MEG II実験の感度向上を目指した超低物質量ガス検出器RPCの開発 -現状と今後-

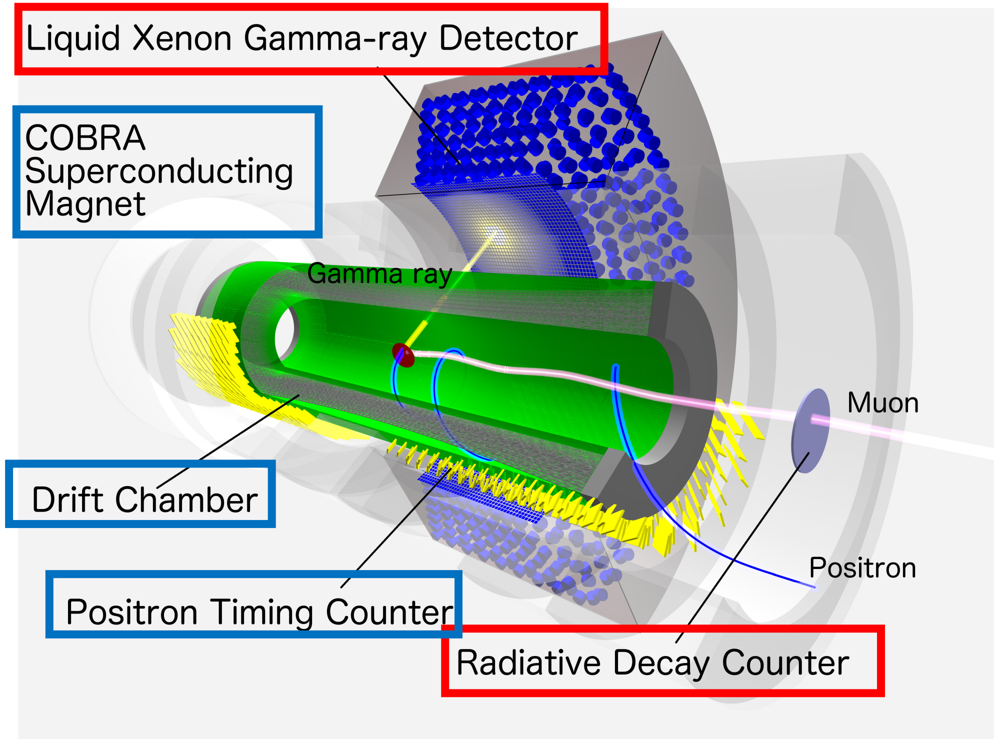
Atsushi Oya (University of Tokyo)

Mu - E - Gamma collaboration

Core-to-Core Program

MEG II experiment for $\mu \rightarrow e\gamma$ search

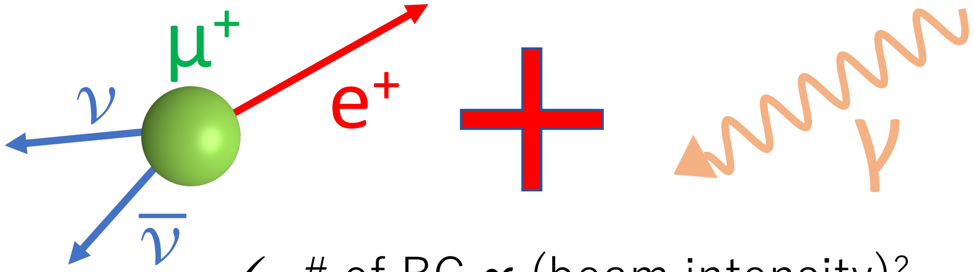
- MEG II: $\mu \rightarrow e\gamma$ branching ratio sensitivity goal is 6×10^{-14} , achieved by
  - High statistics using world's most intense DC muon beam @ PSI (10^8 μ/s)
  - Signal identification utilizing the kinematics
    - ✓ Muon stopped on target
    - ✓ 52.8 MeV energy for both e and γ
    - ✓ 180° relative angle
    - ✓ same timing



- Dominant source of BG come from accidental coincidence of e & γ

→ BG is reduced by
- ✓ High resolution measurement for e & γ
- ✓ Background identification detector

accidental background



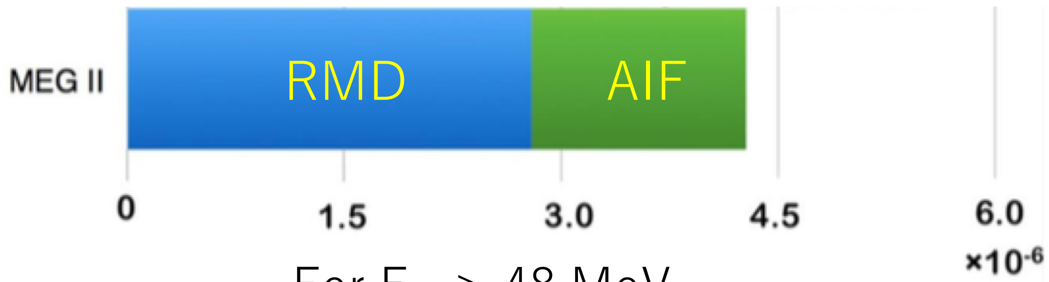
- ✓ # of BG ∝ (beam intensity)^2
- ✓ Accidental coincidence

