科技部国家重点研发计划 - 高能环形正负电子对撞机相关的物理和关键技术预研究
探测器关键技术预研 （2016FYA0400404）

Progress of MOST HCAL R&D

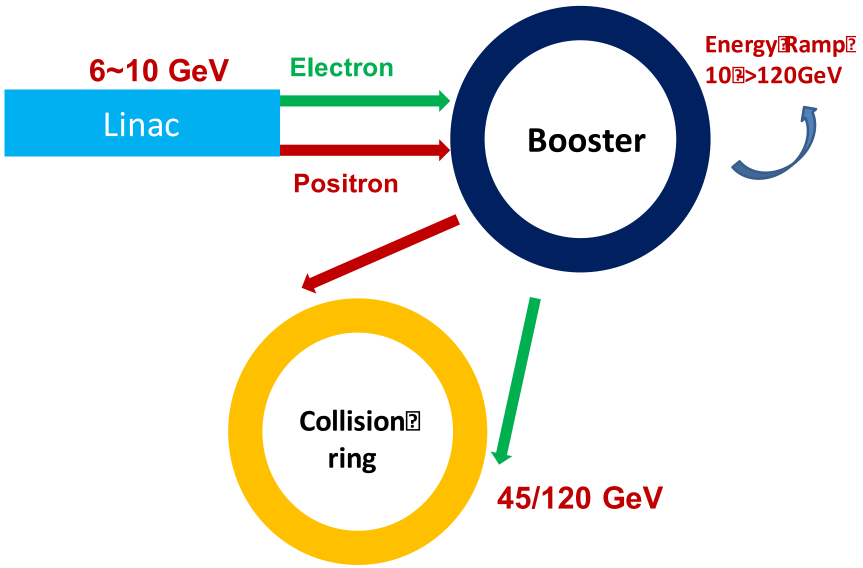
MOST HCAL Working Group

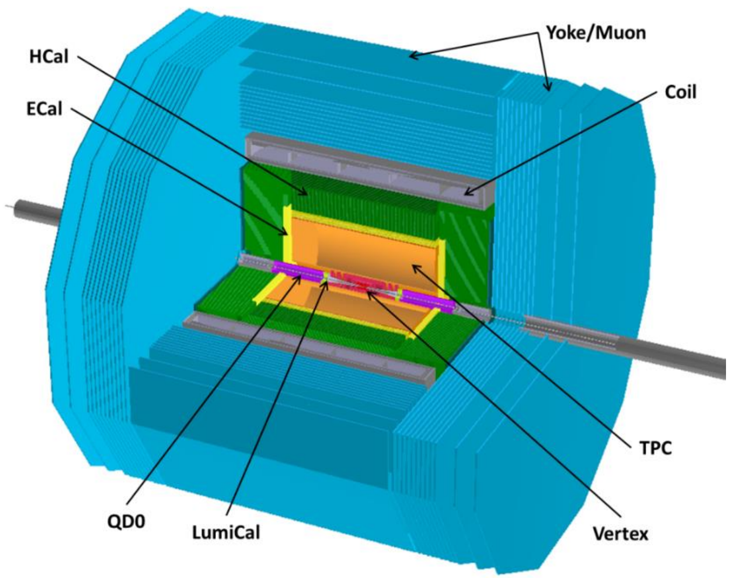
International Review Meeting
IHEP, June 16, 2018

Outline

- **About MOST CEPC R&D (Phase-I)**
- **Requirements of CEPC Calorimeters**
- **SDHCAL based on RPC**
- **SDHCAL based on MPGD**
- **Summary and Future Plans**

MOST R&D Projects (Phase-I)





Project 1
Accelerator Design

Project 2
Key Technologies About Accelerator

Project 3
Detector Simulation & Physics Potential

Project 4
Key Technologies About Detectors

MOST Detector R&D Study (Phase-I)

	IHEP	USTC	Tsinghua	CCNU	SJTU
Silicon	Chip design Perf. test			Chip design Perf. test	
TPC	Prototype Perf. test		Electronics Perf. Test		
ECAL	Prototype Cooling Perf. test	Electronics Prototype Perf. test			
HCAL	MPGD design, construction Performance test				RPC design Construction Perf. test
	THGEM option	GEM option			
Cherenkov PID, MPGD based photon detector R&D		RICH Prototype Perf. test			

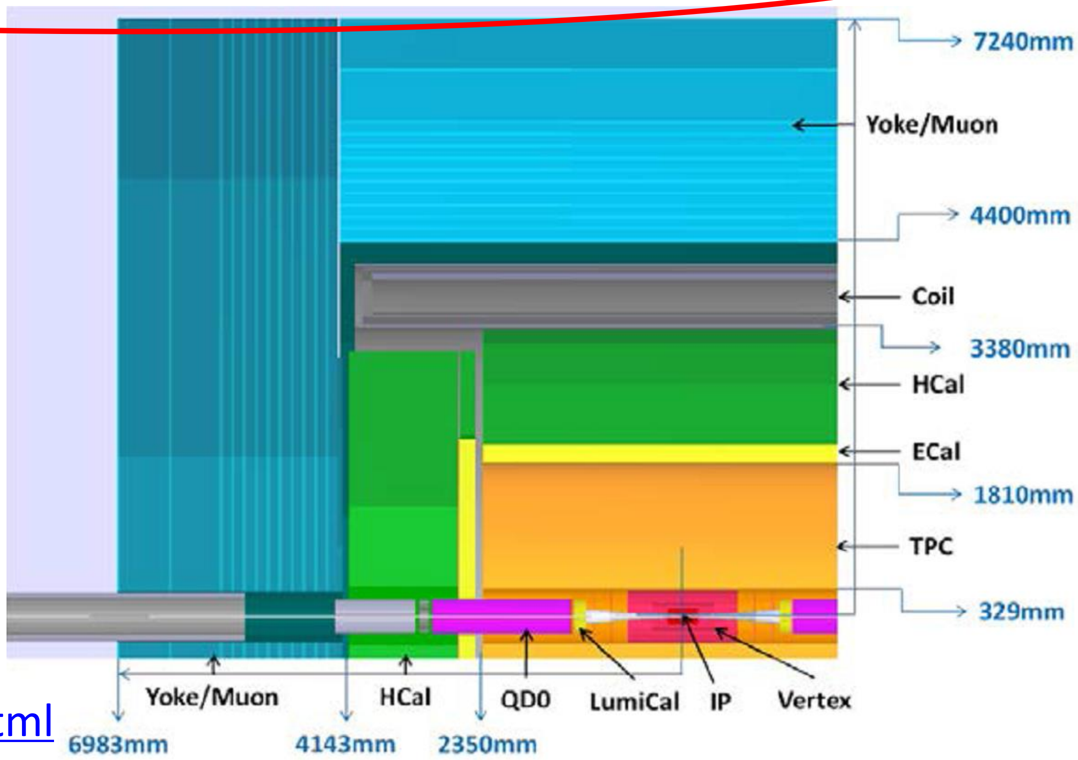
Requirements of CEPC Calorimeters

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

Goal: Jet energy resolution (HCAL+ECAL and tracker):

$$\sigma_E/E \approx (3\% - 4\%)$$

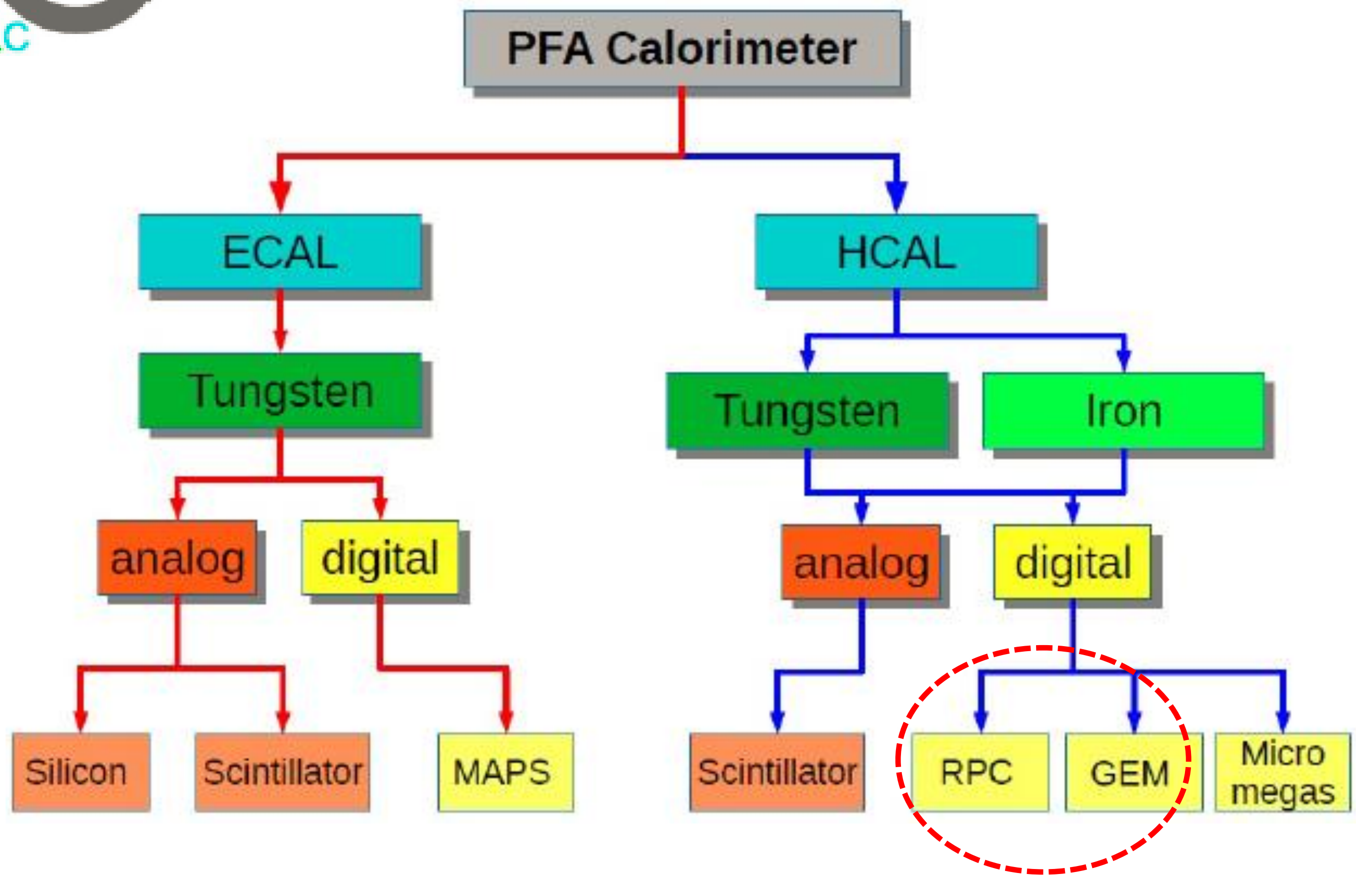
@100GeV based on PFA



- CEPC preCDR documents : http://cepc.ihep.ac.cn/preCDR/volume.html

Options of PFA-based HCAL

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



DHCAL: Gas detector, RPC & MPGD(THGEM/GEM)

Tasks and goals of the MOST HCAL R&D

➔ The proposed tasks and goals for MOST HCAL R&D:

- ✓ to choose appropriate technology options for digital HCAL
- ✓ to build 1m×1m RPC sensor unit with thickness less than 6mm and cell size of 1×1cm^2 , MIP detection efficiency should be better than 95%
- ✓ to build 1m×0.5m MPGD sensor unit with thickness less than 6mm and cell size of 1×1cm^2, detection rate should reach 1M Hz, explore high-rate gaseous detector options for DHCAL

➔ The midterm goals for MOST HCAL R&D:

- ✓ to complete preliminary design of RPC sensor unit and provide some RPC performance study results with MC simulation and TB data.
- ✓ to complete preliminary design of MPGD sensor and electronic readout

