Mass production of RPC readout panels for ATLAS Phase-II upgrade and R&D on thin gas gap production at USTC

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(On behalf of the ATLAS Muon Community)

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Outline

- Introduction
- Readout panel production
- RPC gas gap production
- BIS singlet assembly work
- Summary

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 Cluster (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
  - ✓ ~ 6 RPC gas gap prototypes need to be produced before September 2024 and sent to CERN to do the irradiation test
- BIS singlet assembly without FEE plan to start around October 2024

To fulfill this task →

① **Honeycomb readout panel production**

② **RPC gas gap production**

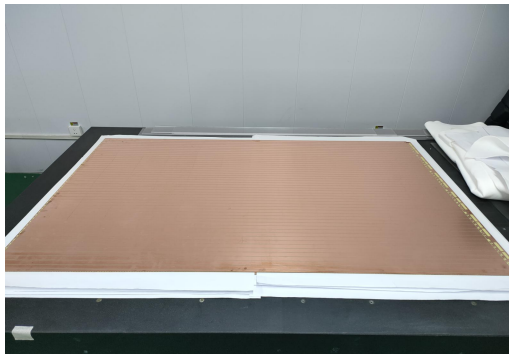
③ **Singlet assembly work in BB5**

Today's topics

Readout panel production

Honeycomb readout panel production

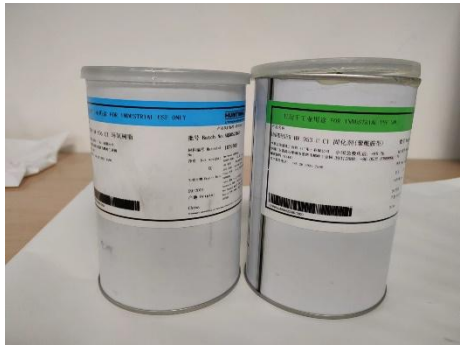
- Materials for production:
  - PCBs: ~0.45mm thick, size: 1706 mm x 1070 mm or 1706 mm * 890 mm
  - Honeycomb core: 3 mm thick
  - Glue: Araldite 2011 (~180 g /side)



PCB: BIS-1

PCB: BIS-2_6

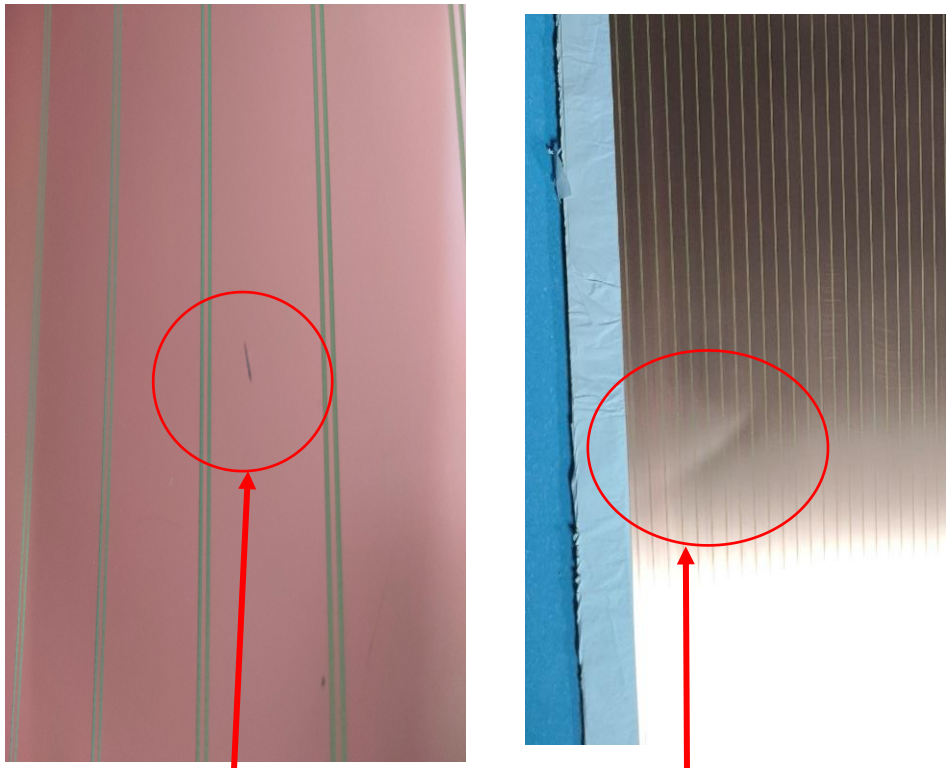
Specifications:
The flatness of readout pannel < 0.1 mm in 7 cm * 7 cm range
The length and width:
1705 +/- 1 mm
1072 +/- 1 mm



Araldite 2011

THINKY MIXER ARE-310

General checks on the PCBs

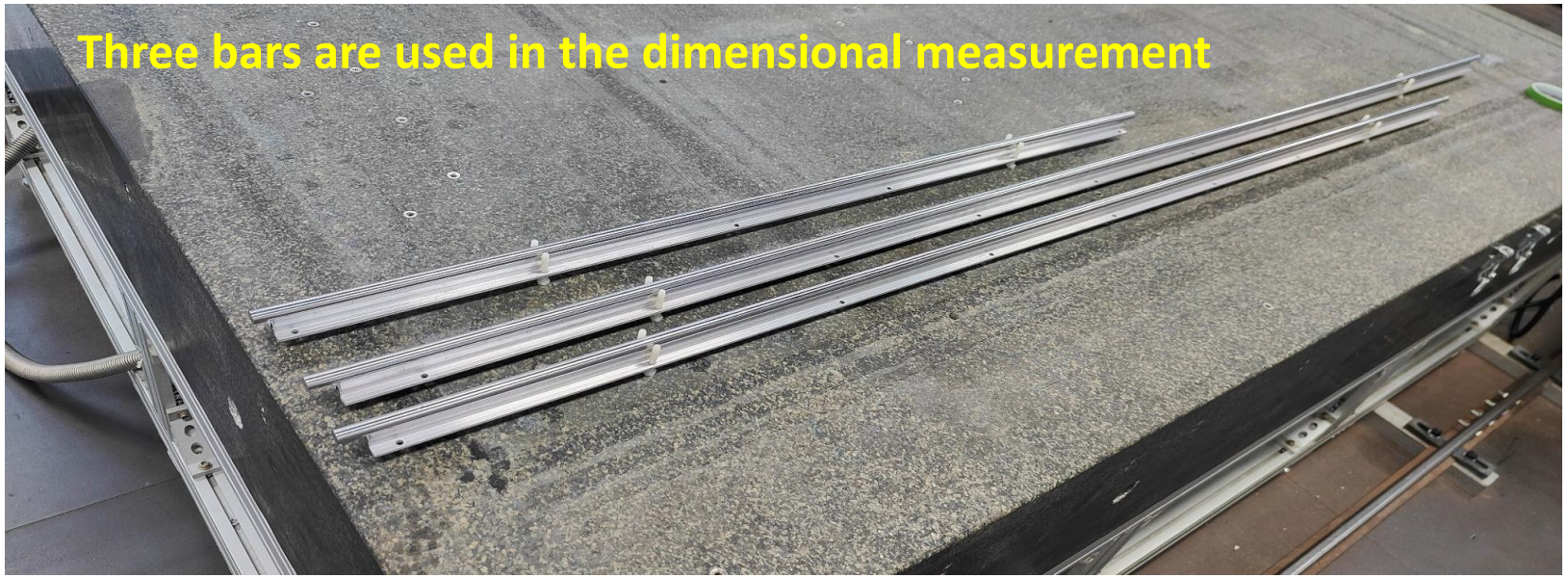


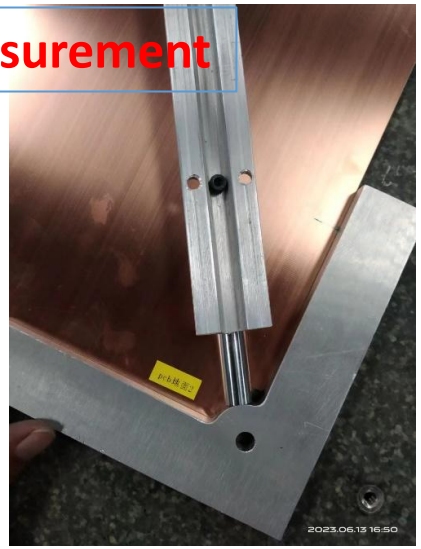
Visual check: Some slight fold marks/ scratches observed on the surface of the PCBs.

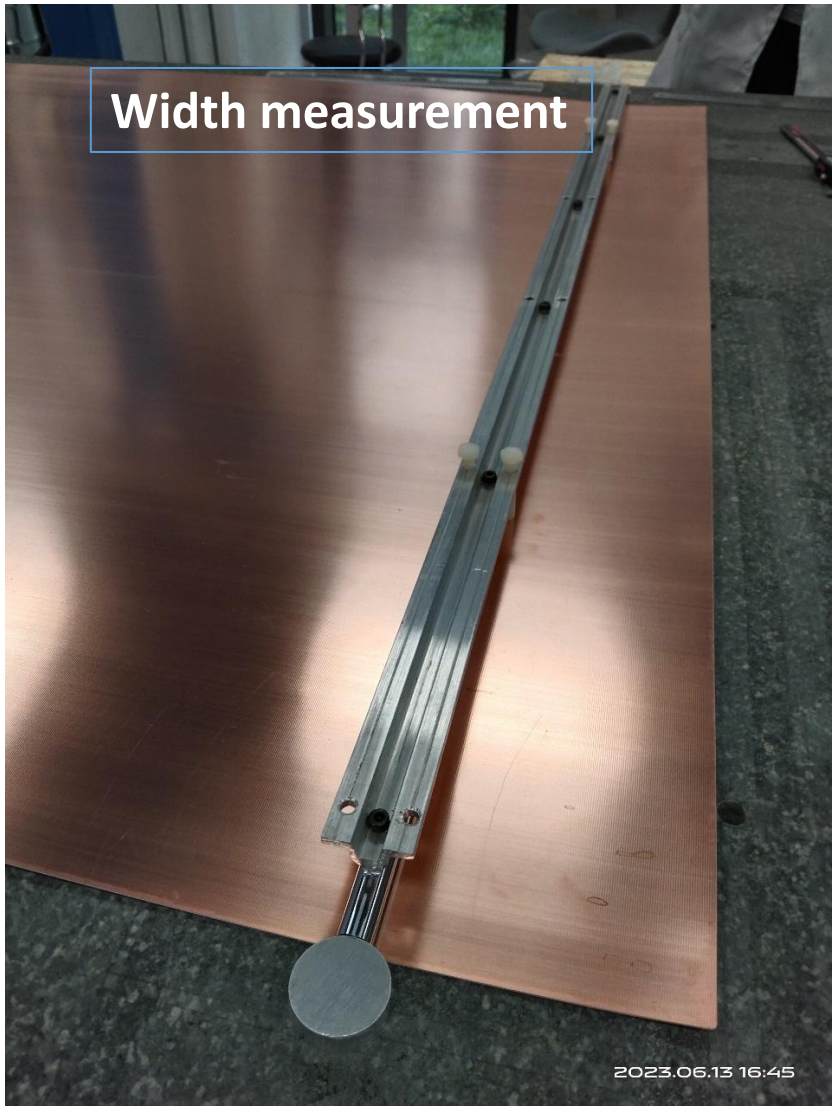
Electrical continuity checks

The PCBs passed the general checks will do the dimension check

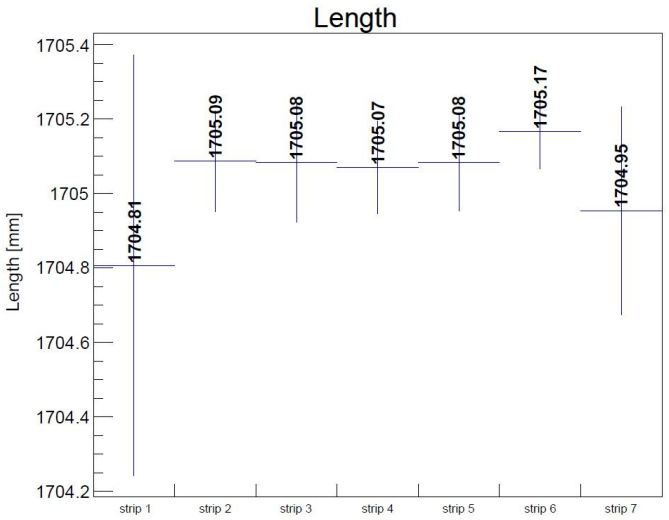
The dimensional measurement

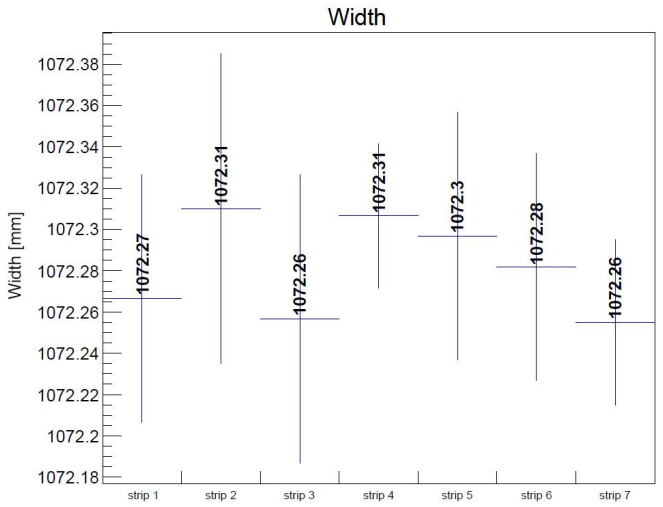


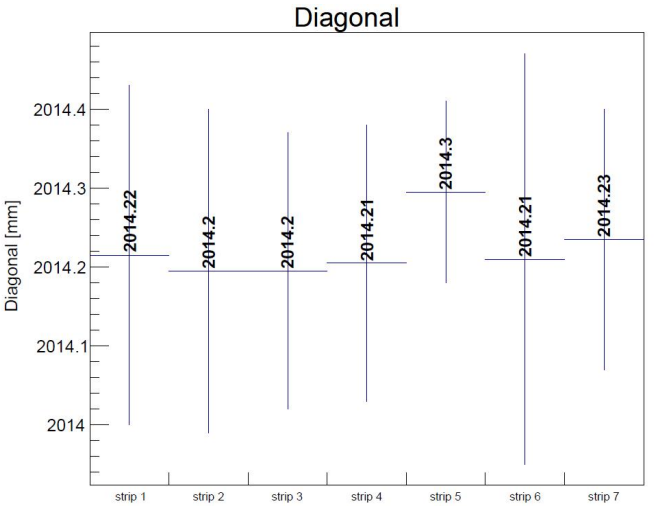




The dimensional results

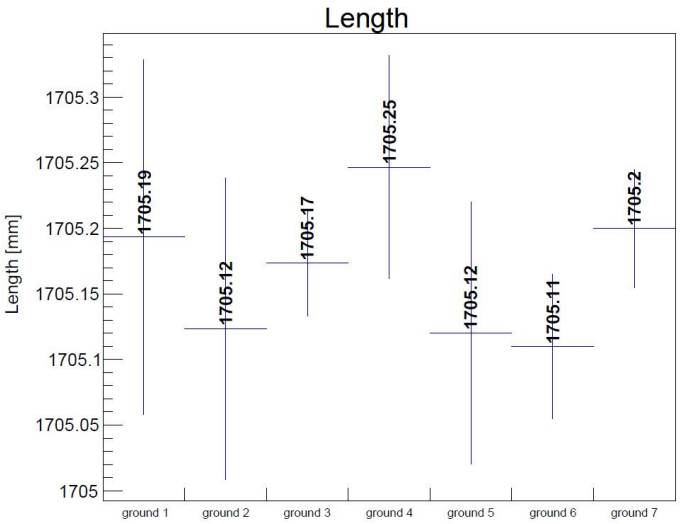


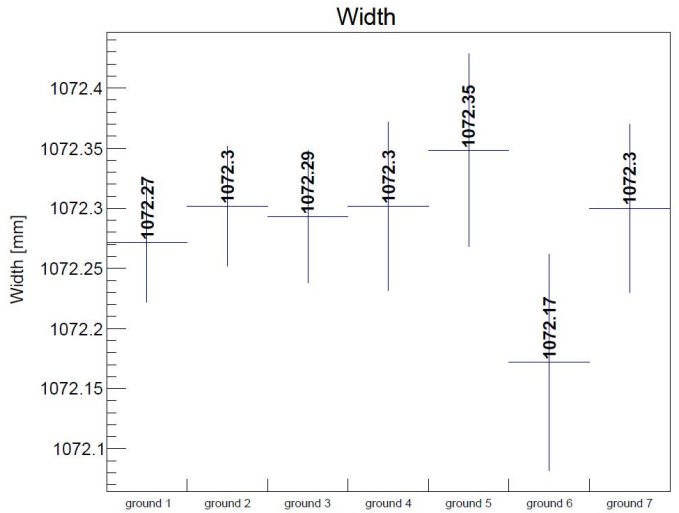


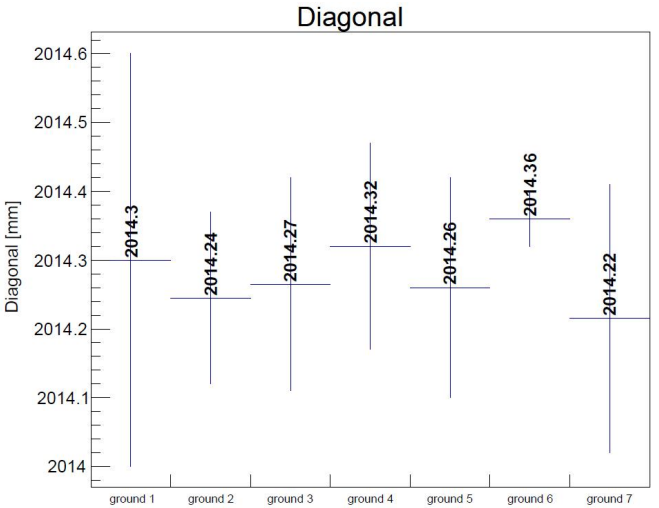


Nominal value:
Length: 1705mm
Width: 1072 mm
Diagonal: 2014 mm
Error: +/- 1 mm

Strip PCBs







GND PCBs

Good quality

The PCBs passed those checks will be used to build the readout panels

Checks on the paper honeycomb

- Size of the paper honeycomb: 1220 x 2440 x 3 mm^3.
- Measure the thickness with micrometer gauge fixed on top of the marble table.

Sample #1	1	2
1	3.03	3.067
2	3.05	3.07
3	3.036	3.067
4	3.022	3.074
5	3.05	3.067
6	3.038	3.055
mean	3.038	3.067

Sample #2	1	2
1	3.102	3.091
2	3.087	3.076
3	3.072	3.049
4	3.078	3.067
5	3.07	3.041
6	3.071	3.043
mean	3.08	3.061

Sample #3	1	2
1	3.062	3.043
2	3.066	3.065
3	3.057	3.049
4	3.064	3.044
5	3.06	3.057
6	3.068	3.059
mean	3.063	3.053

Sample #4	1	2
1	3.039	3.076
2	3.063	3.074
3	3.054	3.082
4	3.061	3.092
5	3.075	3.088
6	3.078	3.079
mean	3.062	3.082

Sample #5	1	2
1	3.107	3.103
2	3.096	3.099
3	3.074	3.097
4	3.079	3.097
5	3.106	3.107
6	3.106	3.119
mean	3.095	3.104

- **5 samples are selected randomly.**
- **All samples are checked with good quality.**
- **Those paper honeycombs will be used to build the readout panel**

Production procedures and main difficulties

➢ Production procedures:

- Stick **X** shape tape on the PCB, and spread Araldite 2011 glue on the PCBs
- Align 2PCBs + honeycomb layers
- Glue 3 layers (2PCBs + honeycomb) together with enough and uniform pressure

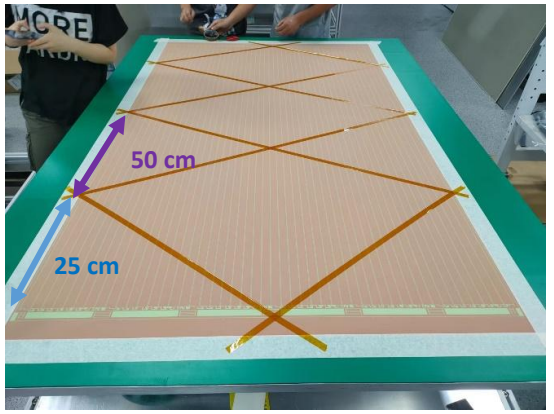
➢ Main difficulties:

① How to make sure the alignment bewteen ground and strip PCBs ?

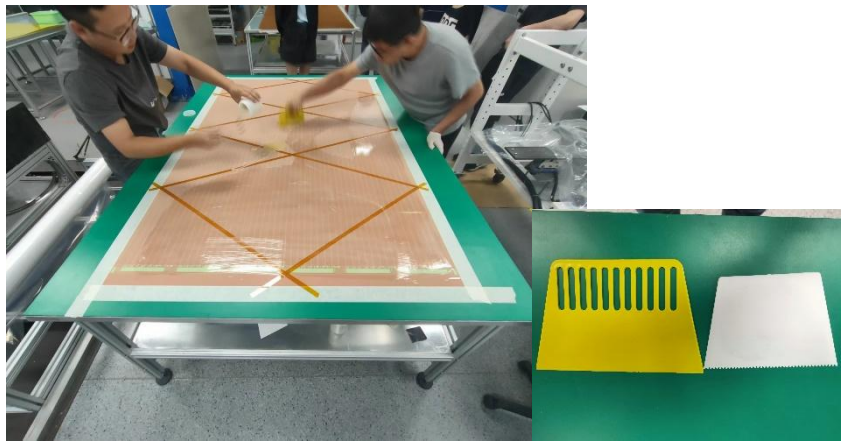
② How to apply enough pressure uniformly over such large area (1706 x 1070 mm^2) ?

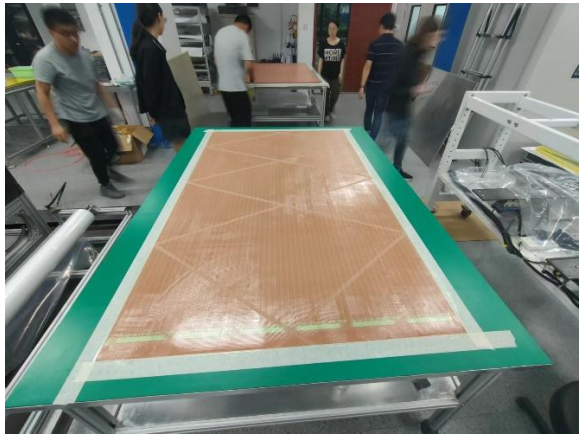
First step: X shape tape sticking and glue spreading

- Stick X shape tape on the strip and GND panel
  - The distance between the two parallel tape is 50 cm
  - The edges of PCB are protected with mask (3mm)



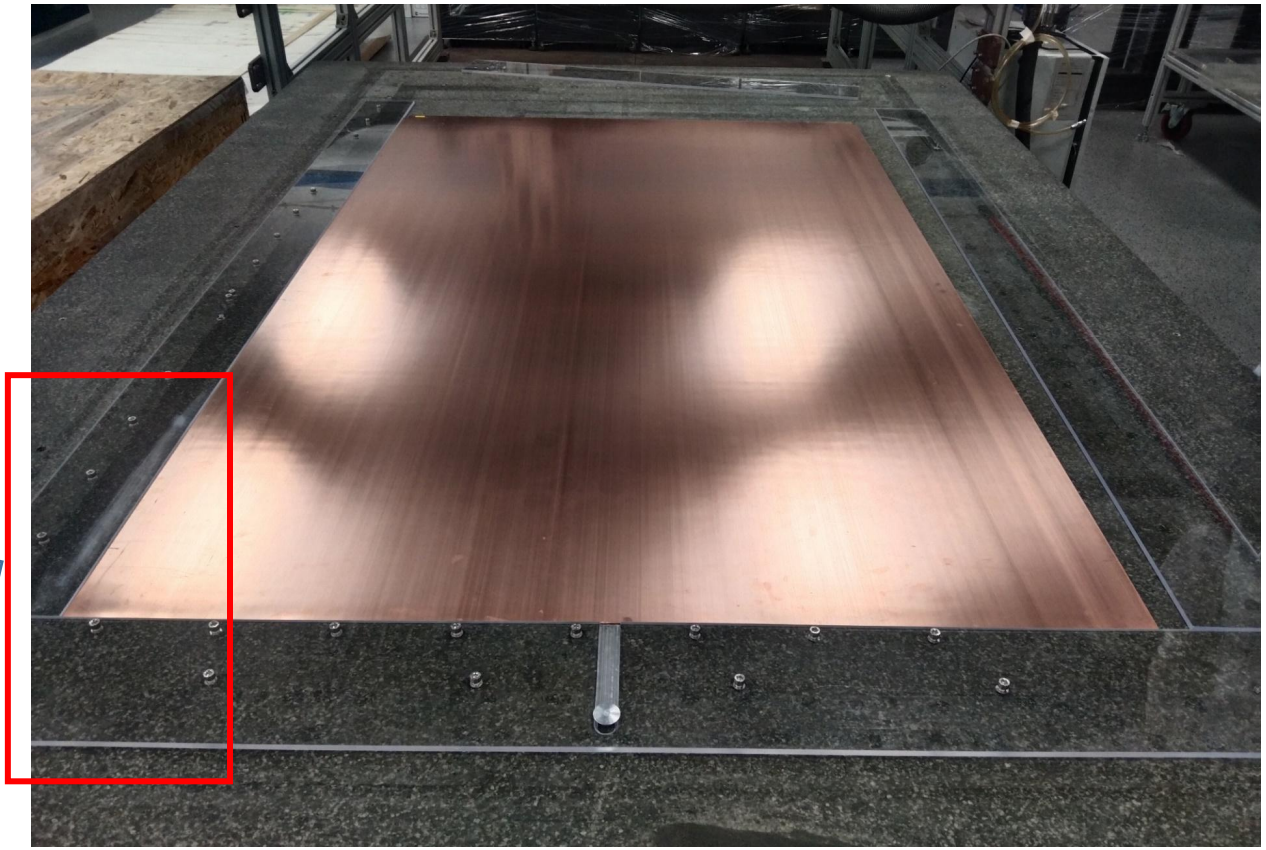
- Distribute the glue on the PCB (~ 10 minutes)
  - Pour the glue onto the panel (ARE-310 mixes the glue and gets rid of the bubbles)
  - Plastic spreader (Yellow) used to distribute the glue and then another spreader (white) with V-shaped notches used to spread the glue uniformly
- Remove the tapes





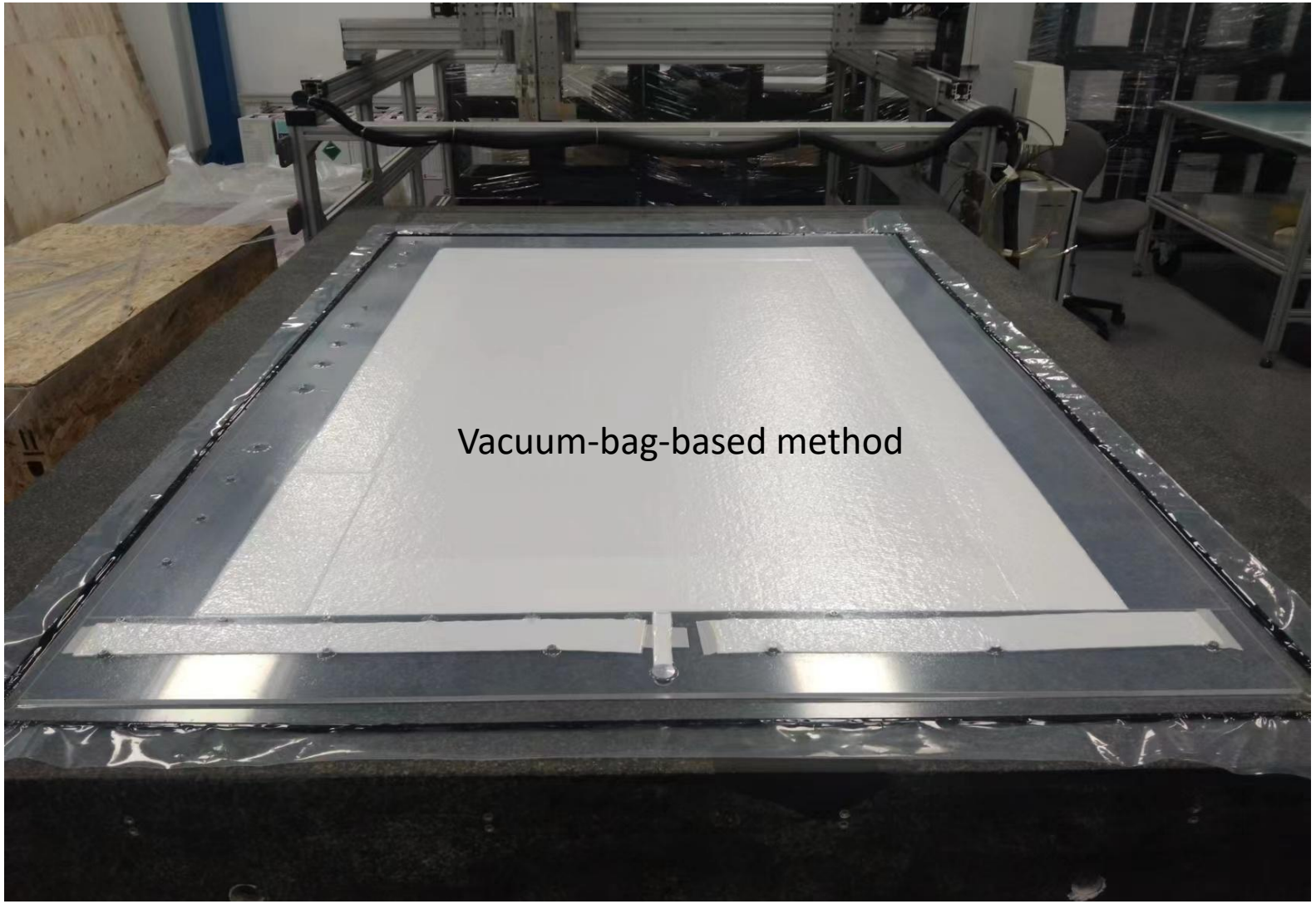
Second step: Alignment of 2PCBs and honeycomb

- All layers (2 PCBs + honeycomb) aligned to two reference bars fixed on the marble table.
- The readout panel can be glued at one time.

