

# An experiment to search for $\mu - e$ conversion by using a pulsed proton beam from J-ARC RCS – DeeMe



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on behalf DeeMe collaborator  
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# DeeMe Collaboration

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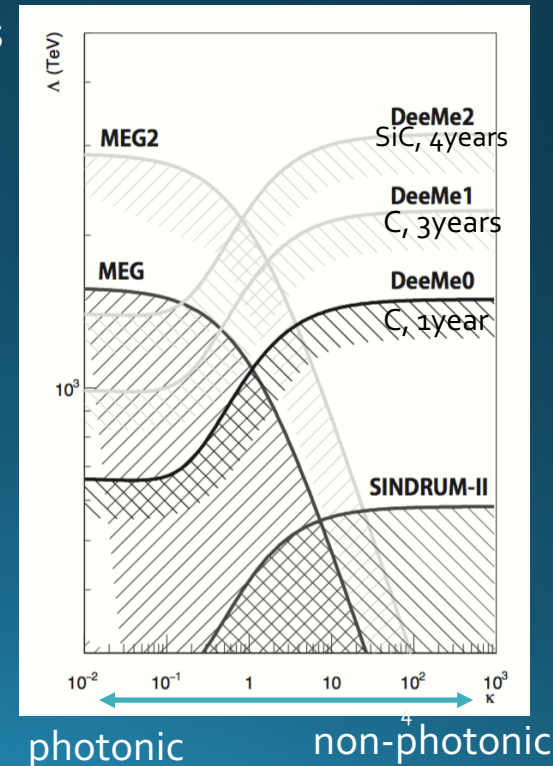
# $\mu$ -e conversion

- Neutrino oscillation was observed by experiments.
- Charged Lepton Flavor Violation (CLFV) is heavily suppressed in the current Standard Model of particle physics with neutrino oscillation.
  - $\text{BR}(\mu \rightarrow e) \sim 10^{-54}$  considering the neutrino oscillation
    - Too small to be observed
- Sizable Branching ratio predicted by theoretical models beyond SM
  - Observation of CLFV is the clear evidence of the new physics

Lagrangian

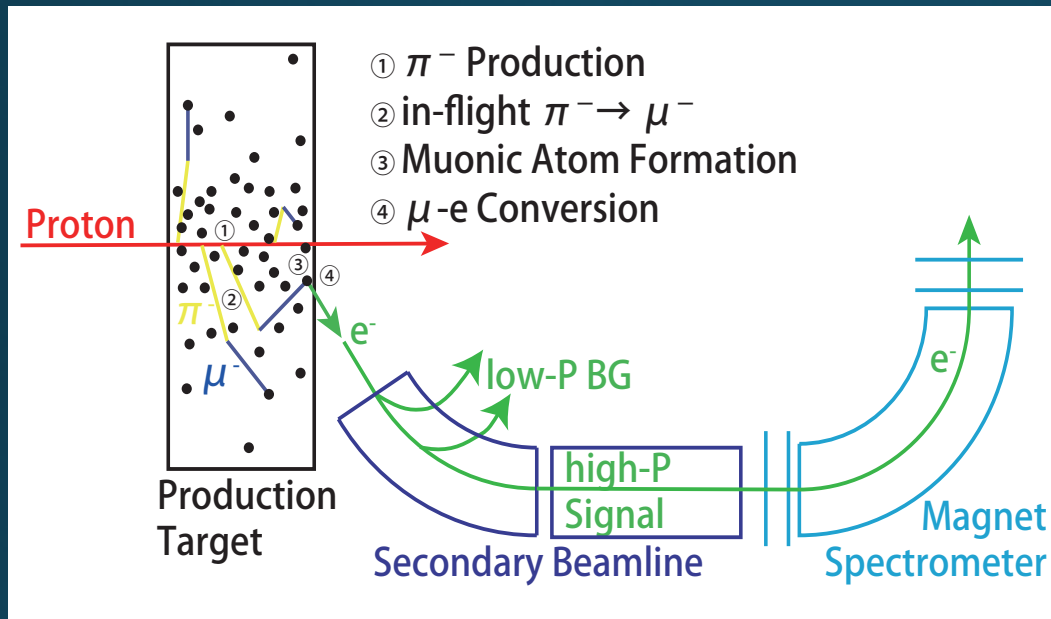
$$L = \underbrace{\frac{1}{1+\kappa} \frac{m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L F^{\mu\nu}}_{\text{photonic}} + \underbrace{\frac{\kappa}{1+\kappa} \frac{1}{\Lambda^2} (\bar{\mu}_L \gamma^\mu e_L)(\bar{q}_L \gamma_\mu q_L)}_{\text{non-photonic}}$$

