Development of the muon beam monitor for COMET experiment using SiC detector

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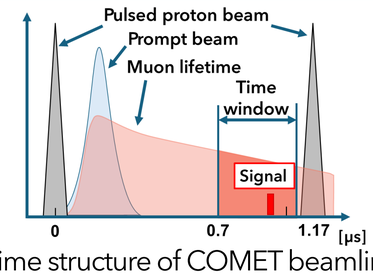
COMET Experiment

- 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 (Single event sensitivity): Phase-I $\mathcal{O}(10^{-15})$, Phase-II $\mathcal{O}(10^{-17})$



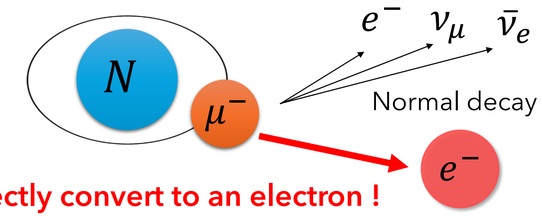
Time structure of COMET beamline

Previous Experiment (SINDRUM-II)

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

μ-e conversion

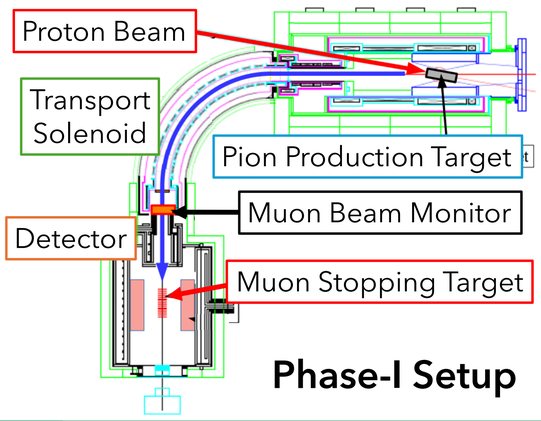
One of the processes that violates the law of charged lepton flavor conservation.



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

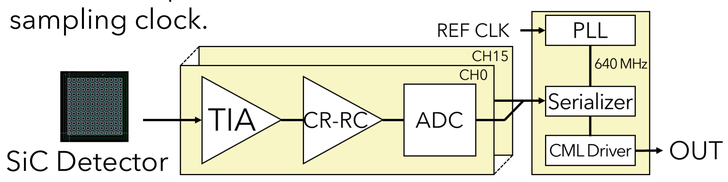
Readout ASIC

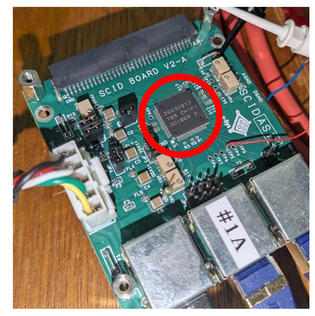
- SCIBER(Silicon Carbide readout IC for muon-BEam monitoR)

- ASIC will be used for readout electronics of the SiC detector.
- **The second prototype had already been developed** by KEK.

Specifications

- Consists of 16 channels per chip.
- Each channel consists of trans-impedance amplifier, CR-RC bandpass filter, and 8bit SAR ADC with 10 MHz sampling clock.





Readout board with SCIBER2 ASIC

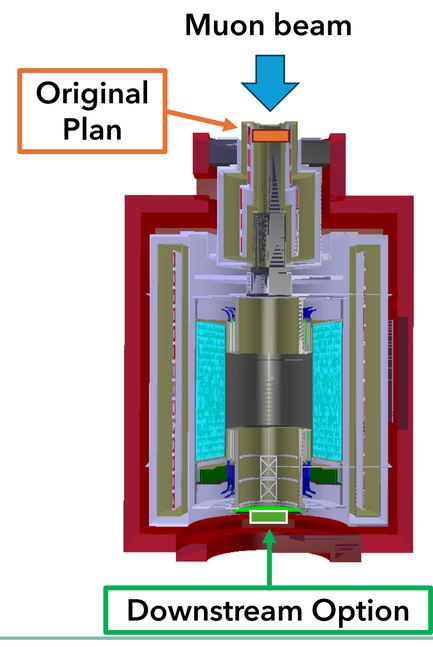
Installation Plan

Original: Upstream

- Installing at the transport solenoid exit
- Sufficient pulse height (~57 muons / chip(centre) / bunch)
- Small beam size, small detector size
- High radiation level
- Hard to access the beam monitor system
- Reduced muon yield

Option: Downstream

- Installing downstream of the primary detector system
- Low radiation level
- Easy to access the beam monitor system
- Does not affect the muon yield
- Smaller pulse height, worse S/N (~16 muons / chip(centre) / bunch)
- Larger beam size, larger detector size (twice the size)