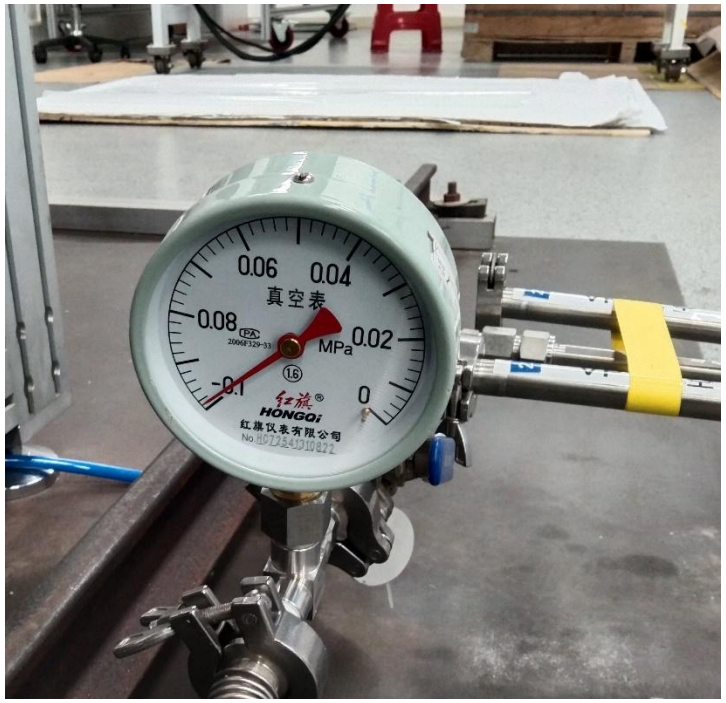


① How to make sure the alignment bewteen ground and strip PCBs ?

Last step: Glue 3 layers together



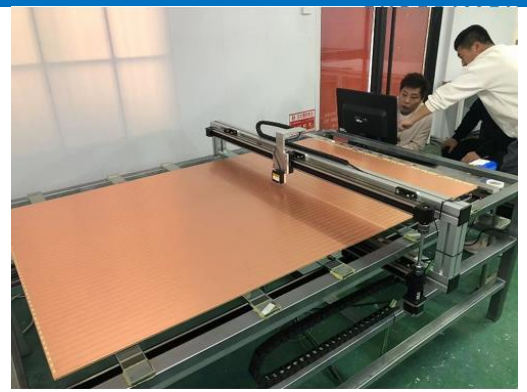
The vacuum power： 1 atm

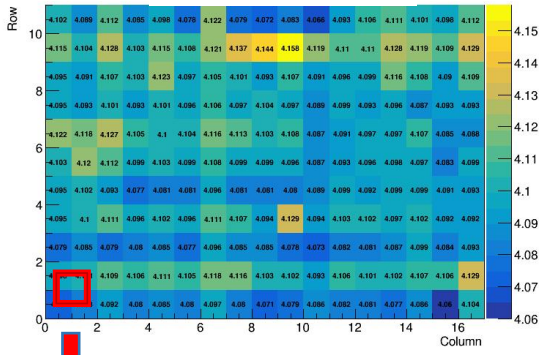


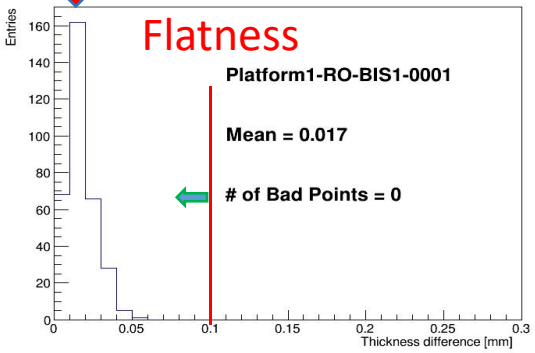
Keep at least 6 hours for the epoxy curing within the vacuum bag.

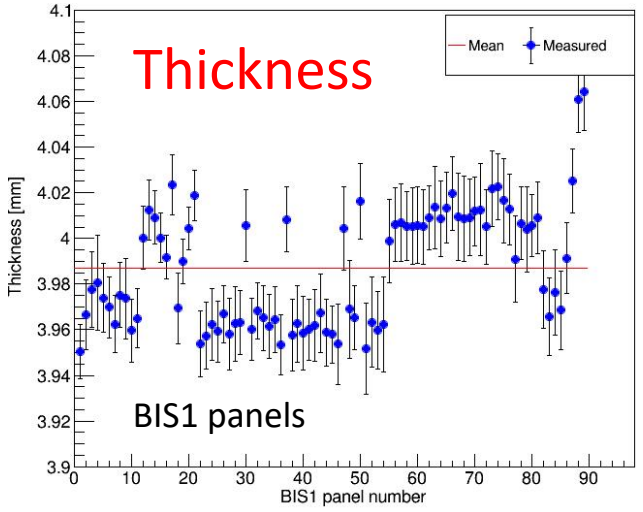
② How to apply enough pressure uniformly over such large area (1706 x 1070 mm²)?

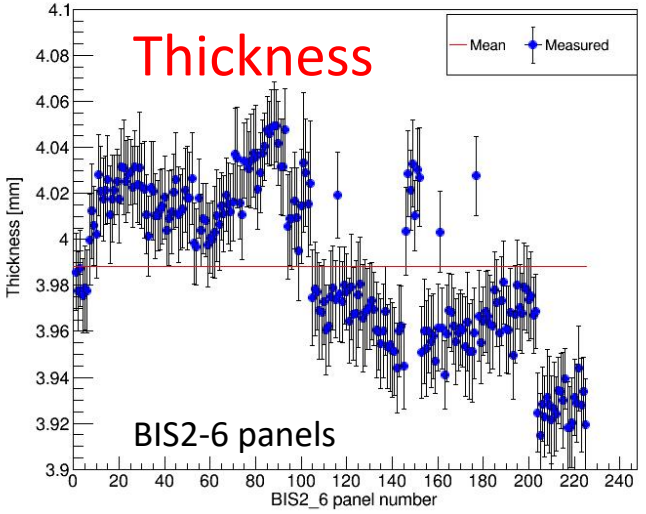
Thickness measurement and results











Summary of readout panels

- The thickness is measured in 7cm * 7 cm matrix by two laser sensors automatically (Top left).
  - The distance between two points is 7 cm
- The flatness < 100 μm can be achieved in 7cm * 7cm range. (Bottom left)
- About 300 readout panels are built in the external company with the same method and the quality is good (Middle two plots)
  - The measured central value is the average value of thickness across the panel
  - The error is the standard derivation
- The speed is about 4 panels per day

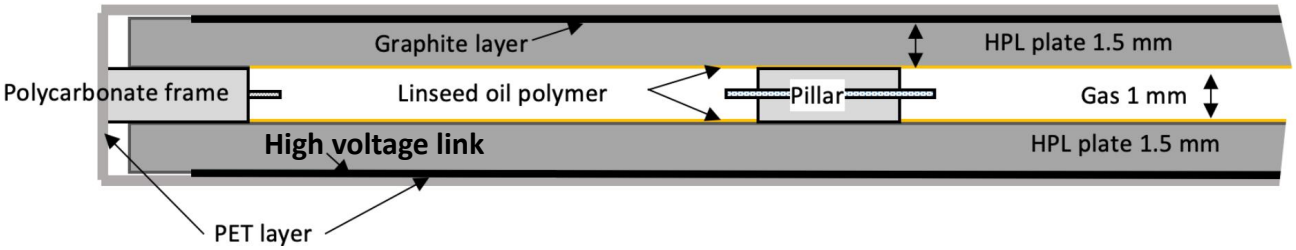
Flatness: Maximum variation of 4 points in a 7cm * 7 cm range

RPC gas gap production

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

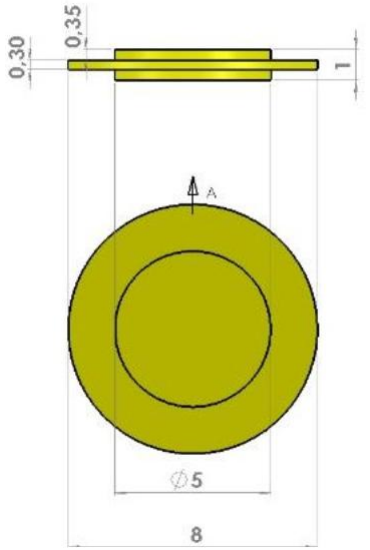
RPC gas gap

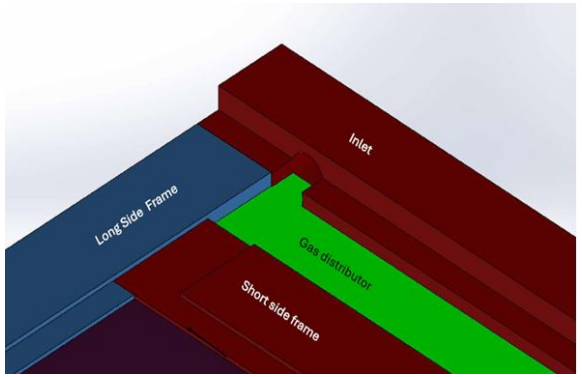
- General description
  - It has large area parallel plate structure
  - It works on the avalanche mode

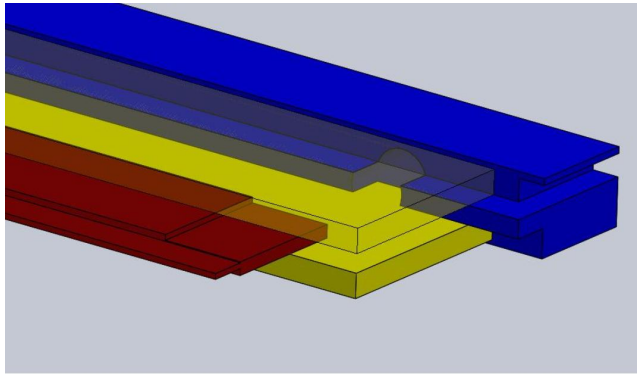


Sketch of a Gas Volume

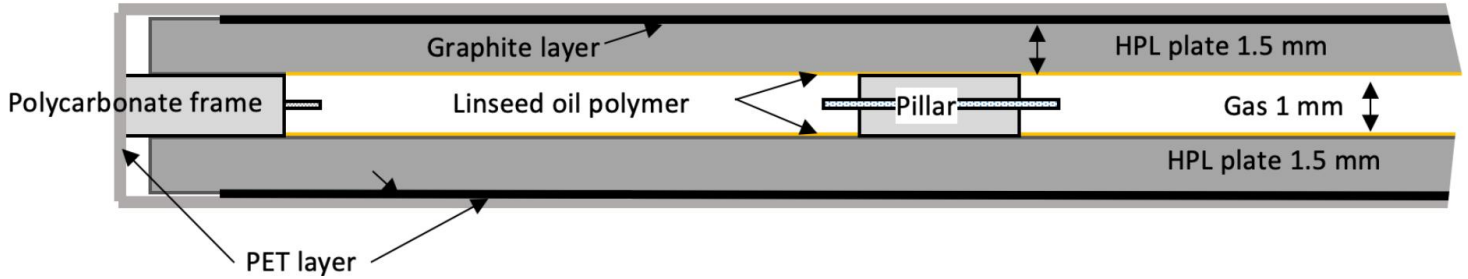
- Components:
  - Closed gas gap (2 HPLs + Spacers + PC frames + Gas distributers)
  - Graphite layers
  - High voltage links
  - PET layers
  - Linseed oil polymer







The main steps/difficulties to build a gas gap



Sketch of a Gas Volume

➢The main steps/difficulties to build a gas gap

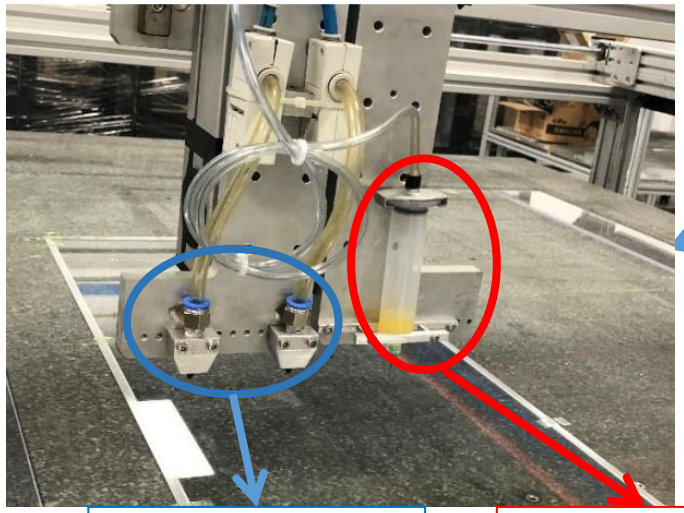
- Closed gas gap with good tightness and flatness
  - ✓ The flatness of the gas gap is guaranteed by spacers and frames.
- Graphite coating
  - ✓ Surface resistivity shall be 350±100 kΩ/□
- PET foiling (absence of bubbles > 2-3 mm^2 between PET foil and graphite layer)
- HV contacting and hot-melt gluing
- Linseed oiling

The platform of gas gap production at USTC

- A marble table as base:

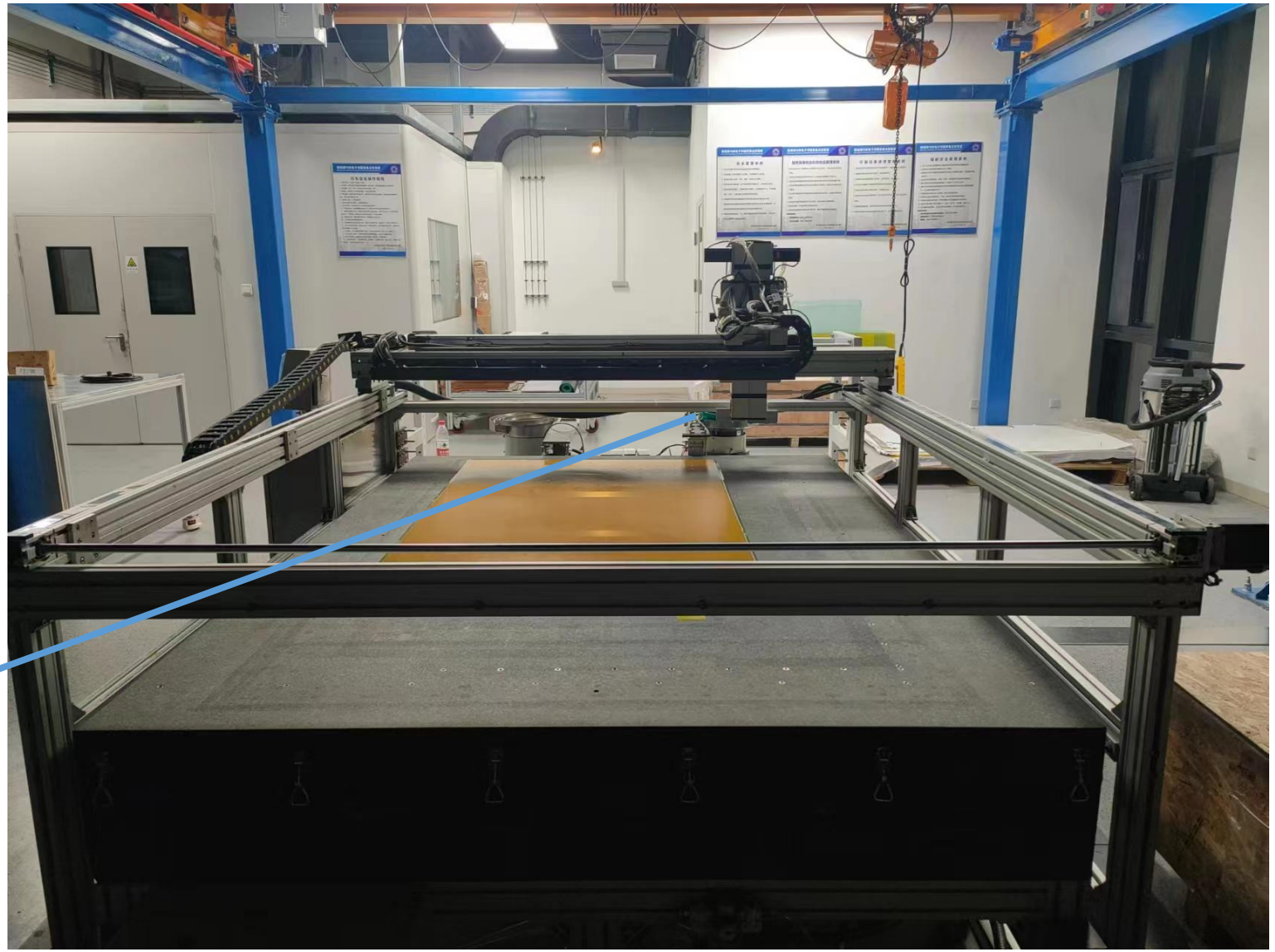
  2.5m×1.8m

- A head stock supported by a gantry moving in 2-dimentional
- 9 holes among the table are connected to the vacuum system.



Spacer pickers

Glue syringe

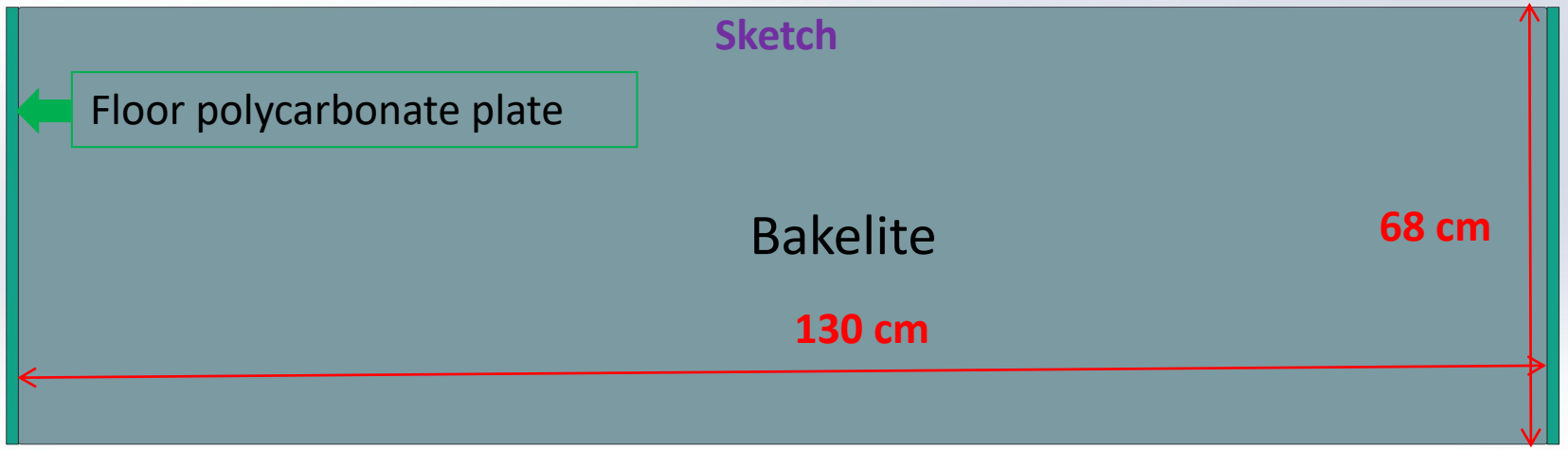


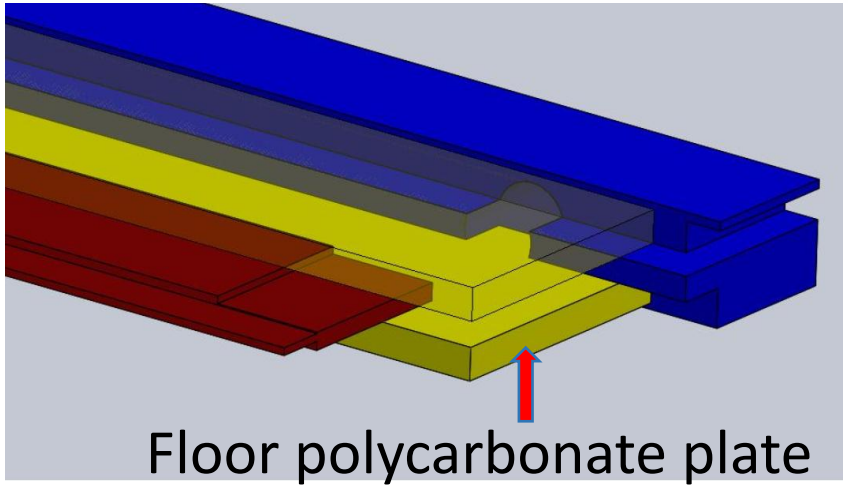
The assembly procedures of the closed gas gap

- 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

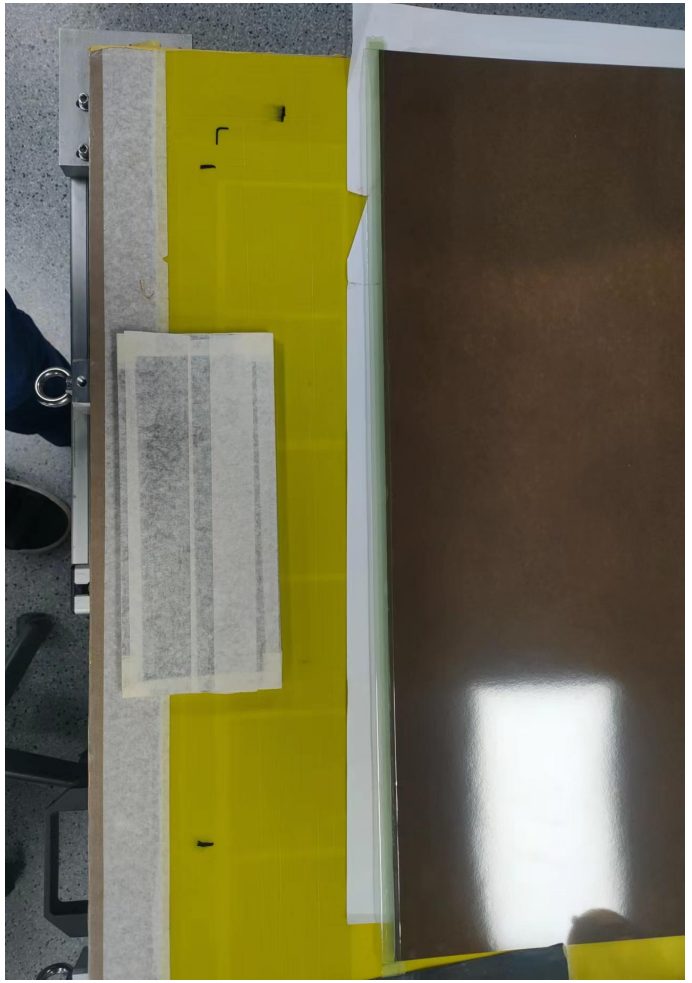
- Attach 2 floor polycarbonate plates to the bottom bakelite with Araldite adhesive glue





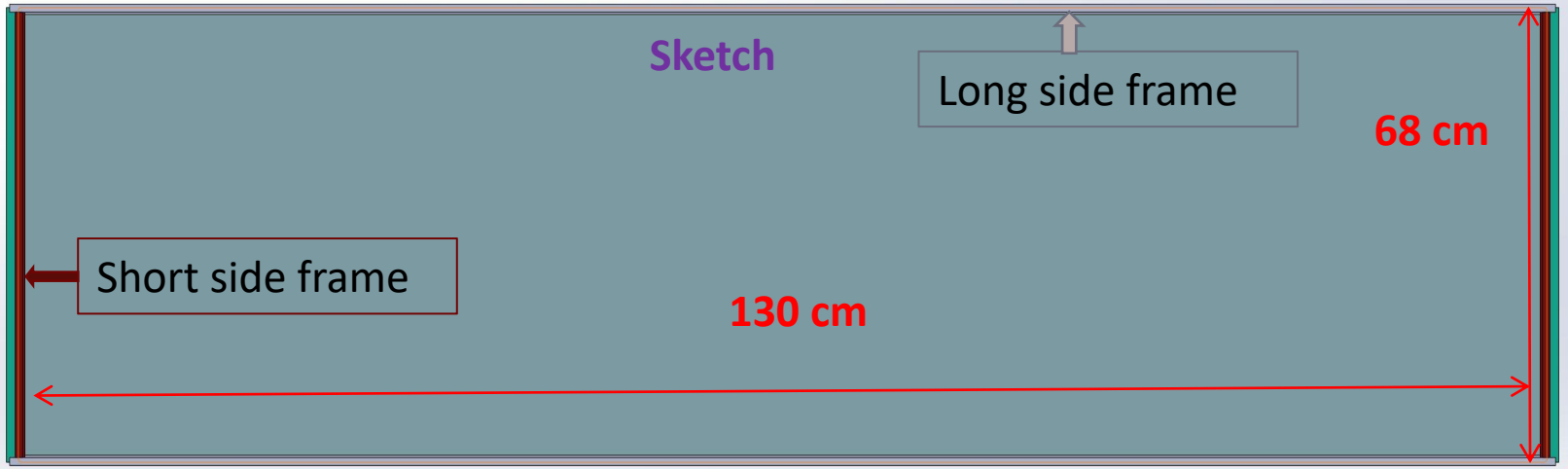
- ✓ The size of Bakelite: 130 cm * 68 cm
- ✓ The piece used in this step is indicated by the red arrow.

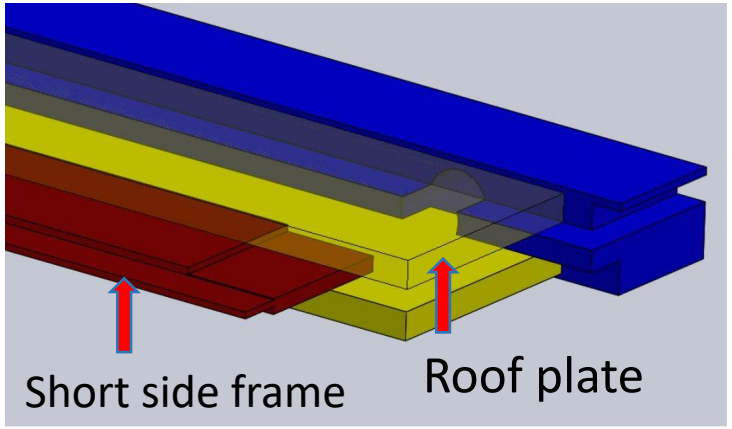
The bakelite and 2 floor plates will on the same plane

