Detectors R&D and Applications at CIAE

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Outline

- R&D of GEM at CIAE
- R&D of MicroMegas at CIAE
- R&D of RPC at CIAE
- R&D of Other Detectors and Electronics at CIAE
- Summary and Perspective

Developments of Advanced Gas Detectors

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R&D of GEM at CIAE

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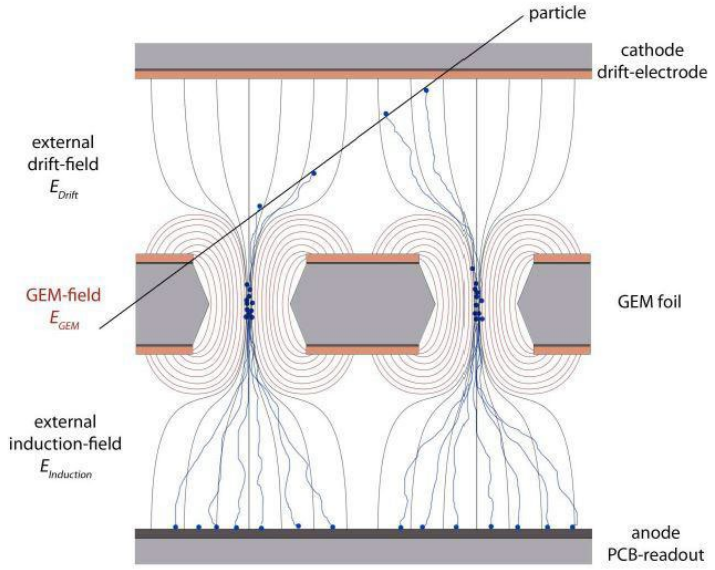
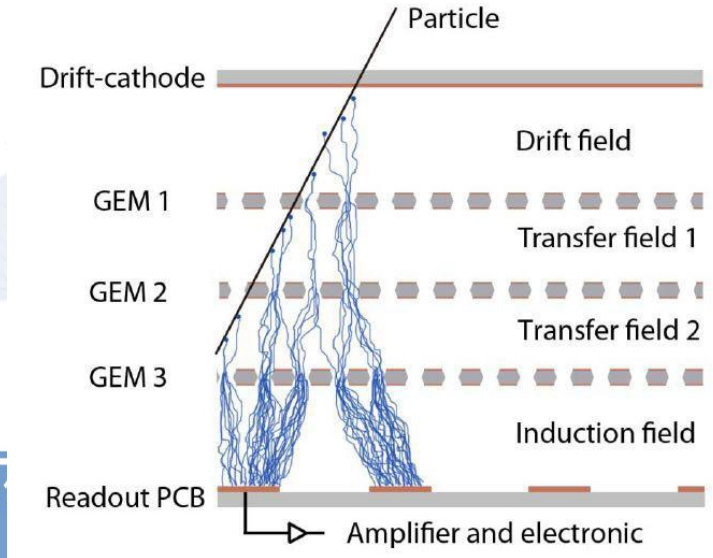
Structure of GEM

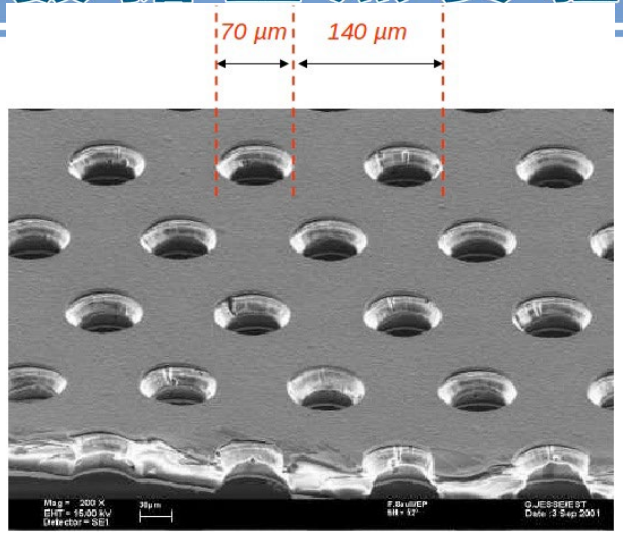
- **GEM detector:**
  - **Cathode, Drift field, GEM foil, Induction field and Readout board.**
  - **GEM foil： the most important part of GEM detector . Normally 3 GEM foils in one GEM detector.**



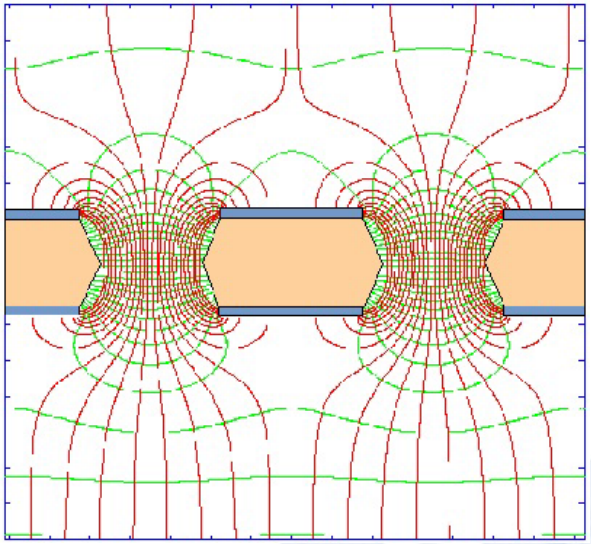


GEM Foil

1. Typical GEM Foil has 3 layers, two 5μm thick copper foils and one 50μm thick kapton foil in the middle.
2. Diameter of the hole is 70 μm , and the distance between them is 140 μm .
3. Apply electric voltages on the two copper layers.
4. Electric Field is very strong in the hole area, and weak outside the hole area.



GEM Foil



GEM Field

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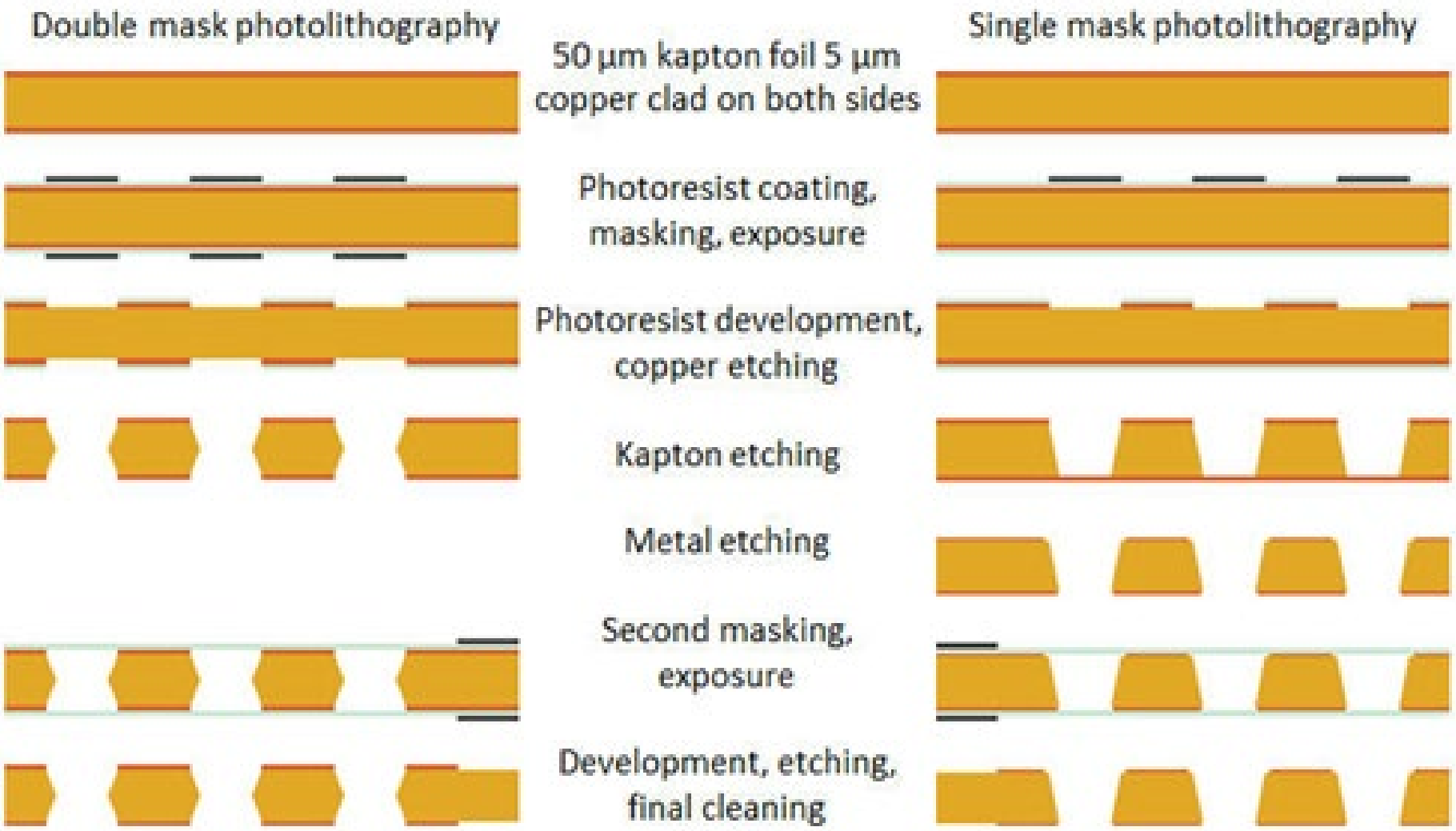
The Procedure of GEM Foil



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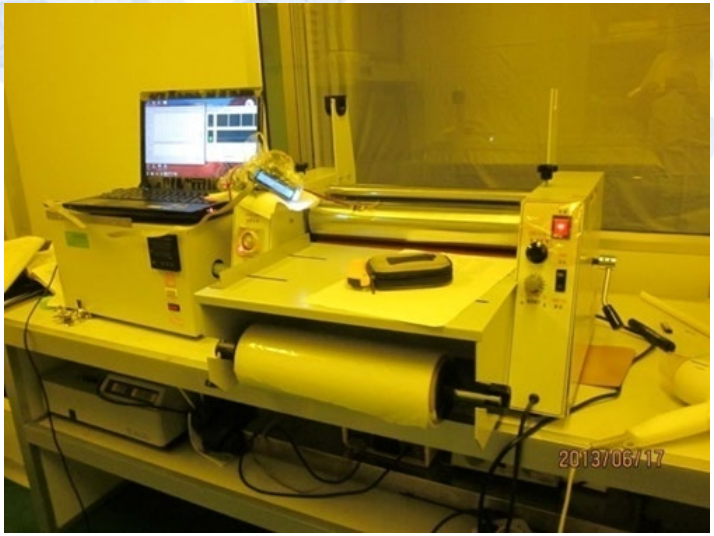
GEM License and Training

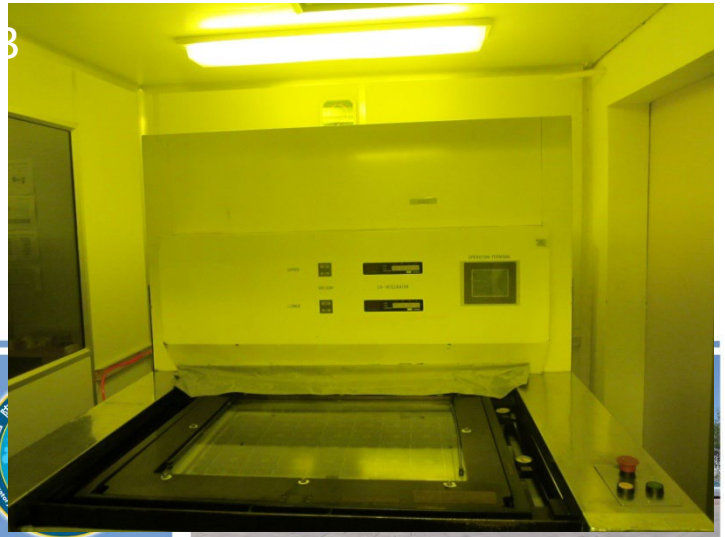
CIAE is the first chinese institution which signed officially the LICENSE AGREEMENT FOR MANUFACTURING AND COMMERCIALISATION OF GEM FOILS AND GEM-BASED PRODUCTS with CERN.

I took a training for GEM foil at CERN.

Photolithography Room Construction At CIAE

The Equipments for Lamination and Exposure of Dry Film Photoresist





Lamination and exposure of dry film photoresist are the most important and difficult steps for GEM foil production.

We have established a yellow light zone, Hot Roll Lamination (HRL) machine and Exposure system.

We invited a senior engineer from a famous electronic factory to CIAE and taught the PCB technology.

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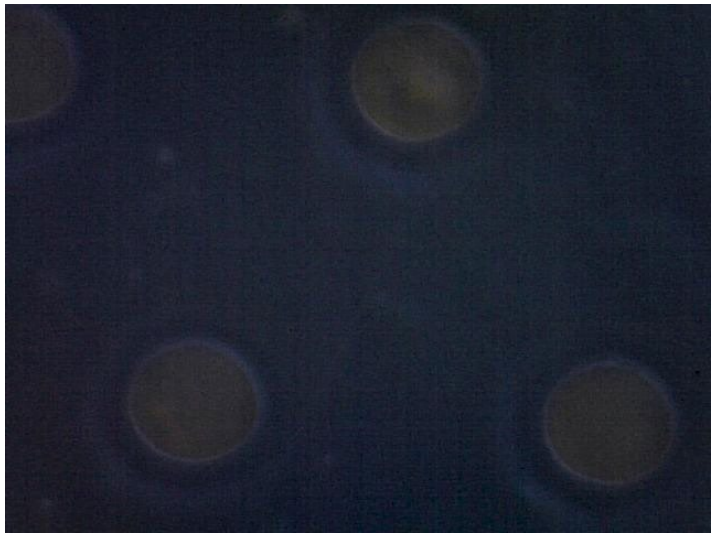
Exposure of Dry Film Photoresist

We use negative photoresist for GEM image transfer, unexposed areas are relatively unchanged and easily washed out during the development.



To obtain an identical copy of the photo-mask to the photoresist, vertical sidewalls in the resist are important.

We can observe the image transfer with good accuracy.

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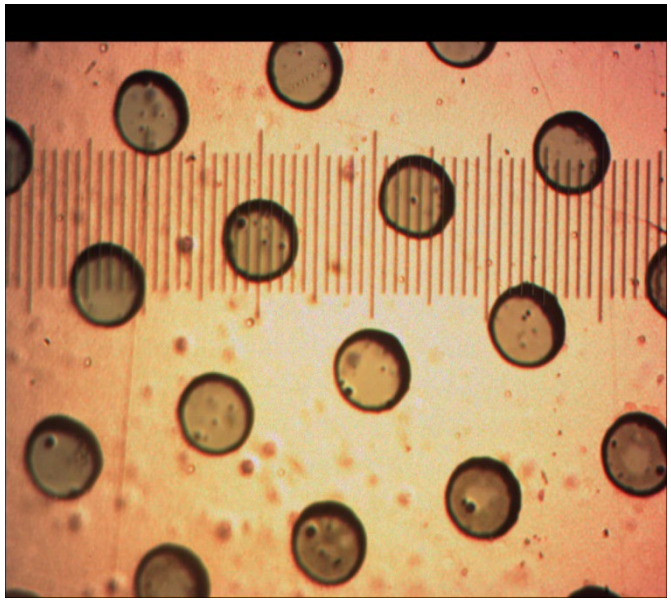
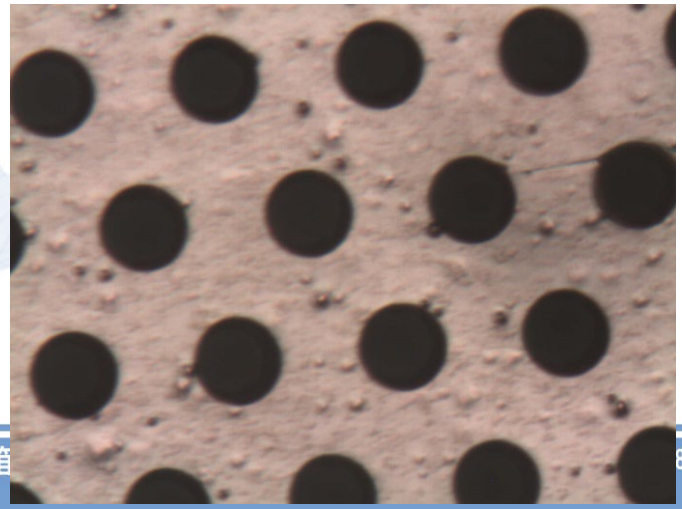
Copper Etching and Kapton Etching

- The size of the hole is 70um as expected

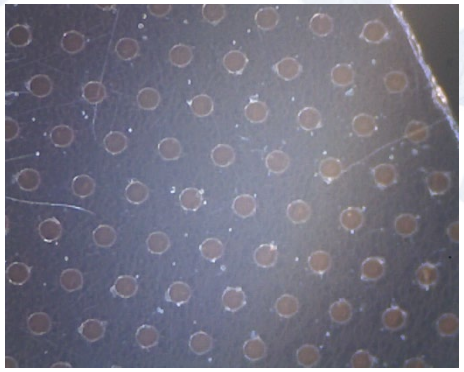




Etching Room Construction

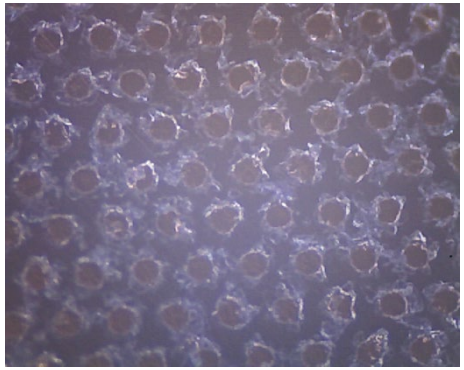
Comparison of Foils Made in Different Conditions

