FIRST TRIAL OF THE MUON ACCELERATION FOR J-PARC MUON g-2/EDM EXPERIMENT

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Abstract

Muon acceleration is an important technique in exploring the new frontier of physics. A new measurement of the muon dipole moments is planned in J-PARC using the muon linear accelerator. The low-energy (LE) muon source using the thin metal foil target and beam diagnostic system were developed for the world's first muon acceleration. Negative muonium ions from the thin metal foil target as the LE muon source was successfully observed. Also the beam profile of the LE positive muon was measured by the LE-dedicated beam profile monitor. The muon acceleration test using a Radio-Frequency Quadrupole linac (RFQ) is being prepared as the first step of the muon accelerator development. In this paper, the latest status of the first muon acceleration test is described.

INTRODUCTION

E821 experiment of Brookhaven National Laboratory measured the muon $(g-2)_\mu$ with the precision of 0.54 ppm and reported the discrepancy of more than 3 σ for the muon $(g-2)_\mu$ [1] from the theoretical prediction. More precise measurement is required in order to search the physics beyond the standard model. The J-PARC E34 experiment which aims to precisely measure the muon anomalous magnetic moment $(g-2)_\mu$ and electric dipole moment (EDM) is planned with brand new techniques [2]. The goals of the precision are 0.1 ppm for the muon $(g-2)_\mu$ and 1×10^{-21} e·cm for the muon EDM. The muon $(g-2)_\mu$ and EDM will be measured at the same time under the no electric focusing in the muon storage ring, using the ultra-cold muons (UCMs) which are produced by the new muon cooling method and the muon linear accelerator (Muon linac). The electric focusing isn't necessary for UCMs, because UCMs have a very small transverse momentum compared with the surface muon beam. The surface muons having a large emittance are stopped the muoniums (Mu: μ^+e^-) production target and become the thermal Mu. Mu are ionized by the muon ionization laser after Mu are evaporated from the surface of the production target to the vacuum. The ultra-slow muons (USMs) with the room temperature (25 meV) are produced by this procedure. The UCMs are obtained by accelerating the USMs with the muon linac.

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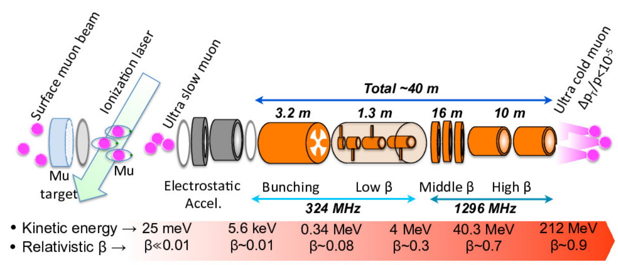

Figure 1: The conceptual diagram of the muon linac.

Figure 1 shows the conceptual diagram of the muon linac [3]. The muons are finally accelerated to 212 MeV by the muon linac.

LOW-ENERGY MUON SOURCE

The LE muon source with energy less than 5.6 keV is required in order to test the muon accelerator, since the design input energy of the initial RF accelerator (RFQ) is 5.6 keV. Negative muoniums (Mu^-: $\mu^+e^-e^-$) that are generated by the muons passing through a thin metal foil is a good candidate of the epi-thermal muon source for the muon acceleration, because the energy dispersion of the Mu^- is smaller than one of the decelerated positive muons from the metal foil [4]. Using the LE muon source like Mu^-, the muon accelerator can be tested even before the ionization laser is ready.

