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Muon Beam Monitor in the COMET experiment

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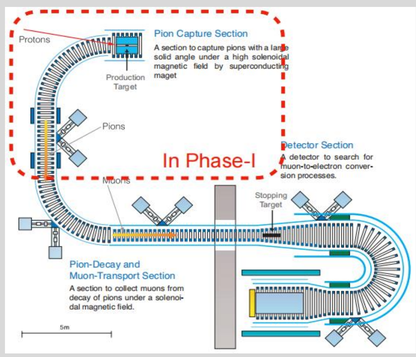
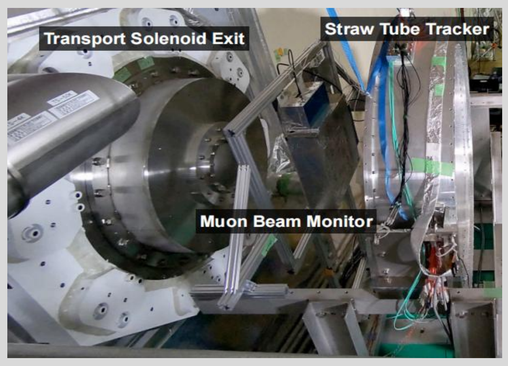
Abstract : COMET is an experiment at J-PARC, Japan, which will search for neutrinoless conversion of muons into electrons in the field of an aluminum nucleus (μ–e conversion, $\mu^- N \rightarrow e^- N$): a lepton flavor violating process. We have designed a plastic scintillation fiber detector for monitoring muon beam flow.

The Phase-α of the COMET experiment

- Charged-Lepton-Flavour Violation (CLFV) is forbidden in the Standard Model (SM) and strongly suppressed in extensions of the model to include finite neutrino mixing.[1]
- The COMET experiment at the Japan High Current Proton Accelerator Center (J-PARC) aims to discover the $\mu^- N \rightarrow e^- N$ process with an sensitivity higher than 10^{-17} .[2]
- The purpose of phase-alpha is to understand the proton beam transported to the COMET experimental area and π/μ production yield in the backward direction at 8 GeV before the Pion Capture Solenoid is installed in the COMET primary beam line area.
- To obtain high-precision experimental results, it is necessary to test the muon beam. Muon Beam Monitor (MBM) is the **first** device after the transport solenoid.



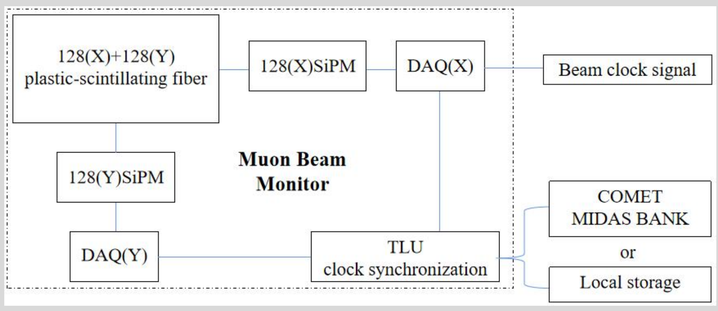
Schematic layout of COMET (Phase-II and Phase-I)



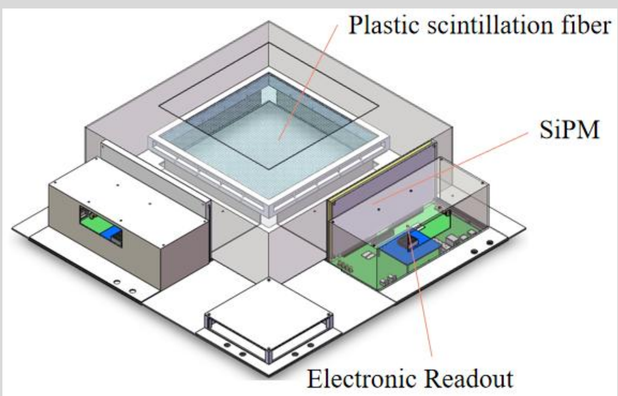
Site photos of COMET experiment phase-alpha

Design of Muon Beam Monitor

- We design the detector with plastic scintillation fiber and SiPM, and the detector showed good performance in beam testing.



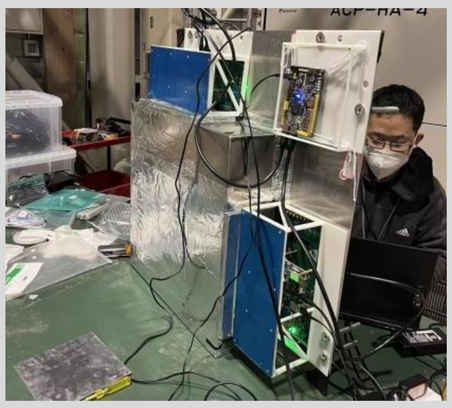
Muon Beam Monitor block diagram



Muon Beam Monitor model diagram

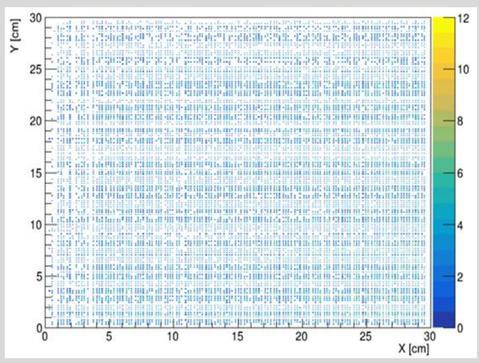
- Muon Beam Monitor consists of two orthogonal layers covering a target area of 30 × 30 cm² with 128 plastic scintillation fibers with 1 × 1 mm² end face per layer.
- Each plastic scintillation fiber has a Silicon Photomultiplier (SiPM) with a photosensitive surface of 1.3 × 1.3 mm² at one end.
- The SiPM signals are processed by the Front-End Board (FEB), and output to the Data Acquisition (DAQ), whose time resolution can reach nanosecond level. And the time logic unit (TLU) is used to achieve X-Y bidirectional signal synchronization.