Insufficient development

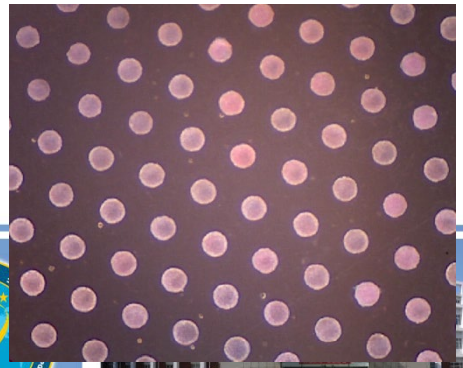


Good development

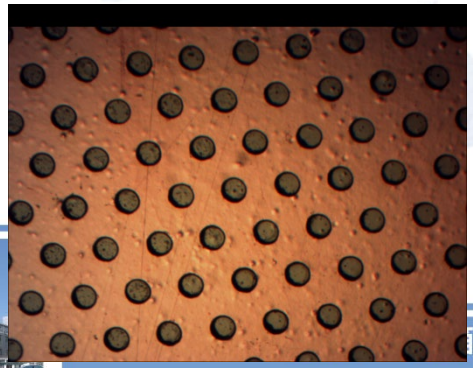
Excessive development



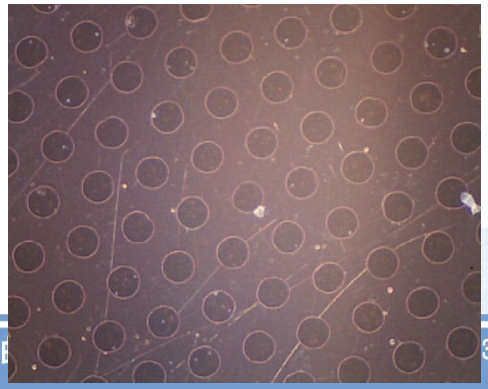
Insufficient copper etching



Good copper etching



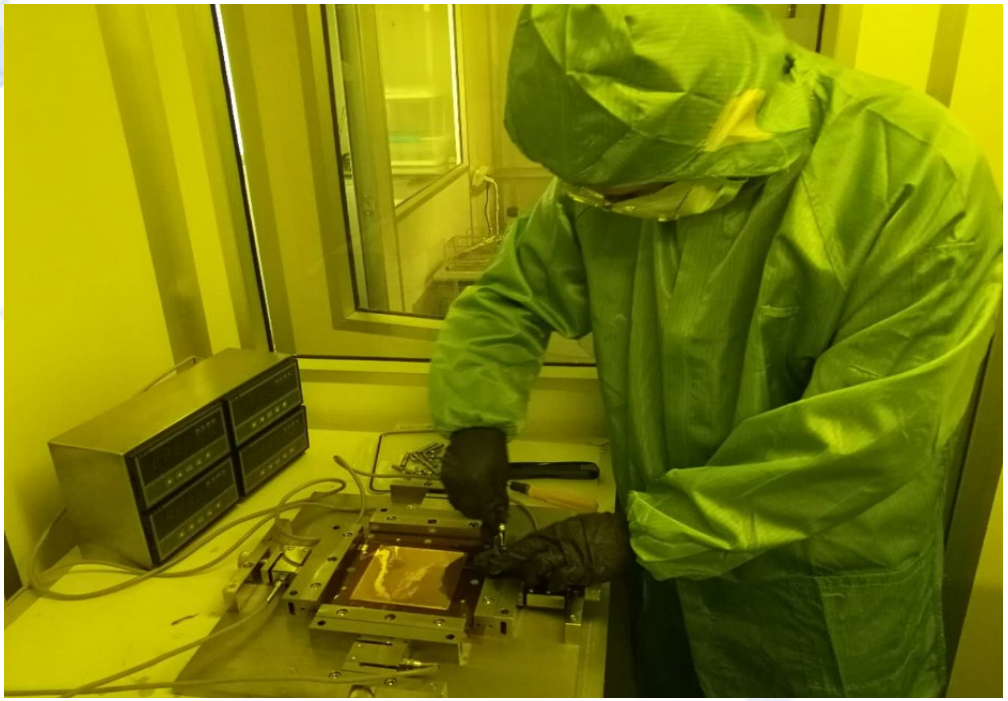
Excessive copper etching



50cm*50cm GEM Foil

- The 50cm*50cm GEM foils were made successfully.
- single-mask method was used.
- We did more than 200 samples before reaching this result.

GEM Detector Assembly at CIAE



active area 10*10cm

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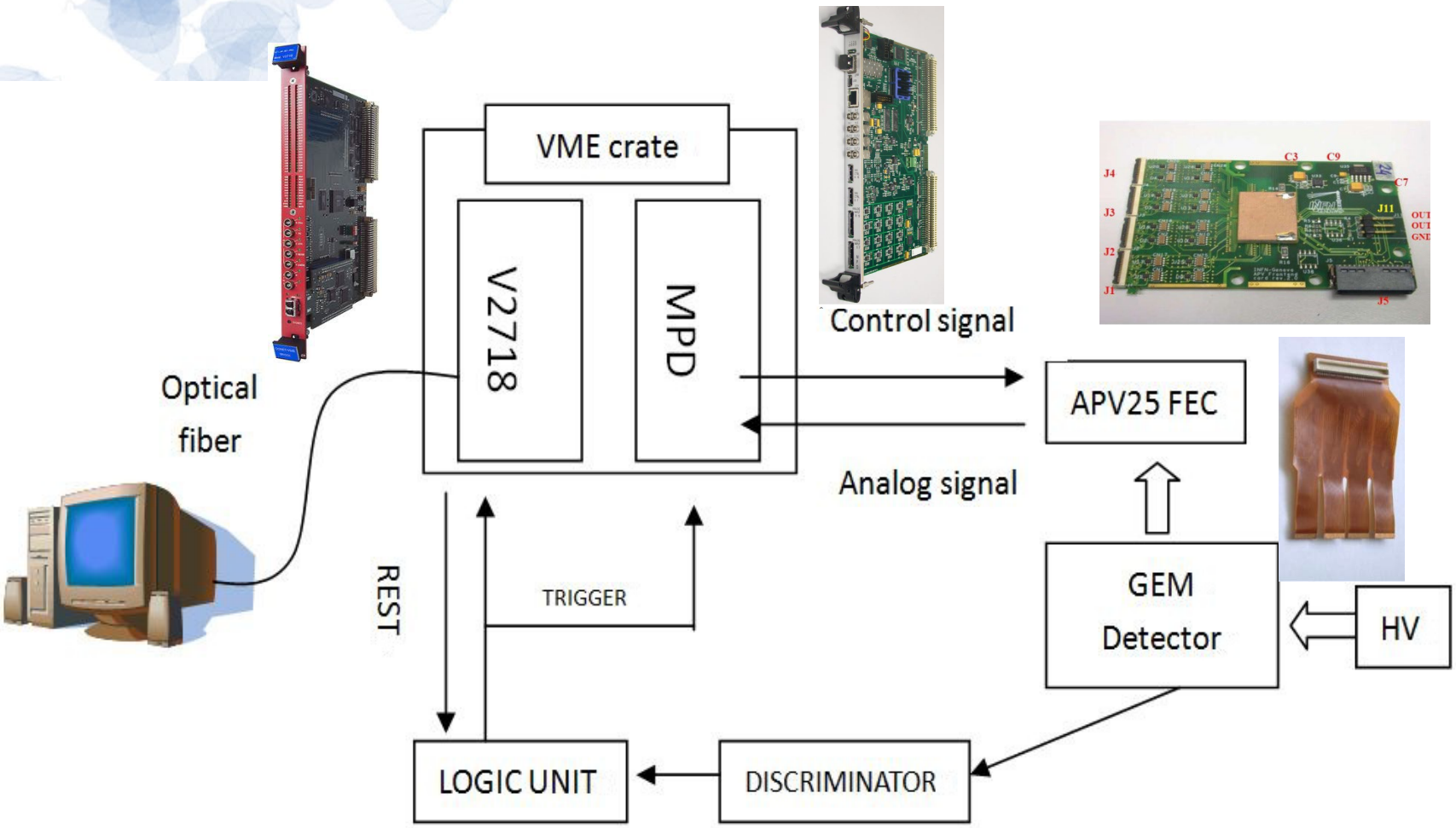
GEM Test system



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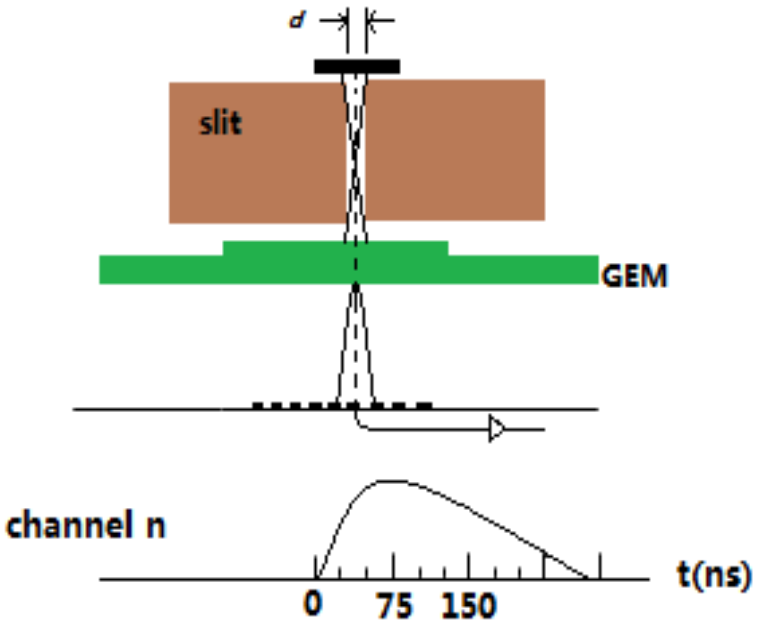
Spatial resolution

$$\sigma_{tot}^2 = \sigma_{GEM}^2 + c_1\sigma_{geometry}^2$$

When: $\sigma_{geometry} \ll \sigma_{GEM}$

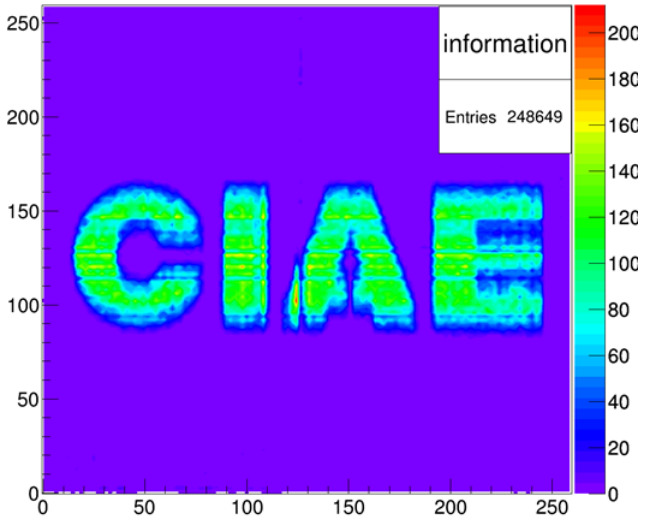
$$\sigma_{tot}^2 \cong \sigma_{GEM}^2$$

- Slit(um): 20;
- Ar: CO_2=70% : 30%;
- HV: 3600V;
- The distance between strips: 400um.

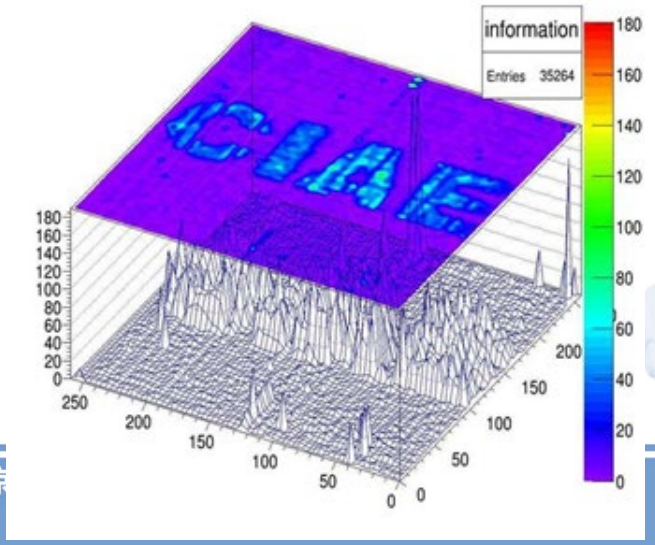


Spatial resolution≈76um

X-ray imaging @ CIAE

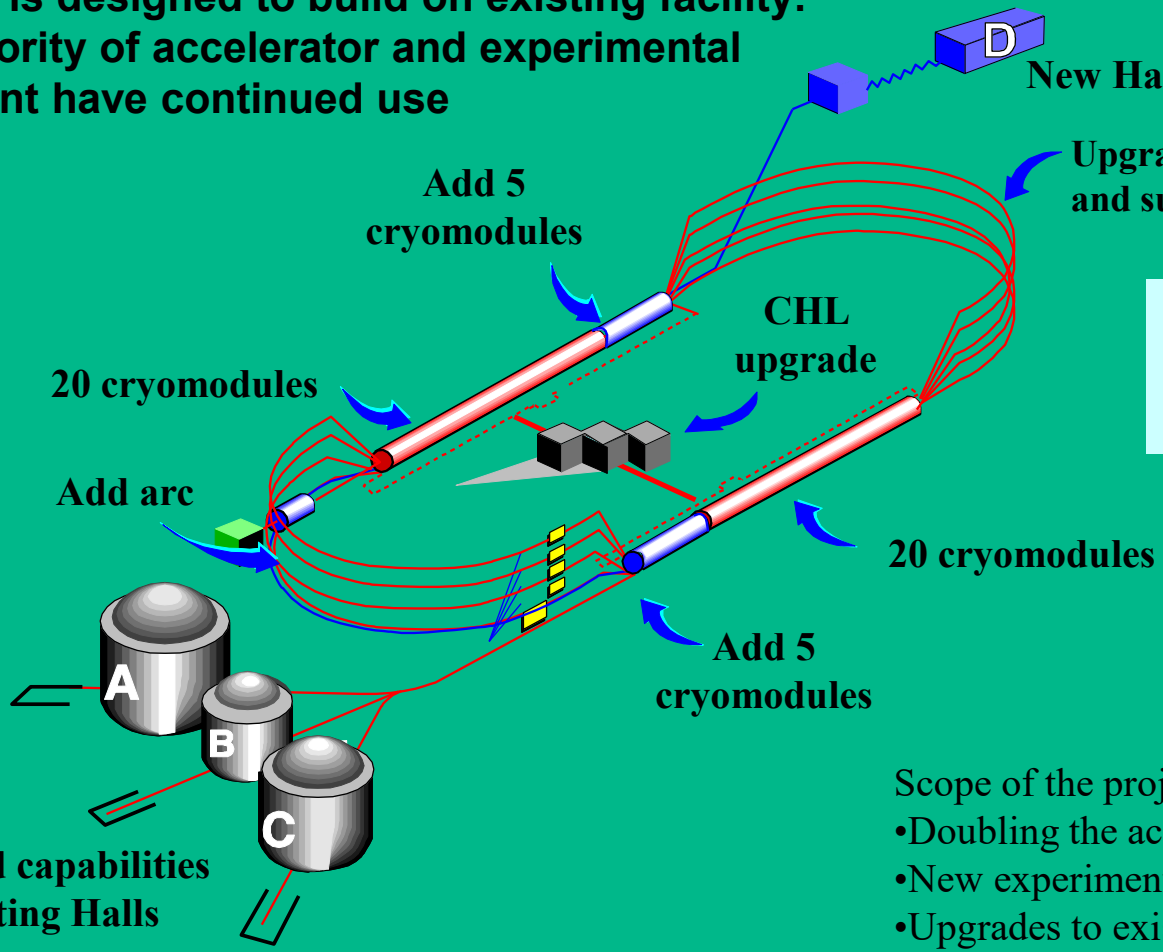


- X ray Energy: 8.9keV;
- 256 channels for each dimension(512 channel in total);
- 4 APV FECs were used (2 for each dimension)



JLab 12 GeV Upgrade

Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use

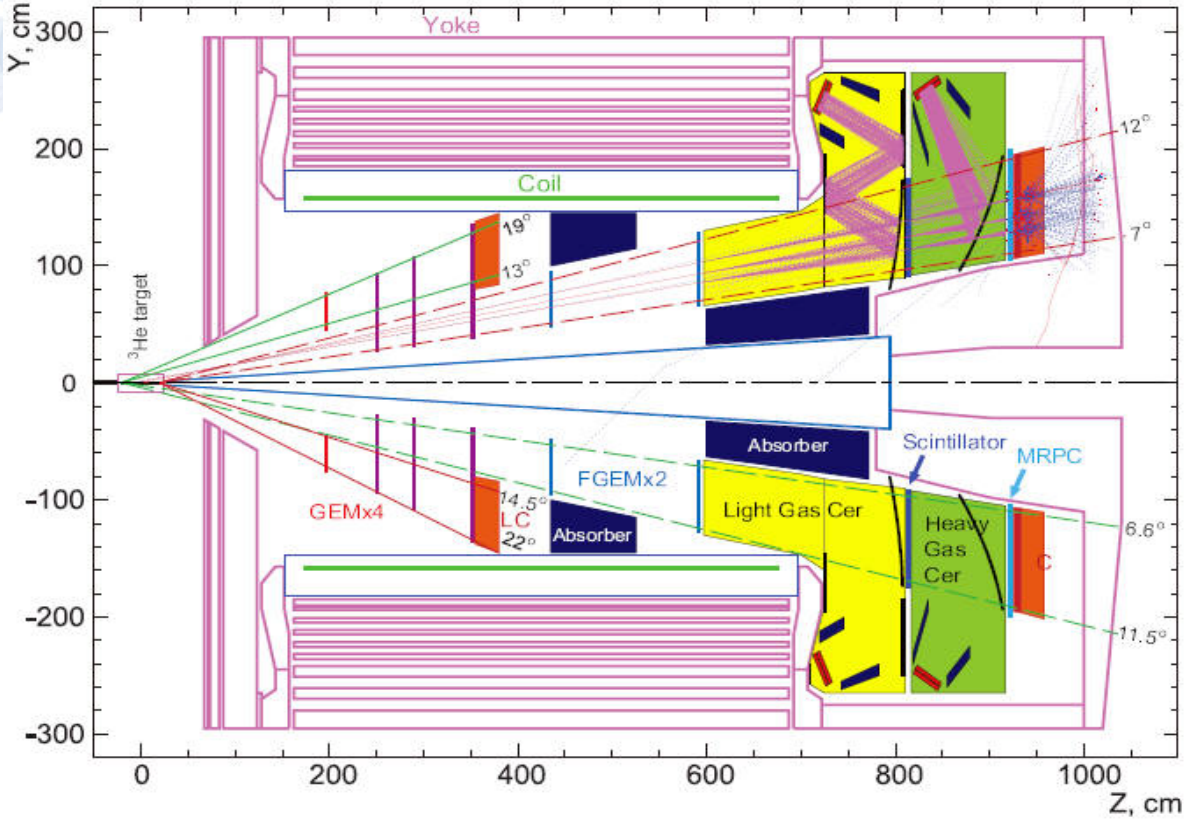


Maintain capability to deliver lower pass beam energies: 2.2, 4.4, 6.6….

