Studies of CEPC AHCAL detector cell performance

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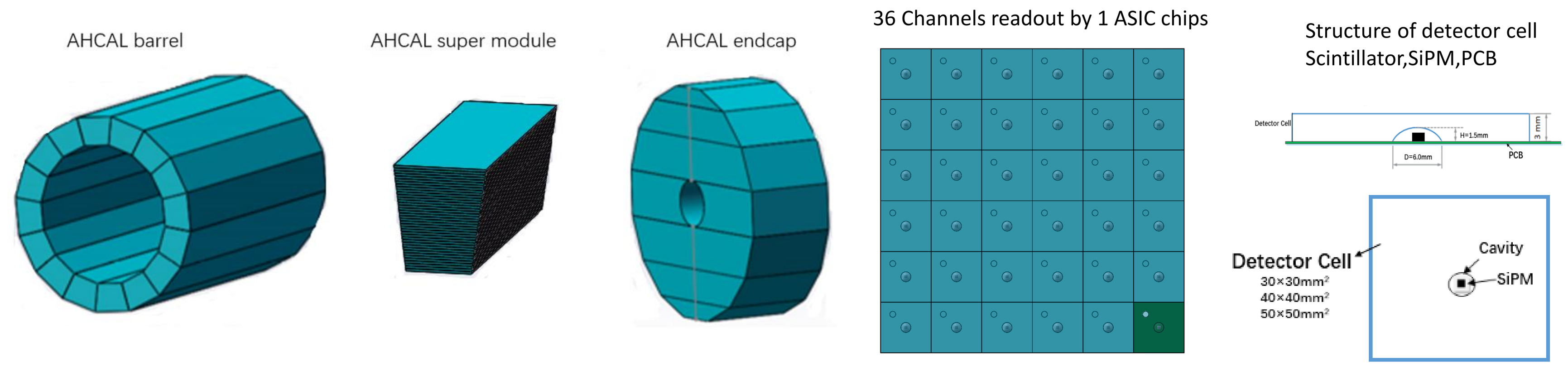
Introduction

The Circular Electron Positron Collider (CEPC) as a Higgs factory was proposed by China in 2013. The CEPC detector design was using International Linear Collider Detector as an initial baseline. The CEPC calorimeters, including the high granularity electromagnetic calorimeter (ECAL) and the hadron calorimeter (HCAL), are designed for precise energy measurements of electrons, photons, taus and hadronic jets. HCAL is a typical sampling calorimeter, whose structure consists of absorber layers (such as iron, lead and tungsten) interleaved with sensitive layers (such as plastic scintillator, GEM, RPC). Analog HCAL (AHCAL) is used for future large-scale linear collider experiments, whose jet energy resolution σE/E = 30%/√E can be achieved by particle flow algorithms in order to efficiently separate Z^0, $W^{\pm}$ and Higgs bosons. AHCAL is an option for HCAL based on plastic scintillator. The preliminary design of AHCAL contains 40 layers. Each layer consists of 5mm sensitive layer and 20mm stainless steel absorber layer in AHCAL.

