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

Status of CEPC Hadron Calorimeter

Haijun Yang (SJTU)

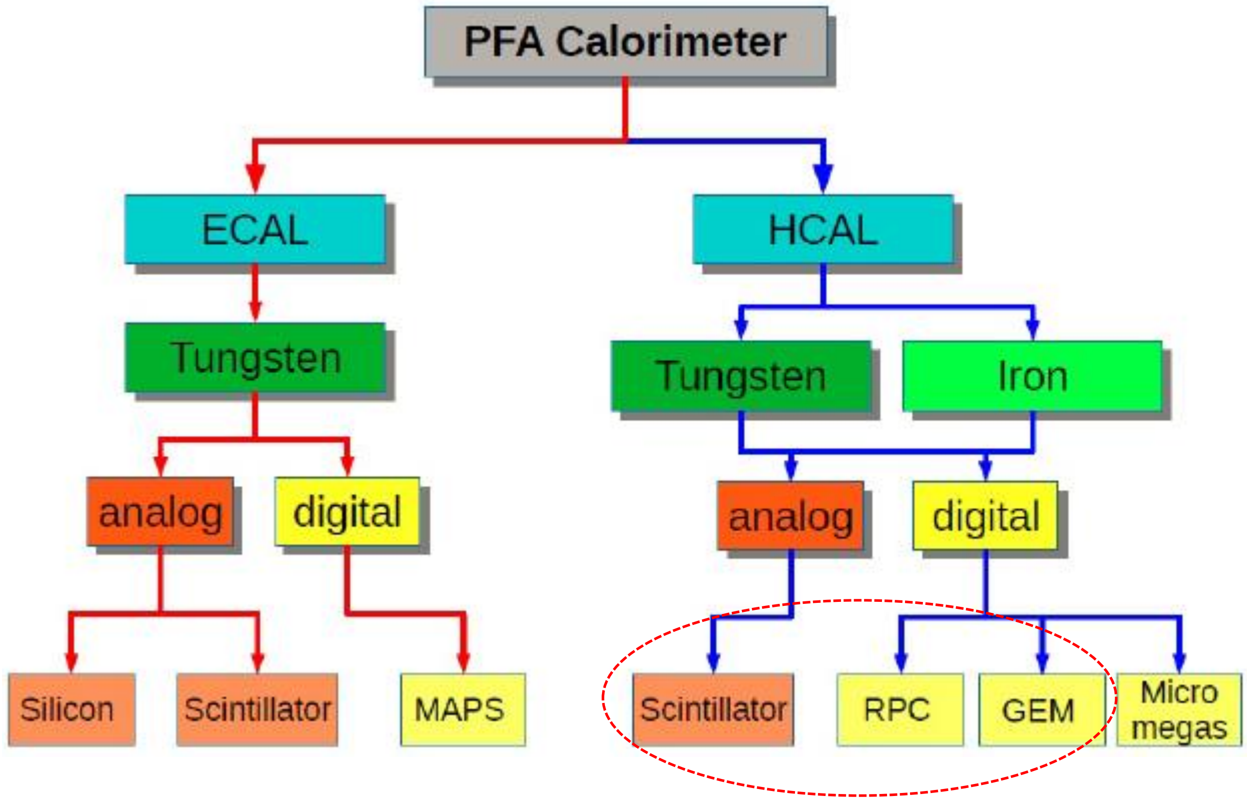
For the CEPC-Calo Group

CEPC Physics and Detector Group Meeting

March 20, 2017

CALICE: Imaging Calorimeter

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



Readout cell size: 144 - 9 cm^2 → 4.5 cm^2 → 1 cm^2 → 0.25 cm^2 → 0.13 cm^2 → 2.5x10^{-5} cm^2

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

CEPC HCAL

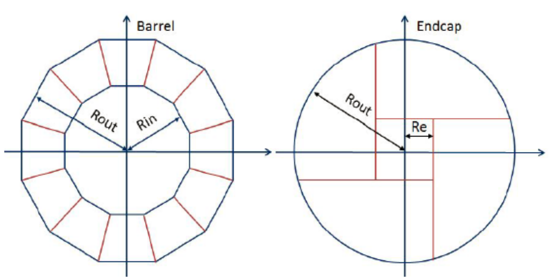
- The HCAL consists of
  - a cylindrical barrel system: 12 modules
  - two endcaps: 4 quarters
- Absorber: Stainless steel

- **Active sensor**
  - Glass RPC
  - Thick GEM or GEM
  - Scintillator + SiPM
- **Readout (1×1 cm^2)**
  - Digital (1 threshold)
  - Semi-digital (3 thresholds)

CEPC DHCAL OPTIMIZATION

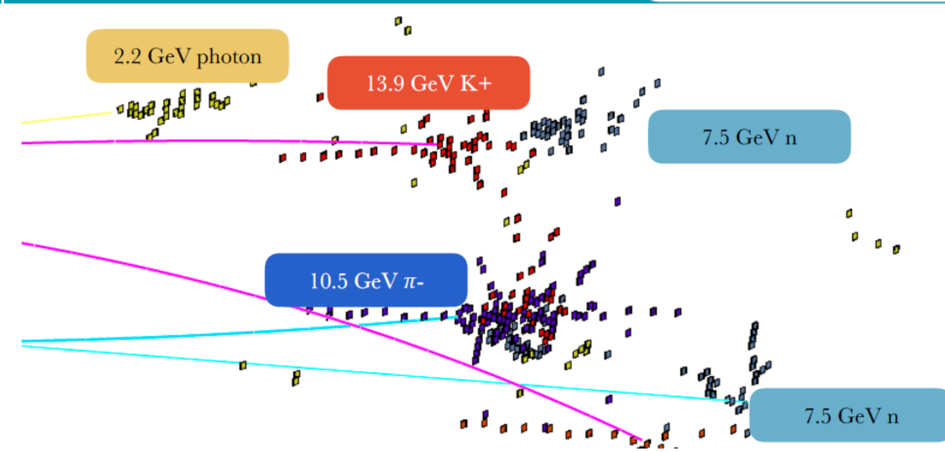
- To full fill the requirements of CEPC PFA, the DHCal is optimized by the following:
  - layers of DHCal, scanned from 20 layers to 48 layers.
  - size of each cell, scanned from 10 mm to 80 mm.
  - digitization (Q spectrum, spatial resolution, semi-Digi, etc..)

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



SIMULATION - PRELIMINARY

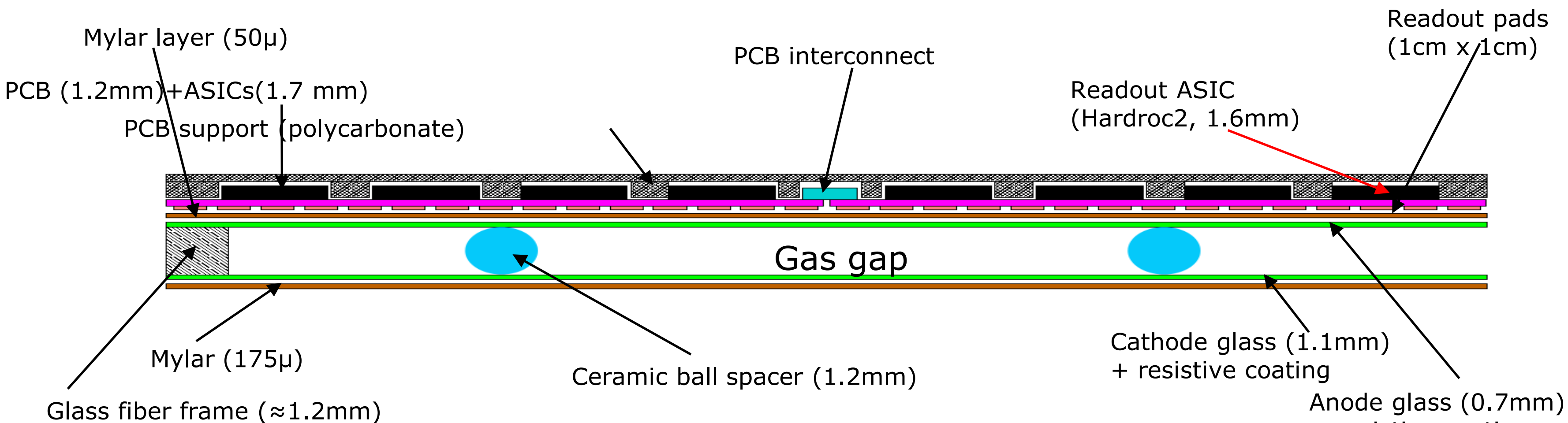
By Shi CHEN (UCAS)



„typical“ jet:

		$(\sigma_{jet})^2$
~ 60% charged particles	tracking	$= (\sigma_{tracks})^2$
~ 30% photons	EM calorimeter	$+ (\sigma_{EMCalo})^2$
~ 10% neutral hadrons	HAD calorimeter	$+ (\sigma_{HADCalo})^2$
~~ 1% neutrinos~~		$+ (\sigma_{loss})^2 + (\sigma_{confusion})^2$

Schematic of RPC



Ran Han (BISEE)

Haijun Yang (SJTU)

Large area gRPC:

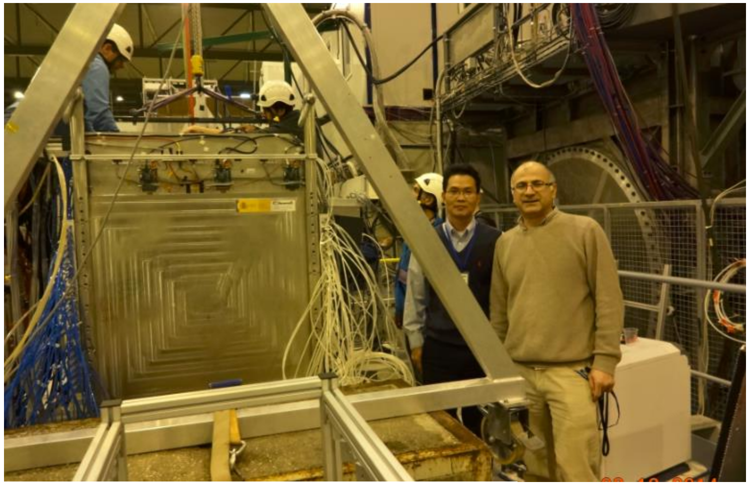
- ✓ Negligible dead zone (tiny ceramic spacers)
- ✓ Large size: 1×1 m^2
- ✓ Cost effective
- ✓ Efficient gas distribution system
- ✓ Homogenous resistive coating

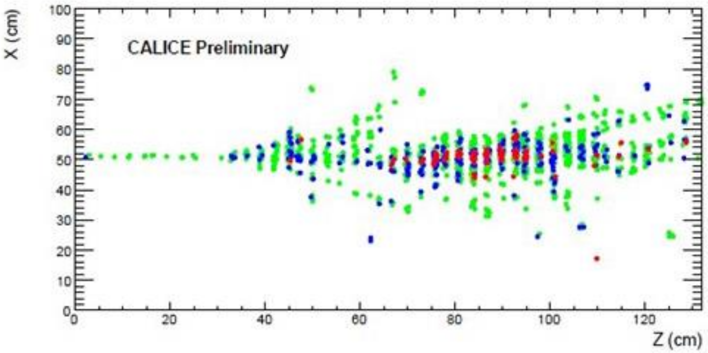
SDHCAL Prototype

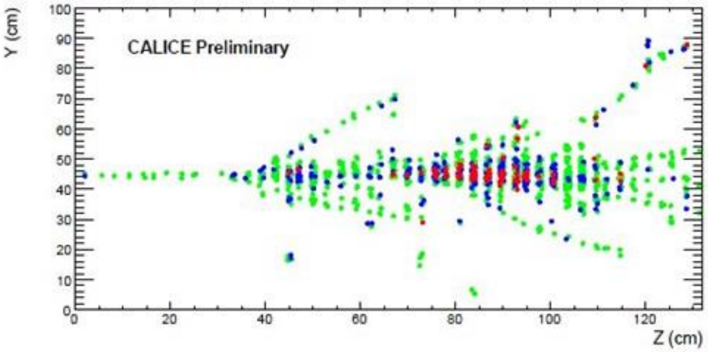
Prototype of SDHCAL based on RPC

- **IPNL (Imad Laktineh et.al.)**

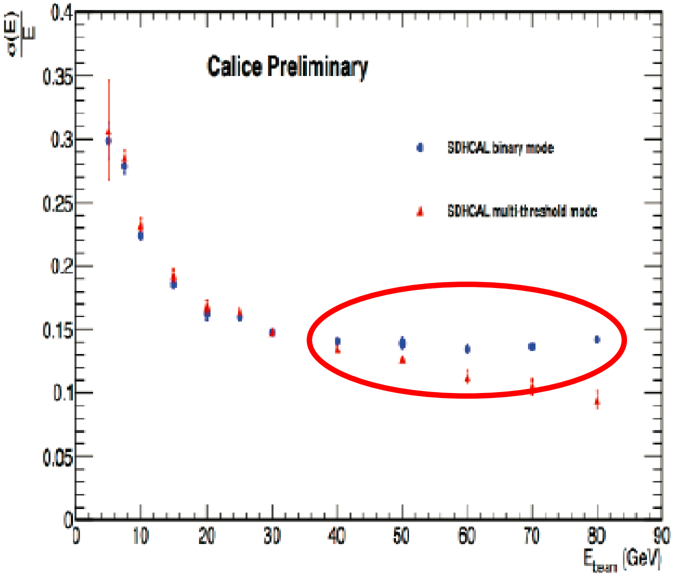
  $1m^3$, 3 thresholds, Test beam at CERN





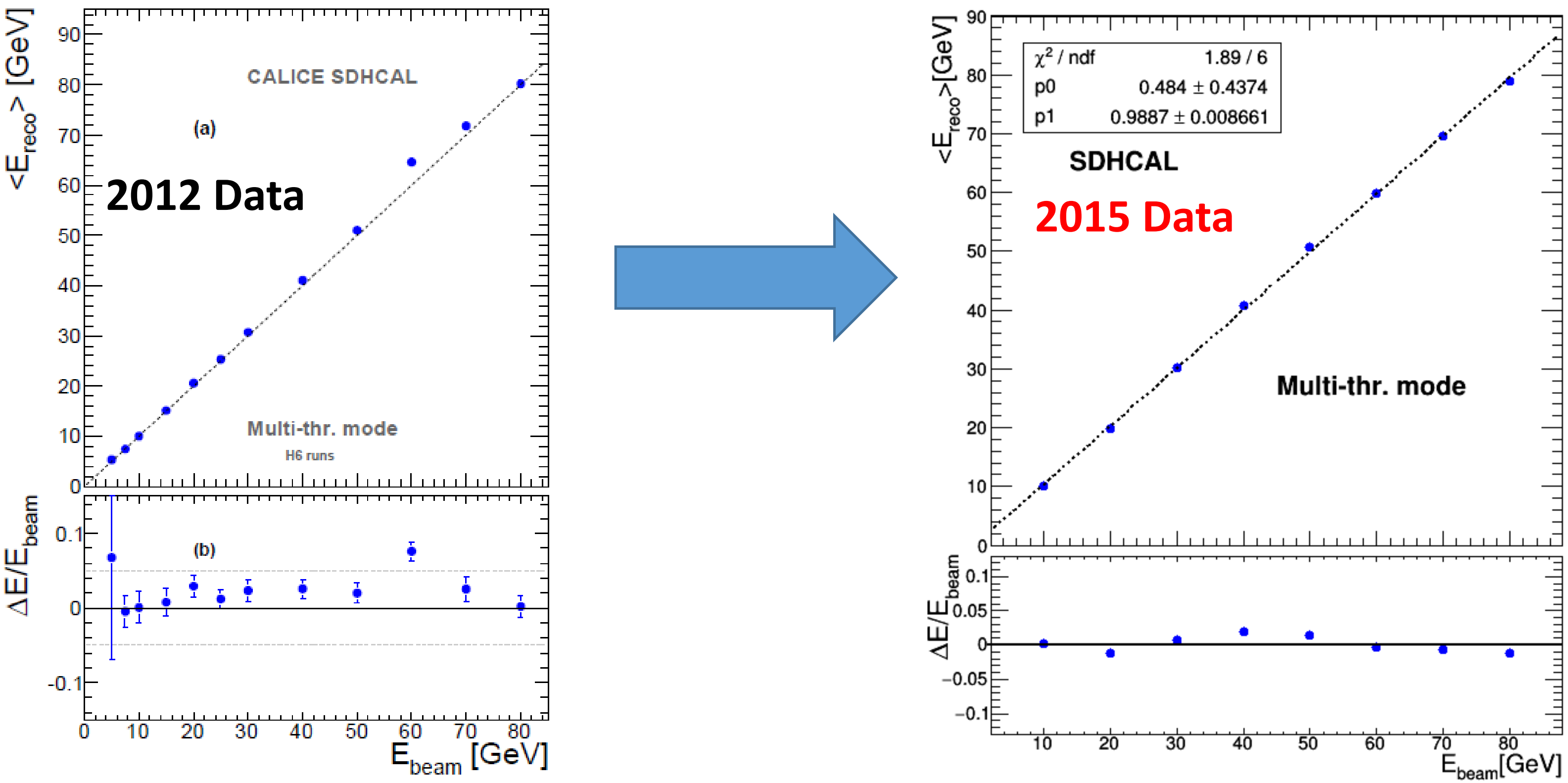


80 GeV Pion



DHCAL with RPC

- Collaborating with Imad Laktineh at IPNL since Sept. 2016, Bing Liu was attending TB at CERN in Oct. 2016 and analyzing 2015 data.
- Bing is applying for joint Ph.D program (CSC) between SJTU and IPNL.