Scope of the project includes:

- Doubling the accelerator beam energy
- New experimental Hall and beamline
- Upgrades to existing Experimental Halls

GEM: SoLID Spectrometer at JLab



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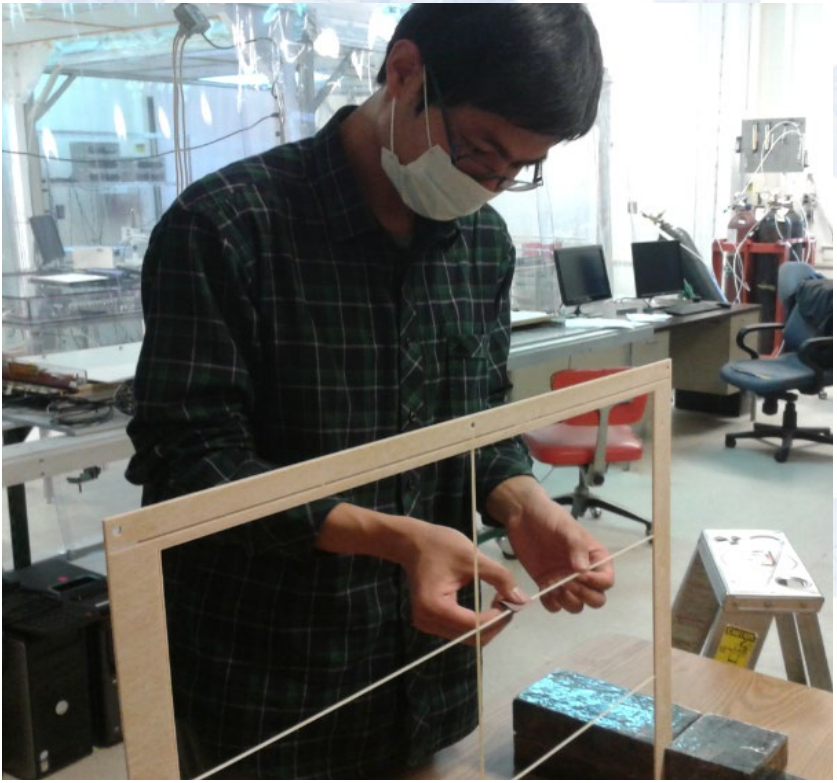
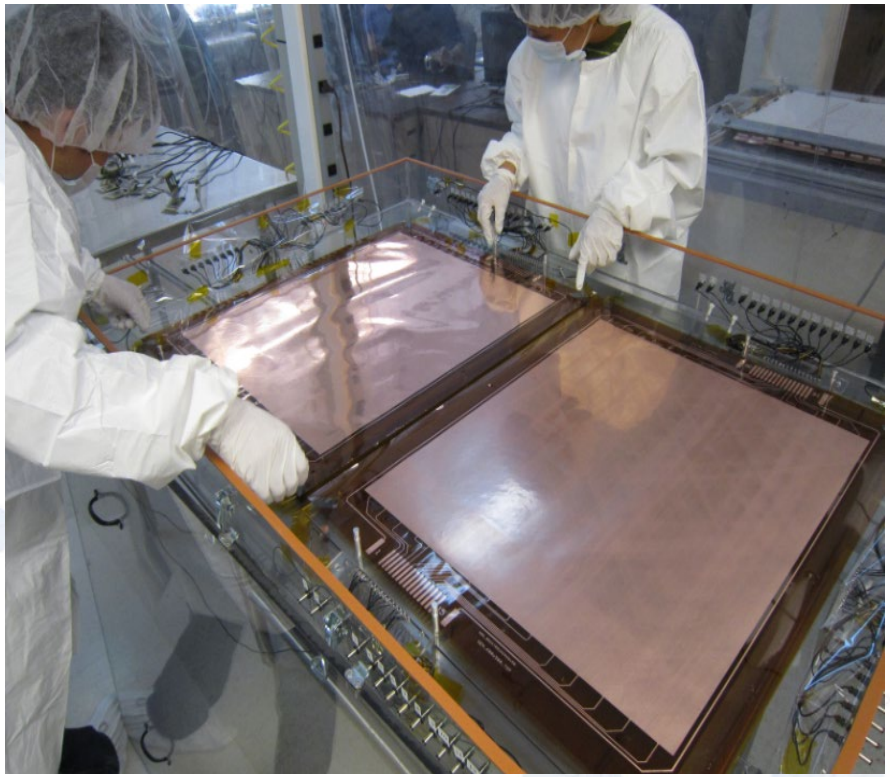
Students working at JLAB and UVA





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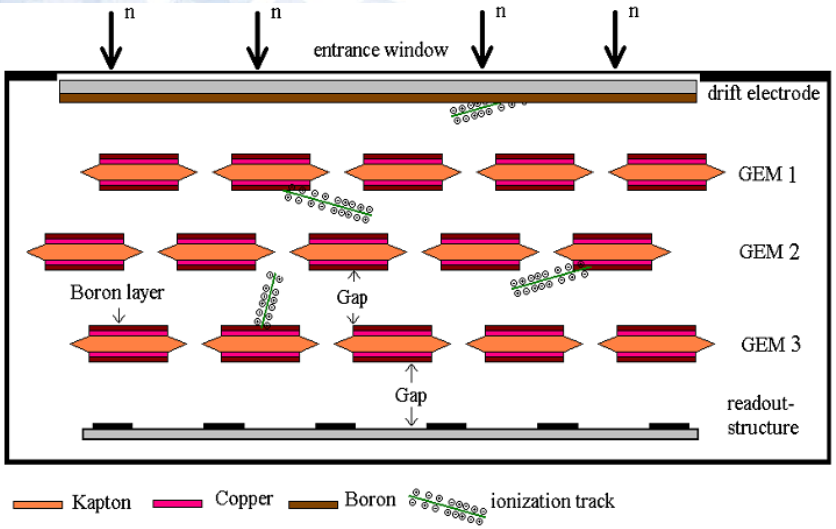
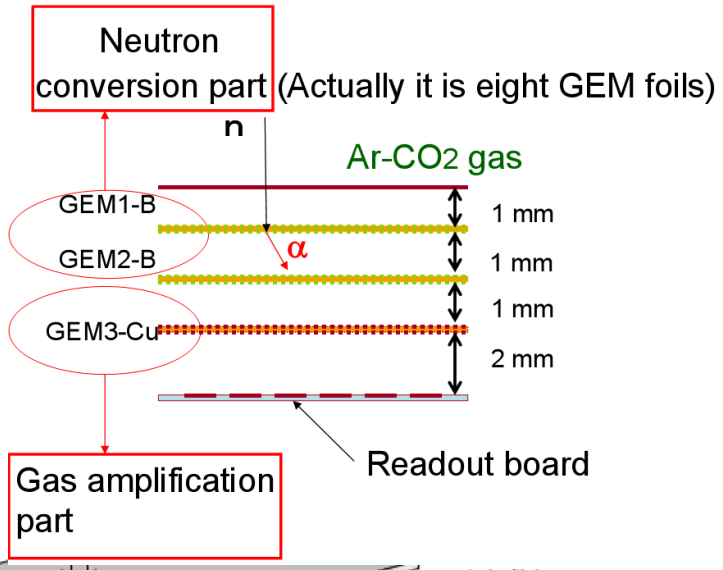
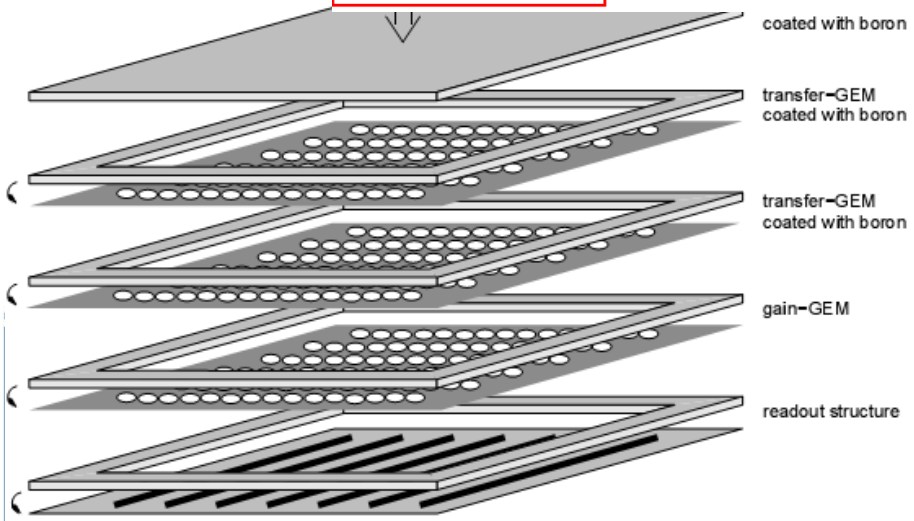
GEM: Neutron Detection



KEK





R&D of MicroMegas at CIAE

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Micromegas Classifications

- Classic Micromegas
  - Mesh on a frame
- Bulk Micromegas
  - photolithography process is used to attach the mesh on the PCB.
- Microbulk Micromegas
  - Mesh and PCB made on a unique kapton foil, the mesh layer is thinner.

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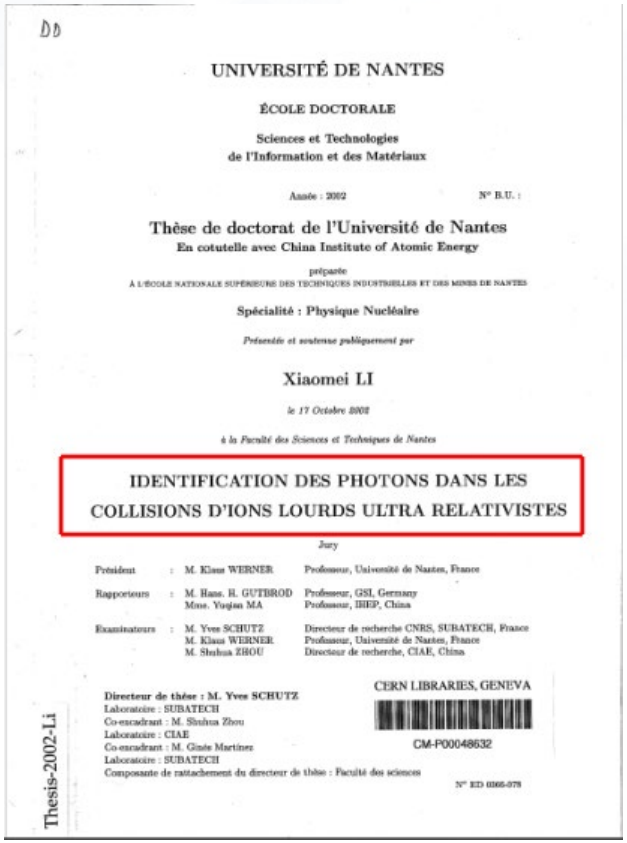
The France-China Collaboration: first joint-PhD



UNIVERSITÉ DE NANTES

ÉCOLE DOCTORALE

Sciences et Technologies
de l'Information et des Matériaux

Année : 2002 N° B.U. :

Thèse de doctorat de l'Université de Nantes
En cotutelle avec China Institute of Atomic Energy

préparée
À L'ÉCOLE NATIONALE SUPÉRIEURE DES TECHNIQUES INDUSTRIELLES ET DES MINES DE NANTES

Spécialité : Physique Nucléaire

Présentée et soutenue publiquement par

Xiaomei LI

le 17 Octobre 2002

à la Faculté des Sciences et Techniques de Nantes

IDENTIFICATION DES PHOTONS DANS LES COLLISIONS D'IONS LOURDS ULTRA RELATIVISTES

Jury

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		M. Klaus WERNER	Professeur, Université de Nantes, France
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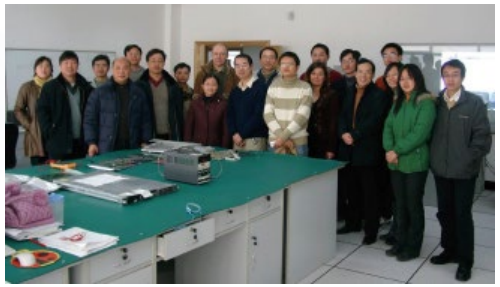
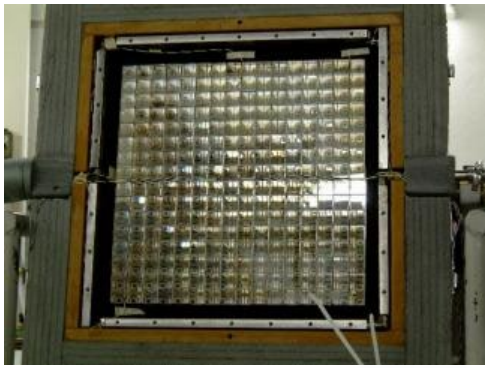
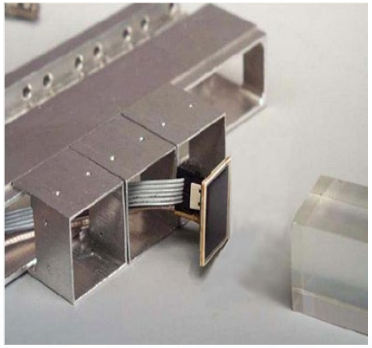




PHOS prototype with $PbWO_4$ crytals

Xiaomei LI
(CIAE Beijing)
Cotutorship PhD Subatech-CIAE
1999-2002
Supervisor: Yves Schutz



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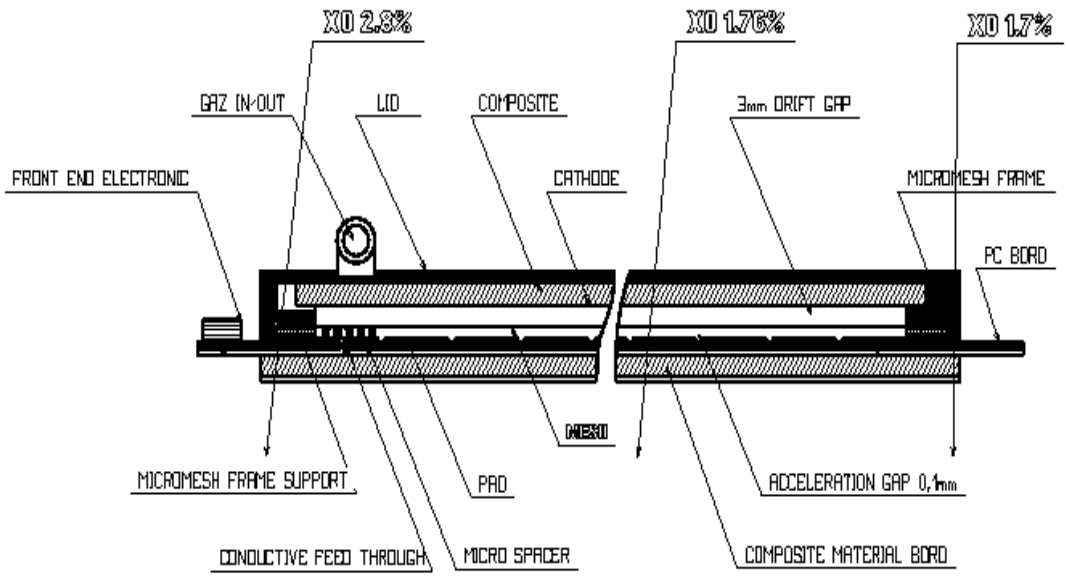
MICROMEGAS detector



- active area 415*375mm^2
- 3mm drift gap
- 100 μm amplification gap

- a high electric field in the amplification region (50kV/cm)
- a low electric field in the drift region (2kV/cm)

Ph.D in SUBATECH, France

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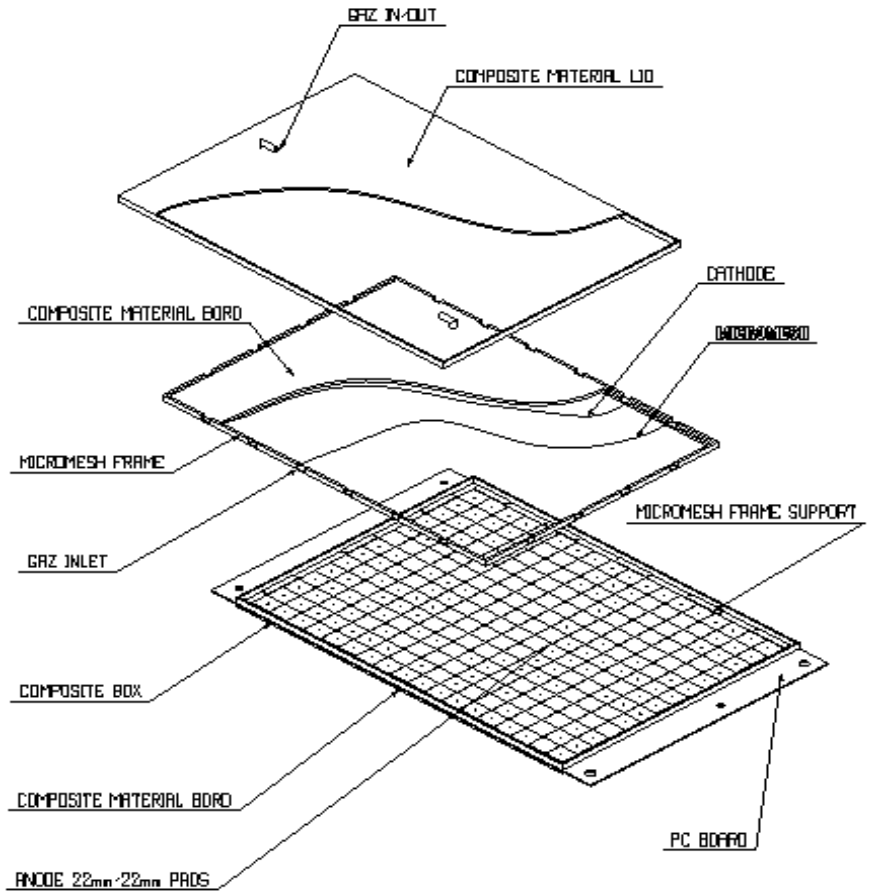
MICROMEGAS detector



- The anode is made of a 1.0mm thick electronic board(GI180) on one side with 2.2*2.2 cm^2 copper pad on other side with signal collecting strip
- The micromesh is made of pure Nickel
- The cathode consists of 9 μm layer of copper, glued on a 3mm thick plate made of composite material

Two different designs to keep micro-spacers

1. The amplification gap is defined by cylindrical micro-spacers of 200 μm high and 250 μm in diameter, glued on to the anode-pads with a pitch of 2 mm in both directions.

