MEG II実験における大強度μ粒子ビーム中での運用を見据えた超低物質量RPCのレート耐性の研究 (2)

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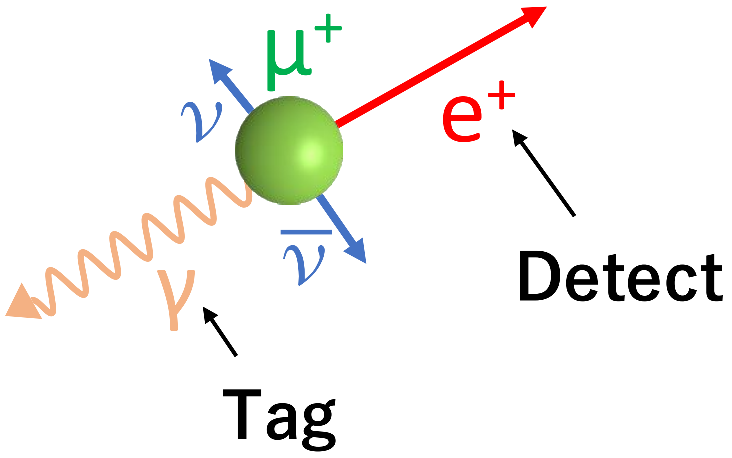
Core-to-Core Program

Contents

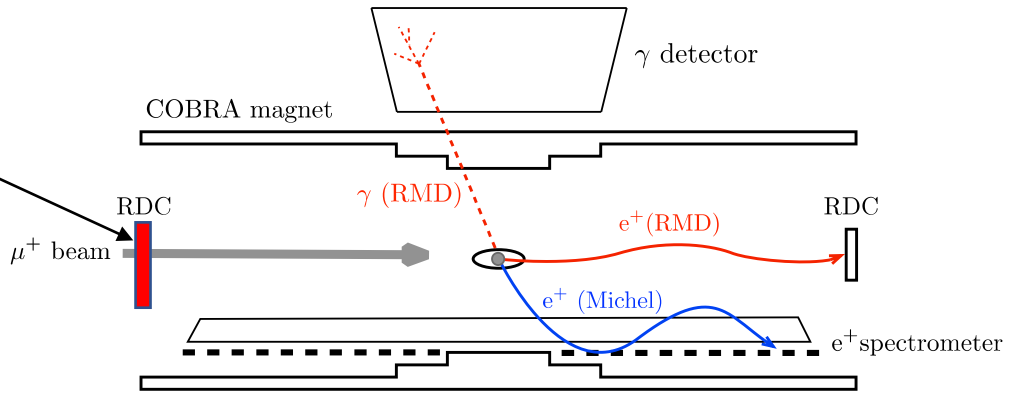
- Introduction
- Measurement with high rate μ beam
  - Setup
  - Height spectra
  - Evaluated voltage drop
- Projection to MEG II performance
- Summary and prospect

Ultra-low material RPC for MEG II



- Detectors to **tag BG-γ** from radiative muon decay

- RPC will be exposed to MEG II high-intensity μ beam
  → **Rate capability is needed**
  - Beam test conducted in 2020



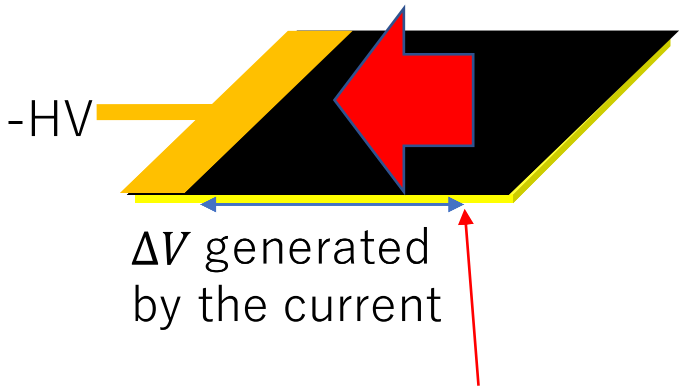
- Previous talk deal with
  - RPC's response to low-momentum μ (Measured without dependence on rate-capability)

(See the slide for the previous talk for detail)

Introduction: Rate capability of RPC

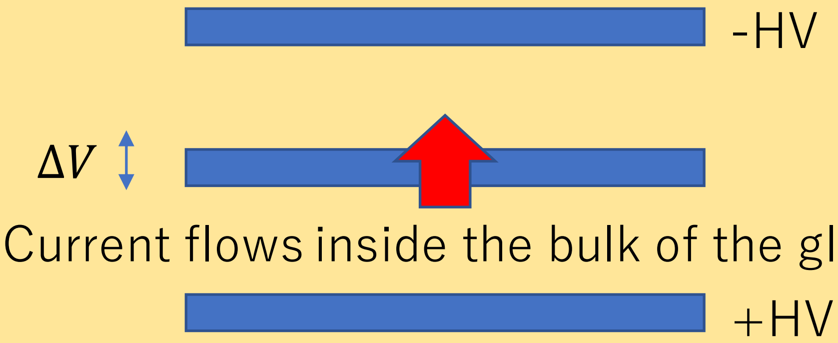
- Amplified electron-ion pairs flow out on the resistive electrodes
  - Large current is generated when hit rate is high
  - The current cause voltage drop: $\Delta V = R \cdot I$
  - RPC's performance get worse with lower effective voltage

- Geometry of flowing current must be taken into account
  - Current flows on the surface of the DLC electrodes



True voltage at this point is $-\mathrm{HV} + \Delta V$

c.f. Conventional glass (m)RPC



Current flows inside the bulk of the glass

Ref: https://doi.org/10.1088/1748-0221/11/07/P07014

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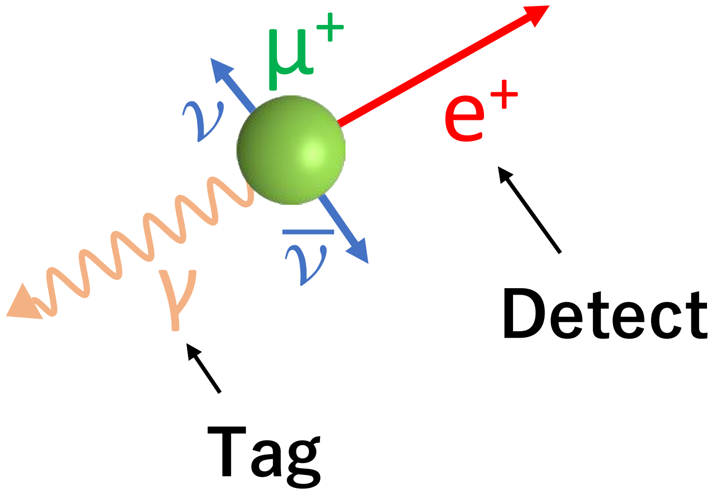
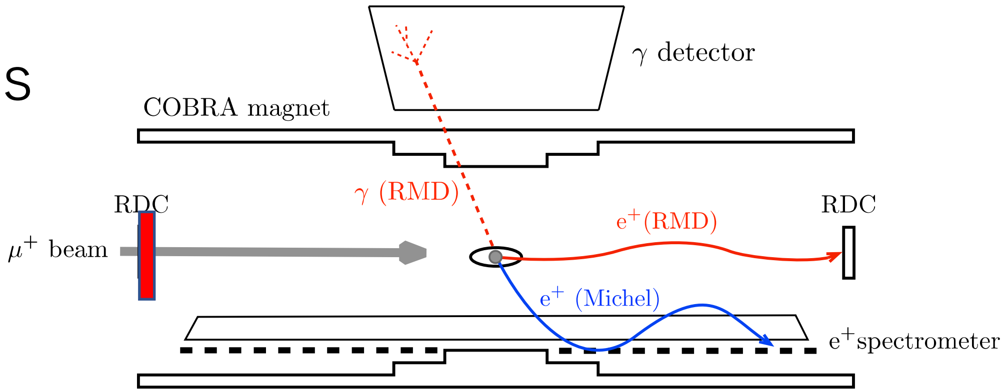
Purpose of test with high-rate beam

