

FRONT END ENERGY DEPOSITION AND COLLIMATION STUDIES FOR IDS-NF*

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Abstract

The function of the Neutrino Factory front end is to reduce the energy spread and size of the muon beam to a manageable level that will allow reasonable throughput to subsequent system components. Since the Neutrino Factory is a tertiary machine (protons to pions to muons), there is an issue of large background from the pion-producing target. The implications of energy deposition in the front end lattice for the Neutrino Factory are addressed. Several approaches to mitigating the effect are proposed and discussed, including proton absorbers, chicanes, beam collimation, and shielding.

INTRODUCTION

The Neutrino Factory muon front end consists of a pion decay channel and longitudinal drift, followed by an adiabatic buncher, phase rotation system, and ionization-cooling channel. The present design is based on the lattice presented in the Neutrino Factory Study 2A report [1] with several modifications: the taper from the target solenoid has been adjusted; the solenoid-field strength in the drift, buncher, and phase rotation sections has been reduced from 1.75 T to 1.5 T; the whole system has been shortened; and the thickness of the lithium hydride absorbers in the cooling section has been increased. These changes result in the same muon-capture performance in a shorter bunch train, reducing requirements on some systems downstream of the muon front end. The latest version of the front end layout is presented in [2].

Beam Losses

There are significant particle losses along the beam line and these may result in a large energy deposition in superconducting magnets and other equipment. Two main risks have been identified: energy deposition by all particles may cause superconducting equipment to quench; and energy deposition by hadrons and other particles may activate equipment preventing handling for maintenance. In Fig. 1, the power deposited by transmission losses per unit length from various particle species is shown as a function of distance along the channel. Note that energy deposition in RF windows and absorbers is not included in this calculation. It is expected that this equipment will absorb several

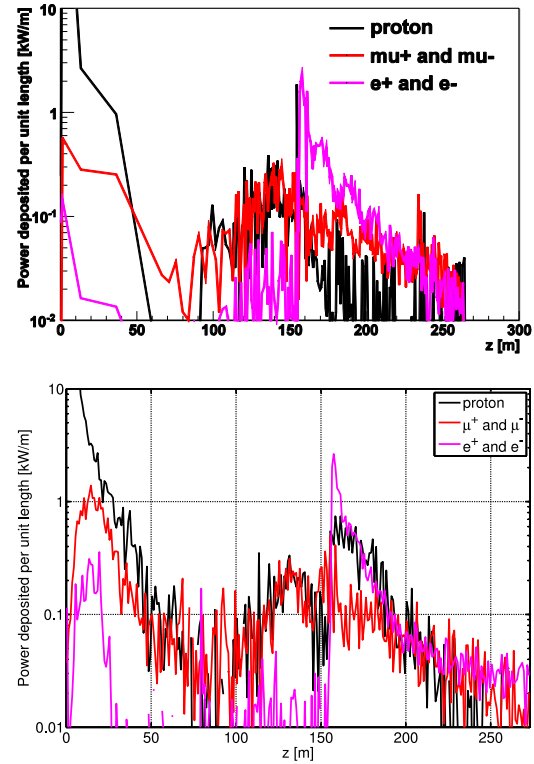


Figure 1: Power loss per unit length along the channel. Top: ICOOL, bottom: g4beamline.

kilowatts of beam power from each particle species. In currently operating accelerators, uncontrolled hadronic losses must be less than 1.0 W/m to enable “hands-on” maintenance without additional time, distance, or shielding constraints. Magnets are expected to quench with beam losses above a few tens of W/cm³. Several schemes are envisaged to control the beam losses and reduce them below these values. Four devices are under study for reducing the transmission losses in the front end:

- Low momentum protons may be removed using a proton absorber. This device takes advantage of the different stopping distance of protons compared with other particles in material.
- Particles with a high momentum, outside of the acceptance of the front end, may be removed using a chicane system. Dispersion is induced in the beam by means of bending magnets in a chicane arrangement and high-momentum particles are passed onto a beam

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dump.

- Particles with transverse amplitude outside of the acceptance of the front end may be removed using transverse collimators.
- Shielding between the beam and superconducting coils.

