Performance Review of the Prototype SiC Muon Beam Monitor for COMET Experiment

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COMET Experiment

- COherent Muon to Electron Transition

- Search for **μ-e conversion** process at J-PARC Hadron Facility
- Establishing a new COMET beamline and conducting exploration using pulsed muon beam
- Experiment will be conducted in two stages, Phase-I & II

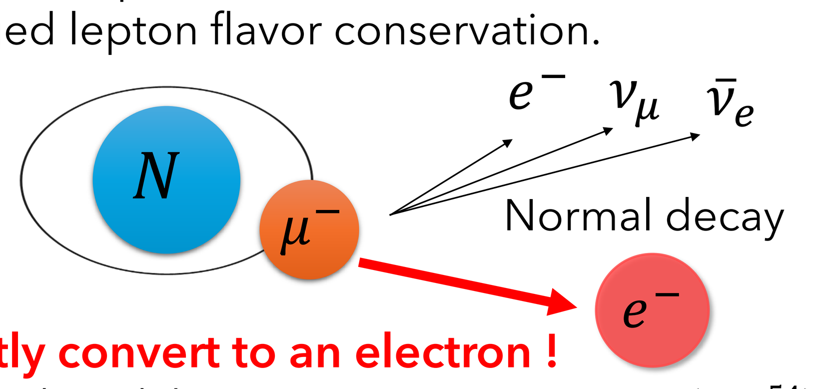
Target Experiment Sensitivity	Phase-I	$\mathcal{O}(10^{-15})$
(Single event sensitivity)	Phase-II	$\mathcal{O}(10^{-17})$

Previous Experiment (SINDRUM-II)

Upper Limit of Branching Ratio 7.0×10^{-13} [1]

μ-e conversion

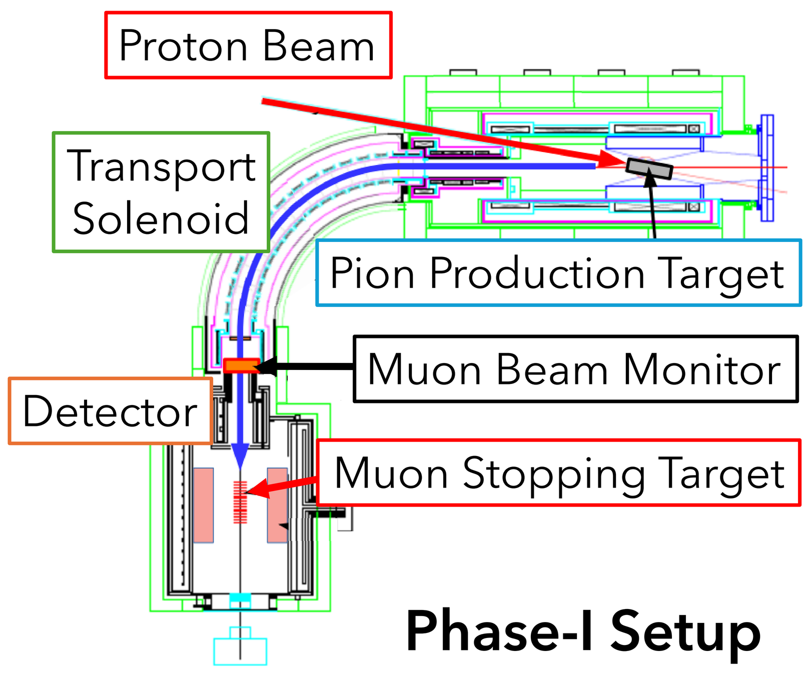
One of the processes that violates the law of charged lepton flavor conservation.



Directly convert to an electron !

