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DEVELOPMENT OF THE LONGITUDINAL BEAM MONITOR WITH HIGH TIME RESOLUTION FOR A MUON LINAC IN THE J-PARC E34 EXPERIMENT

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Abstract

The J-PARC E34 experiment aims to measure the muon anomalous magnetic moment and the electric dipole moment with a high precision. In this experiment, thermal muonium is produced and ionized by laser resonance to generate ultra-slow muons, which are then accelerated in a multistage muon linac. In order to satisfy the experimental requirements, suppression of the emittance growth during the acceleration is necessary. Because the main cause of the emittance growth is beam mismatching between the accelerating stages, the transverse and longitudinal beam monitoring is important. The longitudinal beam monitor has to measure the bunch length with the resolution equivalent to tens of picoseconds, which is 1% of the acceleration phase of 324 MHz. In addition, it should be sensitive to single muon because the beam intensity is limited during the commissioning phase. To realize above requirements, we are developing a longitudinal beam monitor with a micro channel plate, and the test bench to evaluate the monitor performance. So far, the time resolution of the beam monitor was obtained to be 65 ps in RMS including the jitter on the test bench. We also succeeded in measuring the longitudinal bunch size of the muon beam accelerated by RFQ using the beam monitor. Further improvement of the measurement system is needed to guarantee the required accuracy. In this paper, the results of the performance evaluation for this beam monitor are reported.

INTRODUCTION

One of the physical quantities expected to be sensitive of new physics is the muon anomalous magnetic moment ($g-2$). The muon $g-2$ has been measured with 0.54 ppm precision by the E821 experiment at Brookhaven National Laboratory [1]. The result indicates a deviation of more than 3 σ from the Standard Model prediction [1,2]. The J-PARC E34 experiment aims at a measurement of the muon $g-2$ with a precision of 0.1 ppm and the muon Electric-dipole-Moment (EDM) at 10^{-21} e · cm with a novel method [3].

In order to reduce the main systematic errors in the previous experiment, a low-emittance muon beam is used in the J-PARC E34 experiment. It is achieved by re-acceleration of ultra-slow muons with a kinetic energy of 25 meV generated from thermal muonium production and laser dissociation [4]. The muons are accelerated to 212 MeV by a muon linac as shown in Fig. 1. The acceleration frequency is 324 MHz for RFQ [5] and IH-DTL [6], and 1296 MHz for DAW-CCL [7] and DLS [8]. Table 1 shows main parameters of the muon linac. The design beam intensity is 1×10^6 /sec. At the commissioning stage, the beam intensity is limited by the ultra-slow muon source and expected to be order of single muon per pulse.

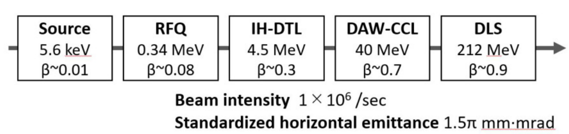

Figure 1: Schematic of the muon linac [3].

Table 1: Main Parameters of the Muon Linac [9]

Particle	μ^+
Energy	212 MeV
Beam intensity	1×10^6 /sec
Repetition rate	25 Hz
Beam pulse width	10 ns
Normalized transverse emittance	1.5 π mm mrad
Momentum spread	1%

In order to satisfy the experimental requirement, beam matching between the acceleration cavities is important to avoid the emittance growth. A beam profile monitor was already developed for beam diagnostic in the transverse direction [10]. The longitudinal beam matching is important especially in the IH-DTL because the IH-DTL adopts an alternative phase focusing (APF) scheme; there is a strong correlation between the longitudinal and transverse directions in the APF scheme, and the longitudinal mismatch results in emittance growth in both the transverse and longitudinal directions.

A longitudinal beam monitor has been developed for the beam diagnostic between the RFQ and IH-DTL. Figure 2 shows expected distribution in the longitudinal direction at

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the IH-DTL entrance. The longitudinal beam monitor has to measure the bunch length with a resolution equivalent to tens of picoseconds, which is 1% of the acceleration phase 324 MHz. In addition, the beam monitor should be sensitive to single muon to be used in the commissioning stage. In order to satisfy these two requirements, we are developing the monitor with a micro channel plate (MCP) which has excellent time resolution and high sensitivity to single muon.

