STATUS OF THE NON-SCALING FIXED FIELD ALTERNATING GRADIENT RING DESIGN FOR THE INTERNATIONAL DESIGN STUDY OF THE NEUTRINO FACTORY*

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Abstract

The International Design Study of the Neutrino Factory is working towards delivering the optimized design of the neutrino factory facility to be presented in the Reference Design Report (RDR) in 2013. In the current baseline design a linear non-scaling fixed field alternating gradient accelerator (FFAG) was chosen as an efficient solution for the final muon acceleration. We describe updates to the design since our previous report [1]. We report on beam dynamics studies on the lattice. We describe recent work on the engineering for the lattice, and the results of a recent first pass at a cost estimate for the machine. Finally, we describe how an FFAG may be applicable to a lower energy neutrino factory in light of recent experimental results regarding the value of the θ_{13} neutrino mixing angle [2, 3].

MACHINE PARAMETERS

A neutrino factory [4] accelerates an intense muon beam to high energy, then allows the muons to decay into a focused beam of neutrinos. To maximize the efficiency and reduce the cost of muon acceleration, we propose to use a linear non-scaling fixed field alternating gradient accelerator (FFAG) to accelerate muons from 12.6 GeV to the final energy of 25 GeV. A design for this machine was most recently described in [1].

Due to an error in optimizing on the energy dependence of the time of flight, we have modified the FFAG design slightly. The current parameters are given in Tables 1 and 2.

BEAM DYNAMICS STUDIES

One of the design criteria for the FFAG was to make main drift long enough to keep the septum field below 2 T. We have performed simulations justifying this criterion. Figure 1 shows a calculation of the stray field from the septum for various septum fields. Those fields were then

Table 1: Main Ring Lattice Parameters for the IDS-NF FFAG. See [1] for precise definitions.

Long drift (m)		5.00
Short drift (m)		0.75
Cells		67
Circumference (m)		699
	D	**F**
Length (m)	1.994466	0.965155
Angle (mrad)	147.626	-26.924
Shift (mm)	39.012	14.371
Field (T)	4.43410	-1.43705
Gradient (T/m)	-14.05981	18.87995
Aperture radius (mm)	130	160
Max field (T)	6.3	4.5

Table 2: RF Parameters for the FFAG Ring. See [1] for precise definitions.

Cavities	50
Cavity voltage (MV)	25.5
Ring voltage (MV)	1212.571
Turns	11.6
Decay (%)	7.0

used in a simulation of acceleration, the results of which are shown in Fig. 2. At 2.6 T, the orbit distortion resulting from the septum is clearly unacceptable, though at 2.2 T the orbit distortion would probably be tolerable. These considerations drove the desire to have a 5 m nominal drift length. These results indicate that we could probably make the drift somewhat shorter, though Fig. 3 shows that there is little space to reduce that length in a practical design (4.3 m is probably a lower limit).

Previous studies of the dynamics of serpentine acceleration [5], the acceleration mode used in the FFAG, have been done when the time of flight is a purely quadratic function of energy, with the minimum at the center of the energy range of the FFAG. However, because our time of flight is not a purely quadratic function of energy, the analysis of the optimal configuration is more complex. We are still in the

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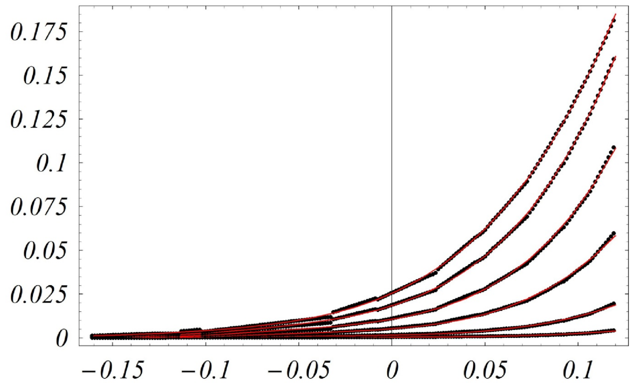

Figure 1: Septum stray field (in T) as a function of horizontal position (in m). Curves are for a main septum field of (bottom to top) 1.8 T, 2.2 T, 2.6 T, 3.1 T, 3.5 T, and 3.9 T.

