MEG II実験のさらなる感度向上を目指したガス検出器RPCの設計最適化

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Core-to-Core Program

Contents

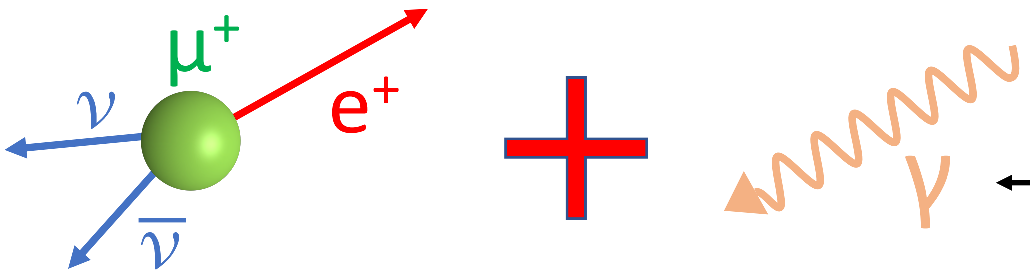
- Introduction
  - MEG II signal and background
  - Background identification detector
  - Concept of RPC for background identification
- Study of rate capability for ultra-low material RPC
- Summary and prospect

MEG II signal and background

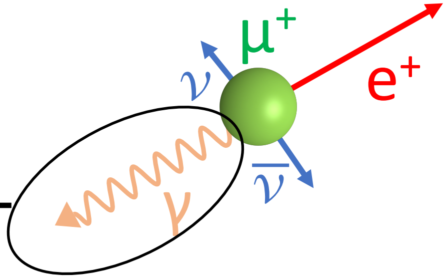
- MEG II will search for $\mu \rightarrow e\gamma$ decay
  - Identified by energy, timing and direction of e and γ

- Dominant source of background is accidental coincidence of BG-e and BG-γ mimicking the signal
  - One of the dominant source of BG-γ is radiative muon decay

<u>accidental background</u>

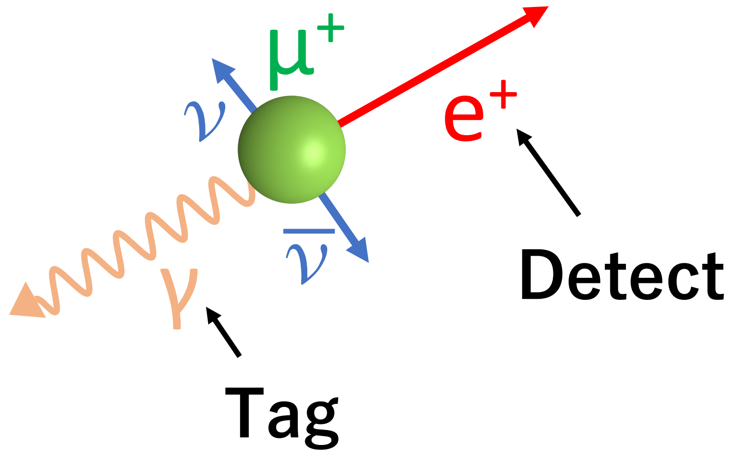


Mimic signal when e^+ and γ behave as
- Opposite direction
- ~ 52.8 MeV
- same timing



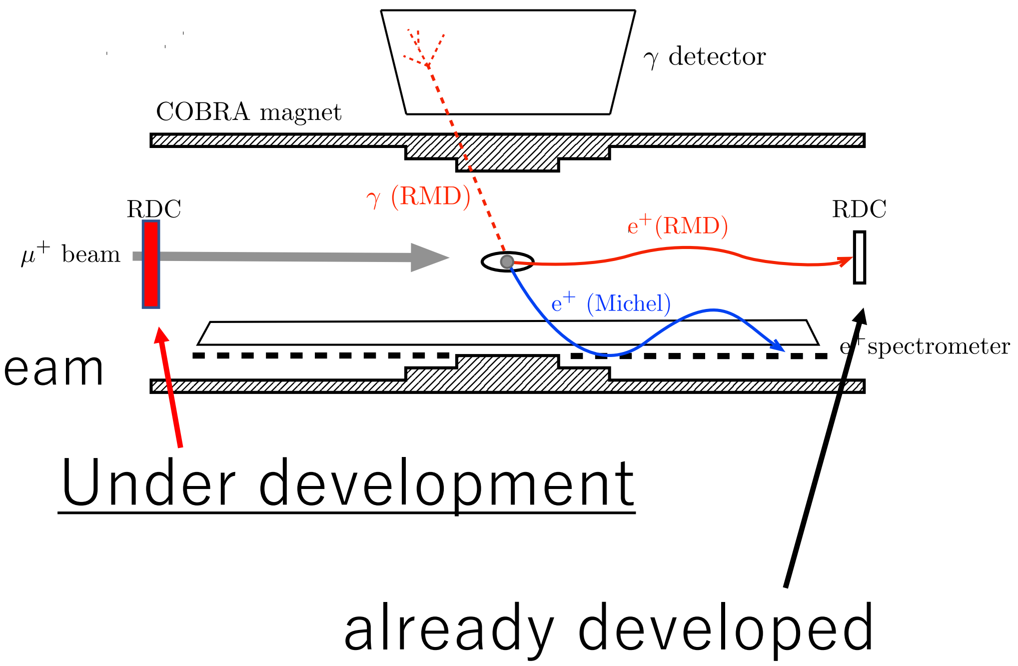
radiative muon decay is one of the source of γ

Background identification detector



- Detectors to **tag BG-γ** from radiative muon decay
  - **Detect low energy positron** (1-5MeV) accompanying BG γ (~52.8MeV)

- Planned to be installed to 2 positions
  - Upstream and downstream of the target
  - MEG II sensitivity
    - ➢ 2—9%(study ongoing) improvement with upstream (Only t measurement)
    - ➢ 10% improvement with downstream (E and t measurement)
  - Upstream one is under development → Today's talk



