Development of µRGroove detectors

UTSC-MPGD Group

If there are questions, please contact :

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Outline

- **Introduction**

- **Large area μRGroove**
  - **50cm×50cm detector**
  - **100cm×50cm detector**

- **Beam test of Cylindrical μRGroove @ 1Tesla**

- **Summary & Outlook**

micro-Resistive Groove

μRGroove

Gap=5mm

Pitch=200μm

Width=70/50μm

Thickness=50μm
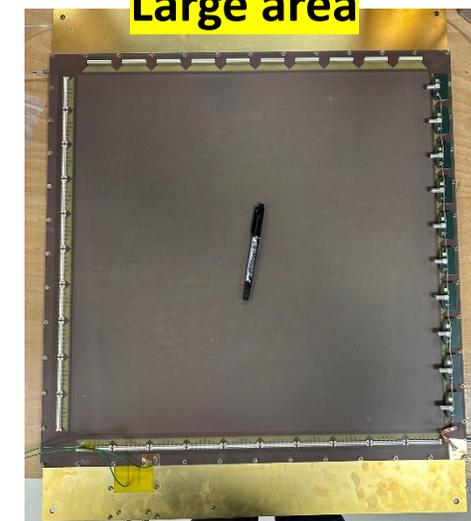
DLC ~50MΩ/□   25μm Pre-Preg + 25μm Polyimide

- ✓ **Decoupled X&Y readout strips, avoided induced charge sharing effect, increased signal amplitude**
- ✓ **Easier to process due to its open geometry**
- ✓ **Easy clean, important for the end user.**
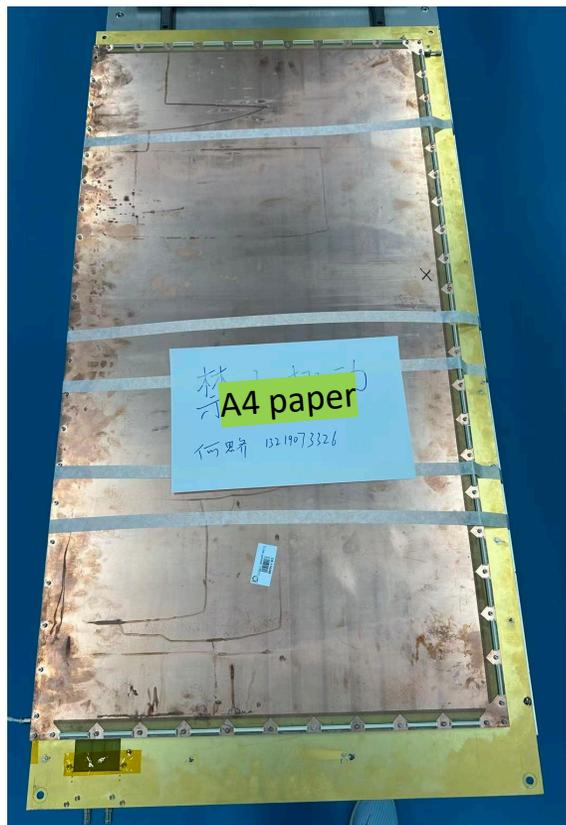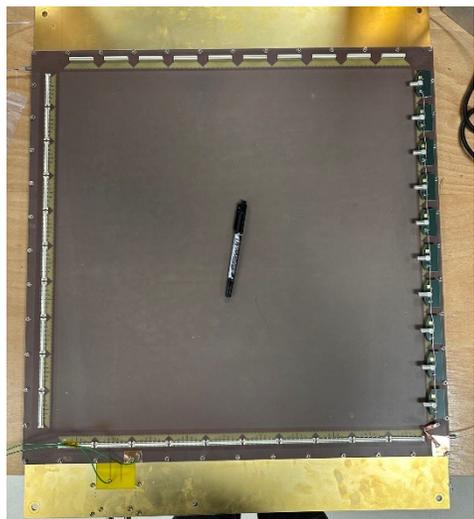- ✓ **Lower material budget**

Drift   μRGroove
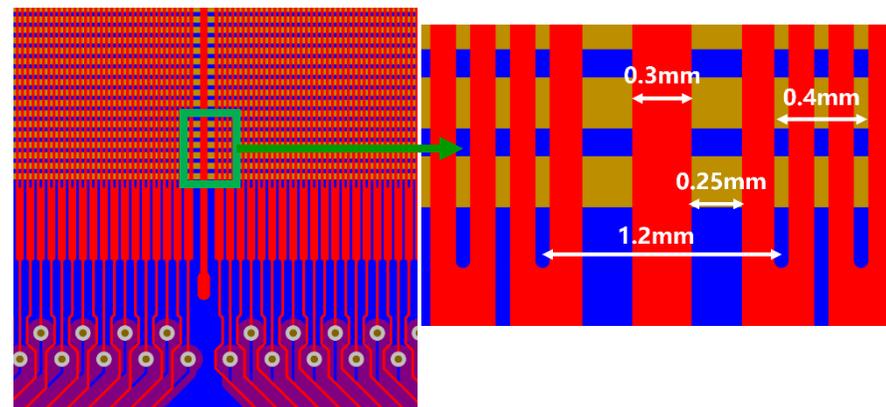
Small prototype

Large area

DLC HV

Drift HV
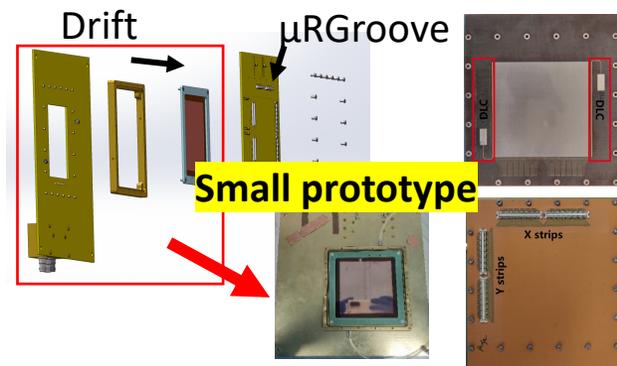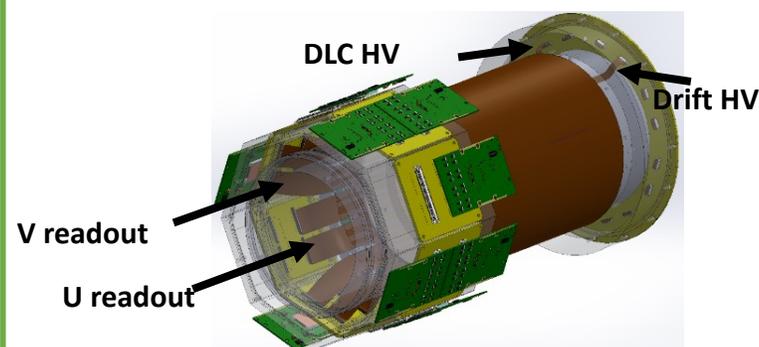
V readout

U readout

Cylindrical μRGroove

➤ **Suitable for cylindrical geometry and large-area tracking application.**

3

The Large-area μRGroove

Active area:

- **50 cm × 50 cm**
- **100 cm × 50 cm**

0.3mm
0.4mm
0.25mm
1.2mm

2 readout strips are replaced by a PEP GND line in each 128 readout strips;

- ➤ **PEP fast grounding line, divided into 10/20 sub-regions of 5 × 10 cm each**
- ➤ **Dead Area (TOP): 2/128 = 1.5625%**
- ➤ **Simple structure, easy installation**

50cm × 50cm: Signal gain and uniformity

50cm × 50cm μRGroove, Irradiated area(6,5)

Legend:
- Ar/iso-C$_4$H$_{10}$ (98/2)
- Ar/iso-C$_4$H$_{10}$ (95/5)
- Ar/iso-C$_4$H$_{10}$ (90/10)

X-axis: HV on DLC (volt)
Y-axis: Signal gain
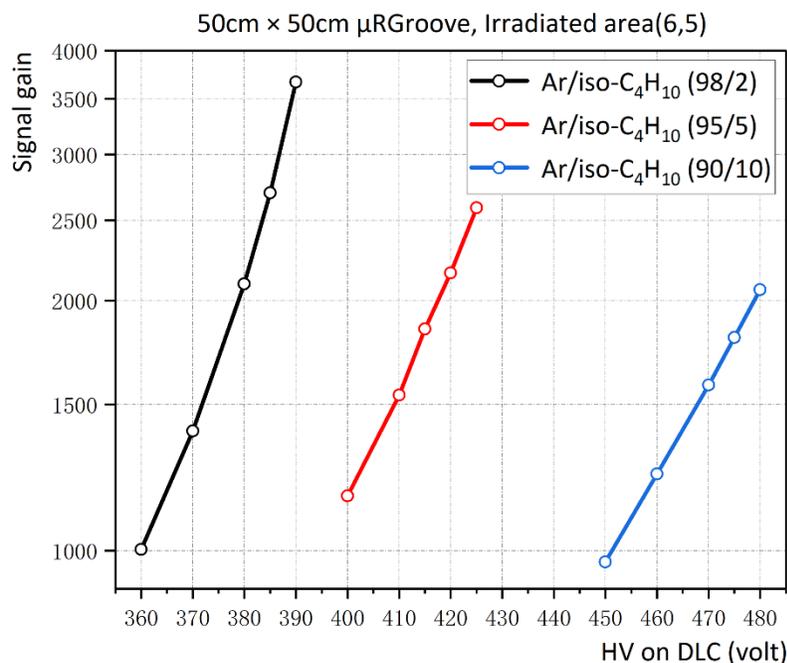
Ar/iso-C$_4$H$_{10}$ (95/5), DLC: 415V, Drift -500V

