



Mass production and QA&QC of thin-gap RPC for ATLAS Phase-II upgrade at USTC

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Outline

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

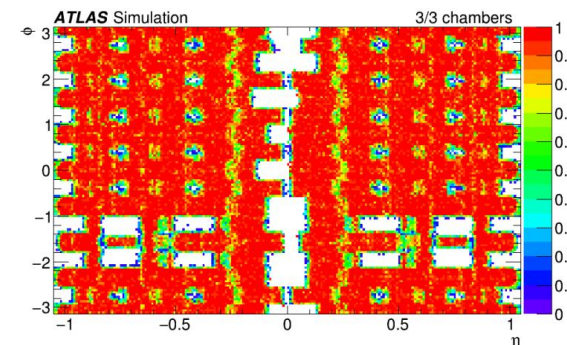
Introduction

➤ Motivation:

- Compared to the original LHC design, the luminosity at the HL-LHC is increased by almost an order of magnitude.
- The muon trigger need to be significantly upgraded to maintain low trigger momentum thresholds while keeping the trigger rates at a manageable level.
- RPCs play a critical role for the muon trigger at the ATLAS detector.

➤ The main limitation of the RPC when operate @HL-LHC

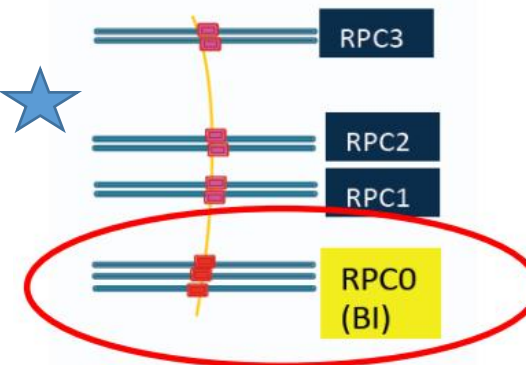
- The redundancy of the present RPC system is insufficient.
- The present geometrical acceptance of the trigger in the barrel region is only around 80%.
- The trigger and electronics do not satisfy the rate and latency requirements of Phase II trigger scheme.
 - ✓ L0 trigger latency is around $2.5 \mu\text{s}$ (Now), but $10 \mu\text{s}$ latency is required for the HL-LHC
- Long-term operation at high rates is not affordable for current RPC
 - ✓ Long term operation is limited to 100 Hz/cm^2 (Now), but $\sim 300 \text{ Hz/cm}^2$ for HL-LHC in the inner barrel (BI) region.
- The greenhouse impact of the RPC gas mixture



Introduction

➤ Solution

- Installation of triplets of new-generation RPCs (2→1 mm gas gap) in the BI-RPC ★
- The replacement of the trigger and readout electronics
- Retrofitting with new front-end electronics in the BO chamber

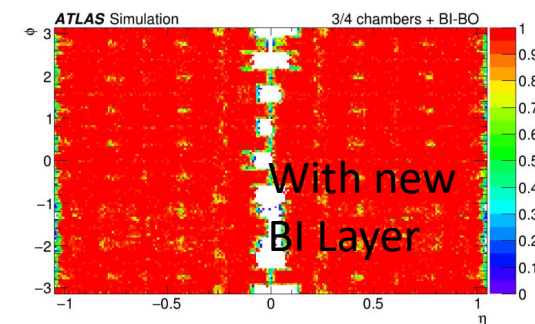
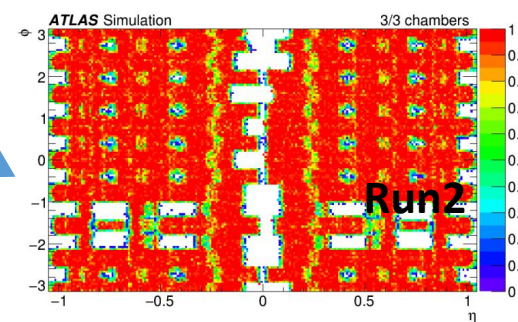


• 9 layers instead of 6

➤ Installation of triplets of new-generation RPCs in the BI-RPC

• Pros:

- ✓ Recover most of the current geometrical acceptance holes
- ✓ The redundancy of the system will be greatly enhanced
- ✓ Full trigger efficiency can be maintained even if the old RPCs have to be operated at reduced efficiency (mix gas or reduced HV)
 - Worse case: A reduction of the high voltage of the BM and BO RPCs to ensure their longevity
- ✓ The counting rate and longevity is improved with 1mm gas gap.



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

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

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 electronics boards

➤ The production plan

- BIS (576) strip panel need to be produced and qualified around end of July 2024
- BIL gas gap prototypes need to be finalized and qualified around the beginning of 2025
 - ✓ ~ 5 RPC gas gap prototypes need to be produced before August 2024 and sent to CERN to do the irradiation test
- BIS singlet assembly without FEE plan to start around the beginning of August 2024
- FEE production plan to start around the October 2024

To fulfill this task



① Honeycomb readout panel production

② RPC gas gap production

③ Singlet assembly training in BB5

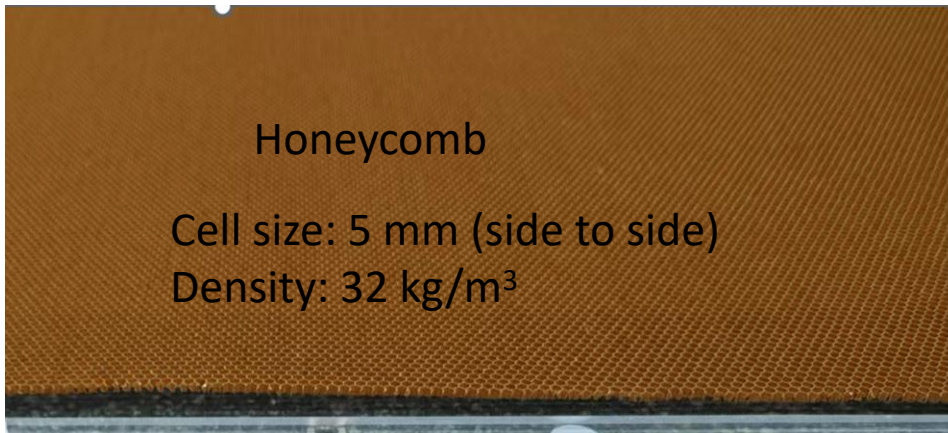
Today's topics

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: 3mm thick
- Glue: Araldite 2011 (~180g /side)



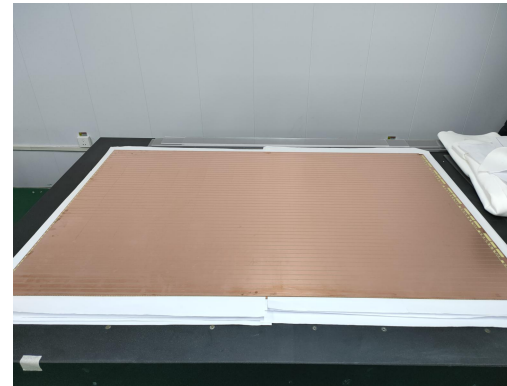
Specification:

The flatness of readout pannel < 0.1 mm

The length and width:

1705 +/- 1 mm

1072 +/- 1 mm



BIS-1 prototype



BIS-2-6 prototype

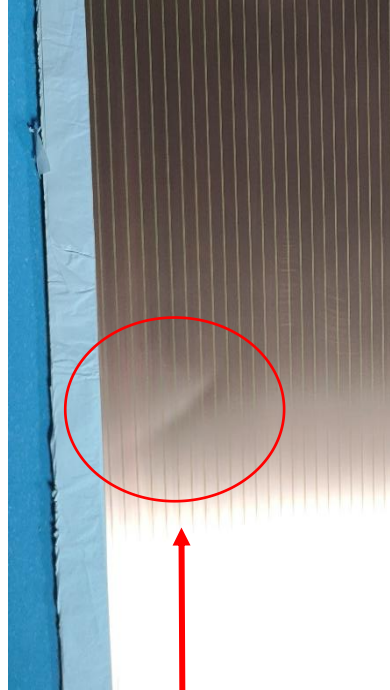
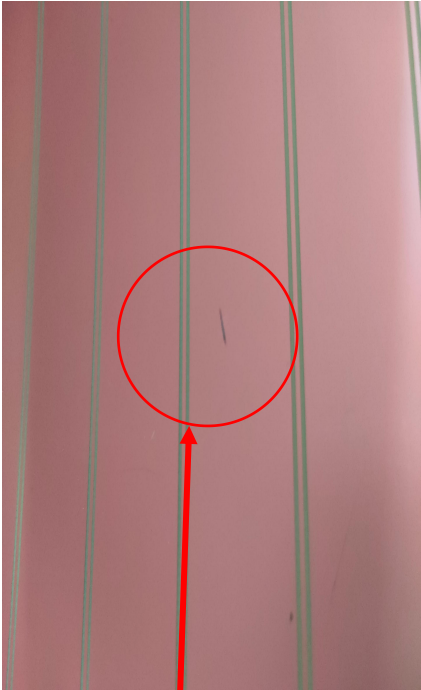


Araldite 2011



THINKY MIXER ARE-310

General checks on the PCBs



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



Electrical continuity checks

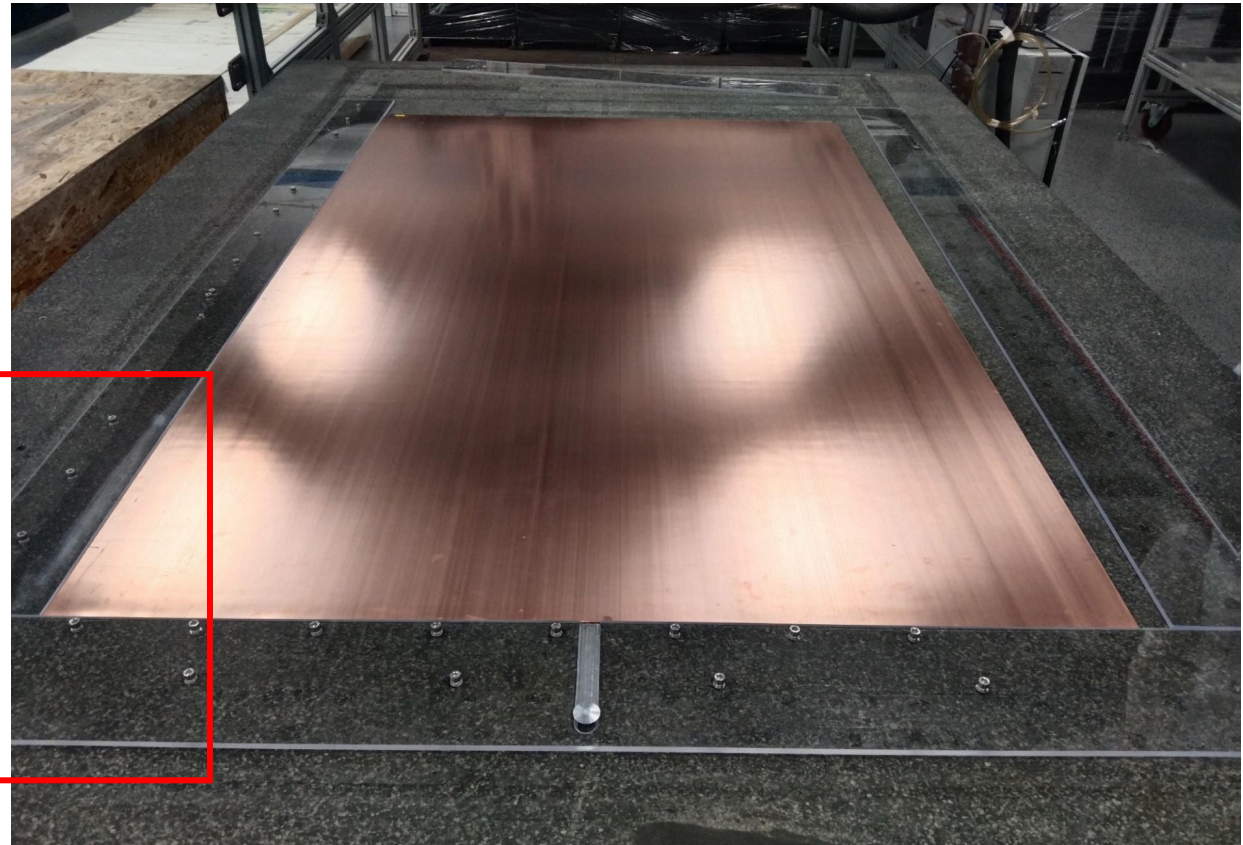
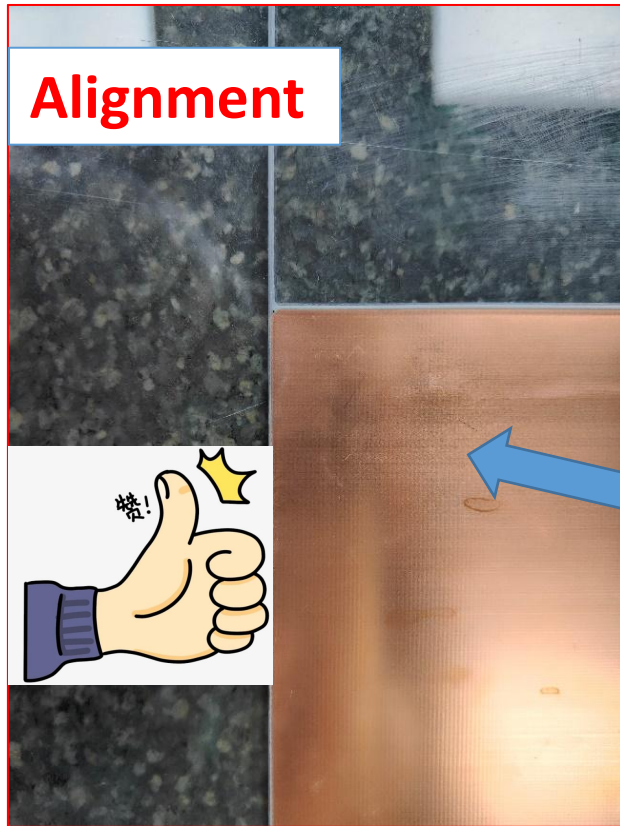
The PCBs passed the checks will be used to build the readout panels

The **major difficulties** in building the readout panel:

- ① How to make sure the alignment between ground and strip pcbs ?
- ② How to apply enough pressure uniformly over such large area (**1706 x 1070 mm**)?

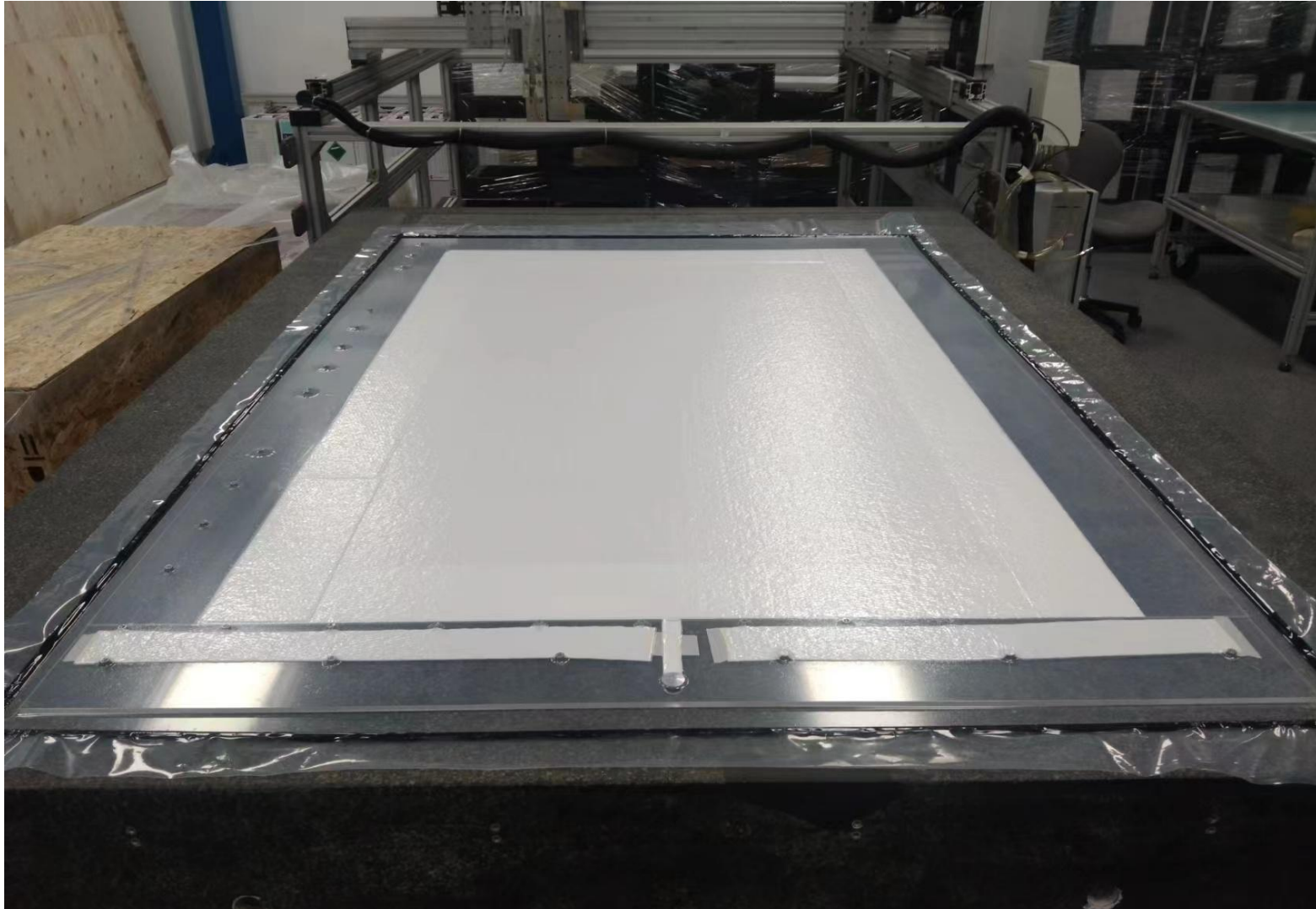
The optimized method to construct readout panel

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

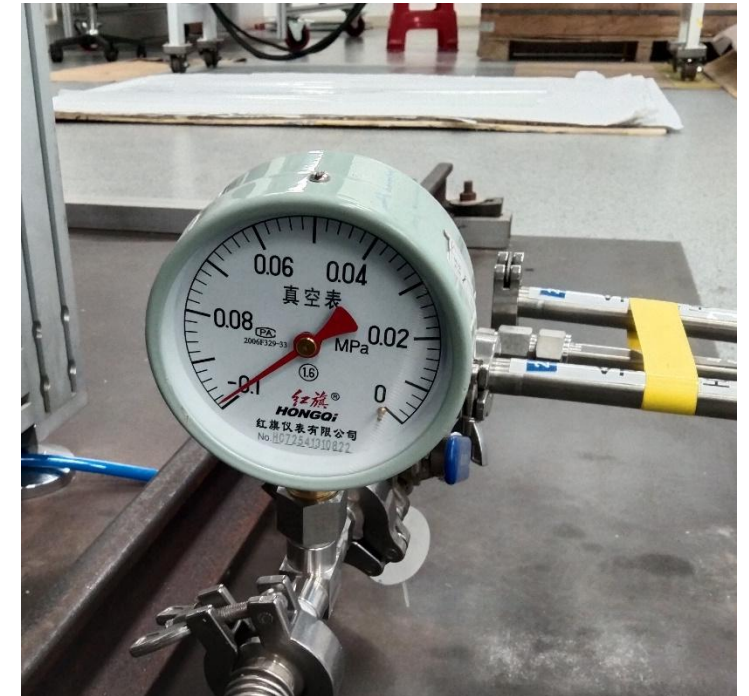


① How to make sure the alignment between ground and strip pcbs ? 

The panel under vacuuming



The vacuum power

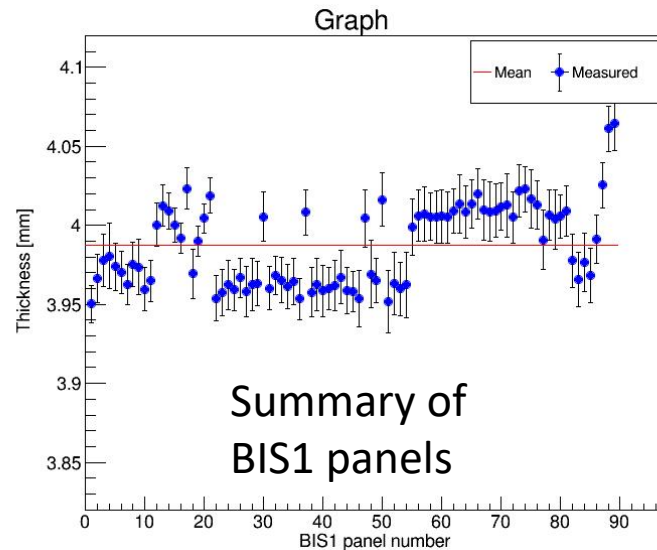
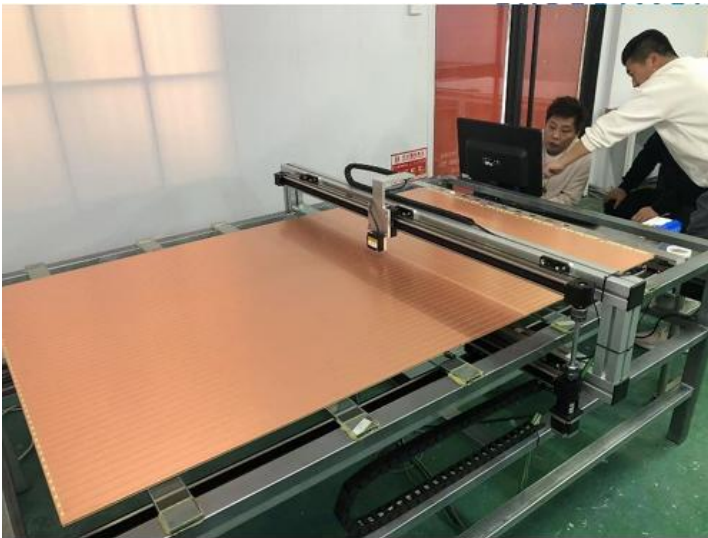


keep at least 6 hours for the epoxy curing within the vacuum bag.

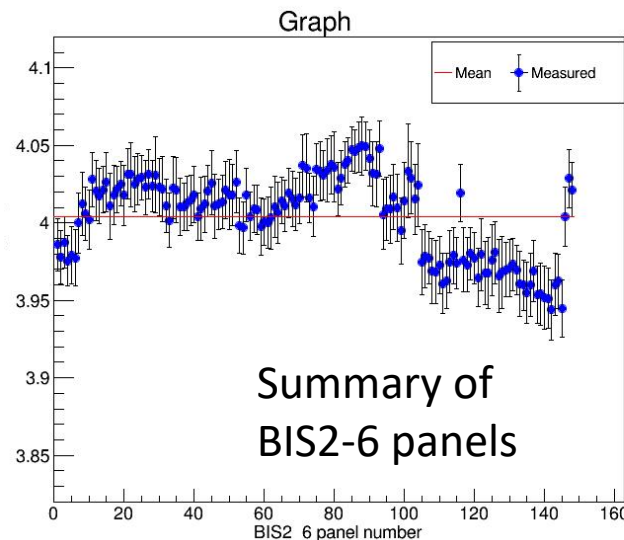
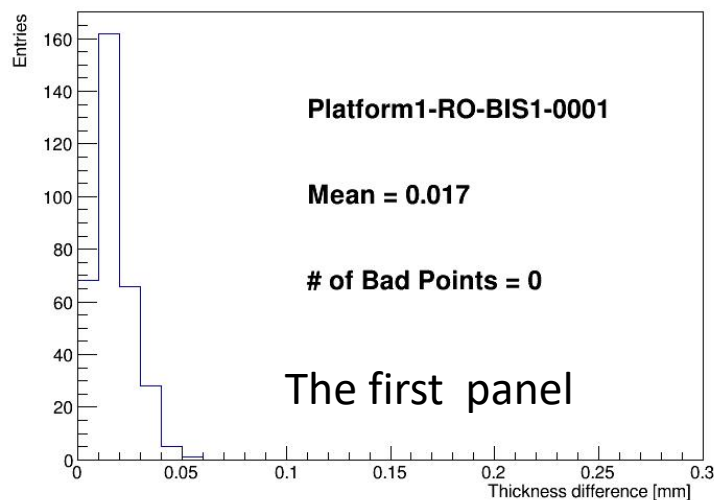
② How to apply enough pressure uniformly over such large area (1706 x 1070 mm)?



