R&D of CEPC HCAL

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On behalf of CEPC Calorimeter working Group

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Outline

—Preliminary design of CEPC-Detector ;

—The options of CEPC-HCAL;

—The progress of three options of HCAL

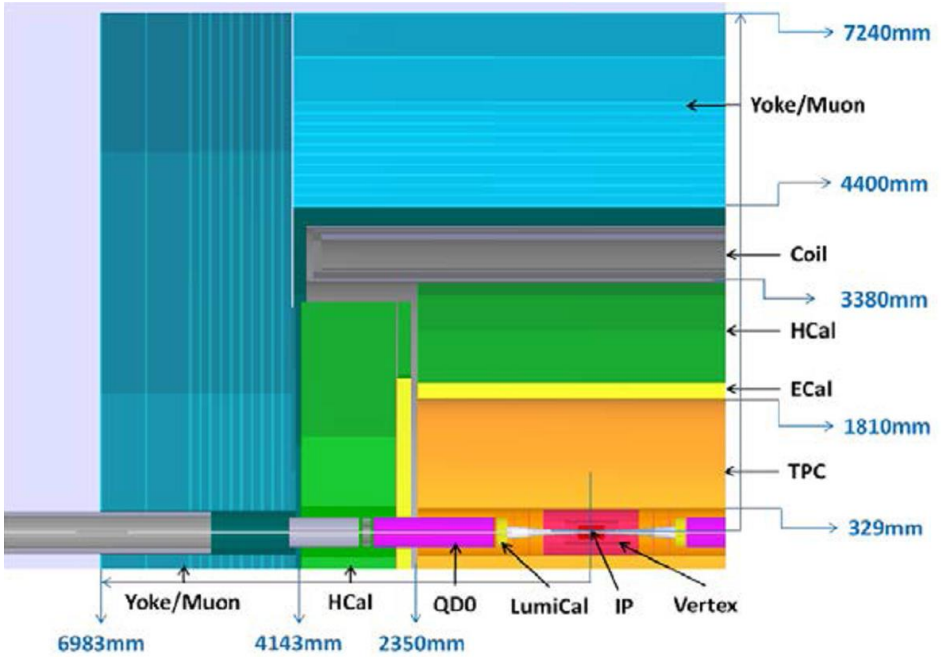
- SDHCAL based on RPC;
- SDHCAL based on GEM/THGEM;
- AHCAL based on scintillator;

—Summary

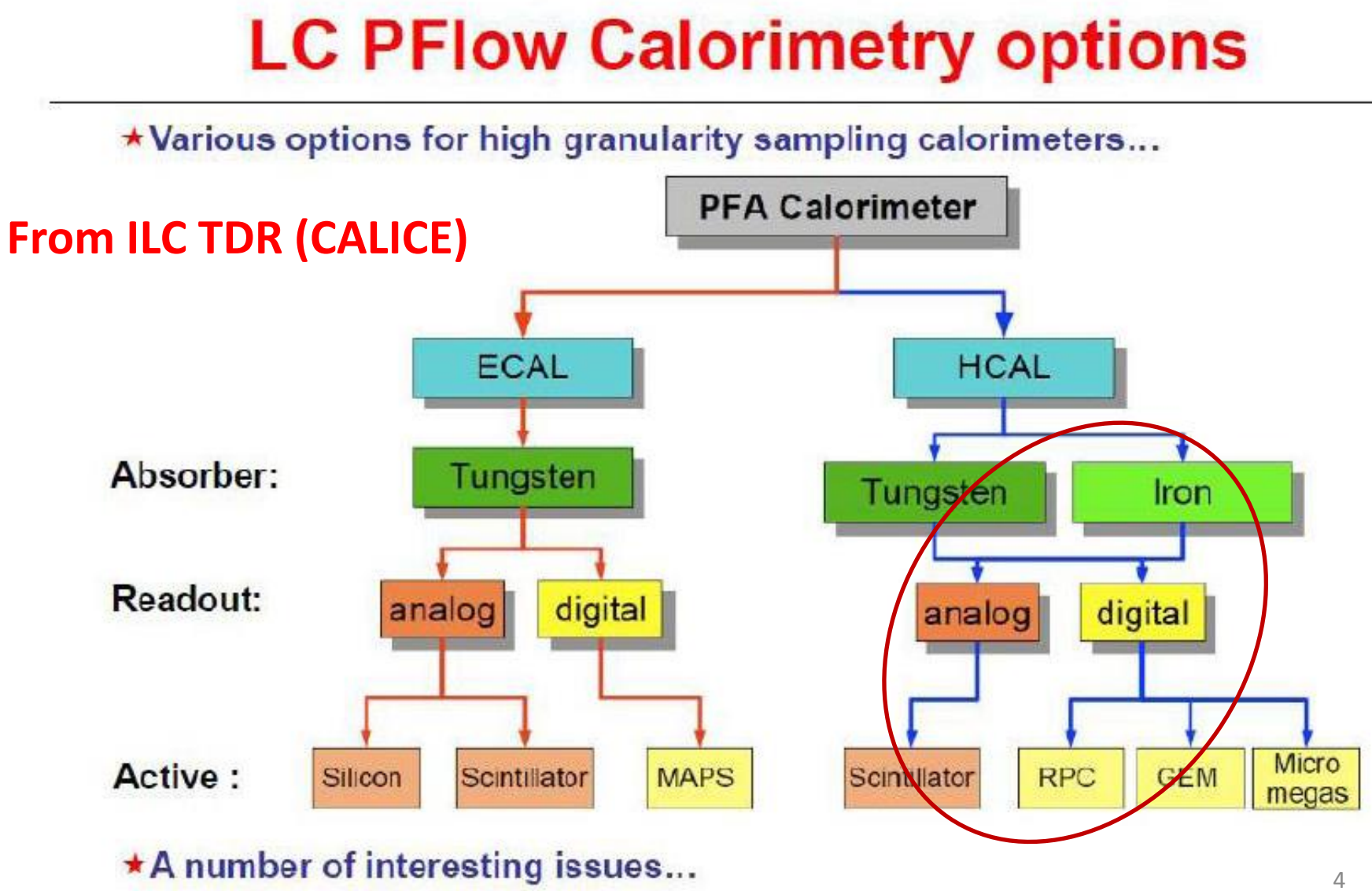
Preliminary design of CEPC-Detector

Requirements of CEPC Calorimeter

- Jet energy resolution (ECAL combined with HCAL and tracker):
  $\sigma_E/E \approx (3\% - 4\%)$
- Detailed information of showers
- High granularity, Compact showers(small radiation length X_0, and small Moliere radius R_M),
  Minimum dead materials



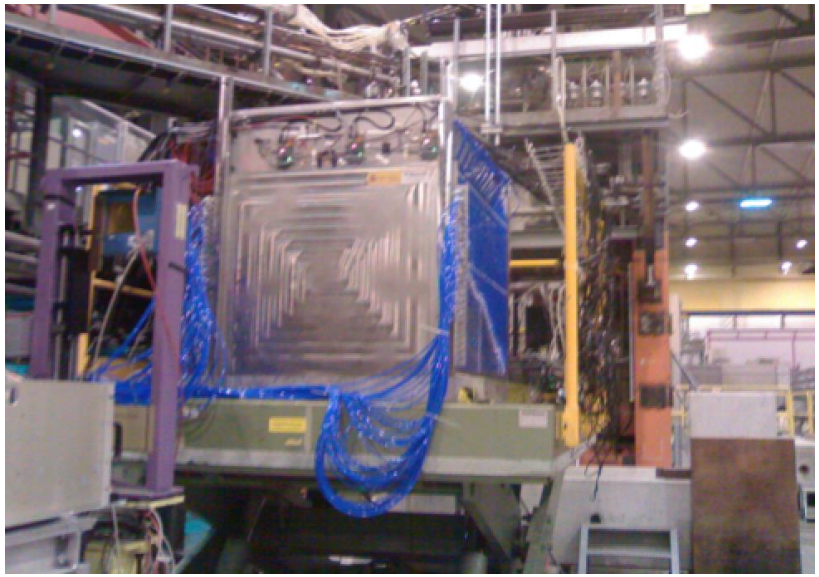
The options of CEPC-HCAL

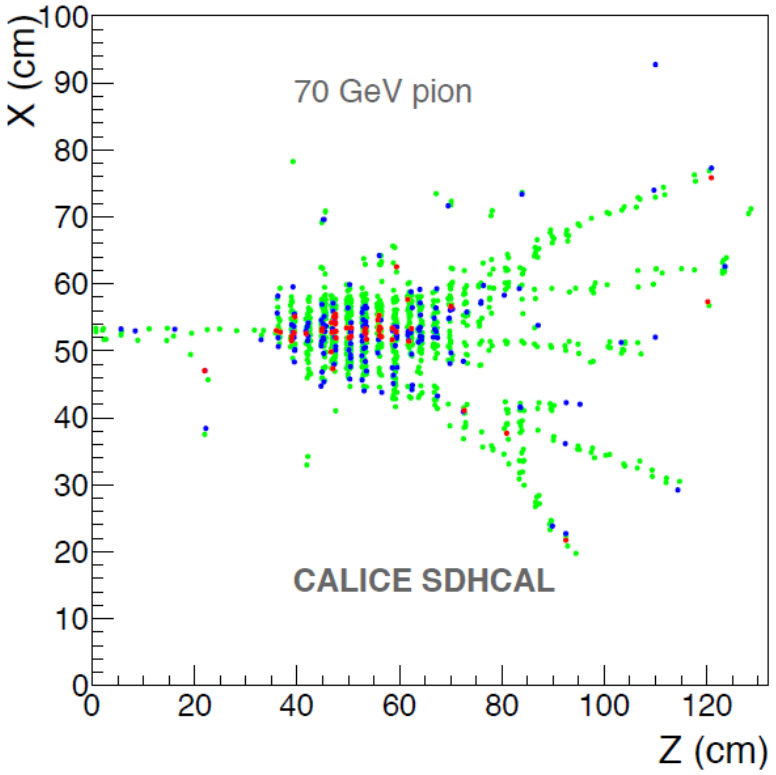


SDHCAL Prototype

- **Total Size:1.0x1.0x1.3m^3**
- **Total Layers: 48**
- **Total Channel(pads):440000**
- **Power consumption:$10\ microW/channel$ for ILC mode. 100 times for CEPC**

