DIO measurement and analysis for DeeMe experiment

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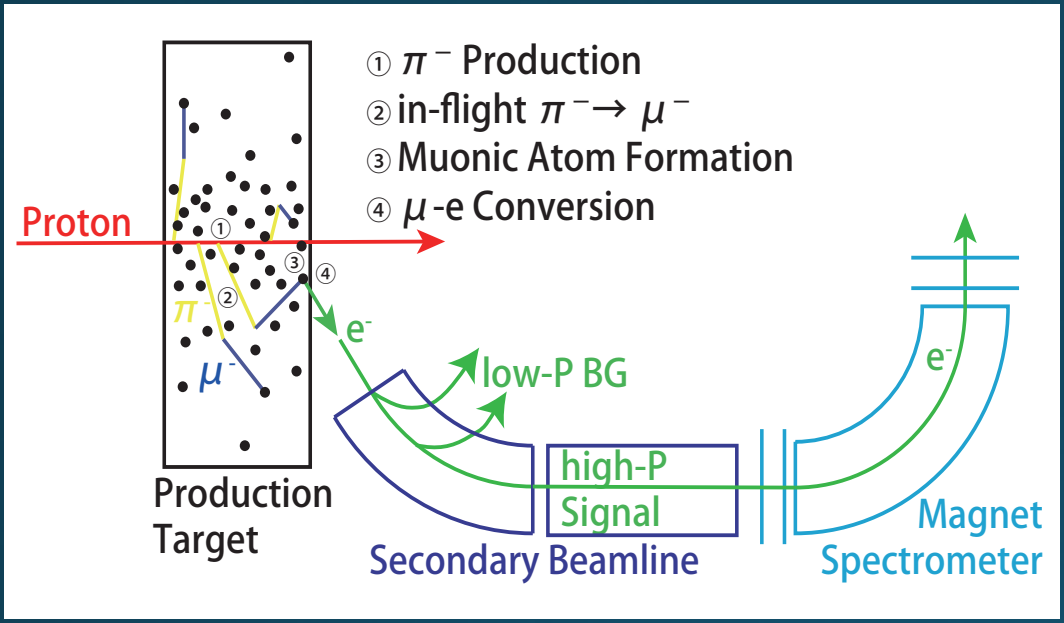
DeeMe experiment



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 ~ 2 μs
- Energy of electron from μ -e conversion = 105 MeV
- Single event sensitivity (1 year = 2×10^{7} sec)
  - 1×10^{-13}
  - 2.5×10^{-14} (4 years)

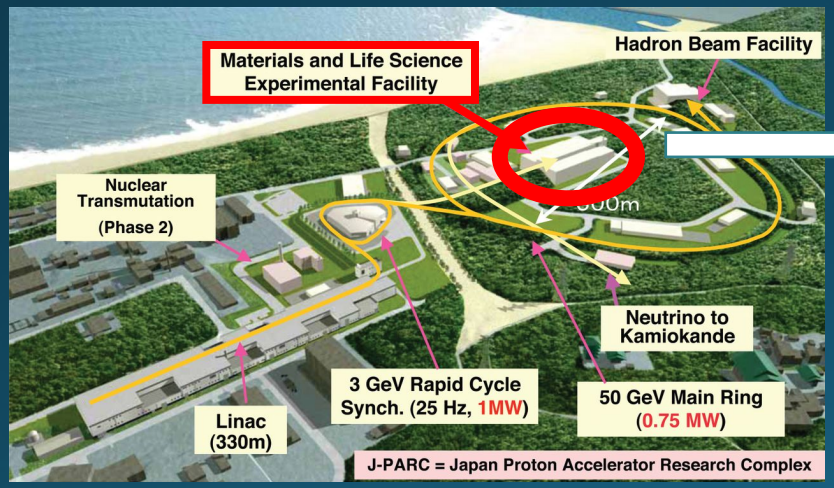
In case of SiC…

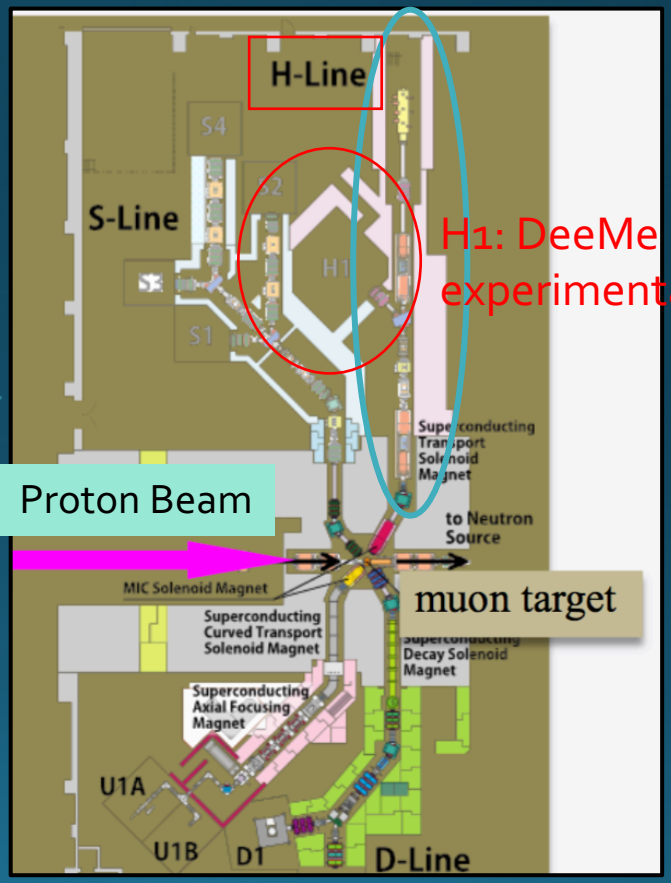
- 2×10^{-14}
- 5×10^{-15} (4years)

