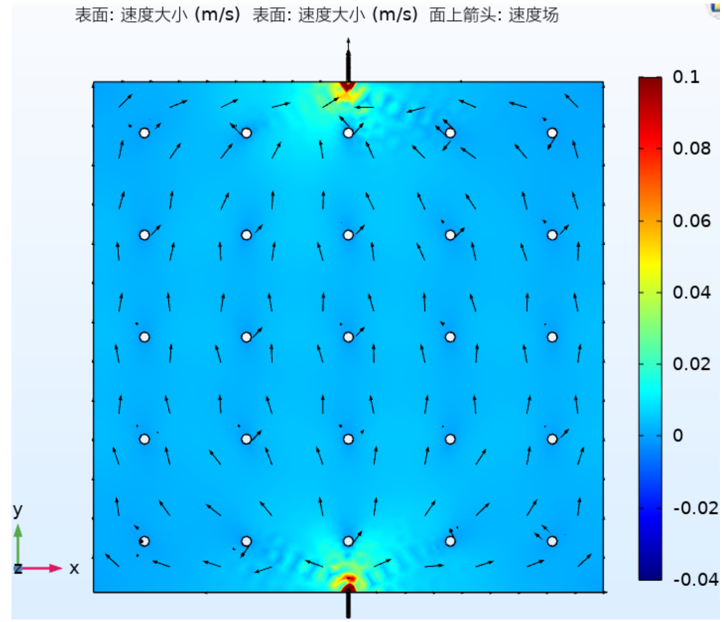


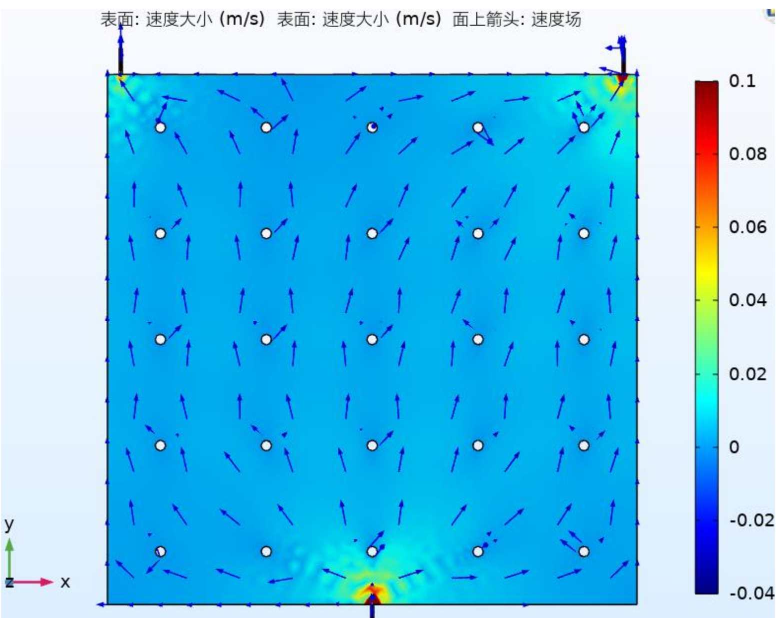
Temp. test of RPC+PCB

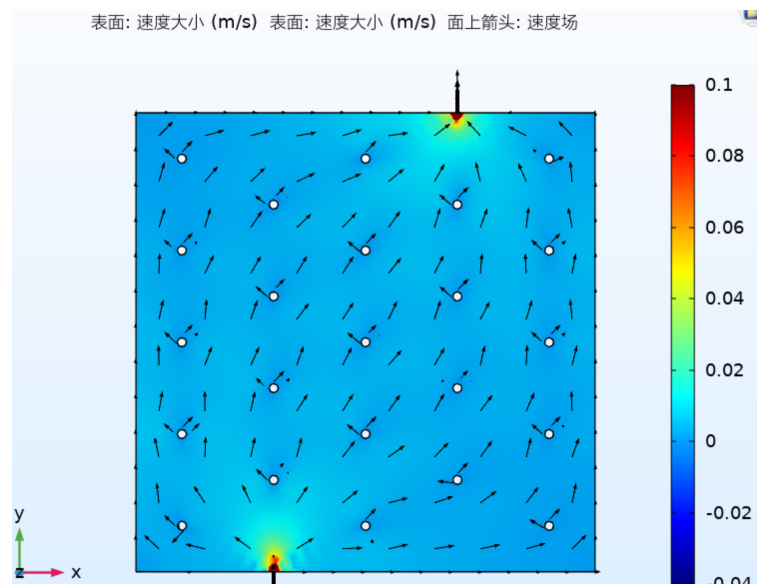


Simulation of RPC Gas Flow

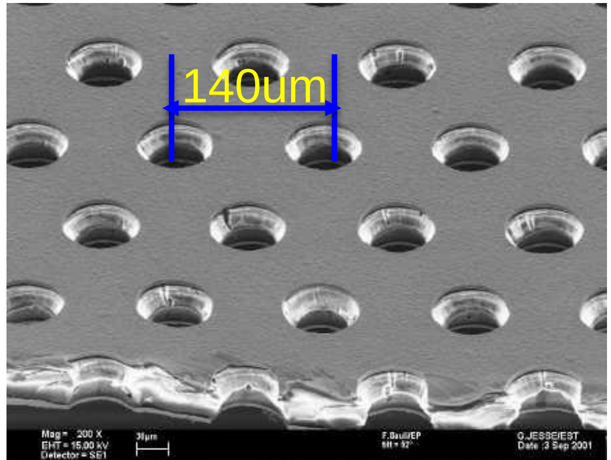








DHCAL based on MPGD(GEM)



Typical parameters

Cu : t = 5µm

Kapton: T = 50µm

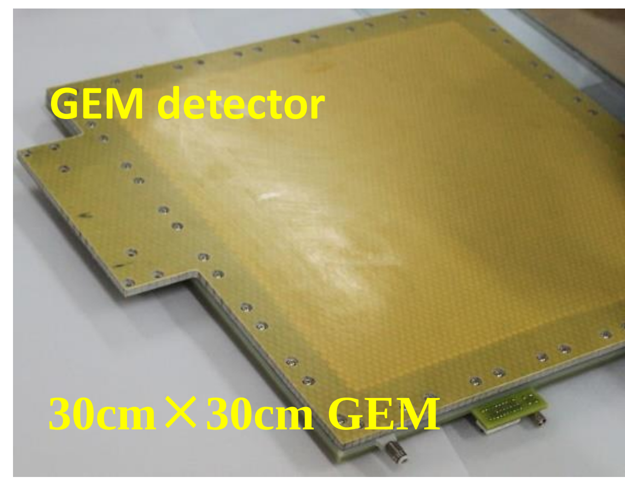
Diameter: d = 60µm

D = 80µm

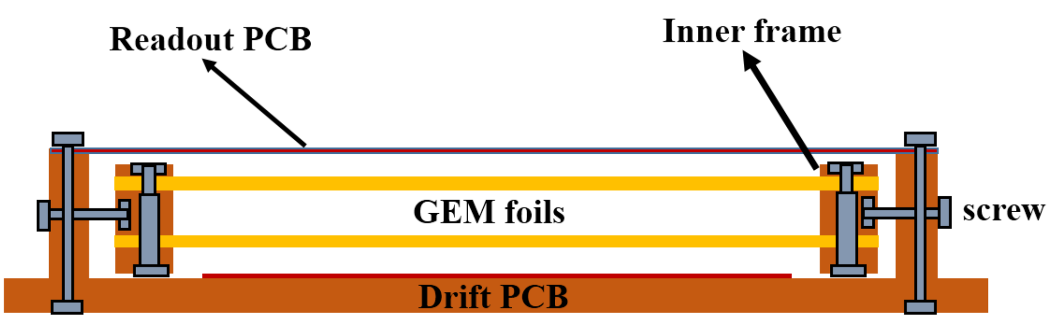
pitch: 140µm

➢ **Advantages:**

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

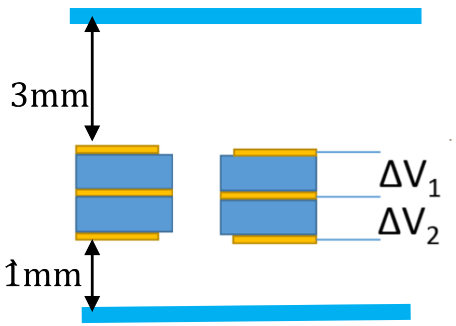


Self-stretching technique (from CERN)