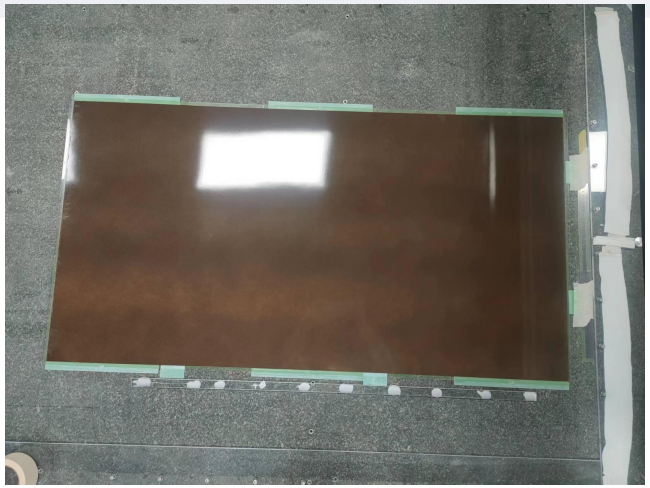


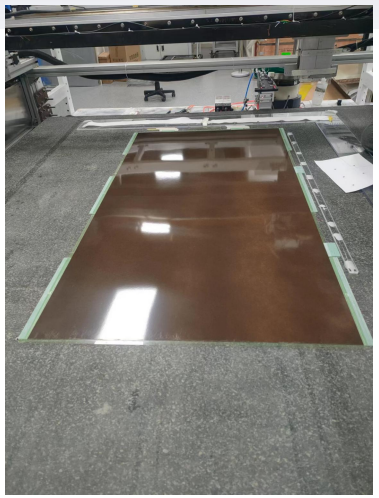
The second step

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





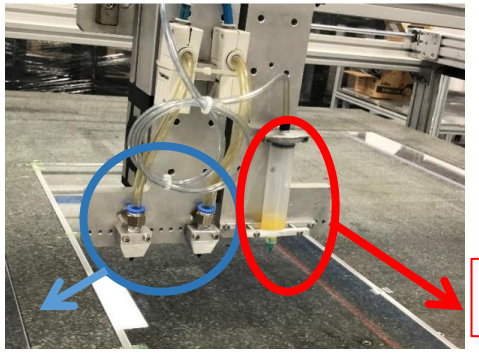


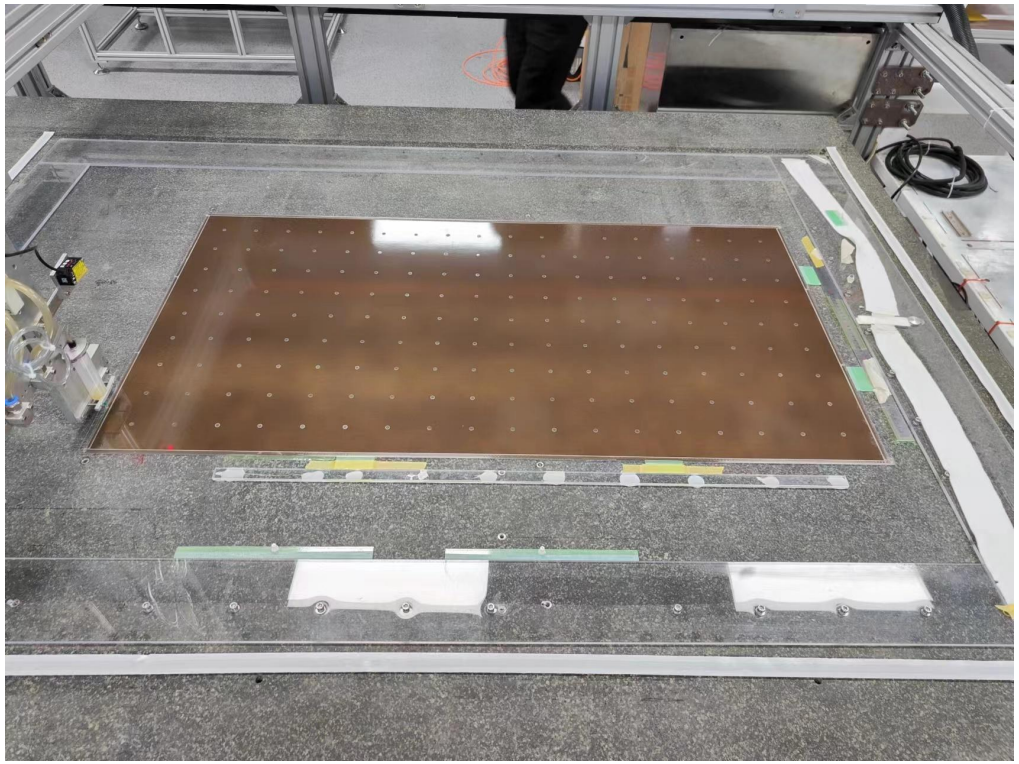


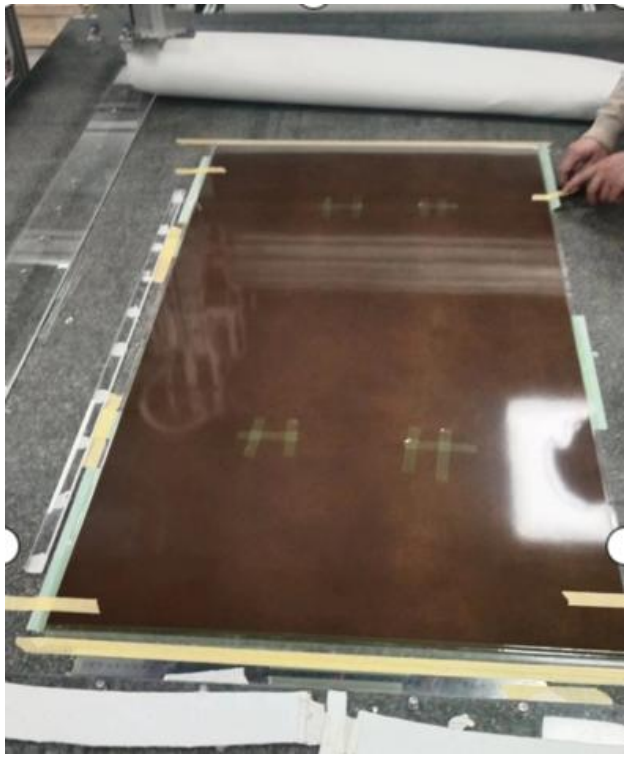
Zoom in

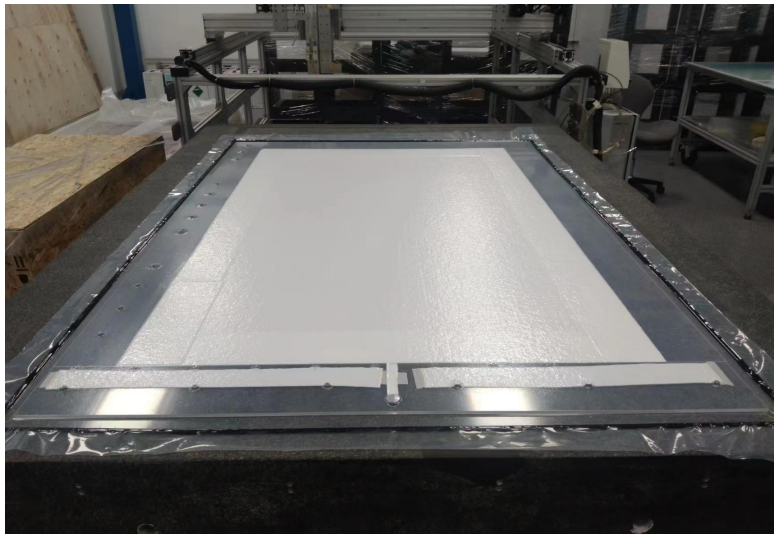
The third step

- 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





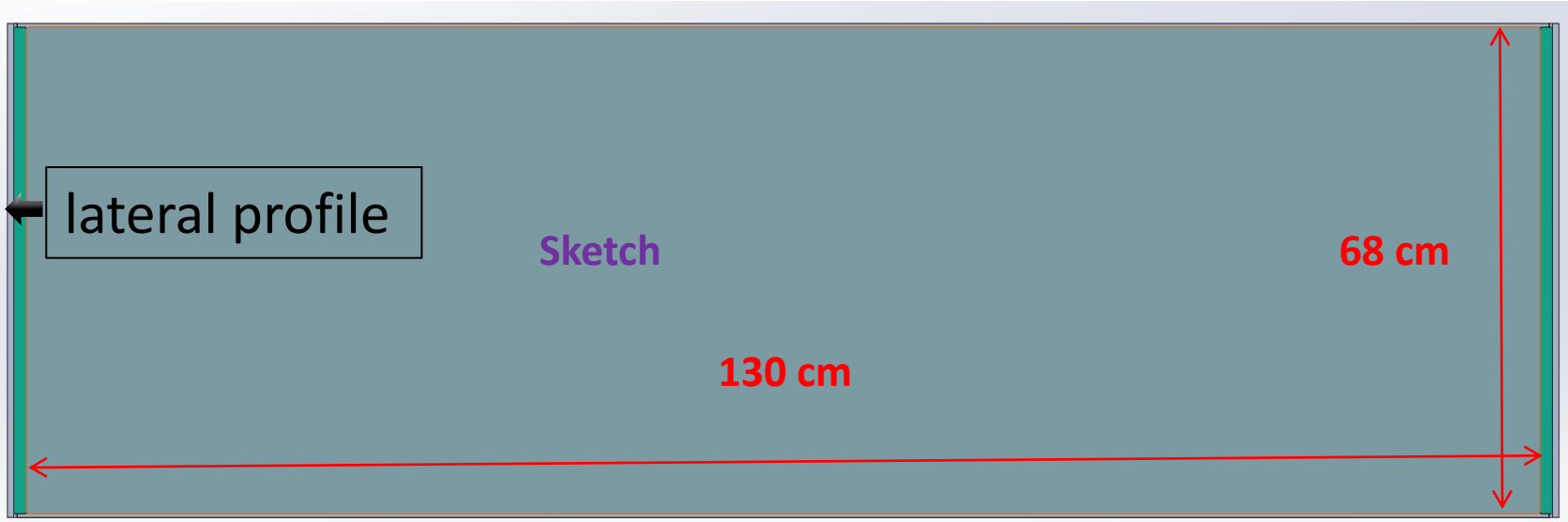


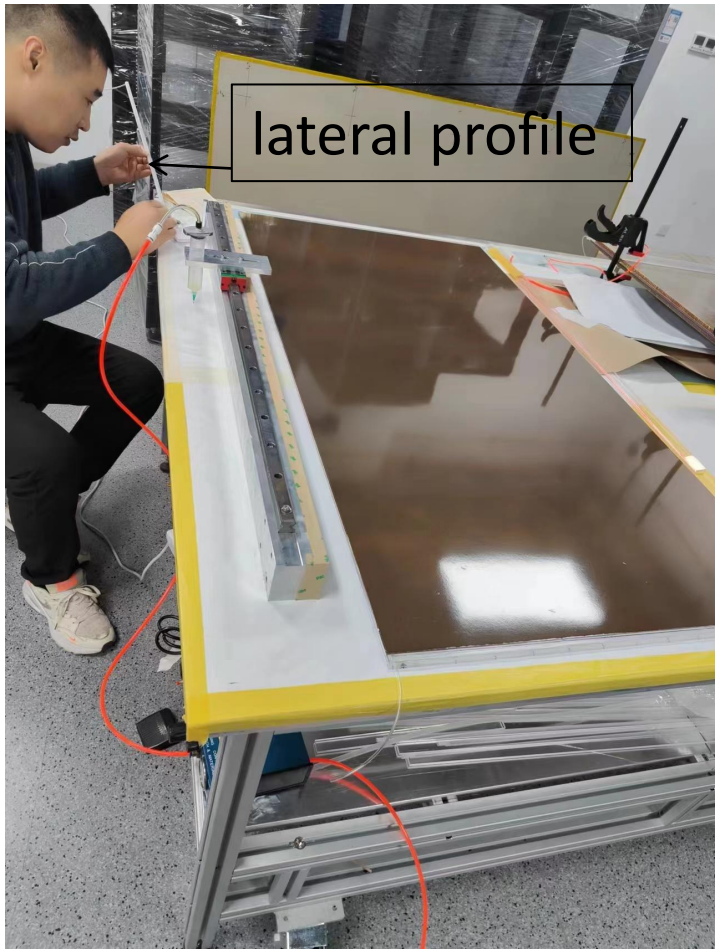


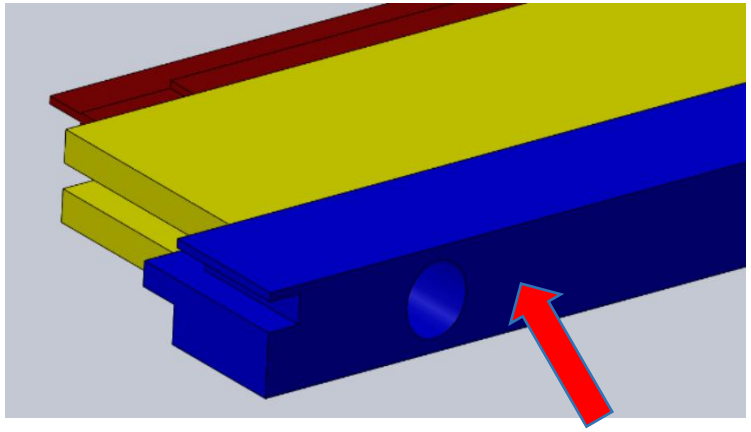
Keep at least 6 hours for the epoxy curing within the vacuum bag.

The last step

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







lateral profile

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

Test the tightness of the gas gap

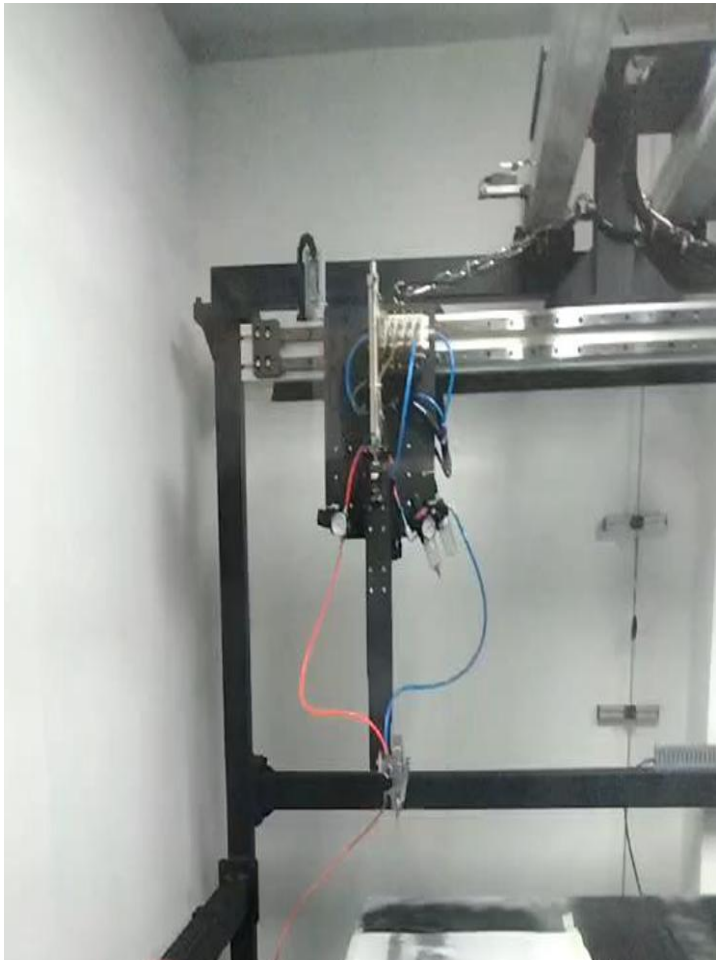
Argon sniffer

Manometer

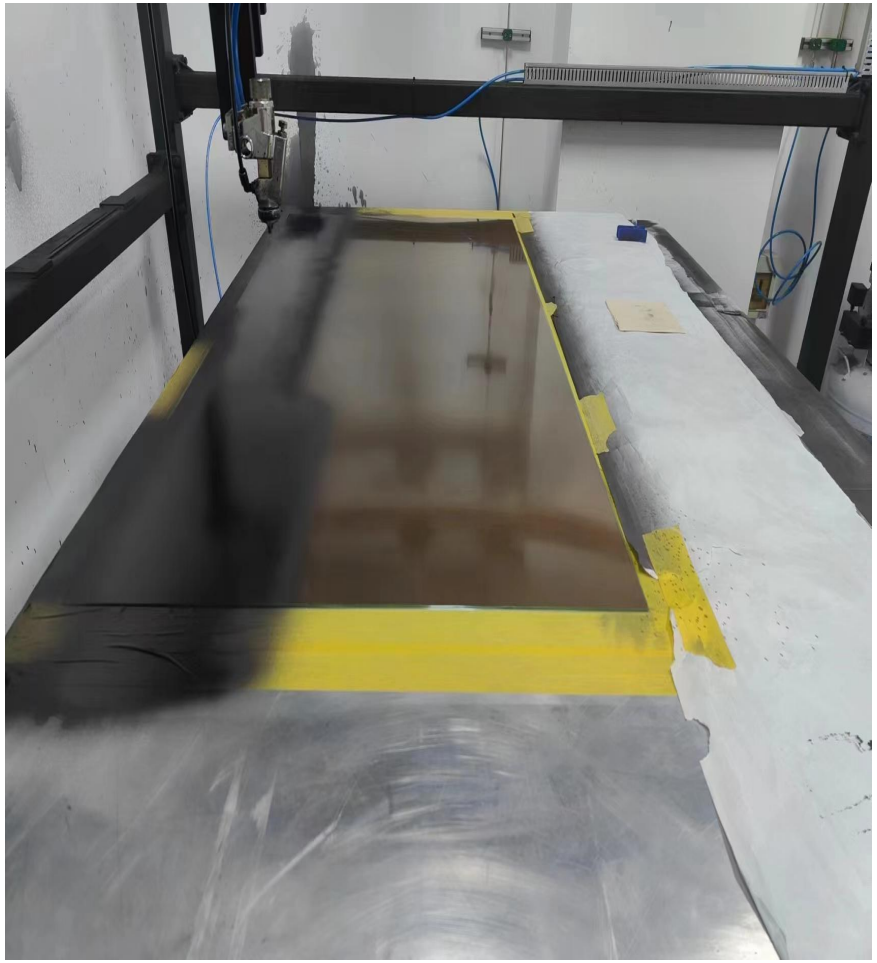
Buffer bag

- 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.**

Graphite coating and HV & Ground link applied

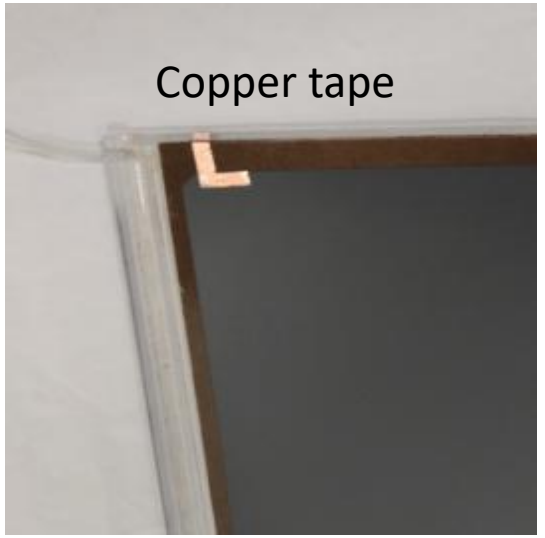


Graphite spraying system:
A spray gun held on a 2-D gantry



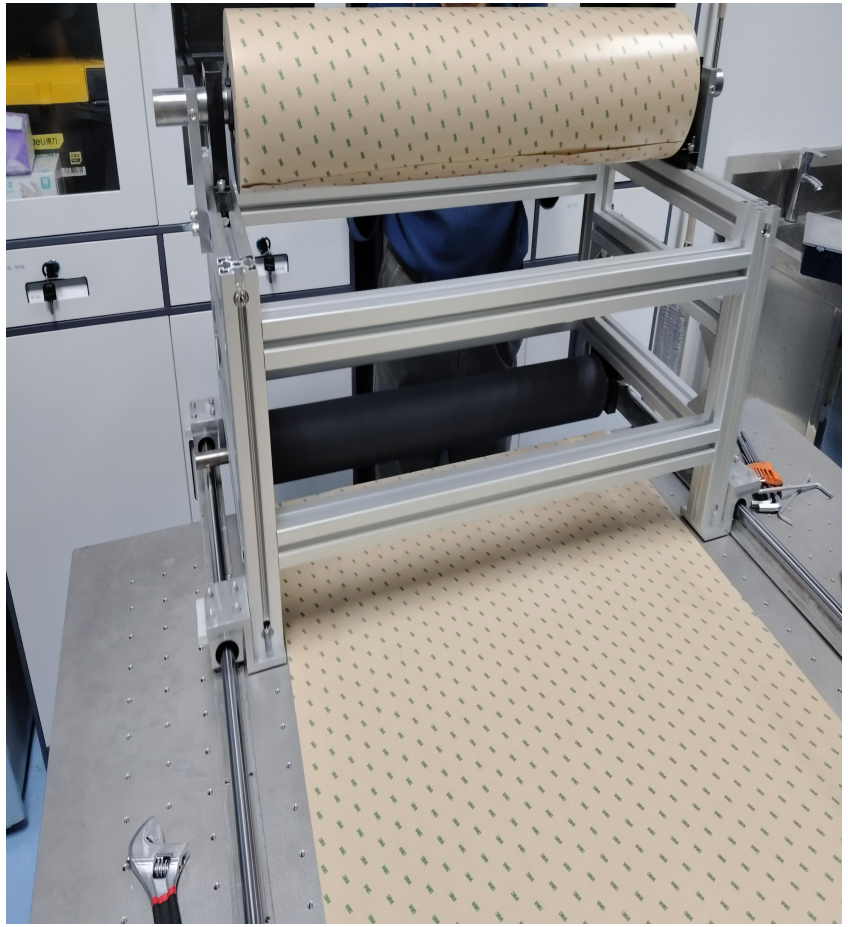
Graphite coating

Zoom in

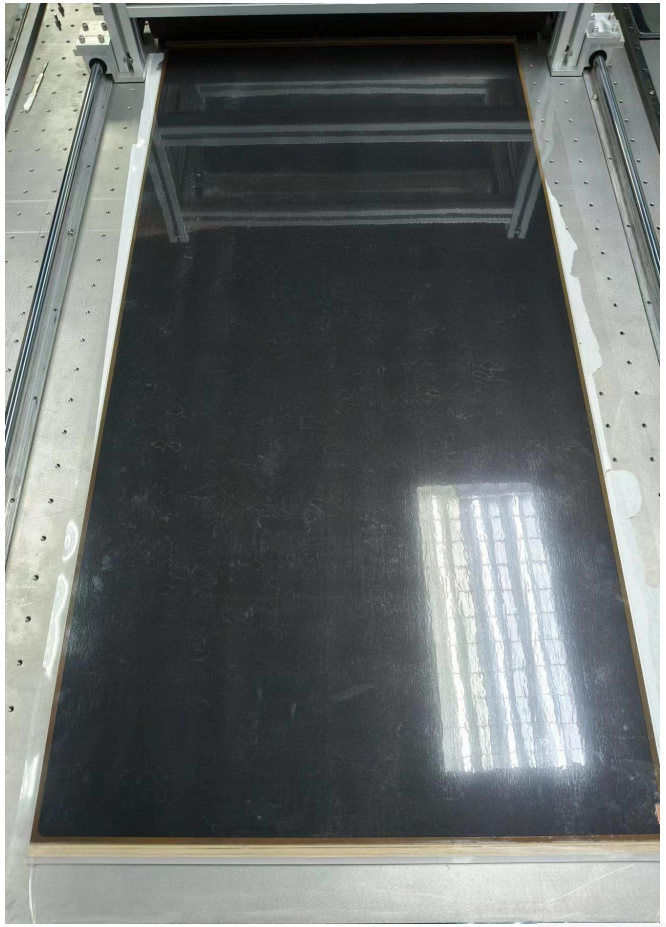


HV & Ground link applied

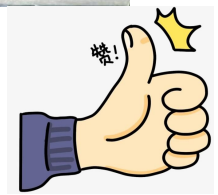
PET foiling



Tooling

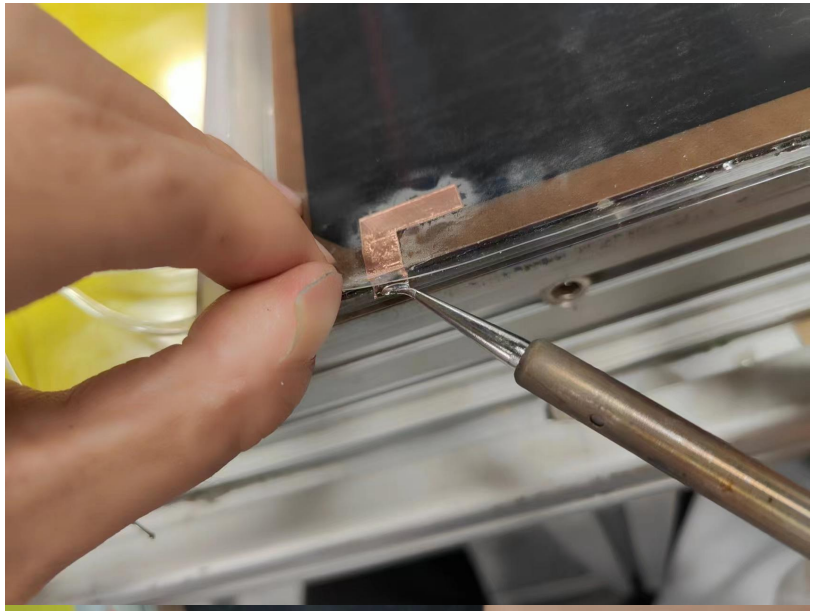


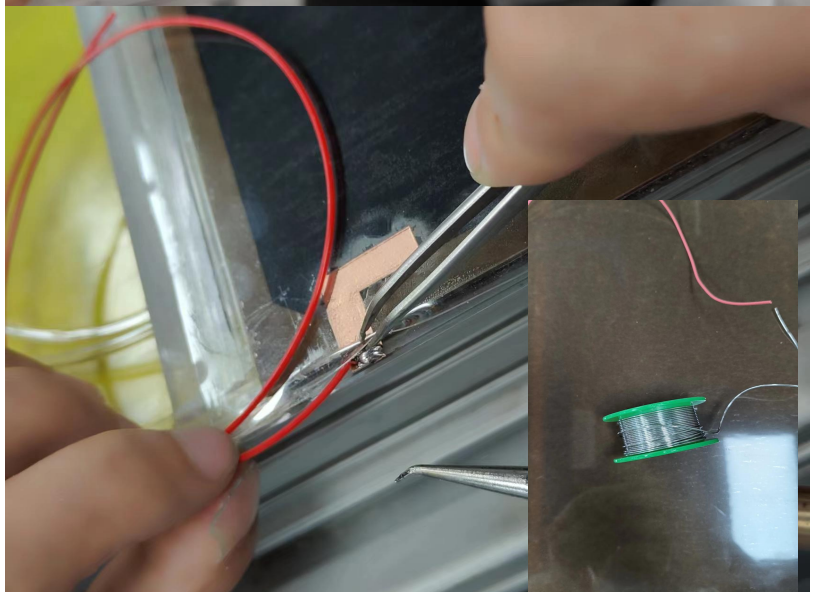
Mirror-like surfacing



- Temporarily, we used double-side tape instead of the thermal laminating film.
- The thermal laminating film and the tool are still in preparation.
- The tightness of gas gap will be checked again after this step

HV contacting and hot-melt gluing

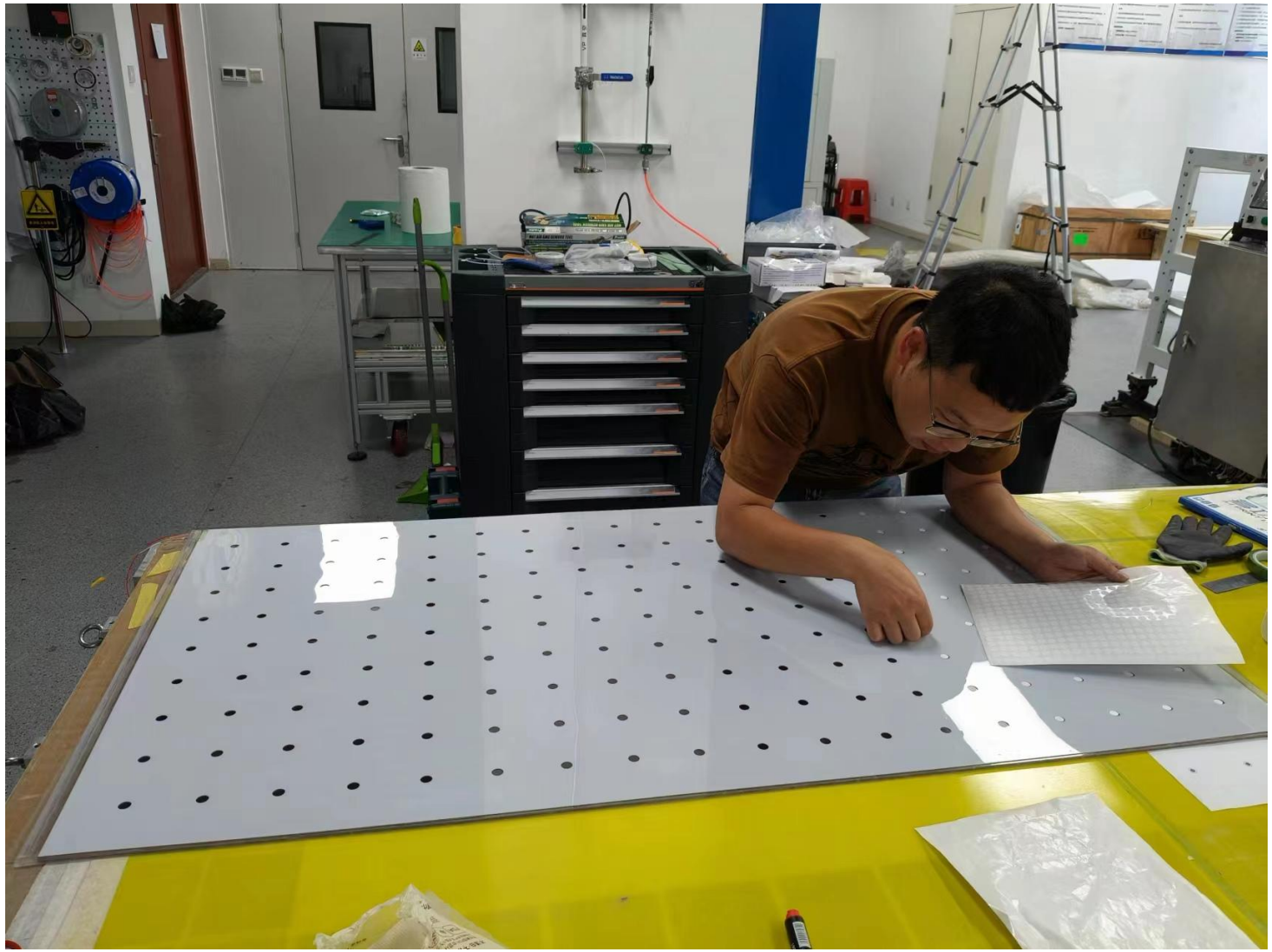


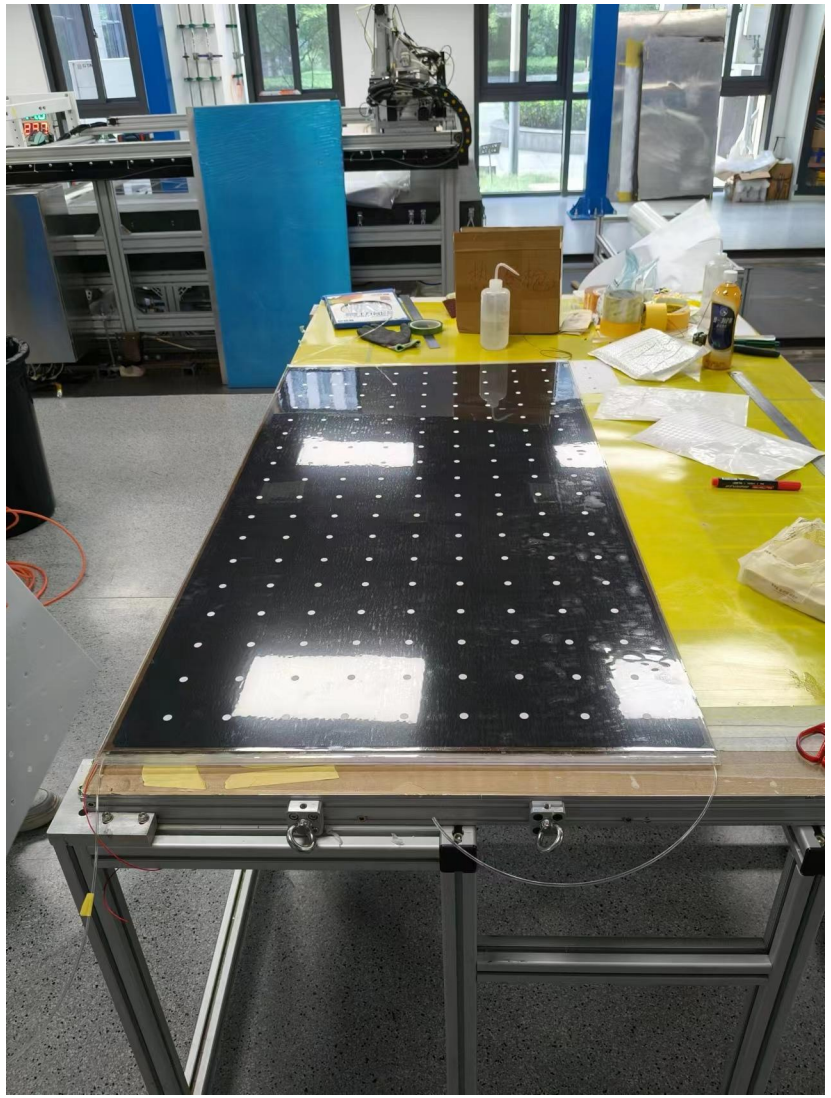


Filling and sealing the edges of the gas gap with hot-melt glue

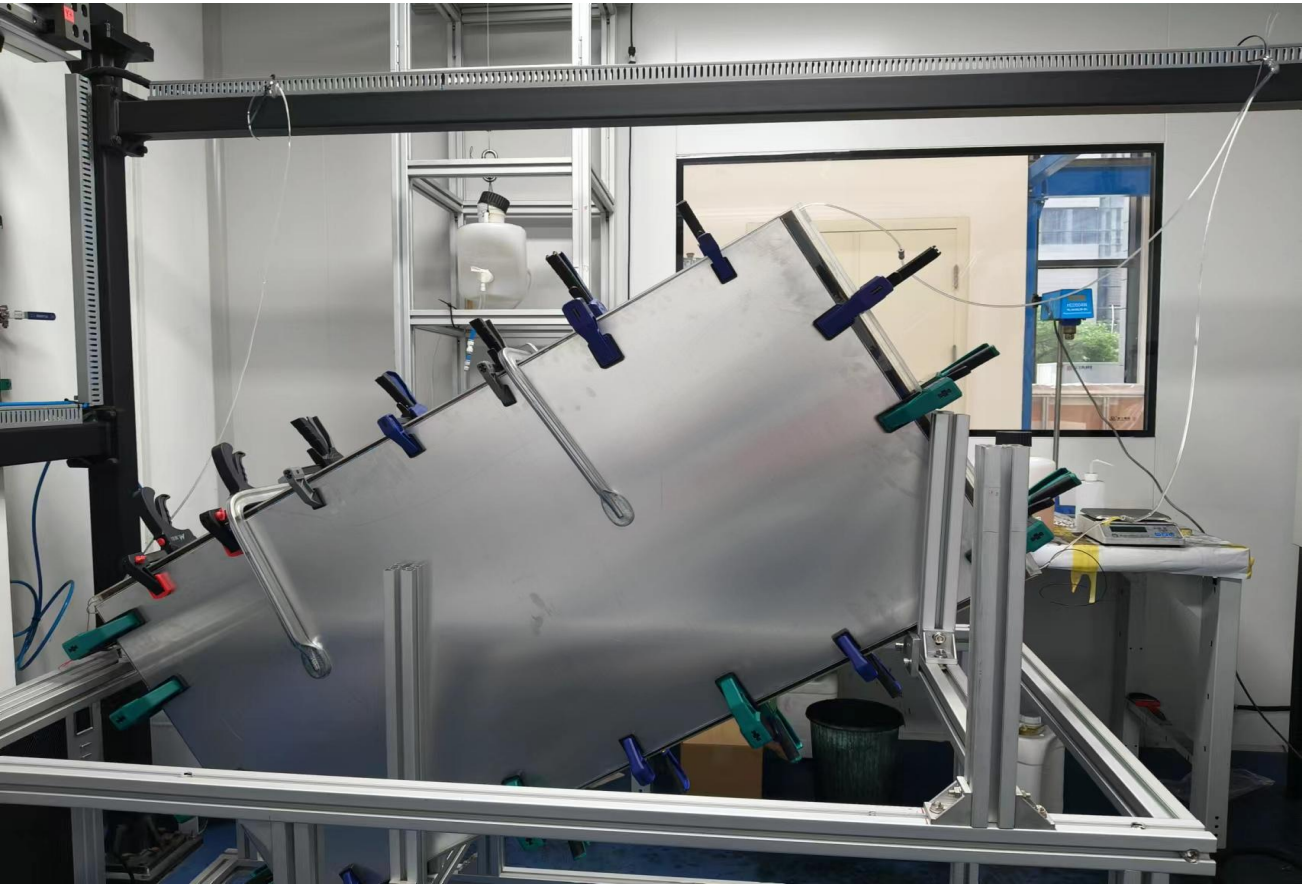
To protect PET foil, special solder wire is used