Thickness measurement and results



- The thickness is directly measured by two laser sensors automatically.
- The flatness $< 100 \mu\text{m}$ can be achieved in $7\text{cm} * 7\text{cm}$ range. (Bottom left)
- About 200 readout panels are built in the external company with the same method and the quality is good (Middle two plots)
- The speed is about 4 panels per day



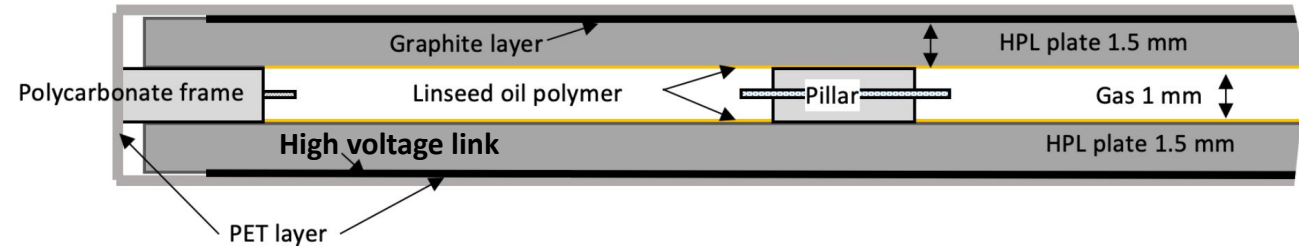
Flatness: Maximum variation of 4 points in a $7\text{cm} * 7\text{cm}$ range

RPC gas gap production

RPC gas gap

➤ General description

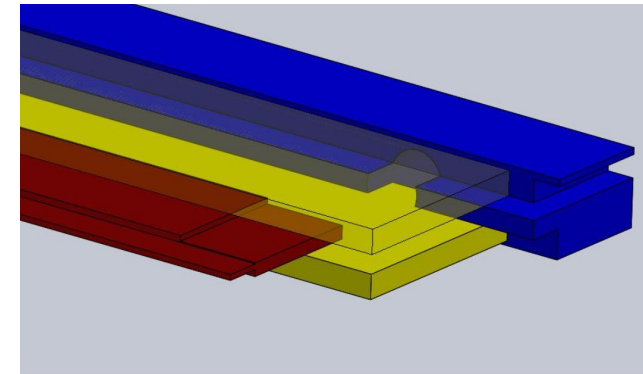
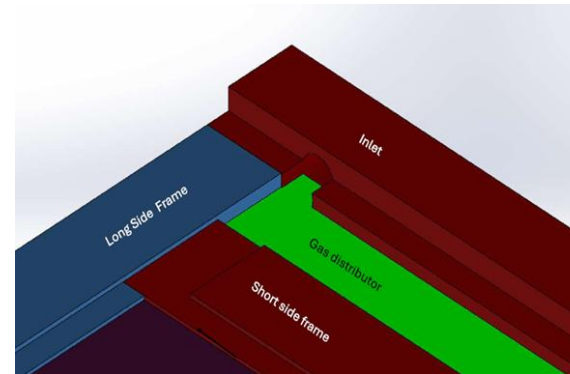
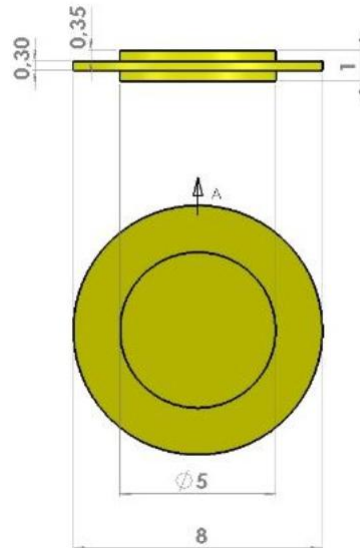
- It has large area parallel plate structure
- it works on the avalanche mode



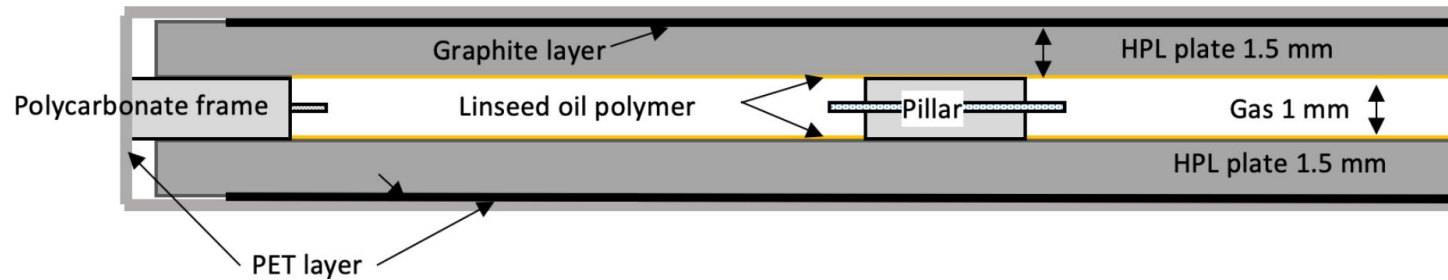
Sketch of a Gas Volume

➤ Components:

- Closed gas gap (2 HPL + spacers + PC frame + Gas distributor)
- Graphite layer
- High voltage link
- PET layer
- Linseed oil polymer



The main steps/difficulties to build a gas gap

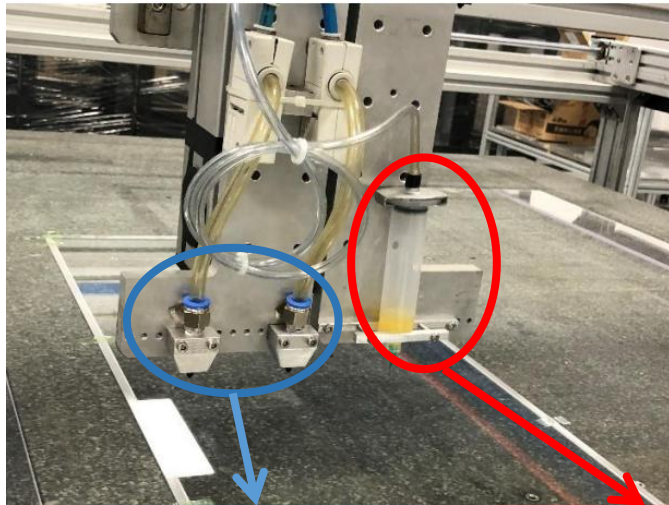


Sketch of a Gas Volume

- 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 (1.000 ± 0.004 mm)
 - Graphite coating
 - ✓ Surface resistivity shall be 350 ± 100 k $\Omega/\square$
 - PET foiling (absence of bubbles $> 2\text{-}3$ mm² between PET foil and graphite layer)
 - HV contacting and hot-melt gluing
 - Linseed oiling

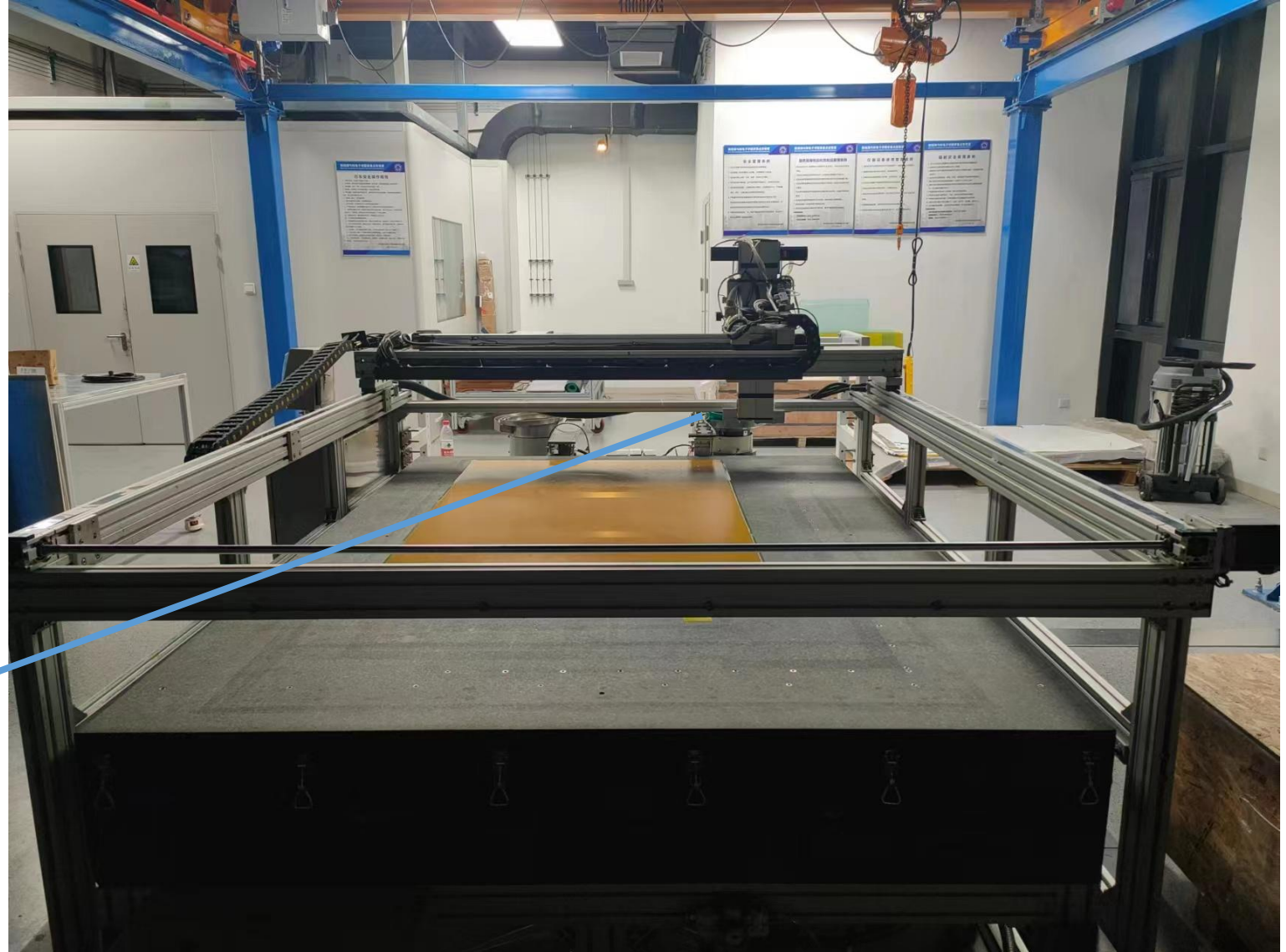
The platform of gas gap production

- 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

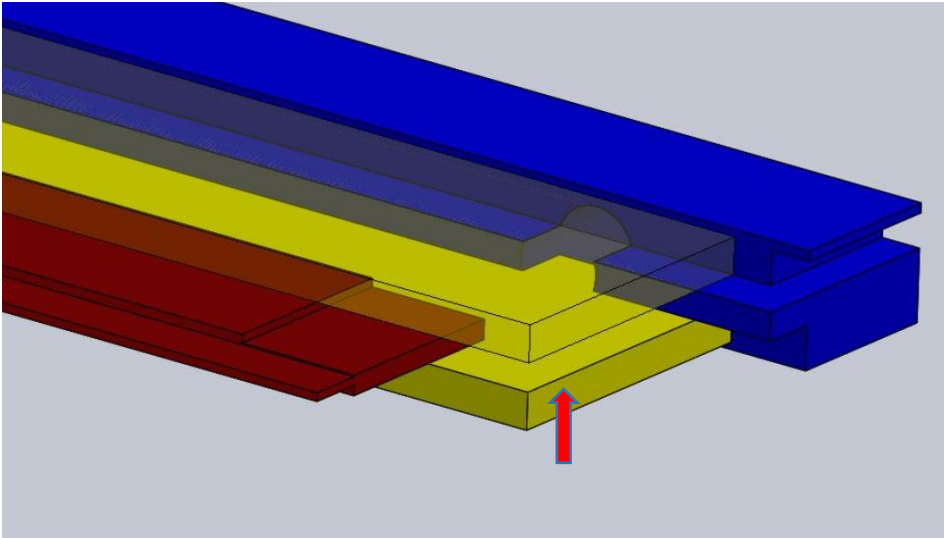
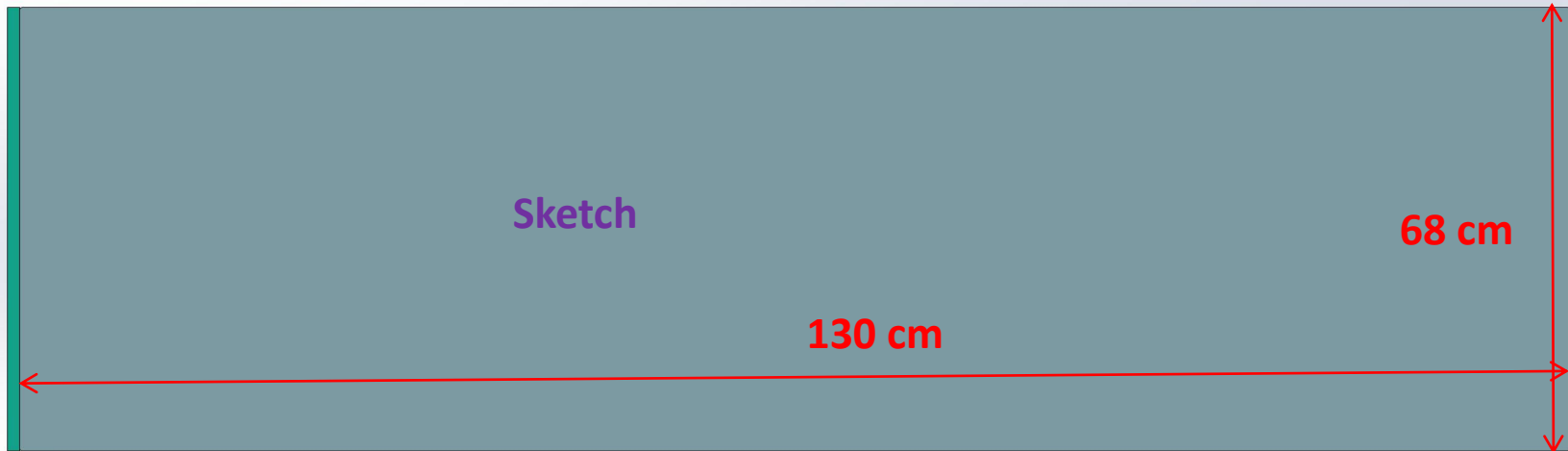


The assembly procedures of the closed gas gap

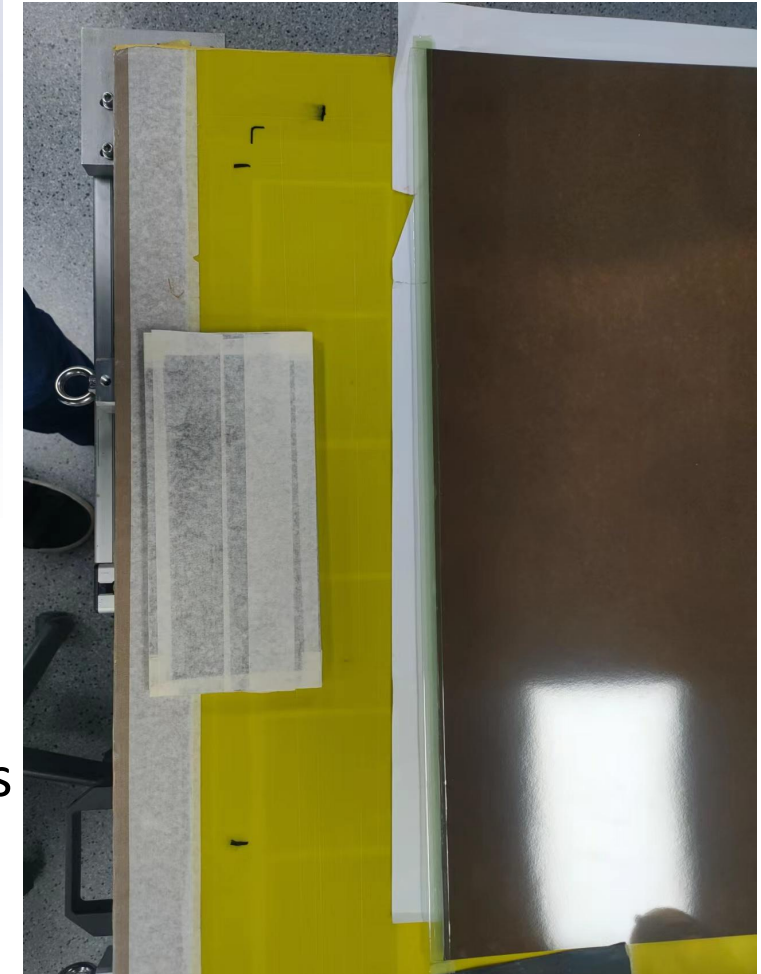
- The first step: Attach the floor plates on the bakelite
- The second step: Attach the long and short side frame on the bakelite and vacuuming
- The third step: Put the spacers and close the gas gap and vacuuming
- The last step: Put the perimetric polycarbonate frame into gas gap

The first step

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

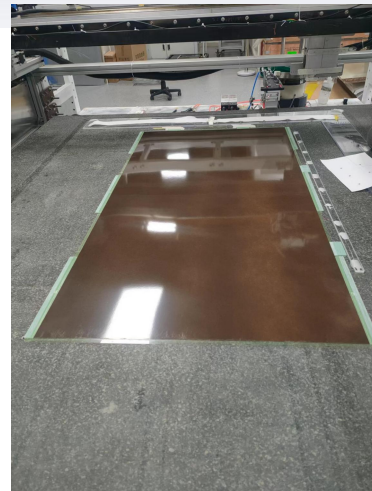
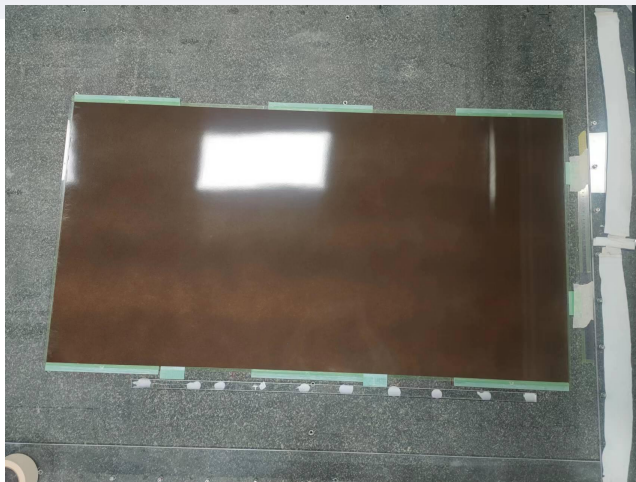
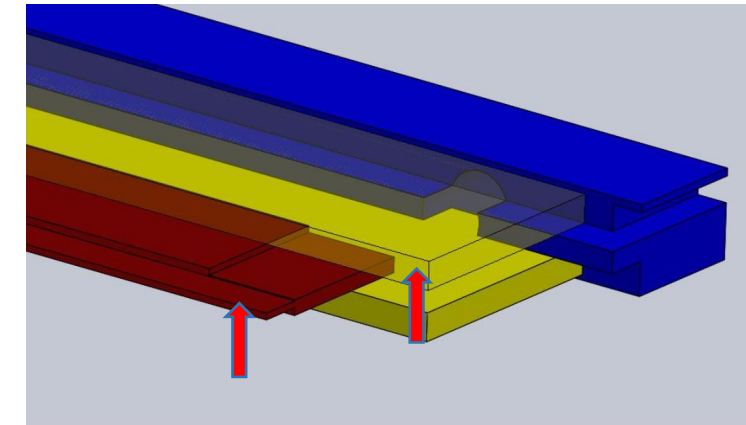
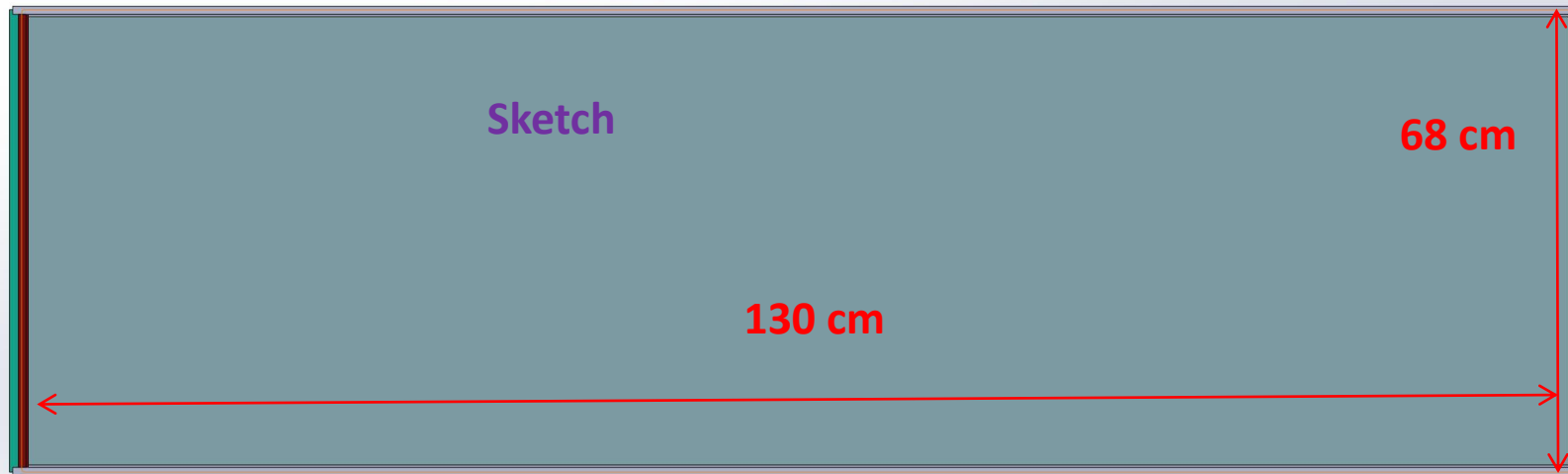


The bakelite and 2 floor plates will on the same plane



The second step

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

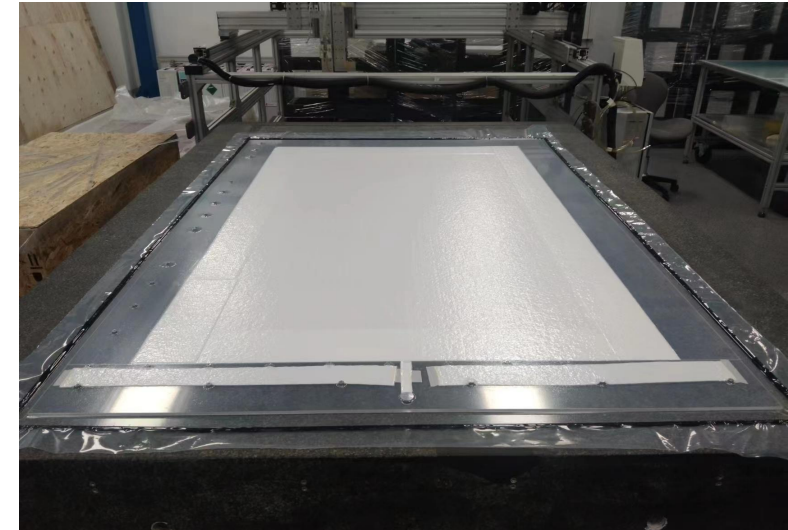
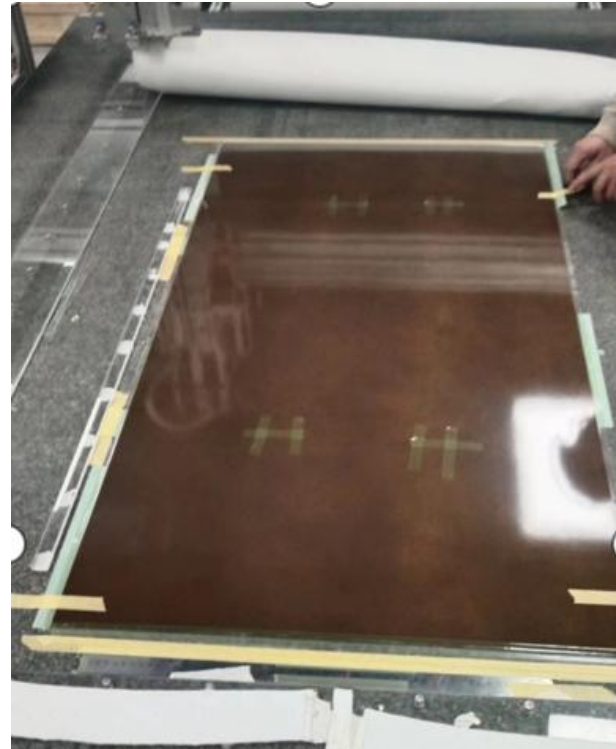
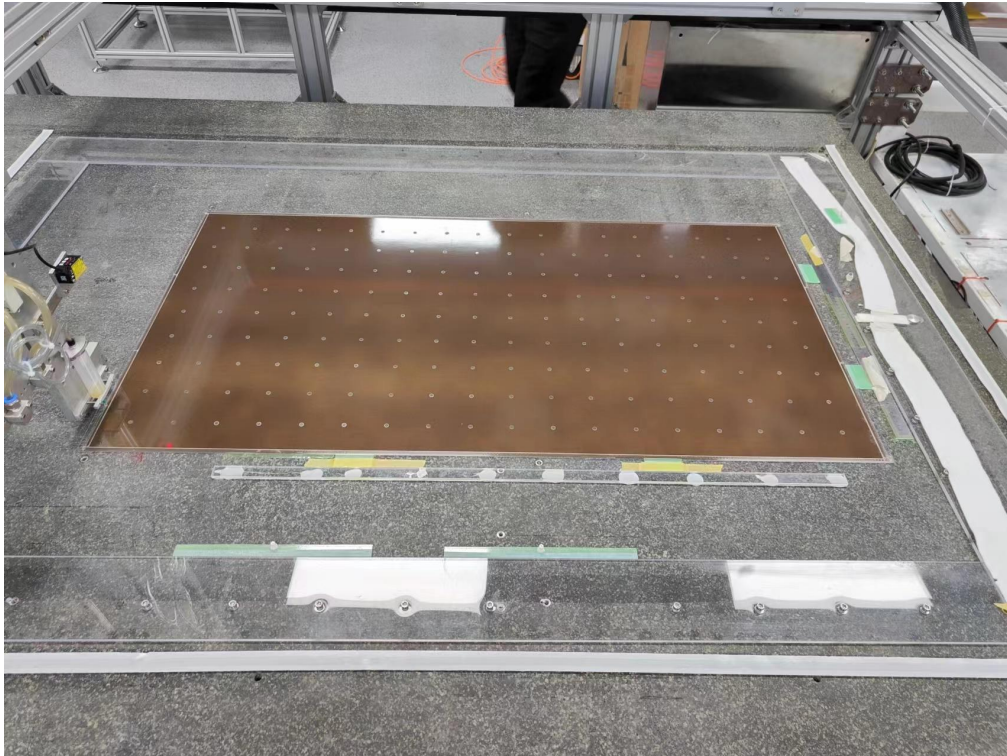


