CEPC AHCAL optimization and R&D progress

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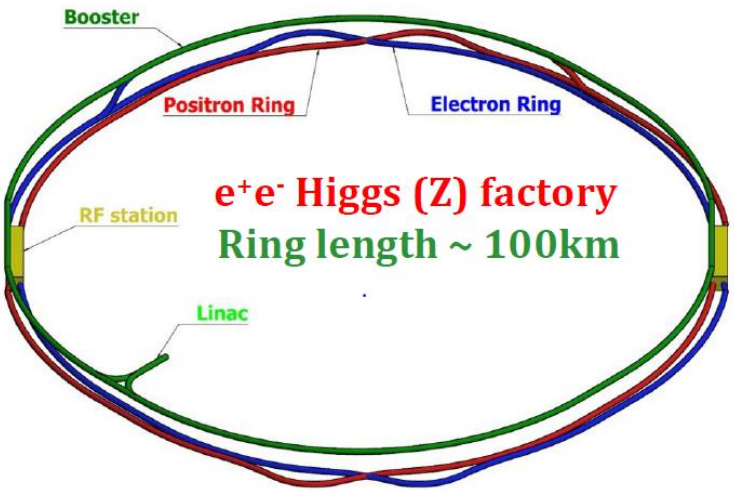
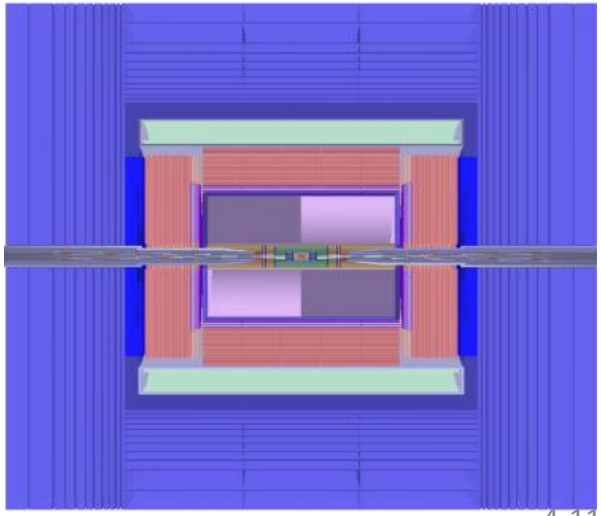
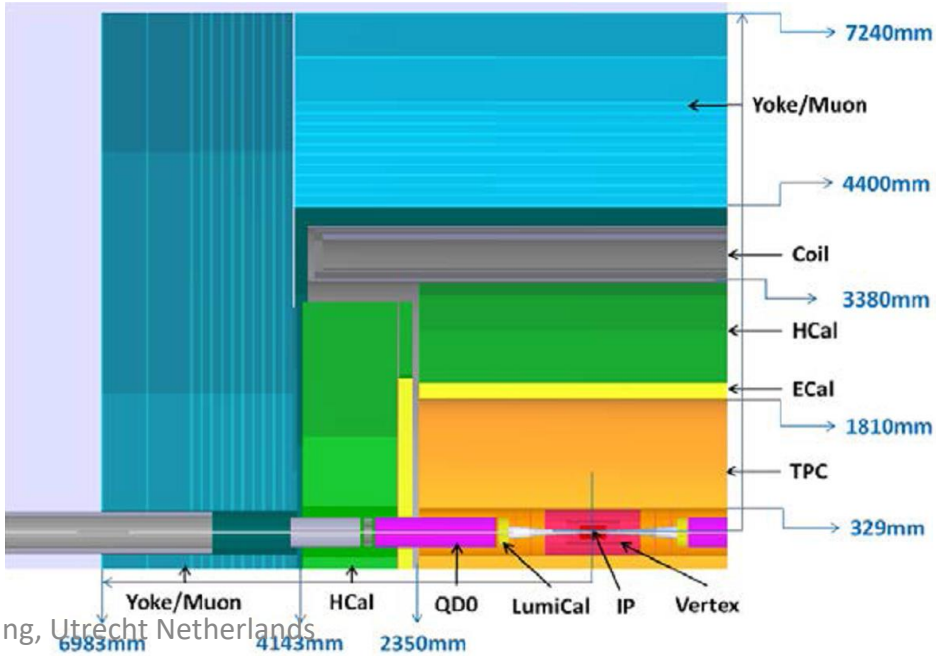
CEPC Detector Concept(s)

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





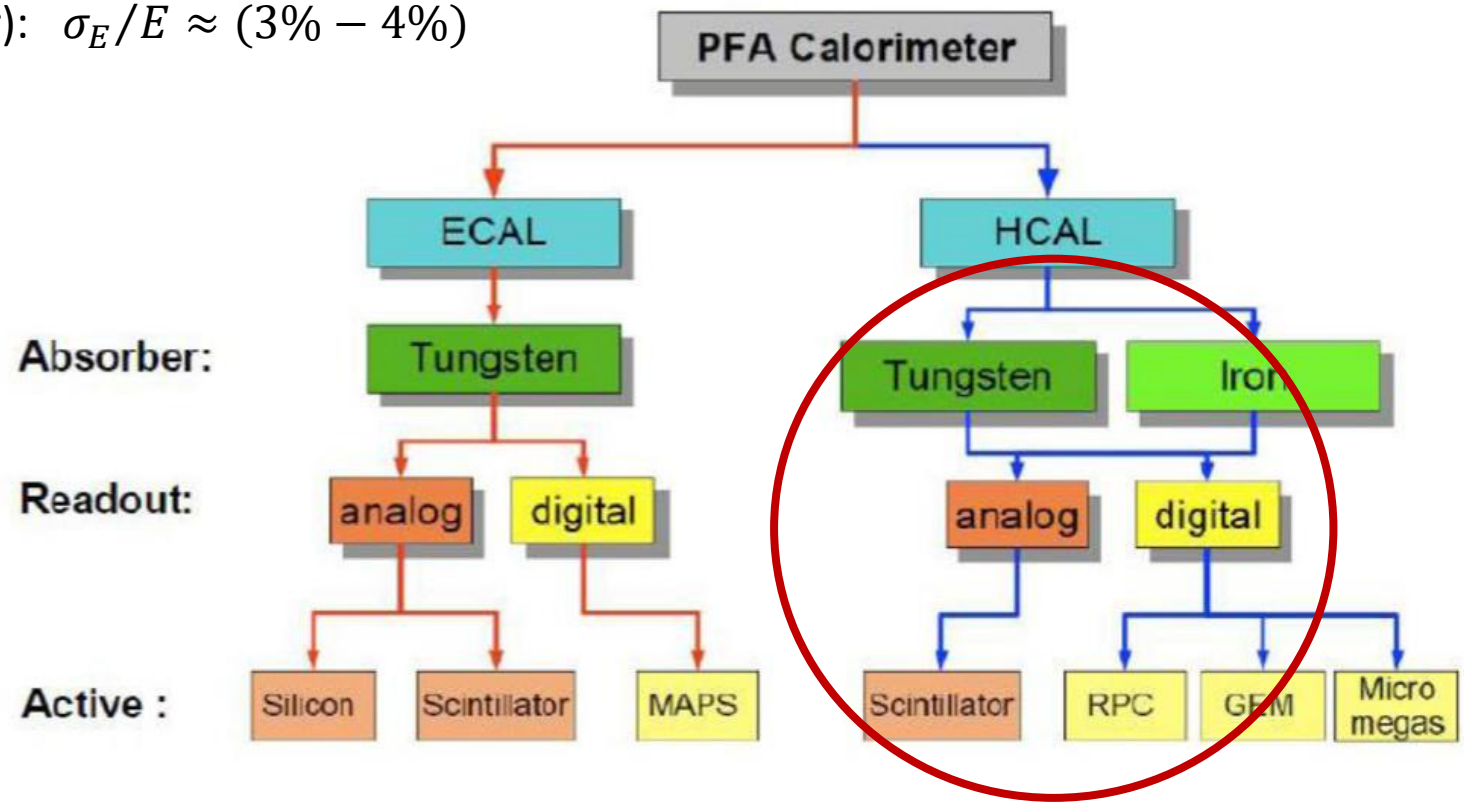


The options of CEPC-PFA-HCAL

Two options:

