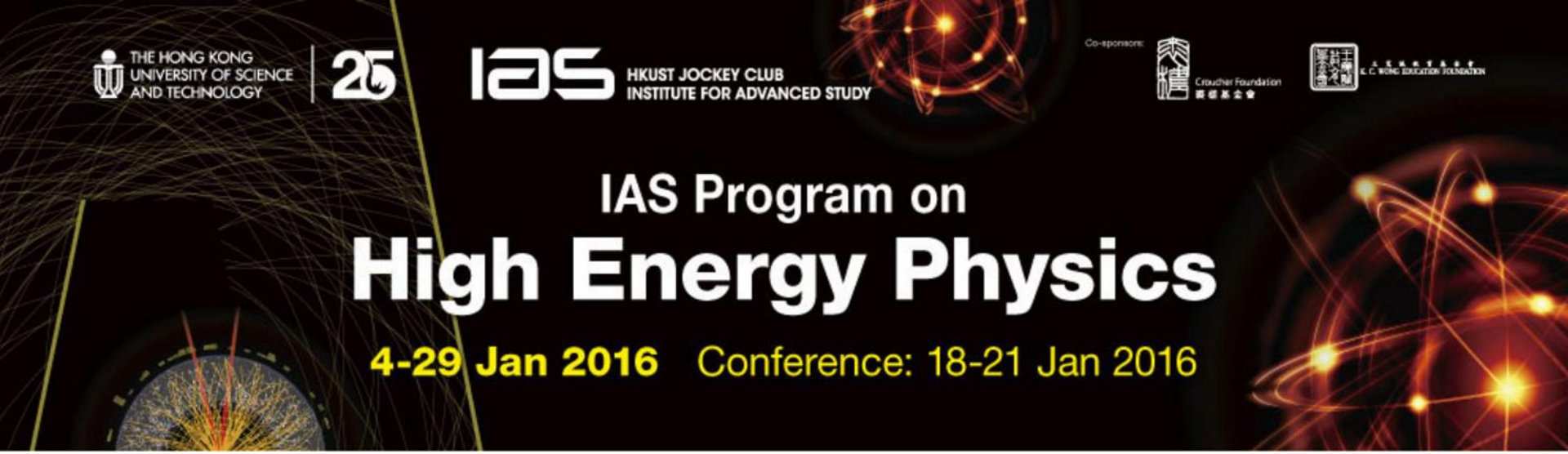


Status Report about the CEPC Calorimeters

Haijun Yang (for CEPC-Calo Group)

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

HKUST-IAS, January 18-21, 2016

Outline

- Motivation and goal
- Calorimeters
  - ECAL with Silicon and Tungsten
  - ECAL with Scintillator and Tungsten
  - HCAL with RPC and Stainless Steel
  - HCAL with ThGEM/GEM and Stainless Steel
- Future plan for CEPC-Calo CDR

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

Requirements for CEPC Detector Design

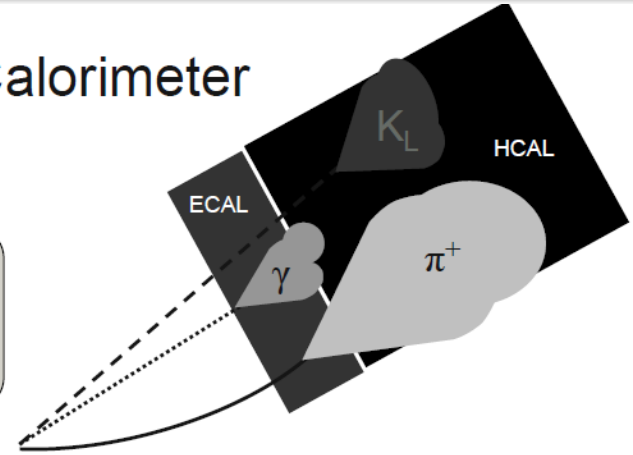
Critical Physics Benchmarks for CEPC Detectors design.

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_{\mathrm{T}}) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_{\mathrm{T}} \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	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	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

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

PFA and Imaging Calorimeter

Particle Flow Algorithms and Imaging Calorimeter



The idea…

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

Neutral particles } 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		$\leq 0.24^2\ E_{jet}$

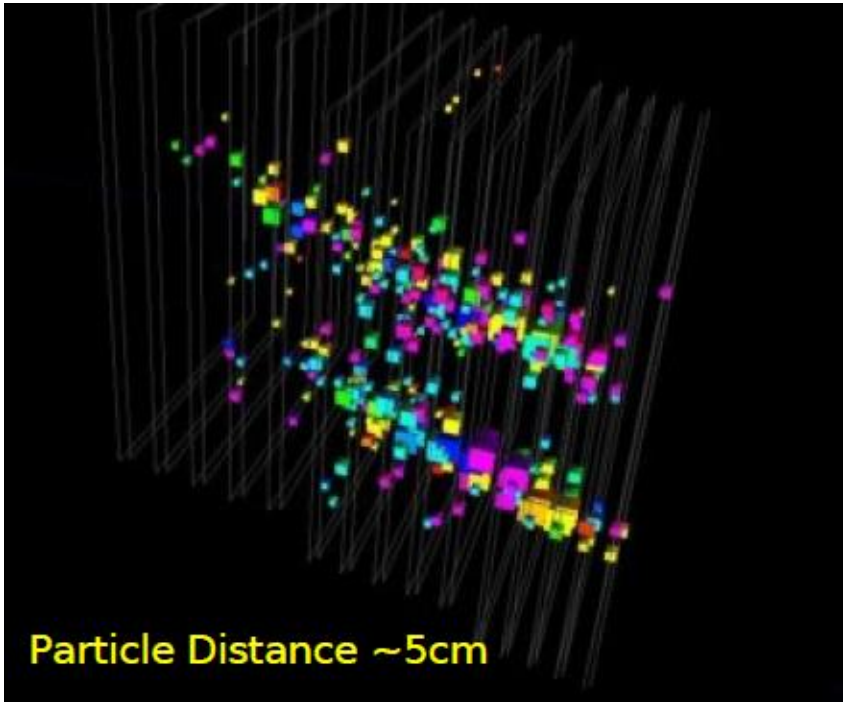
} 18%/√E

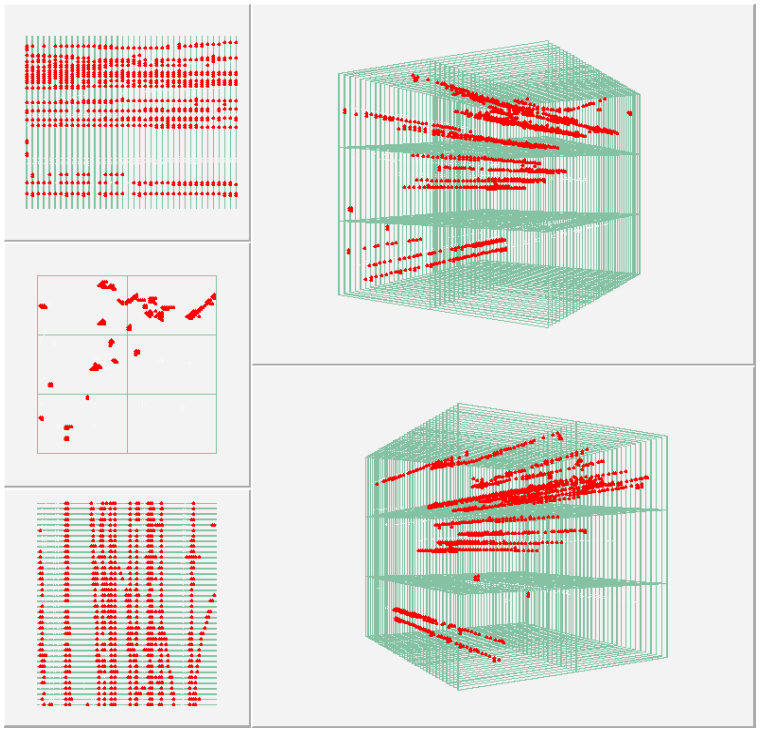
Requirements for detector system

→ 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)
} **thin active medium**
→ Calorimeter with **extremely fine segmentation**

Imaging Calorimeters

L. Xia @ ANL





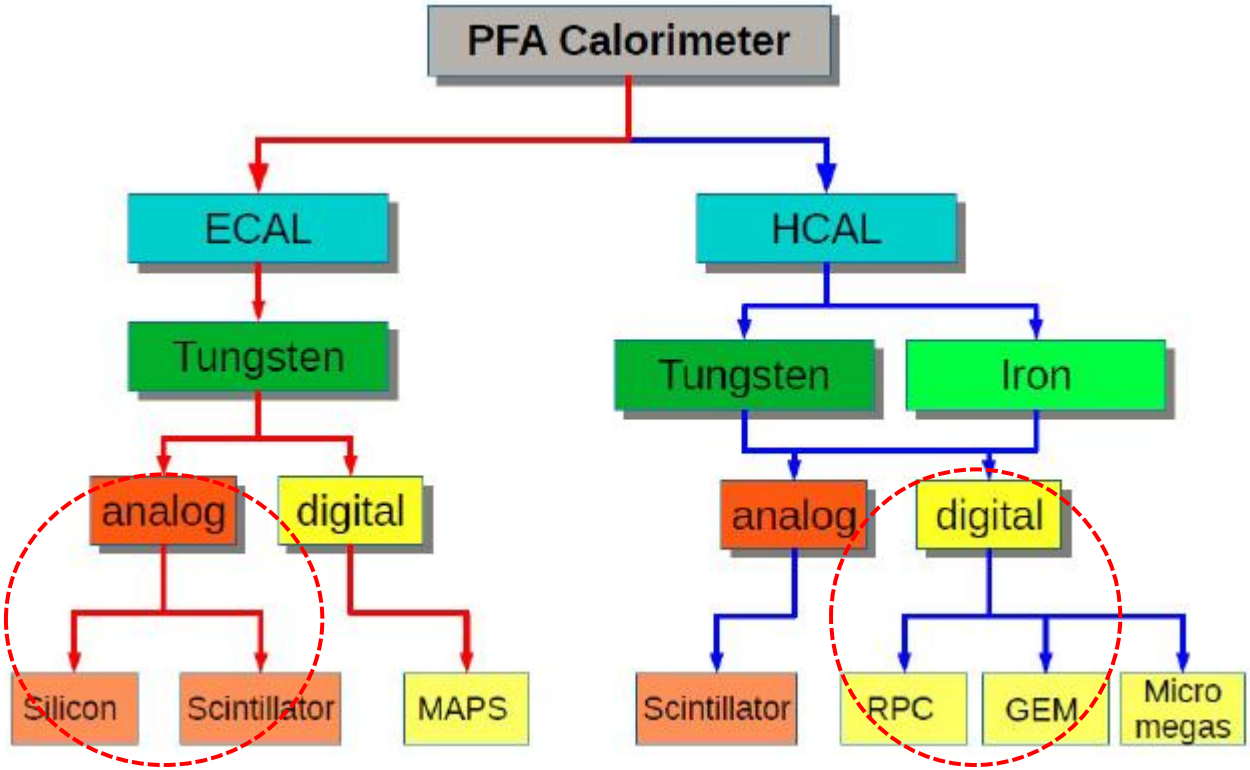
Two electrons ~5cm apart
CALICE SiW ECAL

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

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

Global R&D of Imaging Calorimeters

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



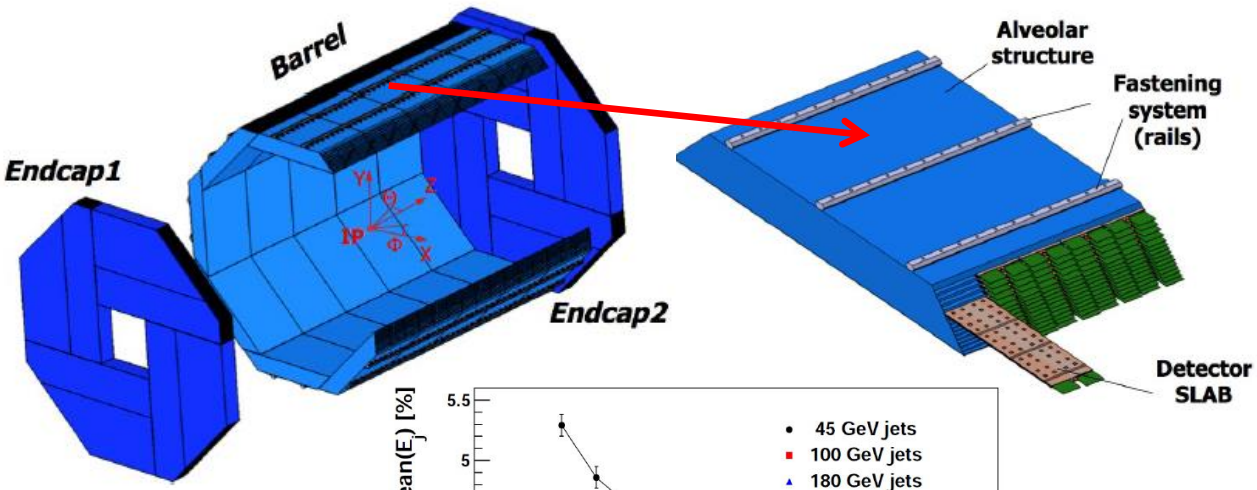
Readout cell size: 144 - 9 cm^2 → 4.5 cm^2 → 1 cm^2 → 0.25 cm^2 → 0.13 cm^2 → 2.5×10^{-5} cm^2

