# Analog HCAL R&D progress and technical challenges for CEPC

**On behalf of the CECP calorimeter working group**


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# Outline

—Motivation

—Introduction of CALICE AHCAL;

—The progress of CEPC AHCAL;

—Technical challenge for CEPC AHCAL;

# Motivation: Future Colliders

— future e+e- colliders offer unique physics possibilities
- precise model-independent Higgs couplings
- precision measurements of W, Z and top properties
- indirect and direct searches for BSM physics

— CEPC: developed in China
- $\sqrt{s}$ up to 240 GeV;
- 100km long, double-ring collider;

— FCC: developed at CERN
- $\sqrt{s}$ up to 100 TeV for FCC-hh;
- 100km long, double-ring collider;

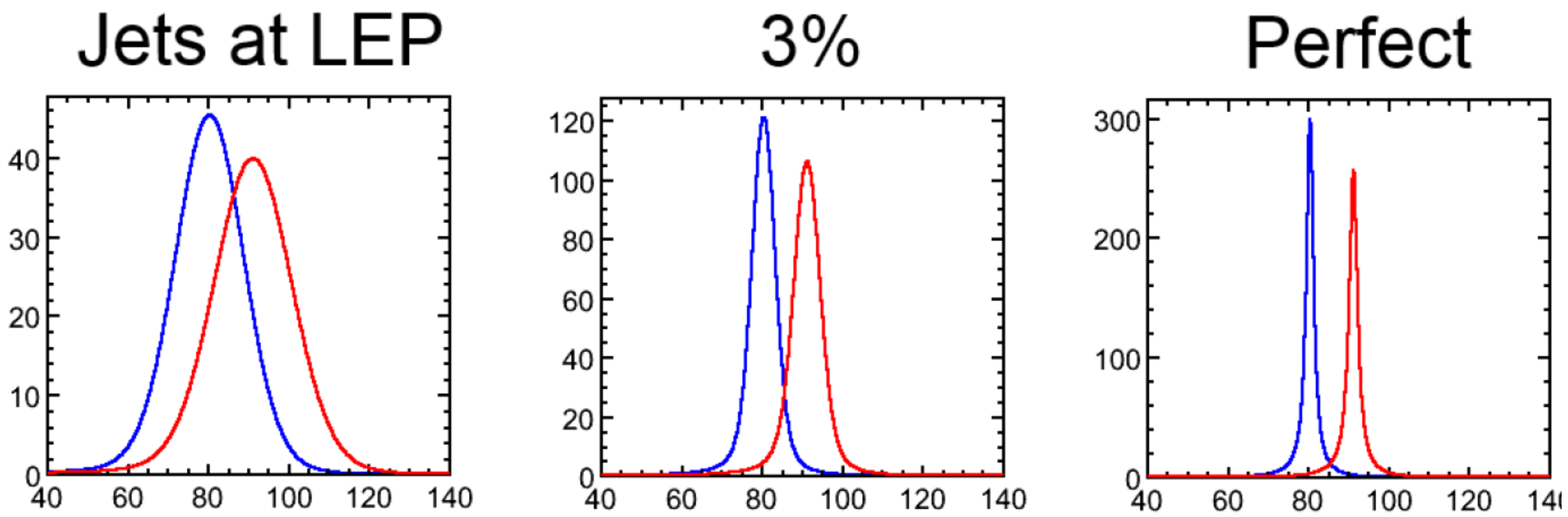
— ILC: under discussion in Japan
- $\sqrt{s}$ up to 500 GeV
- 31 km long, superconducting RF cavities

— CLIC: developed at CERN
- $\sqrt{s}$ up to 3 TeV
- 50 km long, two-beam acceleration

— main interest for calorimeters at colliders: jet energies

# Motivation: distinguish jet

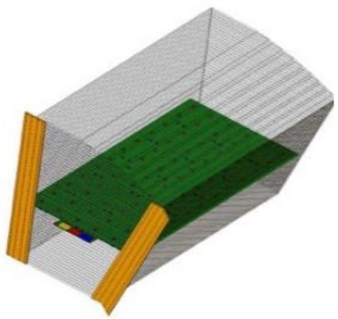
- goal: distinguish the decays $W \rightarrow jet\ jet$ and $Z \rightarrow jet\ jet$ by their reconstructed mass

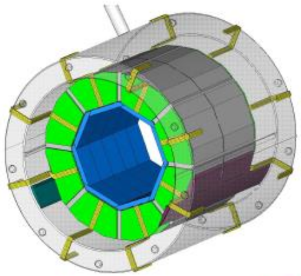


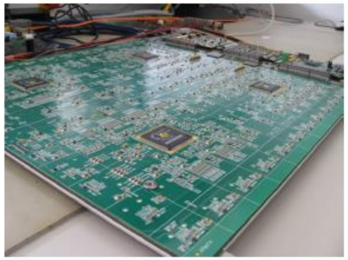

- required resolution: $\sigma(E_{jet})/E_{jet} \approx$ 3-4%
- interesting jet energy range: $E_{jet} \approx$ 40 to 500 GeV
- not possible with calorimeter information alone
  → use Particle Flow Algorithms

# Introduction of CALICE AHCAL (From ILD-TDR )

- The AHCAL
- 60 sub-modules
- 3000 layers
- 10,000 slabs
- 60,000 HBUs
- 200’000 ASICs
- 8,000,000 tiles and SiPMs





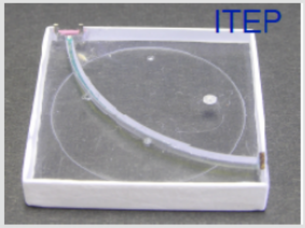


- Absorber: 2cm SS;
- Cell size: 3cm × 3cm;
- ASIC : SPIROC2E.
- Sensitive detector :PS;
- 48 sensitive layers, channel: ≈8 Million

# Introduction of CALICE AHCAL (CHEF2017 Felix's talk)

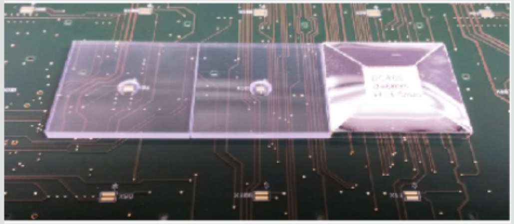
**Physics prototype**

**2006 - 2011**




Old ITEP tiles with WLS fibre
1200 px SiPMs

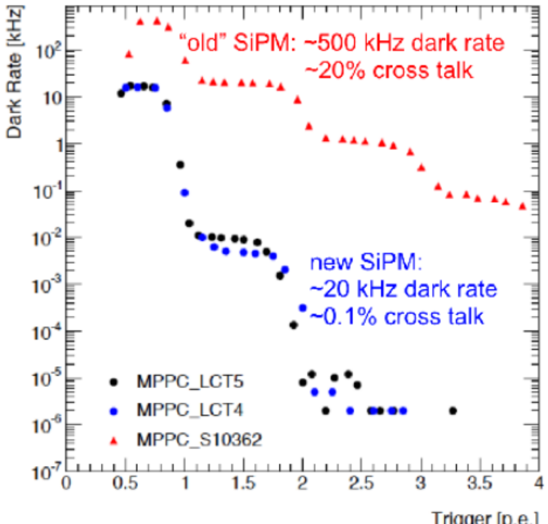
**Technological prototype**



Surface mounted SiPMs & tiles
- with *MPPC* SiPMs 2700 px

**Suitable for automated mass assembly**

- SiPMs sensitive to blue light → no need for WLS fibres
- New generation of industrial SiPMs: drastically improved over the past years
  - Dramatically reduced dark rate and increased photon detection efficiency
  - Better signal-to-noise ratio, allows simpler tile design
  - After-pulses and inter-pixel cross-talk largely reduced
  - Noise rate decreases quickly with threshold, much more stable operation
- Excellent uniformity (operating voltage, gain)
  - Simplified calibration
- High over-voltage operation
  - Reduced temperature sensitivity

