A new intense DC muon beam from a pion capture solenoid, MuSIC

Y. Hino[1]**, I. H. Hashim, Y. Kuno, A. Sato, H. Sakamoto, N. H. Tran, M. Truong**
Department of Physics, Osaka University
1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan

K. Hatanaka, M. Fukuda
Research Center of Nuclear Physics (RCNP), Osaka University

T. Ogitsu, A. Yamamoto, M. Yoshida
High Energy Accelerator Research Organization (KEK)

Y. Mori
Kyoto University Research Reactor Institute

S. Cook, A. Edmonds, M. Lancaster, M. Wing
Department of Physics, university of College London

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 2010. The highest muon production efficiency was demonstrated by the beam test carried out in February 2011. The result concludes that the MuSIC can provide more than 10^9 muons/sec using a 400W proton beam. The pion capture system is one of very important technologies for future muon programs such as moon to electron conversion searches, neutrino factories, and a muon collider. The MuSIC built the first pion capture system and demonstrate its potential to provide an intense muon beam. The construction on the entire beam channel of the MuSIC will be finished in five 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 at RCNP. The design performance has been confirmed by results of muon yield estimations from several beam tests.

36th International Conference on High Energy Physics
July 4-11, 2012
Melbourne, Australia

---

[1] Speaker, E-mail:`y-hino@kuno-g.pnys.sci.osaka-u.ac.jp`

1. The MuSIC system

A high intense muon beam source, MuSIC, is now under construction at Research Center of Nuclear Physics (RCNP), Osaka University (Fig.1). MuSIC consists of a proton beam line, a pion production target with a pion capture solenoid, curved muon transport solenoids and a muon storage ring. It can achieve muon intensity of 10^8 per second, using 392MeV and 1 micro A proton beam provided by the ring cyclotron, since the pion capture system improves the muon collection efficiency dramatically. Such a high intense muon beam will be used in various fields, for example, not only particle physics but also nuclear physics, chemistry, material science, accelerator or instruments R&D and so on. The pion capture solenoid system and transport solenoids with dipole field are most unique technologies in the MuSIC system.

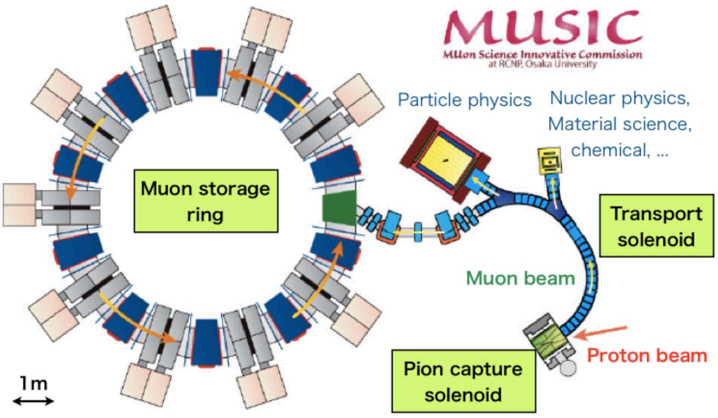

Fig. 1 Final layout of MuSIC

1.1 Pion capture solenoid

The pion and muon collection system is a key point for the highly efficient muon collection. In conventional muon facilities, there are strong limitation that proton beam loss at the pion production target must be small (~5%), because the neutron production target is located at downstream of the pion production target, so the thickness of the target must be enough thin, typical size is 2cm, and they cannot use magnetic field on the proton beam line, this limits solid angle of capture solenoid. On the other hand, in MuSIC, all protons from the ring cyclotron are used to produce pions and muons. The pion production target is very thick, 20cm long and 40mm in diameter, and it is located in a 3.5T solenoidal magnetic field. So, generated pions after proton injection into the target can be collected with a large solid angle and transported. In short, MuSIC can achieve a high muon collection efficiency with thick production target and large capture solid angle, and these techniques would be used in future experiments of particle physics which need a very intense muon beam. For example, charged lepton flavor violation searches, COMET at J-PARC and Mu2e at Fermilab, and accelerator projects such as neutrino factories, muon colliders, and so on.

1.2 Muon transport solenoids

The captured pions decay into muons during passing the curved transport solenoids, whose maximum field is 2.0T. In this, charged particles move helically, and the center of the helical orbit moves to a direction perpendicular to the plane of the torus of the curved solenoid. With an additional dipole field to the same direction of the drift, the center position of the helical orbit is restored. The magnitude of the dipole field B_y can be calculated by the following equation:

$$B_y = \frac{p}{qr}\frac{1}{2}(\cos\theta + \frac{1}{\cos\theta}),$$

where p and q refer the momentum and charge of the particle, r is radius of the torus, and θ is an angle of particle direction.

Fig.2 shows momentum distributions of muons with different B_y, simulated by g4beamline. We can select charge and momentum of the muon beam changing the dipole field.

