MEG II実験背景事象削減に向けた高レート耐性DLC-RPCの高抵抗電極の開発

山本 健介 (東大理)
他MEG IIコラボレーション

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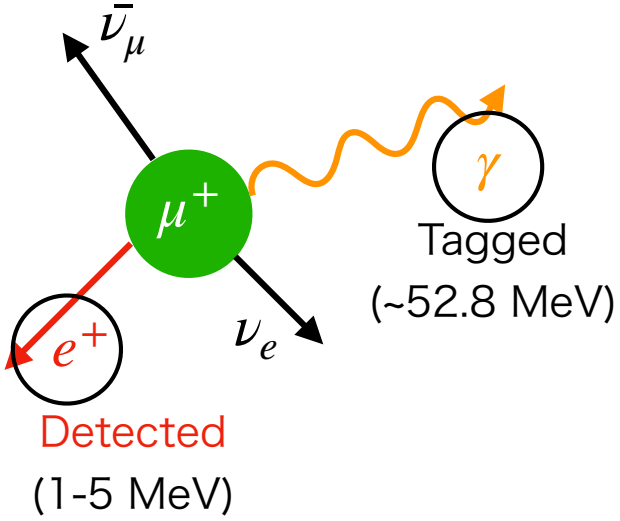
Outline

- Introduction
  - Upstream RDC for MEG II
  - DLC-RPC
  - Motivation for new resistive electrode
- Resistive electrode production
- Performance test
- Summary and prospects

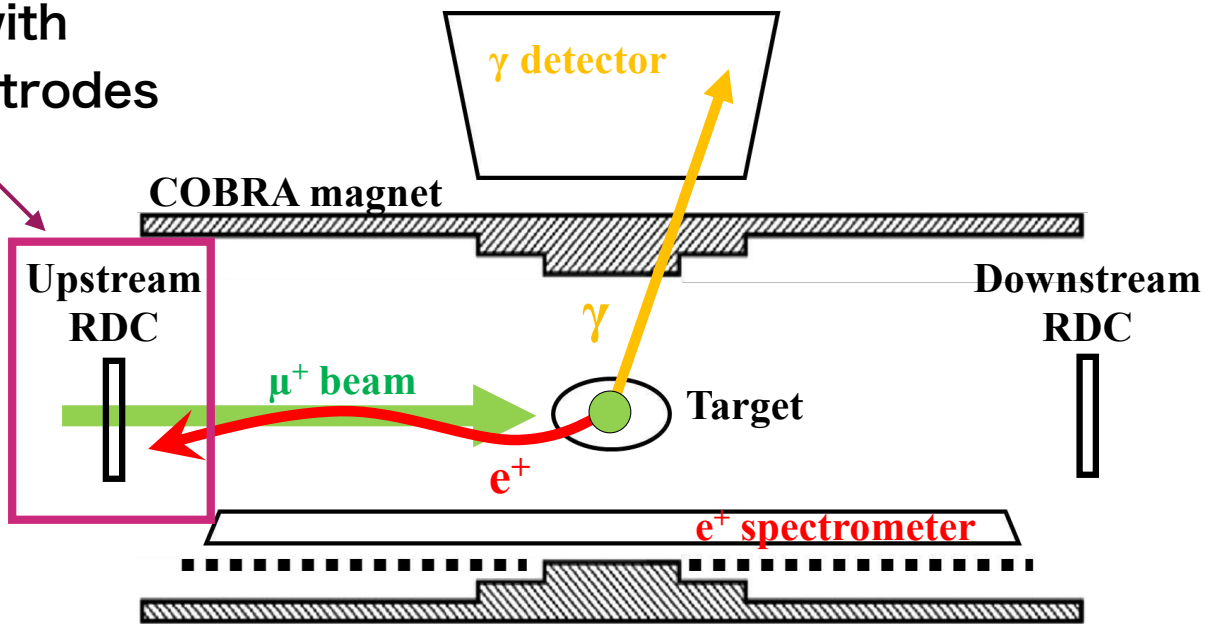
MEG II and RDC

- MEG II searches for $\mu \to e\gamma$ decay
- RDCs are detectors to tag BG-γ from Radiative Muon Decay (RMD)



Upstream RDC candidate:

Resistive Plate Chamber (RPC) with Diamond-Like Carbon (DLC) electrodes = DLC-RPC

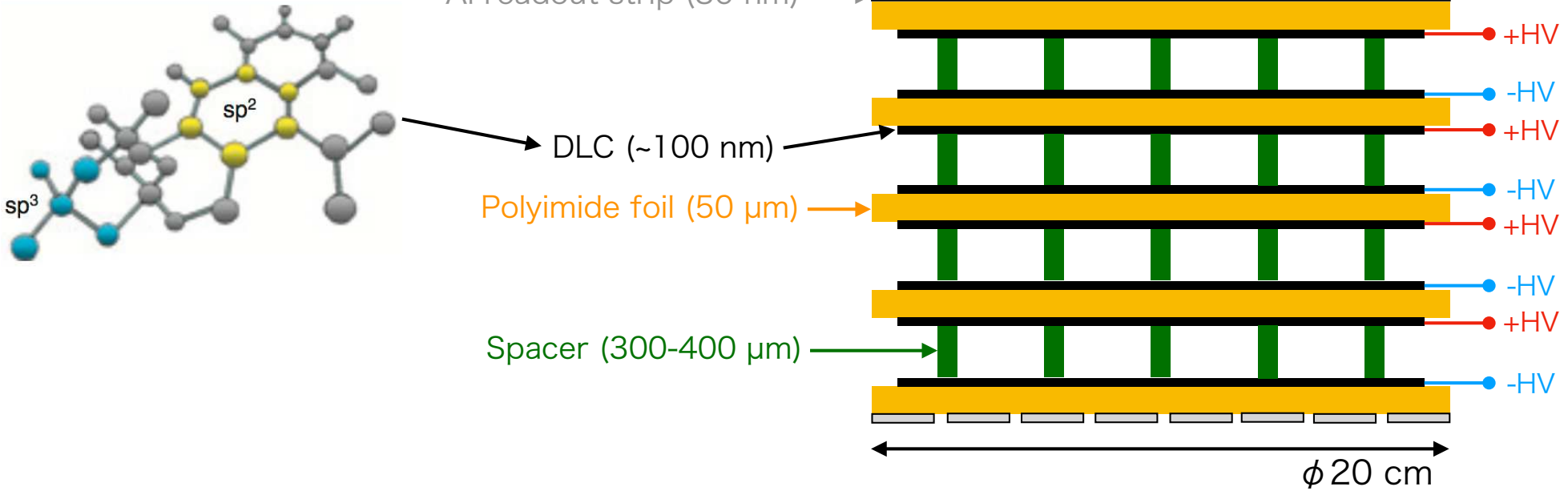


μ^+ beam

- Low momentum (28 MeV/c)
- **High rate (1×10^8 /s)**

DLC-RPC for MEG II

- Multi layers for higher detection efficiency
  - $\epsilon_n = 1 - (1 - \epsilon_1)^n$
- 4 layers limited for suppression of material budget
  - Low-momentum μ^+ beam passes through the detector



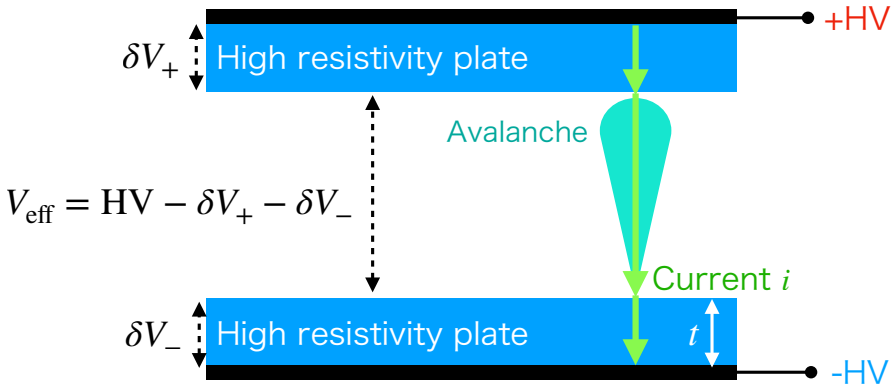
Rate capability & scalability

- Large current on resistive electrodes at high rate

➡ Voltage drop δV reduces effective applied HV V_{eff}

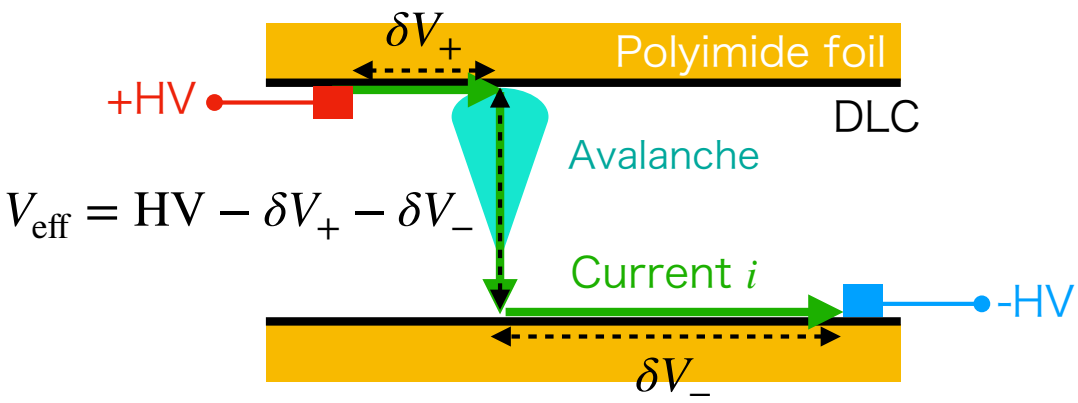
➡ Gas gain reduction

(Conventional) bulk RPC



$$\delta V = Q_{\mathrm{mean}}(V_{\mathrm{eff}}) \cdot f(x,y) \cdot \boxed{\rho_V} \cdot t$$

