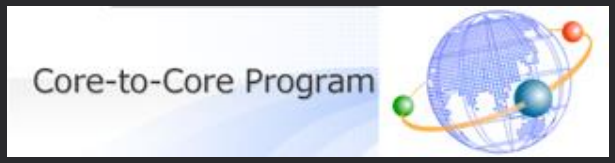


MEG II実験背景事象抑制に向けたDLC-RPCの開発
―新型モジュールの設計と製作―

神戸大理　高橋 真斗

大谷航[A], 大矢淳史[B], 越智敦彦[C], 鈴木大夢[C], 潘晟[A], 山本健介[B], 李維遠[B],
他 MEG IIコラボレーション
(東大素セ[A], 東大理[B], 神戸大理[C])

日本物理学会2024年春季大会 @ Online

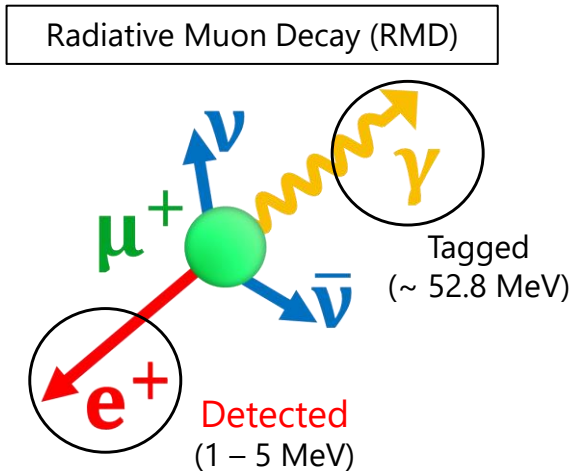
Outline

- Introduction (reminders)
  - Upstream Radiative Decay Counter in MEG II
  - Problems in First prototype
- Distortion of the electric field
  - Structure of First prototype
  - Structure validation using mock-up
- Insufficient quench distance of discharges
  - Discharge at conductive strips
  - Cover width investigation
- Summary and Prospects

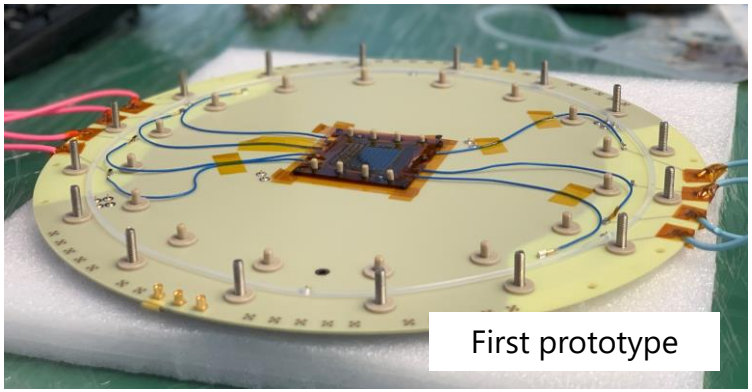
Upstream RDC in MEG II

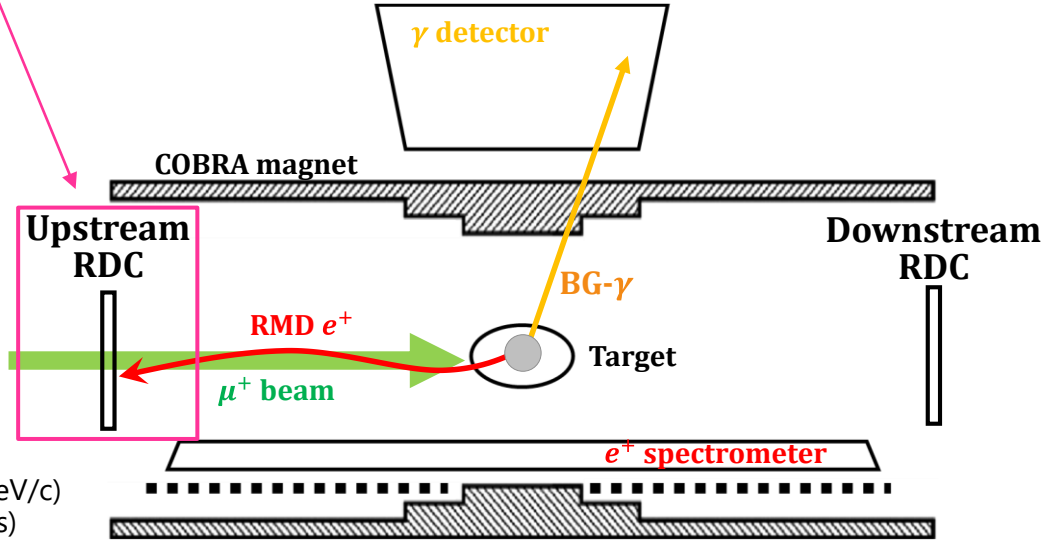
- MEG II searches for $\mu \to e\gamma$ at Paul Scherrer Institut (PSI)
- Radiative Decay Counters;

  Detectors for tagging BG-γ from RMD



Resistive Plate Chamber with Diamond-Like Carbon (DLC-RPC)
being developed as upstream RDC





μ^+ beam at upstream RDC
- Low momentum (28 MeV/c)
- High intensity (7×10^7 /s)

Problems in First prototype

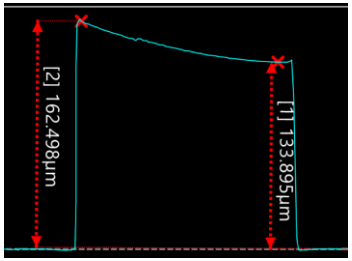
- First prototype for performance evaluation under high-rate μ beam
  - Implement systems to improve rate capability up to 4 MHz/cm^2
  - Operation with a four-layer configuration

- Problems
  - **Distortion of electric field**
    - Low quality of spacing pillar formation (reported in previous talk)
    - ✓ Non-flatness of stacked electrodes (reported in this talk)
  - **Insufficient quench distance for discharge**
    - ✓ Insulation cover on conductive strips (reported in this talk)

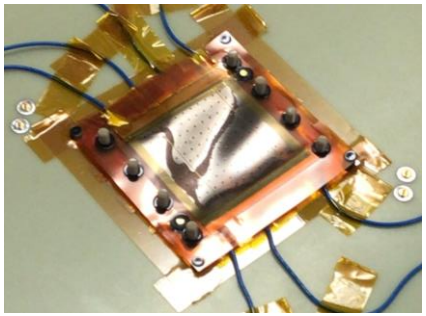
  → **Made the DLC-RPC operation unstable**

→ **Need to improve the structure**

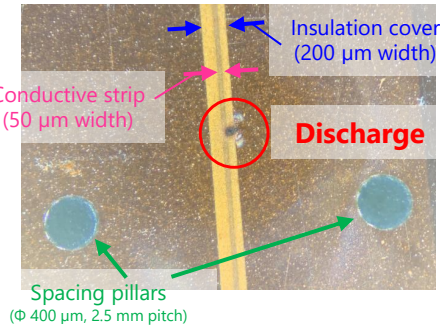
Distorted spacing pillar



Non-flatness of electrodes



Discharge at conductive strip



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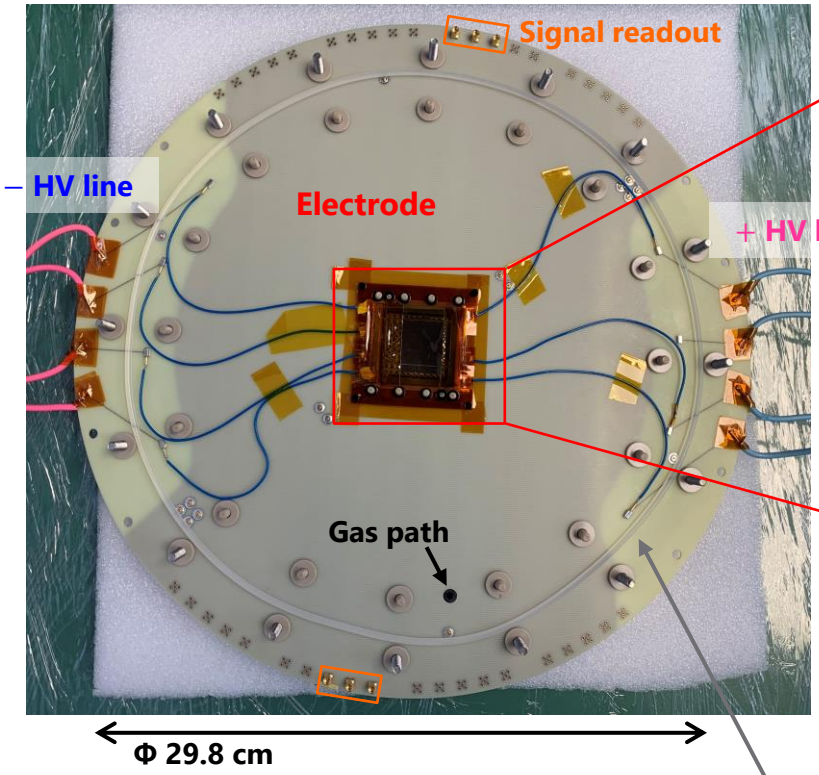
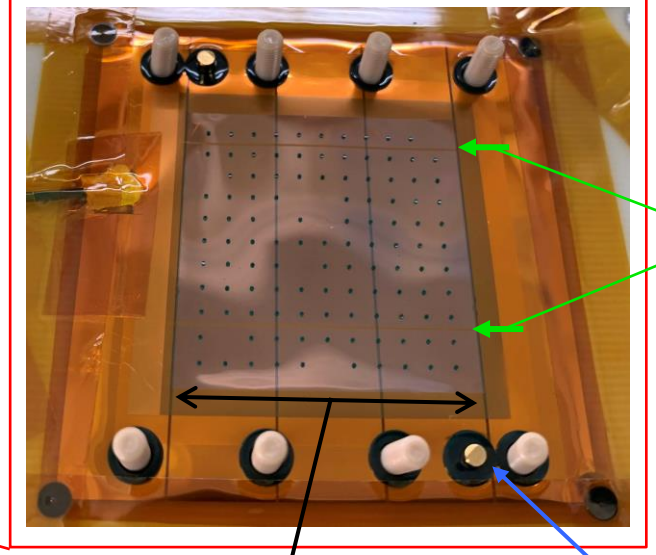
Structure of First prototype

