Study on Calorimeter for CEPC

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The CEPC Program

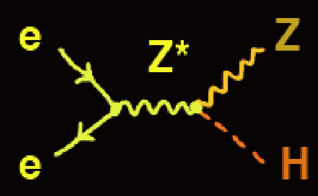
Accelerator Parameters	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
Lifetime (hour)	0.67	1.4	4.0	2.1
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

Current main focus

CEPC: Electron-positron collisions at 91, 160, and 240 GeV)

Higgs factory (10^6 Higgs)

- Precision study of Higgs (m_H, couplings)
- Looking for hints of new physics
  - Higgs rare decays
- Similar & complementary to ILC



Z and W factory (10^{11} Z^0)

L (@ Z pole) > 16× 10^{34} $cm^{-2}s^{-1}$

- Precision test of SM
- Search for rare decays

Flavor factory: *b*, *c*, τ and QCD studies

CEPC “optimistic” Schedule

- Design issues
- R&D items
- preCDR

- Design, funding
- R&D program
- Intl. collaboration
- Site study

- Seek approval, site decision
- Construction during 14th 5-year plan
- Commissioning

- CEPC data-taking starts before the LHC program ends
- Possibly concurrent with the ILC program

Conceptual Design Report (CDR) ~ Status

Pre-CDR completed in 2015

- No show-stoppers
- Technical challenges identified → R&D issues

(http://cepc.ihep.ac.cn/preCDR/volume.html)

Detector and Physics - Conceptual Design Report (CDR)

- Goal: A working concept on paper, including alternatives

October 2018: Planned release date

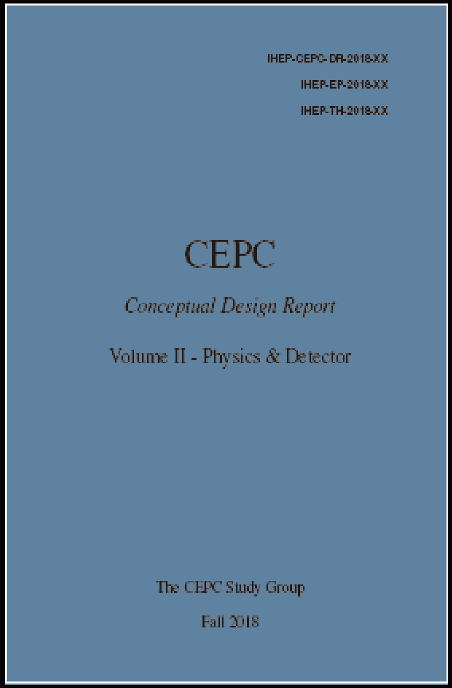
- Soon after CEPC accelerator CDR is released
- Delays to accommodate new accelerator design parameters and solenoid magnetic field

Still

- Plenty of opportunities for people to contribute
- Lots of room to make a serious impact

Weekly meetings:

- https://indico.ihep.ac.cn/category/324/


IHEP-CEPC-DR-2018-XX
IHEP-EP-2018-XX
IHEP-TH-2018-XX

CEPC

Conceptual Design Report

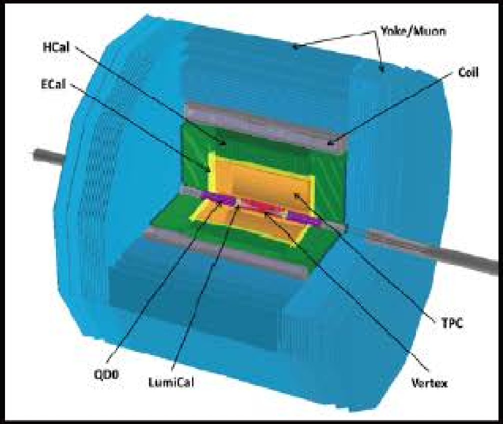
Volume II - Physics & Detector

The CEPC Study Group

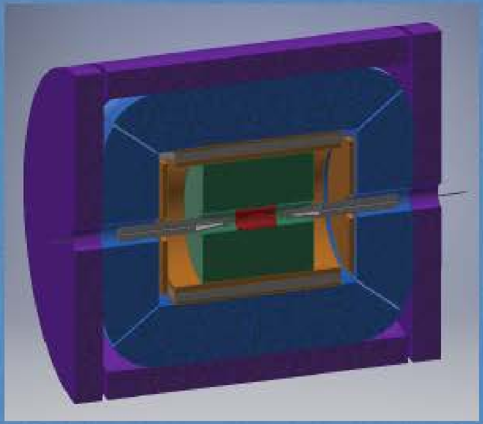
Fall 2018

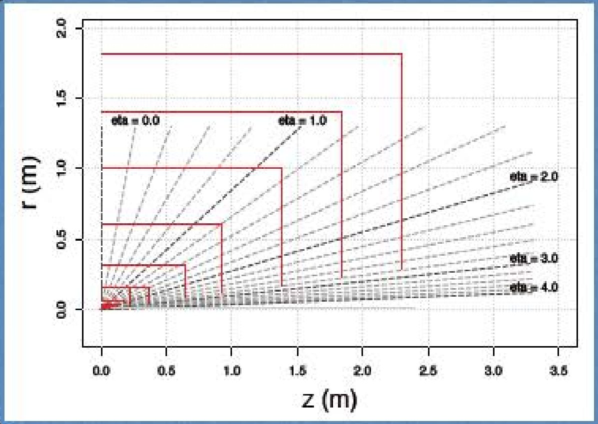
Detector Conceptual Designs (CDR)

Baseline detector (3 Tesla)
ILD-like
(similar to pre-CDR)



Low magnetic field concept (2 Tesla)





Full silicon tracker concept

Final two detectors likely to be a mix and match of different options

CEPC baseline detector: ILD-like

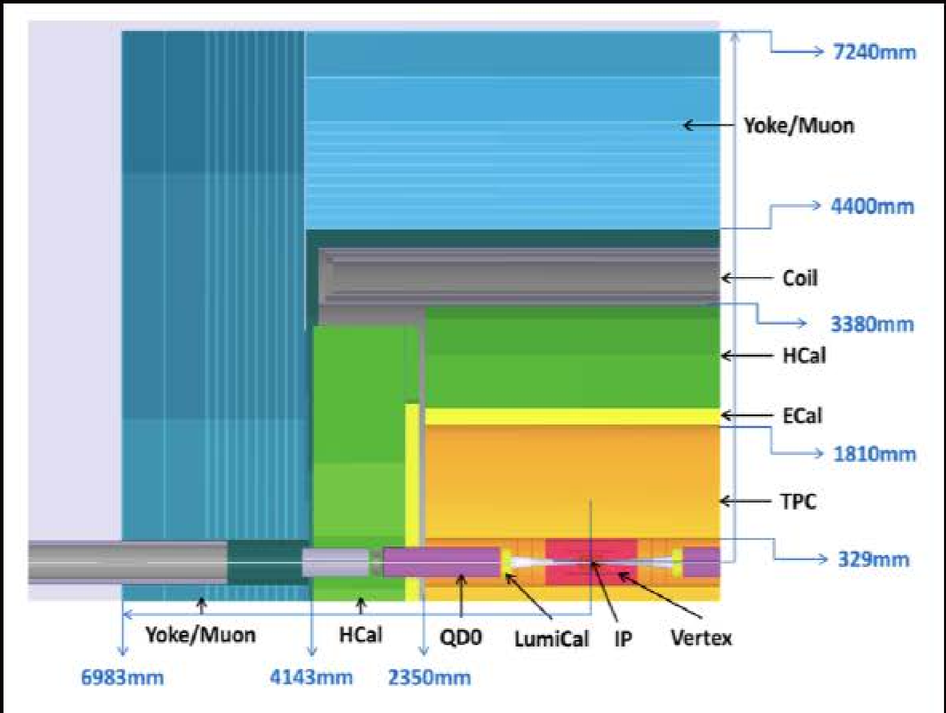
Major concerns being addressed

1. MDI region highly constrained
   L* increased to 2.2 m
   Compensating magnets

2. Low-material Inner Tracker design

3. TPC as tracker in high-luminosity Z-pole scenario

4. ECAL/HCAL granularity needs
   Passive versus active cooling

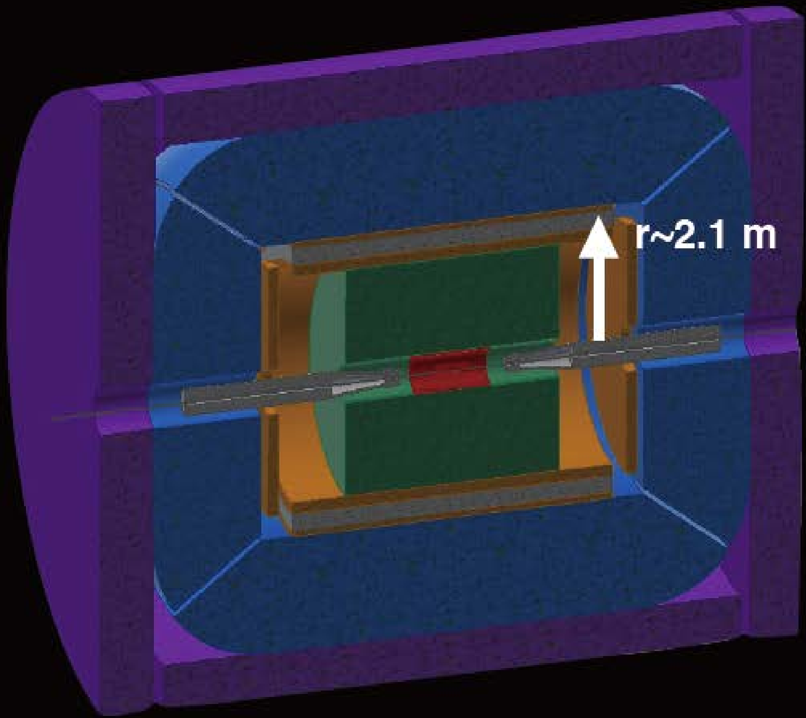


Magnetic Field: 3 Tesla — changed from preCDR

- Impact parameter resolution: less than 5 μm ⟵ Flavor tagging
- Tracking resolution: $\delta(1/Pt) \sim 2\times10^{-5}$ (GeV^{-1}) ⟵ BR(Higgs → μμ)
- Jet energy resolution: $\sigma_E/E \sim 30\%/\sqrt{E}$ ⟵ W/Z dijet mass separation

