

# An Experimental Search for Muon-Electron Conversion in Nuclear Field with Muonic Atoms Produced in a Primary Proton Target — DeeMe —



M. Aoki on behalf of DeeMe Collaboration, Osaka University

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# DeeMe Collaboration

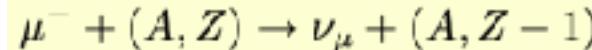
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(4) KEK Accelerator, (5) KEK MUSE, (6) JAEA, (7) KEK IPNS, (8) TRIUMF,  
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(13) UC Davis, (14) IHEP

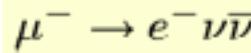
# $\mu$ -e Conversion in Nuclear Field

- Muonic Atom (1S state)

Muon Capture(MC)



Muon Decay in Orbit (DIO)

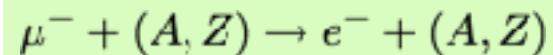


– MC:DIO = 1:1000(H), 2:1(Si), 13:1(Cu)

–  $\tau(\text{free } \mu^-) = 2.2 \mu\text{s}$

–  $\tau(\mu^-;\text{Si}) = 0.76 \mu\text{s}, \tau(\mu^-;\text{C}) = 2.0 \mu\text{s}$

- Charged Lepton Flavor Violation (CLFV)



$\mu$ -e Conversion in Nuclear Field

**Forbidden in the Standard Model of Particle Physics**

Clear evidence of the new physics

# Photonic and non-Photonic Processes

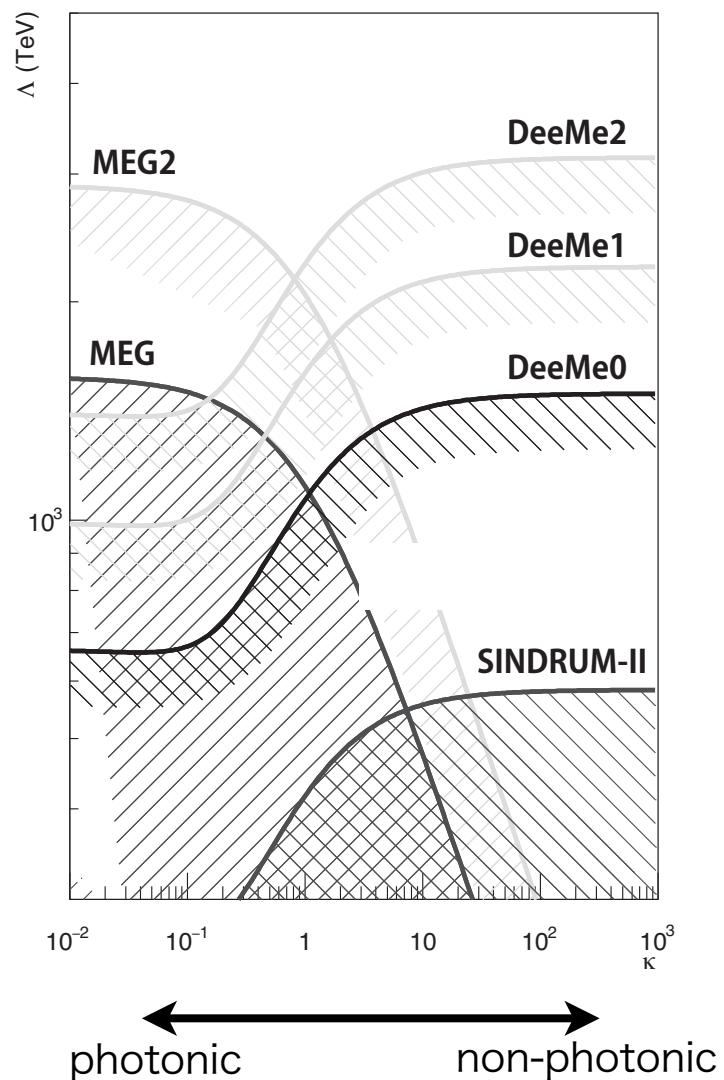
$$\mathcal{L} = \frac{m_\mu}{(\kappa + 1)\Lambda^2} \bar{e} \sigma^{\mu\nu} F_{\mu\nu} \mu + \frac{\kappa}{(1 + \kappa)\Lambda_F^2} \bar{e} \mu (\bar{q} q + \bar{e} e)$$

The diagram shows two Feynman diagrams side-by-side. The left diagram, labeled 'photonic', depicts a muon ( $\mu$ ) interacting with a photon ( $\gamma$ ) to produce an electron ( $e$ ) and a neutrino ( $\bar{\nu}_e$ ). The right diagram, labeled 'non-photonic', shows a muon ( $\mu$ ) interacting with a quark ( $q$ ) to produce an electron ( $e$ ) and a quark ( $\bar{q}$ ).

