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Application of silicon strip detector to μSR measurement at J-PARC MLF

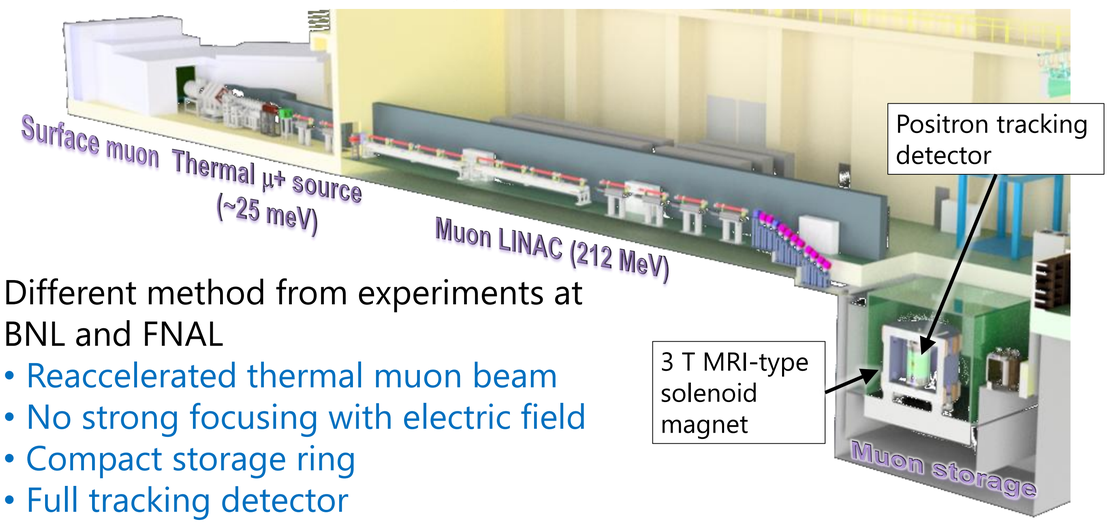
Takashi Yamanaka[1], Yutaro Sato[2], Soshi Takeshita[3], Masatoshi Hiraishi[3], Ryuto Azuma[2], Katsunori Awa[4], Yuta Okazaki[5], Shinji Ogawa[5], Tetsuishi Kishishita[6], Tatsuya Kume[7], Naohito Saito[5], Osamu Sasaki[5], Taiki Sato[8], Masayoshi Shoji[5], Shohei Shirabe[9], Taikan Suehara[10], Junichi Suzuki[5], Toshimi Suda[11], Yoshiaki Seino[12], Hiroshi Sendai[5], Toshikazu Takatomi[7], Manobu M. Tanaka[5], Shunsuke Doi[4], Junji Tojo[9], Seiso Fukumura[2], Yowichi Fujita[5], Yuki Honda[11], Ryotaro Honda[5], Tsutomu Mibe[5], Hiroshi Yamaoka[5], Tamaki Yoshioka[13]

[1] *Faculty of Arts and Science, Kyushu University,* [2] *Graduate School of Science and Technology, Niigata University,*
[3] *Institute of Materials Structure Science, High Energy Accelerator Research Organization,* [4] *Graduate School of Science, Kyushu University,*
[5] *Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization,* [6] *Physikalisches Institut, University of Bonn,*
[7] *Mechanical Engineering Center, High Energy Accelerator Research Organization,* [8] *Graduate School of Science, University of Tokyo,* [9] *Faculty of Science, Kyushu University,*
[10] *ICEPP, University of Tokyo,* [11] *RARiS, Tohoku University,* [12] *National Institute of Technology, Toyama College,* [13] *RCAPP, Kyushu University*

Abstract A silicon strip detector has been developed for positron tracking from muon decay at the J-PARC muon *g*-2/EDM experiment. The detector is composed of silicon strip sensors with a strip pitch of 190 μm and features a readout with a 200 MHz sampling clock. It can be operated at 25 Hz on the J-PARC MLF muon beam line. The application of the detector to μSR measurement at J-PARC MLF is being considered. The specifications of the detector and its prospects for μSR measurement is presented in this article.

J-PARC muon *g*-2/EDM experiment

J-PARC muon $g-2$/EDM (E34) experiment [1] aims to measure
- muon $g-2$ with a precision of 0.46 ppm
- muon EDM with a sensitivity of 1.5×10^{-21} e・cm

