



Thin RPC gas gap development for ATLAS Phase-II upgrade

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Introduction

- The current ATLAS Resistive Plate Chamber (RPC) system provides the first-level muon trigger in the barrel region with $|\eta| < 1.05$.
- The RPC system has operated smoothly with an efficiency of approximately 96% for each individual gas gap during Run 1 to Run 3.
- This system requires significant upgrades to maintain low trigger momentum thresholds while keeping the trigger rates at a manageable level at the High Luminosity Large Hadron Collider.
 - One of the most important solutions is to install triplets of new-generation RPCs in the inner layer of barrel chambers (BI-RPC)
 - 130 BIL + 96 BIS + 80 BOR/BOM chambers (1 chamber = 3 singlets; 1 singlet = 1 gas gap + 2 readout panels) will be manufactured during ATLAS phase-II upgrade

Tasks undertaken and production plan

➤ Tasks undertaken by ATLAS Chinese Group (USTC-SDU-SJTU)

- 912 BIS/BIL/BOM/BOR strip panels will be produced and qualified
- 72 gas gaps will be produced and qualified
- 360 singlets assembly carried out in China
- Manufacture and test of about 5000 front-end electronic boards

➤ The production plan

- 1/3 strip panels are already produced and qualified in China, the remaining strip panels can be produced before middle 2025
- 72 BIL gas gaps to be produced in China
 - ✓ 5 RPC gas gap prototypes are produced and will be sent to CERN to do the irradiation test recently.
- BIS singlet assembly without FEE plan to start around December 2024

To fulfill this task



① Honeycomb readout panel production

② RPC gas gap production

③ Singlet assembly work



Today's topics

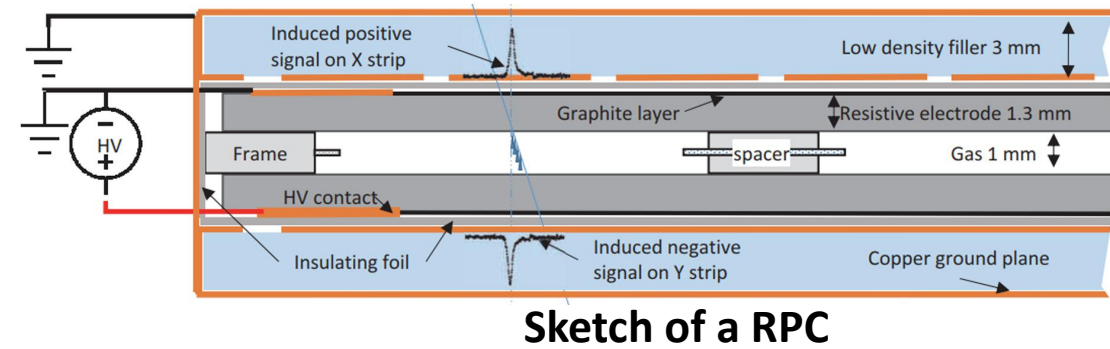
Francois's talk

RPC gas gap production

The first time to build the large area Bakelite gas gap in USTC

RPC gas gap

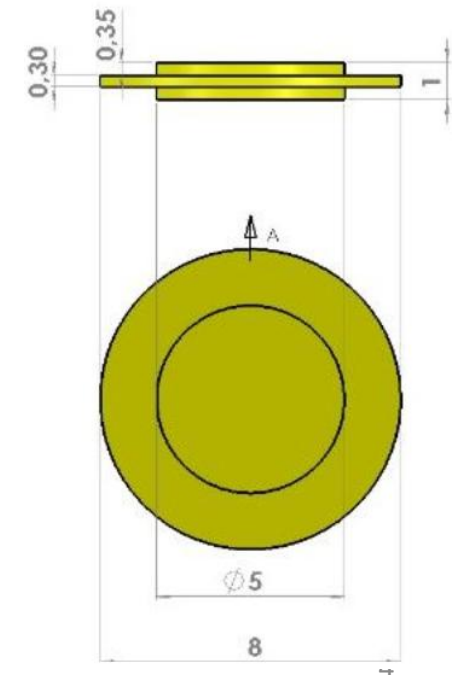
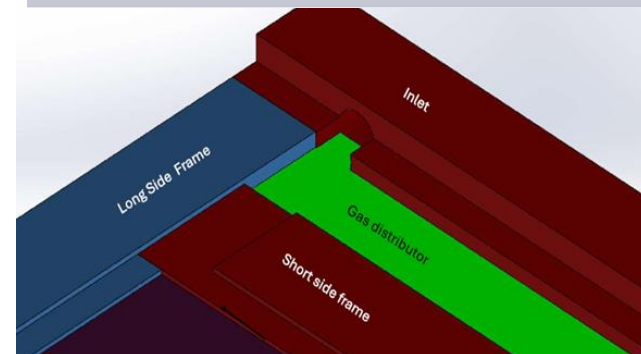
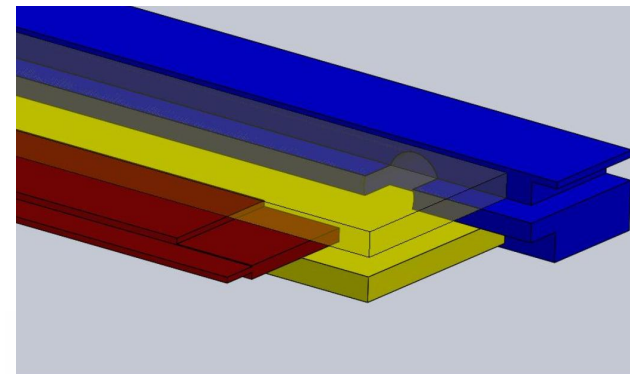
➤ RPC is defined as a device consisting of a gas gap sandwiched between two resistive plates connected to a voltage generator



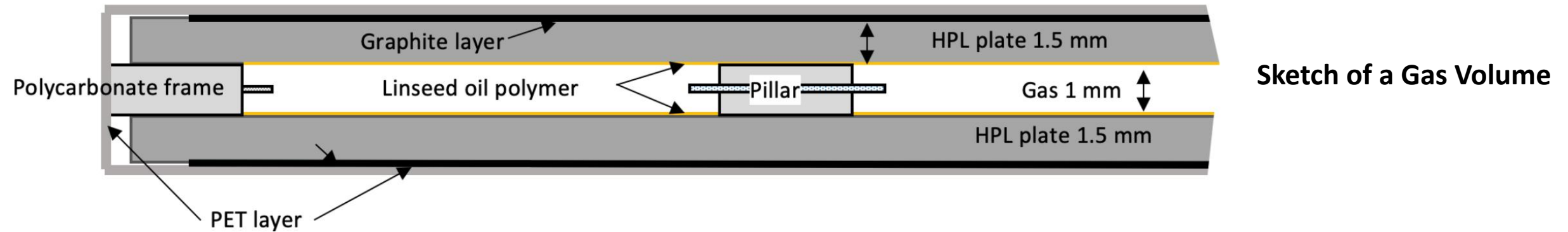
➤ RPC gas gap sandwiched between the two readout strip panels

➤ Gas gap components:

- Frames and spacers
- High Pressure Laminates plates (HPL)
- Graphite electrodes
- HV/Ground contact
- Insulating PET foil



The main difficulties to build a gas gap

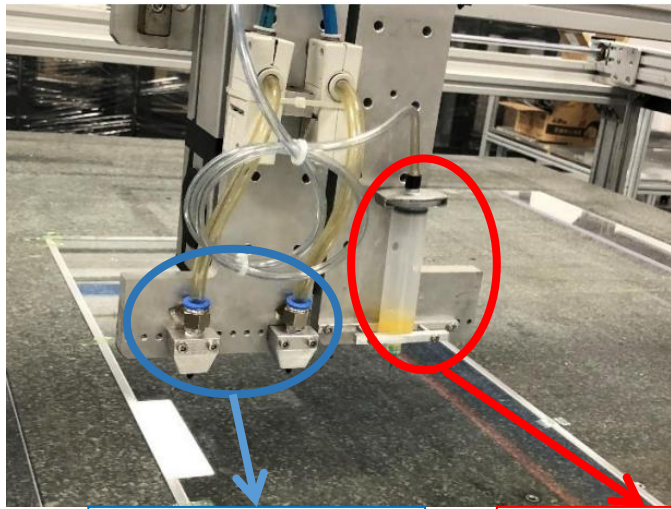


➤ The main difficulties to build a gas gap

- Graphite coating
 - ✓ Surface resistivity shall be $350 \pm 100 \text{ k}\Omega/\square$
- PET foiling (absence of bubbles $> 2\text{-}3 \text{ mm}^2$ between PET foil and graphite layer)
- Closed gas gap with good tightness and flatness
 - ✓ The flatness of the gas gap is guaranteed by spacers and frames.
- Linseed oiling
 - ✓ To improve the smoothness of the electrode surface
 - ✓ Ensure that the final linseed oil coating was thin and well polymerized.

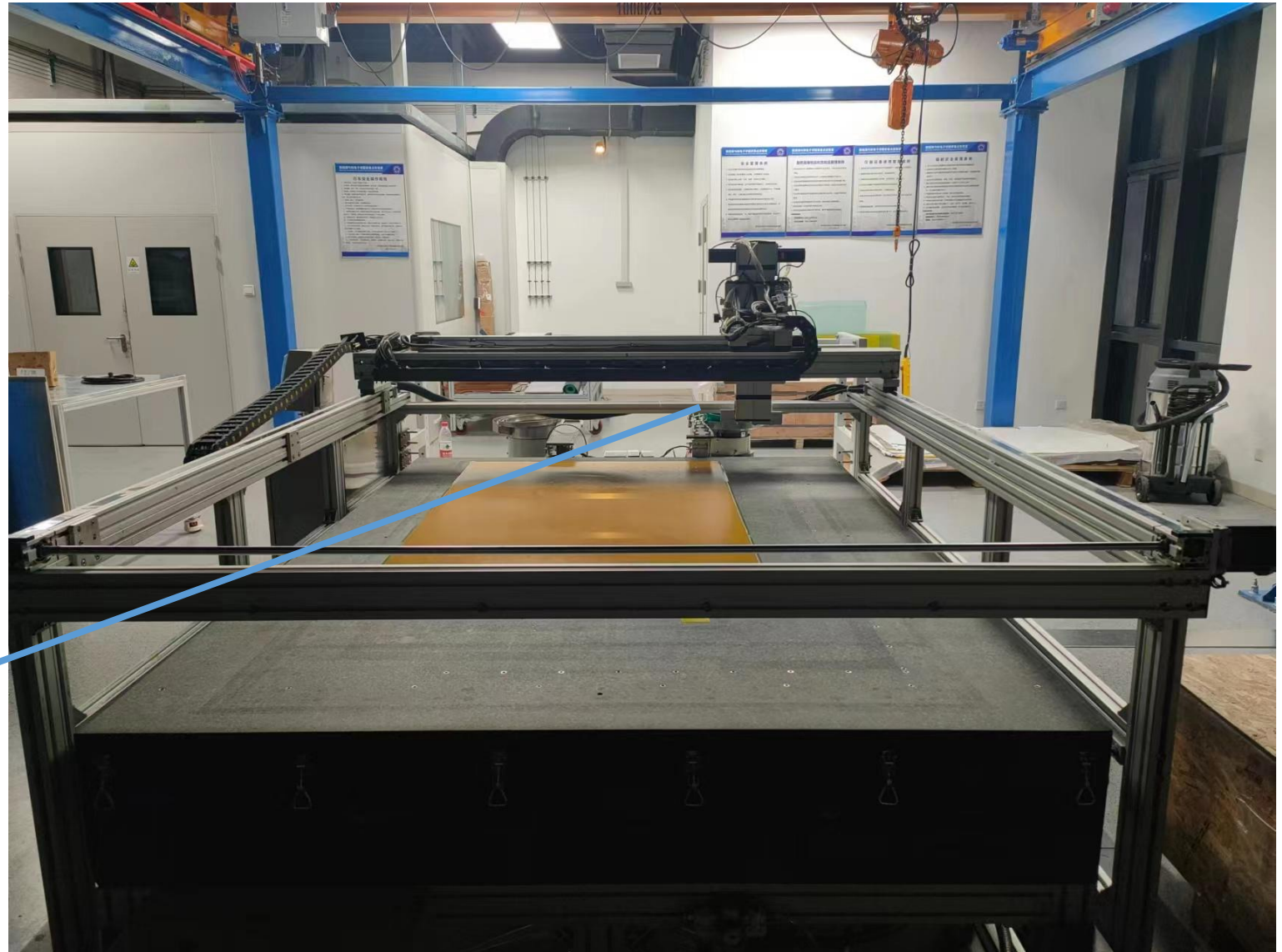
The platform of gas gap production at USTC

- A marble table as base:
2.5m × 1.8m
- Nine holes among the table are connected to the vacuum system.
- A head stock supported by a gantry moving in 2-dimentional

