DESIGN OF THE FINAL FOCUS OF THE PROTON BEAM FOR A NEUTRINO FACTORY

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Abstract

The $\approx$ 8-GeV, 4-MW proton beam that drives a Neutrino Factory has a nominal 50-Hz macropulse structure with 2-3 micropulses $\approx$ 100 ns apart. The nominal geometric beam emittance is 5 μm, and the desired rms beam radius at the liquid-metal-jet target is 1.2 mm. A quadrupole-triplet focusing system to deliver this beam spot is described.

INTRODUCTION

A Muon Collider or a Neutrino Factory [1] is a muon-accelerator complex fed by a nominal 4-MW, 8-GeV proton beam at 50 Hz. The proton beam impinges on a target inside a nominal 20-T solenoid magnet [2], sketched in Fig. 1.

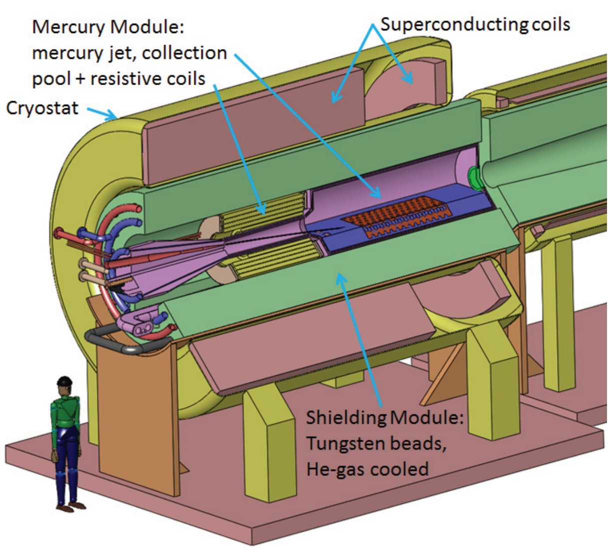

Figure 1: Neutrino Factory/Muon Collider Target System.

The proton beam is prepared in a rapid-cycling synchrotron (RCS)or compressor ring and transported to the target via an arc lattice, sketched in Figs. 2 and 3, designed to maintain bunch compression without an RF system via manipulation of the beam dispersion. Optical functions of the triplets in the arc lattice are represented in Fig. 4.

The nominal beam spot at the target has rms radius $\sigma = 1.2$ mm, and the $\beta^\star$ should be at least 28 cm, corresponding to a maximum geometric transverse emittance of $\epsilon_r = 5\ \mu$ m. Additionally, it is desirable that the last quadrupole of the proton-beam final-focus system be as far upstream of the target system. In particular it was proposed to have long available space for the longitudinal assembly of the target.

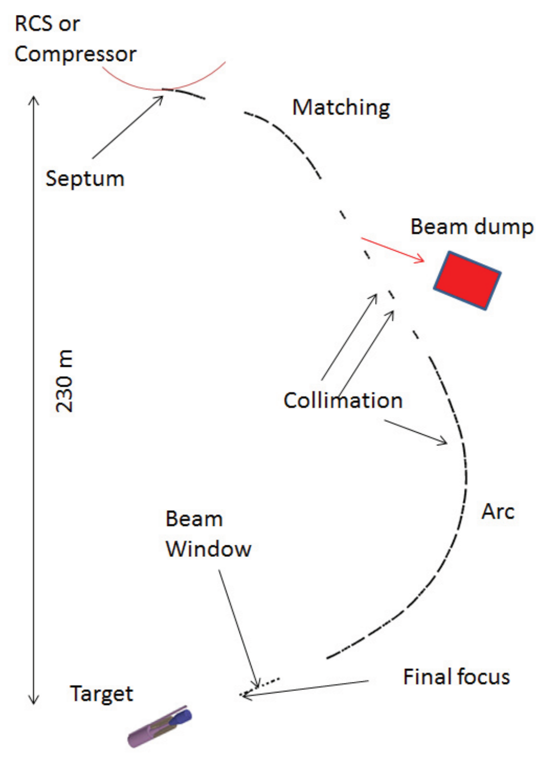

Figure 2: Layout of the proton-beam transport at a Neutrino Factory.

