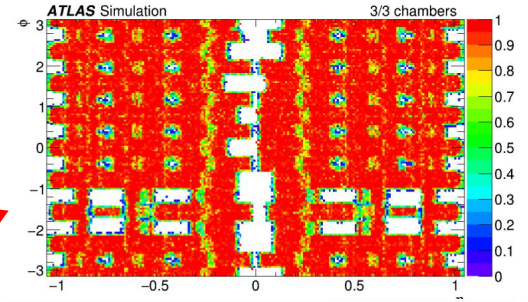
Production of the Readout Panel and Thin Gas Gap for RPC Phase2 Upgrade

Dongshuo Du（杜东硕）
On behalf of USTC RPC group

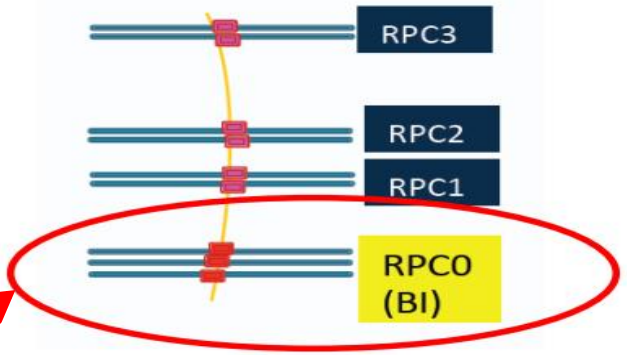
07/06/2025
MOST ATLAS Detector Upgrade Project, 2025 Annual Meeting

Introduction

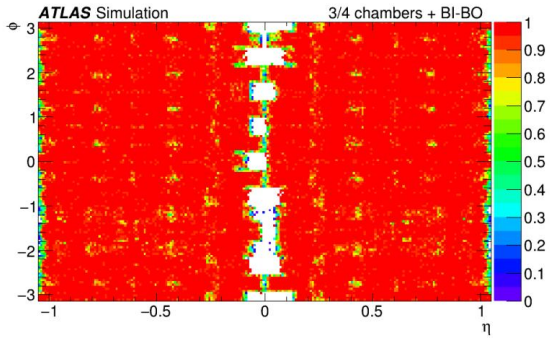
- RPC is a key detector in ATLAS Experiment
  - Provides the **first-level muon trigger** in the barrel region
  - Provides hit information for the **muon reconstruction**
- The main limitations @HL-LHC：
  - The **geometrical acceptance** in the barrel region is ~ 80%
  - **Long-term operation** at high rates is **not affortable** for 2mm gap RPC
    - **Rate < 100 Hz/cm²**
  - The **redundancy** of the present RPC system is **insufficient**
- Solutions： Installation of triplets of new-generation RPCs in the Barrel inner region
  - **Recover** most of the current geometrical **acceptance holes**
  - **Improve** the trigger **efficienty**
  - **The counting rate and longevity** is **improved** with 1mm gas gap
  - The **redundancy** of the system will be greatly **enhanced**



Run2



- 9 layers instead of 6

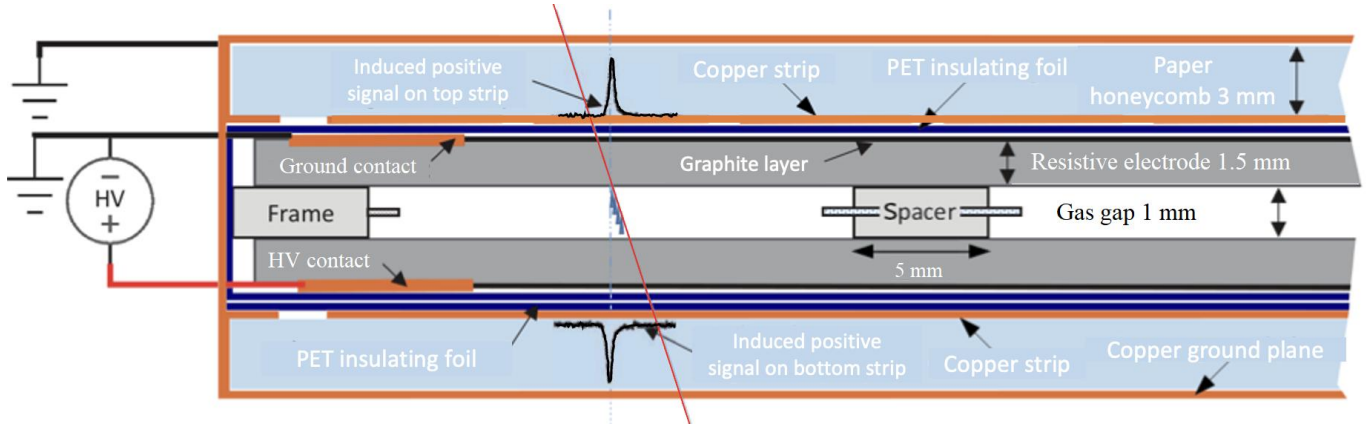


With new BI Layer

New layers: 130 BIL + 96 BIS + 48 BIS78 chambers （1 chamber = 3 singlets; 1 singlet = 1 gas gap + 2 readout panels）

Readout panel production

RPC singlet



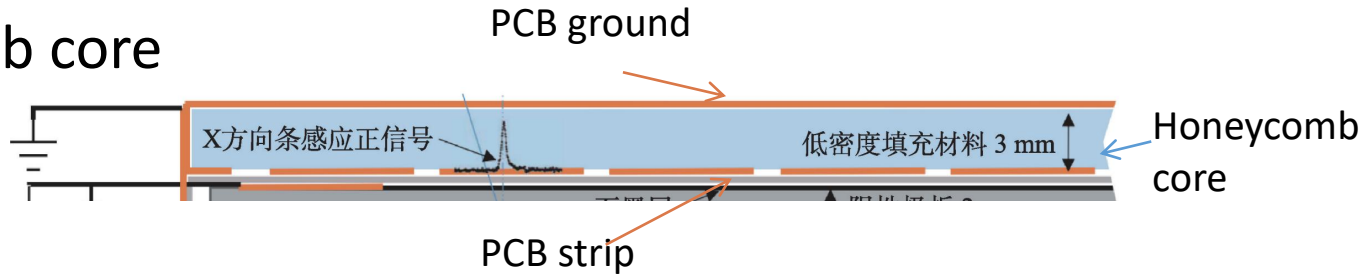
Readout panel

Gas gap

Readout panel

Development of readout panel production

➢ **Components：** 2 PCBs panels + Honeycomb core



➢ **Specifications：**

- Size： **1705 mm * 1072 mm** (BIS-1 type) or **1705mm * 890 mm** (BIS2-6 type)
- Flatness (Max variation in 70 mm * 70 mm range) < 100um
- Precision on length and width: < 1mm

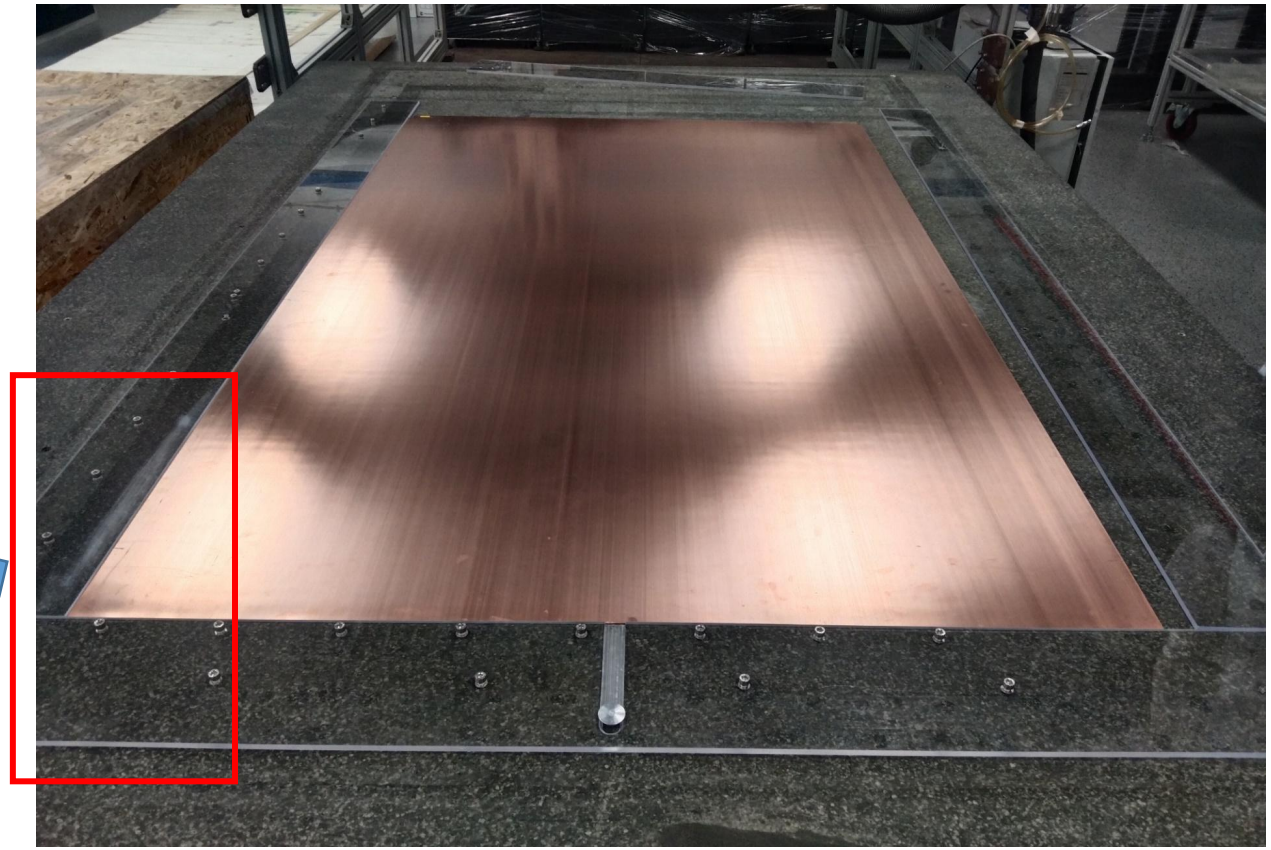
➢ **Main challenges：**

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) ?

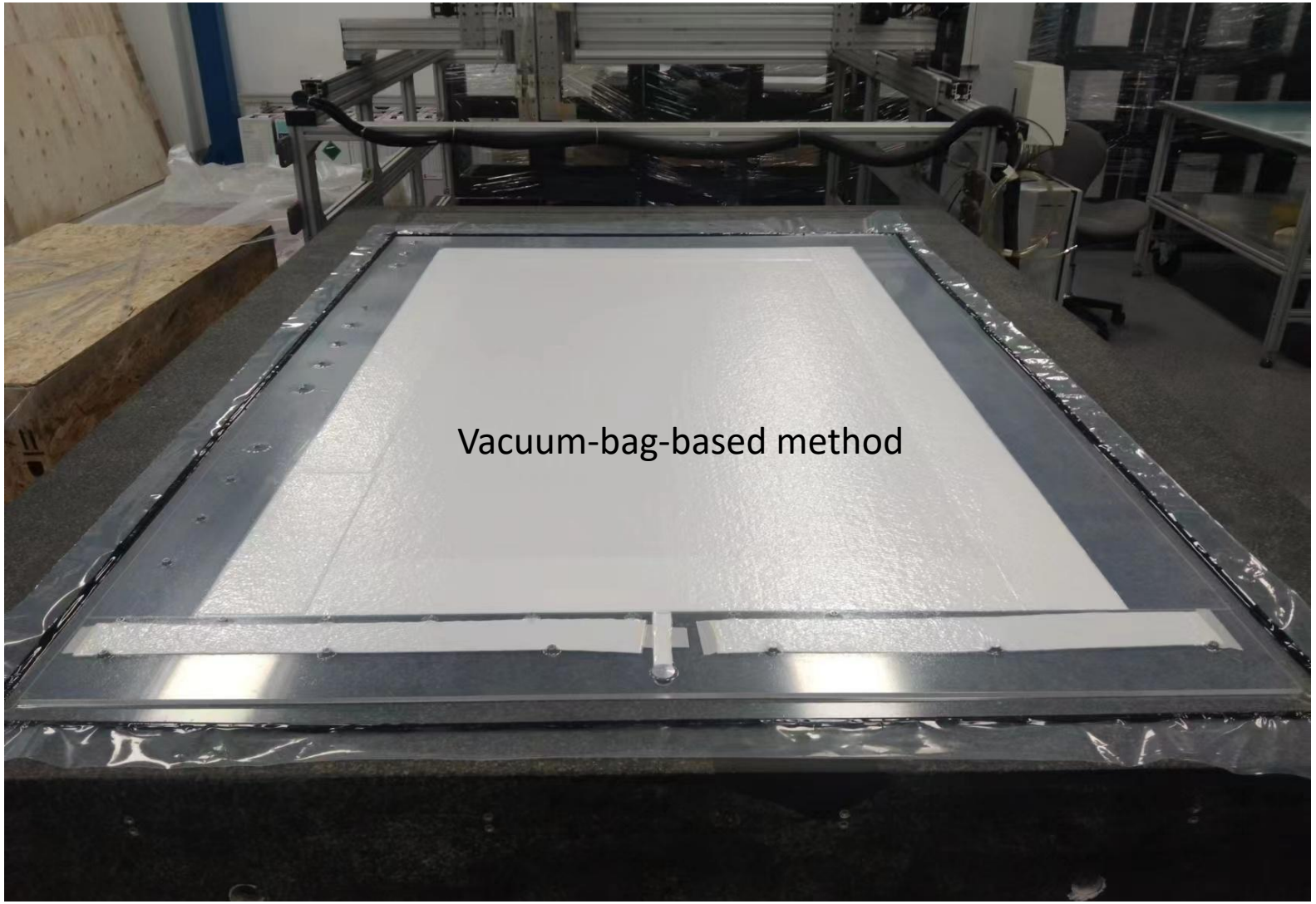
Alignment of 2PCBs and honeycomb

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

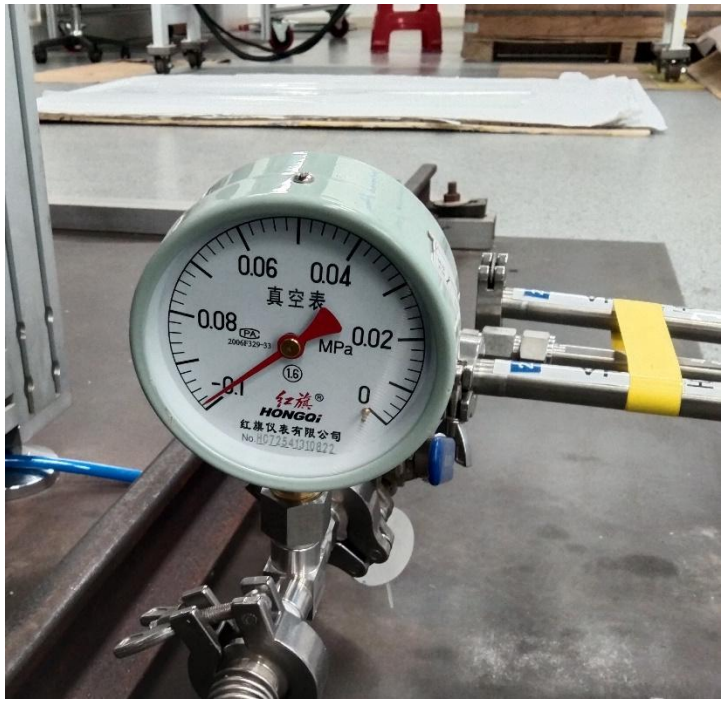


① How to make sure the alignment bewteen ground and strip PCBs ? ✔

Vacuum-bag based method



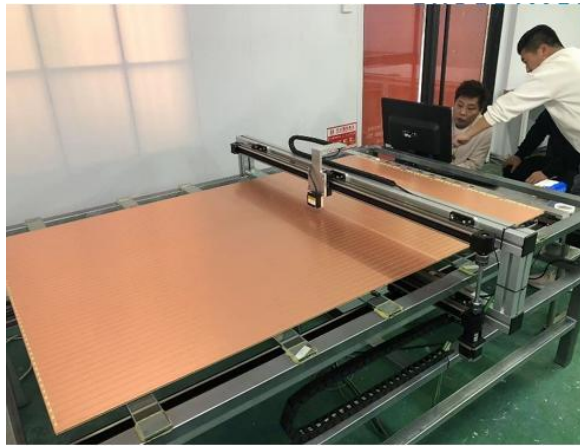
The vacuum power： 1 atm

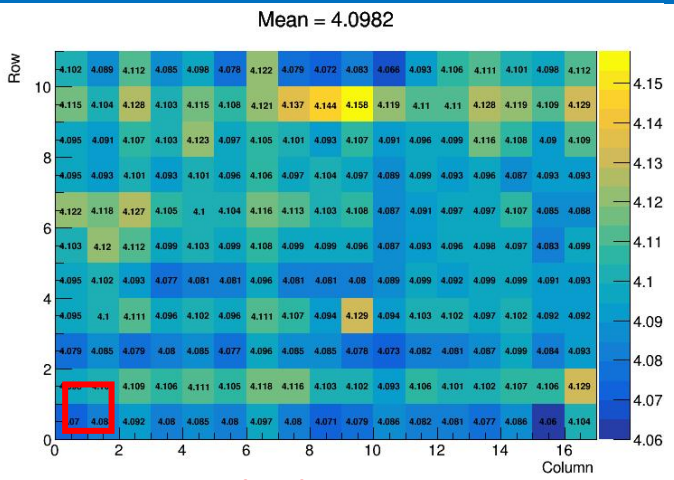


Keep at least 6 hours for the epoxy curing within the vacuum bag.

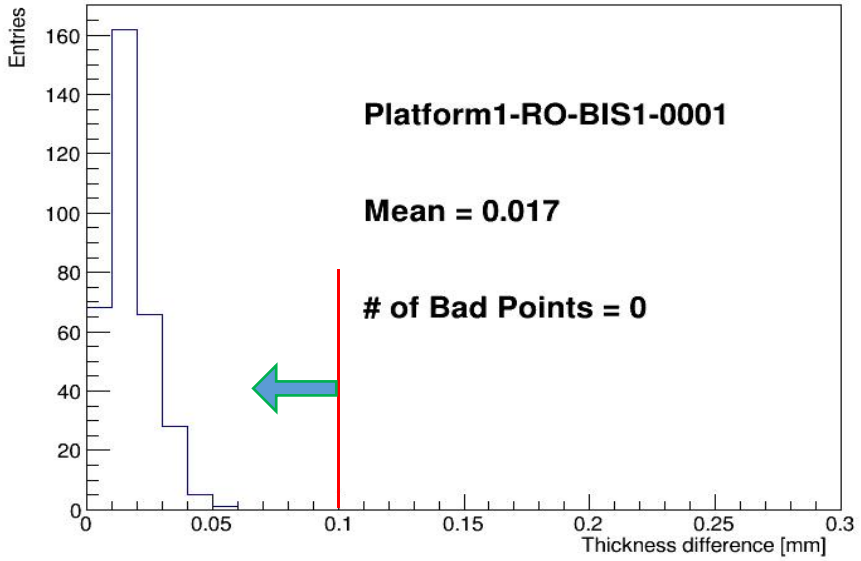
② How to apply enough pressure uniformly over such large area (1706 x 1070 mm^2)?