Definition of Y/N Category

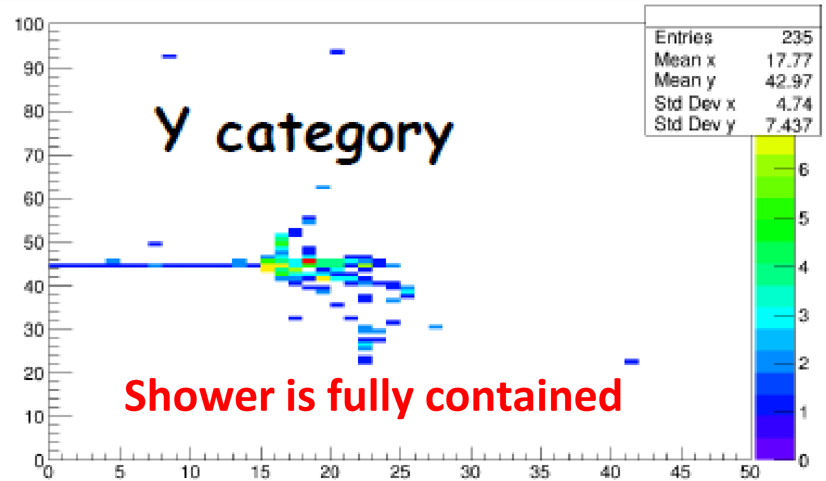
Data sample:SPS_Oco_2015

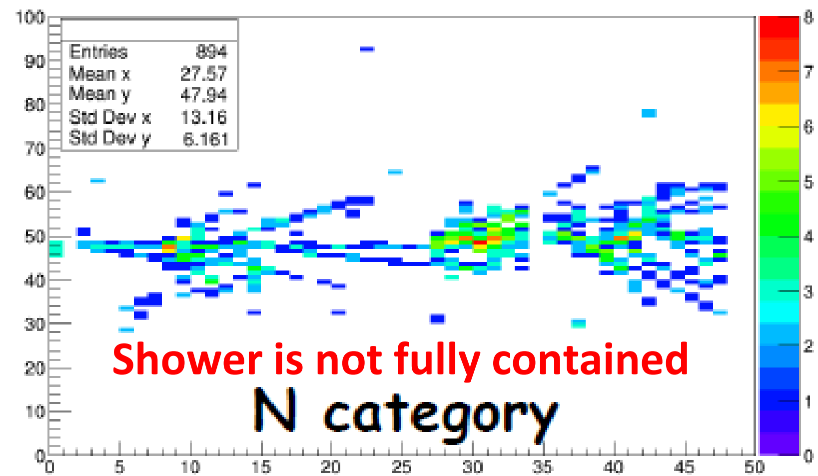
Particle: Pi+

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)



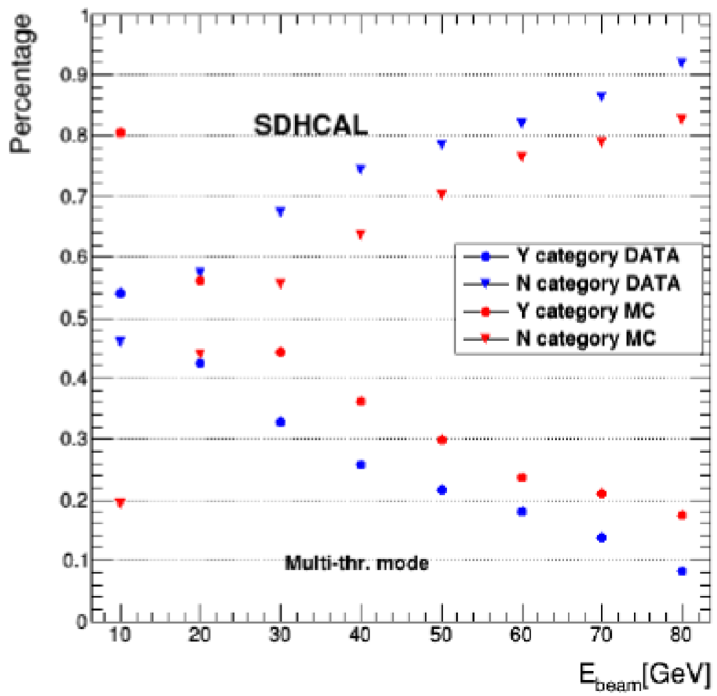


Improve the Muon Rejection

Bing Liu, Haijun Yang, Imad

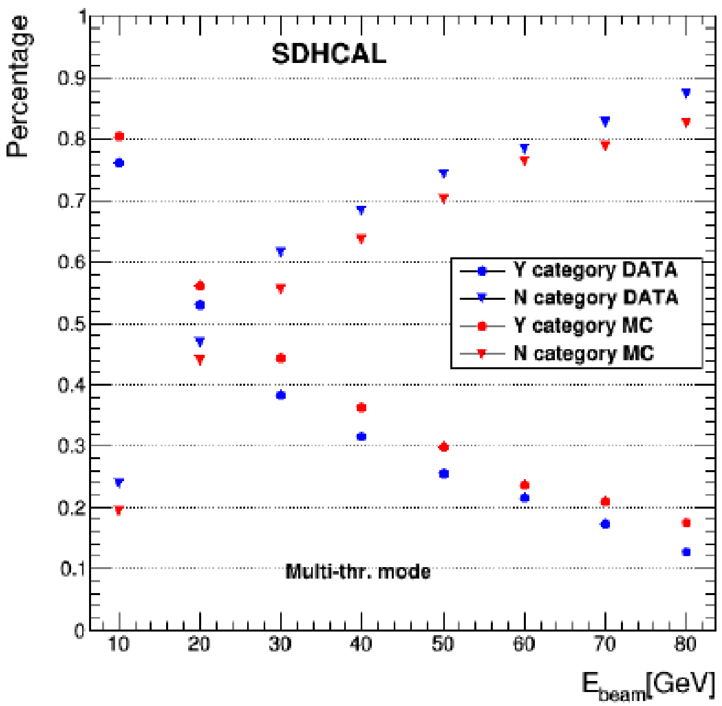
Update

Nhits/Nlayer > 2.2



There is a large difference between MC and data

Nhits/Nlayer > 3.2

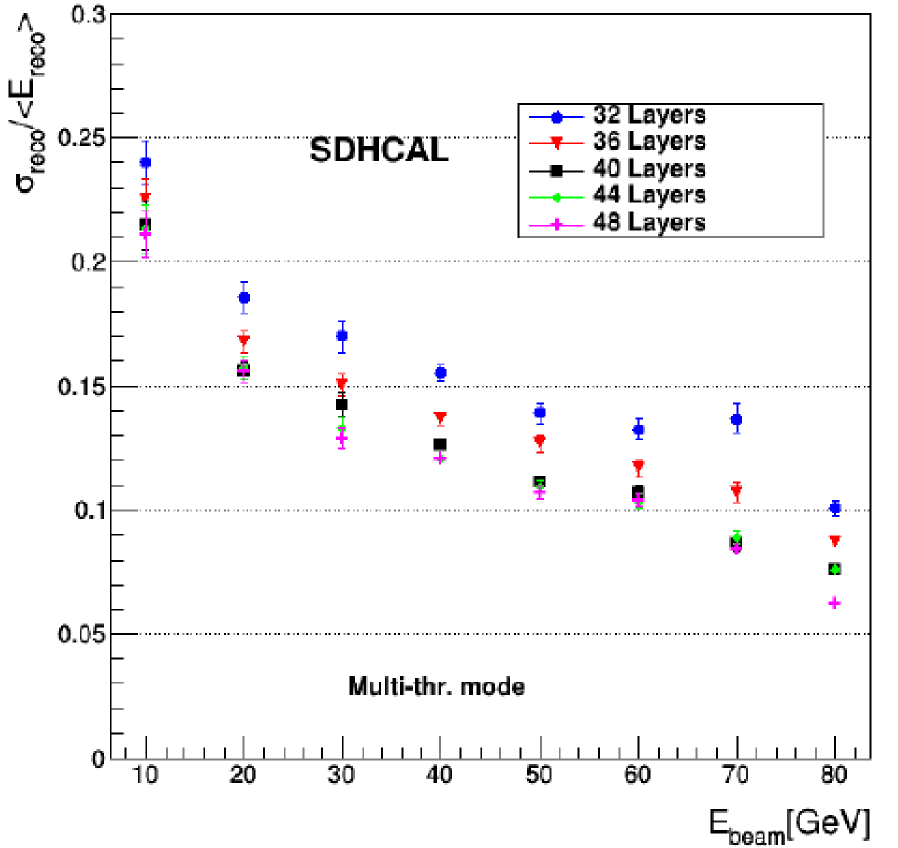


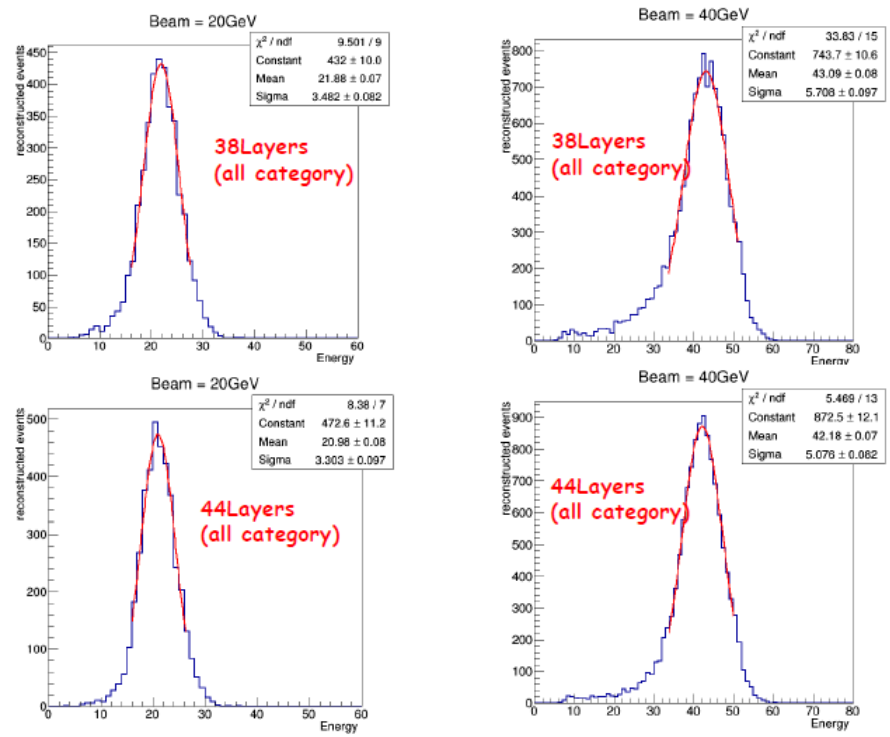
After updating , the difference between MC and data is very little

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)