photonic

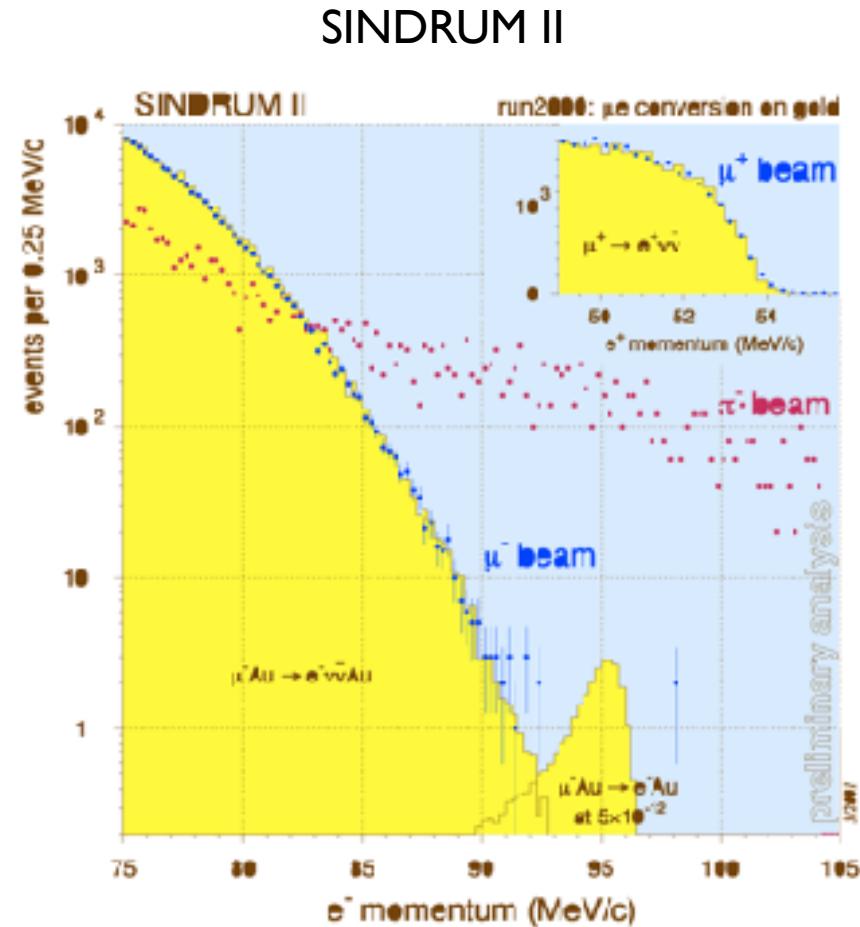
non-photonic

- SUSY-GUT, SUSY-seesaw
- higgs mediated processes
- Doubly Charged Higgs Boson (LRS etc.)
- Little Higgs Models
- Randall-Sundrum Models
- SUSY with R-parity Violation
- Leptquarks
- Heavy Z'
- Multi-Higgs Models



# Principle of Measurement

- Process :  $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
- A single mono-energetic electron
  - 105 MeV
  - Delayed :  $\sim 1\mu\text{s}$
- No accidental backgrounds
- Physics backgrounds
- Muon Decay in Orbit (DIO)
  - $E_e > 102.5 \text{ MeV} (\text{BR}: 10^{-14})$
  - $E_e > 103.5 \text{ MeV} (\text{BR}: 10^{-16})$
- Beam Pion Capture
  - $\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$   
 $\gamma \rightarrow e^+ e^-$
  - Prompt timing
- High-intensity muon beam for high statistics.



Recent Upper Limits

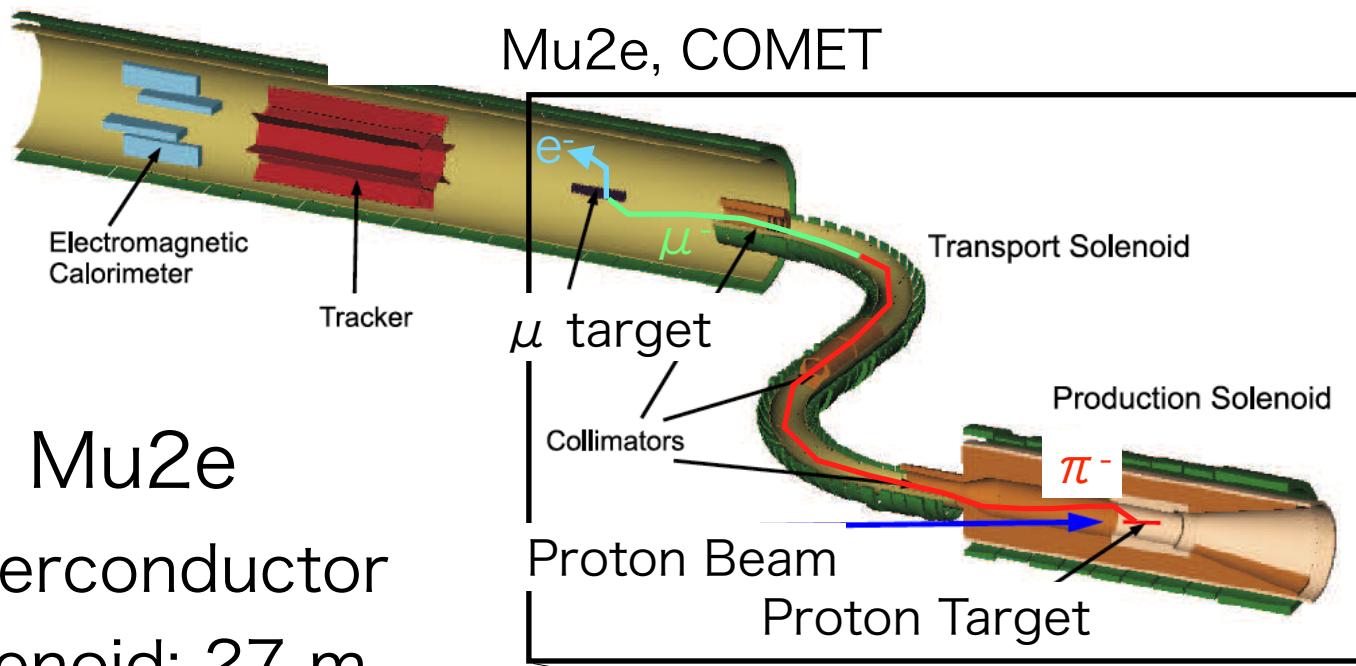
SINDRUM-II:  $\text{BR}[\mu^- + \text{Au} \rightarrow e^- + \text{Au}] < 7 \times 10^{-13}$