Low magnetic field detector concept

Proposed by INFN, Italy colleagues



Similar to Concept Detector for CLIC

Open for collaboration within China

Magnet: 2 Tesla, 2.1 m radius
Thin (~ 30 cm), low-mass (~0.8 X_0)

Vertex: Similar to CEPC default

Drift chamber: 4 m long; Radius ~30-200 cm

Preshower: ~1 X_0

Dual-readout calorimeter: 2 m/8 λ_{int}

(yoke) muon chambers

Integrated into Conceptual Design Report

Dual readout calorimeter: Chapter 5

Drift chamber: Chapter 4

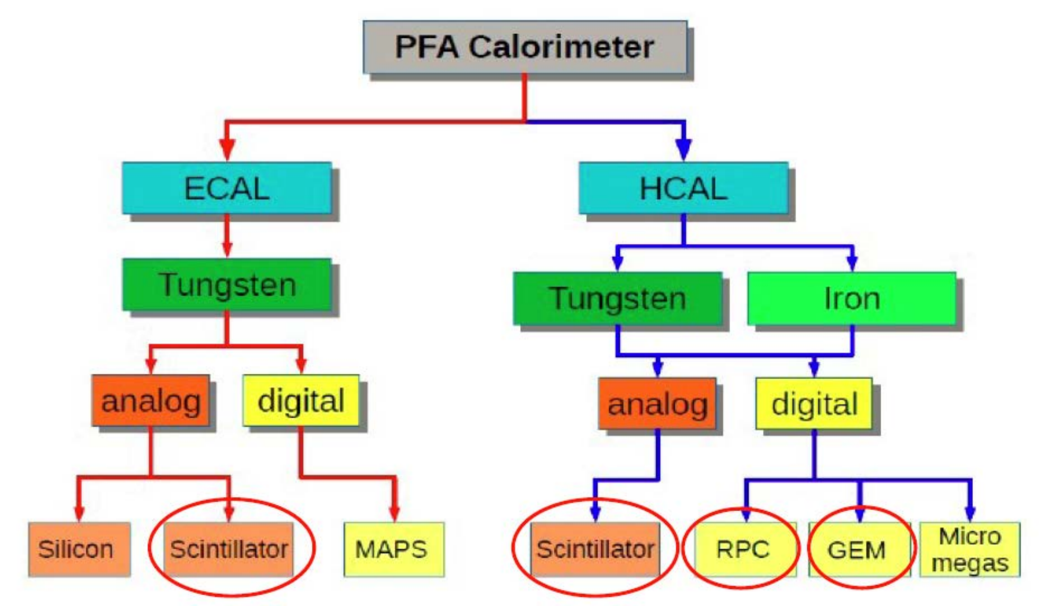
Muon detector (μRwell): Chapter 7

CEPC Calorimeter Options

Chinese institutions have been focusing on Particle Flow calorimeters

R&D supported by MOST, NSFC and IHEP seed funding

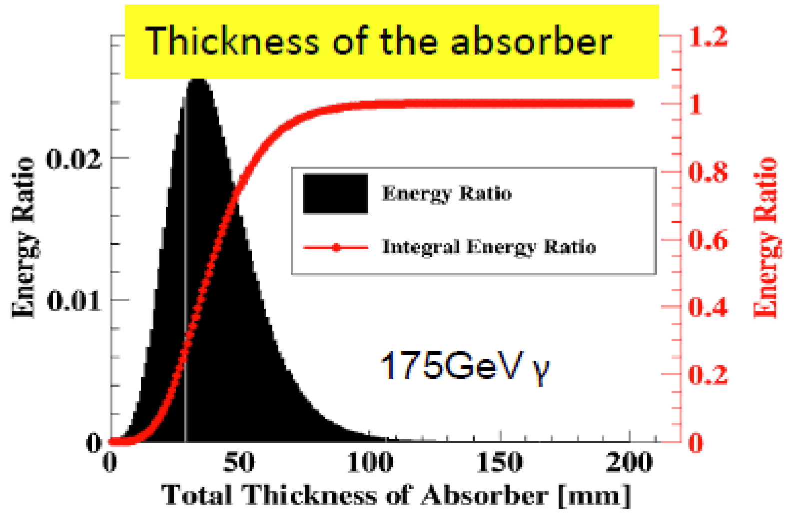
CALICE
Calorimeter for ILC

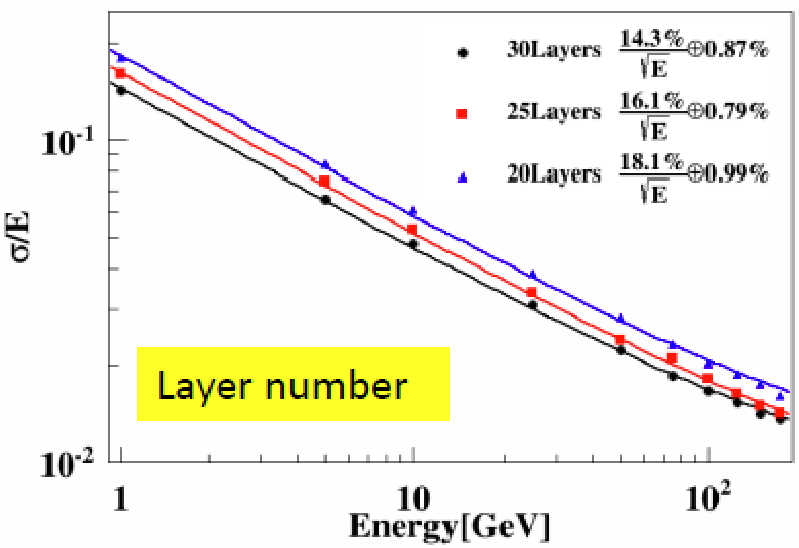


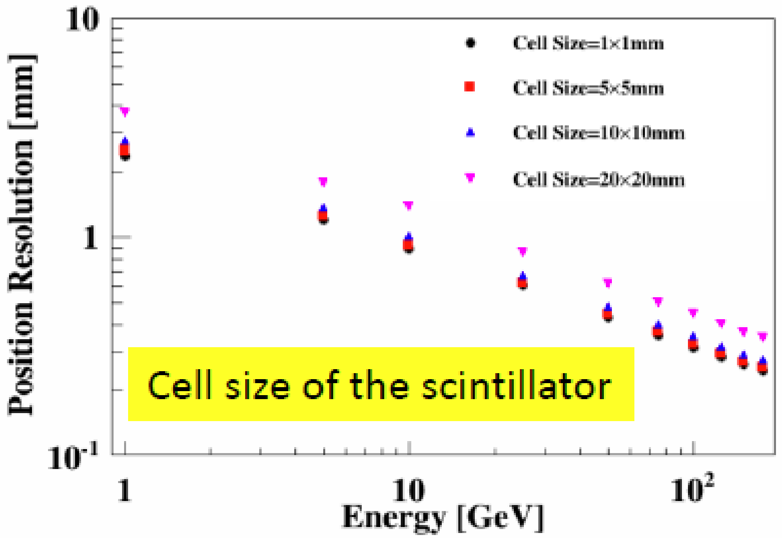
Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) (*) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	(*) SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) (*) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)
New →	(*) Dual readout calorimeters (INFN, Italy + Iowa, USA)

Optimization of Scintillator-tungsten ECAL

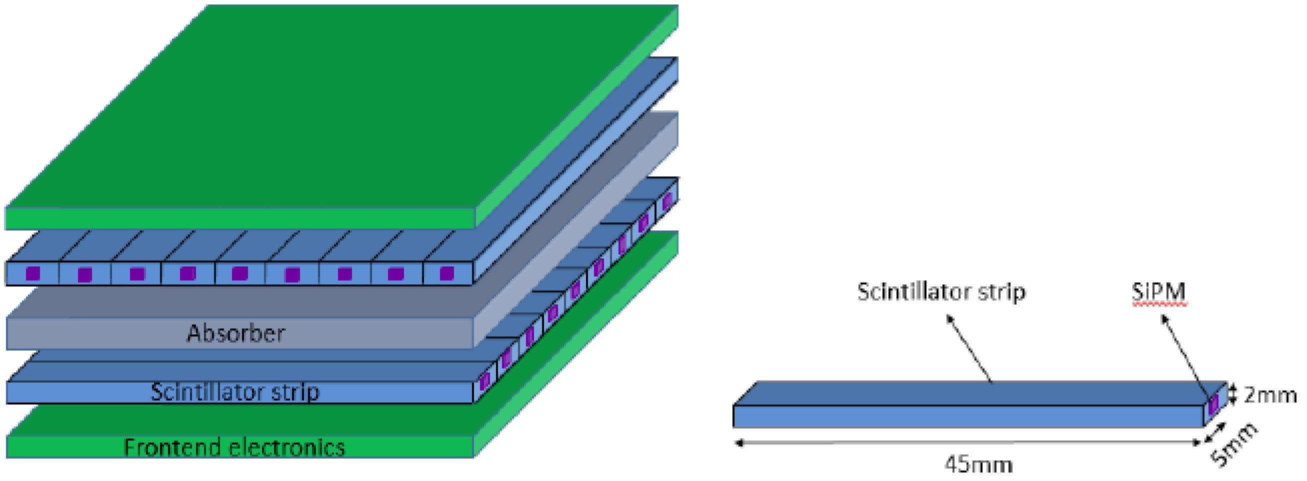
- Simulation and optimization of the structure and geometry to determine the key parameters
  - Total Thickness of the absorber: 80~90mm
  - Layer number: 25
  - Granularity: 5mm × 5mm
  - Thickness of the scintillator: 2mm