Contents

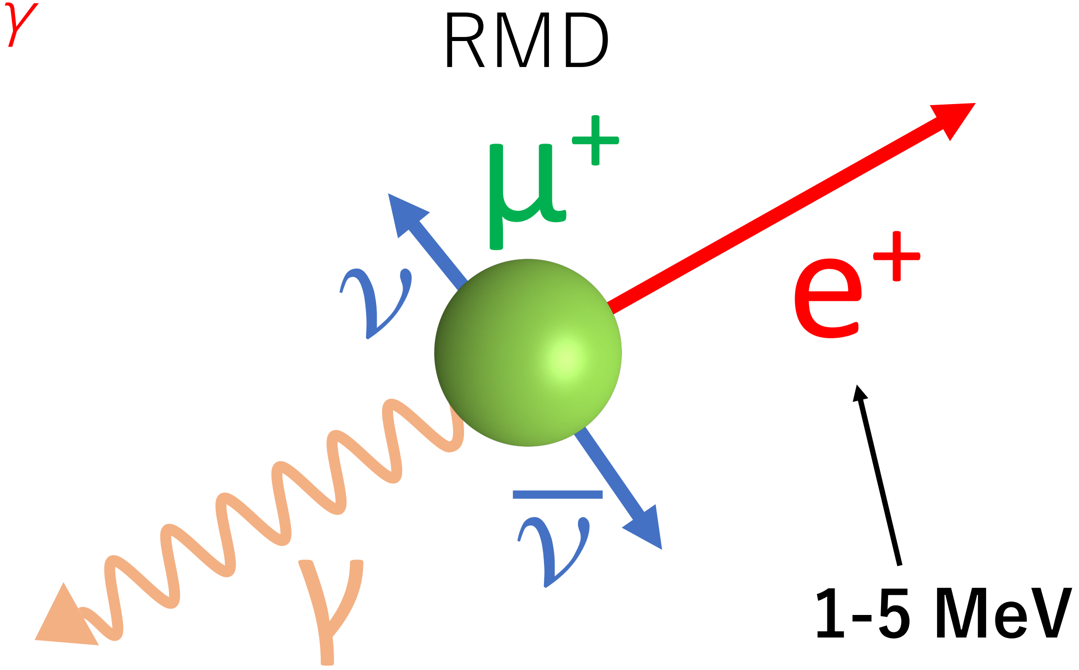
Identification of BG- γ

- 2 sources for BG- γ
  - ✓ Radiative Muon Decay (RMD): $\mu \rightarrow e \nu \nu \gamma$
  - ✓ Positron's annihilation in flight (AIF)

→As RMD accompanies low energy positron, BG- γ from RMD can be identified by detecting positron



For E_{γ} > 48 MeV

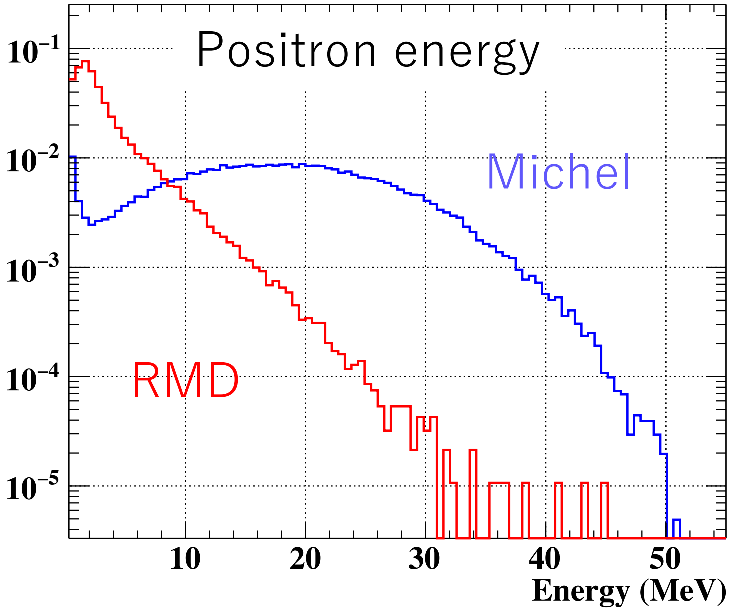


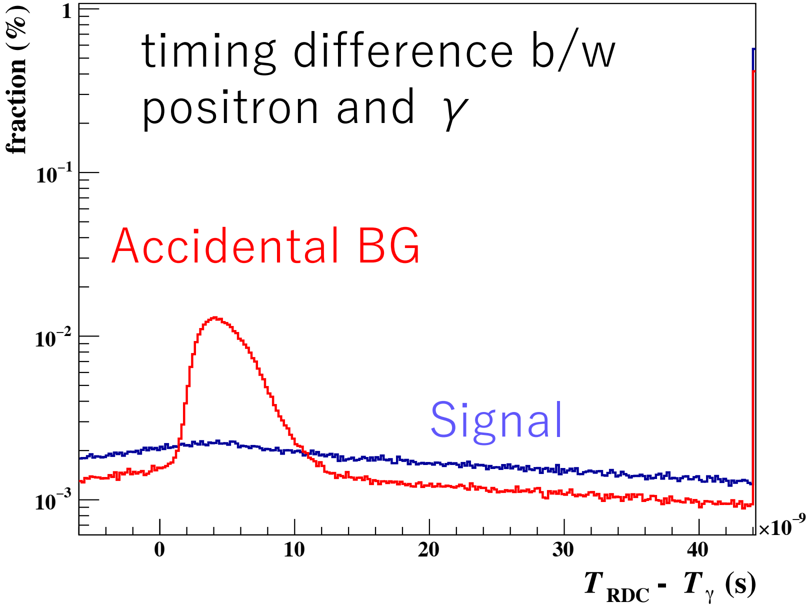
Detector for RMD-γ (1/2)

- Detector to tag **RMD-γ**,
  but practically detect RMD positron
  - ✓ 1 – 5 MeV positron is accompanied by RMD
    (for E_γ > 48 MeV)

- RMD positron
  - ✓ Timing coincidence b/w positron and γ
  - ✓ lower positron energy compared to
    $\mu \rightarrow e \nu \nu$ decay (Michel decay)