Standard Model+ Neutrino mass $\rightarrow BR \sim \mathcal{O}(10^{-54})$

Beyond the Standard Model $\rightarrow BR \sim \mathcal{O}(10^{-15})$



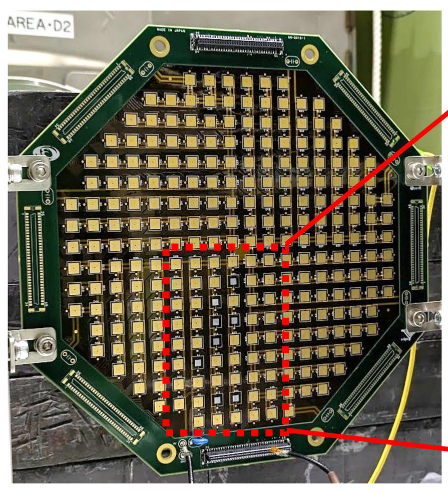
Phase-I Setup

SiC Muon Beam Monitor

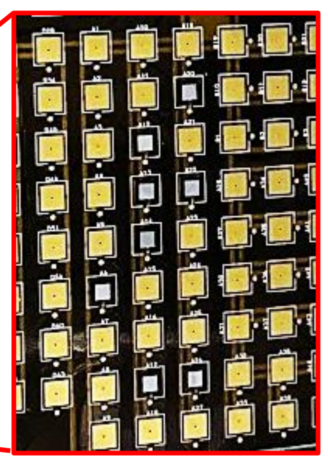
Muon Beam Monitor

Objects: Measure the intensity and stability of the muon beam.

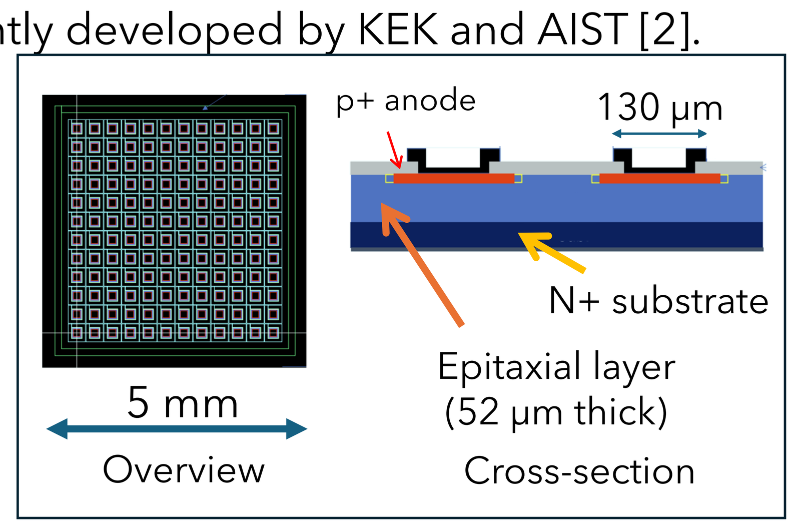
Detector: Made of silicon carbide (SiC) and jointly developed by KEK and AIST [2].



Muon beam monitor board



SiC detector (Silvery chips)



Structure of SiC detector

Why use SiC ?

Muon beam monitor will be directly exposed to a high-intensity muon beam.

→ Resulting in $1.6 \times 10^{13}\ n_{1\mathrm{MeV}}\ /\ \mathrm{cm}^2$ and 1.2 MGy.

Higher Radiation tolerance is required than standard n-type silicon sensor !

Wide bandgap semiconductors have high radiation tolerance.

→ **SiC is an optimal choice !**

Beam Test at MLF

Goal: Check the performance with a pulsed muon beam

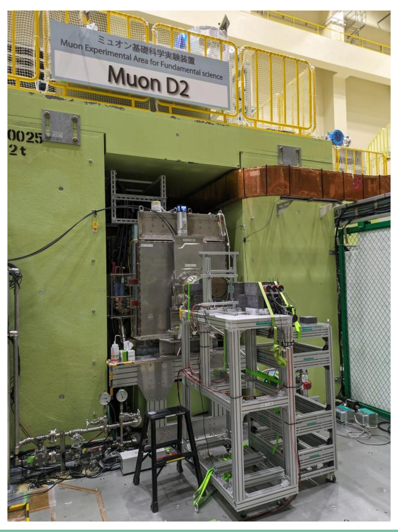
- **Check SiC detector response to muons**
  - Pulse height for a single incident muon → **Detector response**
  - Correlation of the number of incident muons and pulse height → **Linearity**
- Transparency for muons

→ **Beam test was performed at MLF D2 line in June 2024.**

MLF D2 Beamline

- Momentum: 20 ~ 100 MeV/c (μ^+)
- Pulsed muon beam (25 Hz, ~ 20 muons / sensor / bunch)
- Double pulse structure (600 ns interval)

