An Acceleration Scenario for the m-Storage Ring n-Source System

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Abstract

An acceleration scenario for a 50 GeV μ-source is proposed. It consists of a 200 MHz 2 GeV Linac, a 4-pass 200-MHz recirculating linac (RLA) up to 9.5 GeV, and a 5-pass 400-MHz RLA to take the beam up to 50 GeV. Longitudinal simulations show that a 100 MeV μ-beam with an rms emittance of 30 mm is accelerated to full energy with little distortion.

Introduction

In the presently developing μ-storage ring ν-source scenarios, muons are collected, rf rotated and cooled, and then accelerated to (relatively) high energies (10 or more GeV).[1, 2, 3] At the end of the cooling section the beam is in a string of 200 (or 175) MHz bunches with a mean kinetic energy of ~ 100MeV with a transverse emittance of ~0.002 m and a longitudinal rms emittance of ~0.030 m. Longitudinally, the beam fills (or nearly fills) the rf bucket associated with the 200 (or 175)MHz cooling system. The rms energy spread is ~20MeV while the rms bunch length is ~15cm, which implies an rms longitudinal emittance of ~30 mm.

Previously we have discussed μ-acceleration in linacs and RLAs.[4] The intrinsic flexibility of the RLA concept enables a broad range of acceleration scenarios. The transport properties (M_{56}, T_{566}, etc.) can be varied from arc to arc, and the synchronous phase ϕ_s can also be varied from pass to pass. Bunchers and compressor arcs can be added. In the present note we use only a restricted subset of these possibilities.

As noted by Douglas,[5] the experience at CEBAF indicates that it should be relatively straightforward to develop 4 or 5 pass RLA systems, although injection at ~2GeV or more would be desired to make the μ-beam sufficiently relativistic that β=1 cavity systems compatible with all passes can be used. The energy range of the system is so great that a sequence of RLAs should be used. Also since beam sizes may be adiabatically damped in the first RLA, higher-frequency rf systems can be used in the higher-energy RLA's.

After internal discussion and a bit of simulation the simplified scenario presented in Table 1 was developed. It consists of a 200 MHz Linac to take the beam to T_μ = 2 GeV kinetic energy (E_μ = 2.1 GeV total energy). This is followed by a two RLAs: a 4-pass 200MHz RLA to take the beam to 9.5 GeV followed by a 5-pass 400 MHz RLA to take the beam to full energy.

The Linac must capture beam from the cooling system, which is a 10 MV/m (average) gradient linac with absorbers, cooling around a stable phase of ~60°. If one continues the same 200 MHz linac but removes the absorbers, and keeps the central phase near the same value, one obtains stable acceleration, and that is the strategy of the present scenario. As the beam accelerates, it becomes more stable, and one can accelerate closer to crest. In the present scenario the phase starts at 70° and is moved all the way to crest (0°) by the end of the linac (250m long). At some point one could change the linac structure from the pulsed Cu cavity structure of the cooling channel to a 200MHz superconducting rf (SRF) structure; that is a point for future cost optimization.

Longitudinal simulations of the Linac have been performed and some results are displayed in Figure 2. A μ-beam with 100 MeV kinetic energy is accelerated to 2 GeV, with little emittance dilution. A beam with initial energy spread of 20 MeV and bunch length of 15cm rms, generated within a "Neuffer" distribution[6](elliptical phase space with parabolic projections) with full widths of 64cm × 86 MeV, is accelerated to 2 GeV, where the energy spread is 77 GeV and the rms bunch length is 4.2 cm. This closely matches the desired initial beam for the following RLAs.

The linac injects into a 4-turn recirculating linac, which accelerates the beam to 9.5 GeV. Parameters of this first RLA are displayed in Table 1. The central phase in each linac pass is chosen to be 40° and the M_{56} of each arc pass is 0.6m. This means the average dispersion in each arc ($\eta_{ave} = M_{56}/\pi$) is ~0.2m. 1.2 GV of 200 MHz rf is required for each linac (120m at 10 MV/m) The return arc length of 120m is estimated in ref. 5.

After acceleration to 9.5 GeV the beam is injected into a 5-turn RLA for acceleration to 50 GeV. Parameters of this high-energy RLA are also presented in Table 1. The central phase in each linac pass is chosen to be 30° and the M_{56} of each arc pass is 0.2m, which means the mean dispersion is quite small; a nearly isochronous arc lattice is required. 4.2 GV of 400 MHz rf is required for each linac.

Results of longitudinal simulations of this 2-RLA case are shown in Figure 3. An 80 MeV × 4.2cm (rms) 2 GeV beam is accelerated to 50 GeV , obtaining a 250MeV×1.3cm bunch, with very little phase space dilution.

