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 (1)

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Outline

- Introduction
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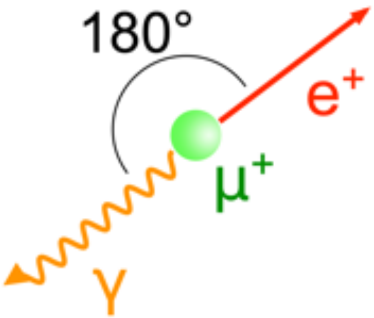
  - Radiative decay counter
  - RPC with DLC electrodes
  - Rate capability
- Beam test for μ signal size measurement
  - Setup
  - Results of μ signal size
- Summary

MEG II signal and background

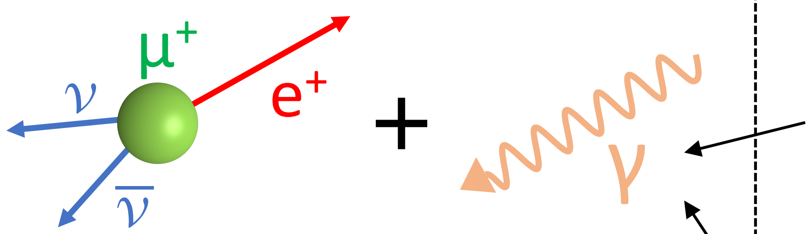
- MEG II searches for μ→eγ decay, one of charged lepton flavour violation (cLFV) channels
- Dominant background is accidental coincidence of BG-e^+ and BG-γ

Signal



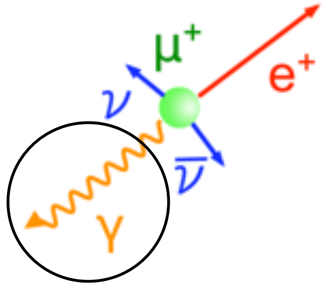
- The same energy of 52.8 MeV
- Opposite direction
- The same timing

Accidental Background

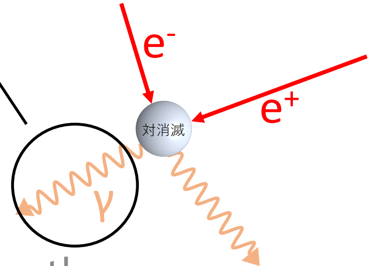


Signal-like accidental coincidence of e^+ and γ with ~52.8 MeV energy

Radiative muon decay (**RMD**)

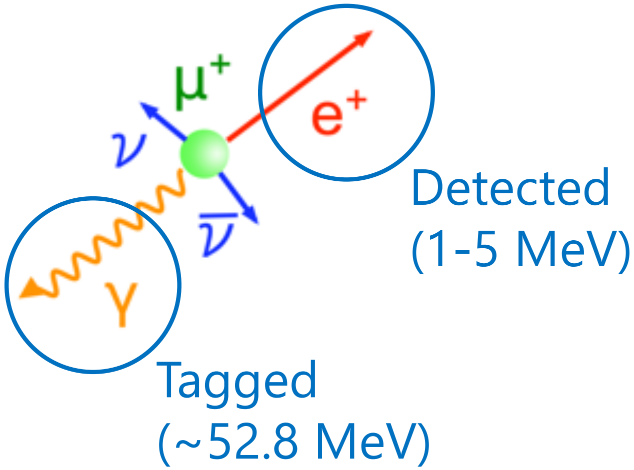


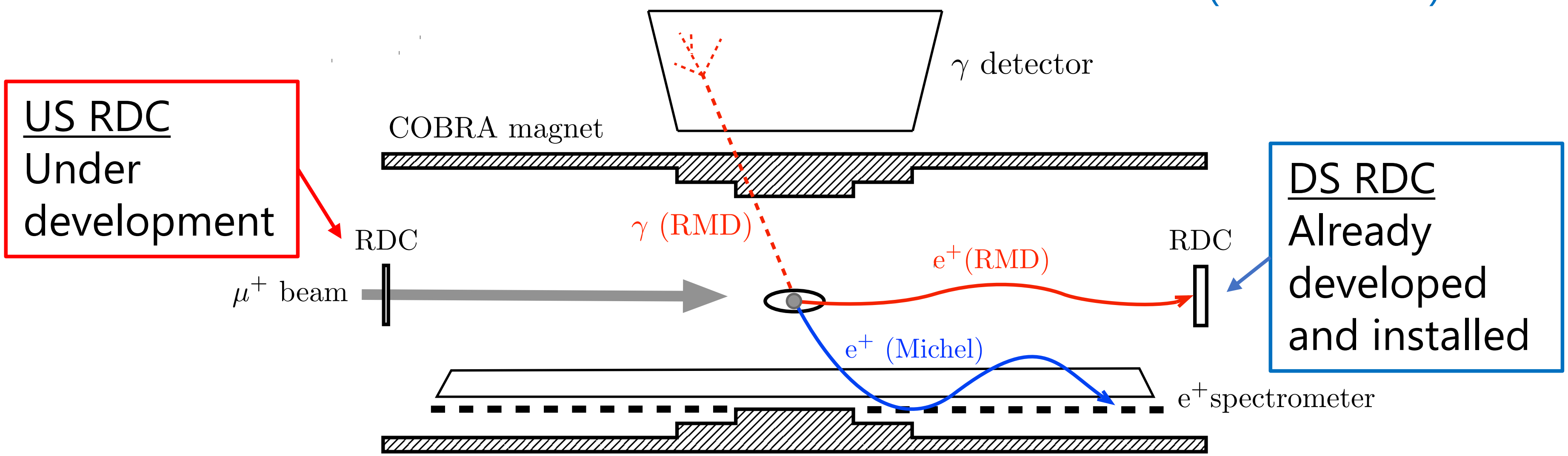
Annihilation In Flight (AIF)



Radiative decay counter

- Radiative decay counter (RDC) detects RMD e^+ with 1-5 MeV energy to tag BG-γ
- RDCs will be installed at both upstream and downstream of the target
- Upstream RDC is under development





Requirements for upstream RDC

1. <0.1% X_0 material budget
   ← μ beam with 28 MeV/c must pass through the detector
2. 90% efficiency for 1-5 MeV e^+
3. 1 ns time resolution
4. Rate capability and radiation hardness for 10^8 μ/s
5. 20-cm diameter detector size

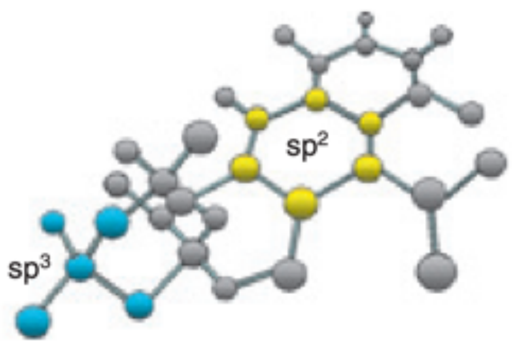
→ Candidate: Ultra-low material Resistive Plate Chamber (RPC) using Diamond-Like Carbon (DLC)