2. The micro-spacers are replaced by an insulating grid sandwiched between the micro-mesh and the anode plane

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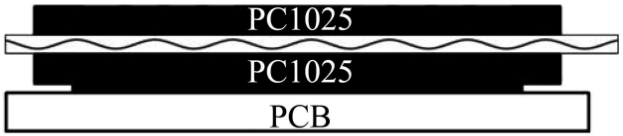
Structure of Bulk MicroMegas

PCB anode

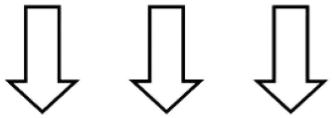
photoimageable film is laminated on PCB

S.S. mesh is placed

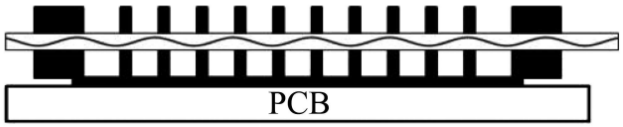
S.S. mesh laminated between two layers of photoimageable film



photolithographic process



completed micromegas



Reference:Study of bulk micromegas detector
Chinese Physics C Vol. 34, No. 10, Oct., 2010

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Manufacture of MicroMegas at CIAE

- **Completed R&D and mass production of bulk MicroMegas.**
- **Developed new photoetching MicroMegas.**

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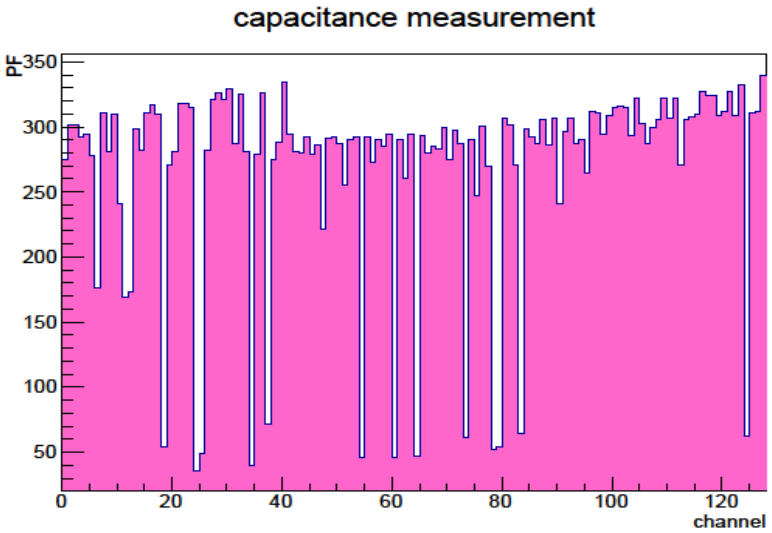
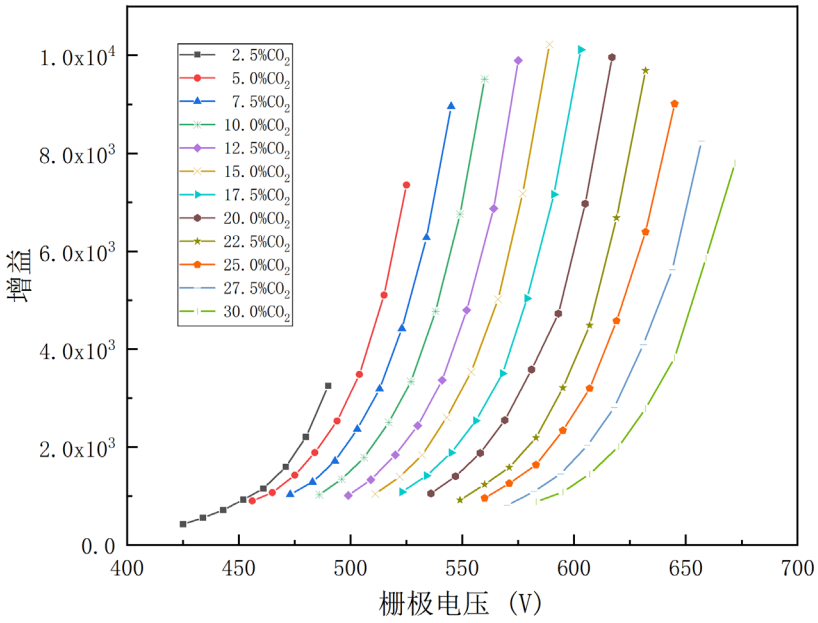
Capacitance and Resistance Automatic Testing System Invented by CIAE



Performance of Micromegas

The gain of the detector varies with the grid voltage under different ratios of Ar and CO_2 working gases



The Micromegas developed independently by our team achieves the best energy resolution of 17.5% in Ar and iC_4H_{10} gases.

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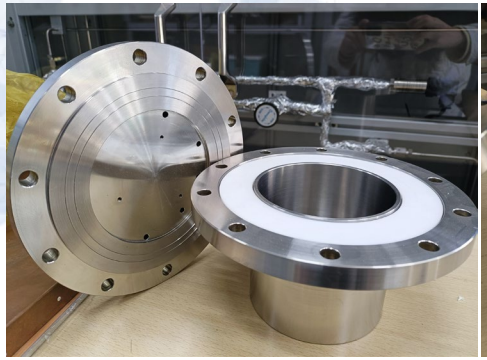
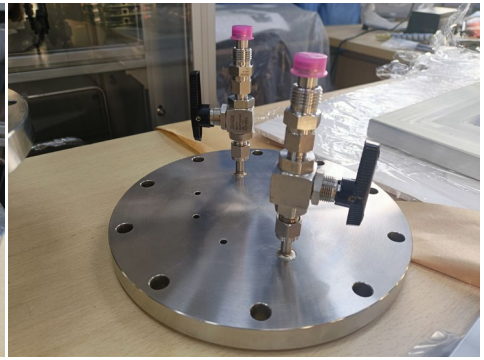
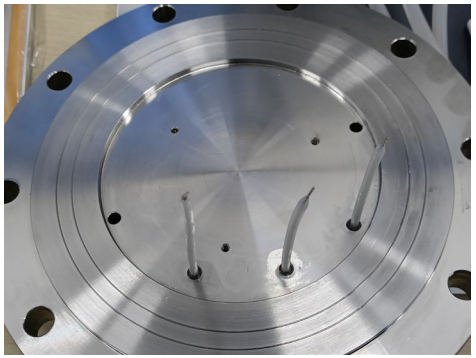
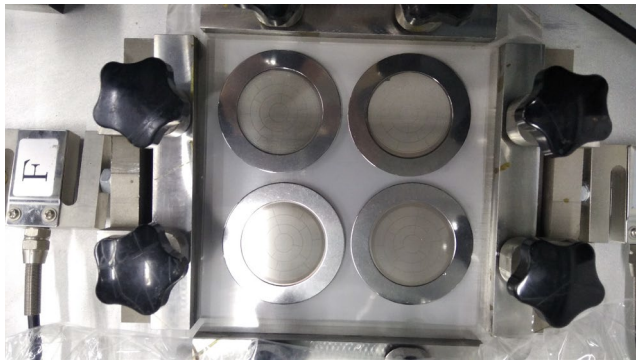
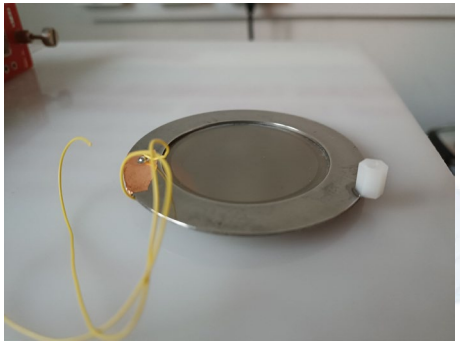
Development of Sealed Chamber MM











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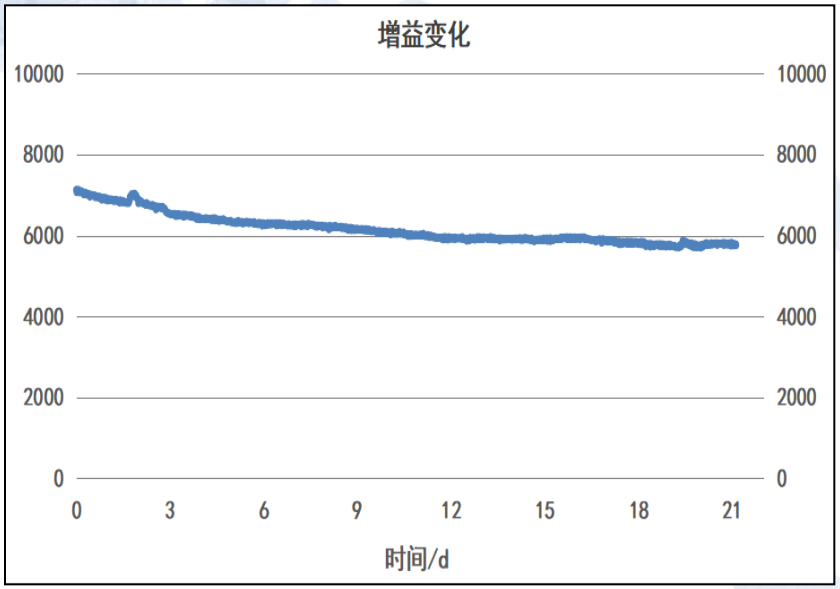
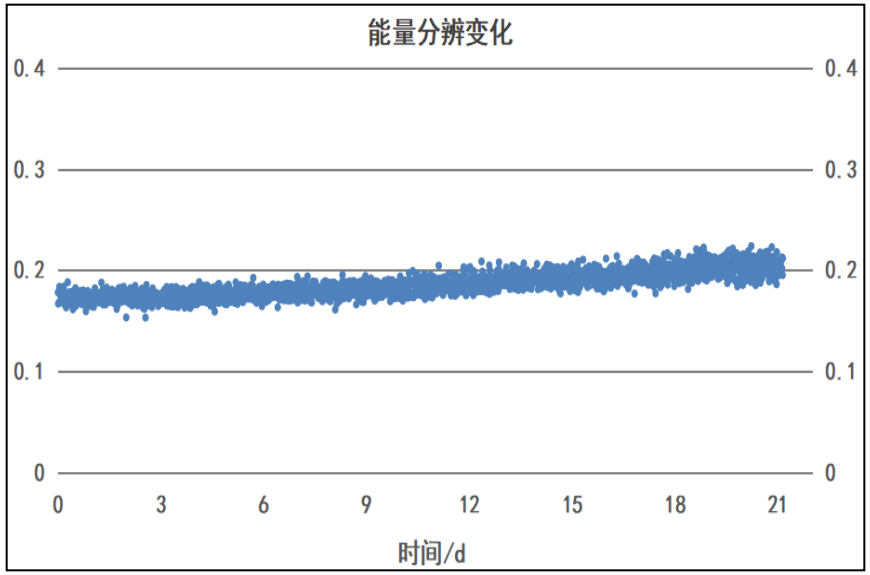
Development of Sealed Chamber MM

V_{Mesh}：510V　　V_{Drift}900V





The energy resolution of the sealed micro-pattern gas detector has consistently remained at an excellent level after 21 days of continuous measurement.

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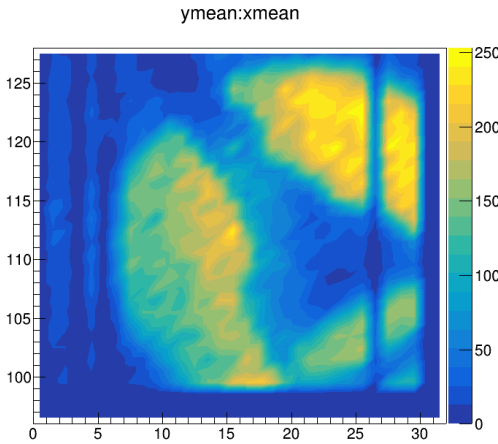
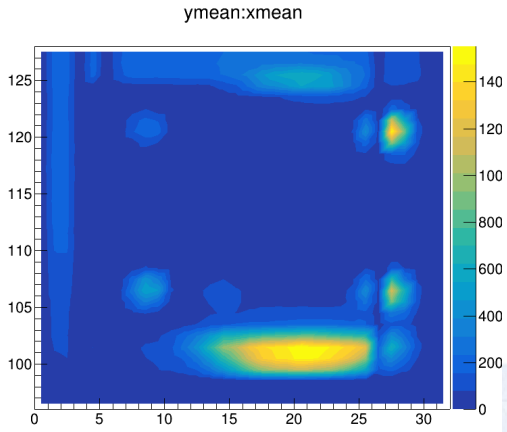
Micromegas X-Ray Imaging

- Argon + 30%CO_2
- Mesh: -550V(max -620V)
- Drift: -2500V
- 50kV X-Ray tube





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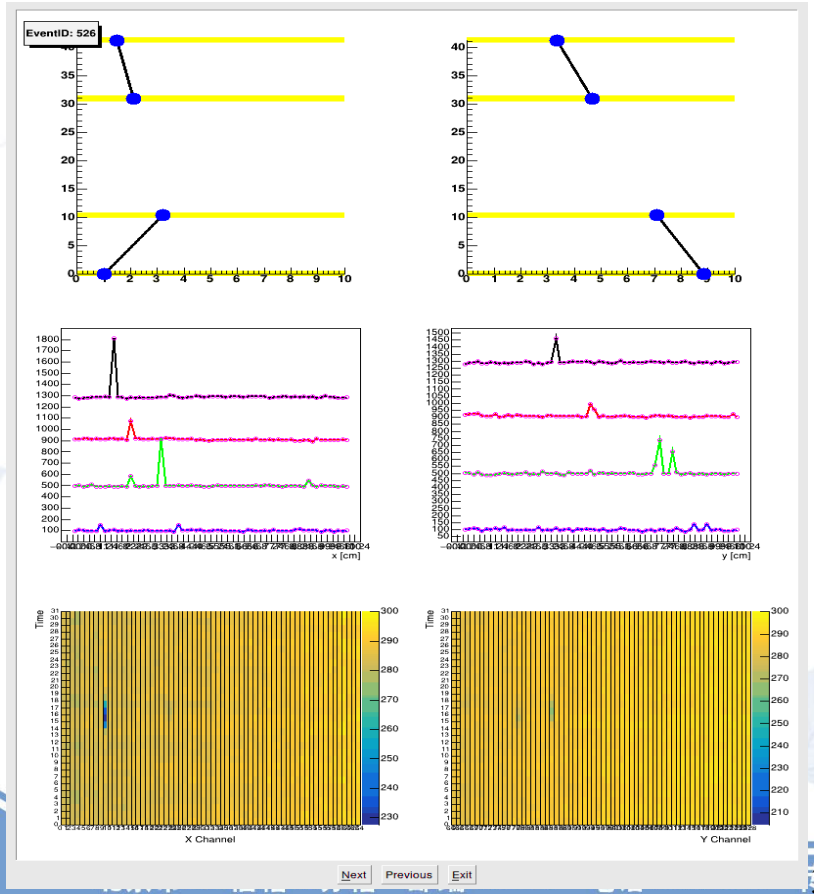
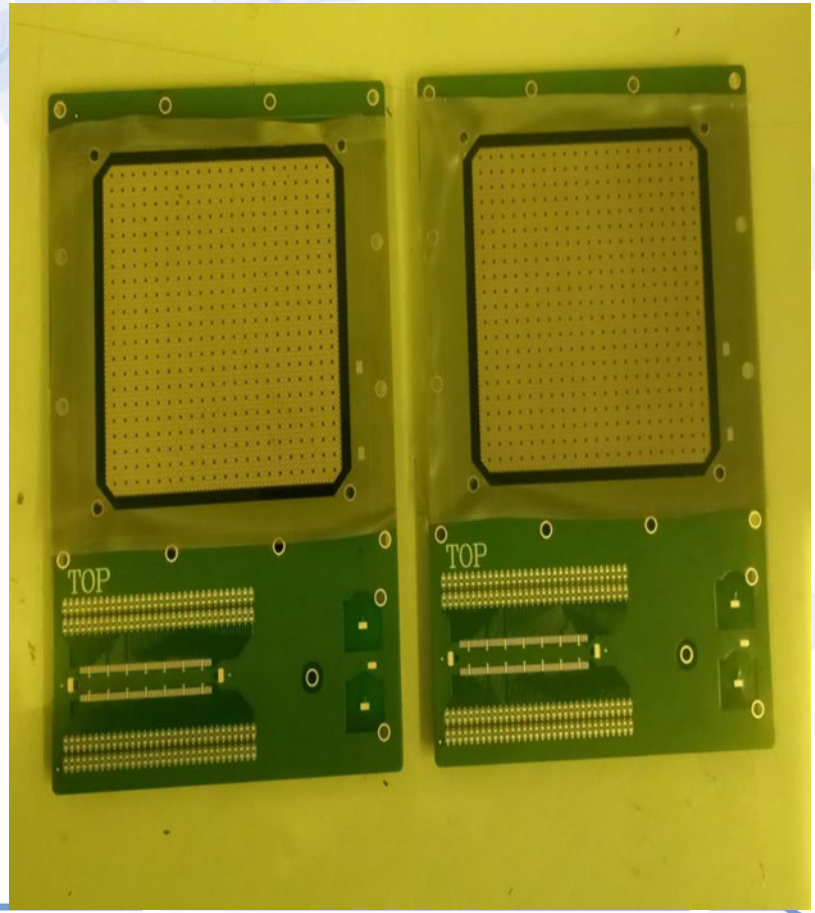
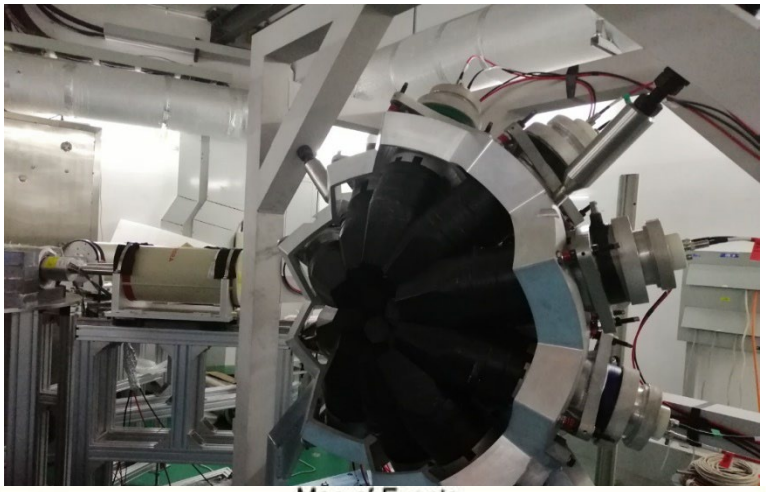
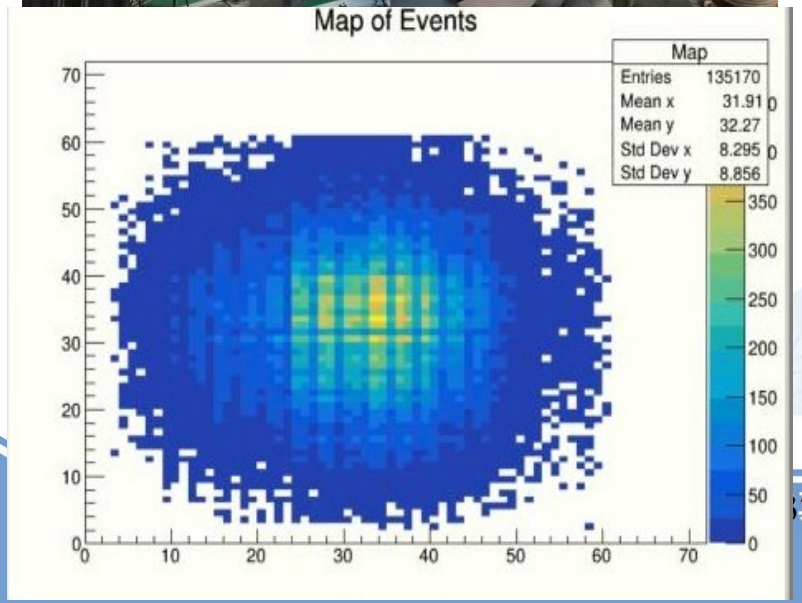
MicroMegas：
Radiation Detection



