Development of the detectors for the DeeMe experiment

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1. Introduction

1.1 Charged Lepton Flavor Violation

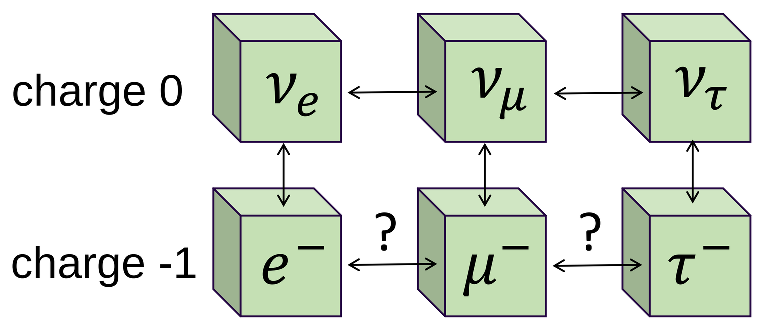


Fig. 1.1 Leptons in the Standard Model

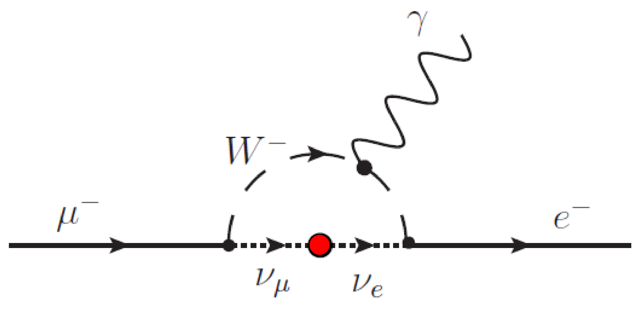
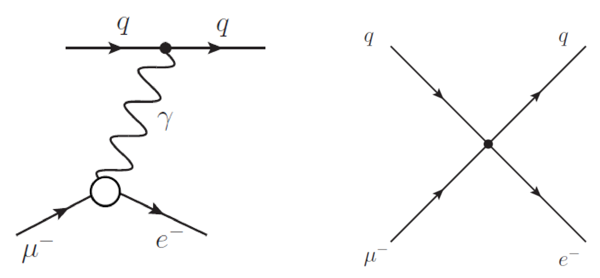


Fig. 1.2 Feynman diagram for $\mu^- \to e^- \gamma$ via neutrino oscillation

Charged Lepton Flavor Violation (cLFV) processes are prohibited in the Standard Model. Even if the neutrino mixing is included, the branching ratio for $\mu \to e\gamma$ is suppressed to less than 10^{-54}.

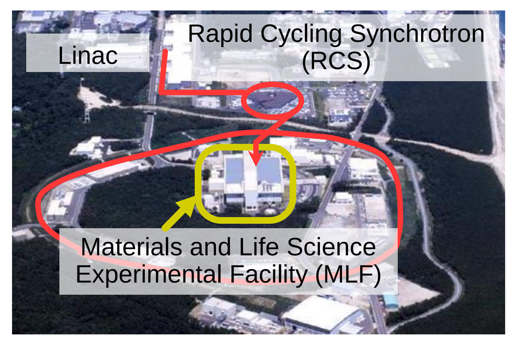
However, some theoretical models beyond the Standard Model predict sizable branching ratios. An observation of the process with a high rate clearly means there is new physics.