Thickness measurement and the quality





Thickness

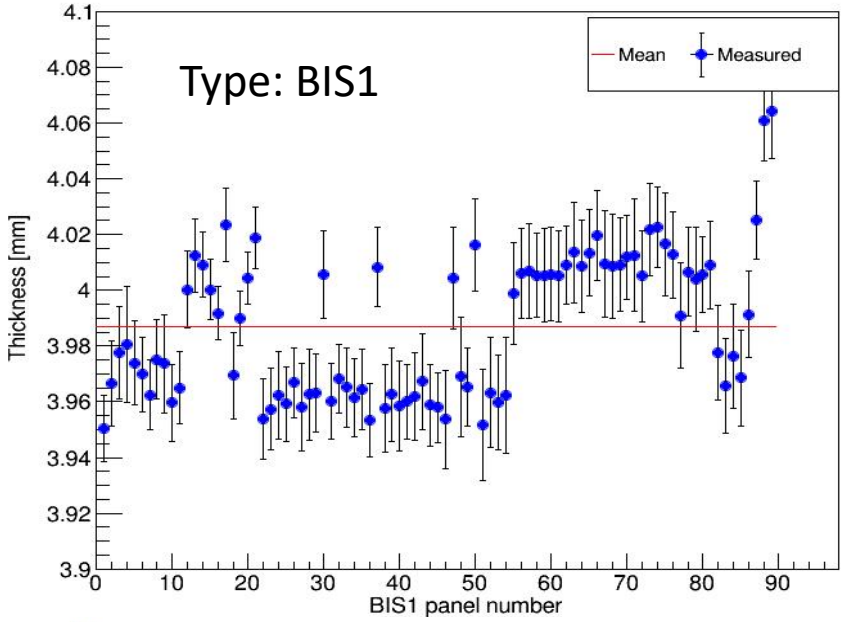


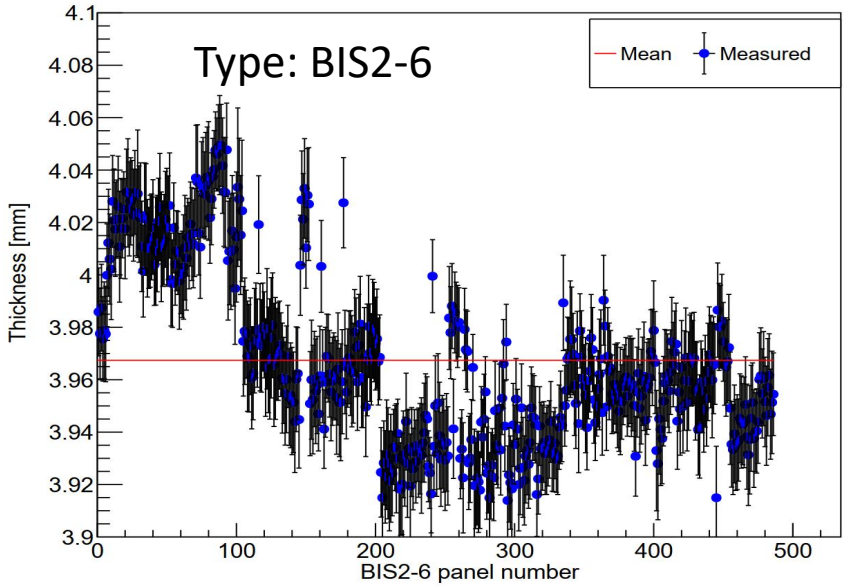
Flatness

- 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)
- 556 (29) readout panels are built in the external company (USTC) with the same method and the quality can satisfy the specification
  - 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/day

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

Thickness measurement and the quality

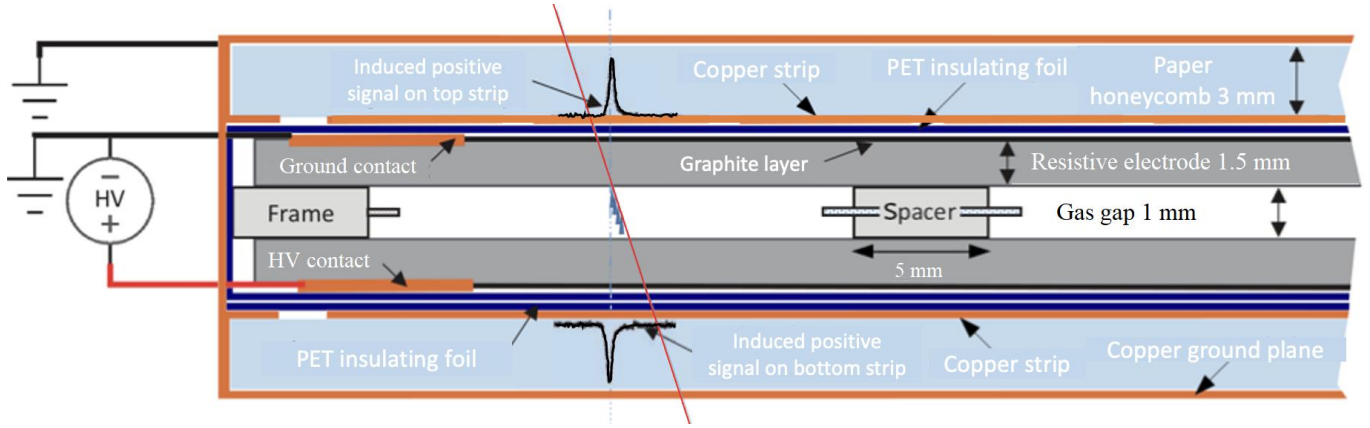




- The thickness is measured in 7cm * 7 cm matrix by two laser sensors automatically
  - The distance between two points is 7 cm
- The flatness < 100 μm can be achieved in 7cm * 7cm range.
- **556 (29) readout panels** are built in the external company (USTC) with the same method and the quality can satisfy the specification (Left 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

RPC gas gap prodcution

RPC singlet



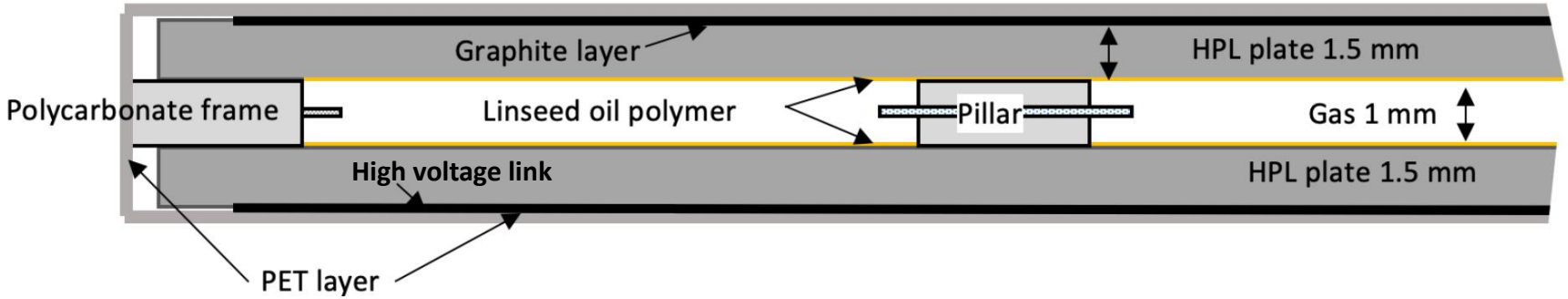
Readout panel

Gas gap

Readout panel

Development of RPC gas gap production

- Components:
  - Closed gas gap
  - Graphite layer
  - High voltage link
  - PET layer
  - Linseed oil polymer



Sketch of a Gas Volume

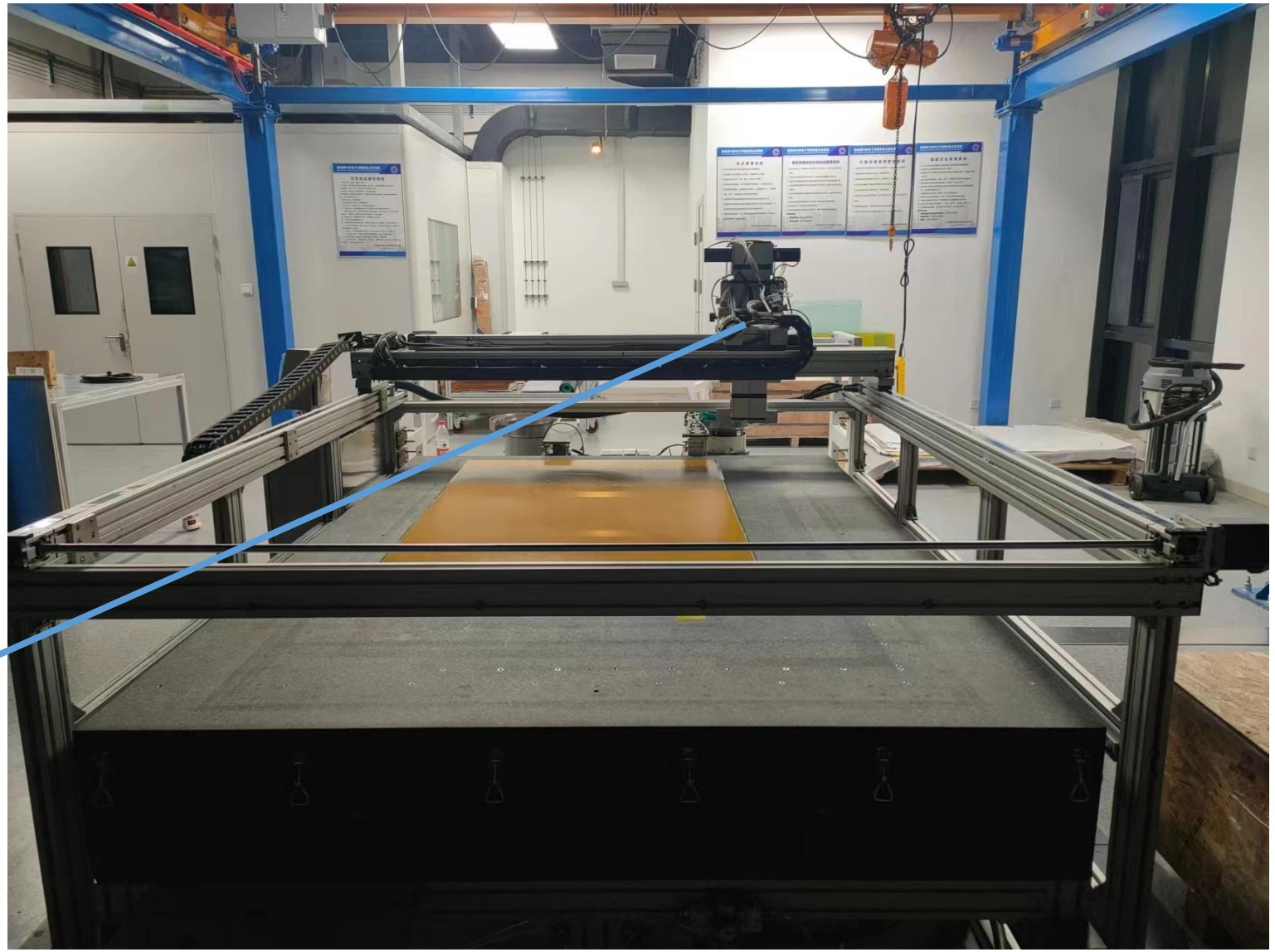
- **Main challenges**:
  - Closed gas gap with good tightness and flatness
    - ✓ The flatness of the gas gap is guaranteed by spacers (1.000 +/- 0.004 mm)
    - ✓ Good tightness: very good assembly techniques and many iterations
  - PET foiling(absence of bubbles > 2-3 mm^2 between PET foil and graphite layer)
  - Linseed oiling
    - ✓ Increase the flatness of the inner surface → Improve the electrical performance

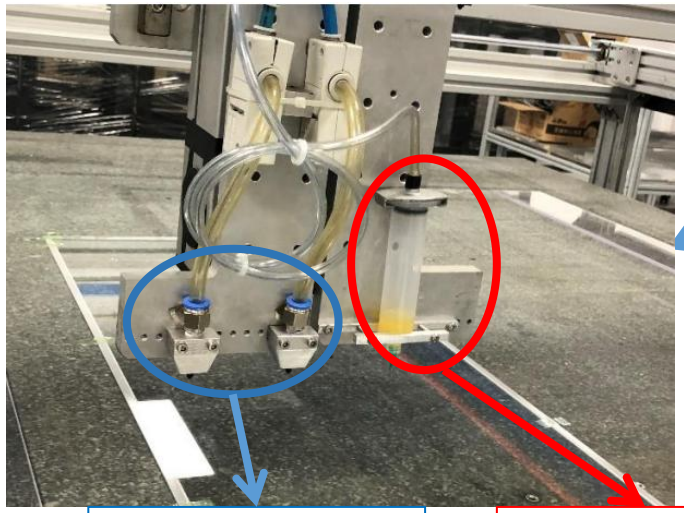
The platform for gas gap production

- 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.

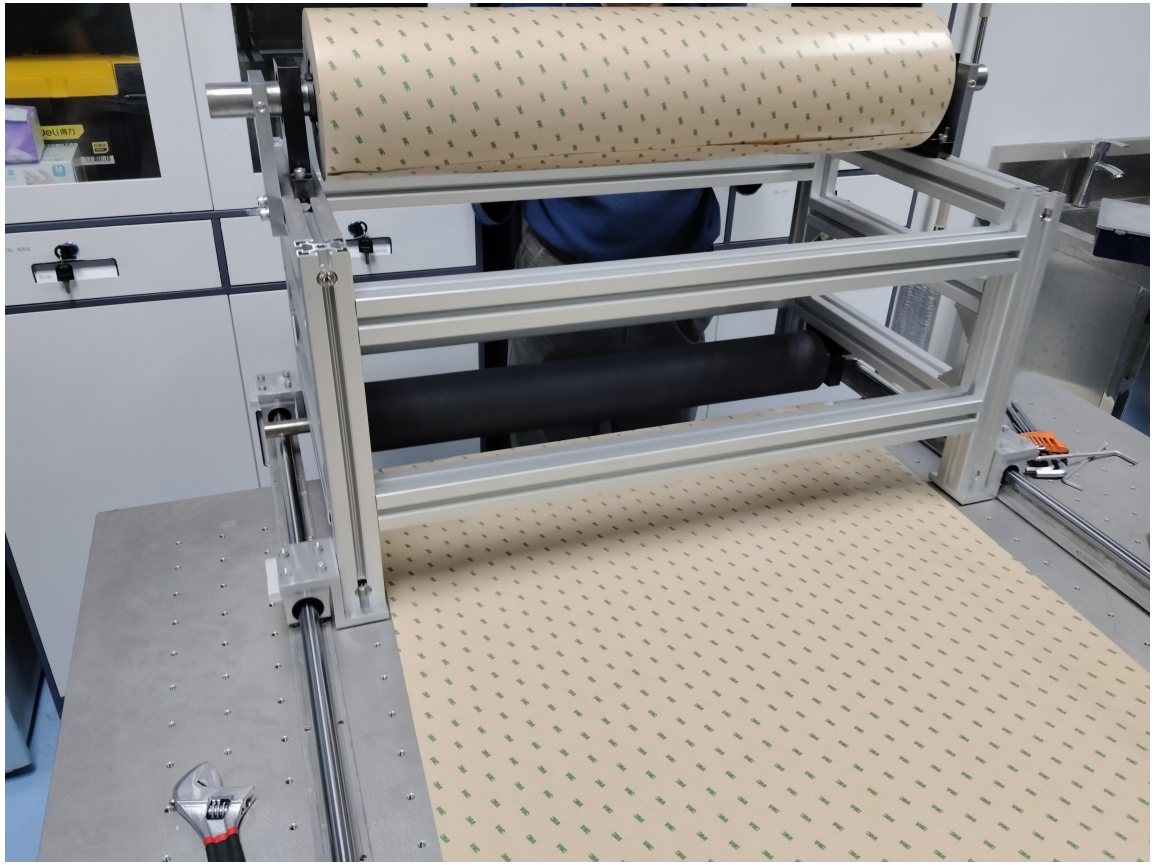




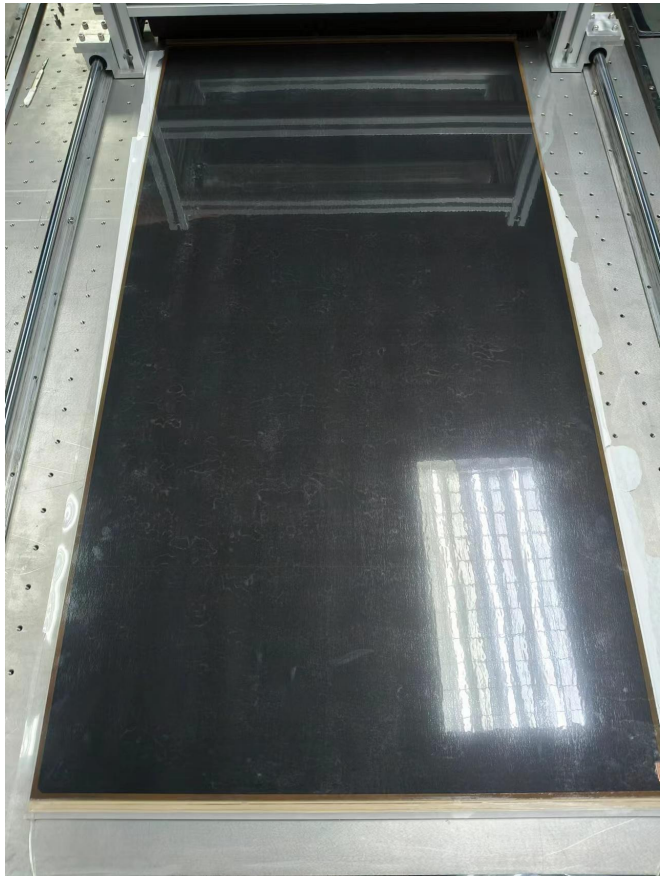
Spacer pickers

Glue syringe

Key technology: PET foiling



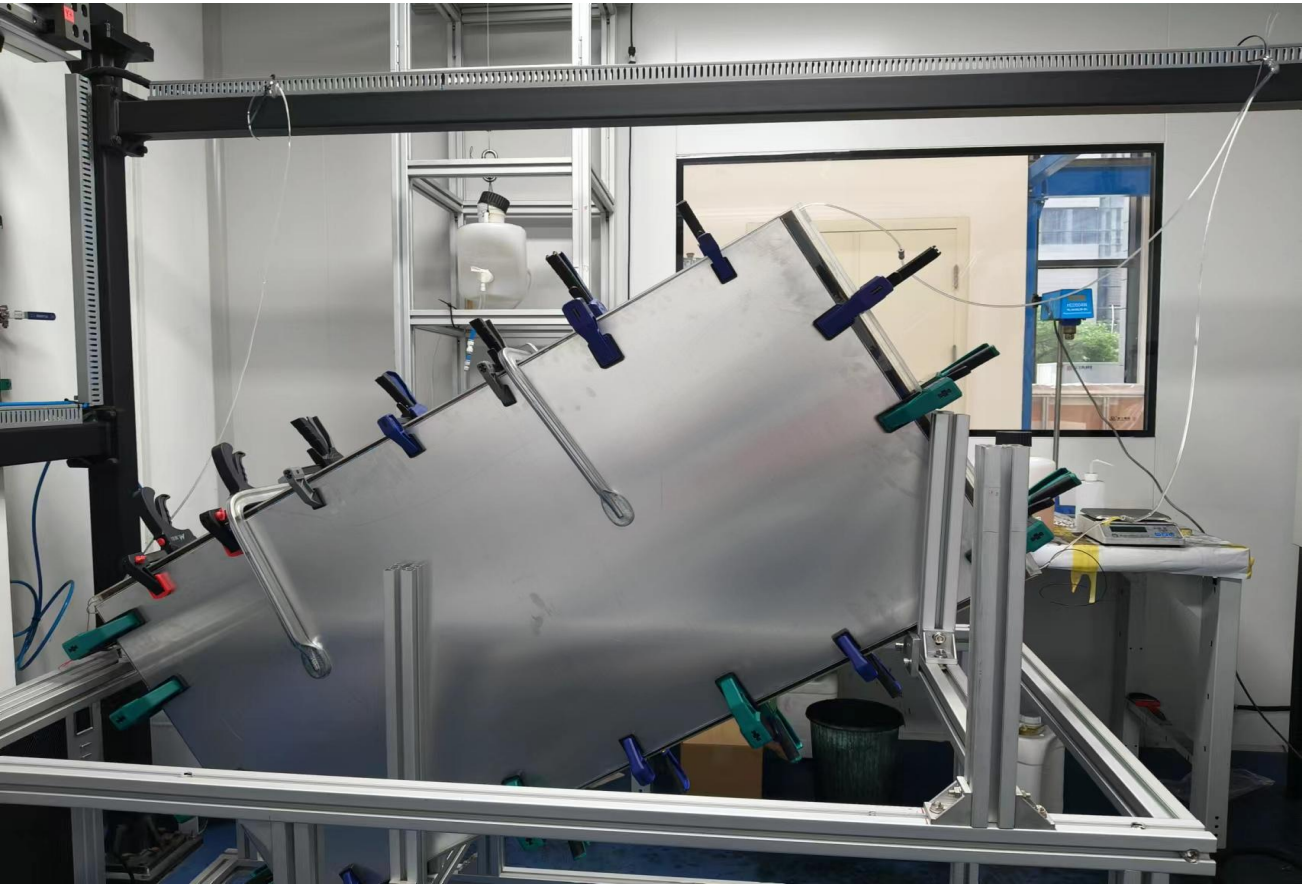
Tooling



Mirror-like surfacing

Use the weight of the roller to provide uniform pressure

Key technology: 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 dry air through the gas gap for one week to achieve Linseed oil polymer (From top gas inlet to bottom).