Paper stacker





Linseed oiling



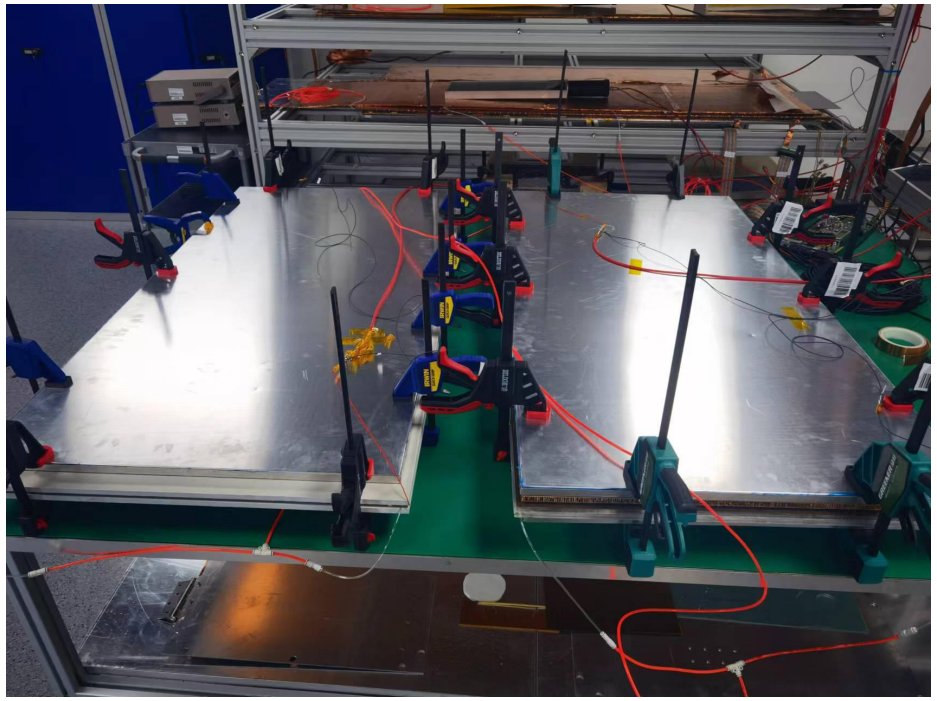
- The gas gaps are flushed with heptane through the gas connections from a supply bottle (From bottom gas inlet to top).
- Fill the gas gap with mixed oil and then empty the oil in the gas gap slowly (< 1m/h)
- Pumping the air through the gas gap for one week to achieve Linseed oil polymer (From top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

Preparatory work:

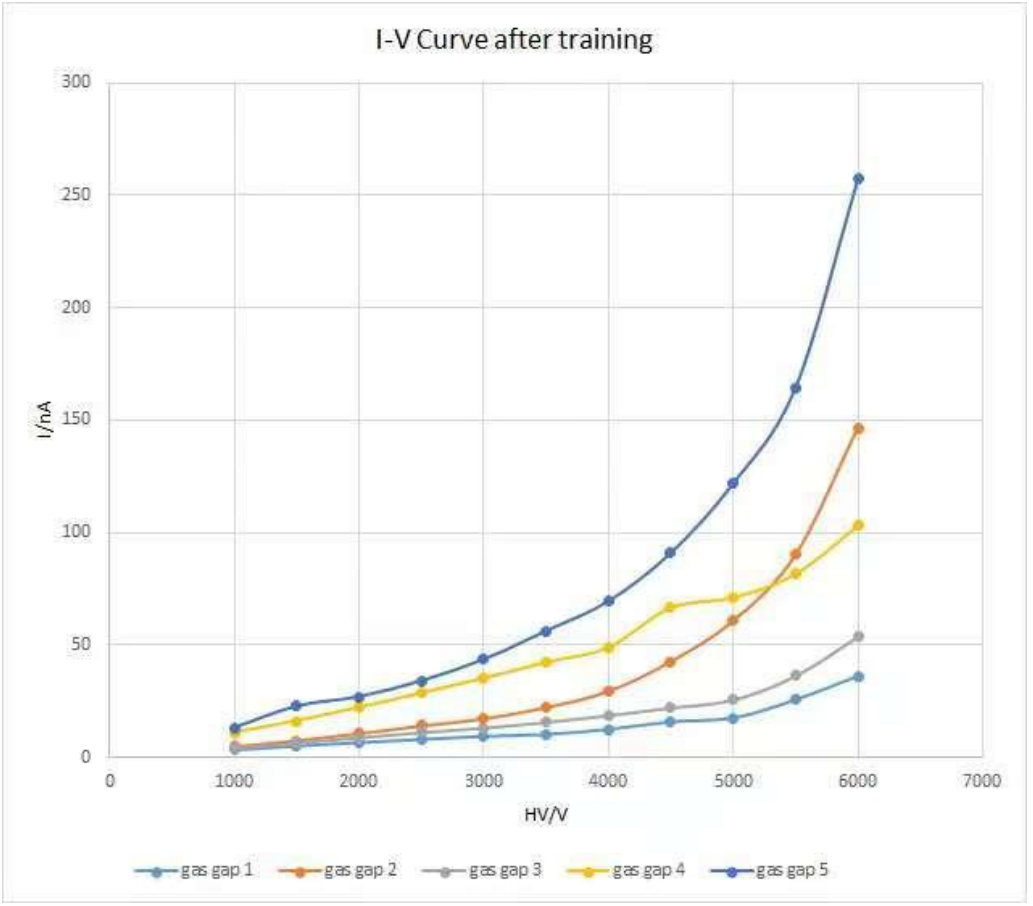
- Room temperature: ~ 40℃
- Mixed oil: 30% linseed oil + 70% heptane
- Use clamps to prevent bursting under oil pressure

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 cm^2

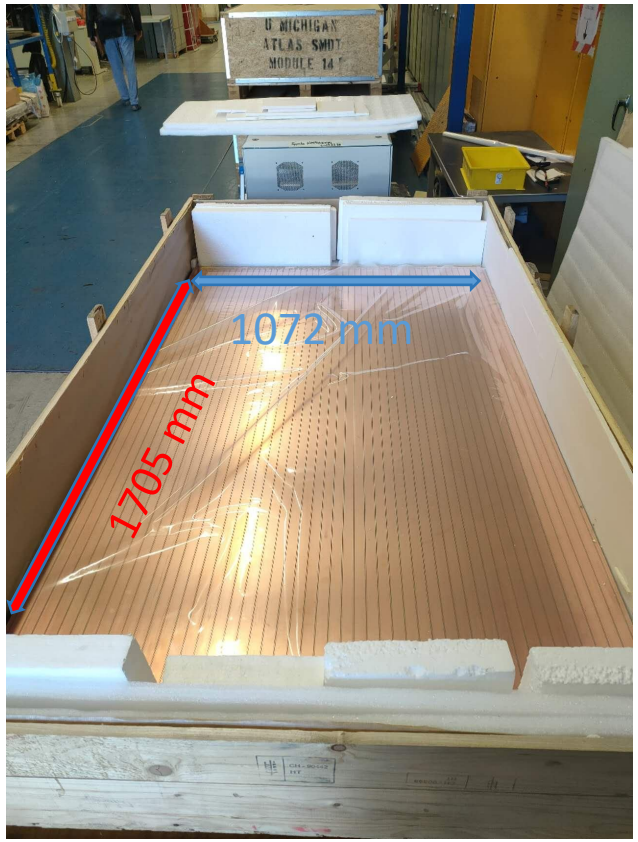


BIS singlet assembly works at CERN

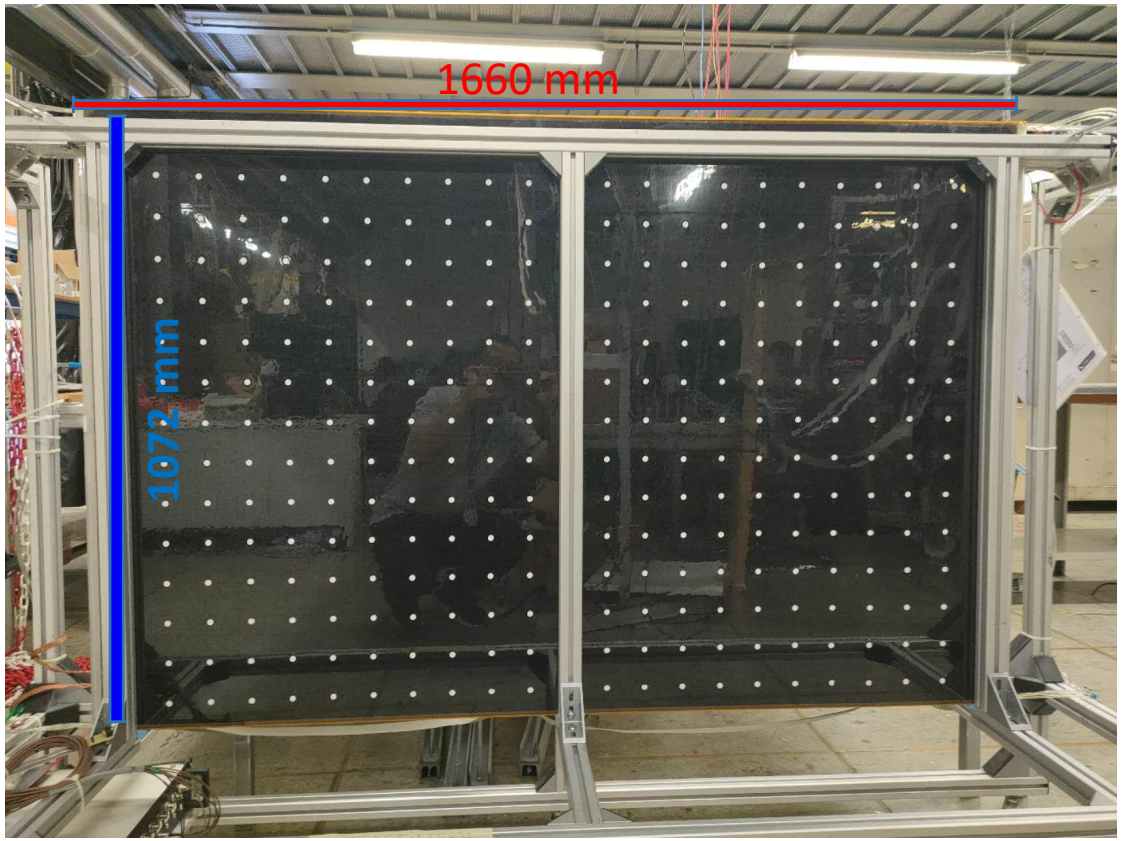
Without front-end electronics

Materials for the BIS singlet assembly

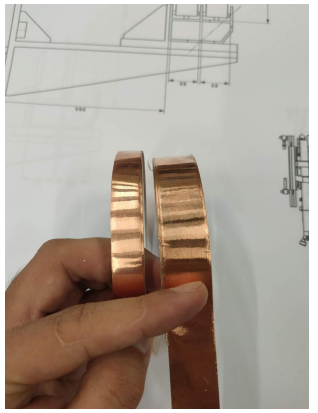
- 8 readout panels produced by USTC (Label: PCB1-PCB8)
- 4 gas-gaps produced by GTE (Label: BIS2A 2/23, BIS2A 3/23, BIS2A 4/23, BIS2A 6/23)



Readout panels



Gas gaps

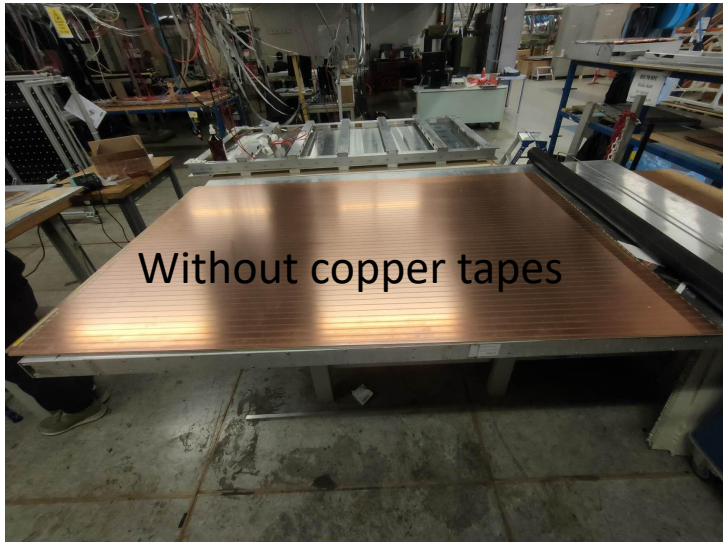


Copper tapes

Resistors

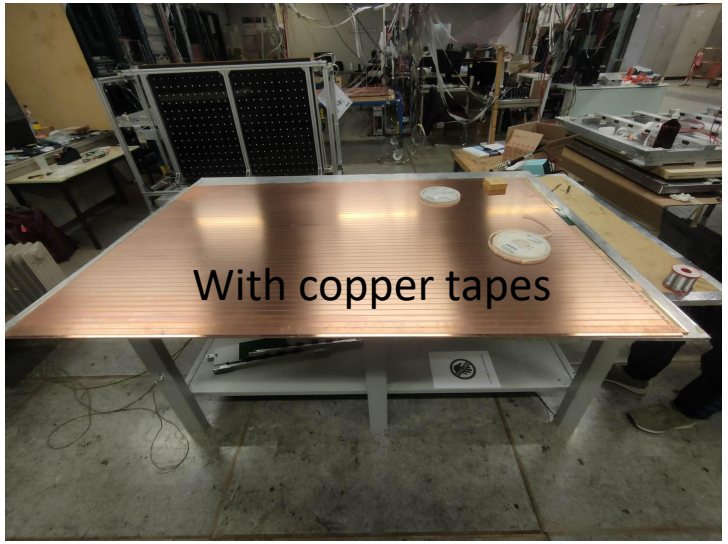
Preparatory works at CERN

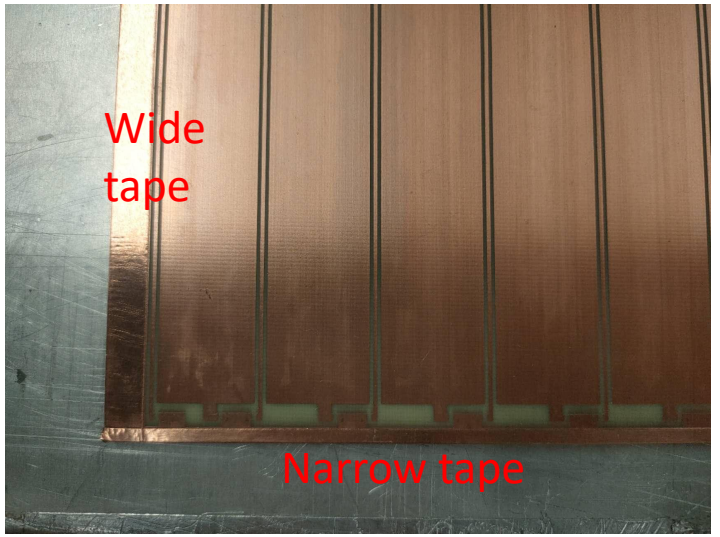
➢Step 1: Attach tapes around the readout panels



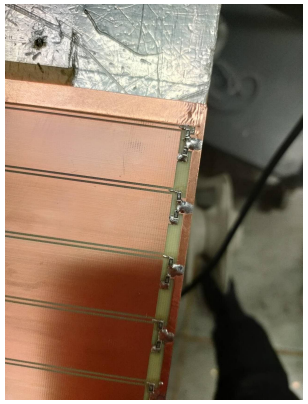
20-30

minutes





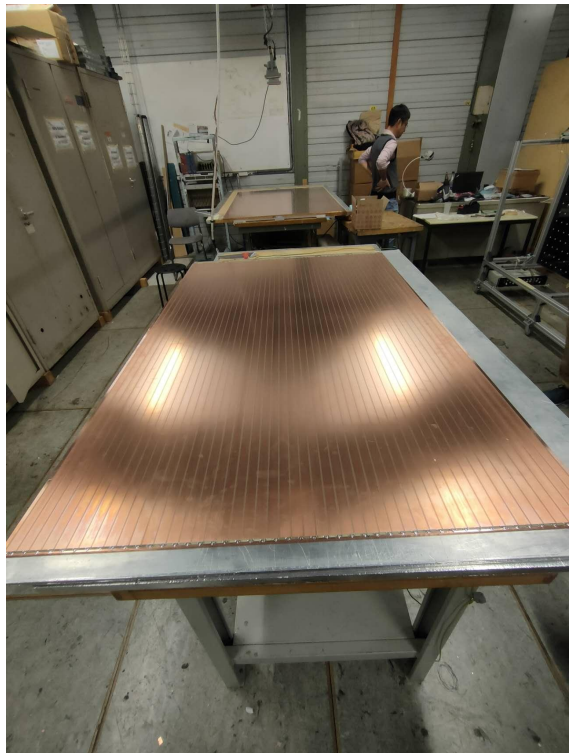
➢Step 2: Solder the matching resistors:



1 readout panel need (48 * 2 + 1) * 2 = 194 resistors,
take 1.5 hours for each readout panel
1 singlet: 194*2= 388 resistors
1 chamber: 3* 388 = **1164** resistors

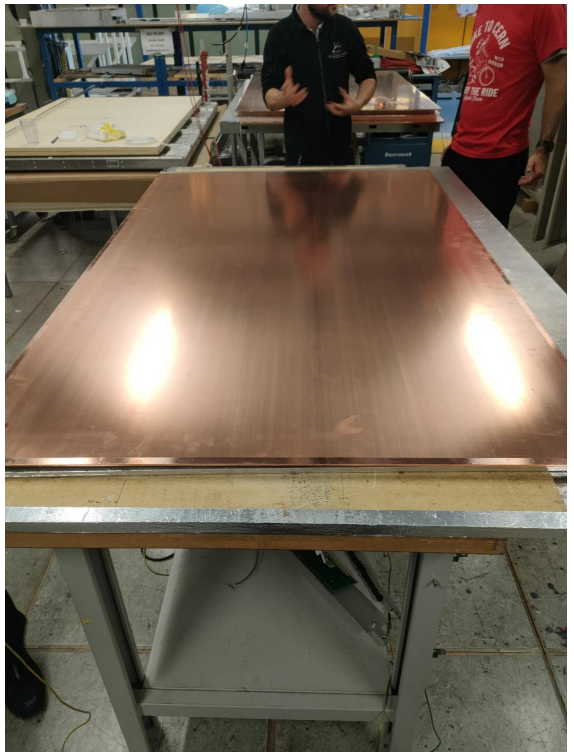
Very time consuming

Singlet assembly works

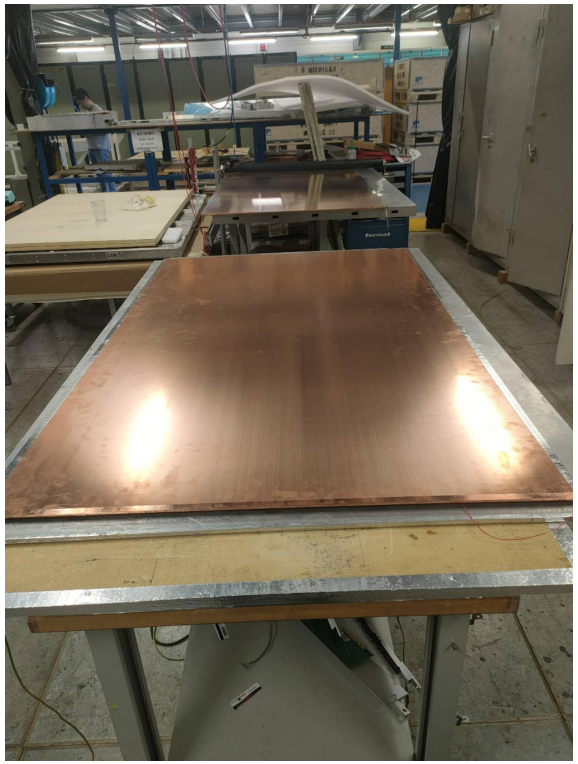


Step1:
Put the readout panel in the table with strip panel on the top

Step2:
Put the gas gap on the top of the readout panel



Step3:
Put another readout panel on the top of the gas gap



Step4:
Use the Aluminium tape to fix those three layers to form the singlet

Summary

- Readout panels production
  - The vacuum-bag-based readout panel production method has been established and optimized at USTC.
  - ~300 readout panels are produced in the external company with the same method, the flatness of the readout panel < 100 um, can satisfy the specification.

- Gas gap production at USTC
  - 5 gas gap prototypes (130 cm * 68 cm) are produced at USTC, the test results (I-V curve) are very promising.
  - Those gas gap prototypes will be shipped to CERN to do the irradiation test soon.

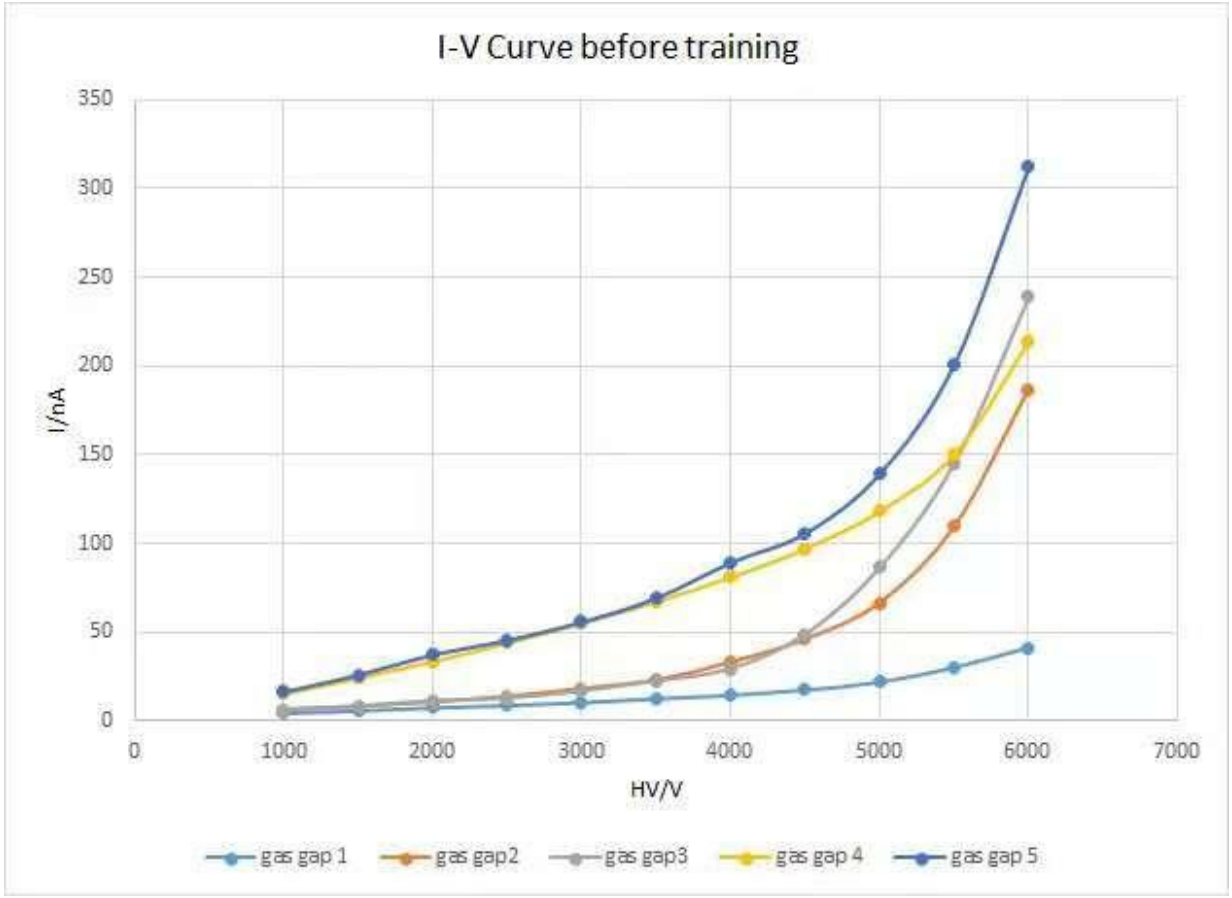
- We are ready to start the singlet assembly work at USTC.

Any questions or comments are welcome

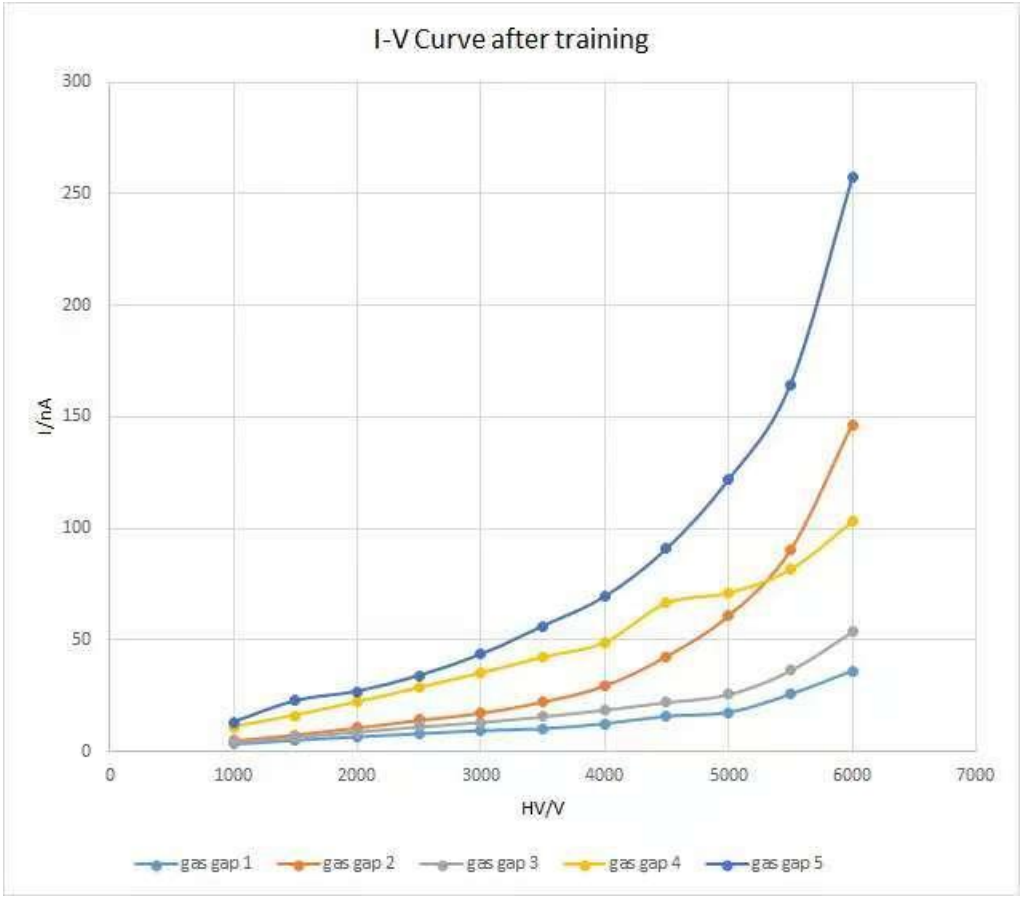
Thank you

Back up

Before and after training comparison



Before



After

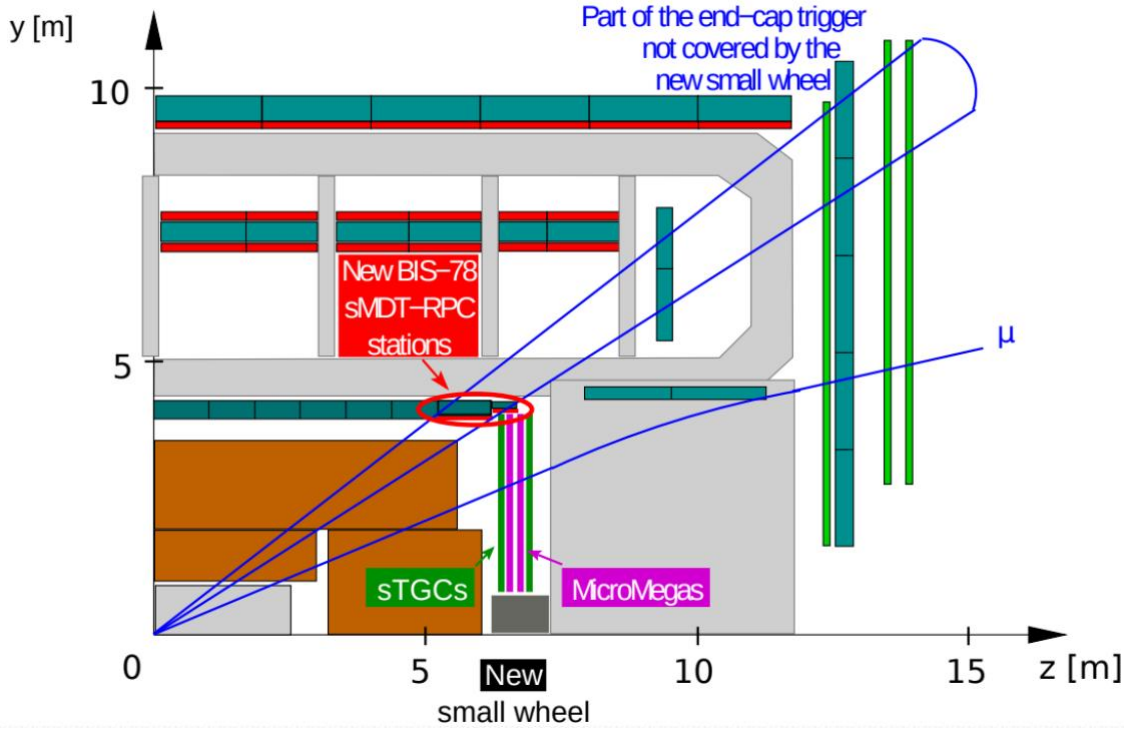
The new method to solder the matching resistors