DLC-RPC



$$\boxed{\nabla^2 \delta V(x,y)} = Q_{\mathrm{mean}}(V_{\mathrm{eff}}) \cdot f(x,y) \cdot \boxed{\rho_S}$$

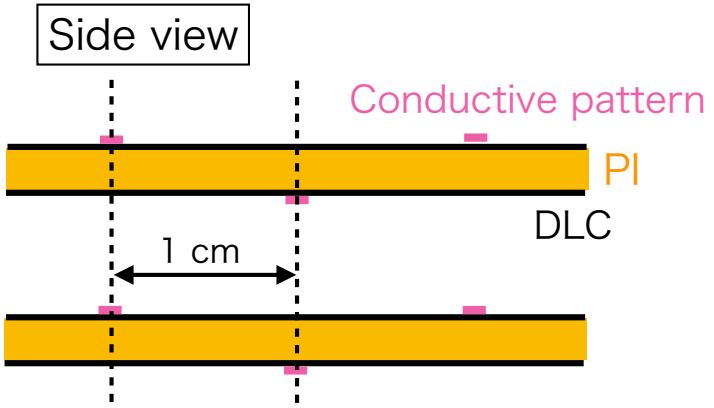
HV supply should be segmented

Motivation for new electrode

	Requirement	Prototype performance
Material budget	0.1% X_0	0.1% X_0
Rate capability	4 MHz/cm^2	**1 MHz/cm^2**
Radiation hardness	60 weeks operation	? Previous talk
Detection efficiency	90% for MIP	60% with single layer
Timing resolution	1 ns	170 ps (Next talk)
Detector size	20 cm diameter	**2 cm squared**

- HV supply segmented in new resistive electrode
  - Conductive pattern deposited on DLC

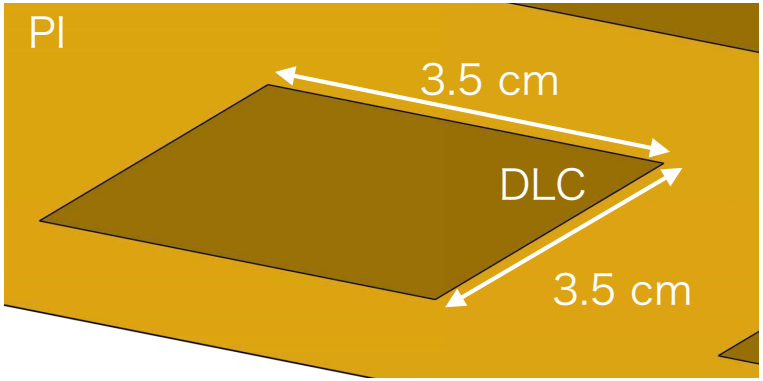
➜ **Higher rate capability and better scalability**



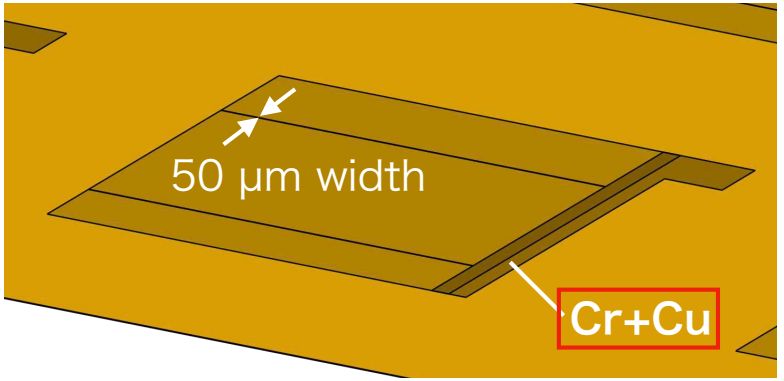
Outline

- Introduction
- Resistive electrode production
  - Production flowchart
  - Conductive pattern on DLC
  - Spacer formation
- Performance test
- Summary and prospects

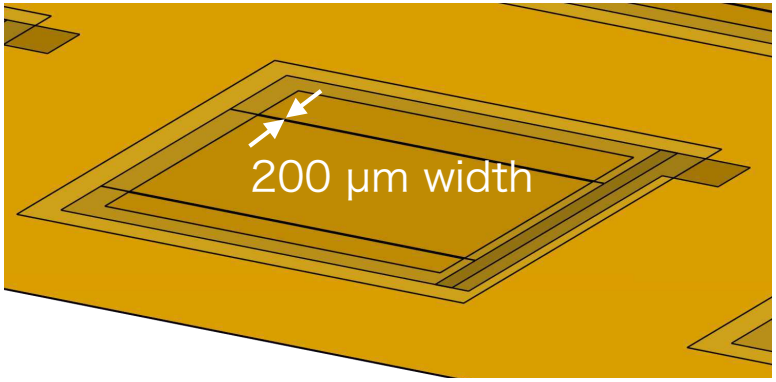
Production flowchart



1 - DLC sputtered on polyimide (PI) film

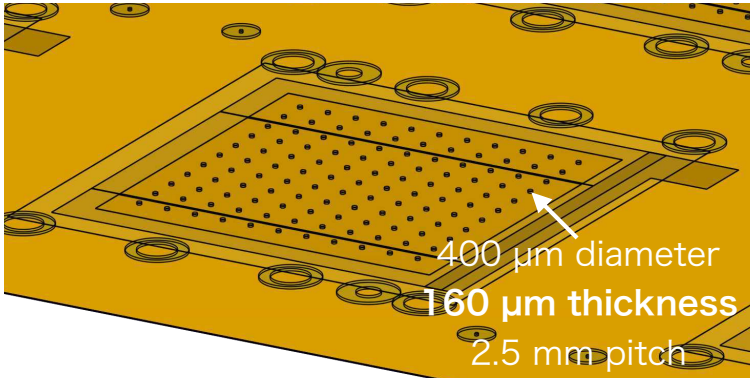


2 - Conductive pattern implemented



3 - Insulation cover deposited

- 25 μm-thick photo-resist
- Deposited on conductive pattern and DLC boundary



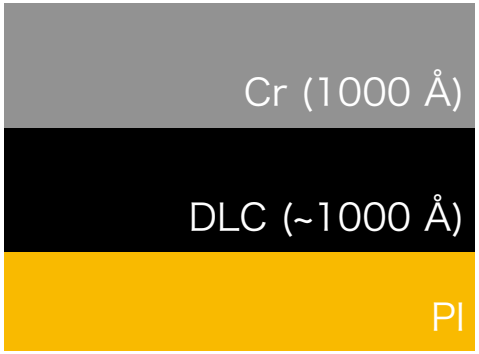
4 - Spacers formed

- ~160 μm-thick photo-resist
- **Doubly accumulated for >300 μm gap thickness**

Conductive pattern structure

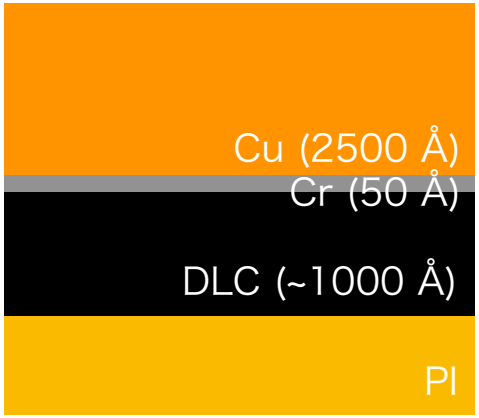
- Not trivial for metal to deposit on DLC
- **Cr can be well-connected**

1st trial

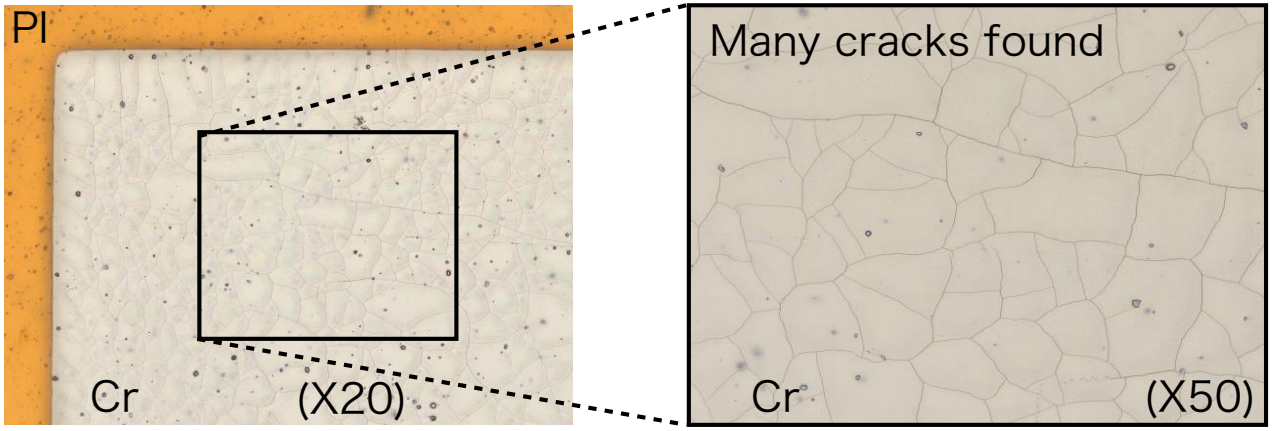


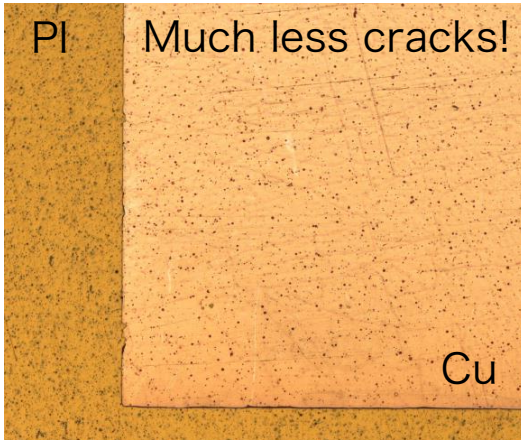
- Crack and removal of Cr
- Cr surface oxidised

