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TEST EXPERIMENT OF 3-D SPIRAL INJECTION SCHEME USING ELECTRON BEAM FOR NEW G-2/EDM EXPERIMENT AT J-PARC*

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Abstract

A new muon g - 2/EDM experiment is in preparation at J-PARC. This experiment will exploit the 3-D (three dimensional) spiral injection to store 300MeV/c muon beam into a 3-T MRI type solenoidal magnet with 0.66m diameter orbit. The 3-D spiral injection scheme is a brand-new idea; therefore, the demonstration of feasibility is required. The test experiment of 3-D spiral injection scheme using electron beam is under development at KEK Tsukuba campus. The test experiment is utilizing an 80keV DC Thermionic electron gun and 82.53 Gauss solenoidal magnet for the storage of electron beam into ~0.24m diameter orbit. In this paper we will describe the current status and results of 3-D spiral injection test experiment.

INTRODUCTION

The BNL(E821) [1] experiment measured the muon g-2 to an accuracy of 0.54 ppm, and there is ~3 σ discrepancy between the experimental value and the Standard Model prediction. Therefore, more precise measurement of the muon g - 2 is required. A new measurement of the muon's anomalous magnetic moment ($g-2$) and its electric dipole moment (EDM) is in preparation at the J-PARC MLF H-Line as shown in Figure 1 and aim to measure the muon g - 2 with the precision 0.1ppm and EDM with sensitivity down to 10^{-21} e .cm to search for new physics beyond the Standard Model [2].

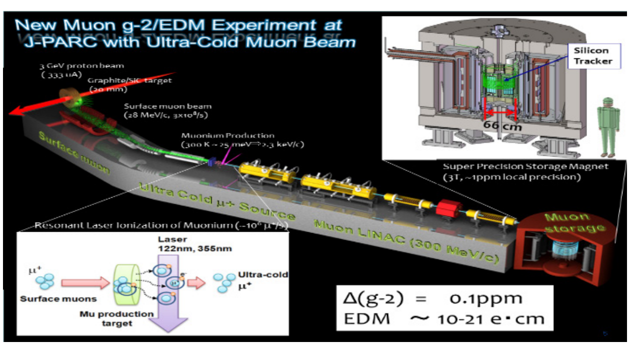

Figure 1: Schematic view of the new muon g - 2/EDM experiment at J-PARC.

In J-PARC experiment the diameter of storage orbit is only 0.66m for such a small storage orbit the BNL injection scheme is not applicable [3]. In J-PARC experiment muon beam will be injected into the storage magnet vertically following a spiral trajectory. A built-in radial field will vertically compress the helix of the muons as they approach the mid-plane, then magnetic kicker a double anti-Helmholtz coils will remove the remaining vertical momentum of the muons, hence muons will store in the mid-plane. The detail study of spiral injection scheme has been published in [3].

To demonstrate the feasibility of spiral injection scheme the test experiment using electron beam is under development at KEK Tsukuba campus. The test experiment is utilizing an 80KeV DC Thermionic electron gun and 82.53 Gauss solenoidal magnet for the storage of electron beam into ~0.24m diameter orbit. Comparison of parameters between g - 2/EDM experiment at J-PARC and test experiment is given in Table 1.

Table 1: Comparison of Parameters between g-2/EDM Experiment and Test Experiment

Parameters	g-2/EDM experiment at J-PARC	Test experiment
Storage magnetic field	3-T	82.52 Gauss
Beam particle	μ^+	e^-
Momentum	300[MeV/c]	0.370 [MeV/c]
Cyclotron Period	7.4nsec	5.0 nsec
Storage Orbit diameter	0.66m	0.24m

In test experiment fluorescence screen monitors are used to perceive electron beam along the beam line. We have successfully transported DC electron beam from electron gun to inside of storage chamber through a dipole magnet. We will fill storage chamber with N_2 gas to observe electron beam as visible light due to ionization along beam track. We are now under trial operation for a stable storage using weak focusing. Our initial results of electron beam injection into the storage magnet are also presented.

