MEG II実験背景事象削減のためのDLC-RPCの放射線耐性評価

神戸大理　高橋 真斗
他 MEG IIコラボレーション

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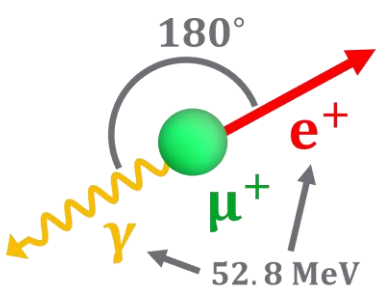
Outline

- **Introduction**
  - MEG II experiment
  - Radiative Decay Counter
  - Requirements for upstream RDC
  - Resistive Plate Chamber using Diamond-Like Carbon electrodes
- **Radiation-hardness of DLC-RPC**
- **Results of irradiation test**
- **Summary and Prospects**

MEG II experiment

- MEG II searches for $\mu^+ \to e^+\gamma$ decay
  - Charged lepton flavor violating decays
- Main background → accidental coincidence of BG-e^+ and BG-γ

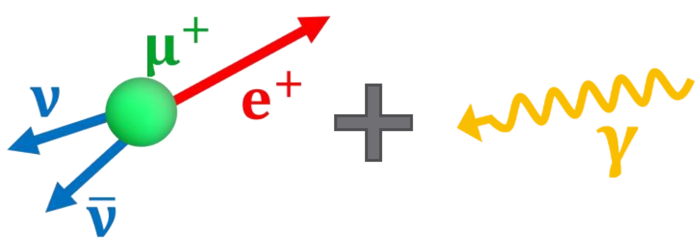
Signal



The signal features are

- The same **energy** (52.8 MeV)
- The same **timing**
- Opposite **direction**

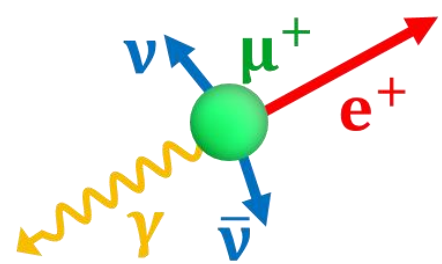
Background event



Accidental coincidence of BG-e^+ and BG-γ with different sources

- Signal-like features

BG-γ source



Radiative muon decay (RMD)

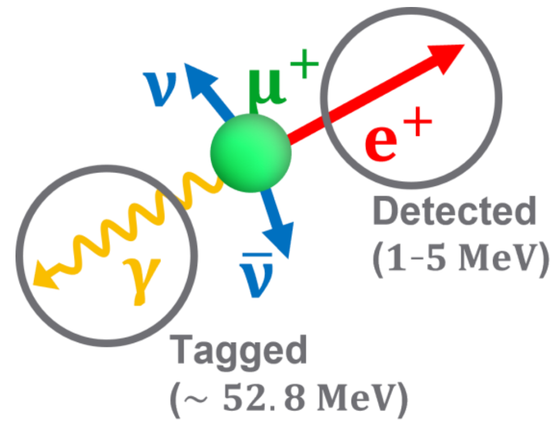
- One of BG-γ source

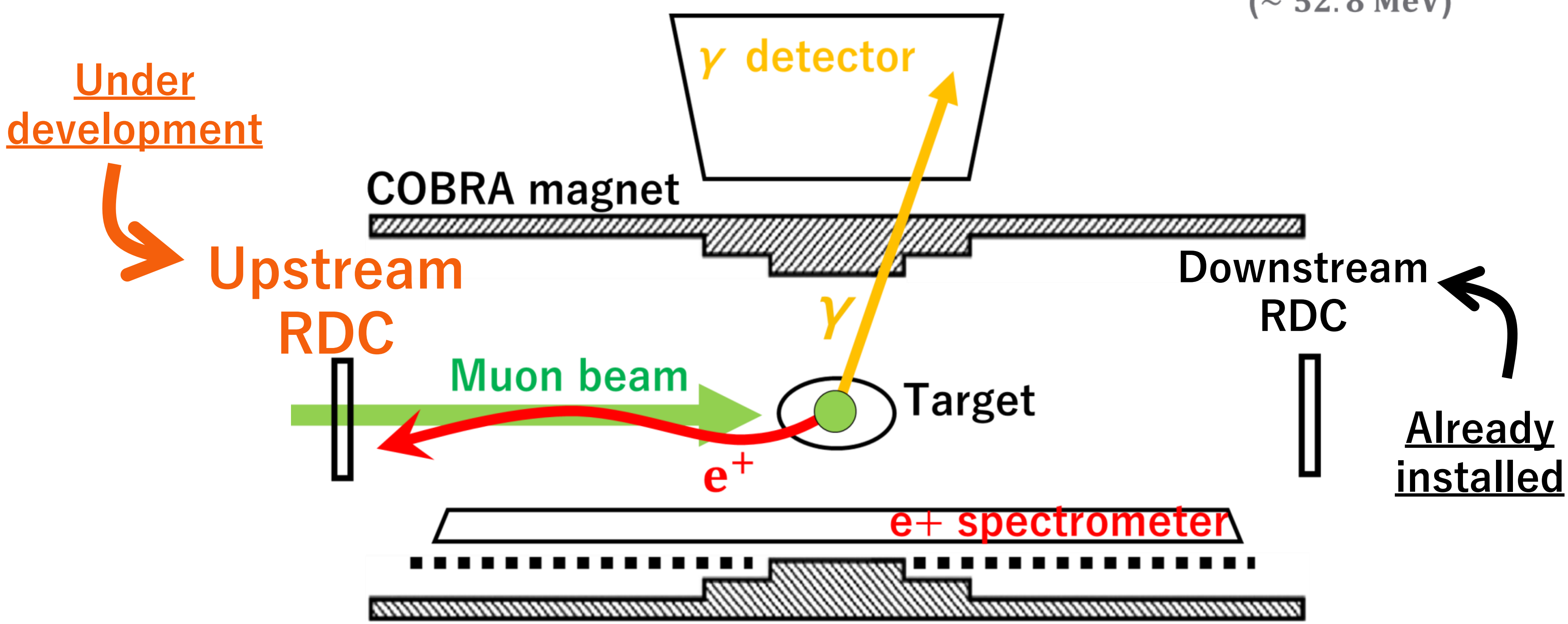
Annihilation in flight (AIF)

- Suppressed by lowering the material budget of the CDCH

Radiative Decay Counter (RDC)

- Detector for tagging BG-γ
  - When BG-γ have a signal-like energy ($\sim 52.8\ \mathrm{MeV}$), most of e^+ have a low energy ($1\text{-}5\ \mathrm{MeV}$)
    → <u>RMD e^+ distributed on the muon beam axis</u>

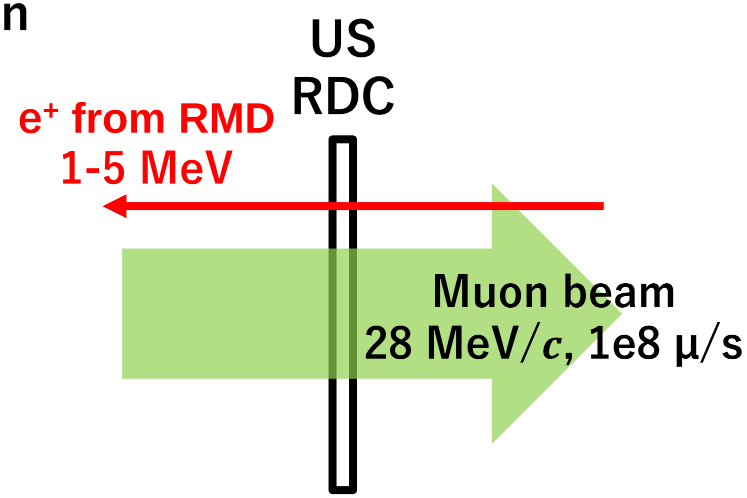




Requirements for upstream RDC

➢ <u>Requirements for US-RDC</u>

1. Material budget: $< 0.1\%$ radiation length
   ➡ muon beam with $28\ \mathrm{MeV}/c$ must pass through the detector
2. Rate capability: $4\ \mathrm{MHz/cm^2}$ of muon beam
3. Radiation hardness: > 60 weeks operation
4. Efficiency: $> 90\%$ for MIP
5. Timing resolution: < 1 ns
6. Detector size: 20 cm (diameter)