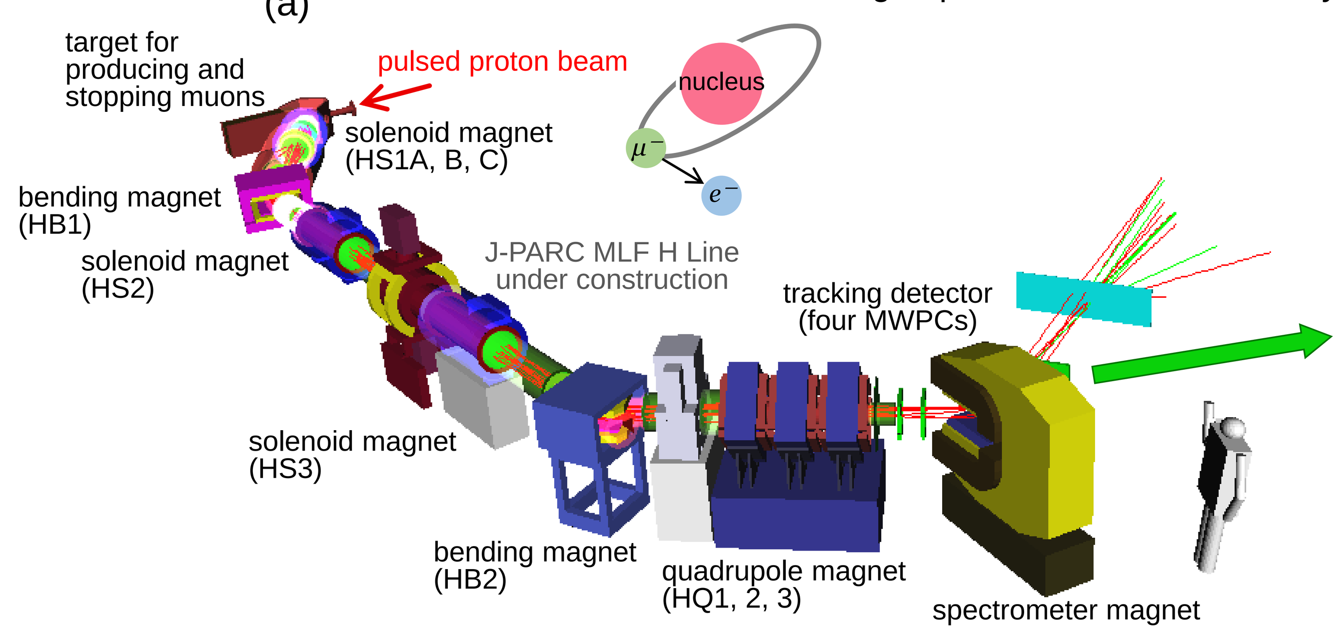
- SUSY-GUT
- SUSY-seesaw
- Extended Higgs sector
- etc.

Fig. 1.3 μ-e conversion diagram classified as (a) photonic and (b) non-photonic

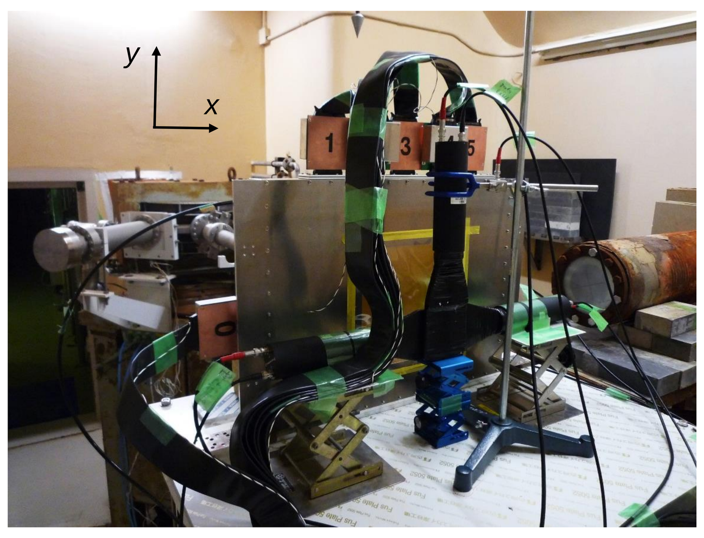
1.2 DeeMe Experiment



(a)



(b)



(c)

Fig. 1.4 (a) Photo of the accelerators and Materials and Life Science Experimental Facility (MLF) in J-PARC (b) Simulated secondary beamline, H Line, in J-PARC MLF (c) Multi-Wire Proportional Chamber (MWPC) and its amplifiers for the DeeMe experiment.

The DeeMe experiment is planned to search for μ-e conversion in the nuclear field at J-PARC MLF H Line. Our goal is to reach a single event sensitivity of $< 1\times10^{-13}$ for a graphite target or that of $< 2\times10^{-14}$ for a silicon carbide target with operating the RCS at 1 MW for 2×10^{7} s/year. This will improve the sensitivity by one or two orders of magnitude.

The signal of μ-e conversion is a delayed electron with a energy of 105 MeV. The momenta of charged particles are measured by a magnetic spectrometer with four MWPCs.