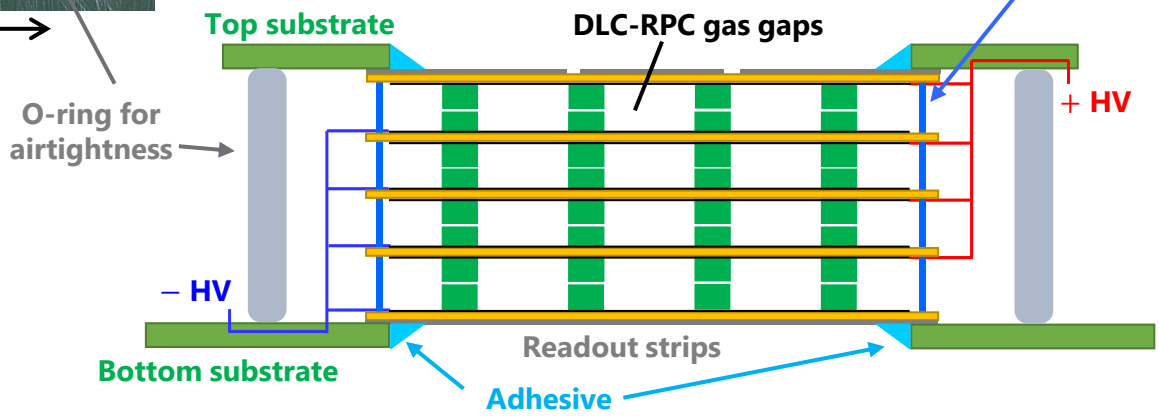
Inner overview of First prototype



Electrode



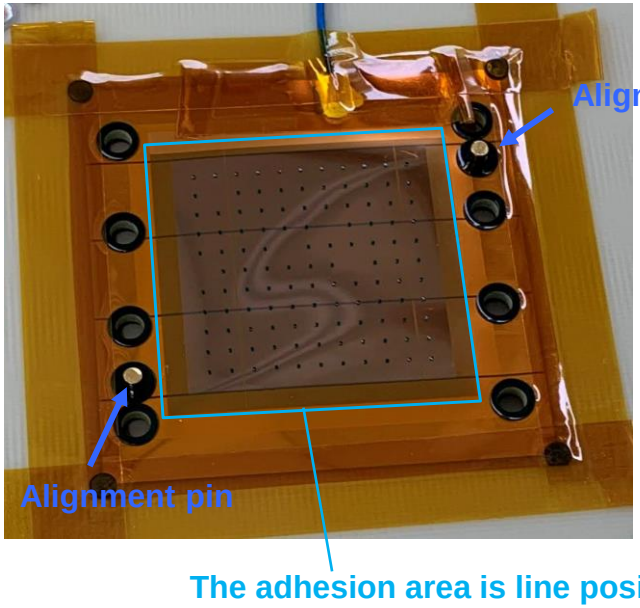
Cross-section scheme

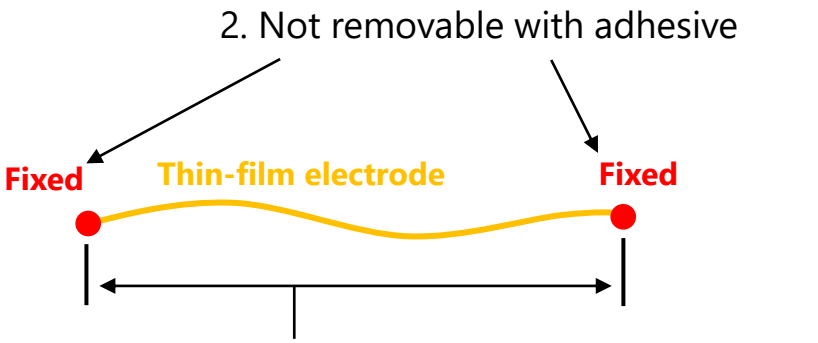


What distorted the electric field?

- Constraints distorting electrodes
  1. **Alignment pins** for precise stacking of electrodes
     → Misalignment of holes and pins due to accuracy during fabrication
  2. **Adhesive** for electrode fixation and gas tightness
     → Technical difficulty in maintaining flatness during electrode installation

→ **Remove these constraints**





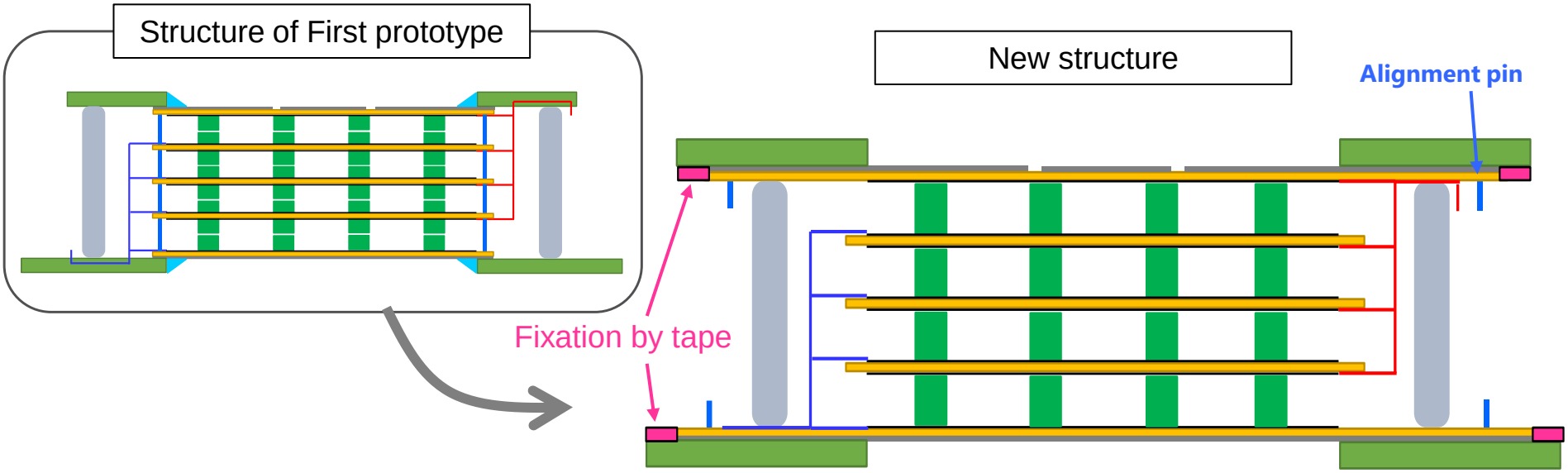
Change the structure

➢ Adhesive-free structure

- Electrode fixation by tape (detachable and fine-tunable)
- Extend the outermost films to the outside of the O-ring to make it gas-tight
  → Tape is for adjustment and substantial electrode fixation is by O-ring

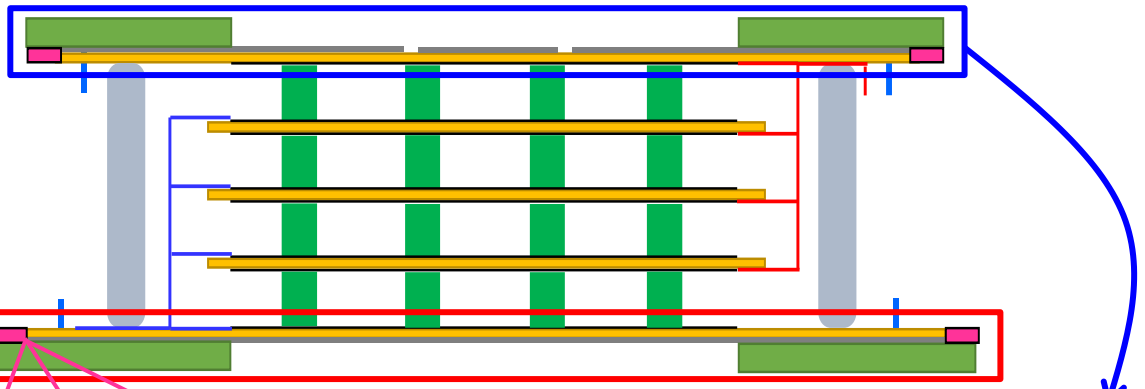
➢ Alignment pins are placed outside the chamber

- Causes gas leaks when placed inside the chamber
- Slightly reducing alignment accuracy

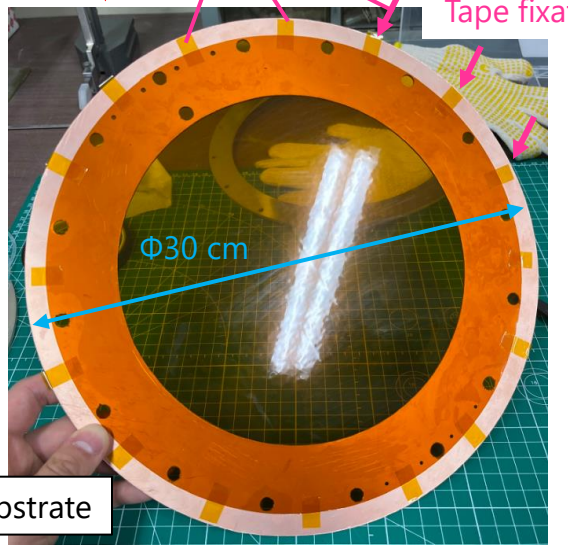


Fabrication of mock-up: substrate

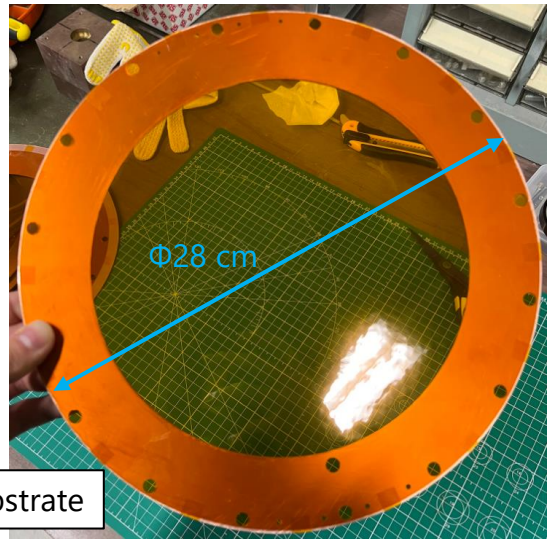
- Full-scale size
  - Φ 30 cm/Φ 28 cm of substrates (Φ 20 cm of an active region)



Tape fixation



Bottom substrate

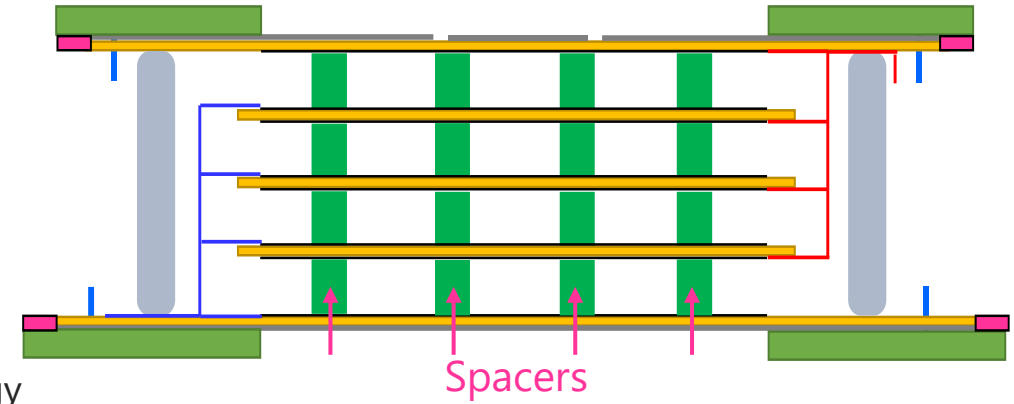


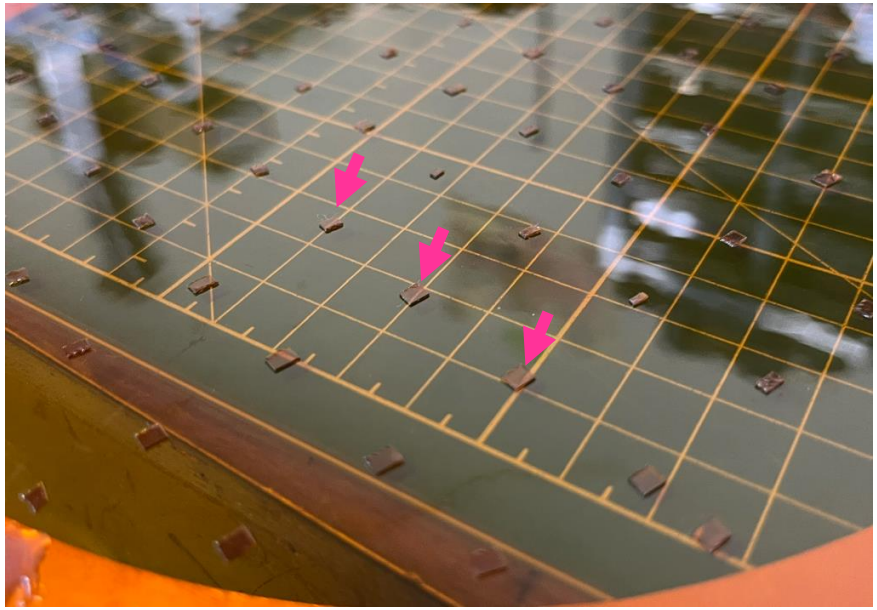
Top substrate

Fabrication of mock-up: spacers

- Spacers
  - Made of Kapton tape
  - ~ 350 μm in thickness
  - 2 – 3 mm square
  - 2 cm pitch