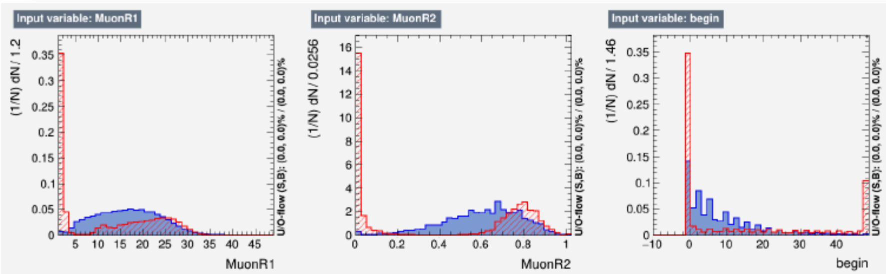


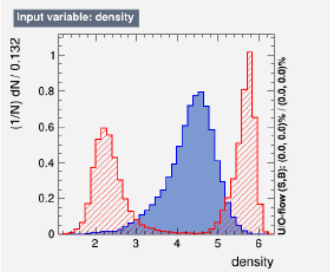
CEPC HCAL Detector Simulation

- 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

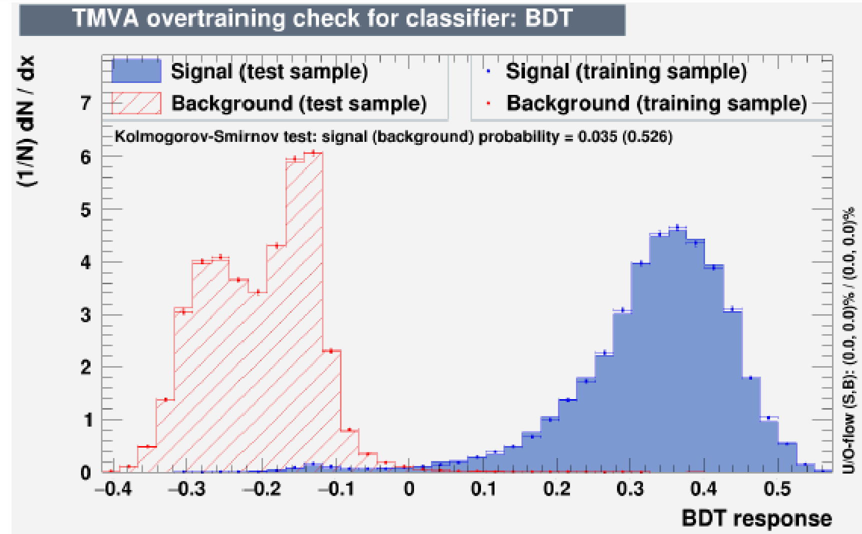
Development of BDT based PID

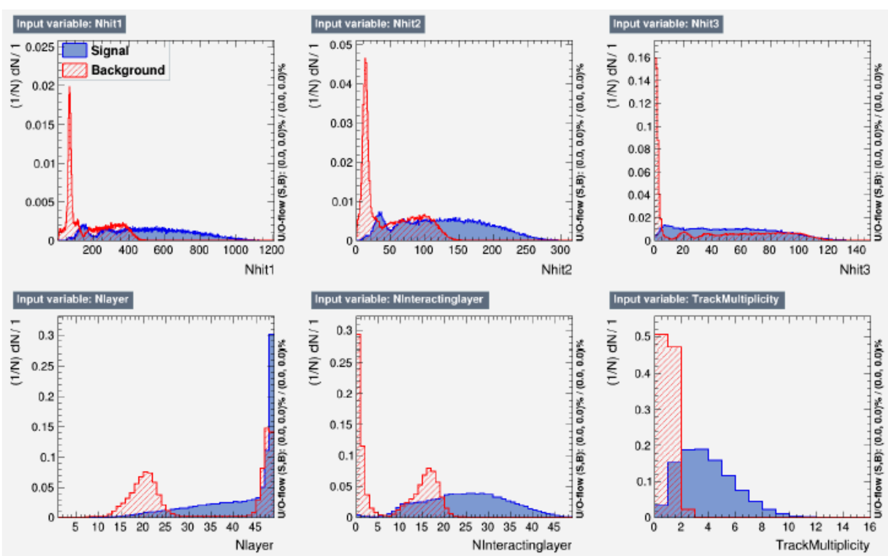


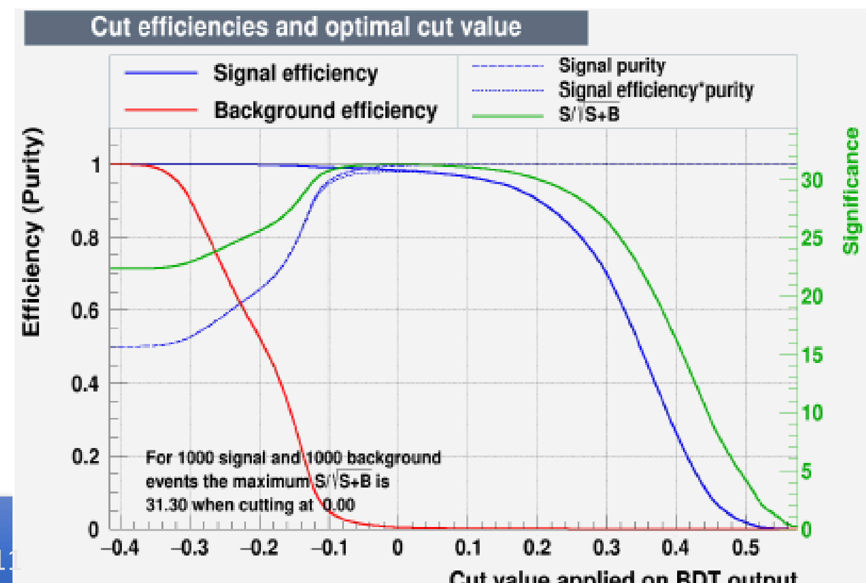


MC sample

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

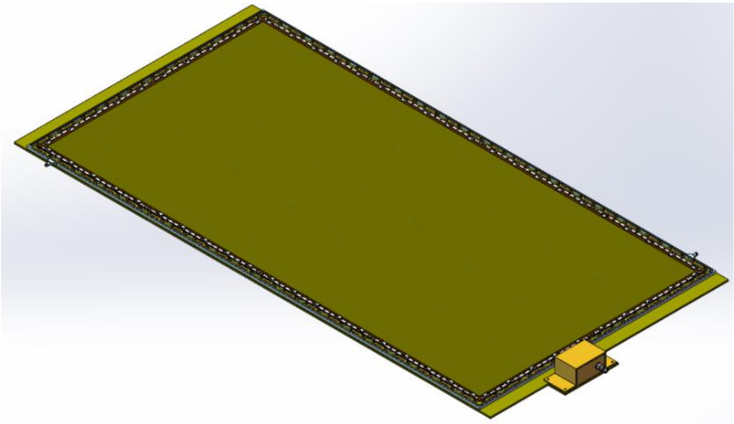


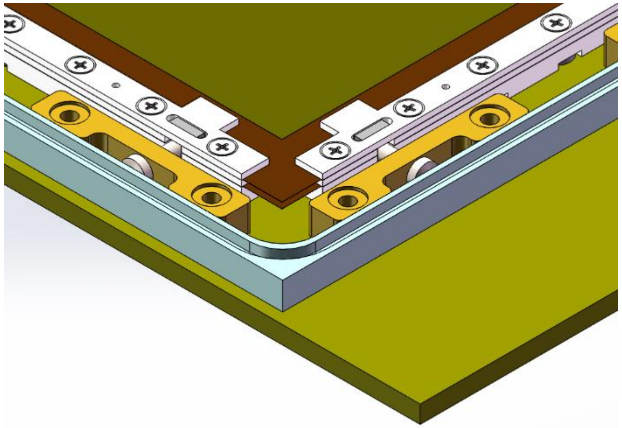




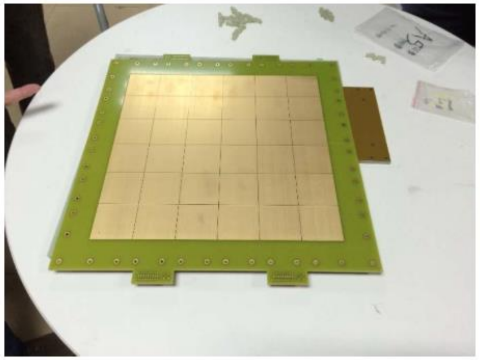
HCAL Based on GEM (USTC)

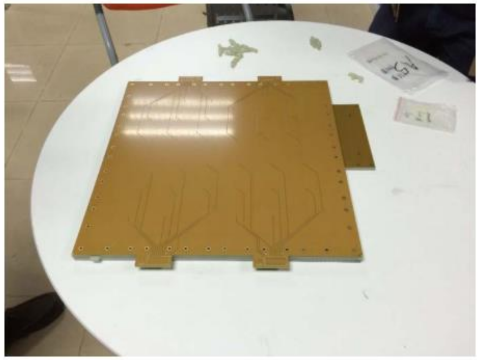
- Design of double-layer GEM, 3mm-1mm-1mm, 0.5m × 1m





- Construction of 30cm × 30cm double-layer GEM

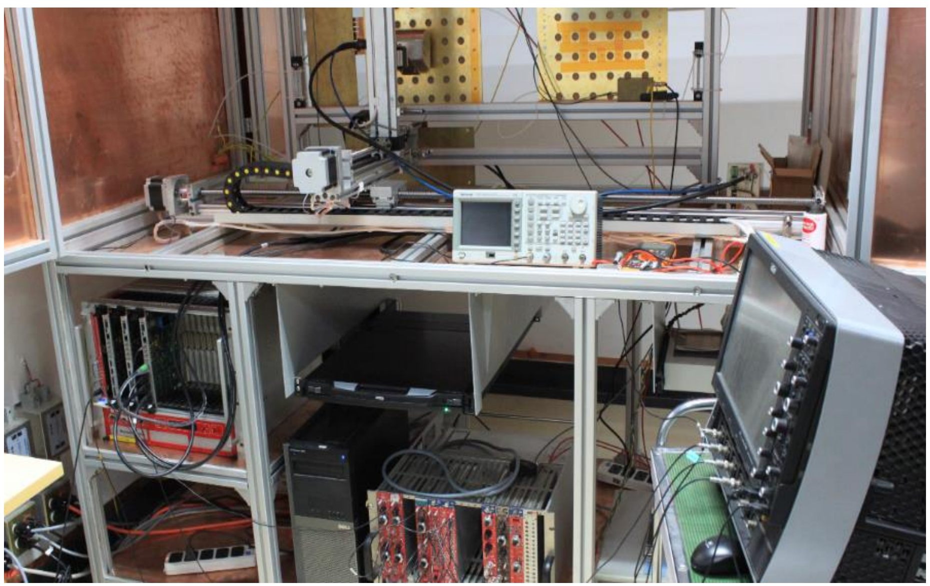




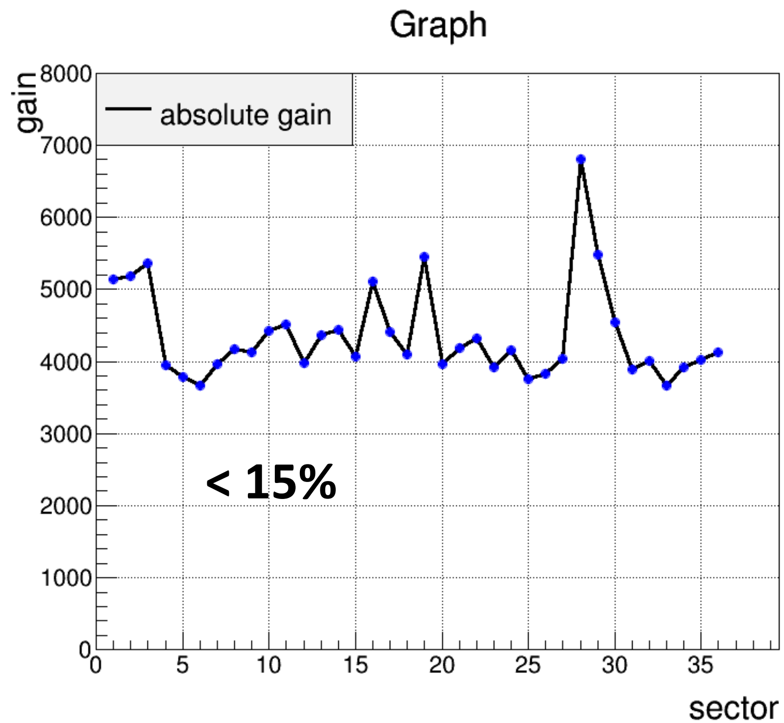
GEM Performance Test

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

Test facility at USTC

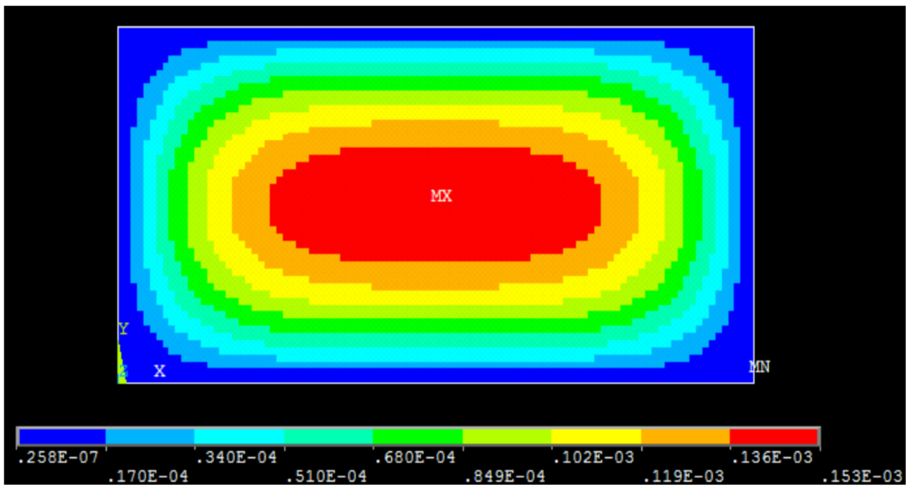


Gain uniformity

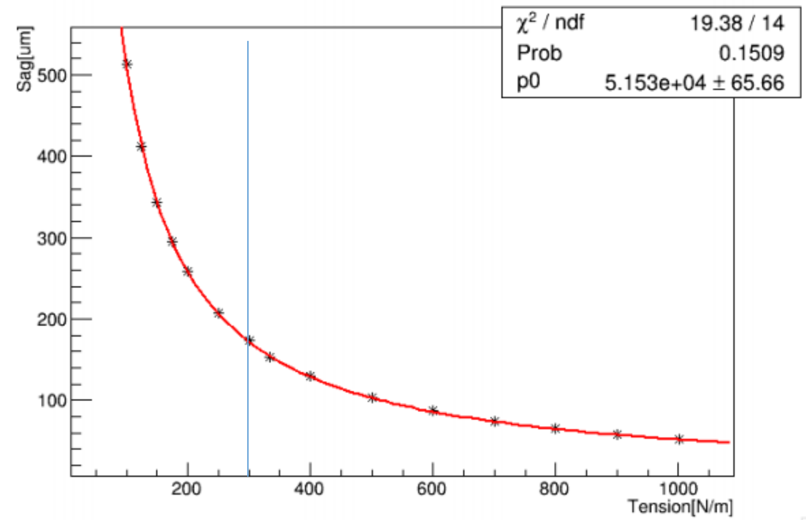


GEM Mechanical Simulation

GEM displacement due to sum of electric force and gravity



GEM displacement vs. tension applied



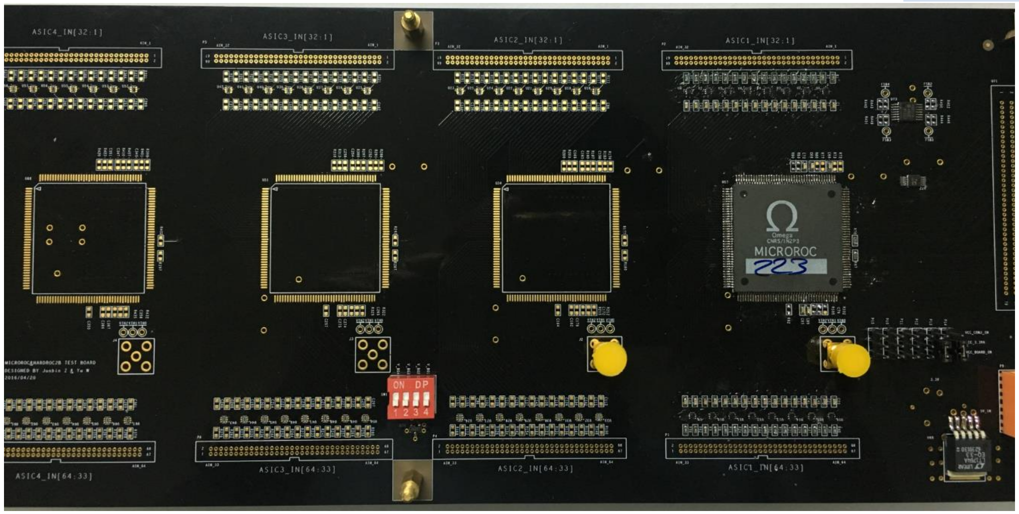
- Maximum GEM displacement ~ 150um when tensioned at ~0.3kg/cm
- More tensioning doesn't help too much in further reducing displacement.

