Development of Micromegas detectors with high radio-purity and energy-resolution using a thermal-bonding method for the PandaX-III experiment

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Outline

- Introduction of PandaX-III experiment
- Thermal-bonding method
- Design and fabrication of the thermal bonding Micromegas detector for PandaX-III experiment
- The performance of detectors
- summary

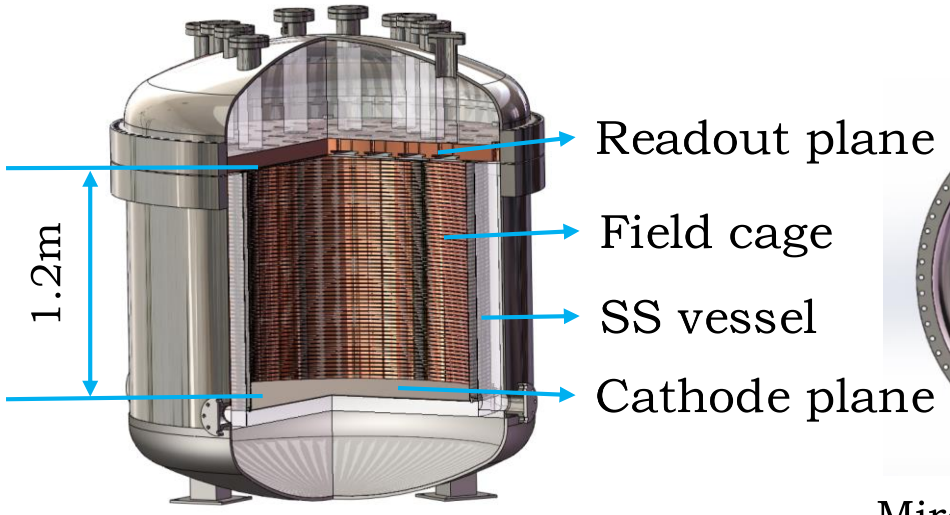
PandaX-III experiment

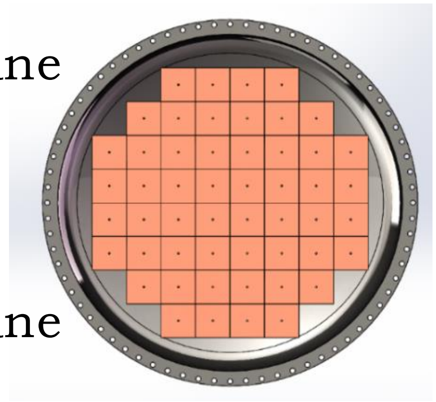
The PandaX-III experiment uses high pressure Time Projection Chambers (TPCs) to search for Neutrinoless Double Beta Decay (NLDBD) of ^{136}Xe, at the China Jin-Ping underground Laboratory II (CJPL-II) .

Working pressure: 10 bar

Working gas : Xe(99%) + TMA(1%)

Readout plane : MicroMegas detector array





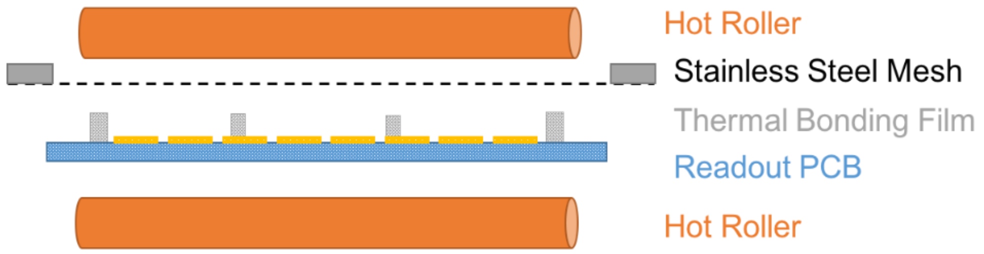
MiroMegas readout plane

Requirements:

- 20×20 cm^2 MMs for charge readout (52)
- 3% energy resolution @ 2.459 MeV
- X-Y strip readout
- Stable operation for a long time under 10 bar

Thermal-Bonding(TB) method

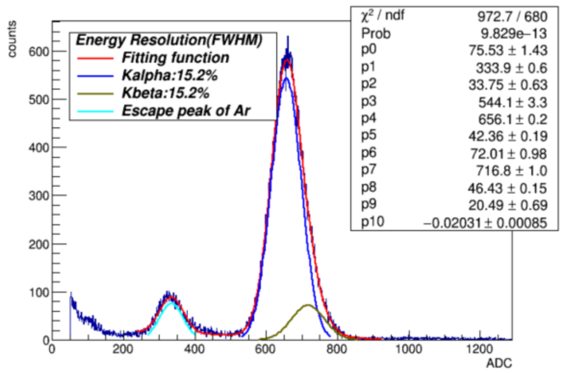
Over the past decade, the thermal bonding method (TBM) has been developed for the efficient fabrication of Micromegas detectors at USTC. This method provides a concise and etching-free mass-productive process to fabricate Micromegas-like detector.

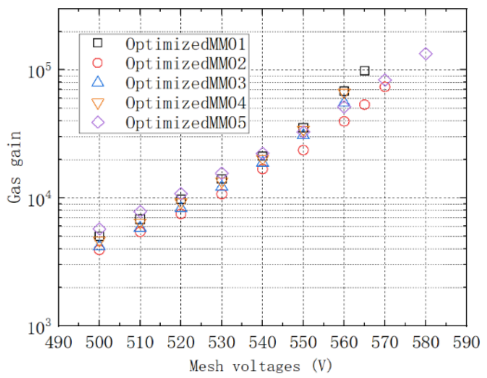


- No etching, no pollution
- Easy to handle at lab
- Easy to make new structures
- Cheap
- Φ0.5mm- Φ1mm spacers, ~1cm pitch
  - ➔easy to clean, especially for large area
  - ➔less than 1% spacer area

5.9keV X-ray test

- High gas gain: ~ 10^5 ($Ar+CO_2$)
- Energy resolution: ~15% (FWHM)
- Non-uniformity: 6.3% @ gain =5000





The production and application of TB Micromegas

The thermal bonding method can realize the mass production of detectors from raw materials to finished products.

The studio can realize:

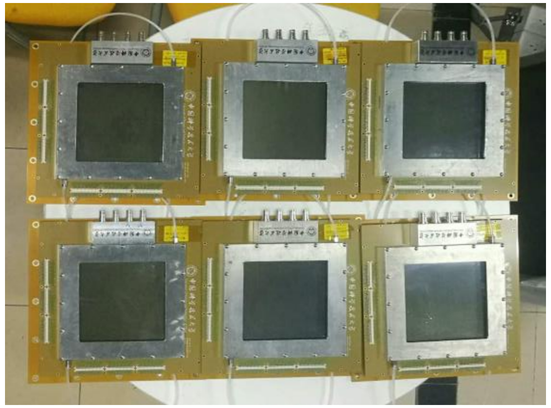
- The mass production of 15cm×15cm detector
- The production of 40cm×40cm detector, and other large area detectors with different sizes

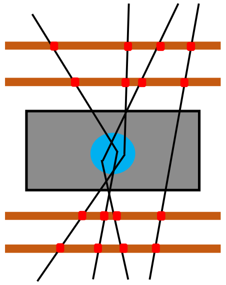
Serving scientific research and application:

SNS 中国散裂中子源 China Spallation Neutron Source

CEPC

STCF

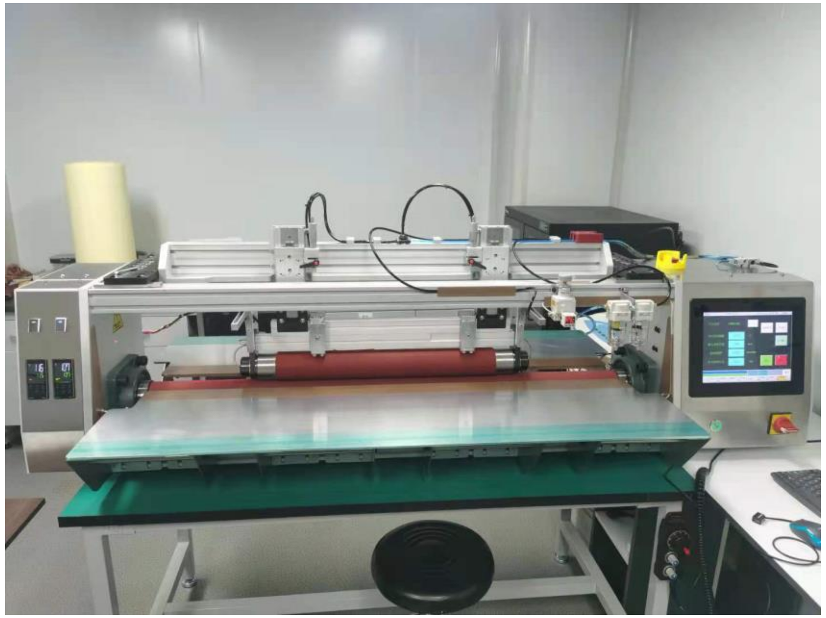




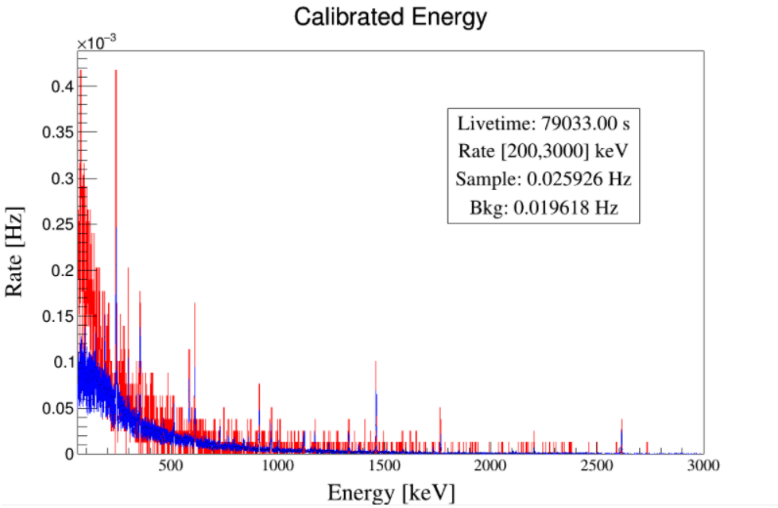
Jianxin Feng, Zhiyong Zhang et al., A thermal bonding method for manufacturing Micromegas detectors, Nuclear Inst. and Methods in Physics Research A, 989 (2021) 164958.

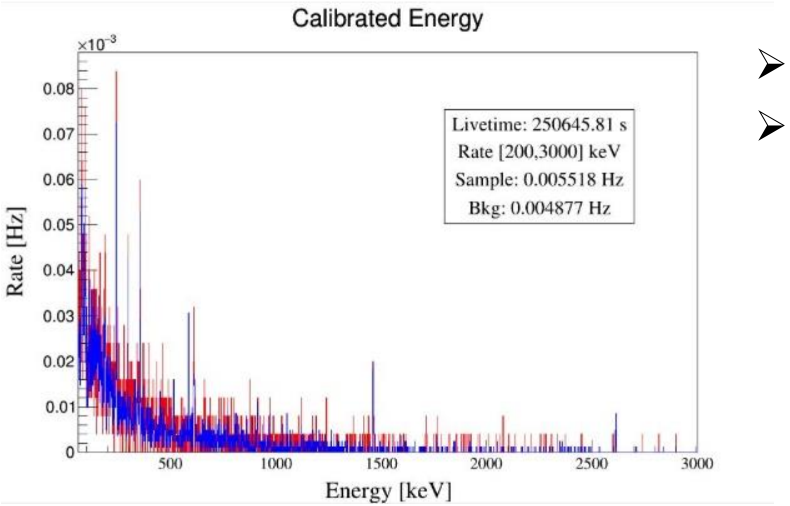
Detector design for PandaX-III experiment

- Flexible PCB + copper substrate to lower the radioactivity
- Follow the current geometry to ensure the installation