SINDRUM-II:  $\text{BR}[\mu^- + \text{Ti} \rightarrow e^- + \text{Ti}] < 4.3 \times 10^{-12}$

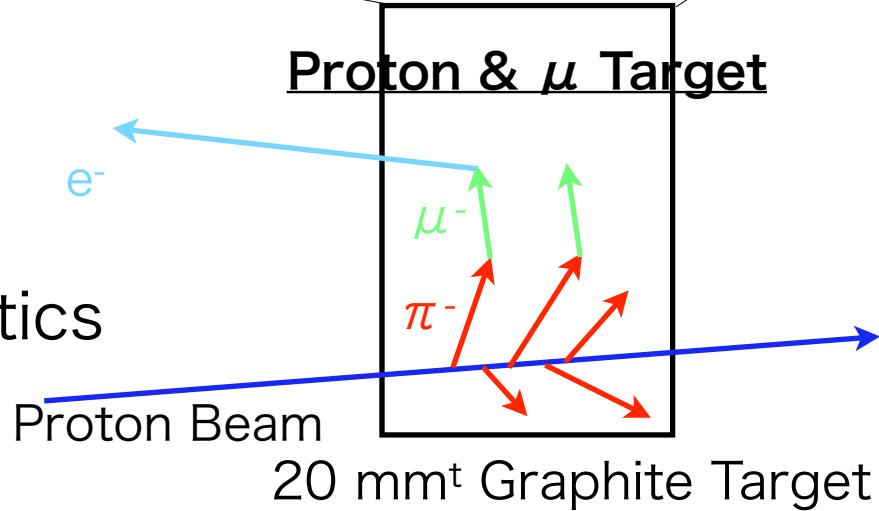
TRIUMF:  $\text{BR}[\mu^- + \text{Ti} \rightarrow e^- + \text{Ti}] < 4.6 \times 10^{-12}$

# Uniqueness of DeeMe

Mu2e  
Superconductor  
Solenoid: 27 m

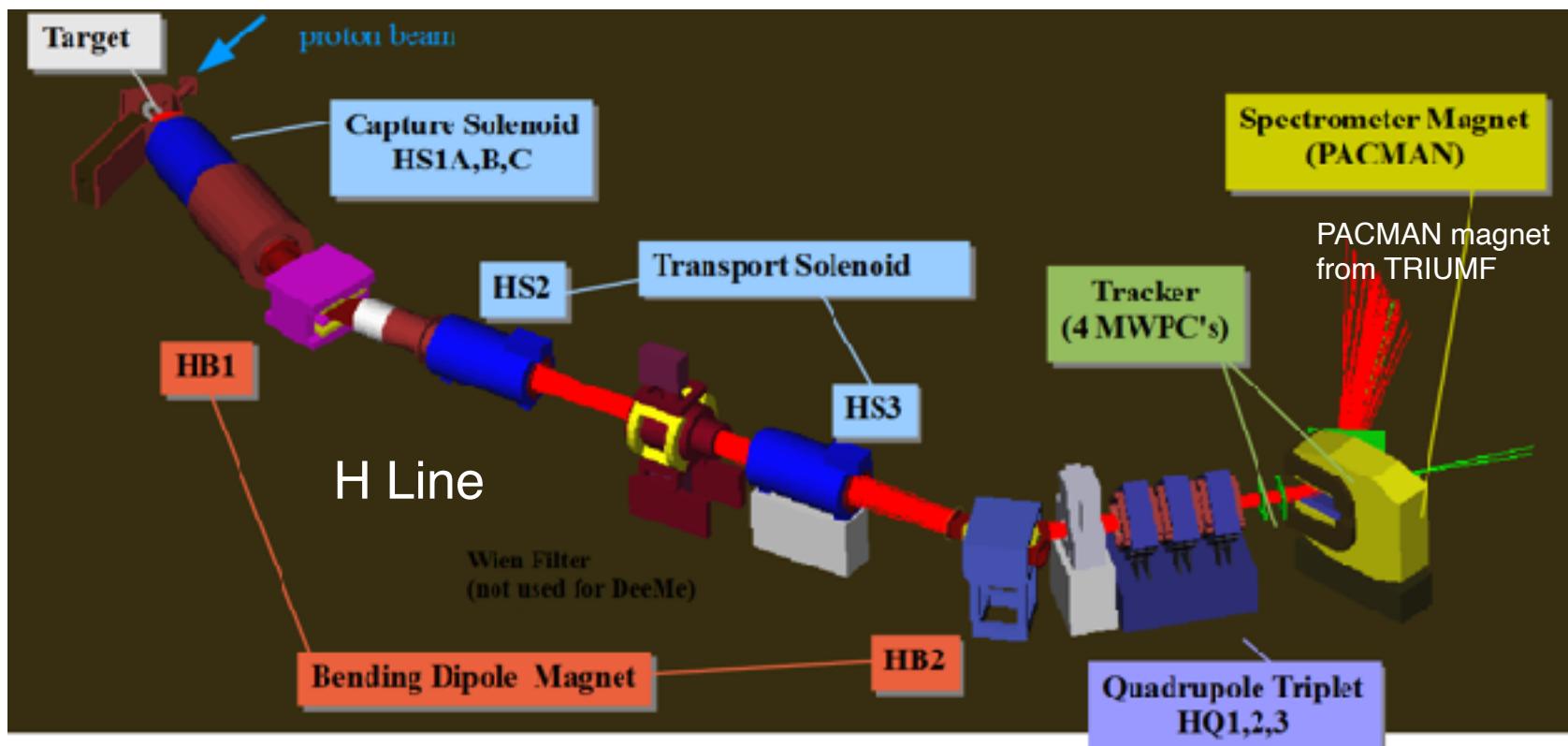
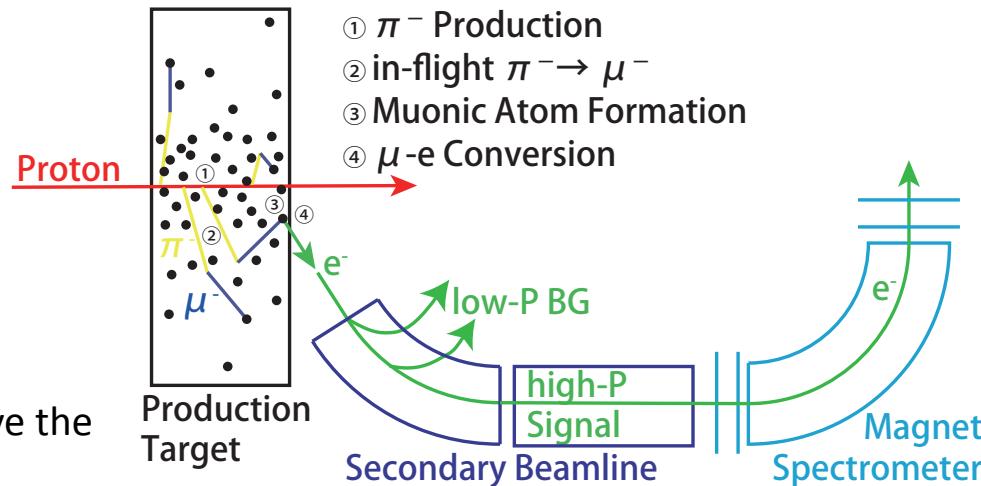


