环形正负电子对撞机
Circular Electron Positron Collider

Status of CEPC Calorimeters R&D

Haijun Yang (SJTU)

(on behalf of the CEPC-Calo Group)

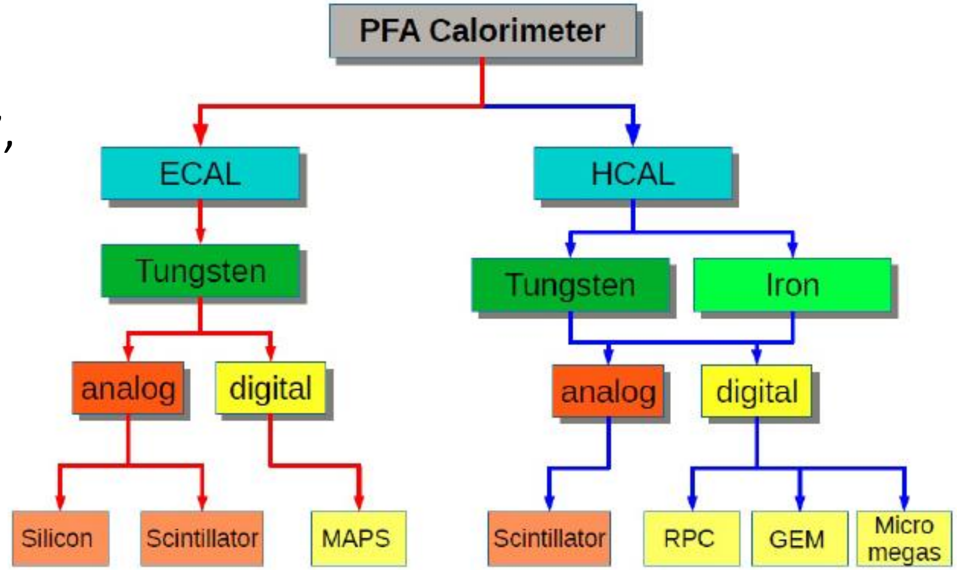
上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Calorimeters Options

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

SJTU group was officially approved by CALICE steering group as a member on Mar. 24, 2017, working on the SDHCAL performance study.

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

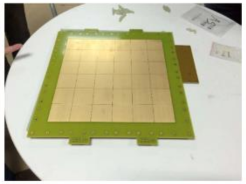
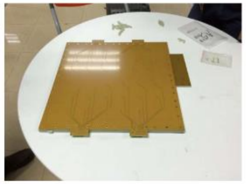


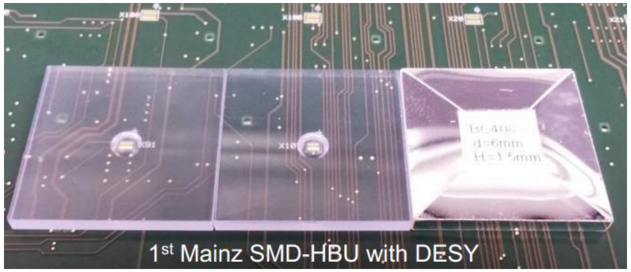
Recent Progress about Calorimeters

- **IHEP:** studies of SiPM response curve, optimization of scintillator light outputs
- **USTC:** design & test of readout electronics (PCB & FPGA firmware), construction of 30cm × 30cm double-layer GEM, study of GEM displacement using mechanical simulation

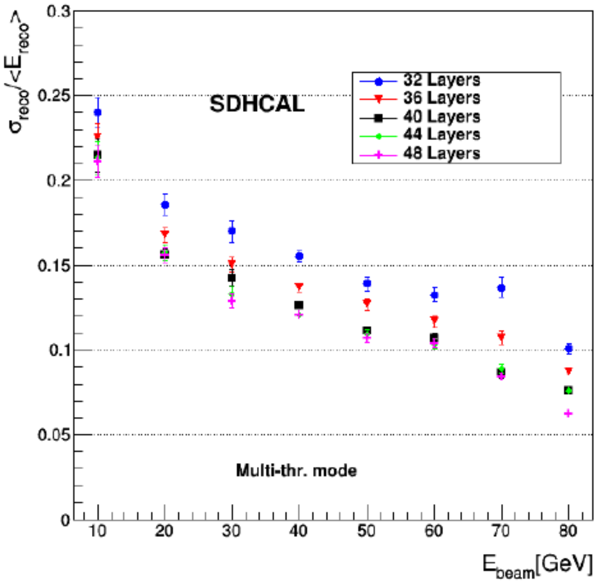
Test board: SPIROC2b chip was selected

Setup:
1. AFG3252 signal generator
2. LPS-305 linear DC regulated power
3. WAVETEK attenuator
4. SPIROC2b test plate
5. Signal exchange coupling plate
6. HDO6104 1Ghz oscilloscope
7. PC



SJTU: SDHCAL TB analysis and optimization of # of layers



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. Need international collab. for CEPC Calo studies.

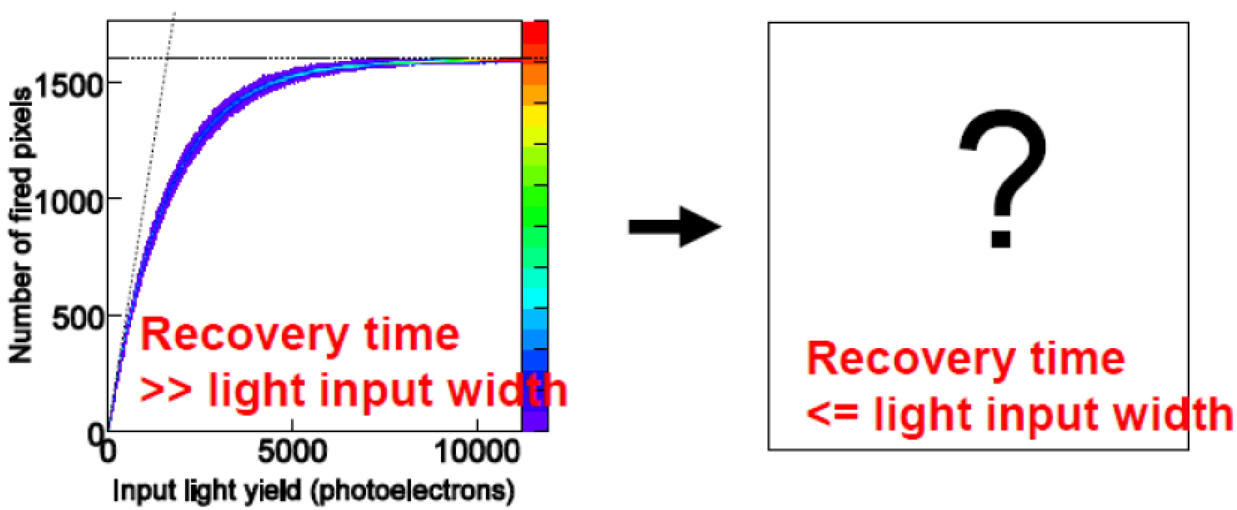
Preparation for CEPC-Calo CDR

- ECAL with Silicon and Tungsten
  Editor: Vincent Boudry (LLR, France)
- ECAL with Scintillator+SiPM and Tungsten
  Editors: Zhigang Wang (IHEP) + Yunlong Zhang (USTC)
- SDHCAL with RPC and Stainless Steel
  Editors: Haijun Yang (SJTU) + Imad Laktineh (IPNL, France)
- HCAL with ThGEM/GEM and Stainless Steel
  Editors: Jianbei Liu (USTC) + Boxiang Yu (IHEP)
- HCAL with Scintillator+SiPM and Stainless Steel
  Editor: Boxiang Yu (IHEP)
- Dual readout calorimeters
  Editor: ?

Backup Slides

SiPM Dynamic Range

- The SiPM is a non-linear device, because one pixel can detect one photon at once.
- For a short light pulse input, response to input light can be theoretically calculated as
  $N_{\mathrm{fired}} = N_{\mathrm{pix}}(1 - e^{-N_{\mathrm{pe}}/N_{\mathrm{pix}}})$.
- However for the ScW ECAL, it is not the case !
  Since recovery time is order of a few ns, one pixel can detect a photon several times.



Expression of SiPM behavior

$$N_{fire} = N_{pix}\,(1 - e^{-\epsilon N_{in}/N_{pix}}) \tag{1}$$

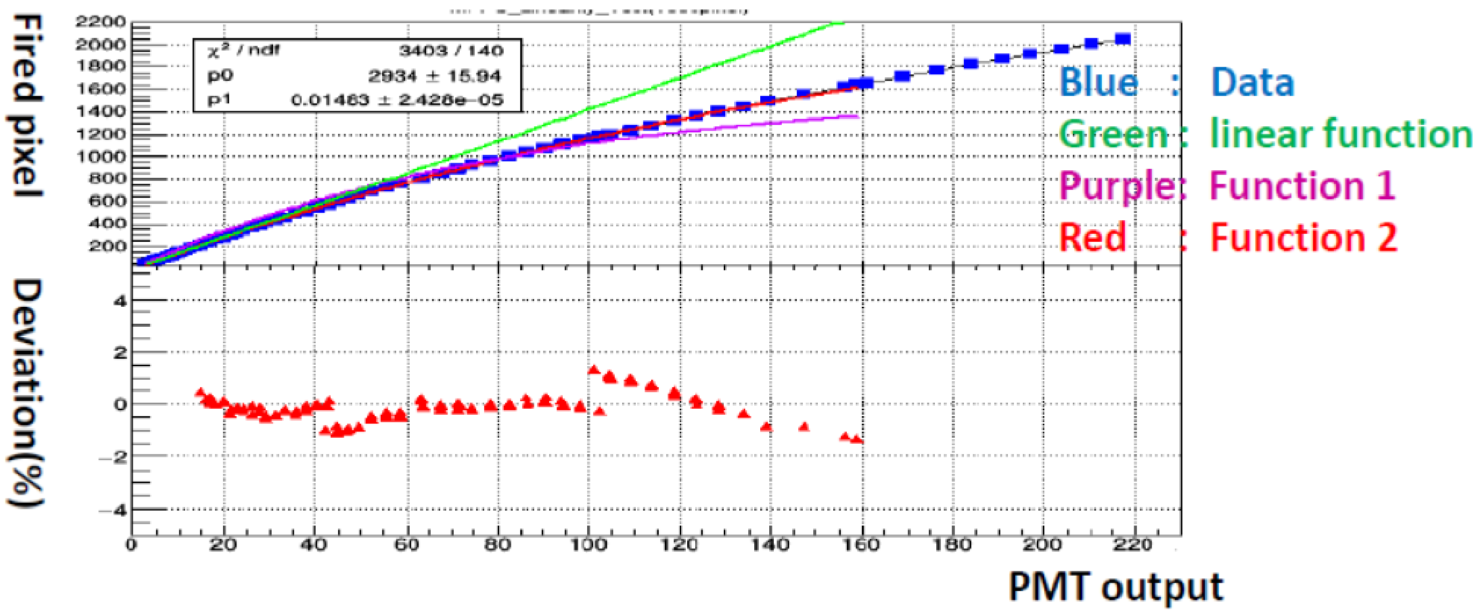
N_{fire}: the number of fired pixels,
N_{pix}: the number of pixels this SiPM has,
Ɛ : photon detection efficiency(PED),
N_{in} : the number of incident photons.
This equation explains the saturation phenomenon of SiPM: the charge of each pixel is released only once in an event by photons so that some multiple hits on a pixel are counted as one hit.