DeeMe experiment

μ-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



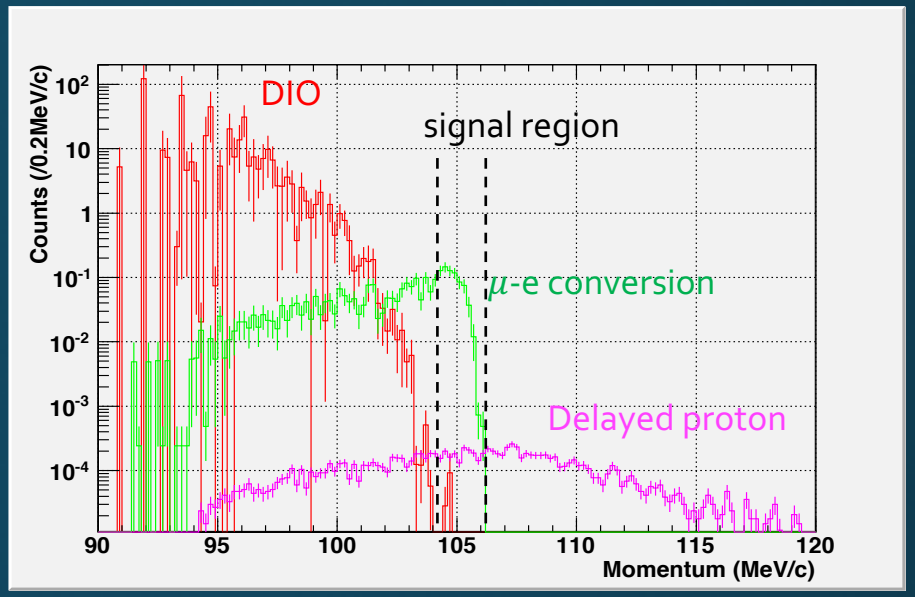


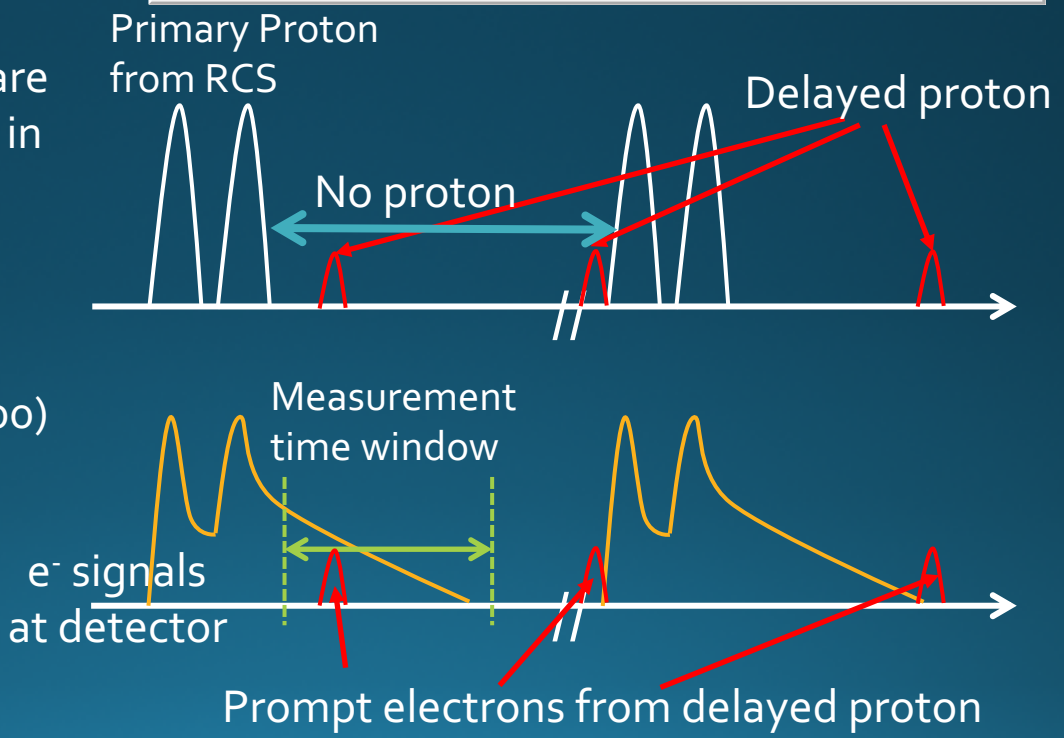
Background

- Decay In Orbit 0.015 (event/year)
  - Distinguished by momentum
- prompt background $<2.9\times10^{-4}$ (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

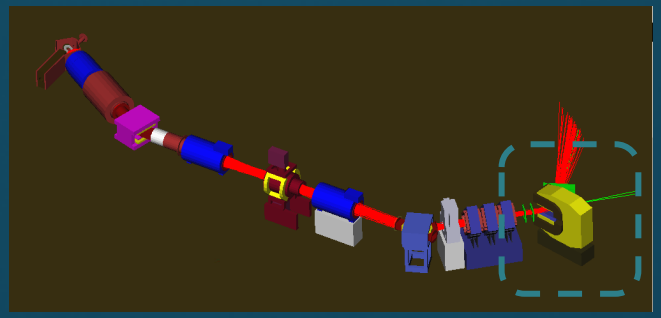
  e: <0.018, μ: <0.001 (event/year)
  - suppressed by duty factor(= 1/20000) and horizontal tracking direction
- Anti-Proton Zero in principle
  - beam energy(=3 GeV)