The beam parameters of the Mu^- should be measured in order to use the Mu^- as the LE muon source for the muon acceleration. Figure 2 shows the setup of the beam diagnostic beam line and detectors to develop the LE muon source. The incident surface muons with 4 MeV hit the thin aluminum foil target. Mu^- are produced by the electron capture at the downstream surface of the foil target. Produced Mu^- are reaccelerated to 20 keV and focused by the electrostatic accelerator called "SOA lens". Accelerated Mu^- are transported by the beam line which consists of the electrostatic deflector, electric quadrupoles and bending magnet. LE electrons produced around the electrodes of the SOA

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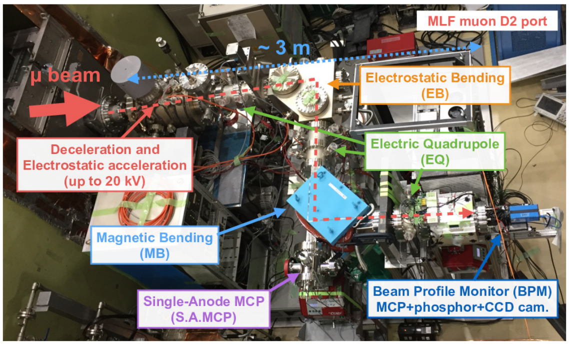

Figure 2: The diagnostic beam line for the LE muon beam using the metal foil target.

lens and transported by the beam line can become the serious background for the Mu$^-$ diagnostics. However the LE electrons can be rejected by the electrostatic deflector and the bending magnet since the energy and momentum of the particles are selected by them. The Mu$^-$ can be identified by the Time-Of-Flight (TOF) measurement. The typical TOF of the LE muons with 20 keV is about 1 μsec.

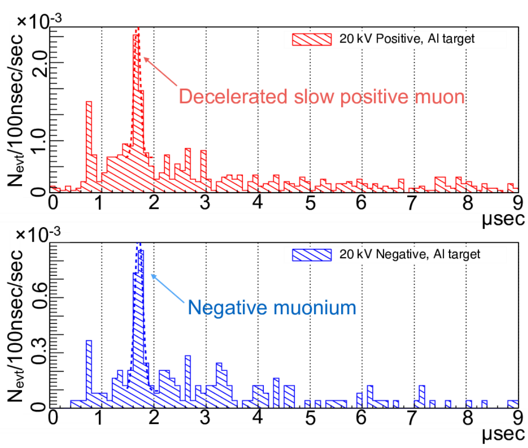

Figure 3: The top figure shows the TOF distribution of the decelerated positive muons. The bottom figure shows the TOF distribution of the negative muonium.

Figure 3 shows the TOF distributions with the positive and negative polarity setting of the diagnostic beam line. The Mu$^-$ peak of TOF can be observed in the bottom plot. The peak position of the Mu$^-$ was very close to that of the decelerated positive muons. So the first observation of Mu$^-$ in J-PARC was successful.

The beam profile should be measured in order to measure the beam emittance. The beam emittance can be measured by the Q scan method [5]. In the Q scan method, a quadrupole is set in front of the beam profile monitor and the beam profiles are measured with changing the focusing power of the quadrupole. From the relation between the focusing power of the quadrupole and the width of the beam profile, the beam emittance can be estimated by parameter fitting. Because the LE muons have too low energy to be detected with the plastic scintillator commonly used, a LE muon-dedicated beam profile monitor (LE BPM) was developed. The LE BPM consists of a micro channel plate (MCP) and a CCD camera; the MCP has good sensitivity for the LE particle and CCD camera has good position resolution. Incident LE muons are amplified by the MCP and produce secondary electrons. The produced secondary electrons are converted to photons by the phosphor screen after the MCP. Finally the converted photons are detected by the CCD camera. The position resolution of the LE BPM is better than 1 mm. The gain of LE BPM was calibrated by the several sources including LE e^-, gamma ray, UV light, H^- and surface muons.

The commissioning of the beam diagnostic line was carried out by the ion beam ahead of the muon beam profile measurement. In the commissioning with the ion beam, the misalignment of the beam line was found to be a serious problem for the beam profile measurement and had to be corrected. The misalignment of a few mm at the SOA lens caused the about 10 mm of the beam position shift at the LE BPM. Eventually the beam was transported effectively and focused at the position of the LE BPM, after tuning the alignment of the components in the beam line and voltages of the beam line .