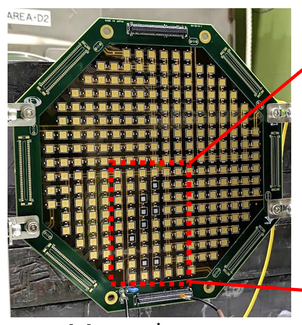


SiC Muon Beam Monitor

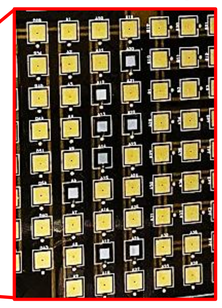
Muon Beam Monitor

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

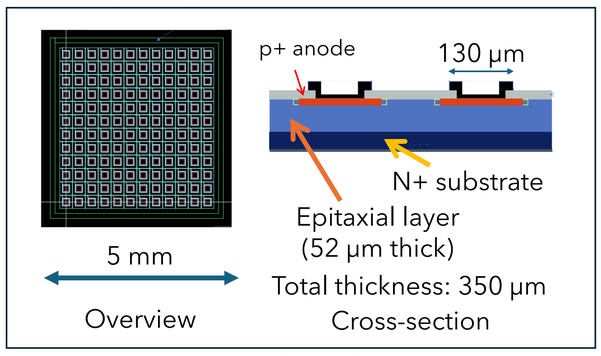
Detector: Made of silicon carbide (SiC) and jointly developed by KEK and AIST [2].



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.

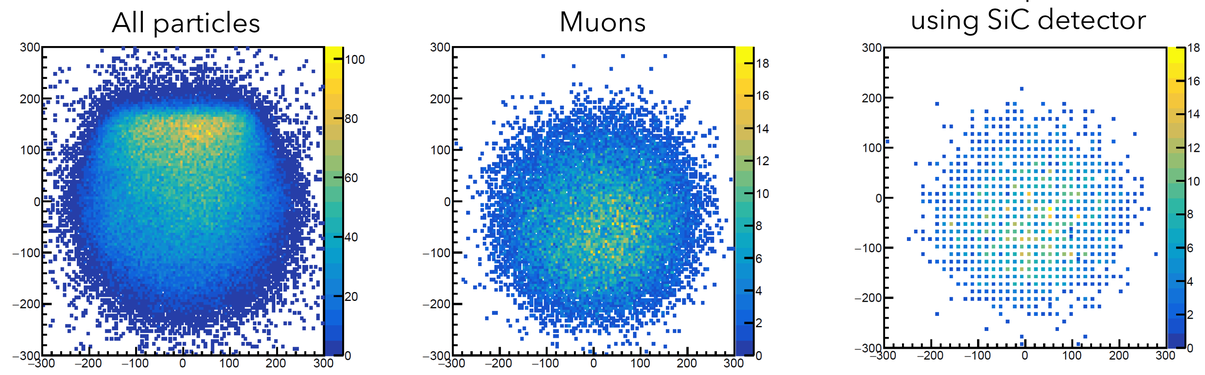
Higher Radiation tolerance is required than standard n-type silicon sensor !

Wide bandgap semiconductors have high radiation tolerance.
→ **SiC is an optimal choice !**

Simulation Study of Downstream Installation

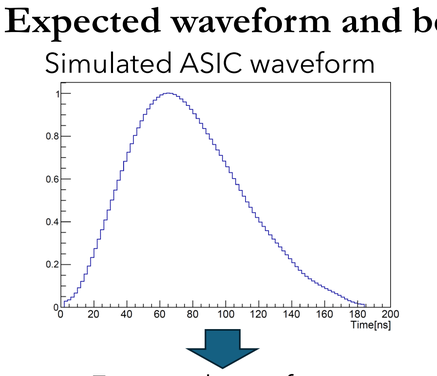
Investigation of muon beam profile and expected waveform using Geant4 based simulation framework for COMET Experiment.

Beam Profile (1 bunch $=1.6 \times 10^7$ Protons on target)

