16 GeV Transfer Line for a New Proton Driver

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Abstract

One of the issues that a new proton driver for the proposed Neutrino Factory faces is the transport of short proton bunches from the proton driver ring to the target. In the present Fermilab scenario the 16GeV ring will be about 2 km. away from the target, as shown in Figure 1. In this note a simple design is presented, and it is shown that short intense proton bunches can be transported without significant increase in the bunch length.

Introduction

One of the main characteristics of the new 16 GeV Proton Driver for the proposed Neutrino Factory and the future high energy physics program at Fermilab is the short length and high intensity of proton bunches. The current design assumes that there will be four bunches with

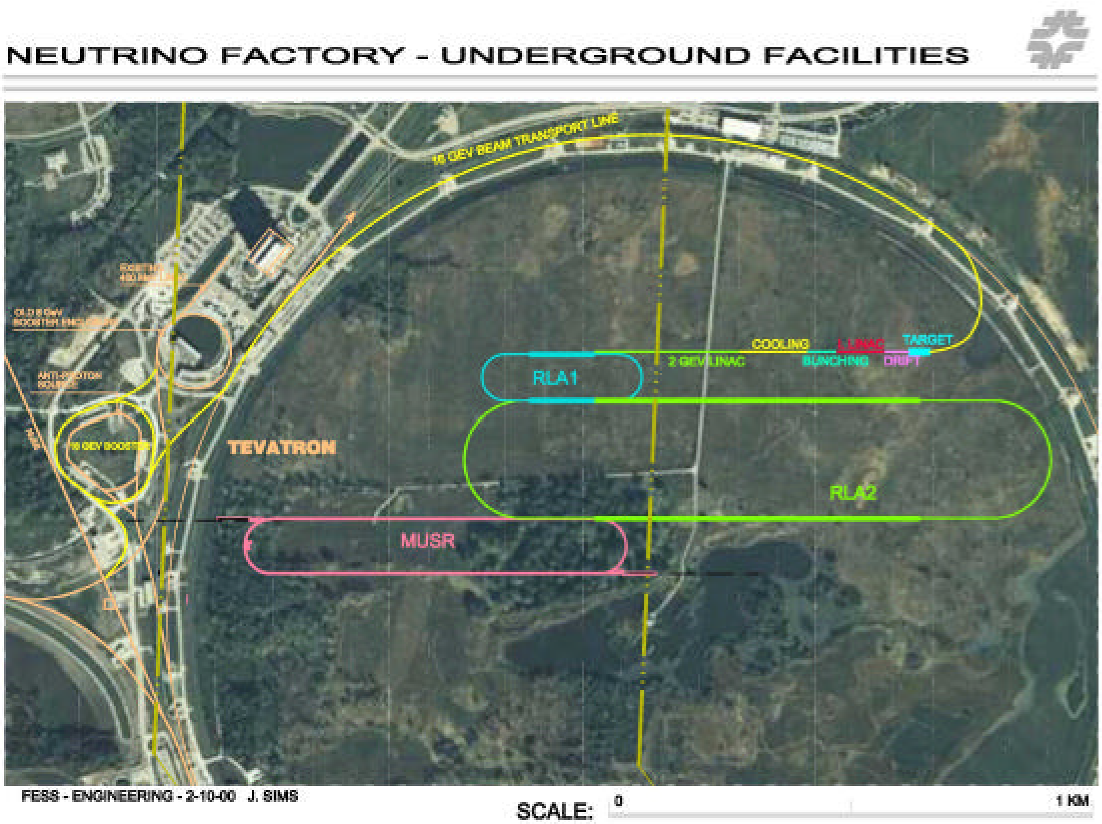


Figure 1

1.0×10^{13} protons per bunch and that each bunch will be 3ns (rms) long at the target. The designed longitudinal emittance for 95% of the beam is 2eV-sec and the normalized transverse emittance for 95% of the beam is 50π mm-mrad. At present it is assumed that the longest part of the transfer line will be in the Tevatron tunnel, and any beam degradation most probably will happen in this portion of the line. Having that in mind, the design presented here is a transport line along one quarter of the Tevatron with a matching section at the beginning and the end. It is also assumed that the line should be made from the components that are easily fabricated or readily available.

Transfer Line Design

We will assume that the beam pipe will be the standard, 8.2cm (3.25 inch) diameter and that the 95% beam size will be less than 3.0cm. The 50π mm-mrad beam will allow for β_{max} ~ 100 meters. To keep the design simple and modular, we will choose a FODO type lattice. To have the option of introducing RF cavities in the line as a means of controlling bunch length and to simplify dispersion matching the line is designed with zero dispersion at the entrance and the exit of the line. Finally to slow down synchrotron motion the line should have γ_t ~18, close to gamma for a 16GeV beam. Table 1 lists the dimension and physical parameters for different elements of the line. There are 24 FODO cells with bending magnet and one straight FODO cell at the entrance and exit of the line.

