Current Status Report about the CEPC Calorimeters

Tao Hu, Jianbei Liu, Haijun Yang
（for the CEPC-Calo Group)

June 6, 2016

电磁量能器研究目标

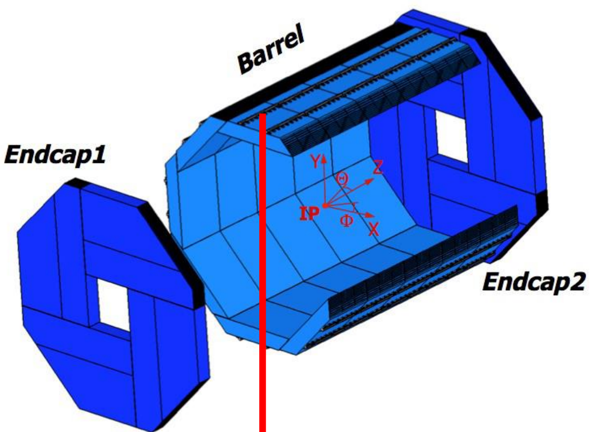
研究目标：

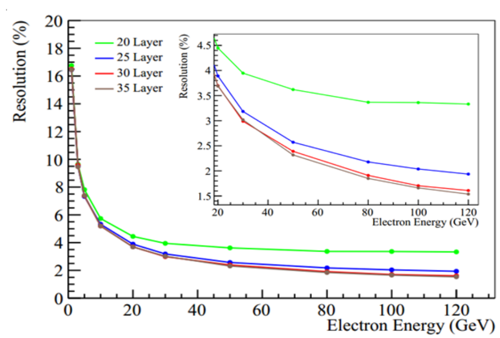
(1)解决基于SiPM读出电磁量能器的技术选型问题；

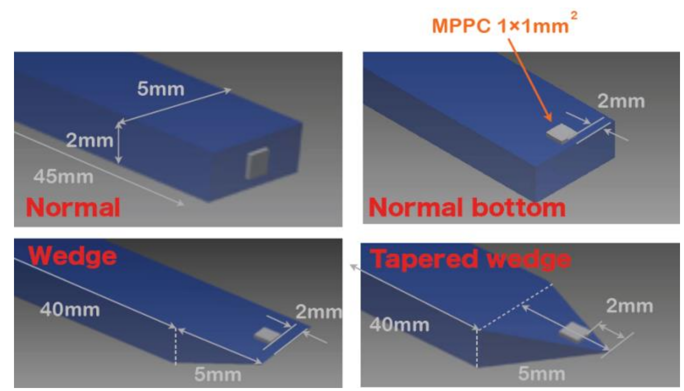
(2)实现电磁量能器读出单元颗粒度达到5×5mm^2；

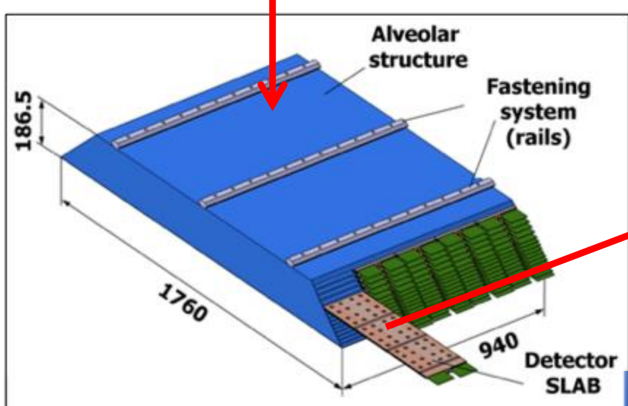
(3)研制小型电磁量能器原理样机；

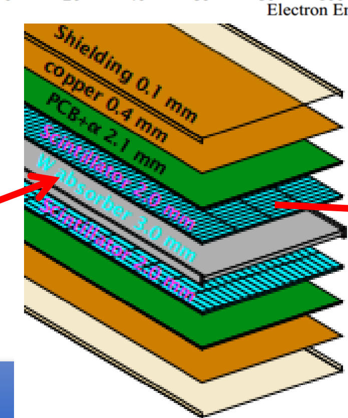
(4)针对CEPC的特点，研制一套基于两相二氧化碳制冷的主动散热系统，在-20^{0}C下，导热量大于30mW/cm^2；

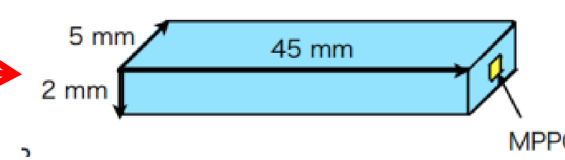












Baseline design of scintillator and SiPM

电磁量能器研究计划（近期）

1. 探测器结构优化设计：针对CEPC电磁量能器进行基本尺寸优化（横截面、层数等），研究不同横截面大小、层数等参数对能量分辨率以及粒子径迹识别的影响，基本确定适用于CEPC对撞能量的PFA电磁量能器尺寸参数。

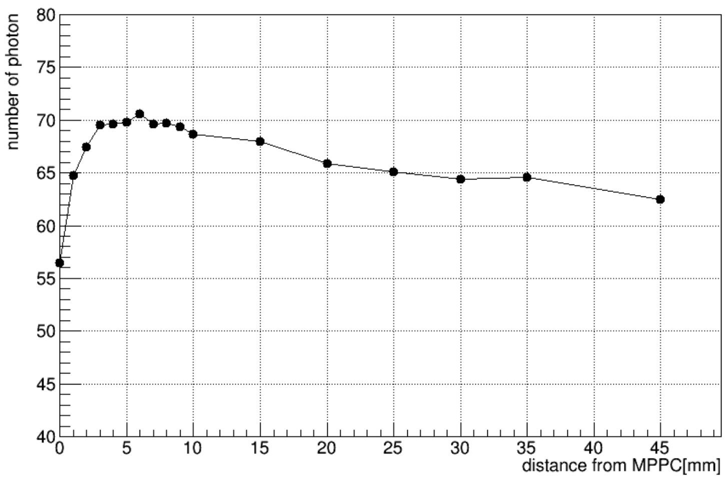
2. 对实验室现有SiPM测试系统进行升级改进，实现SiPM温度效应的电压补偿，进一步提高测试效率。

3. 读出单元结构优化：对读出单元塑闪条不同尺寸下的光输出以及均匀性进行测试；对塑闪条厚度减小到1mm的可行性进行研究；对不同包装方式进行优化选择；对多种规格SiPM进行测试、选型。

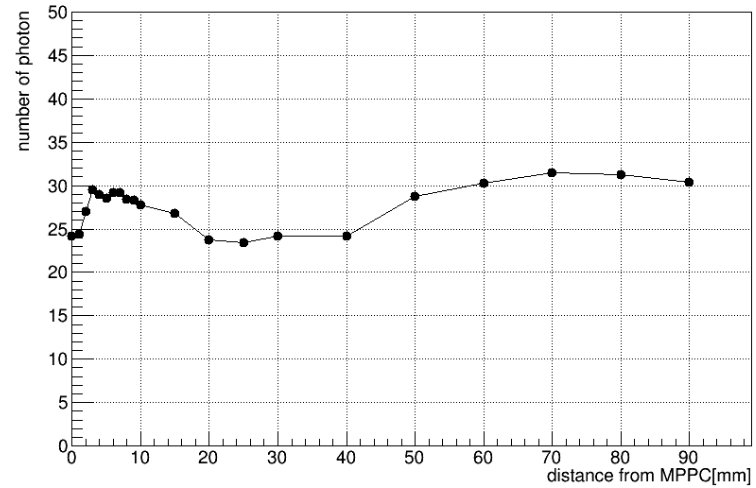
4. 制冷系统初步设计：针对CEPC电磁量能器进行制冷系统参数估算，开始硬件采购与系统搭建。

目前研究现状

5mm*45mm 塑闪条



10mm*90mm 塑闪条



➔ **10mm*90mm 塑闪条 光输出大致是5mm*45mm 塑闪条的一半，基本符合预期（SiPM接收度）。**

➔ **对多种不同材料的反射膜（ESR 、 Tyvek）、反射漆（纳米反射漆、 硫酸钡）进行了对比测试，效果均不如ESR好。制冷系统开始了初步设计与设备调研工作**

