MEG II実験背景事象抑制に向けたDLC-RPCの開発
―電極構造の改良と性能評価―

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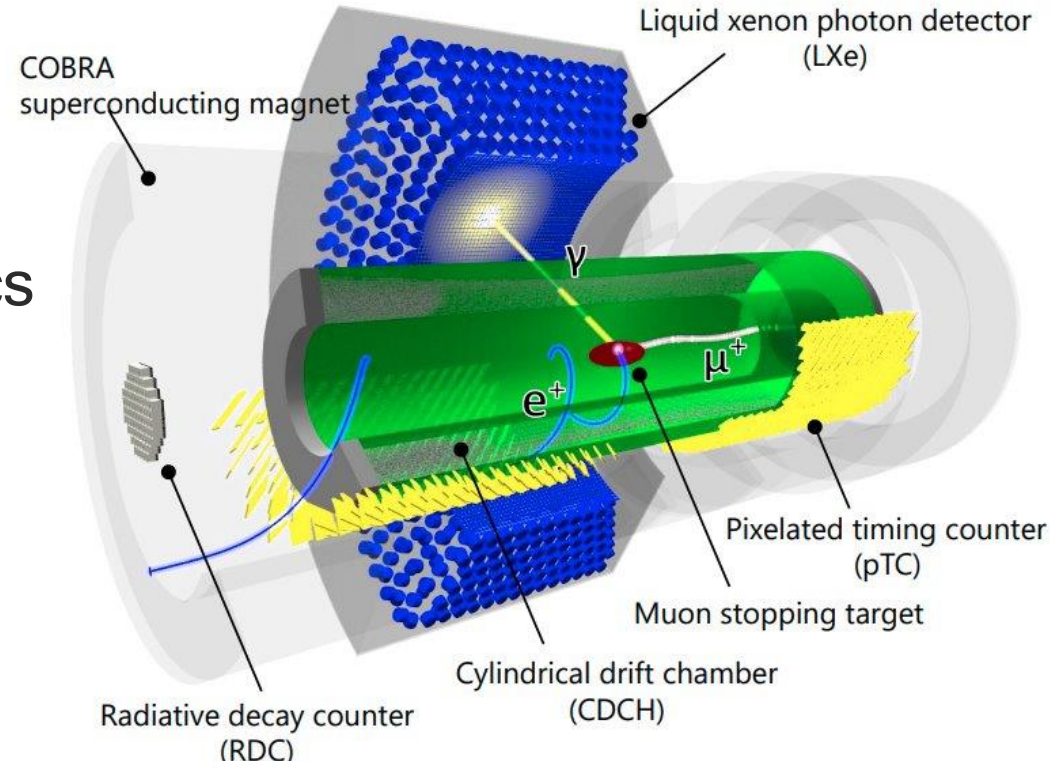
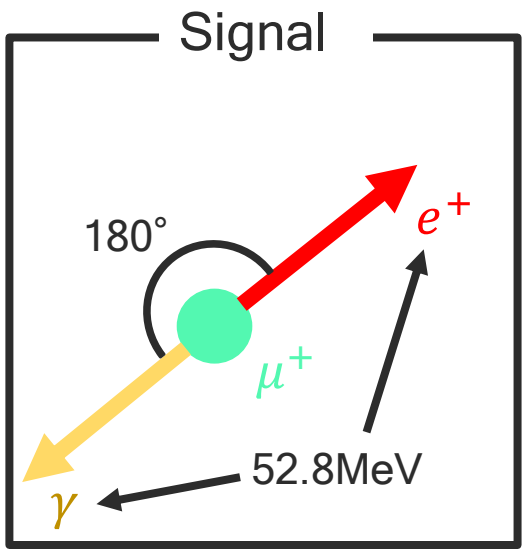
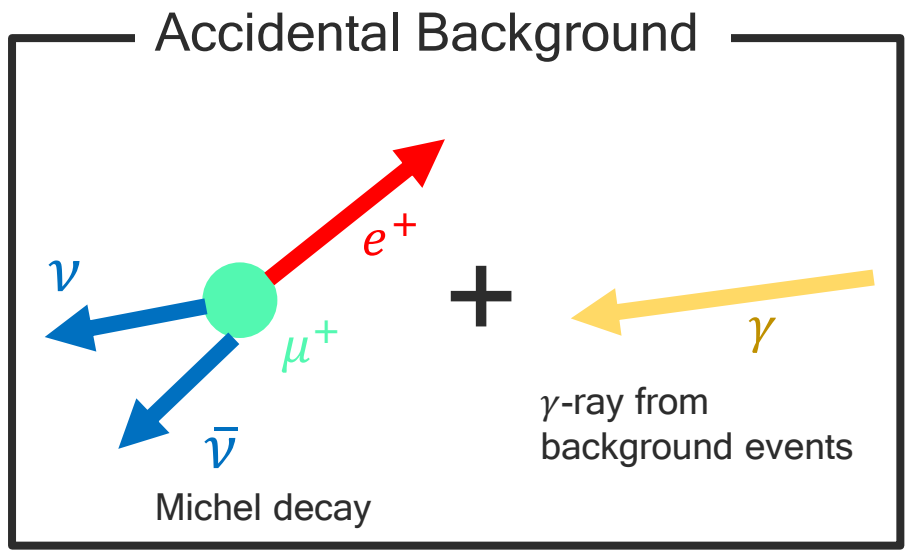
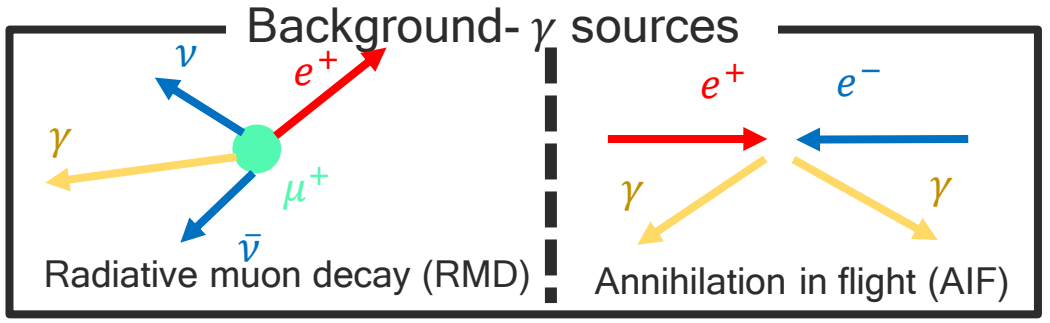
MEG II experiment

- Searches for the $\mu \to e\gamma$ decay
- Charged lepton flavor violation process (cLFV)
- Discovery would be an evidence for new physics
- Aims for a sensitivity of 6×10^{-14}
  (MEG: 5.3×10^{-13})





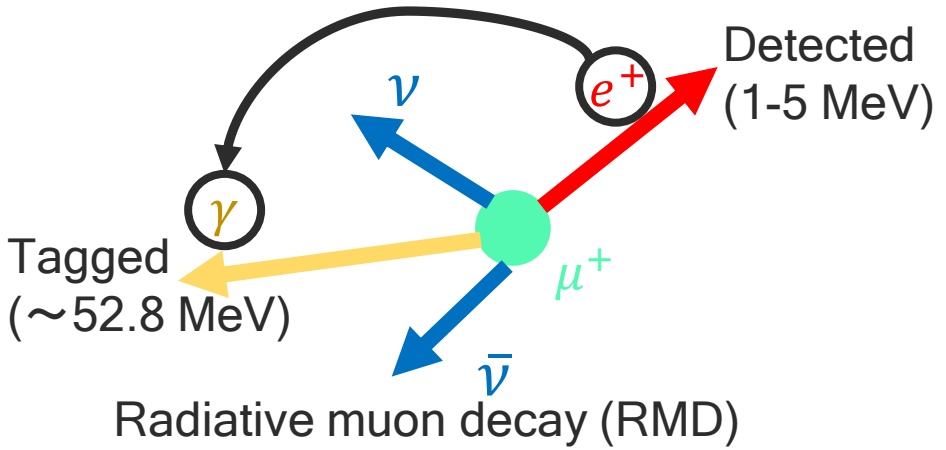




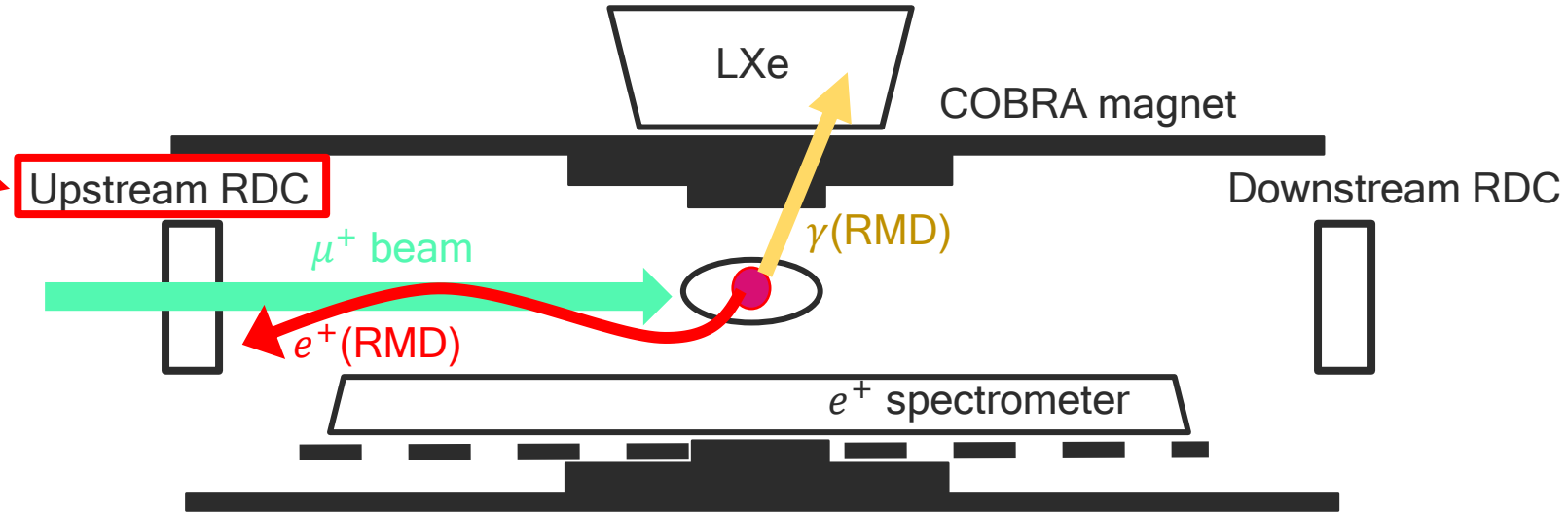
Introduction

Radiative decay counter (RDC)