Preparatory work:

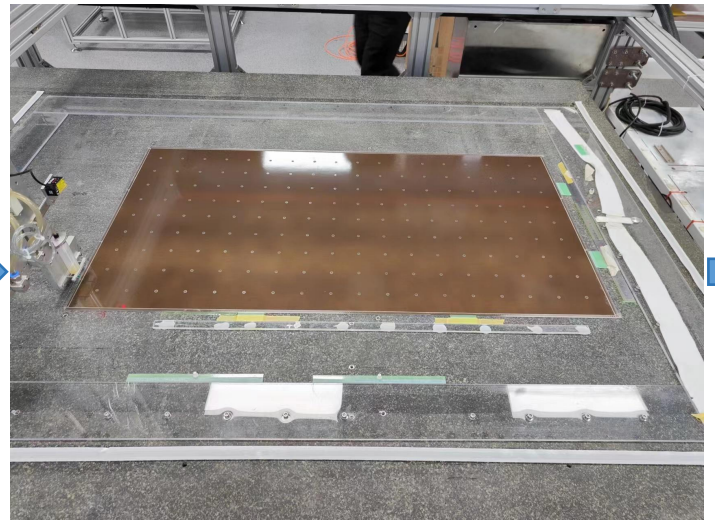
- Room temperature: ~ 40℃
- Mixed oil: 30% linseed oil + 70% heptane
- Use clamps to prevent bursting under oil pressure

Tightness of gas gap will be checked again after oiling

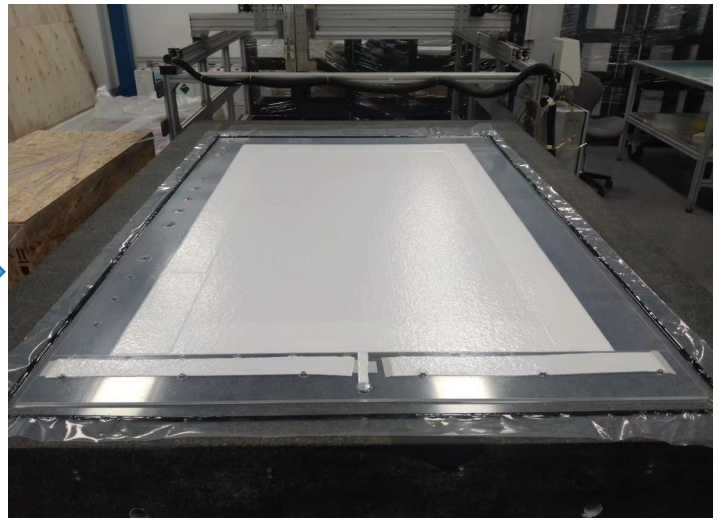
Main procedures

Graphite coating

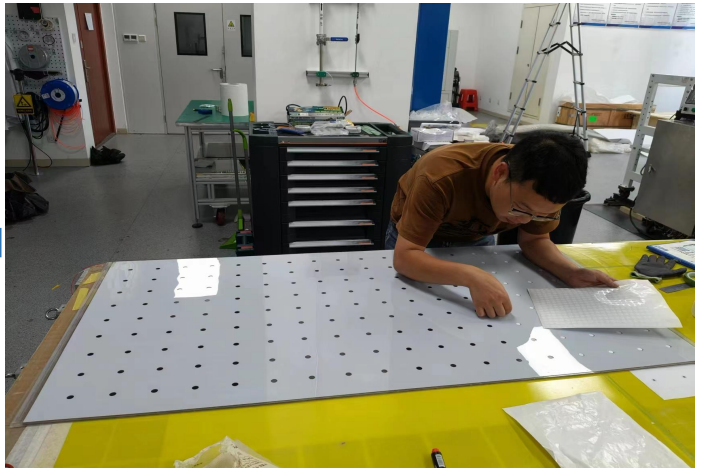
PET foiling



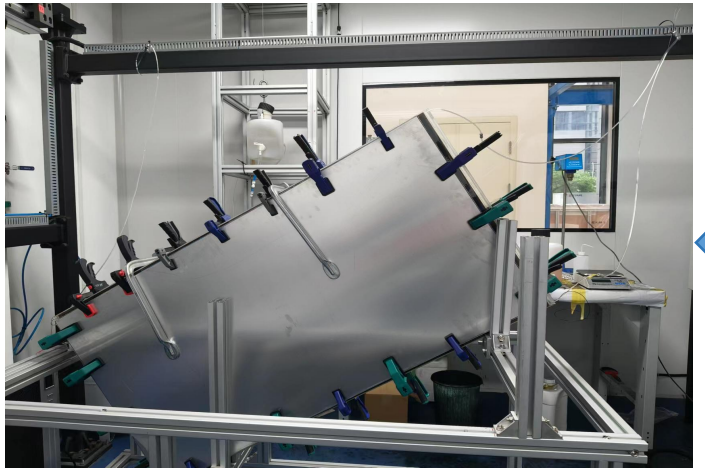
Attach the spacers



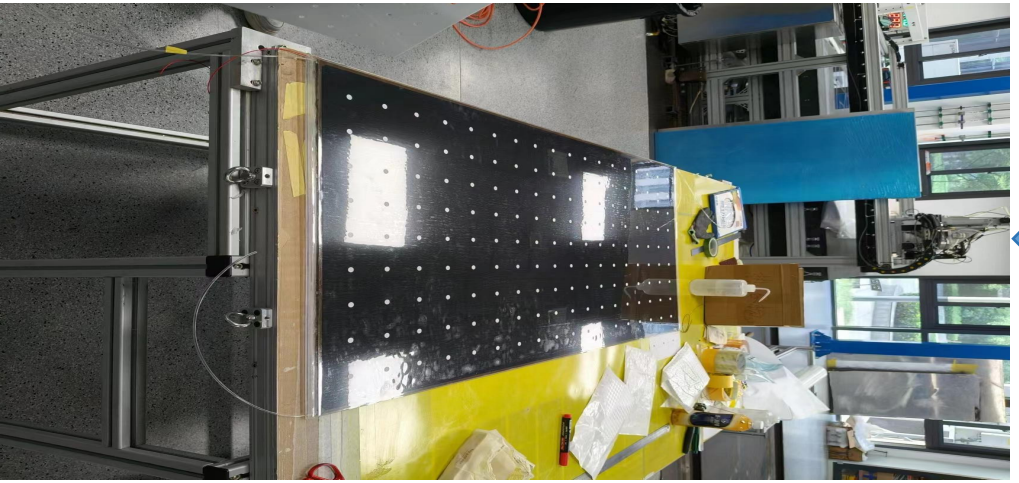
Vacuuming



Paper stacker



Linseed oiling



gas gap

Tightness of the gas gap

Argon sniffer

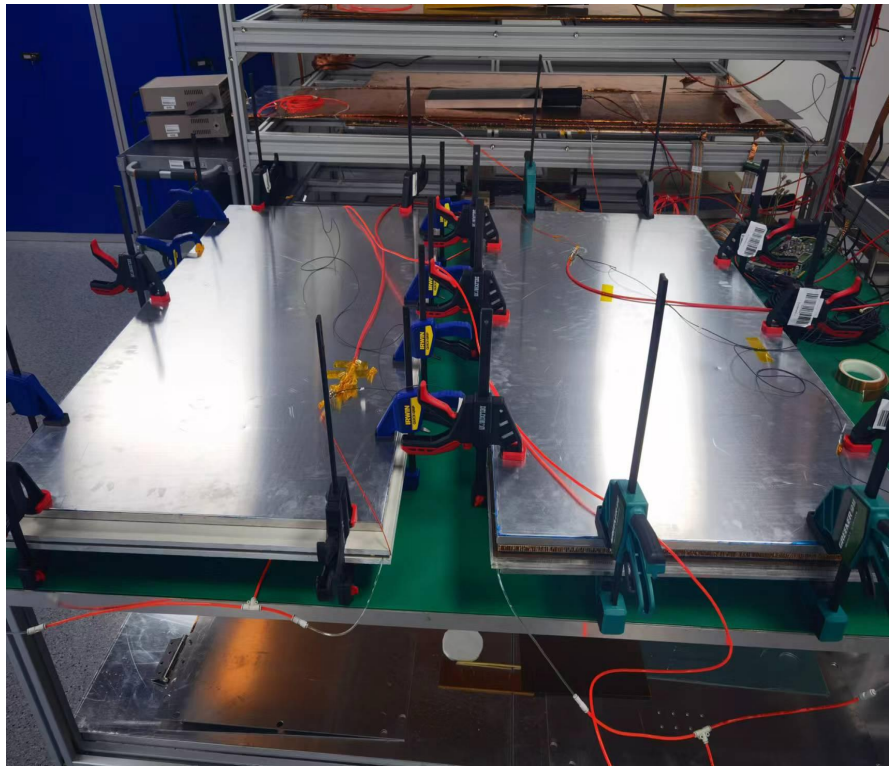
Manometer

Buffer bag

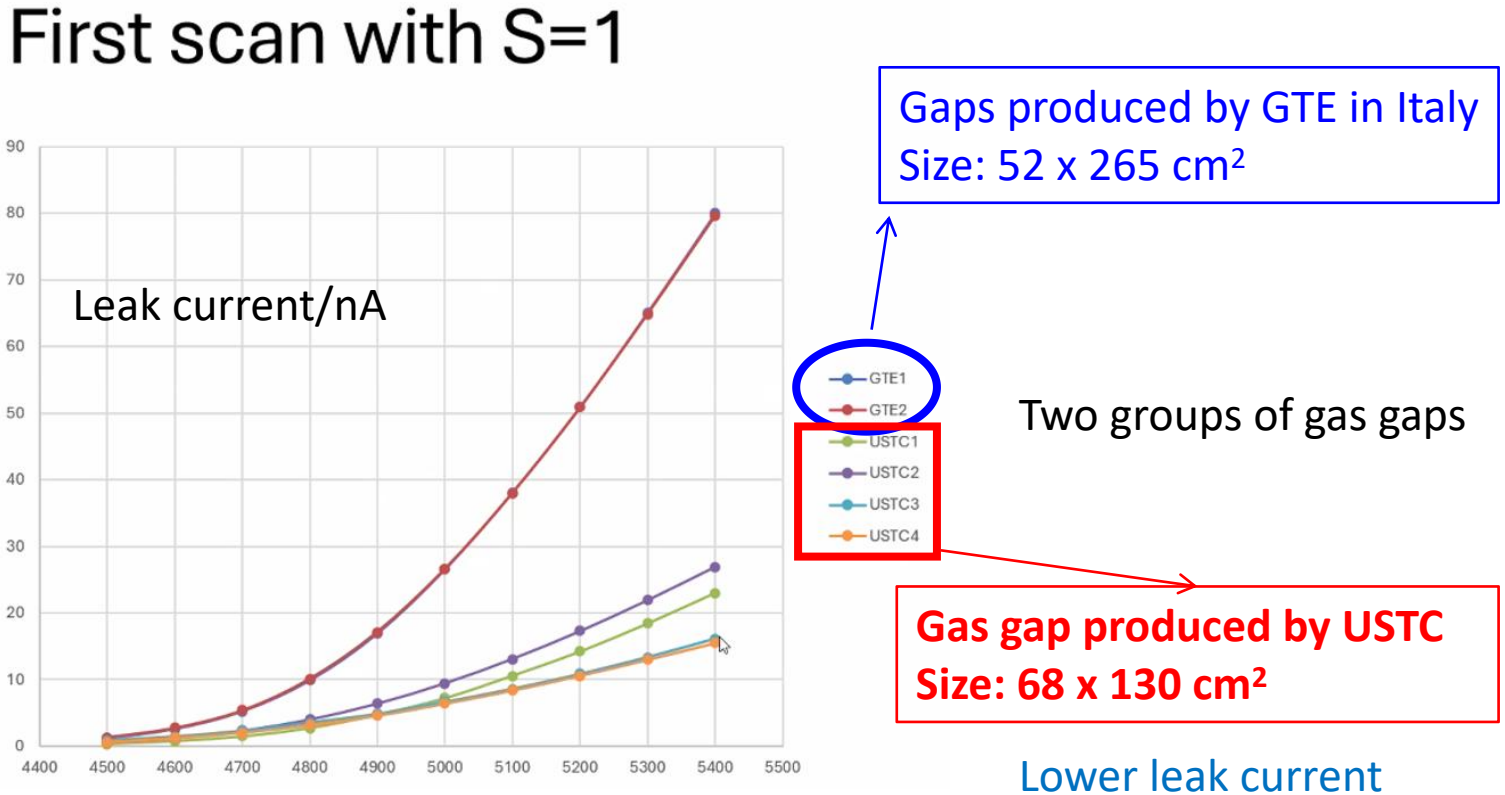
- Gas gap filled with argon at least 3mbar overpressure
- Leaks sealed with Araldite adhesive glue
- The 3mbar overpressure can be maintained for at least 3 minutes
- **All of them passed the tightness test.**

High Voltage performance

- 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.
- HV scan from 4.5 kV to 5.4 kV with gamma source in GIF++



HV training at USTC



Test results at CERN

Summary

- Readout panels production
  - The vacuum-bag-based readout panel production method has been established and optimized at USTC.
  - About 600 readout panels are produced, the flatness of the readout panel < 100 um, can satisfy the specification.
  - The production of readout panel is on schedule.

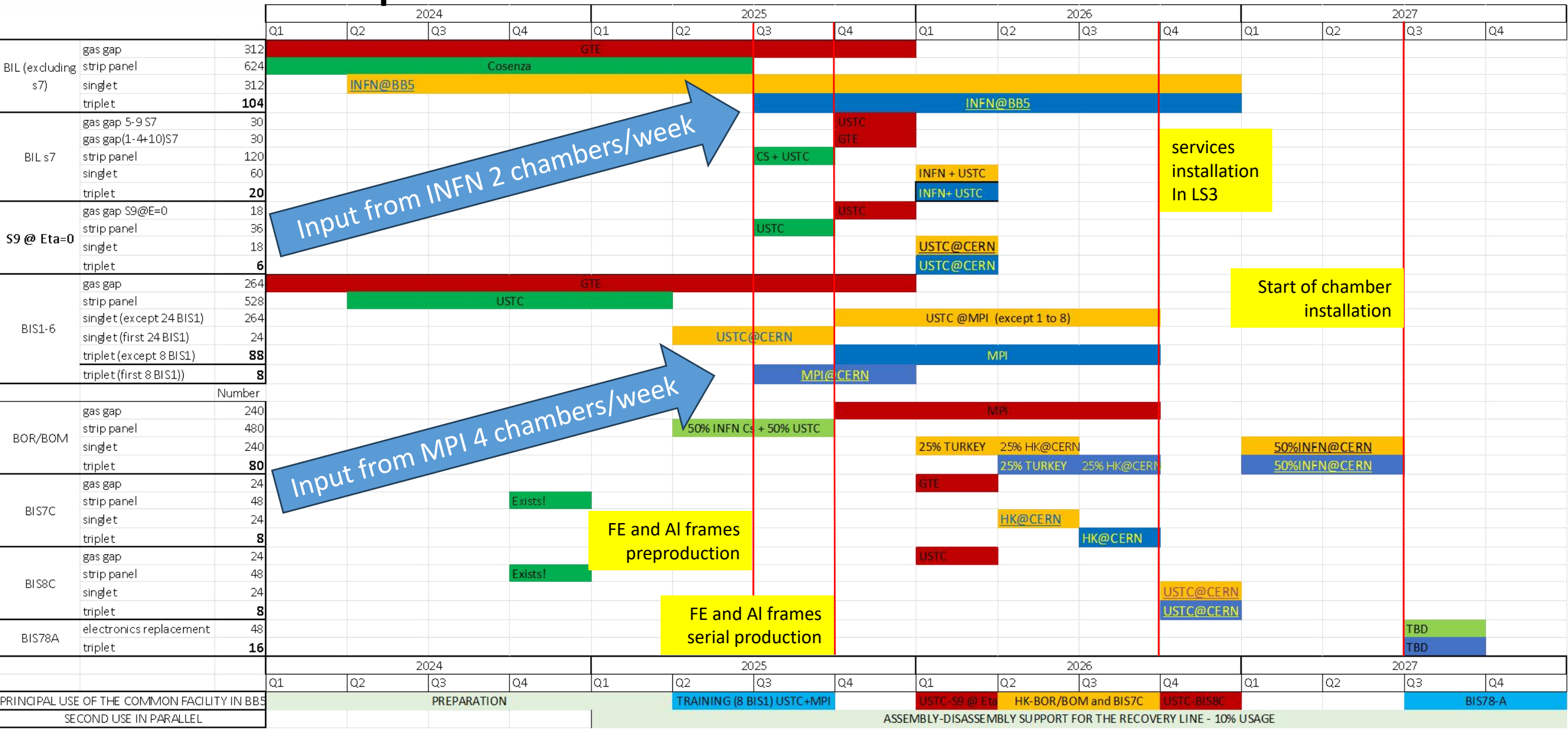
- Gas gap production at USTC
  - 8 gas gap prototypes (130 cm * 68 cm) are produced at USTC, the test results (I-V curve) are very promising.
  - The aging test are ongoing for those gaps in GIF++.
  - Another 4 gaps with optimized design will be produced in USTC around July 2025
  - The real mass production will start from September 2025

Any questions or comments are welcome

Thank you

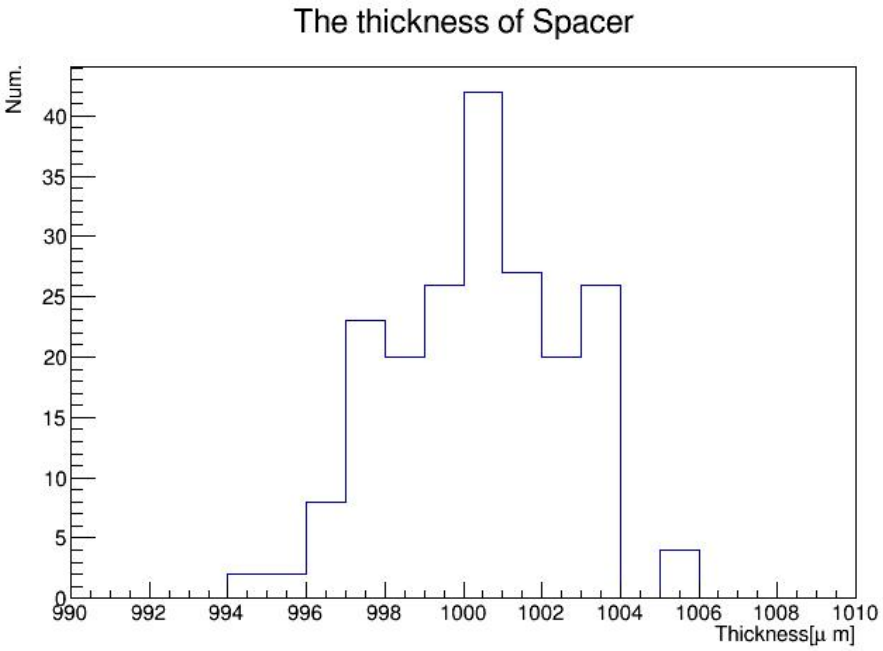
Back up

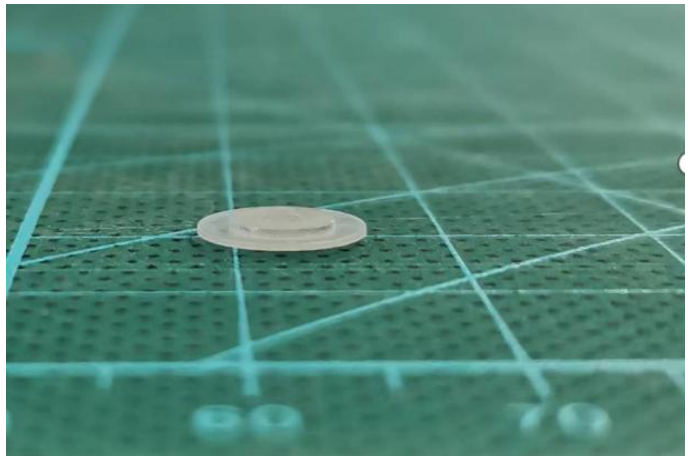
Chamber production schedule flowchart

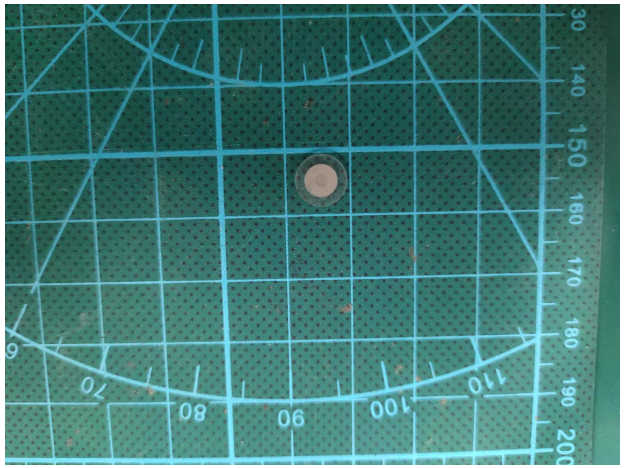


Spacers with guard wing

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



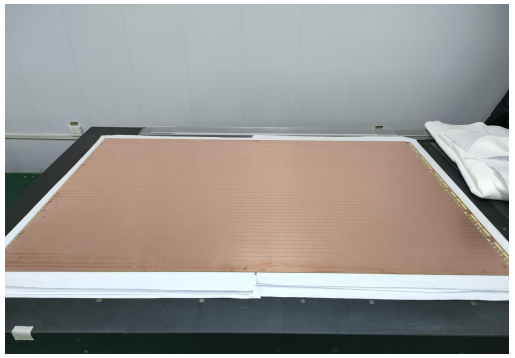




1/100 of all the spacers (20000) are tested
96% in 1.000 +/- 0.004 mm
100% in 1.000 +/- 0.006 mm