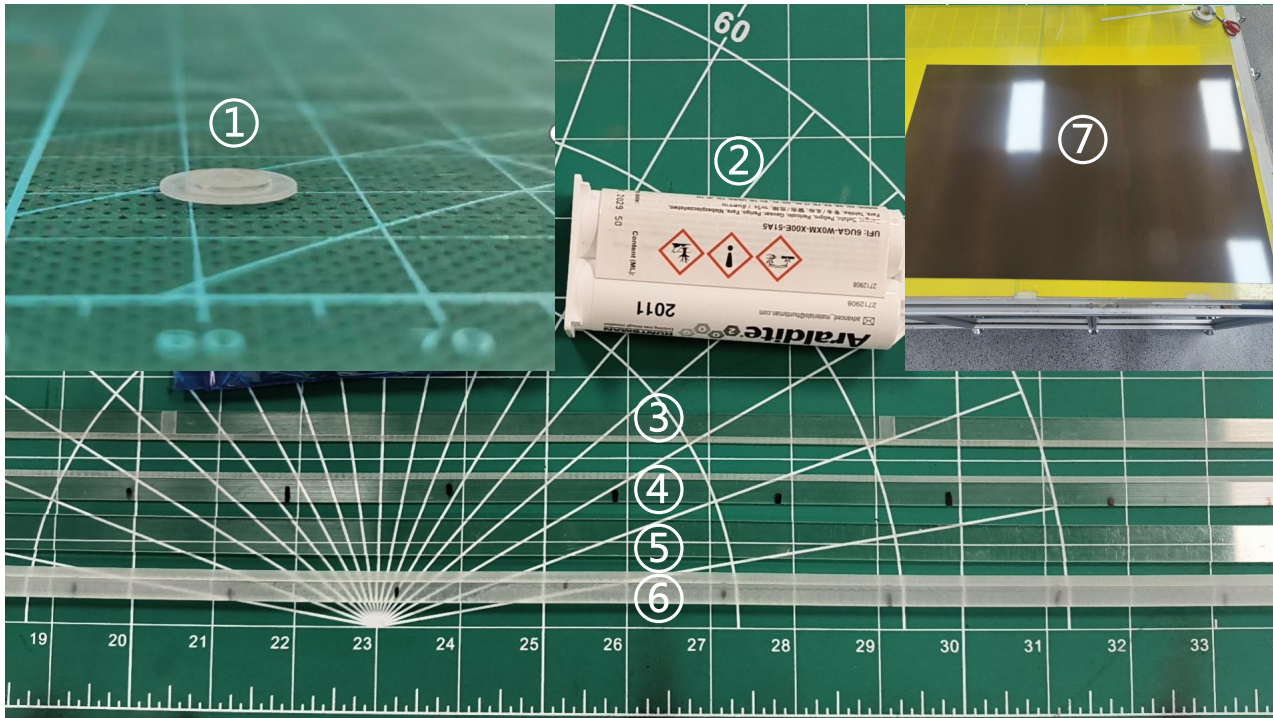
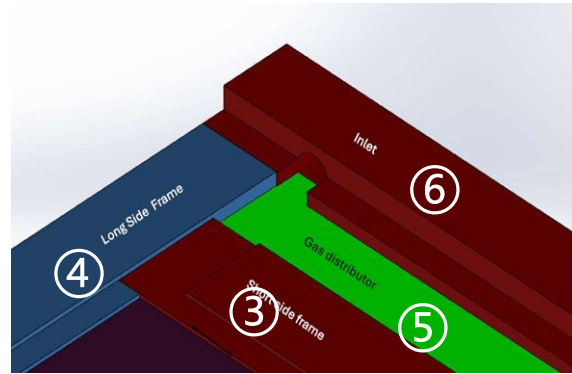
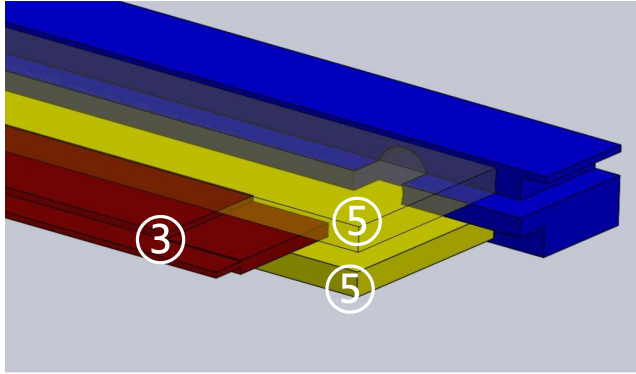


Spacer pickers

Glue syringe



Materials for the gas gap production



① Spacers:

- ✓ Thickness: 1.000 +/- 0.010 mm
- ✓ Inner/outer diameter: 5/8 mm

② Glue:

- ✓ Araldite 2011

③ Short side frame

- ✓ Size: 672 mm * 9 mm * 1 mm

④ Long side frame

- ✓ Size: 1316 mm * 9 mm * 1 mm

⑤ Roof & floor frames

- ✓ Size: 680 mm * 11 mm * 1.5 mm

⑥ Gas inlet (Lateral profile frame)

- ✓ Size: 686 mm * 8 mm * 4.5 mm

⑦ HPL plate:

- ✓ Resistivity: around $5 * 10^{10} \Omega * \text{cm}$
- ✓ Size: 1300mm * 680 mm * 1.5 mm

How to build a RPC gas gap?

➤ Two options

Step1: build the closed gas gap

Step2: conduct leak detection and repair

Step3: apply graphite coating

Step4: attach the HV/ground link

Step5: apply PET foiling

Step6: make HV contacts and seal the edges of the gas gap with hot-melt glue

Step7: glue the paper stackers

Step8: cover inner surfaces of the HPL electrodes with a linseed oil coating

Option 1

Step1: apply graphite coating

Step2: attach the HV/ground link

Step3: apply PET foiling

Step4: build the closed gas gap

Step5: conduct leak detection and repair

Step6: make HV contacts and seal the edges of the gas gap with hot-melt glue

Step7: glue the paper stackers

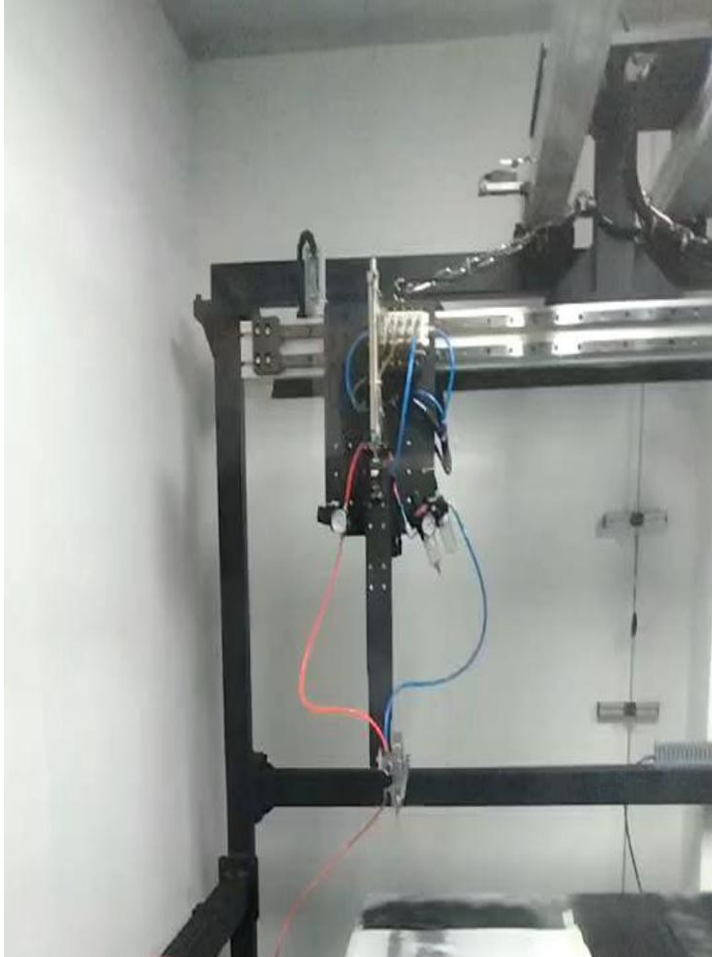
Step8: cover inner surfaces of the HPL electrodes with a linseed oil coating

Option 2

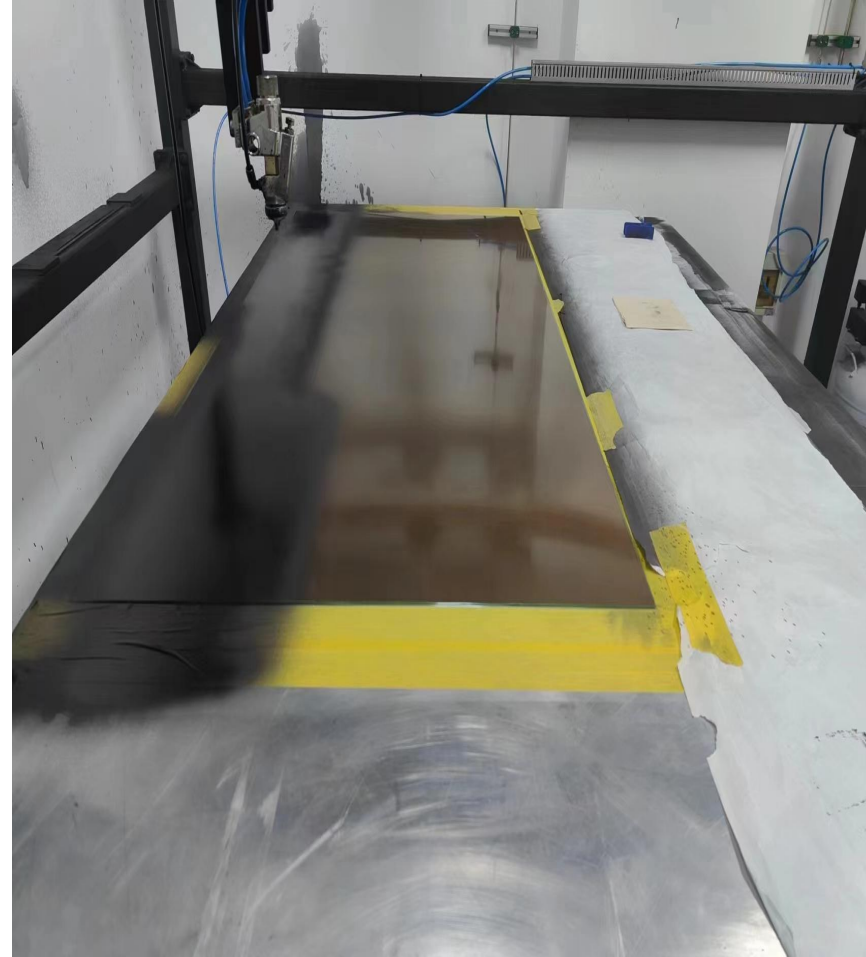


Today's topic

Graphite coating and HV & Ground link applied

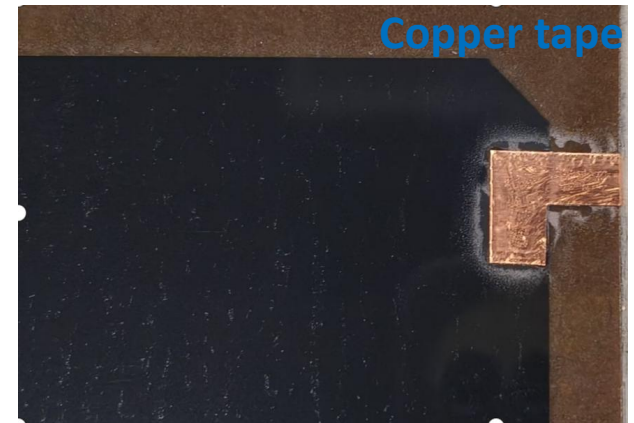
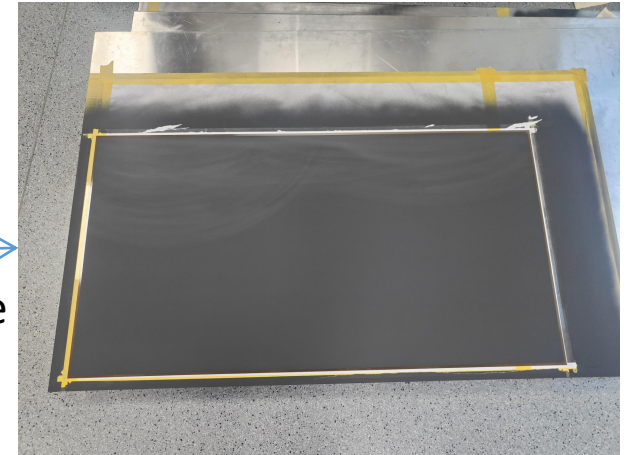


Graphite spraying system:
A spray gun held on a 2-D gantry



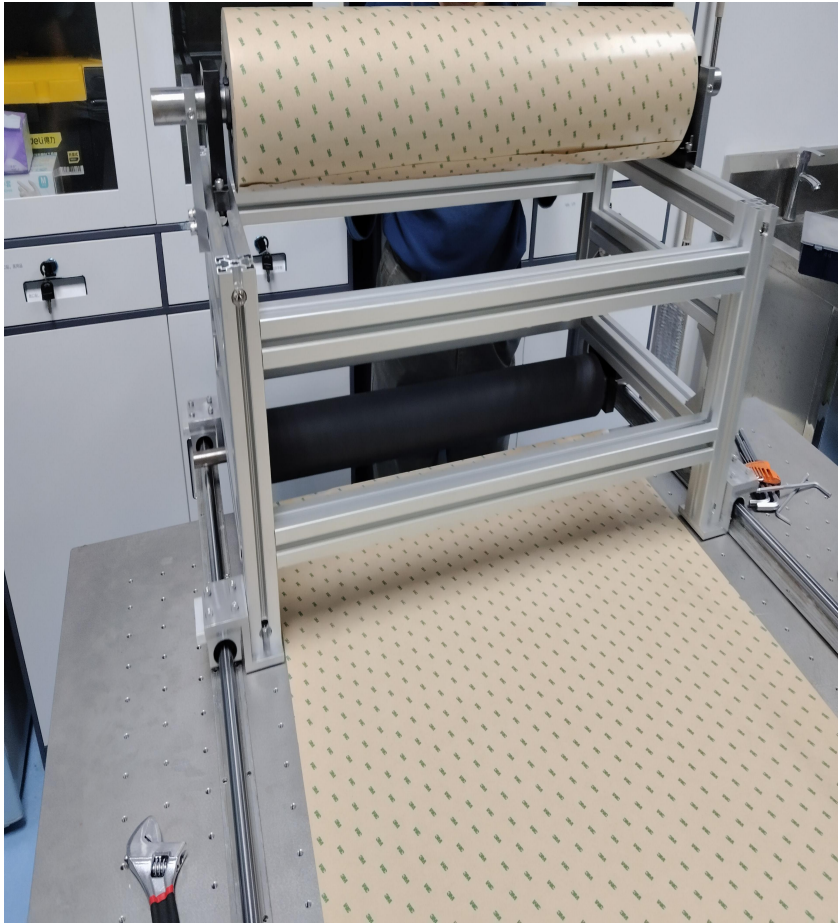
Graphite coating

Final
→
sample

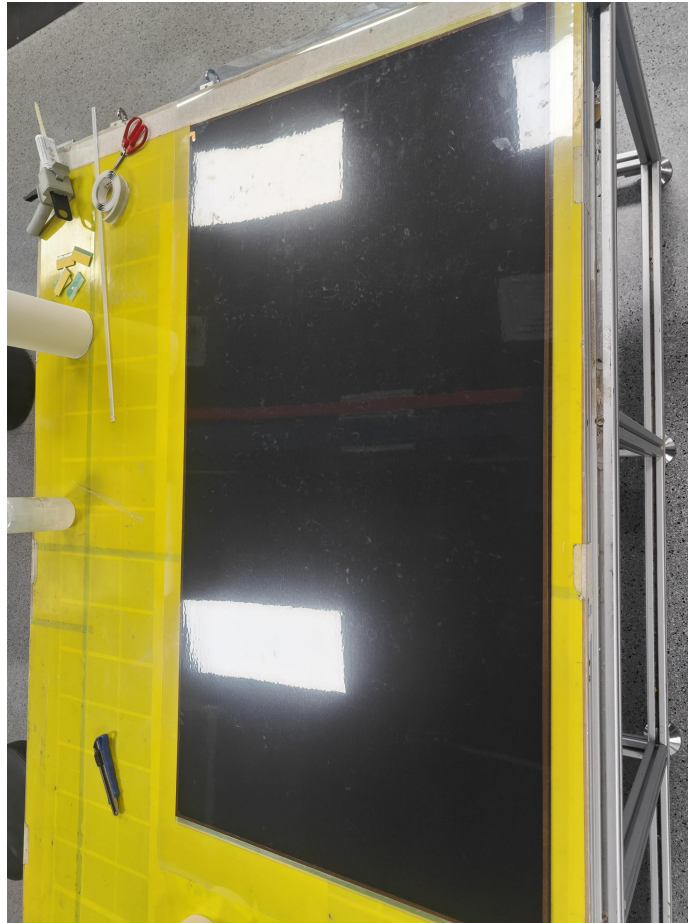


HV & Ground links applied

PET foiling



Tooling



Mirror-like surfacing

- Temporarily, we used double-side tape instead of the thermal laminating film.
- The thermal laminating film and the tool are still in preparation.