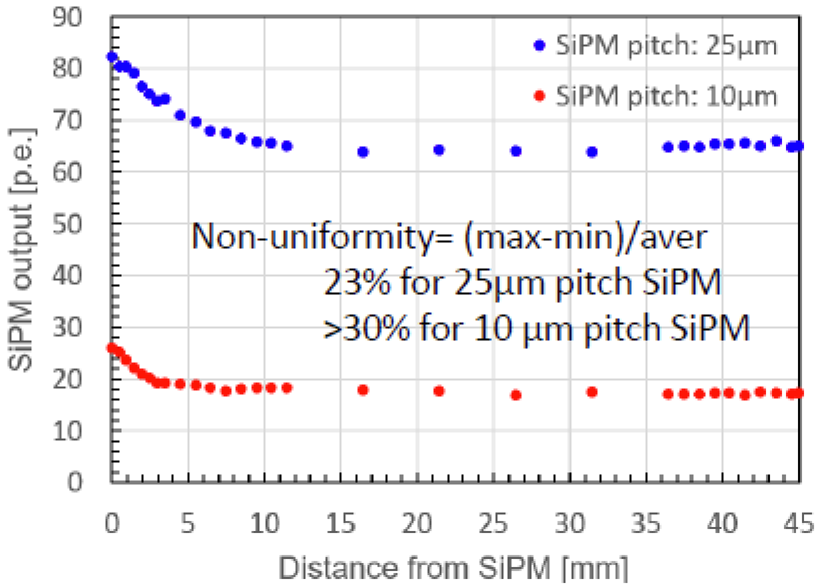


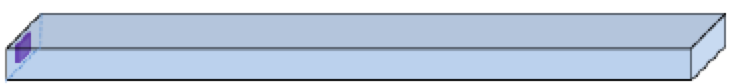
Design of scintillator module



- Scintillator strip module is designed as strip wrapped with enhanced specular reflector (ESR)
- Scintillator dimension : 5mm×45mm×2mm
- Cross arrangement of neighboring layers → a transverse readout cell size of 5×5 mm^2
- Reduction of the readout channels → low cost
- SiPM coupled at the side or the bottom of the scintillator strip → few or negligible dead area

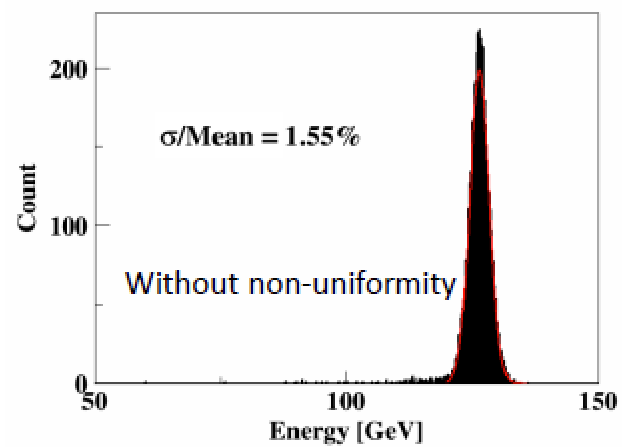
Light output and uniformity test

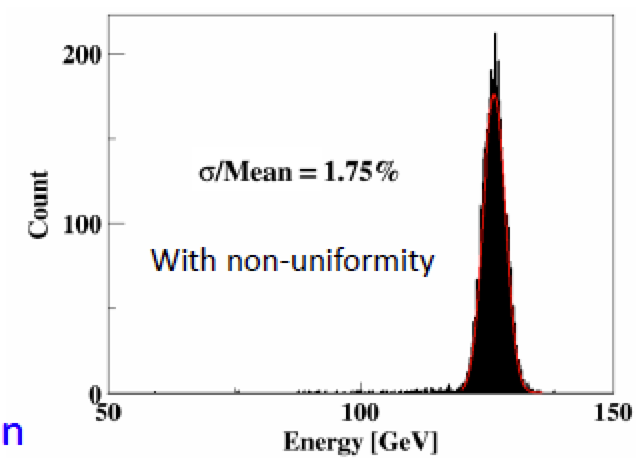




Typical output with SiPM (Hamamatsu S12571-025P or 010P) coupled at the side of the scintillator

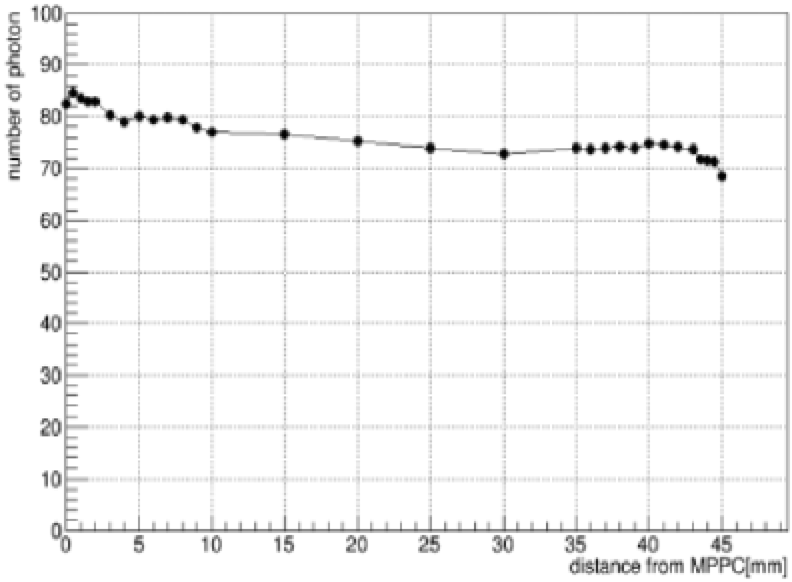
- Light output is non-uniformity along the length of the scintillator, degrades the energy resolution
- Need to be optimized



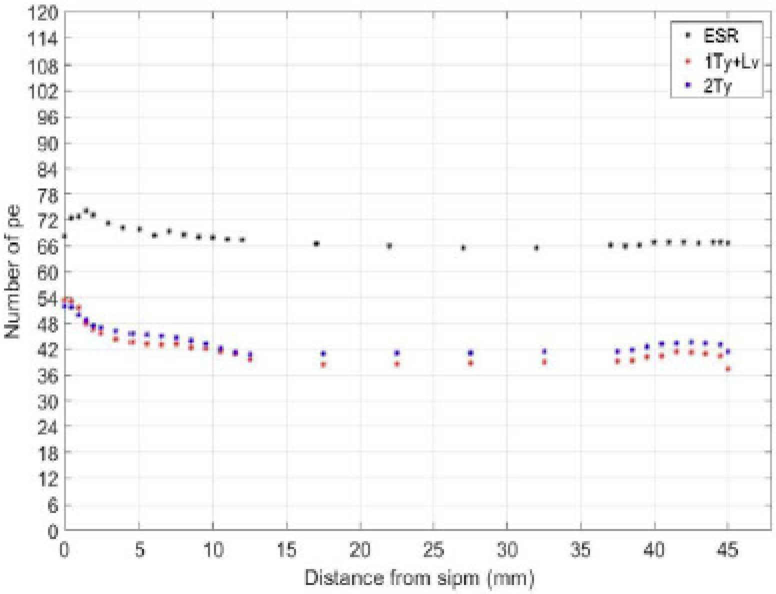


Energy reconstruction of ννHiggs→ γγ

Module optimization (reflective layer)