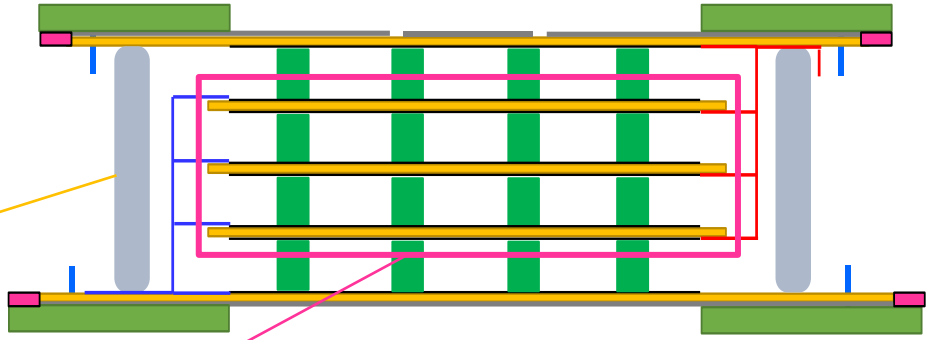
  (Actual design)
  - Made of photolithographic technology
  - ~ 330 μm-t
  - Φ 400 μm
  - 2.5 mm pitch

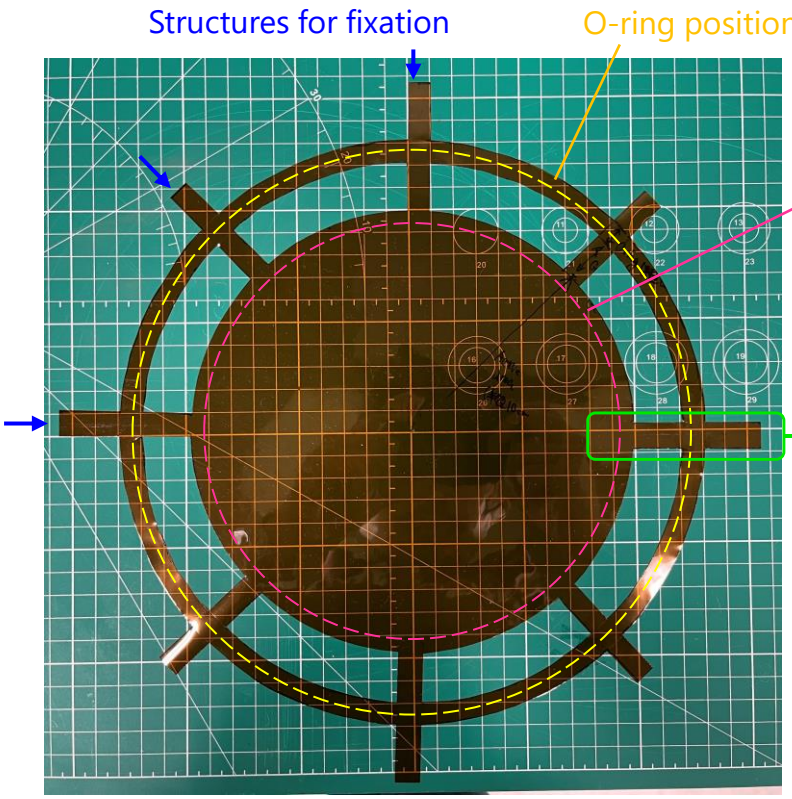


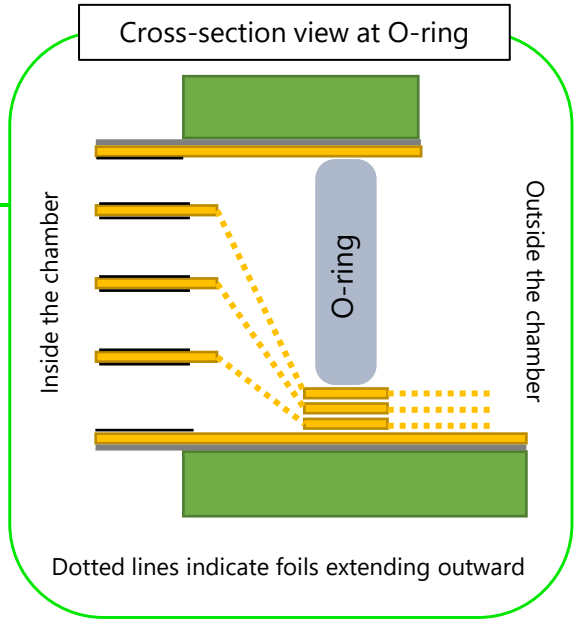


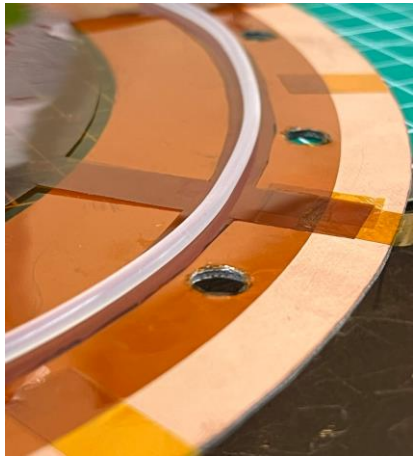
Fabrication of mock-up: inner foil

- Inner foil
  - Φ 20 cm active region
  - structure to be fixed outside the chamber





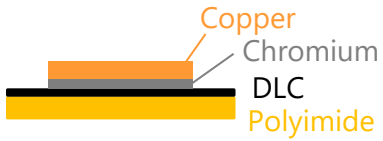


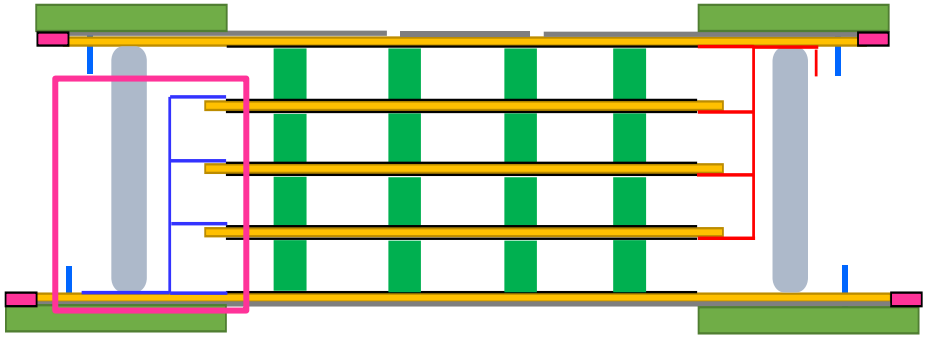


Fabrication of mock-up: HV supply line

- HV supply line formed by sputtering
  - Formed on foils connected to the outside