- Reminder of RPC's use in MEG II
  - Detection of MIP in high-rate muon beam
- Purpose of test with high-rate beam
  1. RPC's performance in high-rate environment
     → To be measured for our RPC for the first time
  2. Check whether ΔV effect reasonably explains the RPC's performance in high-rate beam
- MEG II beam line is used
  - Beam is not collimated, unlike the previous talk



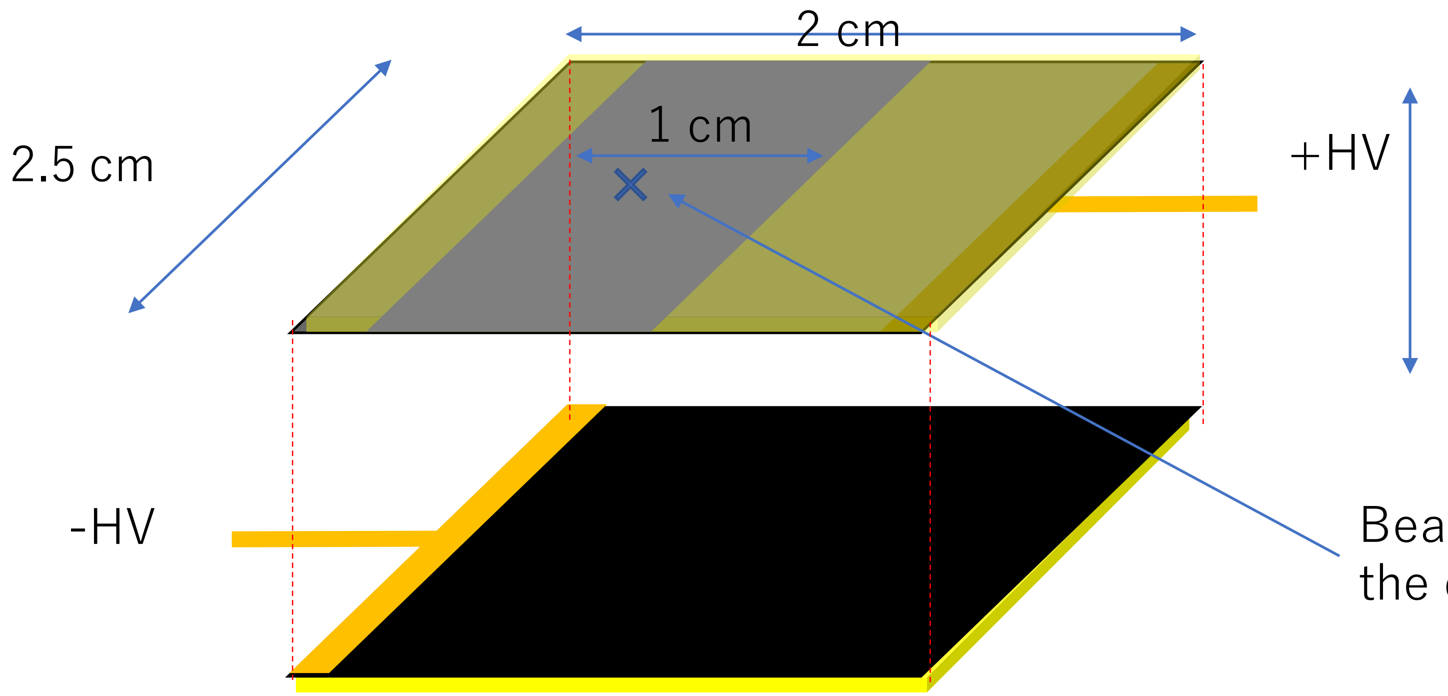


Setup: Detail of RPC structure

- The same prototype as that mentioned in the previous talk

DLC resistivity:
~30 MΩ/sq for +HV side
~10 MΩ/sq for –HV side

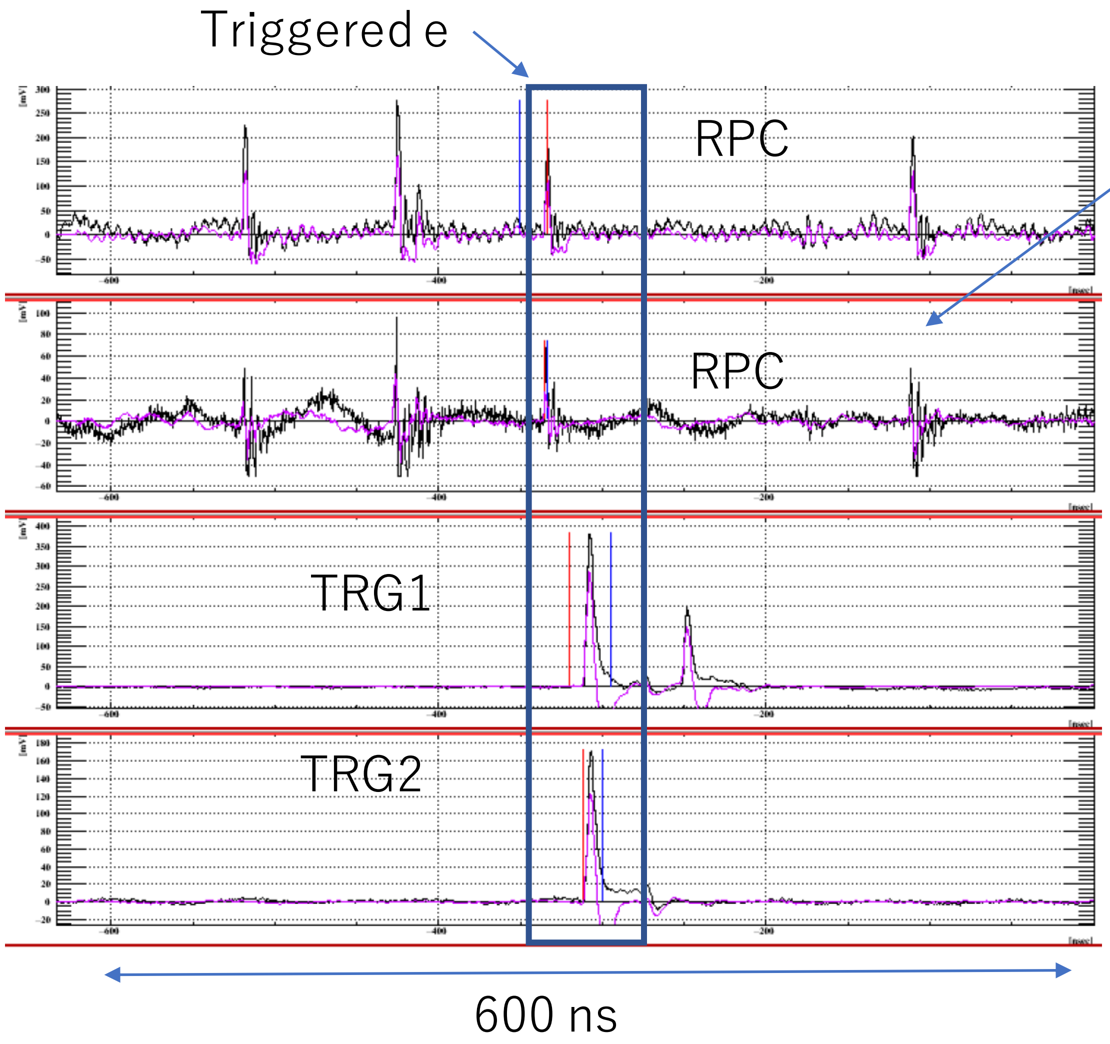
→ The effective resistivity is 20 – 30 MΩ between the sensitive region and the HV supply electrodes