Radioactivity of materials



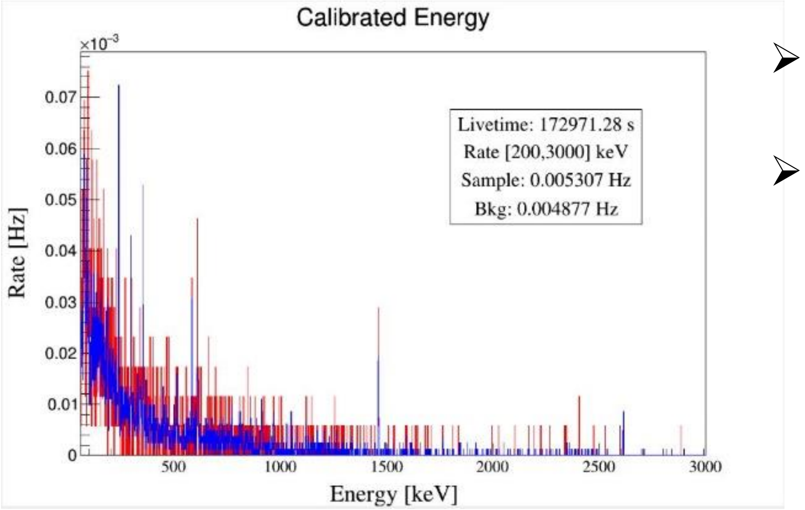


- 400LPI mesh:4.5g per MM (400cm²)
- Test sample : 14g ➔3.1 MMs

Sample/background=1.15

- Flexible PCB: ~400cm² per MM
- Test sample FECV4: 570cm² ➔1.4 MMs

Sample/background=1.3



- Thermal bonding film:1.3g per MM (27.2cm²)
- Test sample: 37g➔28.5MMs

Sample/background=1.10

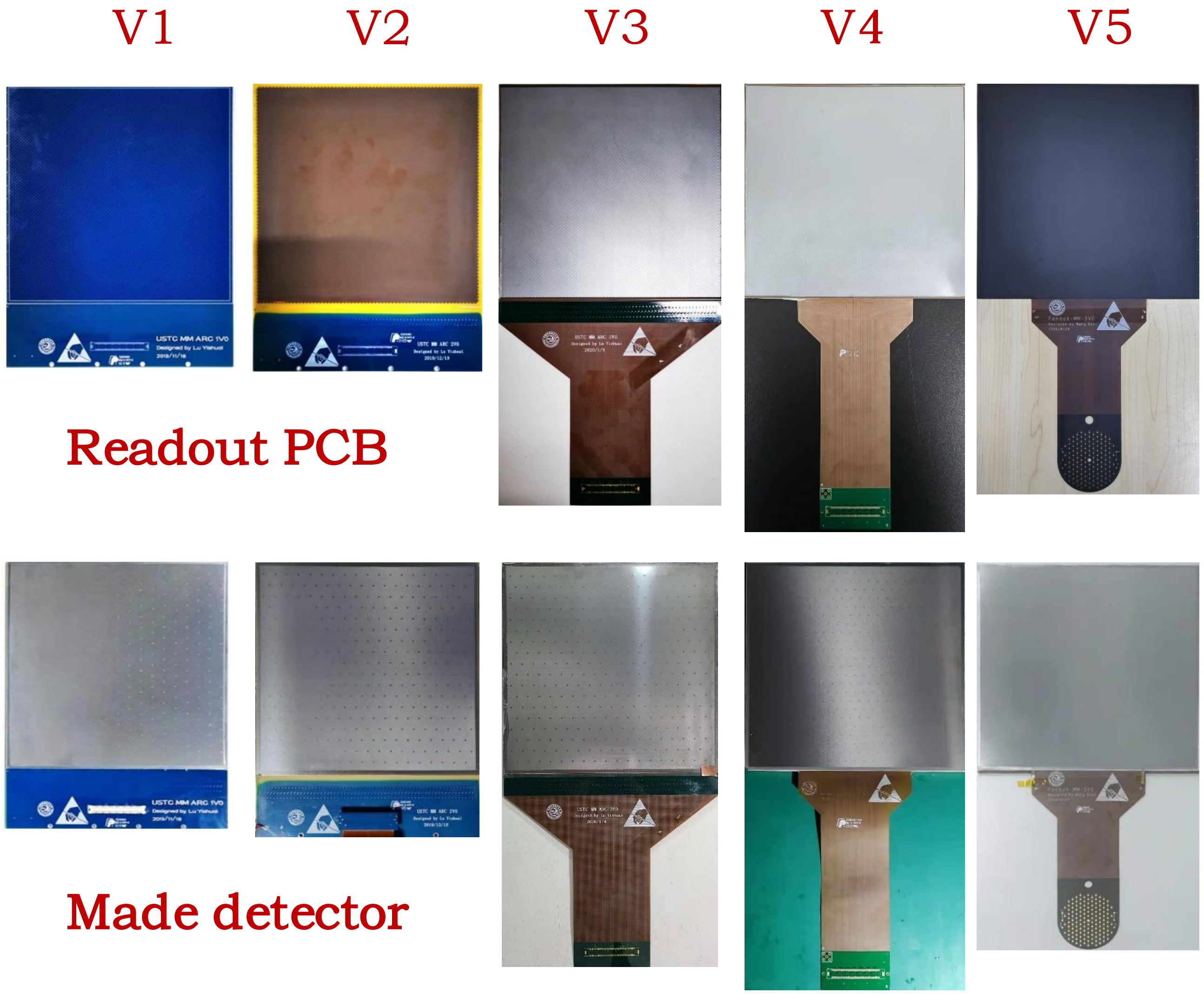
Fabrication of the detector

Hard（FR-4）PCB：V1, V2

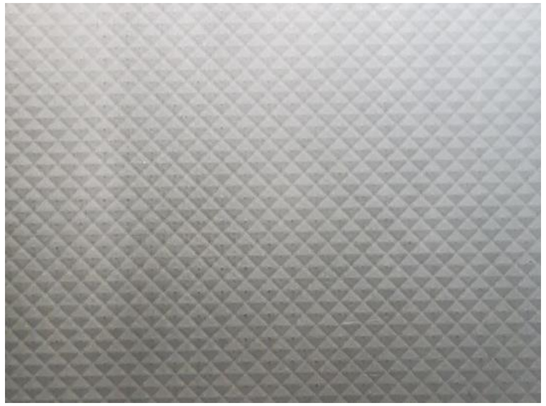
- To validate the narrow bonding region
- performance of energy resolution and long time stable working

Flexible (polyimide) PCB: V3~V5

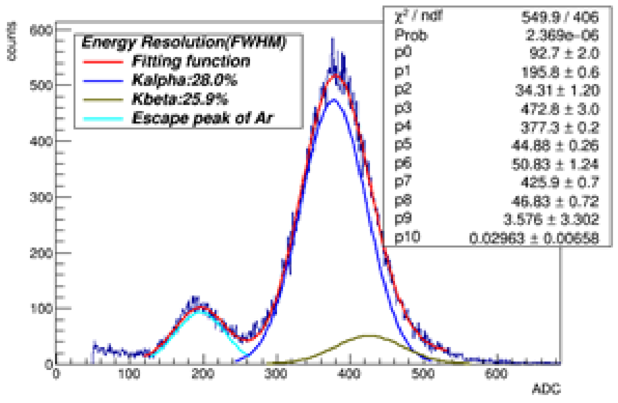
- Low radioactivity and flexible connection



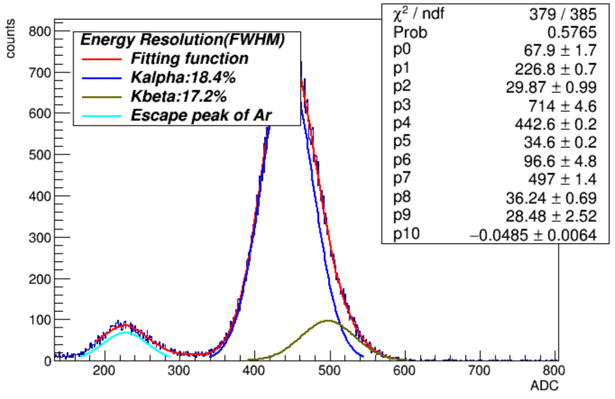
The improvement of energy resolution



In the process of using low radioactivity flexible PCB to make detector, it is found that due to the too thin of the flexible PCB, the insulation layer on the PCB surface is unsmooth, resulting in poor energy resolution.



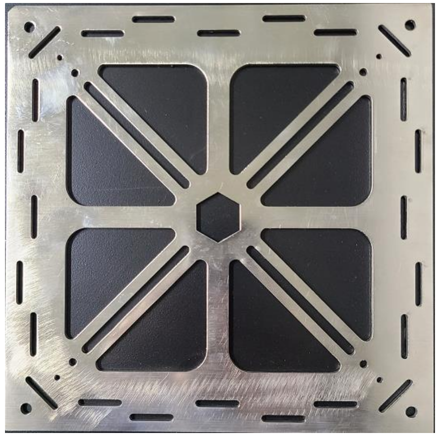
Energy resolution before polishing: ~28% (V3)

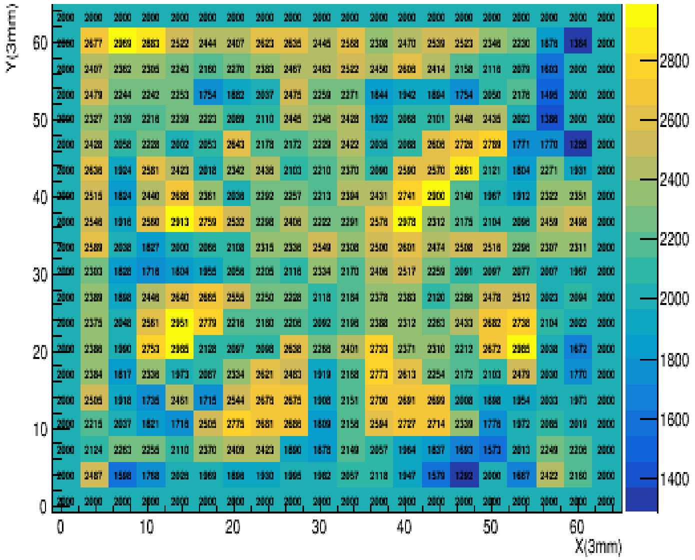


Energy resolution after polishing: ~18% (V5)

