Status of CEPC-AHCAL R&D

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OutLine

- Background introduction of CEPC-AHCAL
- Optimization of scintillator and SiPM
- Study for massive integration of detector cell
- summary

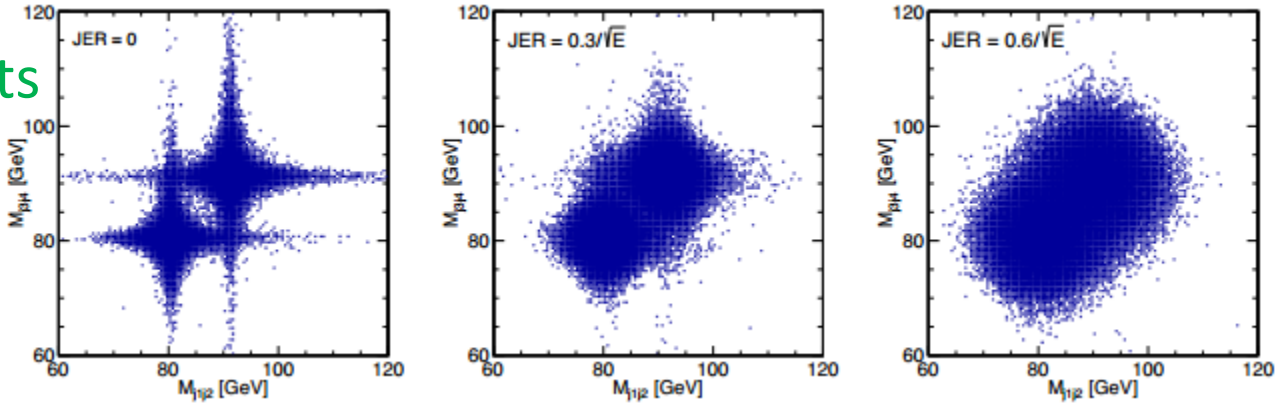
Background introduction

Requirement of jet energy resolution [1]

$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL	$\sigma_E^{\mathrm{jet}}/E =$
		HCAL	$3 \sim 4\%$ at 100 GeV

Typical jet components

- 60% charged particles
- 30% photons
- 10% neutral hadrons



PFA Oriented Calorimeter

$$\sigma^2_{\mathrm{jet}} = \omega_{\mathrm{trk}}\sigma^2_{\mathrm{trk}} + \omega_{\gamma}\sigma^2_{\gamma} + \omega_{\mathrm{n}}\sigma^2_{\mathrm{n}} + \sigma_{confusion} + \sigma_X$$

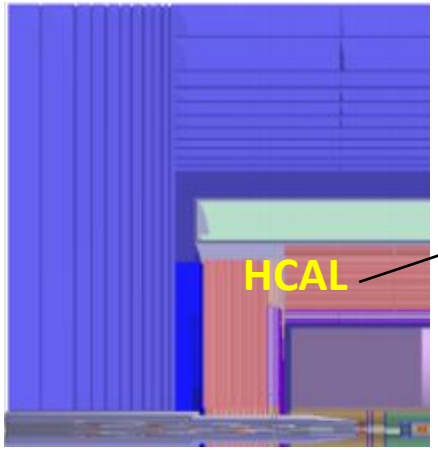
Charged particles — Photons — Neutral hadrons → HCAL $50\%/\sqrt{E}$

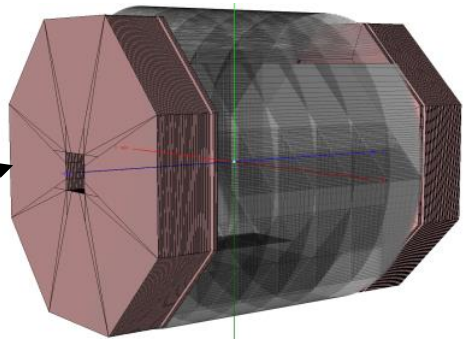
[1]http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf

Background introduction

Characters of Calorimeter

- High granularity
- Compact showers
  - small radiation length
  - moliere radius
- Minimal dead region



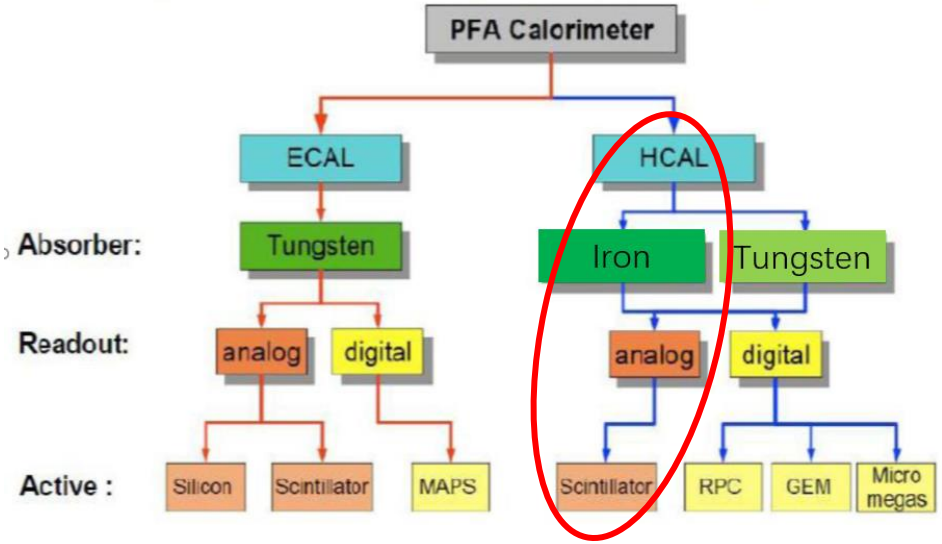


Hadronic Calorimeter(HCAL)

- Digital HCAL (DHCAL):

  RPC & MPGD(GEM and THGEM)
- Analog HCAl (AHCAL)

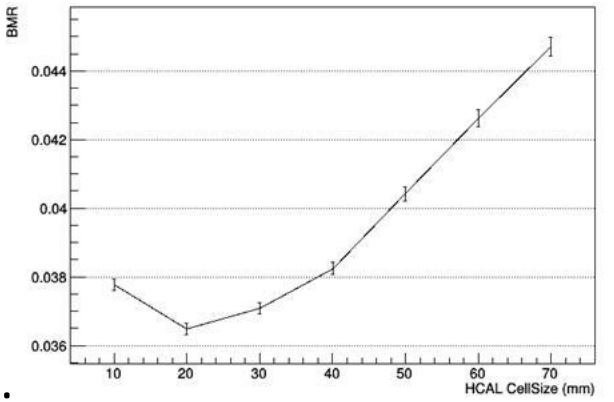
  Plastic scintillator+SiPM



Background introduction

— 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)



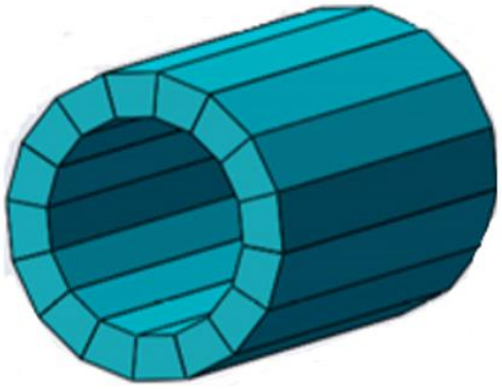
BMR - HCAL Cell Size

BMR: Boson Mass Resolution at di-jet final states

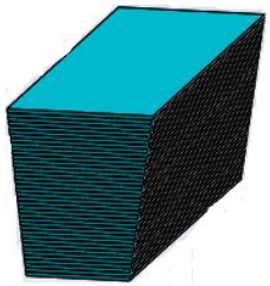
BMR*sqrt(2) = Jet Energy Resolution

BMR better than 4%

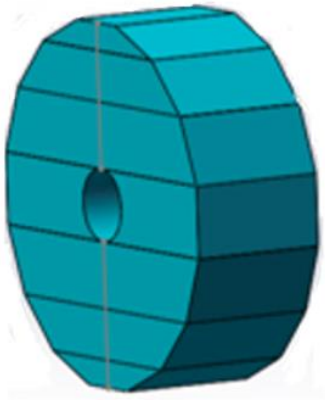
AHCAL barrel



AHCAL super module



AHCAL endcap



AHCAL Project for CEPC

Initiated by the CEPC MOST-2 R&D project in 2018

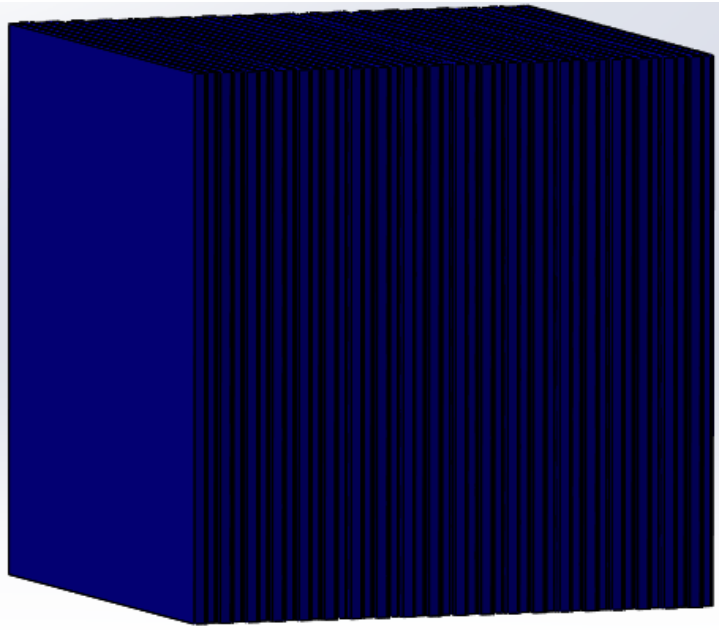
AHCAL option was considered the project later

–Scintillator+SiPM technology

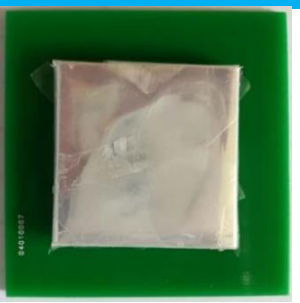
AHCAL prototype

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

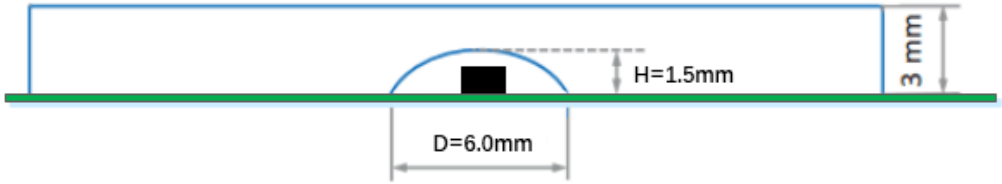
  11560 (3cmx3cm) , 12960 (4cmx4cm)
- Dimension: 51cm*51cm (3cmx3cm), 72cm*72cm (4cmx4c



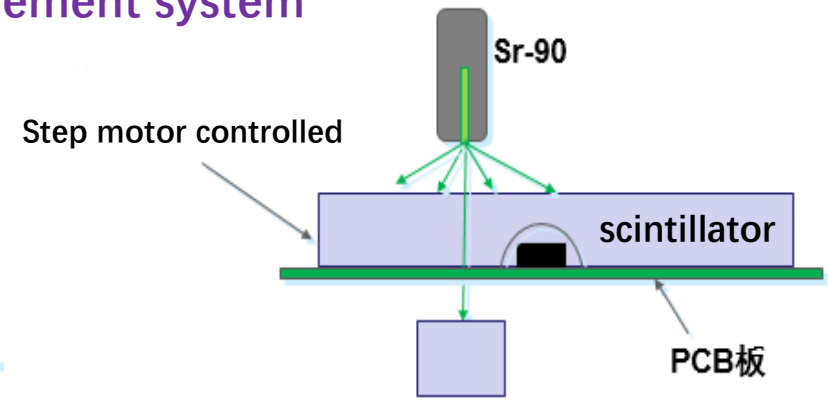
AHCAL detector cell uniformity measurement



Structure of detector cell



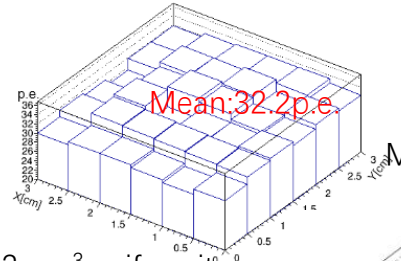
Measurement system



5×5×3mm^3

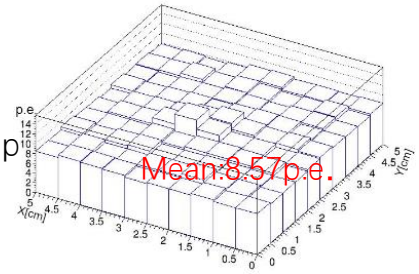
- Uniformity measurement of 3 different dimensions
- 5×5 mm2 scan step
- Scintillator BC408

➢ The deviation of response are winthin 10% from mean value.



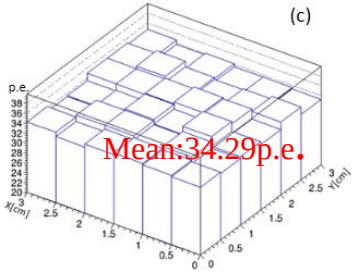
30x30x3mm^3 uniformity

MPPC S12571-025p



50x50x3mm^3 uniformity

(c)



30x30x2mm^3 uniformity

MPPC S13360- 1325PE

Optimization of AHCAL detector cell

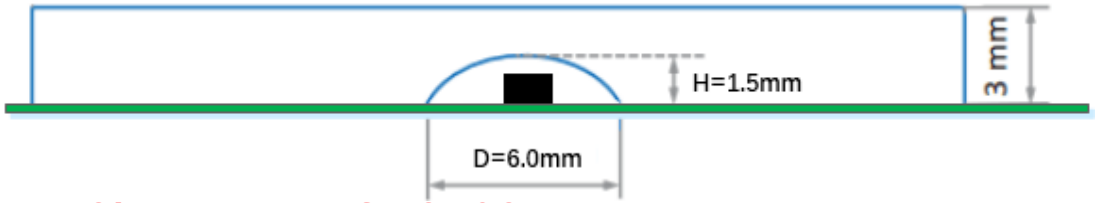
Table 1 Cosmic-ray measurement results of detector cells with different sizes

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

- For same size of detector cell, polishing method is very important;
- Different reflective foil: ESR is better than TYVEK;
- The bigger size detector cell, the less p.e. detected;
- Detector cell is 30mmx30mmx3mm packed with ESR at present.

Requirement of detector cell

Structure of detector cell

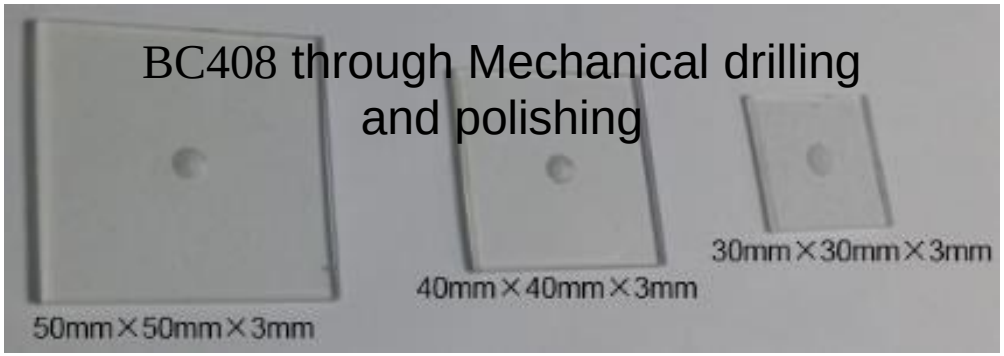


Uniformity measurement：
The deviation of response are winthin 10% from mean value.

