A NEW CONTINUOUS MUON BEAM LINE USING A HIGHLY EFFICIENT PION CAPTURE SYSTEM AT RCNP

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Abstract

A new muon source with continuous time structure is under construction at Research Center of Nuclear Physics (RCNP), Osaka University. The ring cyclotron of RCNP can provide 400W 400MeV proton beam. Using this proton beam, the MuSIC produces a high intense muon beam. The target muon intensity is 10^8 muons/second, which is achieved by a pion capture with great efficiency to collect pions and muons using a solenoidal magnetic field. A pion production target system is located in a 3.5 Tesla solenoidal magnetic field generated by a super-conducting solenoid magnet. The proton beam hits the target, and backward pions and muons are captured by the field. Then they are transported by a curved solenoid beam line to experimental apparatus.The construction has been started in 2010, and would be finished in 5 years. We plan to carry out not only an experiment to search the lepton flavor violating process but also other experiments for muon science and their applications using the intense muon beam.

INTRODUCTION

The MuSIC(MUon Science Innovative Commission), being constructed at RCNP, Osaka University in Japan, is a new muon source with continuous time structure. In Japan, the MuSIC is the first facility to supply high intensity DC muon beams, while the high intensity pulsed muon beams are vailable at the J-PARC in Japan. In the MuSIC, an intensity of muon beams is expected to be 10^8 /second, which is the highest in the world. This feature enables us to study many kinds of subjects on muons in various fields, for example, searching for muon rare decay such as $\mu \to eee$ in particle physics, nuclear muon capture in nuclear physics, μSR in material science, non-destructive inspection in archaeology and studies on high-temperature super-conducting for accelerator.

In 2010, construction of the MuSIC beamline has been started at the RCNP. A capture and transport solenoids by 36 degrees have been installed in an experimental hall at the RCNP (see Fig. 1). In February 2011, with all of the solenoids excited, the first experiment to measure muon yield has been performed in collaboration with UK and successfully completed without any troubles on operation. A preliminary result of the beam test showed that muons of 10^8 /second were measured at the exit of the solenoid, which agreed with a expectation by the G4beamline[1]

simulation.

This document describes a design of MuSIC and its components. Expected rates of secondaries at the exit of the transport solenoid, simulated by the G4beamline, are also presented.

Figure 1: Pion capture and upstream proton beam line.

MuSIC BEAMLINE

A layout of the MuSIC is shown in Fig. 2. 392 MeV proton beams are provided by a cyclotron with 1 μA to a MuSIC beamline. The proton beams direct to a graphite target located in the center of a capture solenoid of 3.5 T, generating secondaries such as pions. Backward pions produced at the target are captured, then transported to following solenoids, while forward protons are directed to a beam dump. The pions are decayed into muons in the
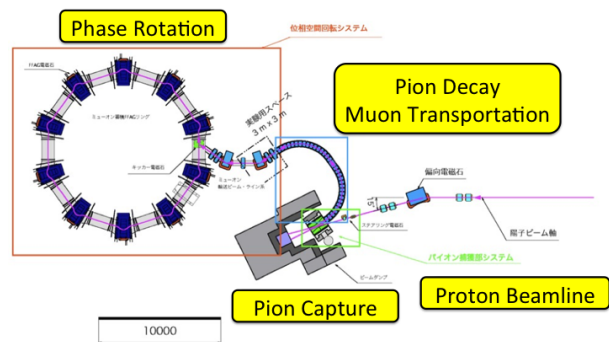

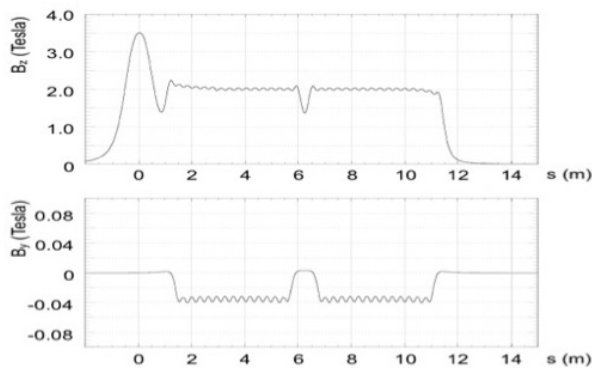Figure 2: Schematic layout of the MuSIC beamline.

