Status Report of the Calorimeter Group

Tao Hu (IHEP) and Haijun Yang (SJTU)
(for the CEPC-Calo group)

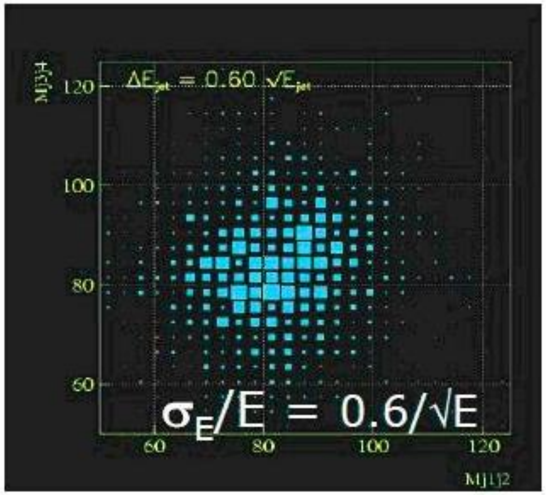
THIRD WORKSHOP ON FUTURE CIRCULAR HIGH ENERGY COLLIDERS
2014/03/19

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

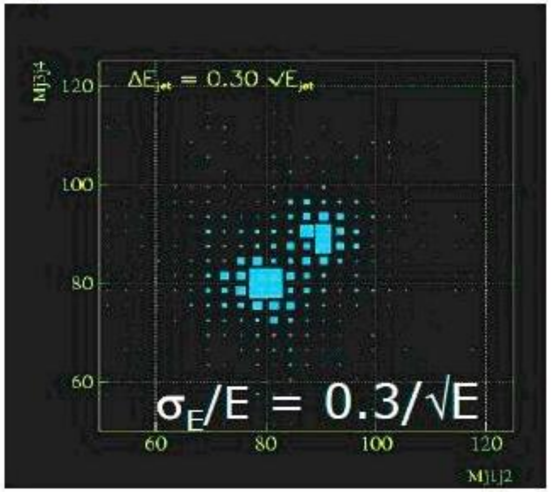
Jet Energy Resolution (JER)

- **Requirement of JER based on separation of hadronic decays of W and Z is ~ 3%-4%.**

Jet E res.	W/Z sep
perfect	3.1 σ
2%	2.9 σ
3%	2.6 σ
4%	2.3 σ
5%	2.0 σ
10%	1.1 σ

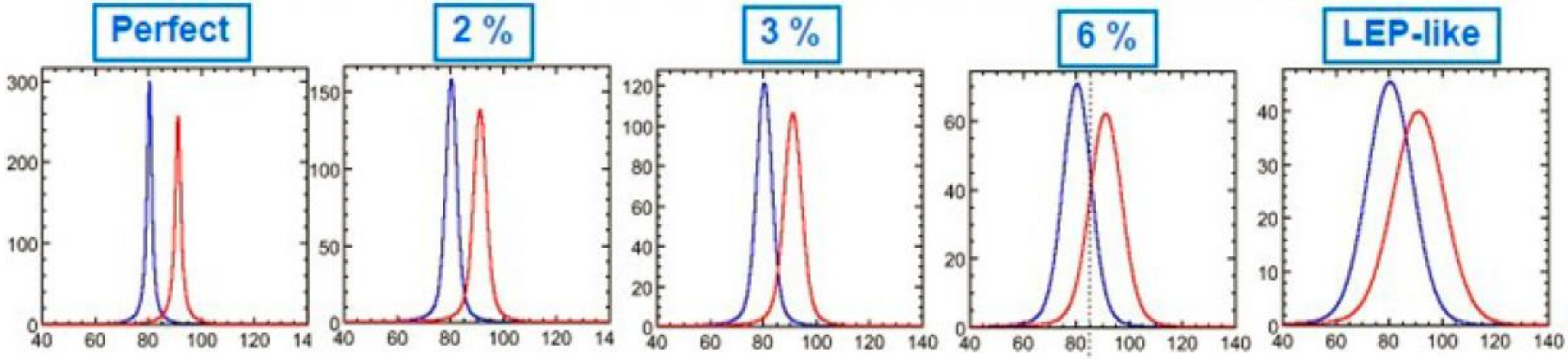


$\sigma_E/E = 0.6/\sqrt{E}$



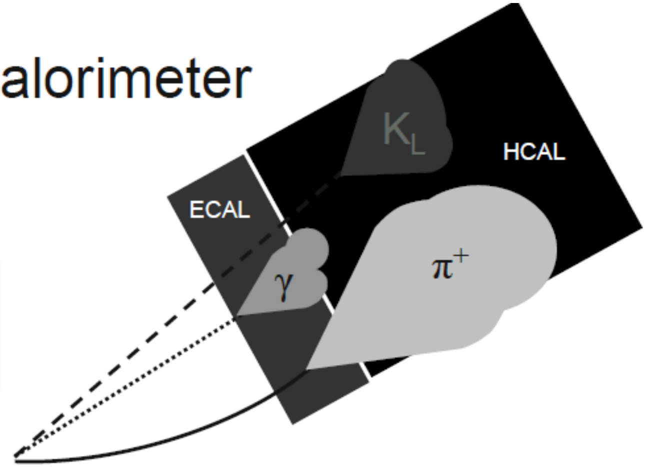
$\sigma_E/E = 0.3/\sqrt{E}$

$\sigma_E/E = 30\%/\sqrt{E(\text{GeV})}$



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

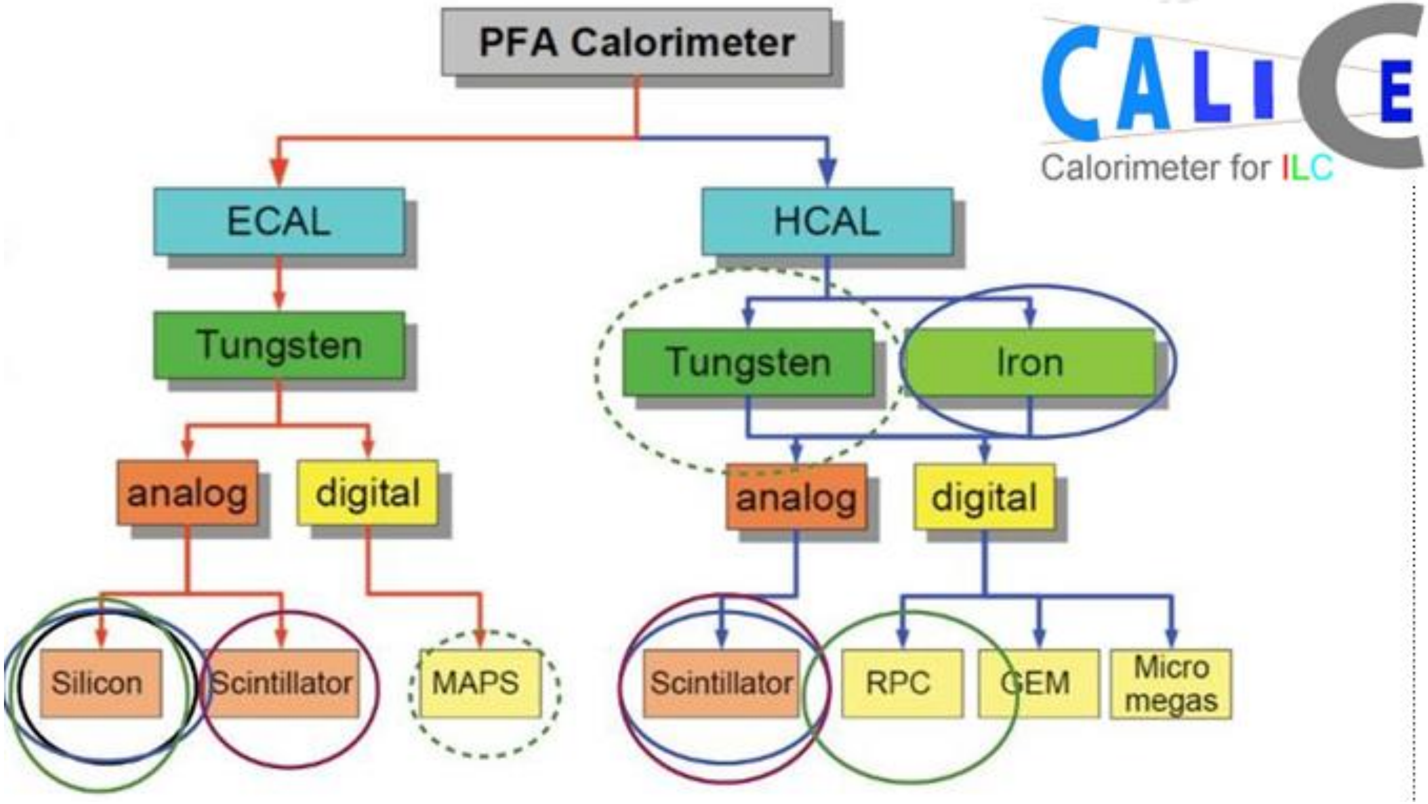
Requirements for detector system

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

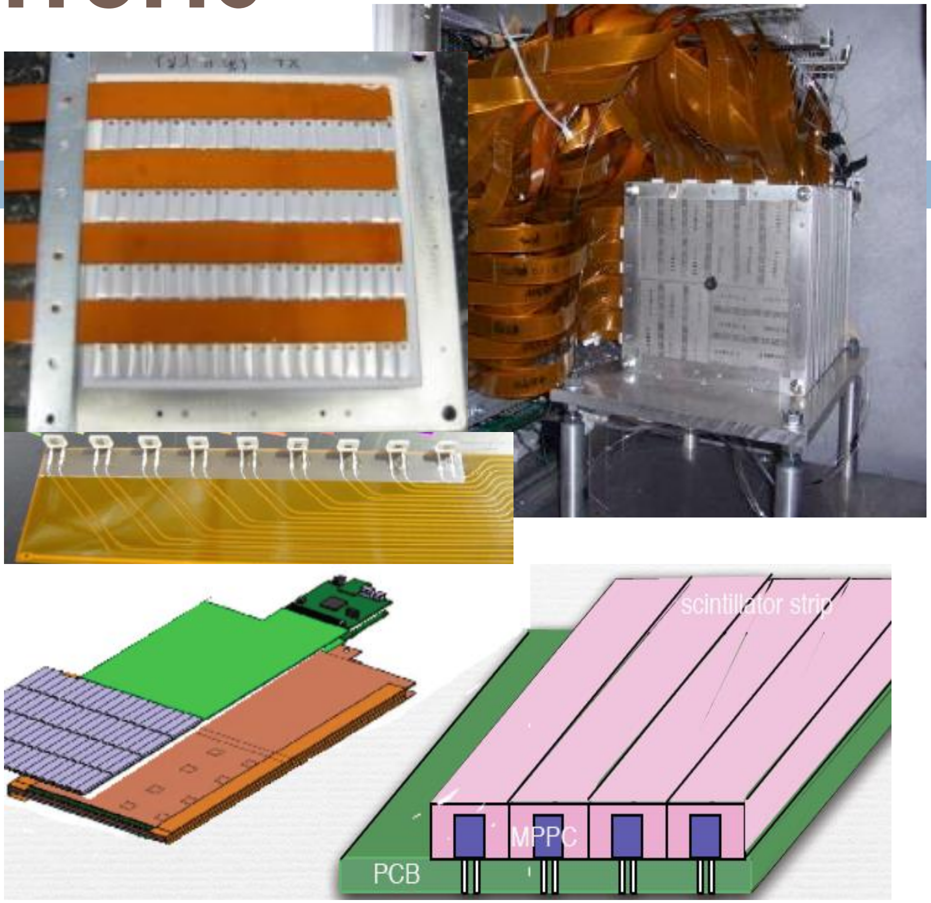
} **thin active medium**

Developing Techniques

- AHCAL(Analog), DHCAL(Digital), SDHCAL(Semi-digital)
- SiWECAL(Silicon-W), ScWECAL(Scintillator-W)



ECal efforts



CALICE Si/W Ecal (IN2P3):