2. Development of the Detectors

2.1 Devices

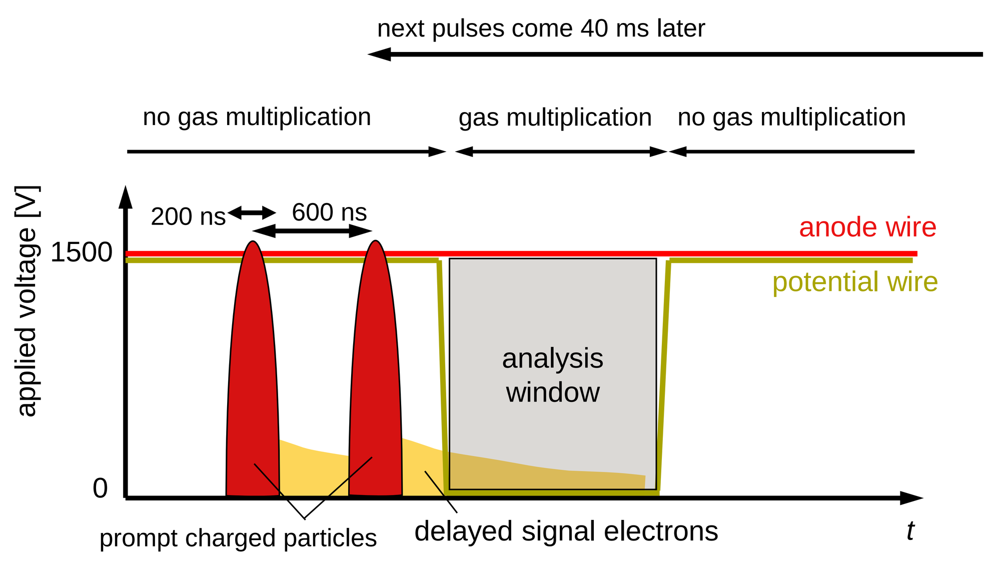
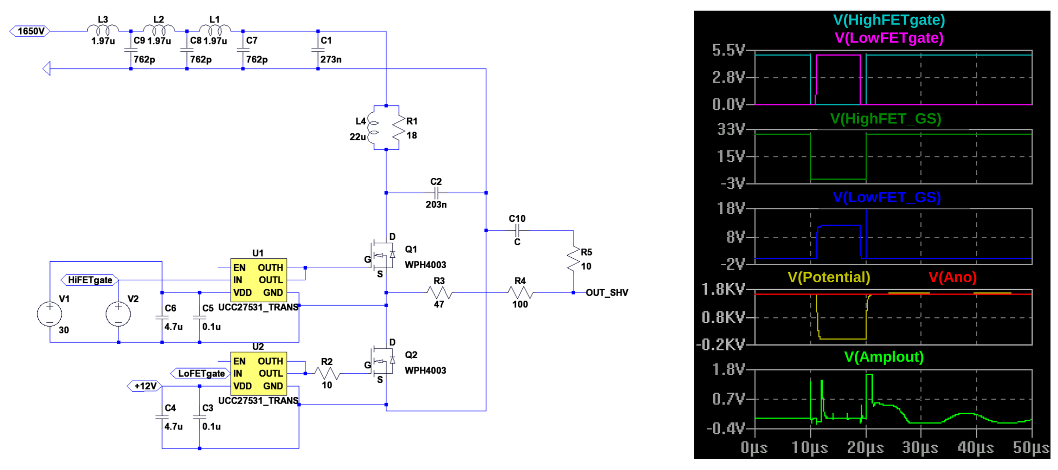


Fig. 2.1 Expected charged particles hitting the MWPCs and how to apply voltage to the MWPCs