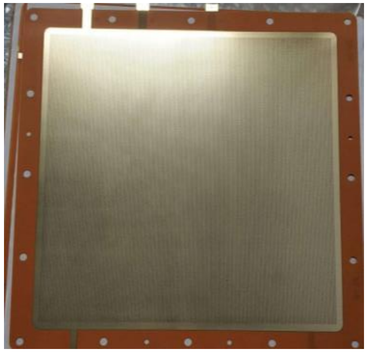


M-THGEM detector

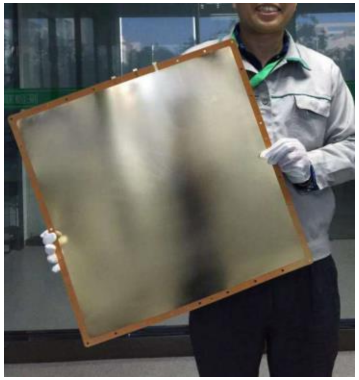
- Structure



200mm ×200mm M-THGEM foil

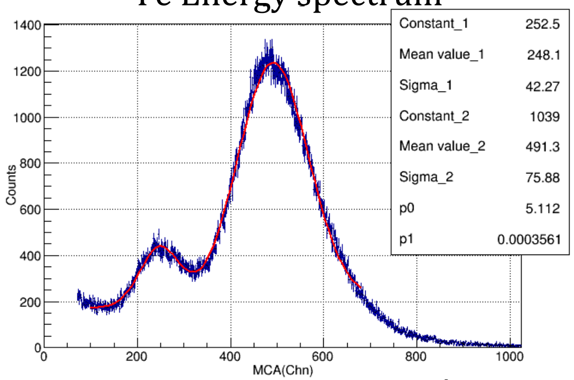


500mm ×500mm M-THGEM detector

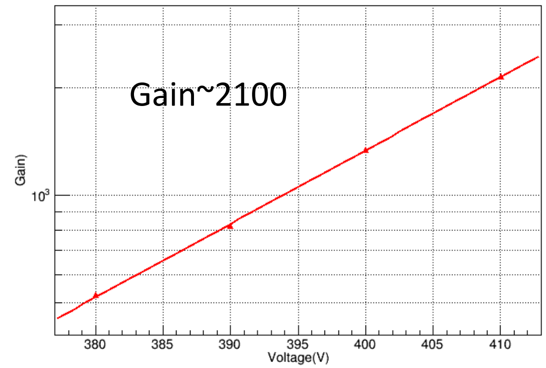


- Performance

^{55}Fe Energy spectrum



Gain VS voltage



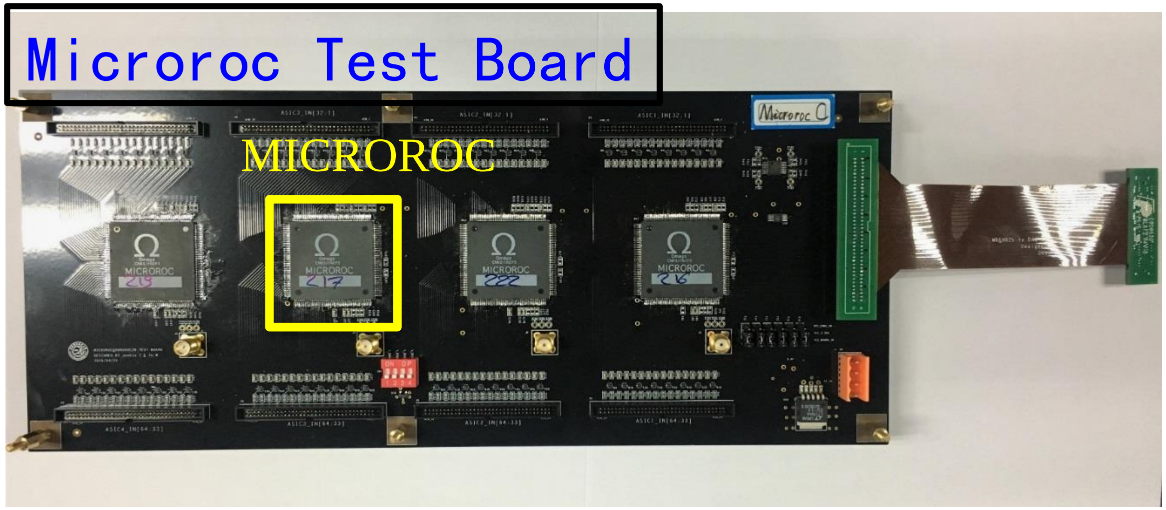
50cm*50cm detector result

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, 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

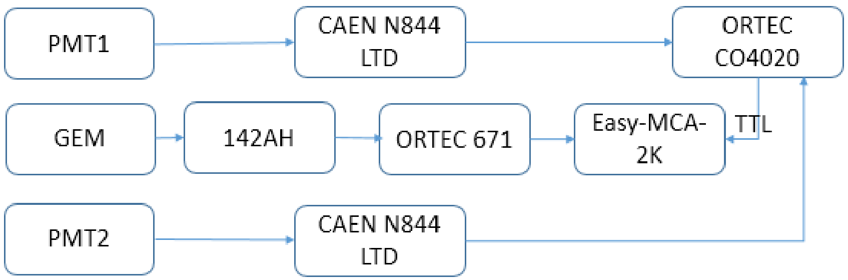


MICROROC Parameters

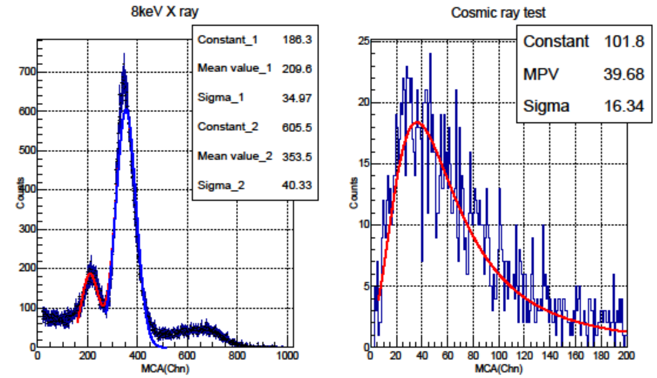
- Thickness: 1.4mm
- 64 Channels
- 3 threshold per channel
- 128 hit storage depth
- Minimum distinguishable charge:2fC