Requirements to the upstream detector

1. $< 0.1\%\ X_0$ material budget (beam must pass through the detector)
2. 90% efficiency for 1-5 MeV positron
3. 1 ns timing resolution
   (RMD identification with the timing difference b/w positron & γ)
4. $10^8\ \mu/s$ capable high rate performance and radiation hardness
   ($10^8\ \mu/s$ with 21 MeV/c , >60 weeks run)
5. 20 cm (diameter) detector size (45% acceptance…total 90% incl. DS)

→ Candidate: Ultra low-material RPC detector using Diamond Like Carbon (DLC)

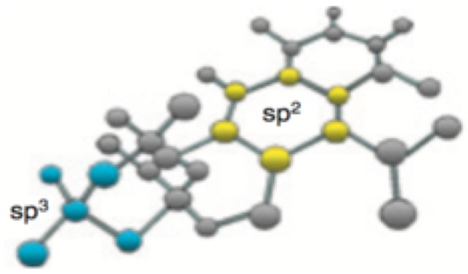
RPC based on DLC technology

Performance of conventional RPC
- time resolution < ns
- material: 1% X_0 → must be improved
- Efficiency ~90% → still requires study
- rate ~kHz/cm^2 → must be improved

- RPC: Gaseous detector with high resistive electrodes placed face to face
  - Gas: R134a (Freon) based
  - Gap thickness: 200 μm—2 mm

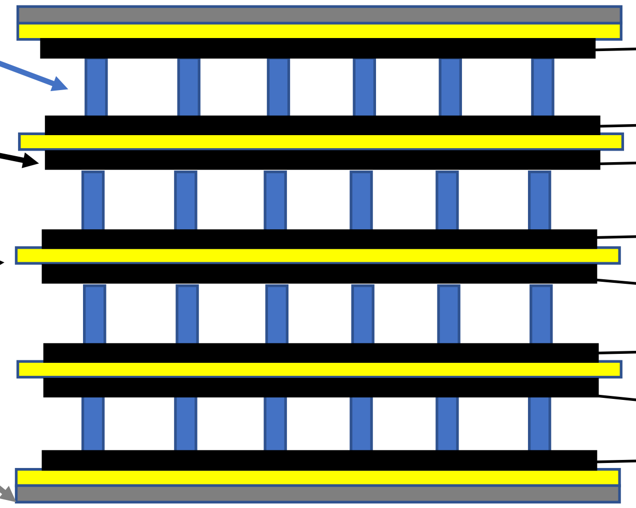
- Diamond Like Carbon(DLC) is used for resistive electrodes
  - DLC: high resistive material w/ mixed structure of sp^2 bond and sp^3 bond
  - Advantages of DLC
    1. low material → Sputter DLC on 50 μm Kapton
    2. Adjustable resistivity
       → Resistivity must be optimized for high rate environment
       (Resistivity must be low to achieve high rate capability)
    3. Multiple layers with lower voltage than conventional ones (next page)
  - Development initiated by a group of Kobe Univ

DLC: chemical structure



Proposed design of RPC for MEG II

- Readout: Al
  → aluminized Kapton will be used on the top & bottom



- High efficiency can be achieved by multilayer design
  - n-layer efficiency: $\epsilon_n = 1 - (1 - \epsilon_1)^n$
  - From requirement on material budget, 4 layers at maximum

Material budget

- Kapton 50 μm → 0.018 % X_0
- Al 100 nm × 2枚→ 0.0023 % X_0

→ < 0.1 % X_0 is achievable

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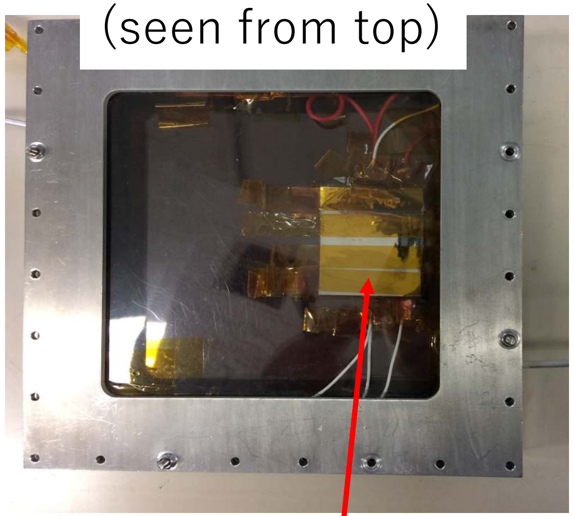
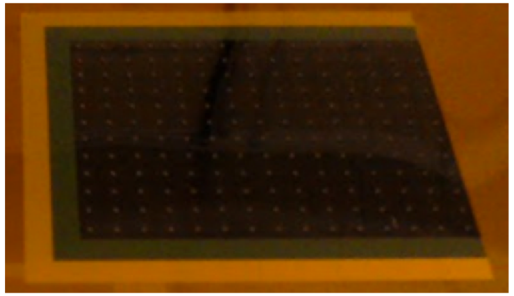
Prototype detector design

Gas package
(seen from top)



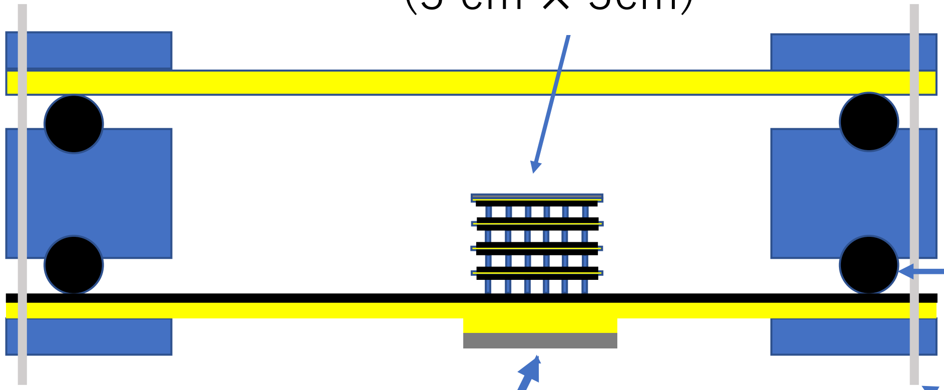
3 cm



3 cm

resistive plate

detector
(3 cm × 3cm)