The circuit of high-voltage switching module and its simulation result

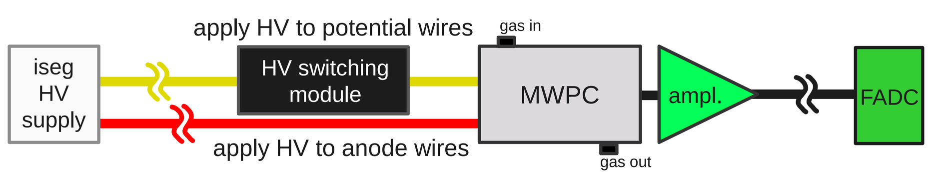
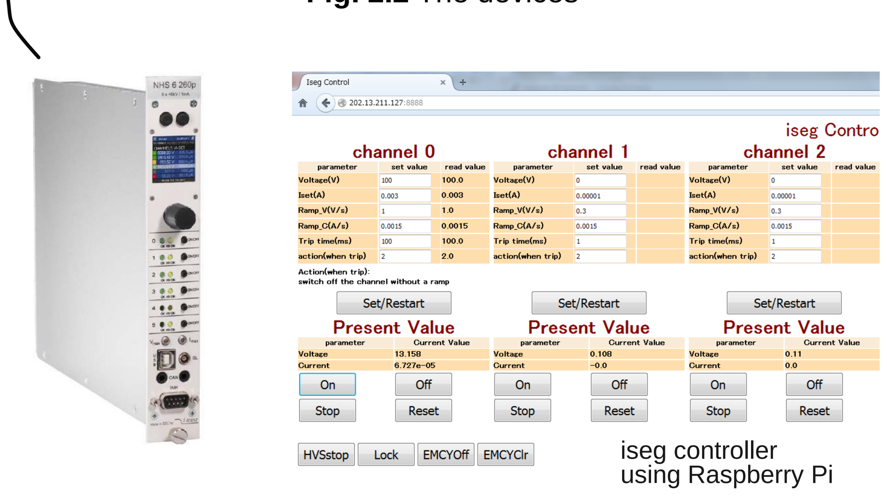
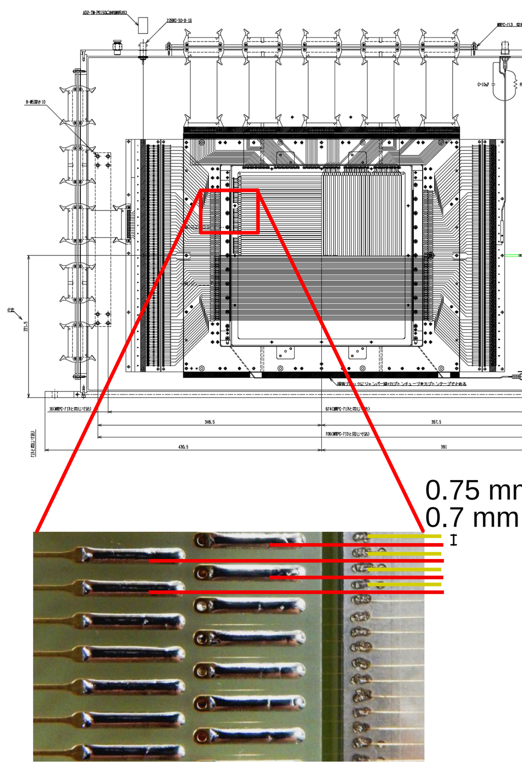


Fig. 2.2 The devices

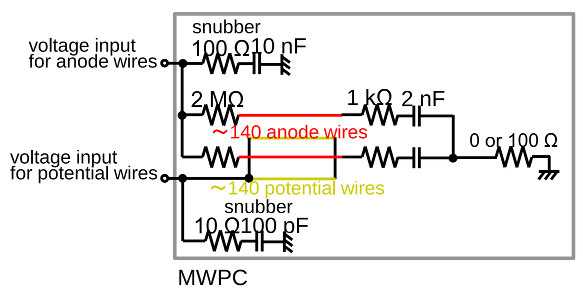


iseg controller using Raspberry Pi



Readout cathode strips
- 3 mm width for x-axis
- 15 mm width for y-axis
- 250x200 mm² active area

