# Detectors R&D at CIAE Beijing

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# Outline

- Developments of MPGD
- R&D of GEM at CIAE
- R&D of MicroMegas at CIAE
- Developments of EMCal Detector for sPHENIX
- ALICE Upgrade
- Summary and Perspective

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# Development of MPGD

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# R&D of GEM at CIAE

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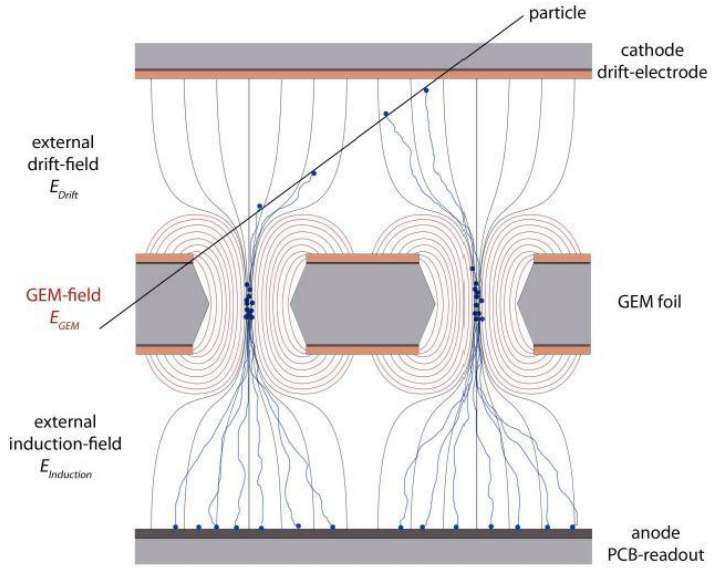
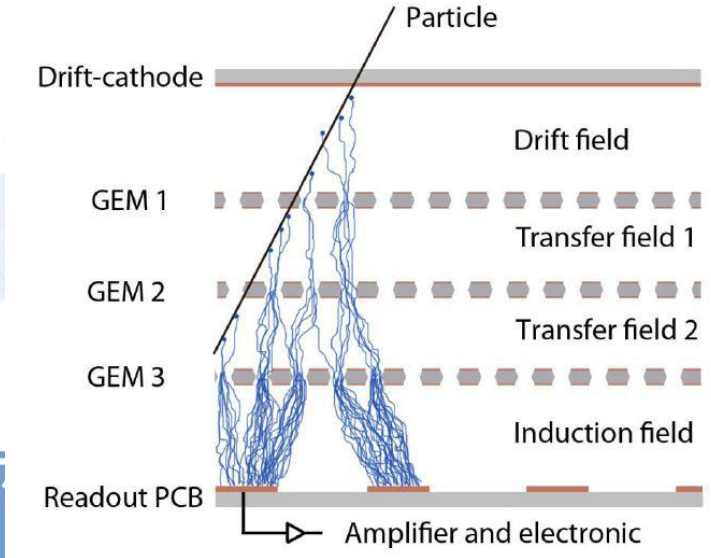
# Structure of GEM

- **GEM detector:**

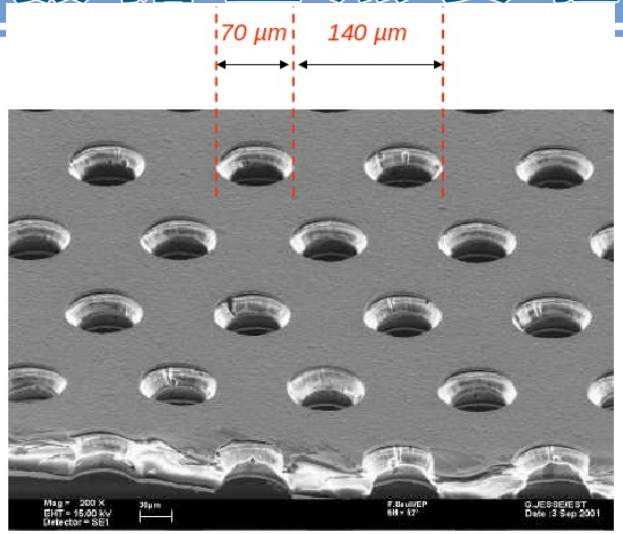
  - **Cathode, Drift field, GEM foil, Induction field and Readout board.**
  - **GEM foil： the most important part of GEM detector . Normally 3 GEM foils in one GEM detector.**



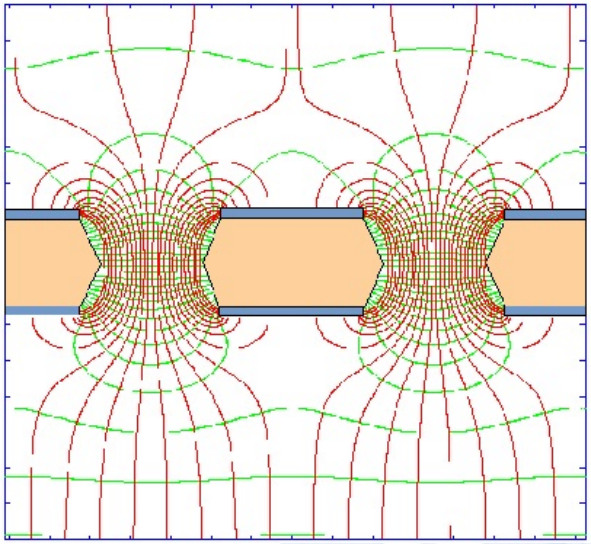




# GEM Foil

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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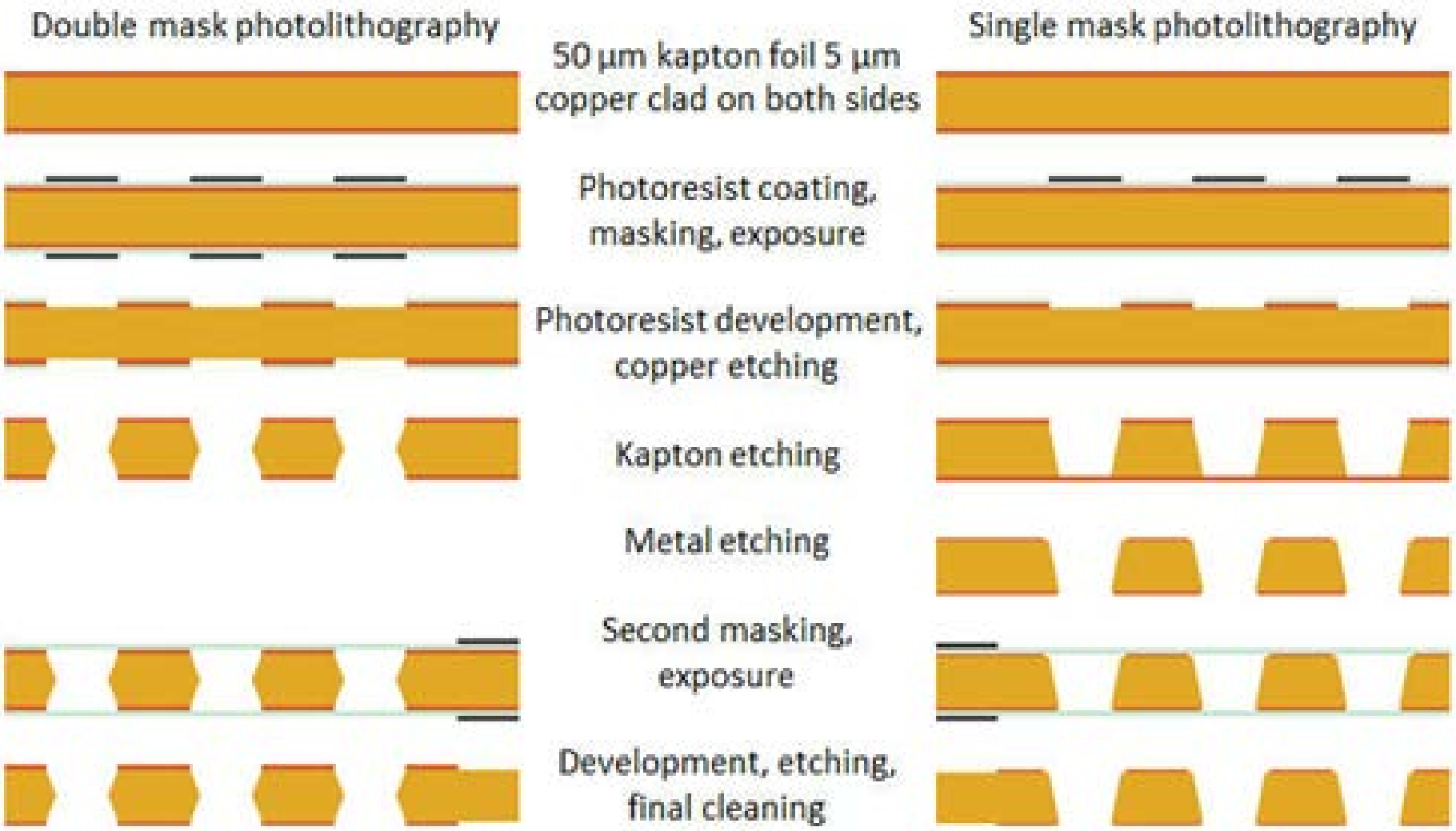
# The Procedure of GEM Foil

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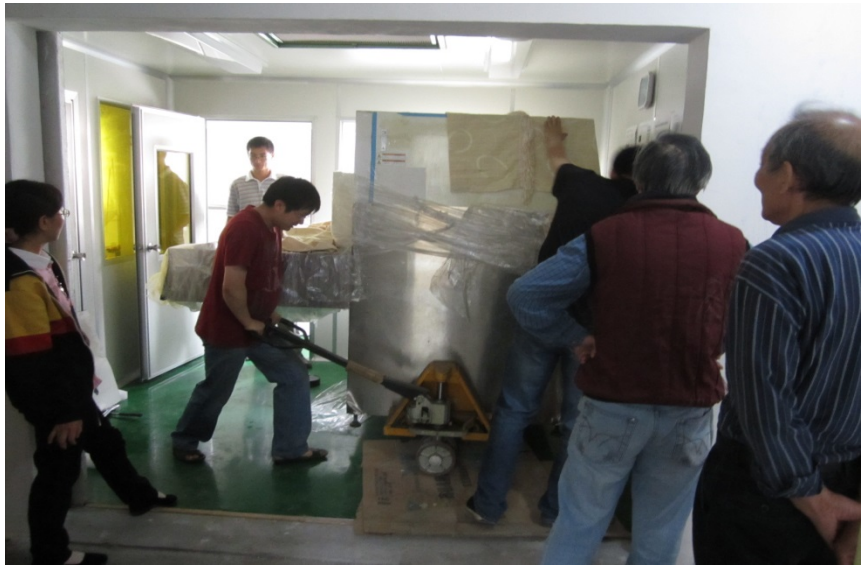
# GEM License and Training

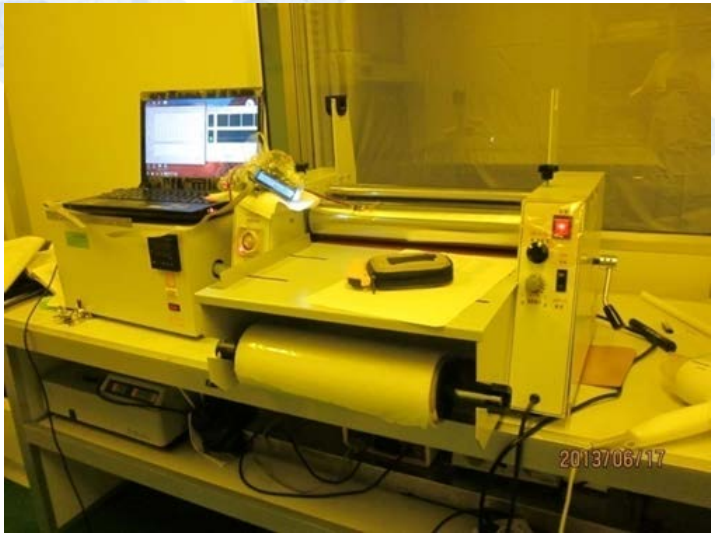
**CIAE is the first chinese institution which signed officially the LICENSE AGREEMENT FOR MANUFACTURING AND COMMERCIALISATION OF GEM FOILS AND GEM-BASED PRODUCTS with CERN.**

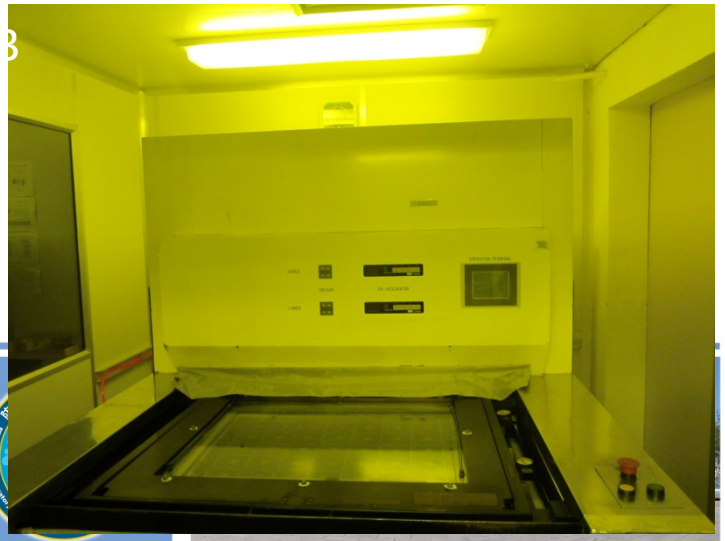
**I took a training for GEM foil at CERN.**

# 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.

# Exposure of Dry Film Photoresist

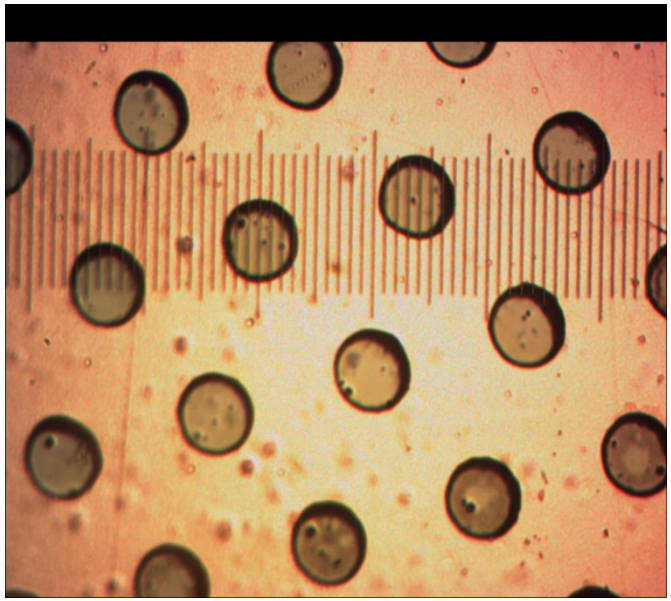
We use negative photoresist for GEM image transfer, unexposed areas are relatively unchanged and easily washed out during the development.

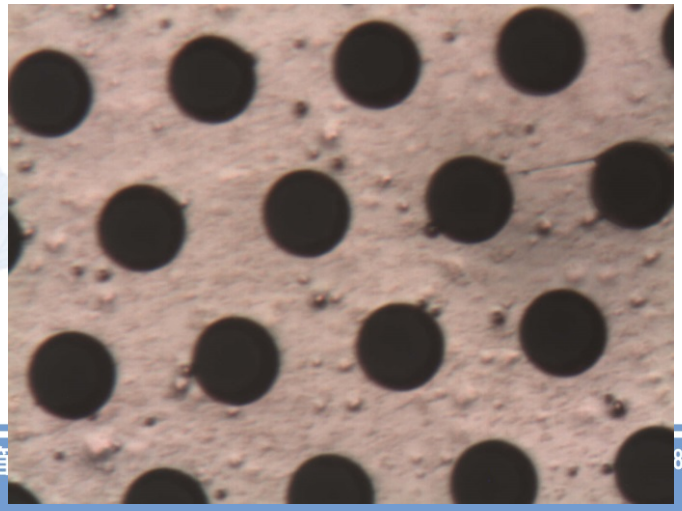
To obtain an identical copy of the photo-mask to the photoresist, vertical sidewalls in the resist are important.