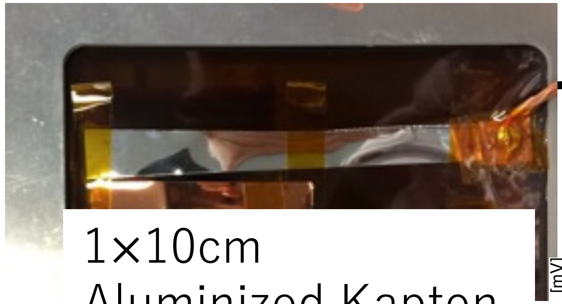
gas :R134a/SF_6 = 93/7

Gas package

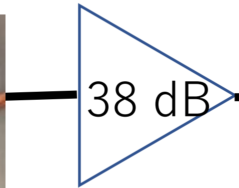
Rubber (for packing)

Screw (fixing the package)

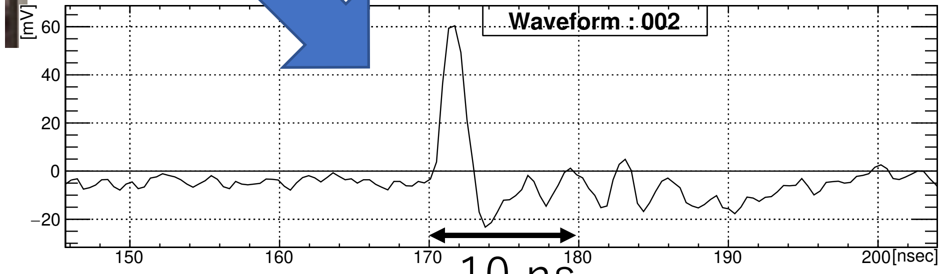
seen from bottom(Al readout)



1×10cm
Aluminized Kapton
(100nm thick)



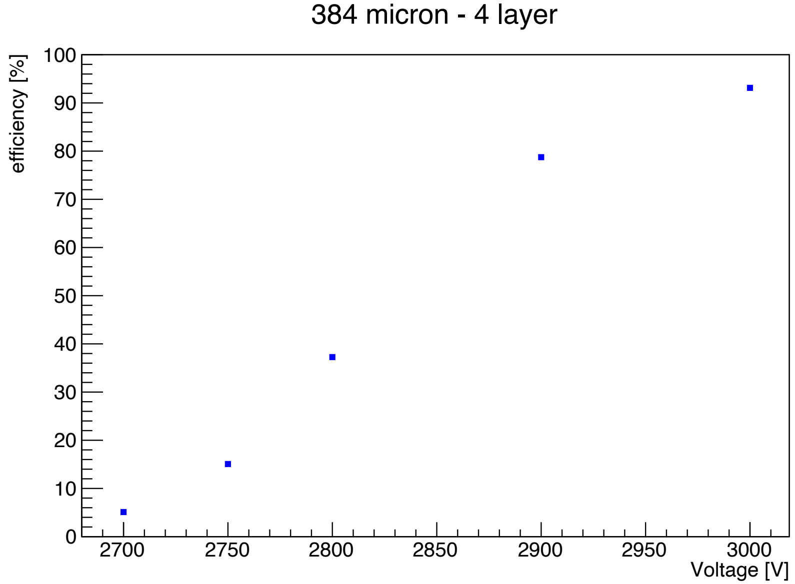
waveform
digitizer
(DRS4, 700 MHz)



Demonstrated low material design

Performance

Efficiency vs RPC operating voltage



- Setup
  - 384 μm gap 4-layer RPC
  - Operated with 10MΩ/sq resistivity
  - Measured for ^{90}Sr beta-ray
    → rate is lower than MEG II environment

- Performance
  - Efficiency: dependent on RPC voltage
  - Timing: ~250 ps,
    weakly dependent on voltage

Today's issue:
Performance appears good enough when rate is low,but this must be achieved under high rate environment

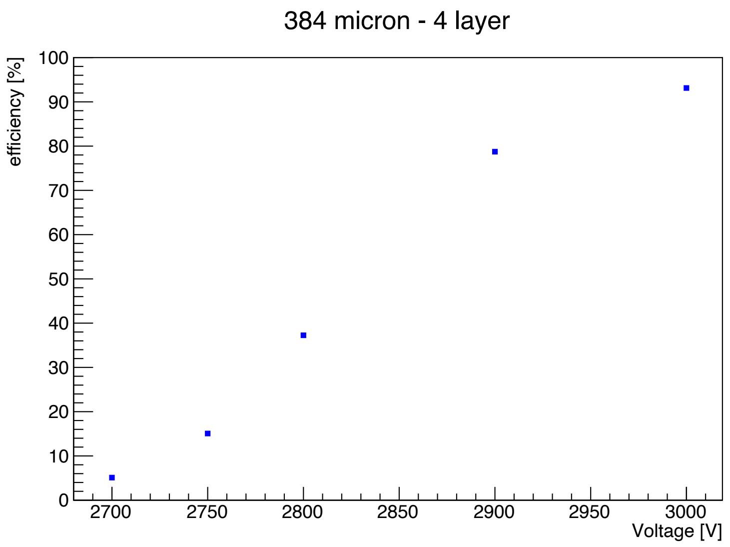
Requirements

✓ < 0.1% X_0 material budget
✓ 90% efficiency for 1-5 MeV positron
✓ 1 ns timing resolution
✓ 20 cm (diameter) detector size