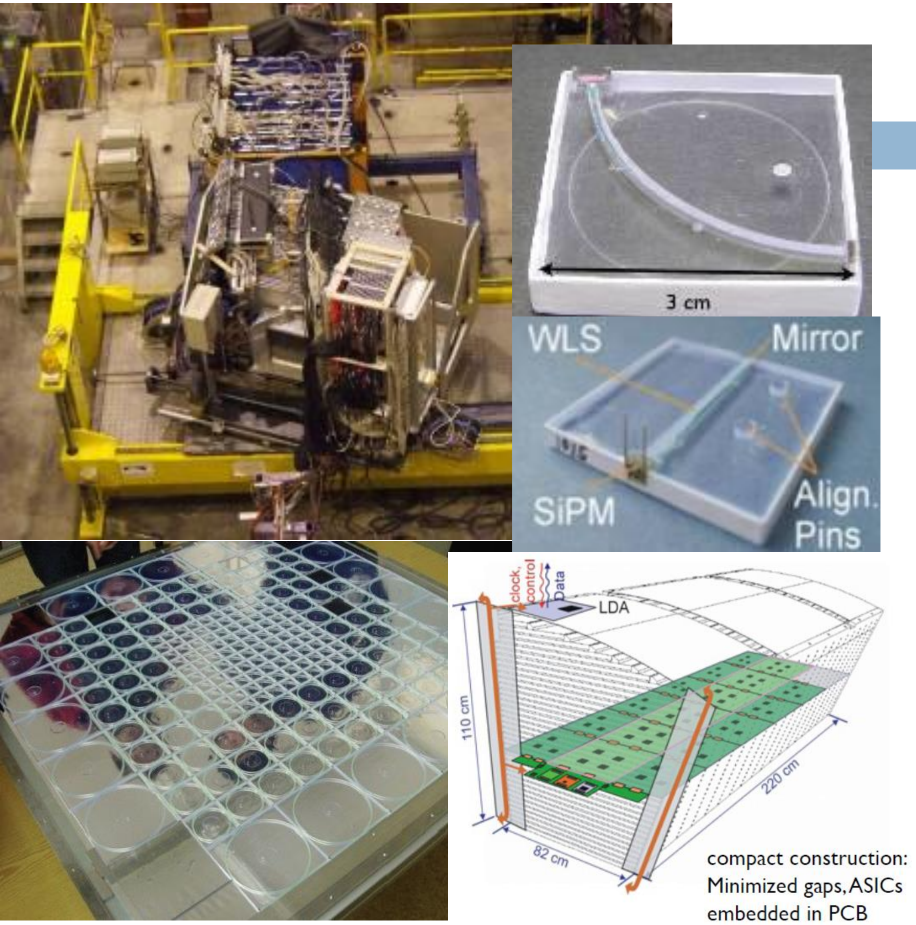
- Physics prototype* tested in beam (1x1cm^2)
- Data analysis well advanced
- R&D/construction for Technical prototype**
- Readout cell reduced to 0.25cm^2 for 2nd prototype

CALICE Sci/W ECal:

- Physics prototype tested in beam (1x4.5cm^2)
- Data analysis done
- R&D for technical prototype

** Physics prototype: proof of principle device*
*** Technical prototype: prototype close to a real detector*

HCal Efforts

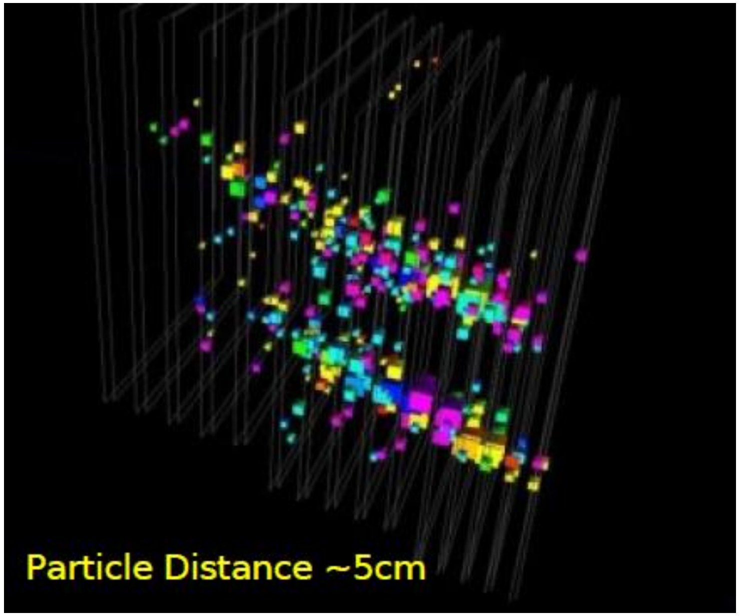


compact construction:
Minimized gaps, ASICs
embedded in PCB

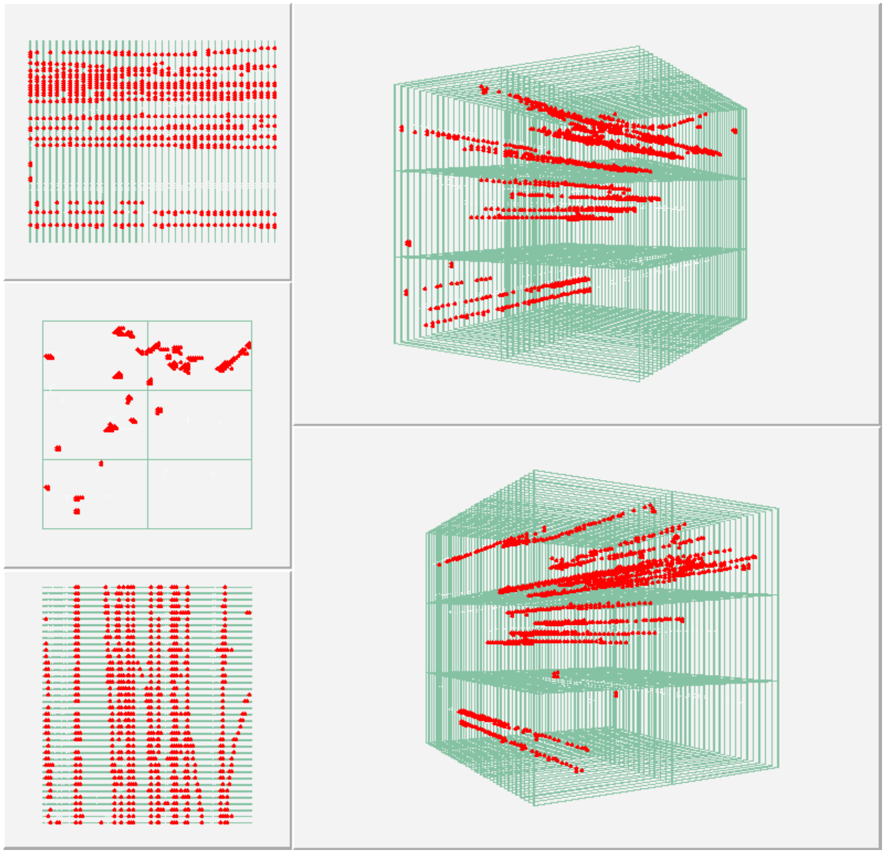
CALICE Sci/SiPM Analog HCal (AHCal):
- Physics prototype (Fe) tested in beam (3x3cm^2)
- Data analysis well advanced
- Physics prototype (W) beam test in 2011
- R&D/construction for Technical prototype

CALICE RPC Digital HCal (DHCal):
- Large (1m^3) prototype (Fe) tested in beam (1cm^2)
- Embedded Front End readout, 480K (!) readout channels
- Beam test with W absorber in 2012
- Data analysis on-going
- R&D for Technical prototype started

Separation of Multiple Particles



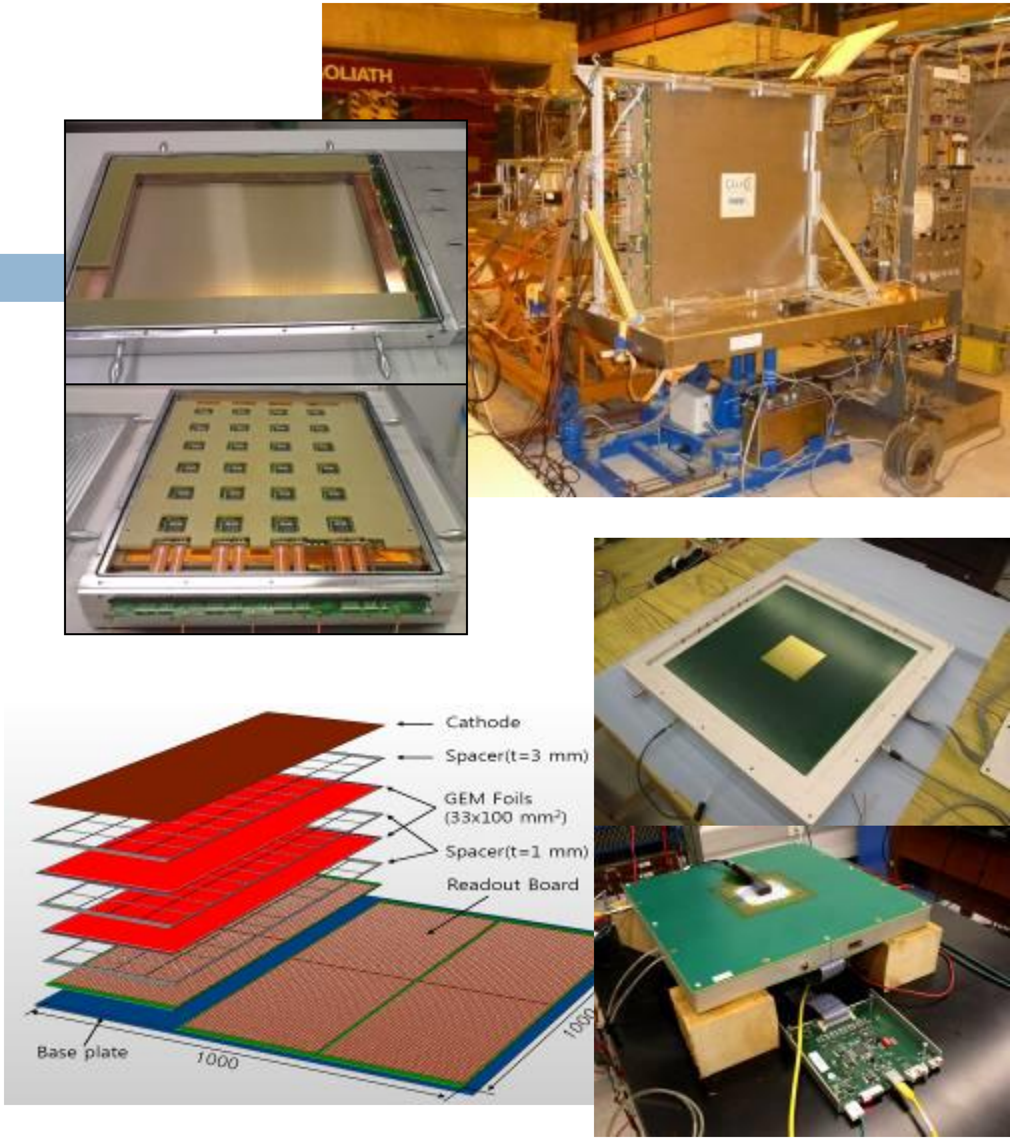
Two electrons ~5cm apart
CALICE SiW ECAL (IN2P3)



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

We have no problem distinguishing these particles by eye
--- a good PFA should be able to distinguish as well !