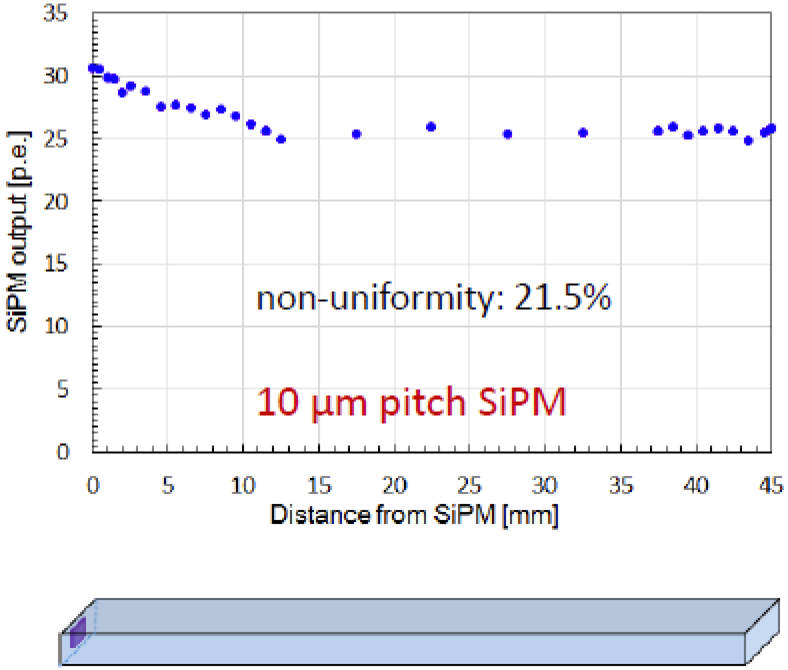
Strip with rough reflective surfaces

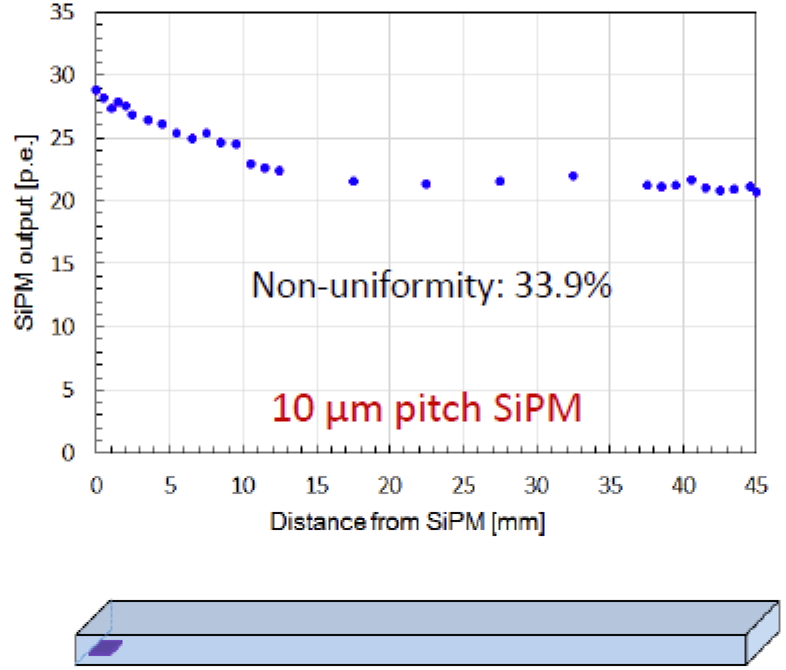


Strip wrapped with different reflective layer

- Rough reflective surfaces vs. polished surfaces
- Diffuse reflective layer vs. ESR
- Slightly improve the uniformity, but not good enough.

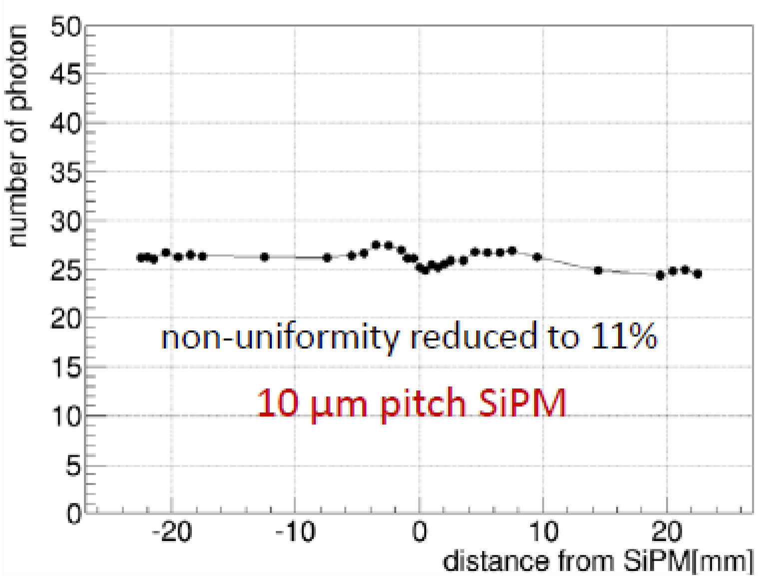
Module optimization (SiPM coupling mode)

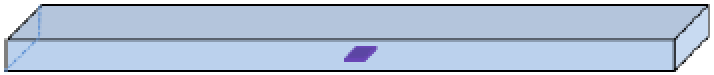




- SiPM (Hamamatsu S12571-010P)embedded at side-end of the strip or the bottom-end of the strip
- Uniformity of light output is not improved

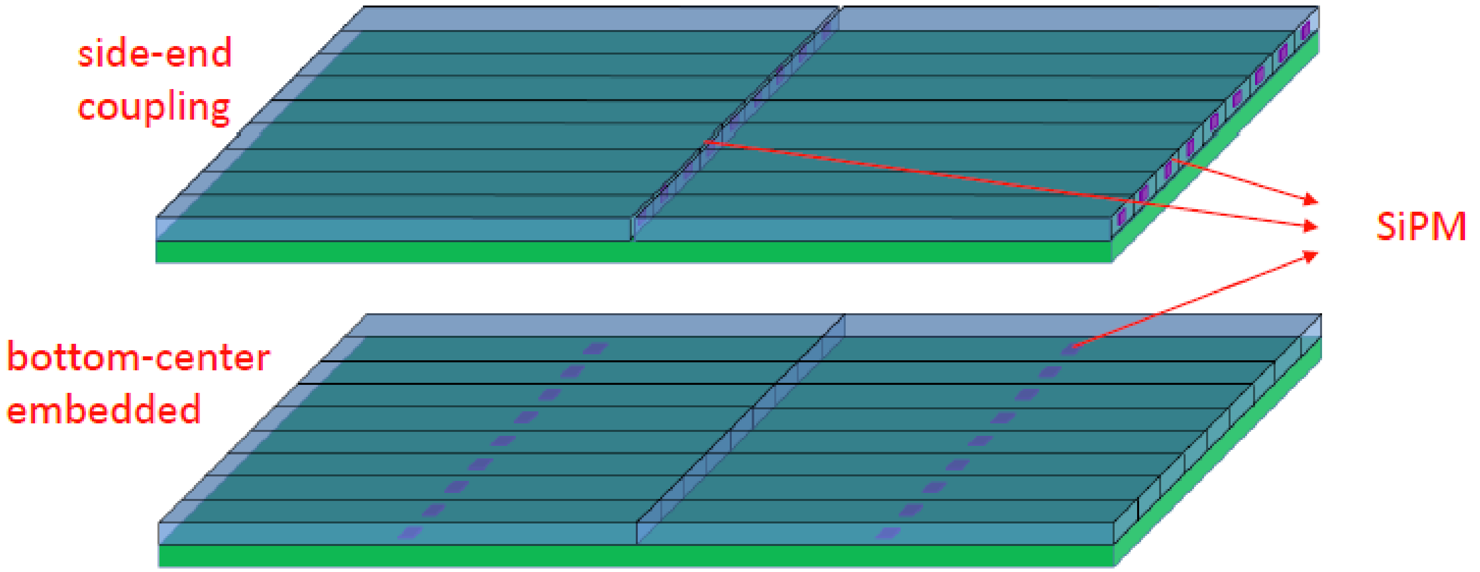
Module optimization (SiPM coupling mode)





- SiPM embedded at bottom-center of the strip
- Uniformity of light output is improved significantly

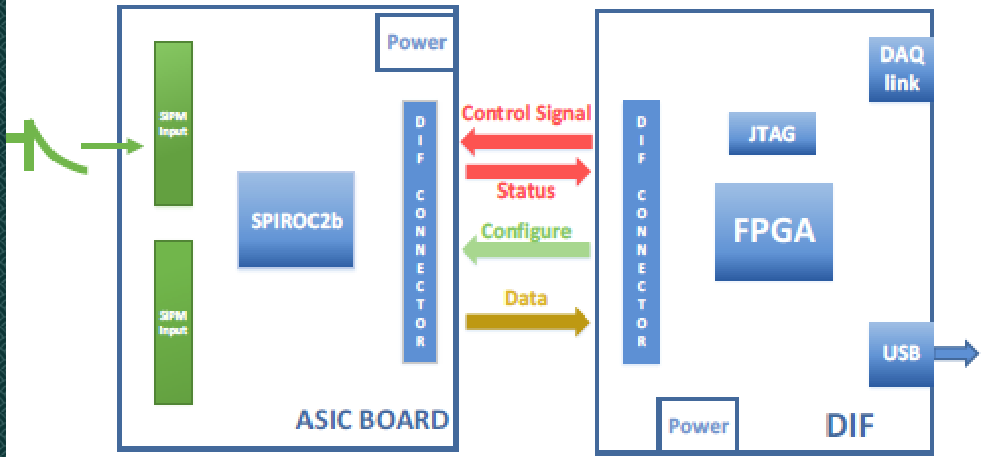
SiPM bottom-center embedded coupling



SiPM bottom-center embedded coupling mode will be adopted in the construction of the ScW ECAL prototype

- Improve the uniformity → The non-uniformity can reach about 10%
- No gap between the scintillators → Avoid the dead area
- Easy to operation in the prototype construction
- Can use SiPM with larger dimension and more pixels to extend the dynamic range of the SiPM

Electronics Development

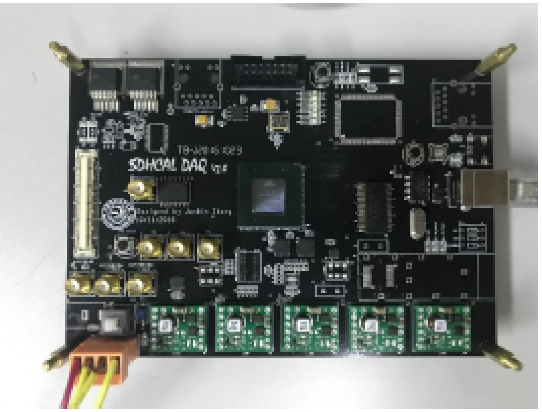


System schematic

- Asic board is developed with **SPIROC2b** chip, which performs amplification, auto-triggering, digitization and zero-suppression
- DIF initializes chips and collects data
- USB for data upload & commands sending
- USB for single DIF, and **serial port for DAQ** when using multiple DIF