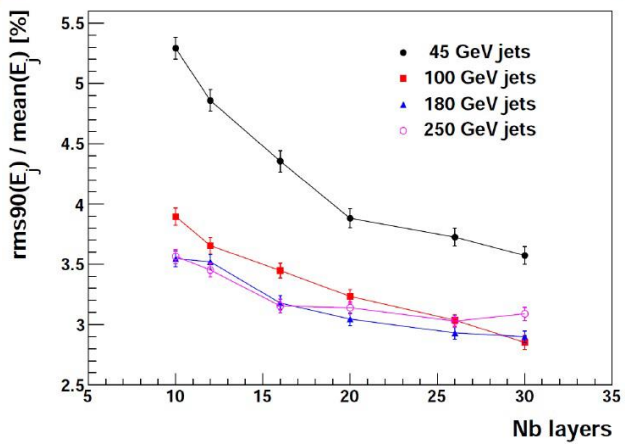
Technology:	Scintillator + SiPM/MPPC	Scintillator + SiPM/MPPC	Gas detectors Silicon	Silicon	Silicon	Silicon (MAPS)

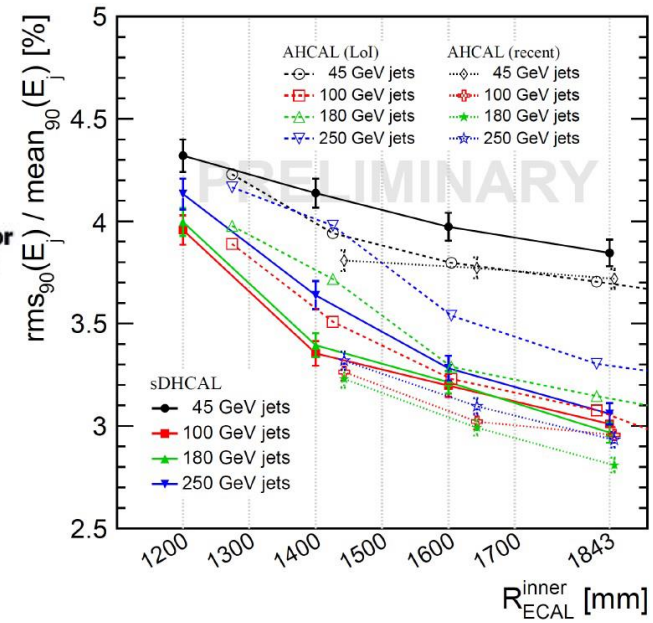
CEPC ECAL: Silicon-W

V. Boudry @ IN2P3

- The ECAL consists of a cylindrical barrel system and two large end caps.
- Two detector active sensors interleaved with tungsten absorber
  - silicon pixel 5 x 5 mm^2; PCB with VFE ASIC





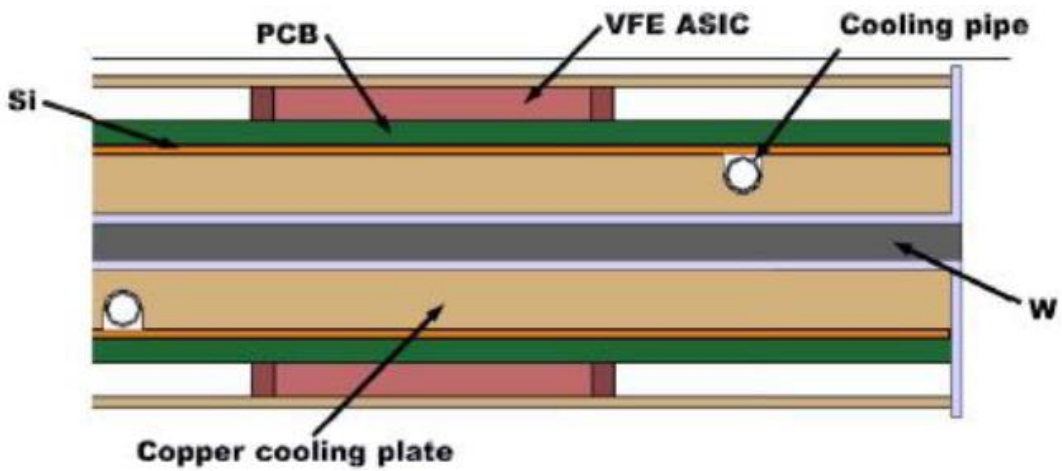


Active Cooling System

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

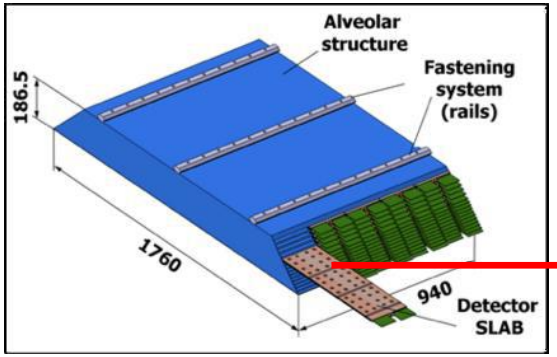


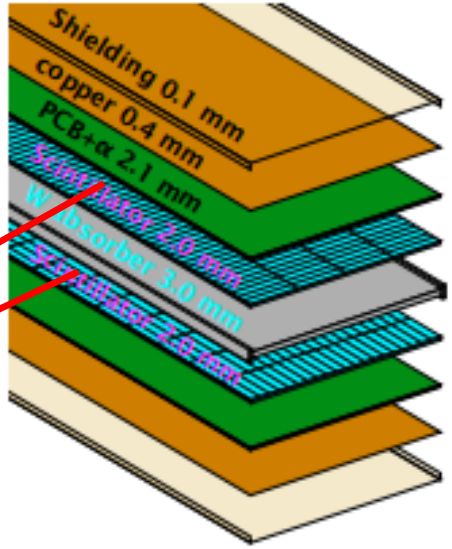
CEPC ECAL: ScW Simulation

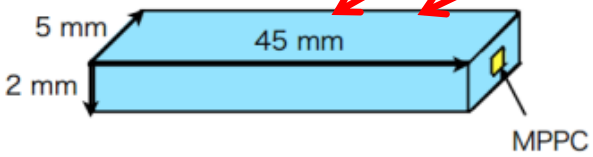
Z.G. Wang @ IHEP

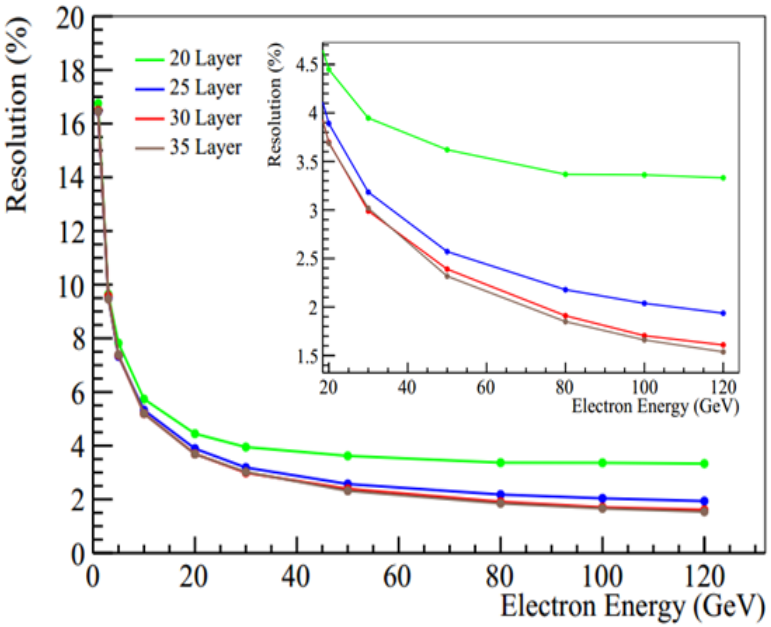
Standalone Simulation of ScW ECAL with Geant4 package.

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









Scintillator + W + Scintillator

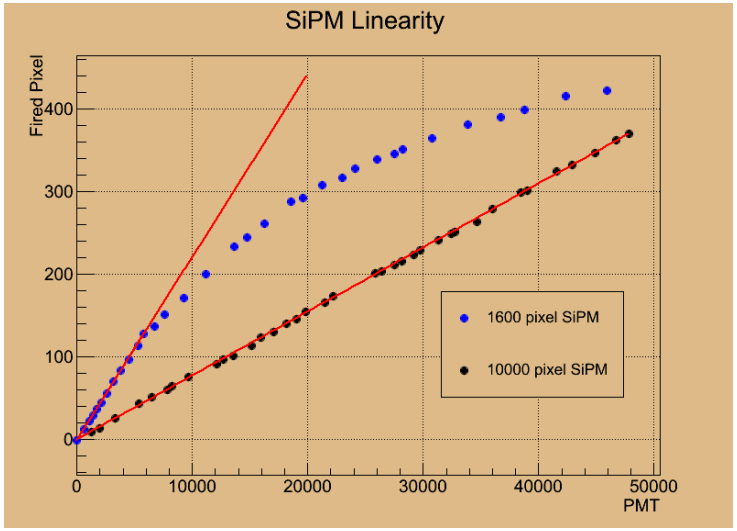
- **The energy resolution of 25GeV electron is about 3.3% (cf. CALICE TB results)**
- **To achieve required energy resolution, the number of layers should be ~ 25.**

Tests of SiPM at IHEP

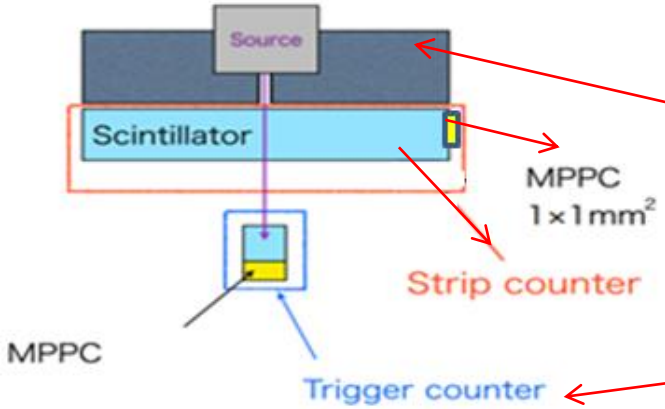
The SiPM dynamic range is determined by the number of pixels.

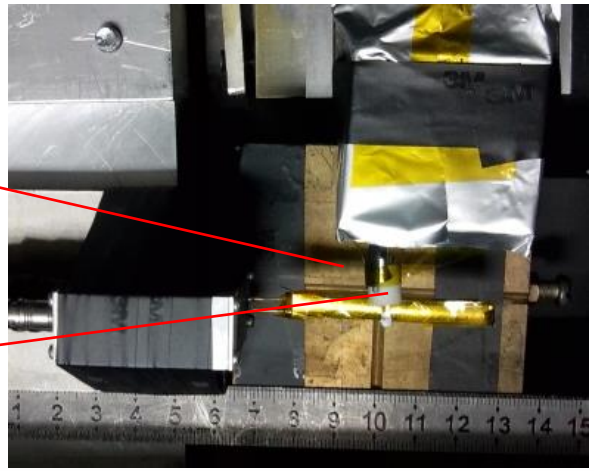
The manufactures have developed the SiPM with 10um pixel which extends the SiPM dynamic range.