Readout Electronics

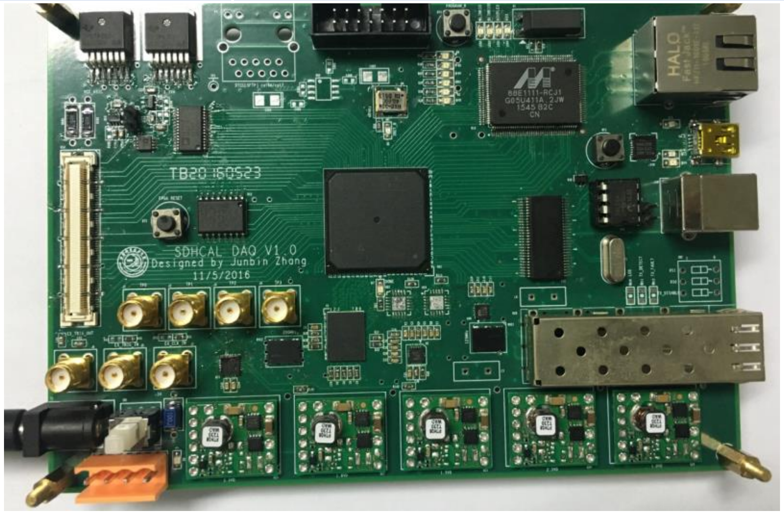
- Design and test of readout electronics by USTC

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

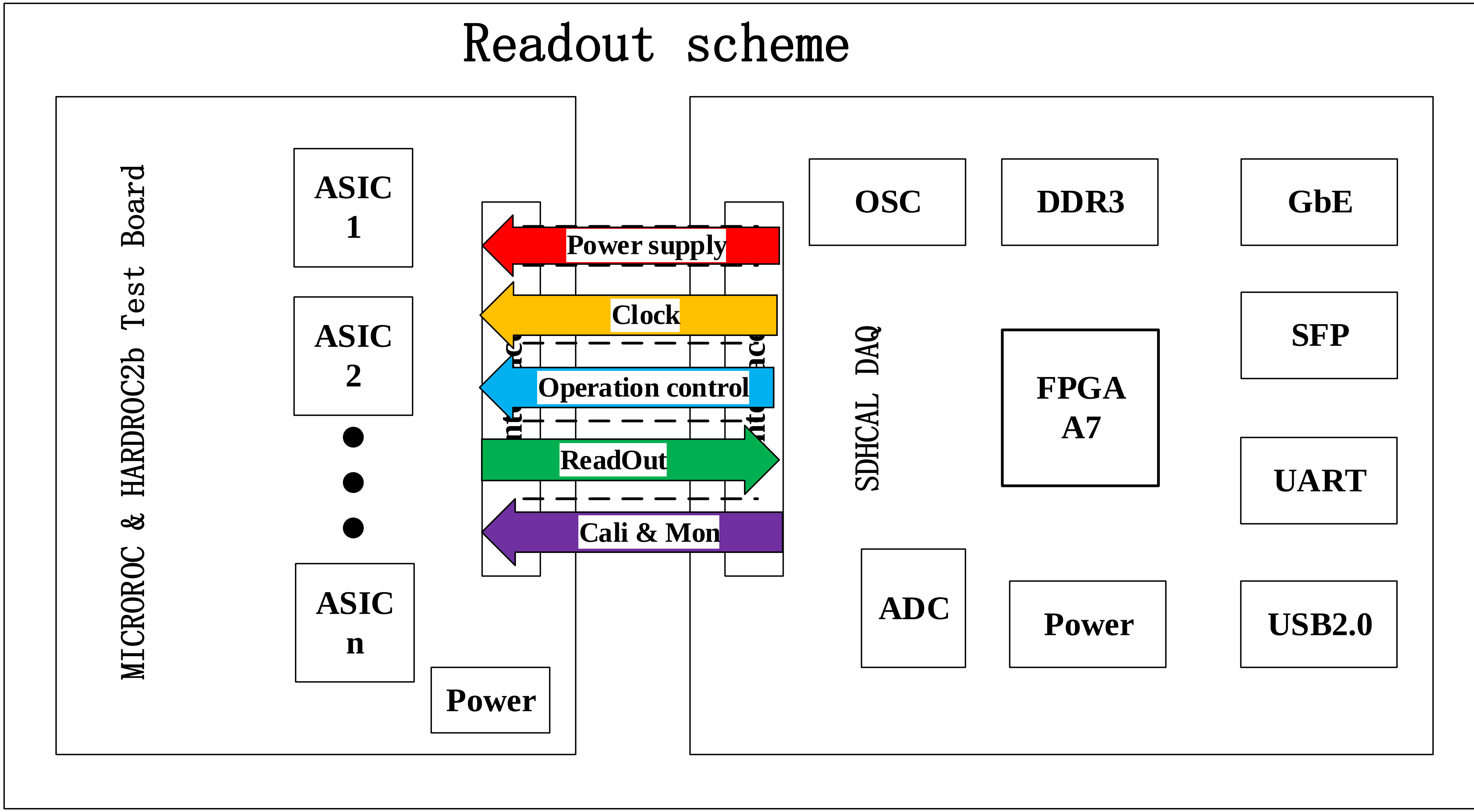


MICROROC & HARDROC2B Test Board

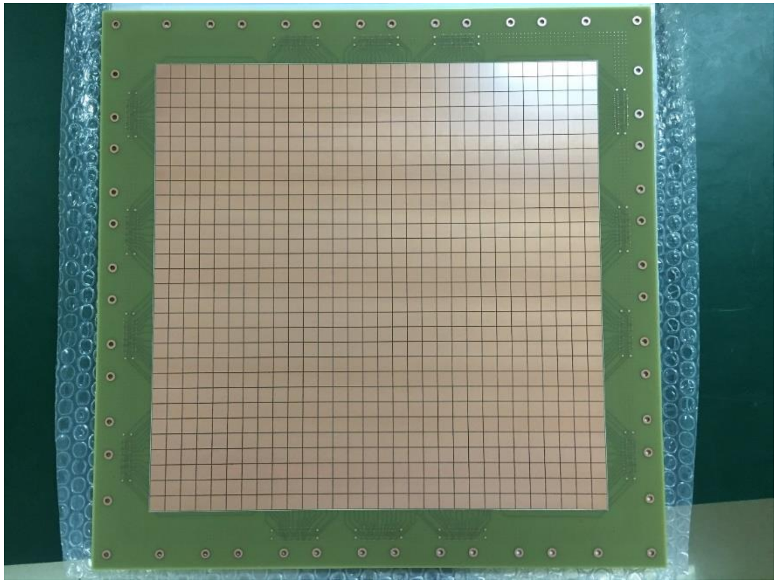


SDHCAL DIF Board

Phase I : Prototype

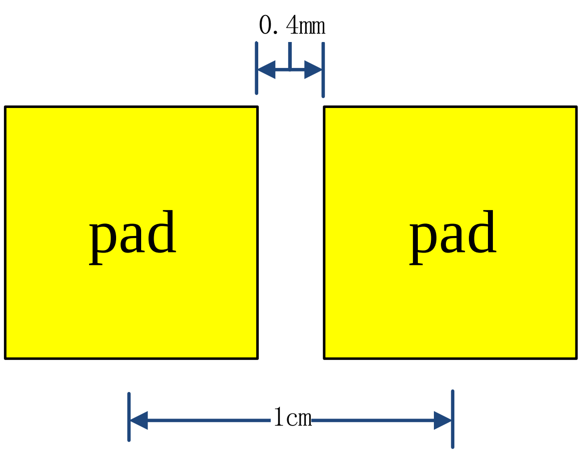


PCB Design and Test



- 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)



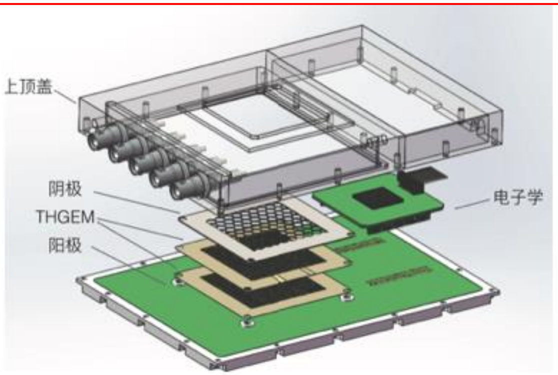
Test board	√
DIF board	√
Active Sensor Array board	√
Test board←→ DIF (Kapton)	√
ASA board←→ Test board(Kapton)	√
FPGA firmware	started
Application software	started

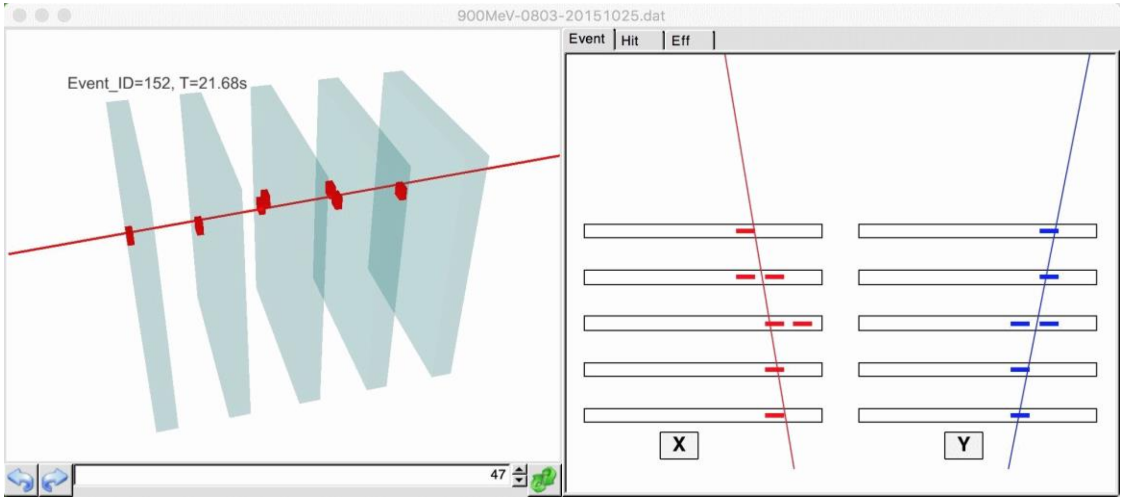
WELL-THGEM Beam Test @ IHEP

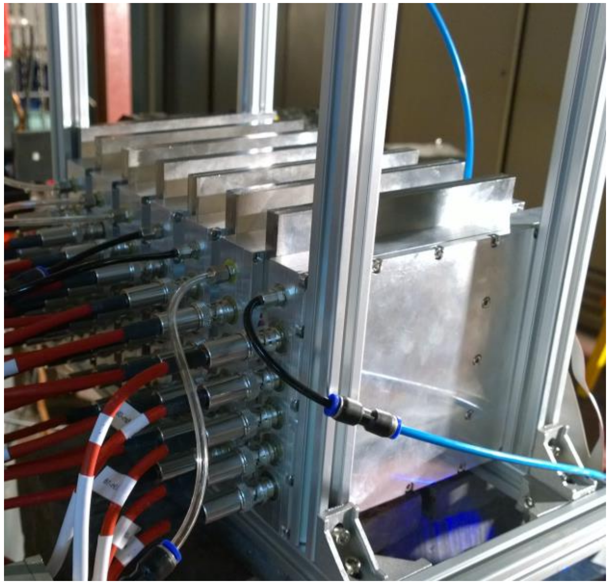
Hongbang Liu, Qian Liu (UCAS)

- 7 THGEMs ware 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
- **5cm × 5cm sensitive region**

  → 20cm × 20 cm





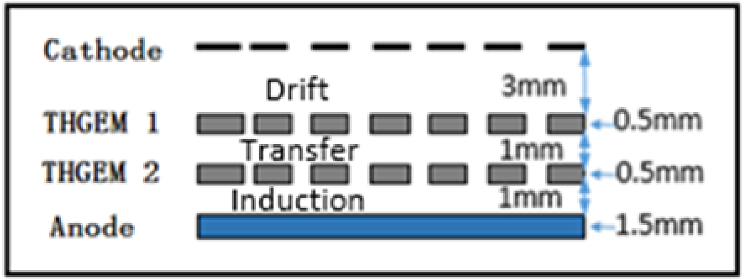


DHCAL based on THGEM (IHEP)

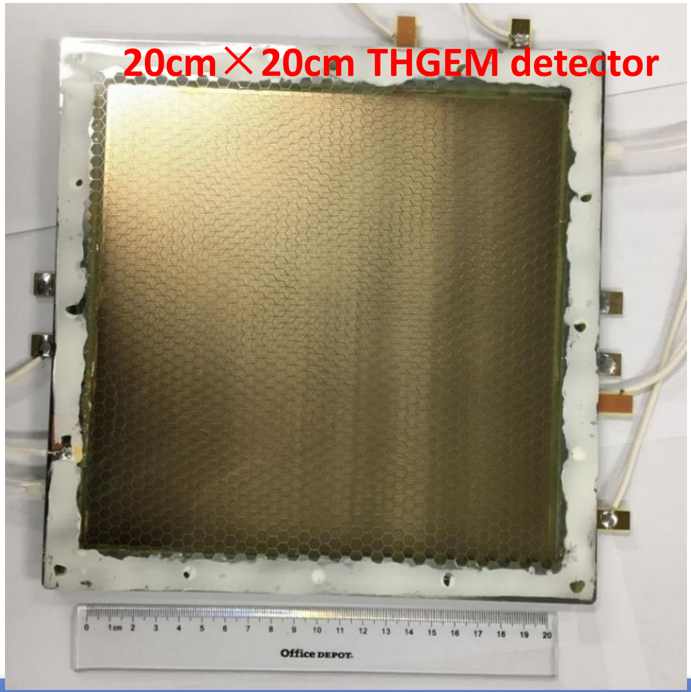
Boxiang Yu et.al. (IHEP)

The active detector thickness of CEPC-DHCAL is important to reduce the cost of DHCAL detector. The thickness of THGEM detector has been reduced to about 8mm, detector performance have been tested.

Several 20cm×20cm THGEM detectors were constructed, the gain stability and detector uniformity were tested.

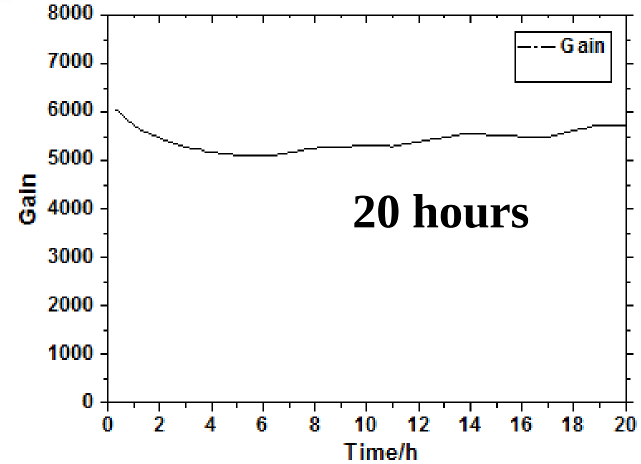


New thinner structure of THGEM detector

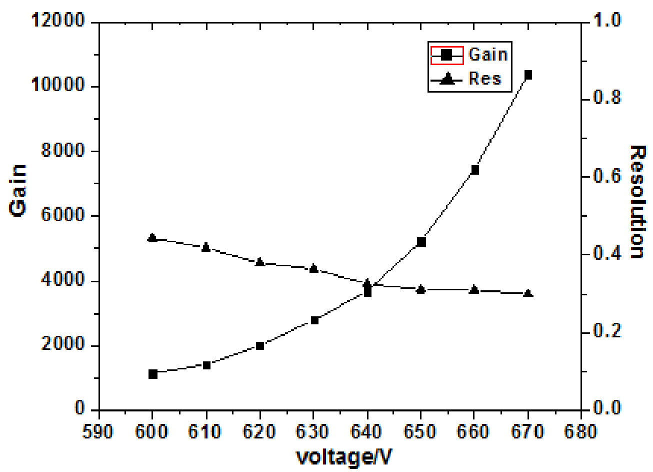


THGEM Performance

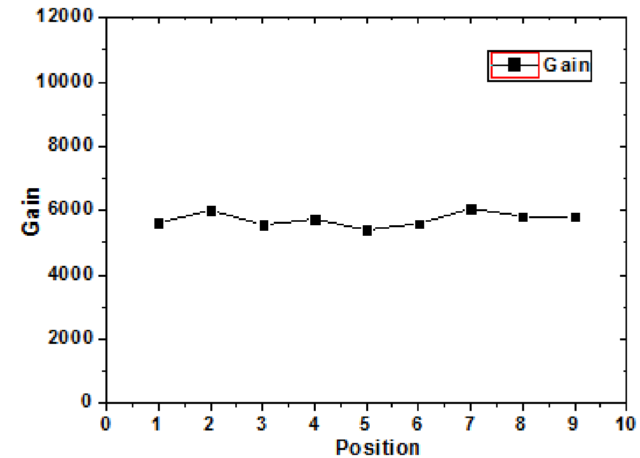
- 20 hours gain stability of 20cm×20cm detector was measured , it works well;
- The gain of THGEM detector was measured, the non-uniformity is ~12%;
- Next step, try to reduce the thickness of THGEM detector to about 6mm, test the performance of the detector.