process of this analysis, but have shown that the current design does not have the location of the minimum chosen optimally. As a result, longitudinal emittance distortion will be larger than necessary. We are in the process of adjusting the design to correct for this. This update should have minimal impact on the machine cost. We have also used these studies to improve the tracking performance of the existing design, as shown in Fig. 4 (once the calculations

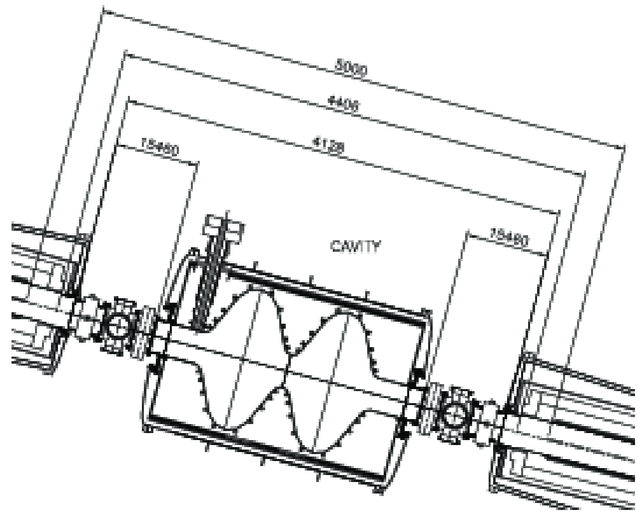

Figure 3: Drawing showing the RF cavity between two triplet cells, all with their cryostats. Dimensions are in mm.

are finalized, we expect even better performance even with the existing design).

The EMMA experiment has recently succeeded in accelerating an electron beam in this serpentine mode of acceleration, and has confirmed much of what we understand about linear non-scaling FFAGs [6]. Continued studies on the machine will help us to understand the performance an

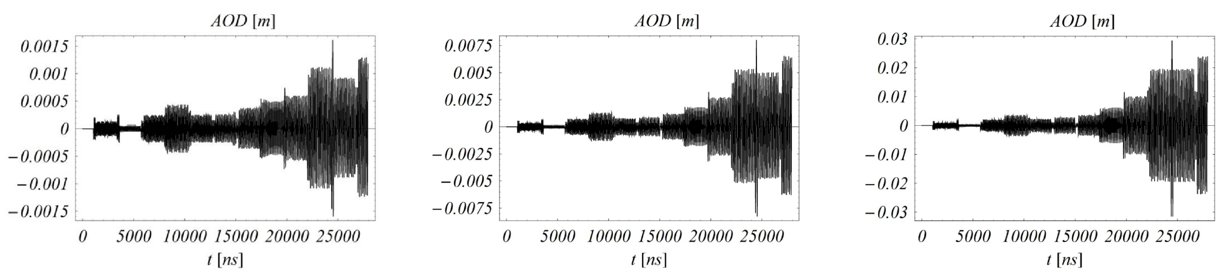

Figure 2: Orbit distortion (in m) during acceleration for septum fields of (left to right) 1.8 T, 2.2 T, and 2.6 T.

