BEAM DYNAMICS STUDIES FOR THE FIRST MUON LINAC OF THE NEUTRNIO FACTORY*

C. Bonţoiu, M. Aslaninejad, J. Pozimski, Imperial College, UK
A. Bogacz, Jefferson Laboratory, USA

Abstract

Within the Neutrino Factory Project the muon acceleration process involves a complex chain of accelerators including a (single-pass) linac, two recirculating linacs and an FFAG. The linac consists of RF cavities and iron shielded solenoids for transverse focusing and has been previously designed relying on idealized field models. However, to predict accurately the transport and acceleration of a high emittance 30 cm wide beam with 10 % energy spread requires detailed knowledge of fringe field distributions. This article presents results of the front-to-end tracking of the muon beam through numerically simulated realistic field distributions for the shielded solenoids and the RF fields. Real and phase space evolution of the beam has been studied along the linac and the results are presented and discussed.

INTRODUCTION

The Neutrino Factory linac is intended to accelerate the muons delivered by the cooling channel, from 244 to 900 MeV based on a lattice which consists of superconducting solenoids and RF cavities in three sections [1, 2]. See Table 1 for details. While solenoids have fixed length in all three sections, the cavities are of single-cell type in the upper section and of double-cell type in the next two sections requiring an average of 10 MeV/cell to reach the design energy. Solenoidal fields have to be increased along each section as acceleration occurs but since larger beta functions are foreseen for the end of the linac, they will basically stay under 2 T.

Table 1: Lattice Figures

Linac section	cell length	no. of solenoids	no. of RF cells
upper	3 m	6	6
middle	5 m	8	16
lower	8 m	11	44

LATTICE DESIGN

The solenoids have been designed using the Poisson code [3] in order to assure that there is no significant leakage of the magnetic field into the neighbouring RF cavities and that the current density is within technical limits. In order to prevent shield saturation, two windings of opposite currents have been used as Fig. 1 shows.

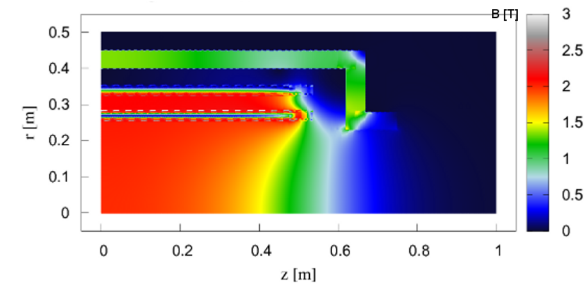

Figure 1: Total magnetic field of the shielded solenoid for a peak value of 2T with the current densities of 165.75 and -82.87 A/mm^2 for the inner and outer coil respectively.

As presented in Table 2, four RF cavities of typical elliptic shape have been analysed numerically with the Superfish code [3] in order to maximize the transit time factor and energy increase while keeping figures like surface electric and magnetic fields as low as possible. Since the injected beam $\beta_{||}$ is centred at 0.9 the 2nd or 3rd type would be suitable in order to maximize the energy gain, but due to lower surface fields and lower necessary peak voltage the 1st type has been chosen. Its electric field is shown in Fig. 2.

Table 2: Parameters for a Target Energy Gain of 10 MeV

Parameter	$\beta = 1$	$\beta = 0.9$ (a)	$\beta = 0.9$ (b)	Study II [1]
l_{cav}[m]	0.7448	0.67034	0.67034	0.8282
r[m]	0.6854	0.7042	0.6804	0.6641
f_0[MHz]	201.247	201.251	201.255	198.575
Q [10^9]	24.67	19.6	18.8	26.7
T	0.650	0.716	0.726	0.591
$\hat{E}$[MV/m]	26.17	27.19	27.83	26.38
$\|E\|^{max}_{surf}$[MV/m]	21.70	24.87	29.45	19.75
$\|H\|^{max}_{surf}$[kA/m]	48.06	58.53	61.92	45.00
U[J]	712	772	797	747
ΔW^{max}[MeV]	8.6142	9.0081	9.1336	8.8466

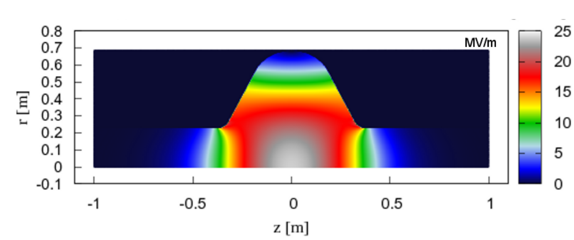

Figure 2: Total electric field for the β = 1 RF cell.