The stability result of THGEM detector



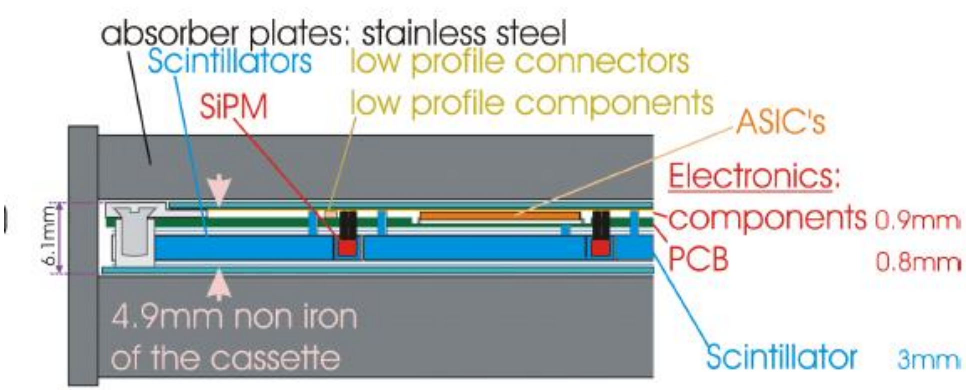
Detector gain of 20cm×20cm

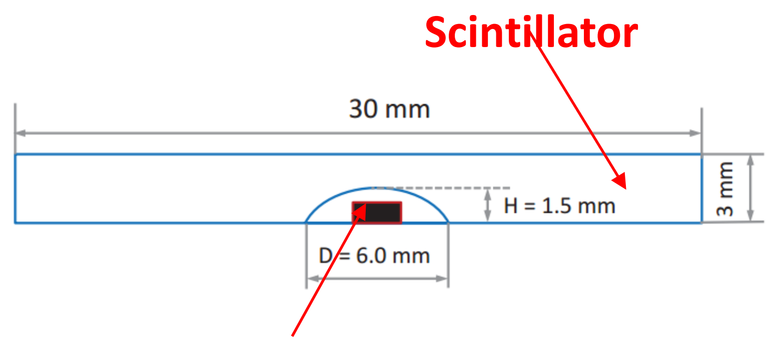


Gain uniform of THGEM detector

AHCAL with Surface-Mounted SiPMs

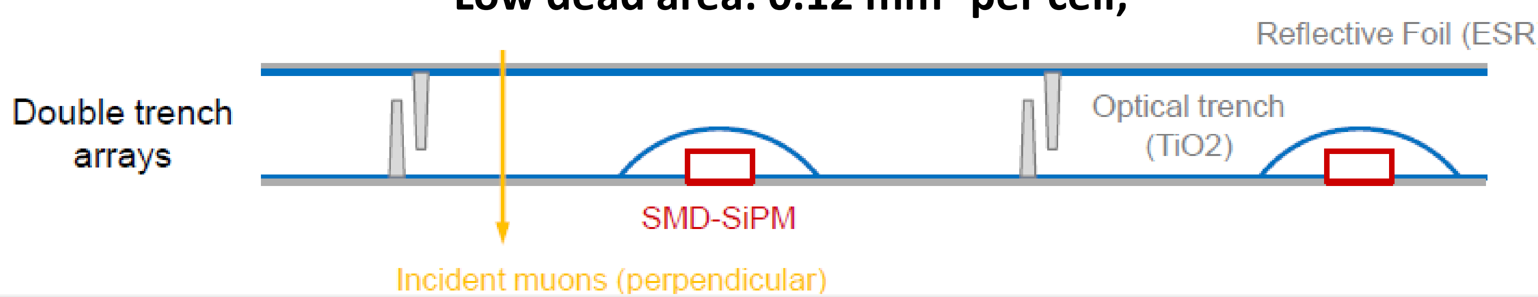
- **Surface-mount tile design –suitable for mass assembly**
- **The thickness of non iron (small): 4.9mm;**
- **Very low dead area: 0.12 mm^2 per cell;**
- **Baseline design for the ILC DHCAL;**





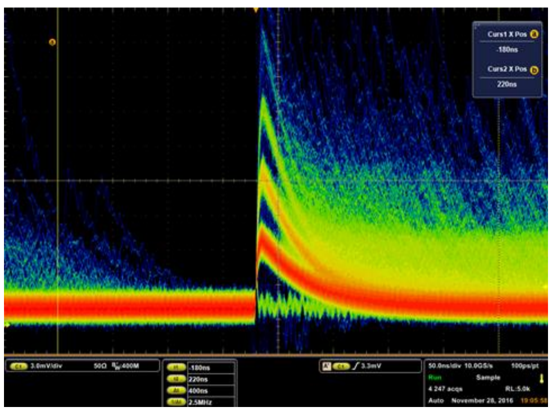
Single detector unit

Low dead area: 0.12 mm^2 per cell;

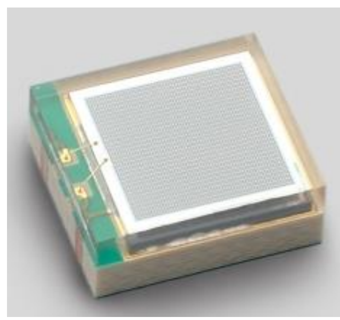


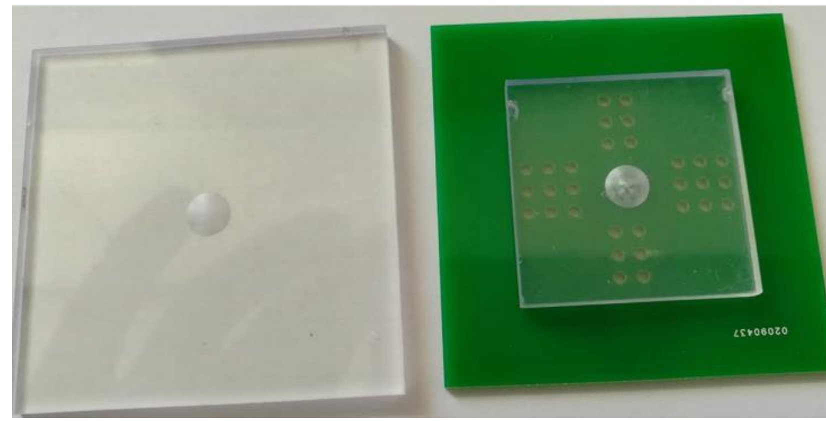
Test of Scintillator with SiPM

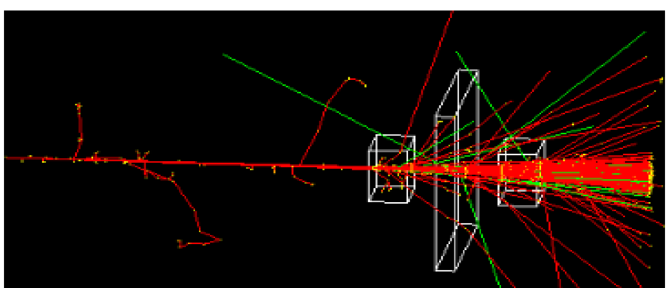
- The scintillator and MPPC (SiPM) were tested;
- Some simulations are ongoing;
- Next step: test the uniformity of the light output of scintillator, measure the light output of MIP using cosmic ray.



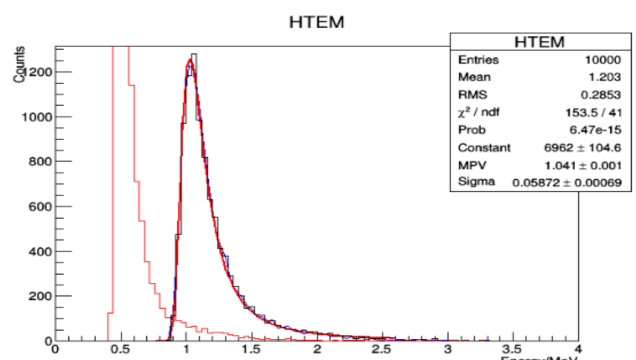
MPPC S12571-025P







Cosmic ray test simulation



Cosmic ray simulation result

International Collaboration

- SJTU group submitted an official proposal to Frank Simon (Max Plank Institute of Physics, Germany) to join the CALICE collaboration, it will be reviewed and discussed at CALICE2017 at LLR, France. Haijun will join this meeting to present our proposal and recent research activity.
- SJTU group also works with Imad Laktineh at Institute of Particle and Nuclear Laboratory (IPNL) at Lyon, France on TB data analysis of SDHCAL since Sept. 2016. We are applying joint Ph.D for Bing Liu to study at IPNL for two years,
    - Optimization of SDHCAL for CEPC project
    - Using MVA-BDT method to improve particle ID of SDHCAL
    - Development of multi-RPC detector and study impact of time measurement on SDHCAL performance and consequence on PFA

Detector Concepts

- **PFA Oriented**
  - CEPC_v1 (same as ILD, used for Pre-CDR)
  - CEPC_o_v2 (80% version)
  - **CEPC_o_v3 (aiming for CEPC CDR study)**
    - **Need to optimize ECAL cell size, layers (ECAL geometry)**
    - **Need to optimize HCAL cell size, layers (HCAL geometry)**
    - **TBD before CEPC meeting at CCNU in April 19-21, 2017**

- **Dual Readout Oriented**
  - See Roberto Ferrari and Gabriella Gaudio's talks

Backup Slides

Forthcoming Workshops

- **MOST-CEPC meeting at IHEP on March 16-17, 2017**

  (第二次高能环形正负电子对撞机相关的物理和关键技术预研究项目会议) http://indico.ihep.ac.cn/event/6775 (cepc2017)

  Talks: ECAL (Zhigang Wang), HCAL (Haijun Yang), PID (Jianbei Liu)

- **CALICE 2017 at LLR, Paris, France, March 22-24**

  https://agenda.linearcollider.org/event/7454/

- Meeting to discuss **R&D on dual readout Calorimetry at Como**, Italy, Mar. 30-31

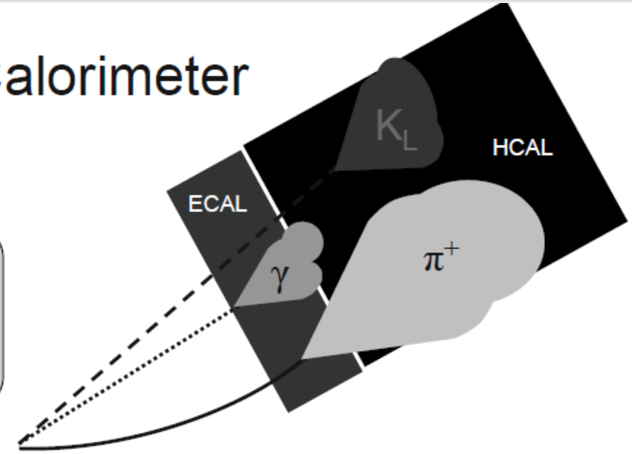
- **CEPC workshop @CCNU, Wuhan** http://indico.ihep.ac.cn/event/6433/

International Collaboration

- ECAL-Scintillator+SiPM (Tao Hu, Zhigang Wang, Yunlong Zhang)
- ECAL-Si+SiPM (Vincent Boudry, LLR, France)
- HCAL-RPC (Haijun Yang + Imad Laktineh, IPNL, France)
- HCAL-THGEM/GEM/Scintillator (Boxiang Yu + Jianbei Liu)
- Dual Readout Calorimetry (John Hauptman, Iowa state + Italy colleagues ?)

Imaging Calorimeter based on PFA

Particle Flow Algorithms and Imaging Calorimeter



The idea…

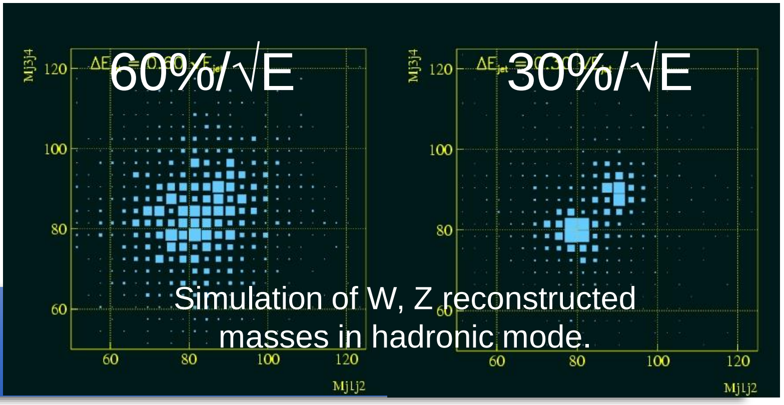
Charged particles	measured with the	**Tracker**
Neutral particles		**Calorimeter**

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

18%/√E

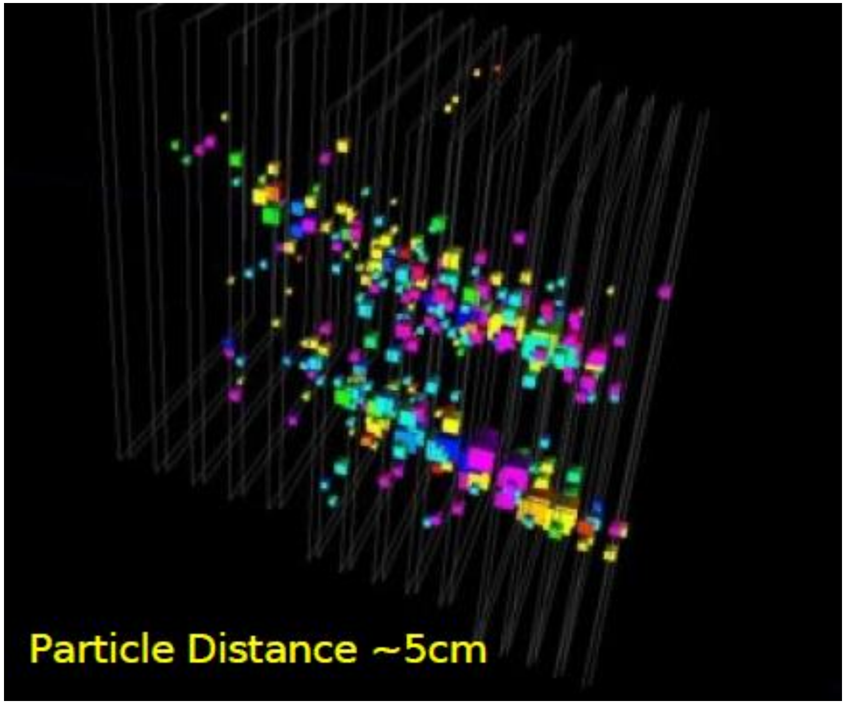
Requirements for detector system

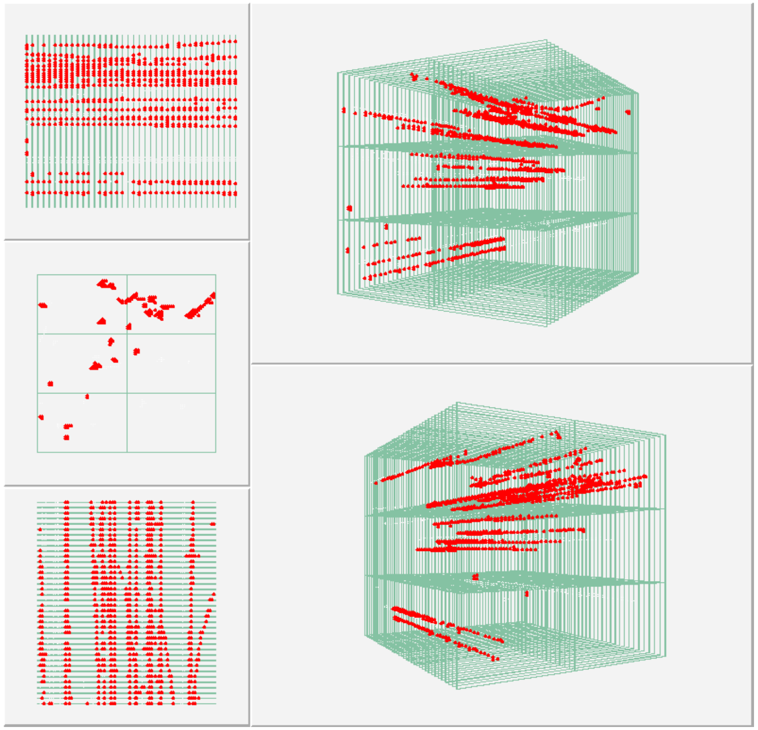
→ Need excellent tracker and high B – field
→ Large R_I of calorimeter
→ Calorimeter inside coil
→ Calorimeter as dense as possible (short X_0, λ_I)
→ Calorimeter with **extremely fine segmentation**