OVERVIEW OF TEST EXPERIMENT

Figure 2 represent the entire beam line and storage magnet. Straight beam line is 2m long including electron gun and the height of solenoidal magnet is 1.9m from the ground. The height of electron gun is 80cm from the ground therefore we bend electron beam at 40° using dipole magnet to inject it into the storage chamber. In this section we will briefly describe some important component of test experiment and their specification.

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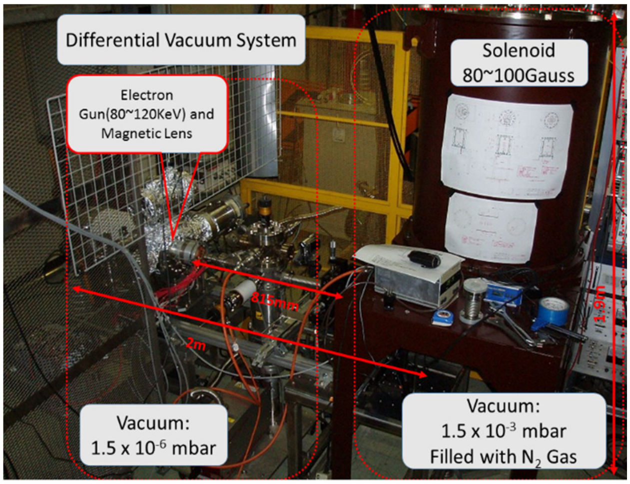

Figure 2: Photo of test experiment setup at the KEK-LINAC building.

Electron Gun

In test experiment we are using a triode type thermionic electron gun with LaB_6 cathode. The maximum power supply available for electron gun is 200keV but in first step we are operating it at 80keV and beam intensity is ~10nA. After electron gun we use magnetic lens to focus electron beam.

Differential Vacuum System and Collimator

In straight section of beam line, we require high vacuum to protect electron gun and transfer electron beam without any disturbance but in storage chamber we need medium vacuum to fill it with N_2 gas to observe fluorescence light due to ionization of nitrogen gas along beam path. Differ-

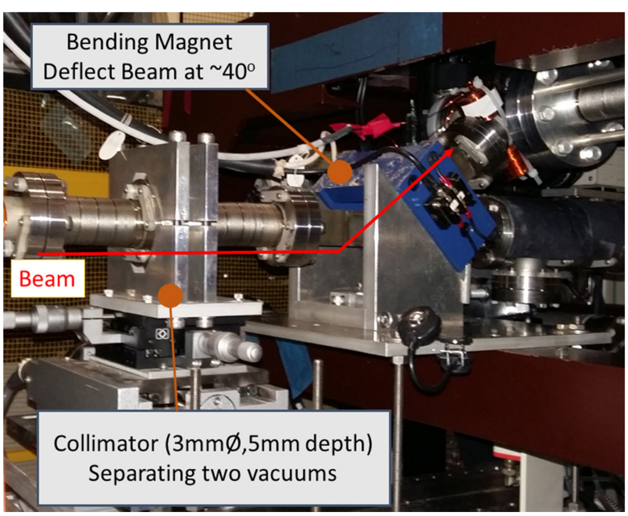

Figure 3: Collimator and Bending magnet.

ential vacuum pumping has been employed to maintain high vacuum ($1.5 \times 10^{-6}\ mbar$) in straight beam line and medium vacuum ($1.5 \times 10^{-3} mbar$) in storage chamber. A collimator of 3mm diameter and 5mm depth is used to separate two vacuum regions. Figure 3 is showing the collimator and bending magnet. Collimator is also reducing a beam halo and related backgrounds.