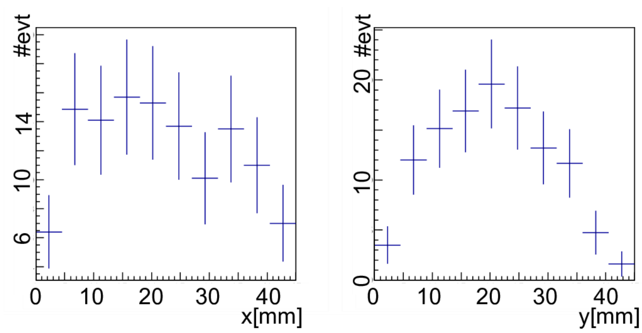

Figure 4: The projections of the beam profile of the LE positive muons decelerated by the thin metal foil. The left and right figures are for the horizontal and vertical direction, respectively. [The projections were corrected based on the geometric shape of the LE BPM. The error was only the statistical error based on Poisson distribution.]

Because the beam intensity of the LE positive muon was higher than that of the Mu$^-$, the beam profile of the LE positive muons was measured first as shown in Fig.4. In conclusion, the beam diagnostic system including the beam line and LE BPM was demonstrated for the muon acceleration test.

FIRST MUON ACCELERATION

The first trial of the muon acceleration using the muon source and the LE beam diagnostic system is planed at the muon test beam line (D line) in the J-PARC Material and Life science Facility (MLF). The prototype RFQ (Fig.5) of the J-PARC linac will be used for the muon acceleration test [6].

Figure 5: J-PARC linac prototype RFQ.

The input energy of the prototype RFQ is 5.6 keV. The structure of the prototype RFQ is similar to the first half of the RFQ which will be used for the muon linac. The surface muons are decelerated by the thin metal foil and reaccelerated to 5.6 keV by the SOA lens. Muons with 5.6 keV energy are accelerated to about 100 keV by the prototype RFQ. The diagnostic beam line after the prototype RFQ consists of the two quadrupole magnets, a bending magnet and LE BPM.

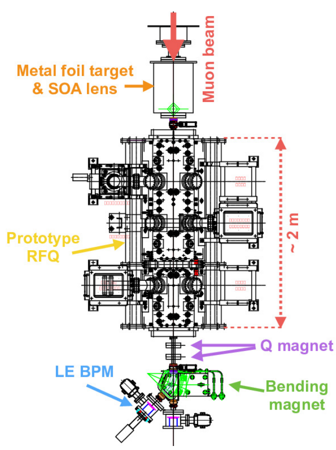

Figure 6: The latest drawing of the muon acceleration test using the prototype RFQ at the muon D line.

Figure 6 shows the latest drawing for the muon acceleration test at the D line. Figure 7 shows the simulation result by PARMTEQM assuming the developed LE muon source at the D line [7]. Detailed particle tracking simulations based on the actual setting are being developed. The setup will be constructed in this summer. The first trial of the muon acceleration is planned in this autumn.

SUMMARY

The world's first muon acceleration will open the door of new frontier of accelerator physics and particle physics. The LE muon source to be used for the commissioning of

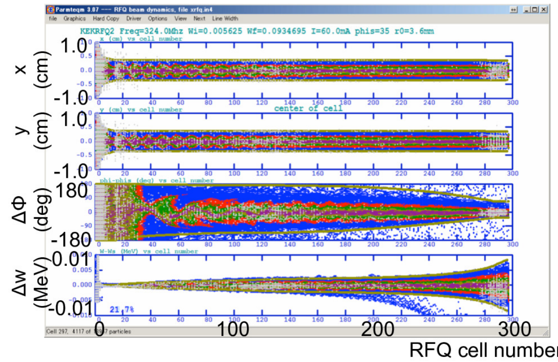

Figure 7: The particle tracking simulation of the prototype RFQ assuming the Mu^-.

the muon accelerator was developed. The diagnostic system of the LE muons was also prepared and the measurement of the LE positive muon beam profile was successfully done. The first trial of the muon acceleration with the prototype RFQ will be demonstrated in this year.

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