- Detecting low momentum e^+ and tagging BG-γ from the RMD
- Reducing the background events



Under development



μ^+ beam at the upstream RDC

- High intensity (7×10^7 /s)
- Low momentum (28 MeV/c)

Introduction

Requirements for the upstream RDC

1. Material budget: < 0.1 % X_0
2. Rate capability: 3 MHz/cm^2
3. Radiation hardness: 20 weeks operation
4. Detection efficiency: > 90 % for MIP
5. Timing resolution: < 1 ns
6. Detector size: 20 cm Φ

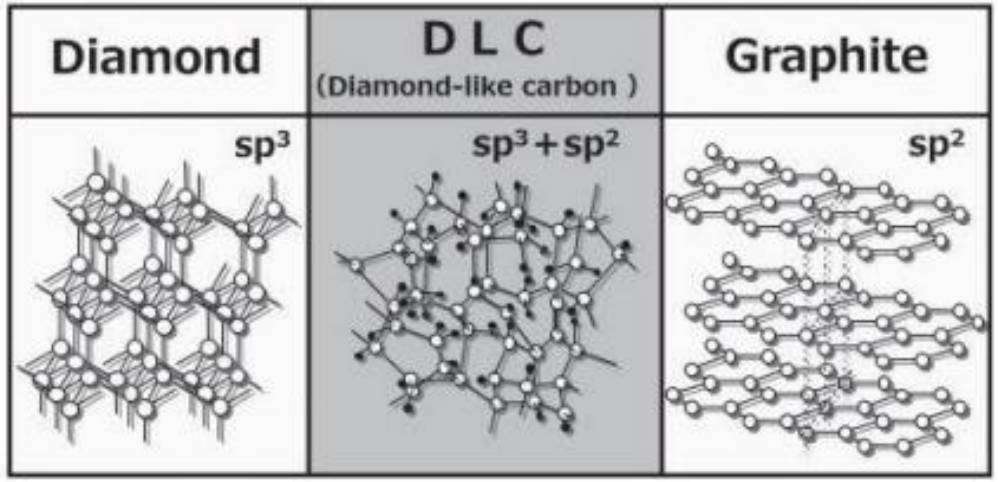
DLC-RPC: Resistive Plate Chamber with electrodes based on Diamond-Like Carbon

Introduction

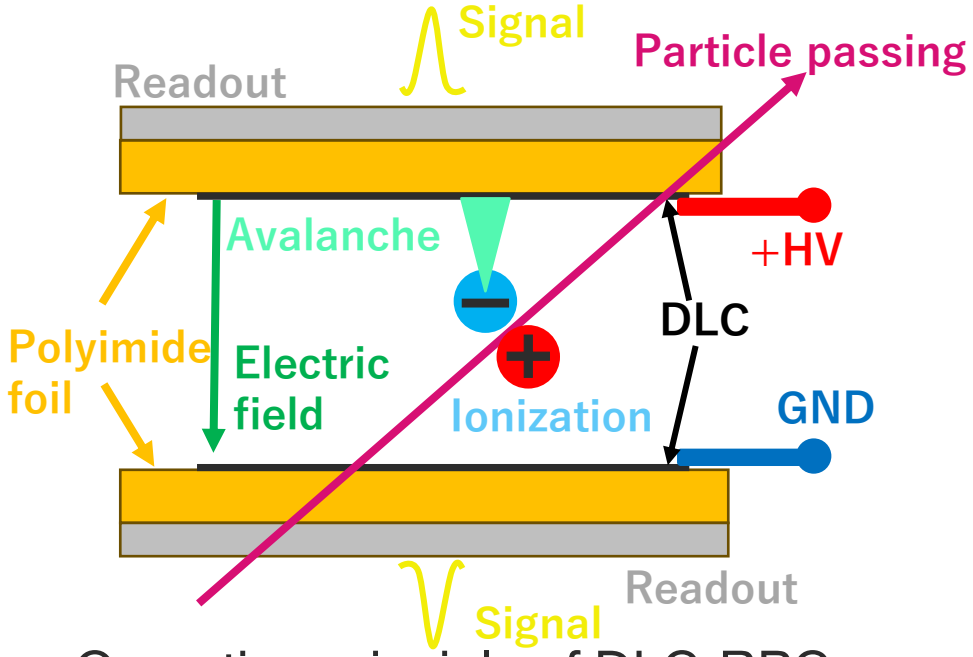
DLC-RPC

Diamond-Like Carbon (DLC)
- High resistivity and thin film
- Adjustable resistivity

Resistive Plate Chamber (RPC)
- Gaseous detector consisting of parallel plate electrodes
- Fast timing efficiency
- Higher detection efficiency by stacking layers
  (Detection efficiency of n-layers: $\epsilon_n = 1 - (1 - \epsilon_1)^n$)



PCS Instruments, The Science Behind Diamond like Coatings (DLC), https://pcs-instruments.com/articles/the-science-behind-diamond-like-coatings-dlcs/, December 3, 2021

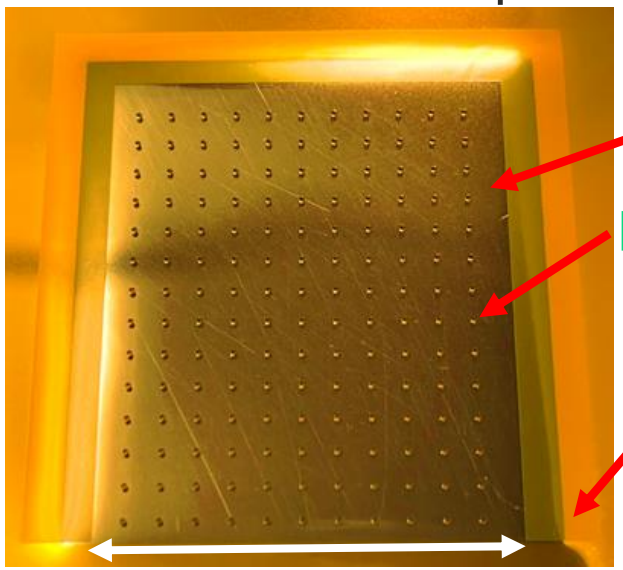


Operation principle of DLC-RPC

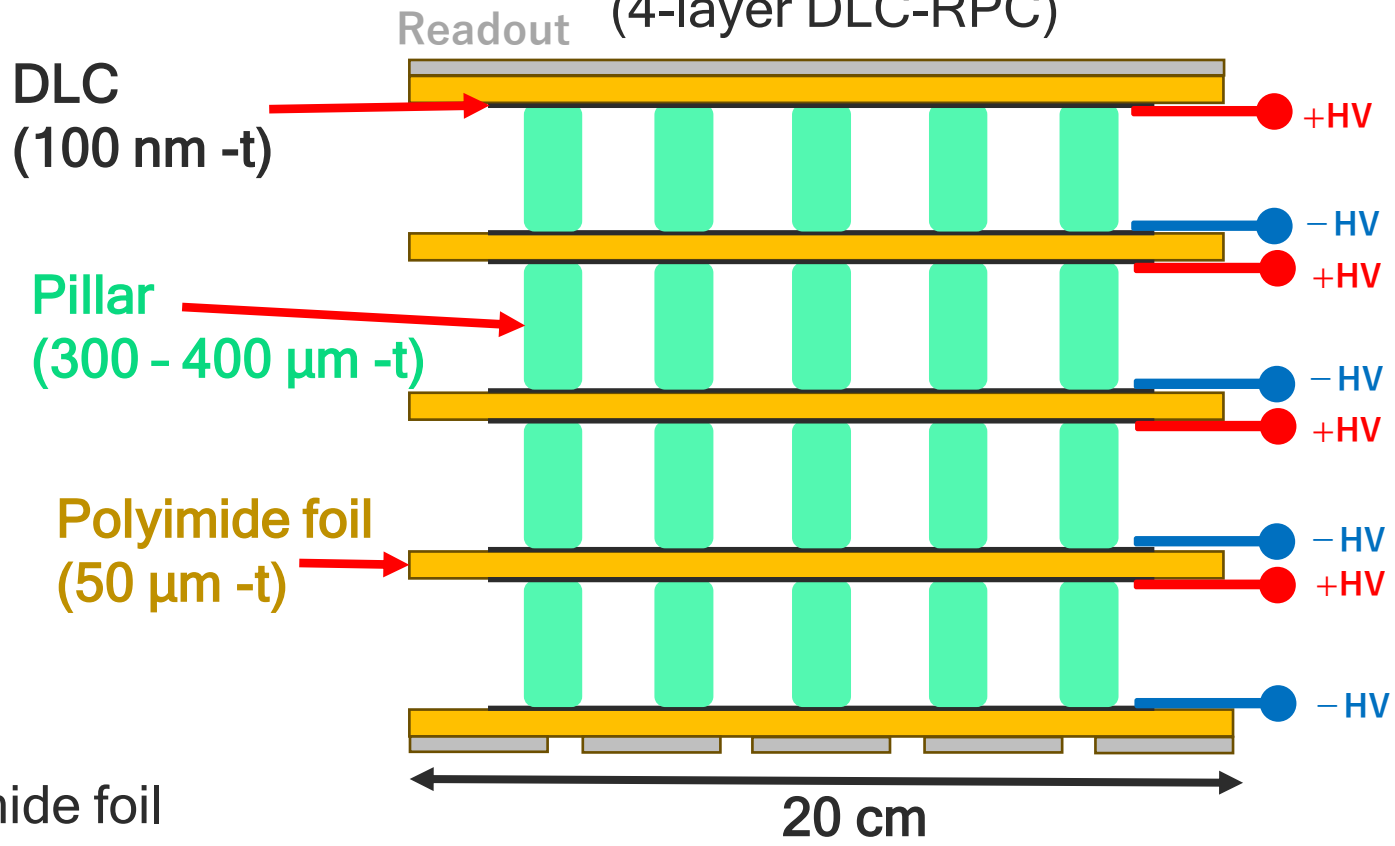
Introduction

DLC-RPC

An electrode for a small prototype



The structure of DLC-RPC for MEG II
(4-layer DLC-RPC)