Anode and potential wires stretched alternately



Equivalent circuit of the MWPC

2.2 Current Status

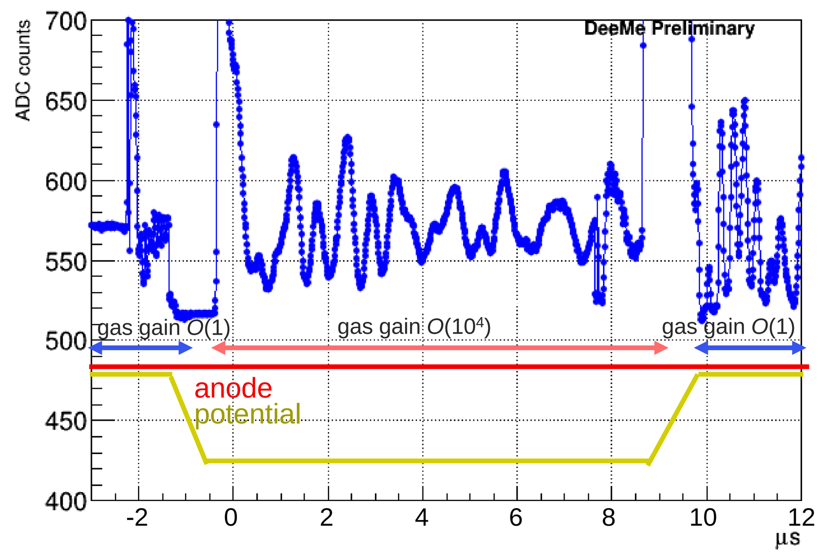


Fig. 2.3 Output waveform of the detector. 1 ADC count equals to 2 mV

For filling gas mixture of argon (35%) ethane (65%) and applying 1630 V to the MWPC, we obtain a gas gain of approximately 4.5×10^4.

In this operation,

- Time period of negative saturation $\simeq$ 1.0 μs (-1.5 to 0.5 μs),
- Oscillation (0 to 8 μs) occurs and the efficiency becomes lower.

In June, 2017, We conducted an experiment for measurement of momenta of electrons from muon Decay in Orbit $\mu^- \to e^- \nu_\mu \overline{\nu_e}$ at the J-PARC MLF D2 Area.

The spectrometer system worked well. Hit efficiency of the MWPCs fluctuated in time as the shape of output waveform oscillated.

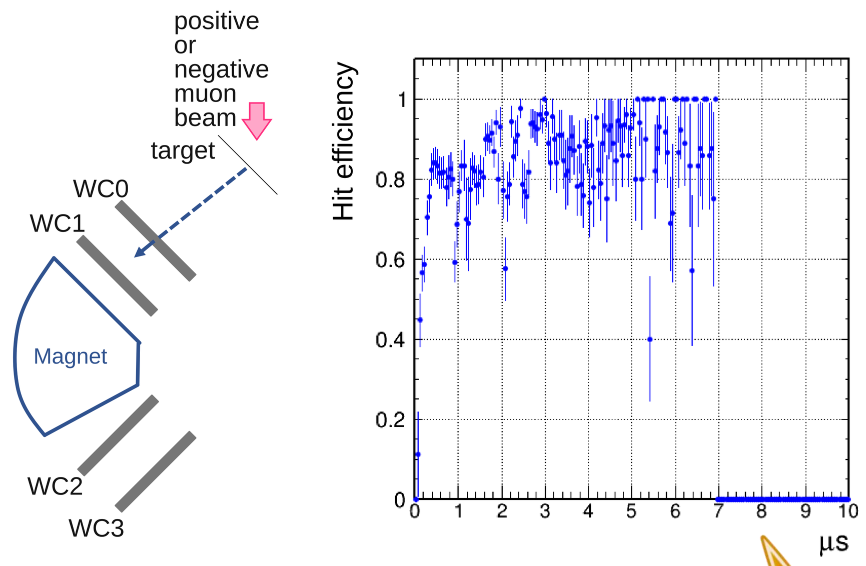


Fig. 2.4 Setup and hit efficiency of the second MWPC (WC1) from the upstream in the experiment at the J-PARC MLF D2 Area in June, 2017

Type	-724	-713
Wire spacing	0.75 mm	0.7 mm
Reference	WC0, 1	WC2, 3
Applied voltage	1630 V	1600 V
Efficiency of x-axis readout	$\simeq$ 90%	$\simeq$ 60%

To avoid negative saturation and decrease in efficiency, we tried

- changing the gas and applying lower voltage,
- increasing the dynamic range of the readout amplifiers.