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

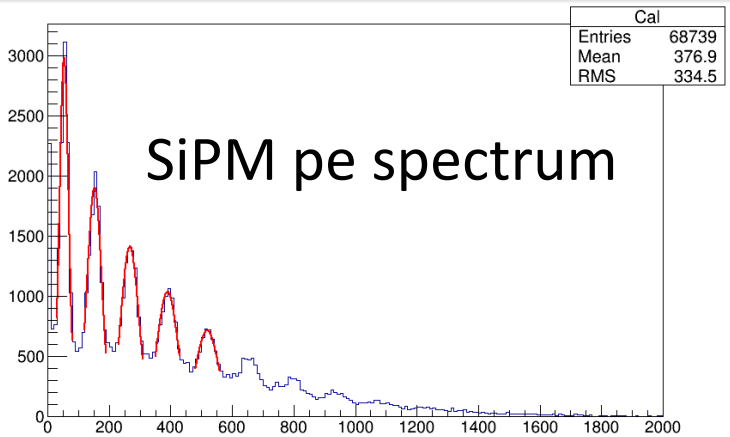


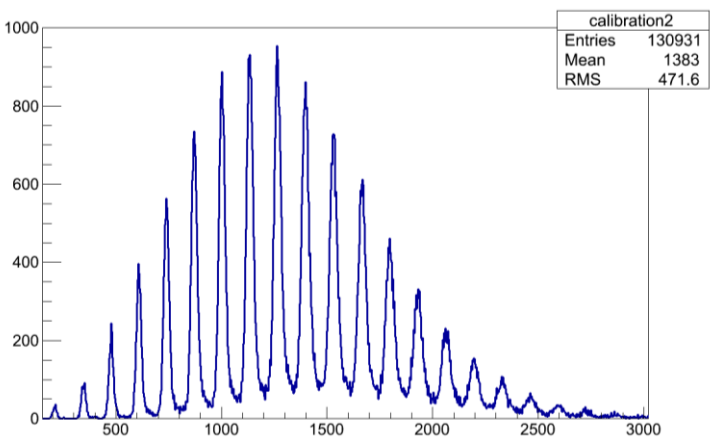
Scintillator strip irradiated with β collimated (1mm) from Sr-90





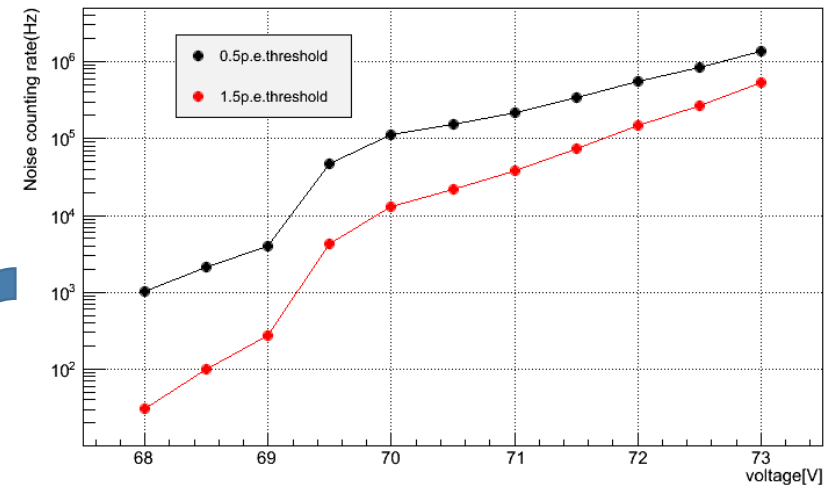
Tests of SiPM at IHEP



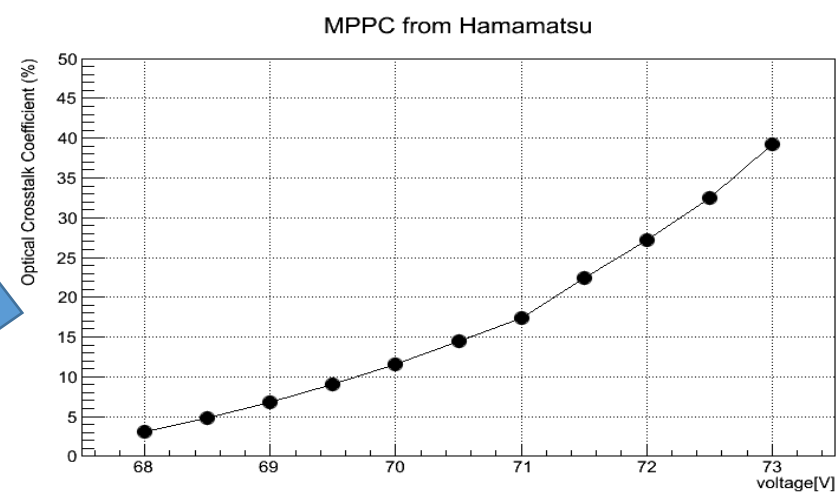


pulse height spectrum.

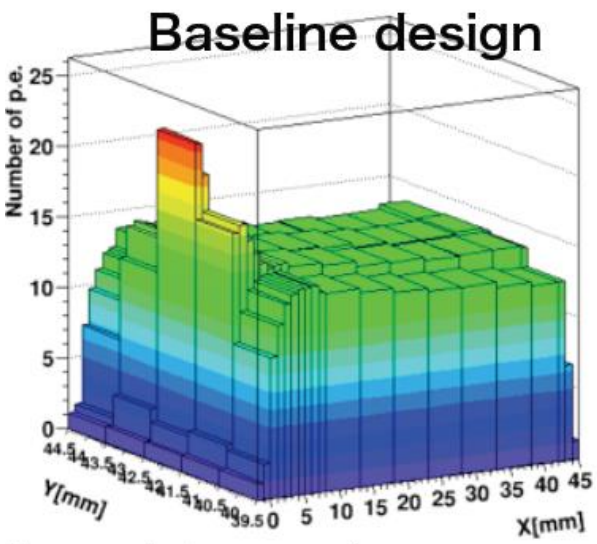
Excellent photon counting

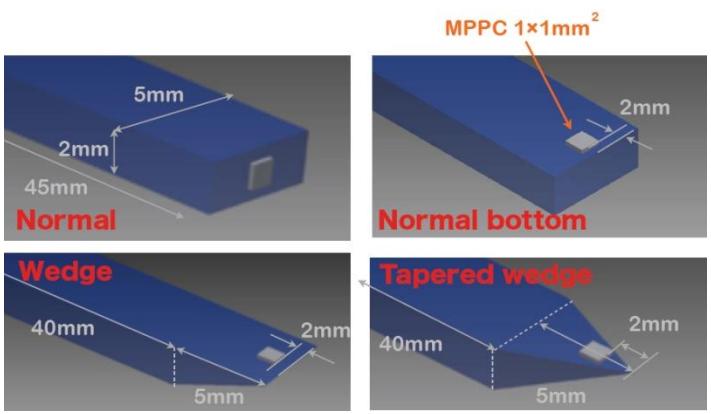


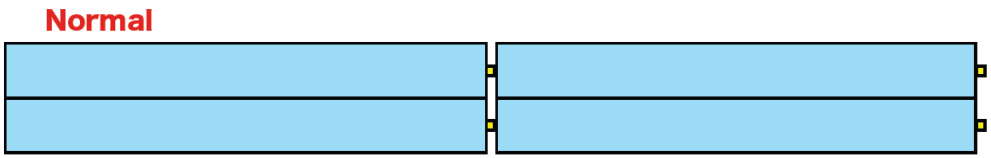
Crosstalk rate = Events (> 1.5p.e)/Events (>0.5p.e)



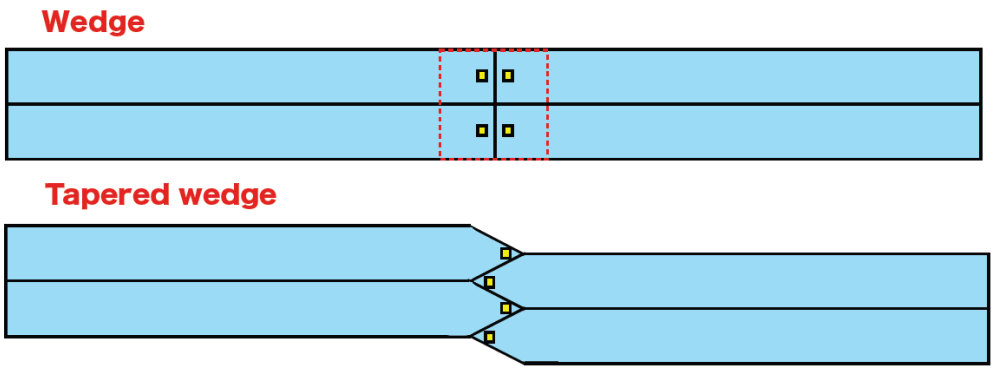
Scintillator Strip Structure Optimization







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.



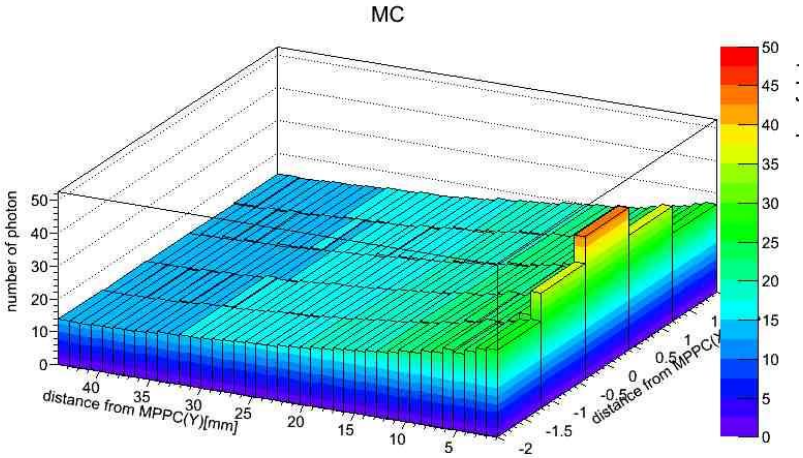
Need MC simulation and experimental tests to optimize the strip structure design.

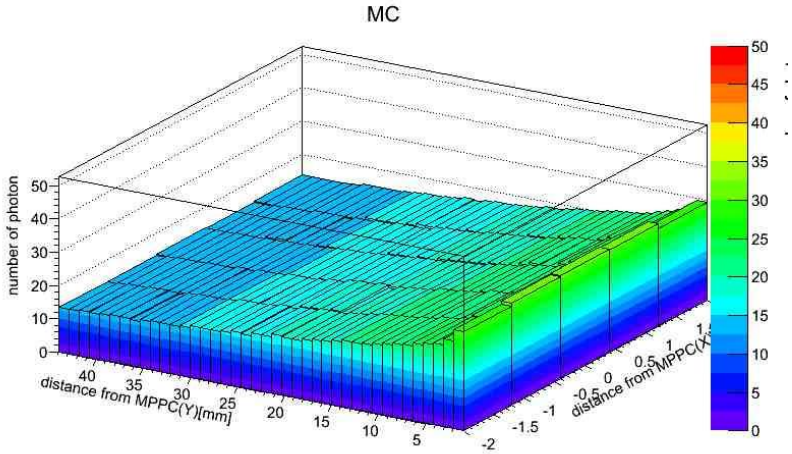
Scintillator Strip Shape Optimization

SiPM sensor area 1×1 mm² ➔ 0.25×4 mm²:

➔ to increase photon acceptance

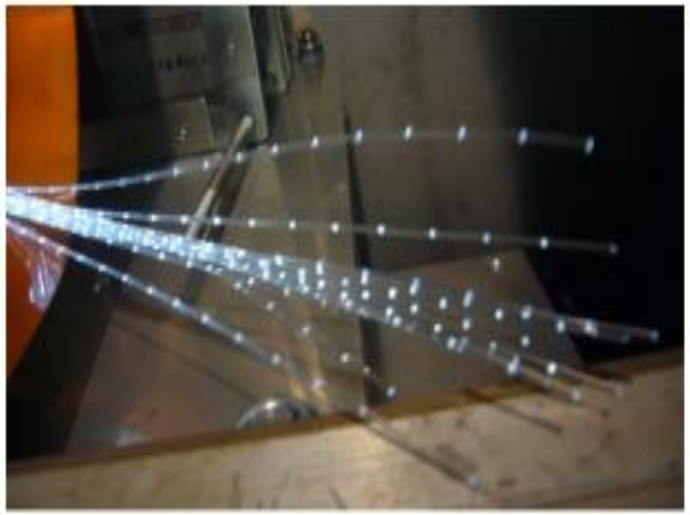
➔ It is easy to make this shape of MPPC with current technology