RPC with DLC technology

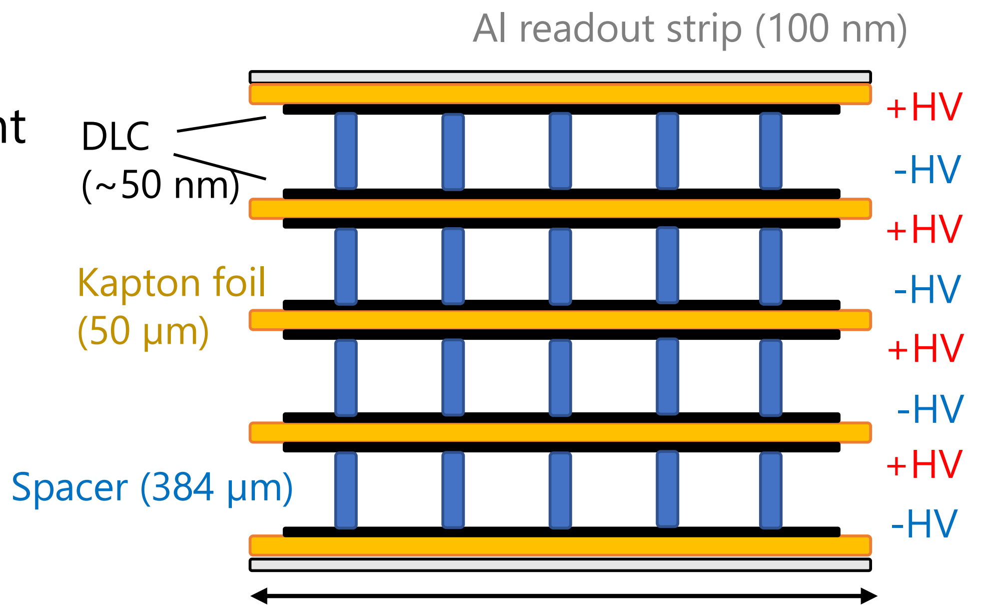
- Diamond-Like Carbon (DLC) is used as resistive electrodes
  - DLC is sputtered on Kapton foil

  → Small material budget can be achieved
  - DLC resistivity is adjustable

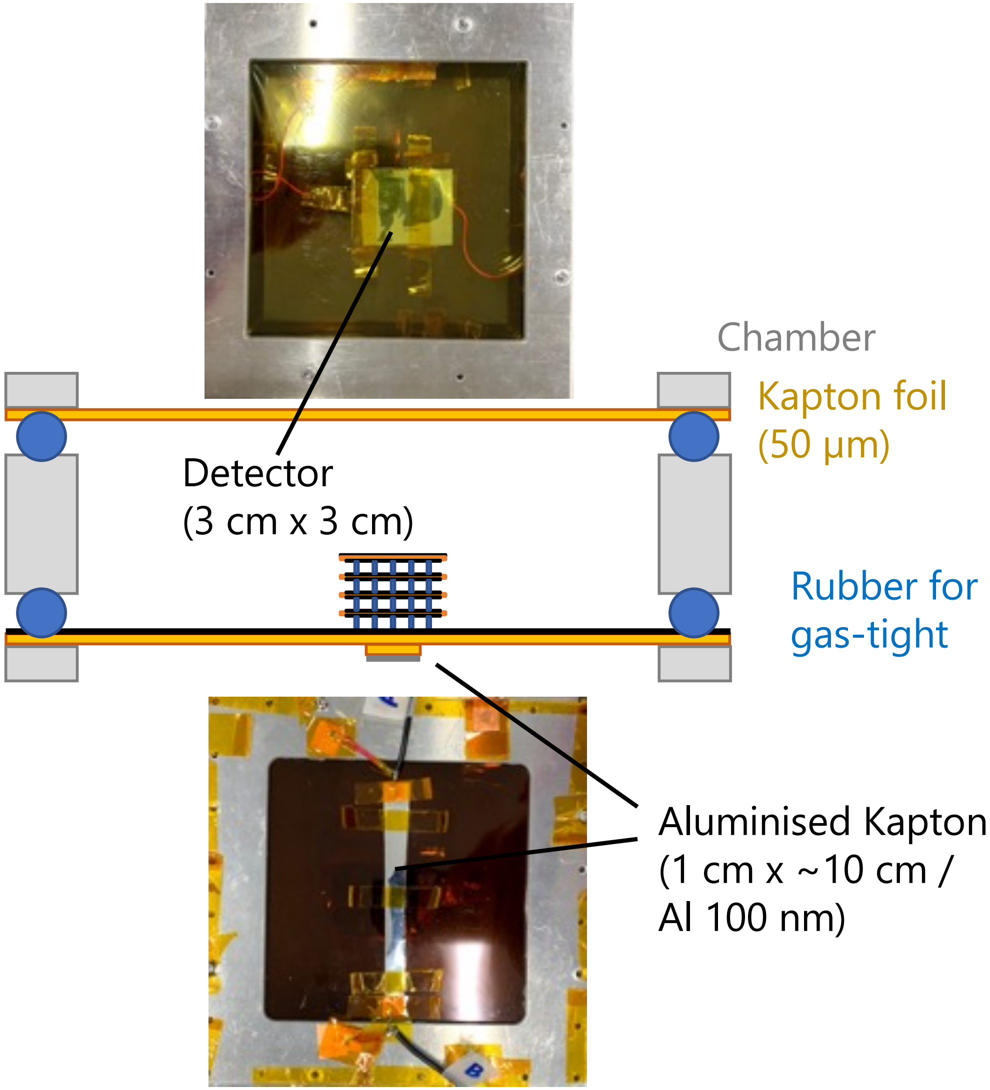
  → Small resistivity can be achieved, which is important for rate capability



- MEG II RPC design
  - 4 layers ← Higher efficiency
    - $\epsilon_n = 1 - (1 - \epsilon_1)^n$
  - <0.1% X_0 material budget
    - 50 μm Kapton foil → 0.018% X_0
    - 100 nm aluminum → 0.0012% X_0