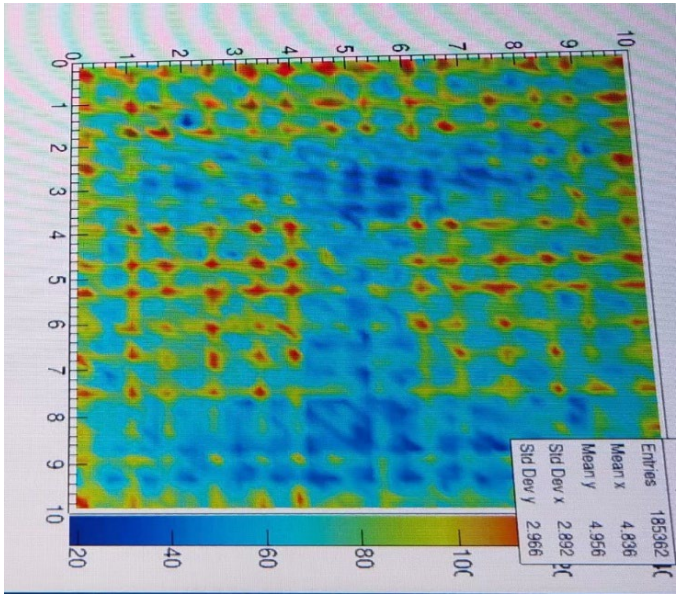
Neutron imaging at China Spallation Neutron Source







Neutron Imaging at CIAE



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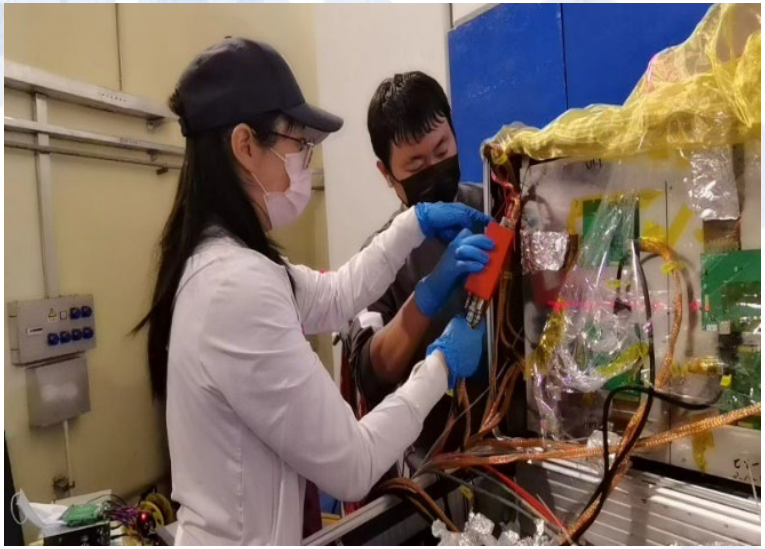
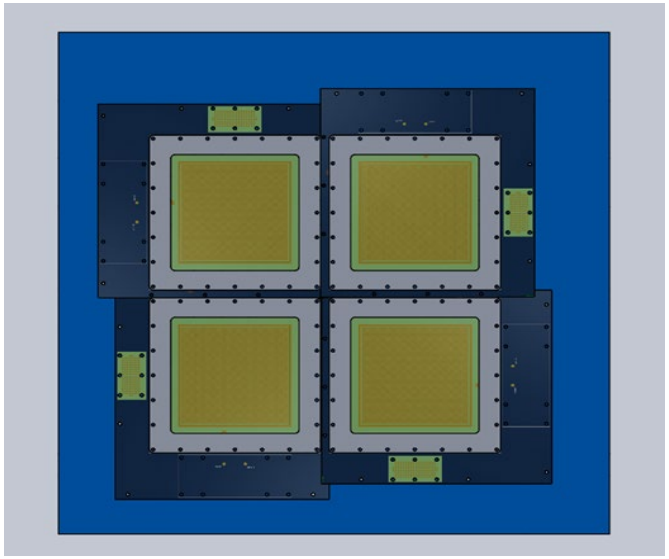
Neutron Imaging at CIAE 100MeV Cyclotron





Using 70-100MeV to measure the cyclotron neutron beam at 28 points online. It is the cyclotron neutron beam spot monitored online for the first time

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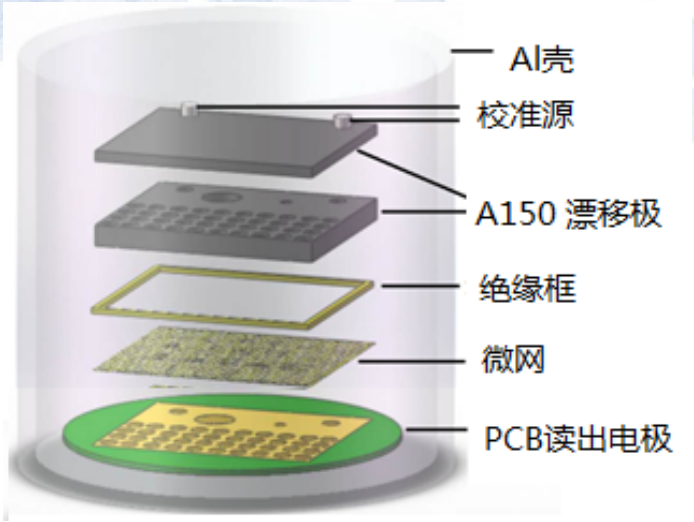
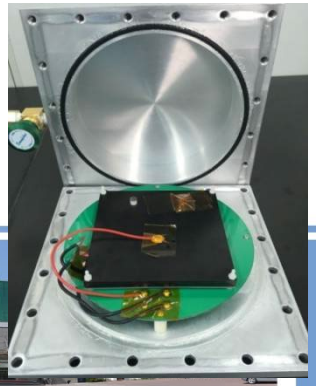
MicroMegas: TEPC at CIAE



TEPC is widely used in microdosimetry.

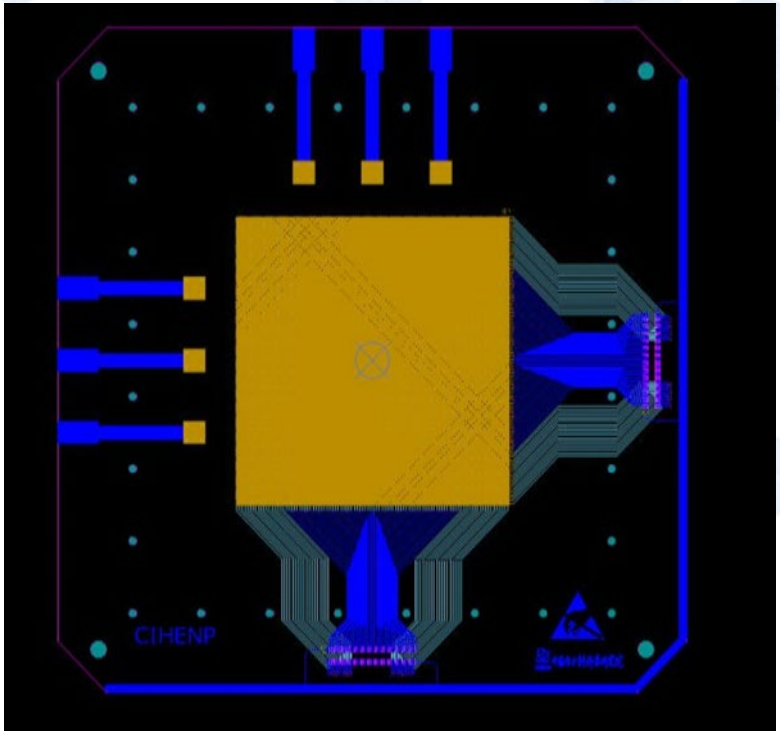
Compare with MWPC: Easy Assembly, More Sensitive



Compare with GEM: More stable

Tissue Equivalent Proportional Counter

MicroMegas for the R&D of CEPC TPC



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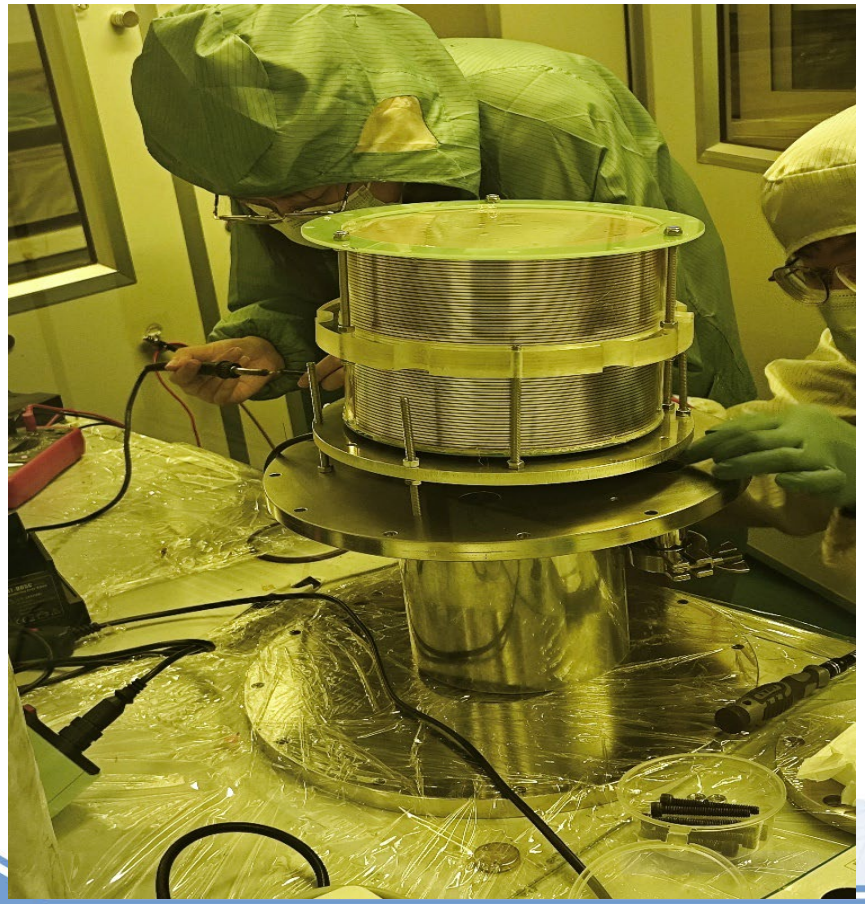
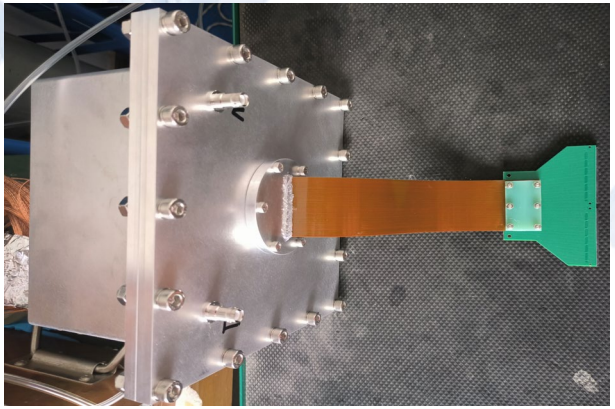
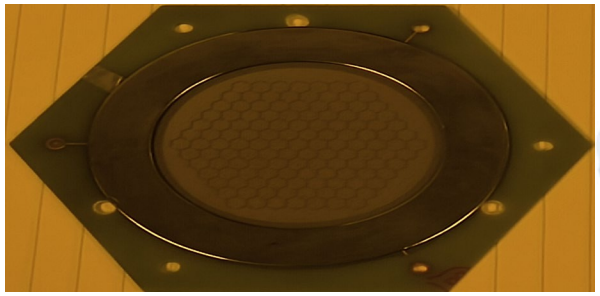
MicroMegas for R&D of Multifunction TPC

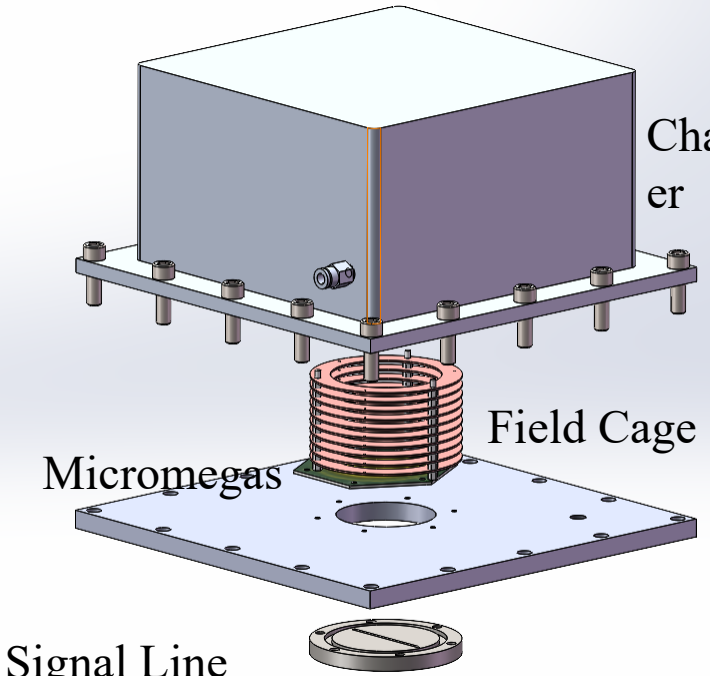


TPC Based On Micromegas





Micromegas



Schematic Diagram of
TPC Structure

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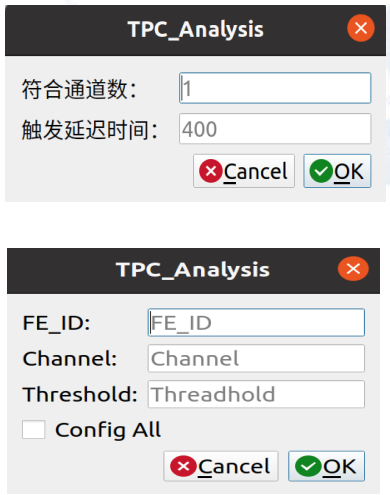
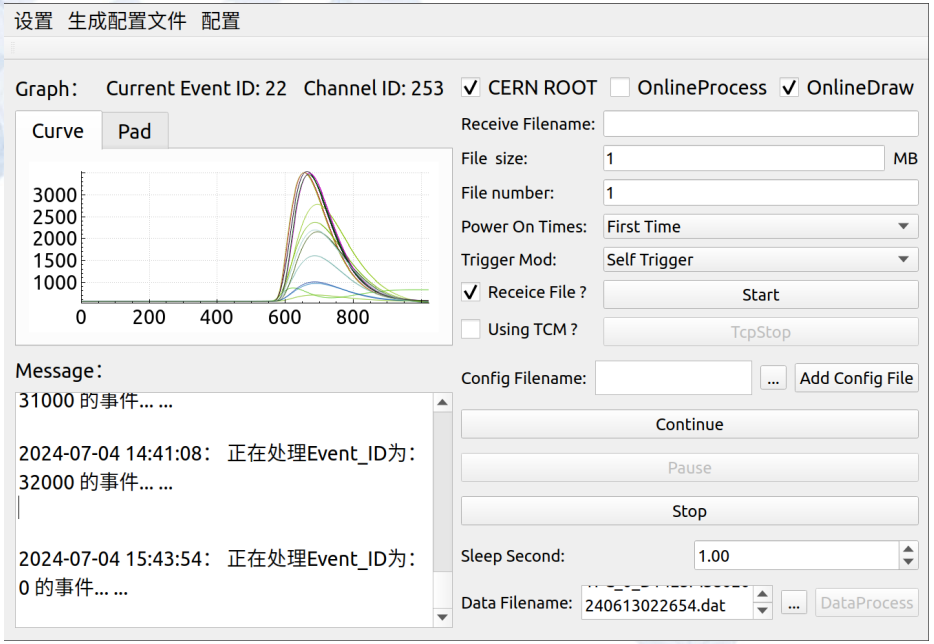
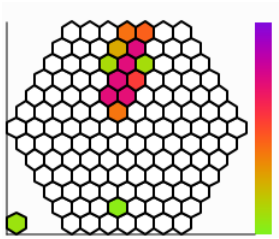
Data Acquisition Software