Characters of BC408：

- High light yield
- Complicated drilling and polishing
- Bad consistency
- High cost
- Long processing period

Scintillator Type BC408



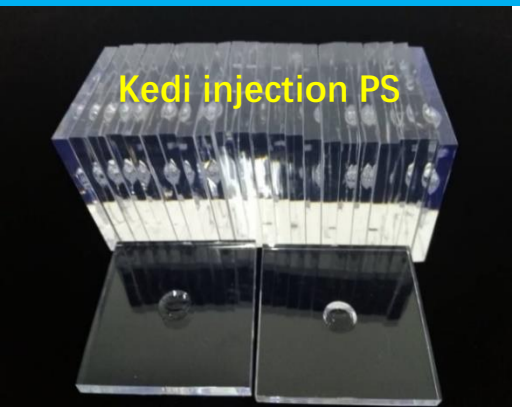
Expectation：
- Massive production
- Good consistency
- Low cost

Cratf of Tiles
- Short period
- No Polishing

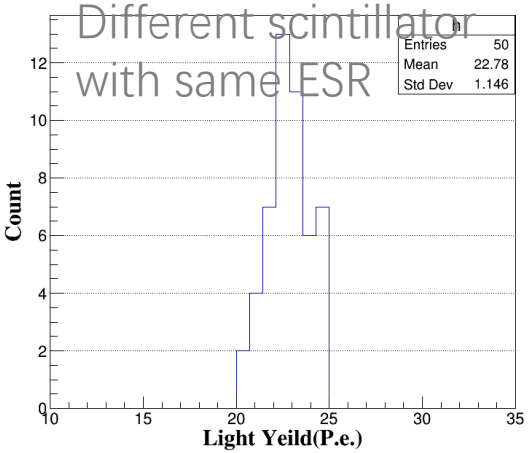
Motivation： Suitable recipe and craft

Requirement：
- Light Yeild:23p.e.
- Deviation: $\pm 10\%$

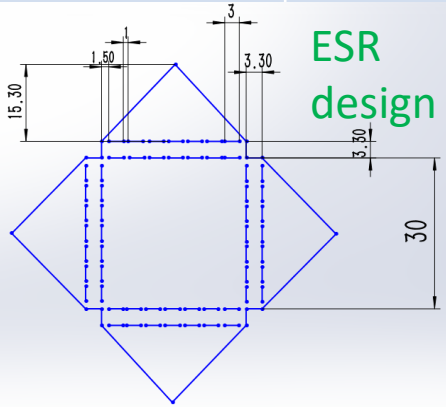
Chinese injection scintillator

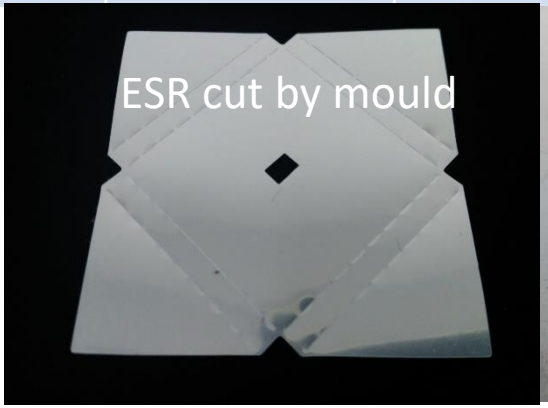


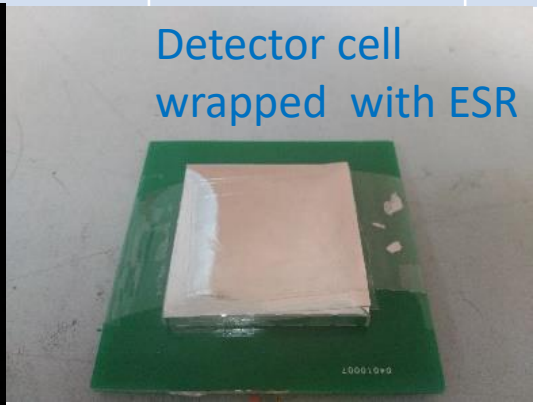
- Made by Injection molding (custom-made and 8 iterations of recipe testing)
- Without polished, smooth
- Dimension deviation below 50um from each other (30 tiles)
- Light yield winthin 10% deviation



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 yield(p.e.)	23.5	22.78	22.86	25.02	23.54



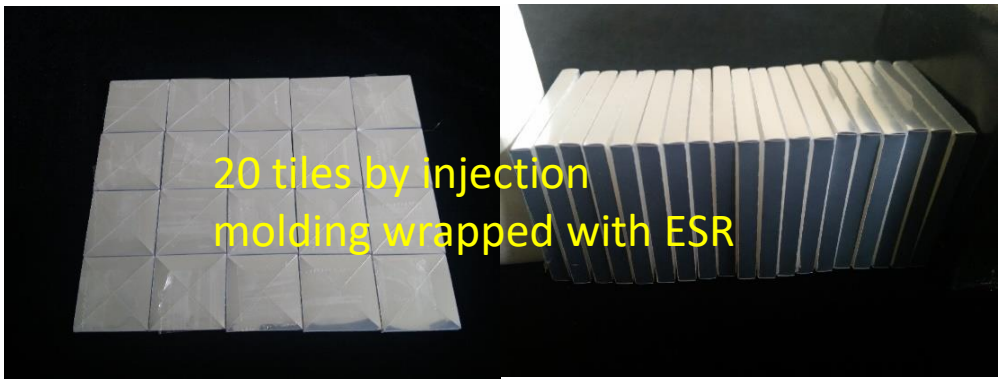




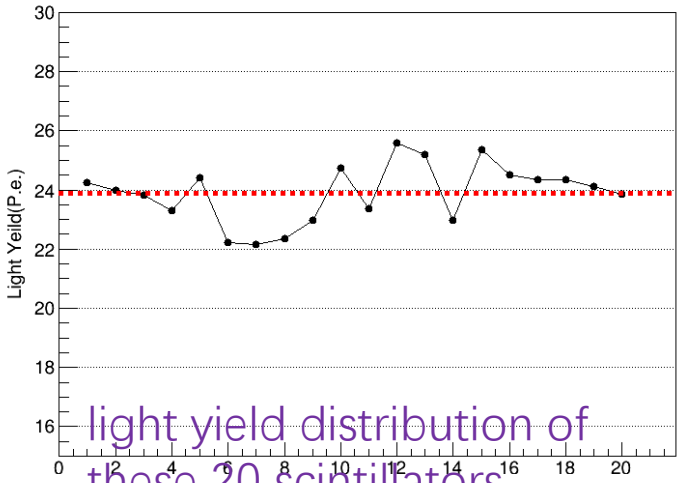
The effect of ESR cut by mould is good and it has few gap, ESR and detector cell can be wrapped compactly.

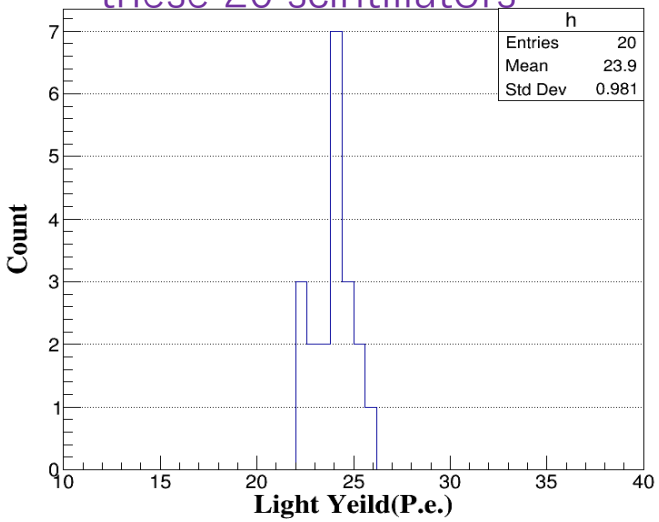
uniformity of Chinese scintillator

Light yield measurement with different scintillator and ESR films



Scintillator	1	2	3	4	5
Light yield(p.e.)	24.25	23.97	23.82	23.29	24.23
Scintillator	6	7	8	9	10
Light yield(p.e.)	22.22	22.17	22.34	22.98	24.73
Scintillator	11	12	13	14	15
Light yield(p.e.)	23.38	25.6	25.21	22.98	25.36
Scintillator	16	17	18	19	20
Light yield(p.e.)	24.52	24.33	24.36	24.12	23.85





The deviation of response are winthin 10% from mean value.
For AHCAL detector cell could be massively produced now.

Compare with CALICE scintillator

Condition:

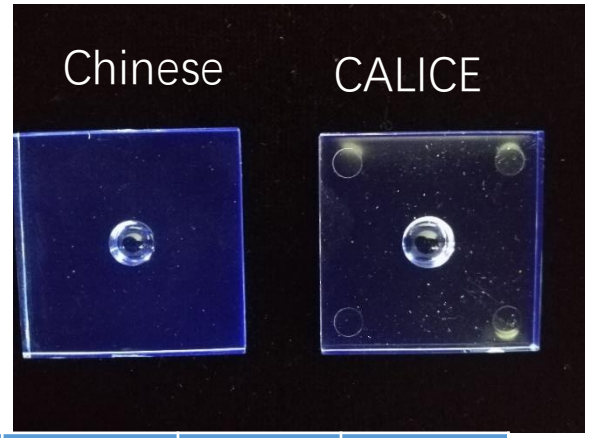
Scintillator: Two types

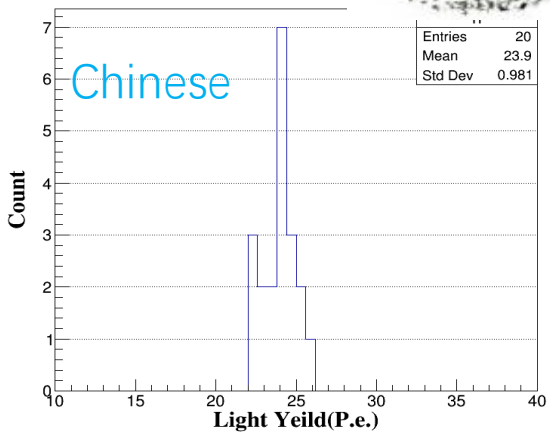
SiPM: MPPC12571-025P

Size: 30mmX30mmX3mm

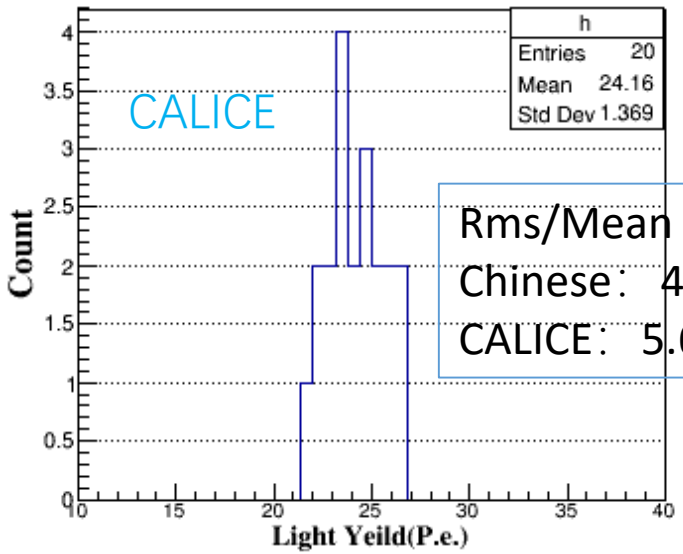
Characters:

- More flat for Chinese scintillator





Sample	1	2	3	4	5
Light output (p.e.)	22.21	23.13	25.77	25.21	23.52
Sample	6	7	8	9	10
Light output (p.e.)	21.57	23.5	23.8	24.2	22.8
Sample	11	12	13	14	15
Light output (p.e.)	26.69	23.25	22.44	25.75	25.32
Sample	16	17	18	19	20
Light output (p.e.)	26.28	24.83	24.54	23.53	24.68



Rms/Mean

Chinese: 4.1%

CALICE: 5.6%

Measurement used 20 scintillators of Chinese and CALICE with same SiPM and ESR.

Result:

- From mean value, light yield of Chinese and CALICE is 23.9p.e. and 24.1p.e. respectively.
- From value of Rms/Mean, the uniformity of Chinese Sc is better than CALICE.