384 μm gap filled by $R134a/iso\text{-}C_4H_{10}/SF_6 = 94/5/1$ gas mixture

Beam center is aligned to the center of readout strip

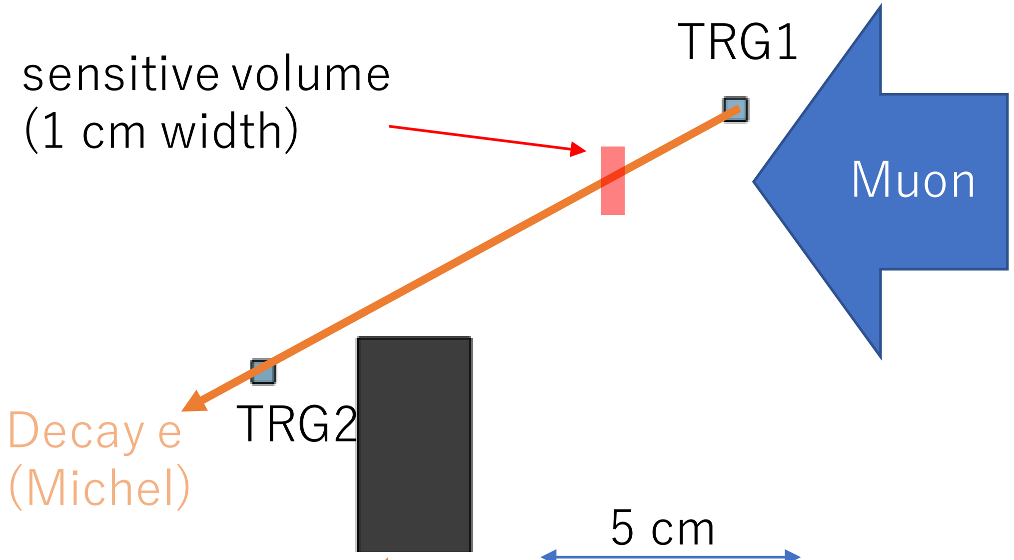
Measurement set up with high-rate beam



(~30 ns timing difference b/w
RPC and TRG is from cabling)

Most likely to be mu

In this setup
- RPC is exposed to beam
- Michel positron is triggered

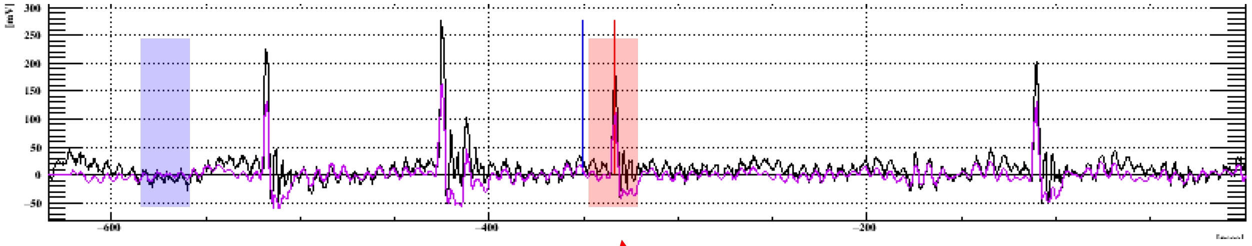


Pb blocker to reduce accidental trigger

Pulse height spectra with high-rate beam

- Beam profile
  - Total beam rate: $2\times10^7\ \mu/s$
  - Beam size: $\sigma_x = 13$ mm, $\sigma_y = 23$ mm

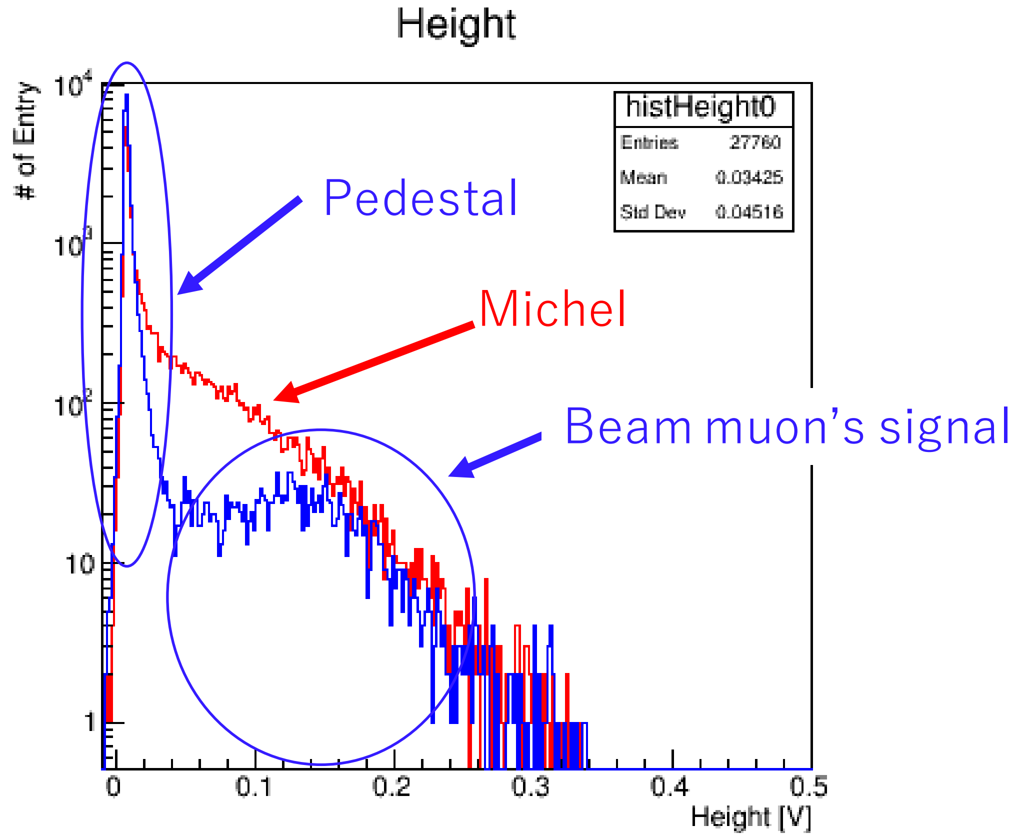
- Operating voltage: 2.75 kV
  - Current: Read as 6.5 μA