电磁量能器研究队伍

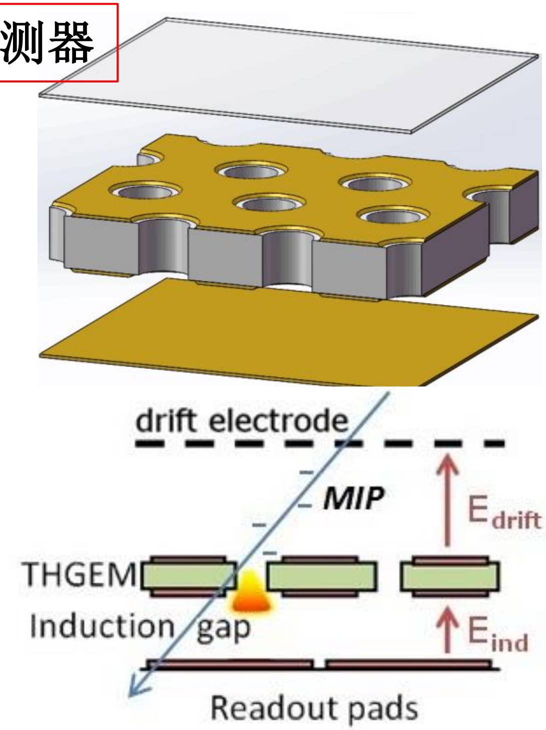
1. 胡涛，　　高能所，研究员，总体负责
2. 王志刚，高能所，副研究员，探测器设计
3. 牛顺利， 高能所，博士后，制冷系统
4. 赵航，　　高能所，博士研究生，软件模拟
5. 科大：刘建北，张云龙 + 研究生

强子量能器研究目标

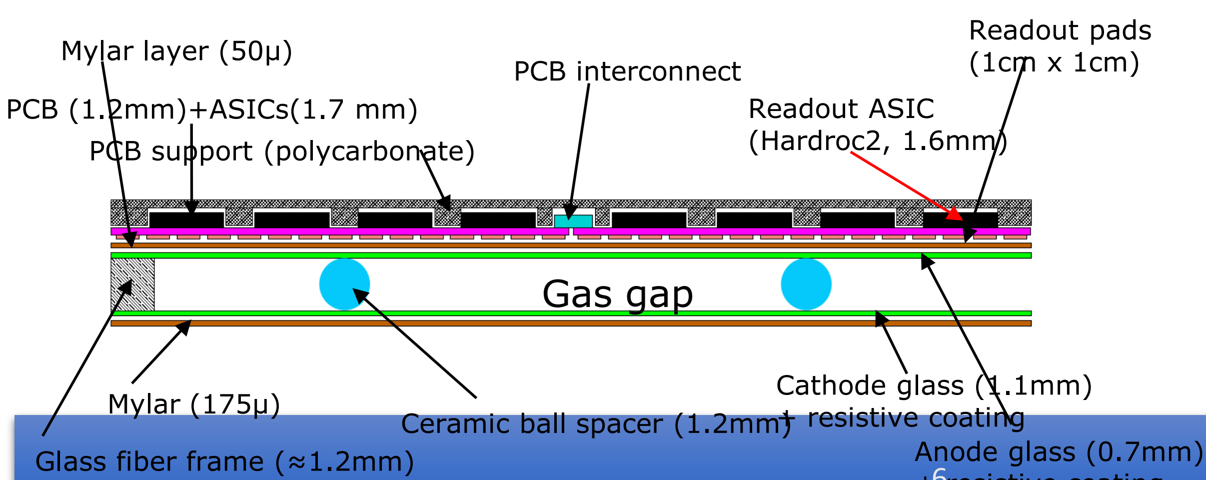
研究目标：

1. 得到数字强子量能器的技术选型；
2. 掌握厚度小于6mm的气体探测器制作工艺；
3. 制作面积达到1m×0.5m的微孔型探测器单元模型，探测器的整体增益均匀性好于20%，计数率达到1MHz/s，探测效率好于95%；
4. 制作面积达1m×1m的平板型探测器单元模型，探测效率好于95%；

微孔型探测器



RPC平板型探测器



HCAL-THGEM

人员情况：

- 俞伯祥（探测器），刘江涛（ASIC电子学），夏莉（联培学生）
- 国科大：刘宏邦，刘倩 + 学生

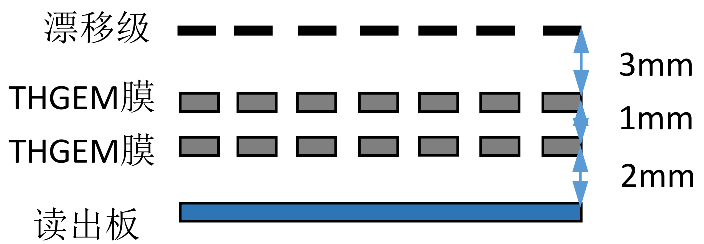
研究现状：

目前，有THGEM测量系统一套，现在正在研究5cm×5cm的THGEM探测器的结构改进，THGEM探测器的基本性能研究；

研究计划（近期）：

- 研究16cm×16cm的THGEM的探测器结构优化，减少探测器结构的厚度，争取达到DHCAL要求的6mm厚度；
- 跟厂家讨论大面积THGEM膜的制作工艺，开始大面积探测器的工艺研究；

HCAL-THGEM (current work)