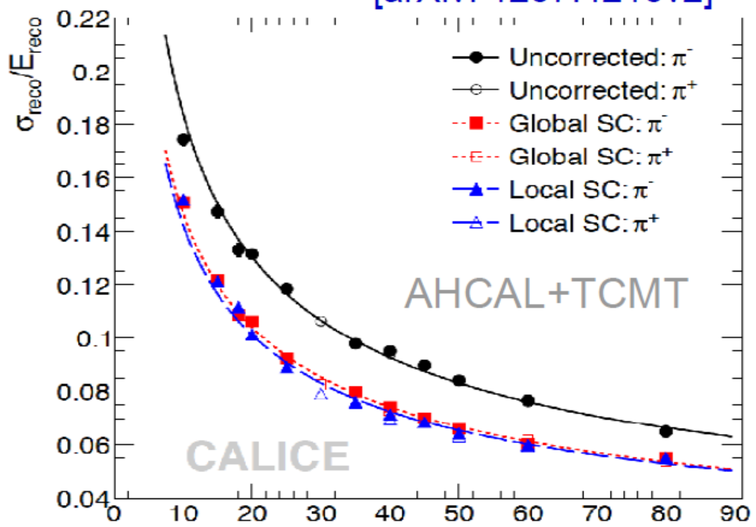


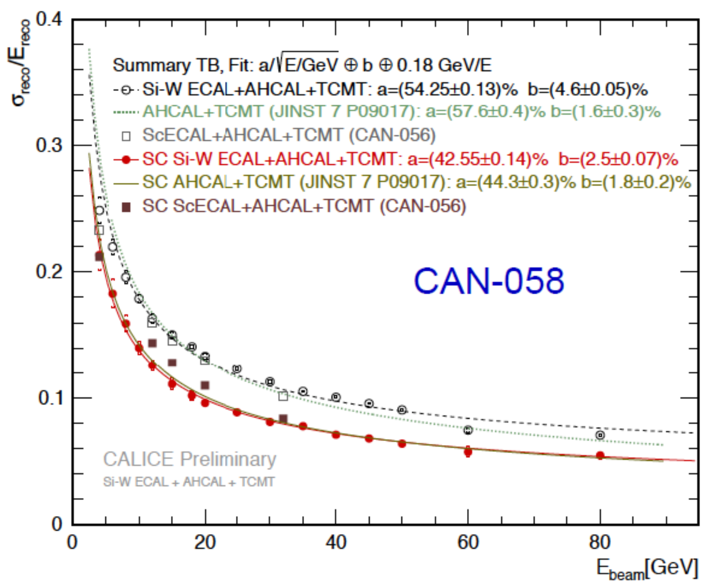

For comparison: SiPMs in physics prototype 2 MHz dark rate, 30% cross talk

# Introduction of CALICE AHCAL (CHEF2017 Katja's talk)

- software compensation for single pions with CALICE AHCAL
  - improvement for hadronic energy resolution by ~20% in the energy range 10 to 80 GeV
- software compensation for single pions with combined calorimeters:
  - ScECAL + AHCAL
  - SiECAL + AHCAL
  - improvement for hadronic energy resolution by 10 to 30%
  - similar improvement in both configurations
  - more details in talk by Yasmine Israeli on Tuesday

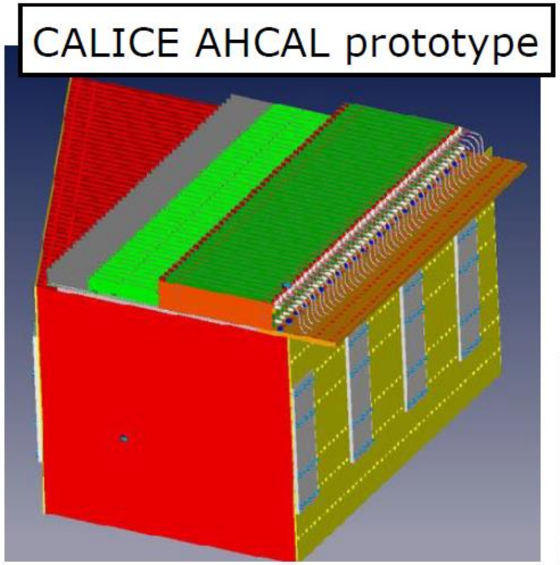
[arXiv: 1207.4210v2]