On-timing (Michel expected)

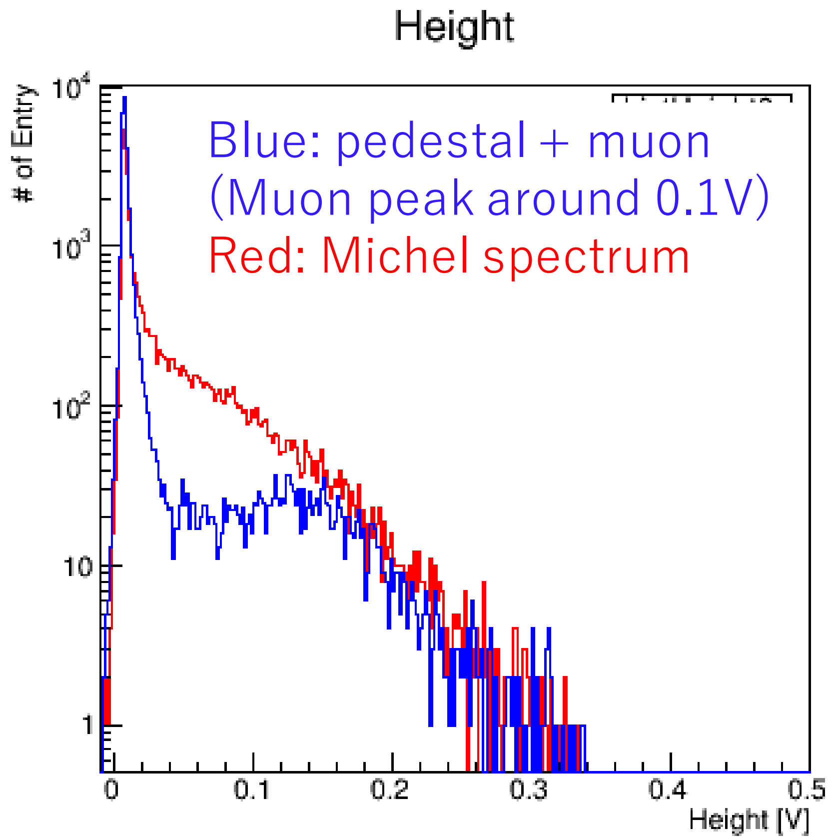
Off-timing; Mostly pedestal.
Beam muon also enter at some probability

Blue: Pulse height spectra for fixed off-timing analysis window: pedestal + Beam muon
Red: Pulse height spectra for triggered timing analysis window; Mostly Michel, w/ accidental

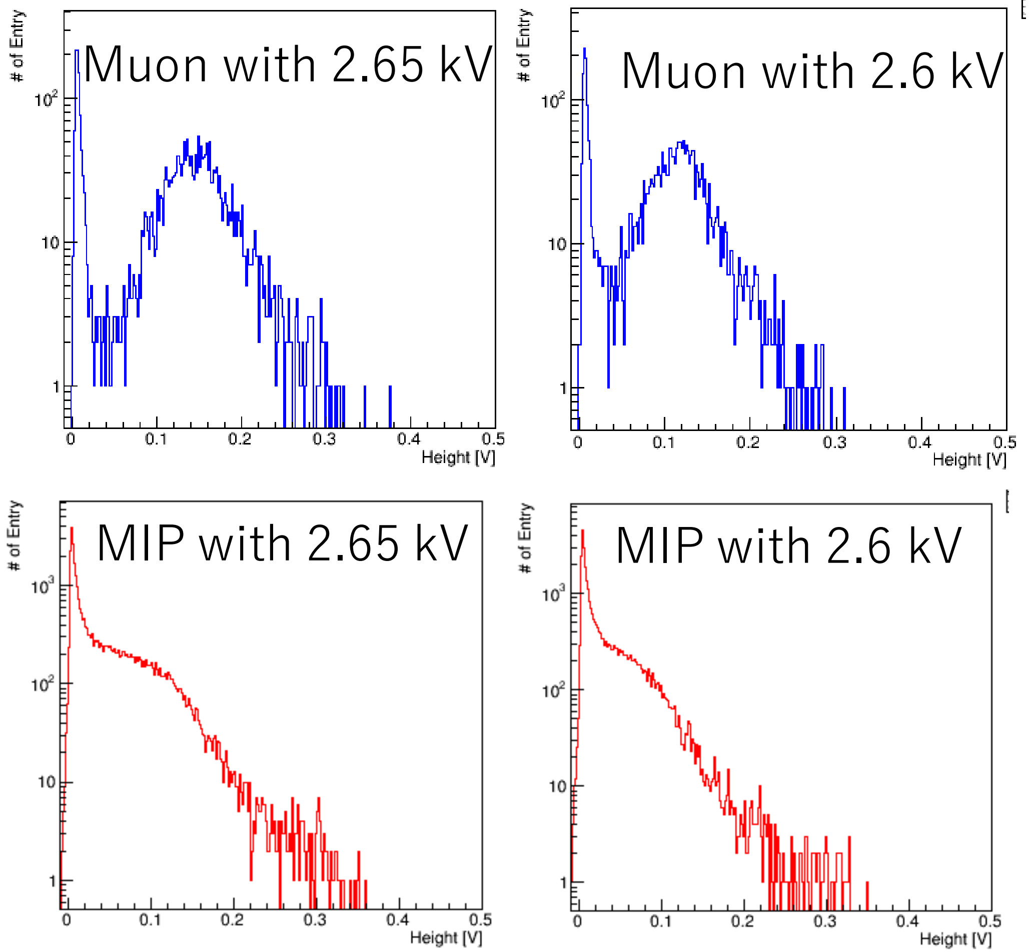


Comparison with measurements at low-rate

- Voltage drop effect appears
  - Distribution looks as that of 2.6 – 2.65 kV
  - Operated @2.75 kV → ~100 V drop