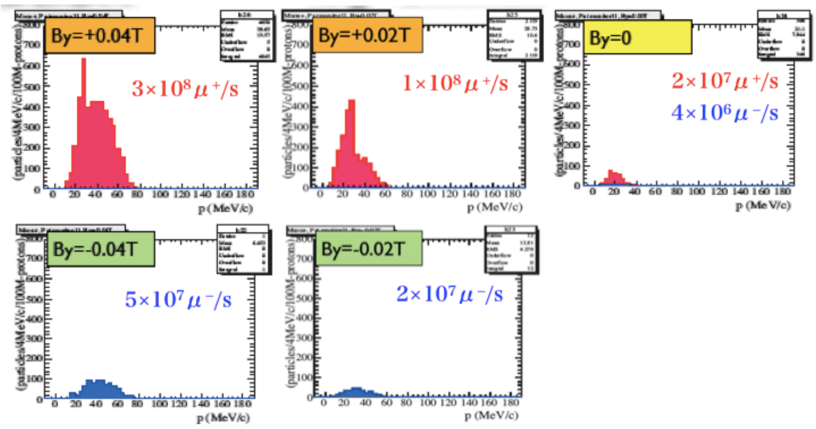

Fig. 2 Momentum distribution of muons at the transport solenoids 180 degrees exit

1.3 Expected muon beam

Using techniques above, MuSIC can provide very intense muon beam, which is same order with PSI or J-PARC MLF, but with small proton beam current. After comparison in Table, we can see that the muon collection efficiency (per beam power) of MuSIC is more than 1,000 times higher than that of the conventional facilities.

Currently, the muon transport solenoids are not completed, then the selection of muon charge or momentum is not enough, so beam is including lot of background particles (neutrons, pions, electrons, positrons, and so on) and it has wide spread of muon momentum.

Table. 1 Comparison of muon facilities in the world

	MuSIC	PSI [1]	J-PARC [2]
Beam power	0.4 kW	1200 kW	1000 kW
Muon intensity	$\sim 10^8$ /sec	$10^8 \sim 10^9$ /sec	$\sim 10^8$ /sec
Time structure	continuous	continuous	pulsed (25Hz)
Beam polarization	medium	high	high
Multiple use	only 1 channel	many channels	many channels

1.4 Construction status

The proton beam line, pion capture solenoid, and transport solenoids (36 degrees out of 180 degrees) have been constructed in 2009, and the construction of other parts will be done step by step, and it would finish probably in 2015 or 2016.

2. Beam tests at MuSIC

In 2009, we finished the construction of present equipment of MuSIC, and from 2010 to now, we have carried out five beam tests with low proton beam current less than ~500pA (because the radiation shield were not enough). To estimate the number of positive and negative muons separately, we measured muon lifetime and muonic X-rays. The experimental setup is shown in Fig.3. We used Cu and Mg metal as the muon-stopping target (Targ) and plastic scintillation counters as trigger counters (S1 and S2). Scintillators were read out by MPPCs (Multi-Pixel Photon Counter, Hamamatsu Photonics K.K.), which are not affected by magnetic field. To measure muonic X-rays, we placed Ge detector (Ge) at the place beam does not hit and put shields to protect Ge from neutrons.

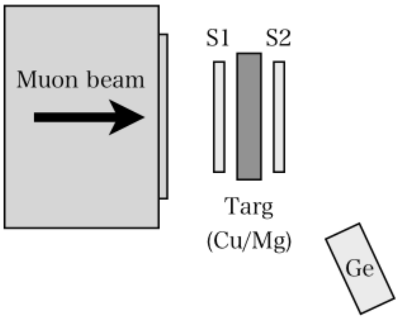

Fig. 3 Experimental setup

2.1 Muon lifetime measurement

In the material, the lifetime of negative muons τ_- is smaller than that of positive muons τ_+ because of nuclear capture effect, so we can measure the yield of them respectively. But in case of Cu target, τ_-~160ns[3] while τ_+~2.2μs, the component of negative muons is small. So in this measurement, we mainly estimated the number of positive muons in the beam. Fig. 4 left shows the time spectrum of muon decay time.

2.2 Muonic X-rays measurement

When negative muon is captured into nuclear orbit and get down to the lower level, it emits characteristic X-rays, muonic X-rays, whose energy and intensity depends on the atomic number. Using energy spectrum (Fig.4 right) from data and Geant4 simulation, we estimated the negative muon yield.

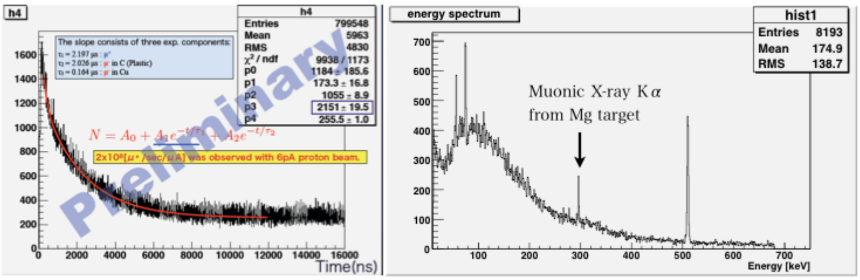

Fig. 4 Time spectrum of muon lifetime measurement (left) and energy spectrum of muonic X-ray measurement (right)

2.3 Comparison with simulation

The results of muon yield estimations are summarized in Table 2. They showed good agreement with the simulation results, so we can conclude that MuSIC system works well as designed, in the point of number of muons.

Table. 2 Number of muons in the beam [/sec /1 micro A]

	Measurement	Data	Simulation
Positive muon yield	muon lifetime	2×10^8	3×10^8
Negative muon yield	muonic X-ray	$(1.7 \pm 0.3) \times 10^8$	1.4×10^8

3. Summary

MuSIC is the high intense DC muon source in Japan, which provides very high muon collection efficiency, 10^8 muons per second, with 400W proton beam. To achieve this intensity, we adopted new techniques to set thick pion production target inside the solenoid. By muon measurements at MuSIC, we confirmed that the present system works well and obtained muon yields are consistent with designed values.

References

[1] http://www.psi.ch/

[2] http://j-parc.jp/researcher/index-e.html

[3] T.Suzuki, D.F.Measday et.al., Physical Review C 35 (1987)