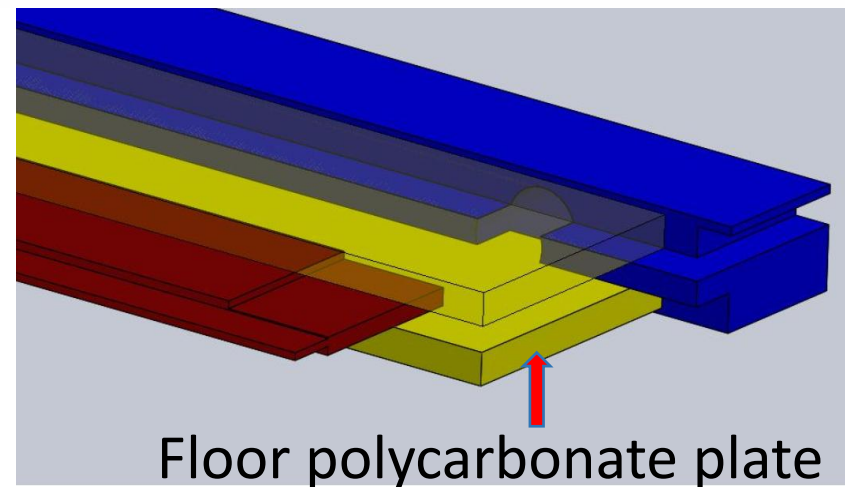
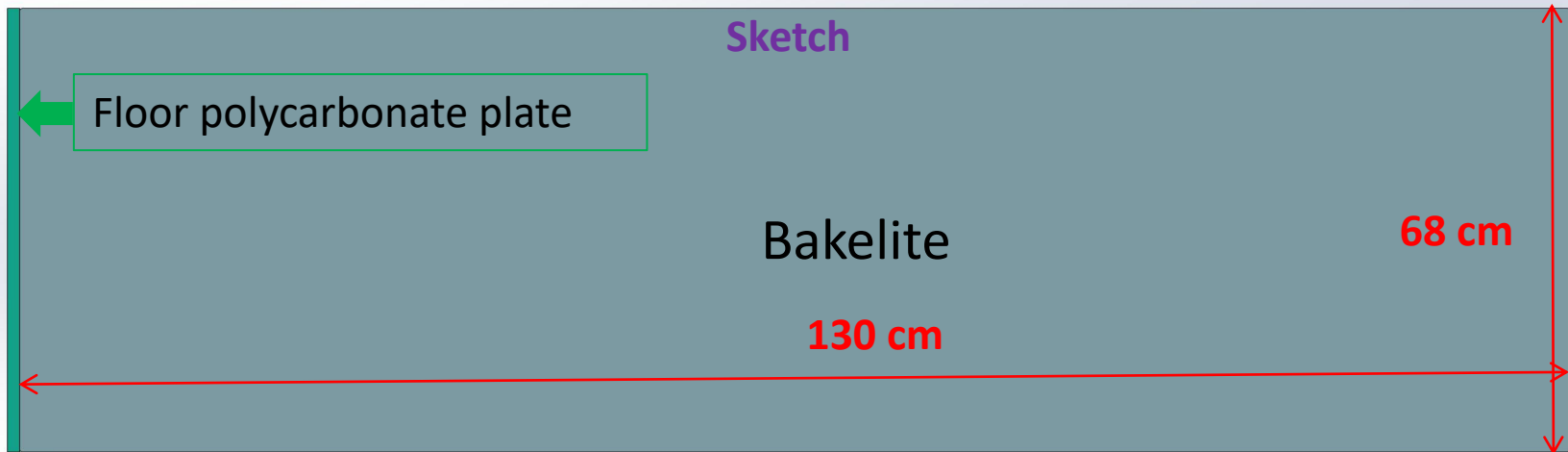


The assembly procedures of the closed gas gap

- The first step: Attach the floor plates on the Bakelite
- The second step: Attach the long and short side frames on the Bakelite and vacuuming
- The third step: Put the spacers and close the gas gap and vacuuming
- The last step: Put the perimetric polycarbonate frame into gas gap

The first step

- Attach 2 floor polycarbonate plates to the bottom Bakelite with Araldite adhesive glue

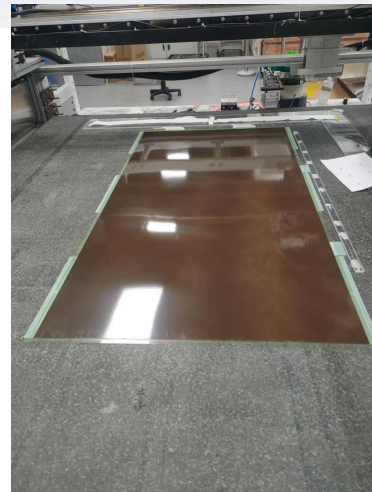
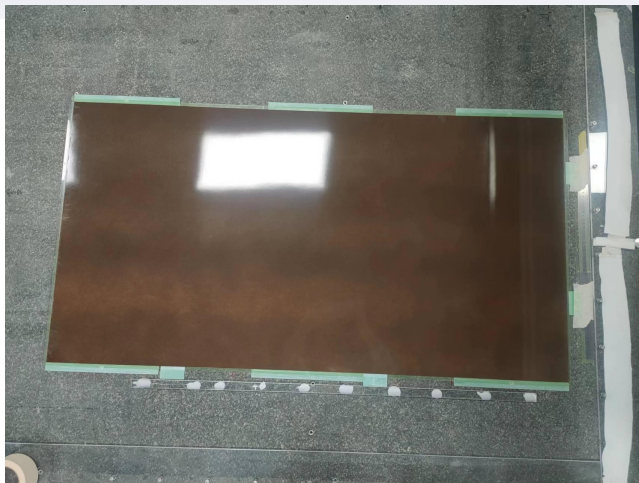
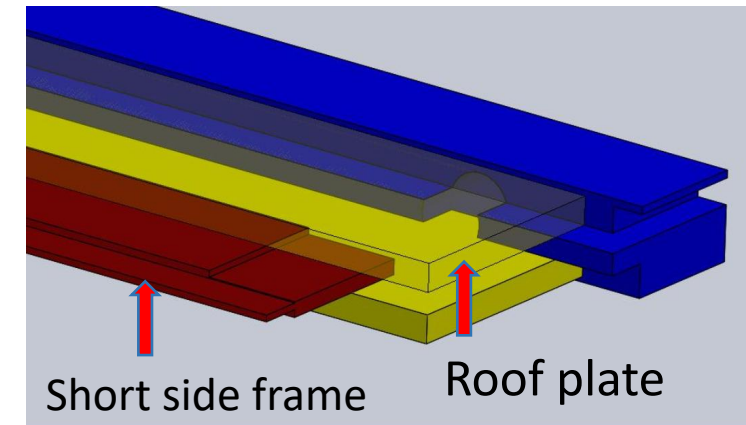
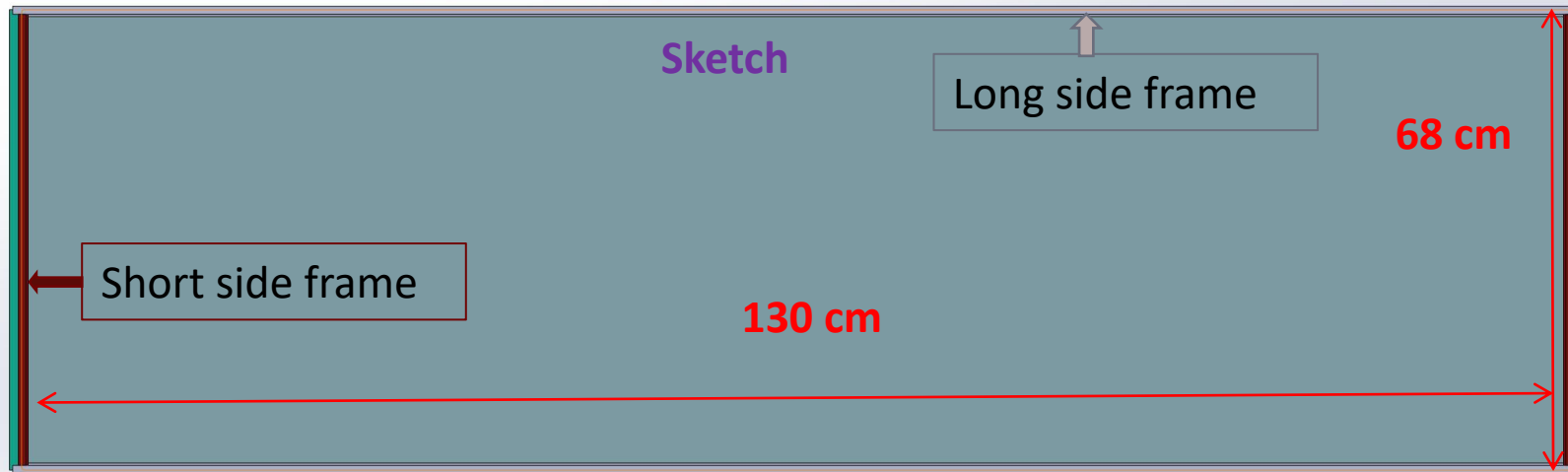


- ✓ The size of Bakelite: 130 cm * 68 cm
- ✓ The piece used in this step is indicated by the red arrow.

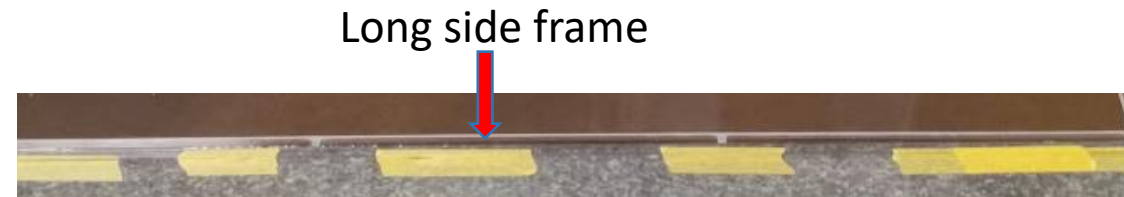
The Bakelite and 2 floor plates will on the same plane

The second step

- Add the glue along the long and short side of the Bakelite
- Attach frames and roof plates with Araldite adhesive glue, and vacuuming



