ENERGY DEPOSITION AND SHIELDING STUDY OF THE FRONT END FOR THE NEUTRINO FACTORY#

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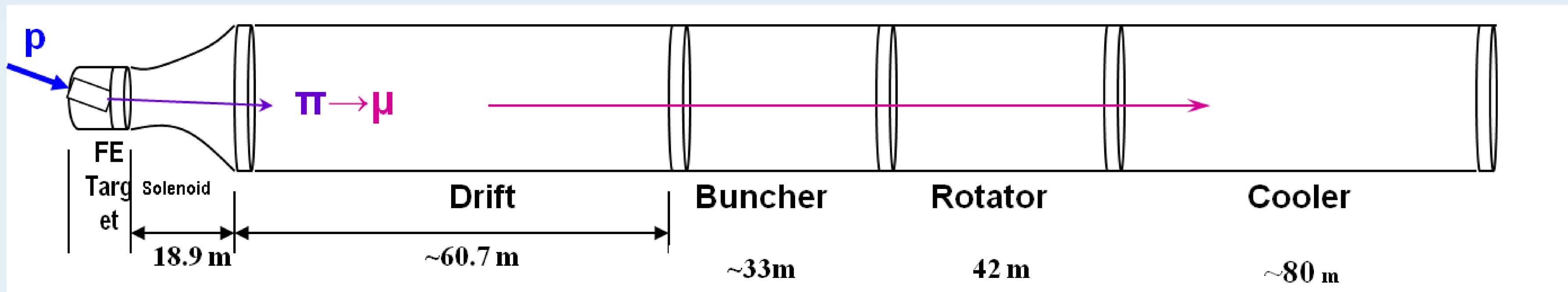
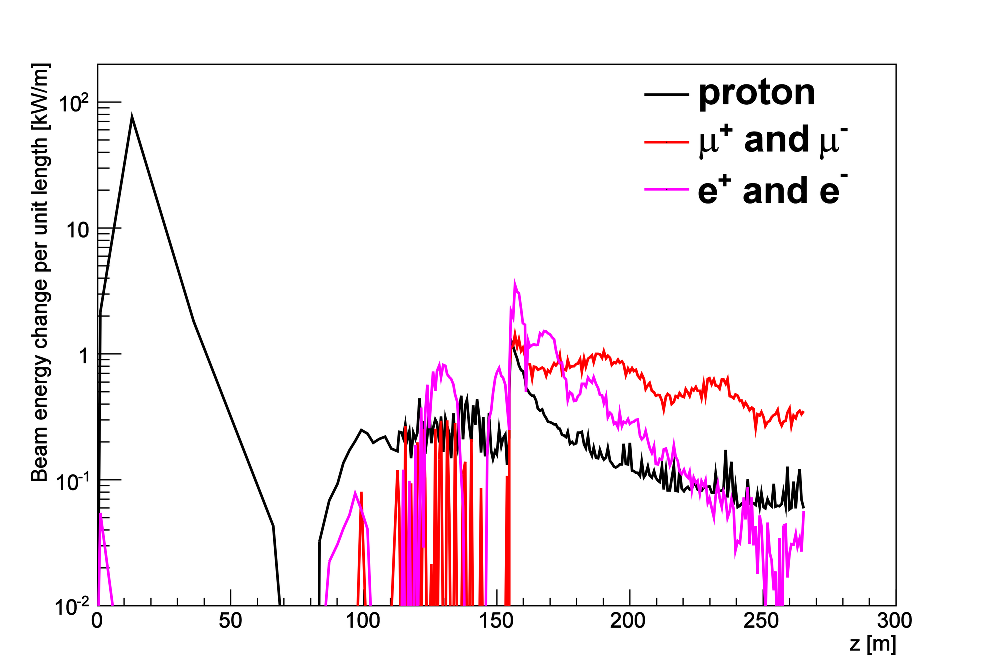
Summary: A particle selection system has been designed for the Neutrino Factory and Muon Collider that reject secondary particle contaminants. The particle selection system has been shown to reject up to 99.9% of proton contaminants as well as creating a better conditioned muon beam at the expense of a slight reduction in muon yield. 4 cm of W shielding reduce energy deposition in the coils significantly, nonetheless, coils between 32 and 36 m downstream of the proton target will have to be replaced by normal-conducting ones in order to withstand power density up to 9.1 mW/g.