✓ The electronics works with good performance

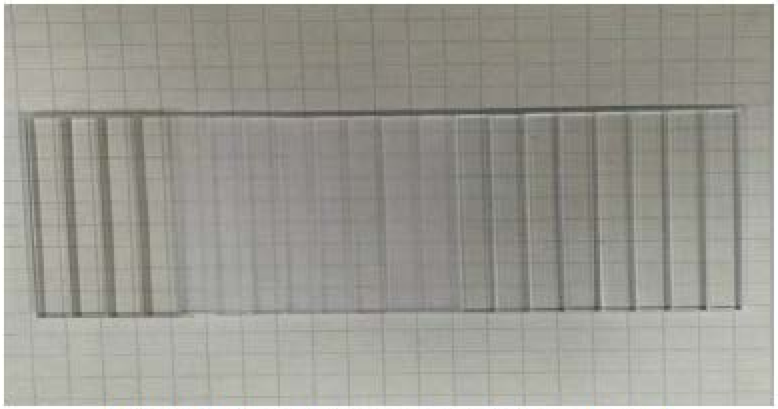
FEB



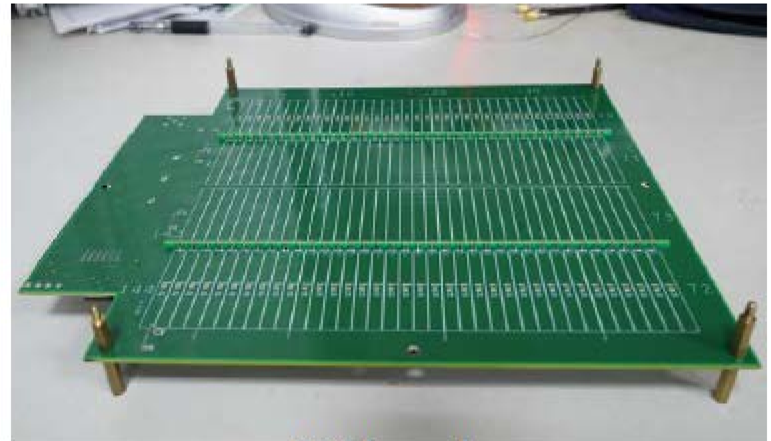
DIF

- Switched capacitor array store charge measurement
- 12 bits ADC conversion
- Variable Gain due to:
  - adjustable Cf of pre-amplifer
  - Rload on the board
  - Shaping time and delay

Preparation for single layer prototype



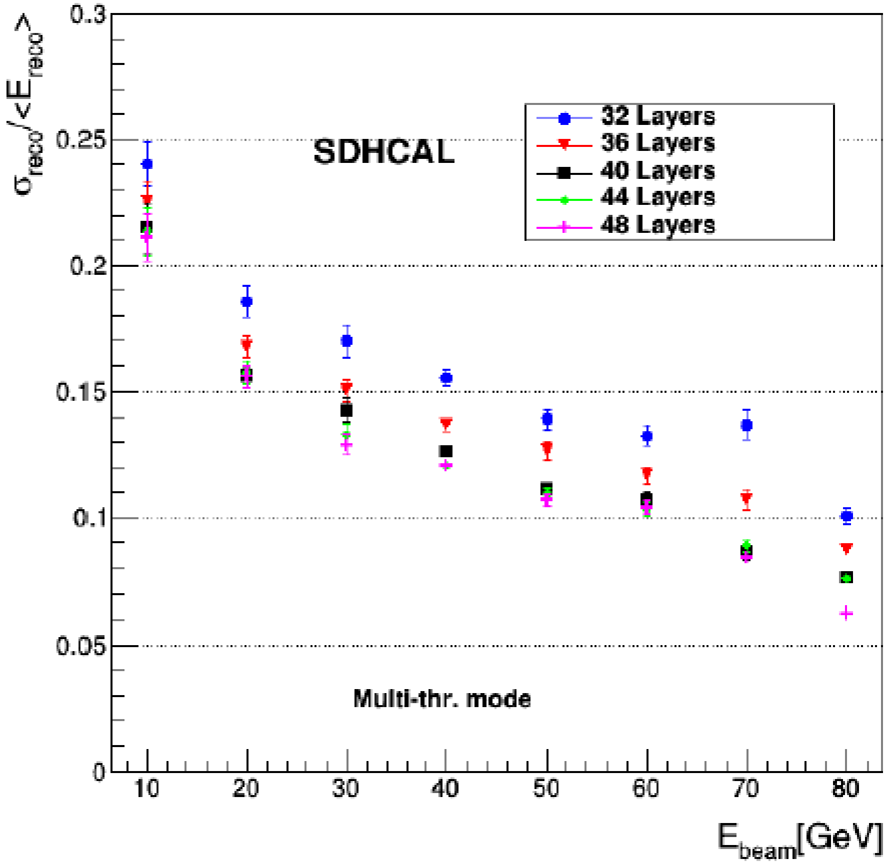
Scintillator strips are incised and wrapped in the SIC (Shanghai Institute of Ceramics)

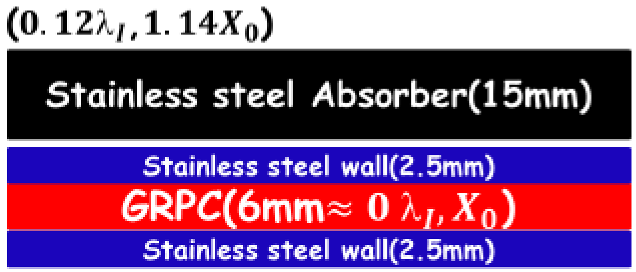


FEE board

- Single layer prototype for the study of module layout, integration, preliminary performance
- Includes 144 scintillator modules (5mm × 45mm × 2mm) with S12571-010P SiPMs
- Half are side-end coupling mode, another half are bottom-center embedded coupling mode

Optimization of HCAL Layers



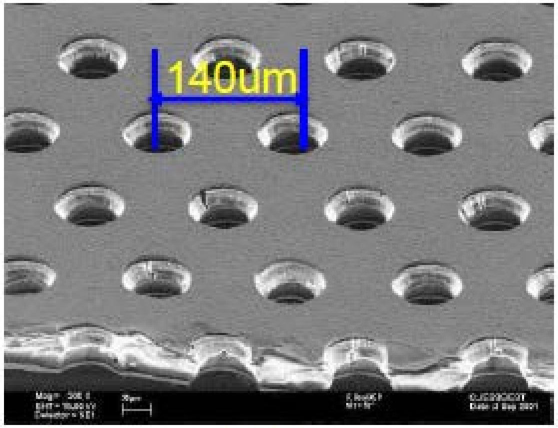


➔SDHCAL has 48 layers which aims for ILC Detector
- 6mm RPC+20mm absorber

➔Optimization no. of layers for CEPC at 240GeV

➔40-layer SDHCAL yields decent energy resolution.

DHCAL based on GEM



Typical parameters

Cu : t = 5μm

Kapton: T = 50μm

Diameter: d = 60μm

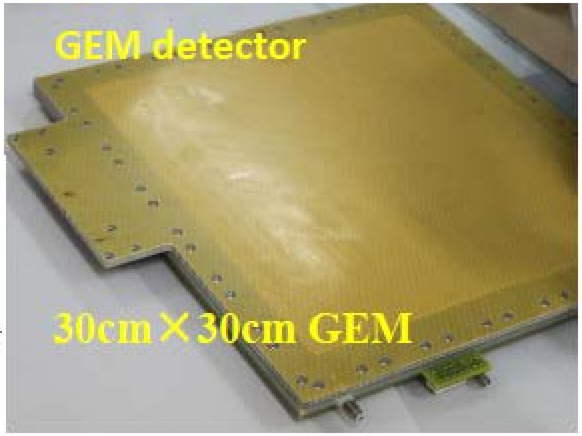
D = 80μm

pitch: 140μm

➢ Advantages:

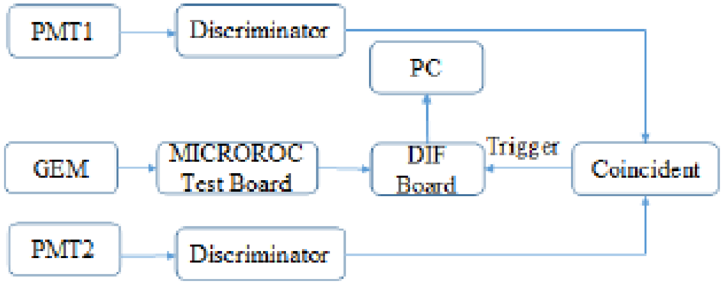
1. assembling process is easy and fast
2. no dead area inside the active area
3. uniform gas flow
4. detachable

Self-stretching technique (from CERN)