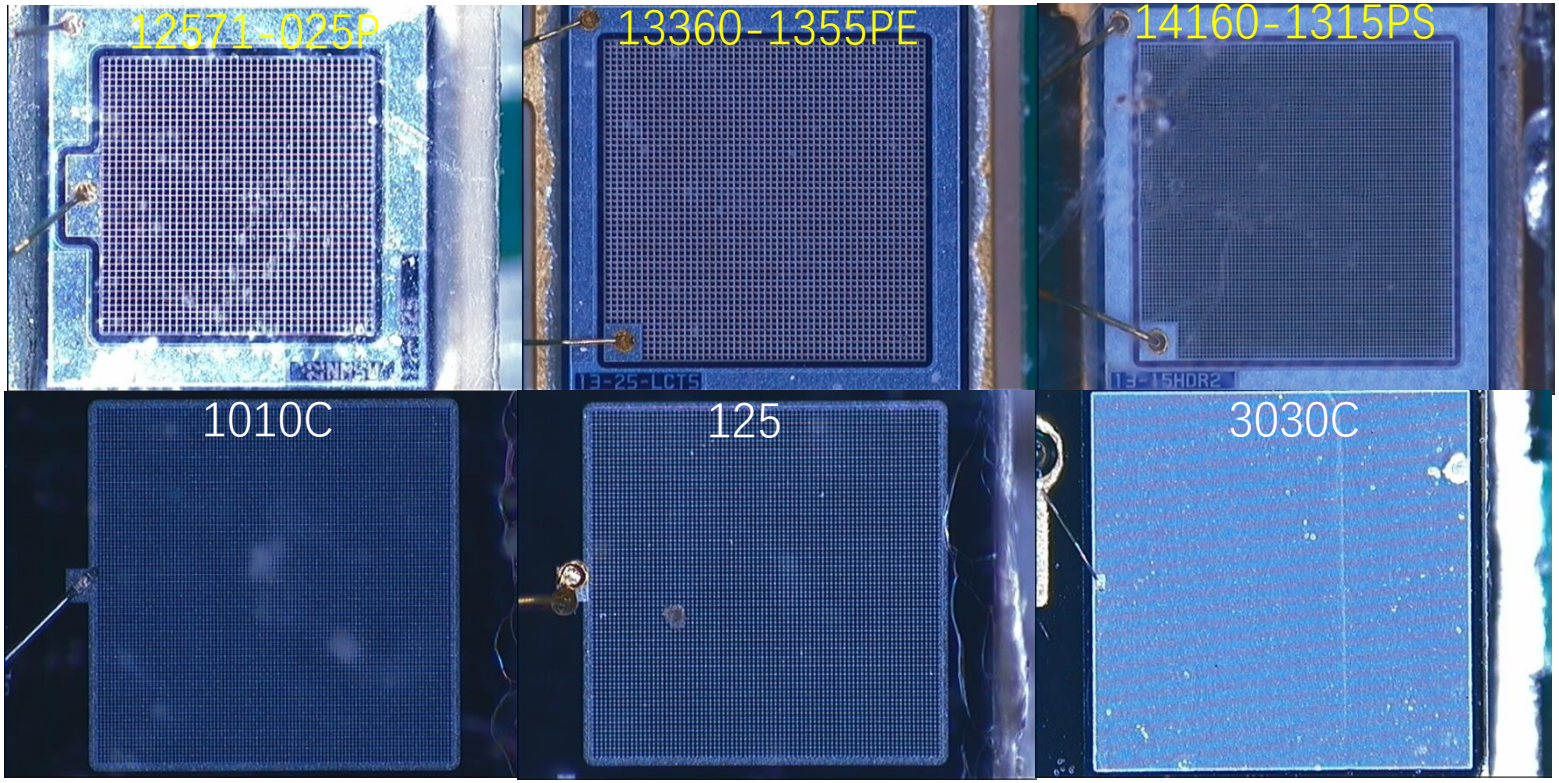
Candidate SiPMs for AHCAL

NDL-SiPM:
- High fill factor
- High gain
- Cheap
- Low breakdown

–High dark rate
–High crosstalk

MPPC-SiPM:
- Low dark rate
- Low crosstalk

–Expensive
–High breakdown



Comparison of different SiPMs

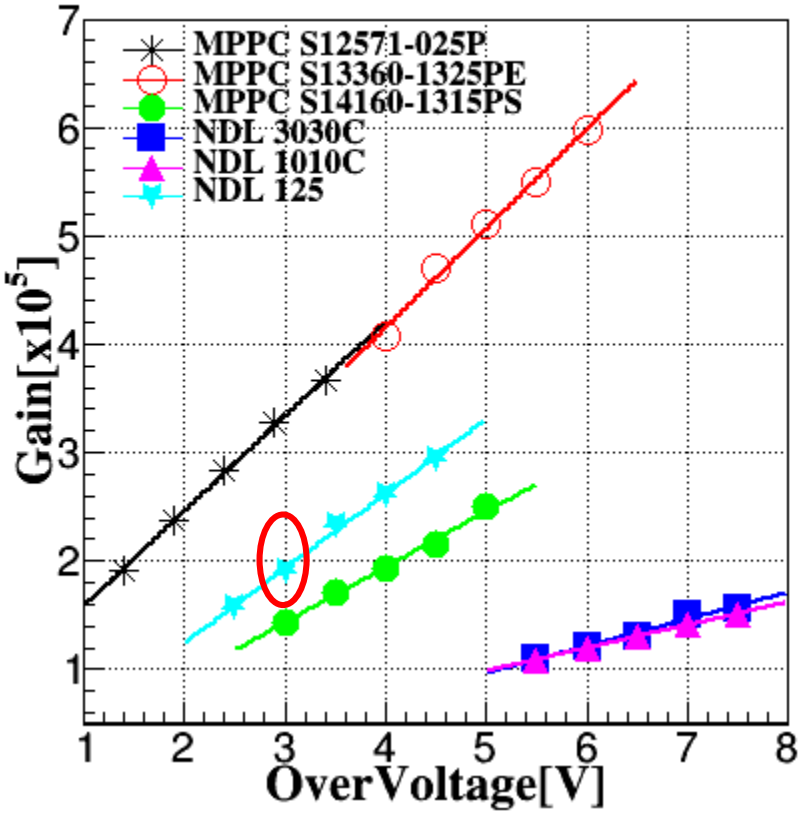
MPPC VS NDL

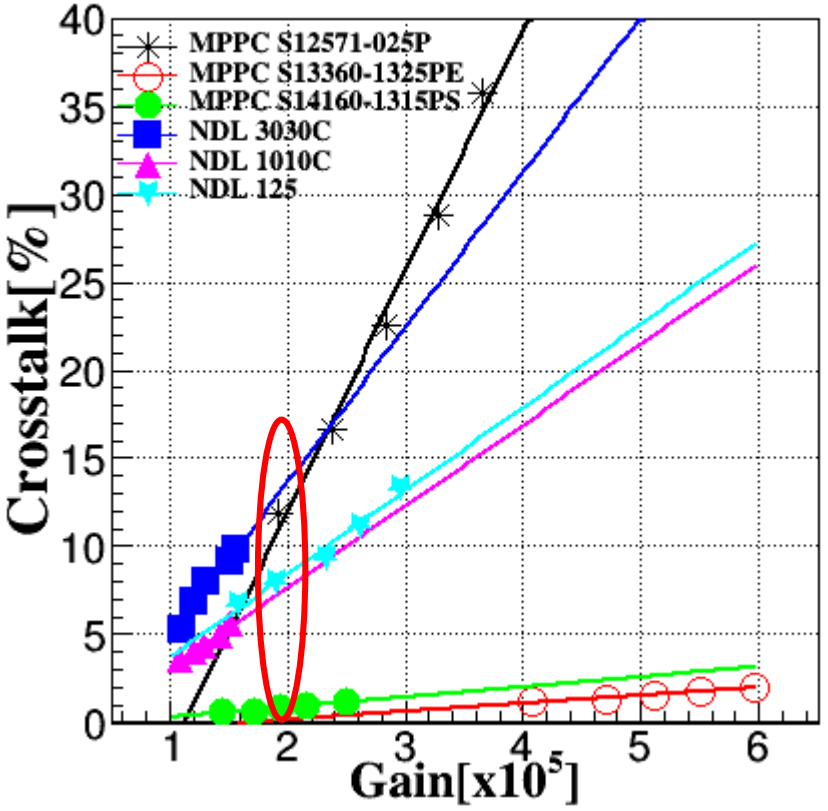
Company	MPPC			NDL		
Type	1251-025P	13360-1325PE	14160-1315PS	1010C	3030C	125
Active area[mm^2]	1	1.69	1.69	1	9	1
Pixel number	1600	2700	4400	10000	90000	6400
Breakdown[V]	65	53	38	27.5	27.5	21.5
Overvoltage[V]	3.4	4	5	6.5	6.5	3
Dark counts[kHz]	82	120	290	550	5150	470
Crosstalk[%]	22.6	1.59	1.17	4.4	8	8.1
Gain[10^5]	2.83	5.11	2.5	1.295	1.3	1.91

All parameters are measured in laboratory at room temperature.

Gain & Crosstalk of different SiPMs

MPPC VS NDL

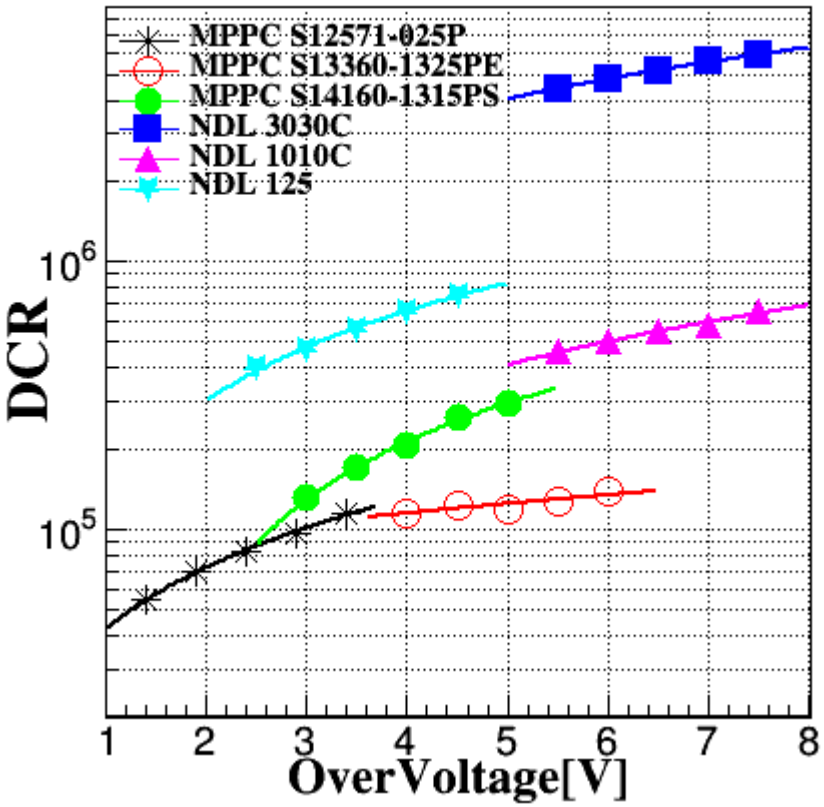


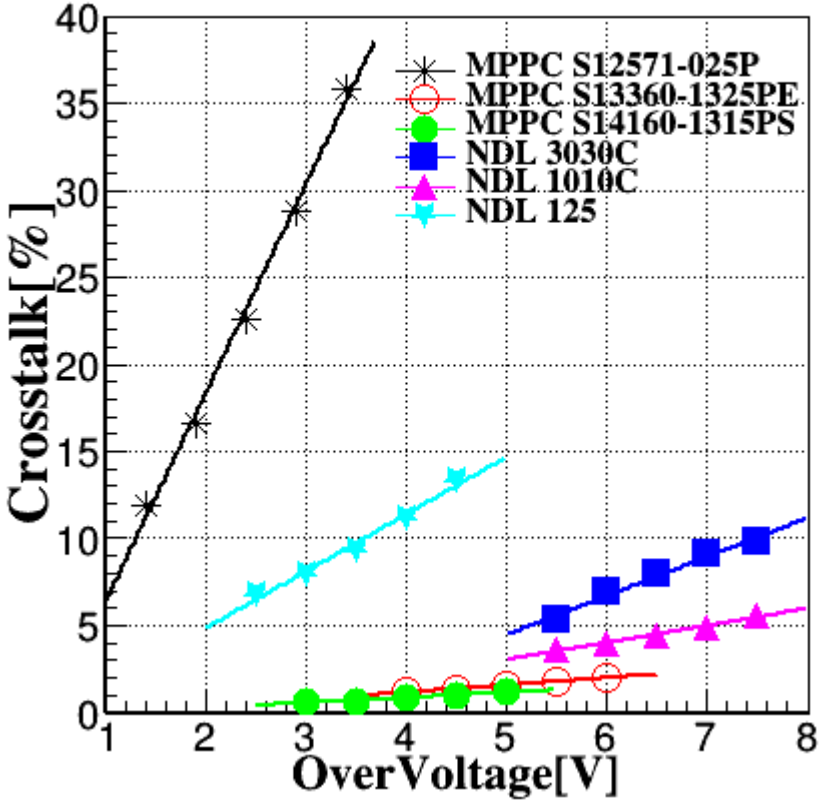


The value of gain which can be calibrated with SPIROC2E is marked on red circle.

DCR & Crosstalk of different SiPMs

MPPC VS NDL





- SiPMs from MPPC with lower DCR and crosstalk characteristics, except type 12571-025P.
- Type 13360-1325PE is a better one for CEPC-AHCAL detector cell.

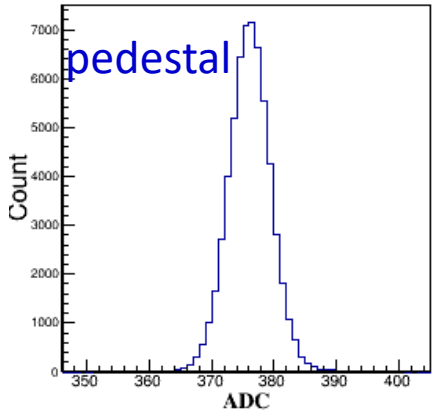
Calibrated by SPIROC2E

SPIROC2E

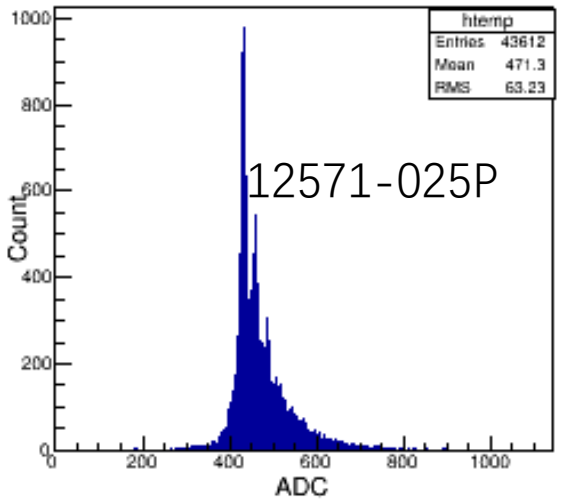
(SiPM Integrated Read Out Chip)

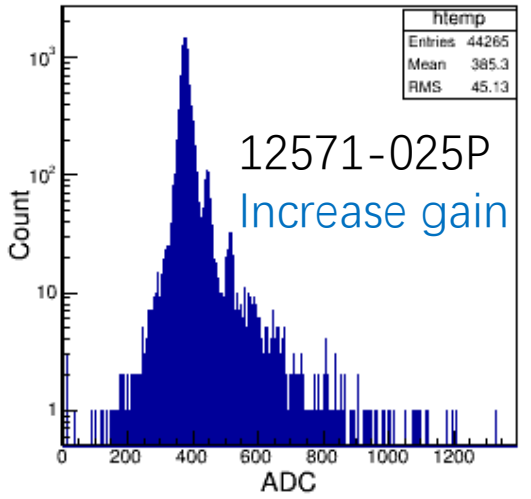
Electronics of AHCAL at present

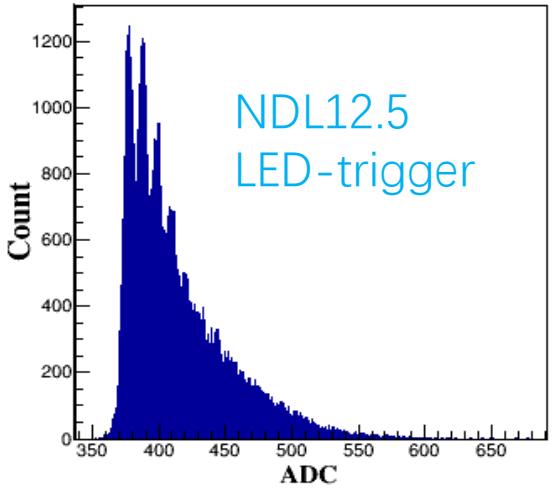
Selftrigger: For MPPC type 12571-025P and NDL-125, different gain of SPIROC2E can be distinguish photon peaks clearly based on multiphoton spectrum.