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

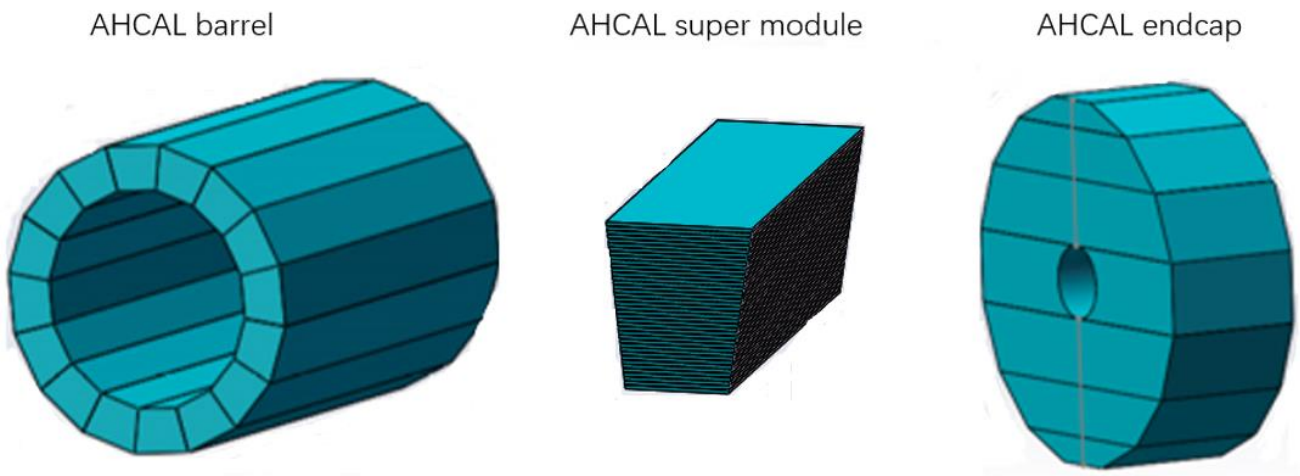
- Jet energy resolution (HCAL combined with ECAL and tracker): $\sigma_E/E \approx (3\% - 4\%)$



The concept design of CEPC AHCAL

— Analog hadron calorimeter in CEPC-CDR:

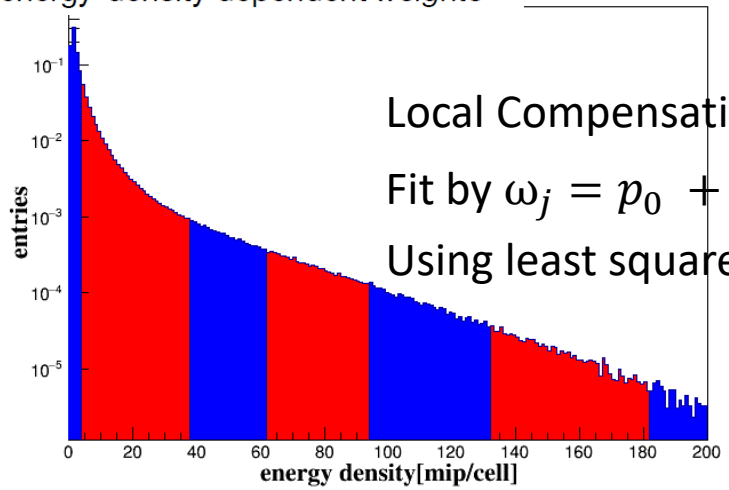
- The absorber: 2cm Stainless steel ($0.12\lambda_I$, $1.14X_0$);
- Detector cell size: 3cm × 3cm or 4cm × 4cm;
- The sensitive detector : Scintillator(organic scintillator);
- About 40 sensitive layers, total readout channel: ≈7 Million (3cm × 3cm)



Software compensation for Energy reconstruction at AHCAL

Local

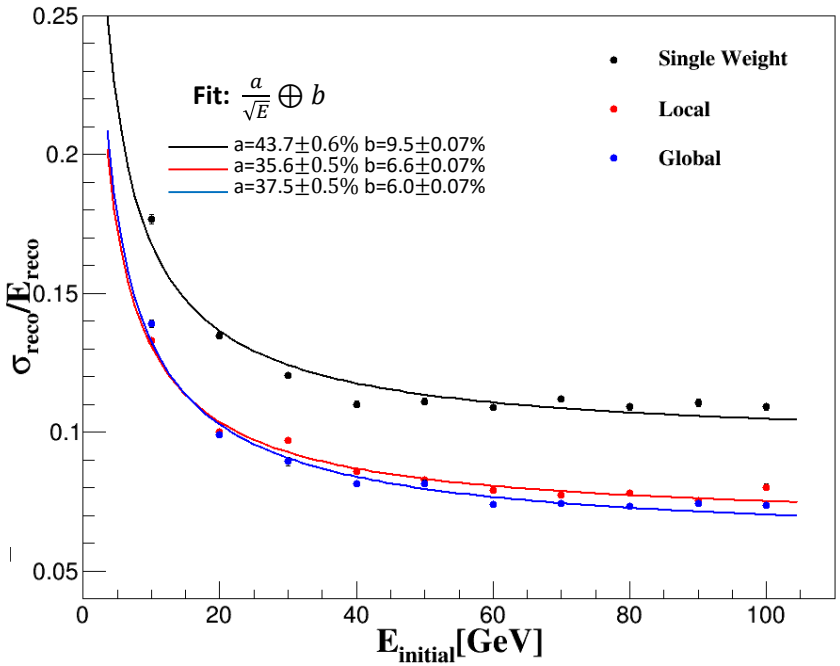
- Cell-by-cell correction of energy with energy-density dependent *weights*



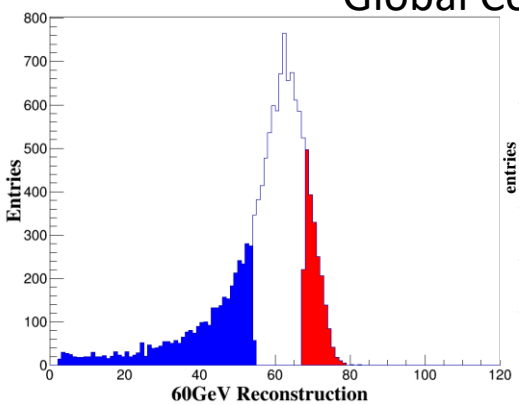
Local Compensation

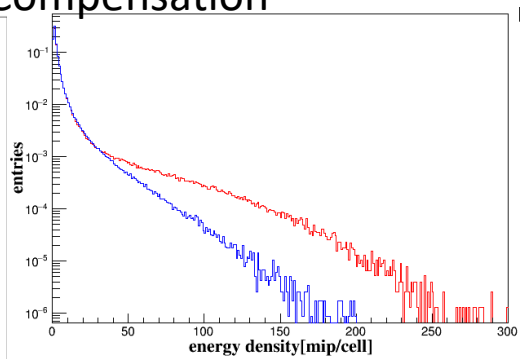
Fit by $\omega_j = p_0 + p_1 e^{(p_2 * e_j)}$

Using least square method



Global Compensation





Local Compensation improves by ~18%

Global Compensation improves by ~15%

Global

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

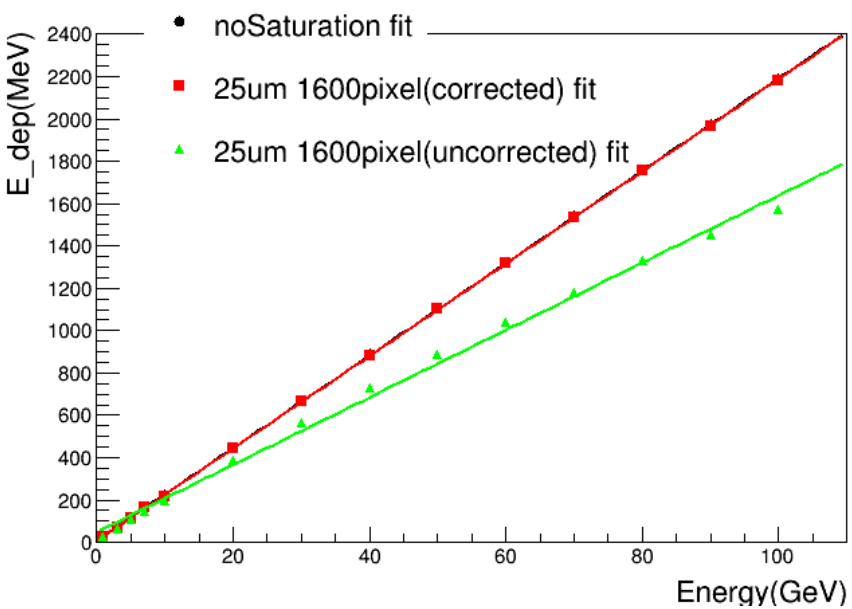
$$E_{rec} = \sum_i (E_{HCAL,i} \times C_{global})$$