Figure 3: Magnetic field in z axis (top) and y axis (bottom). The origin correspond to the target position.

transport solenoids. The transport solenoids are curved, which enables for us to select charge and momentum of muon beams. At the end of the transport solenoids by 180 degrees, a muon storage ring based on FFAG is located, where a phase rotation of muon beams is performed.

Proton Beamline

392 MeV proton beams provided from a cyclotron with 1 μA are transported to the MuSIC beamline located in an west-side experimental hall at the RCNP. At the end of the proton beamline, beam current monitors are installed to measure rates of proton beams during a running. A beam pipe is jointed at a front panel of a capture solenoid, so that beams direct to a target in the capture solenoid.

Graphite Target

A graphite target of 40 mm diameter and 20 cm length is located in the center of a pion capture solenoid. The target is fixed on a head of a target-supporting shaft of about 5 m length, so that the target is removed or inserted easily. The target is tilted by 12 degrees vertically and 20 degrees horizontally in order to penetrate proton beams along with the target since beams are bent by the magnetic force. Fluorescent plates are attached to the upstream and downstream side of the target, so that a beam center on the target can be adjusted by looking at fluorescent light on the plate in a beam tunning.

Pion Capture

A pion capture solenoid utilizes super-conducting coils to generate uniform magnetic fields of 3.5 T. The magnitude of magnetic-fields in the solenoid is shown on the top in Fig. 3. The capture solenoid has a coil of 200 mm length with 480 mm diameter. The specification of the coils is summarized in Table 1.

Radiation shields of stainless steels of 27 cm thickness are installed between the target and the coils to minimize the heat deposit on coils. The super-conducting coils are cooled down to 4K by using three GM cryocoolers. The

Table 1: Specification of Coil for Capture Solenoid

Conductor	Cu-stabilized NbTi
Cable diameter	ϕ1.2mm
Cu/NbTi ratio	4
RRR (R293K/R 10K at 0T)	230-300
Operation current	145A
Max field on axis	3.5T
Bore	ϕ900mm
Length	1000mm
Inductance	400H
Stored energy	5MJ
Quench back heater Cu wire	ϕ1.2mm $\sim$1Ω@4K

cryocoolers have cooling power of 4W at 4K in total, which is powerful enough to maintain the coils to be 4K in the circumstance of 1W heating and 0.6W heat deposit by beams. A neutron flux on the coils is estimated to be 5 x 10^{18} /m^2/year, by which no degradation by neutrons is expected. The temperature of the coils in cooling measured at the beam test is shown in Fig. 4. It shows that the capture coils can be cooled in 17 hours.

Transport Solenoid

The transport solenoids use super-conducting coils to generate uniform magnetic fields of 2.0 T. The magnitude of magnetic-fields along the solenoid is shown in Fig. 3.

The super-conducting coils are cooled down to 4K by using GM cryocoolers as the capture solenoid coils. Two sets of transport solenoids have been constructed and installed. Each transport solenoid has a coil of 200 mm length with 480 mm diameter. The specification of the transport solenoid is summarized in Table 2.

Table 2: Specification of Coil for Transport Solenoid. Parameters not shown are the table is the same as capture coil.

Operation current	145A
Max field on axis	2.0T
Bore	ϕ480mm
Length	200mm x 8 coils
Inductance	124H
Stored energy	1.4MJ
Quench back heater Cu wire	ϕ1.3mm $\sim$0.05Ω/coil@4K

There are dipole coils in the transport solenoid to generate vertical magnetic fields of 0.04 T. The specification of the dipole coil is summarized in Table 3.

The temperature of the coils in cooling measured at the beam test is shown in Fig. 4. It shows that the transport coils can be cooled in 6 hours.

Phase Rotation

At the end of the transport solenoid a muon phase ration ring based on FFAG is located. Muon beams transported

Accelerator Technology

Table 3: Specification of Dipole Coil. Parameters not shown in the table are the same as capture coil.