Detection efficiency for MIPs of GEM detector

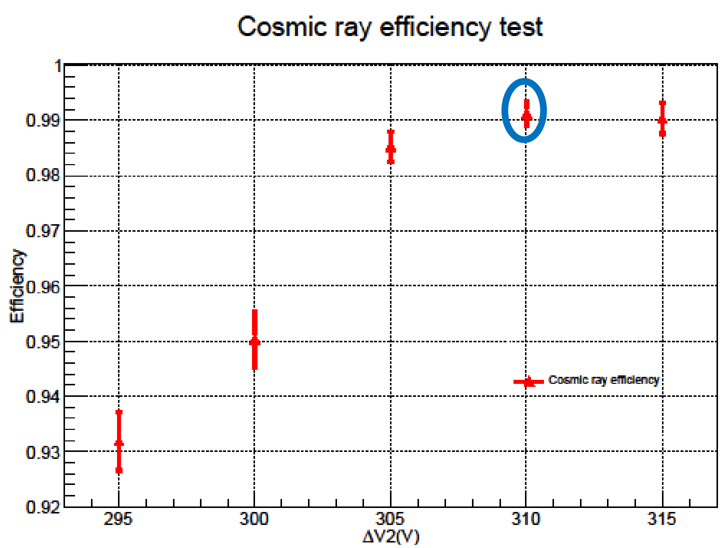
Electronic system

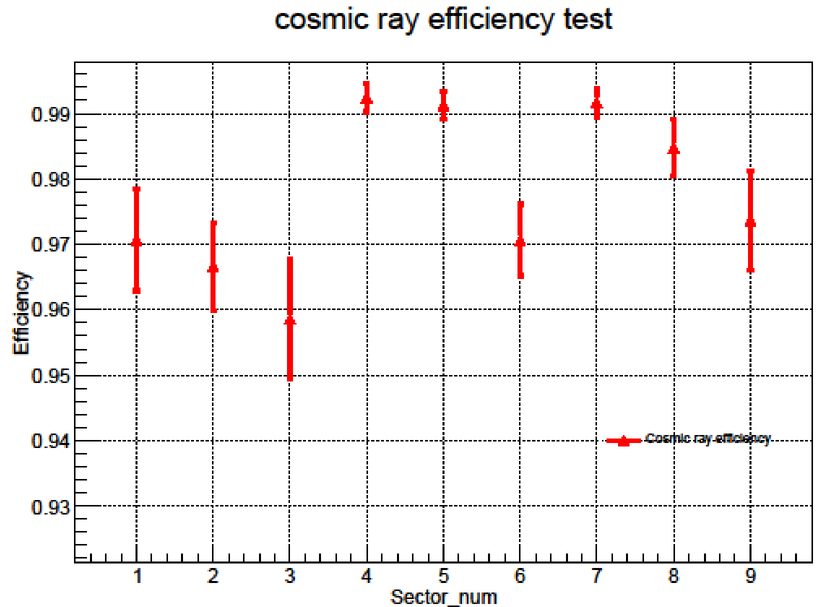


Spectra of X ray and cosmic ray



Detection efficiency vary with voltage



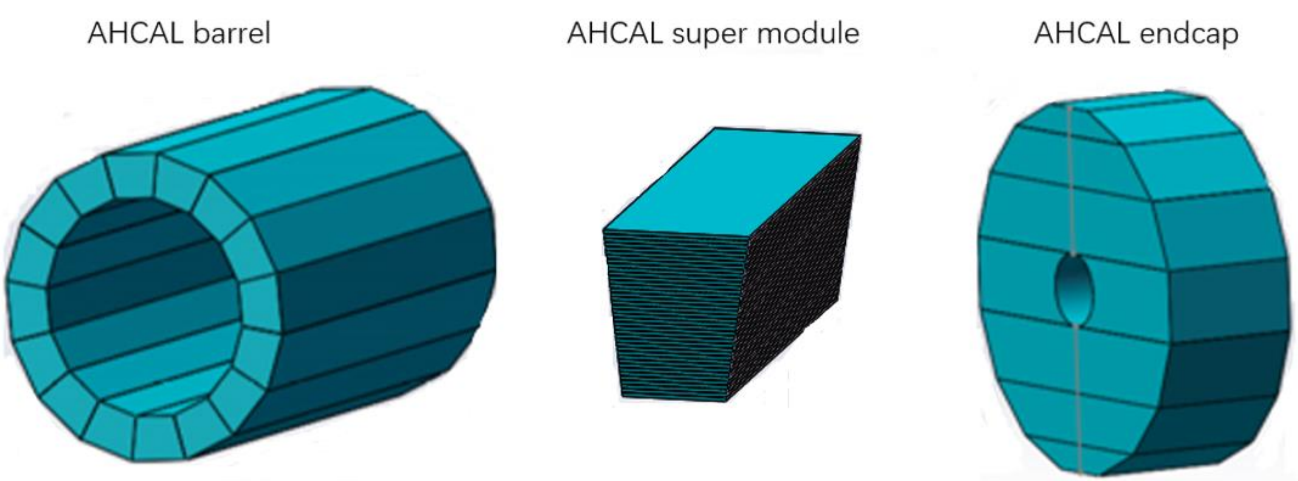


Detection efficiency in different area of GEM detector

The R&D progress of CEPC AHCAL

— Analog hadron calorimeter for CEPC:

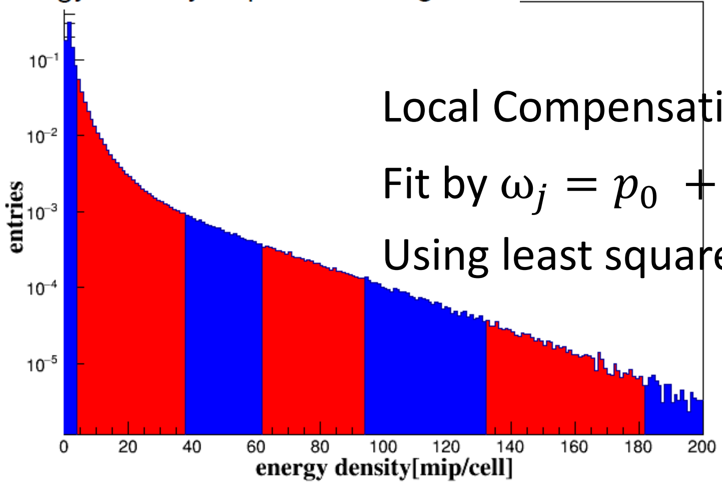
- The absorber: 2cm Stainless steel ($0.12\lambda_I$, $1.14X_0$);
- Detector cell size: 3cm×3cm or 4cm× 4cm;
- ASIC Readout chip: KLauS (KIP, Uni-Heidelberg) SPIROC2E, etc.
- The sensitive detector : Scintillator(organic scintillator);
- About 40 sensitive layers, total readout channel: ≈6 Million (3cm×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



Software compensation for Energy reconstruction at AHCAL

Local

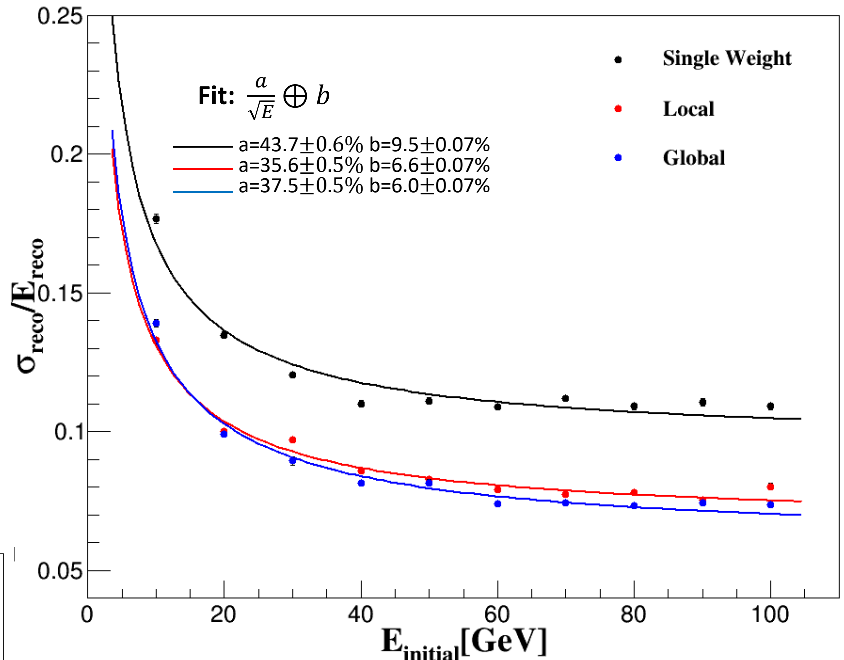
- Cell-by-cell correction of energy with energy-density dependent *weights*



