International Design Study for a Neutrino Factory

Overview and US Participation

MUTAC Review
April 6, 2009
Alan Bross

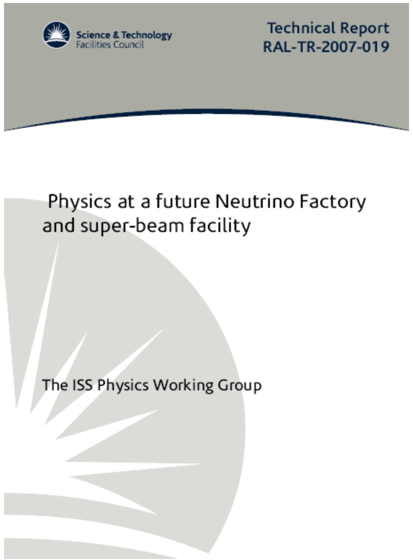
IDS-NF - Overview

- The principal objective of the International Design Study for the Neutrino Factory (the IDS-NF) is to deliver a design report in which:
  - The physics performance of the Neutrino Factory is detailed and the specification of each of the accelerator, diagnostic, and detector systems that make up the facility is defined;
  - The schedule for the implementation of the Neutrino Factory facility is presented;
  - The cost of the Neutrino Factory accelerator, the diagnostics, and the detector systems are presented at a level of accuracy appropriate for the report to inform a decision to initiate the Neutrino Factory project; and
  - The outstanding technical and financial uncertainties are documented and an appropriate uncertainty-mitigation plan is presented.
- This report, the Reference Design Report (RDR), is required in 2012/13.
  - As a step on the way, an Interim Design Report (IDR) is required in 2010/11.
- Current Collaboration: Canada, US, Japan, India, UK, Europe

MCTF

IDS-NF Baseline Design From

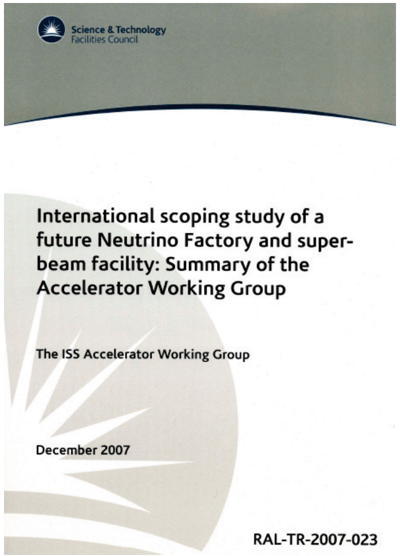
International Scoping Study


Science & Technology Facilities Council

Technical Report
RAL-TR-2007-019

Physics at a future Neutrino Factory and super-beam facility

The ISS Physics Working Group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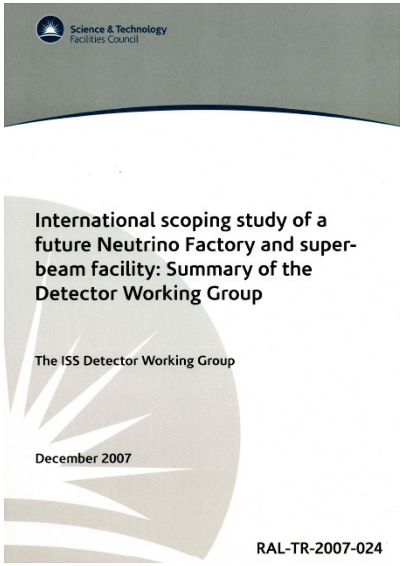
International scoping study of a future Neutrino Factory and super-beam facility: Summary of the Accelerator Working Group

The ISS Accelerator Working Group

December 2007

RAL-TR-2007-023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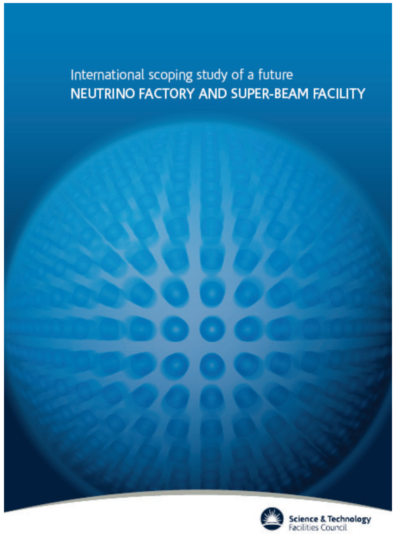
International scoping study of a future Neutrino Factory and super-beam facility: Summary of the Detector Working Group