RPC prototype detector

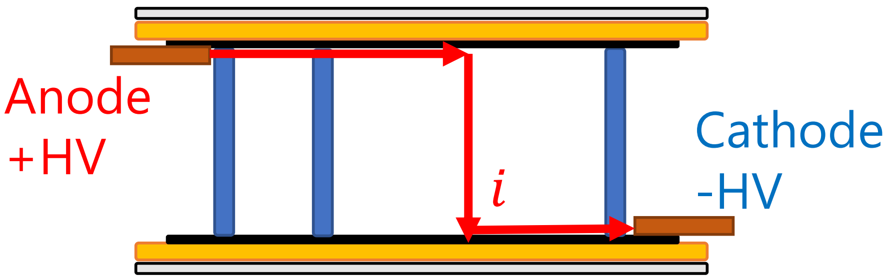


- Prototype detector performance for β from Sr90
  - Operated with ultra-low material design
  - Efficiency is dependent on applied HV
  - 55% efficiency is achieved with single layer
  - 90% efficiency is achieved with 4 layers
  - ~250 ps time resolution
- Remaining question is rate capability

Rate capability

- Current originated from signal flows in resistive electrodes from anode to cathode
- Voltage drop of ir occurs
- Effective HV = nominal HV – voltage drop

→ Less detector performance



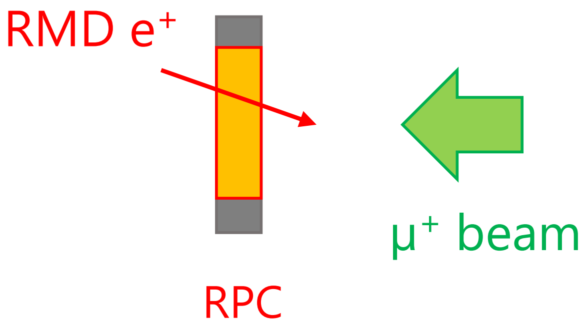
DLC resistance = r

- Current i is dependent on signal charge
- The signal charge of MEG II μ beam is not measured yet

→ Beam test at PSI

  - Obtain μ signal size (pulse height)
  - Obtain MIP e signal size (pulse height)
  - Test detector performance under the high-intensity MEG II μ beam

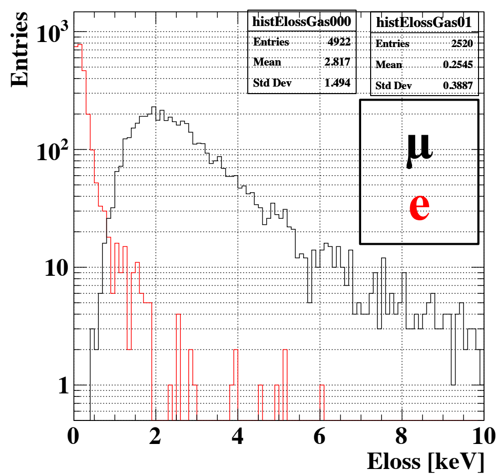
Expectation of μ signal size



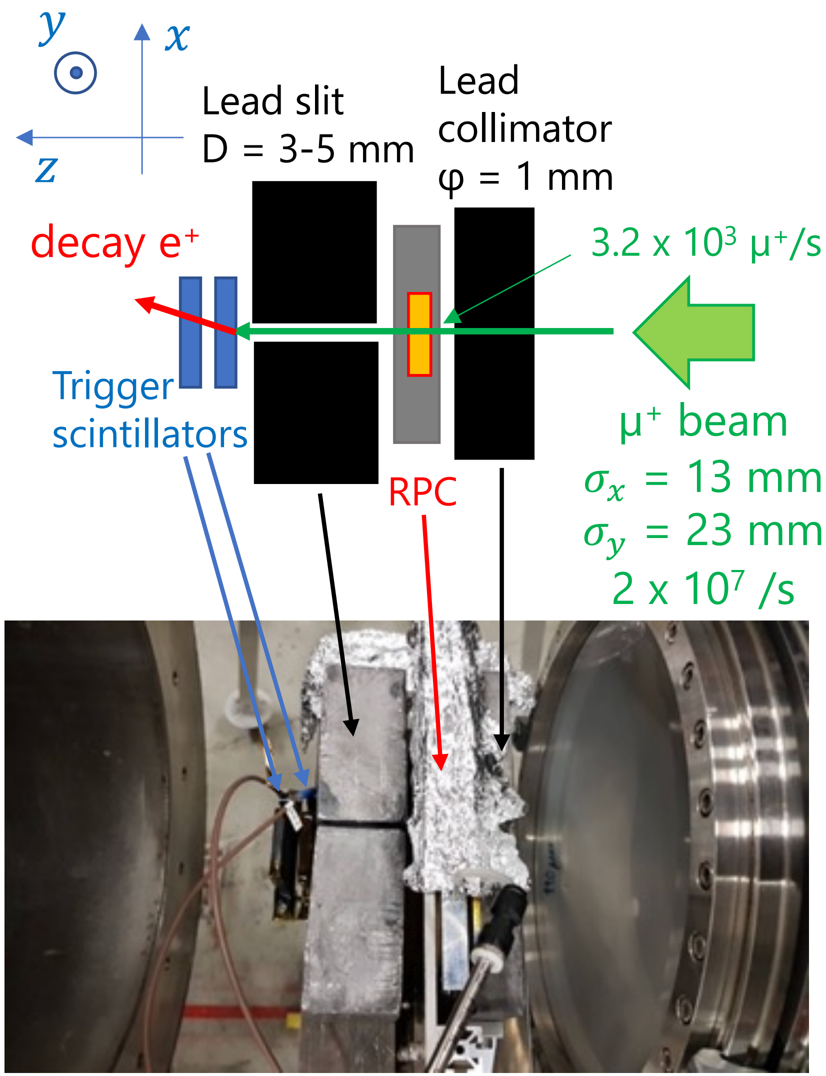
- MEG II μ beam
  - High intensity (<1 x 10^8 /s)
  - → Next talk
  - Low momentum (28 MeV/c)
  - → 10 times larger energy deposit than MIP e
- Signal charge is not proportional to energy deposit due to space charge effect