The polishing process can effectively improve the energy resolution

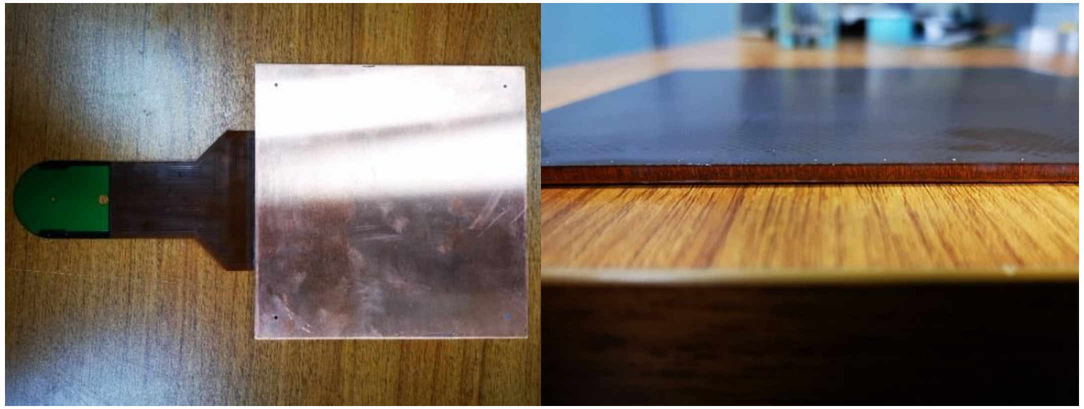
The improvement of uniformity



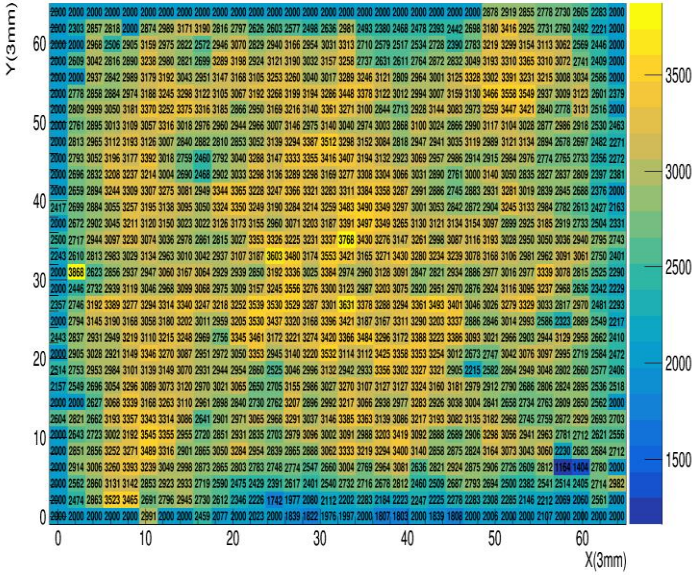


V 4

The back hollow stainless steel substrate plate has obvious influence on the uniformity of the detector

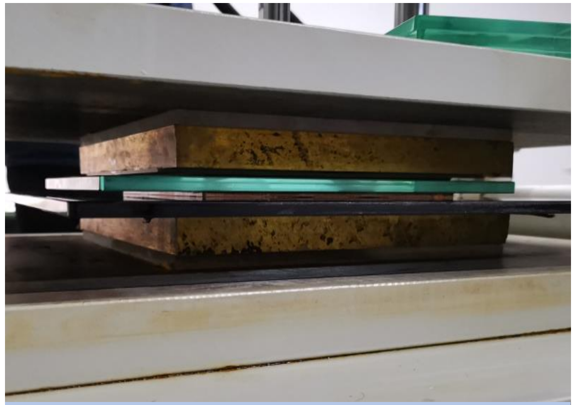


V5



The uniformity of the detector can be improved by the flat copper substrate plate on the back

Manufacturing process



Attaching copper plate

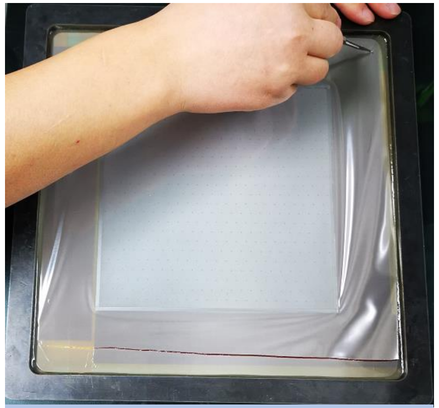
Polishing

Coating Ge

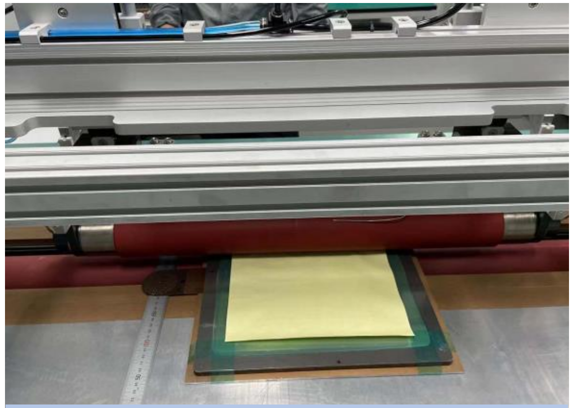
Pillar setting

Finished

check and clear



Cutting

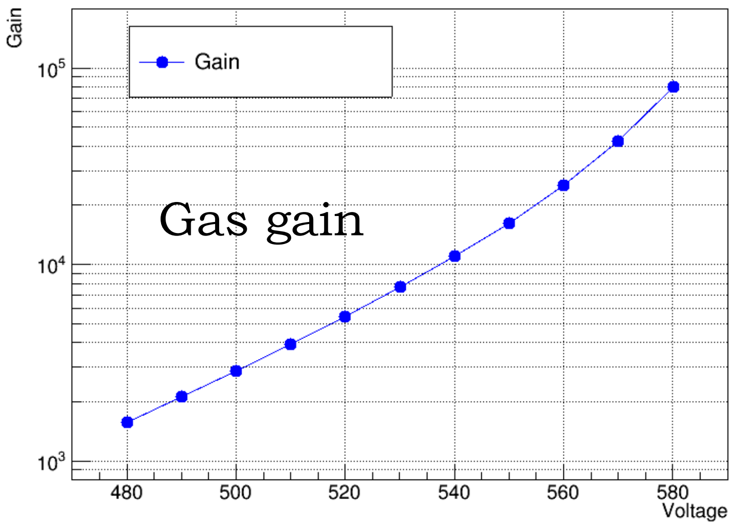


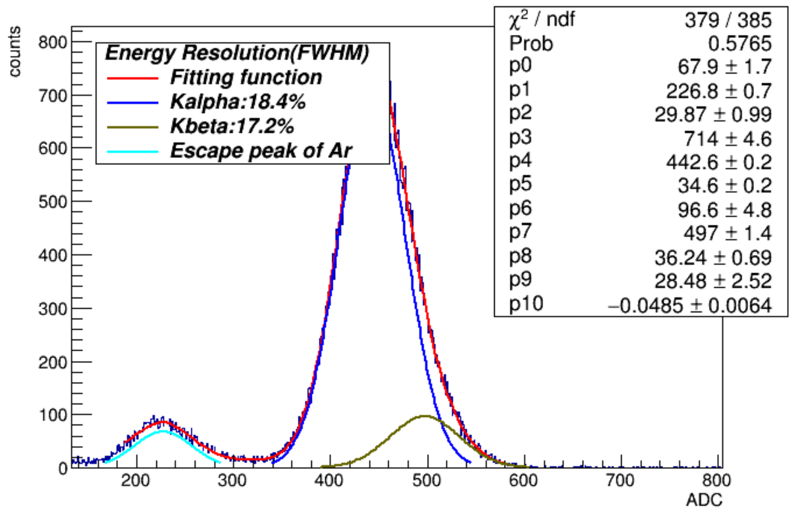
Bonding the mesh to PCB

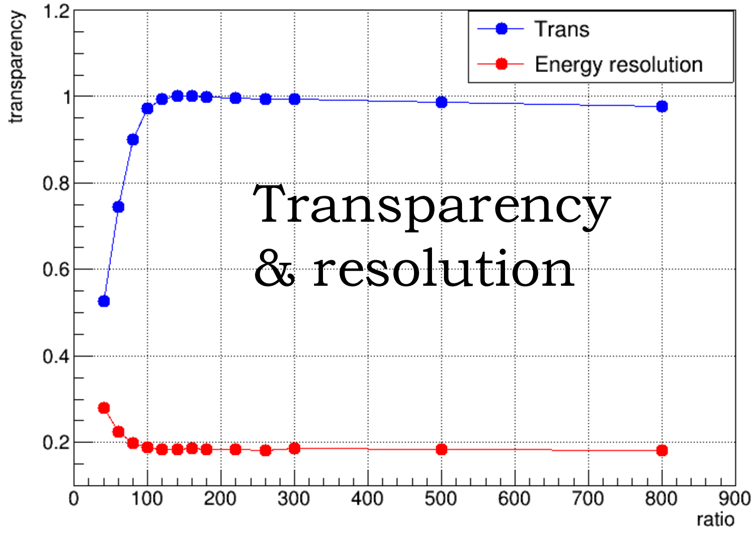
Test in 1 bar Argon (7%CO_2)