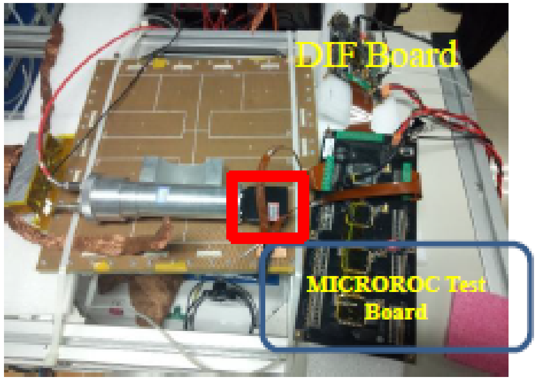


Detection efficiency and multiplicity test

Electronic system based on Microroc chip



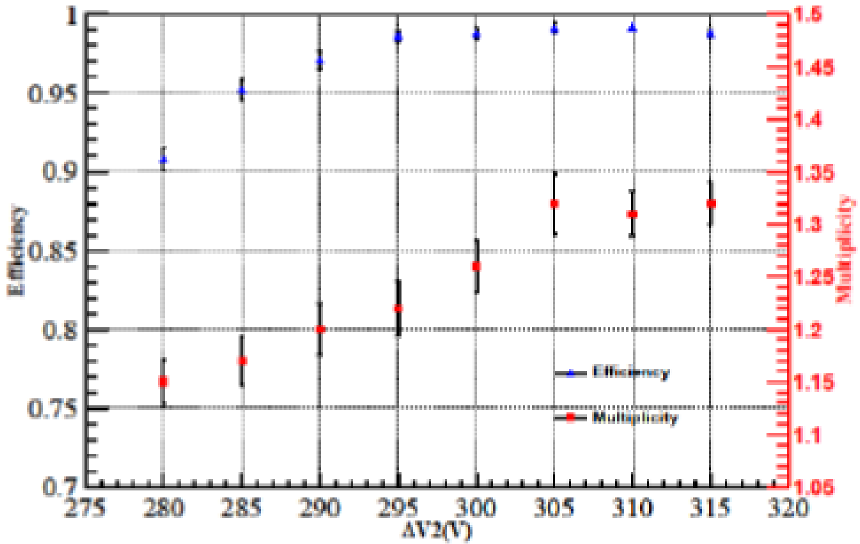
Photograph of the test system



Initial voltage of GEM foil:
△V1: 285 V; △V2: 295 V

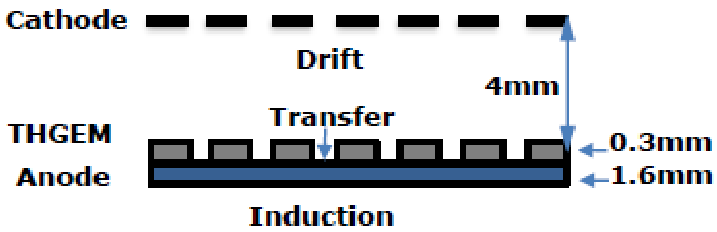
- Edrift: 1.45 kV/cm;
- Etrans: 2.95 kV/cm ;
- Eind: 3 kV/cm

Detection efficiency and multiplicity vary with high voltage

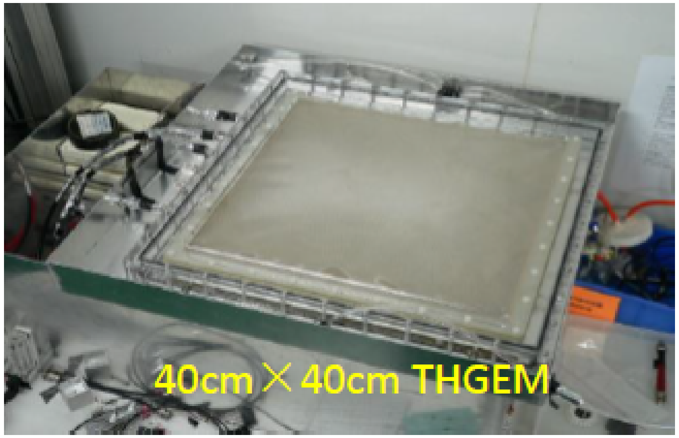


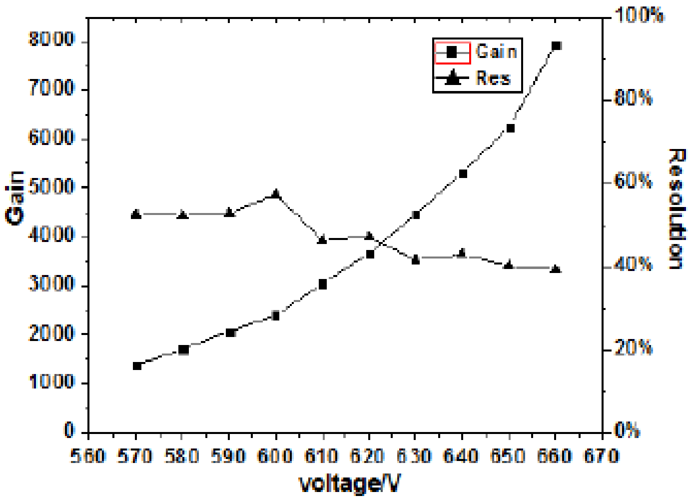
Preliminary study on THGEM-DHCAL

- three structure can be selected;
  - THGEM;
  - WELL-THGEM;
- WELL-THGEM is the-best selection.
  - thinner, high gain, lower discharge



The thickness of WELL-THGEM<6mm



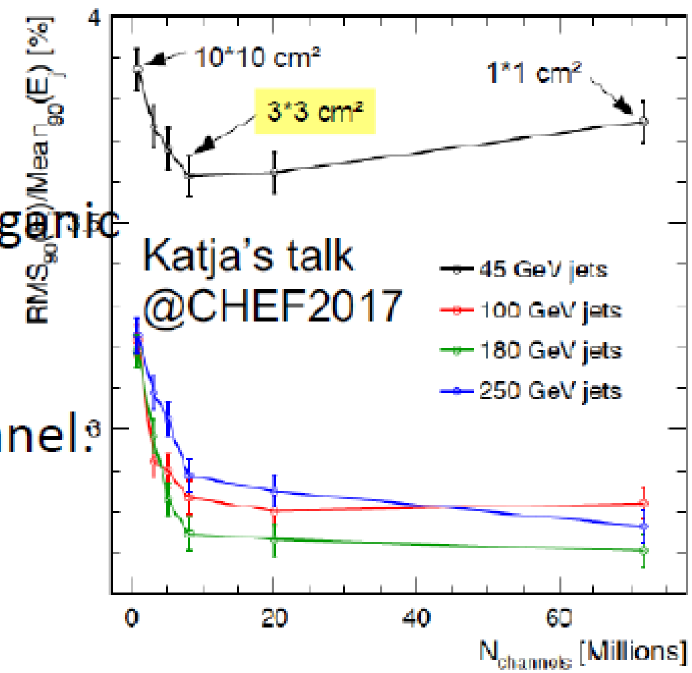


Gain result of 20cmX20cm THGEM

The R&D progress of scintillator AHCAL

— Analog hadron calorimeter for CEPC:

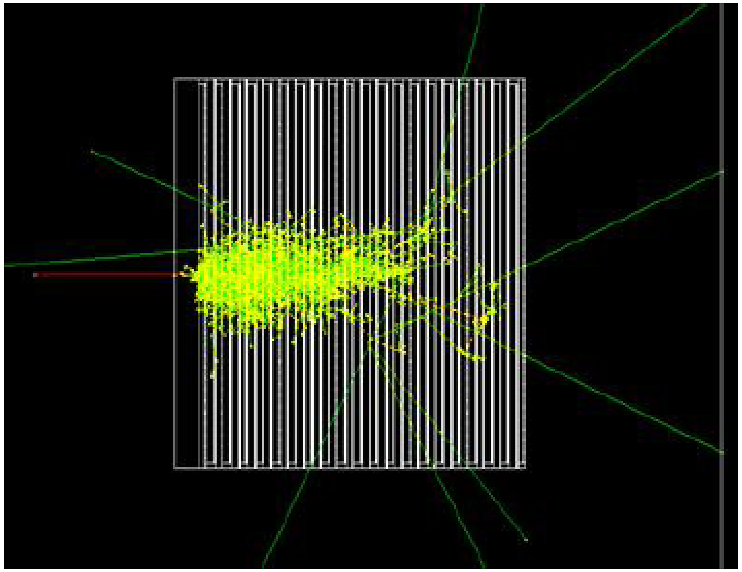
- The absorber: 2cm Stainless steel;
- Detector cell size: 3cm╳3cm (baseline) , 4cm╳ 4cm, 5cm╳ 5cm ;
- Readout chip: ASIC SPIROC2E
- The sensitive detector : Scintillator(organic scintillator);
- 40 sensitive layers, total readout channels ≈6 Million (3cm╳ 3cm)