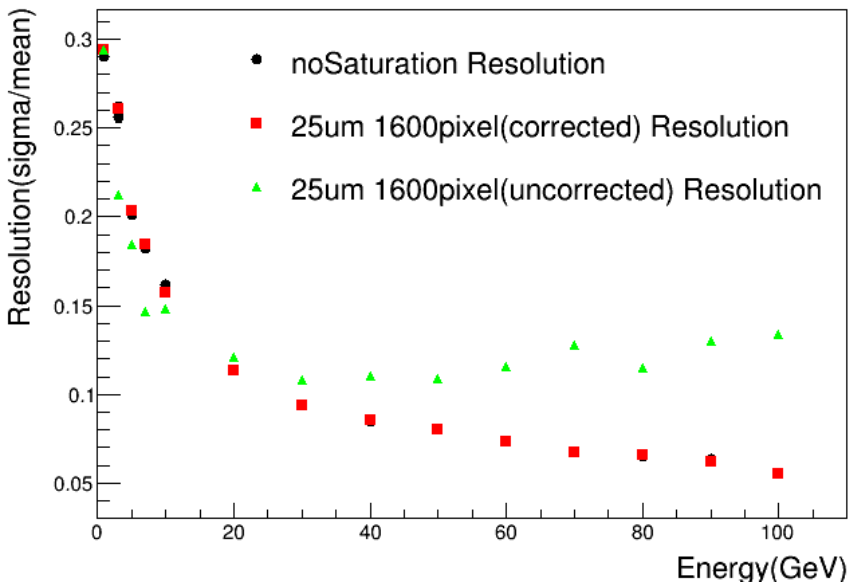
- Event-by-event correction of energy sum with a shower-dependent *global* factor

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.



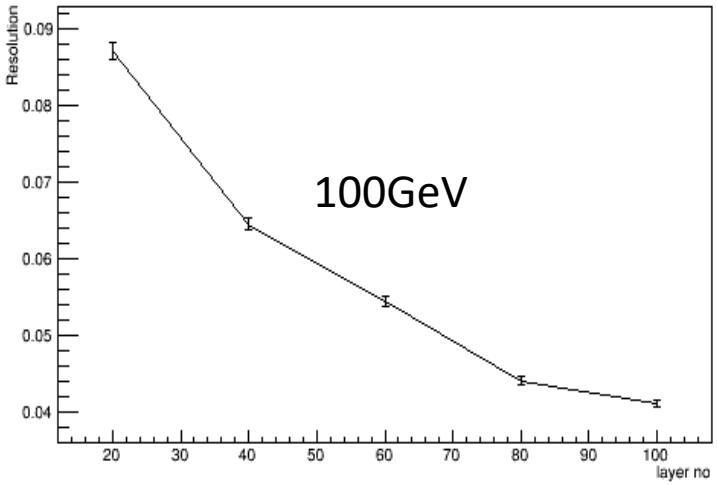


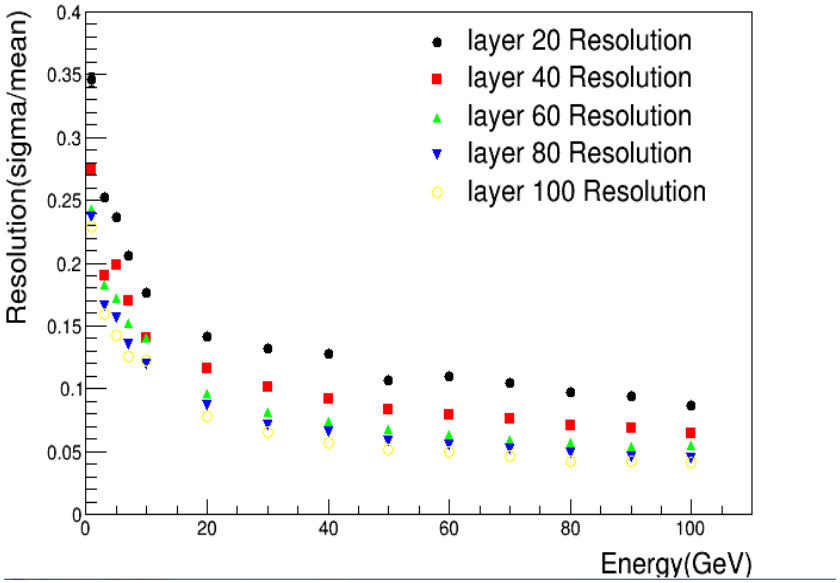
Corrected by $N_{fire}=N_{pix}(1-e^{-\varepsilon N_{in}/N_{pix}})$

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

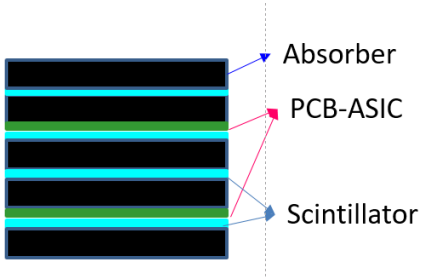
Different sampling fraction for AHCAL

- Scintillator:3mm
- Absorber(Fe) total 80cm
- layer from 20 to 100 by step of 20
- Incident particle: pion-





The energy resolution of single particle π^- changes less when layers over 40 based on variability of slope.



One opinion is increase the sampling layers keep the absorber thickness, but electronics readout will be reduced, two layers using one layer ASIC readout.

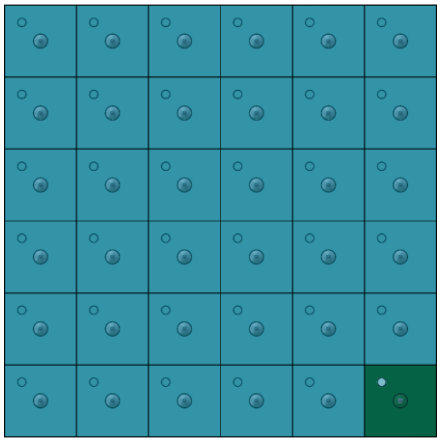
AHCAL prototype Plan

Motivation：

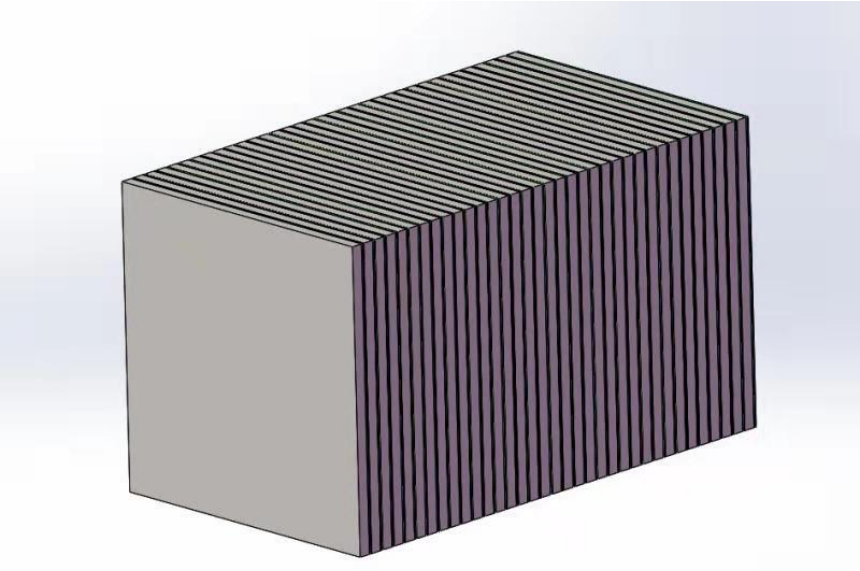
– A AHCAL prototype fit the CEPC requirement.

