DESIGN AND CONSTRUCTION STATUS OF AN FFAG FOR THE PRISM PROJECT

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Abstract

A Fixed Field Alternating Gradient (FFAG) ring is under construction for the PRISM project. Its design and R&D status are reported in this paper.

WHAT IS PRISM?

PRISM is a project aiming to build a super-muon source, which has features of high intensity, narrow energy spread, low energy, pulsed beam, and no contamination [1]. ”PRISM” is the abbreviated name for ”Phase Rotated Intense Slow Muon beam.” Figure 1 shows a schematic layout of PRISM, which consists of mainly three sections. They are 1) a large solid-angle pion capture with a solenoid magnet field of about 10 T, 2) a $\pi-\mu$ decay section consisting of a 10-m long superconducting solenoid magnet, and 3) a phase rotation section to make the beam energy spread narrower. In order to achieve phase rotation, a fixed-field alternating gradient synchrotron (FFAG) is used. FFAG is suitable for a phase rotator of a muon beam for PRISM, since it has large momentum (longitudinal) acceptance, wide transverse acceptance with strong focusing, and synchrotron oscillation, which is needed to perform phase rotation. According to simulations, initial energy spread of 20MeV±40% is reduced down to ±6% after 5 turns of muons in the PRISM-FFAG ring. In the FFAG ring almost all pions decay into muon, hence, the extracted beam has extremely low pion contamination.

The PRISM beam characteristics are summarized in Table 1. Its aimed intensity is about $10^{11} \sim 10^{12}$ muons per sec, which is almost four orders of magnitude higher than that available at present. The muon beam will have a low kinetic energy of 20MeV so that it would be optimize for the stopped muon experiments such as searching the muon lepton flavor violating processes [2].

CONSTRUCTION OF A PRISM-FFAG

Construction of the phase rotator, PRISM-FFAG, has started in JFY 2003 as a five-year program. It is a full-size FFAG ring, which has a one-gap RF system and a kicker magnet. Using this FFAG, phase rotation, muon acceleration, and muon ionization will be studied by the end of JFY 2005.

Some challenging components, which are large aperture FFAG magnets, ultra-high field gradient RF systems and so on, are designed or under construction. In the following sections, their design and the present status are described.

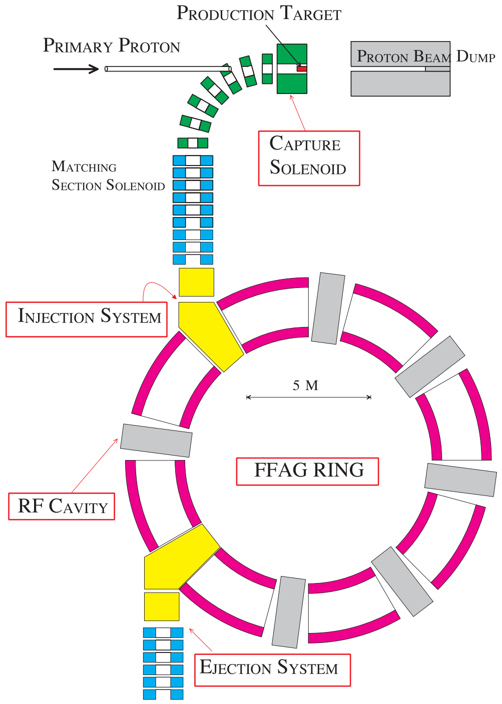

Figure 1: A schematic layout of PRISM

Table 1: Anticipated PRISM beam design characteristics

Parameters	Design goal
Beam Intensity	$10^{11} - 10^{12}\mu^{\pm}$/sec
Muon kinetic energy	20 MeV
Kinetic energy spread	$\pm(0.5 - 1.0)$ MeV
Beam Repetition	100 - 1000 Hz
Pion contamination	$< 10^{-18}$

OPTICS DESIGN

In order to achieve a high intensity muon beam, it is necessary for the PRISM-FFAG to have both of large transverse acceptance and large momentum acceptance. Fur-

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thermore, long straight sections to install RF cavities are required to obtain a high surviving ratio of the muon. Therefore, the PRISM-FFAG requires its magnets to have large aperture and small opening angle. Not only nonlinear effects but also fringing magnetic fields are important to study the beam dynamics of FFAGs with such magnets. Three-dimensional tracking is adopted to study the dynamics of FFAG from the beginning of the lattice design procedure. In this process, quasi-realistic 3D magnetic field maps, which are calculated applying spline interpolation to POISSON 2D field, were used instead of TOSCA field in order to estimate the optical property quickly [3].

