Low Energy Neutrino Factory

for both large and small θ_{13}

- Introduction

- Detector Concept
- Physics Reach
- Vision & Status

- Summary

INTRODUCTION

- Past Neutrino Factory studies have focused on muon energies of 20 GeV or greater. Lower energies required a viable detector concept for identifying measuring the muon sign in a very large detector.

- A new detector concept has recently been proposed: Totally Active Scintillator Detector in a Magnetized Hall, with an affordable magnet scheme. This opens the way for low energy Neutrino Factories.

- Initial physics studies for a 4 GeV Neutrino Factory look very promising, independent of whether θ_{13} is large, small, or zero:

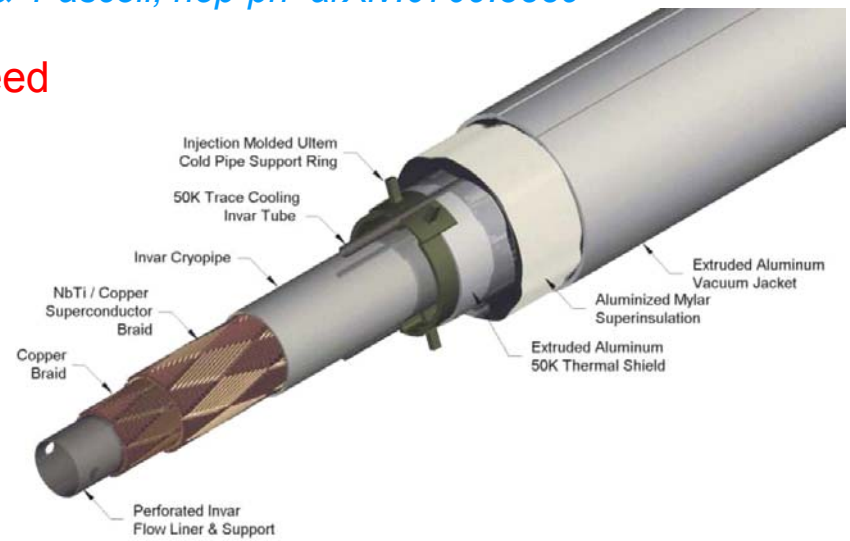
  - *Geer, Mena, & Pascoli, Phys. Rev. D75, 093001, (2007).*
  - *Bross, Ellis, Geer, Mena,& Pascoli, hep-ph arXiv:0709.3889*

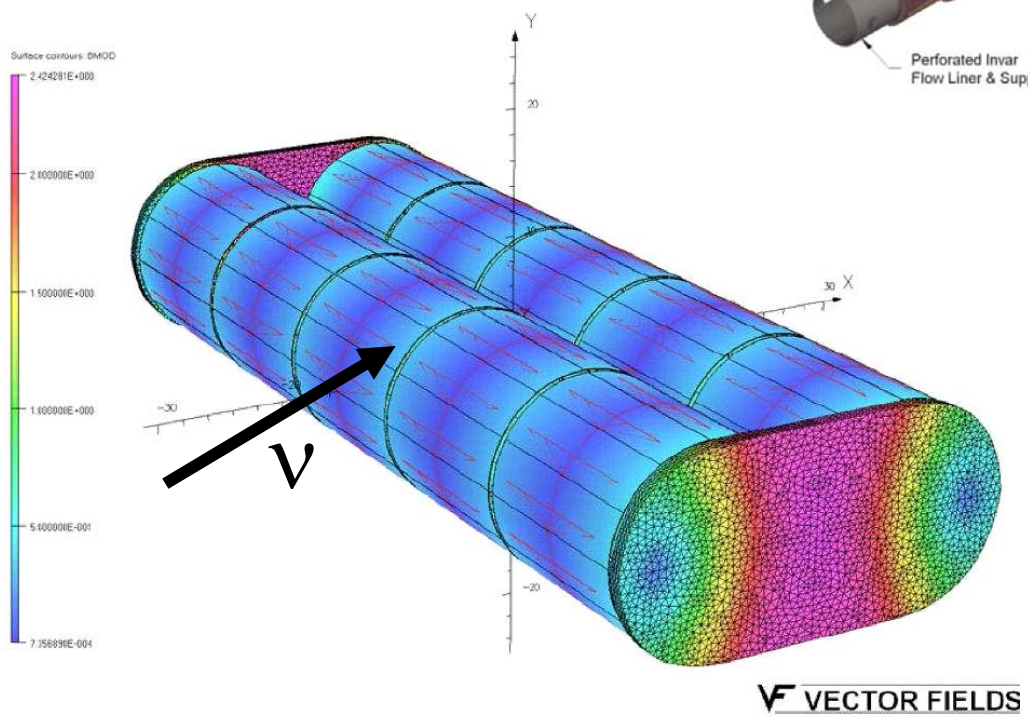
- Design studies are ongoing. There is an attractive concept for how to start with Project X, and develop the complex into a Muon Collider Front End test bed plus a 4 GeV Neutrino Factory pointing at DUSEL.