HCal Efforts



CALICE RPC semi-Digital HCal (sDHCal):

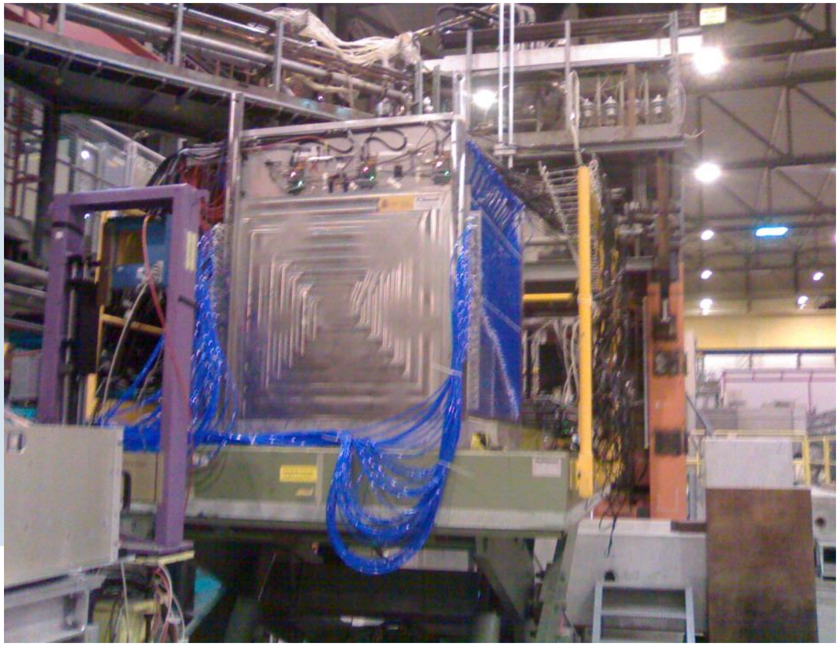
- Large prototype ($1m^3$) under construction ($1cm^2$)
- Beam test in 2011 and 2012
- Addressed some technical issues for real detector
- Explore 3-threshold readout

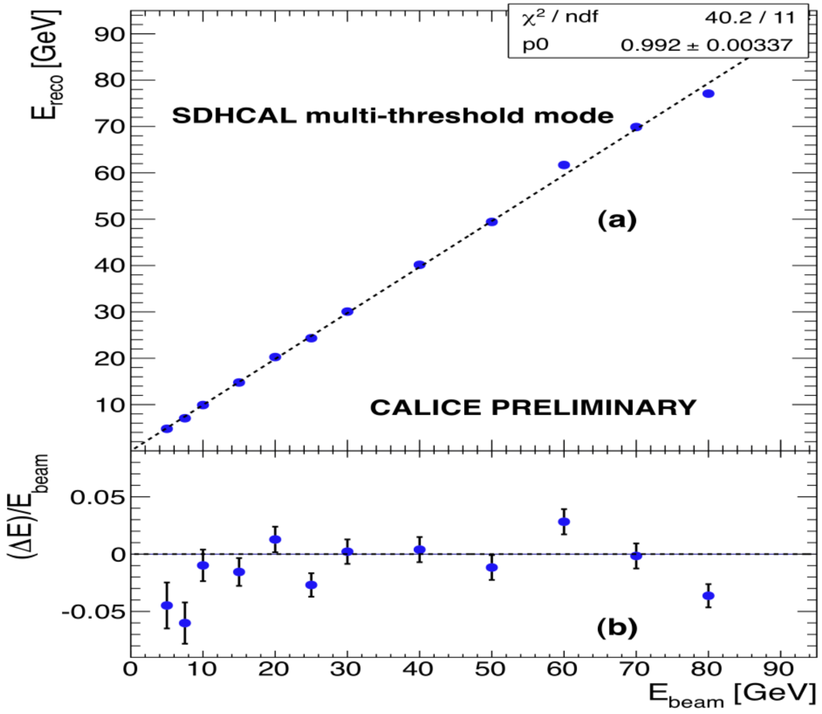
CALICE Micromegas/GEM Digital HCal:

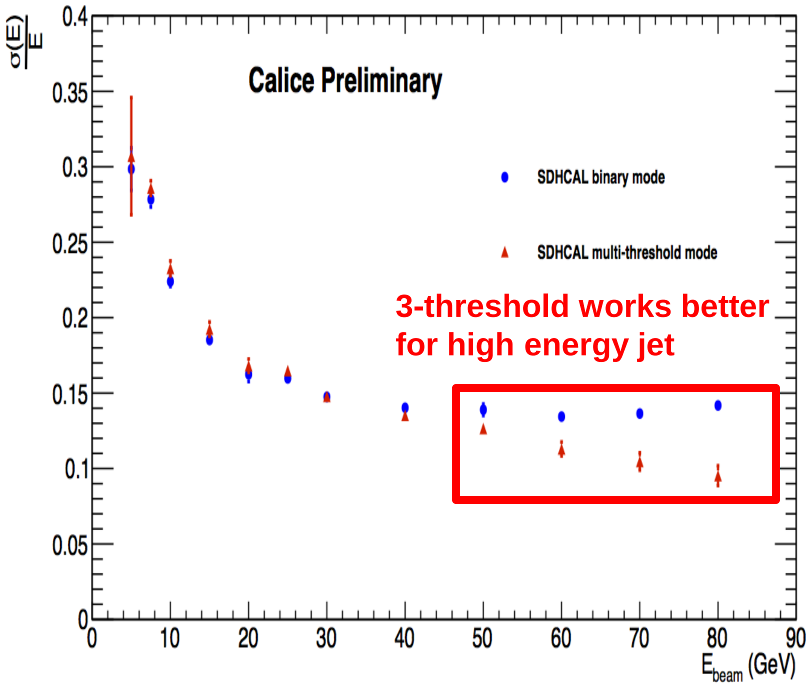
- Prototype layer constructed/expected ($1x1cm^2$)
- Prototype layer beam test done/expected
- Both technologies can handle very high rates

SDHCAL: beam test @ CERN

The SDHCAL team involved in the construction and test of this module are based in France (IPNL in Lyon, LAPP in Annecy, LAL in Orsay and LLR in Palaiseau), Spain (CIEMAT in Madrid) and the universities of Louvain and Ghent in Belgium.





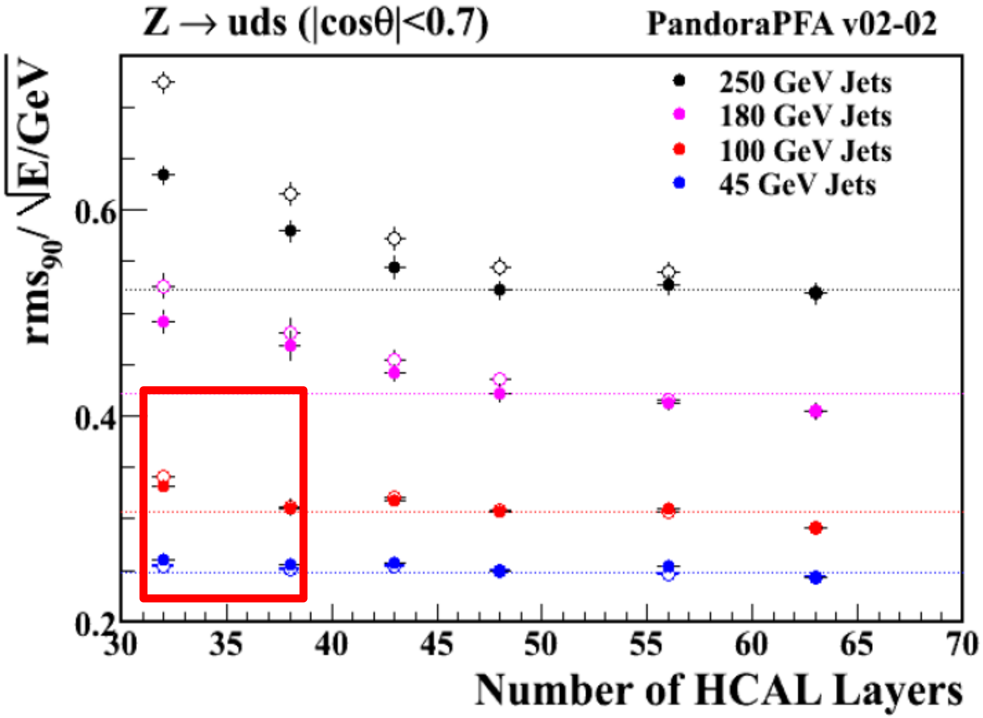


3-threshold works better for high energy jet

Calorimeters for CEPC @ 250 GeV

➔ Optimization for HCAL layers.

- **Open circles** = no use of muon chambers as a "tail-catcher"
- **Solid circles** = including "tail-catcher"

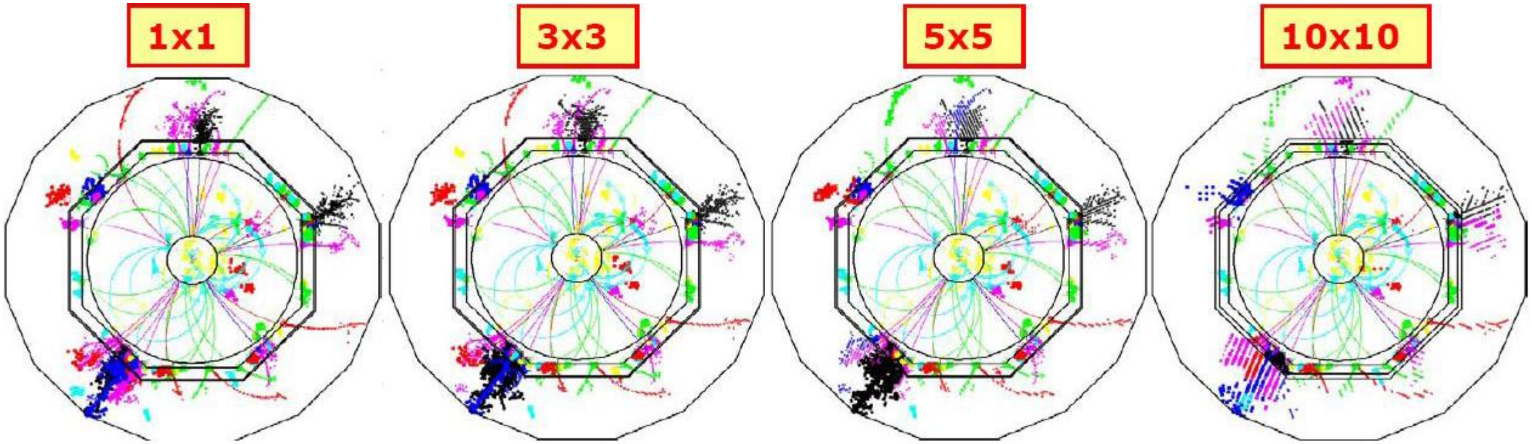


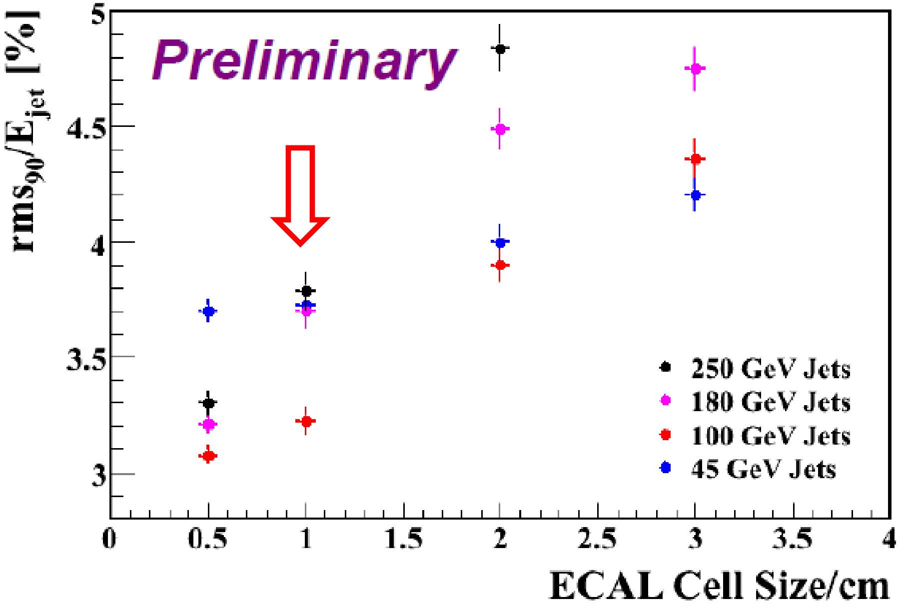
HCAL Layers	λ_I	
	HCAL	+ECAL
32	4.0	4.8
38	4.7	5.5
43	5.4	6.2
48	6.0	6.8
63	7.9	8.7