➤ 10^8 μ/s capable high rate performance and radiation hardness

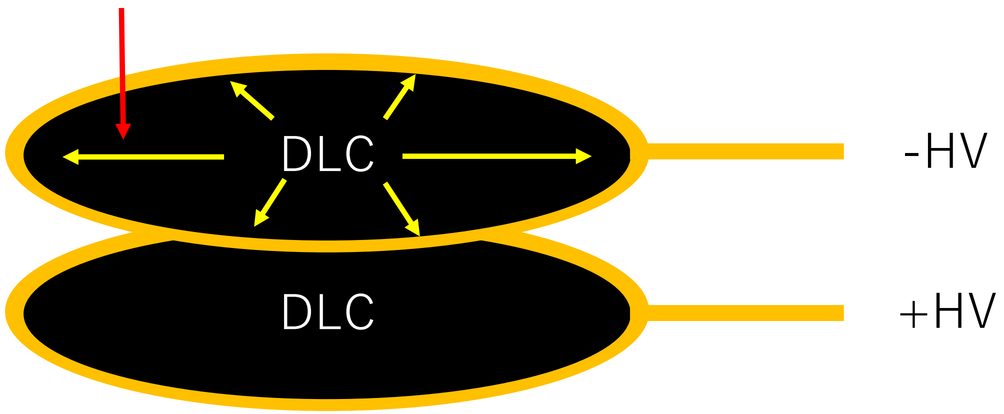
RPC under high rate environment

- Current flowing on the resistive electrodes produces voltage drop
  - The effective voltage between the gas gap is lower than the nominal one
    → Degradation of detection efficiency
  - Ref: G. Aielli *et al* 2016 *JINST* **11** P07014



- Current flows across the surface of the DLC

Current outgoes radially



Rate performance estimation

- Assuming the parameters tested in lab, voltage drop will be ~200V
  1. Electrodes' resistivity: 10 MΩ/sq (Current operating condition)
  2. Size of avalanche charge: 3 pC
     (Assuming similar avalanche size as that of MIP)
  3. Shape of the resistive plate: 20 cm in diameter
  4. Beam condition: 10^8 μ/s with 21 MeV/c, gaussian beam(σ=2 cm)

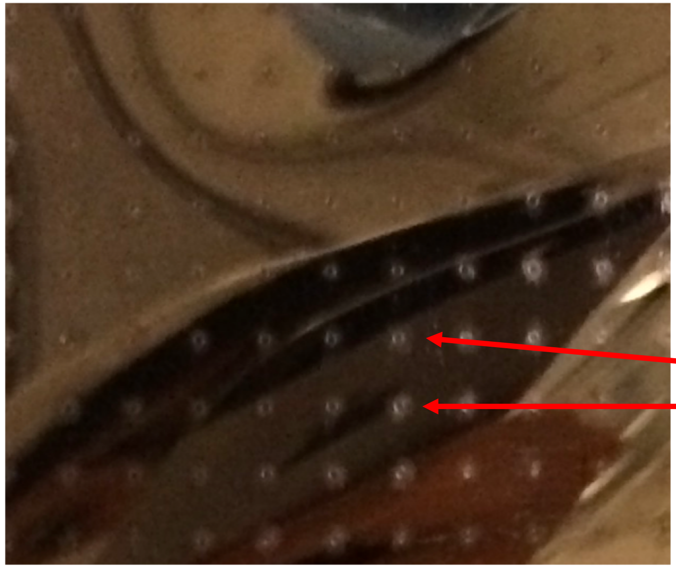
  → Not acceptable

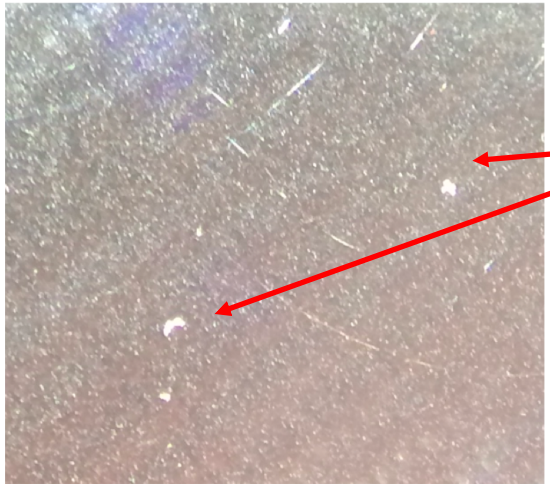
- Required improvements for the studies above
  - Reduce electrodes' resistivity to 1MΩ/sq level
  - Measurement of the RPC response to low momentum μ
    (Since the space charge effect is strong for RPC, saturation is expected)

Problem for lower resistivity

- With 1MΩ/sq resistivity, suffer from frequent discharge
  - Discharge appears typically @2.6—2.9kV
    → 40—50% efficiency
  - At least 3kV is required for 90% efficiency

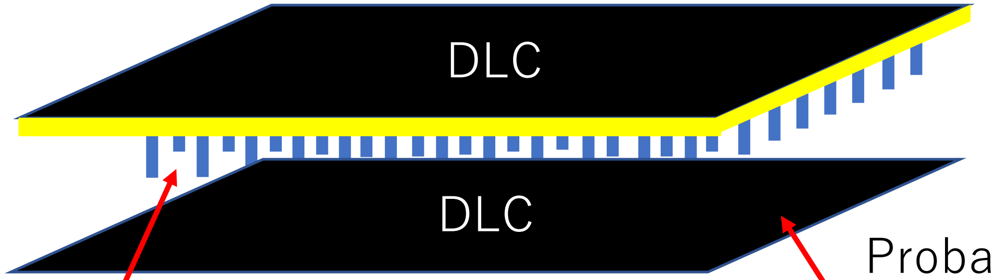
- Electrodes' damages are found after discharge
  - Pattern of the damage suggests discharge is frequent around the spacers



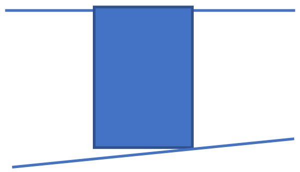


Investigation of the cause of discharge

- Cause of the discharge is under investigation
  - One possibility: Non-uniformity of electric field around the spacers
    → Calculation of the electric field around them suggests this idea