A Magnetic Hall for Large Neutrino Detectors

Bross, Ellis, Geer, Mena,& Pascoli, hep-ph arXiv:0709.3889

If we want to use a low Z detector, we need an affordable way to magnetize a large volume → Eliminate large (expensive) cryostat & vac loads by using superconducting transmission line concept developed for the VLHC – wrap it into a solenoid !



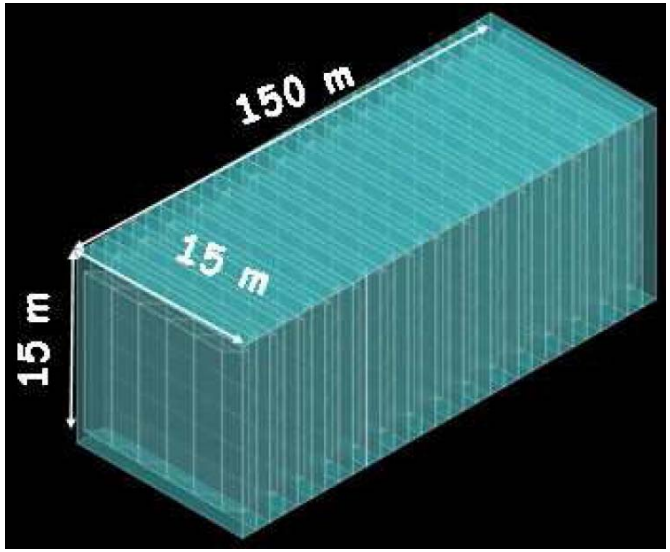


Build a magnetic cavern !

Example:
Build 10 solenoids, each 150 turns, 7.5km cable, I = 50kA, and 1m thick iron end-walls

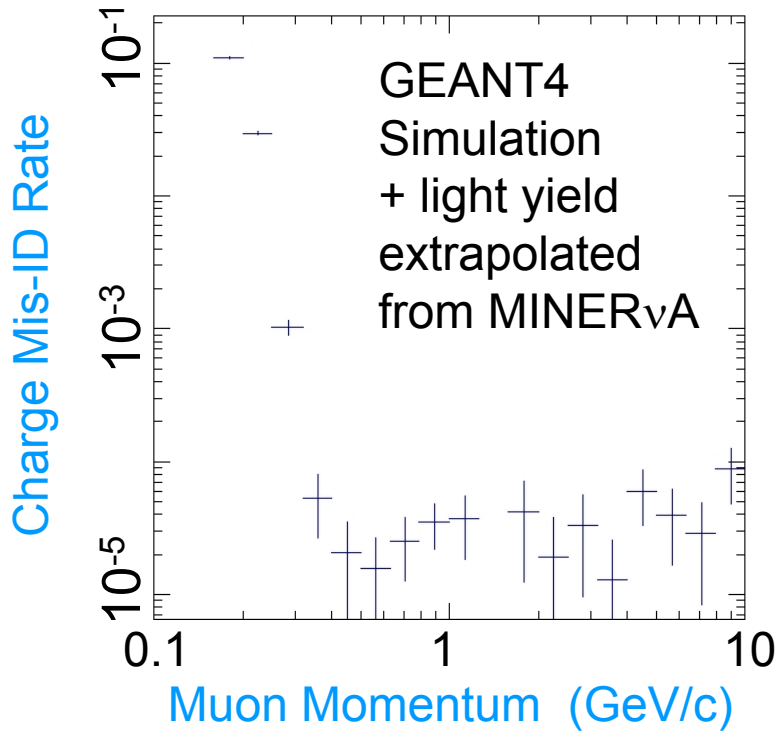
Low Energy Neutrino Factory Detector

Bross, Ellis, Geer, Mena,& Pascoli, hep-ph arXiv:0709.3889



3m long scintillator bars with triangular cross-section (base=3cm, ht=1.5cm)

M_{det} = 35 Kt
M_{fid} = 20 Kt
Vol = 15 × 15 × 150 m^3
B = 0.5T



- Muons reconstructed with ~100% eff if p > 300 MeV/c. Momentum resolution better than 10%
- Effective neutrino energy threshold for Neutrino Factory measurements is ~ 500 MeV/c. Muon charge mis-id < 10^{-4}.
- More work on background rates needed.