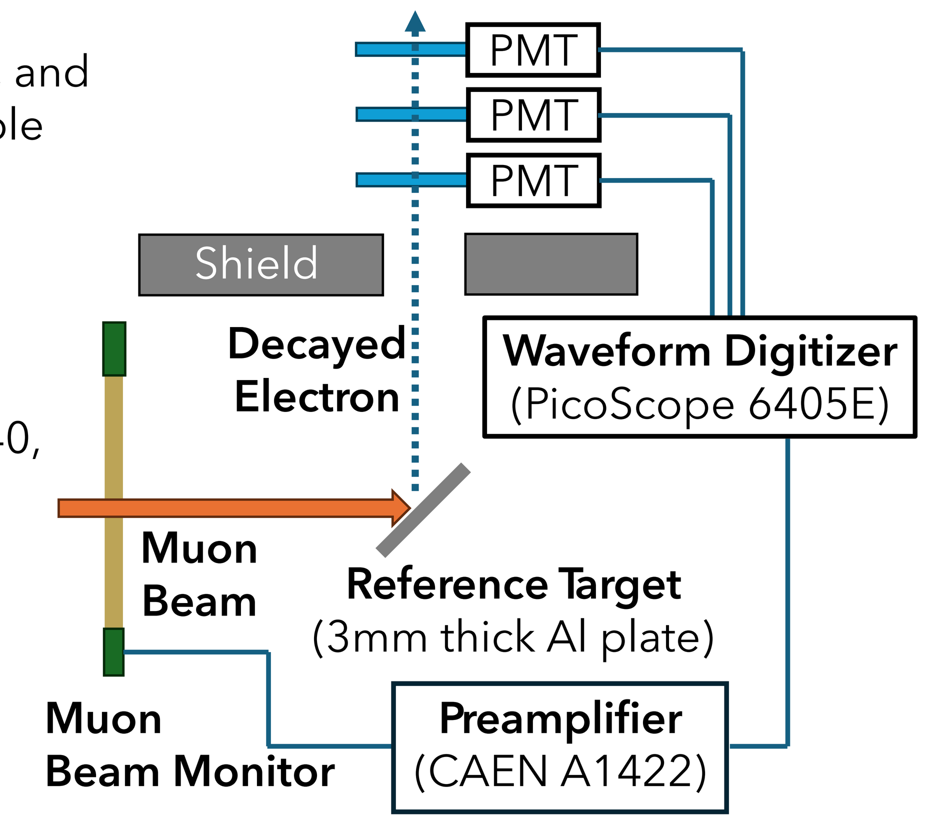
→ This beamline allows experiments with muon beams similar to those used in actual experiment.



Setup for Beam Test

- Muons are stopped at the reference target, and decayed electrons are measured with a triple counter.
  → Estimate the number of incident muons
- Read out one chip at a time, total of two chips are tested.
- Measurements taken at bean momenta of 40, 70 MeV/c, with 3~5 points each at different beam intensities.

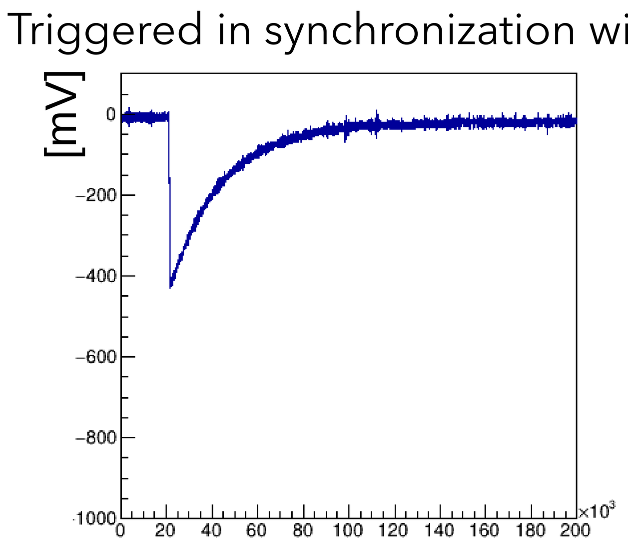
Preamplifier (CAEN A1422)
Gain: 1 V / pC
Time constant: 27 μs