Current structure

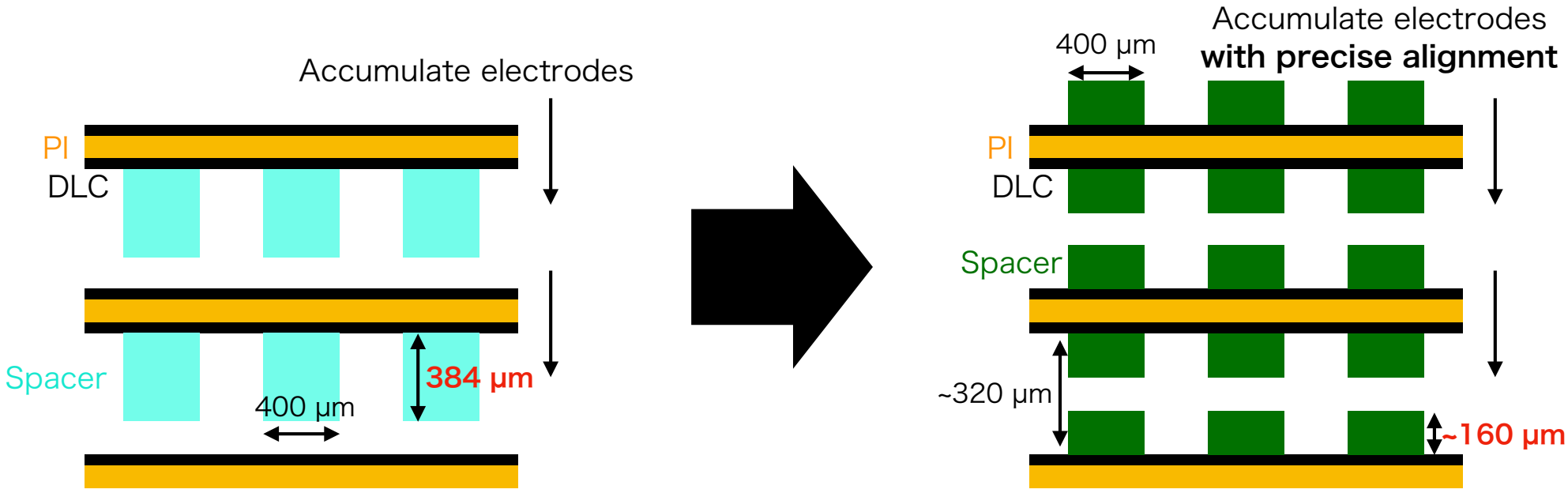


- **No problem found**





Spacer formation

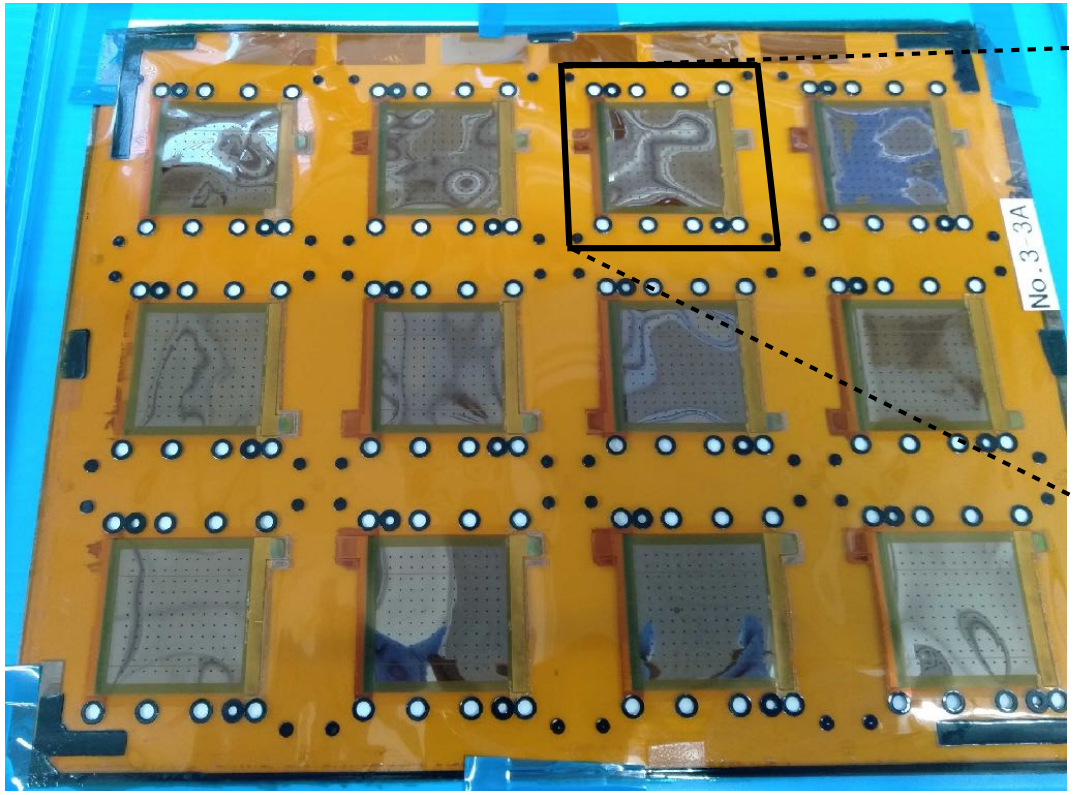


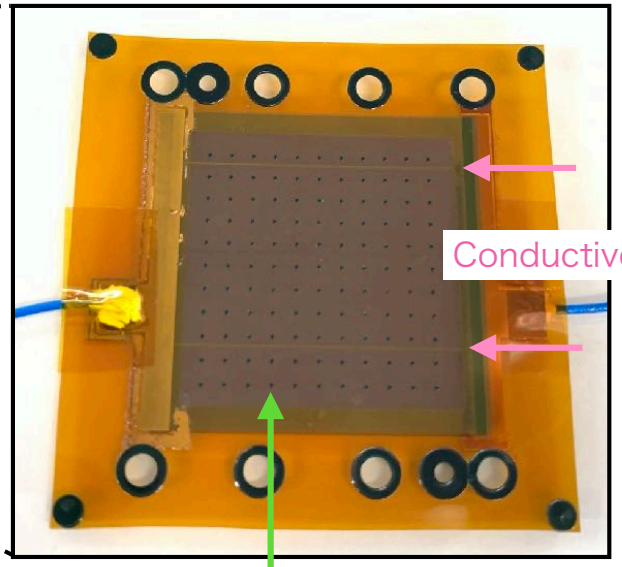
- Previous spacer material production cancellation

➡ New spacer material used

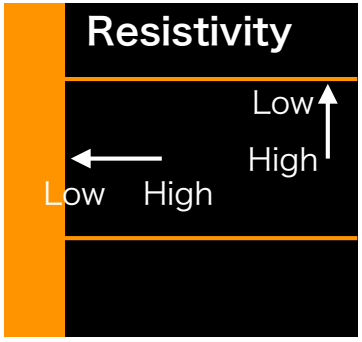
- >300 μm-thick spacers cannot be formed ⟷ 300 μm gap thickness needed for enough efficiency
- Strategies for enough gap thickness
  - **Form ~200 μm-thick spacers**
  - **Doubly accumulate spacers with precise alignment**