The ISS Detector Working Group

December 2007

RAL-TR-2007-024

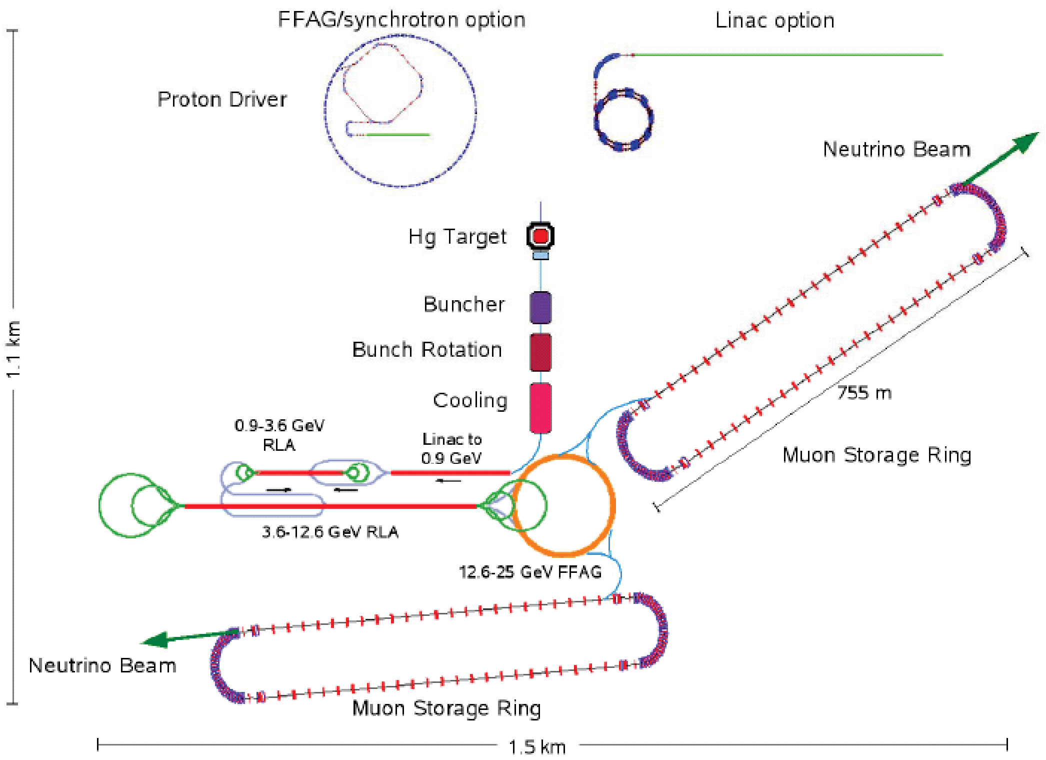

International scoping study of a future
NEUTRINO FACTORY AND SUPER-BEAM FACILITY

Science & Technology Facilities Council

- **Publication of ISS reports:**
  - Physics report accepted for publication in Reports on Progress in Physics
  - Accelerator report submitted to Journal of Instrumentation:
    - Referee comments received
  - Detector report accepted for publication in Journal of Instrumentation

IDS-NF – Baseline
Accelerator Facility

Baseline specification for the Neutrino Factory accelerator complex			Version
Sub-system	**Parameter**	**Value**	**2007/1.0**
Proton driver	Average beam power (MW)	4	
	Pulse repetition frequency (Hz)	50	
	Proton kinetic energy (GeV)	10 ± 5	
	Proton rms bunch length (ns)	2 ± 1	
	Number of proton bunches per pulse	3	
	Sequential extraction delay (μs)	≥ 17	
	Pulse duration, liquid-Hg target (μs)	≤ 40	
Target: liquid-mercury jet	Jet diameter (cm)	1	
	Jet velocity (m/s)	20	
	Solenoidal field at interaction point (T)	20	
Pion collection			
Tapered solenoidal channel	Length (m)	12	
	Field at target (T)	20	
	Diameter at target (cm)	15	
	Field at exit (T)`	1.75	
	Diameter at exit (cm)	25	
Decay channel	Length (m)	100	
Adiabatic buncher	Length (m)	50	
Phase rotator	Length (m)	50	
	Energy spread at exit (%)	10.5	
Ionisation cooling channel	Length (m)	80	
	RF frequency (MHz)	201.25	
	Absorber material	LiH	
	Absorber thickness (cm)	1	
	Input emittance (mm rad)	17	
	Output emittance (mm rad)	7.4	
	Central momentum (MeV/c)	220	
	Solenoidal focussing field (T)	2.8	
Acceleration system	Total energy at input (MeV)	244	
	Total energy at end of acceleration (GeV)	25	
	Input transverse acceptance (mm rad)	30	
	Input longitudinal acceptance (mm rad)	150	
Pre-acceleration linac	Final total energy (GeV)	0.9	
RLA(1)	Final total energy (GeV)	3.6	
RLA(2)	Final total energy (GeV)	12.6	
NFFAG	Final total energy (GeV)	25	
Decay rings	Ring type	Race track	
	Straight-section length (m)	600.2	
	Race-track circumference (m)	1,608.80	
	Number of rings (number of baselines)	**2**	
	Stored muon energy (total energy, GeV)	**25**	
	Beam divergence in production straight (γ^{-1})	**0.1**	
	Bunch spacing (ns)	**≥ 100**	
	Number of $\mu^{\pm}$ decays per year per baseline	**5×10^{20}**	



