

High Energy Physics

9 – 26 Jan 2017

Conference: 23 – 26 Jan 2017



Status of CEPC Calorimeters R&D

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(on behalf of the CEPC-Calo Group)



上海交通大學

SHANGHAI JIAO TONG UNIVERSITY

Outline

- ❑ Motivation and goal
- ❑ Calorimeters
 - ❑ ECAL with Silicon and Tungsten
 - ❑ ECAL with Scintillator and Tungsten
 - ❑ HCAL with RPC and Stainless Steel
 - ❑ HCAL with ThGEM/GEM and Stainless Steel
 - ❑ HCAL with Scintillator and Steel
- ❑ Future plan for CEPC-Calo R&D
- ❑ CEPC preCDR documents :
<http://cepc.ihep.ac.cn/preCDR/volume.html>

Requirements for CEPC Detector Design

Critical Physics Benchmarks for CEPC Detectors design.

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \rightarrow \ell^+ \ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \rightarrow \mu^+ \mu^-$	$\text{BR}(H \rightarrow \mu^+ \mu^-)$		$\oplus 1 \times 10^{-3} / (p_T \sin \theta)$
$H \rightarrow b\bar{b}, c\bar{c}, gg$	$\text{BR}(H \rightarrow b\bar{b}, c\bar{c}, gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10 / (p \sin^{3/2} \theta) \mu\text{m}$
$H \rightarrow q\bar{q}, V^+ V^-$	$\text{BR}(H \rightarrow q\bar{q}, V^+ V^-)$	ECAL, HCAL	$\sigma_E^{\text{jet}} / E \sim 3 - 4\%$
$H \rightarrow \gamma\gamma$	$\text{BR}(H \rightarrow \gamma\gamma)$	ECAL	$\sigma_E \sim 16\% / \sqrt{E} \oplus 1\% (\text{GeV})$

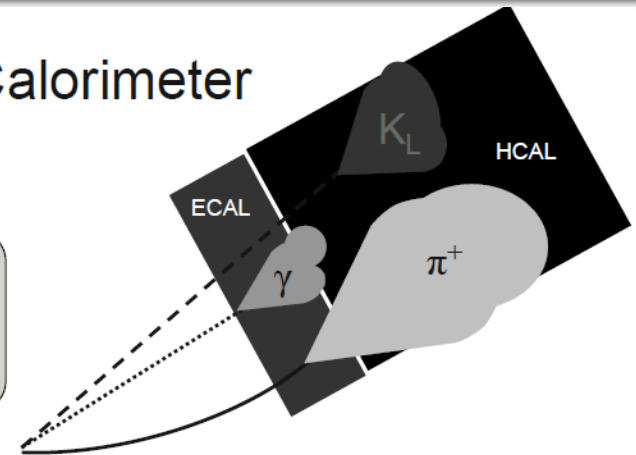
**Goal: Jet Energy Resolution 3 – 4 % or 30% / \sqrt{E} @ 100GeV
based on Particle Flow Algorithm (PFA)**

PFA and Imaging Calorimeter

Particle Flow Algorithms and Imaging Calorimeter

The idea...

Charged particles } measured with the Tracker
 Neutral particles } Calorimeter

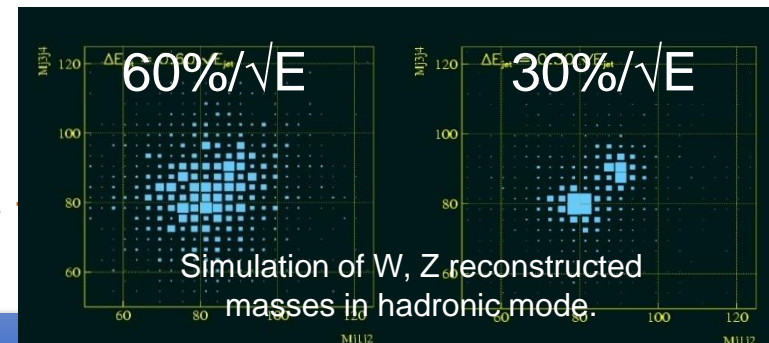


Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with $15\%/\sqrt{E}$	$0.07^2 E_{\text{jet}}$
Neutral Hadrons	10 %	ECAL + HCAL with $50\%/\sqrt{E}$	$0.16^2 E_{\text{jet}}$
Confusion	Required for $30\%/\sqrt{E}$		$\leq 0.24^2 E_{\text{jet}}$

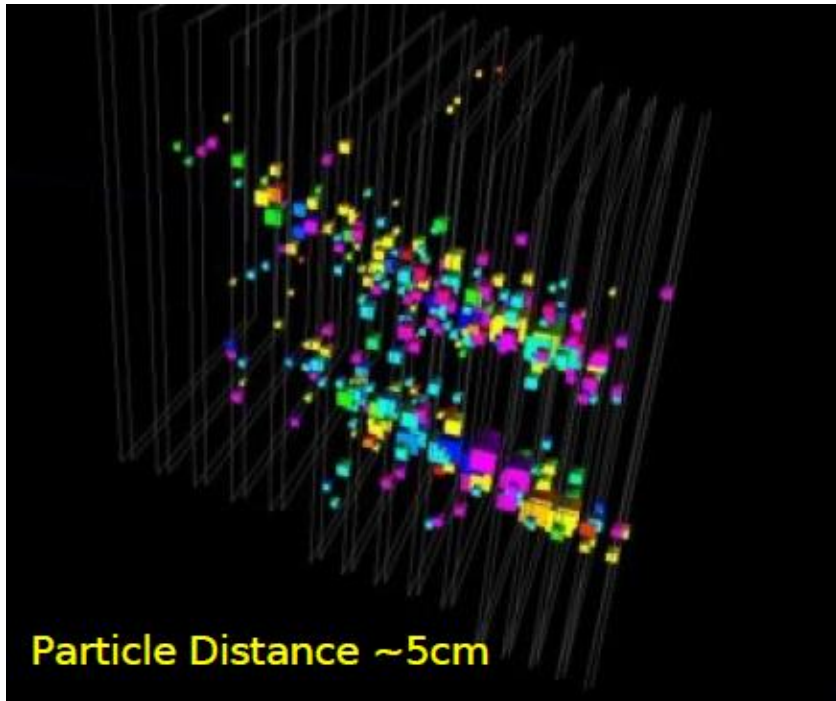
} $18\%/\sqrt{E}$

Requirements for detector system

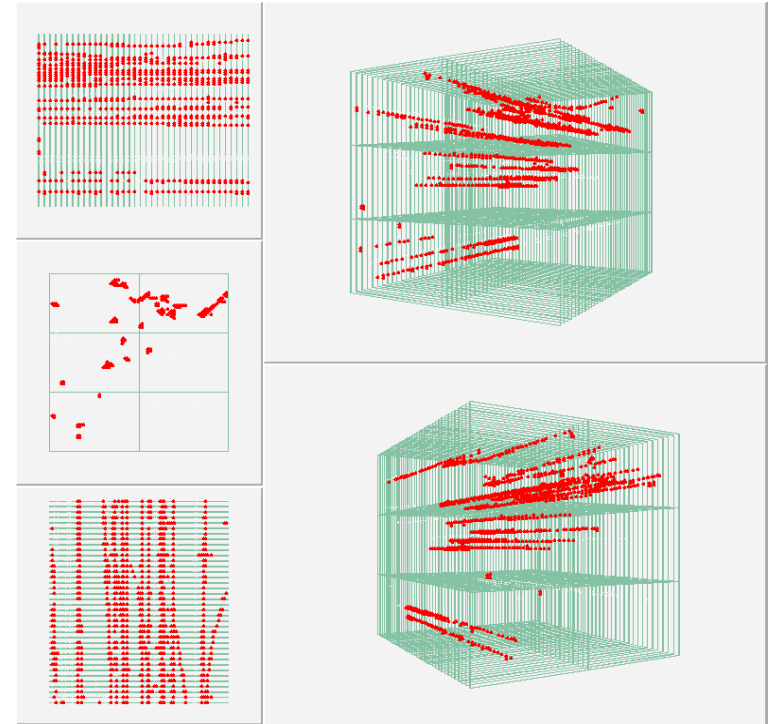
- Need excellent tracker and high B – field
- Large R_1 of calorimeter
- Calorimeter inside coil
- Calorimeter as dense as possible (short X_0 , λ_I)
- Calorimeter with **extremely fine segmentation**



Imaging Calorimeters



Two electrons ~5cm apart
CALICE SiW ECAL



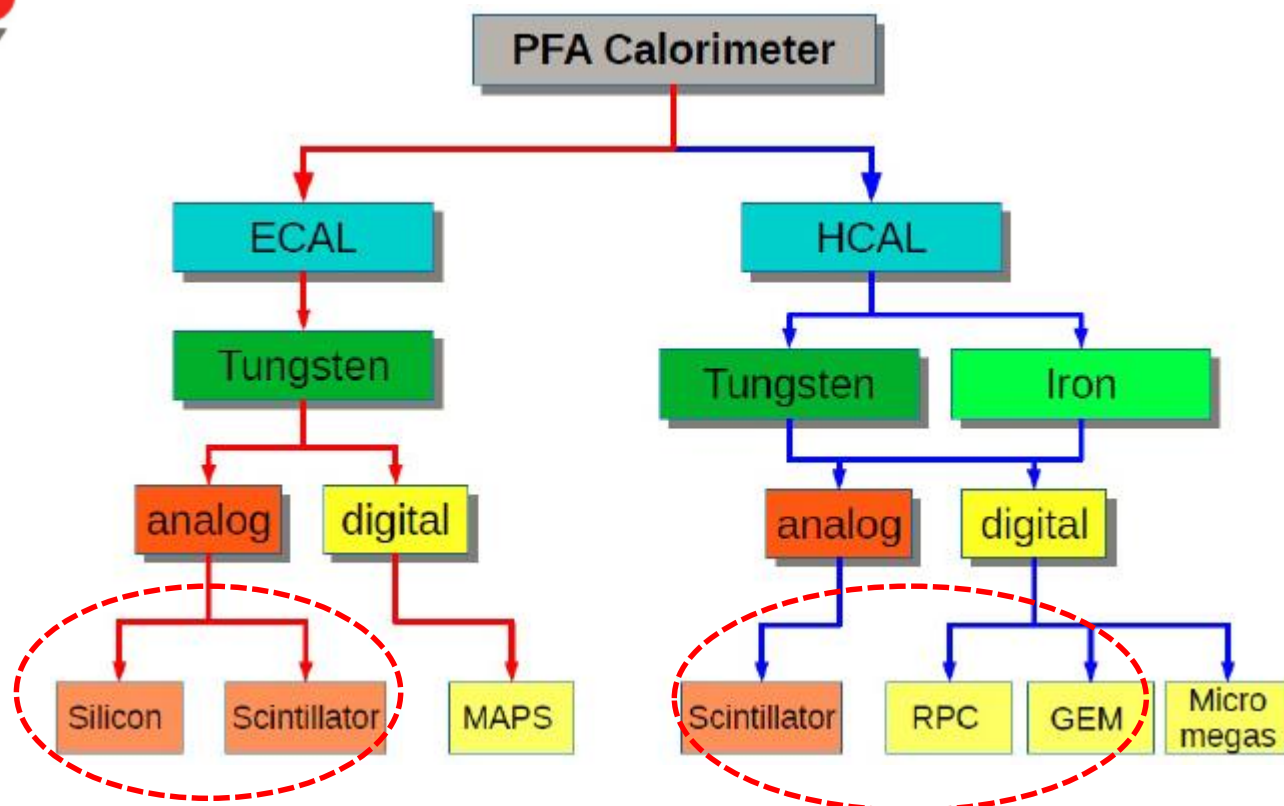
~20 muons in 1m² area
CALICE RPC DHCAL

This is exactly what PFA needs: distinguishing individual showers within jet environment, in order to get excellent jet energy/mass resolution

CALICE: Imaging Calorimeter



<https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers>



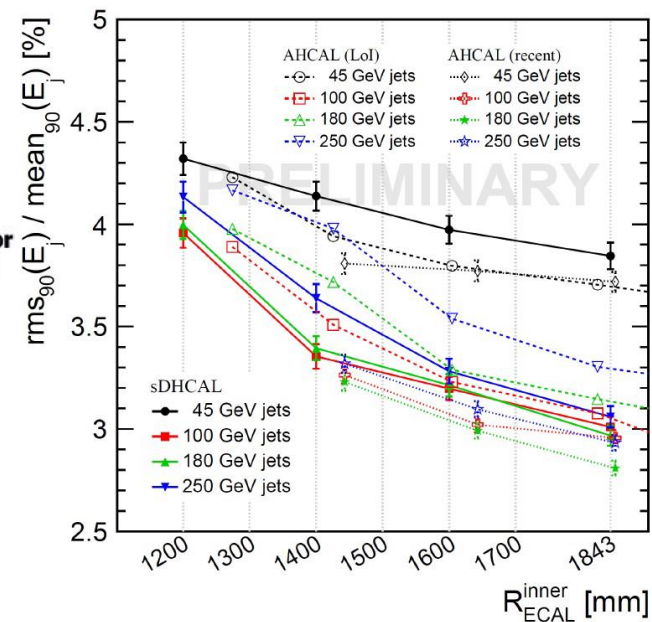
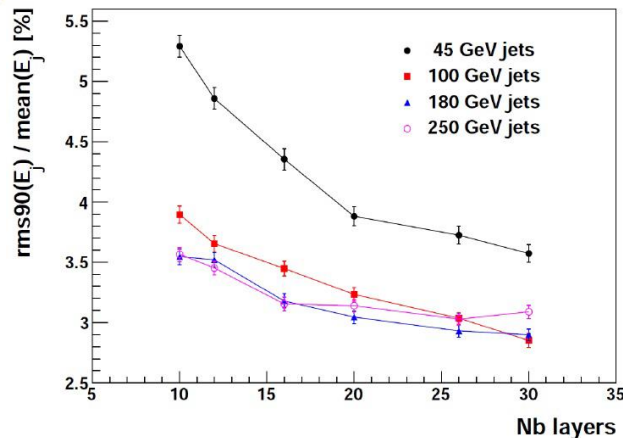
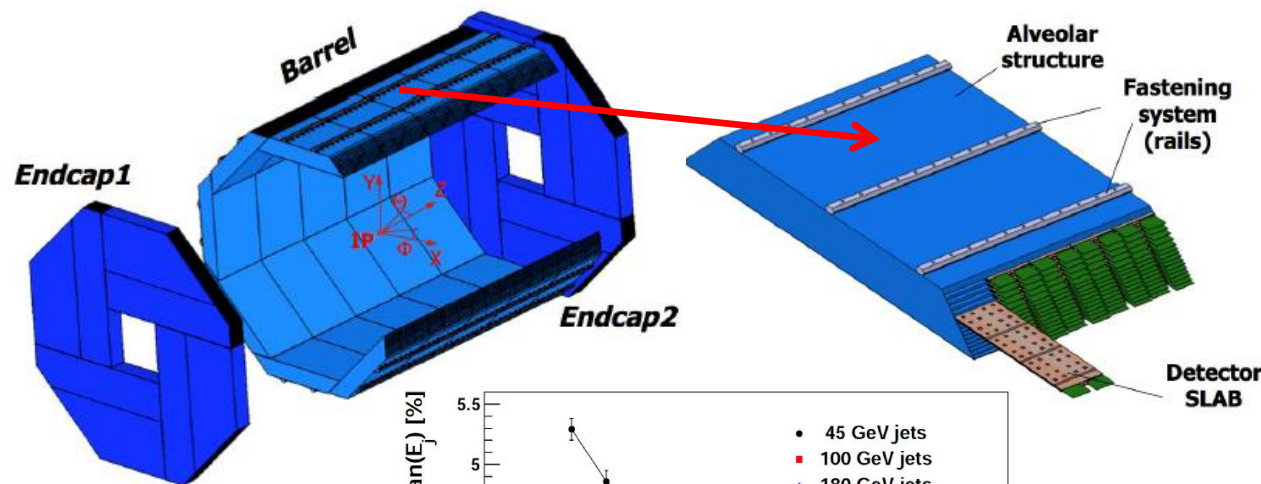
Readout cell size: $144 - 9 \text{ cm}^2 \rightarrow 4.5 \text{ cm}^2 \rightarrow 1 \text{ cm}^2 \rightarrow 0.25 \text{ cm}^2 \rightarrow 0.13 \text{ cm}^2 \rightarrow 2.5 \times 10^{-5} \text{ cm}^2$

Technology: Scintillator + SiPM/MPPC Scintillator + SiPM/MPPC Gas detectors Silicon Silicon Silicon Silicon (MAPS)

CEPC ECAL: Silicon-W

V. Boudry @ IN2P3

- The ECAL consists of a cylindrical barrel system and two large end caps.
- Two detector active sensors interleaved with tungsten absorber
 - silicon pixel 5 x 5 mm²; PCB with VFE ASIC

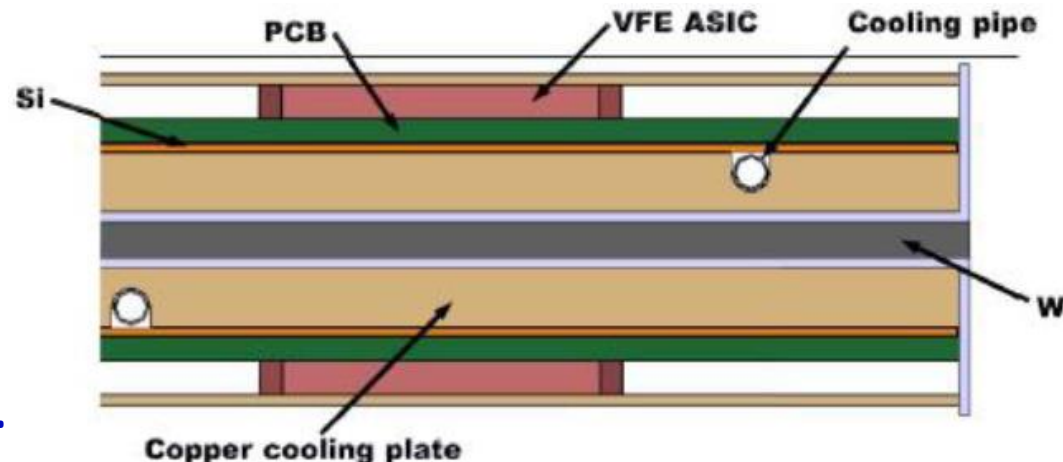


Active Cooling System

- CEPC is designed to operate at continuous mode with beam crossing rate: 2.8×10^5 Hz. Power pulsing will not work at CEPC.
- Compare to ILD, the power consumption of VFE readout electronics at CEPC is about two orders of magnitude higher, hence it requires an active cooling
 - Evaporative CO_2 cooling in thin pipes embedded in Copper exchange plate.
 - For CMS-HGCAL design: heat extraction of 33 mW/cm^2 , allows operation with $6 \times 6 \text{ mm}^2$ pixels with a safety margin of 2

➔ Transverse view of the slab with one absorber and two active layers.