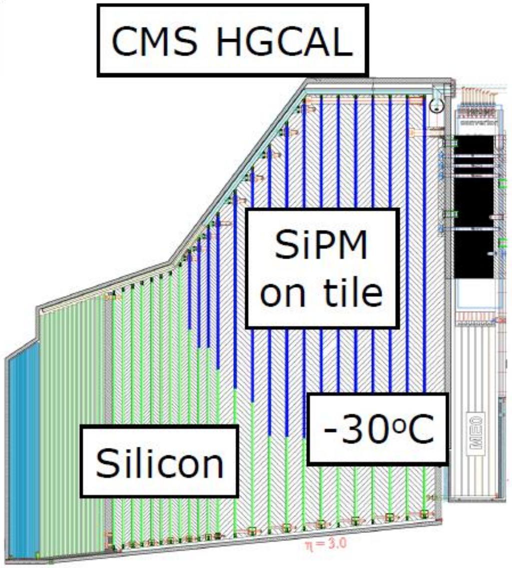


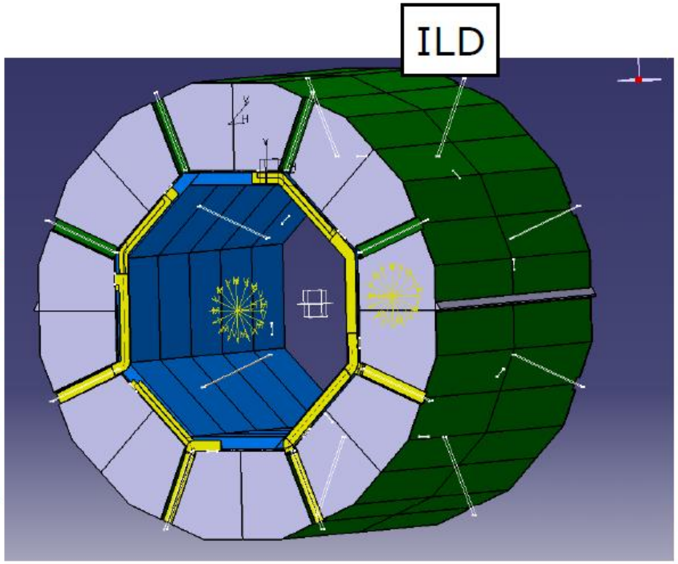



# Introduction of CALICE AHCAL (CHEF2017 Felix's talk)

## Scintillator part of CMS HGCAL




24'000 SiPMs
tile size 3cm

500'000 SiPMs
tile size 2 - 5.5 cm

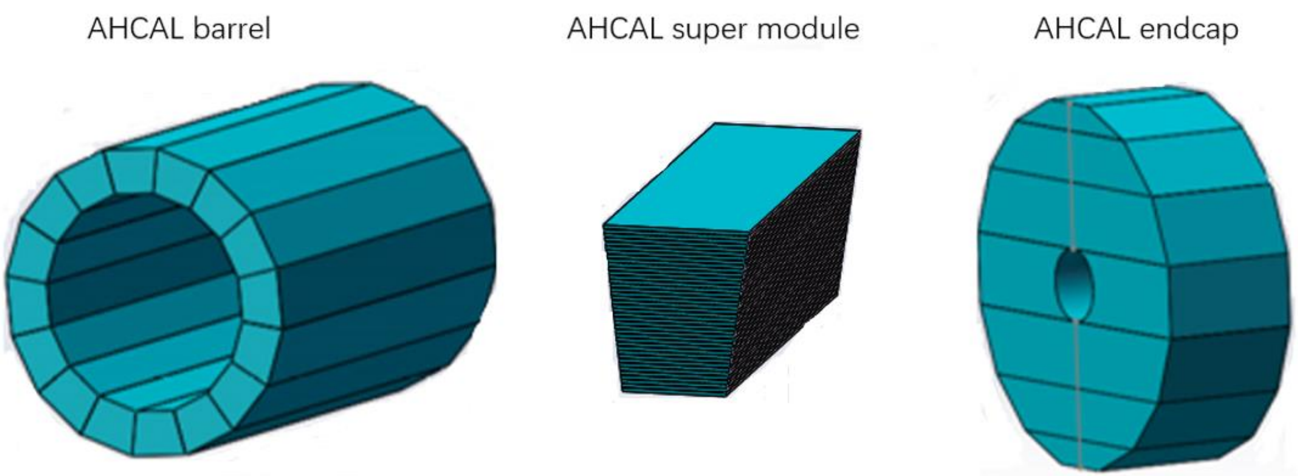
8'000'000 SiPMs
tile size 3 cm

- Intermediate scale, new challenges:
- Radiation damage to silicon and scintillator
  - neutron fluence up to $5 \cdot 10^{13}$ n / s cm$^2$, irradiation up to 200 kRad
  - and limitations to electronics components
- High speed data transmission: several GB/s per ASIC
- Cooling of SiPMs, thermo-mechanical aspects (+30 - -40°C)

# *The R&D progress of CEPC AHCAL*

— Analog hadron calorimeter for CEPC:

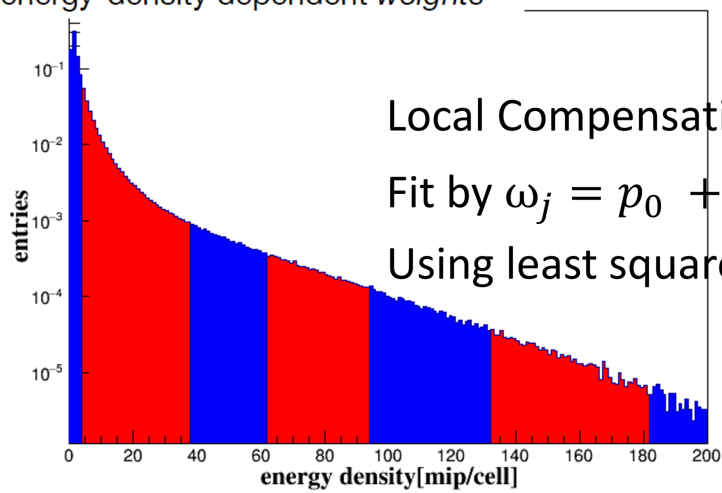
- The absorber: 2cm Stainless steel (0.12$\lambda_I$, 1.14$X_0$);
- Detector cell size: 3cm×3cm or 4cm× 4cm;
- ASIC Readout chip: SPIROC2E, KLauS (KIP, Uni-Heidelberg) etc.
- The sensitive detector : Scintillator(PS);
- About 40 sensitive layers, total readout channel: ≈7.3 Million (3cm× 3cm)



# *Software compensation for Energy reconstruction at AHCAL*

***Local***

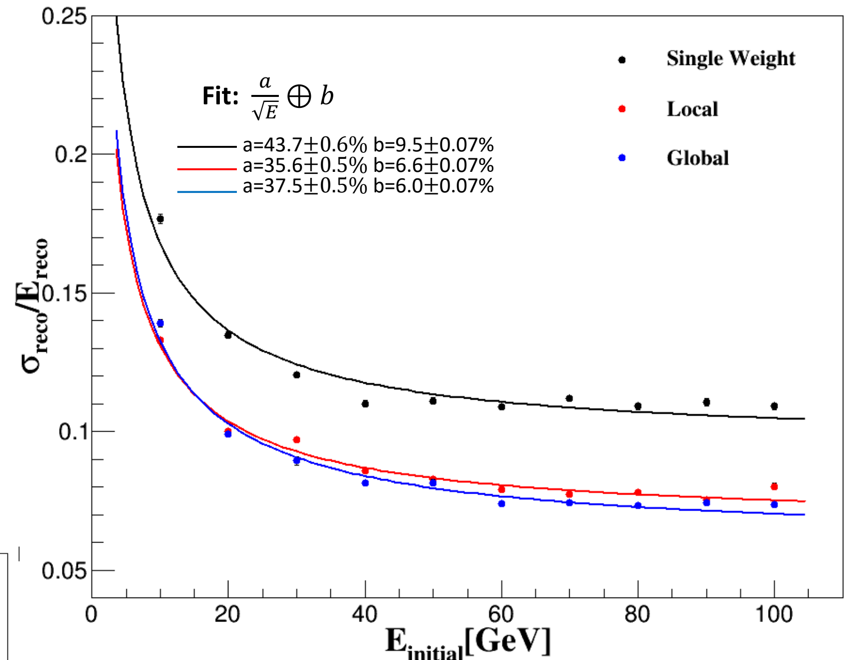
- Cell-by-cell correction of energy with energy-density dependent *weights*



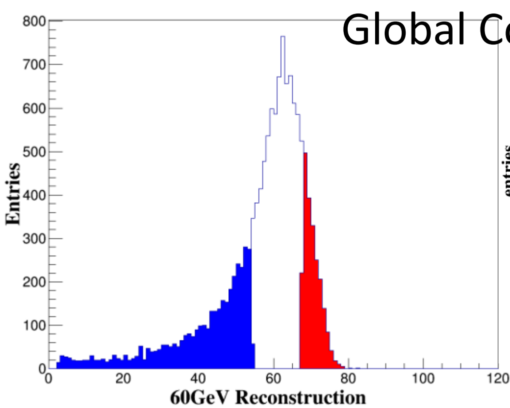

Local Compensation

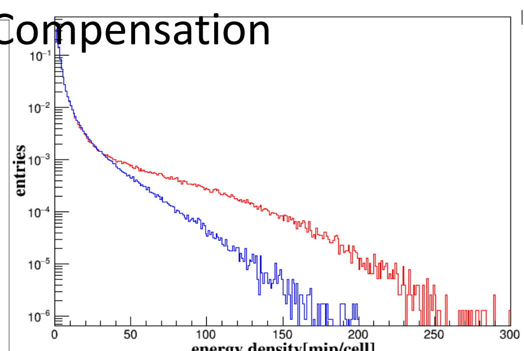
Fit by $\omega_j = p_0 + p_1 e^{(p_2 * e_j)}$

Using least square method




Global Compensation




Local Compensation improves by ~18%

Global Compensation improves by ~15%

***Global***

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

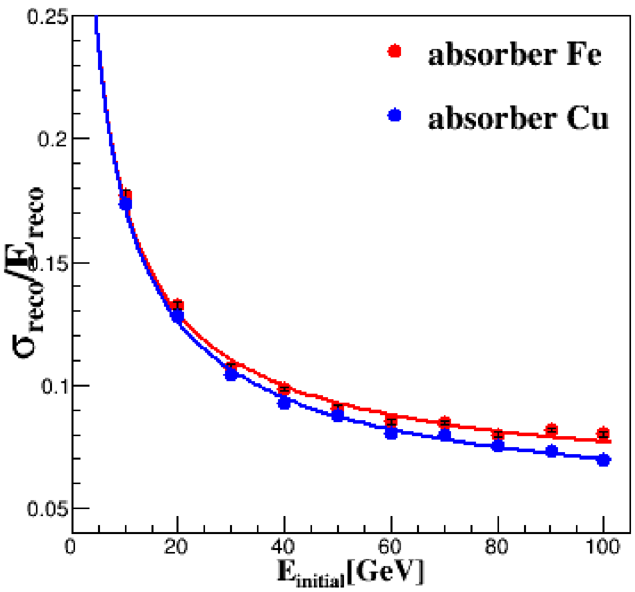
$$E_{rec} = \sum_i (E_{HCAL,i} \times C_{global})$$