The sputtered layer of a conductive pattern

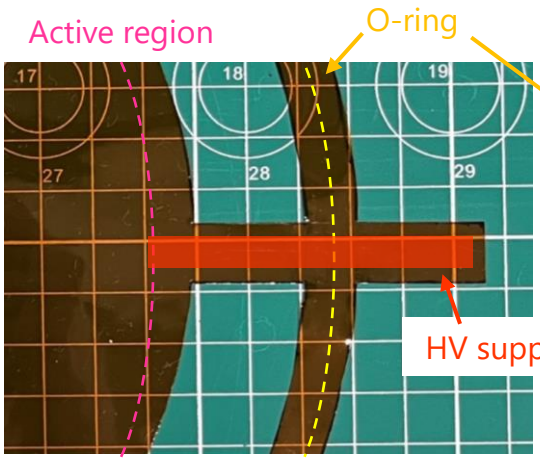


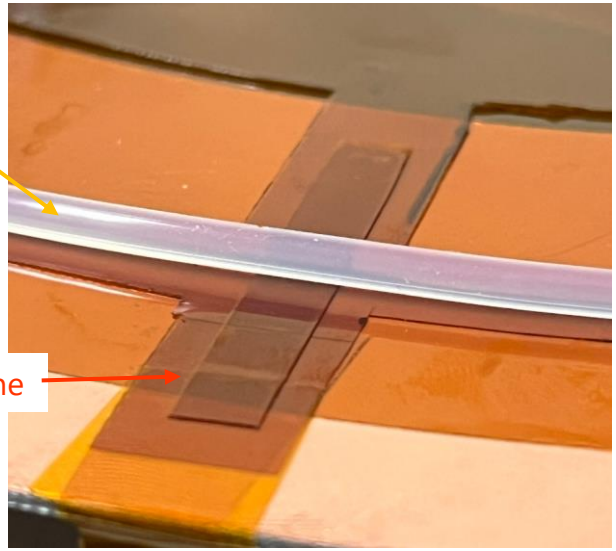


  - Covered with insulation
    - Cover thickness: 75 μm

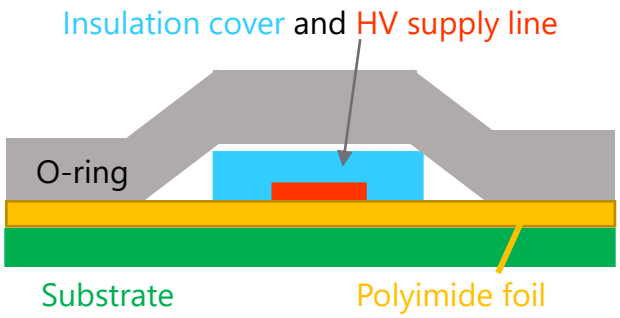
→ Insulation cover is reproduced

- 100 μm thickness





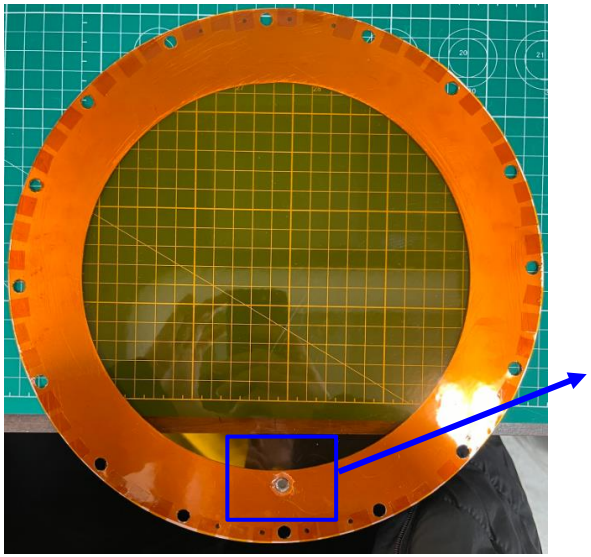
Cross-section view at HV supply line

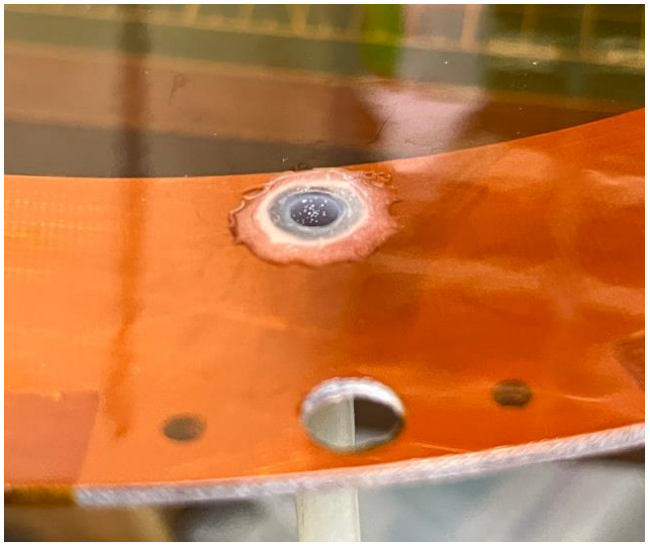


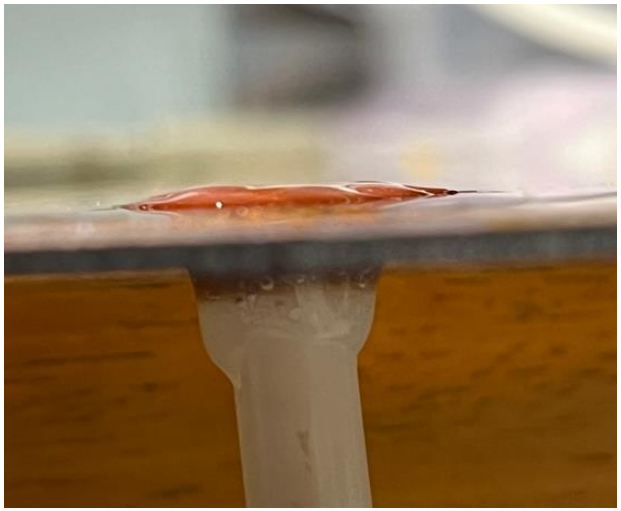
O-ring straddles insulation cover
→ Can cause gas leakage

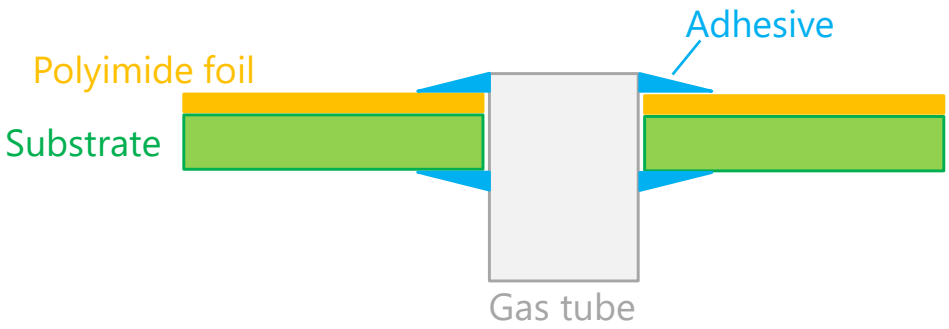
Fabrication of mock-up: gas system

- The tube, the foil, and the substrate are adhered









- The only constraint

However,

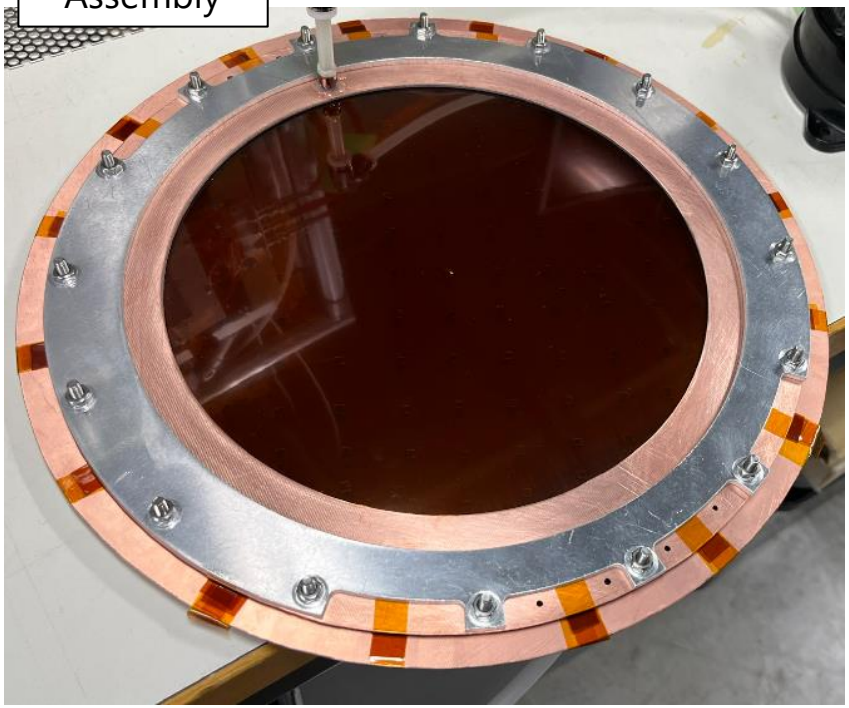
- small area
- it is possible to make sufficient adjustments before adhesive

➔ <u>Small impact on flatness</u>

Structure validation: flatness

- No foil distortion was observed in multiple inner layers

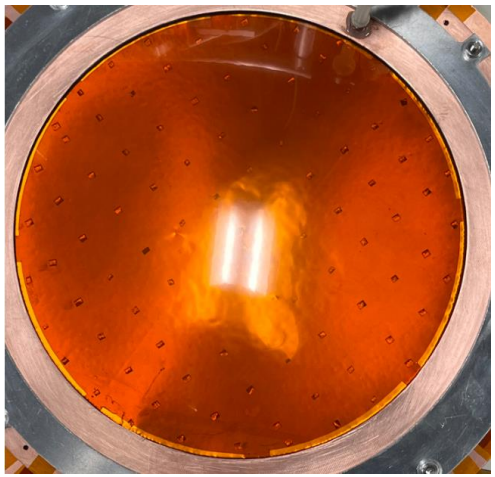
Assembly



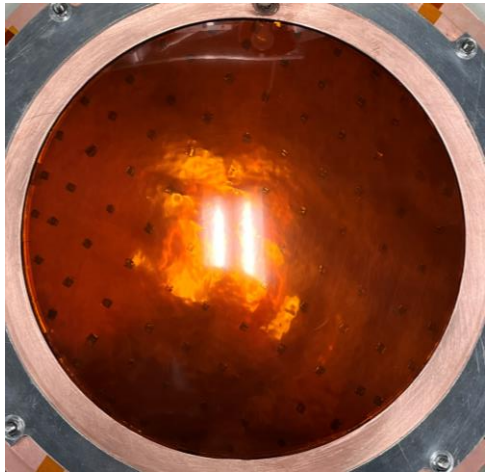
Φ 30 cm (active region Φ 20 cm)

Good flatness of foils

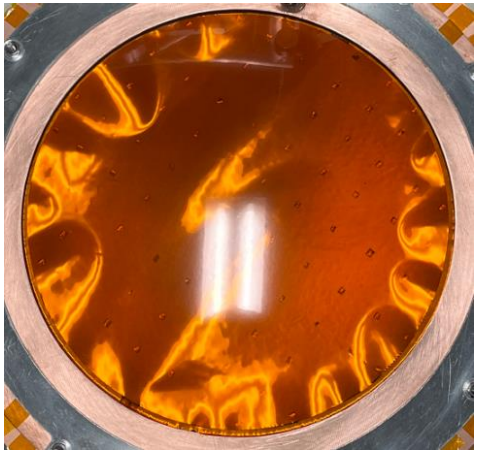
1 inner layer



3 inner layers

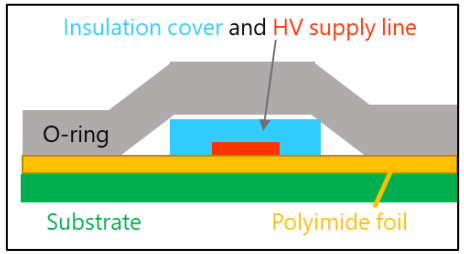


If flatness is bad…



Structure validation: gas tightness

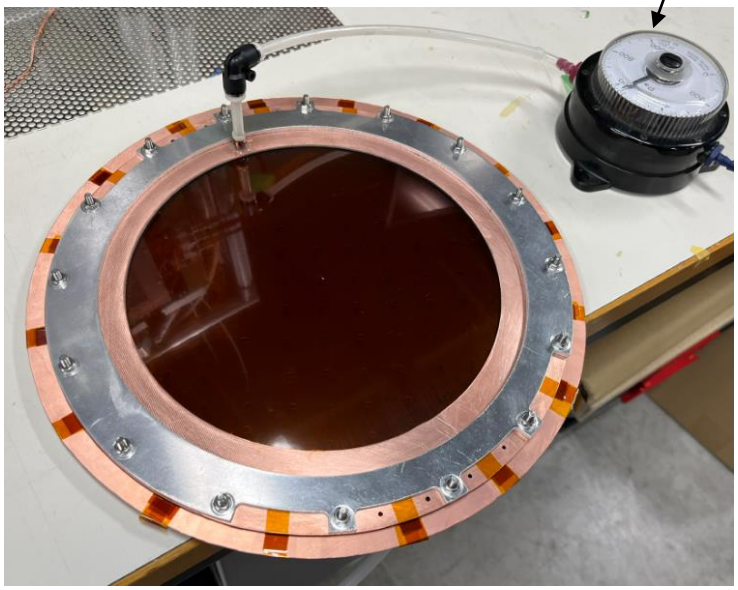
- Many gas leaks at the HV supply line



  - Especially in the case of multiple inner layers

➔ **Need to improve the structure**

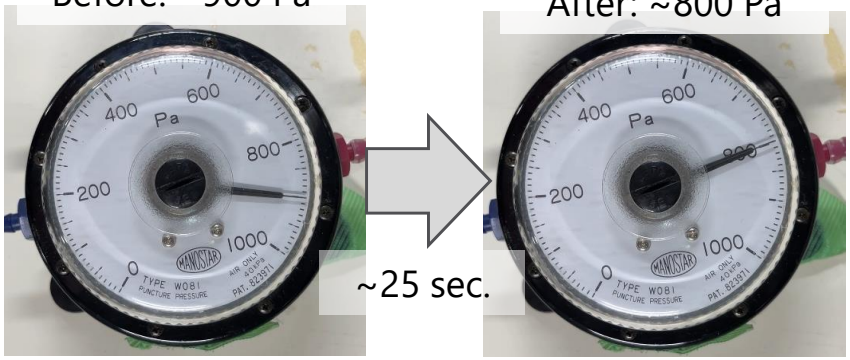
Differential pressure gauge



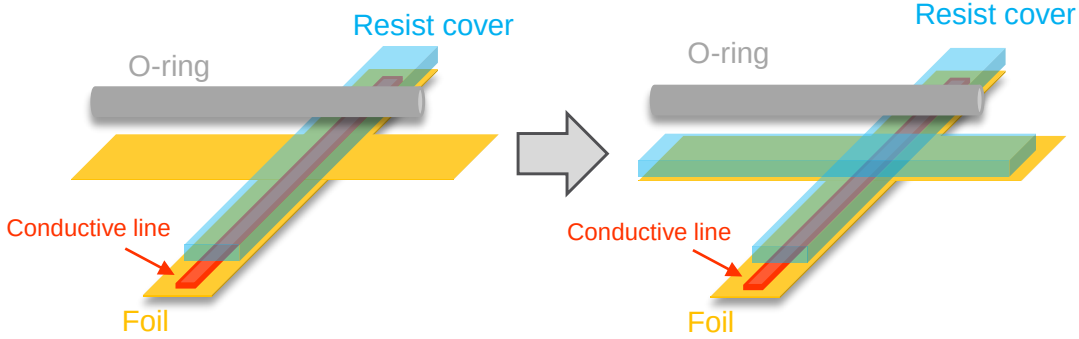
Differential pressure between
inside the chamber and atmospheric pressure