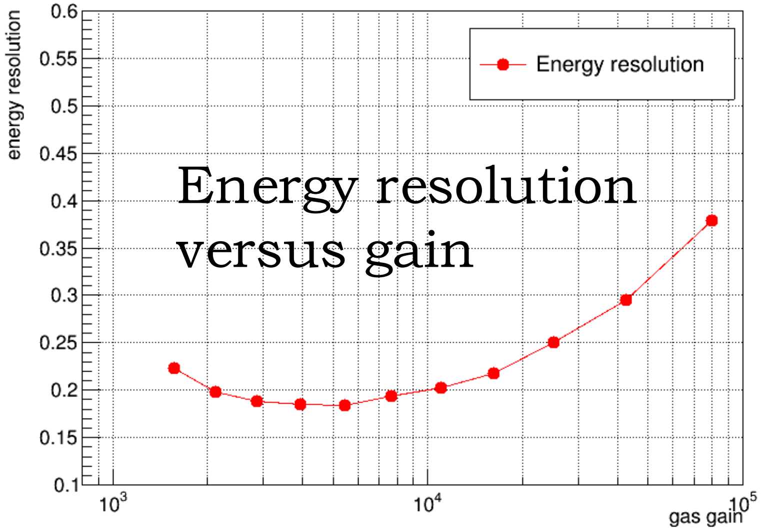
Prototype V5-03 (**5.9keV X-ray**)

- Energy resolution: ~18%
- Gas gain : 8×10^4





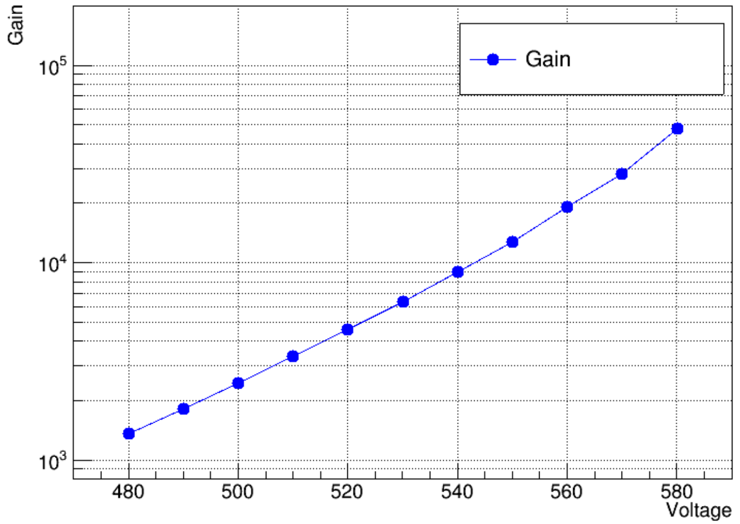


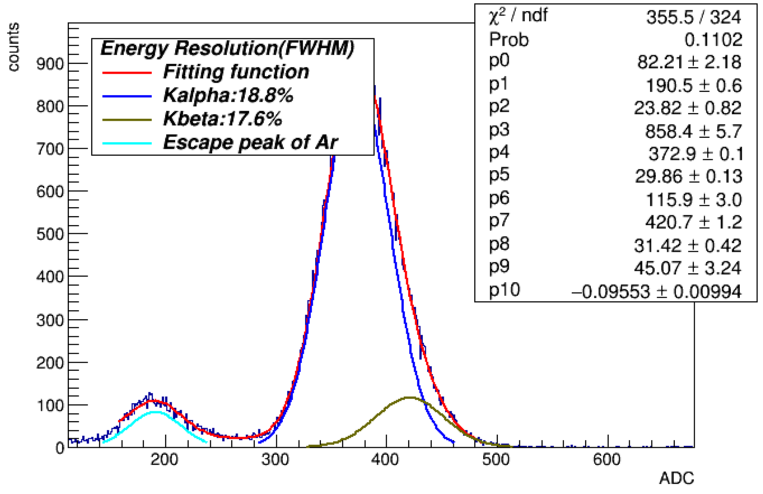


The performance of V504

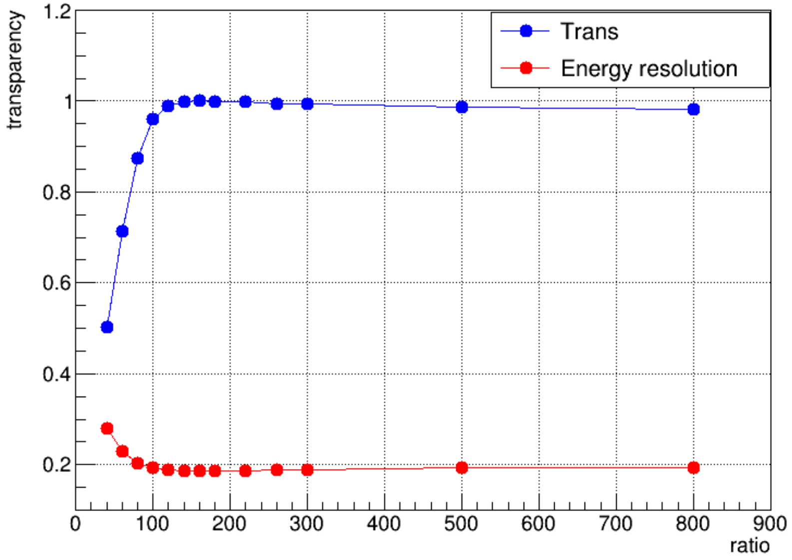
- ➢ The near flat point locates at ~150, and with a wide range of flat.
- ➢ The best energy resolution: ~17.6%
- ➢ The gas gain can up to ~5*10e4.