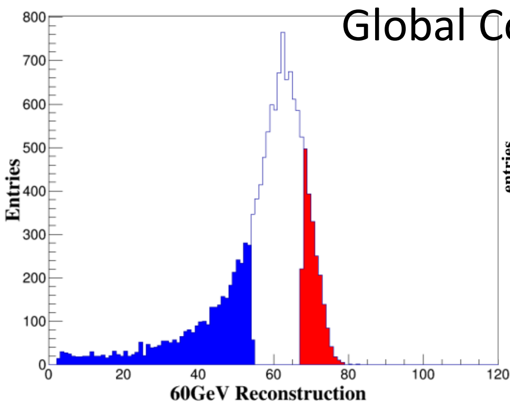
Local Compensation

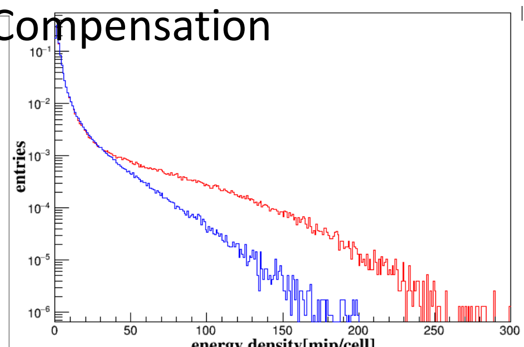
Fit by $\omega_j = p_0 + p_1 e^{(p_2 * e_j)}$

Using least square method



Global Compensation





Local Compensation improves by ~18%

Global Compensation improves by ~15%

Global

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

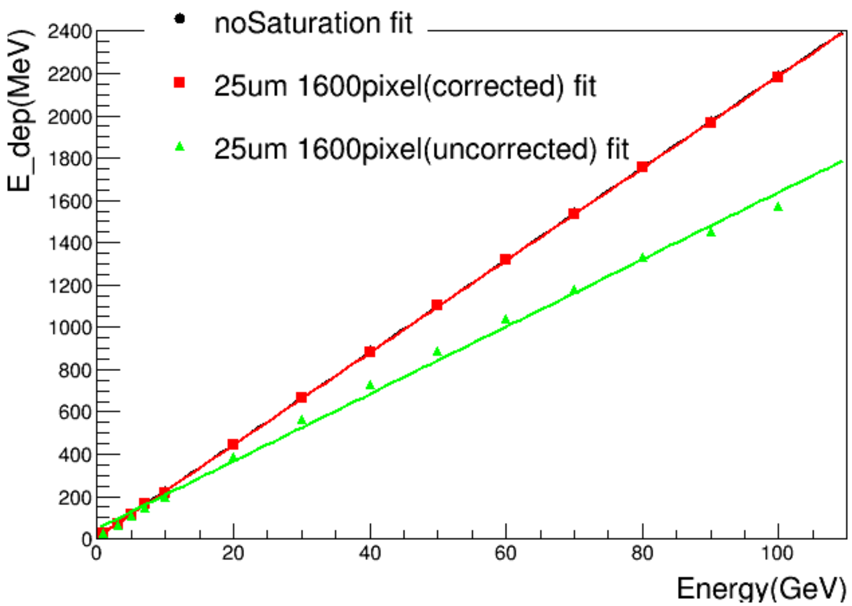
$$E_{rec} = \sum_i (E_{HCAL,i} \times C_{global})$$

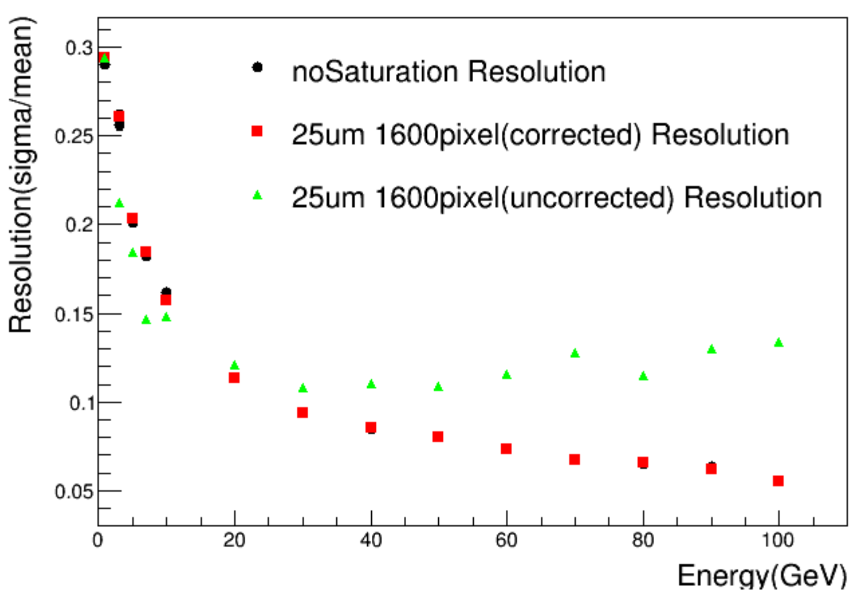
- Event-by-event correction of energy sum with a shower-dependent *global* factor

SiPM saturation effect on AHCAL dynamic range

Scintillator: $30 \times 30 \times 3\mathrm{mm}^3$
SiPM: $1\mathrm{mm}^2$ 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.





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

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

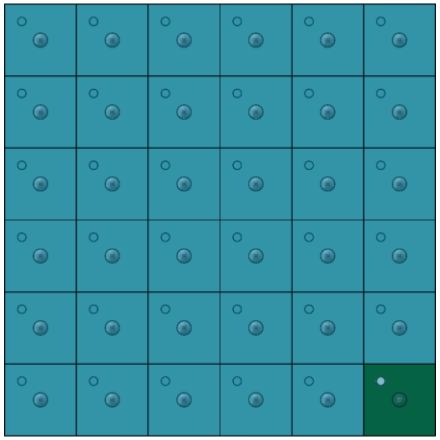
AHCAL prototype Plan

Motivation：

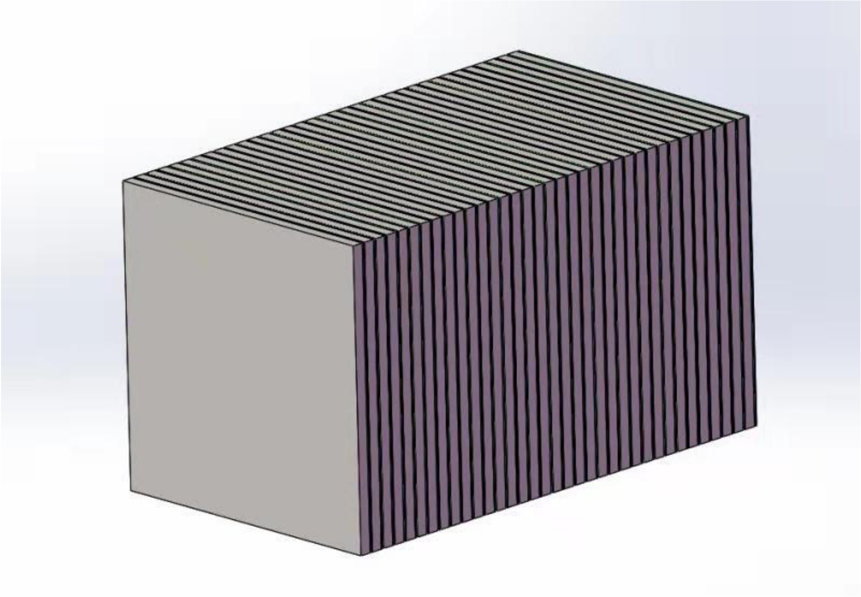
– A AHCAL prototype fit the CEPC requirement.