    < $\bar{p}$ production threshold

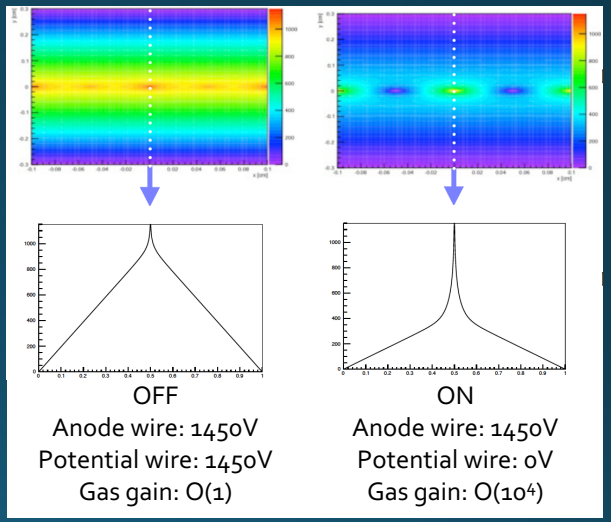


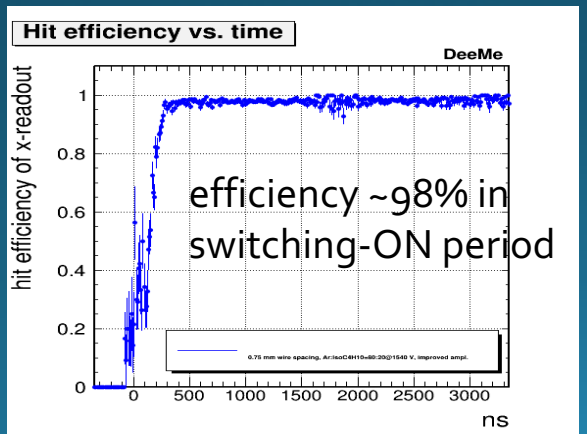


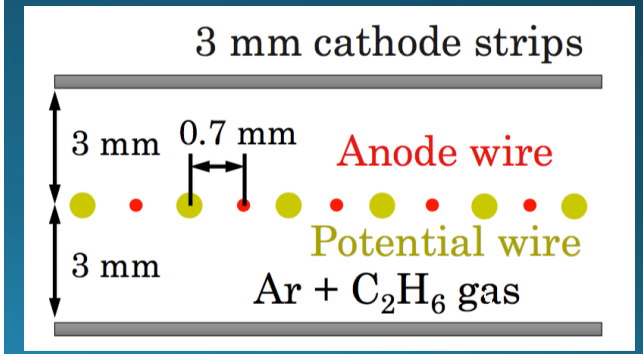
Spectrometer



- 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 ~ 100 GHz/mm^2
    - Usual detector saturated by this burst
  - Gas gain control with changing applied voltage of potential wire quickly
  - Readout by cathode strip







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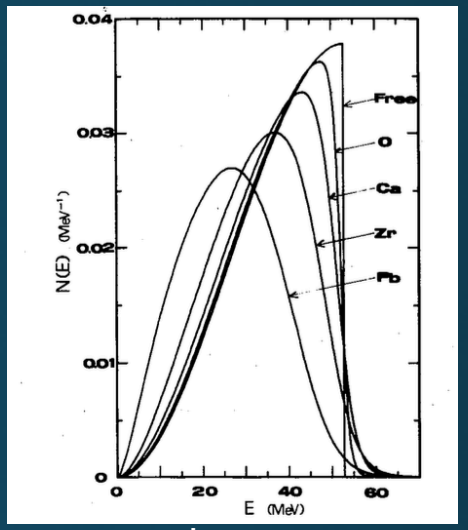
DIO spectrum

- Watanabe calculated the DIO momentum spectrum <90 MeV
  - No spectrum for C in original thesis
  - It is calculated by a theorist in order to compare Watanabe with Czarnecki spectrum in DeeMe experiment
- 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