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

# *Different absorber for AHCAL*

Simplify Geometry (Only AHCAL)
Incident particle: $k_L$
Direction: Z
Position(mm):1000 400 2000

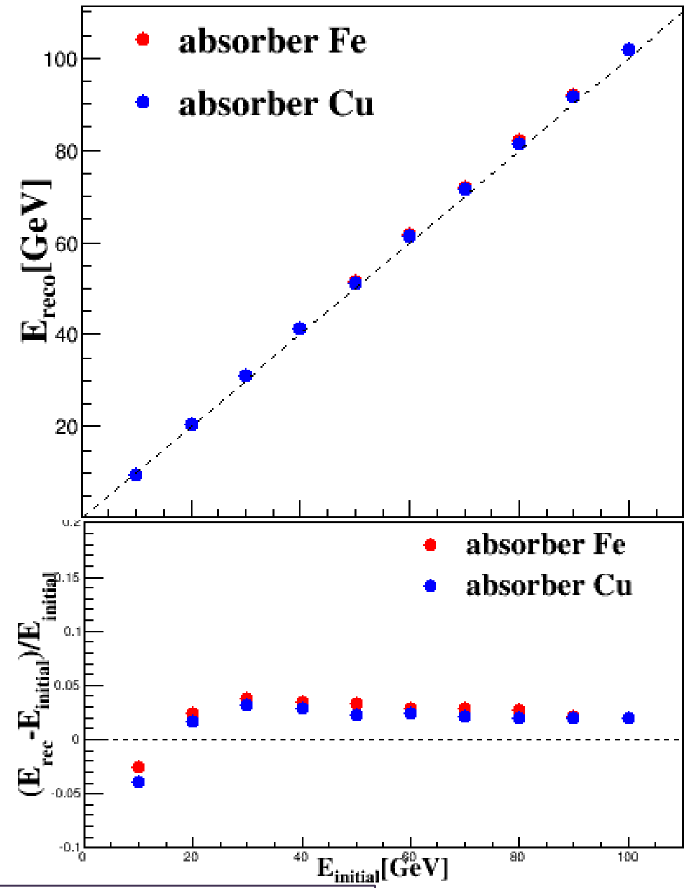
Energy resolution




a=51.8 ± 0.5% b=5.7 ±0.10%

a=52.3 ± 0.6% b=4.7 ±0.13%

Energy linearity and residual

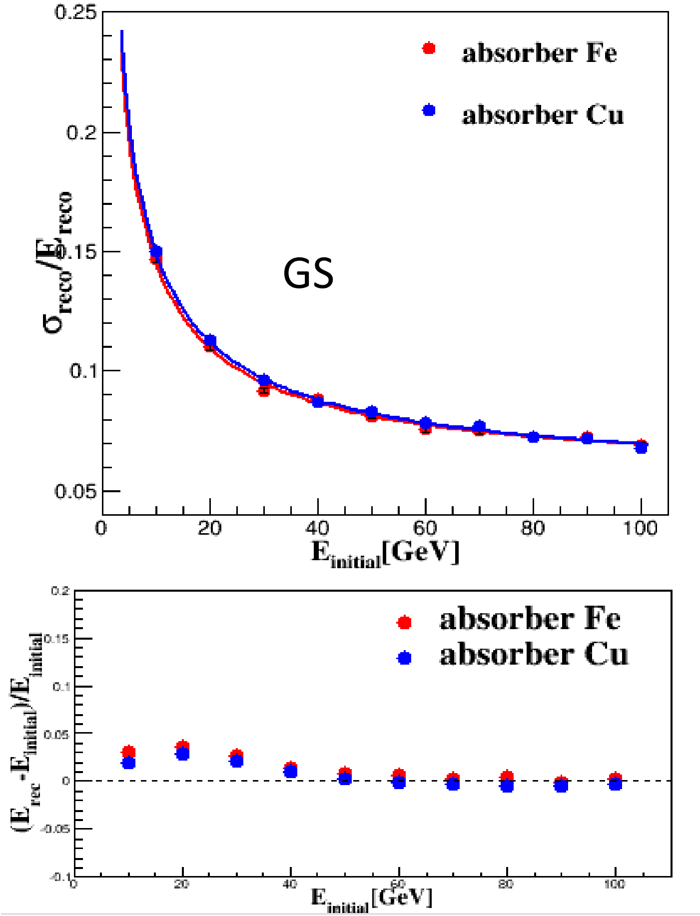


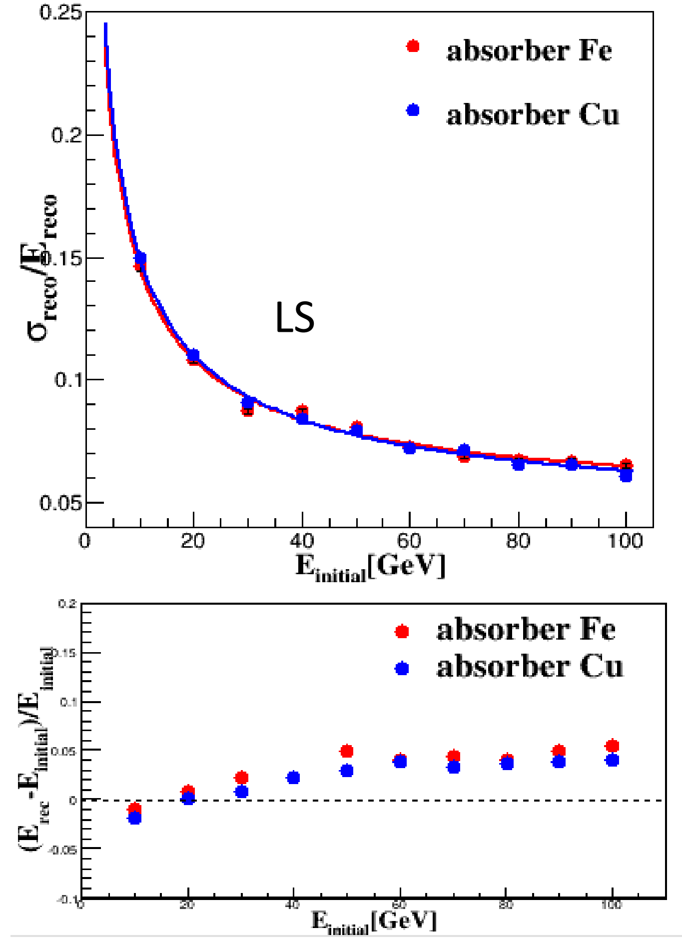

For high Z absorber

- More Ionization(lower fem)
- Lower Bind-energy(more neutron)
- Energy resolution can be better and increases with high-energetic Incident particles for absorber Cu.