Zoom in



The third step

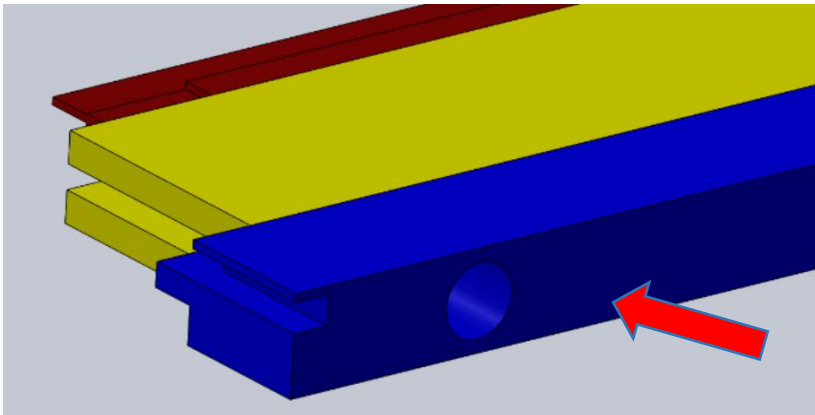
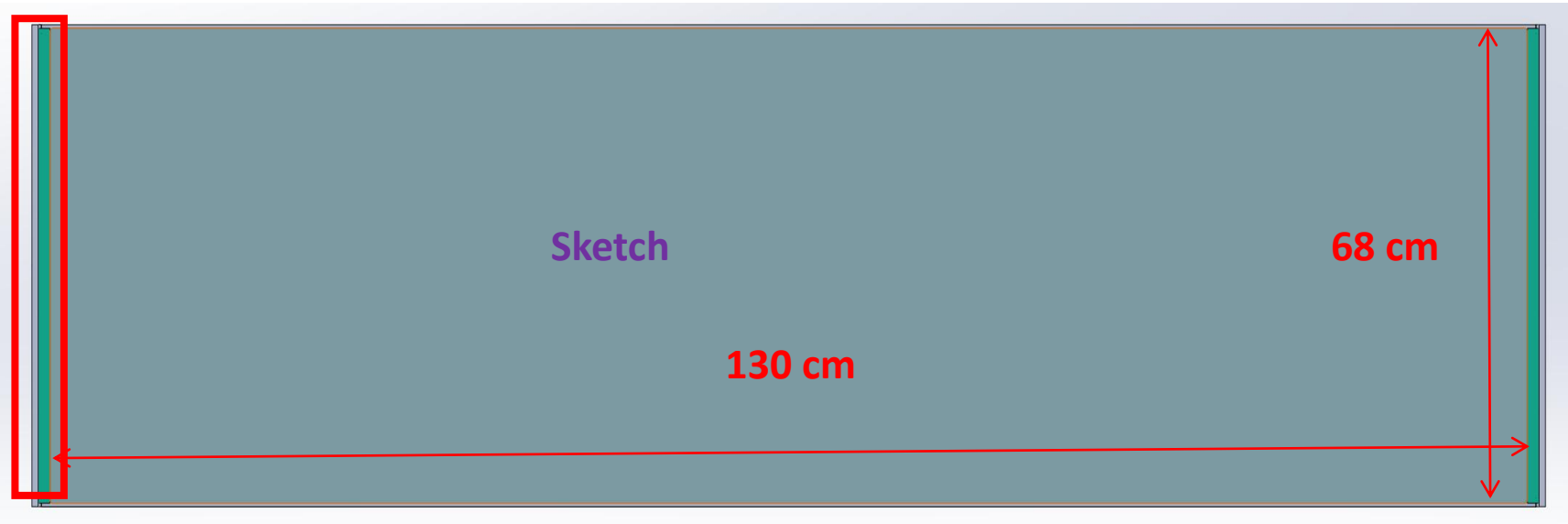
- Attach the spacers on the bakelite
 - dispensing work (Add glue on the bakelite)
 - Put spacers on the glue and the distance between 2 spacers is 70 mm.
- Close the gas gap and vacuuming



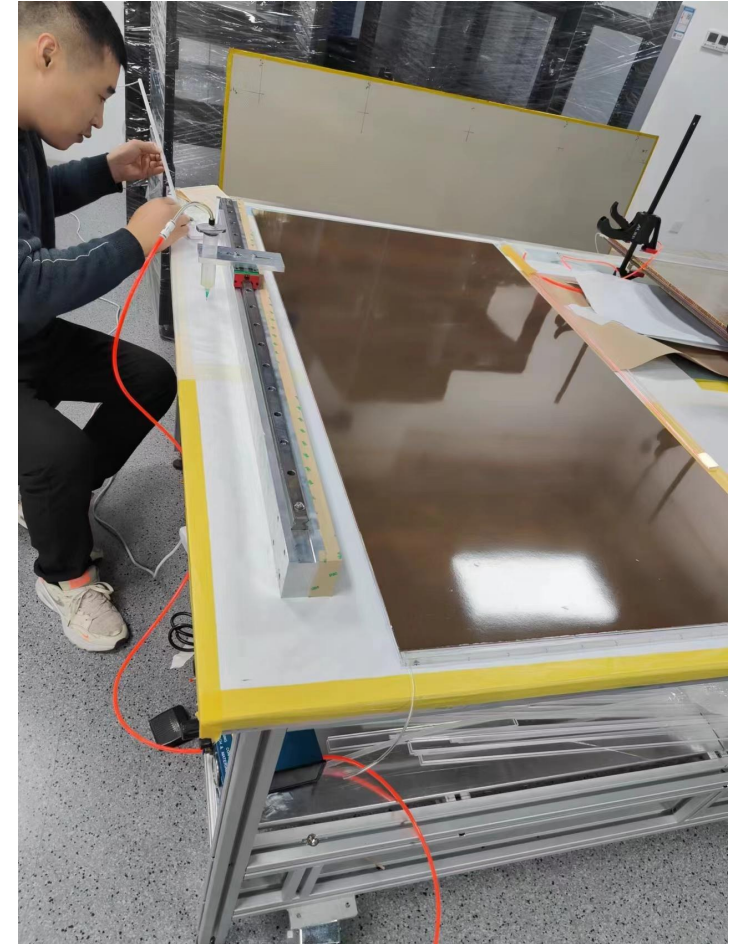
keep at least 6 hours for the epoxy curing within the vacuum bag.

The last step

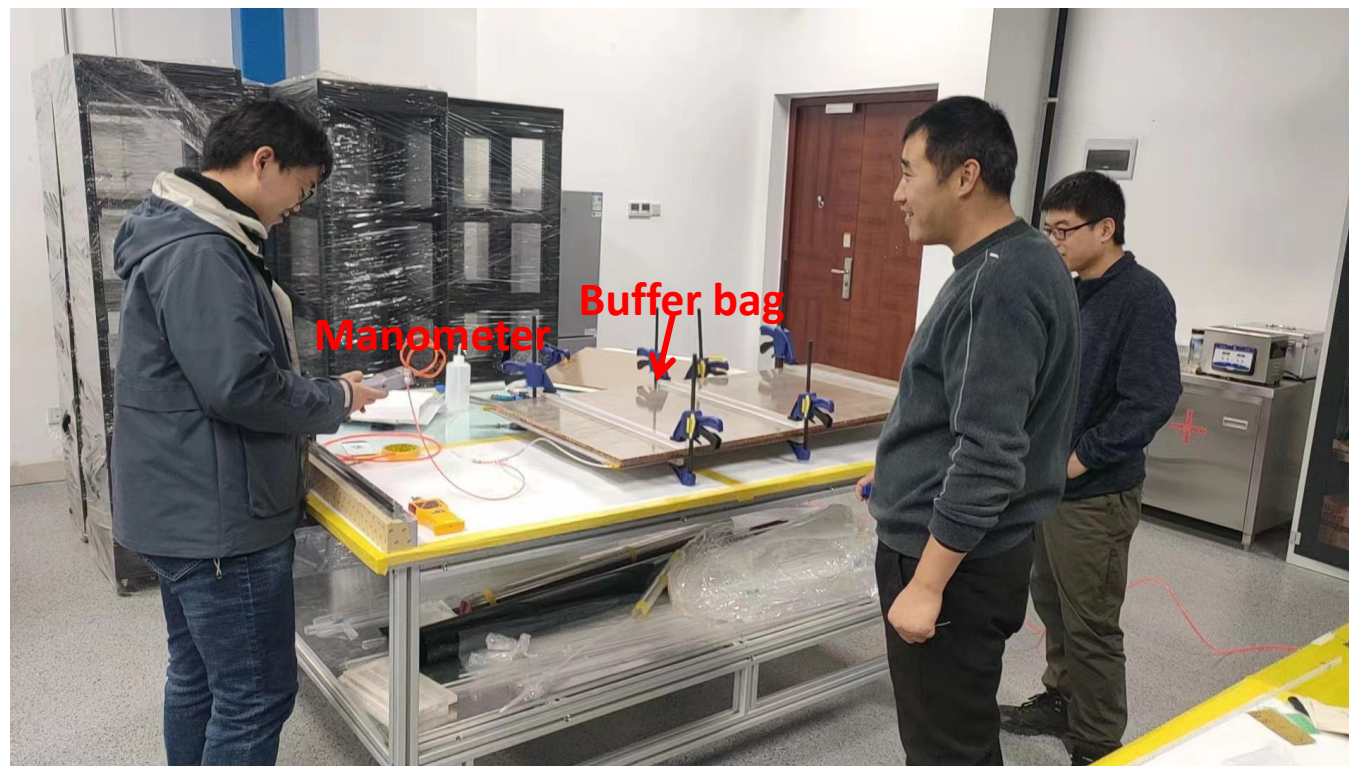
➤ Put the gas inlet into gas gap



5 prototypes are built at USTC



Test the tightness of the gas gap



Argon sniffer



Manometer



Buffer bag

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

Graphite coating and HV link applied



Graphite coating



Graphite painted

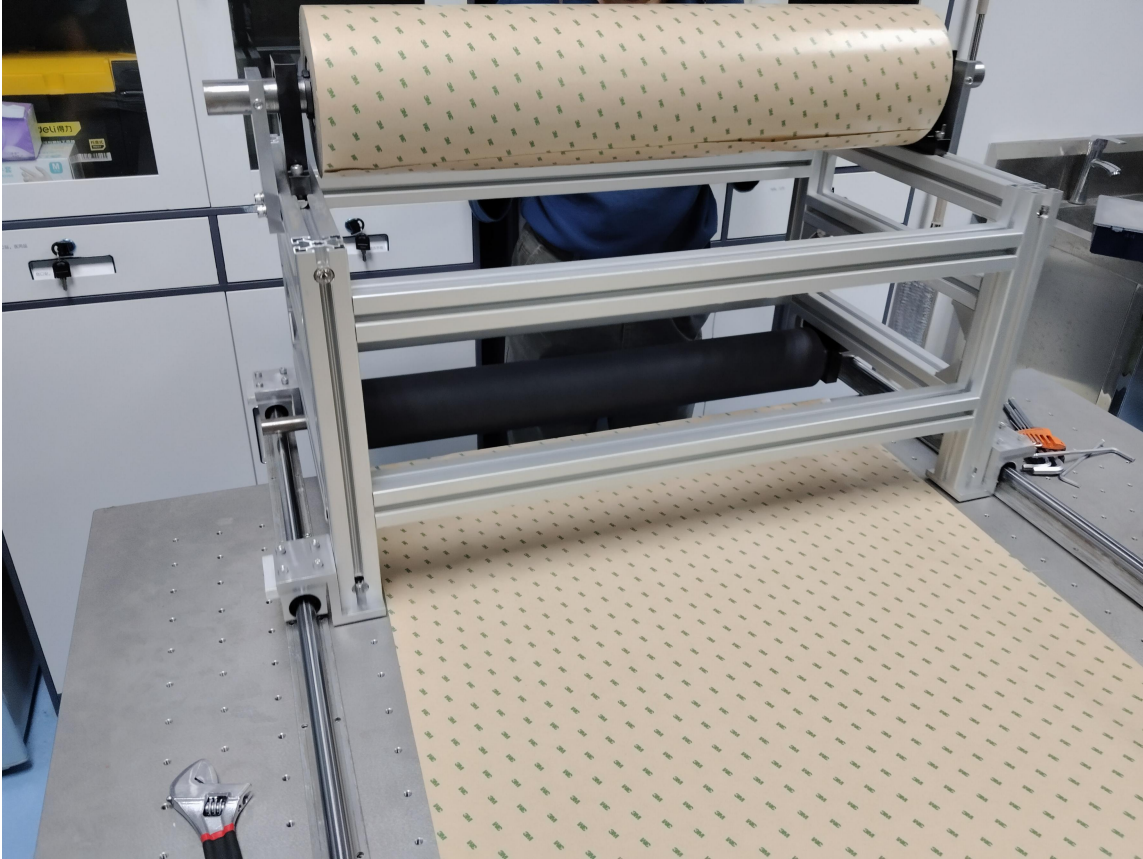


Zoom in



HV link applied

PET foiling



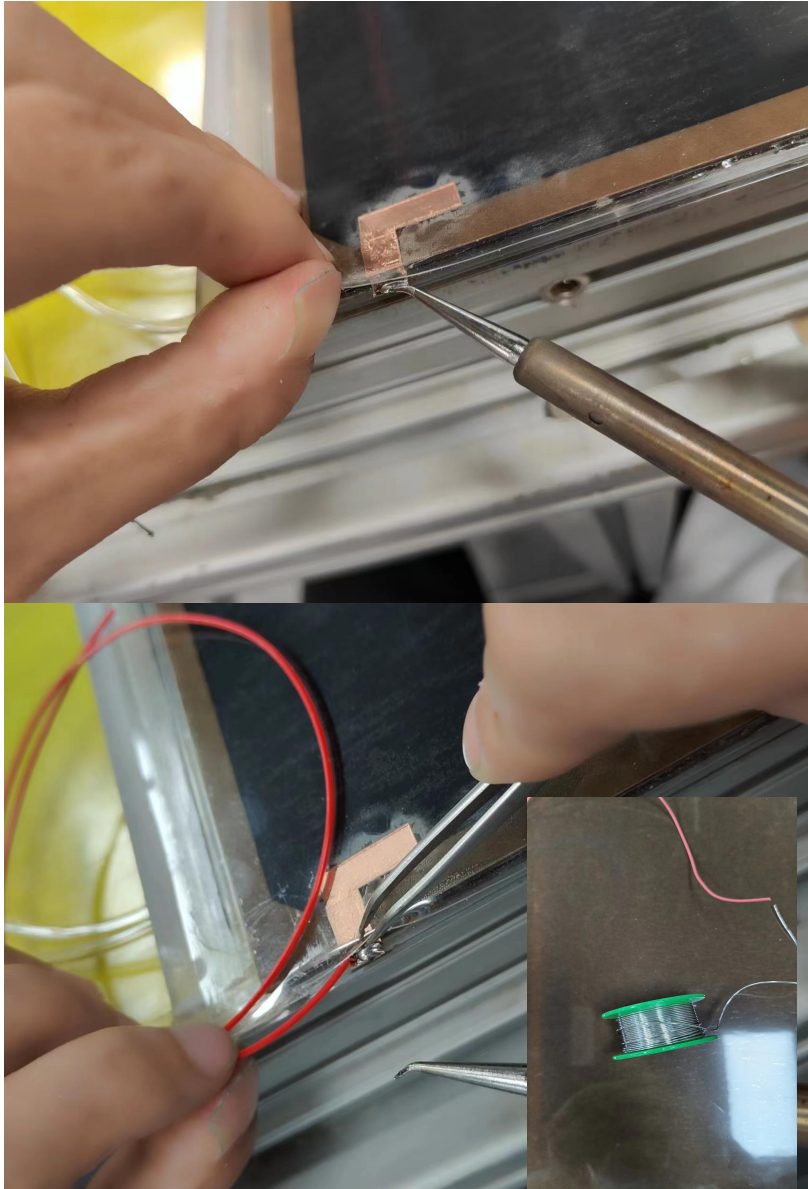
Tooling



Mirror-like surfacing



HV contacting and hot-melt gluing



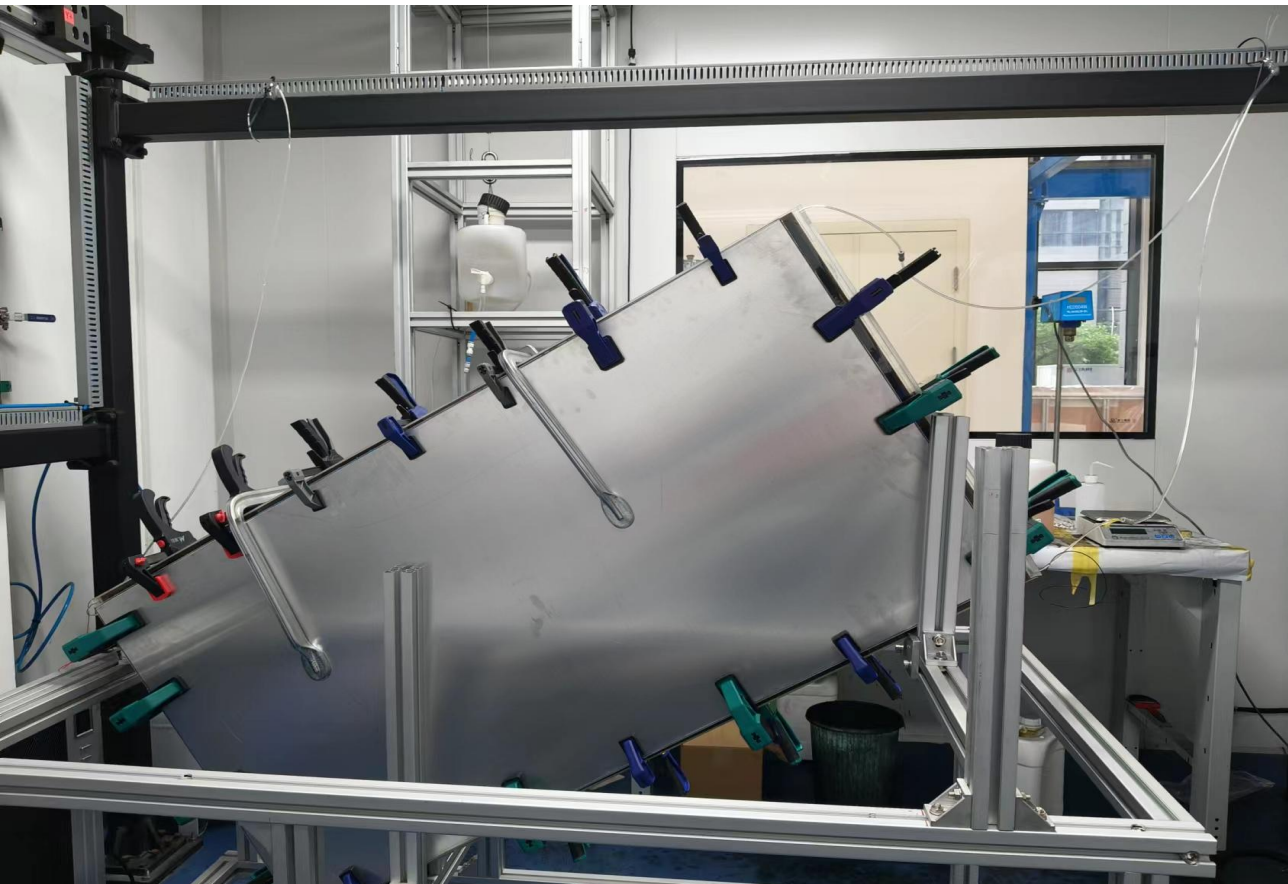
Filling and sealing of the edges of the RPC structure with hot-melt glue

← To protect PET foil, special solder wire is used

Paper stacker



Linseed oiling



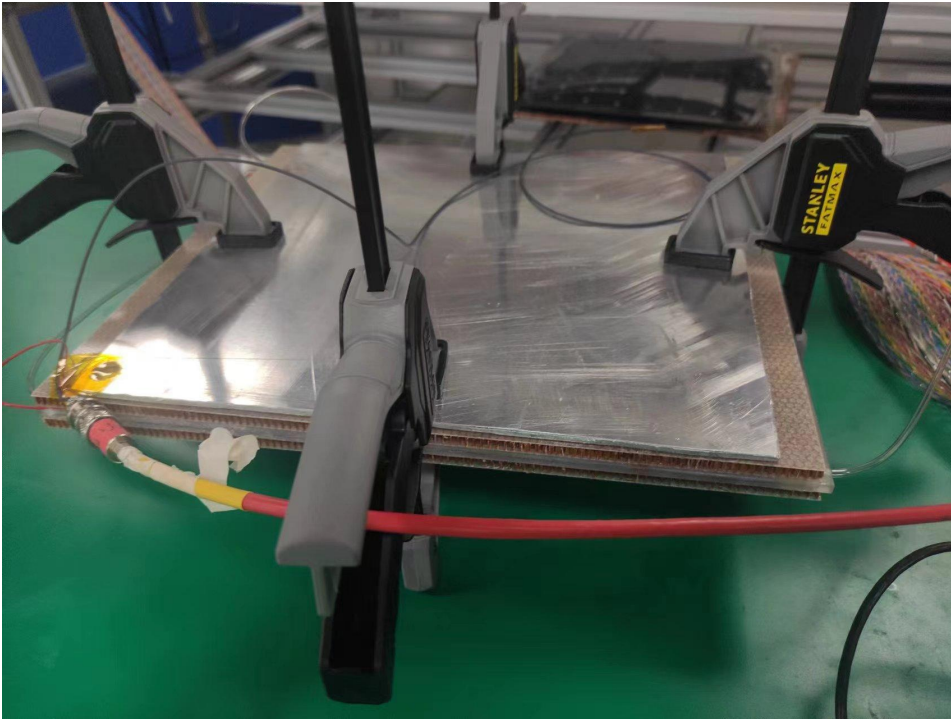
- Preparatory work:
- Room temperature: $\sim 40^{\circ}\text{C}$
 - Mixed oil: 30% linseed oil + 70% heptane
 - Use clamps to prevent bursting under oil pressure

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

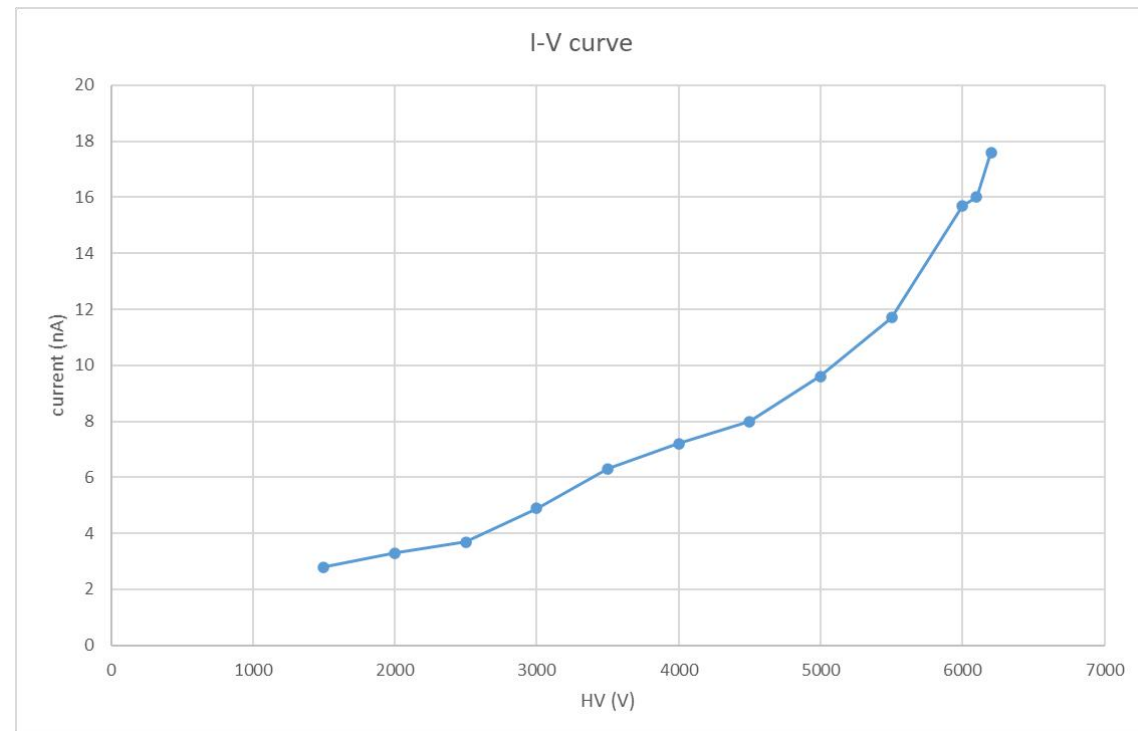
This step is still working in progress
But the quality are checked with small size bakelite gas gap.