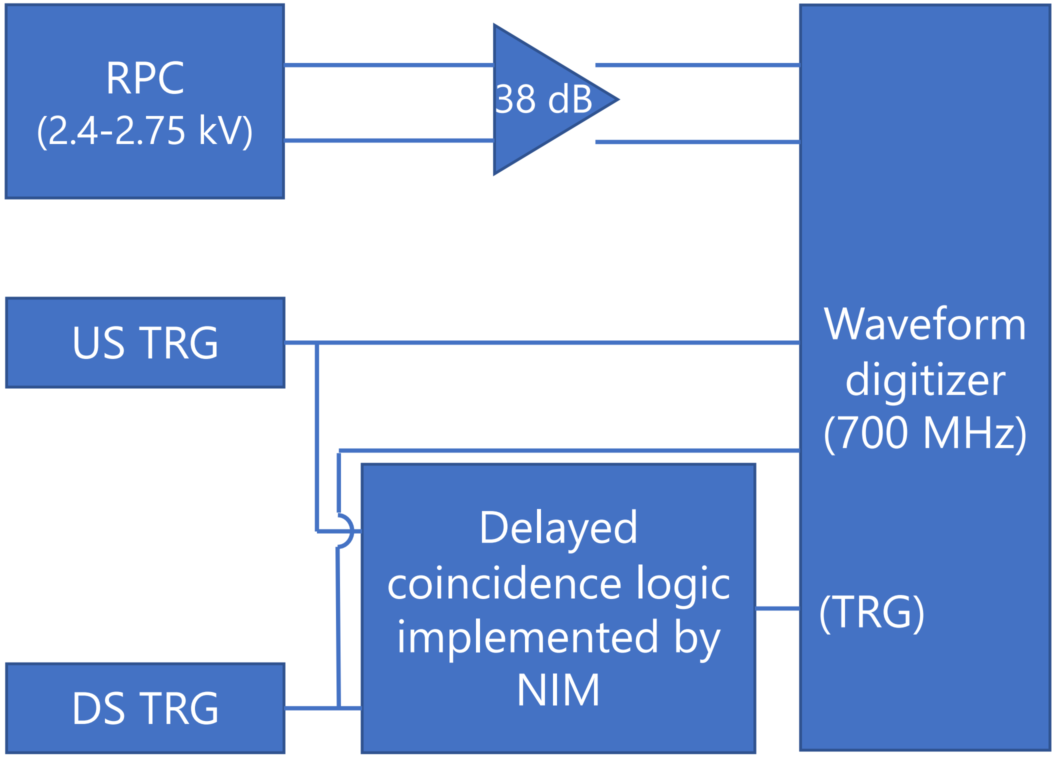
- Rate capability
  - Expect small μ signal charge
- Particle identification (PID)
  - Expect large difference b/w μ and e signal size

Energy deposit in RPC gas volume (MC)



Setup of μ signal size test

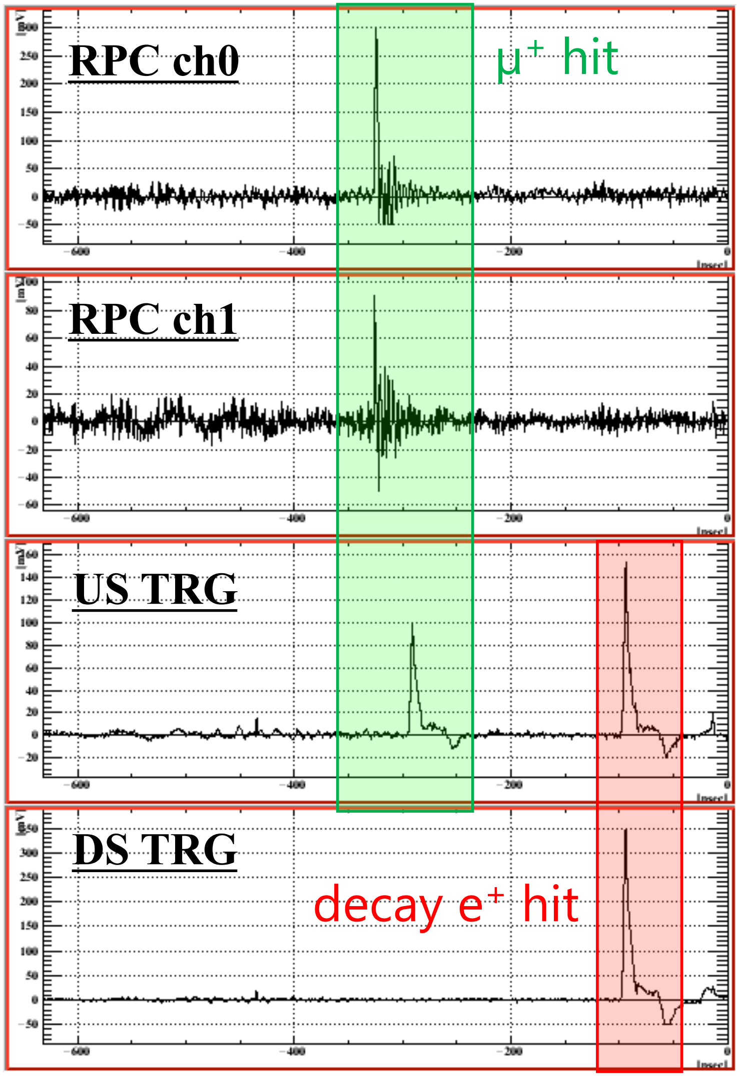


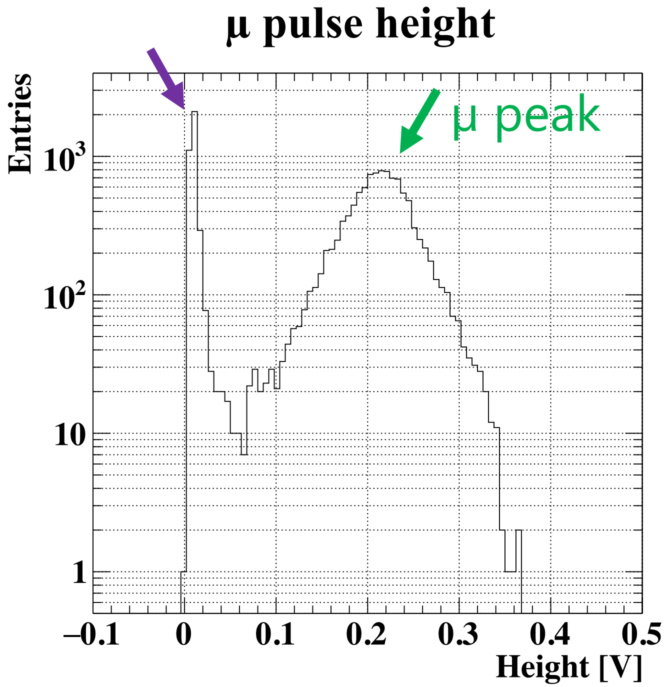


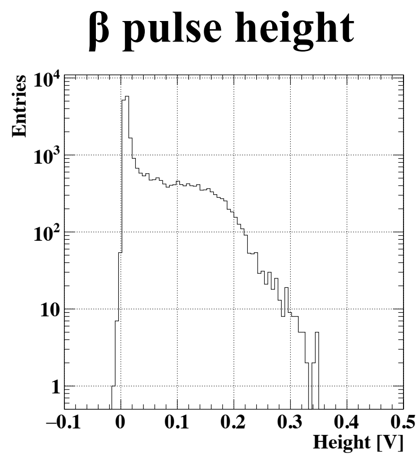
RPC basic information

- Gas: R134a/SF_6/iC_4H_{10} = 94/1/5
- Single layer
- Readout from both edges of strip