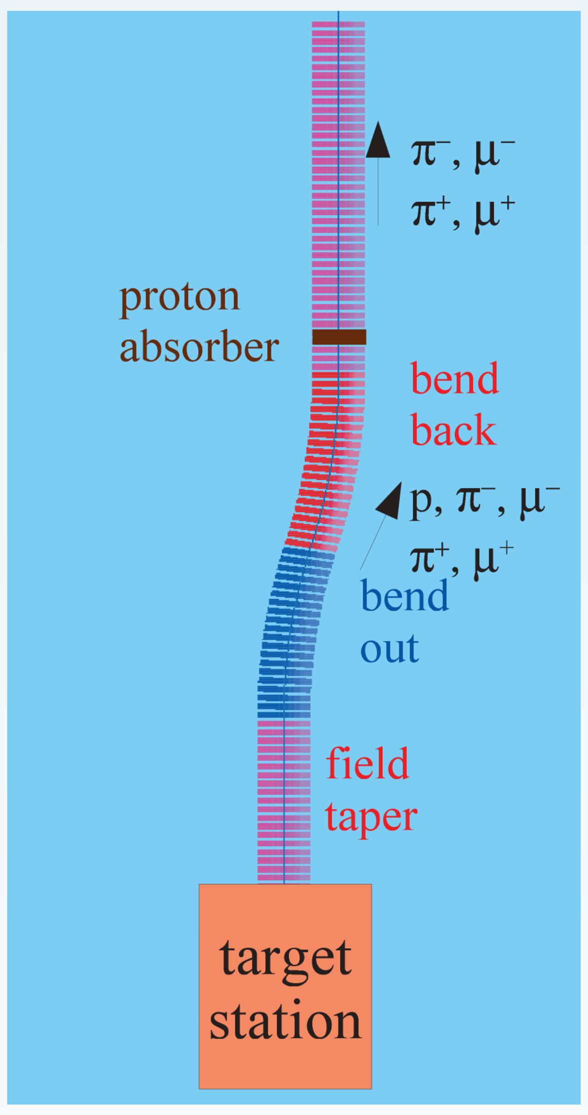


Introduction

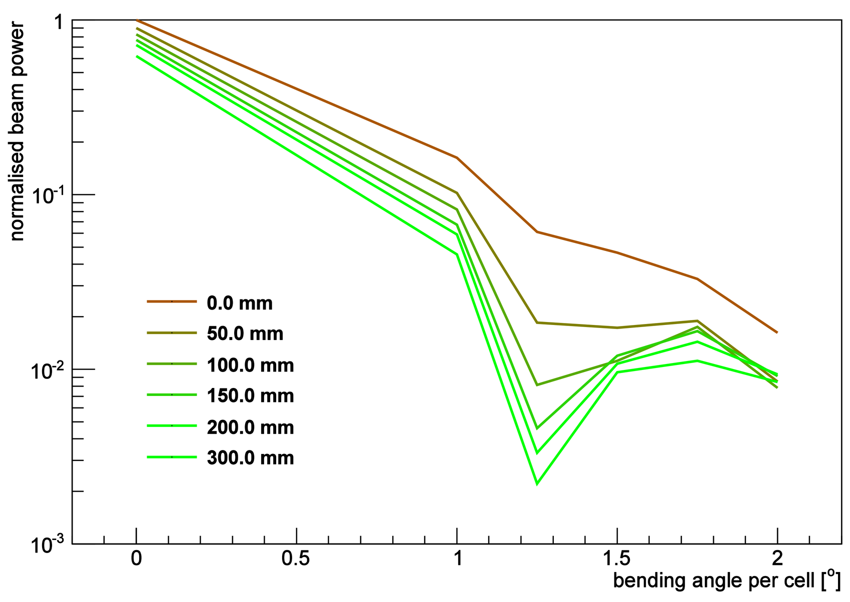


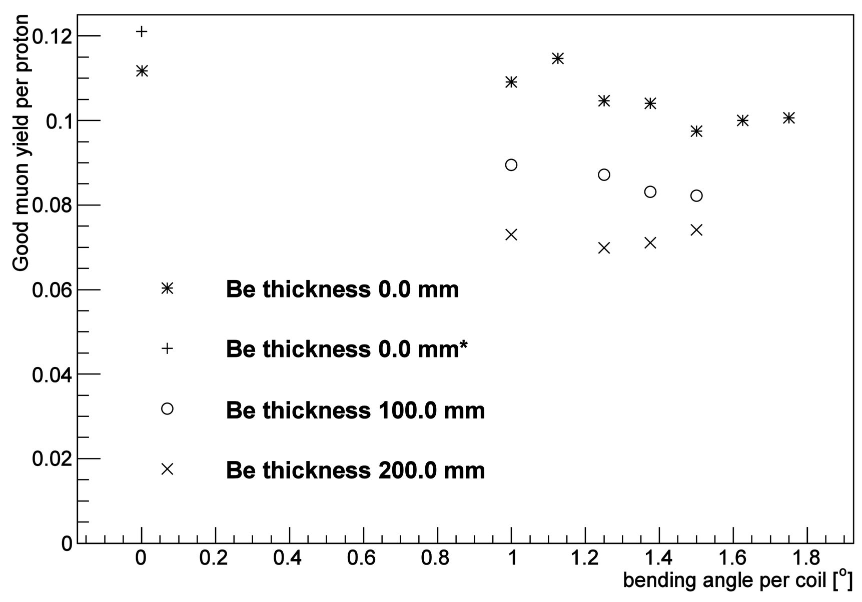
- Neutrino Factory (NF) [1] and Muon Collider (MC): [multi-MW] proton beam on target produce pions, pions decay to muons, muons are captured and accelerated.
- Background from protons and electrons results in heat deposition on SC materials and activation of the machine preventing manual handling.
- Secondary particle handling system: a solenoidal chicane that filters high momentum particles, followed by a proton absorber that filters the low energy protons that pass through the solenoid chicane.

Chicane Design

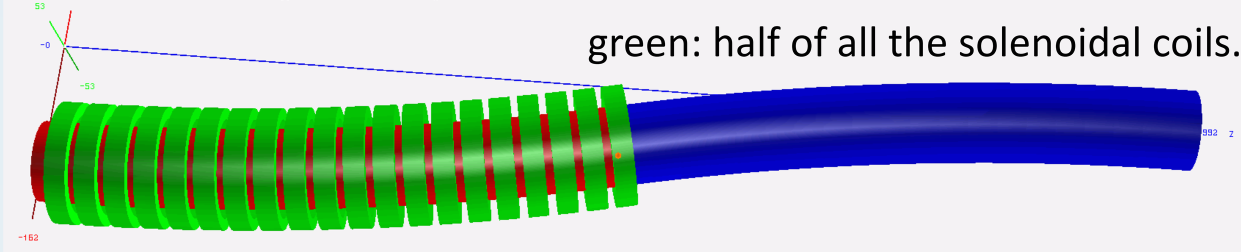


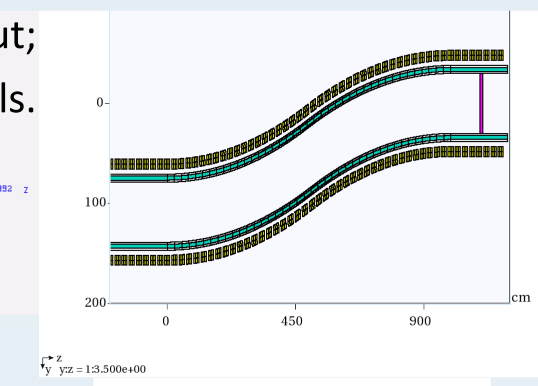
- Design of a chicane system is not trivial: other authors [2] have considered combined function chicanes. Issue: highly challenging to get good transmission over the desired range of momenta.
- NF and MC capture both positive and negative muon species, and any chicane system must do the same. This may be possible with a multipole magnet, but would make any design more difficult.
- Solution: a stellarator-type solenoidal chicane. Solenoidal chicanes induce a vertical dispersion in the beam, resulting in symmetric transmission of both particle charges.
- Issue: not possible to make an open midplane solenoid. Very high radius SC coils with significant shielding or NC coils exposed to beam power in the hundred kW range are required. These components would become active and would be treated as part of the remote handling facility in the target area.
- Beryllium proton absorber after the chicane: lowers the overall energy of particles in the system. This has a more significant effect on the protons that pass the chicane, stopping almost all of them, while leaving most muons in the beam.
- In Figures below the proton beam power passing the proton absorber and good muon yield for the entire front end system is shown for various chicane and proton absorber parameters, as simulated in G4Beamline [3].
- Increasing thickness and angle reduce the good muon yield slightly, while producing a dramatic reduction in the proton beam power escaping the system.
- Based on these simulations a 12.5° chicane angle (1.25° per coil) and 100 mm proton absorber thickness was chosen.





ROOT chicane geometry. Red: shield, bend in; blue: shield, bend out; green: half of all the solenoidal coils.