DeeMe  
Simple  
Totally different systematics



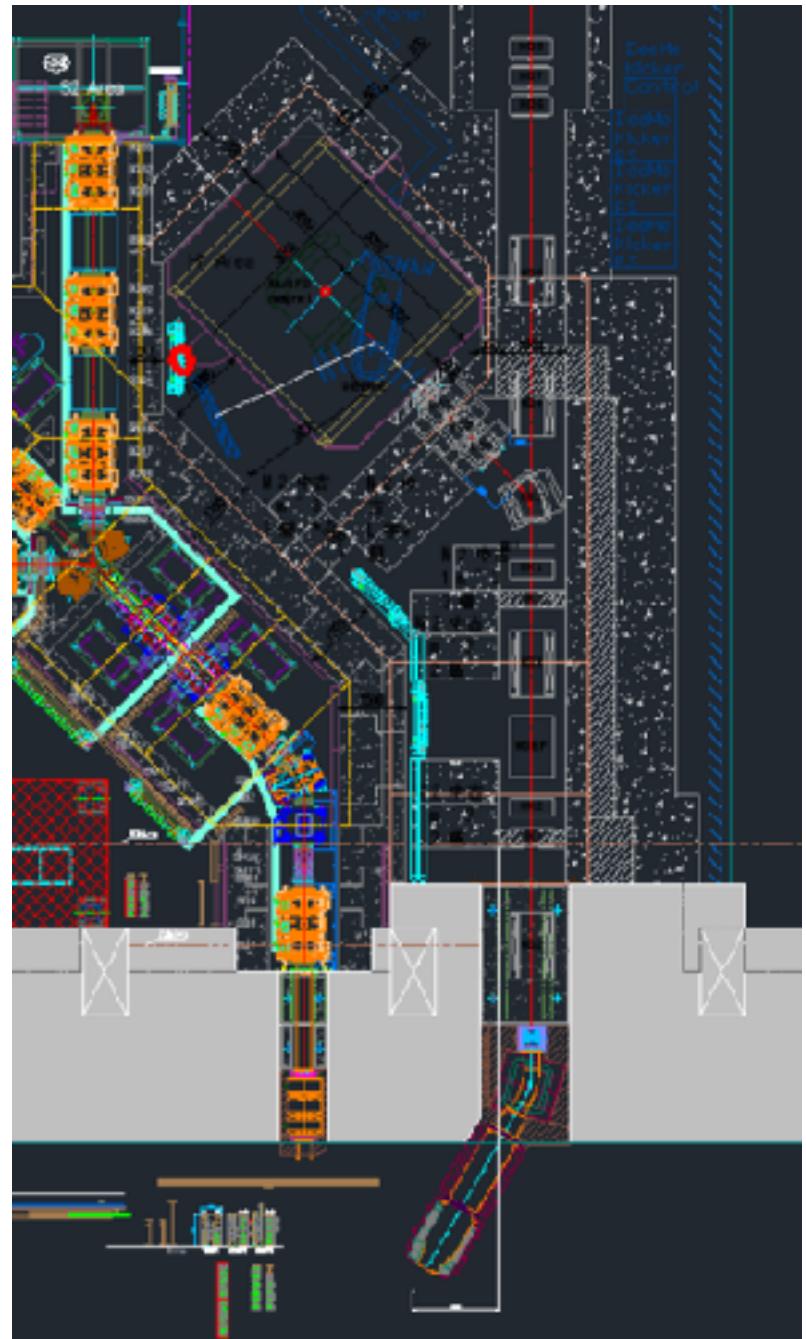
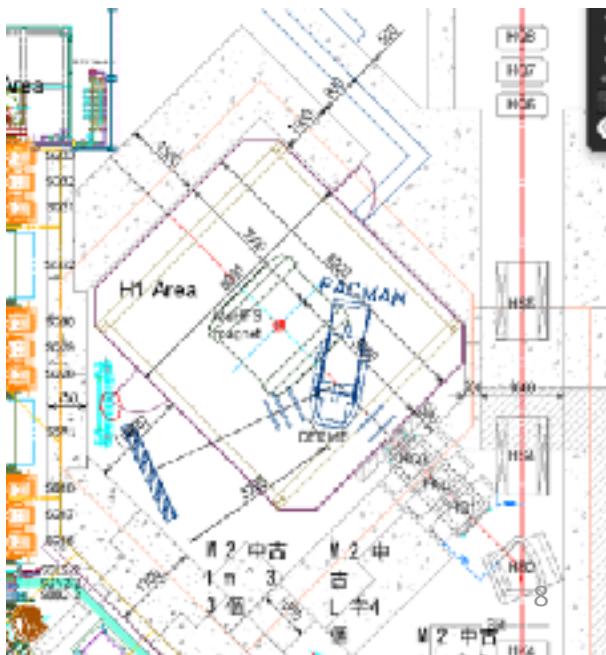
# DeeMe Project