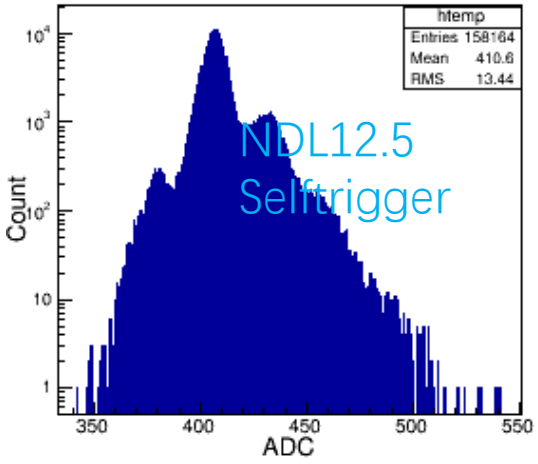


- Thus NDL SiPM can work for SPIROC2E。

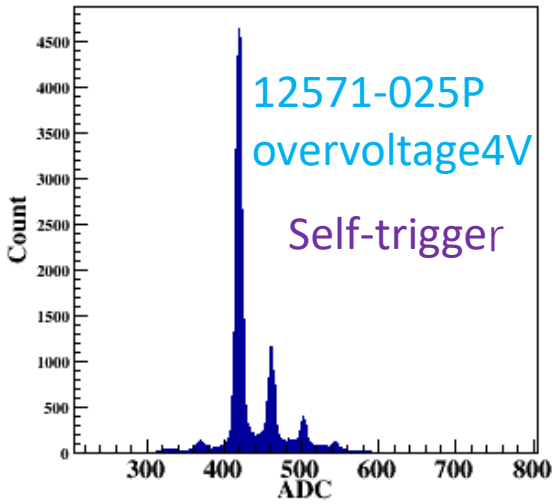


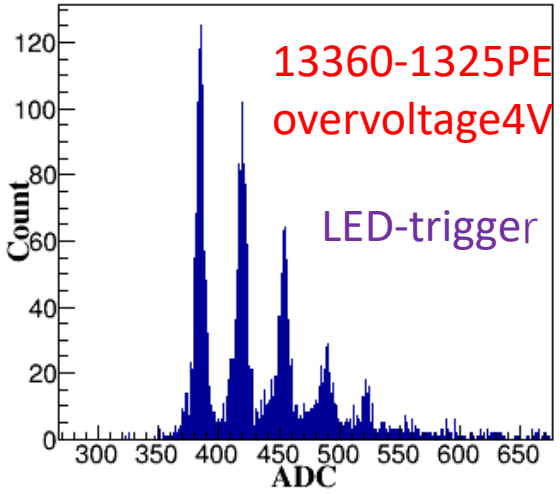


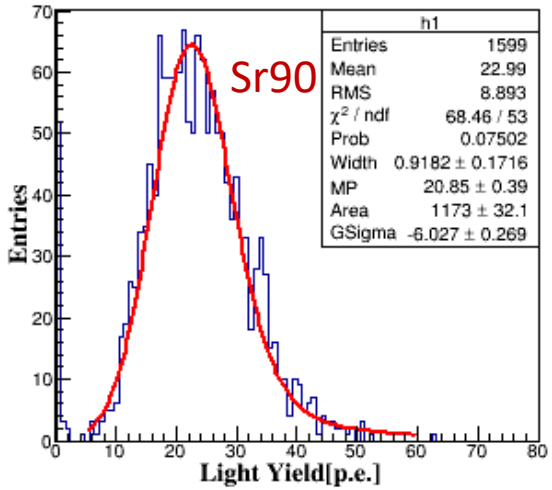


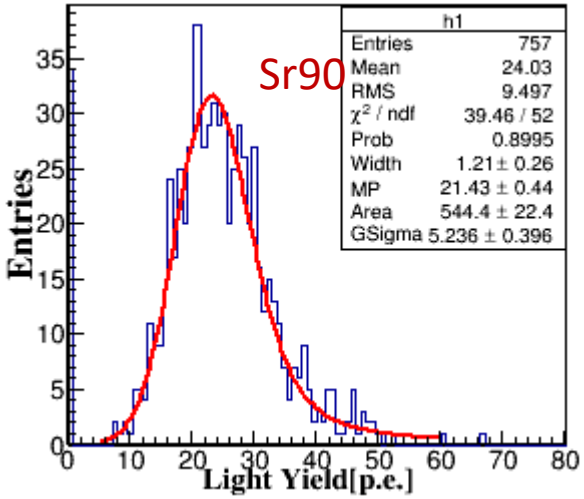


Light yield measurement with SPIROC2E(Sr90)









- The photon peaks can be separated well for both these two types of MPPC.
- It is not much different for light yield with SPIROC2E or MPPC electronics.

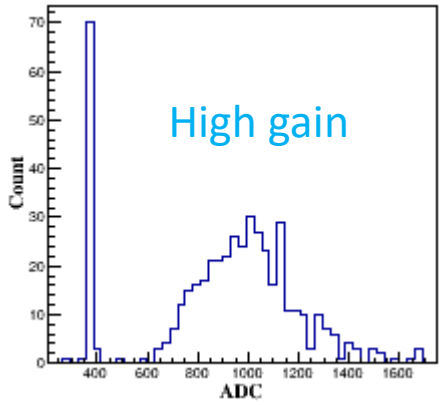
Response of Sr90

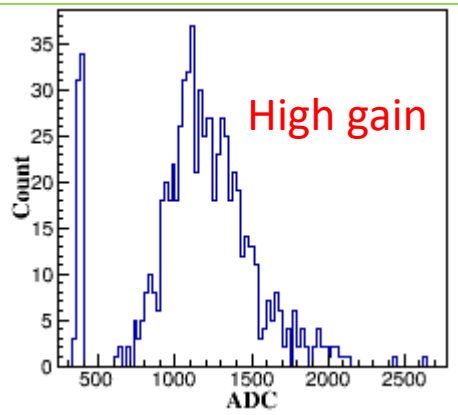
12571-025P overvoltage4V

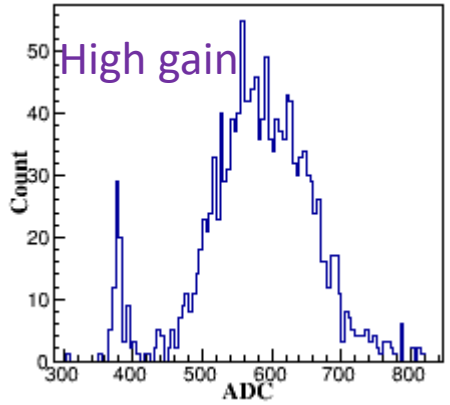
13360-1325PE overvoltage4V

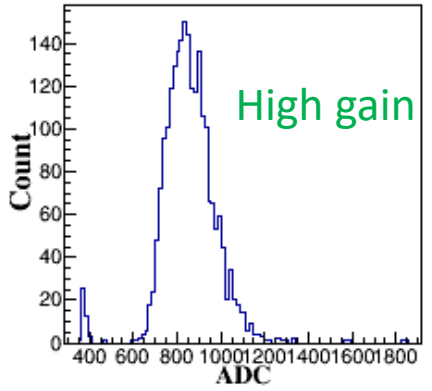
NDL-125 overvoltage4V

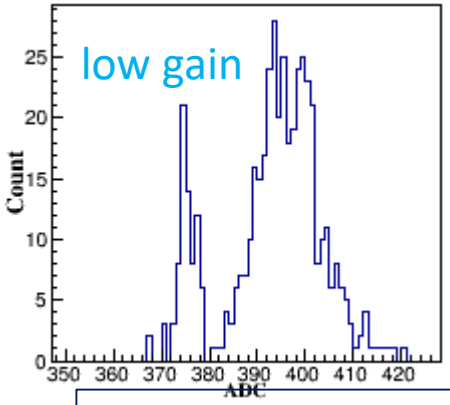
NDL-3030 overvoltage6V

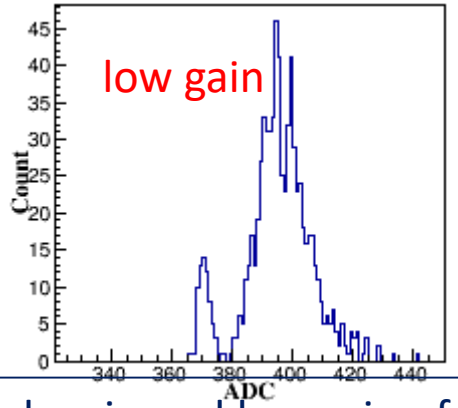


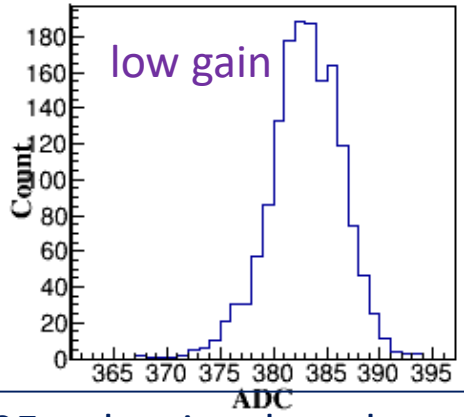


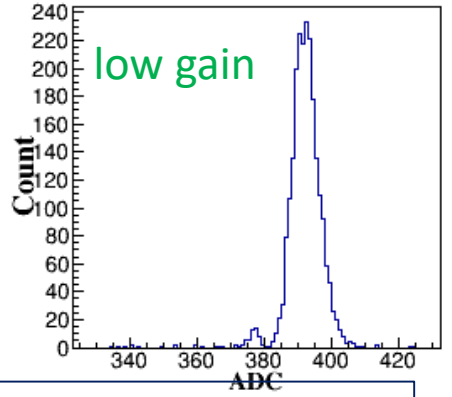










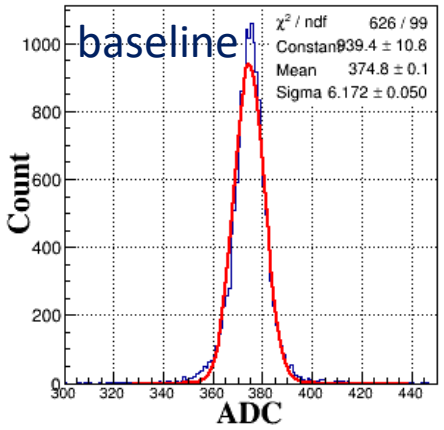


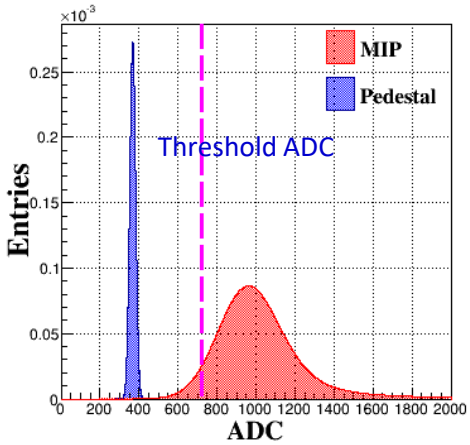
- For two mode high gain and low gain of 2E， the signal can be separated well from pedestal showed on last slide.
- NDL-125 can work at high gain mode. However, MIP signal can be separated at low gain mode. NDL-3030C can work well at high overvoltage.

Pedestal Comparison

MPPC VS NDL

Electronic: SPIROC2E





Type	pedestal	MIP	Threshold ADC
MPPC 12571-025P	$8.90e^{-16}$	95%	722.18
MPPC 13360-1325PE	$7.15e^{-16}$	95%	843.75
MPPC 14160-1315PS	$7.49e^{-16}$	95%	417.04
NDL 1010C	$3.61e^{-13}$	95%	389.52
NDL 125	$8.37e^{-16}$	95%	396.84
NDL 3030C	$3.81e^{-16}$	95%	447.72

For different SiPMs

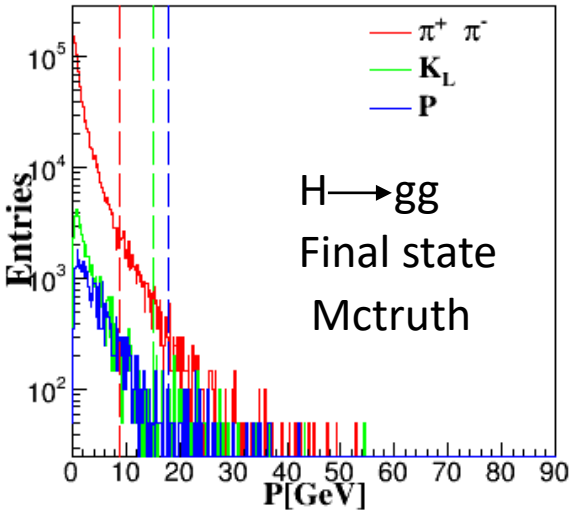
- the pedestal width would be different.
- Signal could be separated well at external mode of electronics.

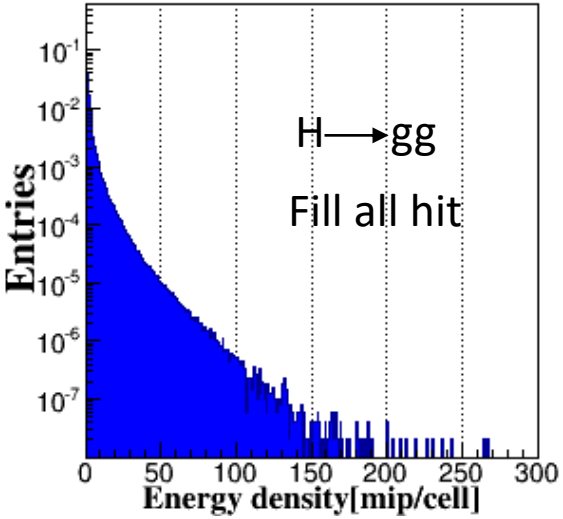
→

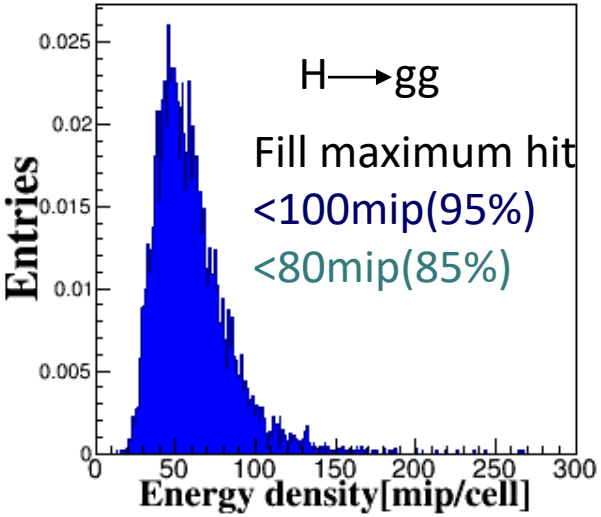
- Dark noisy.
- Capacity.

Dynamic requirement of SiPM

Distribution of Final State particles decayed from H⟶gg







- Momentum of More than 95% particles are below 20GeV.
- More than 99% of energy density is less than 25MIP in all AHCAL hits.

MIP response of different SiPMs

MPPC VS NDL

Electronic: SPIROC2E

Company	MPPC			NDL		
Type	1251-025P	13360-1325PE	14160-1315PS	1010C	3030C	125
Pedestal Width[ADC]	6.172	3.997	13.51	3.718	5.596	3.61
Pedestal Width[fC]	294	191	643	177	266	172
Overvoltage[V]	3.4	4	5	6.5	6.5	3
MIP [ADC]	542	719	395	107	450	135
S/N	87.9	179.9	29.3	28.8	80.5	37.4
Linear range[MIP]	26	40	61	200	200	118

- All type of SiPMs can satisfy the dynamic range requirement of AHCAL
- Type 13360-1325PE can be acquired a better MIP signal from S/N.