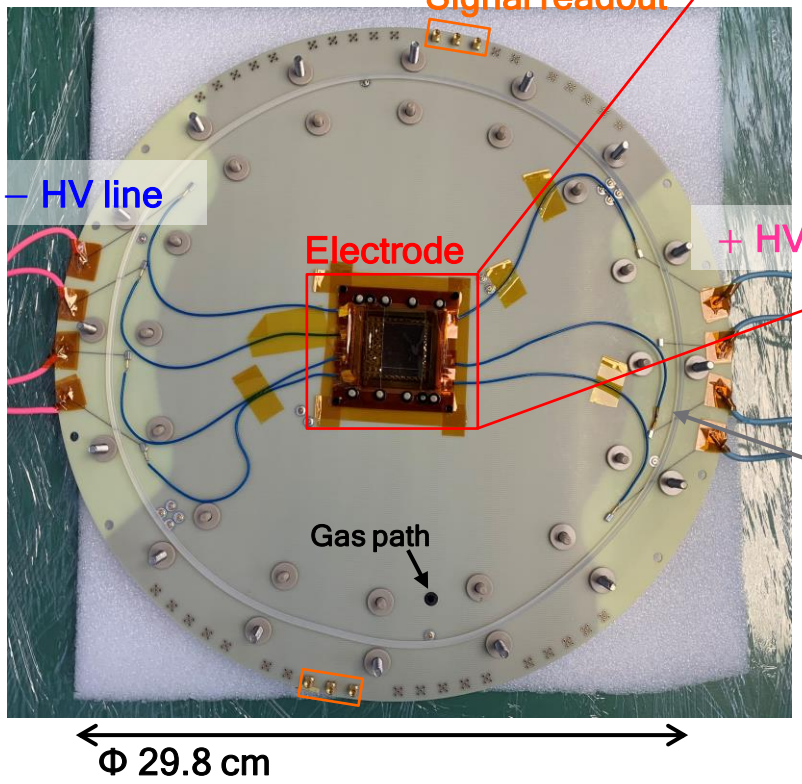
- DLC sputtered on a 50 μm thickness polyimide foil
- Pillars to sustain a gap between electrodes
- More than 40 % detection efficiency with a single layer is required.
  →90 % efficiency with 4 layers

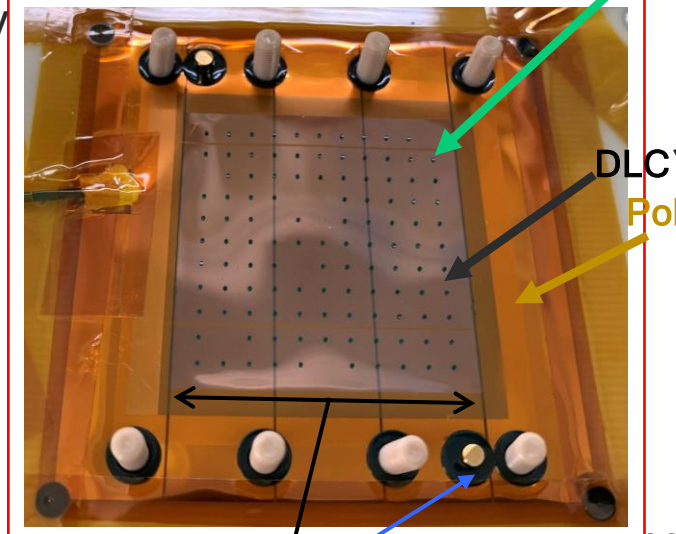
First prototype

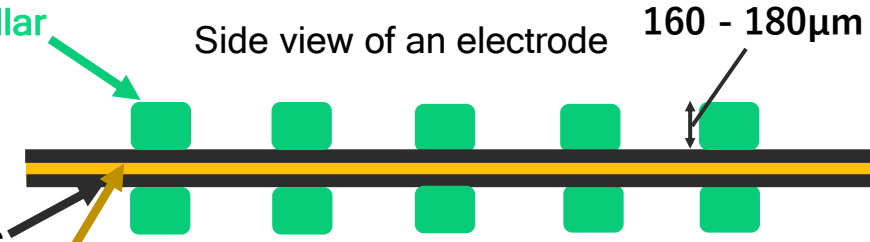
Module

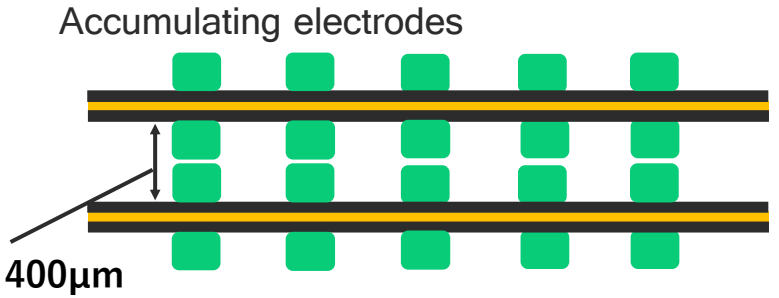
Designed for the evaluation of the rate capability in a high-rate muon beam (JPS 2022 autumn, 6pA421, JPS 2023 spring, 23pT2-5)

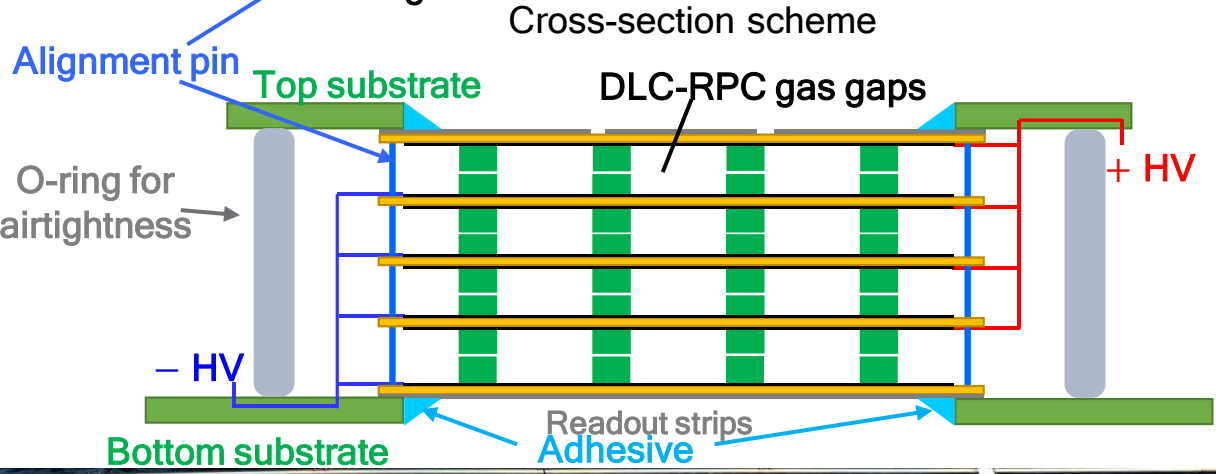
Inner overview of First prototype











First prototype

Issues

1.Distortion of an electric field

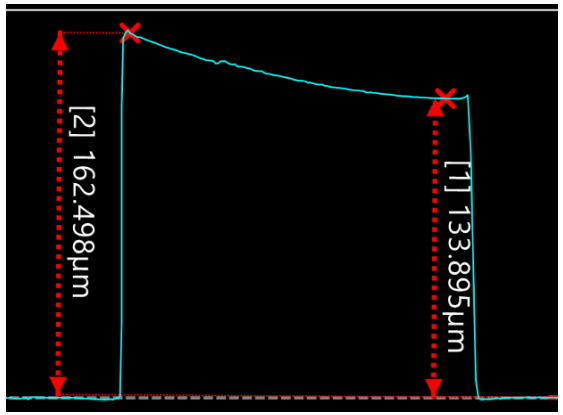
- Inhomogeneous pillars that made the non-uniform gap
- Fixing method that causes the thin-film electrode to be distorted →Reported by Masato in the next talk