Honeycomb readout panel production

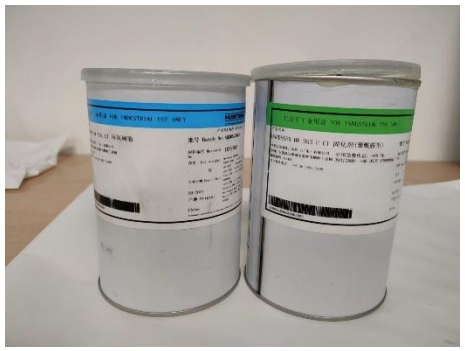
- Materials for production:
  - PCBs: ~0.45mm thick, size: 1706 mm x 1070 mm or 1706 mm * 890 mm
  - Honeycomb core: 3 mm thick
  - Glue: Araldite 2011 (~180 g /side)



PCB: BIS-1

PCB: BIS-2_6

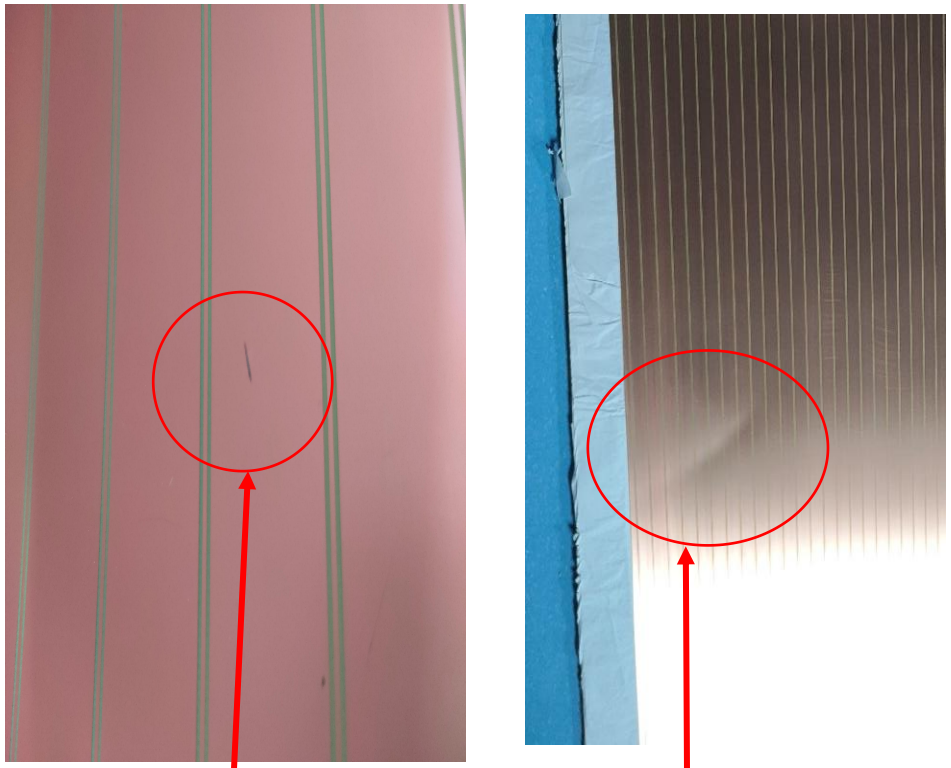
Specifications:
The flatness of readout pannel < 0.1 mm in 7 cm * 7 cm range
The length and width:
1705 +/- 1 mm
1072 +/- 1 mm



Araldite 2011

THINKY MIXER ARE-310

General checks on the PCBs

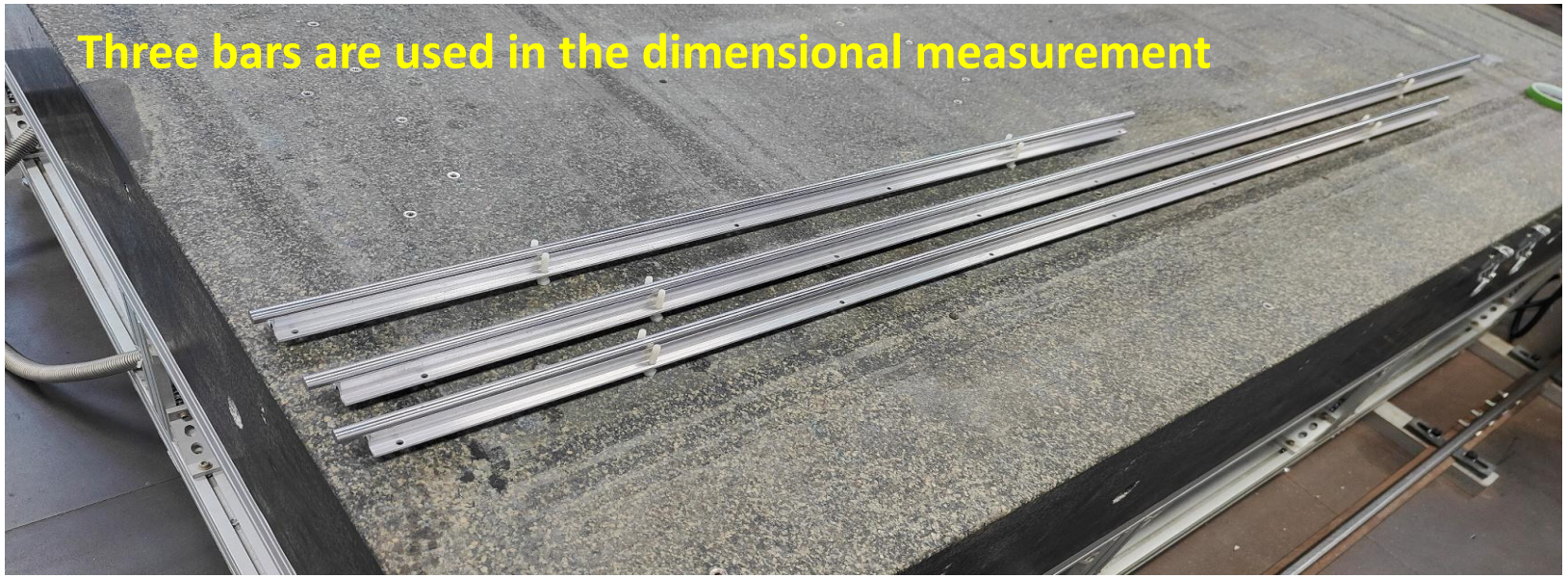


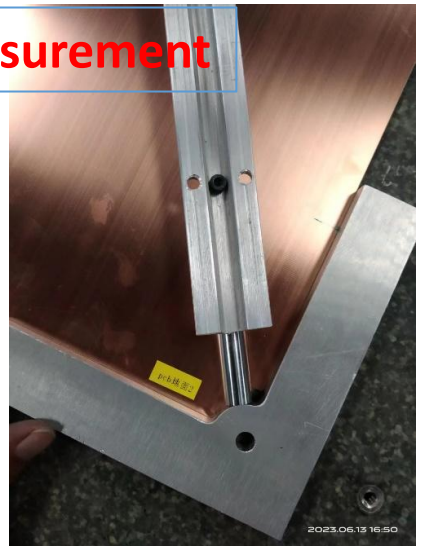
Visual check: Some slight fold marks/ scratches observed on the surface of the PCBs.

Electrical continuity checks

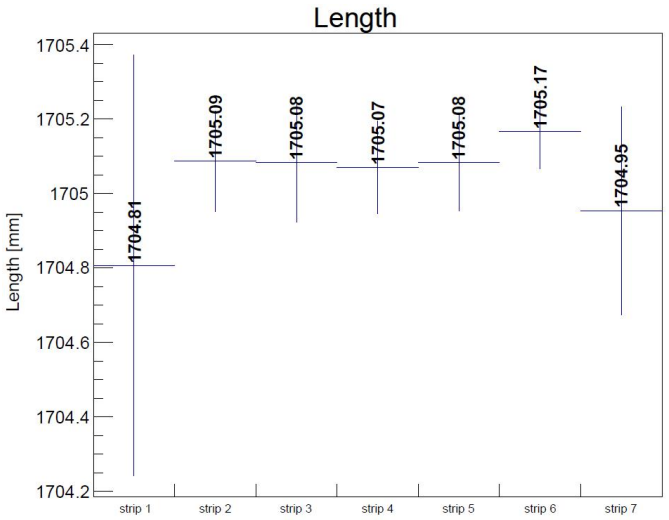
The PCBs passed the general checks will do the dimension check

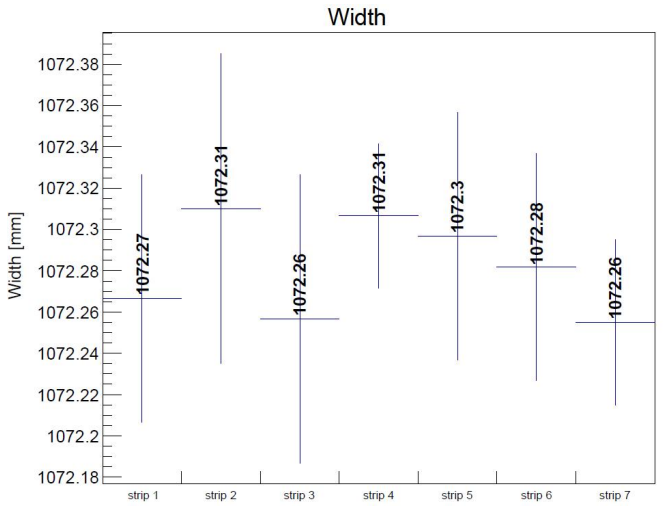
The dimensional measurement

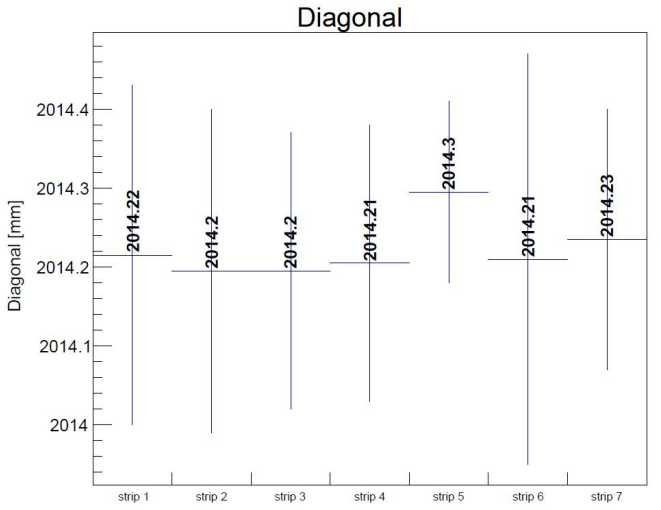




The dimensional results

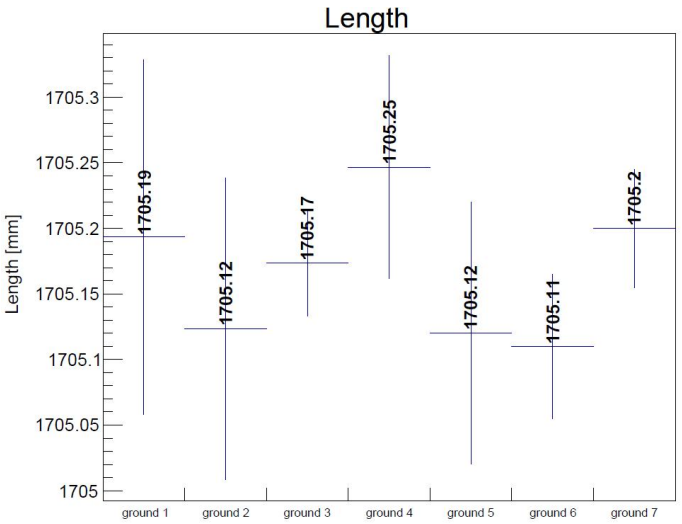


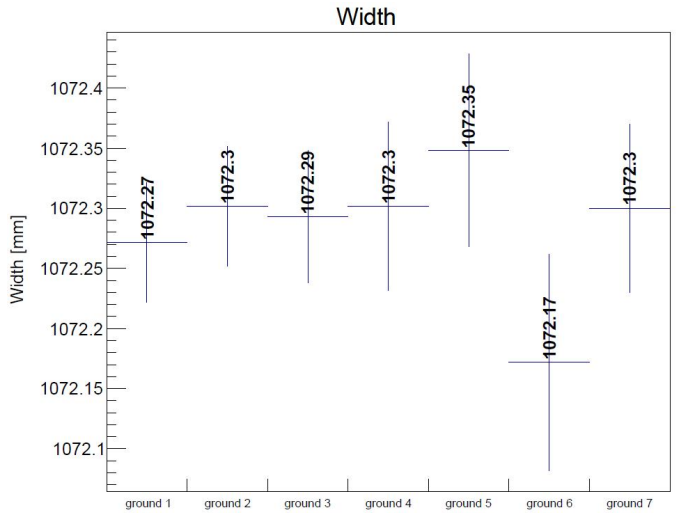


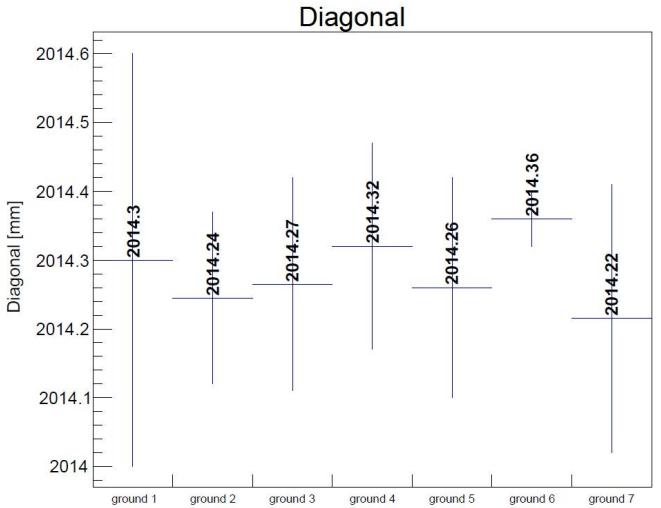


Nominal value:
Length: 1705mm
Width: 1072 mm
Diagonal: 2014 mm
Error: +/- 1 mm

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

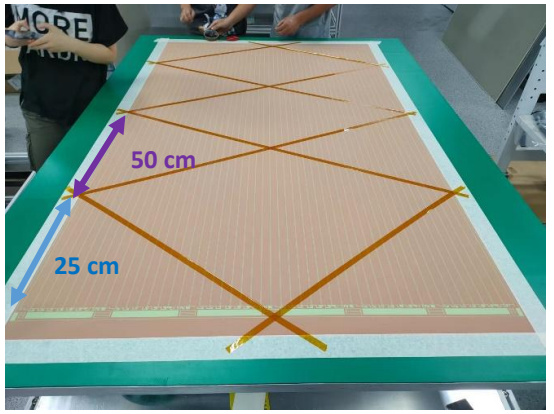
➢ **Main difficulties:**

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

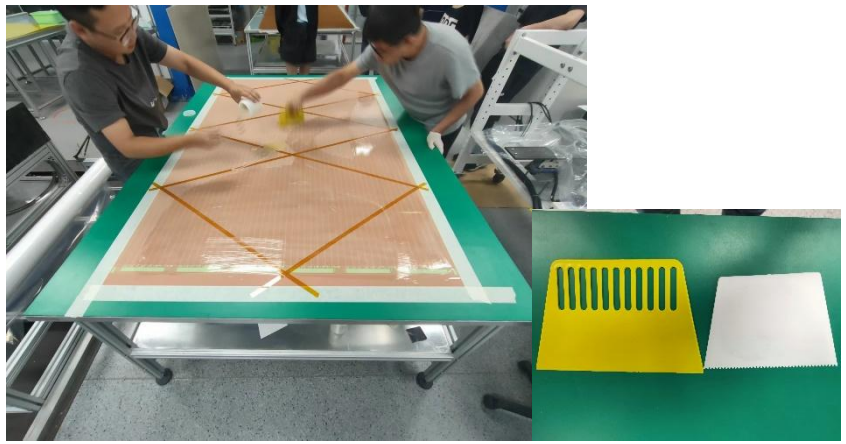
② How to apply enough pressure uniformly over such large area (1706 x 1070 mm^2) ?

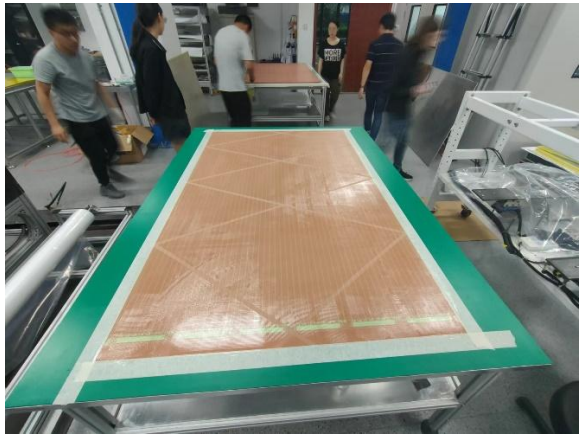
First step: X shape tape sticking and glue spreading

- 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



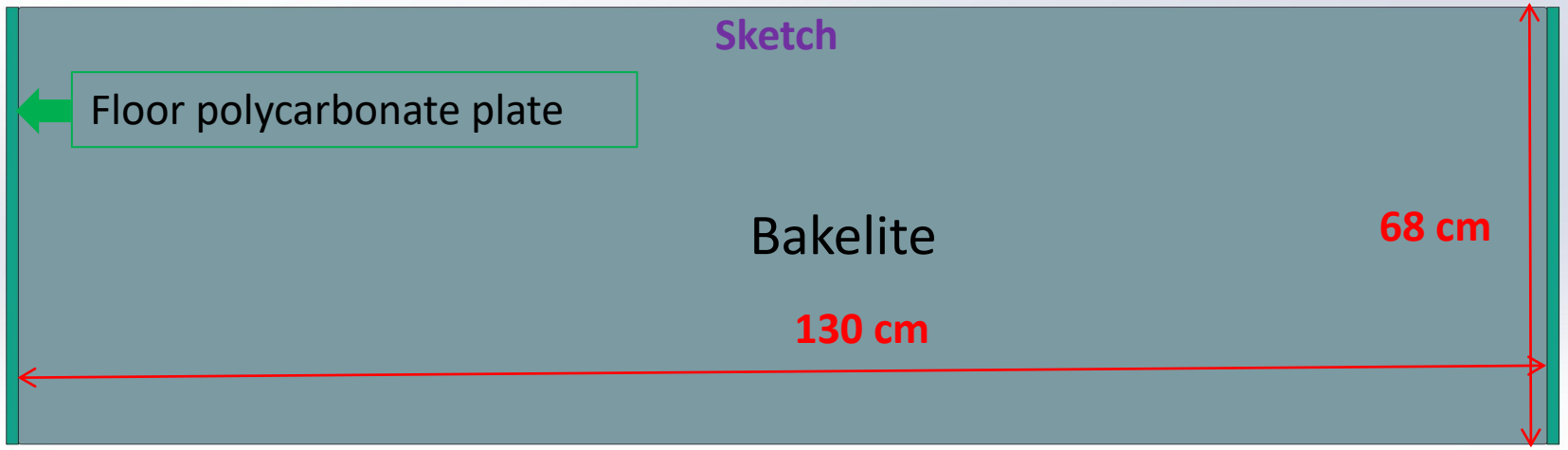


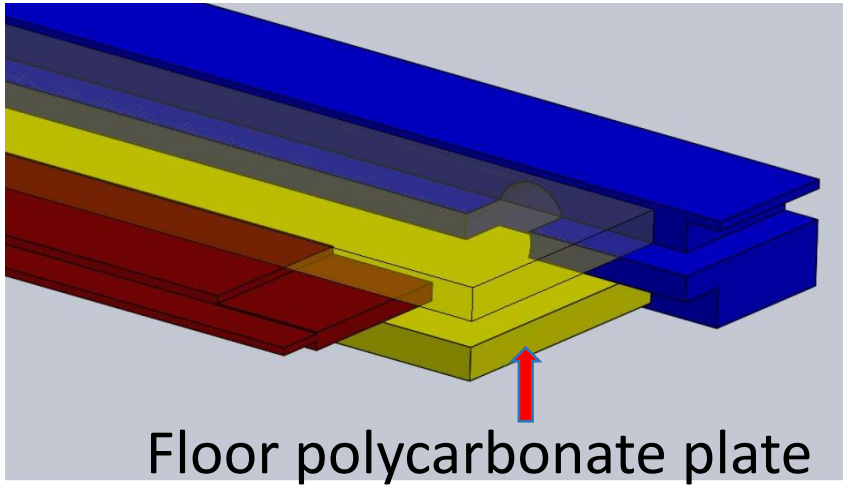
The assembly procedures of the closed gas gap