- Current upper limits
  - $\text{BR}(\mu^- \text{Ti} \rightarrow e^- \text{Ti}) < 4.6 \times 10^{-12}$  (TRIUMF: 1988)
  - $\text{BR}(\mu^- \text{Ti} \rightarrow e^- \text{Ti}) < 4.3 \times 10^{-12}$  (SINDRUM-II: 1993)
  - $\text{BR}(\mu^- \text{Au} \rightarrow e^- \text{Au}) < 7 \times 10^{-13}$  (SINDRUM-II: 2011)





# DeeMe experiment



signal electron is...

- single
- mono energetic
- delayed

The signal electron is identified by their momentum and time information

Start with Carbon target

- Lifetime of muonic atom  $\sim 2 \mu\text{s}$
- Energy of electron from  $\mu^-$ -e conversion = 105 MeV
- Single event sensitivity (1 year =  $2 \times 10^7$  sec)
  - $1 \times 10^{-13}$
  - $2.5 \times 10^{-14}$  (4 years)

In case of SiC...

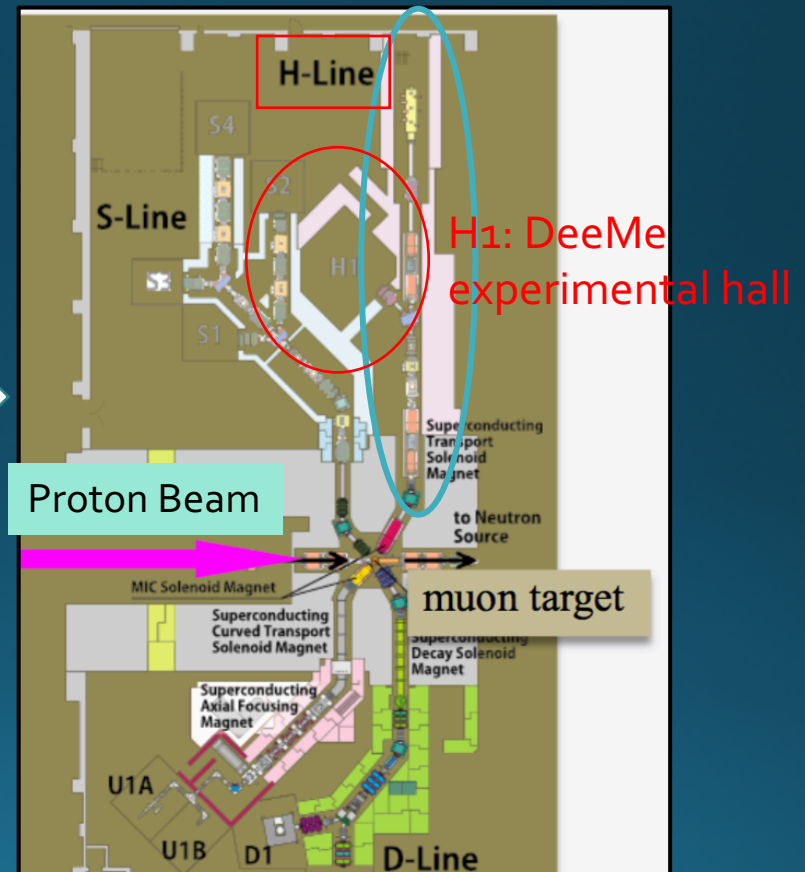
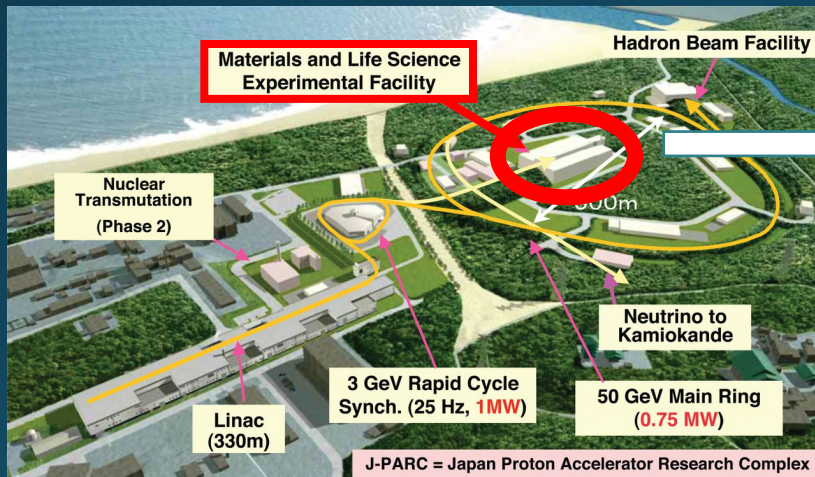
- $2 \times 10^{-14}$
- $5 \times 10^{-15}$  (4 years)