➔ The silicon sensors are glued to PCB with VFE chips, cooled by the copper plates with CO_2 cooling pipes.

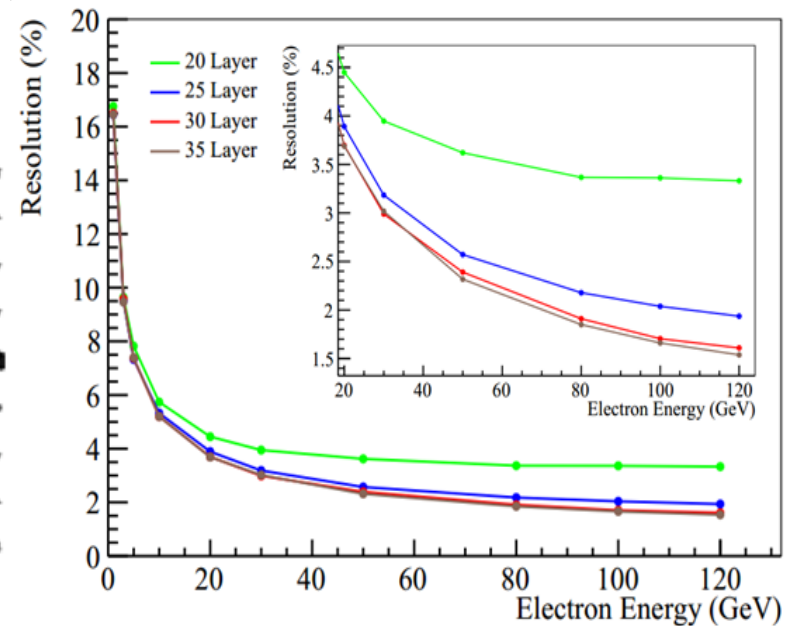
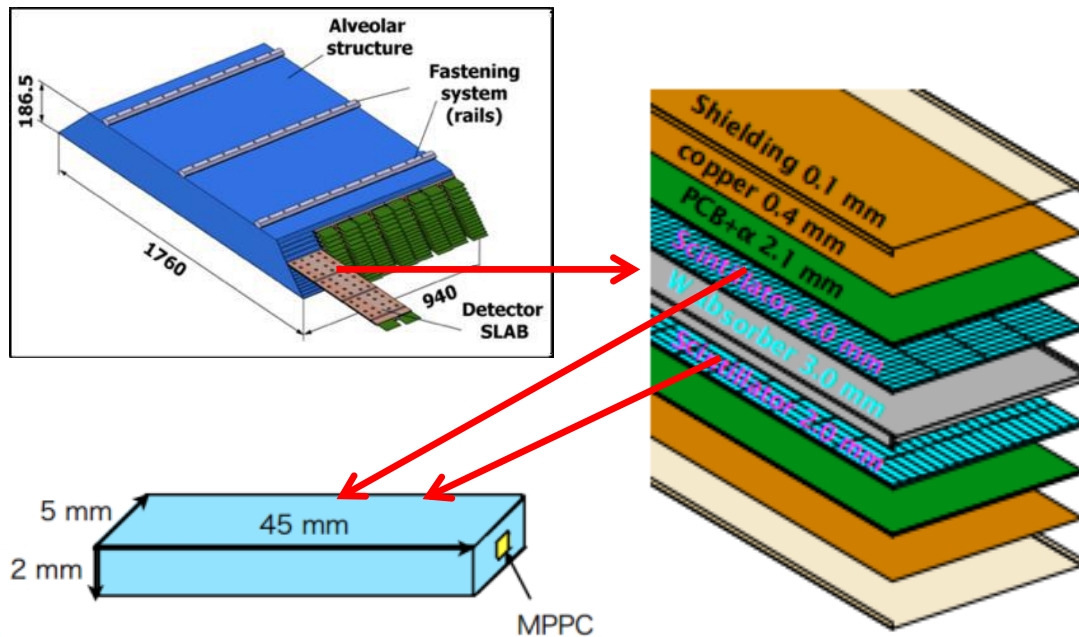


ECAL: Scintillator-W

Zhigang Wang et.al.

A super-layer (7mm) is made of:

- Plastic scintillator (2mm) + Tungsten plate as absorber (3mm thick)
- A readout/service layer (2mm thick)



Scintillator + W + Scintillator

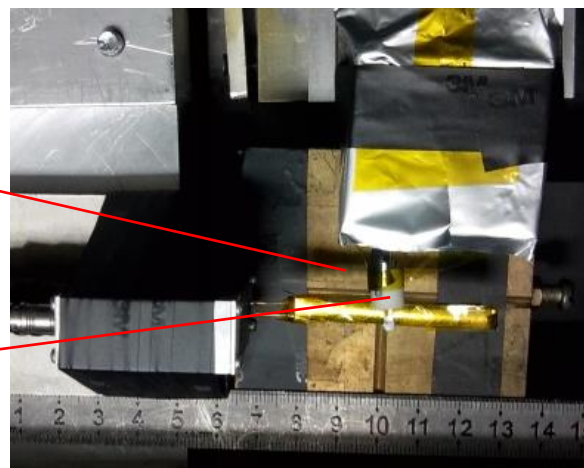
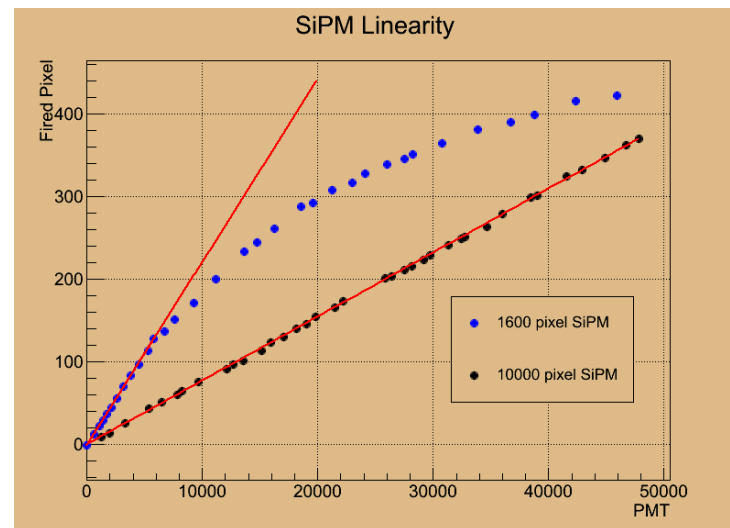
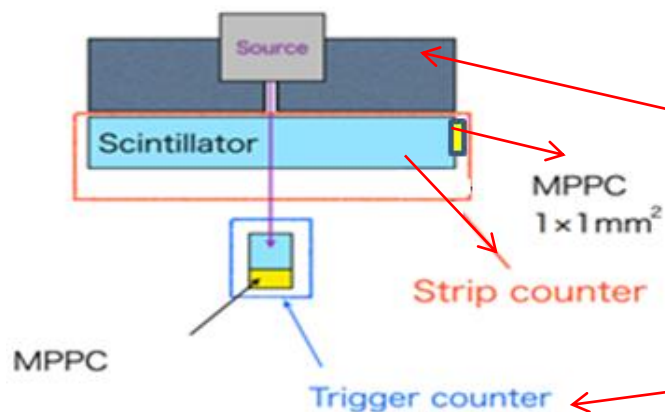
- The energy resolution of 25GeV electron is about 3.3% (cf. CALICE TB results)
- To achieve required energy resolution, the number of layers should be ~ 25.

Test of SiPM (IHEP, USTC)

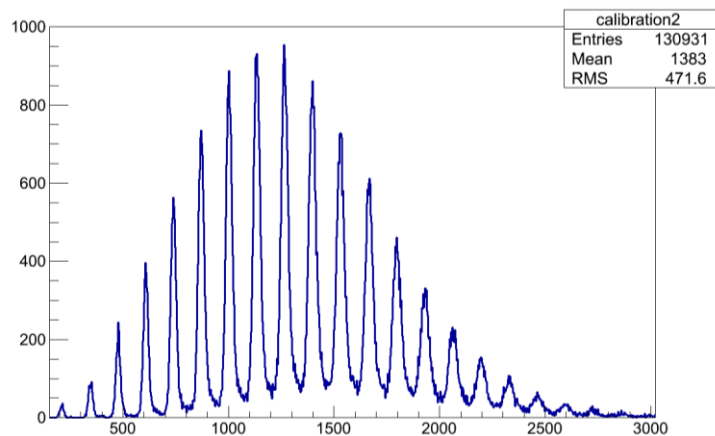
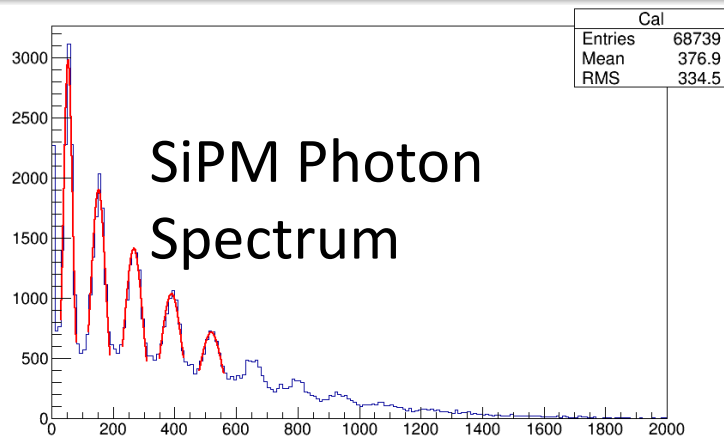
➔ SiPM linearity range depends on number of pixels.

➔ Photon detection efficiency for SiPM (10 μ m) is about 1/3 of that for SiPM (25 μ m).

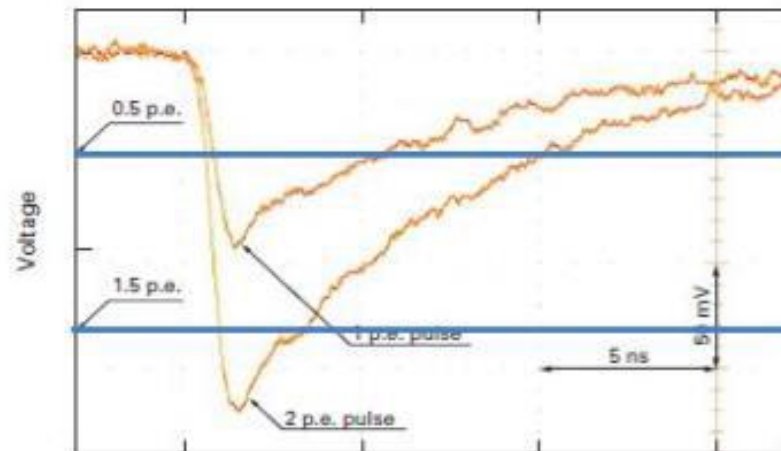
Scintillator strip irradiated with β collimated (1mm) from Sr-90



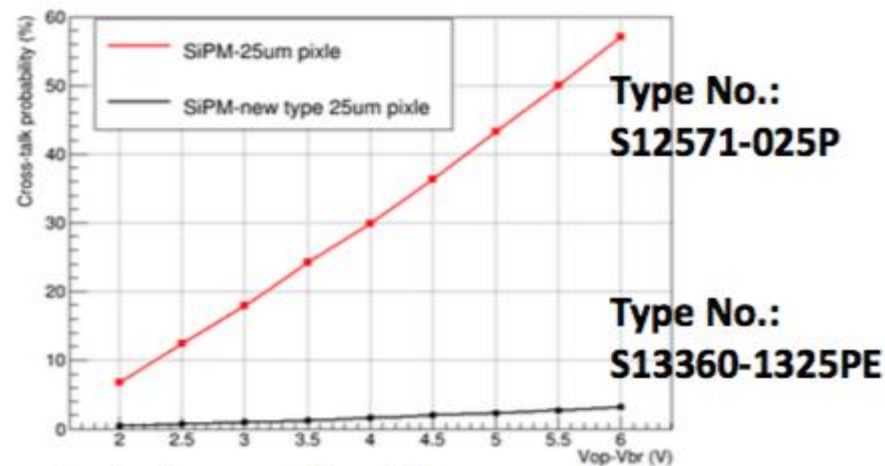
Test of SiPM (IHEP, USTC)



Excellent photon counting



Cross talk rate = Events (> 1.5p.e)/Events (>0.5p.e)

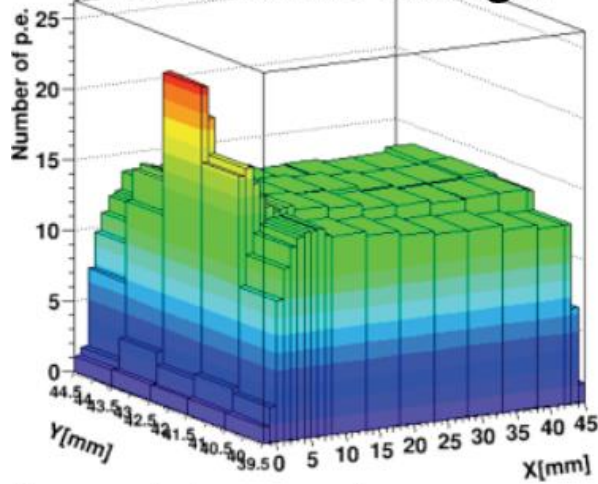


Optimization of Scintillator Strip

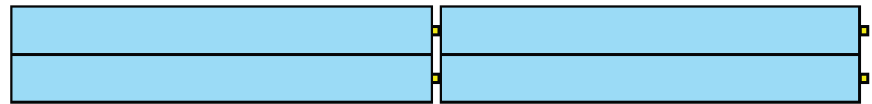
Z.G. Wang et.al.

Optimizing geometry & connection of scintillators.