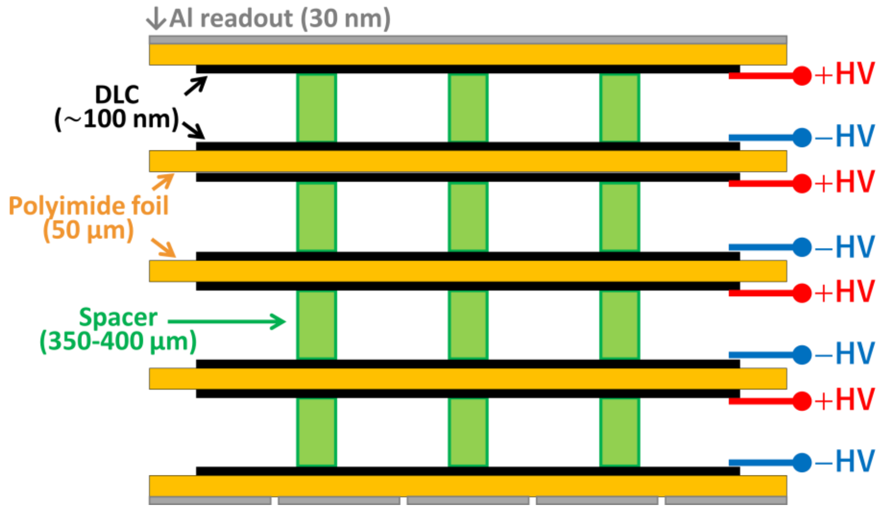


Resistive Plate Chamber (RPC) with Diamond-Like Carbon (DLC) electrodes for US-RDC

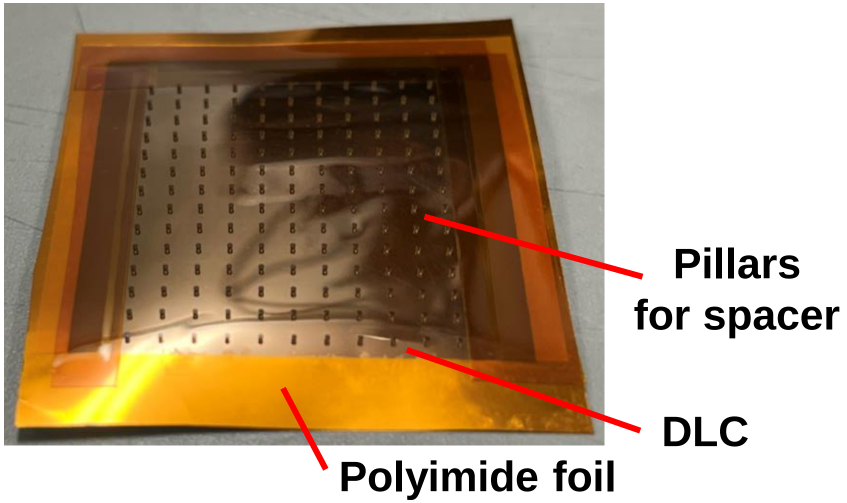
RPC with DLC electrodes (DLC-RPC)

- RPC ➡ Fast response (< 1 ns)
  High detection efficiency (by multi layering)
  ➡ In MEG II, stacked up to 4 layers due to material budget requirements
- DLC ➡ Small material budget (by sputtering directly onto thin polyimide films)
  Controllable resistivity (by changing film thickness)

Scheme of MEG II DLC-RPC structure



DLC-RPC electrode sample



- In this talk, status of radiation-hardness of DLC-RPC
- Yamamoto presents development of DLC-RPC with improved electrode (4pA421-2)
- Li presents time resolution of DLC-RPC (4pA421-3)

Outline

- Introduction
- **Radiation-hardness of DLC-RPC**
  - Requirements of radiation-hardness
  - Neutron irradiation test
- Results of irradiation test
- Summary and Prospects

Radiation-hardness of DLC-RPC

➢ Evaluation the ageing of DLC-RPC performance due to irradiation

→ Evaluation of irradiation doses by
amount of charge flowing over DLC electrodes

➢ Requirement of MEG II

- 60 weeks operation in low-momentum and high-rate muon beam
  28 MeV/c 4 MHz/cm^2

➢ Estimation of irradiation doses in muon beam

- (Current) = (Charge) × (hit rate)
  - Average avalanche charge → 3 pC
    - Sufficient charge for detection efficiency
  - At a centre rate of 4 MHz/cm^2

  → Current = 12 μA/cm^2

  → $\sim \mathcal{O}(100)$ C/cm^2 (for 60 weeks)

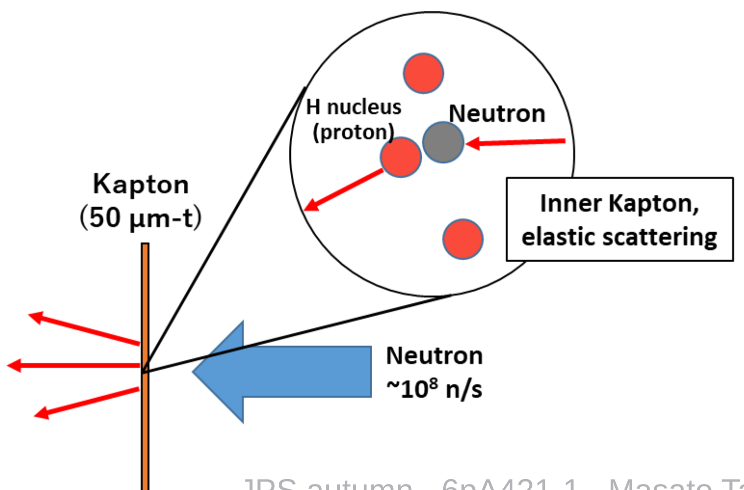
Neutron irradiation test

➢ **Neutron irradiation facility in Kobe Univ.**

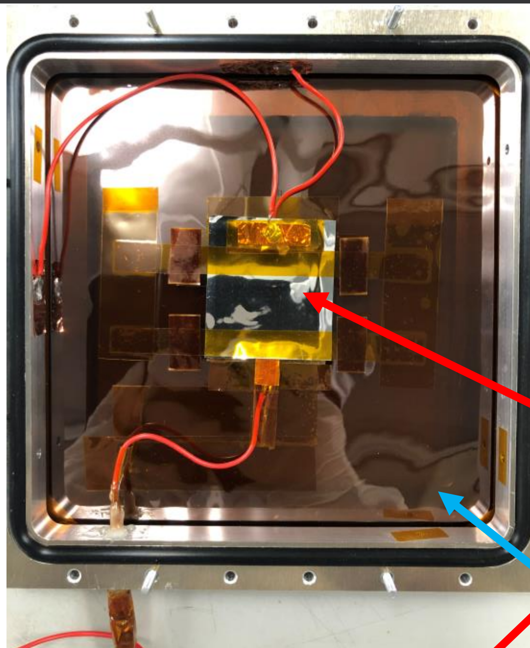
- $^{9}\mathrm{Be} + \mathrm{d} \rightarrow {}^{10}\mathrm{Be} + n + 4.35\ \mathrm{MeV}$
  - Deuteron energy : 3.0 MeV
  - Neutrons energy : Peak at ~2.5 MeV
- Number of neutrons $\mathcal{O}(10^8)\ n/\mathrm{s}$

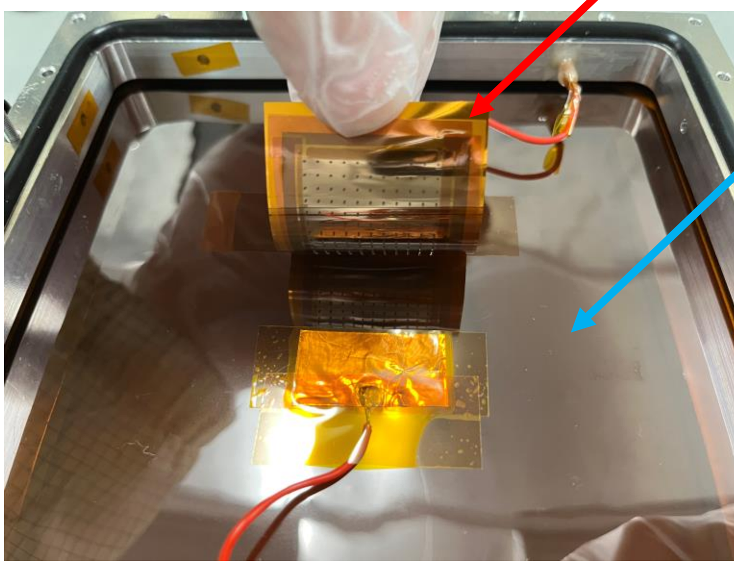
➢ **Accelerated ageing tests on DLC-RPC by neutrons**

