

Muon Acceleration – RLA and FFAG

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Abstract. Various acceleration schemes for muons are presented. The overall goal of the acceleration systems: large acceptance acceleration to 25 GeV and ‘beam shaping’ can be accomplished by various fixed field accelerators at different stages. They involve three superconducting linacs: a single pass linear Pre-accelerator followed by a pair of multi-pass Recirculating Linear Accelerators (RLA) and finally a non-scaling FFAG ring. The present baseline acceleration scenario has been optimized to take maximum advantage of appropriate acceleration scheme at a given stage. The solenoid based Pre-accelerator offers very large acceptance and facilitates correction of energy gain across the bunch and significant longitudinal compression through induced synchrotron motion. However, far off-crest acceleration reduces the effective acceleration gradient and adds complexity through the requirement of individual RF phase control for each cavity. The RLAs offer very efficient usage of high gradient superconducting RF and ability to adjust path-length after each linac pass through individual return arcs with uniformly periodic FODO optics suitable for chromatic compensation of emittance dilution with sextupoles. However, they require spreaders/recombiners switchyards at both linac ends and significant total length of the arcs. The non-scaling Fixed Field Alternating Gradient (FFAG) ring combines compactness with very large chromatic acceptance (twice the injection energy) and it allows for large number of passes through the RF (at least eight, possibly as high as 15)..

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MUON RLA COMPLEX

The proposed RLA muon accelerator complex consists of the following components:

- i) a 201 MHz SCRF linac pre-accelerator that captures the large muon phase space coming from the cooling channel lattice and accelerates the muons to relativistic energies, while adiabatically decreasing the phase-space volume,
- ii) a low energy Recirculating Linear Accelerator (RLA I) that further compresses and shapes the longitudinal and transverse phase-space, while increasing the energy to 3.6 GeV,
- iii) a second stage RLA (RLA II) that further accelerates muons to 12.6 GeV.
- iv) a Non-scaling FFAG that further accelerates muons to about 25 GeV.

Linear Pre-Accelerator

A single-pass linac “pre-accelerator” raises the beam energy to 0.9 GeV. This makes the muons

sufficiently relativistic to facilitate further acceleration in a RLA. In addition, the longitudinal phase space volume is adiabatically compressed in the course of acceleration [2]. The large acceptance of the pre-accelerator requires large aperture and tight focusing at its front-end. Given the large aperture, tight space constraints, moderate beam energies, and the necessity of strong focusing in both planes, we have chosen solenoidal focusing for the entire linac [1]

. Main Acceleration System

The superconducting accelerating structure is expected to be by far the most expensive component of the accelerator complex. Therefore, maximizing the number of passes in the RLA has a significant impact on the cost-effectiveness [3] of the overall acceleration scheme. We propose to use a 4.5 pass ‘Dogbone’ configuration for the RLA (Fig. 1)

The Dogbone multi-pass linac optics are shown in Fig. 2. The Dogbone RLA I simultaneously accelerates the μ^+ and μ^- beams from 0.244 GeV to 3.6 GeV. The injection energy into the RLA and the energy gain per

RLA linac were chosen so that a tolerable level of RF phase slippage along the linac could be maintained.

For the RLA injection energy of 0.9 GeV the critical phase slippage occurs for the initial ‘half-pass’ through the linac.