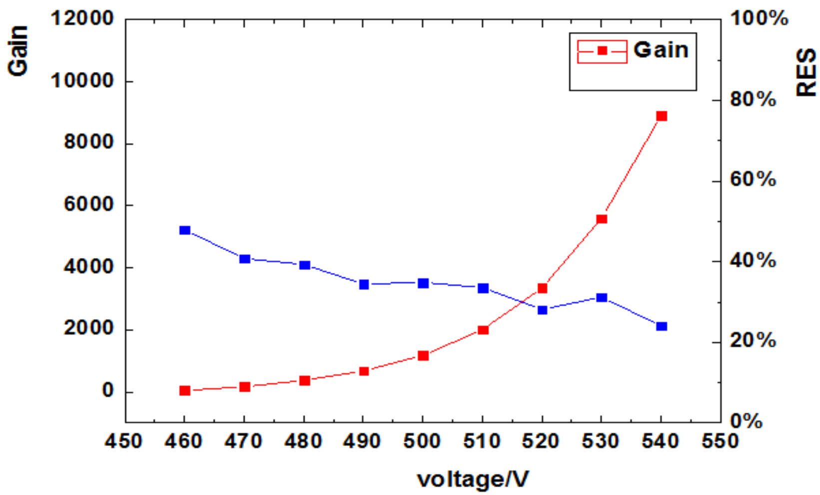


探测器结构（7mm厚）

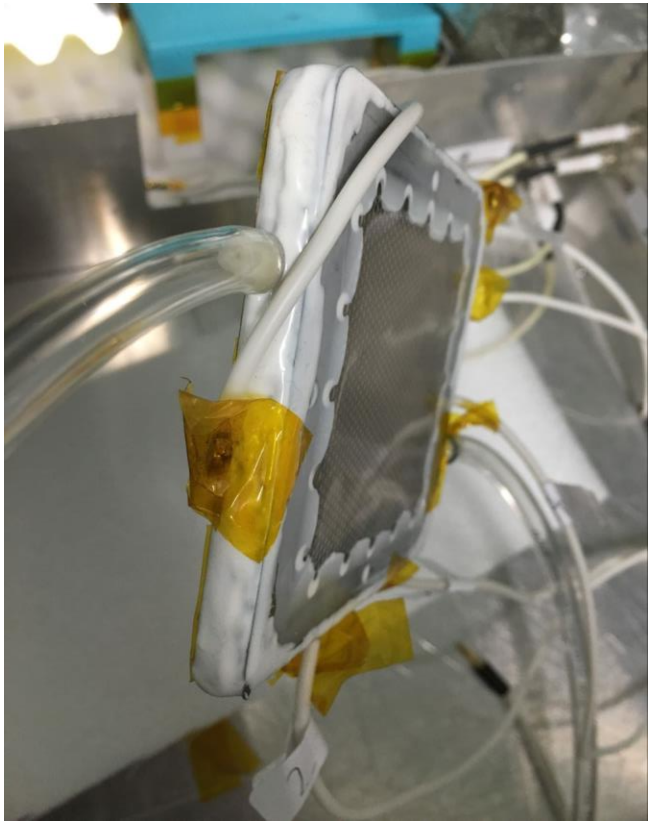
小面积（6cm×6cm）THGEM探测器的结构改造

工作气体：氩气异丁烷（3.00%）

THGEM膜尺寸： 60mm × 60mm × 0.2mm



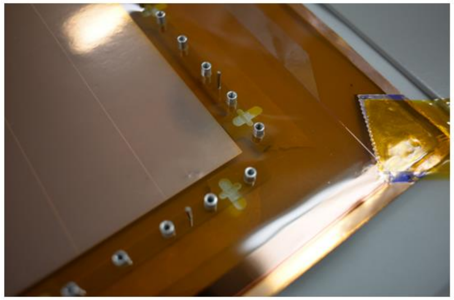
THGEM气体探测器的增益曲线以及能量分辨

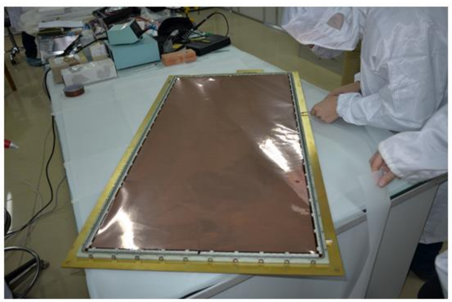


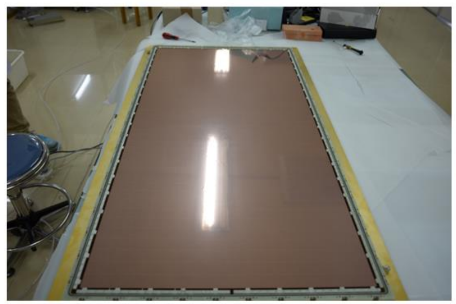
THGEM气体探测器腔室

HCAL-GEM

GEM assembly using a novel self-stretching technique



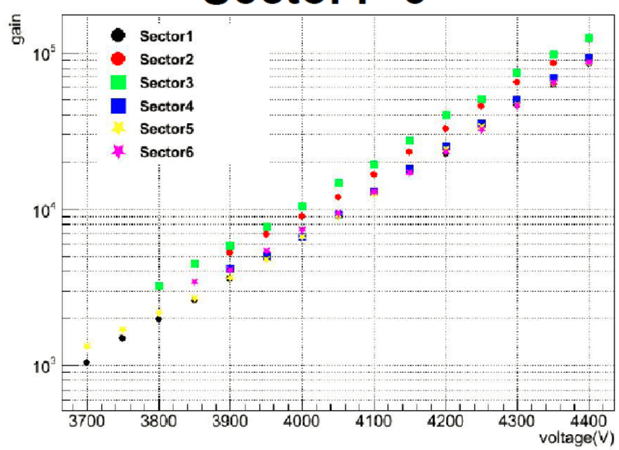




- Large-area GEM (0.5x1m^2) is one of main detector R&D focuses at USTC recently.
- 研究人员：刘建北，李昕 + 学生
- 研究内容：掌握50cm x 100cm 大面积双层GEM的制作工艺，开展性能研究

APV25 GEM readout **INFN APV25 chip**

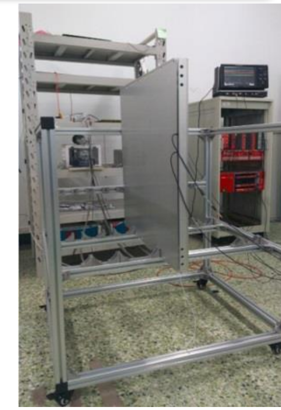
Sector1~6



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

HCAL-RPC

研究队伍：



- 上海交通大学：杨海军，郭军，刘冰，李京
- 北京卫星环境工程研究所：韩然 + 学生
- 西安交通大学：张清民 + 学生

研究现状：

正在开展30cm×100cm的玻璃RPC性能研究

研究计划（近期）：

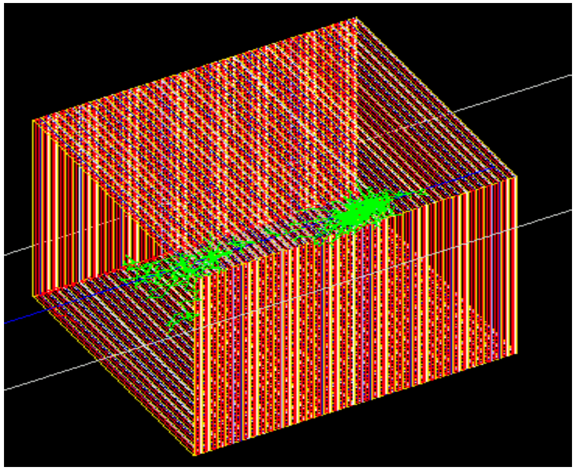
- 与法国IPNL合作开展1m x 2m 大面积紧凑型RPC的制作工艺研究和性能测试。Imad 已经邀请交大博士生刘冰到IPNL访问学习。同时我们也在考虑联合培养博士生项目(2-3年)，开展DHCAL-RPC合作研究，逐步参与和融入CALICE合作组。

Performance Comparison

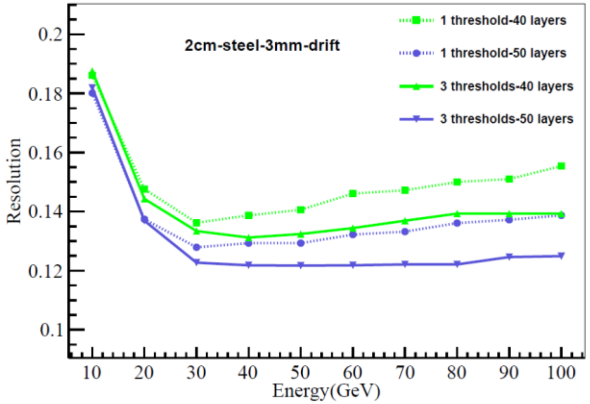
	RPC	THGEM	GEM	CEPC - HCAL
Cost	$	$$	$$	
Gain	~ 10^5	~ 10^4	~ 10^4	
Rate	~ 100 Hz/cm2	~1 MHz/cm2	~1 MHz/cm2	~ Hz/cm2
Noise rate Discharge rate	~ 1 Hz/cm2	~ 1 Hz/cm2 < 1 disch./5’	~ 1 Hz/cm2	
Spatial resolution Pad size (1cmx1cm)	~ 1mm ~ 1cm/√12	~ 0.15mm ~ 1cm/√12	~ 0.1mm ~ 1cm/√12	
Time resolution	~ 1ns	5-7 ns	5-7 ns	
Uniformity	~ 15%	~ 15%-20%	~ 15%-20%	
Multiplicity	~ 1.5 – 1.8	~ 1.1 - 1.2	~ 1.1 - 1.2	
Size (area)	1m x 1m -> 1m x 2m	0.4m x 0.4m- > 0.5m x 1m	0.5m x 1m	
Height	3-4mm	~ 8mm	~ 8mm	
Efficiency (MIP)	>95%	~ 92% - 94.5%	~ 95%	

Detector Optimization

- ECAL/HCAL Simulation & Optimization
  - Number of layers
  - Thickness of Absorber
  - Readout cell size



- Reconstruction software development

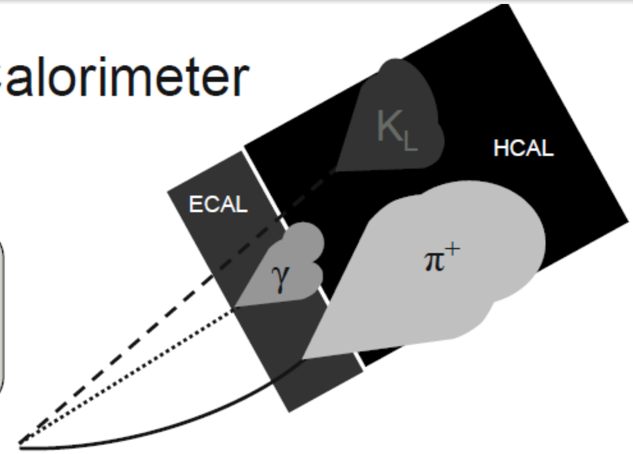


- SJTU recently recruit a senior postdoc Jifeng Hu to work on this topic.

Backup slides

PFA and Imaging Calorimeter

Particle Flow Algorithms and Imaging Calorimeter



The idea…

Charged particles } measured with the { **Tracker**

Neutral particles } measured with the { **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		$\leq 0.24^2\ E_{jet}$

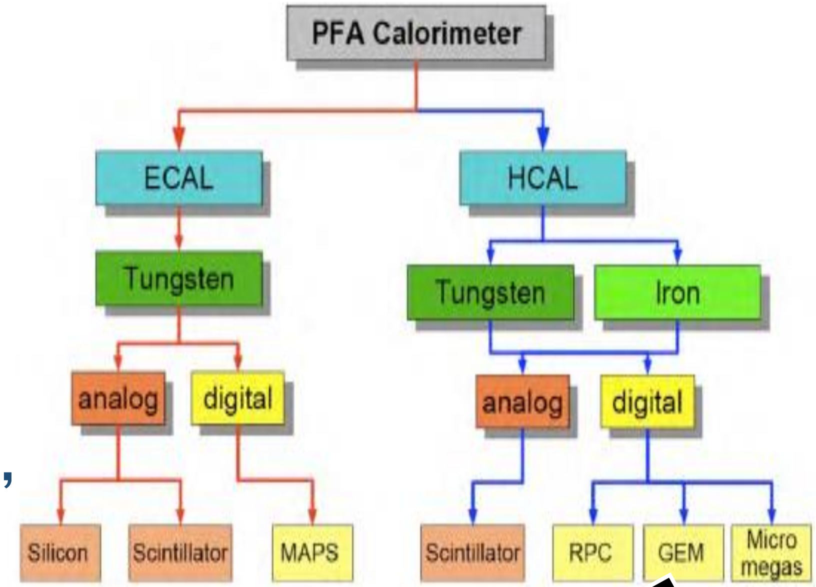
(Charged, Photons, Neutral Hadrons: } 18%/√E)

