THE PRISM PROJECT

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Abstract

PRISM (Phase Rotated Intense Slow Muon source) is a project to produce a pure and high brightness muon beam at low energy. PRISM aims primarily at searches for lepton-flavour-violating processes, such as μ-e conversion in a muonic atom. Energy spread of the PRISM muon beam can be narrowed by phase rotation at a FFAG (Fixed Field Alternating Gradient synchrotron) ring. The PRISM-FFAG ring with RF (Radio Frequency) cavities of a high electric field gradient, such as of exceeding 200kV/m, is being constructed at Osaka University. The construction of the PRISM-FFAG phase rotator will be completed by JFY2007. And by using it, phase rotation of a muon beam will be experimentally demonstrated.

INTRODUCTION

The evidence of neutrino oscillation is strongly indicated by the Super-Kamiokande and many other experiments. Although the phenomenon suggests new physics beyond the standard model of particle physics, naive extension with the modified massive neutrino sector would accommodate neutrino mixing and oscillation. However, the observation of lepton flavour violation processes in charged leptons would definitely indicate new physics, such as supersymmetric (SUSY) models or extra-dimension models. Lepton flavour violation has not been observed yet. It is considered that the muon system is the best to search for lepton flavour violation.

A μ–e conversion phenomenon in a muonic atom is one of the lepton flavour violating processes with muons. An electron with energy of 105MeV, which is emitted in a substance as a result of the conversion, is experimentally searched. A negative charged muon beam of low energy with narrow energy spread is required for the search to improve the electron energy resolution.

In order to obtain such a muon beam, the construction of PRISM [1] (Phase Rotated Intense Slow Muon source) is planned. It aims at mainly searches for lepton flavour violation by using a high quality muon beam. In PRISM, muon momentum is arranged to 68 MeV/c (±3%) by phase rotation. Five or more order of high sensitivity than the present experimental limit [2] on the μ–e conversion is expected in PRISM project.

PRISM OVERVIEW

Phase rotation is performed to produce a muon beam with narrow energy spread. In order to perform phase rotation, PRISM consists of a Fixed Field Alternating Gradient synchrotron (FFAG) ring with high gradient RF (Radio Frequency) cavities, of exceeding 200kV/m.

It is proposed to construct PRISM with the J-PARC 50GeV proton synchrotron (50-GeV PS) [2]. Protons extracted from the 50-GeV PS in about 10nsec time width are injected to a target. The target would be made of, such as, graphite or other materials. Muons produced from pion decays are injected to a phase rotator, PRISM-FFAG, to obtain a high quality muon beam.

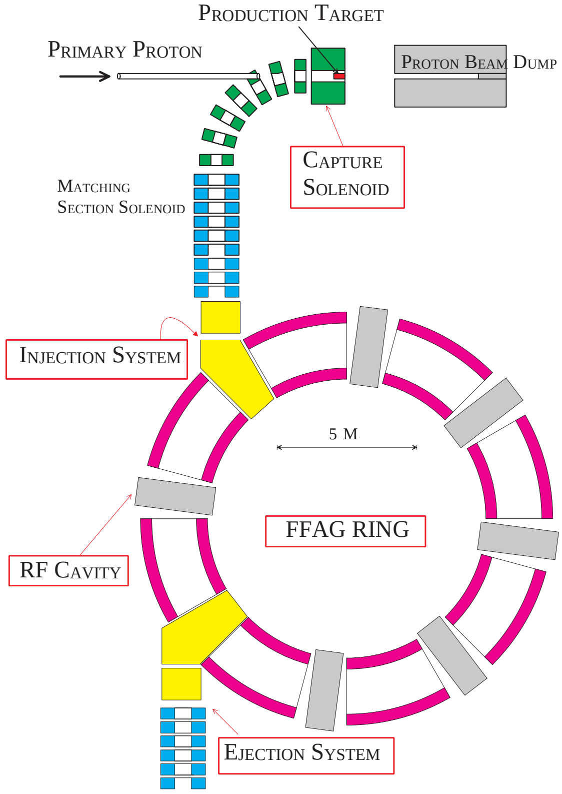

Fig.1: Schematic layout of PRISM

A schematic layout is shown in Fig. 1. As seen in Fig.1, PRISM consists of

a pulsed proton beam (to produce a short pion pulsed beam),

a pion capture system,

a pion decay and muon transport system (in a long solenoid magnet of about 10 m long), and

a phase rotation system.

In the pion-capture system, the pions produced backward from the target are collected with the solenoid magnets of about 10 Teslas. Pions decay to muons in the succeeding decay region, and muons are transported to the PRISM-FFAG to make phase rotation. A muon beam after phase rotation is extracted for experiments. The characteristics of the muon beam obtained by PRISM are as follows.