Pulse height taken with sufficiently low-rate



Interpretation of the results

- Voltage drop is observed at high rate
  - Estimated effective voltage: 2600 – 2650 V
  - Nominal applied voltage: 2750 V

- Voltage drop is estimated to be 100 – 150V:
  This can be understood with $\Delta V = R \cdot I$
  - $R = 20 - 30\ \mathrm{M\Omega}$:
    Determined by
    - DLC's surface resistivity
    - Geometry of the flowing current
  - $I = 6.5\ \mu\mathrm{A}$: Current generated from avalanche charge

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- Introduction
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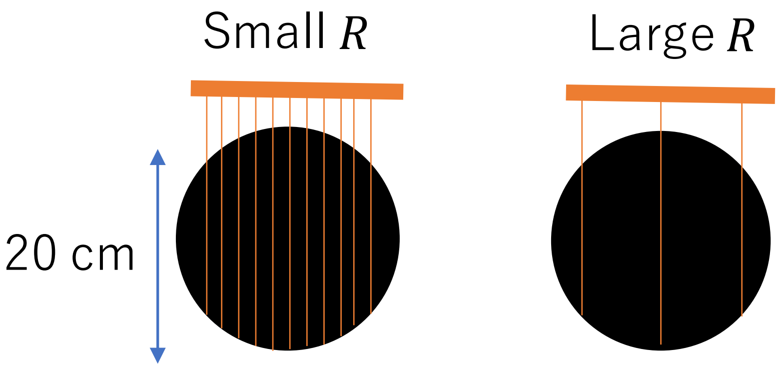
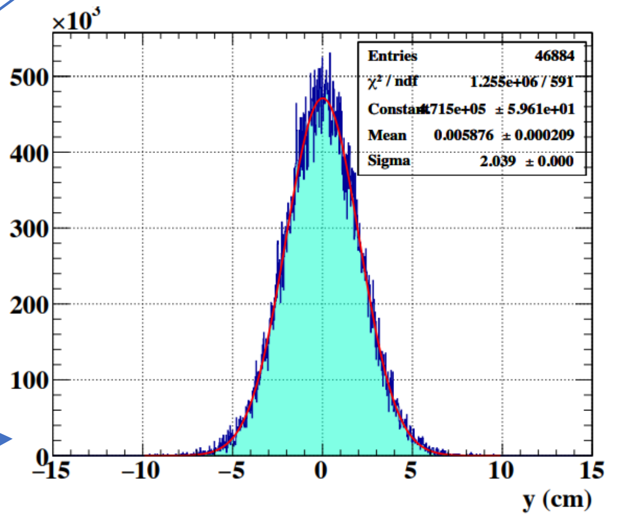
- Projection to MEG II performance
  - Method on projection
  - Avalanche charge evaluation for low momentum μ
  - Expected performance
- Summary and prospect

Strategy of rate capability study

- The test condition with high-rate beam is different from MEG II
  - **Prototype detector** with a size smaller than required one
  - **Beam profile** is different



- $\Delta V = R \cdot I$ evaluation for MEG II is needed
  - I is determined by
    1. Average charge in avalanche (Magnitude of current)
    2. The beam profile (Distribution of current source)
  - R is determined by
    1. Surface resistivity of DLC
       → $> \sim 10$ MΩ/sq is needed to suppress discharge
    2. HV supply arrangement
       → Candidate: 2 cm pitch strip-shaped HV supply



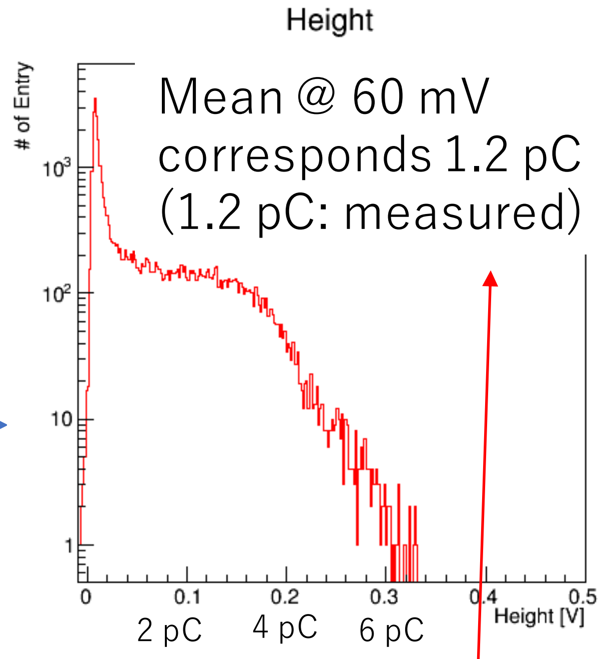
- I evaluation is the topic of the remaining talk
  - Beam profile with $\sigma = 20$ mm
  - Average charge evaluation

Avalanche charge evaluation

- Evaluation of avalanche charge for μ:
  Signal height ∝ *avalanche charge* relation
  - Proportional constant: measured with ^{90}Sr-beta

This measurement with ^{90}Sr-beta agrees with other studies

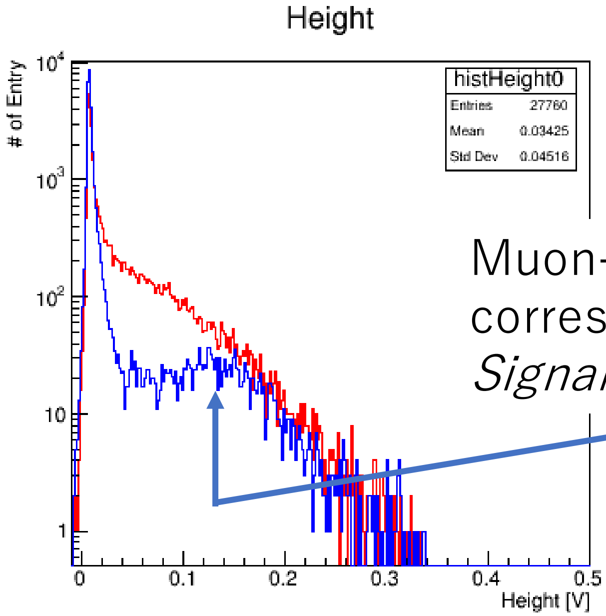
- https://doi.org/10.1016/S0168-9002(01)01914-3
- https://doi.org/10.1088/1748-0221/11/07/P07014



Mean @ 60 mV
corresponds 1.2 pC
(1.2 pC: measured)

- In high-rate μ beam,
  average avalanche charge: 2.4 pC
  - Consistent with generated current:
    2.7 MHz × 2.4 pC ~ 6.5 μA