HV training

- Supplied with standard ATLAS RPC gas mixture ($\text{C}_2\text{H}_2\text{F}_4$: Iso- C_4H_{10} : SF_6 = 94.7% : 5% : 0.3%).
- Applied HV from 1.5 kV to 6.2 kV.
- Trained at 6000V for 5 days and the current drop from 15.7 nA to 5 nA



Size: 28 x 30 cm²

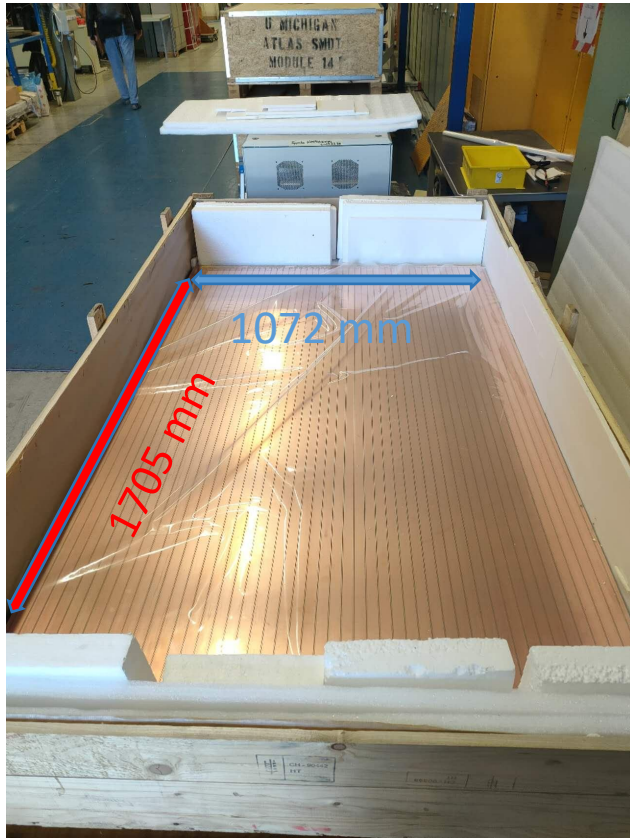


Before training

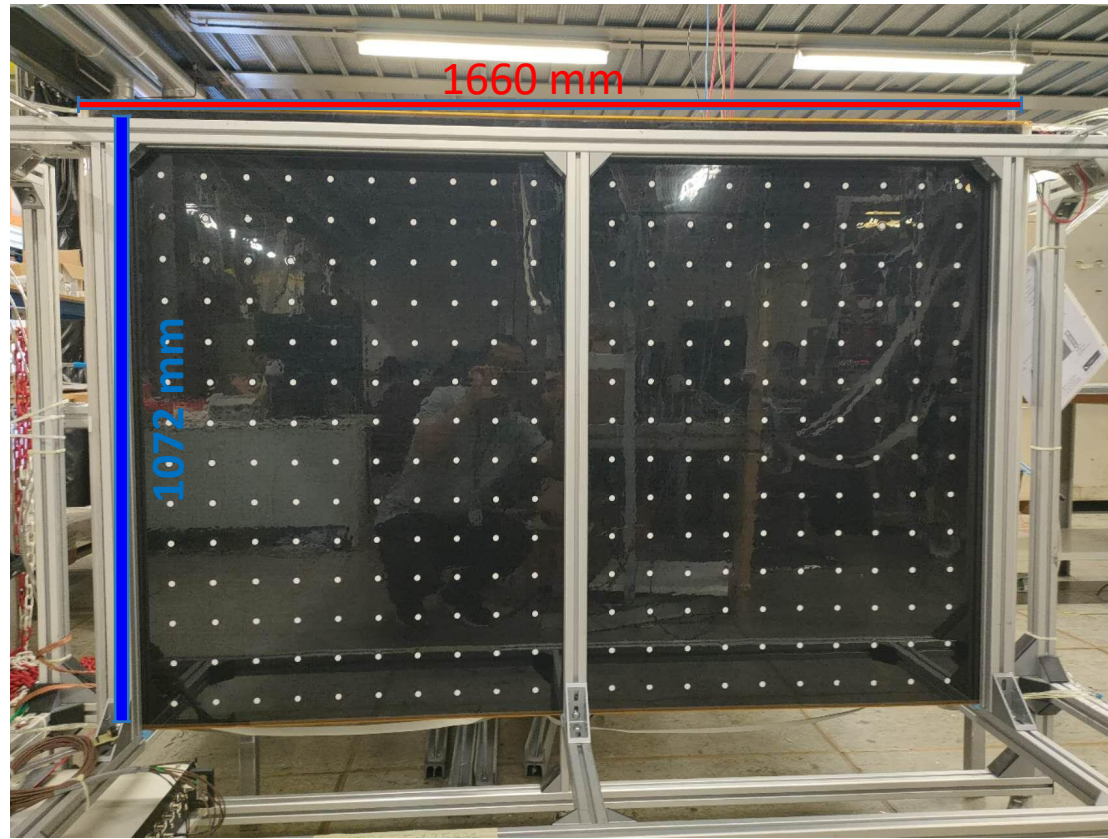
BIS assembly training at CERN

Materials for the BIS assembly

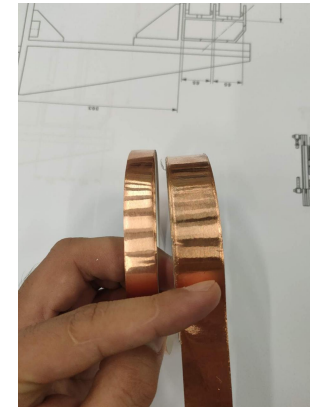
- 8 readout panels produced by USTC (Label: PCB1-PCB8)
- 4 gas-gaps produced by GTE (Label: BIS2A 2/23, BIS2A 3/23, BIS2A 4/23, BIS2A 6/23)



Readout panels



Gas gaps



Copper tapes



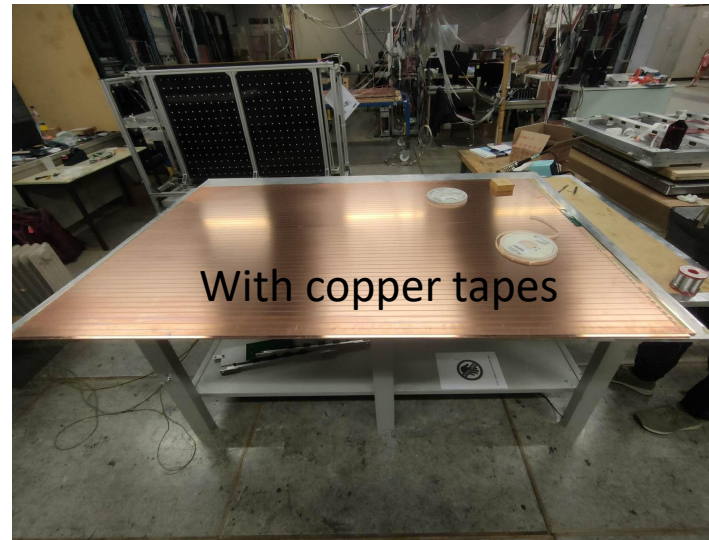
Resistors

Preparatory works

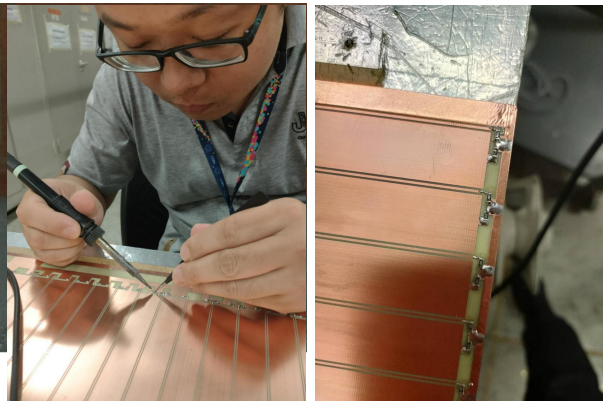
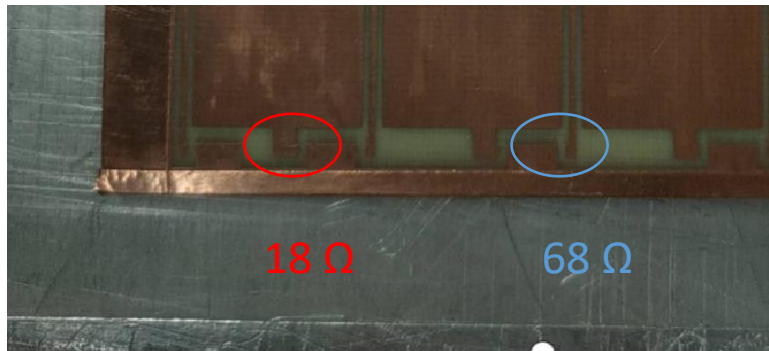
➤ Step 1: Attach tapes around the readout panels



20-30
minutes



➤ Step 2: solder the matching resistors: 18 Ω and 68 Ω



1 readout panel need $(48 * 2 + 1) * 2 = 194$ resistors,

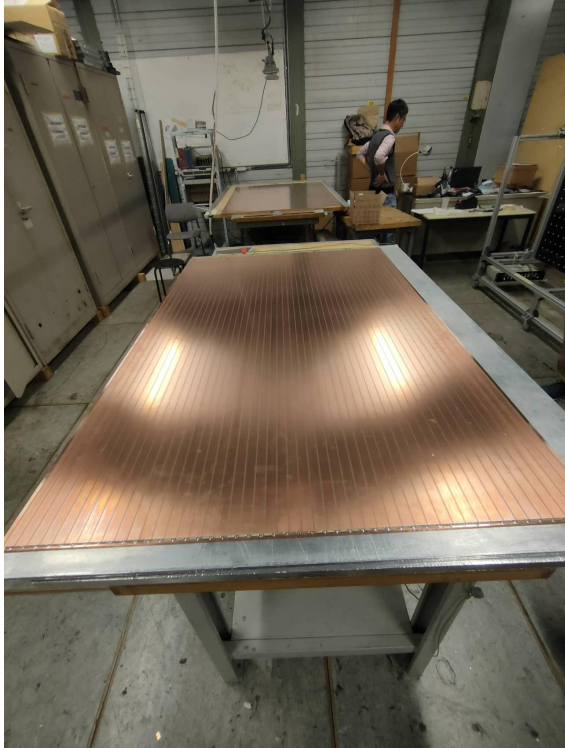
take 2.0 hours for each readout panel

1 singlet: $194 * 2 = 388$ resistors

1 chamber: $3 * 388 = 1164$ resistors

Very time consuming

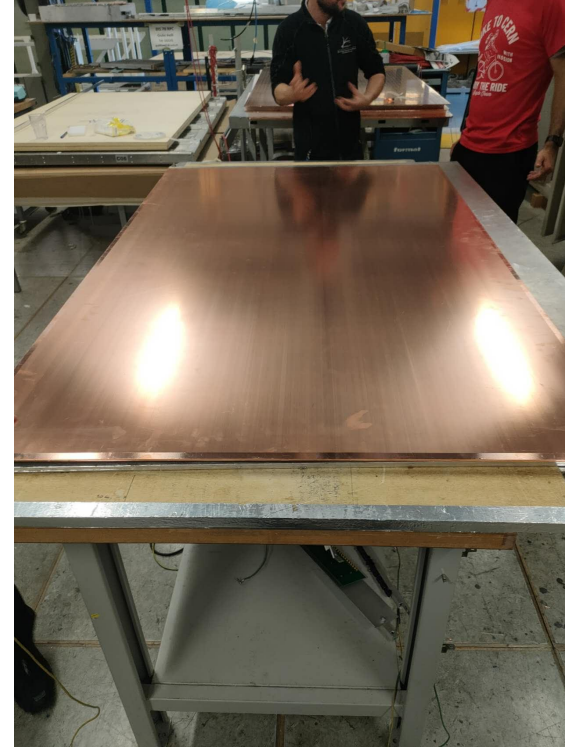
Assembly works



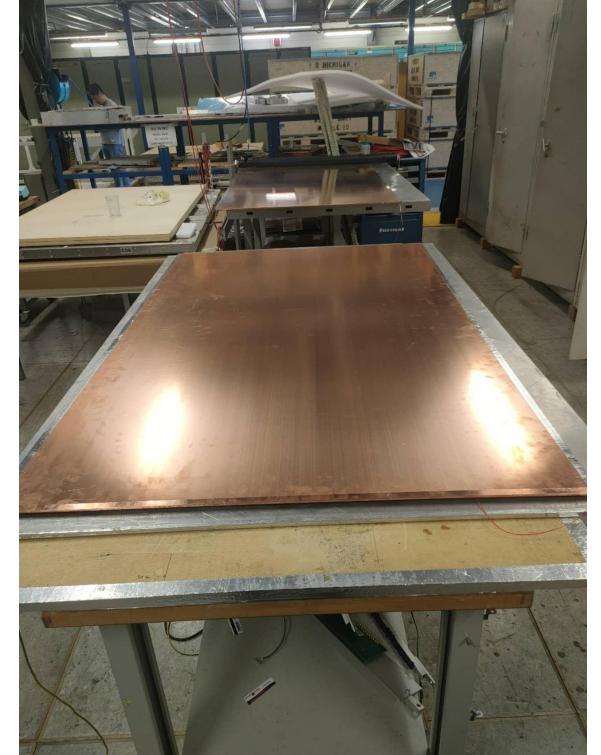
Step1:
Put the readout pannel in
the table with strip pannel
on the top



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



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

Summary

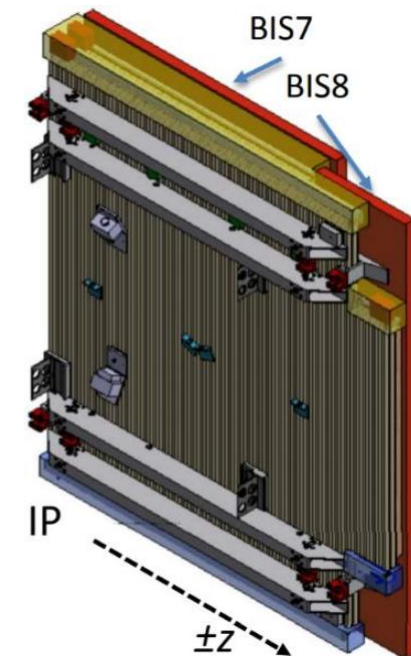
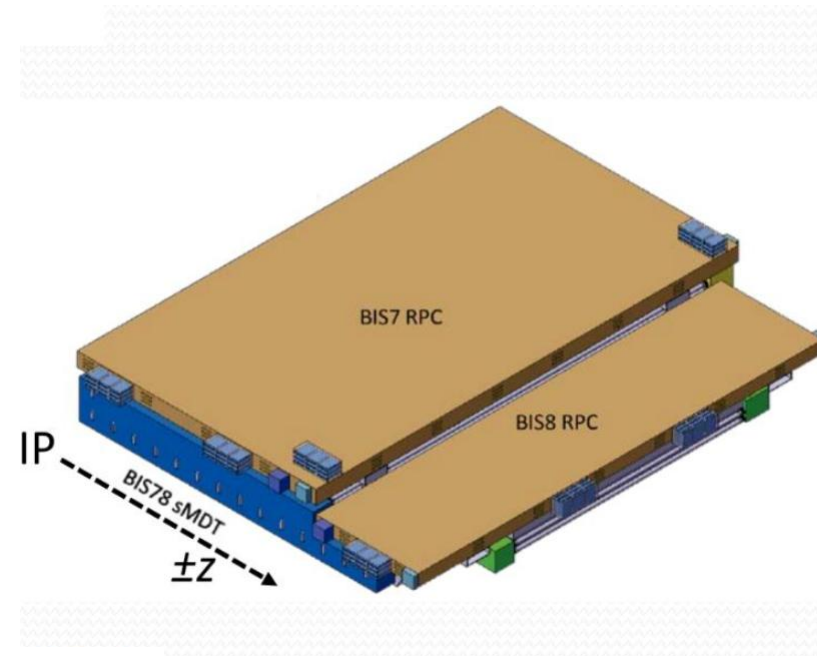
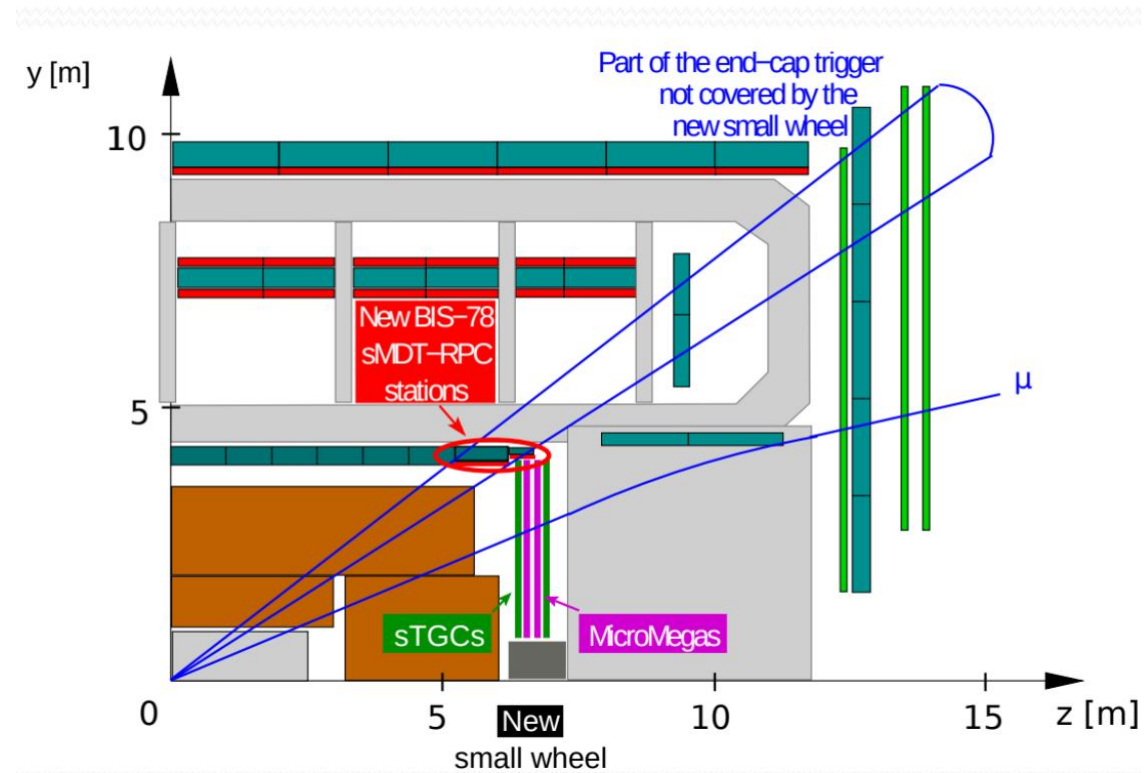
- The vacuum-bag-based honeycomb readout panel production method has been established and optimized at USTC.
- ~200 readout panels are produced in the external company with the same method, the flatness of the Readout panel $< 100\mu\text{m}$, satisfy the specification.
- The production procedures of gas gap are almost finalized, the test results (I-V curve) with small gas gap (28 cm * 30 cm) are very promising and the results will come soon by using large gas gap prototype (130 cm * 68 cm).
- Those five gas gaps will be shipped to CERN to do the irradiation test soon.
- We are ready to assemble the BIS singlet in USTC.

Any questions or comments are welcome

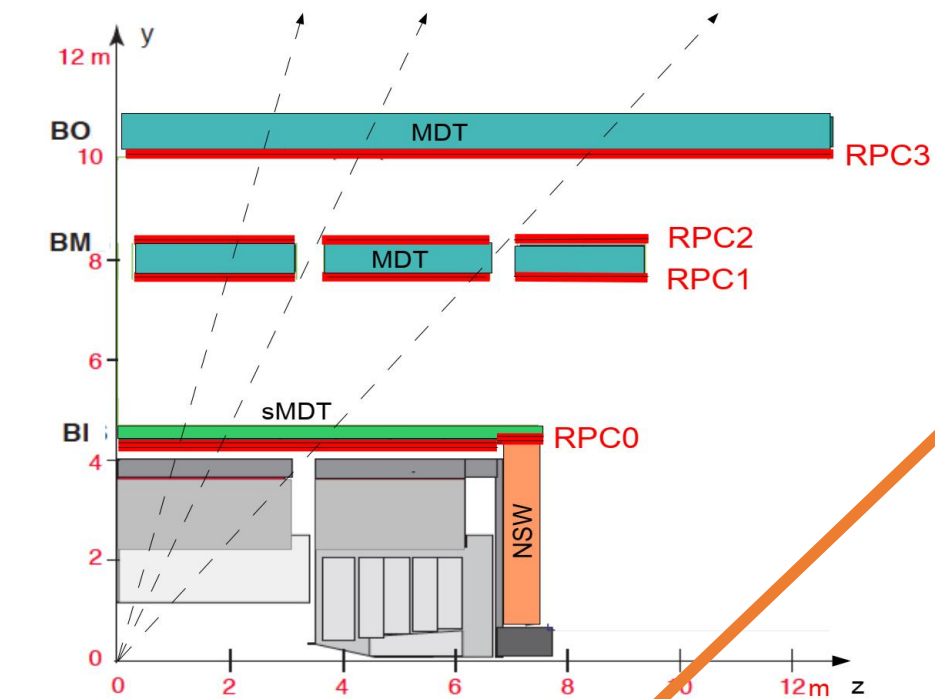
Thank you

Back up

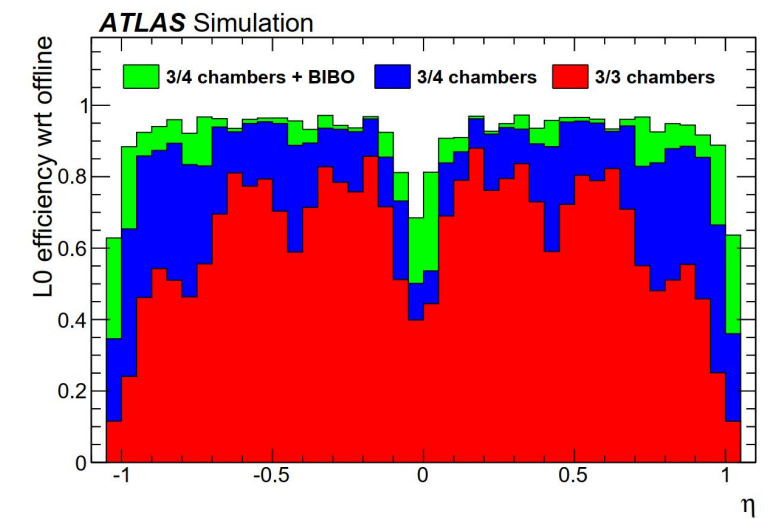
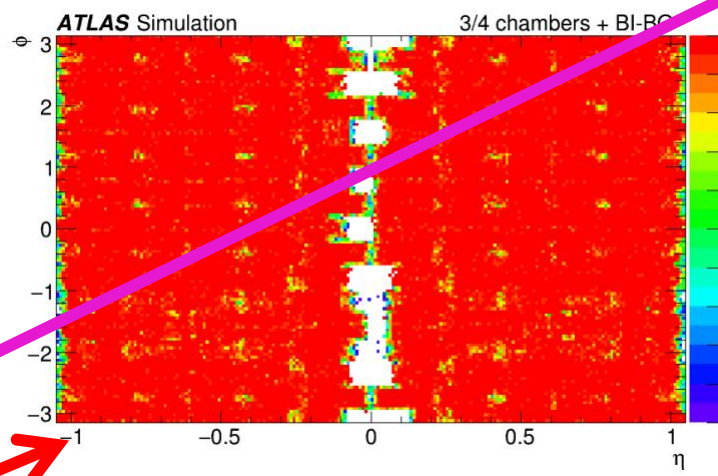
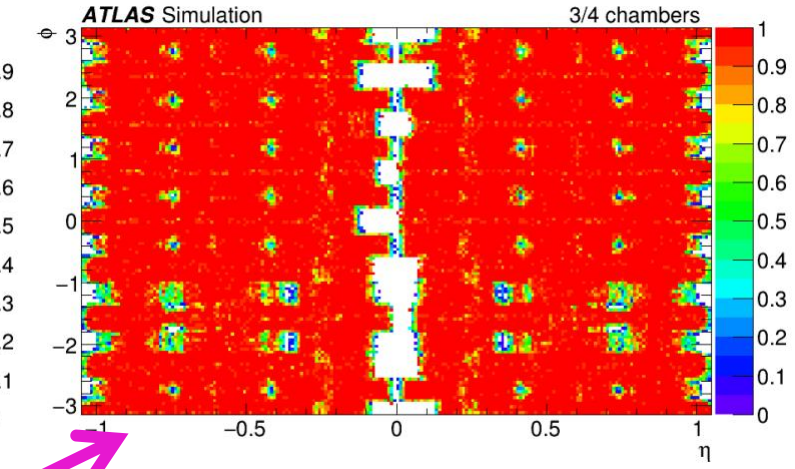
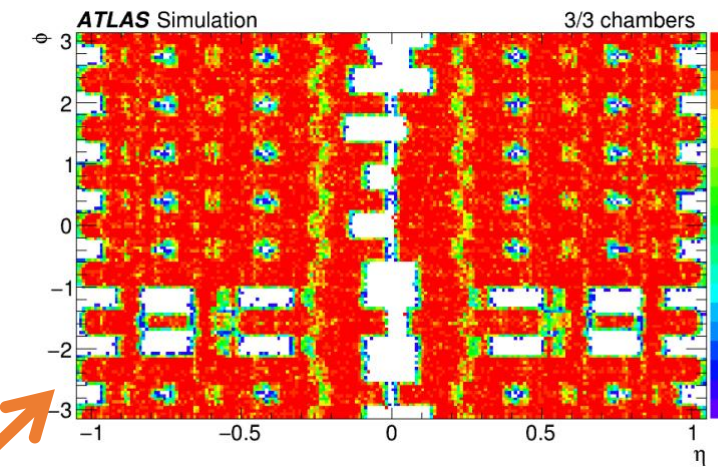
BIS78



Geometrical acceptance and trigger eff.



