MUSIC, THE WORLD'S HIGHEST INTENSE DC MUON BEAM USING A PION CAPTURE SYSTEM

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Abstract

MuSIC is a project to provide the world's highest-intensity muon beam with continuous time structure at Research Center of Nuclear Physics (RCNP) of Osaka University, Japan. A pion capture system using a superconducting solenoid magnet and a part of superconducting muon transport solenoid channel have been build in 2009. The highest muon production efficiency was demonstrated by the beam tests. Results of the beam test conclude that the MuSIC can provide more than 10^8 muons/sec using a 400 W proton beam.

INTRODUCTION

There are many muon related programs proposed or under discussion, such as searches for muon to electron conversion [1],[2], the neutrino factory, and muon colliders. They need an intense muon beam of 10^{11} to 10^{14} muons/sec, while the highest muon intensity currently available is about 10^9 muons/sec at PSI [3]. In conventional muon facilities, for example PSI and J-PARC MUSE, their pion/muon production targets are on a proton beam line followed by a target for a spallation neutron facility. The neutron groups impose a severe restriction on a proton beam loss at the pion/muon production target. The loss must be less than 5∼10%. Therefore, they need a MW class proton beam to reach the muon intensity of $10^{8\sim9}$ muons/sec.

In order to achieve a more intense muon beam, it is necessary to build a dedicated muon production system using new concepts to get a dramatical improvement on the pion/muon production efficiency. A pion capture system is one of the ideas for that. In the system, a thick pion production target is located on a proton beam line, and a strong solenoidal magnetic field is applied to the target region. This system is adopted in the above future muon programs. According to many simulation studies, the pion/muon production efficiency of the pion capture system can be more than 1000 time better than the conventional muon facilities. MuSIC is the first muon beam line with this type of pion capture system.

MUSIC

MuSIC is a project to provide the world's highest-intensity muon beam with a continuous time structure at Research Center of Nuclear Physics (RCNP) of Osaka University, Japan. A pion capture system has 1000 times better efficiency of muon production per proton beam power, and thus MuSIC can provide more than 10^8 muons/sec using a 400W proton beam provided by a cyclotron.

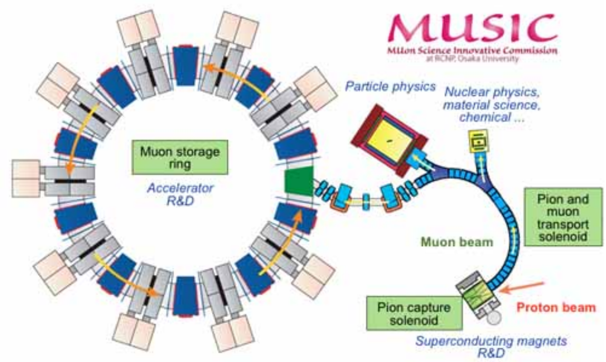

Figure 1: A schematic layout of the MuSIC.

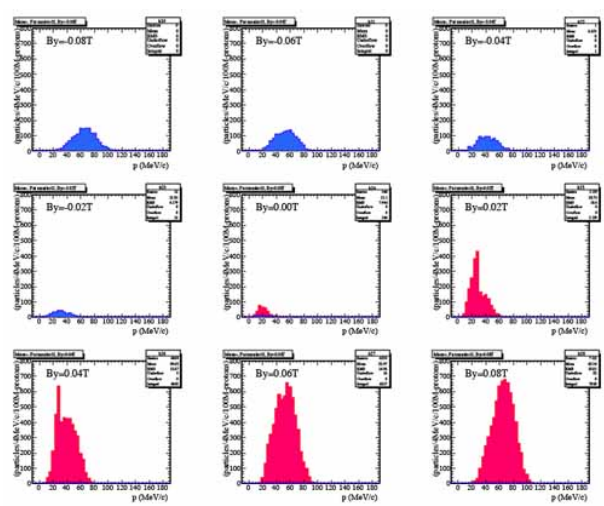

Figure 2: Simulation results of the muon momentum distributions at the end of the 180 degrees of the transport solenoid for the magnitude of the dipole field B_y from -0.08 to +0.08 Tesla. The blue histograms show the distribution of negative muons and red ones show that of positive muons.