	1	2	3	4	5	6	7	8	9	10
1	1682	1660	1894	1850	1682	1749	1694	1794	1526	1794
2	1560	1593	1616	1627	1660	1582	1727	1638	1560	1515
3	1515	1604	1660	1716	1760	1560	1604	1727	1660	1582
4	1549	1649	1694	1716	1783	1716	1794	1727	1660	1571
5	1571	1604	1749	1760	1772	1705	1716	1749	1716	1671
6	1593	1682	1772	1805	1850	1816	1749	1861	1760	1649
7	1437	1526	1649	1705	1772	1649	1671	1760	1727	1593
8	1404	1504	1638	1649	1638	1571	1593	1738	1604	1526
9	-	-	-	-	-	-	-	-	-	-
10	1304	1393	1482	1526	1549	1515	1504	1604	1538	1549

|	
mean	1650.3
sigma	111.86
sigma/mean	0.0678

- **The signal gain is relatively low (<3000) due to insufficient matching capacitance of ORTEC.**

- **The Gas gain is similar with that in small μRGroove**

- **Pretty uniformity, approximately 7%.**

50cm × 50cm: Rate capability

DLC: 415V, Drift: -500V, 8.1keV X-ray
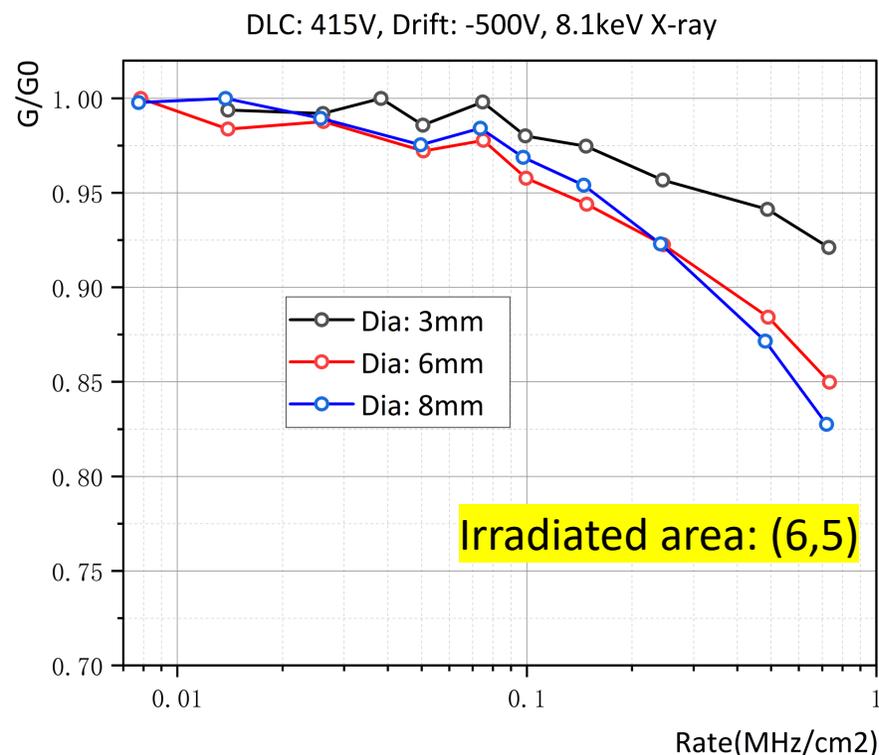
- Read out the current from the top electrode and calculate the "current gain" to obtain the G/G_0 curve.

- Scan different irradiation spot diameters.

- For an **8 mm** irradiation diameter with **8.1 keV X-rays**, the counting rate capability (at 90%) is approximately **300 kHz/cm²**.

- By converting the energy deposition to that of a **MIP**, the corresponding counting rate capability is about **2.4 MHz/cm²**.
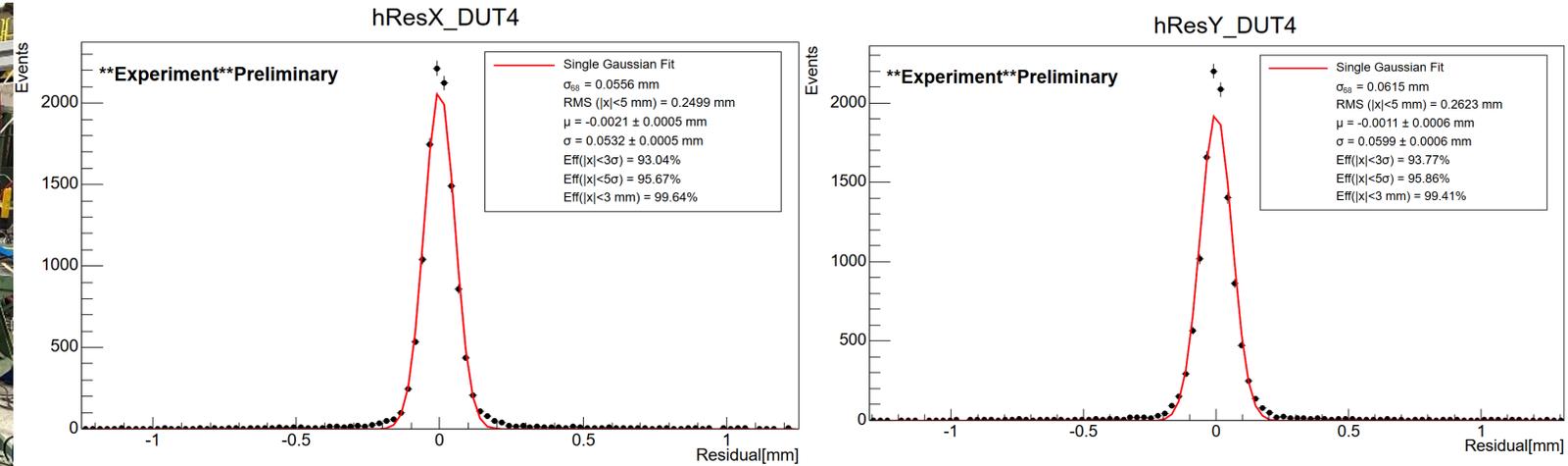
50cm × 50cm: spatial reso & efficency