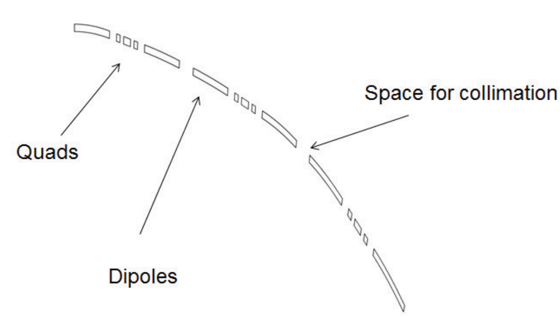

Figure 3: Several cells of the arc lattice.

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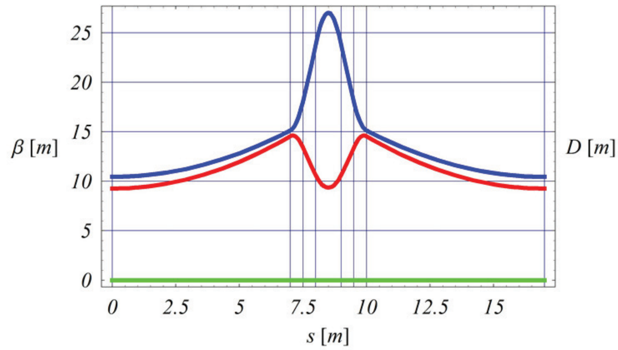

Figure 4: Horizontal and vertical β-functions and dispersion functions D for a typical 17-m-long arc-lattice cell.

LARGE-GAP FINAL-FOCUS SYSTEM

A final-focus system with four room-temperature quadrupoles that provides a very large gap between the last quadrupole and the target is sketched in Fig. 5. The $\beta^\star$ is 0.6 m, which requires a transverse beam emittance of $\epsilon_r = 2.5\ \mu$m, which is problematic for the proton driver.

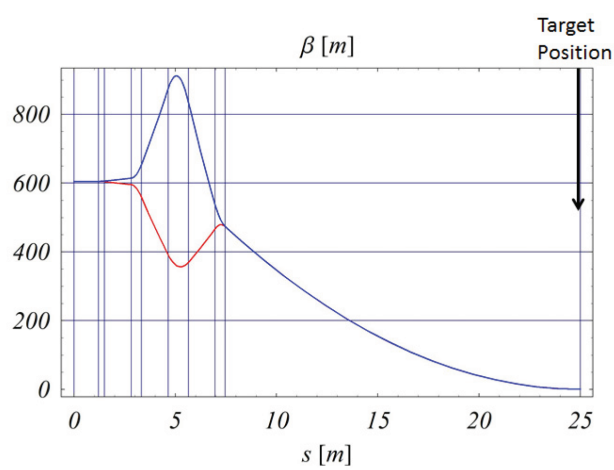

Figure 5: Final focus system with a large gap between the last quad and the target, and $\beta^\star = 0.6$ m.

It is anticipated that the proton beam will be in vacuum up to a beam window several meters upstream of the target, travel in air across a small gap to an entrance window to the target system volume which will contain mercury vapor. The system shown in Fig. 5 would permit these two beam windows to be well upstream of the focus, where the beam intensity on the window is relatively modest. Although this solution allows for a long space between the last quad and the target the beam size becomes an issue in the focusing quads.

SMALL-GAP FINAL-FOCUS SYSTEM

An alternative arrangement of the final focus magnets has been designed in which the last quadrupole is 4-5 m upstream of the target. The proton beam windows will be immediately downstream of the last quadrupole, where the proton-beam intensity is still sufficiently small to permit the windows to be of, for example, TiVaAl6 alloy. The optical parameters in the last six quads, which perform the matching between the triplet cells and the target, are shown in Fig. 6.

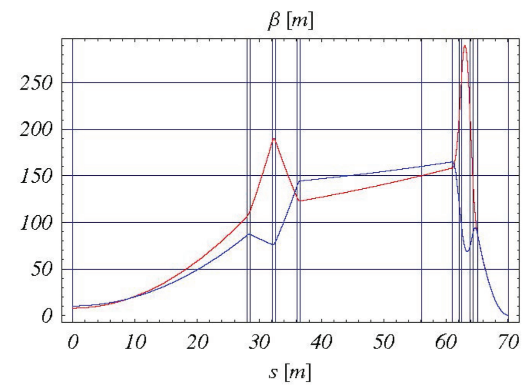

Figure 6: Optics in the final-focus system with 5 m gap between the last quad and the target, and $\beta^\star = 0.288$ m. The red and blue lines are the horizontal and the vertical betatron functions.