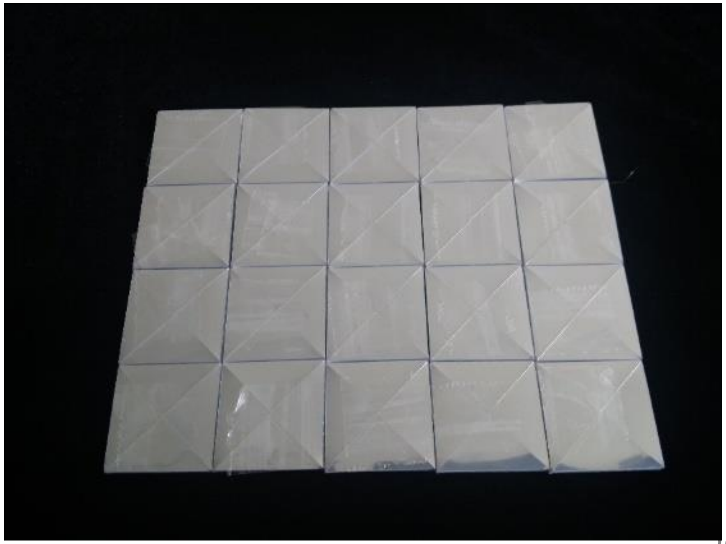
Specification:

- Active layers： under optimization (≈35);
- Detector cell: under optimization (30X30X3mm^3);
- Absorber: stainless steel;
- Readout: SiPM+ASIC



Ability of cell mass production

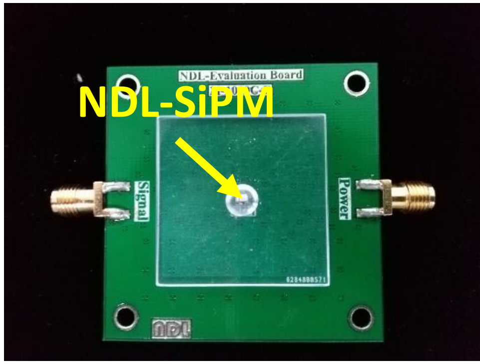


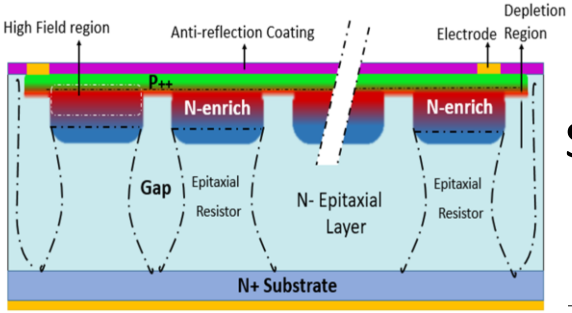


Chinese NDL-SiPM Test-1 (1mmx1mm 10umSiPM)

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

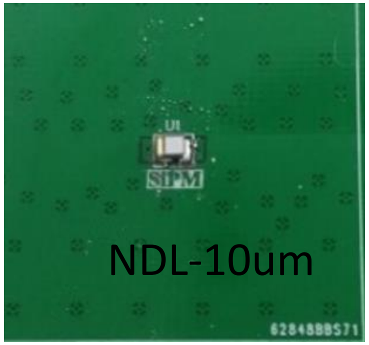
Crosstalk spectrum

NDL-SiPM 11-1010C specification

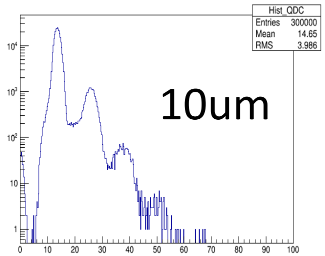
Parameter	Value	Parameter	Value
Effective Active Area	1× 1mm²	Peak PDE@420nm*	39%
Effective Pitch	10 μm	Dark Count Rate*	~500 kHz
Micro-cell Number	~10000	1 p.e. Pulse Width	5 ns
Operating Temperature	-196°C - +40°C	Temperature Coefficient For V_b	25 mV/°C
Breakdown Voltage (V_b)	25.5±0.2 V	Gain	≥2×10⁵
Max. Overvoltage (ΔV_{max})	8 V	Single Photon Time Resolution	≤ 70 ps

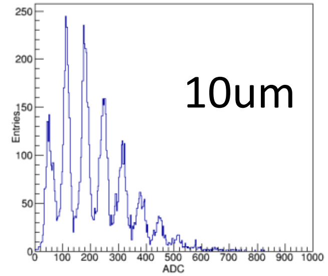
NDL SiPM website => http://www.ndl-sipm.net/

NDL-SiPM + ASIC Test-2



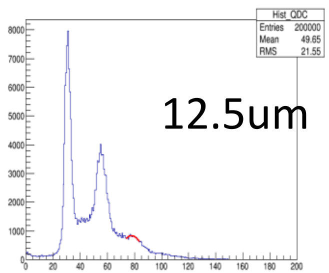
Calibration by their **NDL preamplifier**

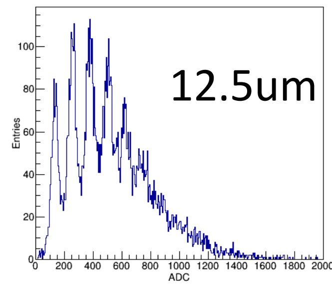




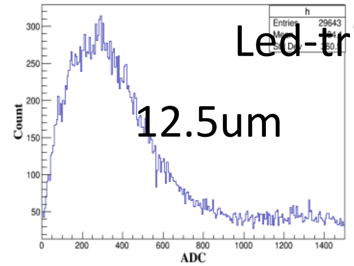
Self-trigger

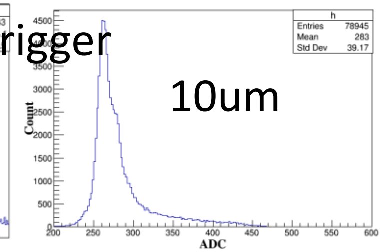
Led-trigger

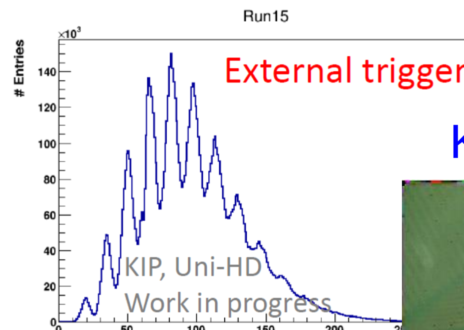




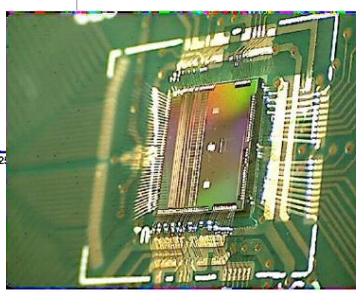
Read-out and Calibration by **Spiroc2b**







KLauS Chip



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

KLauS ASIC (KIP, Uni-HB)