Before: ~900 Pa

After: ~800 Pa



- Create an insulating cover over the entire O-ring location to eliminate steps



Summary of structure studies

- Removed constraints in First prototype
  - Alignment pins and adhesion fixation of electrodes
- Fabricated full-scale mock-up
  - **Flatness of electrodes was sufficient**
  - **Gas tightness of the chamber should be improved**
    - Structure that eliminates steps in the insulation cover
  - Important findings in the construction of the full-scale module
    - Techniques for flattening electrodes
    - Problems in handling
- To be done
  - Design with other systems implemented

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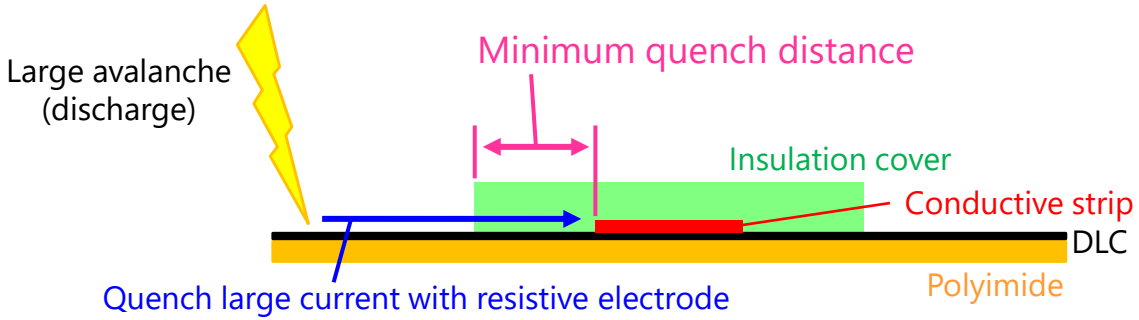
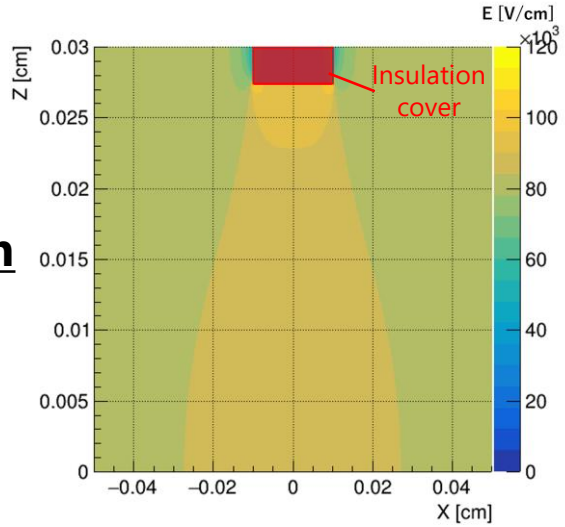
Insufficient quench distance

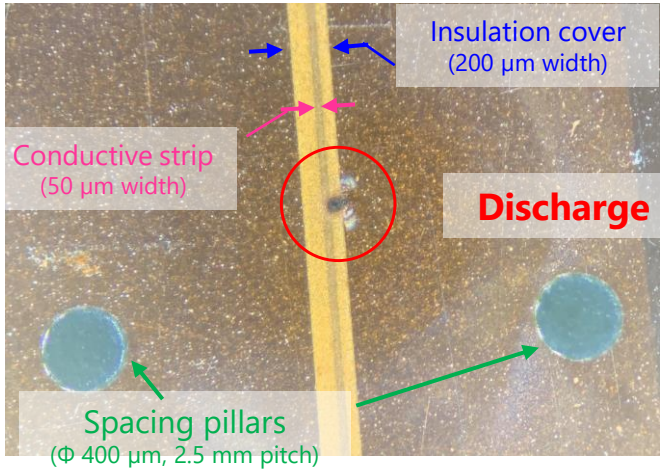
- Insulation cover on conductive strips
  - Conductive strip: improve rate capability
  - Insulation cover: avoid discharges at the conductive pattern



Simulated the electric field on the insulation cover

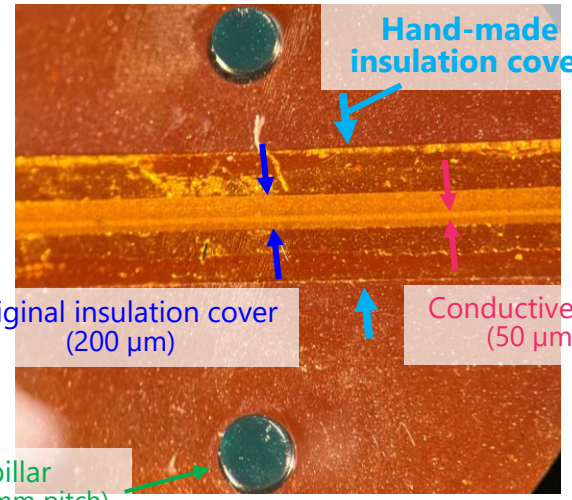


Need to investigate safe insulation cover width

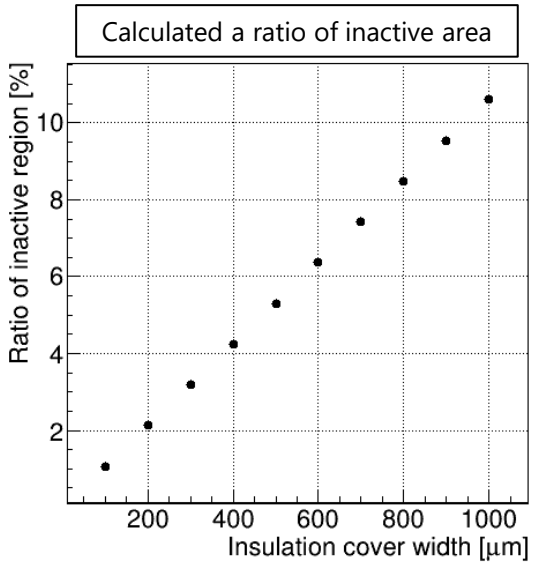


Cover width investigation (ongoing)

- Previous investigation (reported in JPS spring 2023, 23pT2-5)
  - Test using a hand-made insulation cover
    - Margin between conductive strip and cover: 500 – 700 μm
  - Confirmation of improved operation voltage by widening margins



- **Planned to fabricate samples with various cover widths and test**
  - How much margin is required?
  - Insulation covers become inactive areas
    → Width is determined based on acceptance



Summary

- The DLC-RPC is being developed as upstream RDC in MEG II
  - Planned to be installed in a high-intensity and low-momentum μ beam
  - First prototype was fabricated for performance evaluation in a high-intensity μ beam

- Problems in First prototype
  - **Distortion of electric field**
    - Low quality of spacing pillar formation (see previous talk)
      → Established high-quality spacing pillars and confirmed operation
    - Non-flatness of stacked electrodes
      → Changed the substrate structure and validated the flatness of the new structure
  - **Insufficient quench distance of discharges**
    - Insulation cover on conductive strips
      → Fabrication samples with various cover widths and test using it

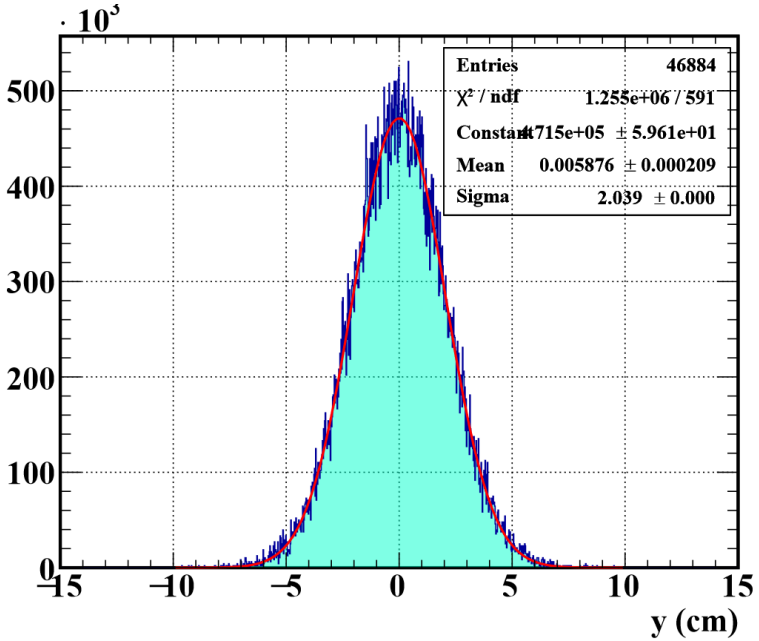
Prospects for the fabrication of the next module and the full-scale module are now in sight

Prospects

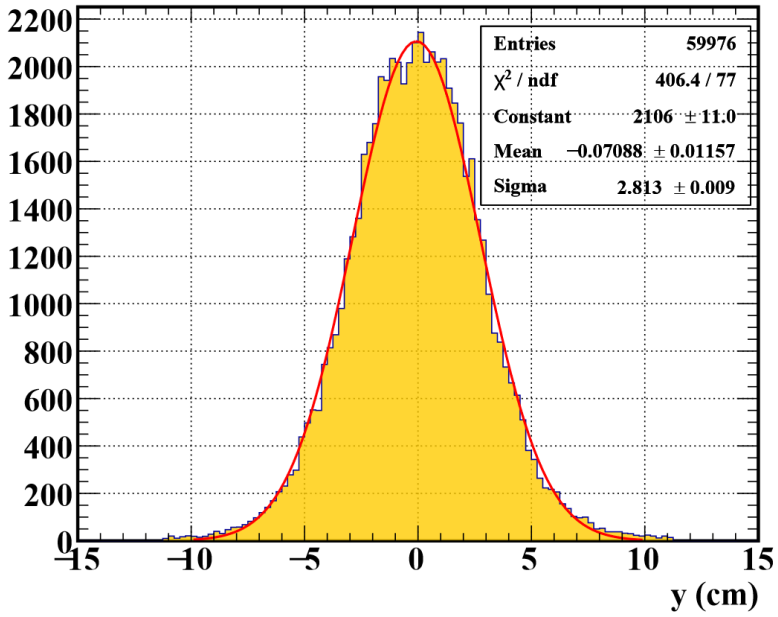
- Study for the problems in First prototype
  - Testing to determine insulation cover width will take place in April – May
  - Fabrication of the next module will start in May – June
- Beam test will be conducted using actual μ beam at PSI this year
  - Performance evaluation in a high-intensity μ^+ beam
  - Demonstration for requirements of upstream RDC
  - Feedback on full-scale module design
- Aim to install at the MEG II 2025 physics run