The first technological prototype among a family of prototypes of high-granularity calorimeters

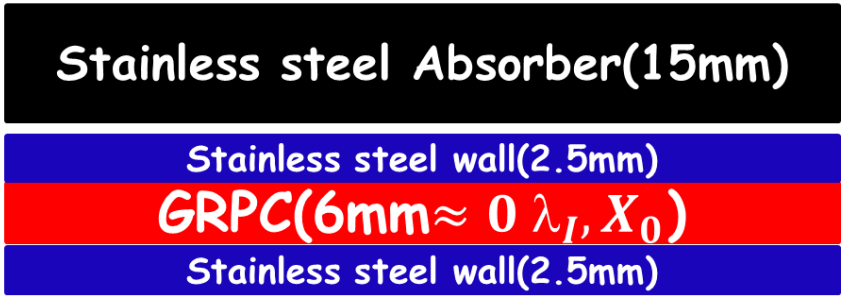


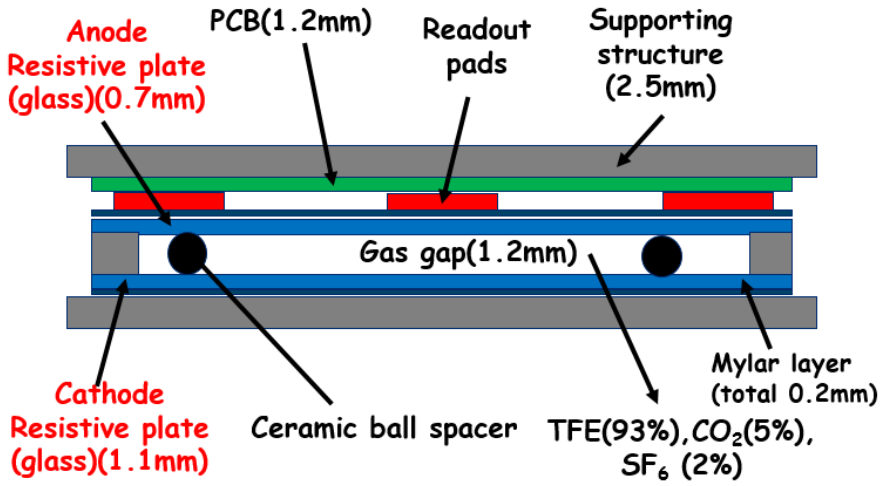


Developed by the CALICE collaboration

Structure of per layer

$(0.12\lambda_I, 1.14X_0)$



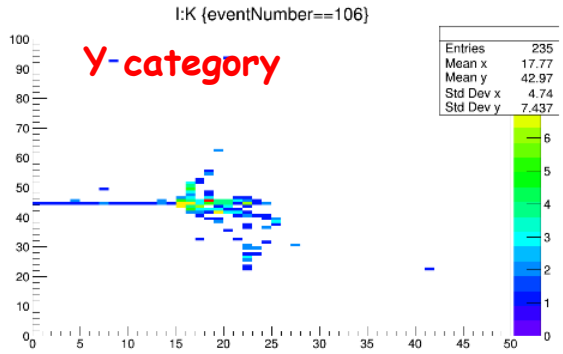


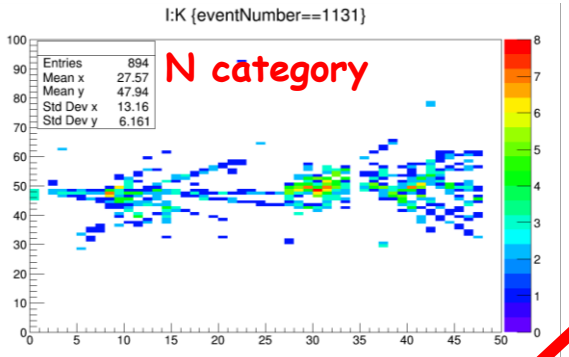
ASIC HARDROC(64 channel)
three-threshold (Semi-digital)
110fC,5pC,15pC

Analysis of beam test

selections

Data sample:SPS_Oct_2015 Particle: pion
Energy:10, 20, 30, 40, 50, 60, 70,80GeV

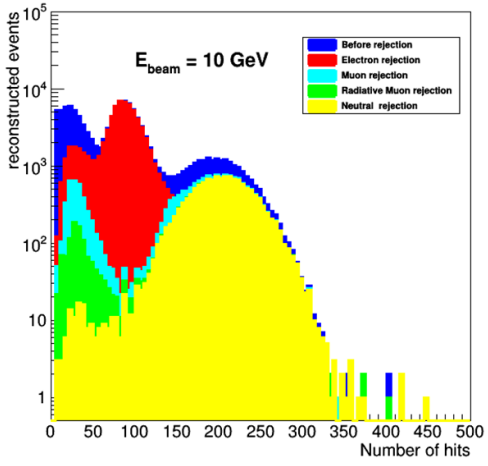


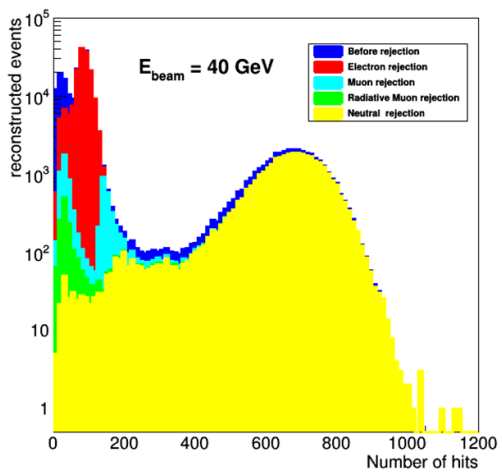


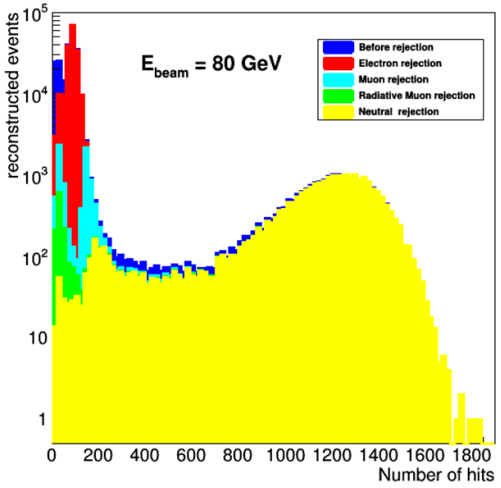
shower is fully contained tag the event Y

shower not fully contained tag the event N

Type	Selections	Detail
Simple cuts	Electron rejection	Shower start >=5 or Nlayer > 30
	Muon rejection	Nhit/Nlayer > 3.2(previous is 2.2)
	Radiative muon rejection	Nlayer(RMS > 5cm)/Nlayer>20%
	Neutral rejection	Nhit(belong to first 5 layers)> =4