Imaging Calorimeters

L. Xia @ ANL





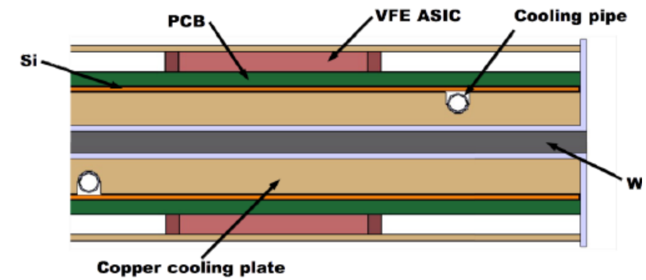
Two electrons ~5cm apart
SiW ECAL

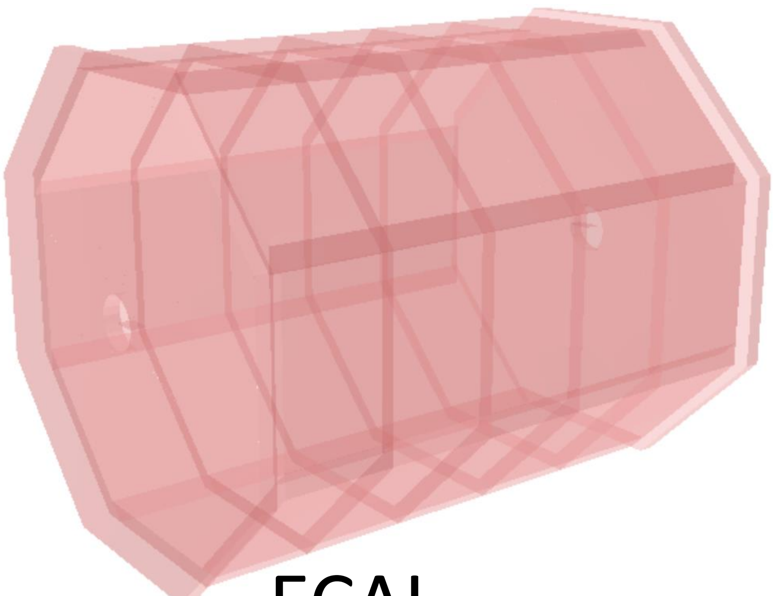
~20 muons in $1m^2$ area
RPC DHCAL

➔ **PFA requires calorimeters to separate the showers of jets.**

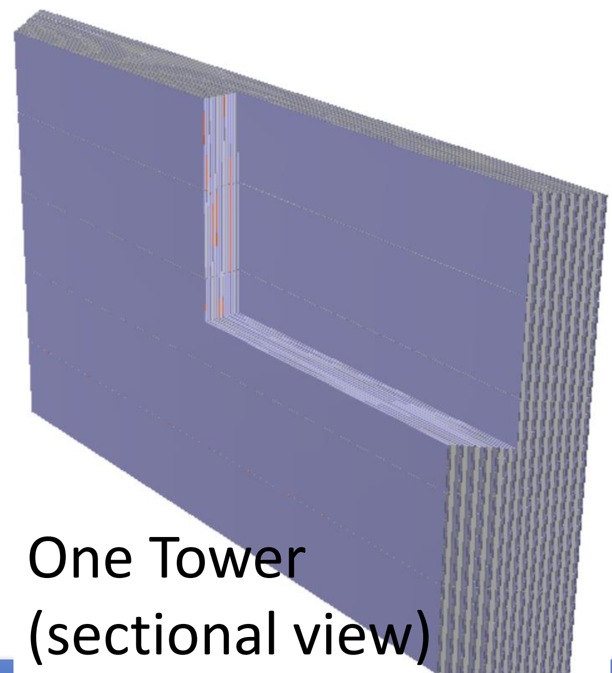
ECAL Geometry Setup

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





ECAL



One Tower
(sectional view)

One tower
(side view)

Zoom in Side View (ROOT Geo)

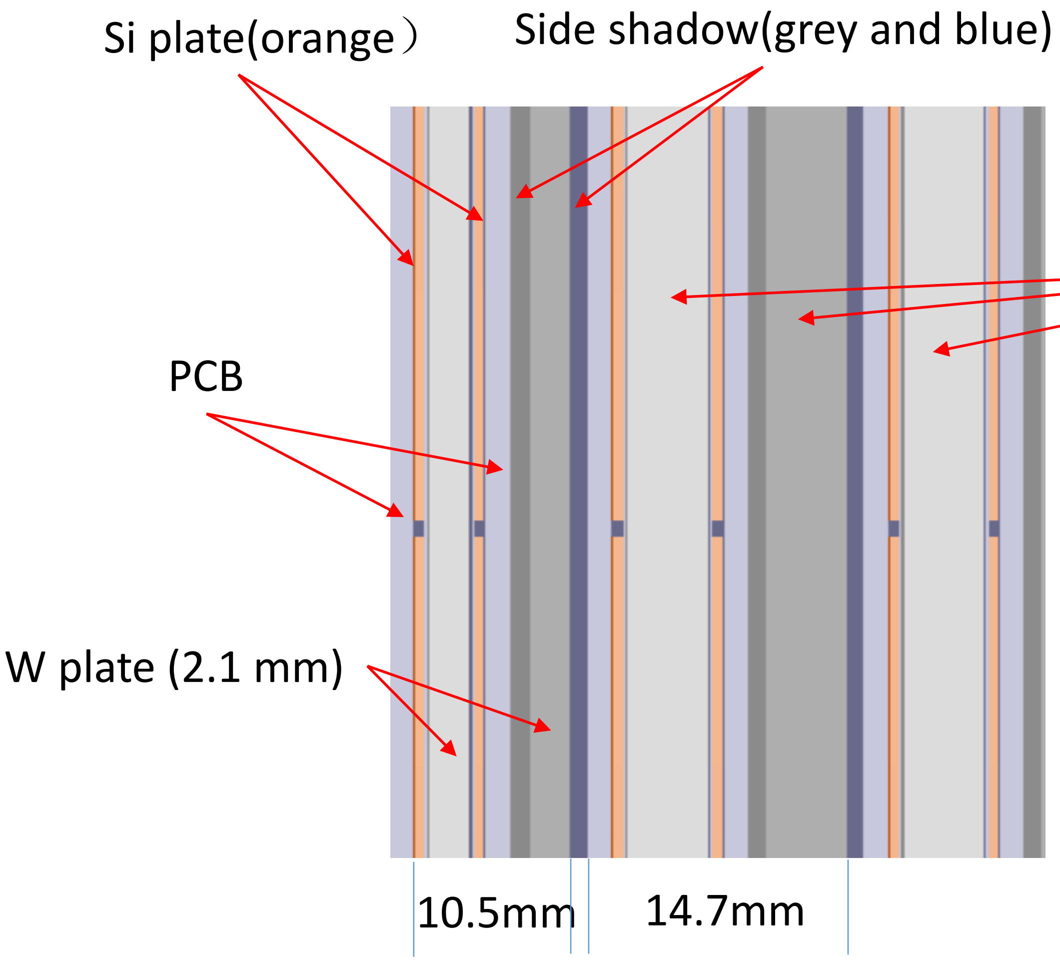


Illustration:
2 thin layers
4 thick layers.

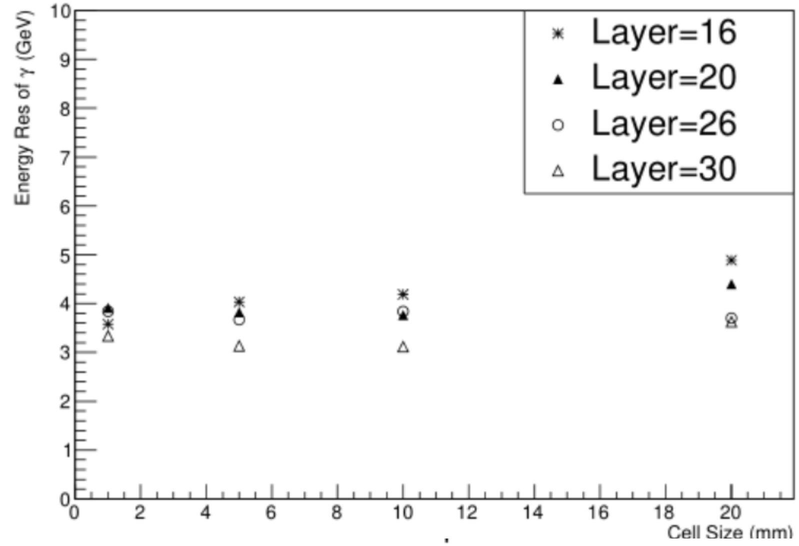
name	Radiation length (cm)
Si plate	9.349
PCB board	2.817
W plate	0.350
GroundorHVMix	2.732

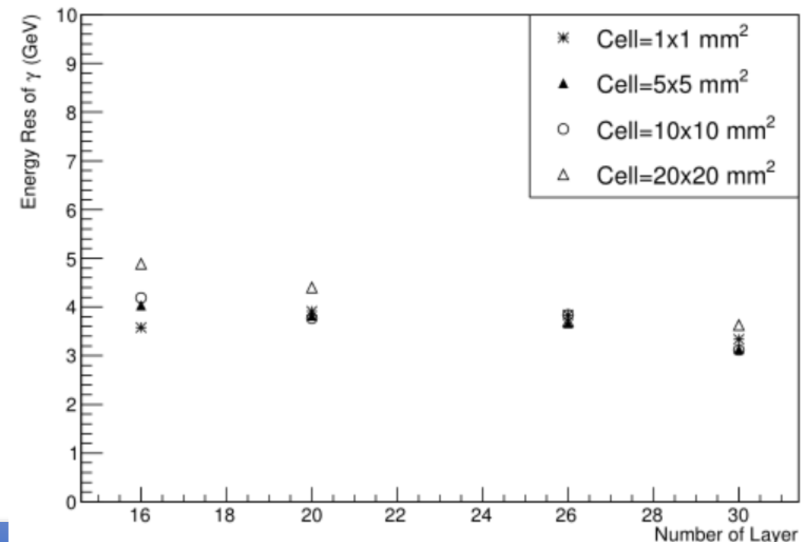
$$X_0 = \frac{716.4 \cdot A}{Z(Z+1)\ln\frac{287}{\sqrt{Z}}} \,\mathrm{g}\cdot\mathrm{cm}^{-2}$$

Calorimeter Optimization

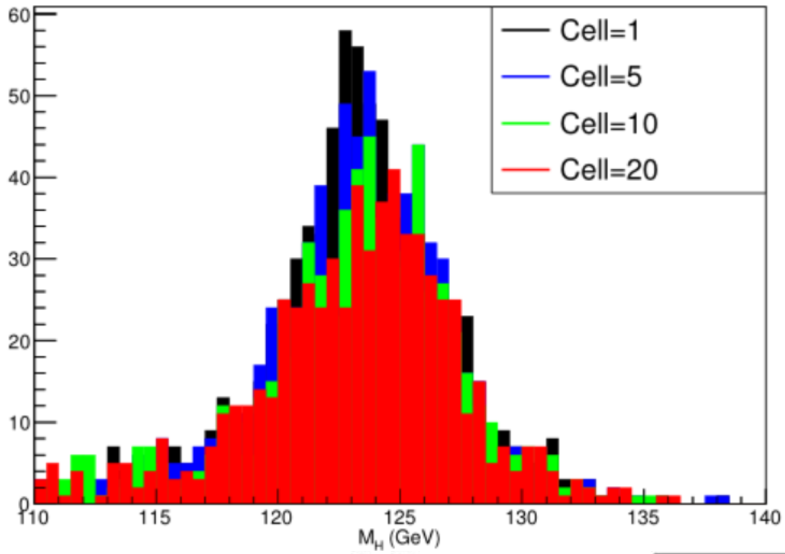
Jifeng Hu, Jing Li, Liang Li, Haijun Yang (SJTU)

- 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
  - $ee \rightarrow ll\gamma\gamma@\sqrt{s} = 250\ GeV$, 1000 Events.
- Geometry: cepc_v1 using SiW in ECAL,
  - Cell size @ 1X1, 5X5, 10X10, 20X20 mm
  - Number of layers @ 15, 19, 25, 29
  - fixed total material.
  - other parameters will be investigated.

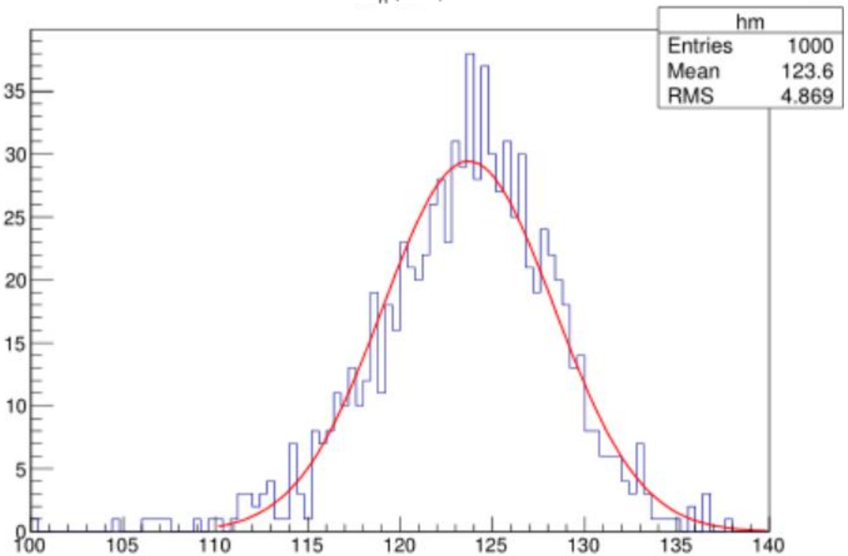


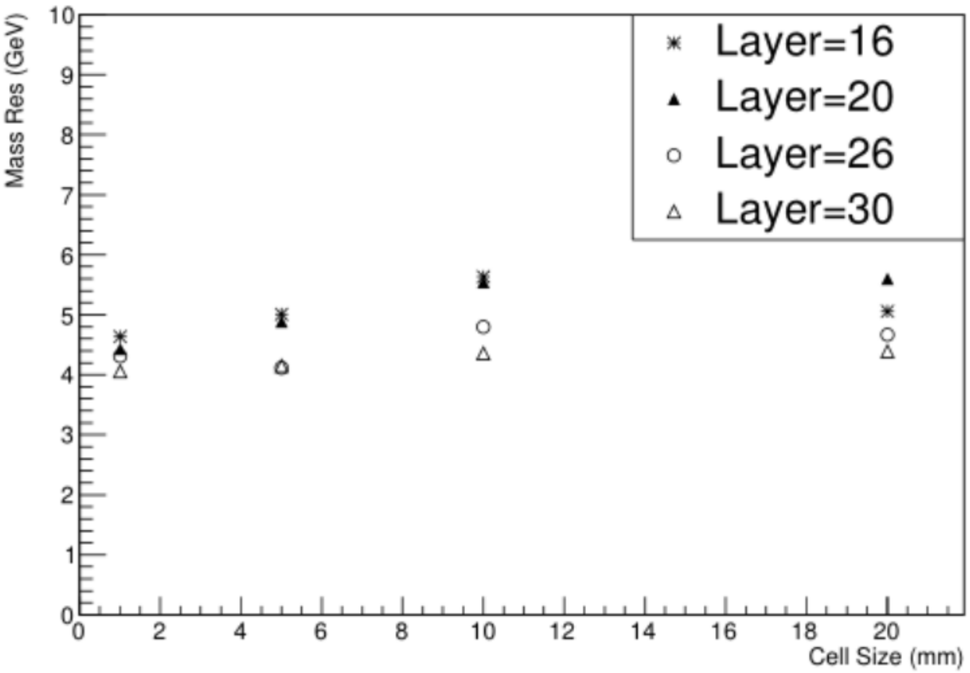


Calorimeter Optimization (ECAL)