Note that in this example we have not exploited the full range of flexibility inherent in the RLA concept. We are using the same stable phases and chronicities M_{56} for each pass of the same RLA. The stable phases are relatively large (40° and 30°) to enable a large stable phase spread; these could be moved closer to crest (0°) for later (higher-energy) passes of each RLA, which would be more efficient use of the rf gradient. We have also not included compressor arcs or added bunching or higher-harmonic rf systems. These variations could be included in future studies; they may permit significant scenario changes.

Discussion

The present scenario is certainly not the only possible and probably not the best possible, but it is useful as an example to set the scale of an appropriate μ-accelerator for a ν-source.

A complete transport and focusing system must be designed to match the components of the present scenario. There is a particularly strong challenge in designing the various spreaders and recombiners for the RLAs. The choice of 4–5 passes was based on the CEBAF example; however economical and efficient arc designs could enable a significant increase in the number of passes, which could reduce the rf requirements dramatically (8-10 passes would halve RLA rf requirements.). Once techniques for arc designs are established and appropriate magnet designs are developed a reoptimization on pass number should be developed.

We have not yet discussed transverse beam dynamics. Transverse emittance after cooling is $\varepsilon_\perp \cong 0.002$ m (rms, normalized). With a 1m $\beta_\perp$ we obtain $\sigma_x \cong 3$cm at the beginning of the linac, which sets the initial scale for aperture requirements. At the 50GeV end and $\beta_\perp = 10$m, we obtain $\sigma_x \cong$

6mm, a more manageable size. Lattices which transport this beam, accepting the full RLA emittance and energy spread for each pass are needed.

The relatively small distortion in the present simulations indicate that the example is a bit over designed, for muons. However, the addition of transverse motion complications plus a more accurate injected beam (not as cold as desired …) could remedy this defect. In any case the purpose was to obtain a working example, not an optimized one.

References

[1] S. Geer, C. Johnstone and D. Neuffer, "Design Concepts for a Muon Storage Ring Neutrino Source," FERMILAB-Pub-99/121 (1999), Proc. Lyon Workshop on Neutrino Factories (1999) to appear in NIM A (2000).
[2] R. Palmer, Muon Collider Note 46, 9/3/99 (1999).
[3] R. B. Palmer, C. Johnson, and E. Keil, Proc. Lyon Workshop on Neutrino Factories (1999) to appear in NIM A (2000).
[4] D. Neuffer, Nucl. Inst. and Meth. A 384, p. 263 (1997).
[5] D. Douglas, "A MAD (Muon Acceleration Driver) Concept for a Neutrino Factory", MUCOOL-69, December 1999.
[6] D. Neuffer, IEEE Trans. NS-26, p. 3031 (1979).

Figure 1: Overview of accelerator for a μ storage ring, showing a linac plus a sequence of two multiturn recirculating linacs.

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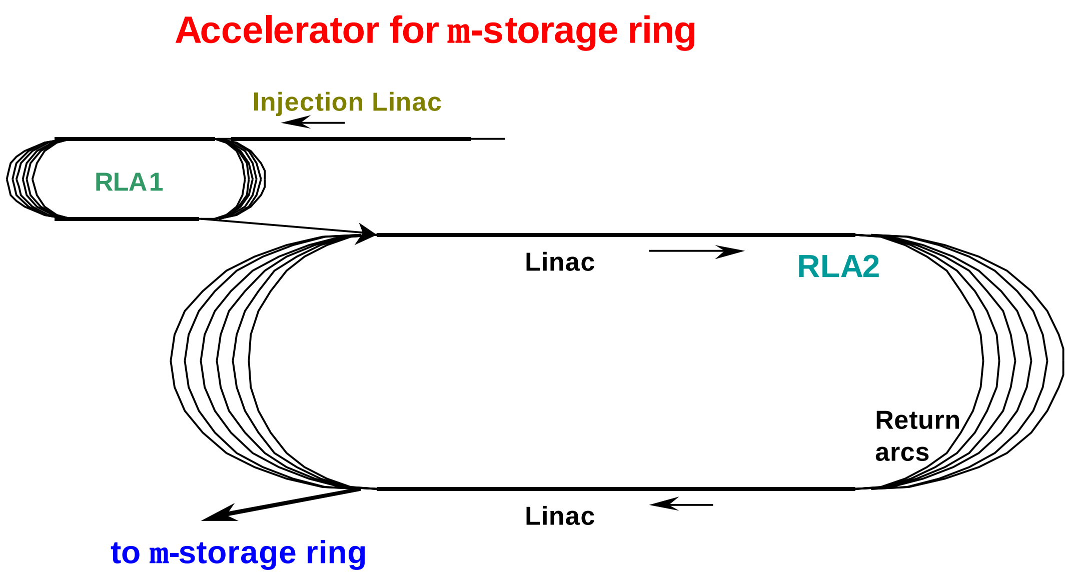
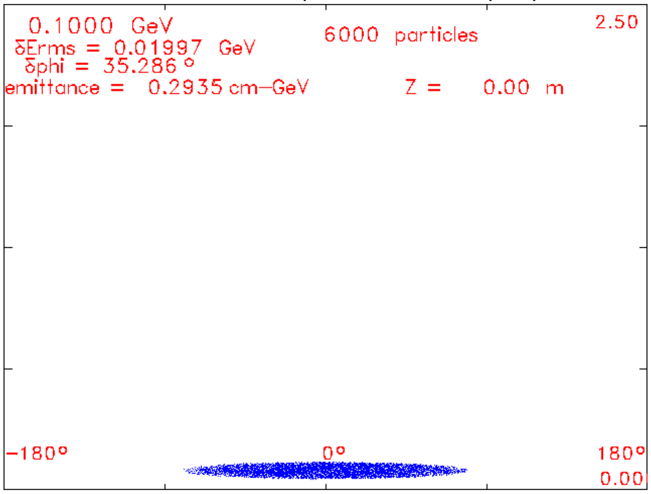


