FFAG AS PHASE ROTATOR FOR THE PRISM PROJECT

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Abstract

A Fixed Field Alternating Gradient (FFAG) ring will be used as a phase rotator of a muon beam in the PRISM project. A program to construct the PRISM-FFAG ring has been started in Japan.

INTRODUCTION

PRISM stands for "Phase Rotated Intense Slow Muon beam." It is a project to realize a super muon beam, which might have high-intensity, low-energy, narrow energy-spread and high purity [1]. Its aimed intensity is about $10^{11} - 10^{12}$ 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].

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 considered to be 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.

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.

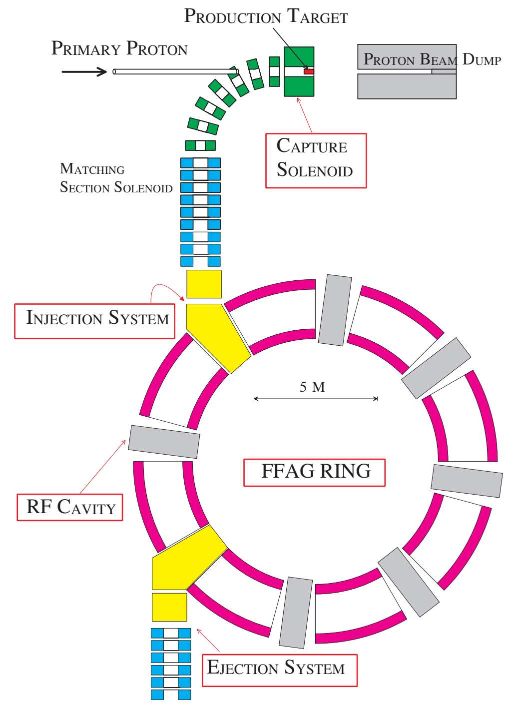

Figure 1: A schematic layout of PRISM

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	$< 10^{-18}$

LATTICE

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. Furthermore, 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. In such magnets, not only nonlinear effects but also fringing magnetic field are important to study the beam dynamics of FFAGs. 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 [**?**].

A present parameters and a schematic layout of PRISM-FFAG are shown in Table 2 and Fig.2 respectively. The PRISM-FFAG consists of 10 normal conducting magnets, 8 RF cavities and 2 kicker magnets. Accoding to the track-

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ing simulations, The present design of PRISM-FFAG has more than about 35,000 πmm·mrad in the horizontal acceptance and about 3000 πmm·mrad in the vertical acceptance.

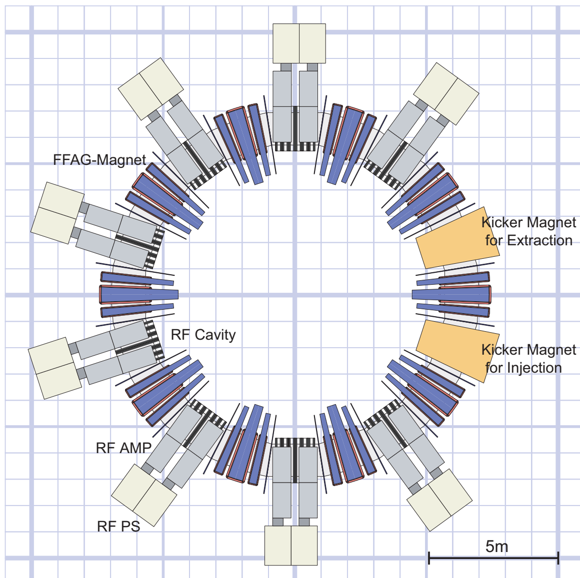

Figure 2: Schematic layout of the PRISM-FFAG

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
F/D ratio	8.0
Opening angle	F/2 : 2.2deg.
	D : 2.2deg.
Half gap	17cm
Maximum field	Focus. : 0.24 Tesla
	Defocus. : 0.026 Tesla
Average radius	6.5m for 68MeV/c
Tune	horizontal : 2.69
	vertical : 1.30

MAGNET

We adopted a scaled radial sector type FFAG with a triplet focusing magnet (DFD). Figure 3 shows schematic views of the PRISM-FFAG magnet. The field gradient (k value=4.6) is generated by the pole shapes basically. The gap distance g is a function of radii r. Identically, the equation is $g = h_0(r_0/r)^k$. Such a gap variation will break a scaling condition because of the fringing field effect. In order to avoid this situation, a intermediate pole made of anisotropic magnet material is used [3]. Owing to the intermediate pole, the magnet can have not only constant gap but also smaller fringing field compared with a conventional one. The magnet have a set of trim coils on the intermediate pole to make the k value tuneable. It is also worth to mention that the intermediate pole filters out local irregularity of the magnetic field distribution. Thus the accuracy of the pole shape is not necessary and the number of trim coils can be reduced.

