DeeMe experiment
An experimental search for a mu-e conversion reaction at J-PARC MLF

Hiroaki Natori, KEK
on behalf of the DeeMe collaboration

1st Conference on Charged Lepton Flavor Violation, 7th May 2013 @ Lecce

DeeMe Collaboration

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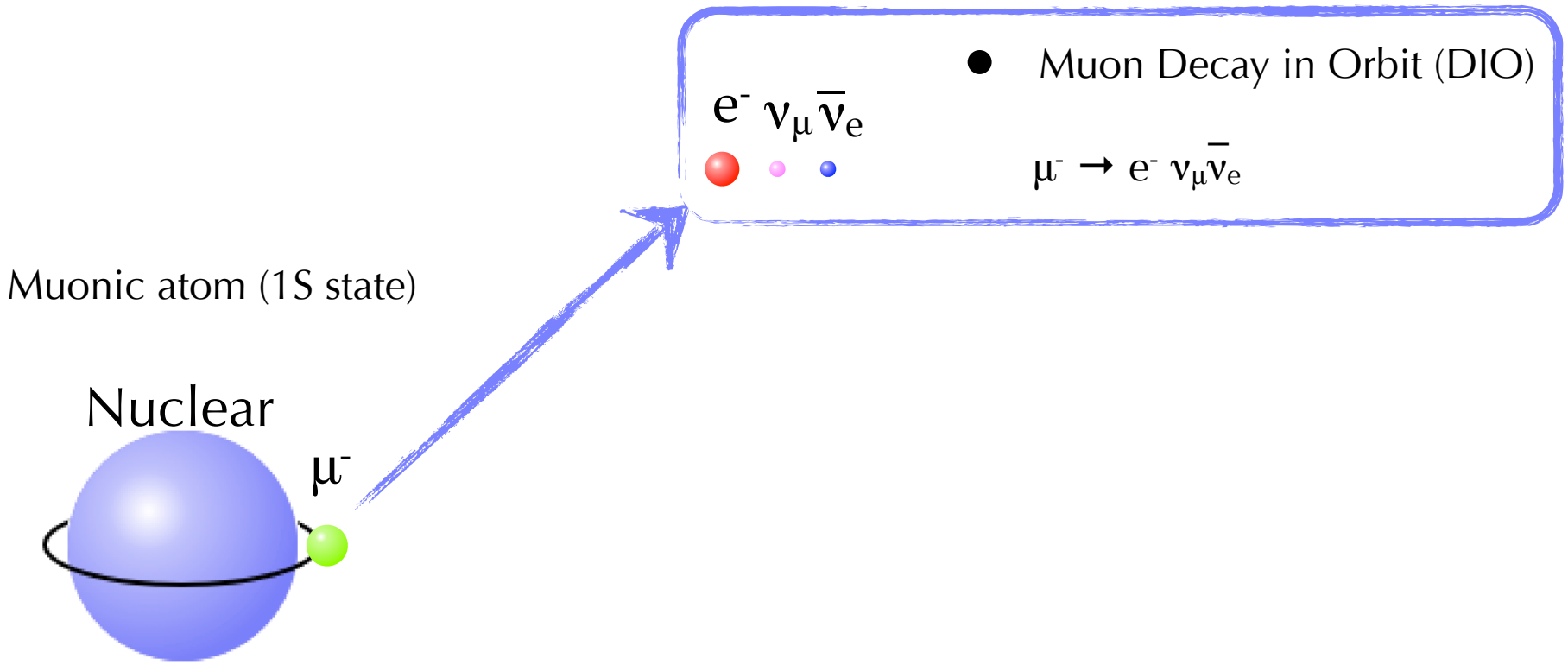
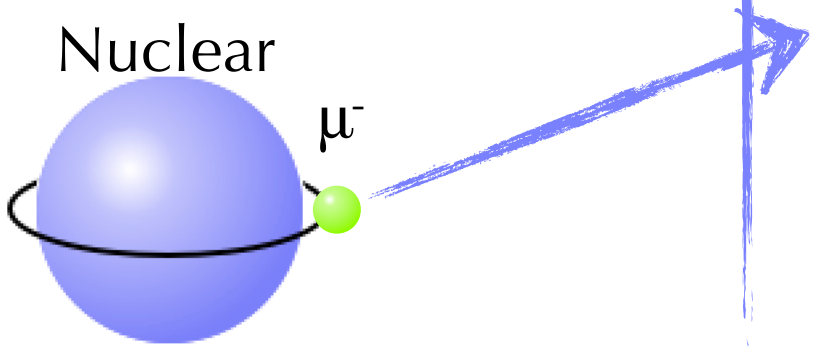
25 min. + 10 min.

Physical processes of Muonic atom



Physical processes of Muonic atom

Muonic atom (1S state)



$e^- \nu_\mu \bar{\nu}_e$

- Muon Decay in Orbit (DIO)

$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$

ν_μ

- Muon Capture (MC)

$\mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z - 1)$

※ Si case (depends on nucleus)

- DIO:MC = 2:1
- τ = 0.76 μs

Physical processes of Muonic atom

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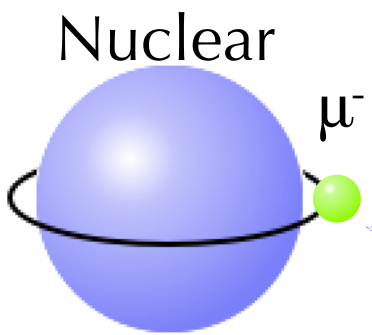

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e^-

- μ-e conversion

$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$

Forbidden in the Standard Model
Clear evidence of new physics

Branching ratio definition :

$$Br(\mu\text{–e conv.}) = \frac{\Gamma(\mu\text{–e conv.})}{\Gamma(\text{MC})}$$

Recent upper limits

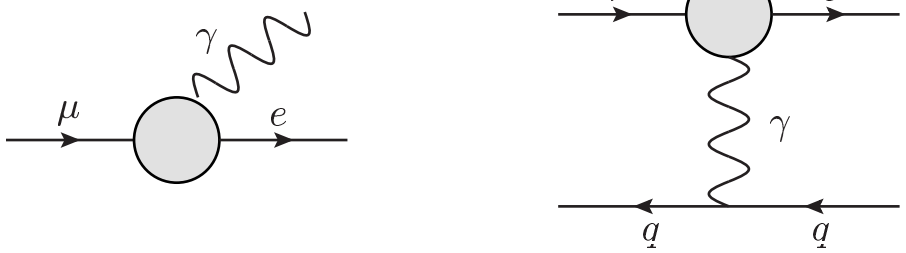
SINDRUM-II: Br(μ-e conv. w/ Au) < 7×10^{-13}

Br(μ-e conv. w/ Ti) < 4.3×10^{-12}

TRIUMF: Br(μ-e conv. w/ Ti) < 4.6×10^{-12}

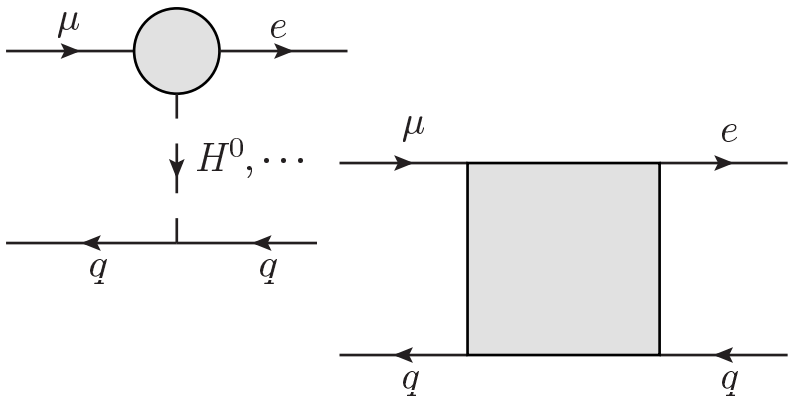
μ→eγ vs μ-e conversion

Photonic

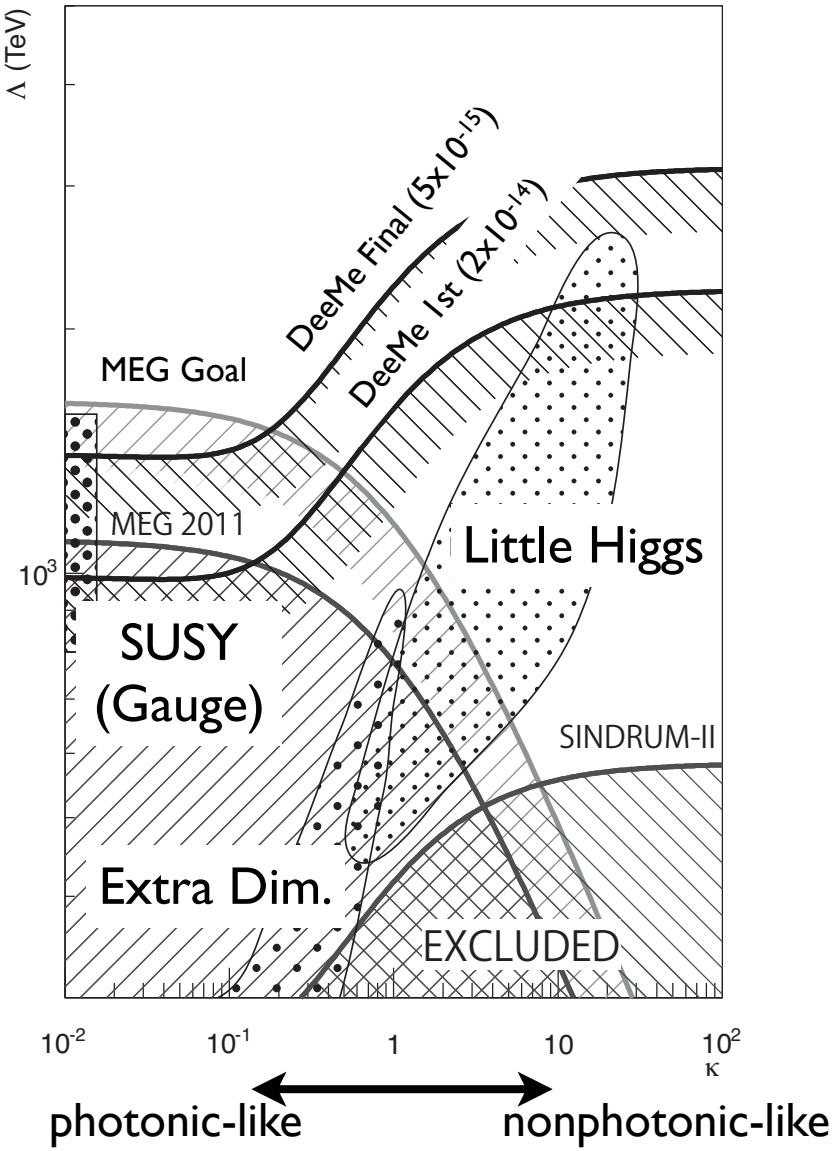


Br(μ-e conv.) ~ Br(μ→eγ) / 100 etc.