We can observe the image transfer with good accuracy.

# Copper Etching and Kapton Etching

- The size of the hole is 70um as expected

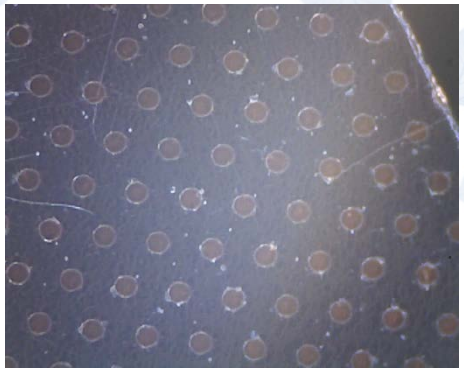




Etching Room Construction

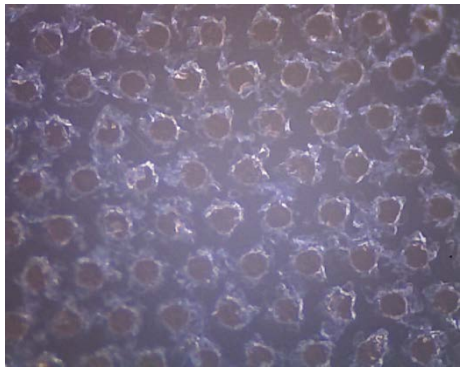
# Comparison of Foils Made in Different Conditions

Insufficient development

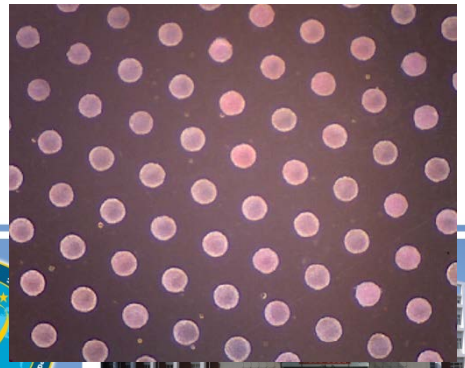


Good development

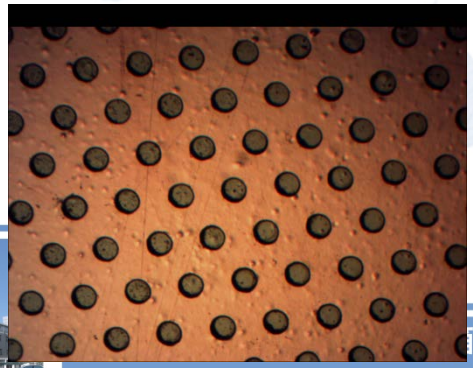
Excessive development



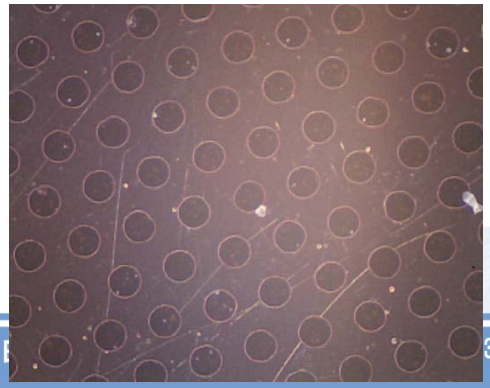
Insufficient copper etching



Good copper etching

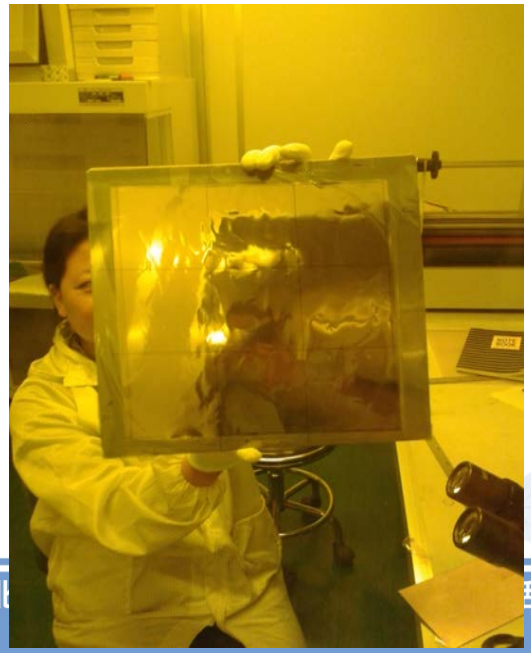


Excessive copper etching

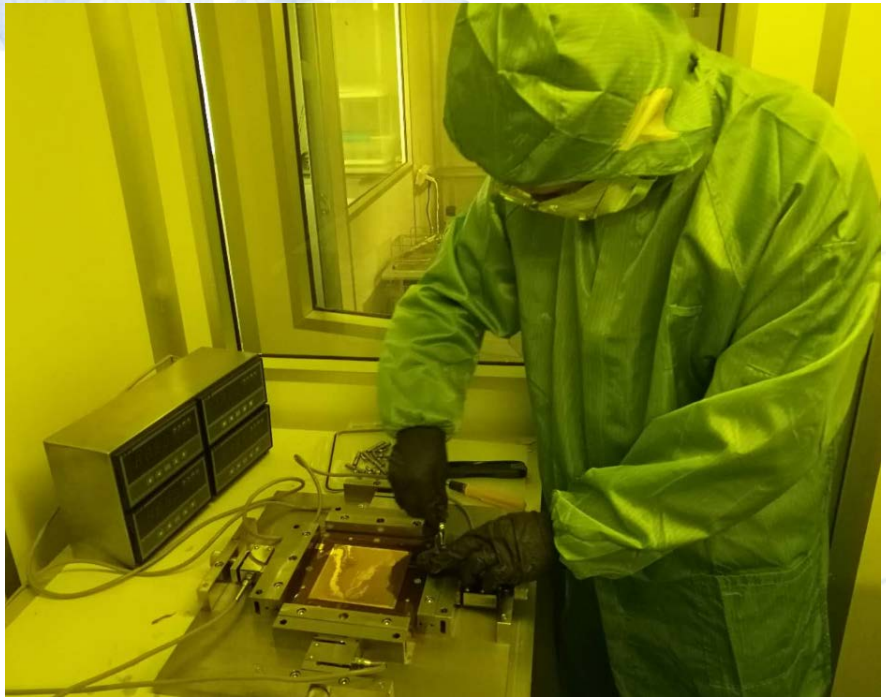


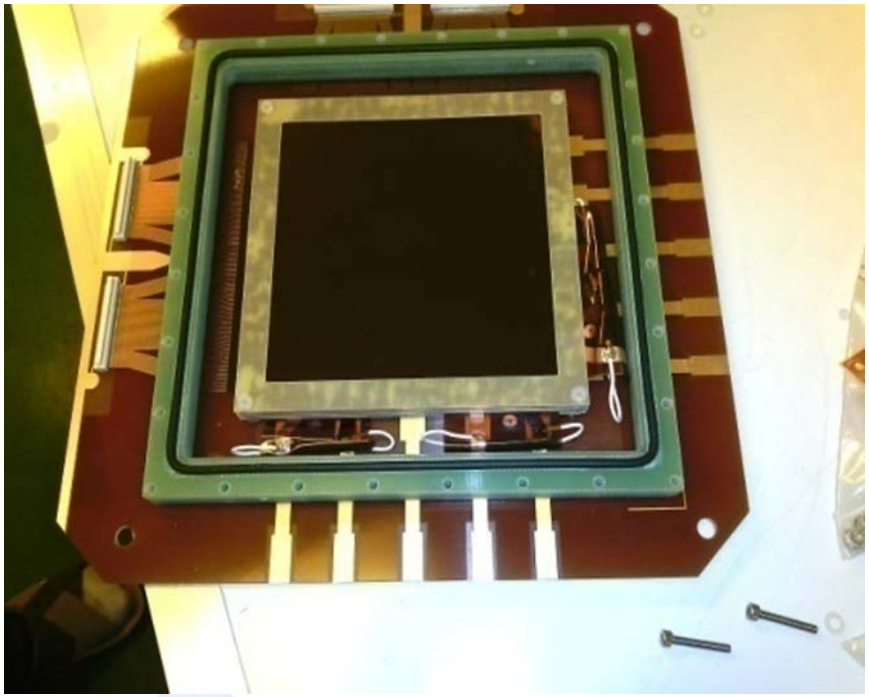
# 50cm*50cm GEM Foil

- The 50cm*50cm GEM foils were made successfully.
- single-mask method was used.
- We did more than 200 samples before reaching this result.
- Sometimes the alignments of top and bottom masks were not perfect especially for large GEM foil. We have upgraded our alignment system.



# GEM Detector Assembly at CIAE





active area 10*10cm

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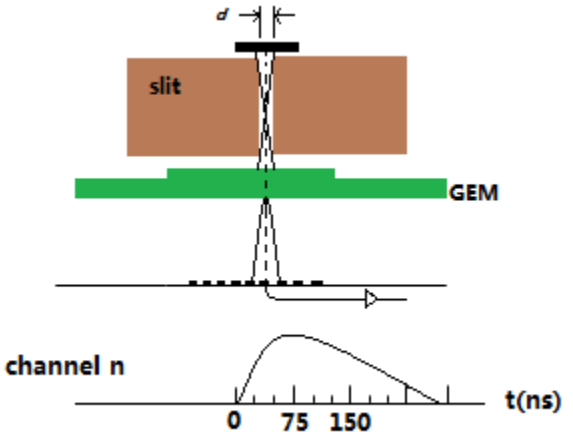
# Spatial resolution

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

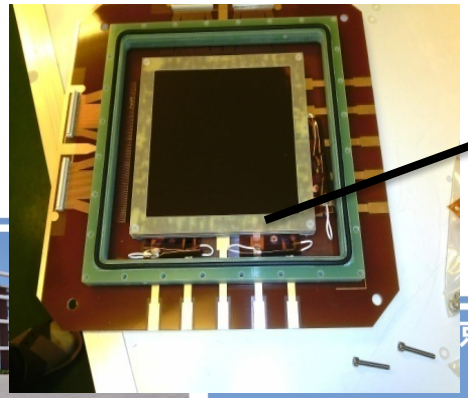
When: $\sigma_{geometry} \ll \sigma_{GEM}$

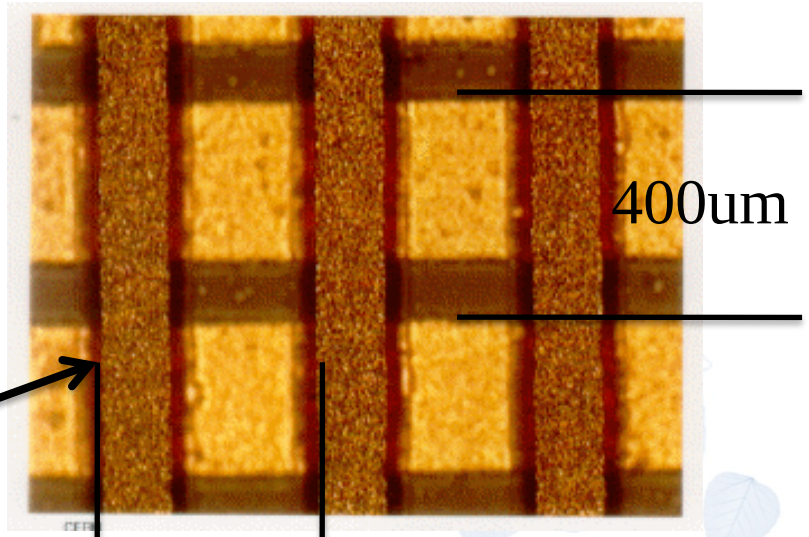
$$\sigma_{tot}^2 \cong \sigma_{GEM}^2$$

**Spatial resolution≈76um**




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



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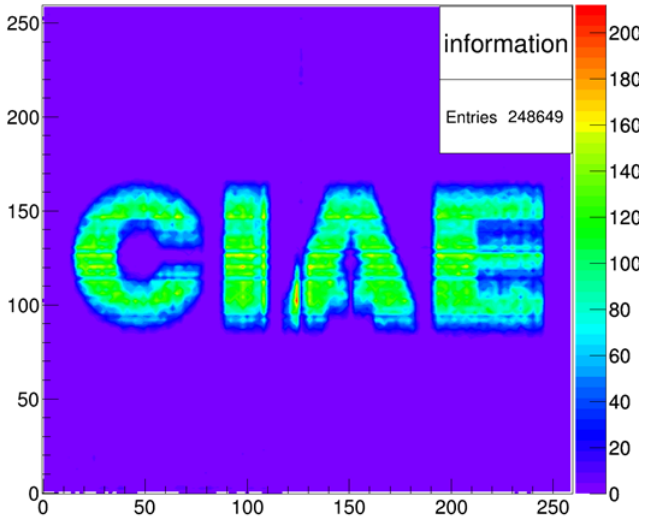
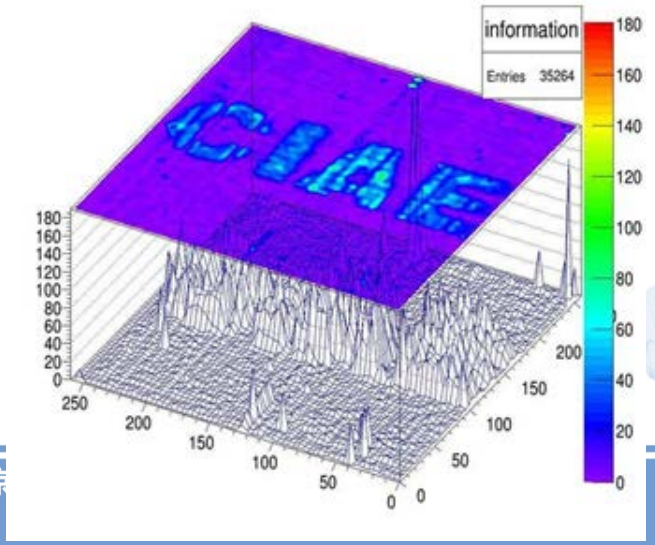
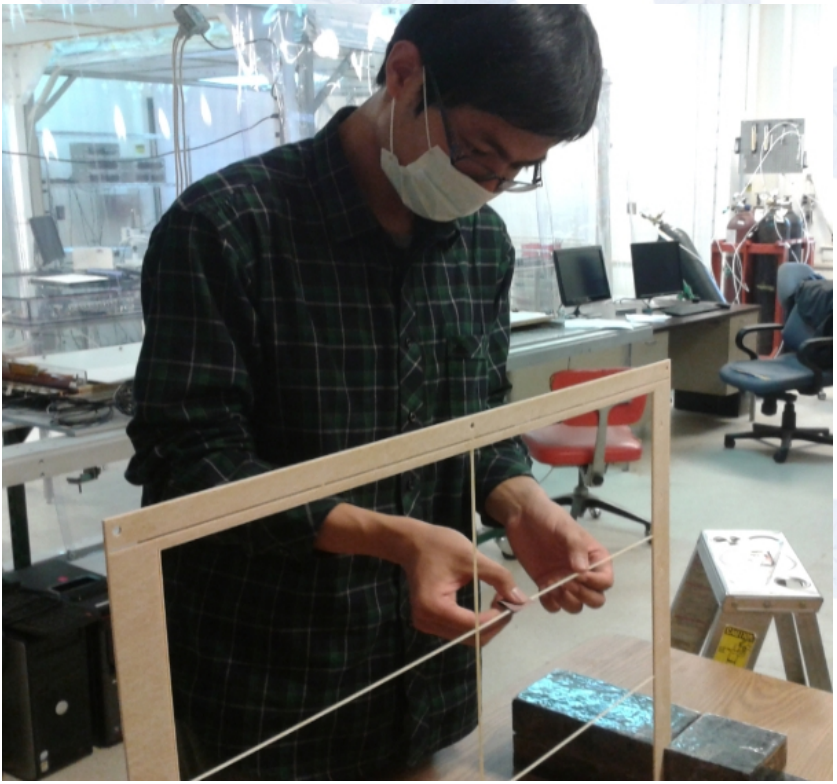
# X-ray imaging @ CIAE

