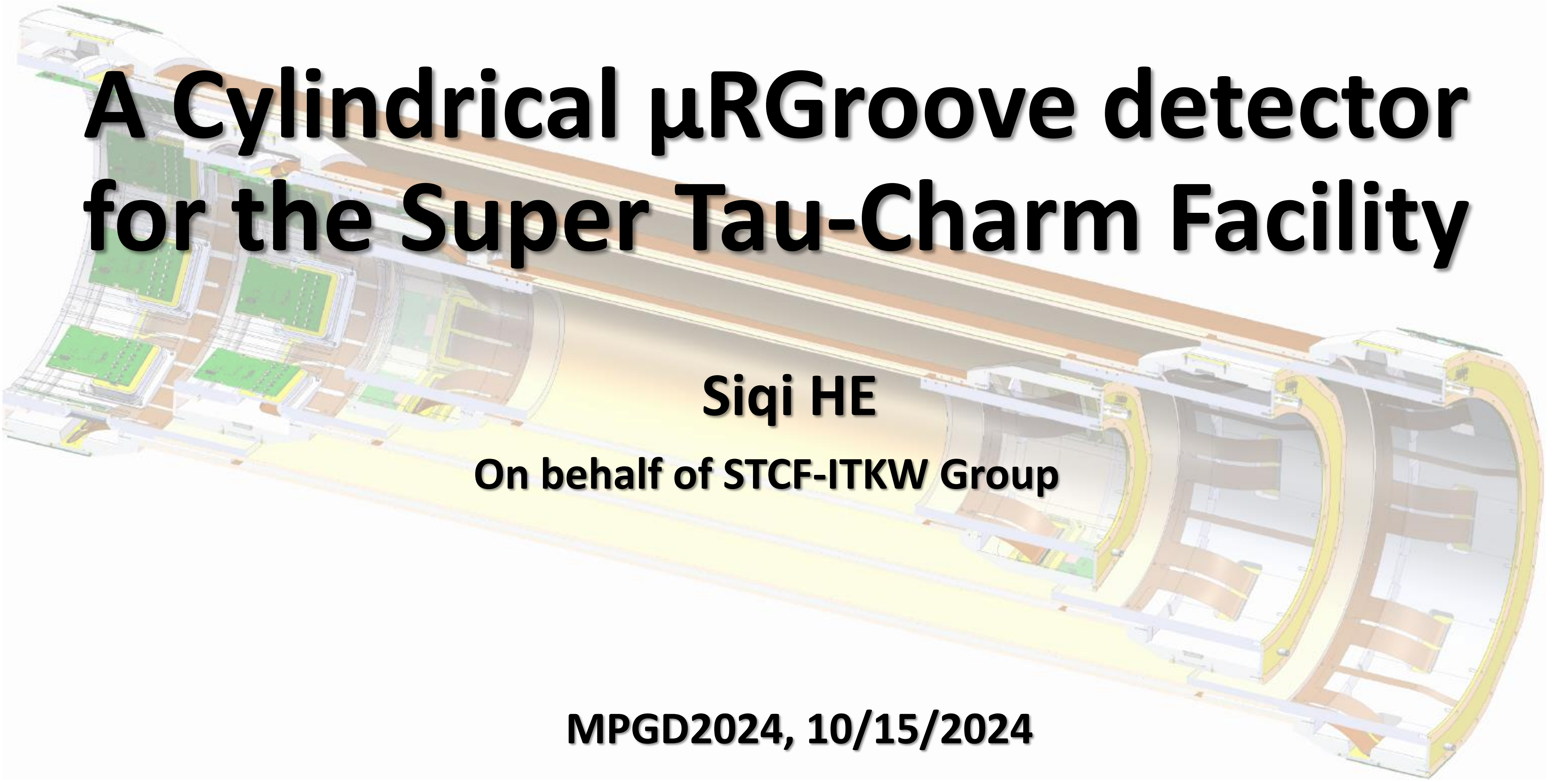
A Cylindrical μRGroove detector for the Super Tau-Charm Facility



Siqi HE

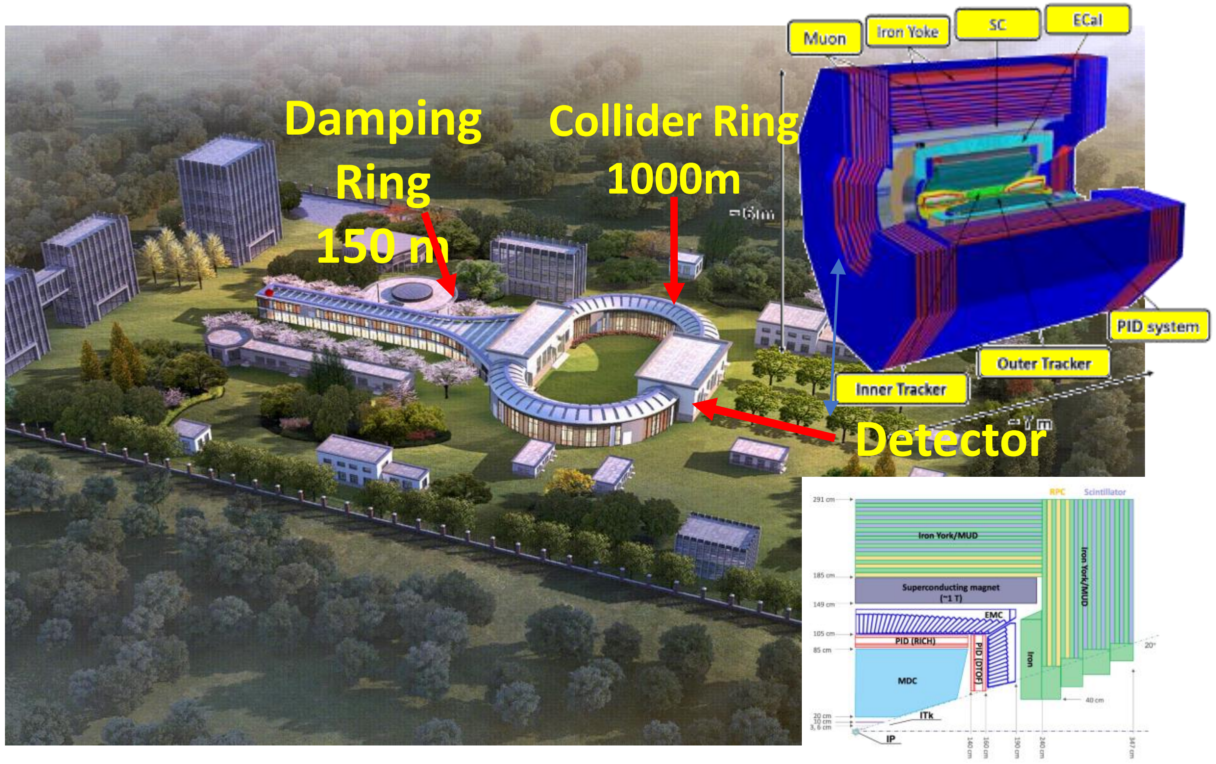
On behalf of STCF-ITKW Group

MPGD2024, 10/15/2024

- **Introduction**
- Detector design & production
- Test result
- Improvement Plan
- Summary & Outlook

Super Tau-Charm Facility

STCF is an e + e- collider operating at $\sqrt{s}$=2～7 GeV with a peak luminosity of 0.5×10^{35} cm^{-2}s^{-1}.



ITK
- <0.3%X_0 /layer
- $\sigma_{xy} < 100\mu m$
- Handle high event rate

Cylindrical MPGD
CMOS MAPS

MDC
- $\sigma_{xy} < 130\mu m$
- σ_p/p ~0.5% @ 1GeV
- dE/dX ~6%
- <5%X_0

Cylindrical Drift chamber

PID
- π/K (and K/p) eff>97%
  Separation up to 2GeV/c

RICH with MPGD
DIRC-like TOF

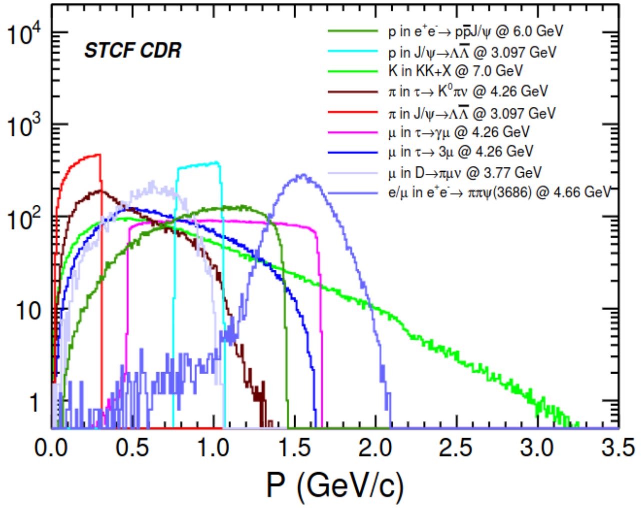
EMC
- E range: 0.025-3.5GeV
- $\sigma_E(\%)@\ 1GeV$
- Barrel: 2.5
- Endcap: 4
- Pos. Res. : 5mm

pCsI + APD

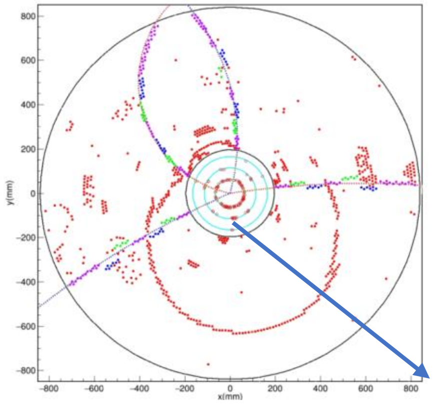
MUD
- 0.4 – 2 GeV
- μ/π suppression >30
- M detection eff>95%@p>0.7GeV/c

RPC + scintillator

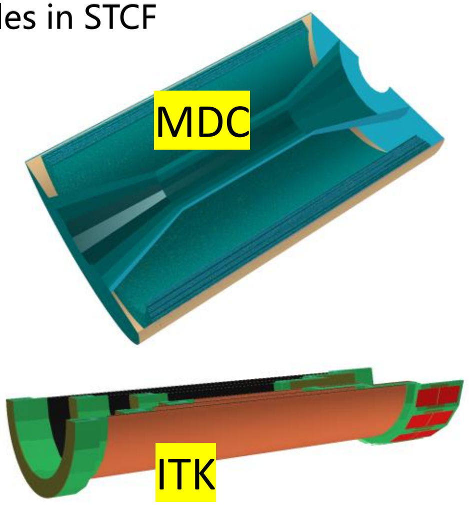
Inner Tracker (ITK)



Momentum distributions of charged particles in STCF

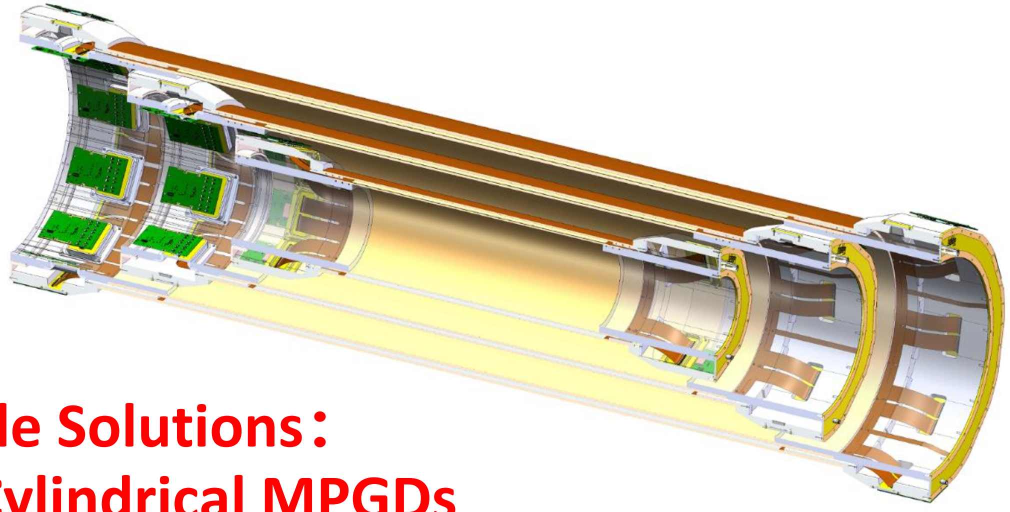


Tracking example



Track detection under extremely high luminosity requires the **ITK** performance includes:

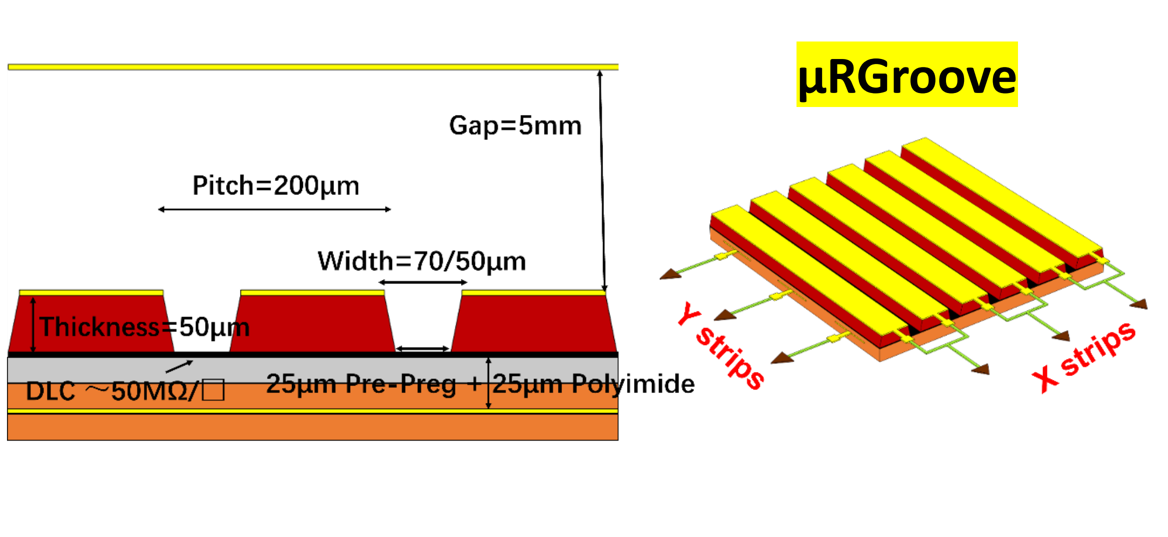
- **Good Spatial resolution @1T magnetic field (<100μm)**
- **Ultra-Low Material Budget (<0.3%X0)**
- **Handle high occupancy operated in μTPC mode**
- **……**