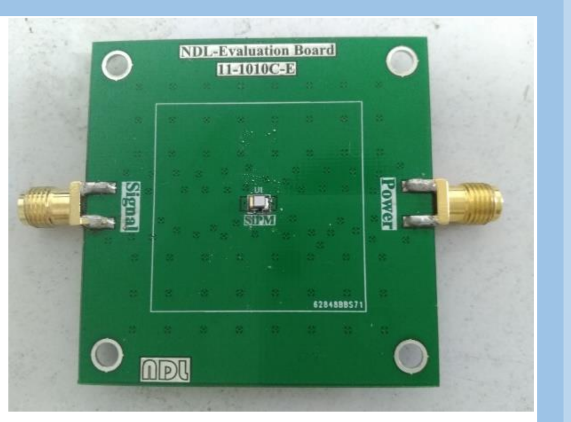


Sideview of one layer in CEPC-AHCAL

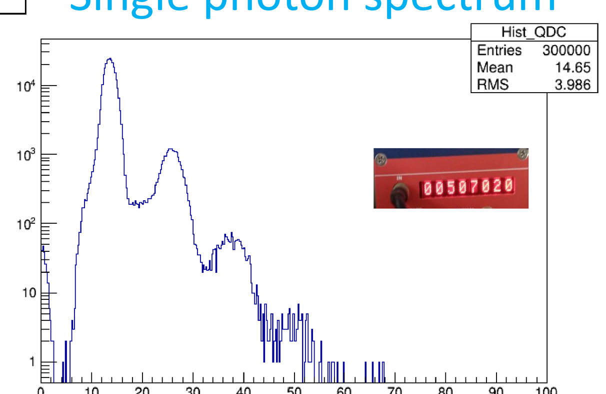
NDL-SiPM 11-1010C

Parameters table and realistic figure

Parameter	Value	Parameter	Value
Effective Active Area	1×1mm²	Peak PDE@420nm*	31%
Effective Pitch	10 μm	Dark Count Rate*	~500 kHz
Micro-cell Number	~10000	1 p.e. Pulse Width	6.8ns
Operating Temperature Down to LN2 (77 K)	Yes	Temperature Coefficient For V_b	25 mV/°C
Breakdown Voltage (V_b)	27.5±0.4V	Gain	⩾2×10⁵
Max. Overvoltage (ΔV_{max})	8 V	Single Photon Time Resolution	≤70 ps

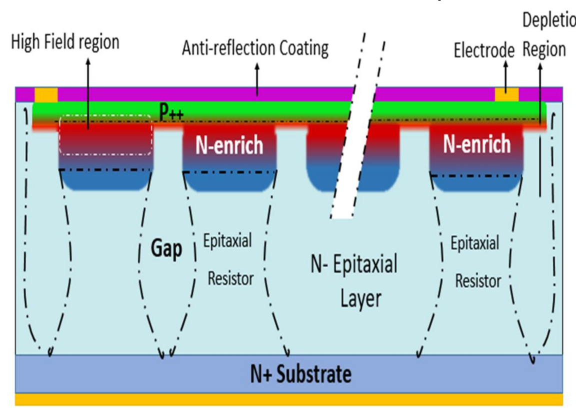


Single photon spectrum



Chinese **Beijing Normal University** (BNU) has developed silicon photomultiplier (SiPM) technologies with epitaxial quenching resistors (EQR).

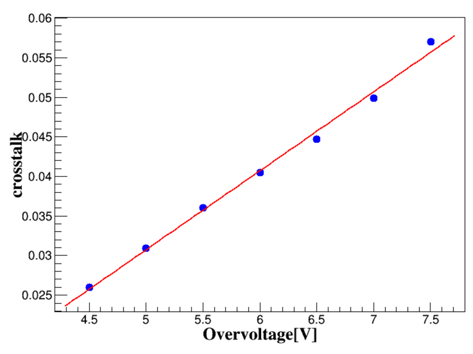
NDL EQR-SiPM is easy to implement owning to its unique structure featuring intrinsic continuous and uniform cap resistor layer. Thus it has higher fill factor.



- Same Size as MPPC 12571-010P
- 3 times PDE than MPPC 12571-010P
- Good uniformity between each SiPM