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

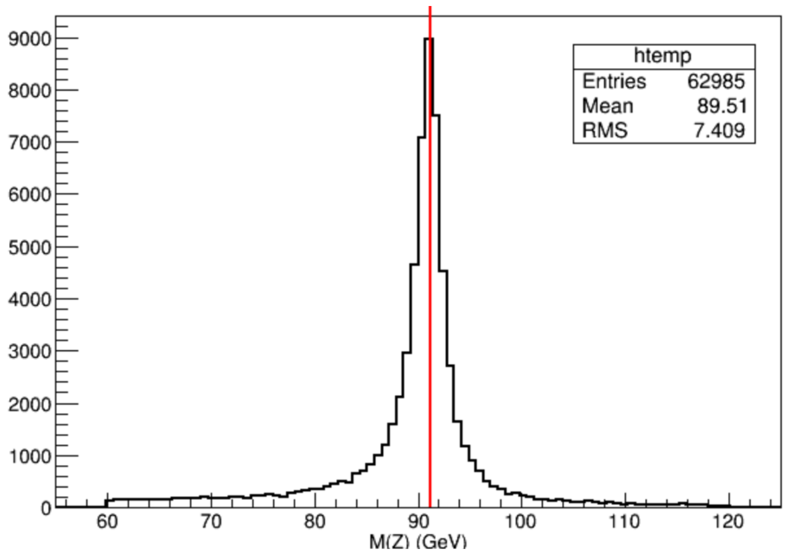




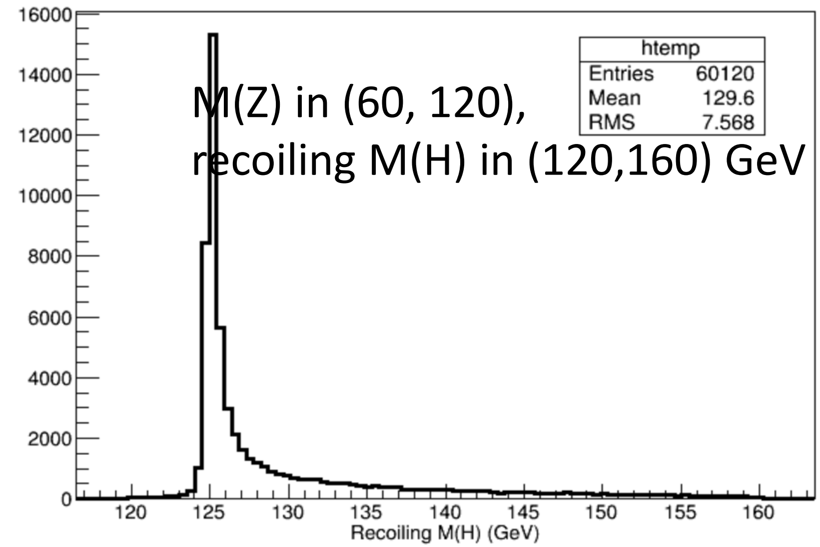
ZH, Higgs→WW→lvqq

→Using H→WW→lvqq events to understand jet energy resolution requirement for HCAL.

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

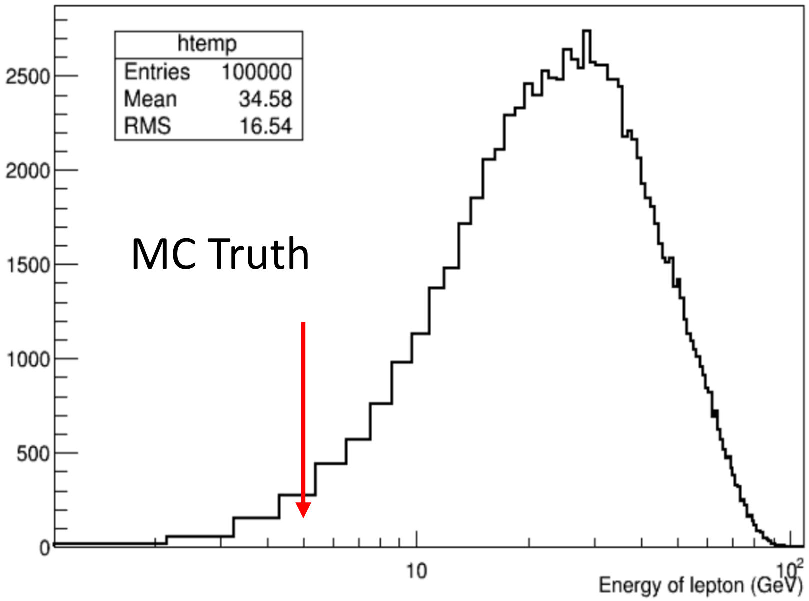


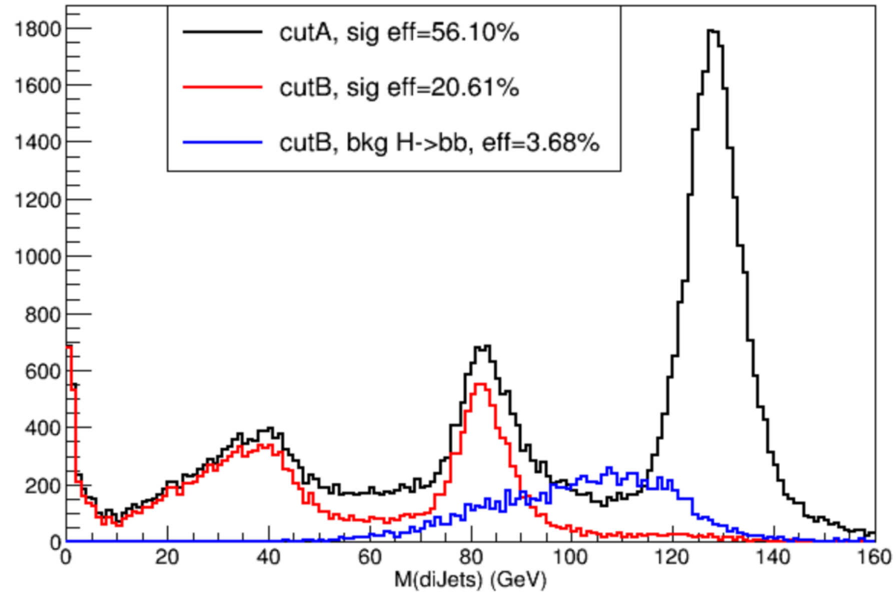
M(Z) in (60, 120) GeV



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

H→WW→lvqq signal





- Cut A, M_Z in (69, 113) GeV,

  Z Recoiling M(H) within (120, 160) GeV

- Cut B, cut A plus number of isolated lepton >=1, its energy >5 GeV (energy threshold needs to be optimized).

Calorimeters R&D Plan (~ 6 months)

1. CEPC ScW ECAl simulation and optimization

- Number of layers, Cell size, Scintillator thickness
- SiPM test and performance study
- Performance of Scintillator strip
- Design of readout electronics
- Optimization of ECAL using H->$\gamma\gamma$ benchmark

2. CEPC DHCAL performance study and optimization

- Number of layers, Cell size
- SDHCAL (RPC) TB energy resolution, linearity
- THGEM and GEM performance study
- Design of readout electronics
- Optimization of HCAL using H->WW benchmark

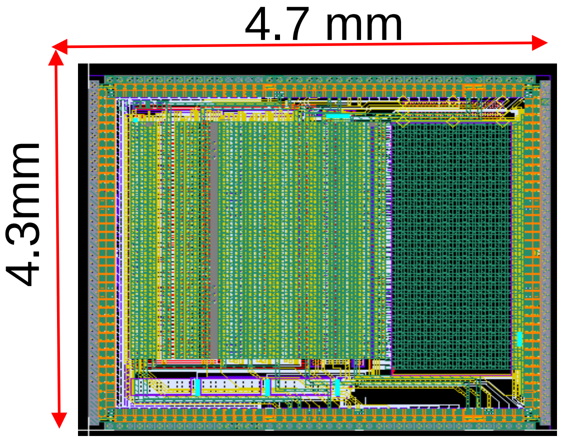
Calorimeters R&D Plan (6 months)

- IHEP: Zhigang Wang, Hang Zhao, Tao Hu
  - ScW ECAL optimization
  - SiPM Test and scintillator strip optimization
- USTC: Yunlong Zhang, Shensen Zhao, Jianbei Liu
  - Si-PMT 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, Qian Liu, Hongbang Liu
  - Thick GEM study with large active area ($20x20cm^2$)

RPC电子学读出系统

Imad Laktineh (IPNL)

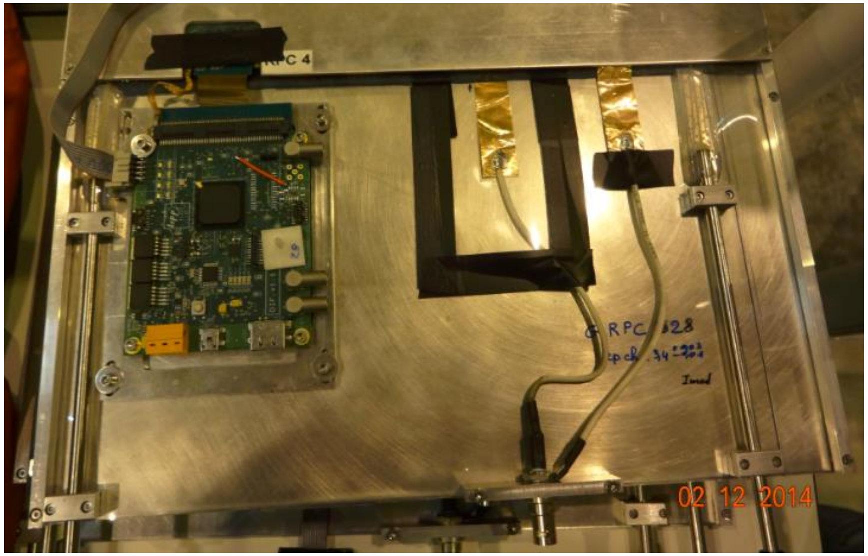
ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity



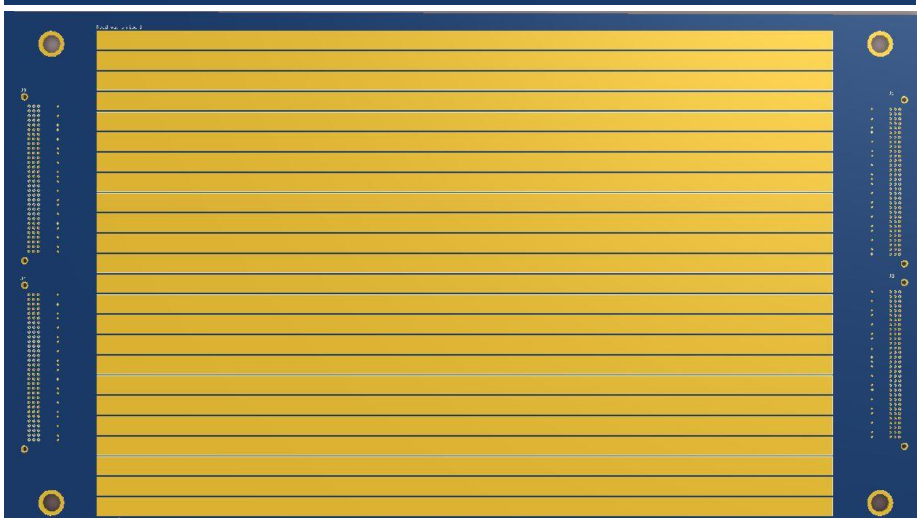
Printed Circuit Boards (PCB) were designed to reduce the cross-talk with 8-layer structure and buried vias.

Tiny connectors were used to connect the PCB two by two so the 24X2 ASICs are daisy-chained. $1\times1m^2$ has 6 PCBs and 9216 pads.

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



Design of PCB for RPC



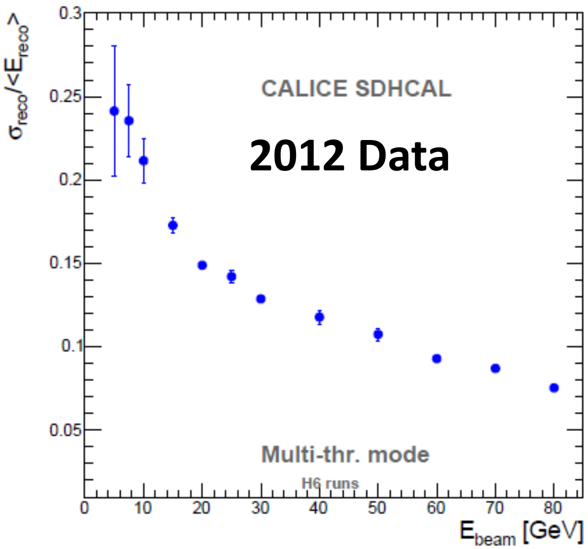
Bing Liu, Haijun Yang (SJTU)

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

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

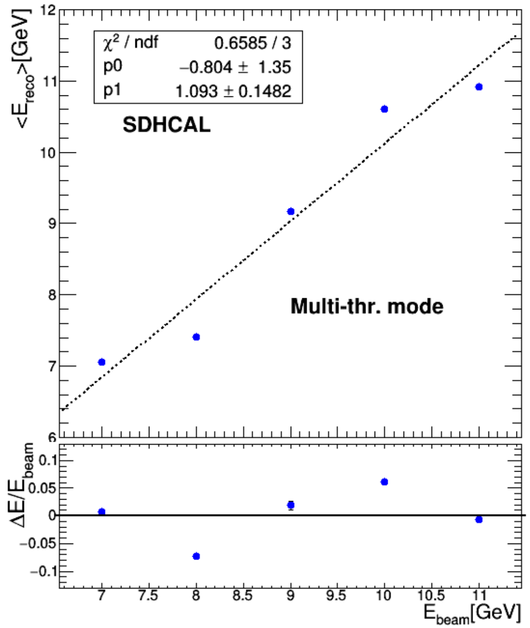
- NINO Input:
  - Molex DIN 41612 connectors (headers)

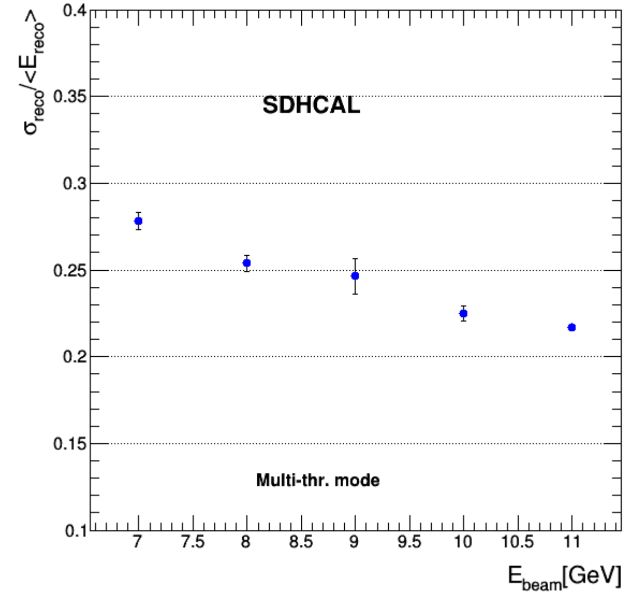
DHCAL with RPC

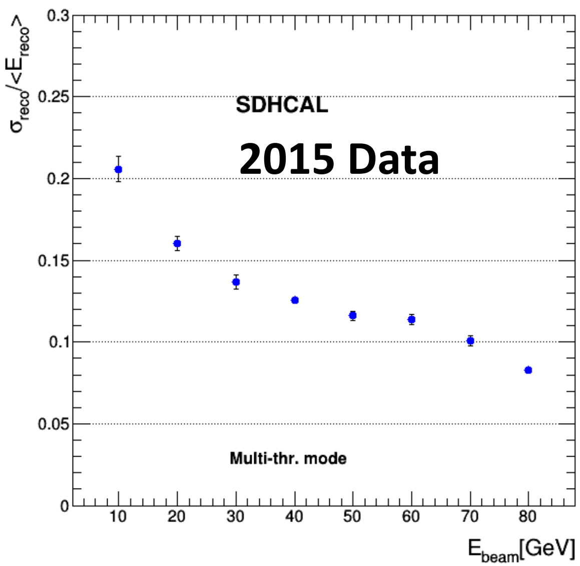


Bing Liu (SJTU)