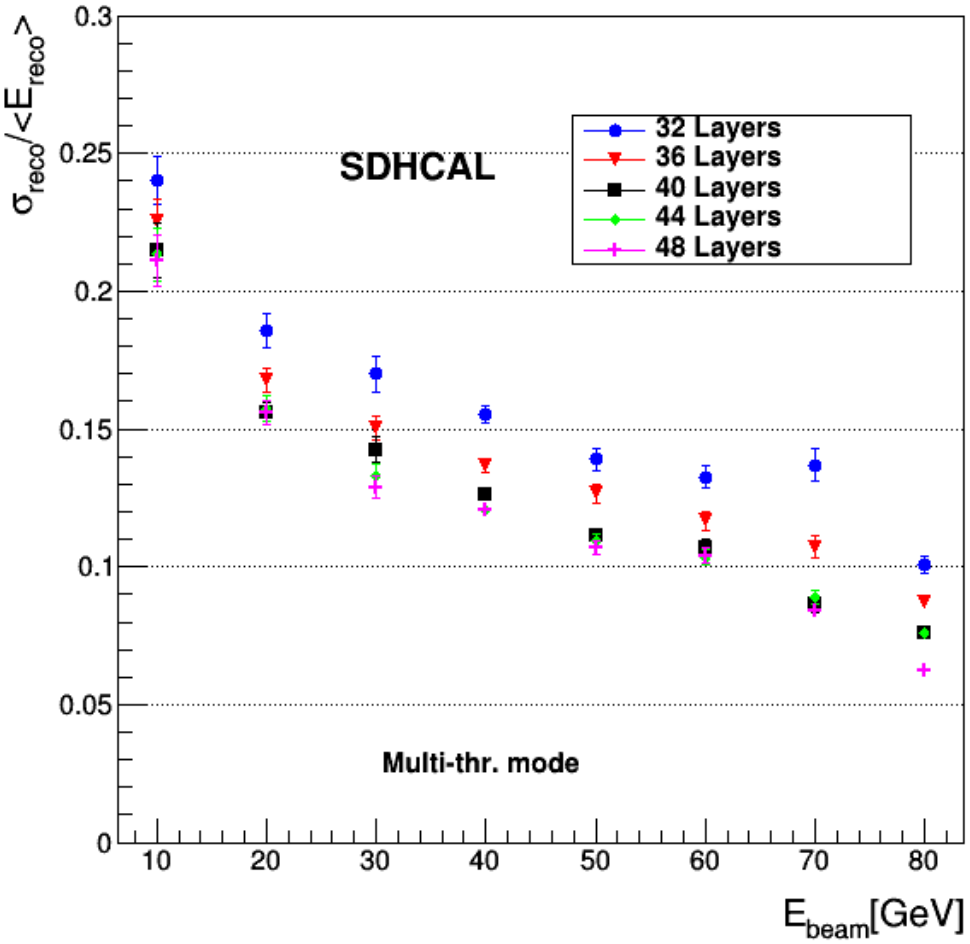






Applying 4 rejections step by step, Almost eliminate backgrounds

Optimization of SDHCAL Layers



$(0.12\lambda_I, 1.14X_0)$

Stainless steel Absorber(15mm)

Stainless steel wall(2.5mm)

GRPC(6mm$\approx 0\ \lambda_I, X_0$)

Stainless steel wall(2.5mm)

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

➔Optimization no. of layers for CEPC at 240GeV

➔40-layer SDHCAL yields decent energy resolution.

➔ Also apply BDT to improve pion/e/mu identification, see Haijun Yang's talk

DHCAL based on GEM

➢ **Advantages：**

1. assembling process is easy and fast

2. no dead area inside the active area

3. uniform gas flow

4. detachable

Typical parameters

Cu : t = 5μm

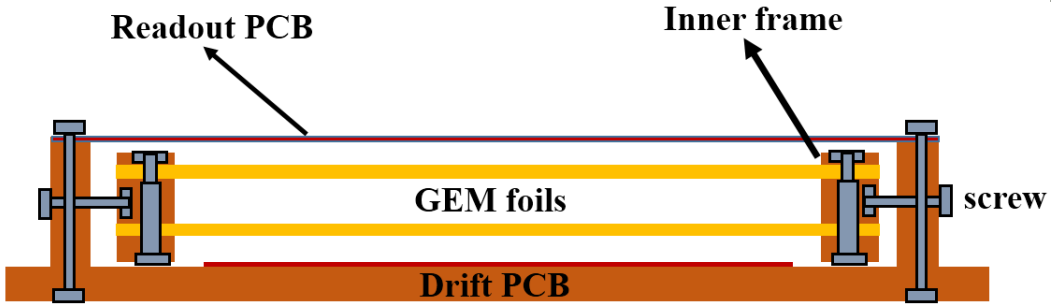
Kapton: T = 50μm

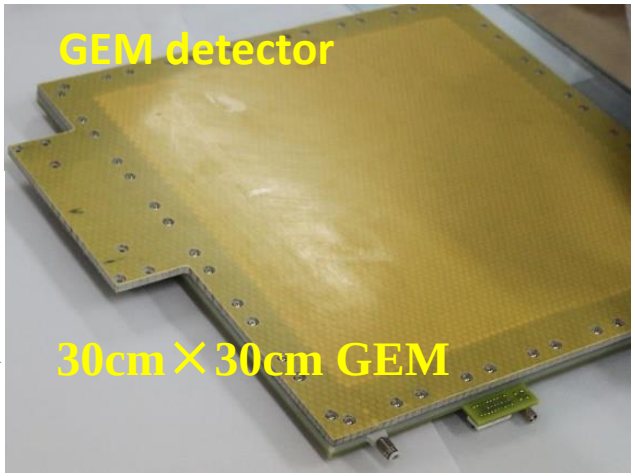
Diameter: d = 60μm

D = 80μm

pitch: 140μm

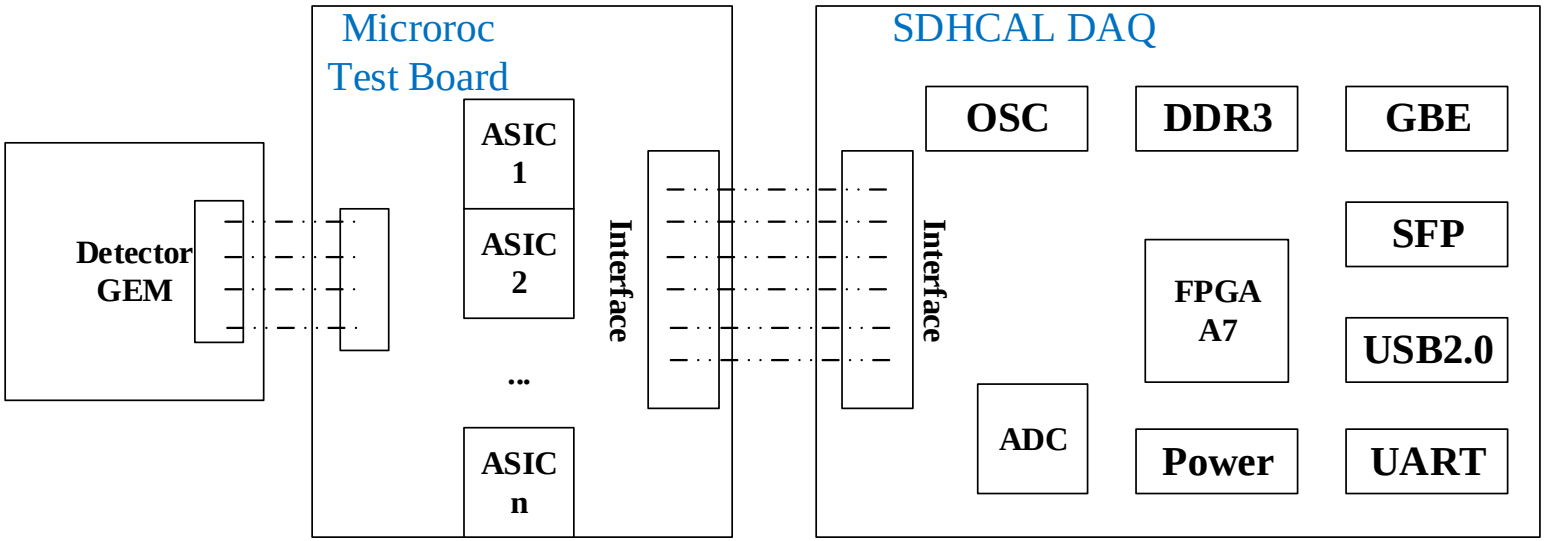
Self-stretching technique (from CERN)





Readout Scheme

- Schematic of the System

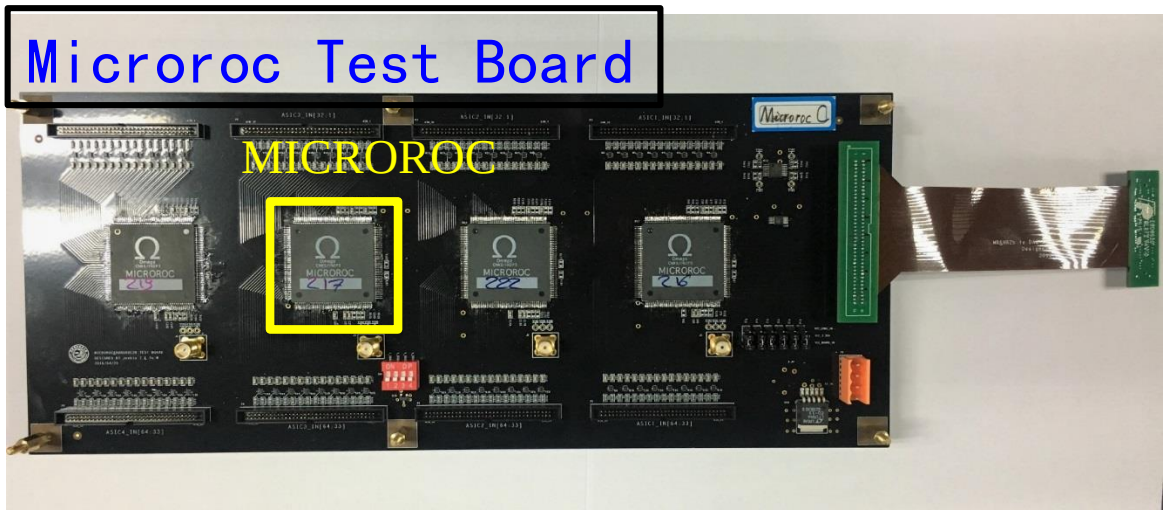


- Readout Board: GEM detector Readout composed by 900 $1cm^2$ pads.
- MICROROC Test Board: Mounted 4 Microroc ASICs, controlled by daisy chain.
- DIF Board: Microroc control, test and data acquisition