Produced electrode

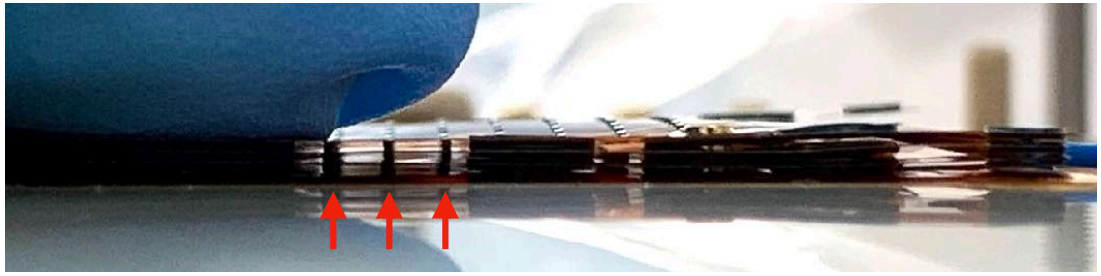




Good connection between Cr & DLC



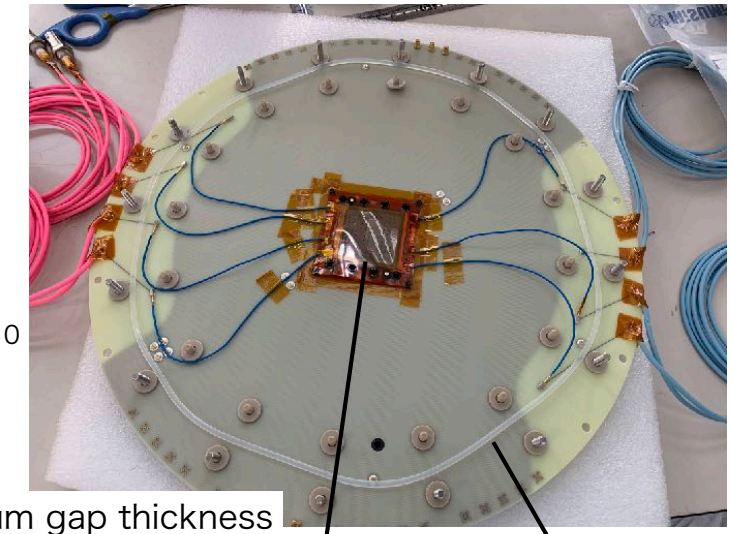
Good alignment

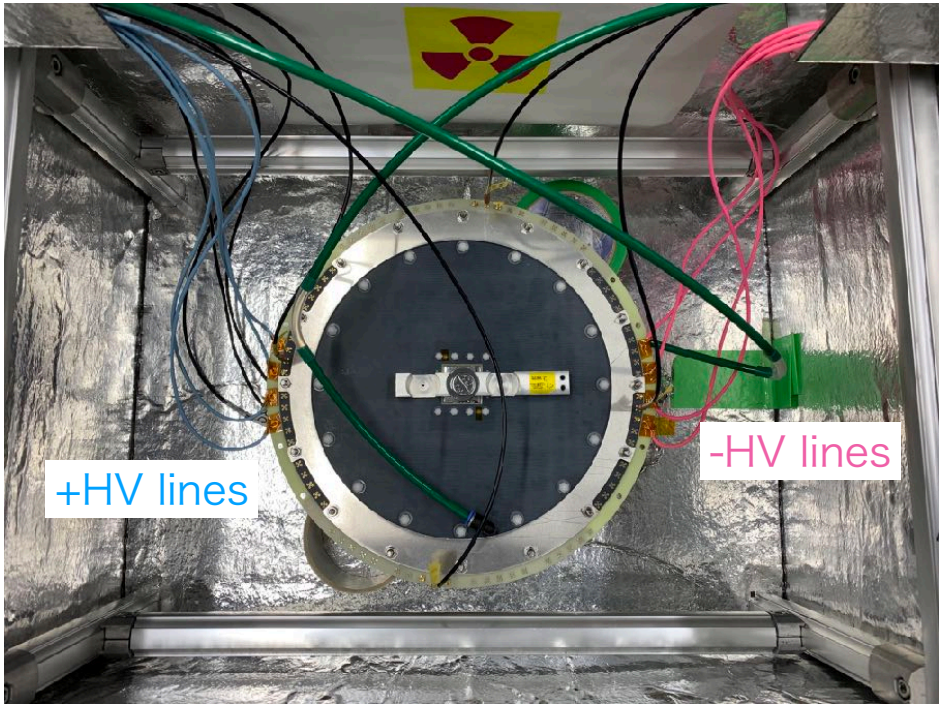


Outline

- Introduction
- Resistive electrode production
- Performance test
  - Setup
  - Gap thickness non-uniformity
  - Performance
- Summary and prospects

Test setup





Gas mixture
$R134a/SF_6/i\text{-}C_4H_{10}$
= 95/1/4

~320 μm gap thickness

Electrodes

O-ring

Sr90

Top

RPC

Bottom

38 dB
Amp.

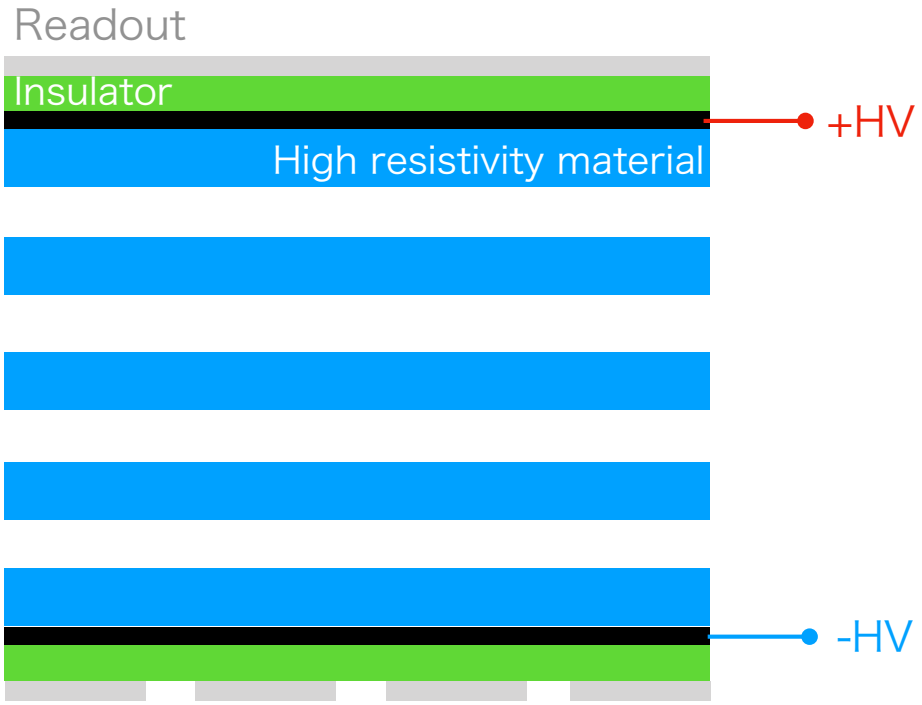
Waveform digitiser
(DRS4, 700 MHz)

Scintillation counter

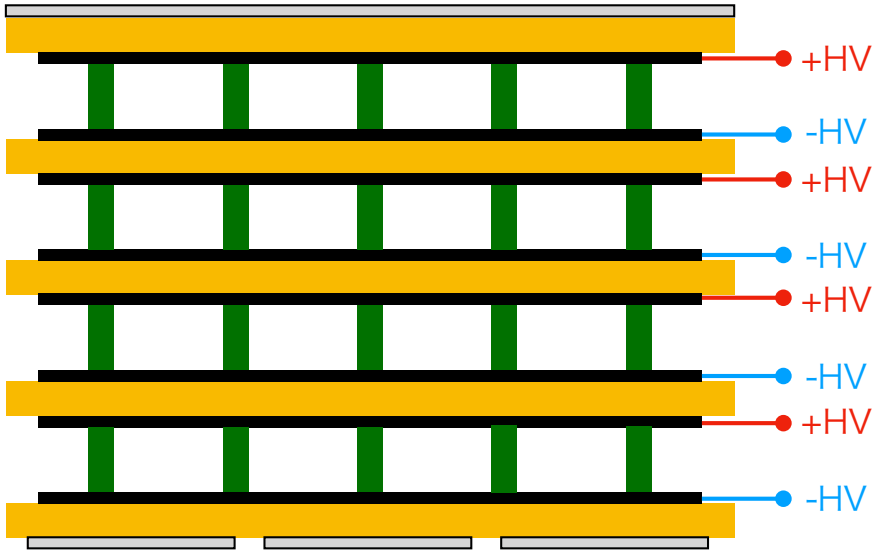
β

HV application system

(Conventional) bulk RPC



DLC-RPC



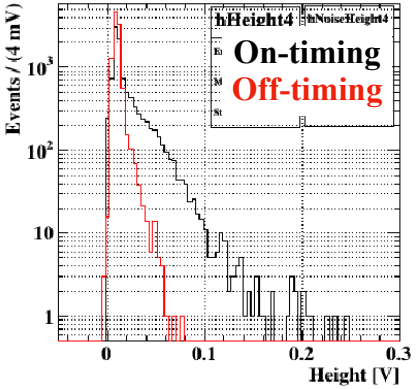
- DLC-RPC can apply HV to each layer
  - Absolute HV value can be small
  - **Operate each layer independently**