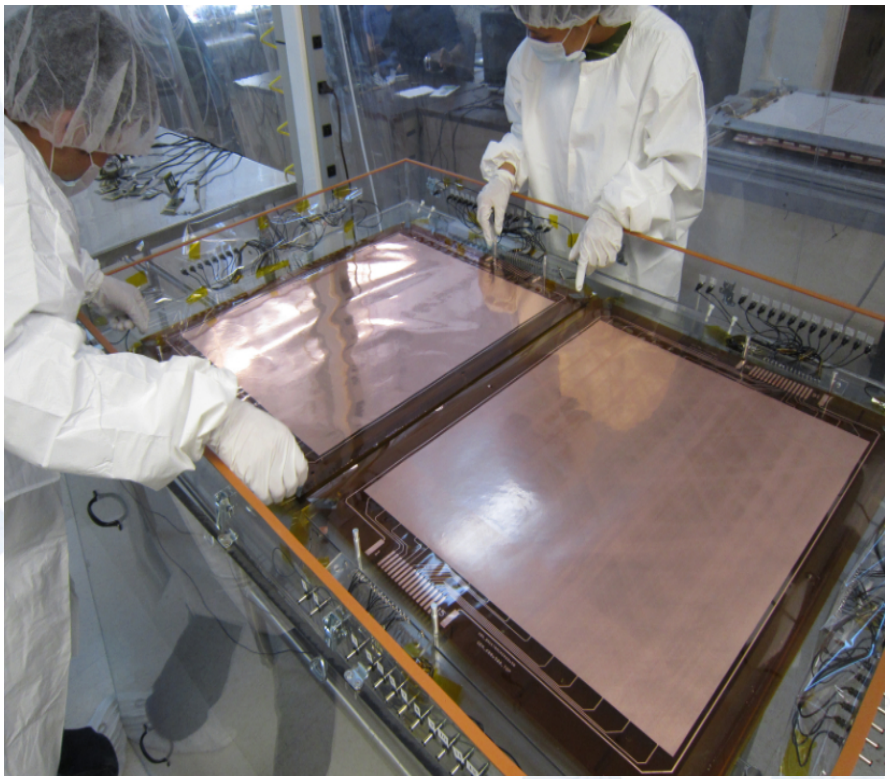




- X ray Energy: 8.9keV;
- 256 channels for each dimension( 512 channel in total);
- 4 APV FECs were used (2 for each dimension)




# Students working at JLAB and UVA





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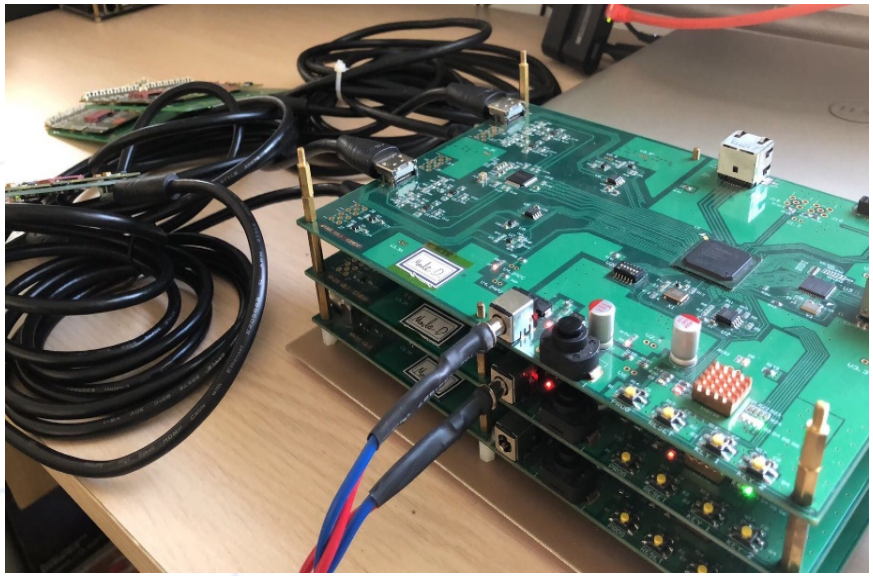
# Electronic and DAQ System for MPGD

**The Electronic and DAQ System developed with *APV25* electronics front-end card, *APVDS* electronic digital system and new data acquisition software *GeoAPV*.**

**Testing in the configuration of 2,048 channels, internal trigger mode while monitoring the sampling waveform, the transmission rate can stably maintain 715 Mbps**



GeoAPV
CHINA INSTITUTE OF ATOMIC ENERGY

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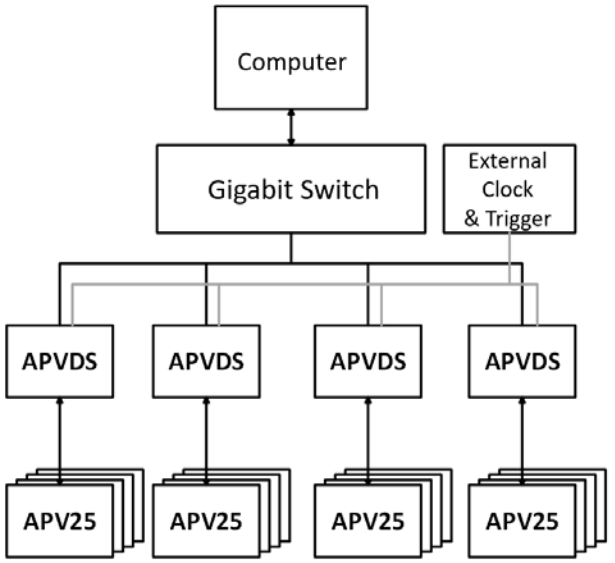
# Electronic Hardware Integration

**Each APVDS digitalization board is capable of processing 512 channels' input.**

**The whole system uses multiple APVDS board to expand the capacity of the system.**




**Every APVDS has an independent IP address and shares a common external clock signal from APVTTS board.**

# 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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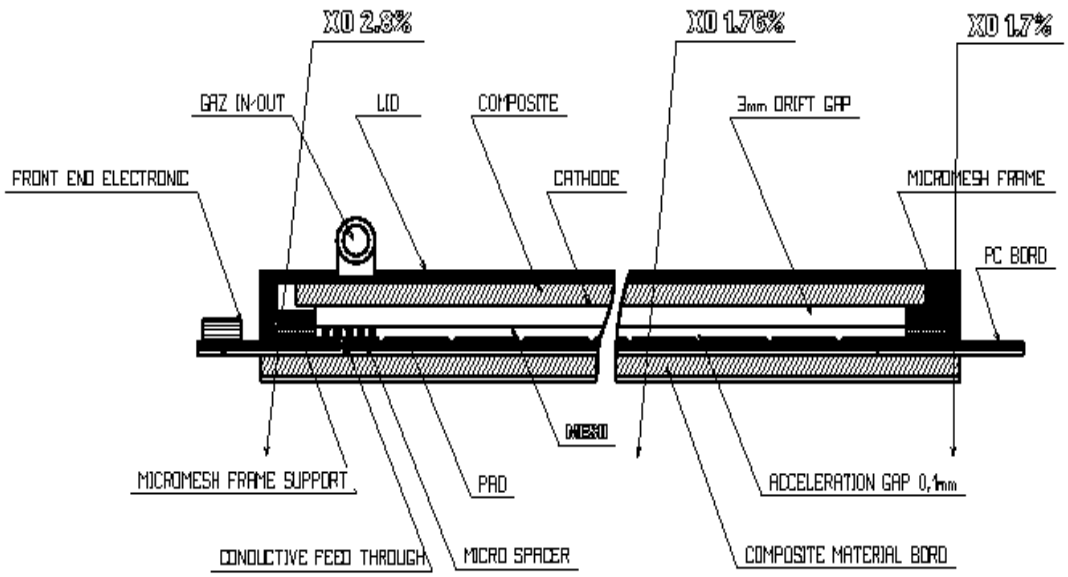
# *MICROMEGAS* detector

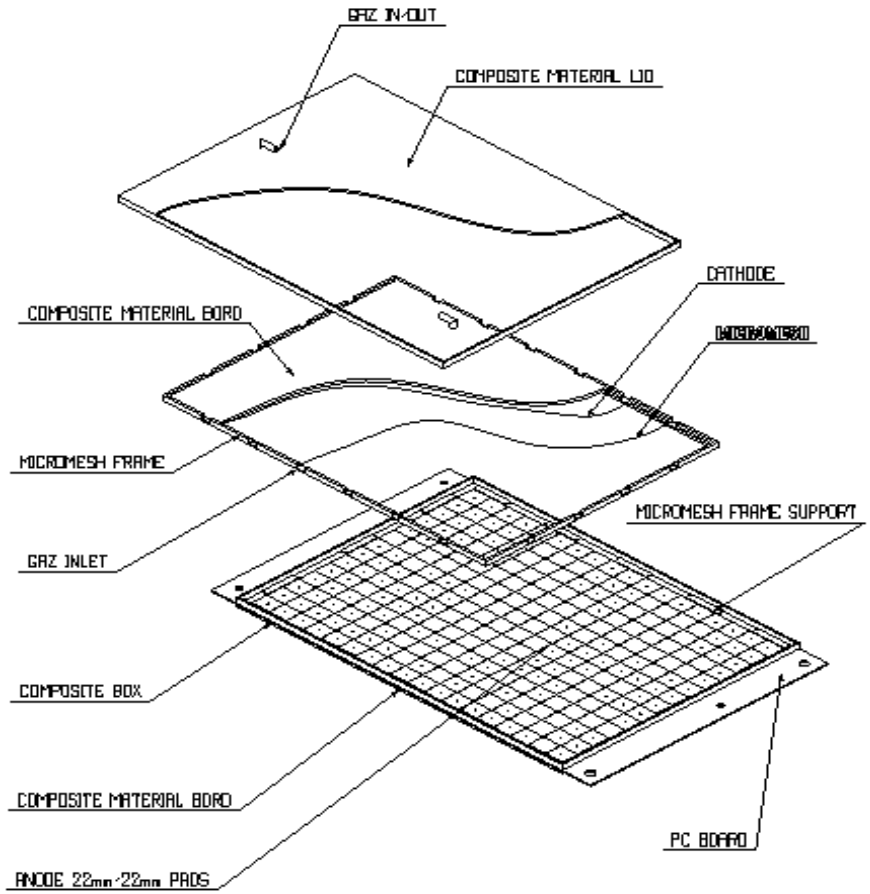



- active area 415*375mm$^2$
- 3mm drift gap
- 100 μm amplification gap

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

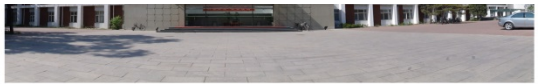
**Ph.D in SUBATECH, France**

# *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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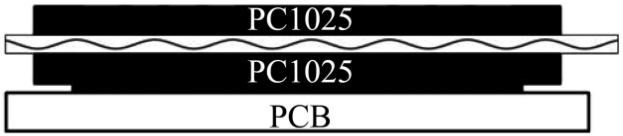
# Stucture of Bulk MicroMegas

PCB anode

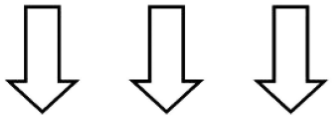

photoimageable film is laminated on PCB


S.S. mesh is placed

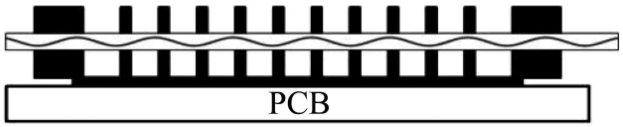

S.S. mesh laminated between two layers of photoimageable film




photolithographic process



completed micromegas




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

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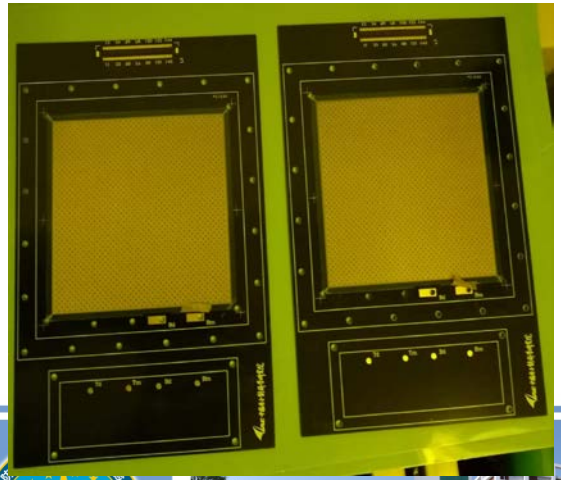
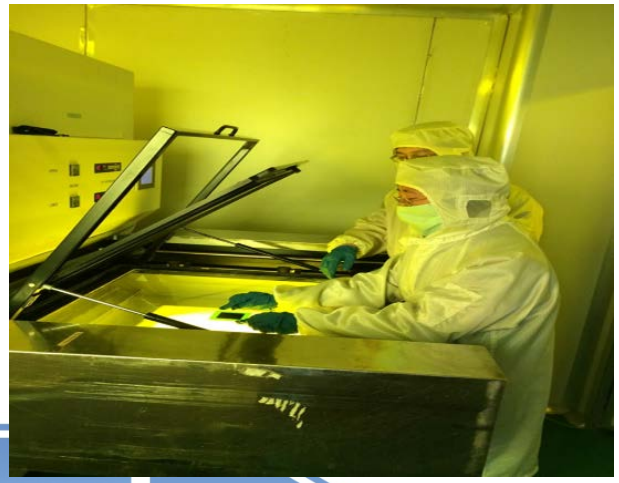
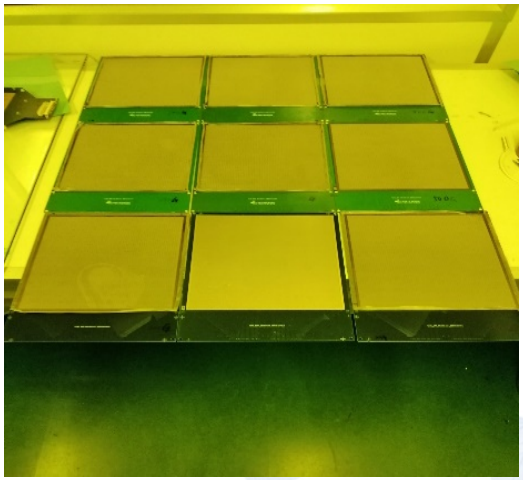
# Manufacture of MicroMegas at CIAE

- Completed R&D and mass production of bulk MicroMegas.
- Developed new photoetching MicroMegas， applied for 13 patents, obtained 1 international patent.