- KEK/IMSS J-PARC S1A type Project
  - SES:  **$1 \times 10^{-13}$  (Graphite,  $2 \times 10^7$  sec)**
    - $2 \times 10^{-14}$  (SiC)、 $5 \times 10^{-15}$  ( $8 \times 10^7$  sec)
- Proposed to KEK/IMSS in 2010
- Stage-2 Approved w/Graphite
- Grant-in-Aid for detector construction
  - completed**
- Large-acceptance H-Line is essential** to achieve the physics goal: @ D-Line, it will be x10 worse.



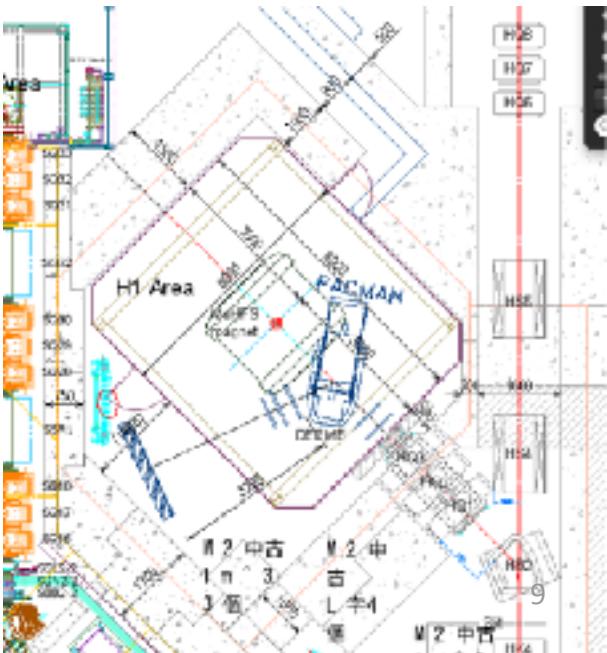
# H Line

- Acceptance of D Line
    - 10 msr for  $\mu$ -e conversion  $e^-$
  - H Line
    - Large acceptance: **110 msr**
    - General Purpose beam line
  - H1 Area
    - Can time-share with other group
    - Under construction.
    - Aiming the 1st beam in JFY2020.