Non-photonic



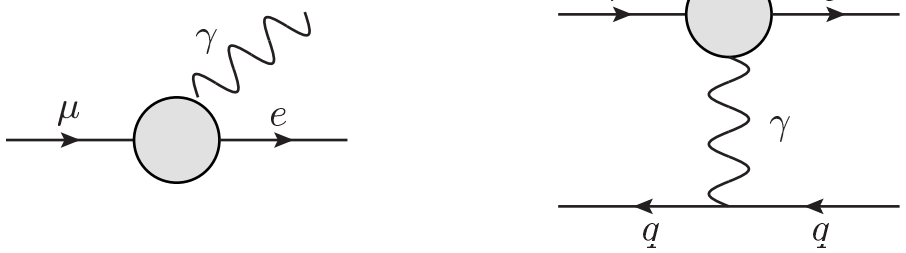
etc.



original plot by Andre de Gouvea

μ→eγ vs μ-e conversion

Photonic



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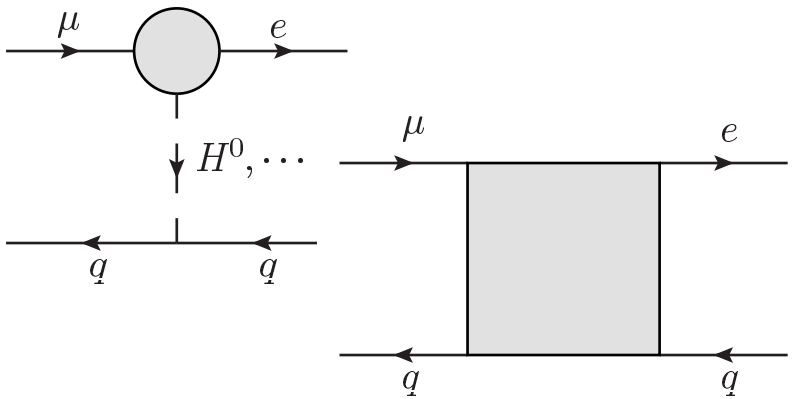
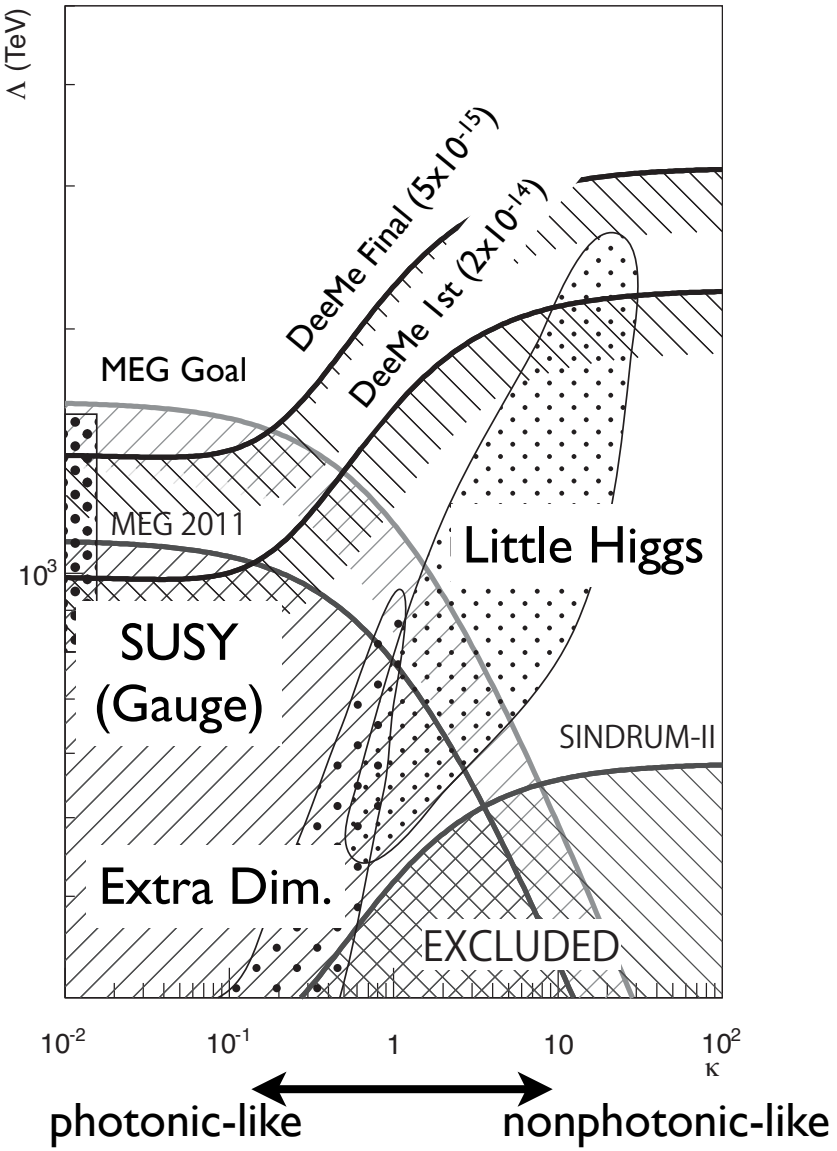


etc.



original plot by Andre de Gouvea

DeeMe experiment

Signal and Background

Signal

- Monochromatic 105MeV electron
- Delayed ~ 1us

- DIO

Same time structure as signal
Momentum < signal

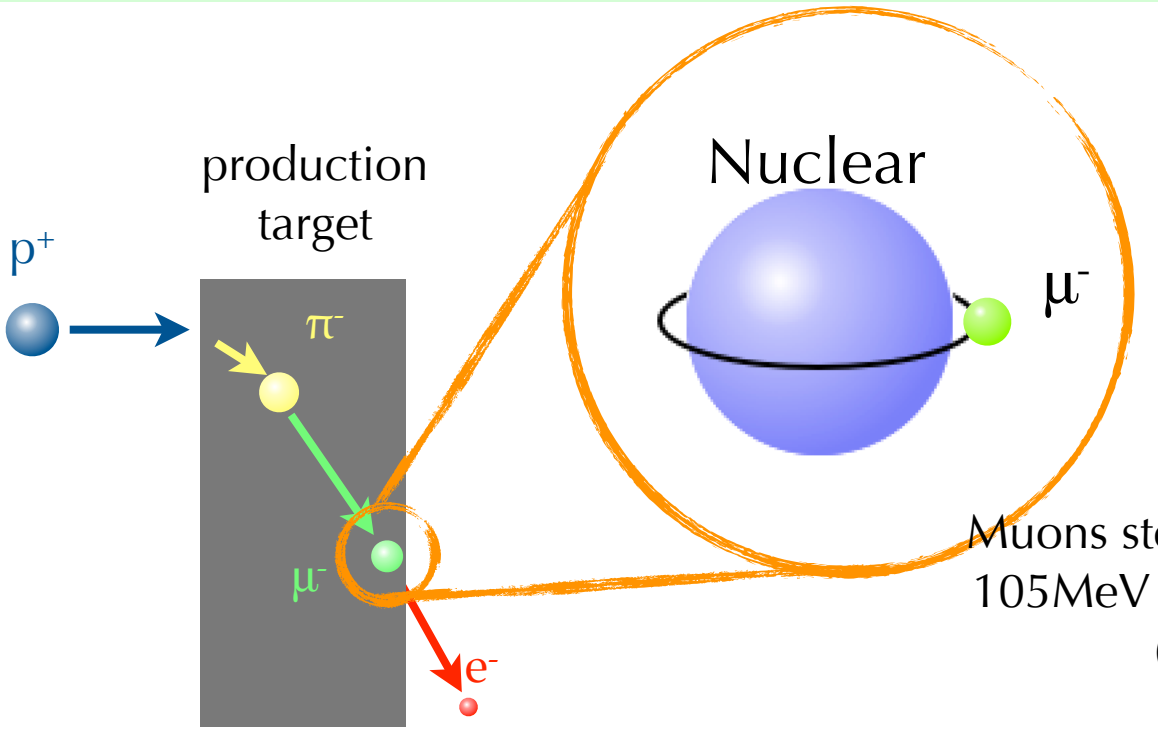
- Cosmic rays

Flat time distribution
Momentum can be ≥ signal

- Beam pion capture
  - $\pi^- + (A, Z) \rightarrow (A, Z\text{-}1)^* \rightarrow \gamma + (A, Z\text{-}1)$, $\gamma \rightarrow e^+ e^-$
- Radiative muon capture
  - $\mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z\text{-}1) + \gamma$, $\gamma \rightarrow e^+ e^-$
- Muon Decay in flight
  - $\mu \rightarrow e\nu\nu$