Developed supporting data acquisition software for the time projection chamber based on Qt Creator and ROOT



Partial Configuration Page





Real-time Display of Trajectory 2D Projection

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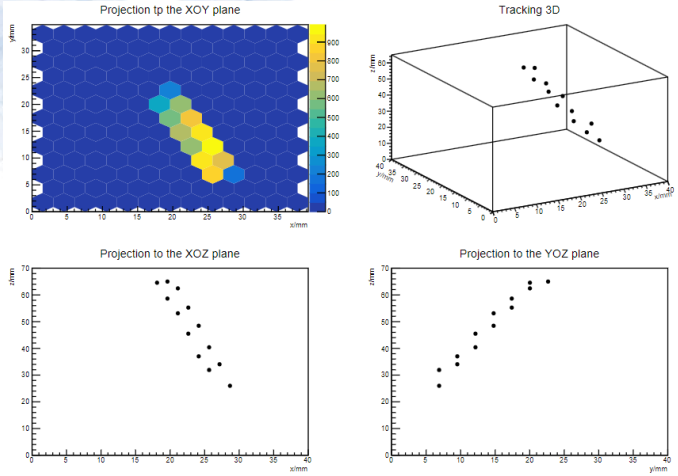
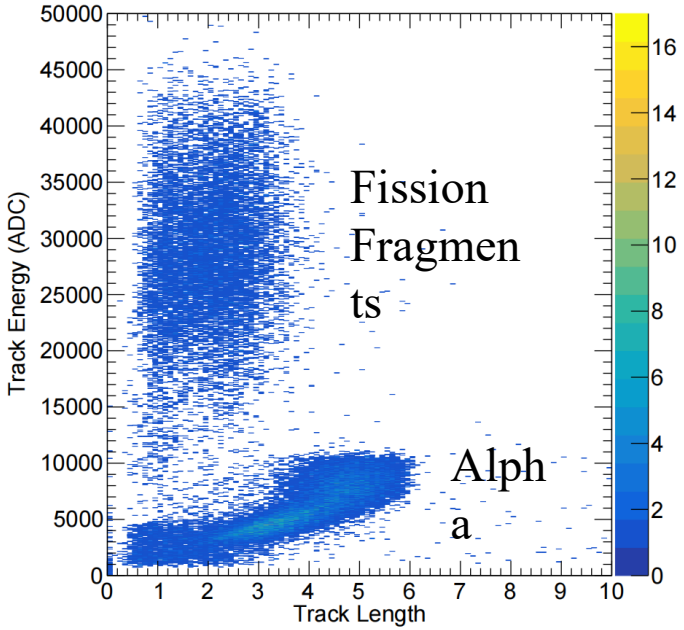
Experiment of Cf^{252}

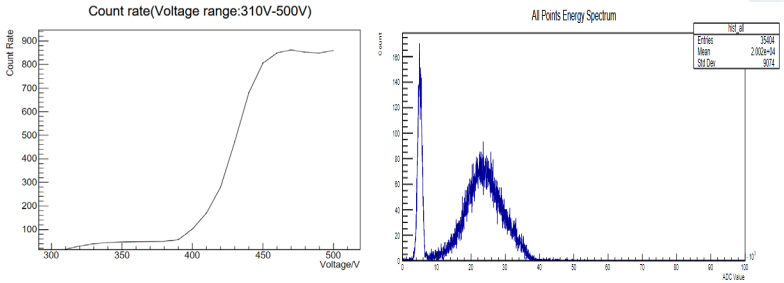


Cf^{252} Emission Particle Trajectory Diagram

We detected the Cf^{252} emission particle trajectories using the self-developed time projection chamber.



2D Statistical Diagram of Energy and Trajectory Length



Counting Rate Curve and Energy Spectrum

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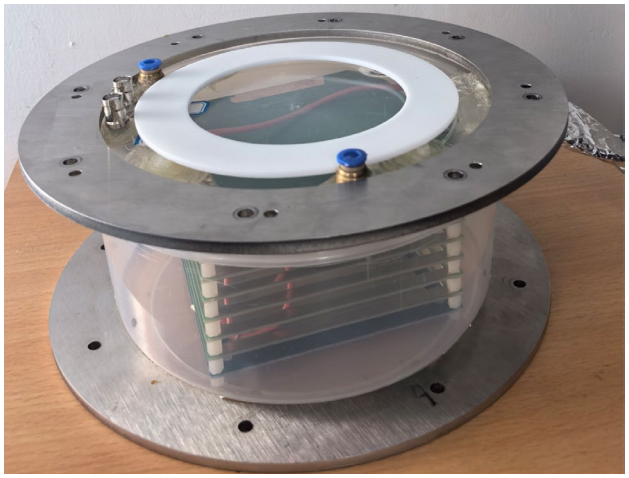
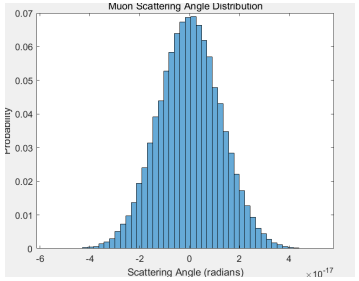
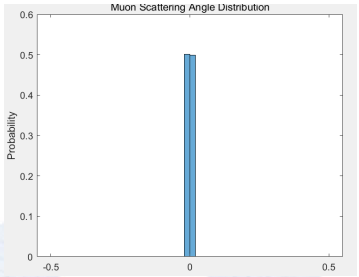
Compact and Lightweight TPC

The compact lightweight TPC is a new type of time projection chamber developed for mobile measurement。

- **Traditional chambers cause unplanned random scattering**
- **The polyethylene chamber can well accommodate the passage of cosmic rays**
- **balancing noise shielding and portability**







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R&D of PRC at CIAE

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PHENIX@ BNL

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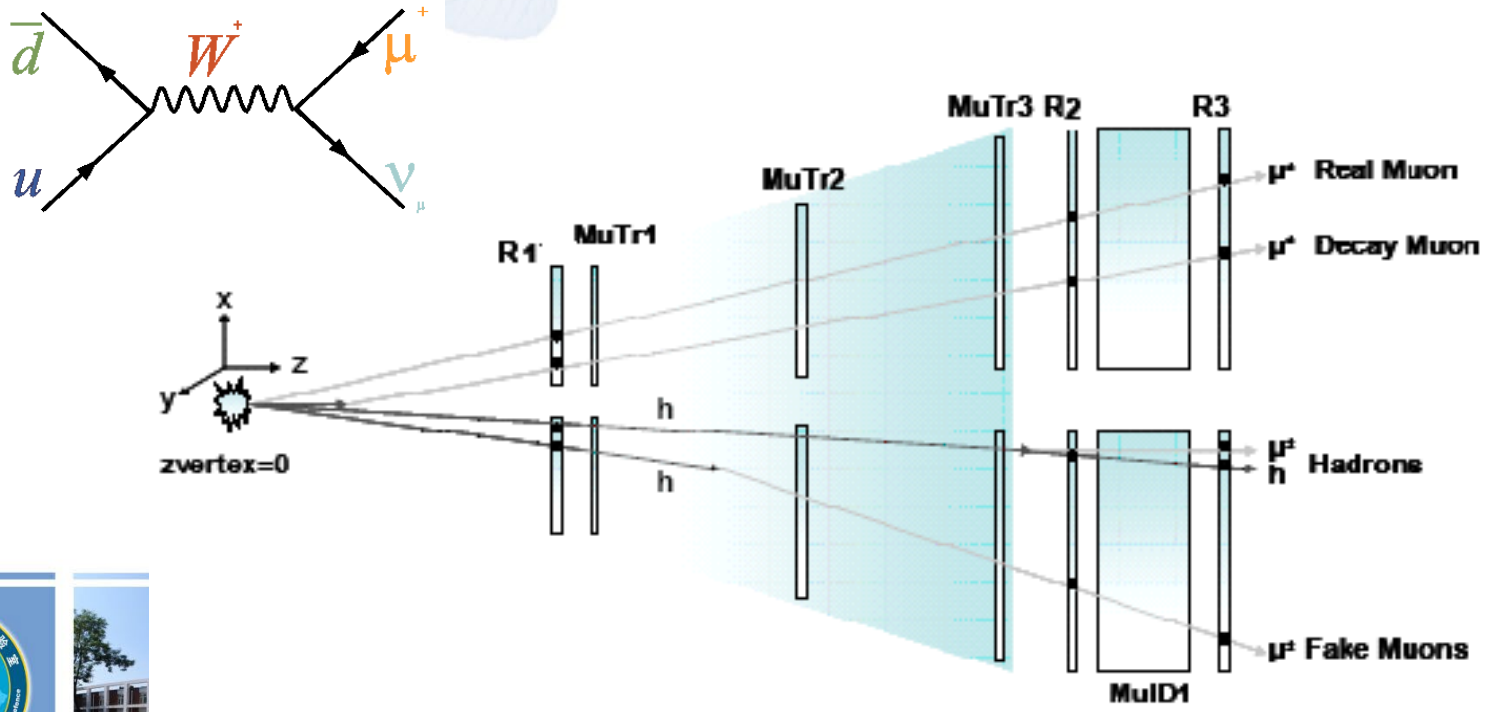
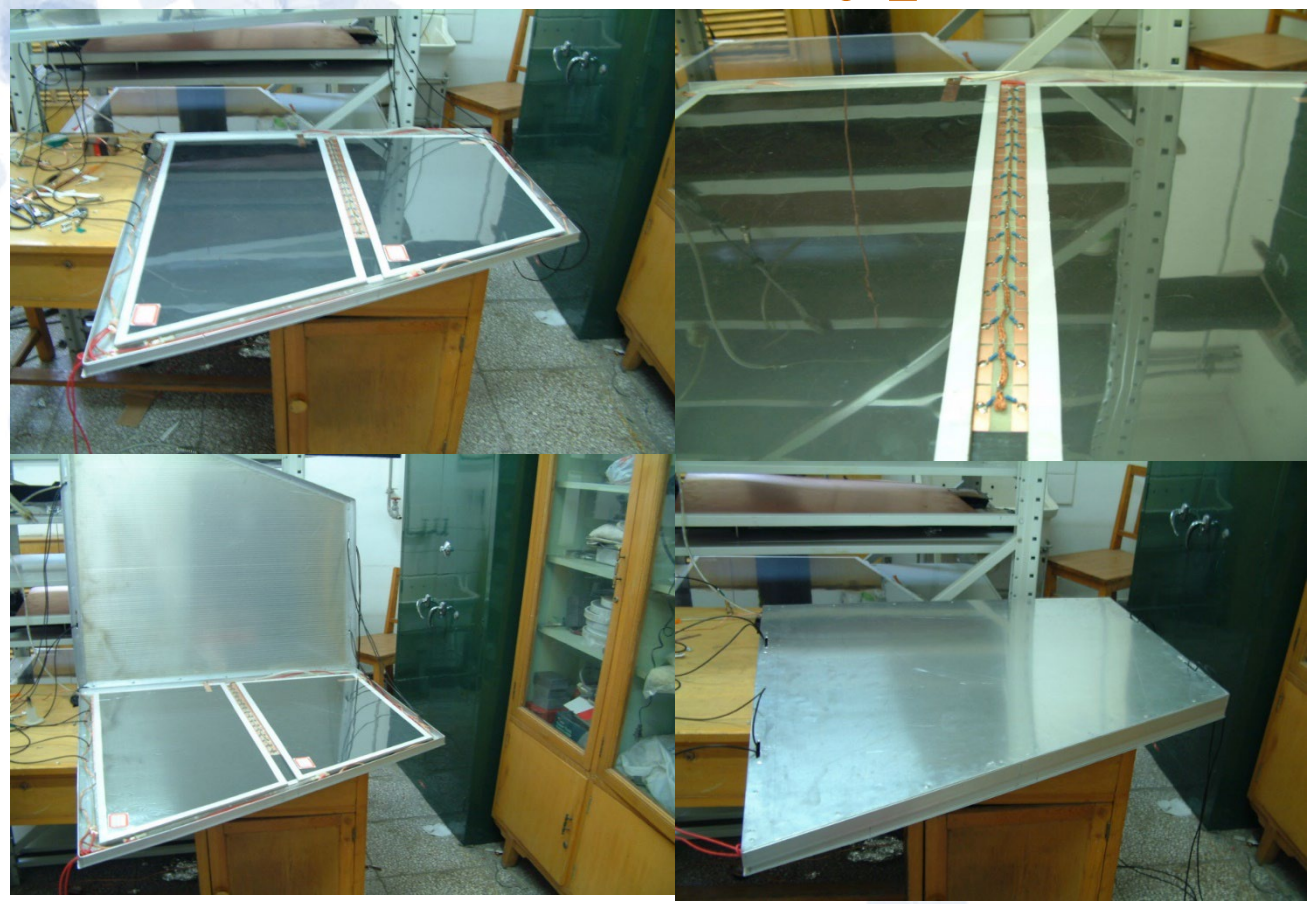
Motivation of the PHENIX Forward Upgrade

Add RPC (Resistive Plate Chamber) as a fast muon trigger to study the quark-gluon structure of the proton by observing W-bosons from colliding polarized proton beams at RHIC.



RPC Prototypes



The upstream of Prototype No.2 is separated into two parts and the readout strips are jointed with ground by matched resistances.

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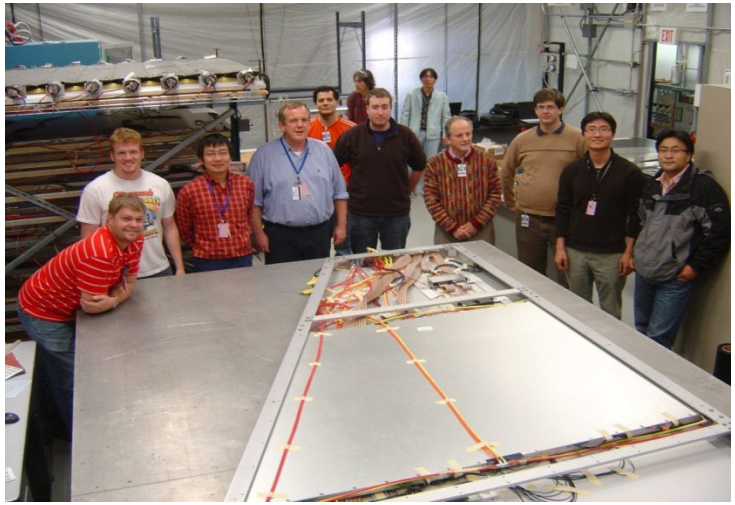
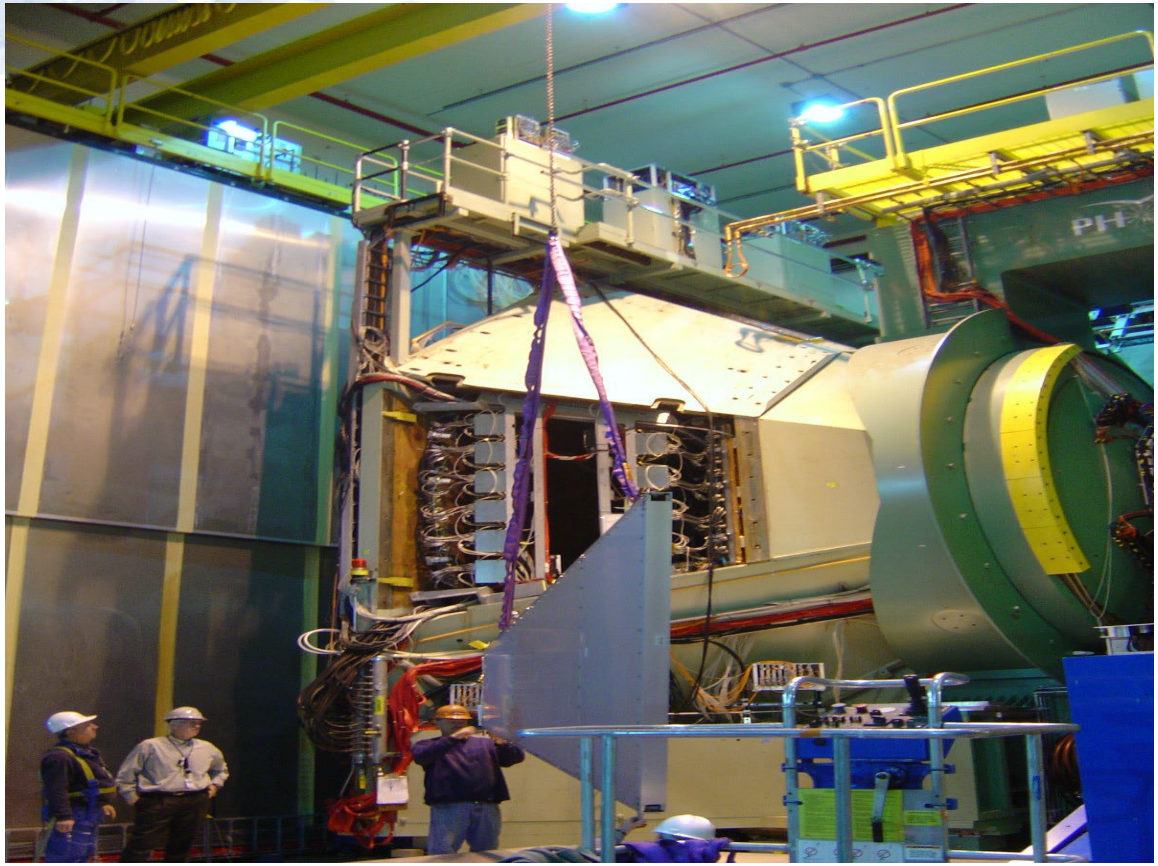
RPC installation at PHENIX

CIAE Carried out the design and production of the module parts of RPC detectors for PHENIX forward upgrade,



RPC installation at PHENIX



This work was awarded the Beijing Science and Technology Prize.

