RECENT PROGRESS TOWARD A MUON RECIRCULATING LINEAR ACCELERATOR*

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Abstract

Both Neutrino Factories (NF) and Muon Colliders (MC) require very rapid acceleration due to the short lifetime of muons. After a capture and bunching section, a linac raises the energy to about 900 MeV, and is followed by one or more Recirculating Linear Accelerators (RLA), possibly followed by a Rapid Cycling Synchrotron (RCS) or Fixed-Field Alternating Gradient (FFAG) ring. A RLA reuses the expensive RF linac section for a number of passes at the price of having to deal with different energies within the same linac. Various techniques including pulsed focusing quadruopoles, beta frequency beating, and multipass arcs have been investigated via simulations to improve the performance and reduce the cost of such RLAs.

BACKGROUND

A neutrino factory and muon collider share many of the same challenges; both must generate pions, then collect muons of both signs from pion decay at relatively low energy, then very quickly accelerate them before the muons all decay. Their acceleration schemes are not quite identical, as the emittance of the beams may not be the same, but most of the features discussed here are applicable to both.

A Recirculating Linear Accelerator (RLA) passes particles through the same linac multiple times. To maintain a sufficient focusing on subsequent passes, we investigated using rapidly ramped quadruopoles [2], but found that for this application beta frequency beating [3] alone was a sufficient solution.

INTERNATIONAL DESIGN STUDY

The International Design Study for the Neutrino Factory (IDS-NF) baseline design involves a complex chain of accelerators including a single-pass prelinac, two recirculating linacs (RLA) and a fixed field alternating gradient accelerator (FFAG).[1] As part of the study, our group simulated the muon acceleration from 0.2 to 12.6 GeV using OptiM [4], Elegant [5] and G4beamline [6] in the prelinac and RLAs.

The baseline design will evolve in light of recent measurements, but the current design was basis for this work.

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Prelinac

The first linac follows the capture and bunching section and accelerates muons of both signs from about 244 to 900 MeV [7][8] total energy. It must accept a high emittance beam about 30 cm wide with a 10% energy spread.[9] This linac uses counterwound, shielded superconducting solenoids and 201 MHz superconducting cavities. The prelinac uses two types of cryomodules, both with a bore radius of 23 cm. The first is 3m long with a single RF cell, while the second is 5m long with a double RF cell.

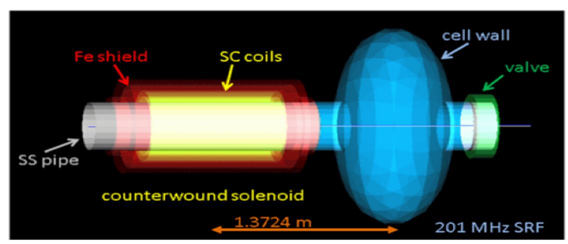

Figure 1a: G4beamline model of a 3m prelinac cryomodule.

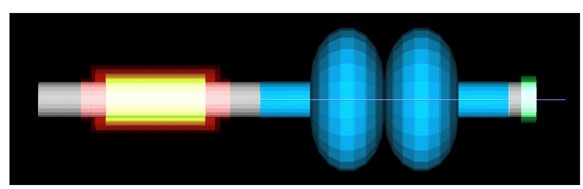

Figure 1b: G4beamline model of a 5m prelinac cryomodule.

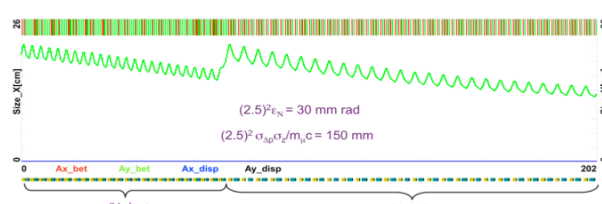

Figure 1c: OptiM model of the prelinac.

Chicane

The current chicane separates the $\mu^{\pm}$ with a dipole, then each is directed down 1.75m into the plane of RLA I, then directed by dipoles into the middle of the linac. On subsequent passes, the injection dipole separates the returning $\mu^{\pm}$, so a mini-chicane in the linac is used to correct the paths.