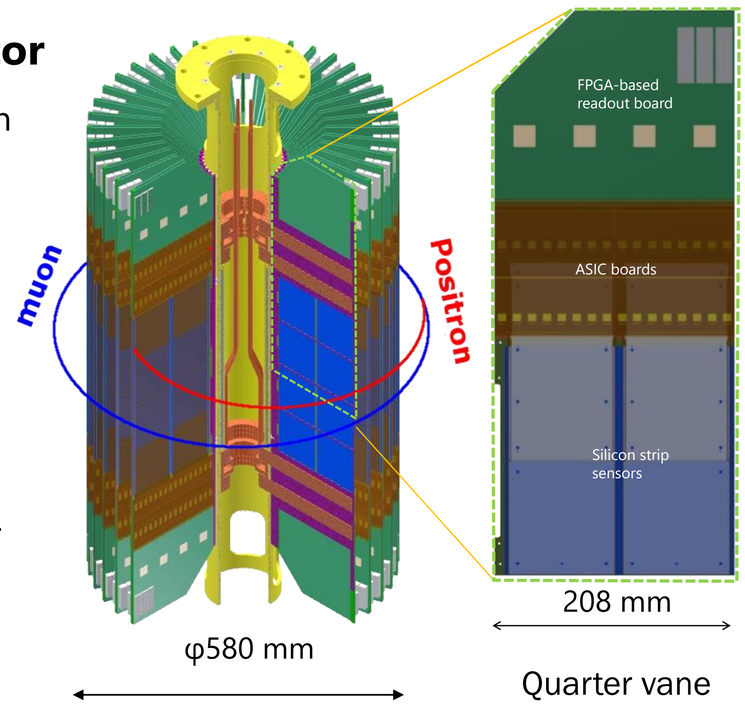


Different method from experiments at BNL and FNAL
- Reaccelerated thermal muon beam
- No strong focusing with electric field
- Compact storage ring
- Full tracking detector

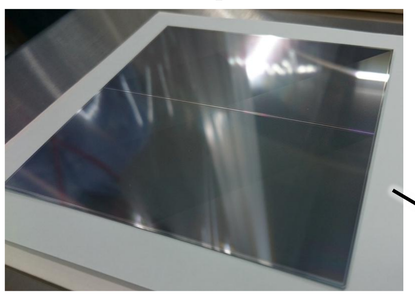
Positron Tracking Detector

Positron tracks from stored muon decays are detected by a silicon strip detector.
- The detector consists of 40-vane like modules.
- One vane consists of four quarter vanes.

Requirements on the detector
- Operate in 3 T magnetic field and 0.1 atm vacuum
- Tolerate 6 muon decays/ns for detection
- 10 μrad accuracy (in r-z plane) for sensor alignment



Silicon Strip Sensor

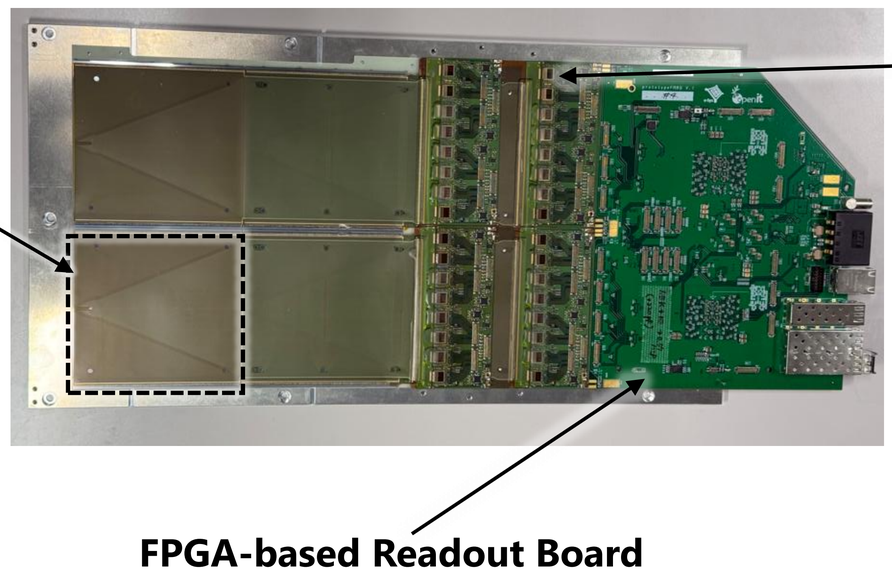


S13804 (Hamamatsu Photonics K.K.)

Sensor type	p^+ on n
Size	98.77 mm × 98.77 mm
Active area	97.28 mm × 97.28 mm
Strip length	48.365 mm
Thickness	320 μm
Strip pitch	190 μm
Number of strips	512 × 2 blocks

Detection efficiency (99.8% at 0.3 MIP threshold) and time resolution (3.4 ns at the bias voltage of 120 V) were evaluated with the previous version of the detector module [2].

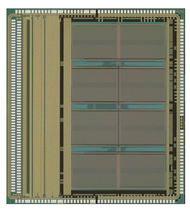
Prototype Quarter Vane



FPGA-based Readout Board

- Two FPGAs (XC7A200T-1FFG1156C) process digital output of 32 ASICs and send data through the SFP transceiver.
- Data readout test was succeeded up to 720 k hits/event (720 Mbps), which correspond to 176 hits/strip.