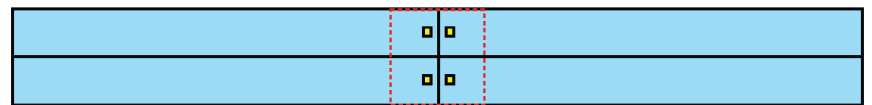
Baseline design



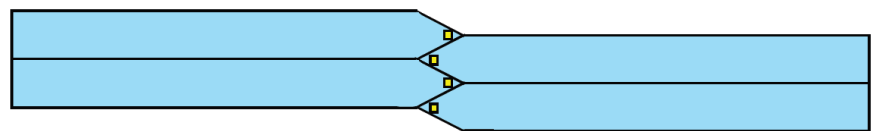
Normal



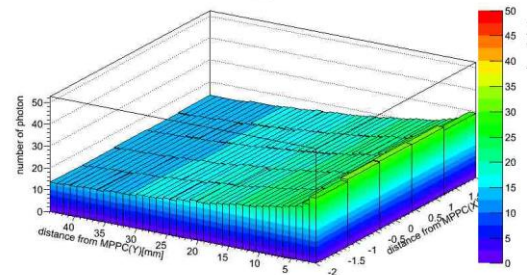
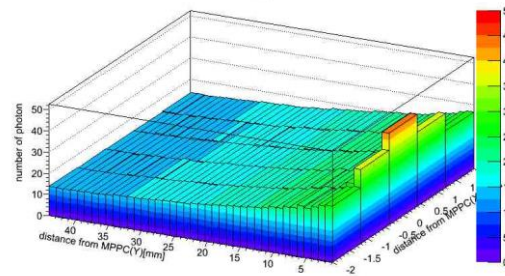
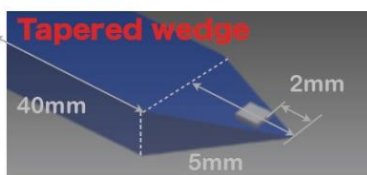
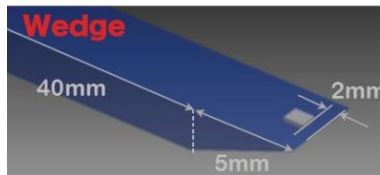
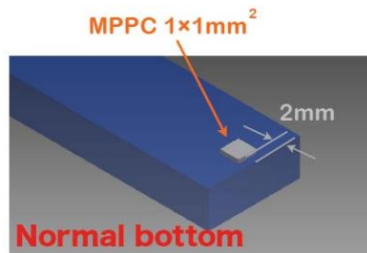
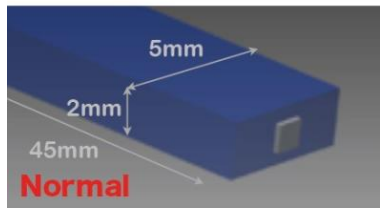
Wedge



Tapered wedge

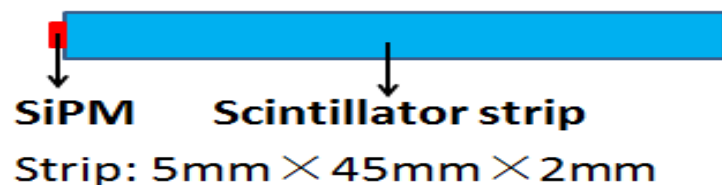
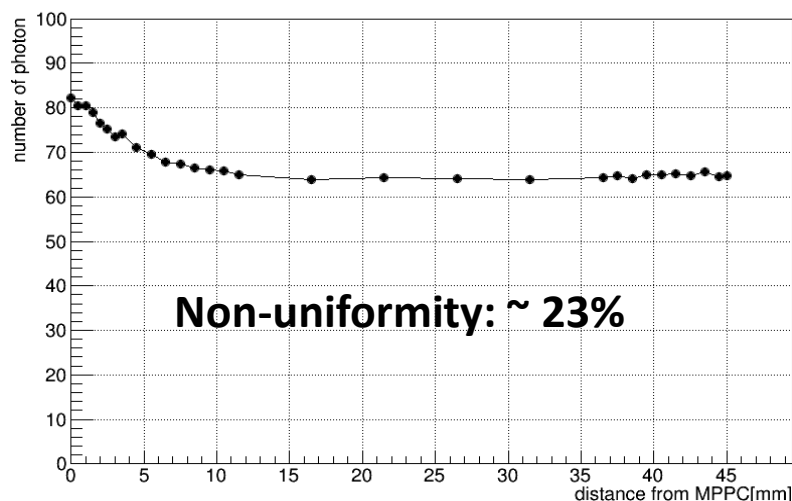


SiPM area: $1 \times 1 \text{ mm}^2 \rightarrow 0.25 \times 4 \text{ mm}^2$:

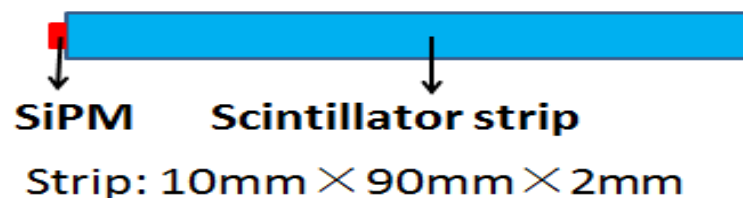
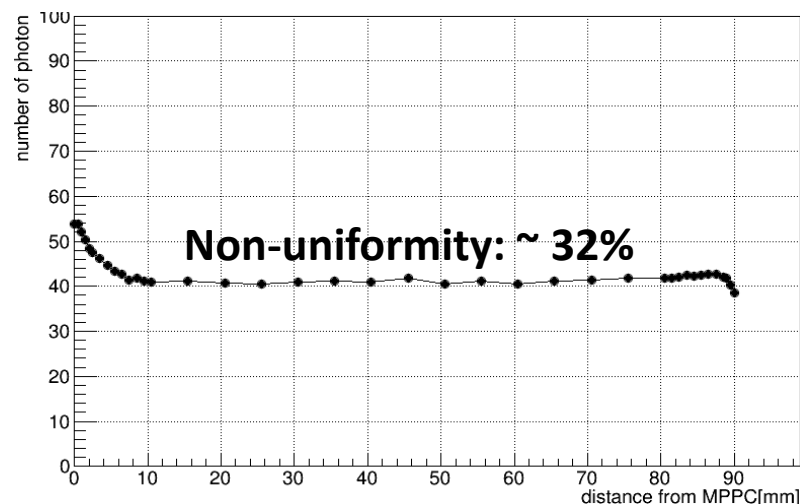


Scintillator strip light output

5mm \times 45mm scintillator strip



10mm \times 90mm scintillator strip



Scintillator: BC408, SiPM: 1mm \times 1mm, 25 μ m pixel size

The uniformity of scintillator strip light output needs to be optimized.

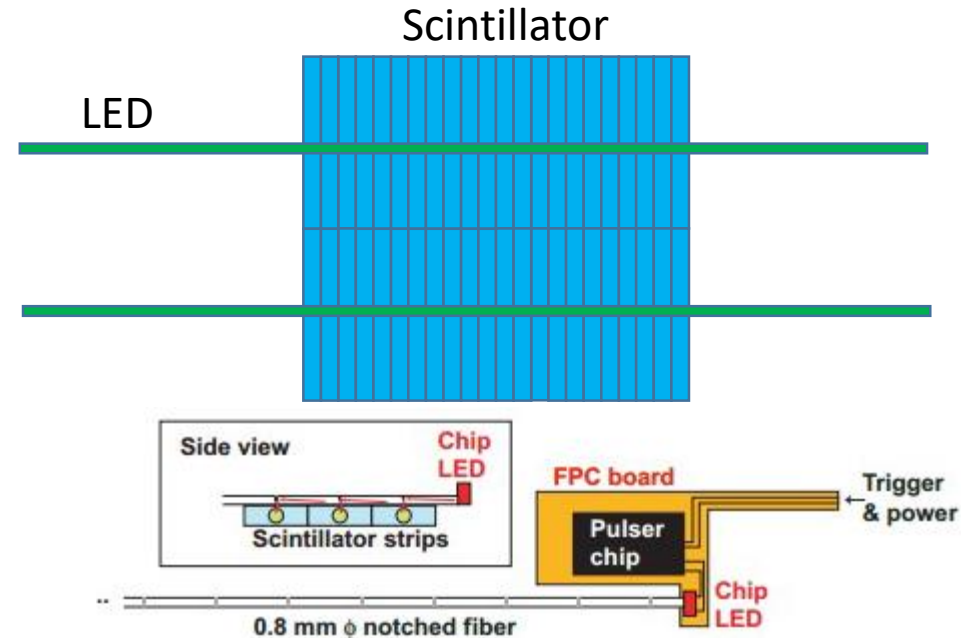
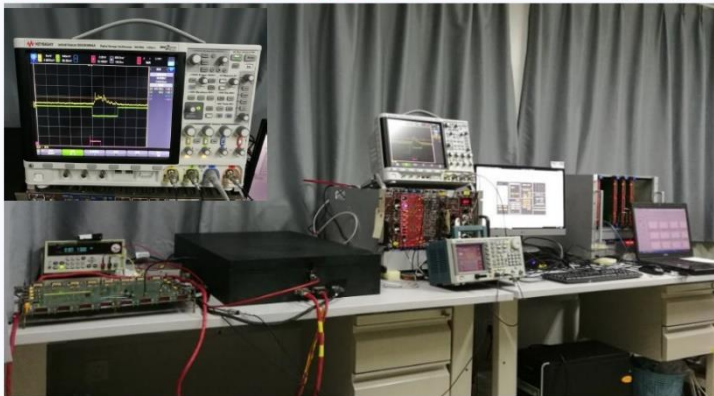
Calibration for Scintillator and SiPM

The ScW ECAL consists of ~8 million channels of scintillator strip units. The stability of the light output has to be monitored. A light distribution system is under study to monitor possible gain drifts of the SiPMs by monitoring photoelectron peaks.



LED calibration system

USTC

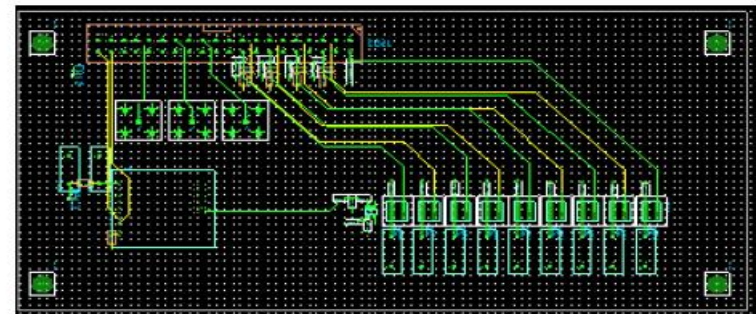
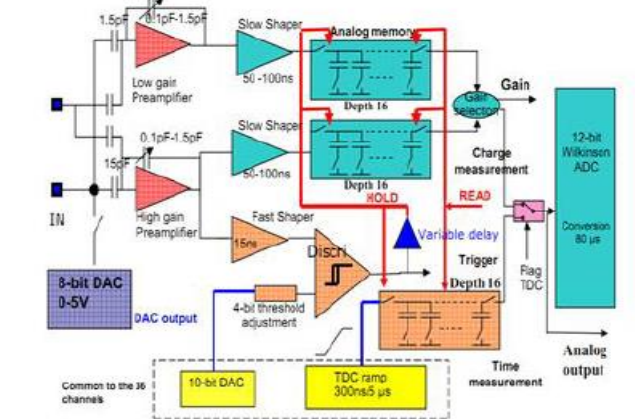


LED – Fiber calibration system:

- A pulse generator, a chip LED connect to fibers
- Notched Fiber distribute lights to scint. strips

Electronics Board of ECAL (USTC)

- The PCB Board of ECAL ,which based on the SPIROC2b chips, has been designed & produced
- The FPGA firmware is being designed



CEPC HCAL

- The HCAL consists of
 - a cylindrical barrel system: 12 modules
 - two endcaps: 4 quarters
- Absorber: Stainless steel

Active sensor

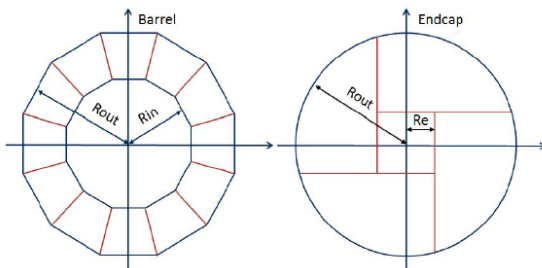
- Glass RPC
- Thick GEM or GEM

Readout ($1 \times 1 \text{ cm}^2$)

- Digital (1 threshold)
- Semi-digital (3 thresholds)

CEPC DHCal OPTIMIZATION

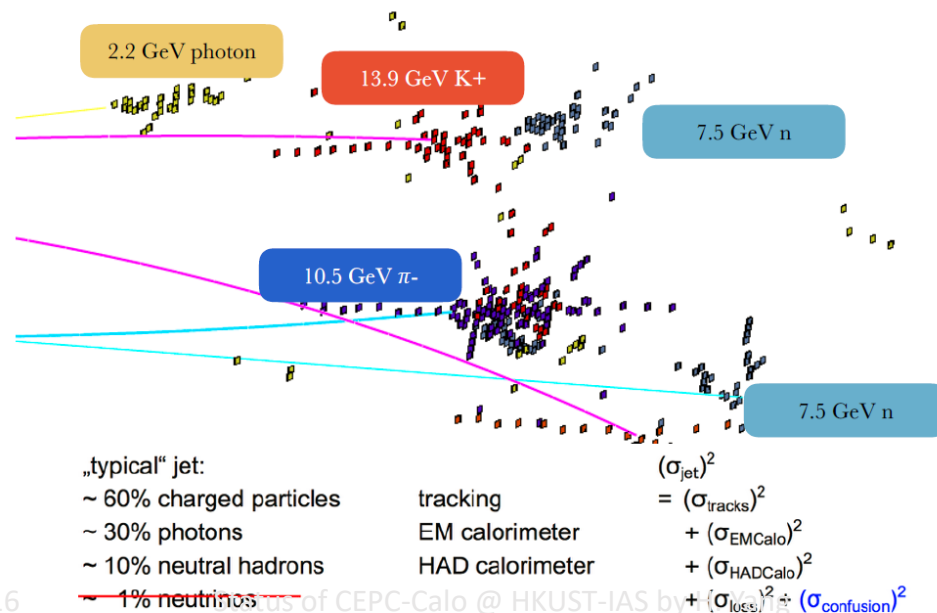
- To full fill the requirements of CEPC PFA, the DHCal is optimized by the following:
 - layers of DHCal, scanned from 20 layers to 48 layers.
 - size of each cell, scanned from 10 mm to 80 mm.
 - digitization (Q spectrum, spatial resolution, semi-Digi, etc..)



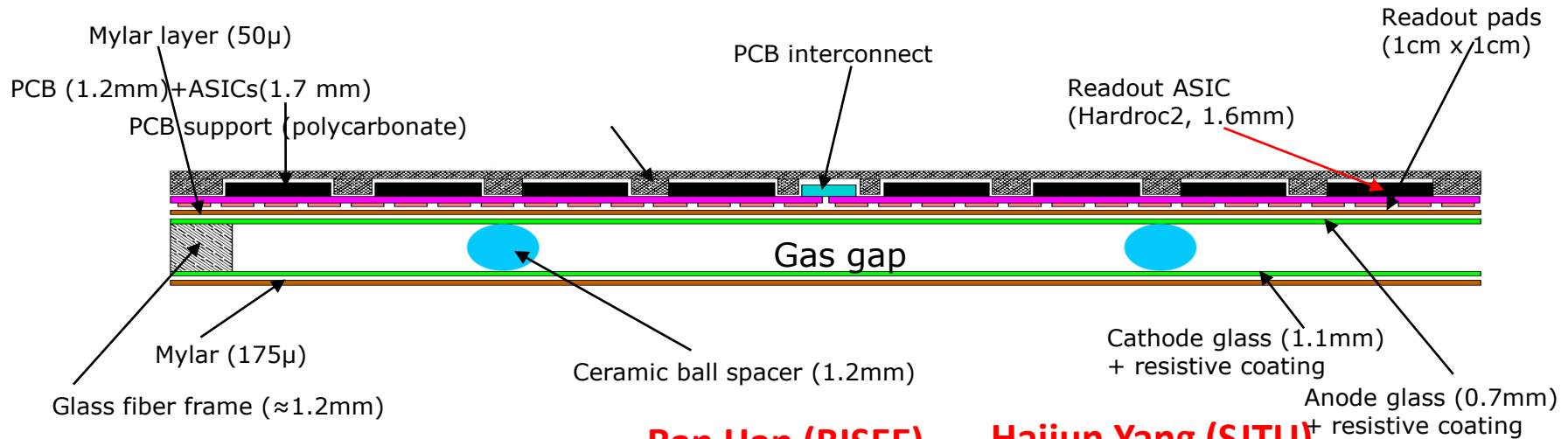
- The HCAL consists of
 - a cylindrical barrel system: 12 modules
 - two endcaps: 4 quarters
- Absorber: Stainless steel

SIMULATION - PRELIMINARY

By Shi CHEN (UCAS)



Schematic of RPC



Ran Han (BISEE)

Haijun Yang (SJTU)

Large area gRPC:

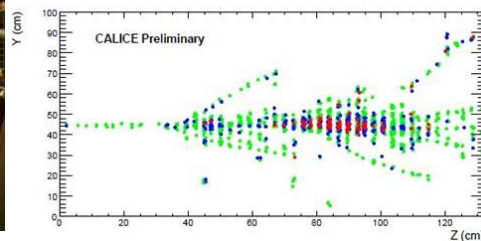
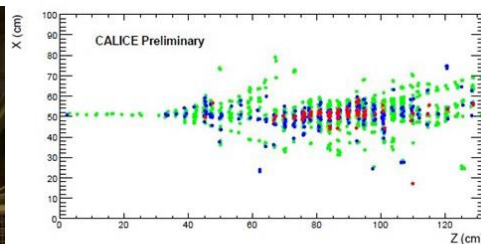
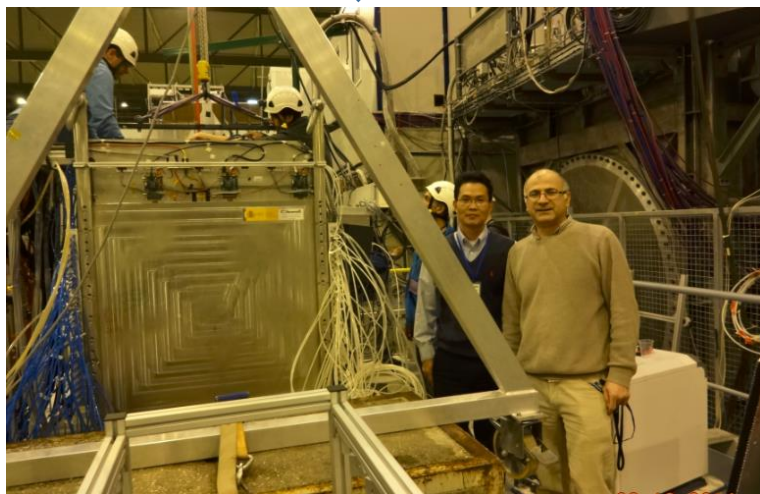
- ✓ Negligible dead zone (tiny ceramic spacers)
- ✓ Large size: $1 \times 1 \text{ m}^2$
- ✓ Cost effective
- ✓ Efficient gas distribution system
- ✓ Homogenous resistive coating