2024.04
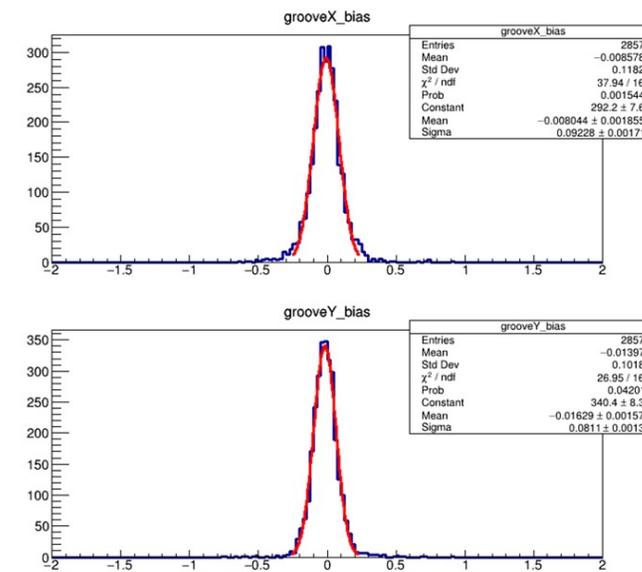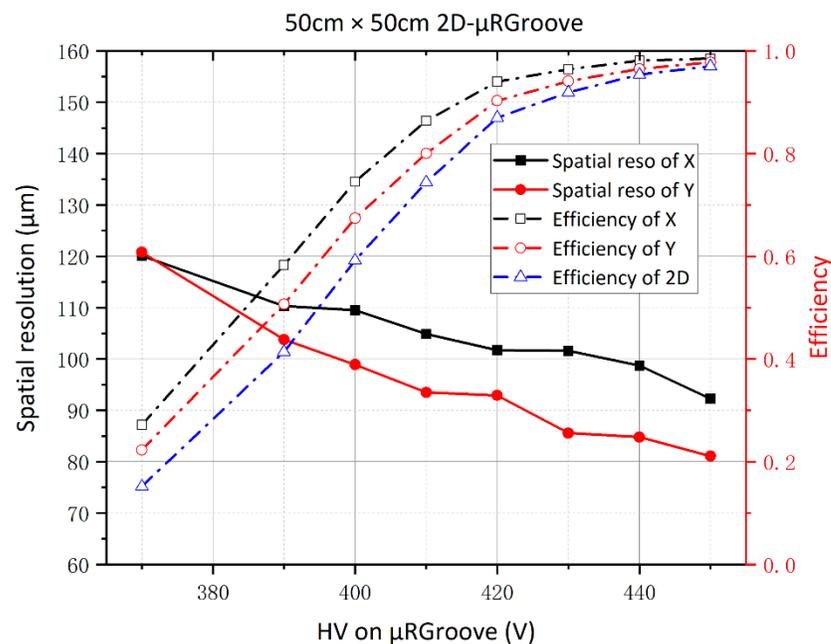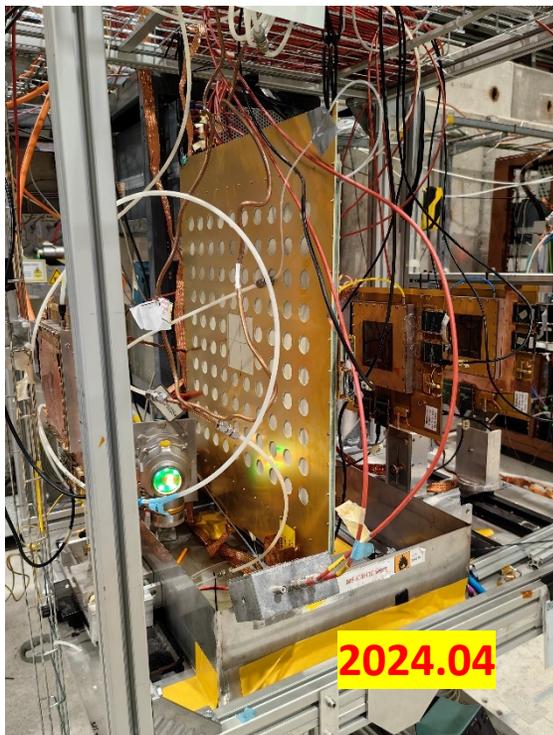
- **CERN SPS-H4**
- **150GeV/c muon**
- **APV25 + SRS + mmDAQ**

- **Work gas: Ar/iC_4H_10(90/10)**

$\checkmark$ **The combined efficiency is >96%**

$\checkmark$ **Spatial resolution is ~93μm for X readout and ~81μm for Y readout**

50cm × 50cm: New beam test

2025.11

hResX_DUT4

ExperimentPreliminary

Single Gaussian Fit
σ_{68} = 0.0556 mm
RMS (|x|<5 mm) = 0.2499 mm
μ = -0.0021 ± 0.0005 mm
σ = 0.0532 ± 0.0005 mm
Eff(|x|<3σ) = 93.04%
Eff(|x|<5σ) = 95.67%
Eff(|x|<3 mm) = 99.64%

hResY_DUT4

ExperimentPreliminary

Single Gaussian Fit
σ_{68} = 0.0615 mm
RMS (|x|<5 mm) = 0.2623 mm
μ = -0.0011 ± 0.0006 mm
σ = 0.0599 ± 0.0006 mm
Eff(|x|<3σ) = 93.77%
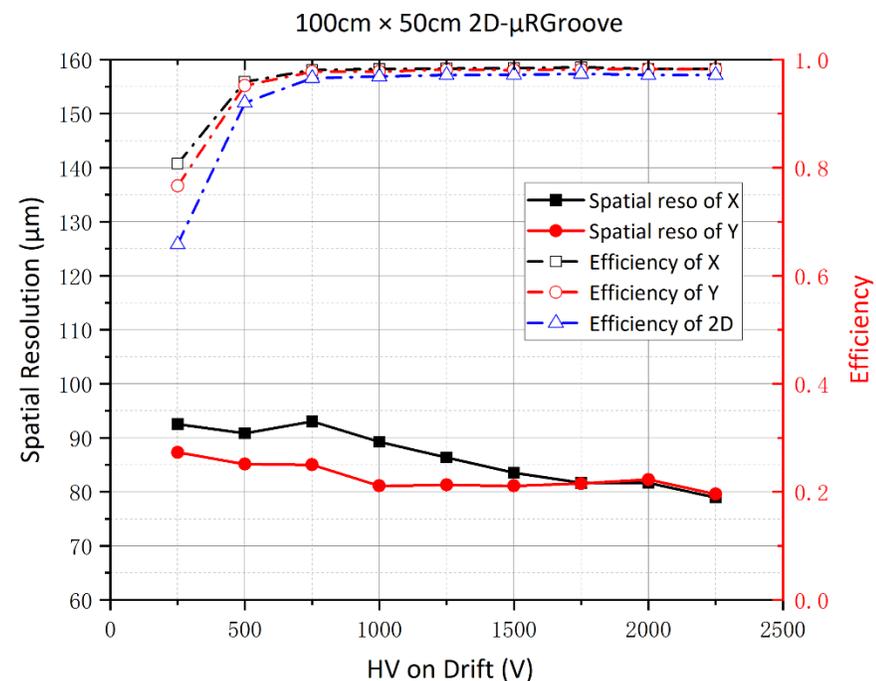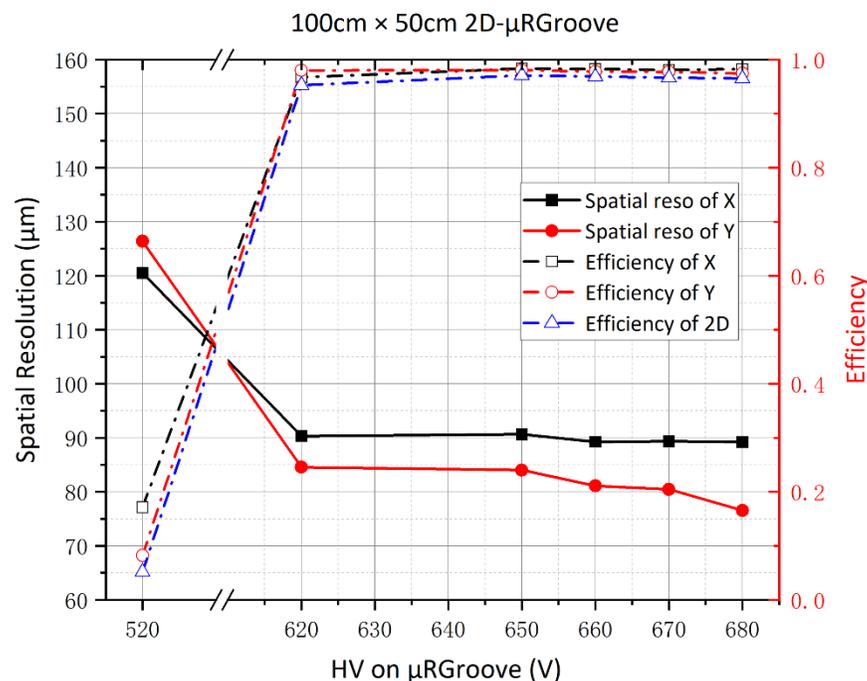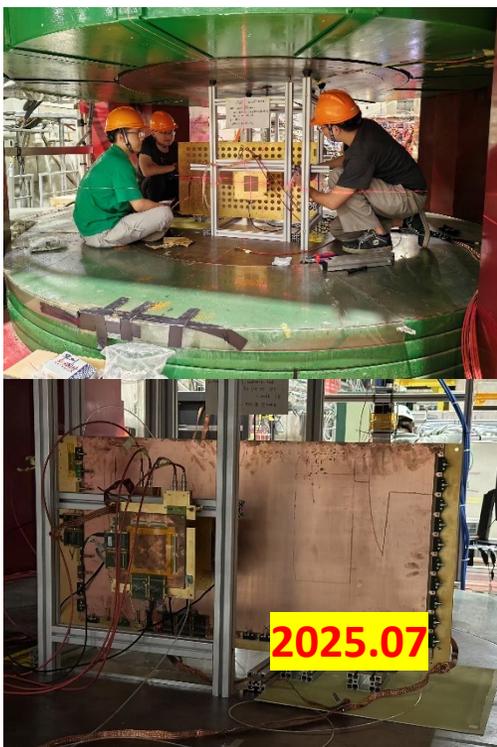Eff(|x|<5σ) = 95.86%
Eff(|x|<3 mm) = 99.41%

- CERN SPS-H4
- 150GeV/c muon
- APV25 + SRS + mmDAQ
- **Rotatable around the X-axis**