Gap thickness non-uniformity

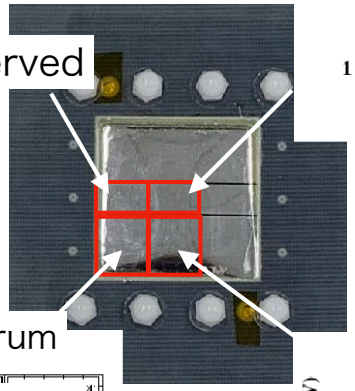
Non-uniformity in a layer

Detector response depends on β incident position

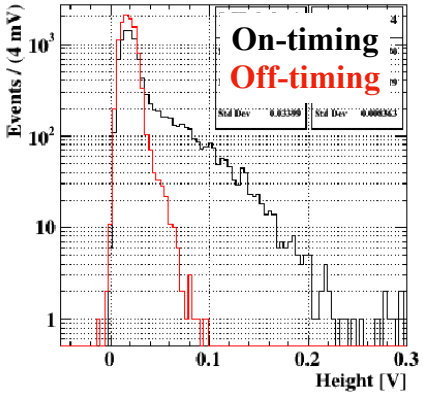
Height spectrum



No signal observed

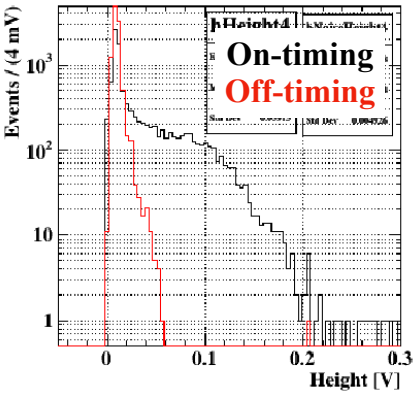


Height spectrum

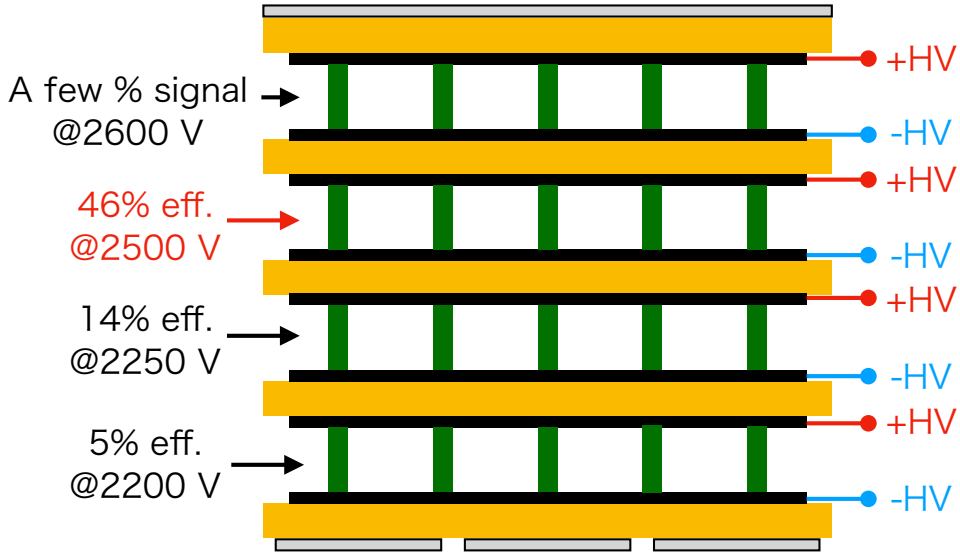


Large noise in this strip

Height spectrum



Non-uniformity among different layer

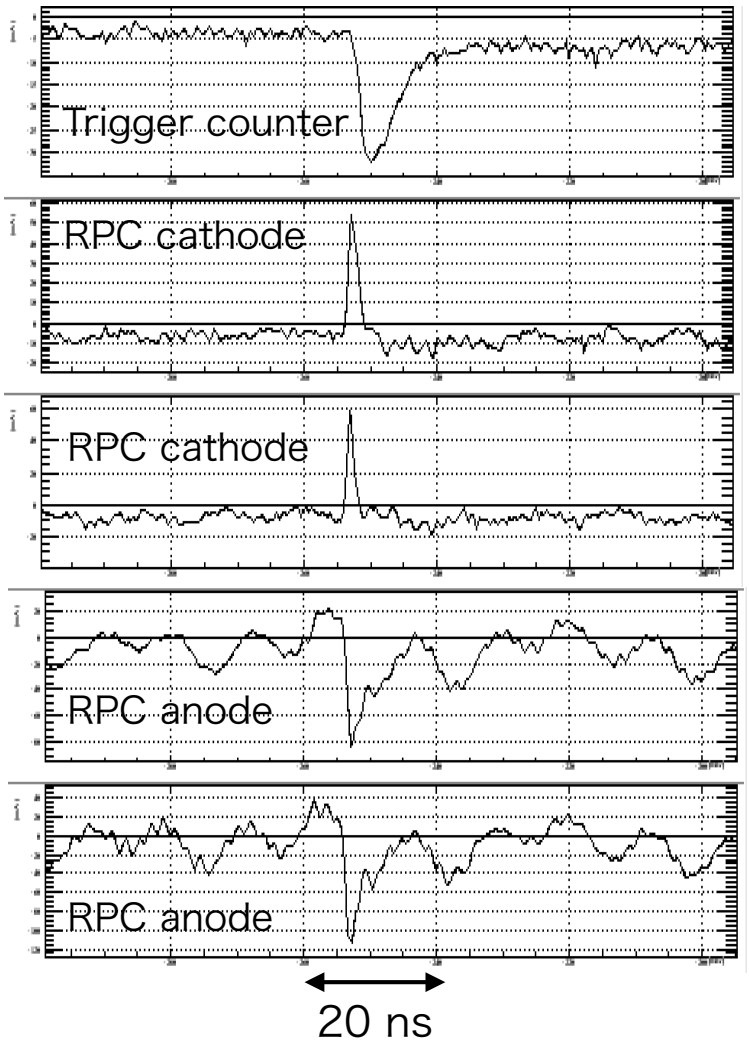


Different gap thickness among different layers

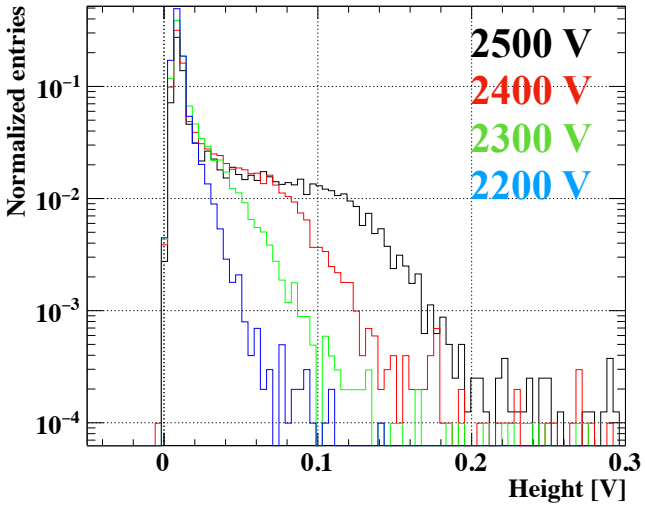
To be controlled for uniform gap thickness

Performance with only single layer

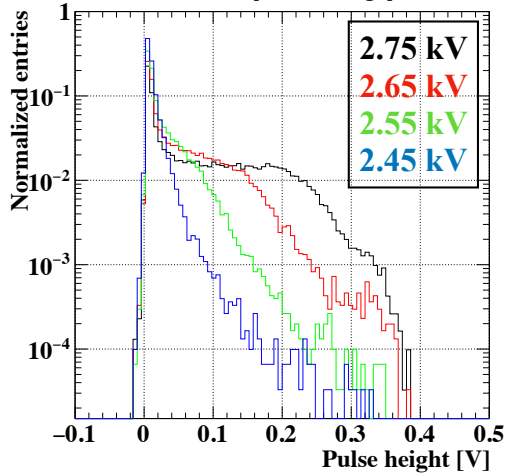
Event display



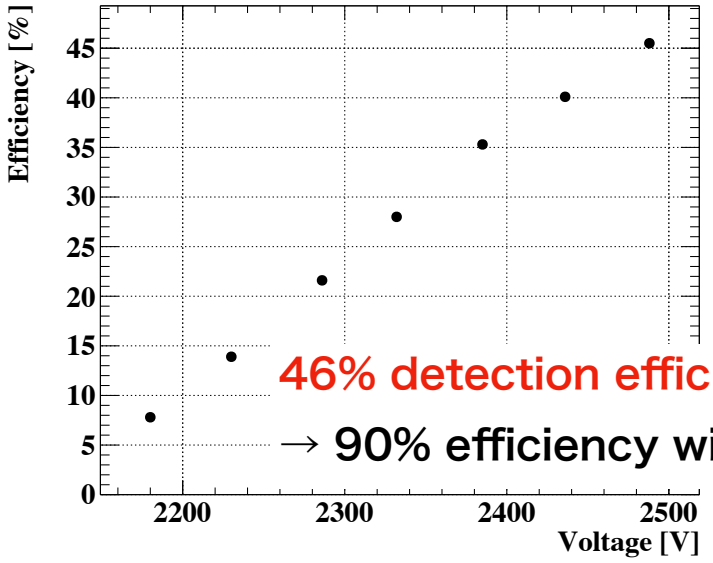
Pulse height spectra



Ref: height spectra with old prototype



Efficiency vs voltage



46% detection efficiency with single layer

→ **90% efficiency with 4 layer** $(1-(1-\epsilon_1)^4)$

Outline

- Introduction
- Resistive electrode production
- Performance test
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Summary

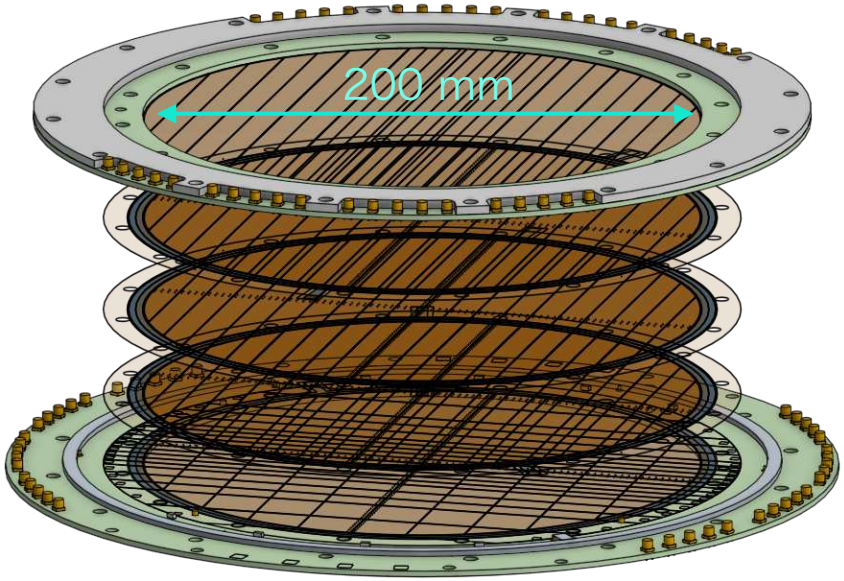
- High-rate capable DLC-RPC is under development for background reduction in MEG II experiment