μ pulse height

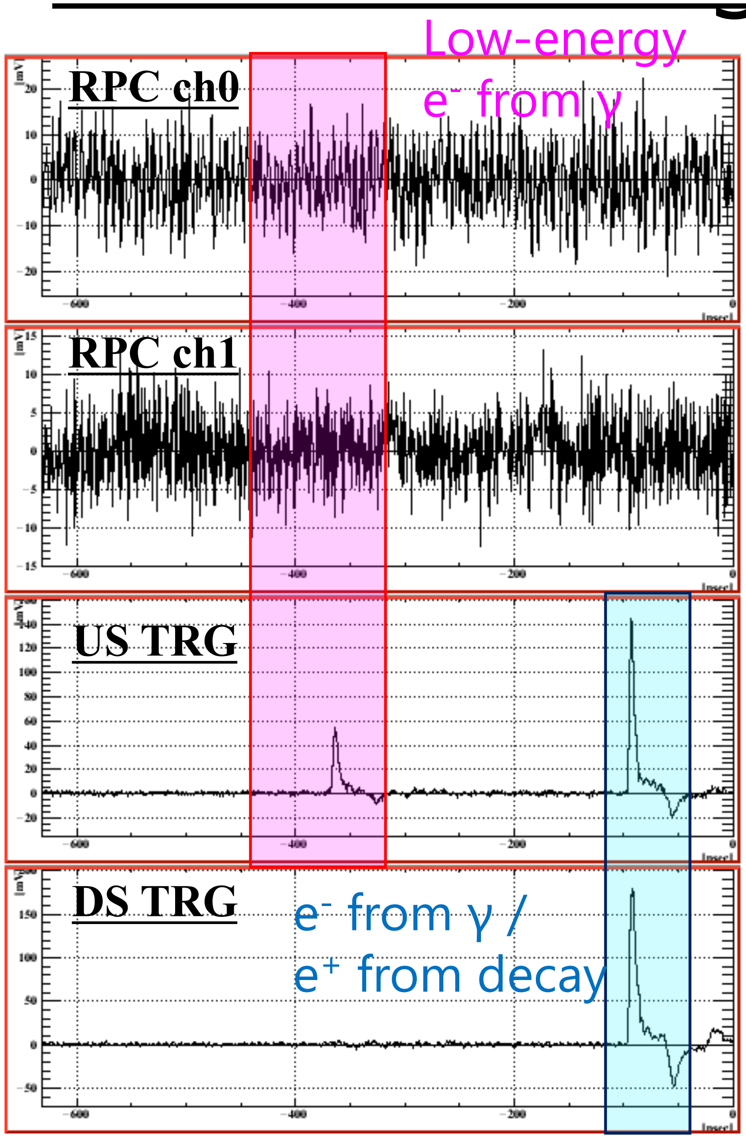


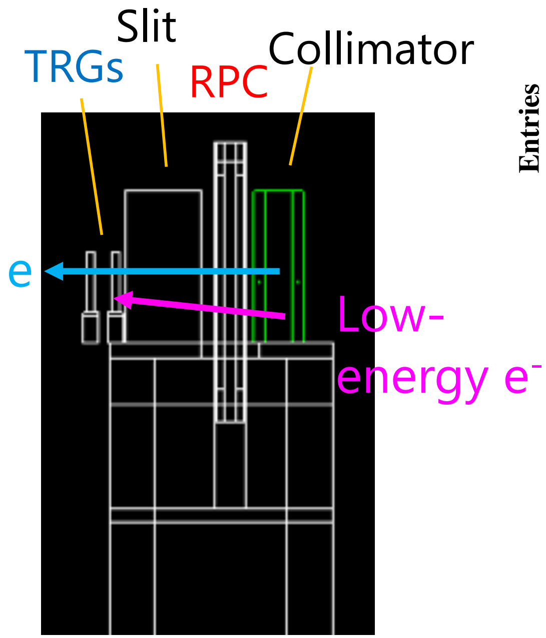


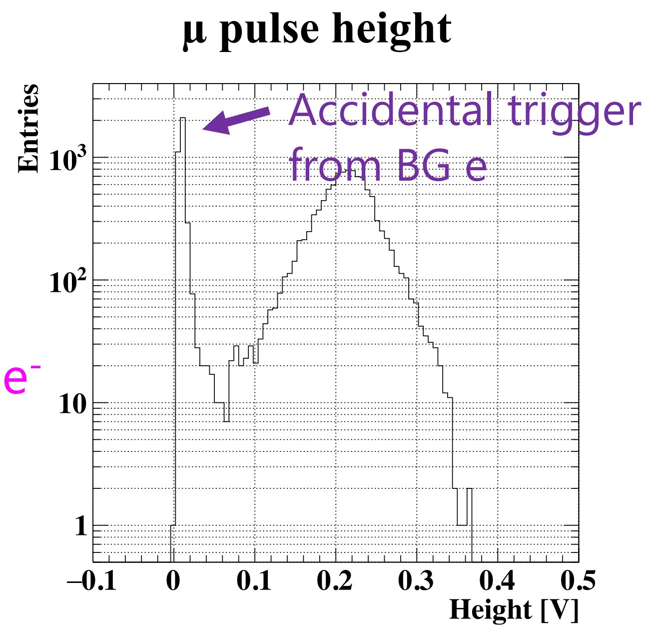


- RPC detects low-momentum μ for the first time
- Signal size of μ is 2-3 times larger than that of e due to more clusters and space charge effect

Accidental trigger in μ signal size test







- Monte Carlo (MC) simulation was done
- γ interacts in lead and generates BG e^-