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

Voltage of all SiPM are 35V and results after calibration

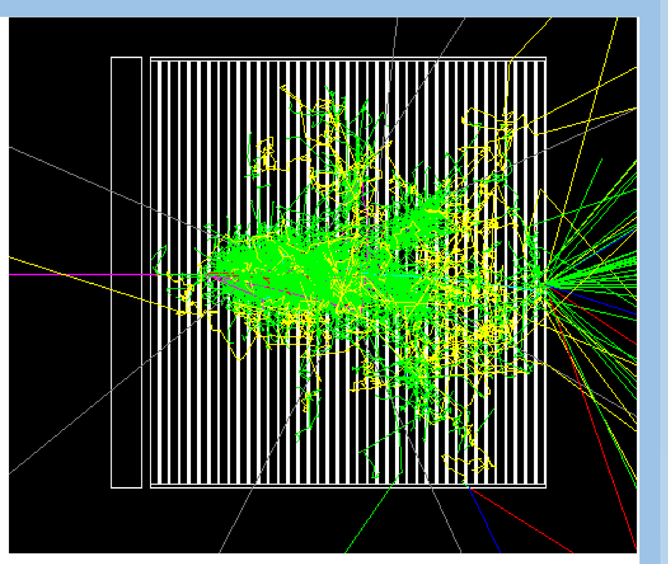


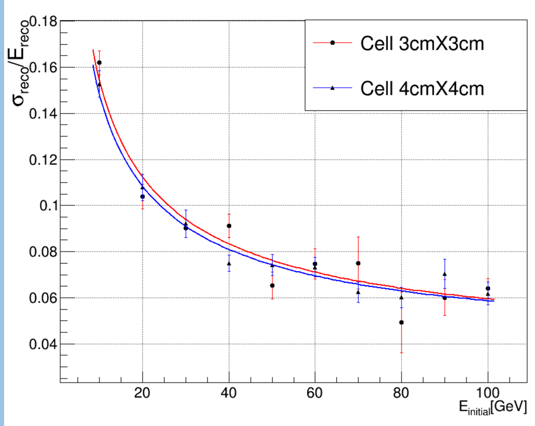
The crosstalk measurement of NDL 11-1010C SiPM is linearity with overvoltage increasement.

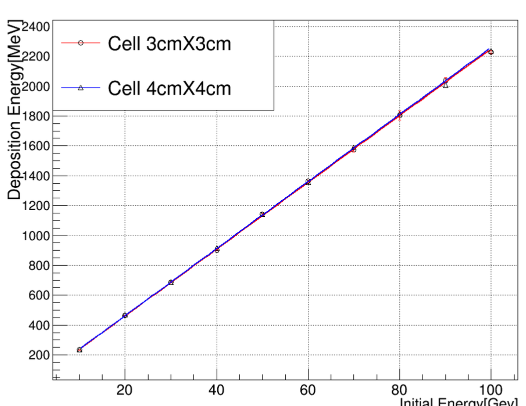
Simulation of AHCAL prototype

Preliminary design of AHCAL Prototype

- Dimension: 51*51*87.5cm³
- Total layers：35
- Detector cell size: 3cm×3cm
- Absorber: stainless steel
- Read-out chips：SPIROC-2E
- Total channel：17*17*35=10115





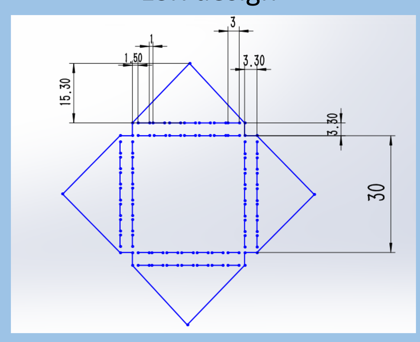


The result just be obtained by adding deposition energy of scintillator cells. For AHCAL prototype performace, Single hadronic energy resolution is not important.
It can not be used as a criterion for detector cell optimization

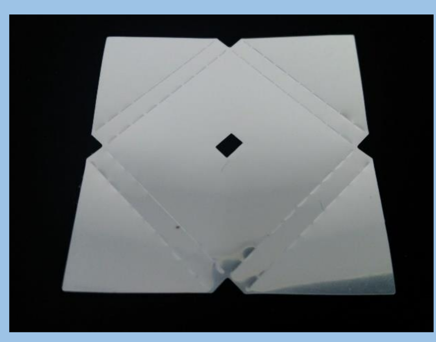
Studies of domestic technology

◆ ESR design for tiles wrapping

ESR design



ESR cut by mould



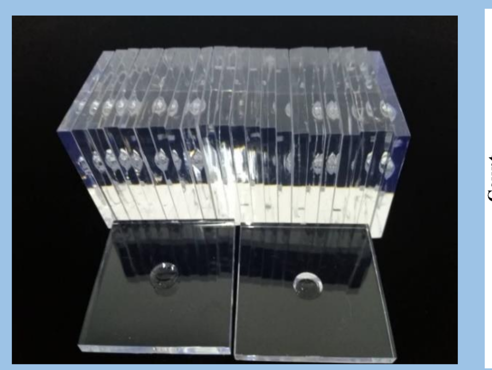
- Cheaper
- Minimal ESR consumption
- Minumum damage for ESR
- A few gap in the crease
- Easy wrapping and automation