Coincident with beam
Momentum can be ≥ signal

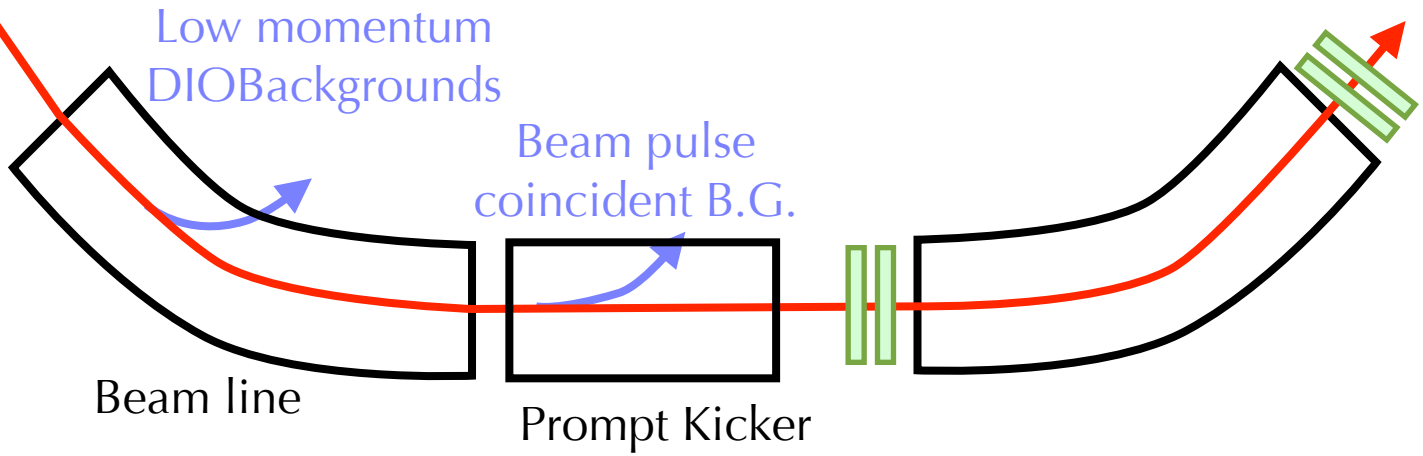
DeeMe concept



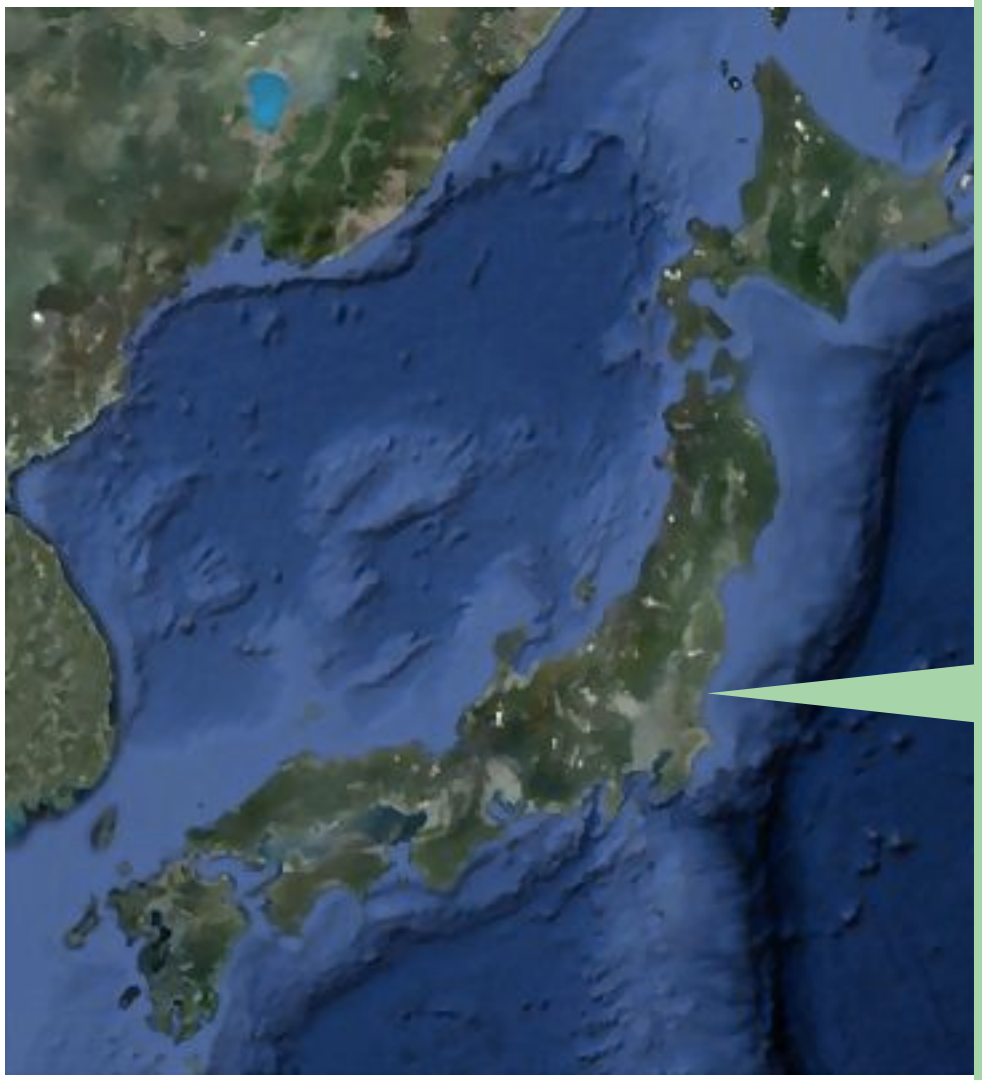
Muons stopped near the surface may emit
105MeV signal mu-e conversion electron
(Surface muon analogy)

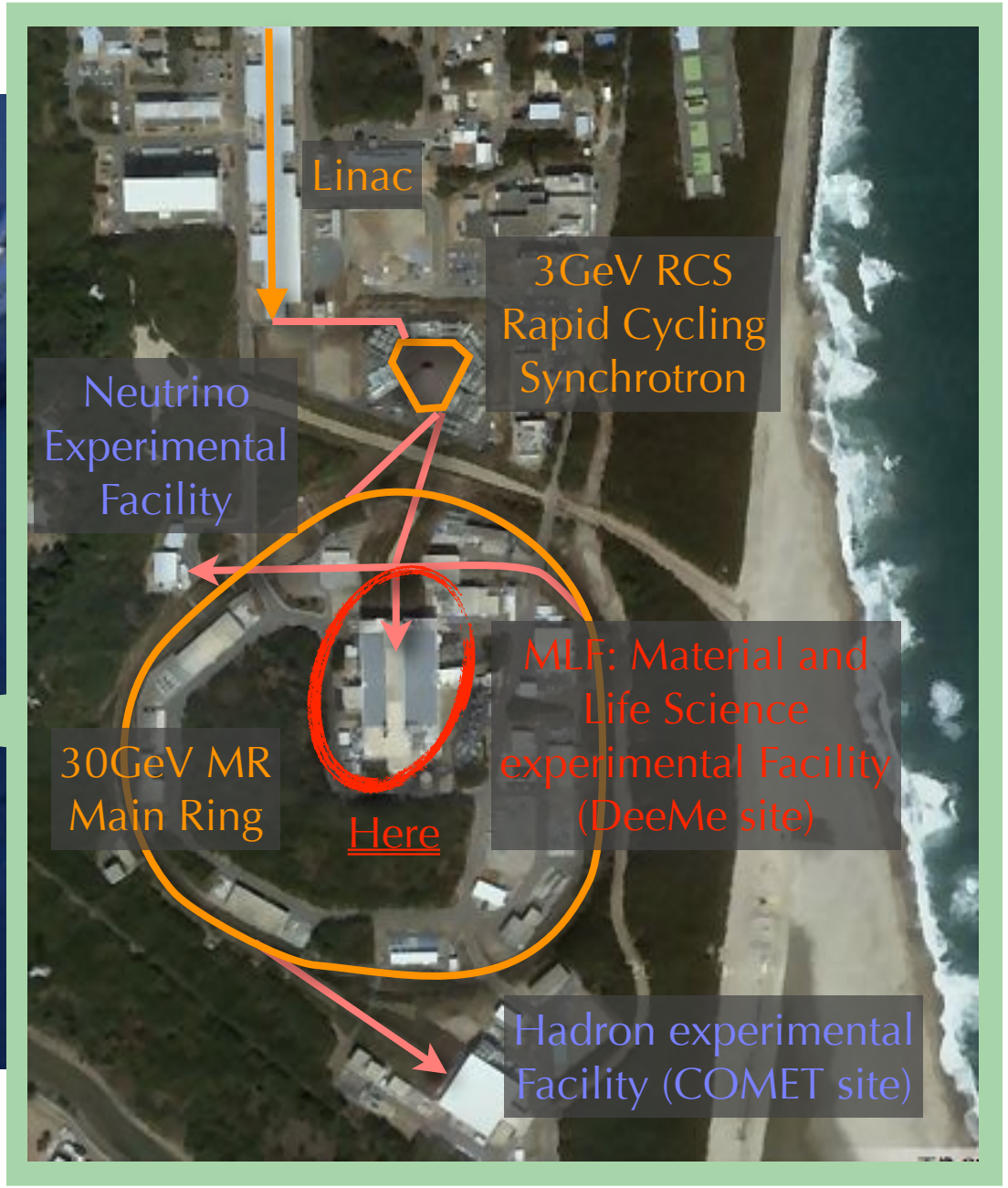
- Pion production
- Pion decay into muon
- Muonic atom formation