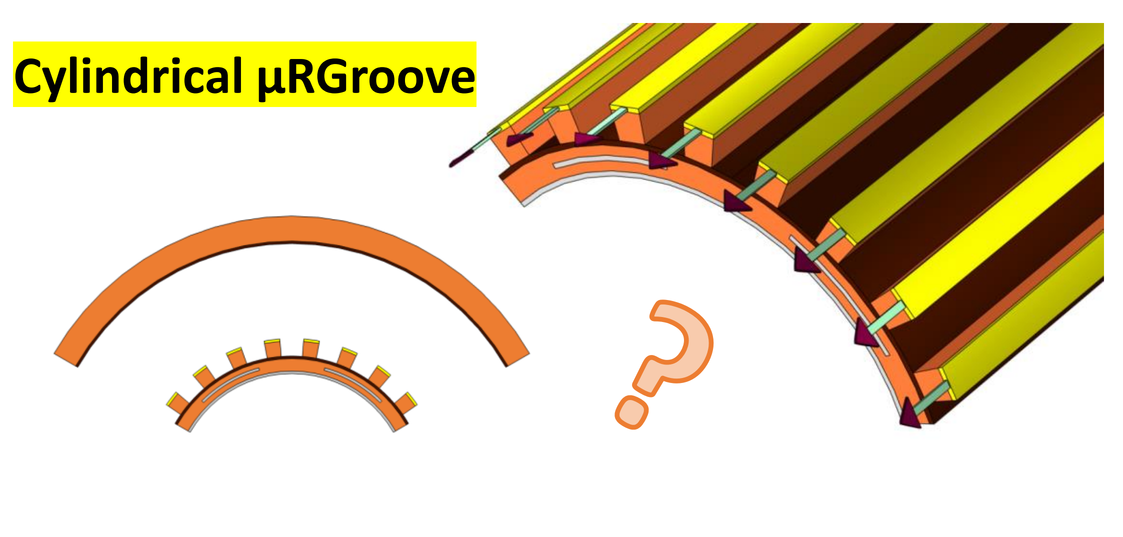


Possible Solutions：

Cylindrical MPGDs

Micro Resistive Groove (μRGroove)

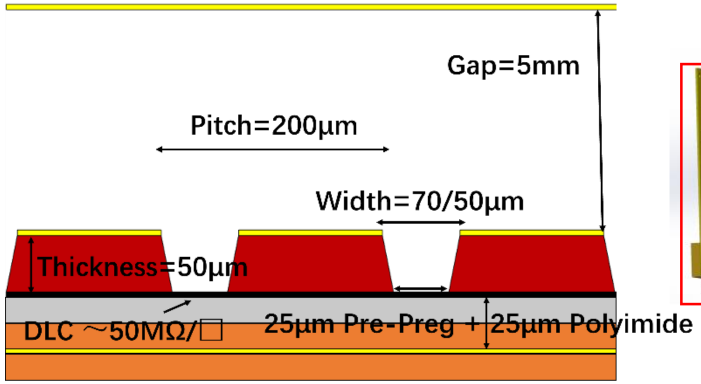


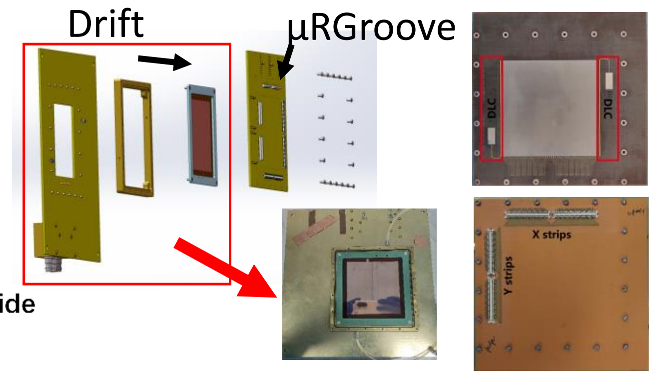


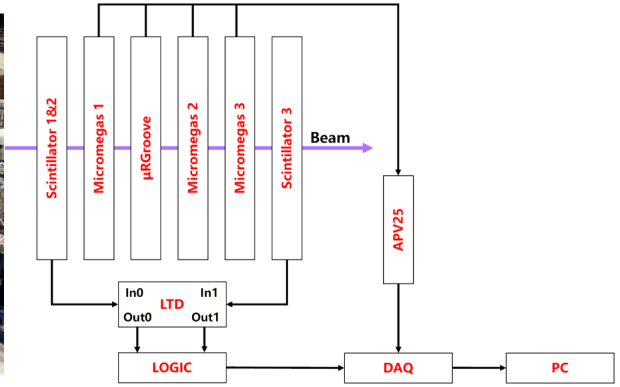
- **The cathode of μRGroove itself can be used as 1D-readout strip.**
  - ✓ Decoupled X&Y readout strips, no induced charge sharing effect, increased signal amplitude.
  - ✓ Easy to produce with low cost;

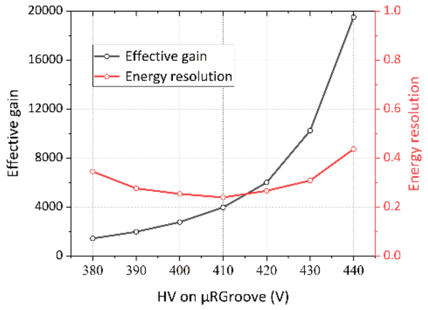
- **Cylindrical μRGroove:**
  - ✓ Simple structure: Only contains drift and single-layer detector electrodes
  - ✓ Each electrode contains support structure
  - ✓ Lower material budget: Only 1D additional readout strips is needed
  - ✓ Easy to clean for long-term maintenance.

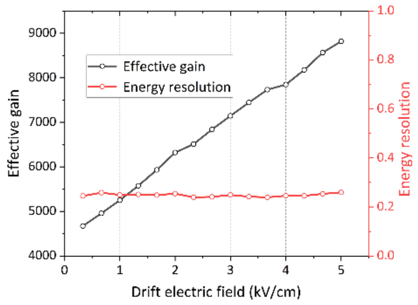
Planar μRGroove

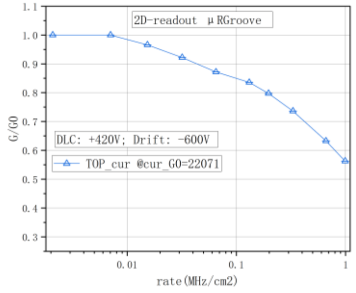




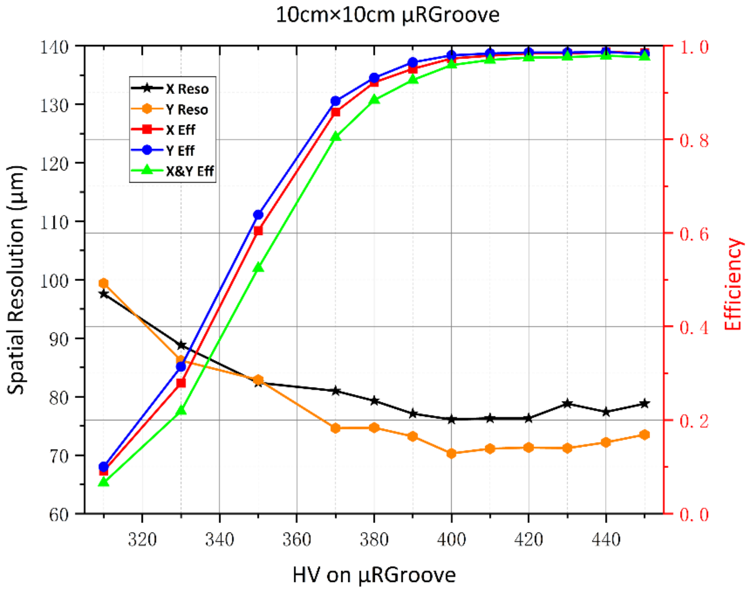








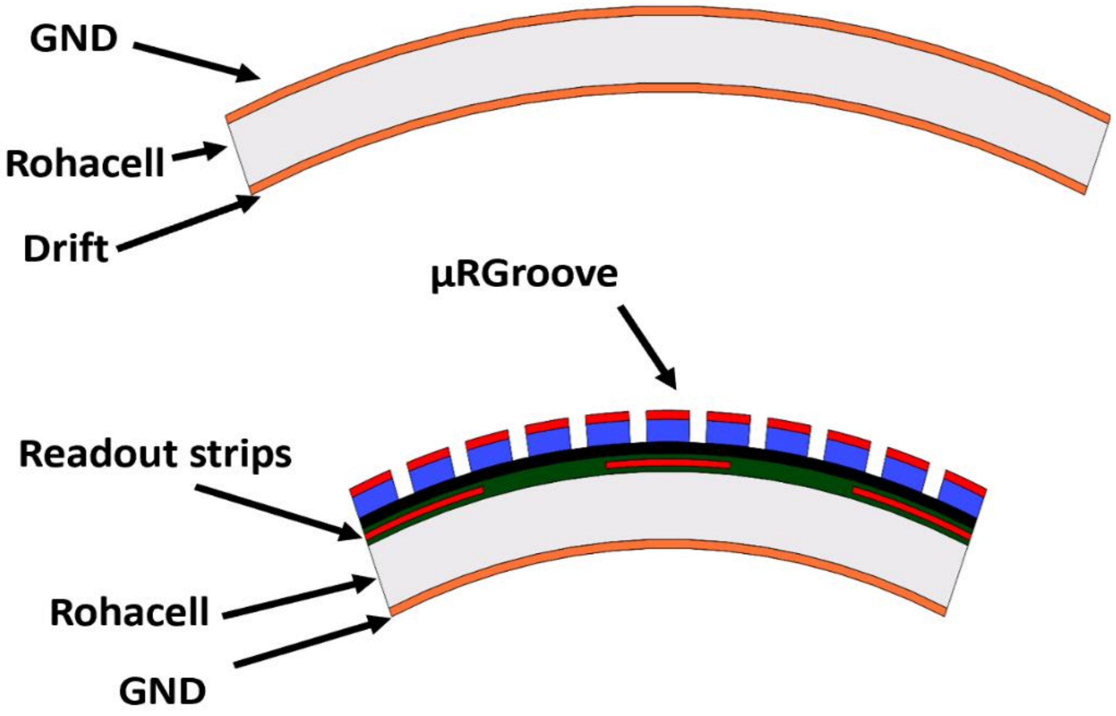
- 10cm×10cm prototype
  - ✓ Gain> 10^4； Energy resolution~25%
  - ✓ Detection efficiency~97.9%; Spatial resolution<80μm



μRGroove is a good candidate of STCF inner tracker

- Introduction
- **Detector design & production**
- Test result
- Improvement plan
- Summary

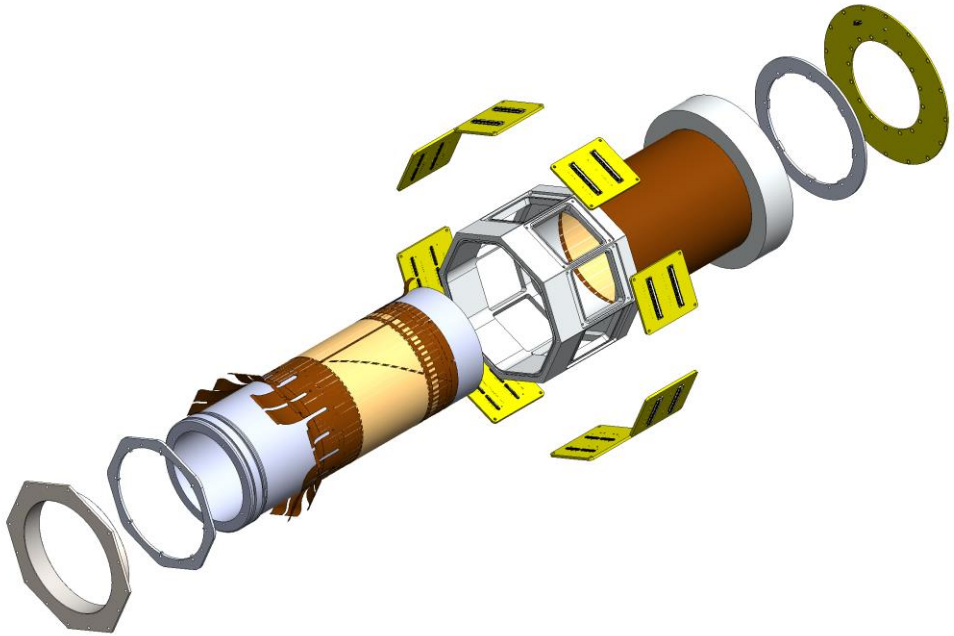
Conceptual design of Prototype

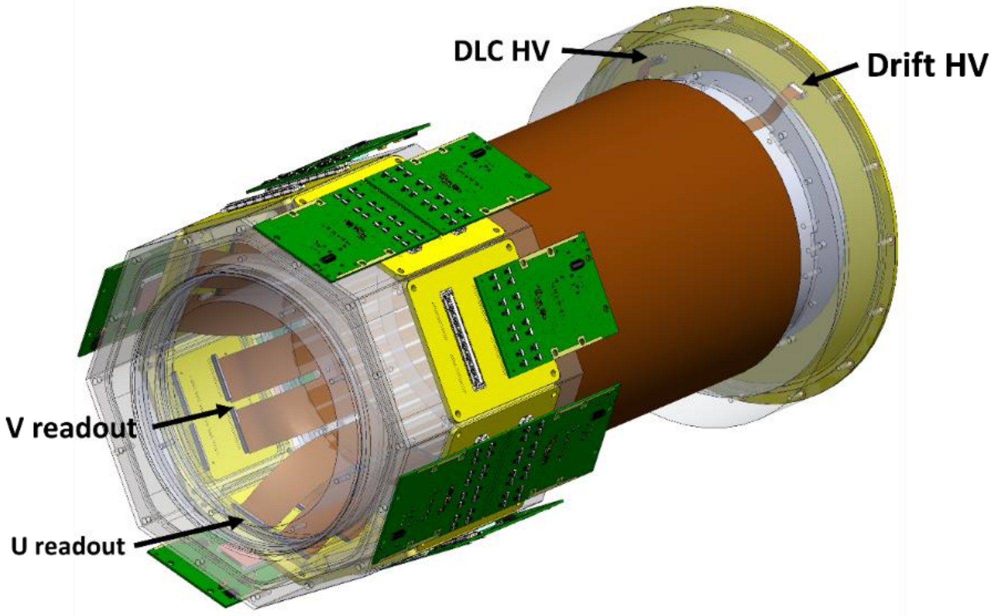


□ 1st C-μRGroove prototype:

- Size of active area: D=131.0mm, L=100.0mm;
- Out cylinder is drift and inner is μRGroove-PCB
- Both cylinders contain independent support structures
- Detachable mechanical design
- Low-mass electrode design

Mechanical design

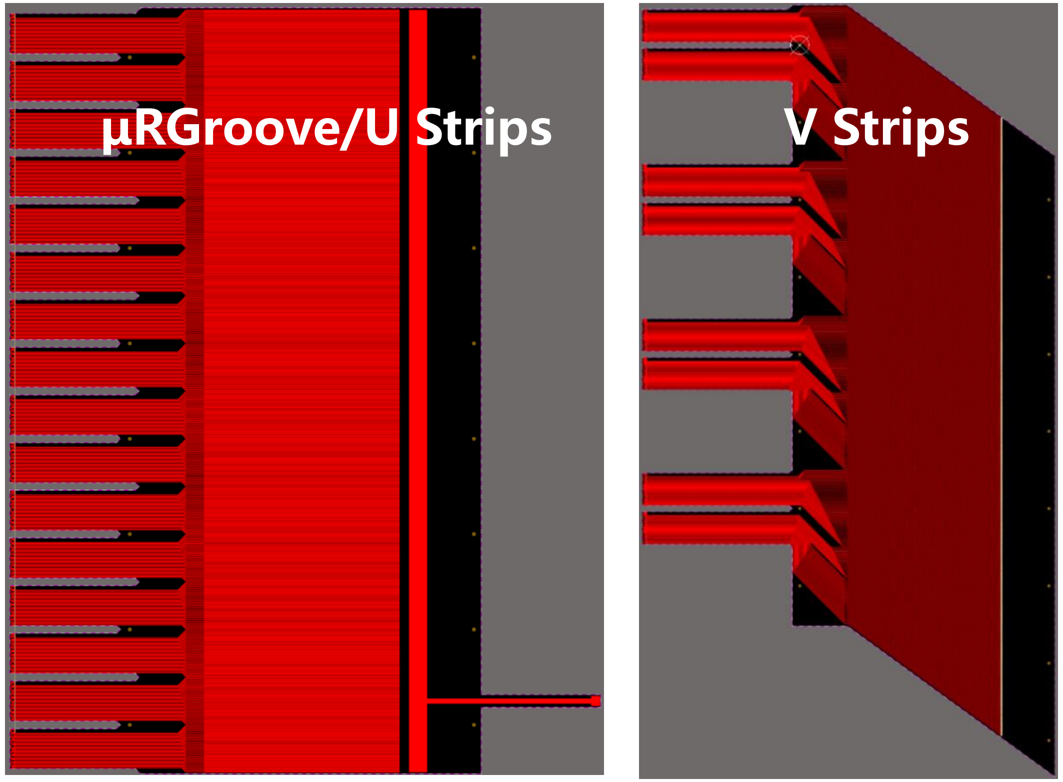


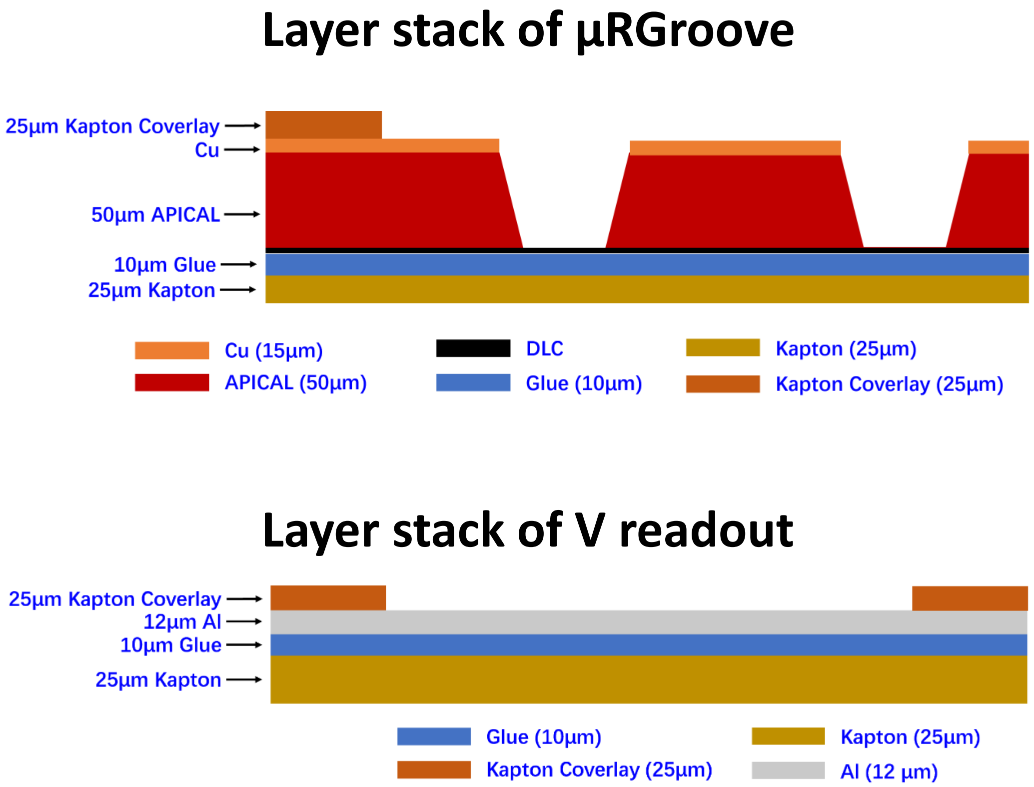


- Aluminum (metal) sleeves benefits grounding and noise shielding.
- Mechanical sealing ensures the detector is detachable
- The spacers provide an uniform 5mm drift gap

- consists of three parts: FEE side, active area, HV side
- The electrode substrate is a flexible and the soft branch can bent up to connect to adapter

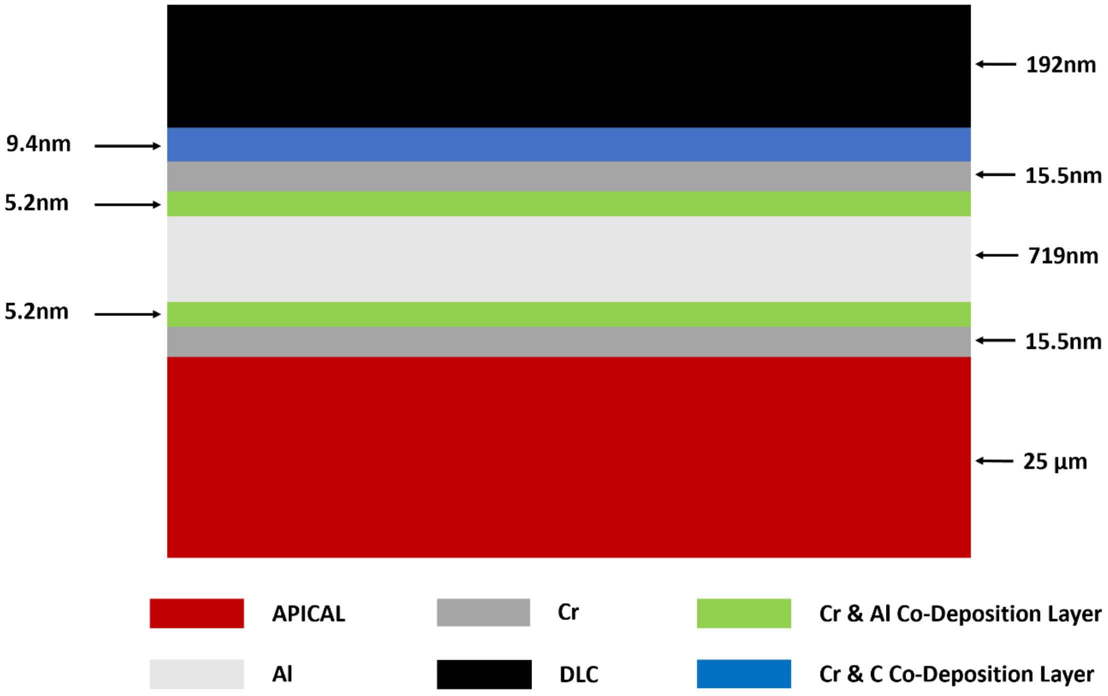
µRGroove and Readout Strips





- U/V 2D strip-readout. Pitch: U strip is 0.4mm, V strip is 0.8mm, angel between UV is 15° .
- 2 PCBs each containing 1d strips are used.
- 25µm Kapton substrate
- Aluminum V-strips

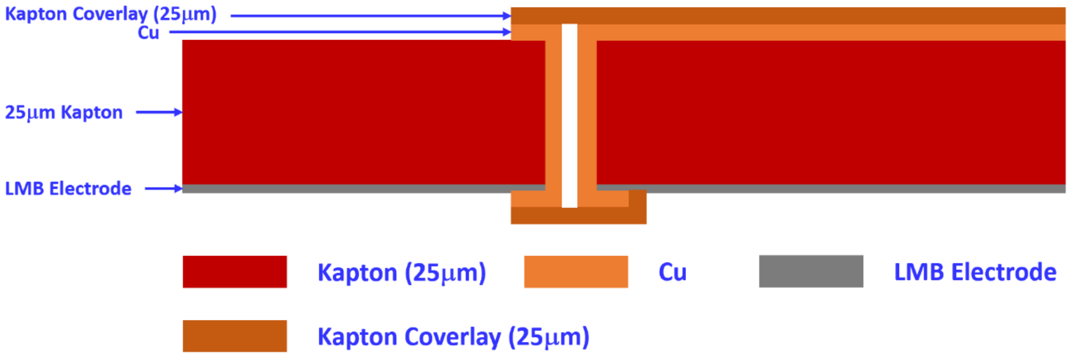
Low-mass electrode



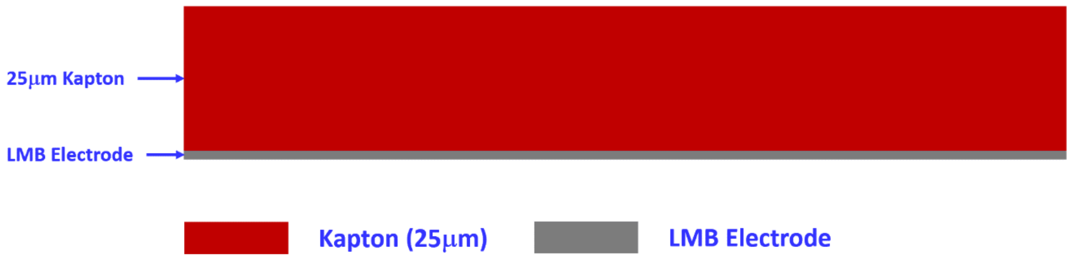
	X0 (mm)	Thickness (nm)	Material Budget (%X0)
C	188.4	193.6	0.0001028
Al	88.97	721.6	0.0008110
Cr	20.7	46.5	0.0002246
Total:			0.0011384

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

Layer stack of drift electrode

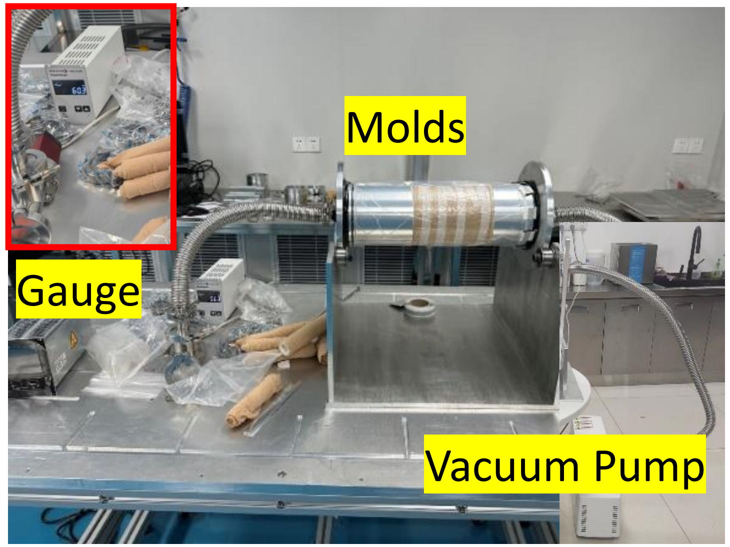


Layer stack of GND electrode

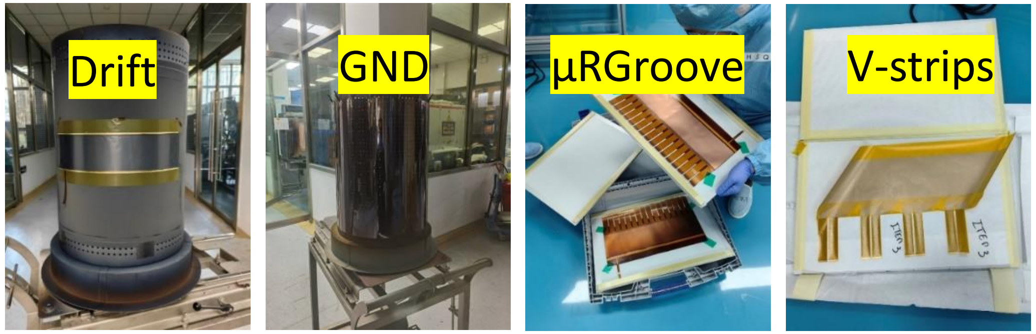


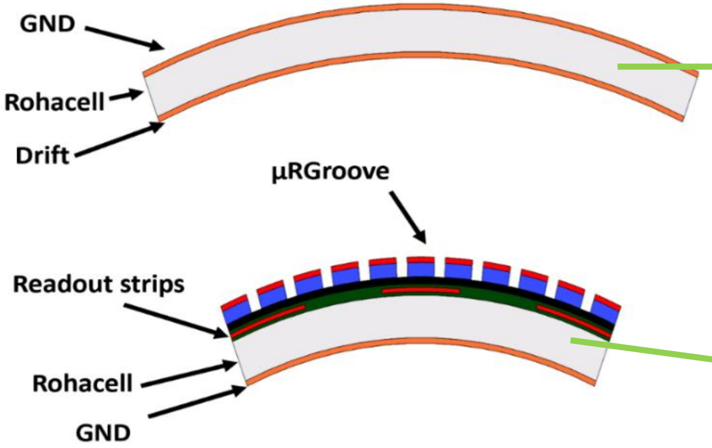
- Low-mass electrode used for both drift and GND