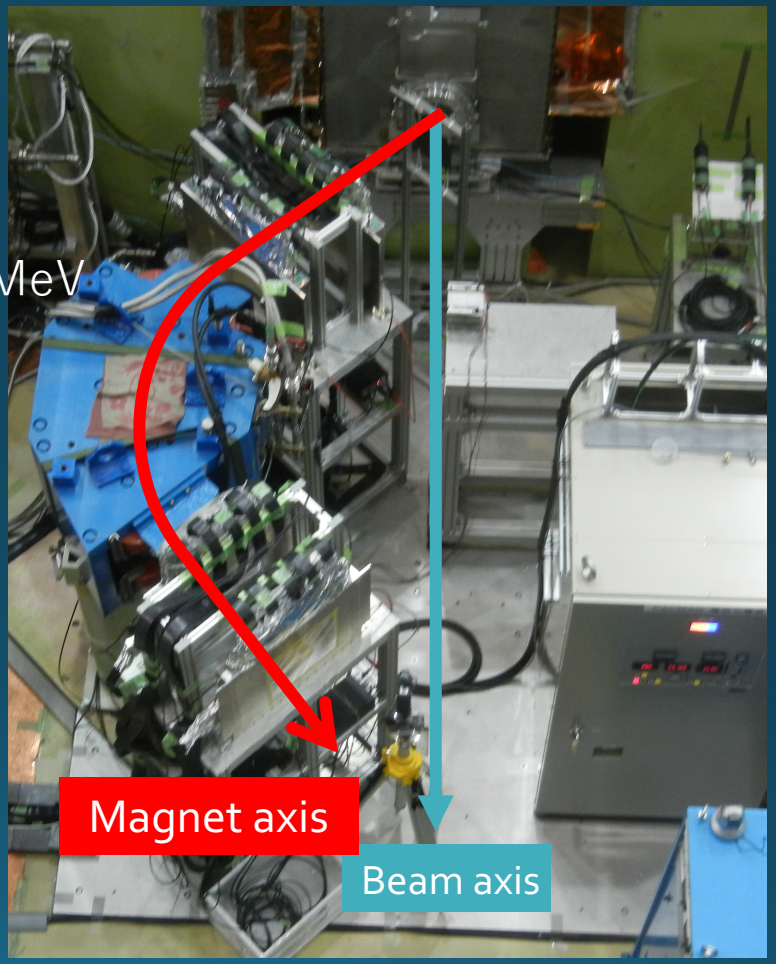
Watanabe spectrum

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

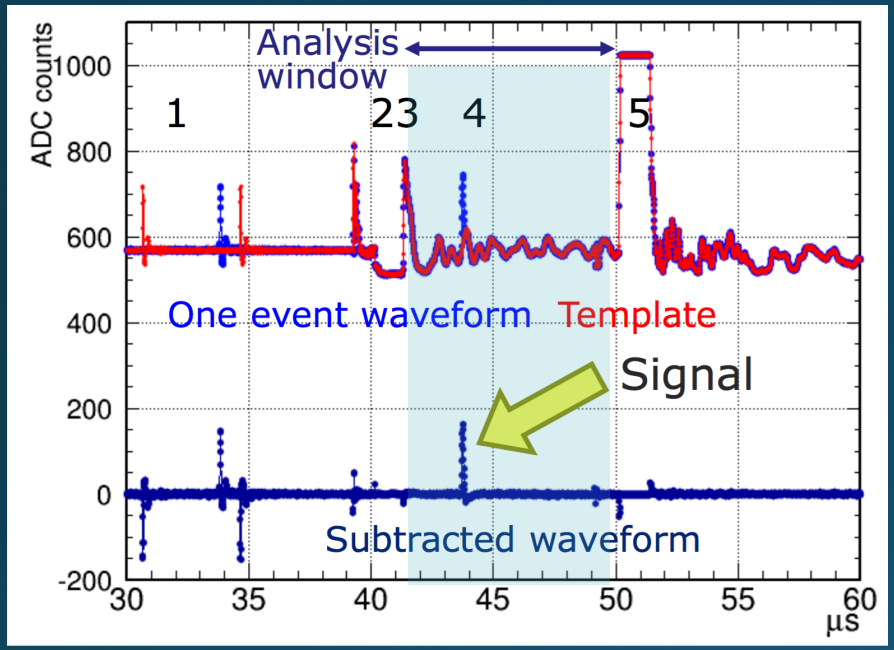


Setup

- 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

Waveform analysis

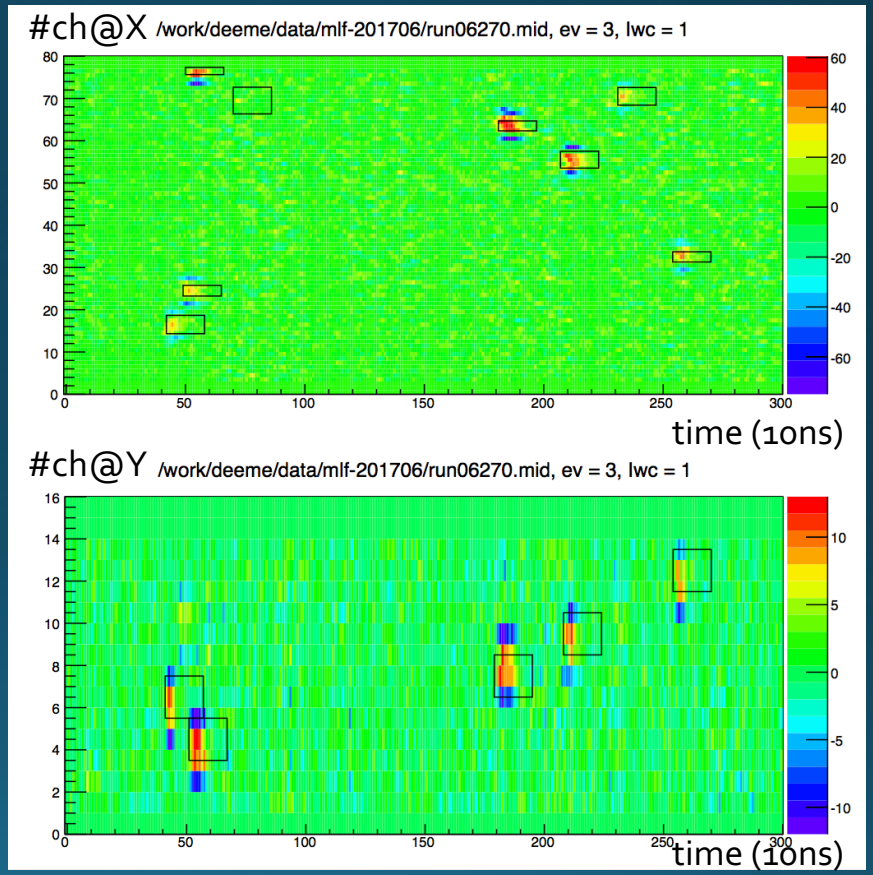
- Baseline subtraction



1. test pulse
2. HV-switching OFF->ON
3. over shoot by PZC circuit
4. signal
5. HV-switching ON->OFF

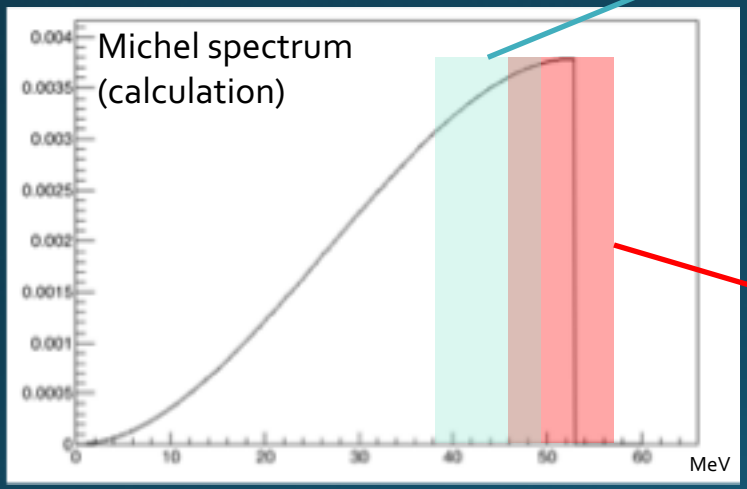
A template waveform is a set of most frequent value in each sample points