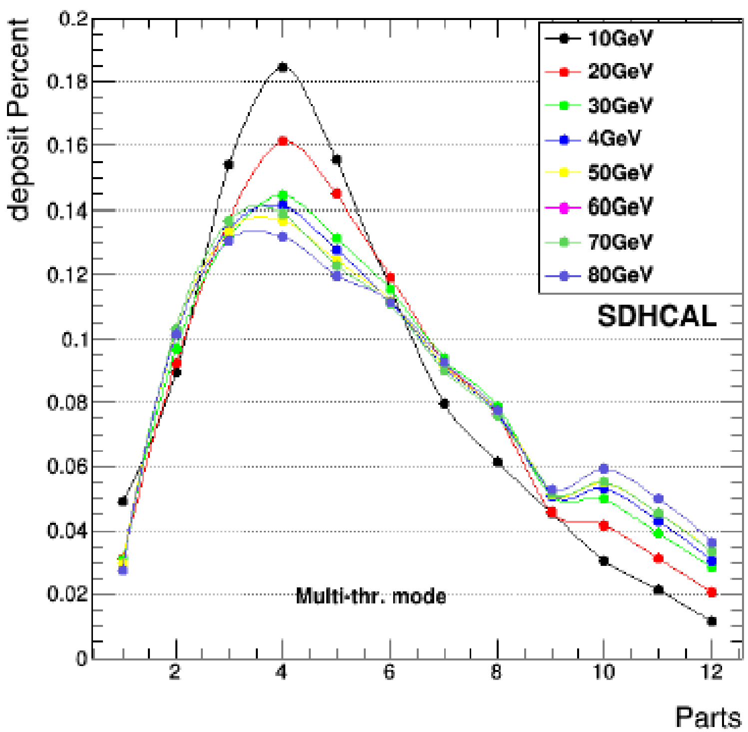
Low Energy Region (7 – 11 GeV)



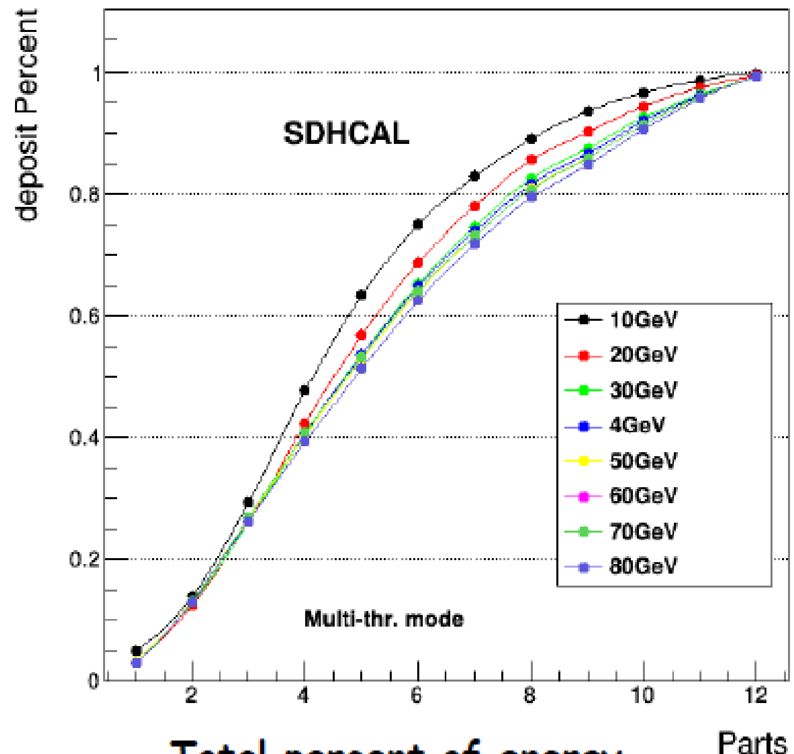




Energy deposited in every 4 layers



Percent of energy deposit in per parts



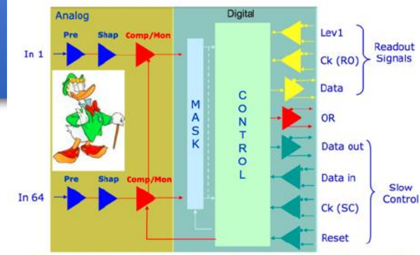
Total percent of energy deposit before a part you choose;

CONCLUSION

- Detector simulation:
  - Granularity of calorimeters optimization
  - Number of layers of calorimeters optimization
  - Digitization (RPC/GEM/THGEM)
- Detector R&D
  - RPC (Glass RPC, Polyamide RPC)
  - GEM (double GEM structure, self-stretching)
  - THGEM (Well-THGEM, double THGEM structure)

DAQ SYSTEM: GASTONE

From Qian LIU/Hongbang LIU (UCAS / GXU)

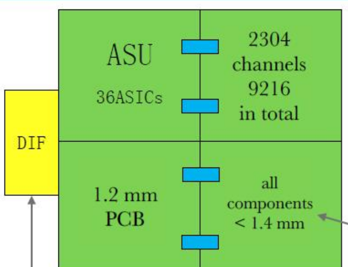


GASTONE (Gem Amplifier Shaper Tracking ON Events)

N channels	64
Chip dimensions	4.5×4.5 mm^2
Input impedance	120 Ω
Charge sensitivity	16 mV/fC (C_{det} = 100 pF)
Peaking time	90 ns (C_{det} = 100 pF)
Crosstalk	< 3%
ENC	800 e^- +40 e^-/pF
Power consumption	~6 mW/ch
Readout	Serial LVDS (100 Mbps)

HARDROC/MICROROC

From Jianbei LIU (USTC)

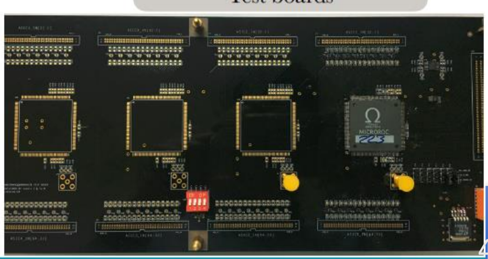


Detector InterFace (DIF)

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

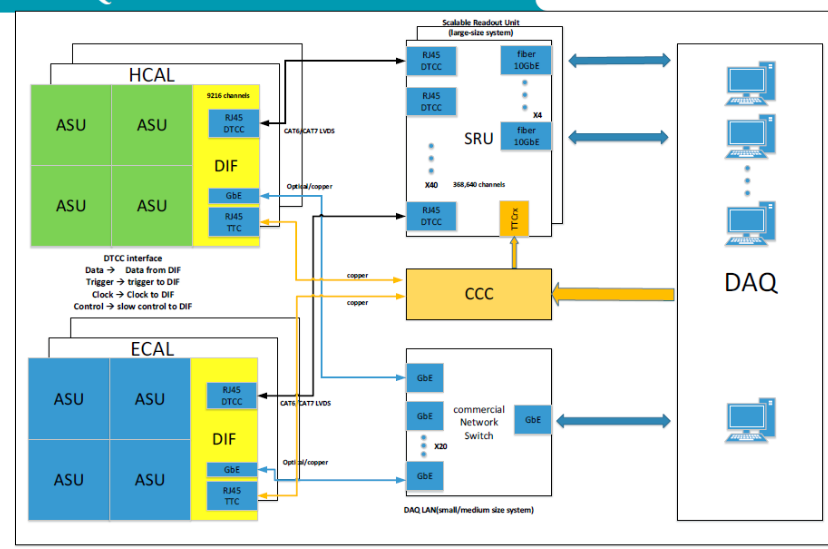
MICROROC is dedicated chip for GEM/MICROMEGAS. MICROROC (pin pin compatible with HR2b) is based on HR2b same back-end, same readout format, same pinout, only the preamplifier is changing.

Active Sensor Unit (**ASU**) Test boards



DAQ SYSTEM DESIGN

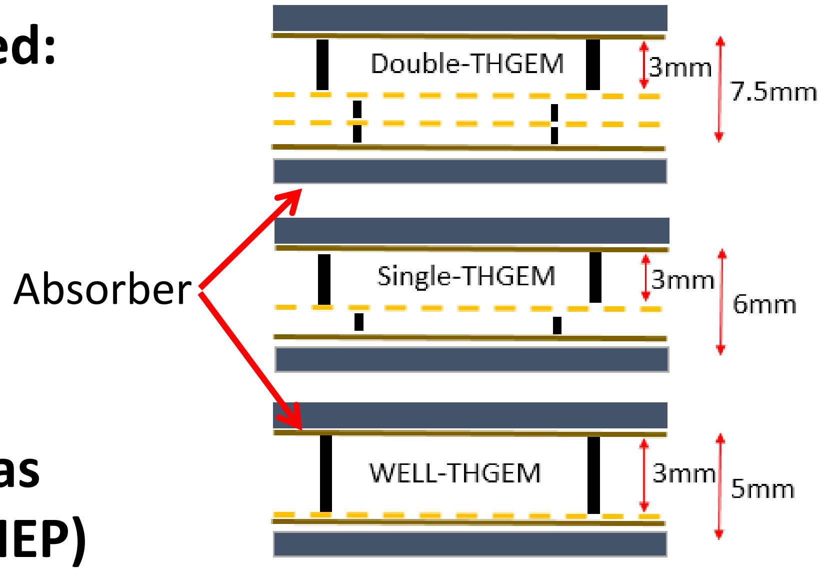
From Jianbei LIU (USTC)

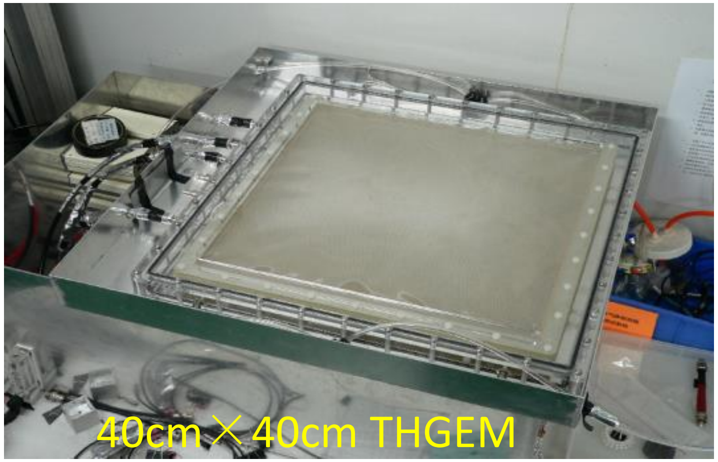


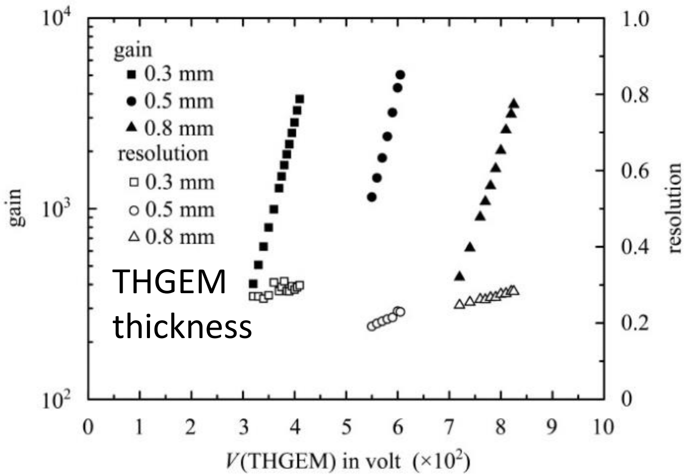
DHCAL based on THGEM

Boxiang Yu (IHEP)

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



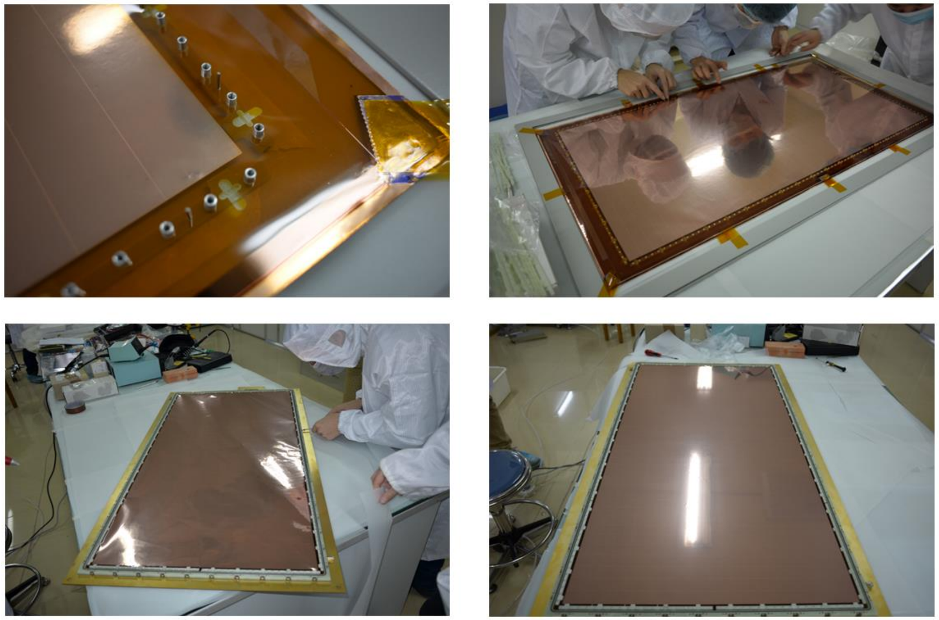




Large-area GEM @ USTC

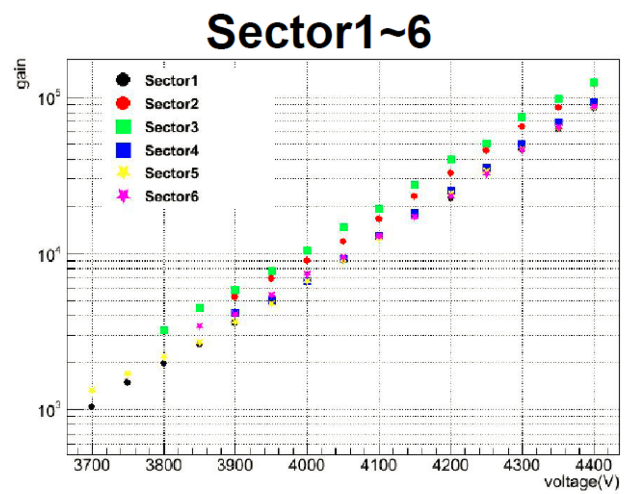
Jianbei Liu (USTC)

GEM assembly using a novel self-stretching technique



APV25 GEM readout

INFN APV25 chip



- Large-area GEM ($0.5x1m^2$) 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 ~$1m^2$ that are also applicable to CEPC DHCAL.

➔ **Resolution uniformity ~11%**
➔ **Gain uniformity ~16%**
➔ **Can reach gain of 10^4 at 4000V**

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