Development of a Polarization Monitor for the J-PARC Muon g-2/EDM Experiment

Meng Lv[a], Xintong Cai[b], Fangyuan Yu[c], Siyuan Chen[d] and Kim Siang Khaw[d,e]

[a] *School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China*
[b] *School of Material Science and Engineering, Shanghai Jiao Tong University, Shanghai, China*
[c] *Zhiyuan College, Shanghai Jiao Tong University, Shanghai, China*
[d] *School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai, China*
[e] *Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai, China*

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ABSTRACT

The polarization monitor aims to monitor the muon spin polarization in the muonium production chamber in the J-PARC Muon g-2/EDM experiment to monitor the beam quality through muon decay asymmetry. The R&D of the detector system is divided into three phases, while the first two phases are validated using atmospheric muons. The simulation study of Phase 1, combined with the energy deposition calibration from data, can help reduce the background in which muon decays in the scintillator. Besides, the Phase 1 apparatus has been built, and the data collected shows a significant asymmetry discrepancy between polarized and unpolarized muon, making it possible to step forward further the construction of Phase 2 and Phase 3.

1. Introduction

The Standard Model (SM) has been established for more than half a century and has proven to be one of the most successful theories in describing elementary particles. Despite its achievement, there are still phenomena that could not be explained by the SM, such as the dark matter and the origin of the neutrino mass, which motivates physicists to keep searching beyond standard model (BSM) physics. In 2021, Fermilab published their measurement of the muon anomalous magnetic moment[1]. Combined with the result from Brookhaven National Laboratory in 2001[2], a discrepancy of 4.2σ between the measurement and SM prediction was shown, making the muon g-2 a promising indicator for BSM physics.

To provide a cross-check, as well as a search for the BSM through muon electric dipole moment (EDM), physicists at J-PARC proposed to use a new approach with a unique muon cooling technique to measure the muon g-2 and EDM simultaneously[3]. Figure 1 shows the muon cooling process as a part of muon production. The surface muon will hit the silica aerogel to produce muonium, which then is ionized and produce the ultra-slow muon beam. After acceleration, a much smaller beam emittance could be obtained.

During the muonium production, the polarization of the muon beam will decrease from 100% to 50%[3]. The development of the polarization monitor is to provide real-time monitoring of this polarization loss for data quality control (DQC).

The project is divided into 3 phases, as Figure 2 shows. In the first two phases, we utilize the atmospheric muon from cosmic rays to study the feasibility of the polarization monitor. The polarization is measured through the asymmetric angular distribution of decayed electrons and positrons. The absorber has two versions with different materials: Copper(Cu) and Iron(Fe). The former will not depolarize muons stopping in it while the latter does. By measuring and comparing the decay asymmetry between atmospheric muons decaying in two different absorbers, we can validate the feasibility of the polarization monitor design. Phase 1 aims at validating the idea of this cosmic-ray-based experiment. Phase 2 aims at applying the polarization monitor to the atmospheric muon. Phase 3 will install the monitor around the muon source chamber at J-PARC to test and improve its sensitivity.

meng.lv@sjtu.edu.cn (M. Lv)
ORCID(s): 0000-0002-7562-5211 (M. Lv)

2. Phase 1 Simulation and Analysis

In Phase 1, the simulation setup is shown in Figure 3. An upward muon decay event would be characterized by the detector A and B receiving both the muon signal and the decayed positron signal, namely the muon stops in the absorber and the decayed positron flies upward. Meanwhile, a downward decay event is defined as the detector A and B receiving a muon signal while C and D receive a decayed positron signal, namely the muon stops in the absorber and the decayed positron flies downward. However, the case where muons decay in detector B, which shows the same waveform structure (Figure 7) as the upward decay event, is a dominant background that will cause the systematic bias.

A Monte Carlo simulation based on GEANT4 is carried out to study the differences between muon decaying in detector B and absorber. The two cases' energy deposition distribution in detectors B and C is shown in Figure 5. The energy deposition distribution shows that muons decay in detector B deposit more energy than those decay in the Cu absorber, and an energy cut can be applied to distinguish the two cases, i.e., if energy deposition in detector B exceeds the threshold, the event is considered as decay in detector B.