Low energy NF Event Rates

Wrong-sign μ Rates, L=1480 km for normal (inverted) hierarchies, θ_{13}=8°

statistics (Kt-decays)	$\delta(^o)$	μ^+ stored (wrong-sign: μ^-)	μ^- stored (wrong-sign: μ^+)
3×10^{22} 20 Kt × 3 years	0	2640 (1020)	540 (1550)
	90	3700 (1520)	270 (990)
	180	2990 (1020)	510 (1310)
	270	1930 (520)	780 (1870)
1×10^{23} 20 Kt × 10 years	0	8830 (3400)	1800 (5170)
	90	12330 (5070)	900 (3300)
	180	9970 (3400)	1700 (4370)
	270	6430 (1730)	2600 (6240)

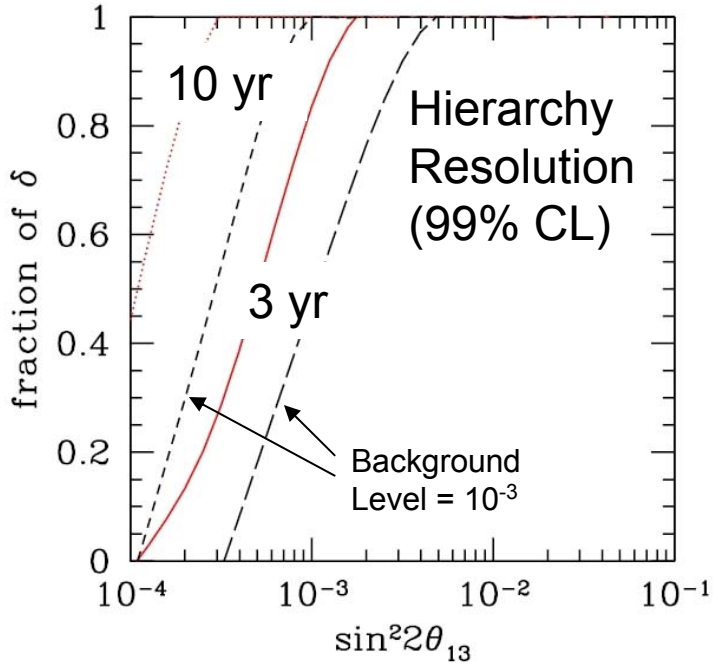
Wrong-sign μ Rates, L=1480 km for normal (inverted) hierarchies, θ_{13}=1°

statistics (Kt-decays)	$\delta(^o)$	μ^+ stored (wrong-sign: μ^-)	μ^- stored (wrong-sign: μ^+)
3×10^{22}	0	160 (150)	80 (110)
	90	300 (210)	40 (30)
	180	200 (150)	70 (75)
	270	65 (90)	110 (150)
1×10^{23}	0	530 (500)	270 (370)
	90	1000 (700)	130 (100)
	180	670 (500)	230 (250)
	270	220 (300)	370 (500)

NOTE: $\sin^2 2\theta_{13}$ sensitivity to ~10^{-4} or better !

Mass Hierarchy & CPV

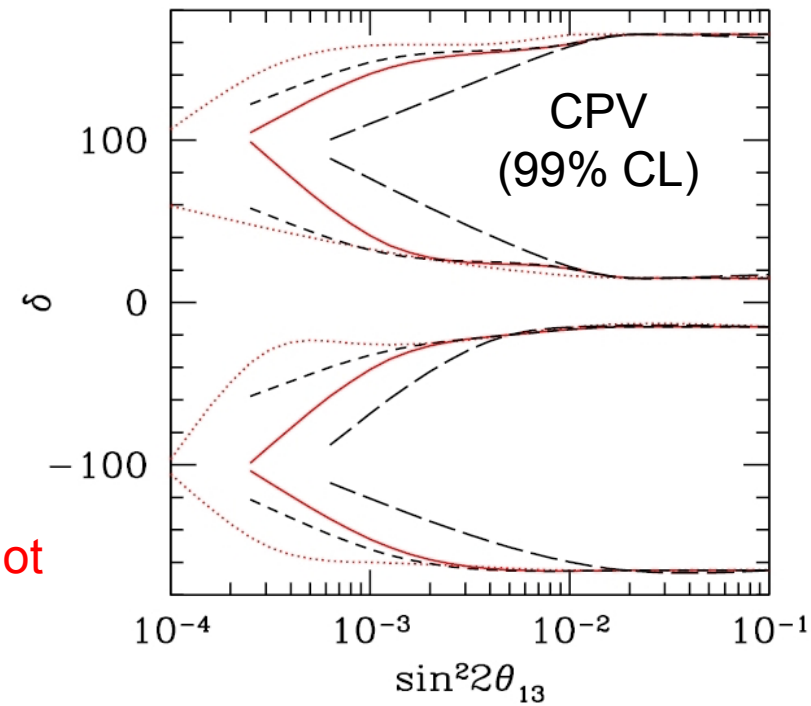
Bross, Ellis, Geer, Mena,& Pascoli, hep-ph arXiv:0709.3889