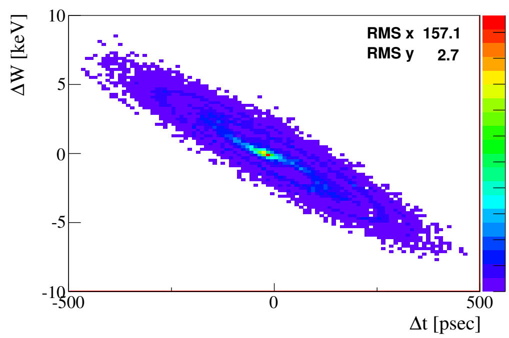

Figure 2: Expected distribution in the longitudinal direction at the IH-DTL entrance.

In this paper, first we describe the design of the beam monitor and the test bench for the performance evaluation. Then, we show the results of the evaluation. Finally, the future prospects are presented.

DESIGN OF THE BEAM MONITOR

A multi-anode MCP assembly (Hamamatsu photonics (F1217)) was used for the longitudinal beam monitor. It has two stages of chevron-type MCPs with an effective area of φ42 mm and typical gain of 10^6–10^7. The thickness of each stage was 480 μm. The channel pitch and diameter were 15 μm and 12 μm, respectively. The bias angle of the channel was 12°. The anode is divided into four to mitigate the deterioration of the time resolution due to the beam spread by the bending magnet on the basis of the momentum dispersion in the beam test experiment [12].

The Constant Fraction Discriminator (CFD) circuit is used for the readout system as shown in Fig. 3. The CFD circuit has a digital output with reduced time walk effect and an amplified analog output. The charge information is read by an ADC (0.1 pC/count), and the time information with respect to the linac RF signal by a TDC CAEN V1290, which has a time resolution about 35 ps [11].

PERFORMANCE EVALUATION

Test Bench

A test bench has been developed to evaluate the time resolution of the beam monitor. We utilize photo-electrons as signal source instead of muon in the test bench. Photo-electrons are produced at the MCP surface by irradiating a picosecond pulse laser as shown in Fig. 4.

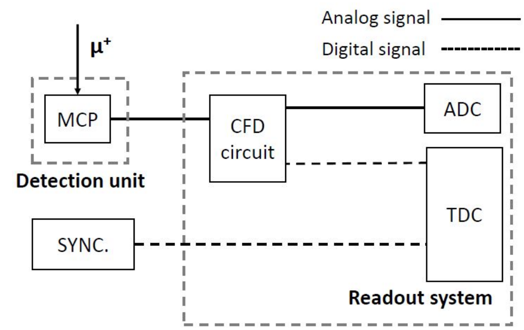

Figure 3: Readout system diagram.

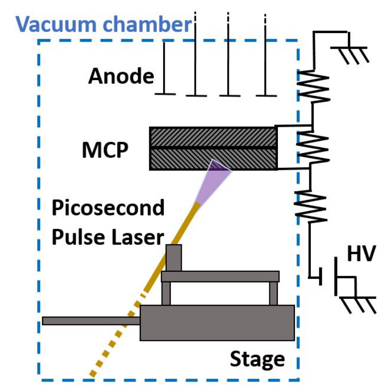

Figure 4: Configurations of the test bench.

A PLP10-040 module made by Hamamatsu Photonics K.K. is used as the laser source. The wavelength of the laser is 404 nm and the pulse width is 74 ps in FWHM. The laser trigger (SYNC in Fig. 3) is used as the timing reference. The laser fiber is placed on a two-axis stage which changes the incident position of the laser on the MCP. The time resolution at the different incident position will be measured near future. The secondary electrons emitted from the MCP surface are accelerated by the electrostatic field in MCP. The HV applied to the MCP surface, MCP exit, and the anode is -2300 V, -480 V, 0 V, respectively.

Performance of the Readout System

A digital pulse generator (DG 645, Stanford Research Systems) was used to check the performance. Two outputs from the generator were used for the measurement, which were fed into the TDC after through CFD circuit: one was as a test signal, and the other was as SYNC in Fig. 3. The interval of the two outputs was changed in the range of the actual beam measurement, and the difference of the TDC values from the two outputs was measured as shown in Fig. 5.

The, time resolution of the readout system was 30–35 ps for the output interval of 0 to 3000 ns. We concluded that the time resolution of the readout system is better than 35 ps.