Readout ASIC

Readout ASIC	Channels	Dynamic Range	Threshold	Consumption
GASTONE	64	200fC	Single	2.4mW/ch
VFAT2	128	18.5fC	Single	1.5mW/ch
DIRAC	64	200fC for MPGD	Multiple	1mW/ch, 10μW/ch(ILC)
DCAL	64	20fC~200fC	Single	——
HARDROC2	64	10fC~10pC	Multiple	1.42mW/ch,10μW/ch(ILC)
MICROROC	64	1fC~500fC	Multiple	335μW/ch, 10μW/ch (ILC)

Considered the multi-thresholds readout, dynamic range and power consumption, MICROROC is an appropriate readout ASIC

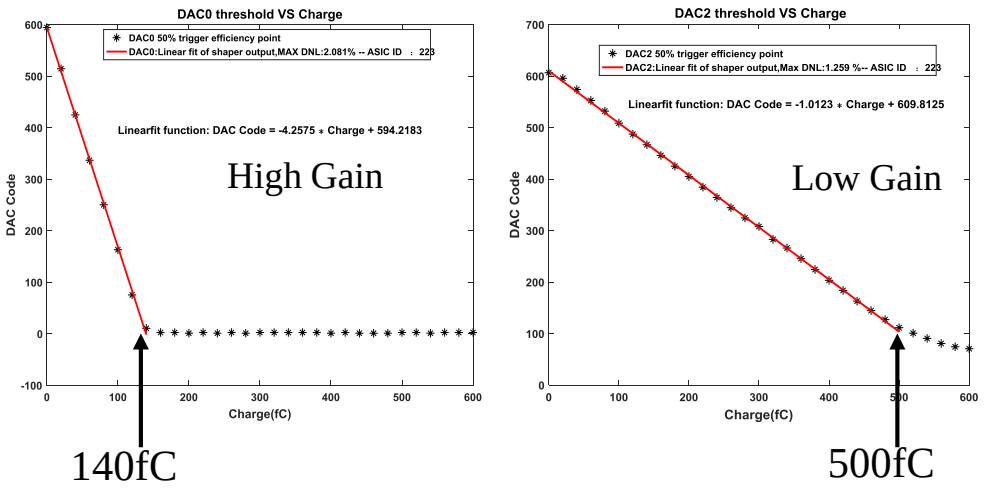


MICROROC Parameters

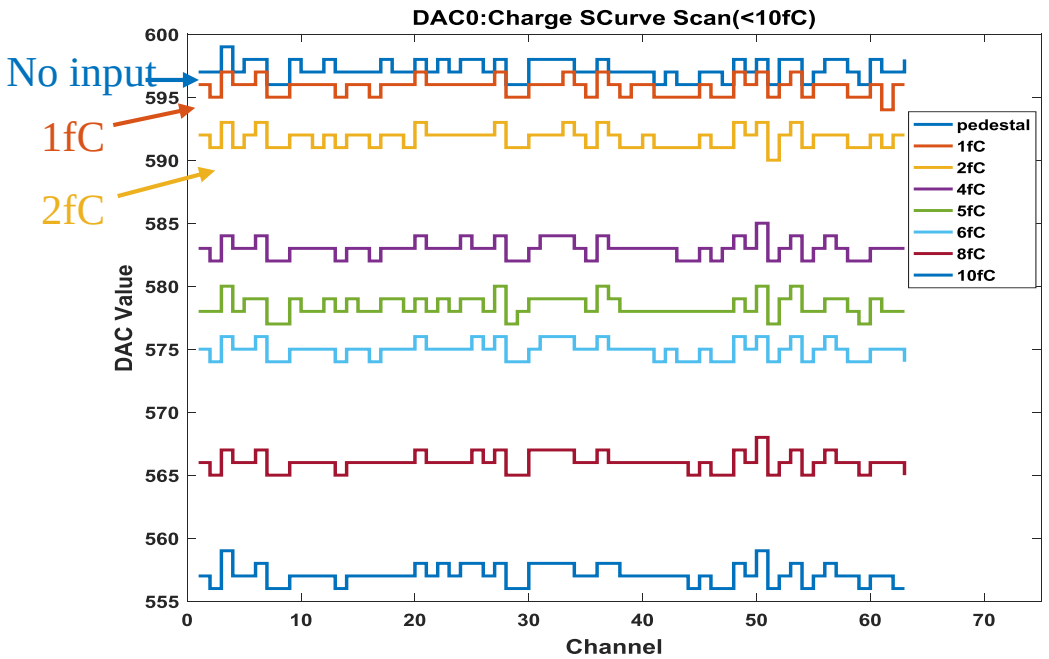
- Thickness: 1.4mm
- 64 Channels
- 3 threshold per channel
- 128 hit storage depth
- Minimum distinguishable charge:2fC