2.Insufficient quench

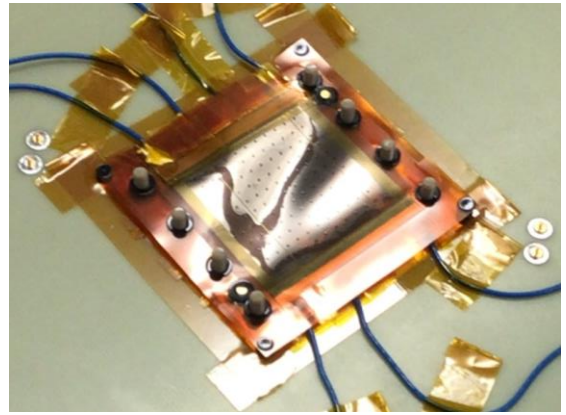
→Reported by Masato in the next talk

Unstable operation

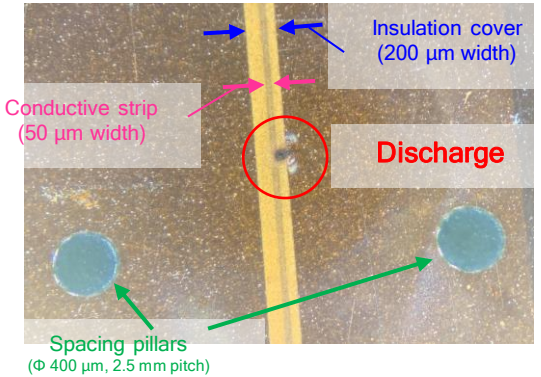
Distorted spacing pillar



Non-flatness of electrodes



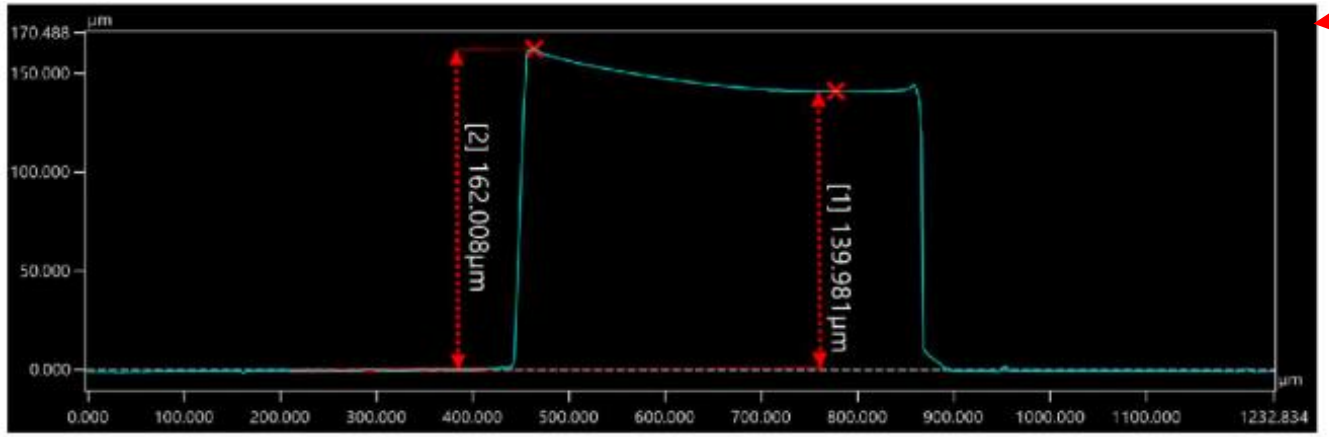
Discharge at conductive strip

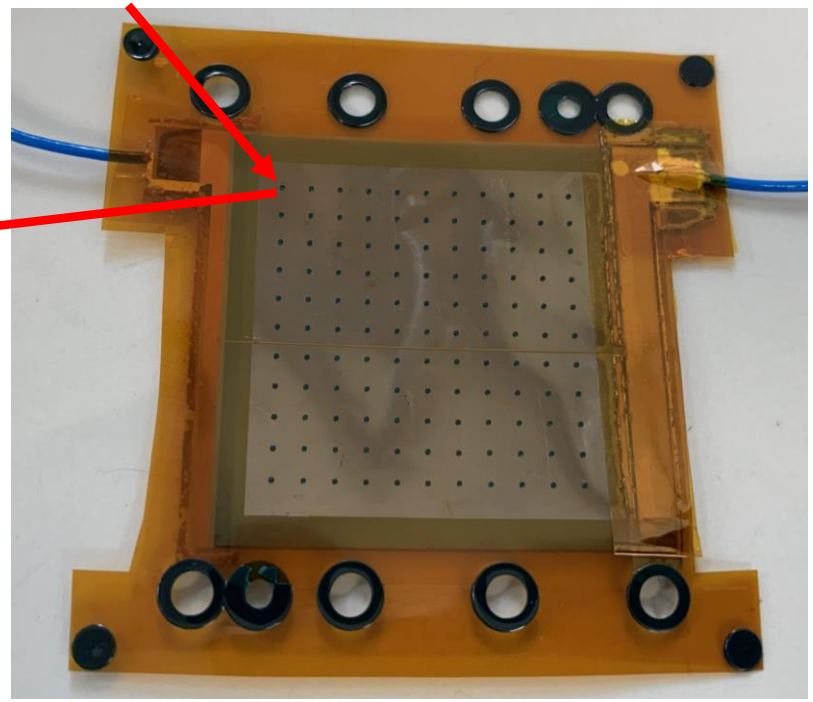


First prototype

Pillars on the first prototype electrodes
(JPS 2023 spring,23pT2-6)

Side view of a pillar on an electrode





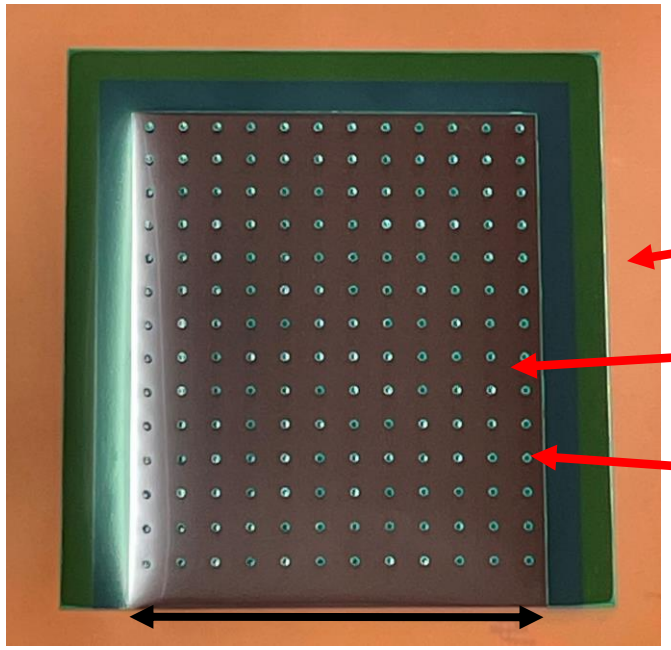
- Variation in thickness:～20 μm
- Distortion in a top face of a pillar
- Facing each pillar increased non-uniformity.
  →A non-uniform gap distorts an electric field!

Improvements are required.

- Variation in thickness:<10 μm
- Flatness of a top face
- Pillar thickness: 300 μm - 400μm

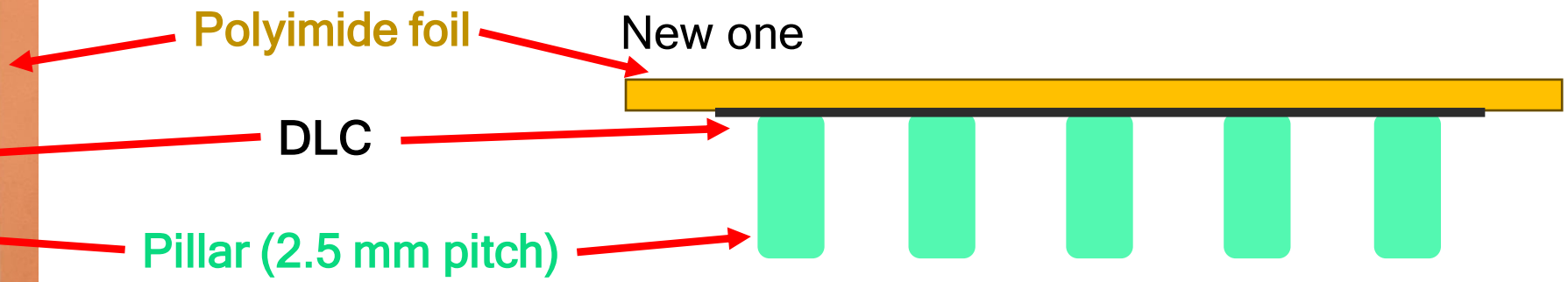
Production of new electrodes

Structure



Side view of electrodes

Previous electrode



- Attaching 300 μm thickness pillars onto an electrode
- Pillars formed on one side
- A new material (Dynamask) enables to produce thicker pillars

Production of new electrodes

Properties

Pillar thickness

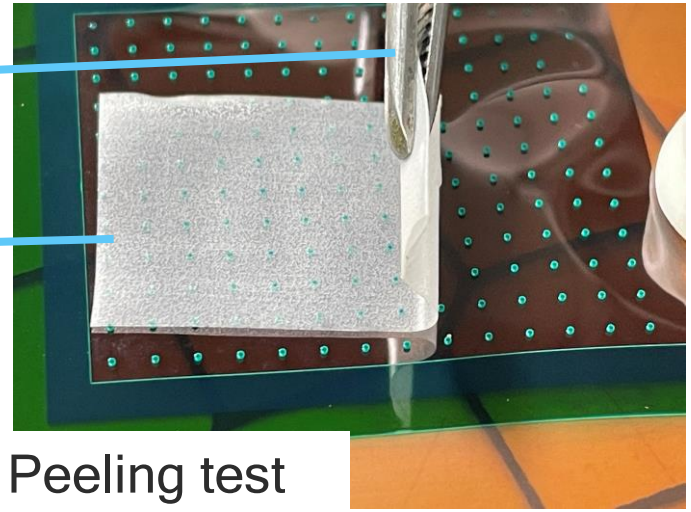
Required
- Variation in thickness:<10 μm
- Flatness of a top face
- Pillar thickness: 300 μm – 400μm

Achieved
- 333 ± 5 μm
- A more than 330 μm gap will be guaranteed.