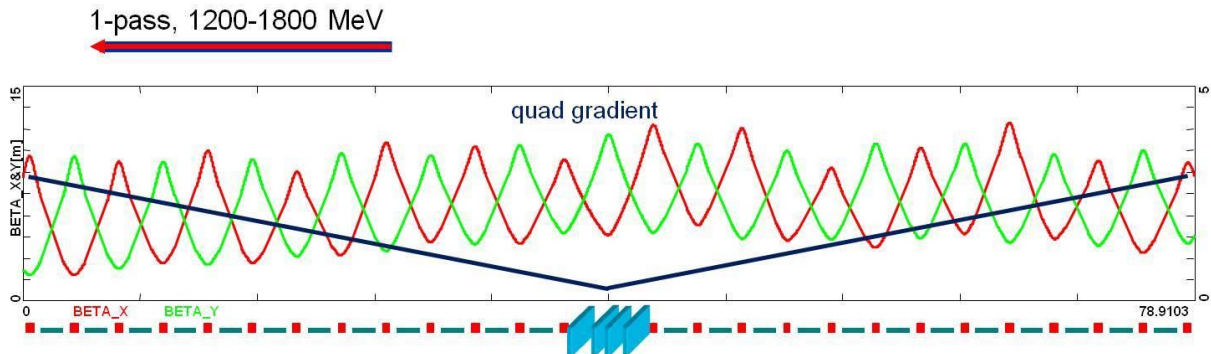


FIGURE 2. FODO based multi-pass linac optics. The quadrupole gradients scale up with momentum to maintain 90° phase advance per cell for the first half of the linac, then they are mirror reflected in the second half. The resulting linac optics is well balanced in terms of Twiss functions and beam envelopes.

The focusing profile along the linac of the ‘Dogbone’ RLA is designed so that beams within a vast energy range can be transported within the given aperture. It is also desirable that the focusing profile is optimized to accommodate the maximum number of passes through the RLA. In addition, to facilitate simultaneous acceleration of both μ^+ and μ^- bunches, a mirror symmetry must be imposed on the ‘droplet’ arc optics (oppositely charged bunches move in opposite directions through the arcs)..

At the ends of the RLA linacs the beams need to be directed into the appropriate energy-dependent (pass-

dependent) ‘droplet’ arc for recirculation [4]. For practical reasons, horizontal rather than vertical beam separation was chosen. Rather than suppressing the horizontal dispersion created by the spreader, the horizontal dispersion has been smoothly matched to that of the outward 60° arc. Then, by an appropriate pattern of removed dipoles in three transition cells, the dispersion for the inward bending 300° arc is flipped. The droplet arc layout is shown in Fig. 3. The entire ‘droplet’ arc architecture is based on 90° phase advance cells with periodic beta functions.

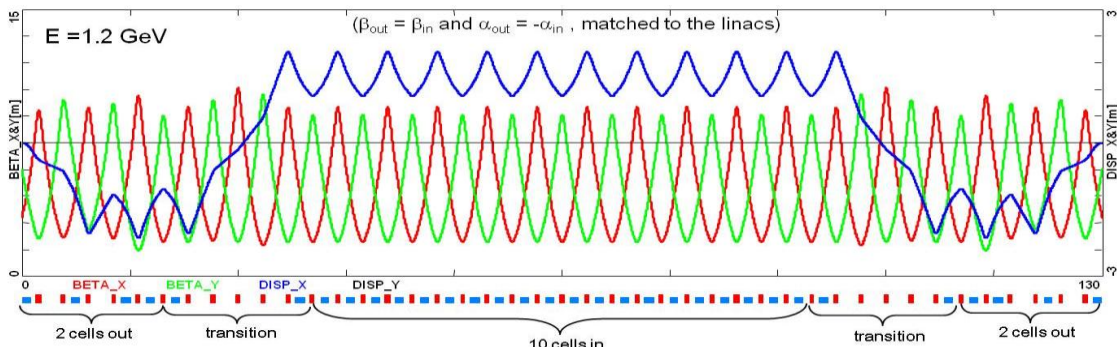


FIGURE 3. ‘Droplet’ arc optics, showing the uniform periodicity of beta functions and dispersion.

ALTERNATIVE FFAG ARC OPTICS

We explored an alternative scheme with a single linac and two droplet-shaped return arcs at each end of

the linac. We employ Non-Scaling Fixed-Field Alternating-Gradient (NS-FFAG) arc lattice, which allows transport of two consecutive passes with very different energies through the same string of arc magnets. Each droplet arc consists of a 60° outward bend, a 300° inward bend and another 60° outward

bend so that the net bend is 180°. Such arc geometry has the advantage that if the outward and inward bends are made up of similar cells, the geometry automatically closes without the need for any additional straight sections. In presented 4-pass scheme, there are 1.2 and 2.4 GeV/c passes through

one arc and 1.8 and 3.0 GeV/c passes through the other. In addition to accommodating the appropriate momenta, each arc must satisfy the following requirements: the arc must be near isochronous for both energies to ensure proper phasing with the linac.