$$N_{fire} = N_{eff}(1 - e^{-\epsilon N_{in}/N_{eff}}) \tag{2}$$

N_{eff}: the effective pixel number of pixels this SiPM has.
When the recovery time of each cell of SiPM is faster than the duration of one event, some of cell will contributing to an signal more than once. It makes the N_{pix} greater than the real number of pixels effectively.
N_{eff} functions as a fitting parameter when this equation is fitted to real data.

SiPM Test

Response curve of 1600 pixel sipm

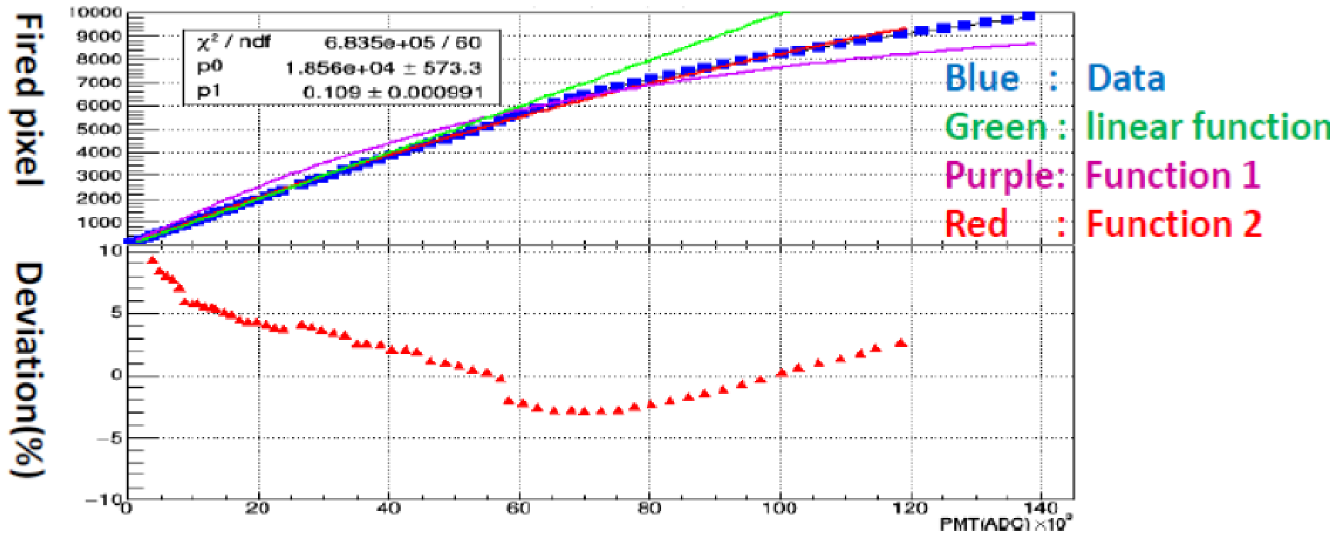


SiPM: S12571-025C

N_{eff} = 2934 >> 1600
The behavior of 1600 pixel SiPM can be described by function 2 very well, the deviation of experimental data and fitting function is less than 2%.

SiPM Test

Response curve of 10000 pixel sipm



SiPM: S12571-010C

N_{eff} = 18560 >> 10000

The deviation of experimental data and fitting function is larger than 1600 pixel sipm.

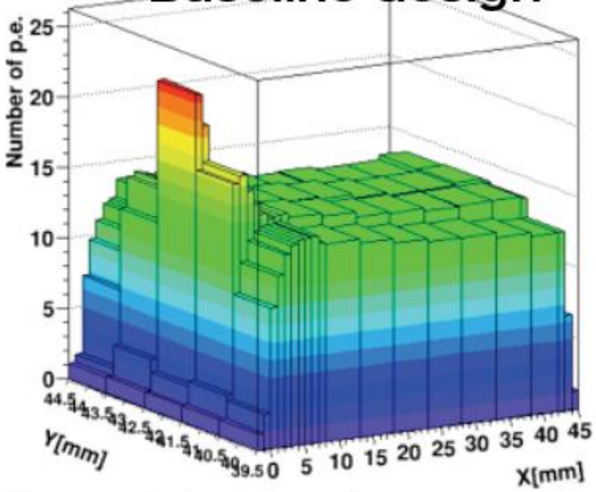
Next: The response curve of 10000 SiPM will input to calorimeter digitization progress to study the influence on energy resolution.

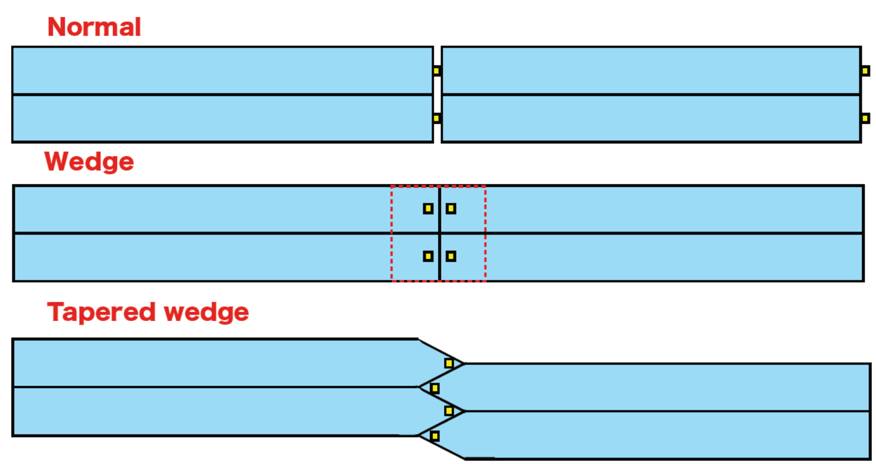
Optimization of Scintillator Strip

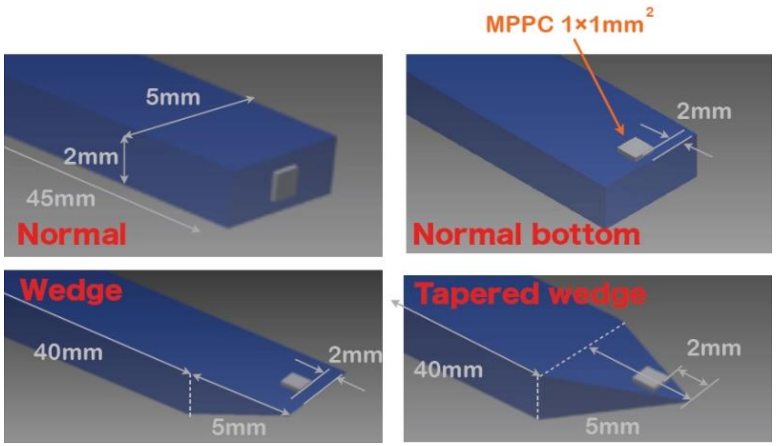
Z.G. Wang et.al.

Optimizing geometry & connection of scintillators.

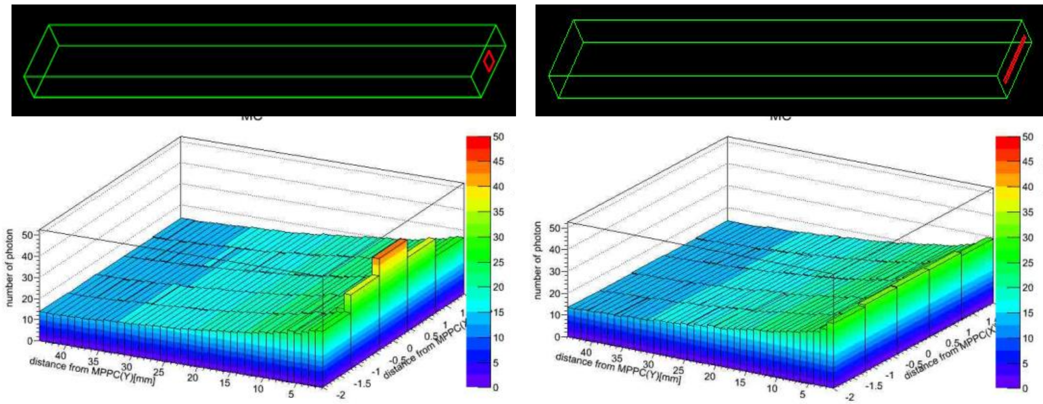
Baseline design





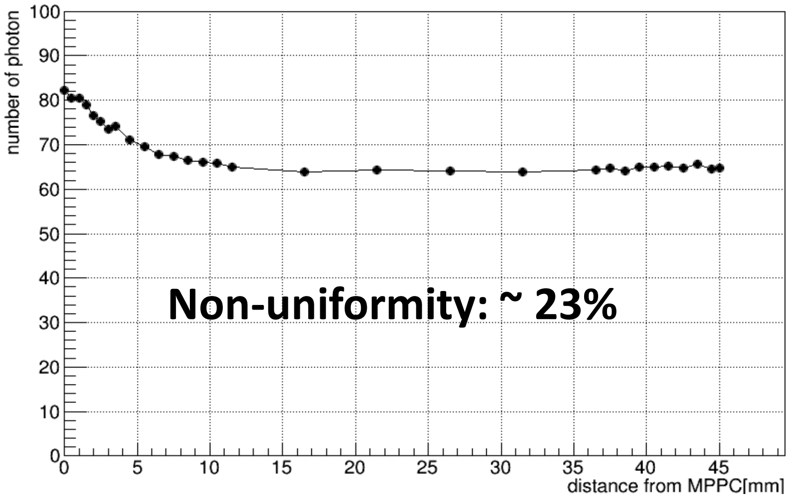


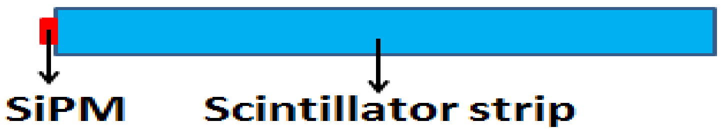
SiPM area: 1×1 mm² ➔ 0.25×4 mm²:



Scintillator strip light output

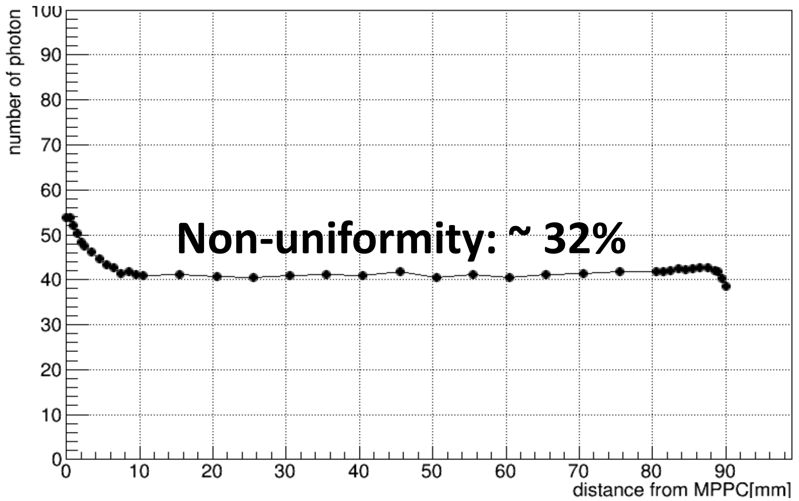
5mm×45mm scintillator strip

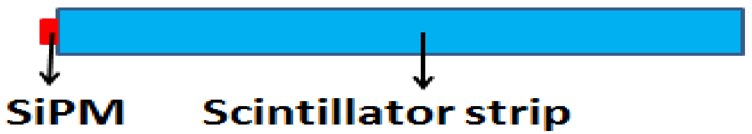




Strip: 5mm×45mm×2mm

10mm×90mm scintillator strip





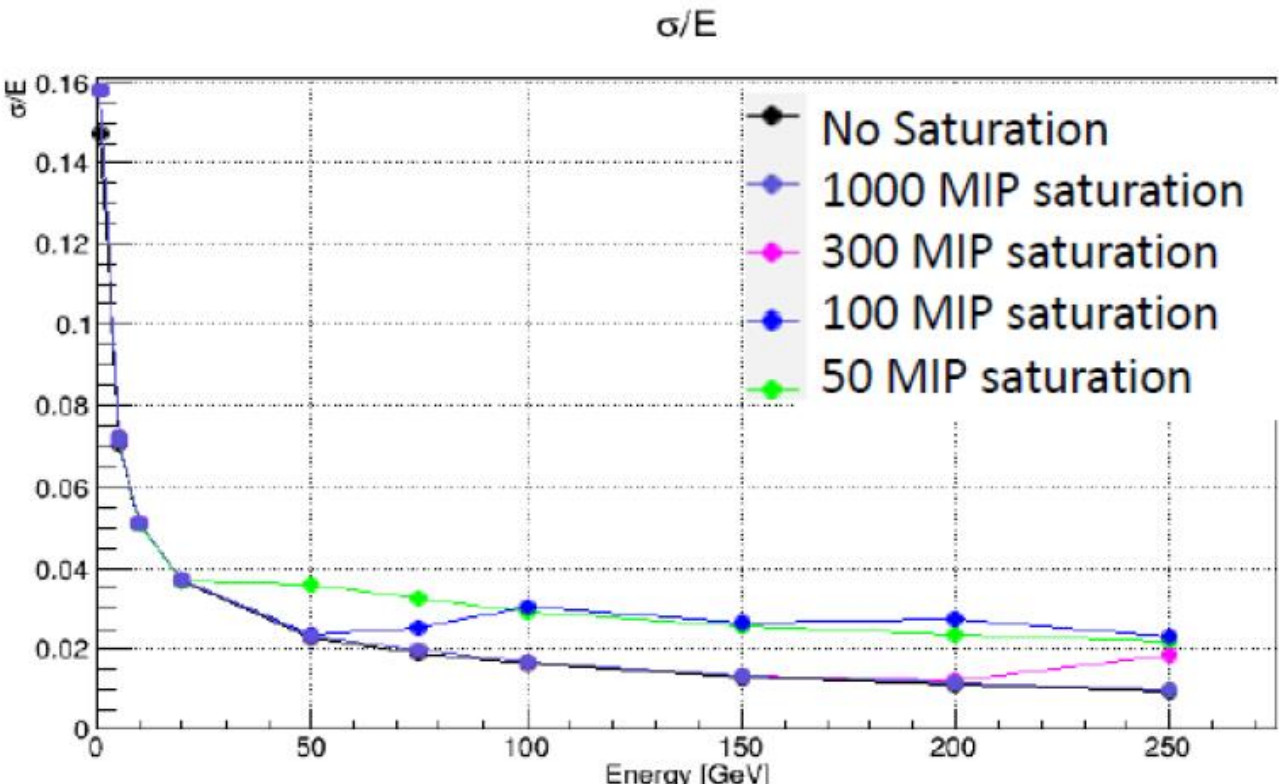
Strip: 10mm×90mm×2mm

Scintillator: BC408， SiPM: 1mm×1mm,25um pixel size

Baseline design of the CEPC ScW ECAL readout structure.

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

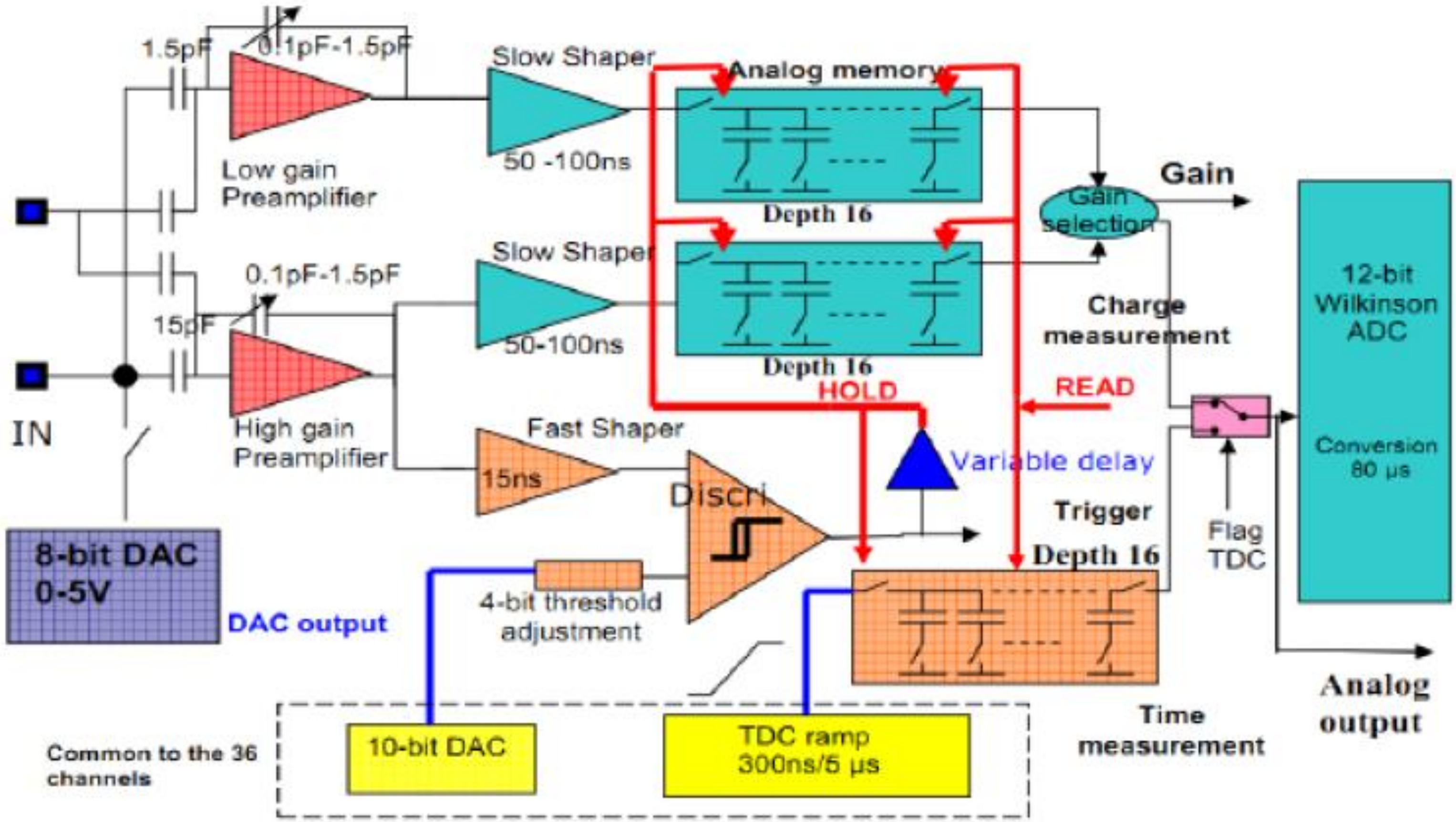
Saturation effect on energy resolution



Energy Resolution

Photon， Cell Size 5x5mm
(W:3,Air:0.5,Scintillator:2,Air:0.5,PCB:2,Air:0.5)*50

Readout Electronics of ECAL



Design of SiPM readout system based on SPIROC chip

Electronics Board of ECAL (USTC)

