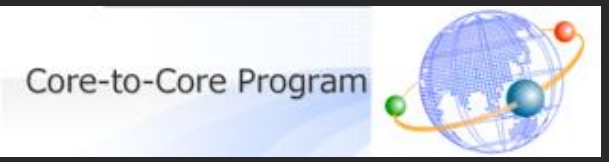


MEG II 実験 DLC-RPC の放射線耐性と動作安定性の研究

神戸大理　高橋 真斗

家城 佳[A], 大谷 航[A], 大矢 淳史[B], 越智 敦彦, 恩田 理奈[B], 鈴木 大夢, 潘 晟[A],
山本 健介[B], 李 維遠[B], 他 MEG II コラボレーション
(神戸大理, 東大素セ[A], 東大理[B])

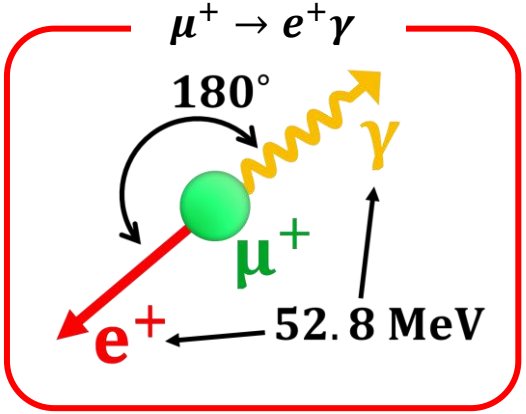
日本物理学会第78回年次大会 (2023 年)

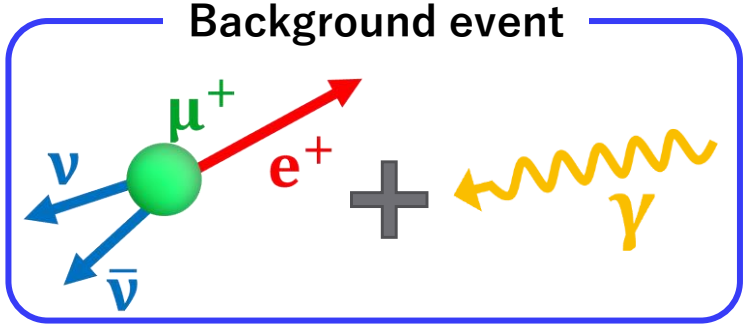
Outline

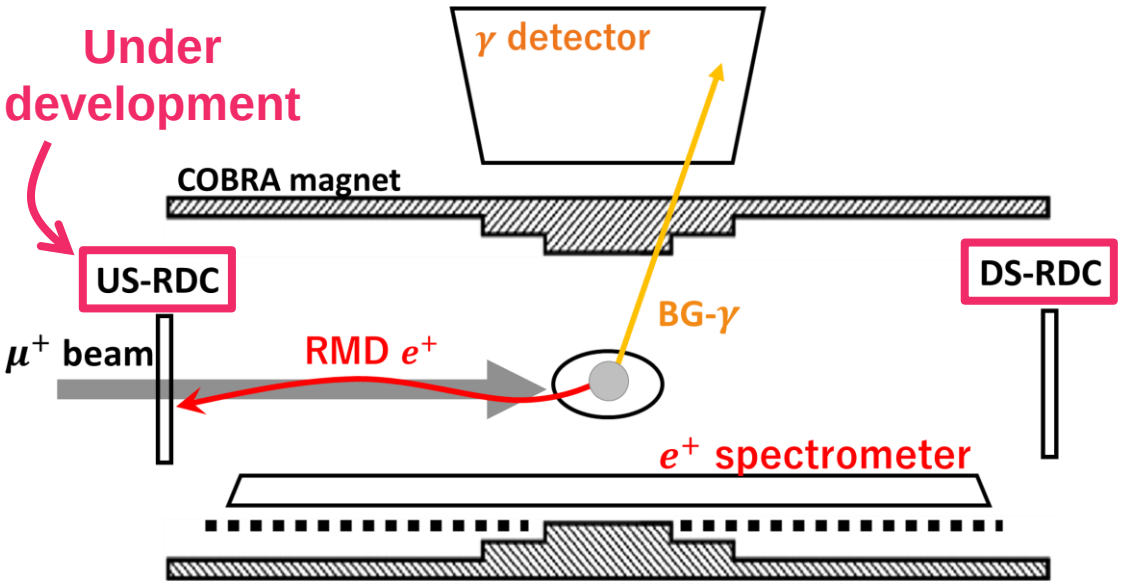
- **Introduction**
  - MEG II experiment and Radiative Decay Counter
  - Upstream RDC and RPC using Diamond-Like Carbon electrodes
  - Requirement of radiation hardness for DLC-RPC
  - Previous aging tests
- **The aging test of DLC-RPC**
  - Irradiation facility and test setup
  - Status of long-term irradiation
  - Aging effects
- **Summary and Prospects**

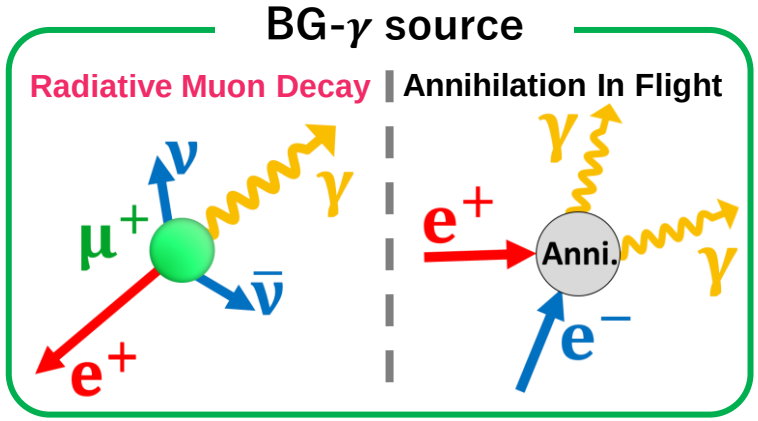
MEG II experiment and RDC

- MEG II searches for $\mu^+ \to e^+\gamma$ decay
  - Charged lepton flavor violation process
    ➔ Clear evidence for new physics
- Main background is accidental background
  - BG-γ from radiative muon decay will be tagged by Radiative Decay Counter





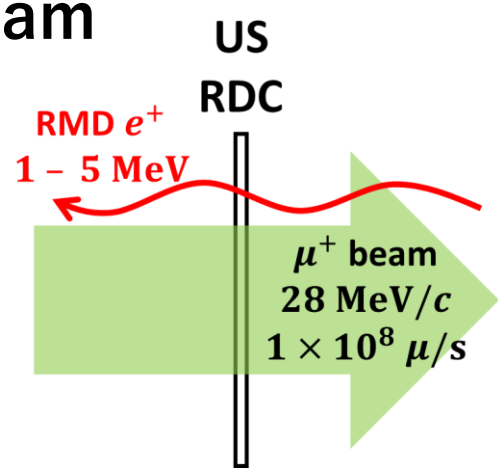




Requirements for upstream RDC

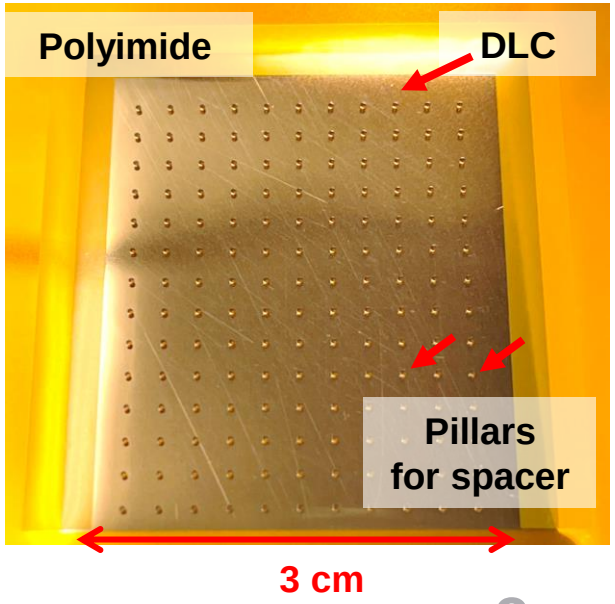
- Upstream RDC need to detect positrons from RMD in high-rate and low-momentum muon beam

		$(5.7 \times 10^7\ \mu/s)$ / $(28\ \mathrm{MeV/c})$
1.	Material budget:	$< 0.1\%$ of radiation length
2.	Rate capability:	$2.3\ \mathrm{MHz/cm^2}$
3.	Radiation hardness:	> 30 weeks operation
4.	Detection efficiency:	$> 90\%$ for MIP e^+
5.	Time resolution:	< 1 ns
6.	Detector size:	20 cm diameter



Development of RPC using Diamond-Like Carbon electrodes

- Features of DLC-RPC
  - Low mass by sputtered DLC on polyimide
  - Rate capability improved by low DLC resistivity
  - Spacers formed by photolithography technology