→ Accidental trigger source

- MC reproduced the accidentally triggered events

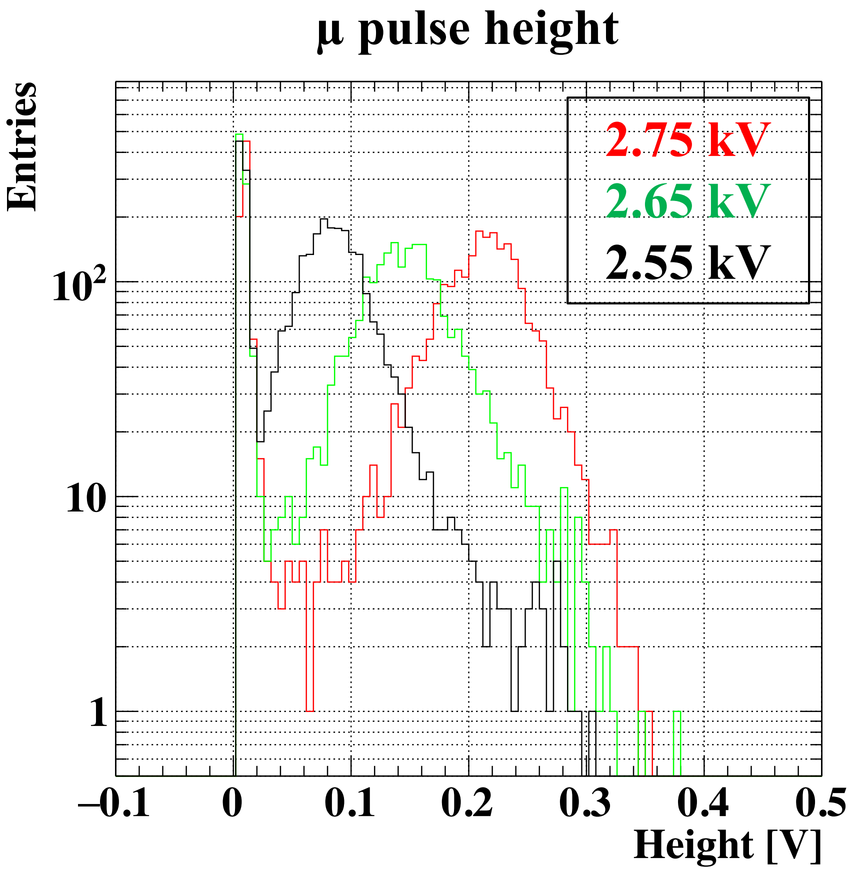
Summary

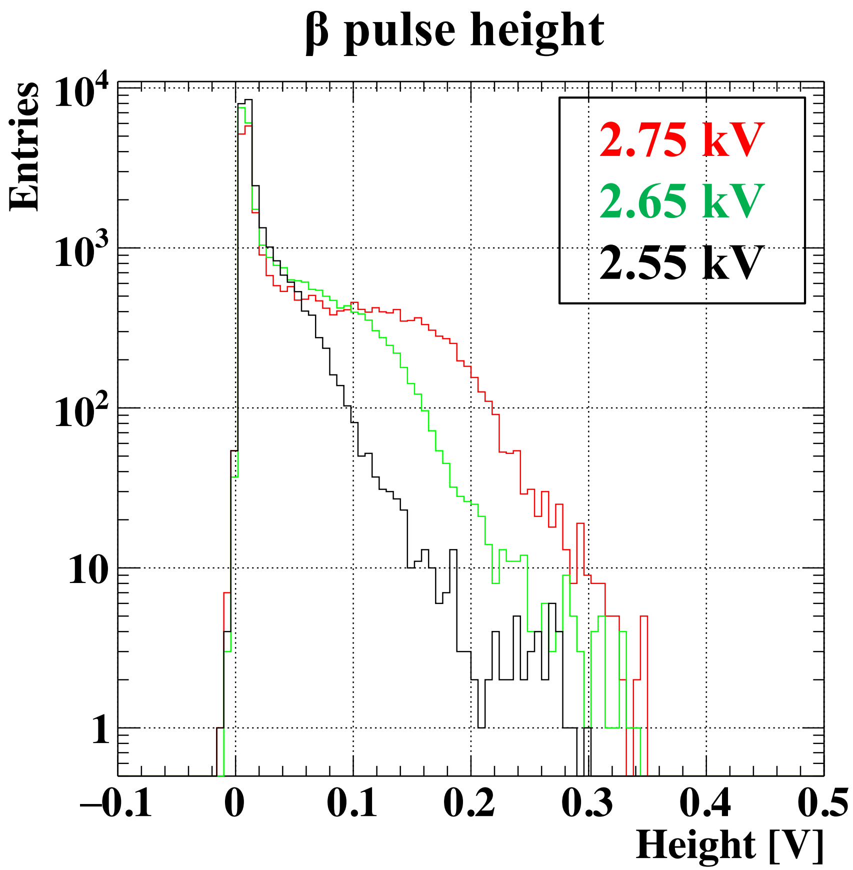
- We are developing ultra-low material RPC with DLC electrodes as MEG II upstream RDC
- Prototype detector has enough performance except for rate capability
- Beam test using MEG II beam took place at PSI
- We measured RPC response to low-momentum μ for the first time
  - μ signal is 2-3 times larger than e signal although μ energy deposit is 10 times larger than e due to space charge effect
  - Most of entries at pedestal would be generated by accidental trigger from BG e
- Discuss rate capability based on obtained μ signal size

Backup

Voltage dependence

- β: Efficiency is dependent on HV
- μ: Peak height moves by HV due to more clusters than e

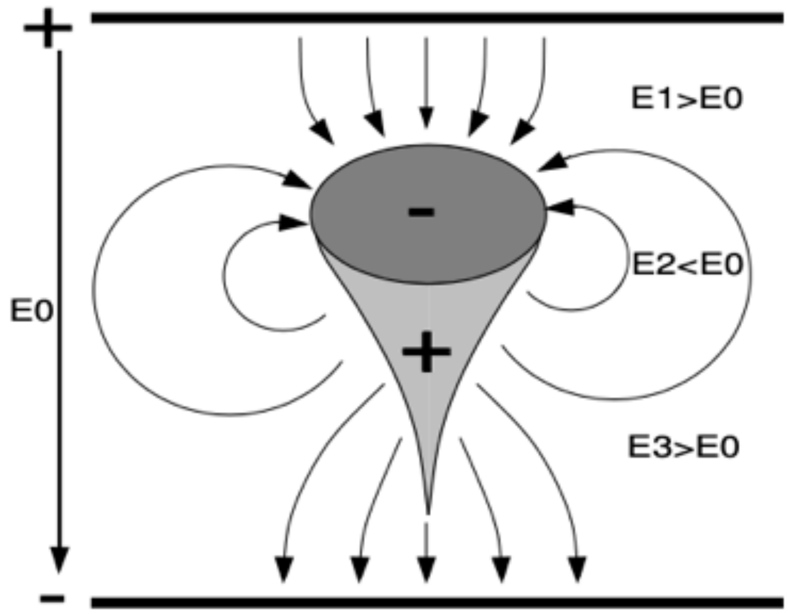




Space charge effect

- Ionized e is amplified by avalanche
- Positive ions move to cathode slowly
- Electric field deformation is caused by the charged carriers
- E_0 is applied electric field
- The value of the gas parameters like drift velocity and Townsend coefficient may vary with the position in the gas gap

Schematic view of avalanche and electric field deformation



http://home.iitb.ac.in/~pradeepsarin/students/tether/NiladriSaurabh_20123/RPC/frankfurt_thesis_RPC_physics.pdf