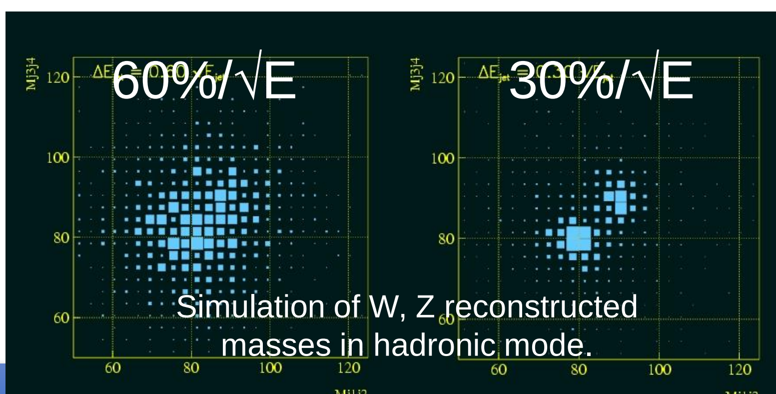
Requirements for detector system

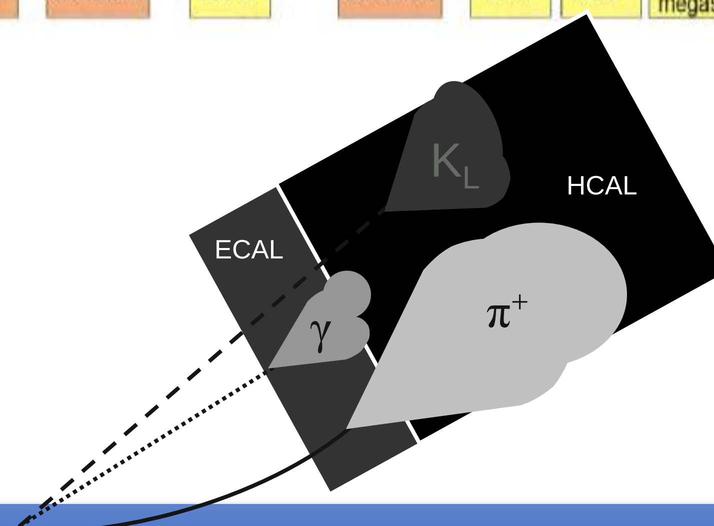
→ Need excellent tracker and high B – field
→ Large R_l of calorimeter
→ Calorimeter inside coil
→ Calorimeter as dense as possible (short X_0, λ_I)
} **thin active medium**
→ Calorimeter with **extremely fine segmentation**

量能器关键技术研究

- 成像式量能器是伴随着粒子流重建方法（PFA）的发展应运而生的新型粒子探测器，具有高位置分辨，高能量分辨等技术优势，成为下一代高能粒子量能器的主要发展方向。
- PFA通过全面综合探测器各子系统测量到粒子的能量、动量、径迹位置等信息对带电粒子，光子和中性强子进行测量和区分，显著提高粒子的能量分辨。PFA要求量能器具有非常高的颗粒度和读出电子学通道，这在实验技术上是一个巨大的挑战。





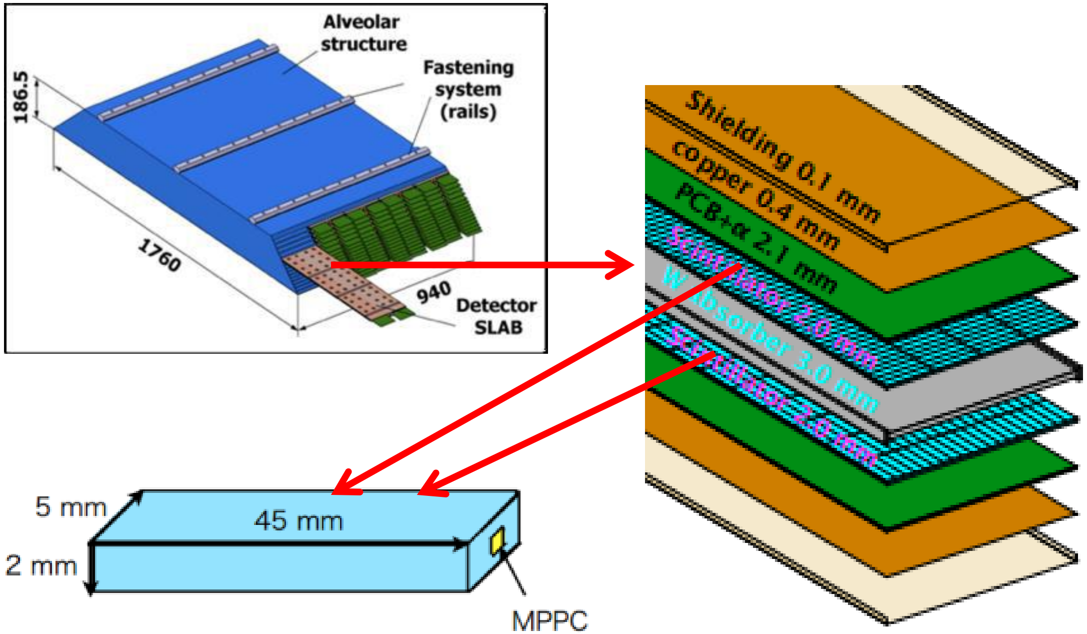


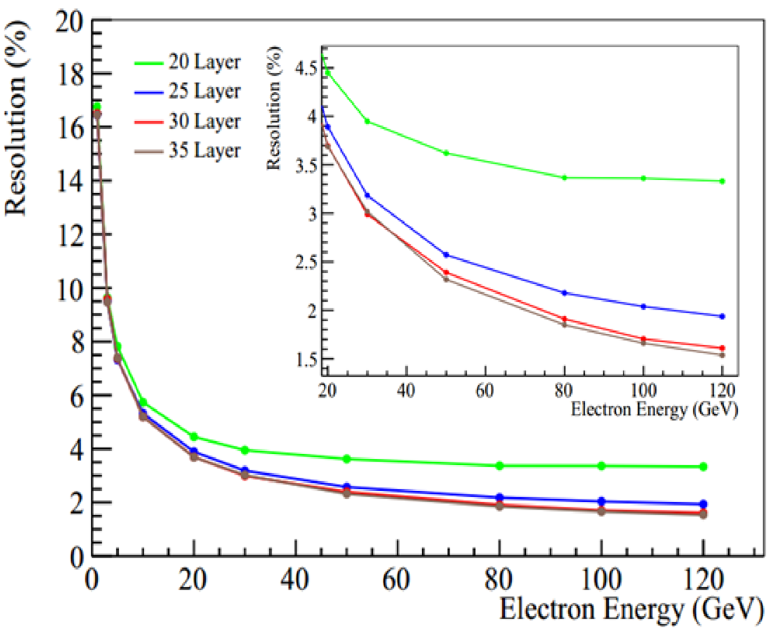
CEPC ECAL: ScW Simulation

Z.G. Wang @ IHEP

Standalone Simulation of ScW ECAL with Geant4 package.

- **Plastic scintillator (2mm)**
- **Tungsten plate as absorber (3mm)**





Scintillator + W + Scintillator

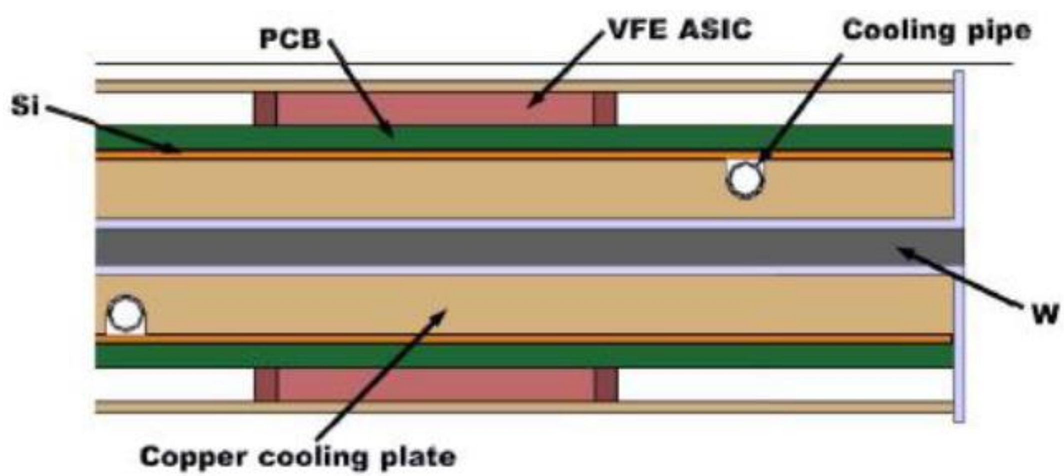
- **The energy resolution of 25GeV electron is about 3.3% (cf. CALICE TB results)**
- **To achieve required energy resolution, the number of layers should be ~ 25.**

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 6×6 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.