Requirements of radiation hardness

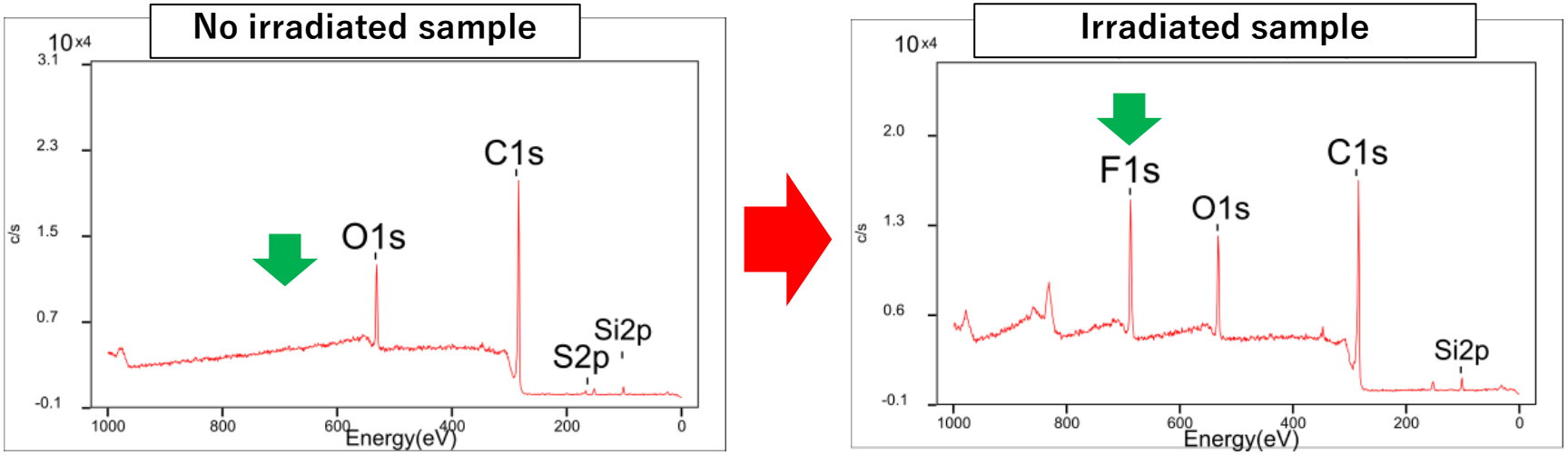
- Continuous operation during the physics run in the MEG II experiment
  - Physics run period : $30\ \mathrm{weeks/year}$
  - Rate of muon beam at the center: $2.3\ \mathrm{MHz/cm^2}$
  - Average avalanche charge of muon: $3\ \mathrm{pC}$

➔ $\sim 125\ \mathrm{C/cm^2}$ equivalent irradiation dose

- Carried out the aging tests to evaluate the radiation hardness of DLC-RPC

DLC-RPC irradiation campaign in 2022

- Aging tests using fast neutron and X-ray in 2022
  - Total irradiation dose
    - For neutron: $\sim 165\ \mathrm{mC/cm^2}$
    - For X-ray: $\sim 8.2\ \mathrm{C/cm^2}$
  - Results
    - Fluorine deposited on DLC electrodes
    - No change in DLC-RPC performance



Reported on JPS 2022 autumn

DLC-RPC irradiation campaign in 2023

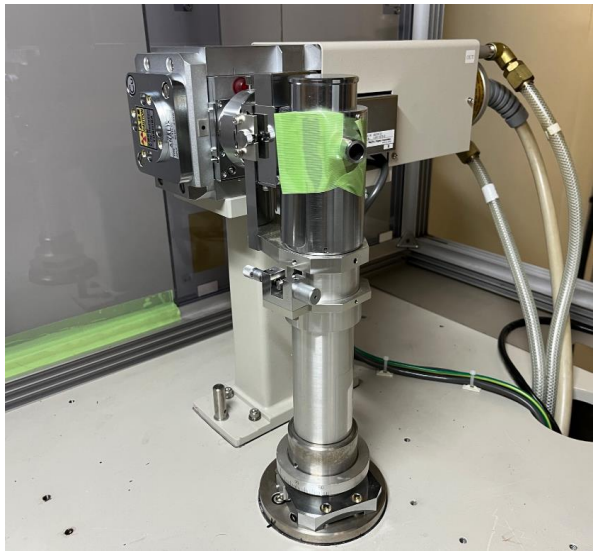
- The aging test using X-ray carried out again in 2023
  - Aging tests 2022 obtained less irradiation than expected
    ➔ Further irradiation required
- Test period: 2023/8/17 – 9/11

Today's topics

- The results of DLC-RPC aging test using X-ray
  - Reported preliminary results in this talk (17pR81-1)
- Development for ionization chamber for X-ray monitoring detector
  - Hiromu will report on next talk (17pR82-2)
  - For more detailed X-ray intensity studies

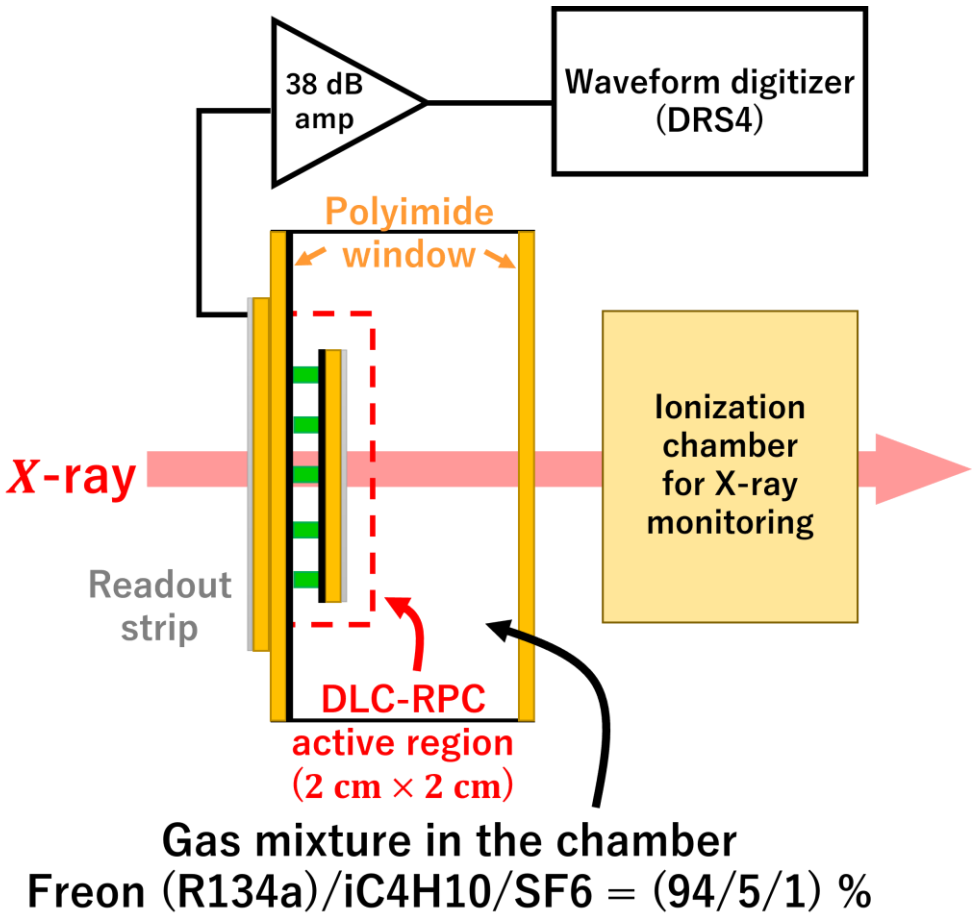
X-ray irradiation test

- X-ray generator at KEK Platform-C
  - Also using in the aging test in 2022
- Properties
  - Target: Cu (X-ray with $8\ \mathrm{keV}$)
    - With monochromator
  - Maximum output: $1.8\ \mathrm{kW}$
    - Tube voltage: 60 kV (50 kV in this test)
    - Tube current: 30 mA



