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Status of the Super-Omega Muon Beamline at J-PARC

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The Materials and Life Science Facility (MLF) is currently under construction at J-PARC in Tokai, Japan. The muon section of the facility will house the muon production target and four secondary beamlines used to transport the muons into two experimental halls. One of the beamlines is a large acceptance beamline (the so called Super-Omega Muon beamline) which, when completed, will produce the largest intensity pulsed muon beam in the world. The beamline is designed to capture both surface (positive) and cloud (negative) muons for simultaneous use in a variety of experiments such as lepton flavor violation through muonium anti-muonium conversion, ultra-slow muon generation, and muon catalyzed fusion. The expected rate of surface muons for this beamline is $4\text{x}10^{8}$ μ^{+}/s,and 10^{7} μ^{-}/s for cloud muons.

The beamline consists of the normal-conducting capture solenoids, the superconducting curved transport solenoids, an axial focusing magnet, and a beam separator to separate the positive and negative muons. At the moment, the construction of the capture solenoids have been completed, and the transport solenoids are under design with prototype coils being constructed for testing during the summer. The calculation of the beamline optics involving the axial focusing magnet and the beam separator are underway with particular care to ensure their compatibility with the transport solenoids.

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1. Introduction

Muons have traditionally been used to test Standard Model (SM) predictions in a variety of manners, from the measurement of the muon anomalous magnetic moment (g-2)[1] to the search for lepton flavor violation (LFV) through neutrinoless decay modes such as $\mu \rightarrow e\gamma$ [2]. These SM tests, however, are precision experiments which require high intensity muon beams. This is also the case for the search for LFV through muonium anti-muonium conversion, which is one of the experiments that is expected to take place at the Super-Omega Muon beamline. The interest in muonium anti-muonium conversion, as in the case for $\mu \rightarrow e\gamma$, comes from the fact that while the hadronic sector shows a mixing of various quark states, the leptonic sector has shown no mixing of the various generations of leptons. This is in spite of the observation of tiny neutrino masses, discovered through neutrino oscillations[3], that can be explained by the existance of ultra heavy right-handed neutrinos which, in supersymmetric theories, can induce large LFV in the charged lepton sector. While the g-2 experiment has shown that the measured anomalous magnetic moment to be 3.4σ from the SM prediction, the observation of LFV, which would suggest an extension to SM, is yet to be observed.

At the Super-Omega Muon beamline[4], surface muons will be captured and converted into muonium by bombarding them on a tungsten target. In addition to testing for lepton flavor violation through muonium anti-muonium conversion, the muonium can be converted into ultra-slow muons via laser-resonant ionization which can be used to push μSR into the realm of surface/interface phenomenon. Although similar efforts to produce ultra-slow muons have been made at RIKEN/RAL[5], but were of limited intensity.

The 3GeV proton beam injected into the MLF is incident on a graphite muon production target in order to produce both positive and negative muons for use in various experiments. Four secondary beamlines extend out from the target, each capable of capturing and transporting muons of varying momentum into two experimental halls. The Super-Omega Muon beamline, which extends at 45° into backward angles, is capable of capturing both positive surface muons and negative cloud muons simultaneously for transport. While the beam intensities of convensional beamlines are limited, in large part, by their relatively small solid angle acceptance to capture surface muons, the Super-Omega Muon beamline will have a large solid angle acceptance of 400msr. This, combined with a high intensity primary proton beam (3GeV, 333μA), and improved focusing at the experimental target will allow the beamline to capture surface muons of higher intensity than what is currently available. Whereas conventional beamlines are capable of producing up to 10^7 surface muons/s, the Super-Omega Muon beamline will be capable of capturing and transporting 4×10^8 surface muons/s into the experimental hall.

2. Beamline Design

With a solid angle acceptance of 400msr, the capture solenoid is capable of capturing up to 5×10^8 surface muons/s and in excess of 10^7 cloud muons/s at 30MeV/c. The capture solenoids consist of four coils that are wound using radiation-resistant mineral insulation cables (MIC), with a maximum allowable current of 2000A. While the operating current at 30 MeV/c is approximately 1000A (0.3T peak central field), field measurements have been performed and seen to agree with TOSCA calculations up to 1500A. Fabrication of the capture solenoids was completed in March 2008, and is scheduled to be installed on the beamline in early 2009.

The curved transport solenoids consist of two curved sections and a 6 m straight section. It is designed to have a central field of 1.4T at 30MeV/c, and transport both positive and negative muons simultaneously into experimental hall 2. Each curved section is segmented into 7 individual solenoids connected in series with a radius of curvature of 1m in order to bend the captured muons by 45°. The transport solenoids will be cooled using a series of 1.5W Gifford-McMahon (GM) refrigirators. Currently, two segments of the curved section are being fabricated in order to perform tests to determine the feasibility of the design. A test chamber available at the cryogenics science center at KEK will be used to determine whether the expected field strength can be achieved, and to see whether the structures holding the solenoids in place are sturdy enough to withstand the mechanical stress.

The focusing magnet used for the beamline will be similar to the Dai-Omega[6] focusing magnet used at KEK, but modified to match the transport optics of the capture and transport solenoids. The focusing magnet is particularly crucial in laser-resonant ionization, since the final ultra-slow muon rate depends on how many muons can be focused to within the width of the laser pulse (~1cm×3cm). At present design, approximately $1x10^8$ surface muons/s can be focused to within this width. For LFV experiments using muonium, however, the constraints on spatial focusing are not as severe, and higher rates can be expected.

3. Summary

The Super-Omega Muon beamline is currently being built in the Materials and Life Science Facility at J-PARC. The capture section of the beamline have been built, and is awaiting installation in early 2009. The beamline is expected to produce the highest intensity pulsed muon beam in the world, allowing for the search for new physics beyond the Standard Model as well as new phenomena in material science.

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