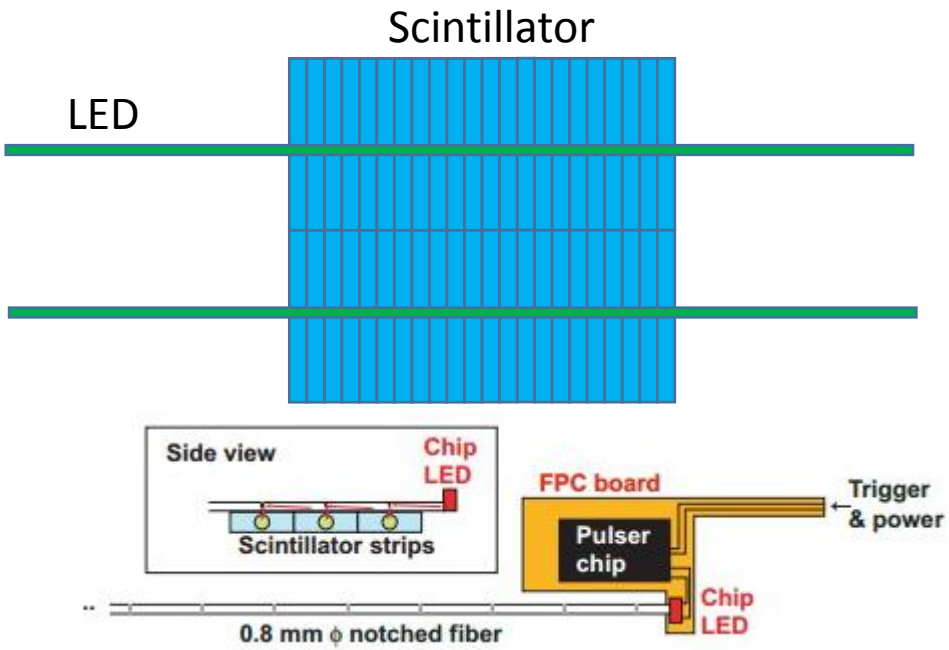




Calibration for Scintillator and SiPM

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.





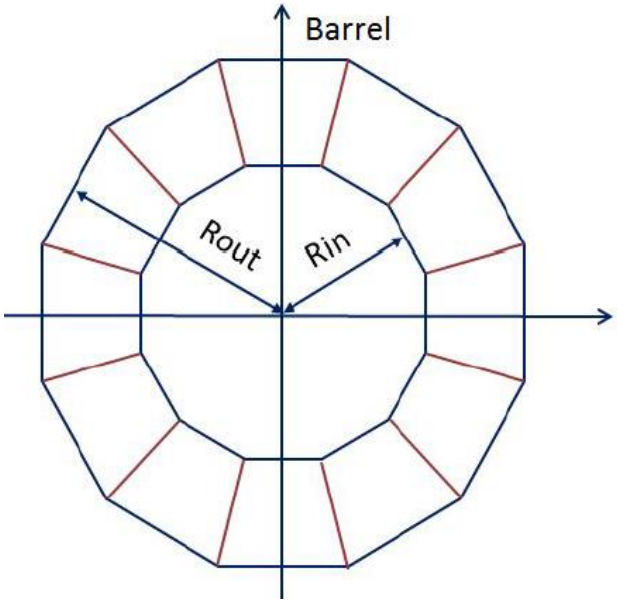
LED – Fiber calibration system:

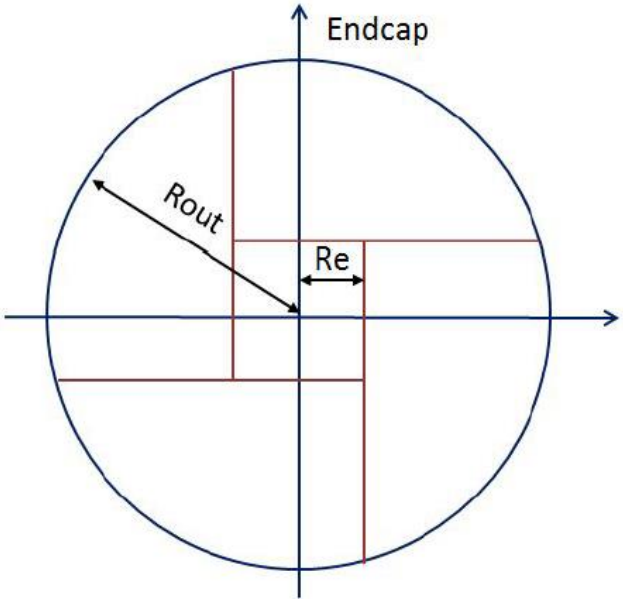
- A pulse generator, a chip LED connect to notched fibers
- Notched Fiber distribute lights to ~ 80 scintillator strips

Hadron Calorimeter

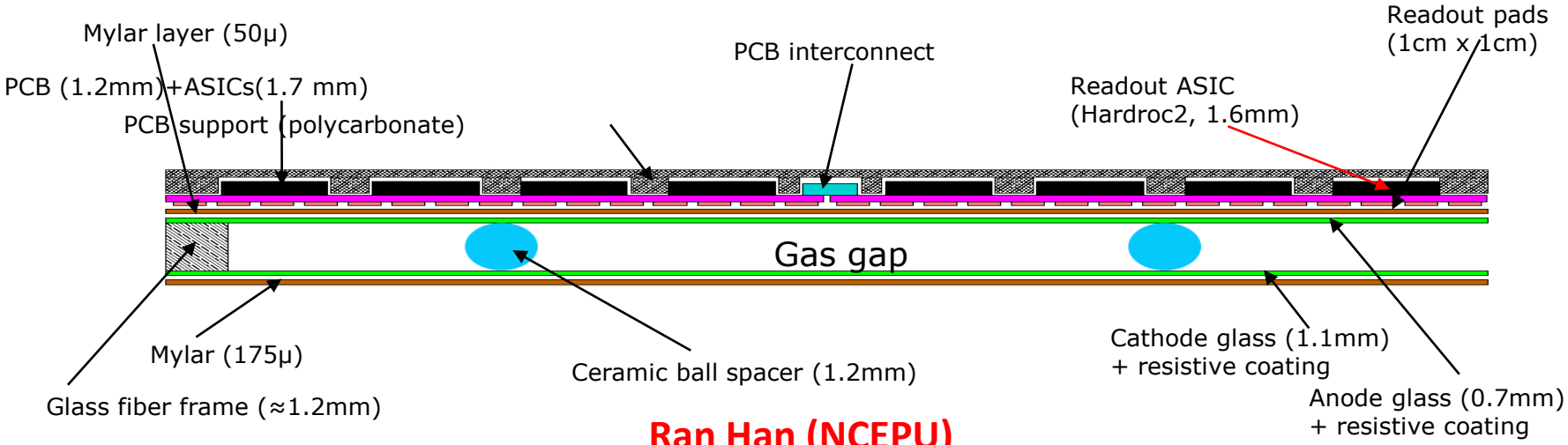
- The HCAL consists of
  - a cylindrical barrel system: 12 modules
  - two endcaps: 4 quarters
- Absorber: Stainless steel

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

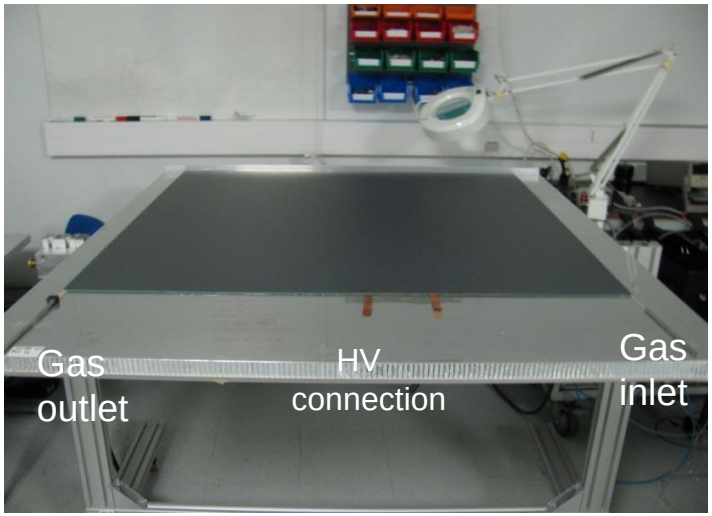




RPC Construction & Performance Study



Ran Han (NCEPU)



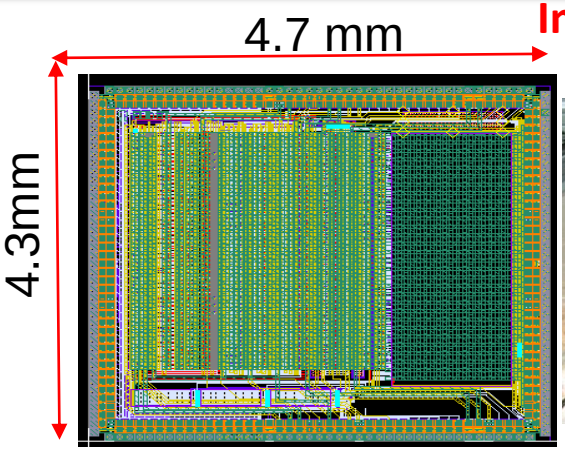
Large GRPC R&D

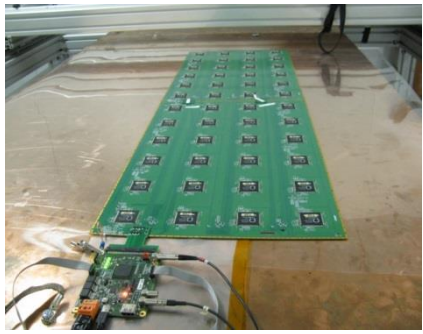
- ✓ Negligible dead zone (tiny ceramic spacers)
- ✓ Large size: $1 \times 1\ m^2$
- ✓ Cost effective
- ✓ Efficient gas distribution system
- ✓ Homogenous resistive coating

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

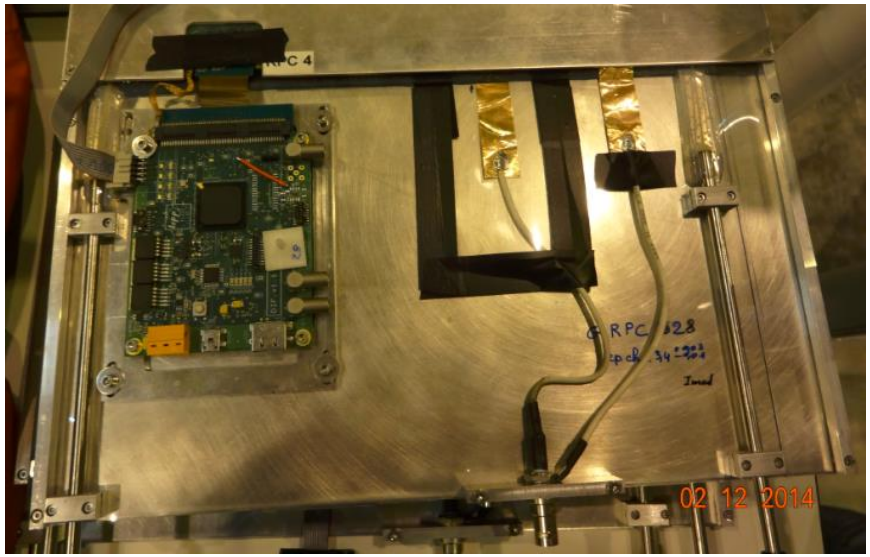




Printed Circuit Boards (PCB) were designed to reduce the cross-talk with 8-layer structure and buried vias.

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.

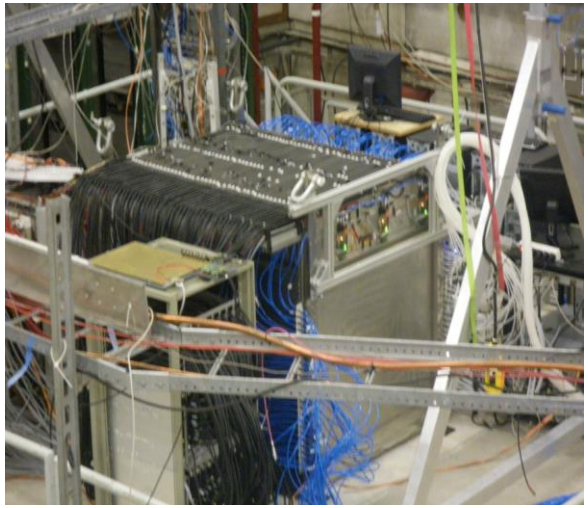
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.