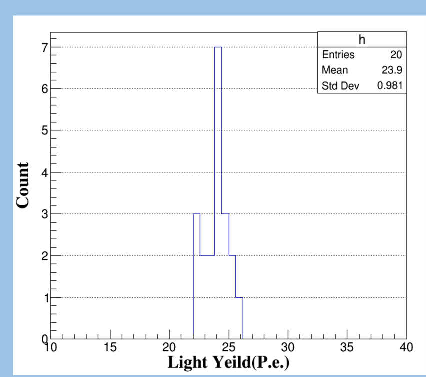
20 tiles by injection molding wrapped with ESR

- Campactly wrapping
- Samply intergrating

◆ Domestic scintillators

- Made by Injection molding (custom-made and 8 iterations of recipe testing)
- Without polished, smooth and transparent
- Dimension deviation below 50um from each other (30 tiles)
- Light yield winthin 10% deviation



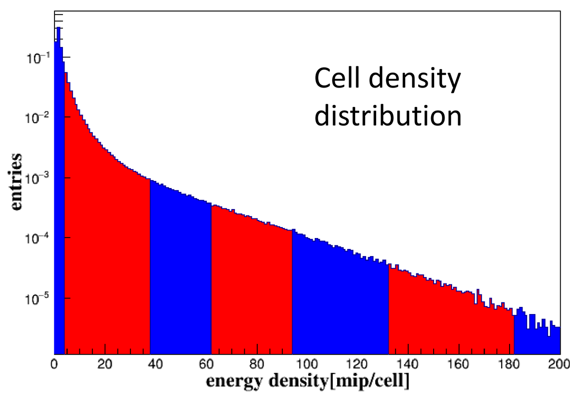


For AHCAL detector cell could be massively produced now.

Studies of software compensation

Hadron-induced shower:
EM and hadronic component
Production of π^0s and ηs are statisitical, fluctuates from shower to shower
Non detectable energy for hadronic component (break-up of absorber nuclei, undetected neutrons)
Character:Non-linear response for non-compensating calorimeters

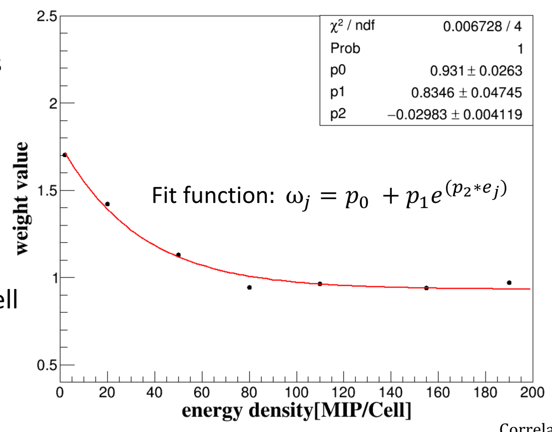
Simply multiplying the visible signal can not get good performace of energy reconstruction for AHCAL. Think about software compensation(SC) as CALICE done before



Sample : 10-100GeV π^- particles

Event selection:
- Cell energy >0.5MIP
- Event energy>100MIP

applying weights w_i to the different energy deposition of cell to improve response of EM and hadronic component