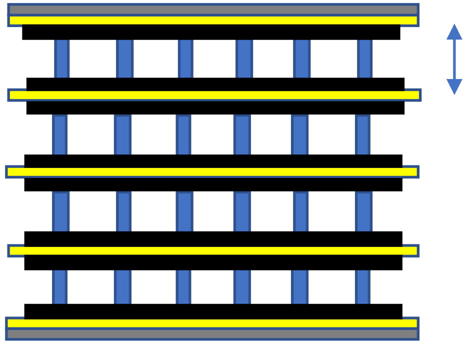
Estimated hit rate

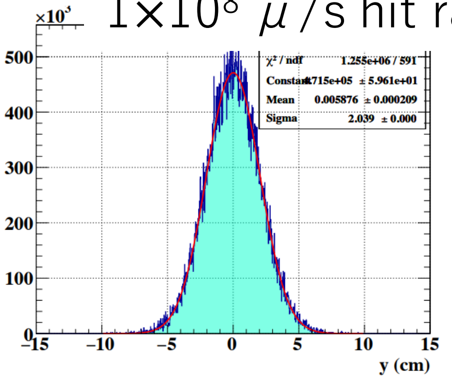


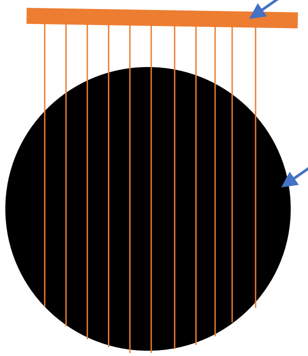
Muon-originated 120 mV
corresponds 2.4 pC
Signal height ∝ *avalanche charge*

Expected performance in MEG II

- Assumptions on detector configuration







- Result
  - $\Delta V \sim 100$ V
    → Effective voltage is 2.65 kV
  - Single layer efficiency is measured to be > 40% with 2.65 kV
    → **90 % efficiency is achievable with 4-layers**
    $(1-\epsilon_n = (1-\epsilon_1)^n$: ϵ_n is n-layer efficiency)

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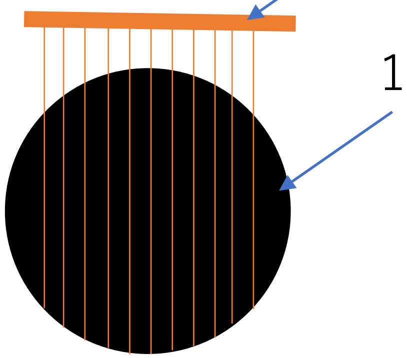
Summary and Prospect

- Rate capability of RPC in MEG II experiment is studied
  - **RPC is operational even in MEG II beam**
  - But with some uncertain assumptions

- Studies are needed on the uncertain assumptions



2cm pitch HV supply with 100 μm width each
(Formation technique has not been established)

10MΩ/sq DLC (Smaller resistivity results in discharge)

← Is this design really feasible ?

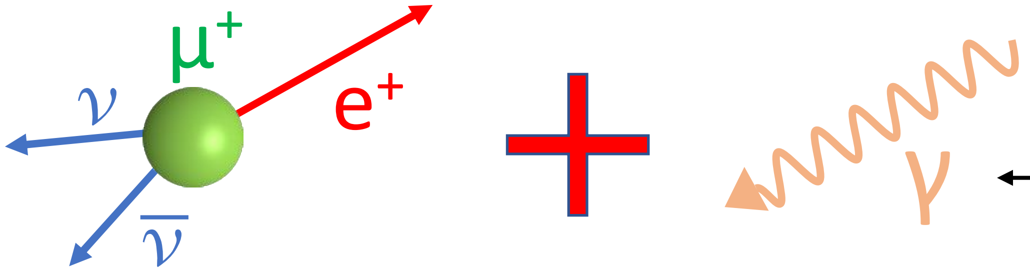
Backup

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

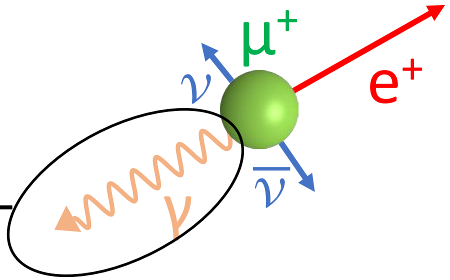
- Dominant source of background is accidental coincidence of BG-e and BG-γ mimicking the signal
  - One of the dominant source of BG-γ is radiative muon decay

<u>accidental background</u>



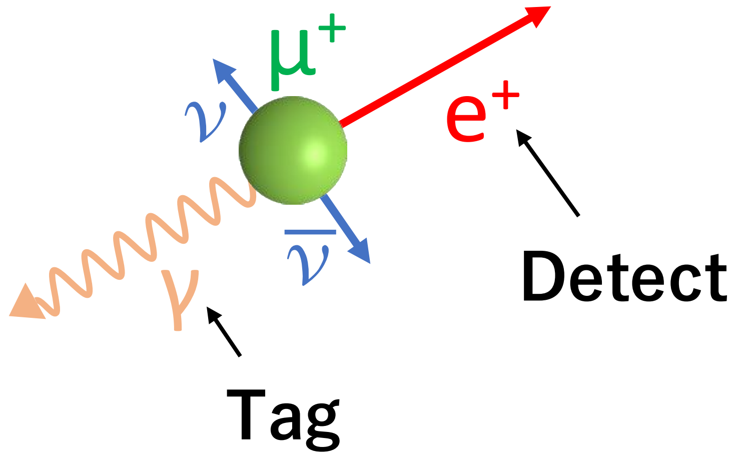
Mimic signal when e$^+$ and γ behave as

- Opposite direction
- ~ 52.8 MeV
- same timing



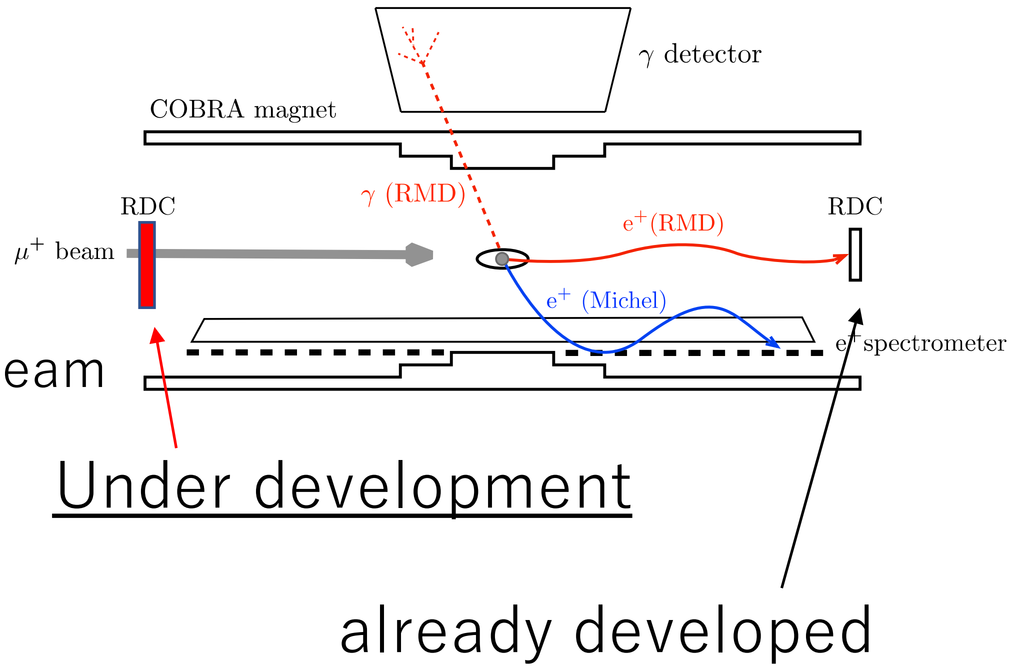
radiative muon decay is one of the source of γ