Setup:
1. AFG3252 signal generator
2. LPS-305 linear DC regulated power
3. WAVETEK attenuator
4. SPIROC2b test plate
5. Signal exchange coupling plate
6. HDO6104 1Ghz oscilloscope
7. PC

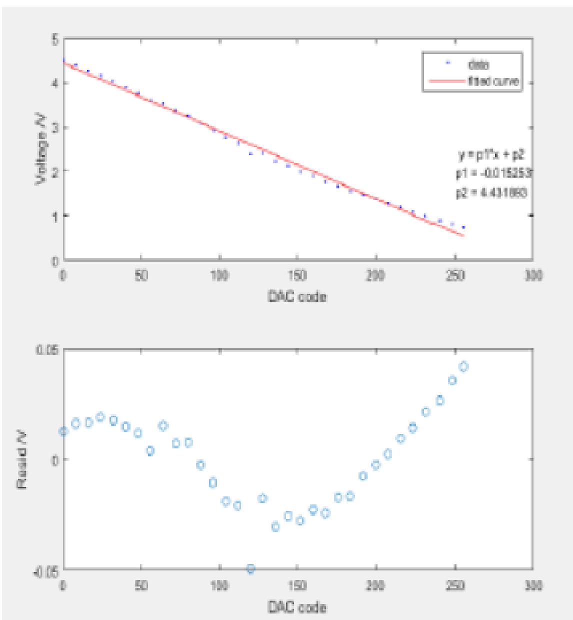
14

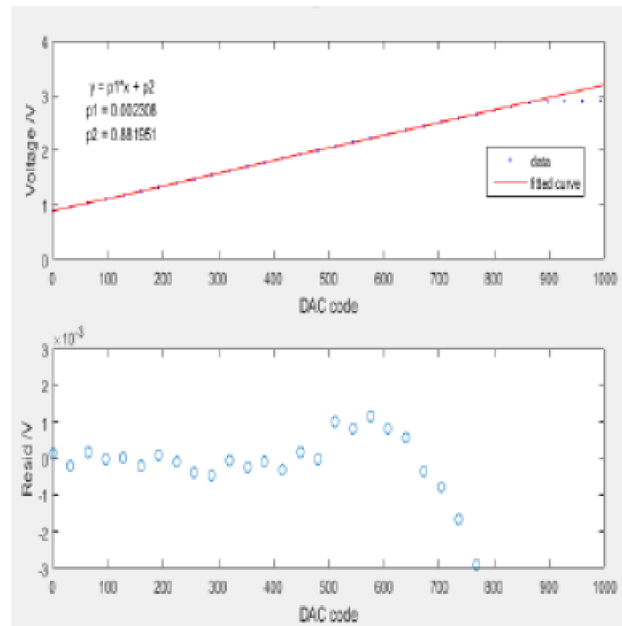
Test board: SPIROC2b chip was selected

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

DAC Linear Test

- 8 bit DAC linear test for high voltage：
  - range： 0.5-4.5 V
  - precision: $\pm 5\%$
- 10 bit DAC linear test for threshold :
  - range： 1.0- 2.9V
  - precision: $\pm 0.2\%$





Energy Reconstruction for SDHCAL

Energy reconstruction

Energy reconstruction formula:

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

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

N is the number of total events.

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

α, β, γ are parameterized as functions of total number of hits(N1+N2+N3)

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

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

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

After the first step:

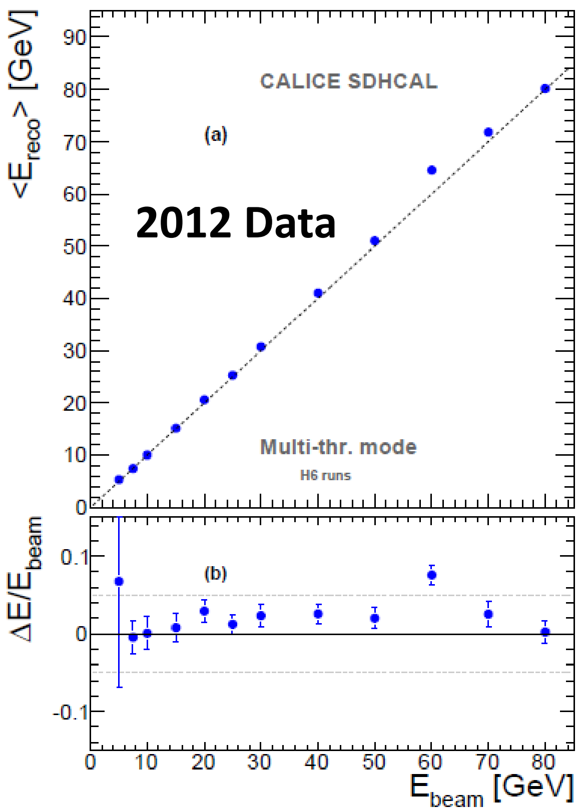
$$\sigma_i = \sqrt{p0 * E_{beam}^i + p1 + p2 * E_{beam}^i * E_{beam}^i}$$

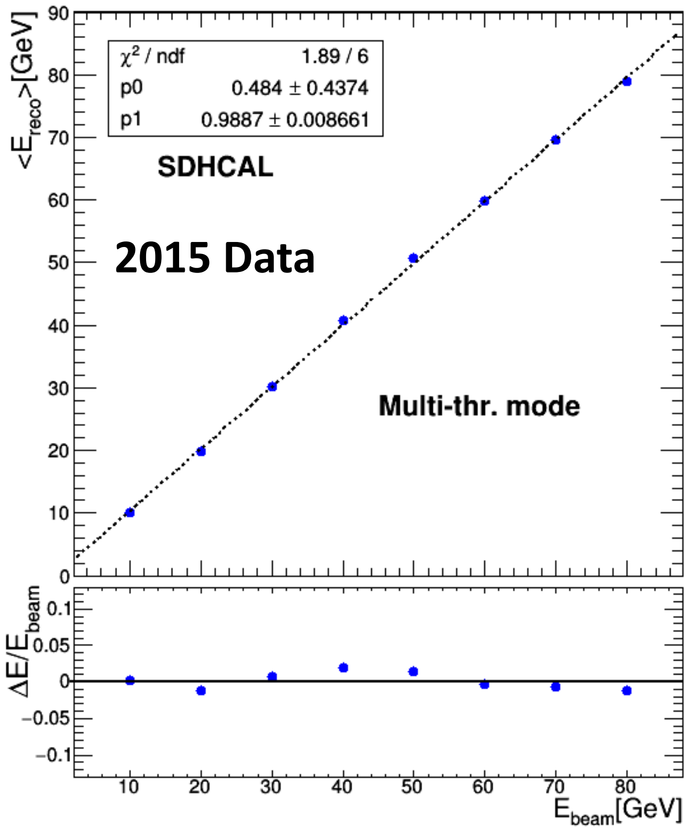
2017/1/13 SJTU-IPNL 15

DHCAL with RPC

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

B. Liu, H. Yang, Imad





Definition of Y/N Category

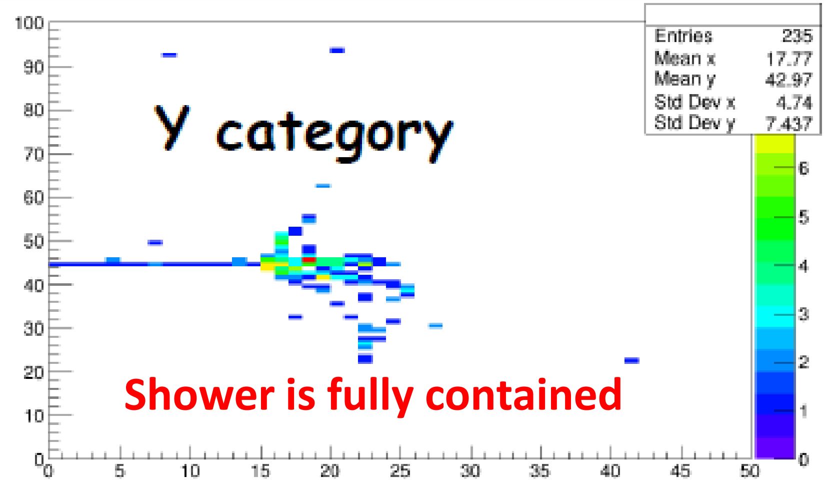
Data sample:SPS_Oco_2015

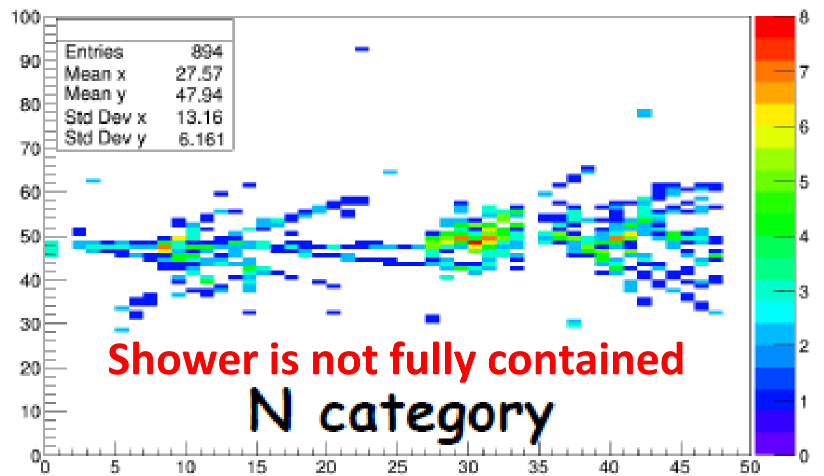
Particle: Pi+

Energy:10-80GeV with uniform

10 GeV energy gap

Type	Selections	Detail
Physical cut	Electron rejection	Shower start >=5 or 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
Artificial cut	Beam position cut	r<r(given)