➢ Work gas: Ar:CF$_4$:CO$_2$/45:40:15. Better gas parameters but smaller gain

✓ The **efficiency** is >95%

✓ Spatial **resolution** is ~56μm for X readout and ~62μm for Y readout

➢ Better resolution is related to gas parameters such as smaller gas diffusion.
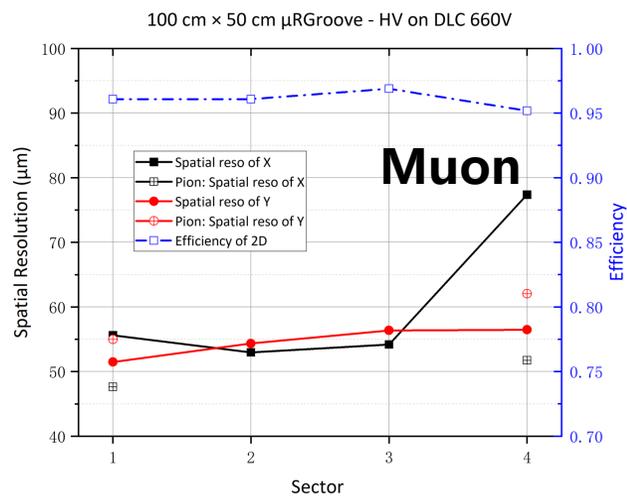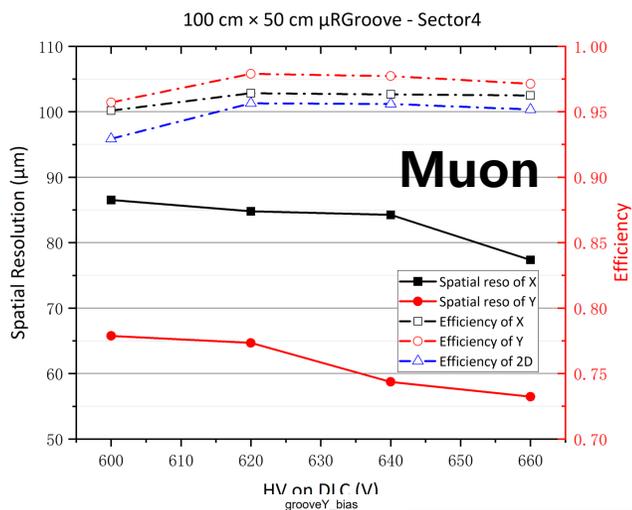➢ More μTPC-related analyses are underway.

100cm × 50cm: spatial reso & efficency

2025.07

100cm × 50cm 2D-μRGroove

- Spatial reso of X
- Spatial reso of Y
- Efficiency of X
- Efficiency of Y
- Efficiency of 2D

(X-axis: HV on μRGroove (V); Y-axis: Spatial Resolution (μm) / Efficiency)

100cm × 50cm 2D-μRGroove

- Spatial reso of X
- Spatial reso of Y
- Efficiency of X
- Efficiency of Y
- Efficiency of 2D

(X-axis: HV on Drift (V); Y-axis: Spatial Resolution (μm) / Efficiency)

- ➢ CERN SPS-H4
- ➢ 150GeV/c muon
- ➢ APV25 + SRS + mmDAQ

- ➢ Work gas: $Ar:CF_4:CO_2/45:40:15$.
- ✓ The efficiency is >96%
- ✓ Spatial resolution is ~90μm for X readout and ~80μm for Y readout
- ➢ More detailed tests about uniformity and rate capability are ongoing
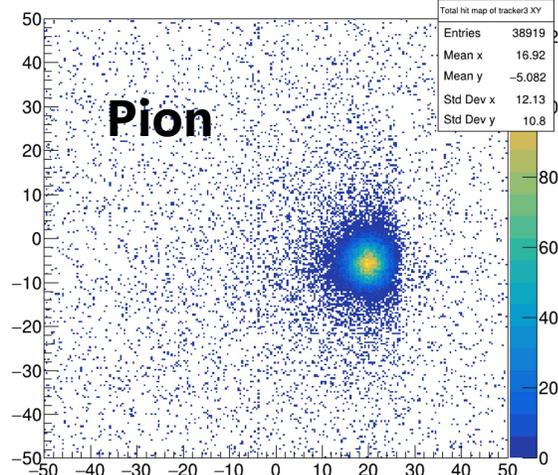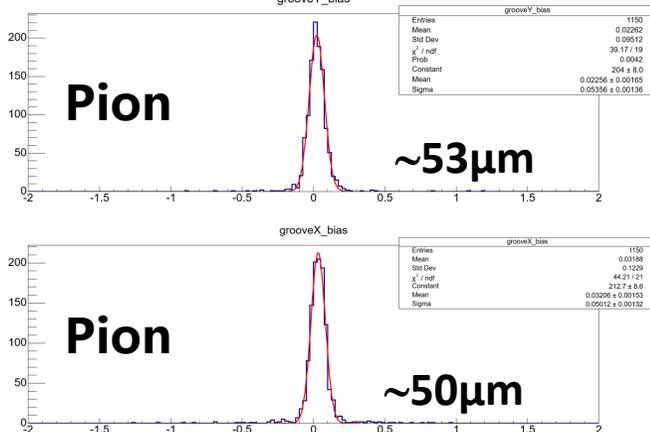
100cm × 50cm: New beam test

100 cm × 50 cm µRGroove - Sector4

100 cm × 50 cm µRGroove - HV on DLC 660V

Muon

grooveY_bias

Pion ~53µm

grooveX_bias

Pion ~50µm

Total hit map of tracker3 XY

Pion

Ar:CF₄:CO₂/45:40:15
全区域工作

2025.11

➤ **Work gas: Ar:CF₄:CO₂/45:40:15**
➤ **APV25 + SRS + mmDAQ**

Muon

- **Spatial Resolution**： ~52µm to ~78µm
  (small bending on sector4)
- **Detection Efficiency**： ≥95%

Pion (Ultra High Rate: ~1.73MHz/cm²)

- **Spatial Resolution**： ~50µm to ~53µm
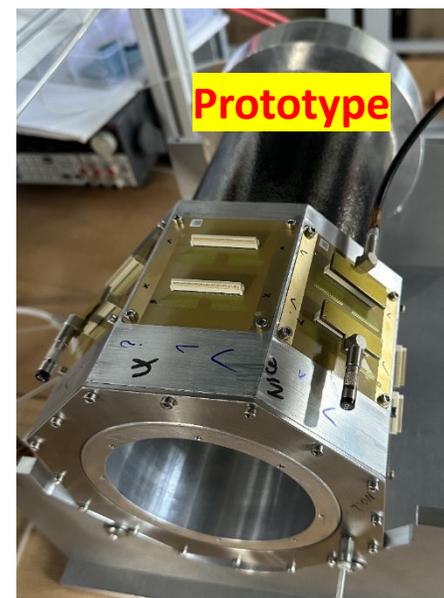- **Detection Efficiency**： ~96%

The low-mass Cylindrical µRGroove
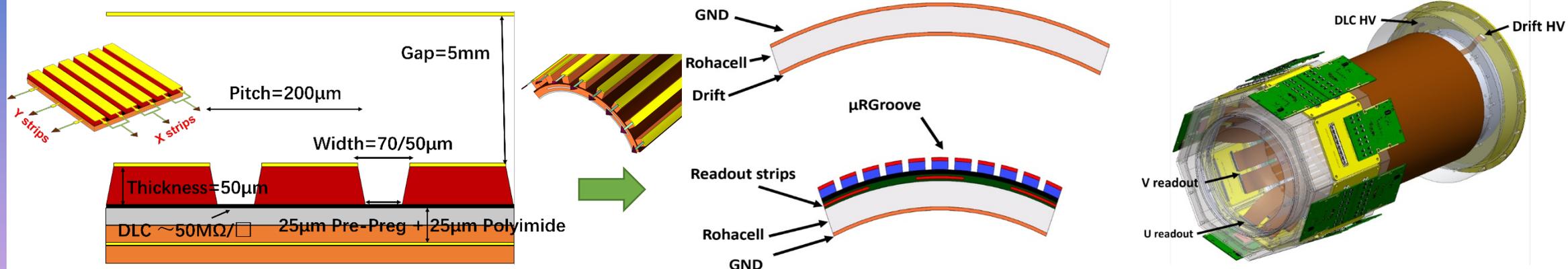
☐ 1st C-µRGroove prototype:

- Size of active area: **D=131.0mm, L=100.0mm**;
- Material budget of active area: **~0.23% X_0**
- Out cylinder is drift and inner is µRGroove-PCB
- Detachable mechanical design
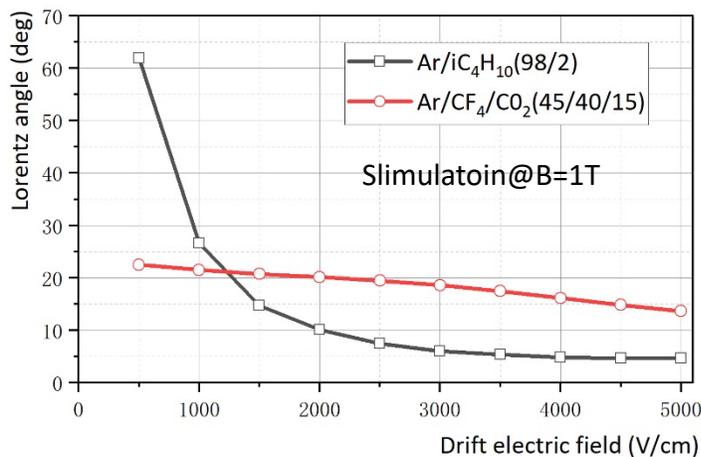
➢ **One of the options for STCF inner tracker**