Specification:

- Active layers： under optimization (>35);
- Detector cell: under optimization ;
- Absorber: stainless steel;
- Readout: SiPM+ASIC



Ability of cell mass production

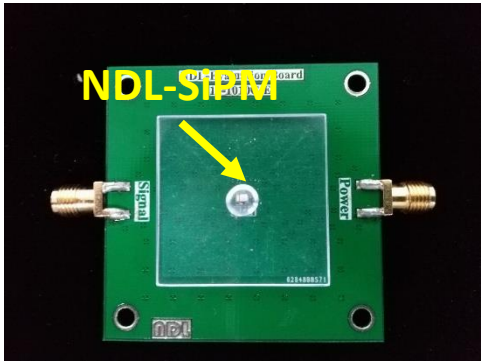


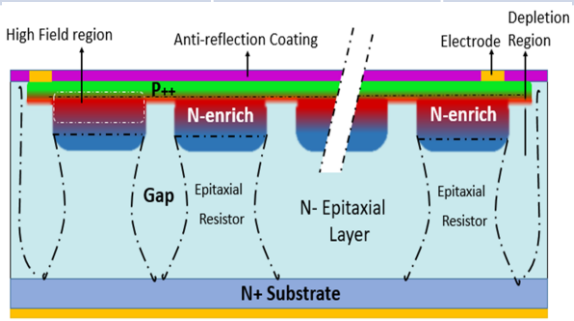
Chinese NDL-SiPM Test-1 (1mmx1mm 10umSiPM)

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

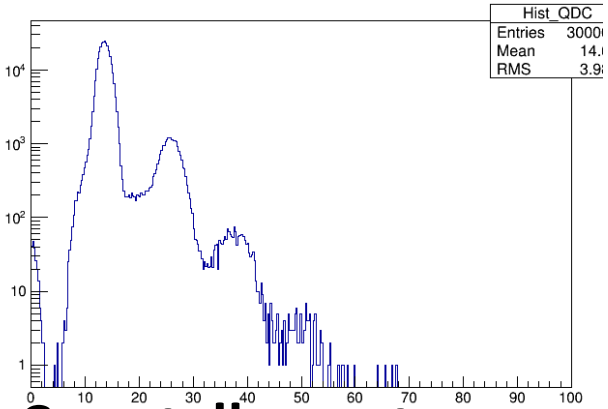
Six NDL-SiPMs was tested (electron-Sr90): 30mmx30mmx3mm with PL Scintillator

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

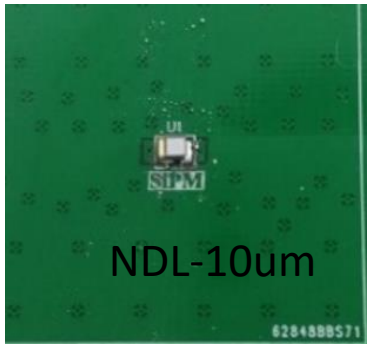


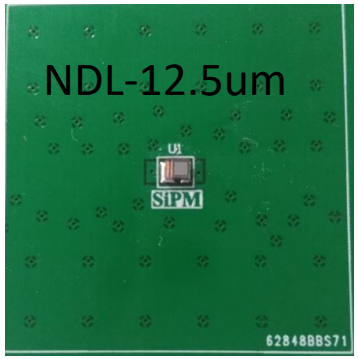
Crosstalk spectrum

NDL-SiPM 11-1010C specification

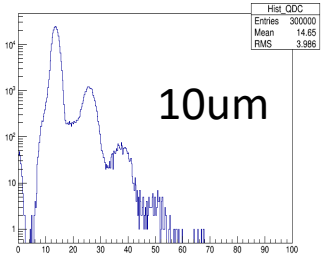
Parameter	Value	Parameter	Value
Effective Active Area	$1\times 1\,mm^2$	Peak PDE@420nm*	39%
Effective Pitch	10 μm	Dark Count Rate*	~500 kHz
Micro-cell Number	~10000	1 p.e. Pulse Width	5 ns
Operating Temperature	-196°C - +40°C	Temperature Coefficient For V_b	25 mV/℃
Breakdown Voltage (V_b)	25.5±0.2 V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

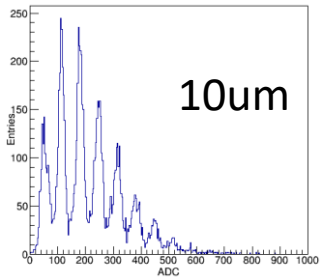
NDL-SiPM + ASIC Test-2



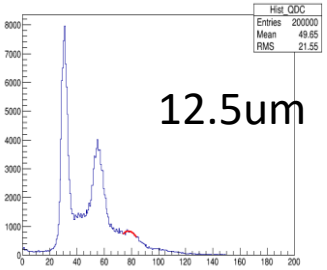


Calibration by their **NDL preamplifier**

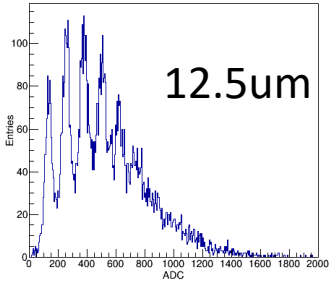




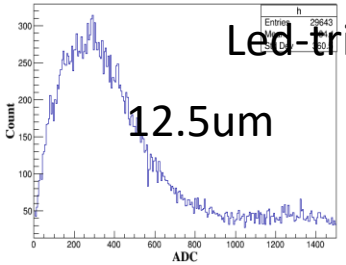
Self-trigger

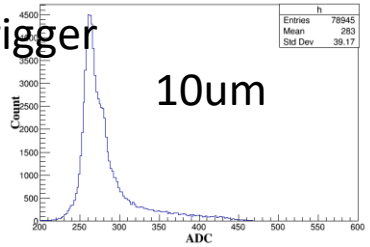


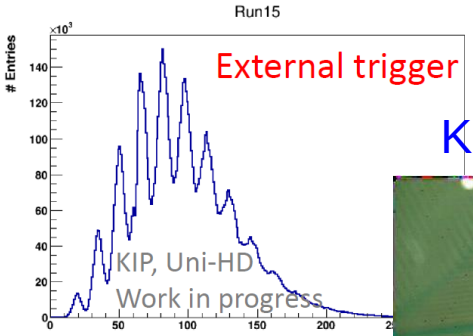
Led-trigger



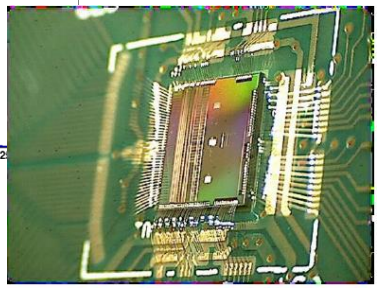
Read-out and Calibration by **Spiroc2b**







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	

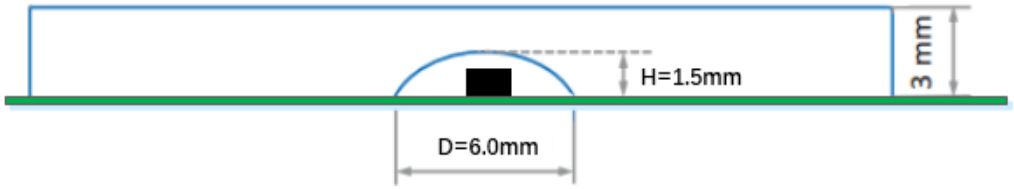
KLauS ASIC (KIP, Uni-HB)

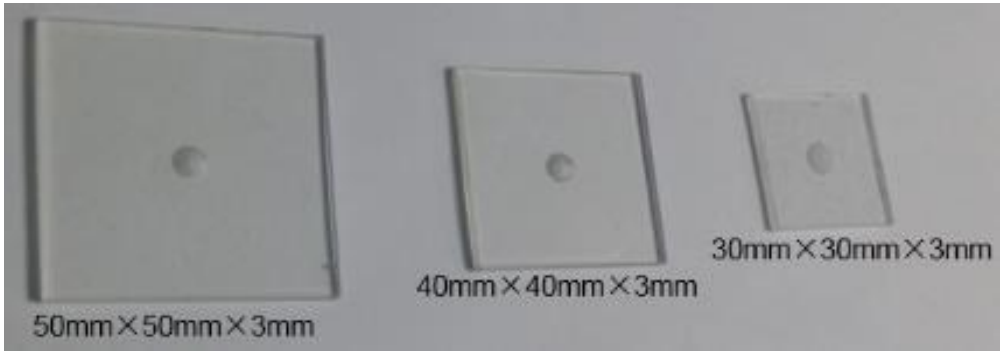
- Low noise, low power dissipation
- Continuous readout without dead time