- Muon beam intensity: 10^{11}–10^{12}/sec (Proton beam intensity of 10^{14}/sec is assumed)
- Central momentum: 68 MeV/c.
- Momentum spread: ±3% (after phase rotation)

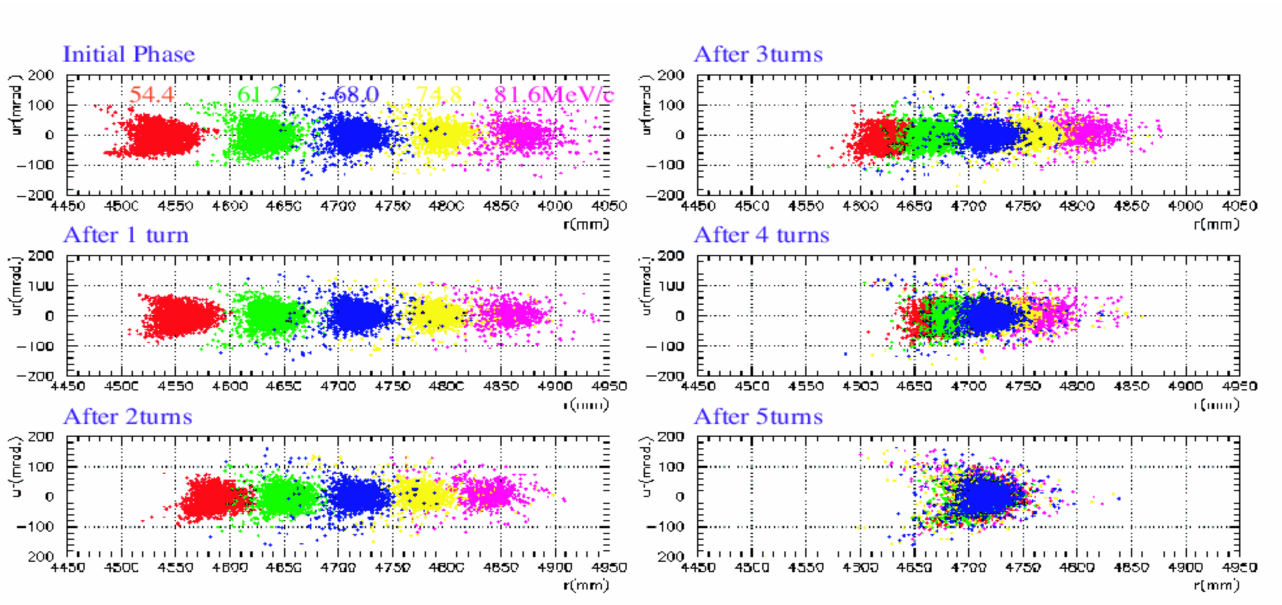

Figure 2: Horizontal phase space of the PRISM-FFAG by Monte-Carlo simulation. The left-hand upper figure shows an initial phase space at an injection, and the right-hand lower shows the one after the fifth turn. Phase space is plotted at each turns only for muons which survive in the fifth turn. Muon was injected with the momentum of 54.4MeV/c, 61.2MeV/c, 68.0MeV/, 74.8MeV/, and 81.6MeV/c, and with a time spread of ±5 nsec.

PION CAPTURE SYSTEM

Since it is necessary to stop muons in target material in a μ–e conversion experiment, PRISM aims to produce a low energy muon beam. Therefore, it is necessary to choose low energy pions generated at the proton beam target. The 50GeV protons from the J-PARC accelerator are considered to be used in PRISM.

The expected-pion momentum distribution was simulated using MARS and GEANT3.21. The transverse momentum distribution of the pion generated at the target of graphite has a peak around 100 MeV/c. Although the total momentum of the generated forward in the beam axis is distributed from 200 MeV/c up to over 400 MeV/c, the backward pions has a peak at 120 MeV/c and has smaller amount of a high energy tail, which may cause a background in a μ–e conversion experiment. Therefore, the backward pions are collected for PRISM.

In order to capture pions as many as possible at the target, a solenoid magnet with large solid angle would be used. In order to optimize the magnitudes of a solenoid magnetic field, the production and capture of pions at the target are simulated using GEANT3.21. It turns out that the more muons can be extracted from the pion decay and muon transport system, if a solenoid magnetic field is larger. It is expected that 0.2 pions can be captured per proton with a configuration of magnetic field of 6T and the inner bore radius of 10cm of a magnet.

In order to obtain a higher magnetic field, it is examined whether a superconductive solenoid magnet can be used in PRISM. Extensive studies of the pion capture system are underway.

FFAG AS A PHASE ROTATOR

In a phase rotation, slower particles are accelerated and faster particles are decelerated by high gradient RF electric fields. Assuming the initial muon beam has a momentum spread of 68MeV/c±30% and a time spread of ±5ns for each momentum region, the final momentum spread of muon beam can be reduced to less than ±3% by phase rotation.