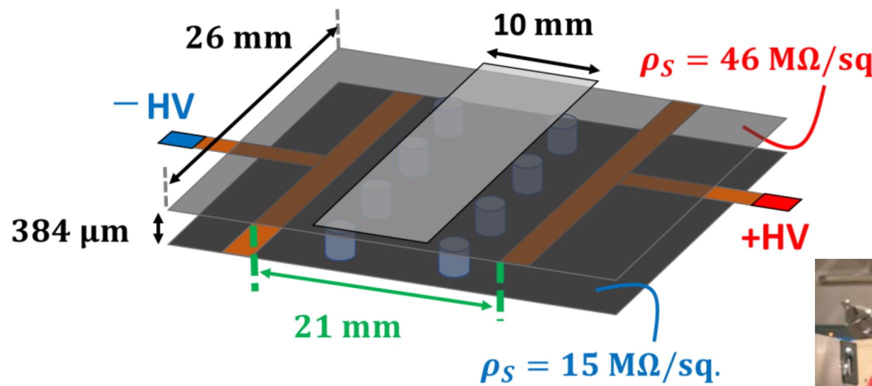
- High energy deposit of recoil nuclei due to neutrons
- Focus only on the integral charge due to neutrons



Setup of neutron irradiation

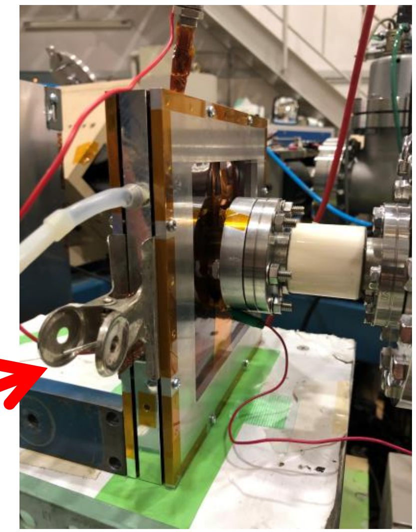






DLC-RPC electrode

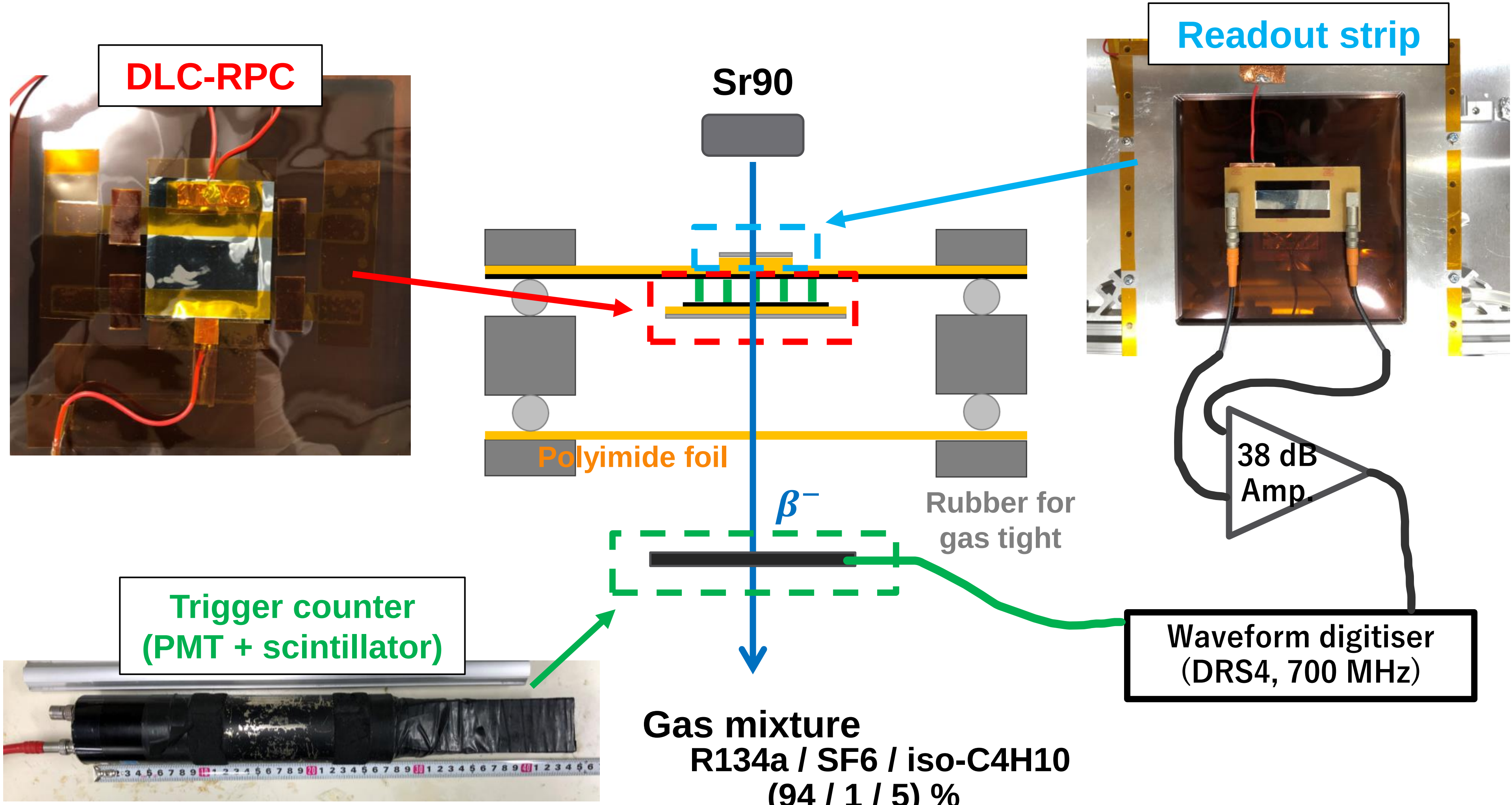
DLC sputtered Kapton window



- Chamber are placed as close to the target as possible
  - Neutron flux : ~ 6.0 × $10^7\ n/\mathrm{s/cm^2}$
    cf) In MEG II, neutron flux : 11 $n/\mathrm{s/cm^2}$
  - Scattered proton flux : ~ 2.6 × $10^4\ p/\mathrm{s/cm^2}$
    (calculated from cross-section with Kapton)
- Acquire HV current during irradiation

Setup of HV scan with Sr90

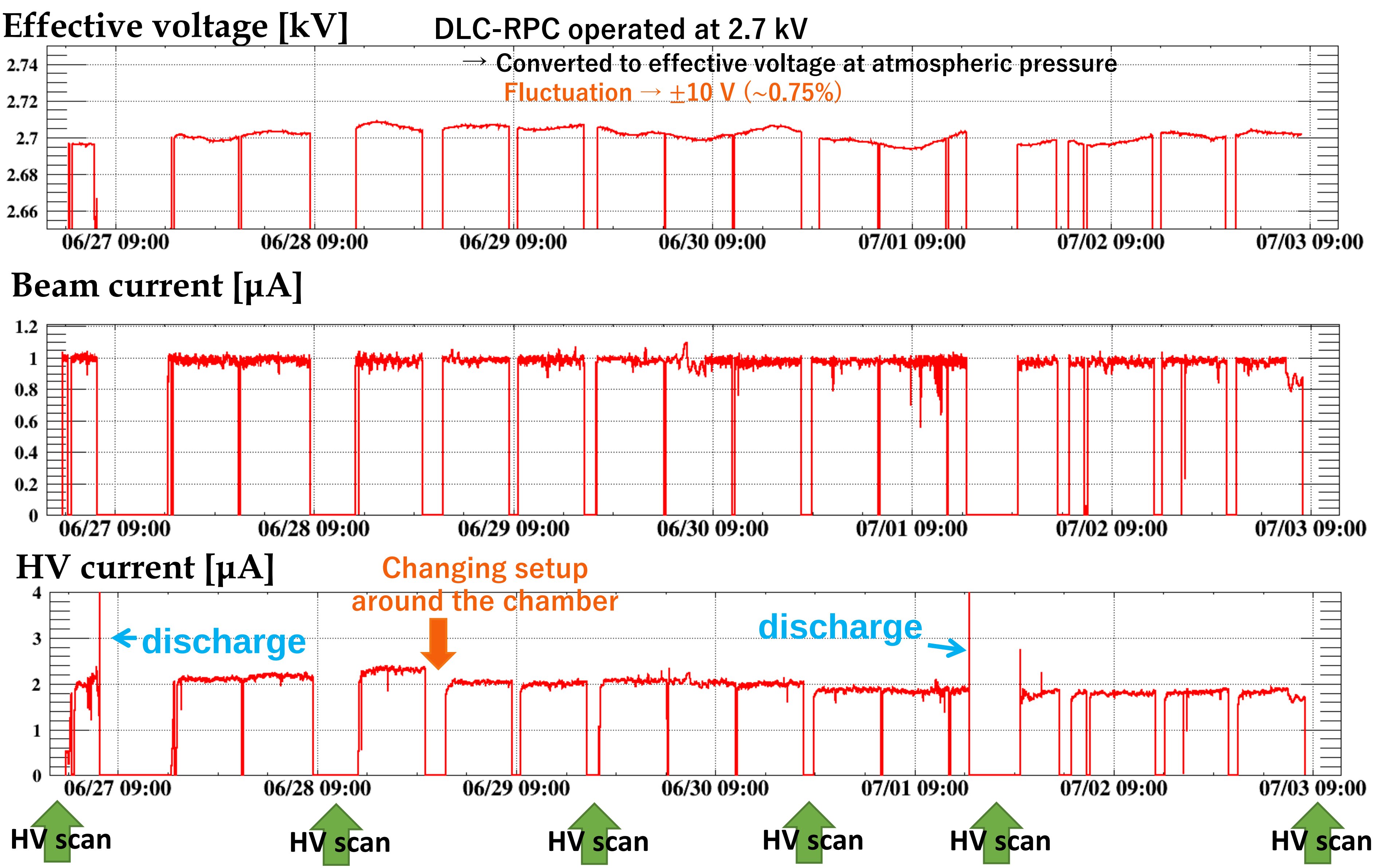
➢Check the performance transition due to neutron irradiation