Measurement of pillar heights

Adhesion of pillars

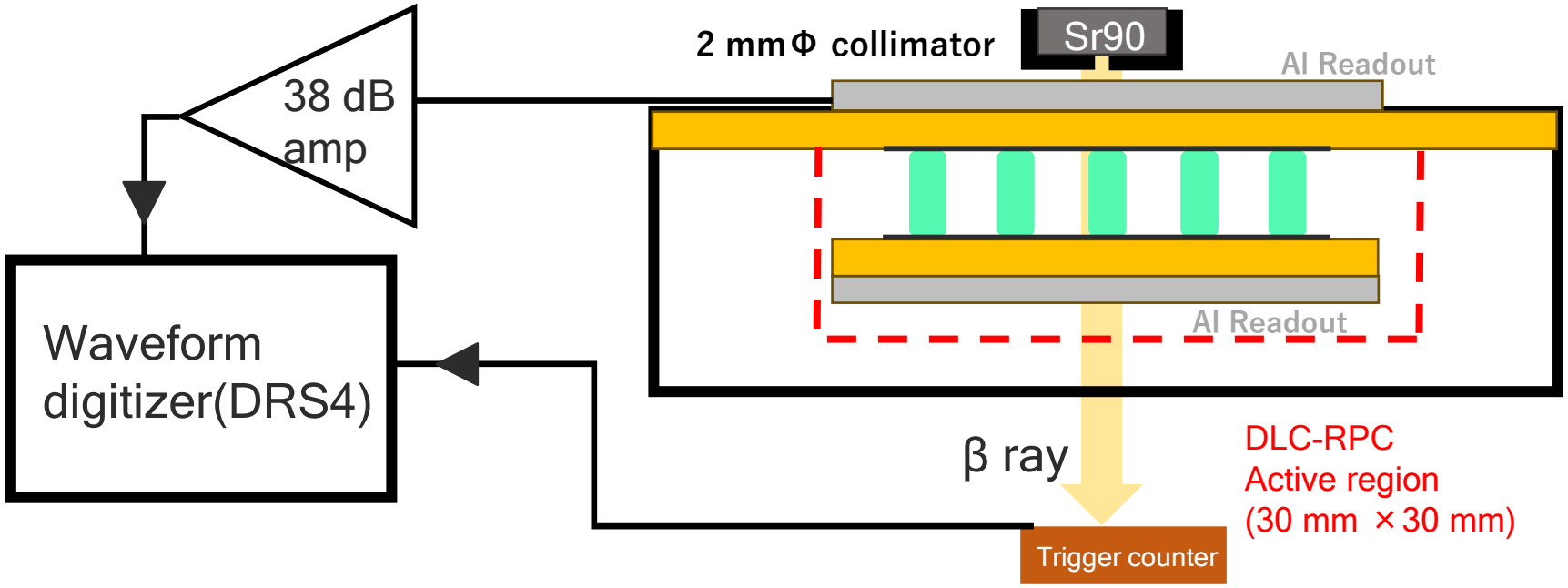
- Firm adhesion was confirmed.
- Tolerable to vertical forces

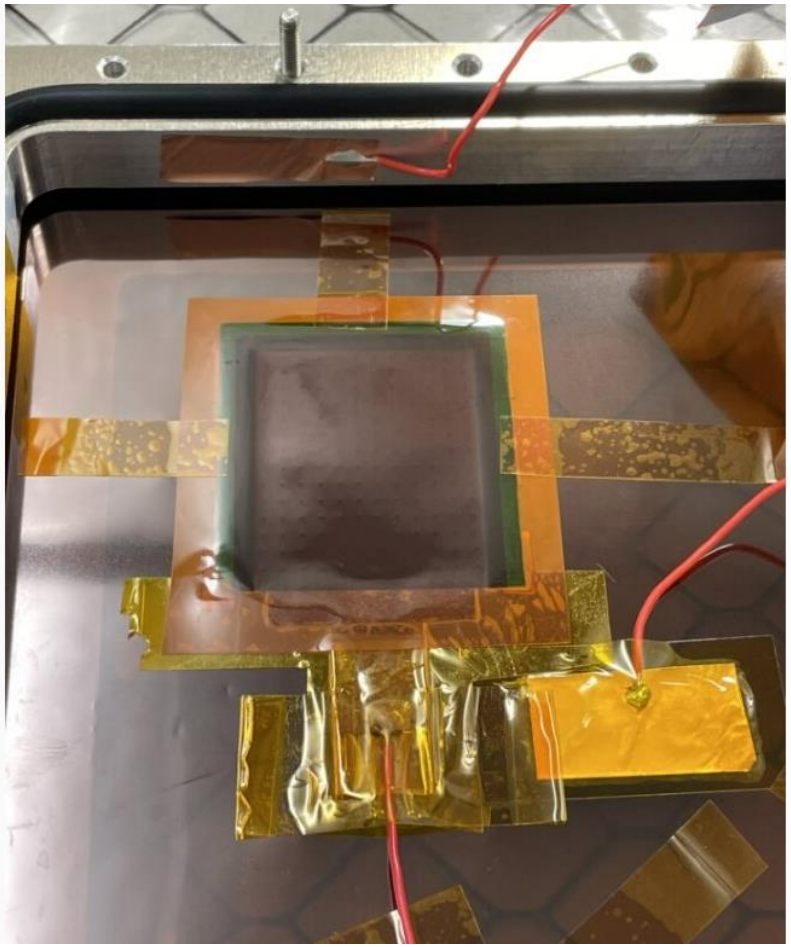


Peeling test

Performances with new electrodes

Test bench



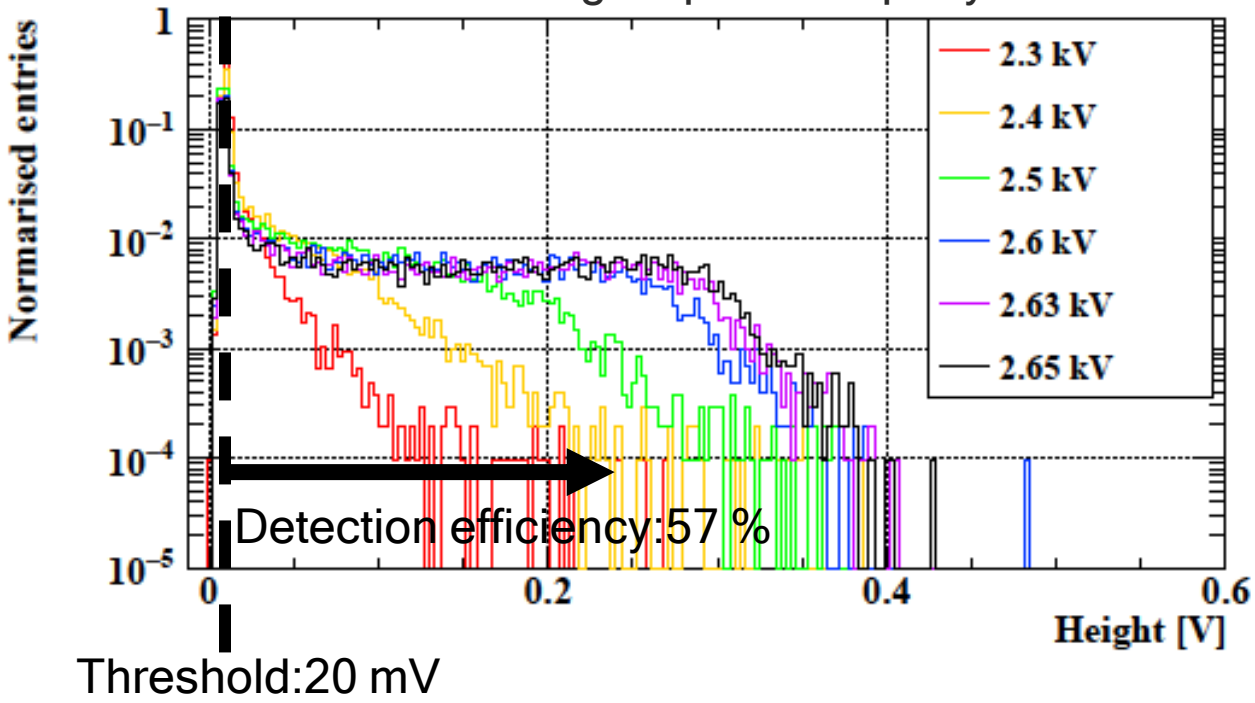


Gas:$C_2H_2F_4$(R134a)/ iC_4H_{10}/SF_6 = (94/5/1)%

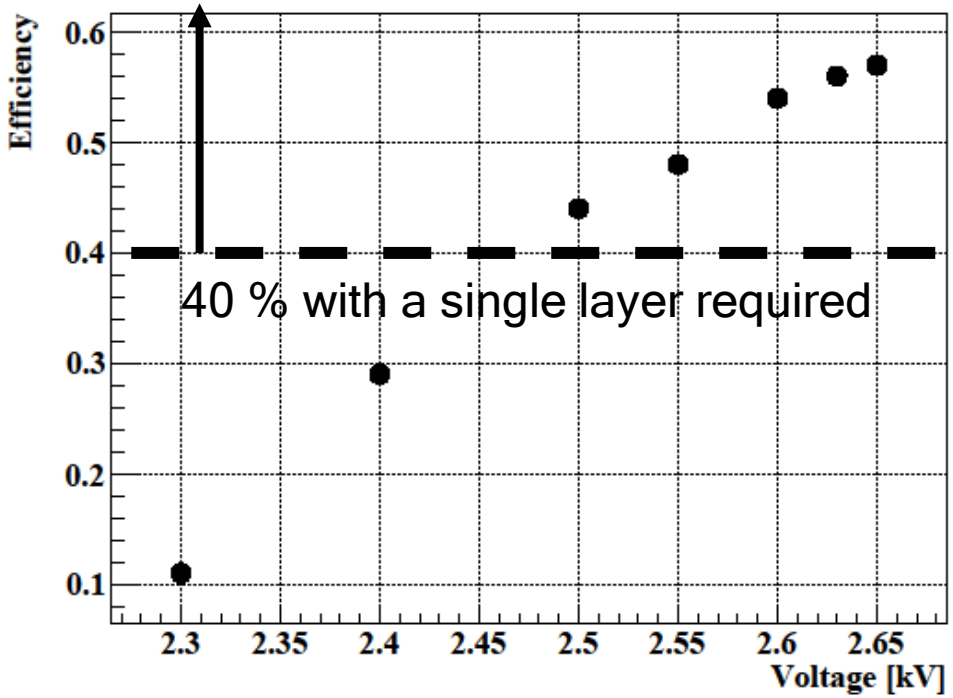
Performances with new electrodes

Result

Pulse height spectra of β rays



Detection efficiency vs applied voltage



- 57 % detection efficiency was achieved at 2.65 kV.
- The operation will be performed at 2.63 kV for its stability.