High gain1 PC~210ADC
S/N=MIP/peddstal

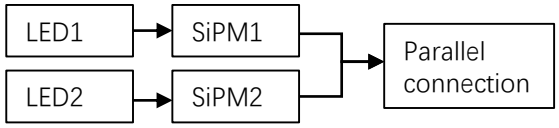
Parallel connection of detector cell

Reduce the channel number

LED trigger

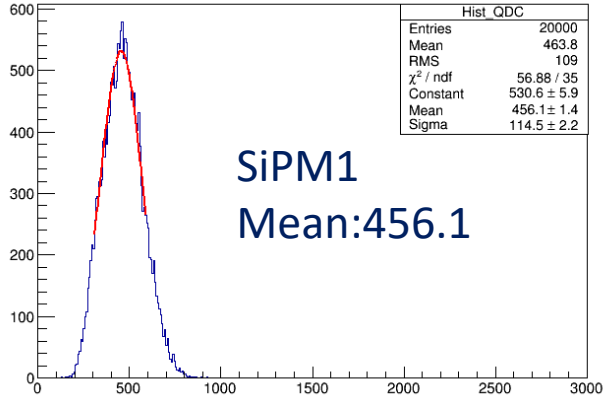
quickly judge the measurement systems

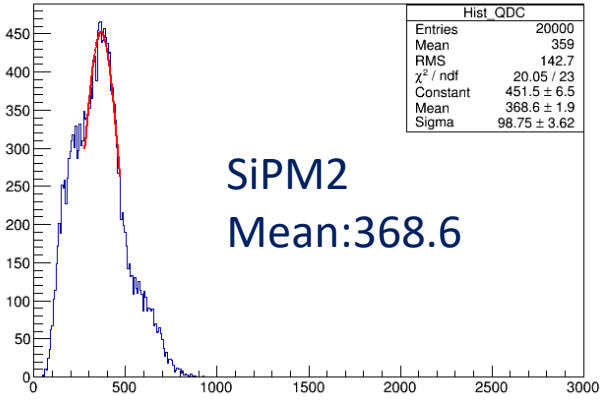
Schematic

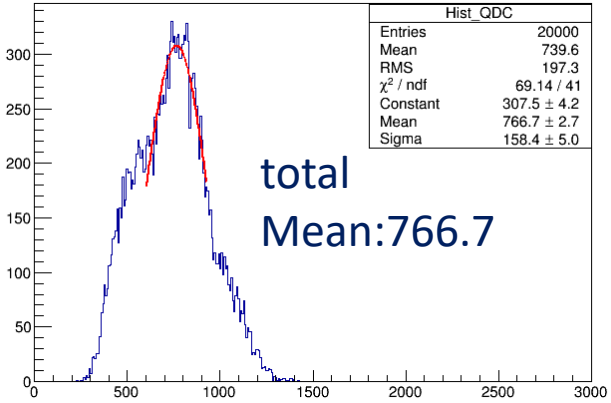


- Change the light intensity of LED

SiPM1(ADC)	625.9	979.7	703.6	456.1
SiPM2(ADC)	169.4	259.3	392.1	368.6
SiPM mergence(ADC)	714.8	1180	1007	766.7



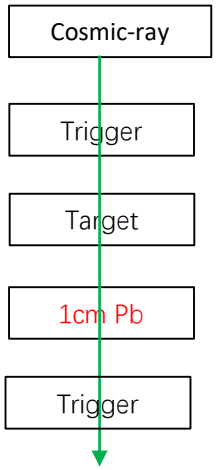


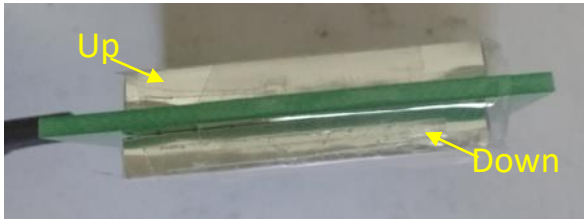


- Change the condition of LED， the signal of merging SiPM is the sum of single SiPM.
- The measurement system can work normally without scintillator.

Measurement of merging detector cell

Schematic

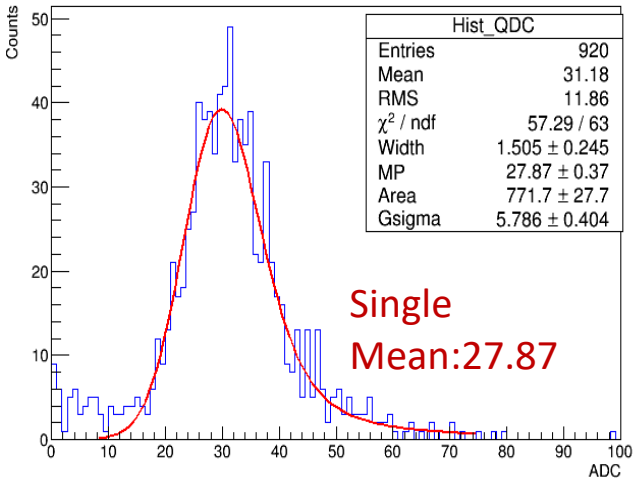


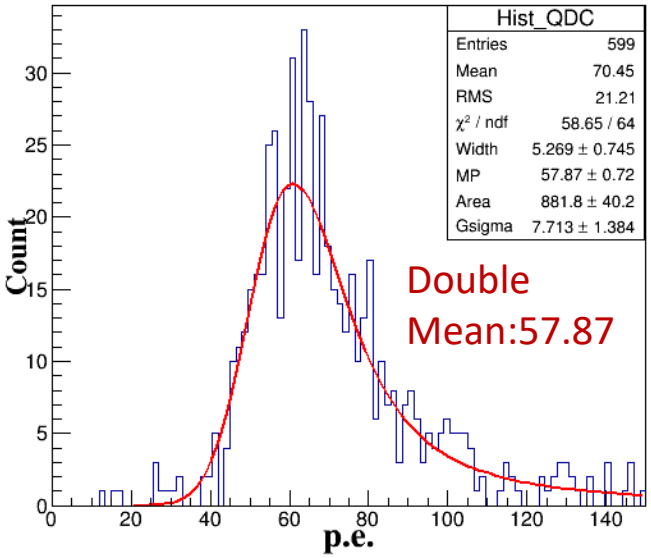


Most of gamma radiation can be shielded by 1cm thickness Pb.

$$I = I_0 e^{-\sigma_r N x} = I_0 e^{-\mu x}$$

能　量/MeV	衰减系数	
	钨[a]	铅
0.1	64.8	60.4
0.2	11.5	10.6
0.5	2.14	1.70
1.0	1.08	0.77
1.25	0.929	0.598



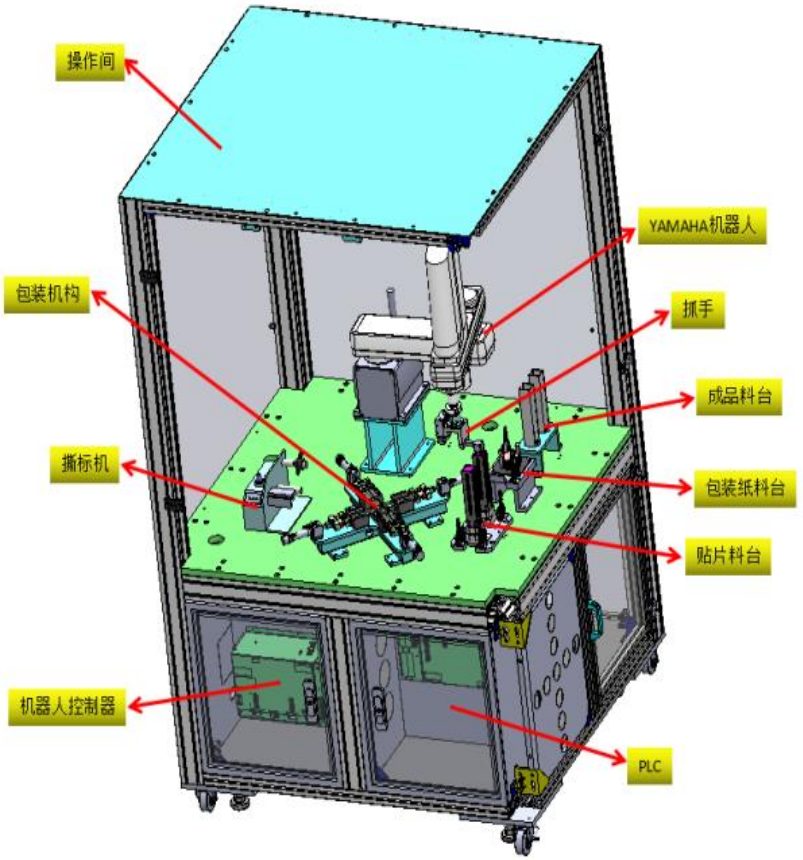


- The signal of merging SiPM is near 2 times compared with single SiPM after shielding most of gamma radiation. It is consistent with theory.

Detector cell Automatic assemble system

—Motivation:

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



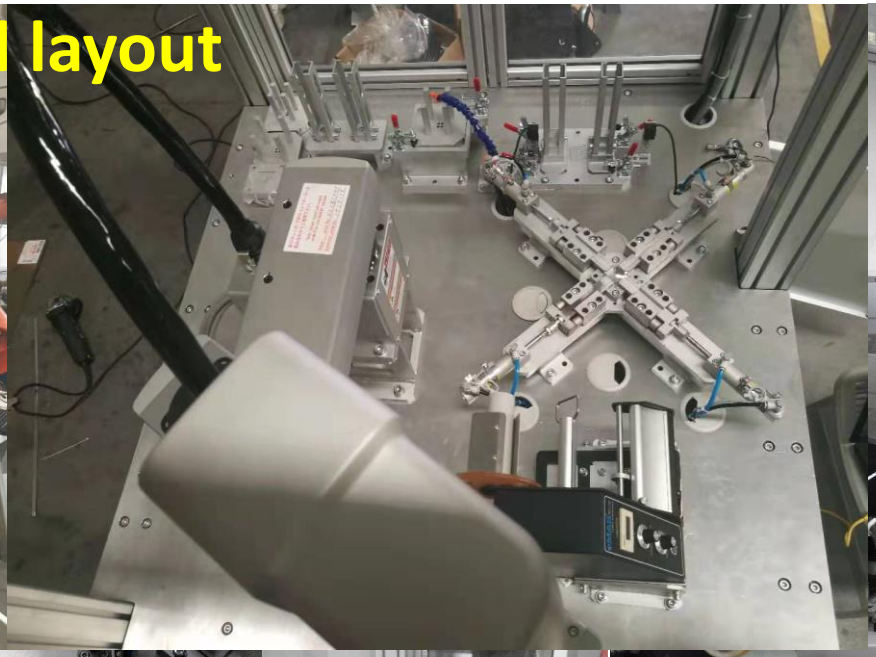
—Progress

- Companies give their preliminary design;
- Robotic arm design is a novel way;

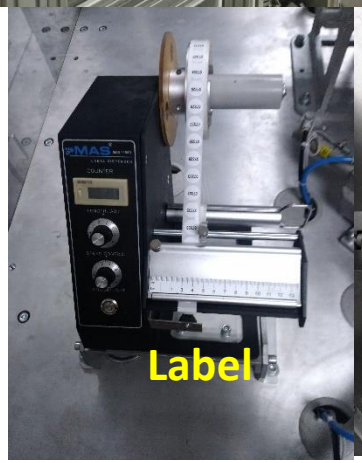
It can be used for 2cm*2cm, 3cm*3cm and 4cm*4cm detector cell;

Automatic packing machine

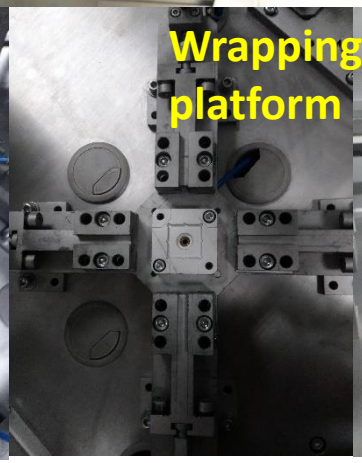
Overall layout



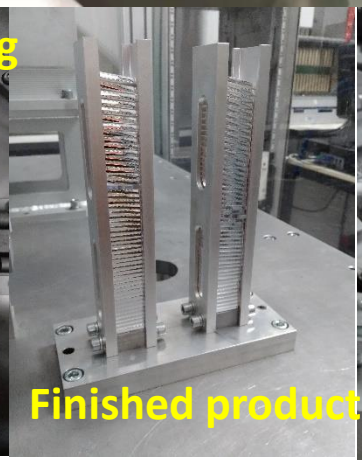
Robot arm



Label



Wrapping platform



Finished product

ESR Films

Scintillator

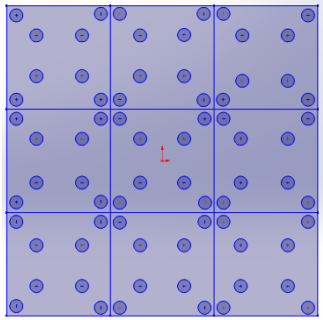
Detector cell gluing experiment

motivation：

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

Materials：

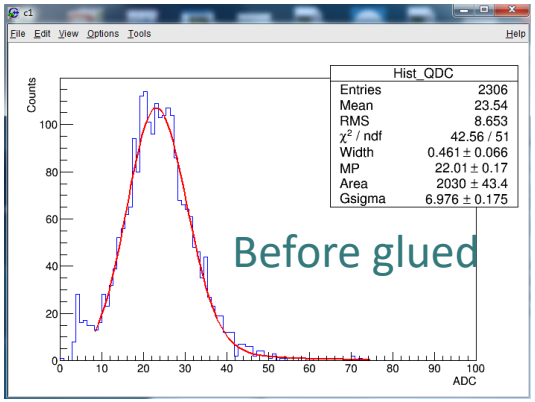
1. Araldite 2011 epoxy glue
2. 3×3 PCB board
3. Detector cell;
4. A film used to brush glue

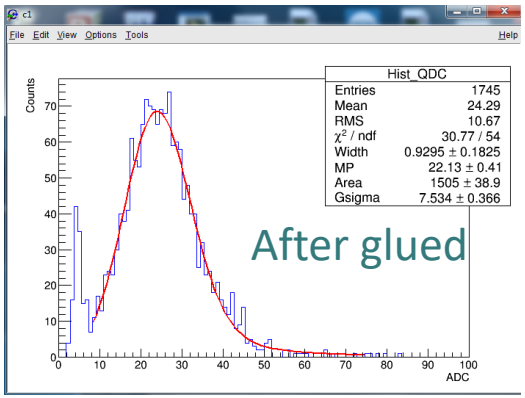


Result:

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

Light output





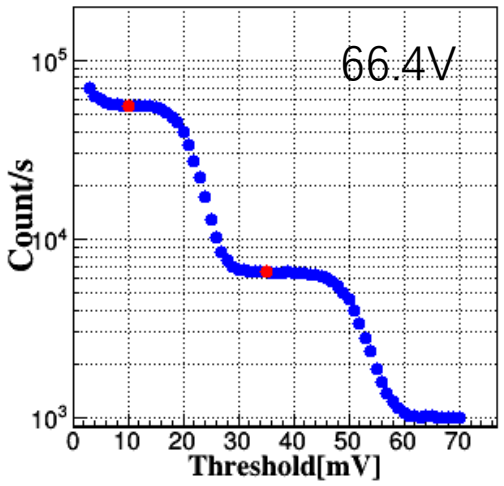
Summary

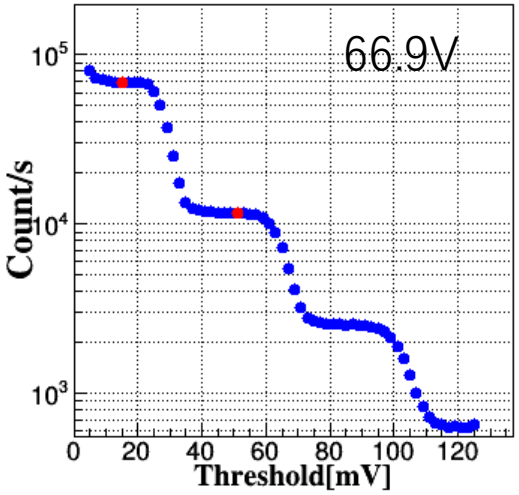
- 30mmx30mmx3mm detector cell of AHCAL could work well and could be massively produced later.
- Candidate SiPMs of AHCAL could satisfy dynamic range requirement, good S/N from MIP spectrum at external mode of electronics.
- The feasibility of detector cells with parallel connection read-out and scheme about massively gluing on PCB of tiles.
- Optimization of 40mmx40mmx3mm detector cells is on going.