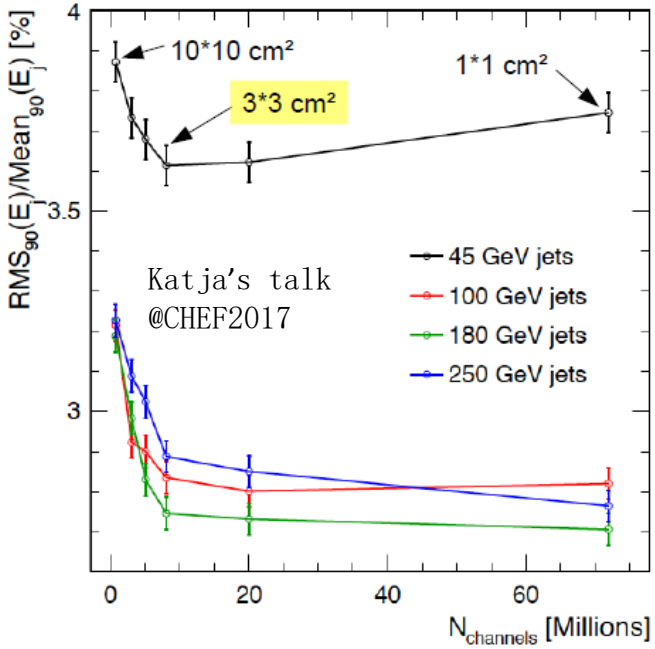
25 uW / channel @ duty cycle 0.5%

Scintillator Detector Cells study

– The four sizes of 30×30×3mm^3,40×40×3mm^3 and 50×50×3mm^3 were studied.
– SiPM or MPPC(surface-mounted)
– PS were wrapped by ESR foil





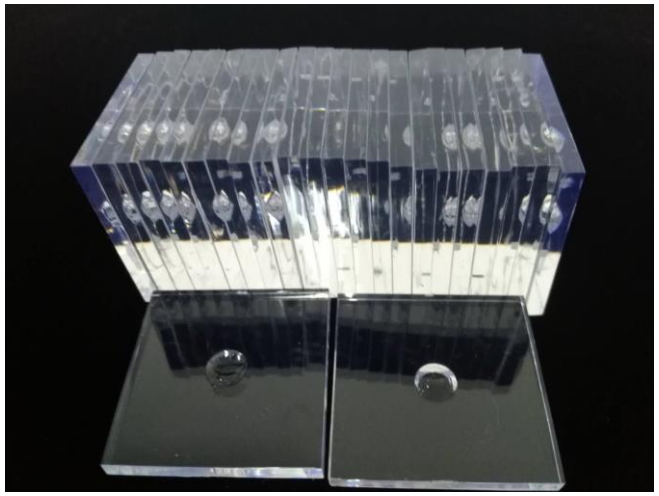


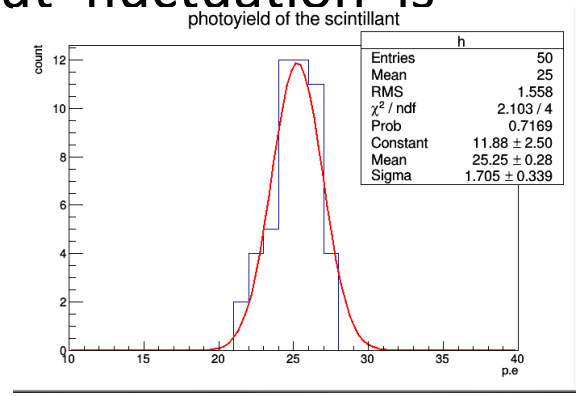
Detector cell size VS jet energy resolution

From the result show, the light output of 30×30×3mm^3 and 40×40×3mm^3 can reach to about 22p.e and 15 p.e for MIPs, it is acceptable. But the light output 50×50×3mm^3 is too low to separate MIPs from noise.

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%;

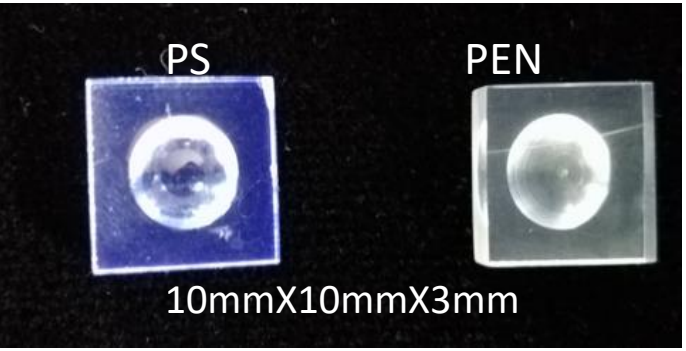




Size uniformity

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

Preliminary study of Injection PEN Scintillator



H. Nakamura et al., EPL, 95 (2011) 22001

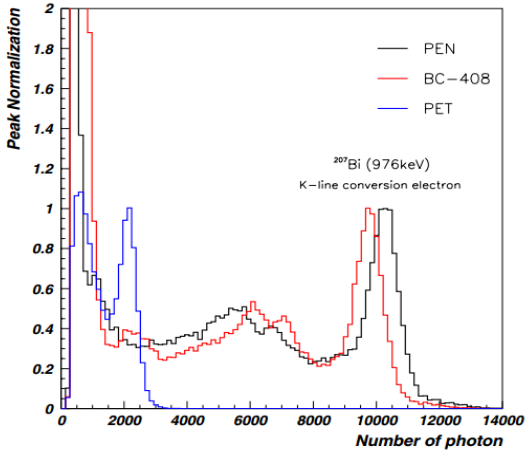
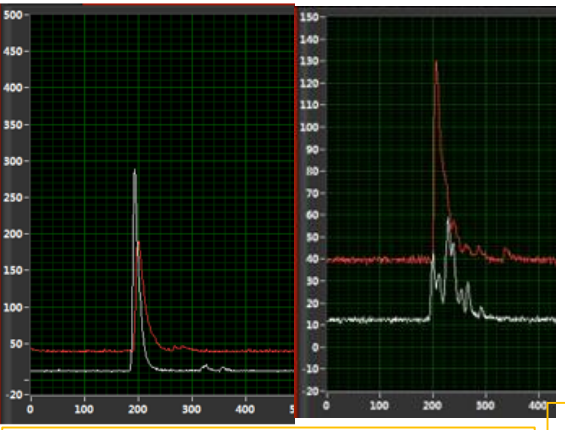


Fig. 2: Light output spectra of polyethylene naphthalate (PEN; black line), commercial organic scintillator (BC-408 (ref. [14]); red line) and a plastic bottle (PET; blue line).

Characters of PEN
- Not transparent
- Can't observe emission deep-blue photons



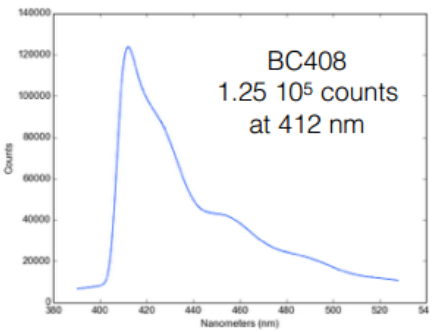
Materail	PS	PS	PEN	PEN
Size(mm)	10.09X10.07X3.00	10.13X10.08X3.00	9.96X9.98X3.14	10.00X9.99X3.05
Light Yeild(p.e.)	77.85	83.44	14.46	12.85
Size(mm)	30.04x30.01x3.00	30.04x30.04x3.01		
Light Yeild(p.e.)	22.95	22.27		

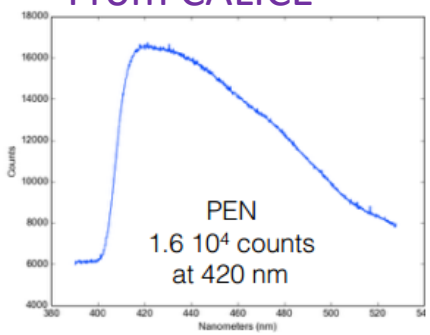
Characters of Ware form
- Multiple peak
- Wider signal

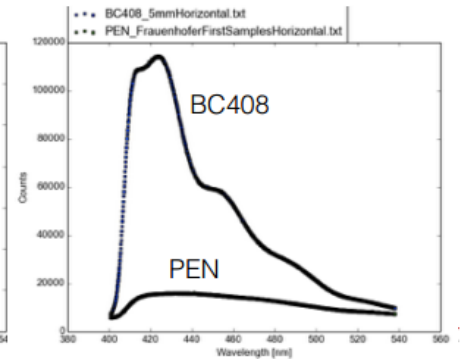
Light yield
- Only 1/7 compared to same size of PS
- Only 4~5 p.e. for 30mmx30mmX3mm PEN injection scintillator based on result of PS.

