MUON CAPTURE IN THE FRONT END OF THE IDS NEUTRINO FACTORY

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Introduction

We discuss the design of the muon capture front end of the neutrino factory International Design Study. In the front end, a proton bunch on a target creates secondary pions that drift into a capture transport channel, decaying into muons. A sequence of rf cavities forms the resulting muon beams into strings of bunches of differing energies, aligns the bunches to (nearly) equal central energies, and initiates ionization cooling. For the International Design Study (IDS), a baseline design must be developed and optimized for an engineering and cost study. We present a baseline design that can be used to establish the scope of a future Neutrino Factory.

Neutrino Factory and Front End

A neutrino factory captures and cools muons, then accelerates them to ~20GeV, where decays in a storage ring form collimated multi-GeV ν-beams that can interact with a detector.

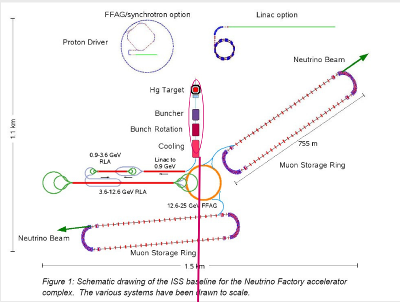
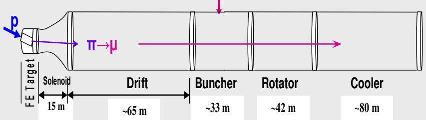
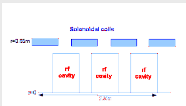


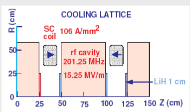
Figure 1: Schematic drawing of the ISS baseline for the Neutrino Factory accelerator complex. The various systems have been drawn to scale.

The "front end" takes π's from the target, confining them transversely into a drift (π→μ+ν). The beam is captured into a string of μ bunches, the bunches are phase-energy rotated into a string of ~200MeV/c bunches, the bunches are cooled.





Buncher-Rotator cells



Cooler cells

Front end Cooling

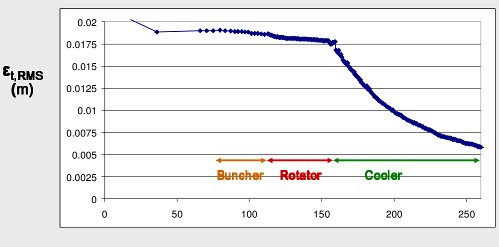
The cooling equation is:

$$\frac{d\varepsilon_N}{ds} = -\frac{1}{\beta^2 E}\frac{dE}{ds}\varepsilon_N + \frac{\beta_\perp E_s^2}{2\beta^3 m_\mu c^2 L_R E}$$

The equilibrium emittance is:

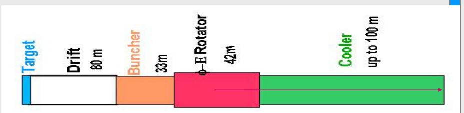
$$\varepsilon_{N,eq} = \frac{\beta_\perp E_s^2}{2\beta m_\mu c^2 L_R \frac{dE}{ds}}$$

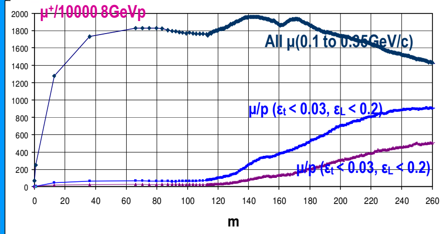
Transverse rms emittance in channel

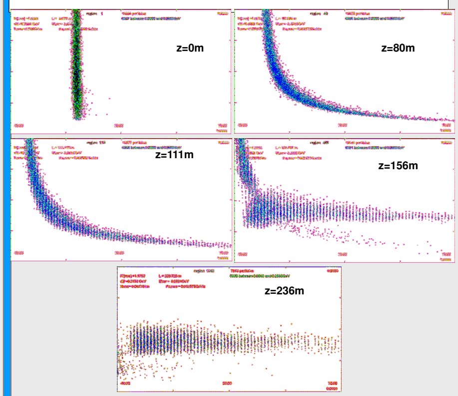


Front End – Overview

Drift from Target, Adiabatic Bunching, Bunch phase-energy Rotation, and Initial Cooler







ICOOL simulation results of the buncher and phase rotation: A: π's and μ's as produced at z=0 B: at the end of the solenoidal capture + drift.(z=80m) C: μ's at z=111m after the buncher. D: μ's at z=156m, the end of the rotator. The beam has been formed into a string of ~200MHz bunches at ~equal energies. E: At z= 236m after ~80m of cooling. μ's captured within rf buckets are cooled. In each plot the vertical axis is momentum (0 to 0.6 GeV/c) and the horizontal axis is longitudinal position (-30 to 70m).

Simulation Results:

At the end of the channel μ's are captured in a train of 201.25 MHz bunches ~75m long (~50 bunches).