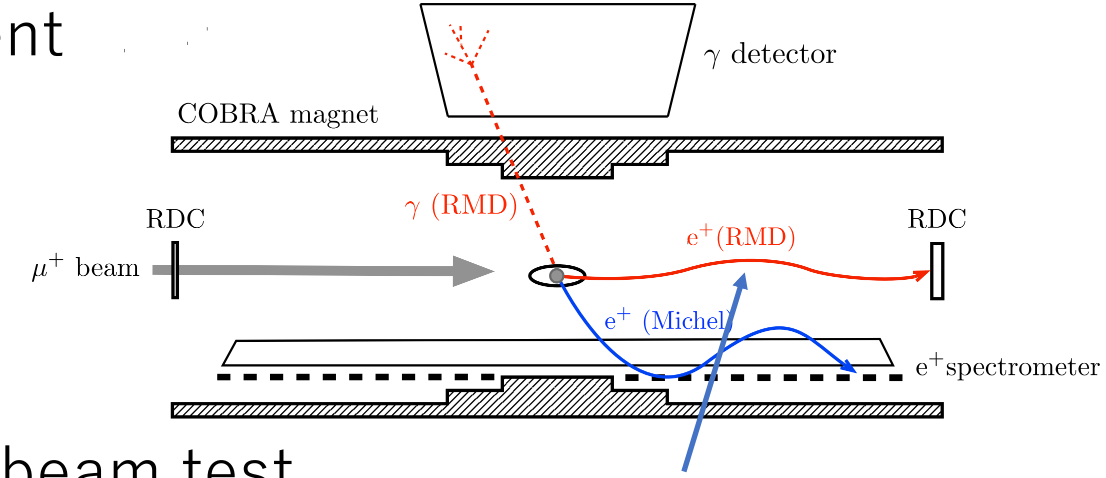
→ RMD-γ can be identified
from these measurements





Detector for RMD- γ (2/2)

- Planning to install to upstream & downstream of the target
  - downstream → 15% sensitivity improvement
  - upstream → 10% sensitivity improvement



flight around the beam axis
(magnetic field is applied)

- Downstream
  - ✓ Measure positron energy & timing
  - ✓ Demonstrated the performance with μ beam test

- upstream
  - ✓ under development
  - ✓ μ beam (21 MeV/c) must pass through the detector
  - ✓ Identify RMD gamma by only measuring the timing difference b/w low energy positron & gamma

Requirements to the upstream detector

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

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

Contents

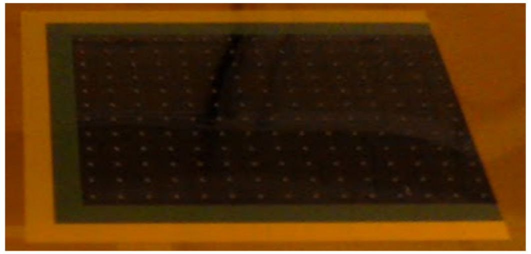
- Detector for background γ
- Development of ultra-low material RPC
  - ✓ Concept
  - ✓ Prototype design
  - ✓ Performance study
  - ✓ Design optimization

  This talk
  - ✓ Readout study and pileup → Next talk
- Summary and prospect

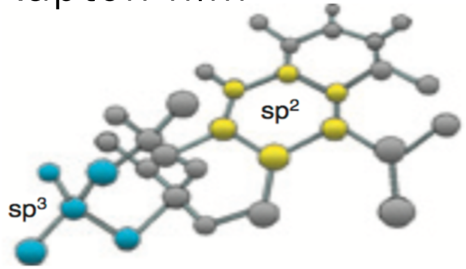
RPC based on DLC technology

RPC performance in general
- ✓ 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: 200μm—2 mm

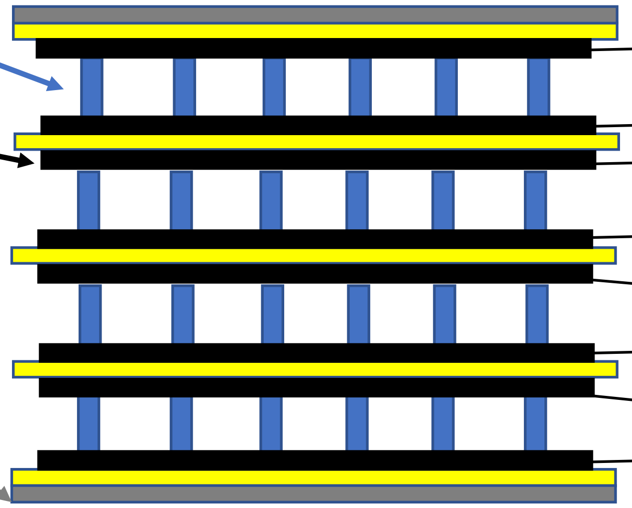


resistive plate made of DLC sputtered Kapton film



- Diamond Like Carbon 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 50μm Kapton
    2. Adjustable resistivity → Resistivity must be optimized for high rate environment
  - ✓ Firstly developed by a group of Kobe Univ