# *Software compensation for AHCAL absorber optimization*

Energy resolution and residual



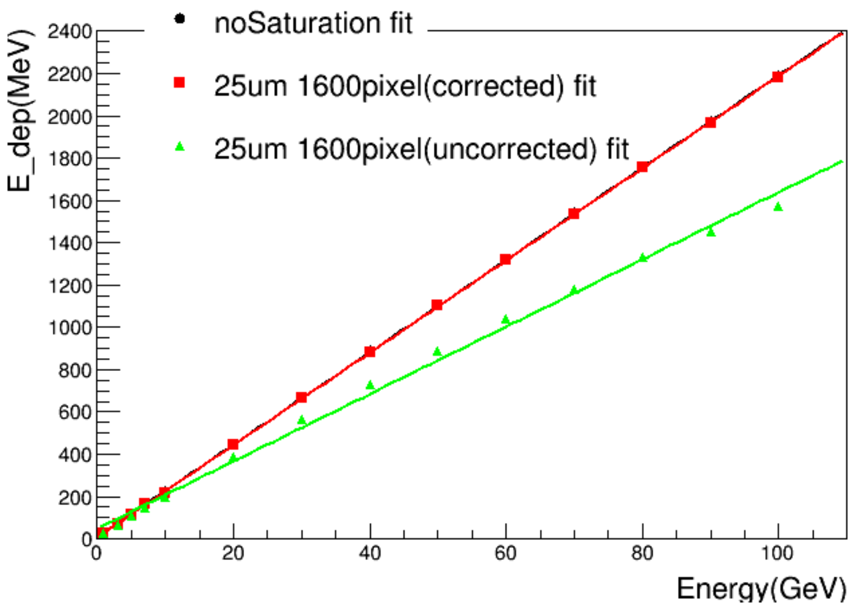



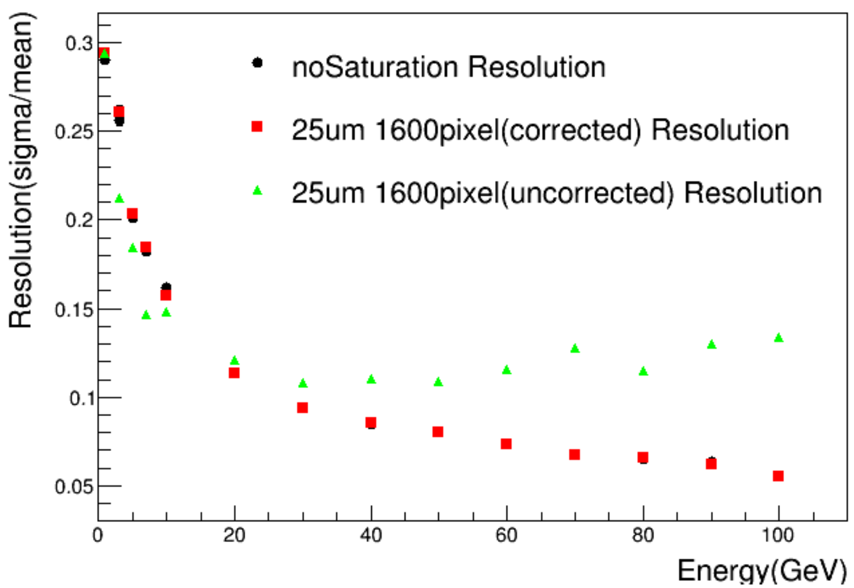

- The tendency of energy resolution is similar for absorber Fe and Cu by SC.
- The  differences of different absorbers can be reduced by SC.

# SiPM saturation effect on AHCAL dynamic range

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



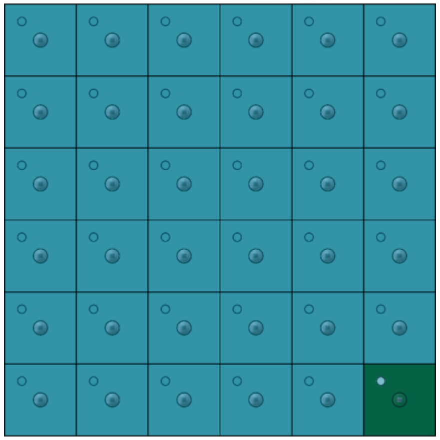




Corrected by $N_{fire} = N_{pix}(1 - e^{-\varepsilon N_{in}/N_{pix}})$

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

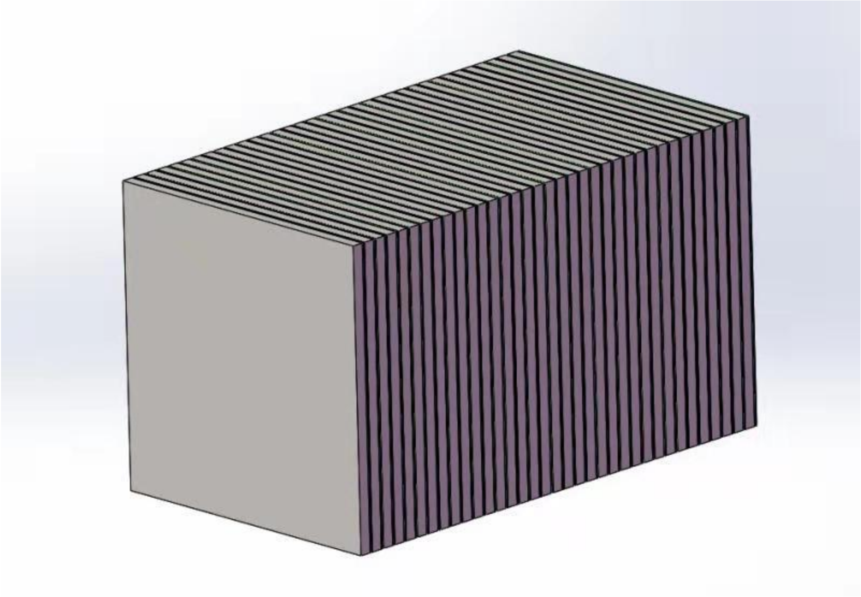
# *AHCAL prototype Plan (Got funding)*

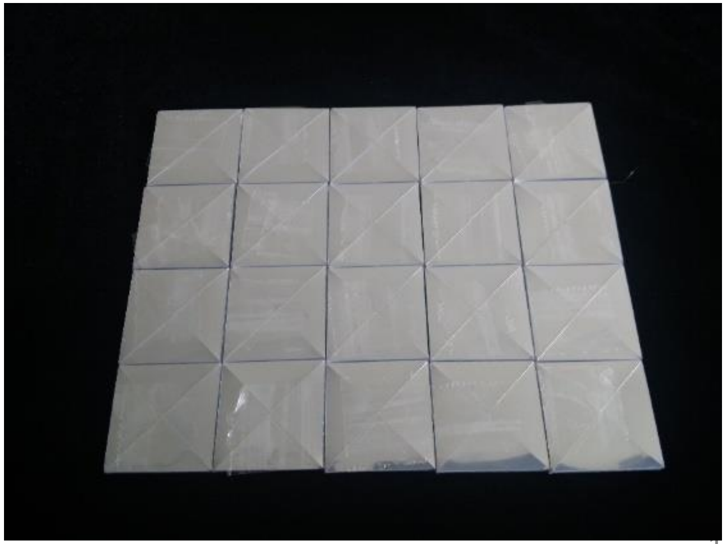
Motivation：
– A AHCAL prototype fit the CEPC requirement.