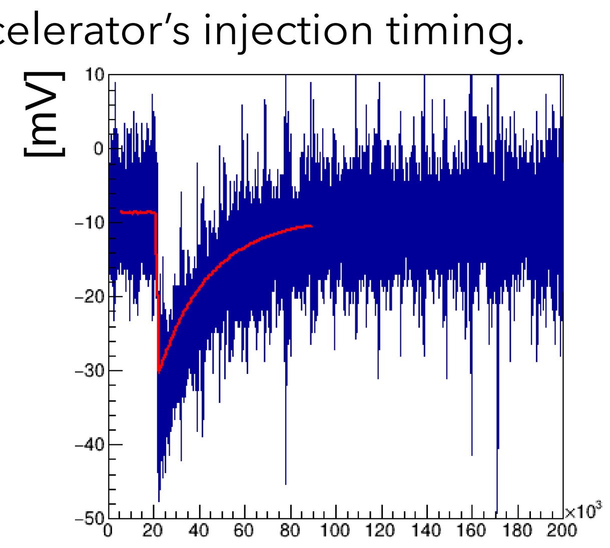
Results & Discussion

Typical Waveform from SiC Detector (40 MeV/c)

- Triggered in synchronization with the accelerator's injection timing.



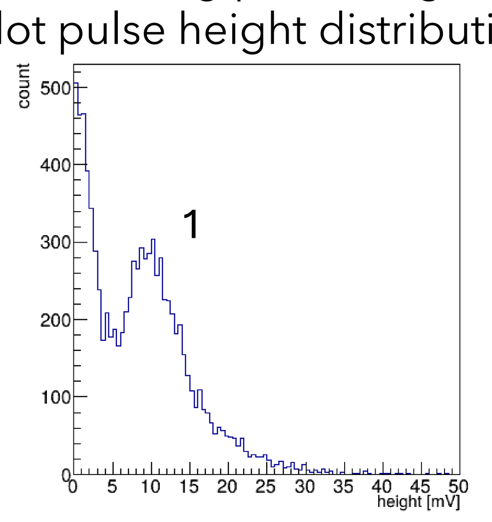
Signal with more than 10 incident muons



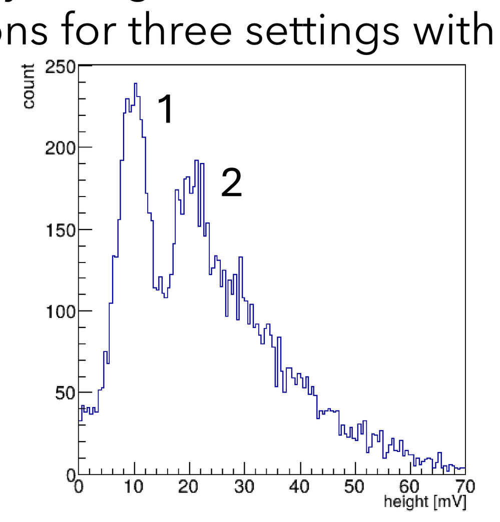
Signal with a few incident muons

Pulse Height Distribution

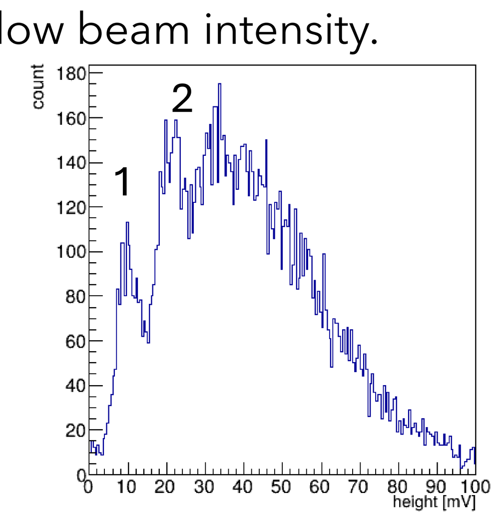
- Determining pulse height by fitting.
- Plot pulse height distributions for three settings with low beam intensity.