- 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

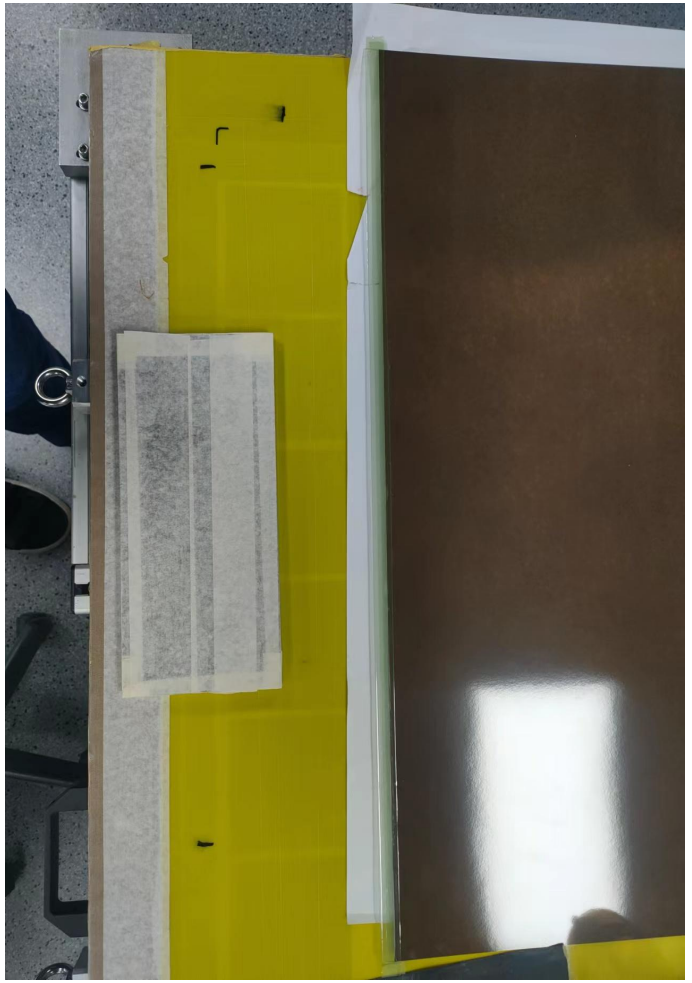
- Attach 2 floor polycarbonate plates to the bottom bakelite with Araldite adhesive glue





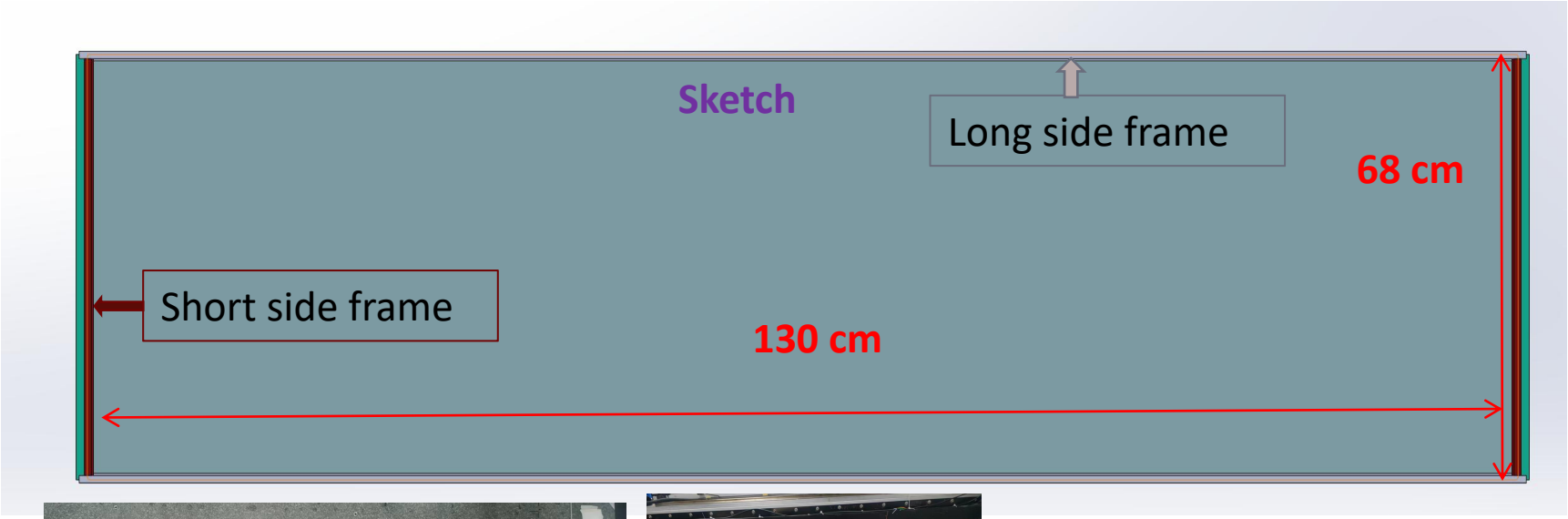
- ✓ The size of Bakelite: 130 cm * 68 cm
- ✓ The piece used in this step is indicated by the red arrow.

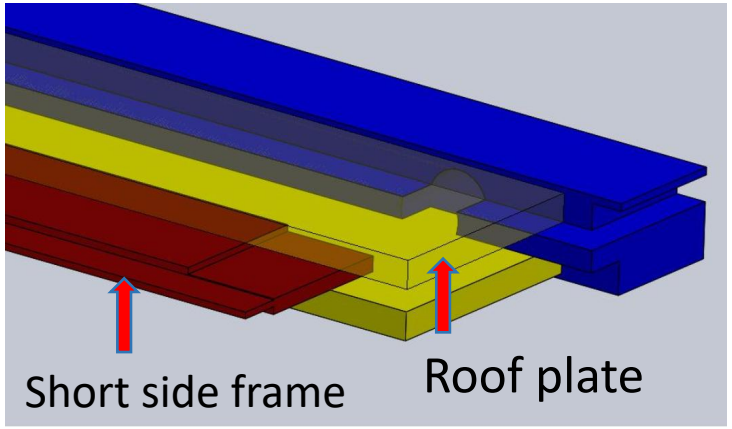
The bakelite and 2 floor plates will on the same plane

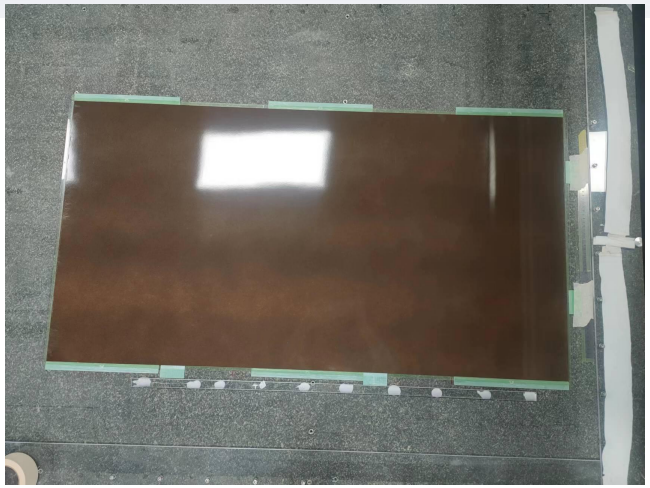


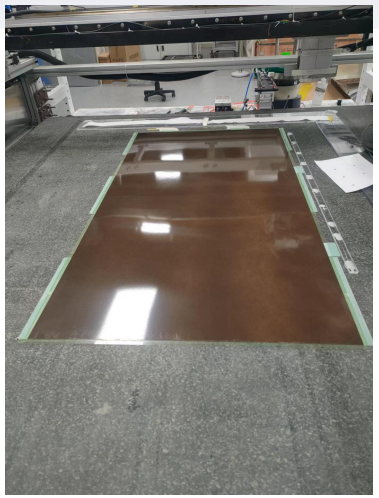
The second step

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





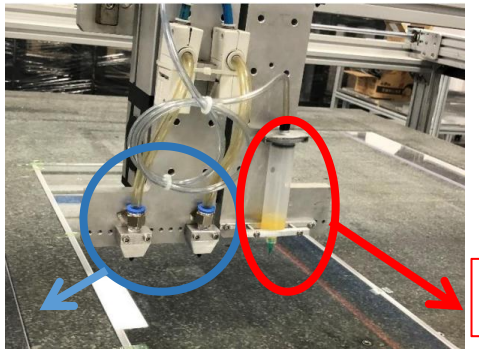


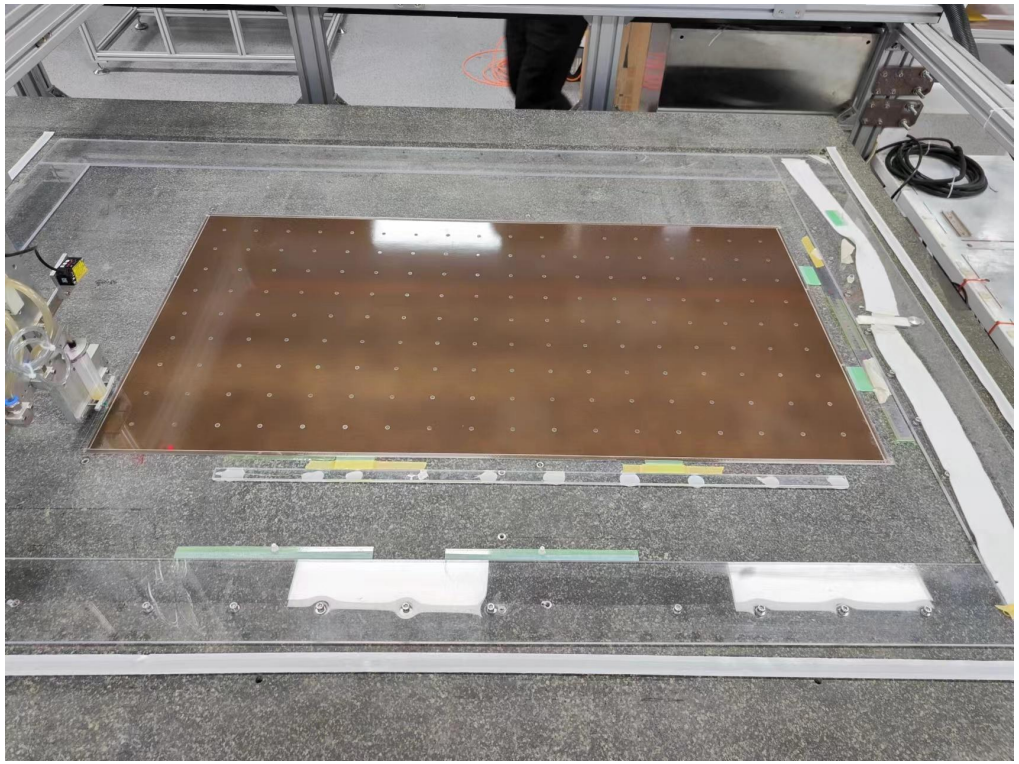


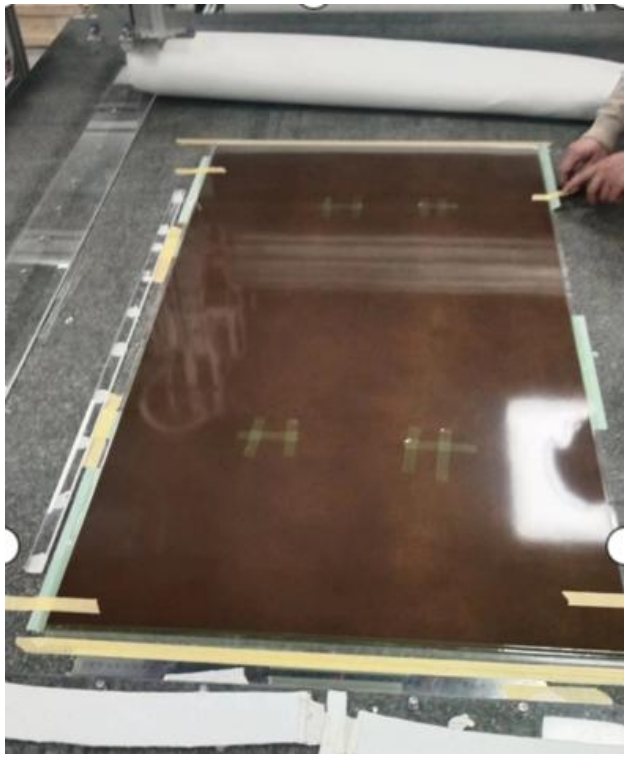
Zoom in

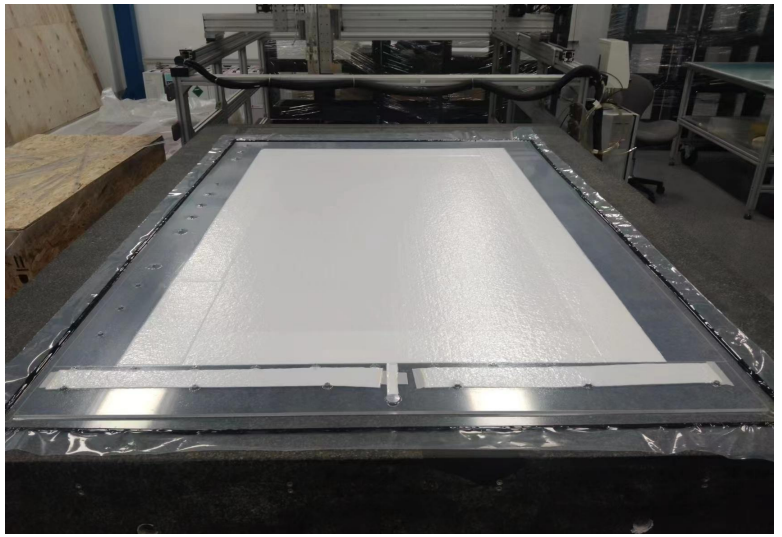
The third step

- 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





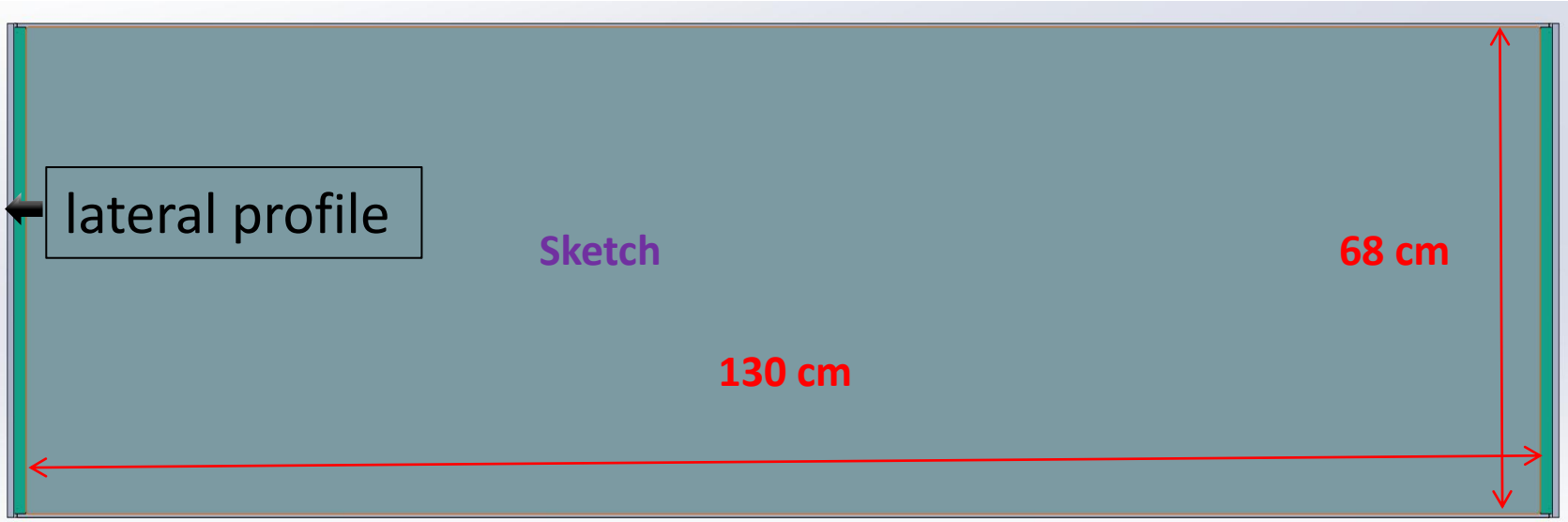


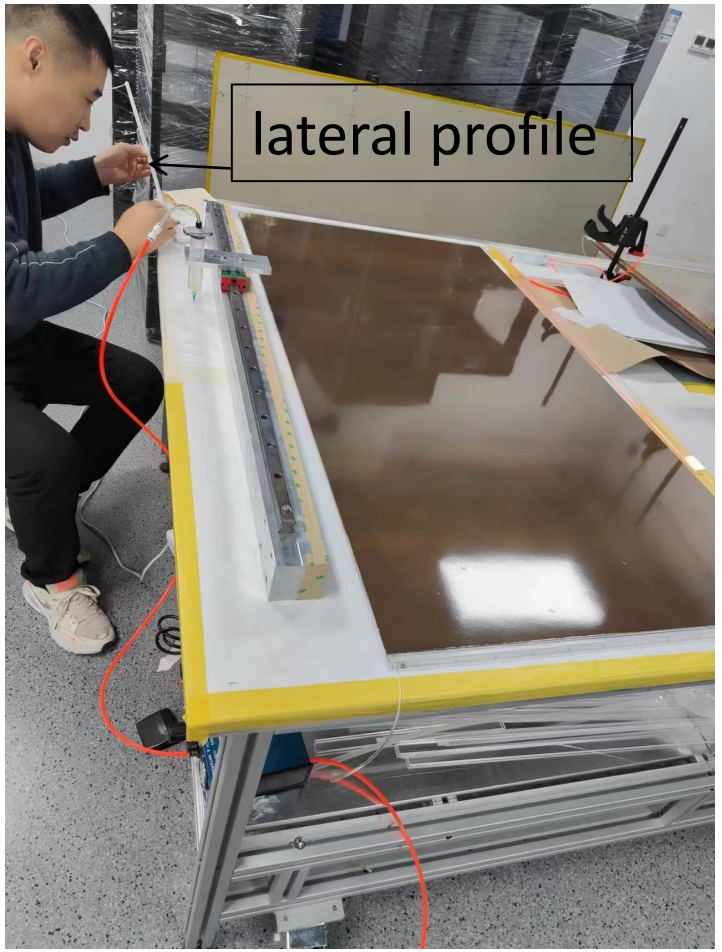


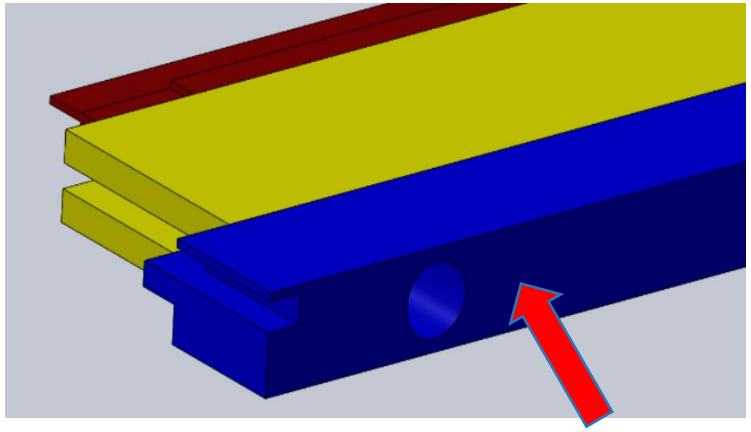
Keep at least 6 hours for the epoxy curing within the vacuum bag.