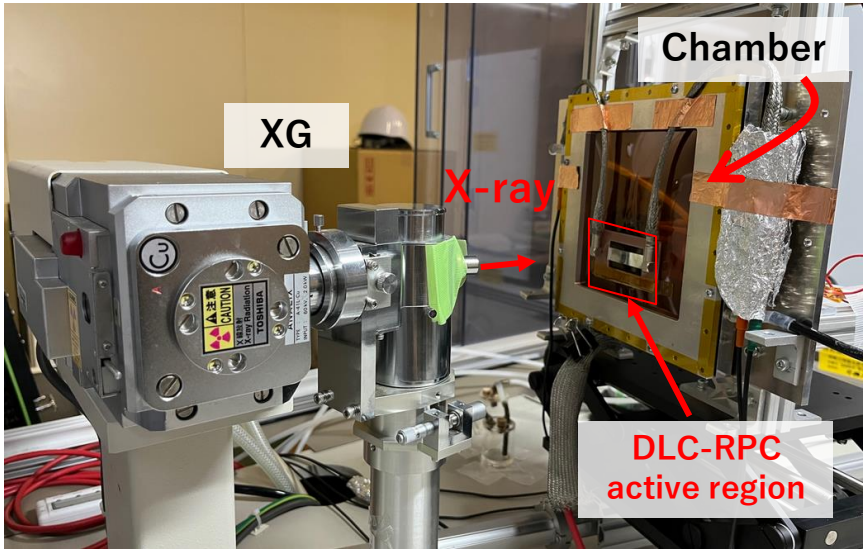
Setup of tests

Scheme of setup



Gas mixture in the chamber
Freon (R134a)/iC4H10/SF6 = (94/5/1) %

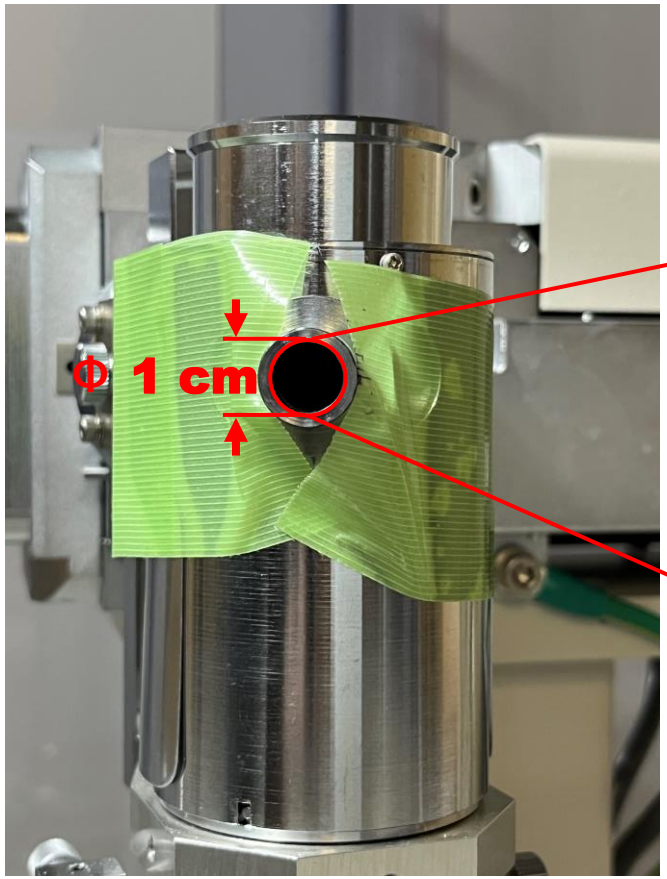
Front of the chamber

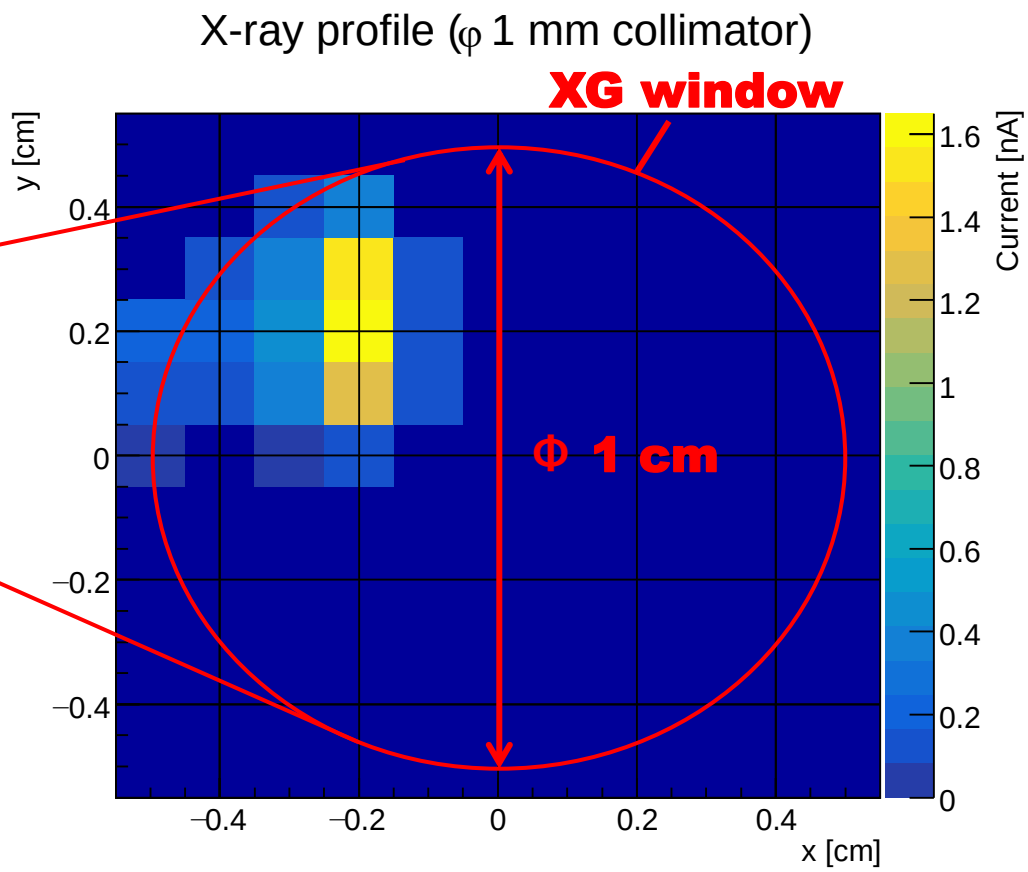


Actually irradiated at close range

Profile of *X*-ray beam

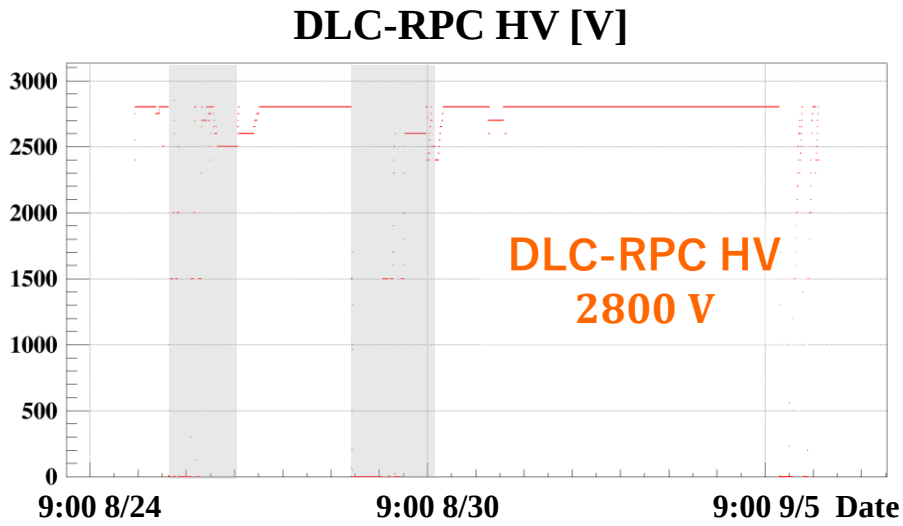
- Measurement by ionization chamber with Pb collimator (see next talk)