RPC based on DLC technology



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

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

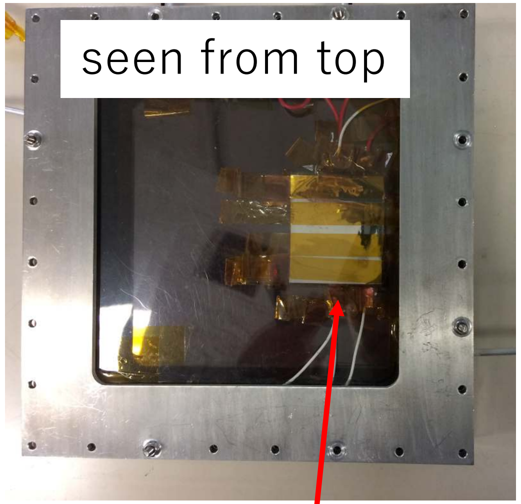
Material budget

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

→ < 0.1 % X_0 is satisfied

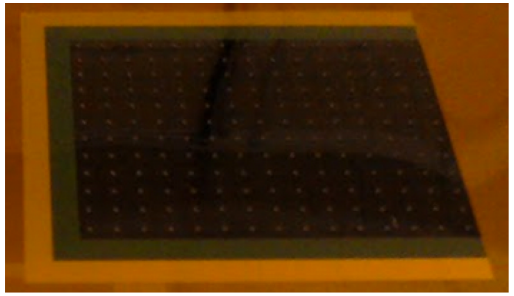
Prototype detector for performance study

- Size: 3 cm× 3cm

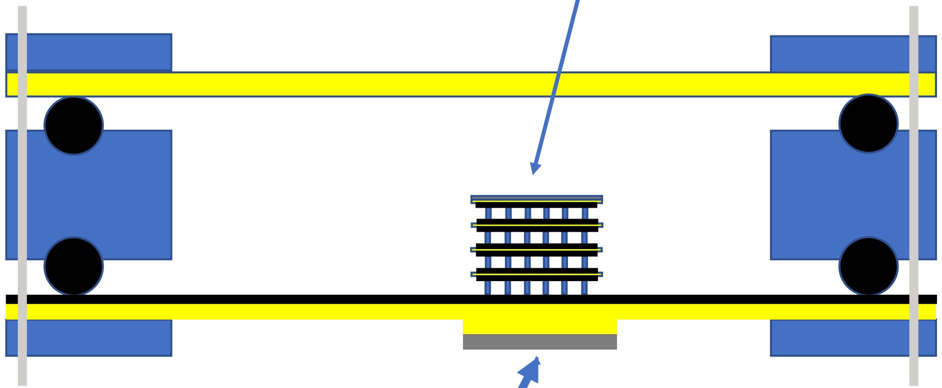


3 cm

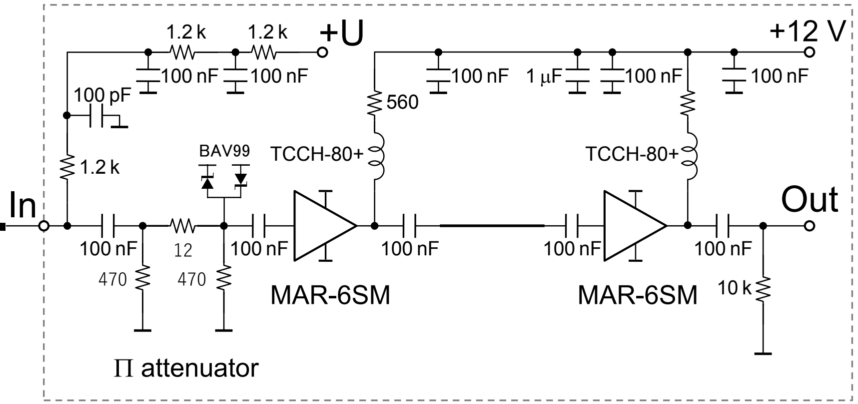
3 cm



gas :R134a/SF_6 = 93/7



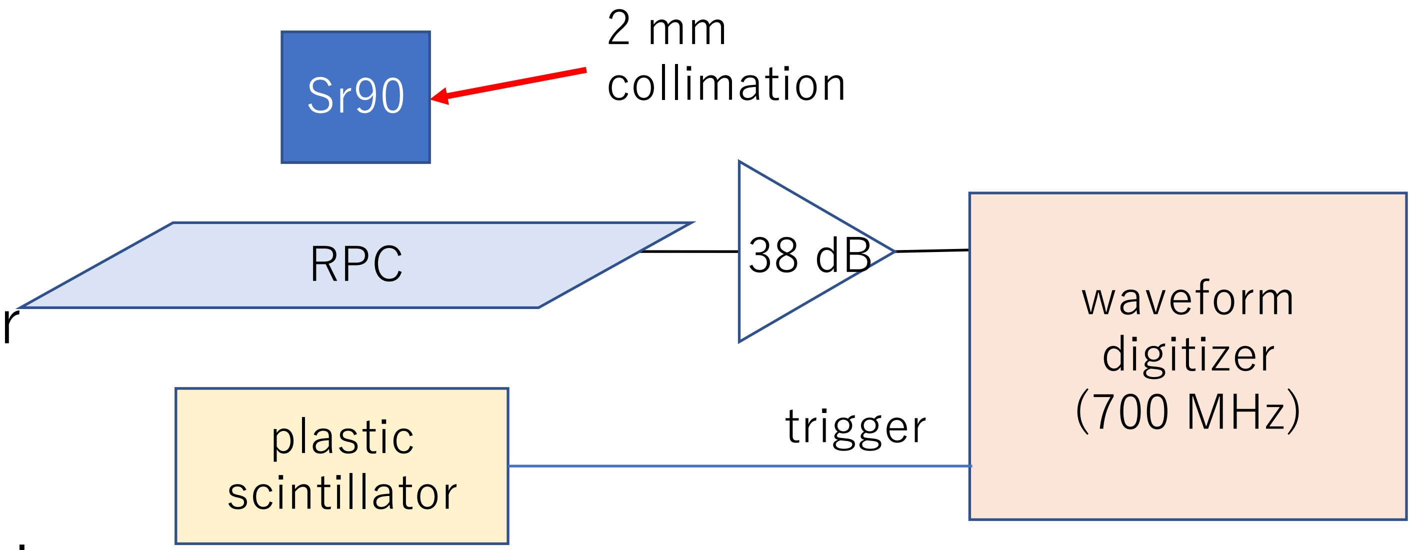
1×10cm
Aluminium
(100nm thick)