Inside production target

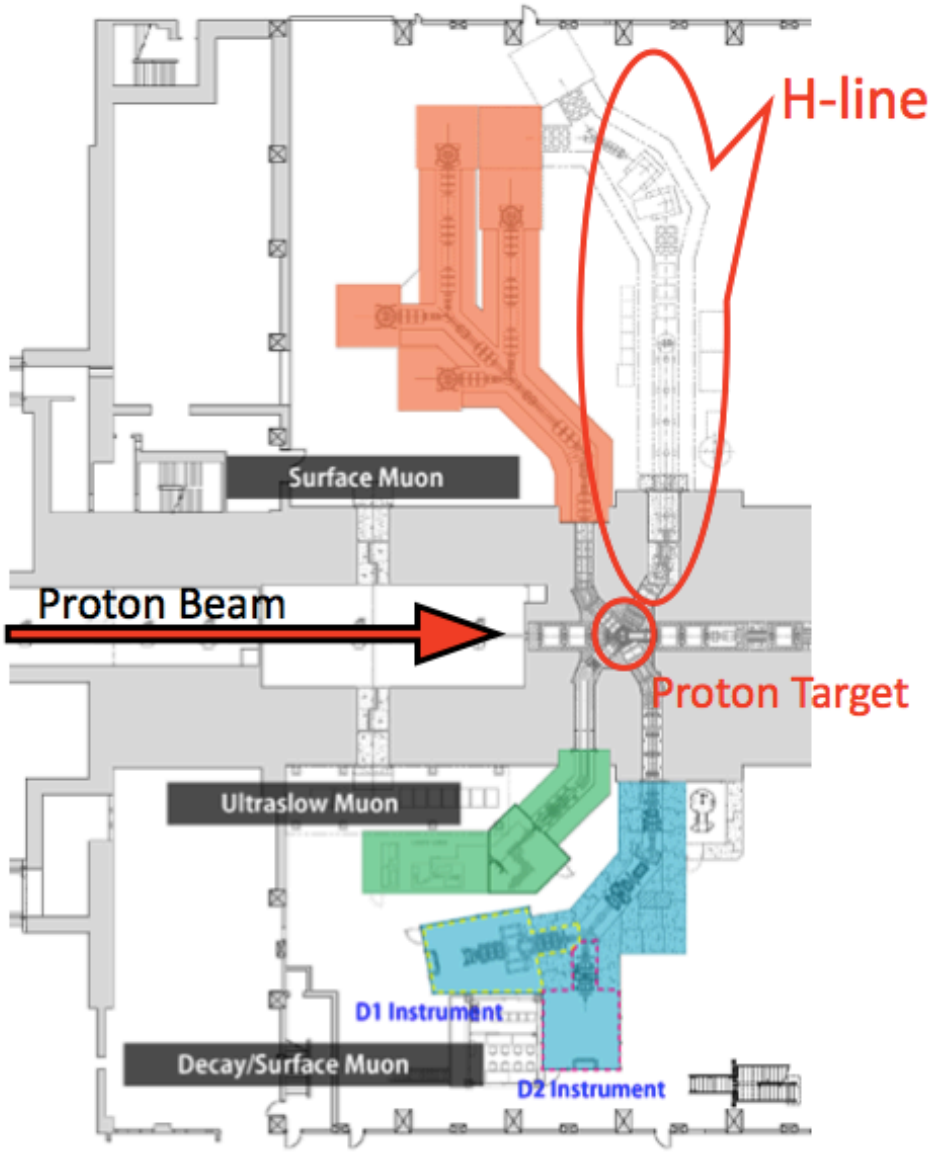


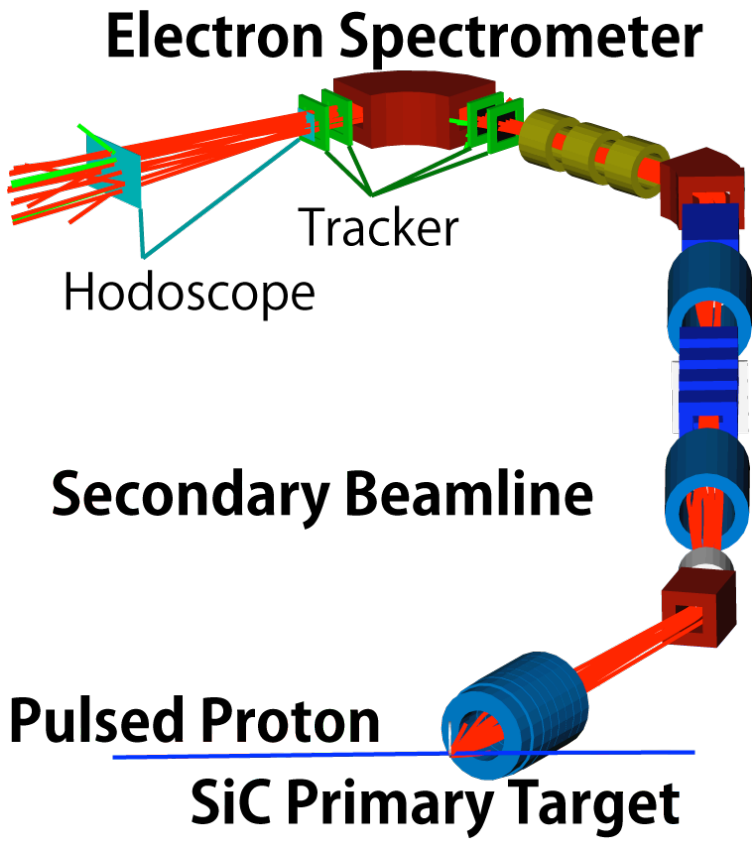
Experimental site: J-PARC MLF





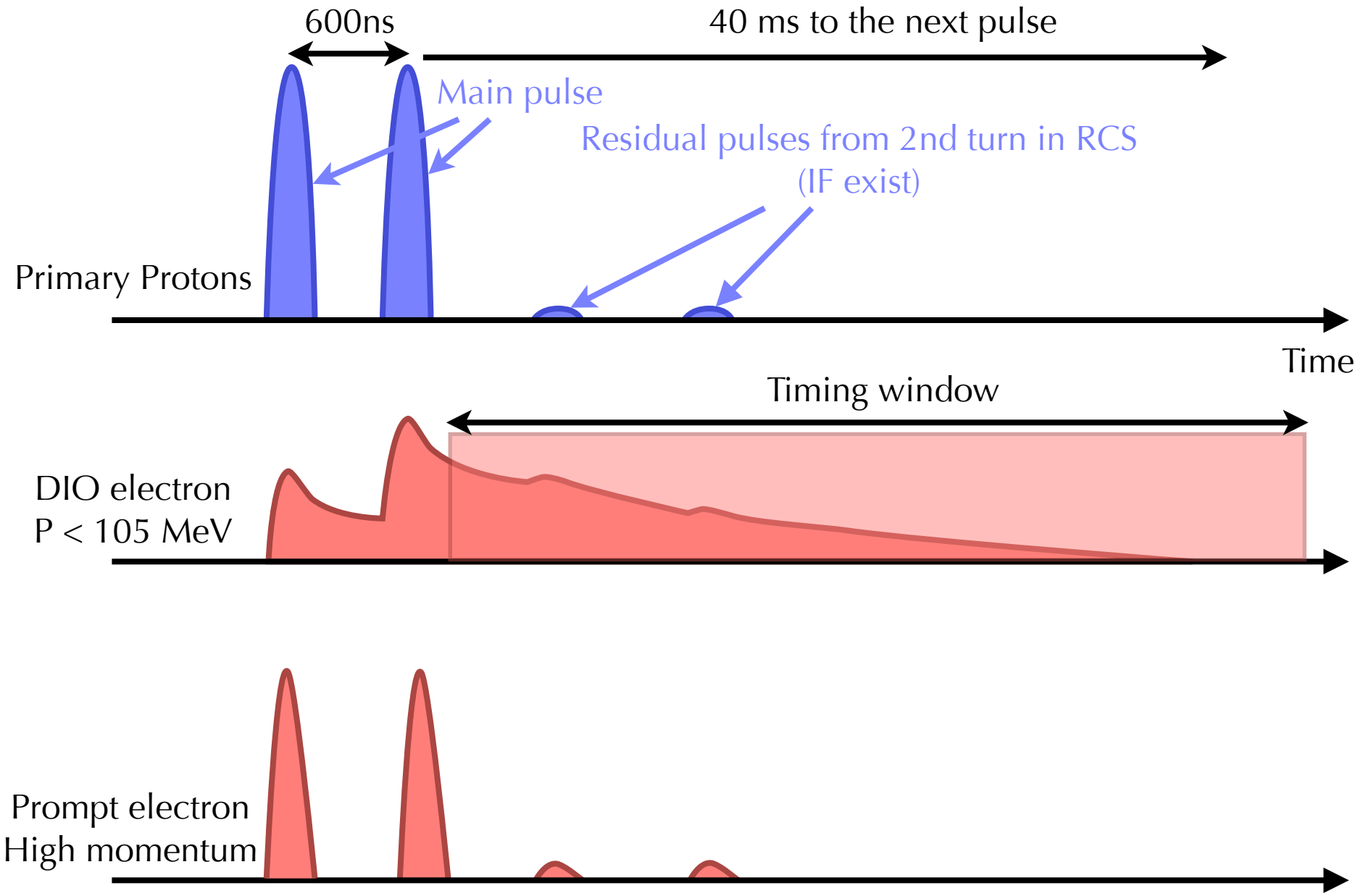
DeeMe @ MLF MUSE





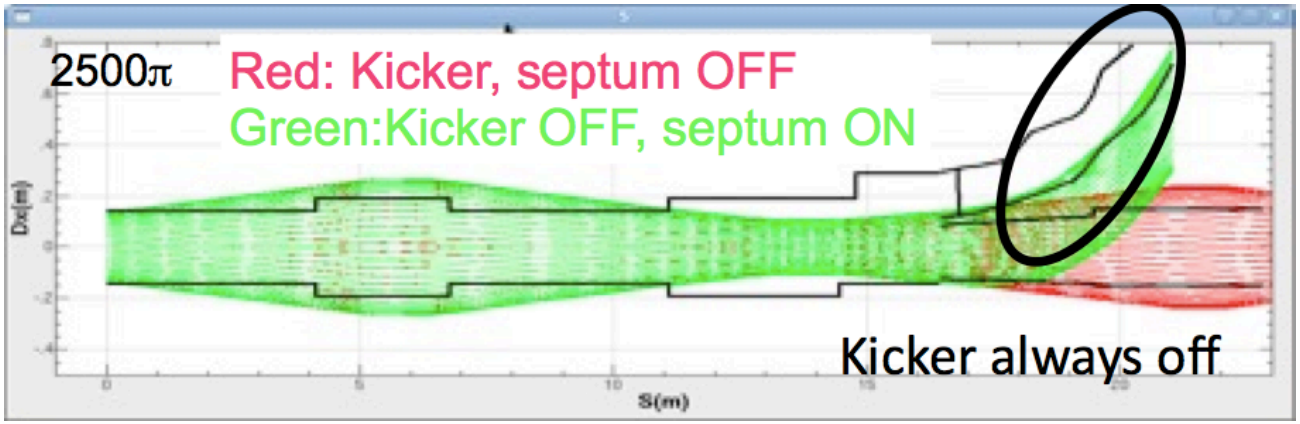
- 1MW : 3GeV, 333uA
- 25 Hz

After proton background



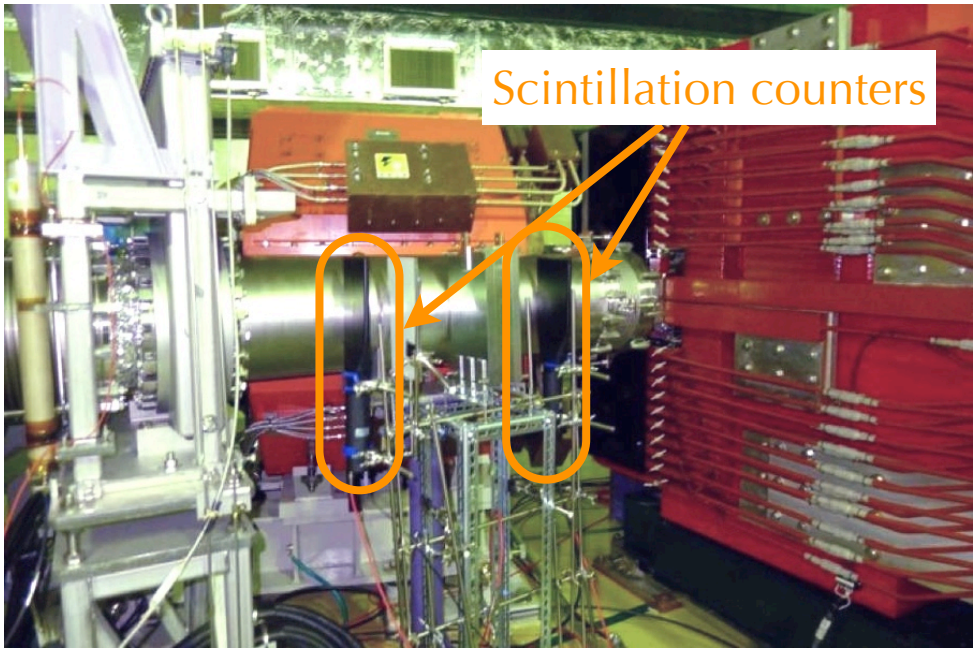
Source of after proton

To MLF Beamline



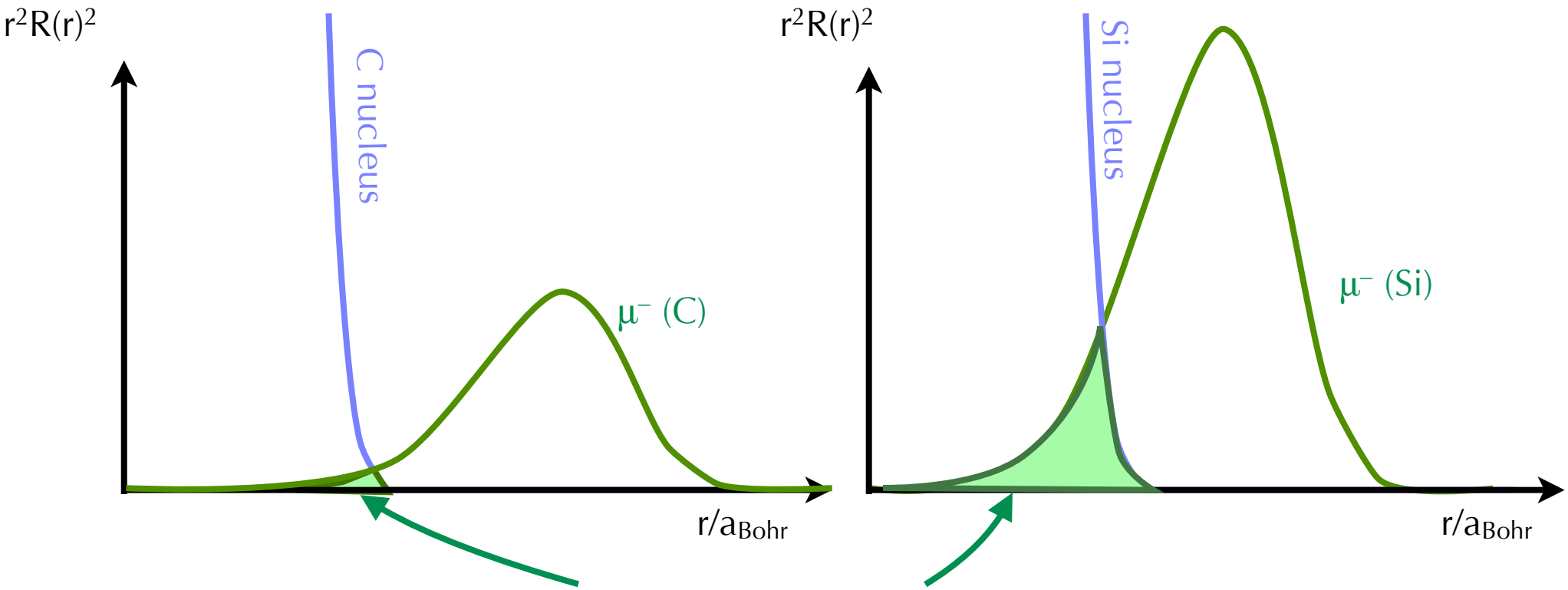
RCS Beamline

- Beam halo (2500π ~ 5 × Physical aperture) may become after proton pulse



Measurement of abnormal beam halo is on going