Test of MICROROC

- Calibration curve



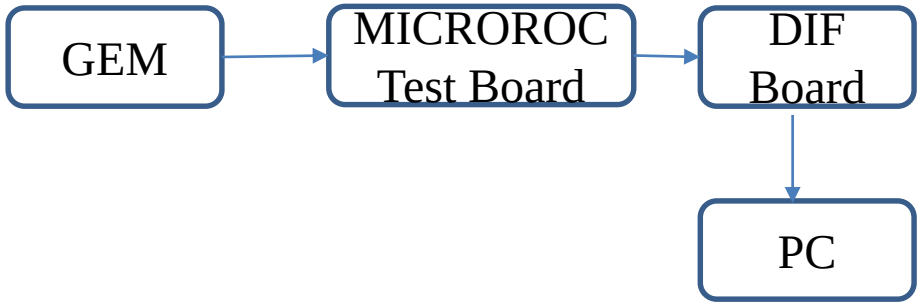
- Uniform between 64 channels



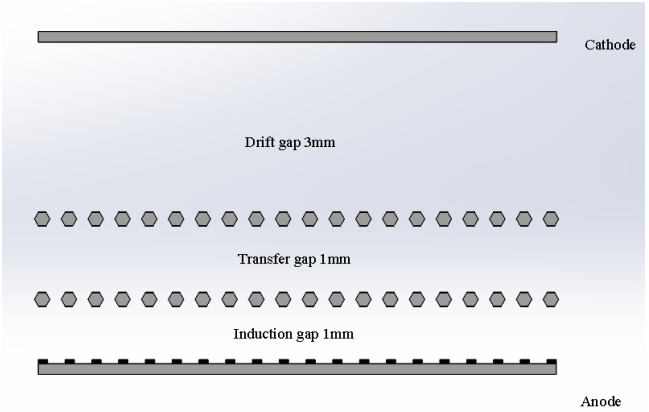
Minimum distinguishable charge: 2fC

Noise Test

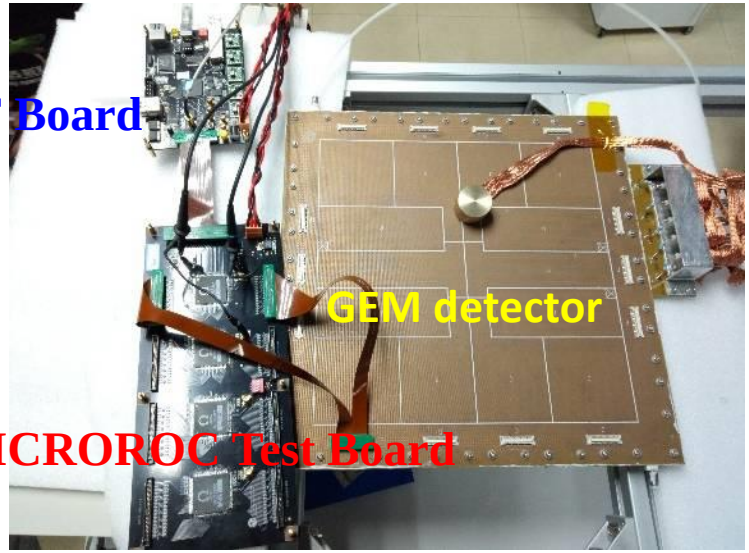
Diagram of noise test

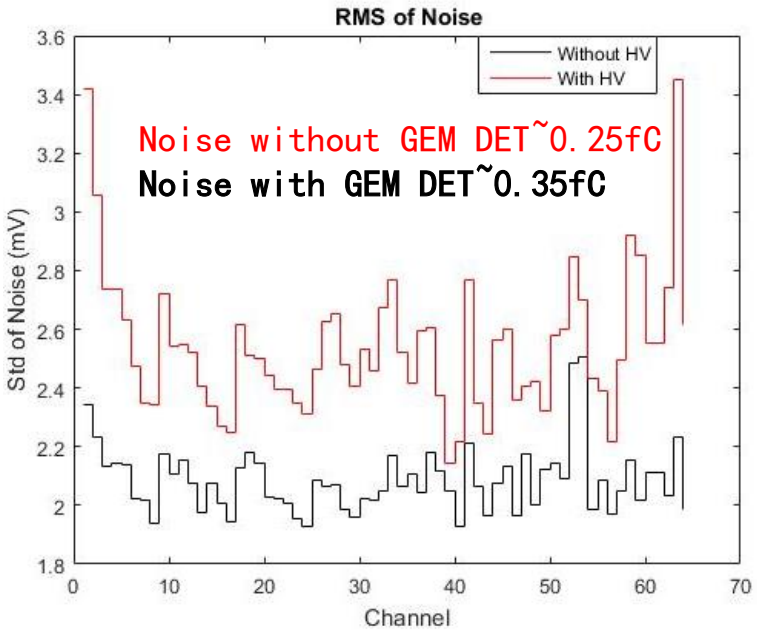


Structure of GEM Detector

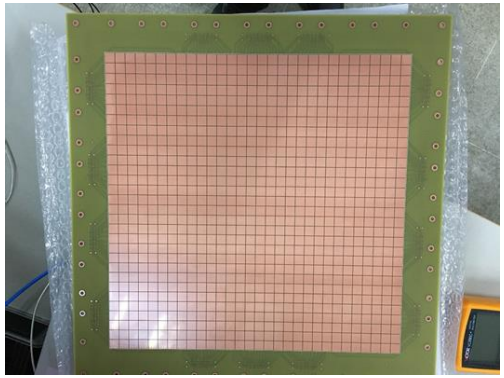


Test system



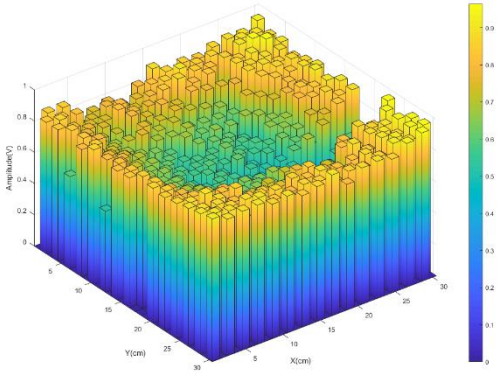


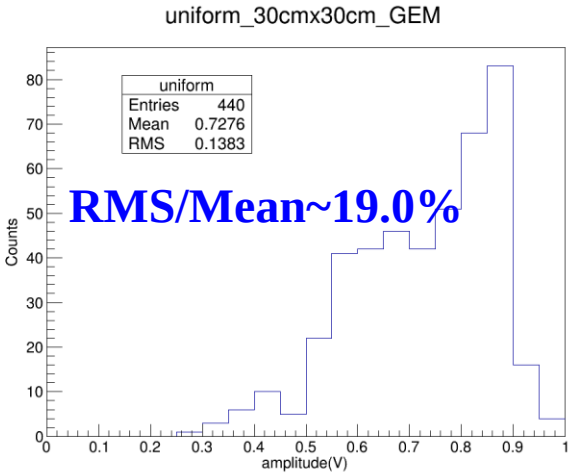
Uniformity results



Pad Size: 1cmx1cm

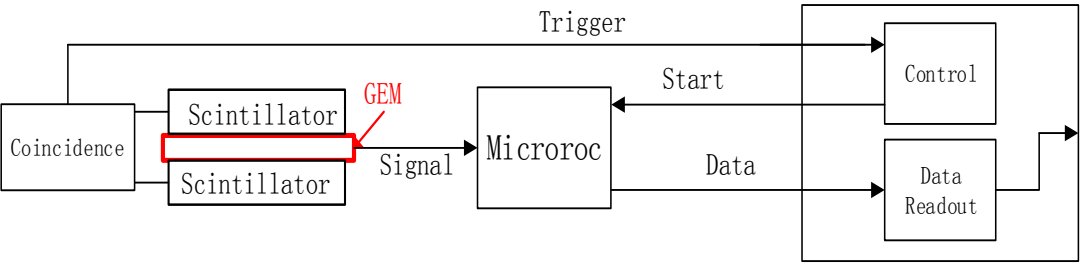
Uniformity Distribution





Crosstalk Test result

Utilizing Cosmic-Ray as Test Source

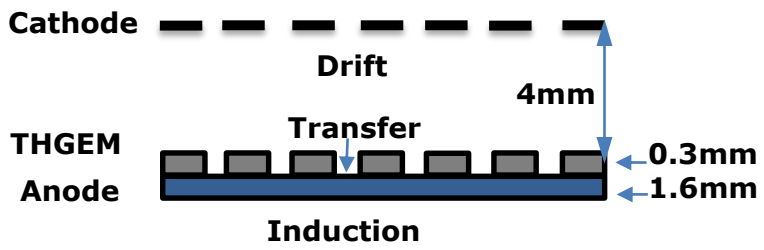


- the ratio of nearby pad response is **1.54%**

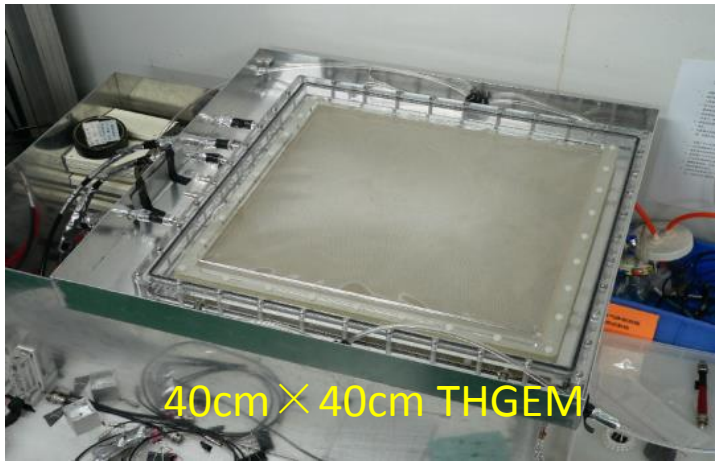
Preliminary research on THGEM-DHCAL

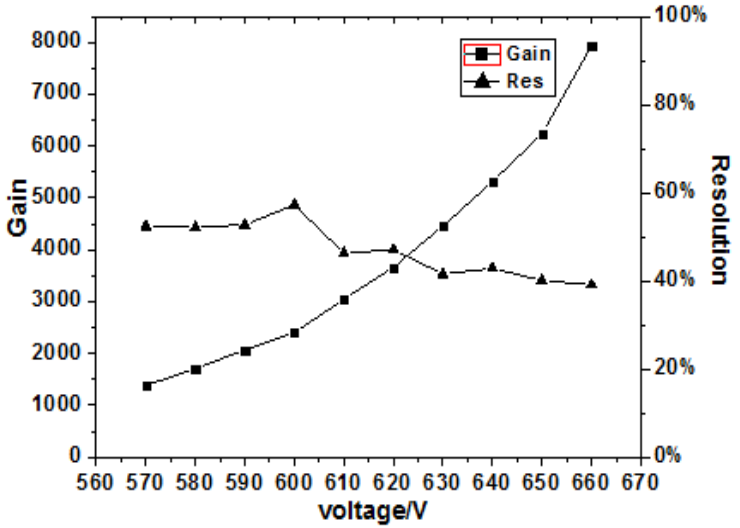
— three structure can be selected;
- Double THGEM;
- Single-THGEM;
- WELL-THGEM;

— WELL-THGEM is the-best selection.
- thinner, high gain, lower discharge



The thickness of WELL-THGEM<6mm



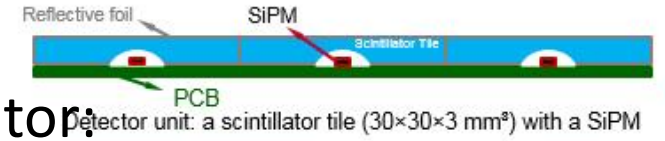


Gain result of 20cmX20cm WELL-THGEM

GEM DHCAL Next Step

- Integrate ASIC to the back-end of Detector
- Design and assemble 50cm×100cm GEM detector with 3mm drift gap、1mm transfer gap and 1mm induction gap.
- Test performances of the 50cm×100cm GEM detector

The progress of scintillator AHCAL



Detector unit: a scintillator tile (30×30×3 mm³) with a SiPM

— Analog hadron calorimeter based on scintillator:

- The absorber: 2cm Stainless steel;
- Detector cell size: 3cm×3cm (baseline) , 4cm× 4cm, 5cm× 5cm ;
- Readout chip: ASIC SPIROC2E
- The sensitive detector : Scintillator(PS or inorganic scintillator);
- 40 sensitive layers, total readout channel
  ≈5 Million (3cm× 3cm)
  ≈2.8 Million (4cm× 4cm)