# DeeMe experiment

$\mu$ -e conversion searching experiment at J-PARC MLF H-Line

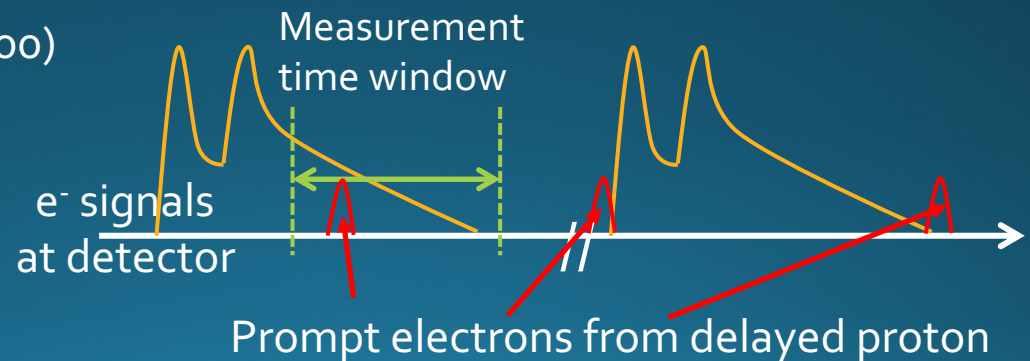
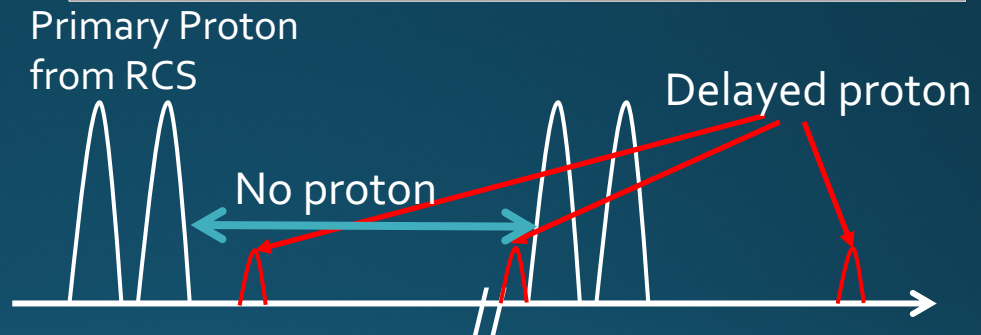
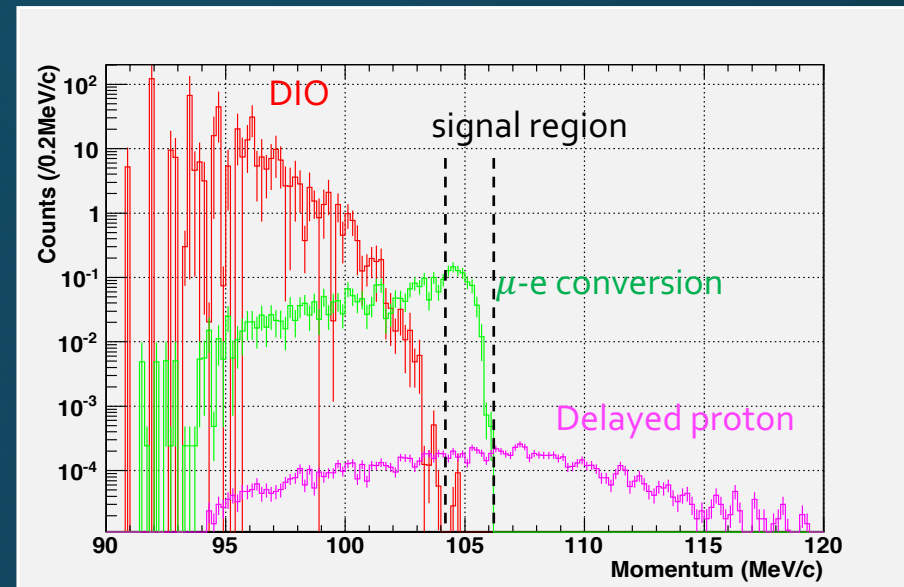
Experimental groups are working to complete H-Line with the facility group.