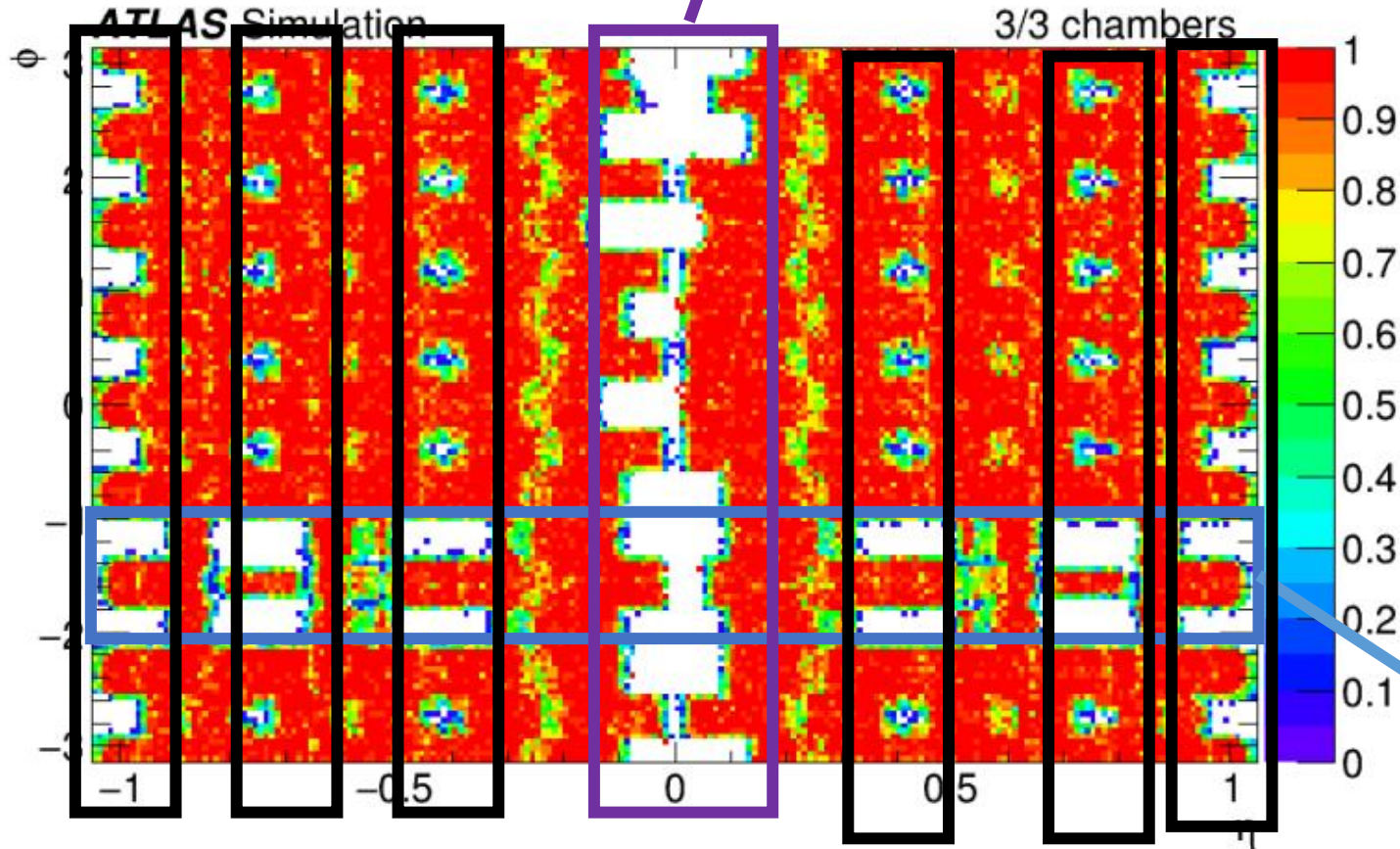
Trigger	Requirement
3/3 chambers	$3[\text{RPC1}+\text{RPC2}] \text{ AND } 1[\text{RPC3}]$
3/4 chambers	$(3[\text{RPC1}+\text{RPC2}] \text{ AND } 1[\text{RPC3}]) \text{ OR } (2[\text{RPC0}] \text{ AND } 3[\text{RPC1}+\text{RPC2}+\text{RPC3}])$
3/4 ch. + BI-BO	$(3[\text{RPC1}+\text{RPC2}] \text{ AND }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



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 $\times$ 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 supports of the toroidal magnets

WORK
sharing

WORK IN PROGRESS									
PRIORITY			Number	GTE	INFN	MPI	USTC	HK	TK
1	BIL (excluding s7)	gas gap	312	100%					
		strip panel	624		100%				
		singlet	312		100%				
		triplet	104		100%				
1	BIL s7	gas gap 5-9 S7	30	backup			100%		
		gas gap(1-4+10)S7	30	100%					
		strip panel	120		50%		50%		
		singlet	60		50%		50%		
		triplet	20		50%		50%		
2	S9 @ Eta=0	gas gap S9@E=0	18	backup			100%		
		strip panel	36				100%		
		singlet	18				100%		
		triplet	6				100%		
1	BIS1-6	gas gap	288	100%					
		strip panel	576				100%		
		singlet	288				100%		
		triplet	96			100%			
2	BOR/BOM	gas gap	240	backup		100%			
		strip panel	480		50%		50%		
		singlet	240		25%	25%		25%	
		triplet	80		25%	25%		25%	
3	BIS7	gas gap	24	100%					
		strip panel	48						
		singlet	24		100%			100%	
		triplet	8		100%			100%	
3	BIS8C	gas gap	24	backup			100%		
		strip panel	48						
		singlet	24				100%		
		triplet	8				100%		
3	BIS78A	electronics replacement	48		50%			50%	
		triplet	16		50%			50%	
			Number	GTE	INFN	MPI	USTC	HK	TK
		Total Singlets assigned to be built	942	624	402	60	360	60	60
		Total Chambers assigned to be built	314		134	116	24	20	20
		Total Singlets unassigned	24		24			24	
		Total Chambers unassigned	8		8			8	
		Total refurbishing unassigned	16		16			16	

Last refined balance the between p to optimize

Gas lines Germany qualified and expected

Close to final but waiting for formal approval

Giulio Aielli - PC BI Singlets PRR

Last refinements needed to balance the workload in between partner Institutes so to optimize the schedule slack

Close to final but waiting for formal approval

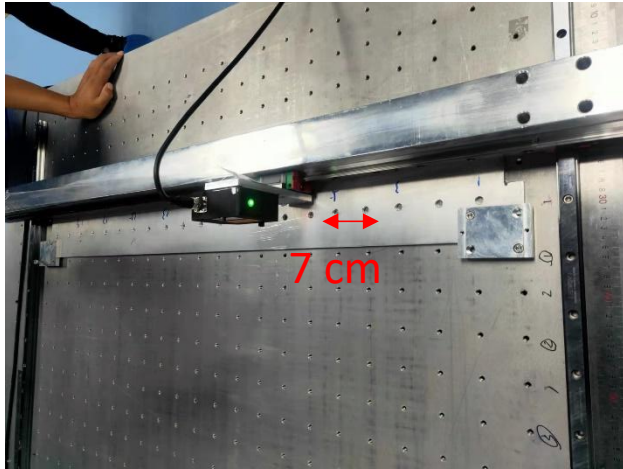
Gas gap production lines in USTC and Germany need to be qualified specifically and will undergo a dedicated PRR, expected in 10/24

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

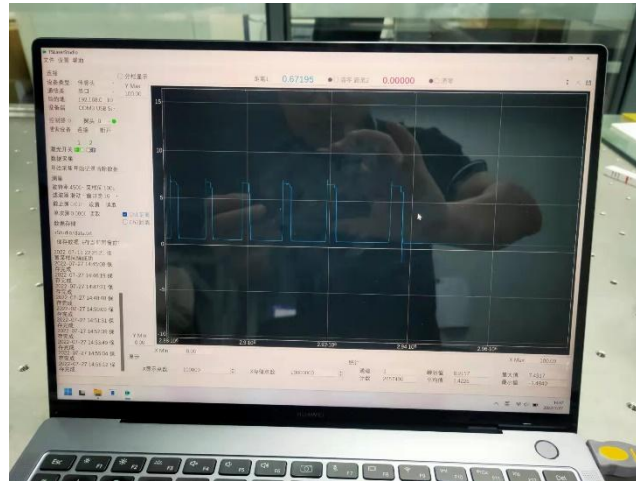


Measure the baseline

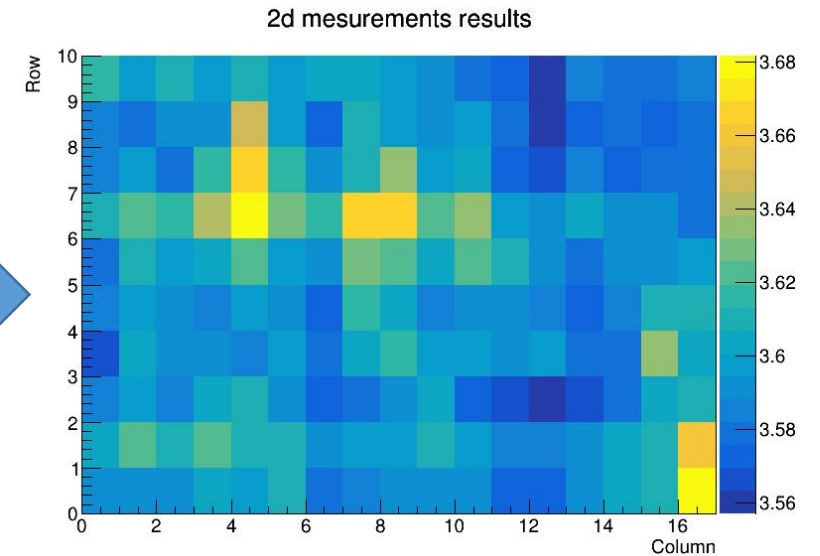


Baseline + PCB/panel

- 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.

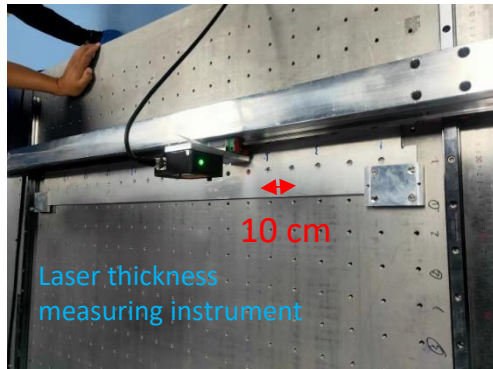
The dimentional measurement



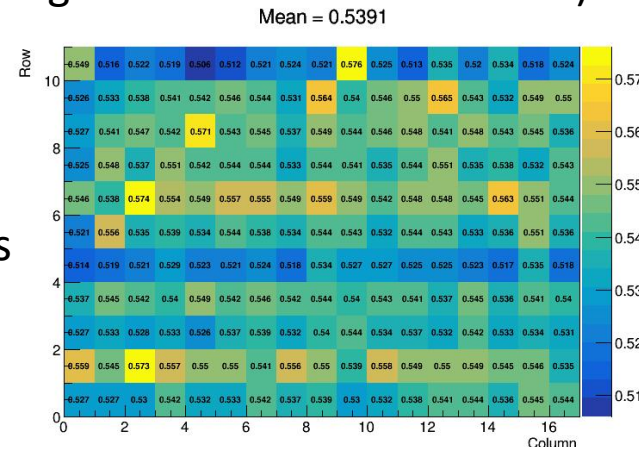
The method to check the flatness of PCB/RO panel

- 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.

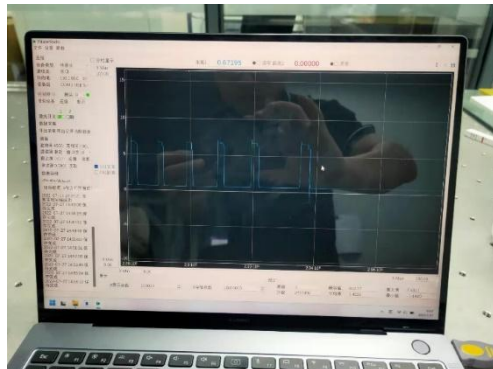
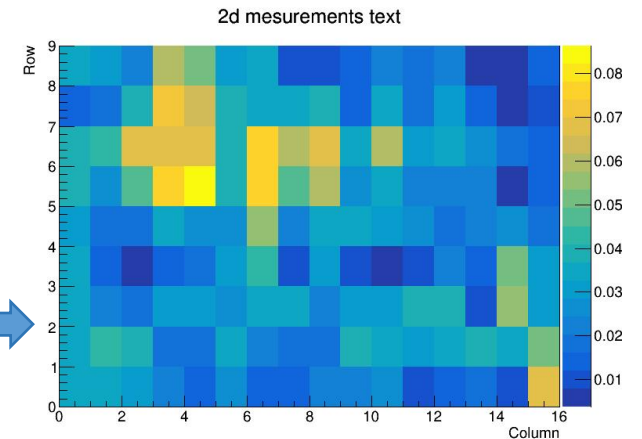
Thickness is thicker than nominal value due to PCB plate (wrong thickness FR4 board used)



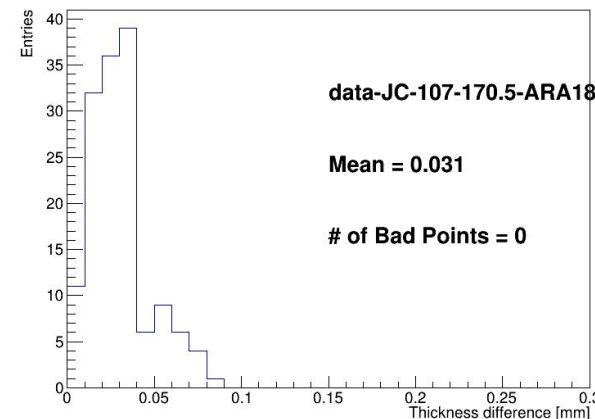
Thickness



2D Flatness

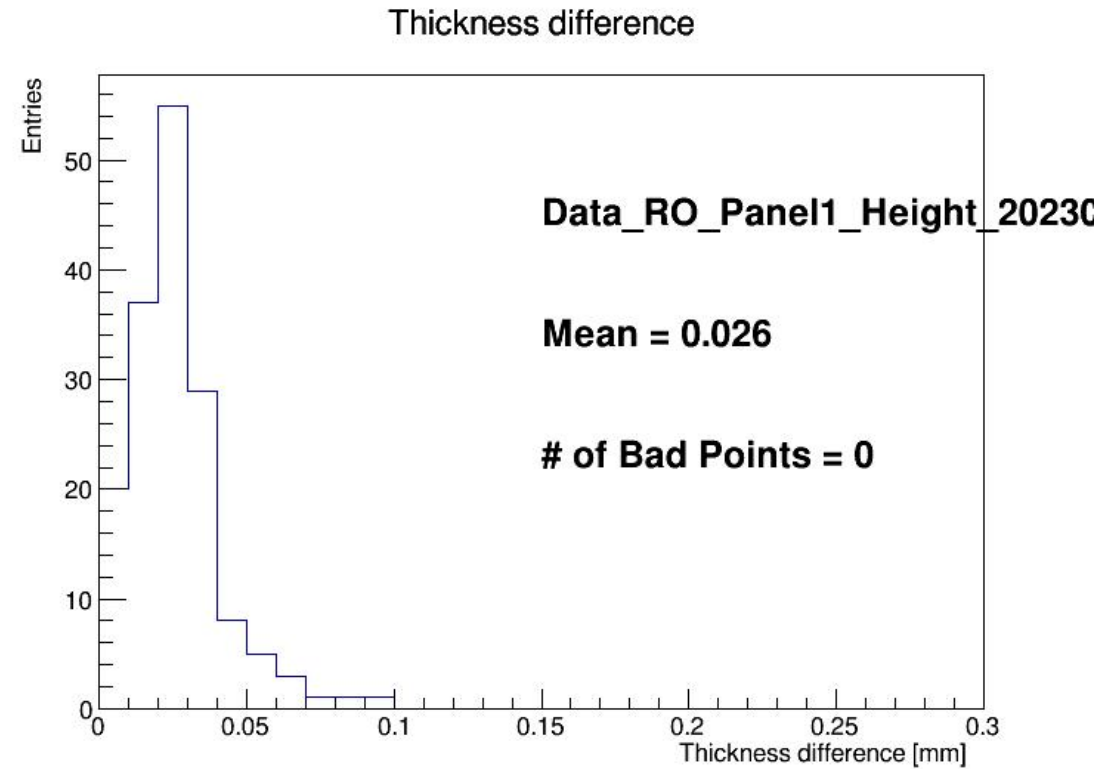
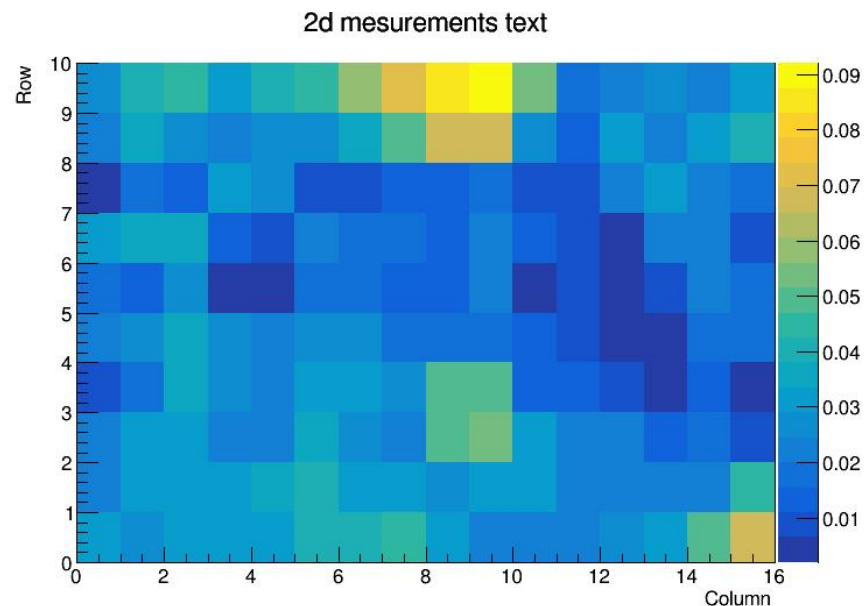
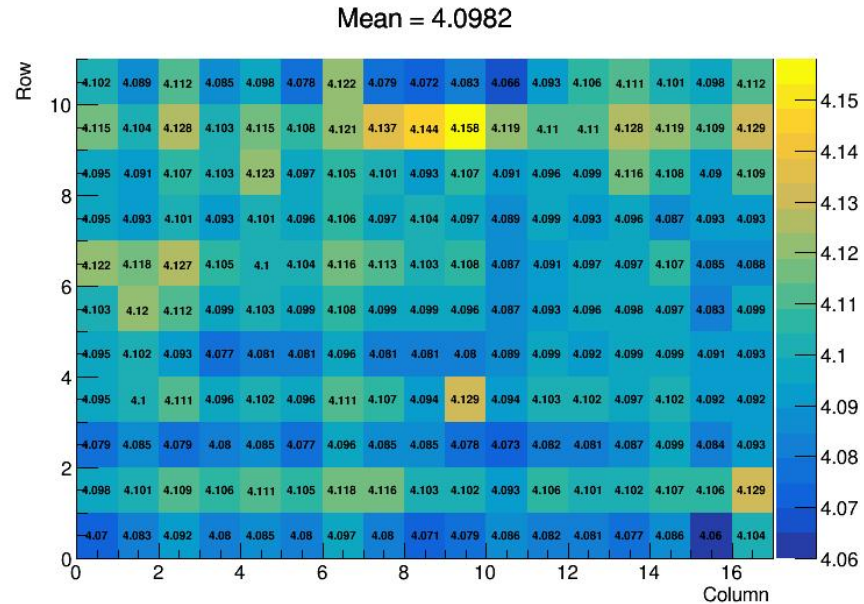


Thickness difference



1D Flatness

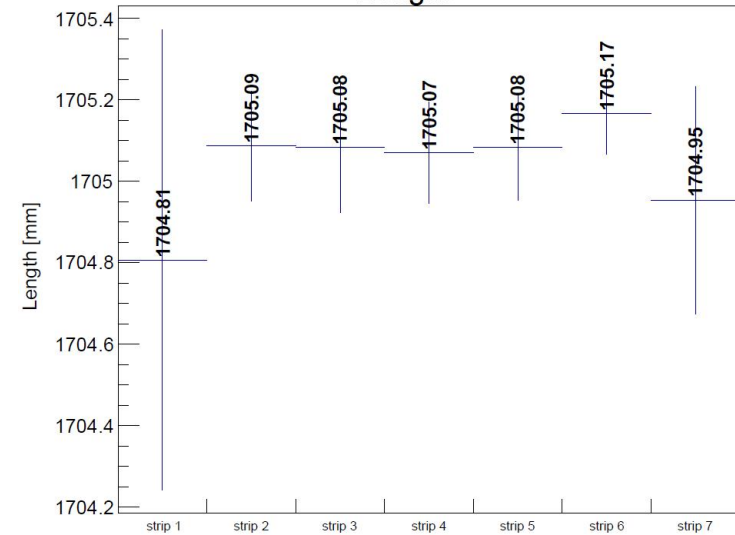
Thickness measurement of the readout panel



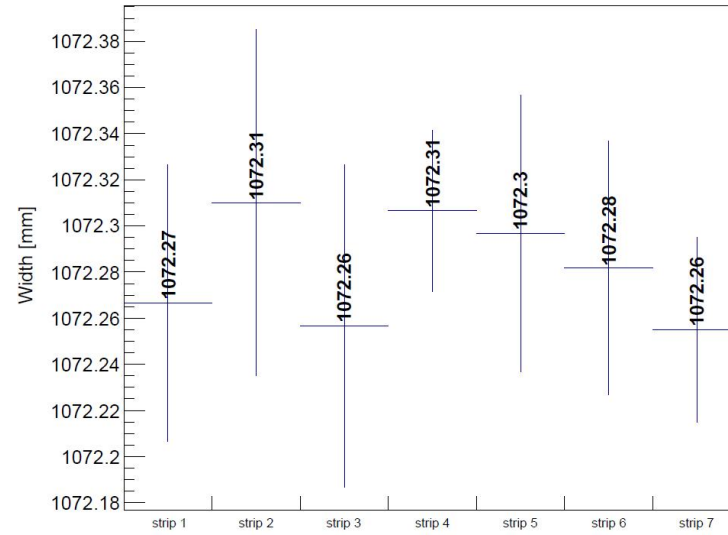
Thickness mean value = 4.098 mm
Flatness: good