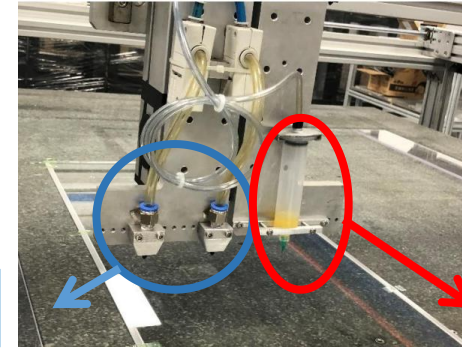
Zoom in



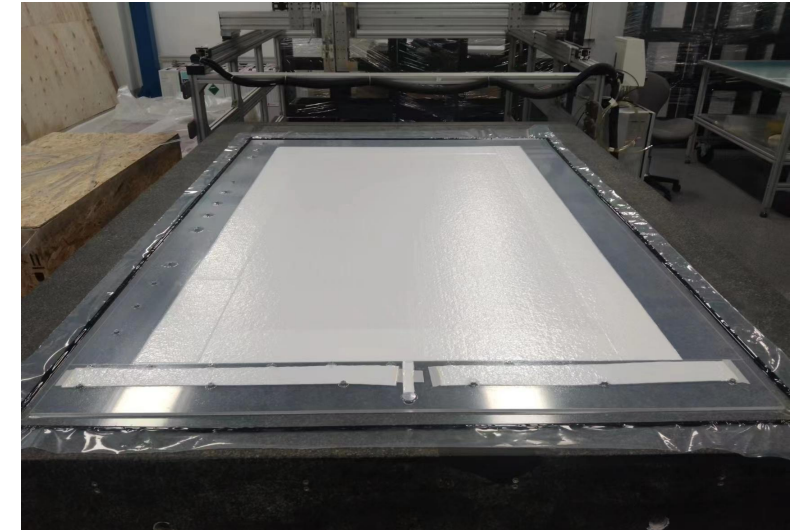
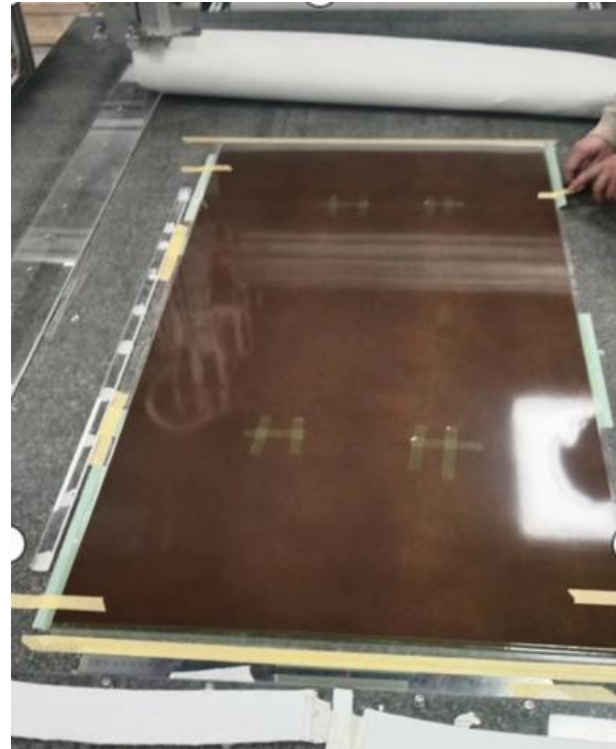
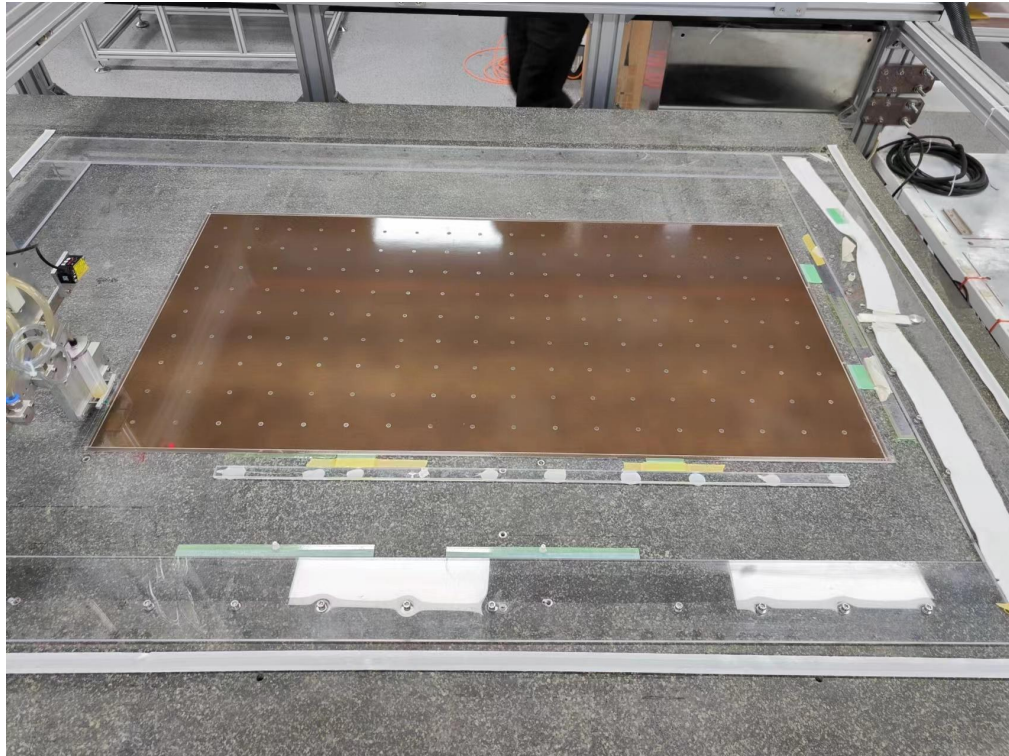
The third step

- Attach the spacers on the Bakelite
 - Add the glue on the Bakelite with glue syringe
 - Put spacers on the glue with spacer pickers.
- Close the gas gap and vacuuming

Spacer pickers



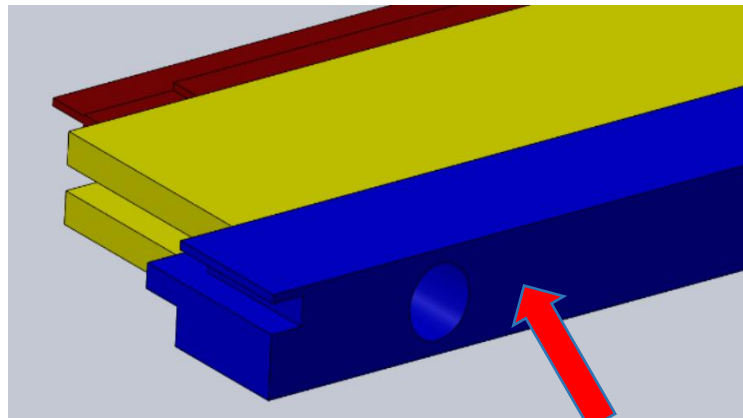
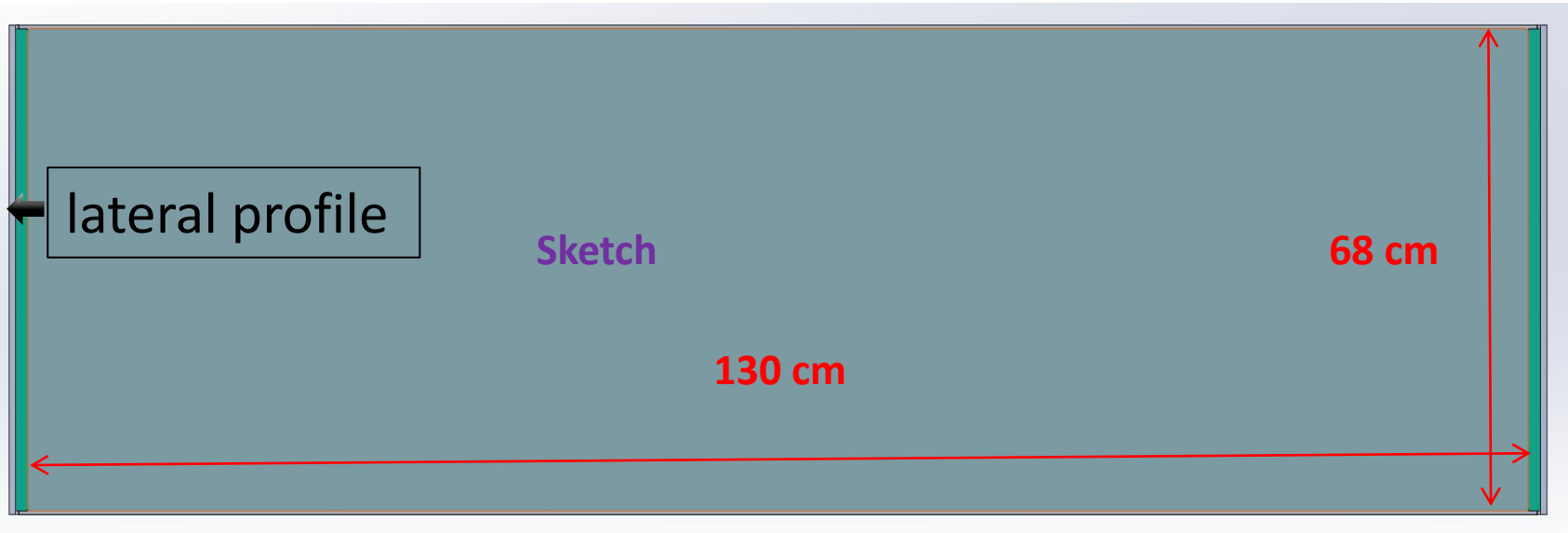
Glue syringe



Keep at least 6 hours for the epoxy curing within the vacuum bag.

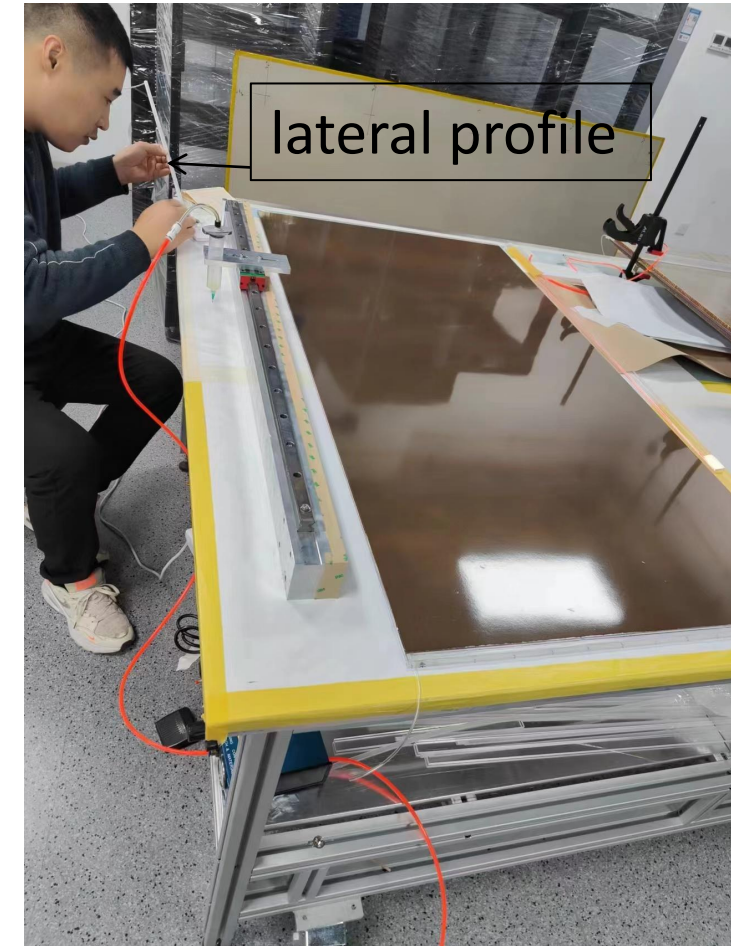
The last step

- Install the gas pipe into the hole of lateral profile and then insert it into gas gap

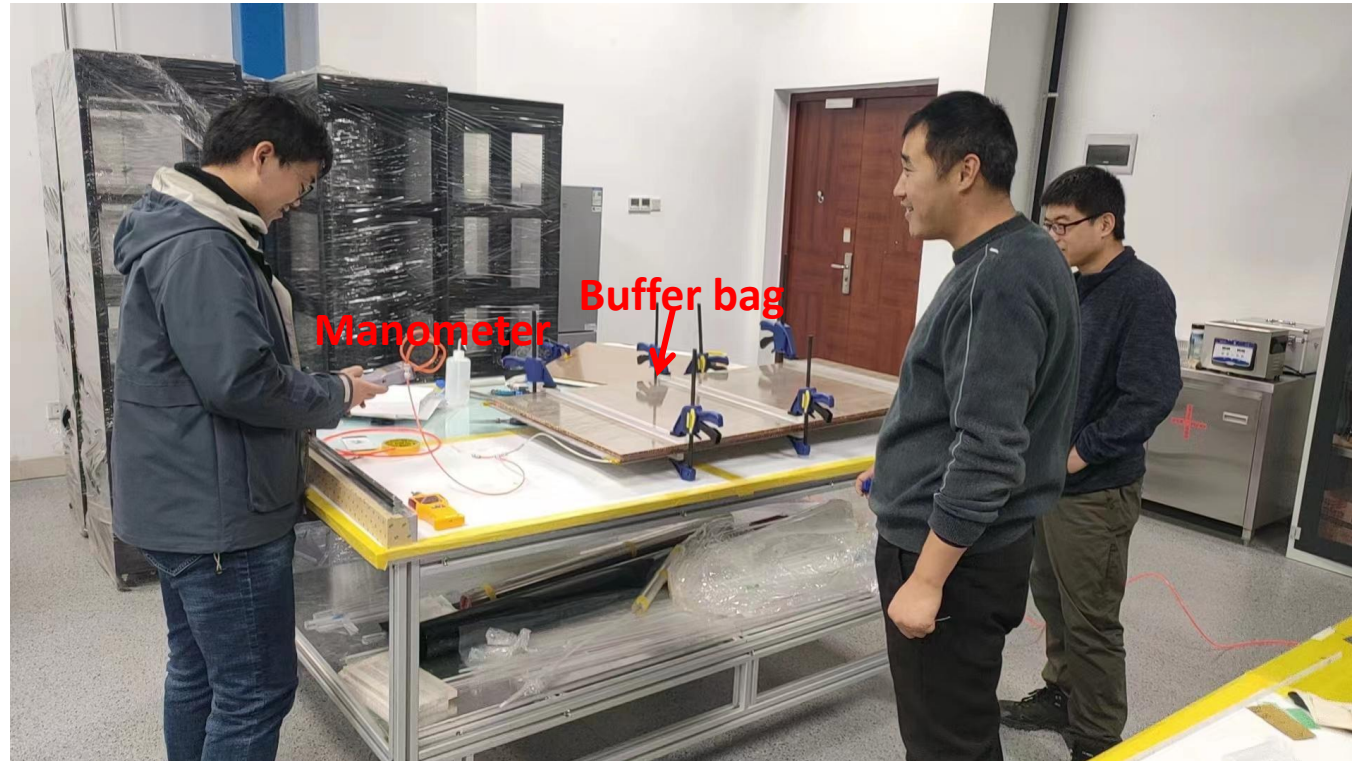


lateral profile

5 gas gap prototypes (130 cm * 68 cm) are built with this method at USTC



Test the tightness of the gas gap



Argon sniffer



Manometer

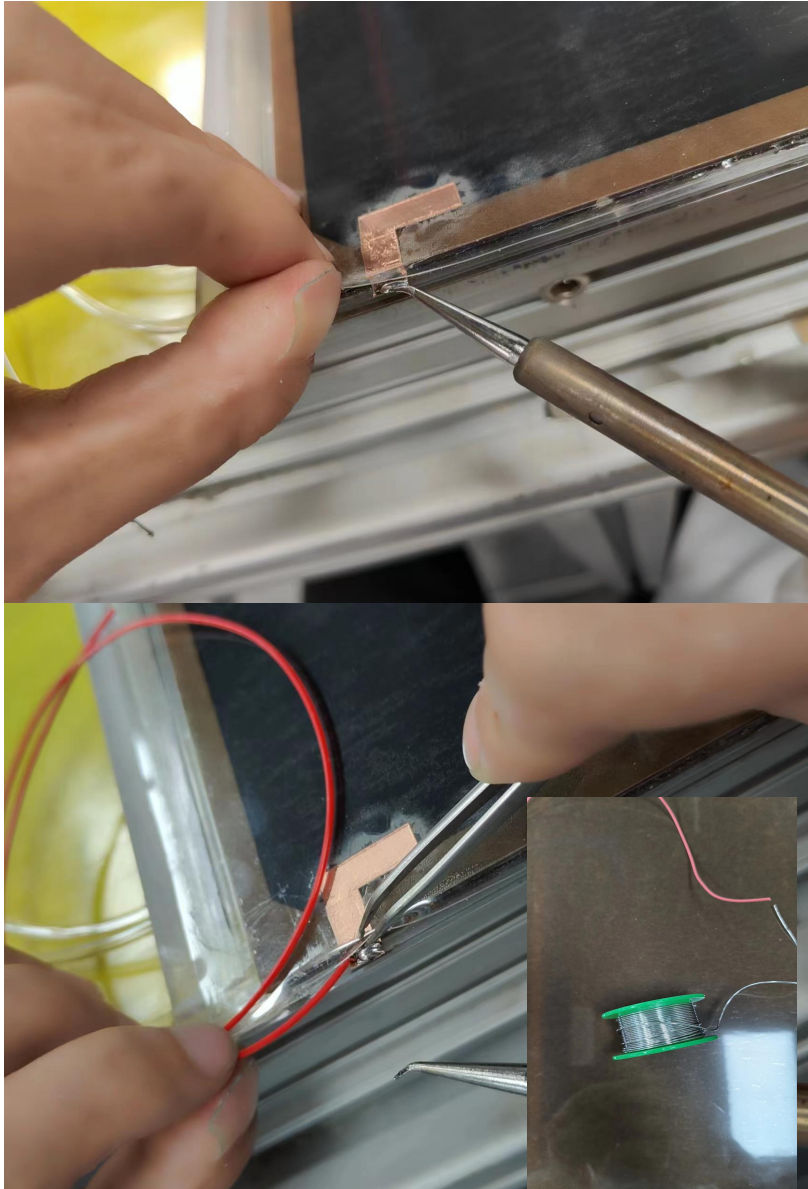


Buffer bag

- Gas gap filled with argon with at least 3mbar overpressure
- if gas leakage found, then sealed with Araldite glue