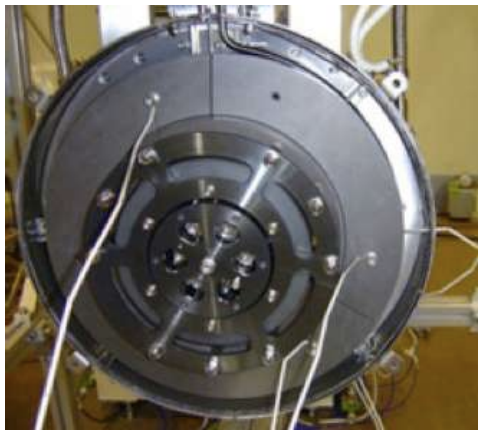
SiC target



11-times larger overlap

ε(μ reaction with nucleus): 8%(C) → 47% (SiC)

C Rotating target

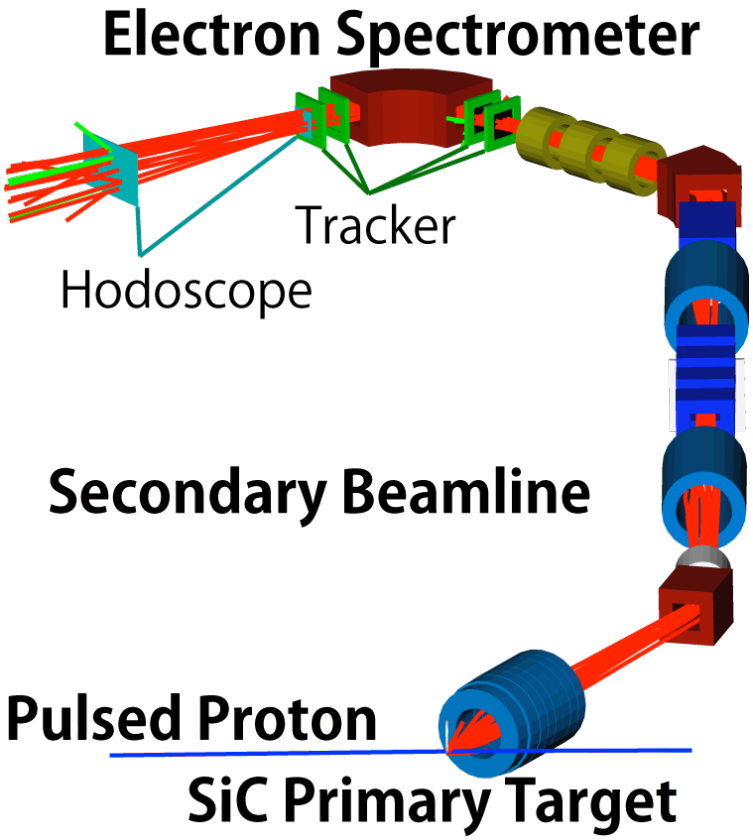


SiC sample

Surface muon yield: almost ×2

Studies of thermal stress studies and the effect to downstream neutron production target is on going

Detector



- Required resolution: $\delta P < 0.5$ MeV/c (RMS)

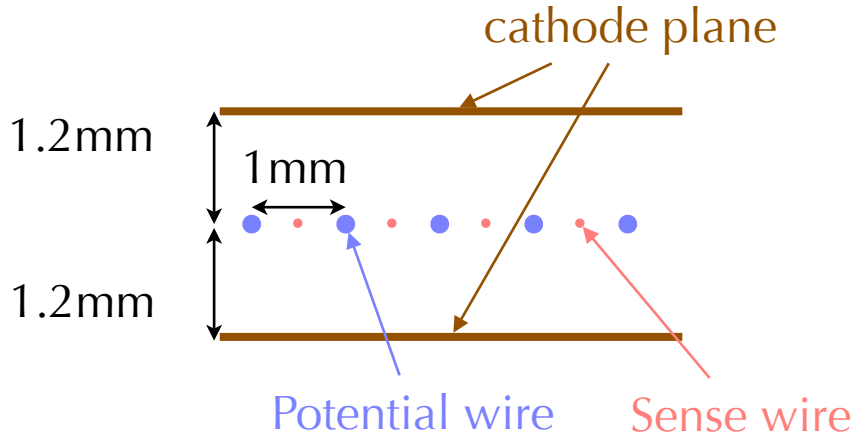
  Prior MC study says this can be achieved when

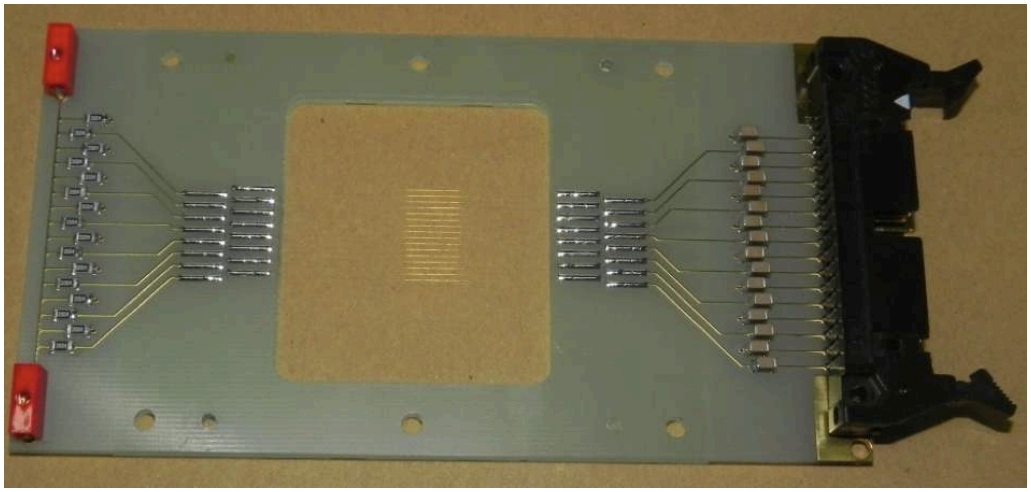
  - tracker position resolution: 0.3mm,
  - 50 degree bending
  - $0.1\% X_0$