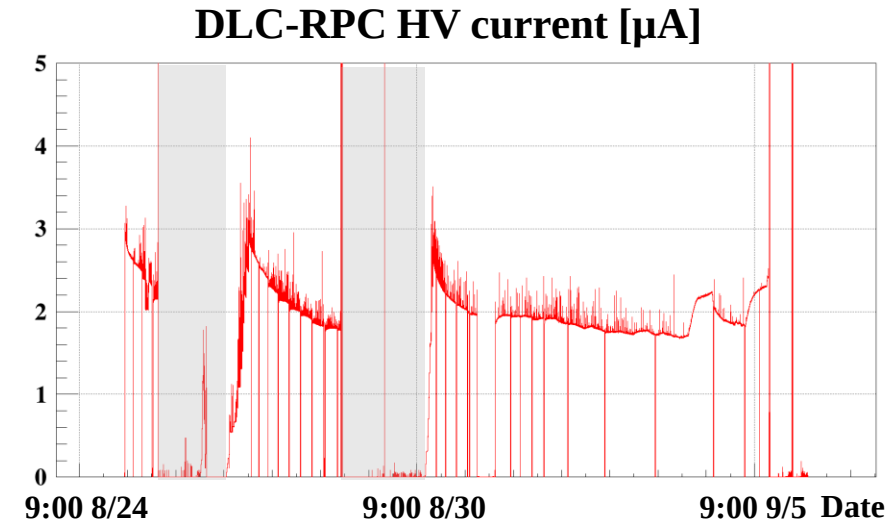


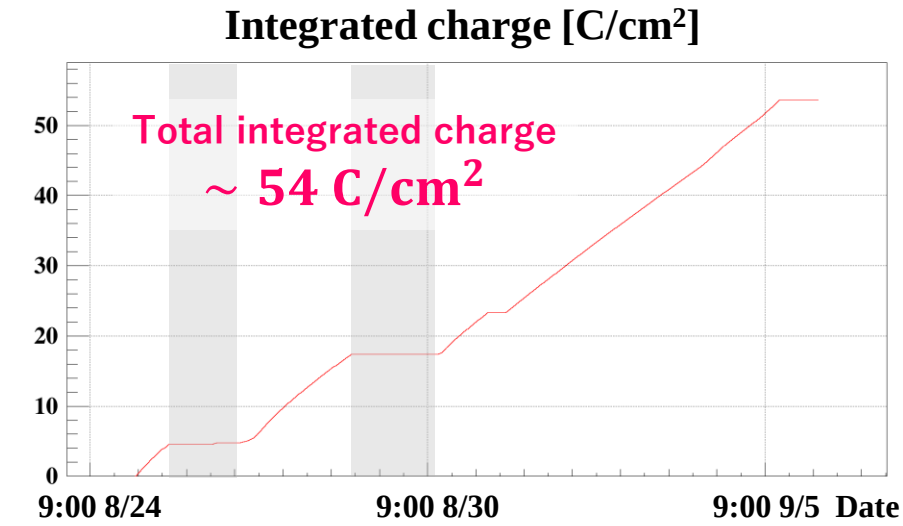


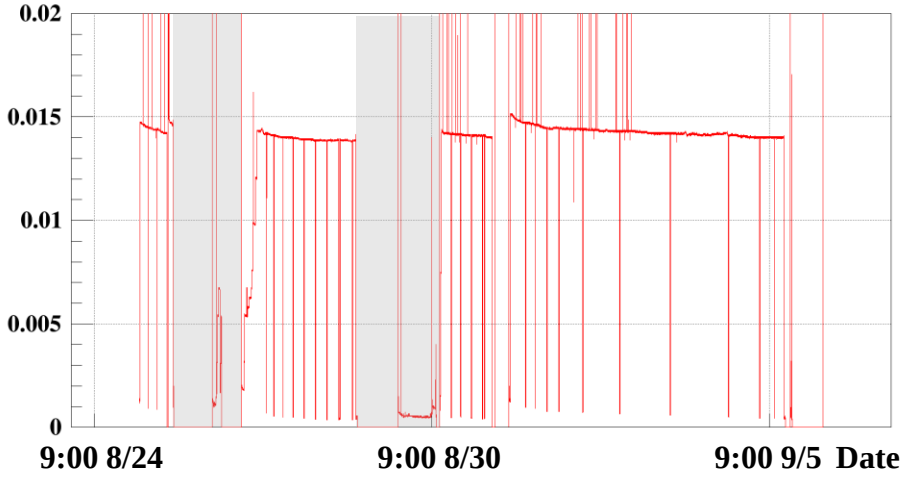
Status of DLC-RPC during irradiation

- Shaded period: not irradiated due to discharge problems



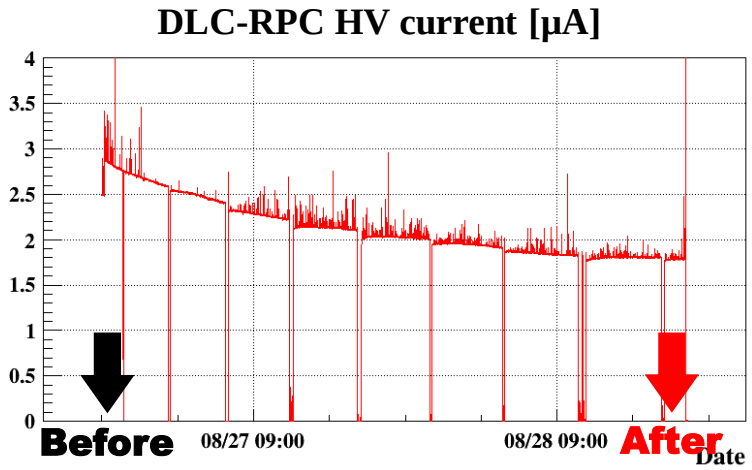


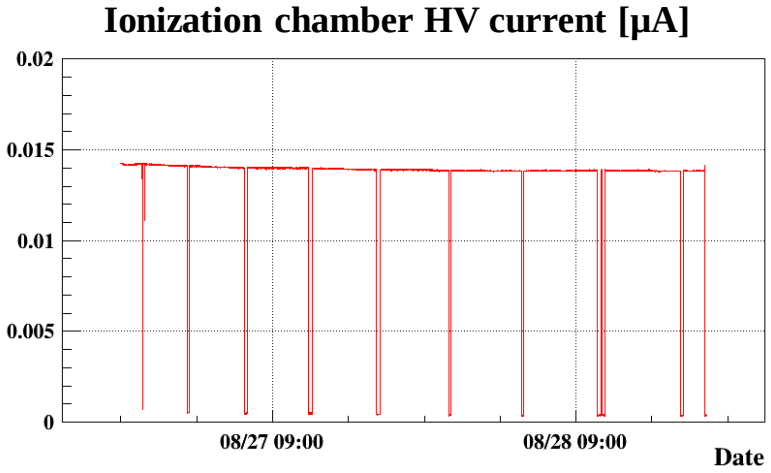


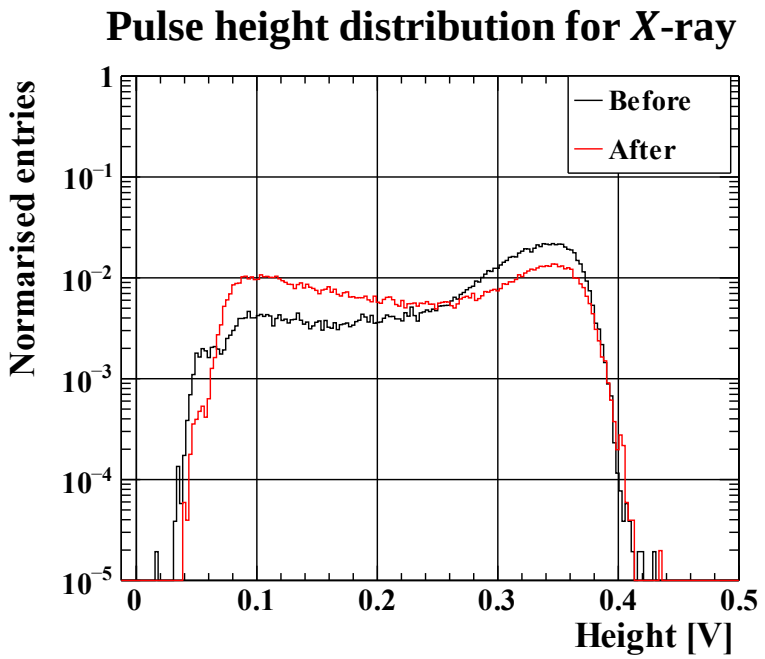


DLC-RPC current transition

- DLC-RPC HV current decreased during irradiation
  - Different from the ionization chamber HV current change
    - ➔ Changes in DLC-RPC performance



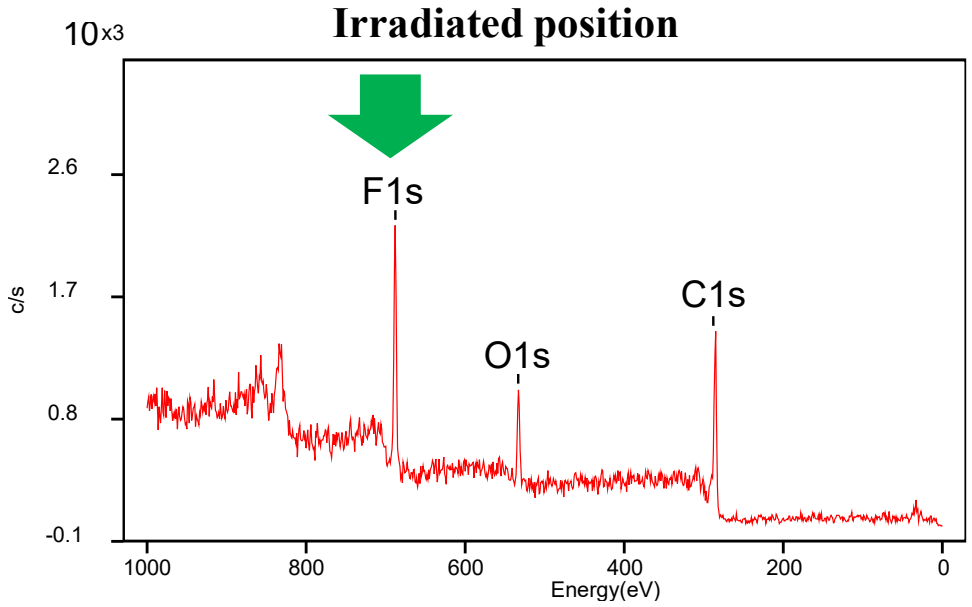


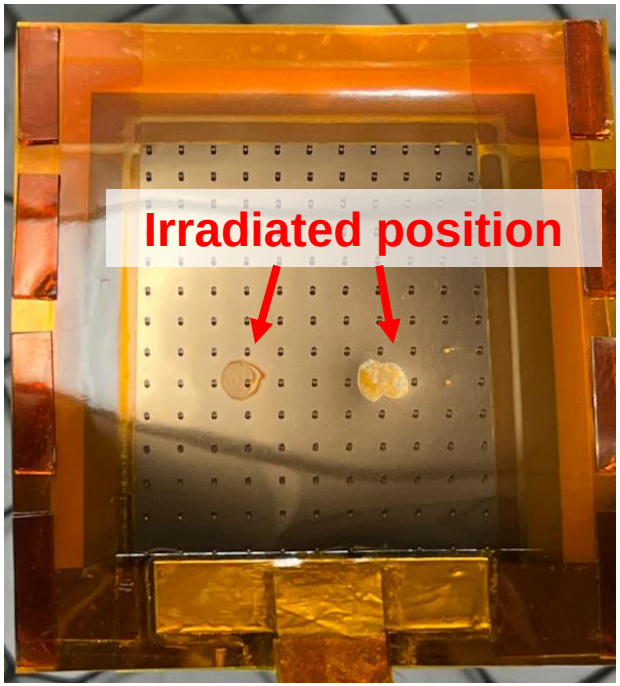


- ➢ No recovery with gas flow or HV off
- ➢ Cleaning electrodes recovers current
  - ➔ Effects of some deposition