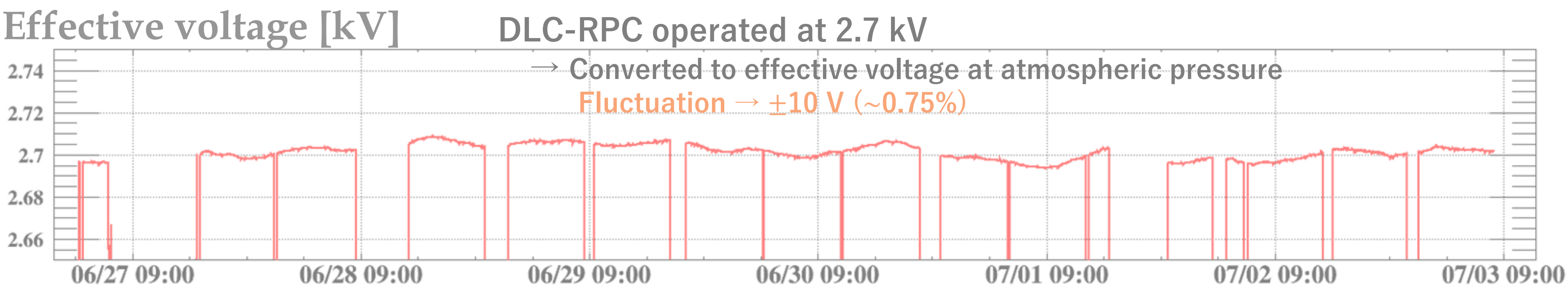
Outline

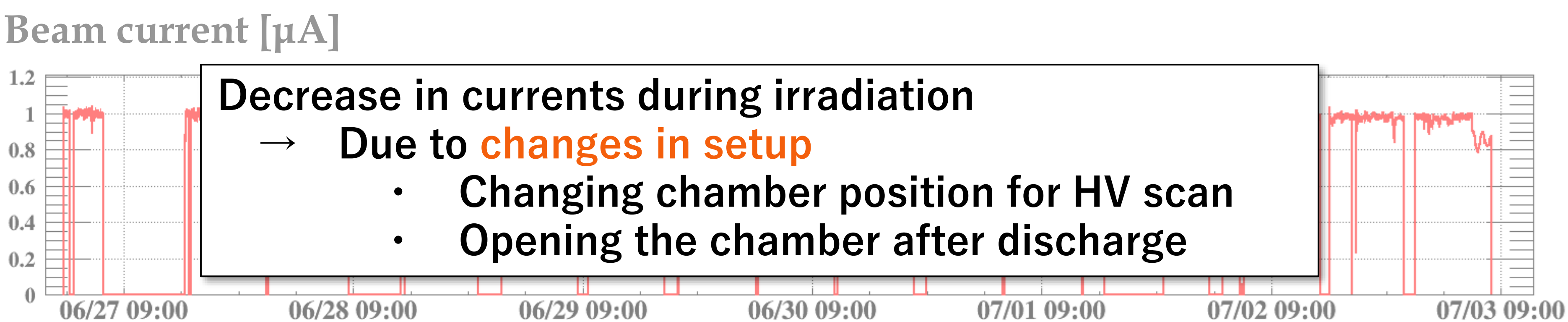
- ➢Introduction
- ➢Radiation-hardness of DLC-RPC
- ➢Results of irradiation test
  - ・Status during irradiation
  - ・DLC-RPC performance with Sr90
  - ・X-ray Photoelectron Spectroscopy
  - ・Problems of discharge
- ➢Summary and Prospects

DLC-RPC status during irradiation



DLC-RPC status during irradiation

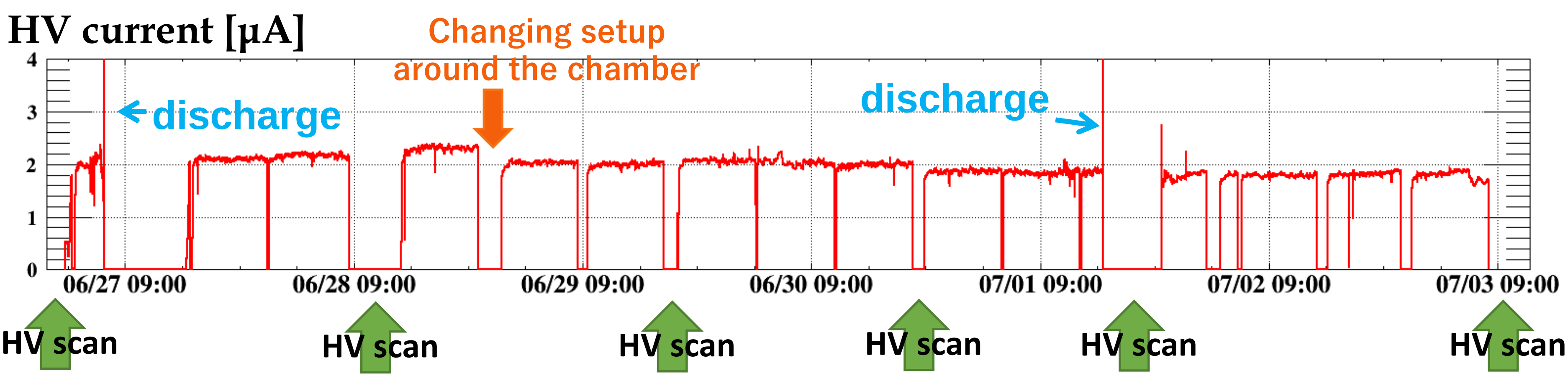




Decrease in currents during irradiation

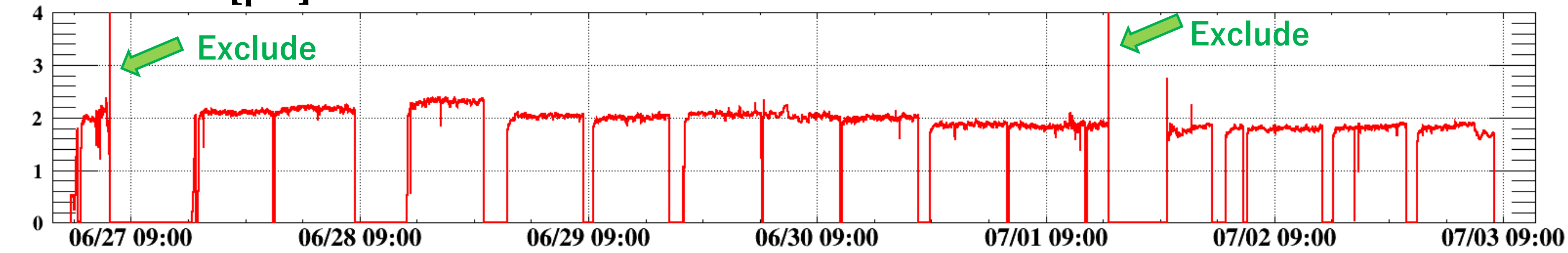
→ Due to changes in setup

- Changing chamber position for HV scan
- Opening the chamber after discharge



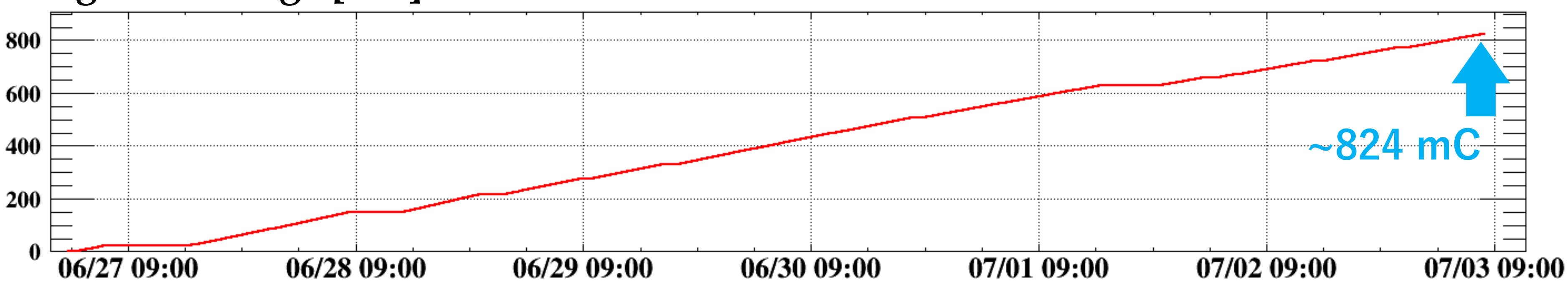
Total charge due to neutron irradiation

HV current [μA]