MLF Muon facility



# Background

- Decay In Orbit  $0.015$  (event/year)
  - Distinguished by momentum
- prompt background  $< 2.9 \times 10^{-4}$  (event/year)  
(zero in principle)
  - Distinguished by time distribution
  - Delayed protons from main pulse are monitored by a beam loss monitor in RCS
- Cosmic-ray induced
  - e:  $< 0.018$ ,  $\mu$ :  $< 0.001$  (event/year)
    - suppressed by duty factor(=  $1/20000$ ) and horizontal tracking direction
- Anti-Proton Zero in principle
  - beam energy(=3 GeV)  
 $< \bar{p}$  production threshold



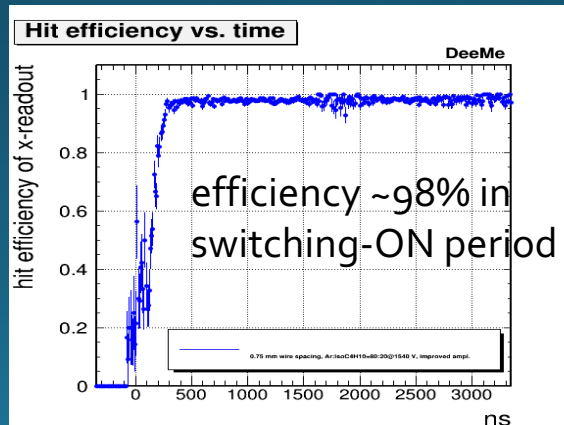
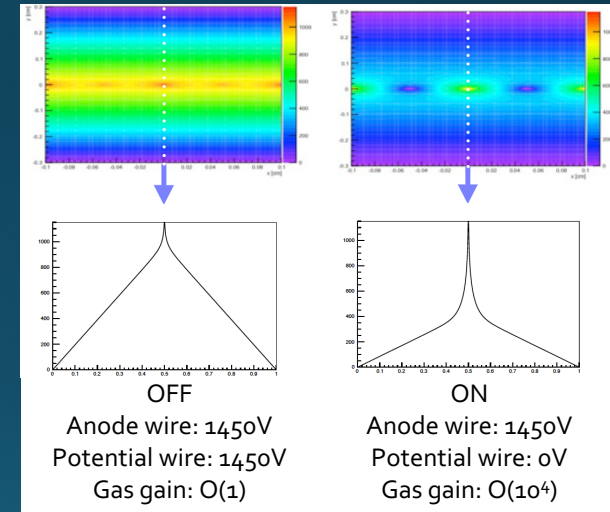
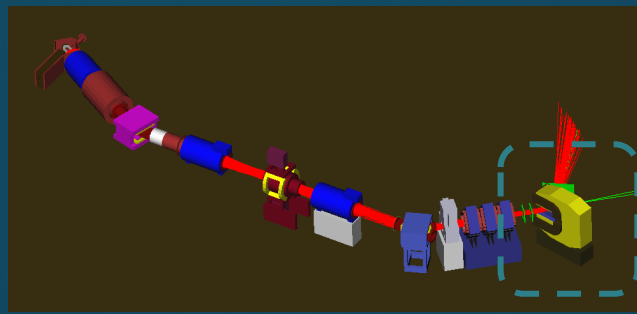
# Spectrometer