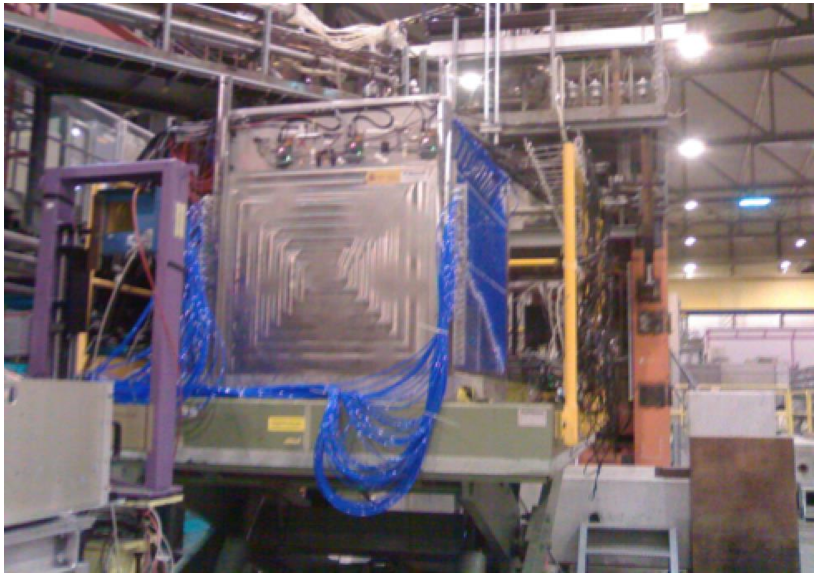
SDHCAL-RPC (IPNL+SJTU)

Prototype

- Total Size:1.0x1.0x1.4m^3
- Total Layers: 48
- Total Channel(pads):440000
- Power consumption:$10\mu W/channel$

(Power pulsing)

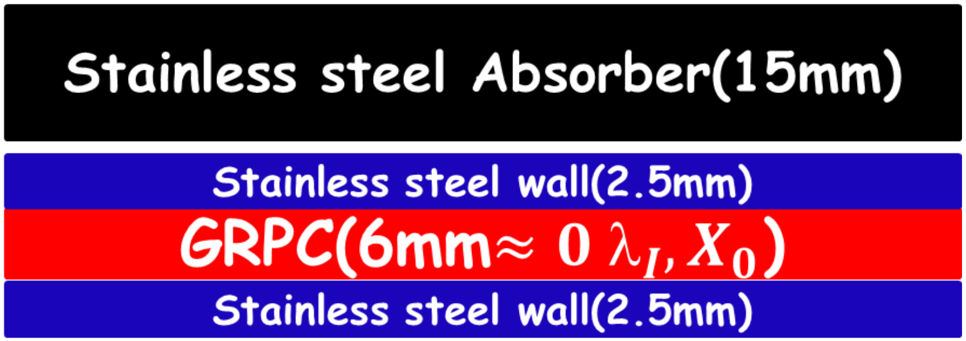
the first technological prototype among a family of prototypes of high-granularity calorimeters

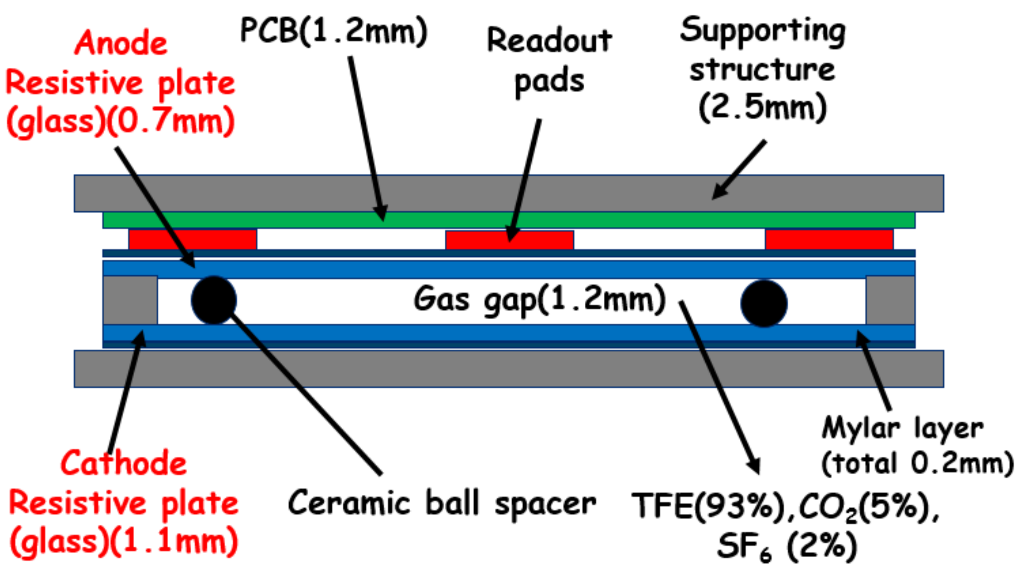


Developed by the CALICE collaboration

Structure of RPC layer

$(0.12\lambda_I, 1.14X_0)$

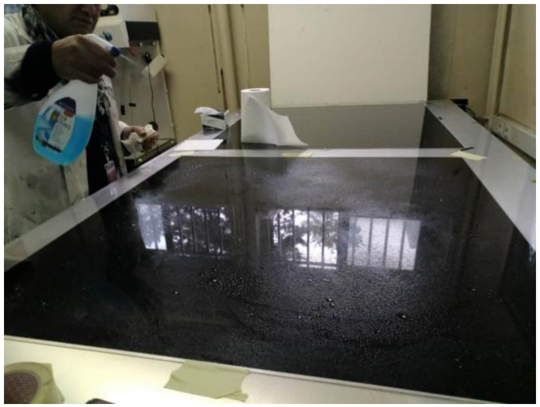




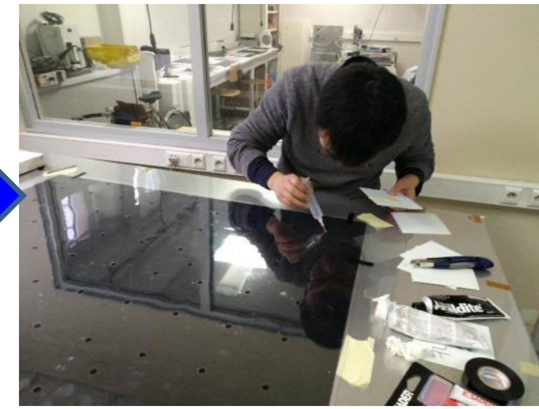
ASIC HARDROC(64 channel)
three-threshold (Semi-digital)
110fC, 5pC, 15pC

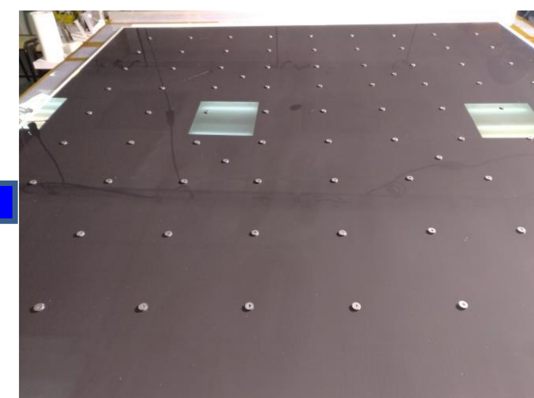
RPC Construction at IPNL

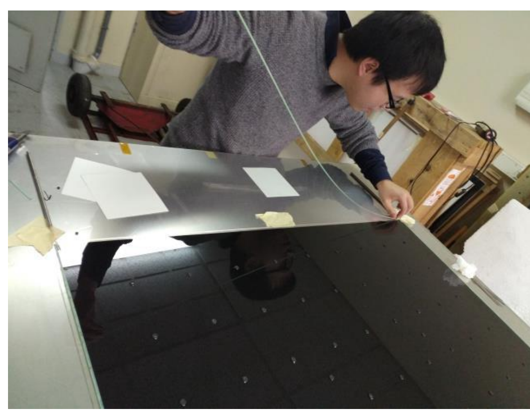
Cleaning of glass



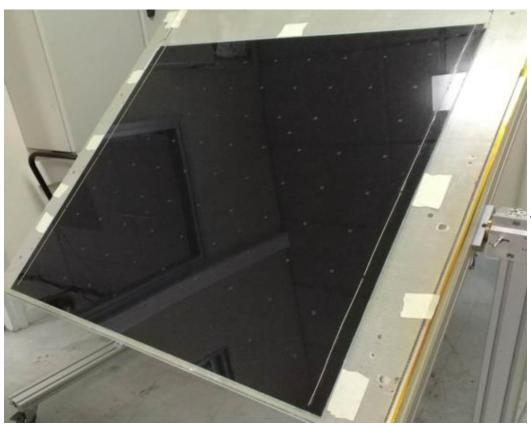
Place spacers





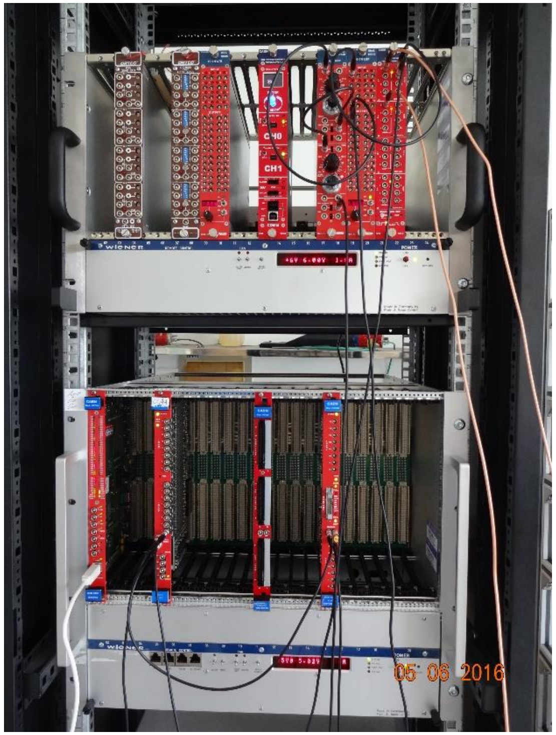


Sealing RPC chamber



RPC chamber

RPC Test Facility at SJTU



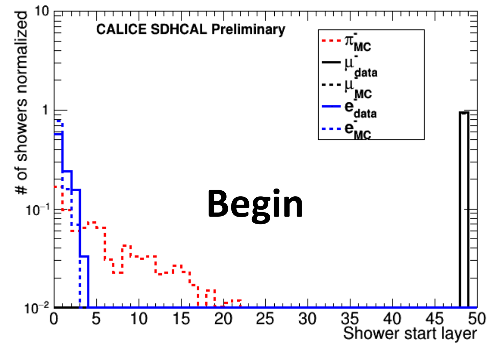
RPC Test Facility to be built at SJTU

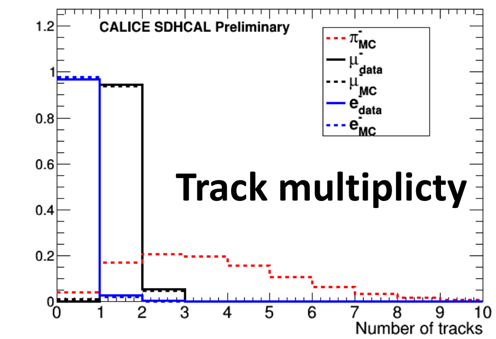
Analysis of TB data： Particle identification

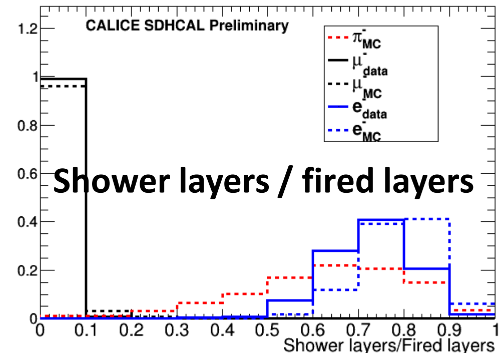
- Using MVA-BDT method to identify pion vs electron, pion vs muon
- To select purified pion sample from TB data

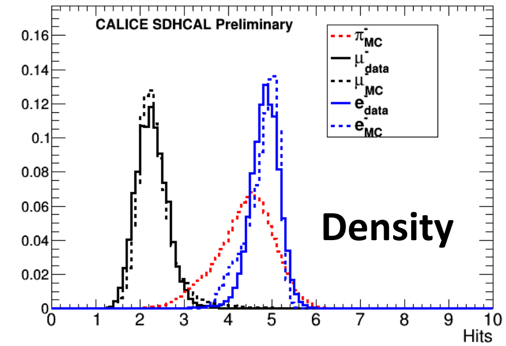
◆ BDT 6 var Input:

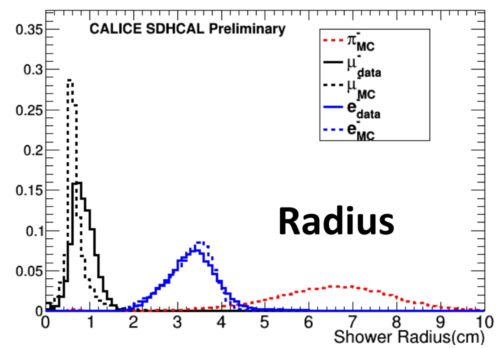
1. First layer of the shower(Begin)
2. Number of tracks in the shower (TrackMultiplicity)
3. Ratio of shower layers over total fired layers(NInteractinglayer/Nlayers)
4. Shower density(Density)
5. Shower radius(Radius)
6. Maximum shower position(Length)