Spacers are attached on one side.
Made of photoresist,
with relative permittivity~3
(400 μm diameter, 384 μm height)

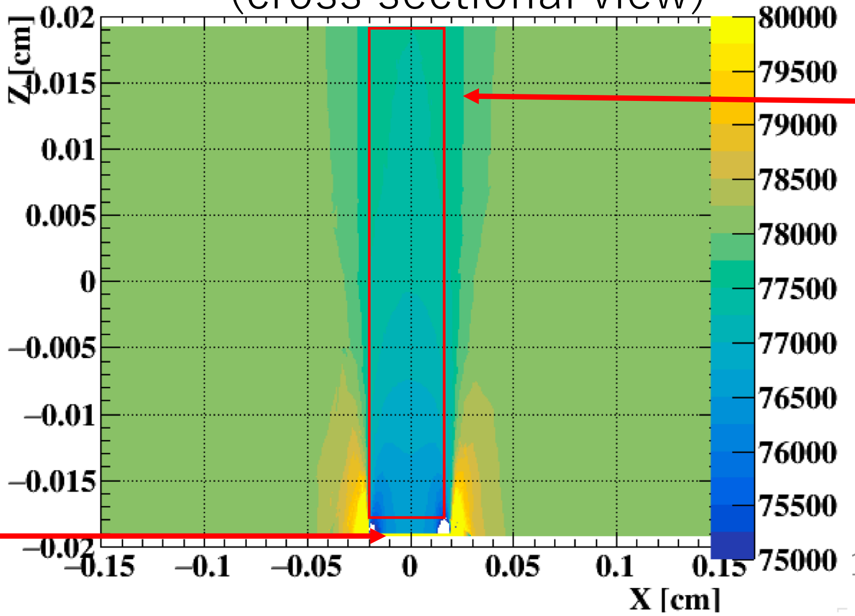


Probably, point contacted
on this side.
(film thickness 50 μm)

If spacer is slightly
floated, electric field
is strengthened

E field strength map
(cross sectional view)

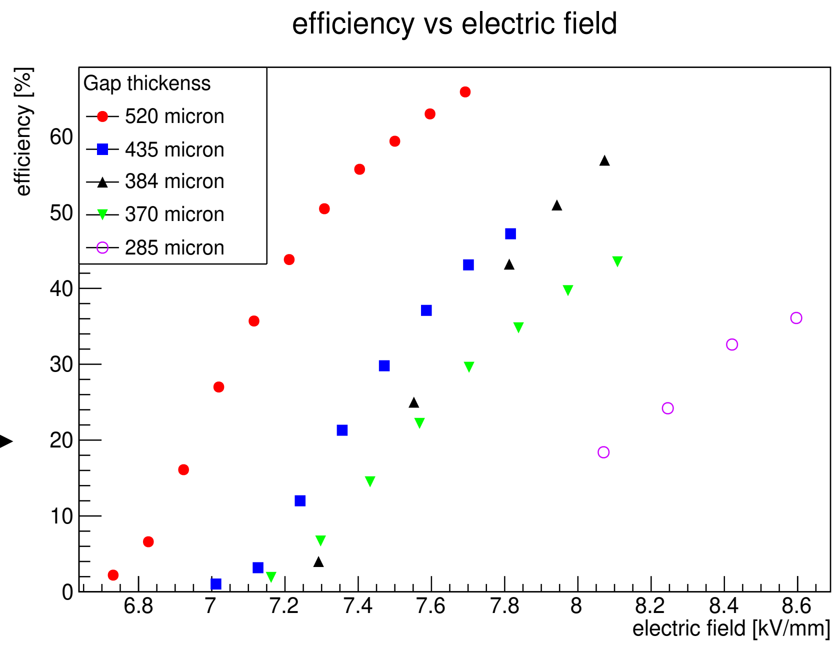
Contour of the spacer



Possible solutions

- Fix discharge problem to reach nominal HV with low resistivity DLC
  - The cause of the discharge must be better understood

- Thicker gap
  - Larger efficiency is easily obtained
  - Discussion so far is based on 384 μm design



- Other ideas ?

Single layer efficiency. To translate into 4 layer, apply $\epsilon_n = 1 - (1 - \epsilon_1)^n$