Summary & Prospects

Summary

- DLC-RPC for the MEG II upstream RDC is under development.
- High-quality pillars enabled by the new material ensured a uniform gap.
- 57 % detection efficiency was achieved with a single layer.
  →More than 90 % is expected with 4-layer. ($\epsilon_4 = 1 - (1 - \epsilon_1)^4$)

Prospects

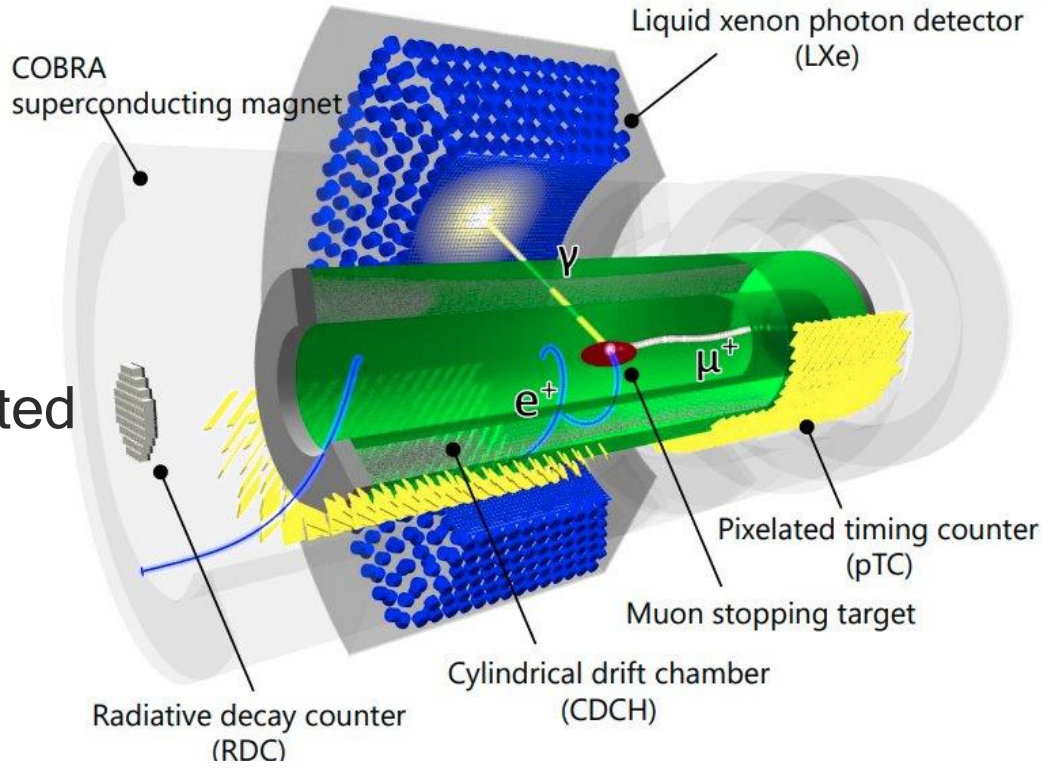
- Study on a long-term stability of the operation
  - Discharges still can occur and hinder the operation during a long-term irradiation.
  - The factors will be investigated.

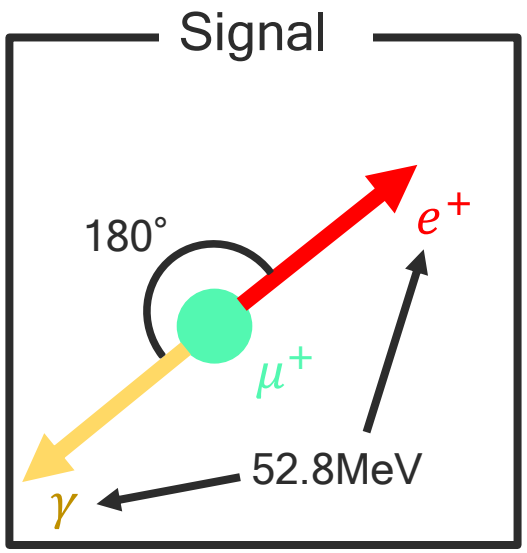
Backup

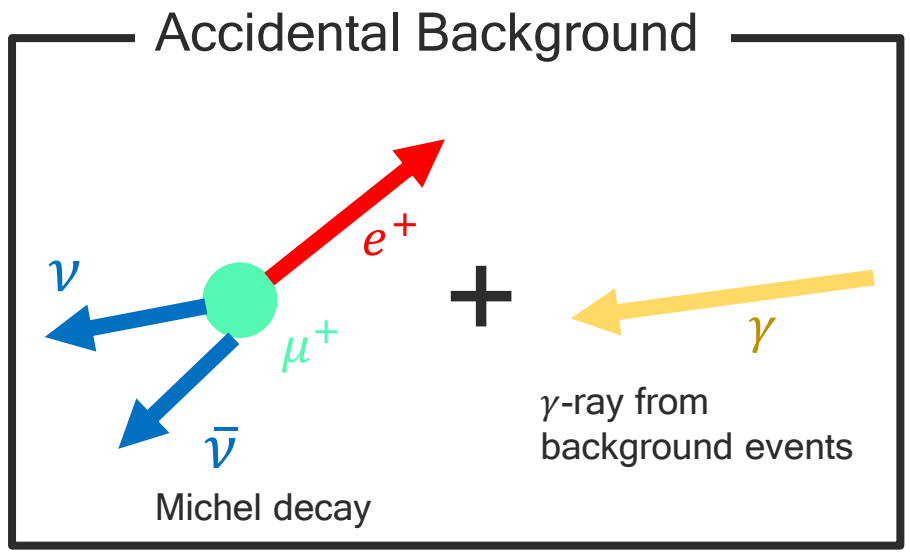
Introduction

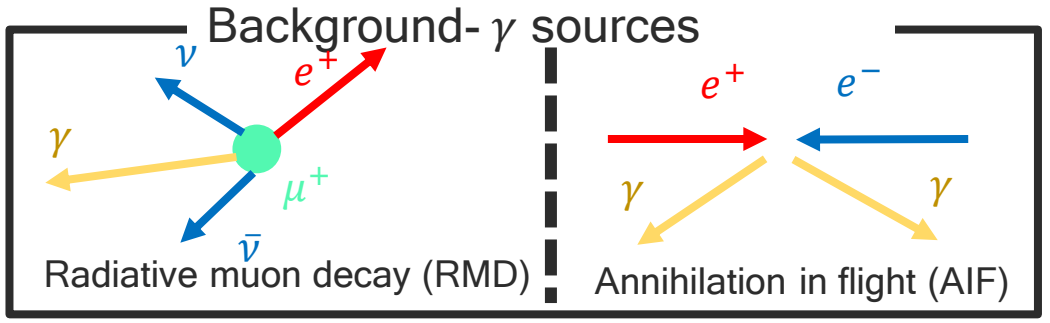
MEG II experiment

- Searches for the $\mu \to e\gamma$ decay
- Charged lepton flavor violation process (cLFV)
- Evidence for new physics
- Aims for a sensitivity of 6×10^{-14}
  (MEG: 5.3×10^{-13}, MEG+MEG II:4.3×10^{-13} reported in arXiv:2310.12614)