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

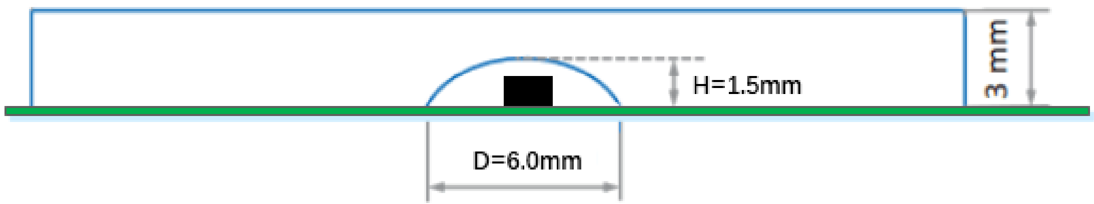
25 uW / channel @ duty cycle 0.5%

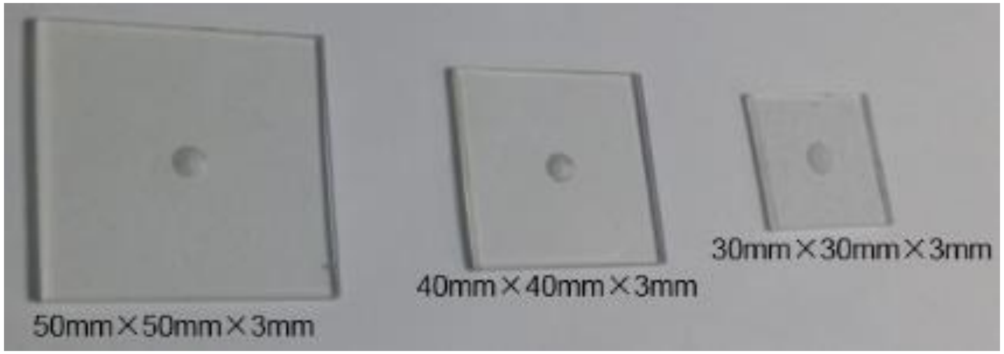
Scintillator Detector Cells study

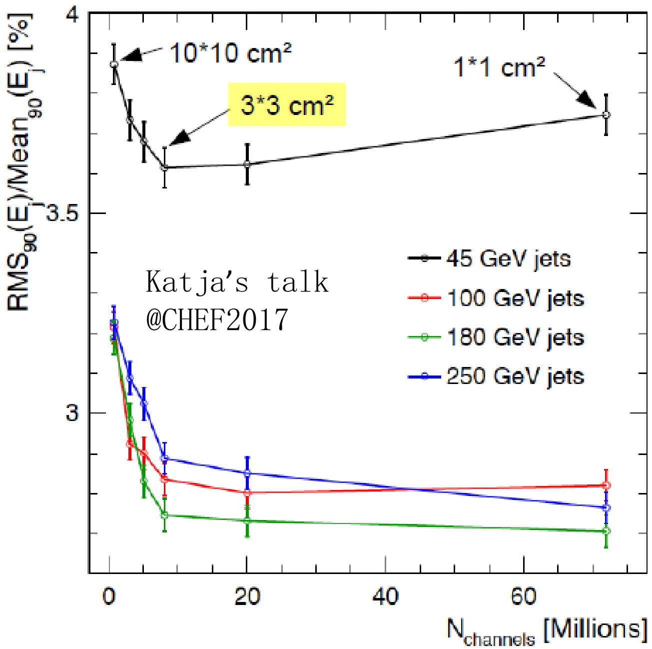
– The four sizes of 30×30×3mm³,40×40×3mm³ and 50×50×3mm³ were studied.

– SiPM or MPPC(surface-mounted)

– PS were wrapped by ESR foil







Detector cell size VS jet energy resolution

Cosmic-rays Mips measurement results

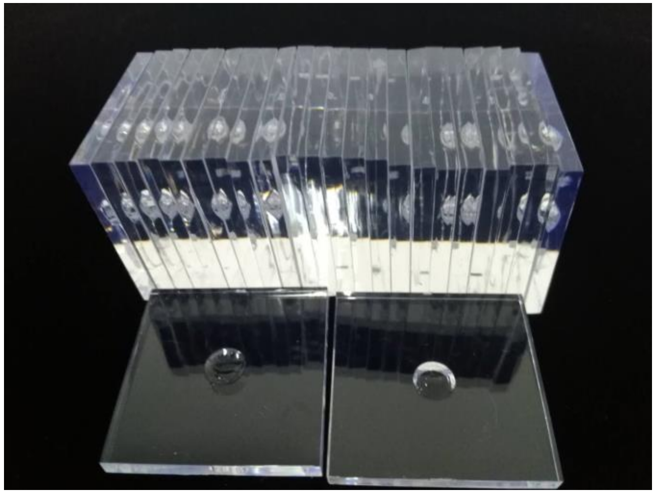
Table 1 Cosmic-ray measurement results of detector cells with different sizes

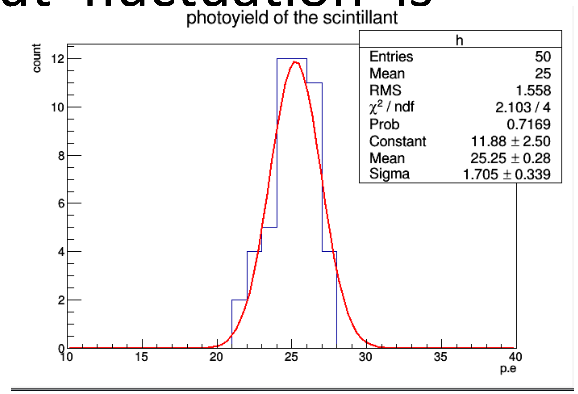
No.	Detector Cell	MPPC Type	Reflective Foil Type	Mean $N_{p.e.}$	Polishing Methods
1	$30\times30\times3mm^3$	S12571-025P	ESR	31.39±0.65	Ultra Precise Polishing
2	$30\times30\times3mm^3$	S12571-025P	ESR	22.55±0.7	Precise Polishing
3	$30\times30\times3mm^3$	S12571-025P	ESR	18.92±0.39	Rough Polishing
4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