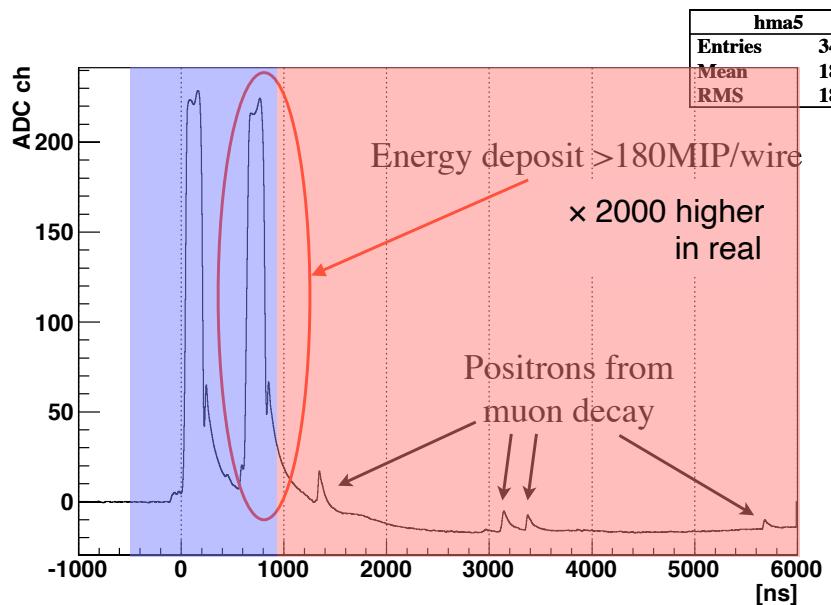


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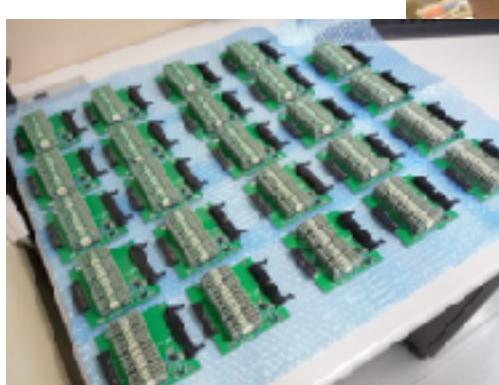
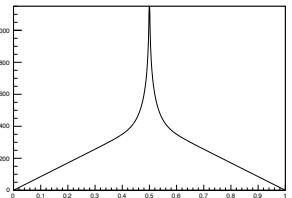
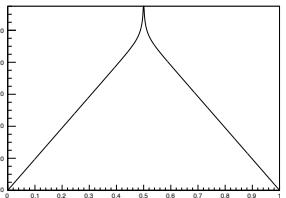
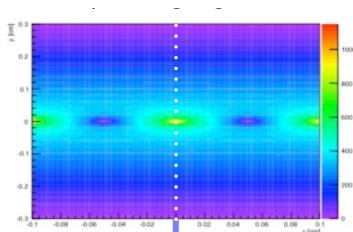
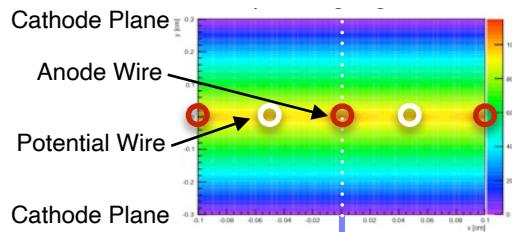


# Detector: HV-switching MWPC



Anode wire: HV  
Potential wire: HV

Anode wire: HV  
Potential wire: 0 V



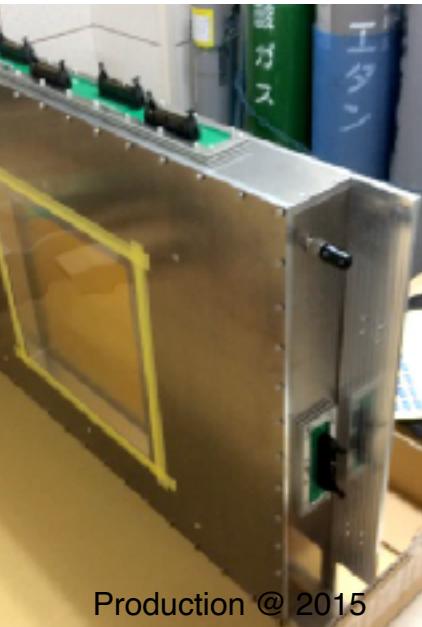
Preamps @ 2015



FADC



Magnet borrowed from TRIUMF

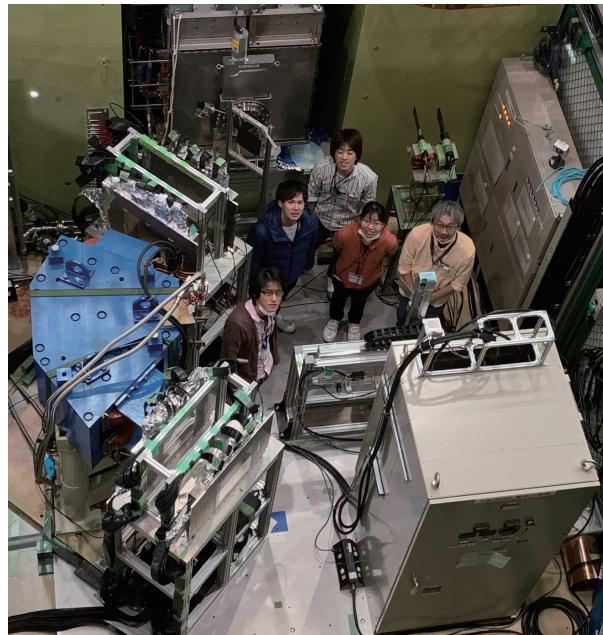
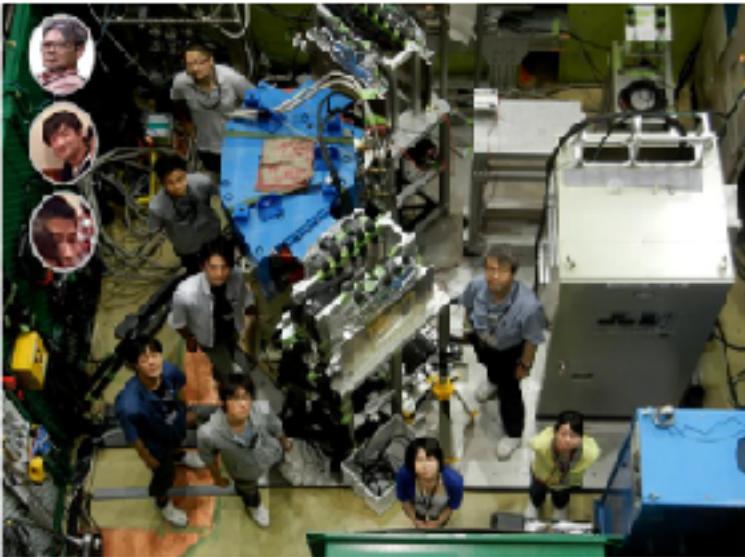