- The 3 mbar overpressure must be maintained for at least 3 minutes (the change should < 0.1 mbar)
- **All of them passed the tightness test.**

HV contacting and hot-melt gluing



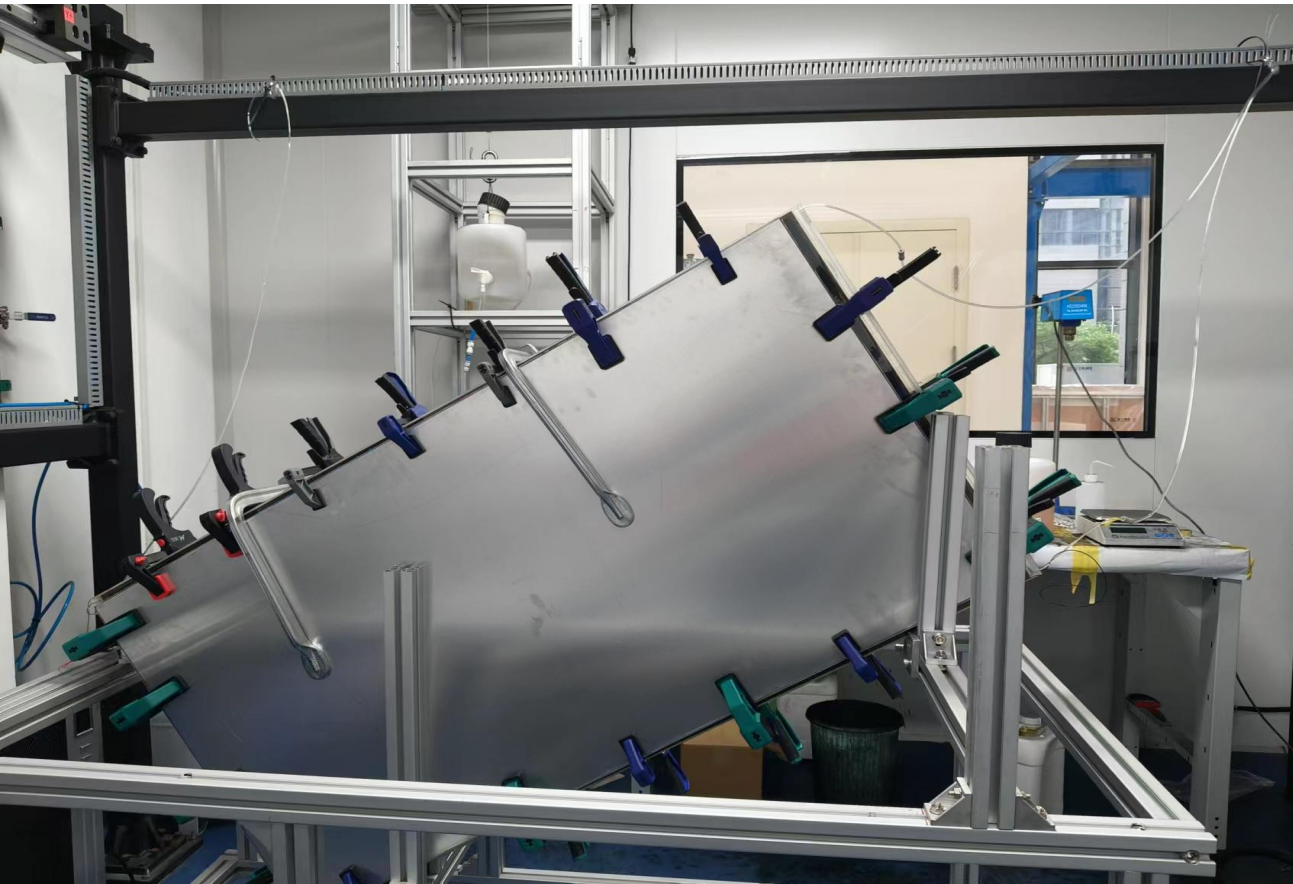
Filling and sealing the edges of the gas gap with hot-melt glue

← To protect PET foil, special solder wire is used

Paper stacker



Linseed oiling

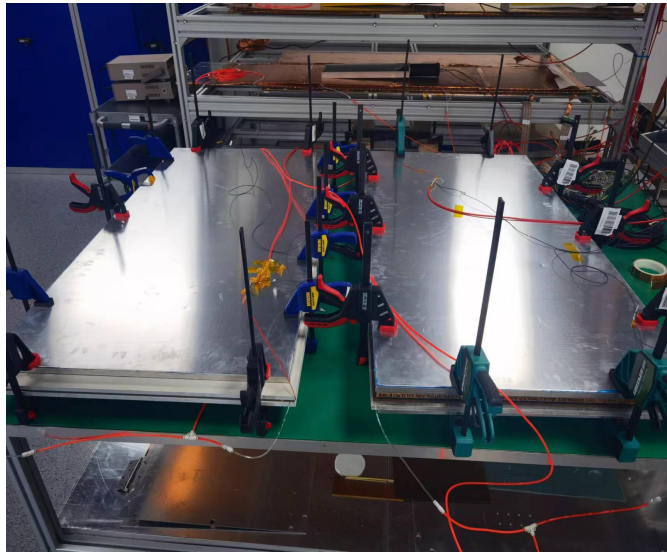


- The gas gaps are flushed with heptane through the gas connections from a supply bottle (From bottom gas inlet to top).
- Fill the gas gap with mixed oil and then empty the oil in the gas gap slowly ($< 1\text{m/h}$)
- Pumping the air through the gas gap for one week to achieve Linseed oil polymer (From top gas inlet to bottom).
- The tightness of gas gap will be checked again after Linseed oiling

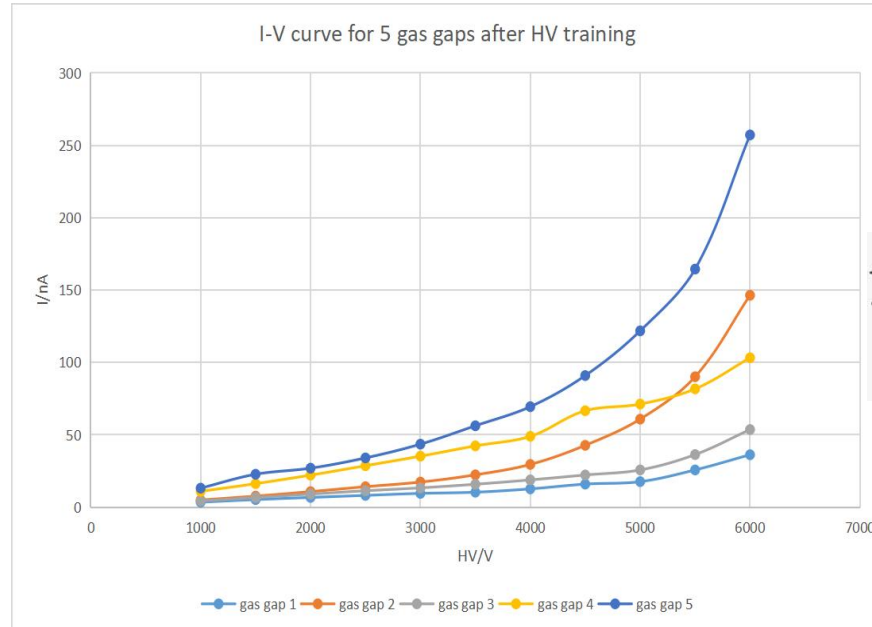
- Preparatory work:
- Room temperature: $\sim 40^{\circ}\text{C}$
 - Mixed oil: 30% linseed oil + 70% heptane
 - Use clamps to prevent bursting under oil pressure

HV test

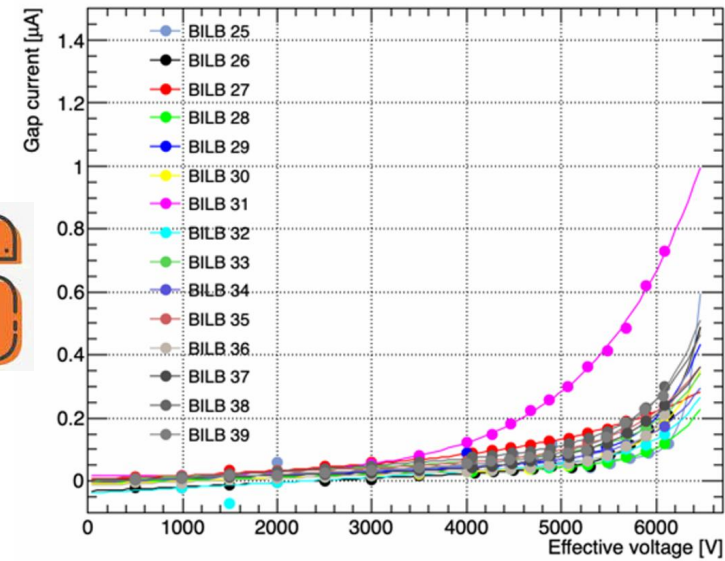
- Supplied with standard ATLAS RPC gas mixture ($C_2H_2F_4$: Iso- C_4H_{10} : SF_6 = 94.7% : 5% : 0.3%).
- Trained at 6000V for 1 week.
- Applied HV from 1.0 kV to 6.0 kV.



Size: 68 x 130 cm²



Our test results



Gaps produced by GTE
Size: 52 x 265 cm²



Summary

- Gas gap production at USTC
 - The method for constructing an RPC gas gap is presented in this talk.
 - The first time to build the large area Bakelite gas gap (130 cm * 68 cm) in USTC.
 - 5 gas gap prototypes are produced at USTC, the test results (I-V curve) are very promising.
 - Those gas gap prototypes are scheduled to be shipped to CERN for irradiation testing in the following days.
- The mass production of real size (234 cm * 68cm) gas gap will start from 2025.