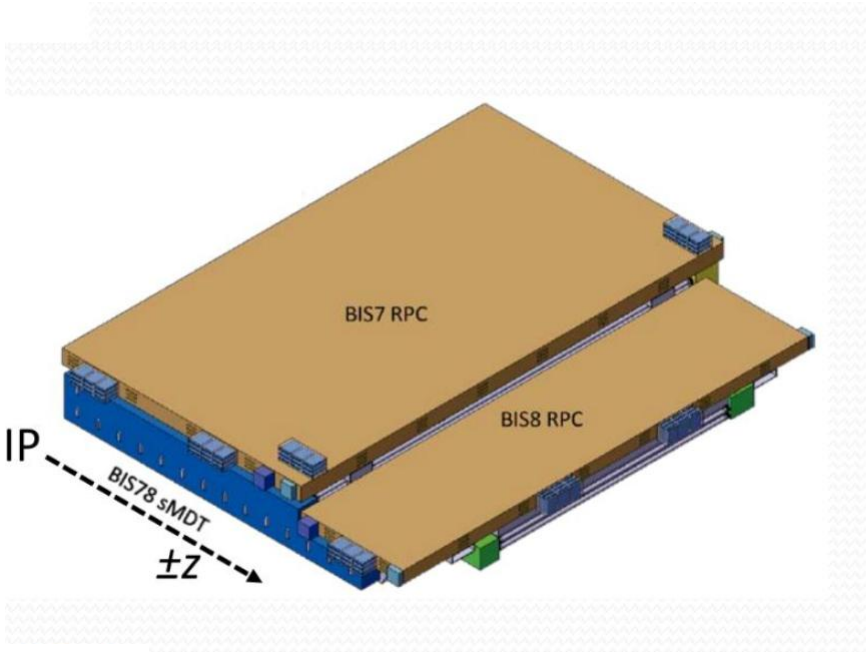
Mask plate

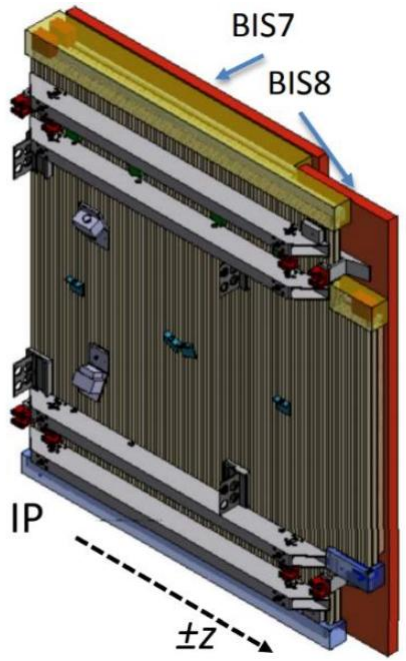
Solder paste

Tweezer welding table

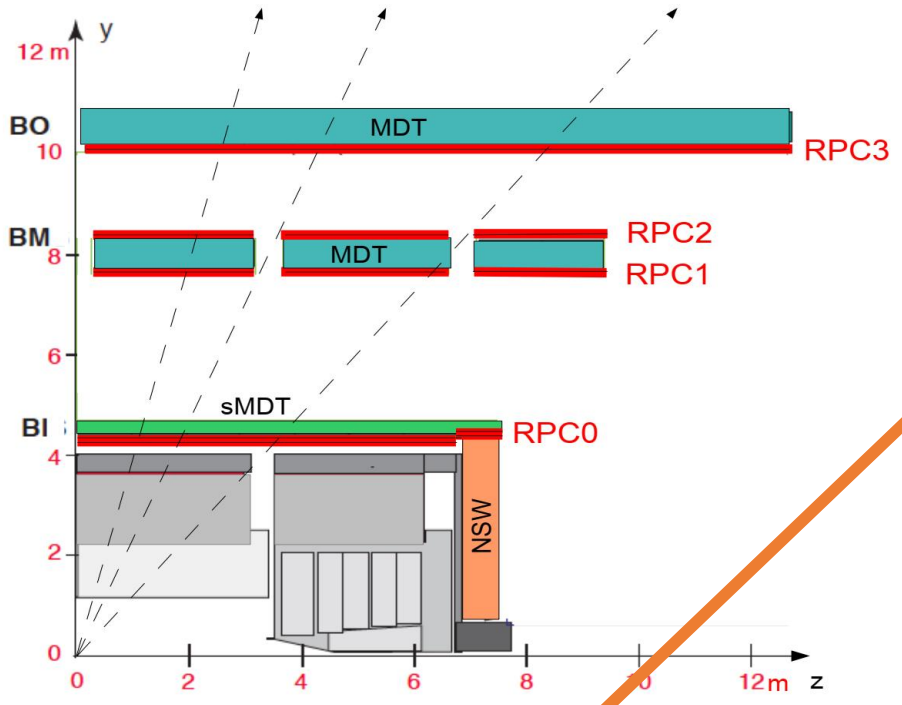
BIS78


y [m]
10
5
0
5
10
15
z [m]
Part of the end−cap trigger
not covered by the
new small wheel
New BIS−78
sMDT−RPC
stations
μ
sTGCs
MicroMegas
New
small wheel

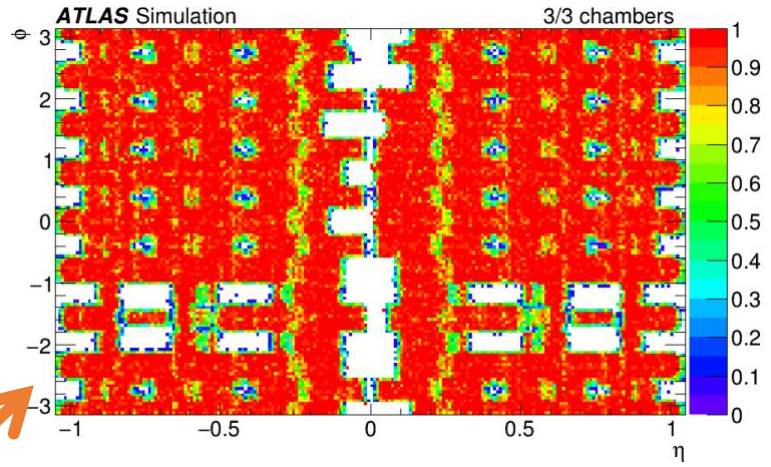

BIS7 RPC
BIS8 RPC
IP
BIS78 sMDT
±z

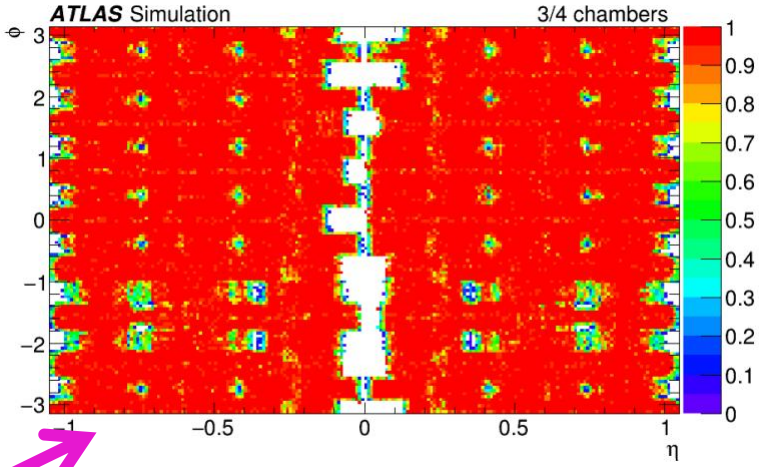

BIS7
BIS8
IP
±z

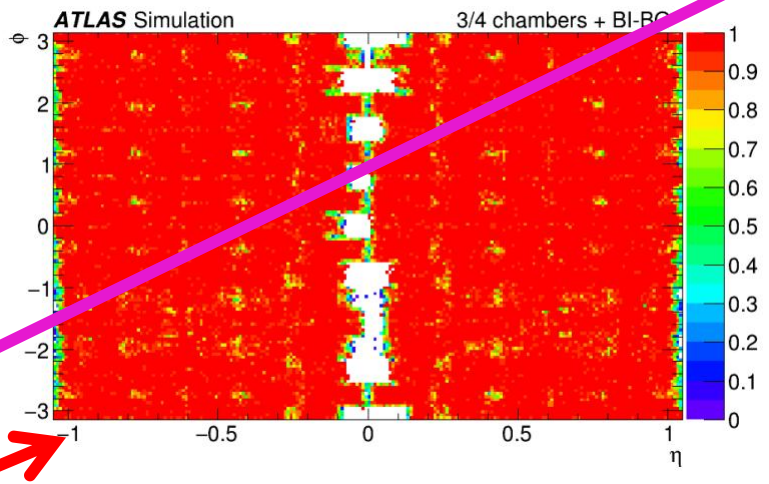
Geometrical acceptance and trigger eff.

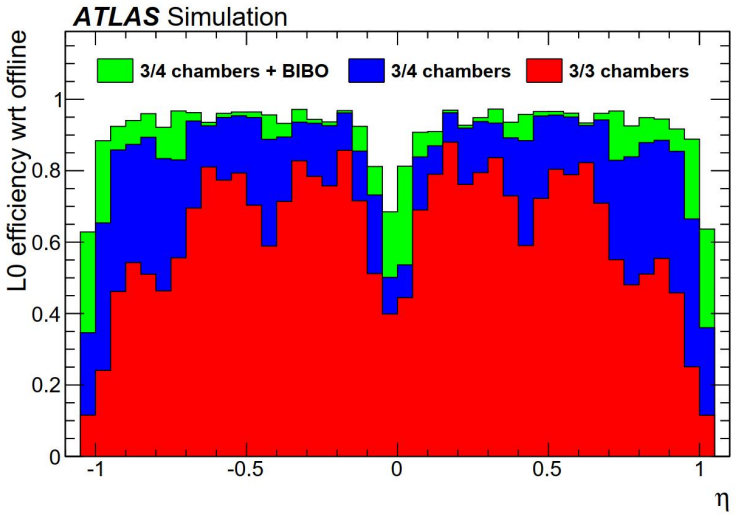


Trigger	Requirement
3/3 chambers	3[RPC1+RPC2] AND 1[RPC3]
3/4 chambers	(3[RPC1+RPC2] AND 1[RPC3]) OR (2[RPC0] AND 3[RPC1+RPC2+RPC3])
3/4 ch. + BI-BO	(3[RPC1+RPC2] AND 1[RPC3]) OR (2[RPC0] AND 3[RPC1+RPC2+RPC3]) OR (2[RPC0] AND 1[RPC3])





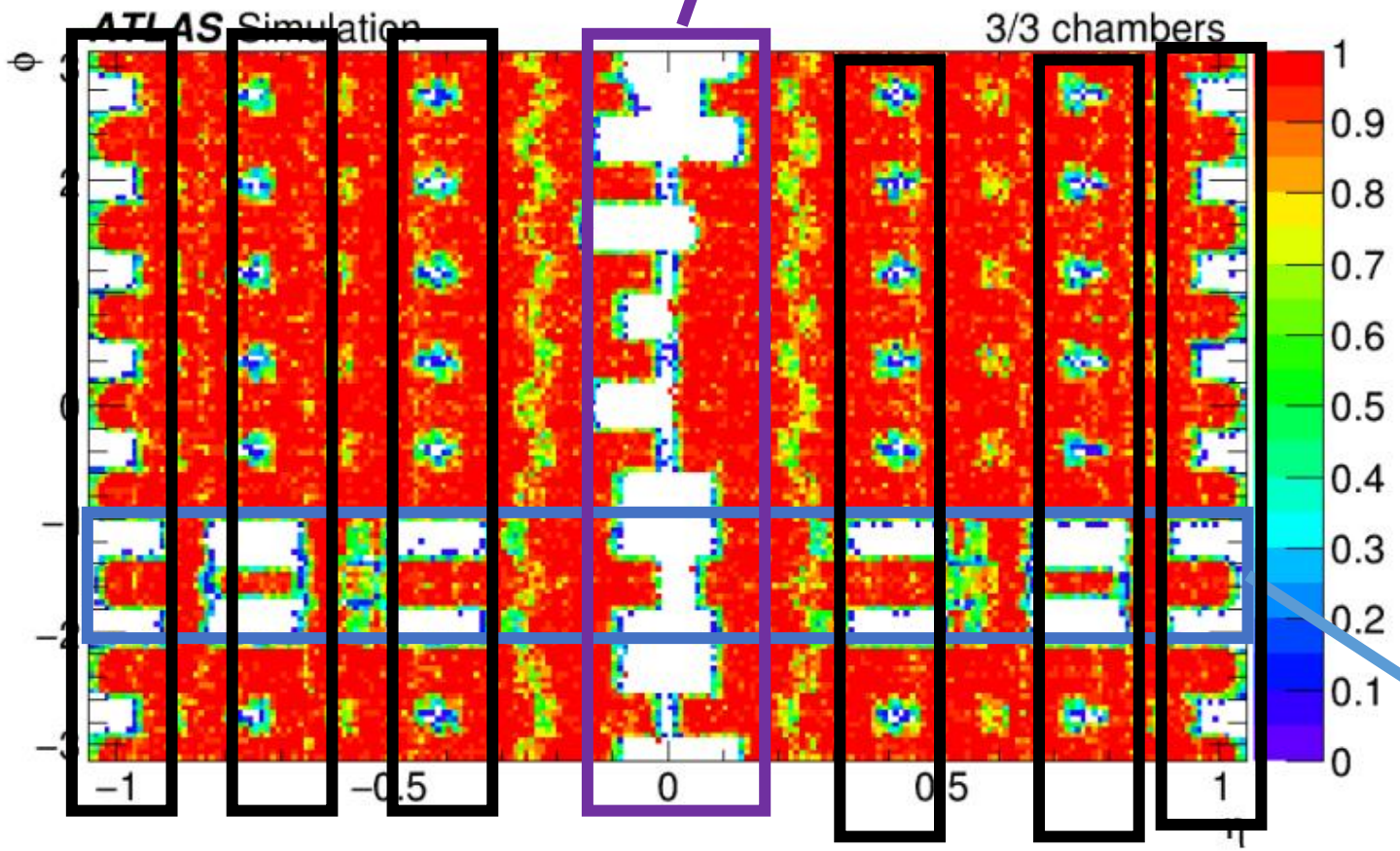




Increase the trigger coverage in the region where no BM coverage due to the coverage hole

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

The platforms in the factory

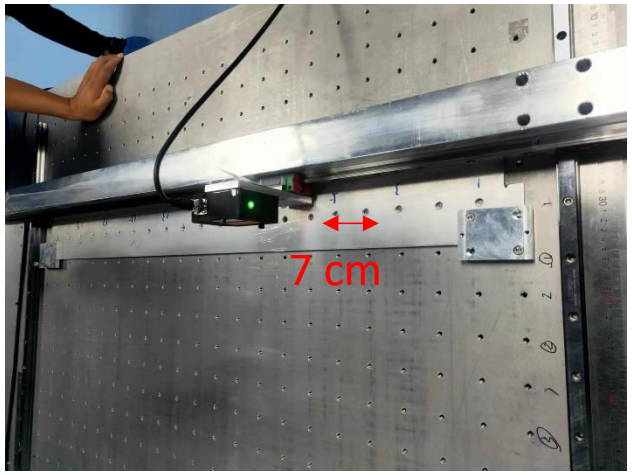
- 7 marble tables:

  2.3m×1.8m

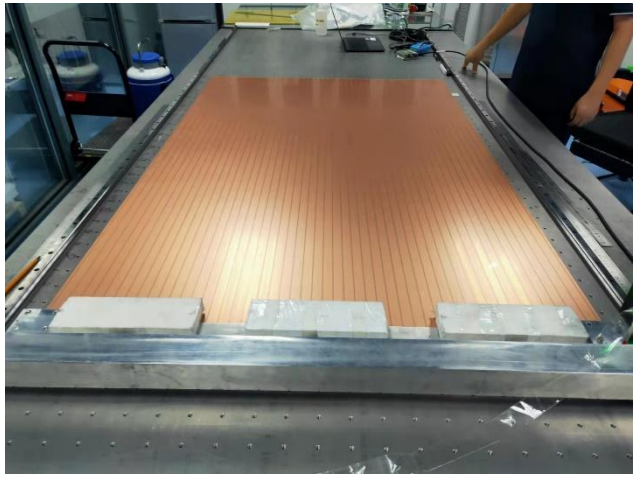
- Four of them will be used for vacuuming

- The remaining 3 marble tables will be used during the readout panel production

The method to get the thickness of PCB/panel

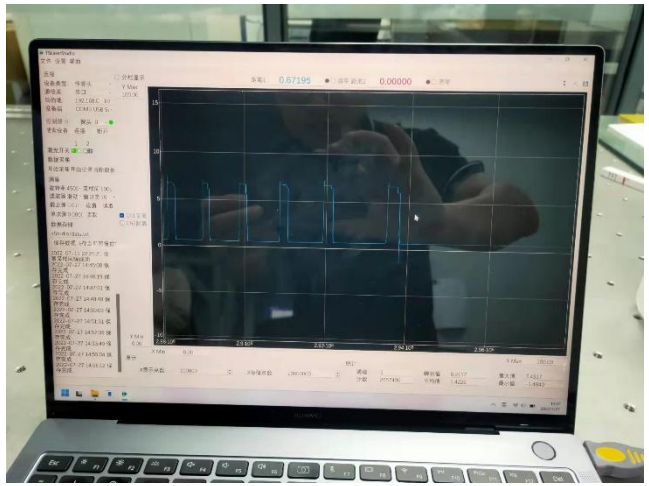


Measure the baseline

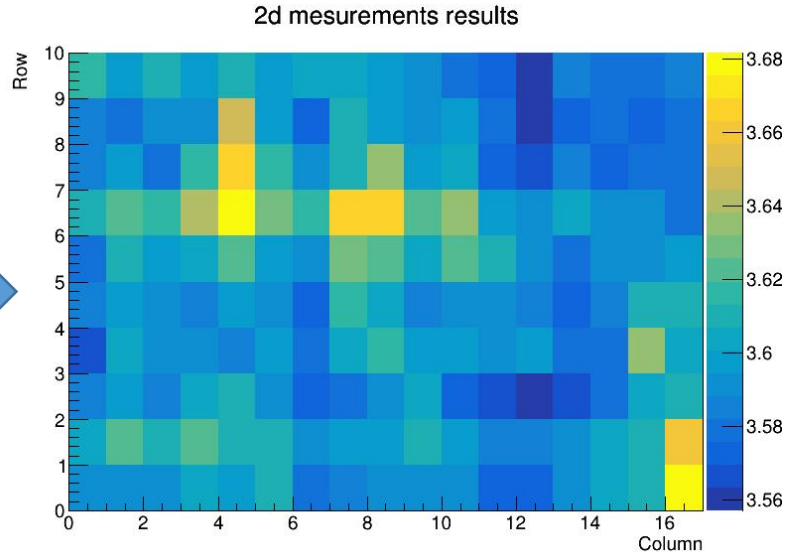


Baseline + PCB/panel

- A laser sensor sliding along a rail taking data continuously.
- The thickness at the sampling point (7 cm interval) achieved by a mask with holes.

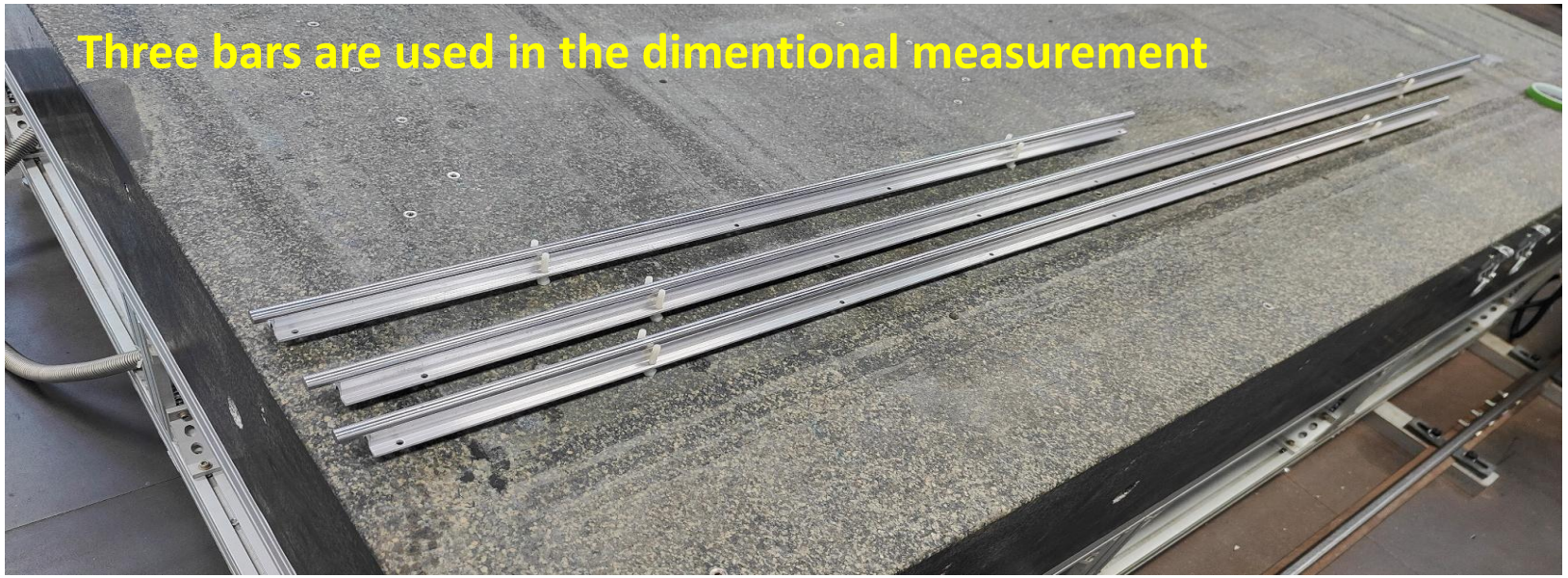


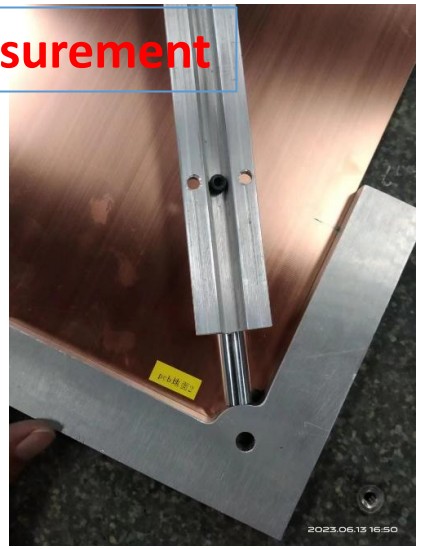
The dips along the measurement show the thickness of the panel.

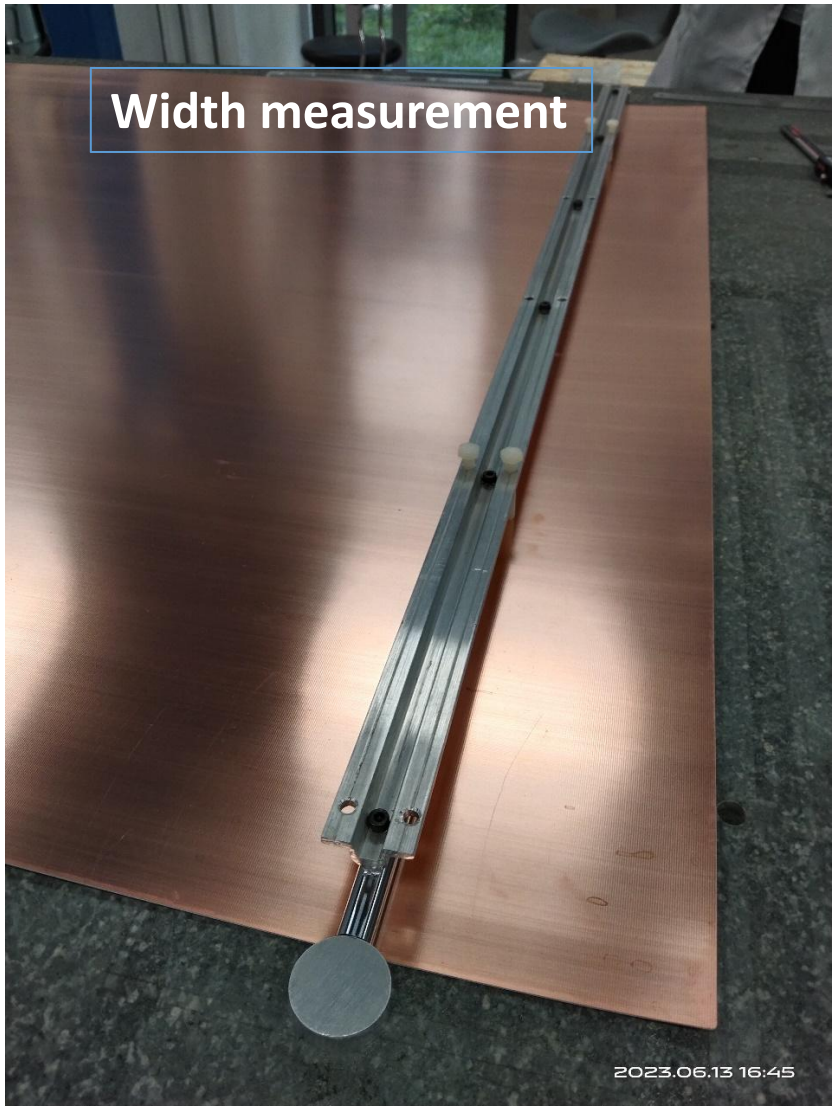


The real height of the panel after baseline correction.

The dimentional measurement



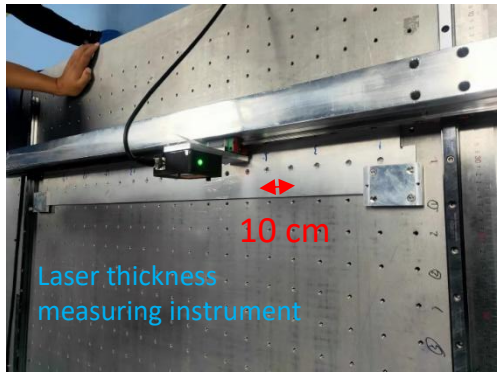


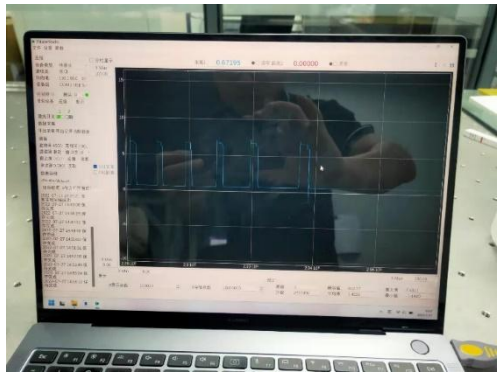


The method to check the flatness of PCB/RO panel

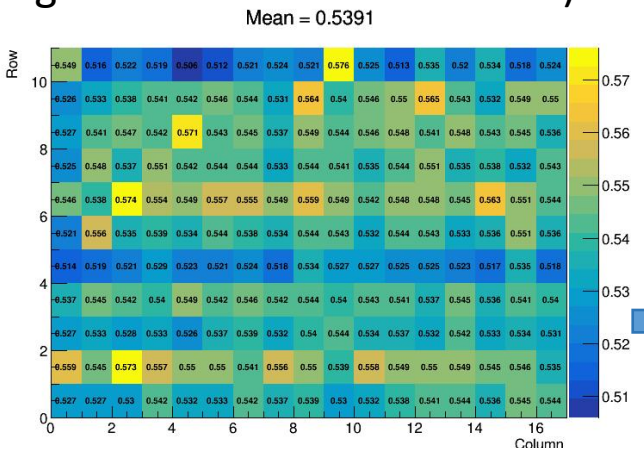
- The thickness is measured in a 10 x 10 cm matrix with a laser sensor.
- Flatness: Maximum variation of 4 points in a 10 x 10 cm range based on thickness.