Optics parameters were searched using this method to obtain larger acceptance FFAG. Present parameters and a schematic layout of the PRISM-FFAG are shown in Table 2 and Fig.2 respectively.

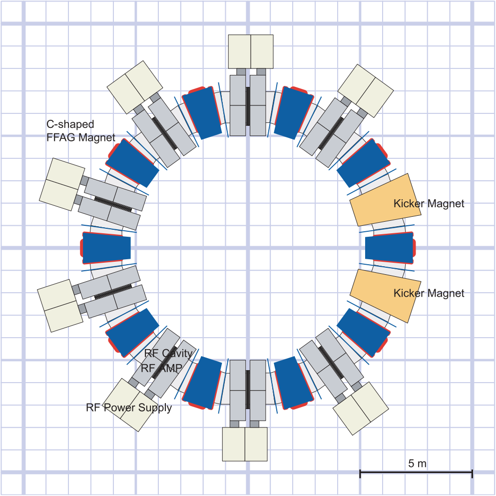

Figure 2: Schematic layout of the PRISM-FFAG

Table 2: Present parameters of PRISM-FFAG

No. of sectors	10
Magnet type	Radial sector DFD triplet C-shaped
Field index (k-value)	4.6 (variable 4.4-5.2)
F/D ratio	6.2 (variable 4-8)
Opening angle	F/2 : 2.2deg. D : 1.1deg.
Aperture	H 100cm x V 30cm
Average radius	6.5m for 68MeV/c
Tune	horizontal : 2.71 vertical : 1.52

MAGNET

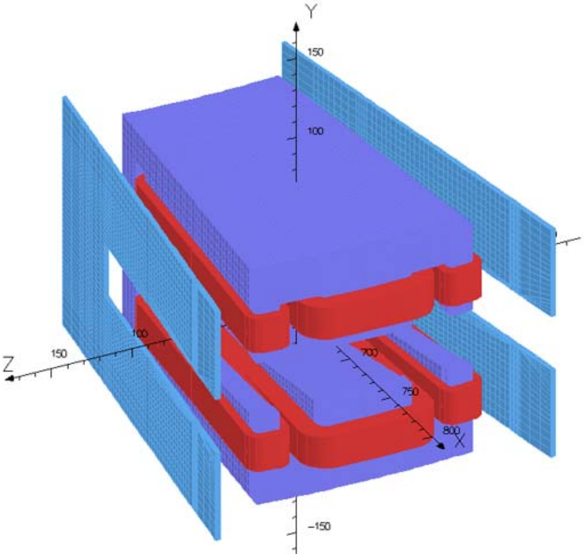

Figure 3: A 3D model of the PRISM-FFAG magnet.

The details of the magnet design will not be described here since there exists another paper which dealts with this topic [4], but we outline features of the design.

We adopted a scaled radial sector type FFAG with a triplet focusing magnet (DFD). Figure 3 shows a 3D model, which used in TOSCA, of the PRISM-FFAG magnet. We designed a C-shaped FFAG magnet so that the beam can extract/inject from/to the ring passing outside of the magnets. Two field clumps are at both end in order to avoid stray fields to the RF cavities. It has very large aperture of H :100 cm × V : 30 cm. The field gradient is generated by the pole shapes. It shape was decided so as to satisfy scaling conditions. Two sets of trim coils are installed on the top/bottom of beam chamber to enable k-value variable. The magnets have small opening angle, so that the ring has enough space to locate RF cavities.

The three-dimensional magnetic field was calculated by using a 3D field calculation code, TOSCA. According to the tracking simulations using this TOSCA field, the present design of PRISM-FFAG has more than about 40,000 πmm·mrad in the horizontal acceptance and about 6,500 πmm·mrad in the vertical acceptance.