- Improved resistive electrode developed
  - Conductive pattern implemented on DLC
  - Spacers formed and accumulated

- Performance tested
  - 46% detection efficiency achieved with single layer
    - 90% detection efficiency achievable with 4 layers
  - Gap thickness non-uniformity found

Prospects

- Operation with all the layers
  - Gap thickness to be controlled
- Performance evaluation with
  - β-ray at $\mathcal{O}(100\ \mathrm{kHz/cm^2})$
  - μ^+ beam at $4\ \mathrm{MHz/cm^2}$ at PSI

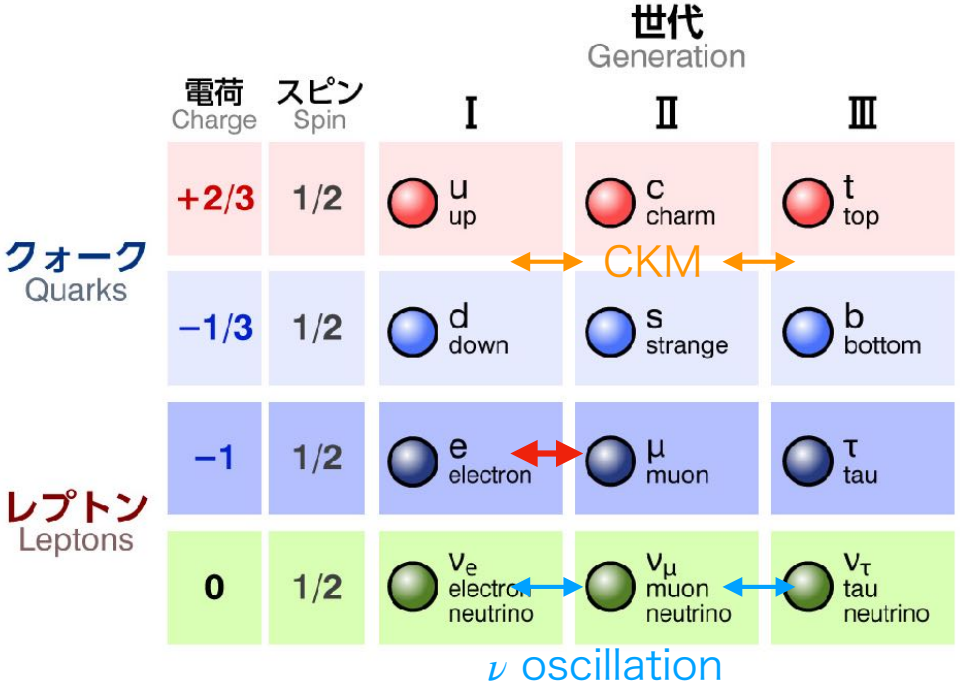


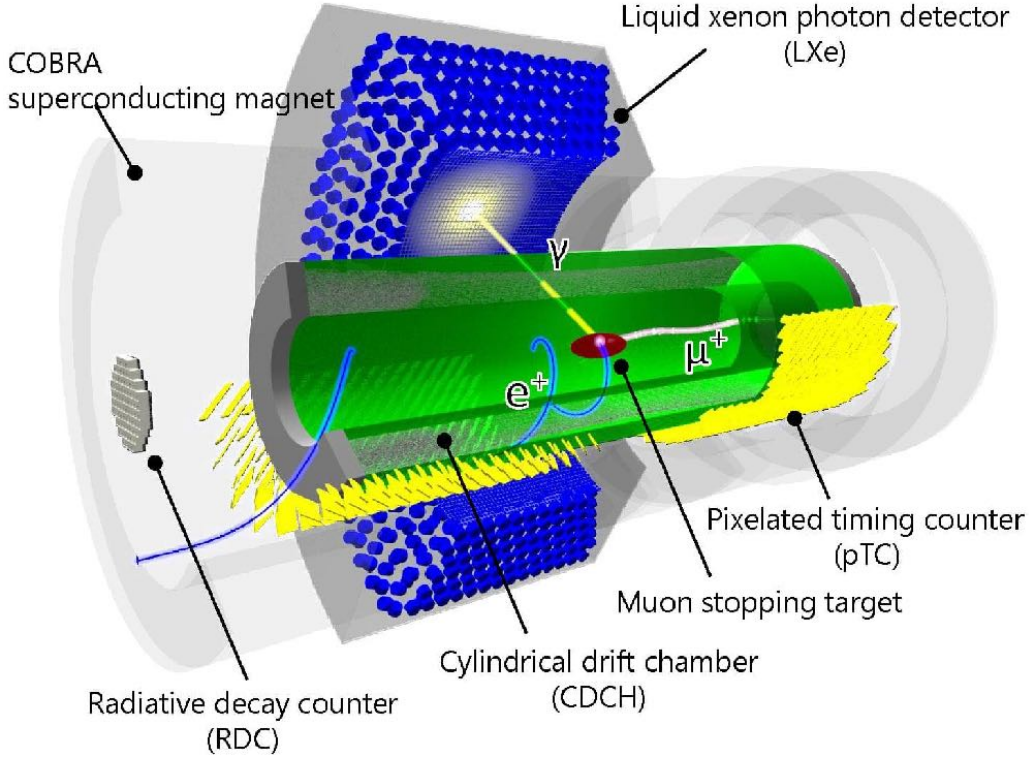
- Actual detector production and construction
- Aim at installation to MEG II in 2023 physics run

Backup

MEG II experiment

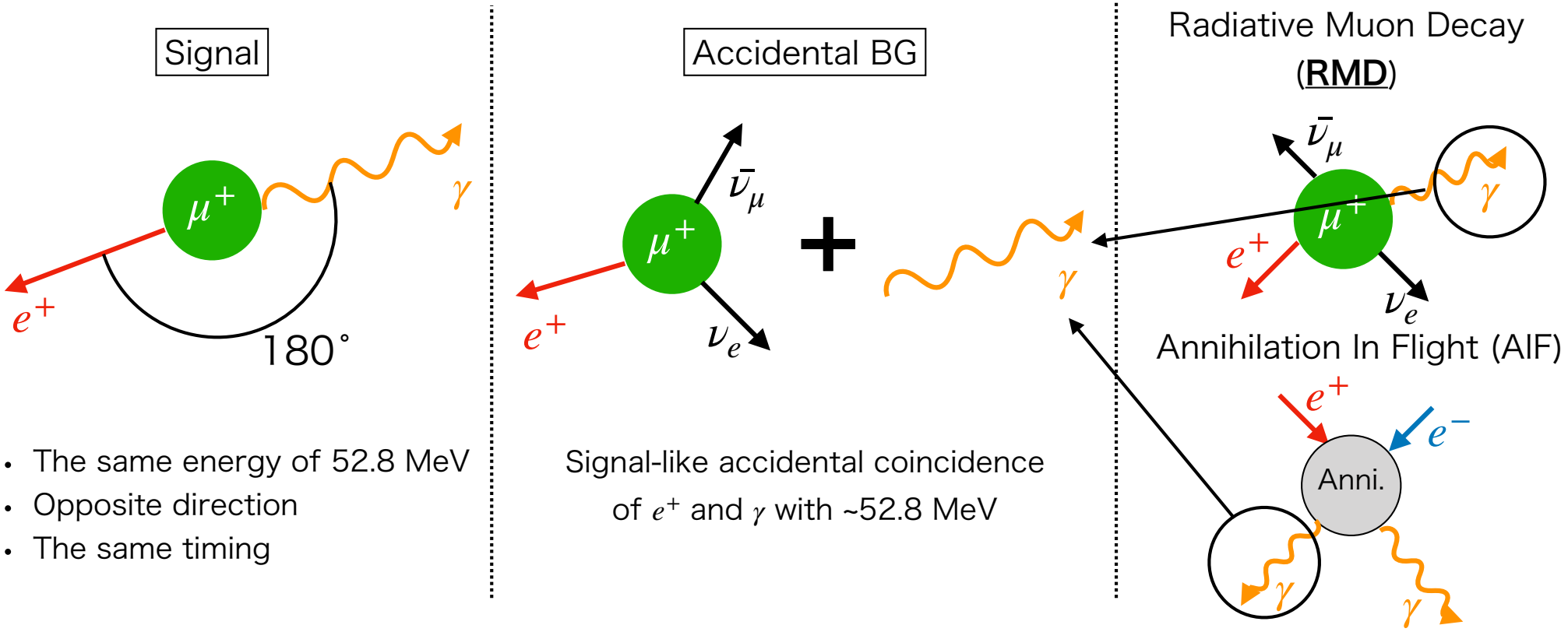
- MEG II searches for $\mu^+ \to e^+\gamma$ decay with the sensitivity of 6×10^{-14}
  - SM + ν osc: $\mathcal{B}(\mu^+ \to e^+\gamma) \sim 10^{-54}$
  - BSM (SUSY-GUT, SUSY-seesaw): $\mathcal{B}(\mu^+ \to e^+\gamma) \sim 10^{-11} - 10^{-15}$





MEG II signal and background

- MEG II searches for $\mu \to e\gamma$ decay, one of charged lepton flavour violation (cLFV) channels
- Dominant background is accidental coincidence of BG-e^+ and BG-γ