* c.bontoiu@imperial.ac.uk

FRONT-TO-END TRACKING

Both solenoids and RF cavities have been implemented into the GPT code [4] as 3D field maps for particle tracking. The muon bunch has been prepared generating 1000 particles with limits on the energy spread, time span, radial velocity and position. Longitudinal phase space evolution along the linac is strongly correlated with the RF phases and since the beam is not paraxial, also with the transverse-longitudinal coupling in solenoidal fields. As it can be seen from Fig. 3, the bunch can be confined in the longitudinal phase space if the RF phases are shifted from the values necessary to impinge the maximum acceleration. A number of concentrical rings of particle distributions have been tracked through the upper linac using the most suitable RF phases for longitudinal bunching. The transverse emittance associated with these longitudinal phase space rings was $\varepsilon_{\perp}$ = 5 mm rad in each case. As shown in Fig. 4 it resulted that the longitudinal acceptance is about $\varepsilon_{||}$ = 3 MeV ns. The linac can accommodate a 0.6 ns bunch of 20 MeV energy spread. Confining the longitudinal phase space to this value and tracking the beam with the RF phases optimized for bunching rather than for maximum acceleration, confirms that acceleration can be achieved at an average rate of 7.77 MeV/cell till the end of the middle linac section preserving the energy spread. However, as shown in Fig. 5 for the lower linac there is a gradual increase of the energy spread from 20 to 70 MeV, though the RF phases have been set to minimize it. A reason for this might be that solenoids are 8 m apart with 4 RF cells in-between and thus their transverse phase focusing cannot couple sufficiently with the longitudinal phase motion. Evolution of the transverse phase space shown in Fig. 6 confirms a reduction of the beam angular spread by a factor of two for the whole linac. Finally, the vertical projection of the trajectories along the linac is shown in Fig. 7. It can be seen that the beam remains within the vacuum chamber with minor losses estimated to less than 5 % for this tracking session.

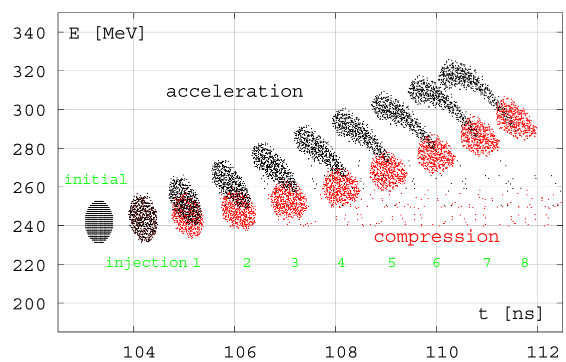

Figure 3: Two choices for the RF phases depending whether acceleration or longitudinal phase space compression is desired.

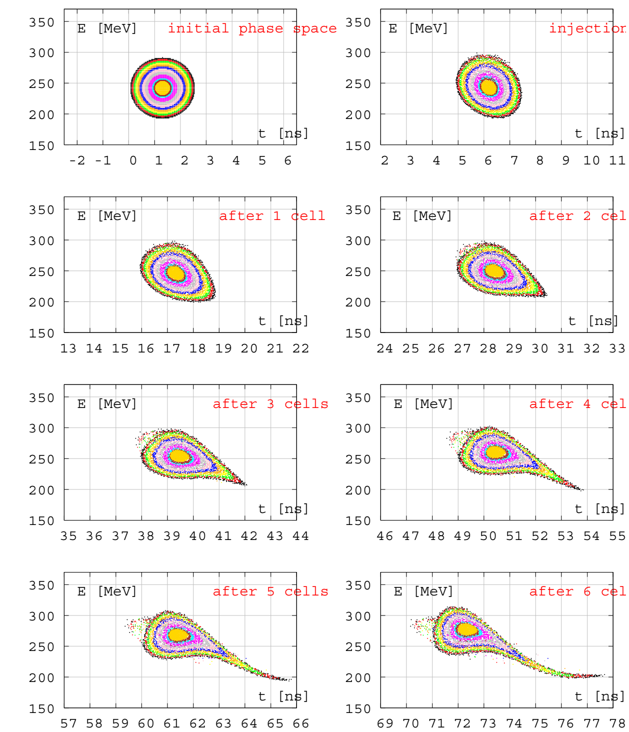

Figure 4: Filamentation of the longitudinal phase space.