The three-dimensional magnetic field was calculated by using a 3D field calculation code, TOSCA. Figure 4 shows results of the calculation of B_z as a function of θ (top), the local k value (middle) and the F/D ration (bottom) as a function of radius. The local k and F/D ratio were calculated by the BL integration and they are almost constant over the beam region. Therefore, the scaling condition is fulfilled.

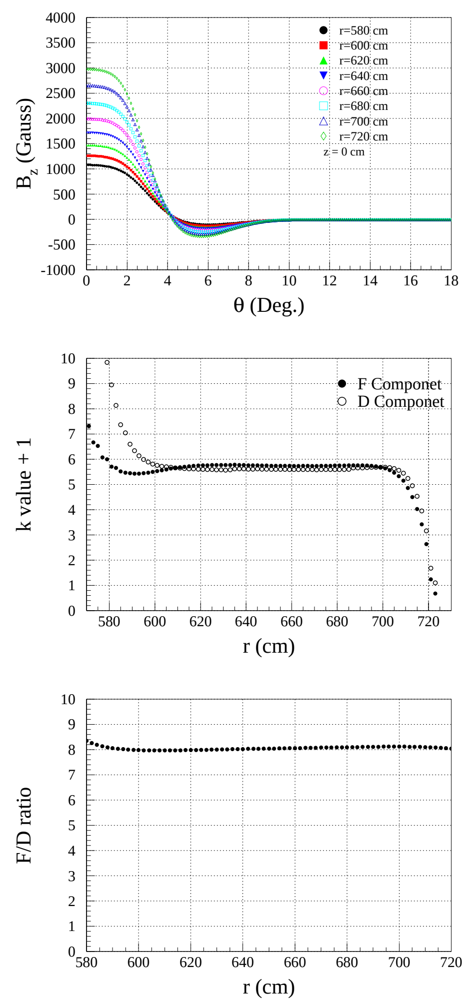

Figure 4: Calculation results of the magnetic field using TOSCA.

RF SYSTEM

Since the muon is an unstable particle (life time$\sim$2.2μs), it is crucial to complete phase rotation as quickly as possi-

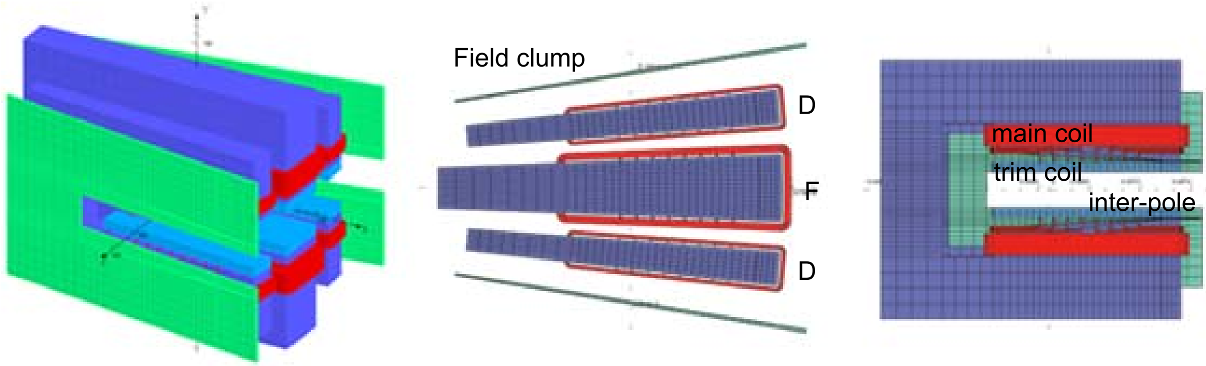

Figure 3: Schematic views of a PRISM-FFAG magnet. A bird's-eye view (left), a top view (center) and a side view (right).

ble 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 [4]. MA core [5] has stable impedance at a required magnetic field for PRISM(320-490 Gauss). 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 small duty factor (about 0.1%).

To optimize phase rotation, not only a high field gradient but also the shape of RF voltage are 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 [6], a wide band RF system with μQf @ 5MHz = 5.5 $\times$ 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 !ˆ25-38 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, 4CW150,000E. The plate voltage of 30-40 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 1.8 MW. Parameters of the RF system are summarized in Table 3.

Number of gap per cavity	5
Length of cavity	1.75 m
Number of core per gap	6
Core material	Magnetic Alloy
Core shape	Racetrack
Core size	1.4m $\times$ 1.0m $\times$ 3.5cm
Shunt impedance	$\sim$159Ω/core @ 5MHz
RF frequency	4$\sim$5MHz
Field gradient	200kV/m
Flux density in core	320 Gauss
Tetrode	4CW150,000E
Duty	$<$0.1%

Table 3: Parameters of PRISM-FFAG RF system.

SUMMARY

The lattice and magnet design of PRISM-FFAG will be finalized soon. The design of RF system had almost been finished, and its construction will start. RF tests, magnets construction and its field measurements will be carried out in JFY 2004 to JFY 2005. The FFAG-ring will be completed by the end of JFY 2005. After commissioning, phase rotation, muon acceleration, and muon ionization will be studied.

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