Electrodes surface condition

- **Fluorine deposition to DLC**
  - Using X-ray photoelectron spectroscopy
- **Discoloration of DLC due to irradiation**
  - Increased in resistivity of DLC (~ 60 MΩ/sq. ➔ ~ 100 MΩ/sq.)
    - Affects rate capability of DLC-RPC
  - Easy peeling of DLC





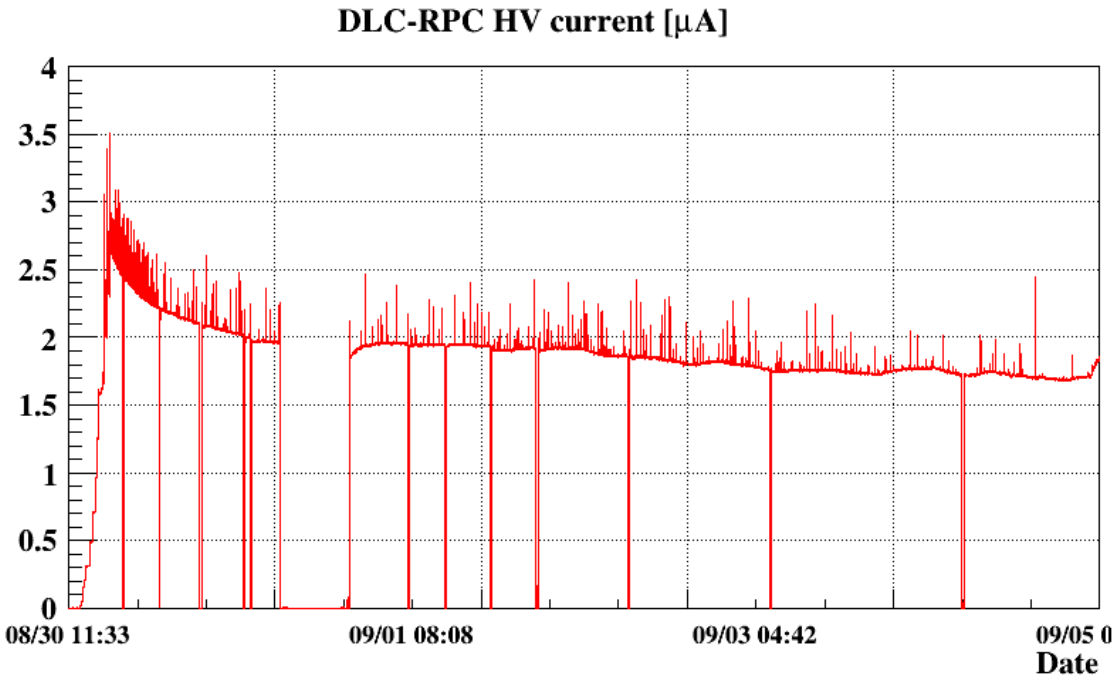
Summary

- DLC-RPC is under development for MEG II US-RDC
  - The low-momentum and high-intensity muon beam passage
    ➔ Several stringent requirements are imposed
  - Expected irradiation dose is $\sim 125\ \mathrm{C/cm^2}$
- Additional aging test of DLC-RPC was carried out
  - Using X-ray generator at KEK Platform-C
  - Total irradiation dose: $\sim 54\ \mathrm{C/cm^2}$
- Aging effects
  - Decrease in DLC-RPC HV current
  - Defects of DLC electrodes

Prospects

- Investigation of currently observed damage and changes in behavior of DLC-RPC

- Estimated aging effects in MEG II environment
  - Irradiation dose in this test: ~ $54\ \mathrm{C/cm^2}$
  - Expected in MEG II: ~ $125\ \mathrm{C/cm^2}$



Acknowledgements

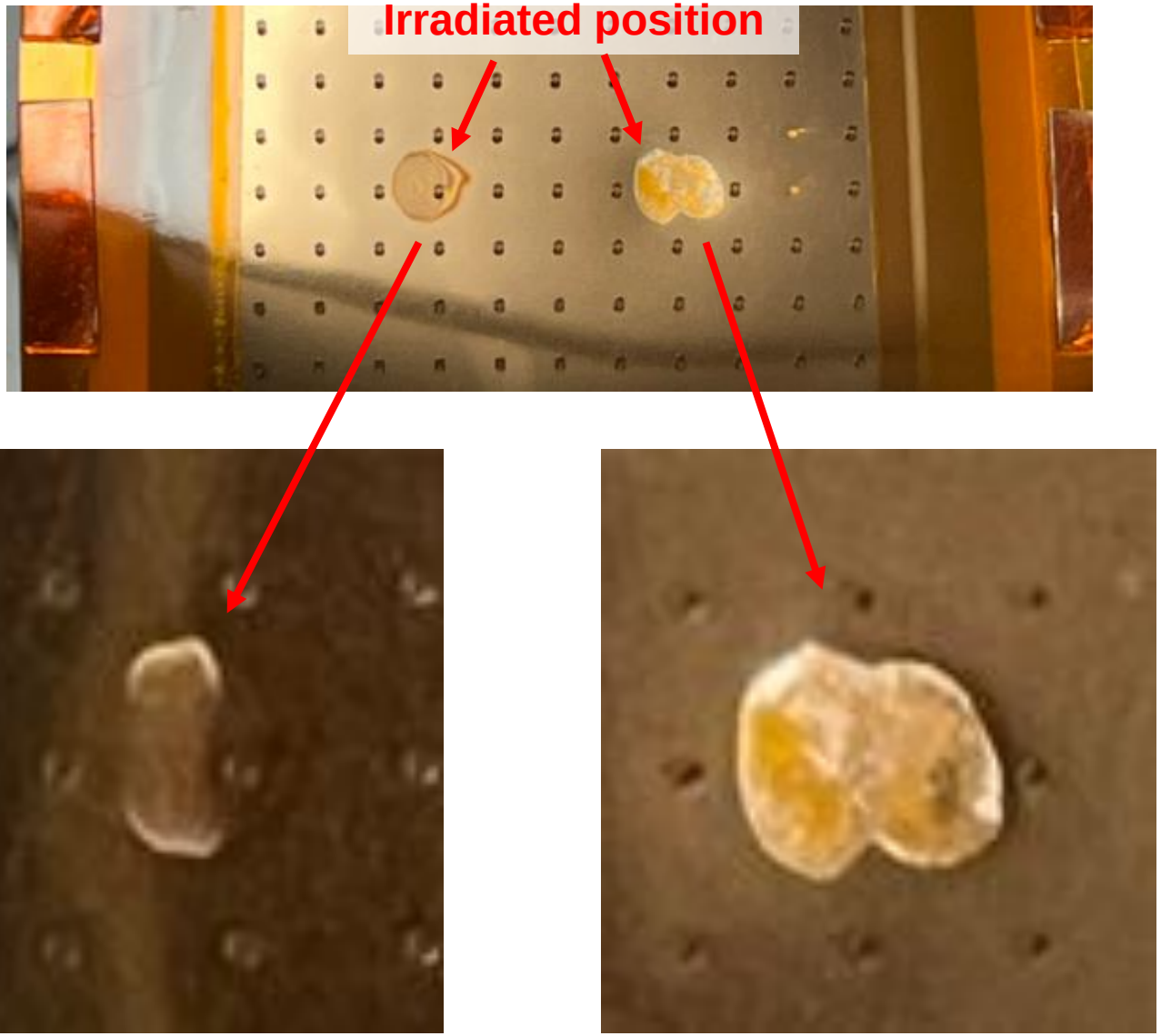
- This work was partially supported by
  - The KEK Detector R&D Platform
  - Grant-in-Aid for Scientific Research (S)
    Grant Number JP21H04991

Backup

Fluorine deposition

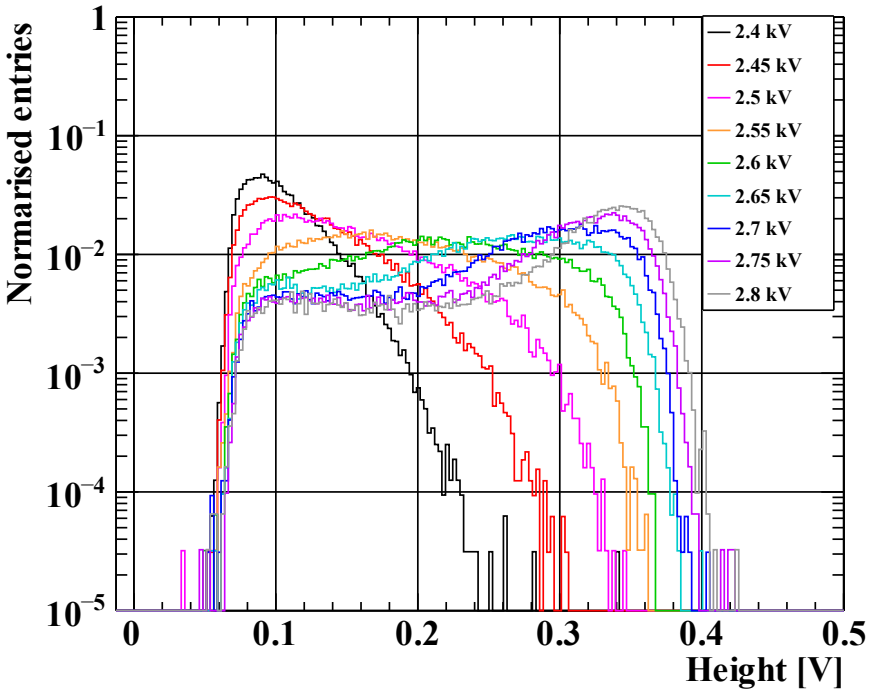
- Fluorine source is operating gas of DLC-RPC
  - DLC-RPC gas: Freon (R134a/C2H2F4) / SF6 / i-C4H10
  - SF6 generates fluorine during avalanche process
    - $\mathbf{SF_6 + e^- \rightarrow SF_6^{-*}, \quad SF_6^{-*} \rightarrow SF_5^- + F}$