The last step

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



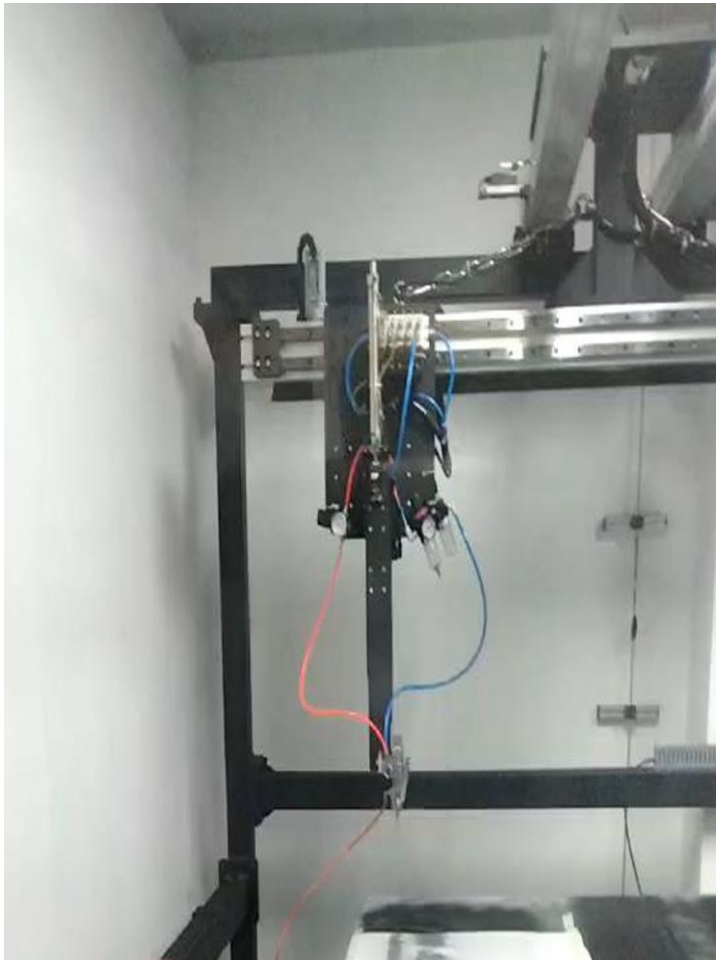




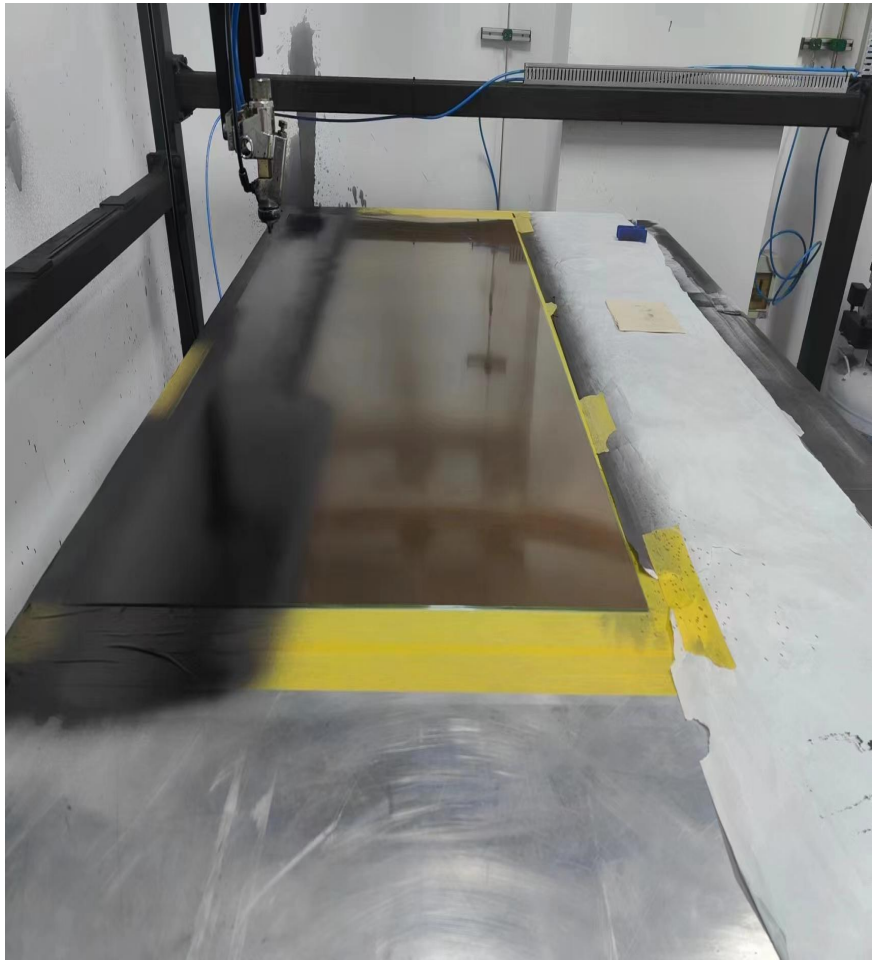
lateral profile

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

Graphite coating and HV & Ground link applied

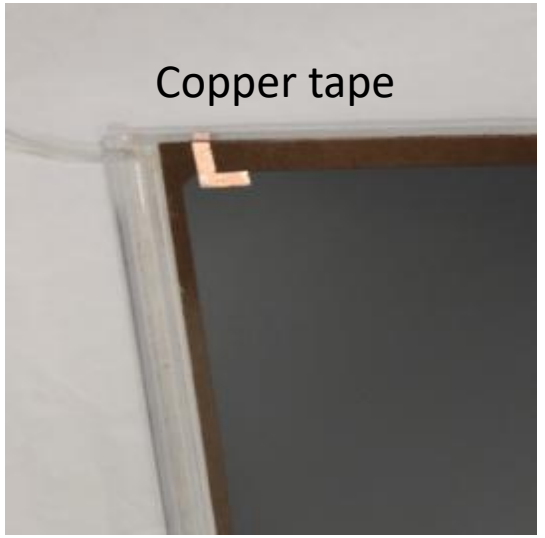


Graphite spraying system:
A spray gun held on a 2-D gantry



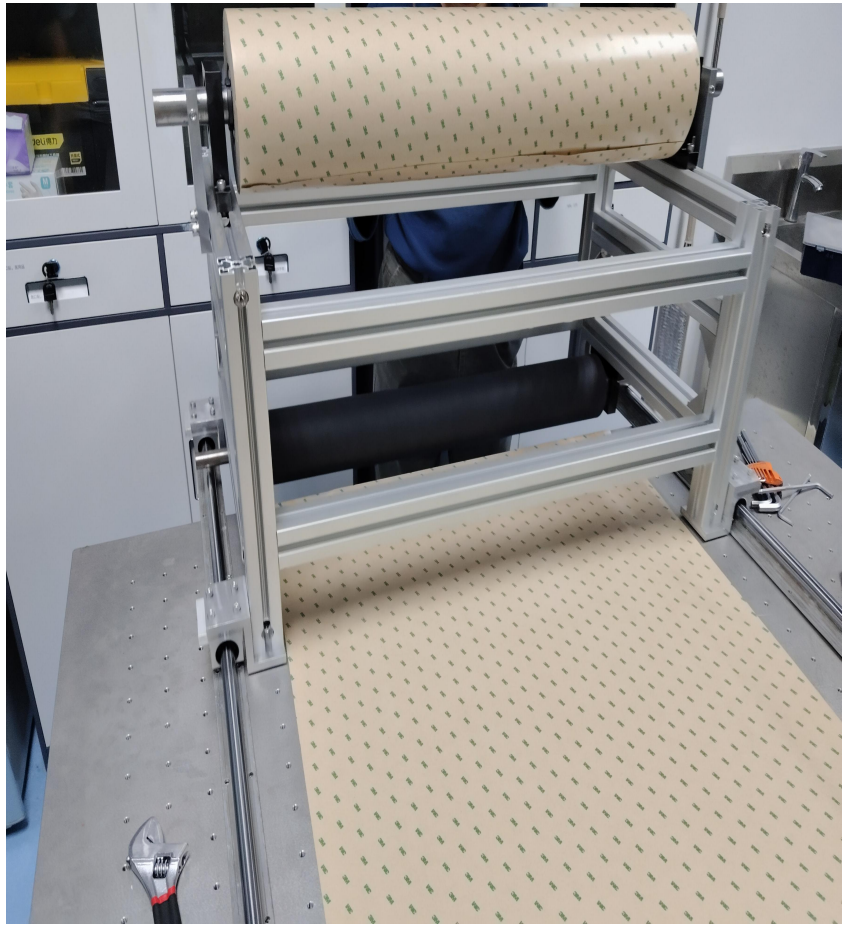
Graphite coating

Zoom in

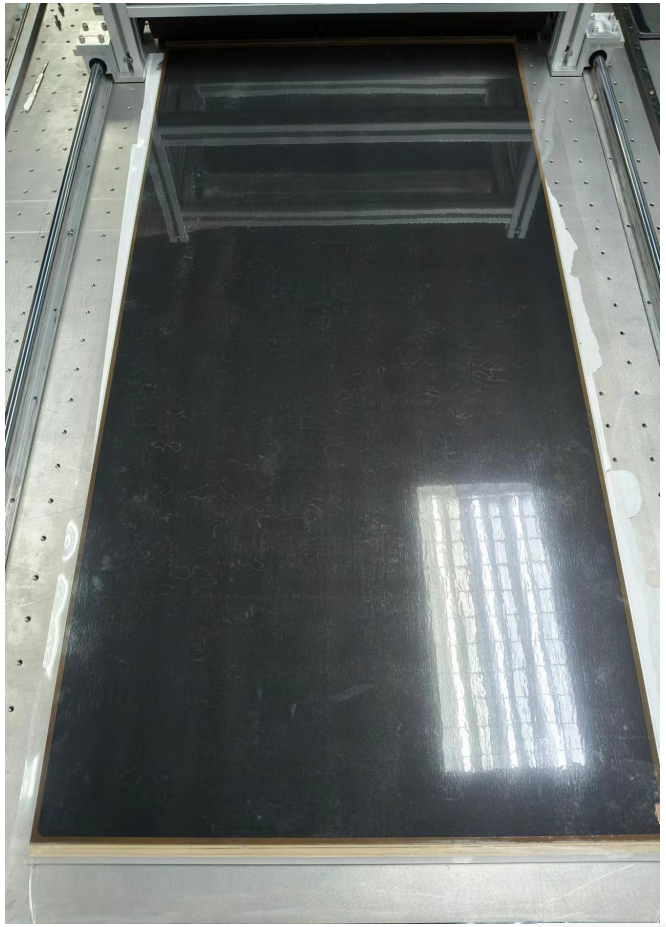


HV & Ground links applied

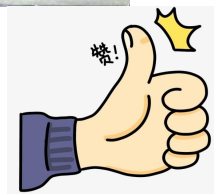
PET foiling



Tooling

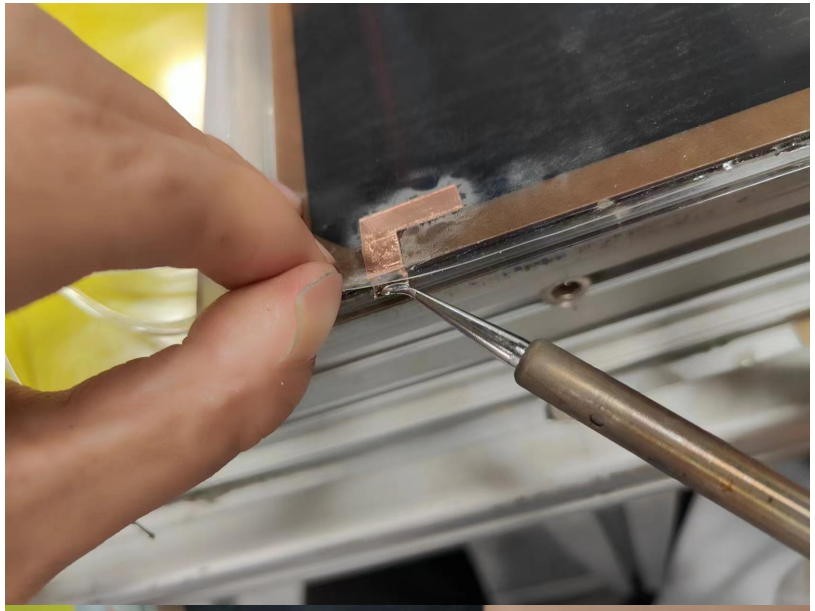


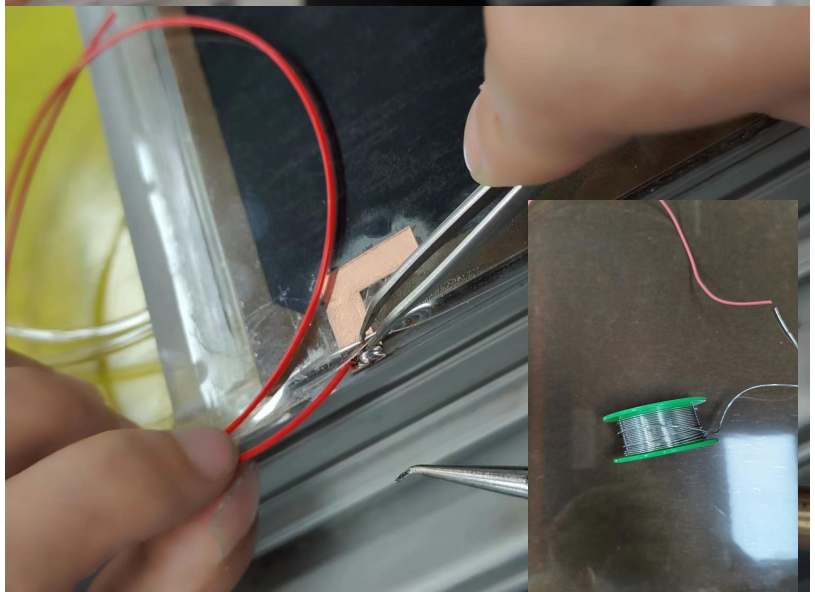
Mirror-like surfacing



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

HV contacting and hot-melt gluing

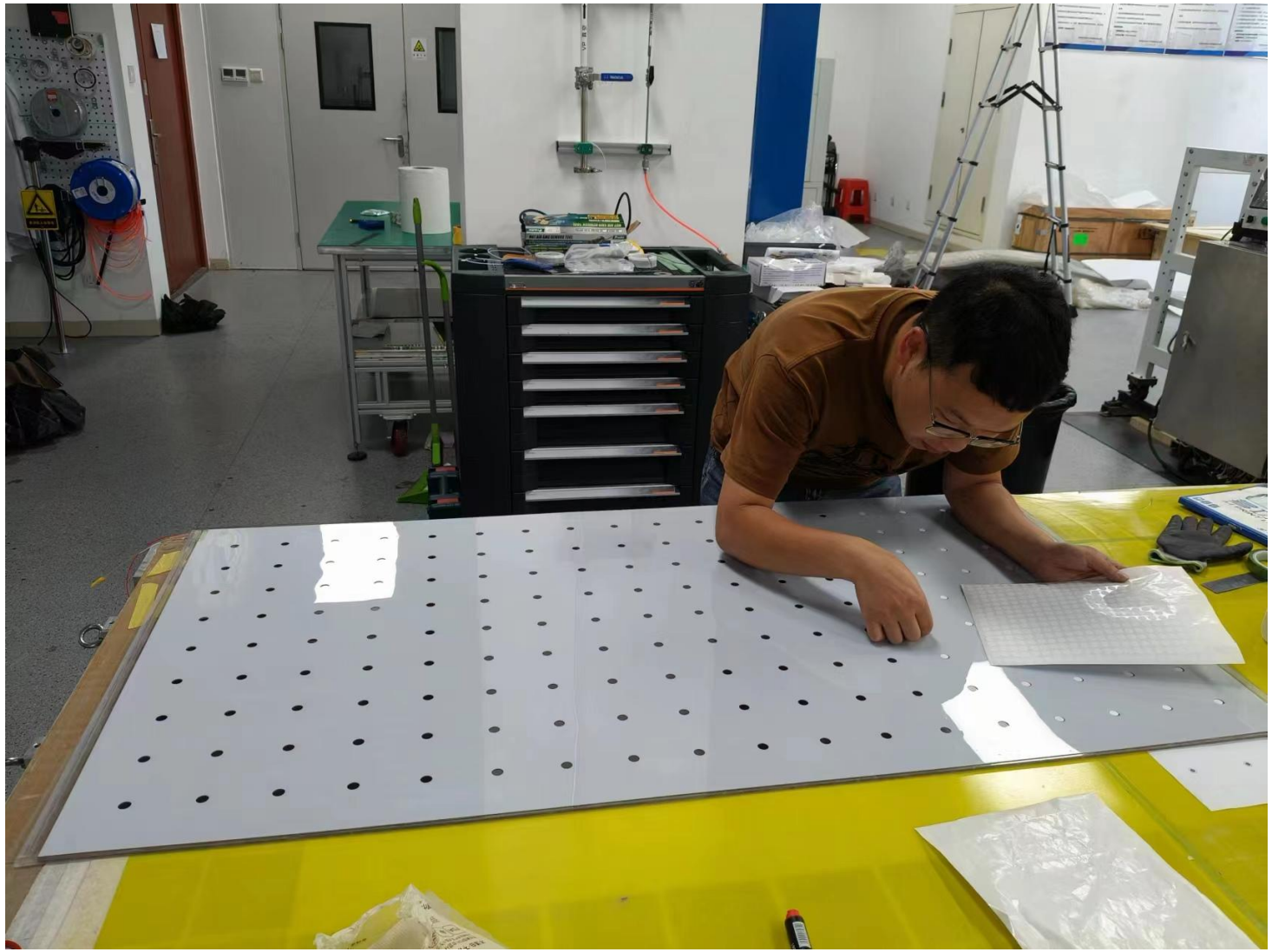


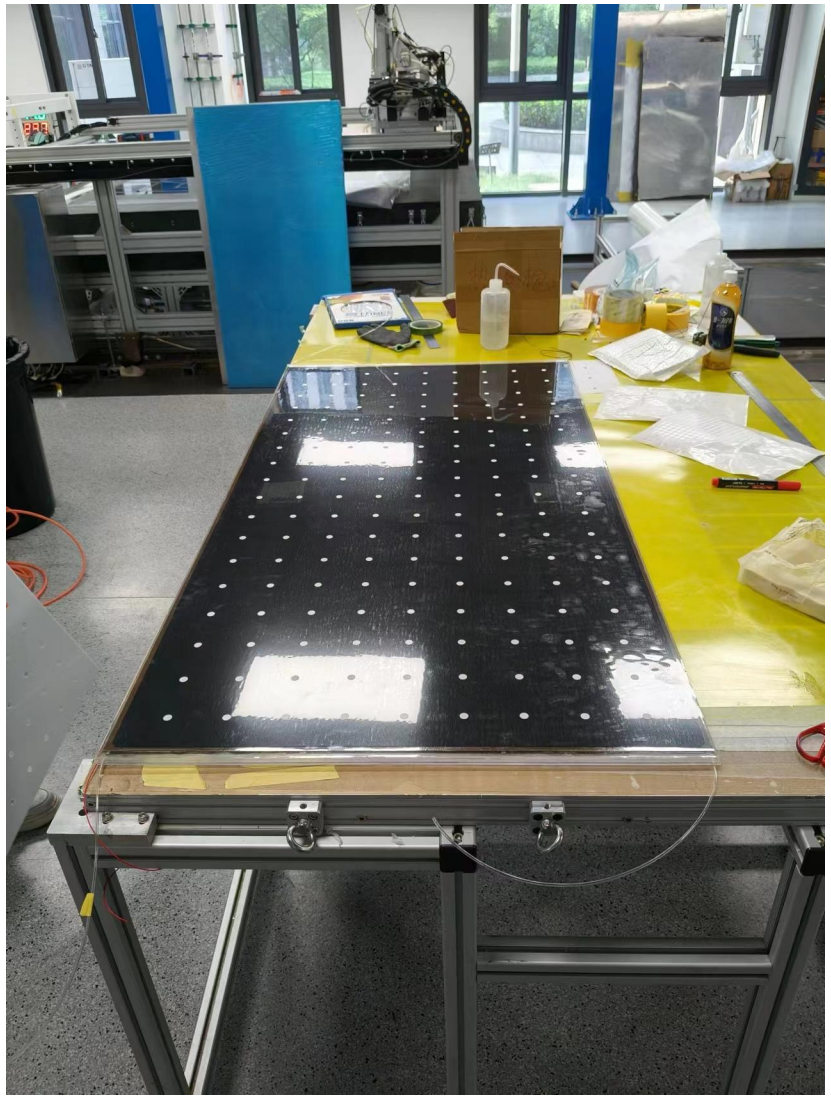


Filling and sealing the edges of the gas gap with hot-melt glue

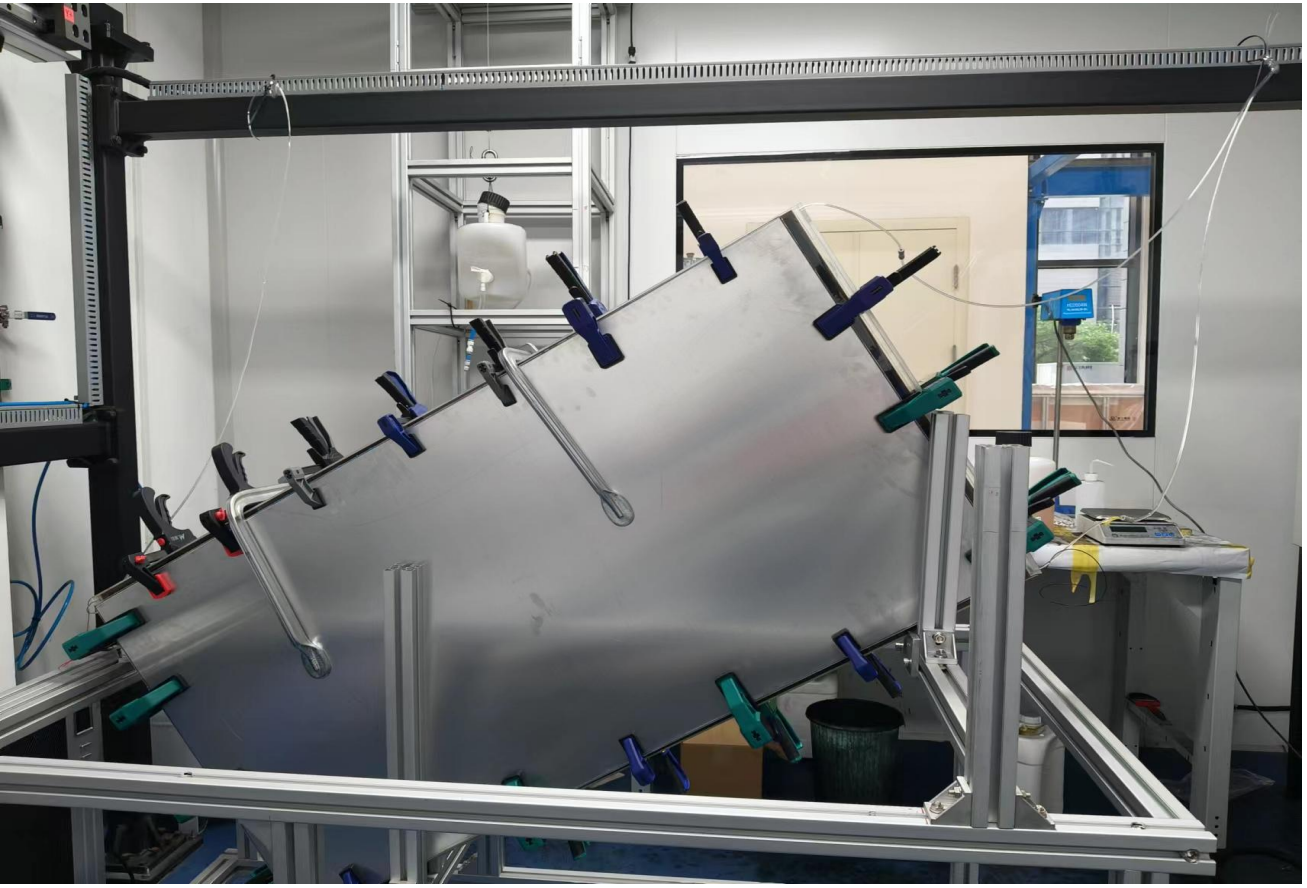
To protect PET foil, special solder wire is used