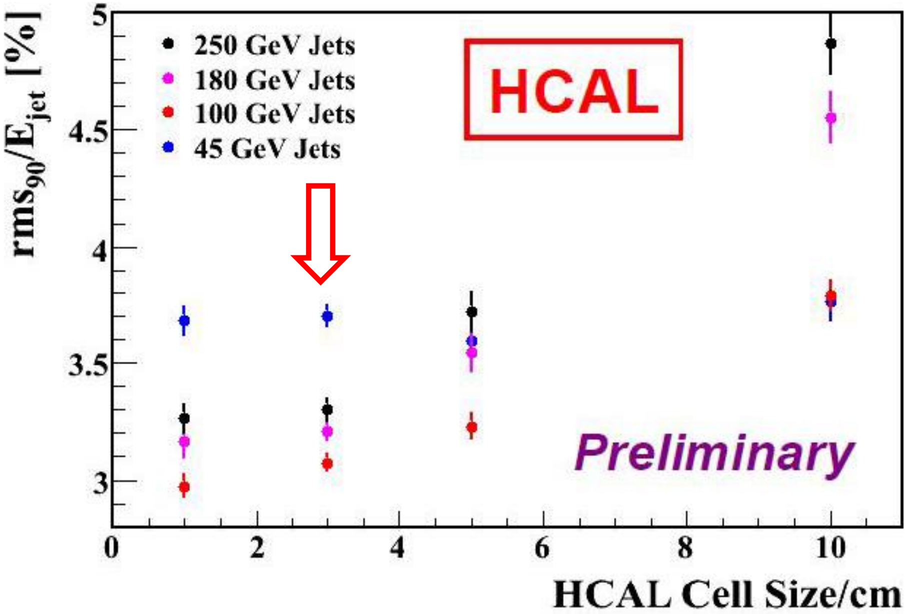
ECAL : λ_I = 0.8
HCAL : λ_I includes scintillator

★ Little motivation for going beyond a 48 layer (6 λ_I) HCAL
★ Depends on Hadron Shower simulation
★ "Tail-catcher": corrects ~50% effect of leakage, limited by thick solenoid

Segmentation: JER vs Cell Size







ThickGEM-DHCAL (China)

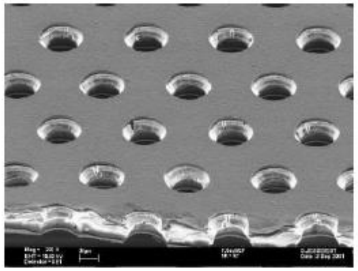
- □ Collab. Institutions: IHEP, UCAS, GXU, XJTU

Standard GEM

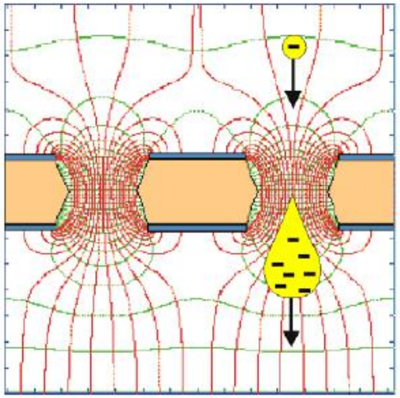
Developed from 1997 by F. Sauli (CERN)

Typical parameters:

- 50μm Kapton
- Ø60μm holes
- 100-200μm pitch



F. Sauli NIM A 433 (1997) 531

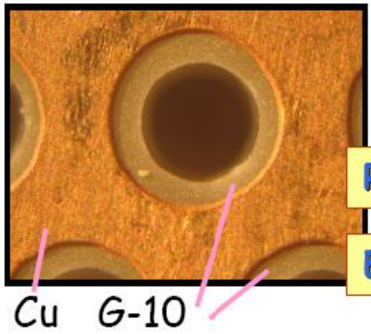


THGEM

Developed from 2004 by A. Breskin (Israel, CERN) :

Typical parameters:

Thickness t = 0.4 - 3 mm
Hole diameter d = 0.3 - 1 mm
Pitch a = 0.7- 7 mm



ROBUST !

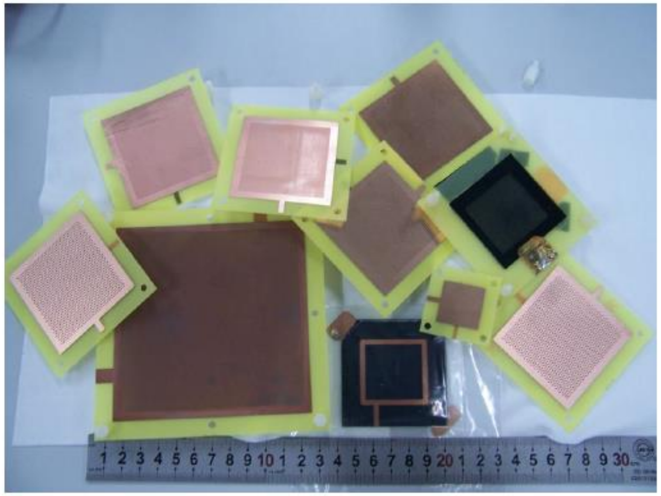
Easy produced

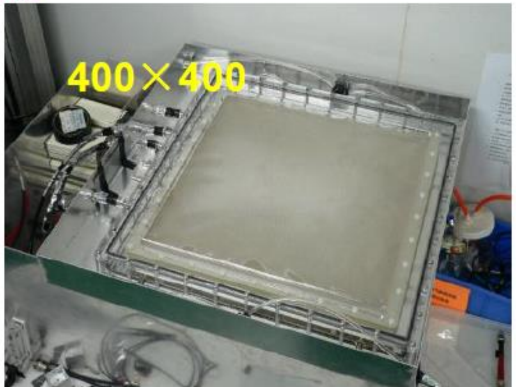
Chechik et al. NIM A535 (2004) 303

THGEM Designs and Measurements

● Production of THGEM

- ➢ Thickness=0.3~2.0mm,
- ➢ Size=3cm×3cm~40cm×40cm,
- ➢ Two factory can produce THGEM in China,
- ➢ 40×40cm THGEM have pass 120 hours stability test,
- ➢ The maximum size is 60cm×60cm.

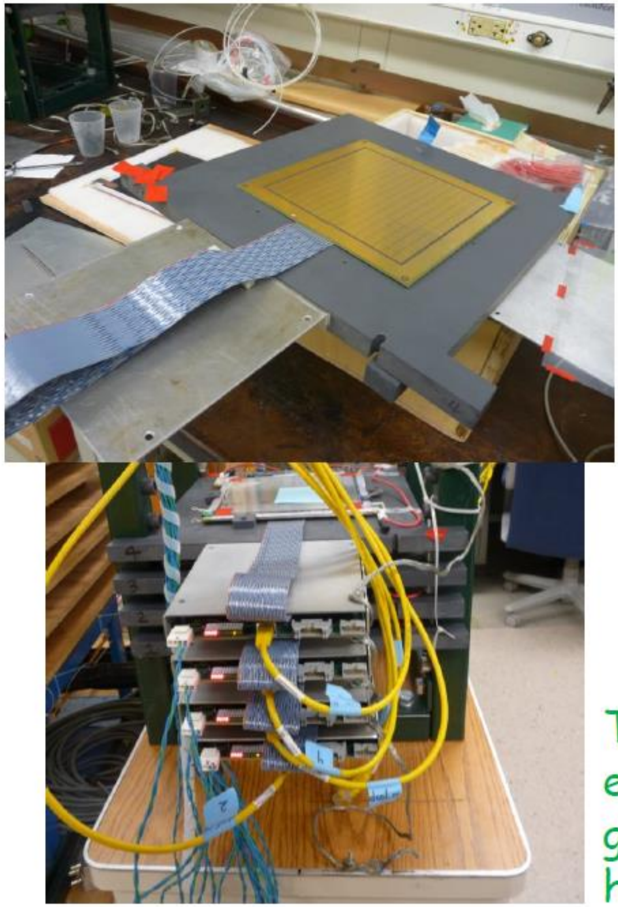




Designed by Xie Yuguang

Designed and produced by UCAS

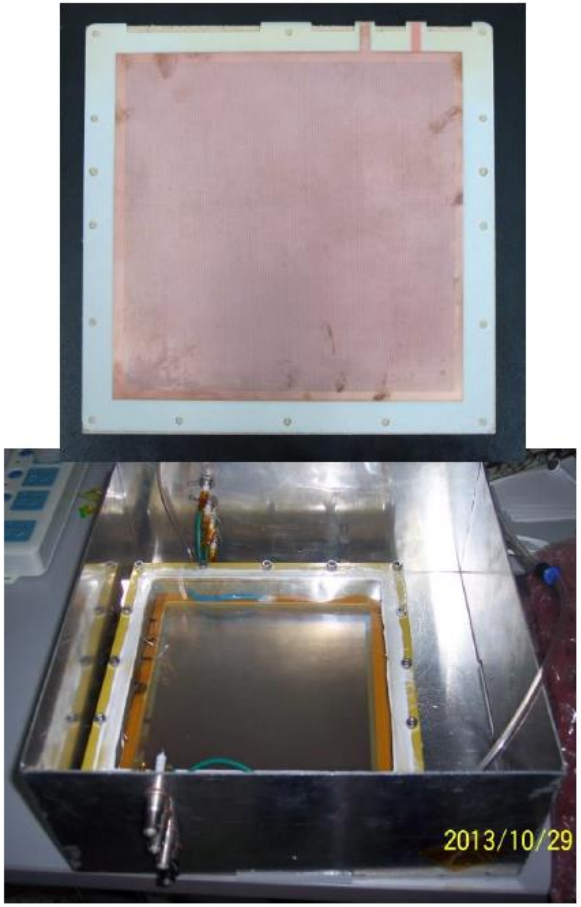
CEPC-DHCAL (Testing at UCAS)



Thank ANL electronics group for their help

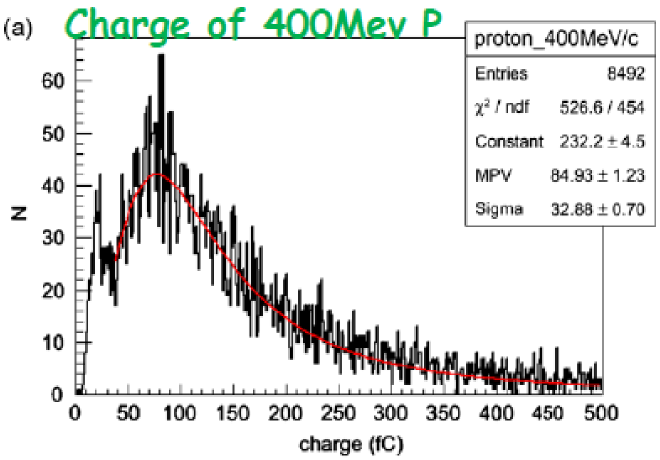
Electronics in CALICE

+



16X16cm^2 THGEM and Chamber

Results from Beam Test



The result of beam test:

NIMA 722 (2013) 43-48

The detection efficiency is about 90%, using Ne/CH4;

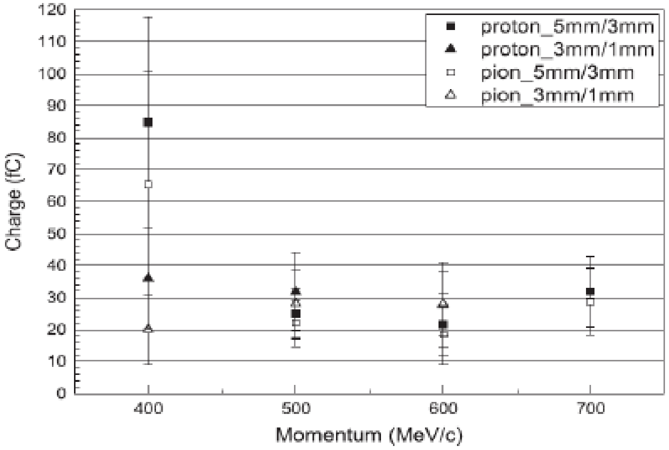


Fig. 6. Electric charge measured for p/π^+ at different momenta.