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

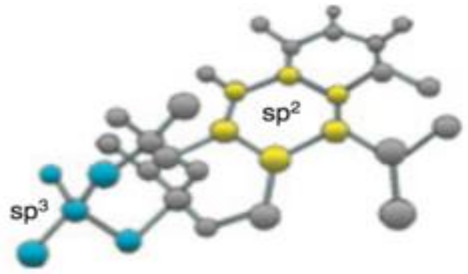
RPC based on DLC technology

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

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

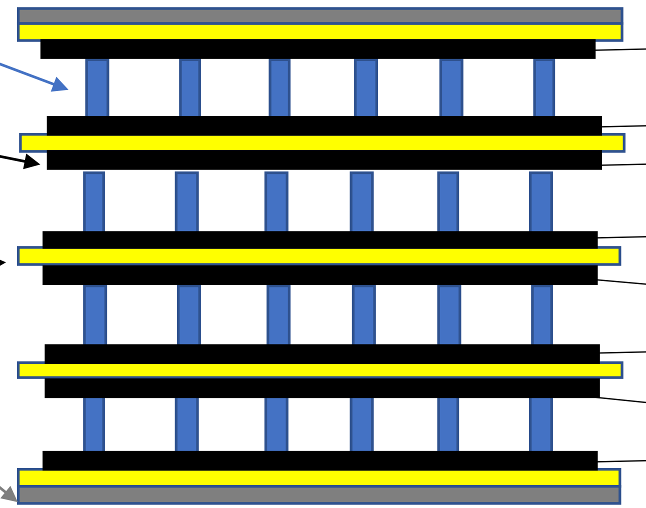
● Diamond Like Carbon(DLC) is used for resistive electrodes
  - DLC: high resistive material w/ mixed structure of sp^2 bond and sp^3 bond
  - Advantages of DLC
    1. low material → Sputter DLC on 50 μm Kapton
    2. Adjustable resistivity
       → Resistivity must be optimized for high rate environment
       (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

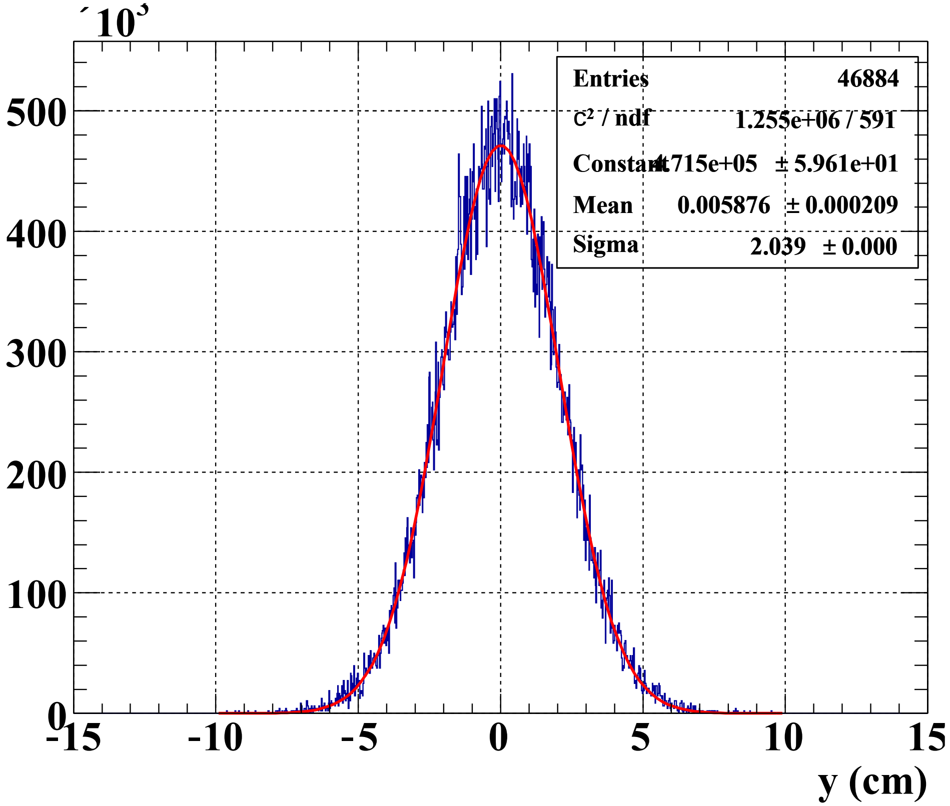
Material budget

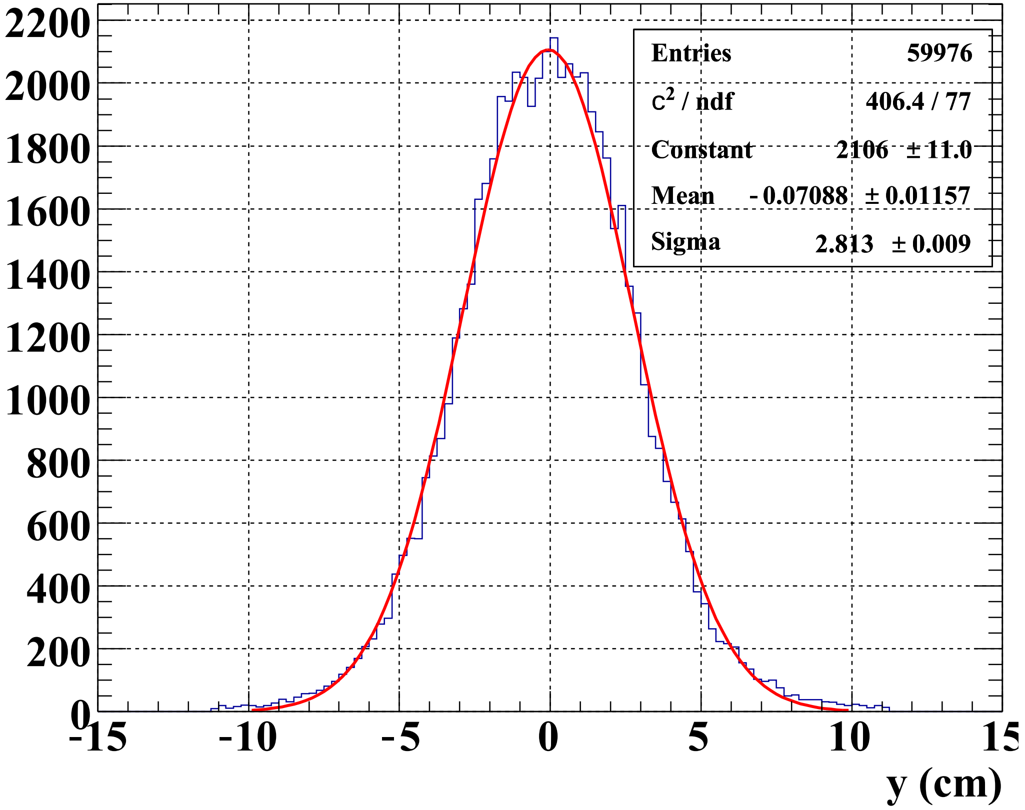
- Kapton 50 μm → 0.018 % X_0
- Al 100 nm × 2枚→ 0.0023 % X_0