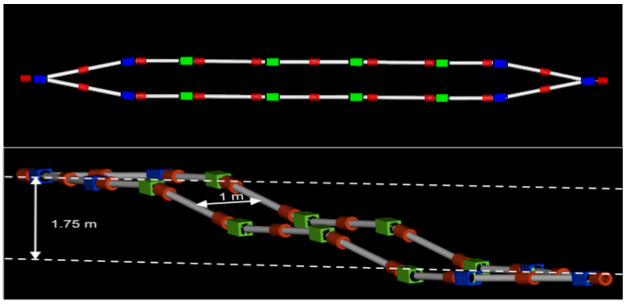

Figure 2a: G4beamline model of the prelinac to RLA I chicane.

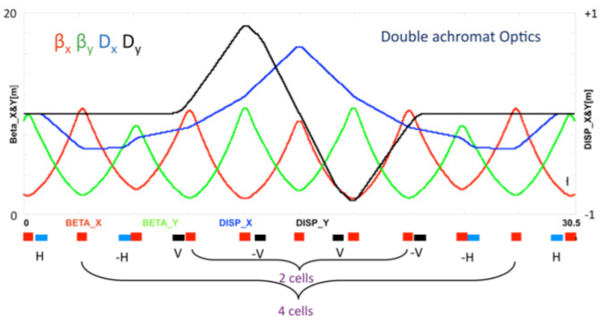

Figure 2b: OptiM model of the prelinac to RLA I chicane.

The current version of the chicane was found to interfere mechanically with the cryomodules and is being redesigned.

RLA I

RLA I is a 4½ pass 0.6 GeV/pass RLA which takes the beam from 0.9 to 3.6 GeV. To preserve the symmetry for the beta beating technique, the beam is injected into the middle of the linac. The strength of the quadrupoles is set with their gradients decreasing roughly linearly with distance from the middle of the linac. The beta functions then oscillate, but remain reasonable at the entrances to the arcs.

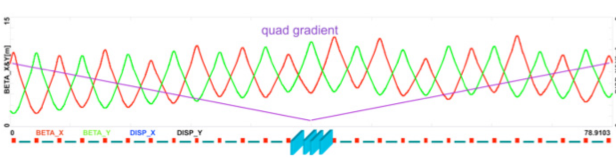

Figure 3a. Increasing quadrupole strength with distance to center of linac and 1st whole pass beta functions.

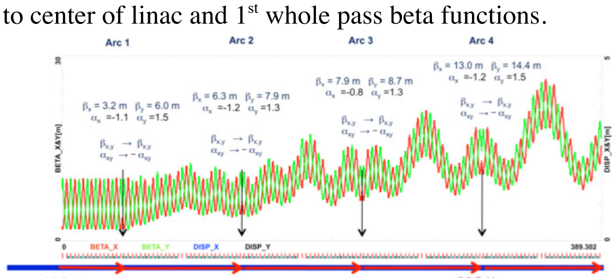

Figure 3b. Beta beating in the RLA I linac for all passes.

There are 2 teardrop-shaped arcs at either end of the linac; each arc is matched to the beta function at that exit of the linac for its pass. Muons of opposite sign travel in the same direction through the linac and in opposite directions around the arcs. To avoid interference, dipoles lift the plane of the lower energy arc by 1m. The beam in then extracted at the end of the linac.

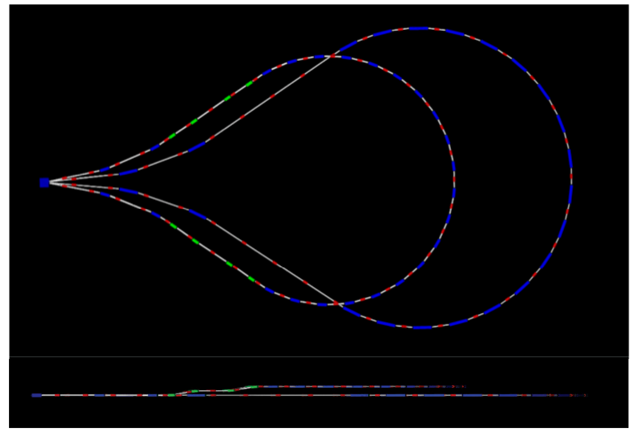
Figure 4a: Top and side views of a G4beamline model of the RLA I arcs#1 (1.2 GeV) and #3 (2.4 GeV).