Gas gain

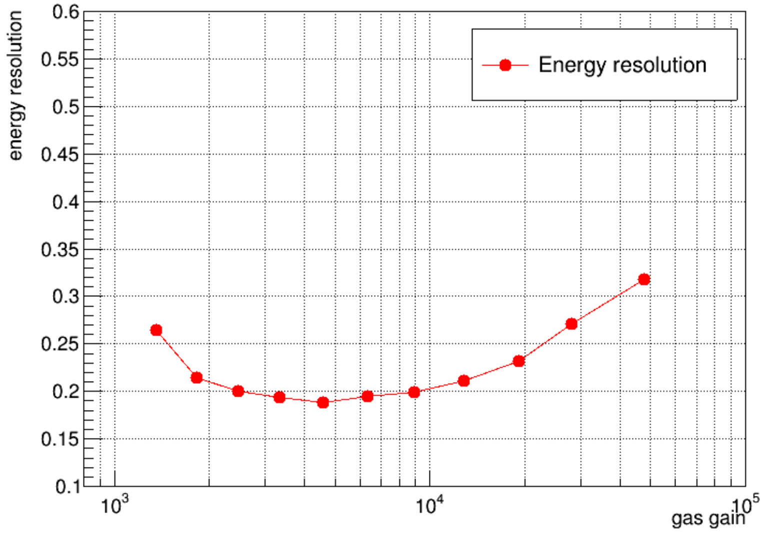




Transparency

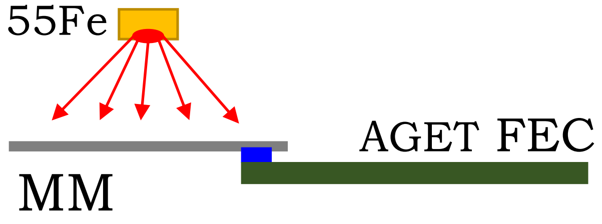


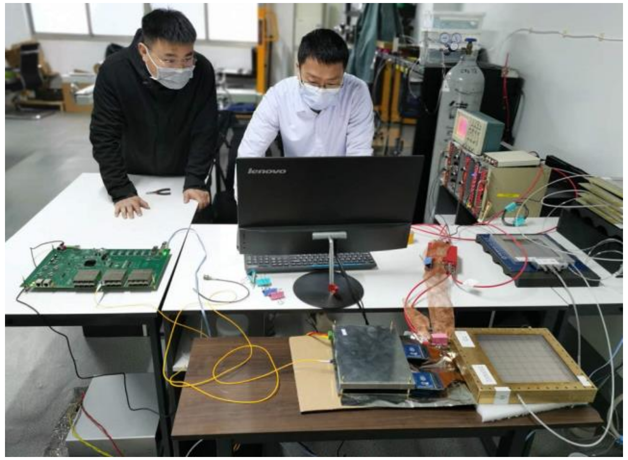
Energy resolution

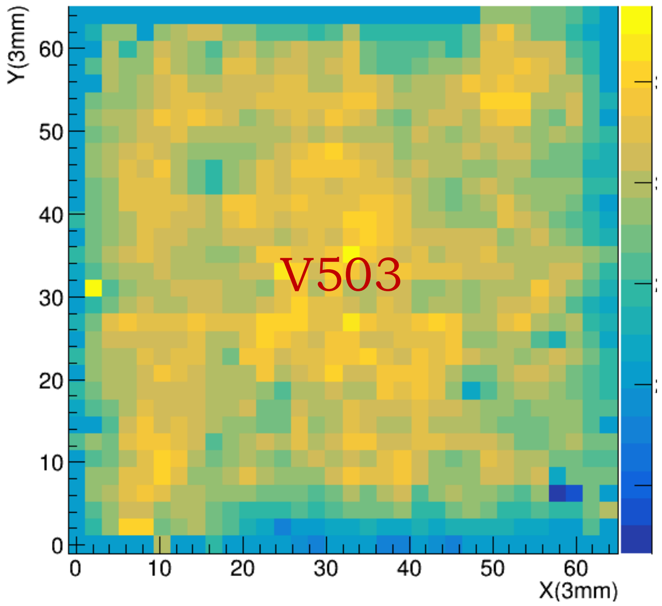


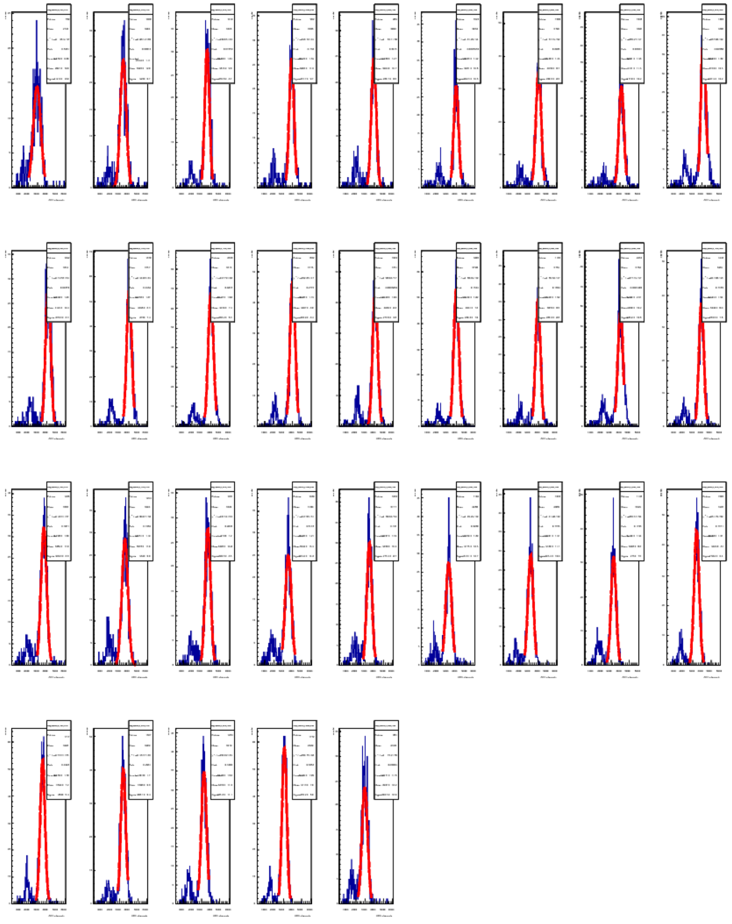
Performance of uniformity

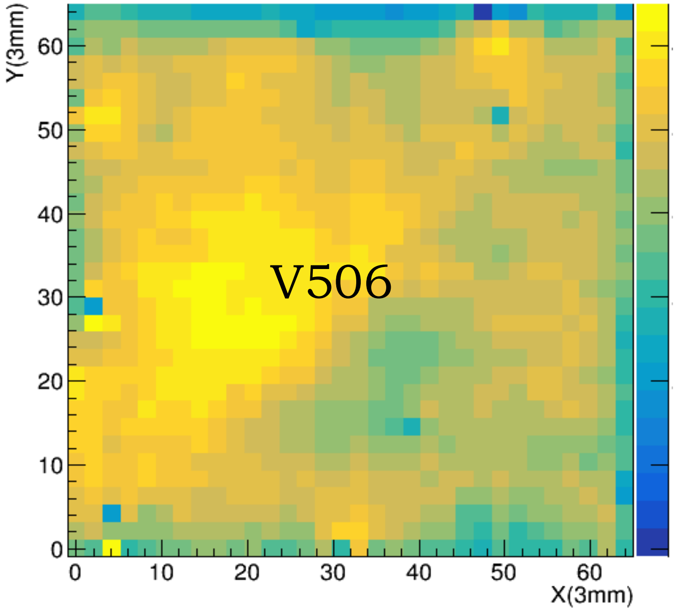
Scanning the effective area of detector with radioactive source. divide the effective area into many bins, and then reconstruct the spectrum of very bin, fit the peak.