- Bending magnet will be operated with 80 degree bending, whose MC study on going
- Should be operational 300ns after prompt electrons (33k/ pulse w/ reduction by kicker)
- Planed final detector: 300mm x 300mm thin MWPC with 1mm wire spacings

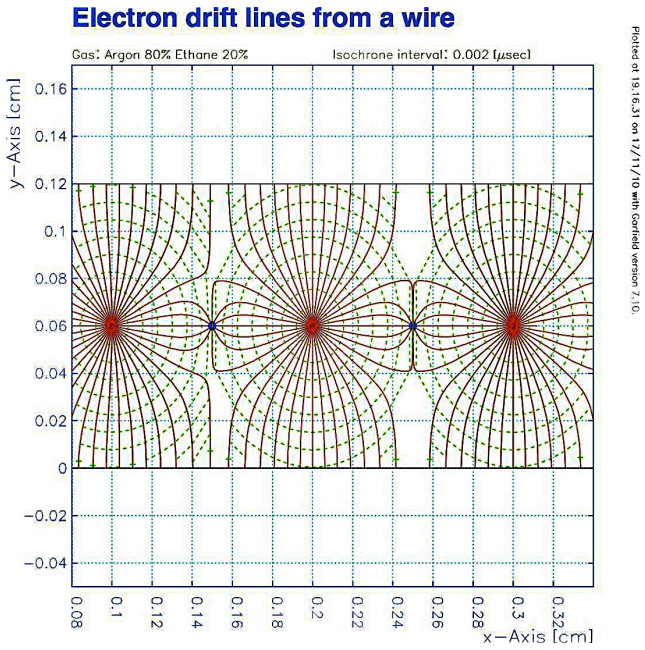
Prototype MWPC

- Prototype
  - Active volume: 16mm x 16mm
  - 0.5mm pitch 16 sense wires(ϕ10um), 17 potential wires (ϕ30um)
  - Anode-Cathode gap: adjustable (0.6mm, or 1.2mm, or so)



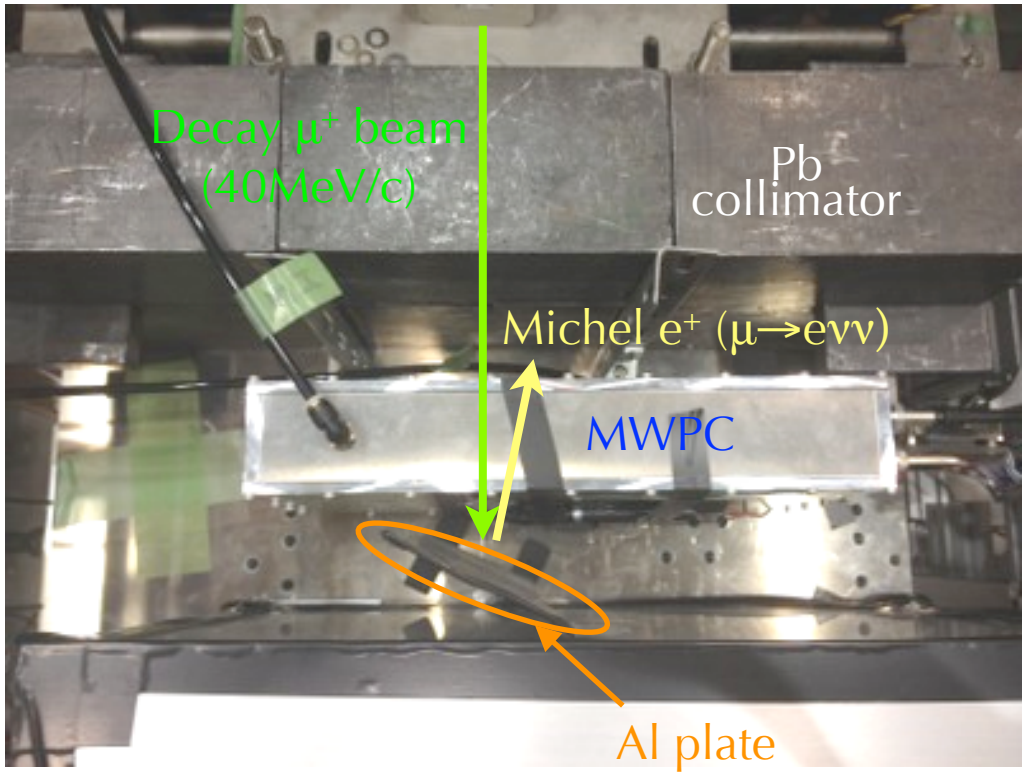


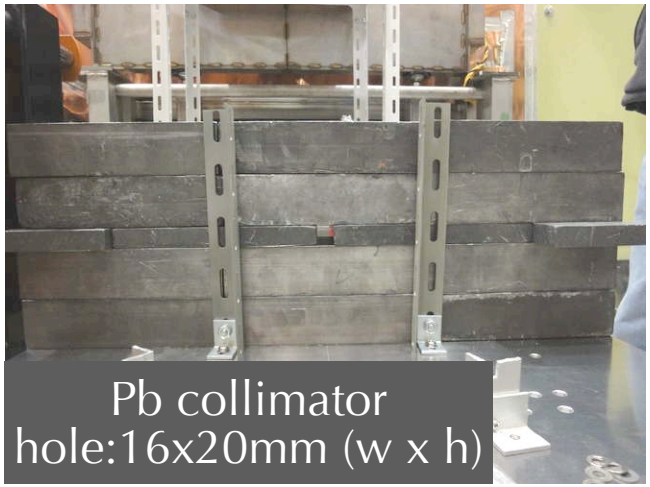
Anode wire frame

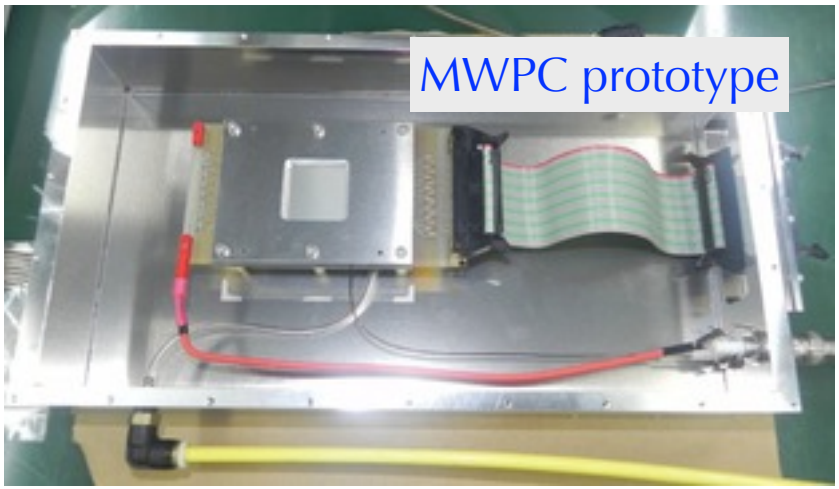


Drift line by Garfield
(when gap=0.6mm)