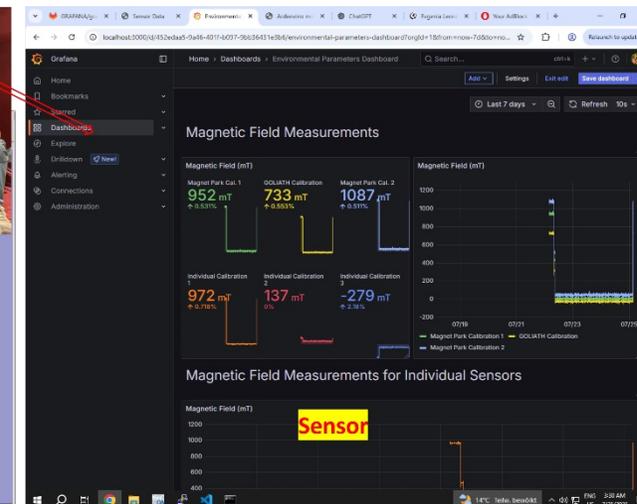**Prototype**

- **2021.09 - 2024.05: design and production**
- **2024.07：Beam test**
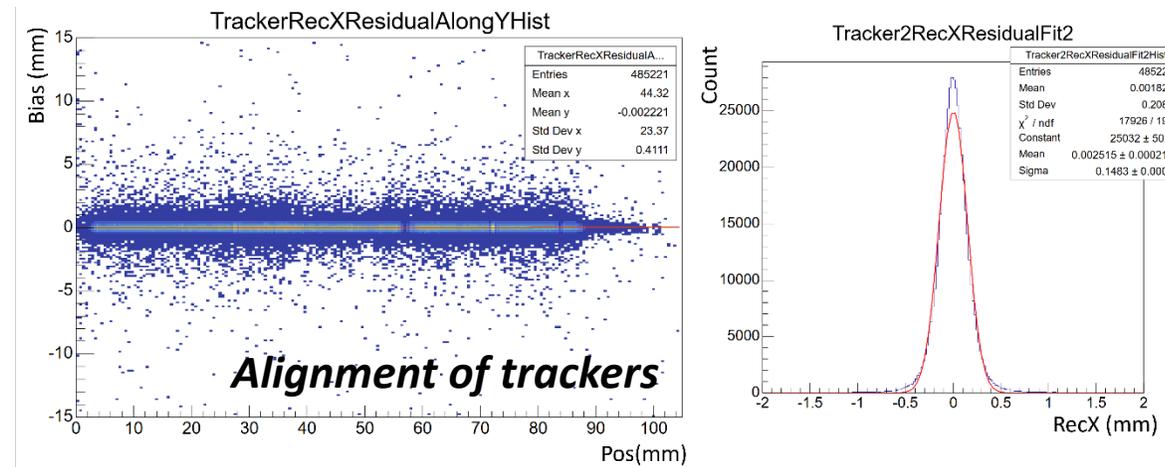- **2024.11: 1st beam test under magnetic field**

Beam test in magnet

2025. 07

Trackers and c-µRGroove in magnet
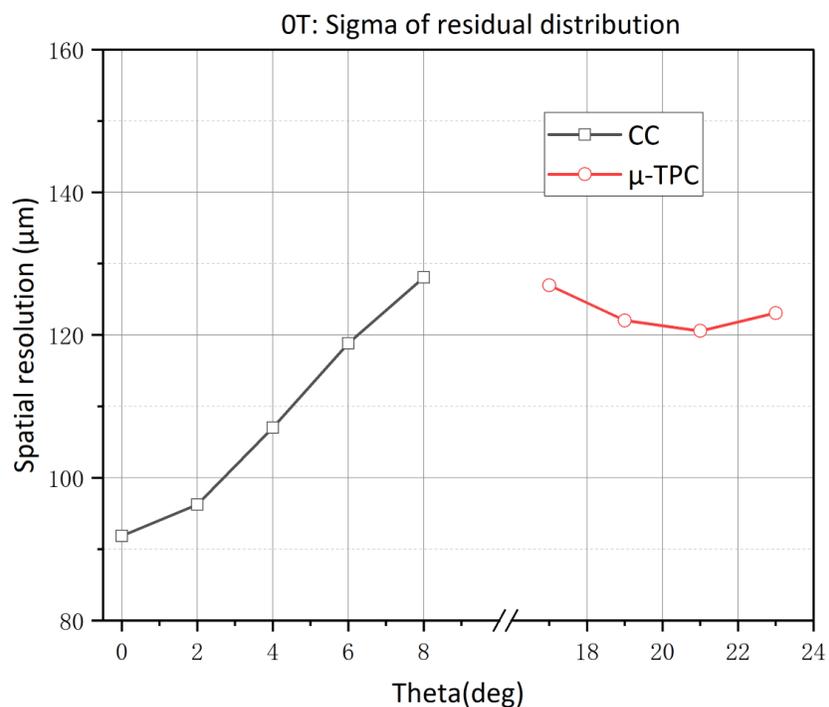
- B = 1T

Sensor

Control

Sensor

Slimulatoin@B=1T

- Goliath magnet at SPS-H4, B = 1T

- Trackers: µRGroove, Ar/iC$_4$H$_{10}$(98/2), 3kV/cm drift field, Lorentz angle: ~6°

- c-µRGroove: Ar/CF$_4$/CO$_2$(45/40/15), 0.5kV/cm drift field, Lorentz angle: ~22°

- APV25 + SRS + mmDAQ

Spatial resolution @B = 0T

- **B = 0T**

Reconstruction Methods for c-μRGroove:
- ✓ Charge centroid (CC) for tracks at small angles
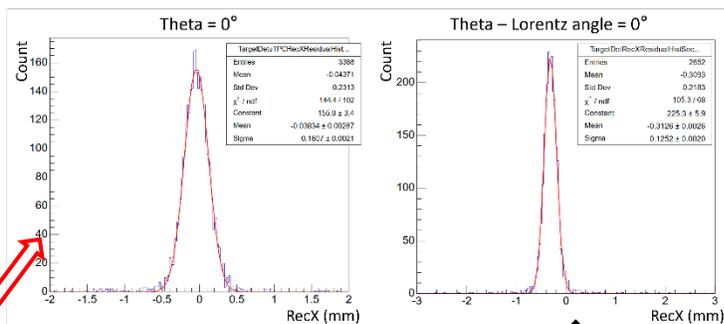- ✓ Micro-Time projection chamber (μTPC) for tracks at big angles

0T: Sigma of residual distribution

TrackerRecXResidualAlongYHist

TrackerRecXResidualA...	
Entries	485221
Mean x	44.32
Mean y	-0.002221
Std Dev x	23.37
Std Dev y	0.4111

Alignment of trackers

Tracker2RecXResidualFit2

Tracker2RecXResidualFit2Hist	
Entries	485221
Mean	0.001825
Std Dev	0.2081
x^2 / ndf	17926 / 197
Constant	25032 ± 50.3
Mean	0.002515 ± 0.000217
Sigma	0.1483 ± 0.0002

Tracker:
- the sigma of Tracker2 is ~148μm, So that its resolution is ~115μm
- Track error is ~66μm

c-μRGroove：

- Sigma: μTPC (23°) ~120μm, CC (0°) ~92μm
- Resolution without track error: μTPC (23°) ~100μm, CC (0°) 64μm