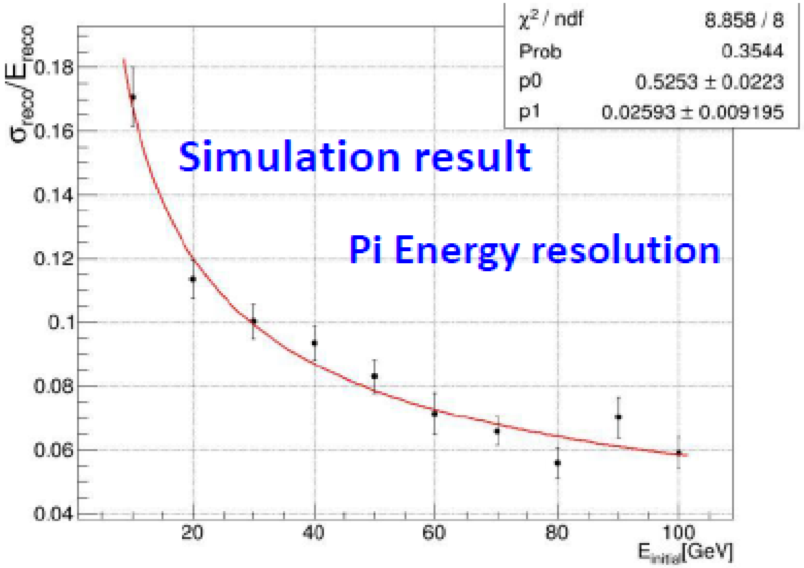


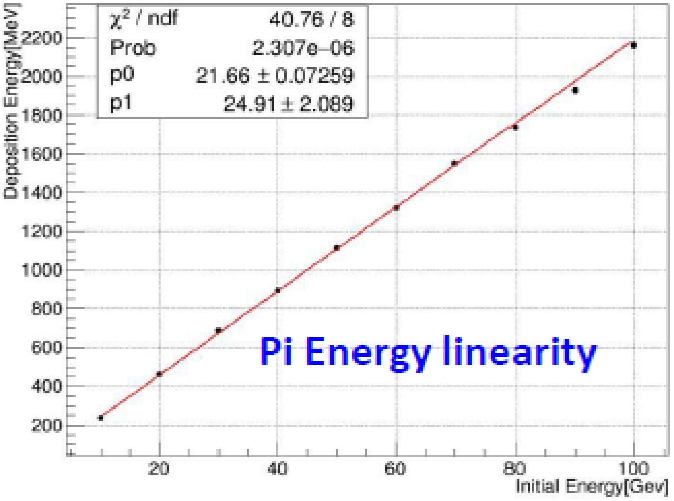
AHCAL prototype Plan

Specification:

- 35 active layers;
- Detector cell:17*17*35=10115;
- Absorber: stainless steel;
- ASIC Chip： SPIROC-2E；
- Prototype size:51*51*87.5cm^3

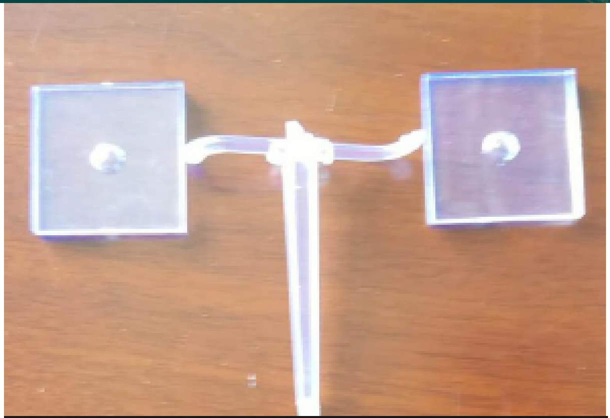


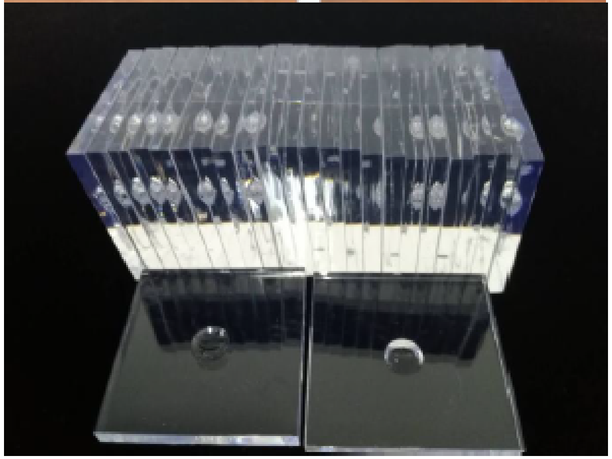




Injection moulded Scintillator tiles

- 4000 tiles polystyrene, POPOP
  - injection moulded at Beijing
  - incl. dimple, no further surface treatment;
- Mechanical tolerances OK for assembly, the size error less than 50um;
- One batch scintillators Light yield is not very uniform, but the problem has been found, caused by material mixer, new batch scintillator under production;

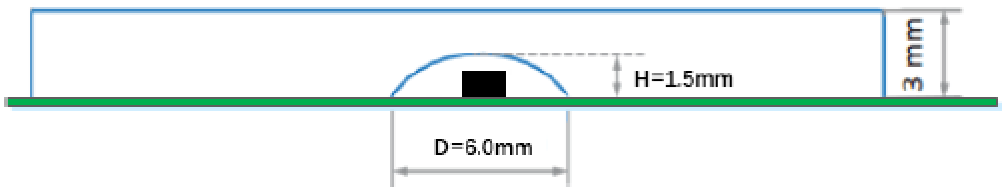




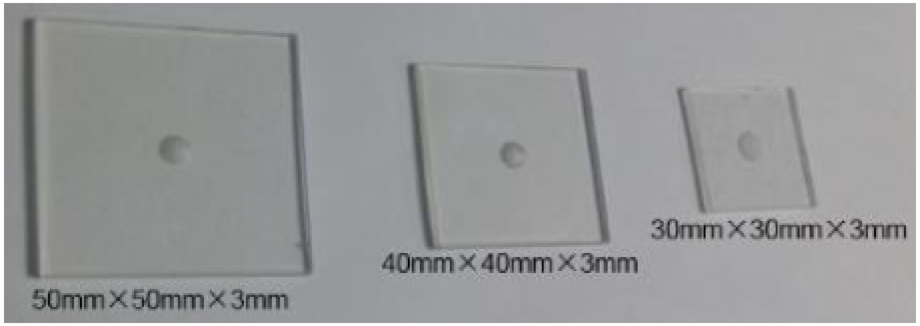
Tiles size(mm)	30.08x30.01 x3.08	30.07x30.04 x3.09	30.04x30.02 x3.09	30.09x30.09 x3.09	30.05x30.03 x3.09
Light yield(p.e.)	23.5	22.78	22.86	25.02	23.54

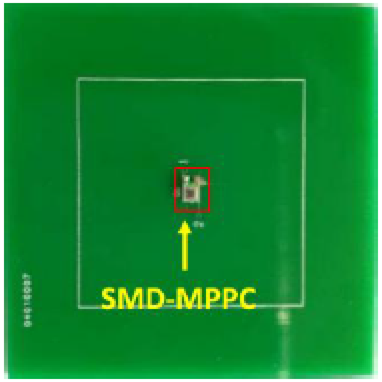
Detector Cells study

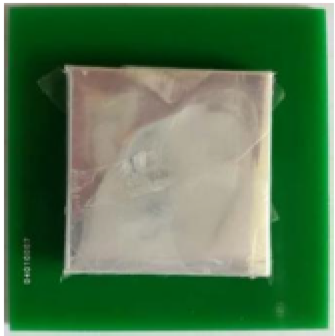
- Via mechanical drilling and polishing, detector cell was made
- The four sizes of 30×30×3mm³,30×30×2mm³ , 40×40×3mm³and 50×50×3mm³ were made.
- SiPM or MPPC(surface-mounted)
- Scintillator(BC408) were wrapped by ESR foil