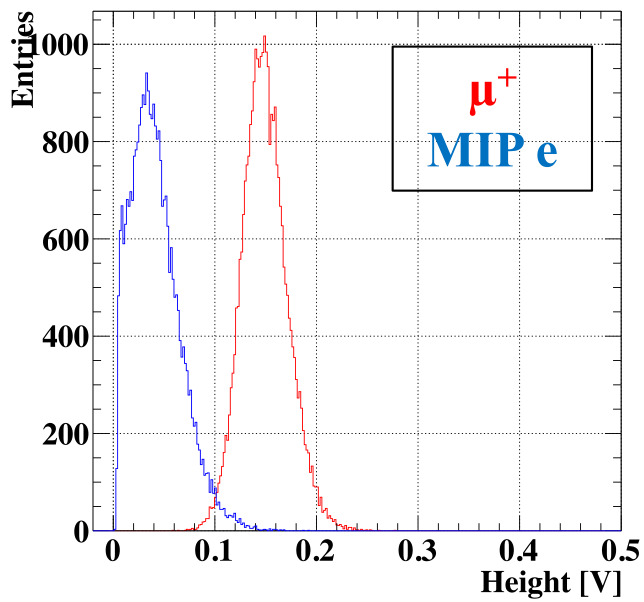
Particle identification

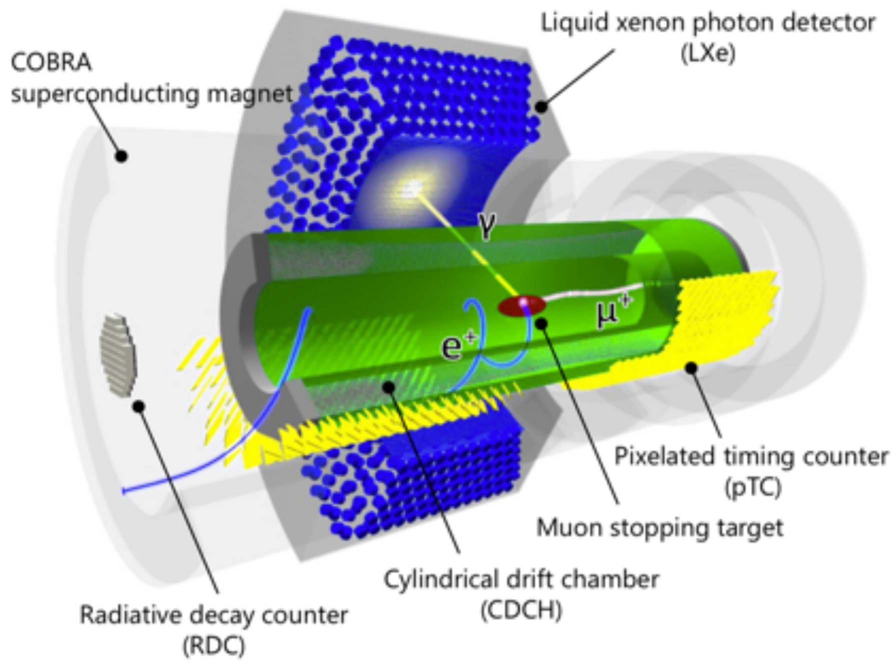
- RDC signals will be analyzed in LXe γ detected timing

→ RMD is basically identified by timing in "US" RDC

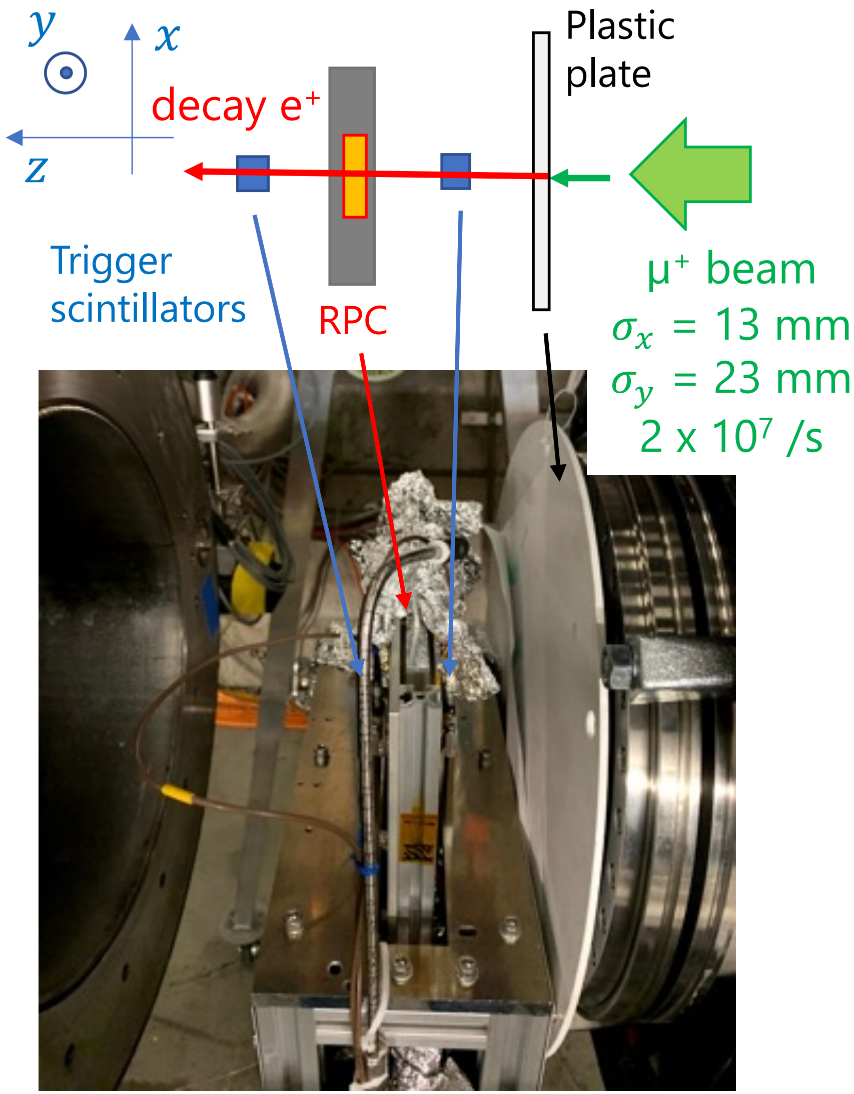
- Pulse height of μ and e helps RMD tagging