Backup

μ^+ beam/RMD e^+ distribution

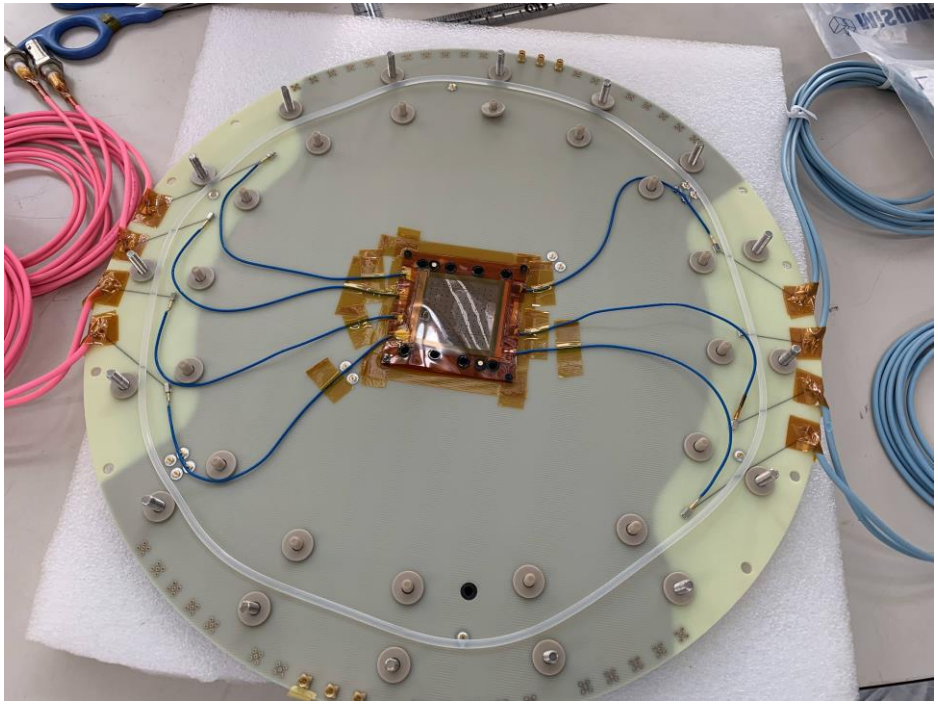


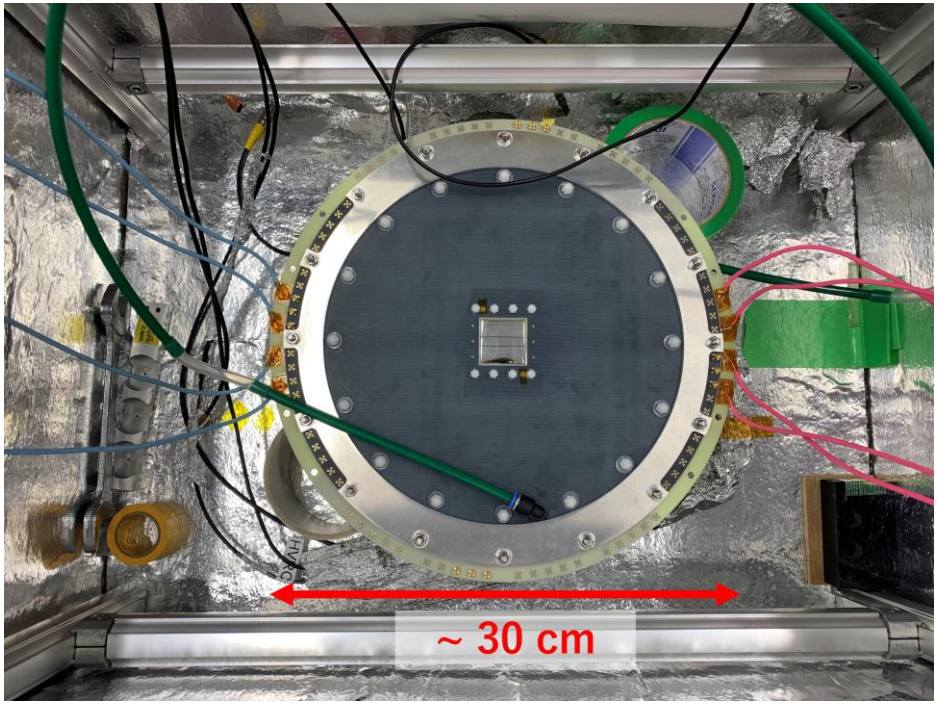
μ^+ beam (σ = 2.0 cm)

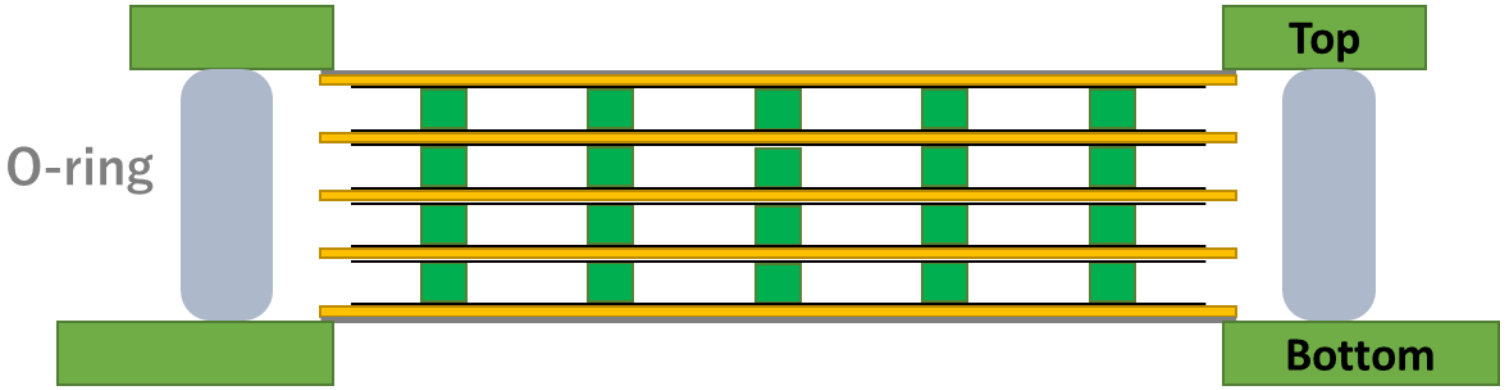


RMD e^+ (σ = 2.8 cm)

First prototype (2022)



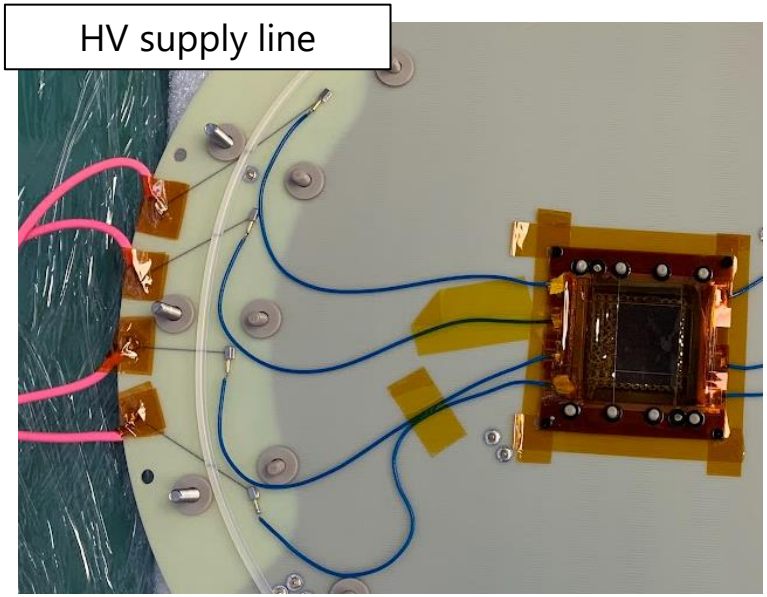


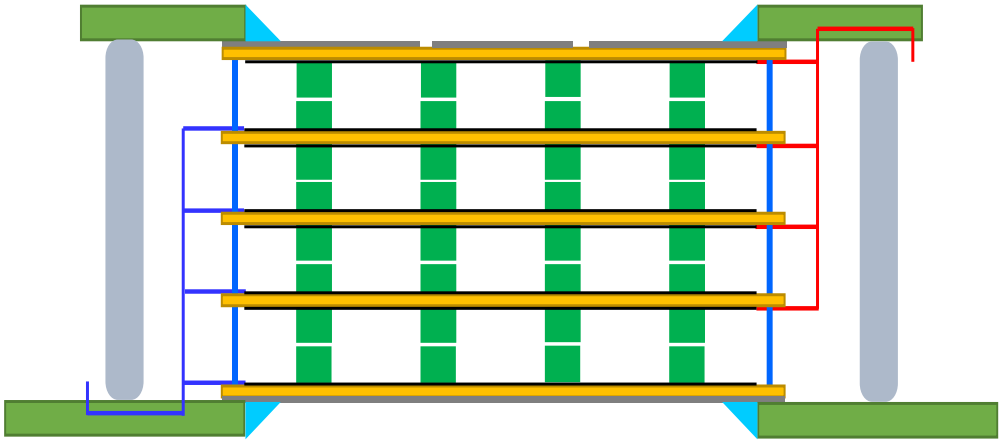


Concept of First prototype

- Systems inside and outside the O-ring are fed through the interior of the substrate
  - HV supply lines, signal lines, gas input/output ports
- Avoid covering the substrate surface with the outermost electrode