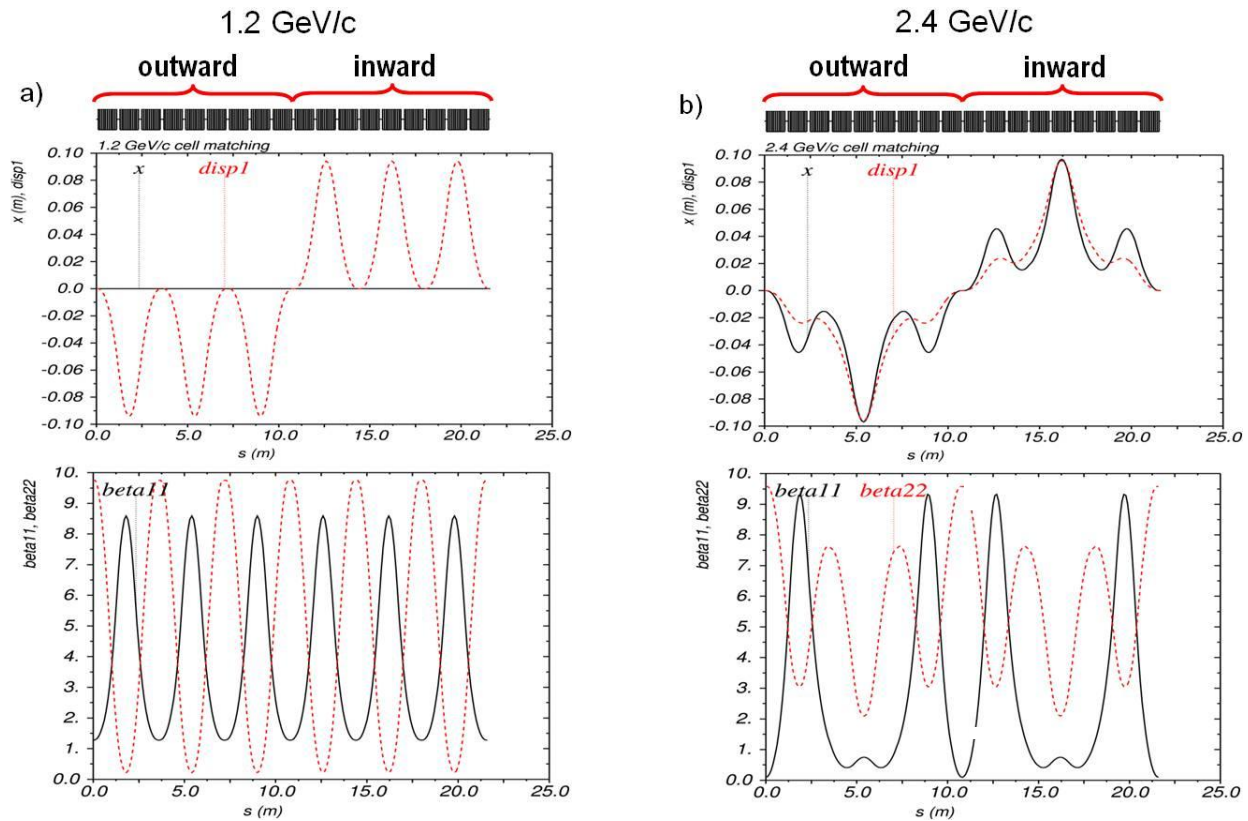


FIGURE 4. Two energies of interest: 1.2 GeV and 2.4 GeV/c: periodic orbit, dispersion and beta functions for the inward-outward bending super cell transition. Optics generated by Polymorphic Tracking Code (PTC) module of the MAD-X program.

We used an NS-FFAG triplet magnet arrangement as the basic cell of our arc design. The inward-bending triplet cell has an outward-bending combined-function magnet with positive gradient (horizontally focusing) at the center and two inward-bending magnets located on either side with equal negative gradients. The outward-bending triplet cell has the same structure but reversed dipole fields. The cells' symmetry ensures that their periodic solutions have $\alpha_x = \alpha_y = 0$ and $D'_x = 0$ at the beginning and the end.

CONCLUSIONS

The overall goal of the acceleration systems: large acceptance acceleration to 25 GeV and 'beam shaping' can be accomplished by various fixed field accelerators at different stages to take maximum

advantage of appropriate acceleration scheme at a given stage. Pros and cons of various stages should guide the layout of the engineering design foundation.

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