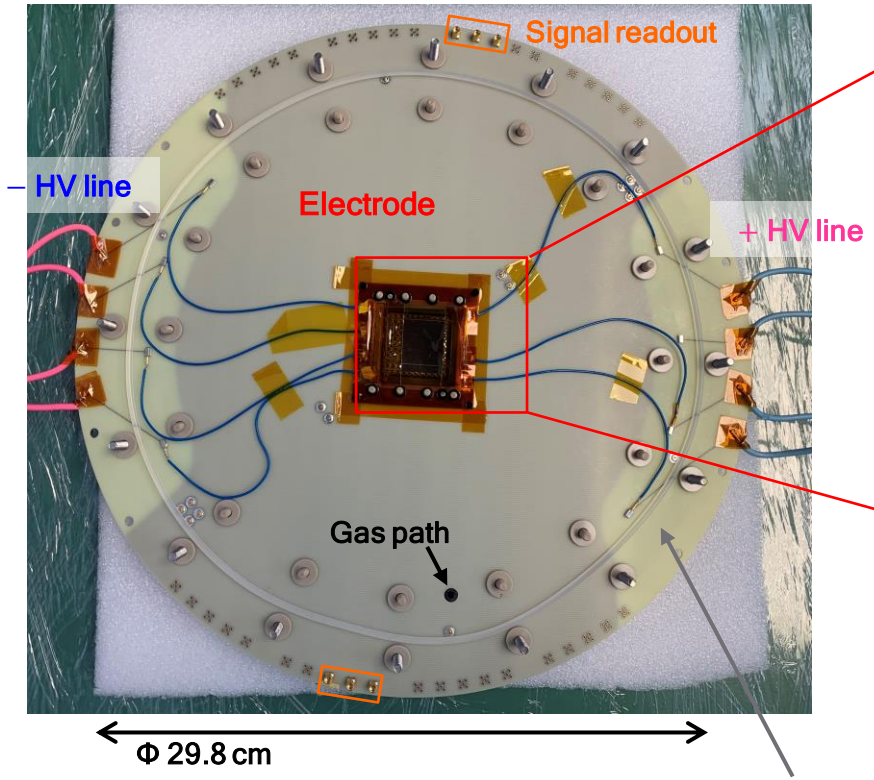


Introduction

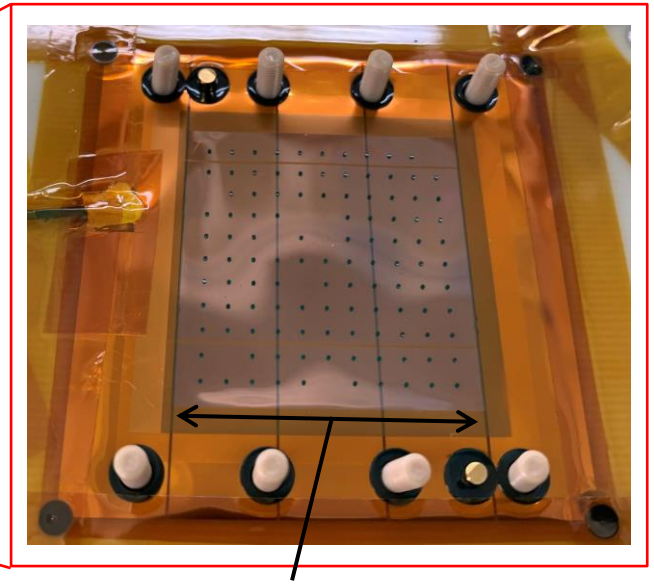
DLC-RPC

Requirements	Goal	Current status
Material budget	< 0.1 % X_0	～0.095 %X_0 (4 layers)
Rate Capability	3 MHz/cm^2	1 MHz/cm^2
Radiation hardness	～100 C/ cm^2 for 20 weeks operation	～54 C/ cm^2
Detection efficiency	> 90 %	> 90 % (4 layers)
Timing resolution	<1 ns	160 ps
Detector size	20 cm Φ	3 cm × 3cm

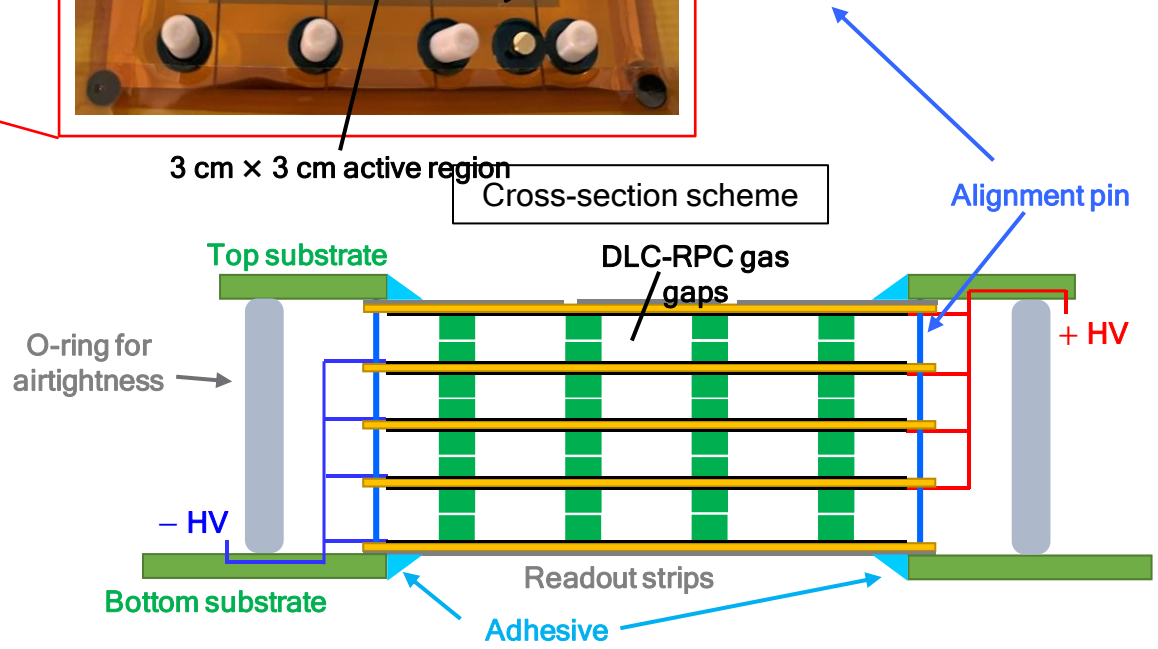
Inner overview of First prototype



Electrode

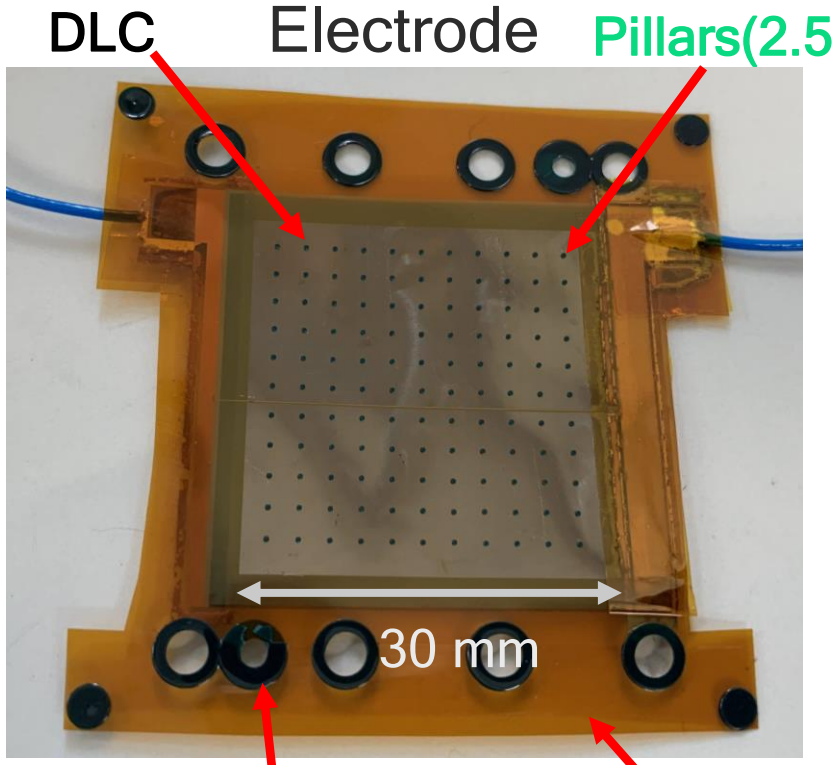


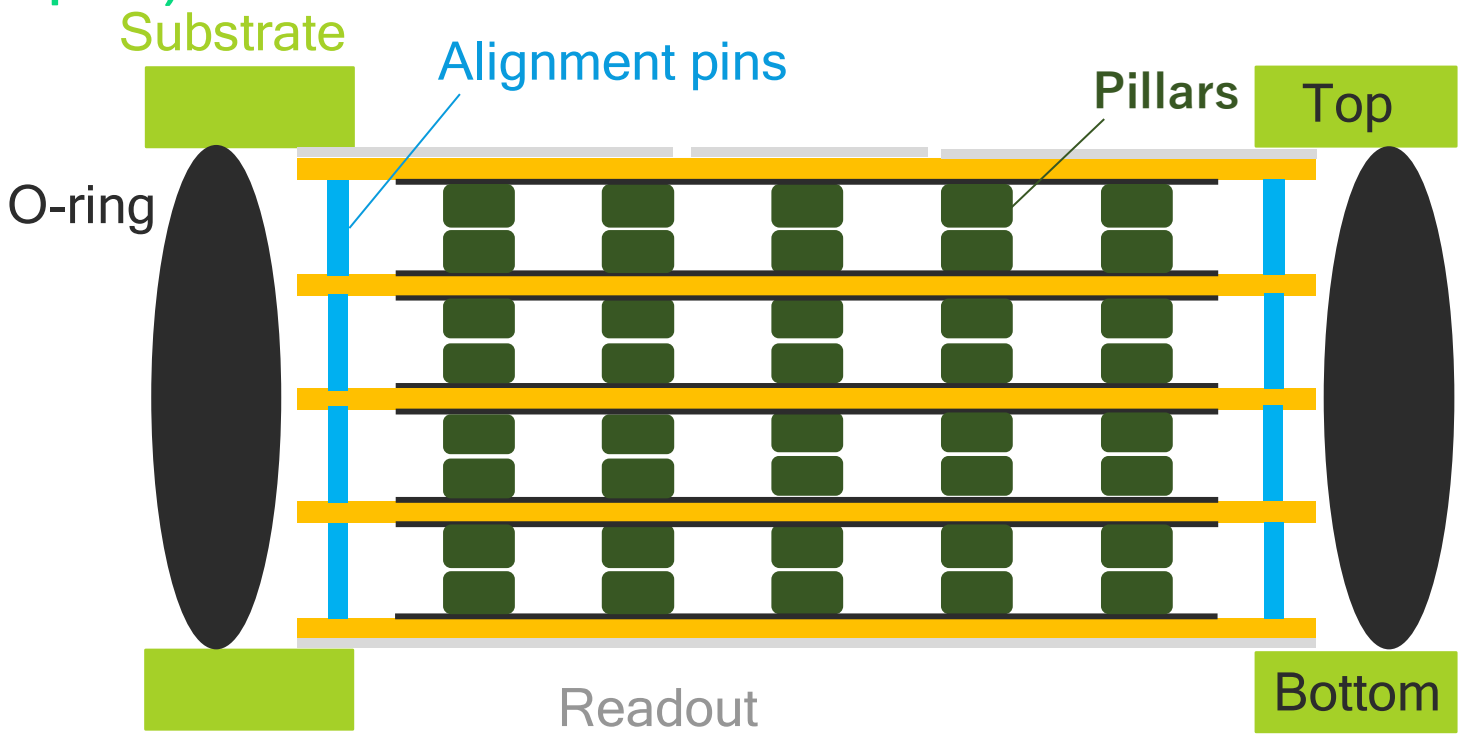
Cross-section scheme



- ◆Accumulating 4 layers
- ◆Facing each pillar to sustain a gap
- ◆The adjusted position by alignment pins