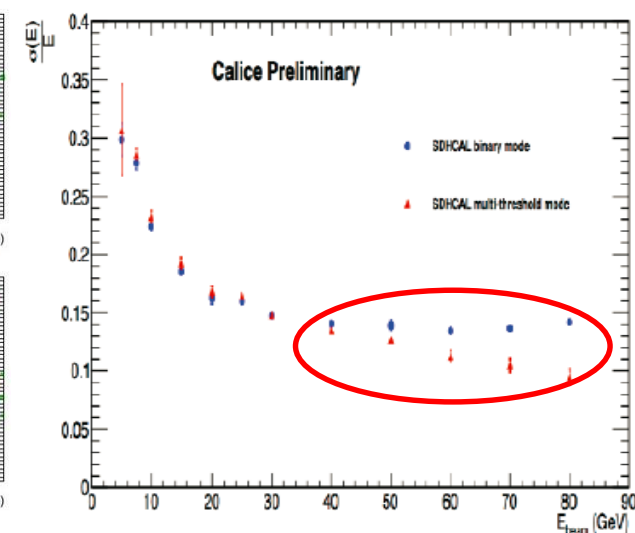
DHCAL with RPC

Prototypes of DHCAL based on RPC

- ANL (J. Repond, L. Xia et.al.)
1m³, 1 threshold, TB at CERN/Fermilab
- IPNL (I. Laktineh et.al.)
1m³, 3 thresholds, TB at CERN since 2012



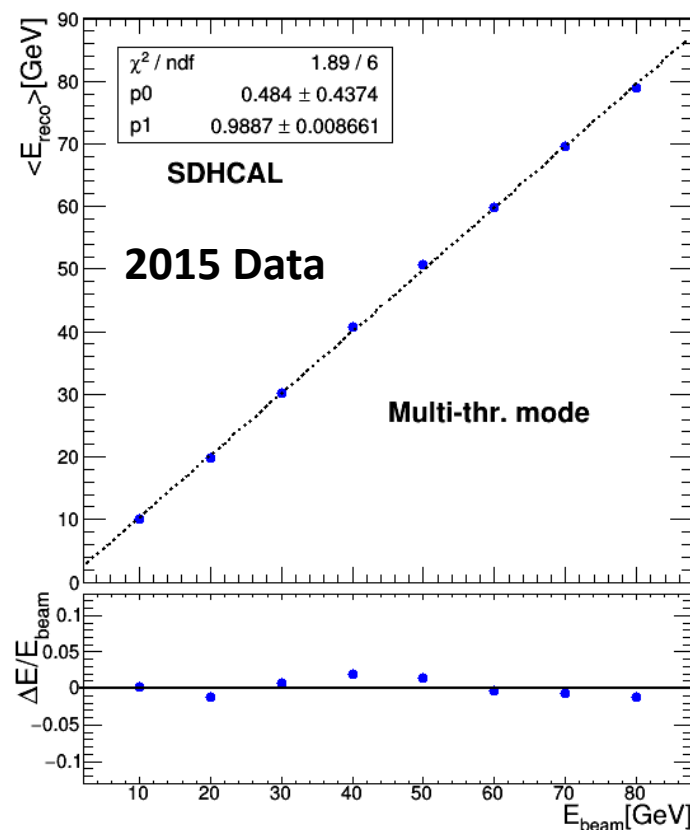
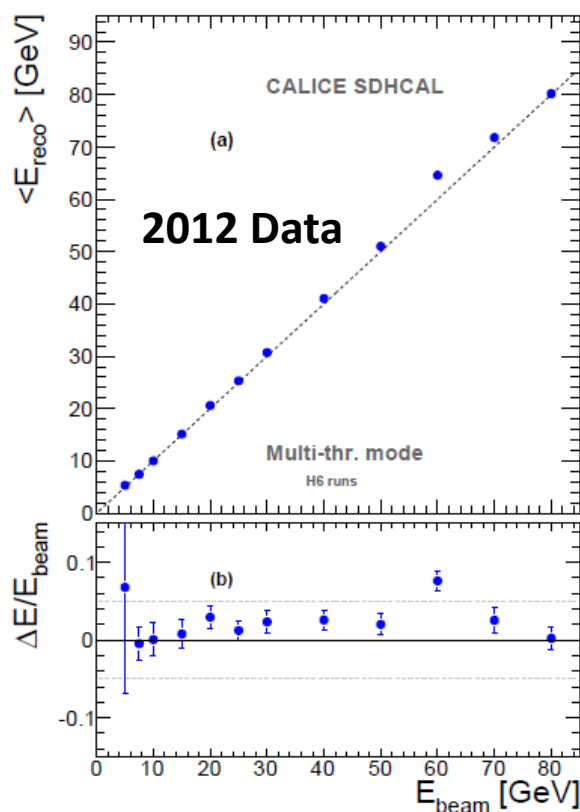
80 GeV Pion



DHCAL with RPC

Collaborating with Imad Laktineh at IPNL
to analyze TB data of SDHCAL since 2016.

B. Liu, H. Yang, Imad



Energy Resolution vs No. of Layers

SDHCAL has 48 layers which aims for ILC Detector

- layer: 6mm RPC and 20mm Stainless steel absorber

→ Optimization no. of layers for CEPC at 240GeV
40-layer is quite optimal based SDHCAL TB data.

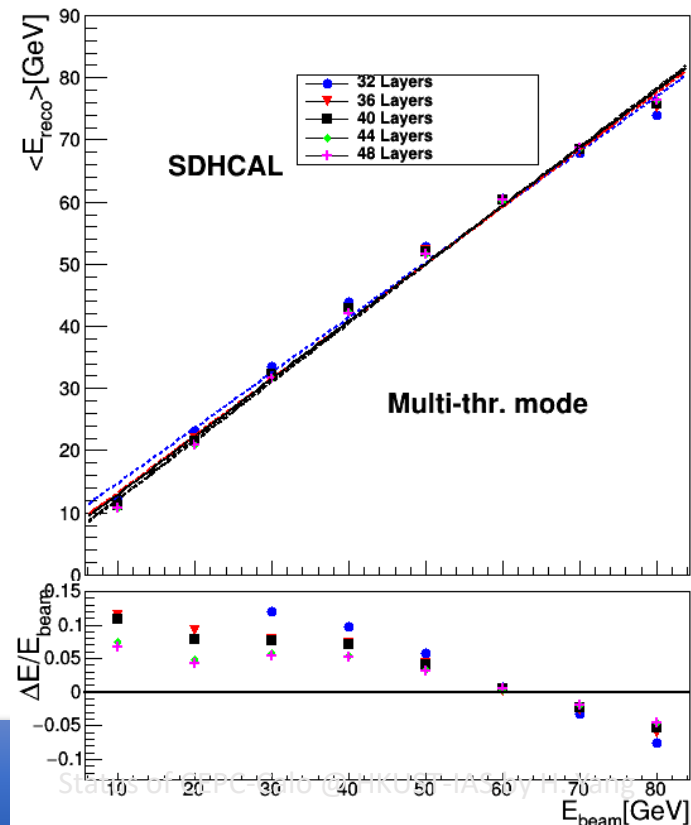
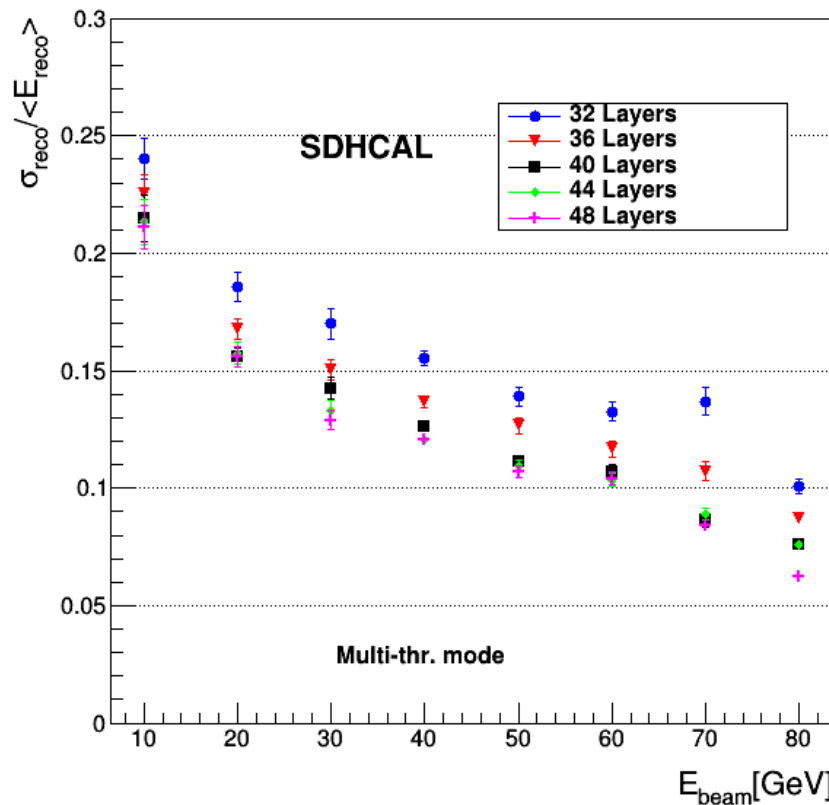
Bing Liu, Haijun Yang, Imad

Stainless steel Absorber(15mm,
 $0.12\lambda_I, 1.14X_0$)

Stainless steel wall(2.5mm)

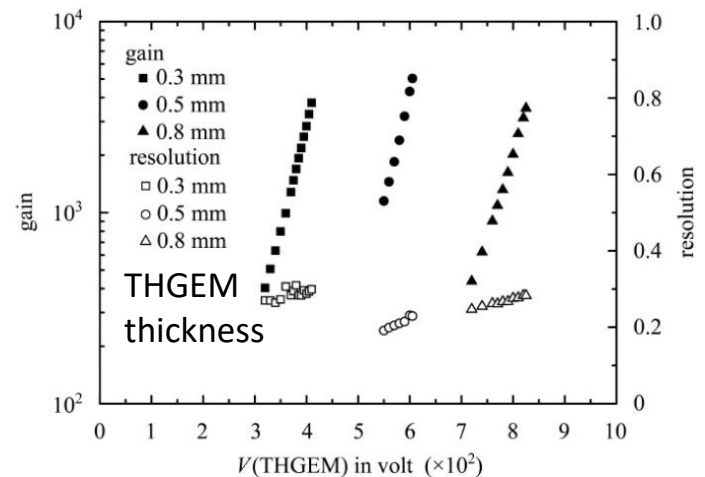
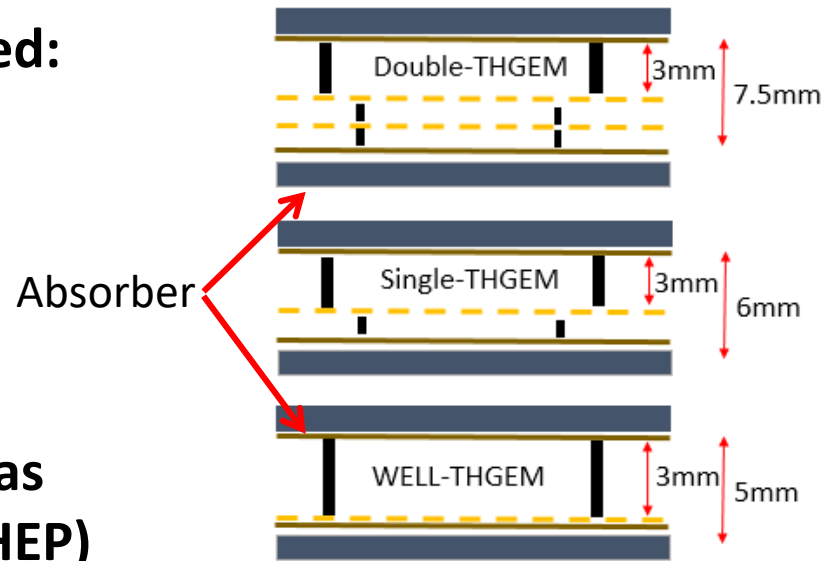
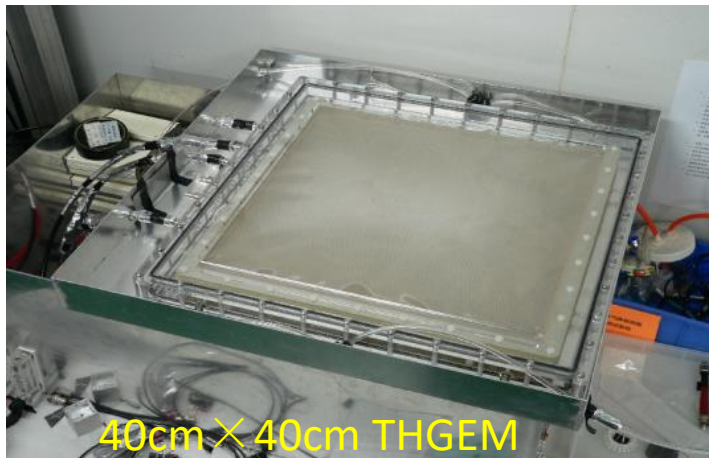
GRPC(6mm $\approx 0\lambda_I, X_0$)

Stainless steel wall(2.5mm)



DHCAL based on THGEM

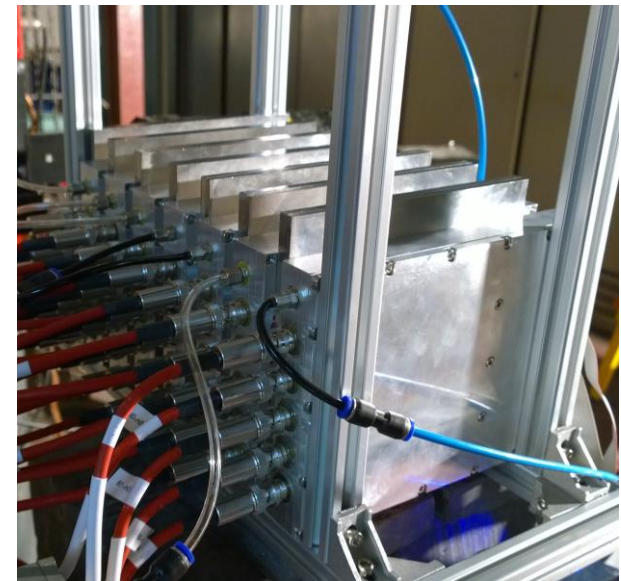
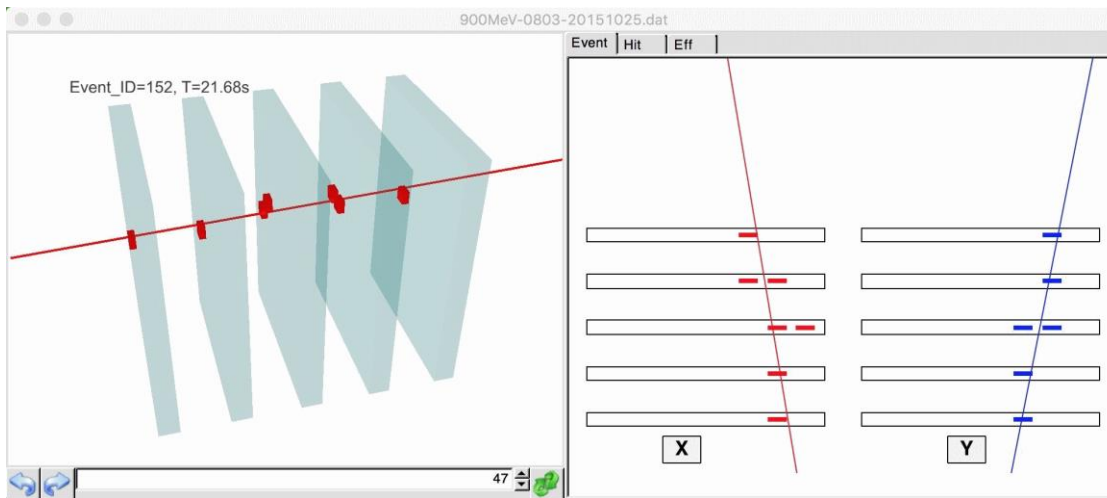
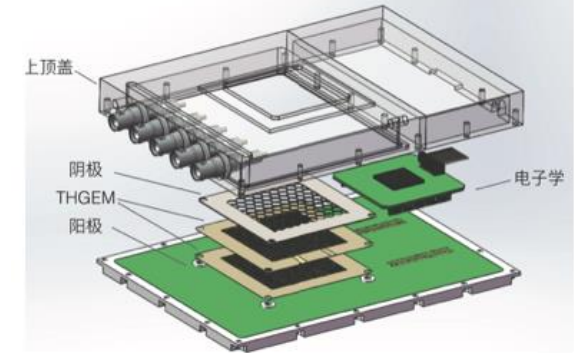
- Three THGEM options are explored:
 - Double - THGEM
 - Single - THGEM
 - WELL - THGEM
- WELL-THGEM is optimal choice
Thinner, lower discharge
- $40 \times 40 \text{ cm}^2$ of THGEM (below) was produced in China (UCAS, GXU, IHEP)