Integrate HV current
(Excluding high current discharges)

Integrated charge [mC]



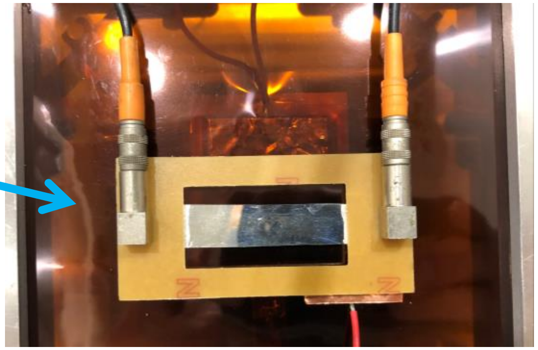
Total charge flowed to the DLC electrode

→Q_{tot} ~ 824 mC (~165 mC/cm^2)

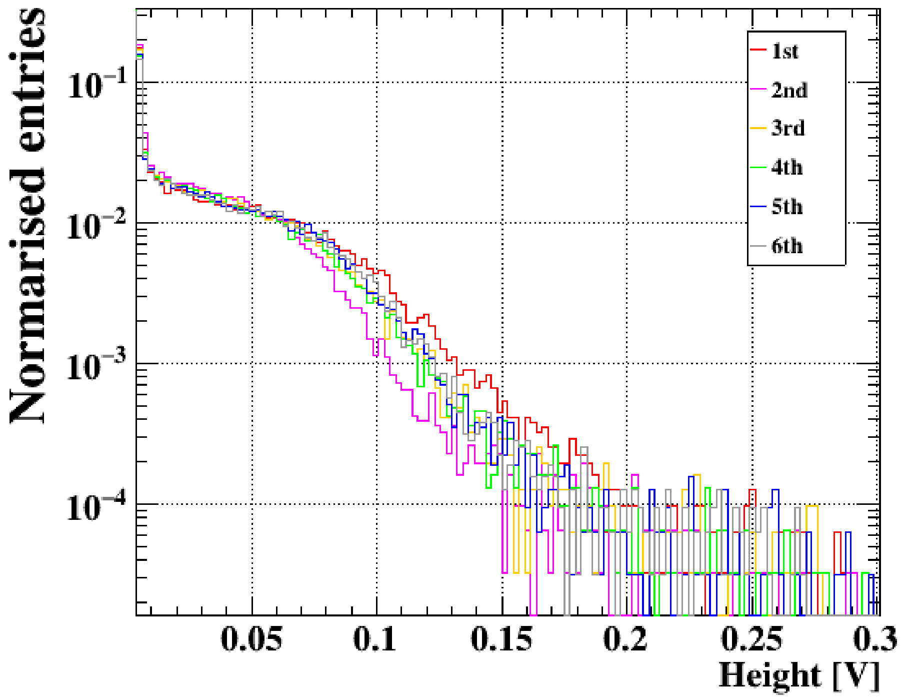
→Irradiation is 3 orders of magnitude less than requirement

Result of performance test with Sr90

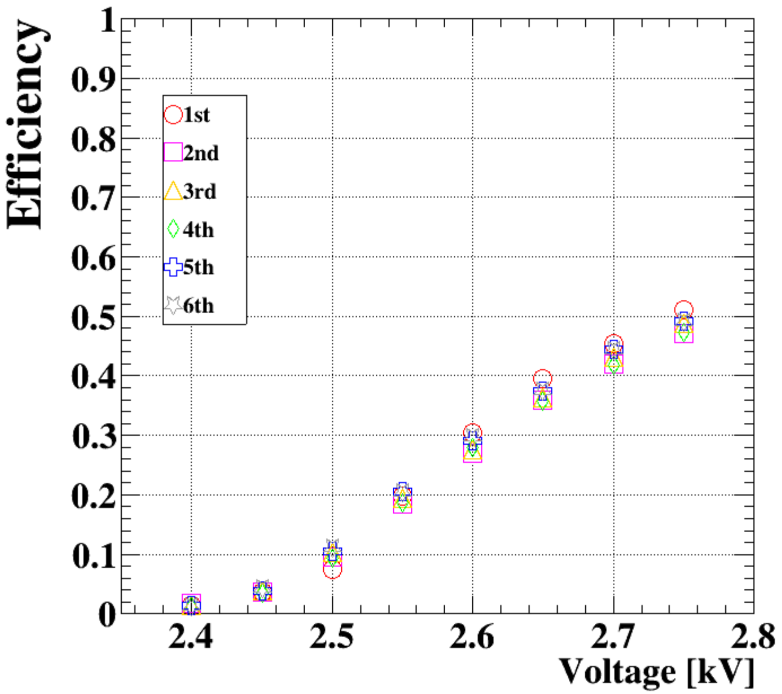
- ➢**No deterioration in performance seen**
  - ・1st and 2nd, Al readout was not in place
  - ・From 3rd and 6th, agreement at ~ 5%



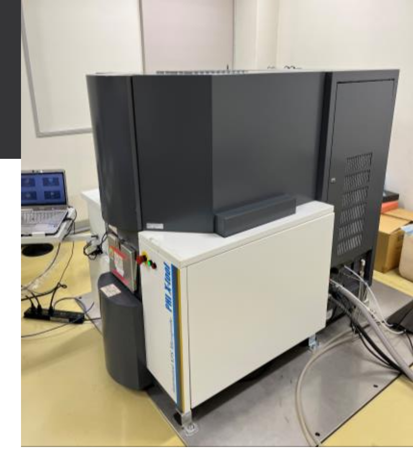
RPC height distribution at 2.75 kV



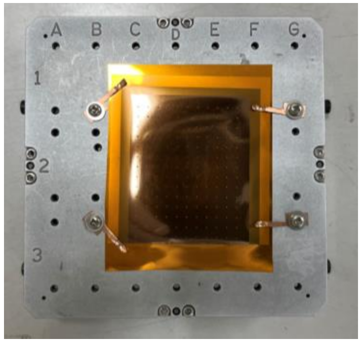
RPC detection efficiency



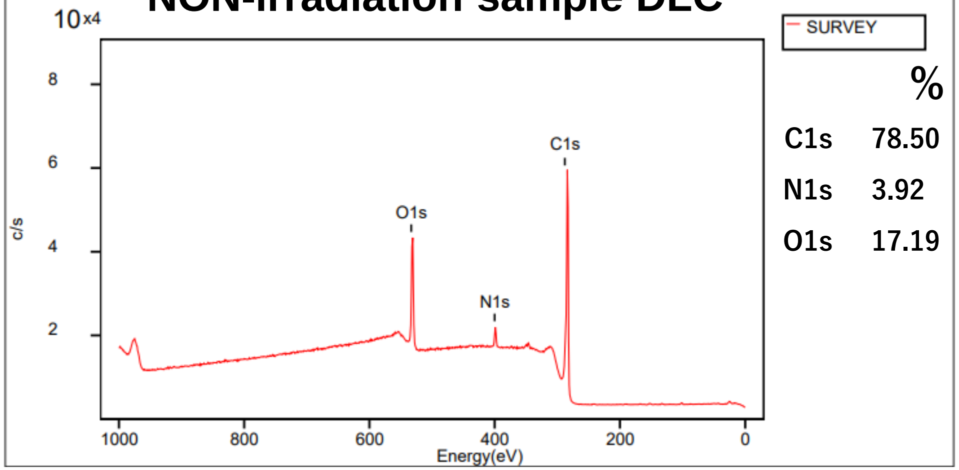
Surface condition survey



- Using X-ray Photoelectron Spectroscopy
  - Survey for non-irradiation and irradiation electrode sample
- Fluorine build-up on DLC due to long-term irradiation
  - Fluorine used in gas (R134a/SF6/iso C4H10 = 94/1/5)
- No effect of fluorine on performance can be seen at present