The energy-dependent wrong-sign muon rates would enable all the ambiguities to be resolved, and the mass hierarchy to be determined for all δ provided $\sin^2 2\theta_{13} > (10^{-3} - 10^{-4})$*

*) Depending on background levels and run time.

In addition, if $\sin^2 2\theta_{13} > (10^{-3} - 10^{-4})$* CPV would be established if δ is More than 20° away from a CP-conserving value.



NOTE: If θ_{13} large background level not an issue (even if we don't know it well yet)

If θ_{13}=0 maybe we can still determine the mass hierarchy

- Use very precise measurements of ν_μ disappearance

de Gouvea, Jenkins & Kayser, Phys. Rev. D71, 113009 (2005)
de Gouvea & Winter, Phys. Rev. D73, 033003 (2006)
Minakata, Nunokawa, Parke, Funchal, Phys. Rev. D74, 053008 (2006)

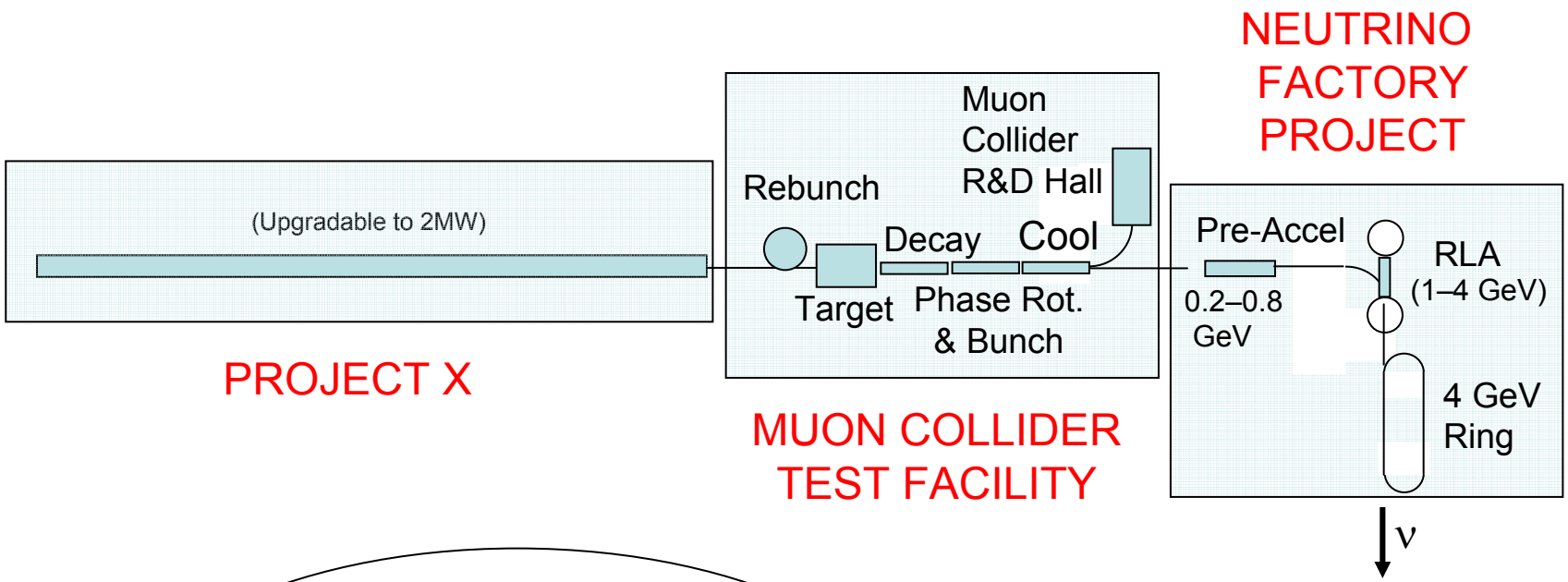
- Disappearance depends on both $|\Delta m^2_{13}|$ and $|\Delta m^2_{23}|$ → can determine who is larger than who :

$$P(\nu_\mu \to \nu_\mu) = 1 - 4|U_{\mu 1}|^2|U_{\mu 2}|^2 \sin^2 \frac{\Delta m^2_{12} L}{4E} - 4|U_{\mu 1}|^2|U_{\mu 3}|^2 \sin^2 \frac{\Delta m^2_{13} L}{4E} - 4|U_{\mu 2}|^2|U_{\mu 3}|^2 \sin^2 \frac{\Delta m^2_{23} L}{4E}$$