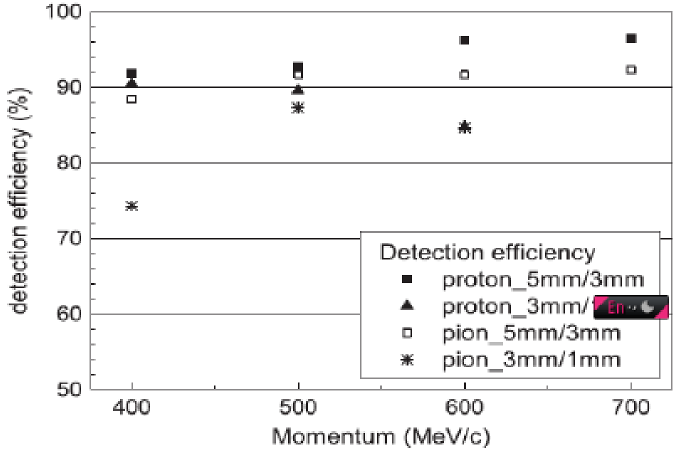
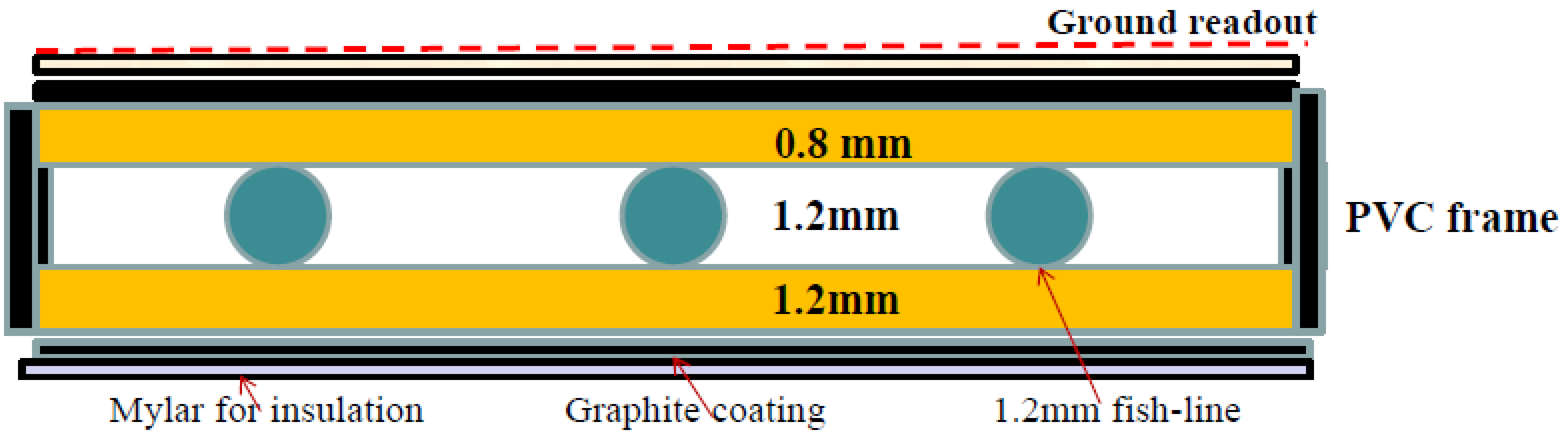


Fig. 7. Detection efficiency for p/π^+ at different momenta.

Thin-gap RPC design

- **Prototype:** Time & Position Resolution study

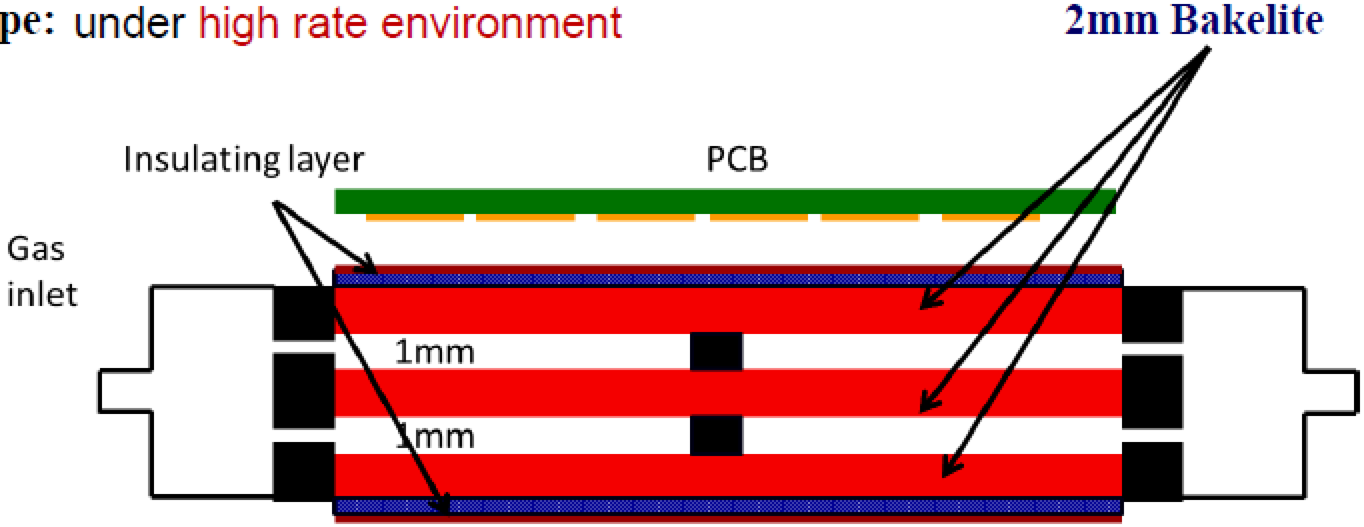


- Gas: $C_2H_2F_4$(94.7%), Iso-C_4H_{10}(5.0%), SF_6 (0.3%) → Avalanche mode
- Gap: **2 mm** → **1.2mm**
- Plate : Glass, $5\times10^{12}\Omega\cdot cm$, ~ **1mm**
- Readout pitch: **3cm** → **1.27mm**, strip width 1.0mm, **72** pitches
- Electronics: ATLAS Muon drift tube (**MDT**) readout, time resolution ~ 0.8ns

→ Good time resolution as < 0.5ns with full detection efficiency of >97%.
→ With fine readout pitch as 1.27mm, primary position resolution ~300μm, <1cm resolution for 2nd coordinate along strips, can be achieved.

Low resistive tgRPC

- **Prototype:** under high rate environment



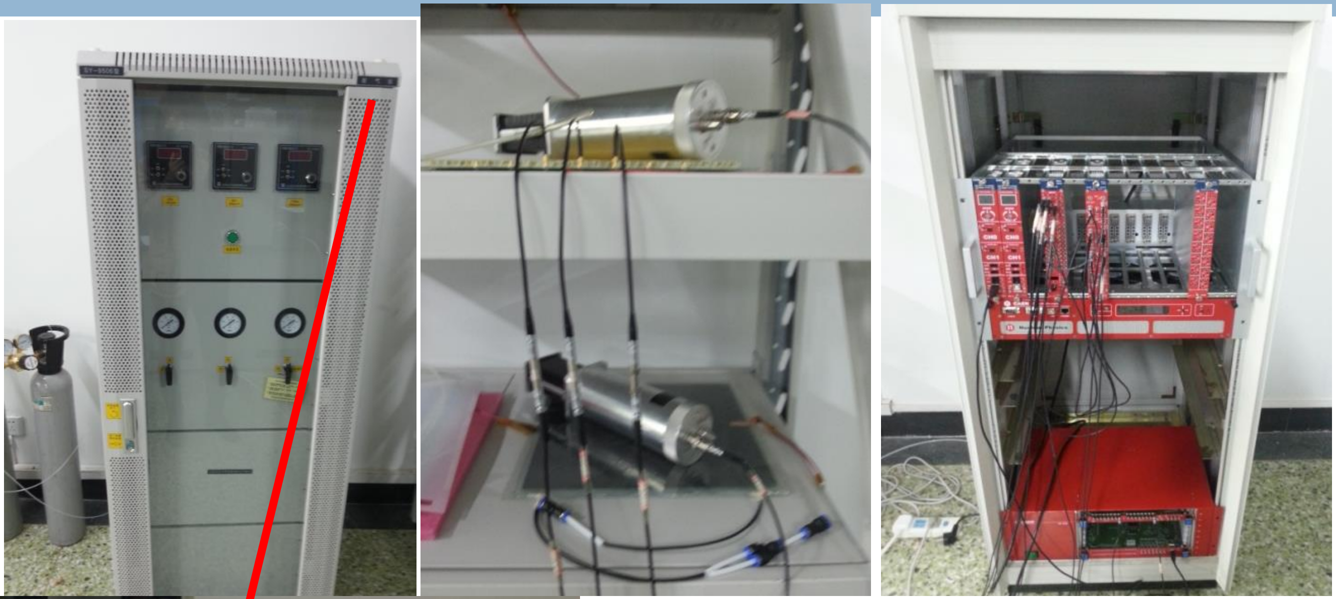
- Plate: Glass 5×10^{12}Ω·cm,1mm → Bakelite **1×10^{10}Ω·cm, 2mm**
- Bi-gap: improve efficiency at high rate operation, HV 2×6500V → ~ **13000V**
- Electronics : new front-end, working at low gas gain to reduce operating current

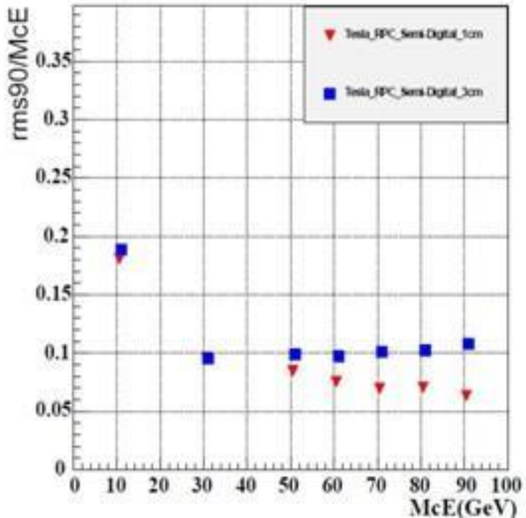
→ Bakelite bi-gap RPC fully function in 7kHz/cm^2 high rate test !

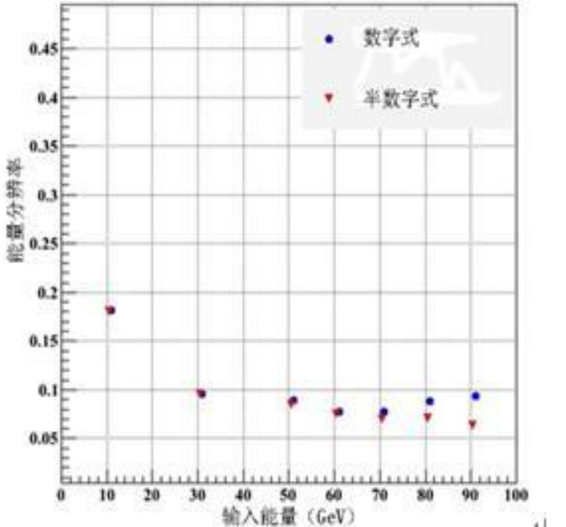
GRPC Test System

华北电力大学
NORTH CHINA ELECTRIC POWER UNIVERSITY

1- GRPC test system
2- 5 GRPC chambers with different glass
3- MC simulation: pad size vs energy resolution







TOC for CEPC-Calo CDR

- Introduction to calorimeters
- General layout

- ECAL for Particle Flow Approach (with different sensor and absorber options, may choose 2-3 options for CEPC)
  - Scintillator Tungsten Sandwich – Zhigang Wang(IHEP)
  - LAr+Pb (ATLAS) – Hong Ma (BNL)

  - Silicon Tungsten Sandwich
  - Monolithic Active Pixel Sensor (MAPS)

TOC for CEPC-Calo CDR

- **HCAL for Particle Flow Approach (with different sensors and absorbers options, may choose 2-3 options for CEPC)**
  - DHCAL (RPCs) – Lei Xia (ANL/SJTU) 、Liang Han(USTC)
  - SDHCAL (GRPCs) – Ran Han (NCEPU)
  - DHCAL (ThGEM) – Boxiang Yu (IHEP)
  - Liquid Scintillator + Pb + SiPMT – Junguang Lv (IHEP)
  - Fe-scint + Cu-LAr (ATLAS) – Hong Ma (BNL)
- **Muon (Scint., RPC)- Yuguang Xie(IHEP), Qinmin Zhang(XJTU)**
- **Calorimeter Calibration and Alignment**
- **Front-End Readout System**
- **Power and Cooling System**
- **Cost Estimation**

2014年相关自然科学基金申请

- 高能所俞伯祥申请“基于THGEM的数字量能器的研究”- 面上项目
- 华北电力大学韩然申请“基于GRPC高粒度强子量能器的读出系统研究”-青年基金
- 上海交大杨海军，李亮和美国ANL的Lei Xia, Jose Repond 联合申请“高性能成像式量能器的研究”- 重点国际合作研究项目
- 希望能得到同行专家的大力支持和基金委的资助，使相关项目能顺利启动和开展。