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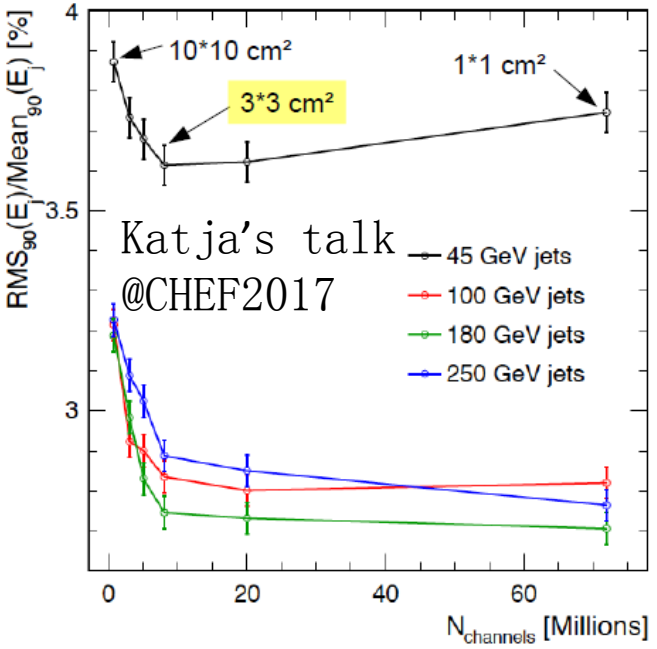
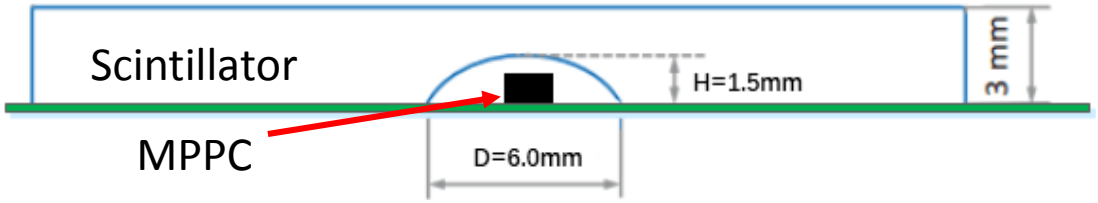
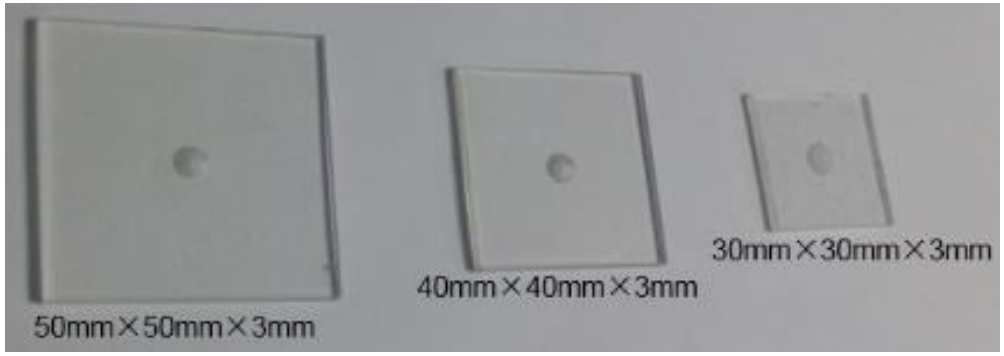


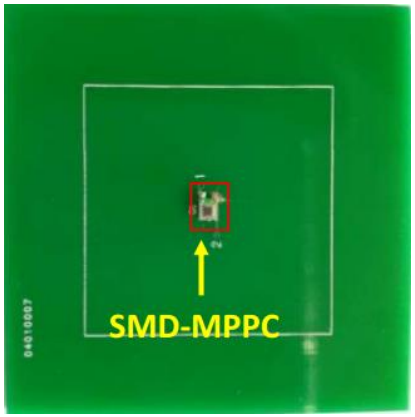
Detector Cells Research

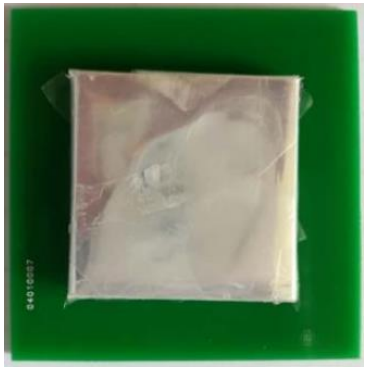
– Via mechanical drilling and polishing, a dome-shaped cavity in the center of plastic scintillator was made
– The sizes of $30\times30\times3mm^3$,$30\times30\times2mm^3$, $40\times40\times3mm^3$and $50\times50\times3mm^3$ were made.
– SiPM or MPPC(surface-mounted)
– Scintillator(BC408) were wrapped by ESR foil



Scintillator tile wrapped by ESR foil was glued on the PCB

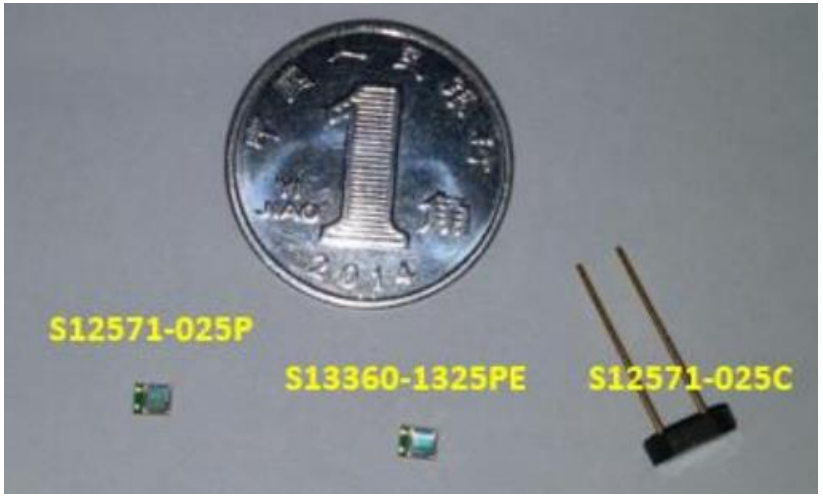


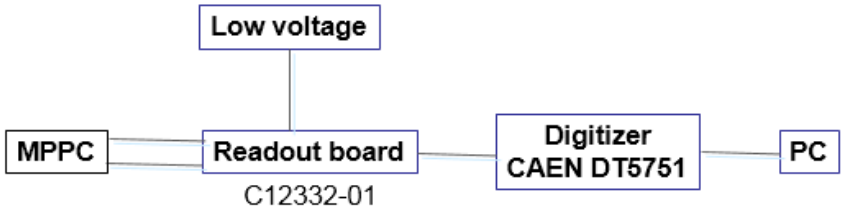




Readout electronics

- Electronic readout board is Hamamatsu C12332-01
- Temperature compensation keep amplitude of the SiPM stable

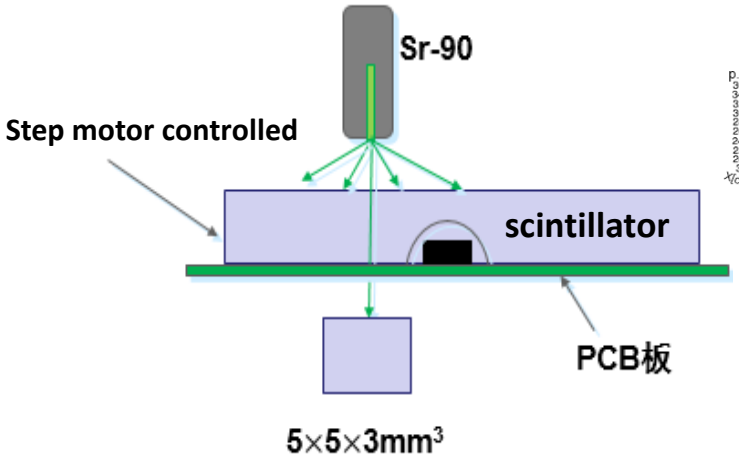


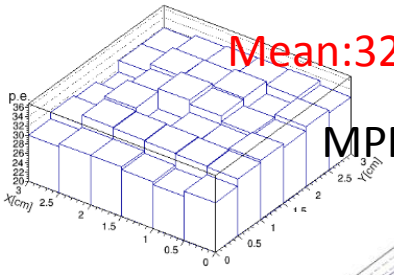


S12571-025P parameter :
Sensitive area :1×1mm²
Pixel size :25×25μm²
Pixel number:1600
Gain: 5.15E+05

S13360-1325PE parameter :
Sensitive area :1.3×1.3mm²
Pixel size :25×25μm²
Pixel number:2668
Gain: 1.1E+06