Figure 1 is a schematic layout of the proposed system of the MuSIC. It consists of a pion capture system followed by a pion/muon transport solenoid. Both solenoid magnets are superconducting. The maximum field magnitude is 3.5 Testa and 2.0 Tesla, respectively. The transport solenoid forms a 180 degrees arc, and can make a dipole field up to 0.04 Tesla in addition to the solenoidal field to select charge and momentum of the muon beam. A detailed description on the design of the solenoid magnets is available in Ref. [4]. The ring cyclotron of RCNP can accelerate proton beams up to 400 MeV. A beam current of 1 μA is available at present, and it will be upgraded to 5 μA in the near future. The proton beam hits a cylindrical graphite target of 4 cm in diameter and 20 cm long. The produced pions and muons are captured by the pion capture system and delivered to experimental areas through the transport solenoid.

Figure 2 shows momentum distributions simulated by g4beamline [5] for muons at the end of the 180 degrees of the transport solenoid. The expected muon yield is more than 10^8 muons/sec with 392 MeV, 1 μA proton beam for both charges of muons.

We plan to use the muon beam for various experiments not only for particle physics, but also nuclear physics, material science with the μSR method, and accelerator R&D such as muon phase rotation [6].

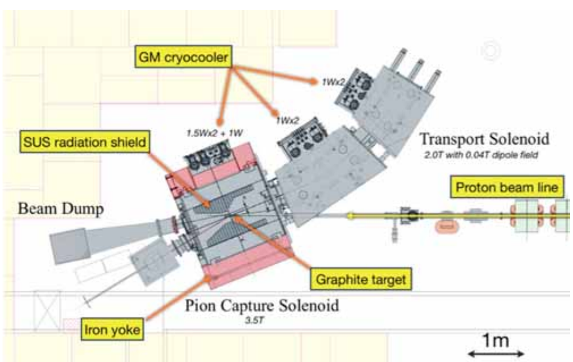

Figure 3: A drawing of parts of the MuSIC built in 2009.

CONSTRUCTION

MuSIC is now under construction at the west-experimental hall in RCNP of Osaka University. The construction was started in 2009, and would be finished in 4 years hopefully. The pion capture system and the transport solenoid up to 36 degrees was constructed in 2009, and successfully operated in 2010. Figure 3 shows a drawing of the constructed parts. A proton beam line, named WSS, was rebuilt and optimized for MuSIC. A photograph of the MuSIC is shown in Fig. 4.

BEAM TESTS

Three beam tests have been already performed to check the performance of the muon beam from MuSIC. Proton

Figure 4: Photograph of the MuSIC system taken in August 2010.

beams with up to 10 nA were injected to the graphite target. All systems were successfully tested in this configuration. Figure 5 shows the simulated momentum distributions and beam profiles at the end of the 36 degrees transport solenoid. Detectors and a stopping target were located at the end of the solenoid as shown in Fig. 6 and 7. Two plas-

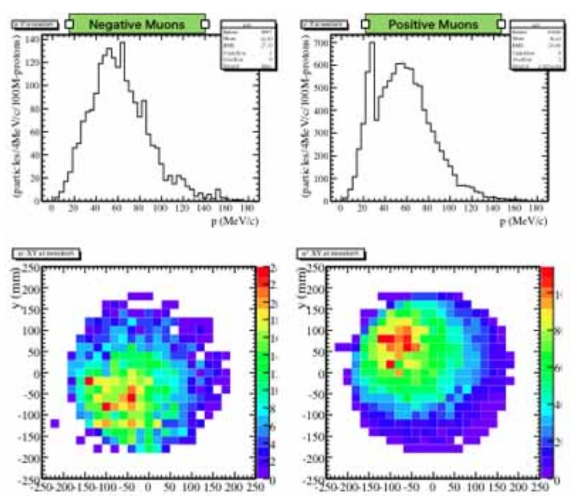

Figure 5: Simulation result to predict momentum distributions (up) and beam profiles (down) for negative (left) and negative (right) muons, respectively.