Electrode

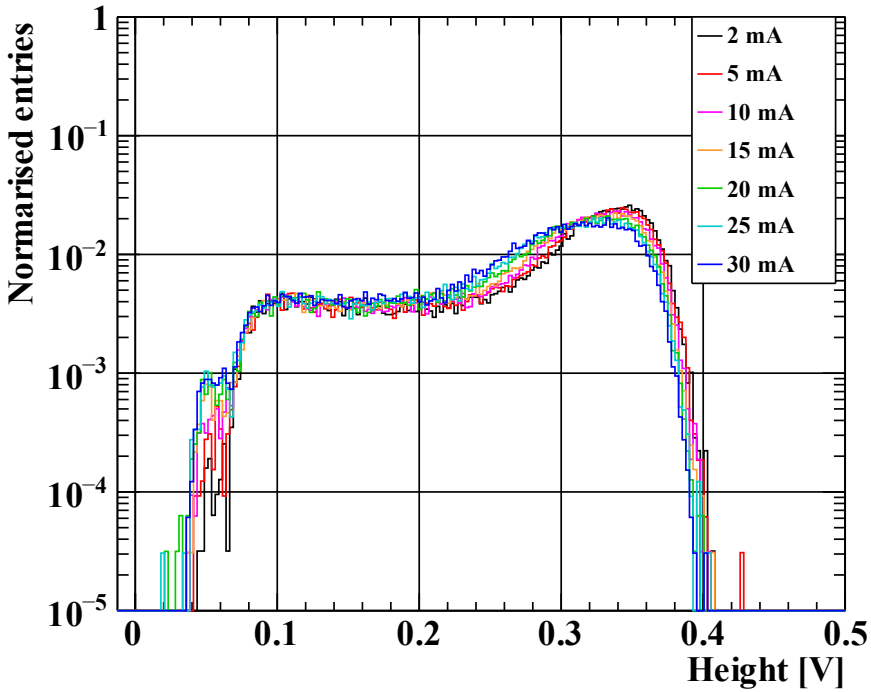


Pulse height distribution for X-ray

DLC-RPC HV scan at minimum X-ray intensity

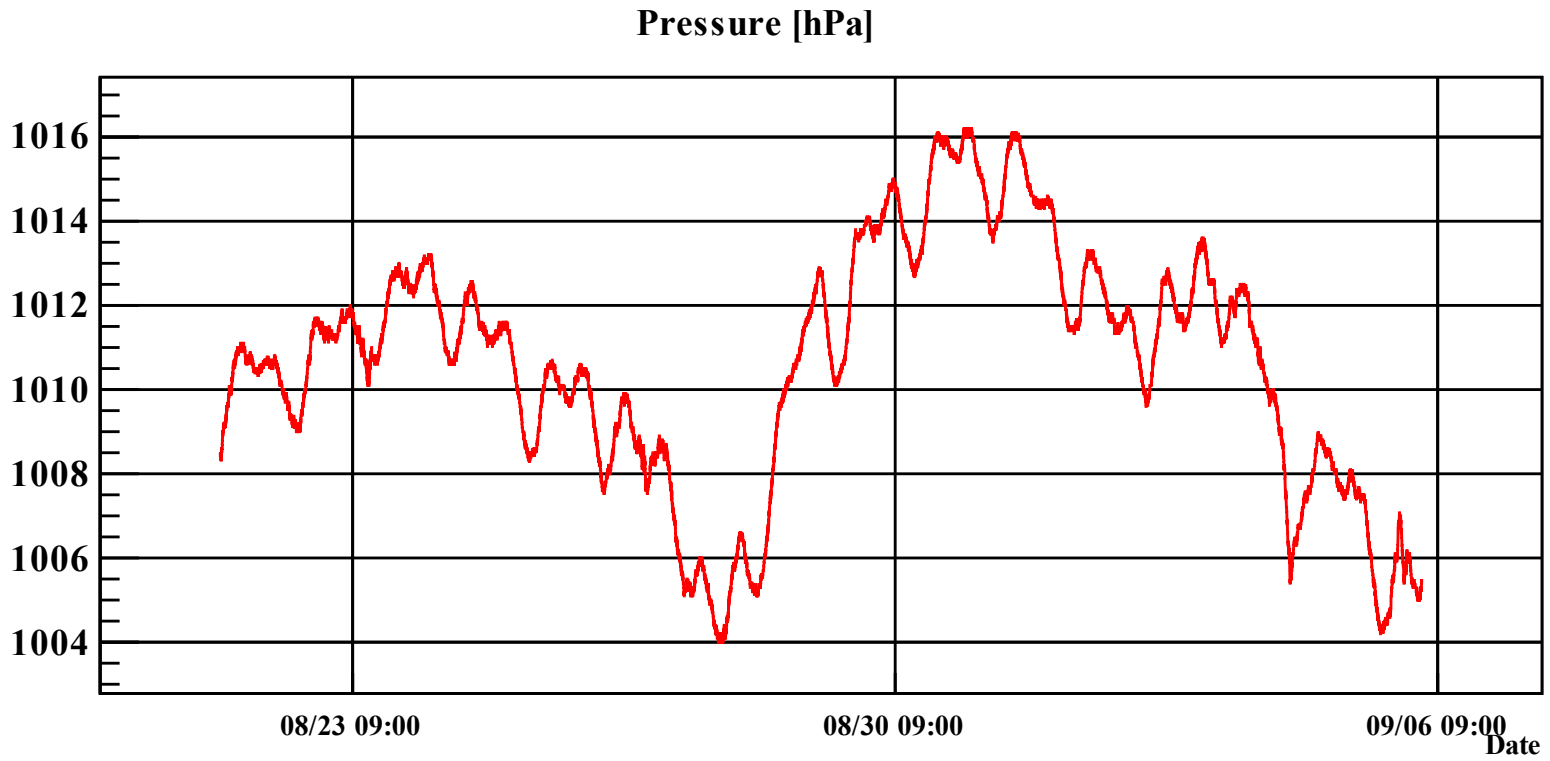


X-ray intensity scan at DLC-RPC WP



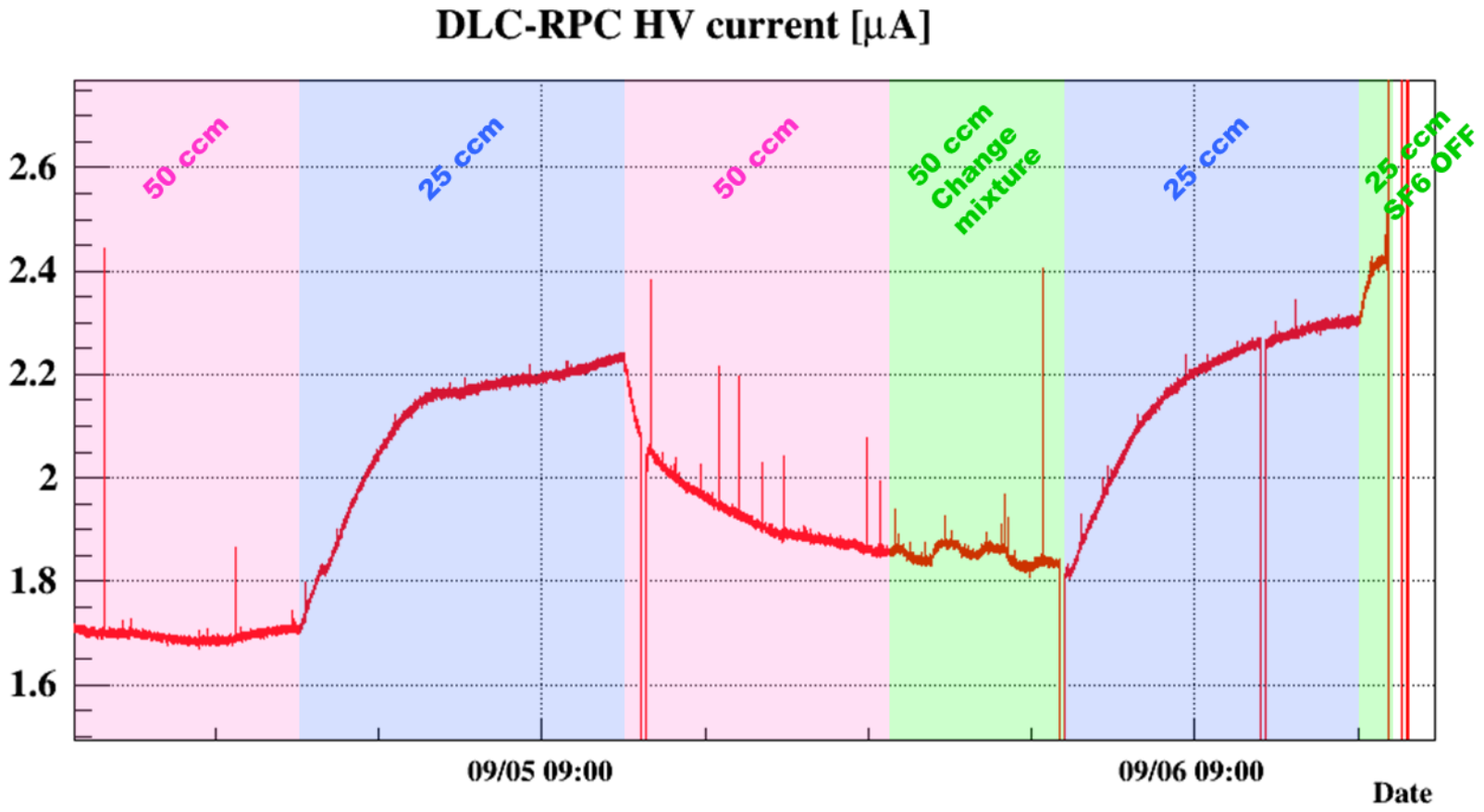
Environment - pressure

- Long-term period: 8/24 – 9/5

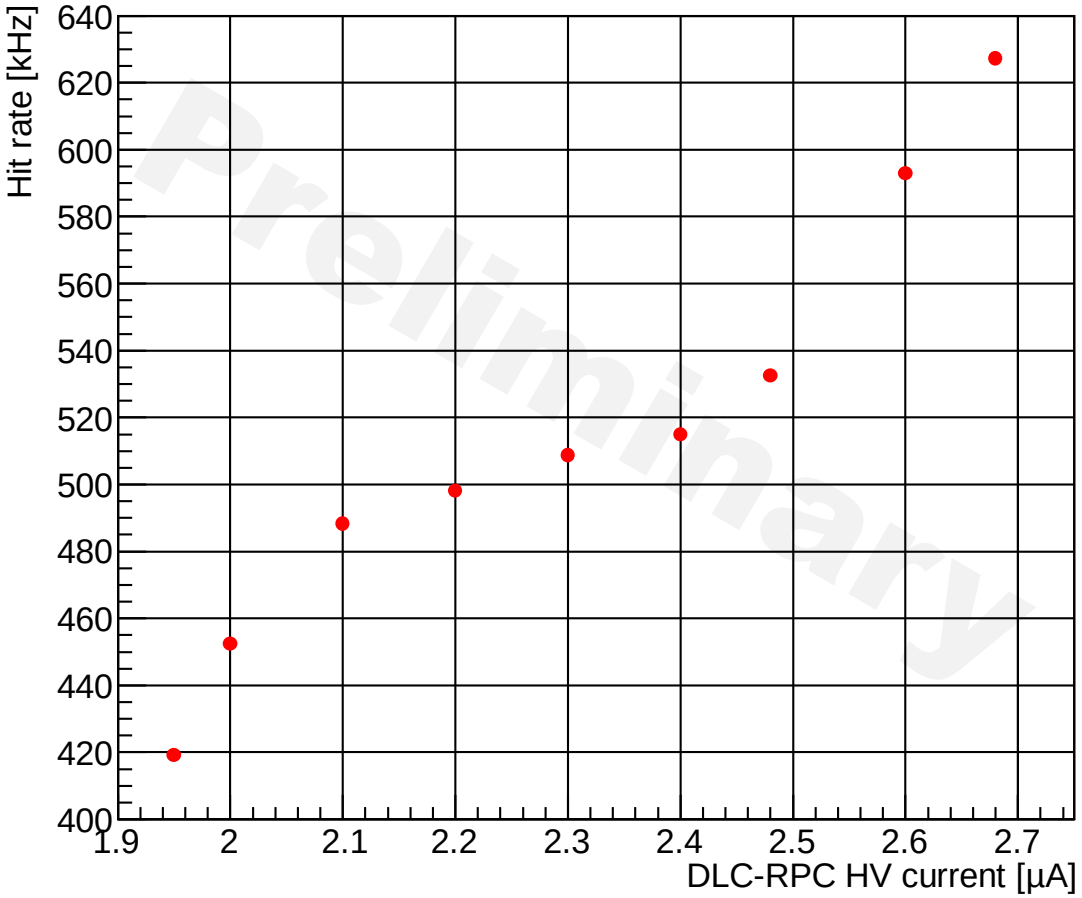


Gas flow study

