

# Recent studies on the PRISM FFAG ring

**J Pasternak<sup>1,2</sup>, on behalf of the PRISM Task Force**

<sup>1</sup>Imperial College London, London, UK

<sup>2</sup>ISIS, Rutherford Appleton Laboratory, STFC, OX11 0QX, UK

E-mail: j.pasternak@imperial.ac.uk

**Abstract.** Next generation lepton flavour violation experiments require high intensity and high quality muon beams. The PRISM Task Force focuses on accelerator R&D for realizing such beams using an FFAG ring. The scaling and non-scaling designs for the PRISM FFAG ring are discussed. The recent studies on injection/extraction systems and matching to the solenoid channel are outlined. The future plans for the study are presented.

## 1. Introduction

Although the Standard Model (SM) has proven to be extremely successful describing elementary particles and their interactions, it is believed to be only an approximation to a more fundamental theory, which yet needs to be discovered. Currently many experiments are intensively searching for any new phenomena setting new limits on various SM extensions. It is believed, that charged lepton flavour violating processes and in particular muon to electron conversion, are expected to be a fruitful tool to search for physics beyond the SM. The COMET and Mu2e experiments, which are capable of measuring muon to electron conversion with a sensitivity of  $<10^{-16}$ , are now in the advanced stage of the approval. In order to achieve even greater sensitivity ( $<10^{-18}$ ) beyond the current generation experiments, the PRISM (Phase Rotated Intense Source of Muons) experiment was proposed, which will use an FFAG ring for longitudinal phase-space rotation. This will not only allow for reduction of the muon beam energy spread, but will also purify muons from any unwanted contamination like pions. Substantial progress in defining the PRISM system was achieved, including the baseline ring design based on 10 identical cells with triplet scaling FFAG configuration, together with its large aperture magnets construction and the development of an RF system with Magnetic Alloy (MA) cores. A test ring accelerator with six cells equipped with the prototype RF system was successfully assembled at RCNP in Osaka and phase rotation was demonstrated using alpha particles [1].

However, several technological challenges remains to be solved before a feasibility of the PRISM/PRIME system (PRIME denotes the dedicated detector system to be used with the PRISM muon beam) could be established and the experiment proposed. The PRISM Task Force currently addresses [2, 3] these issues utilizing synergies with other muon accelerator projects such as the Neutrino Factory and the Muon Collider. The activities of the Task Force include the detailed design of the injection and extraction system and the transfer line between the solenoidal pion decay channel and the FFAG ring; search for an alternative FFAG ring designs; developments for high gradient RF systems [4]; and the studies of kicker and septum magnets. This paper reports briefly on the progress obtained by the PRISM Task Force.

## 2. The baseline design

The PRISM/PRIME system requires a proton driver capable to produce an ultra short proton bunch length ( $\sim 10$ ns) at the pion production target in order to efficiently use the phase rotation. Several options to produce such a proton beam have been considered including using the Main Ring at J-PARC or the Booster at Fermilab but it is rather clear, that in order to produce the high power required future new facilities are needed with the specification similar to the Neutrino Factory proton driver [5].

For the pion capture the backward collection in the high field solenoid is preferred, which allows to deliver sufficient pion intensity at low energy reducing the unwanted high intensity pion contamination. The pions will decay producing a muon beam in the solenoidal transport channel, which may contain the bend solenoids for further background reduction. The muon beam will then be injected into the FFAG ring, where the beam energy spread will be reduced (by a factor of  $\sim 10$ ) using RF phase rotation and muons will be cleaned from any contamination in several turns. The high quality muon beam would be then extracted and sent to the stopping target, where the muon to electron conversion may occur. Downstream the stopping target the PRIME detector will be located, which will be optimized for detection of the electron signal from muon to electron conversion events. The main accelerator parameters for the PRISM are collected in Table 1.