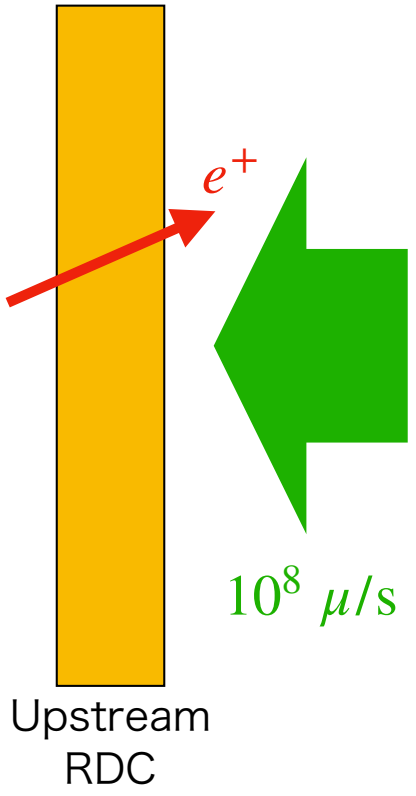


- The same energy of 52.8 MeV
- Opposite direction
- The same timing

Signal-like accidental coincidence of e^+ and γ with ~52.8 MeV

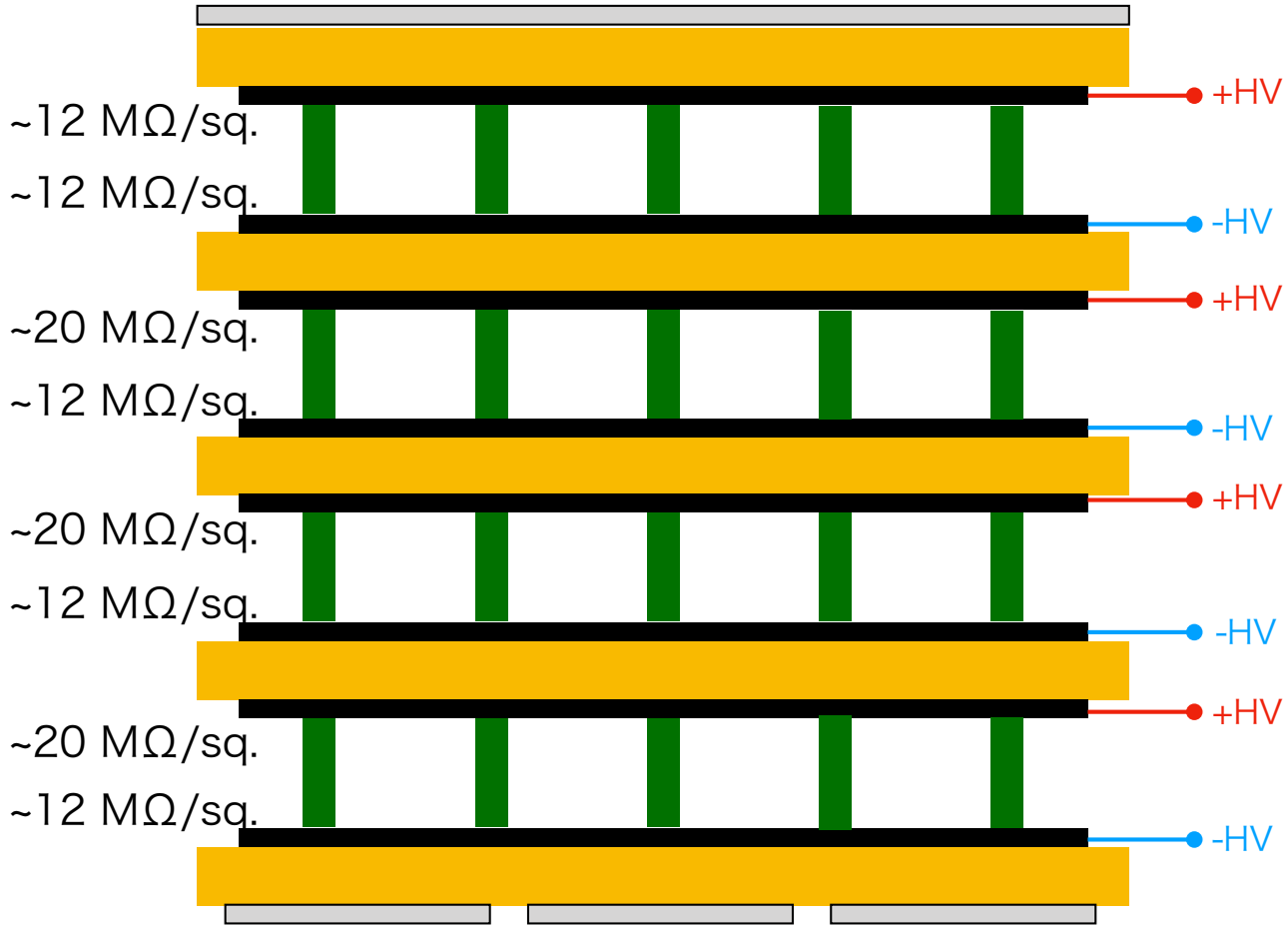
Requirements for upstream RDC

1. <0.1% X_0 material budget
   - μ beam with 21 MeV/c must pass through the detector
2. Rate capability for 10^8 μ/s (4 MHz/cm^2)
3. Radiation hardness for >60 weeks operation
4. 90% efficiency for RMD e^+ with 1-5 MeV
5. 1 ns timing resolution
6. 20-cm diameter detector size

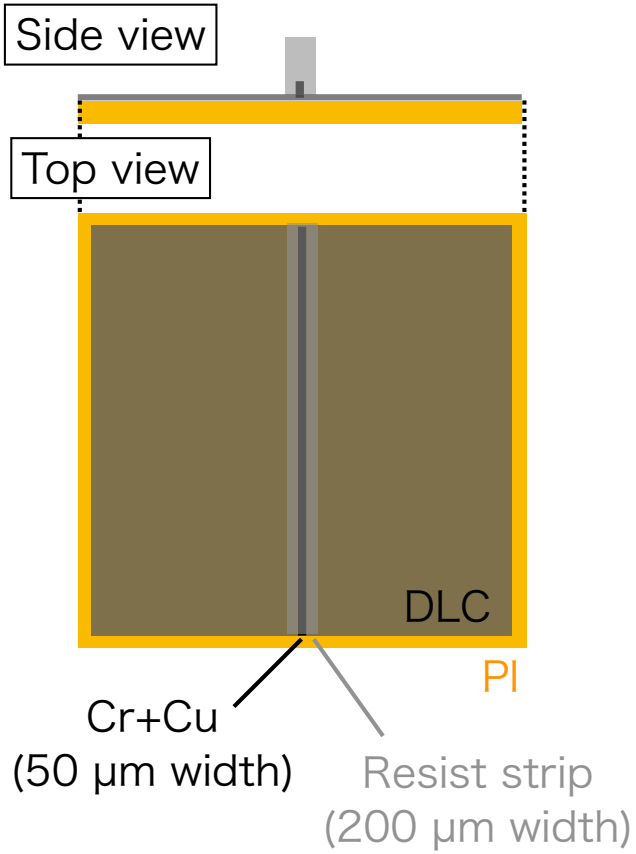


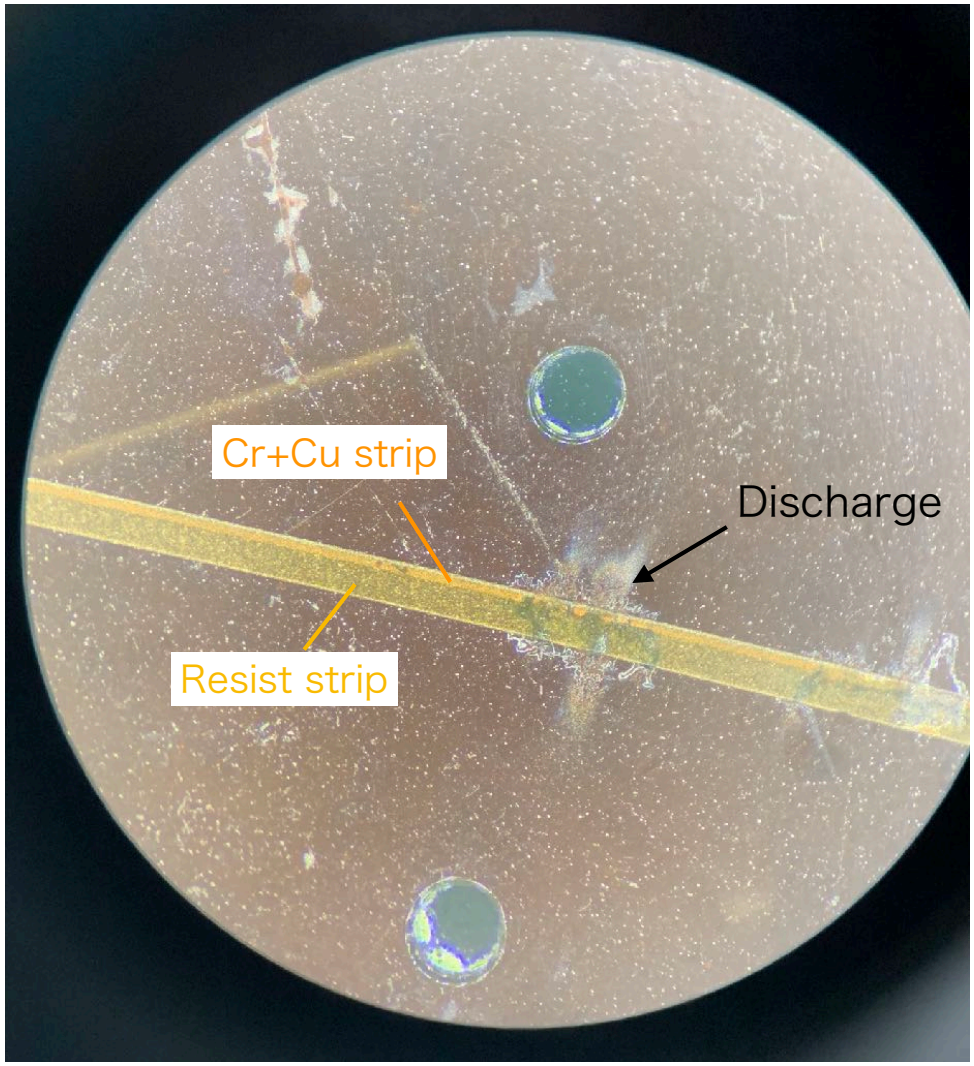
High-rate capable RPC with Diamond-Like Carbon electrodes for upstream RDC