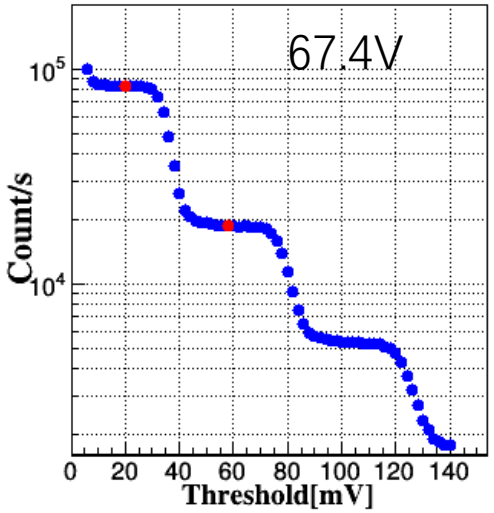
Thanks for your attention!

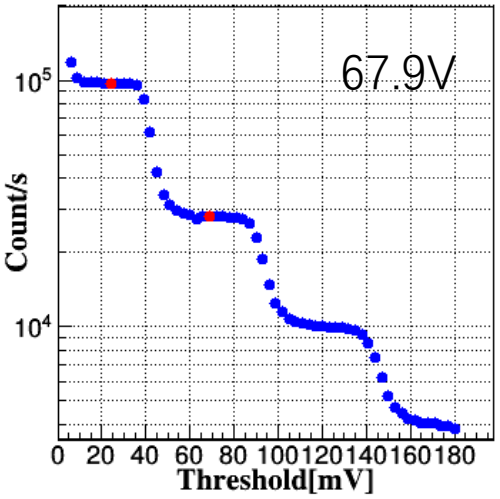
Backup

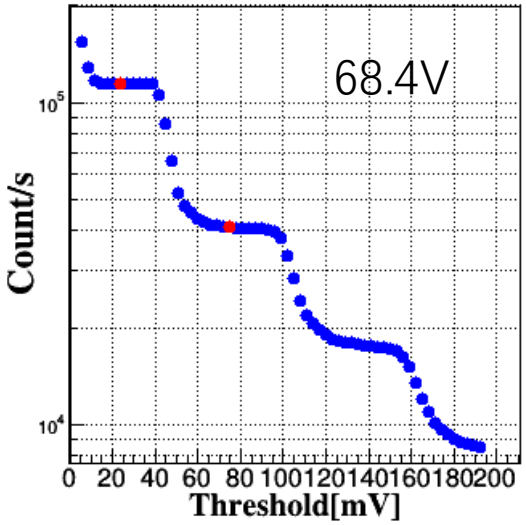
MPPC 12571-025P



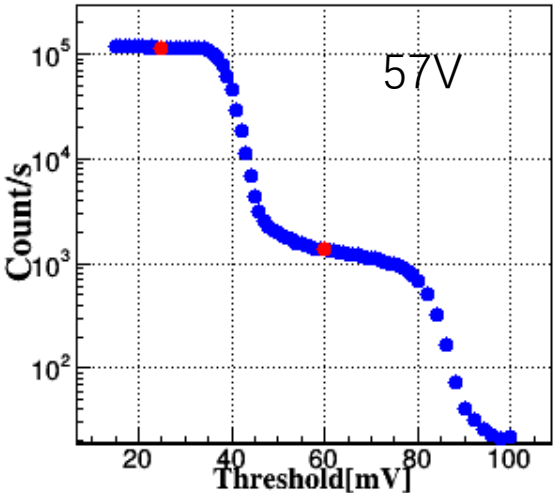


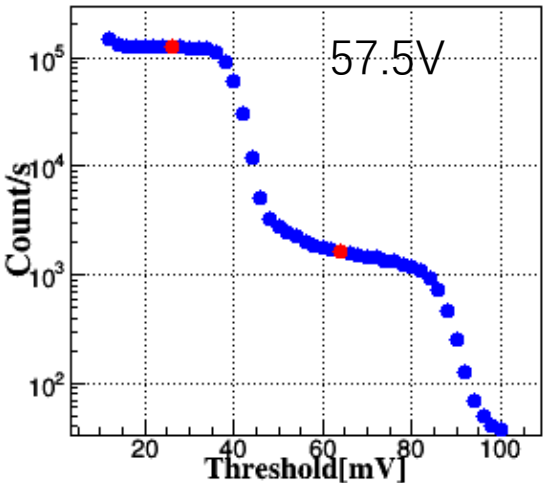


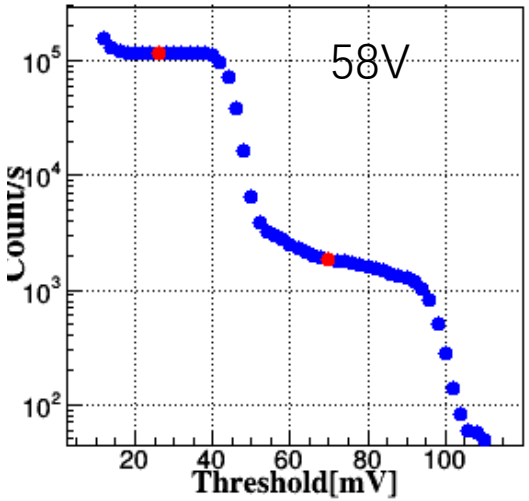


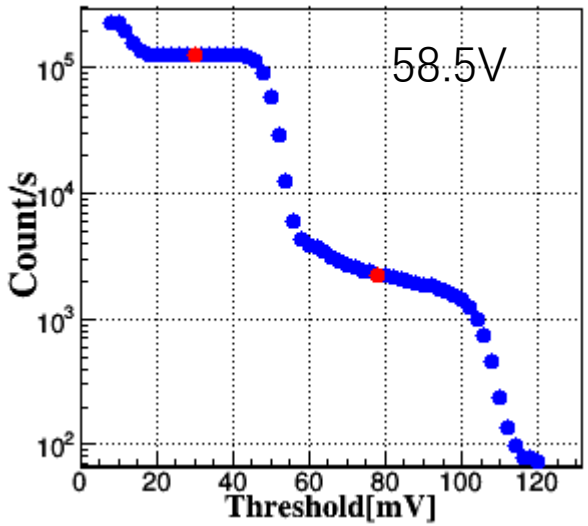


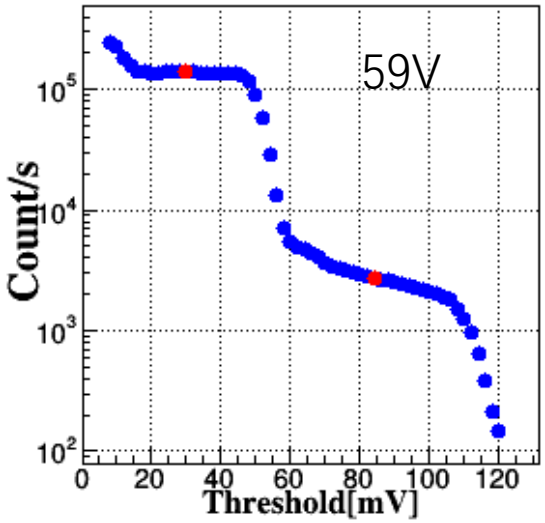
MPPC 13360-1325PE



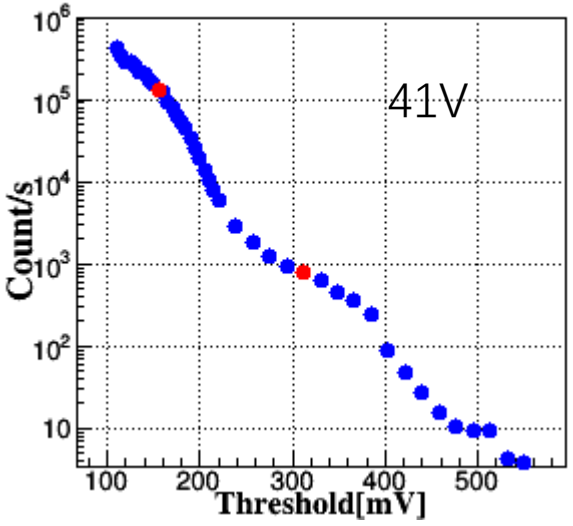


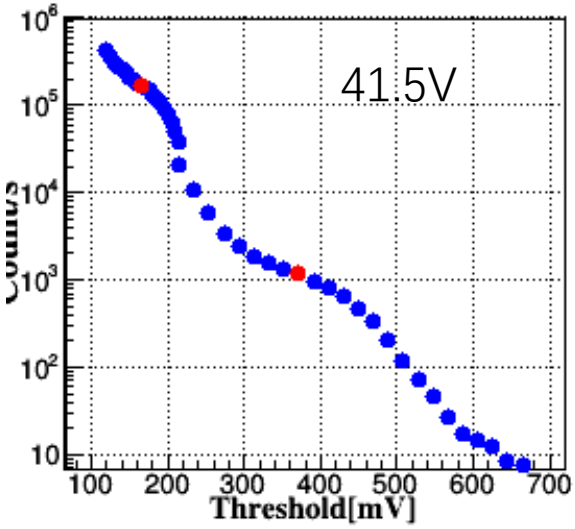


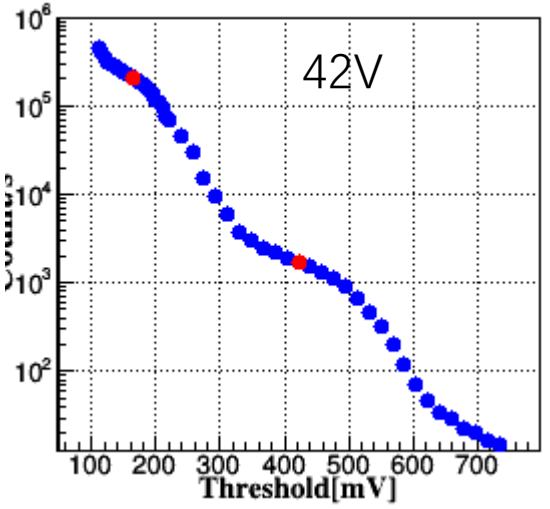


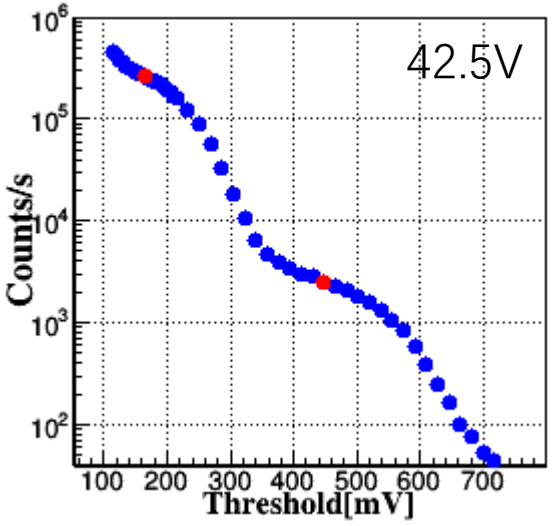


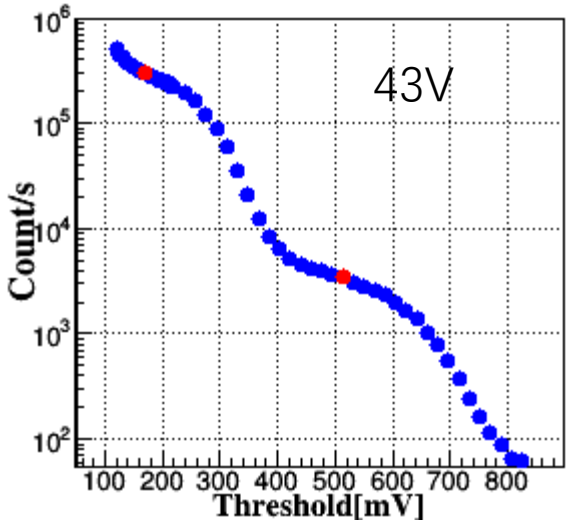
MPPC 14160-1315PS



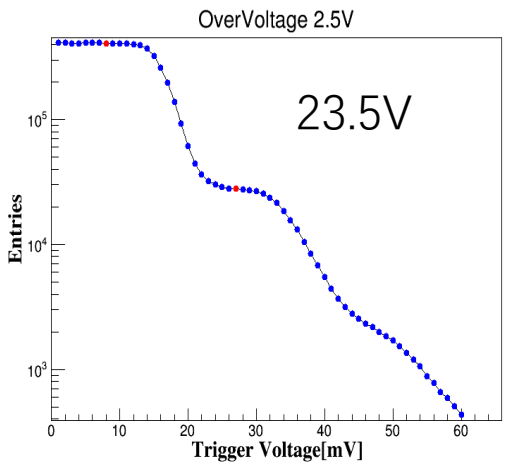


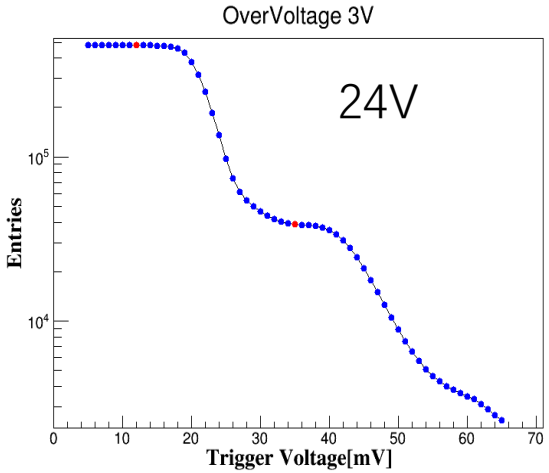


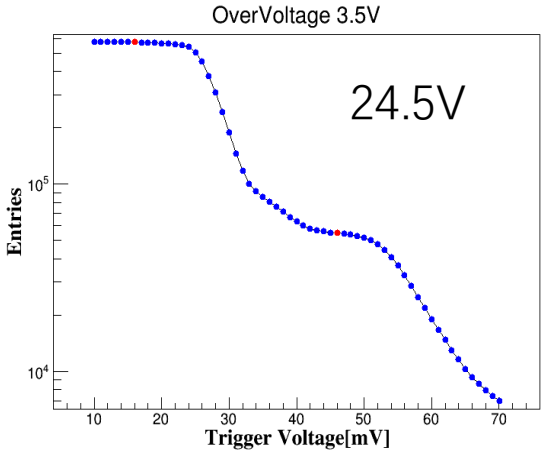


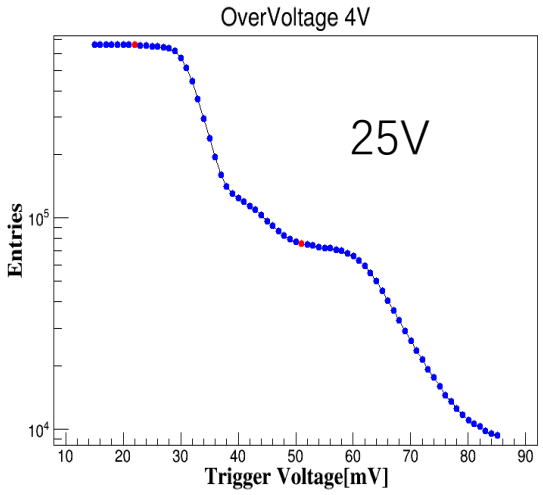


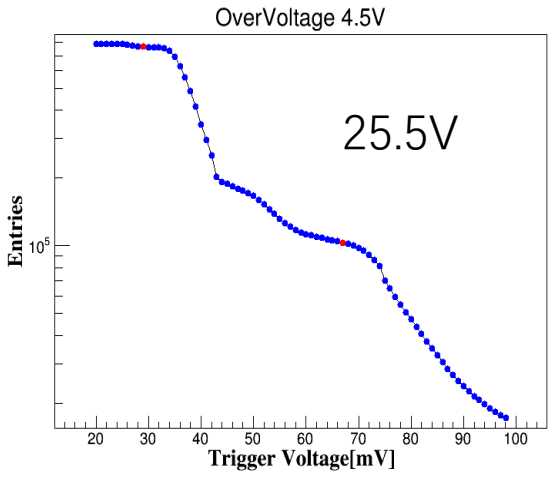
NDL 125


OverVoltage 2.5V
23.5V
Entries
Trigger Voltage[mV]