- 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 σ<7%；





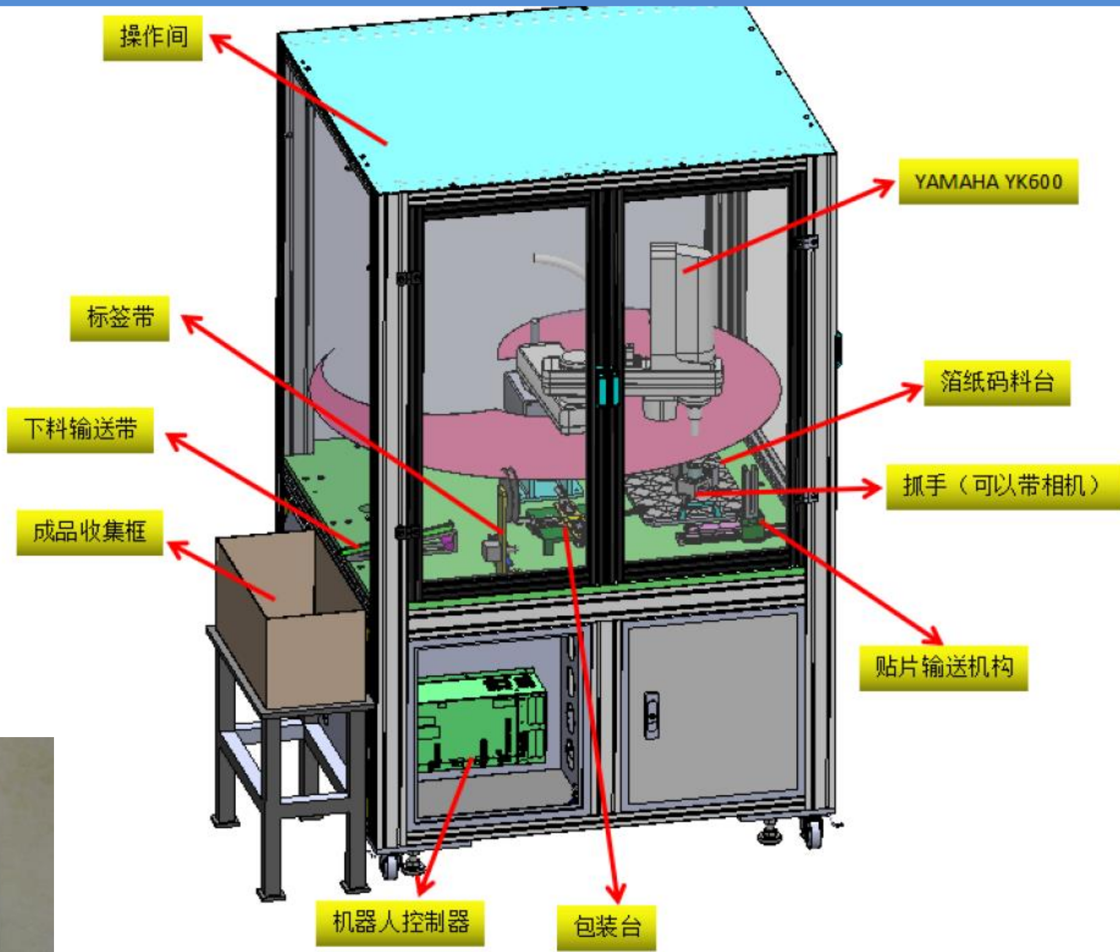
Size uniformity

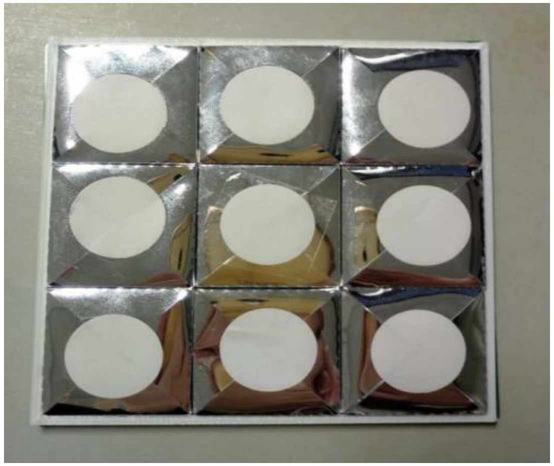
Tiles size(mm)	30.08x30.01 x3.08	30.07x30.04 x3.09	30.04x30.02 x3.09	30.09x30.09 x3.09	30.05x30.03 x3.09
Light output(p.e.)	23.5	22.78	22.86	25.02	23.54

Detector cell Automatic assemble system

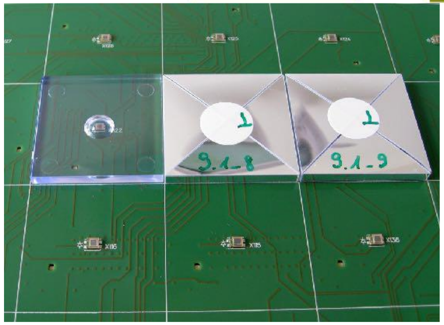
— Motivation:
- 7M detector cells;
- Reflective foils packaging can't be done by manual;

— Progress:
- Three companies give they preliminary design;
- Robotic arm design is the best way;





Packaged cell



It can be used for 3cm*3cm and 4cm*4cm detector cell;

Detector cell gluing experiment

motivation：

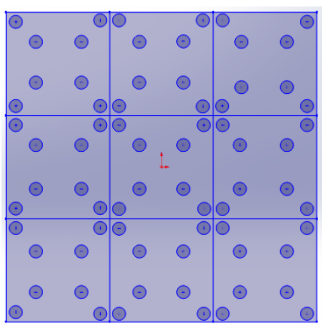
In order to quickly and effectively realize the integration of large area AHCAL detection unit.

Materials：

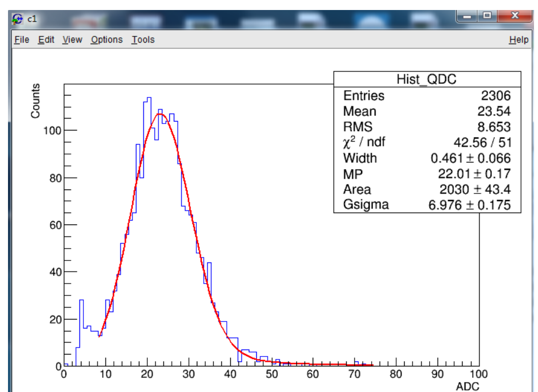
1. Araldite 2011 epoxy glue
2. 3×3 PCB board
3. Detector cell;
4. A film used to brush glue

Result:

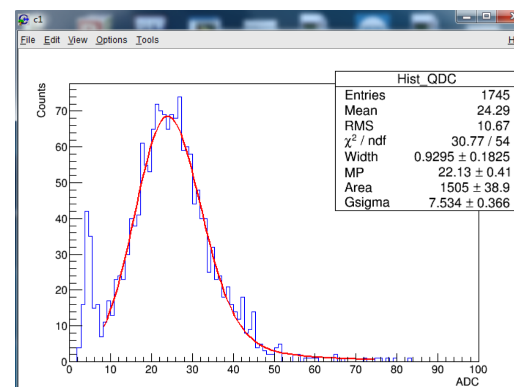
1. This way is working;
2. The detector cell was glued on PCB board fasten;
3. Maybe reduce to 4 glue hole;
4. Plan to test crosstalk and prototype.