2.3 Gas Mixture Study

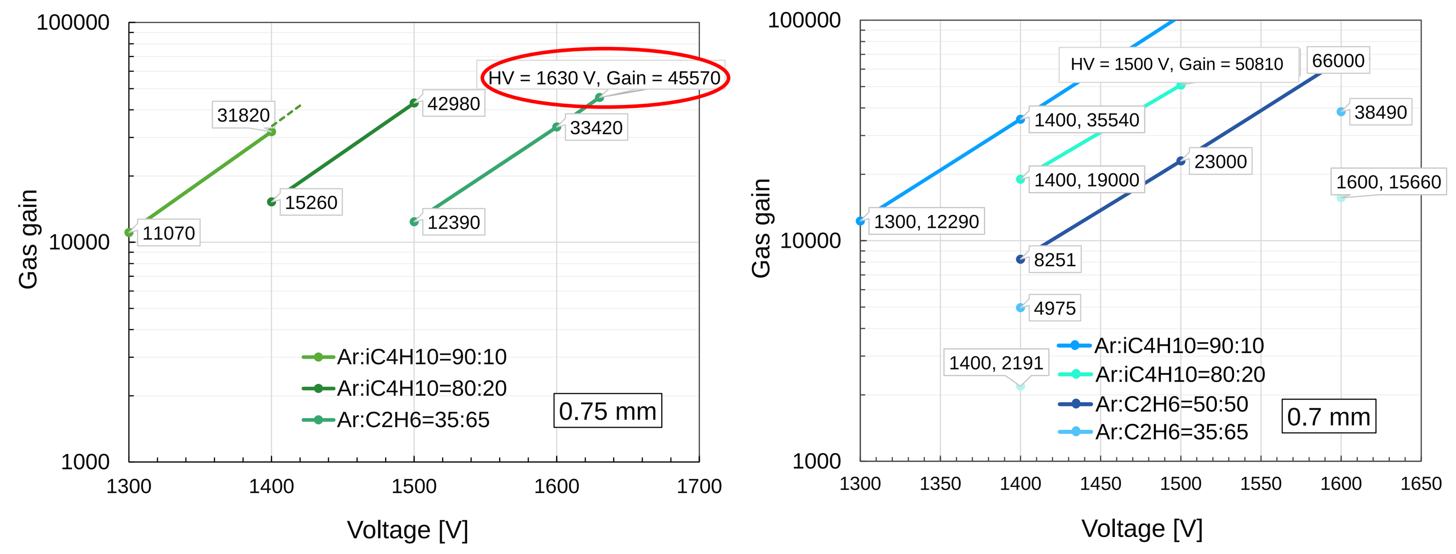
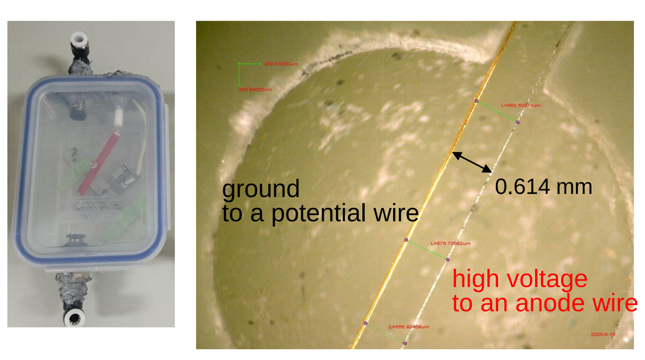


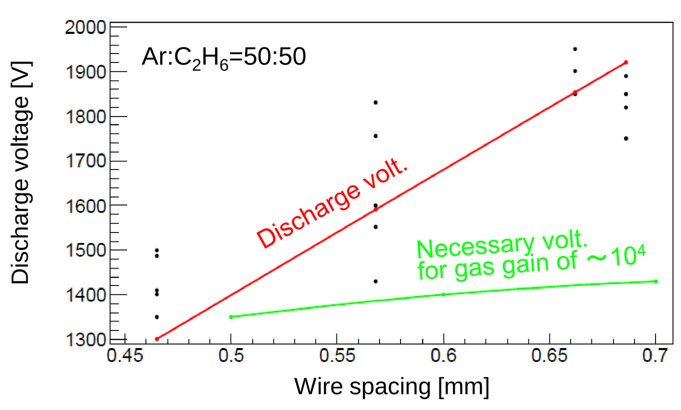
Fig. 2.5 Simulated gas gain as a function of applied voltage for a wire spacing of 0.75 mm (left) or 0.7 mm (right)



- To obtain a gas gain of 4.6×10^4, we need to apply 1510 V to the MWPC with a 0.75 mm wire spacing for argon (80%) isobutane (20%).
- For the gas mixture, discharge occurs between two wires (0.614 mm) at 1600 V. From Paschen's law

  (Discharge voltage)$\propto$(distance of two electrodes)

  for 0.1 to 1 mm. For a wire spacing of 0.75 mm, discharge will thus occur at $\simeq$ 1950 V.
- $\simeq$ 100 V applied voltage can be reduced and we have $\simeq$ 400 V margin for discharge.