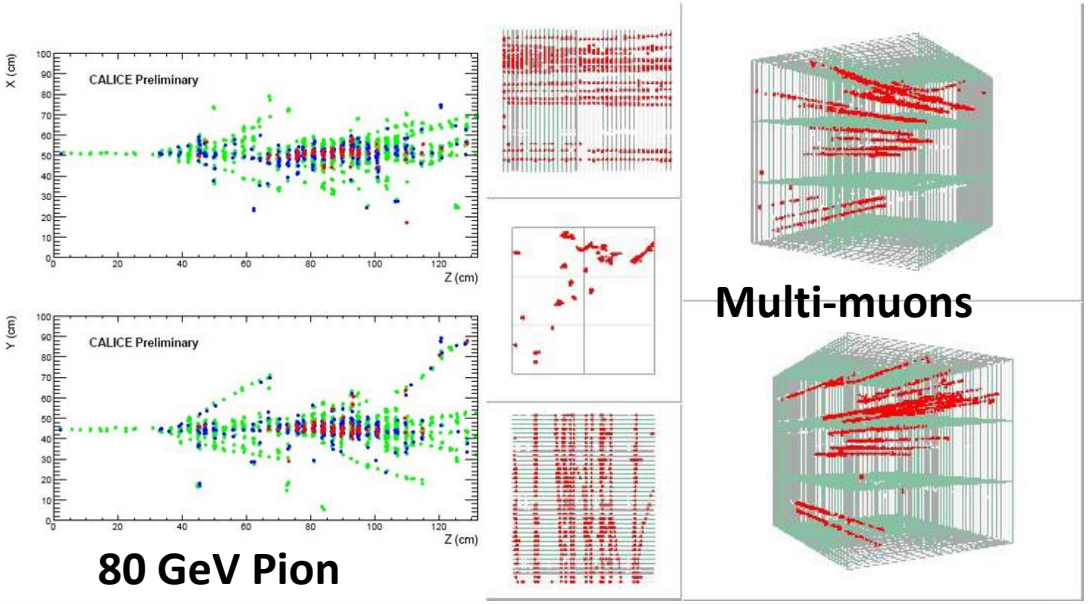


Prototypes of DHCAL with RPC

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



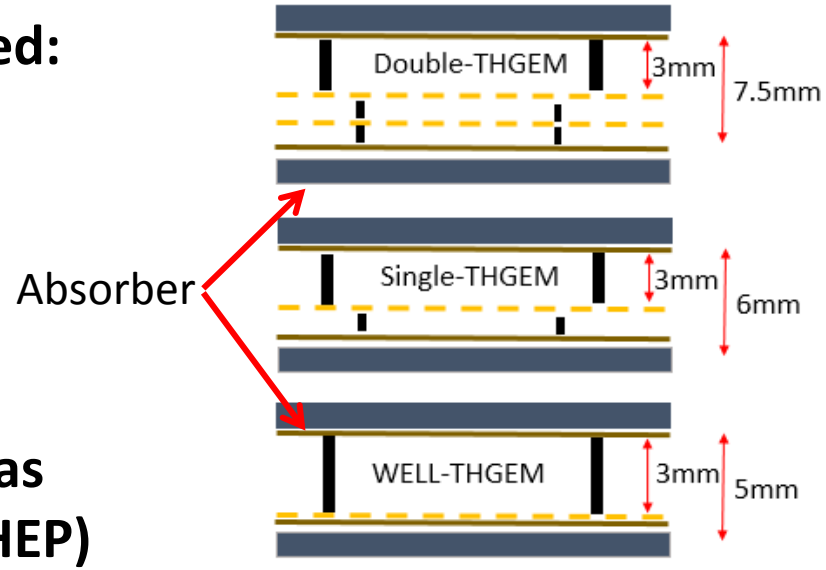


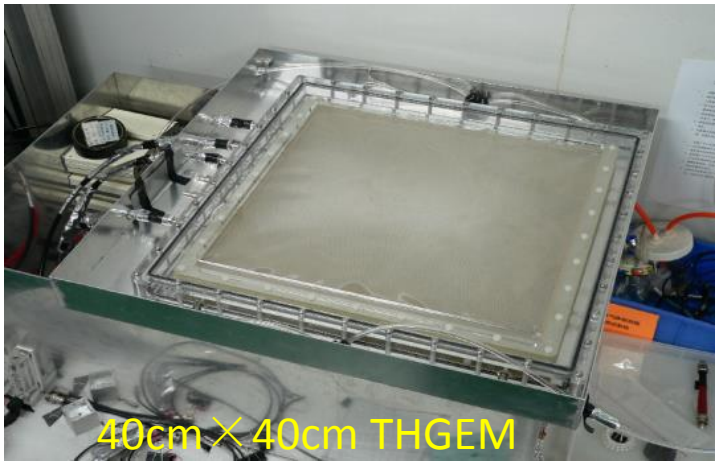
80 GeV Pion

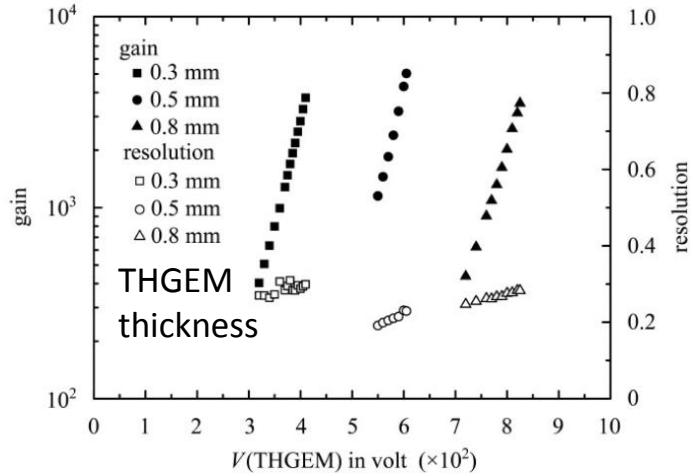
DHCAL based on THGEM

Boxiang Yu (IHEP)

- Three THGEM options are explored:
  - Double - THGEM
  - Single - THGEM
  - WELL - THGEM
- WELL-THGEM is optimal choice
  Thinner, lower discharge
- 40 × 40 cm² of THGEM (below) was produced in China (UCAS, GXU, IHEP)

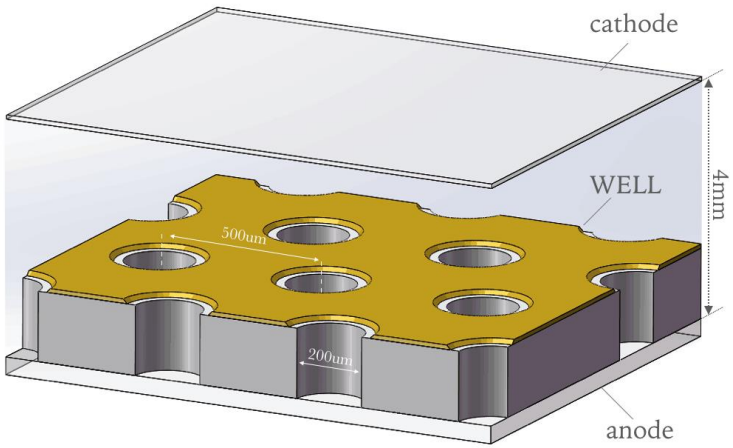


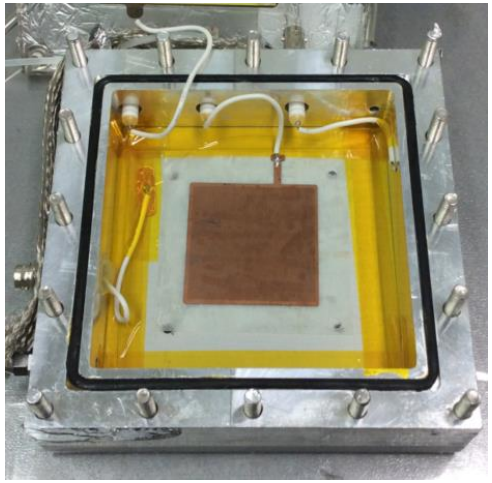


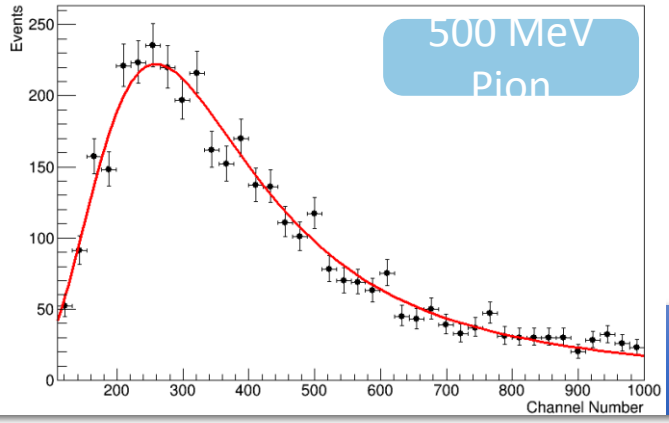


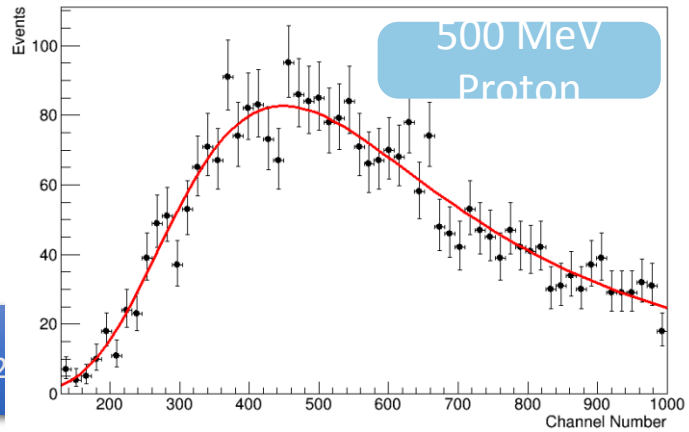
WELL-THGEM Beam Test at IHEP

- **Detection efficiency of well-THGEM was measured with BEPC pion / proton beams.**
- **Efficiency:**
  - Ar/iso (97/3) ,Gain ~ 2000; Eff (proton) > 93%; Eff(Pion) > 82%
  - Ne/CH4 (95/5) ,Gain ~ 9000; Eff (proton) > 99%; Eff(Pion) > 94%