- PACMAN Magnet

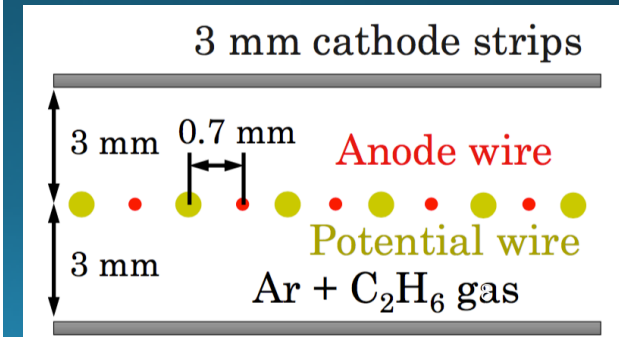
- Central field = 0.4 T (at 300A) for 105 MeV/c, 70 degree bending
- Transported from TRIUMF to J-PARC
- Test operation and magnetic field measurement finished in J-PARC.

- Multi-Wire Proportional Chamber (MWPC)

- exposed to prompt burst ( $10^8$  particles/pulse)
  - Instantaneous hit rate  $\sim 100$  GHz/mm<sup>2</sup>
  - Usual detector saturated by this burst
- Gas gain control with changing applied voltage of potential wire quickly
- Readout by cathode strip



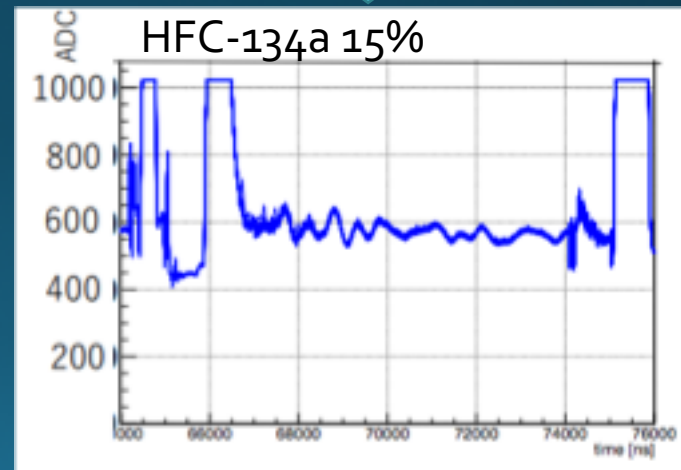
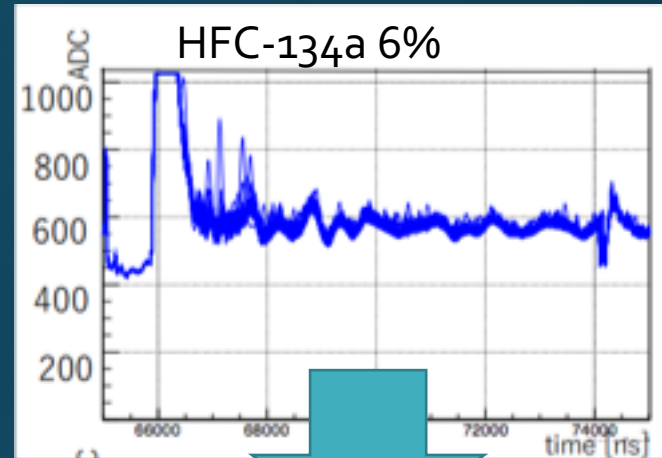
Publication: PTEP, Volume 2017, Issue 2, 023C01





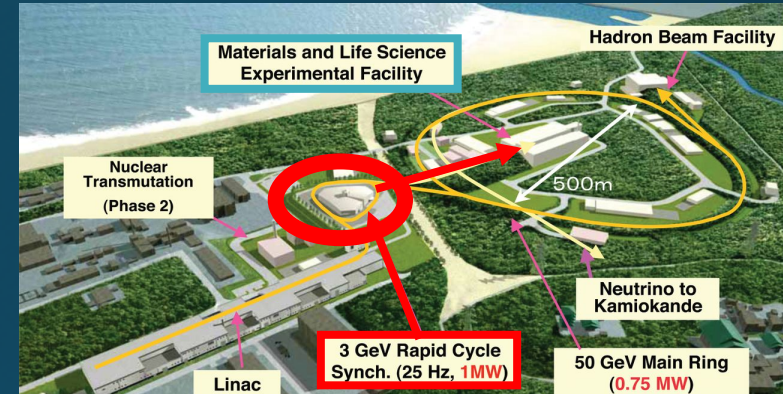
# MWPC gas mixture optimization

- Delayed pulses have been observed when the beam with  $\sim 10^7$  electrons / pulse hit the MWPC.
- We confirmed that Freon gas (HFC-134a) reduced delayed pulses.
- A beam test was performed in KURNS (Kyoto University Institute for Integrated Radiation and Nuclear Science) in July 2019.
- 15% of Freon suppressed delayed pulses.
  - Slightly affected to the detection efficiency.
- Analysis is ongoing.
- We will try to use methylal gas for some reasons.
  - To suppress the delayed pulses (as HFC-134a)
  - To prevent growth of whiskers on wires and lengthen the lifetime of MWPC