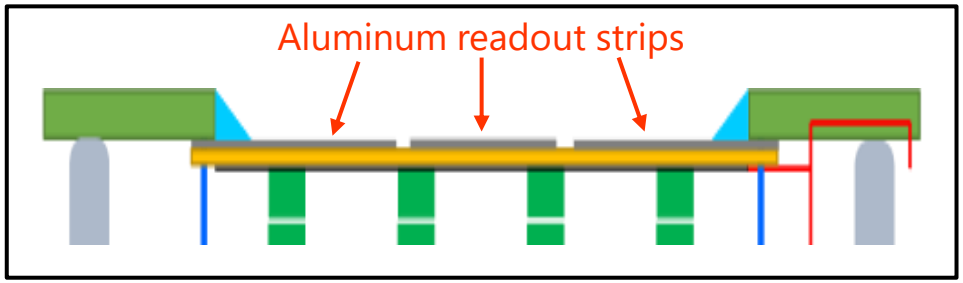
  ➔ Needed the adhesive for gas-tight

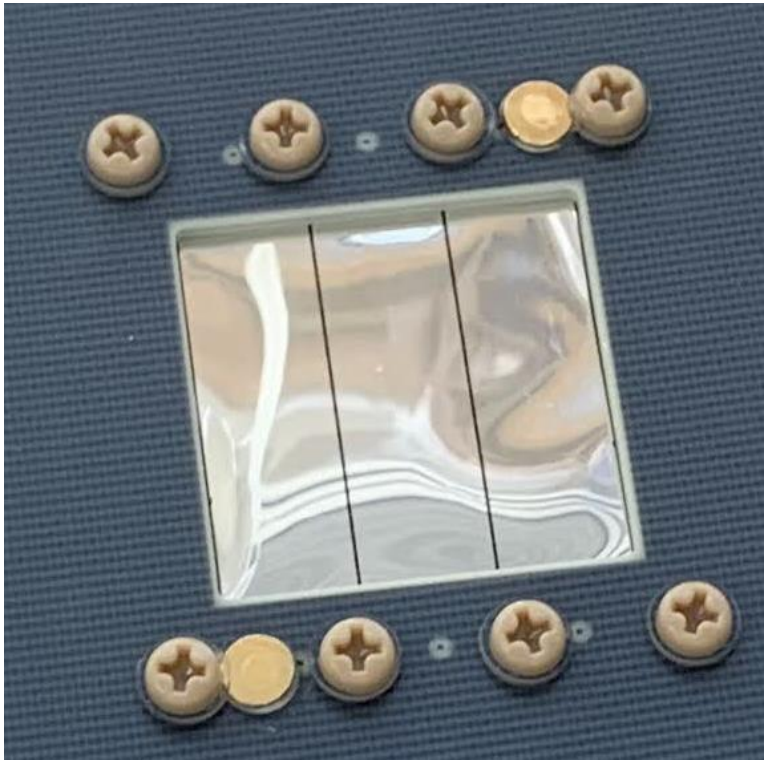




Signal readout

- Signal readout is performed by aluminum strips
- Aluminum strips are formed by etching after being deposited on electrode foils



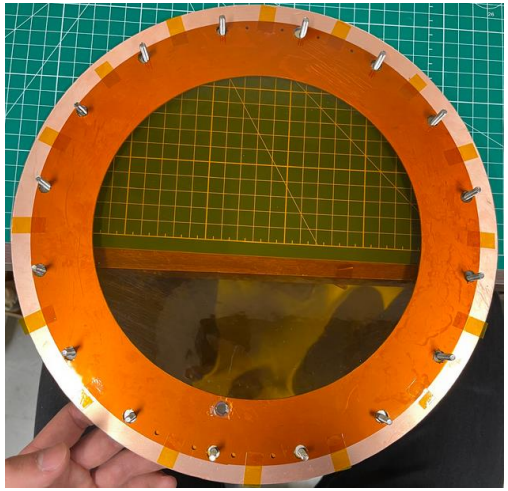


- Aluminum strips bonded to conductive pads on substrate

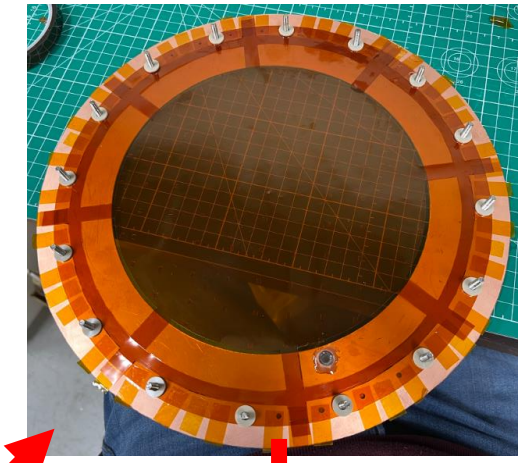
Mock-up assembly flow

1. Support frame (bottom)

2. Bottom board

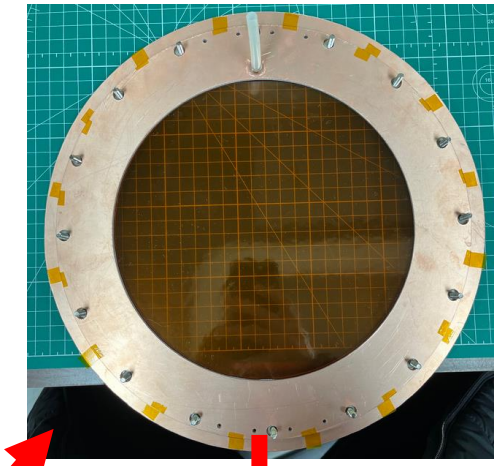


3. Implement inner foils (×3)

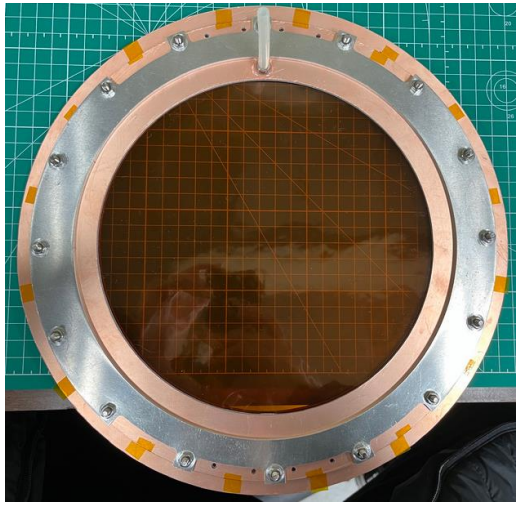


4. Implement O-ring

5. Top board

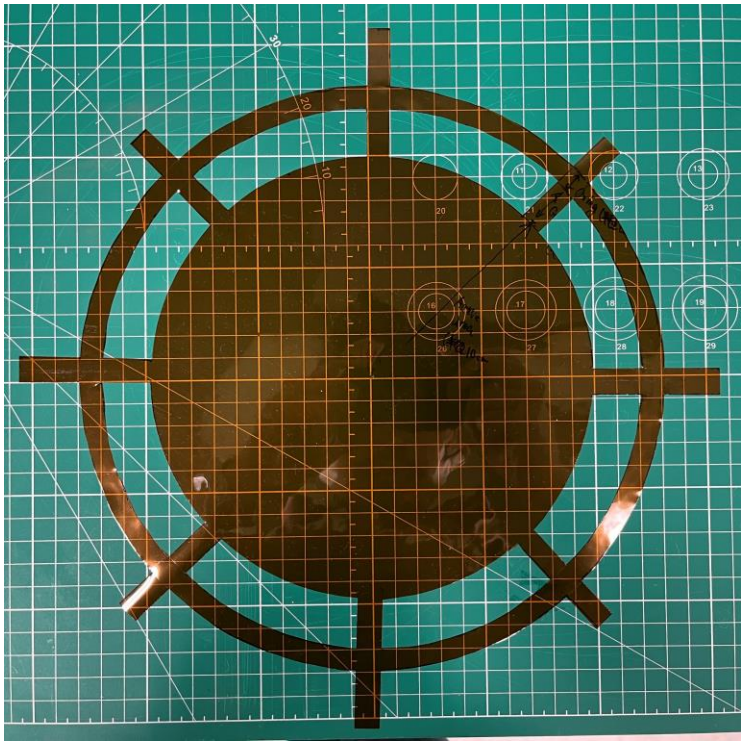


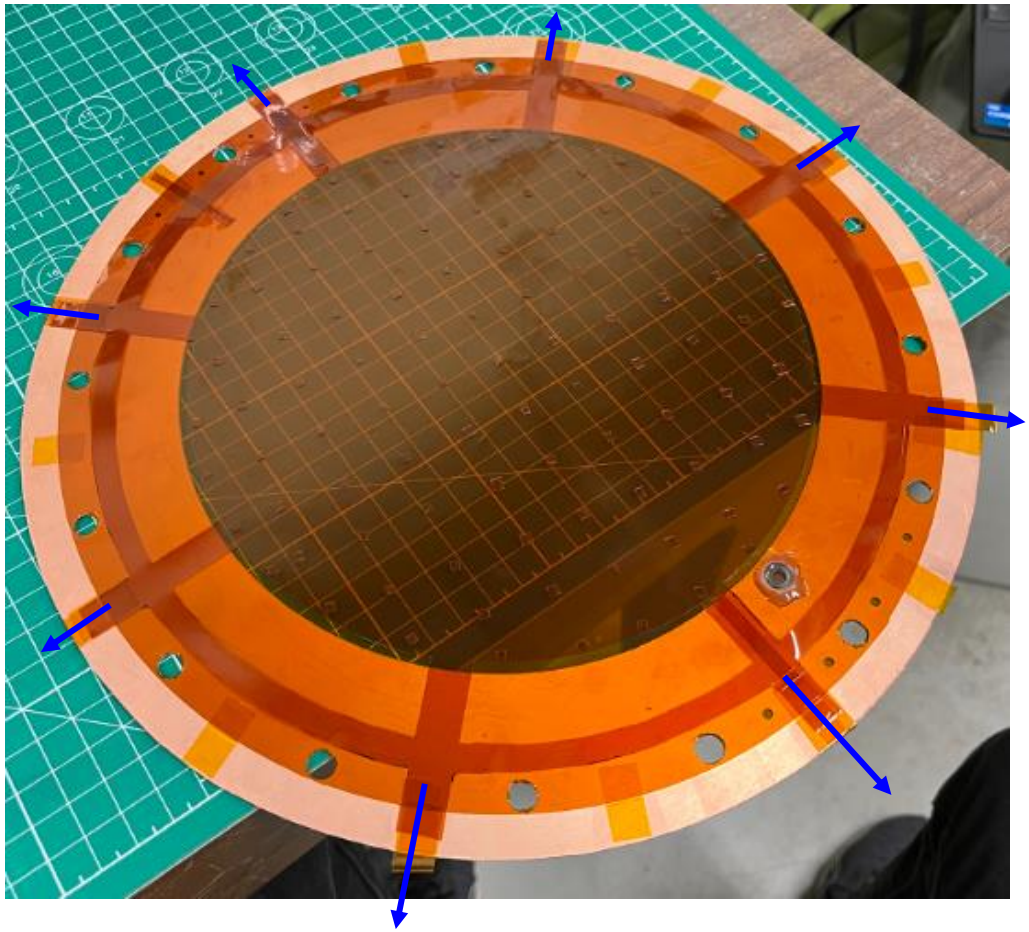
6. Support frame (top)