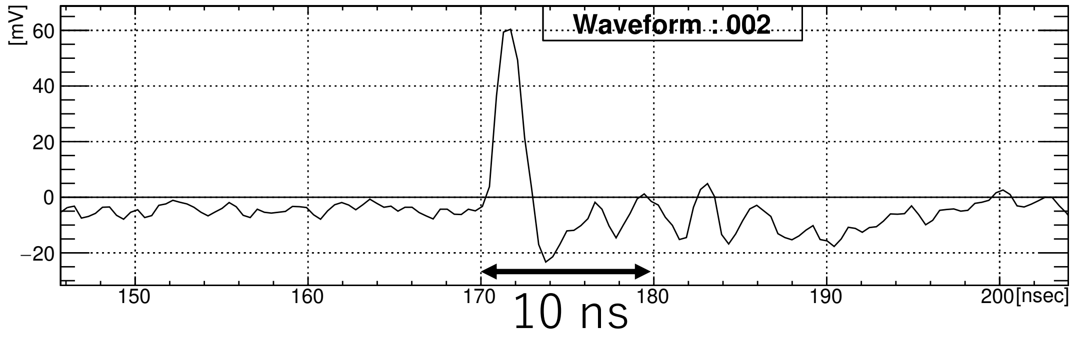
38 dB amplifier

Measurement

- Measurement setup
  - ✓ Collimated beta-ray
  - ✓ Reference counter is used for trigger



- Signal is readout by 700 MHz waveform digitizer

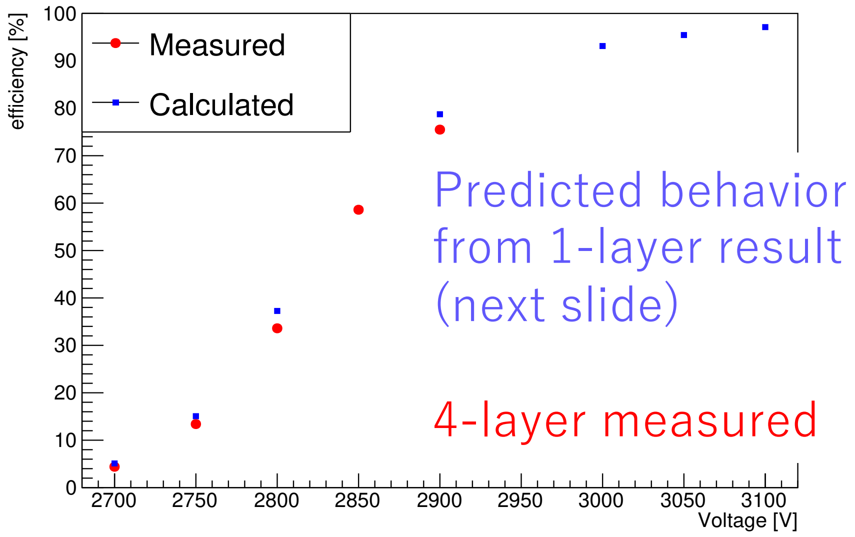


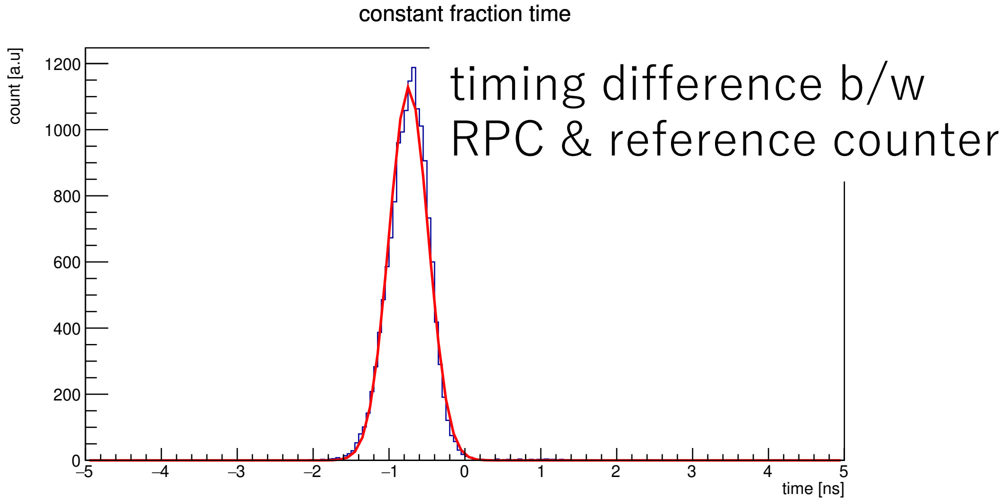
- Measurement purpose
  - ✓ Check whether the 90% efficiency & $<$ 1 ns timing resolution can be achieved
  - ✓ Check dependence on gap thickness
    - ➢ RPC performance is known to depend on the gap thickness

Performance for 384 μm gap 4-layer RPC

- Efficiency
  - ✓ Determined from the fraction of RPC hits in the triggered events
  - ✓ RPC threshold = 10 mV
  - ✓ 90% efficiency can be achieved
- Timing resolution
  - ✓ Determined from the timing difference b/w RPC and reference counter
  - ✓ RPC timing: 50% constant fraction
  - ✓ 250 ps timing resolution