- Pulse finding

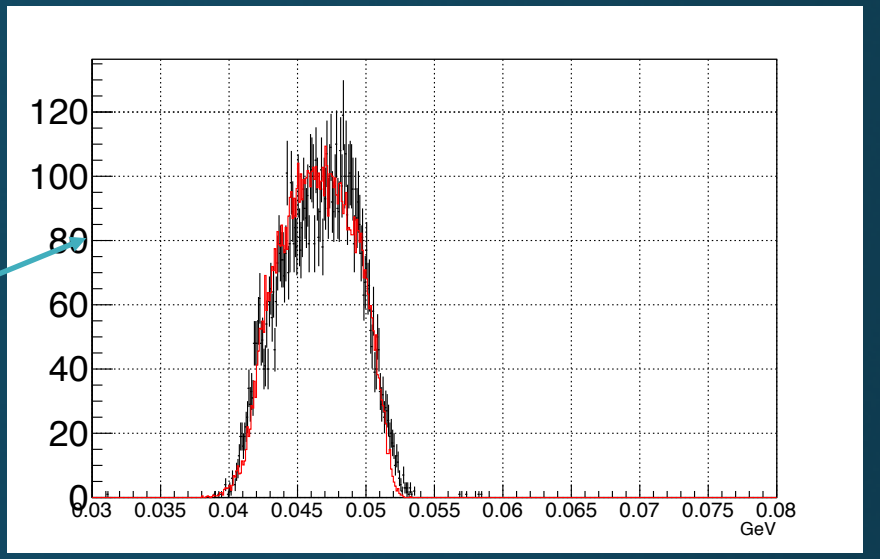


Analysis

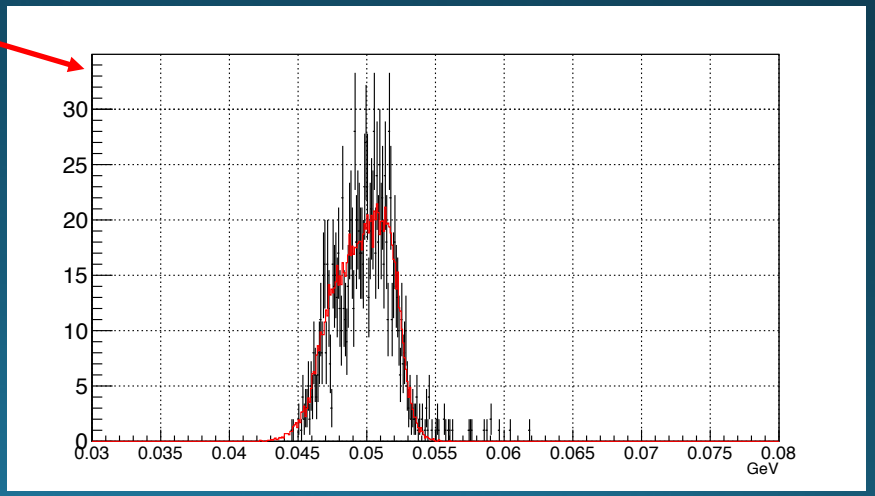
compared the shape of measured momentum spectrum with MC simulation



- C target, μ^+, 45 MeV



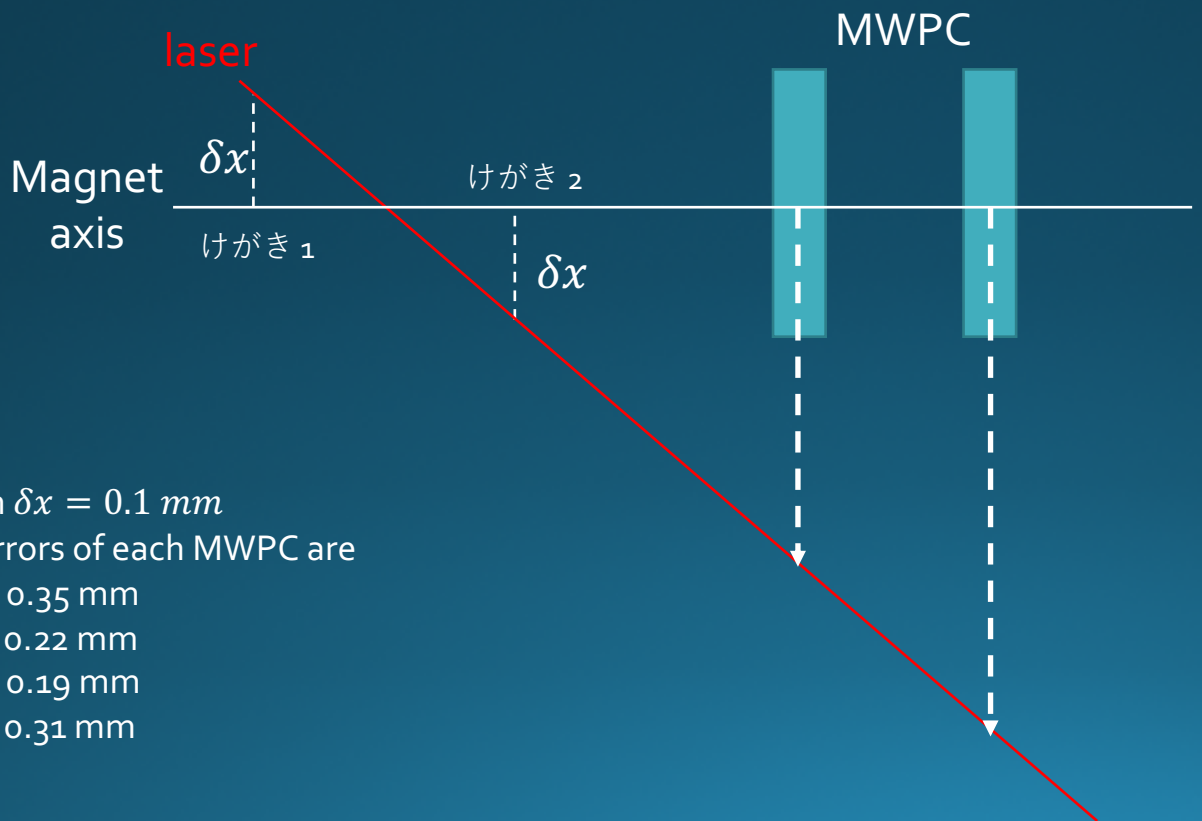
- C target, μ^+, 52.5 MeV



Momentum spectra of data are consistent to that of MC
Calibrated with MC spectrum

Systematic error by MWPC misplacement

- Estimate the systematic error by MWPC misplacement in tracking analysis
  - The detectors' positions were measured based on the laser that was set as parallel to the magnet axis as possible
  - The error of X direction most affect to tracking analysis

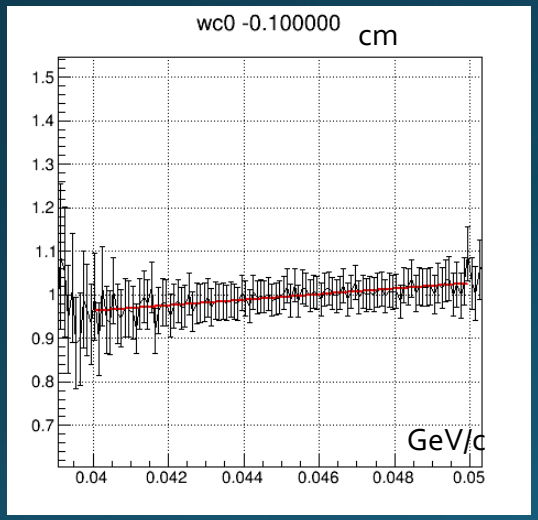


When $\delta x = 0.1\ mm$
the errors of each MWPC are
WC0: 0.35 mm
WC1: 0.22 mm
WC2: 0.19 mm
WC3: 0.31 mm