Prototype beamtest

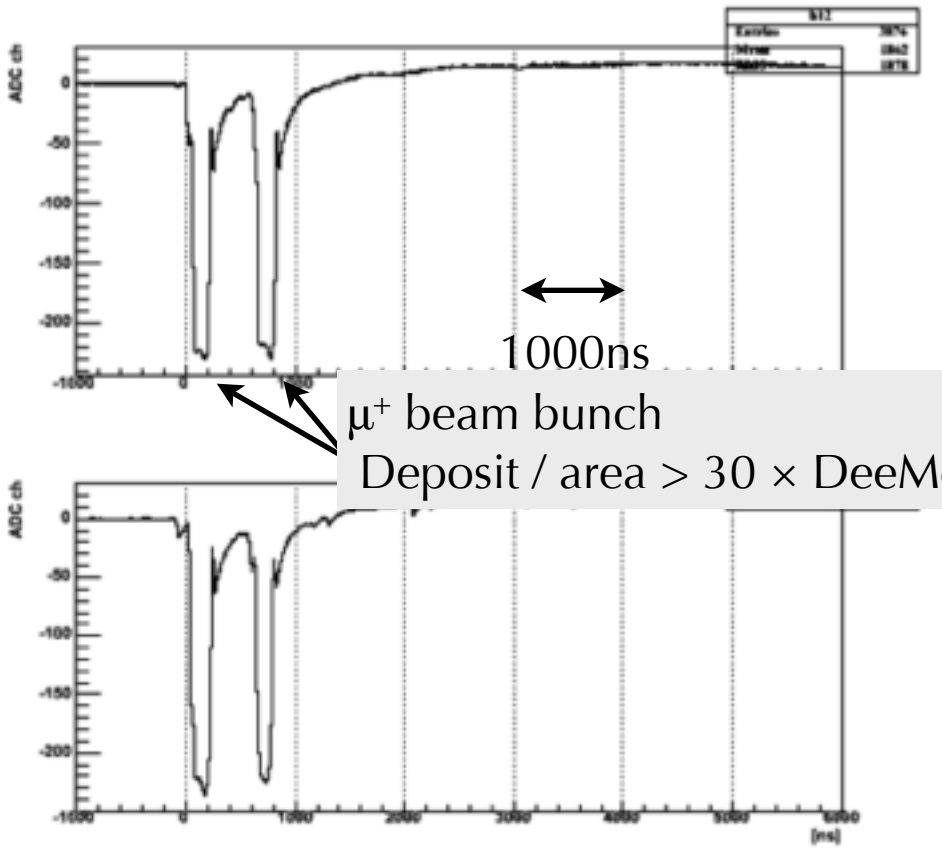


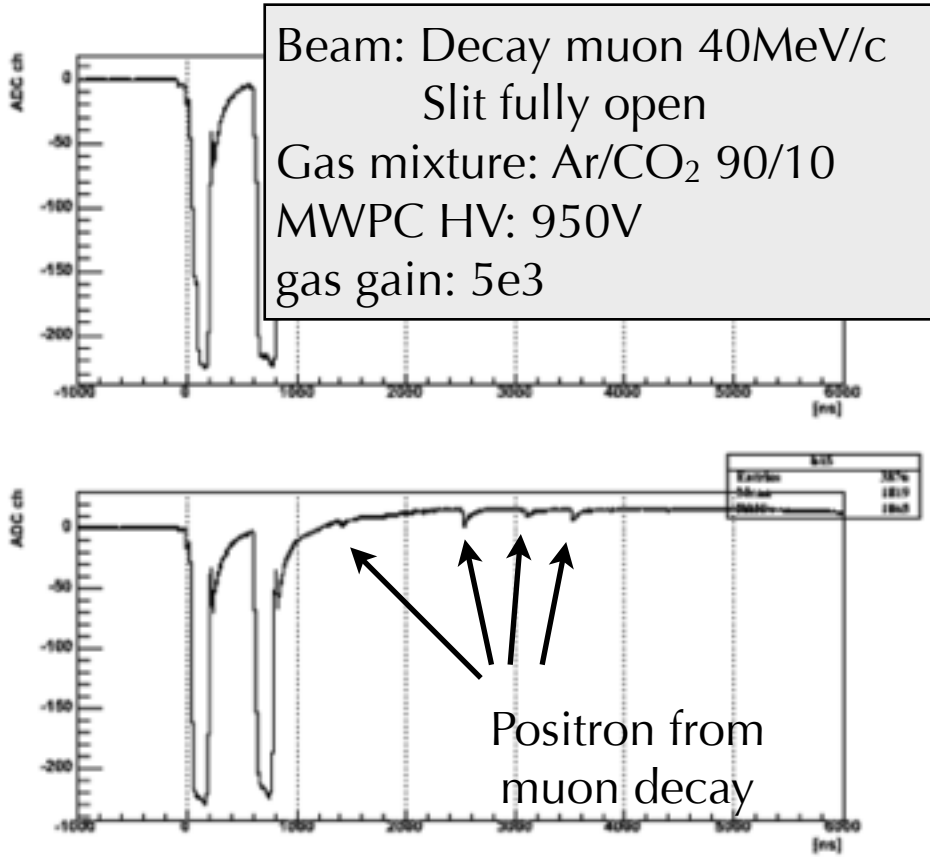


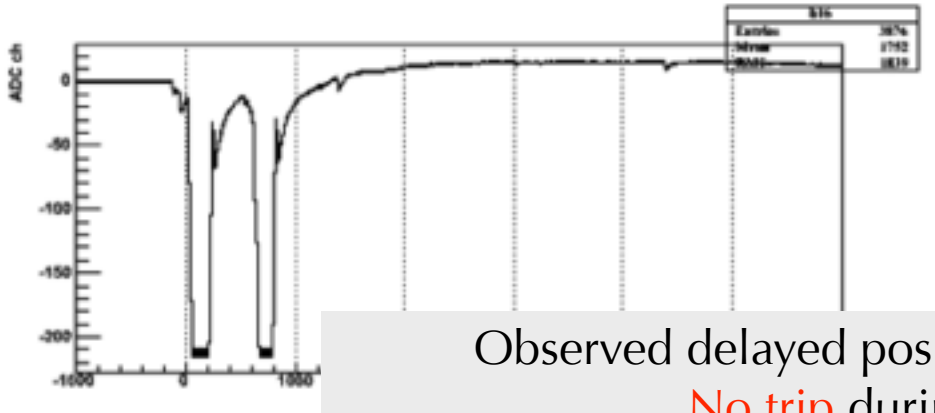


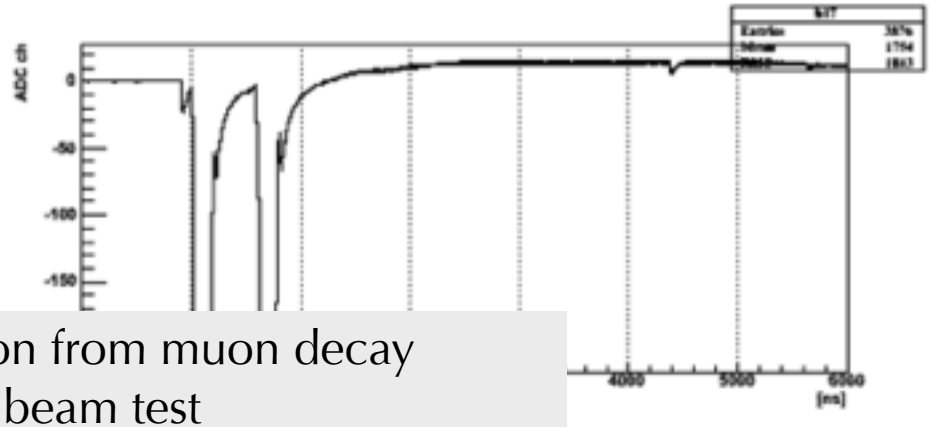
- Performed at J-PARC D2 beamline
  - Same bunch-structure
- Check tolerability to high rate beam
  - 33k / (300mm x 300mm) = 0.37 / mm^2
  - 33k / 300 wires = 110 / wire
- Measure delayed positrons

Tolerance test







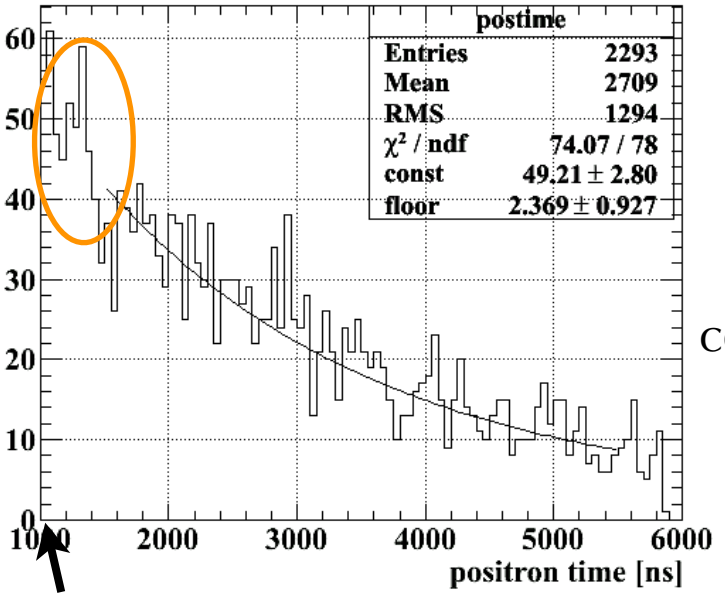


Beam: Decay muon 40MeV/c
Slit fully open
Gas mixture: Ar/CO_2 90/10
MWPC HV: 950V
gas gain: 5e3

Observed delayed positron from muon decay
No trip during beam test
Also survived with electron beam ~ 90 × DeeMe condition

Positron time
when pulse height > ~40mV

No Efficiency drop



300ns after 2nd pulse

※ Fit curve:
const × exp(-time/2.2us) + floor

- No efficiency drop by height > threshold(~40mV) → No significant gain drop

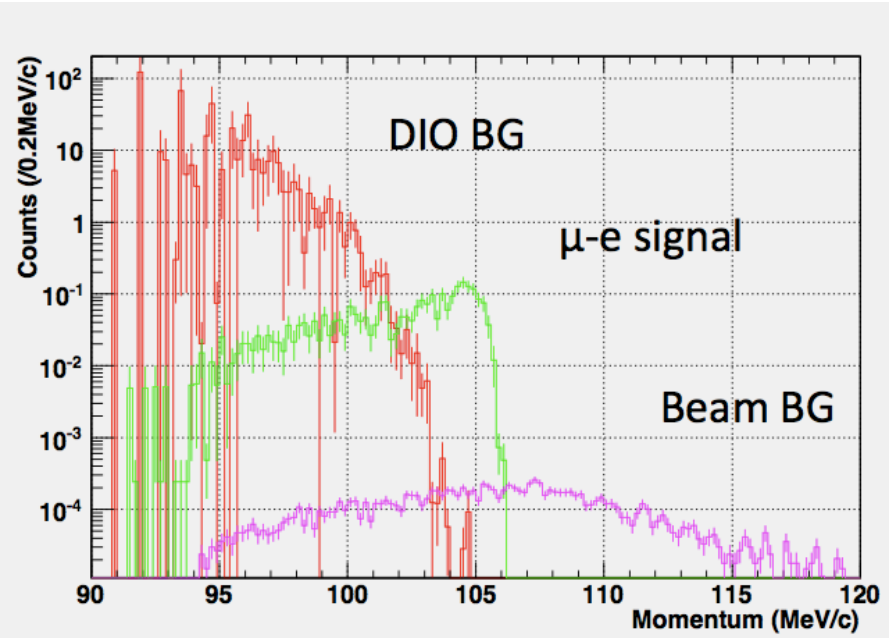
MWPC summary and prospects

- Thin MWPC with 1mm spacing (0.5mm between sense and potential wire) was constructed
- MWPC prototype survived with energy deposit > physics data taking
  - > × 90 / area, × 5 / wire
- Operational 300ns after beam bunch with no significant gain drop

- 300mm wire Large Prototype design on going
- Gating HV is studied for further high rate tolerance

Sensitivity and Backgrounds

- Signal sensitivity : 2×10^{-14} (1MW, 2×10^{7} s)
- Backgrounds
  - After proton rate $< 9 \times 10^{-19}$
  - Detector live-time duty = 1/20000
  - No anti-protons



DIO B.G.	0.09
After proton B.G.	< 0.027 (0.05 90%C.L.)
Cosmic induced e	< 0.018 (MC stat. limited)
Cosmic induced μ	< 0.001
Radiative muon capture	< 0.0009

- If extended running time 8×10^{7} s
  - Standard cut: S.E.S. = 0.5×10^{-14} ($N_{BG} < 0.64$)
  - Tighter cut: S.E.S. = 0.6×10^{-14} ($N_{BG} < 0.17$)

Current status

- Proposal is Stage-1 approved by IMSS/MUSE (MLF muon facility group)
- Detector and SiC target construction will be fulfilled with KAKENHI
- PACMAN magnet in TRIUMF is going to be borrowed for spectrometer bending magnet. Transportation procedures and examination of the performance with MC study are in preparation.
- H-line design work is in progress. Funding of S1-line part is determined (by supplimental budget). H-line will come the next.