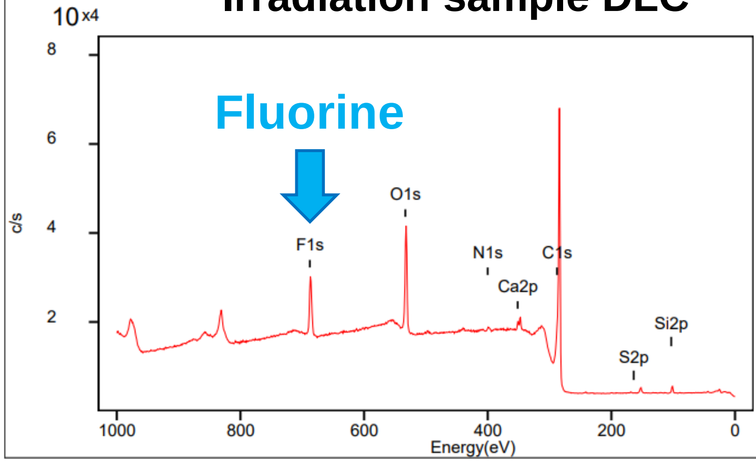


NON-irradiation sample DLC



	%
C1s	78.50
N1s	3.92
O1s	17.19

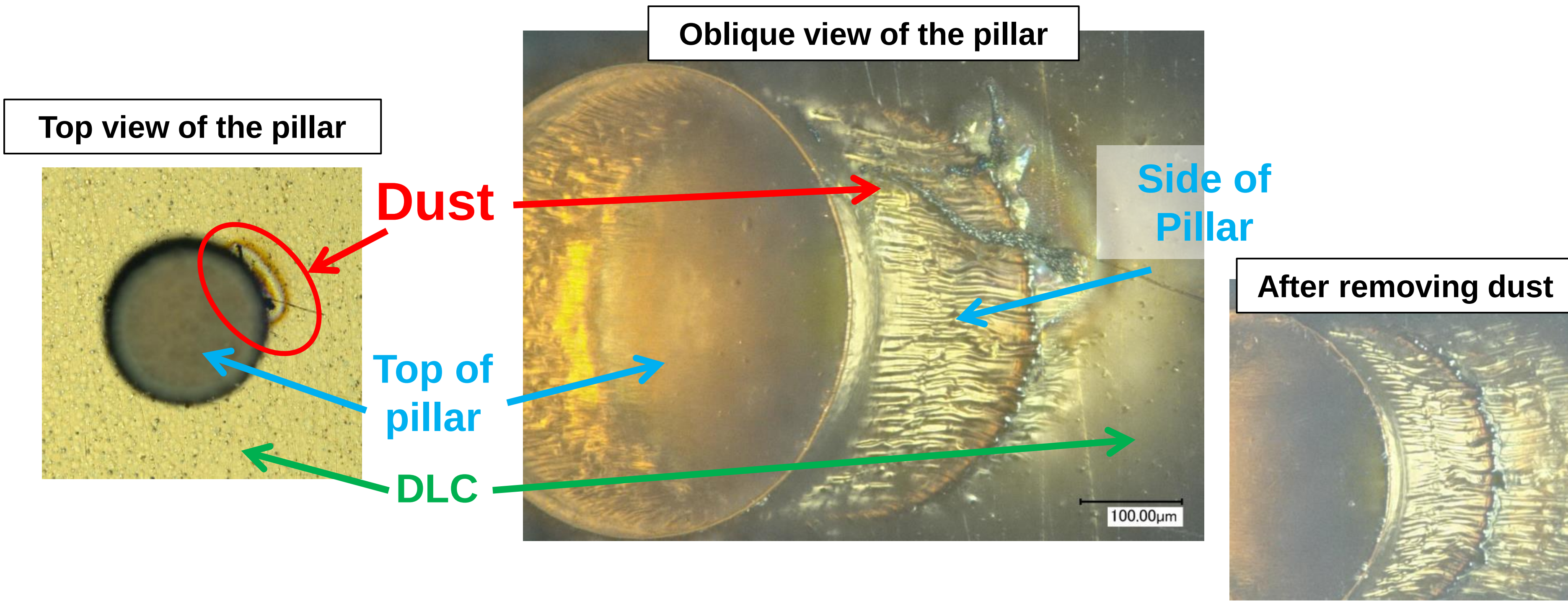
Irradiation sample DLC



	%
C1s	76.85
N1s	0.62
O1s	14.44
F1s	6.11
Si2p	1.25
S2p	0.06
Ca2p	0.57

Discharge problems

- **Long-term operation hampered by discharges**
  - Cannot operate w/o opening and cleaning the chamber
- **Discharge due to dust, especially around pillars**
  - It has not been possible to determine whether it is neutron-specific
    - Caused by large clusters of neutrons?
  - → Plans for testing with other RI source



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Summary

- RPC with DLC electrodes is under development for MEG II US-RDC
  - Several stringent requirements are imposed because of the low-momentum and high-rate muon beam passage

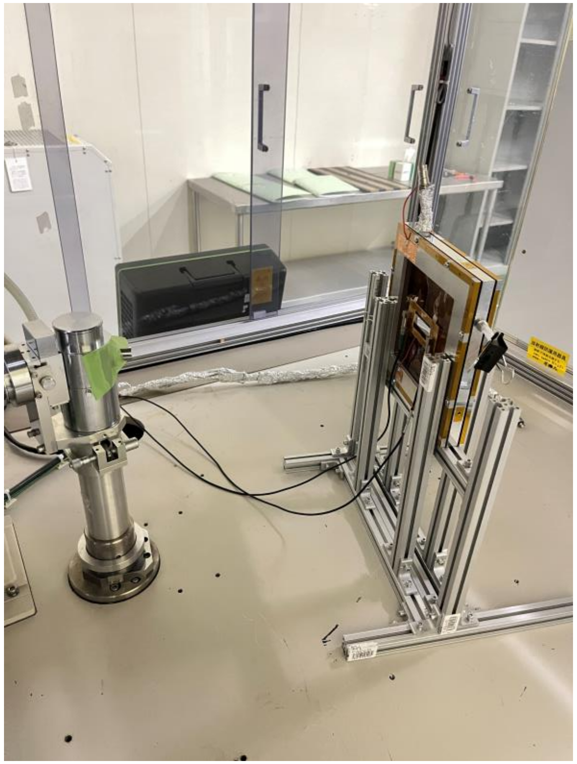
- Evaluated Radiation-hardness one of the requirements
  - Using neutron accelerated facility
  - Not yet up to the required irradiation level
  - Pulse height distribution is agreement at ~ 5%
    → No deterioration in this accuracy was observed

- Problem and remarks
  - Fluorine accumulation on DLC
  - Long-term operation was unstable due to discharge around pillars
    - It has not been possible to distinguish whether it is a neutron-specific

Prospects

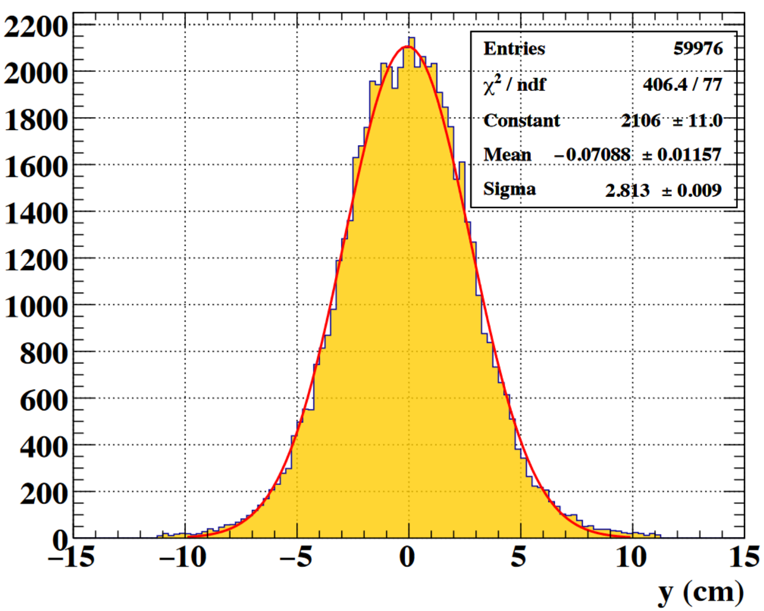
- **Need more irradiation and longer periods of operation**
- **Irradiation tests will be carried out using the X-ray generator in KEK Platform-C**
  - **Isolating the unique effects of neutrons**