**Table 1.** Main parameters for PRISM.

Parameter	Value
Proton beam power	1-2 MW
Target type	solid
Pion capture field	5-10 T
Momentum acceptance	$\pm 20$ %
Reference $\mu^-$ momentum	40-68 MeV/c
Harmonic number	1
Minimal acceptance (H/V)	$3.8/0.5 \pi$ cm rad
Repetition rate	100-1000 Hz
RF voltage per turn	3-5.5 MV
RF frequency	3-6 MHz

## 3. Front end and injection

The muon transport and injection for PRISM are particularly demanding as beam with not only large transverse emittances but also with a large momentum spread needs to be simultaneously matched into the FFAG ring acceptance. The beam optics of the superconducting solenoidal channel and the FFAG accelerator are quite different, which requires a careful adjustment of the beam conditions between the two systems to minimize the losses. One of the key points is the necessary dispersion matching: as injection is foreseen in the vertical direction, the unavoidable vertical dispersion created by the septum needs to be corrected to zero and the horizontal dispersion (small or zero in the solenoidal channel) needs to be adjusted to a correct value in the ring.

A dedicated front end system has been designed to meet these difficult requirements. It consists of several modules, each playing an important role in the beam transport. Firstly, a solenoidal adiabatic matching section is used to increase the beta function from the low value in the superconducting decay solenoid to the value in the alternating gradient (AG) part and the FFAG ring. It is followed by a quadrupole matching section (currently quadruplet, but more can be added). Downstream the

horizontal dispersion creator is located consisting of a pair of equal, but opposite strength rectangular dipole magnets, followed by two circular FFAG cells with total  $\pi$  horizontal phase advance. Once the horizontal dispersion is introduced, it needs to be kept constant up to the FFAG ring. This is achieved using the straight FFAG sections [6], which are also used for the betatron matching. Finally, two vertical deflection sections (one incorporating the injection septum), which independently match the vertical dispersion and adjust the direction of the incoming beam line are used. The vertical and horizontal layouts of the AG part of the front end are shown in Fig 1. and Fig 2., respectively. The performance of the beam transport in the front end is currently being addressed via the particle tracking.

Several injection geometries were studied. The initial design used the same kickers for both injection and extraction. The current solution separates injection and extraction systems. The injection will use 1 vertical septum followed by either 1 or preferentially 2 kickers each located in consecutive cells. The kicker magnet design has been studied assuming the existing pulsed magnet technology to be used. No show-stopper has been found so far, but due to a high repetition rate and a short rise time dedicated prototyping is mandatory.

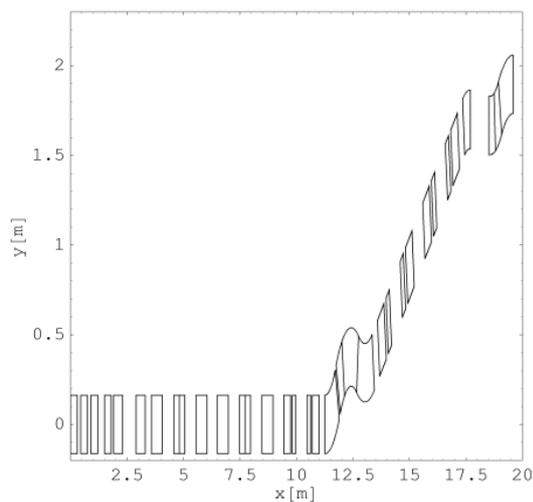


Figure 1. The vertical layout of the PRISM front end (AG part). The decay solenoid, located on the left would be on the different level than the FFAG injection septum located on the right.

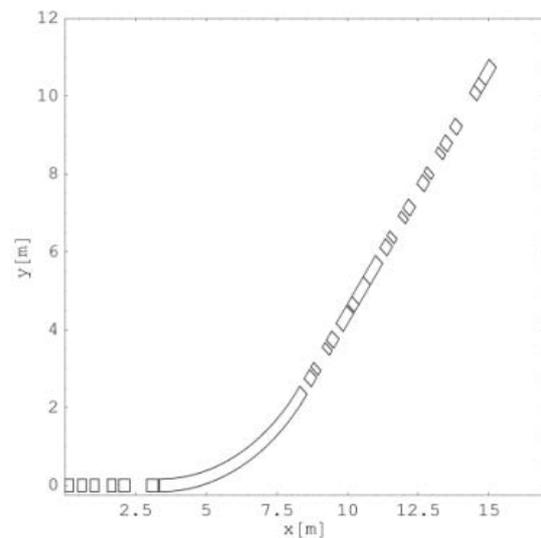


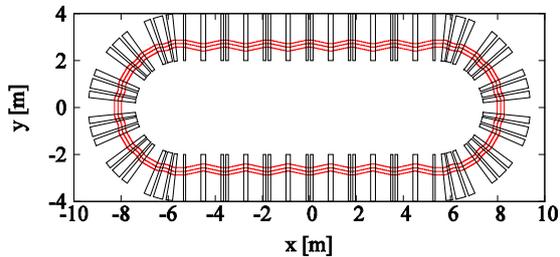
Figure 2. The horizontal layout of the PRISM front end (AG part). The big curved section is the FFAG dispersion creator. The injection septum is the last element on the upper right.