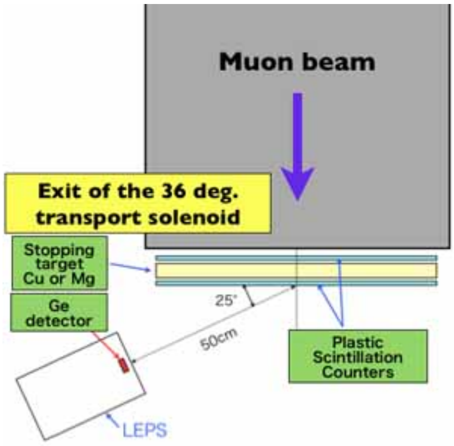

Figure 6: An illustration of the detector layout of the third MuSIC beam test in June, 2011.

Figure 7: Picture of detectors for the third beam test.

tic scintillators were used to make trigger signals to select stopped muons in the stopping target. Figure 8 and 9 show results of the muon lifetime and muonic X-ray measurements. An expected muon yield for the full proton beam current (1 μA) was estimated from the both results. Although the data analysis is still underway, preliminary results indicate that more than 10^8 muons/sec is achievable with the full current proton beam.

We will have another two beam tests in this year, the proton current will be increased to the 1 μA.

SUMMARY AND PROSPECTS

Aiming to provide the worldfs highest intensity DC muon beam, MuSIC is under construction at RCNP, Osaka University. The beam tests showed that more than 10^8 muons/sec is achievable with a 392 MeV, 1 μA proton beam. The next important step is a beam test with a 1 μA proton beam to check operation under a high radiation environment. We will also plan to continue the construction of MuSIC, which will be finished in 4 years.

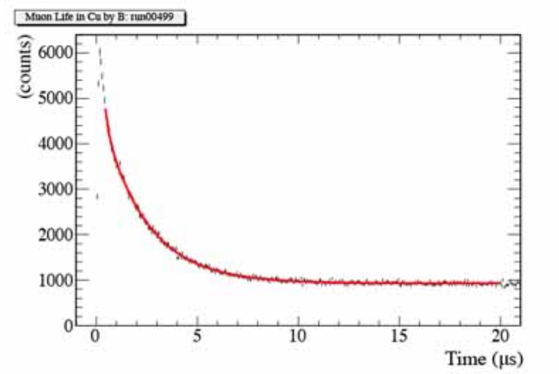

Figure 8: A time distribution of the decay electrons for the muon life measurement. A Cu plate was used as the stopping target. The red curve is a fitting result to the function.

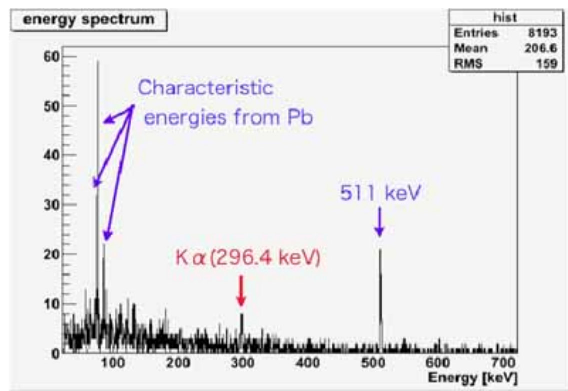

Figure 9: Energy spectrum measured by the Ge detector. A Mg plate was used as the stopping target. A peak of K_α muonic X-rays from a Mg muonic atom is at 296.4 keV.

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