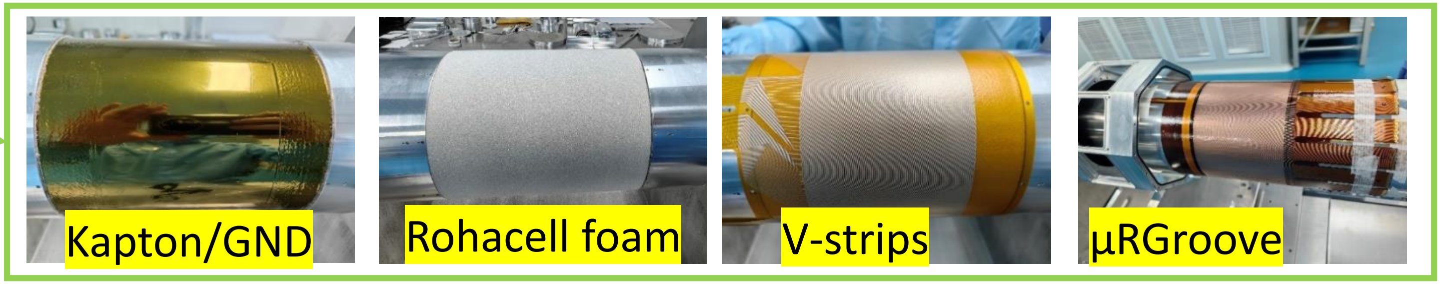
Electrode gluing process



- ✓ Vacuum gluing system
- ✓ The uniform thin glue process: **thickness of glue film <10μm**

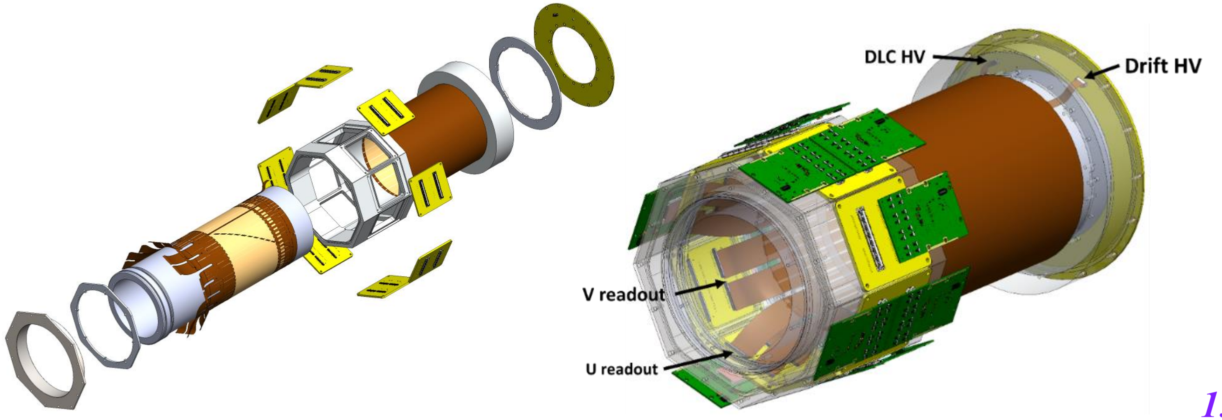




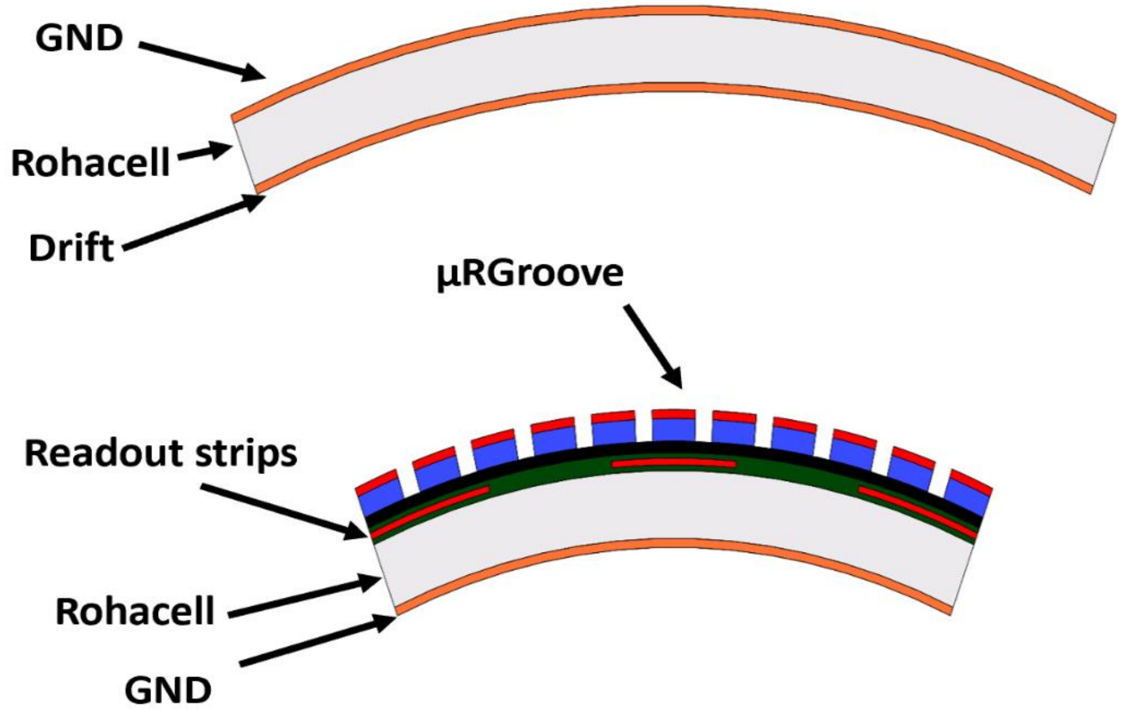


Detector assembling

- ✓ An installation platform is designed
- ✓ Reversible installation process



Material budget



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*33.6%)	0.00453%
	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			0.2302%

Consider Low-mass electrode, foams and bonding glues:

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

- Introduction
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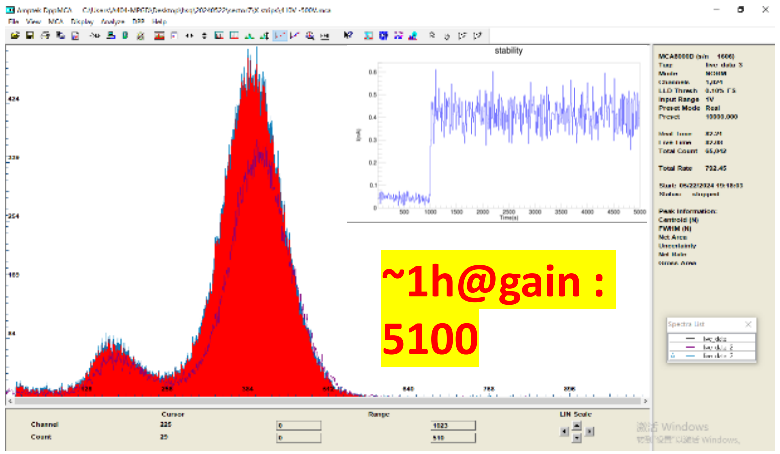
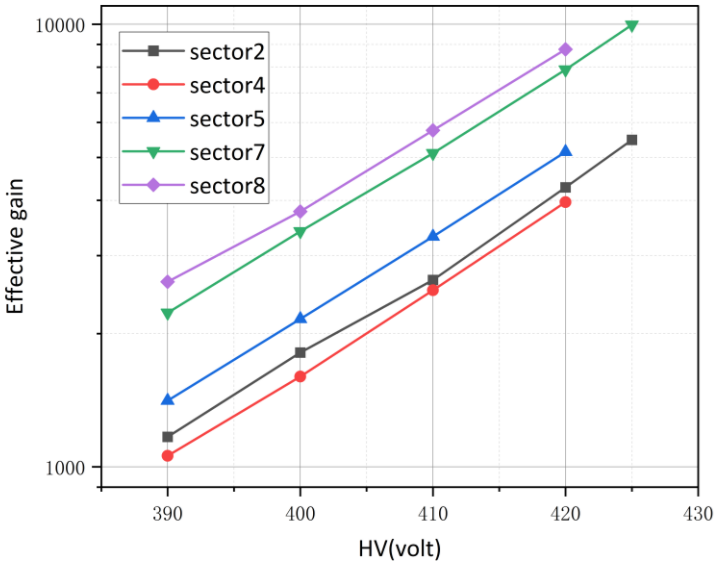
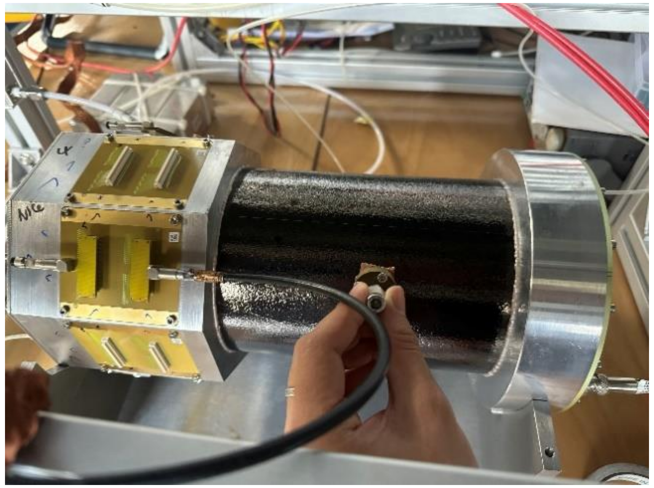
Gain and energy spectrum measurement

Setup：

- Gas: Ar:iC_4H_{10}/95:5
- Source: ^{55}Fe
- Readout from U strips (cathode)
- V strips are grounded
- Ortec142AH/671 + MCA
- Gain measured by signal amplitude spectrum





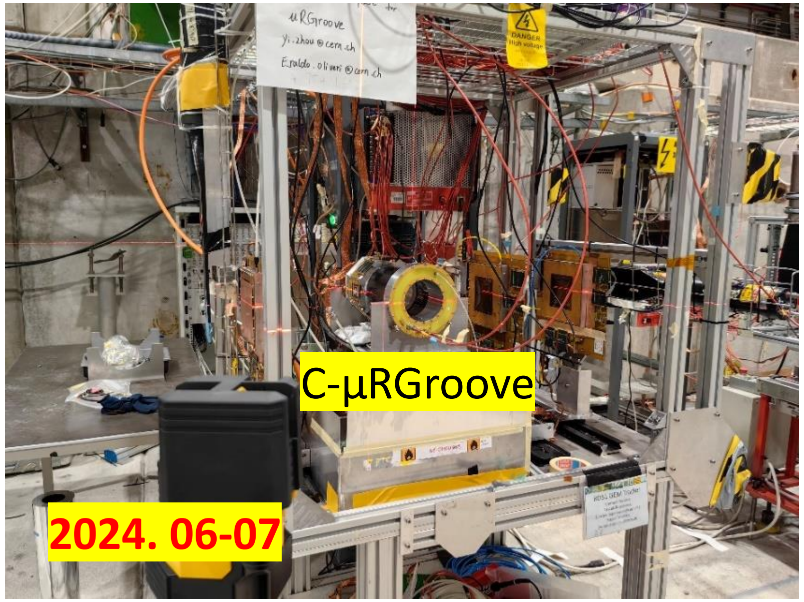


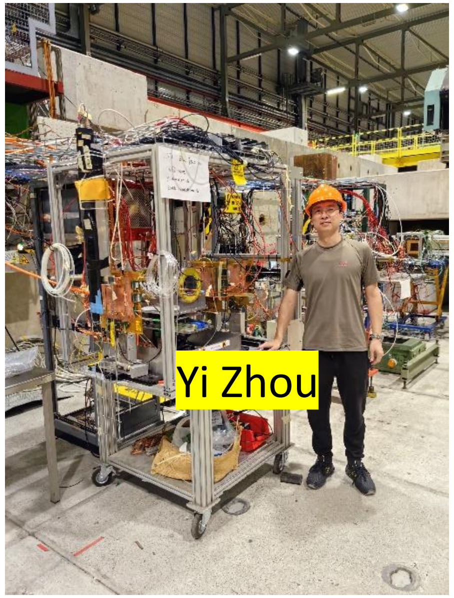
- ✓ Energy resolution: ~26%;
- ✓ Effective gain: 4000~10000;
- ✓ Similar signal amplitude on X&V readout strips;
- ✓ Good stability if the humidity can keep low enough;
- × 3 sectors not work (8 sectors in total);
- × Bad gain uniformity, caused by the gas(flow);