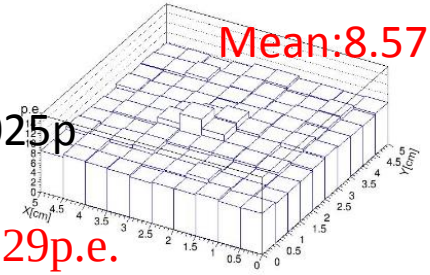
Uniformity measurement



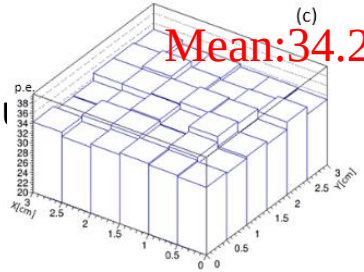


MPPC S12571-025p

30x30x3mm³



50x50x3mm³ uniformity



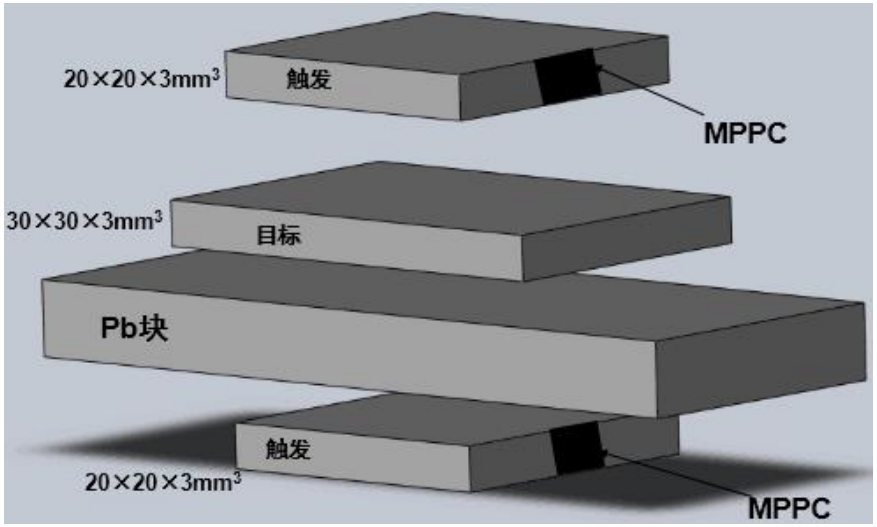
30x30x2mm³ uniformity

MPPC S13360- 1325PE

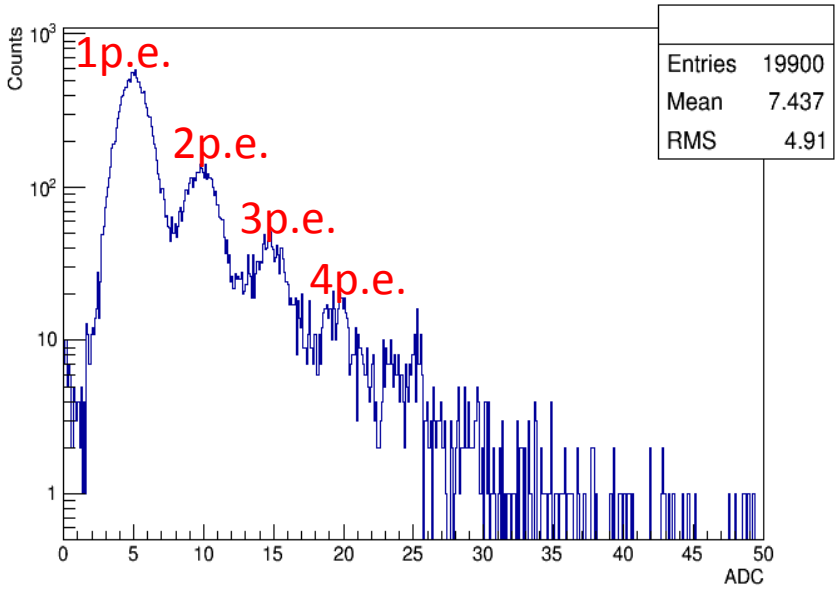
- Uniformity scans (MPPC: S12571-025P and)
- Scintillator tile under study can be moved in a step size of 5×5 mm²
- 30x30x3mm³, 30x30x2mm³and 50x50x3mm³ were measured .

- The mean response can reach 100%,94% within 10% deviation from the mean value, respectively.

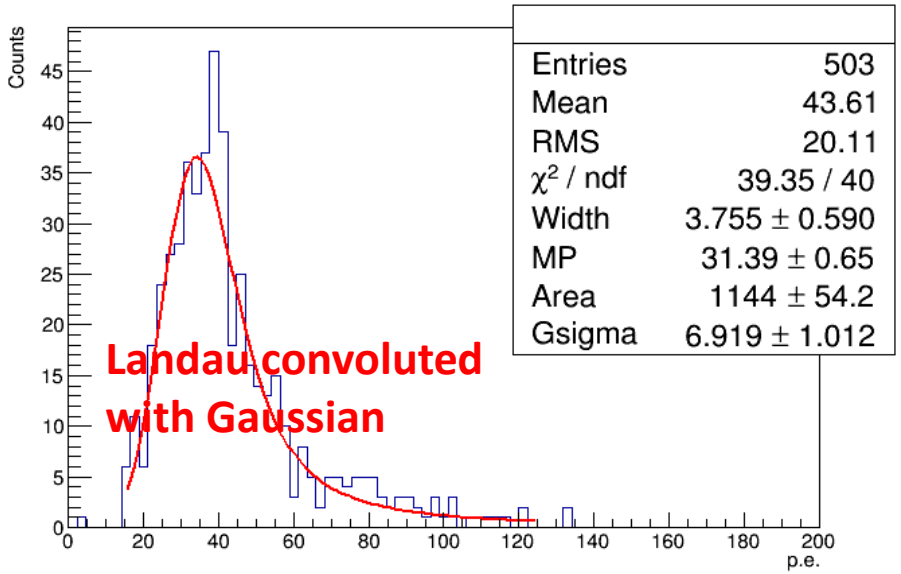
Cosmic-ray measurement



- 30x30x3mm^3, 30x30x2mm^3, 40x40x3mm^3,50x50x3mm^3 plastic scintillator were tested
- MPPC type: S12571-025p and S13360- 1325PE



MPPC cross talk spectrum



result of 30×30×3mm3 scintillator

The result of AHCAL detector cell

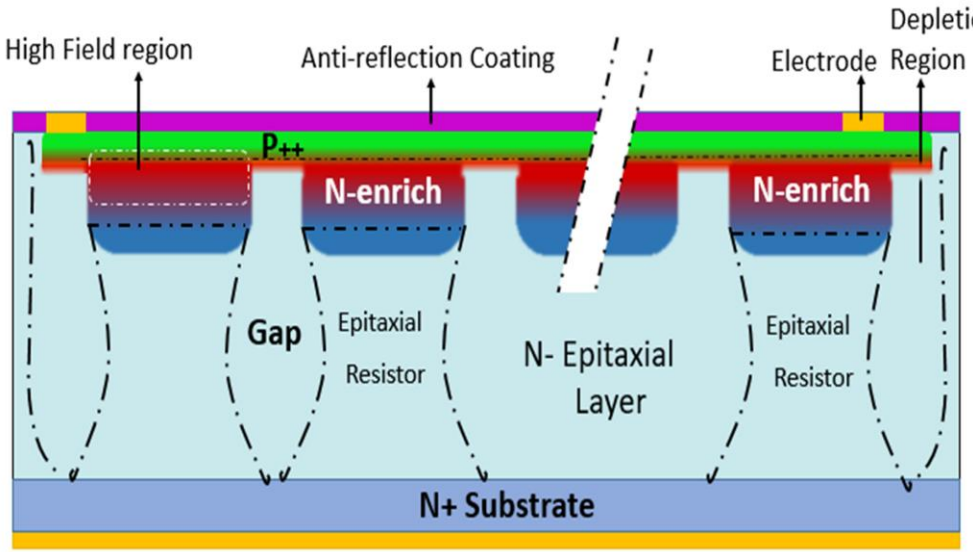
Table 1 Cosmic-ray measurement results of detector cells with different sizes

No.	Detector Cell	MPPC Type	Reflective Foil Type	Mean $N_{p.e.}$	Polishing Methods
1	$30\times30\times3mm^3$	S12571-025P	ESR	31.39±0.65	Ultra Precise Polishing
2	$30\times30\times3mm^3$	S12571-025P	ESR	22.55±0.7	Precise Polishing
3	$30\times30\times3mm^3$	S12571-025P	ESR	18.92±0.39	Rough Polishing
4	$30\times30\times3mm^3$	S12571-025P	TYVEK	13.63±0.33	Precise Polishing
5	$40\times40\times3mm^3$	S12571-025P	ESR	14.89±0.73	Precise Polishing
6	$50\times50\times3mm^3$	S12571-025P	ESR	9.87±0.43	Precise Polishing
7	$30\times30\times2mm^3$	S13360-1325PE	ESR	33.89±0.49	Precise Polishing

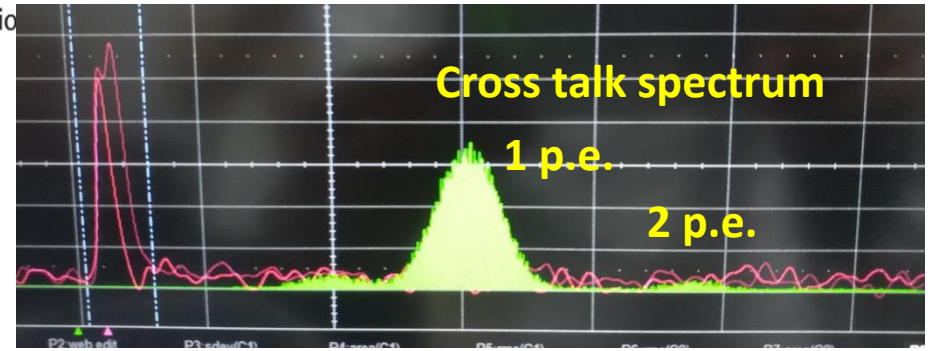
- The detector cell： $30\times30\times3mm^3$， $40\times40\times3mm^3$， $50\times50\times3mm^3$ and $30\times30\times2mm^2$ was tested;
- MIPs response of them is meet the requirement of HCAL;
- Which kind detector cell will be used depend on the simulation result;

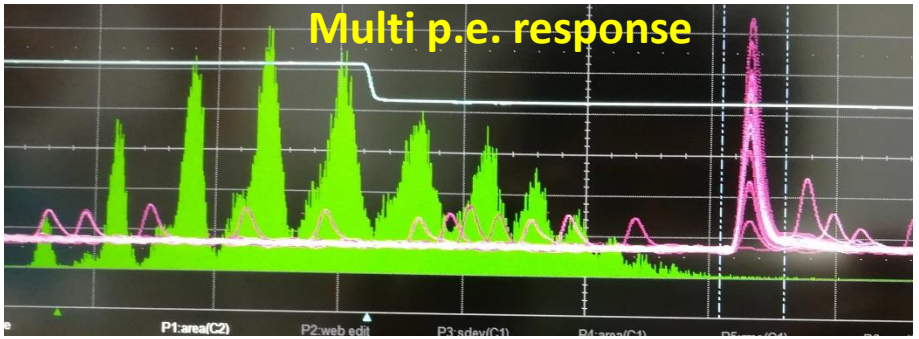
Chinese EQR SiPMs（Developed by Beijing Normal University）