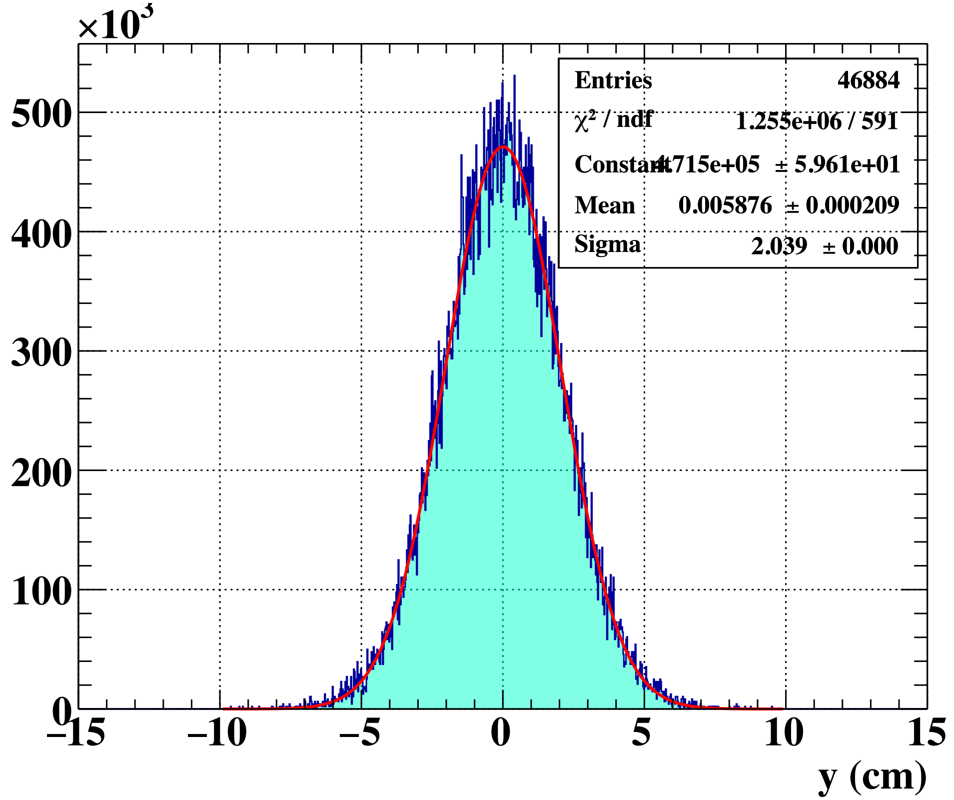
Summary and Prospect

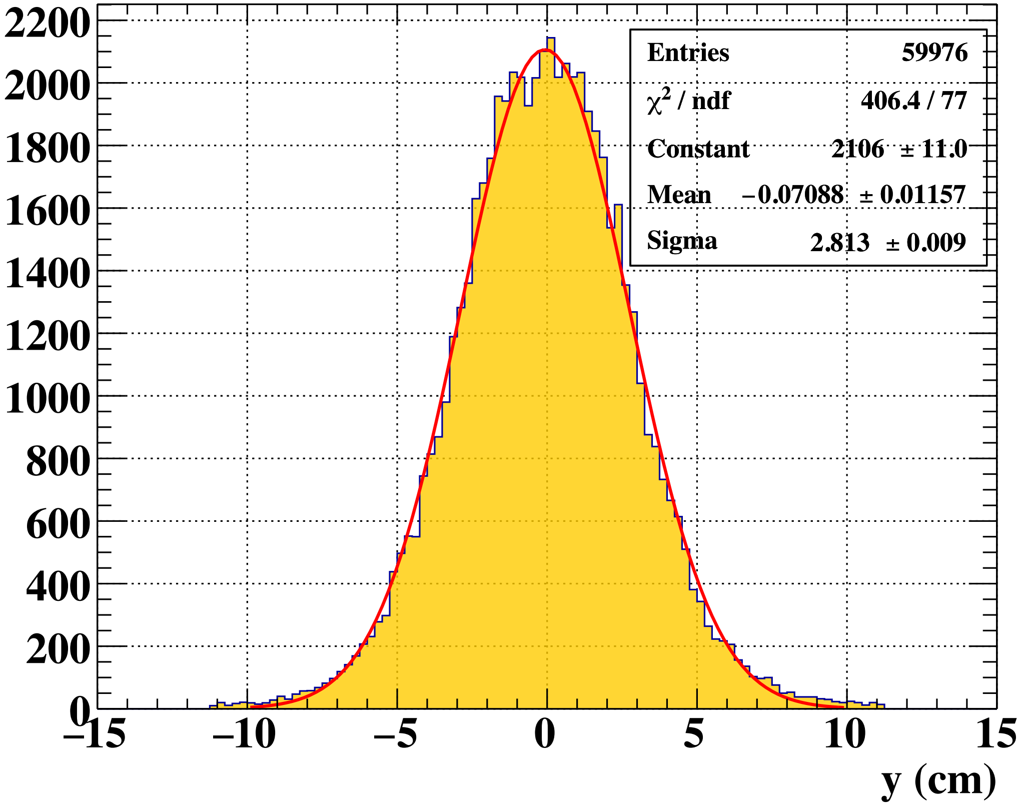
- Developing ultra-low material RPC for MEG II experiment
  - Tag BG-γ to improve the sensitivity
  - Performance requirements have been met except for rate capability
- Ongoing study on RPC rate capability has been discussed
  - W/ operating condition so far, rate capability is insufficient
    - Large efficiency decrease under high rate environment
    - Electrodes' resistivity must be smaller, but we suffer from discharge when sufficiently low resistivity electrodes are used
  - Looking for a solution
    - Investigation of RPC's discharge problem to enable low resistivity RPC
    - Optimization of gap thickness or other solutions
- Need to confirm the signal saturation for low momentum muon
  - Beam test @PSI planned this winter