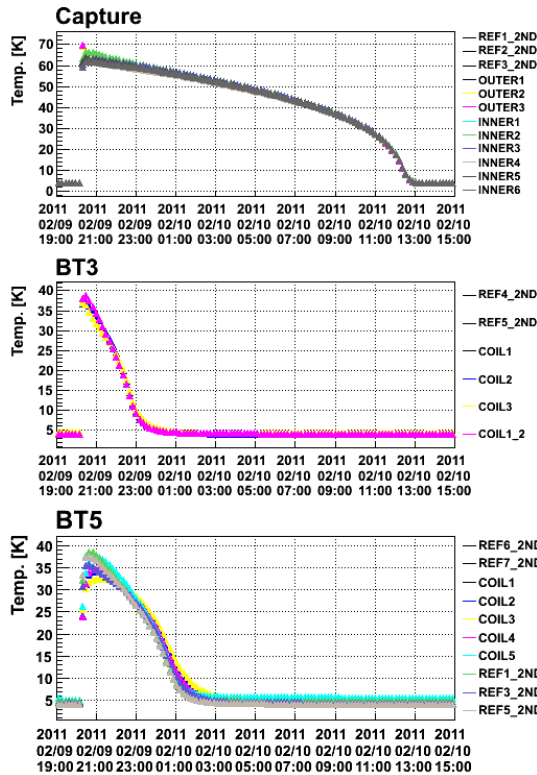| Operation current	115A (Bipolar)
Max field on axis	0.04T
Bore	$\phi460mm$
Length	200mm
Inductance	0.04H/coil
Stored energy	280J/coil

Figure 4: Coil temperature curve in cooling for capture solenoid (top), the first transport solenoid (middle) and the second transport solenoid (bottom).

through the solenoids with a large momentum spread can be injected into the large acceptance FFAG ring. A phase rotation by muon beams will be studied.

SIMULATION BY G4BEAMLINE

Using the G4beamline, rates of secondary particles at the exit of simulation are calculated. In simulation the graphite target, the capture solenoid with a iron yoke and the two transport solenoids are set. A physic list of QGSP_BERT is adopted. Kinematic energy of proton is set to be 392 MeV and no momentum bite is considered in this study. Initial position of proton is set by the Gaussian of 2 cm sigma for both x and y axis at fixed point of z. A virtual detector is set to be 10 cm apart from at the exit of solenoid to count numbers of secondaries. The result on rate of secondaries calculated with 5×10^6 protons is shown in Fig. 6, by which
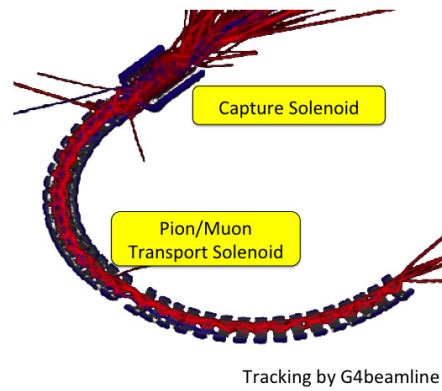

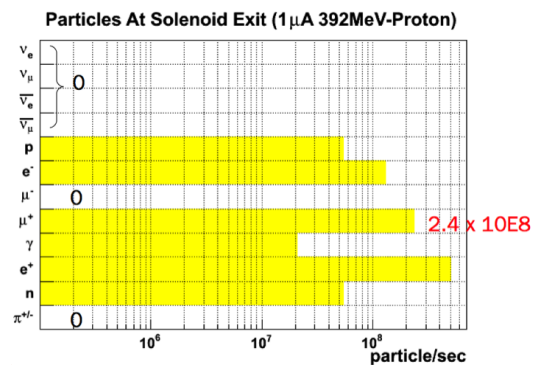Figure 5: Tracking by G4beamline from the target to the exit of the solenoid.

Figure 6: Expected rates of secondaries at the exit of the transport solenoid. The numbers are extrapolated in case of the beam current of 1 μA.

yields of muon beams is expected to be 10^8 /second in the case of 1 μA proton beams.

SUMMARY

The MuSIC, being constructed at RCNP, Osaka University in Japan, is a new muon source with continuous time structure. In 2010, construction has been started and a capture and two transport solenoids by 36 degrees have been installed. By the first beam test performed in February 2011, it is confirmed that all of the system including cooling system for super-conducting coils worked with stable.

REFERENCES

[1] http://www.muonsinc.com/tiki-index.php?page=G4 beamline.