Paper stacker





Linseed oiling



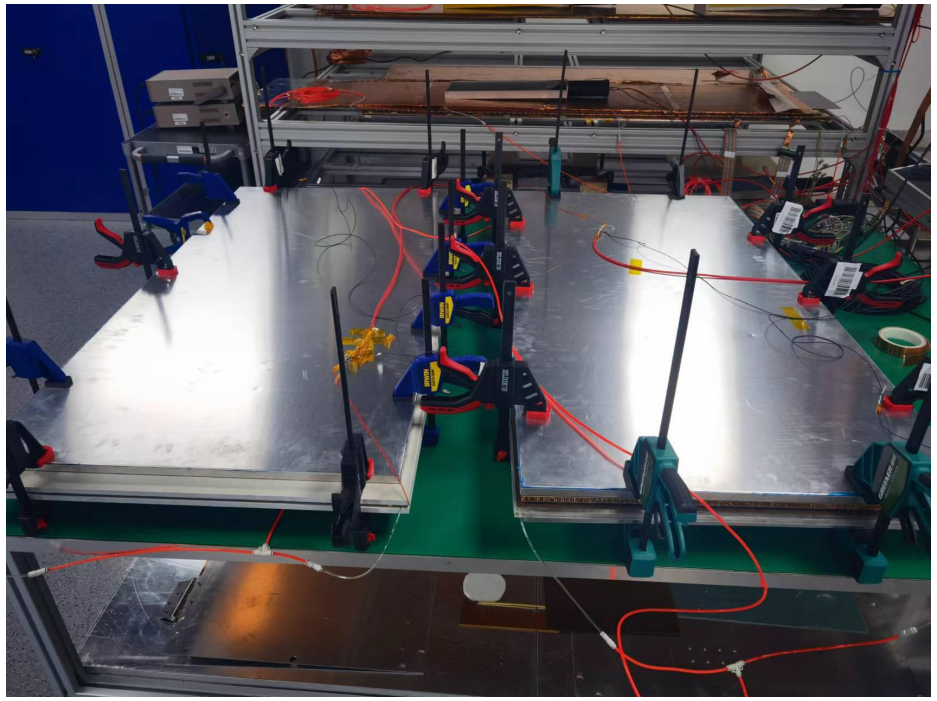
- The gas gaps are flushed with heptane through the gas connections from a supply bottle (From bottom gas inlet to top).
- Fill the gas gap with mixed oil and then empty the oil in the gas gap slowly (< 1m/h)
- Pumping the air through the gas gap for one week to achieve Linseed oil polymer (From top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

Preparatory work:

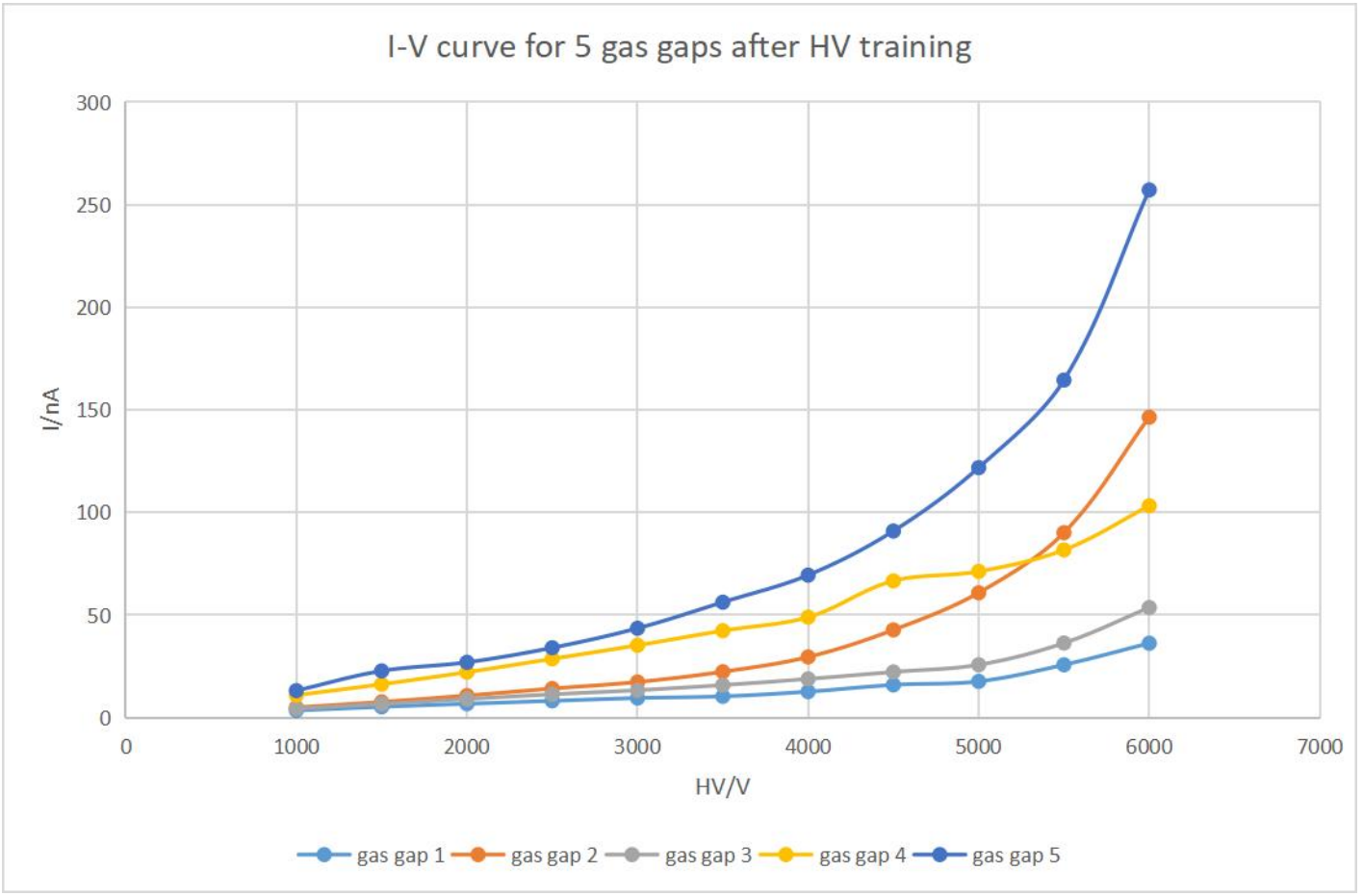
- Room temperature: ~ 40℃
- Mixed oil: 30% linseed oil + 70% heptane
- Use clamps to prevent bursting under oil pressure

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



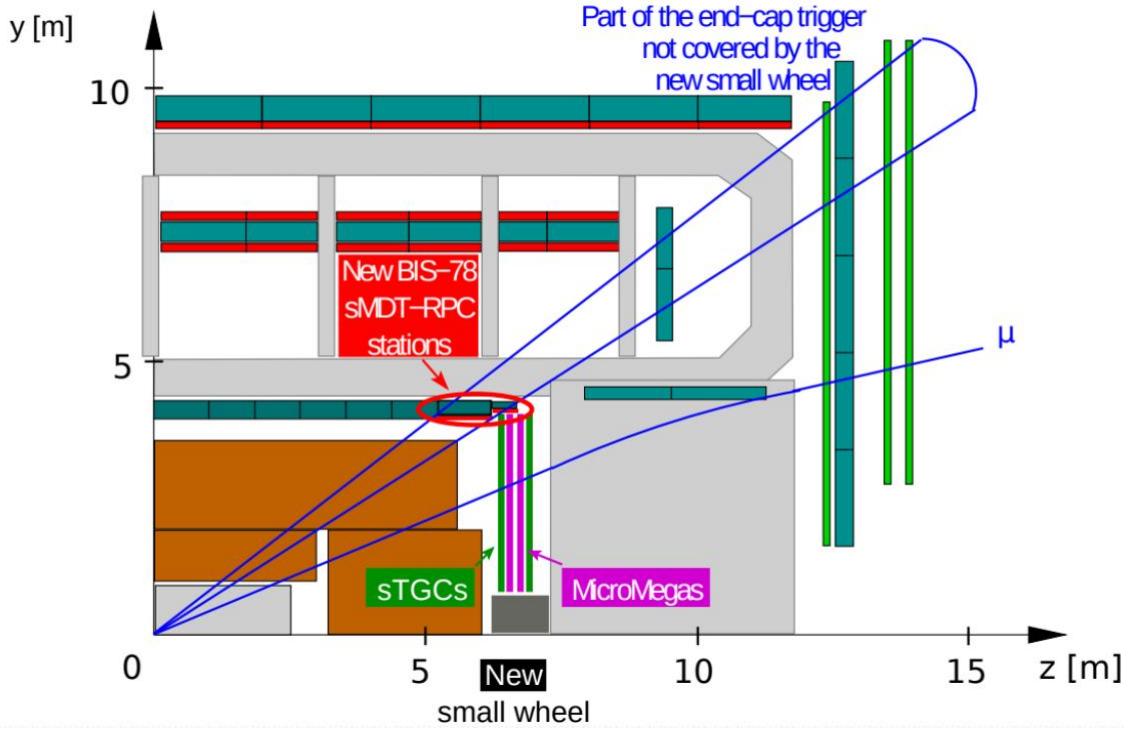
The new method to solder the matching resistors

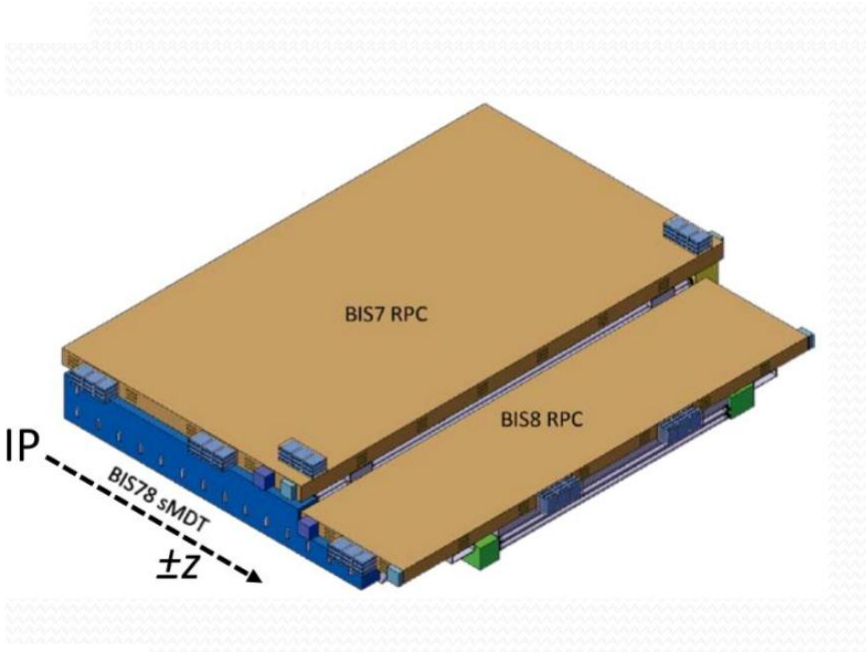
Mask plate

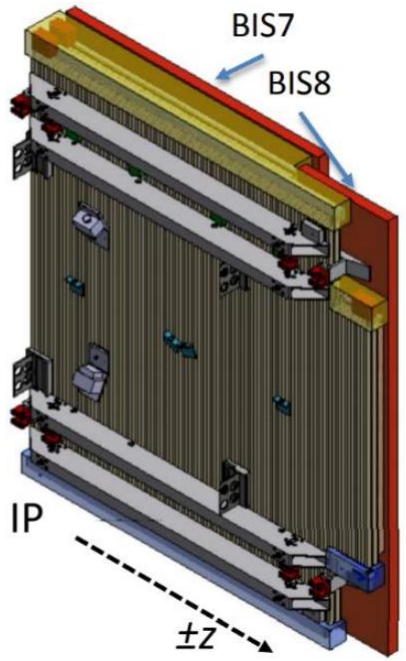
Solder paste

Tweezer welding table

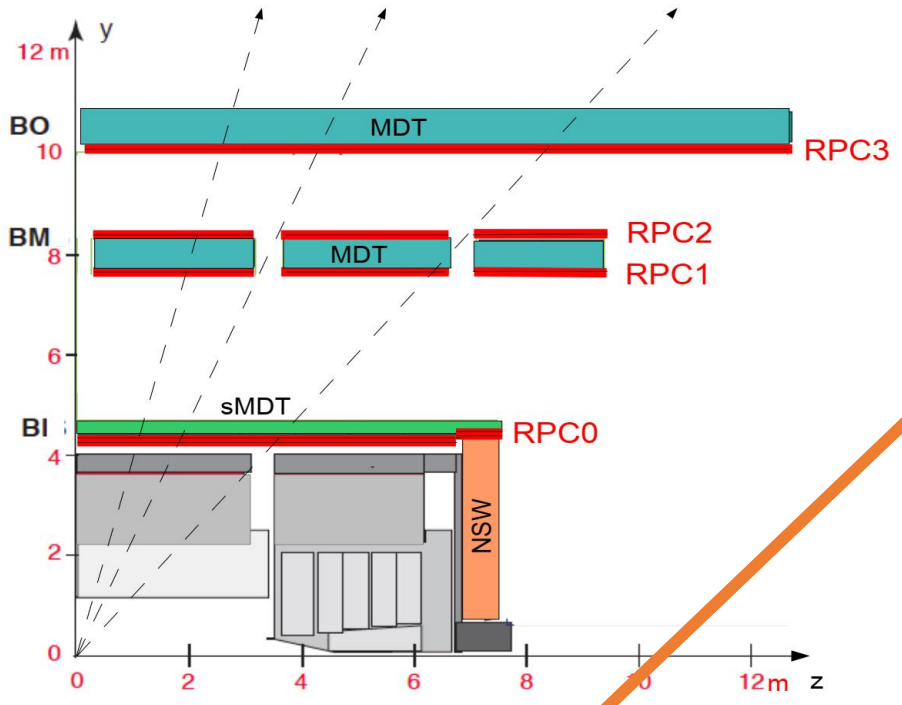
BIS78


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

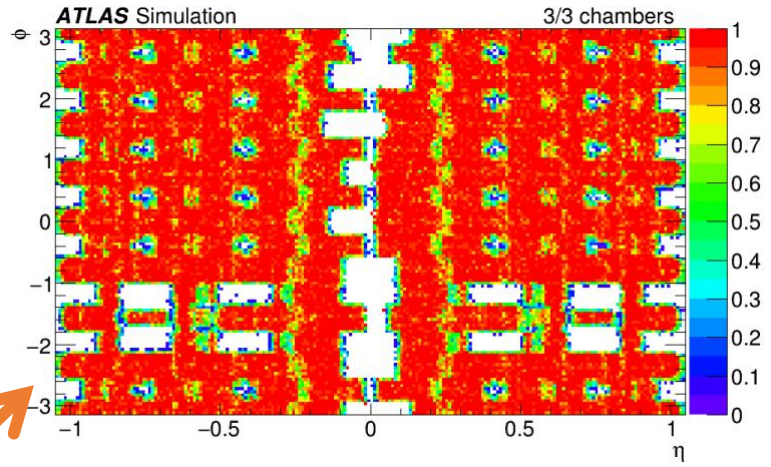

BIS7 RPC
BIS8 RPC
IP
BIS78 sMDT
±z

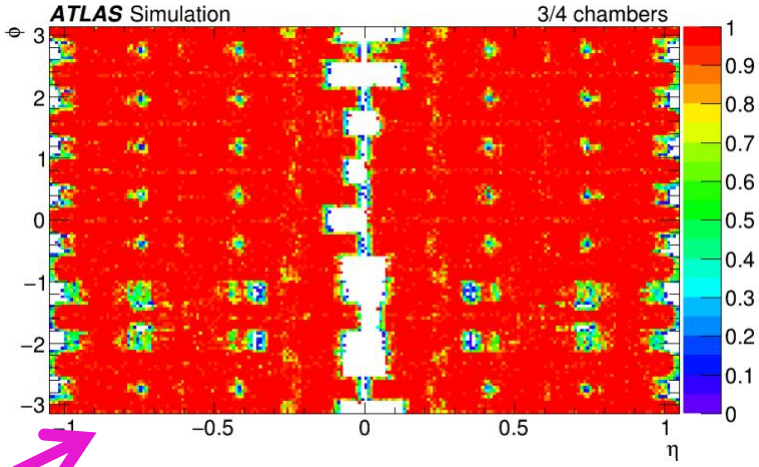

BIS7
BIS8
IP
±z

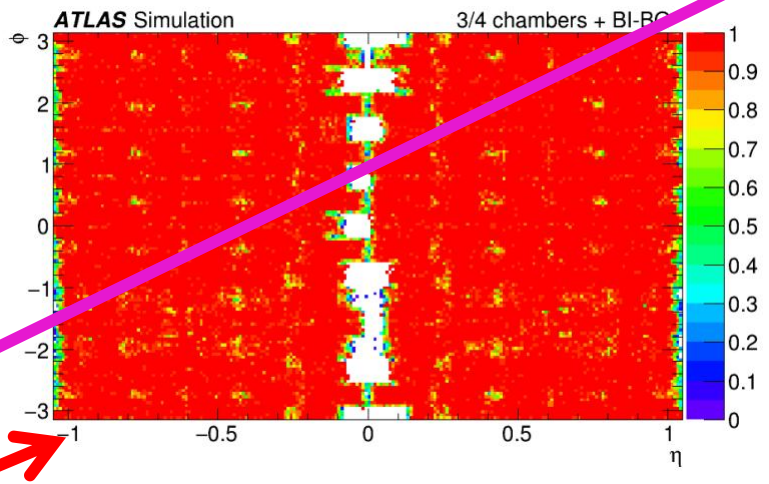
Geometrical acceptance and trigger eff.