Backup

ビームμとか

- ●粒子の拡がり
  - ✓ビームの拡がりはσ=2 cm
  - ✓輻射崩壊陽電子は 2.8 cm

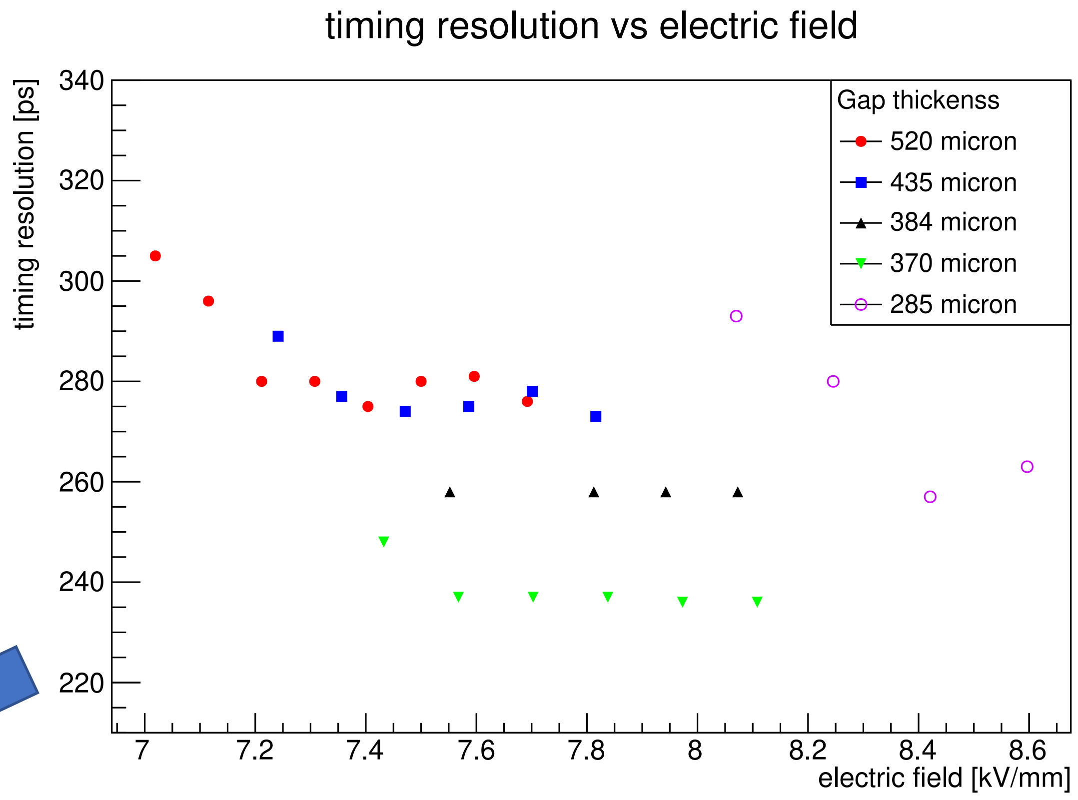




Result: Timing resolution for single layer

- Single layer timing resolution is measured changing the gap thickness
  - (Normally, 4-layer resolution is better)

- Timing resolution
  - Determined from the timing difference b/w RPC and reference counter
  - RPC timing: 50% constant fraction

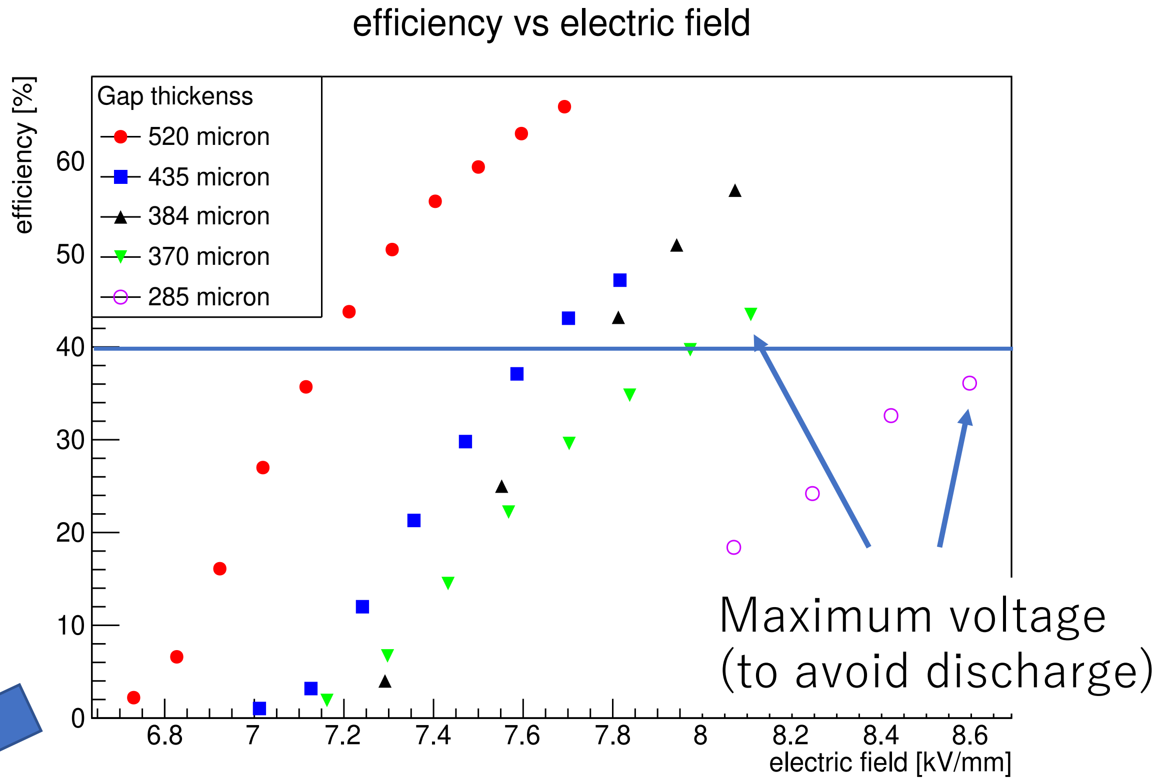


Timing resolution is good enough at least up to 520μm
(< 1ns required)

At least, gap thickness can be b/w 370 μm and 520 μm

Result: Detection efficiency for single layer

- Single layer efficiency is measured changing the gap thickness
  - 40% single layer efficiency is required to achieve 90% w/ 4-layer
  - $\epsilon_n = 1 - (1 - \epsilon_1)^n$
  - For each thickness, measured changing the operating voltage



- Efficiency
  - Determined from the fraction of RPC hits in the triggered events
  - RPC threshold = 10 mV

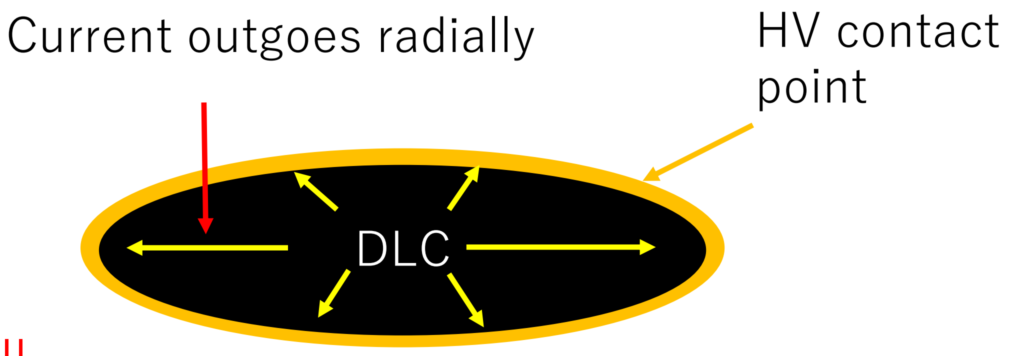
sufficient efficiency for ⩾370 μm thickness