Summary

- DeeMe experiment will search for mu-e conversion
- R&D works are in progress
- Physics data taking is planed to start from 2015

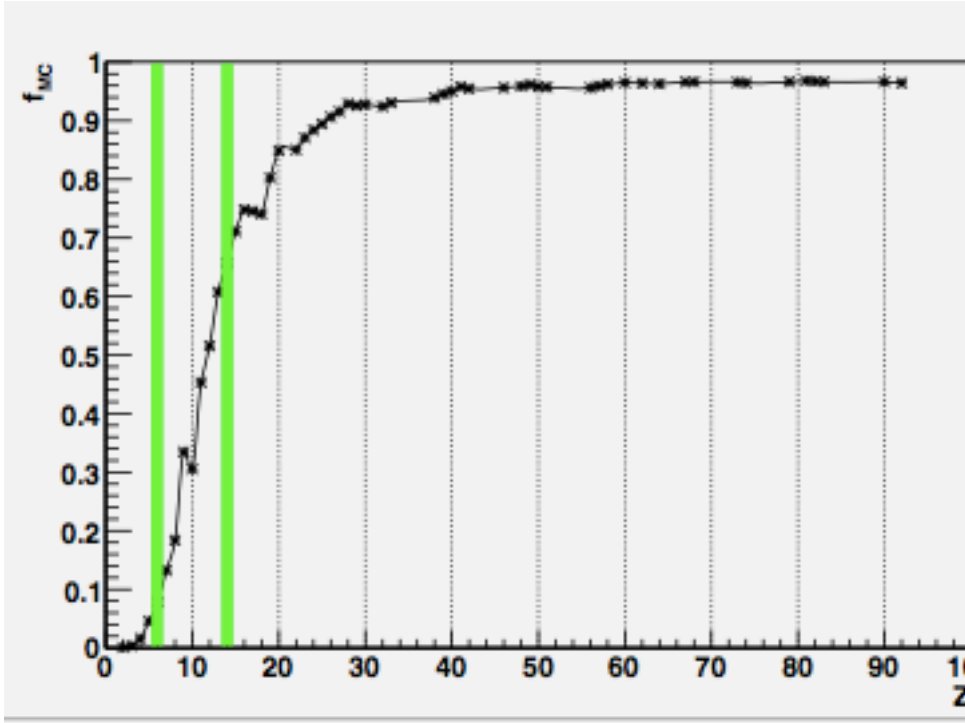
End of slide

SiC target

f_{MC}: muonic nuclear-capture rate

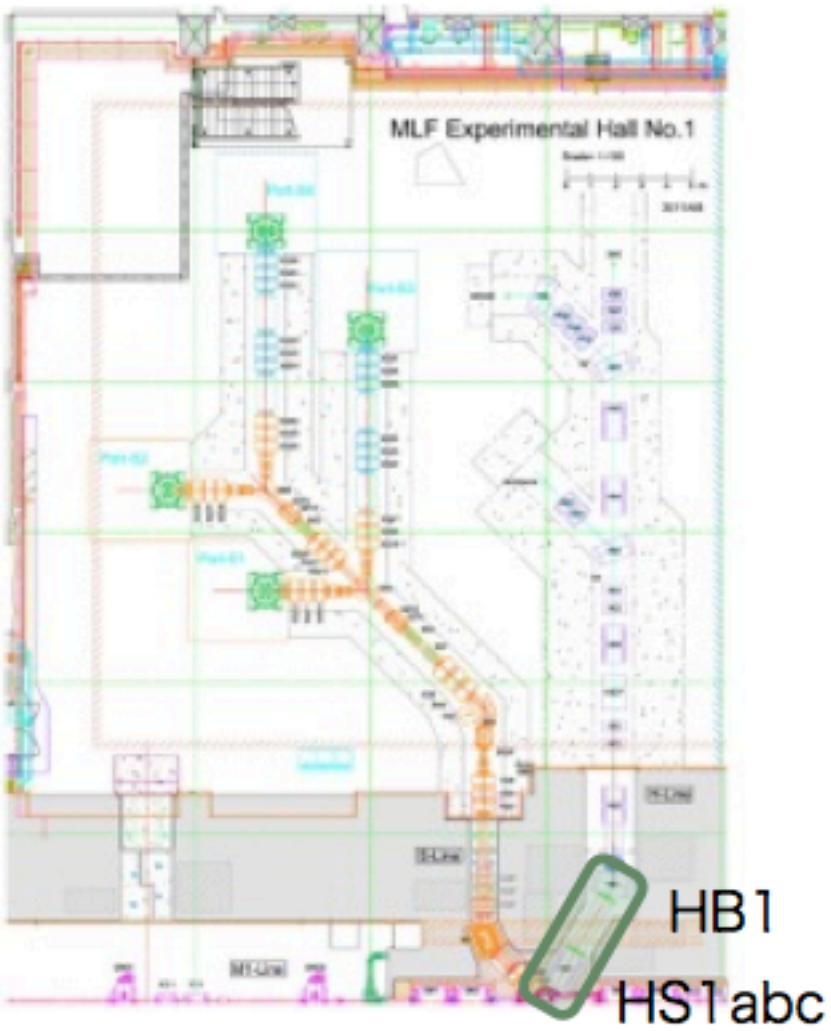
- $(1-f_{MC})=f_{free\text{-}decay}$ --- useless muons: large f_{MC} is better: larger Z.

On the other hand, $\tau_{\mu^-} > 300$ nsec (light Z) to avoid the prompt background



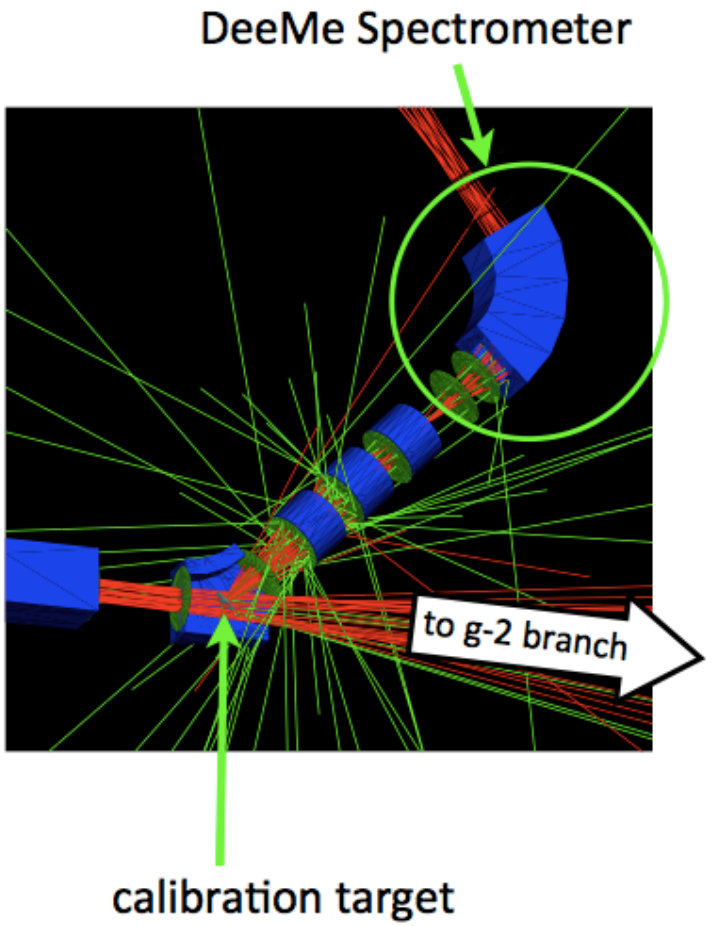
Silicon-Carbide:

- good thermal shock resistance: $\Delta T=450°C$
- high melting point: >1450°C
- good radiation resistance
  - 10 dpa @ 1000°C or more

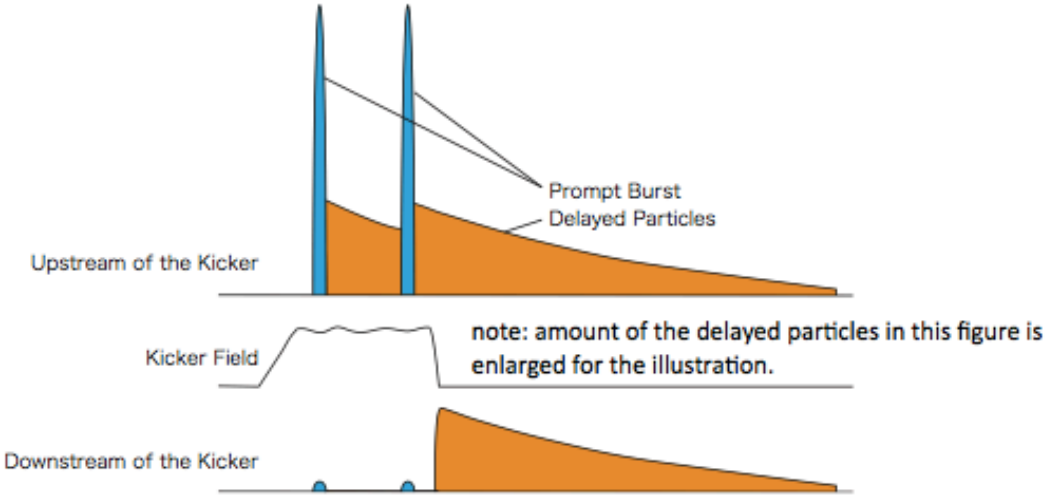


Front-end magnets are already fabricated.

- Momentum Scale and Resolution
  - place a calibration target in HB2
  - prompt positron burst --> g-2 branch
  - beam π+, μ+ stop in the target --> π_{e2}, Michel positrons
- Acceptance Curve of H-line
  - exactly the same H-line settings: momentum@105 MeV/*c*, slits
  - reduce the primary proton by 10^{-8}
    - LINAC chopper: 10^{-7}
    - Length of macro-pulse: $<10^{-1}$



- prompt burst: coincide with the primary proton pulse from RCS.
  - ~100M particles/pulse (test measurement at 2009 && Geant4 MC)
    - detector (counter and wire chamber) will be blind for while.
- Reduce the prompt burst by kicker <1/20000 ~ 1/150000
  - detector rate will be ~20k particles/extraction, and it is acceptable.



Mag. Field	> 385 Gauss
Gap	320 mm
Width	320 mm
Length	400 mm
No.	4
Fall Time	< 300 nsec
Rep. Rate	25Hz
Electric Noise	Minimum