# MAP Acceleration Meeting, April 2011: IDS-NF Linac and RLA Design


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**Abstract**

The baseline accelerator design of the International Design Study of the Neutrino Factory accelerates the muon beam with a linac followed by two recirculating linear accelerators (RLAs). In the Intermediate Design Report (IDR), a design for these accelerators was specified. We discussed that design, identified the parts that were missing and inconsistencies in the design. We found that the beam sizes would not fit within the apertures specified, which will require a re-design of the initial linac. The linac in the first RLA will also need to use larger aperture (and lower gradient) cavities. We chose to make a new design using arc cells that increased in length as the beam momentum increased. We produced a timetable for completion of the steps required to have a design ready for the reference design report (RDR).


## 1. The IDR Design

First we will discuss the design as presented in the IDR. We describe missing parameters (in addition to parts identified as being absent in the document), and identify problems with the design that was presented.

In the cells for the initial linac, the solenoid length is 1 m. Aperture radii of solenoids are 19.5 cm for short and medium cells, and 15 cm for long cells. Nominal cavity lengths are $c$ divided by the RF frequency. Between cavities in the long drift, there is 150 cm. Between solenoid and cavity, there is 50 cm for the short cells, and 100 cm for the other two cells. At the end of the cell, there is 30 cm for the short cells, 80 cm for the remaining cells. The front drift is computed from this and full cell lengths (3 m, 5 m, and 8 m).

The short cells use the low-gradient, high-aperture cavities. High-gradient, smaller-aperture cavities are used in the medium and long cells.

The beam sizes in both the initial linac and the linac in RLA 1 are too high for the cavity (and in the initial linac, the solenoid) apertures.

Both the arcs and the linacs end in F quads. One must end in D quads. The arcs don't close at the moment.

The chromatic correction sextupoles for the 1.8 GeV arc have been specified. The strengths were chosen empirically to reduce the beam blowup in the horizontal phase space. Two sextupoles were used, placed at the quadrupoles in the direction change which lie between a drift and an arc. The integrated strengths were -0.9 kG/cm.

For the match in the 1.8 GeV arc, in the IDR, the linac actually ended in a D quad. Higher energy arcs will also be matched.

Table XIX in the IDR (with the quadrupole gradients in the linac of RLA II) appears to be wrong. Correct numbers, starting from the linac end going to the middle, are

| QF grad. kG/cm | QD grad. kG/cm |
|---|---|
| 0.308 | -0.313 |
| 0.305 | -0.306 |
| 0.298 | -0.299 |
| 0.291 | -0.292 |
| 0.285 | -0.285 |
| 0.278 | -0.278 |
| 0.271 | -0.271 |
| 0.264 | -0.264 |
| 0.257 | -0.257 |
| 0.251 | -0.250 |
| 0.244 | -0.244 |

For the table of quadrupole gradients in the arcs, the gradients in the first arcs should be close to the gradients at the end of the linac. They clearly are not, this needs to be addressed.

## 2. Plan for an Improved Design

The transit time factor is not taken into account in the energy gains in the linac. Kevin will produce a table of transit time factor vs. momentum, Alex will adjust the phase profile to take this into account, possibly adding an additional cell. Note that the cavities have RF focusing model of Rosenzweig-Serafini.

Since the beam sizes are too high for the cavity and solenoid apertures, the initial linac structure will be changed to use only short and medium cells and large aperture cavities everywhere. There are similar problems in the first RLA linac, so we will switch to large aperture cavities there. For the linac in RLA II, we are currently assuming two double-cell cavities per drift with the 30 cm diameter aperture. The beam radius at the start is about 13.5 cm. We need to verify that the beta beats for higher passes do not make the beam exceed this aperture. The aperture is a bit tight, we may consider shortening the cells.

A beta matching section from the initial linac into the RLA chicane has been designed, but we will need to re-design it for the new linac. In addition, the match will start in the section that still contains RF, since the geometric emittance should be small enough at that point.

The injection chicane will immediately follow the linac. In the IDR, the second table describing the injection chicane (with the quadrupole positions) has the longitudinal positions wrong (dipole positions are correct); they should be 50 cm earlier (50, 350, etc.). Sextupoles will need to be added. They will only be needed to be added at the peaks of the vertical dispersion (5th and 7th quadrupoles).