Now in progress

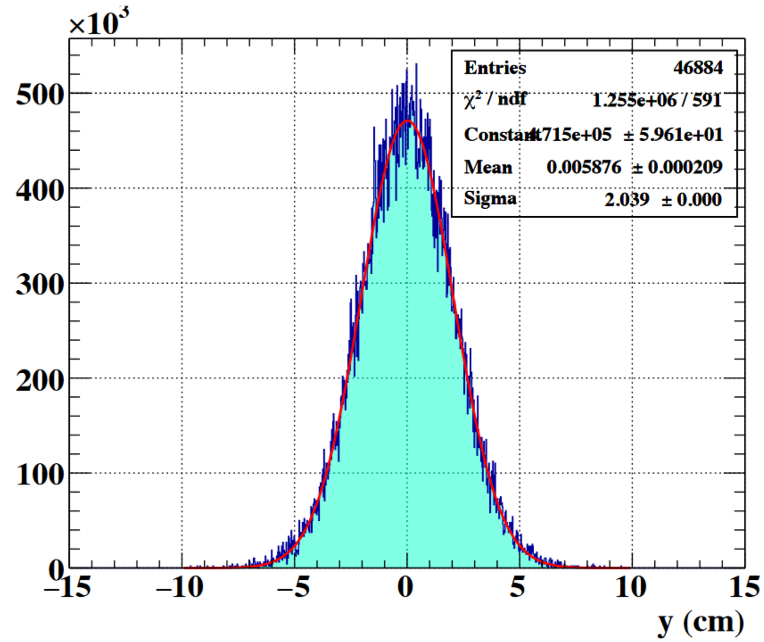


Backup

e^+ distribution from Radiative Muon Decay

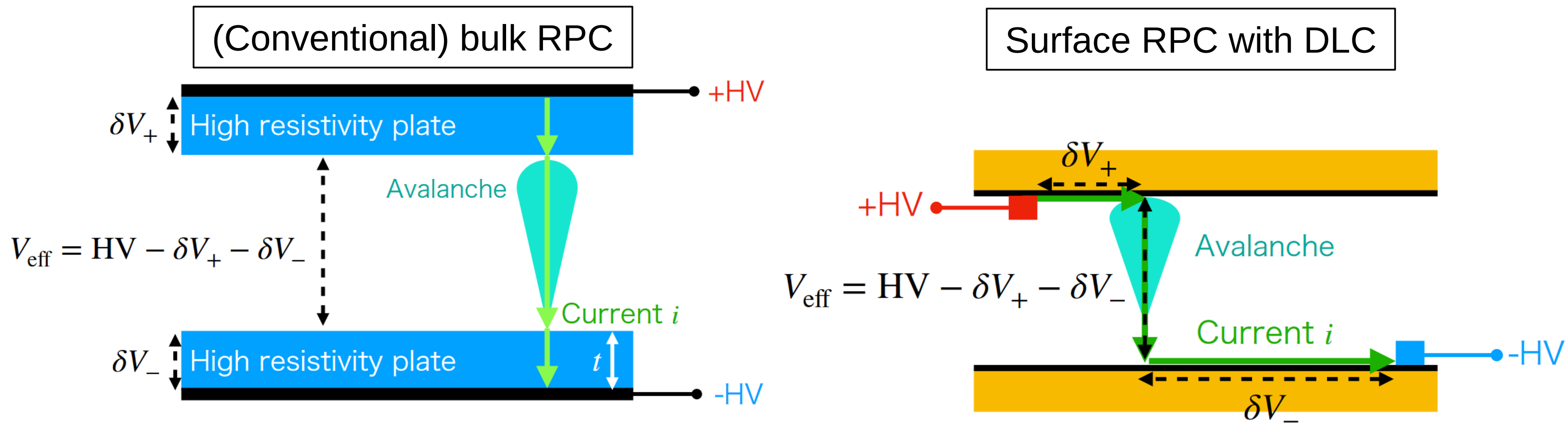


RMD e^+ $(E_\gamma > 48\ \mathrm{MeV})$
$\sigma = 2.8$ cm



μ^+ beam profile
$\sigma = 2.0$ cm

Differences b/w conventional RPC and DLC-RPC



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

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

➢ **The voltage drop due to high current on resistive electrodes**

・Current paths are different between conventional and surface type

➡ In surface RPC, the distance between conductors affects voltage drop

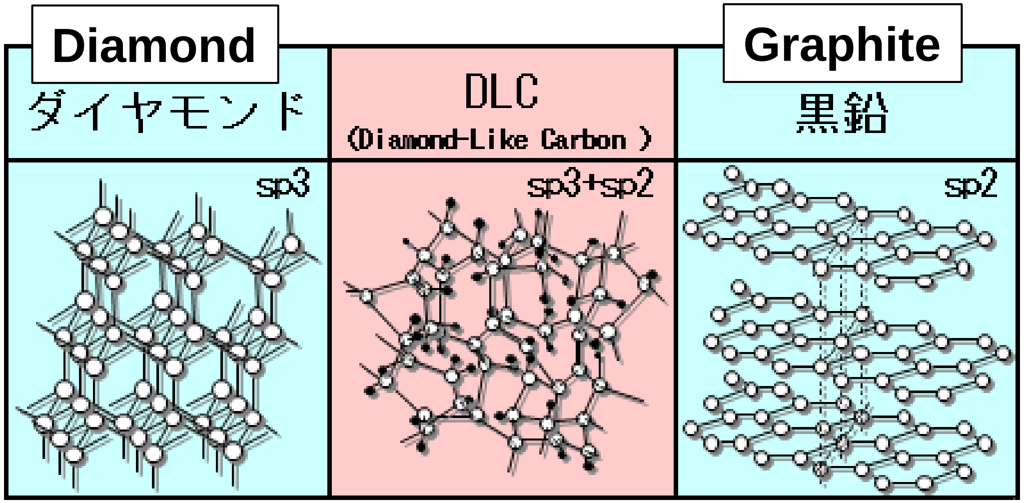
Diamond-Like Carbon (DLC)

➢Amorphous structure with graphite ($\mathbf{sp^2}$) and diamond ($\mathbf{sp^3}$) bonds

- $\mathbf{sp^2}$: Electrically conductivity
- $\mathbf{sp^3}$: Insulating properties

➢Features:

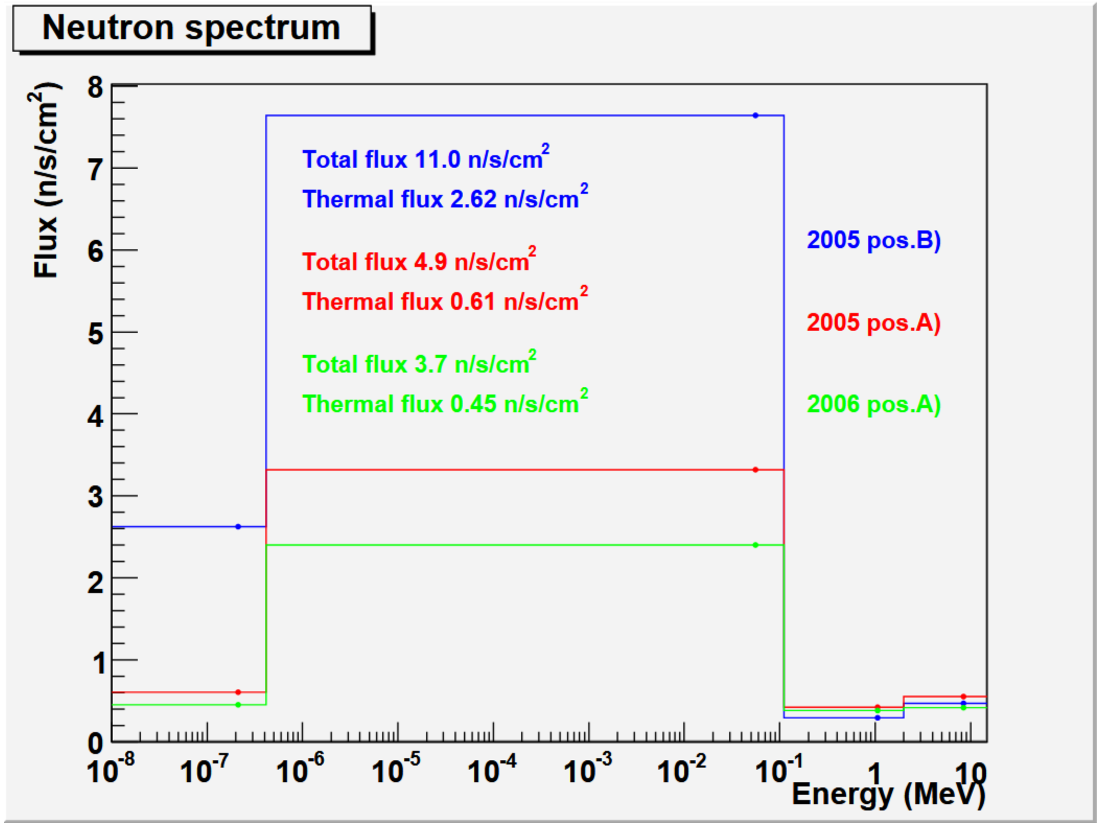
- High-definition patterning ($< \mathbf{10\ \mu m}$)
- Wide range of surface resistivity can be set ($\mathbf{50\ k - 3\ G\Omega/sq}$)
  - Film thickness adjustment
  - Nitrogen doping
- High adhesion to polyimide
- Chemically stable