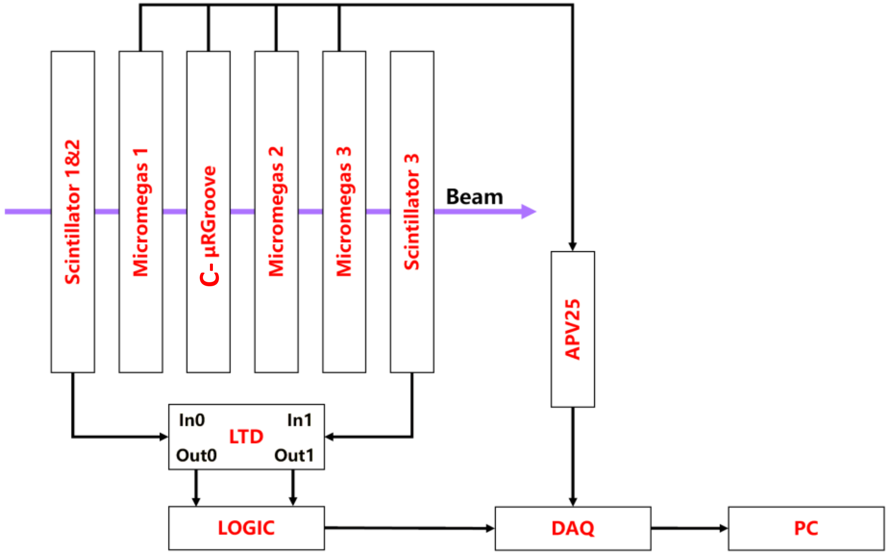
Beam test

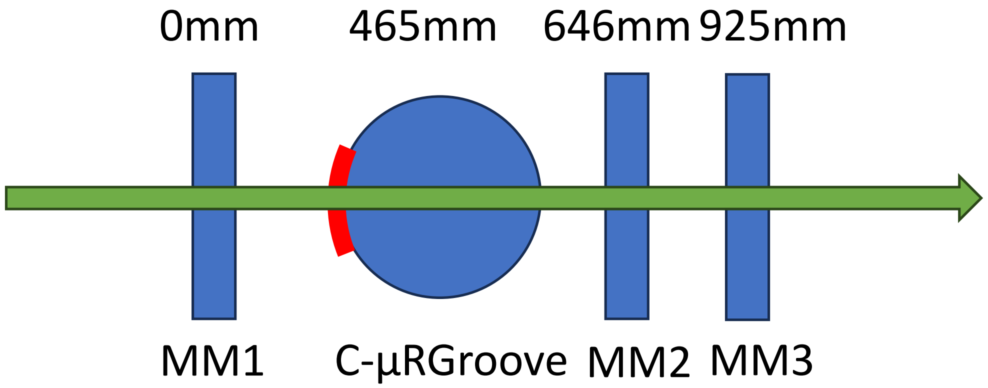
Setup:

- 150GeV/C muon
- Gas: Ar:CF_4:CO_2/45:40:15
- Readout from U strips (top cooper of µRGroove)
- V strips are grounded
- 3 micromegas trackers
- APV25+SRS+mmDAQ



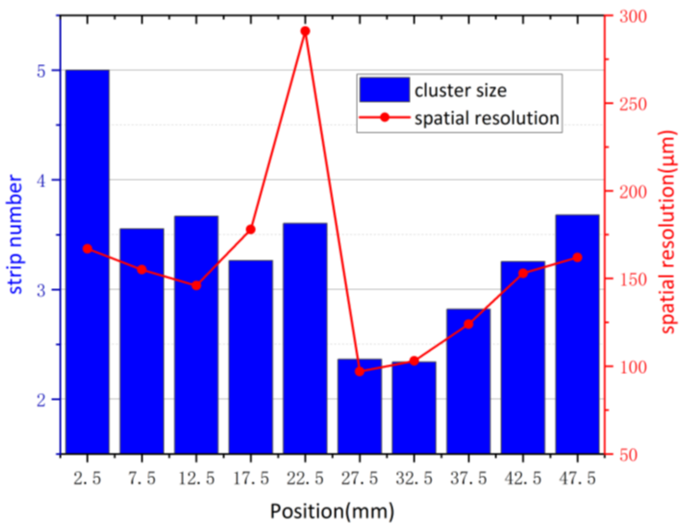


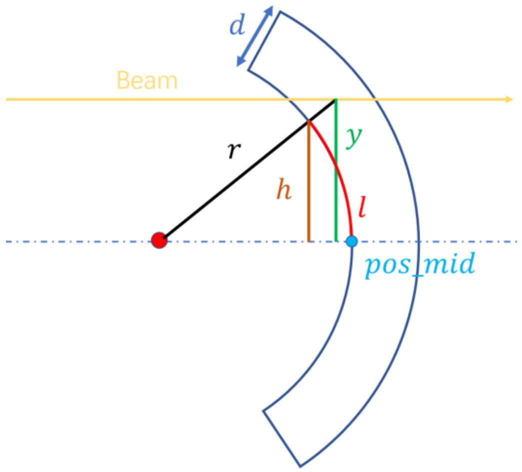




Detection efficiency and spatial resolution

- **Charge Center of gravity(CC) for perpendicular tracks**

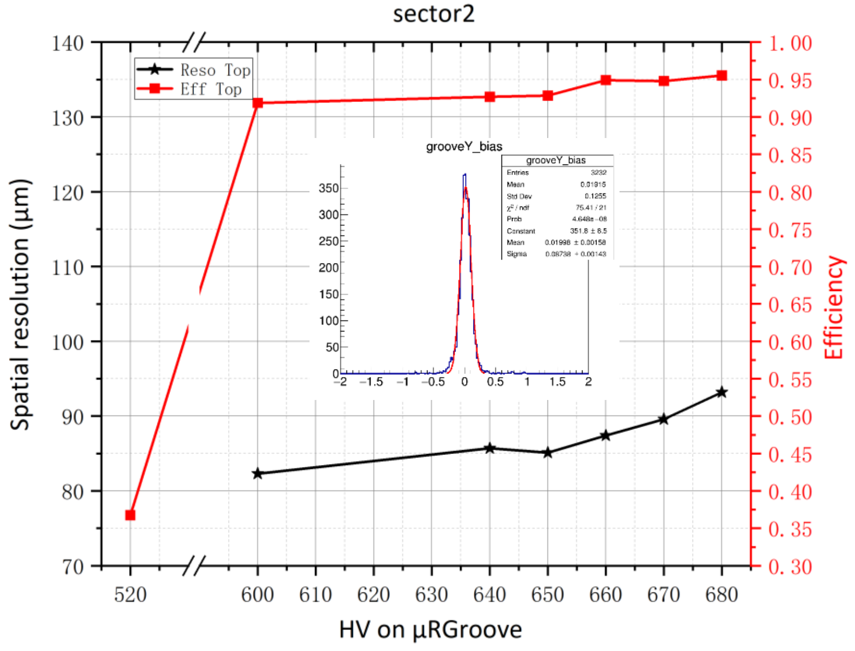




$$y = \left(r + \frac{d}{2}\right) \times \sin\frac{l}{r} + pos\_mid$$

l : reconstructed position
y: truth hit position
pos_mid: middle point

After correction

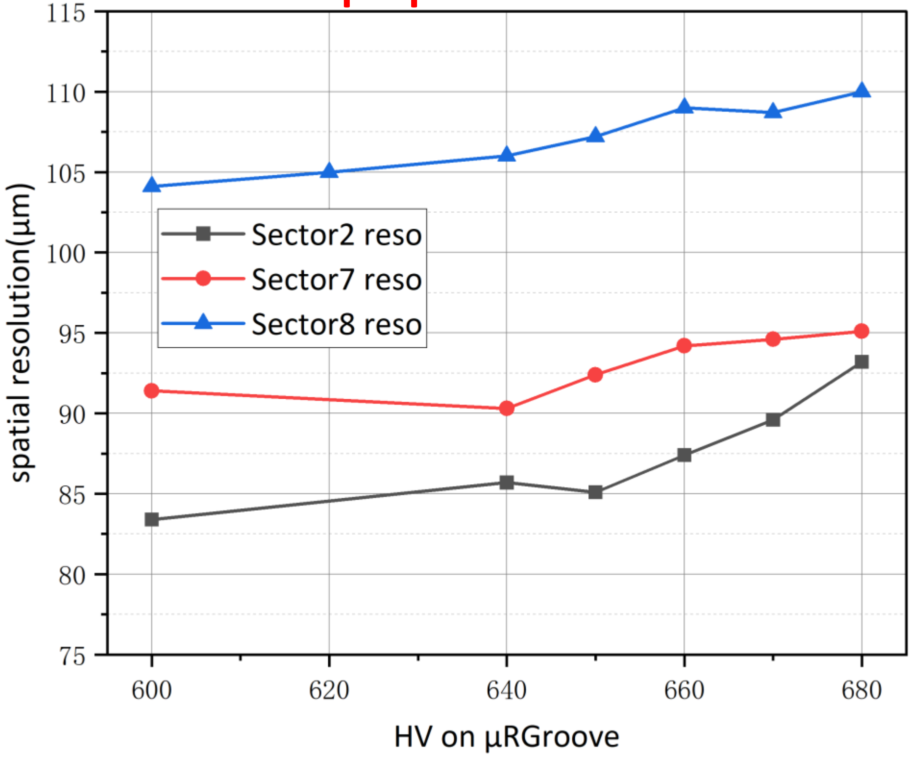


- ✓ Find the middle area.
- ✓ Alignment and rotation correction
- ✓ Position correction of circular surface
- X **Wrinkles may degrade spatial resolution**

- ✓ **Spatial resolution for perpendicular tracks: 83~93μm.**
- ✓ **Detection efficiency >95%.**

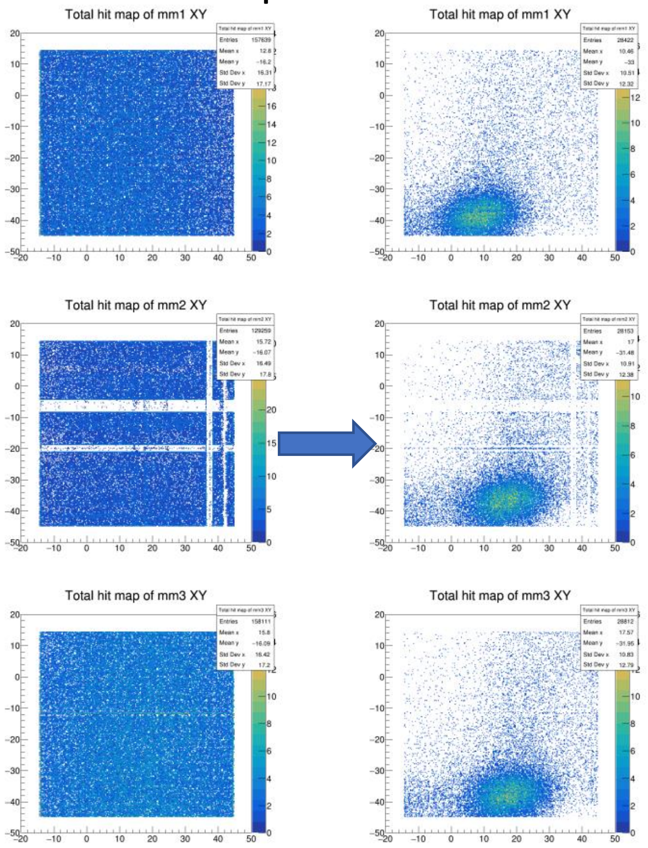
Uniformity issues and A pion test

For perpendicular tracks

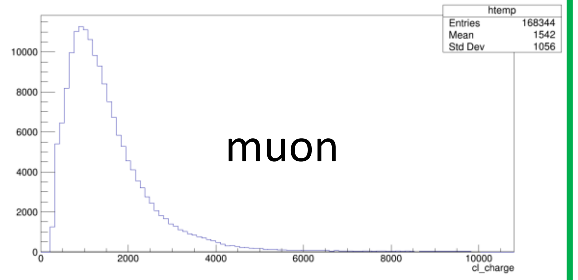


X Uniformity issues for different sectors

Hit map of trackers

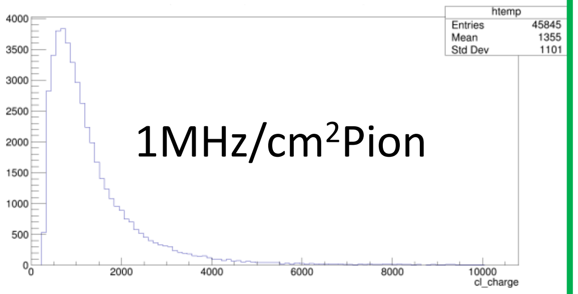


muon | $1MHz/cm^2$Pion



muon

Charge of C-μRGroove

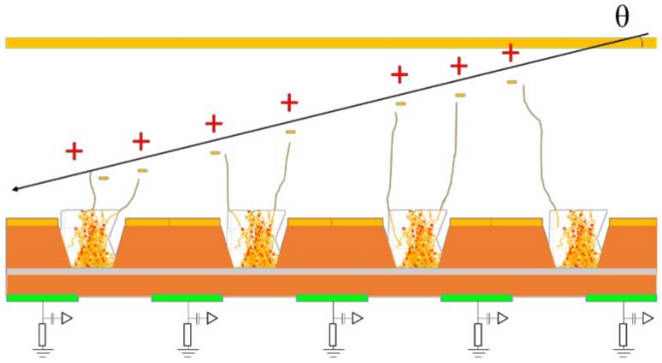


$1MHz/cm^2$Pion

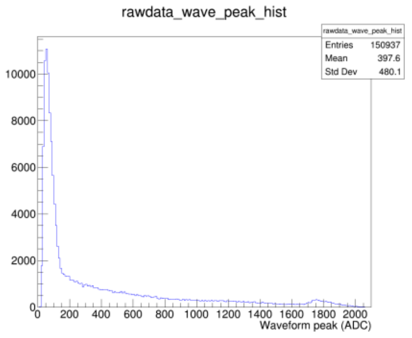
Charge: 1542->1355

Drop ~12%

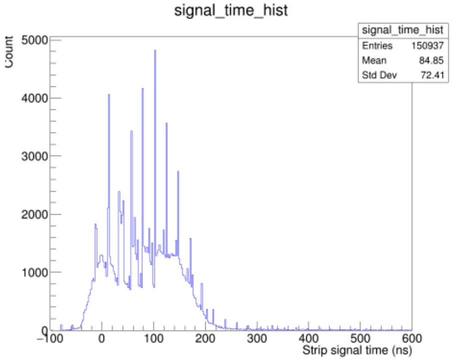
First result of micro-TPC



- μTPC
  - Alignment &rotation cor.
  - Position correction of circular surface
  - Time walk correction
  - Drift time correction