参与单位和初步的人员安排

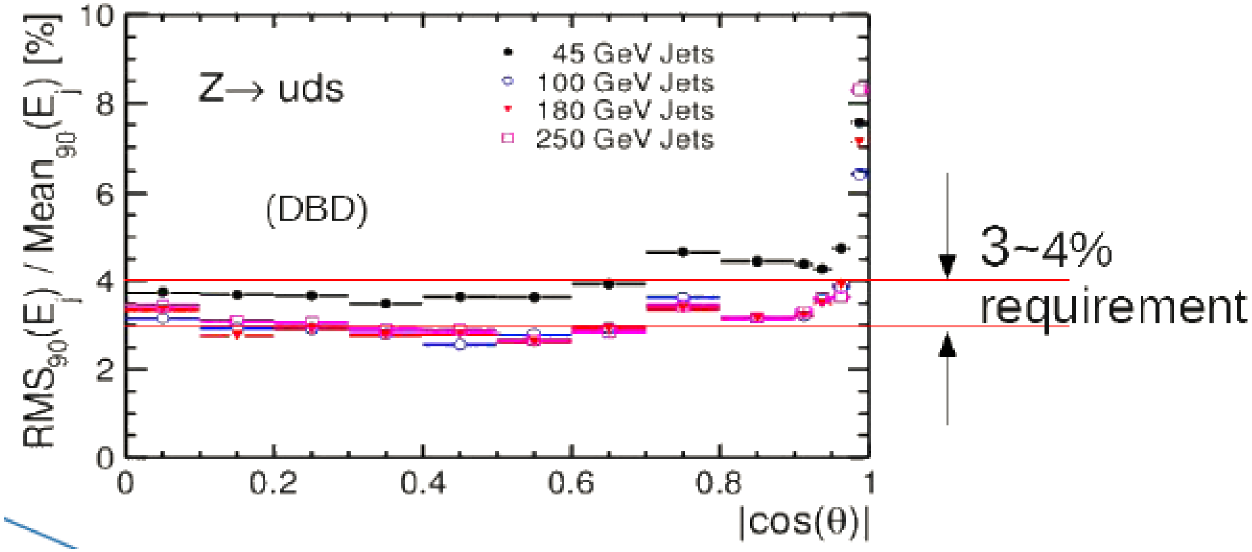
- 工作组邮箱：cepc-calo@maillist.ihep.ac.cn
- 高能所:胡涛，张家文，方建，俞伯祥，谢宇广，王志刚等，ECAL/HCAL
- 国科大：郑阳恒，谢一刚，刘谦，陈思等，THGEM-DHCAL
- 南京大学:陈申见，张慧君等，模拟和优化
- 武汉大学：周详，张振宇,王峰等，电磁量能器的材料选型，性能优化
- 科大：韩良，鄢文标，刘明辉，王驰，魏逸丰等，RPC，muon子系统
- 华北电力大学：韩然，曹博，杨全瑞等，SDHCAL研发
- 南开大学：喻纯旭，徐音等,模拟和优化
- 北京大学：王大勇，磁铁和muon子系统
- 山东大学：都艳艳，muon子系统
- 西安交大：张清民，muon子系统
- 上海交大：杨海军,李亮,符长波等，RPC
- 美国ANL：Lei Xia （DHCAL based on RPC）
- 美国BNL：Hong Ma （ATLAS Calo）

Thank You ！

Baseline Approach (PFA)

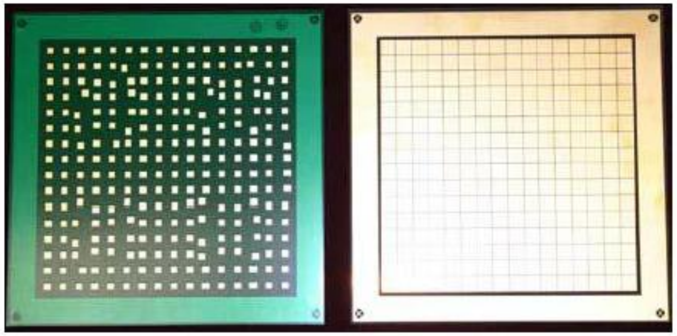
- **Particle Flow Algorithm requires high granularity and segmentations in both lateral and longitudinal directions.**
  - ECAL(~ 5x5 mm^2)
  - HCAL(1x1 to 3x3 cm^2)

- **PandoraPFA**
- **ArborPFA**

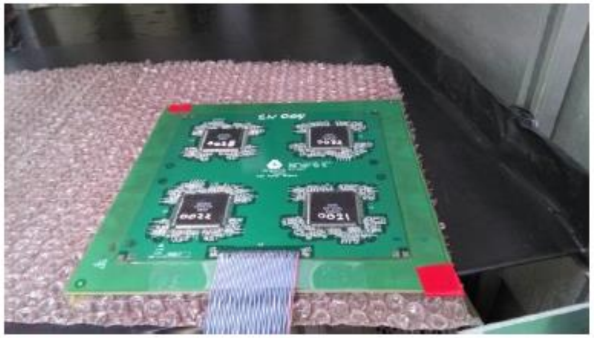


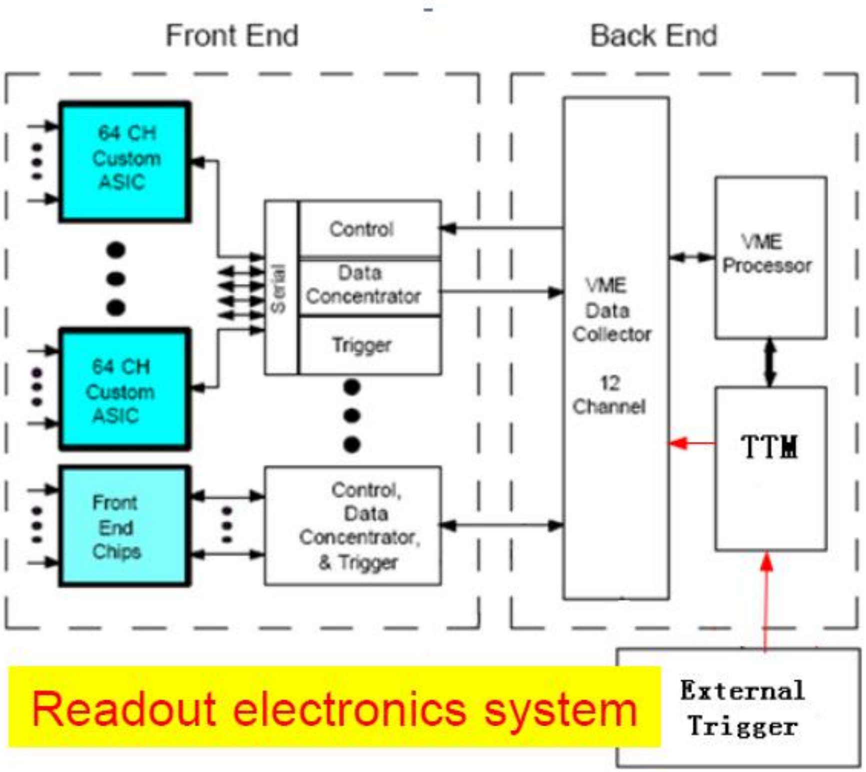
Readout Electronics System

We have 4 set 256 channels readout system



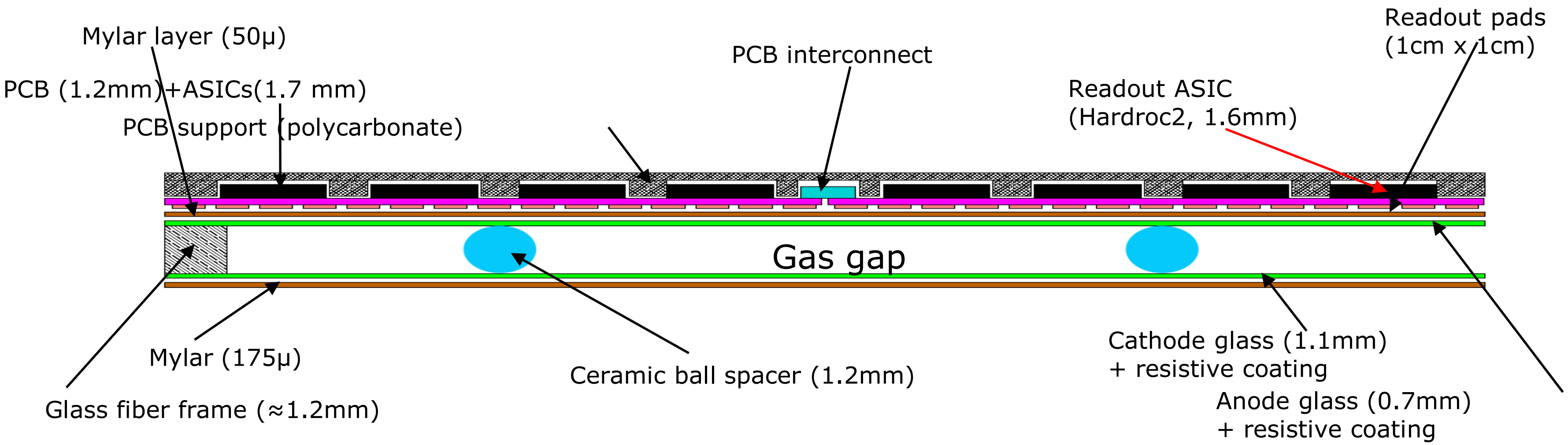
readout electronics board
$16\times16\text{cm}^2$





Readout electronics system

Structure of an active layer of the SDHCAL



Mylar layer (50µ)

PCB (1.2mm)+ASICs(1.7 mm)

PCB support (polycarbonate)

PCB interconnect

Readout ASIC
(Hardroc2, 1.6mm)

Readout pads
(1cm x 1cm)

Gas gap

Mylar (175µ)

Glass fiber frame (≈1.2mm)

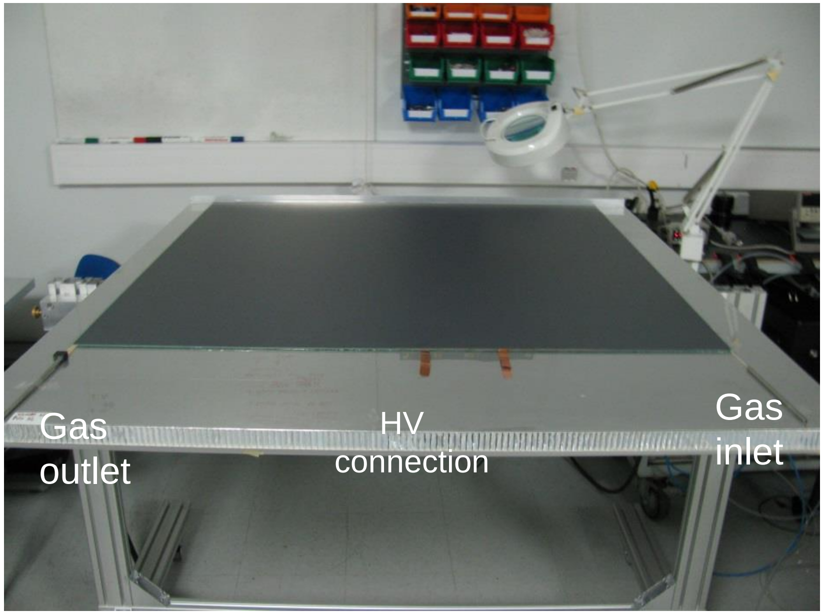
Ceramic ball spacer (1.2mm)