→ < 0.1 % X_0 is achievable

ビームμとか

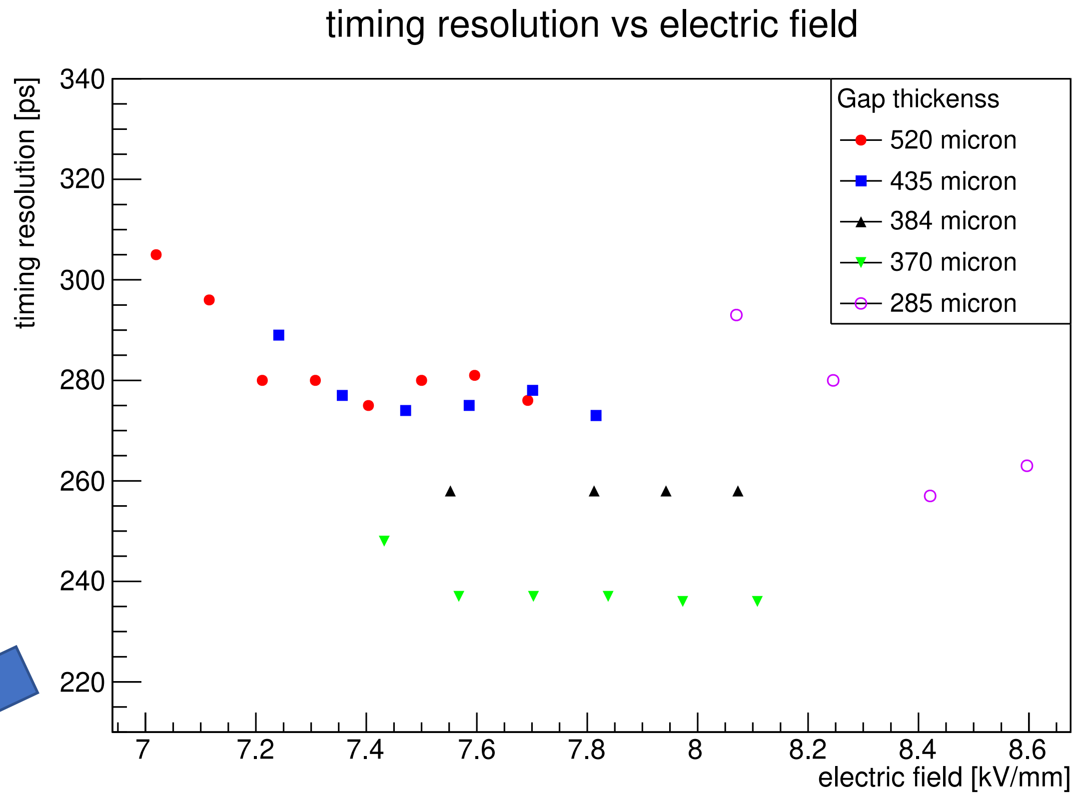
- 粒子の拡がり
  - ✓ビームの拡がりはσ=2 cm
  - ✓輻射崩壊陽電子は 2.8 cm





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

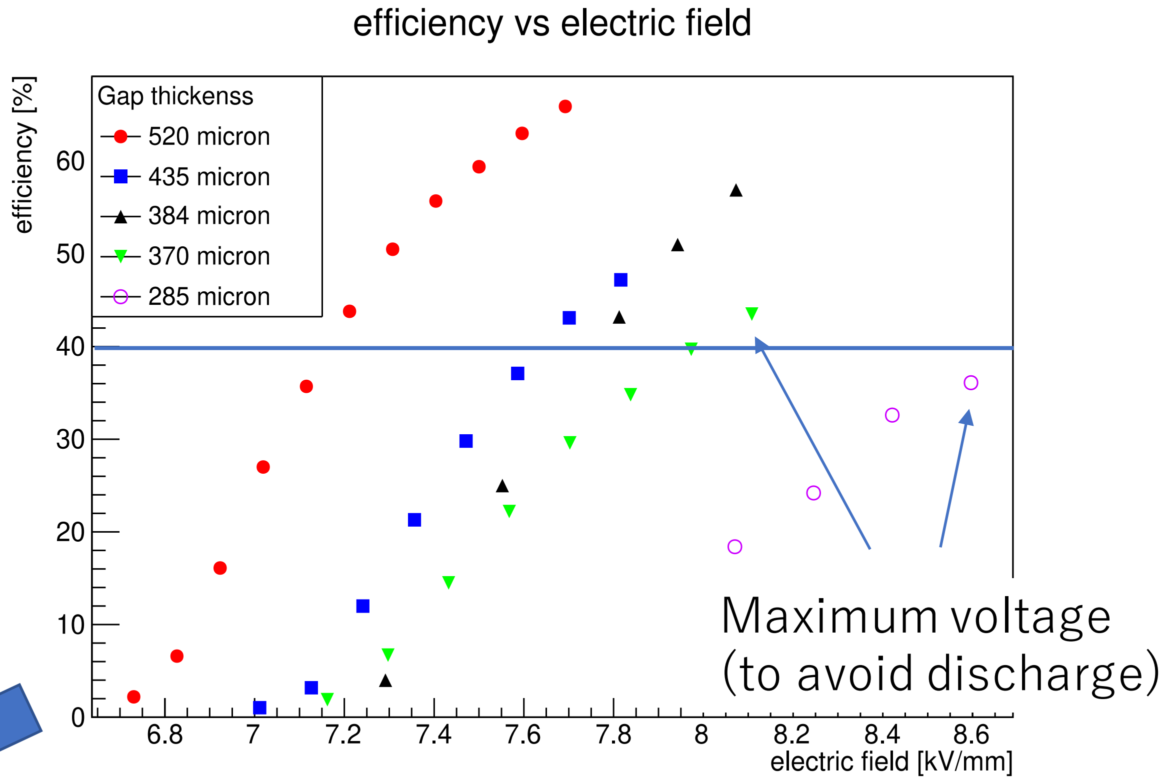
Timing resolution is good enough at least up to 520 μm
(< 1ns required)

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