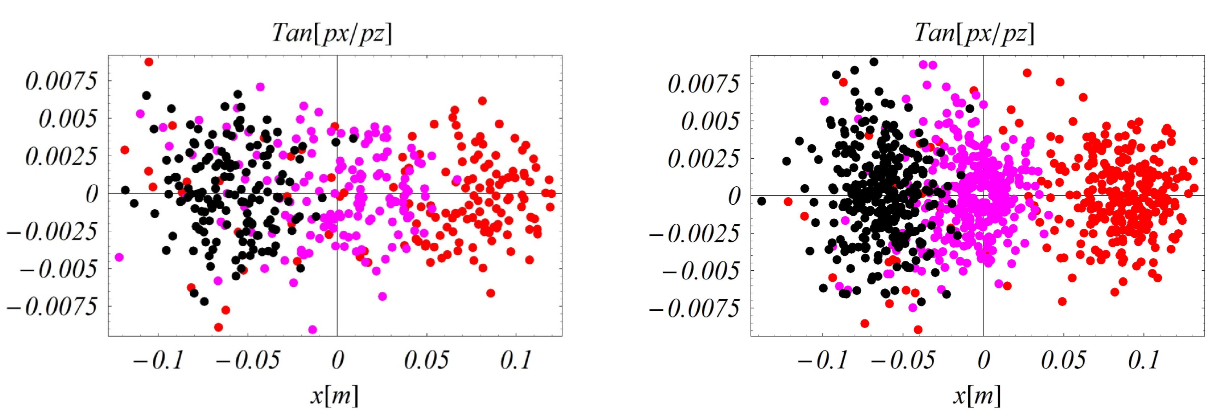

Figure 4: Horizontal phase space during acceleration before (left) and after (right) adjusting initial conditions to take into account the non-parabolic energy dependence in the time of flight. Colors are black for the initial distribution, pink at an intermediate energy, and red at the final energy. The large density after the adjustment demonstrates our improved transmission. The horizontal position of the beam becomes more positive with increasing energy.

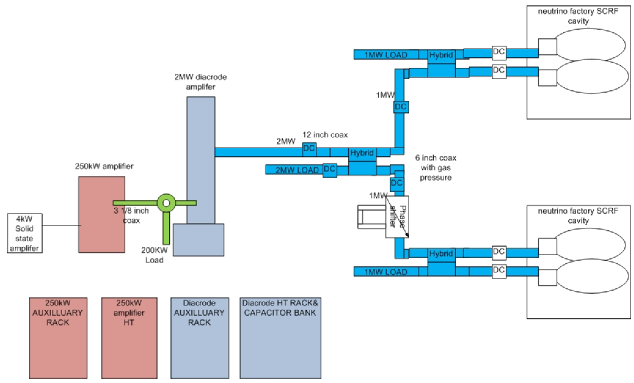

Figure 5: RF power source and distribution schematic.

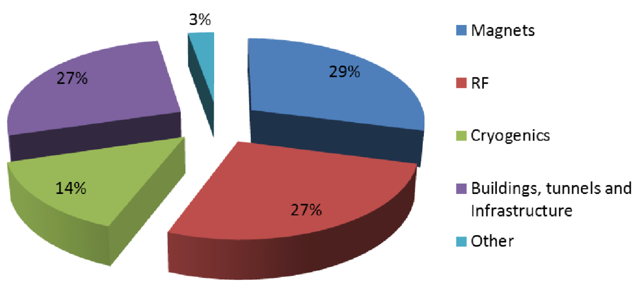

Figure 6: Fractional cost of various subsystems of the FFAG [7].

limitations of this type of machine design.

ENGINEERING

Subsequent to [1], additional engineering effort has gone into the design of the FFAG. We now have a configuration for the RF power sources and distribution (see Fig. 5). We have estimated the requirements for buildings, services, and cryogenics for the machine. All of the subsystems of the FFAG have been examined, and we have a relative cost for those systems (see Fig. 6) and for the FFAG relative to the rest of the neutrino factory [7]. The FFAG is only 29% of the cost of the acceleration systems (which are 43% of the full system cost), yet they perform over half of the acceleration. This supports our motivation for using an FFAG to increase the efficiency of muon acceleration.

RECENT θ_{13} RESULTS

Recent experimental results [2, 3] have shown that $\sin^2 2\theta_{13}$ is around 0.1. This leads to an optimal neutrino factory muon energy of about 10 GeV [4, 8]. We have made a first design for an FFAG that would accelerate from 5 to 10 GeV, and the resulting machine has 55 cells and a 492 m circumference, accelerating in about 6.5 turns. Based on a simple cost model [9], this machine will have about 80% of the cost of the 12.6–25 GeV FFAG. If we make an approximate cost comparison between two acceleration scenarios for reaching 10 GeV, one with a linac and two RLAs, another with a linac, one RLA, and an FFAG, the costs of the two scenarios appear similar. As our understanding of the cost models and design optimization for both the FFAG and RLAs are refined, we will revisit this comparison to determine whether an FFAG would be a more cost effective (or otherwise preferable) option for the 10 GeV neutrino factory.

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