Light output



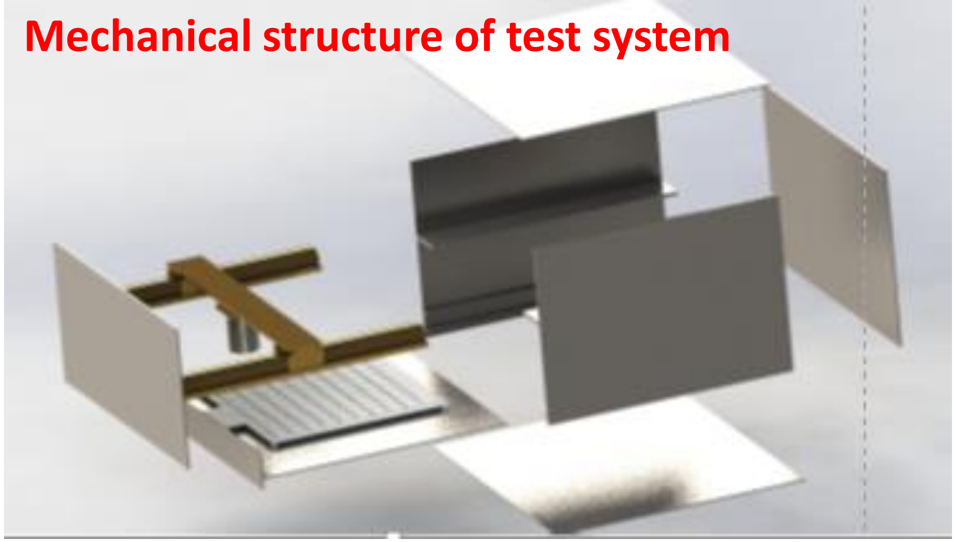
Before glued

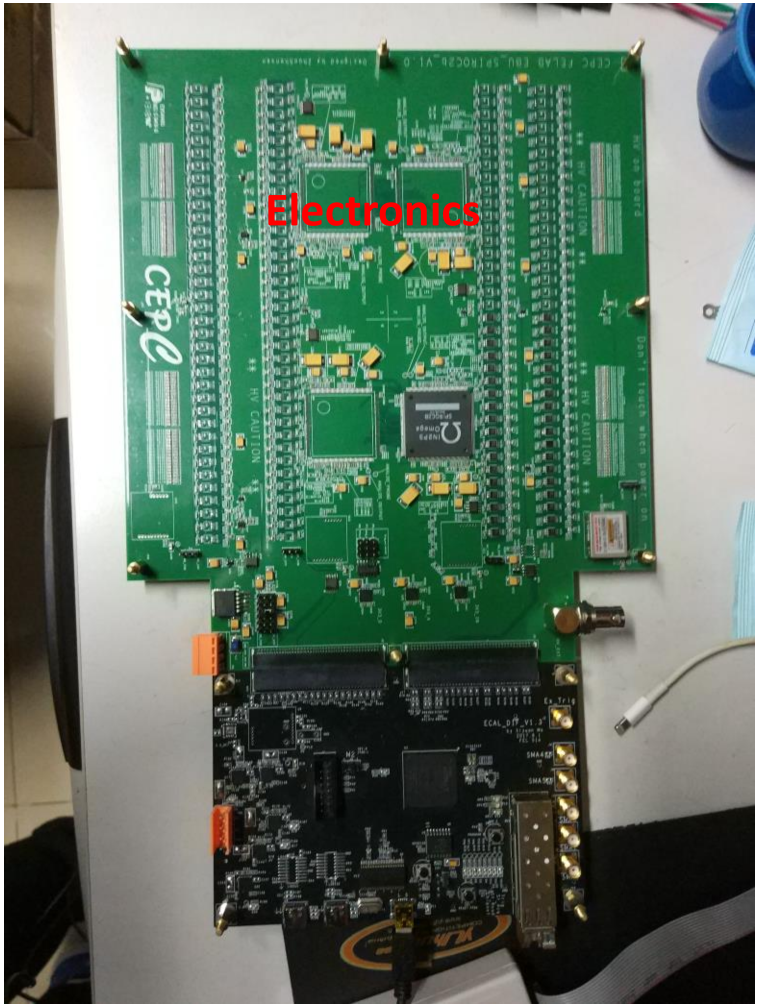


After glued

Detector cell test system design

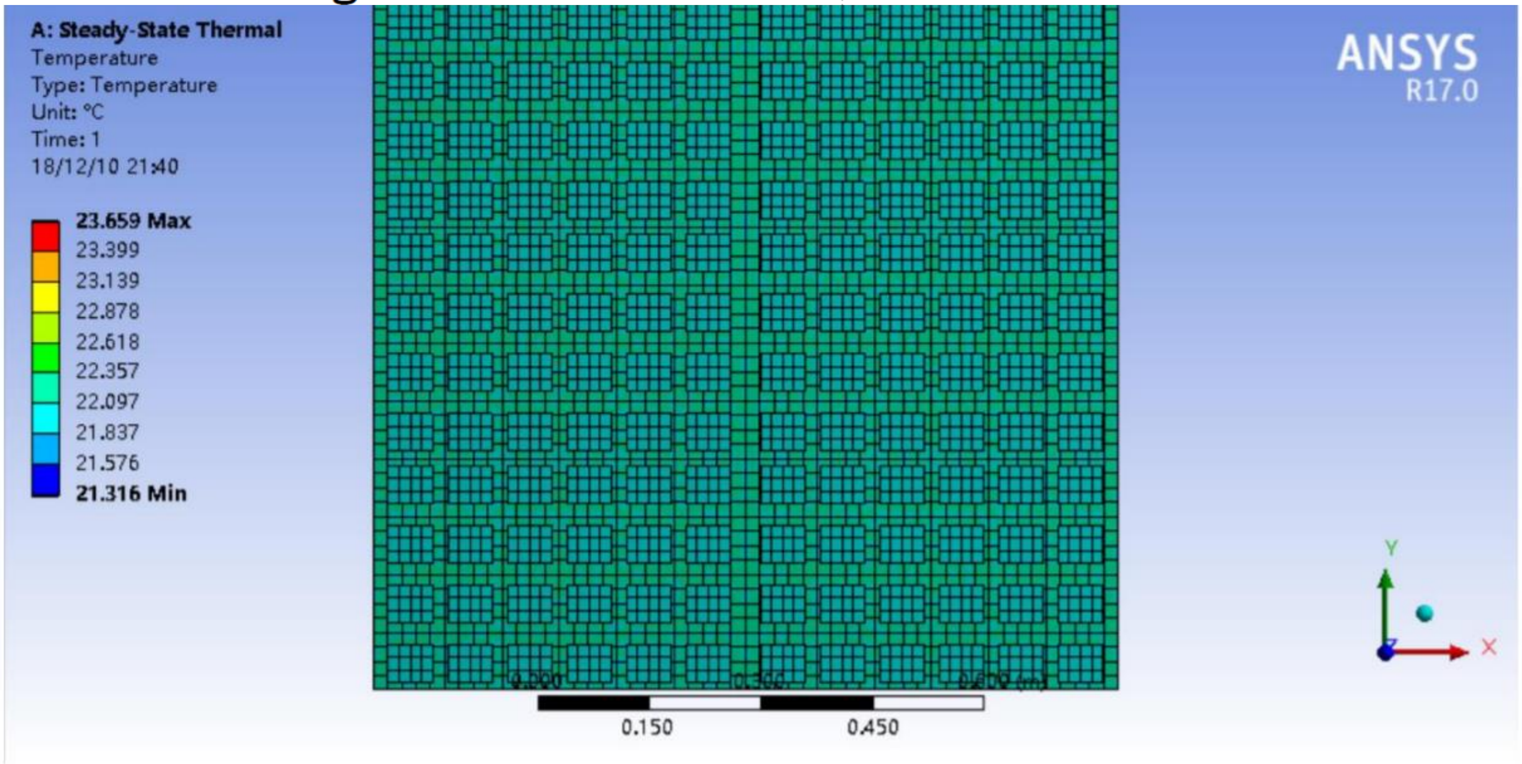
- About 100 detector cells one batch;
- Electronics under design;
- Mechanical structure under design;





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℃

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.

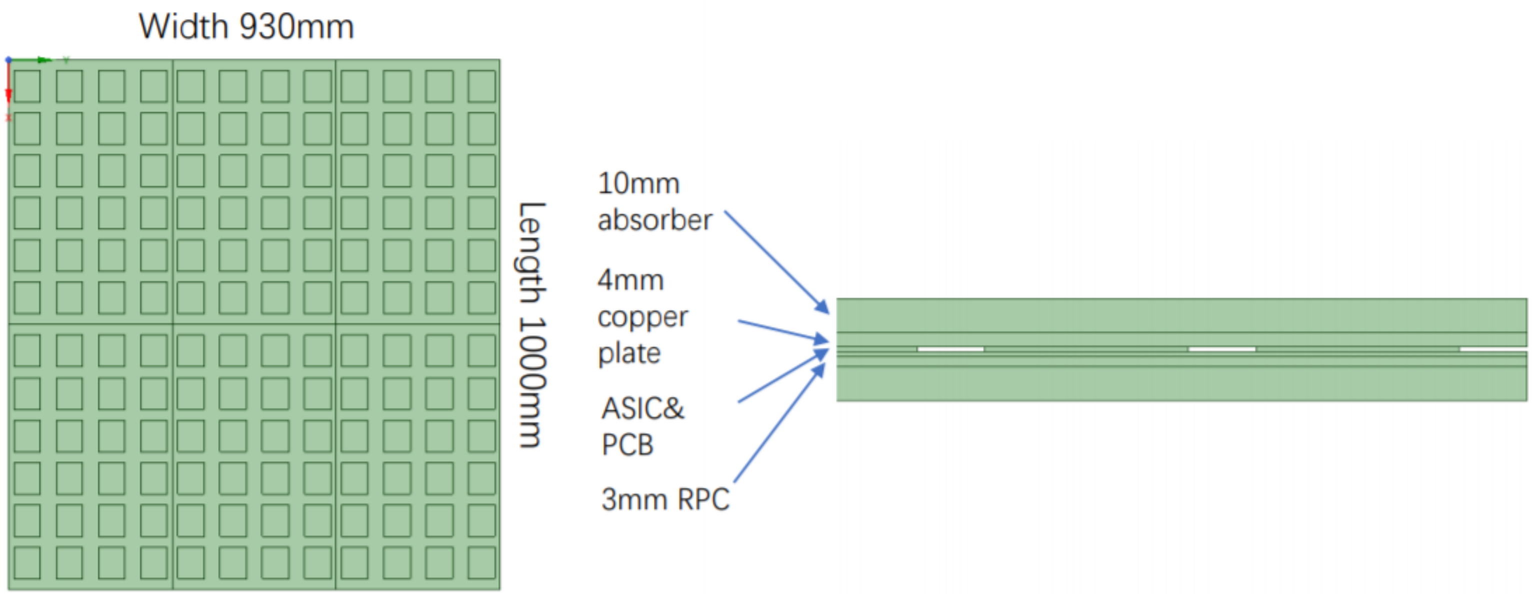
—We have joined in the CALICE group last year;


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

Model



Width 930mm
Length 1000mm
10mm absorber
4mm copper plate
ASIC& PCB
3mm RPC

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 6×6 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.