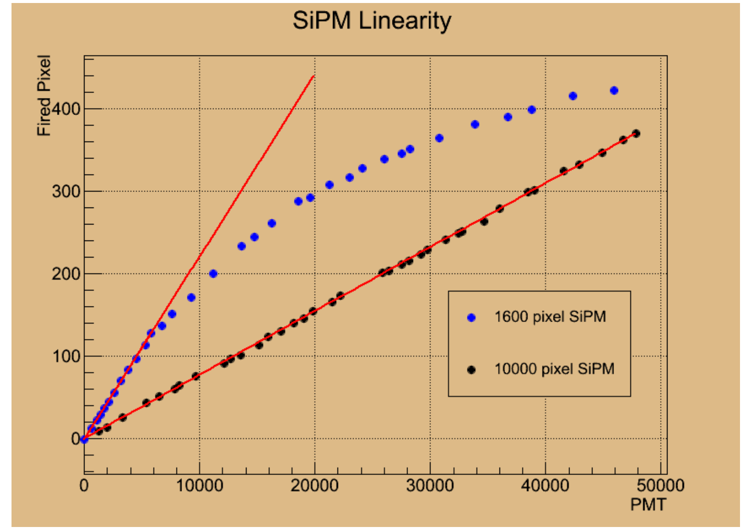


Tests of SiPM at IHEP

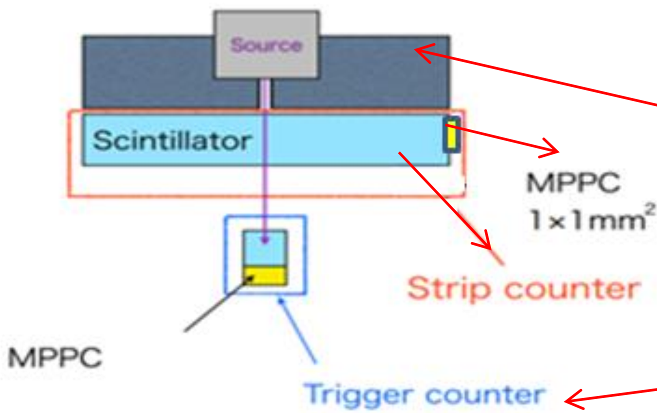
The SiPM dynamic range is determined by the number of pixels.

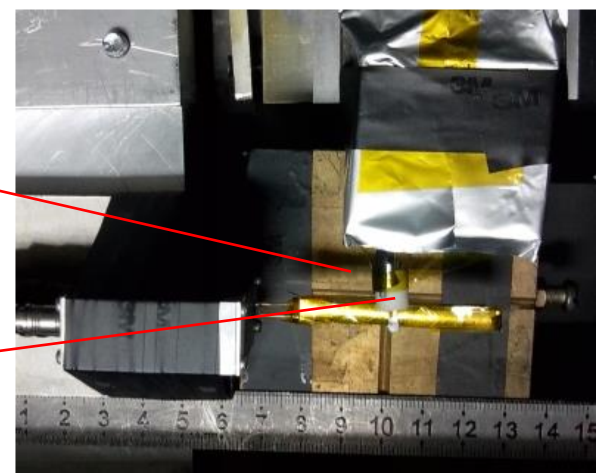
The manufactures have developed the SiPM with 10um pixel which extends the SiPM dynamic range.

But, the photon detection efficiency of 10um SiPM is only 1/3 of 25um SiPM.

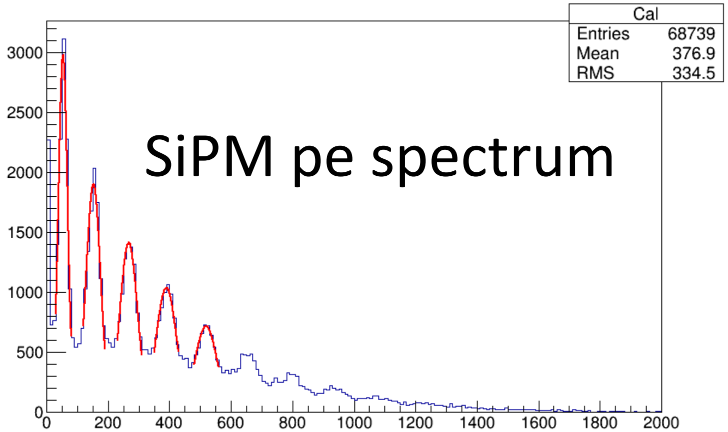


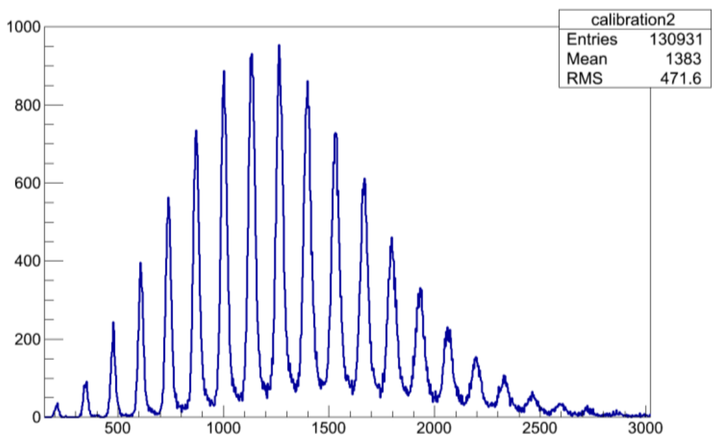
Scintillator strip irradiated with β collimated (1mm) from Sr-90





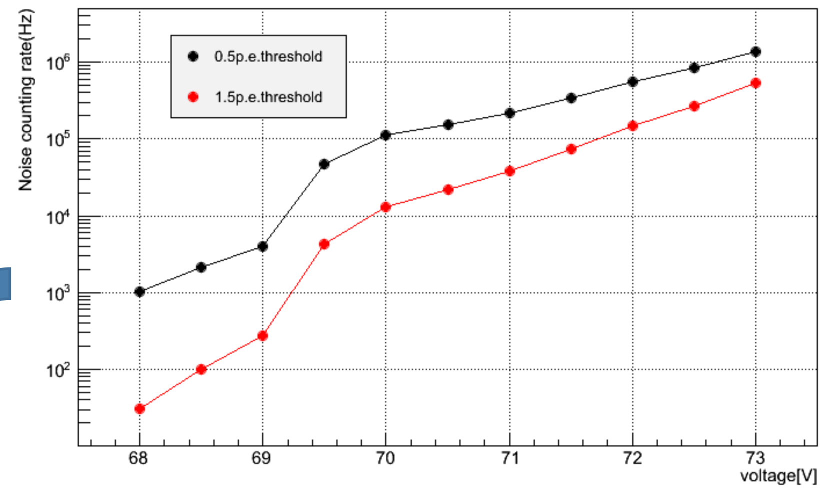
Tests of SiPM at IHEP



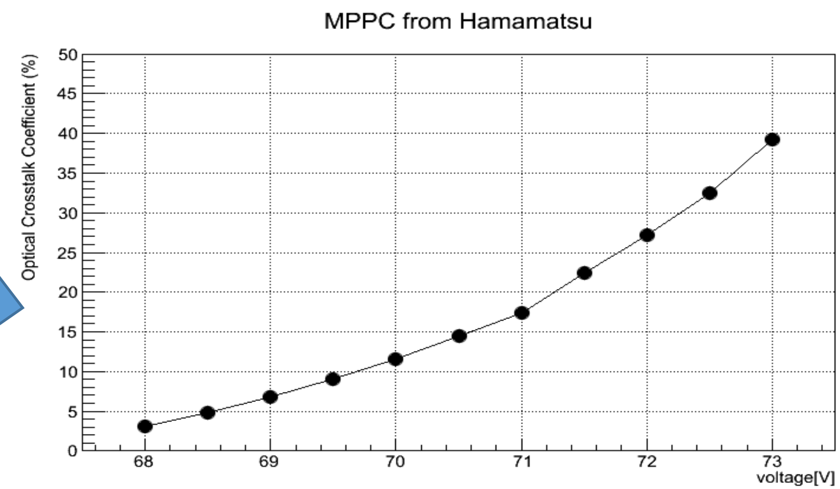


pulse height spectrum.