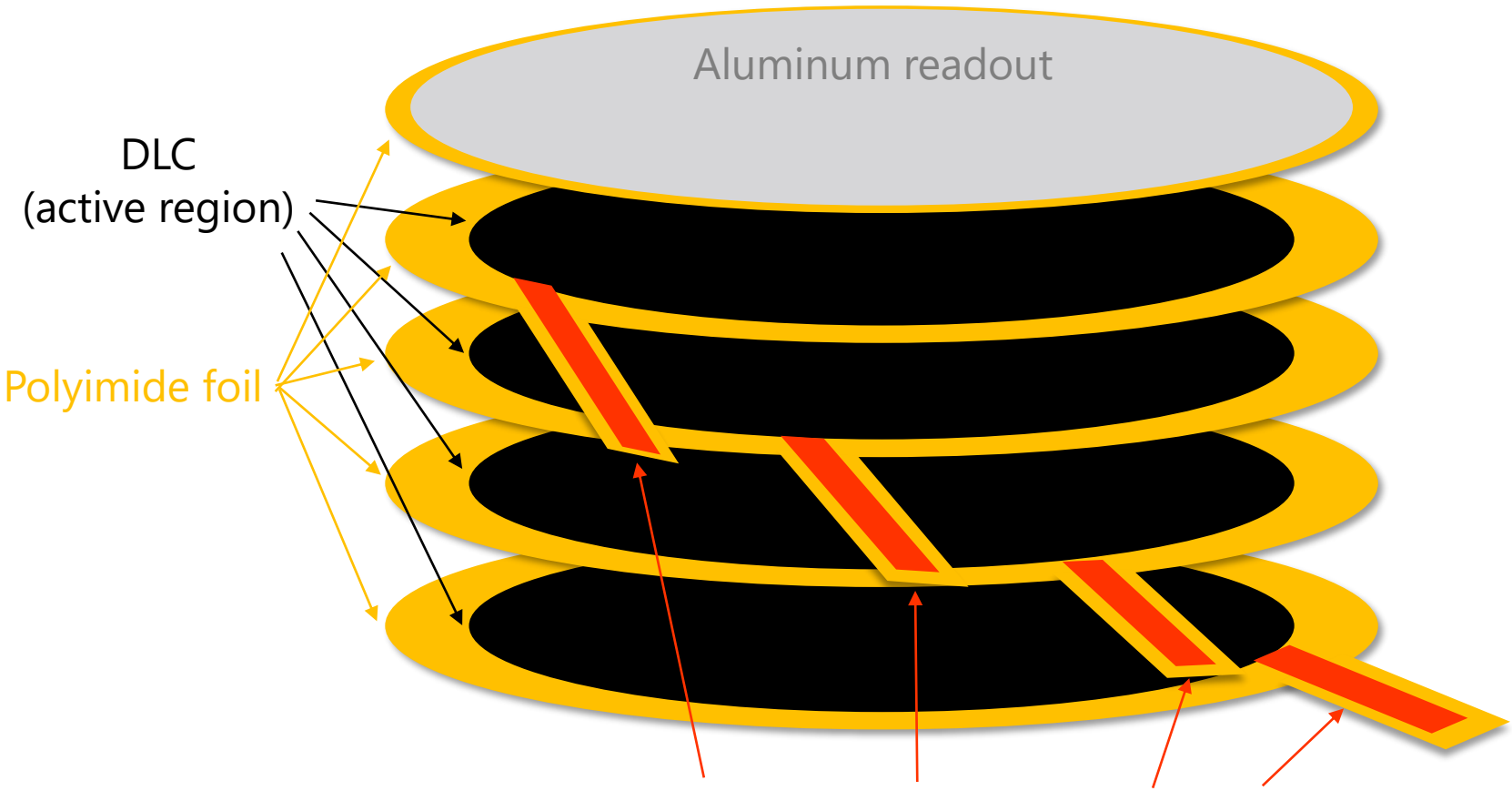
Implement inner foils

- 8 wings are fixed to the substrate with tape
- Fine-tune tension to prevent foils from distorting

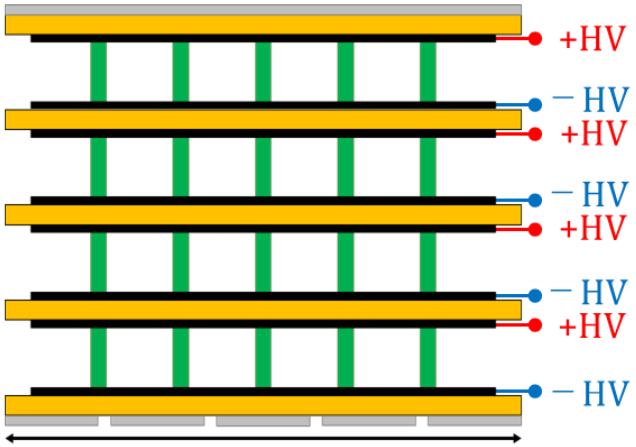


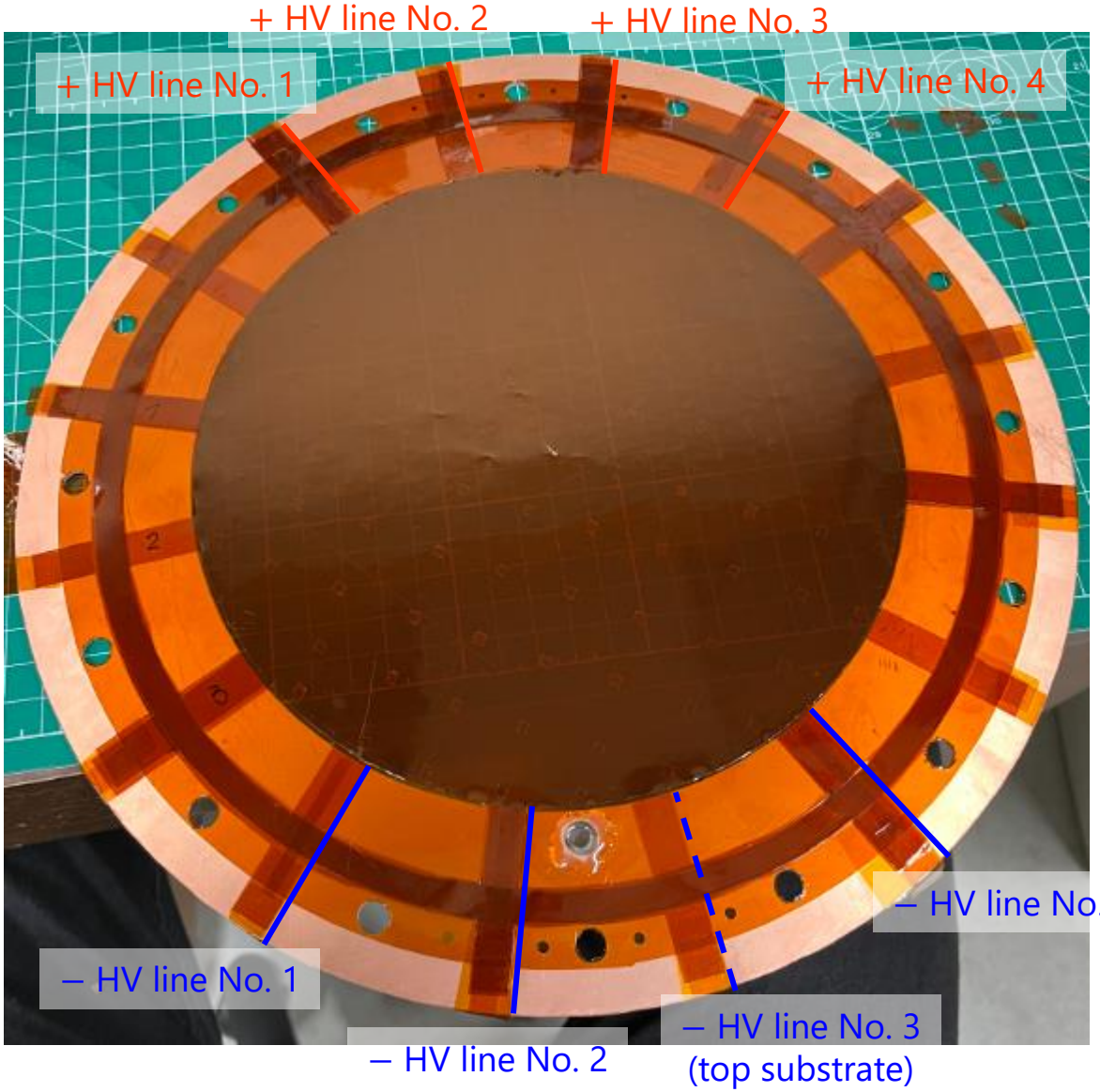


Concept of HV supply lines

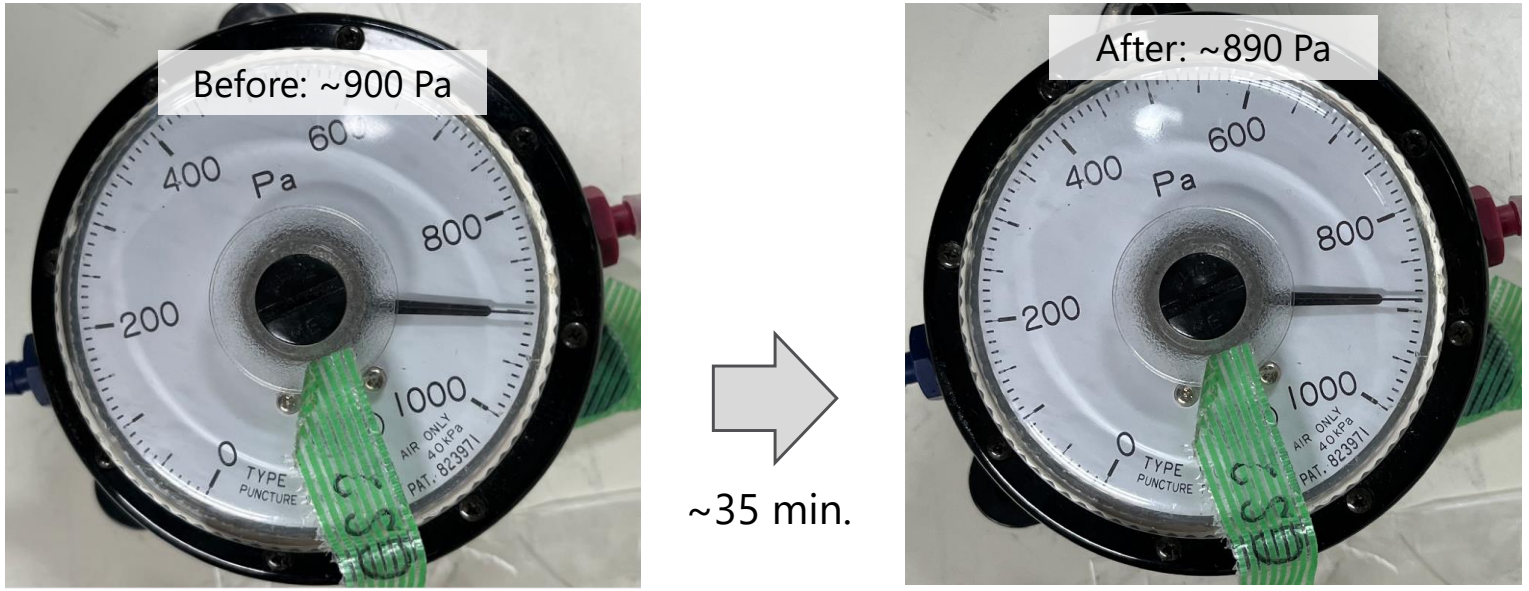


HV supply lines





Gas tightness with single inner layer

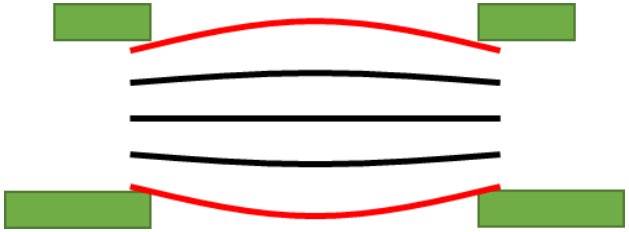


Differential pressure between inside chamber and atmospheric pressure

Pressure in the chamber

- DLC-RPC will be operated under negative pressure

If positive pressure …



Gas gaps become wider