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

Ability of cell mass production



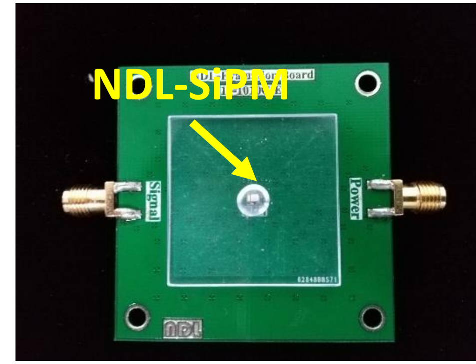


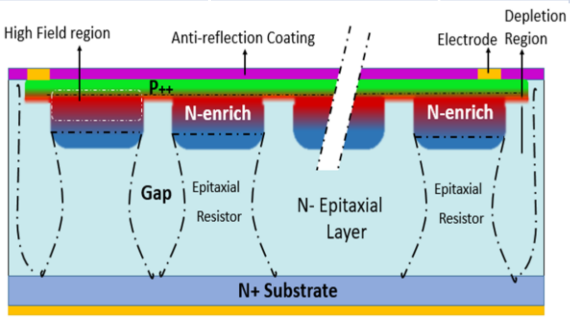
# *Chinese NDL-SiPM Test-1 (1mmx1mm 10umSiPM)*

**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. |

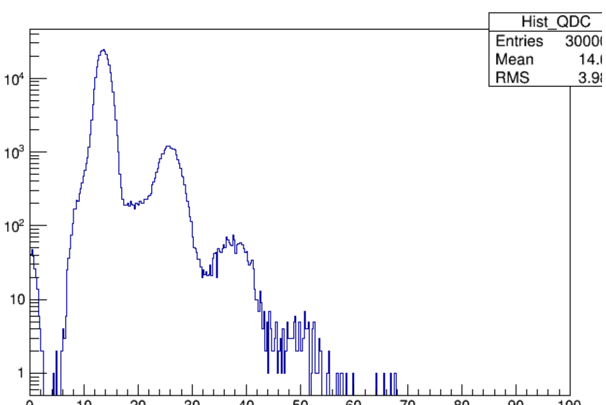



Structure of EQR SiPM

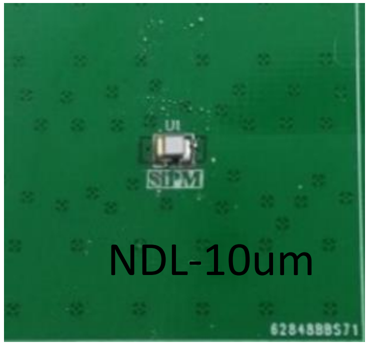
## NDL-SiPM 11-1010C specification

| 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℃ - +40℃ | Temperature Coefficient For $V_b$ | 25 mV/℃ |
| Breakdown Voltage ($V_b$) | $25.5\pm0.2$ V | Gain | $\geqslant 2\times10^5$ |
| Max. Overvoltage ($\Delta V_{max}$) | 8 V | Single Photon Time Resolution | $\leq$ 70 ps |



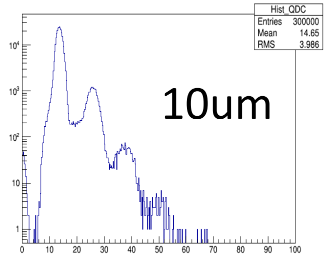

**Crosstalk spectrum**

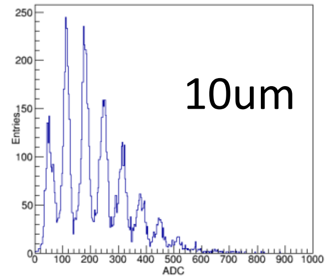
# NDL-SiPM + ASIC Test-2





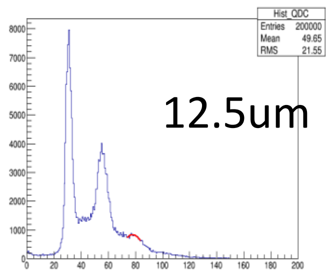
Calibration by their **NDL preamplifier**

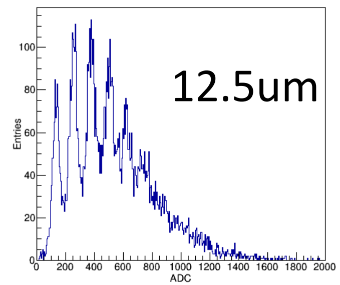


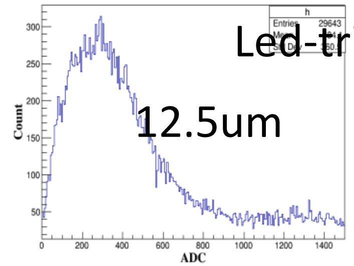

Self-trigger

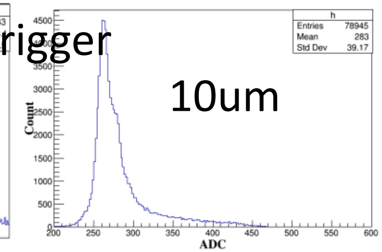
Led-trigger

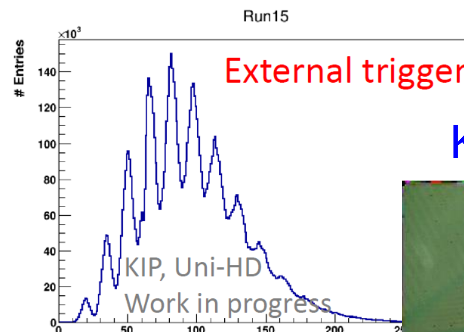


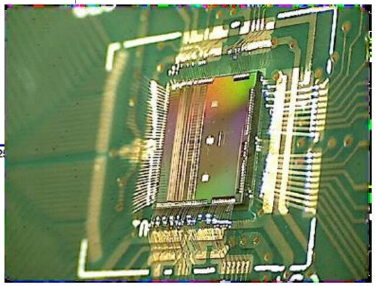

Read-out and Calibration by **Spiroc2b**




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 | |

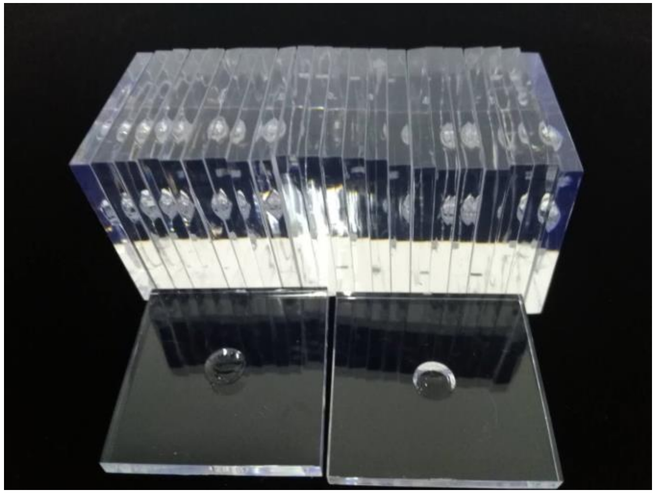
KLauS ASIC (KIP, Uni-HB)

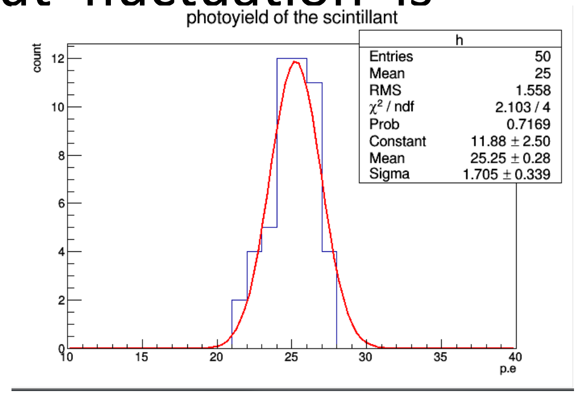
- Low noise, low power dissipation
- Continuous readout without dead time