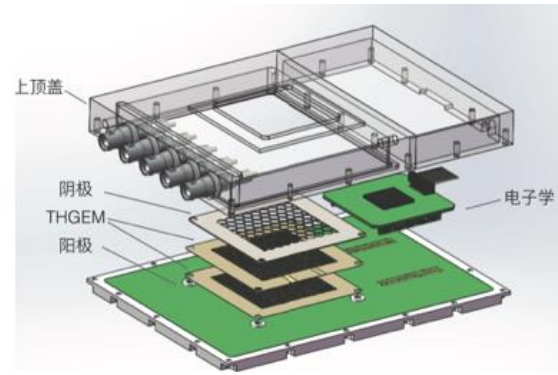


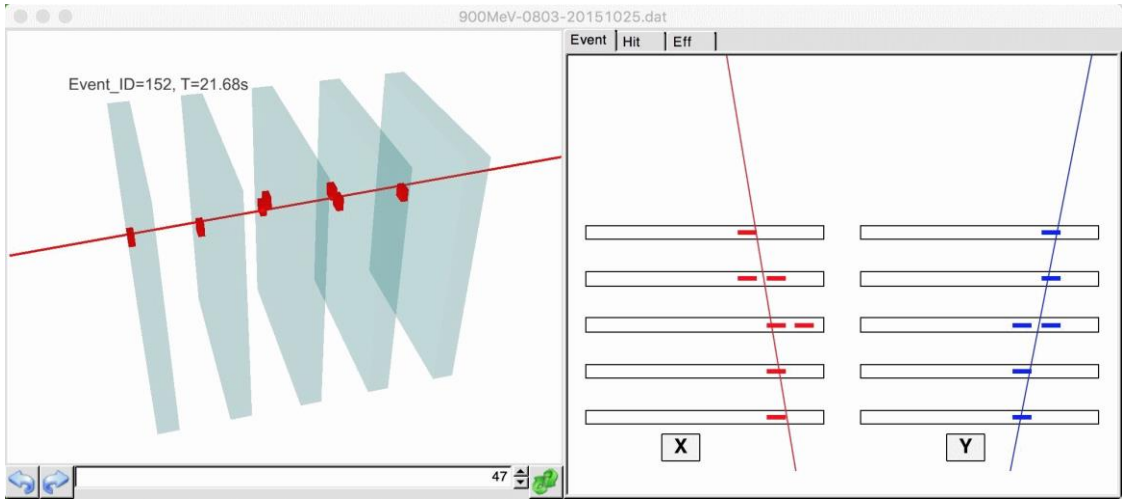


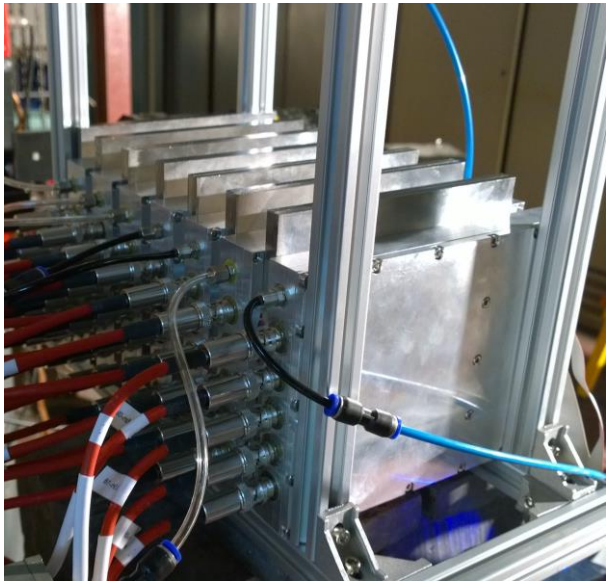
WELL-THGEM Beam Test in Oct., 2015

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



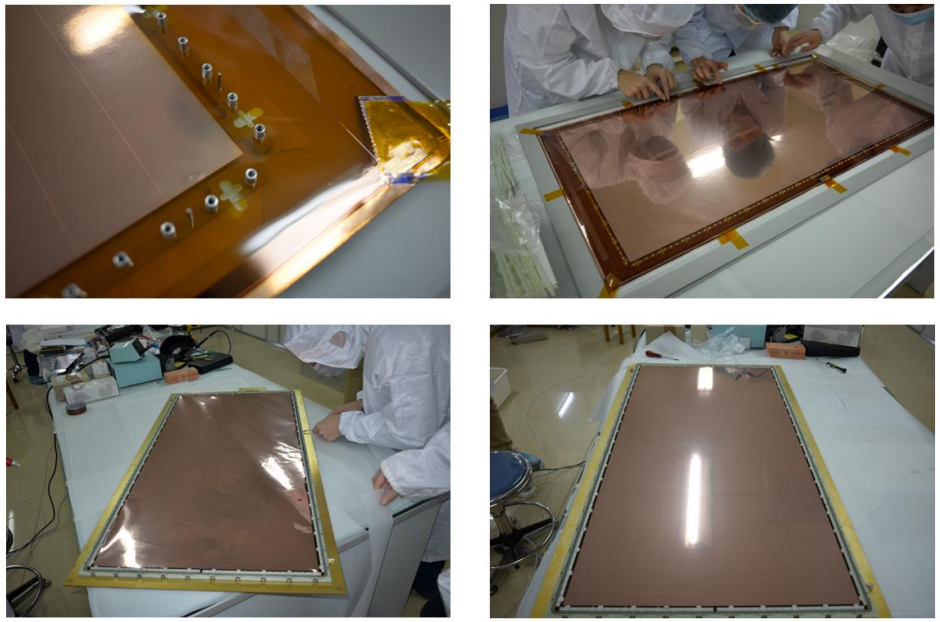




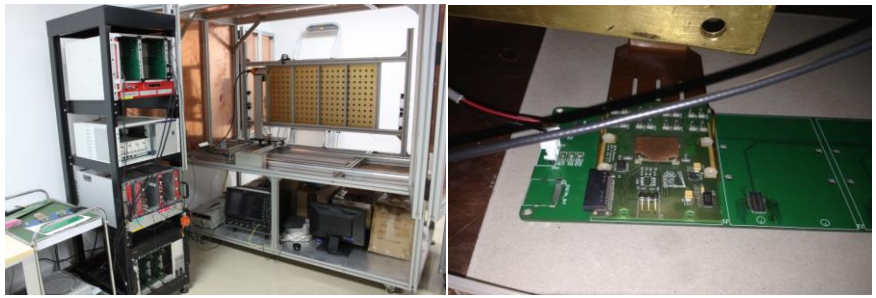
Large-area GEM @ USTC

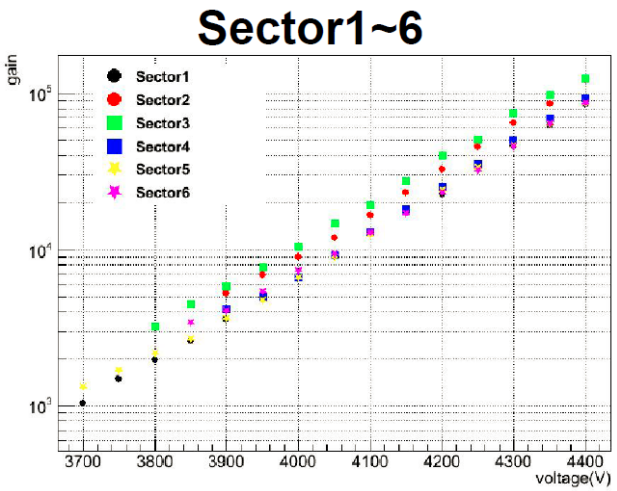
Jianbei Liu (USTC)

GEM assembly using a novel self-stretching technique



APV25 GEM readout **INFN APV25 chip**



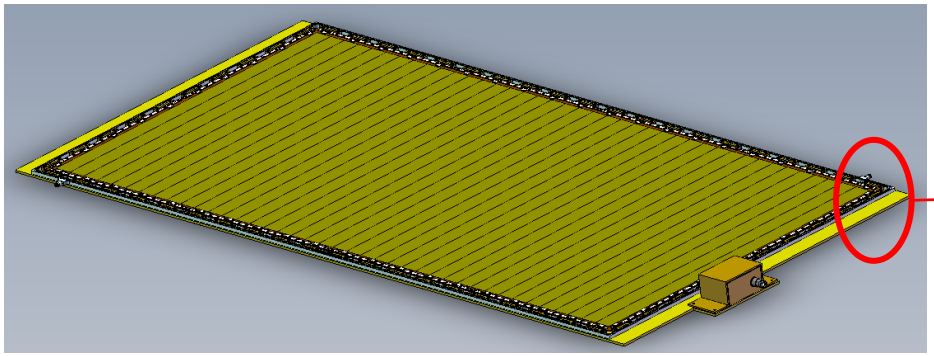


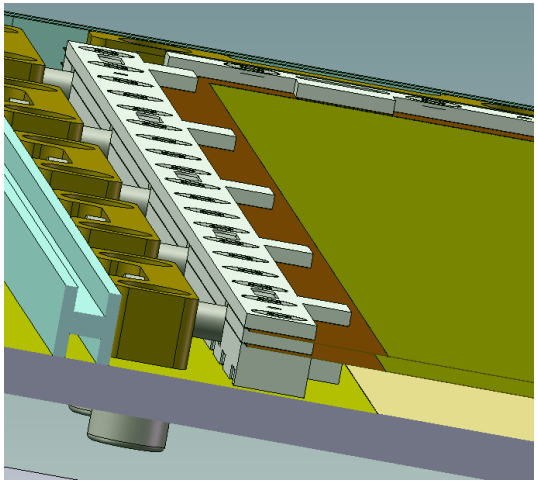
- Large-area GEM (0.5x1m^2) is one of main detector R&D focuses at USTC recently.
- Technology has been developed and matured to produce high-quality GEM detectors as large as ~1m^2 that are also applicable to CEPC DHCAL.

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

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.

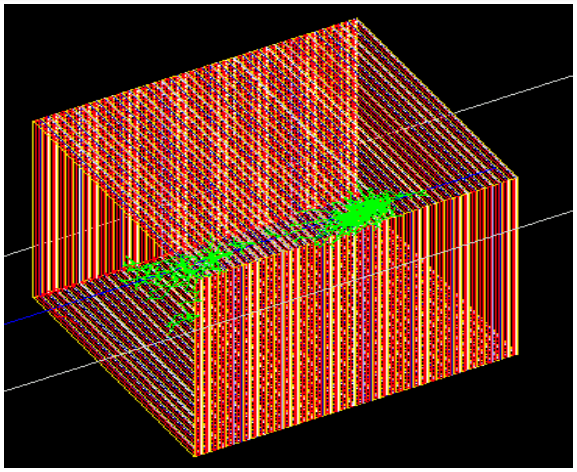




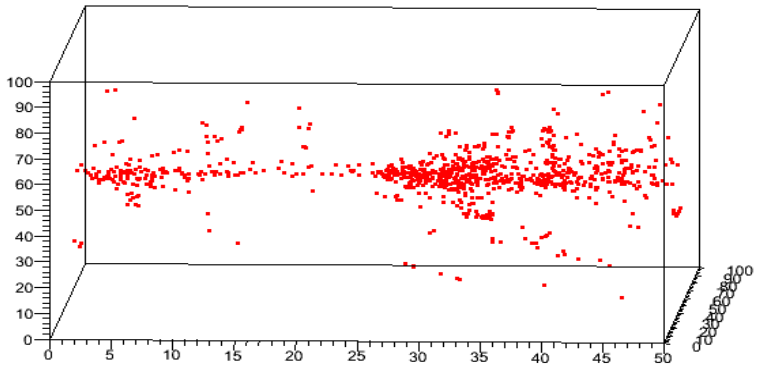
Mechanical design already finished !

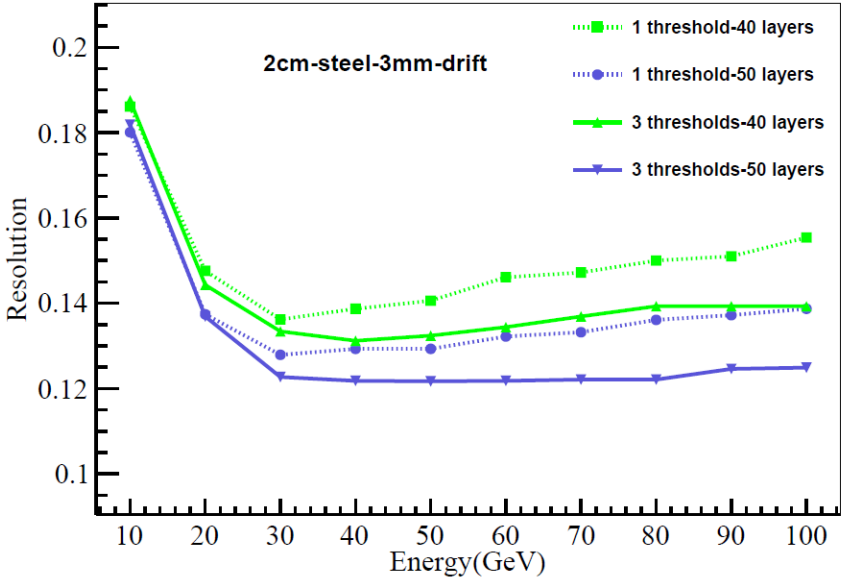
DHCAL Detector Optimization

- DHCAL Simulation and Optimization
  - Standardalone ➔ Full simulation (eg. single particle, ZH→qqbb events)
  - Number of layers
  - Thickness of Absorber
  - Readout cell size
  - Thresholds (1, 3, ..)