Spatial resolution @B = 1T

- **B = 1T**
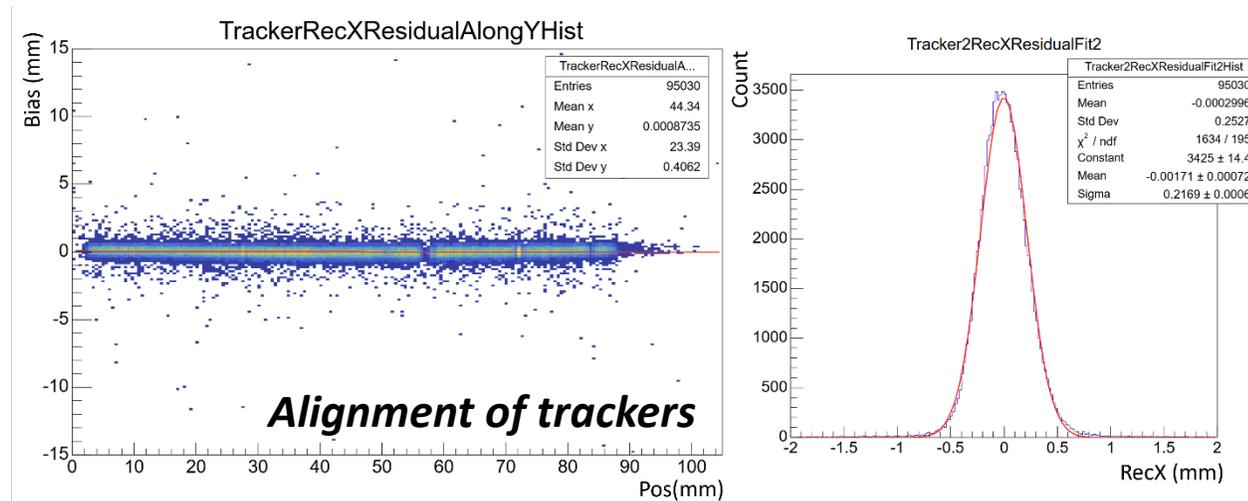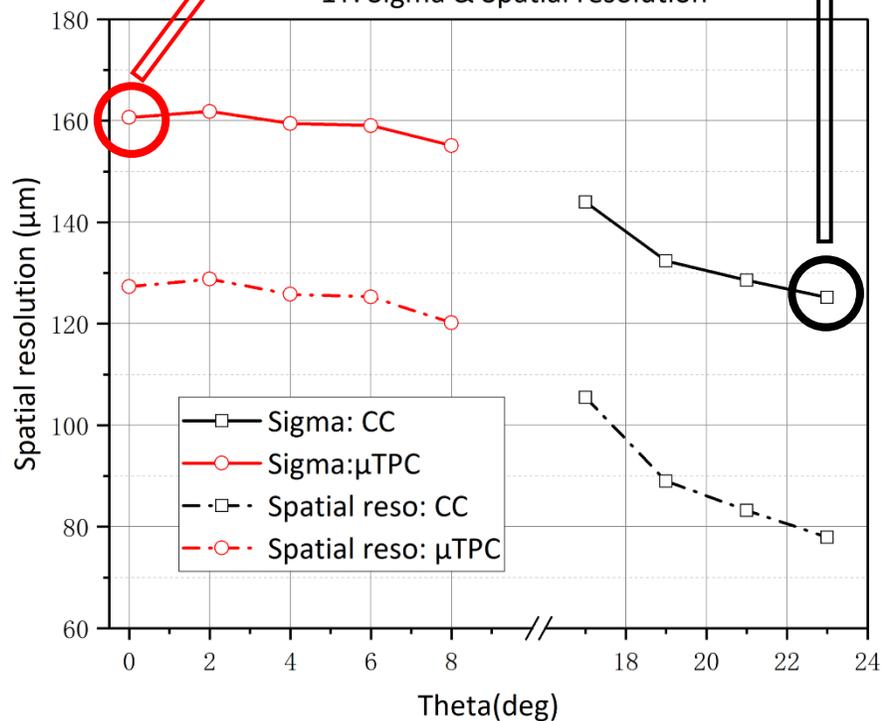
Alignment of trackers

Tracker:
- the sigma of Tracker2 is ~217μm, So that its resolution is ~169μm
- Track error is ~98μm

c-μRGroove：

- Lorentz angle ~23°

- Sigma: μTPC (0°) ~160μm, CC (Theta − Lorentz angle = 0°) ~125μm
- Resolution without track error: μTPC ~127μm, CC ~78μm

Summary

□ **50cm×50cm planar µRGroove**

- **Pretty gain uniformity: better than 7%.**
- **Rate capability: $300kHz/cm^2$@8mm diameter@8.1keV X-ray.**
- **New beam test: Spatial resolution is ~60µm.**

□ **100cm×50cm planar µRGroove**

- **Efficiency is > 96%.**
- **Spatial resolution is better than 60µm(except the bending area).**

□ **Cylindrical µRGroove**

- **Lorentz angle is ~ 23° @1T @Ar/CF4/CO2(45/40/15), 0.5kV/cm drift field.**
- **Spatial resolution @0T: µTPC (23°) ~100µm, CC (0°) ~64µm (track error deducted).**
- **Spatial resolution @1T: µTPC (0°) ~127µm, CC (Theta – Lorentz angle = 0°) ~78µm (track error deducted).**

Outlook

- ☐ **Detailed test of 100cm×50cm μRGroove**
- ☐ **Develop μTPC algorithm based on several beam tests**
- ☐ **Analyze new beam data of large area μRGrooves**
- ☐ **Optimize the detector structure, such as groove structure and readout, etc.**

Backup

Influence of capacitance

➤ Irradiated area: (6,5)，DLC: 415 V; Drift: -500 V

Test setups	Signal gain
Full size connected；Bottom is readout	1749
Central 10cm×10cm area connected Bottom is readout	1872
Central 10cm×10cm area connected Top is readout	1905

X By reducing the connected area, the signal gain only increased by 7%.

✓ Under the same setups, the top and bottom maintain similar amplitudes.

Small µRGroove 5×5cm connected 45×50cm connected

➤ It is necessary to determine the effect of capacitance by comparing with a small-area µRGroove.
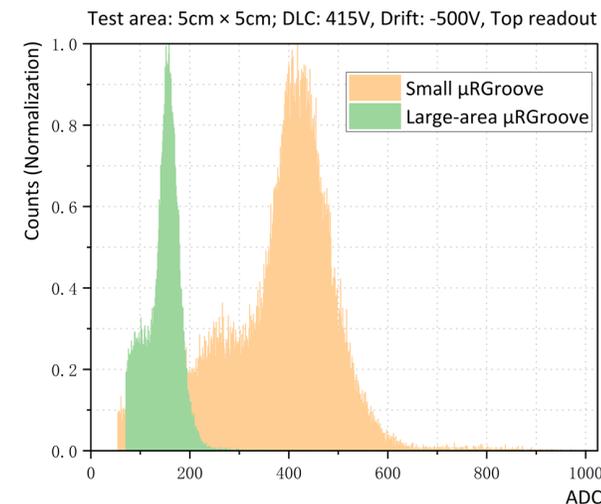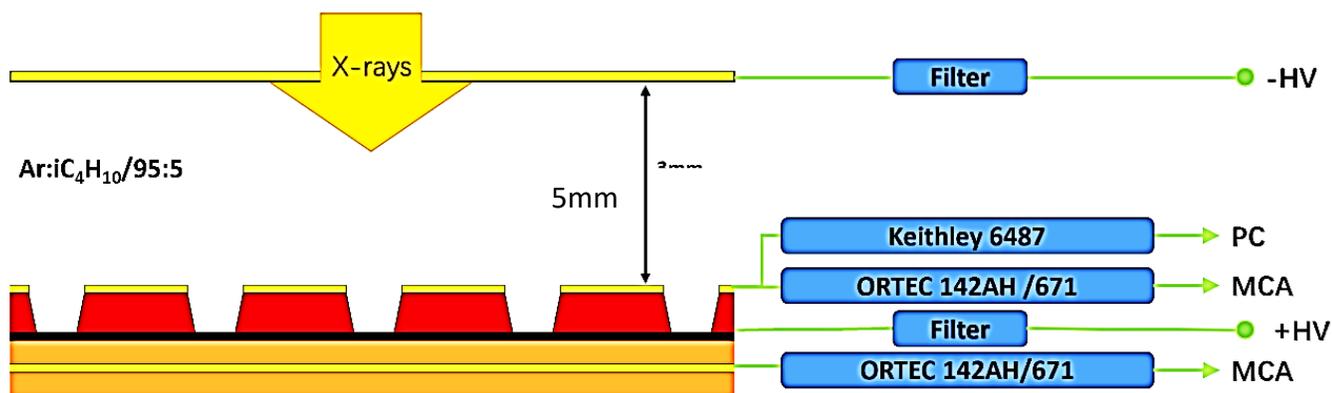
Capacitance measurement:
- small µRGroove, 5 × 5 cm connected: 1.53 nF
- Large µRGroove, 5 × 5 cm connected : 7.66 nF
- Large µRGroove, 45 × 50 cm connected : 9.02 nF

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Further check between large and small detectors

X-rays

Filter — -HV

Ar:iC$_4$H$_{10}$/95:5

5mm

3mm

Keithley 6487 → PC

ORTEC 142AH /671 → MCA

Filter — +HV

ORTEC 142AH/671 → MCA

Test area: 5cm × 5cm; DLC: 415V, Drift: -500V, Top readout

Test setups	"Current gain"	Signal gain	G_{sig}/G_{cur}
Large μRGroove 5×5cm (6,5) connected; Top readout	7573	2139	3.54
Small μRGroove 5×5cm connected Top readout	8914	5079	1.76

- The difference in current gain between the large and small detectors is relatively minor, where the difference in signal gain is substantial.

- This suggests that the electron multiplication is likely similar, but the reduced signal result from insufficient matching capacitance in the *ORTEC* preamplifier.