Efficiency vs RPC operating voltage





→ Timing resolution and efficiency is good enough

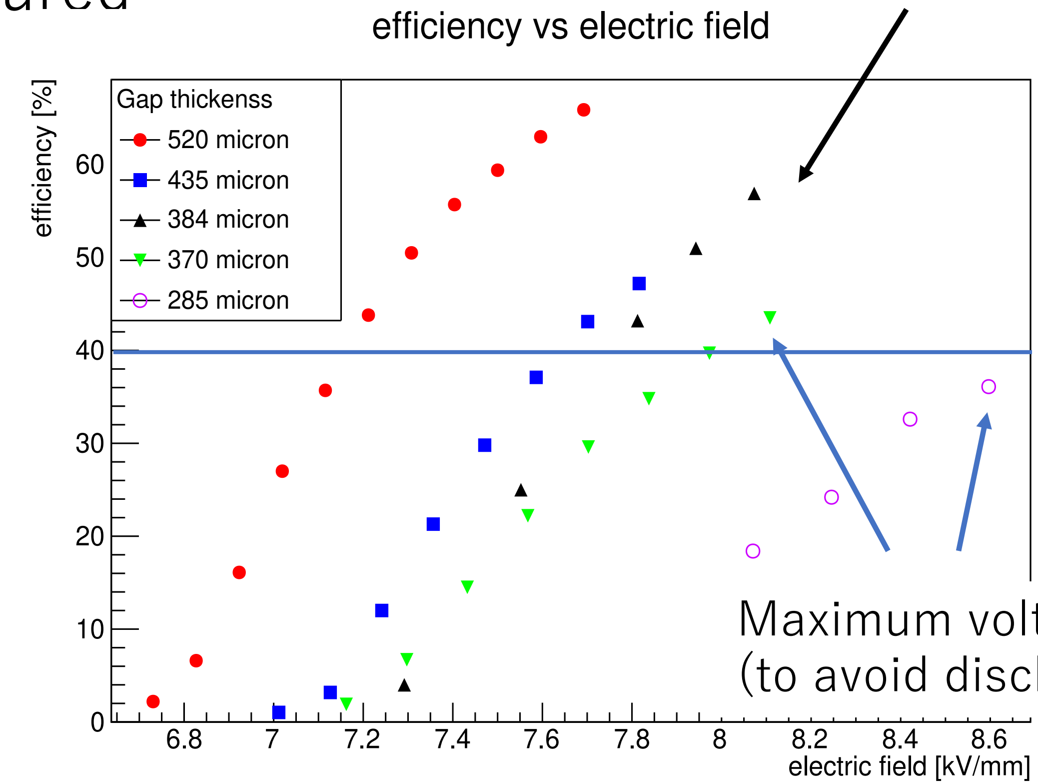
Gap thickness optimization (1/2)

- While 384 μ m gap RPC has already shown good performance, **further optimization** is also considered
  →Dependence on gap thickness is measured

- 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

384 μ m discussed in the previous slide



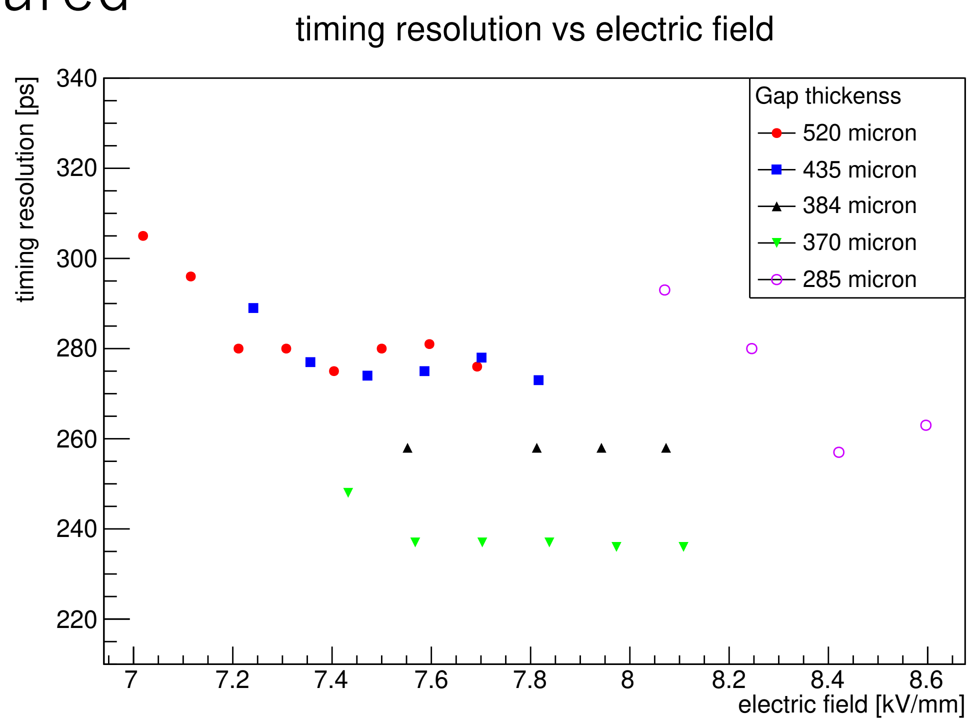
Maximum voltage (to avoid discharge)

sufficient efficiency for ≳400 μ m thickness

Gap thickness optimization (2/2)

- While 384 μm gap RPC has already shown good performance, further optimization is also considered
  →Dependence on gap thickness is measured

- Timing resolution is measured changing the gap thickness
  ✓ single layer resolution is shown
  ✓ Normally, 4-layer resolution is better



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

➡ **Timing resolution is good enough at least for ≤ 520 μm**

Contents

- Detector for background γ
- Development of ultra-low material RPC
- Summary and prospect