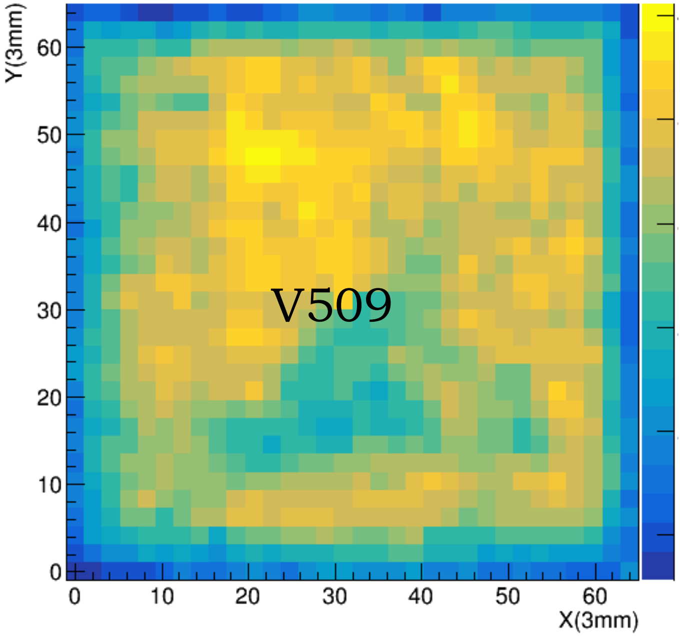


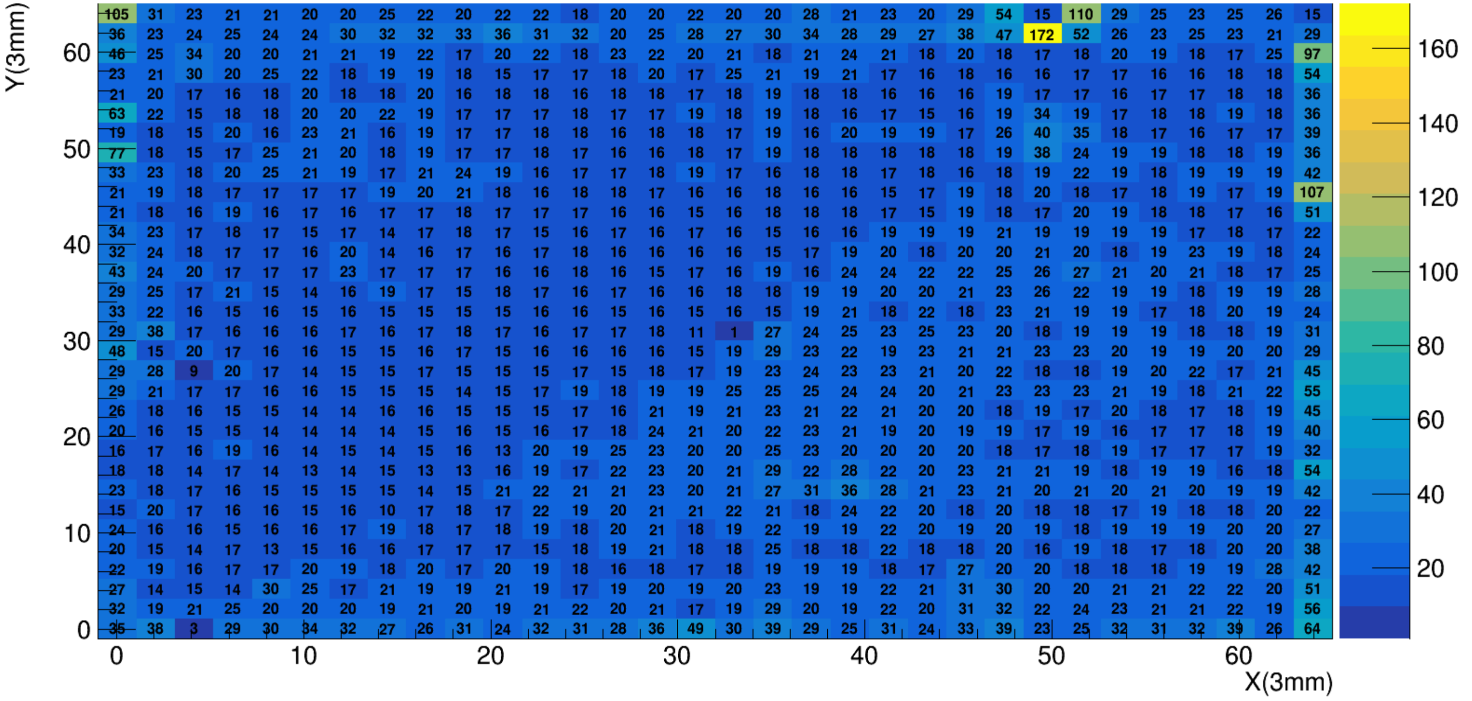


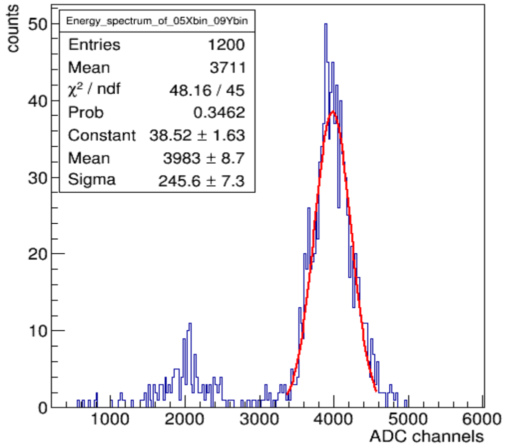












FWHM = 14.5%

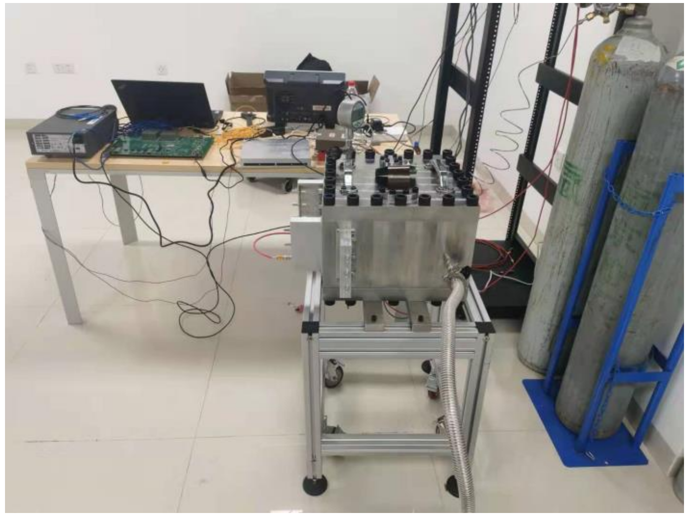
The average value of the energy resolution (V506) = ~16% (FWHM)

High pressure test

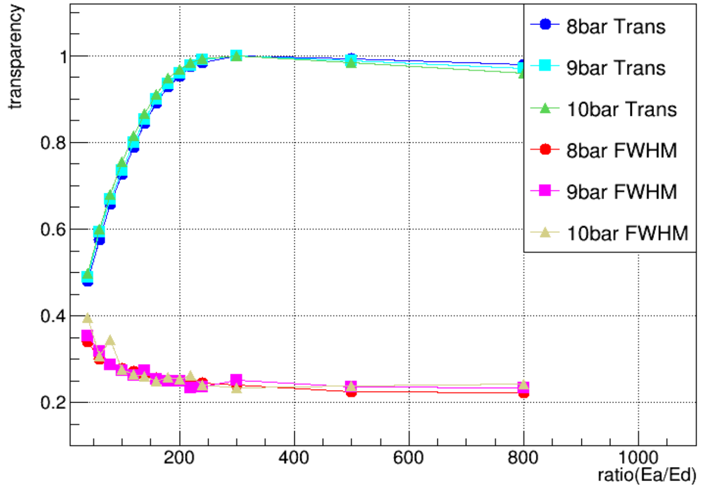
The stable operation in high pressure gas is one of the important requirement of pandax-iii experiment