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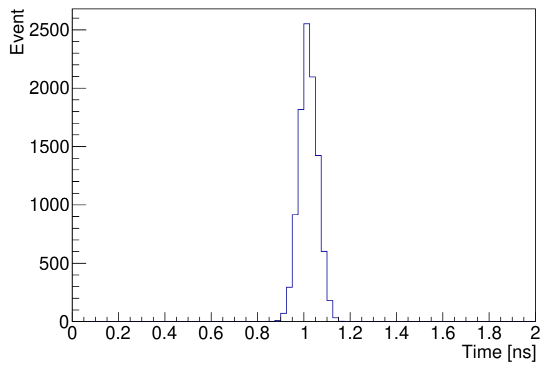

Figure 5: Time difference of the channels of TDC.

Performance of the Beam Monitor

Figure 6 shows the time distribution of the laser signal respect to SYNC. In this measurement, multi-hit events among two electrodes were rejected to avoid the crosstalk between the electrodes. Therefore, Fig. 6 plots only when there is a hit in only one channel. The RMS of the distribution is 65 ps. Because it includes the time resolution of the beam monitor and the laser pulse width, we concluded that the time resolution of the beam monitor is better than 65 ps. We are planning to perform same measurement using a faster laser pulse.

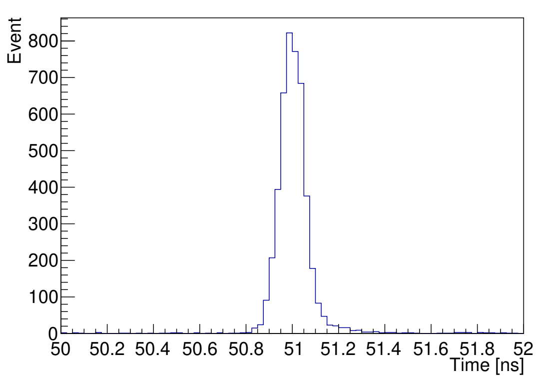

Figure 6: Measurement results after the tuning of the laser.

Figure 7 shows a two-dimensional distribution of charge and time. The horizontal axis represents time, and the vertical axis represents the charge. If serious time walk is occurred, time distribution is biased to depend on charge. Low charge is shifted toward later time, and the time resolution is worse. In Fig. 7, the timing shift depending on the charge is 30 ps, and is enough less by comparing from signal raising time of MCP which is several hundred ps. The suppression of time walk by the CFD circuit looks functioning.

Commissioning with the Accelerator

The beam monitor was commissioned with the RFQ [12] and the beam monitor performance at the actual experimental site was evaluated. During the experiment, noise events

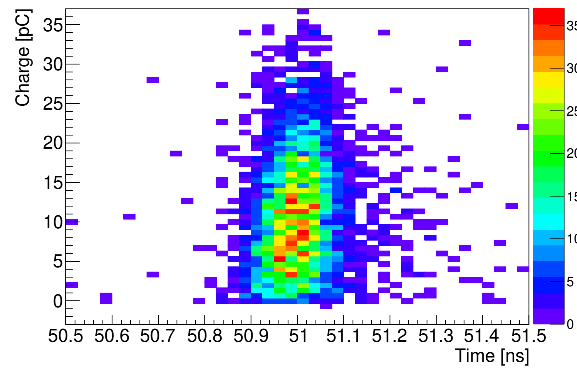

Figure 7: Two-dimensional distribution of charge and time for the MCP signal.

synchronized to the accelerator RF were observed. Because charge amount of the noise event is smaller than that of the muon signal, we succeeded in discriminating the noise event from the muon signal using the ADC data. The muon bunch width measured by the beam monitor is consistent to the simulation [12].

SUMMARY

We have developed the longitudinal beam monitor with high time resolution for the J-PARC E34 experiment. The time resolution of the readout system was measured to be better than 35 ps. The beam monitor was tested using the test bench with photo-electrons generated by pulse laser. The time resolution of the beam monitor is evaluated to be better than 65 ps Because the current precision at the test bench is limited by the laser pulse width, we are planning to perform same measurement using a faster laser pulse. In addition to that, the dependence of the time resolution on the position will be investigated.

The beam monitor was commissioned the RFQ and measured the longitudinal bunch size of the muon beam. The RF synchronized noise was discriminated by the charge information and we succeeded in measuring the bunch size.

ACKNOWLEDGEMENTS

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