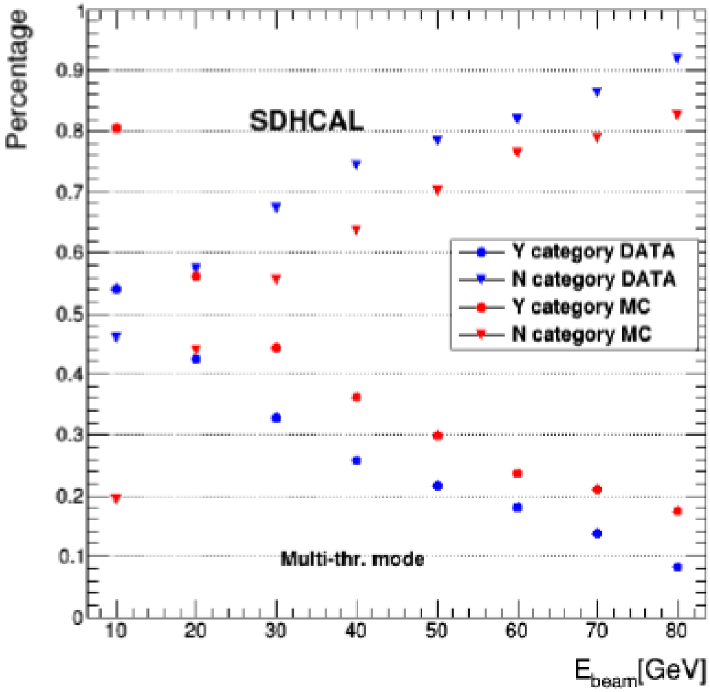
Improve the Muon Rejection

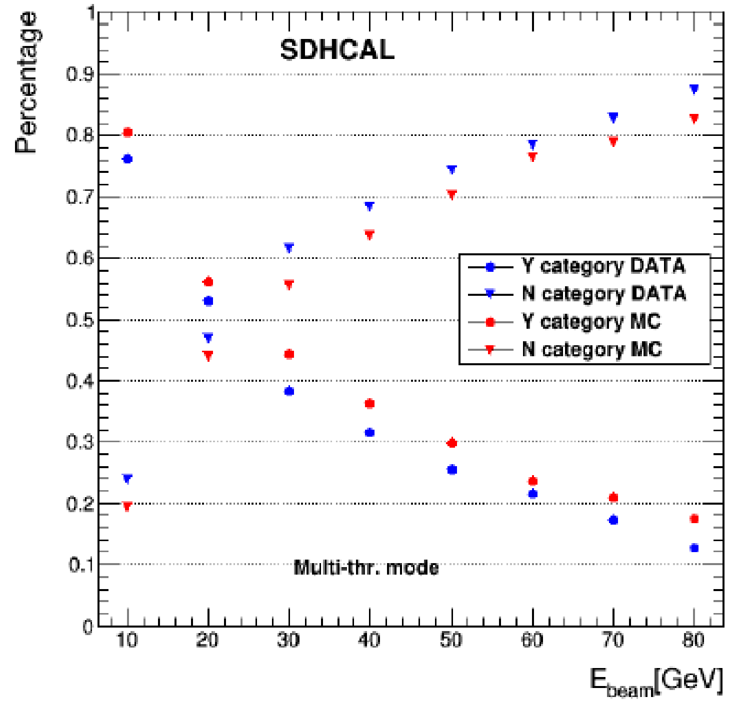
Bing Liu, Haijun Yang, Imad

Nhits/Nlayer > 2.2

Update

Nhits/Nlayer > 3.2





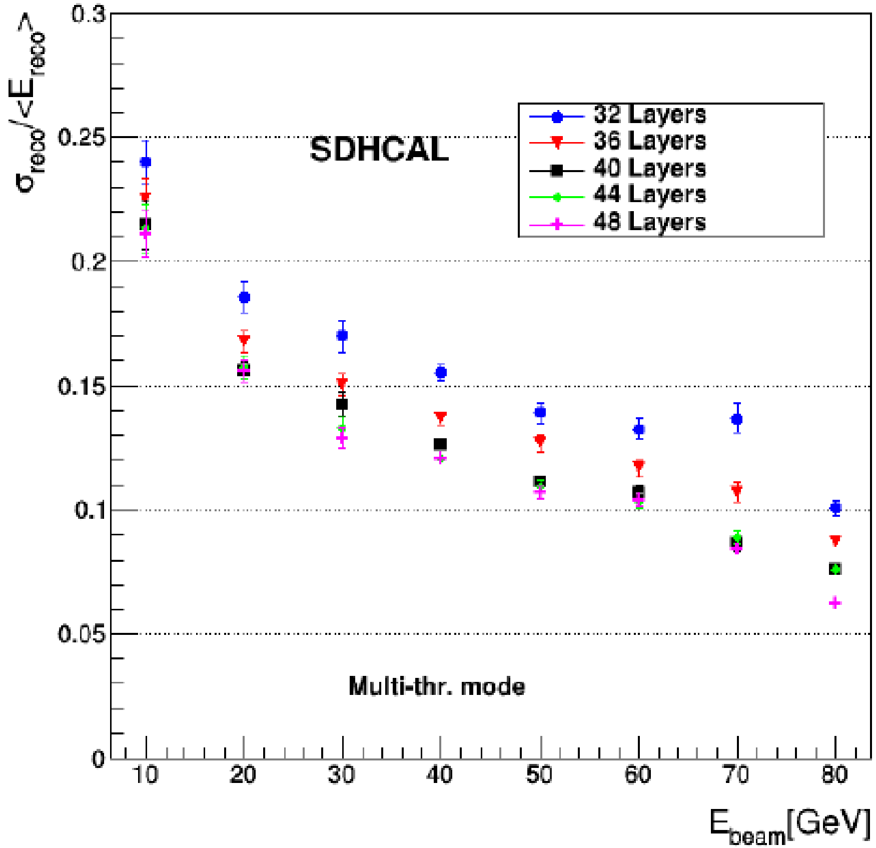
There is a large difference between MC and data

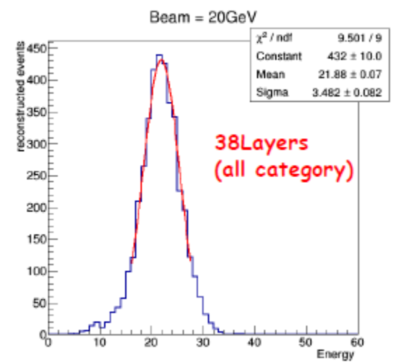
After updating , the difference between MC and data is very little

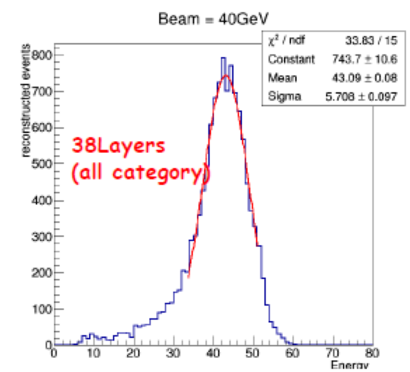
Energy Resolution vs No. of Layers

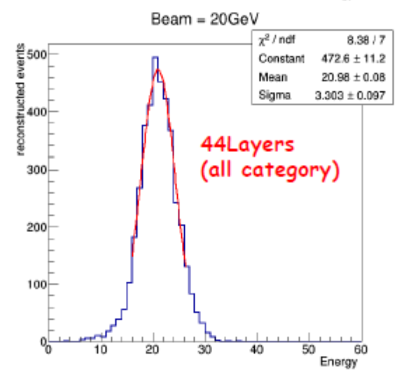
SDHCAL has 48 layers which aims for ILC Detector
- 6mm RPC and 20mm Stainless steel absorber
➔ Optimization no. of layers for CEPC at 240GeV

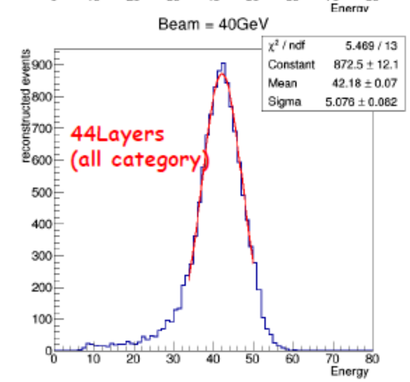
Stainless steel Absorber(15mm, $0.12\lambda_I, 1.14X_0$)
Stainless steel wall(2.5mm)
GRPC(6mm≈ $0\ \lambda_I, X_0$)
Stainless steel wall(2.5mm)









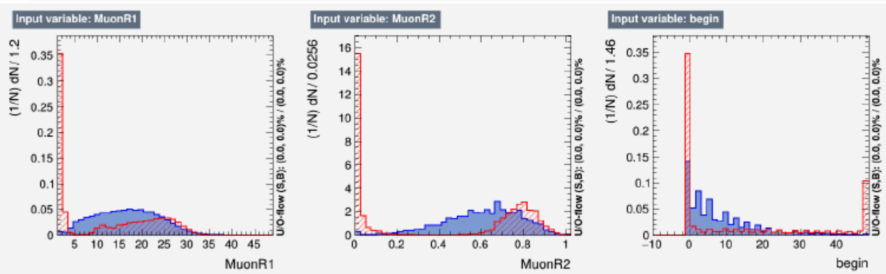


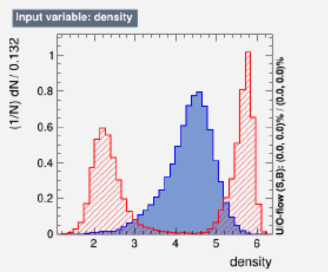
CEPC HCAL Detector Simulation

- Tianjue: at H->gg
  - Reduce the #layer to 42/30, the resolution degrade by 0-4/12%
  - Significant depend on reconstruction algorithm...
- Jifeng: Similar result at H->WW

	nlayer	Hist Mean	Hist RMS
Arbor3.3	48	127.60 ± 0.06	7.73 ± 0.04
	42	127.36 ± 0.06	7.73 ± 0.04
	36	126.98 ± 0.06	7.85 ± 0.04
	30	126.39 ± 0.06	8.05 ± 0.04
ArborLICH	48	124.15 ± 0.05	7.66 ± 0.04
	42	123.82 ± 0.06	7.76 ± 0.04
	36	123.23 ± 0.06	8.13 ± 0.04
	30	122.34 ± 0.06	8.67 ± 0.04