Chicane as simulated in MARS, top view.

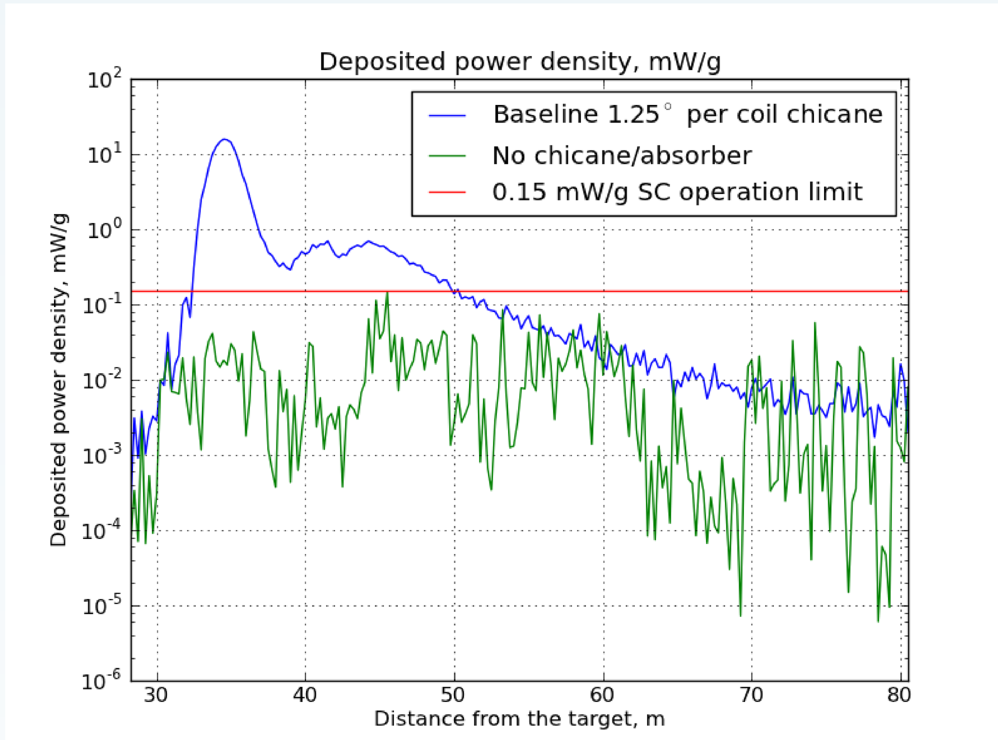
Energy Deposition Studies

- For irradiation study the chicane is simulated in MARS15 [4]. Field maps for MARS simulations are generated by G4beamline.
- Complicated geometry of the chicane, => adding shielding is not possible using only MARS extended geometry.
- ROOT-based geometry framework for MARS is used with a wide variety of basic volumes provided by the ROOT TGeo module.
- The volume of each shielding or coil segment can be calculated precisely in ROOT; removes the uncertainty intrinsic to MARS Monte-Carlo based volume calculation.
- Coils: inner radius of 43 cm, outer radius of 53 cm, length of 18 cm, on-axis field 1.5 T throughout the channel.
- Proton absorber: 10 cm Be disk of outer radius of 30 cm.
- Shielding: stainless steel pipe at the radii of 30-32 cm and 36-38 cm to enclose the W shield at 32-36 cm, yet stay 5 cm clear of the coils.

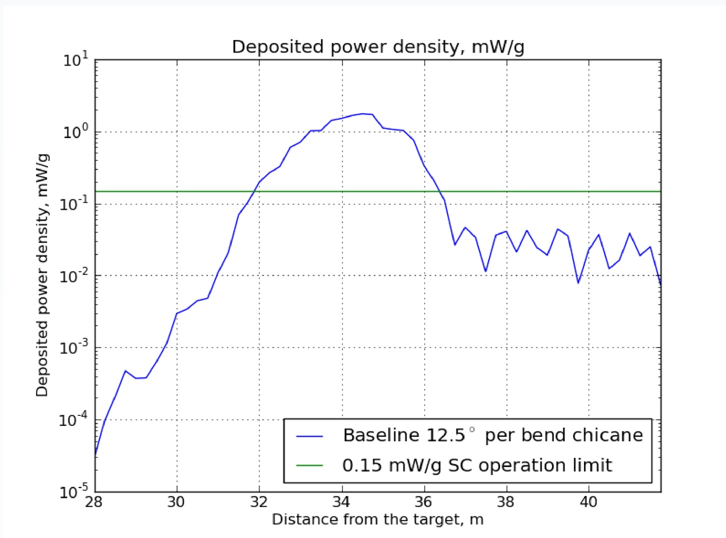
No shielding in the chicane:

- The limit of 0.15 mW/g is exceeded in a number of coils; however, it could be reduced to within the limits by providing extra shielding in about half of the coils.
- DPD peaks at 15.8 mW/g, that translates into 42.6 kW/m for Cu coils (see Figure above) or 33.3 kW/m for SC coils.