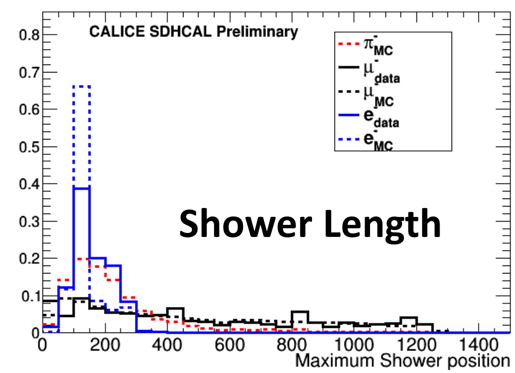




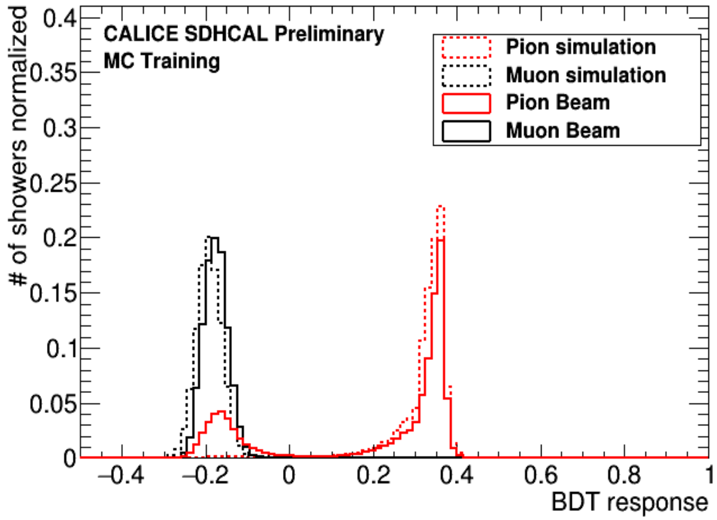


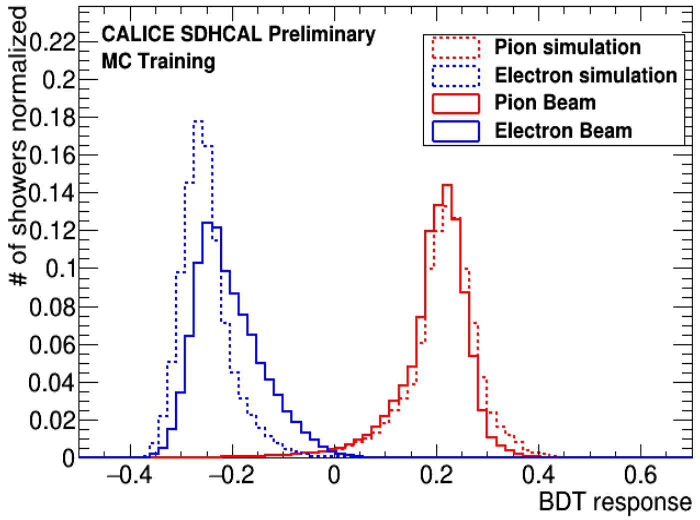




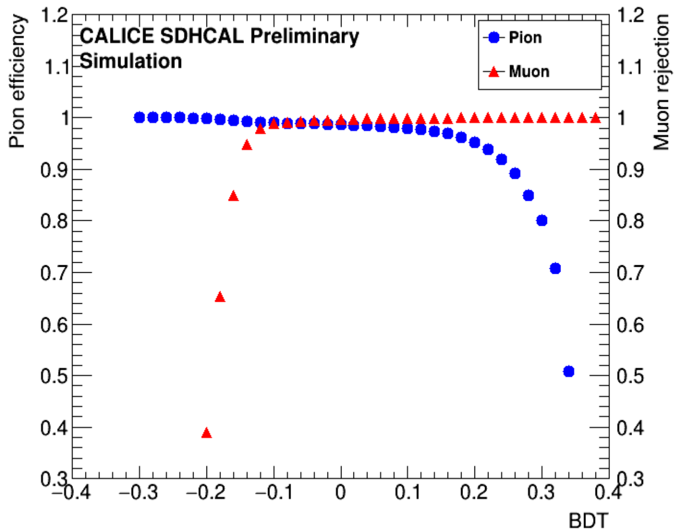


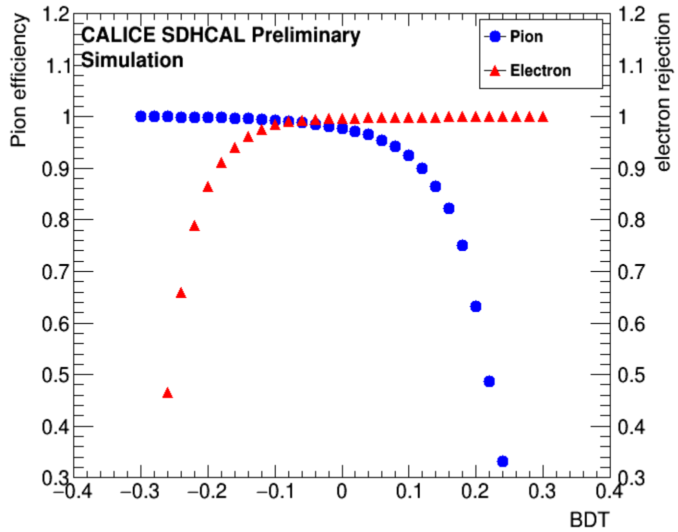
SDHCAL: Particle Identification





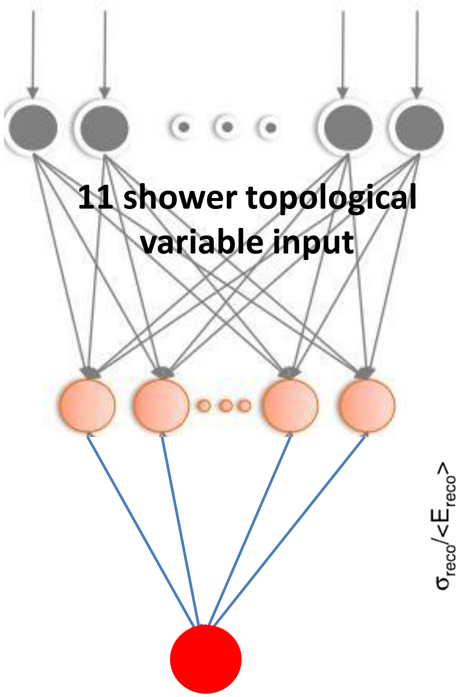
Eff(pion)>99% with Eff(e/mu) rejection rate >99%