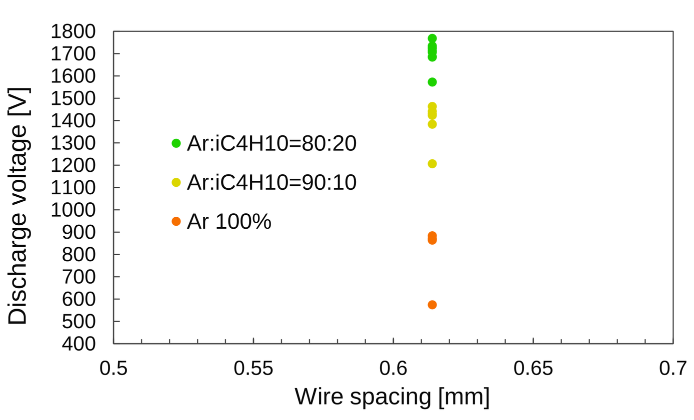


Fig. 2.6 Measurement of discharge voltage between two wires in a small chamber (from Y. *Takezaki*'s master's thesis)

2.5 Results of the Latest Beam Test

We performed a beam test in Feb. 2017 at Institute for Integrated Radiation and Nuclear Science, Kyoto University.

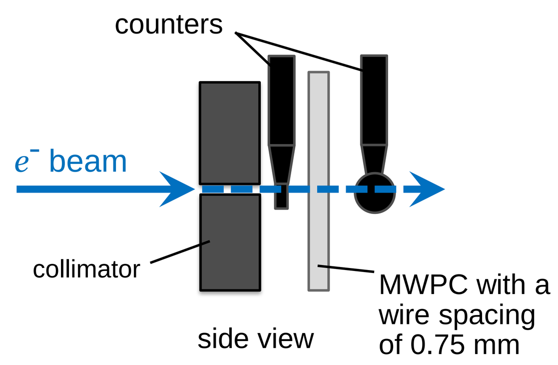
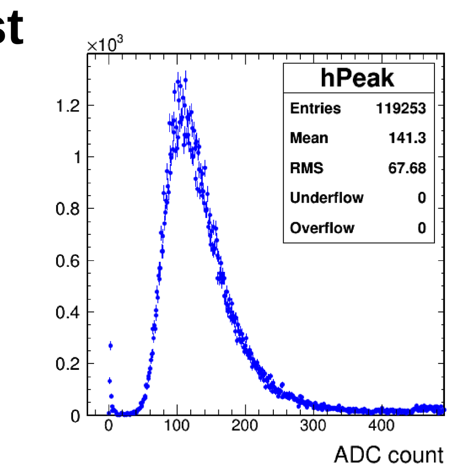
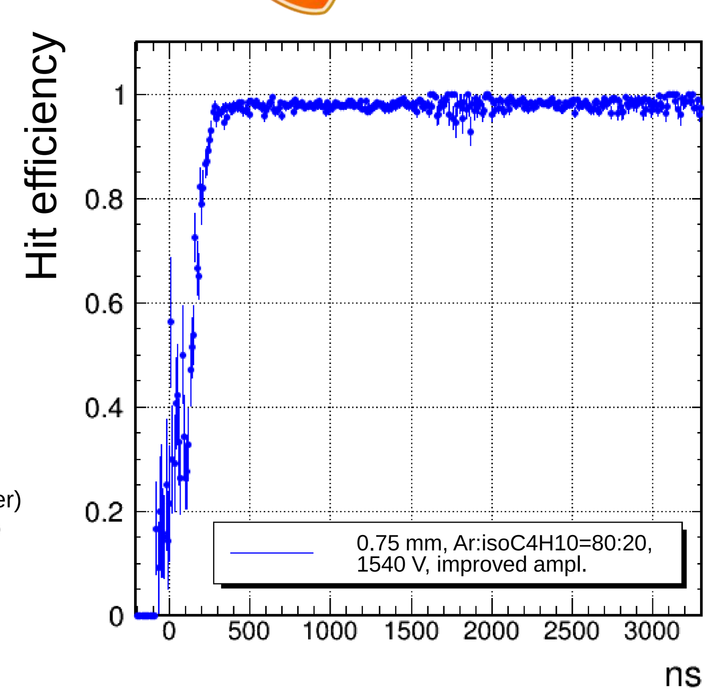
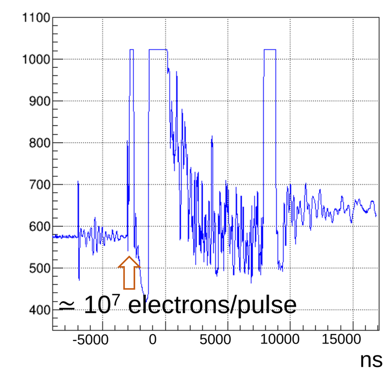