Scintillator tile wrapped by ESR foil was glued on the PCB

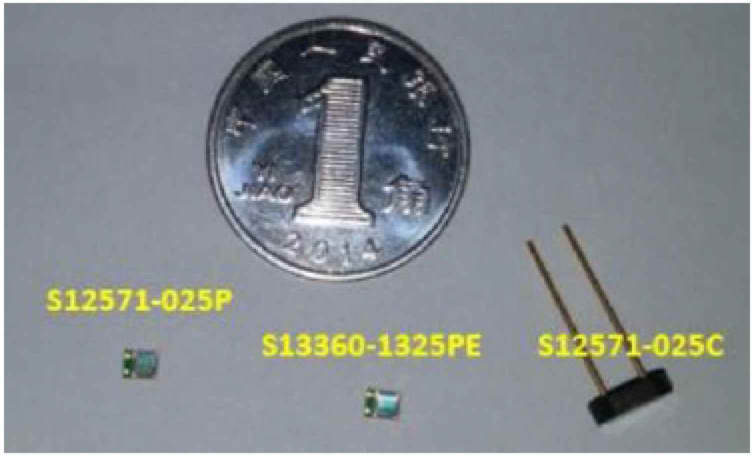


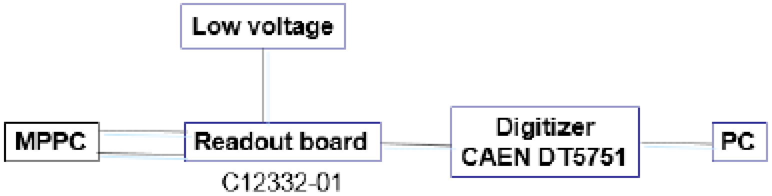




Readout electronics

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

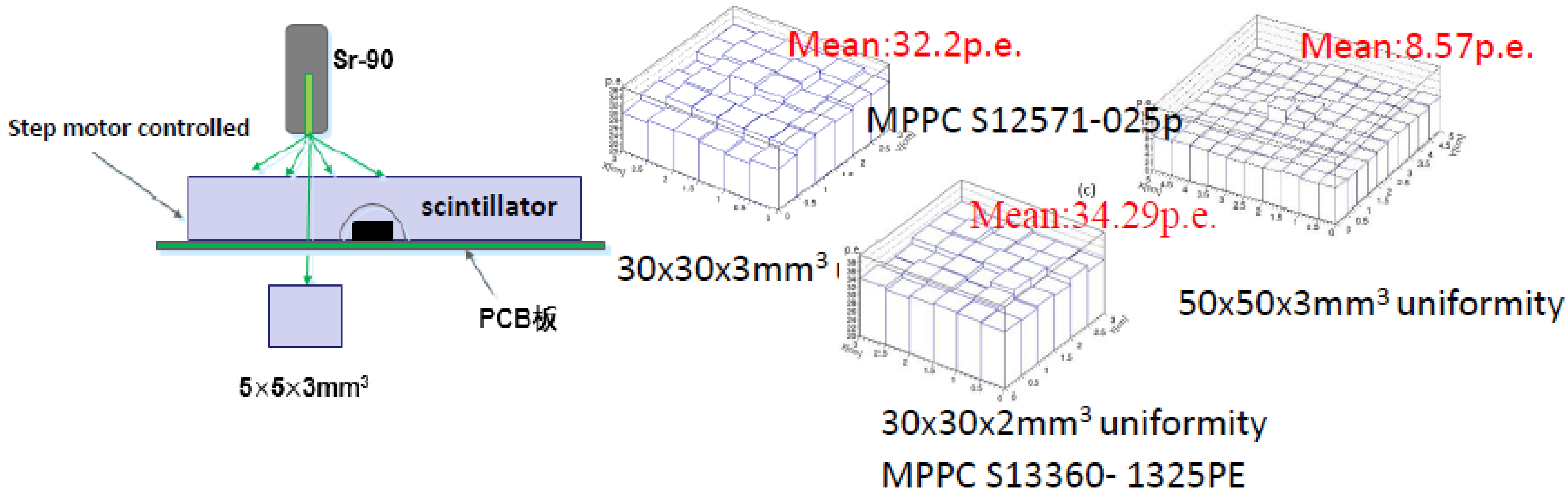




S12571-025P parameter :
Sensitive area :$1 \times 1mm^2$
Pixel size :$25 \times 25\mu m^2$
Pixel number:1600
Gain: 5.15E+05

S13360-1325PE parameter :
Sensitive area :$1.3 \times 1.3mm^2$
Pixel size :$25 \times 25\mu m^2$
Pixel number:2668
Gain: 1.1E+06

Uniformity measurement

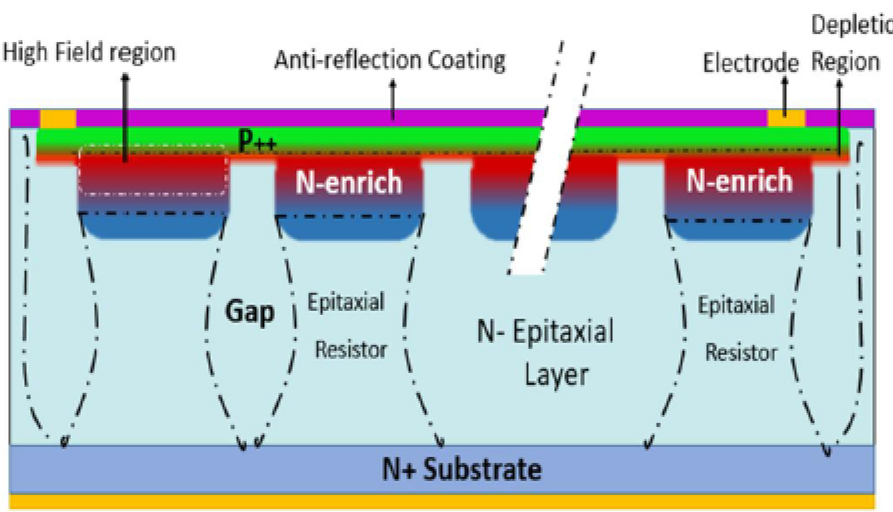


- Uniformity scans (MPPC: S12571-025P and)
- Scintillator tile under study can be moved in a step size of 5×5 mm^2
- 30x30x3mm^3, 30x30x2$mm^3$and 50x50x3mm^3 were measured .

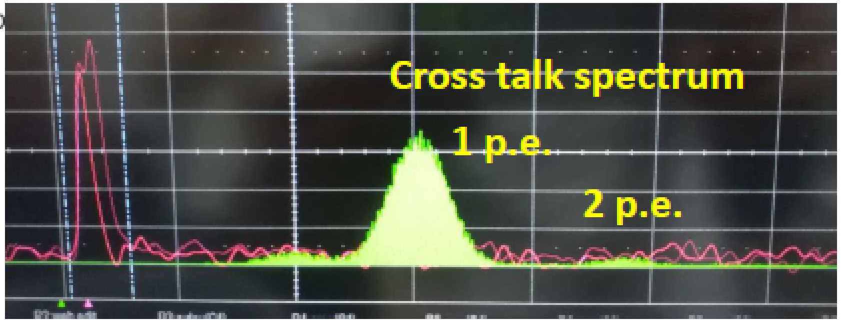
- The mean response can reach 100%,94% within 10% deviation from the mean value, respectively.

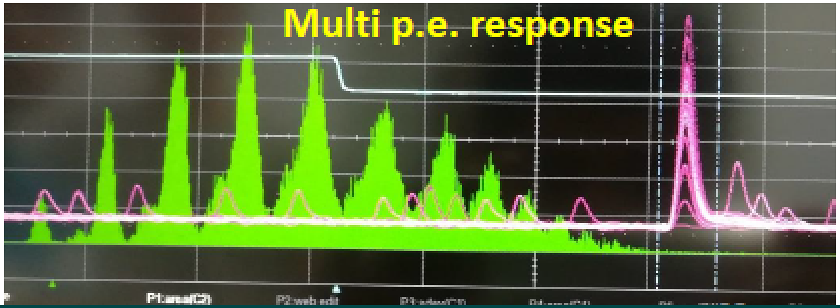
Chinese EQR SiPMs
Developed by Beijing Normal University

- 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 AHCAL.**



Schematic structure of EQR SiPM



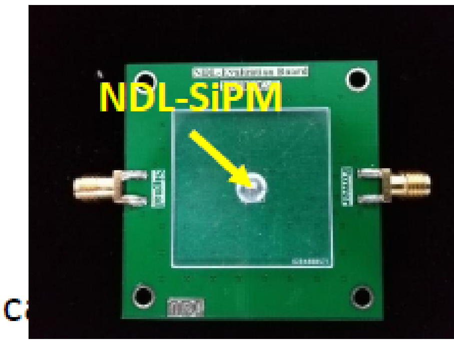


NDL-SiPMTest result

1mmx1mm10umSiPM -new type

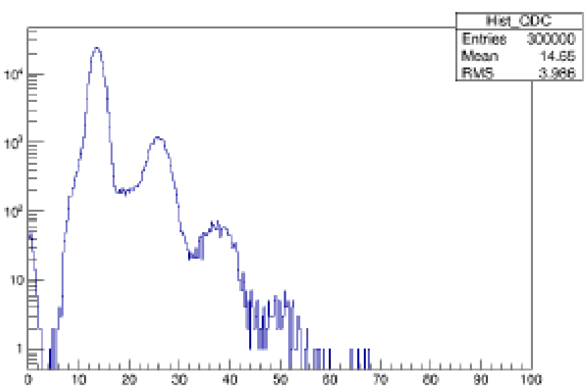
Six NDL-SiPMs was tested: 30mmx30mmx3mm with PL Scintillator

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



The light yield deviation smaller than 2p.e.

All SiPMs' high Voltage are 35V, each of which is measured after c



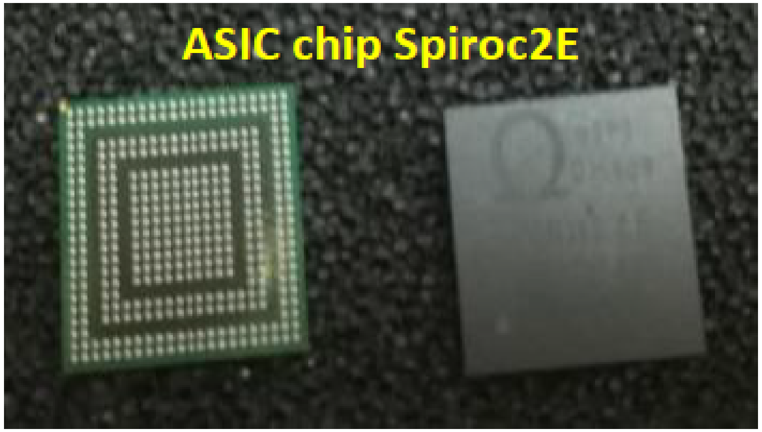
Crosstalk spectrum

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±0.2 V	Gain	$\geqslant 2\times 10^5$
Max. Overvoltage (ΔV_{max})	8 V	Single Photon Time Resolution	≤ 70 ps

CEPC-AHCAL Next

- ASCI chip readout study;
- Injection moulded plastic scintillator production;
- Test the Chinese NDL-SiPM;
- Detector cell test system construction;
- Simulation and optimization AHCAL



Summary

- CEPC CDR will be released this year
- R&D is on progress
- One ScW ECAL and Scint-AHCAL prototype will be built

You are welcome to join us !

Thanks !

Detector optimization

	Optimized (CDR)	Comments
B Field	3 Tesla	Required from beam emmitance
TPC radius	1.8 m	Required by $Br(H\rightarrow\mu\mu)$ measurement
TOF	50 ps	Pi-Kaon separation at Z pole
ECAL thickness	84 mm	Optimized for $Br(H\text{->}\gamma\gamma)$ at 250 GeV
ECAL cell size	10 mm	Maximum for EW measurements, better 5 mm but passive cooling needs 20 mm
ECAL num. layers	25	Depends on silicon sensor thickness
HCAL thickness	1 m	
HCAL num. layers	40	Optimized for Higgs at 250 GeV