Systematic error by MWPC misplacement

- the position of any one MWPC moved along X-axis in tracking analysis of MC generated data
- compare the momentum with the original one in order to confirm systematic error

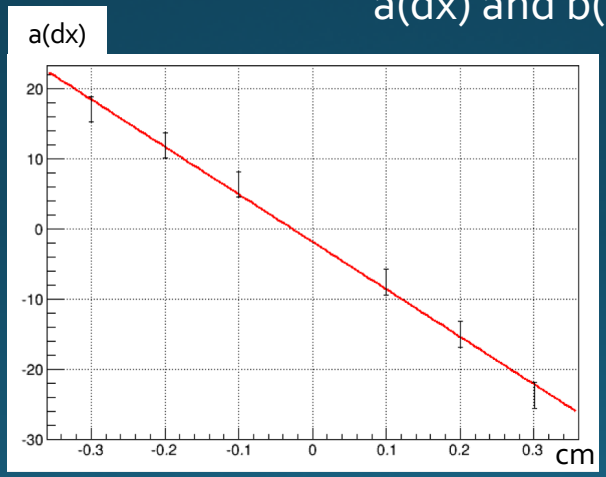
$$\frac{\text{(Momentum spectrum with moved MWPC)}}{\text{(Momentum spectrum with original position)}}$$

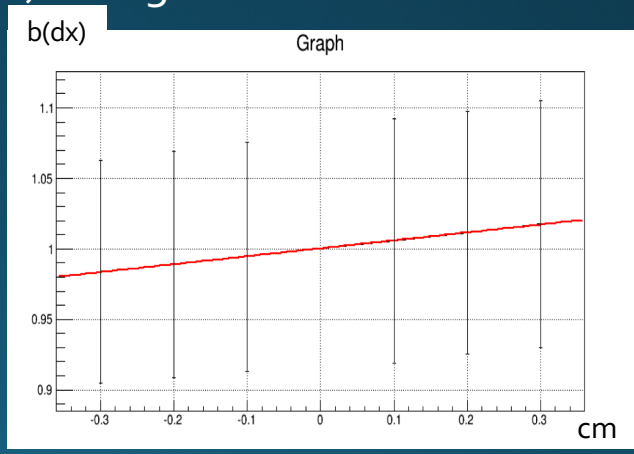


fitting with liner function in 40~50MeV/c region

$f(p) = a(p - 0.045) + b$

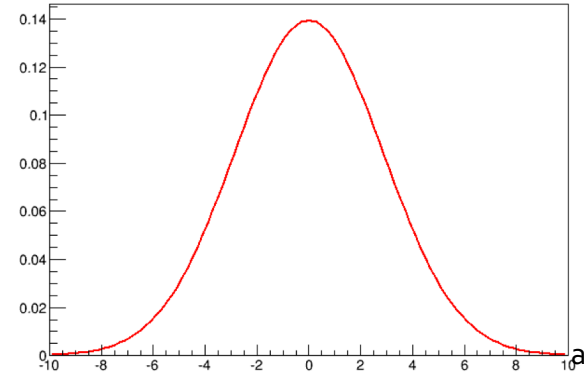
a(dx) and b(dx) fitting with liner function