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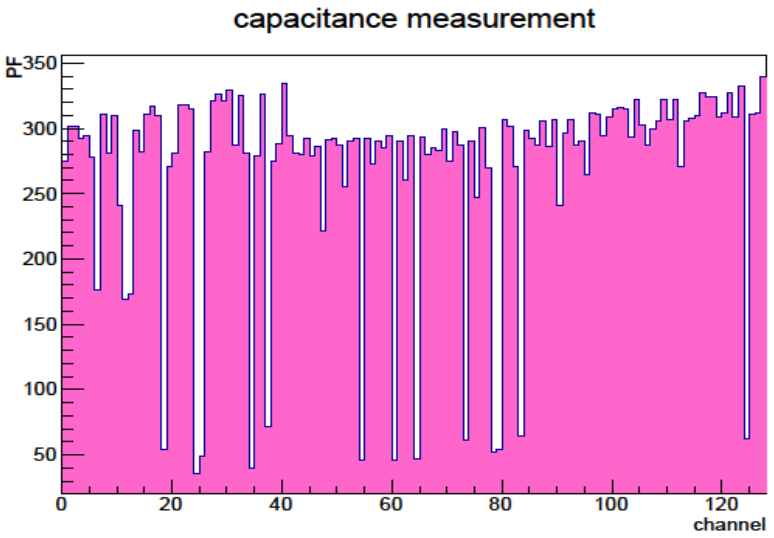
# Capacitance and Resistance Automatic Testing System Invented by CIAE

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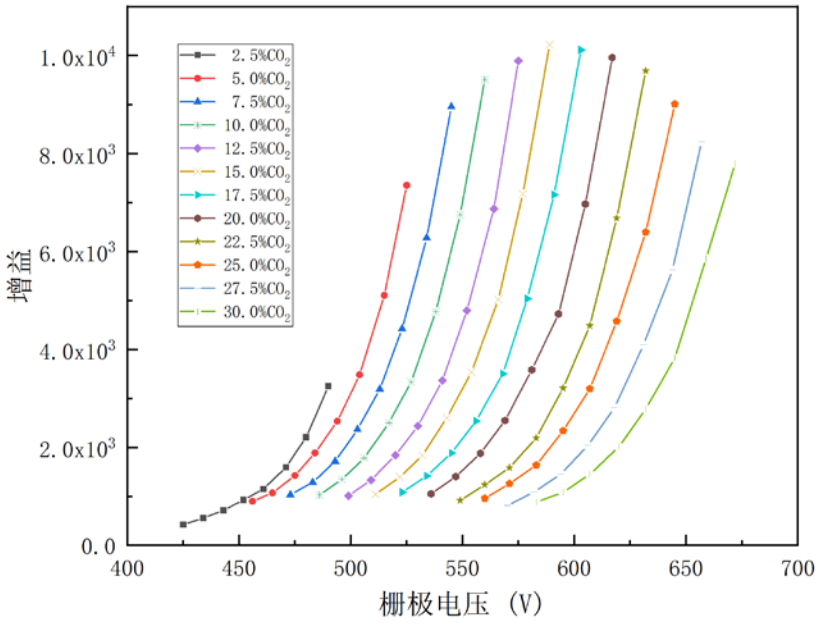
# Performance of Micromegas

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. It has reached the best level of energy resolution of similar multi-channel non-resistive Micromegas in the world.

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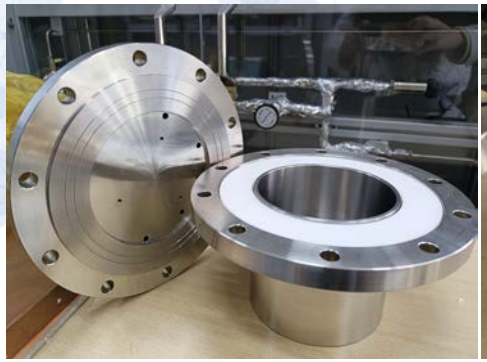
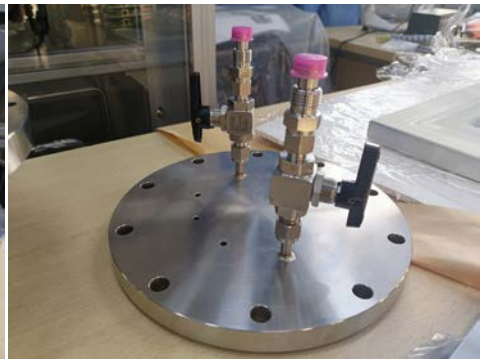
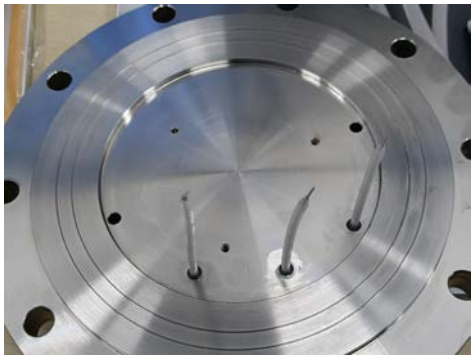
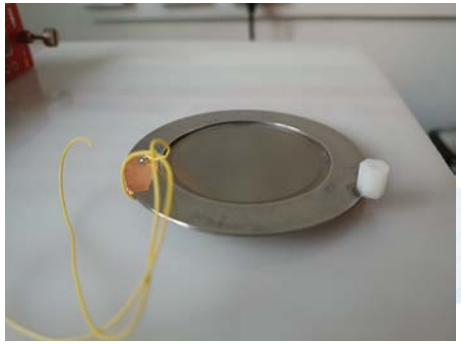
# Development of Sealed Chamber MM

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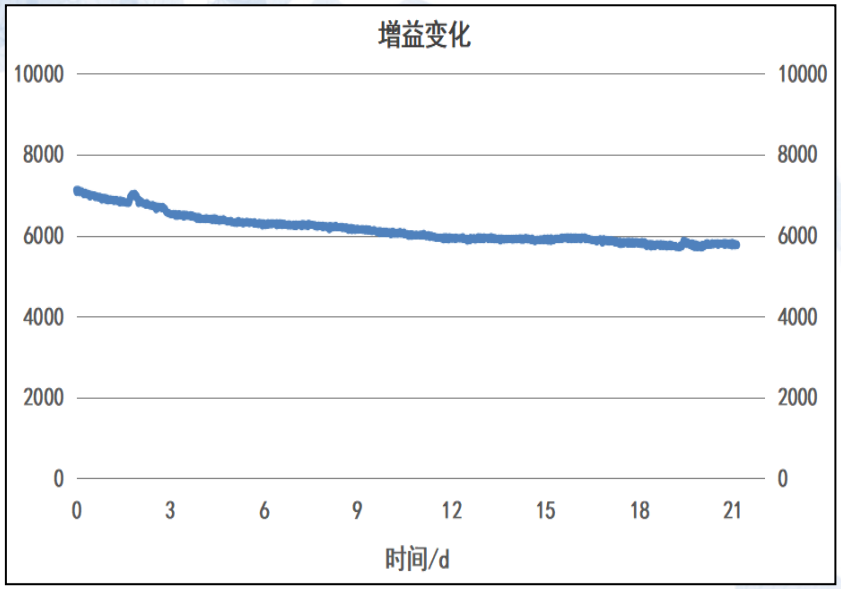
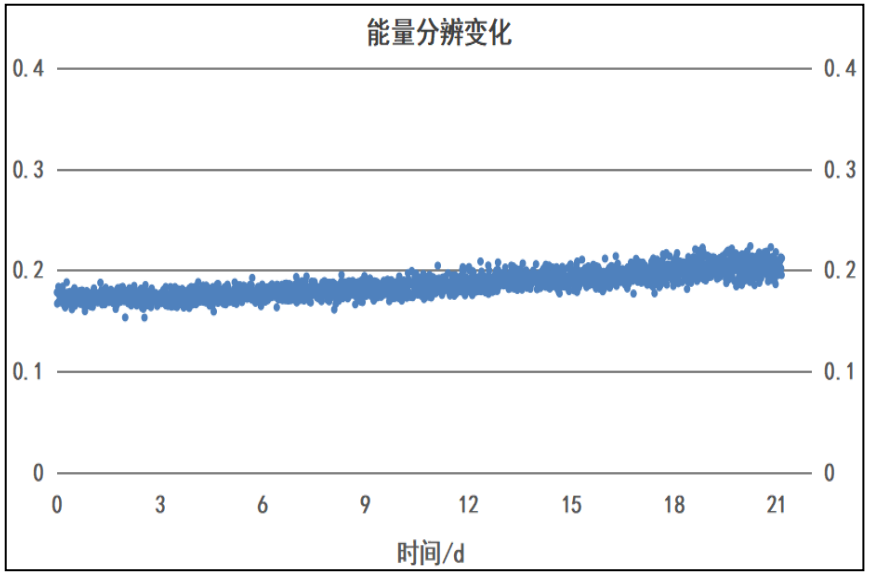
# Development of Sealed Chamber MM

$V_{Mesh}$：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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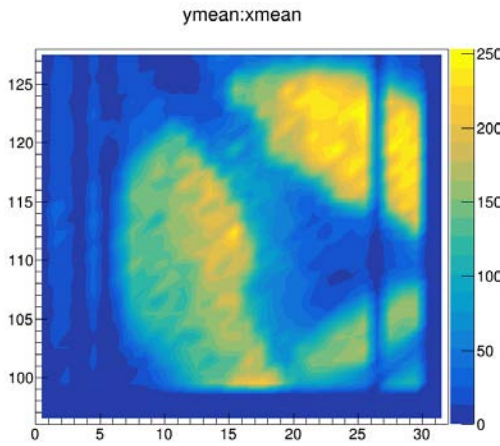
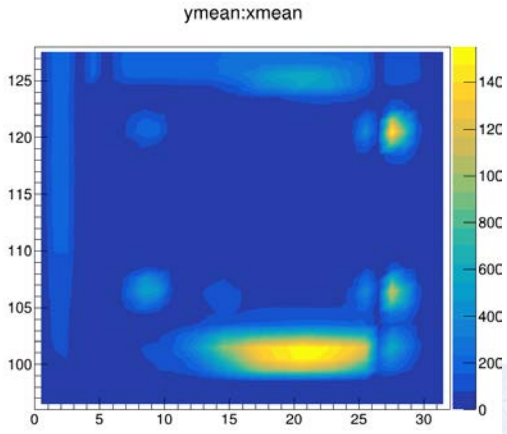
# Micromegas X-Ray Imaging

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

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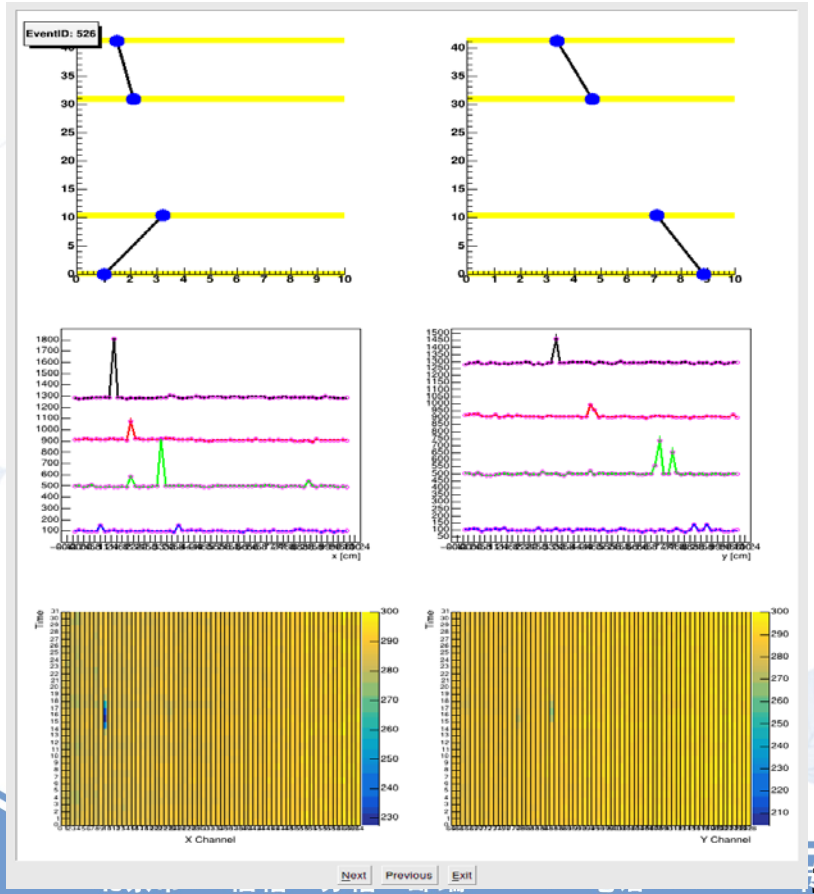
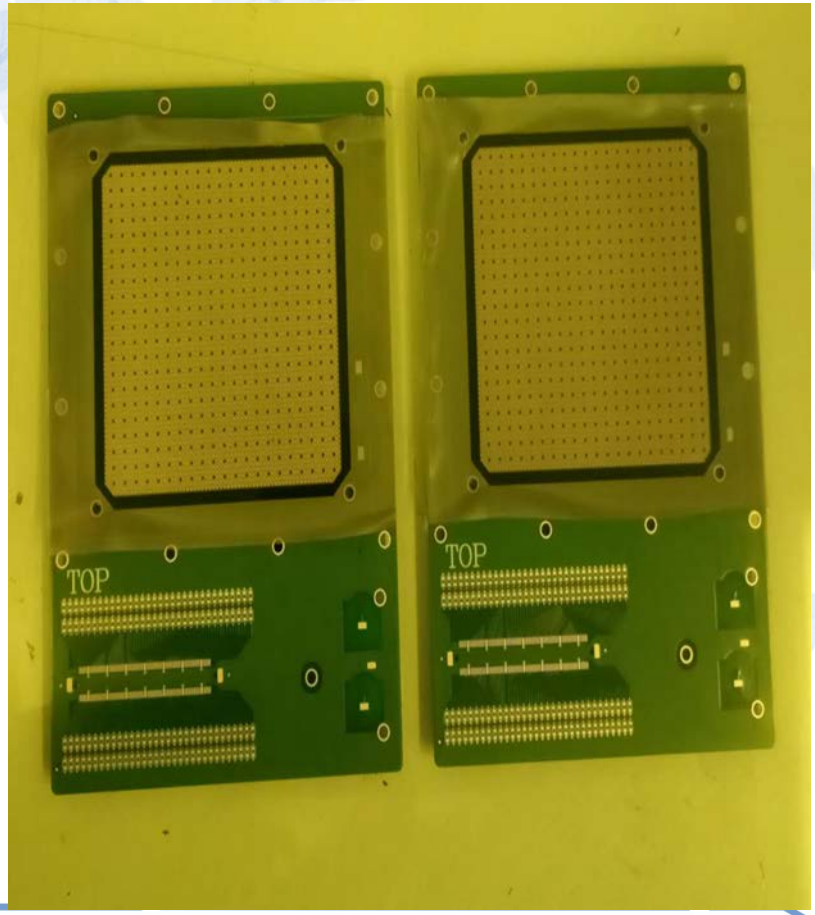
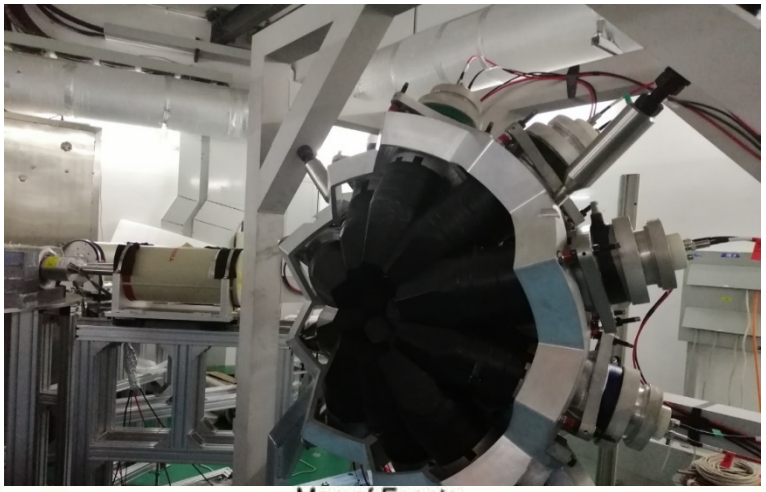
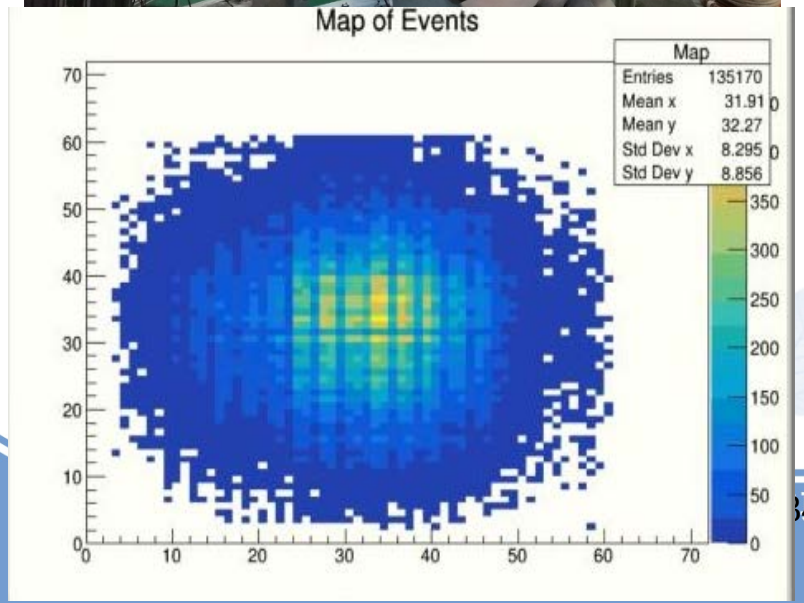
# MicroMegas：
# Radiation Detection