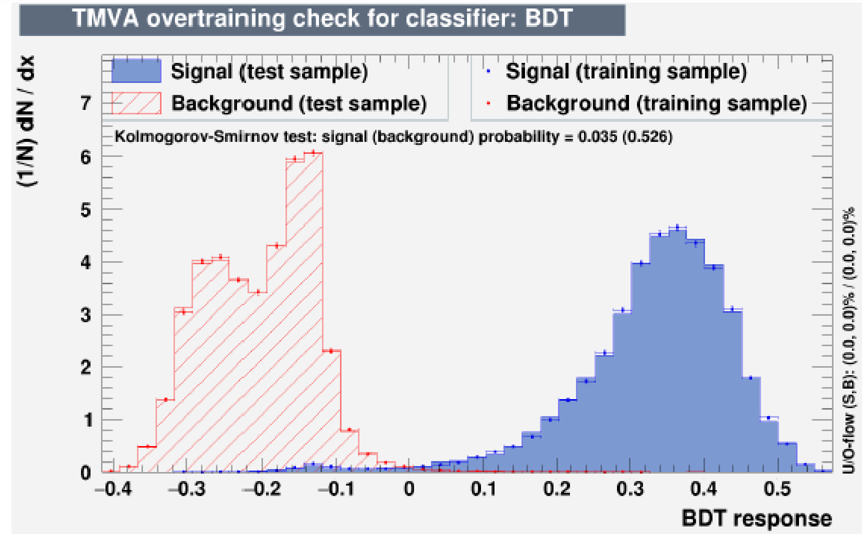
Development of BDT based PID

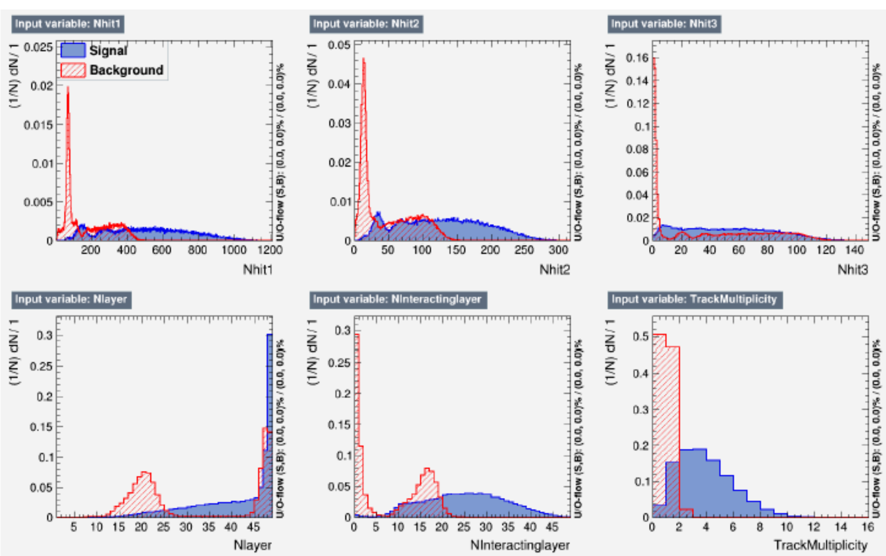




MC sample

Signal sample:	Background sample:	
Pi-_10GeV.root	e-_10GeV.root	mu-_10GeV.root
Pi-_20GeV.root	e-_20GeV.root	mu-_20GeV.root
Pi-_30GeV.root	e-_30GeV.root	mu-_30GeV.root
Pi-_40GeV.root	e-_40GeV.root	mu-_40GeV.root
Pi-_50GeV.root	e-_50GeV.root	mu-_50GeV.root
Pi-_60GeV.root	e-_60GeV.root	mu-_60GeV.root
Pi-_70GeV.root	e-_70GeV.root	mu-_70GeV.root
Pi-_80GeV.root	e-_80GeV.root	mu-_80GeV.root





Type	Selections	Detail
Physical cut	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
Artifici al cut	Beam position cut	r<r(given)

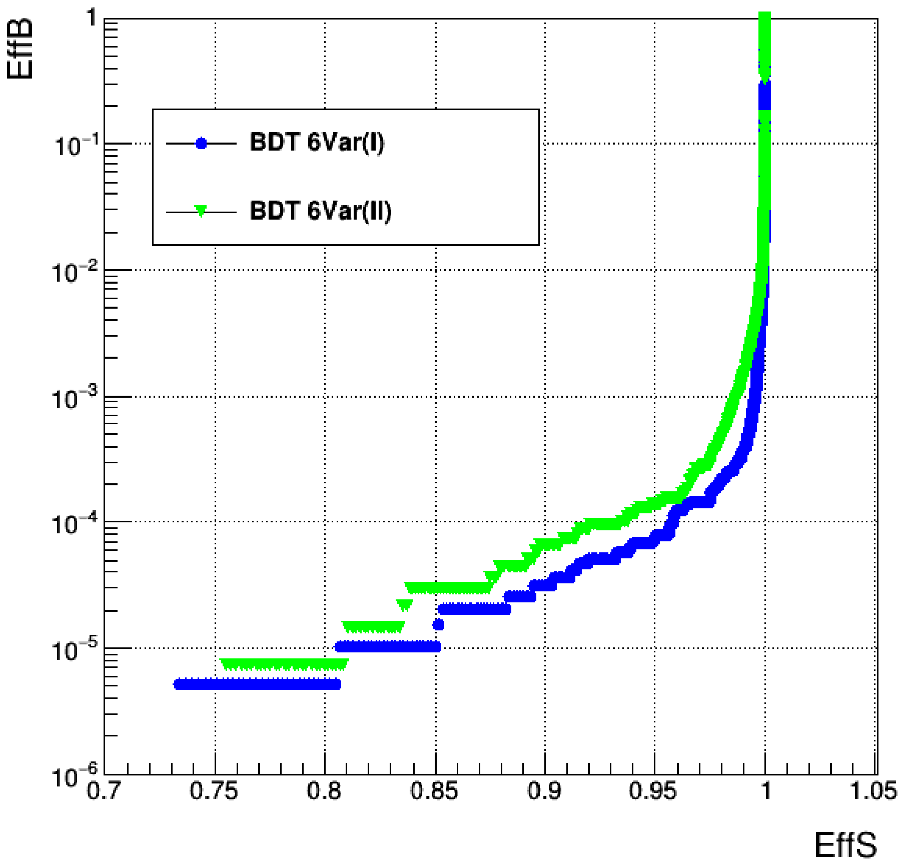
- simple cuts
- The comparison result of BDT and simple cuts from 10 to 80 GeV

- BDT 6 var(I): Begin ,Ninteractinglayer, TrackMultiplicity, MuonR1,MuonR2,Density
- BDT 6 var(II): Begin,TrackMultiplicity, MuonR1,MuonR2,Density,radius

Energy(GeV)	Pion eff(%)	Electron contamination(%)	Muon contamination(%)
10 Simple cuts	62.01	0.09	0.06
10 BDT 6 var I	62.02	0.00	0.00
10 BDT 6 var II	62.29	0.00	0.00
20 Simple cuts	77.02	0.05	0.23
20 BDT 6 var I	77.10	0.00	0.00
20 BDT 6 var II	77.06	0.00	0.00
30 Simple cuts	84.17	0.05	0.54
30 BDT 6 var I	84.13	0.00	0.00
30 BDT 6 var II	84.29	0.00	0.00
40 Simple cuts	90.07	0.20	0.69
40 BDT 6 var I	90.00	0.06	0.00
40 BDT 6 var II	90.08	0.04	0.00
50 Simple cuts	93.21	0.09	0.64
50 BDT 6 var I	93.17	0.00	0.02
50 BDT 6 var II	93.23	0.00	0.00
60 Simple cuts	94.89	0.23	0.79
60 BDT 6 var I	94.88	0.02	0.02
60 BDT 6 var II	94.84	0.02	0.02
70 Simple cuts	95.60	0.31	1.08
70 BDT 6 var I	95.59	0.06	0.00
70 BDT 6 var II	95.63	0.08	0.00
80 Simple cuts	96.22	0.37	1.13
80 BDT 6 var I	96.22	0.10	0.00
80 BDT 6 var II	96.24	0.12	0.02

- BDT 6 var(I): Begin ,Ninteractinglayer, TrackMultiplicity, MuonR1,MuonR2,Density

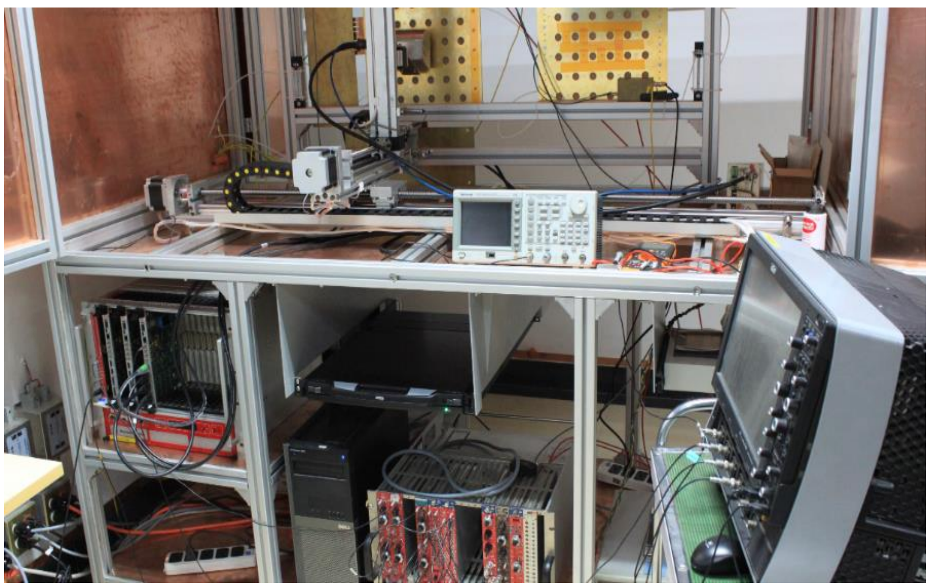
- BDT 6 var(II): Begin,TrackMultiplicity, MuonR1,MuonR2,Density,radius