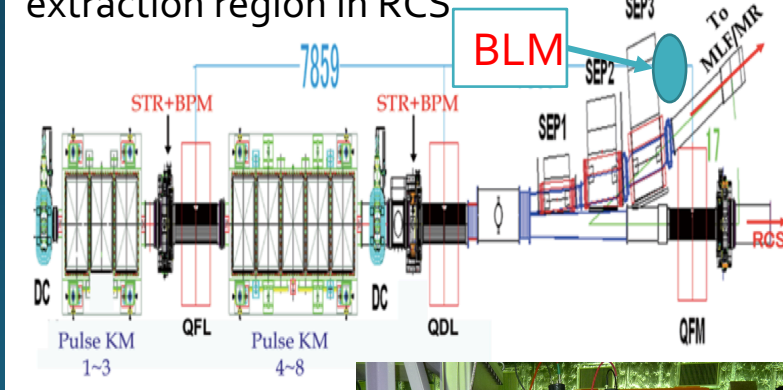


# Delayed-Proton monitoring

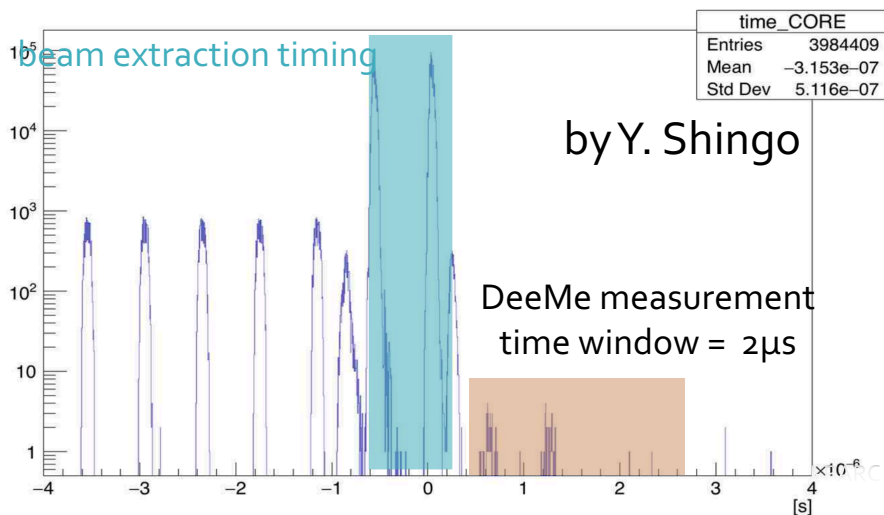
- Proton beam is extracted by fast extraction in RCS
  - no proton delayed from main pulse in principle
- Large emittance proton may be extracted in kicker magnet OFF timing
- This proton may produce background after several micro second from extraction
- Monitoring large emittance proton by a beam loss monitor (BLM)



extraction region in RCS

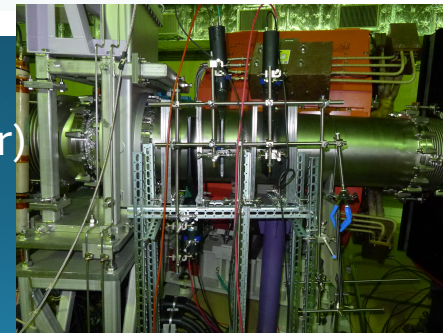


time spectrum of BLM hit



DP background  
 $< 2.9 \times 10^{-4}$  (event/year)  
 (3σ C.L.)