Simulations show that channel accepts ~0.14 μ+/ 8GeV p with ~0.08μ+/8GeV p within the IDS accelerator acceptance. Both signs (μ^+ and μ^-) are captured with roughly equal intensities.

rf/Magnet Requirements

The capture concept requires using relatively high gradient rf fields interleaved with relatively strong solenoidal magnetic fields. In the Buncher, rf gradients of ~7MV/m at ~200MHz within 1.5T solenoids are needed. The Rotator uses 12MV/m gradients within 1.5T, and the Cooler uses ~15MV/m within 2.7T alternating solenoid fields.

In a first approximation, the rf cavities are copper pillbox shapes (at 200 MHz, a=0.57m, Q=58000) and are similar to the 200 MHz rf cavities (rounded Cu cylinders with Be windows) built for MICE.

Table 1: Baseline rf requirements

Region	Number of rf cavities	rf Frequencies	Rf gradients, Power required
Buncher	37	320 to 231.6 MHz, 13 rf frequencies	0 to 7.5 MV/m, 0.5 to 3.5 MW per frequency
Rotator	56	230 to 202.3 MHz, 15 rf frequencies	12 MV/m. ~2/5 MW per cavity
Cooler	100	201.25 MHz	15 MV/m, ~4 MW/cavity

Acknowledgements

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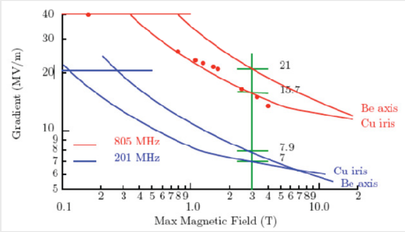
Rf Gradient Limitations?

Tests of 800 MHz "pillbox" rf within magnetic fields show limitations on peak gradients. Extrapolation of these results to ~200 MHz rf show possible limitations on Front End rf.

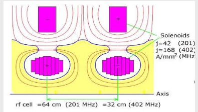


Mitigation Strategies

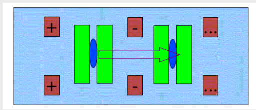
•Reduced gradients in front end: Reduction of rf gradients in Buncher/Rotator from baseline maximum of ~12 MV/m to ~6MV/m does not greatly reduce muon capture. (rf Reductions in the Cooling section are more limiting.)

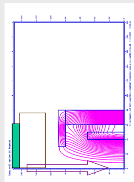
•Use Be cavities; Be should have higher rf breakdown limits.

•Use magnetically-insulated rf cavities

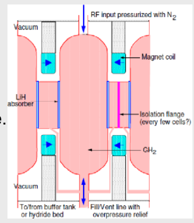


•Use magnetically shielded rf lattice





•Use gas-filled rf in Cooling. H_2 gas suppresses breakdown in rf cavities, and could be incorporated into the Cooler with good cooling performance.



Rf experiments will determine safe gradients within magnetic fields; parameters and designs will be modified to be within the experimentally determined limits.

Conclusions

We have presented a baseline design that sets the scale of the IDS front end system. rf R&D may require changes in that baseline, but should not change the scale of the system. That scale will be used to obtain first-order cost and scope estimates of a Neutrino Factory facility.

Variations that improve performance and/or reduce cost will be considered and developed.

References

[1] "Cost-effective Design for a Neutrino Factory", with J. S. Berg, S. A. Bogazs, S. Caspi, J. Cobb, R. C. Fernow, J. C. Gallardo, S. Kahn, H. Kirk, R. Palmer, K. Paul, H. Witte, M. Zisman, Phys. Rev. STAB 9,011001(2006)
[2] M. Appollonio et al., "Accelerator Concept for Future Neutrino Facilities", RAL-TR-2007-23, JINST 4 P07001 (2009).
[3] F. Soler et al., "Status of MICE" NuFACT09, AIP Conf. Proc. 1222, p. 288 (2010).
[4] R. Fernow, "ICOOL", Proc. 1999 PAC, New York, p. 3020, see http://pubweb.bnl.gov/people/fernow/
[5] T. Roberts,G4beamline,http://g4beamline.muonsinc.com
[6] C. Rogers et al., Proc. EPAC06, p.2400 (2006)
[7] D. Huang et al., Proc. PAC2009, Vancouver.
[8] D. Stratakis, J. Gallardo and R. Palmer, Proc. NuFACT09, AIP Conf. Proc. 1222, p. 303 (2010).
[9] J. Gallardo and M. Zisman, Proc. NuFACT09, AIP Conf. Proc. 1222, p. 308 (2010).
[10] C. T. Rogers, Proc. NuFACT09, AIP Conf. Proc. 1222, p. 298 (2010).
[11] D. Neuffer, "'High Frequency' Buncher and Phase Rotation", Proc. NuFACT03, AIP Conf. Proc. 721, p. 407. (2004).