Sheet resistivity

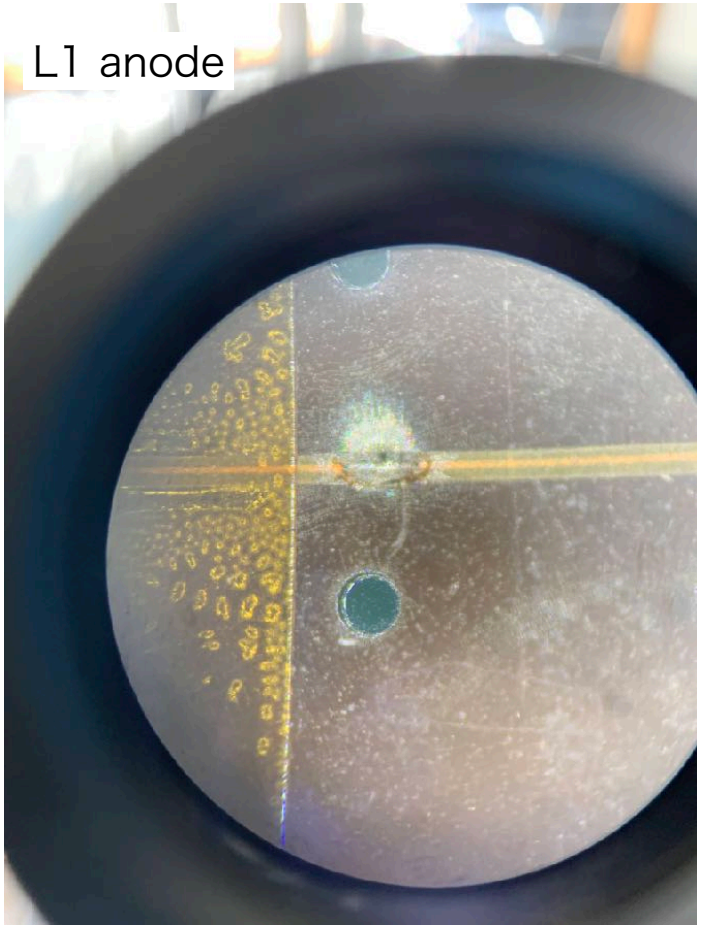


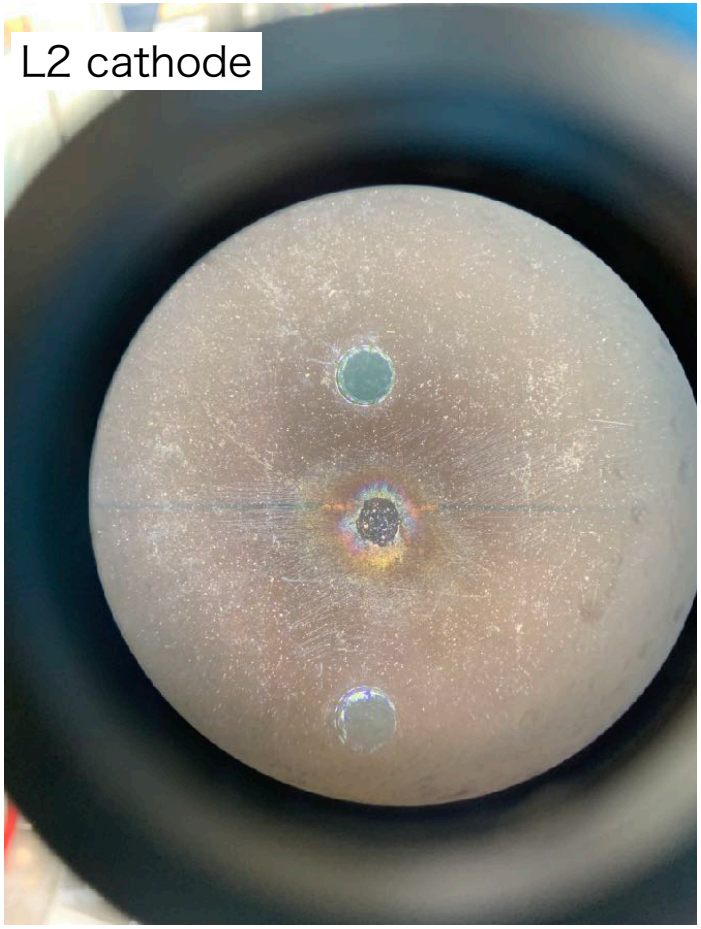
Strip alignment





Damages in electrodes

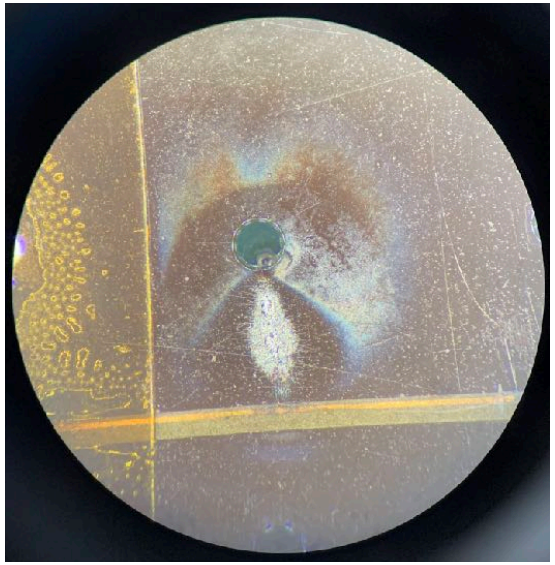




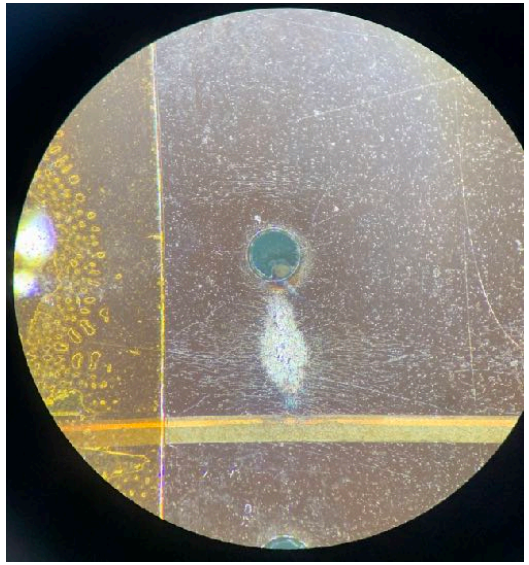
カプトンを突き抜けて導通している
一度掃除したら導通しなくなったが、1200 Vあたりまでかけると再発

Damages in electrodes

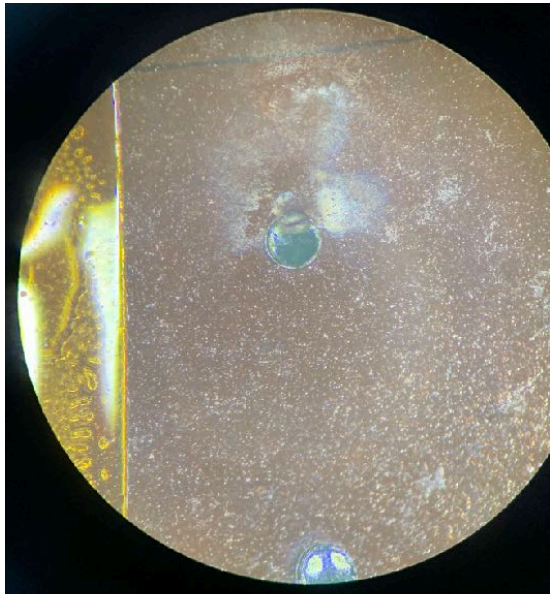
Anode

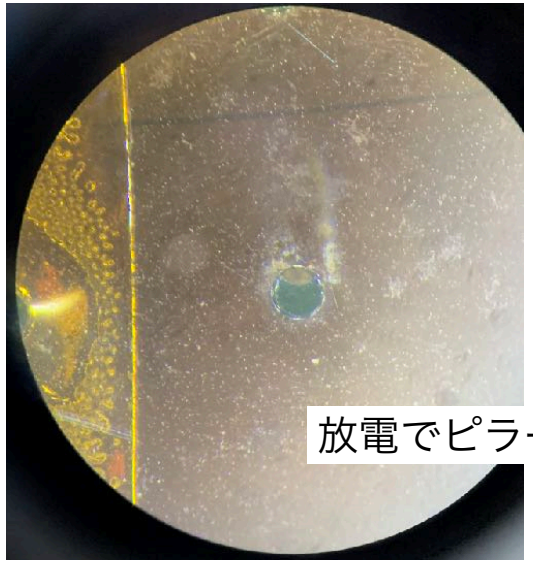


イソプロパノールで拭く



Cathode





放電でピラーが欠ける