Study ongoing



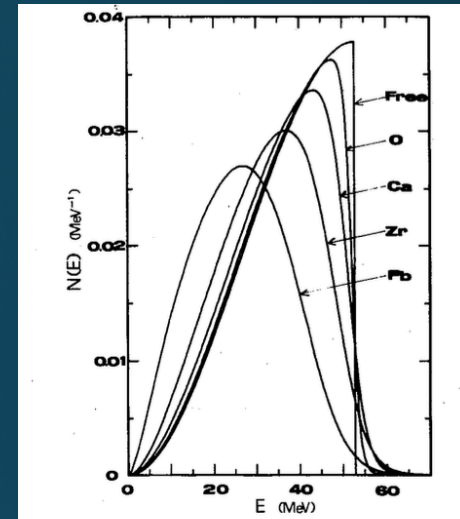


# DIO spectrum

- Watanabe calculated the DIO momentum spectrum  $< 90$  MeV
- Then, Shanker calculated the spectrum of high momentum region including recoil energy

We call the combined momentum for mu-e conversion experiments “Watanabe-Shanker spectrum”

- “Czarnecki” spectrum
  - detail calculation including recoil and relativity effect



Watanabe spectrum

Beamtime had been held in MLF D-line

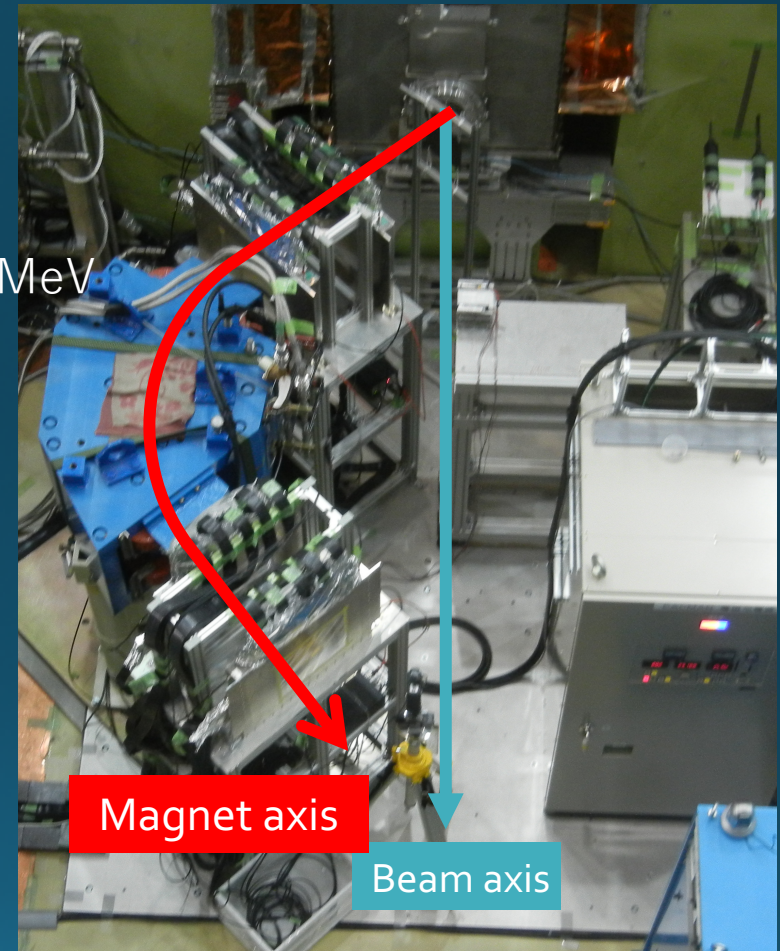
- Performance test of spectrometer system
  - DAQ test with 4 MWPCs
  - Development of tracking analysis codes with real data
- DIO spectrum analysis
  - Confirmation of Czarnecki C spectrum