CHICANE

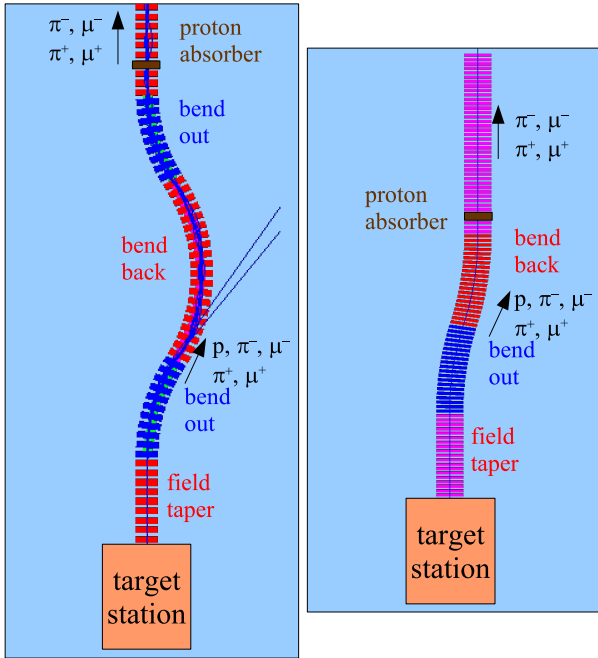


Figure 2: Double and single chicane schematics.

It is proposed that part of the straight decay channel is replaced with a double or single chicane (Fig. 2). The goal of the chicane is to remove all high-momentum particles. Fig. 3 shows that particles with $p > 500$ MeV/c are essentially removed while low-momentum particles are kept in the channel. The chicane uses bent solenoid optics that induces a vertical dispersion. The lattice is charge invariant; particle sign change only switches the direction of angular momentum and dispersion. Hence, there is no need for two separate chicanes, since one arc is capable of transmitting particles of both signs. A separate task is the design of the beam dump and the extraction system for the discarded part of the beam.

PROTON ABSORBER

The proton absorber is meant to remove low-momentum (below 500 MeV/c) protons. If the absorber is placed towards the end of the decay channel, the longitudinal distribution is not properly matched to the downstream components. Therefore, the absorber is placed closer to the beginning of the decay channel. The thickness of the absorber is determined based on a trade-off: too much material means

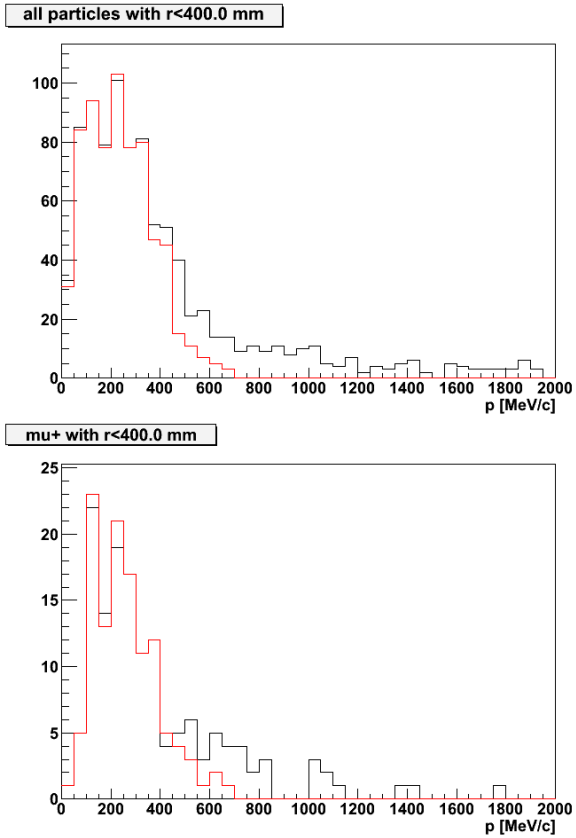


Figure 3: Particle transmission vs momentum, double chicane. Top: all particles within a 400 mm radius, bottom: μ^+ only within a 400 mm radius. Black histogram: no chicane; red histogram: with double chicane.

more muon losses and at the same time more protons removed, and vice versa. One of the configurations is shown in Fig. 4; here an absorber of 10 cm carbon was used.

For the purposes of performance comparison, two absorbers were considered: 10 cm and 20 cm of carbon. Simulations showed that there was not much difference in terms of proton beam power reduction, but there was a significant difference in terms of muon rate. For the 10 cm case the ultimate number of useful muons is comparable with the baseline scenario, while for the 20 cm case it is much lower.

10 cm of carbon is a fairly large perturbation in the front end scenario, and a relatively thickness independent improvement is a question to be investigated. A thinner Be absorber could be as effective.