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Development of EMCal Detector

for sPHENIX

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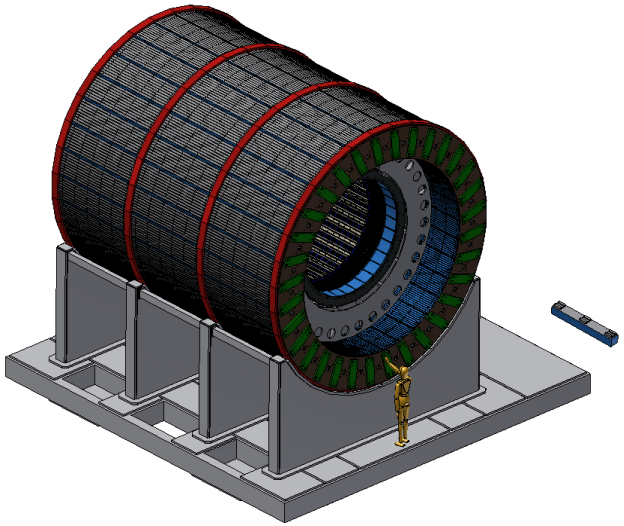
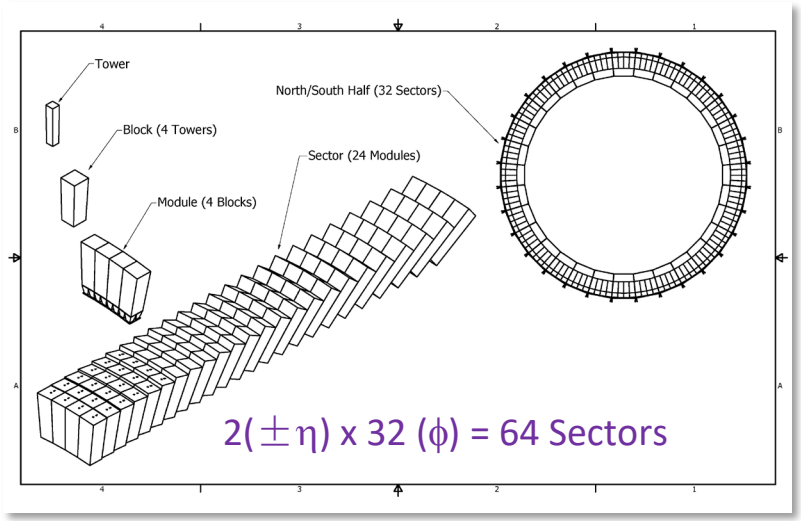
EMCal Design Performance

The EMCal (Electromagnetic Calorimeter) is an essential sub-detector for sPHENIX to measure the QGP near the critical temperature.

EMCal covering $\pm$ 1.1 in η and 2π in ϕ. $\Delta\phi$ x $\Delta\eta \sim$ 0.025x 0.025

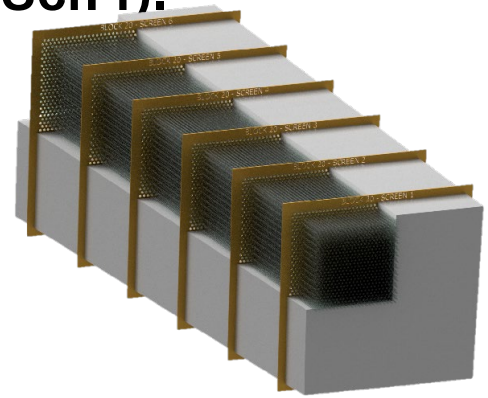


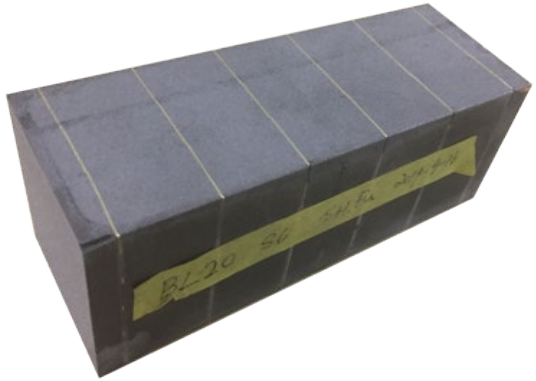


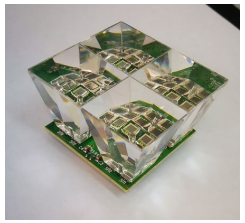
The EMCal performance is central to the direct photon and Upsilon measurements and it is also a key component, along with the HCal, of the jet reconstruction.

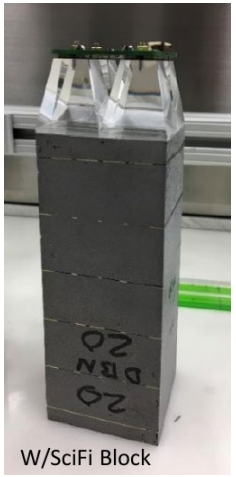
EMCal Block Design

The EMCal block design consists of scintillating fibers embedded in the absorber material, which is a matrix of tungsten powder infused with epoxy (W/SciFi).

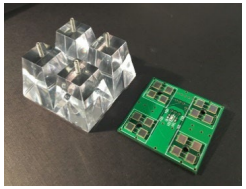




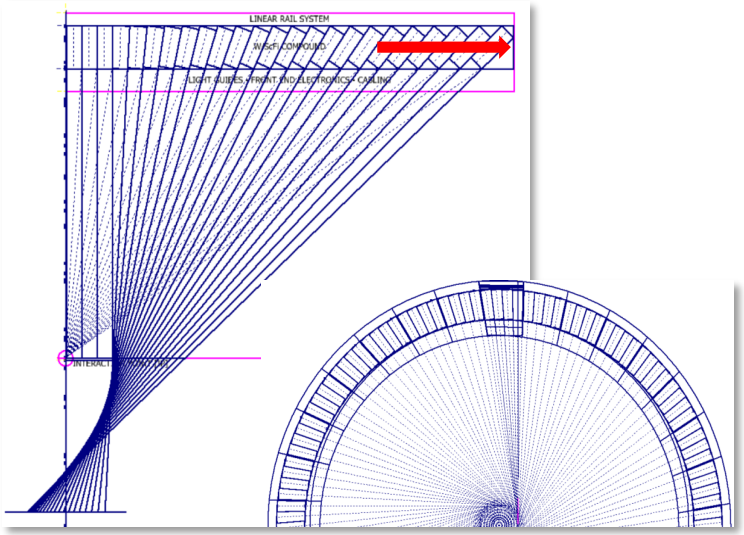




- High density (9-10 g/cm^3), low radiation length (~7 mm), small Molière radius (~ 2 cm), compact structure and low cost.
- The readout system adopts light guide combined with SiPM.



The Contribution from China

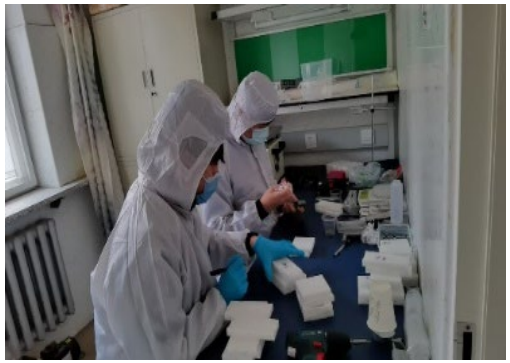


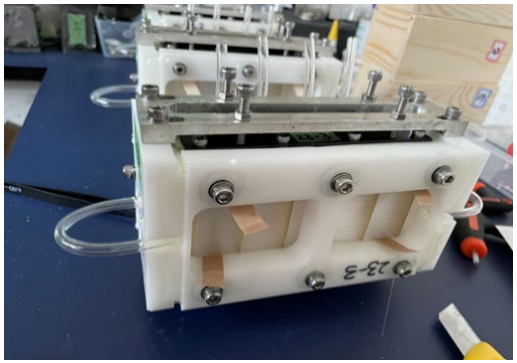
- Total 6144 blocks for EMCal
- 1248 blocks will be made in China.

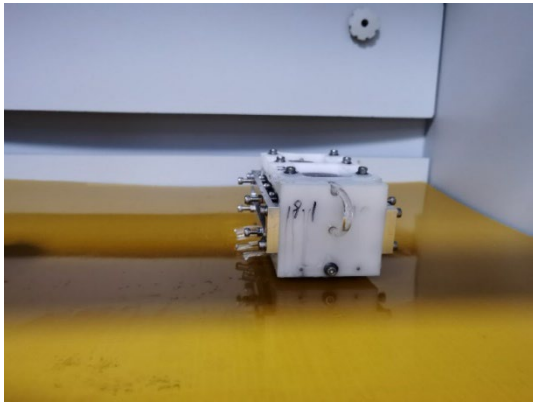
- Fudan, CIAE, and PKU are the main cooperative sites in EMCal construction and make an important contribution to the sPHENIX experiment.

sPHENIX EMCal R&D Center

- 2668 scintillating fibres in one block
- 6340 kg in total
- 97% finished product ratio



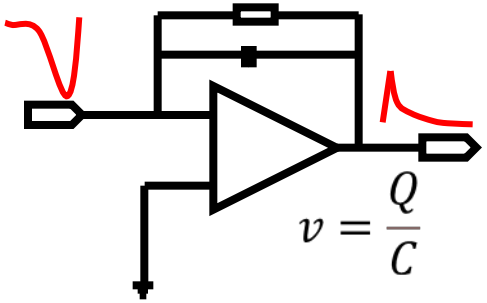




Block Mass Production

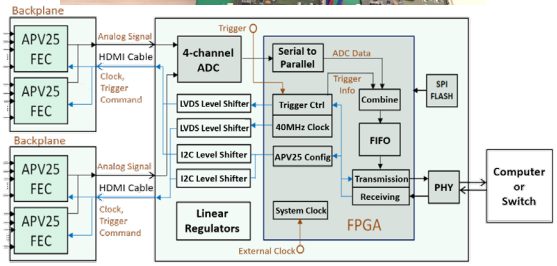
Block Mass Production

FPGA-Based Readout System for SiPM

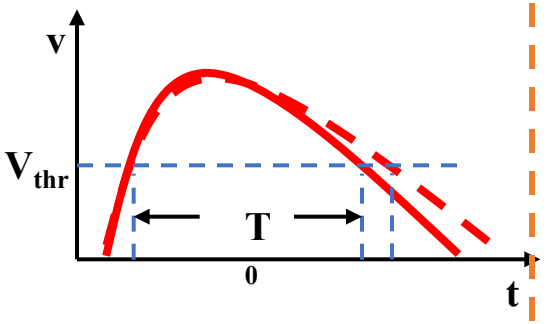


How to measure the voltage?

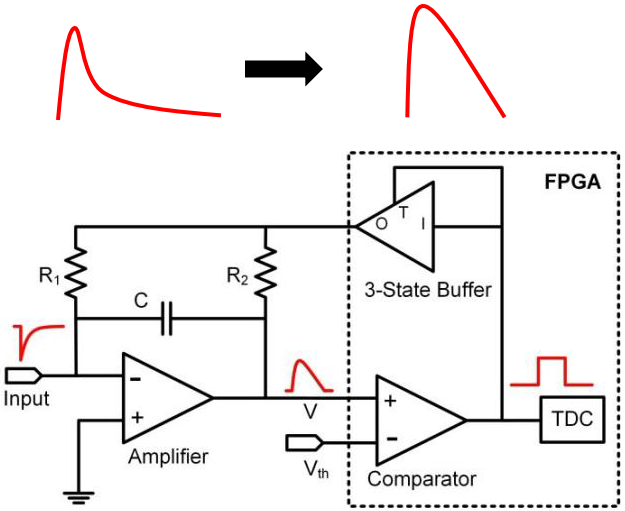
- **ADC**
- **TOT**
- **FPGA-based method**



APV readout system(adc-based)



TOT method



Flexible, low cost, fast speed

$$\int_0^{T_{start}} \frac{V}{R_1+R_2}dt + \int_{T_{start}}^{T_{end}} \frac{U_0}{R_1}dt + CV_{th} = \int_0^{T_{end}} i(t)dt$$

$$\frac{U_0}{R_1}(T_{end} - T_{start}) \approx \int_0^{T_{end}} i(t)dt \approx Q$$

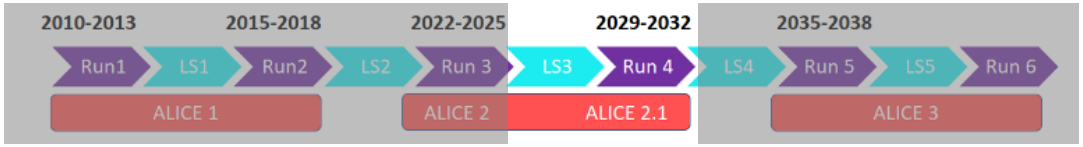
TNS.2017.2648787

Linear discharge readout method (FPGA-based)

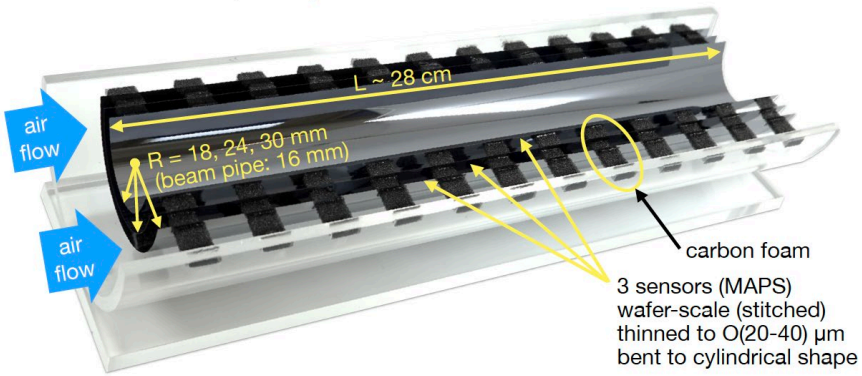
ALICE Upgrade

北京市275信箱46分箱　邮编102413　电话69357849　传真69357787

The ALICE 2.1

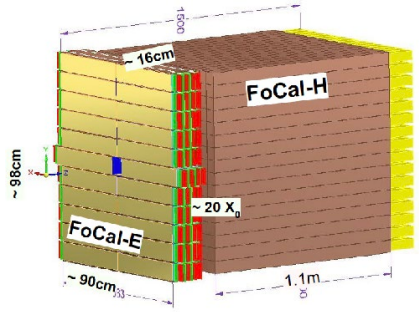


Stiching MAPS-based ITS3

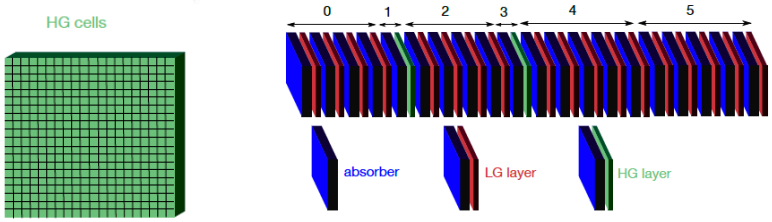


- Replacement of 3 innermost layers of ITS2
- Curved wafer-scale ultra-thin silicon sensors: cylindrical layers (1 sensor per half layer)
- Low power → air cooling → low material budget
- Improved tracking precision and efficiency at low p_T

Silicon-based FoCal



$3.4 < \eta < 5.8$



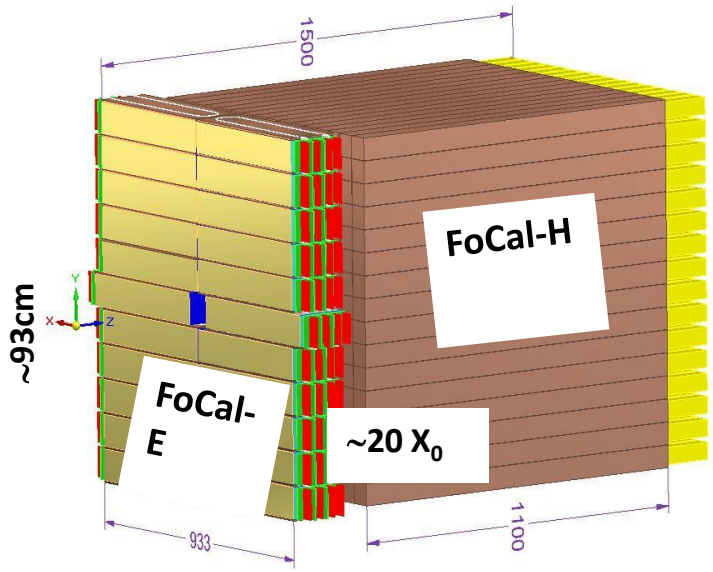
- ✓ Pad (1x1 cm^2): shower profile and total energy
- ✓ Pixel (30x30 µm^2): position resolution to resolve overlapping showers

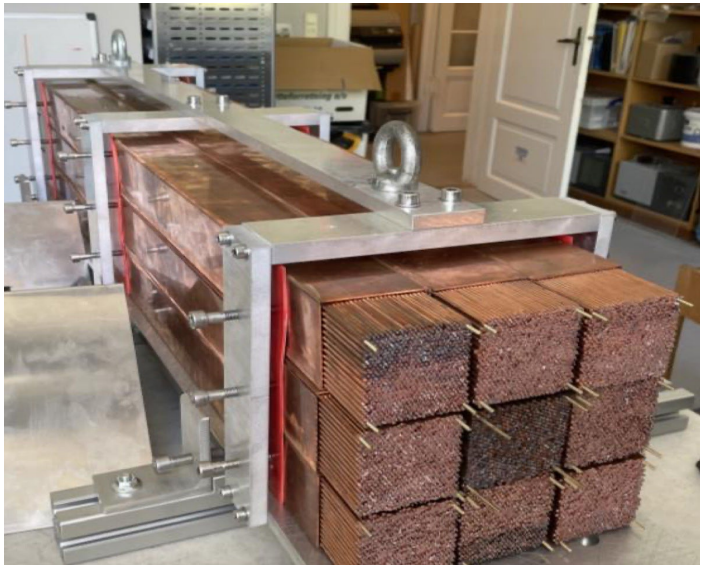
ALICE 2.1 – FoCal Detector

FoCal-H

Spaghetti-like hadronic calorimeter

- **Copper tubes with length of 110 cm ~ $7\lambda_I$ (length constrained by space)**
- **Inside the copper tubes are scintillating optical fibers**
- **readout using SiPMs**