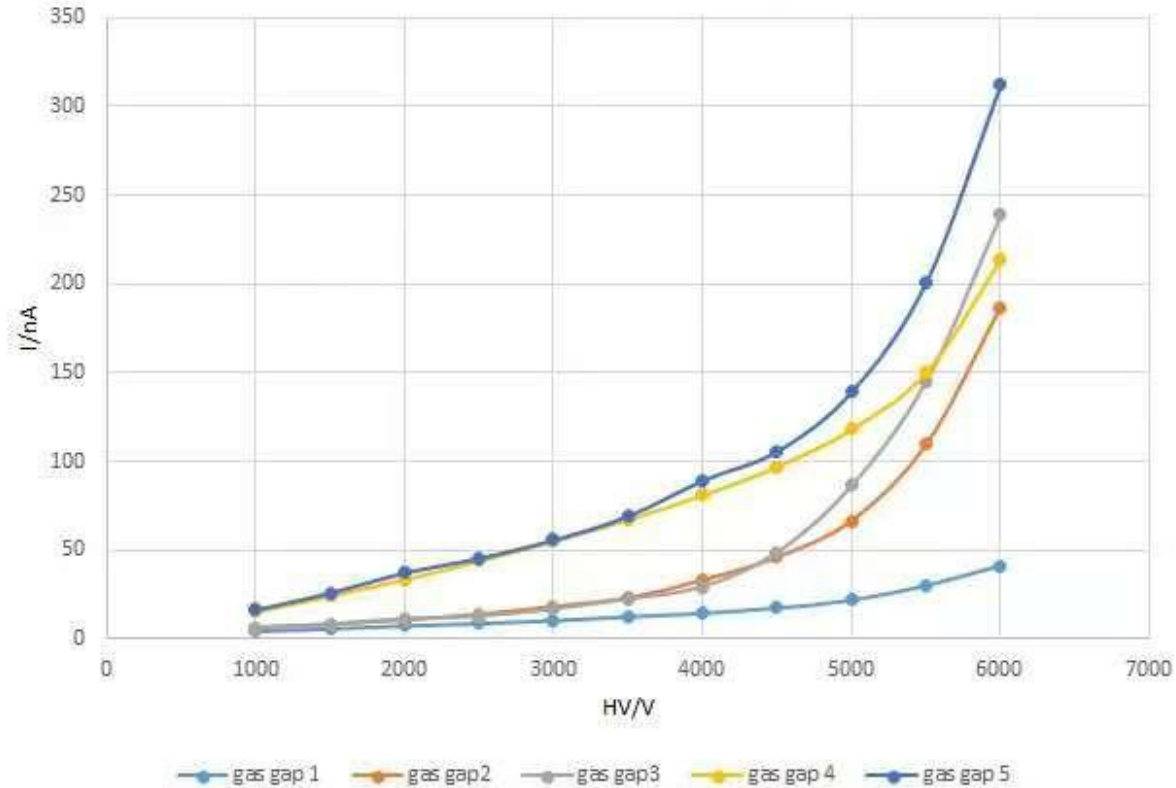
Any questions or comments are welcome

Thank you

Back up

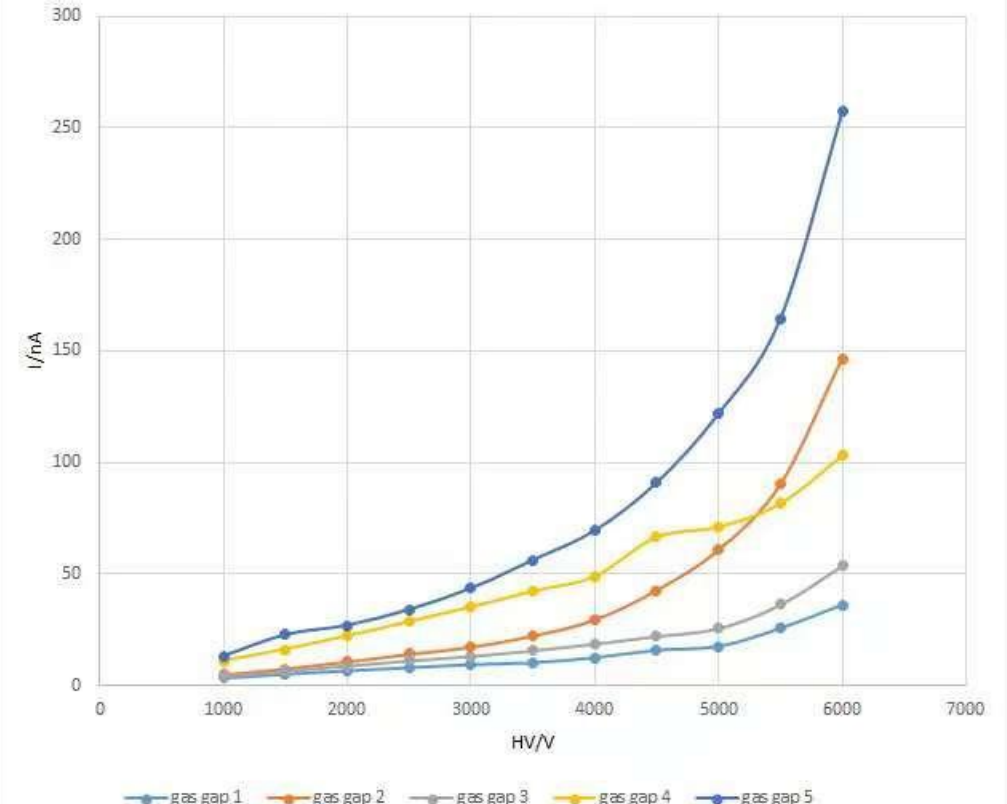
Before and after training comparison

I-V Curve before training



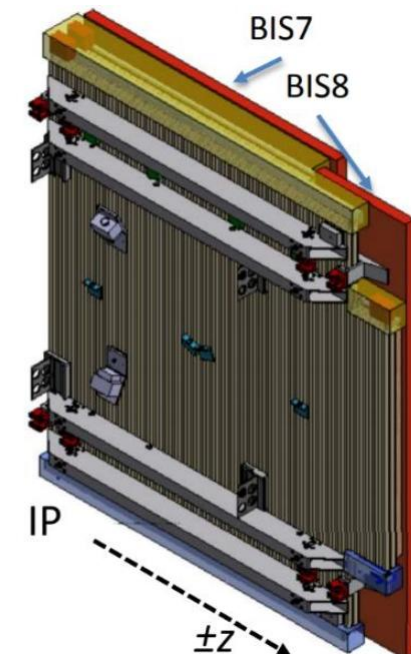
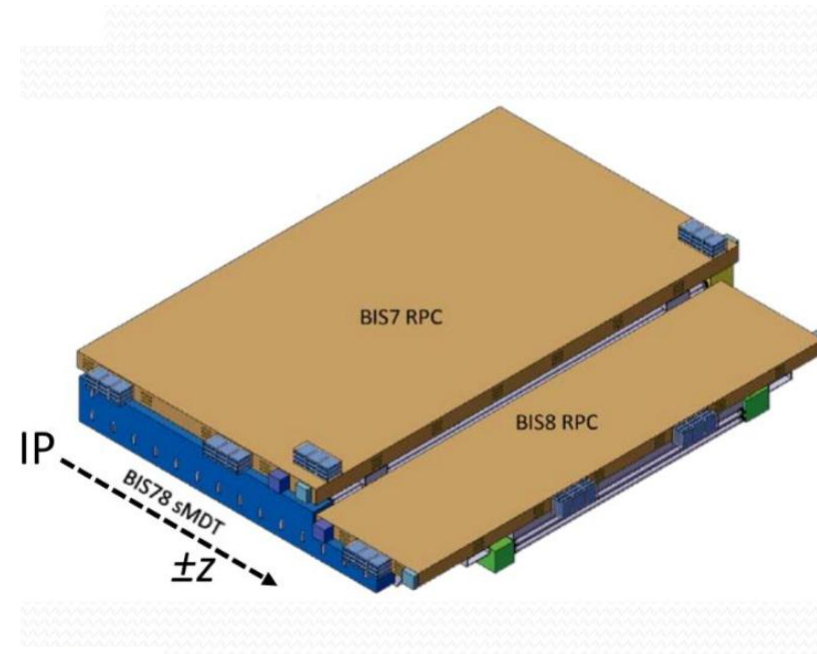
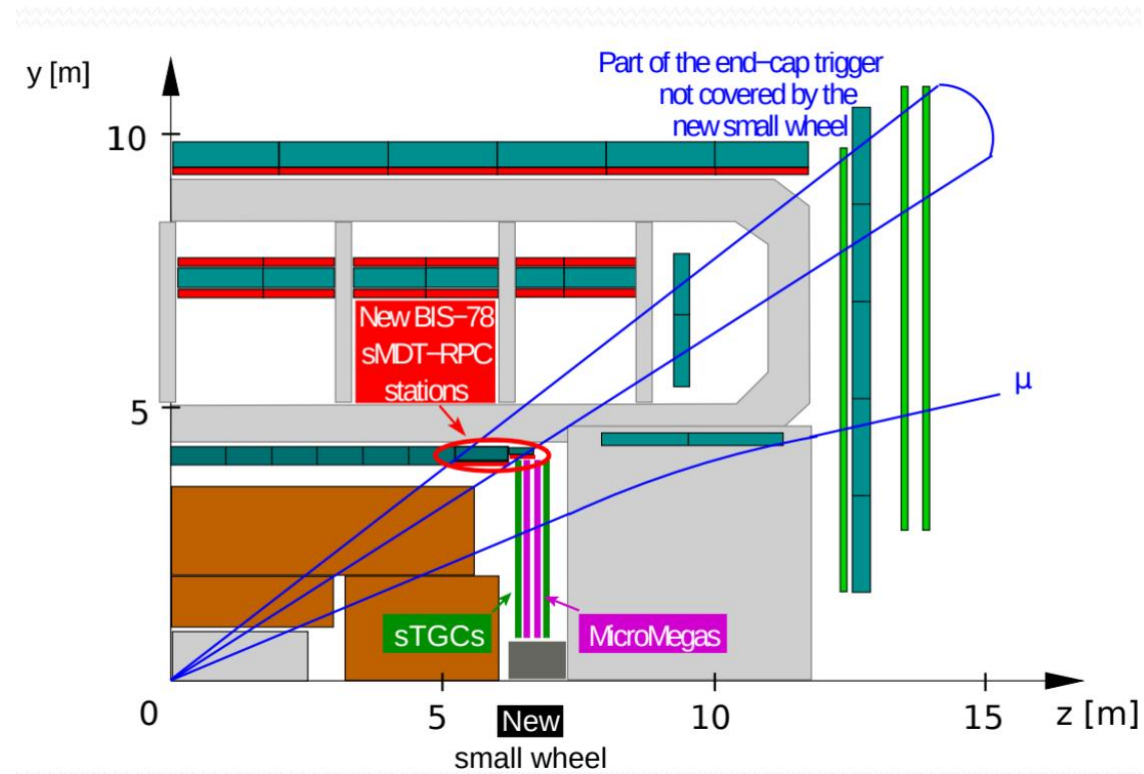
Before

I-V Curve after training

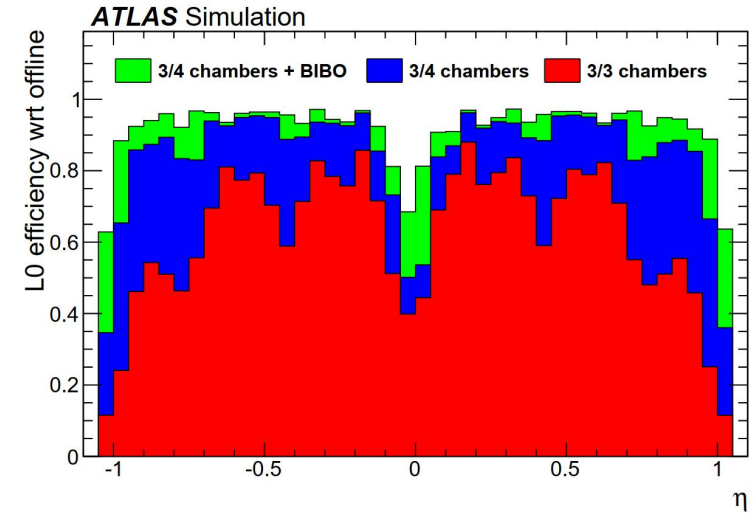
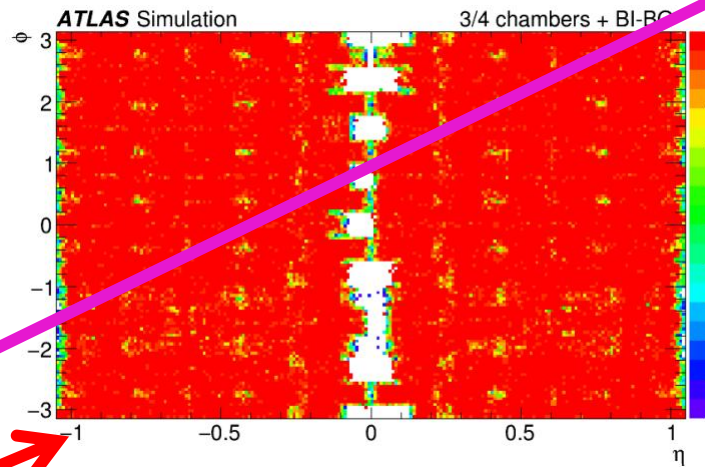
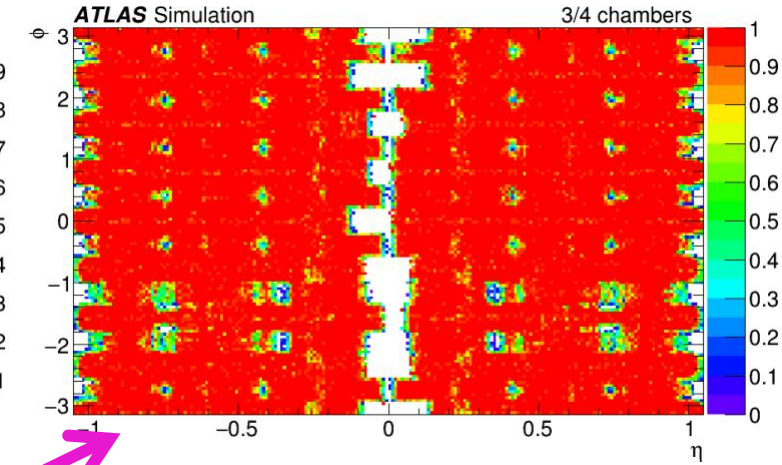
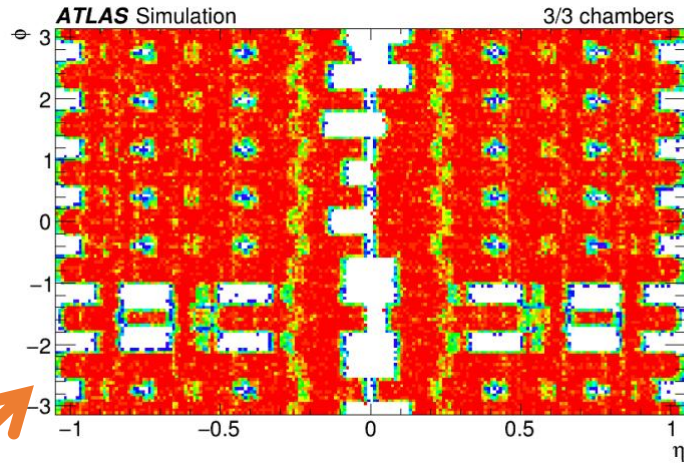
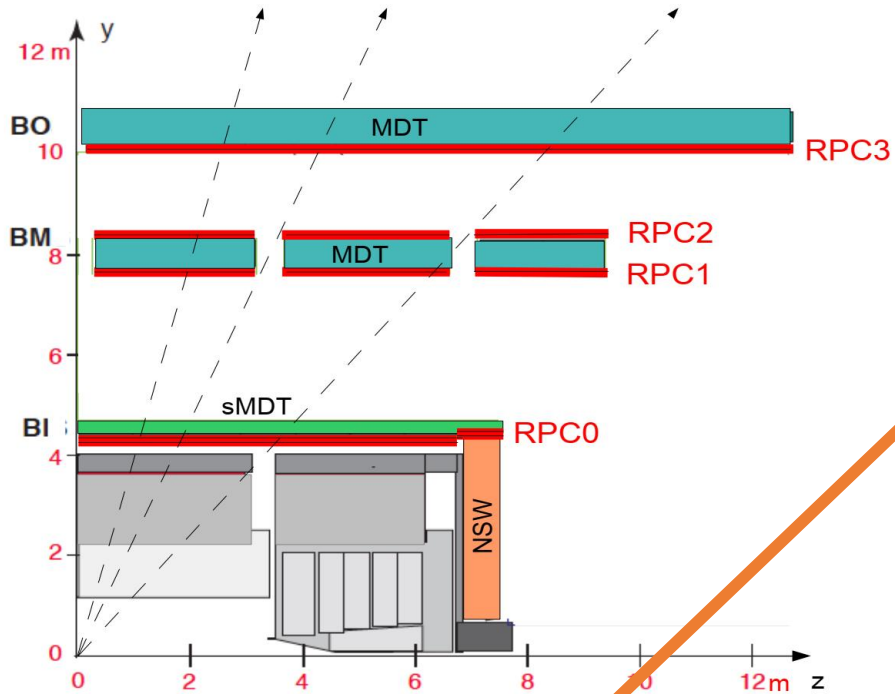


After

BIS78



Geometrical acceptance and trigger eff.