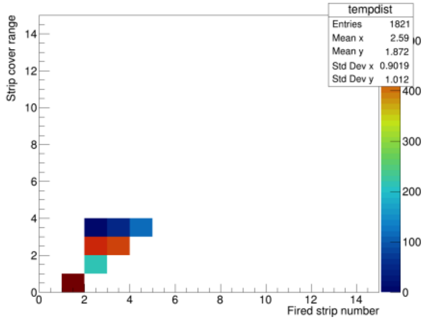


Amplitude(adc) distribution

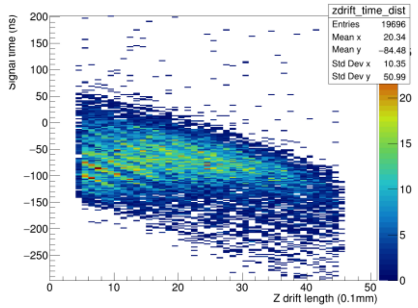


Signal time distribution

20deg tracks

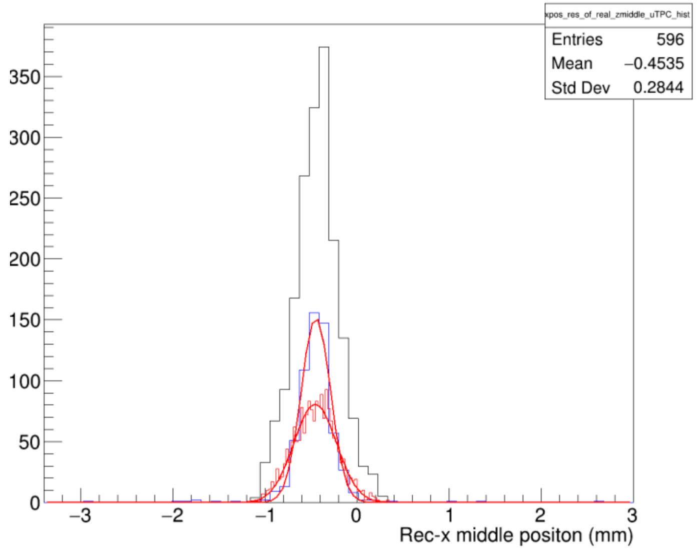


Fired strips



Relationship between time bias and drift length

X **Issues of time fitting**



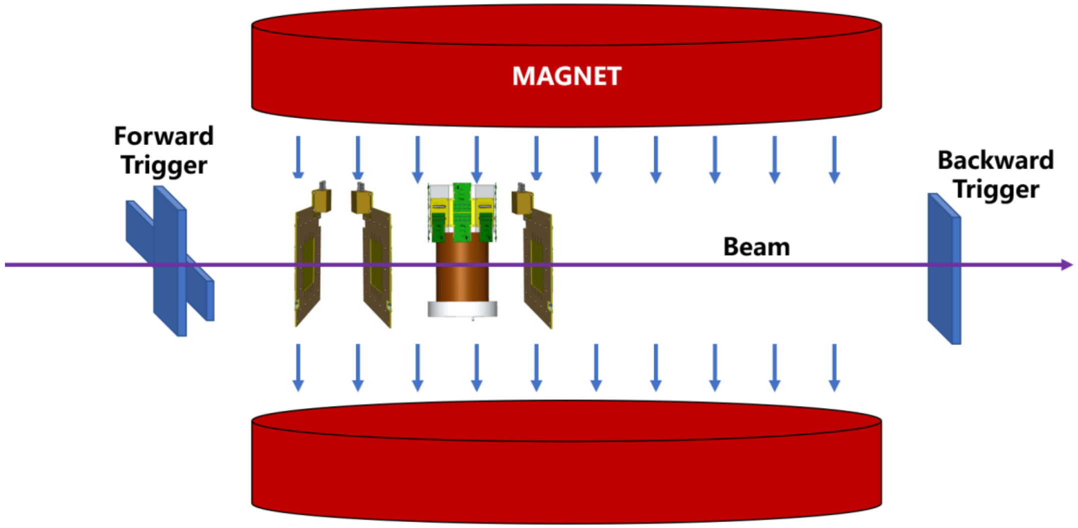
- ✓ A preliminary algorithm of μTPC has been developed
- ✓ with the incident angle is 20 °, the preliminary spatial resolution obtained by the μTPC is ~150μm.

➢ **Requires a lot of optimization**

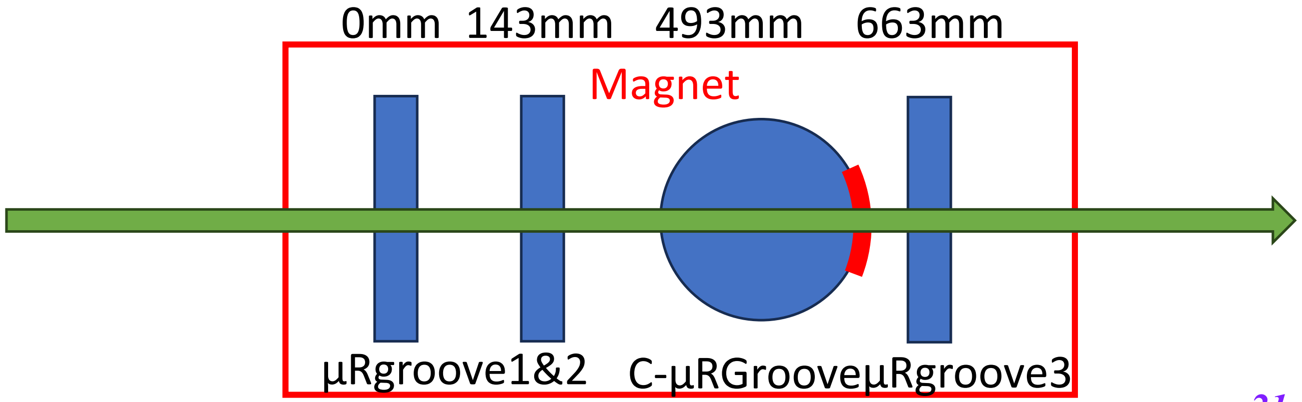
Beam test with magnetic filed

Setup：

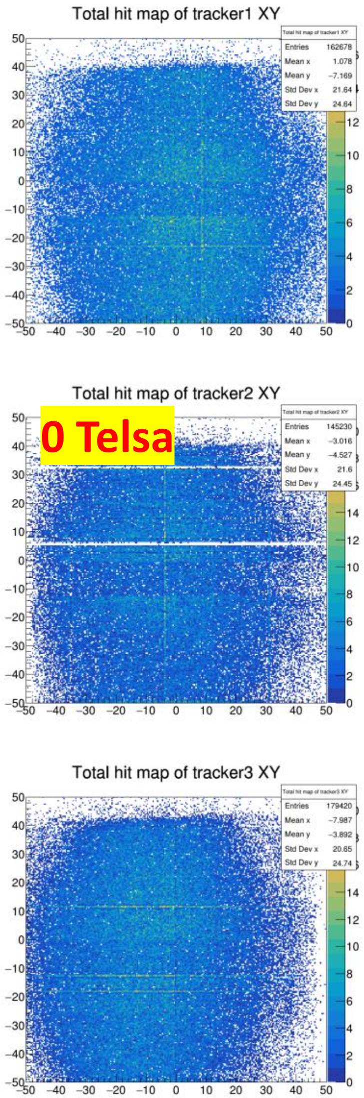
- 150GeV/c muon
- Gas: Ar:CF_4:CO_2/45:40:15
- Readout from U strips (cathode)
- V strips are grounded
- APV25+SRS+mmDAQ
- 3 μRGroove trackers
- 0.5-1.5Tesla magnetic filed



- Distance between forward and backward triggers is ~8m

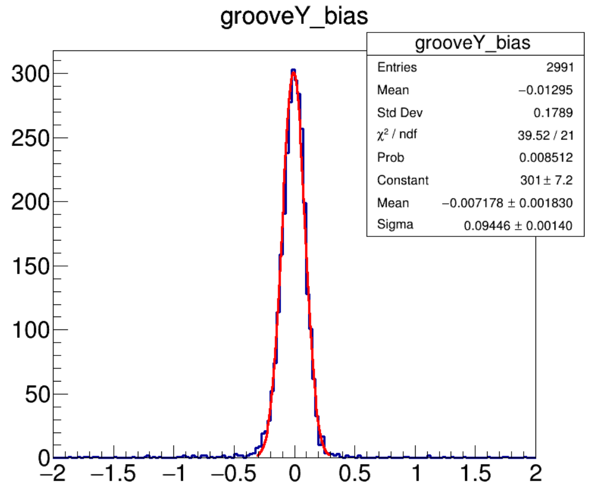


Beam test with magnetic filed



0 Telsa

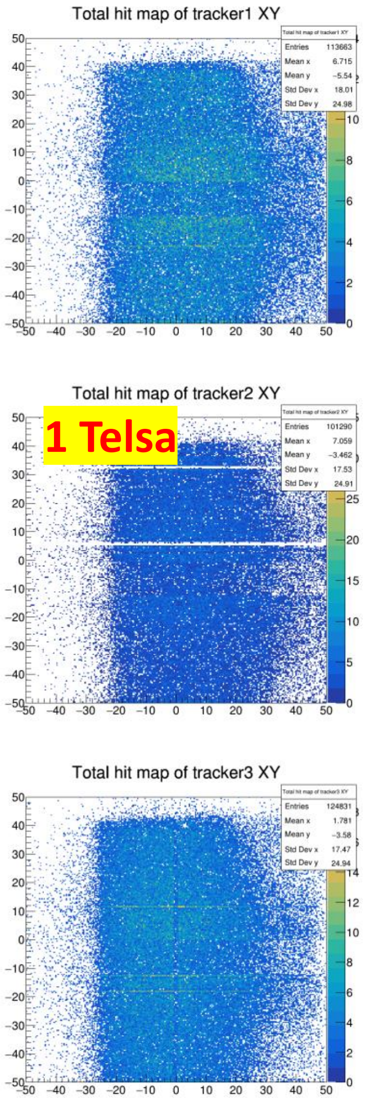
For perpendicular tracks, CC method



Spatial resolution is ~94μm as a reference @B=0T

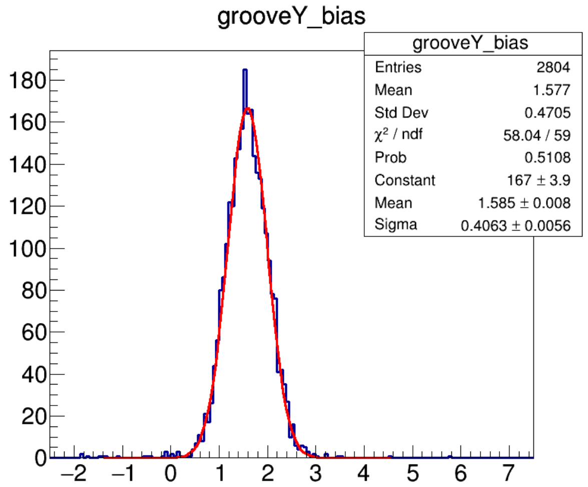
For 150GeV/c muon, $m \approx P$

$r = \frac{mv}{Bq} \approx 500m$ @B=1T



1 Telsa

For perpendicular tracks, CC method



Spatial resolution is ~400μm
Bias: ~1.592mm, sigma: ~400μm
Lorenz angle: ~17.7°

Trackers' hit map shift caused by long distance between triggers.

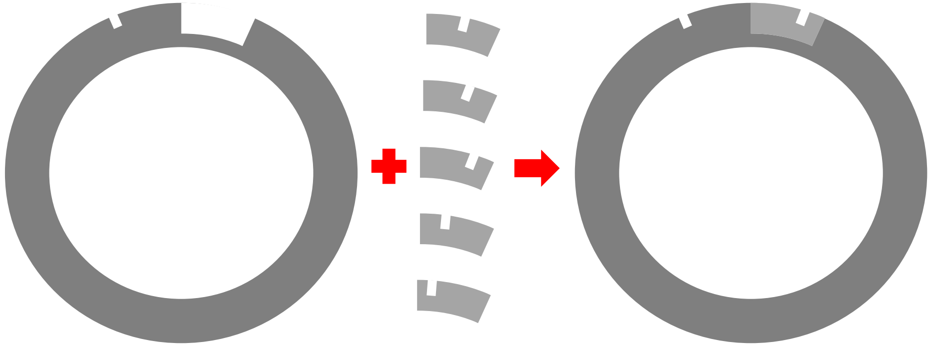
Further analysis based on μTPC needed

- Introduction
- Detector design & production
- Test result
- **Improvement plan**
- Summary & Outlook

Redesign alignment holes to reduce the wrinkling

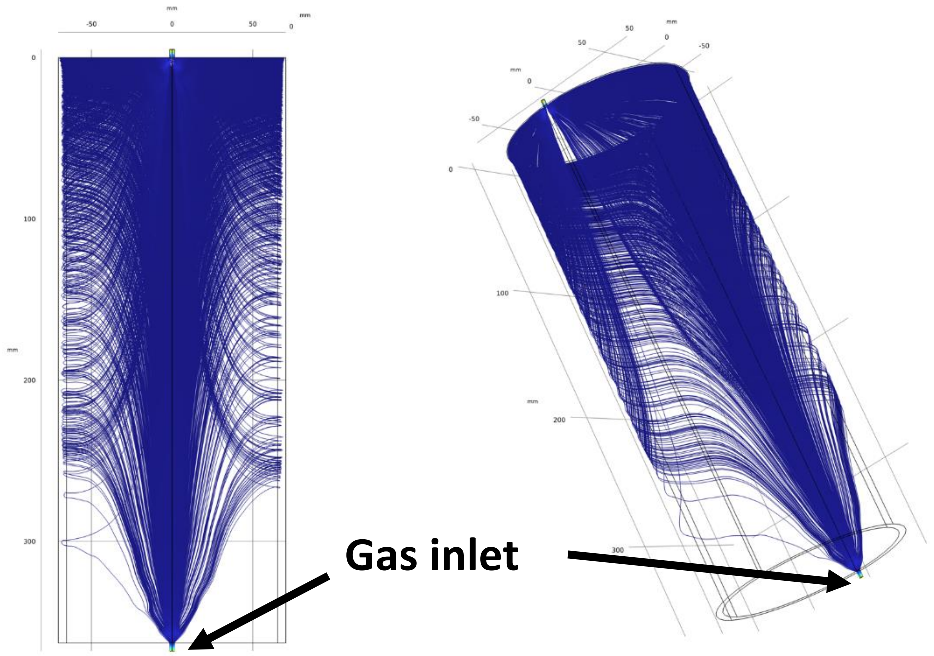
Impossible to predict the position of alignment holes