Number of Dipole Magnets	48
Dipole Magnet Length	2.31 meters
Dipole Bending Angle	~2.0 degree
Dipole Magnetic Field	~8.5 Tesla
Dipole Full Gap Size	0.06 meters
Quad Length	1.0 meters
Quad Gradient	0.033 m^{-2}
Quad Bore Radius	0.05 m
Quad Magnetic Field at Tip	~0.5 Tesla
Half Length of the FODO Cell	27.6 meters
Total Length of Transport Line	1488.0 meters

Table 1

The numbers above were used as input parameters for the computer code MAD. Zero values for the dispersion and its derivative in the x-plane were used as boundary conditions to fix values for the quad gradients and the FODO cell length. The position of the dipole magnet between the two quads was based on the assumption that the transition γ_t should be around eighteen and that the maximal dispersion should be kept as low as possible. Table 2 lists the relevant values of the lattice functions.

β_x max	87 meters
β_x min	26 meters
β_y max	118 meters
β_y min	40 meters
D_x max	5.9 meters
ν_x Phase Advance per Cell	1.3 radian
γ_t Transition Gamma	21.9

Table 2.

Figure 2 shows the Lattice functions, $\beta_{x,}$ β_y and D_x along the transfer line.

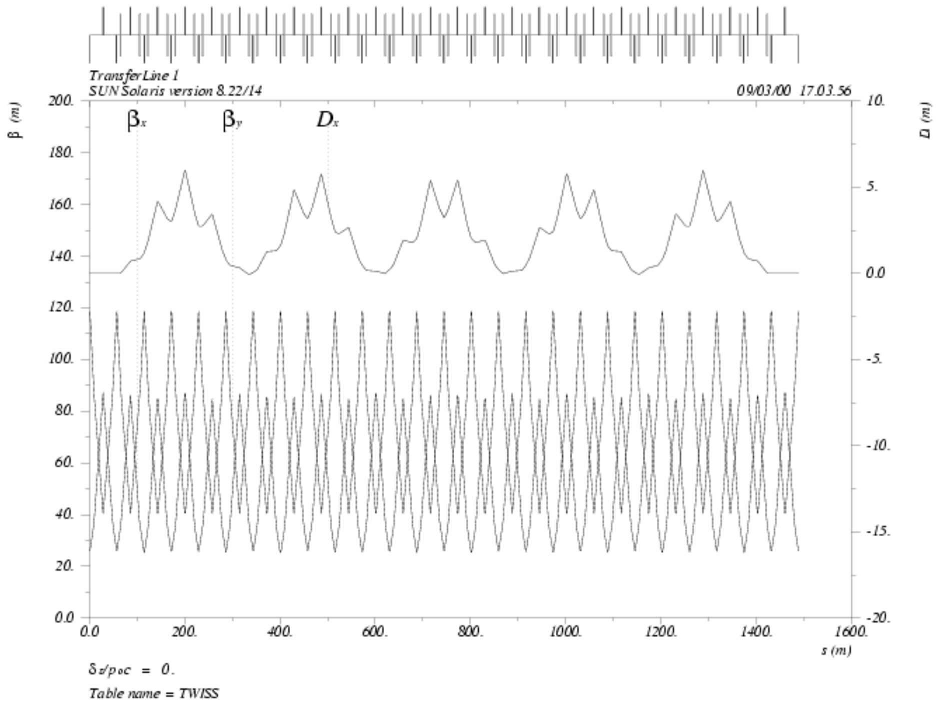


Figure 2

Space Charge Considerations

Proton bunches that are transferred to the target are short and very intense. To study the