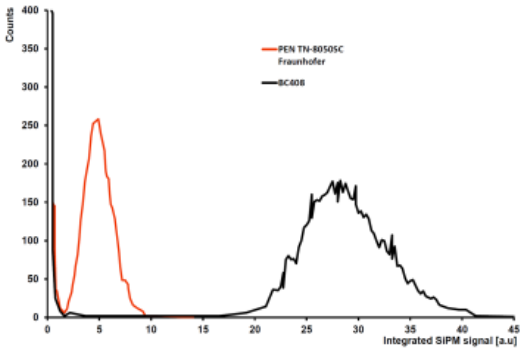
Emission spectrum of different scintillator

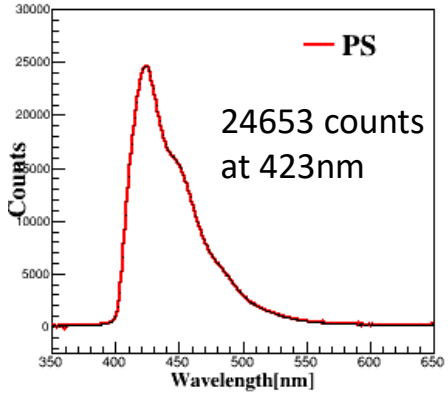
From CALICE

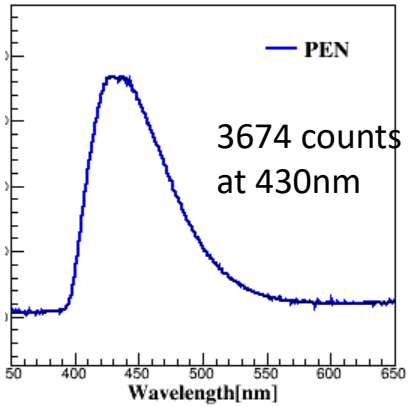


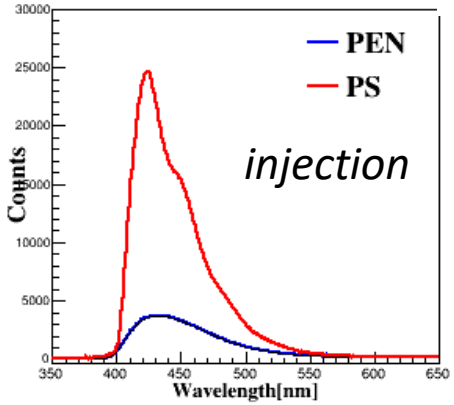












Only 4~5 p.e. for 30mmx30mmX3mm PEN injection scintillator based on our result.

- The result of *emission spectrum* is consistent with CALICE.
- The peak photon counts is only around 1/7 for PEN compared to PS.

Two Reasons:

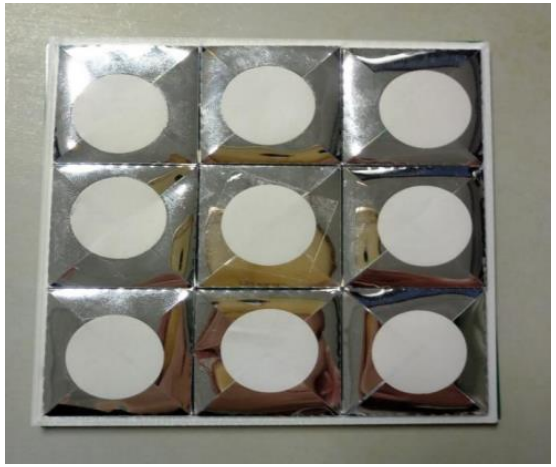
For high light yield of PEN, those measurements were always made with thin plates of PEN, and very large areal coverage by photon sensors.

For low light yield of our pen scintillator, the light is collected after multiple reflections and after traveling some distance in the scintillator.

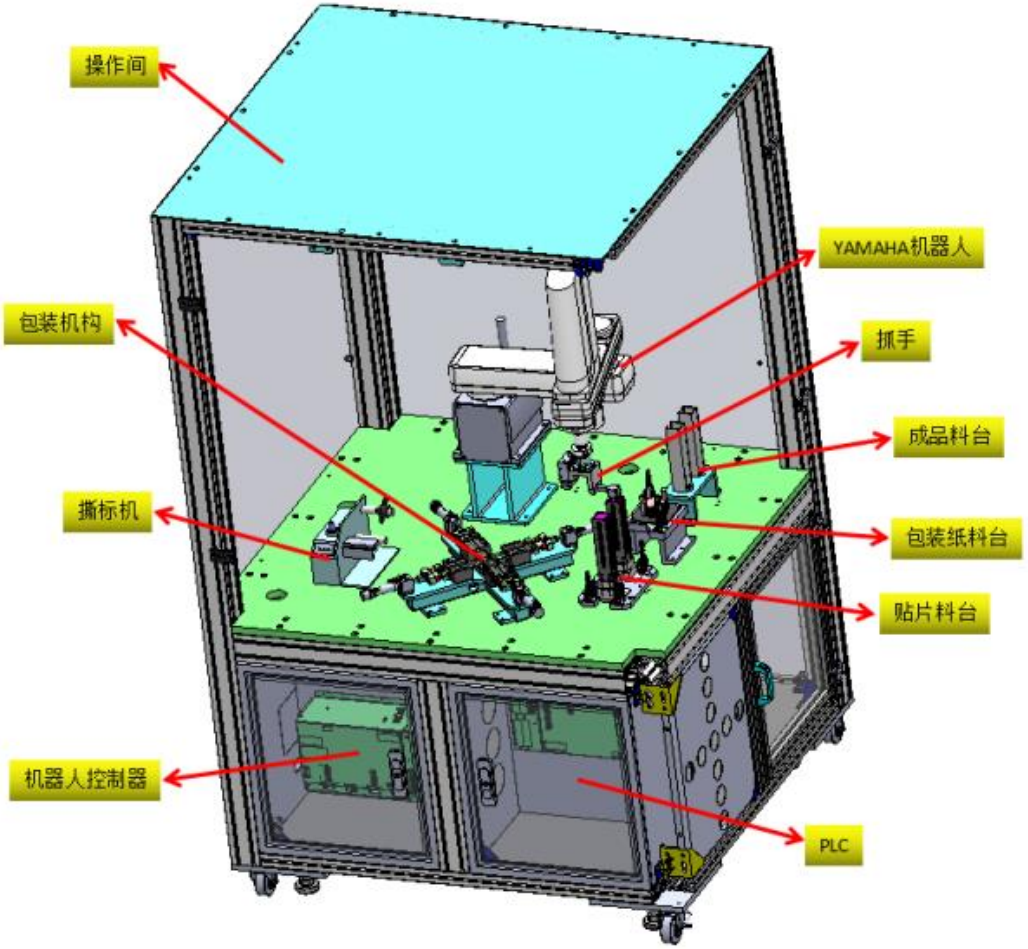
Detector cell Automatic assemble system

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

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



Packaged cell by manual



It can be used for 3cm*3cm, 4cm*4cm and 5cm*5cm detector cell;