- Low energy NF studies suggest this facility offers sufficiently precise measurements to, maybe, do the job. For example, from the disappearance channel: $\sigma(\Delta m_{13}^2)$ ~ 1-2%

- In our low energy NF scenario (10 yrs running) with θ_{13}=0, if systematic uncertainties are assumed 0 (2%) we find the hierarchy can be resolved at the 95% (90%) CL. Not a proof that it can be done … but very encouraging → Illustrates the power of precision measurements

Project X, Neutrino Factory & Muon Collider R&D



<u>Illustrative Vision</u>

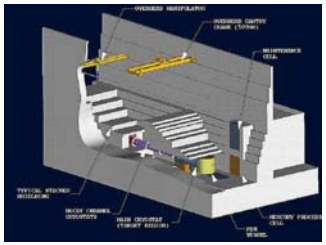
Three projects of comparable scope:

- Project X (upgraded to 2MW)
- Muon Collider Test Facility
- 4 GeV Neutrino Factory

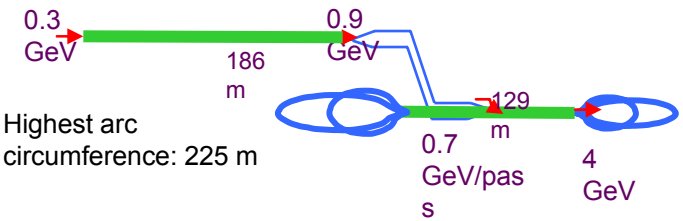
Far Detector at Homestake

DESIGN & DEVELOPMENT

Ankenbrandt, Bogacz, Bross, Geer, Johnstone, Neuffer, Palmer, Popovic



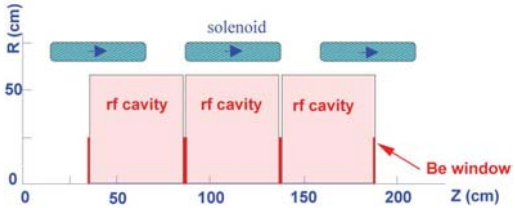
Target Hall Design (ORNL/TM-2001/124)



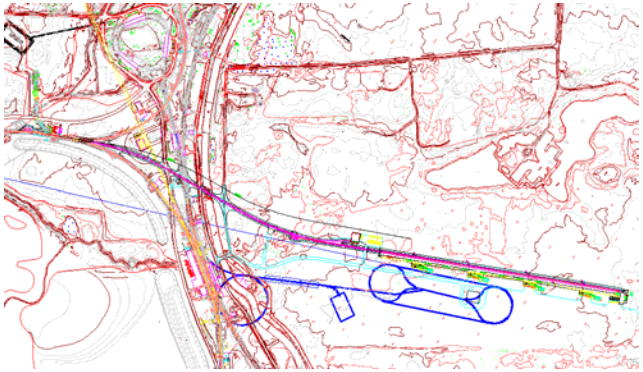
Acceleration Design (A. Bogacz)

Hg Jet Target R&D: MERIT Expt

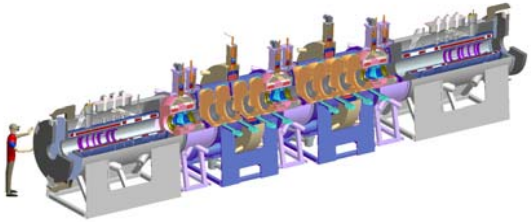
Storage Ring (C. Johnstone)



Bunching & Phase Rotation (D. Neuffer)



Site Layout (Ankenbrandt & Popovic)



Cooling Channel (MICE Expt)

SUMMARY

By about 2012 we anticipate that we will have the technical know-how to build a Neutrino Factory.

The low energy (4 GeV) NF physics reach is impressive, for both large and small θ_{13}. Further detector studies are needed to better understand the physics capabilities.

If the Muon Collider is ever to become an option, we need a viable path that enables development of a suitable intense muon source. One vision is, after Project X, to build a Muon Collider test facility (target, decay channel, bunch & phase rotation, and a little bit of cooling). We think that the add-on needed for a 4 GeV NF would then be comparable in scope to Project X.