Bending magnet

After straight section we have a bending magnet to deflect the beam at 40°. Figure 4 is showing the bottom view

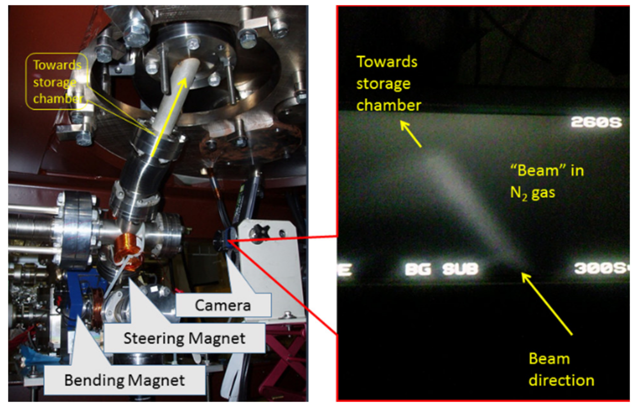

Figure 4: Left: Injection region view. Right: Electron beam trajectory in N_2 Gas.

of storage chamber and beam trajectory in N_2 gas after 40° bend by bending magnet. We covered our apparatus with curtains while taking this picture to avoid any background light. At the injection region we also installed two fluorescent plates. First plate was mounted at 40° degree with re-

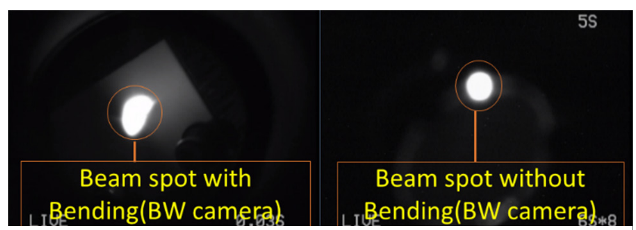

Figure 5: Electron beam spots at fluorescent plate. Left: Beam spot at fluorescent plate after bending. Right: Beam spot without bending magnet.

spect to straight section after bending magnet while the second plate was placed at straight section. We can move these fluorescent plates remotely to control the position of them. Figure 5 represent the situation when plates were in the way of beam, left: shows the beam spot after bending the beam at 40°, right: represent beam spot without bending. These pictures are taken by a Black and White Hamamatsu CCD camera.

STORAGE MAGNET

Storage magnet is a solenoidal electromagnet placed inside a cylindrical iron yoke. Auxiliary coil was mounted on the middle of main coil for the weak focusing. The storage chamber was installed inside the solenoid magnet. Figure 6 is showing the schematic of storage magnet with reference trajectory and dimensions of coils and iron yoke.

Field measurement of Storage magnet

The magnetic field is measured by a Gauss meter (Lakeshore model 460) with three axis hall probe. The probe can move vertically and radially to measure the axial and radial component of solenoid magnetic field. We set the main coil current 8A and vary the current of auxiliary coil for field measurement. We have computed a single electron tracking in storage magnet field by using OPERA. Reference trajectory with radius ~12cm is shown at mid plane of storage magnet in Figure 6.

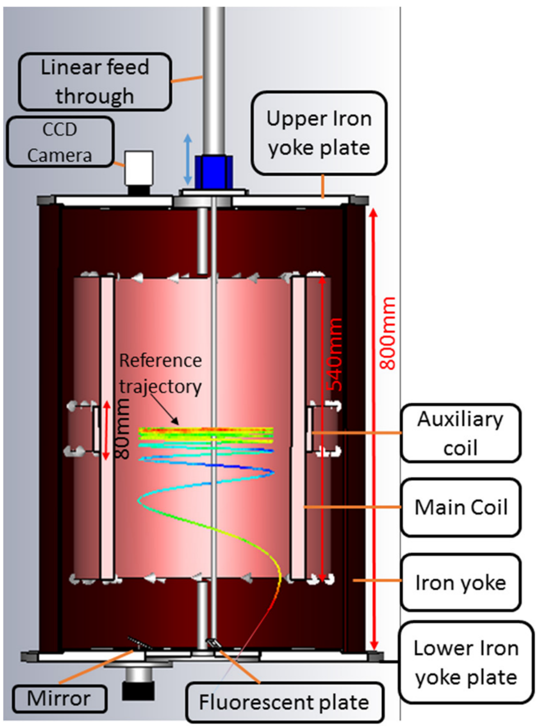

Figure 6: Schematic view of storage magnet with reference trajectory and monitors.

We also performed the simulation of storage magnet in OPERA [4]. Figure 7 is showing the field measurement result of storage magnet; main coil current is 8A, colour data represent different auxiliary coil current and grey lines are OPERA [4] results.