Thickness is thicker than nominal value due to PCB plate (wrong thickness FR4 board used)

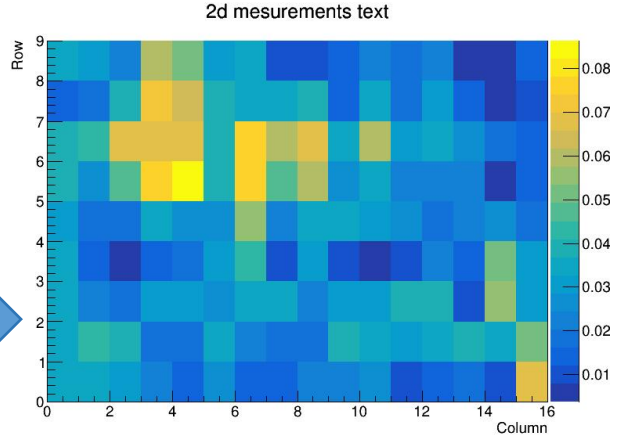


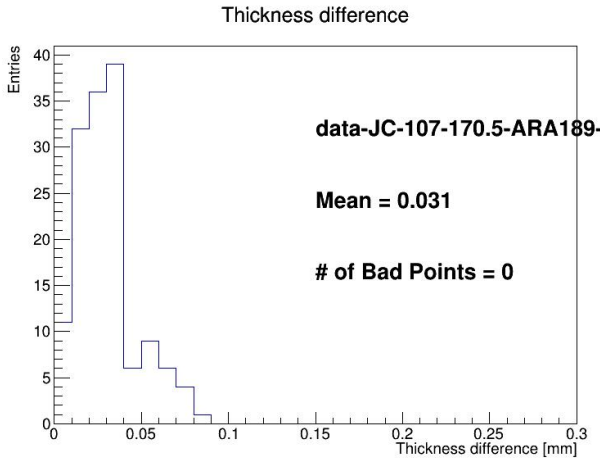


Thickness



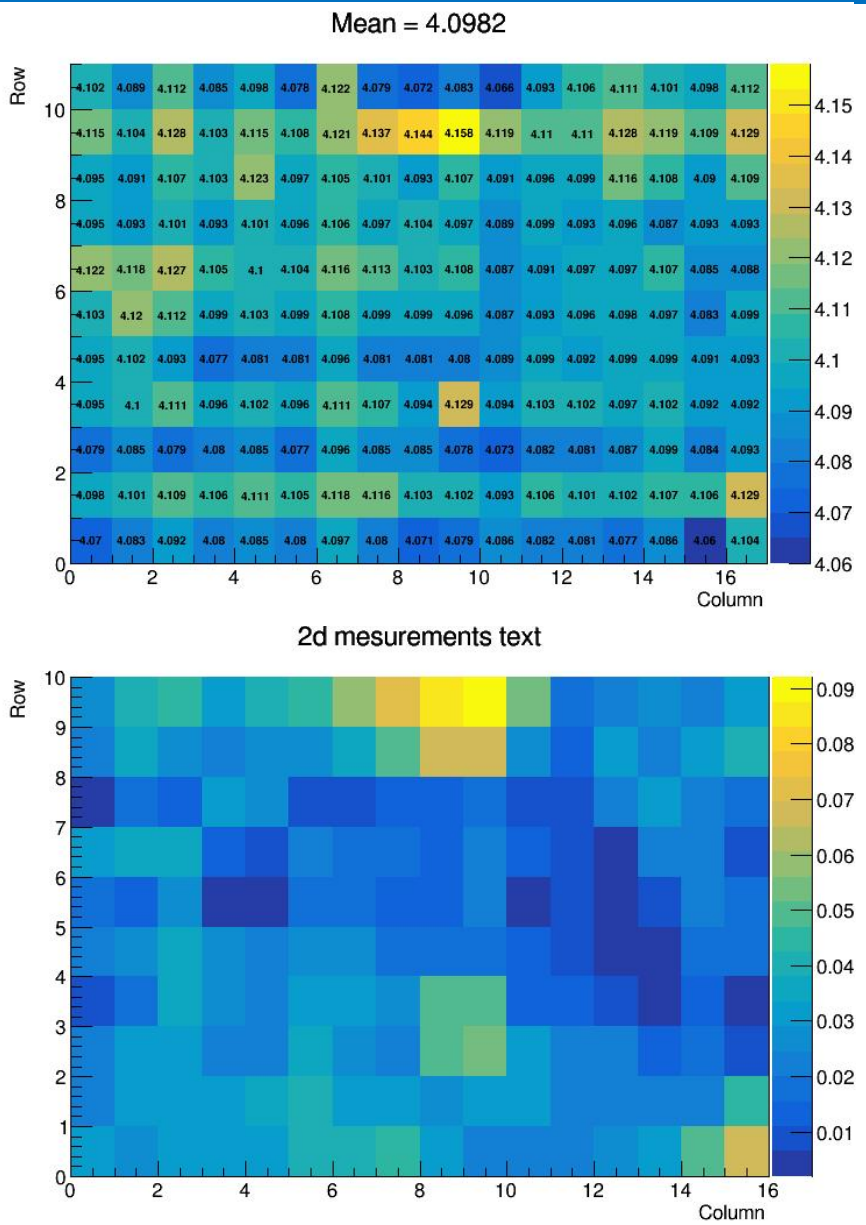
2D Flatness

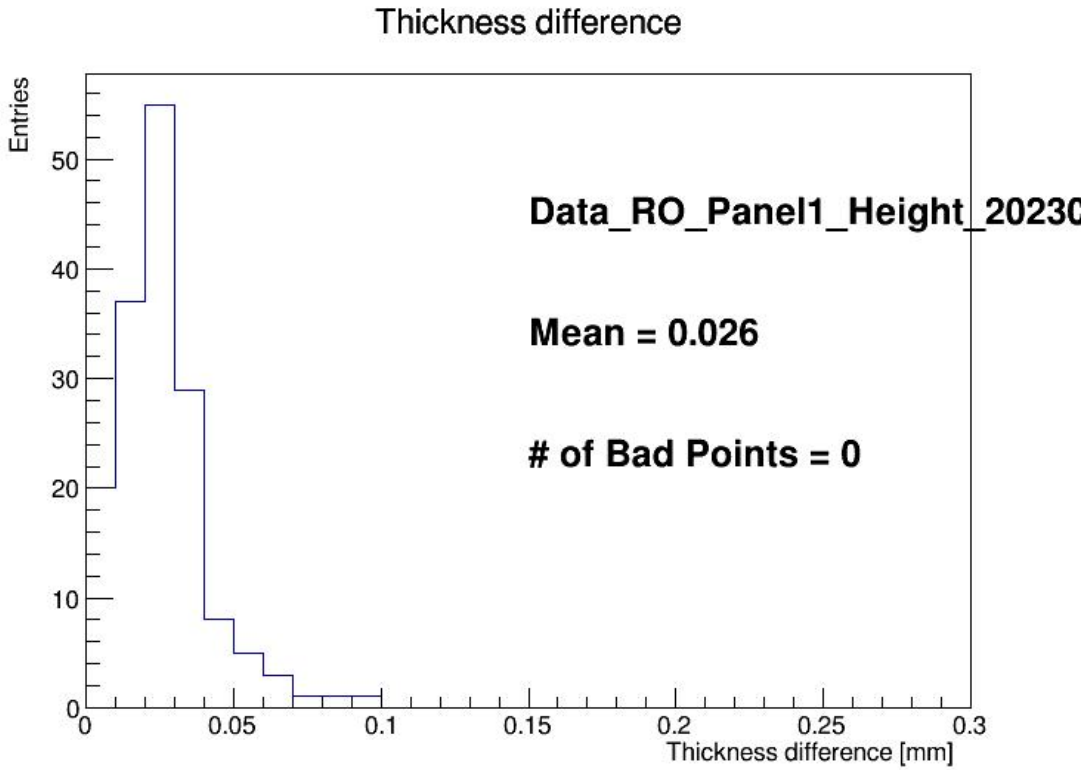




1D Flatness

Thickness measurement of the readout panel

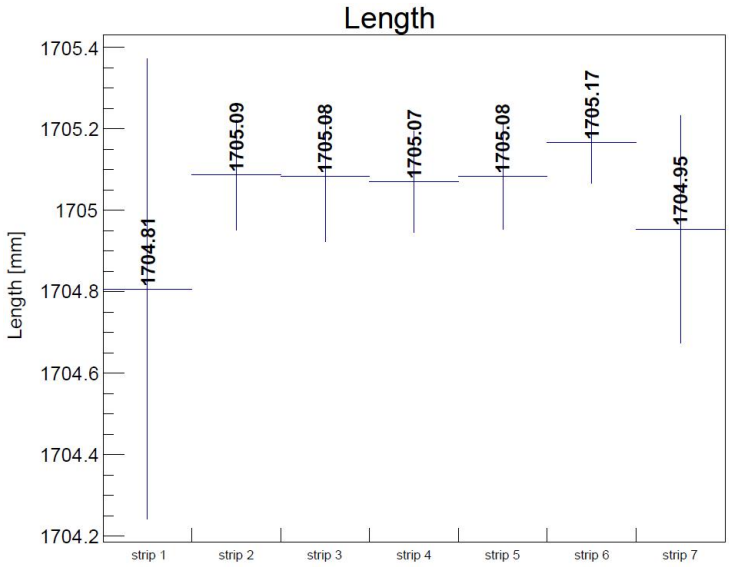


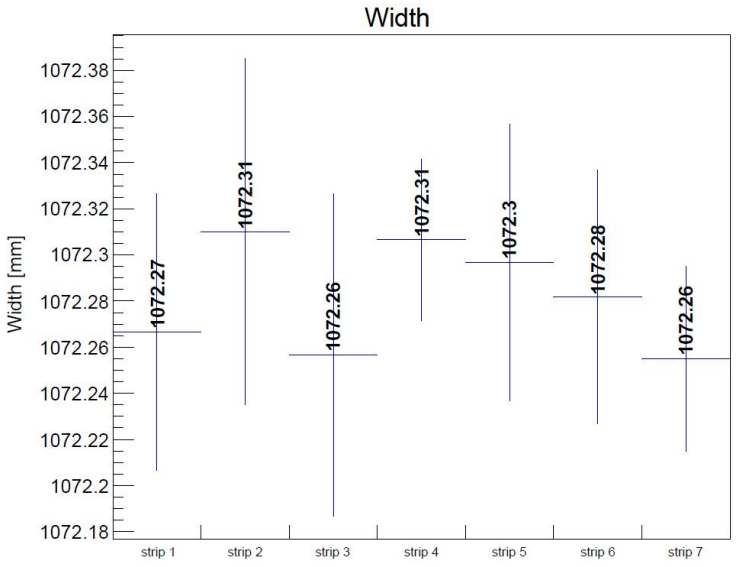


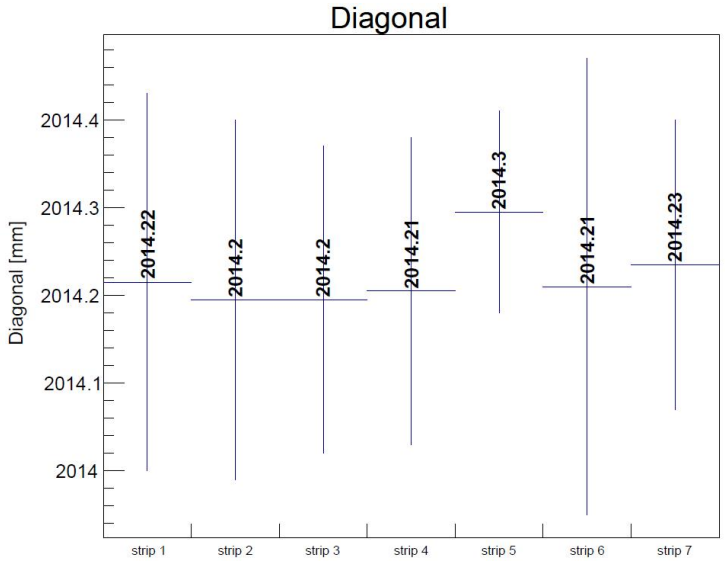
Thickness mean value = 4.098 mm

Flatness: good

The dimentional results

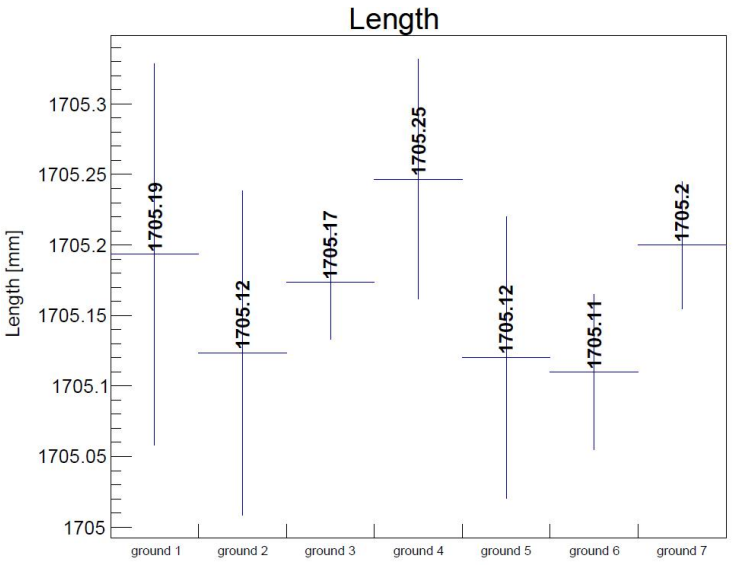


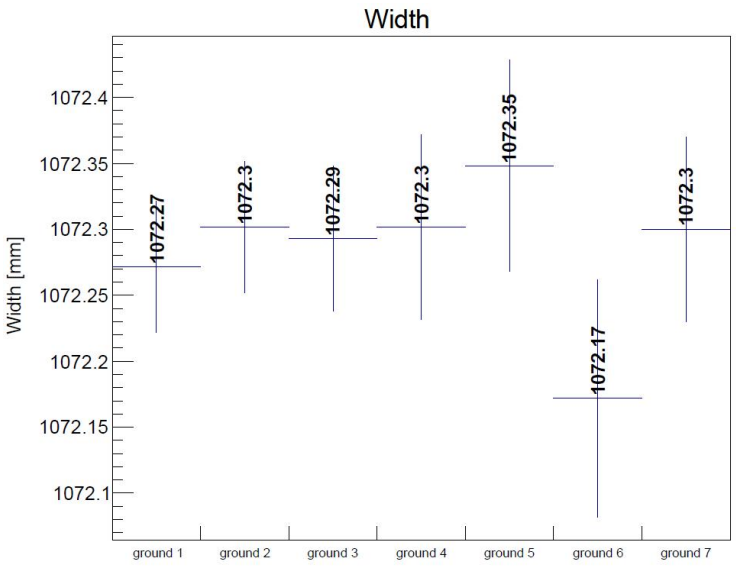


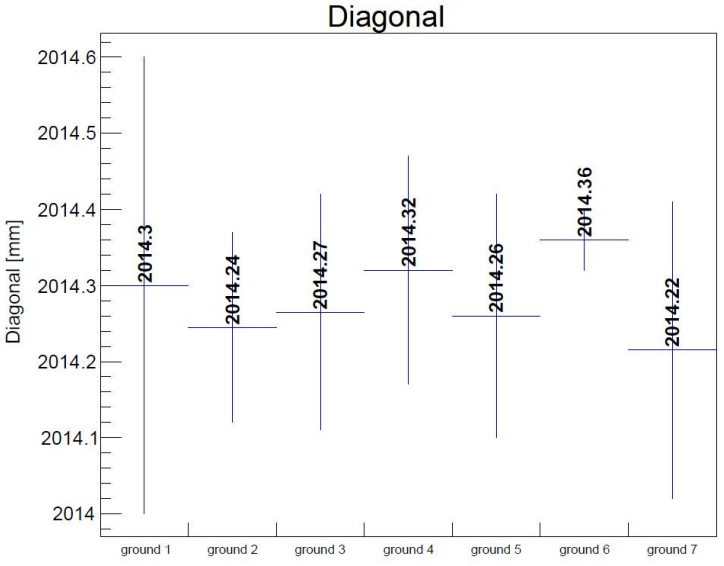


Nominal value:
Length: 1705mm
Width: 1072 mm
Diagonal: 2014 mm
Error: +/- 1 mm

Strip PCB







GND PCB

The quality of paper honeycomb

- 50 pieces of paper honeycomb (1220 x 2440 x 3 mm) received.
- Measure the thickness with micrometer gauge fixed on top of the marble table.

Sample #1	1	2
1	3.03	3.067
2	3.05	3.07
3	3.036	3.067
4	3.022	3.074
5	3.05	3.067
6	3.038	3.055
mean	3.038	3.067

Sample #2	1	2
1	3.102	3.091
2	3.087	3.076
3	3.072	3.049
4	3.078	3.067
5	3.07	3.041
6	3.071	3.043
mean	3.08	3.061

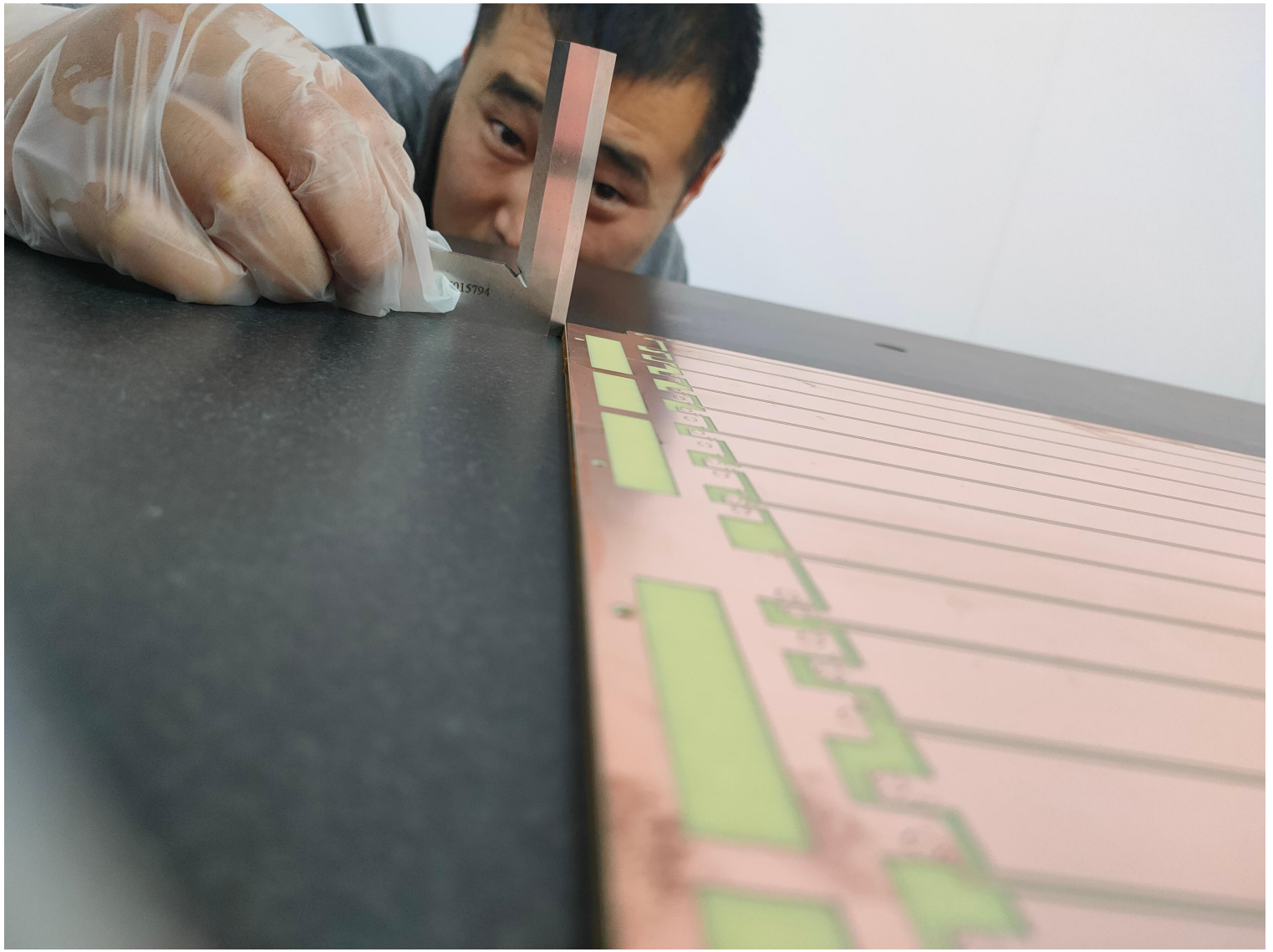
Sample #3	1	2
1	3.062	3.043
2	3.066	3.065
3	3.057	3.049
4	3.064	3.044
5	3.06	3.057
6	3.068	3.059
mean	3.063	3.053

Sample #4	1	2
1	3.039	3.076
2	3.063	3.074
3	3.054	3.082
4	3.061	3.092
5	3.075	3.088
6	3.078	3.079
mean	3.062	3.082

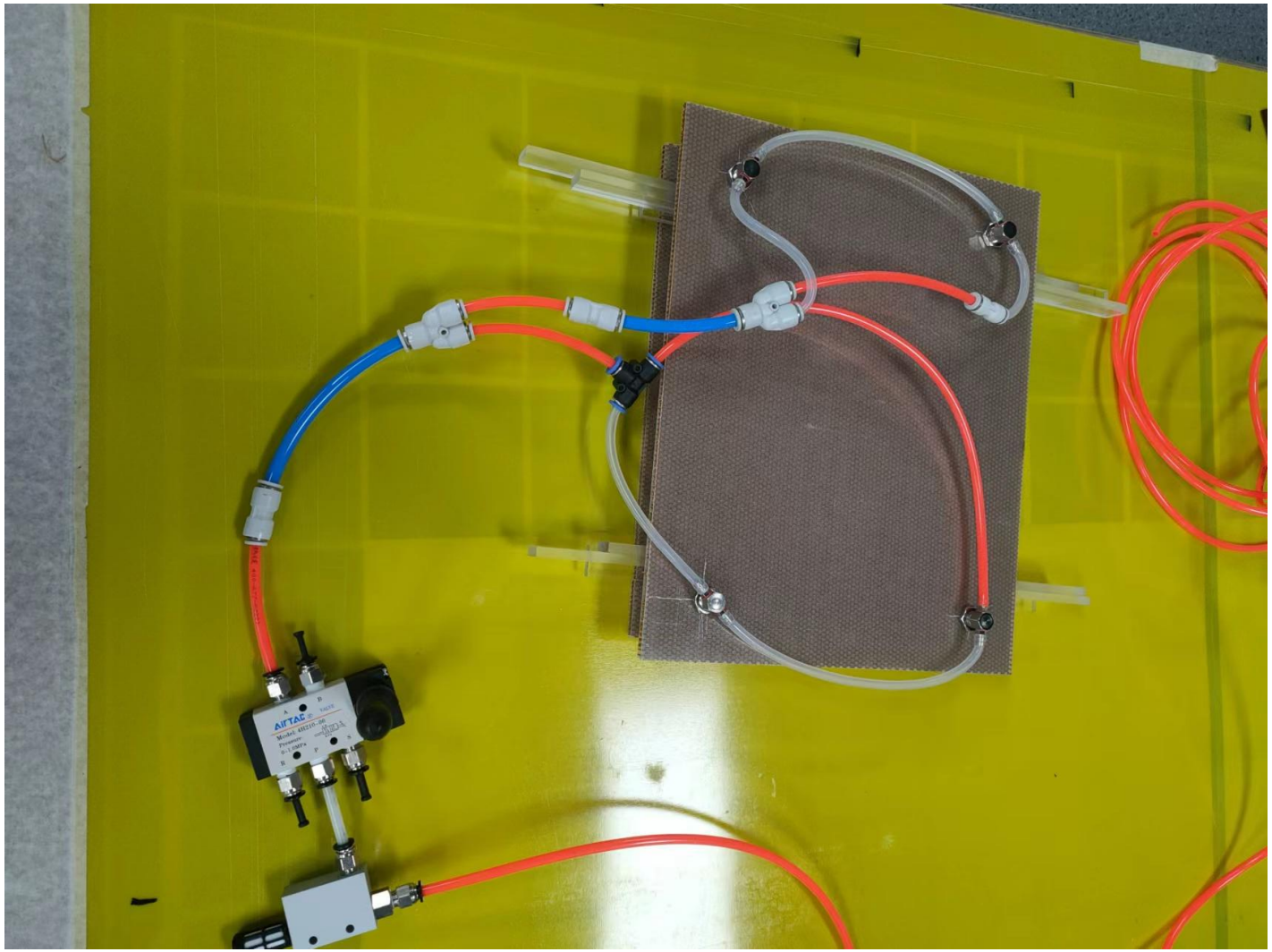
Sample #5	1	2
1	3.107	3.103
2	3.096	3.099
3	3.074	3.097
4	3.079	3.097
5	3.106	3.107
6	3.106	3.119
mean	3.095	3.104

- **5 samples are selected randomly.**
- **All samples are checked with good quality.**

The quality of alignment



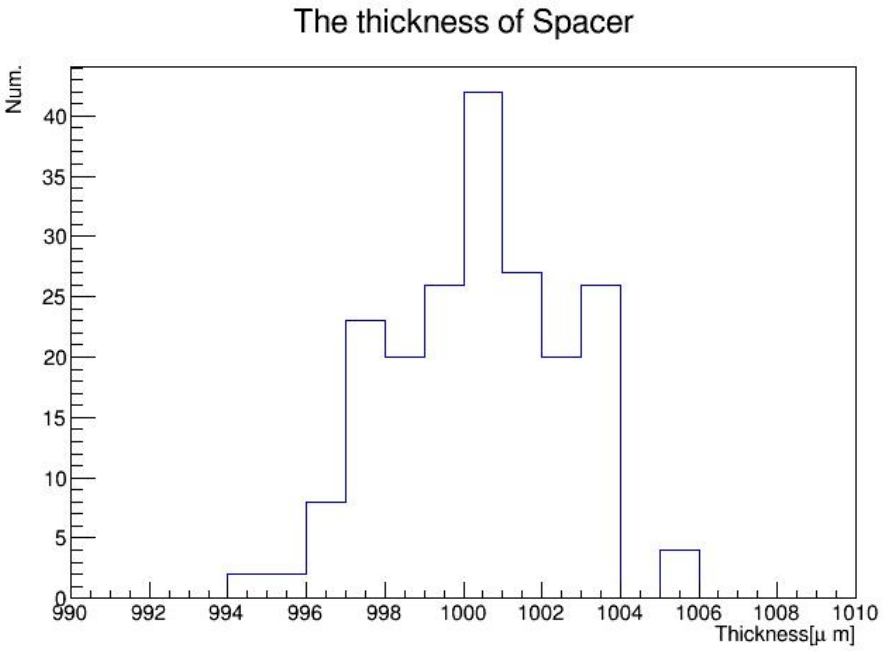
Vacuum Sucker

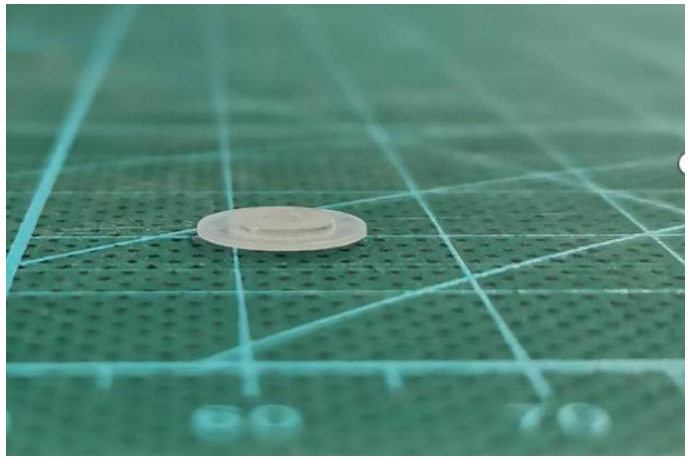


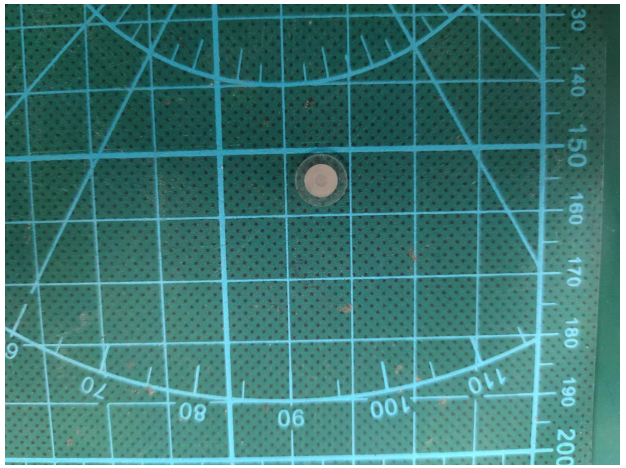
To hold the top bakelike

Spacers with guard wing

outer diameter: 8 +/- 0.05mm
inner diameter: 5 +/- 0.03mm
thickness: 1.000 mm







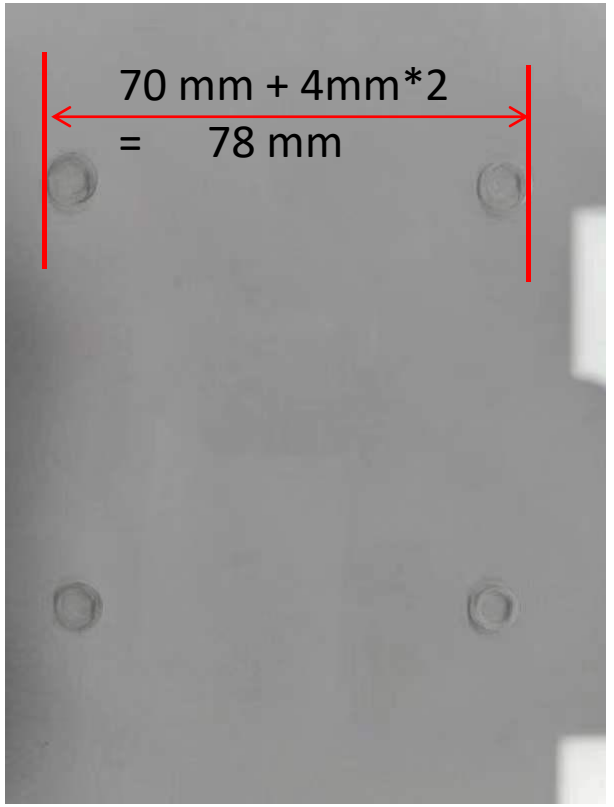
1/100 of all the spacers (20000) are tested
96% in 1.000 +/- 0.004 mm
100% in 1.000 +/- 0.006 mm

Y

X

Nominal value:

radius of spacer:4mm
height of spacer:1mm
distance： 70mm*70mm



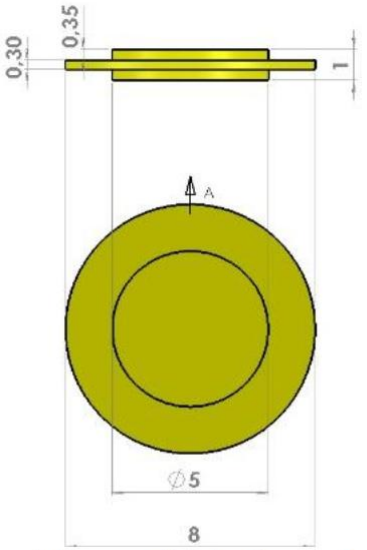
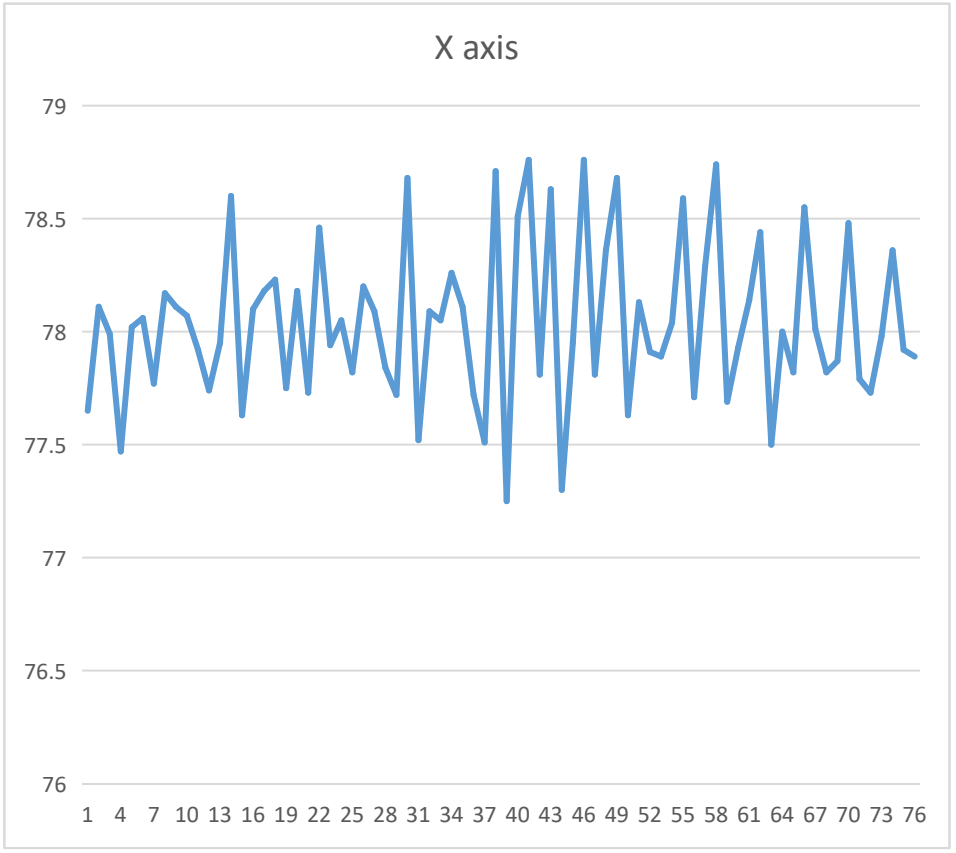


Figure 5: design of the cylindrical pillar with the guard ring.