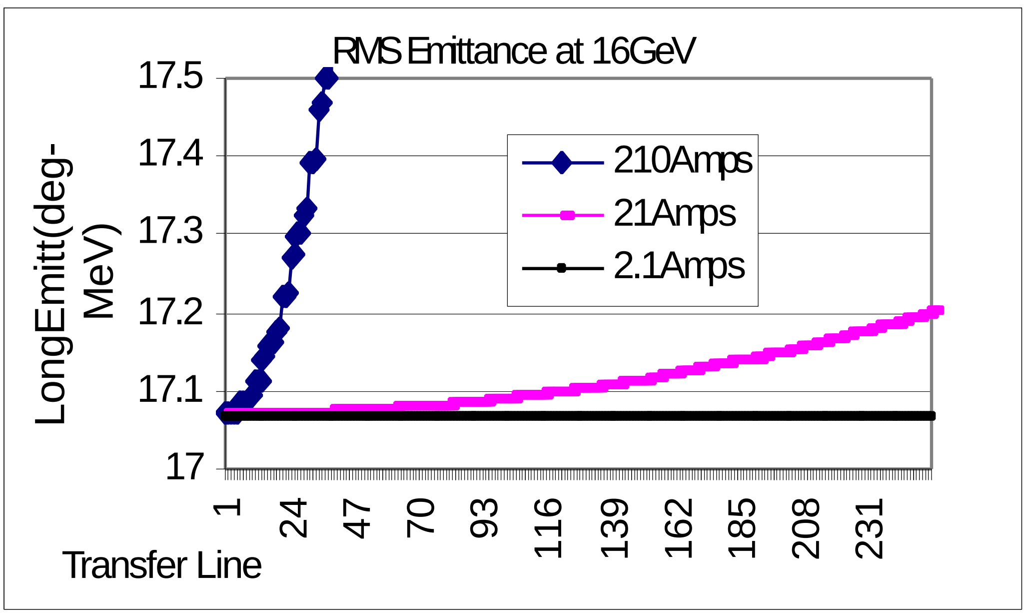
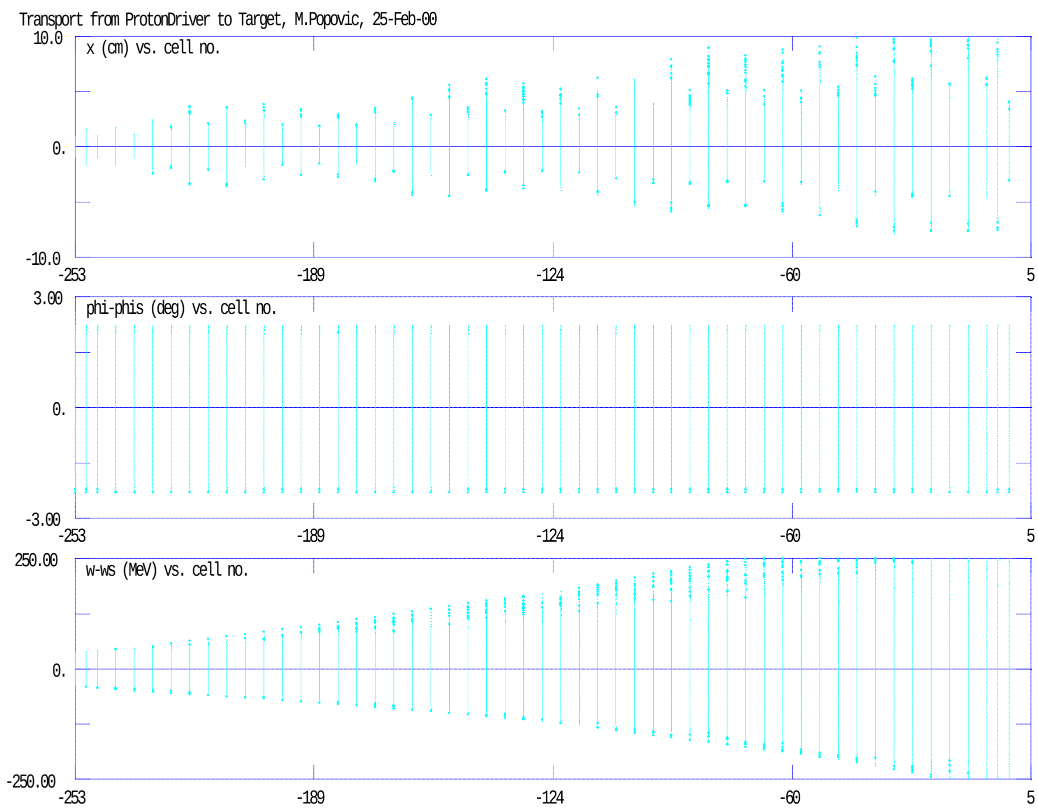


Figure 3

influence of space charge on the bunch length, we have simulated the transport of the proton bunches along design line using the PARMILA code. We transported fifty thousand particles along the transfer line designed, with the MAD code. For the initial distribution, we assumed a uniformly populated ellipsoid in 6-dim phase space, upright in each plane. The beam size in each plane is fixed assuming 50π mm-mrad for the x-y normalized beam emittance and 2eV-sec for the beam longitudinal emittance with the 3ns rms bunch length. The beam is bunched with a 1.9MHz structure, and there are four bunches coming from the ring. Space charge kicks were applied every two meters, and the bunch was divided into twenty concentric rings radially and into on 100 pieces longitudinally. At the nominal average current of 2.1 Amps, there was no longitudinal emittance growth. To see the effects of space charge, two more runs were performed, for 21.0 Amps. and 210.0 Amps. Figure 4 shows the longitudinal emittance as a function of position along the line for the three different currents.



The upper plot in Figure 5 shows the beam size in horizontal plane, the middle plot is the half bunch length in 1.9Mhz degrees, and the lower plot is the half energy spread along the transfer beam line for 210 Amps of average beam current. From this simulation it is clear that even for the hundred times higher current there will be no bunch length increase in the transfer line as it is designed.

References

1. C. Ankenbrandt et al., Proton Driver ???
2. The MAD Program, CERN/SL/90-13
3. The PARMILA Program, LANL, LA-UR-98-4478