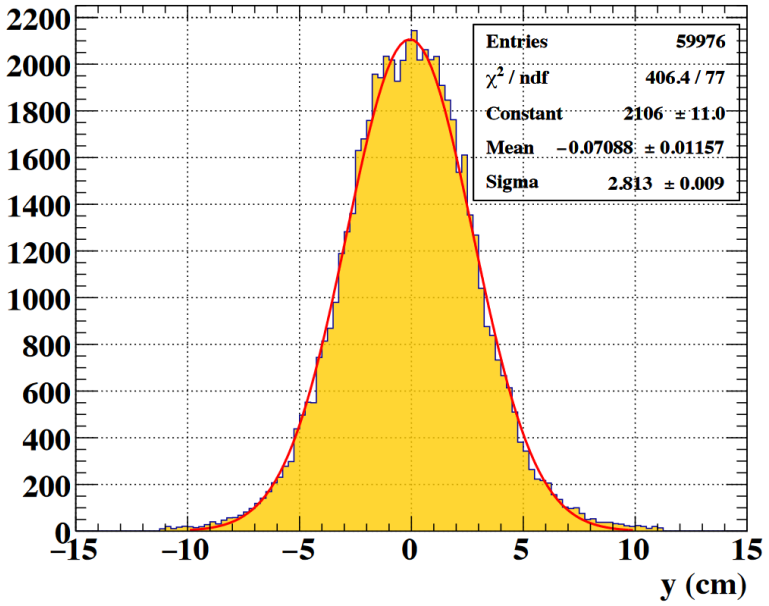
- DLC-RPC operated in high-flow rate and low-flow rate
  - High-flow rate (~50 ccm) / low-flow rate (~25 ccm)
  - Gas mixture did not change



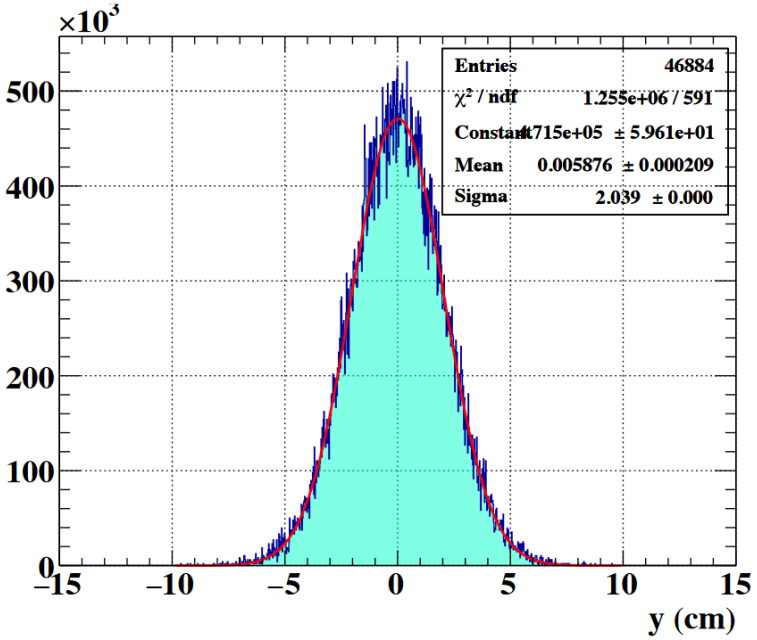
Hit rate vs. DLC-RPC HV current



e^+ distribution from RMD



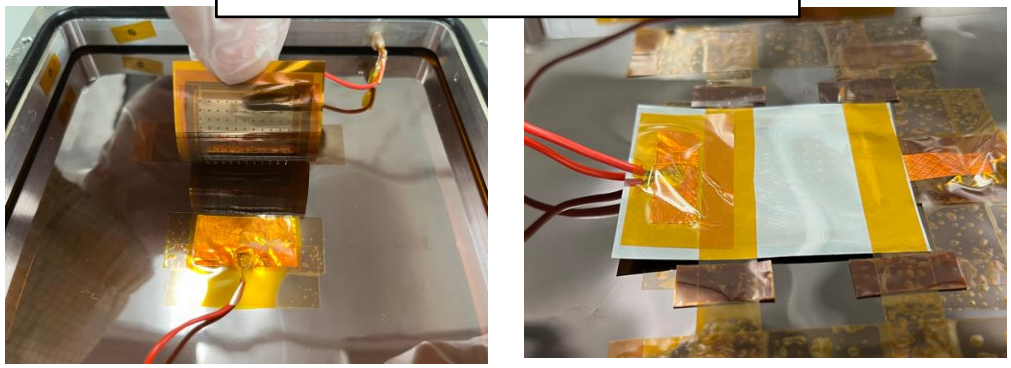
RMD e^+ ($E_\gamma > 48$ MeV)
$\sigma = 2.8$ cm