#### 4. Alternative FFAG ring designs

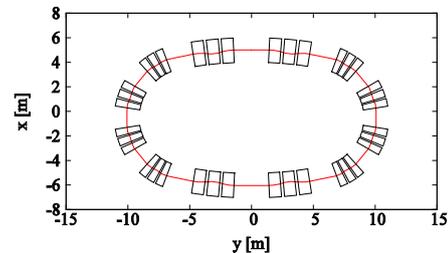
The PRISM Task Force not only continues the development of the baseline ring, but also undertakes studies of alternative options. The goal of this task is to maximize the ring acceptance, facilitating the injection/extraction requirements and space constraints. Several alternative ring designs have been produced and various options include.

- New symmetric scaling FFAG ring, in particular based on FDF triplet arrangements.
- Advanced scaling FFAG [7] using the straight FFAG cells in the "straight sections" with zero net bending and the circular FFAG cells in the compact arcs. The layout of such a racetrack ring is shown in Fig. 3.
- Advanced scaling FFAG incorporating arc sections with different radii ("egg-shaped", as shown in Fig. 4).
- Scaling FFAGs with superperiods introduced by rearranging the geometry in circular cells.
- Non-scaling FFAG utilizing the combined function magnets with only dipole and quadrupole magnetic field components.

The acceptance and performance tracking studies for the proposed alternative rings are under way using alternative accelerator codes and the first results look promising.



**Figure 1.** The layout of the advanced racetrack scaling FFAG ring for PRISM.



**Figure 2.** : The layout of the advanced scaling FFAG using arcs with different radii ("the egg-shaped ring").

## 5. Summary and future plans

The PRISM Task Force continues to work on the challenges, which need to be overcome before the feasibility of the PRISM system can be established. Substantial progress has been achieved in many areas such as: the design of the muon front end, studies of the injection system geometry, in development of the high gradient RF system (see [3, 4]). In addition several alternative ring designs, based on recently developed advanced concepts in the domain of FFAG accelerators, have been proposed. Future studies will focus on further optimization of the front end and the injection system, systematic comparison of the performance achieved by alternative ring designs and continuation of the hardware studies including the RF system, the kicker and septum magnets. The PRISM Task Force aims to publish the feasibility report in 2012. If it turns successful, it may start working on the possible tests of muon phase rotation and various PRISM subsystems using the MuSIC muon beam at RCNP in Osaka [8], which opens a possibility for experimental verifications of the developed solutions.

## References

- [1] Sato A 2010 *Demonstration of phase rotation using alpha particles in the six-sector PRISM-FFAG* in Proc. of IPAC'10 Kyoto
- [2] Pasternak J *et al.* 2010 WEPE056 in Proc. of IPAC'10 Kyoto
- [3] Pasternak J *et al.* 2011 MOPZ004 in Proc. of IPAC'11 San Sebastian
- [4] Ohmori C *et al.* 2011 *High Gradient Magnetic Alloy Cavities for J-PARC Upgrade* in Proc. of IPAC'11 San Sebastian
- [5] Abrams R J *et al.* 2011 *Interim Design Report (IDR) IDS-NF-020 Preprint* arXiv:1112.2853v1 [hep-ex]
- [6] Lagrange J-B *et al.* 2009 *Zero-chromatic FFAG straight section* in Proc. of FFAG'09 Chicago
- [7] Lagrange J-B *et al.* 2009 *Zero-chromatic FFAG straight section* in Proc. of FFAG'09 Chicago
- [8] Sato A *et al.* 2011 *MuSIC the World's Highest Intensity DC Muon Beam using a Pion Capture System* in Proc. of IPAC'11 San Sebastian