25 uW / channel @ duty cycle 0.5%

# *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%；

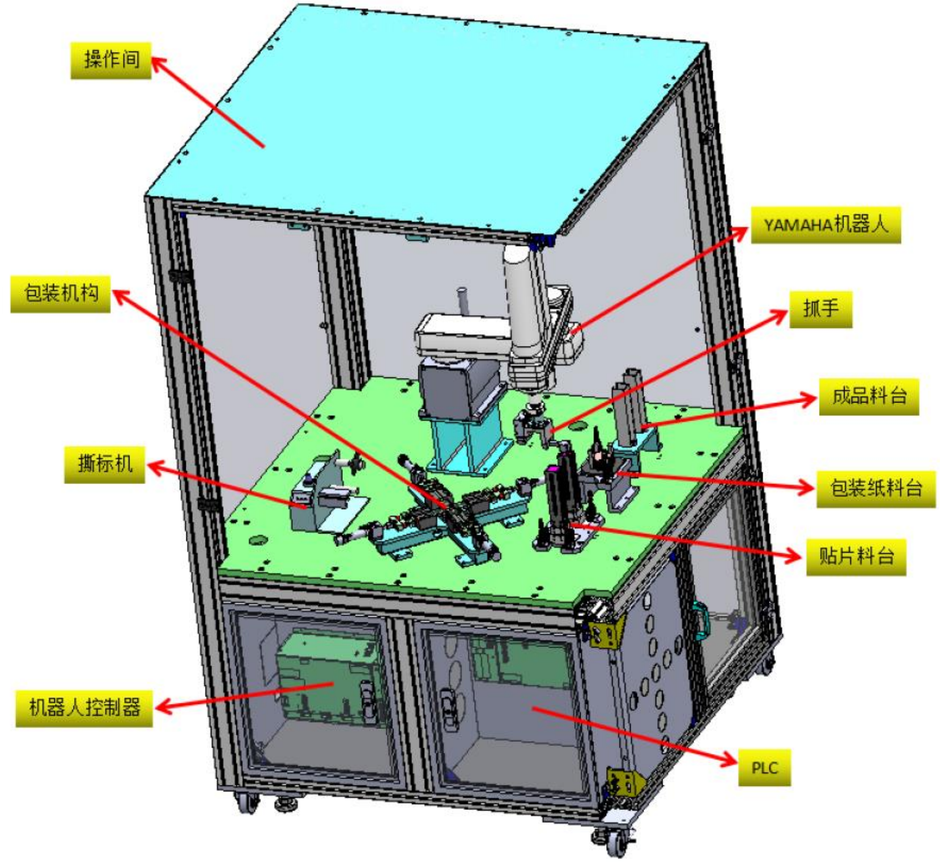





Size uniformity

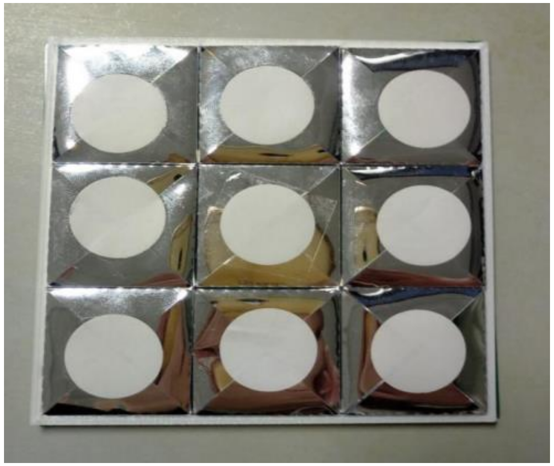
| | | | | | |
|---|---|---|---|---|---|
| Tiles size(mm) | 30.08x30.01 x3.08 | 30.07x30.04 x3.09 | 30.04x30.02 x3.09 | 30.09x30.09 x3.09 | 30.05x30.03 x3.09 |
| Light output(p.e.) | 23.5 | 22.78 | 22.86 | 25.02 | 23.54 |

# *Detector cell Automatic assemble system*

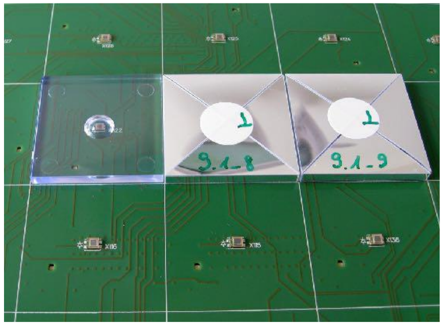



- Motivation:
  - 7M detector cells;
  - Reflective foils packaging can't be done by manual;

- 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:

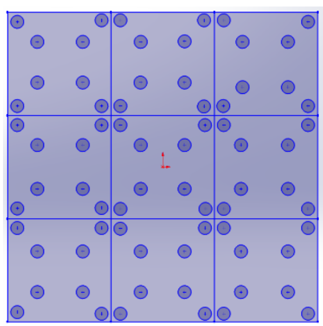
In order to quickly and effectively realize the integration of large area AHCAL detection unit.

Materials:

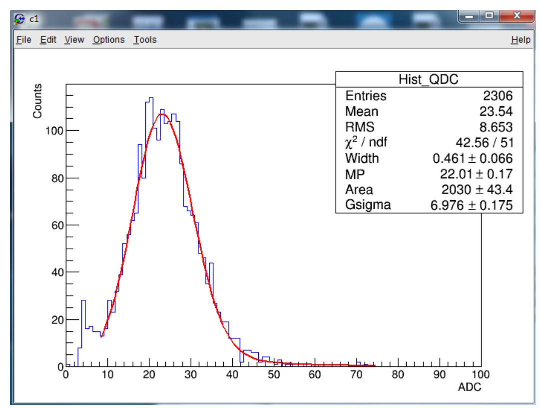
1. Araldite 2011 epoxy glue
2. 3×3 PCB board
3. Detector cell;
4. A film used to brush glue

Result:

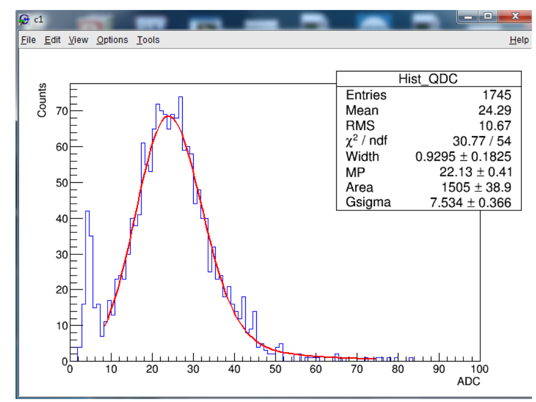
1. This way is working;
2. The detector cell was glued on PCB board fasten;
3. Maybe reduce to 4 glue hole;
4. Plan to test crosstalk and prototype.