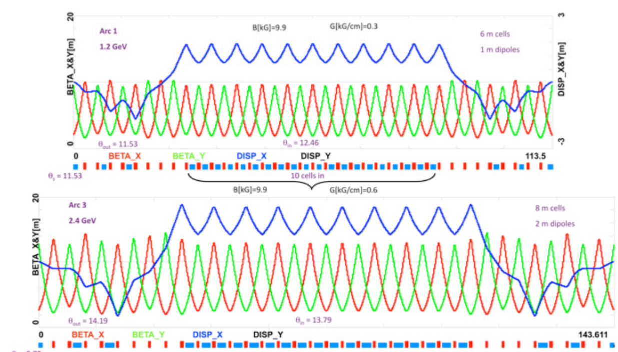

Figure 4b: OptiM model of RLA I arc #1 and #3.

Each switchyard only accommodates only 2 momenta.

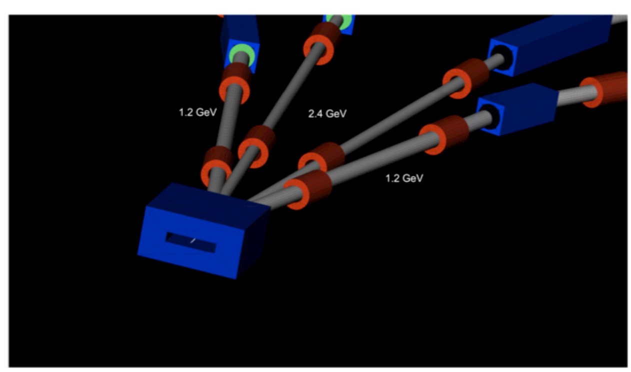

Figure 5. G4beamline model of RLA I switchyard for arc#1 and #3.

RLA II

RLA I is followed by very similar, but larger, 4½ pass 2 GeV/pass RLA II that takes the beam from 3.6 to 12.6 GeV.

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Table 1: RLA I and II Properties

	RLA I	L_{cell}	L_{dipole}	RLA II	L_{cell}	L_{dipole}
	GeV	m	m	GeV	m	m
enter	0.9			3.6		
linac	0.6	6.0		2.0	12.0	
arc1	1.2	6.0	1.0	4.6	12.0	2.0
arc2	1.8	7.0	1.5	6.6	14.0	3.0
arc3	2.4	8.0	2.0	8.6	16.0	4.0
arc4	3.2	9.0	2.5	10.6	18.0	5.0
exit	3.6			12.6		

MULTIPASS ARCS

If two arcs could be replaced by a single arc that could transport two very different momentum beams, the RLA could be greatly simplified by eliminating the one arc's chicanes and the most of the switchyard.

While the concept of a multipass arc is described in detail elsewhere [10], a brief description is given here. The arc is built of cells, and those cells are constructed of linear combined-functions magnets with variable dipole and quadrupole field components. Those components and magnet orientations are adjusted to control the optics of the multiple passes. Unlike a fixed field alternating gradient design, opposing bends are not required.

The cells are set such that the dispersion and displacement is zero at the end of each cell and the beta functions are the same and match that of the linac for each pass. A prototype system using multipass arcs is being considered [11].

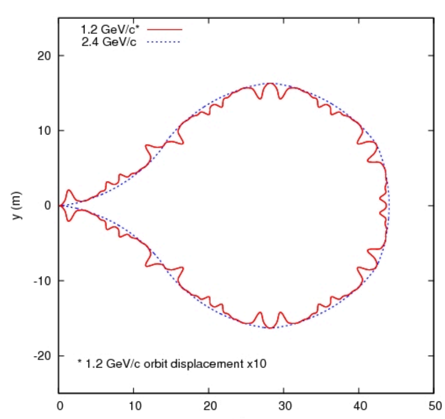

Figure 6. Multipass arc with orbits.

FUTURE WORK

Very recent results have significantly altered the requirements for a neutrino factory.[12] The final energy is now expected to be 10 GeV, so the RLAs would directly feed the decay ring, eliminating the need for a synchrotron to follow the RLAs. This will require a re-optimization of both the current prelinac and RLA designs.

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