"Current gain" refers to the *"gain"* based on the current read out from the top electrode.
Although it's not the total current on the DLC, it is still suitable for comparative analysis.
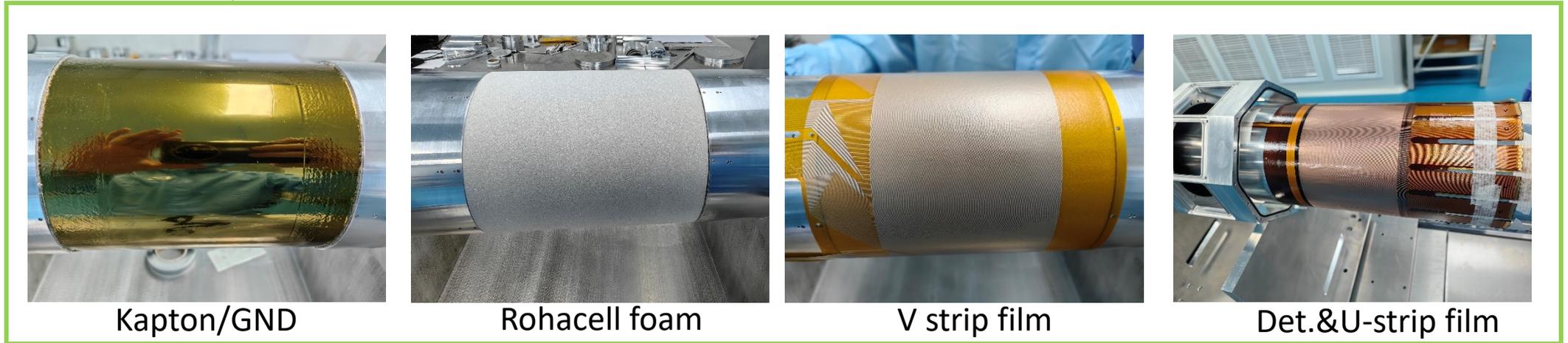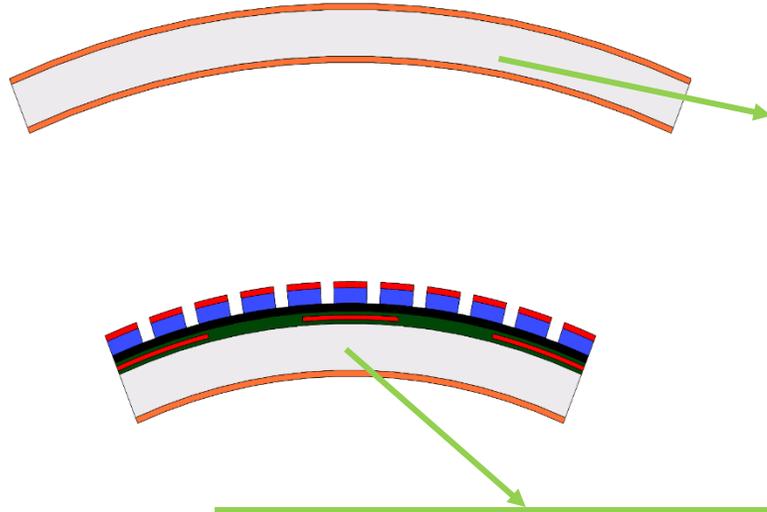
C-μRGroove: Low-Mass Electrode
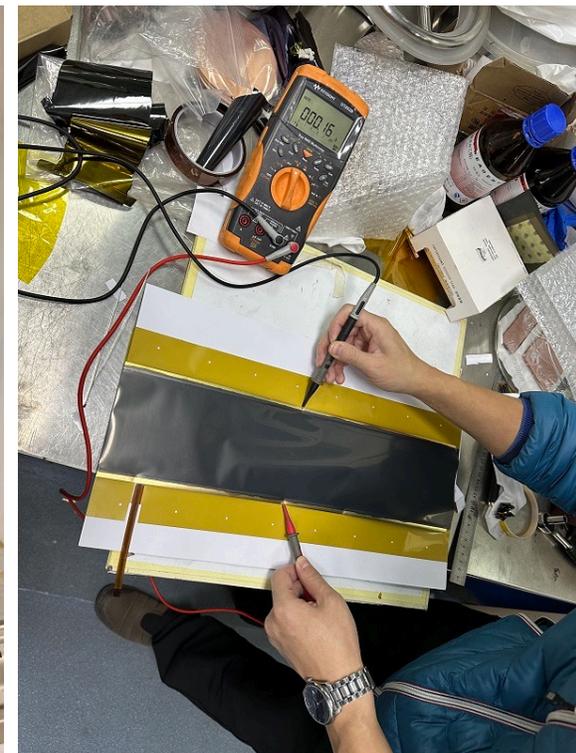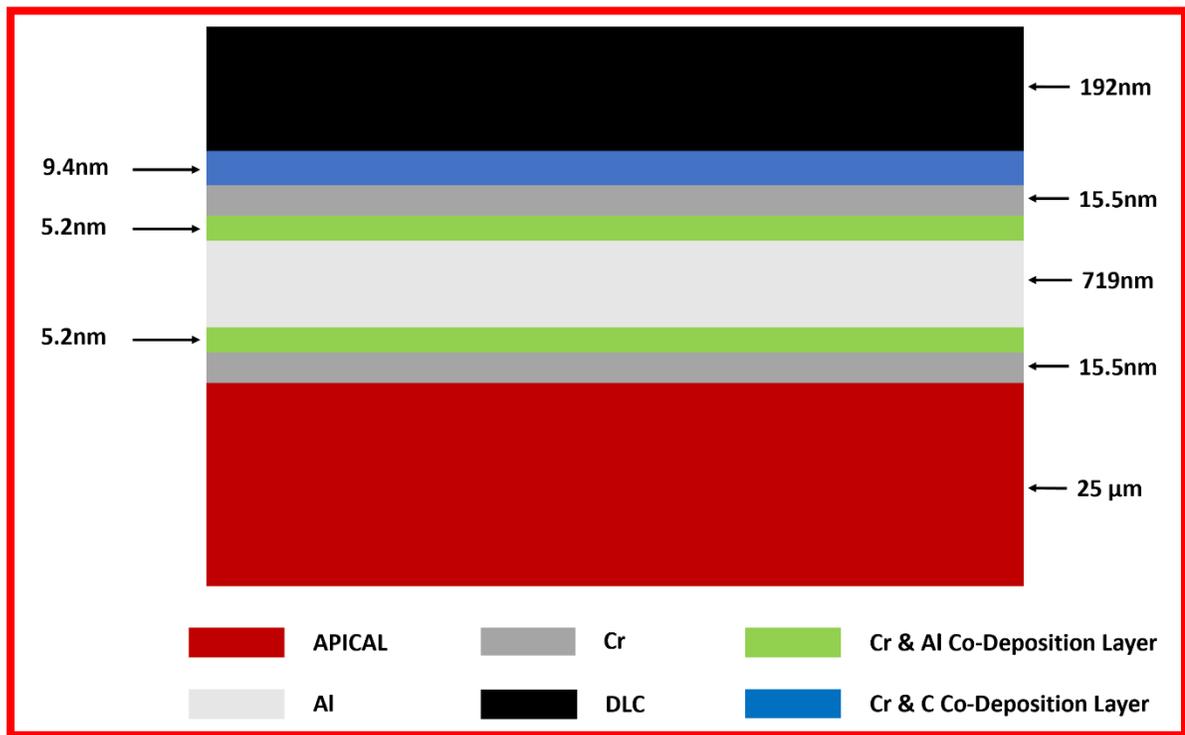
	X0 (mm)	Thickness (nm)	Material Budget (%X0)
C	188.4	193.6	0.0001028
Al	88.97	721.6	0.0008110
Cr	20.7	46.5	0.0002246
Total:			0.0011384

➤ **DLC: Diamond Like Carbon**

LM Drift & GND are both made

Zhou Lin, RD51 Collaboration Meeting, 21/06/2023

C-μRGroove: Manufacture

Drift electrode   Rohacell foam   Kapton/GND

Kapton/GND   Rohacell foam   V strip film   Det.&U-strip film

✓ **Total material budget: ~0.23%X_0**

C-μRGroove: Electrodes design

μRGroove/U Strips

V Strips

Layer stack of μRGroove

25μm Kapton Coverlay →
Cu →
50μm APICAL →
10μm Glue →
25μm Kapton →

Cu (15μm)   DLC   Kapton (25μm)
APICAL (50μm)   Glue (10μm)   Kapton Coverlay (25μm)