RF SYSTEM

Since the muon is an unstable particle (lifetime$\sim$2.2μs), it is crucial to complete phase rotation as quickly as possible in order to increase a number of surviving muons. In present design, PRISM requires very high field gradient of 200kV/m at the low frequency (4$\sim$5 MHz). As compared with usual cavities, PRISM has to operate its cavities at a remarkably outstanding condition. Such an operation can be achieved by a low duty factor and ultra-thin magnetic alloy (MA) cavities [5]. MA core [6] has stable impedance at a required magnetic field for PRISM(320Gauss). The thickness of MA cores is 35 mm. The racetrack-shaped core is adopted. Cores are all air-cooled since the RF power loss into the core is very small owing to the small duty fac-

Number of gap per cavity	5
Length	33cm/gap
Number of core per gap	6
Core material	Magnetic Alloy
Core shape	Racetrack
Core size	1.7m × 1.0m × 3.5cm
Inner aperture	1.0m × 0.3m
Shunt impedance	∼900Ω/gap
RF frequency	4∼5MHz
Field gradient	150 ∼ 200kV/m
Flux density in core	320 Gauss
Power tube	tetrode : 4CW100,000E plate voltage : DC33-37kV
Maximum current	60A/gap
Maximum RF power	1.5MW
Core cooling	Air cooling
Duty	<0.1%

Table 3: Parameters of PRISM-FFAG RF system.

tor (about 0.1%).

To optimize phase rotation, not only a high field gradient but also the shape of RF voltage is important. According to our simulations, a saw-tooth RF voltage makes a final energy spread narrower than that by a sinusoidal one. Therefore, adding higher frequency harmonics to form a saw-tooth pulse shape is being considered. By using the cut core configuration, a wide band RF system with μQf @ 5MHz = 5.5 × 10^9 can be designed. The first and second harmonics could be applied on RF simultaneously with sufficient efficiency. A cavity, which consists of 5 gaps, is installed in one straight section. In the current design, each gap has 6 MA cores and has a length of 35 cm along the beam direction. One gap generates the RF voltage of ± 25-38 kV and is driven by two bus bars which are connected to an RF amplifier. Each gap will be driven by push-pull amplifiers using tetrode tubes, 4CW100,000E. The plate voltage of 33-37 kV will be applied and RF current of 60 A per gap maximum is possible to generate. Tetrode amplifiers are installed either on-the-top-of or underneath the cavity. A low duty factor enables the tubes to generate the maximum RF power of 1.5 MW. Parameters of the RF system are summarized in Table 3.

An RF system,which consists of an amplifier and an anode power supply and an auxiliary power supply, has been build. RF tests are underway. RF voltage of ± 43kV/gap has already achieved with a test cavity, which has a shunt impedance of 735 Ω at 5MHz. It promises a field gradient with a PRISM cavity, which would have a shunt impedance of 900 Ω, to be 165kV/m. A simulation result of phase rotation in the PRISM-FFAG ring is shown in Fig.4. The initial momentum spread of 68MeV/c± 20% is reduced to ± 2% in 6 turns (=1.5μs). A muon surviving rate is 56%.

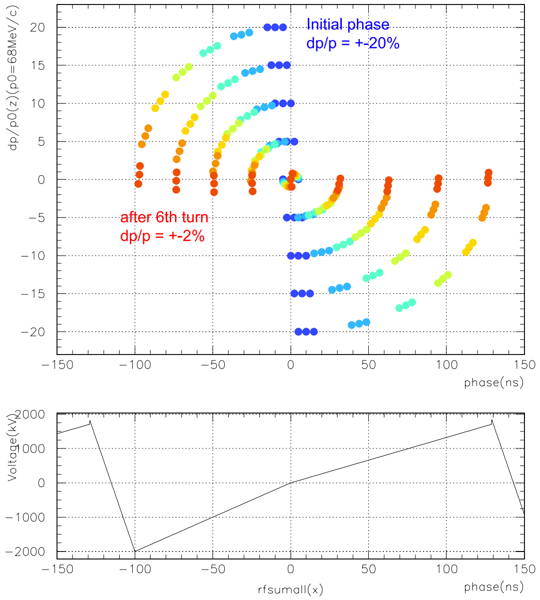

Figure 4: A result of simulation of phase rotation in the PRISM-FFAG ring. 6 turns in the ring is enough for finishing the phase rotation. Initial momentum spread of 68MeV/c± 20% is reduced to ± 2%. RF voltage applied is shown in the bottom figure.

SUMMARY

A program to construct the PRISM-FFAG has been started. This prototype FFAG consists of a full-size FFAG ring, a one-gap RF system, and a kicker system. Its optics and magnet design have almost been finalized. The design of RF system has also almost been finished, and its construction and tests are underway. Commissioning and studies with the FFAG are scheduled in JFY 2006 to 2007.

The PRISM-FFAG is an important first step not only for the PRISM project, but also for FFAG based Neutrino Factories.

REFERENCES

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