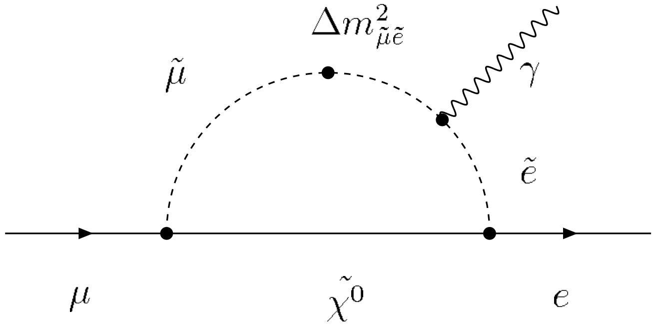
Summary and prospect

- Following requirements have already been satisfied
  - ✓ Material budget: <0.1% X_0
  - ✓ Timing resolution: < 1ns → 300 ps achieved
  - ✓ Detection efficiency: >90% → shown to be reachable
- The remaining works are
  - ✓ Construction of 20 cm detector
  - ✓ Rate capability measurement
  - ✓ Pileup (next talk for detail)
- Possibility for further detector design optimization
  - ✓ Widening gap thickness to 500 μm is a possible option

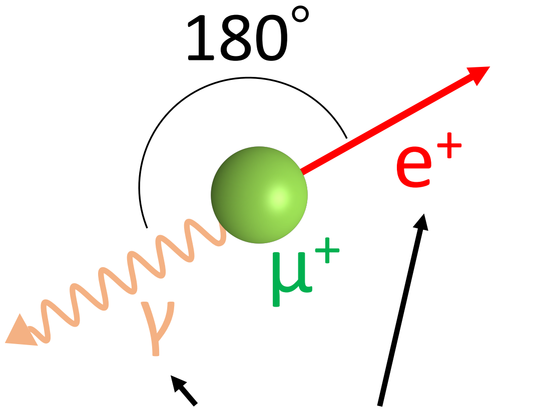
BackUp

$\mu \to e\gamma$ search

$\mu \to e\gamma$ enhanced
by slepton mixing



- Motivation for $\mu \to e\gamma$ decay
  - ✓ Mixing in the charged lepton sector (cLFV), which is forbidden In the SM (even w/ ν oscillation)
  - ✓ Related bSM models: SUSY-GUT, SUSY-seesaw
  - ✓ Simple kinematics of two body decay