First prototype

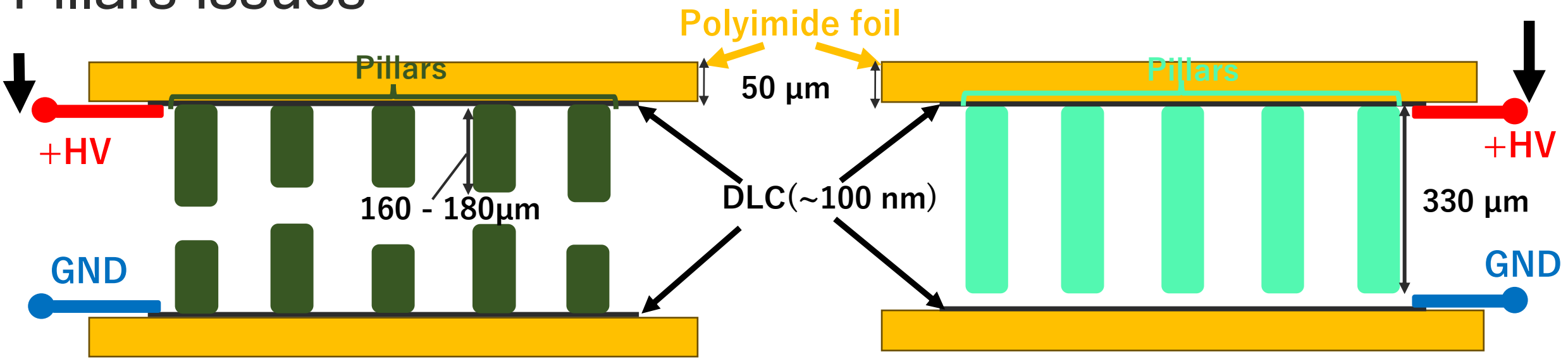




- Accumulating 4 layers
- Facing each pillar to sustain a gap
- The adjusted position by alignment pins

Distortion of electric field

Pillars issues



The structure of DLC-RPC

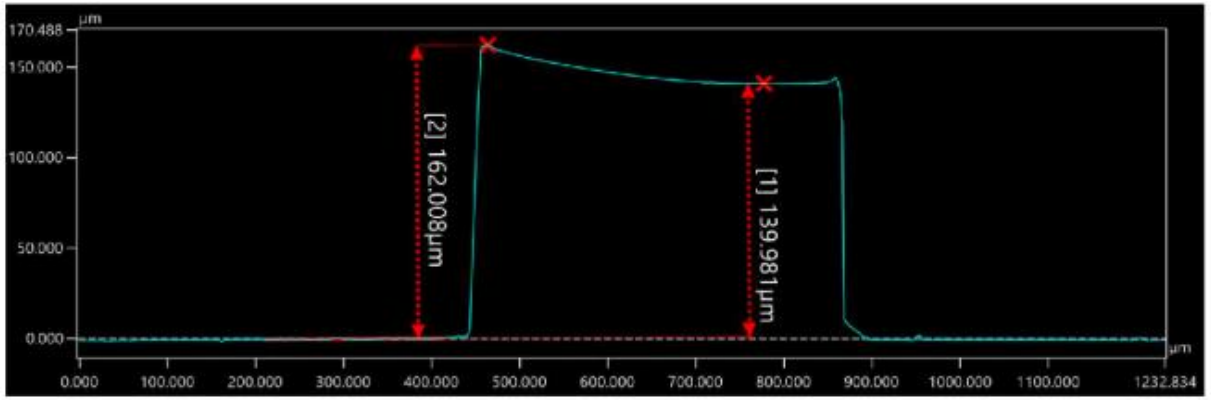
Improved structure

- 330 μm gap is needed to operate the detector.
- Accumulating inhomogeneous pillars makes an non-uniform gap.
- Higher pillars are attached to one side.

Distortion of electric field

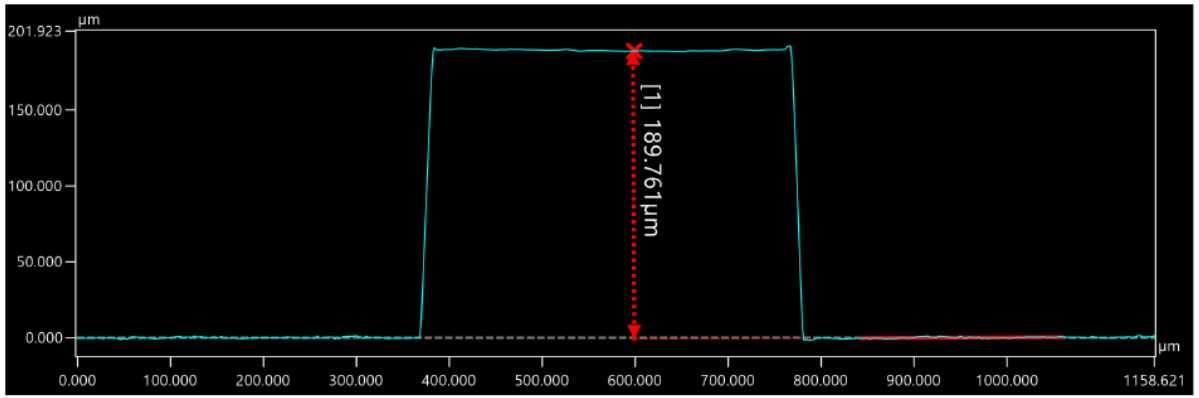
Pillars issues

Side view of a pillar on an electrode



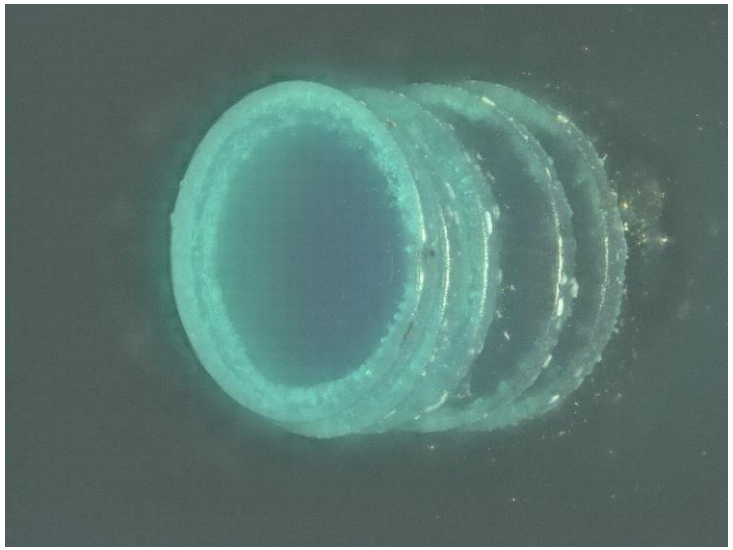
- Variation in thickness:～20 μm
- Distortion in a top face of a pillar
- Facing the pillars
  →An unstable gap which distorts electric field

Side view of a pillar on another electrode

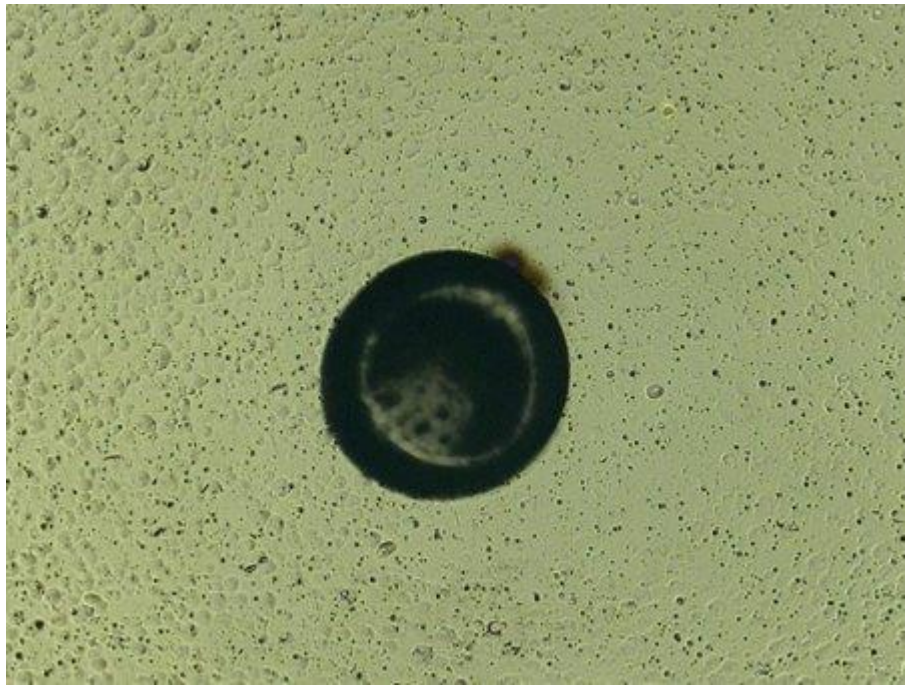


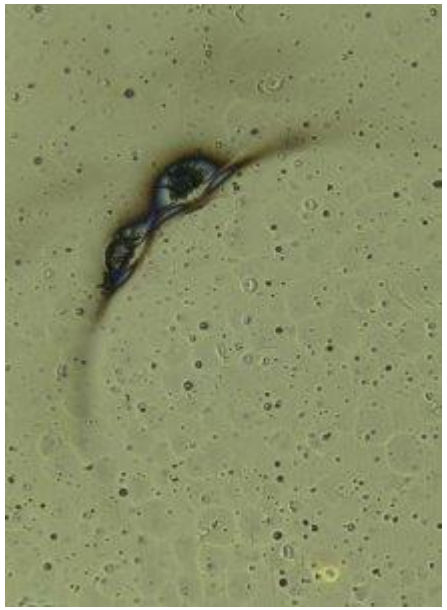
- Variation in thickness:～10 μm
- Higher quality
- Production was cancelled
- No alternatives

Piilars



Discharge mark near a pillar





Performances with new electrodes

Test bench