Production @ 2015

- Spectrometer R&D has completed.
  - Prog. Theo. Exp. Phys. 2017, 023C01 (2017)
  - IEEE Trans. Nucl. Sci. 65, 2650 (2017)

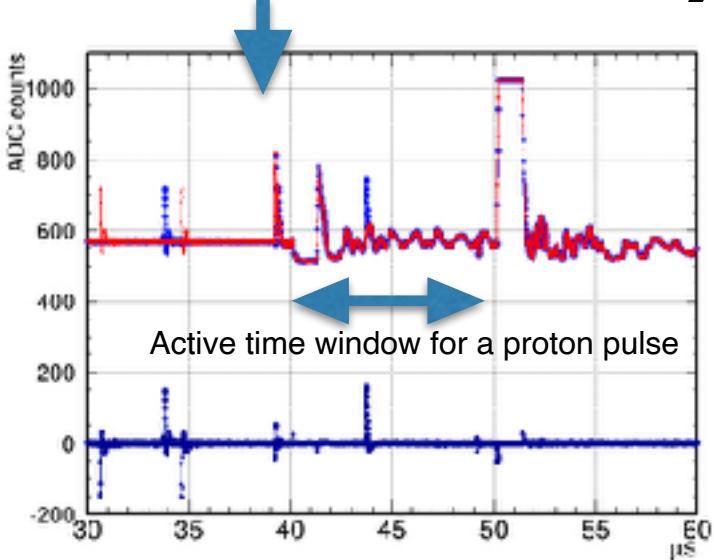
# Integration Test & DIO Measurement

- Integration test of the system:  
MWPC×4 + Amp. + FADC + DAQ
    - Used yet-another smaller magnet.
  - Measurement of DIO spectrum in mid. mom.
    - target: C, Si and SiC
  - 2017/3 — 2 days: 2016B0277
  - 2017/6 — 5 days: 2017A0267
- 
- **The whole system worked very well**
    - no MWPC breakdown at all.
    - DAQ efficiency ~ 100%
  - **High-Statistics run: 6 days in 2019/3.**
    - better MWPC performance
    - **Successfully accumulated more events.**

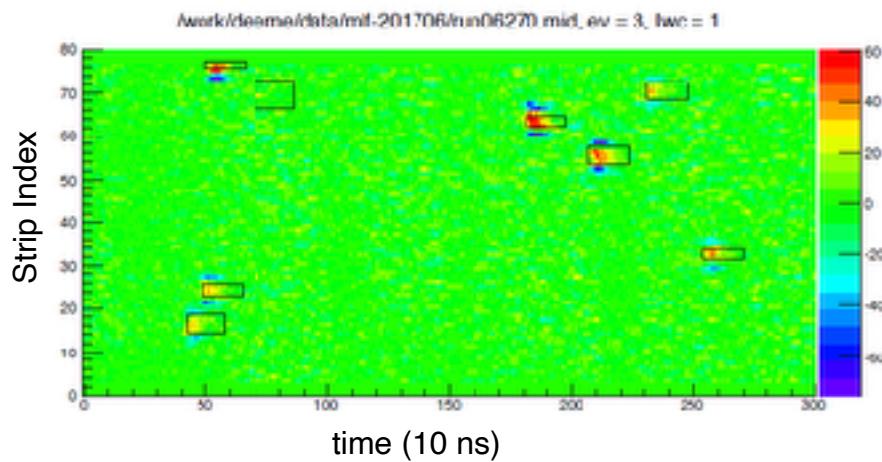


# Analysis

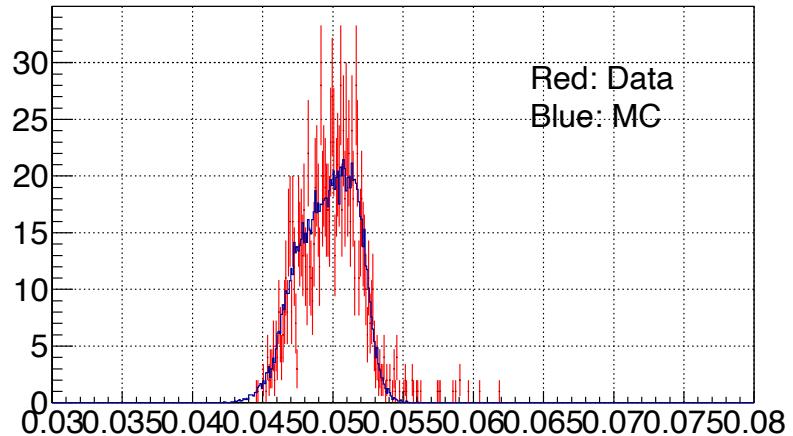
A pulse proton hits a target



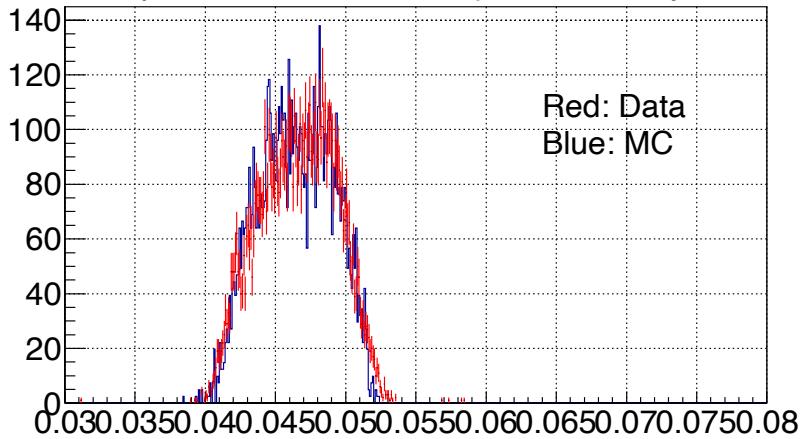
- non-flat baseline of waveforms due to the HV-switching
- baseline waveforms are very STABLE: can be subtracted.
- Further common-noise reduction with adjacent strips
- Good hit-finding performance