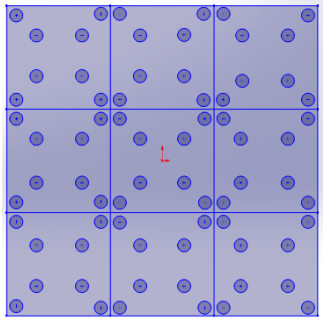
Detector cell gluing experiment

motivation：

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

Materials：

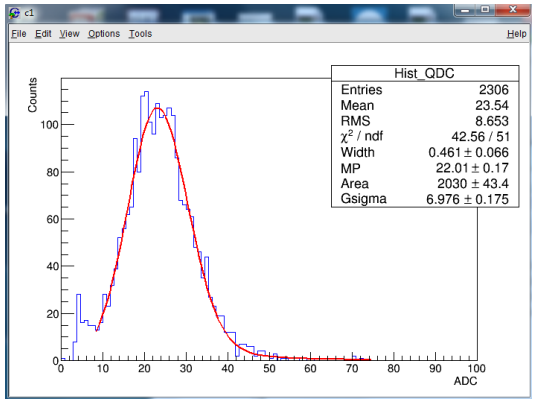
1. Araldite 2011 epoxy glue
2. 3×3 PCB board
3. Detector cell;
4. A film used to brush glue



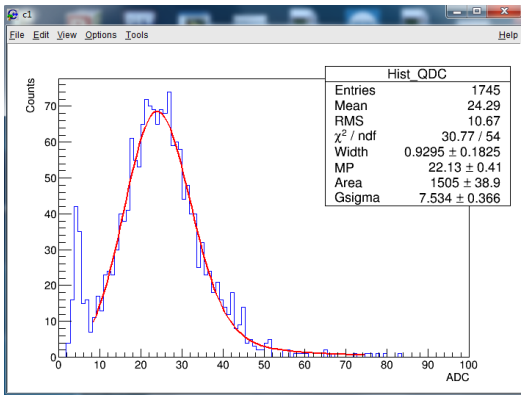
Result:

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



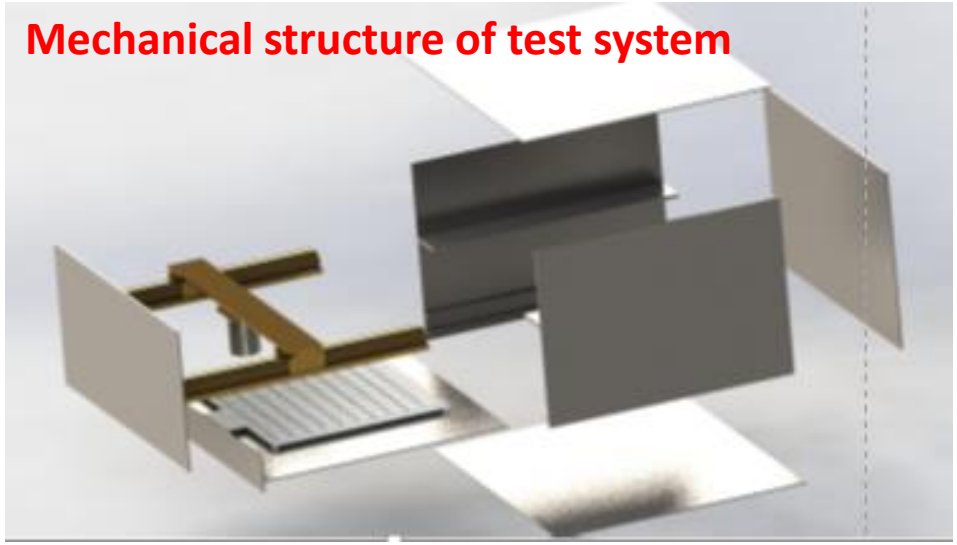
Before glued

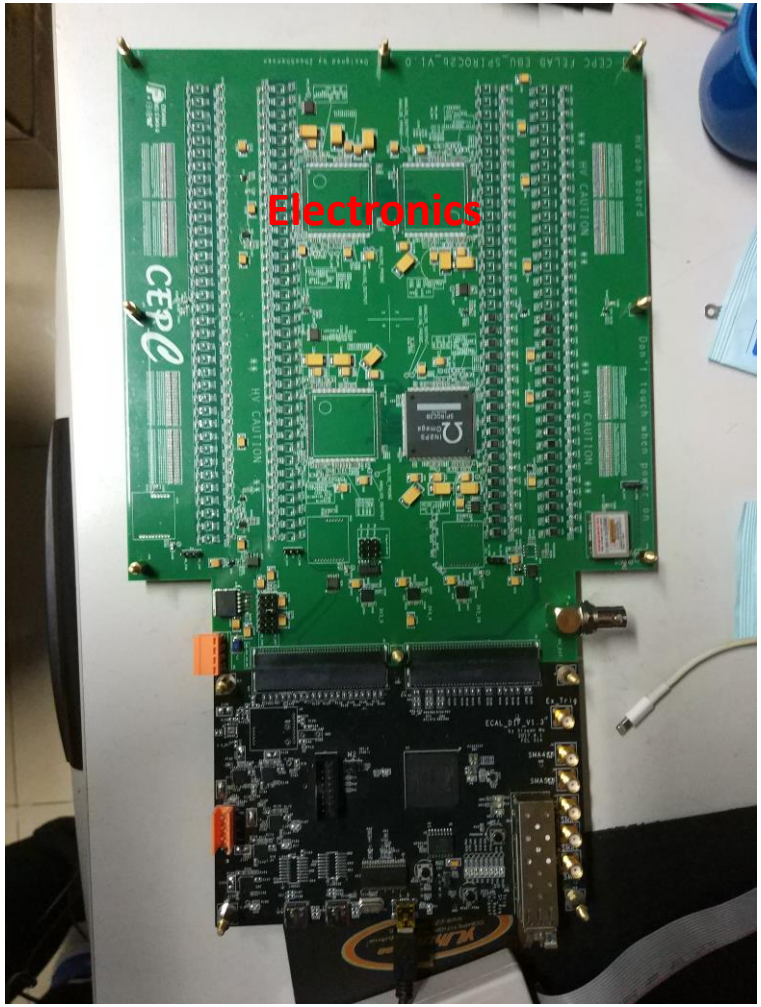


After glued

Detector cell test system design

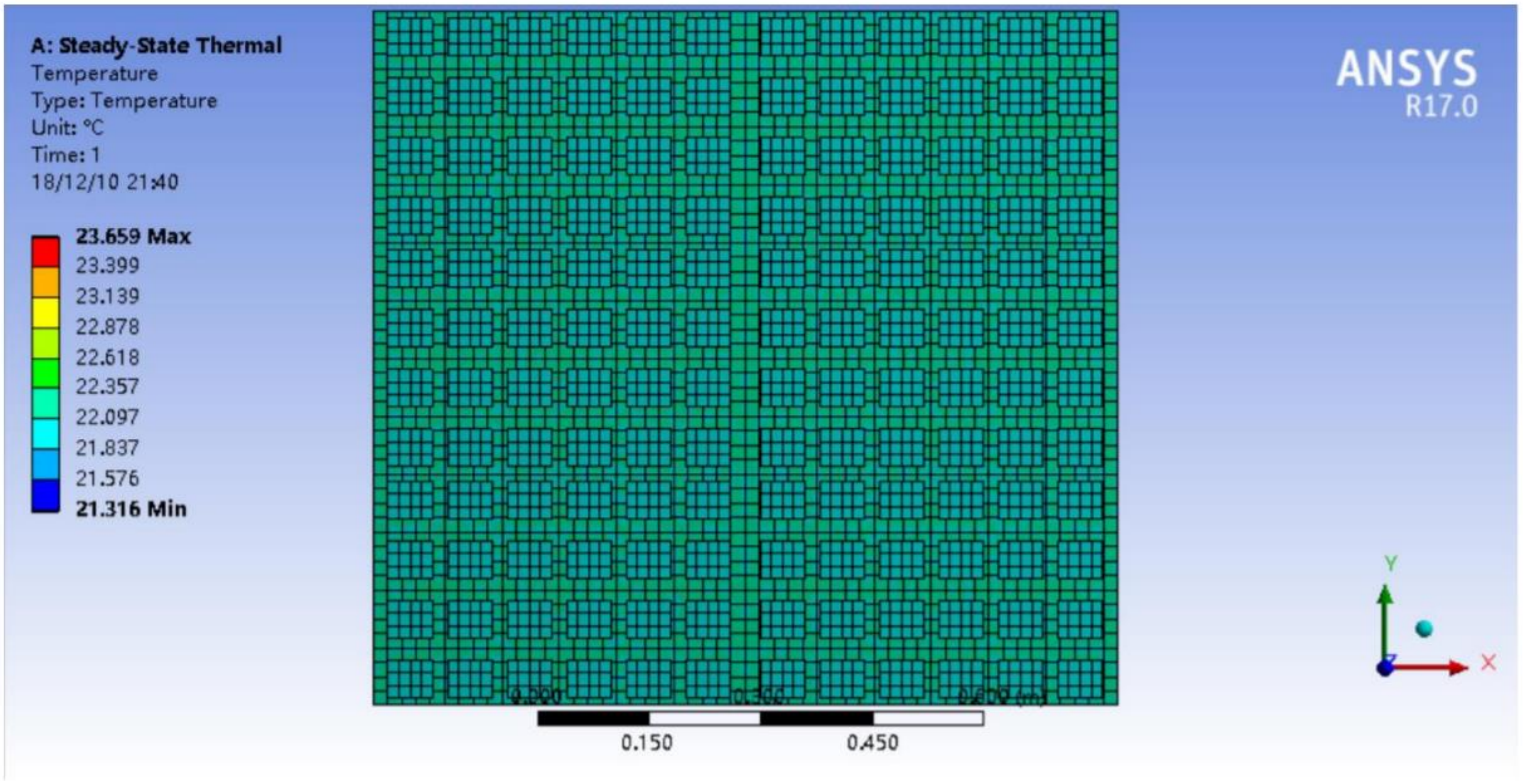
- About 100 detector cells one batch;
- Electronics under design;
- Mechanical structure under design;