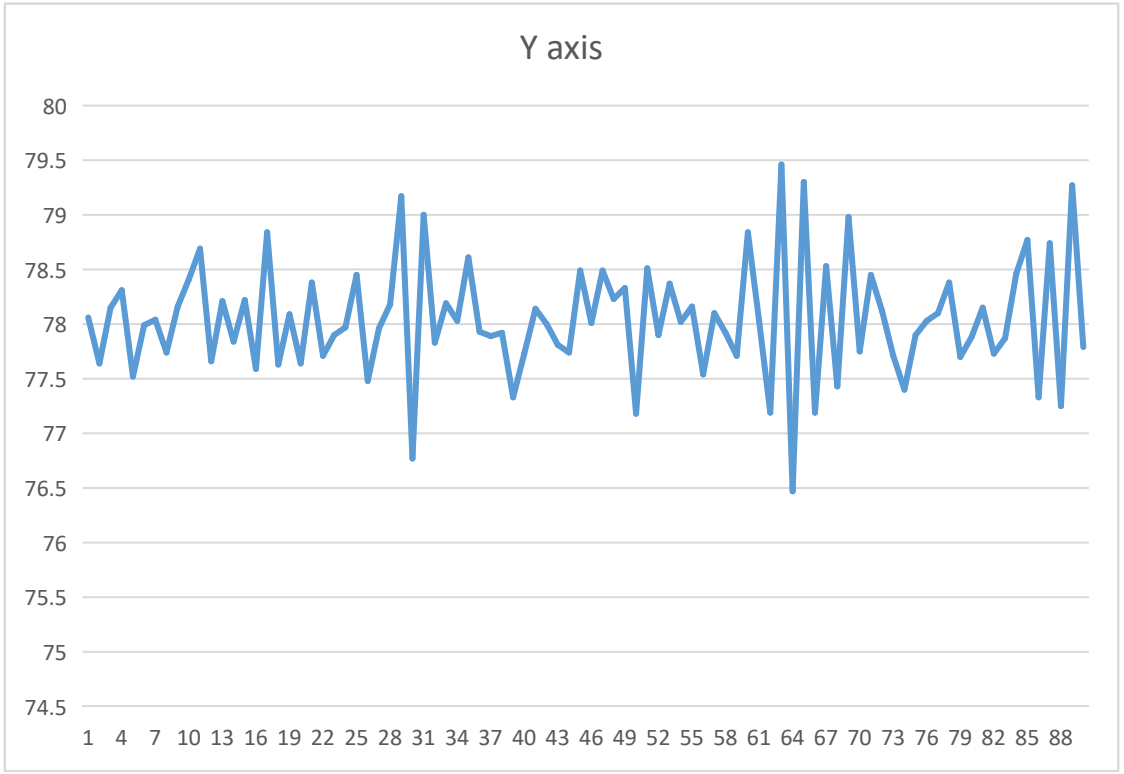
X axis

X mean=78.0429333



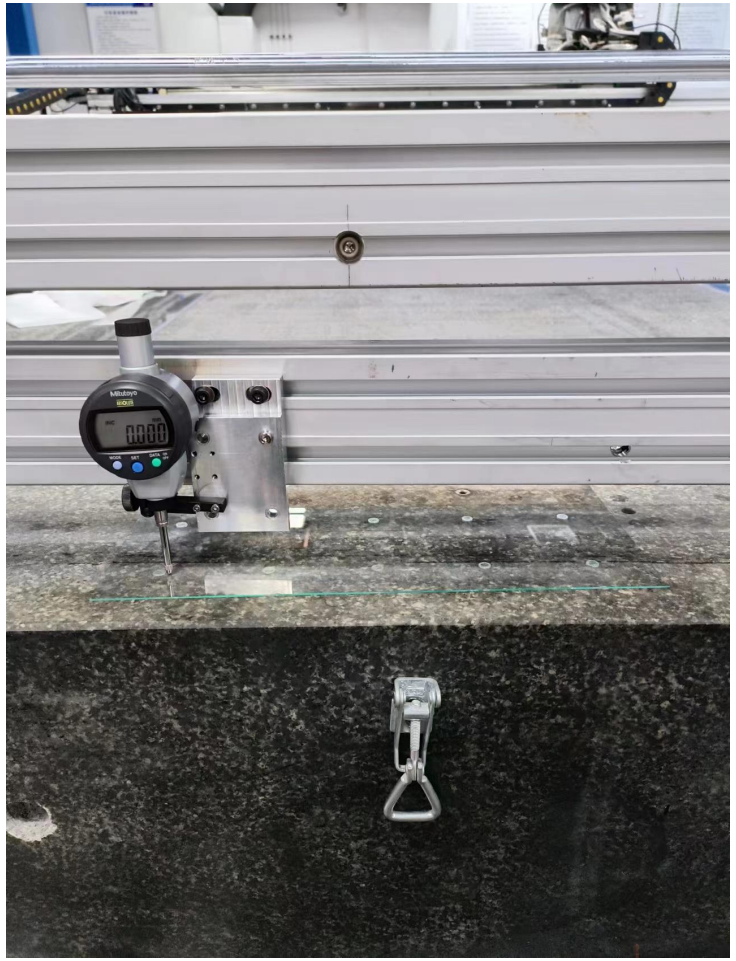
Y axis

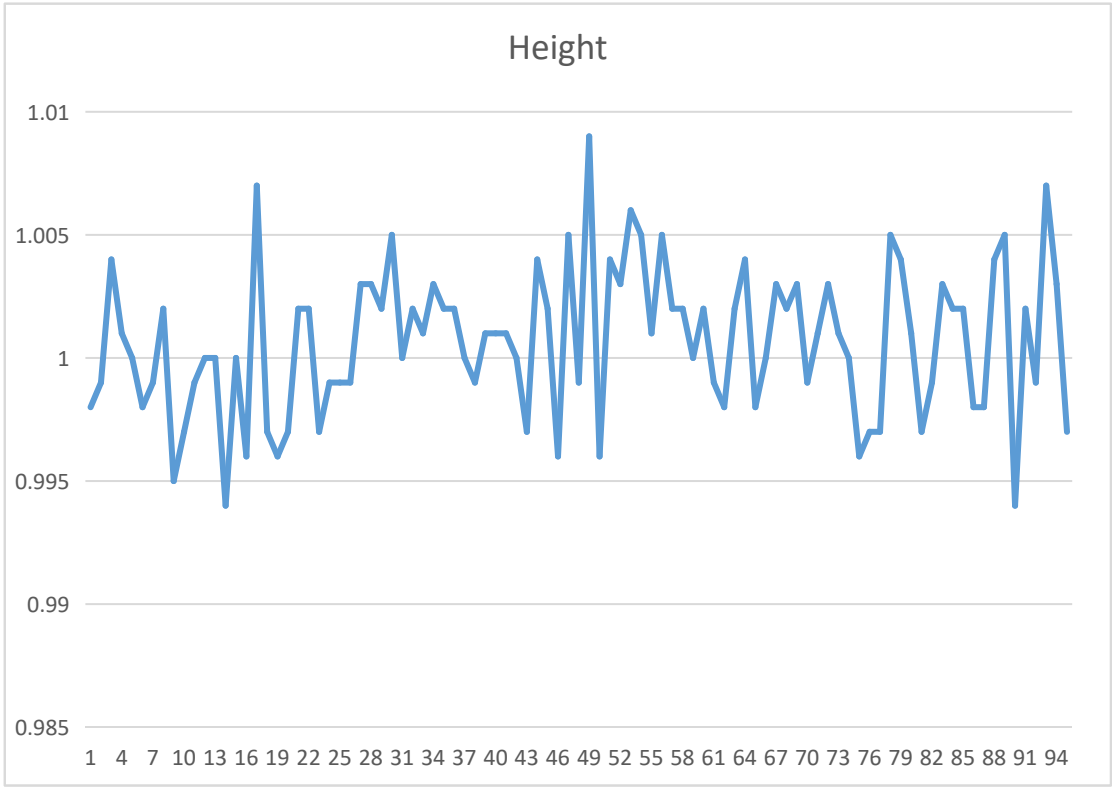
Y mean=78.0412222



Height

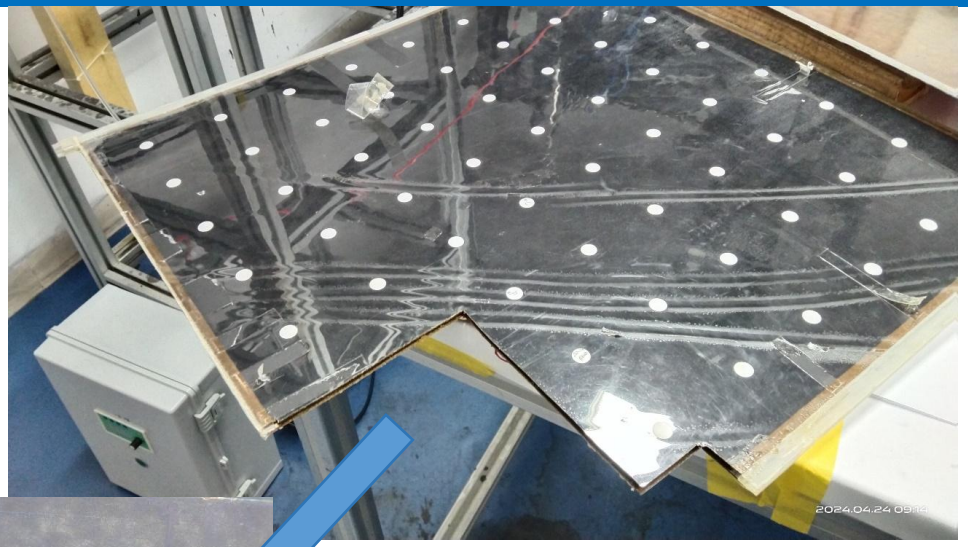
H mean=1.000663158

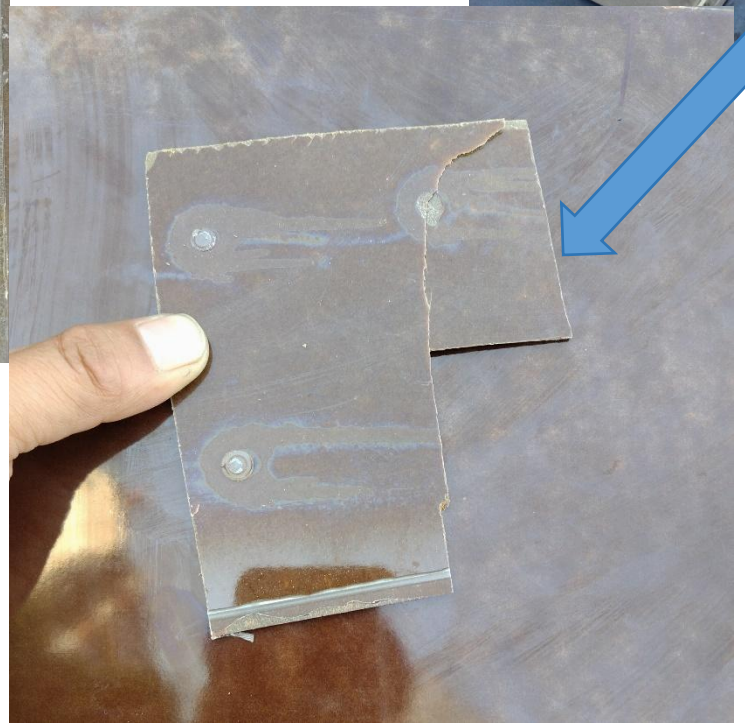




Comparison with GTE gap

The last USTC oiled gap



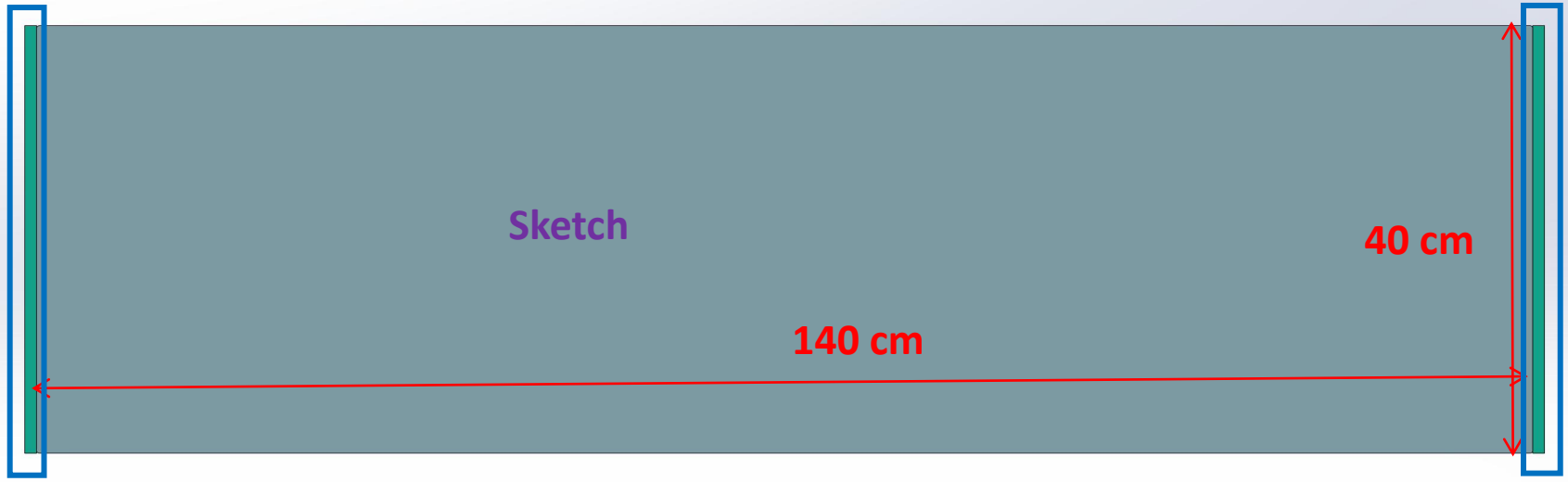


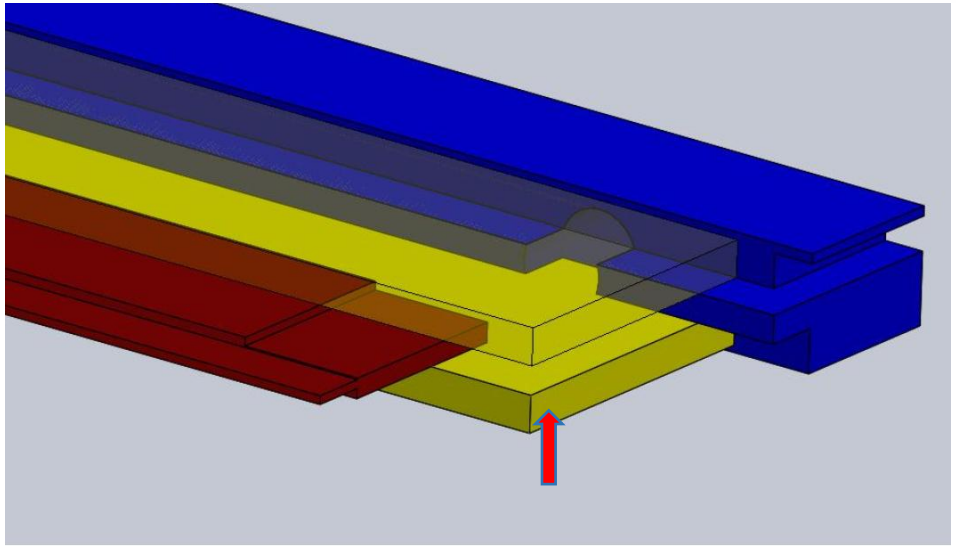
- A 50x50cm gap bought from GTE years ago.
- Originally, it worked properly.
- It was deformed due to the humidity problem.
- We opened it and checked the surface inside.

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

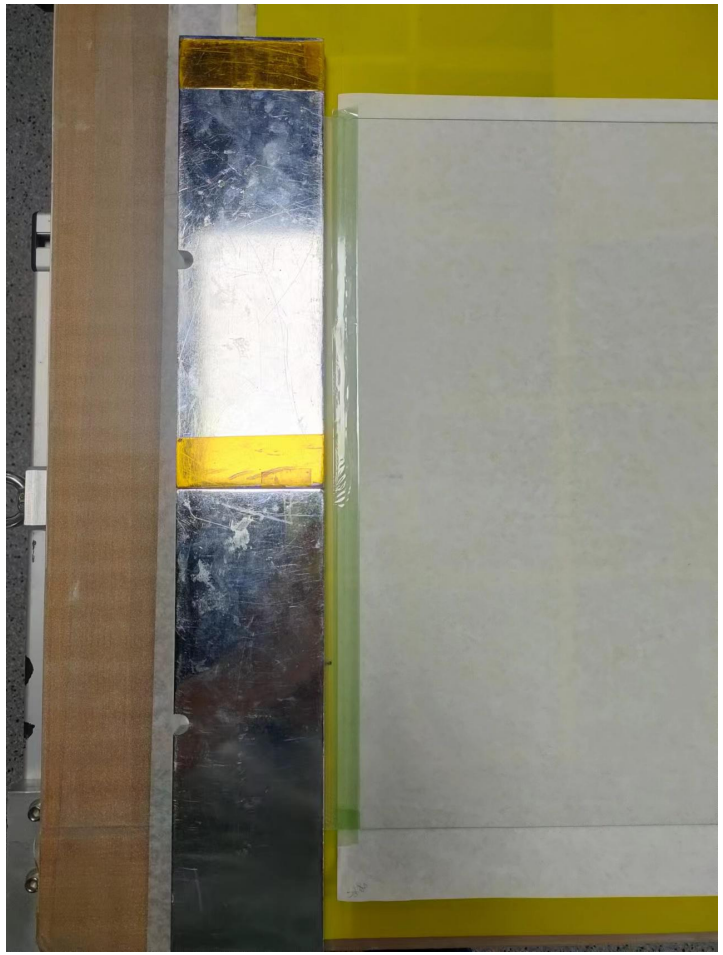
The first step

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





The glass and 2 floor plates will on the same plane



The second step (preparatory work)

Zoom in

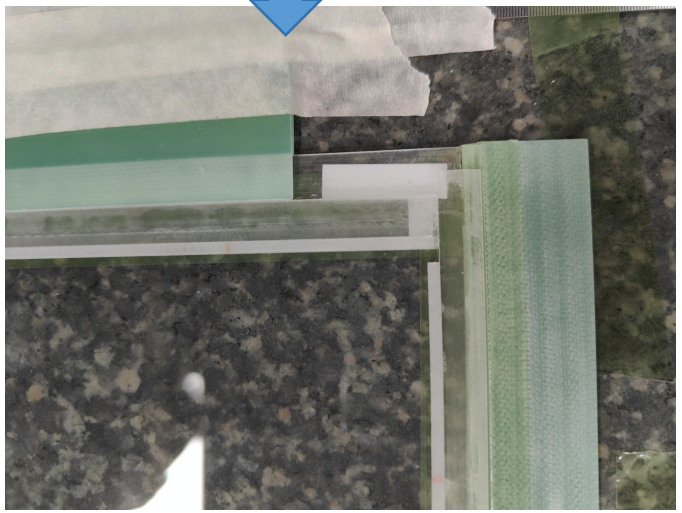
1. Use the tooling to find the correct position of the long side frame
2. Use tape to fix the tooling and protect the marble platform (avoid glue seeping on it)

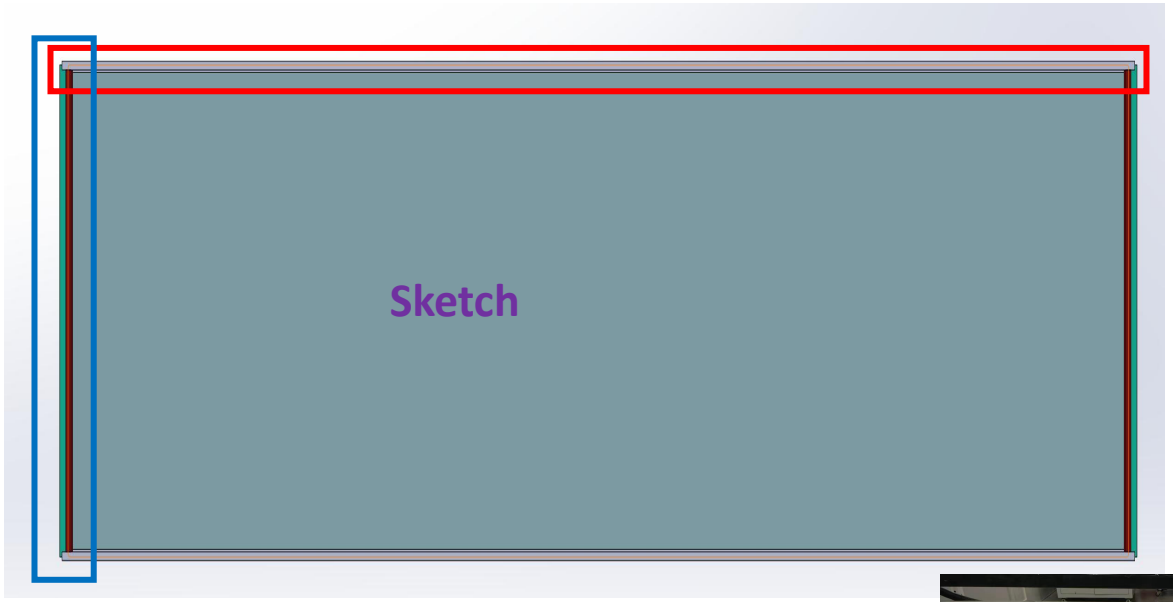
1. Move the glass on the marble platform carefully
2. Use the tooling to find the correct position of long and short side of frames

The second step

- Add the glue on the glass and attach the **long** and **short side** of polycarbonate frames with Araldite adhesive glue
- Vacumming for 6 hours

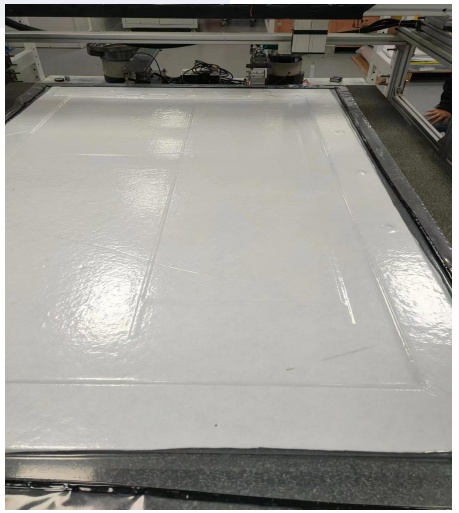
Zoom in





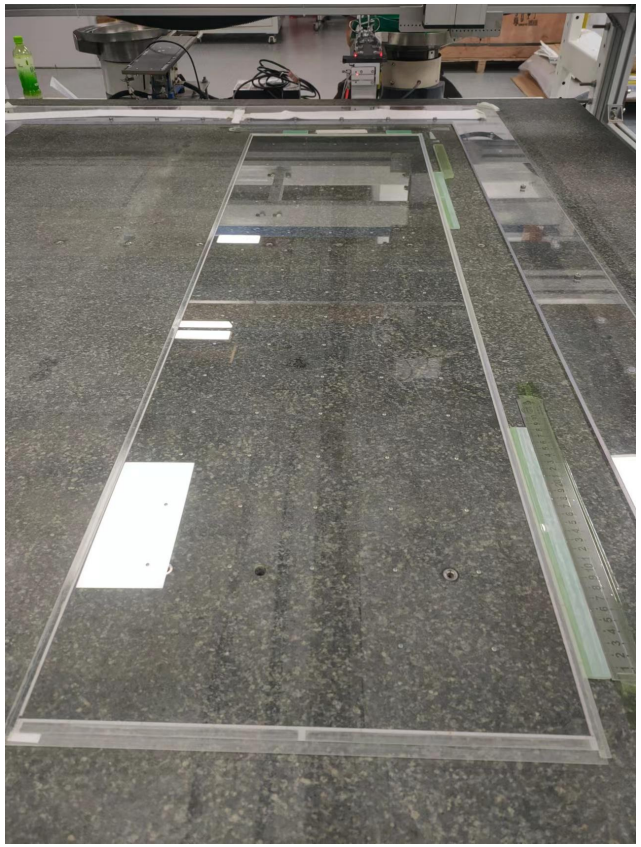
Vacumming

Slight less than 0.01Mpa

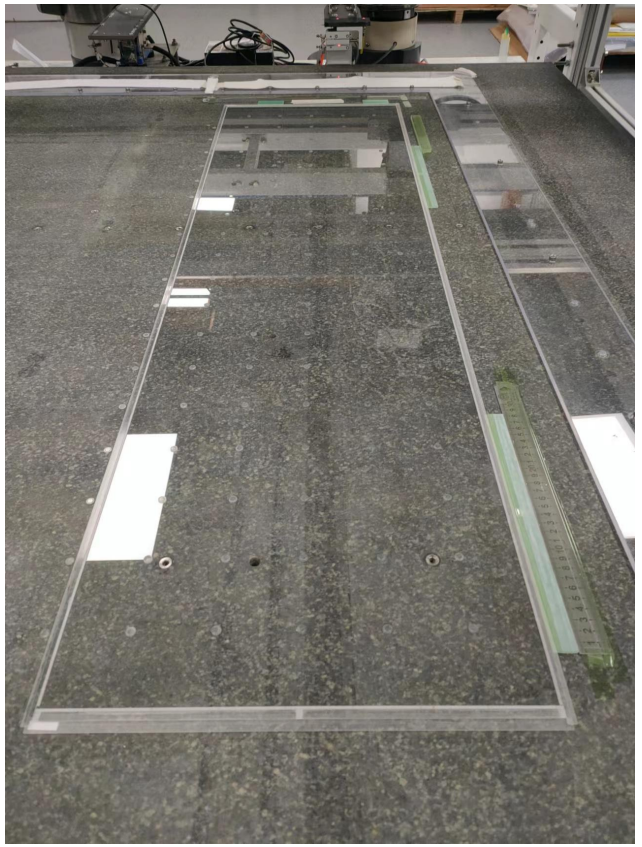


The third step (1)

- Attach the spacers on the glass
  - dispensing work (Add glue on the glass)
  - Put the spacers on the glue and the distance between 2 spacers is 70 mm.

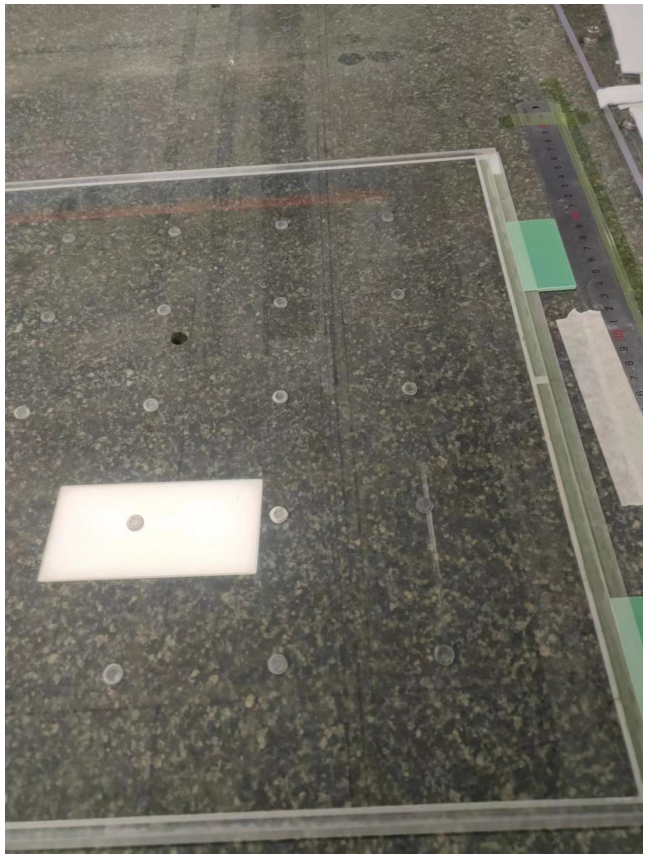


~15 minutes



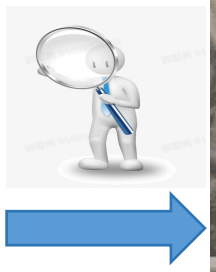
~36 minutes

Zoom in

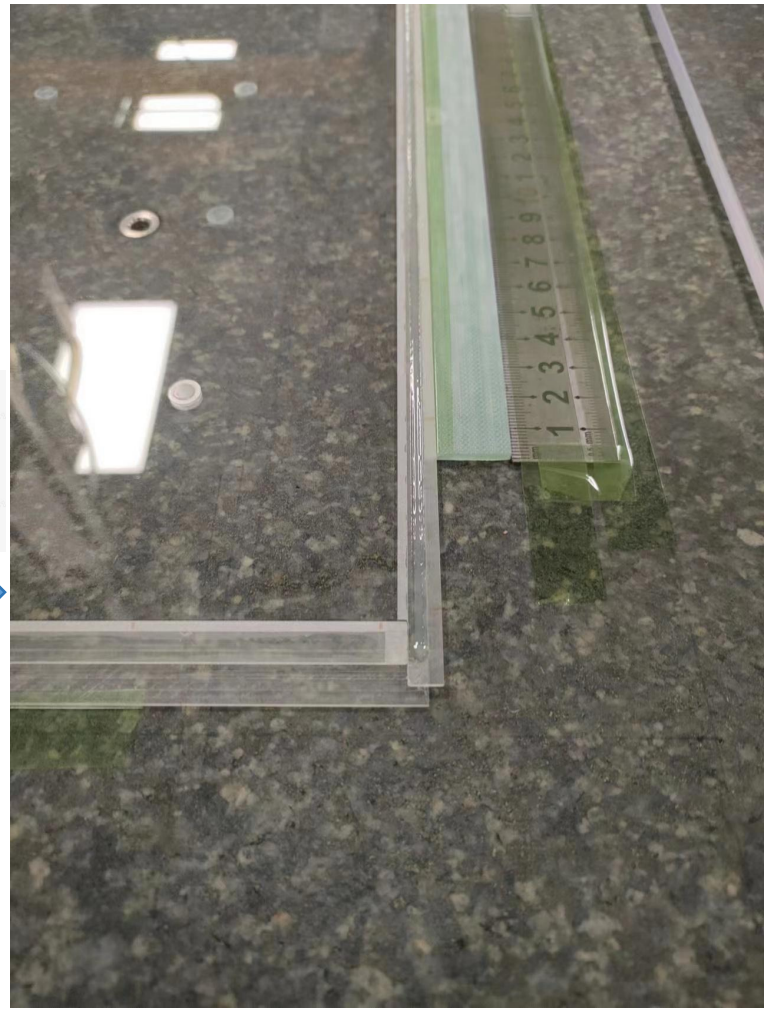


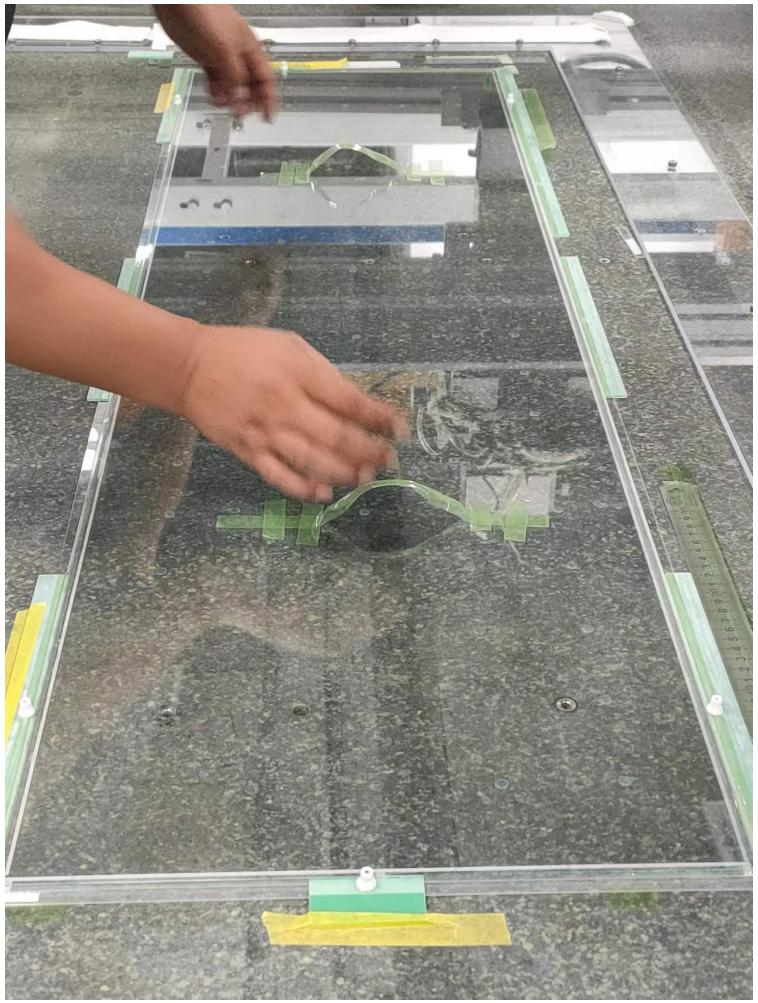
The third step (2)