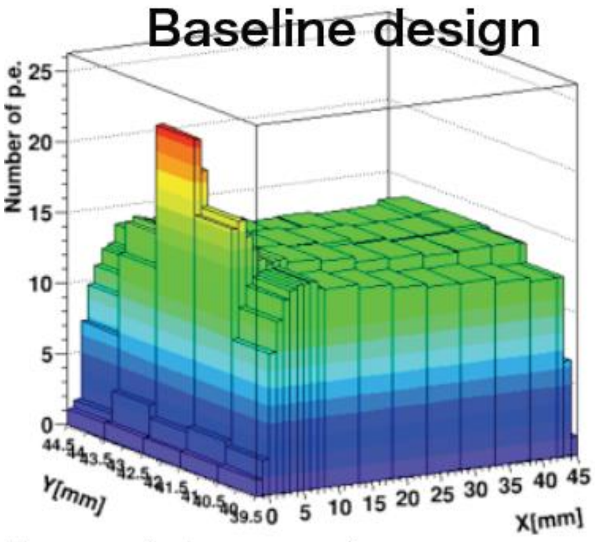
Excellent photon counting

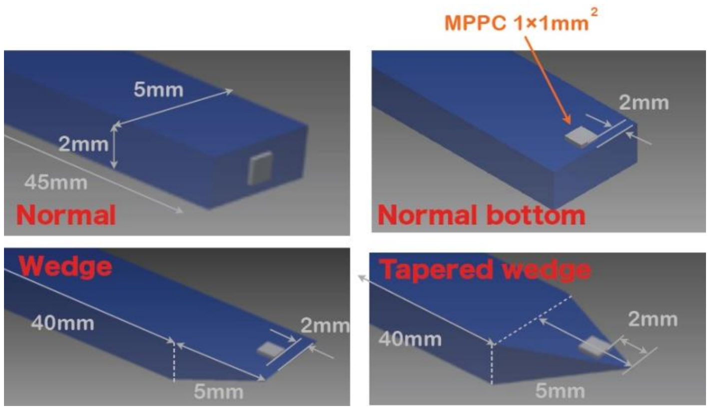


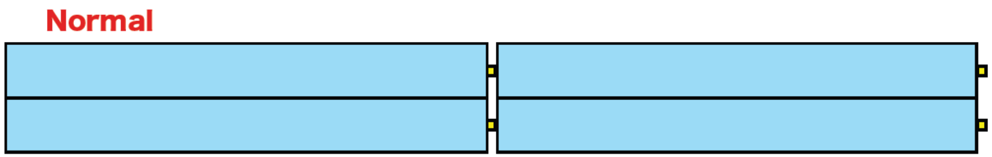
Crosstalk rate = Events (> 1.5p.e)/Events (>0.5p.e)



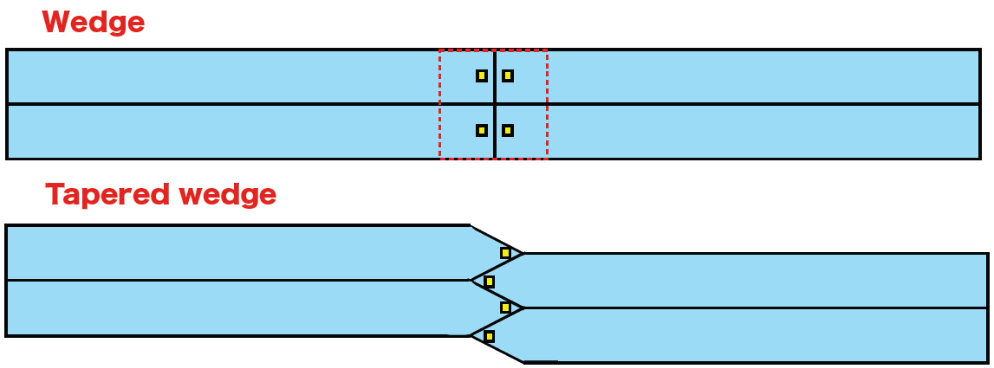
Scintillator Strip Structure Optimization







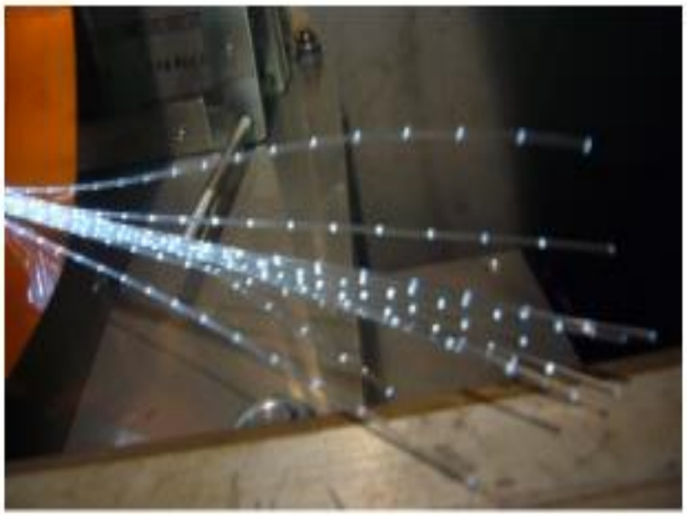
With normal design, the signal is not uniform with peak response for hits near SiPM. What's more, the dead gap between strips is large due to SiPM installation.

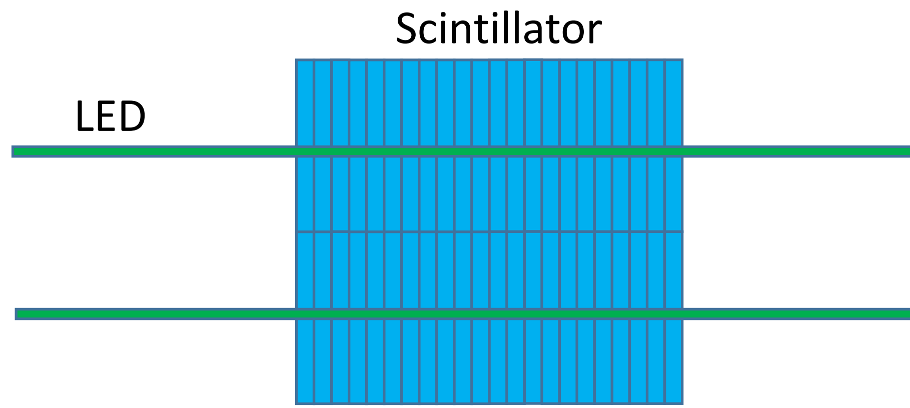


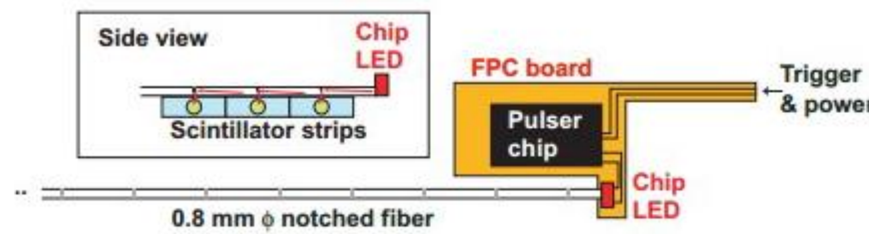
Need MC simulation and experimental tests to optimize the strip structure design.

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.







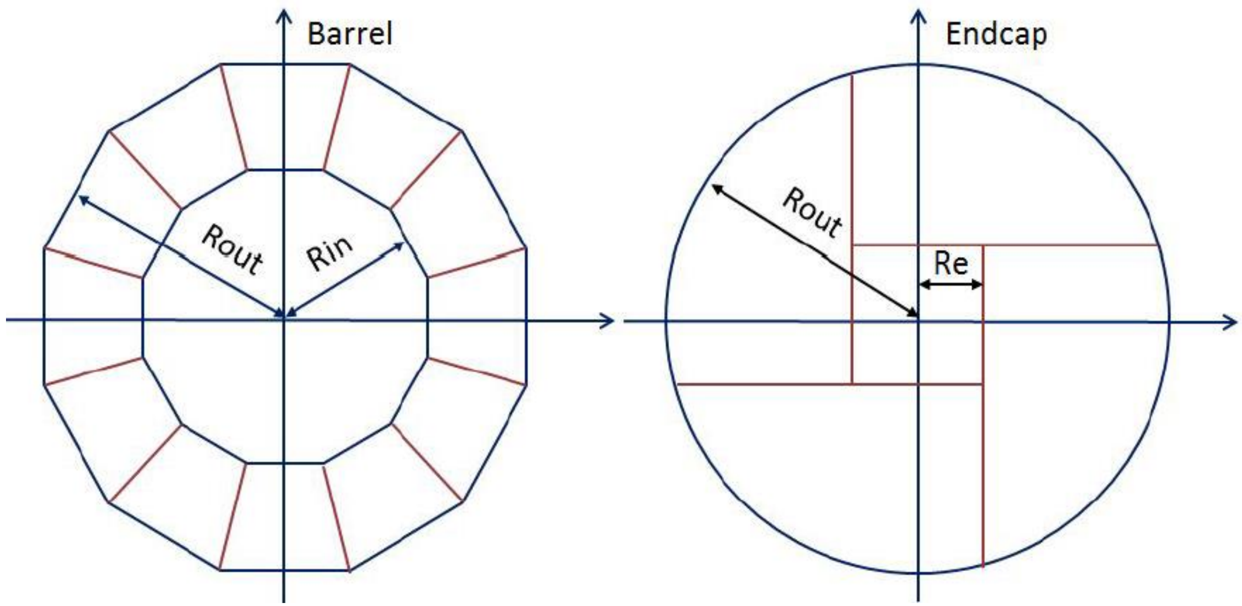
LED – Fiber calibration system:

- A pulse generator, a chip LED connect to notched fibers
- Notched Fiber distribute lights to ~ 80 scintillator strips

Hadron Calorimeter

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

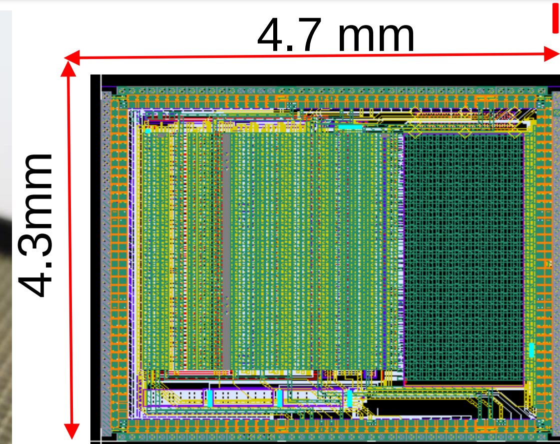
- **Active sensor**
  - Glass RPC
  - Thick GEM or GEM
- **Readout (1×1 cm^2)**
  - Digital (1 threshold)
  - Semi-digital (3 thresholds)



Electronics Readout System R&D

Imad Laktineh (IPNL)

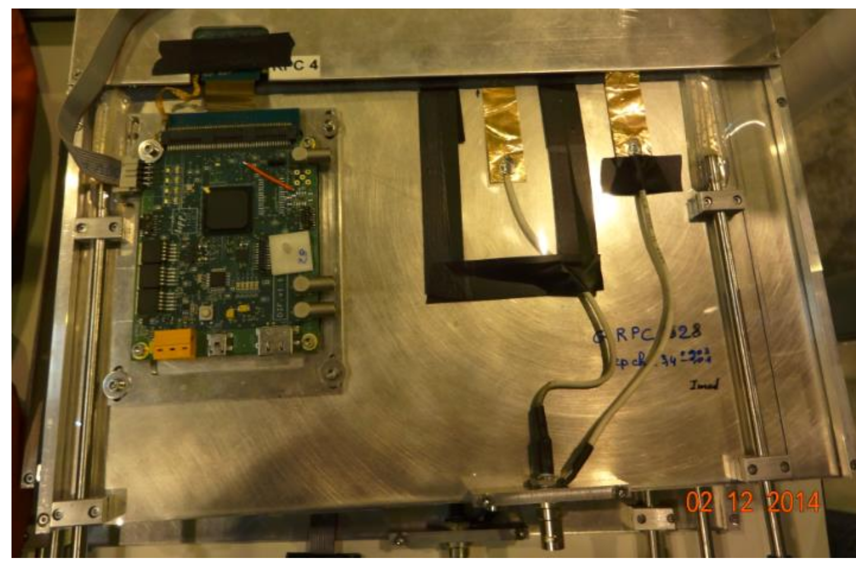
ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity



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. 1×1m^2 has 6 PCBs and 9216 pads.

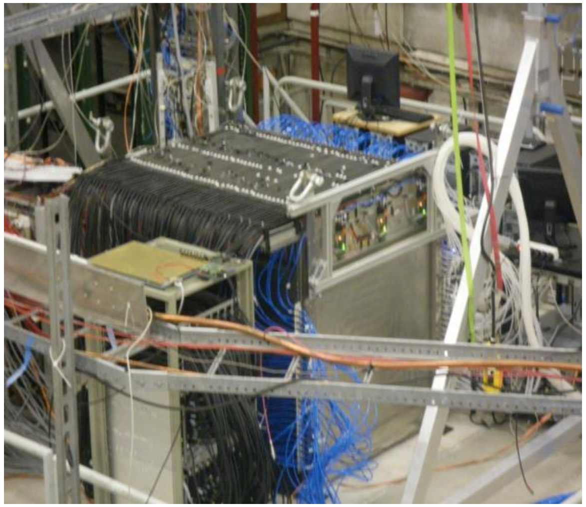
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.

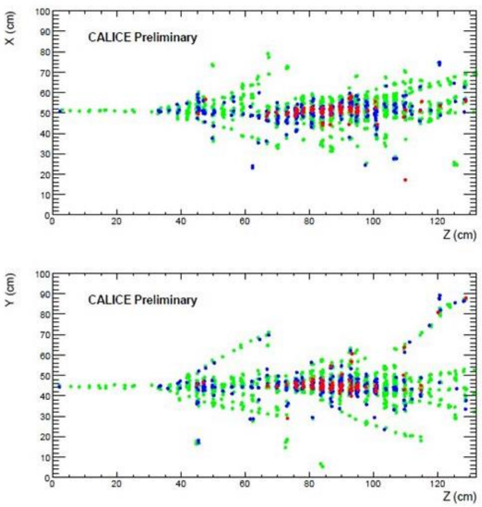


Prototypes of DHCAL with RPC

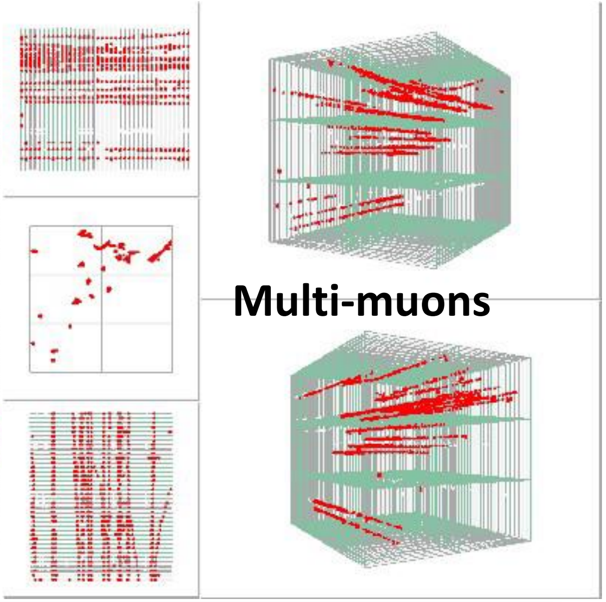
Prototypes of DHCAL based on RPC

- **ANL (J. Repond, L. Xia et.al.)**
  1m^3, 1 threshold, TB at CERN/Fermilab
- **IPNL (I. Laktineh, R. Han et.al.)**
  1m^3, 3 thresholds, TB at CERN in 2014.12