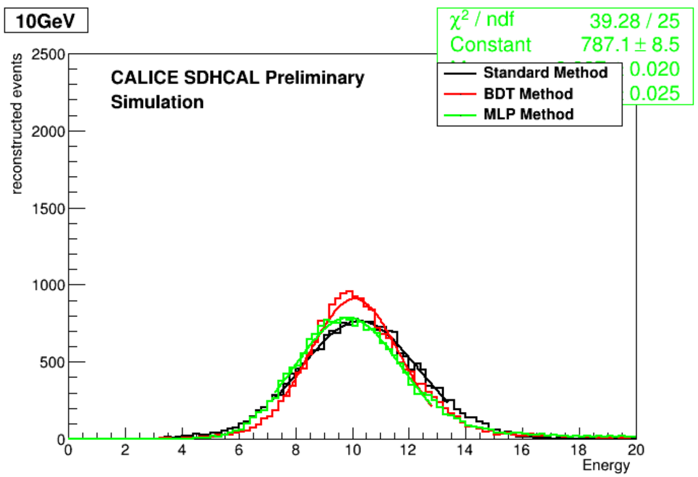


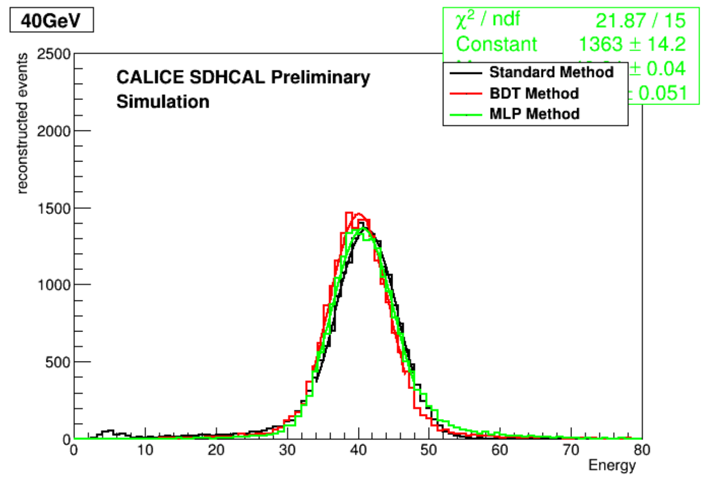
Energy Reconstruction using MLP and BDT

MLP Structure

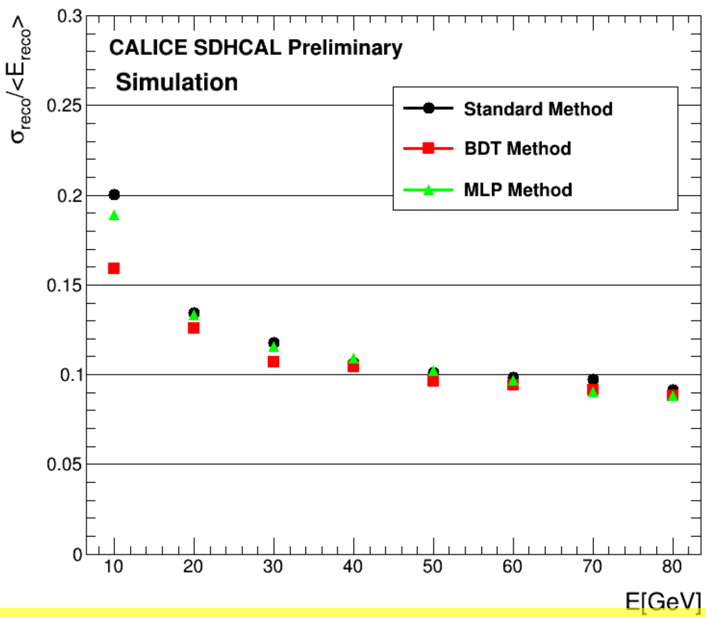


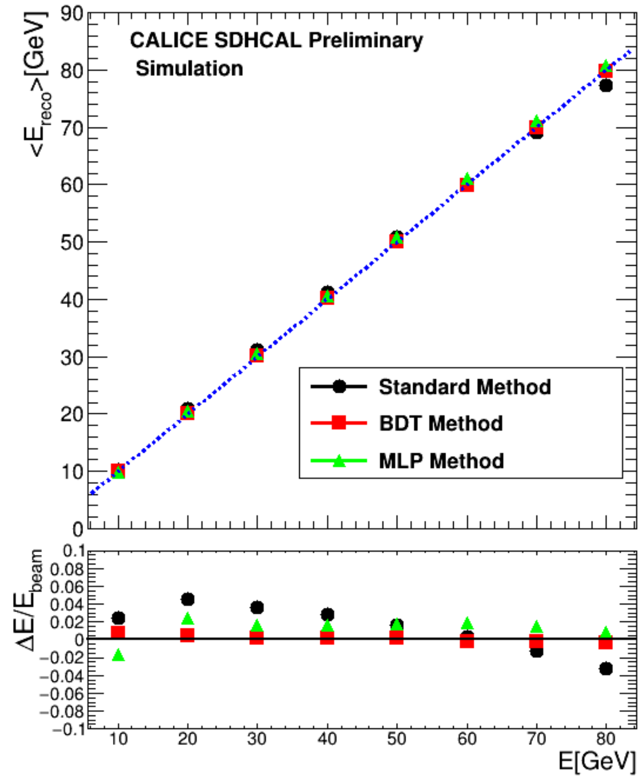
Energy reconstruction





One hidden layer

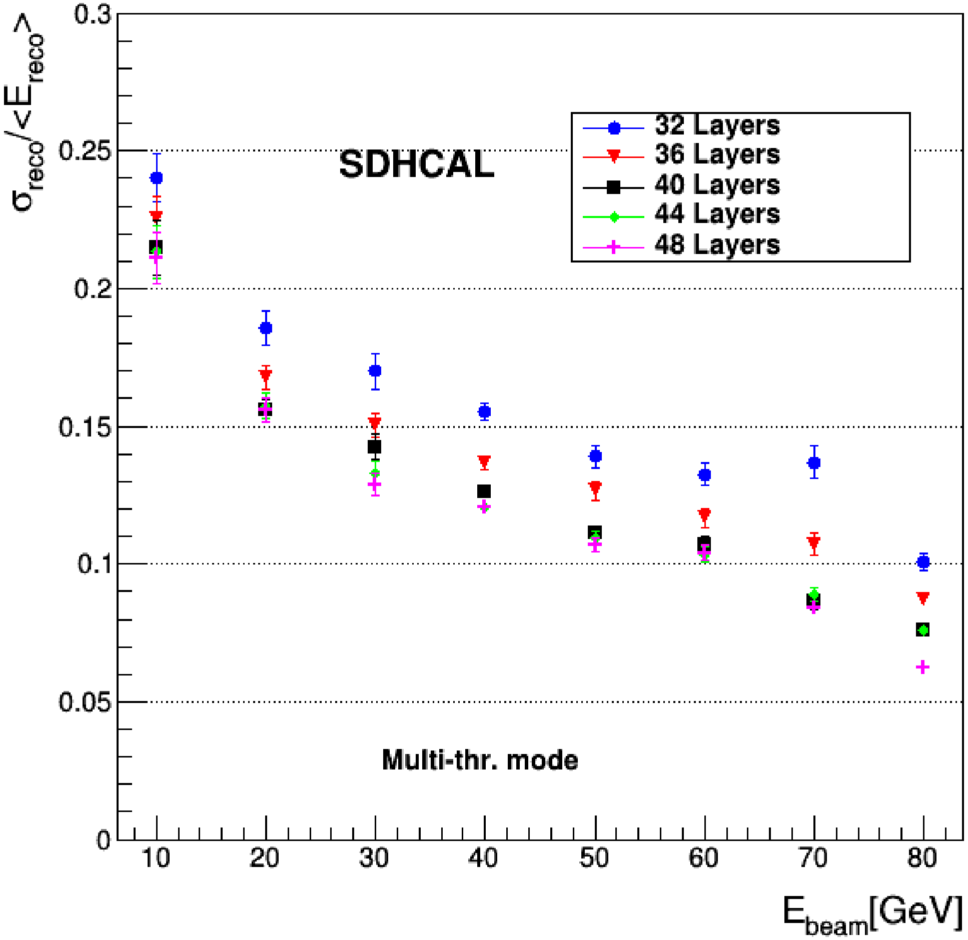


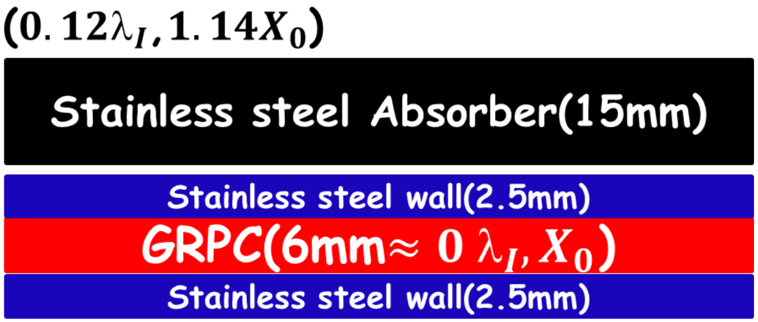


BDT works better, especially at low E region (10-30GeV)

➔ **BDT has significant improvement on $\Delta E/E$ ~ 1%**

Optimization of SDHCAL Layers





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

➔ **Optimization no. of layers for CEPC at 240GeV**

➔ **40-layer SDHCAL yields decent energy resolution.**

SDHCAL-MPGD

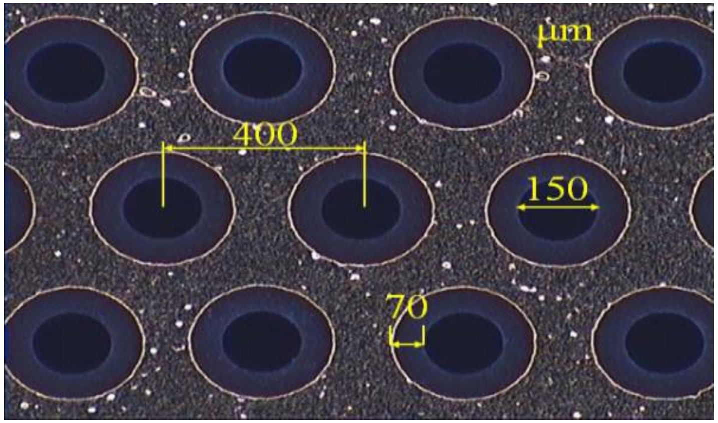
Mid-term tasks:

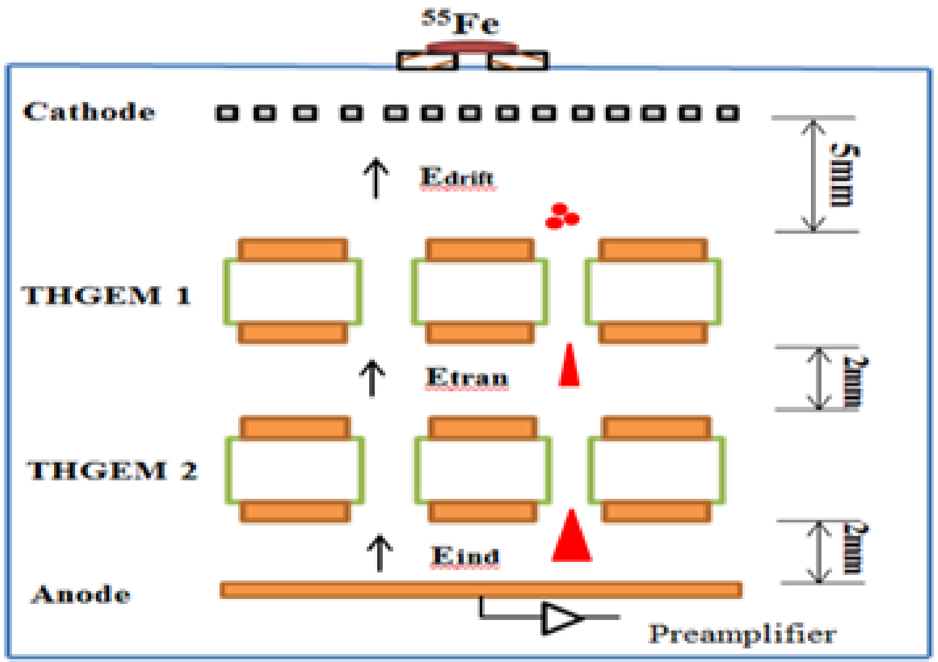
- ✓ MPGD detector design for DHCAL;
- ✓ Two options explored: GEM and THGEM;
- ✓ Development of small-size MPGD prototypes for DHCAL;
- ✓ Performance studies of the prototype ;

Research goals of the MPGD-DHCAL R&D task and assessment indicators:

- ➢ 100cm×50cm MPGD detector construction;
- ➢ Thickness of active detector <6mm;
- ➢ MIPs detection efficiency >95% and rate reaches 1MHz;

THGEM detector introduction

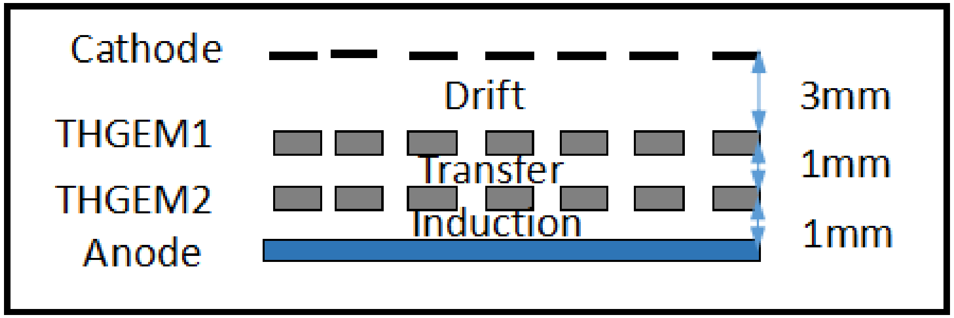




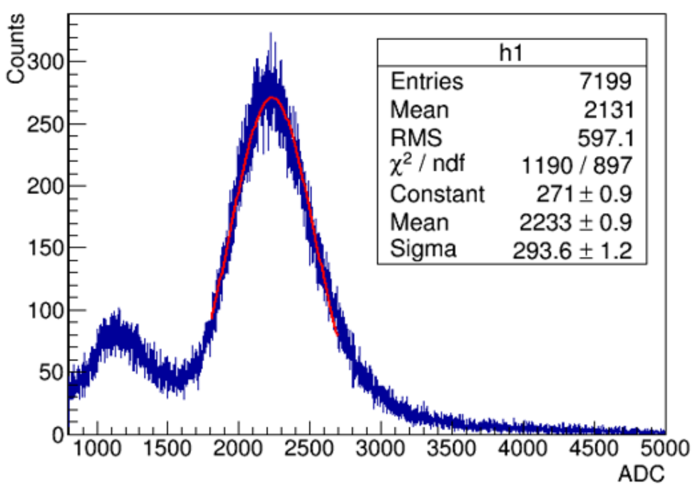
- THGEM detector: robust, high gain, high count rate, low price, it is a good candidate for DHCAL sensitive detector;
- Original THGEM detector structure: thickness is about 12mm, it can be reduced to about 6mm (MOST R&D requirement);
- Thinner THGEM detector needs to be developed for DHCAL including thinner THGEM and WELL-THGEM.

New Design of the detector

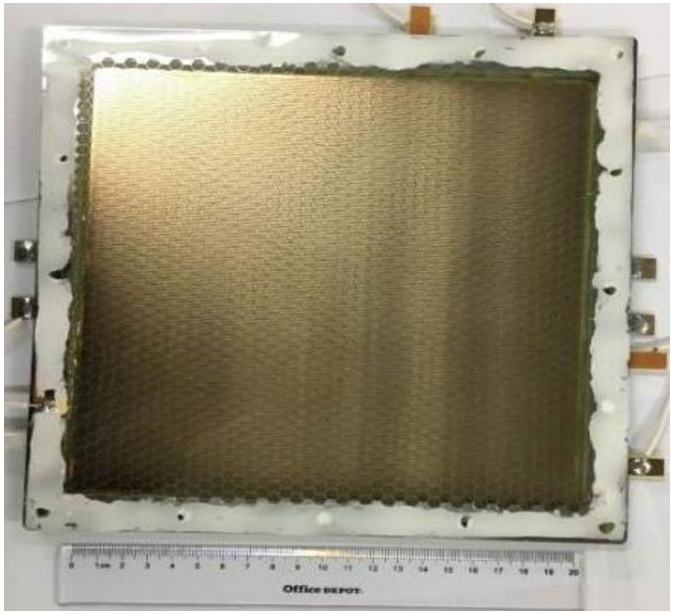
1. New design: 20cm×20cm;
2. Reducing the thickness of drift region from 5mm to 3mm. The transfer region and induction region reduced to 1mm. The total thickness reach to 8mm, including the thickness of readout board.