Fig. 2.8 Setup of the beam test



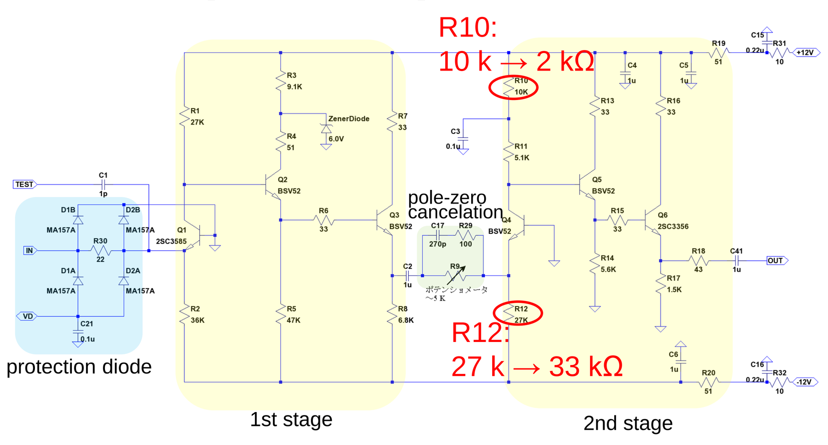
- (Number of initial ion pairs) $\times$ (gas gain) $\times$ (elementary charge) $\times$ (gain of amplifier) $\times$ (ratio of inputting to one cathode strip) $\simeq 60\times4.6\times10^4\times1.6\times10^{-19}$ C $\times$ 6 V/pC $\times$ 1/9 $\simeq$ 290 mV (145 ADC count).





- For single electron, hit efficiency $\simeq$ 98% 300 ns after finishing high voltage switching.
- When beams with the intensity equivalent to the prompt burst hit the MWPCs, we observed random spikes in waveform.
- It appears that ions hit the cathode planes and that electrons are emitted and gas-amplified again.
- We have a plan to mix freon with the filling gas to absorb the electrons between the cathode and anode planes.

2.4 Amplifier Improvement



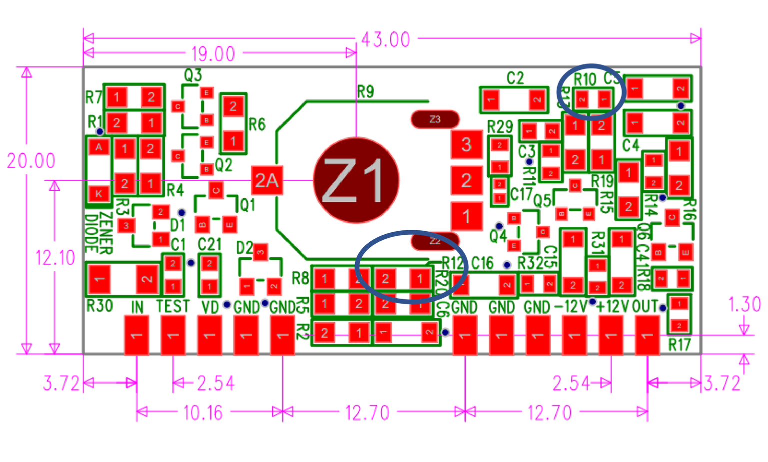


Fig. 2.7 Circuit and drawing of the readout amplifier. Changing some values of resistors, we increased the negative range $\simeq$ 120 mV (version 1) to $\simeq$ 280 mV (version 3)

3. Summary

- DeeMe aims to search for μ-e conversion with a single event sensitivity of 1×10^{-13} (C target) or 2×10^{-14} (SiC target).
- The spectrometer is ready.
- By optimizing the gas mixture filling the MWPCs and increasing the negative range of the readout amplifiers, hit-efficient performance has been improved for single electrons.
- The gas optimization of the MWPC is in progress.