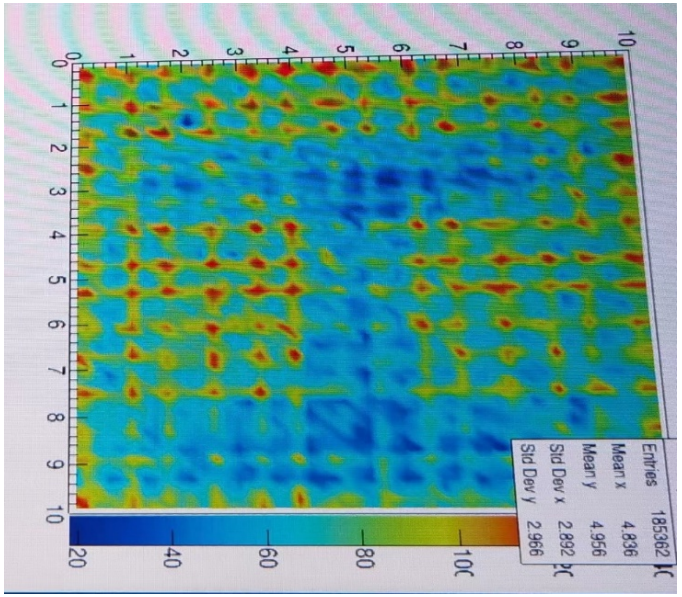
# Neutron imaging at China Spallation Neutron Source






# Neutron Imaging at CIAE



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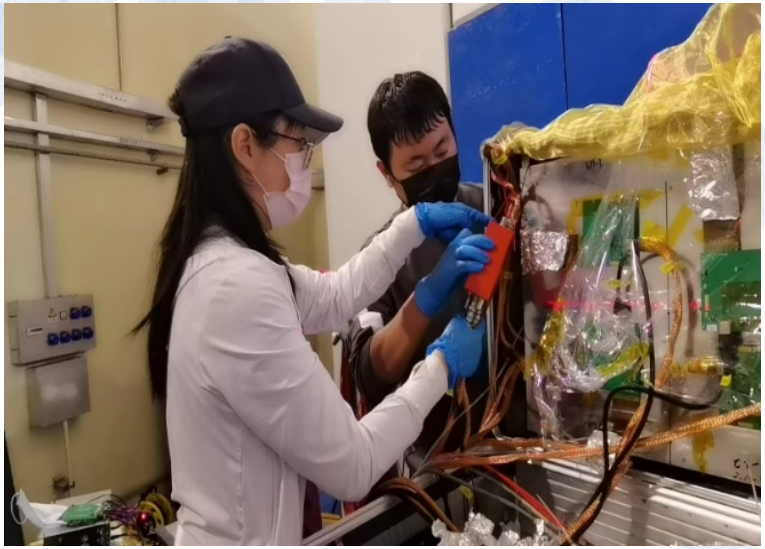
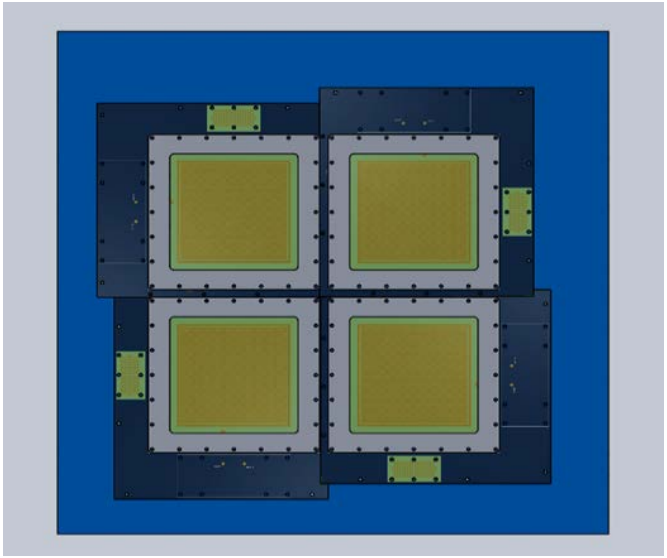
# Neutron Imaging at CIAE 100MeV Cyclotron





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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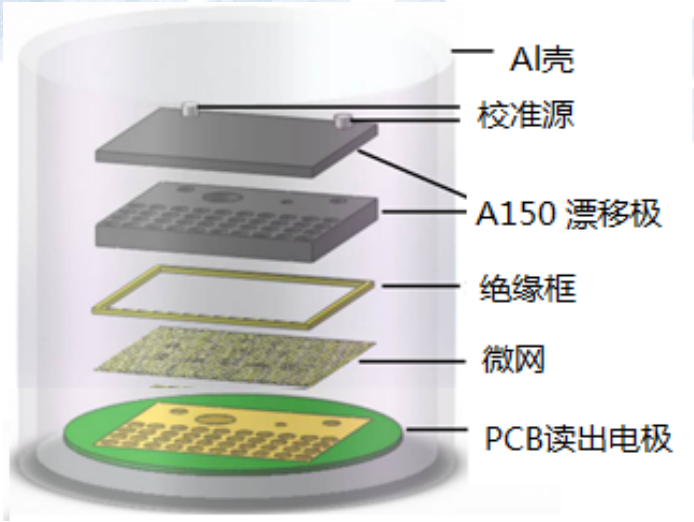
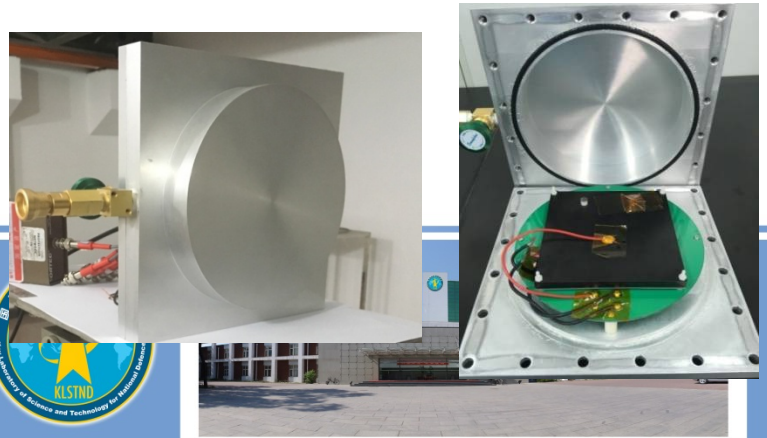
# MicroMegas: TEPC at CIAE




**TEPC is widely used in microdosimetry.**

**Compare with MWPC:**
**Easy Assembly,**
**More Sensitive**



**Compare with GEM:**
**More stable**

**Tissue Equivalent Proportional Counter**

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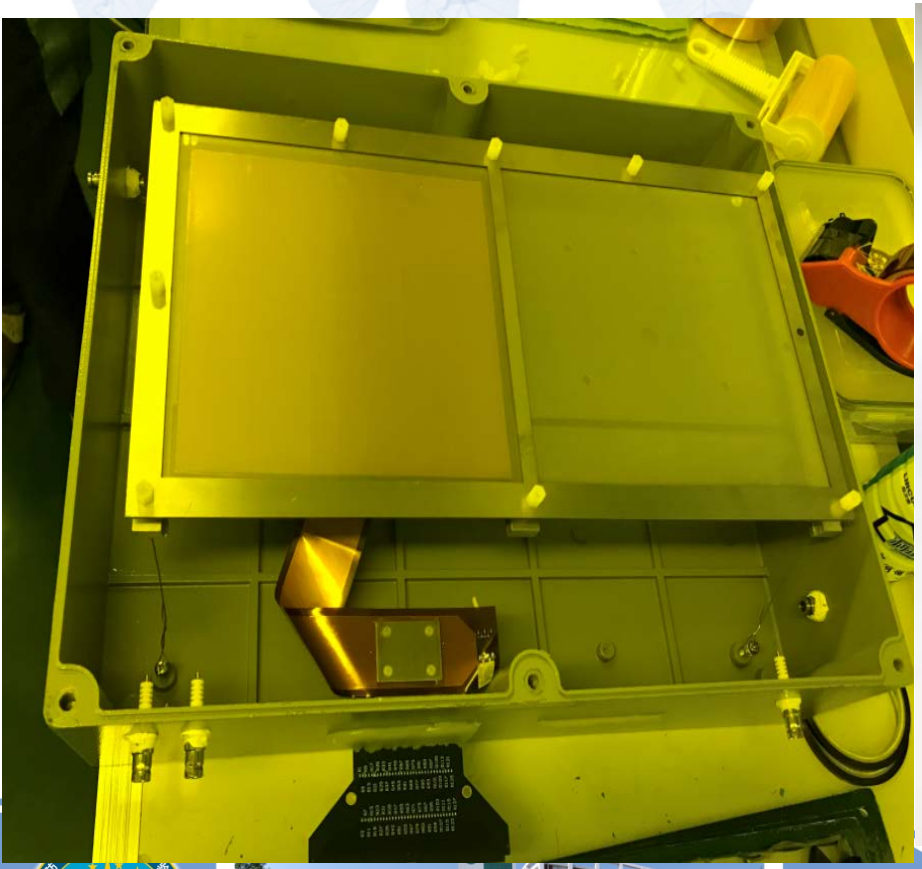
# PandaX-III MM Test Platform at CIAE

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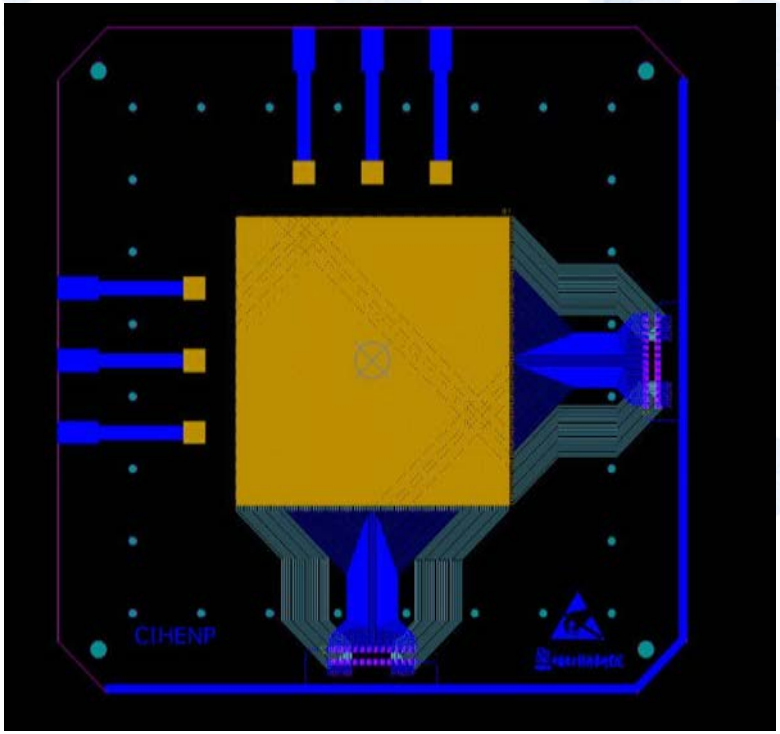
# MicroMegas for the R&D of CEPC TPC

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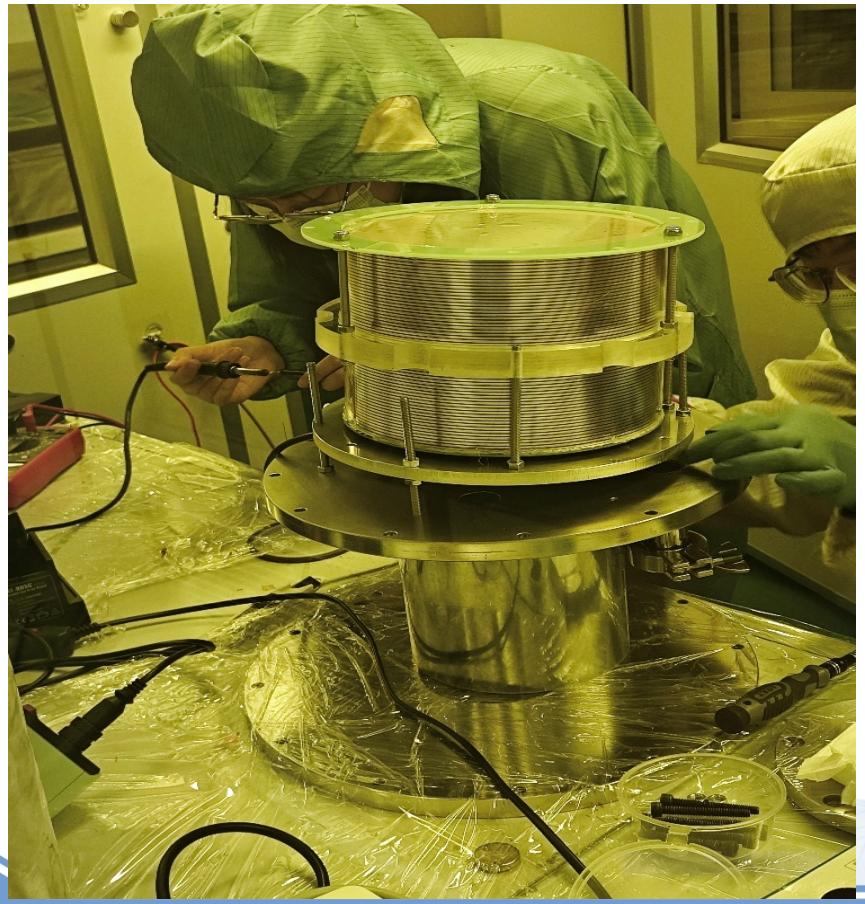
# MicroMegas for R&D of Multifunction TPC