➢Apply glue on the frame and close the gas gap



Zoom in

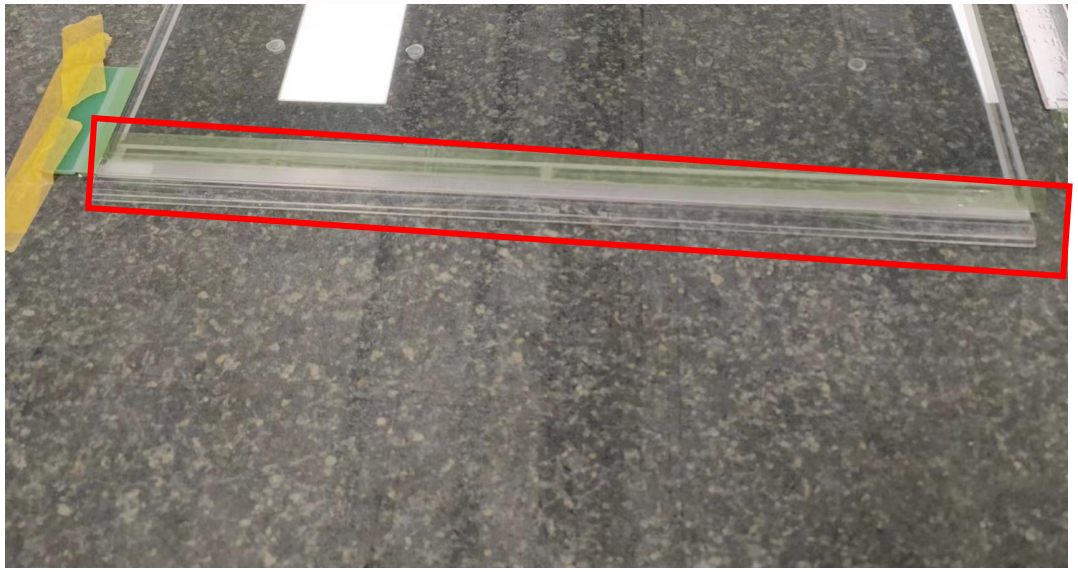




The third step (3)

- Attach 2 roof polycarbonate plates on it

Zoom in



The third step (4)

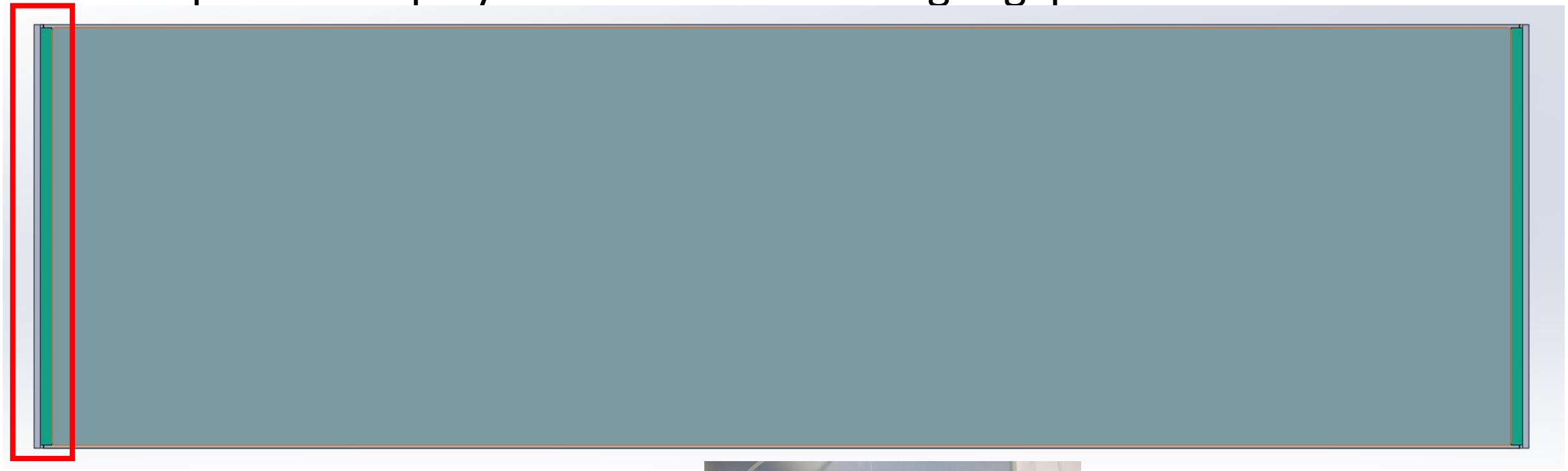
- Vacuuming

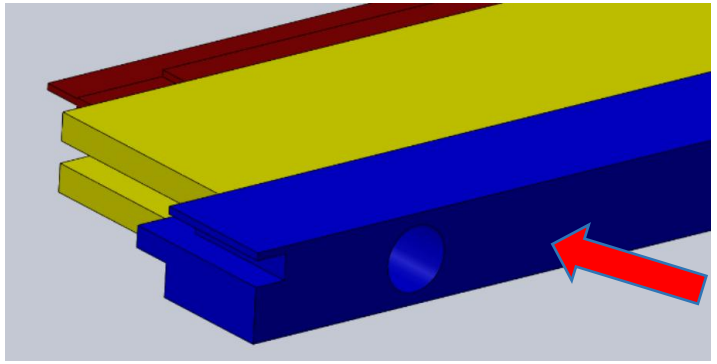
Use oiled paper to protect the ventilated felt

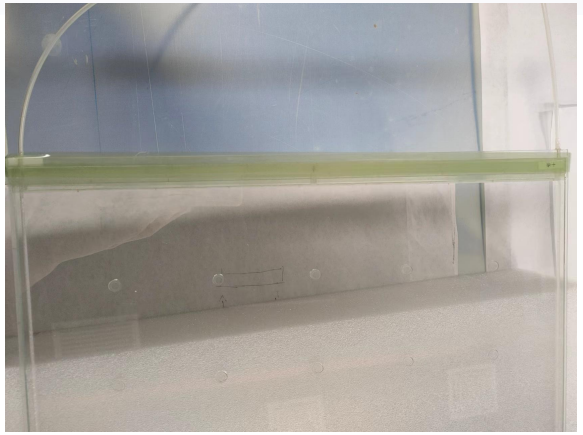
Hold for at least 6 hours

The final step

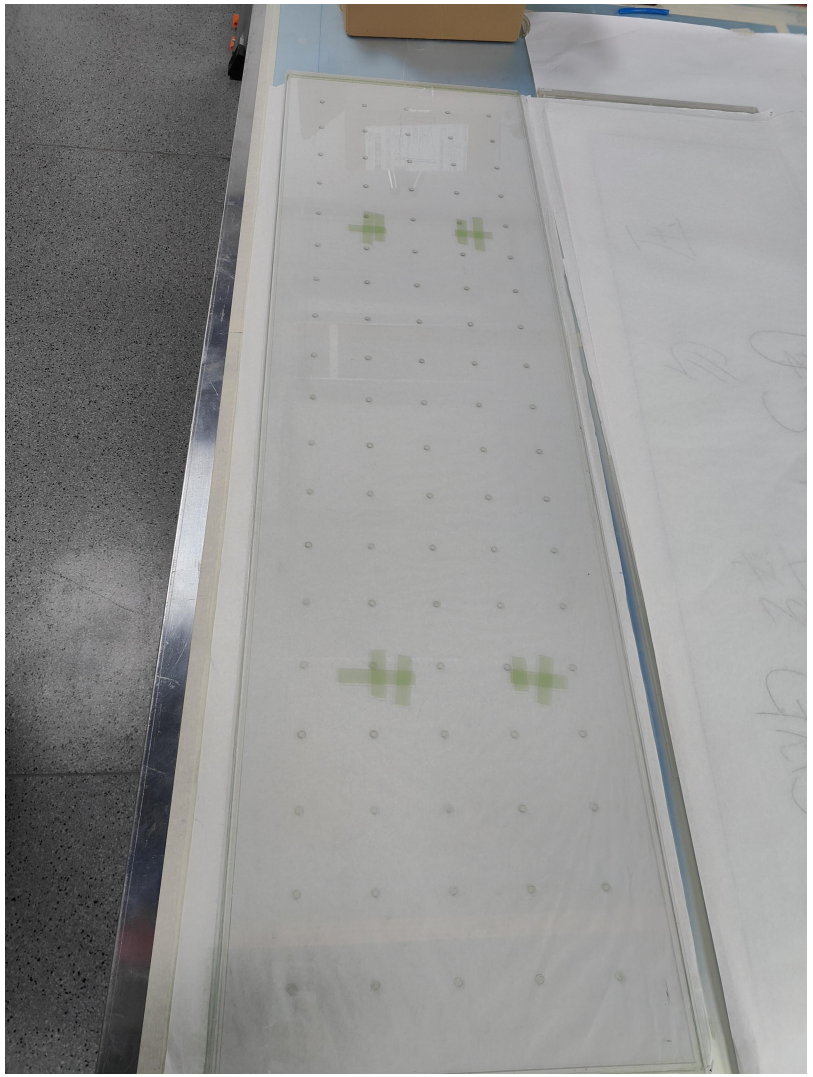
- Put the perimetric polycarbonate frame into gas gap

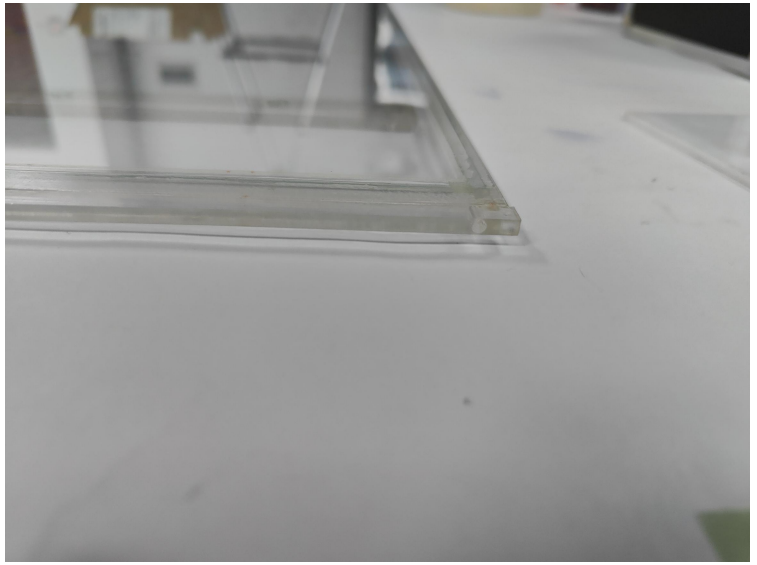


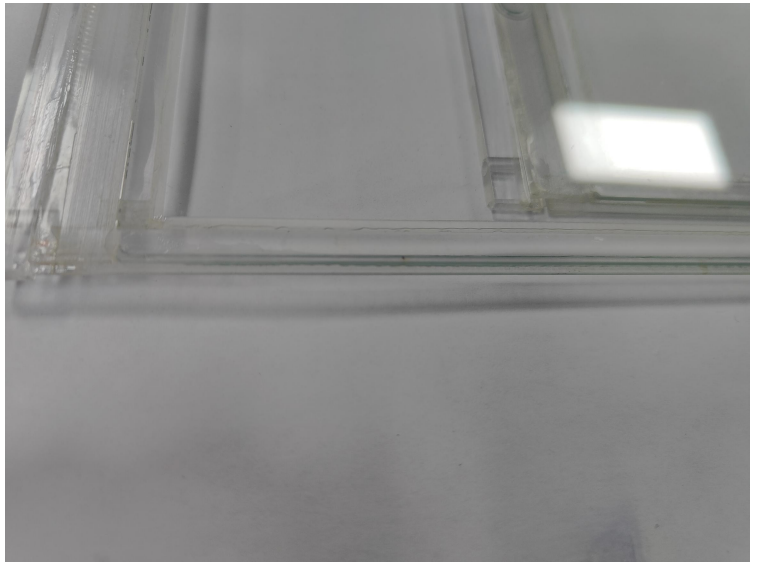


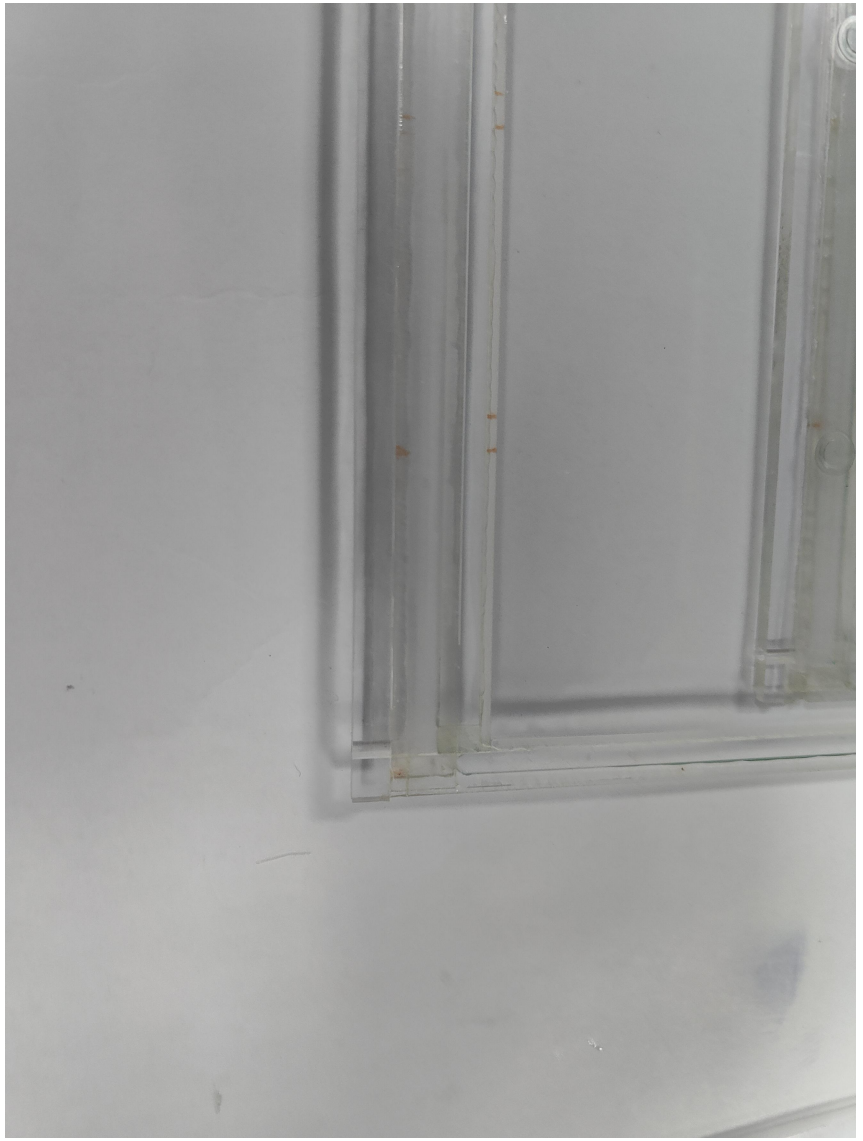


The final product

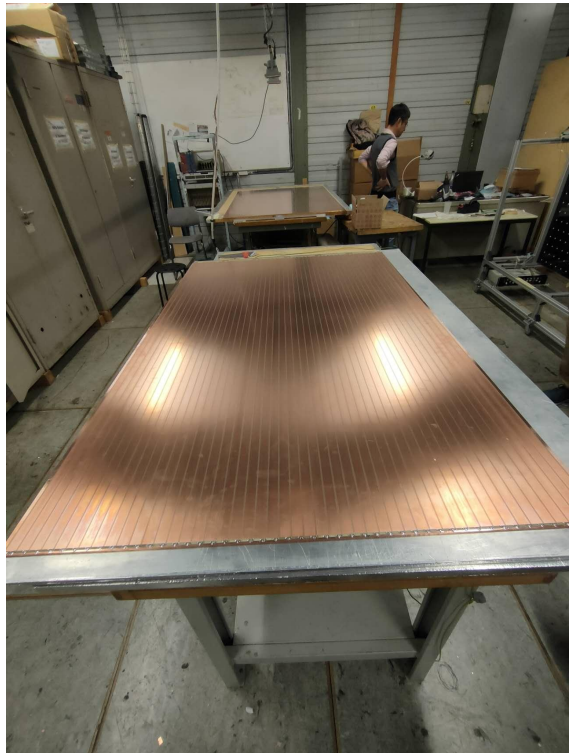




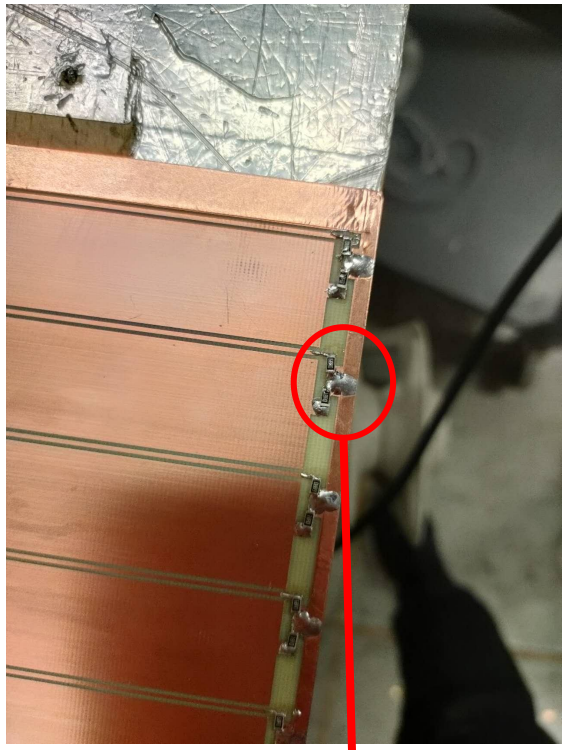


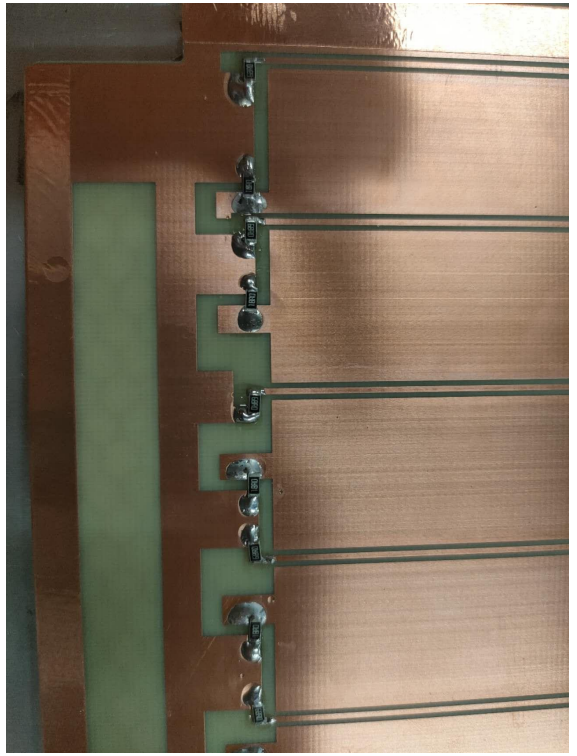


More detail information for each step (Step 1)



Step1:
Put the readout pannel in the table with strip pannel on the top

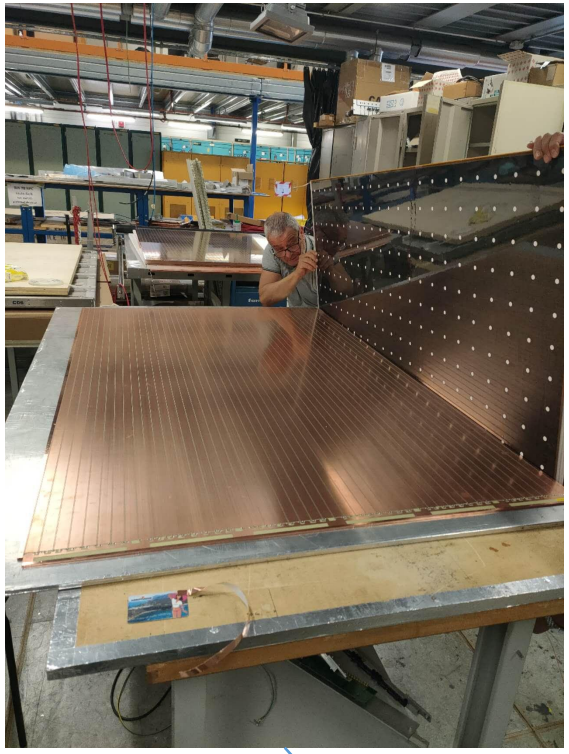


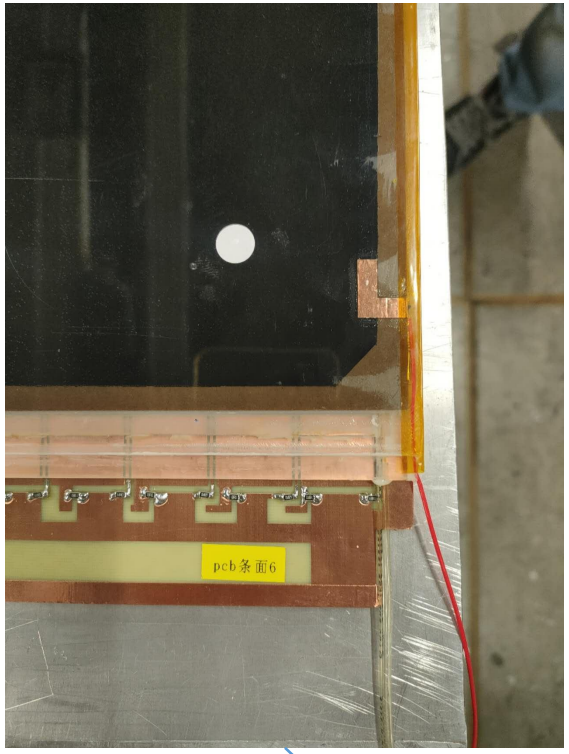


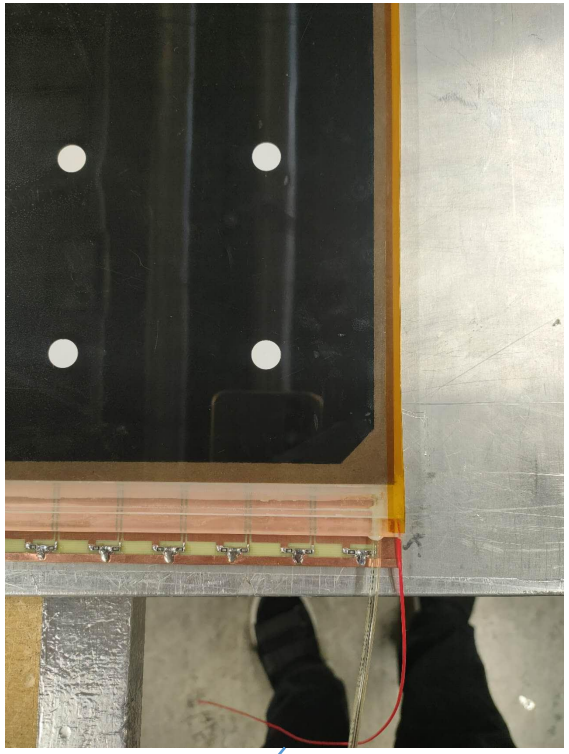
The resistors are mounted on the readout pannel and also solder the copper sheet to the ground

Suggested by Alessia

More detail information for each step (Step 2)





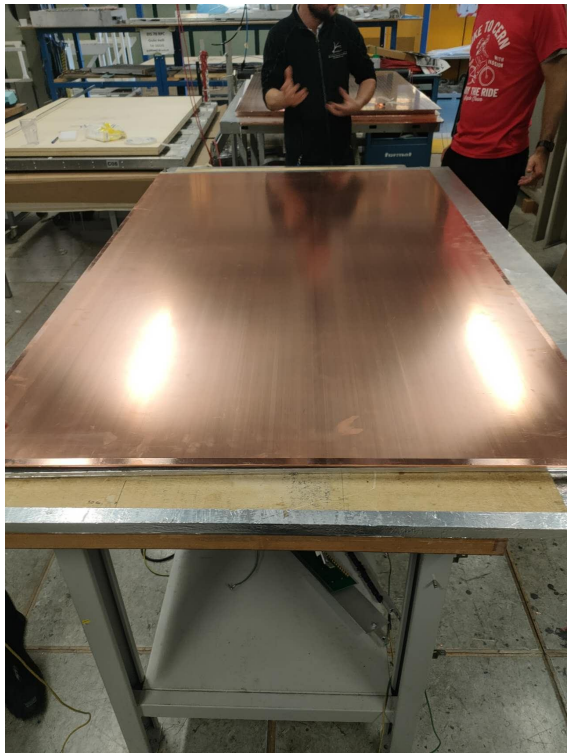


Step2:
Put the gas gap on the top of the readout pannel

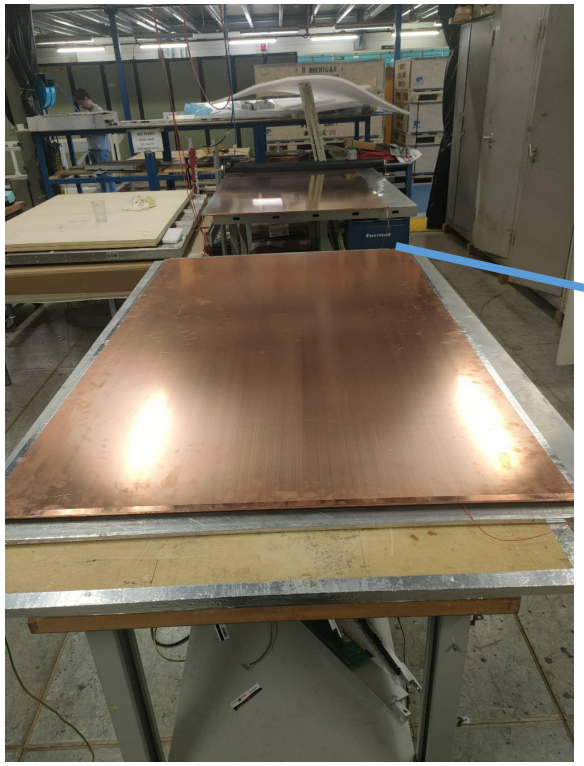
How to put the gas gap on the readout pannel ?

HV far away from the FEE and the HV wire is on the right side

More detail information for each step (Step 3 + Step4)

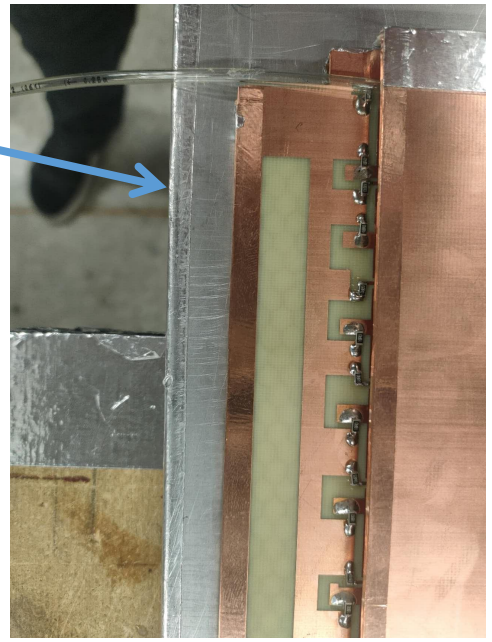


Step3:
Put another readout pannel
on the top of the gas gap

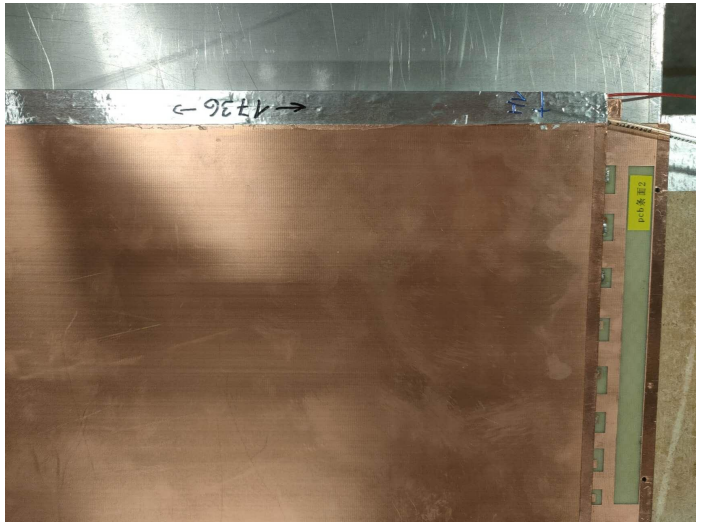


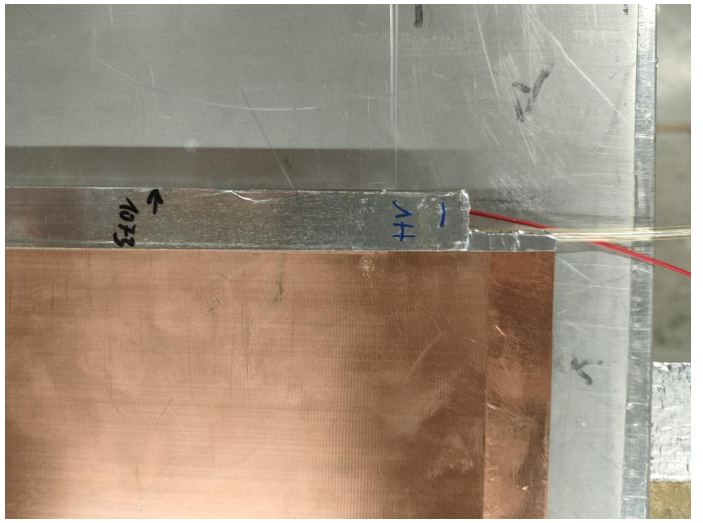
Step4:
Use the Aluminium tape
to fix those three layers
to form the singlet

Zoom in



The length of singlet is **1736 mm**





The width of singlet is **1073 mm**

The dimentional quality of this BIS singlet is very good