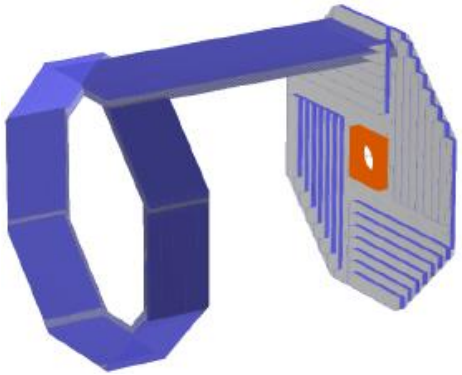
1×1cm^2-50 Layers-100GeV π+

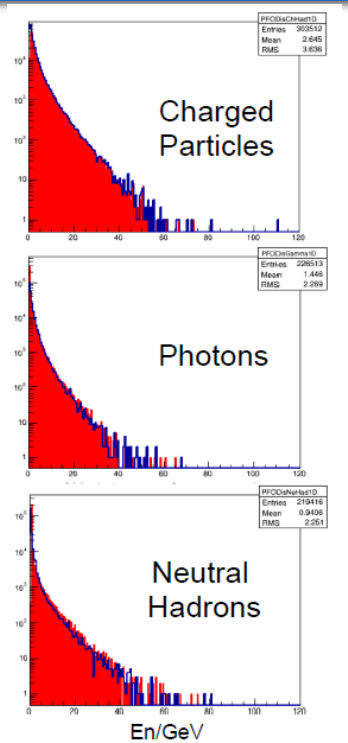




Detector Simulation and Optimization

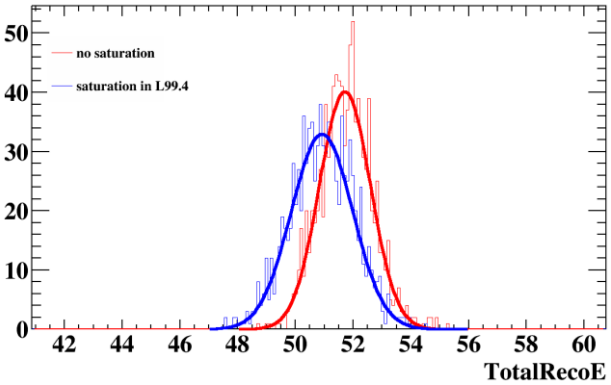
Manqi Ruan (IHEP)



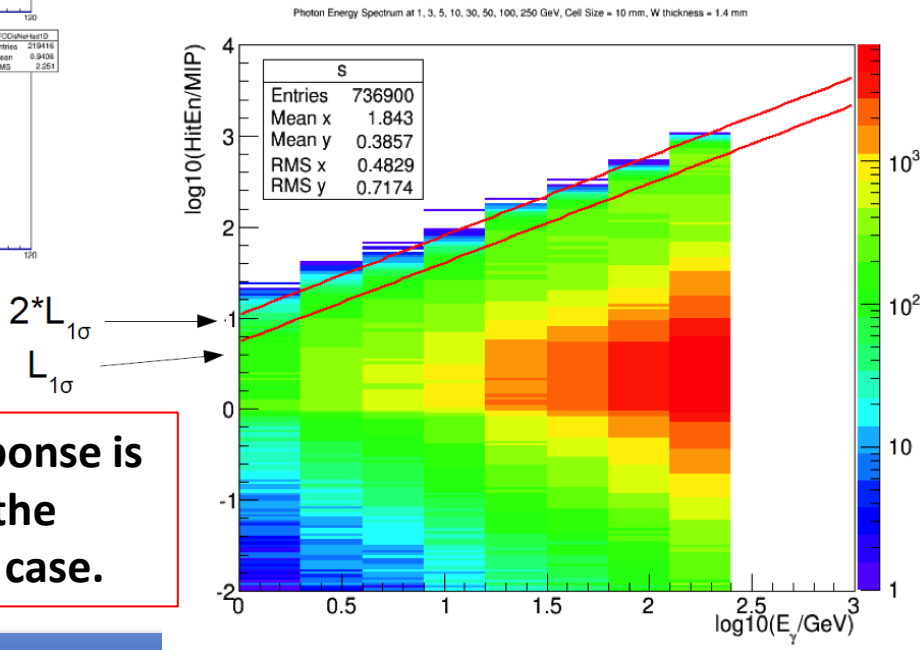


Flexible simulation toolkit: local geometry (cell size, layer thickness, global size), used to explore energy response, saturation, PID performance etc.

ECAL saturation at 1000 MIP



$L_{1\sigma}$: ECAL E response is 1σ lower than the non-saturation case.



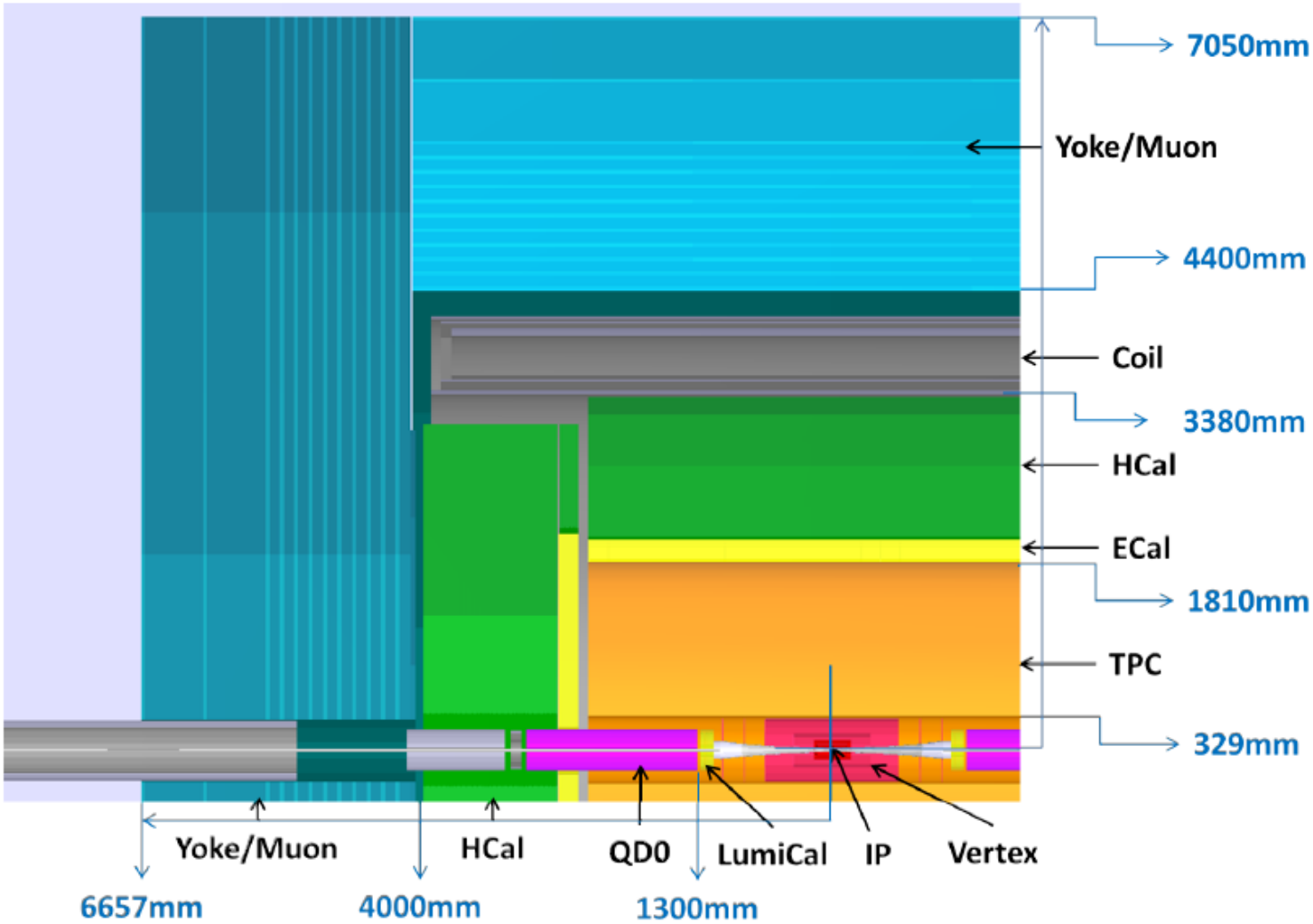
Future Plans for CDR: Critical R&D

- **Detector design and optimization**
  - Granularity of calorimeters
  - Number of layers of calorimeters
  - Absorber thickness
- **Detector R&D(SiW/ScW+SiPM, RPC/THGEM/GEM+Iron)**
- **Readout electronics (PCB, low power VFE ASIC)**
- **Cooling system**
  - Power pulsing will NOT work at the CEPC, effective cooling and power saving strategy need to be developed and tested
- **Gas recirculation system**
- **High voltage distribution system**
- **Calibration system**
- **Mechanical: self-support and compact module**

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

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

Overview of the CEPC Detector



Future R&D Plans

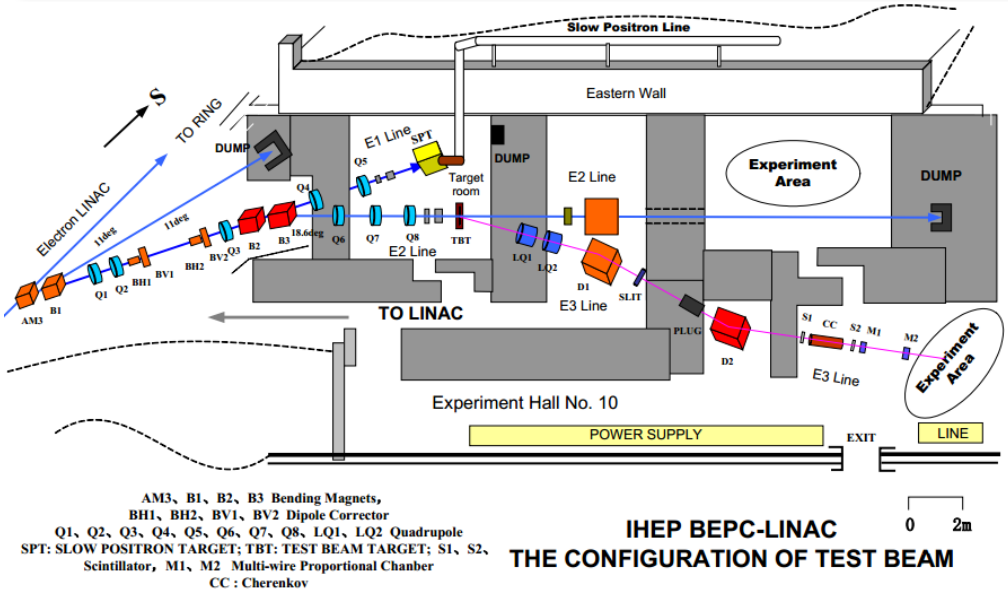
- Detector simulation and optimization based on PFA (open)
  - Full detector simulation with different geometry
  - Optimizing layers number, size of readout pad, absorber;
- Large area gaseous detector research (open)
  - Design and produce large area RPC, WELL-THGEM
  - Performance test and study
- PCB and ASIC readout (open)
  - ASIC chip design and test
  - Small readout board design and domestic production;
- DHCAL cooling system (open)
  - Design and calculation of cooling system ;
- DHCAL calibration system (open)
  - Design the calibration system;

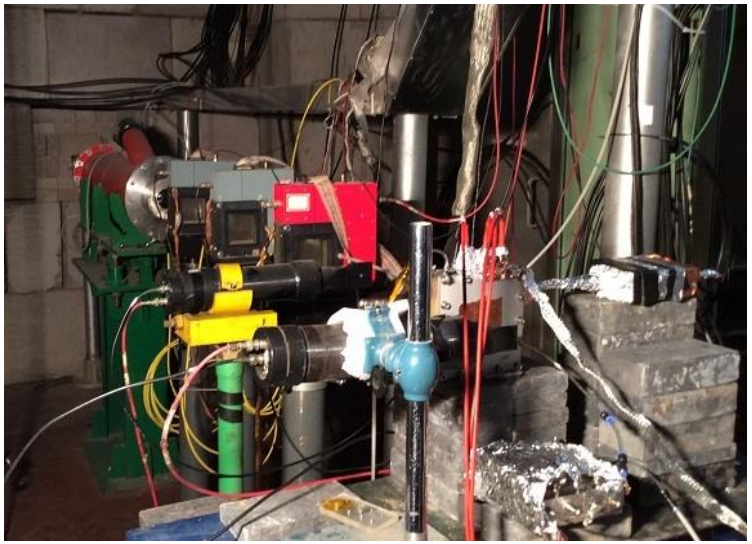
Towards to CEPC CDR

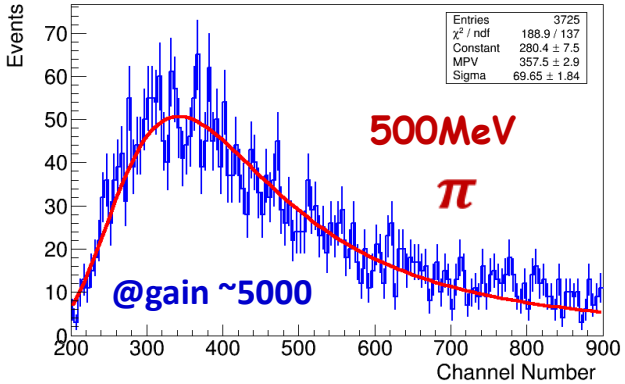
- **Full Detector simulation and optimization, based on ILD (with simulation group, ~ 4 students), eg.**
  - **Layers: ECAL 30→24 layers, HCAL 48→40 layers**
  - **Cell size: ECAL 0.5x0.5→ 1x1 cm^2 , HCAL 1x1 → 2x2 cm^2**
- **Sensors performance (eg. Si, Sct, RPC, ThGEM, GEM): counting rate, acceptance, linearity, time response, energy resolution etc., large area sensors**
- **Electronics (existing technologies and performance, ASIC design, comparison of 1 vs. 3 thresholds)**
- **Active Cooling system: simulation and calculation of heat dissipation, design etc. for CDR**
- **Longer term: PCB and ASIC design and test**