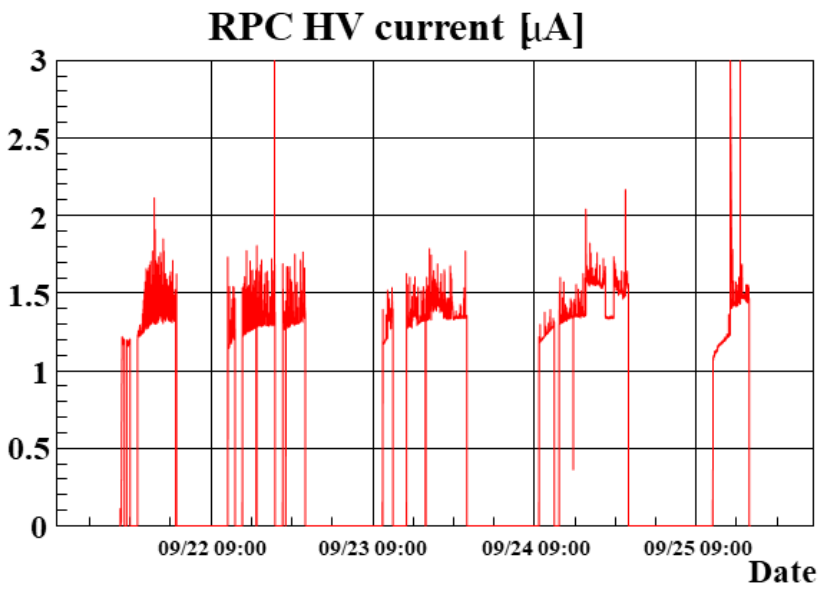
μ^+ beam profile
$\sigma = 2.0$ cm

Aging test at KEK 2022

チェンバー内部のセットアップ



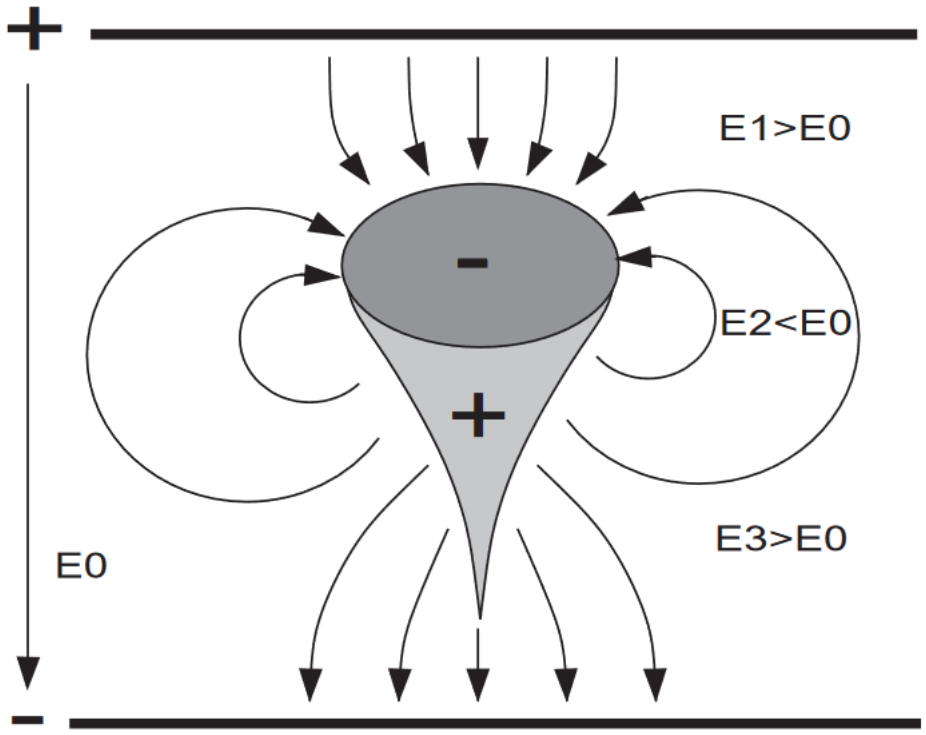
X線照射中



- $8.2\ \mathrm{C/cm^2}$ 相当の照射量
- 放電の問題で動作電圧は落としている
  - WP: 2.8 kV ➔ 2.7 kV
- X線照射時間は非常に短い

Space charge effect

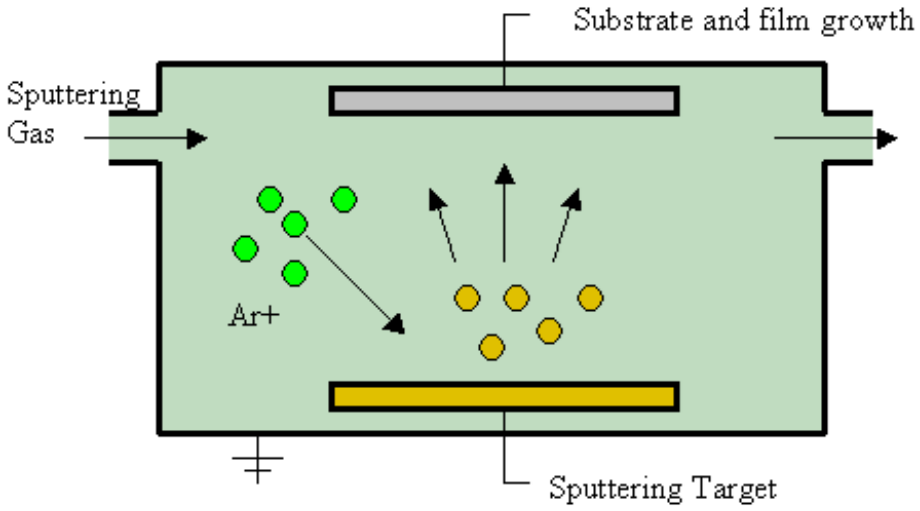
- Avalanche saturates at gas gain of 10^{7-8}

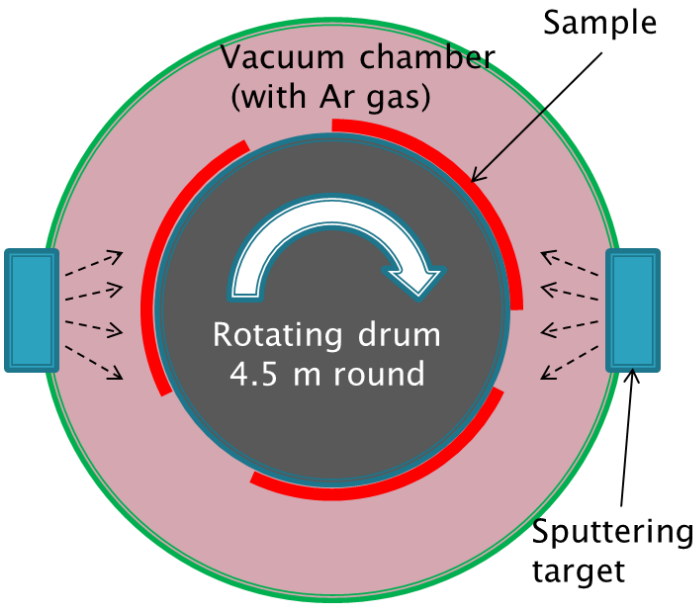


DLC sputtering

➢ Sputtering method

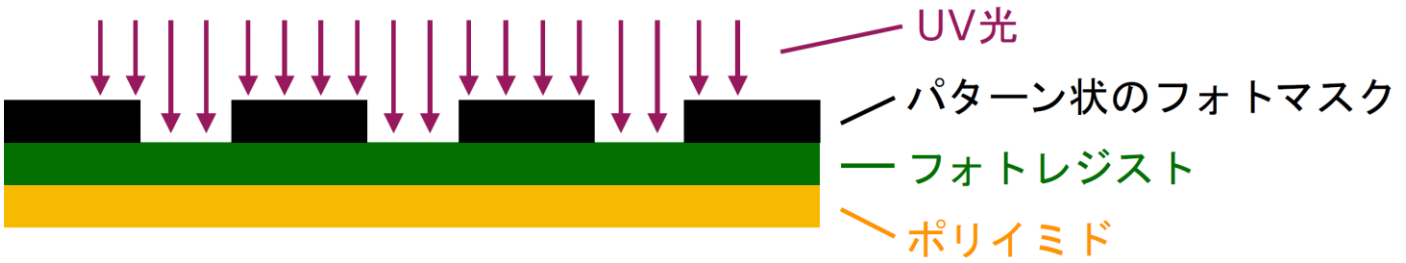
1. Inert gas (mainly Ar) is added in a vacuum
2. Provides a negative charge to a deposition material
   ➔Ionising gas atoms by glow discharge
3. Gas ions collide with target at high velosity
4. Tapped target constituent particles adhere to and are deposited on the substrate surface
   ➔Forms thin films





Photoresist

1. マスクをかけて
   UV光で露光する



2. 現像液によって
   非露光領域を溶かす

3. ピラーが完成する