WELL-THGEM Beam Test @ IHEP

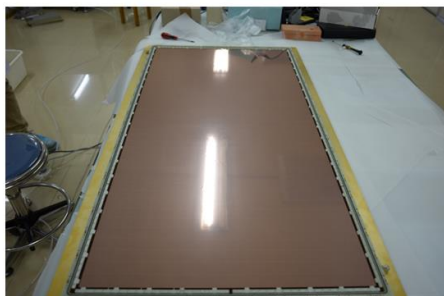
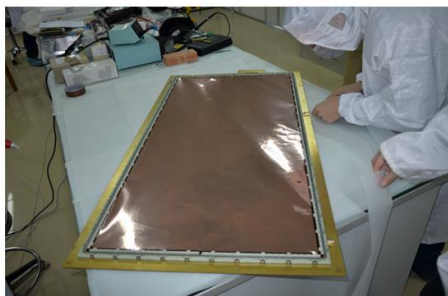
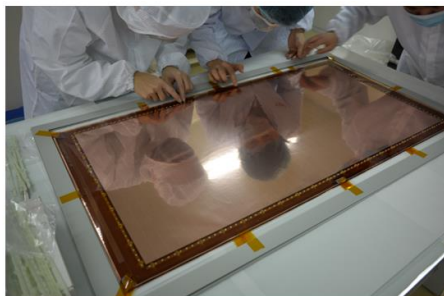
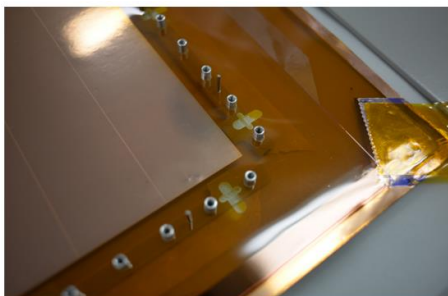
- 7 THGEMs were installed, and 5 of them were used, and flushed with Ar/iso-butane = 97:3.
- 1 threshold, binary readout
- 900 MeV proton beam was used
- 5x5cm² sensitive region
→ 20 x 20 cm² (in progress)

Hongbang Liu, Qian Liu (UCAS)



Large-area GEM @ USTC

GEM assembly using a novel self-stretching technique

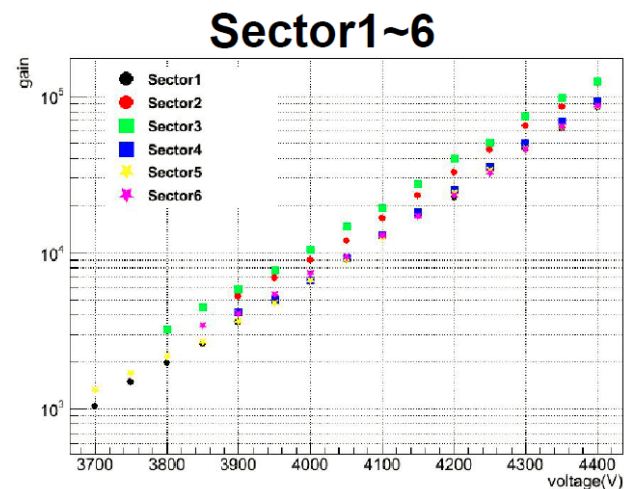


- Large-area GEM ($0.5 \times 1 \text{m}^2$) is one of main detector R&D focuses at USTC recently.
- Technology has been developed and matured to produce high-quality GEM detectors as large as $\sim 1 \text{m}^2$ that are also applicable to CEPC DHCAL.

APV25 GEM readout



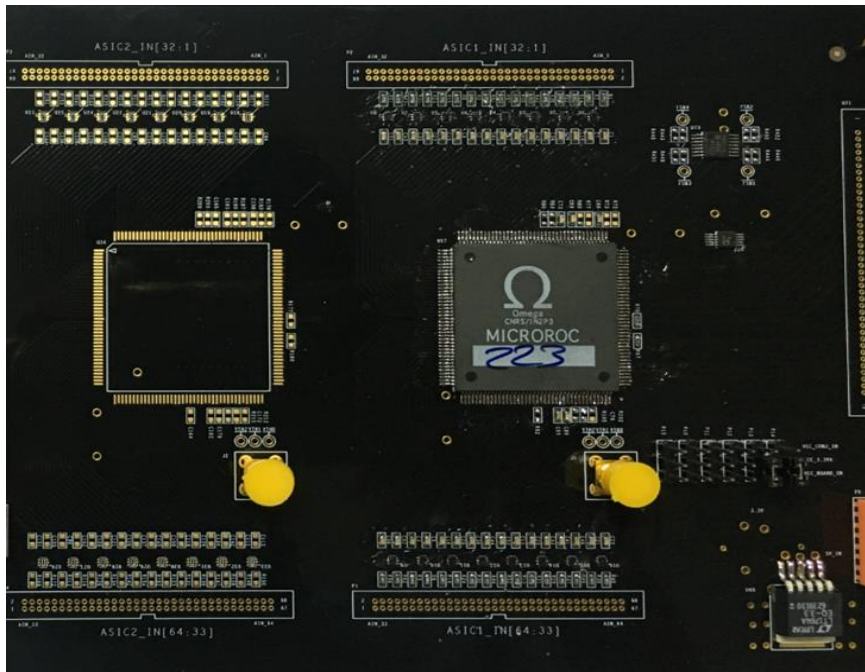
INFN APV25 chip



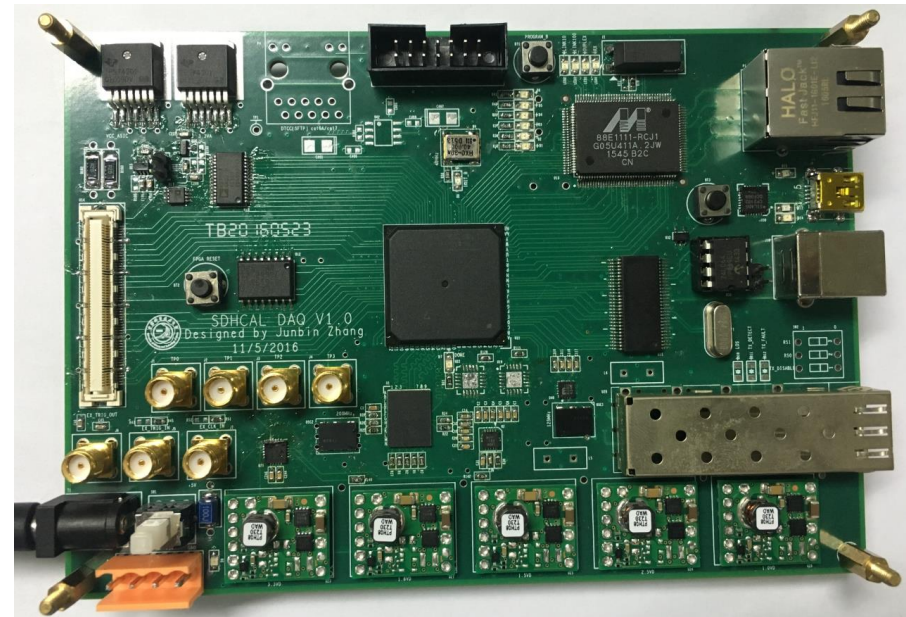
- ➔ Resolution uniformity $\sim 11\%$
- ➔ Gain uniformity $\sim 16\%$
- ➔ Can reach gain of 10^4 at 4000V

HCAL Based on GEM (USTC)

■ Design of readout electronics by USTC



Front-End Electronics

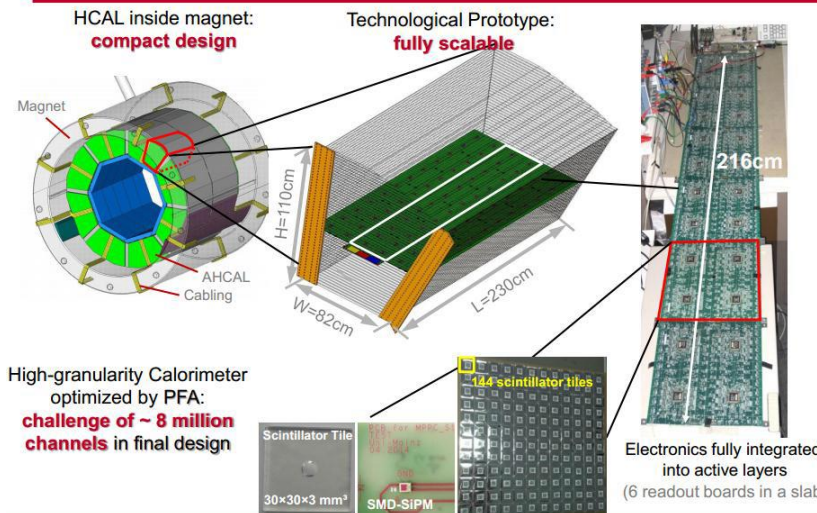
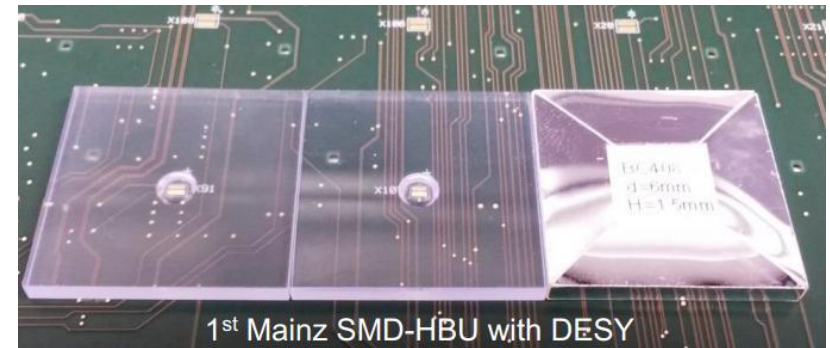
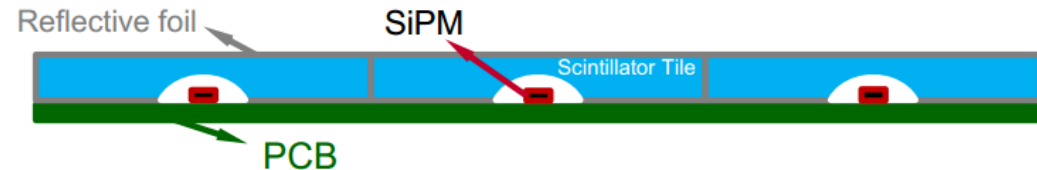


DAQ

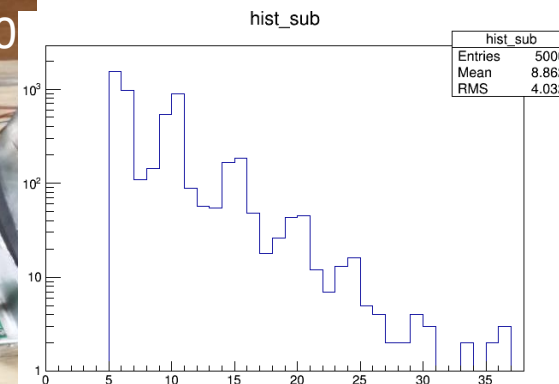
HCAL Based on Scintillator + SiPM

Zhe Wu, Boxiang Yu (IHEP)

- Considering HCAL based on scintillator with SiPM.
- SiPM can be mounted on a readout PCB and fully placed inside a cavity. Polished surface of the tile and cavity can improve response uniformity.

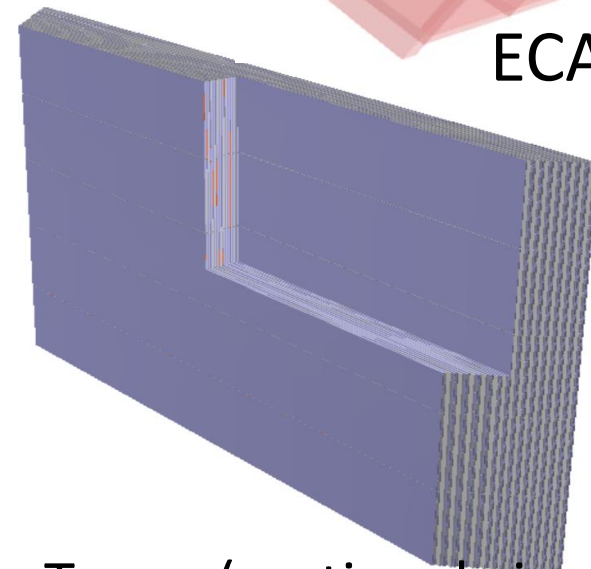
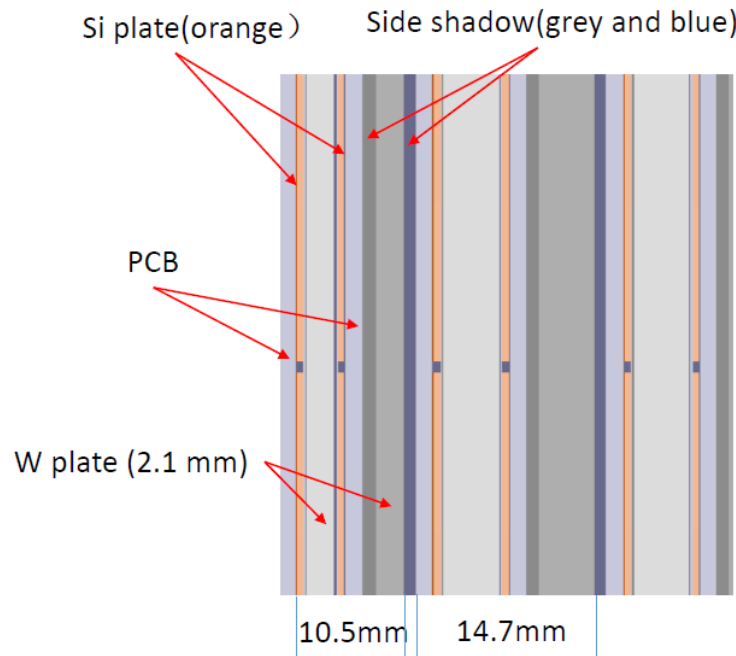
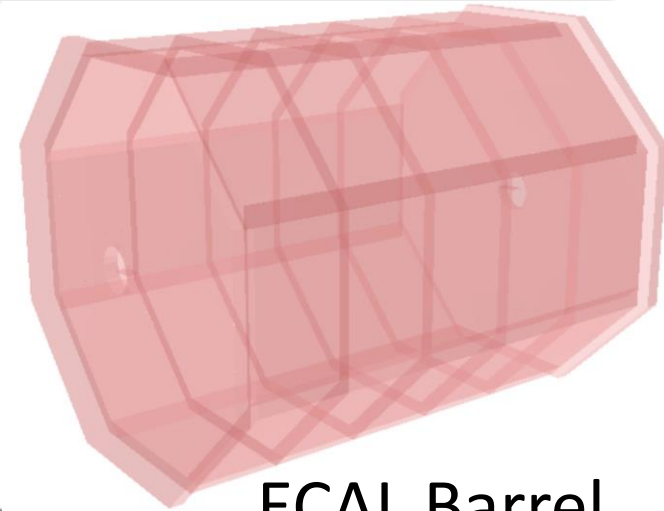


Preliminary test of two Scint. at IHEP with Sr-90



ECAL Geometry Setup

Parts	Thickness (mm)	Absorber (mm)	Dimension (mm)	Cell size (mm ²)
Barrel	5.25 (L0-19)	2.1	R, 1843 -2028	5.08x5.08
	7.35 (L20-29)	4.2	Z, 0.00-2350	
Endcap	5.25 (L0-19)	2.1	R, 226.8-2088	5.08x5.08
	7.35 (L20-29)	4.2	Z, 2450-2635	



Calorimeter Optimization

Jifeng Hu, Jing Li, Liang Li, Haijun Yang (SJTU)

■ Software versions,

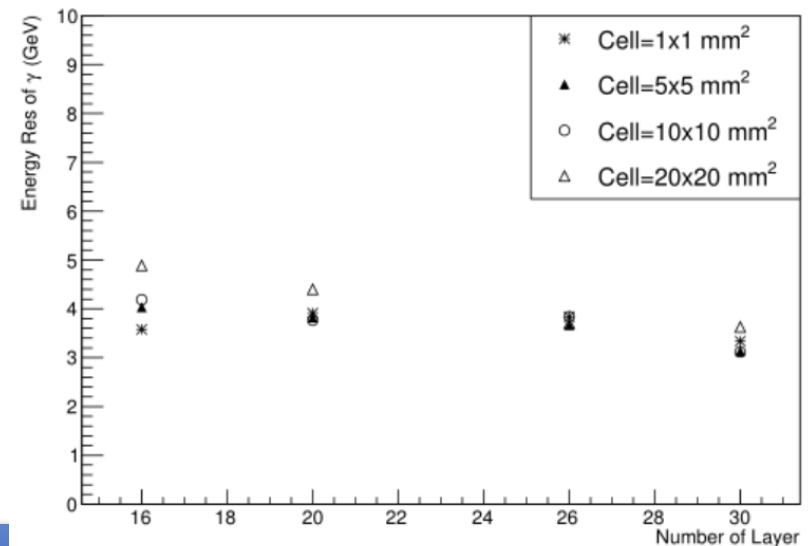
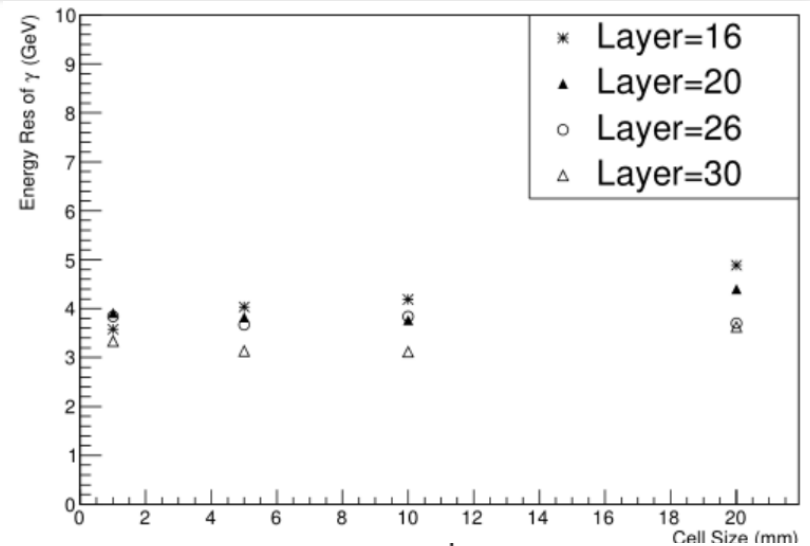
- Simulation: Mokka-08-03
- Reconstruction: Arbor_KD_3.3 plus track-related processors
- Digitization : G2CDArbor