Trash

Parameters relevant to rate performance

- Dependent on following factors
  1. Electrodes' resistivity
  2. Size of avalanche charge
  3. Shape of the resistive plate
     → 20 cm in diameter
  4. Beam condition
     → 10^8 μ/s with 21 MeV/c, gaussian beam(σ=2 cm)

In MEG II



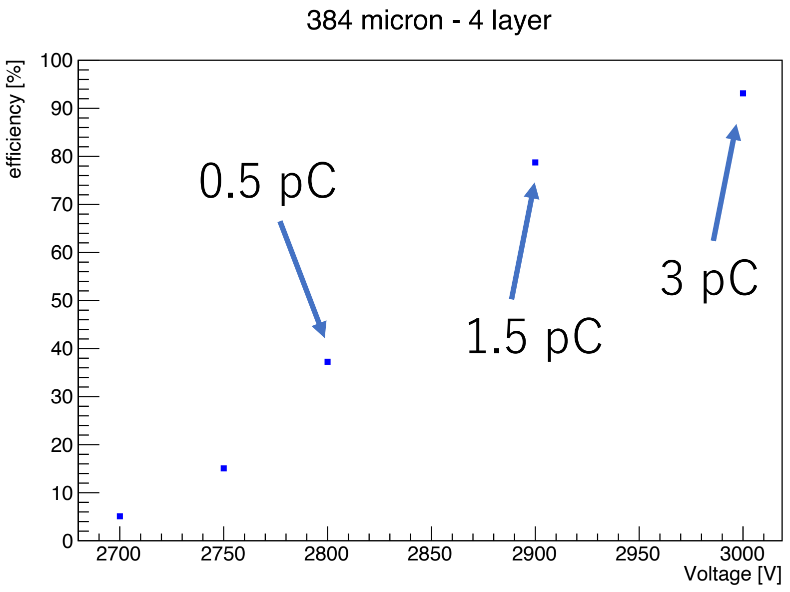
- With parameters as follows, good rate capability is expected
  - Electrodes' resistivity: 1MΩ/sq
  - Size of avalanche charge: 1 pC

More detailed study required (following slides)

→ Result in 25V voltage drop at maximum (< 10 % efficiency loss)

Study on the avalanche charge

- Measured using ^{90}Sr beta ray
  - 3 pC on average at 3 kV for 384 μm gap
  - Similar result is reported in G. Aielli *et al* 2016 *JINST* **11** P07014



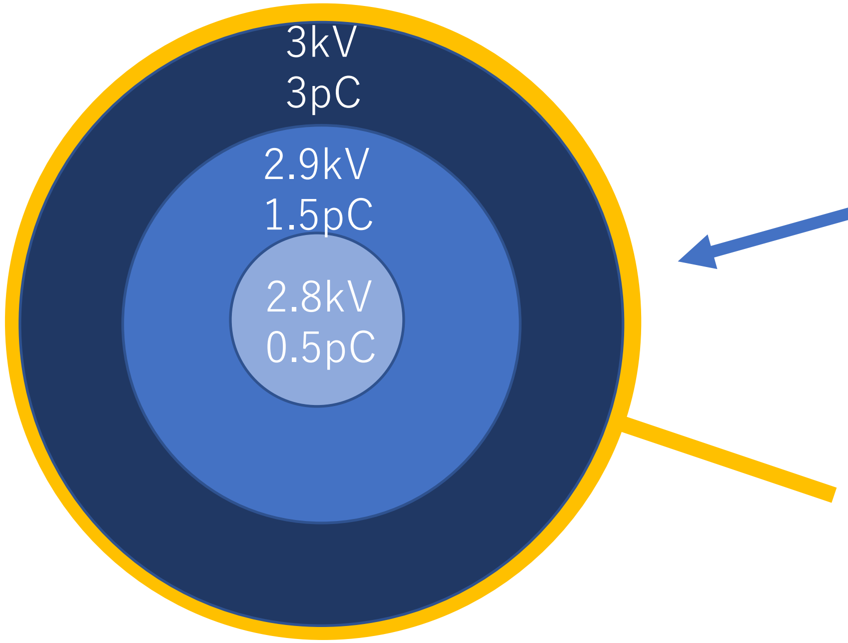
- In MEG II experiment, rate capability against 21 MeV/c muon is relevant
  - Larger ionization is expected for muon

- Measurement using low momentum muon is necessary to look into the rate capability in MEG II experiment

  → Planning a measurement using muon beam this year @PSI

Efficiency under more realistic assumptions

- For both of the following scenarios, 40—50% efficiency is expected
  - Operate RPC with 10MΩ/sq DLC at 3kV (voltage drop will be 200V level)
  - Operate RPC with 1MΩ/sq DLC at 2.9kV (voltage drop will be 30V level)
  - These results use the avalanche charge measured for ^{90}Sr electron
    …This might become worse with the muon's larger ionization



10MΩ/sq case:
The effect of voltage drop is taken into account when calculating current flowing the electrodes

3kV HV supply is connected around the electrodes

Rate performance estimation

- Assuming the parameters tested in lab, voltage drop will be ~200V
  1. Electrodes' resistivity: 10 MΩ/sq (Current operating condition)
  2. Size of avalanche charge: 3 pC
     (Assuming similar avalanche size as that of MIP)
  3. Shape of the resistive plate: 20 cm in diameter
  4. Beam condition: 10^8 μ/s with 21 MeV/c, gaussian beam(σ=2 cm)

- aa

  → Not acceptable. Electrodes' resistivity must be lower

(*) : In other studies, avalanche size is measured with MIP,
whereas avalanche size for 21MeV/c muon is relevant in our case.

→ Expecting RPC's well-known strong saturation effect,
we are planning a measurement @PSI