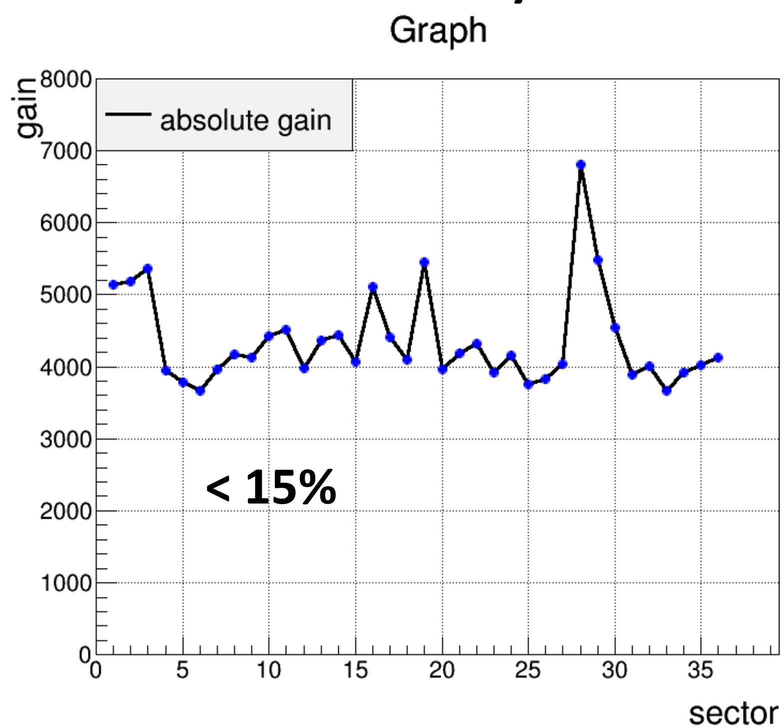
GEM Performance Test

- **Using X-ray to test double-layer GEM**

Test facility at USTC

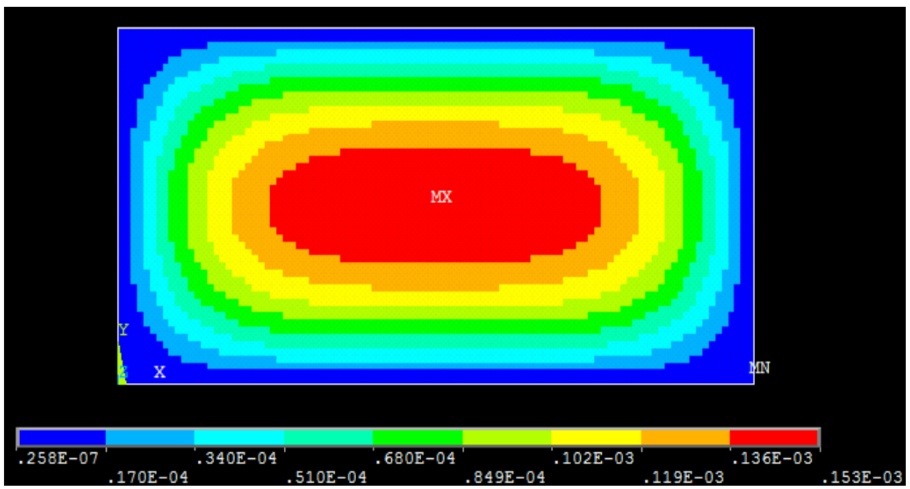


Gain uniformity

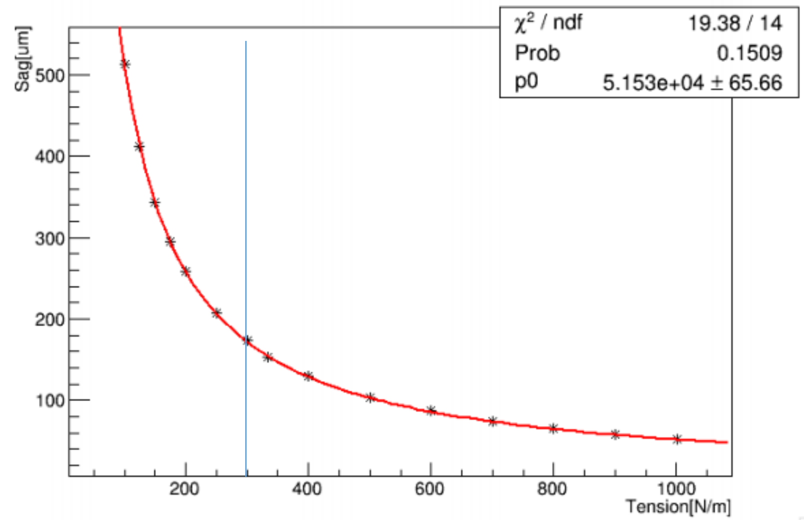


GEM Mechanical Simulation

GEM displacement due to sum of electric force and gravity



GEM displacement vs. tension applied



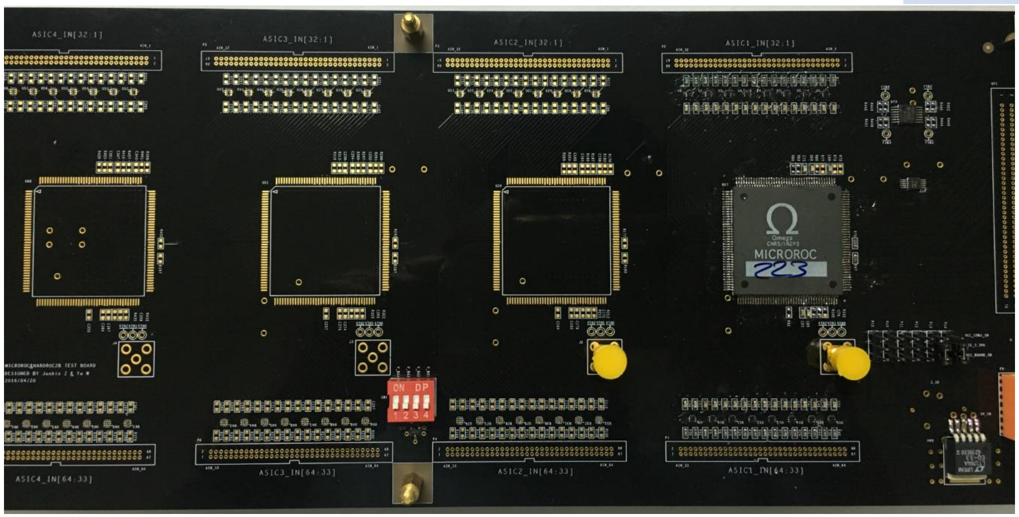
- Maximum GEM displacement ~ 150um when tensioned at ~0.3kg/cm
- More tensioning doesn’t help too much in further reducing displacement.

Readout Electronics

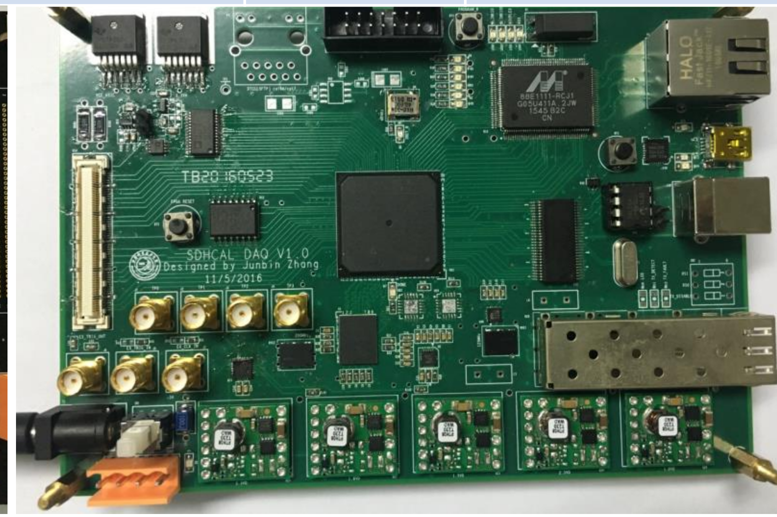
- Design and test of readout electronics by USTC

Microroc is dedicated chip for GEM / MICROMEGAS. Microroc (pin pin compatible with HR2b) is based on HR2b same back-end, readout format, same pinout, only preamplifier is changing.