New design



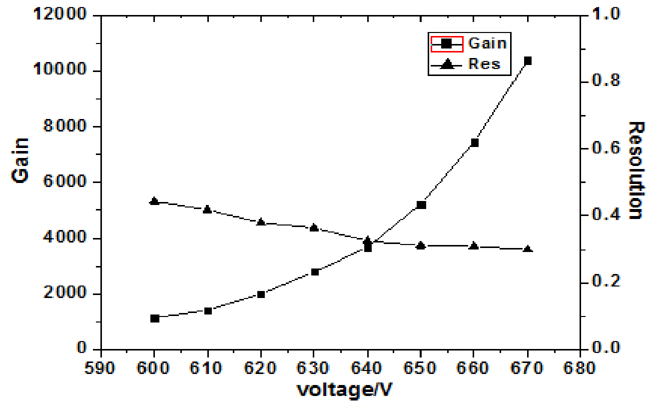
spectrum of source 5.9keV X ray of 8mm 20cm×20cm detector THGEM detector



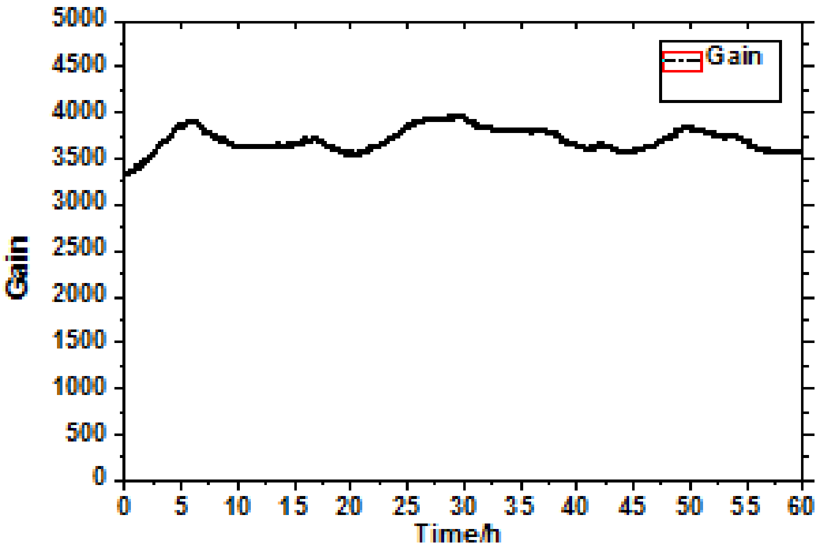
8mm 20cm×20cm detector THGEM detector

Performance of 20cm×20cm 8mm THGEM

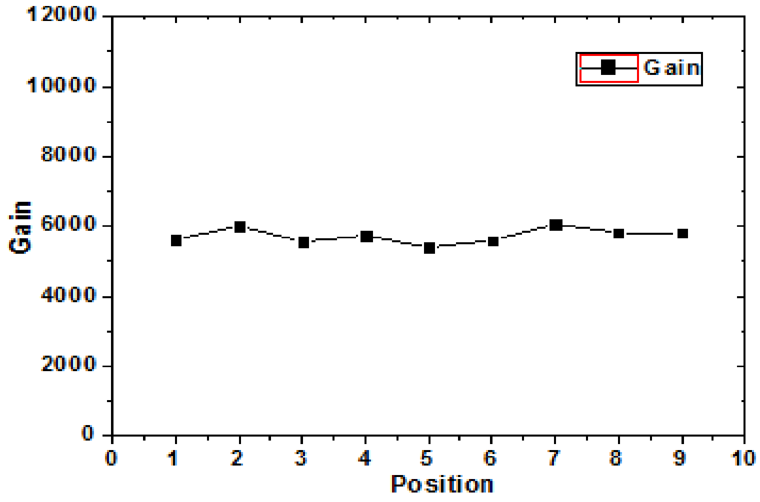
- The gas gain can reach to 10^4
- Long time stability is good
- The gain uniformity meet the requirement



Gain and energy resolution vs voltage



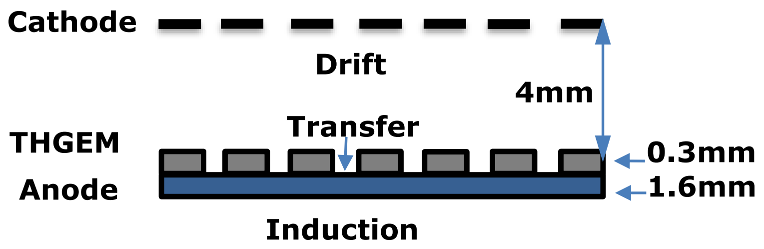
Stability measurement of THGEM detector



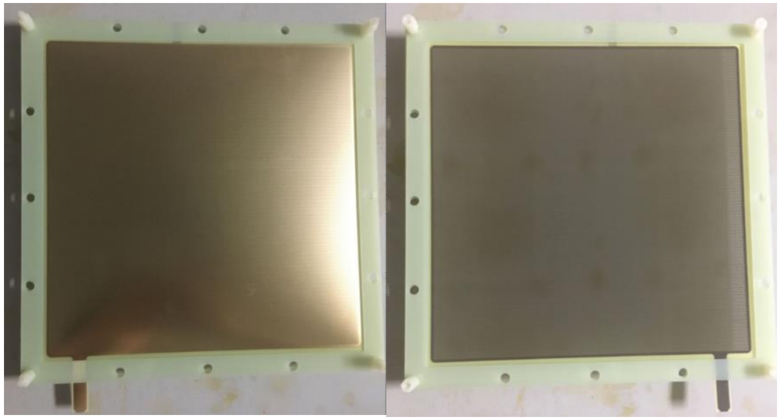
Gain uniformity measurement of THGEM detector

Study on WELL-THGEM

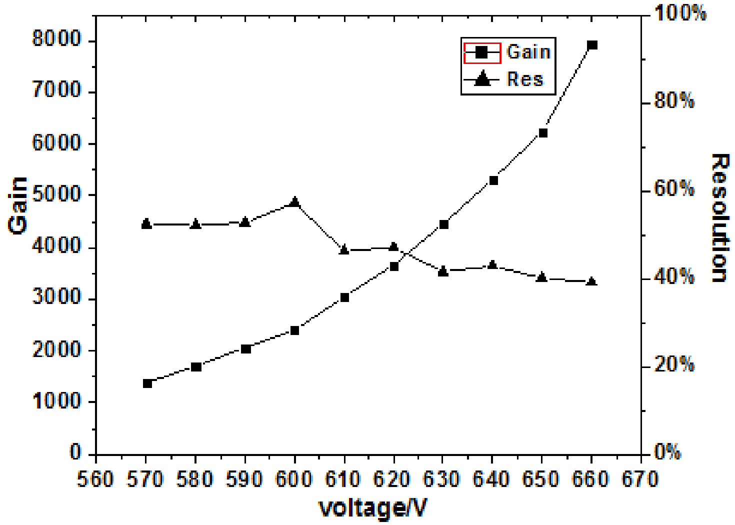
- WELL-THGEM can be thinner <6mm
- Readout by resistive anode
- Thinner, high gain, lower discharge



The thickness of WELL-THGEM<6mm

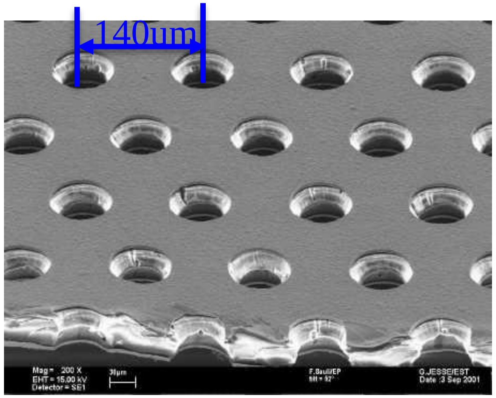


20cm×20cm WELL-THGEM

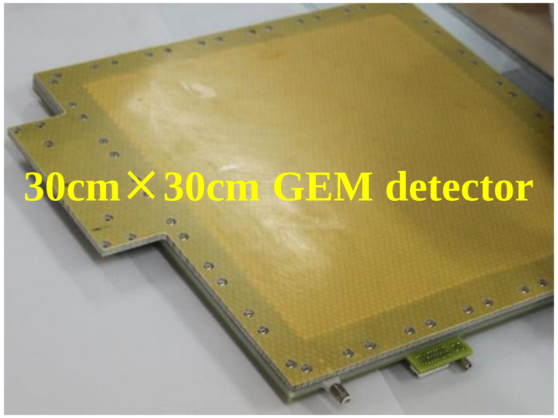


Gain result of 20cmX20cm THGEM

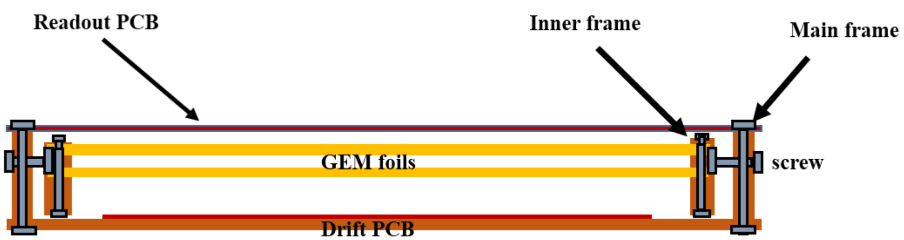
GEM (Gas Electron Multiplier)



Typical parameters
Cu : t = 5μm
Kapton: T = 50μm
Diameter: d = 60μm
D = 80μm
pitch: 140μm



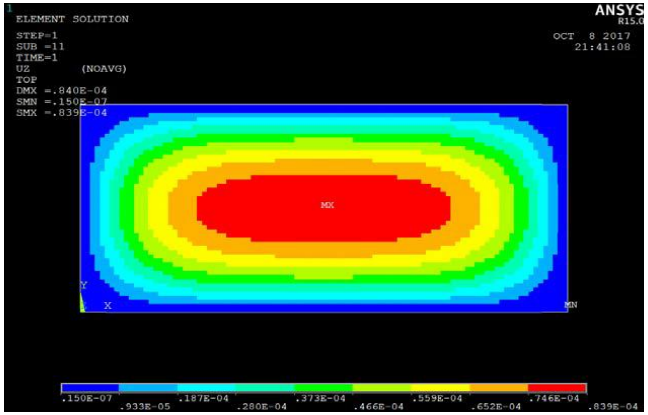
Self-stretching technique (from CERN)



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

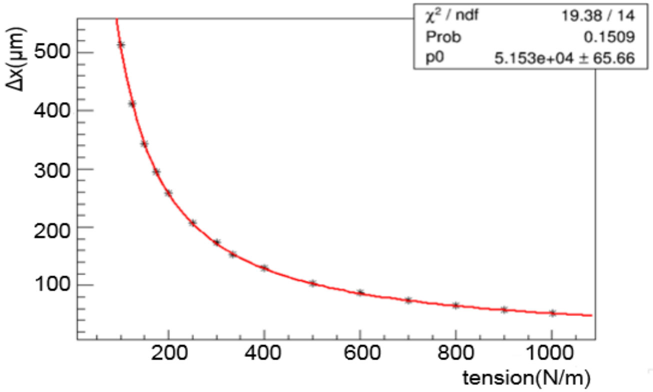
Deformation simulation of GEM foil

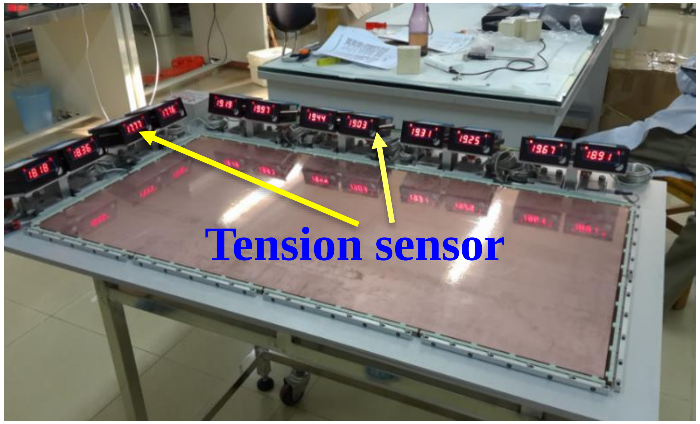
Vertical displacements simulation of GEM foil



1m×0.5m GEM foils

Maximum deformation as a function of tension



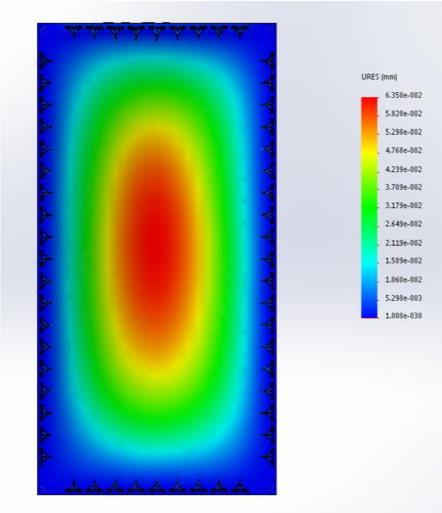


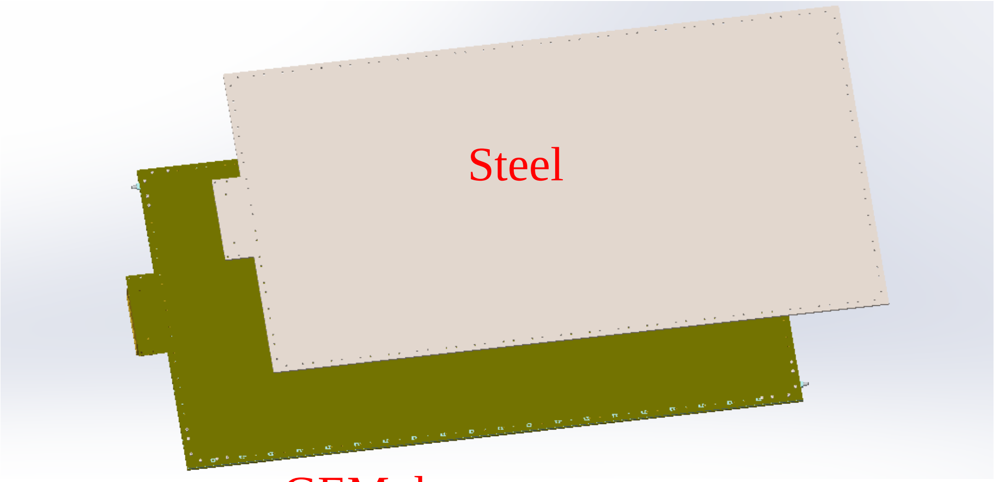
When tension is 500N/m,

- the maxiumum displacement is about **100μm**,
- extension of GEM foil is about **2.5mm**。