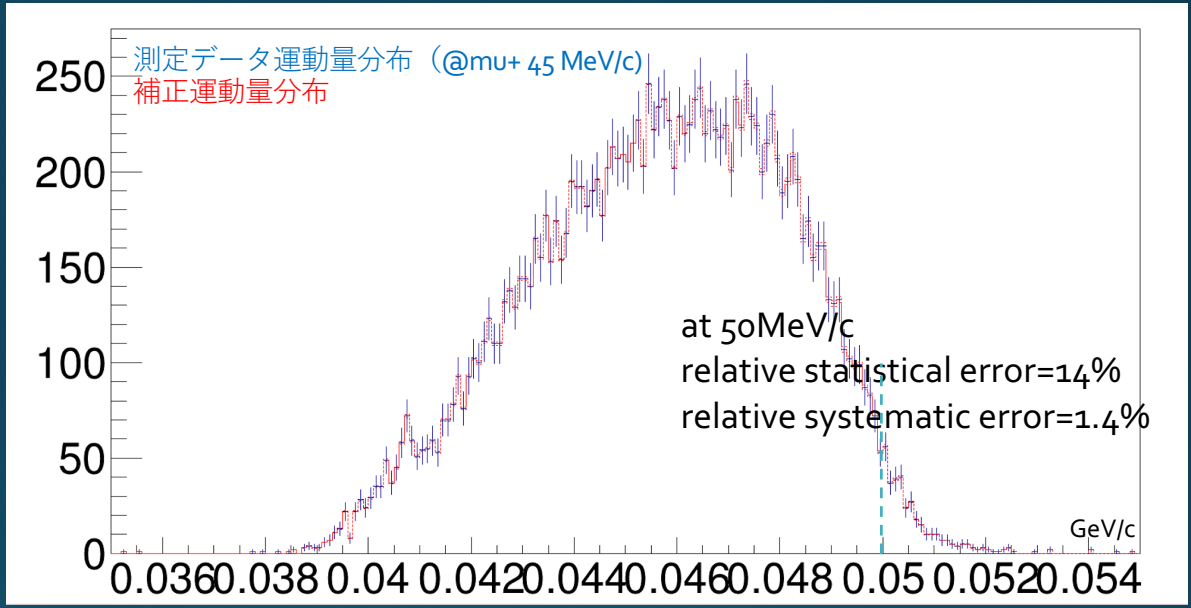


Iteration for MWPC 1-4

Systematic error by MWPC misplacement

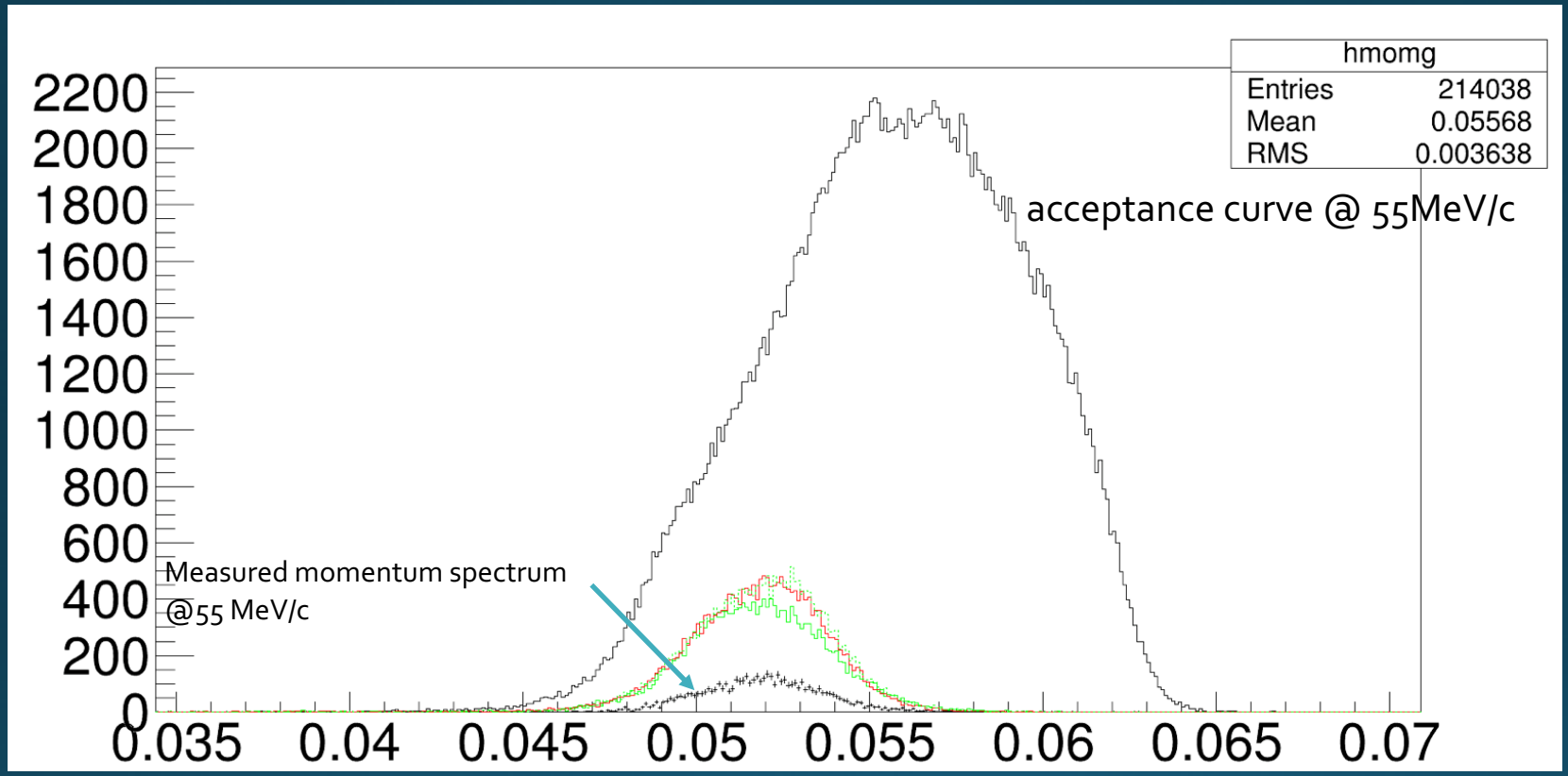


Calculate pdf of a in possible dx region



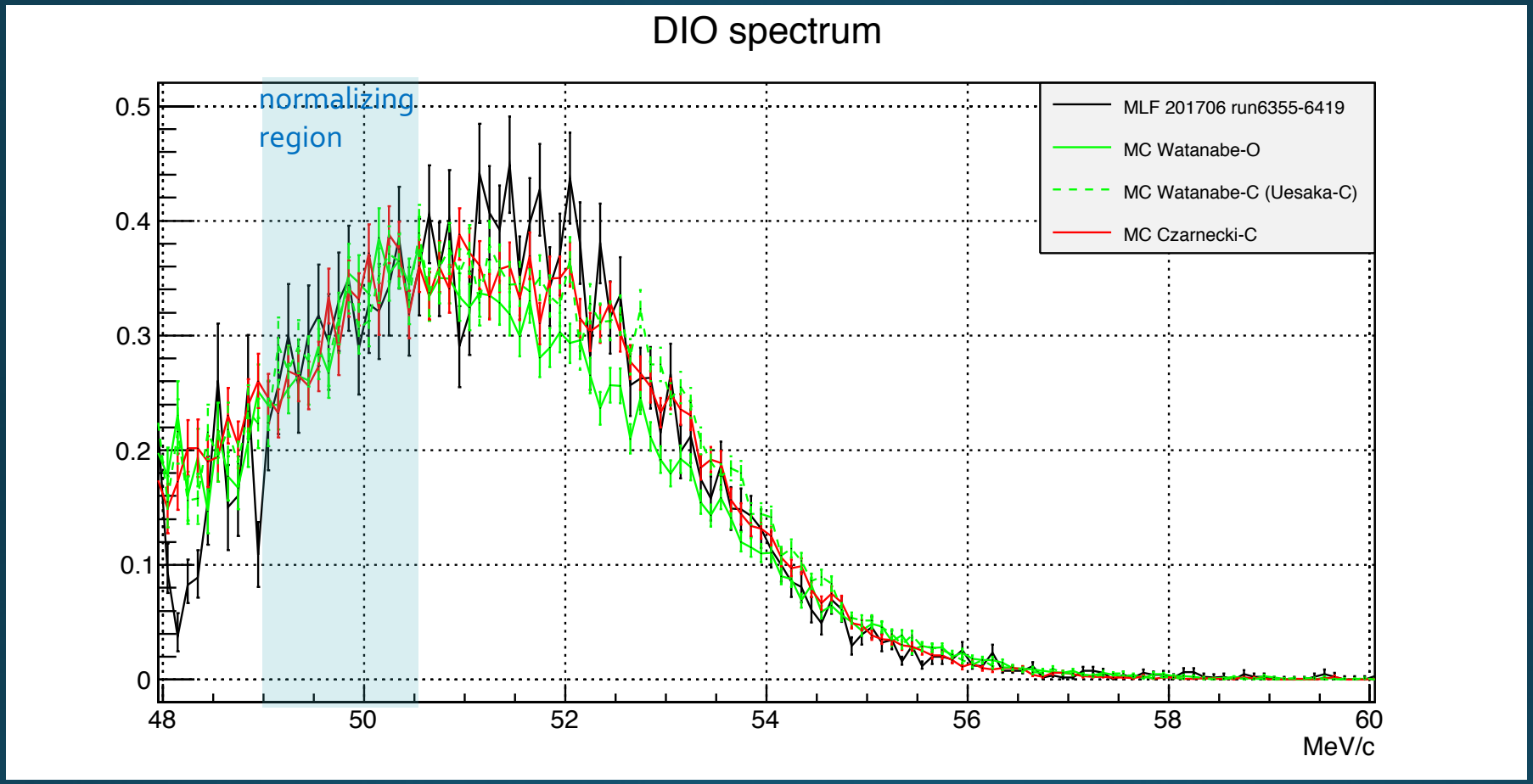
Calculate momentum distribution of
-> the systematic error is smaller than statistical error