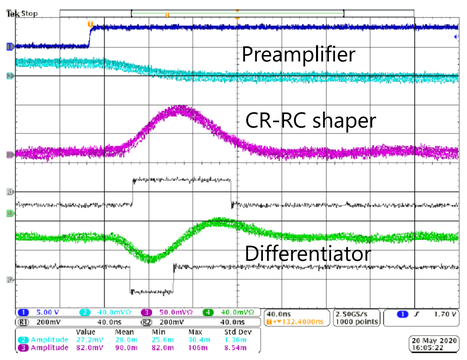
Readout ASIC



SliT128D

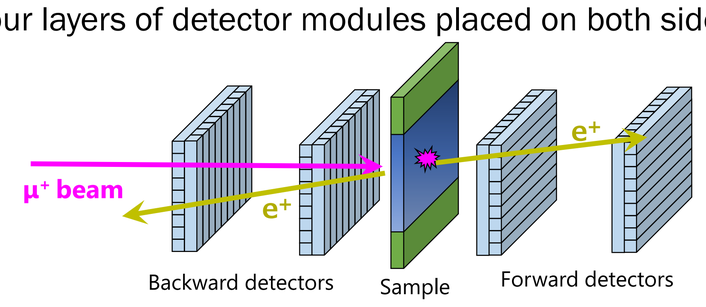
Process	SilTerra 0.18 μm CMOS
Size	6580 μm × 7240 μm
Sampling rate	200 MHz (nominal)
Repetition rate	25 Hz (nominal)
Time buffer	8192/channel
Number of channels	128/chip

Output waveforms
- Preamplifier (analog monitor only)
- Semi-Gaussian waveform (CR-RC) as shaper output
  * A hit is detected with typically 0.3 MIP threshold.
  * ENC = 1547 e^- at C_{det}=33 pF
- Differentiator output
  * Zero-cross timing is used for hit time determination
  * Time walk < 1 ns was confirmed [3].

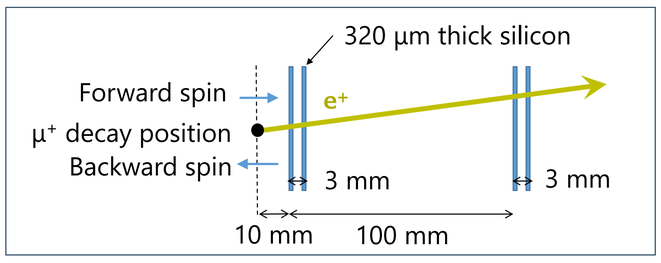


Application to μSR Measurement

Application of quarter vanes to μSR measurement is being considered at J-PARC MLF. The quarter vanes are suitable for use with the J-PARC muon beam, which has a repetition rate of 25 Hz. The data acquisition window of 40.96 μs and a time stamp of 5 ns are appropriate for detecting decay positrons from stopped muons. In our μSR measurement, not only the time spectrum of the decay positrons but also determination of muon decay positions are considered using four layers of detector modules placed on both sides of the sample.

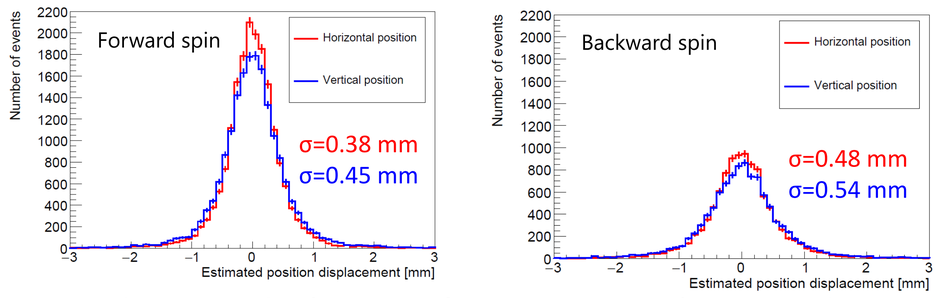


Concept of detector layout for μSR measurement



Simulation setup

The expected position resolution, when placing the nearest detector layer 10 mm from the muon decay point, was estimated using Geant4 simulation. Horizontal and vertical decay positions are determined by linearly extrapolating the hit positions at the respective detection layers. Even when the muon spin direction is opposite to the detectors, the estimated position resolution remains better than 1 mm. By determining the muon decay position with such high precision, position-dependent μSR measurements will become feasible.



Estimated position displacement from Geant4 simulation. 100 k muon decay events were simulated for each condition.

Summary A silicon strip detector is currently being developed for the J-PARC muon g-2/EDM experiment to track positrons from muon decay. This detector incorporates features optimized for muon experiments at J-PARC MLF. Its application to μSR measurements is also under consideration, along with a detector layout designed to determine the muon decay position. Under simulated conditions, a position resolution better than 1 mm is expected, enabling position-dependent μSR measurements.

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References

[1] M. Abe *et al.*, "A New approach for Measuring the Muon Anomalous Magnetic Moment and Electric Dipole Moment", PTEP 2019, 053C02 (2019)
[2] T. Aoyagi *et al.*, "Performance evaluation of a silicon strip detector for positrons/electrons from a pulsed a muon beam", JINST 015 P04027 (2020)
[3] T. Kishishita *et al.*, "SliT: A strip-sensor readout chip with subnanosecond time walk for the J-PARC muon g-2/EDM experiment", IEEE TNS 67 2089-2095 (2020)