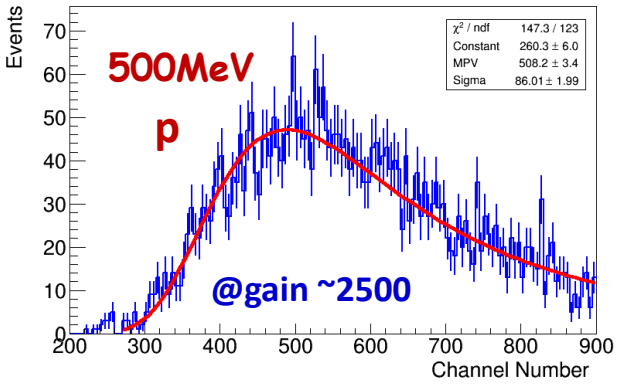
WELL-THGEM Beam Test at IHEP

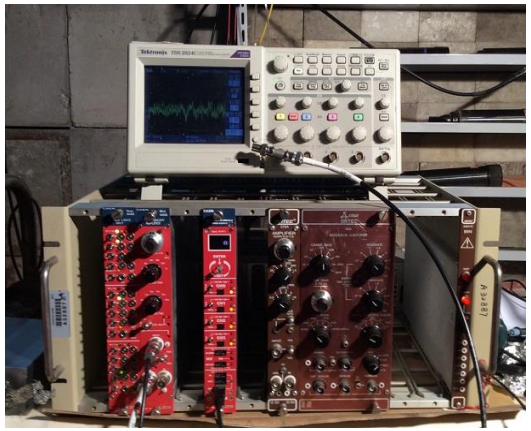
Hongbang Liu (GXU)











Well-THGEM, Ar/3%iC4H10;

CEPC Muon System

Yuguang Xie @ IHEP

Functions of muon system

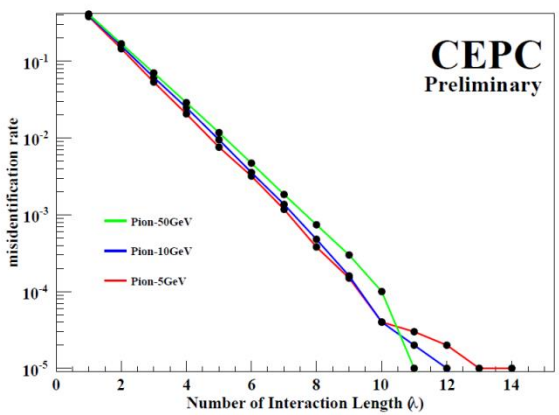
- To separate muons from hadrons
- A tail catcher of HCAL
- Solenoid return roke & support structure

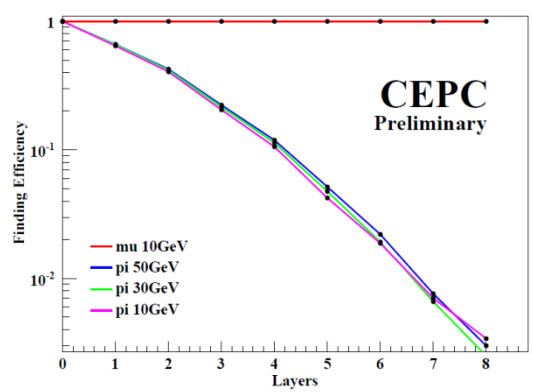
Performance requirements

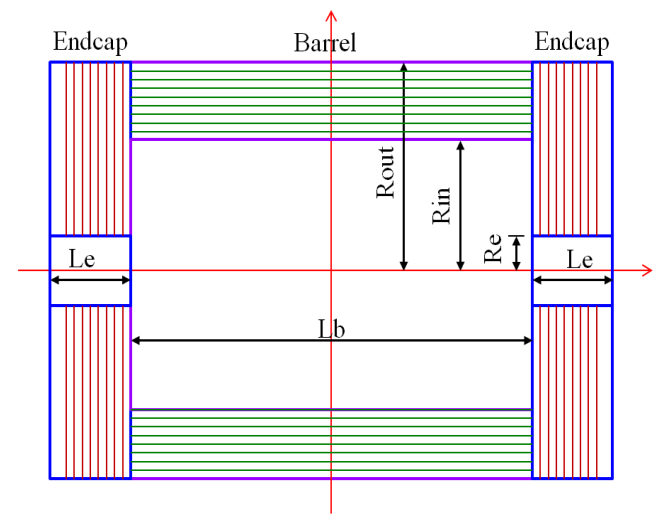
- nLayer >=8, iron thickness >= 6λ
- Eff >=95%, resolution<=2cm
- Misidentification rate (pi->mu)@40GeV <1%

Item	Option	Baseline
Lb	3.6~5.6m	~4.6
Rin	2.5~3.5m	~3.0
Rout	4.5~5.5m	~5.0
Le	1.6~2.4m	~2.0
Re	0.6~1.0m	~0.8
Segmentation	8/10/12	10
Number of layers	6~10	8(~3cm per layer)
Total thickness of iron	6~10λ (λ=16.77cm)	8 (8/8/12/12/16/16/20/20/24cm, Sum=136cm)
Solid angle coverage	0.92~0.96×4	0.94
Position resolution	1.5~2.5cm	2
	: 1~2cm	1.5
Average strip width	Wstrip: 2~4cm	3
Detection efficiency	92%~98%	95%
Reconstruction efficiency	92%~96%	94%

The standalone simulation results show the number of layers and the thickness of iron are reasonable.



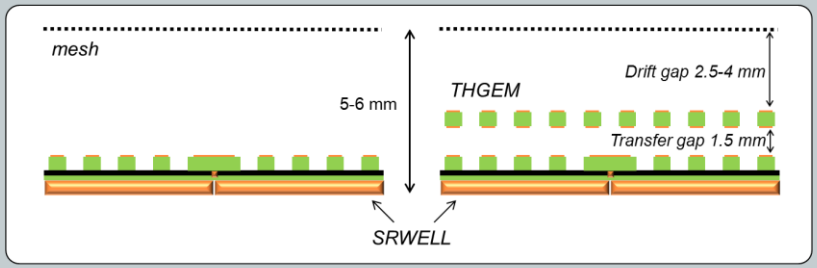


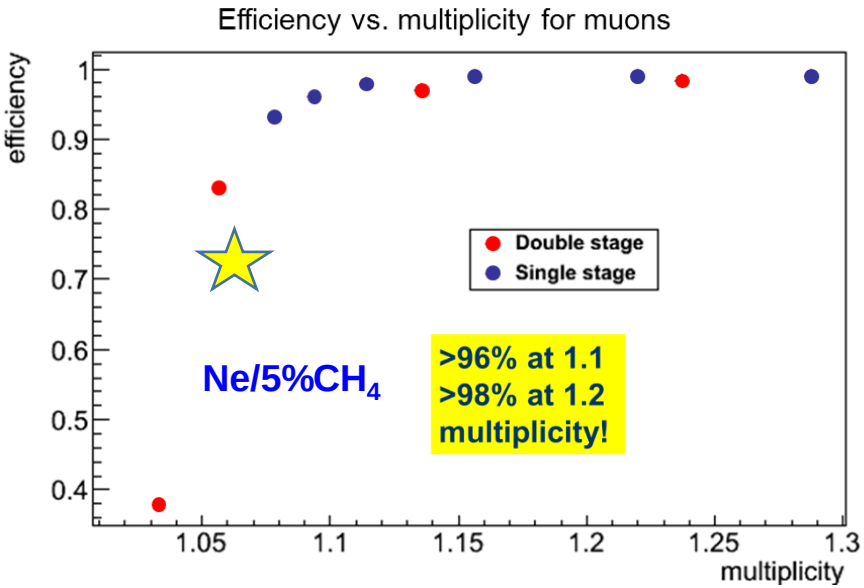


Weizmann Group (A. Breskin, inventor of THGEM)

Single- or double-stage SRWELL detector?

- Double-stage detector expected to be **more stable** in hadronic showers
- Can be accommodated in the same space at the expense of the drift and conversion gap
- But: more expensive…



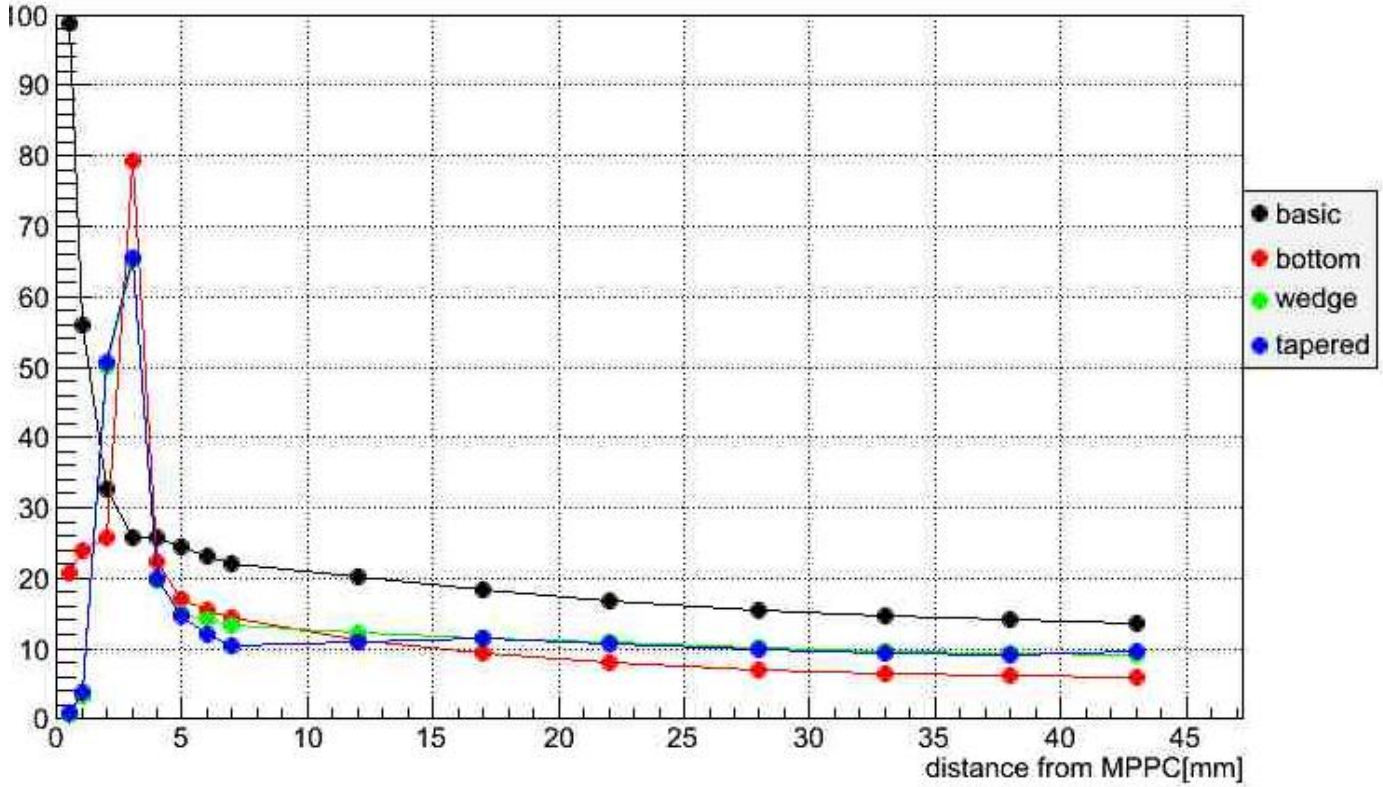


-**High efficiency (>96%/98%)** with **minimal multiplicity (~1.1/1.2)** for muons
- **Total thickness** (w/o electronics) : **5-6 mm.**

■ R&D Activities (Amos Breskin, Weizmann group, Isreal)

- optimization studies & R&D on **large-area detectors.**
- Preparing high energy pion beam test.

Simulation



Geant4-based simulation of scintillation photon propagation.
Monte Carlo simulation parameters are still to be optimized.
Only relative comparison makes sense for the moment.