■ Samples,

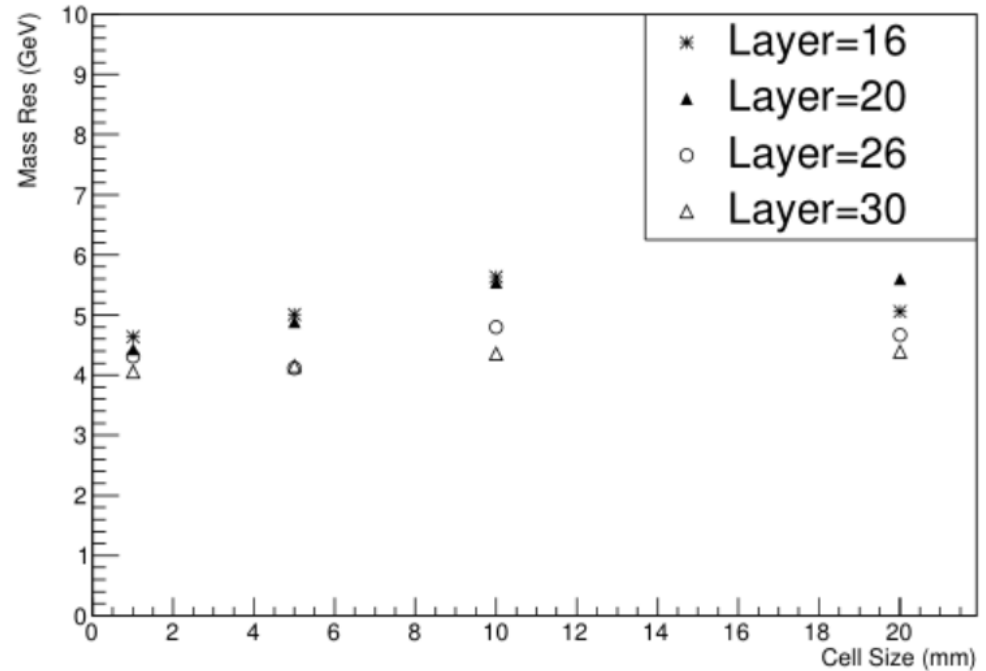
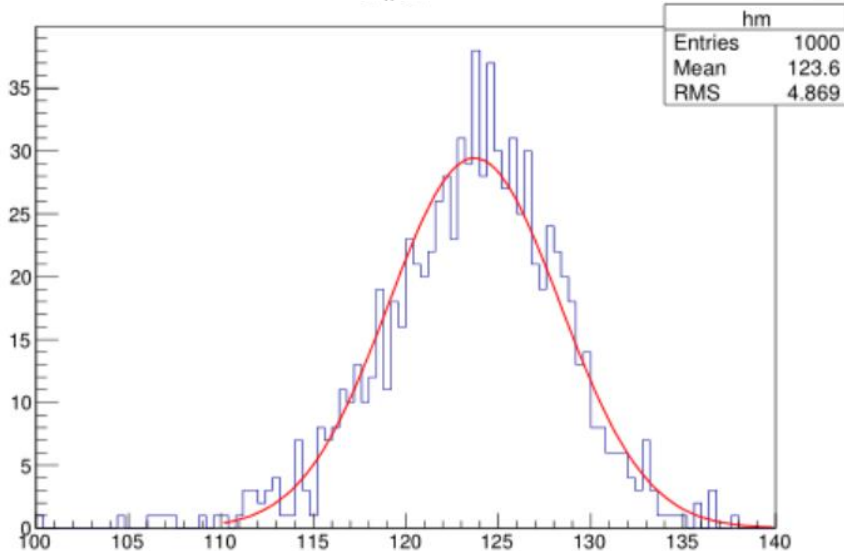
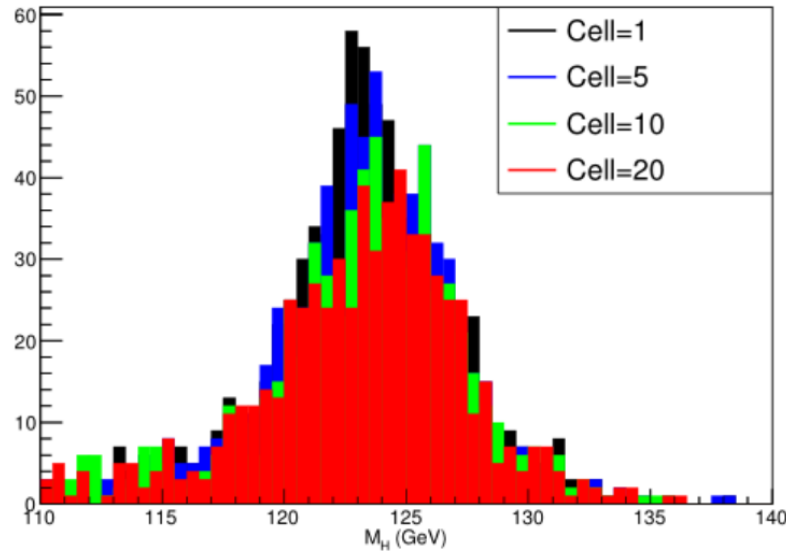
- e^-/γ single particle, energy@5,10,20,50,100 GeV
- $ee \rightarrow ll\gamma\gamma @ \sqrt{s} = 250 \text{ GeV}$, 1000 Events.

■ Geometry: cepc_v1 using SiW ECAL,

- Cell size @ 1X1, 5X5, 10X10, 20X20 mm
- Number of layers @ 15, 19, 25, 29
- fixed total material.
- other parameters will be investigated.



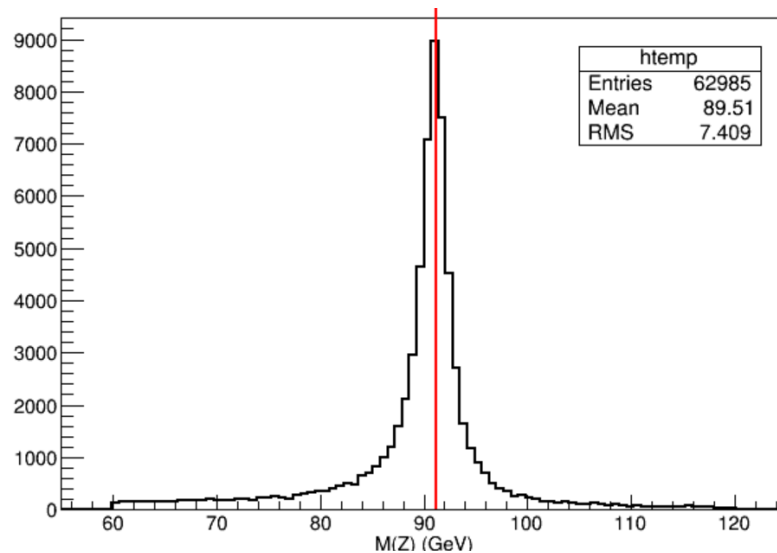
Calorimeter Optimization (ECAL)



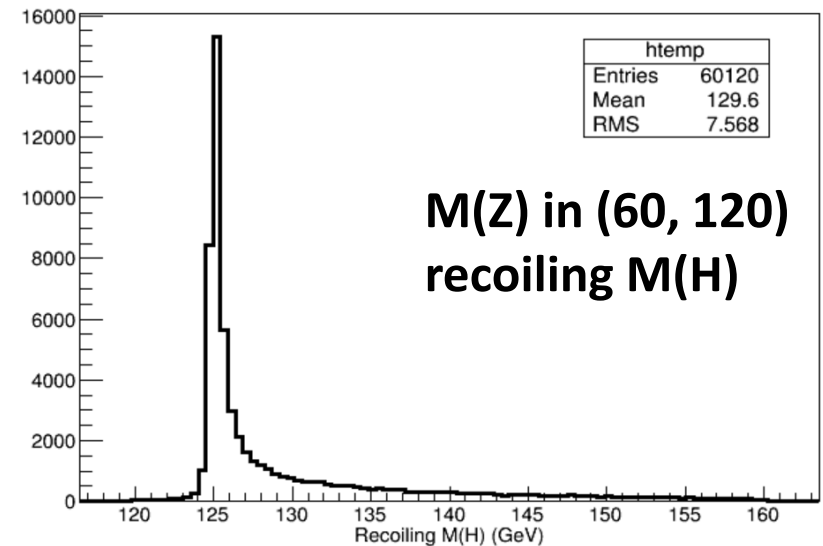
Higgs $\rightarrow \gamma\gamma$ mass resolution is quite Stable for cell size between $1 \times 1 \text{ mm}^2$ and $20 \times 20 \text{ mm}^2$

ZH, Higgs \rightarrow WW

➔ Using $H \rightarrow WW \rightarrow l\nu qq$ events to understand jet energy resolution requirement for HCAL.



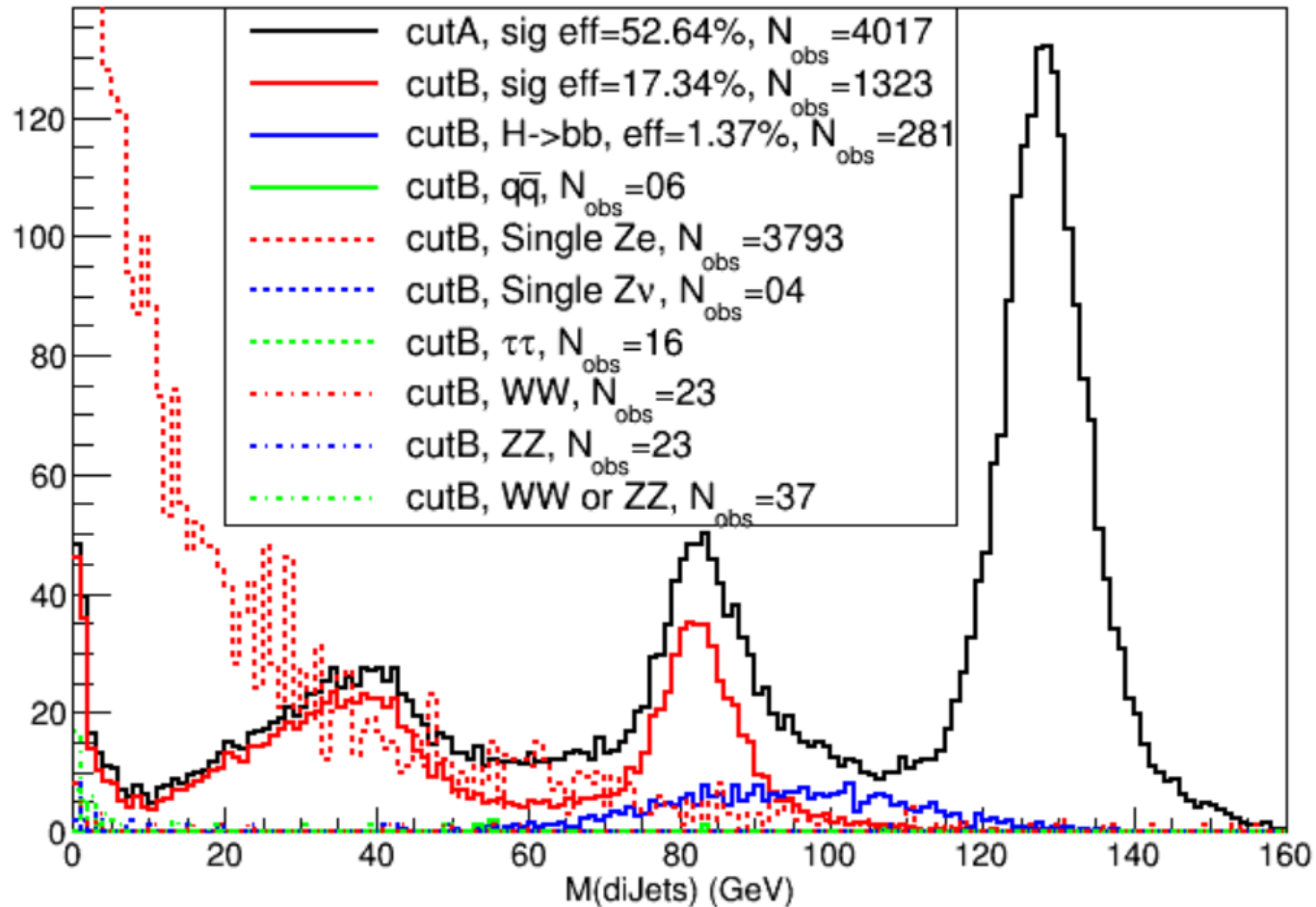
M(Z) in (60, 120) GeV



M(Z) in (60, 120)
recoiling M(H)

- (Left), Z mass, (red) line indicates the nominal mass.
- (Right), the recoiling mass, $M = \sqrt{E^2 - (\vec{p}_{l1} + \vec{p}_{l2})^2}$, lepton 1 and lepton 2 are coming from Z.

Higgs Signal vs. Background



Calorimeters R&D Plan

Supported by MOST, NSFC and IHEP seed funds, about \$ 1M

1. CEPC ScW ECAL simulation and optimization

- Optimization of ECAL: layers, Cell size, Scintillator thick etc.
- SiPM test and performance of scintillator strip
- Design of readout electronics
- Preparing for ScW ECAL module construction and beam test

2. CEPC DHCAL performance study and optimization

- Optimization of HCAL: layers, cell size
- Comparison of different technologies: RPC, GEM, Scintillator
- SDHCAL (RPC) TB data analysis for performance study
- Design of readout electronics

3. Call for international collab. for CEPC Calo studies !

**Many thanks to all members of
the CEPC Calo working group.**

**We need more manpower,
more concept designs,
more dedicated efforts
for the CEPC-CDR !**

Backup Slides

Manpower for Calorimeters R&D

- IHEP: Zhigang Wang, Hang Zhao, Tao Hu
 - ▣ ScW ECAL optimization
 - ▣ SiPM Test and scintillator strip optimization
- USTC: Yunlong Zhang, Shensen Zhao, Jianbei Liu
 - ▣ SiPM linearity test
 - ▣ Electronics board design and test for ECAL and HCAL
- SJTU: Haijun Yang, Liang Li, Jifeng Hu, Bing Liu, Jing Li
 - ▣ SDHCAL (RPC) TB performance study, PCB design
 - ▣ Calorimeter design based on benchmark $H \rightarrow \gamma\gamma$ and WW
- IHEP+UCAS: Boxiang Yu, Zhe Wu, Qian Liu, H.B. Liu
 - ▣ Thick GEM study with large active area (20x20cm²)
 - ▣ HCAL based on Scintillator + SiPM

Readout Electronics for RPC

Imad Laktineh (IPNL)

ASICs : HARDROC2

64 channels

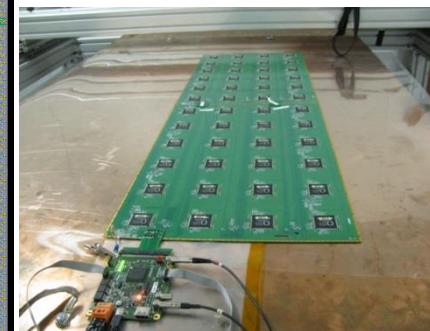
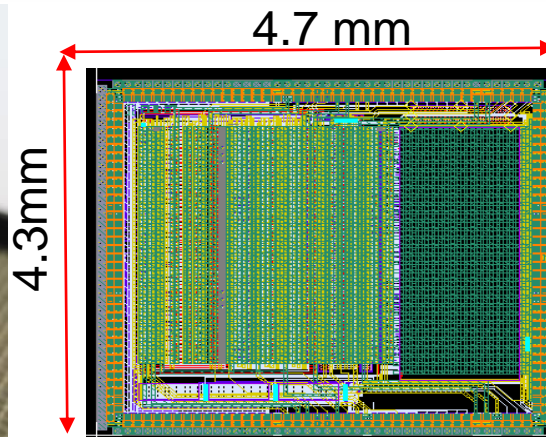
Trigger less mode

Memory depth : 127 events

3 thresholds

Range: 10 fC-15 pC

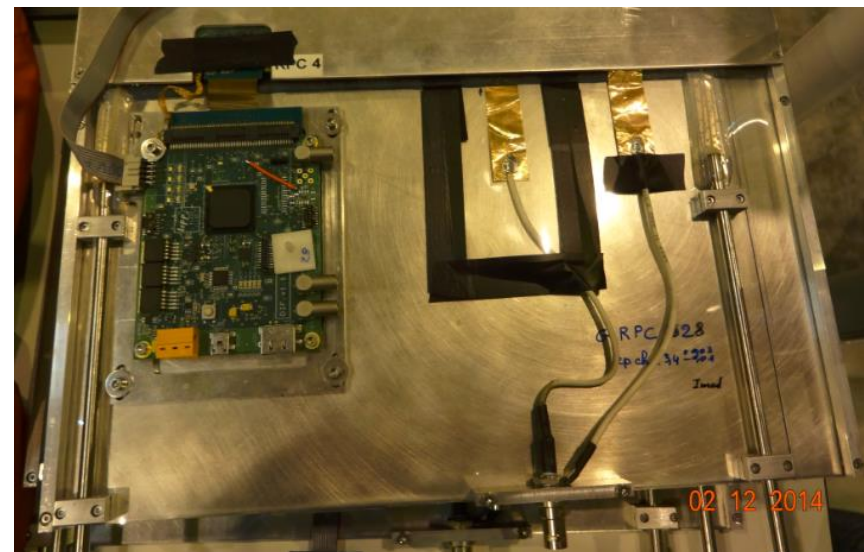
Gain correction → uniformity



Printed Circuit Boards (PCB) were designed to reduce the cross-talk with 8-layer structure and buried vias.