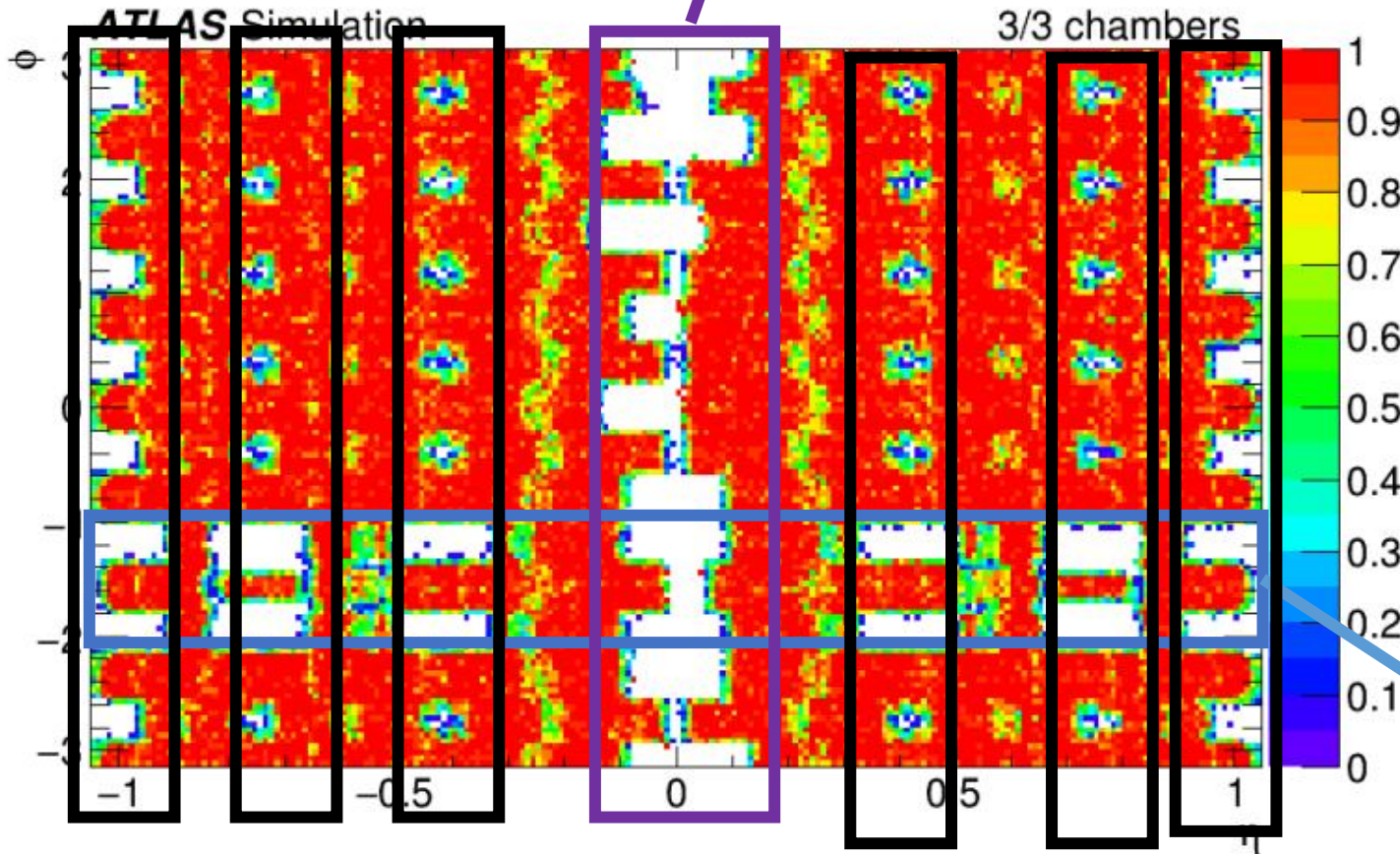


Trigger	Requirement
3/3 chambers	$3[\text{RPC1}+\text{RPC2}] \text{ AND } 1[\text{RPC3}]$
3/4 chambers	$(3[\text{RPC1}+\text{RPC2}] \text{ AND } 1[\text{RPC3}]) \text{ OR } (2[\text{RPC0}] \text{ AND } 3[\text{RPC1}+\text{RPC2}+\text{RPC3}])$
3/4 ch. + BI-BO	$(3[\text{RPC1}+\text{RPC2}] \text{ AND } 1[\text{RPC3}]) \text{ OR } (2[\text{RPC0}] \text{ AND } 3[\text{RPC1}+\text{RPC2}+\text{RPC3}])$ OR (2[RPC0] AND 1[RPC3])

Increase the trigger coverage in the region where no BM coverage due to the coverage hole

Geometrical acceptance and trigger eff.

No muon chambers due to services



BM and BO efficiency (%)	Trigger efficiency × acceptance (%)		
	3/3 chambers	3/4 chambers	3/4 chambers + BI-BO
100	78	91	96
90	73	90	95
80	62	87	93
Worst case	63	85	92

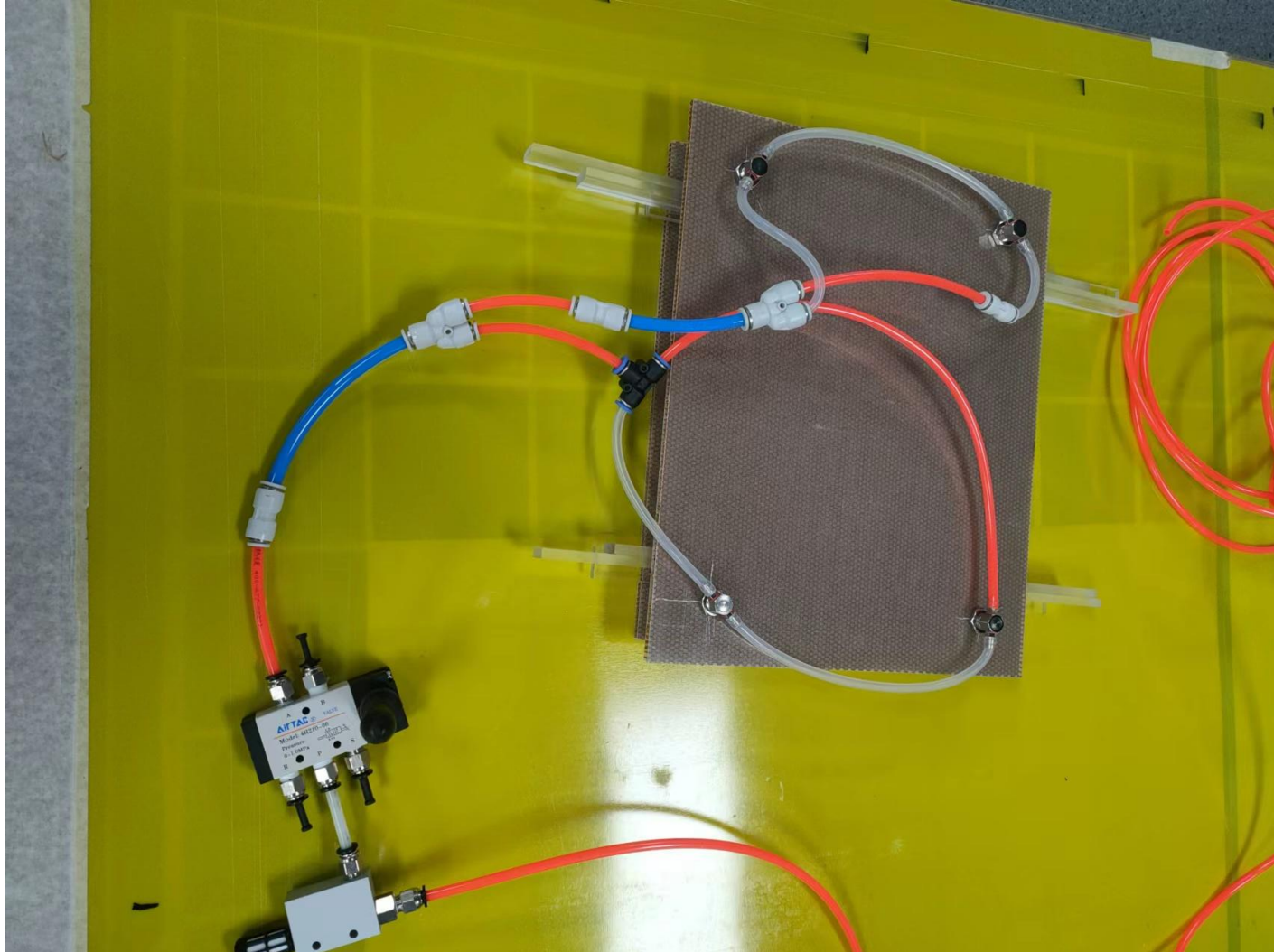
RPC hit efficiency decreases as a function of eta from approximately 90% at eta= 0 to an average of 65% (56–75% depending on the sector) at eta = 1.

Due to the calorimeter feet and rails

Due to the supports of the toroidal magnets

Type	Factory Naming (FN)	Technical coord. Naming (TN)	Length (mm)	Width (mm)	Special Features	Number of Chambers
BIL	A	680	2650	680	No	56
	B	520	2650	520	No	41
	C	680C	2218	680	No	16
	D	520C	2218	520	No	2
	E	680Z	2340	680	No	2
	X	520X	2650	520	Yes	1
	Y	520Y	2650	520	Yes	2
	YB	520YB	?	?	Yes	2
	Z	520CZ	2218	520	Yes	2
	V	520S	1422	520	Yes	4
	W	360S	1822	360	Yes	1
	W'	360SS	1500	360	Yes	1
BIS	A	1	1744	1087	No	16
	B	2-6	1744	908	No	80
BIS78	T7-1	7L				9
	T7-2	7S				15
	T8-1	8L				12
	T8-2	8S				12

Vacuum Sucker



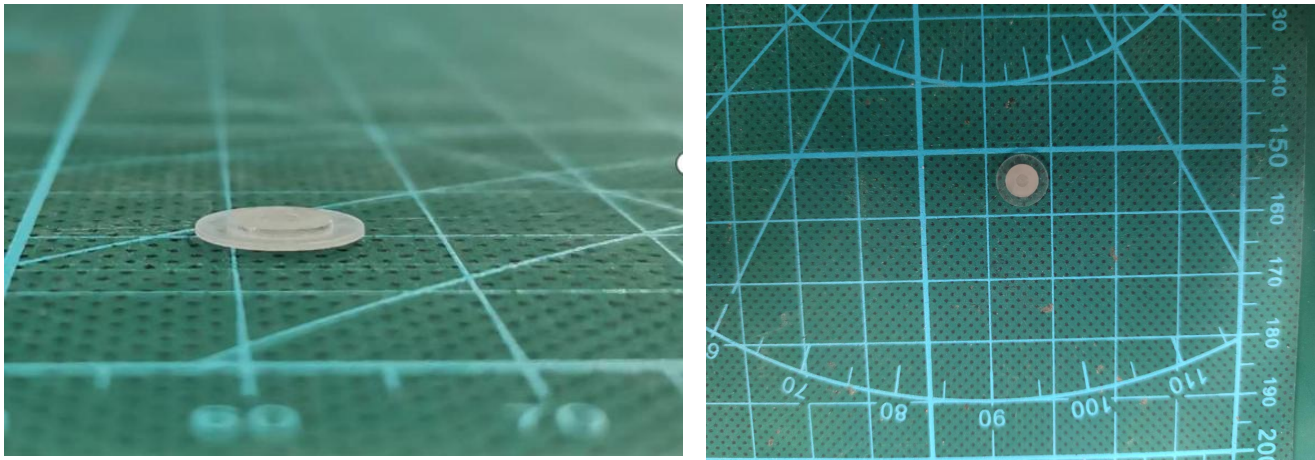
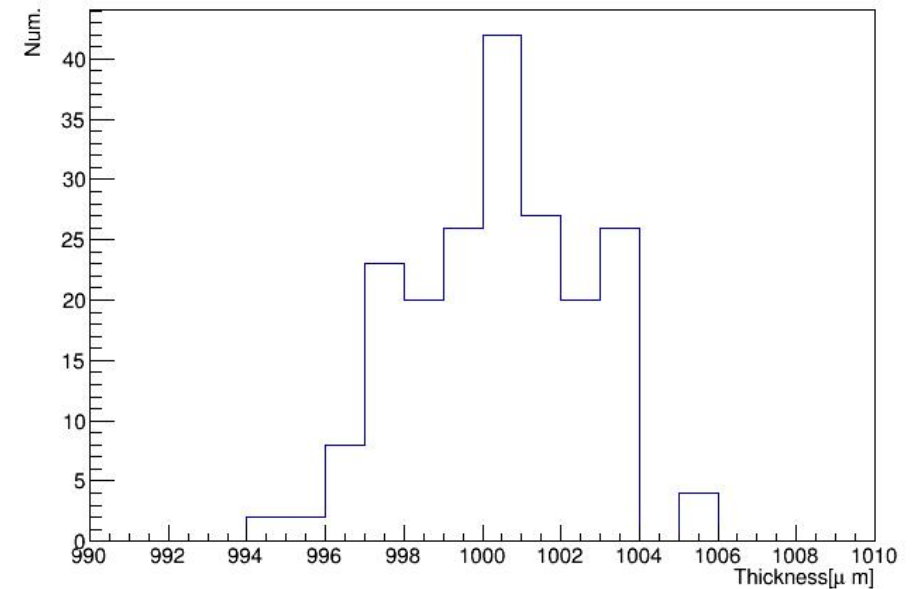
To hold the top bakelite

Spacers with guard wing



outer diameter: $8 \pm 0.05\text{mm}$
inner diameter: $5 \pm 0.03\text{mm}$
thickness: 1.000 mm

The thickness of Spacer



1/100 of all the spacers (20000) are tested
96% in $1.000 \pm 0.004\text{ mm}$
100% in $1.000 \pm 0.006\text{ mm}$