Multi-thresholds	channels	Dynamic range
Hardroc2	64	10fC~10pC
Hardroc3	64	10fC~50pC
Microroc	64	1fC~500fC

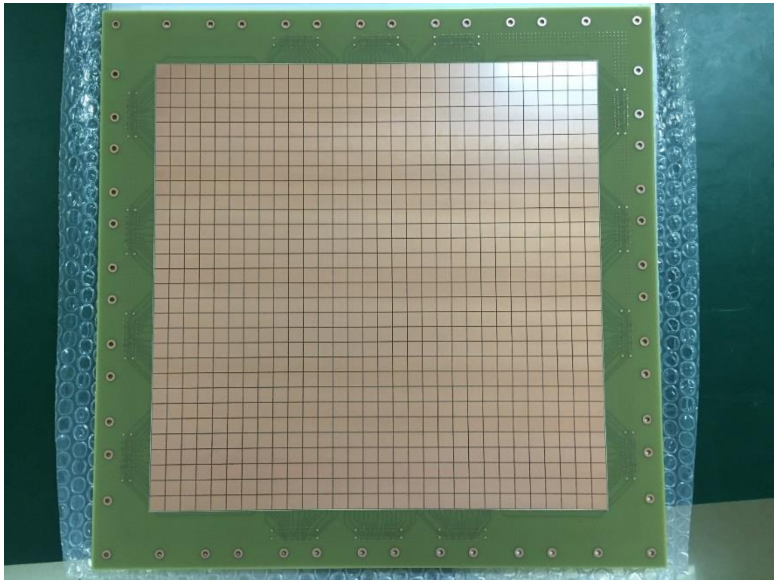


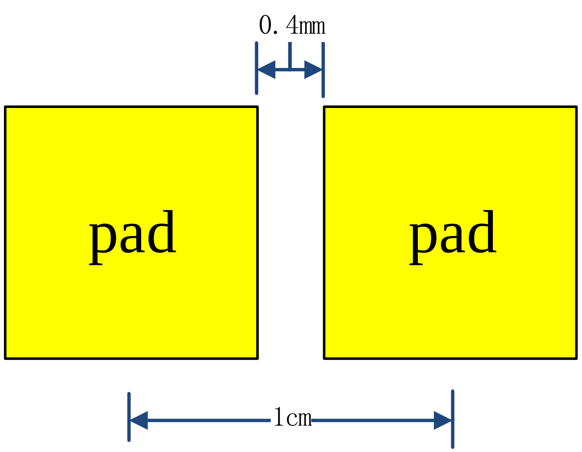
MICROROC & HARDROC2B Test Board



SDHCAL DIF Board

PCB Design and Test





- Active area: $30cm \times 30cm$
- 900 pads in total (4 pads unused)
- 14 connectors
- Layout Cross Section:

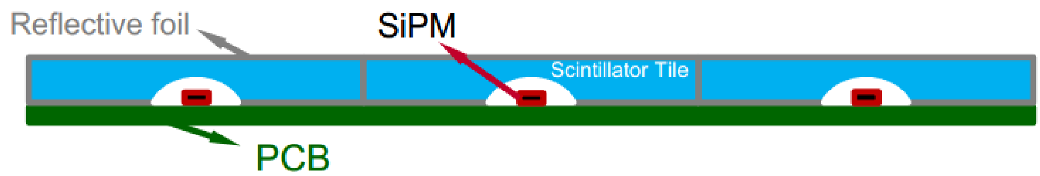
GND--SIG1--GND--SIG2--GND--SIG3--GND--PADs
(Top ---bottom)

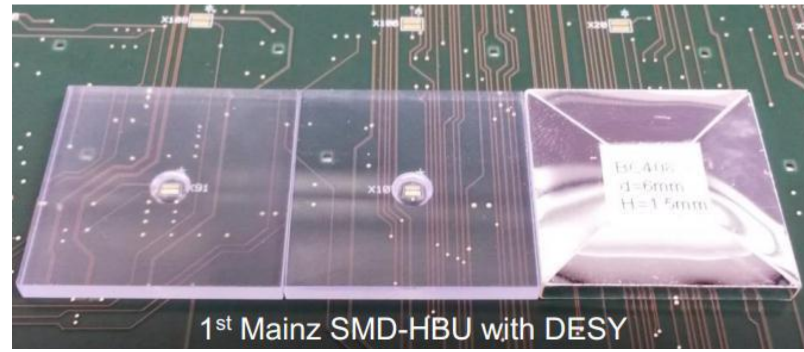
Test board	√
DIF board	√
Active Sensor Array board	√
Test board←→ DIF (Kapton)	√
ASA board←→ Test board(Kapton)	√
FPGA firmware	started
Application software	started

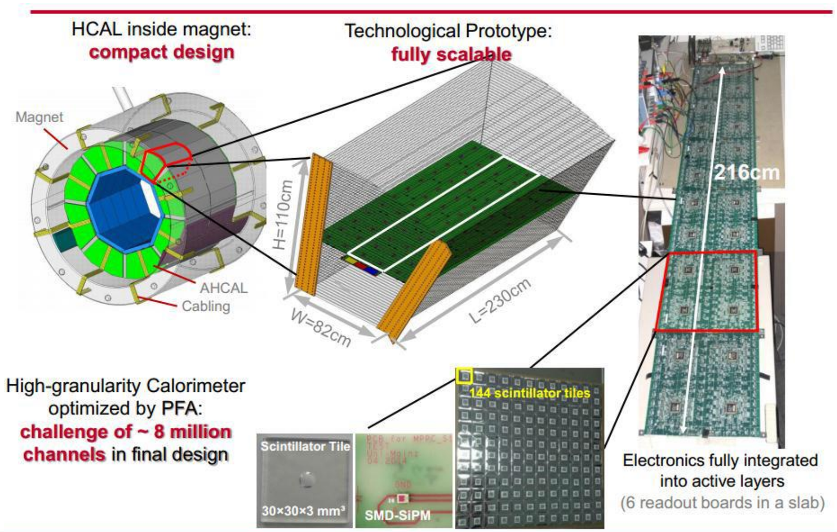
HCAL Based on Scintillator + SiPM

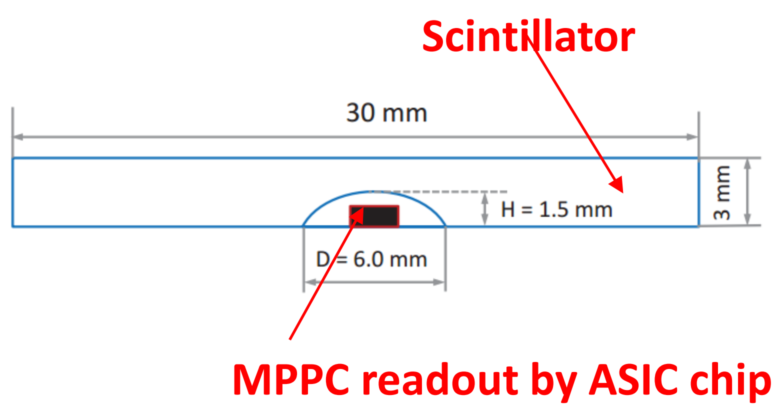
Zhe Wu, Boxiang Yu (IHEP)

- 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.





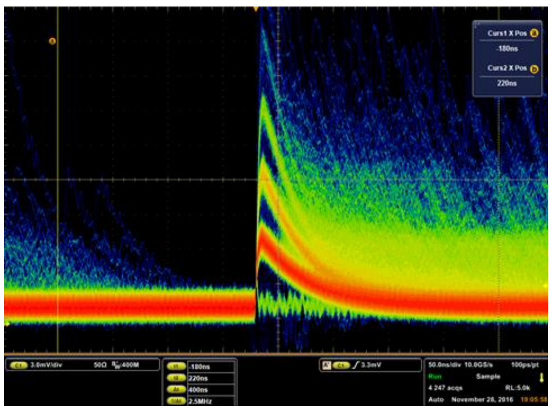




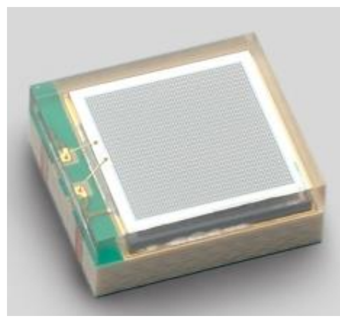
Single detector unit

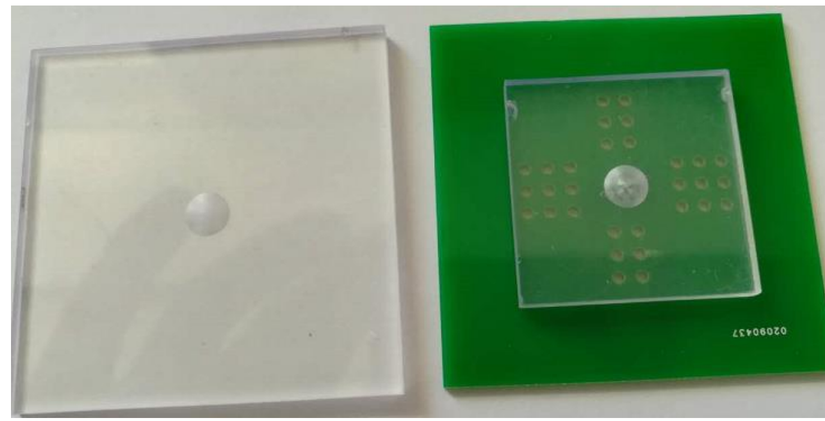
Test of Scintillator with SiPM

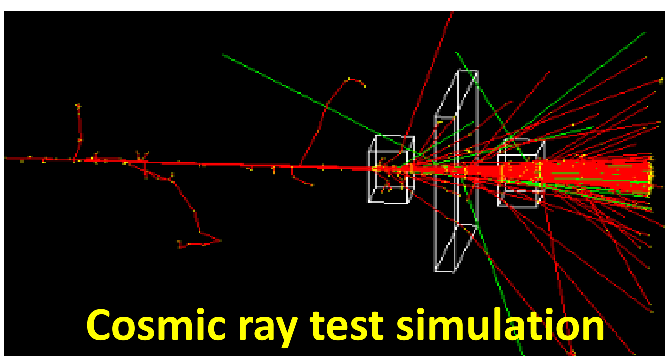
- The scintillator and MPPC (SiPM) were tested;
- Some simulations are ongoing;
- Next step: test the uniformity of the light output of scintillator, measure the light output of MIP using cosmic ray.

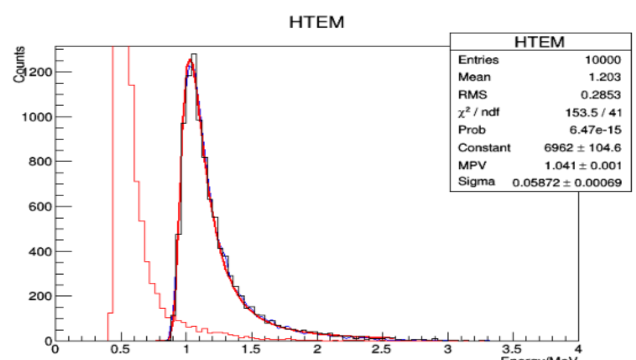


MPPC S12571-025P









Cosmic ray simulation result

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, Dajin Hong
  - 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 ($20 \times 20 cm^2$)
  - HCAL based on Scintillator + SiPM