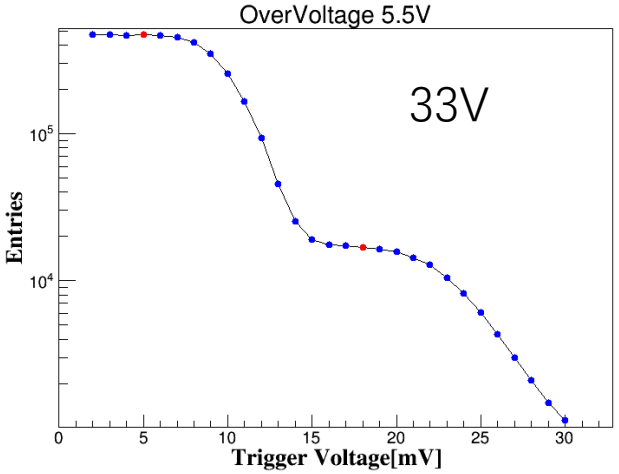

OverVoltage 3V
24V
Entries
Trigger Voltage[mV]

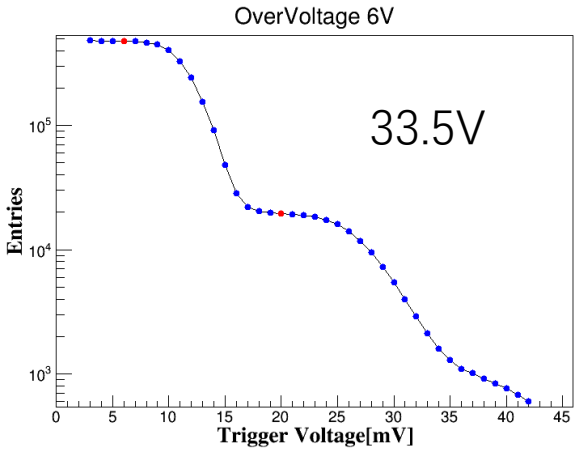

OverVoltage 3.5V
24.5V
Entries
Trigger Voltage[mV]

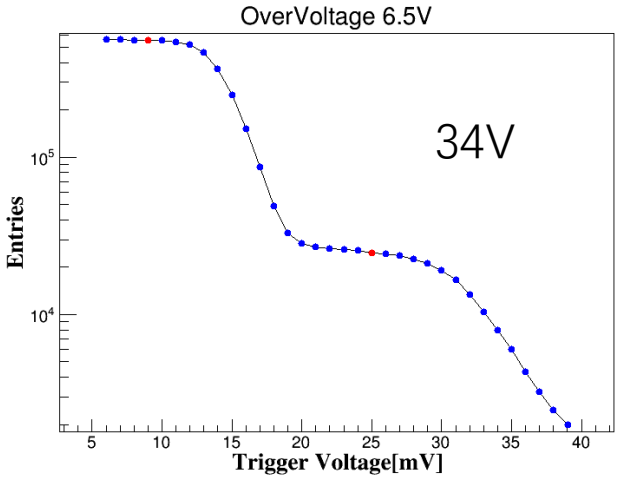

OverVoltage 4V
25V
Entries
Trigger Voltage[mV]

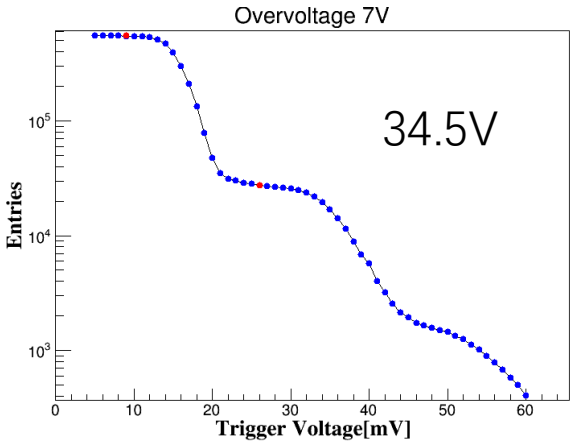

OverVoltage 4.5V
25.5V
Entries
Trigger Voltage[mV]

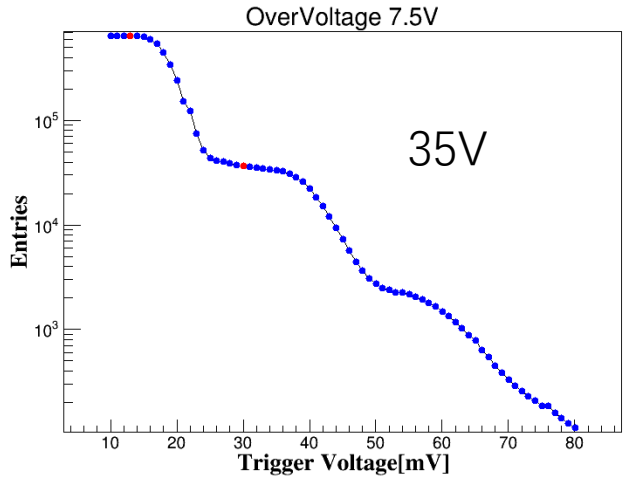
NDL 1010C


OverVoltage 5.5V
33V
Entries
Trigger Voltage[mV]

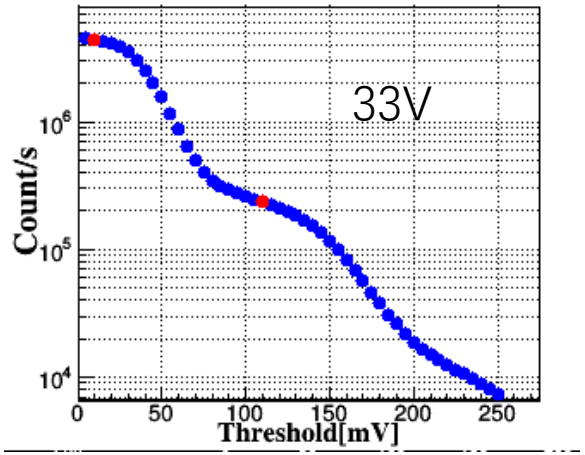

OverVoltage 6V
33.5V
Entries
Trigger Voltage[mV]

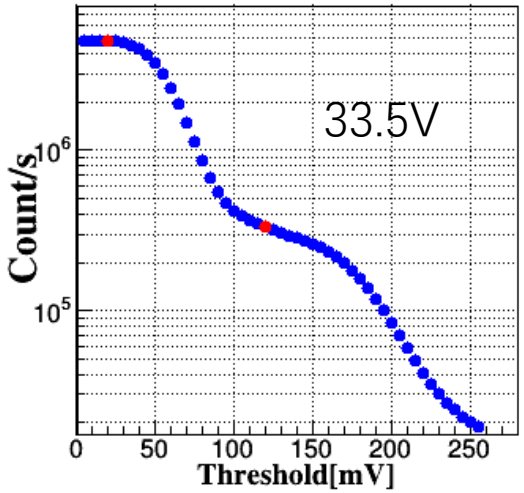

OverVoltage 6.5V
34V
Entries
Trigger Voltage[mV]

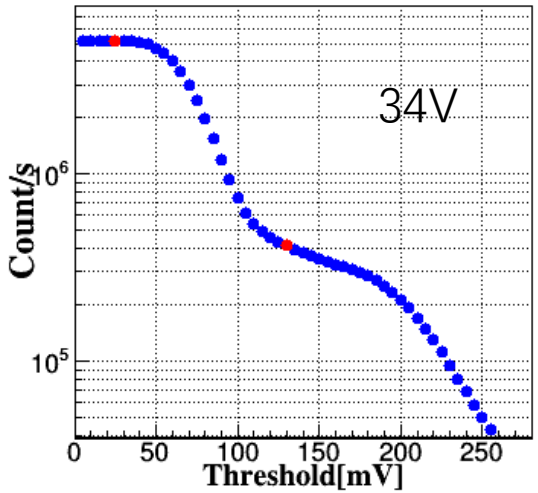

Overvoltage 7V
34.5V
Entries
Trigger Voltage[mV]

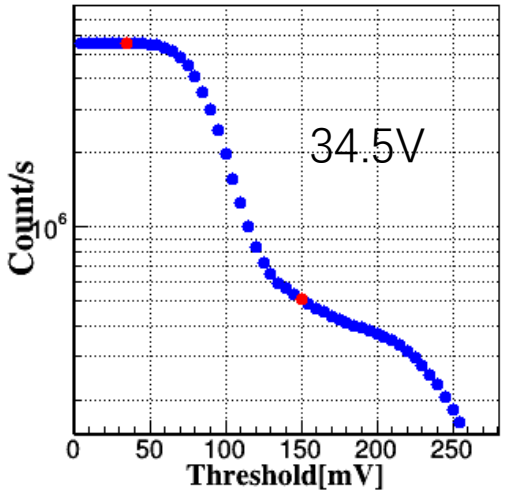

OverVoltage 7.5V
35V
Entries
Trigger Voltage[mV]

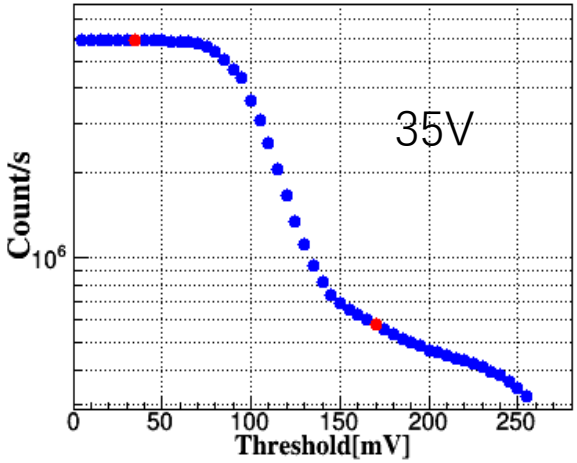
NDL 3030C


33V
Count/s
Threshold[mV]


33.5V
Count/s
Threshold[mV]

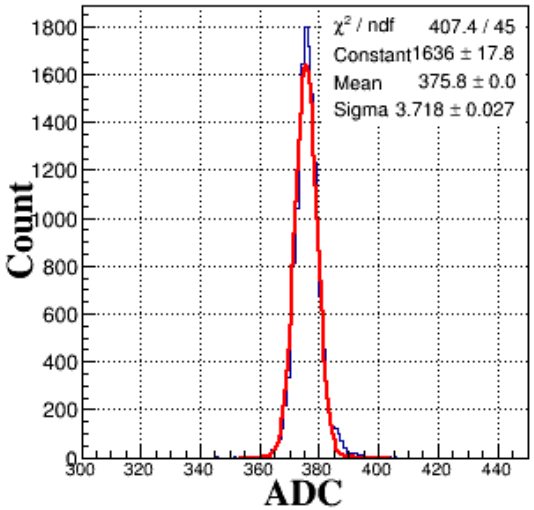

34V
Count/s
Threshold[mV]


34.5V
Count/s
Threshold[mV]

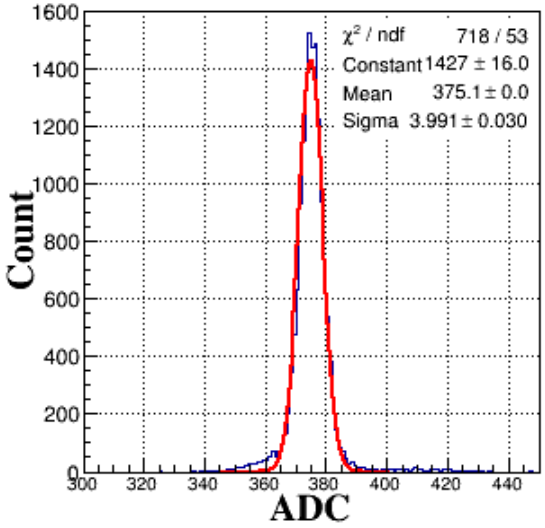

35V
Count/s
Threshold[mV]