Mechanical deformation simulation and design

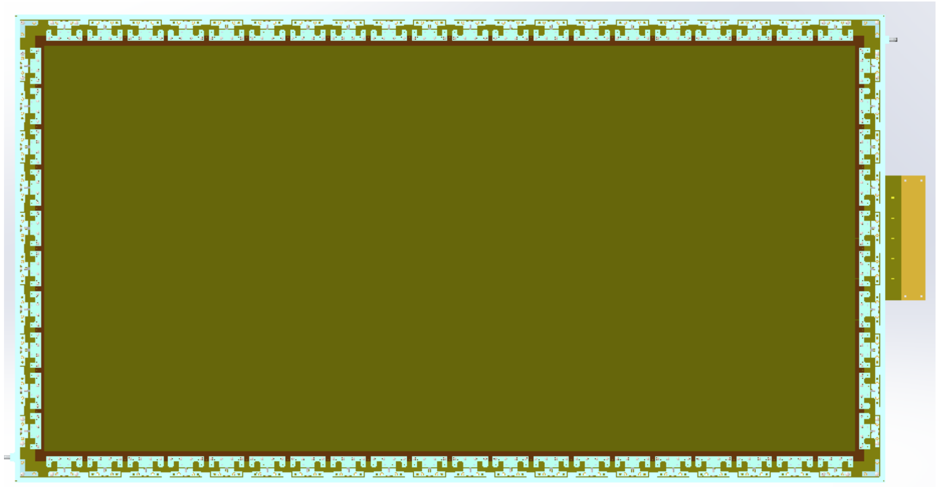
- **Main frame of the detector is fixed on a 4mm steel layer. When tension is 500N/m, the maximal deformation was found to be 63.5 um.**





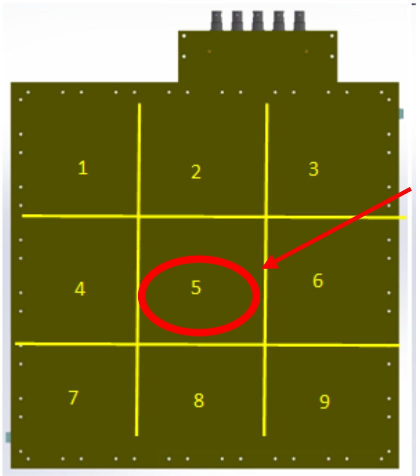
GEM detector

- **Design of a 0.5 m × 1 m double-GEM detector**

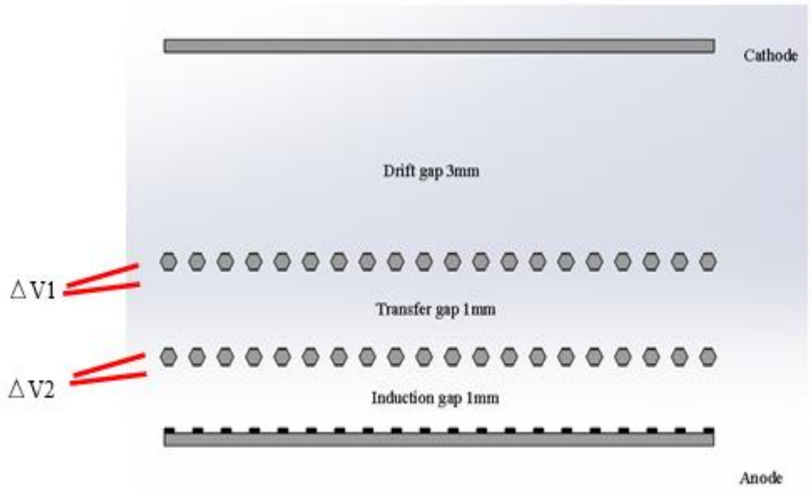


Performance test of GEM detector

Division of a 30cm×30cm GEM detector



Structure of GEM detector

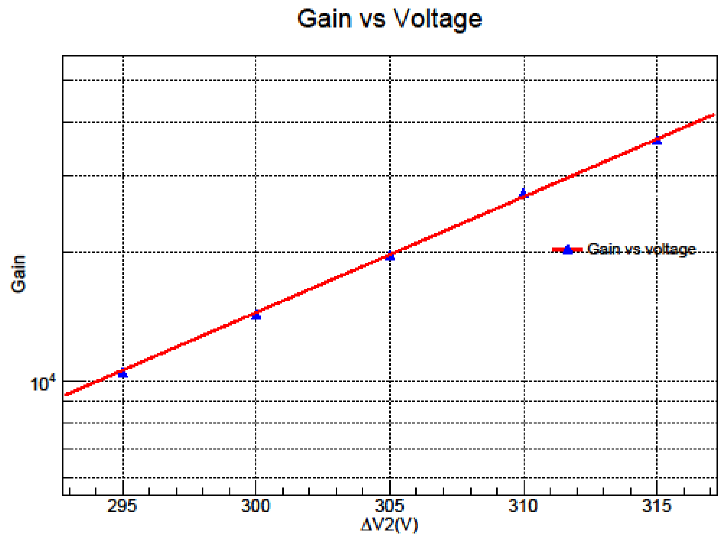


$Ar\text{-}5\%iC_4H_{10}$

Working condition of the GEM detector：

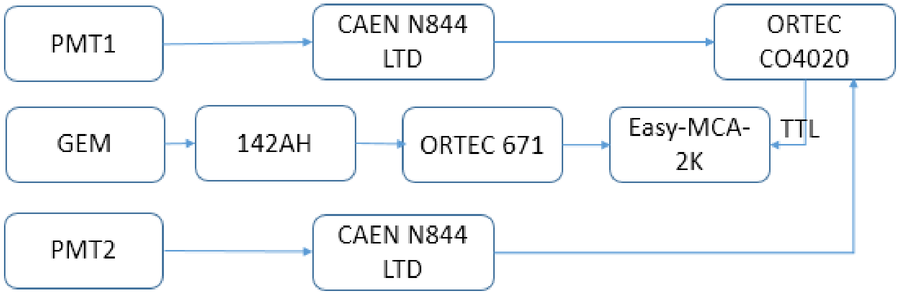
- △V1: 285 V;
- △V2: 295 V
- Step： 5V
- E_{drift}: 1.45 kV/cm;
- E_{trans}: 2.95 kV/cm ;
- E_{ind}: 3 kV/cm

Effective gain of the double-GEM detector

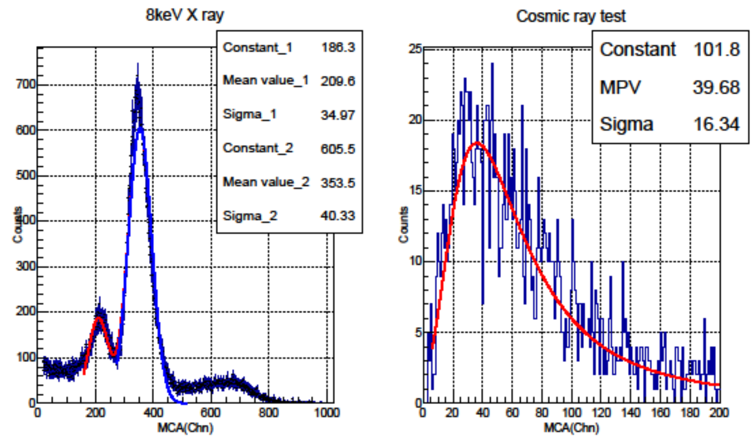


MIP detection efficiency

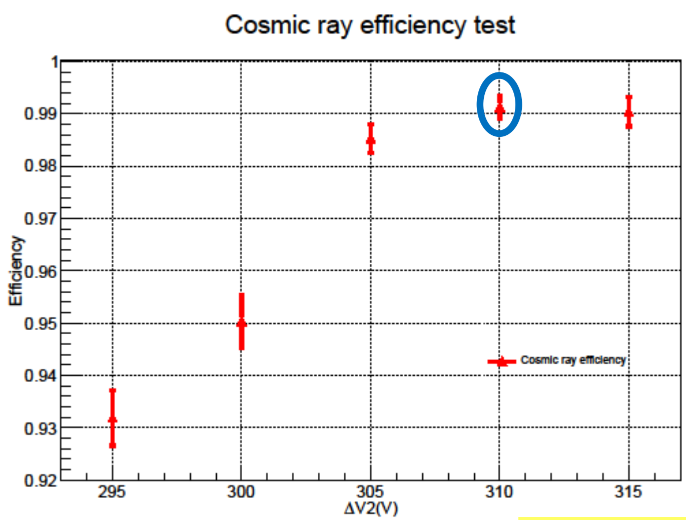
Electronic system



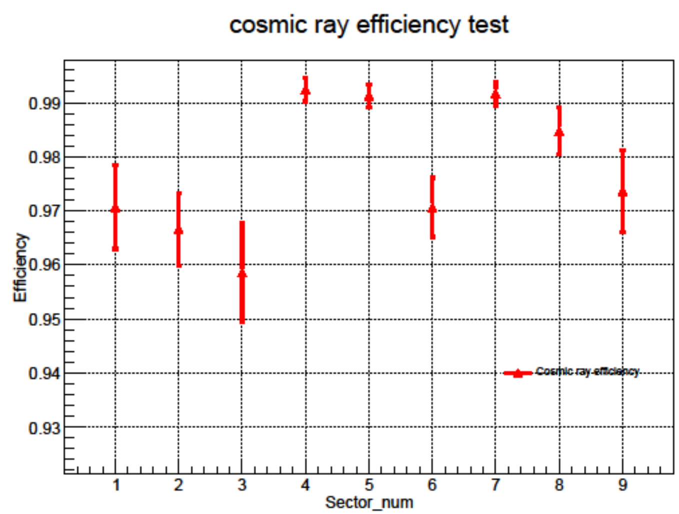
Spectra of X ray and cosmic ray



MIP detection efficiency as a function of voltage



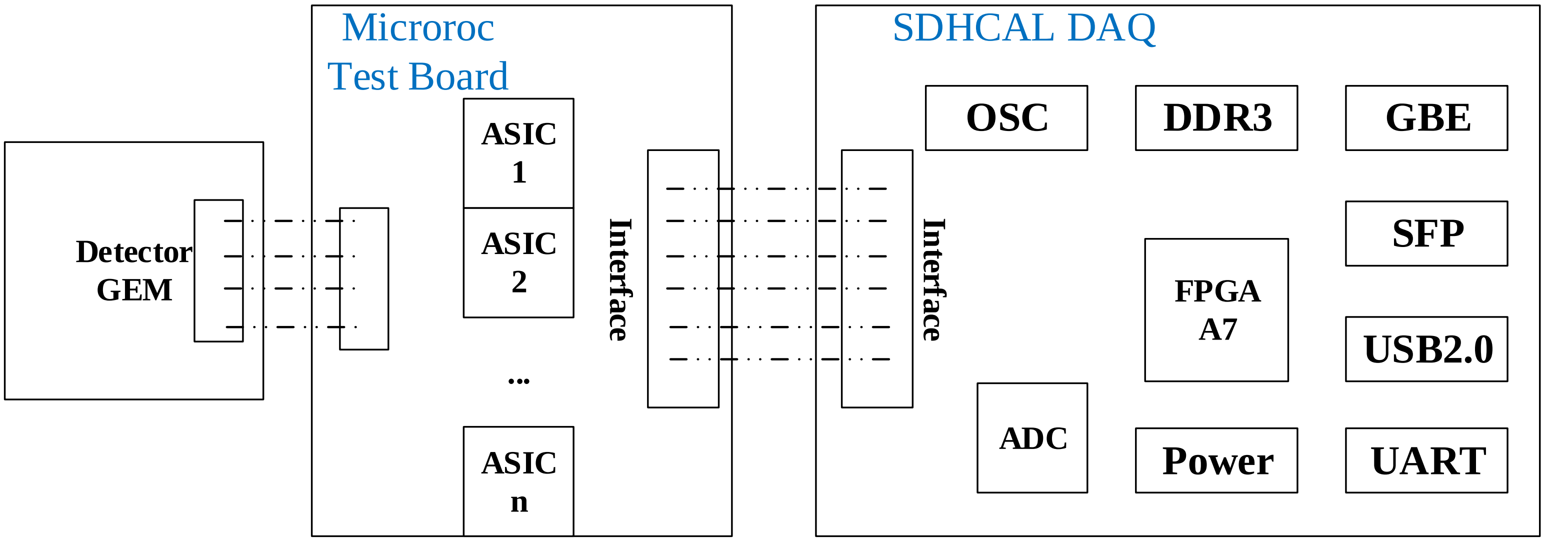
MIP detection efficiencies in different sectors