DIO Momentum spectrum

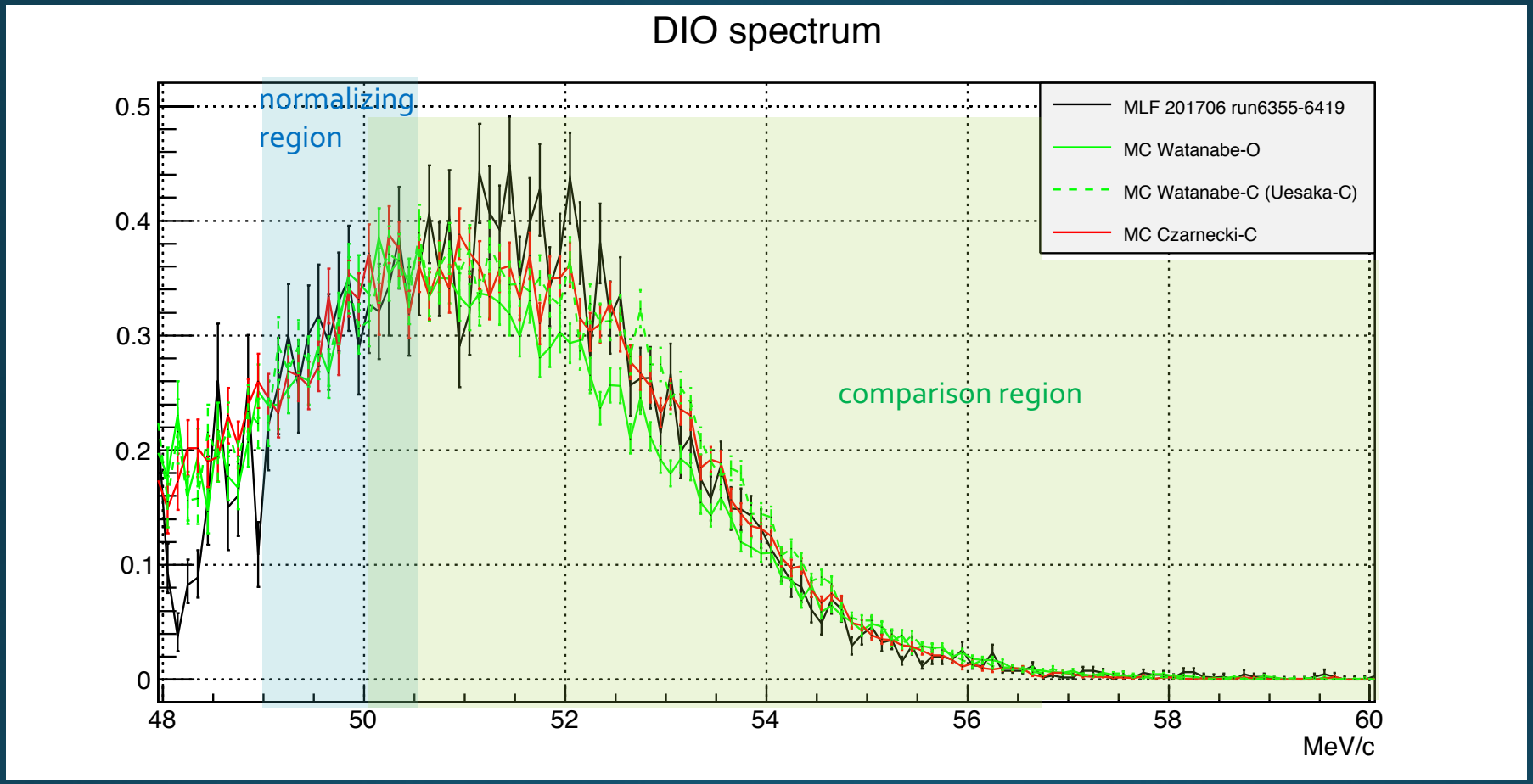


DIO momentum spectrum can be calculated as
(Measured DIO momentum spectrum) / (acceptance curve)

Acceptance curve is generated by MC simulation with flat momentum gun file



- Each spectrum normalized in the normalizing region
- The measured spectrum and each MC spectrum are compared in the comparison region



- Each spectrum normalized in the normalizing region
- The measured spectrum and each MC spectrum are compared in the comparison region

fit measured spectrum with each MC spectrum
Watanabe-O : prob. = 21.5%
Czarnecki-C : prob. = 92.9%
Watanabe-C : prob. = 43.7%

Summary

- DeeMe is aiming to start soon with the single event sensitivity of 1×10^{-13} for C
  - The single event sensitivity of 5×10^{-15} for SiC 4-years
- 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)
  - Comprehensive study of systematic errors are ongoing.