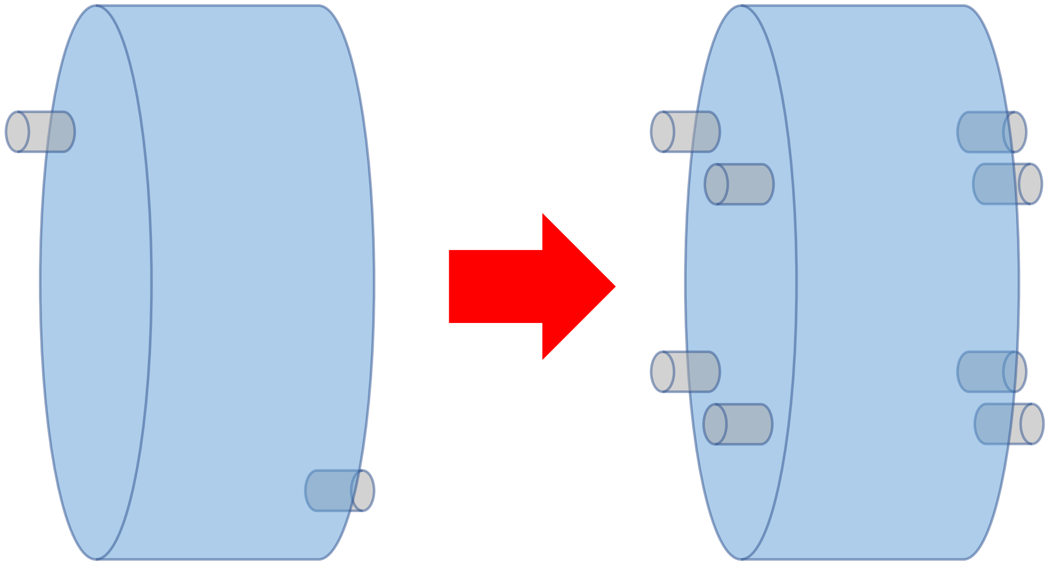
× **The fabrication tolerance of the detector parts in different batch;**
× **Alignment accuracy during the detector assembling;**
× **Tolerance of the Rohecall thickness and gluing process;**



✓ **This design can eliminate all the tolerance, we can even measure where the alignment holes should be before the foil gluing, then made the correct alignment parts.**

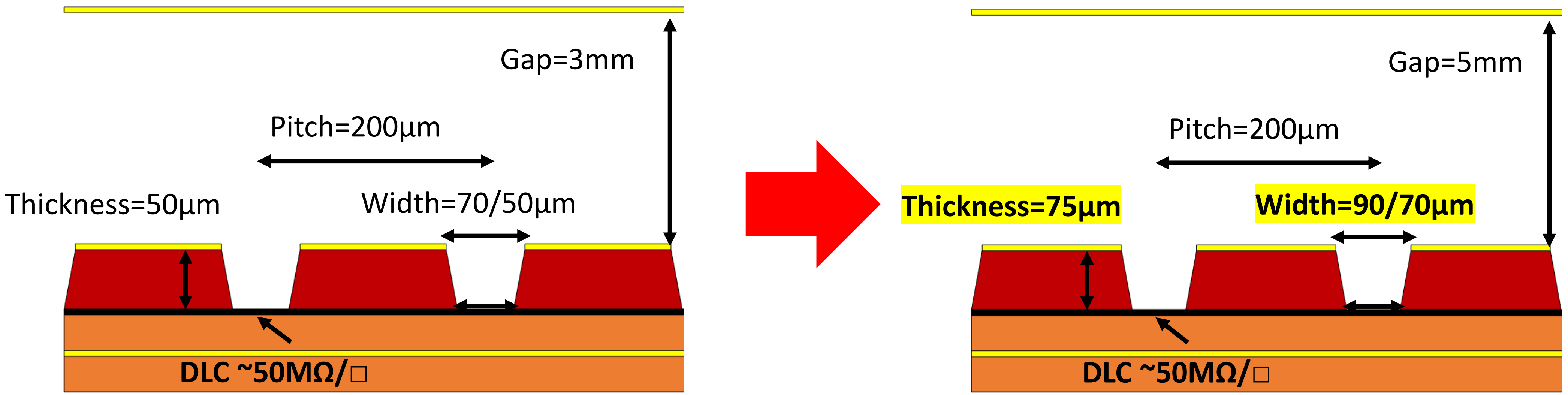
Improve the gas flow for better gain uniformity





- Gas path optimization, more gas inlets and outlets will be added to optimize the gas flow uniformity;

Optimize the geometry of the groove



- Thicker APICAL can reduce the capacitance of readout strips;
- Thicker APICAL can use larger groove width, which can reduce the capacitance of readout strips again;
- Possibility to increase induce signal amplitude under the same charge gain (this should be checked)
- Have completed the production of planar Thick-µRGroove(75µm) prototype

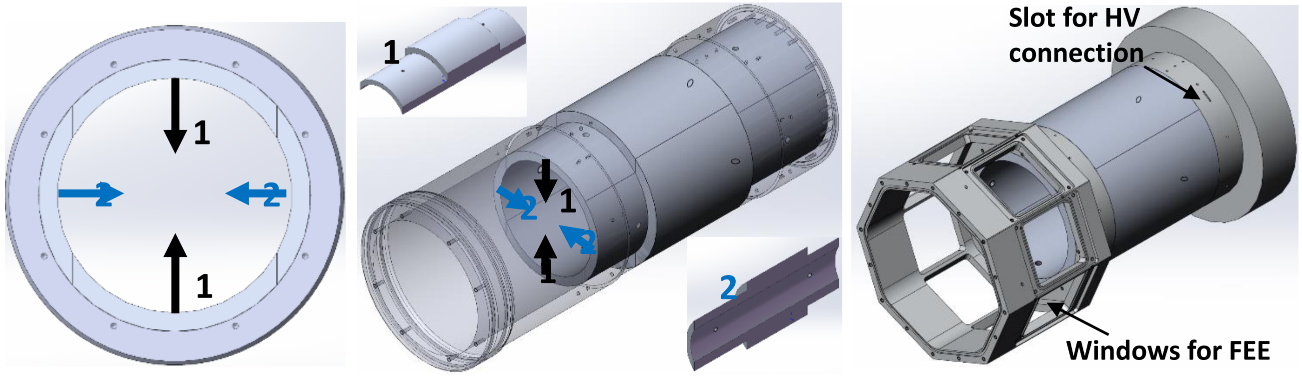
- Introduction
- Detector design & production
- Test result
- Improvement plan
- **Summary & Outlook**

Summary & Outlook

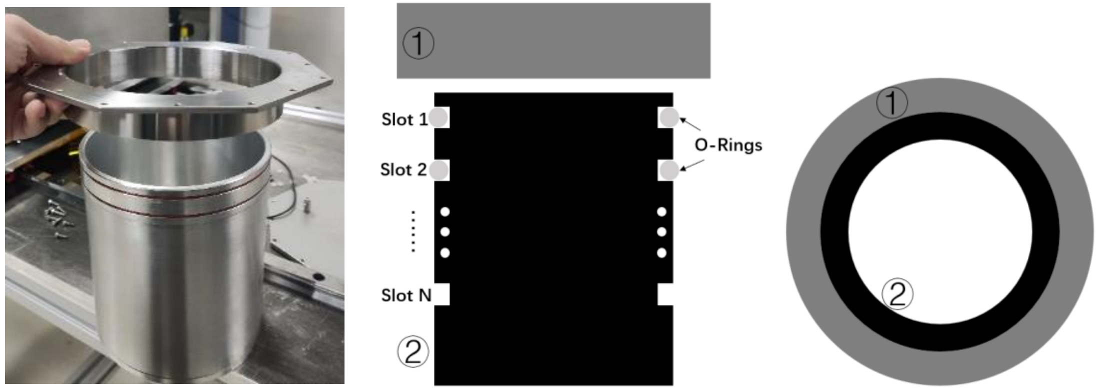
- Completed the 1st C-μRGroove prototype production and testing
- Develop the μTPC algorithm
- Analyze beam data from tests in magnetic fields
- Make the improvements mentioned above;
- Completed a 10cm×10cm prototype with 75μm APICAL, and will check if we can get larger induce signal under the same charge gain;

Thanks to Rui and his team, for their help on detector design and manufacture, All Partners at SPS-H4 for their great help during the beam test !!!

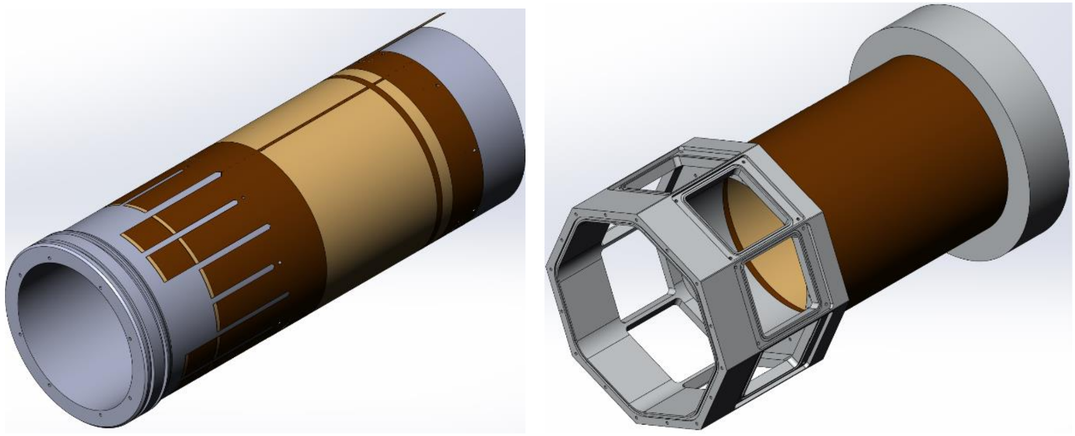
Mechanical design



Aluminum Cylindrical molds



Dynamic sealing



Cylinders after electrodes gluing

- The cylindrical molds consists of 4 pieces;
- After electrodes gluing, piece1 can be removed vertically, then piece2 can be removed horizontally.
- 8 windows on FEE sleeve used for adaptor assembling
- A slot on HV sleeve used for the HV connection
- Dynamic sealing insure detector detachable

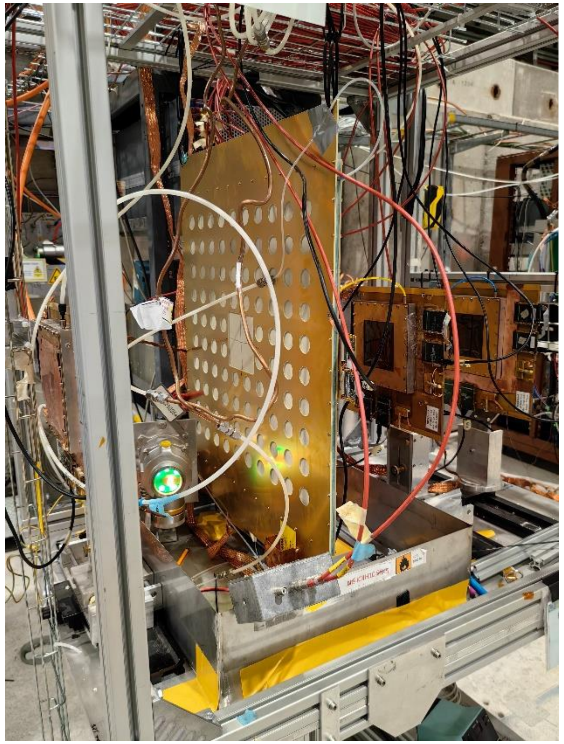
Background Rate

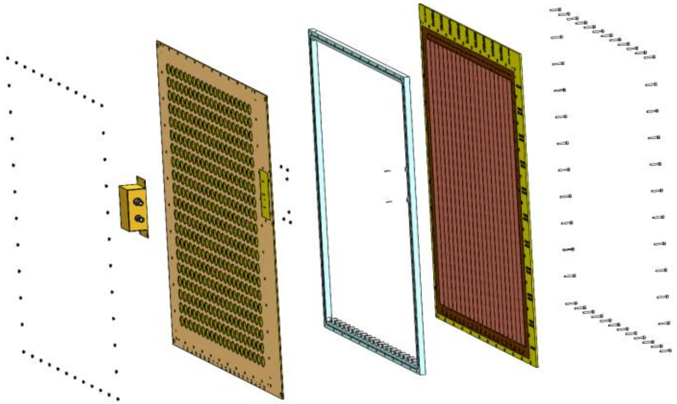
Table 3.6 GEANT4 simulated TID and NIEL in the STCF subdetectors. The numbers are given as the maximum values along the beam direction for each subdetector. For the inner tracker, the results are given for two different design options, the silicon pixel-based and the μRWELL-based designs.