This quad system is 70.1 m long and consists of normal conducting quadrupoles. Beam-tracking simulations have been produced using the General Particle Tracer code [3]. The tracking studies were performed with the space charge turned off, but the inclusion of this effect can be addressed in a future. The semiparabolic particle distribution with nominal rms geometrical emittances of 5 μm in both transverse plains has been used in the study.

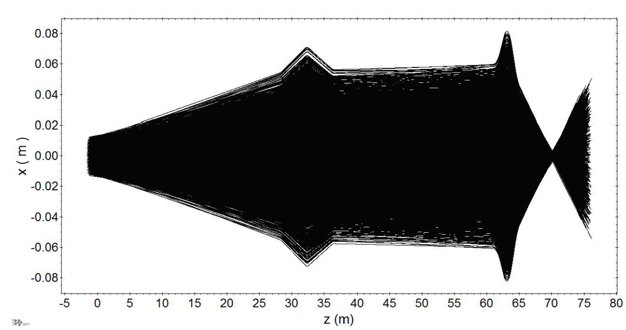

Figure 7: Horizontal beam trajectories in the final focus simulated with the GPT code.

The beam trajectories in the horizontal and vertical planes are shown in Fig. 7 and Fig. 8, respectively. The beam size is firstly increased and has maximum size of

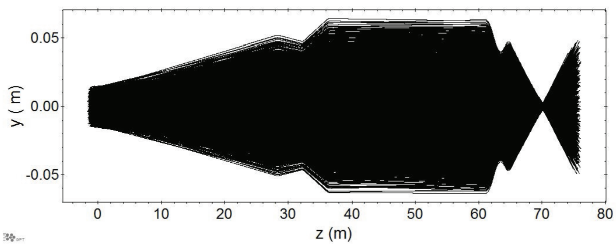

Figure 8: Vertical beam trajectories in the final focus.

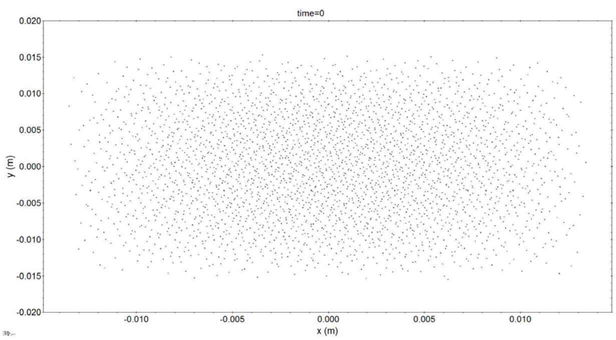

Figure 9: Beam size in real space at the input to the final focus.

$\approx$ 8 cm in the horizontal plane in the middle of the focusing central quad and finally is squeezed to the required nominal spot size of $\approx$ 1.2 mm rms in both planes. The rms beam size obtained at the target focus are 1.23 and 1.19 mm in the horizontal and the vertical planes respectively.

SUMMARY AND FUTURE PLANS

The preliminary design of the final focus system for the Neutrino Factory or a Muon Collider pion-production target, which meets the baseline specifications has been created. The beam-tracking studies have been performed using the GPT code and were able to reproduce the specifications. In particular the rms beam spot size of 1.2 mm has been successfully produced. Future work will address the effect of the target-solenoid magnetic field on the proton beam focusing and steering. The study will be extended to include the effects of the beam window and of space charge.

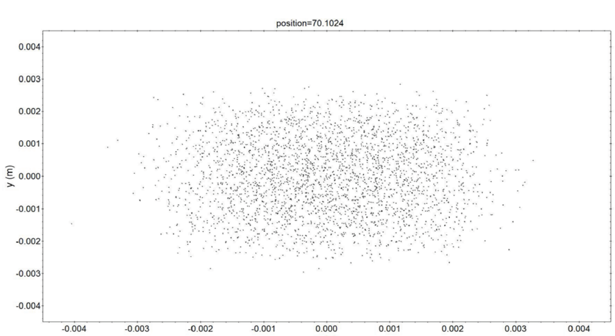

Figure 10: Beam size in real space at the output (at the target location).

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