Pedestal

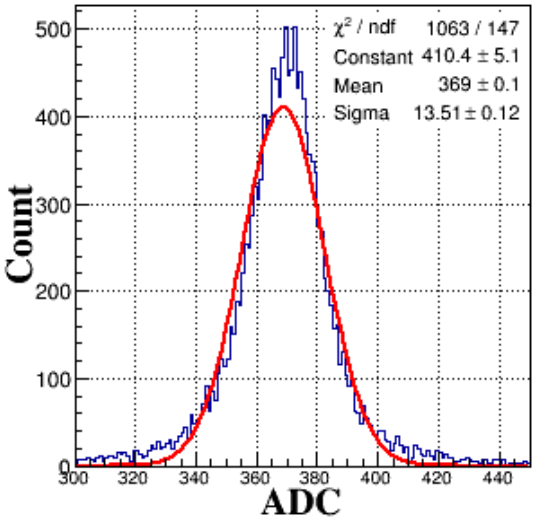
12571-025P 68.4V



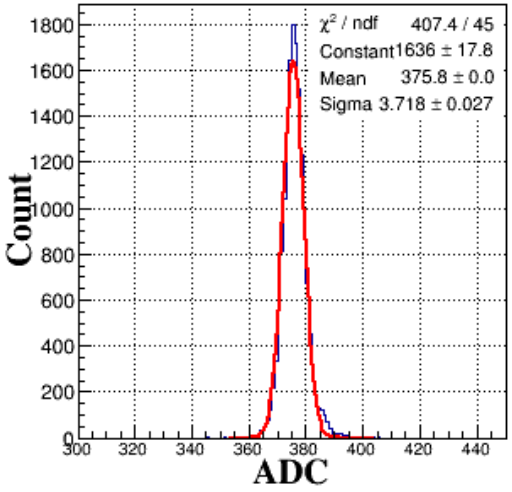
13360-1325PE 58V



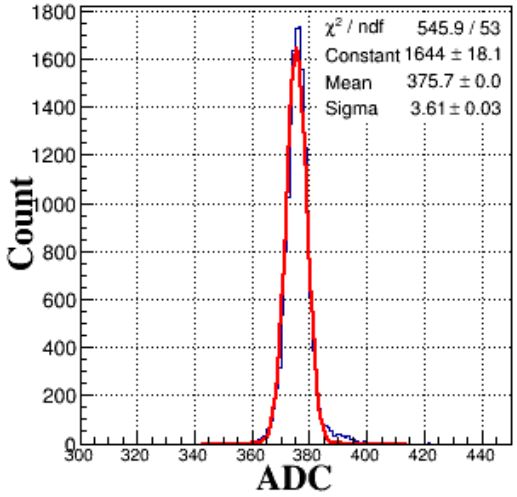
14160-1315PS 43V



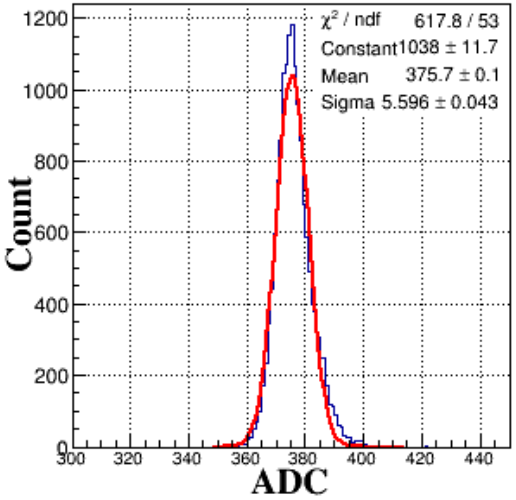
1010C 33.5V



125 24.5V

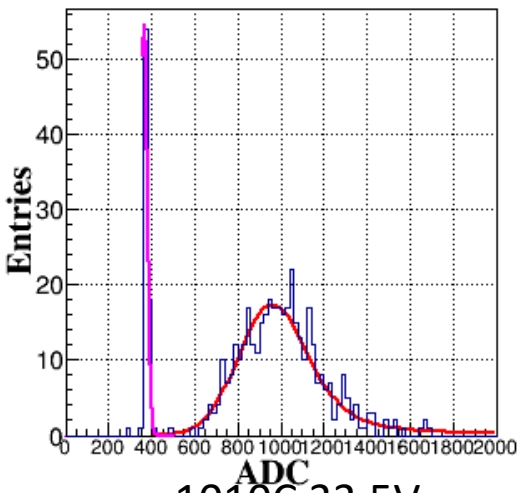


3030C 33.5V

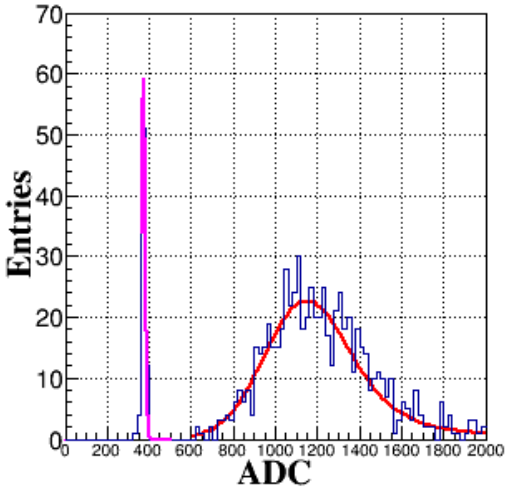


MIP Spectrum

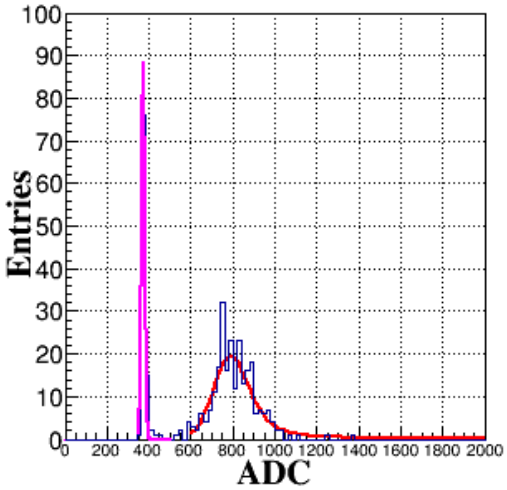
12571-025P 68.4V



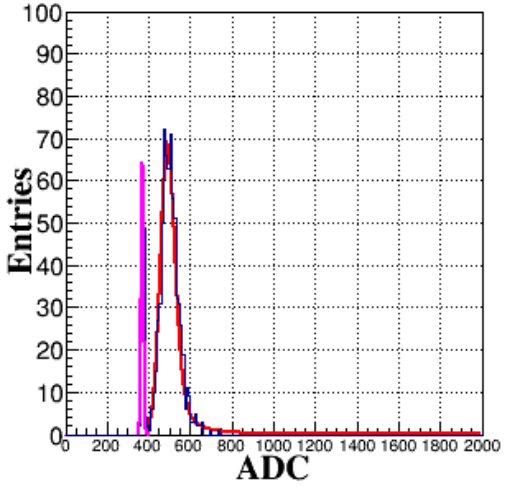
13360-1325PE 58V



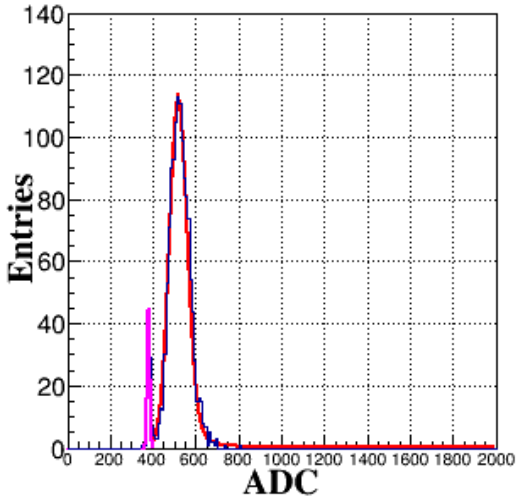
14160-1315PS 43V



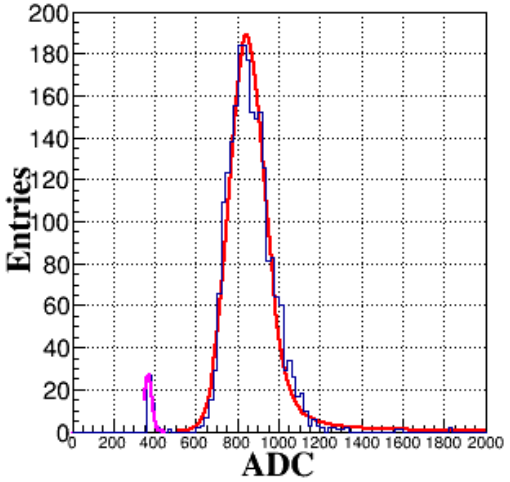
1010C 33.5V



125 24.5V

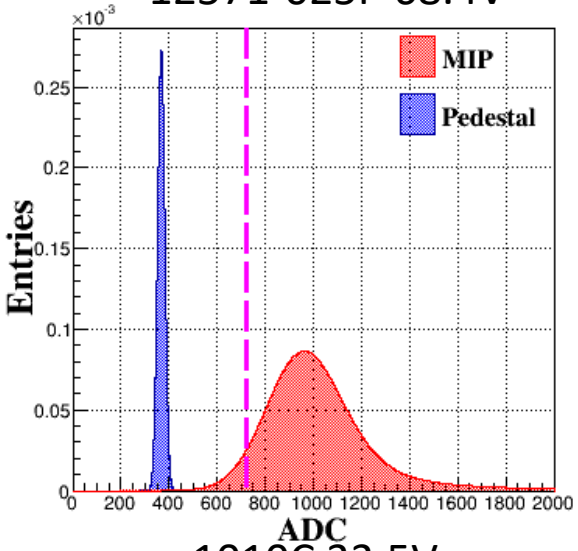


3030C 33.5V

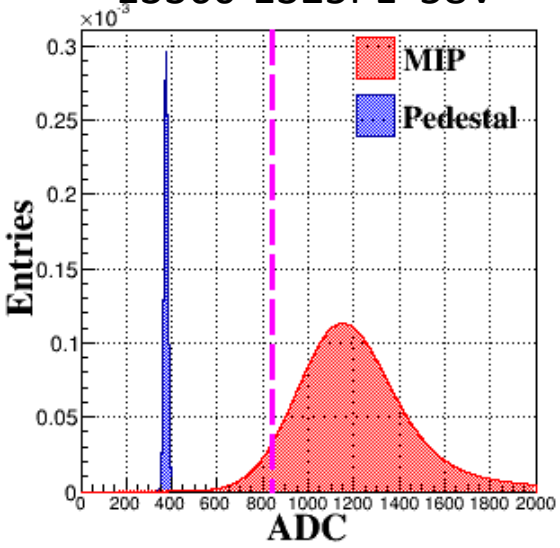


%95 Efficiency cut of MIP

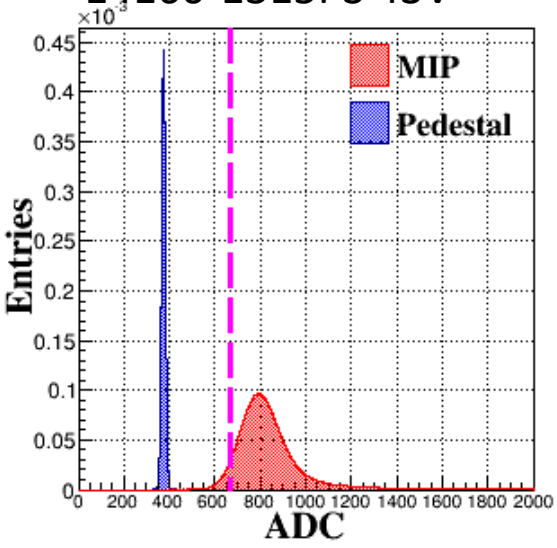
12571-025P 68.4V



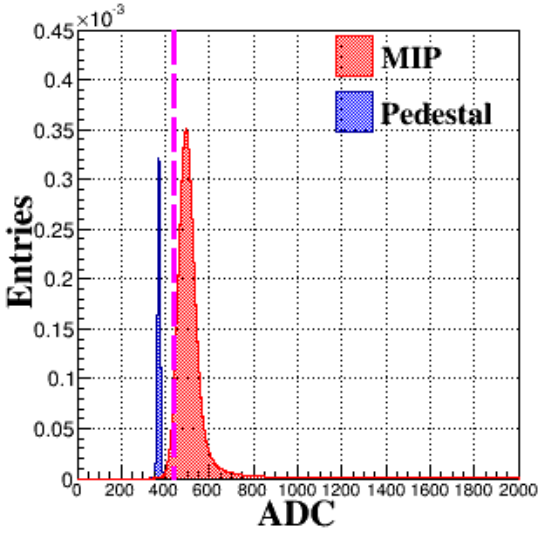
13360-1325PE 58V



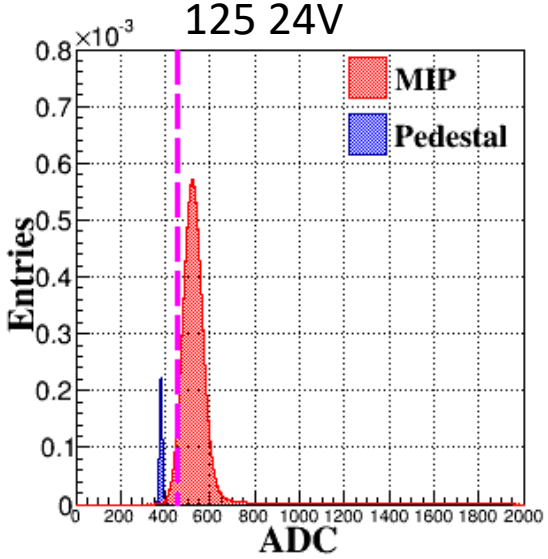
14160-1315PS 43V



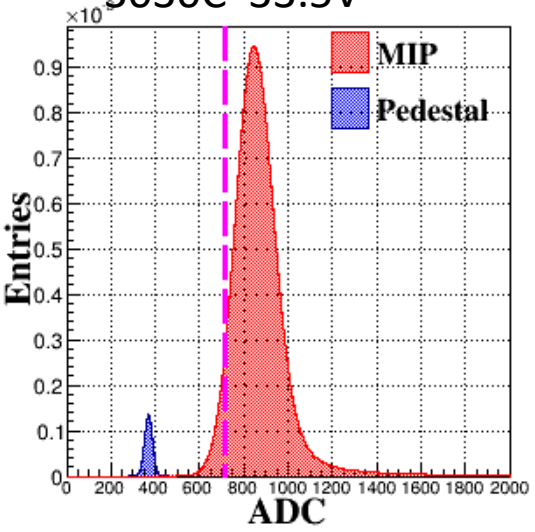
1010C 33.5V



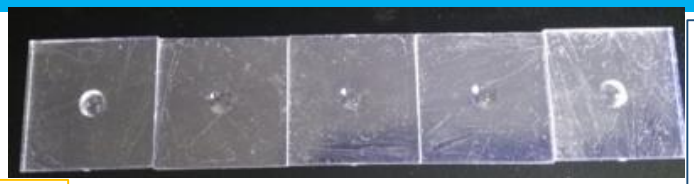
125 24V



3030C 33.5V



Different batches Injection scintillator



Detector cell:
Szie:30mm*30mm*3mm
SiPM:S12571-029P
ESR Cut by mould

The First batch

Size (mm^3)	30.08x30.01x3.08	30.07x30.04x3.09	30.04x30.02x3.09	30.09x30.09x3.09	30.05x30.03x3.09
Light Yeild(p.e.)	15.24	13.55	13.03	12.08	

The Second batch

Number	1	2	3	4	5	6
Light yeild(p.e.)	18	8.16	18.36	15.61	17.93	19.26
Number	7	8	9	10	11	12
Light yeild(p.e.)	18.32	17.11	15	9.86	10.78	9.94

Result:

- **Low Light yeild**
- **Bad consistenc between different scintillator tiles**

Different batches Injection scintillator

The third, fourth, fifth batch

The Third batch	1	2	3	4	5	6
Light Yeild(p.e.)	17.79	18.06	18.12	16.7	16.26	16.5

- The third batch of tiles had low light yield
- The fourth batch had bad consistency after adding more PPO
- The fifth batch of tiles also had low light yield

The Fourth batch	1	2	3	4	5
Light Yeild(p.e.)	22.35	22.18	19.58	19.62	21.59
The Fourth batch	6	7	8	9	10
Light Yeild(p.e.)	20.63	21.01	18.98	19.13	19.08

The Fifth batch	1	2	3	4	5
Light Yeild(p.e.)	20.3	20.77	20.82	20.96	20.21
The Fifth batch	6	7	8	9	10
Light Yeild(p.e.)	21.68	18.77	19.73	20.04	20.18

Different batches Injection scintillator

The sixth batch of tiles

The sixth batch	1	2	3	4	5
Light Yeild(p.e.)	23.52	23.95	22.98	23.77	21.79
The sixth batch	6	7	8	9	10
Light Yeild(p.e.)	23.68	22.77	21.35	22.12	21.44

The seventh batch of tiles

The seventh batch	1	2	3	4	5
Light Yeild(p.e.)	21.64	21.84	21.72	20.35	20.60

- The average of the sixth is around 22.74p.e., deviation below 3p.e..
- The seventh batch is also low and need to be improved.