# Development of EMCal Detector

# for sPHENIX

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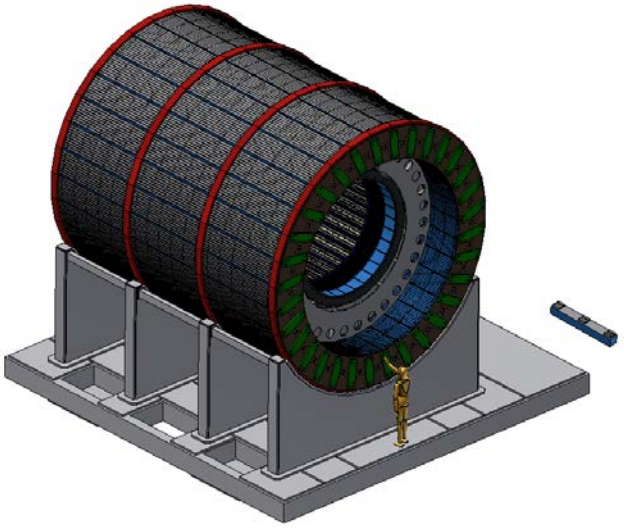
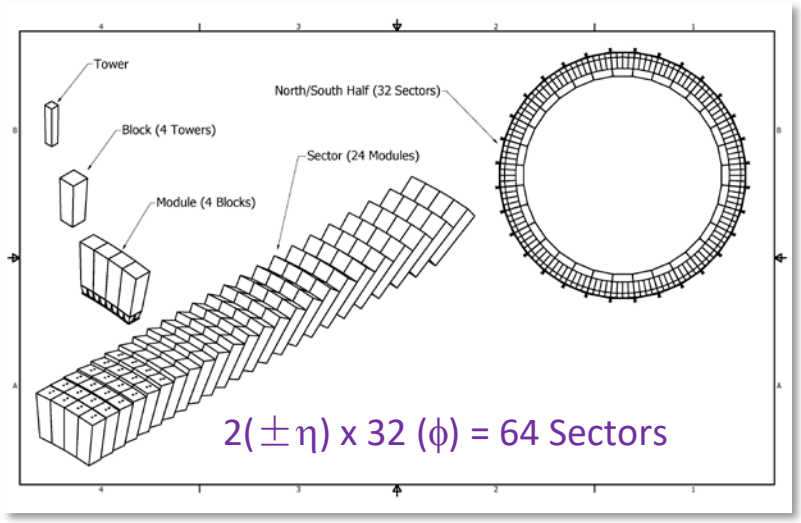
# EMCal Design Performance

**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 $\eta$ and $2\pi$ in $\phi$. $\Delta\phi$ x $\Delta\eta$ ~ 0.025x 0.025

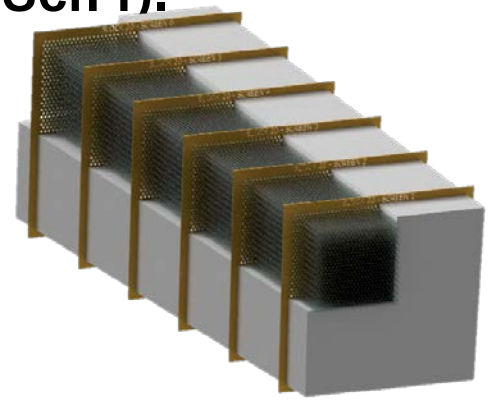


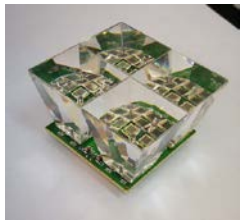



The EMCal performance is central to the direct photon and Upsilon measurements and it is also a key component, along with the HCal, of the jet reconstruction.

# EMCal Block Design

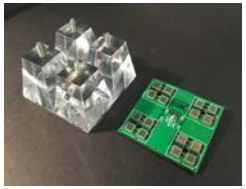
**The EMCal block design consists of scintillating fibers embedded in the absorber material, which is a matrix of tungsten powder infused with epoxy (W/SciFi).**



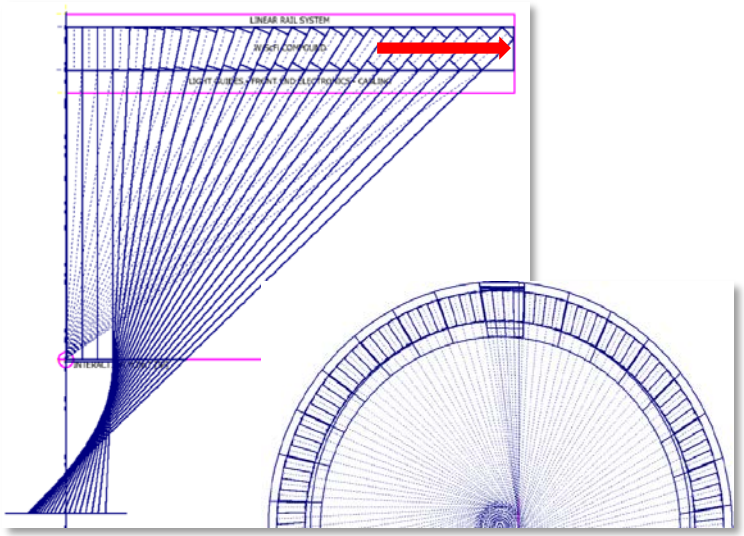


W/SciFi Block

- 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

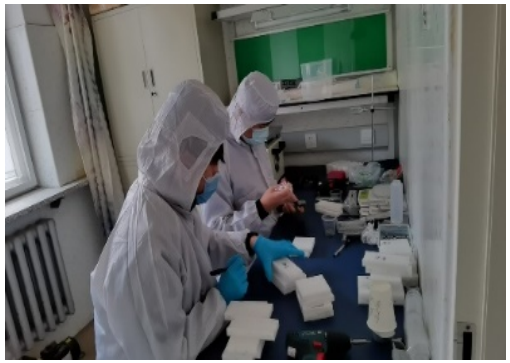


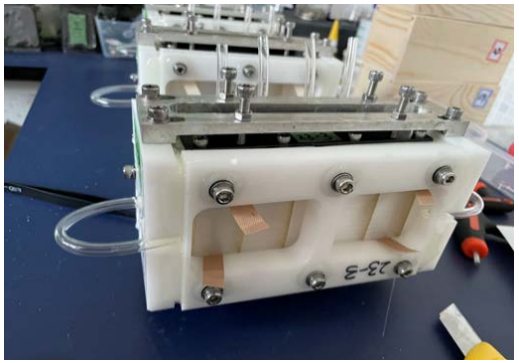
- Total 6144 blocks for EMCal
- 1248 blocks will be made in China.

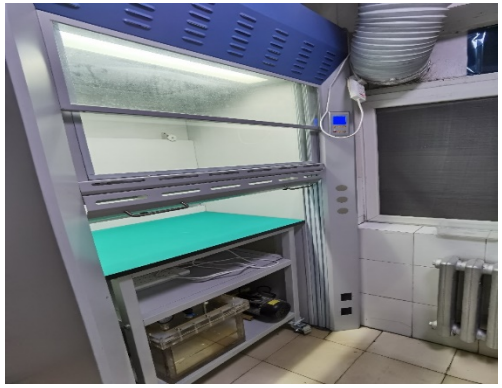
- Fudan, CIAE, and PKU are the main cooperative sites in EMCal construction and make an important contribution to the sPHENIX experiment.

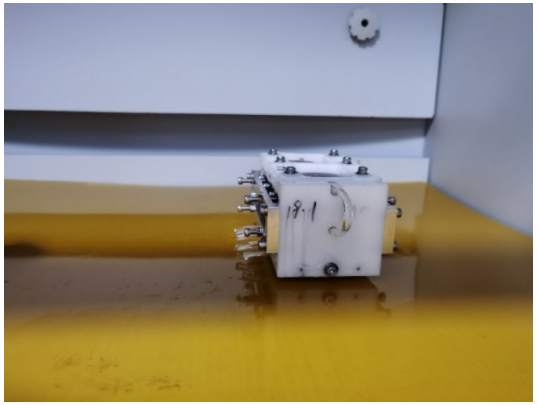
# sPHENIX EMCal R&D Center

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

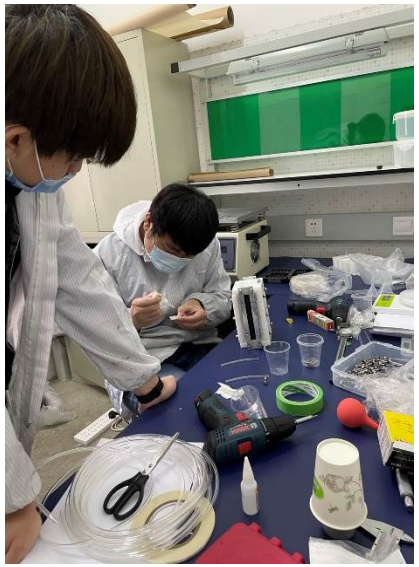






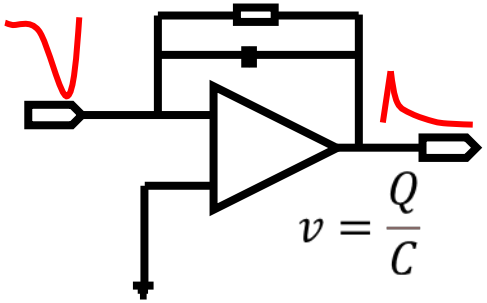


# Block Mass Production



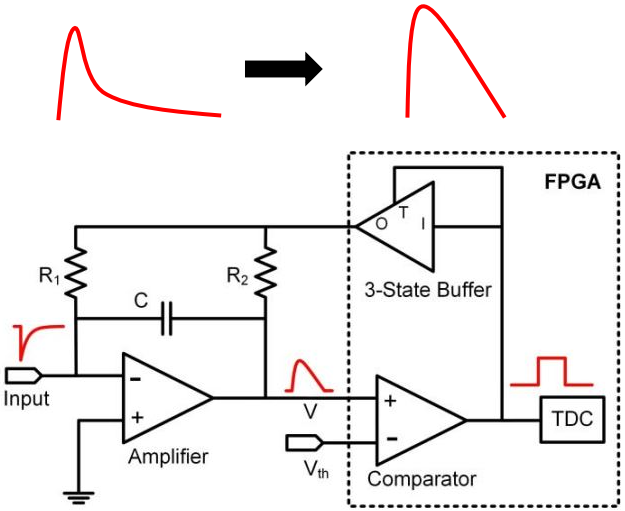
# Block Mass Production


# FPGA-Based Readout System for SiPM




**How to measure the voltage?**

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



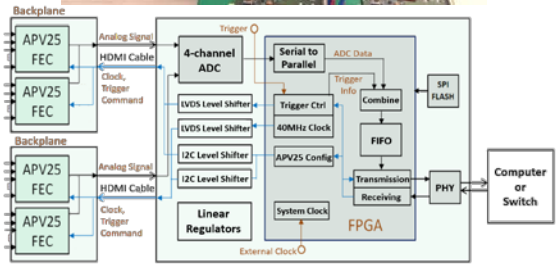

**Flexible, low cost, fast speed**

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

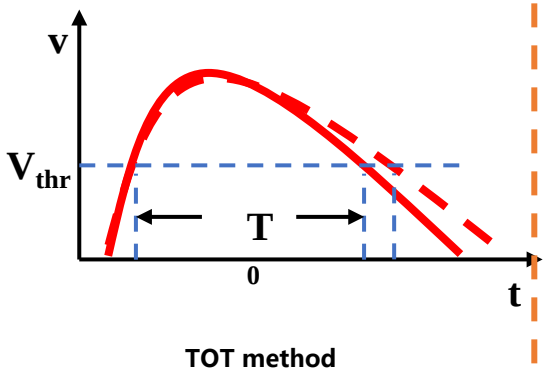
$$\frac{U_0}{R_1}(T_{end} - T_{start}) \approx \int_0^{T_{end}} i(t)dt \approx Q$$

TNS.2017.2648787

**Linear discharge readout method (FPGA-based)**



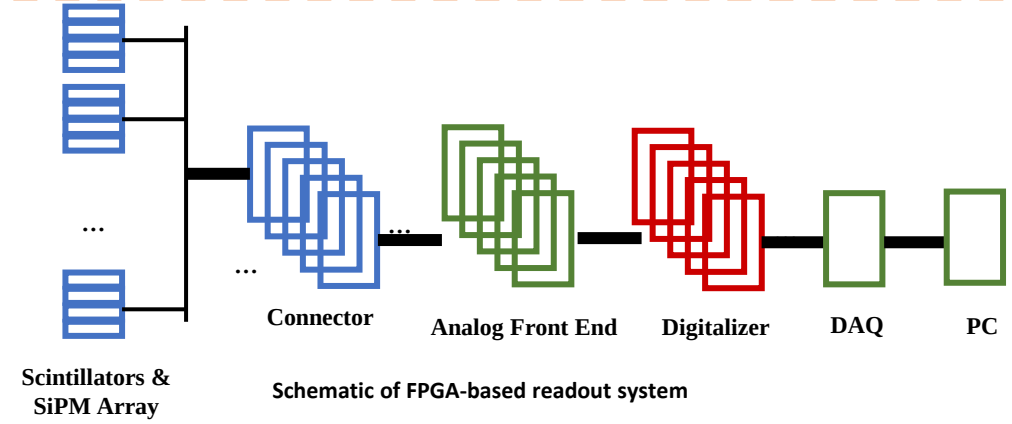

**APV readout system(adc-based)**

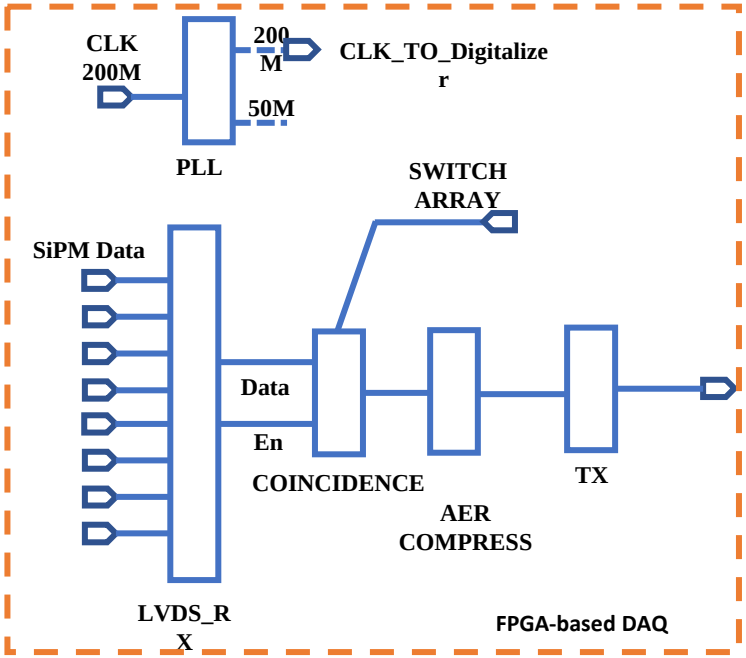


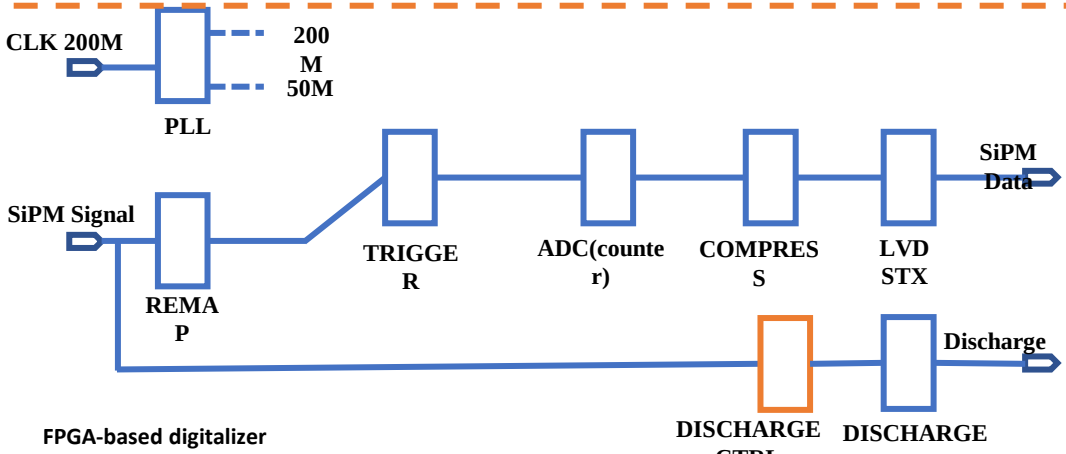

**TOT method**

# FPGA-based readout system

FPGA-based linear discharge electronics system for SiPMs.