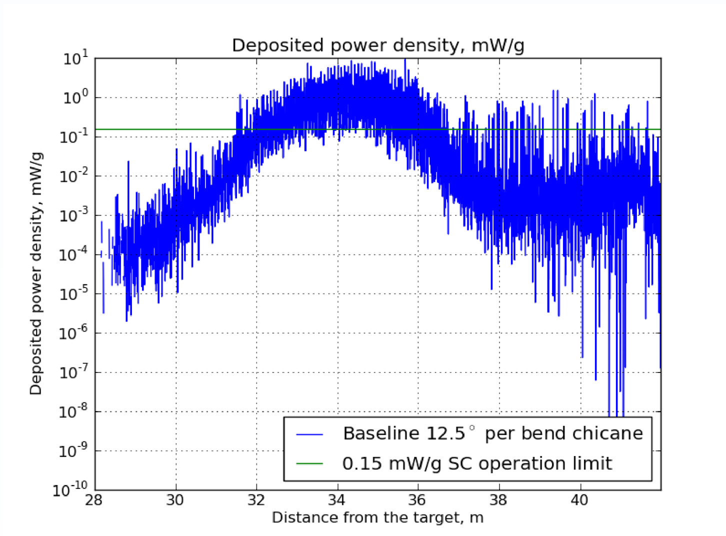
Max average DPD = **15.8** mW/g



With 4 cm of W shielding in the chicane:

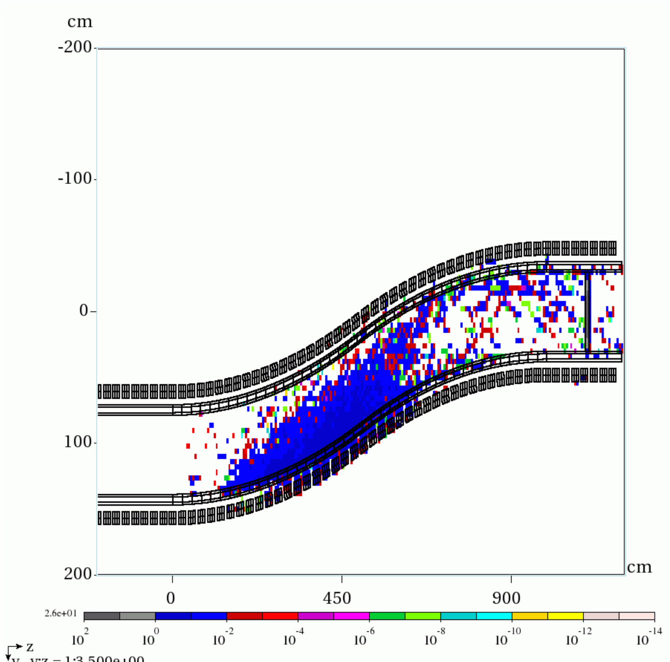


Max average DPD = **1.7** mW/g



Max DPD per segment = **9.1** mW/g

- Average deposited power density in the coils is at maximum 1.7 mW/g.
- On average: the limit of 0.15 mW/g is exceeded in a smaller number of coils, only those between 32 and 36 m downstream of the target.
- At the same time, certain coil segments can get up to 9.1 mW/g (2 radial segments, 12 azimuthal segments, 3 longitudinal segments per coil) due to the non-uniformity of energy deposition.



Non-uniformity of DPD, proton impact only

References:

[1] Choubey S. et al., International Design Study for the Neutrino Factory: Interim Design Report (2011), arXiv 1112.2853 [hep-ex]

[2] Rees G. et al, Muon Front-End Chicane and Acceleration, J. Phys. G Nucl. Part. Phys. 29, p.1673–1677, 2003.

[3] T. J. Roberts et al, G4beamline Particle Tracking in Matter Dominated Beam Lines, p. 373–375, Proc. PAC 2011.

[4] MARS Code System, http://www-ap.fnal.gov/MARS/.

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