Light output



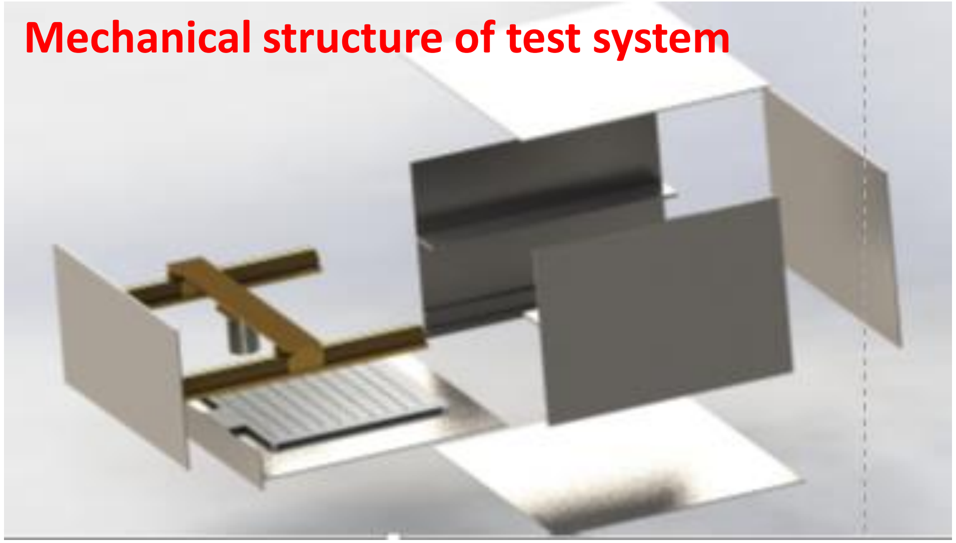

Before glued

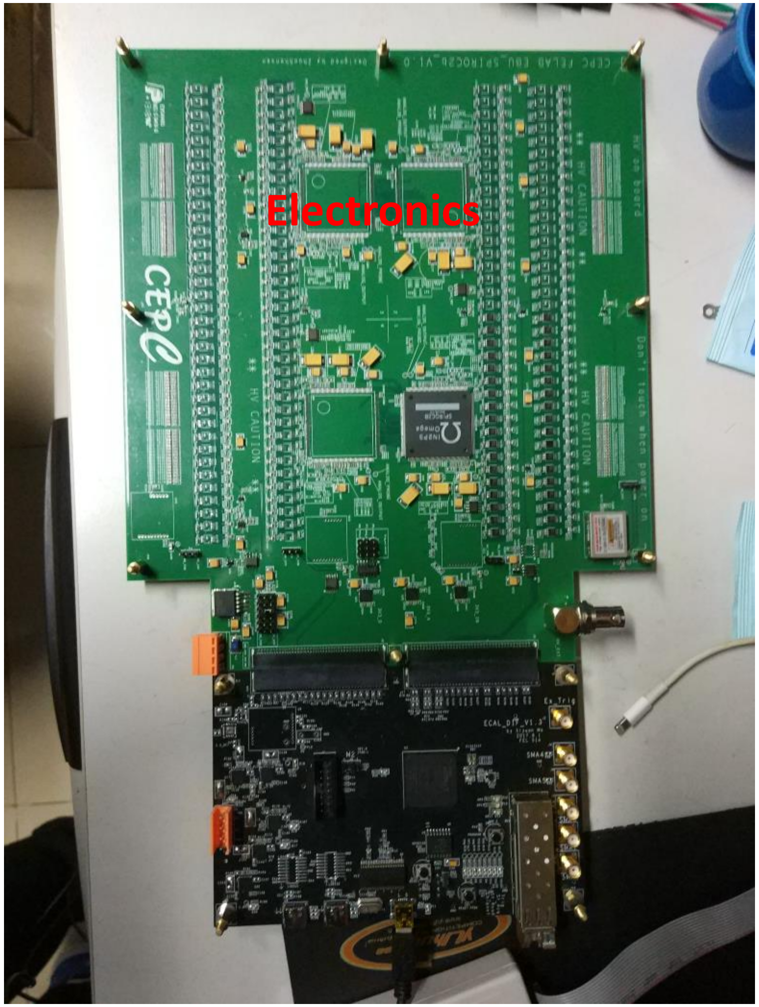



After glued

# *Detector cell test system design*

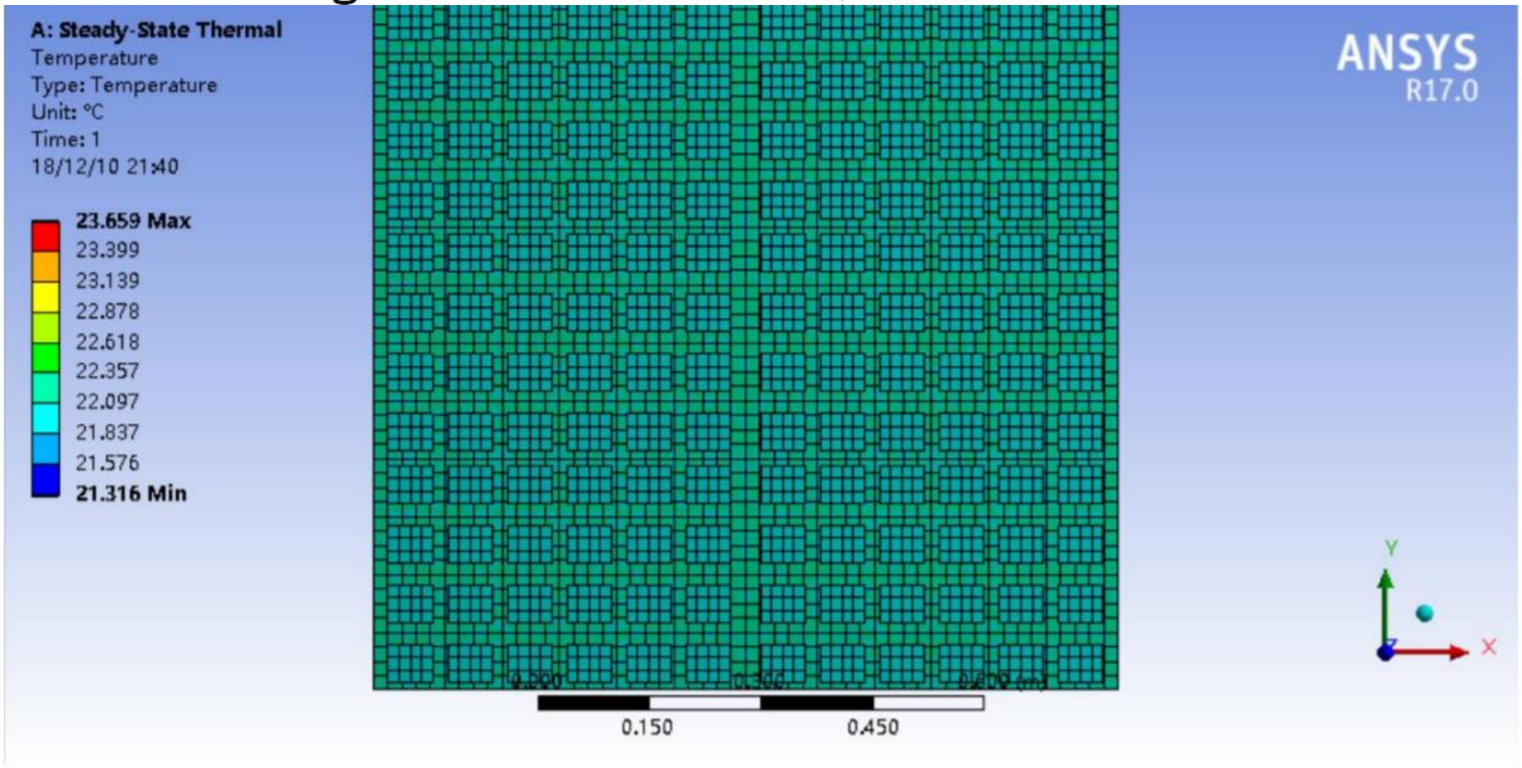
- About 100 detector cells one batch;
- Electronics under design;
- Mechanical structure under design;



# Cooling is under study

- CEPC is designed to operate at continuous mode with beam crossing rate: $2.8\times10^5$ 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℃

# Technical challenge for CEPC AHCAL

—Cooling is a technical challenge for CEPC AHCAL;

- CEPC will work at continues mode, the power will increase 100 times than ILC AHCAL;
- A active cooling system is needed;
- 4 mm copper cooling layer replace stainless steel?

—ASIC and electronics

- SPIROC2E ASIC fit the requirement of CEPC AHCAL? Big noise, low gain.
- KLauS (KIP, Uni-Heidelberg) is still under developed.
- How to reduce the power of electronics?

—Calibration

- More study is needed;

— SiPM, we hope NDL-SiPM can be used to reduce the price of SiPM, need more study.

Thanks for your attention!