# DIO measurement

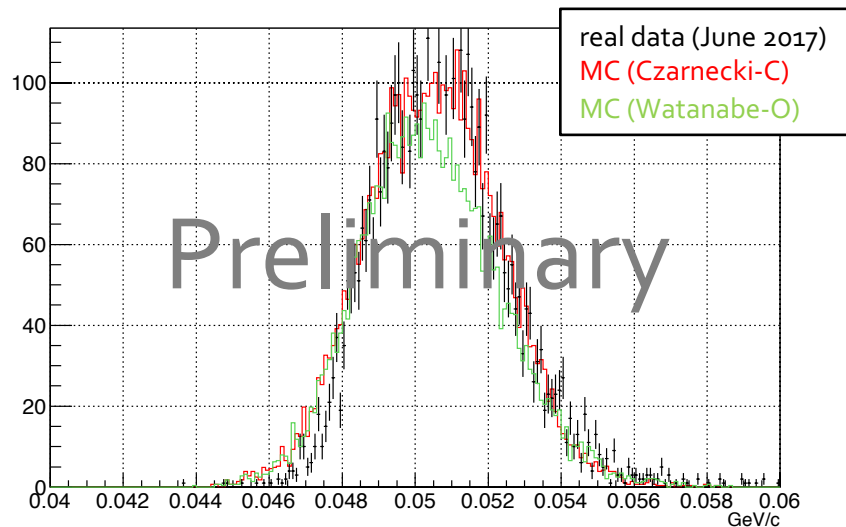
- J-PARC, MLF, D line
  - H line was not available
- Measurement energy = 55 MeV
  - The dependence on Z can be seen at 55 MeV

## Setup

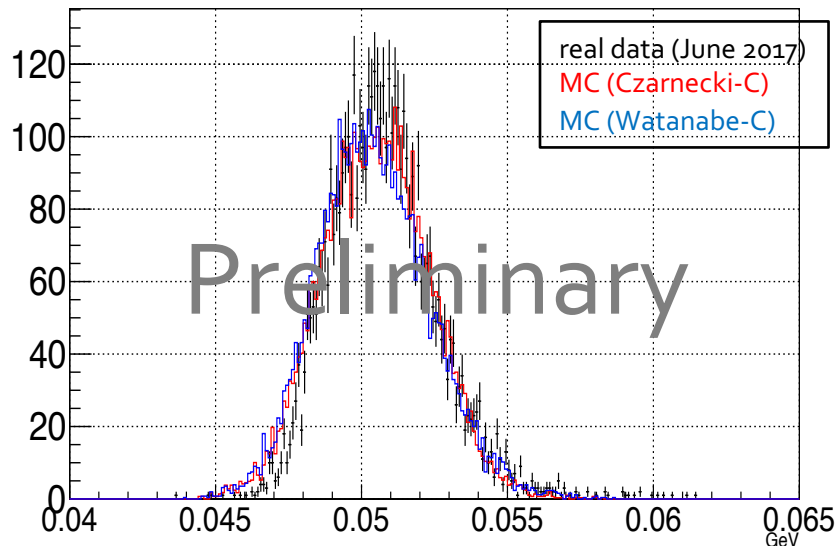
- Beam
  - 30 MeV/c decay muon
- Target
  - Right next to the beam window
  - 45° and 90° against to beam axis and magnet axis
- Spectrometer
  - Full MWPC set and sector bending magnet
- Trigger and DAQ
  - Trigger of DAQ synchronized with that of accelerator (triggered every 40 ms)
  - Waveform recorded by 12 32ch-100MHz-Flash ADC



# DIO analysis (C target, $\mu^-$ , 55 MeV)



- 1/3 of 2017 data of DIO-C
- MC histograms are normalized by the number of muon of analyzed data
- Original Watanabe spectrum was not calculated for C
  - Watanabe-O spectrum was used as C when DeeMe experiment was designed in 2009
- Watanabe spectrum had been updated
  - Watanabe and Czarnecki spectrum are still different



We had a beamtime in MLF2018B period the statistics increases 12 times.  
The difference between the histograms of Czarnecki-C and that of Watanabe-C is expected to become clear.

Analysis is ongoing.

# Summary

- DeeMe is aiming to start soon with the single event sensitivity of  $1 \times 10^{-13}$  for C
  - The single event sensitivity of  $5 \times 10^{-15}$  for SiC 4-years
- The spectrometer system is ready.
  - Delayed pulse can be suppressed by using Freon gas
  - Gas mixture optimization ongoing
- We are working with the facility on H-Line construction
- DIO spectrum measured at J-PARC
  - The spectrometer system worked very well
  - Development of analysis methods (programs, systematics, methodologies, etc.) are being developed.
  - measured momentum is not inconsistent with Czarnecki spectrum (analysis is still ongoing)
  - Statistics increases 12 times by MLF2018B beamtime
  - Comprehensive study of systematic errors are ongoing.
- We want to start  $\mu$ -e conversion run soon after the completion of H-Line.