Table 1: Accelerator Parameters

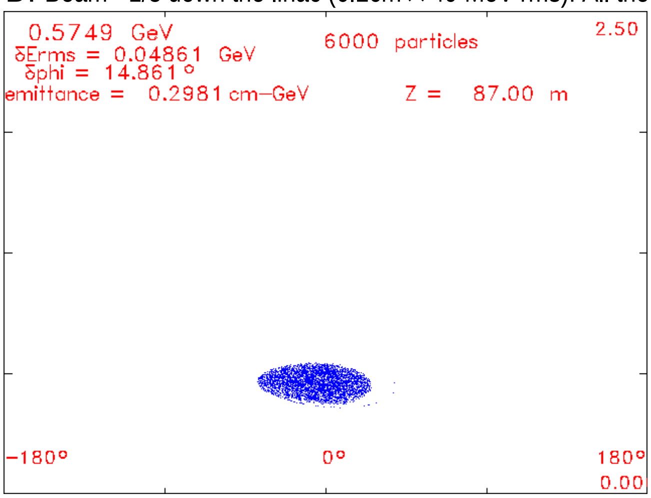
Parameter	**Linac**	**RLA1**	**RLA2**
Initial Energy	0.2	2.1	9.5 GeV
Final Energy	2.1	9.5	50 GeV
Number of turns	1	4	5
Rf Voltage/linac	2.5	1.2	4.2 GV
Acceleration phase	70→0°	40°	30°
M_{56} per arc	---	0.6	0.2 m
Rf frequency	200	200	400 MHz
Rms bunch length	15 → 4.2	→ 2.5	→ 1.3 cm
Rms energy spread	20 → 80	→ 200	→ 250 MeV
Linac length(10MV/m)	250	120	420 m
Arc length	---	120	400 m
Decay survival	0.92	0.93	0.953

Figure 2: Beam properties before and after the 2 GeV linac. Acceleration of a 30mm rms emittance beam with no loss and little phase space distribution dilution is obtained.

A: Initial beam distribution (15cm × 20 MeV (rms) or 64cm×86MeV (full width)) Initial kinetic energy=100MeV.



B: Beam ~1/3 down the linac (6.2cm × 49 MeV rms): All the beam is captured.



C: Beam at end of linac (4.2cm × 77 MeV rms); some phase space distortion is seen.

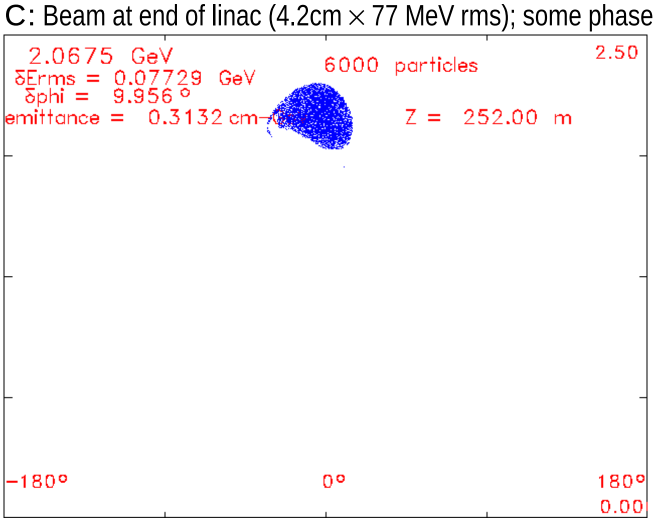


Figure 3. Simulation results of RLA acceleration in the 2RLA system. Horizontal scale is phase (degrees), vertical scale is relative energy offset (δE/E). Modest phase space distortion and emittance dilution occurs.