Beam Intensity: Lowest



2nd Lowest



3rd Lowest

- Clearly seen 1 or 2 muons peaks.
- Fitting a single muon peak reveals a pulse height of ~10 mV.

Detector Response – The Number of Electron-Hole Pairs

Check the number of electron-hole pairs created in SiC detector.

- Pulse height of single incident muon → 10.52 mV
- Pulse height when 50 mV test pulse is applied to a preamp with 1 pF input capacitance → 233.68 mV
- Estimated depletion layer thickness under 600 V bias voltage → ~ 40 μm
  → **The number of e-h pairs created per 1 μm depletion layer is** ~ $3.5 \times 10^2\ /\ \mu m$

Calculated number of e-h pairs

- Energy deposit of a 40 MeV/c muon per 1 μm in SiC → ~ 2.7 keV / μm
- Electron-hole pair creation energy in SiC → 7.8 eV

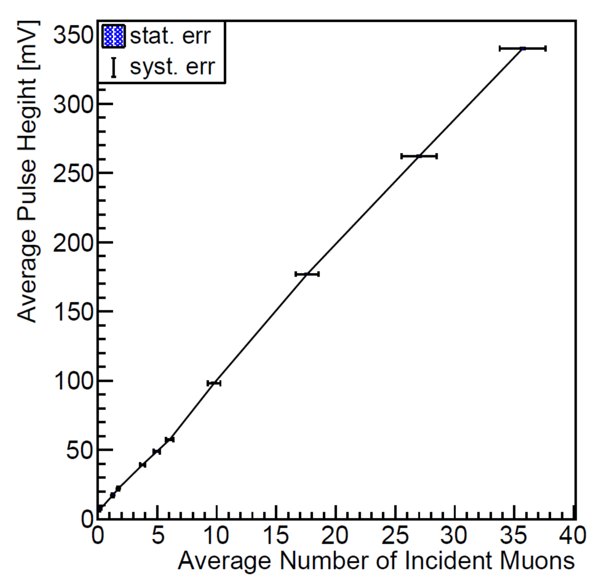
→ **The number of e-h pairs created by a muon in 1 μm of SiC is** $3.4 \times 10^2\ /\ \mu m$

→ Experimental result and calculated number are consistent !

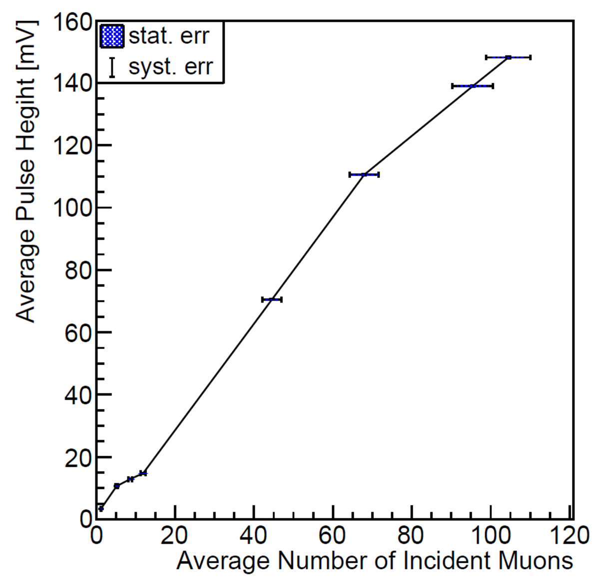
Linearity

- Confirming the correspondence between the number of incident muons and the pulse height.

40 MeV/c



70 MeV/c



- **Linearity was confirmed with up to around 35 incident muons at 40 MeV/c.**

While approximately 50 incident muons are expected in the actual experiment.

Summary

- SiC muon beam monitor will be used to measure the beam intensity and the stability of the muon beam in the COMET experiment.
- Beam test was performed at MLF to check the performance with a pulsed muon beam.
- Analysis confirmed linearity for incident muons up to around 35.
- The development of the muon beam monitor system is ongoing, with a full system performance evaluation planned.

[1] Wilhelm H. Bertl, et al., Eur. Phys. J. C, Vol. 47, pp. 337–346, 2006.
[2] T. Kishishita et al., IEEE Trans.Nucl.Sci. 70(2023)6, 1210-1214.

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