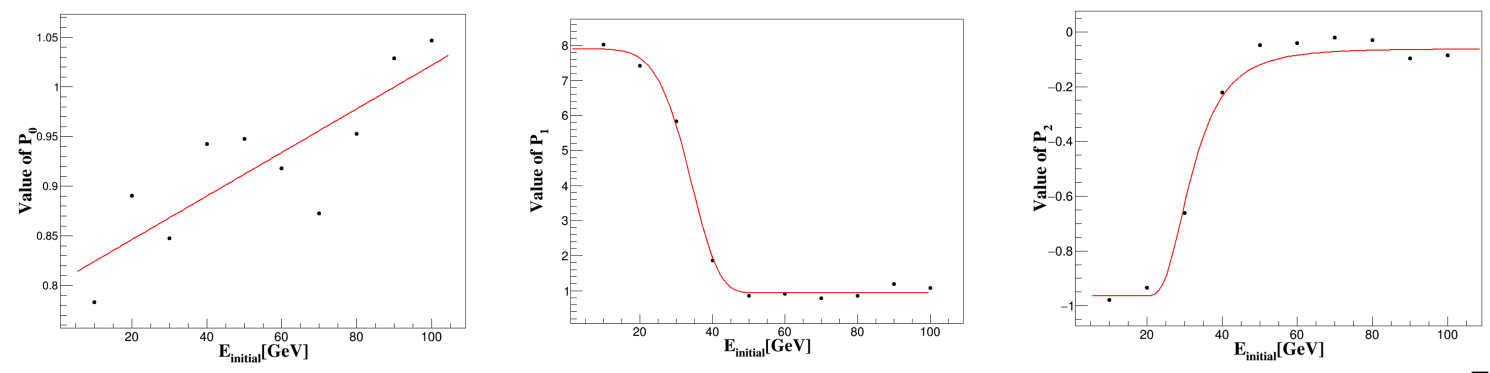
Correlation matrix

$$\begin{pmatrix} 1 & -0.939 & 0.783 \\ -0.939 & 1 & -0.934 \\ 0.783 & -0.934 & 1 \end{pmatrix}$$

Weight determination througt χ^2 minimisation

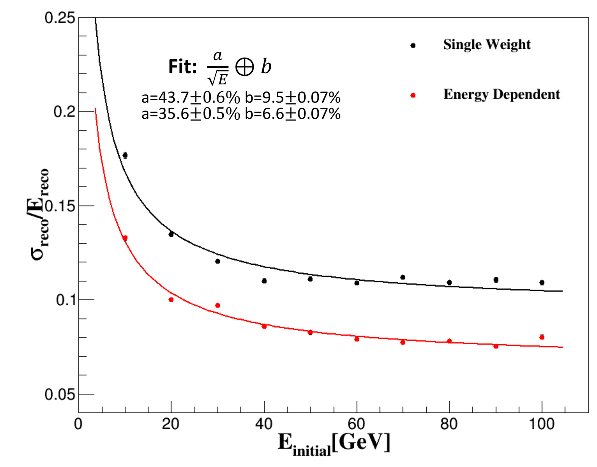
$$\chi^2=\sum_j(E_{ini} - \sum_i(E_{HCAL,i} \times w_i))^2)$$

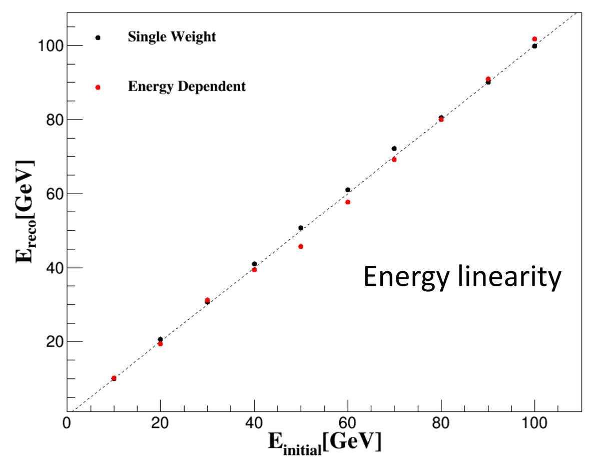
Using fit function:
Reduce the number of parameters
Enforce a smooth behavior of the weight
Eliminating fluctuations



The parameters p_0, p_1, p_2 were energy dependent. To improve the stability of the determination of the energy dependence of the three parameters, finding three function to fit these three parameters which is variable with different induce energy particles.

$$p_0 = a_1 + a_2 \times E$$
$$p_1 = a_0 + a_1 \times e^{a_2 x^{a_3}}$$
$$p_2 = a_0 + a_1 \times e^{a_2 x^{a_3}}$$





Energy reconstruction:($E_{rec} = \sum_i(E_{HCAL,i} \times w_i)$XC, χ^2=$\sum_i(E_{ini} - E_{rec})^2$
Energy resolution is improved near 20%.

Conclusion

◆ Domestic scintillator by injection molding satisfied our requirement and could be massively produced now.
◆ NDL-SiPM 11-1010C has good PDE but dark count rate is a little higher.
◆ Local software compensation can improve energy resolution about 20%