Some primary results of Muon Beam Monitor



After complete assembly, on-site debugging was carried out in beam hall

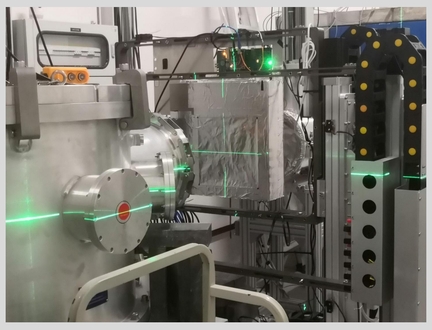
- To avoid the impact of beam speckle on electronic devices, we have installed aluminum alloy on the outer layer to shield the particles scattered by the beam
- When a fiber is triggered in either the X and Y directions, it outputs a signal and stored in the DAQ cache.The data in the cache can be extracted to a local file or imported into the MIDAS Bank of COMET experiments.
- We plot the historical event data of the past 1s as a beam cross-section histogram, while generating a two-dimensional cross-section.
- We monitored the Cosmic Ray muons for 3 hours, and from the distribution map obtained, it can be seen that each channel has a good response to muons.



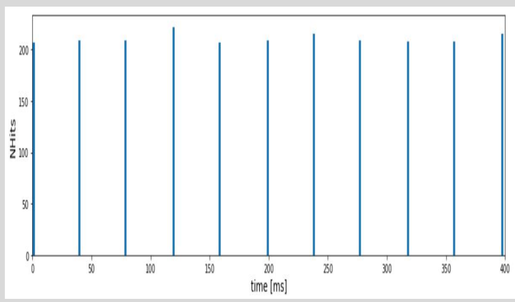
MBM Response to Cosmic Rays

Proton beam test at CSNS

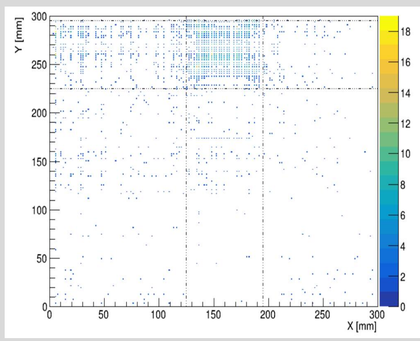
- We use an associated proton beam with an energy of about 80 MeV and a flux of 2.9 × 10⁸ /(cm²·s) for beam testing at China Spallation Neutron Source.
- By analyzing the impact time of the beam, it can be seen that the time of events matches the beam time well, indicating that MBM has good time resolution for proton beam lines.



MBM is installed in the Associated Proton beam Experiment Platform and centered using a laser collimator.



Time distribution chart of Muon Beam Monitor case data

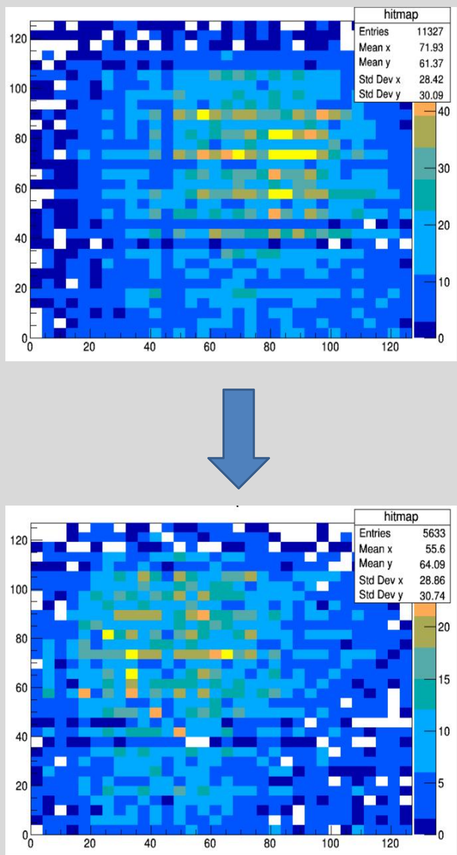


Two-dimensional imaging of proton beam spot using Muon Beam Monitor

After threshold screening, a clear beam spot cross-section can be seen in the two-dimensional cross-sectional view. Muon Beam Monitor has good time and position resolution capabilities for beam flow.

COMET Phase alpha Muon Beam Test

- Due to the large beam spot in the phase-alpha of the COMET experiment, which almost covers the entire beam window area of the Muon Beam Monitor, data processing focuses on matching the beam received by the back-end detector.
- Match the data collected by Muon Beam Monitor with the backend Range Counter to obtain a two-dimensional distribution image of the beam.
- As the position of the Range Counter shifts, it is clear to see the displacement of the corresponding beam spot position. The results indicate that MBM can effectively distinguish the beam position.



The changes in beam spot position were observed during the experiment

Muon Beam Monitor performed well in the second beam time of the phase-alpha of the COMET experiment!

Acknowledgements

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Team

References: [1]. De Gouvêa A, Vogel P. Lepton flavor and number conservation, and physics beyond the standard model[J]. Progress in Particle and Nuclear Physics, 2013, 71: 75-92.

[2]. Lee M J. Comet Muon conversion experiment in J-PARC[J]. Frontiers in Physics, 2018, 6:133.