MIPs detection efficiency > 95%

Readout Design and Development

- **Schematic of the System**

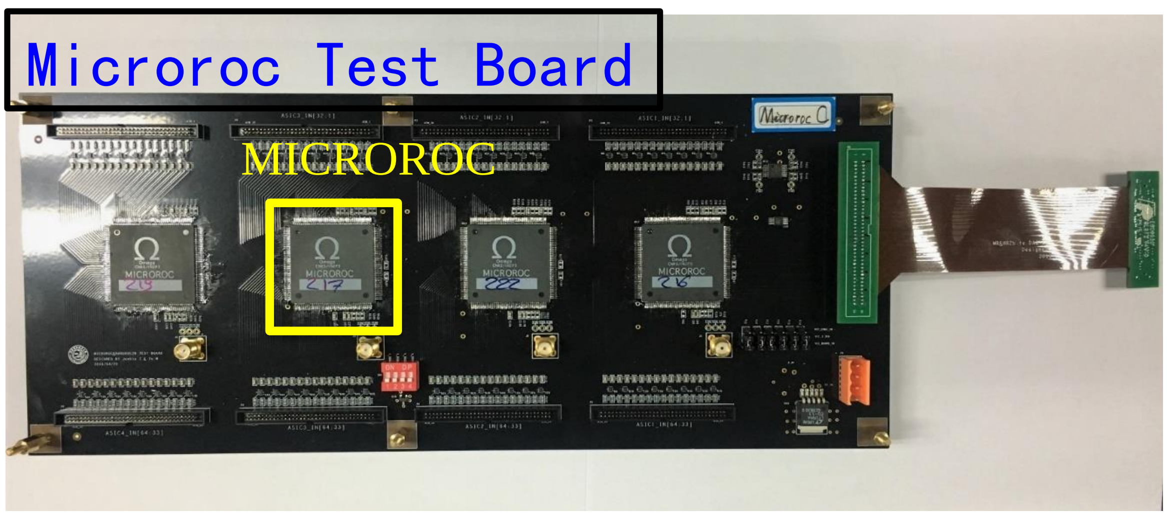


- ☐ Readout Board： GEM detector Readout composed by 900 1cm^2 pads.
- ☐ MICROROC Test Board： Mounted 4 Microroc ASICs, controlled by daisy chain.
- ☐ DIF Board： Microroc control, test and data acquisition

Readout ASIC

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

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

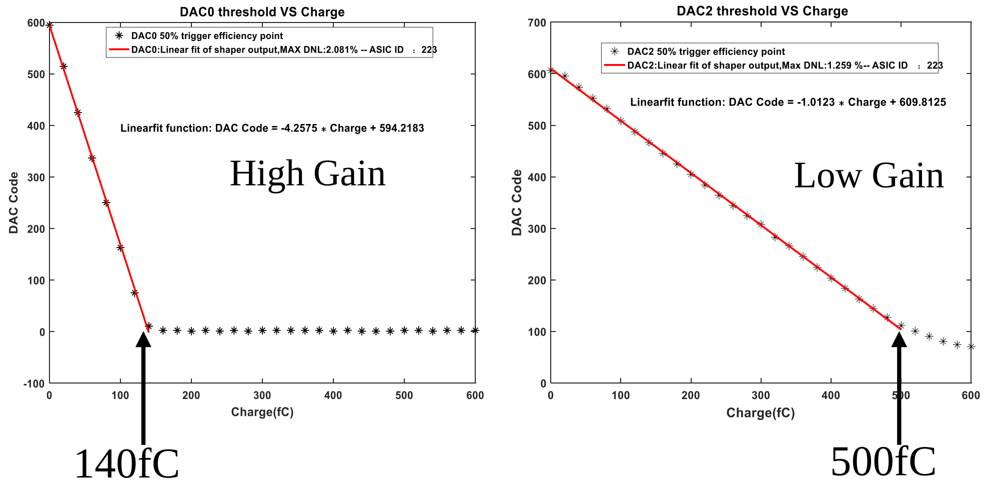


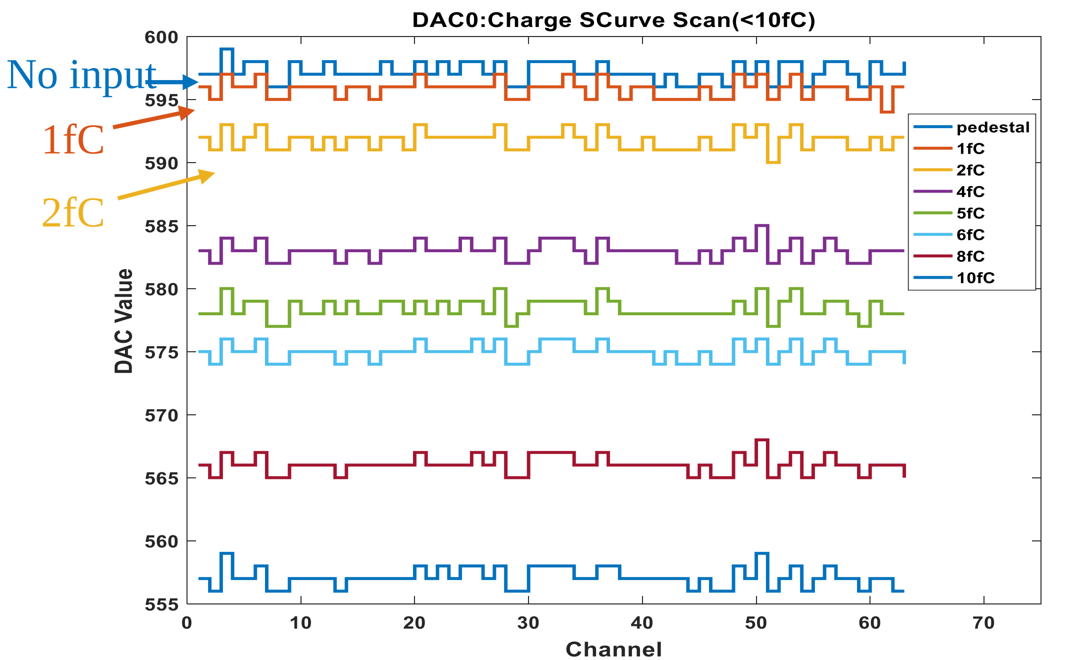
MICROROC Parameters

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

Test of MICROROC

- Calibration curve
- Uniform between 64 channels

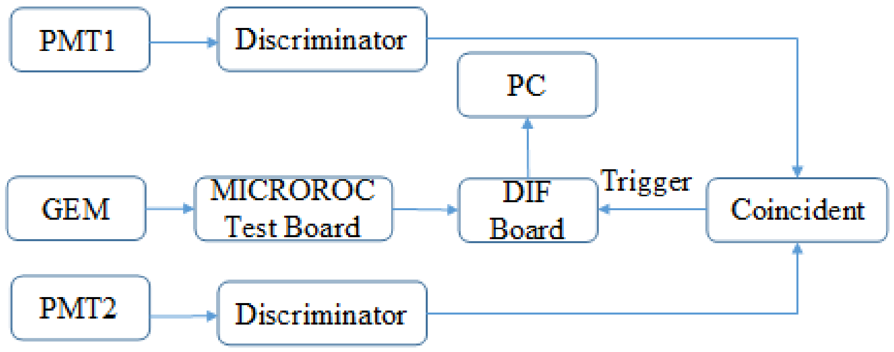


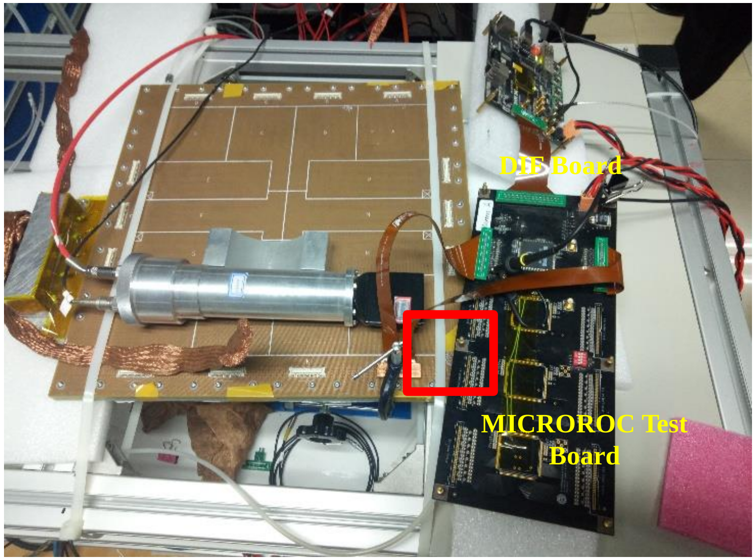


Minimum distinguishable charge: 2fC

Detection Efficiency and Multiplicity test_1

Electronics system based on MICROROC chip



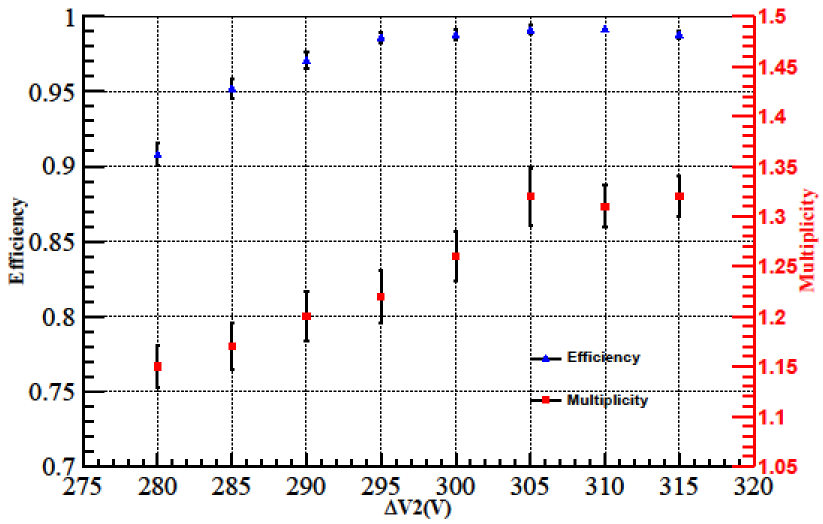


Ar-5%iC_4H_{10}

Working condition:

- △V1: 285 V;
- △V2: 295 V
- Step: 5V
- E_{drift}: 1.45 kV/cm;
- E_{trans}: 2.95 kV/cm ;
- E_{ind}: 3 kV/cm

Detection efficiency and multiplicity vs voltage

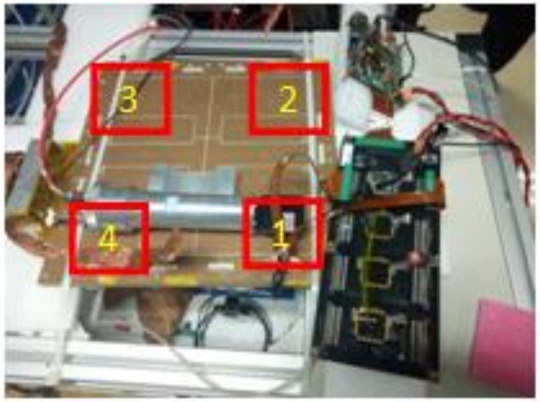


Detection Efficiency and Multiplicity test_2

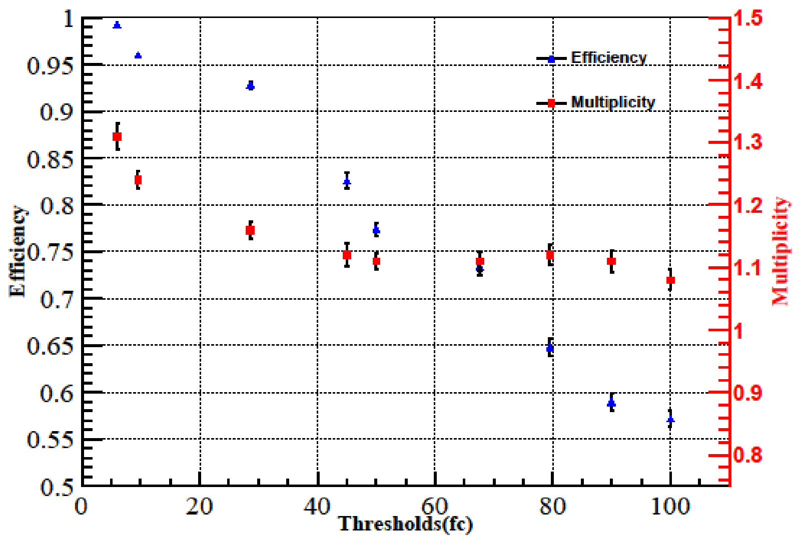
$Ar\text{-}5\%iC_4H_{10}$

Working condition:

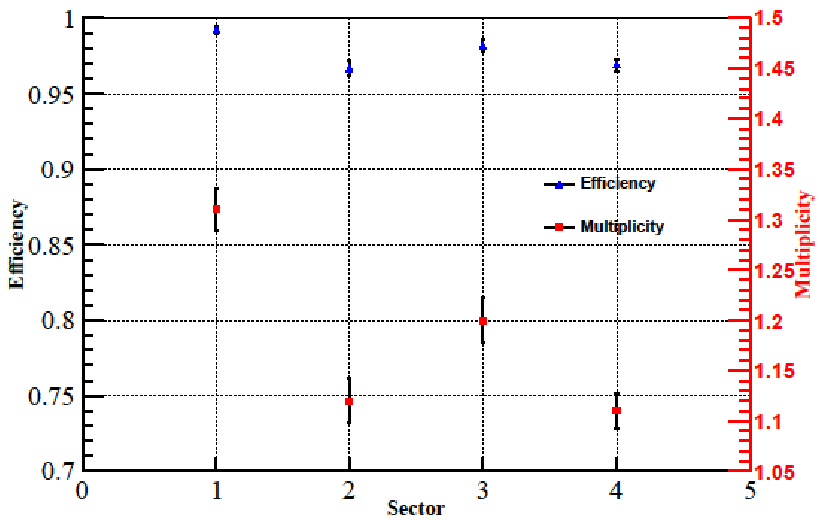
- △V1: 285 V;
- △V2: 295 V
- E_{drift}: 1.45 kV/cm;
- E_{trans}: 2.95 kV/cm ;
- E_{ind}: 3 kV/cm



Detection efficiency and multiplicity vary with thresholds

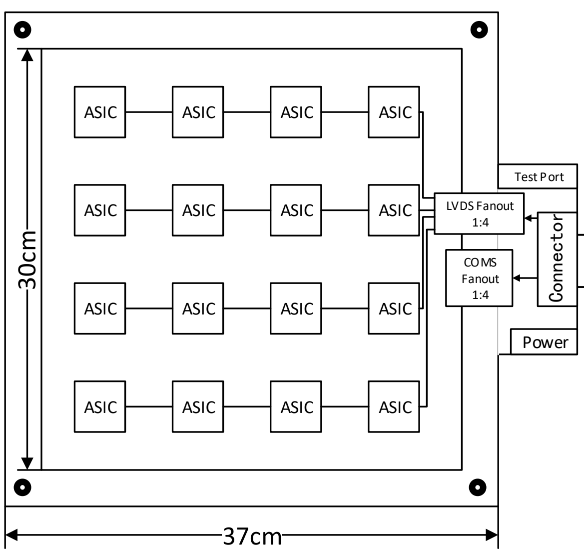


Detection efficiency and multiplicity in different areas

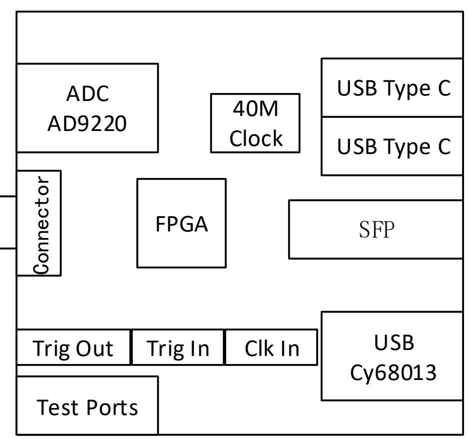


Next Step

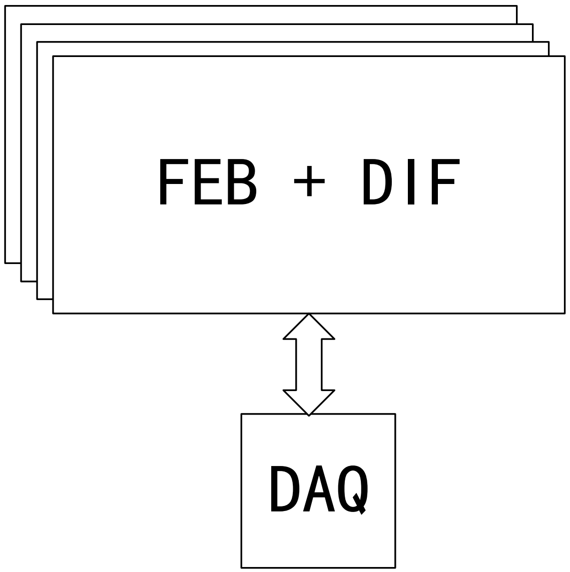
- Integration of ASIC and detector
  - FEB： Buried & Blind via technology
    - Each FEB is controlled by a DIF board
  - DIF： Connect FEB via flexibility board
    - Several DIF board are readout by one DAQ board



FEB

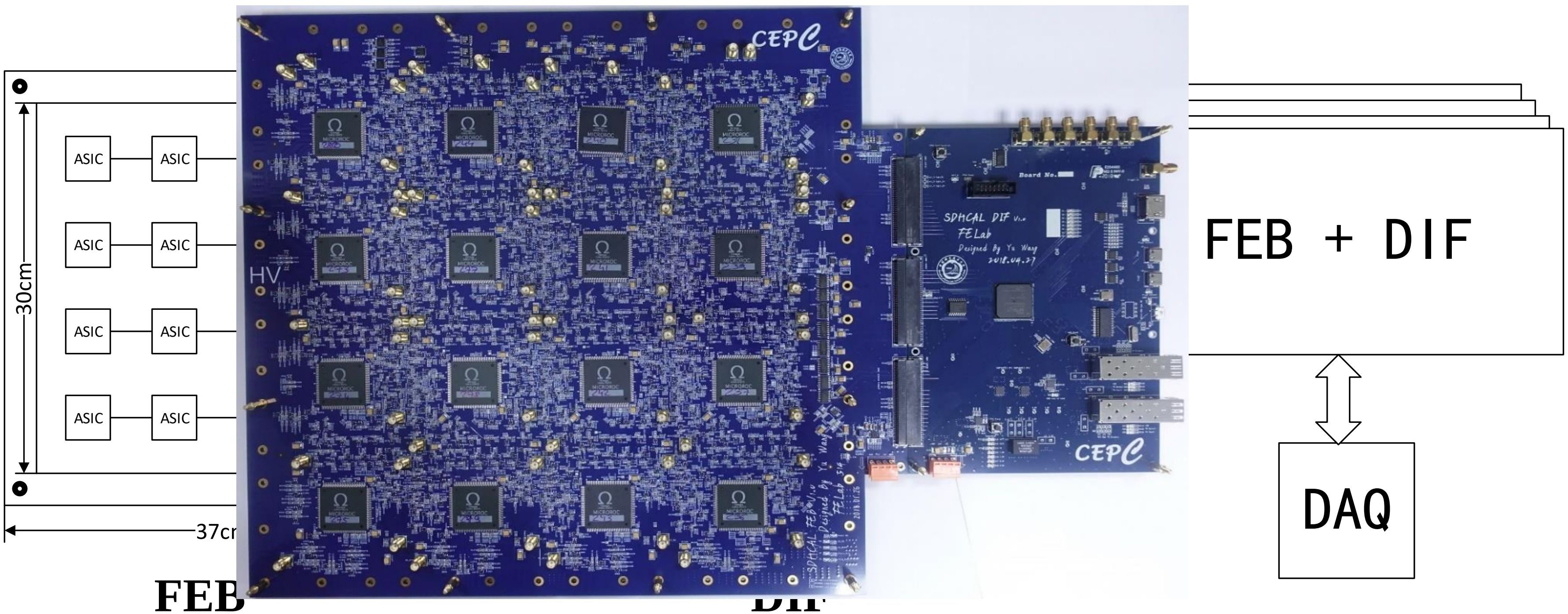


DIF



Next Step (combined test)

- Integration of ASIC and detector
  - FEB: Buried & Blind via technology
    - Each FEB is controlled by a DIF board
  - DIF: Connect FEB via flexibility board
    - Several DIF board are readout by one DAQ board



Summary and Future Plans

- More study of RPC-SDHCAL will be done;
- Based on study status, THGEM&GEM will be merged to resistive THGEM detector
- Integrate ASIC readout with THGEM detector;
- Design and test 50cm×100cm THGEM detector.

Thanks for your attention!

Published Papers (Notes)

(1) 基于波形采样的 **CEPC** 电磁量能器读出单元测试系统. 李明慧，牛萍娟，董明义，赵航，胡 鹏，于丽媛，胡 涛，王志刚. 核技术，2018,41(1).

(2) Particle Flow Oriented Electromagnetic Calorimeter Optimization for the Circular Electron Positron Collider. H.Zhao,C.Fu,D.Yu,Z.Wang, T.Hu, M.Ruan. Accepted

(3) R&D of the CEPC scintillator-tungsten ECAL. MingYi Dong. JINST. Accepted.

(4) 《薄型较大面积THGEM气体探测器的研制》，核电子学与核探测技术，已经接收;

(5) Studies of the detector cells in hadronic calorimeter based on plastic scintillators，RDTM，正在投稿

(6) Development of a double-GEM detector using the self-stretching technique for digital hadron calorimetry 2018 JINST 13 P01020

(7) Research of the Thin Large-Area THGEM Gas Detector, Xia Li, Yu Boxiang, etc. Nuclear Electronics and Detection Technology, 2017.3

(8) Research of the Detector Cells in Calorimeter Based on Domestic SiPM， Wu Zhe, Xia Dongmei, etc. Nuclear Electronics and Detection Technology, accepted;

(9) Studies of the detector cells in hadronic calorimeter based on plastic scintillators, Wu Zhe, etc. Nuclear Science and Techniques, accepted

(10) CALICE Note CAN-059, under internal review

Conference Talks (Incomplete list)

- An improved self-stretching GEM assembly technique ，刘建北， International Conference on Technology and Instrumentation in Particle Physics in 2017 (TIPP2017)，北京，2017.05.22-05.26，国际会议。
- CEPC 强子量能器GEM方案预研进展，王宇，第七届全国先进气体探测器研讨会，广西，2017.11.11-12，国内会议。
- The progress of the CEPC HCAL, Boxiang Yu, CHEF, Lyon, 2017.10.2-6
- The progress of the CEPC ECAL, Mingyi Dong, CHEF, Lyon, 2017.10.2-6
- "Conceptual design of the CEPC calorimeters" , Haijun Yang, Asian Forum for Accelerators and Detectors, Jan 16-17, 2017
- "Status of CEPC Calorimeter R&D" , Haijun Yang, HKUST-IAS High Energy Physics Conference, Jan 23-26, 2017
- "Recent SDHCAL results from beam test" , Bing Liu, CALICE Collaboration Meeting, LLR, France, March 22-24, 2017
- "BDT Application in SDHCAL" , Haijun Yang, CALICE Collaboration Meeting, U. Tokyo, Japan, Sept. 25-27, 2017
- "Status of semi-digital Hadronic Calorimeter (SDHCAL)" , Haijun Yang, International workshop on Future High Energy Electron Positron Collider, Beijing, Nov. 6-8, 2017
- Status of CEPC Scintillator-tungsten ECAL, Mingyi Dong, HKUST-IAS, Jan. 22-25, 2018
- Status of CEPC HCAL R&D in China, Jianbei Liu, HKUST-IAS, Jan. 22-25, 2018
- "BDT Application in SDHCAL" , Bing Liu, CALICE Collaboration Meeting, U. Mainz, Germany, March 7-9, 2018

Backup!

Backup