The dimentional results

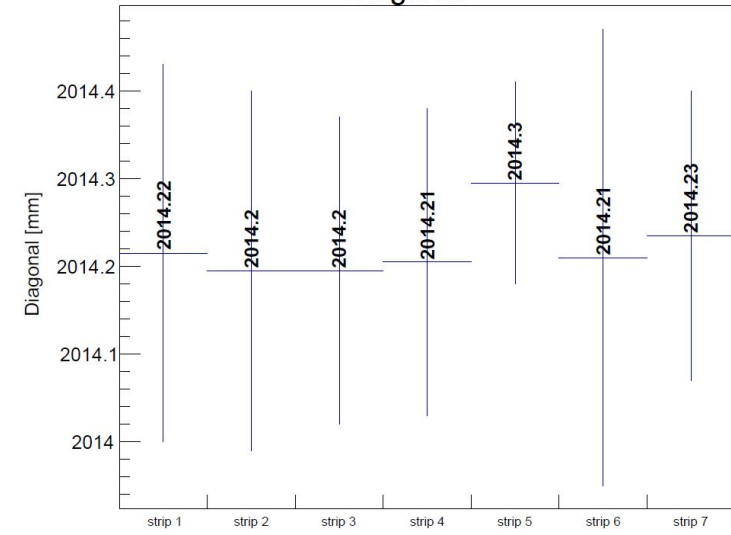
Length



Width



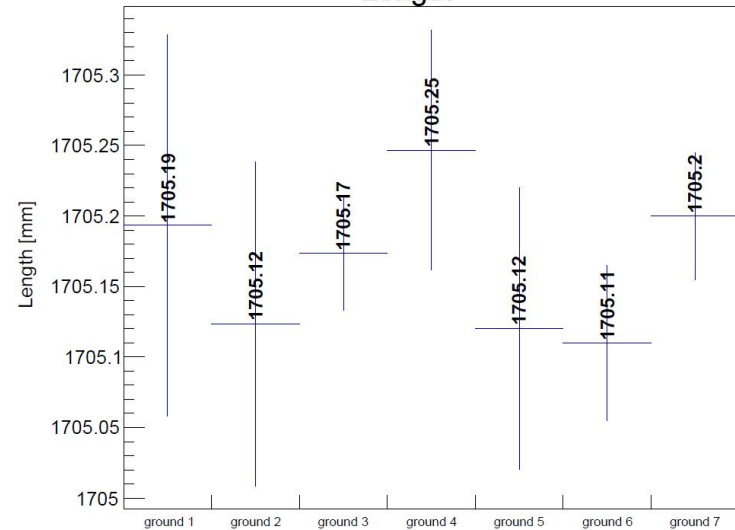
Diagonal



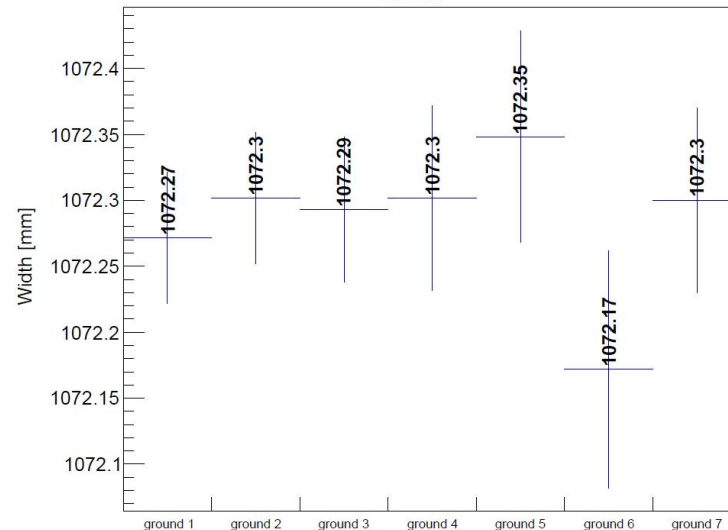
Nominal value:
Length: 1705mm
Width: 1072 mm
Diagonal: 2014 mm
Error: +/- 1 mm

Strip PCB

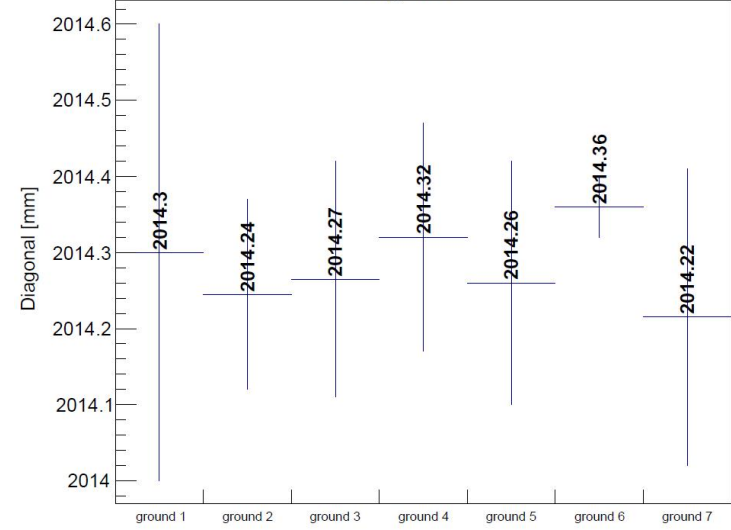
Length



Width



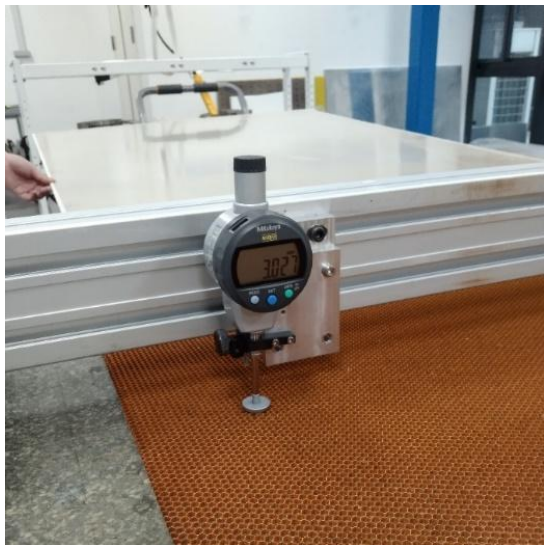
Diagonal



GND PCB

The quality of paper honeycomb

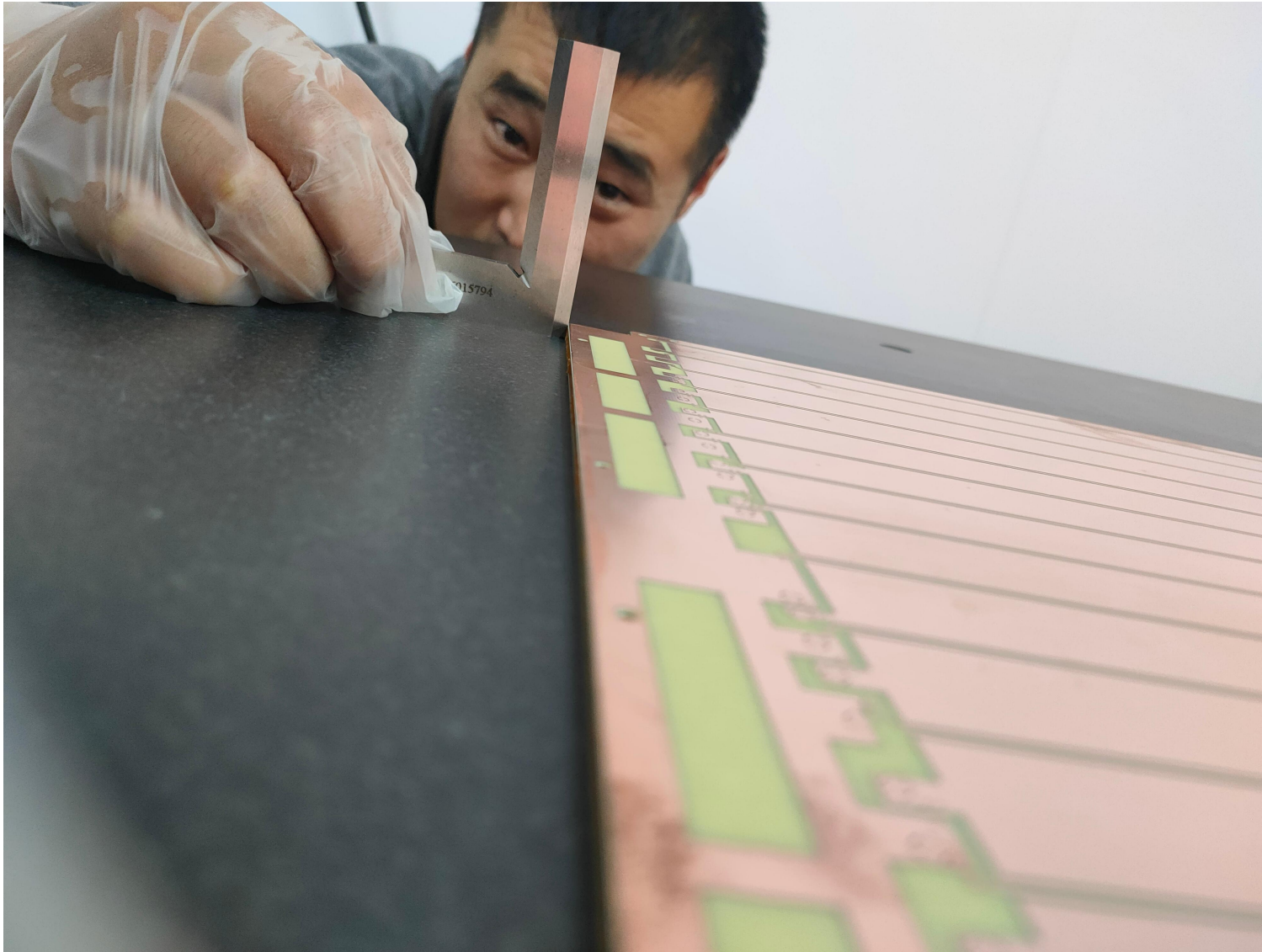
- 50 pieces of paper honeycomb (1220 x 2440 x 3 mm) received.
- Measure the thickness with micrometer gauge fixed on top of the marble table.



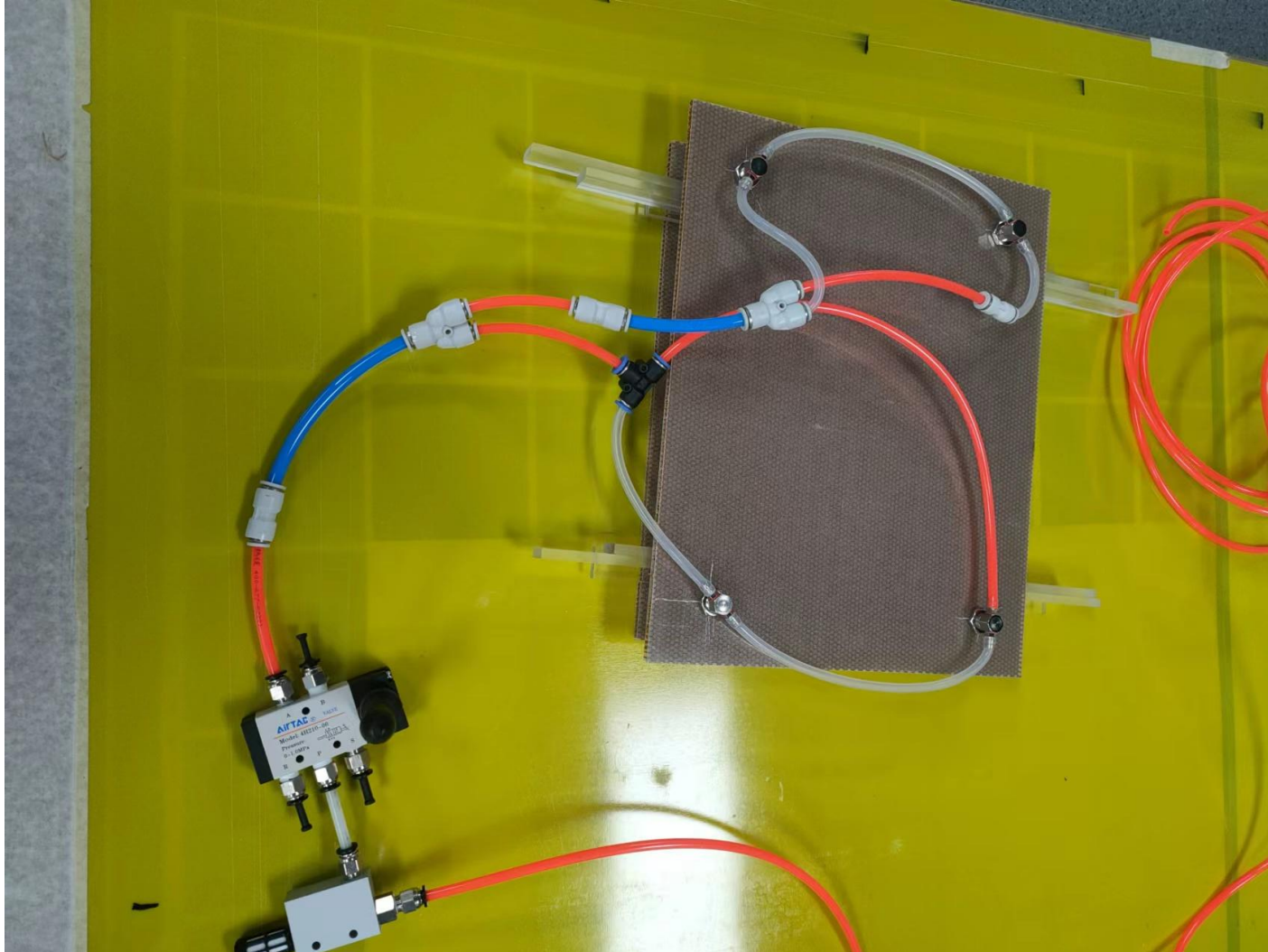
Sample #1			Sample #2			Sample #3		
	1	2		1	2		1	2
1	3.03	3.067	1	3.102	3.091	1	3.062	3.043
2	3.05	3.07	2	3.087	3.076	2	3.066	3.065
3	3.036	3.067	3	3.072	3.049	3	3.057	3.049
4	3.022	3.074	4	3.078	3.067	4	3.064	3.044
5	3.05	3.067	5	3.07	3.041	5	3.06	3.057
6	3.038	3.055	6	3.071	3.043	6	3.068	3.059
mean	3.038	3.067		3.08	3.061		3.063	3.053
Sample #4			Sample #5					
	1	2		1	2			
1	3.039	3.076	1	3.107	3.103			
2	3.063	3.074	2	3.096	3.099			
3	3.054	3.082	3	3.074	3.097			
4	3.061	3.092	4	3.079	3.097			
5	3.075	3.088	5	3.106	3.107			
6	3.078	3.079	6	3.106	3.119			
mean	3.062	3.082		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

Y

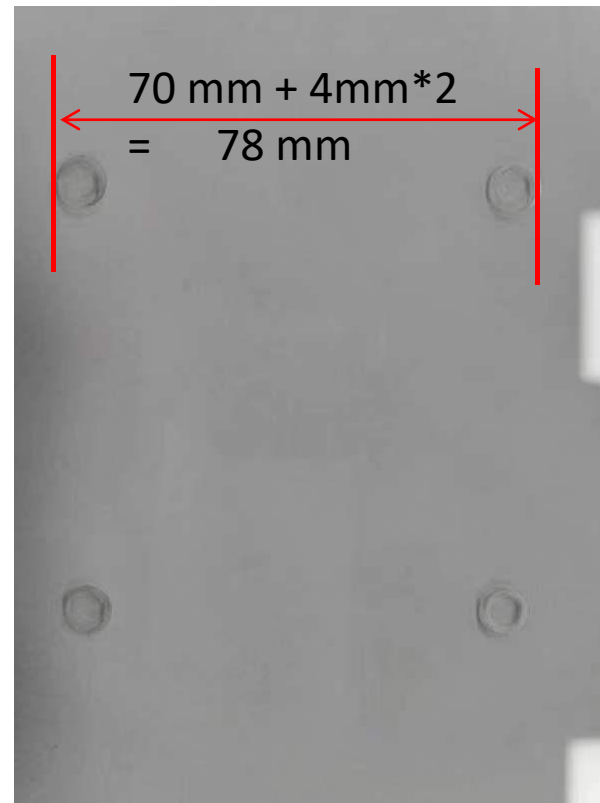


Nominal value:

radius of spacer: 4mm

height of spacer: 1mm

distance: 70mm*70mm



X

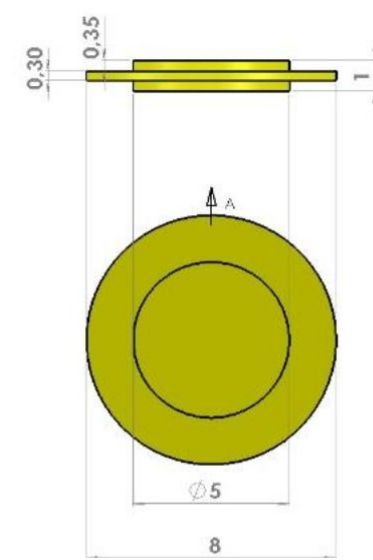
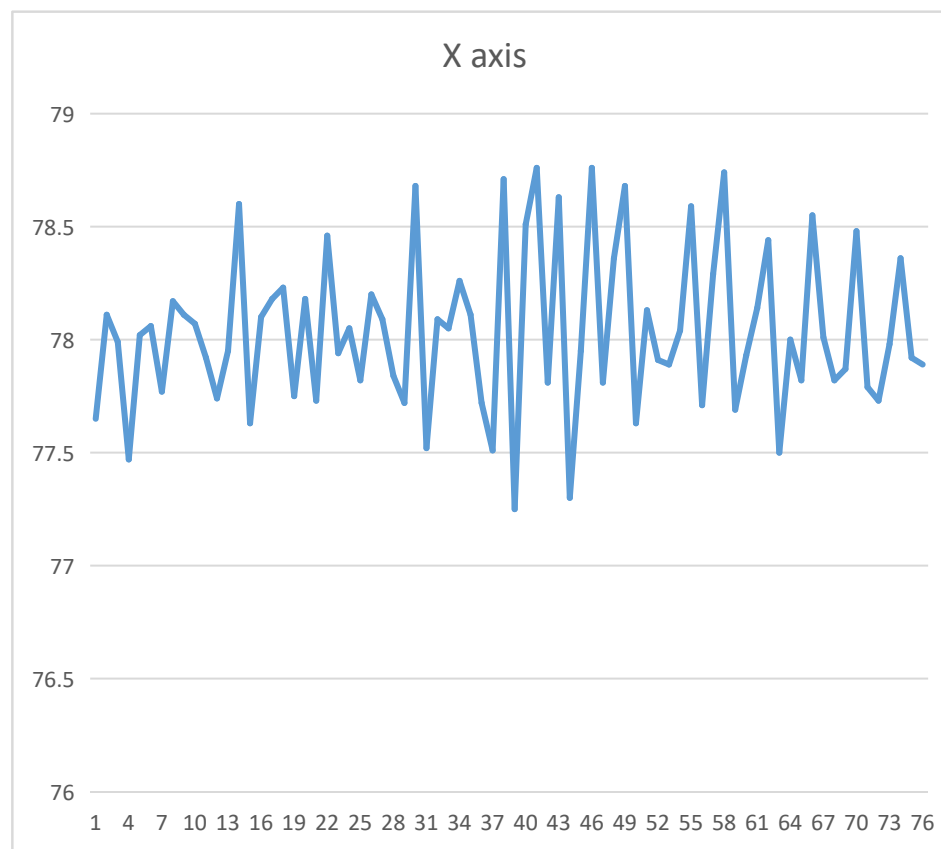


Figure 5: design of the cylindrical pillar with the guard ring.

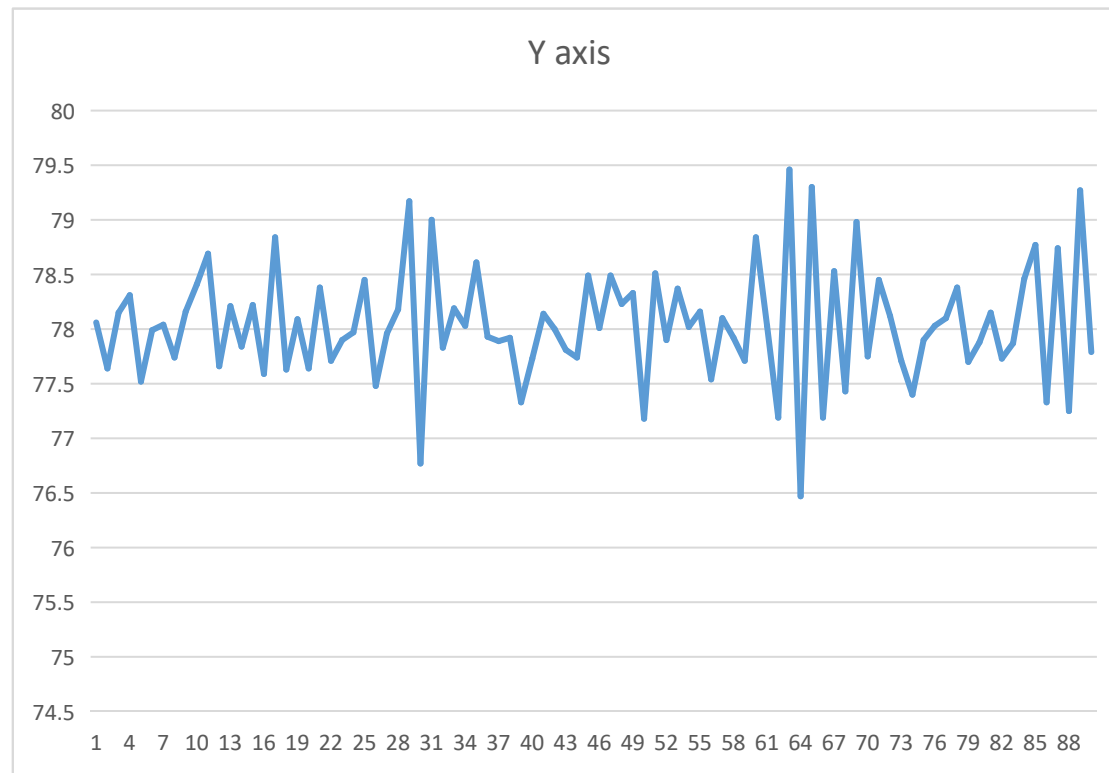
X axis

X mean=78.0429333



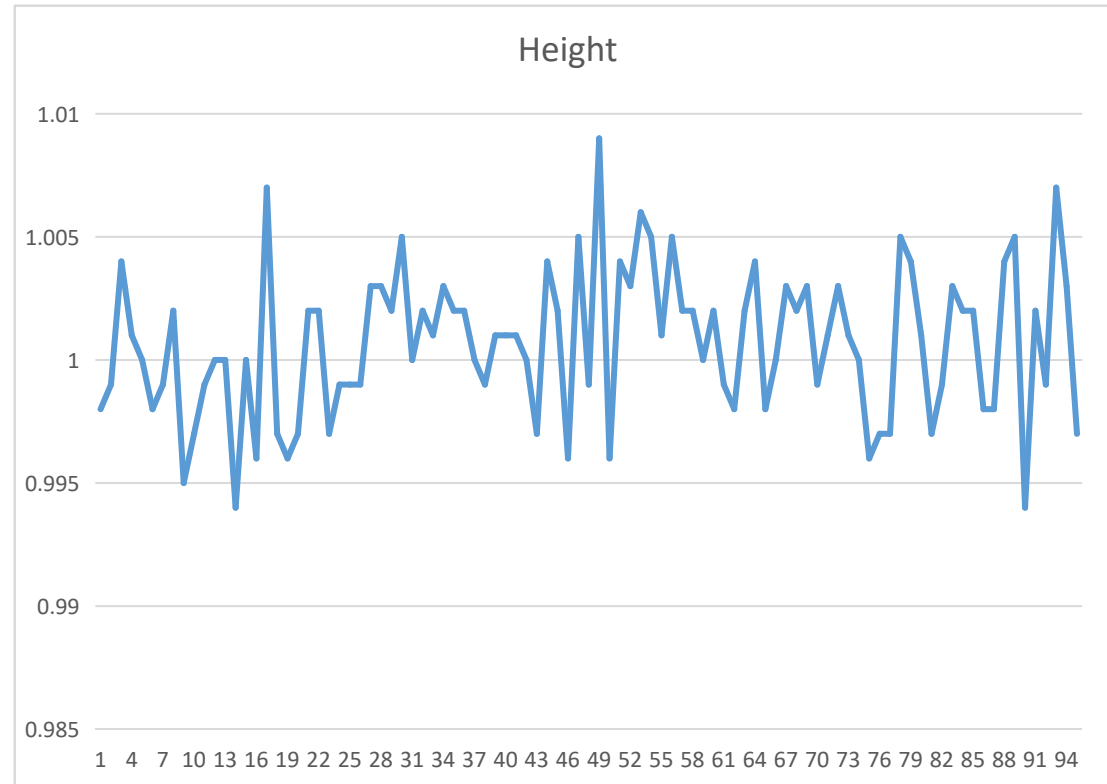
Y axis

Y mean=78.041222



Height

H mean=1.000663158

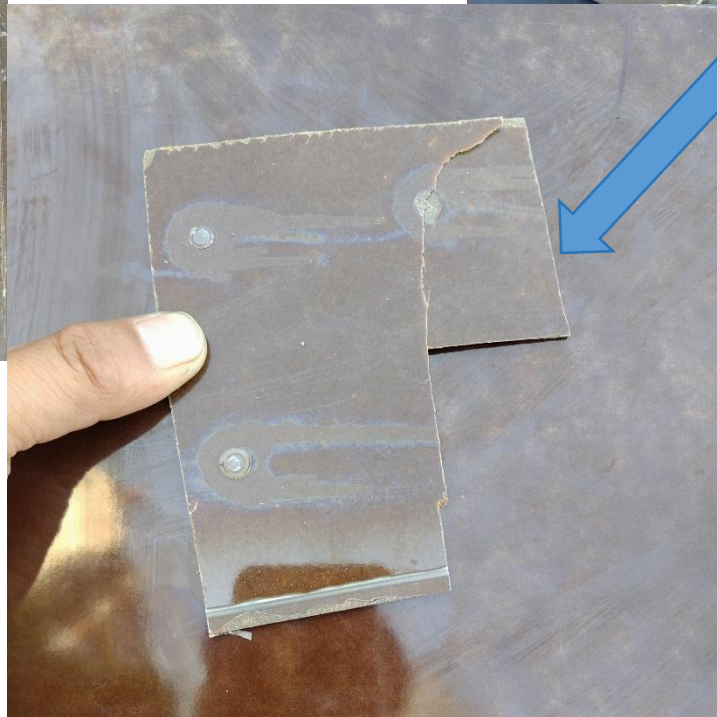
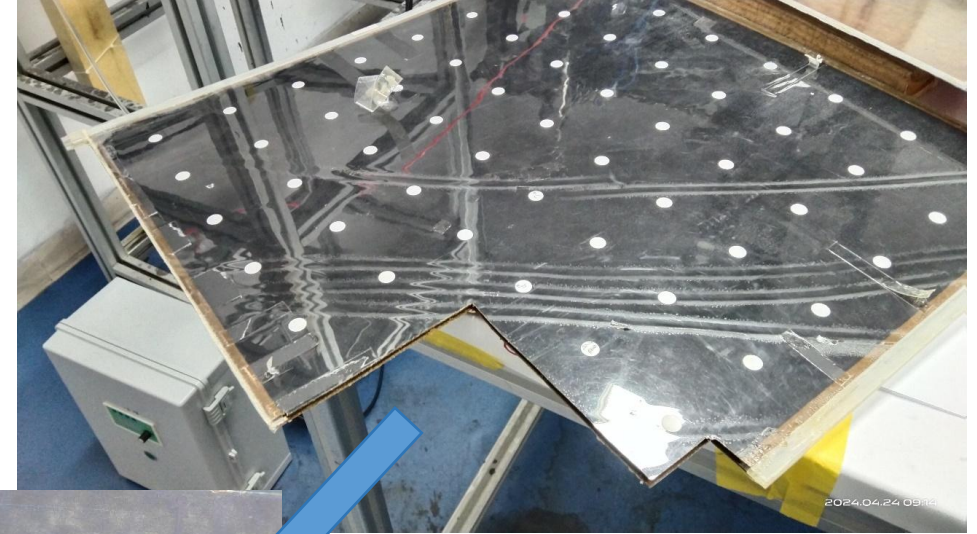