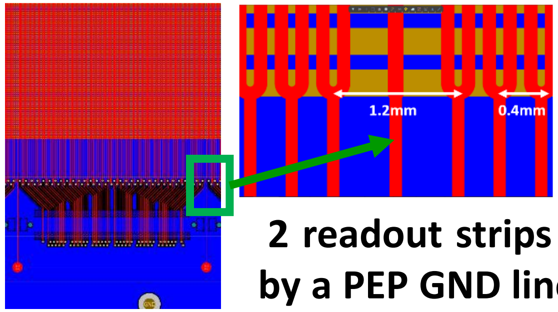
Detector	Highest TID value per pixel (Gy/y)	Highest NIEL damage per pixel (1 MeV neutron·cm^{-2}·y^{-1})	Highest count rate per channel (Hz/channel)
Silicon-inner-1	3490	1.75×10^{11}	2.61×10^{2}
Silicon-inner-2	320	3.72×10^{10}	2.74×10^{1}
Silicon-inner-3	150	2.68×10^{10}	8.51×10^{0}
μRWELL-inner-1	118	1.12×10^{10}	3.35×10^{5}
μRWELL-inner-2	61.8	1.46×10^{10}	1.63×10^{5}
μRWELL-inner-3	38.6	5.67×10^{10}	1.61×10^{5}
MDC	60.5	4.87×10^{10}	4.00×10^{5}
PID-Barrel (RICH)	4.25	1.07×10^{10}	3.3×10^{3}
PID-Endcap (DTOF)	44.3	1.98×10^{10}	1.20×10^{5}
EMC-Barrel	21.1	1.76×10^{10}	9.00×10^{5}
EMC-Endcap	45.1	1.88×10^{10}	1.50×10^{6}
MUD-Barrel-RPC	0.093	3.74×10^{11}	1.76×10^{3}
MUD-Barrel-Scintillator	0.047	4.88×10^{11}	1.15×10^{3}
MUD-Endcap-RPC	0.37	1.22×10^{10}	2.83×10^{4}
MUD-Endcap-Scintillator	0.24	2.79×10^{12}	9.8×10^{4}

- Rate： **~26.8kHz/ cm^2**
- Event rate: **~400kHz/channel**

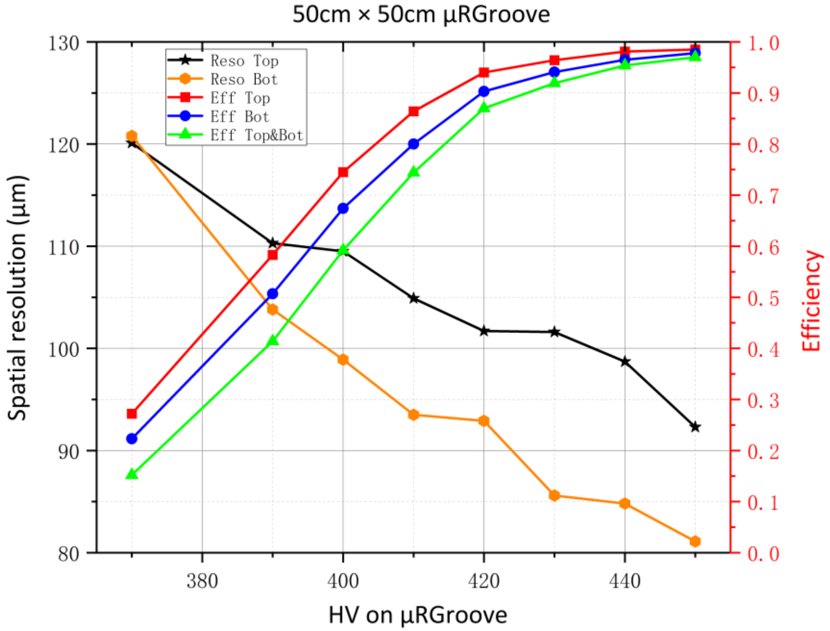
50cm×50cm 2D-μRGroove







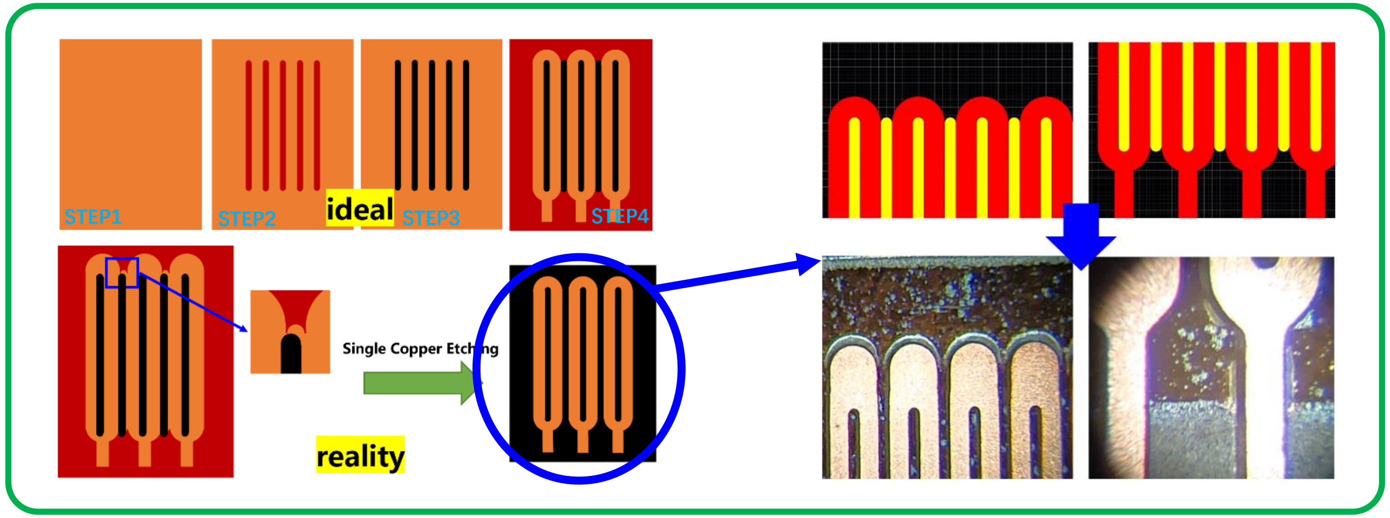
2 readout strips are replaced by a PEP GND line in each 128 readout strips;



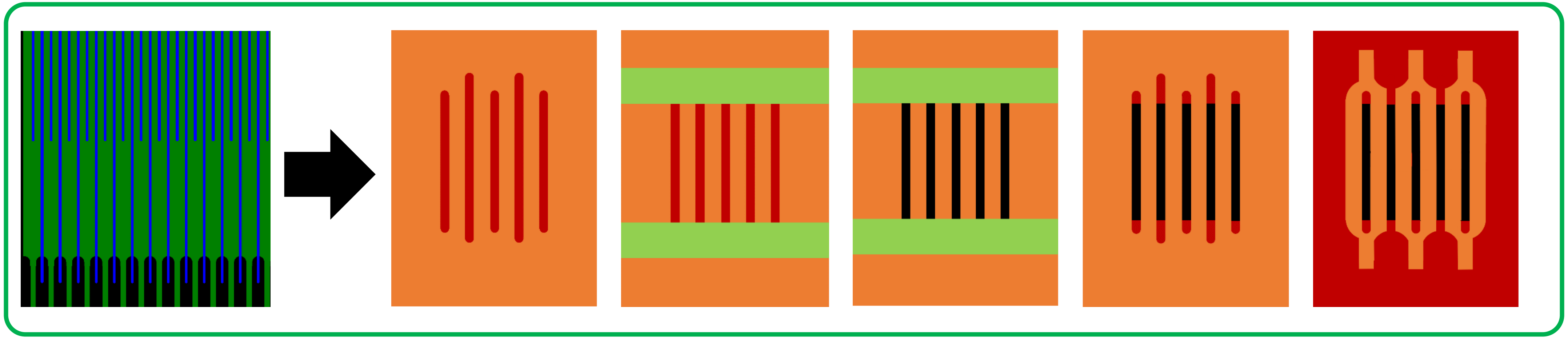
- **The central 10cm×10cm area is connected to the electronic system for testing with the rest readout strips grounded**

Dead Area (TOP): 2/128=1.5625%

Etching APICAL only inside groove



- Old design of the groove will cause alignment problems during the 2nd copper etching process;
- Only one copper etching, all the APICAL without copper clad in active area on was removed ;
- Maximum HV was reduced about 50V in air (670V→620V);



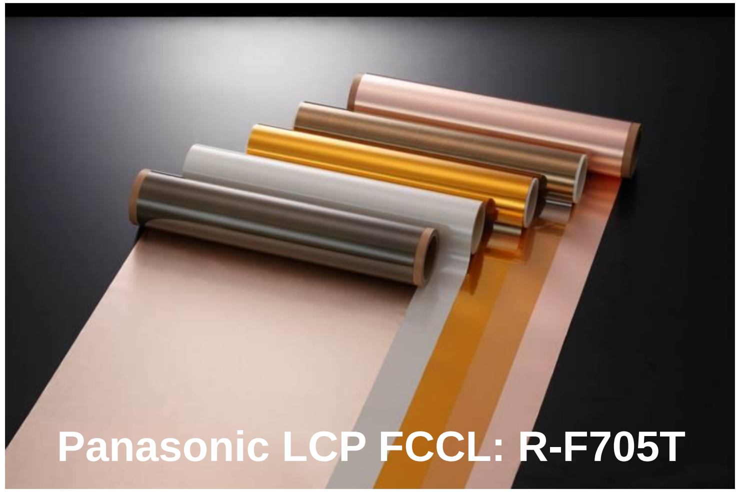
Increase the hydrophobicity of the detector

Table 2
Typical mechanical, thermal, and hygroscopic properties of LCP and polyimide provided by SciEnergy Co., Ltd.

	LCP	Polyimide	Note
Tensile strength (MPa)	200	274	
Tensile elongation (%)	40	57	
Tensile modulus (MPa)	2900	4606	
CTE (ppm/K)	20	20	
Thermal conductivity (W/m K)	0.5	0.2	
Water absorption (%)	0.04	3.2	24 h in water
Moisture absorption (%)	≤ 0.04	1.5	24 h in 50%RH at 25 °C
CHE (ppm/%RH)	1	28	

CTE: coefficient of thermal expansion; RH: relative humidity; CHE: coefficient of hydroscopic expansion.

T.Tamagawa et, al, NIMA, 608 (2009) 390-396



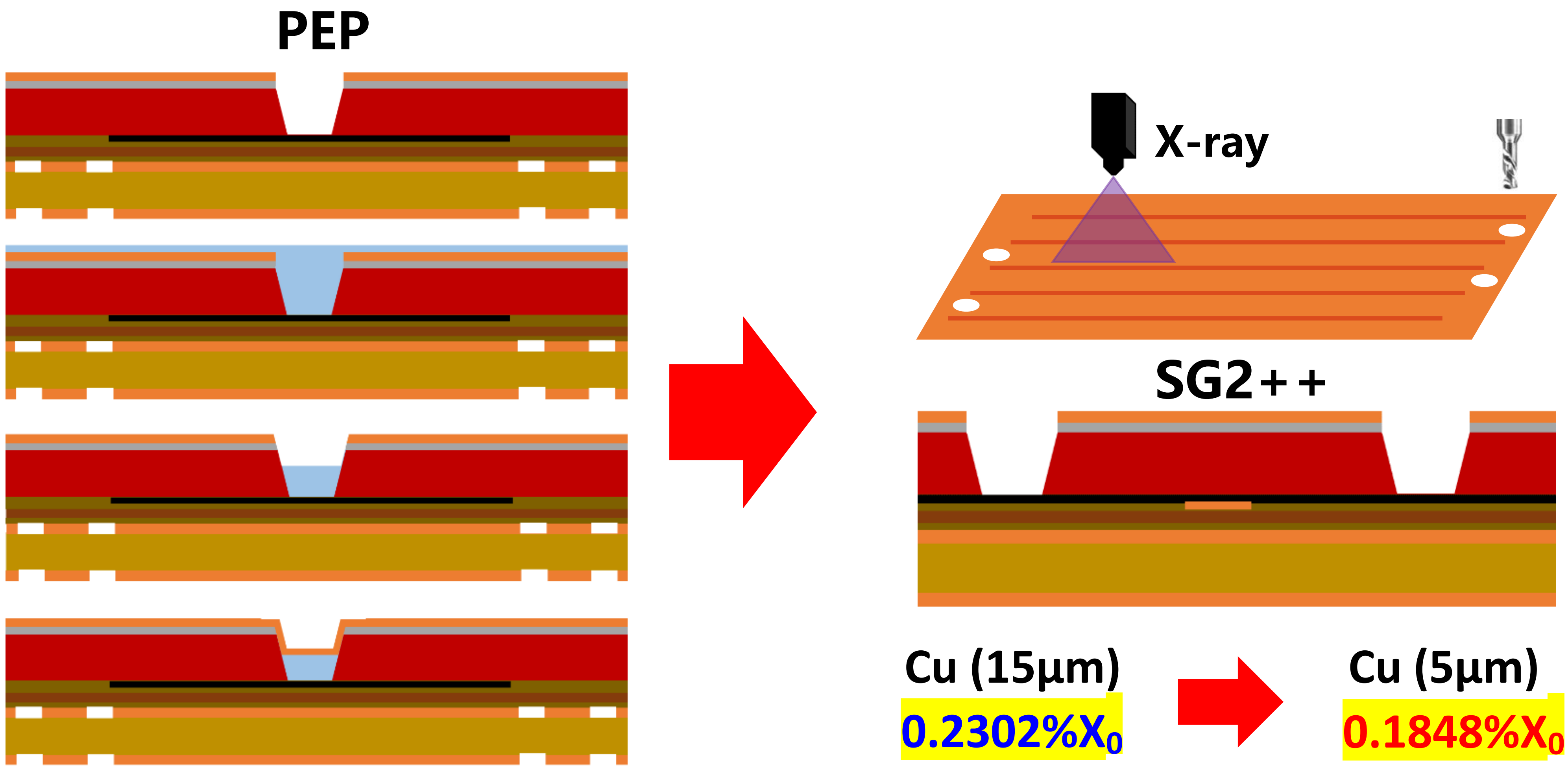
4-5. "R-F705T" General Properties

Examination item	conditions	Unit	R-F705T LCP50μm Cu 12um				Test method
			ED	New ED	RA	New RA	
Tensile Modulus	A	GPa	3.4				IPC-TM-650
Surface resistance	A	Ω	4.9E+14				JIS C6471
Specific inductive capacity	A 2GHz	-	3.0				IPC-TM650 Method2.5.5.5
	A 10GHz		3.0				
Dielectric dissipation factor	A 2GHz	-	0.0008				IPC-TM650 Method2.5.5.5
	A 10GHz		0.0016				
Transmission Loss	A 10GHz	dB/10cm	2.00	2.10	2.74	2.12	※Slide 4-3 (P10)
Water absorption	25℃ 50h immersion	%	0.04				-
Peel intensity	A	N/mm	1.0	0.8	0.7	0.7	IPC-TM-650
	260℃ solder 5 sec						
Fire retardancy (the UL method)	A, and E-168/70	-	94VTM-0				-
Chemical resistance	HCl 2 mol/l 23℃ 5 min	-	With no abnormalities				JIS C6471
	NaOH 2 mol/l 23℃ 5 min						
	IPA 23 degree-C 5 min						
Solder heat resistance	Solder float 10sec.	℃	288				In-company method
Moisture absorption solder heat resistance	C-96/ 40/90 260℃ solder 1min float	-	With no abnormalities				
CTE	CTE-x,CTE-y (RT-180℃)	ppm/Celsius	19、18				In-company method (TMA)
	CTE-z (RT-150℃)	ppm/Celsius	209				
Dimensional stability	After etching MD	%	0.007	-0.006	0.018	0.021	IPC-TM650
	After etching TD		0.008	-0.002	0.014	0.019	
	After E-0.5/150 MD		0.046	0.036	0.047	0.052	
	After E-0.5/150 TD		0.059	0.046	0.067	0.061	

＊ The above-mentioned data is actual measurement of our company, and is not a guaranteed performance.

Use 25μm LCP to replace all the 25μm Kapton, to increase the stability of the detector under high humidity environment.

Reduce the material budge of the detector



Maximum width of c-μRGroove foil is only 421.6mm, small enough to use SG2++