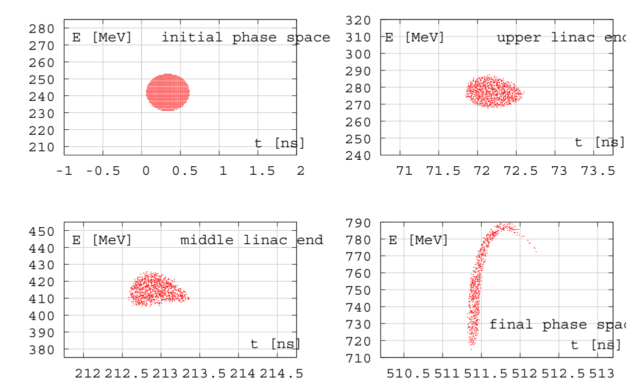

Figure 5: Longitudinal phase space at four points along the linac.

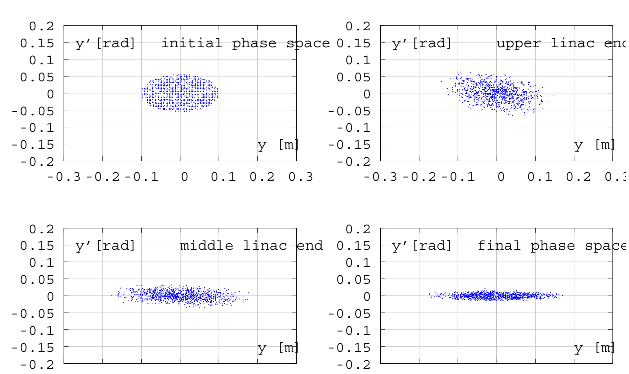

Figure 6: Vertical phase space at four points along the linac

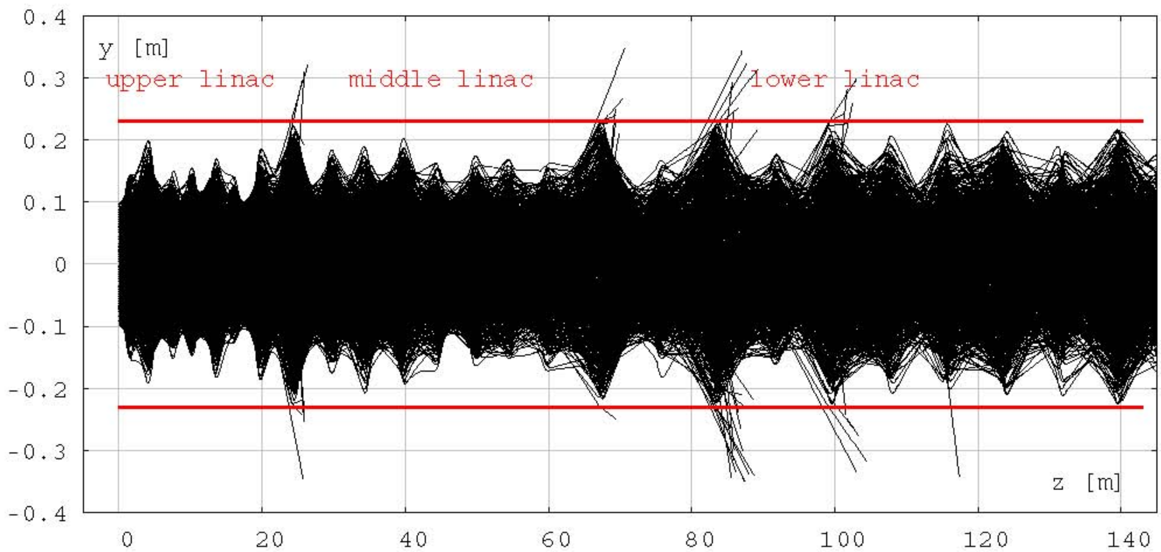

Figure 7: Vertical projection of the muon trajectories along the linac confined within the vacuum chamber walls.

CONCLUSIONS

The lower linac cell has to be reviewed since longitudinal phase focusing is not as efficient as in the other two cell types. Modifications may include adding an extra solenoid between the four RF cells or even its replacement with the middle cell type. Longitudinal and transverse acceptances of the linac are smaller than the beam phase space areas at the end of the cooling channel by a factor of 15 and 4 respectively. Therefore a significant effort must be put in designing a matching section for a reasonable beam capture.

REFERENCES

[1] J.C. Gallardo (ed.), "Feasibility Study-II of a Muon-Based Neutrino Source", June 2001, `http://www.ids-nf.org`.

[2] M. Aslaninejad et.al, "Solenoid fringe fields effects for the Neutrino Factory linac - MADX investigation" these proceedings.

[3] `http://laacg1.lanl.gov`.

[4] `http://www.pulsar.nl/gpt/`.