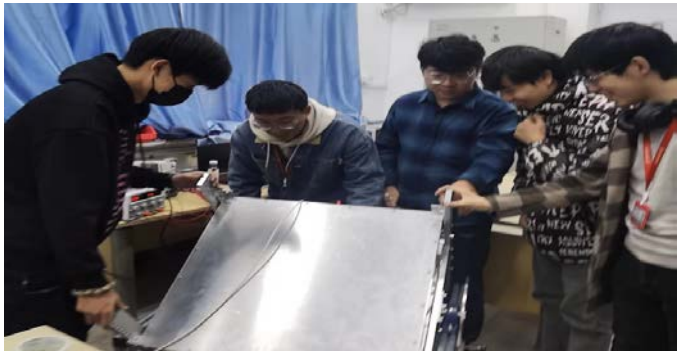



The main control FPGA of the digital board integrates functions such as discharge control and triggering, analog-to-digital conversion, and data compression. The FPGA of the data acquisition board integrates a coincidence module and a data compression module.

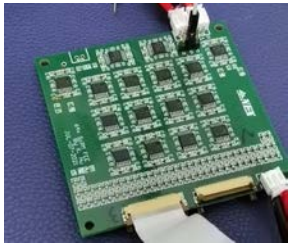
# Scintillation Detector Array



The test system with scintillators and SiPMs forming a detector array, connected to the analog front end via connectors, and the signal is digitized through a digitizer board and transmitted to a data acquisition board.

# Cosmic ray test

Detector



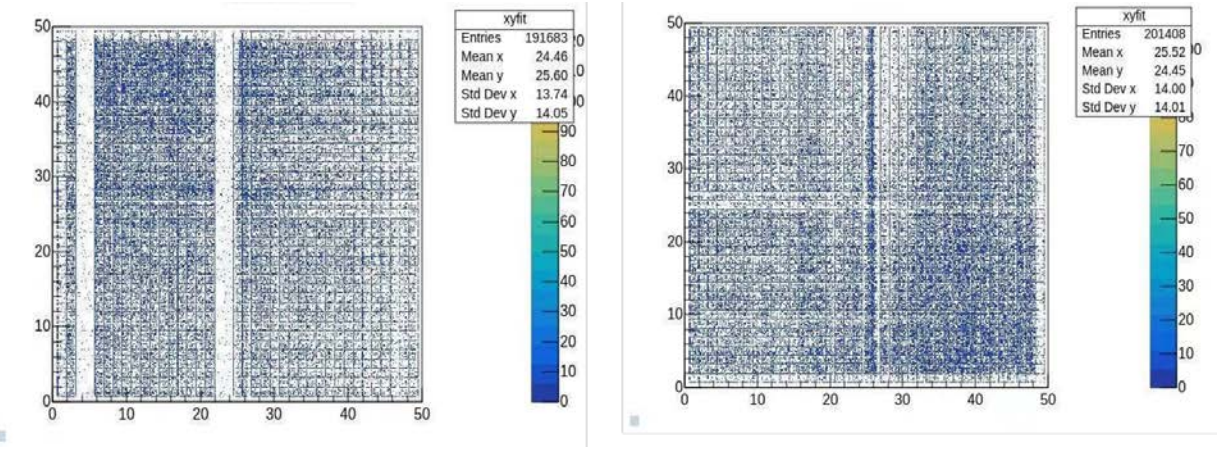
Analog Front End

Digitalizer

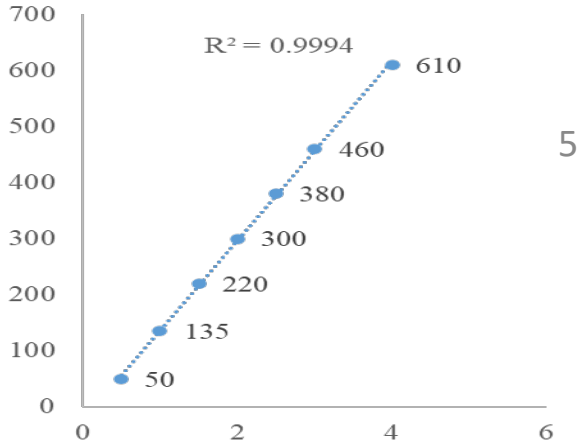
DA
Q

we have carried out cosmic ray testing.

In addition, we estimate the linearity of the system, which is good.

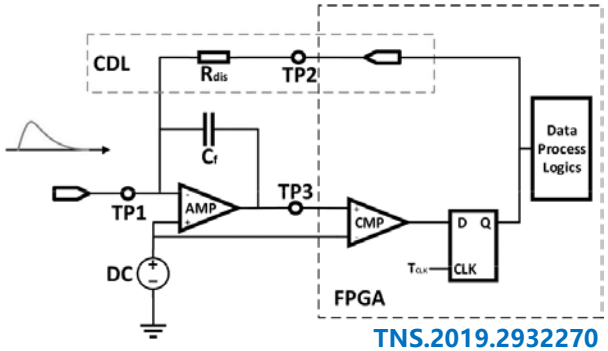



cosmic ray event



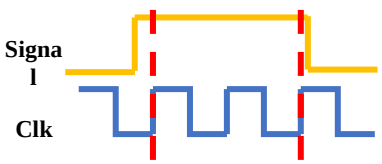

Linearity

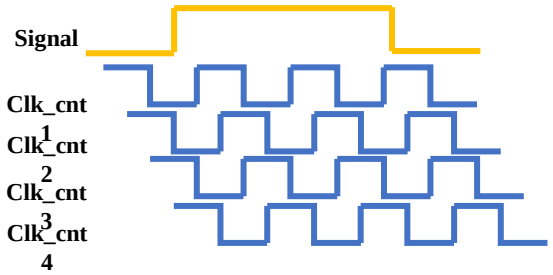
# Improvement of Readout System




TNS.2019.2932270

Dual-Polarity Readout




TBCAS.2018.2865581

Use Multiphase Counter Increase accuracy

**trade-off between resource and precision**

**Front board**

1. FEE front-end electronics board (suitable for direct connection detector)
2. Receiver board (acquire multiple digital signals)
3. Clock board, used as clock distribution, data acquisition

**FPGA board**

1.Digitalizer
2. Data Aggregation
3. Data Processing

**Interface**

1.Uart
2.USB3.0
3. Optical communication
4. Data & CLK Port
5. Ethernet port

PWR JTAG…

- **FPGA upgrade for IOs and power consumption**
- **Deploy some algorithms on the FPGA, such as noise filters, data compression**

# ALICE Upgrade

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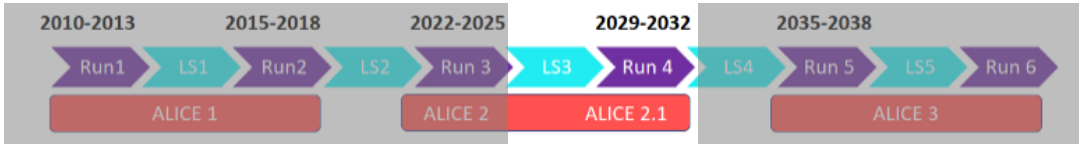
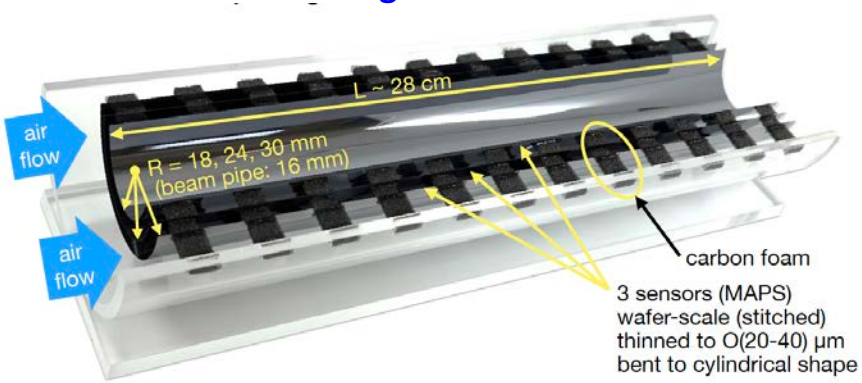
# The ALICE 2.1

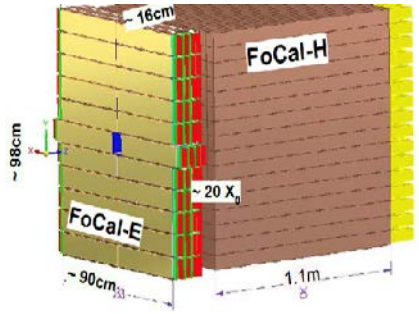



## Stiching MAPS-based ITS3

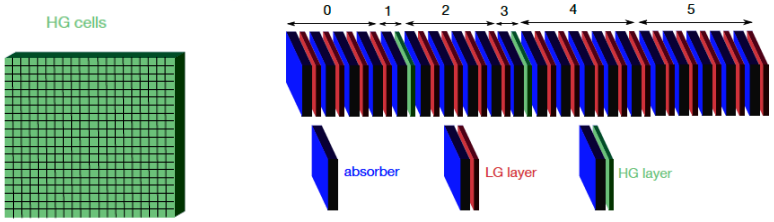



- Replacement of 3 innermost layers of ITS2
- Curved wafer-scale ultra-thin silicon sensors: cylindrical layers (1 sensor per half layer)
- Low power → air cooling → low material budget
- Improved tracking precision and efficiency at low $p_T$

## Silicon-based FoCal




$3.4 < \eta < 5.8$



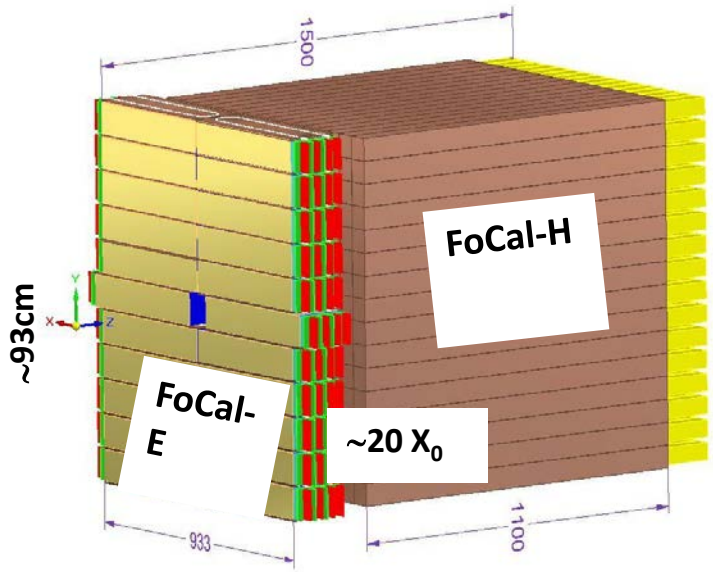

- ✓ Pad (1x1 cm$^2$): shower profile and total energy
- ✓ Pixel (30x30 µm$^2$): position resolution to resolve overlapping showers

# 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**



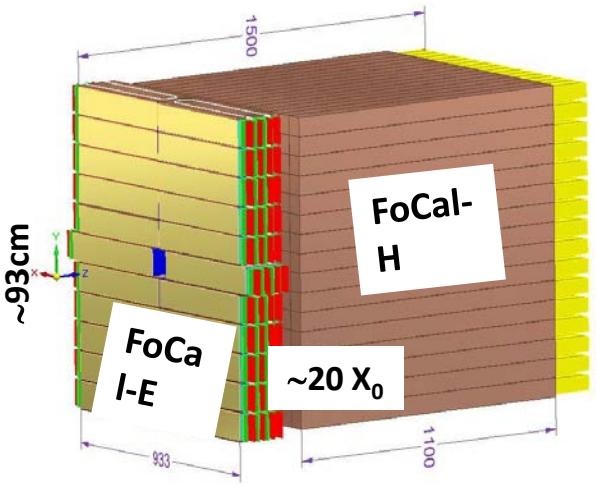

**FoCal-H prototype, 9 x (6.5 x 6.5 x 110 cm$^3$)**

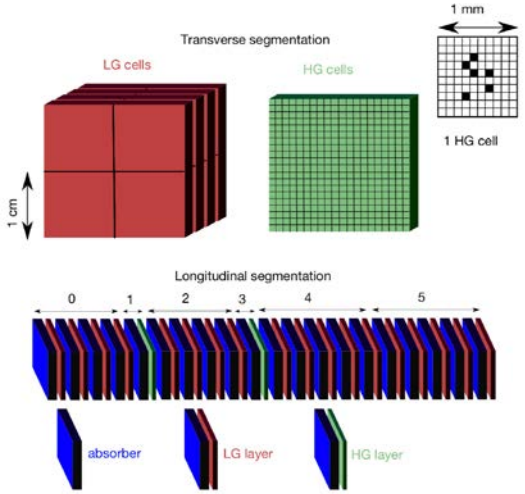
# ALICE 2.1 – FoCal Detector

## FoCal-E

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

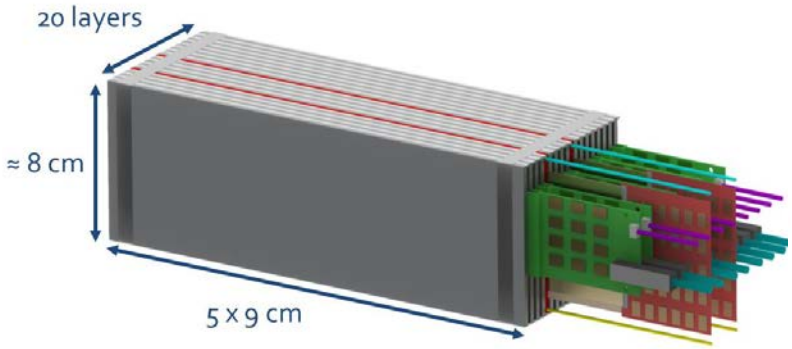
- **20 layers: Tungsten (3.5 mm ≈ 1$X_0$) + Silicon sensor**
- **Two types: Silicon strip (LG) and Silicon pixel (HG).**
- **Silicon strip provides cluster shape information**
- **Pixel layer provides high position resolution to resolve clusters with partial overlap**

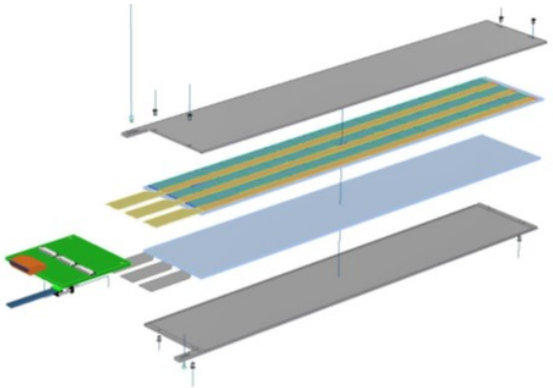


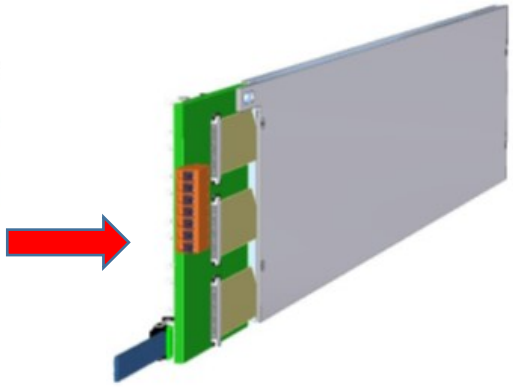



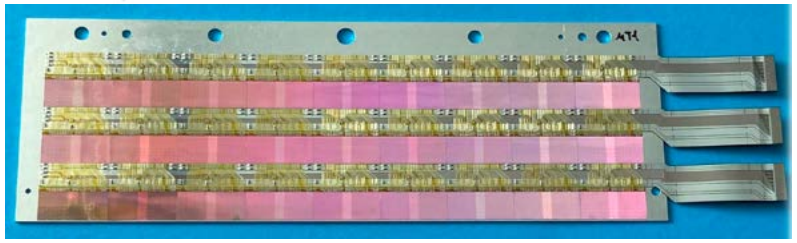
# ALICE 2.1 – FoCal-E module

## FoCal-E





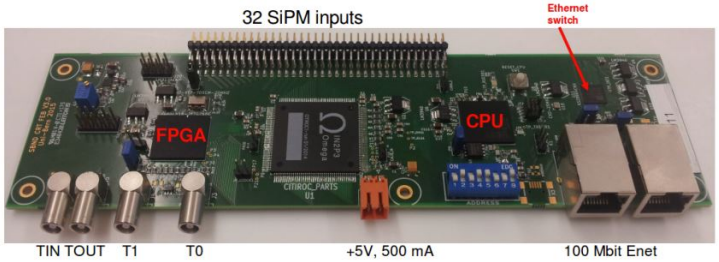


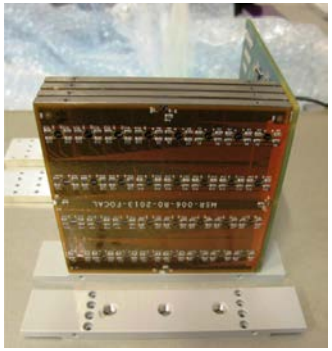
- **Sensitive region:** 45 cm x 8 cm
- **power distribution, data control, and transmission**
- **Capable of vertical stacking to form a complete detector.**
- **A total of 22 modules**