Cathode glass (1.1mm)
+ resistive coating

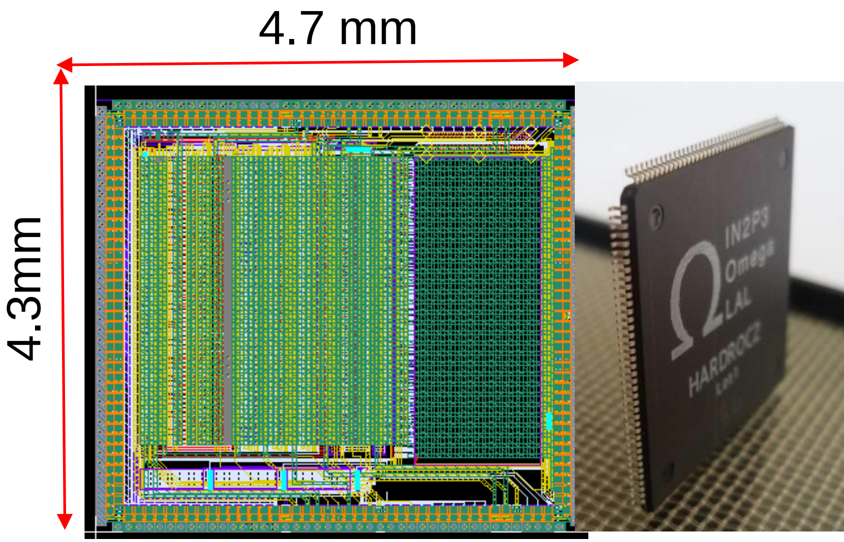
Anode glass (0.7mm)
+ resistive coating

Large GRPC R&D

- ✓ Negligible dead zone
  (tiny ceramic spacers)
- ✓ Efficient gas distribution system
  (channeling gas inlet and outlet)
- ✓ Homogenous resistive coating
  (special paint mixture, silk screen print)



Electronics readout system R&D

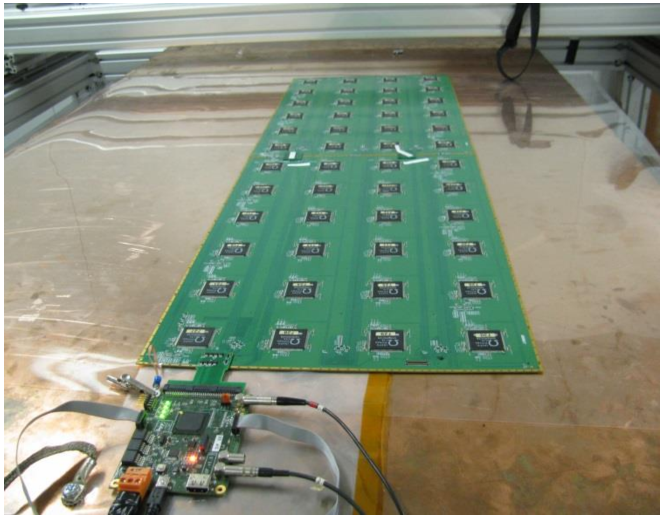


ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity
Power-Pulsed (7.5 μW in case of ILC duty cycle)

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

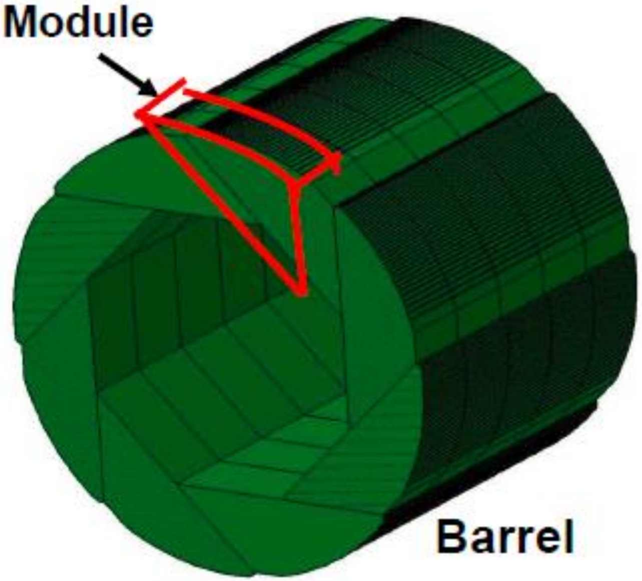
Tiny connectors were used to connect the PCB two by two so the 24X2 ASIC are daisy-chained. Power-Pulsed,70million

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



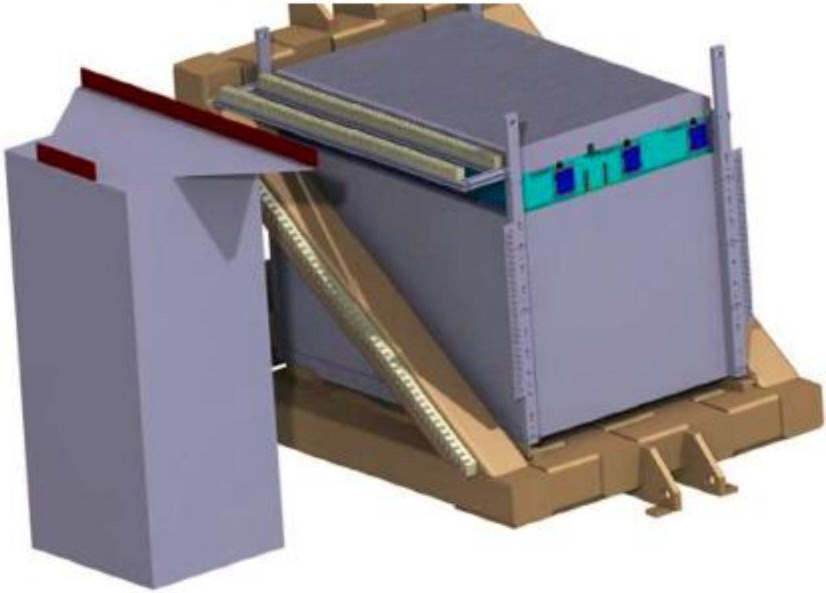
SDHCAL technological prototype

From Ran Han’s talk



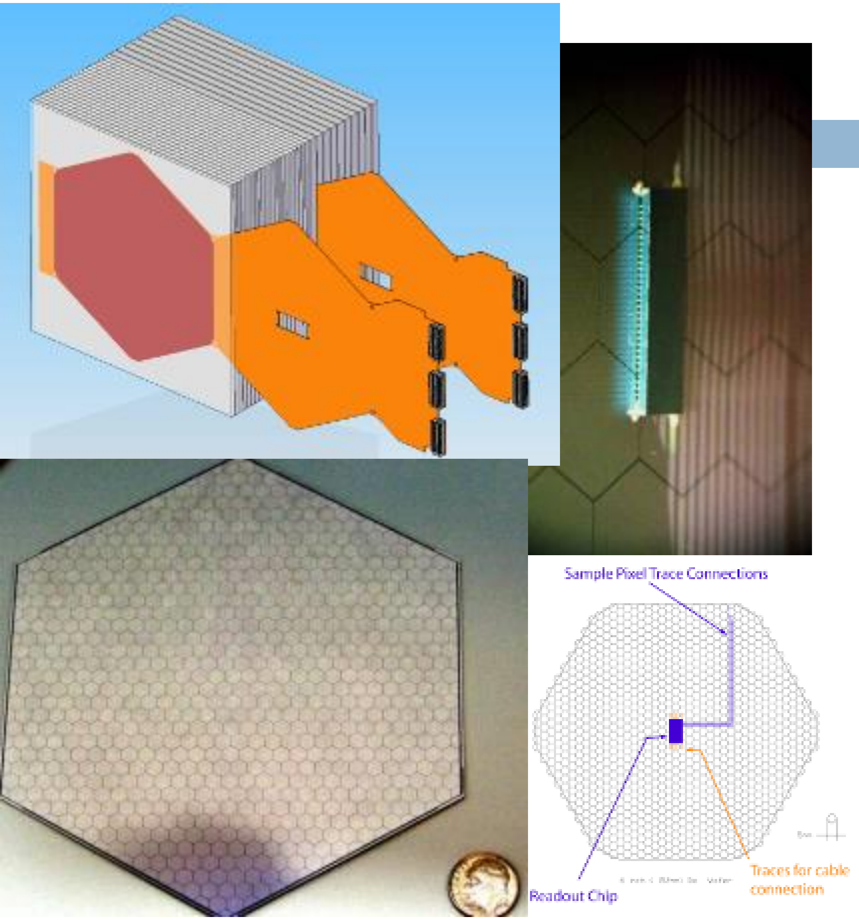
-For PFA, higher granularity is essential. 1cm2 lateral segmentation is a good compromise

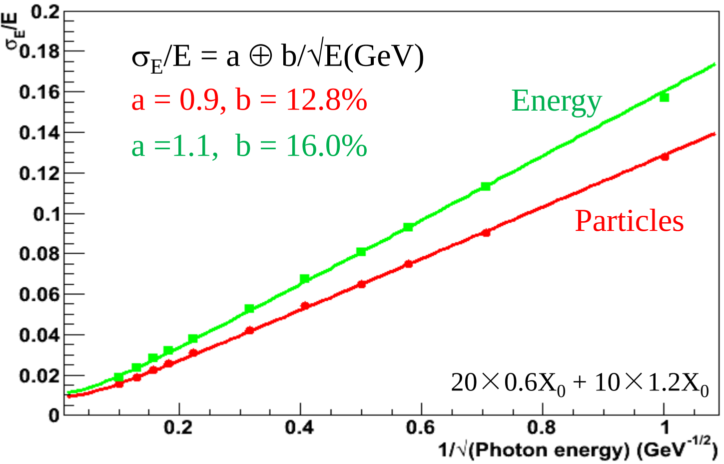
GRPC was chosen has Challenges
-homogeneity for large surfaces (3m*1m)
-Thickness of only few mms
(the detector in magnetic filed)
-Services from one side
-Embedded power-cycled electronics
-Self-supporting mechanical structure

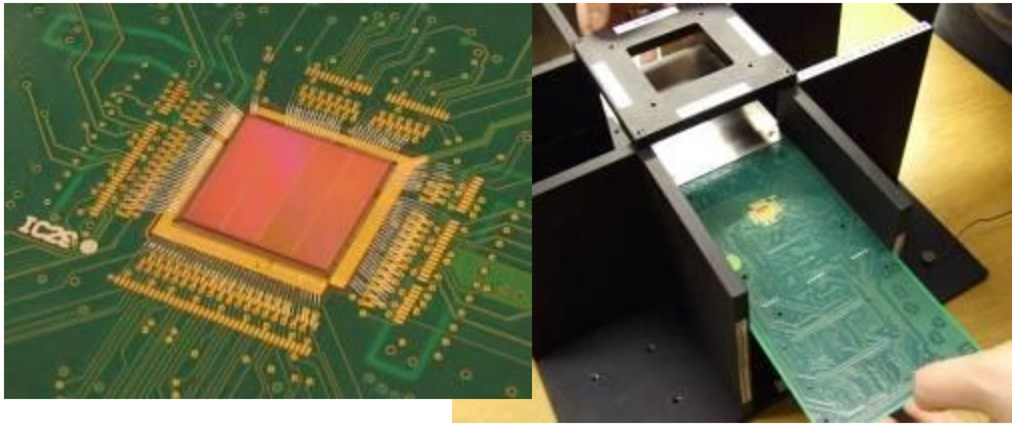


A prototype with 48 GRPC of 1 m2 is conceived as a demonstrator

ECal efforts







SiD Si/W ECal:

- Target at very compact readout and small cell (~0.13cm^2)
- Address all technical issues from the beginning
- Push technical limits in many aspects
- Total active medium thickness targets at ~1mm
- Test beam module expected soon

CALICE MAPS Digital ECal:

- Extremely small cell size (0.005x0.005cm^2)
- Working on sensor R&D
- Did sensor test beam

Feature of THGEM :

- Simplicity, Robustness, is similar to glass RPC
- Sub-mm spatial resolution, better than glass RPC
- Few-ns temporal resolution , better than glass RPC
- 1 MHz/mm^2 rate capability . better than glass RPC
- But glass RPC may be cheaper (or expensive)