An option to use a linear accelerator has been considered to be a phase rotator. However, since the momentum spread of the incidence muons is large, a relatively low frequency RF, ranging 1–10MHz, must be used. In this case, a total length of a linear accelerator is expected to be 150m long beam line.

On the other hand, when a circular accelerator is used, number of magnets can be reduced and a total cost can be kept down. Recently, FFAG has been demonstrated experimentally to accelerate protons at KEK. It is also suitable for the PRISM phase rotation ring, since (1) it has synchrotron oscillation, which is indispensable to phase rotation, and (2) it has large transverse acceptance and momentum acceptance to allow high intensity.

The current design of the PRISM-FFAG ring is shown in Fig.1. A radial type FFAG with eight D-F-D triplet magnets is considered. The diameter of the ring is about 10m. Two straight sections are used for injection and extraction systems. A total of 12 RF cavities are installed to the remaining straight sections.

In order to perform phase rotation efficiently, the high gradient electric field, exceeding 200kV/m, is required on RF. An RF wave shape has been studied with simulations. It shows that a saw-tooth shape could only yields narrower energy spread than a sinusoidal shape does.

Then, a saw-tooth shape RF of 5 MHz will be made with the combination of different RFs of higher harmonics frequencies of sinusoidal-shape.

A detailed design work to optimize the PRISM-FFAG parameters is now going. Experimental demonstration of high gradient RF and the PRISM-FFAG phase-rotator would be planned in Research Center for Nuclear Physics (RCNP) in Osaka University in a five-year program until JFY2007. The current parameters of PRISM-FFAG are shown in Table 1.

Table 1: Parameters of PRISM-FFAG

Parameters	Values
Central Energy	20MeV
Number of Sector	8
k value	5
Transition Gamma	2.45
Average Radius	5m
B@F/B	0.435/0.0717 T
F/2 angle	0.037 rad
D angle	0.031 rad
F/2 bend angle	26 degree
Packing f	0.18
Tune(H/V)	3.404/2.641

To study that the PRISM-FFAG ring has sufficiently large acceptance, Monte-Carlo simulation was performed. GEANT3.21 was used for tracking to take into account muon decays, scattering in iron yoke, and so on. The injected muons are assumed to have a time spread of ±5ns at each momentum, which was predicted by the simulation for the pion decay and muon transport system. A FFAG magnet produces a magnetic field B at radius R as

$$B = B_0 (R / R_0)^k \qquad (1)$$

, where R_0 is the radius of the central momentum and B_0 is the magnitude of magnetic field at R_0, and k is the field index. A 3-dimensional magnetic field of the FFAG magnets was calculated by using TOSCA and applied to the simulation code.

Figure 2 shows the result of the simulation. It is seen in Fig.2 that the closed orbits of muons with five different momenta are located in five different radii, where the lower momentum tracks are at smaller radius. The muons injected with various momenta come into an orbit of the central momentum as phase rotation goes. After 5 turns, all muons come to the central momentum and the orbit. It is noted that most of pion contamination in a beam decay out and the surviving rate is about 10-18. The result of the simulation shows that PRISM-FFAG has a very large horizontal acceptance of more than about 10,000π mm mrad and a vertical acceptance of more than about 2000π mm mrad. In this simulation, a smaller gap at high-energy side of the magnet limits the vertical acceptance. This problem can be solved with a flat yoke of the FFAG ring. A flat-gap FFAG magnet system with trim coils is being designed for PRISM, and tested by JFY2004.

FUTURE PROSPECT WITH PRISM

A neutrino factory [4] is considered as future application of PRISM. Since a FFAG ring has large acceptance, muons can be accelerated, without muon ionization cooling, up to 10 GeV or more. At a neutrino factory, neutrinos are produced from the muons decaying in a muon accumulation ring. If muons of high energy decay in the straight section of the ring, neutrinos are boosted to the forward direction, yielding an extremely high intensity neutrino source. At a neutrino factory, the discovery of new phenomena such as CP violating in the neutrino sector is expected, as well as determination of the neutrino mass hierarchy.

CONCLUSION

The PRISM project aims to construct a high intensity muon source by using phase rotation. The muon beam from PRISM is expected to have low energy of about 68 MeV/c with a narrow spread, such as ±3%.

The Letters of Intent for the PRISM project have been submitted to J-PARC. From the review committee, strong encouragement with high grade (A+) of the scientific evaluation on PRISM has been obtained. We further are strongly requesting the early realization of the experimental search for μ–e conversion with PRISM.

Regarding the PRISM-FFAG ring, high gradient RF cavities and the FFAG ring are being constructed. Phase rotation of muon beam will be demonstrated in our 5-year program by JFY2007.

REFERENCES

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