Momentum Calibration with  $\mu^+$  Michel Edge



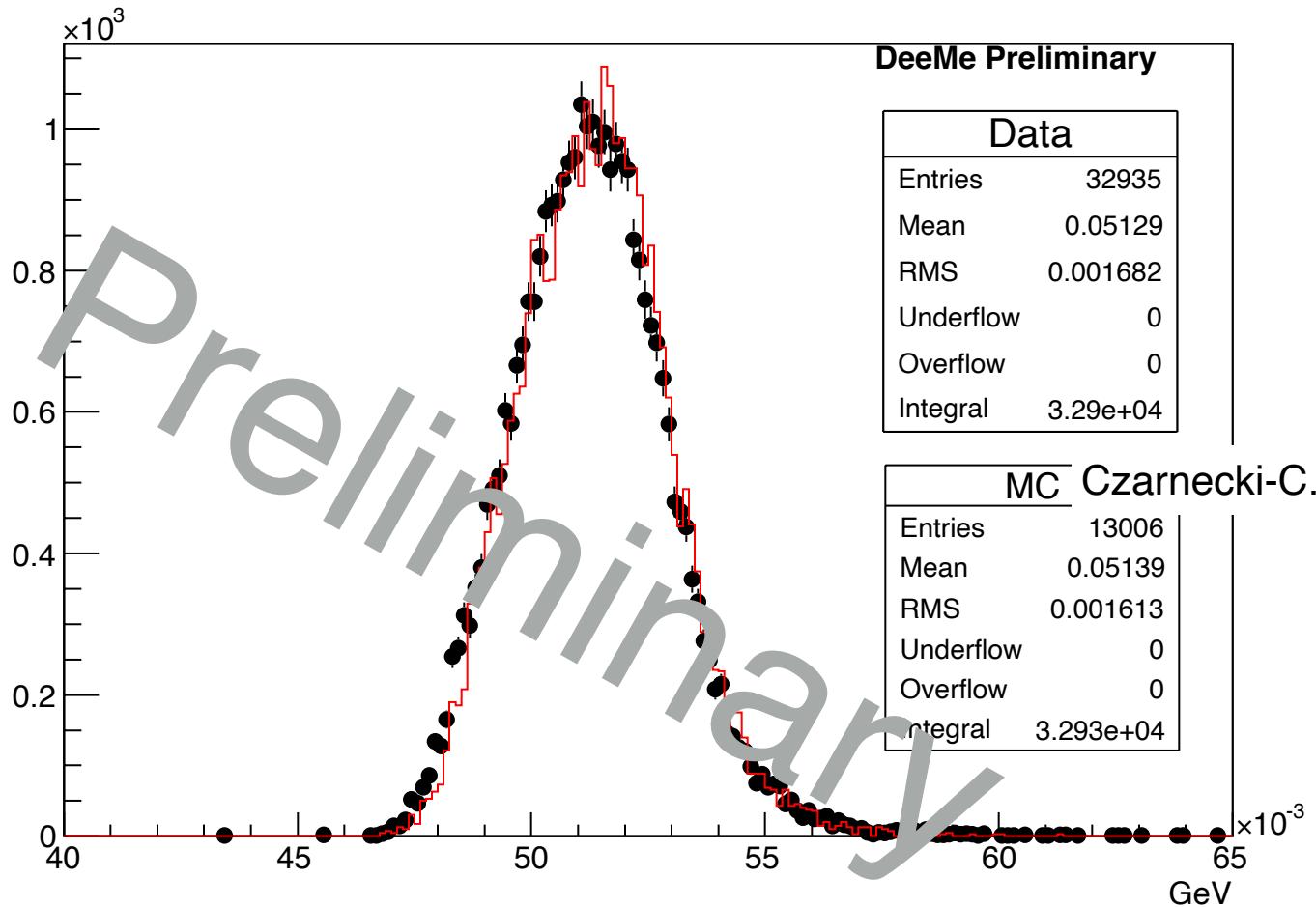
Acceptance Calibration with  $\mu^+$  Michel Body



Clear observation of the Michel Edge.  
Acceptance Curve of MC matches to Data.  

- Magnet: OK
- Hit-finding and Track-fitting: OK

# $C(\mu^-)$ DIO Spectrum (2019 data)



# Summary

- There is a competitive merit of physics in searching for  $\mu$ -e conversion at sensitivity better than the current upper limits in timely manner.
- It is important to maximize the potential of major discovery at J-PARC.
- DeeMe, yet another mu-e conversion search with totally different method from COMET and Mu2e, creates harmonious diversity for J-PARC.
- DeeMe has already acquired Stage-2 Approval from muon-PAC of KEK/IMSS.
- Construction of detector system has completed with Grant-in-Aid for Scientific Research of Japan (Basic Science S, 2012–2016).
- It is necessary to build a large-acceptance beamline (H-line). The H-line can be used for other experiments, such as g-2/EDM, muonium HFS measurement and so on.
- We are hoping to start soon after the completion of the beamline construction. No beam-time conflicts with T2K, KOTO, COMET or whatever the physics programs with the main ring of J-PARC.



# End of Slides