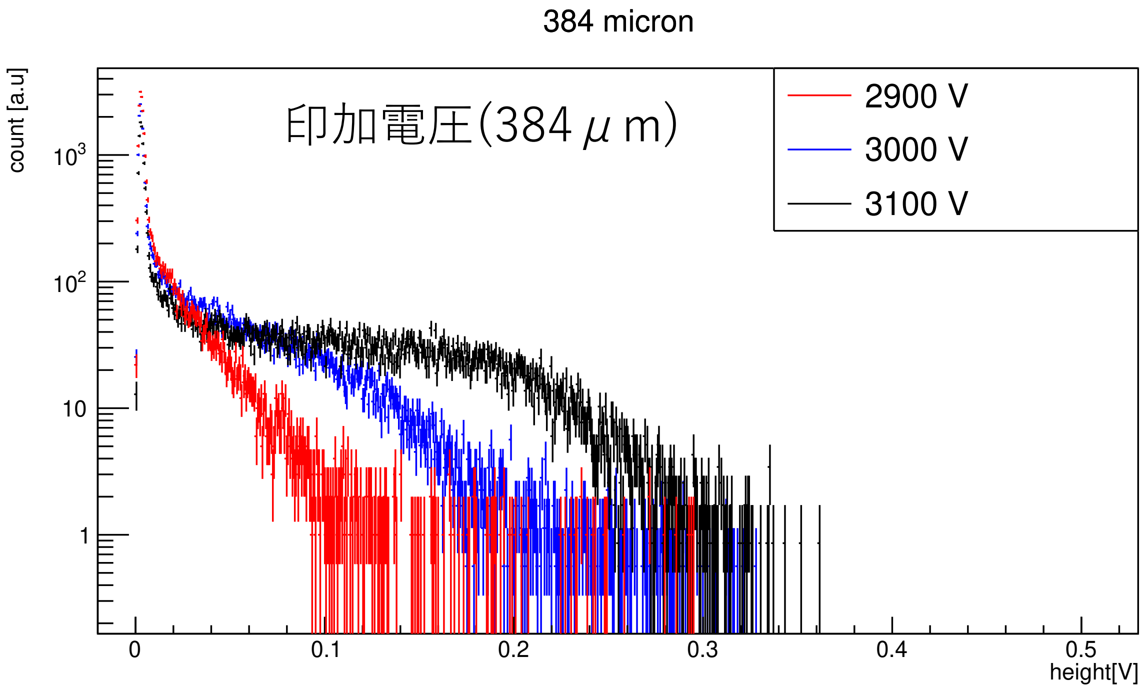


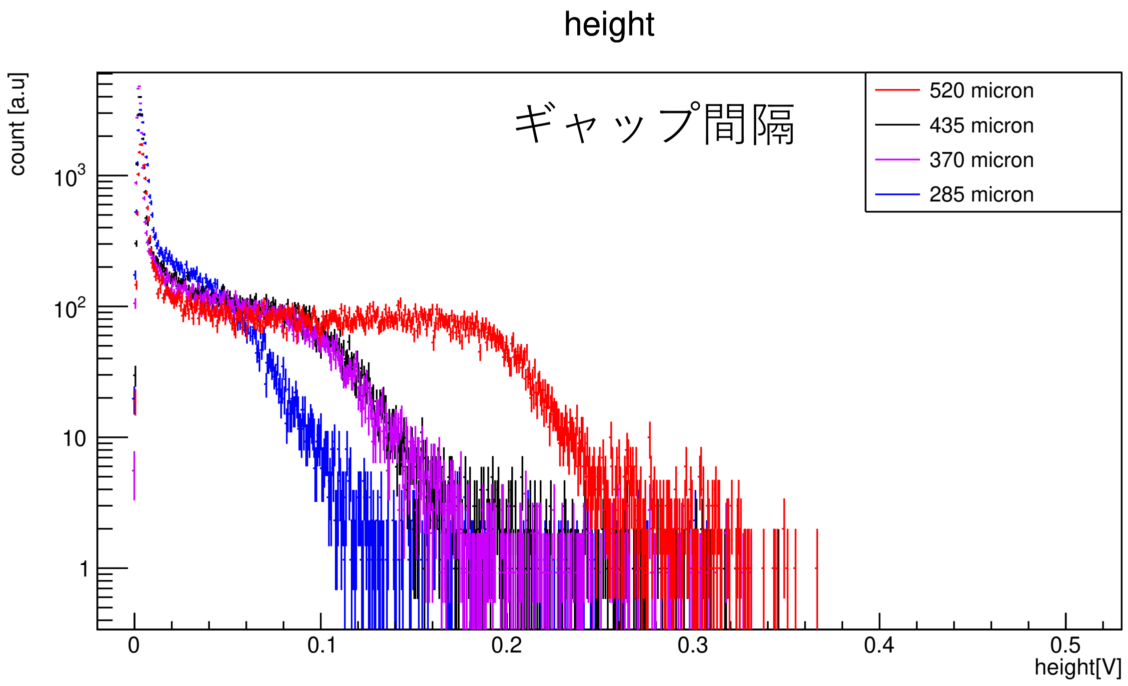
- Recent cLFV searches with other modes
  - ✓ $\mu \to eee$ @Mu3e
  - ✓ $\mu N \to eN$ @COMET & Fermilab
  - ✓ $\tau \to \mu\gamma$, $\tau \to \mu\mu\mu$ @Belle II (&LHCb?)
  - ✓ Z,H or meson decay (e.g. $Z \to \tau\mu$)

$\mu \to e\gamma$ is complementary with these other cLFV search;
→Strengthen the model discrimination power for bSM test

Single layer efficiency – detail -

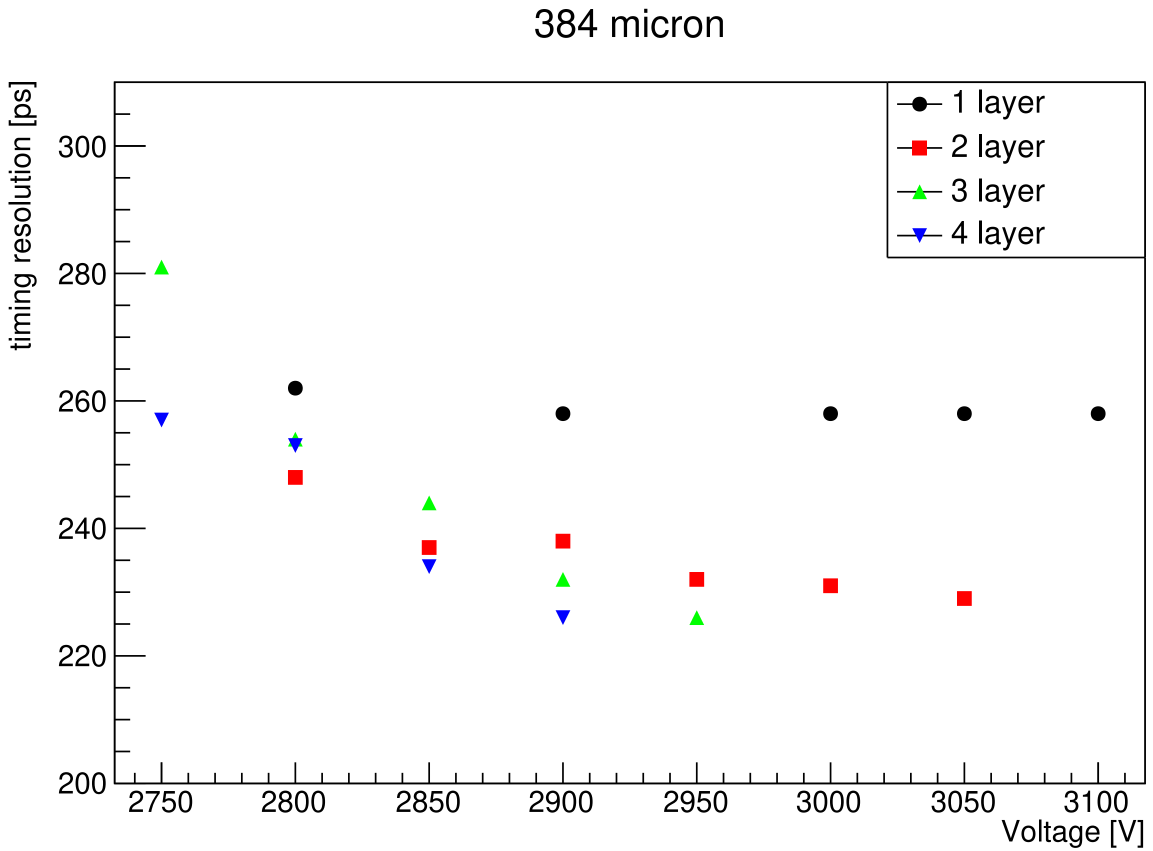
- Pulse height spectra for different conditions
  - ✓ Dependence on applied voltage (for 384 μ m)
  - ✓ Dependence on gap thickness (maximum voltage before spark)





timing resolution vs # of layer

- 250 ps resolution
- dominant contribution is from S/N



Design parameters to be studied

- Design optimization is required
  - ✓ 40% single layer efficiency and 1 ns timing resolution is required
    → Gap thickness to be optimized
    - ➢ For wider gap, better efficiency but worse timing resolution
  - ✓ Resistivity of DLC electrode ⟶ Will not be reported today
  - ✓ Optimization of readout
    → Signal waveform and pileup effect to be studied] next talk