TRANSVERSE COLLIMATION

It was suggested that the chicane should be followed by a collimation system removing the particles with large transverse amplitude. However, by the time the beam reaches 30 meters down the decay channel (approximate length required for the chicane), it is focussed and matched to the transverse acceptance of the downstream channel with very

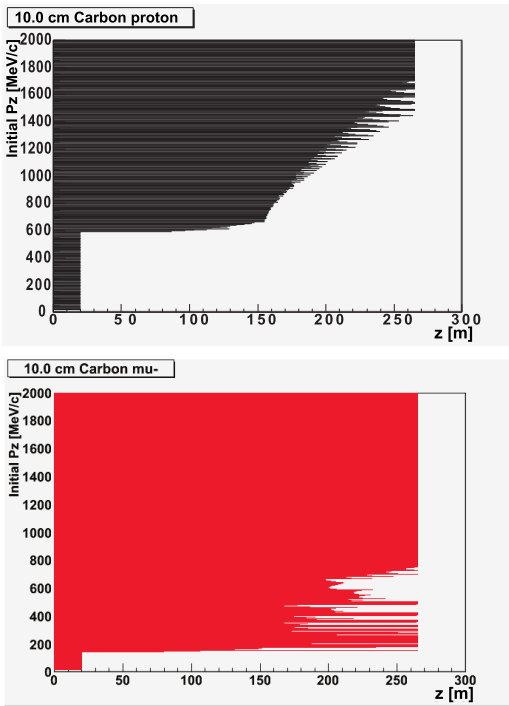


Figure 4: Effect of a 10 cm carbon absorber on protons (top) and muons (bottom).

few particles lost in the buncher, phase rotator and cooler due to the fact that their transverse amplitude is large, as shown in Fig. 5. In this simulation particle decay processes are turned off.

SHIELDING

The decay part of the front end has room for up to 30 cm shielding between the beam and the magnet coils (see Fig. 6). This shielding would protect the superconducting coils, and control much of the large beam loss in the decay channel (up to $z = 79.6$ m) shown in Fig. 1. Shielding is more problematic and less effective but still helpful in the RF and cooling regions.

Energy loss simulations and irradiation studies of the front end are required, using MARS or similar codes, to select shielding thickness and material, and assess the radiation escaping the shielding layer and energy deposited in the superconducting coils.

SUMMARY

Technical risk to the muon front end is presented by irradiation of the accelerator hardware due to uncontrolled particle losses. Strategies have been outlined by which these risks can be mitigated, and the progress and plans on the corresponding studies has been reported. These studies indicate that we can dramatically reduce the pollution of the muon beam due to proton and electron secondaries without strongly impacting the muon yield of the front end. Further

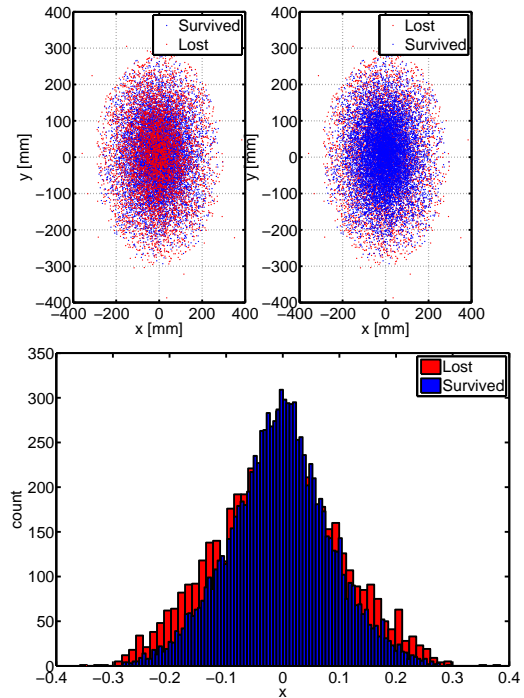


Figure 5: Top: comparison of the two distributions of particles, those that are lost (red), and those that survived to the end of the cooling channel (blue). Top-left: lost particles on top of survivors; top-right: survivors on top of the lost particles. Bottom: comparison of the histograms (horizontal displacement) of the two distributions.

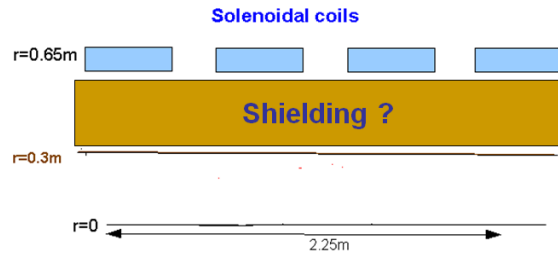


Figure 6: Approximately 30 cm of space is available between the beam pipe and the superconducting coils to place shielding material.

studies are required to determine the configuration of beam dumps, collimators and shielding.

REFERENCES

- [1] The Neutrino Factory and Muon Collider Collaboration Study 2A, <http://www.cap.bnl.gov/mumu/study2a/>.
- [2] IDS-NF Collaboration Interim Design Report, Tech. note IDS-NF-020, <https://www.ids-nf.org/wiki/FrontPage/Documentation?action=AttachFile&do=get&target=IDS-NF-020-v1.0.pdf>.