Tiny connectors were used to connect the PCB two by two so the 24X2 ASICs are daisy-chained. 1×1m² has 6 PCBs and 9216 pads.

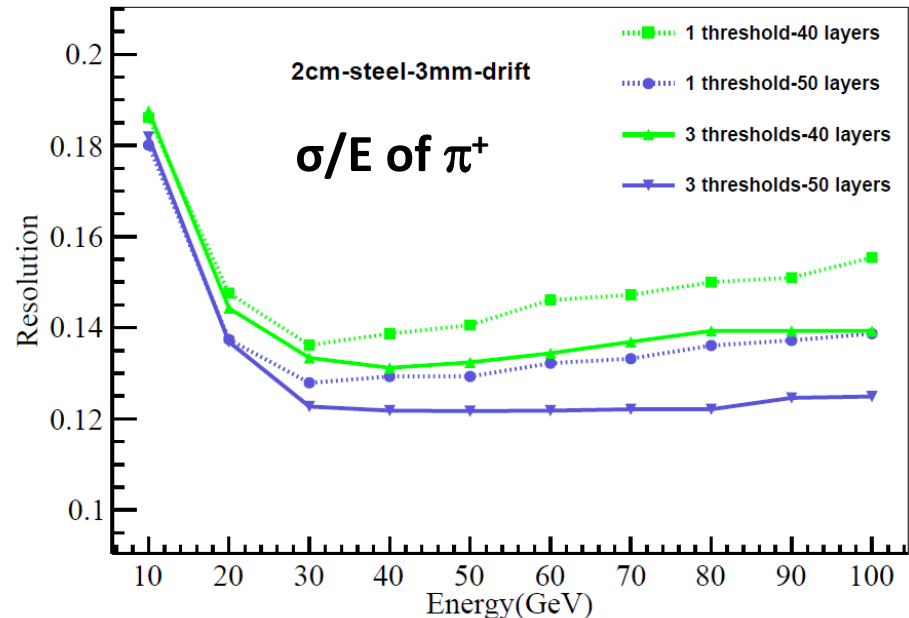
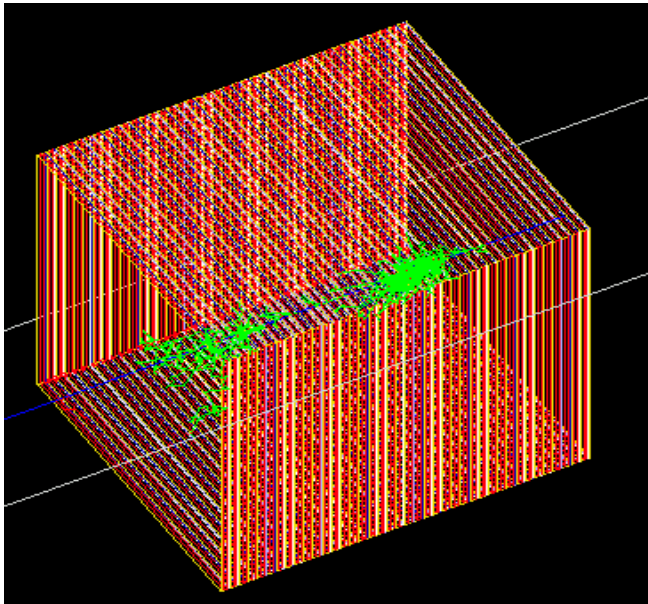
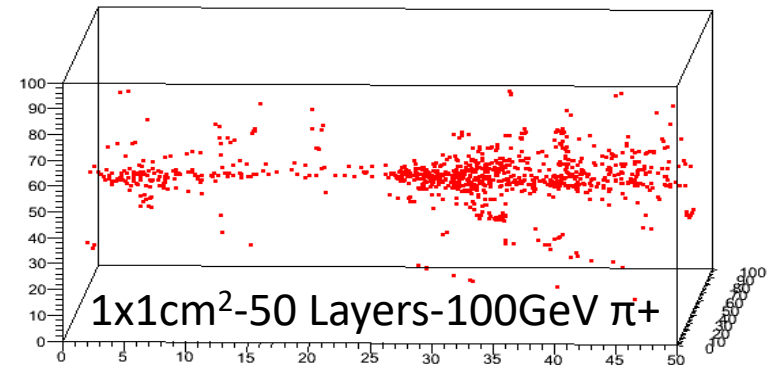
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.



DHCAL Simulation

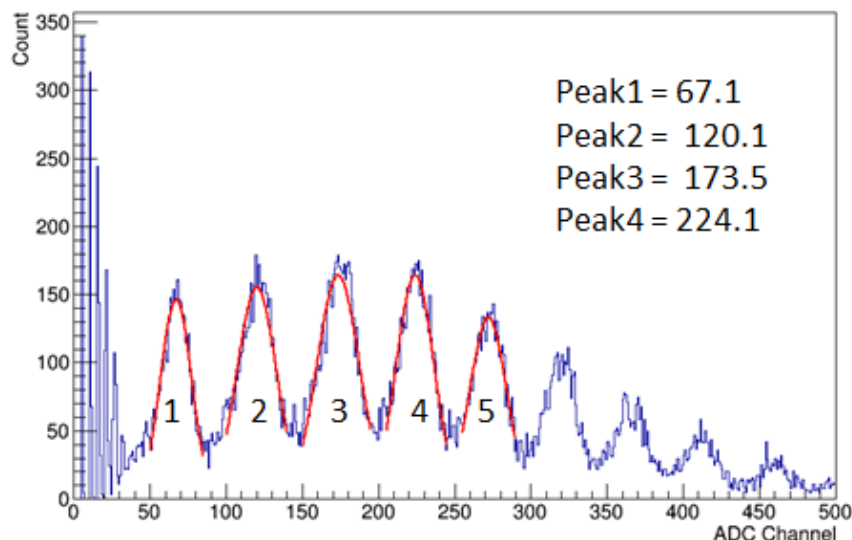
Boxiang Yu (IHEP)

- Absorber: 2cm stainless steel
- Drift gap: 3mm
- No. of layers: 40, 50
- Ecell = 1, 5 and 10MIP if the charge is above the thresholds typically placed at 0.1, 1.5 and 2.5 MIPs



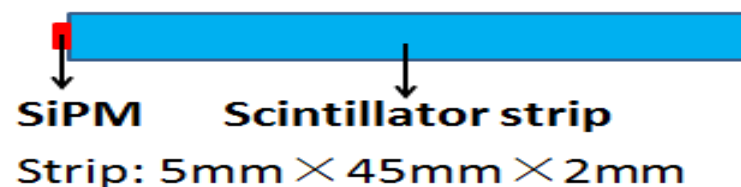
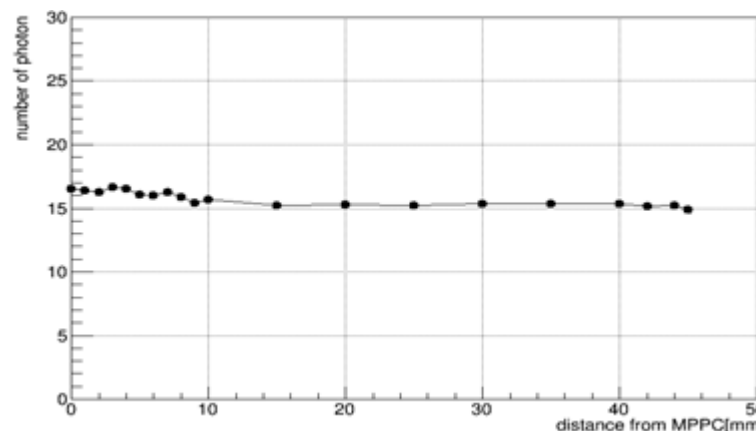
SiPM light output

SiPM type No.: S12571-010C



Pulse height spectrum

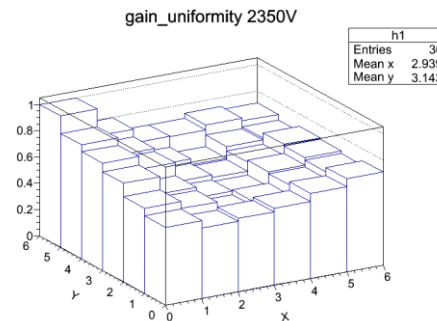
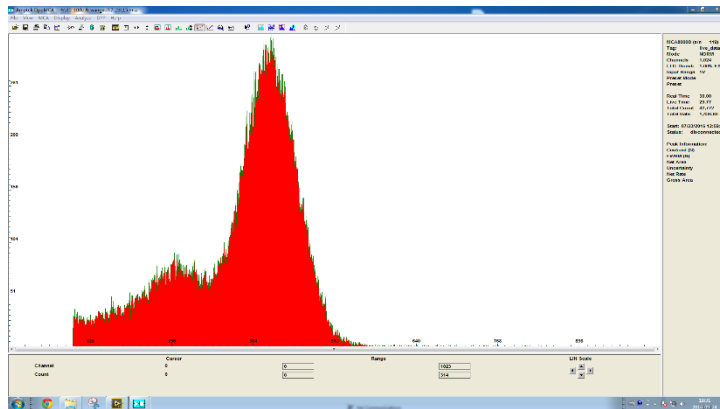
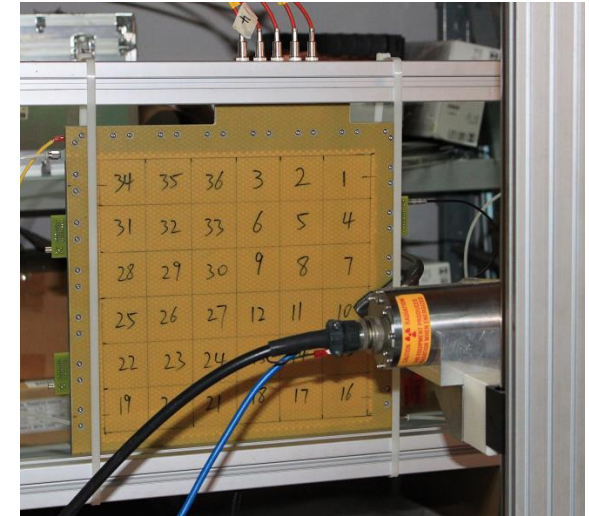
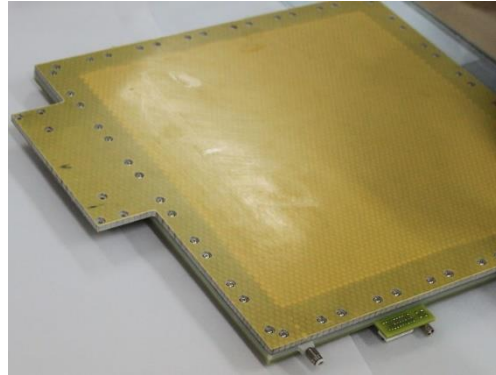
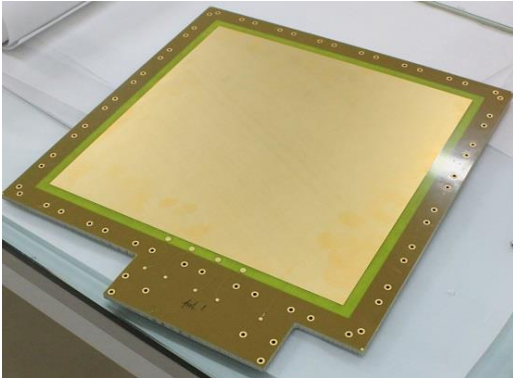
Light output of 45mm strip coupled with 10um SiPM



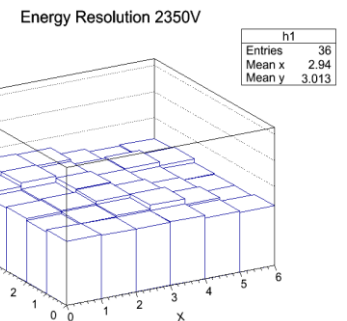
Photon detection efficiency of 10um SiPM is about 23% photon detection efficiency from the 25um SiPM

HCAL Based on GEM (USTC)

Construction of GEM at USTC

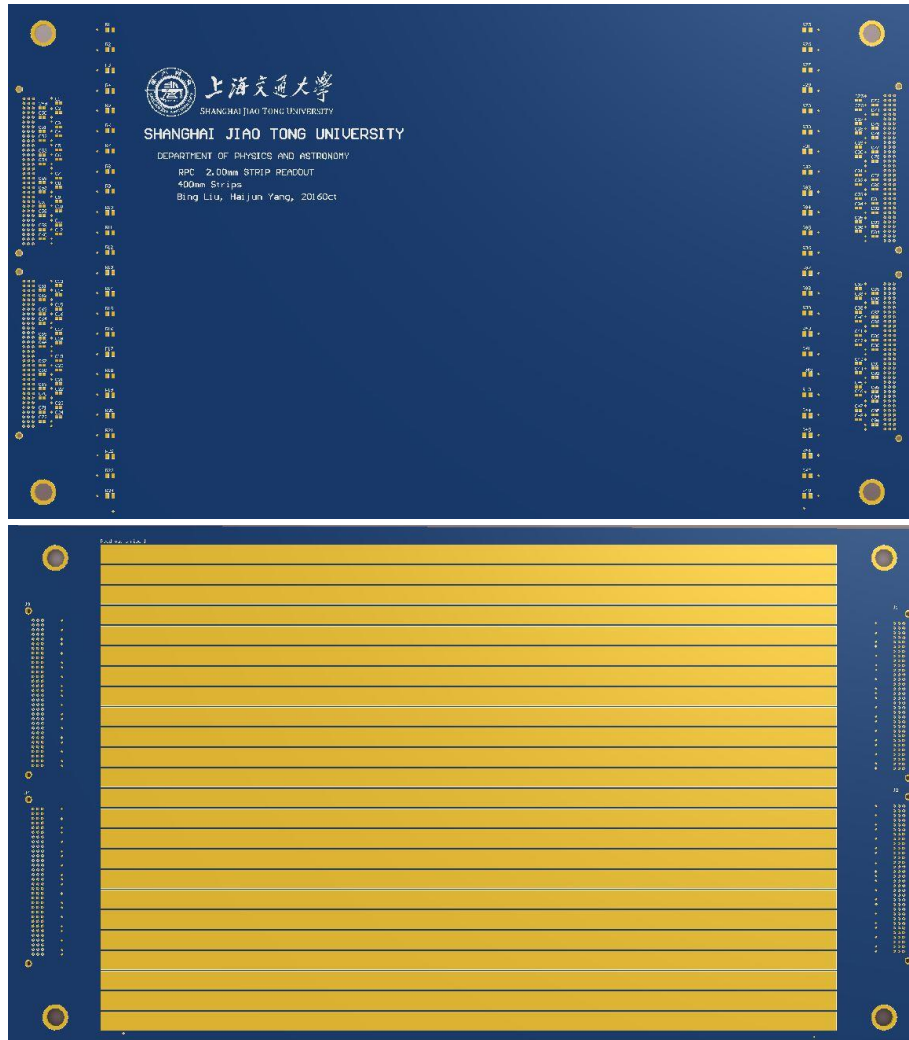


✓ **Gain:** ~4000
Non-uniformity ~15.6%



✓ **Energy resolution:** ~24.1%
✓ **Non-uniformity:** ~5.4%

Design of PCB for RPC



Bing Liu, Haijun Yang (SJTU)

**24 strips with 1cm/strip,
gap = 1mm, length = 40cm**

- PCB Output: 3 bins \times 32 column = 96 pins
 - Molex DIN 41612 connectors (receptacles)



- NINO Input:
 - Molex DIN 41612 connectors (headers)



Energy Reconstruction for SDHCAL

Energy reconstruction

Energy reconstruction formula:

$$E_{reco} = \alpha N_1 + \beta N_2 + \gamma N_3$$

α, β, γ are parameterized as functions of total number of hits ($N_1 + N_2 + N_3$)


$$\alpha = \alpha_1 + \alpha_2 N_{total} + \alpha_3 N_{total}^2$$

$$\beta = \beta_1 + \beta_2 N_{total} + \beta_3 N_{total}^2$$

$$\gamma = \gamma_1 + \gamma_2 N_{total} + \gamma_3 N_{total}^2$$

$$\chi^2 = \sum_{i=1}^N \frac{(E_{beam}^i - E_{reco}^i)^2}{\sigma_i^2}$$

N is the number of total events.