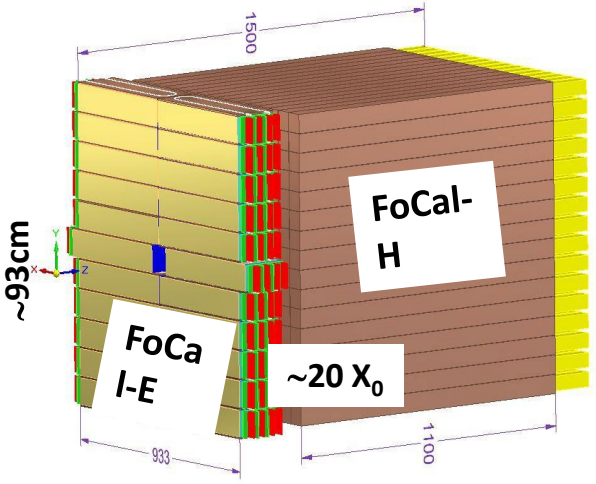
FoCal-H prototype, 9 x (6.5 x 6.5 x 110 cm^3)

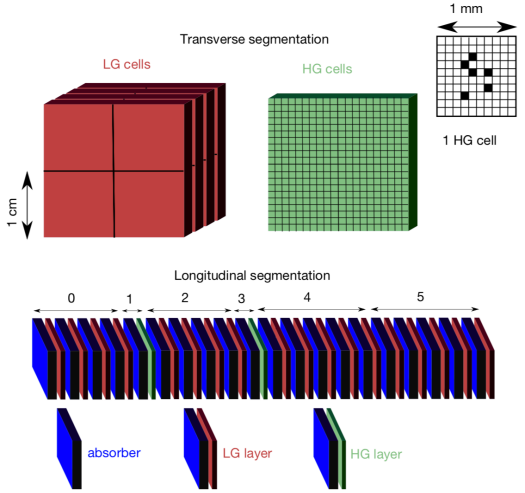
ALICE 2.1 – FoCal Detector

FoCal-E

Silicon and tungsten constitute an electro-magnetic calorimetor with an equivalent granularity of approximately 1 mm²

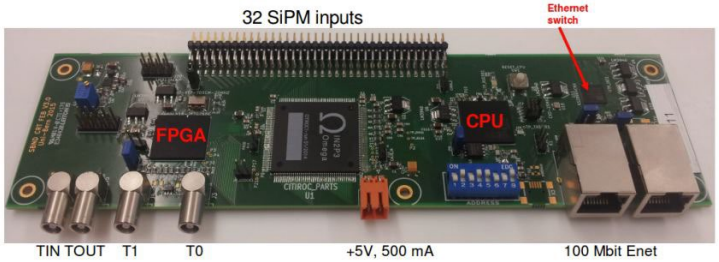
- **20 layers: Tungsten (3.5 mm ≈ 1X_0) + Silicon sensor**
- **Two types: Silicon strip (LG) and Silicon pixel (HG).**
- **Silicon strip provides cluster shape information**
- **Pixel layer provides high position resolution to resolve cluster s with partial overlap**

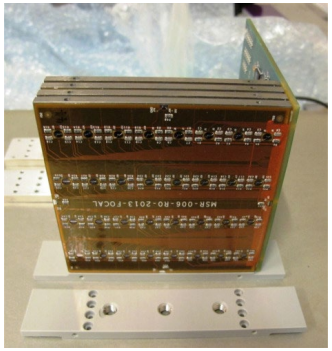


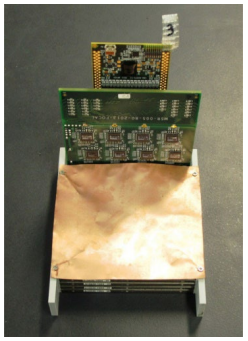


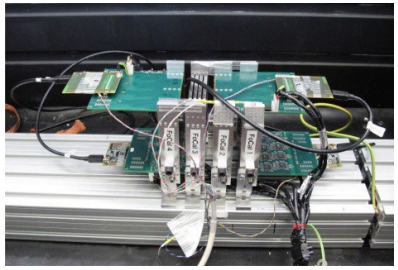
ALICE 2.1-Focal Readout Electronics

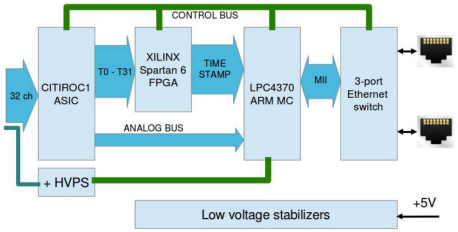
M. Auger et al 2016 JINST 11 P10005







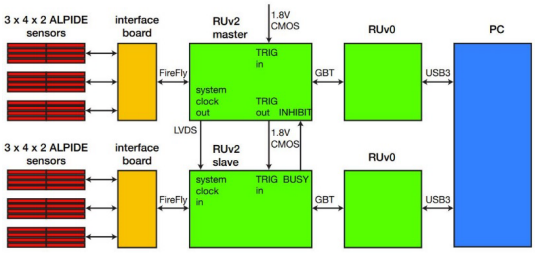




FoCal-H 2021 prototype readout electronics

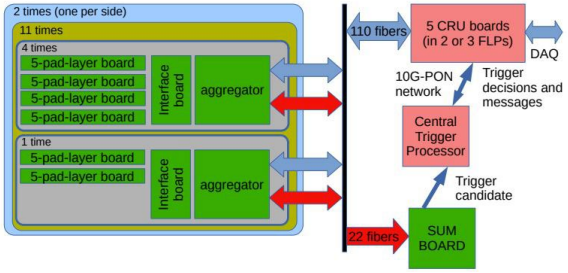
arXiv:1912.11115

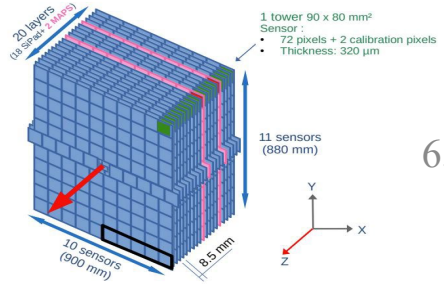
For the readout electronics of Focal-H, with a focus on the readout of the SiPM, a number of prototype electronics have been developed that use an ASIC as an analog front-end and an FPGA as a digital back-end. In the case of Focal-E, the electronics scheme chosen is also different due to the different granularity of the pad layer and the pixel layer.



arXiv:2209.02511

FoCal-E pixel layer prototype EPICAL-2 readout electronics

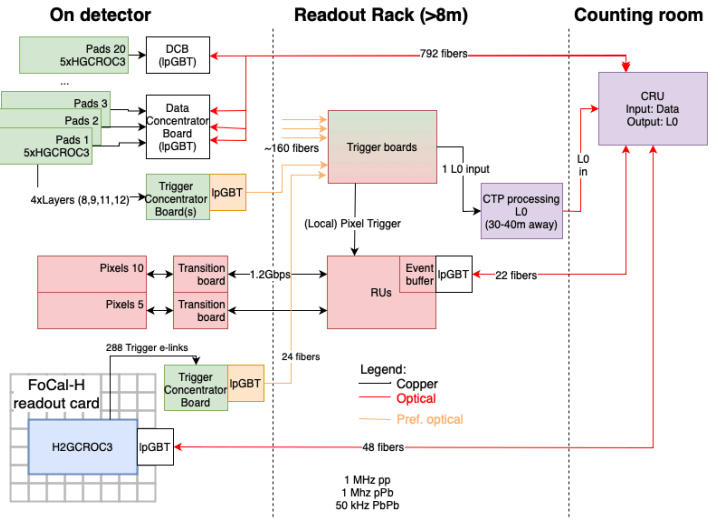




arXiv:2302.13912

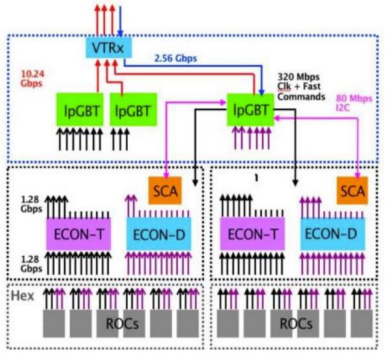
FoCal-E pad layer prototype readout electronics

ALICE 2.1-Focal Readout System

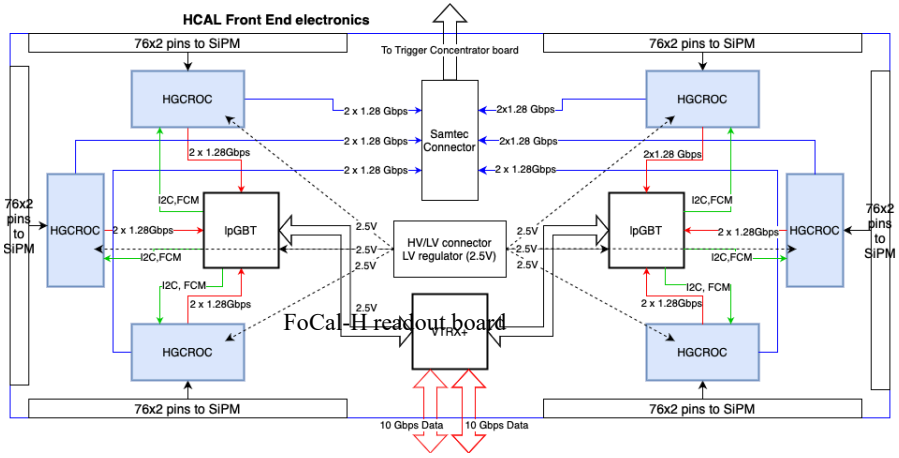


FoCal readout system

Focal Electronics uses HGCROC as the front-end chip, ECON chip for data compression, lpGBT chip for data transmission, and FPGA for control.



CMS CR -2021/228



FoCal-H readout board

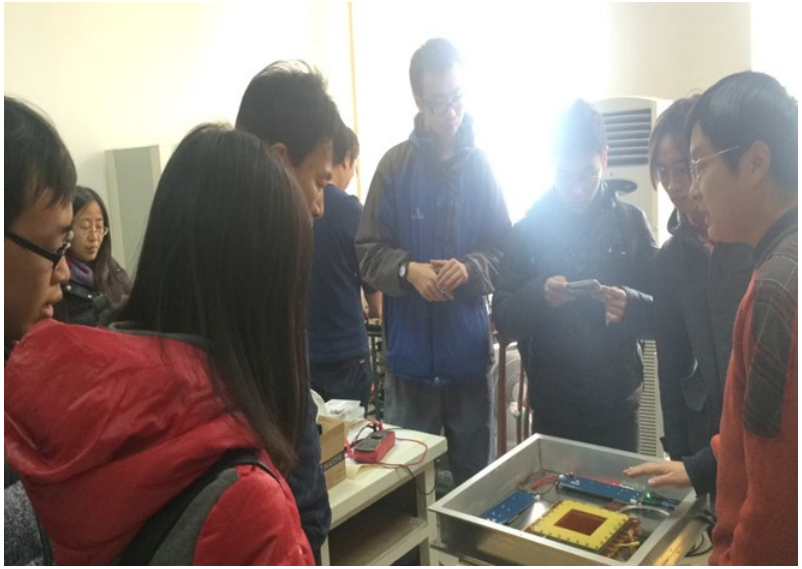
- Protect FPGAs with Long Readout Rack
- Use ECON-D and lpGBT readout pixel data
- ALPIDE pixels use continuous trigger mode, or through signals provided by the Pad layer

- 6 HGCROC, 2 LpGBT, 1 VTRX+
- 6x72 = 432 channels
- Use ECON-D / ECON-T ASIC compress data

CIAE Intermediate and High Energy Physics Team Members

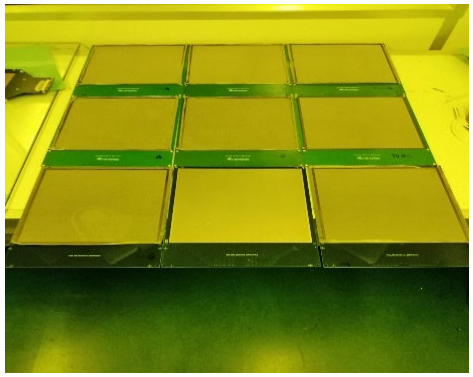
- 2 Professors
- 1 Associate Professor
- 1 Assistant Professor
- 3 Technicians
- ~12 Students

Visitors



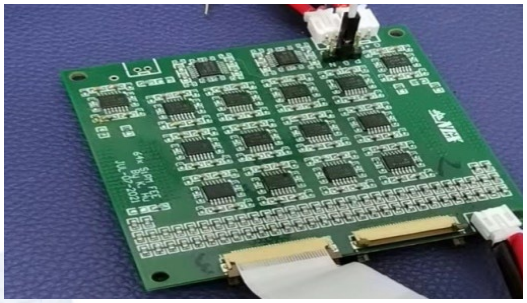
Summary and Prospect

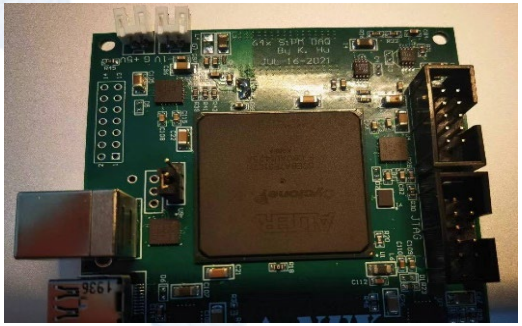
1. Complete R&D and mass production of Advance Gas detectors
2. Complete R&D and mass production of scintillating fibre detectors.
3. Electronics for MPGD and Electronics for SiPM developed by our team are working well. Now we are working on the electronics of ALICE Focal upgrade.
4. CERN/ALICE –CIAE joint lab is under construction.



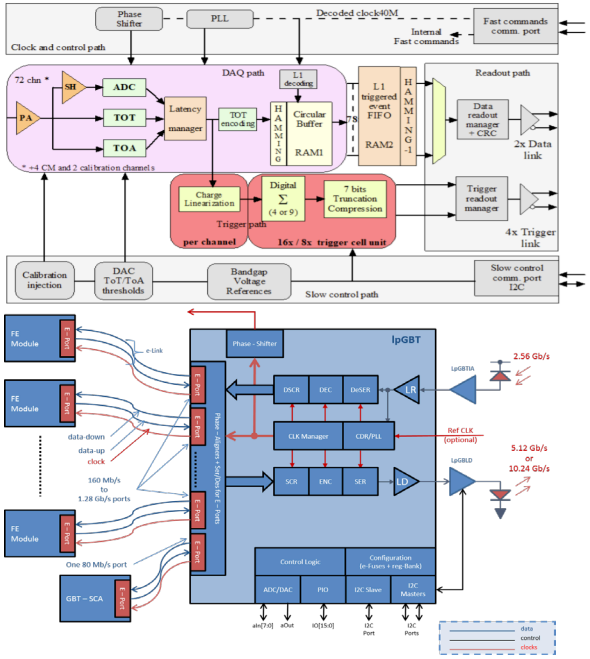
Electronics for Different Detectors

Electronics for MPGD





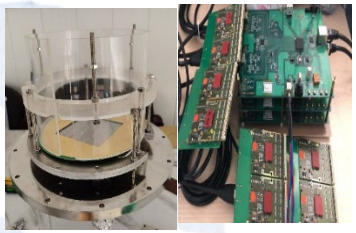
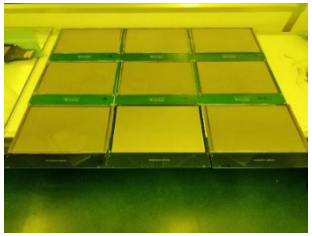
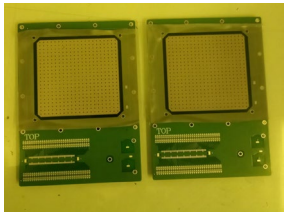
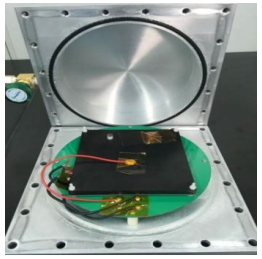
Electronics for SiPM

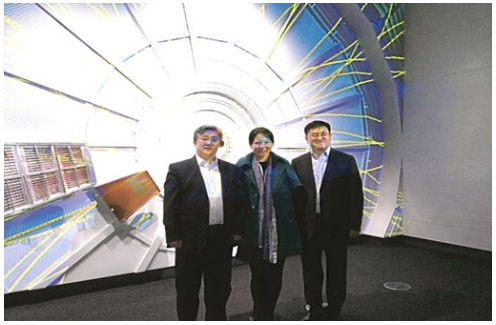


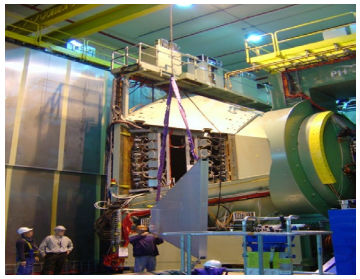
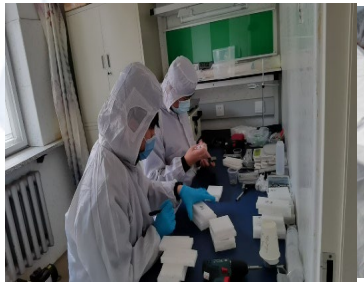
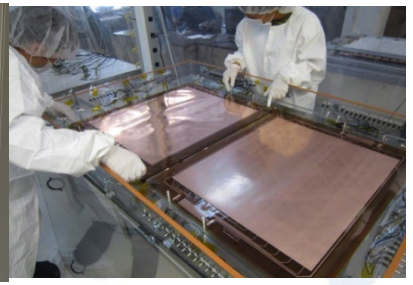
Electronics for ALICE FoCal

Detector Applications and Collaborations





Thanks for your attention!

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