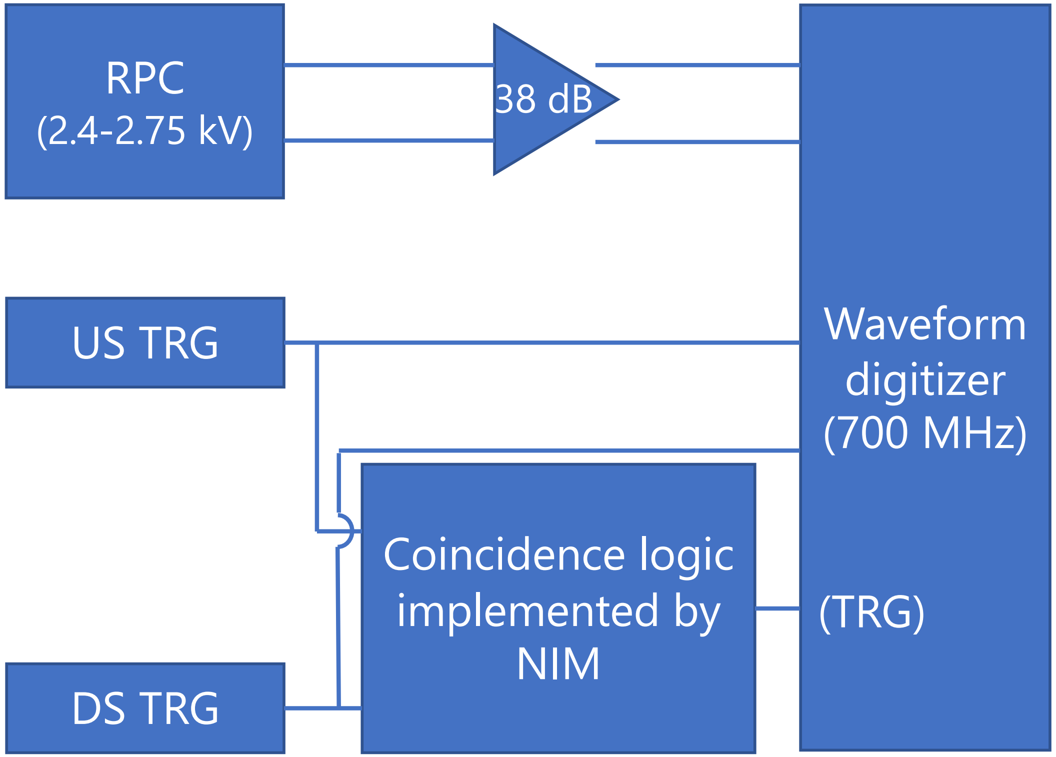
Pulse height with 4-layer config





Setup of MIP e signal size test





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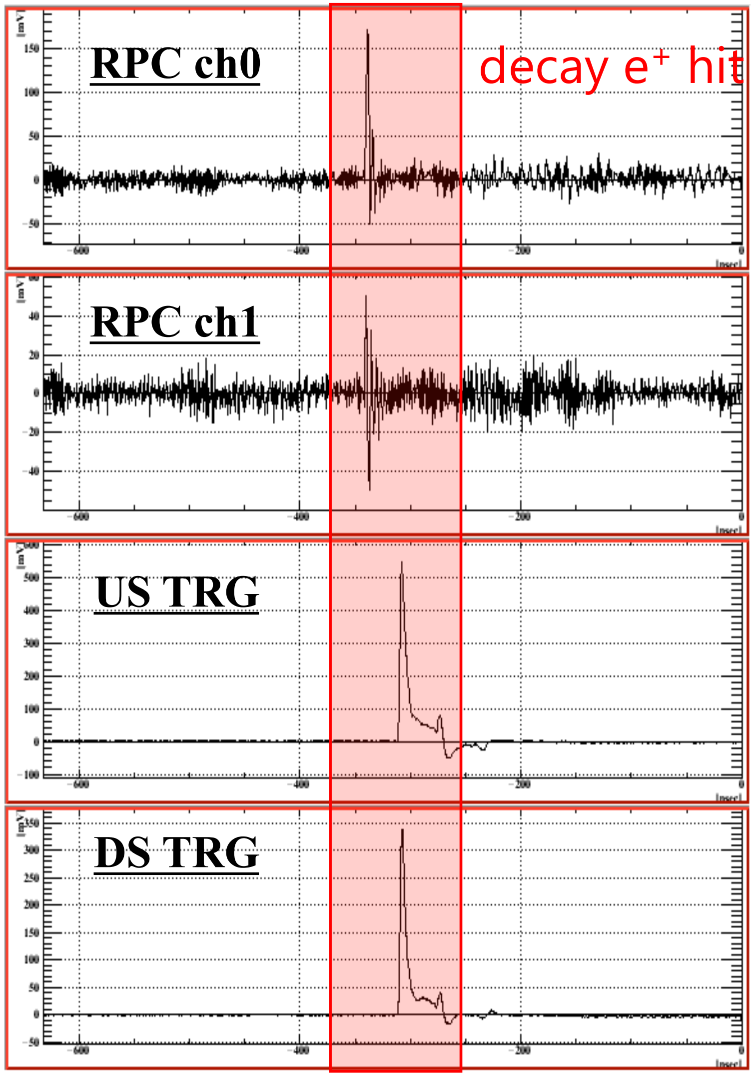
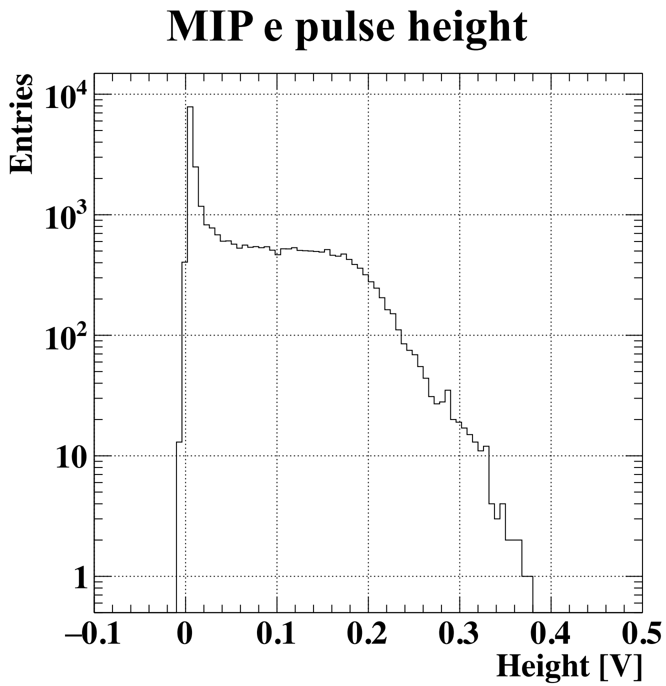
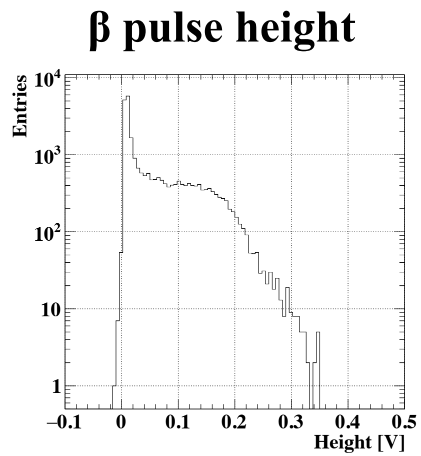
Pulse height spectrum of MIP e







- Pulse height spectrum of MIP e is similar to that of β