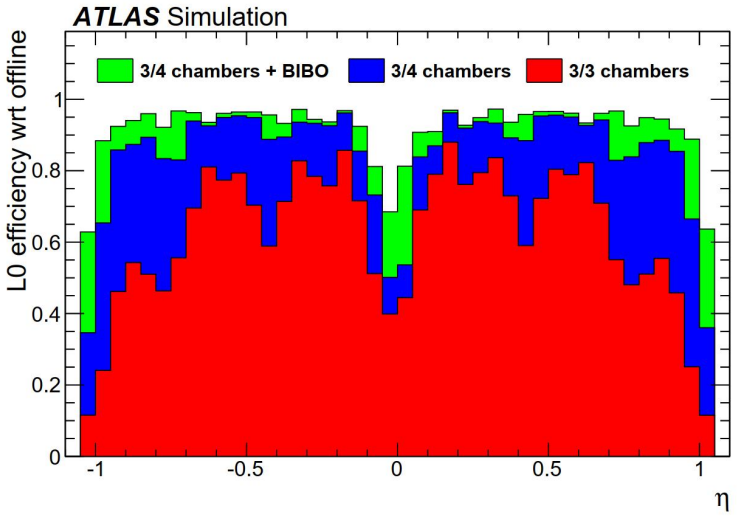


Trigger	Requirement
3/3 chambers	3[RPC1+RPC2] AND 1[RPC3]
3/4 chambers	(3[RPC1+RPC2] AND 1[RPC3]) OR (2[RPC0] AND 3[RPC1+RPC2+RPC3])
3/4 ch. + BI-BO	(3[RPC1+RPC2] AND 1[RPC3]) OR (2[RPC0] AND 3[RPC1+RPC2+RPC3]) OR (2[RPC0] AND 1[RPC3])





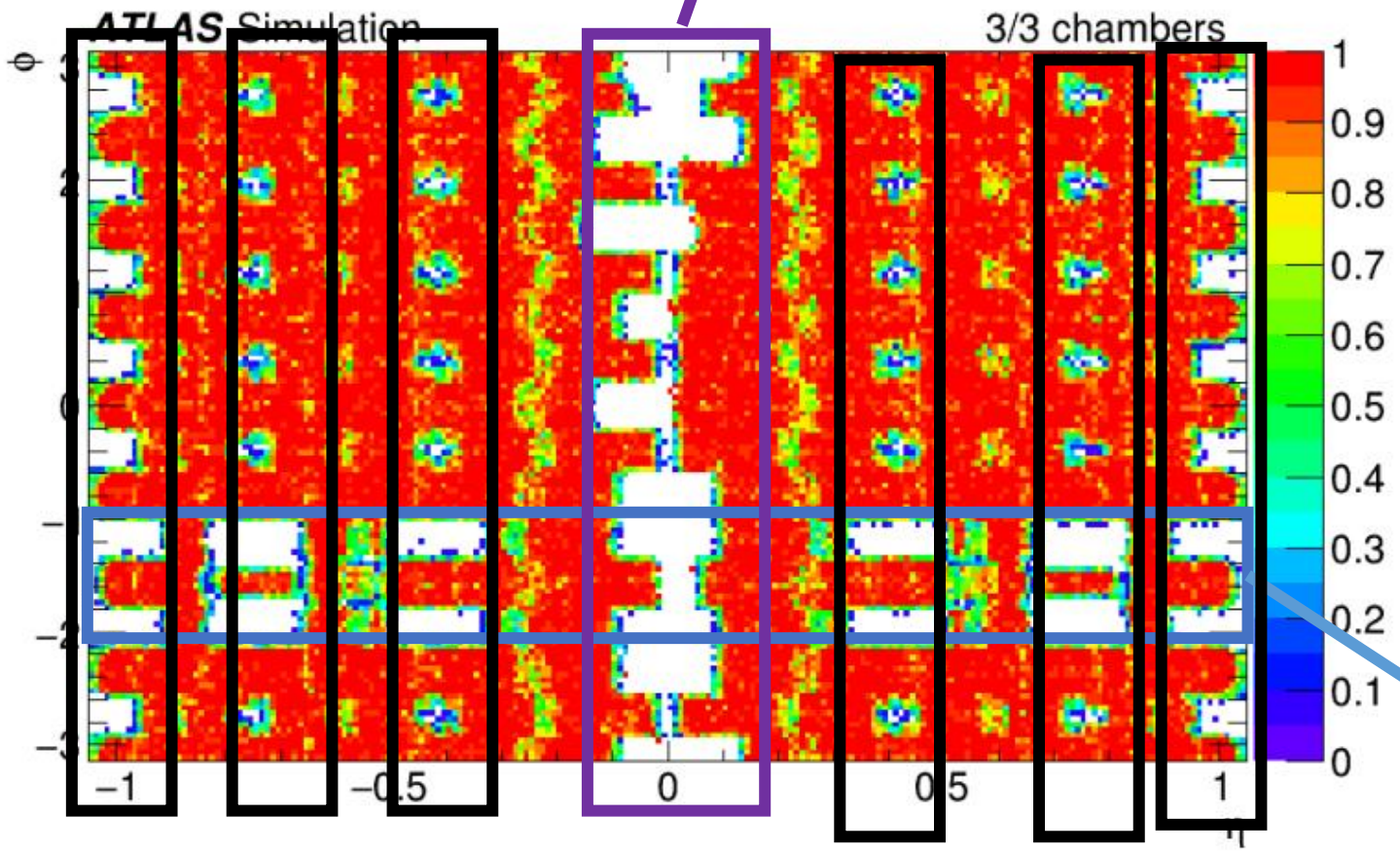




Increase the trigger coverage in the region where no BM coverage due to the coverage hole

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

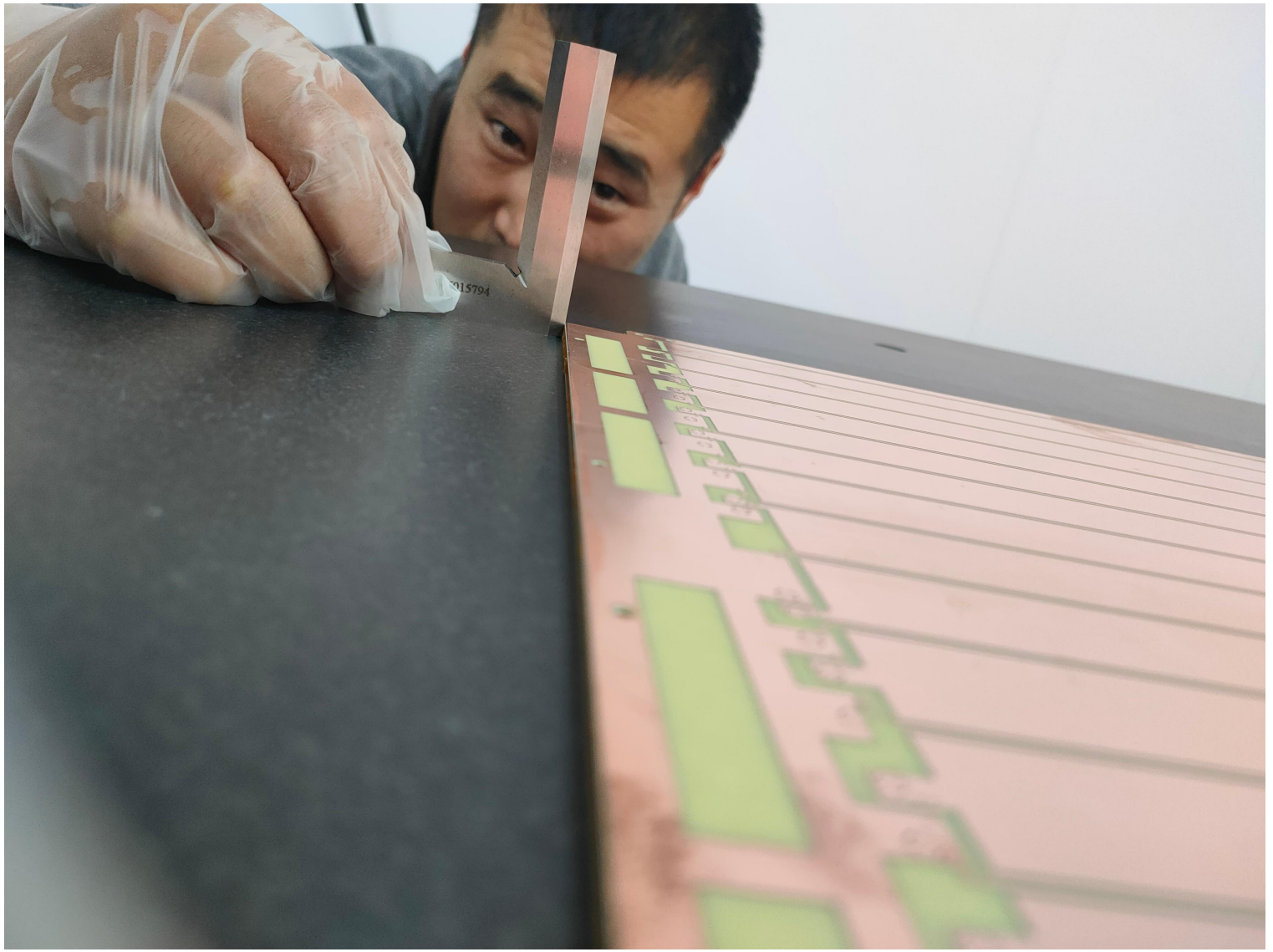
- 7 marble tables:

  2.3m×1.8m

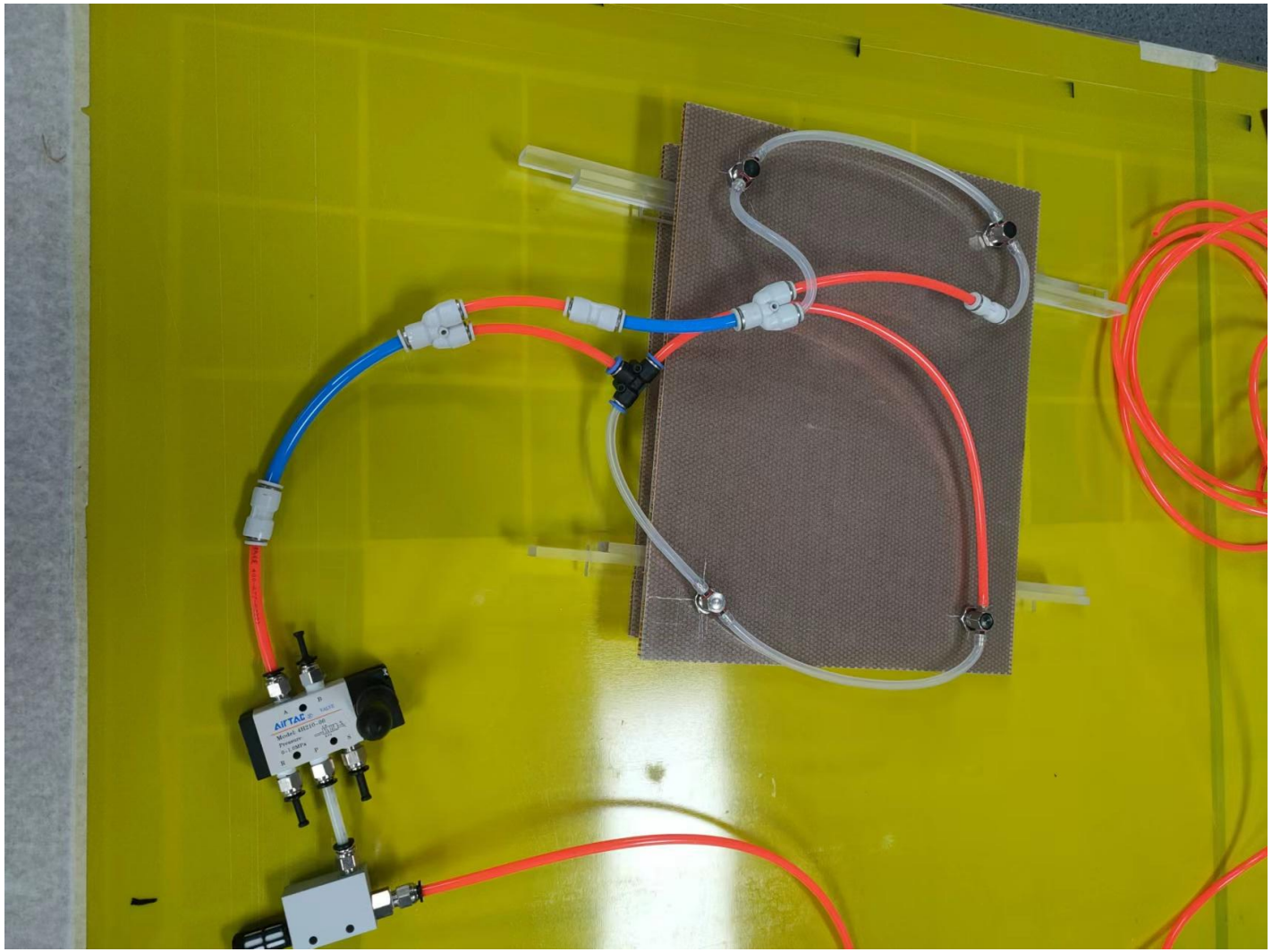
- Four of them will be used for vacuuming

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

The quality of alignment



Vacuum Sucker



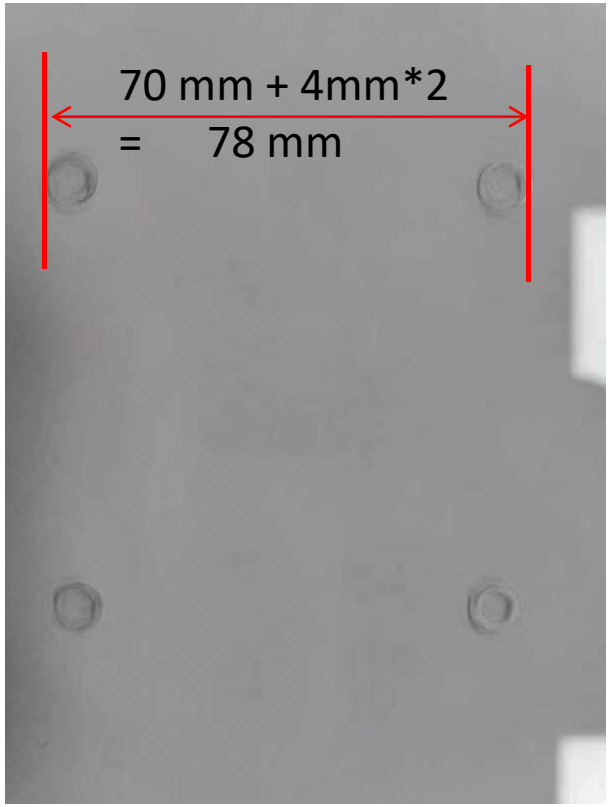
To hold the top bakelike

Y

X

Nominal value:

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



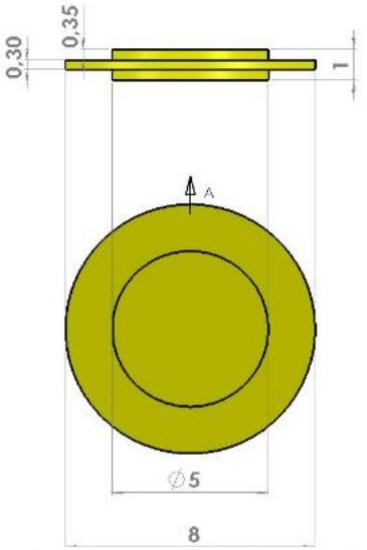
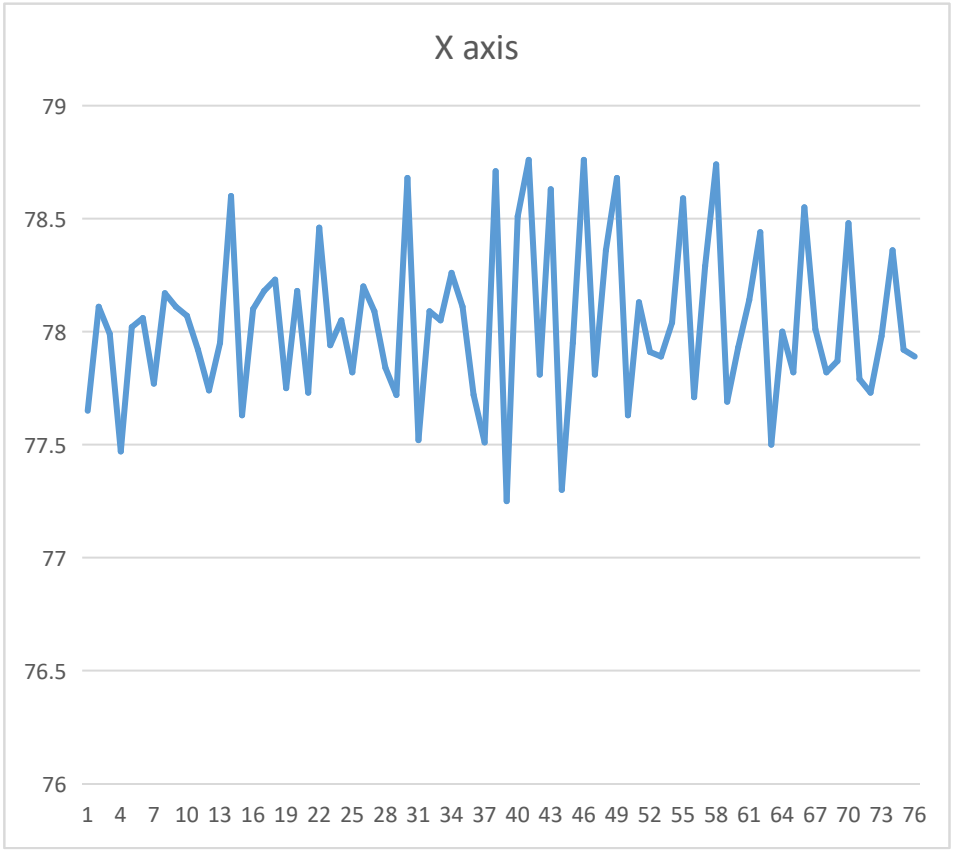


Figure 5: design of the cylindrical pillar with the guard ring.

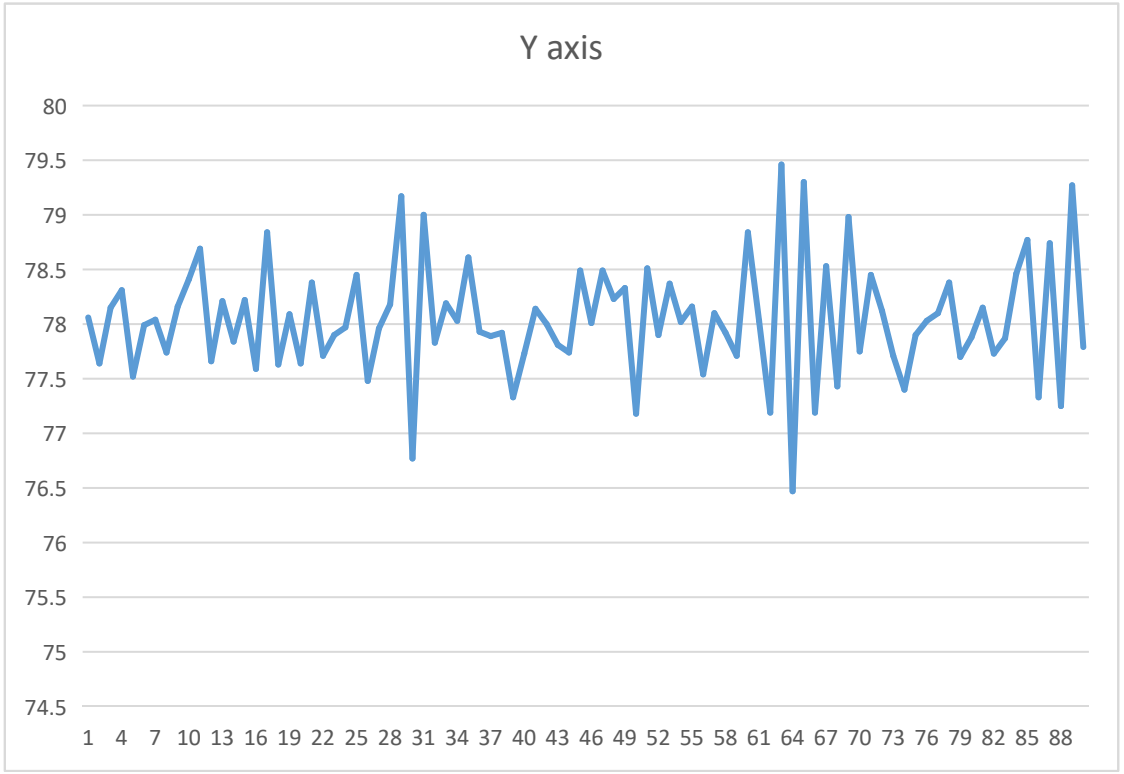
X axis

X mean=78.0429333



Y axis

Y mean=78.0412222



Height

H mean=1.000663158