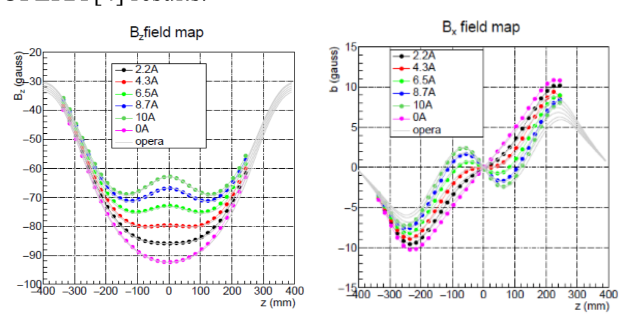

Figure 7: Left. Measurement of B_Z component as a function of vertical position. Colour data correspond to different auxiliary coil current Grey data represent OPERA results. Right: B_X component as a function of vertical position.

Figure 7, Left: represent B_Z component (vertical) as a function of vertical position, Right is showing the B_X component (radial) as a function of vertical position. B_Z component is in good agreement with OPERA at the level of few gausses. However, there is a discrepancy between measurement and OPERA results for B_X component. This discrepancy increases as we increase the value of z (vertical position). During field measurement some flanges were opened which may cause the disagreement between measured and OPERA results. We will modify our OPERA model for further confirmation.

Beam inside Storage Magnet

We mounted a fluorescent plate on linear feed through (a device to move fluorescent plate vertically and rotationally) and a mirror in front of fluorescent plate to observe beam hit at plate using a camera located on the top of storage magnet. Setup of beam monitors inside storage magnet is shown in figure 6.

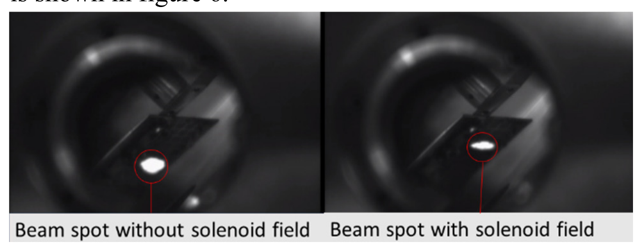

Figure 8: Camera focus on mirror. Left: Beam hit at fluorescent plate without magnetic field. Right: Beam hit with magnetic field.

We injected beam from the bottom of storage magnet and moved the linear feed through near injection point. Figure 8 left represent the beam hit at fluorescent plate without magnetic field, right shows the beam hit with magnetic field. Beam deflect ~1.5cm with magnetic field on the fluorescent plate which is in good agreement with our simulation results.

In next step we removed the fluorescent plate from the beam path and filled the storage chamber with N_2 gas. We covered the storage magnet with curtains to avoid light leak inside storage magnet. We captured the beam track by using Black and White Hamamatsu CCD camera as a visible light due to ionization of N_2 gas inside storage magnet. Figure 9 left shows the inside view of storage chamber without beam and right is representing the beam track as a visible light.

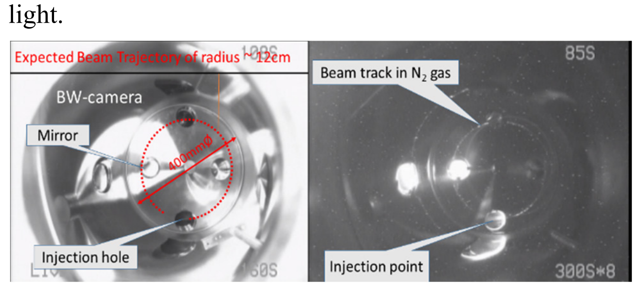

Figure 9: Left: Inside view of storage chamber without beam. Right: Beam track inside storage chamber due to ionization of N_2 gas.

SUMMARY

The 3-D spiral injection scheme is among the important techniques for the new muon g-2/EDM experiment at J-PARC. We have presented our current status of test experiment of 3-D spiral injection scheme using electron beam. Starting from the electron gun we presented electron beam at different spots along beam line. Differential vacuum system has been used to observe beam track in storage magnet. Storage magnet field measurement and simulation results have presented. We have also shown our initial results of beam track in N_2 gas.

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