Layer stack of V readout

25μm Kapton Coverlay →
12μm Al →
10μm Glue →
25μm Kapton →

Glue (10μm)   Kapton (25μm)
Kapton Coverlay (25μm)   Al (12 μm)
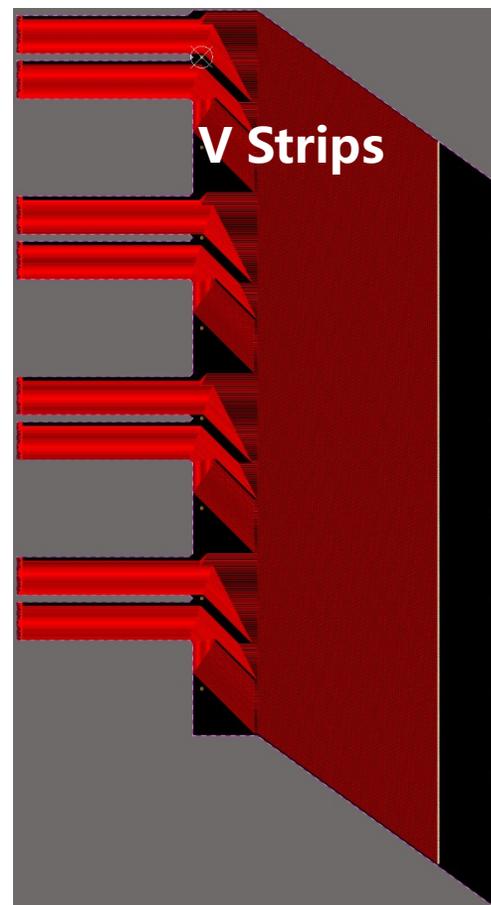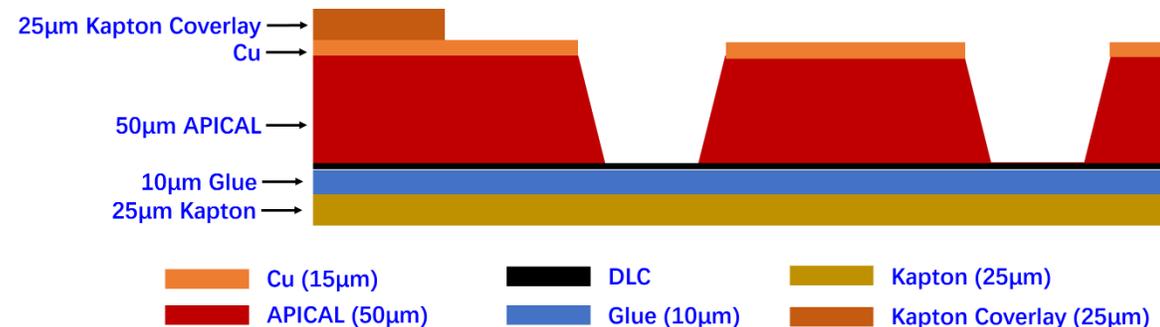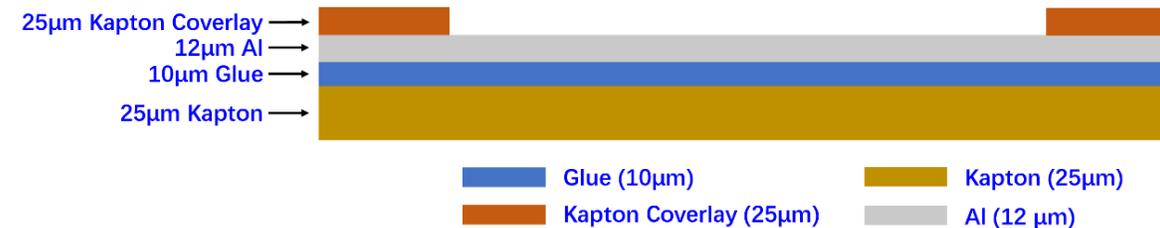
U/V 2D strip-readout, pitch of U strips is 0.4mm, Pitch of V strips is 0.8mm, angel between UV is 15°

C-μRGroove

Structure	Material	Thickness（cm）	Material budget（X0）
Drift electrode	LMB-GND	---	2*0.001138%
	Polyimide (X0=28.57cm)	0.0025*2	0.0175%
	Glue（X≈20cm）	0.001*2	0.01%
	Rohacell (X0≈689cm)	0.2	0.029%
Gas volume	Argon-based gas mixture (X0=11760cm)	0.5	0.00425%
Inner cylinder (μRGroove foil)	Cu (X0=1.43cm)	0.0015*65%	0.0682%
	Cr (X0=2.077cm)	0.000001*65%	0.0000313%
	Apical (X0=28.57cm)	0.005*70%	0.01225%
	Glue（X0≈20cm）	0.001*5	0.025%
	Kapton (X0=28.57cm)	0.0025*2	0.0175%
	Al (X0=8.892cm)	0.0012*(1*32.5%)	0.00439%
	DLC (X0=12.13cm)	0.0001	0.00082%
	Polyimide (X0=28.57cm)	0.0025	0.00875%
	Rohacell (X0≈689cm)	0.2	0.029%
	LMB-GND	---	0.001138%
Total			0.2301%

Gain and energy spectrum measurement

Setup：

- Gas: Ar:iC$_4$H$_{10}$/95:5
- Source: ^{55}Fe
- Readout from X strips (cathode)
- V strips are grounded
- Ortec142AH/671 + MCA
- Gain measured by signal amplitude spectrum

~1h@gain : 5100
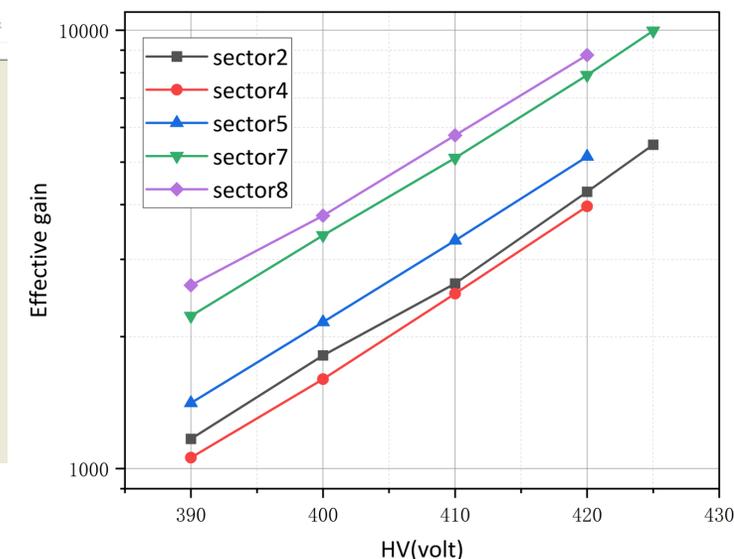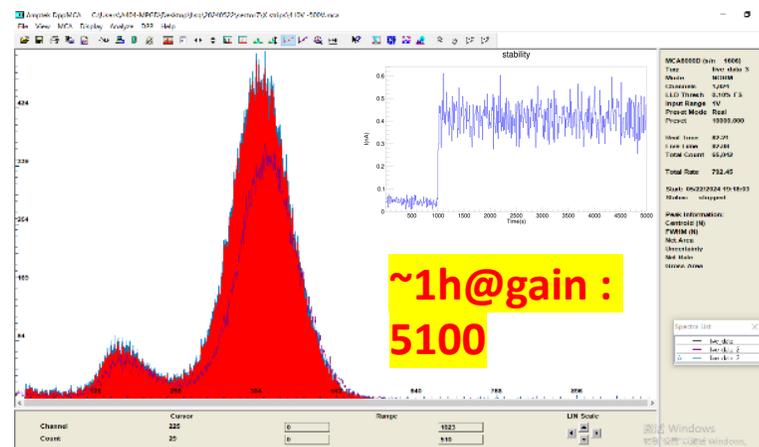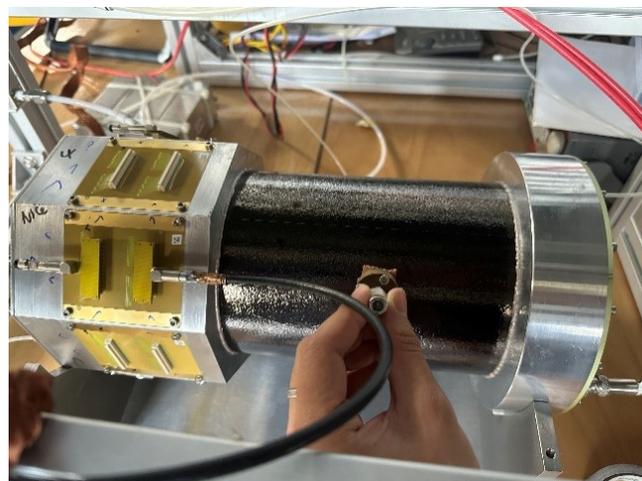
- ✓ Energy resolution: ~26%;
- ✓ Effective gain: 4000~10000;
- ✓ Similar signal amplitude on X&V readout strips;
- ✓ Good stability if the humidity can keep low enough;
- ✗ 3 sectors not work (8 sectors in total);
- ✗ Bad gain uniformity, caused by the gas(flow);