Result from Breskin's group

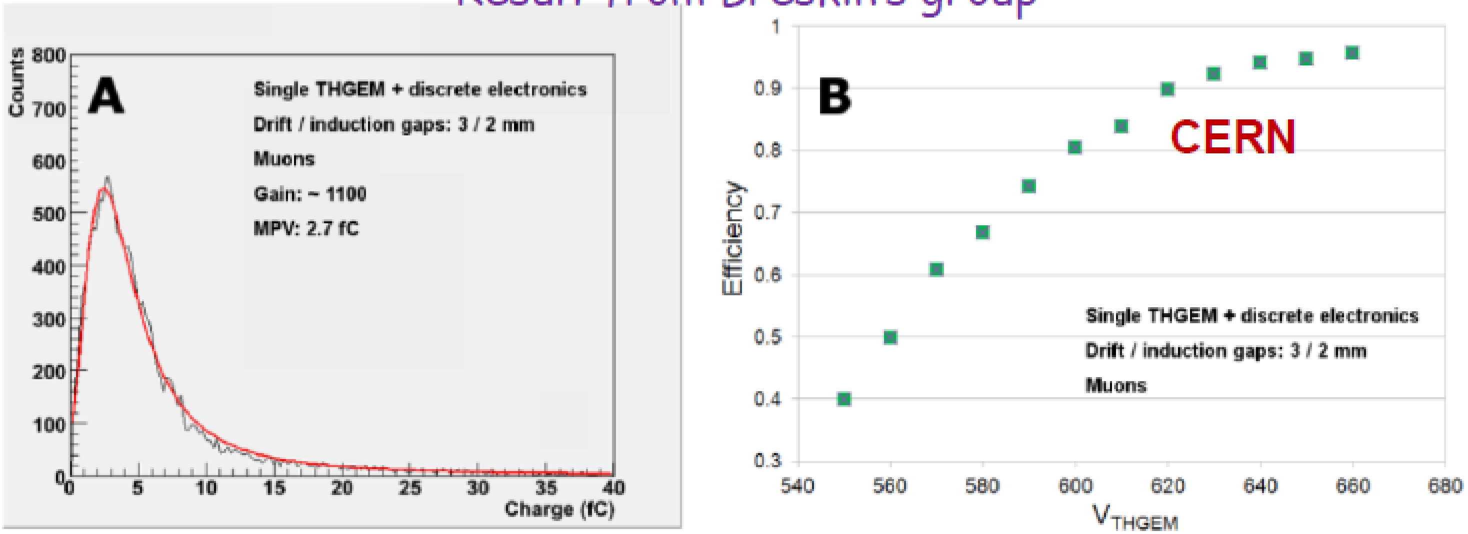
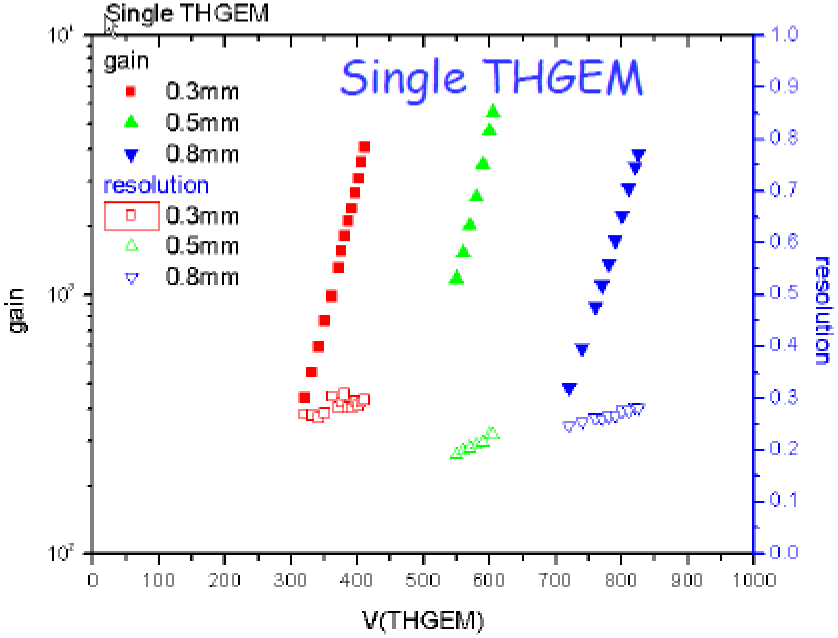
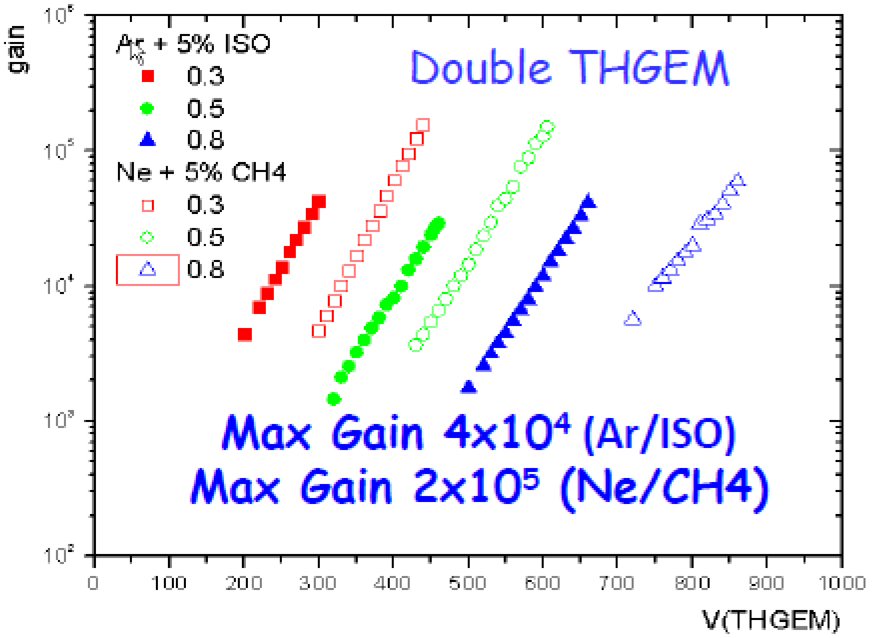


Figure 4: (A) Charge distribution of muons recorded with a 10×10 cm^2 single-THGEM detector (3 mm drift and 2 mm induction gaps) using a charge sensitive preamplifier connected to 4 pads. Ne/5%CH_4; gain ~1.1×10^3. The line matching the distribution is a Landau fit to the data. (B) Muon detection efficiency vs. THGEM voltage for the same configuration.

➤ Gas gain

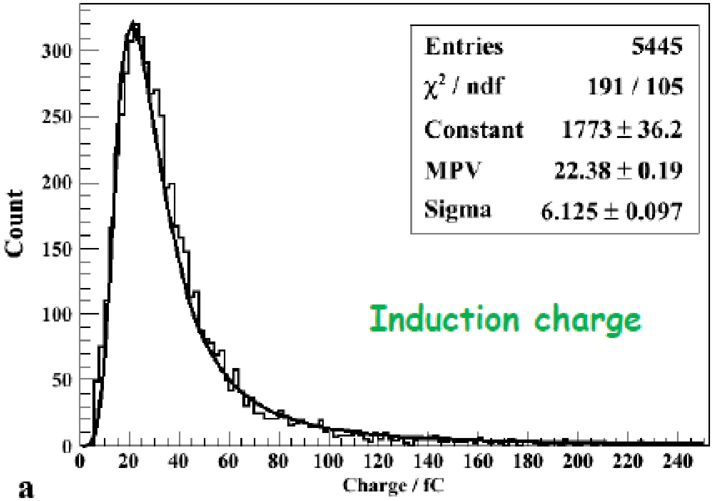




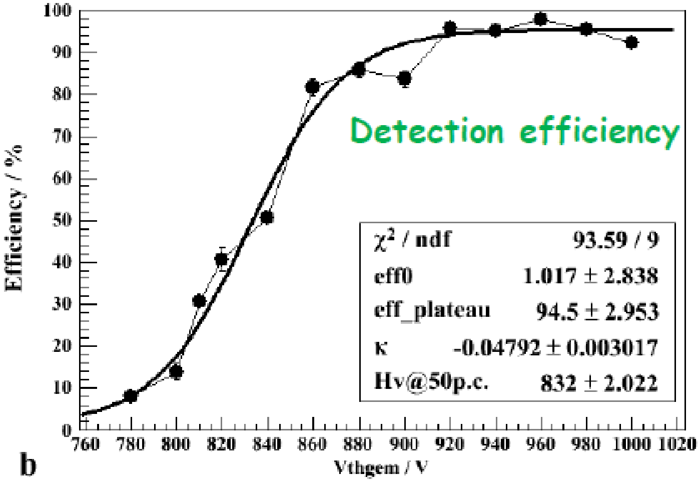
Max Gain 4×10^4 (Ar/ISO)
Max Gain 2×10^5 (Ne/CH4)

Gain

Results from Cosmic Ray Test



a



b

- ➢**Result of Cosmic Ray**

Single Layer Structure(0.2mm):

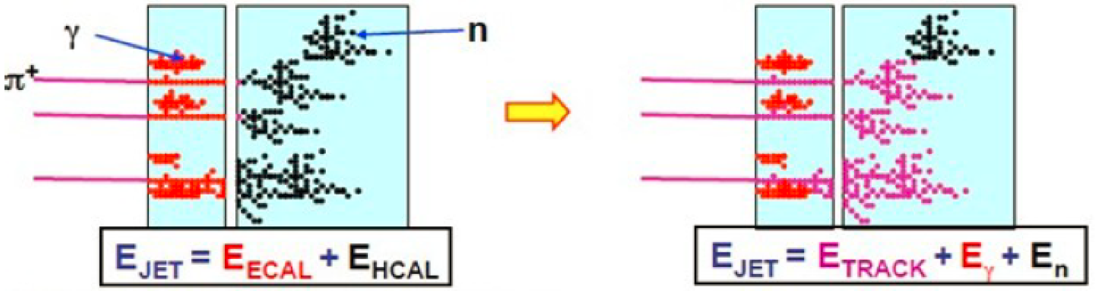
Drift:	8mm
Induction :	2mm

Detection efficiency: 94.5%

Tested by Dr. Xie Yuguang

Particle Flow Calorimetry

- **In a typical jet**
  - 60% of jet energy in charged hadrons
  - 30% in photons (mainly from pin0->gamagama)
  - 10% in neutral hadrons (mainly n and K_L)



$\sigma_E / E = 60\% / \sqrt{E(GeV)}$ $\sigma_E / E = 20\% / \sqrt{E(GeV)}$

- **Traditional Calorimetric Approach**
  - Measure all components of jet energy in ECAL/HCAL
  - ~70% of energy measured in HCAL:
  - Intrinsically “poor” HCAL resolution limits jet energy resolution
- **Particle Flow Calorimetry paradigm**
  - charged particles measured in tracker (essentially perfectly)
  - Photons in ECAL:
  - **Neutral hadrons(ONLY) in HCALOnly 10% of jet energy from HCAL->** Much imporved resolution

3.1.2 Electromagnetic Calorimetry

The SiD ECAL consists of alternating layers of tungsten radiator and large-area silicon diode detectors. The design minimizes the effective Moliere radius by packing 300 μ m thick silicon sensors into 1 mm gaps between tungsten plates. Longitudinally, the ECAL consists of 30 alternating layers of tungsten and silicon. The first 20 layers of tungsten each have a thickness of 2.7 mm; the last 10 layers have double this thickness, making a total depth of about 29 radiation lengths at normal incidence. This results in an energy resolution of $17\%/\sqrt{E(\mathrm{GeV})}$. The inner radius (length) of the barrel is kept relatively small 127 (359) cm, to minimize the required area of silicon needed. The endcaps are located inside the barrel and start at a distance of 168 cm from the interaction point.

Figure 3.3 is a diagram of a single channel of the 1024-channel ASIC readout chip, called KPiX, indicating its functional features. KPiX has a 1:2500 dynamic range to accommodate the tremendous range in energy densities between MIPs and the cores of very high energy EM showers. The calculated noise level is about 1000 e's, to be compared with the MIP signal charge 25 times larger. The chip can store four hits (times and pulse heights) per bunch train for each pixel. The chip, a modification of which is adapted to reading out the tracker microstrip sensors, is power-pulsed. The chip has been prototyped, and is in the final debug stages prior to a full submission.

The HCAL is a sandwich of absorber plates and detector elements. The SiD starting point uses steel for the absorber and resistive plate chambers (RPCs) as the detector. One of the criteria for the HCAL is to minimize the gaps between absorber plates, because an increase in the gap size has a large impact on the overall detector cost. The current gap size is 12mm. To satisfy the stringent imaging requirements of the PFA algorithm, the transverse segmentation is required to be as small as 1 to a few cm^2, and every layer is read out separately. The absorber consists of steel plates with a thickness of 20 mm (approximately 1.1 X_0). The cell structure, which is the same for the barrel and the endcaps, is repeated 34 times, leading to an overall depth of the HCAL corresponding to four interaction lengths. Tungsten is also being considered for the absorber. Several detector options are under consideration. Glass RPCs have been shown to be reliable and highly efficient. The development of economical large area GEM foils and Micromegas are making these approaches viable as well. Scintillating tiles, readout with silicon photomultipliers, are another option.