and $\sigma_i = \sqrt{E_{beam}^i}$.  First step

After the first step:

$$\sigma_i = \sqrt{p0 * E_{beam}^i + p1 + p2 * E_{beam}^i * E_{beam}^i}$$

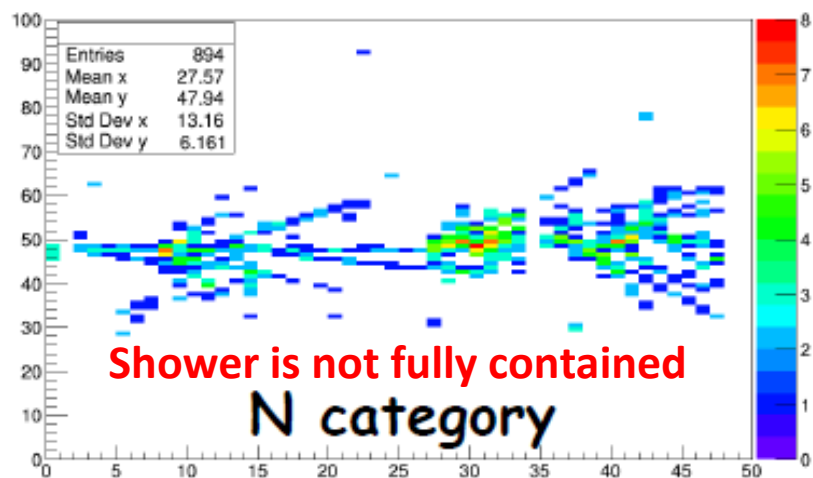
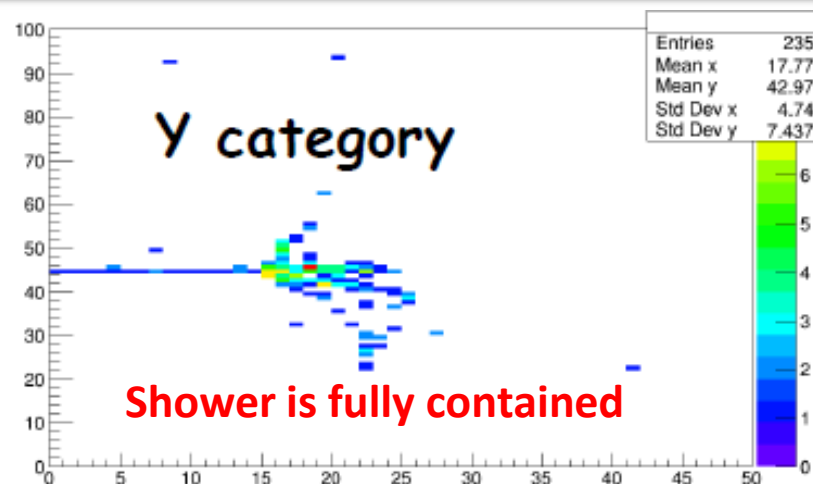
Definition of Y/N Category

Data sample:SPS_Oco_2015

Particle: Pi^+

Energy:10-80GeV with uniform
10 GeV energy gap

Type	Selections	Detail
Physical cut	Electron rejection	Shower start ≥ 5 or $N_{\text{layer}} > 30$
	Muon rejection	$N_{\text{hit}}/N_{\text{layer}} > 3.2$ (previous is 2.2)
	Radiative muon rejection	$N_{\text{layer}}(\text{RMS} > 5\text{cm})/N_{\text{layer}} > 20\%$
	Neutral rejection	$N_{\text{hit}}(\text{belong to first 5 layers}) > 4$
Artificial cut	Beam position cut	$r < r(\text{given})$



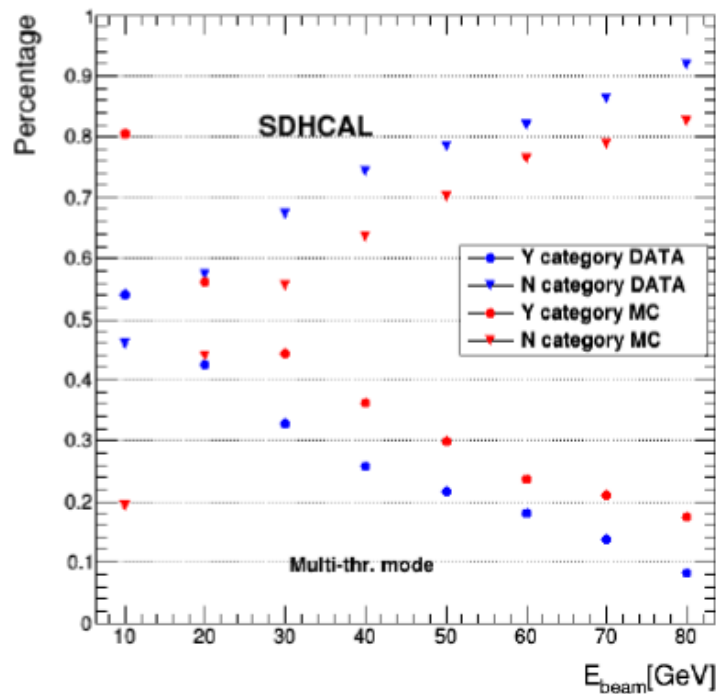
Improve the Muon Rejection

Bing Liu, Haijun Yang, Imad

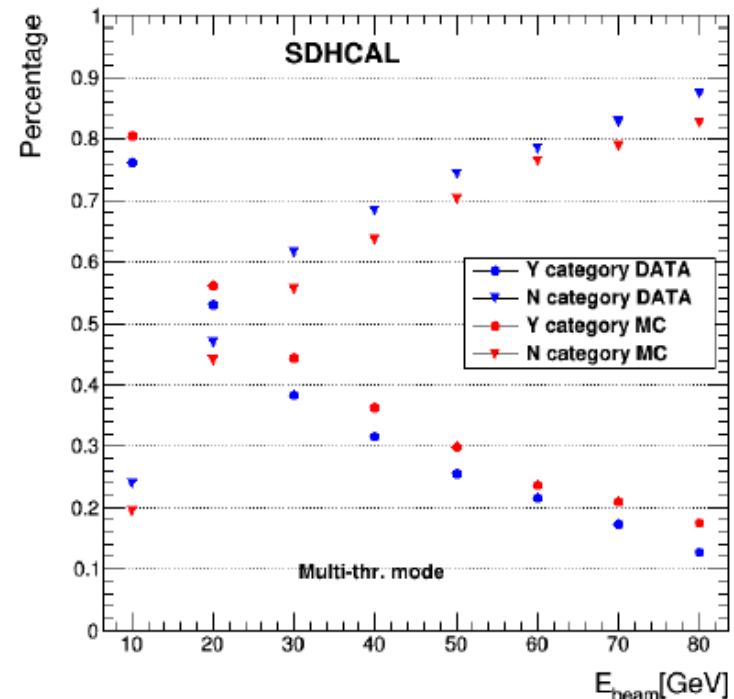
Nhits/Nlayer > 2.2

Update

Nhits/Nlayer > 3.2

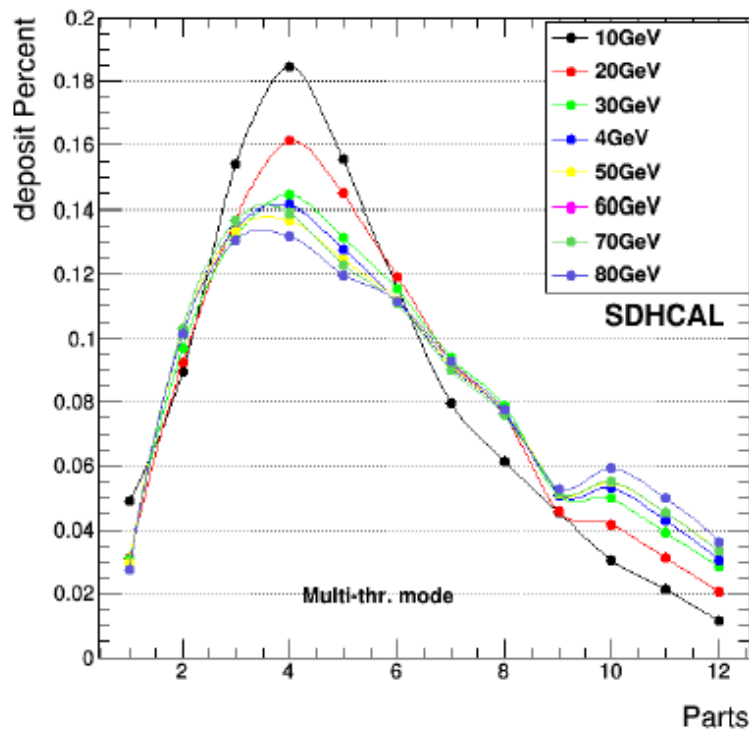


There is a large difference between MC and data

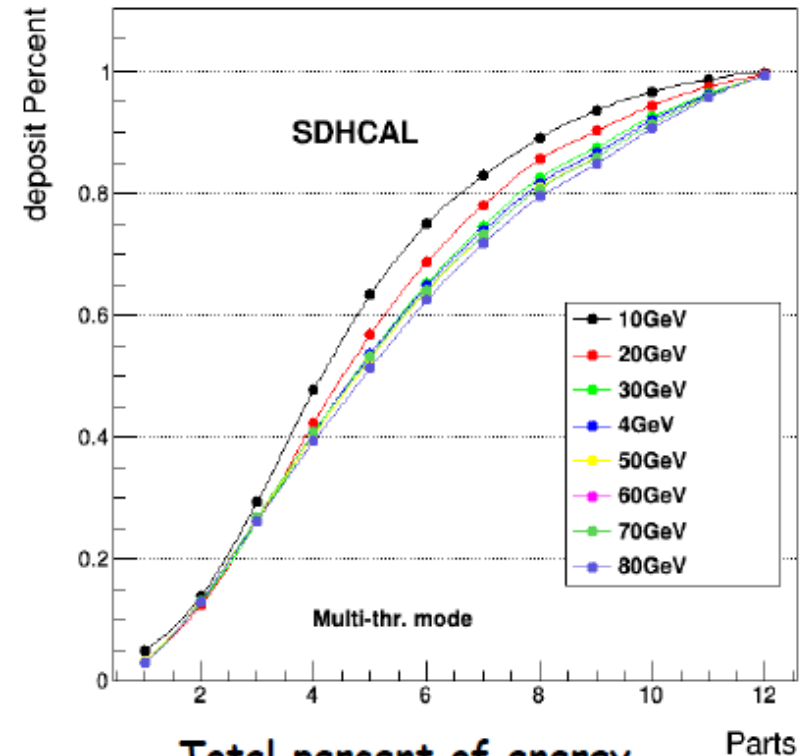


After updating , the difference between MC and data is very little

Energy deposited in every 4 layers



Percent of energy deposit in
per parts



Total percent of energy
deposit before a part you
choose;

Cutflow of the SDHCAL TB data

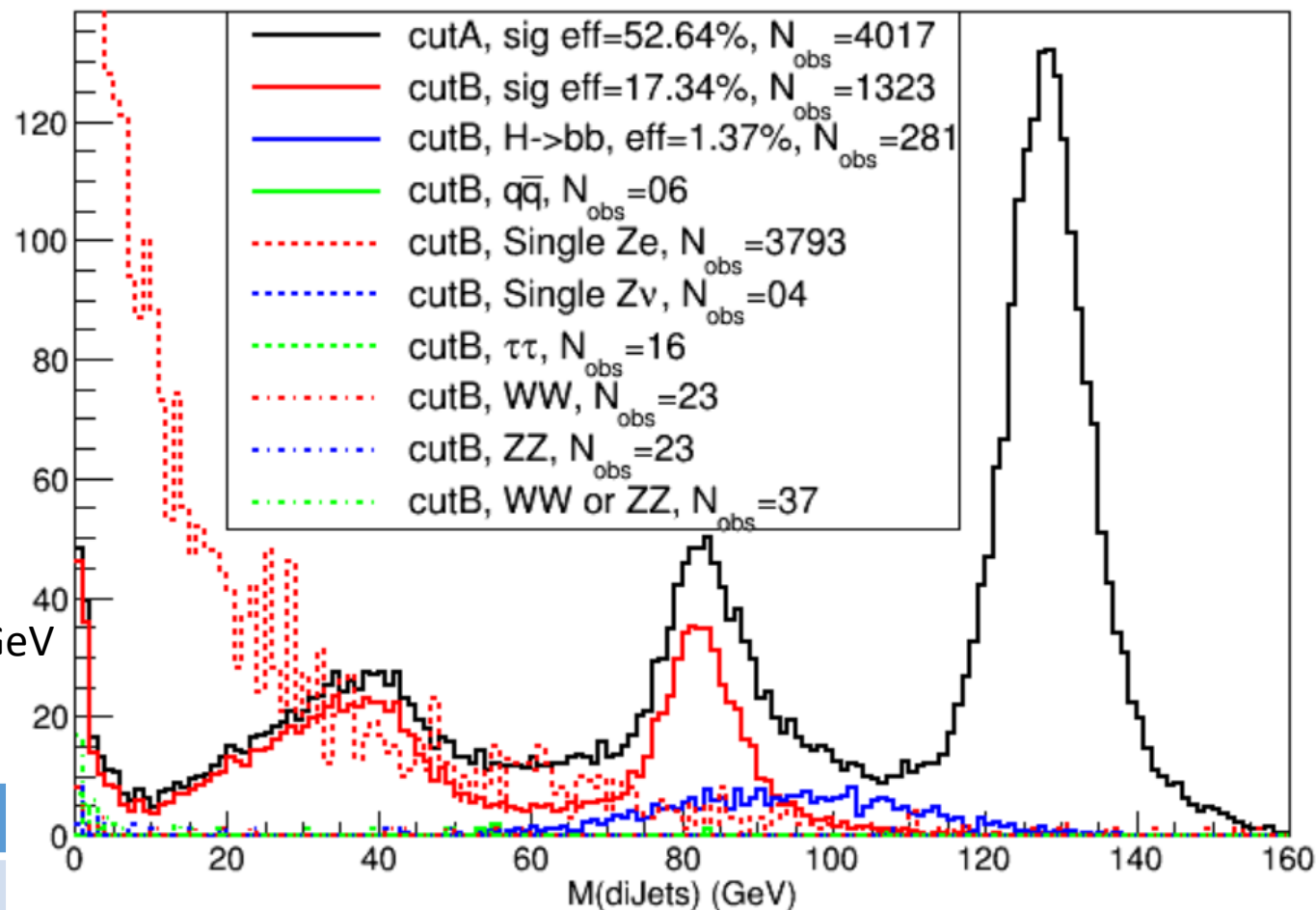
Cut flow for 2015 TB data

Energy(GeV)	Total Events	After Electron rejection	After Muon rejection	After Radiative muon rejection	After Neutral rejection
10	123974	82223	10810	9685	9675
20	92053	68981	10250	9710	9701
30	49299	38134	7715	7319	7313
40	247428	190603	31329	29582	29544
50	97496	74933	14556	13644	13627
60	97988	76819	13629	12642	12625
70	101626	78547	10914	9865	9852
80	249478	196340	18884	15577	15541

Signal VS Background

$76 < M(z) < 106 \text{ GeV}$
 $120 < M(H) \text{ recoil} < 150 \text{ GeV}$
 $E(\text{iso lepton}) > 10 \text{ GeV}$

mean	width
82.32 GeV	5.47 GeV



Signal Production

Table 17: The information of the Higgs signal samples

Process	Final states	σ [fb]	ILC result [fb]	Events expected	Events generated
ffh_X	h, f, \bar{f}	211.01	208.77	1065619	1065111
qqh_X	h, q, \bar{q}	143.39	141.99	724097	723755
uuh_X	h, u, \bar{u}	24.52	—	123802	123733
ddh_X	h, d, \bar{d}	31.45	—	158830	158742
cch_X	h, c, \bar{c}	24.51	—	123766	123711
ssh_X	h, s, \bar{s}	31.46	—	158891	158803
bbh_X	h, b, \bar{b}	31.18	—	157479	157412
e1e1h_X	h, e^-, e^+	7.60	7.19	38357	99938
e2e2h_X	h, μ^-, μ^+	7.10	7.03	35849	99952
e3e3h_X	h, τ^-, τ^+	7.08	7.02	35770	99951
nnh_X	$h, \nu_{e,\mu,\tau}, \bar{\nu}_{e,\mu,\tau}$	48.96	48.43	247273	247167
n1n1h_X	$h, \nu_e, \bar{\nu}_e$	20.91	—	105574	105533
n2n2h_X	$h, \nu_\mu, \bar{\nu}_\mu$	14.03	—	70862	99961
n3n3h_X	$h, \nu_\tau, \bar{\nu}_\tau$	14.01	—	70773	99944

Background (2 fermions)

Table 18: The information of the two fermions background samples

Process	Final states	σ [fb]	ILC result [fb]	Events expected	Events generated
uu	u, \bar{u}	9995.35	10110.43	50476527	50476526
dd	d, \bar{d}	9808.71	10010.07	49533965	49533961
cc	c, \bar{c}	9974.20	10102.75	50369725	50369718
ss	s, \bar{s}	9805.39	9924.40	49517234	49517231
bb	b, \bar{b}	9803.04	9957.70	49505372	49504516
qq	q, \bar{q}	49561.30	50105.35	250284565	250283714
e2e2	$\mu^- \mu^+$	4967.58	4991.91	25086253	25086255
e3e3	$\tau^- \tau^+$	4374.94	4432.18	22093447	22093445
bhabha	e^-, e^+, γ	24992.21	24937.95	126210660	126210654

4 fermions background not listed here

Table 2: The value of the cross section at 250GeV

Process	$q\bar{q}$	$\mu^+ \mu^-$	Single Z	Single W	Bhabha
σ [fb]	50216.20	4404.69	4733.74	5144.28	25060.22
Process	WW	ZZ	ZH	Z fusion	W fusion
σ [fb]	15483.95	1033.38	212.13	0.63	6.72