Comparison with GTE gap

The last USTC oiled gap



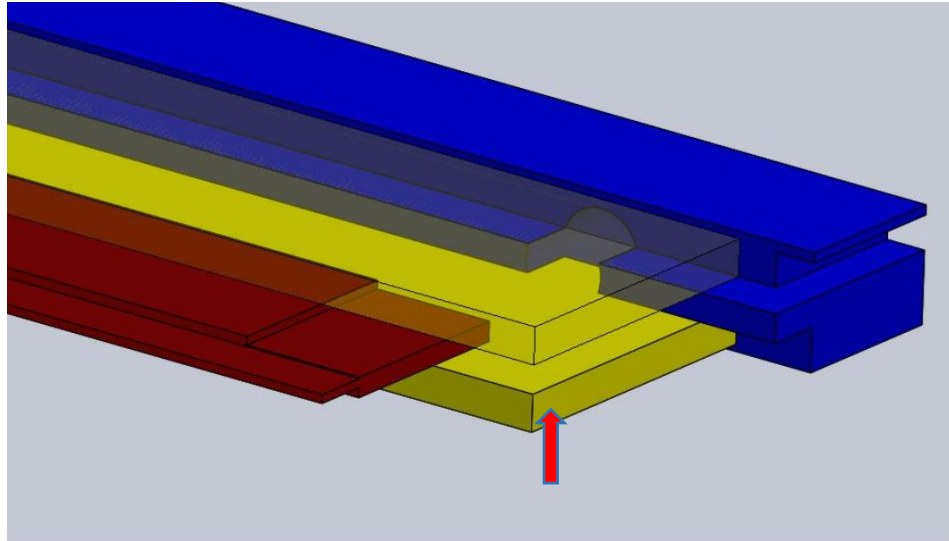
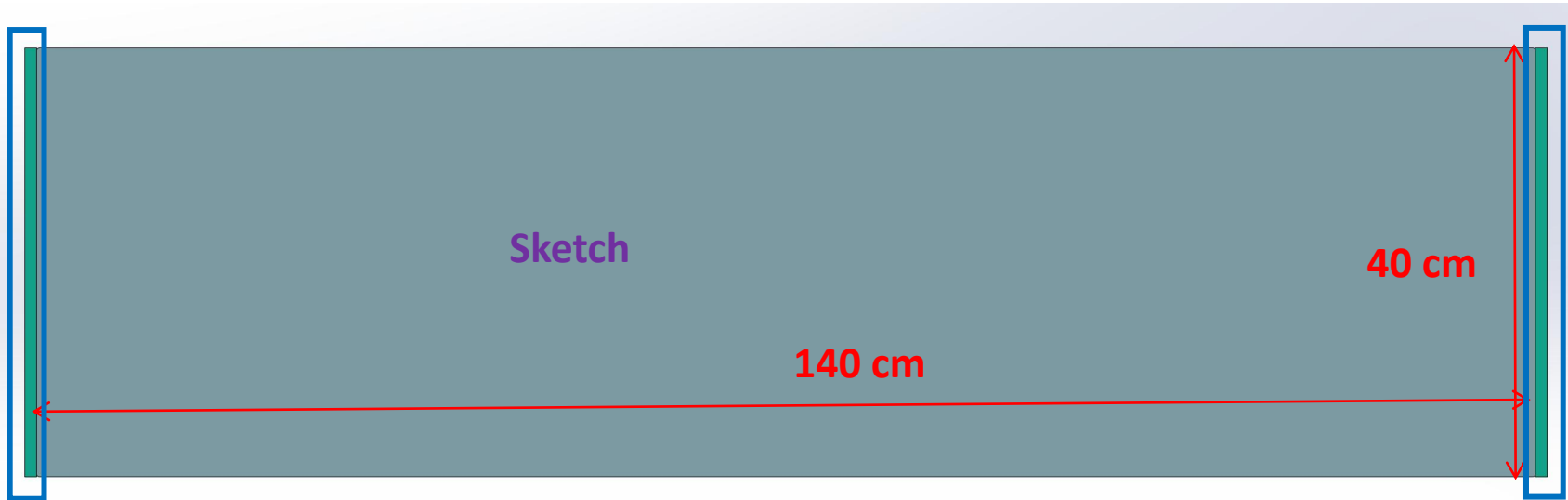
The quality is comparable with the GTE-produced gas gap.



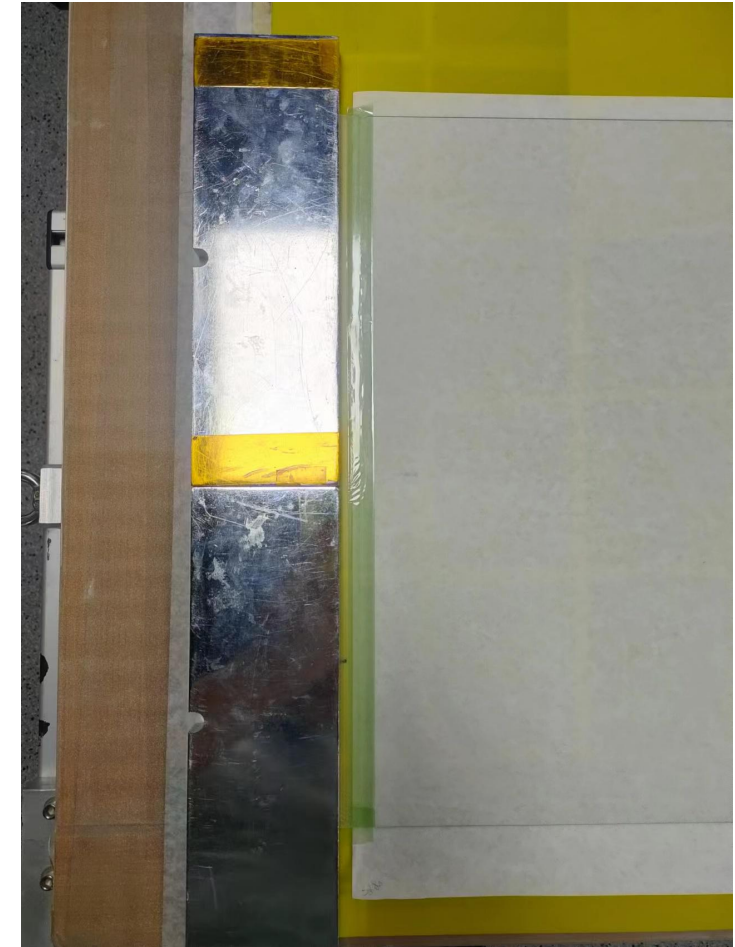
- A 50x50cm gap bought from GTE years ago.
- Originally, it worked properly.
- It was deformed due to the humidity problem.
- We opened it and checked the surface inside.

The first step

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



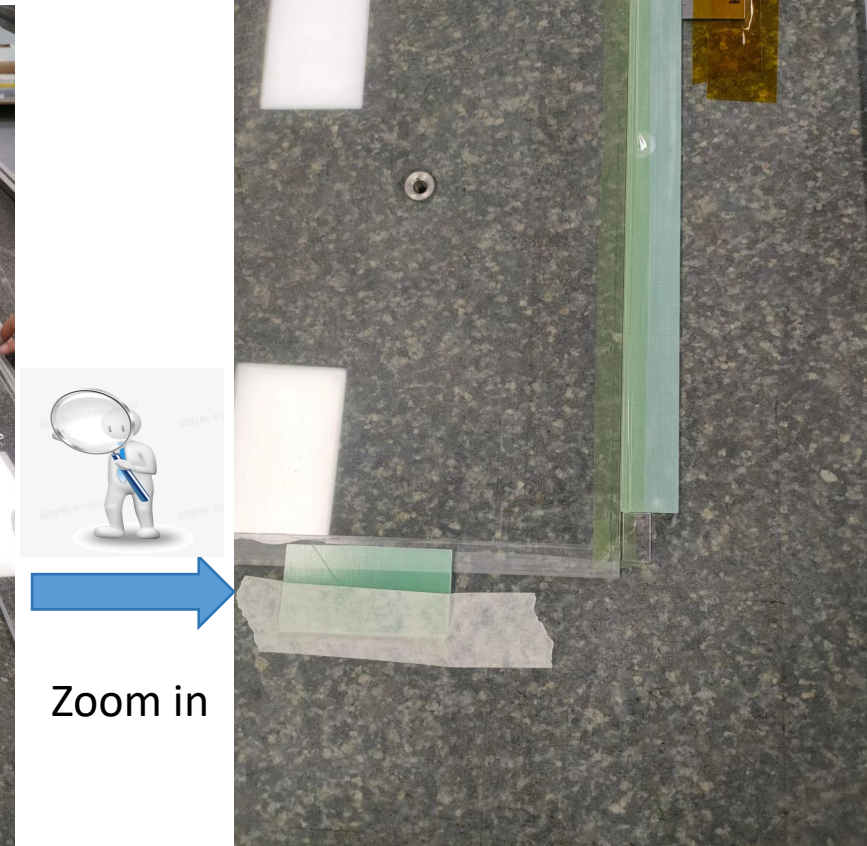
The glass and 2 floor plates will on the same plane



The second step (preparatory work)



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)



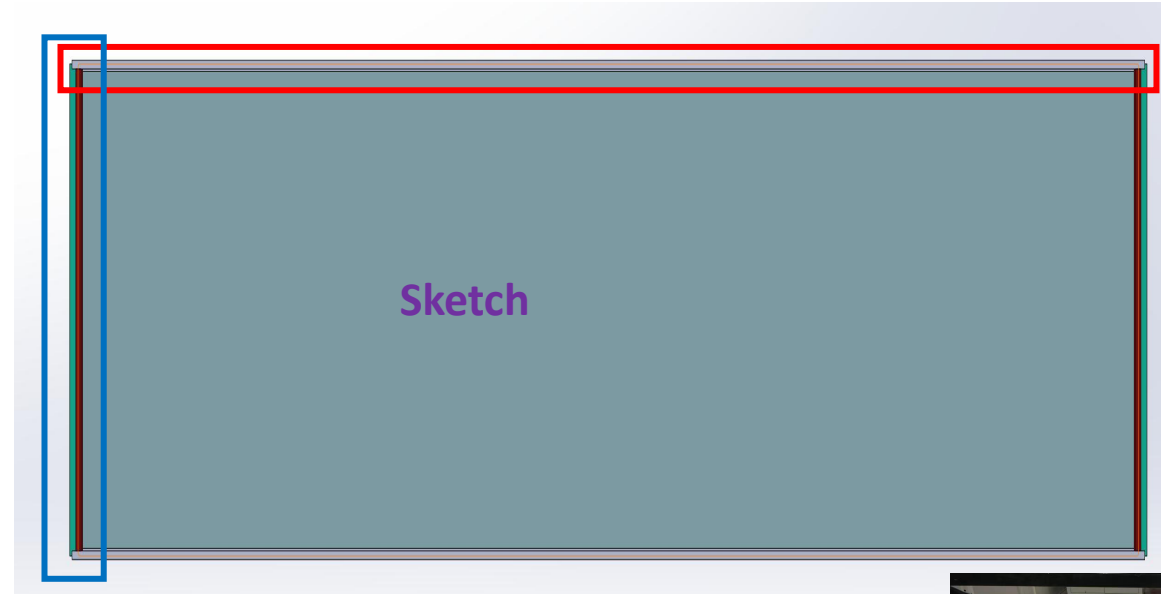
1. Move the glass on the marble platform carefully
2. Use the tooling to find the correct position of long and short side of frames

The second step

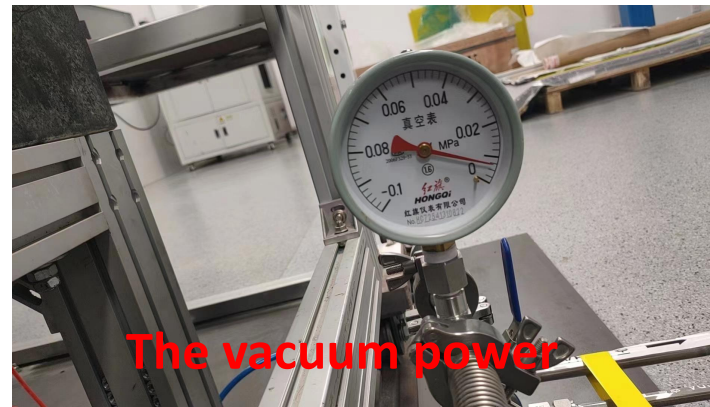
- Add the glue on the glass and attach the **long** and **short side** of polycarbonate frames with Araldite adhesive glue
- Vacuuming for 6 hours



Zoom in



Vacuuming



The vacuum power

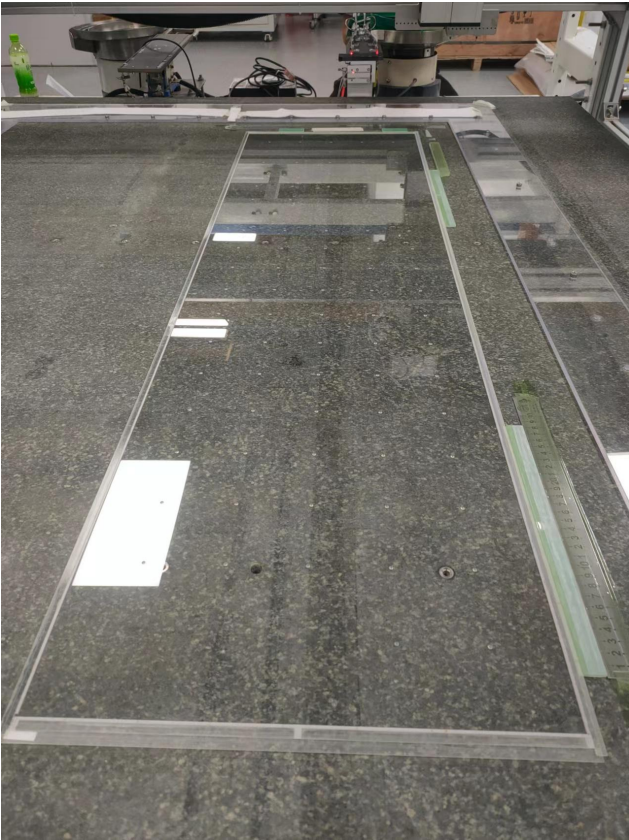
Slight less than 0.01Mpa



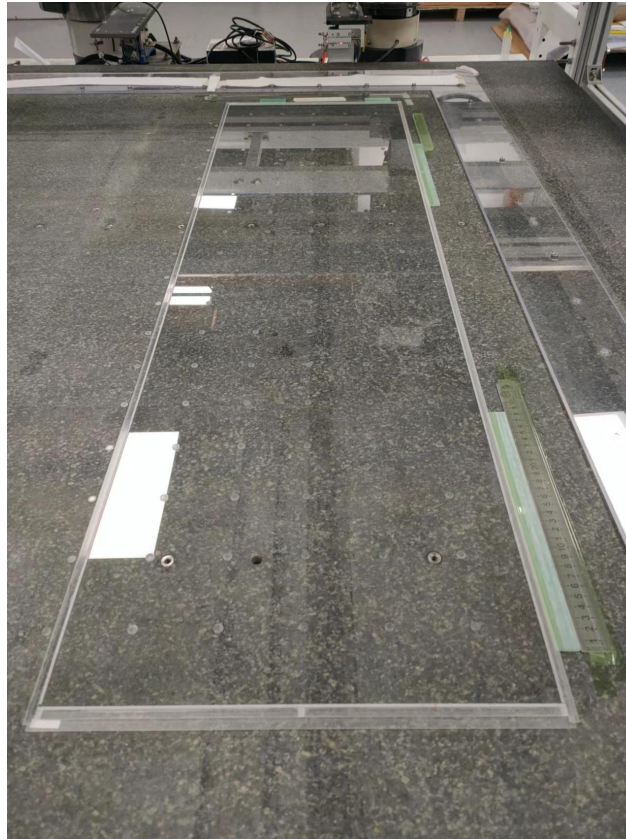
The third step (1)

➤ Attach the spacers on the glass

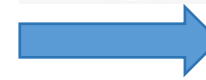
- dispensing work (Add glue on the glass)
- Put the spacers on the glue and the distance between 2 spacers is 70 mm.



~15 minutes



~36 minutes

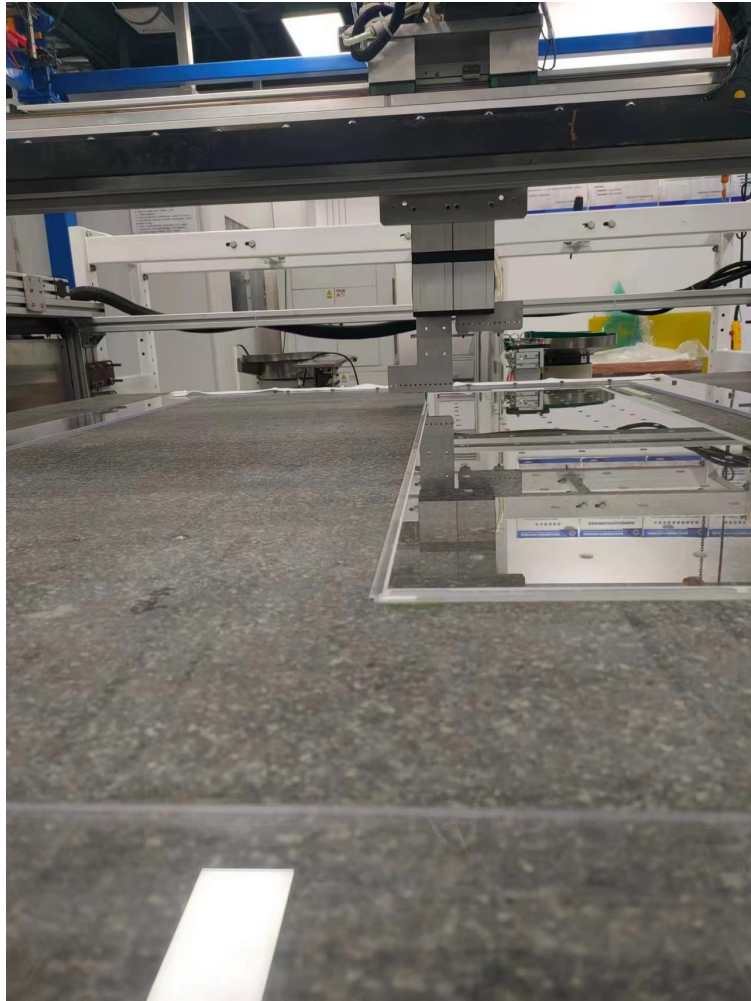


Zoom in

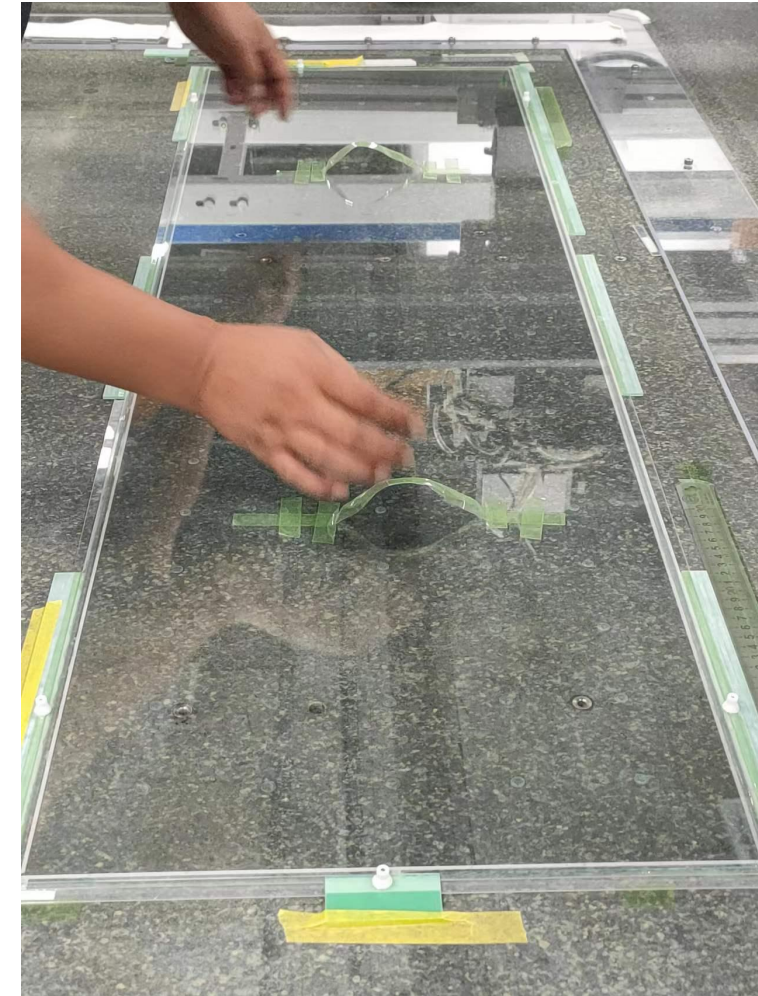


The third step (2)

- Apply glue on the frame and close the gas gap



Zoom in

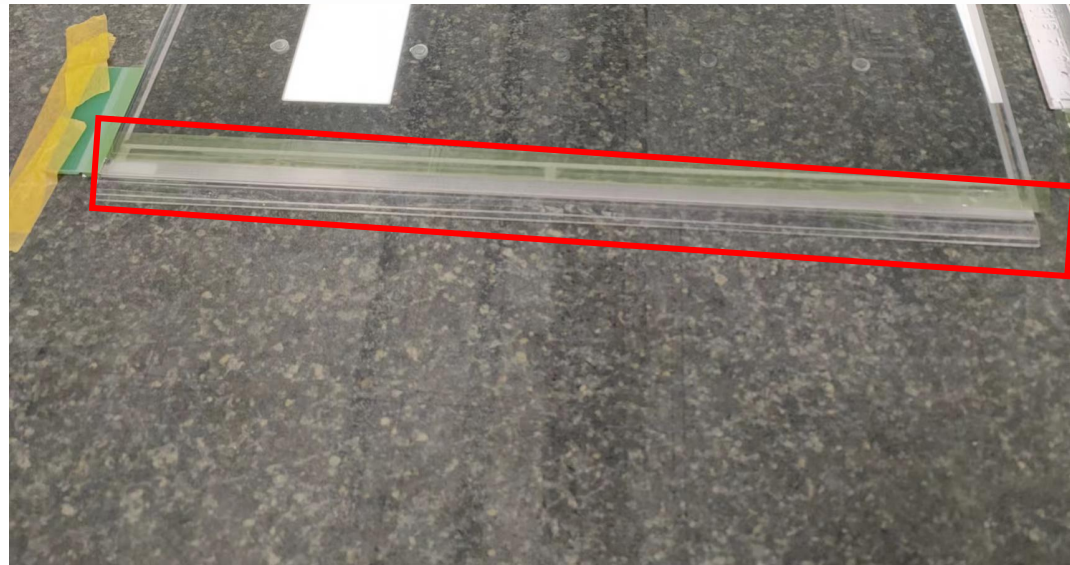


The third step (3)