Within the RLA linac, the chicane will be closed with all magnets in the same drift, not as in Fig. 46 in the IDR. The transverse separation between the beamlines is currently insufficient, so the chicane will need to be redesigned. Stronger magnets can be used, maybe with the two dipoles in the injection chicane in separate drifts (not possible in the main linac). The main linac may need longer cells to get all the chicane magnets into the same drift. In principle the chicane in the main linac can be accomplished with three instead of four magnets.

The arc designs will be changed so that the arcs end in D magnets. Of the end quadrupoles in the linac and arcs, one must end in an F magnet and the other must end in a D. We chose for the arcs to end in a D if one uses a common quadrupole between the beamlines after the final linac pass, the D will push the two beams apart.

The arc designs will be adjusted so that they close. A drawing of the switchyard will be made to ensure that the beams are sufficiently separated in the first arc quadrupoles.

The separation at the arc crossings needs to be more precisely designed. Somewhat more separation is needed. It is probably not necessary to bring the beam back down, we only need to ensure that the vertical dispersion is restored to zero. The magnets shown in the IDR are too short. We could use the empty drifts in the match or direction cross, or could rotate a dipole.

We discussed a new idea for improving the match from the linac to the arc in the RLA: keep the quadrupoles as free parameters in the linac (but maintain mirror symmetry), and match to the arc beta functions. If the quadrupole strengths are chosen carefully, the beta functions at the ends of the linac on each pass will match the corresponding beta functions in the arcs, with the beta functions rising to larger values between those points.

Another idea we discussed was to maintain the same number of cells in all arcs and let the beta function rise. This matches the natural rise of the beta functions in the linac, thus eliminating (or reducing) the need for chromatic correction sextupoles in the higher arcs that require matching (the method where the quadrupole strengths in the linac are adjusted also accomplishes this). In addition, if the method of adjusting the quadrupole strengths in the linac to accomplish the match is used, the increase in the beta functions at the points between the linac ends will be less than if all the arcs have low beta functions as in the IDR design.

We decided to use the same number of cells in all arcs. We felt that this would not add substantial work beyond what already needed to be accomplished. The matching between the arcs and linacs (which only exists for one arc, and even that matching needs to be re-designed) would be significantly simplified, reducing the work to be done in that area. In all likelihood, chromatic corrections would not be needed.

The transfer line with an injection chicane to RLA II needs to be designed.

For the arcs in RLA II, we have the same issues as RLA I. In addition, since different passes require different dipole fields, some adjustment for a dispersion match will be necessary since the first dipole is common to two energies.

The length of the final arc will be adjusted to set the phase in the final linac pass so as to give the beam the appropriate longitudinal phase space distribution for the following FFAG acceleration stage.

## 3. Tasks

We should additionally look at energy deposition in the linacs and RLAs. For now it will just be a preliminary look, to see what the scale of the problem might be, probably just tracking decay electrons.

### *3.1. Tracking*

We discussed field modeling in G4beamline for the solenoid magnets. It would be nice to have a model that closely matches the Optim field model, for the purposes of checking whether the source of problems is the original design or additional factors that come from using a more realistic field map. We will produce a solenoid field map that closely matches what is in Optim. We will also look at the linear map for the realistic field map to try to make it closely match what is in the Optim design. Dipoles and quadrupoles will initially be modeled using hard-edge field maps.

In addition, for RF cavities, we will track using the realistic cavity field map. We will find the transit time factor as a function of momentum, and find the scaling factor to make the energy gain for a speed of light particle is what is specified in the IDR. We will compare the RF focusing to what is in the Optim model.

### *3.2. Timeline*

We created a preliminary timeline for completion of the lattice design and tracking studies:

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|---|---|
| Aug 2011 | Complete lattice designs through RLA1 |
| Sep 2011 | Decision on magnet types through RLA1 |
| Sep 2011 | Tracking through RLA1 |
| Oct 2011 | Physical layout through RLA1 |
| Dec 2011 | Complete lattice for everything |
| Jan 2012 | Decision on magnet types through RLA2 |
| Jan 2012 | Tracking through everything |
| Feb 2012 | Physical layout for everything |
| Mar 2012 | Linac and RLA designs for system scaled up to 25 GeV |
| Jun 2012 | Finalized design after updates from tracking and engineering |