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℃

Cooling Simulation vs Measurements

IPNL+SJTU

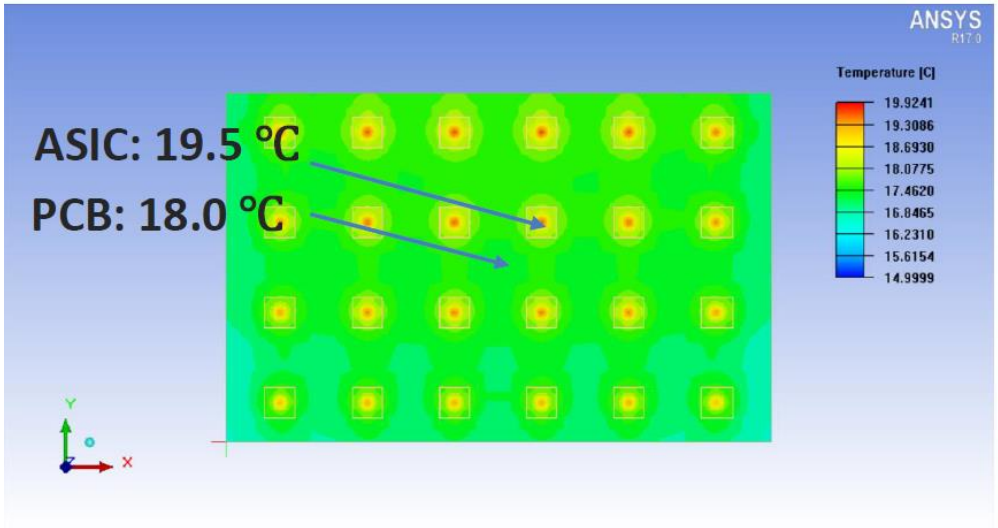
Temperature Simulation:

- PCB+ASIC: 18 – 19.5 ℃
- ΔT: 1.5℃

Temperature Measurements:

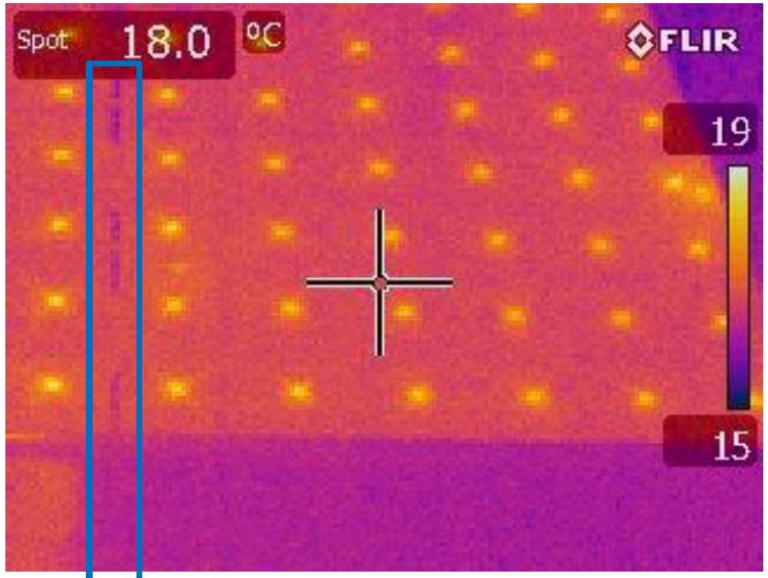
- PCB+ASIC: 18 – 19 ℃
- ΔT: 1.0 ℃

Simulation at SJTU



Initial temperature: 15℃,
convection parameter: 3W/(K*m²)
Simulation with Icepak

Measured at IPNL



Low temperature at the gap region between two PCBs

Summary and next

—The construction of CEPC-HCAL prototype based on scintillator is started, the direction is NDL SiPM+ new ASIC;

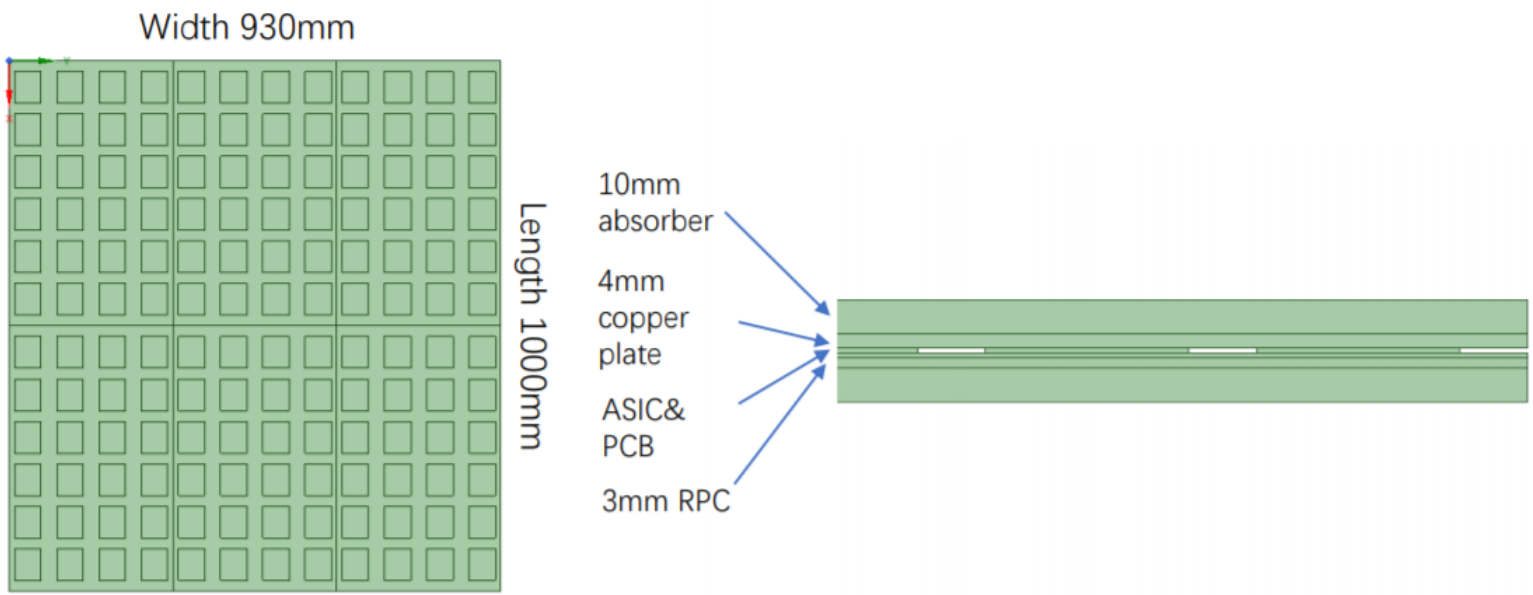
—Some critical R&D items identified, which will be followed up.

— We need more cooperation and help to finish the CEPC-AHCAL prototype.

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.