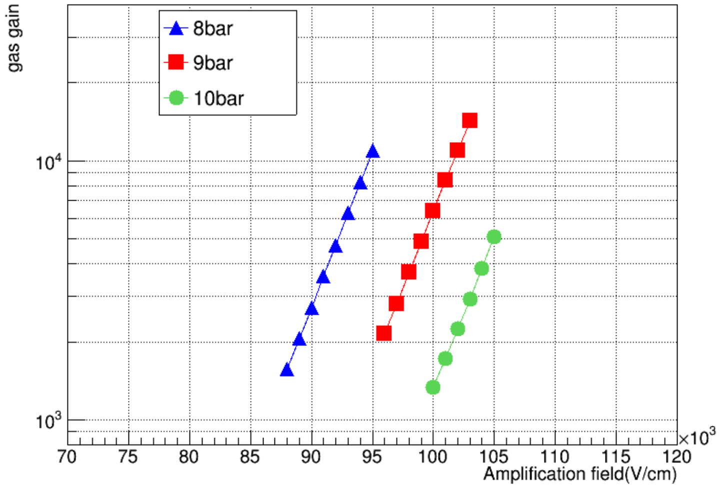
Test in high pressure Argon (2.5% Iso)

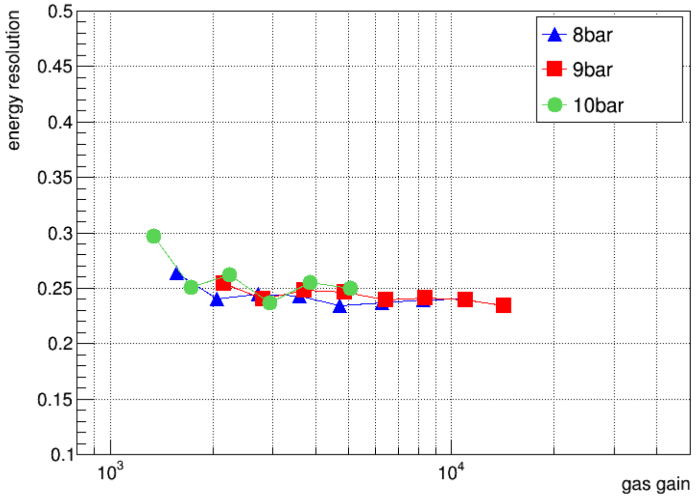
Radioactive source: Fe55



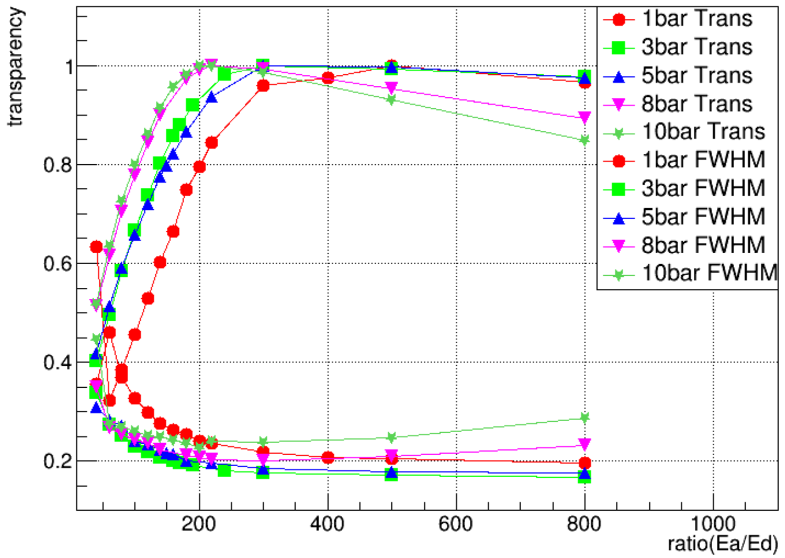
Prototype V5-03

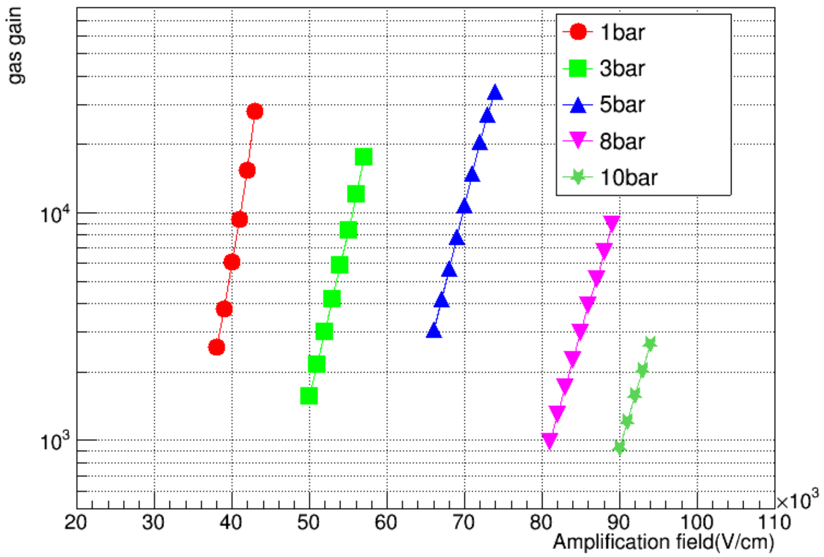


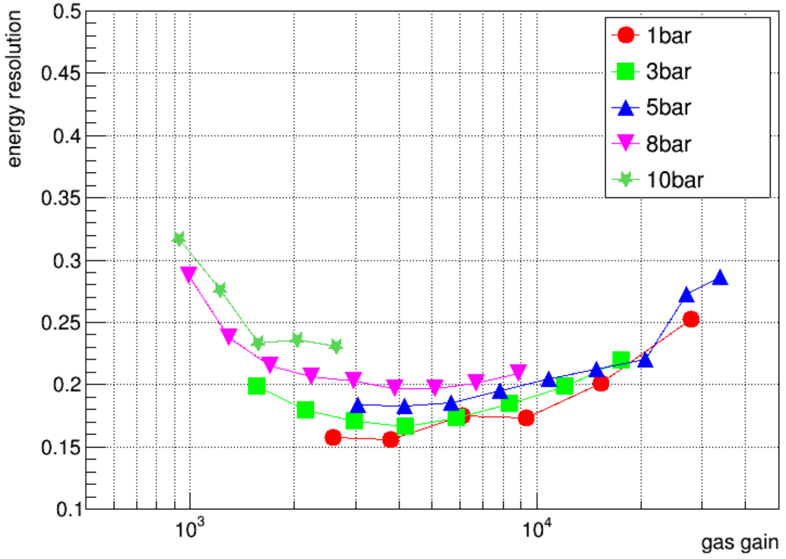




High pressure test result of V509

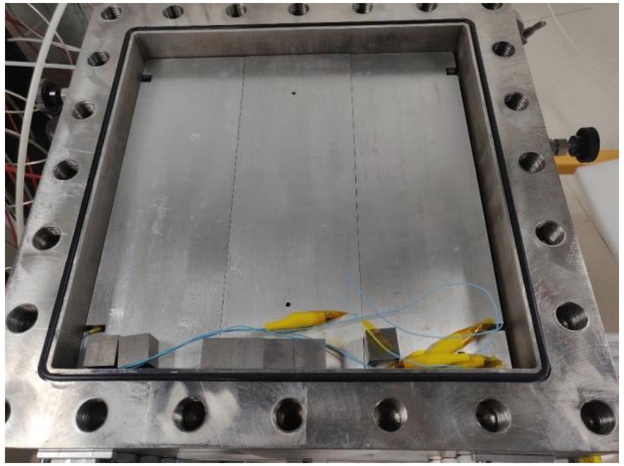






Gas: Ar(97.5%) + Iso(2.5%)

1. The gas contamination caused by Al blocks
2. Since the various gain of detectors and the deviation of gas ratio, the performance is a little different between V503 and V509 at high pressure



Summary

- Thermal bonding method developed at USTC is a very promising method in low background and high energy resolution experiments.
- After 5 versions detector fabrication, the manufacturing process has been developed and fixed
- The uniformity and withstand voltage in high pressure gas still have room for improvement

Thank you!