- 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 reducing the cost of the fabrication.**



Schematic structure of EQR SiPM





Chinese EQR-SiPM performance

	NDL SiPM	
Effective Active Area	11-3030 B-S	22-1414 B-S
	3.0×3.0 mm^2	1.4×1.4 mm^2 (2×2 Array)
Effective Pitch	10 μm	10 μm
Micro-cell Number	90000	19600
Fill Factor	40%	40%
Breakdown Voltage (V_b)	23.7±0.1V	23.7±0.1V
Measurement Overvoltage (V)	3.3	3.3
Peak PDE	27%@420nm	35%@420nm
Max. Dark Count (kcps)	< 7000	<1500
Gain	2×10^5	2×10^5
Temp. Coef. For V_b	17mV/° C	17mV/° C

- Chinese SiPM already can work with some good performance
- Some performance need more improvements

Higher dynamic range
Higher fill-factor

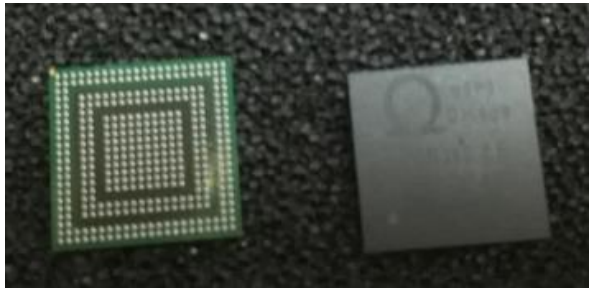
High Dark count rate

A little low Gain

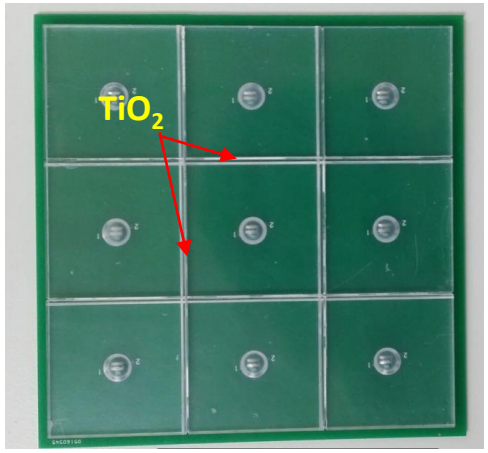
CEPC-AHCAL Next step

- ASCI chip readout research;
- Test Chinese (GNKD) plastic scintillator;
- Test the Chinese EQR-SiPM;
- Scintillator mega tiles test;

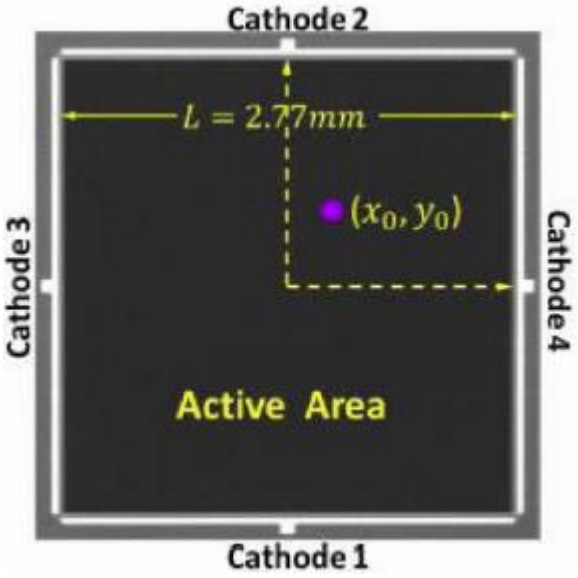
ASIC chip Spiroc2E



Mega tiles



Chinese SiPM



Summary and next

—CEPC-HCAL have got some progress;

—Now we have three options, RPC-SDHCAL, GEM-DHCAL , Scint-AHCAL;

—The CEPC-HCAL-CDR is on way;

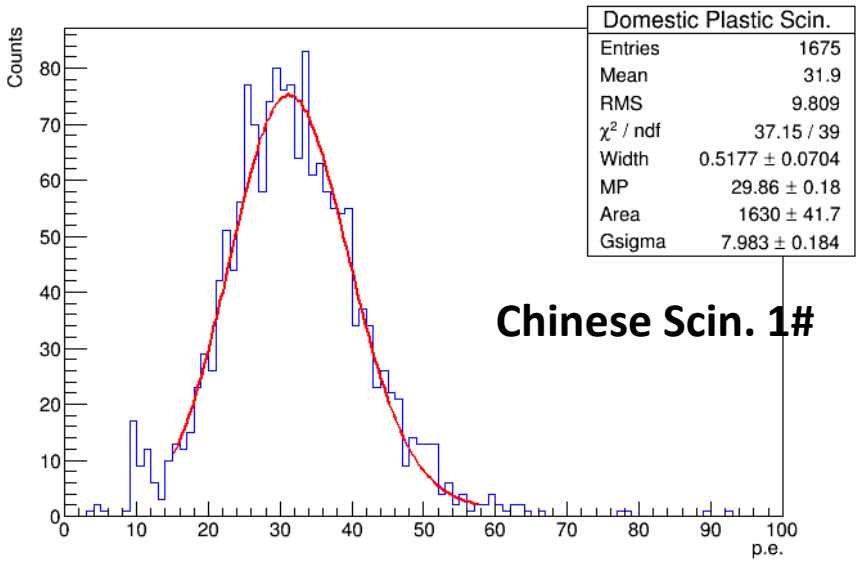
—Apply new funding for HCAL prototype;

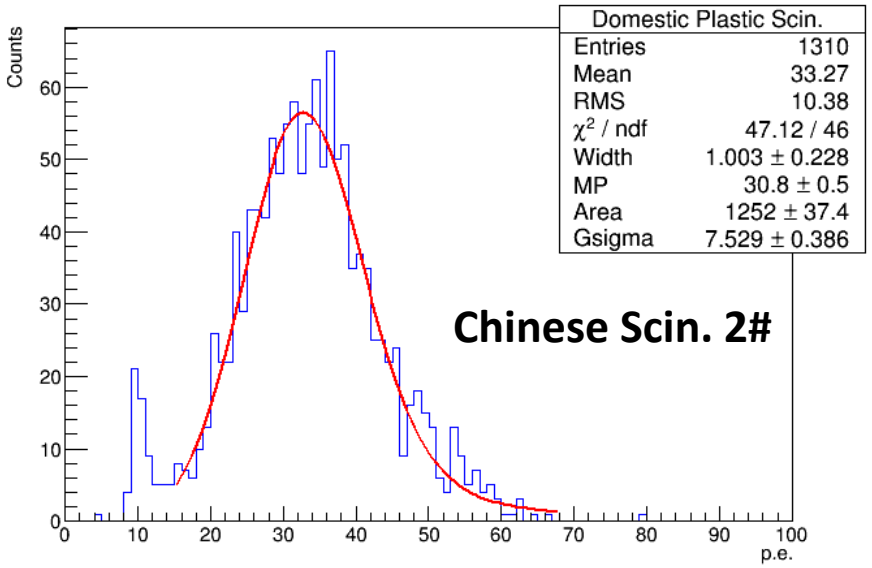
Welcome to join us!

Thanks for your attention!

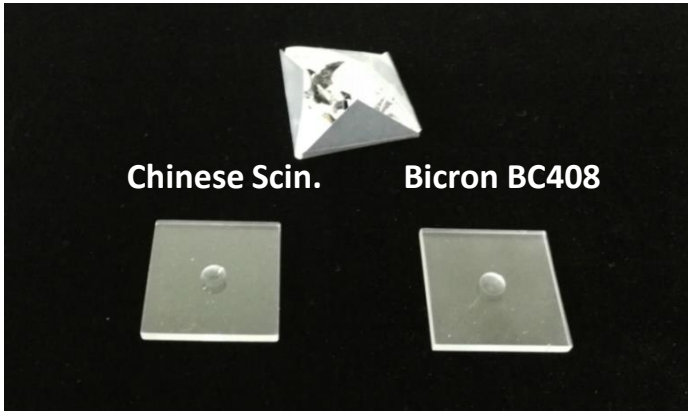
Backup!

Chinese plastic scintillator test





- 2 tiles of Chinese scintillators were tested;
- Sr-90 results: **29.86**p.e. & **30.8**p.e;
- The result of Bicron BC408 tiles is 26 p.e.;



NDL EQR-SiPM VS Hamamatsu MPPC

	NDL SiPM		Hamamatsu MPPC	
Effective Active Area	11-3030 B-S	22-1414 B-S	S13360-3025PE	S13360-1325PE
	3.0×3.0 mm^2	1.4×1.4 mm^2 (2×2 Array)	3.0×3.0 mm^2	1.3×1.3 mm^2
Effective Pitch	10 μm	10 μm	25 μm	25μm
Micro-cell Number	90000	19600	14400	2668
Fill Factor	40%	40%	47%	47%
Breakdown Voltage (V_b)	23.7±0.1V	23.7±0.1V	53±5V	53±5V
Measurement Overvoltage (V)	3.3	3.3	5	5
Peak PDE	27%@420nm	35%@420nm	25%@450nm	25%@450nm
Max. Dark Count (kcps)	< 7000	<1500	1200	210
Gain	2×10^5	2×10^5	7.0×10^5	7.0×10^5
Temp. Coef. For V_b	17mV/° C	17mV/° C	54mV/° C	54mV/° C