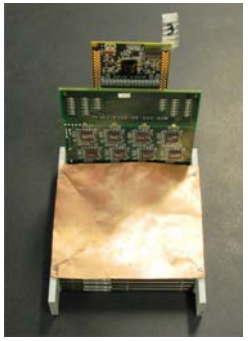
- **A long strip composed of 15 ALPIDE chips**
- **2 x 3 long strips form the silicon pixel layer module**
- **Each module contains 90 ALPIDE chips**
- **44 silicon pixel modules, totally 3960 ALPIDE chips**

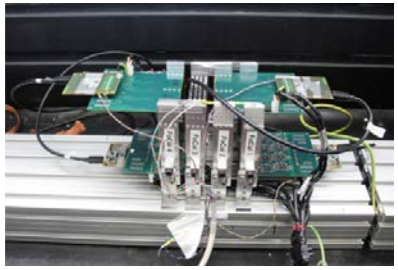
# ALICE 2.1-Focal Readout Electronics

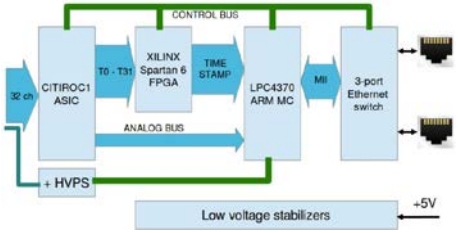
M. Auger et al 2016 JINST 11 P10005





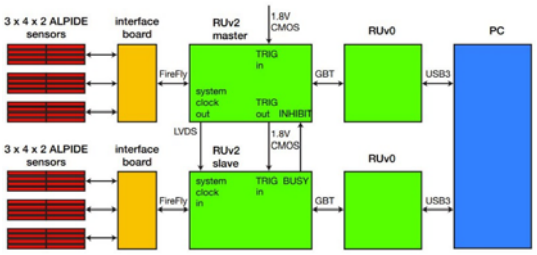





FoCal-H 2021 prototype readout electronics

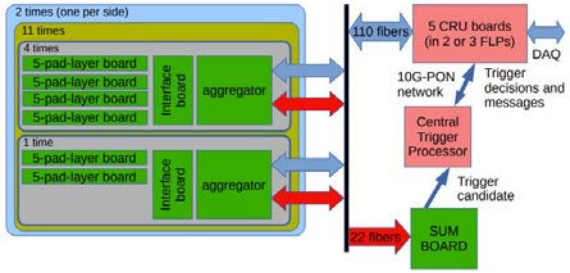
arXiv:1912.11115

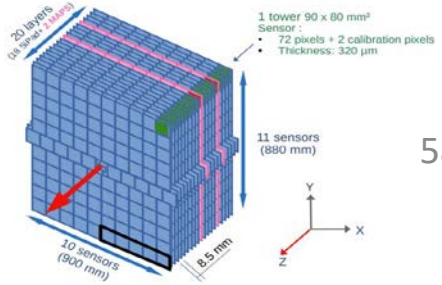
For the readout electronics of Focal-H, with a focus on the readout of the SiPM, a number of prototype electronics have been developed that use an ASIC as an analog front-end and an FPGA as a digital back-end. In the case of Focal-E, the electronics scheme chosen is also different due to the different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




arXiv:2209.02511

FoCal-E pixel layer prototype EPICAL-2 readout electronics

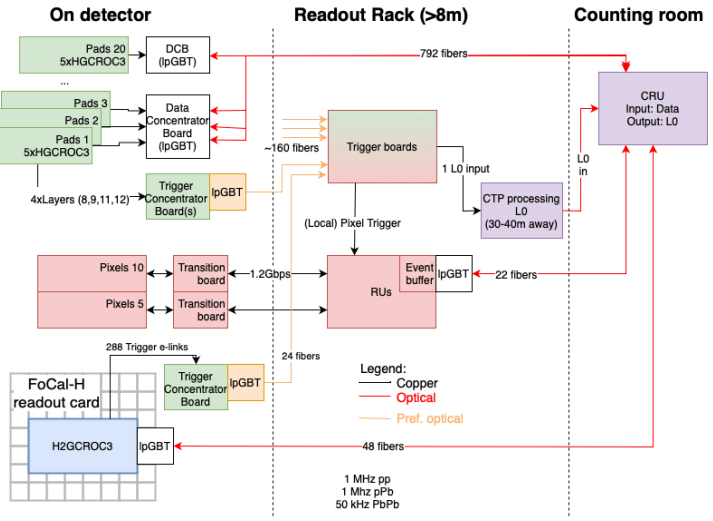



arXiv:2302.13912

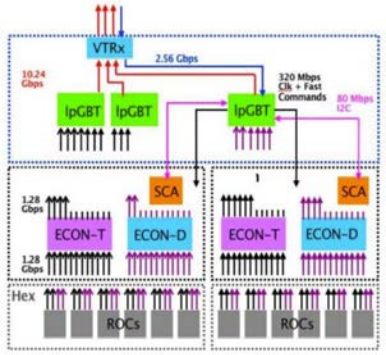
FoCal-E pad layer prototype readout electronics

# ALICE 2.1-Focal Readout System



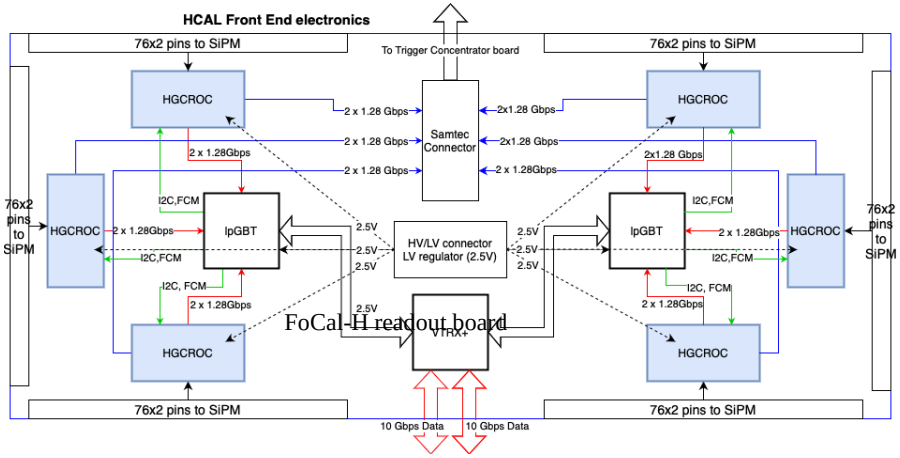

FoCal readout system

Focal Electronics' research borrowed part of the CMS design, and it is planned to use HGCROC as the front-end chip, ECON chip for data compression, lpGBT chip for data transmission, and FPGA for control.




CMS CR -2021/228

- 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



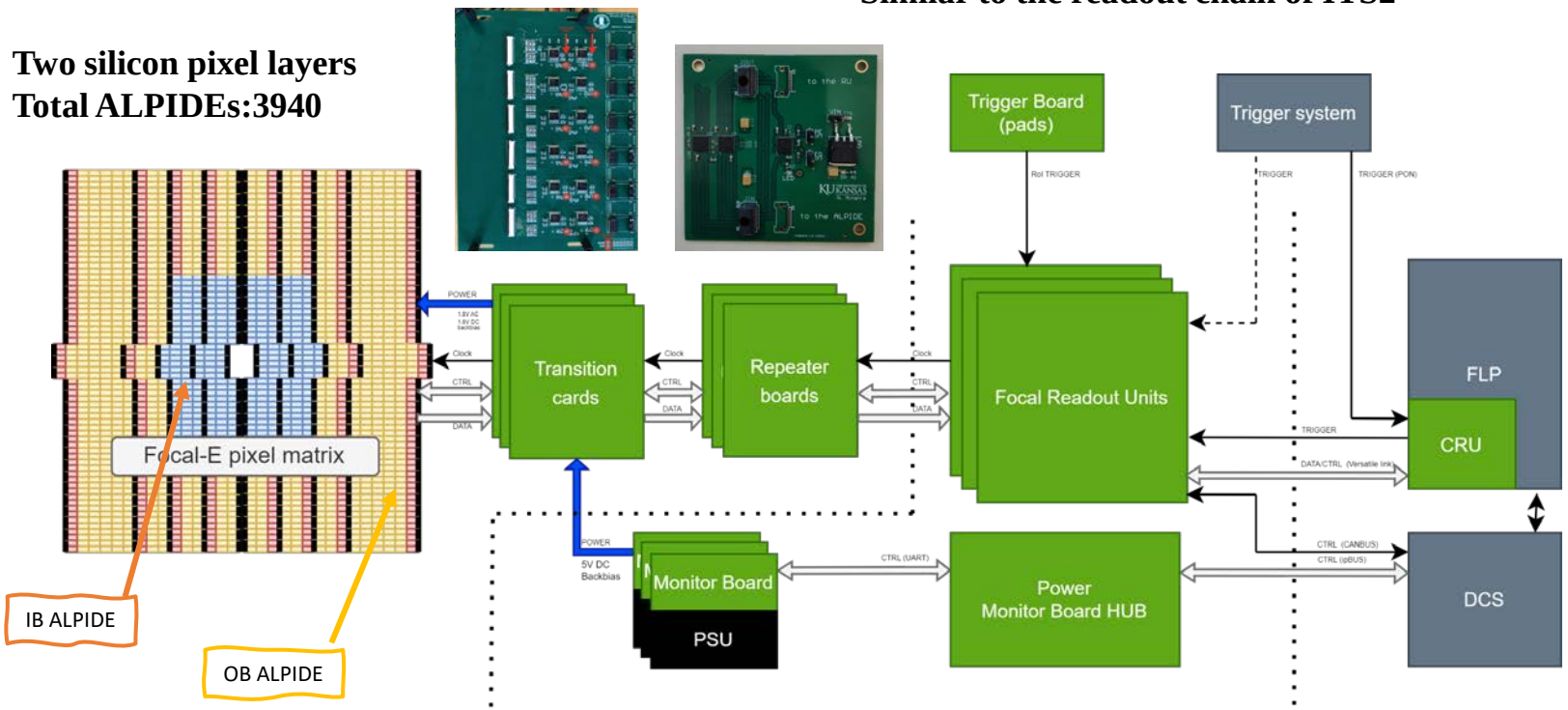

FoCal-H readout board

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

# ALICE 2.1 – Readout chain for the silicon pixel layer

**Similar to the readout chain of ITS2**

**Two silicon pixel layers**
**Total ALPIDEs:3940**

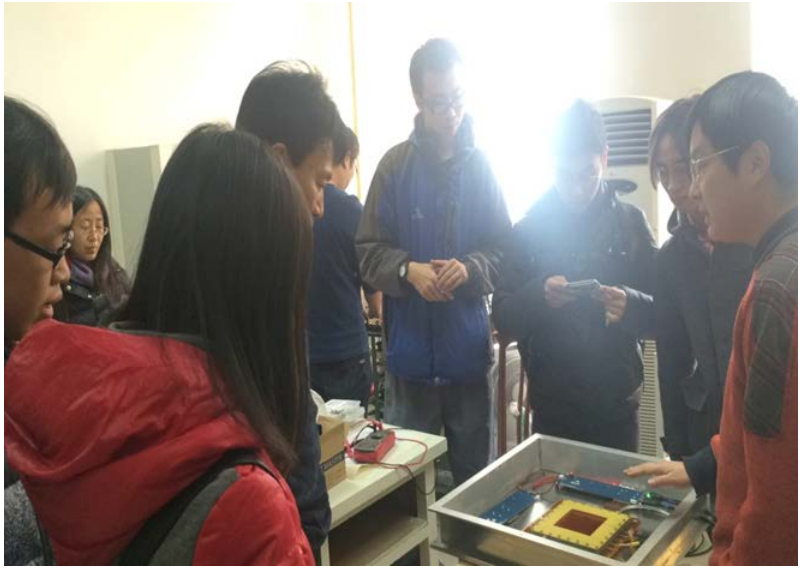



The readout link of the whole silicon pixel layer is extremely similar to the readout link of ITS2. There are some readout units, which we have to make some improvements.

# CIAE Intermediate and High Energy Physics Team Members

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

# Visitors

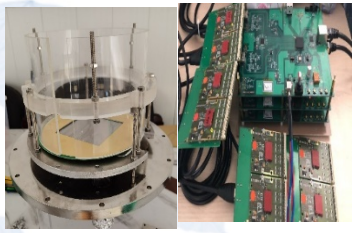
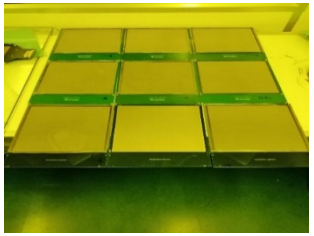
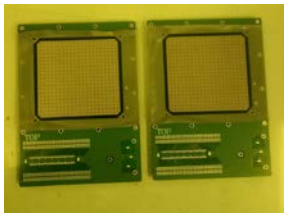
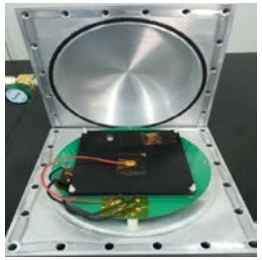


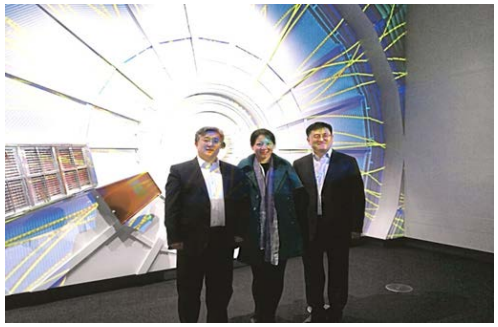
# Summary and Prospect

1. Complete R&D and mass production of photoetching MicroMegas.
2. Complete R&D and mass production of scintillating fibre detectors.
3. Electronics for MPGD and Electronics for SiPM developed by our team works well.
4. A new scintillating fibre detector lab will be builded.

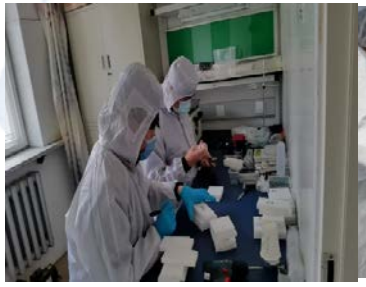
# Detector Applications and Collaborations










# Thanks for your attention!

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