Y

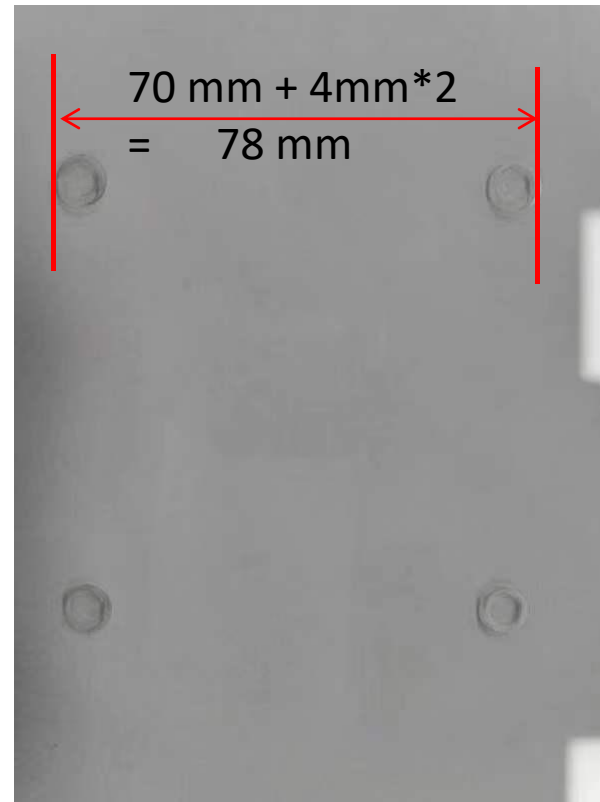


Nominal value:

radius of spacer:4mm

height of spacer:1mm

distance: 70mm*70mm



X

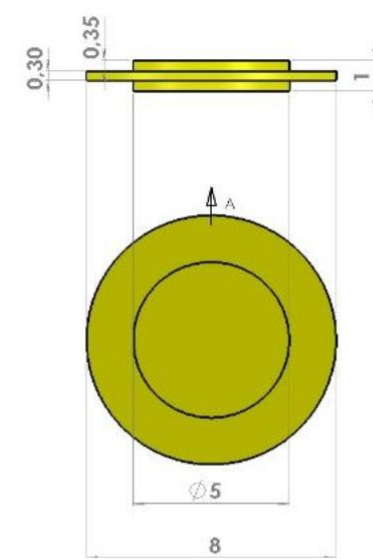
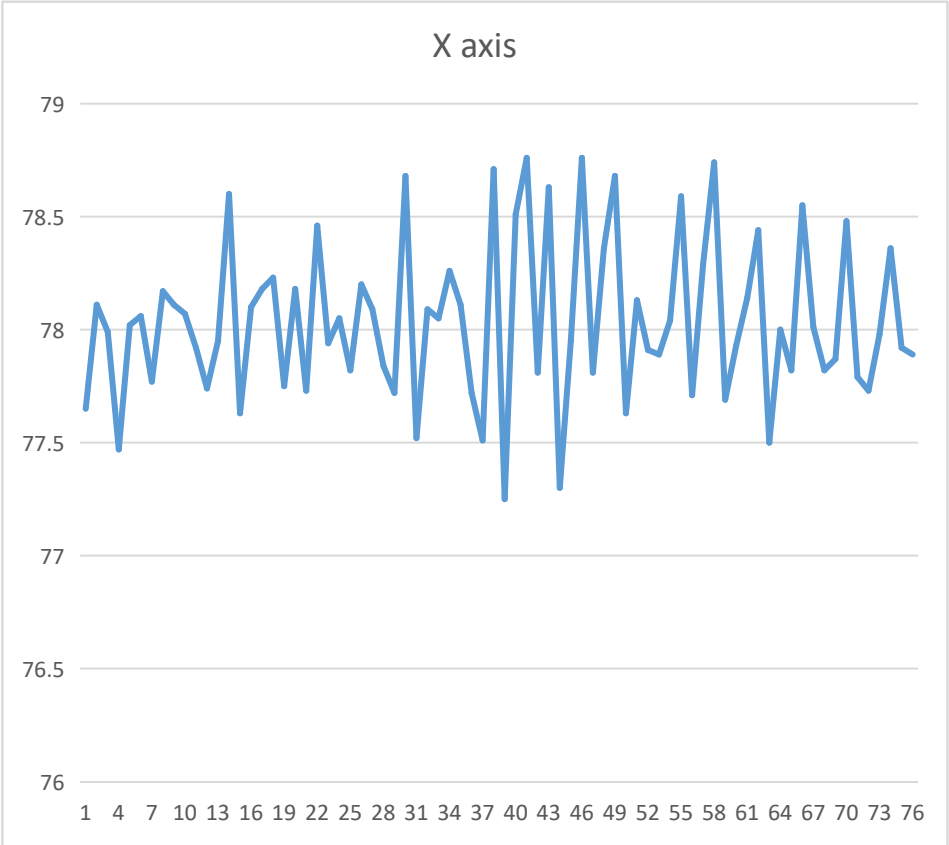


Figure 5: design of the cylindrical pillar with the guard ring.

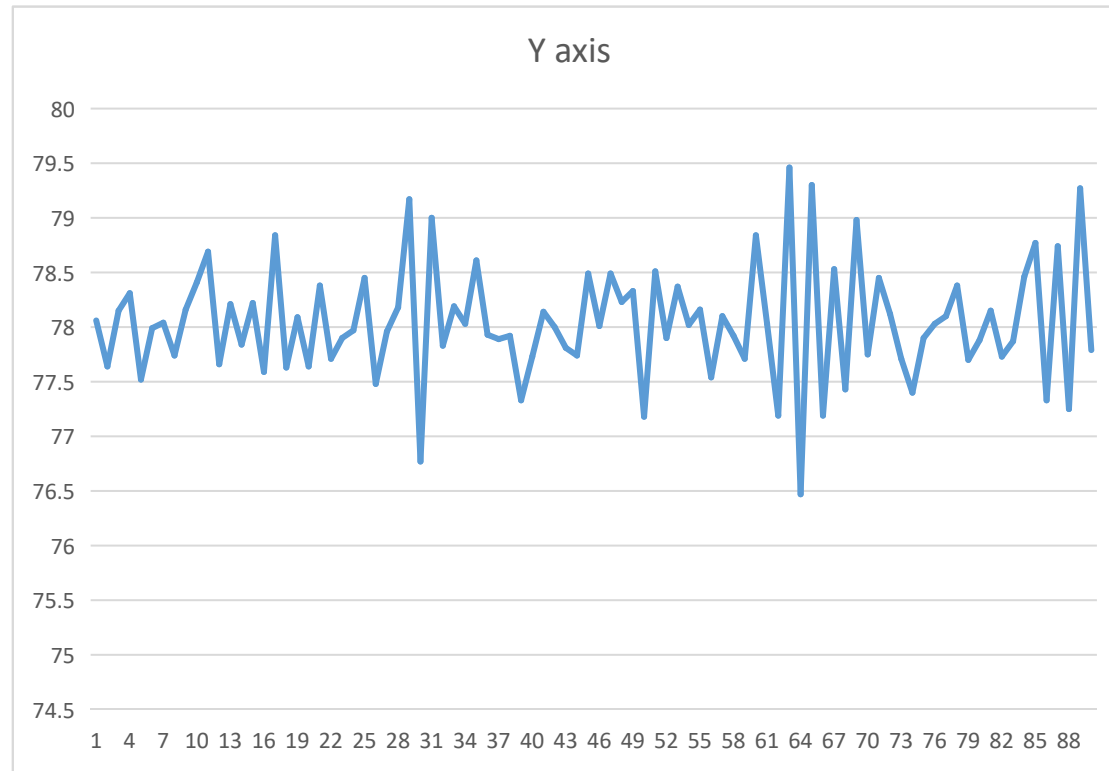
X axis

X mean=78.0429333



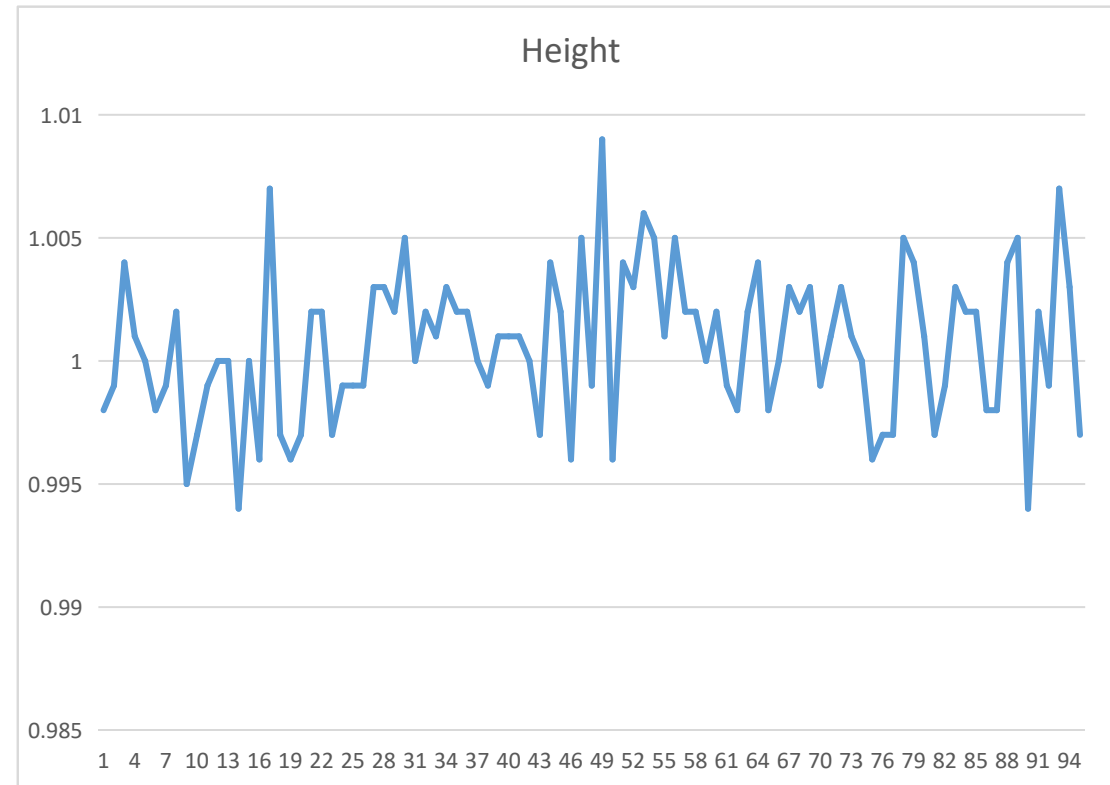
Y axis

Y mean=78.0412222



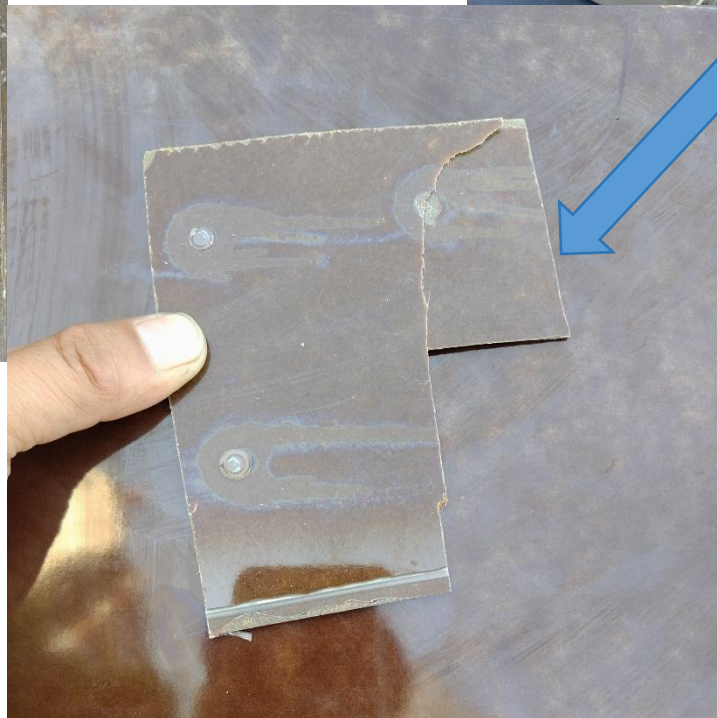
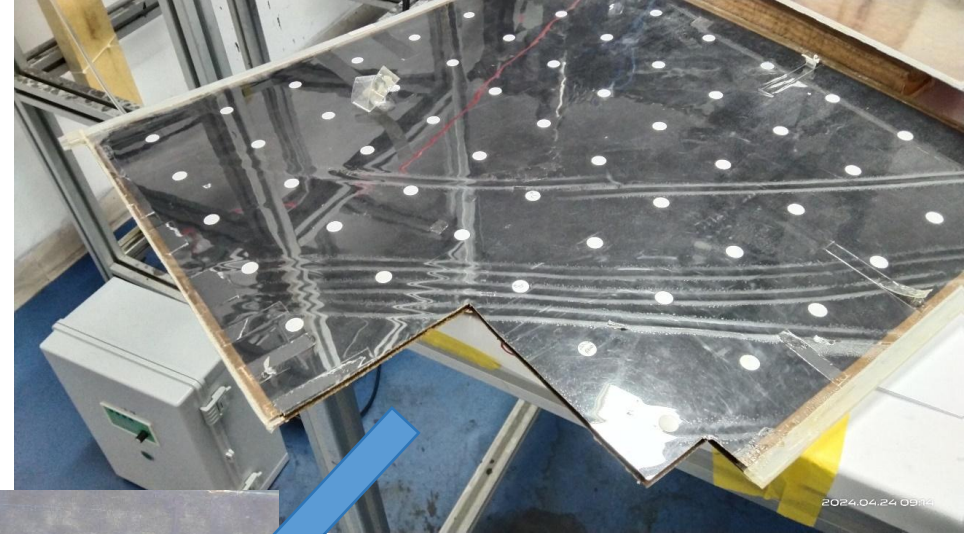
Height

H mean=1.000663158



Comparison with GTE gap

The last USTC oiled gap



The quality is comparable with the GTE-produced gas gap.

- A 50x50cm gap bought from GTE years ago.
- Originally, it worked properly.
- It was deformed due to the humidity problem.
- We opened it and checked the surface inside.

The final product