Comparison of diamond, DLC and graphite structures
Ref) https://nippon-itf.co.jp/technical/article/about-dlc.html

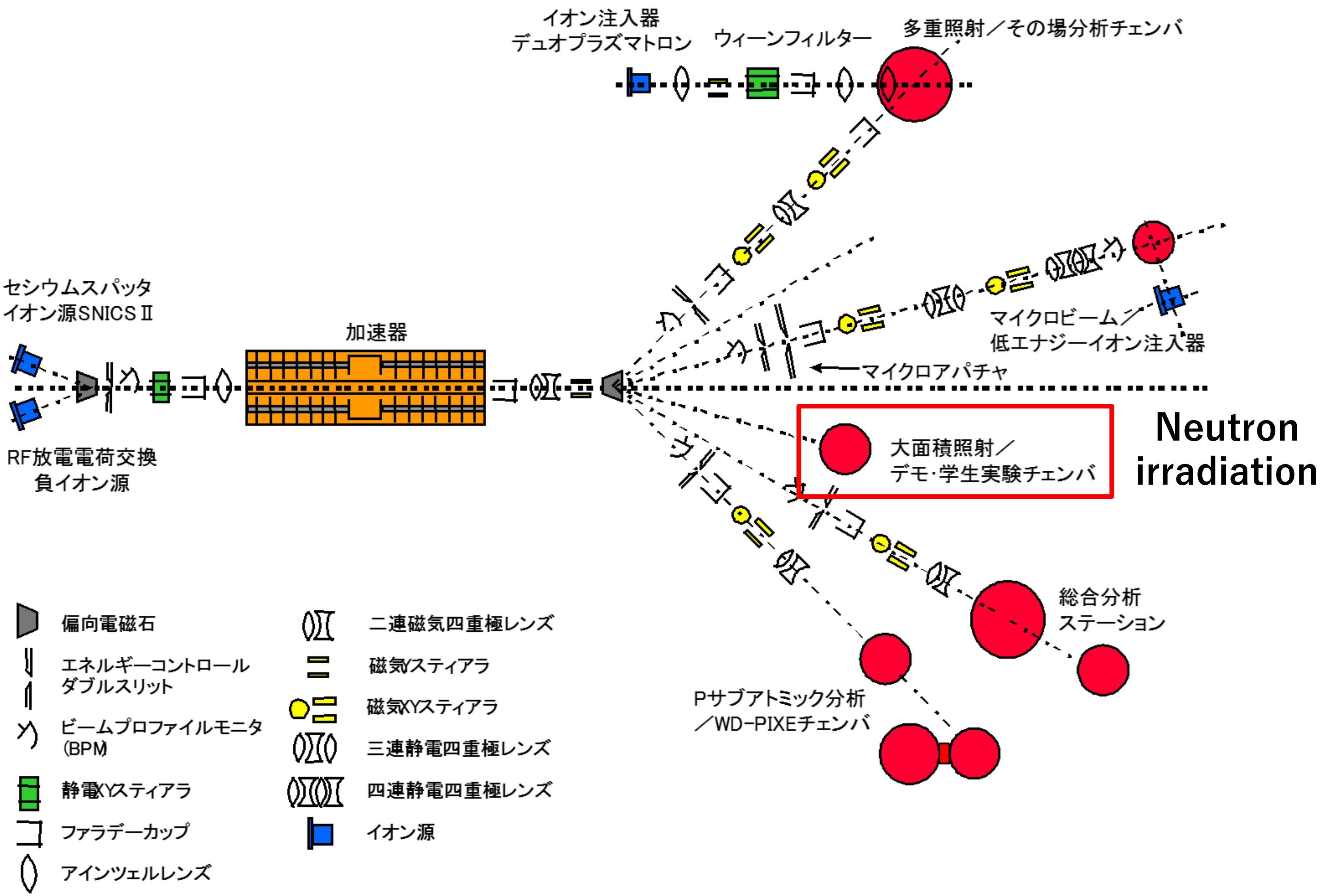
Neutron flux in MEG II environment

- DLC-RPC will be installed in pos.B)
  - pos.B) Total flux : 11.0 n/s/cm²
  - Neutron irradiation test) Flux : 6.0×10^{7} n/s/cm²

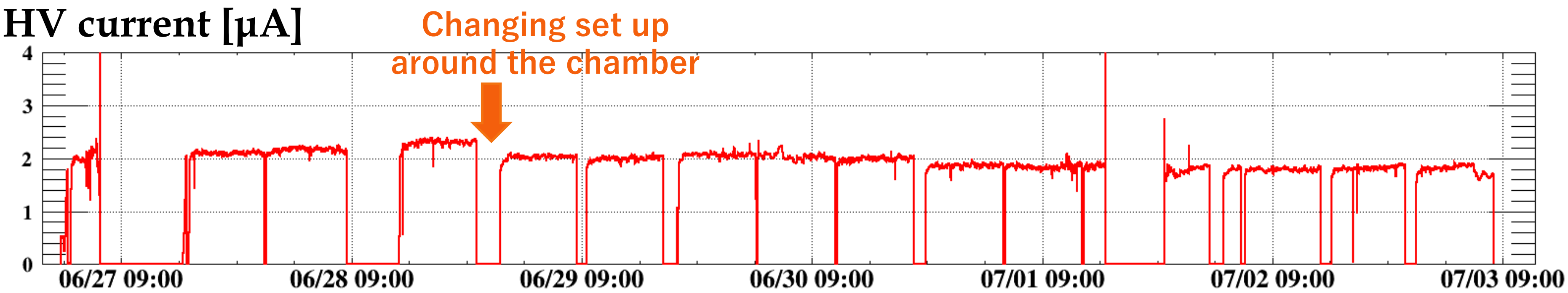


A. Baldini, et al, "Neutron background measurements in the $\pi E5$ area.", (2007)

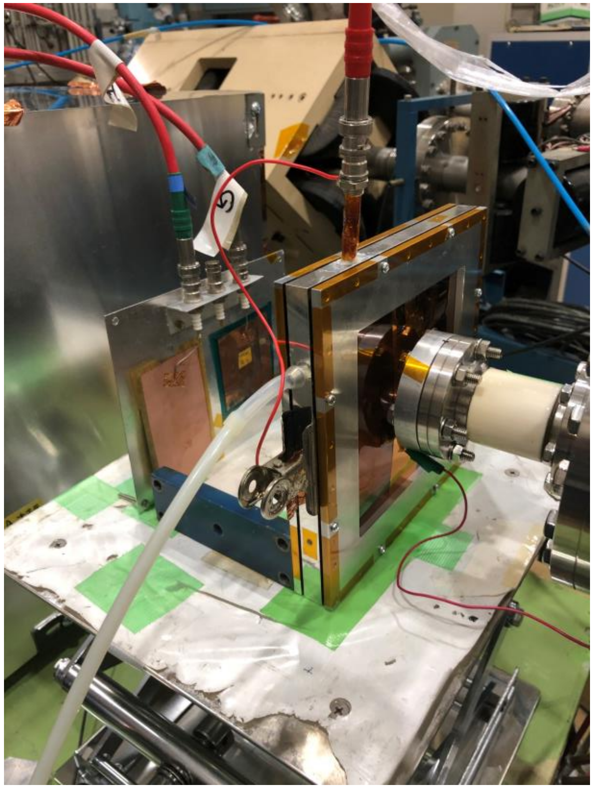
Tandem electrostatic accelerator



Changing setup



- **Frequent discharges around pillars**
  - Concerns about the effects of neutrons on the pillar material
  - → Neutron irradiation to pillar material
- **No particular changes were observed**
  - Rough setup
  - Low irradiation dose



Mean of pulse height distributions