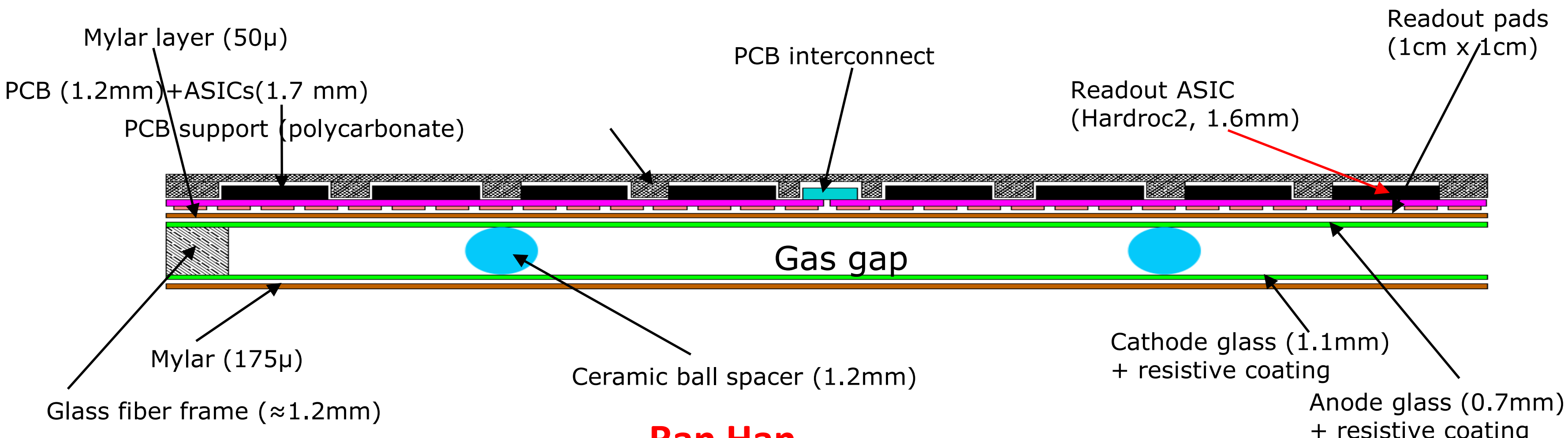


80 GeV Pion

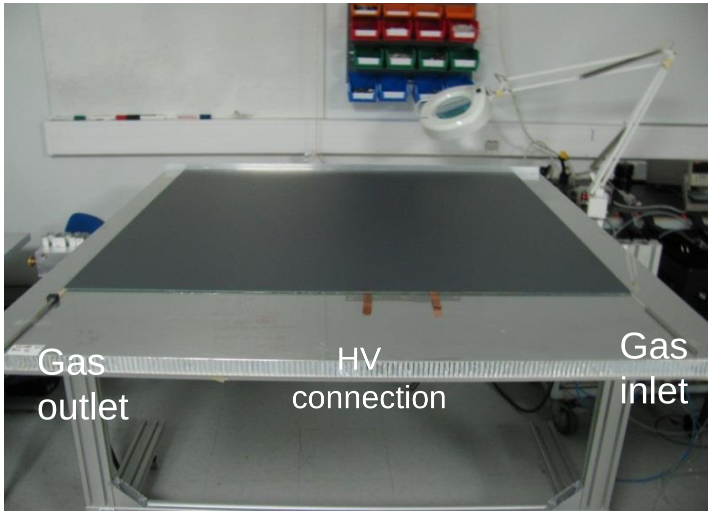


Multi-muons

RPC Construction & Performance Study



Ran Han



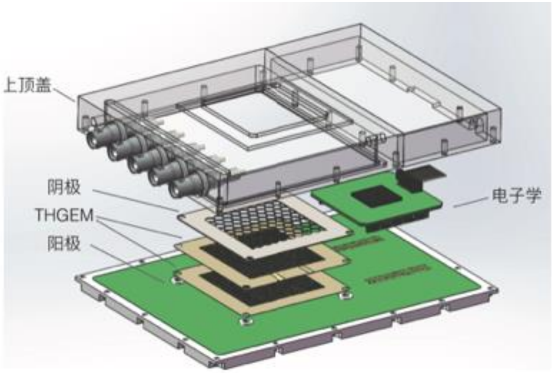
Large GRPC R&D

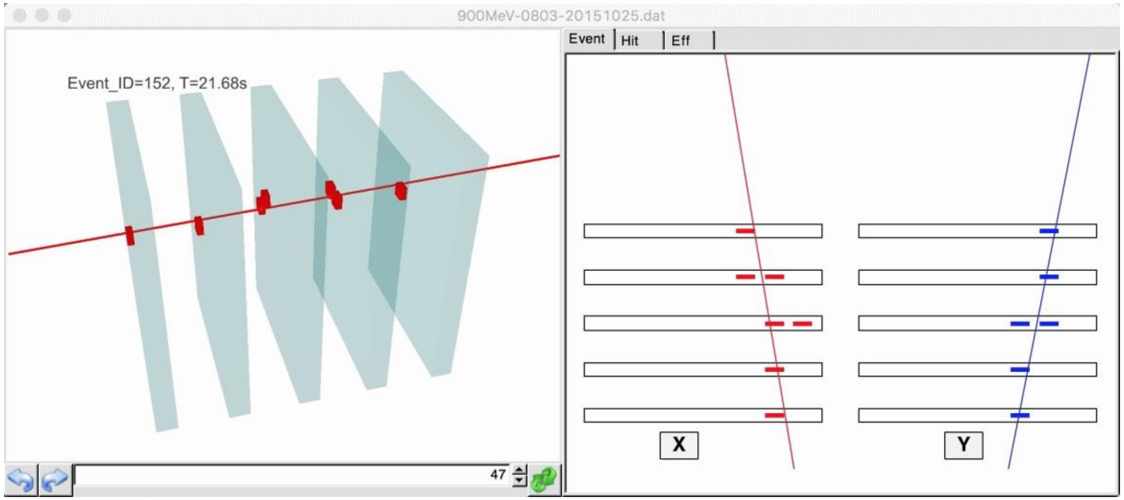
- ✓ Negligible dead zone (tiny ceramic spacers)
- ✓ Large size: 1×1 m^2
- ✓ Cost effective
- ✓ Efficient gas distribution system
- ✓ Homogenous resistive coating

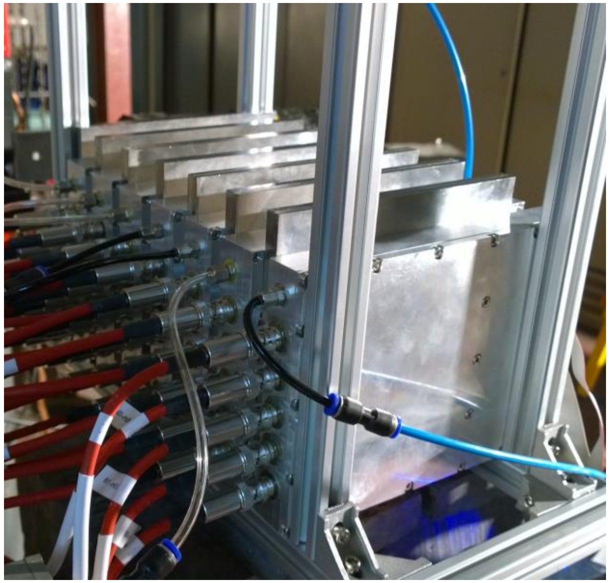
WELL-THGEM Beam Test in Oct., 2015

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 x 5cm sensitive region

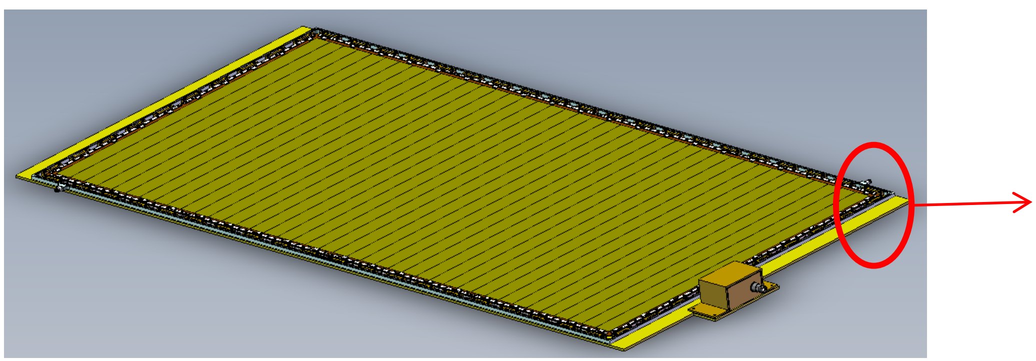


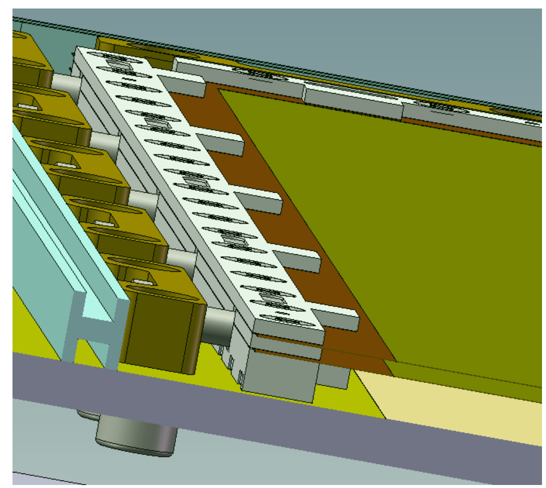




Conceptual Design for DHCAL GEM

- Detector size: 1m*0.5m, limited by GEM foil size
- Double-GEM structure (3mm-1mm-1mm) adopted to minimize the thickness of detectors to accommodate the compactness requirement of DHCAL.
- Double-GEM can still produce reasonable gain under safe operation condition according to our measurements and experience.





Mechanical design already finished !

强子量能器研究内容

- 通过量能器的设计与模拟优化，读出单元结构优化测试，不同灵敏材料性能测试和对比等，开展量能器的技术选型。
- 针对平板型（RPC）和微孔型（THGEM / GEM）两种气体探测器进行性能研究和比较。探测器的设计优化要求量能器的灵敏层尽可能的紧凑，降低量能器的尺寸和造价。通过探测器单元原型的研制掌握大面积紧凑型气体探测器的设计与制作的方法和工艺。大面积探测器有助于减少死区。
- 研制强子量能器单元样机，对量能器的关键技术进行原理验证。通过宇宙射线，束流实验测试单元样机的各项性能指标包括增益、能量分辨、探测效率、多重度、计数率、时间分辨率、空间分辨以及稳定性等。