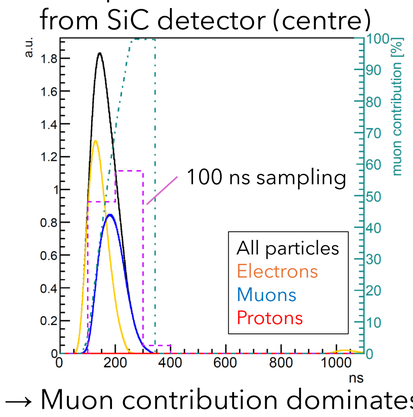


→ 16 muons will incident on center SiC detector chip

Expected waveform and beam profile monitor

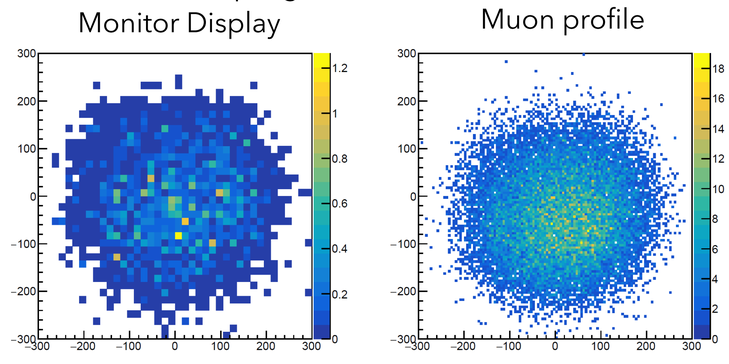


Expected waveform from SiC detector (centre)



→ Muon contribution dominates within 200 ~ 300 ns

Sampling waveform at 260 ns



→ By sampling the waveform at this timing, the muon profile can be roughly reproduced.

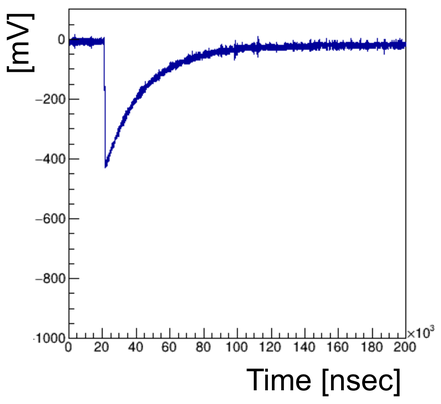
Beam Test at MLF

Goal: Check the performance with a pulsed muon beam

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

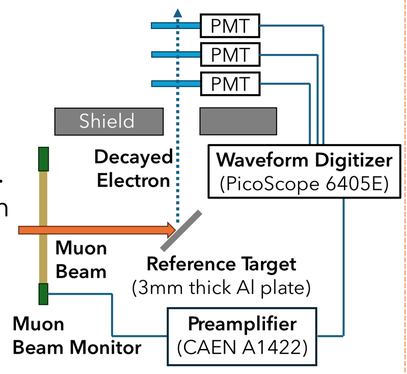
→ Beam test was performed at MLF D2 line in June 2024.

Typical Waveform from SiC Detector (40 MeV/c)



Beam Test Setup

- Read out by commercial preamplifier(1 V / pC, 27 μs time constant).
- Read out one chip at a time.
- Triggered in synchronization with the accelerator's injection timing.

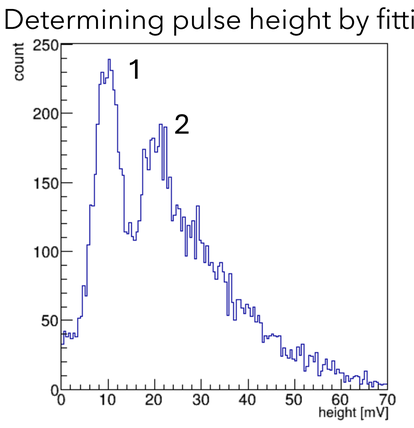


MLF D2 Beamline

- Momentum: 20 ~ 100 MeV/c (μ^+)
- Pulsed muon beam (25 Hz, ~ 20 muons / sensor / bunch)

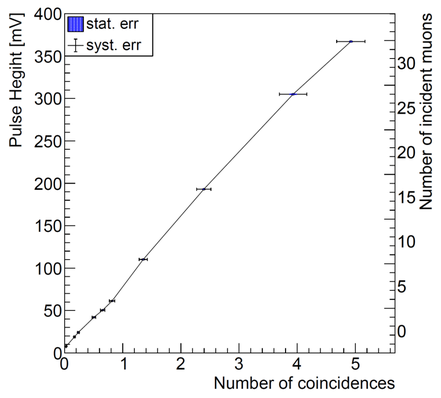
Pulse Height Distribution

- Determining pulse height by fitting.



- Clearly seen 1 or 2 muons peaks

Linearity (40 MeV/c, 1000 V HV)



- Sufficient linearity was confirmed up to approximately **35 incident muons**.

Summary

- A beam test was performed to check the performance of SiC detector, confirming sufficient linearity up to around 35 incident muons.
- Simulation study of downstream installation option revealed that approximately 16 muons are incident on center chip, and the output waveform is dominated by muons in the range of 200~300 ns.
- Determining the installation location and producing the monitor board for Phase-I. Evaluation of the next prototype ASIC will be conducted, followed by the production of the final version, aiming for the overall system completion.

[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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