- Attach 2 roof polycarbonate plates on it



Zoom in



The third step (4)

➤ Vacuuming



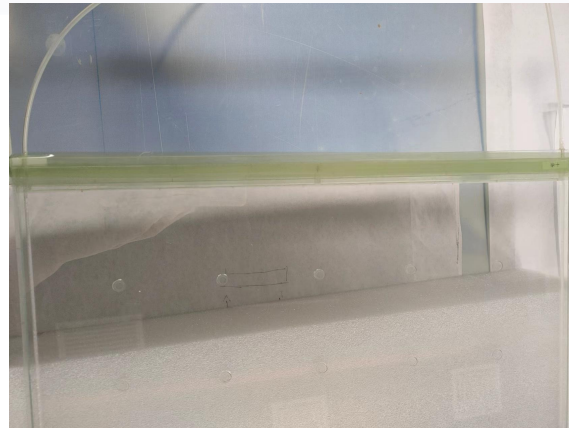
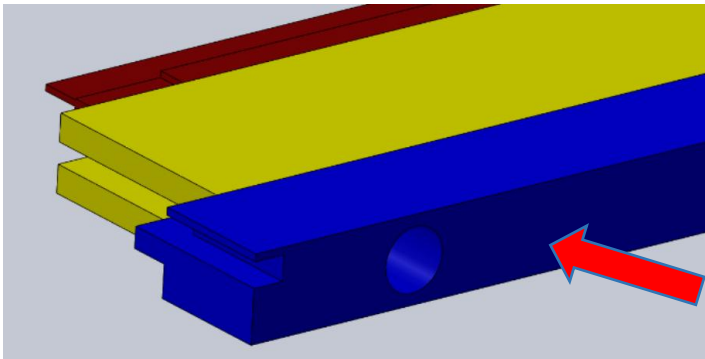
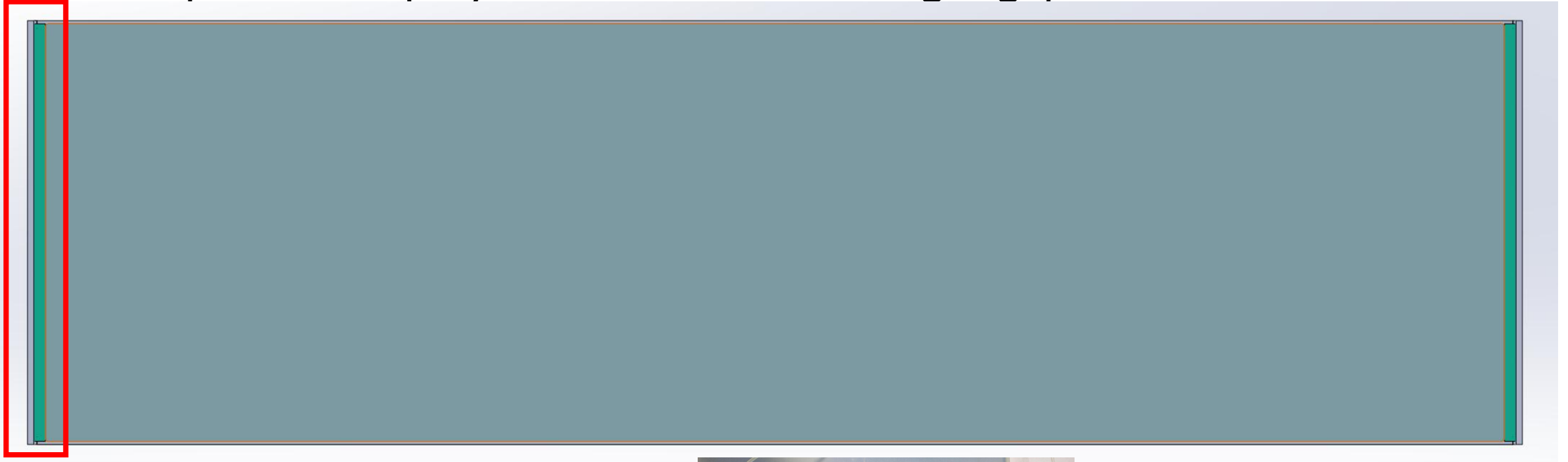
Use oiled paper to protect the ventilated felt



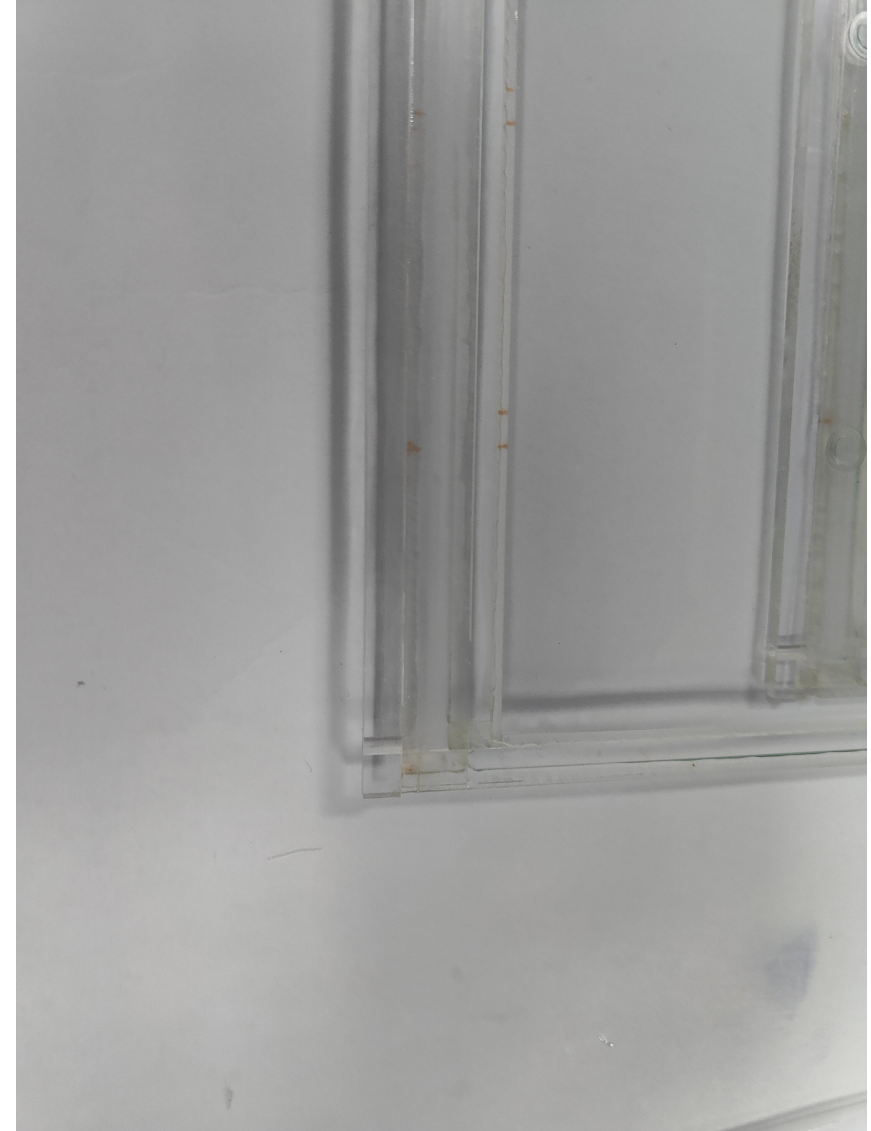
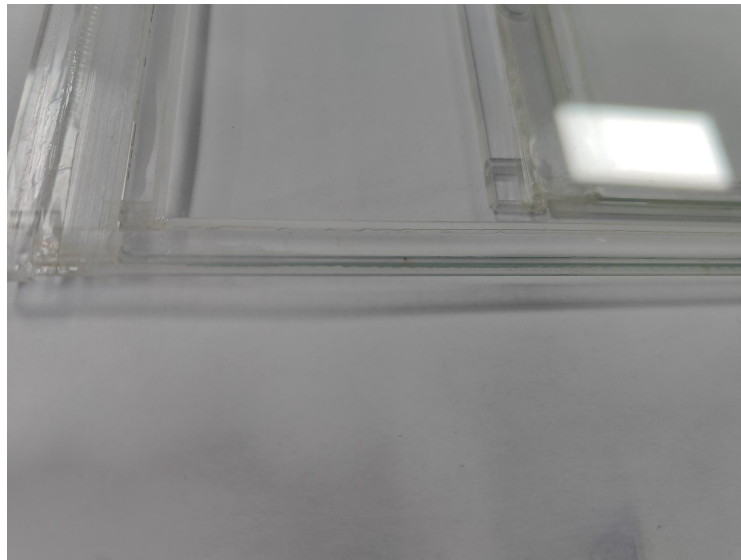
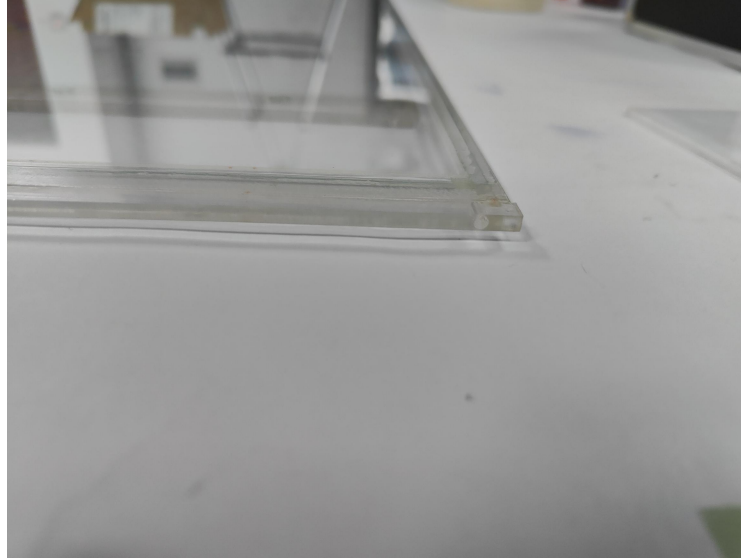
Hold for at least 6 hours

The final step

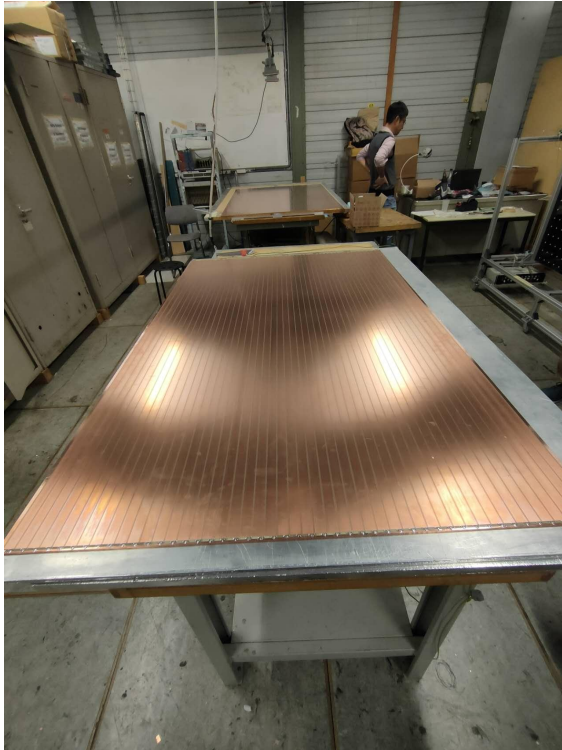
- Put the perimetric polycarbonate frame into gas gap



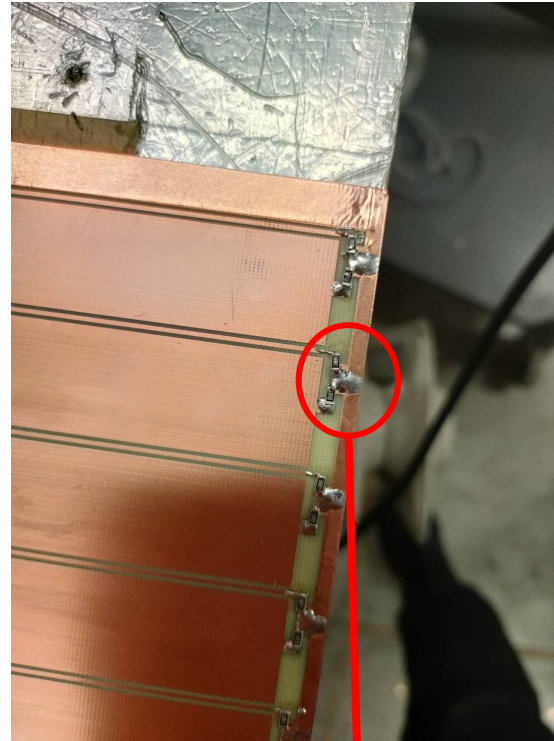
The final product



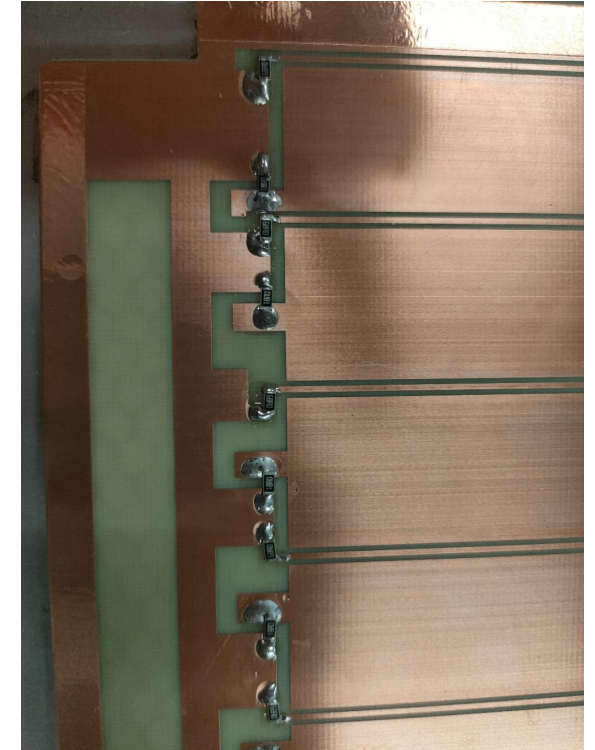
More detail information for each step (Step 1)



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

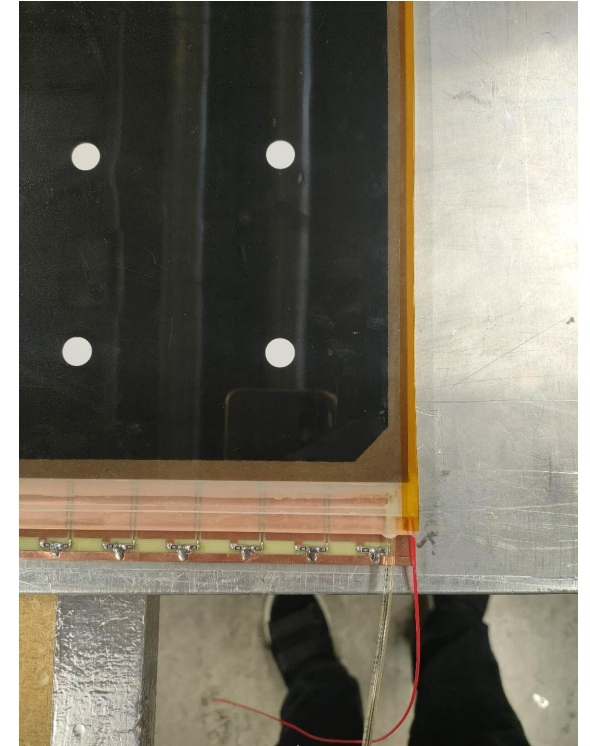
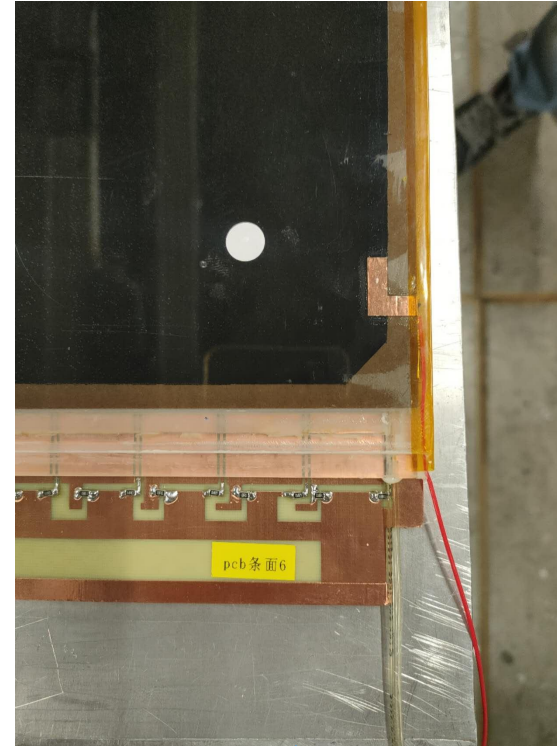
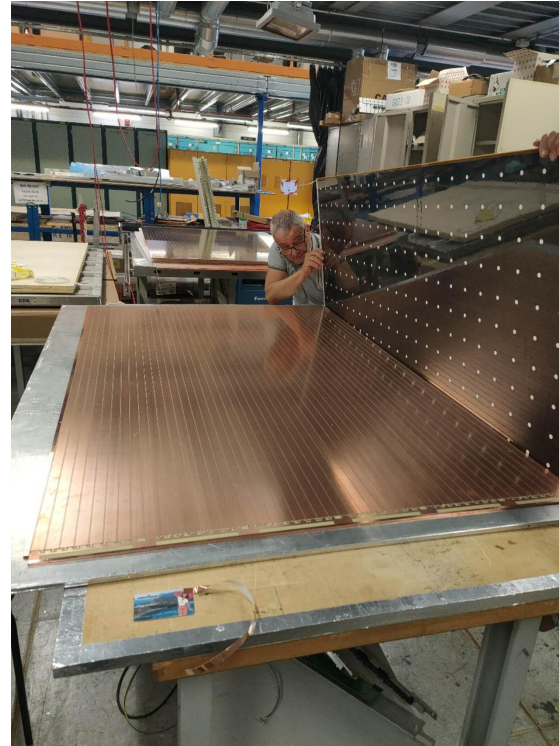


The resistors are mounted on the readout pannel and also
solder the copper sheet to the ground



Suggested by Alessia

More detail information for each step (Step 2)

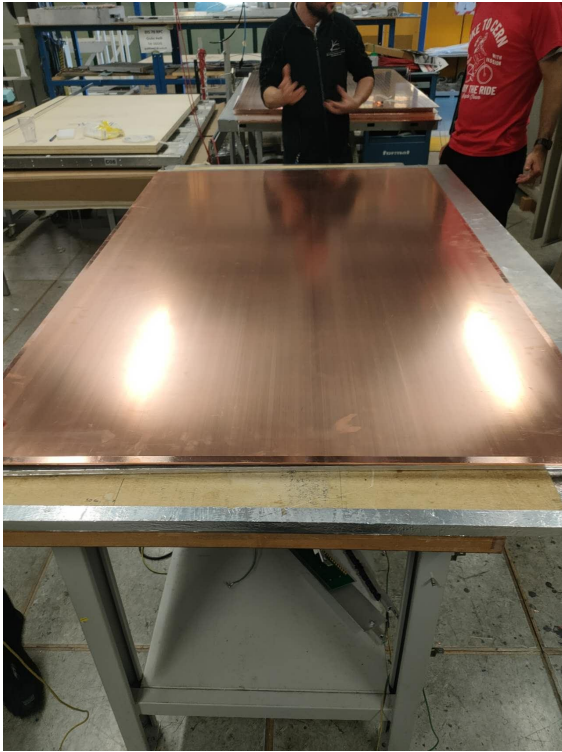


Step2:
Put the gas gap on the top
of the readout pannel

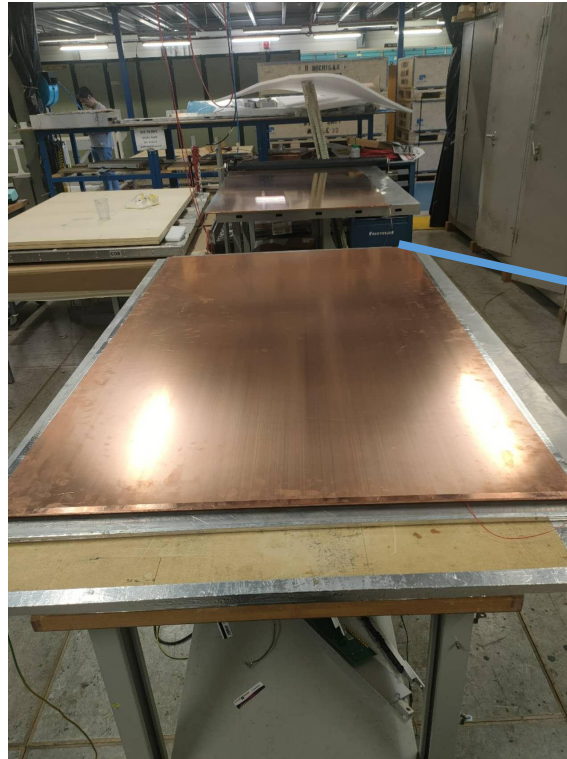
How to put the gas gap on the readout pannel ?

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

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

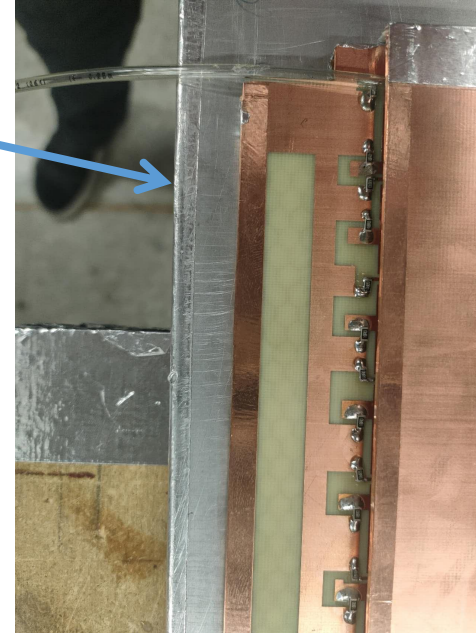


Step3:
Put another readout pannel
on the top of the gas gap

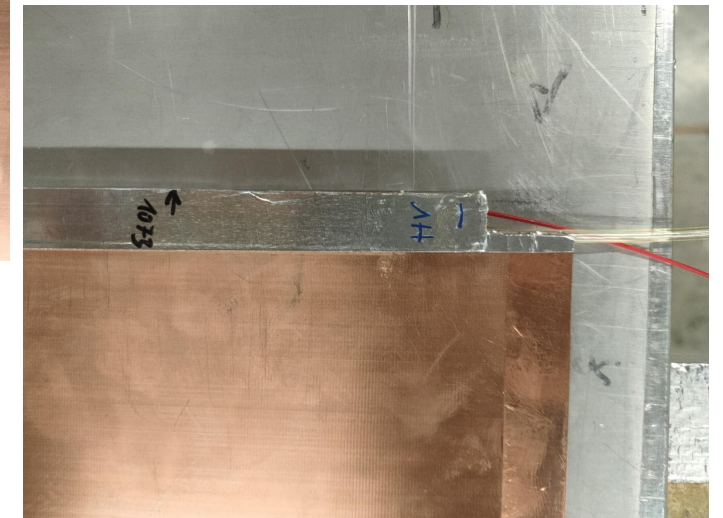
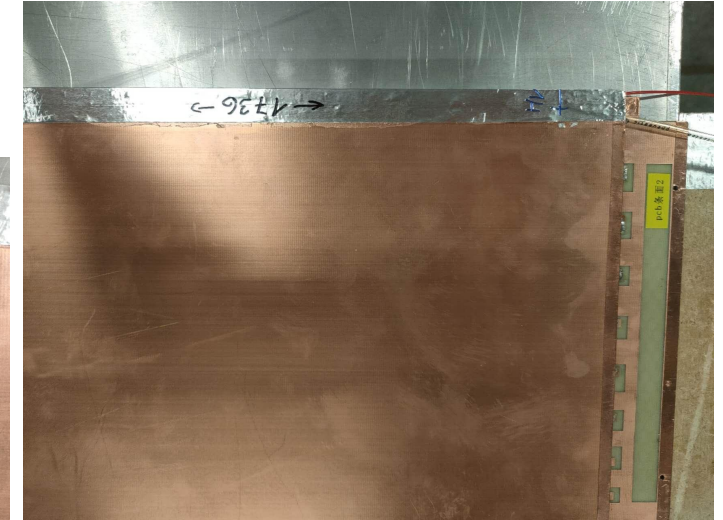


Step4:
Use the Aluminium tape
to fix those three layers
to form the singlet

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