IDS-NF Organization – Steering Group

- Steering Committee
  - A. Blondel, Geneva
  - M Zisman, LBNL
  - Y Kuno, Osaka
  - K Long, Imperial (Chair)
- Accelerator Conveners
  - S Berg, BNL
  - M. Medahi, CERN
  - Y. Mori, Kyoto
  - C. Prior, STFC
- Detector Conveners
  - A Bross, FNAL
  - P Soler, Glasgow
  - N. Mondal, Tata
  - A. Cervera, Valencia
- Physics and Performance Evaluation Group Conveners
  - A Donini, Madrid
  - P. Huber, Virginia Tech
  - S. Pascoli, Durham University
  - W. Winter, Universität Würzburg
  - O. Yasuda, Tokyo Metropolitan University

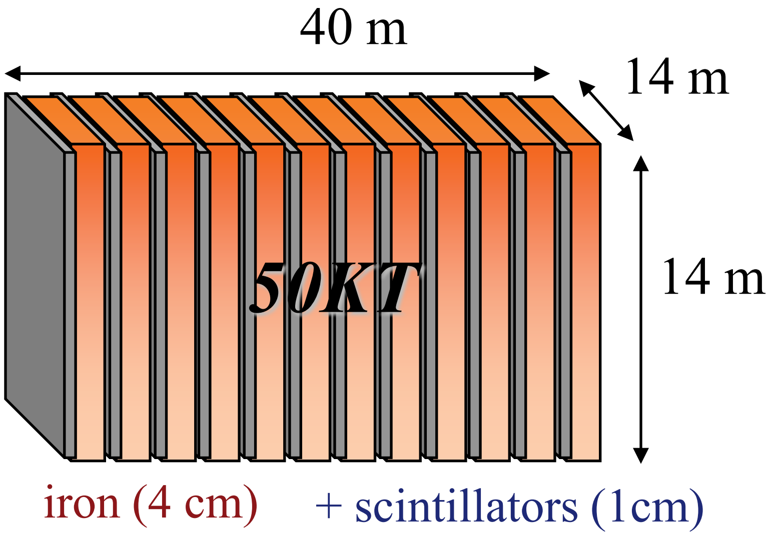
IDS-NF Organization - Accelerator

System	**Task list**		**Coordinators**	**Comments**
Sub-system	**Performed**	**Required**		
Target `	Optics Tracking 1 Tracking 2	CDR IDR costing	C.Densham (RAL), H.Kirk (BNL)	Particle production must be revisited when HARP results are included in MARS/Geant4
Muon front-end ***Capture***	Optics Tracking 1	Tracking 2 CDR IDR costing	C.Rogers (ASTeC), D.Neuffer (FNAL)	
Bunching and phase rotation	Optics → Tracking 1 →	Tracking 2 CDR IDR costing		Risk mitigation: evaluate to what extent minor lattice revisions are required if it is demonstrated that the baseline gradient can not be achieved in the magnetic field.
Cooling	Optics → Tracking 1 →	Tracking 2 CDR IDR costing		Risk mitigation: evaluate to what extent minor lattice revisions are required if it is demonstrated that the baseline gradient can not be achieved in the magnetic field.
Acceleration ***Linear accelerators***	Optics	Tracking 1 Tracking 2 CDR IDR costing	A.Bogacz (JLab), J.Pozimski (ICL)	
FFAG	Optics → Tracking 1 →	Tracking 2 CDR IDR costing	S.Berg (BNL), S.Machida (RAL)	While initial optics and tracking work has been done, the fact that an injection and extraction scheme has not been proposed implies that it is necessary to revisit both the optics analysis and the tracking.
Storage ring		Optics Tracking 1 Tracking 2 CDR IDR costing	C.Prior (ASTeC), ANO	Present lattices store muons of a single charge only. A modification of the optics is required to allow positive and negative muons to be stored simultaneously.

IDS-NF Baseline Specifications

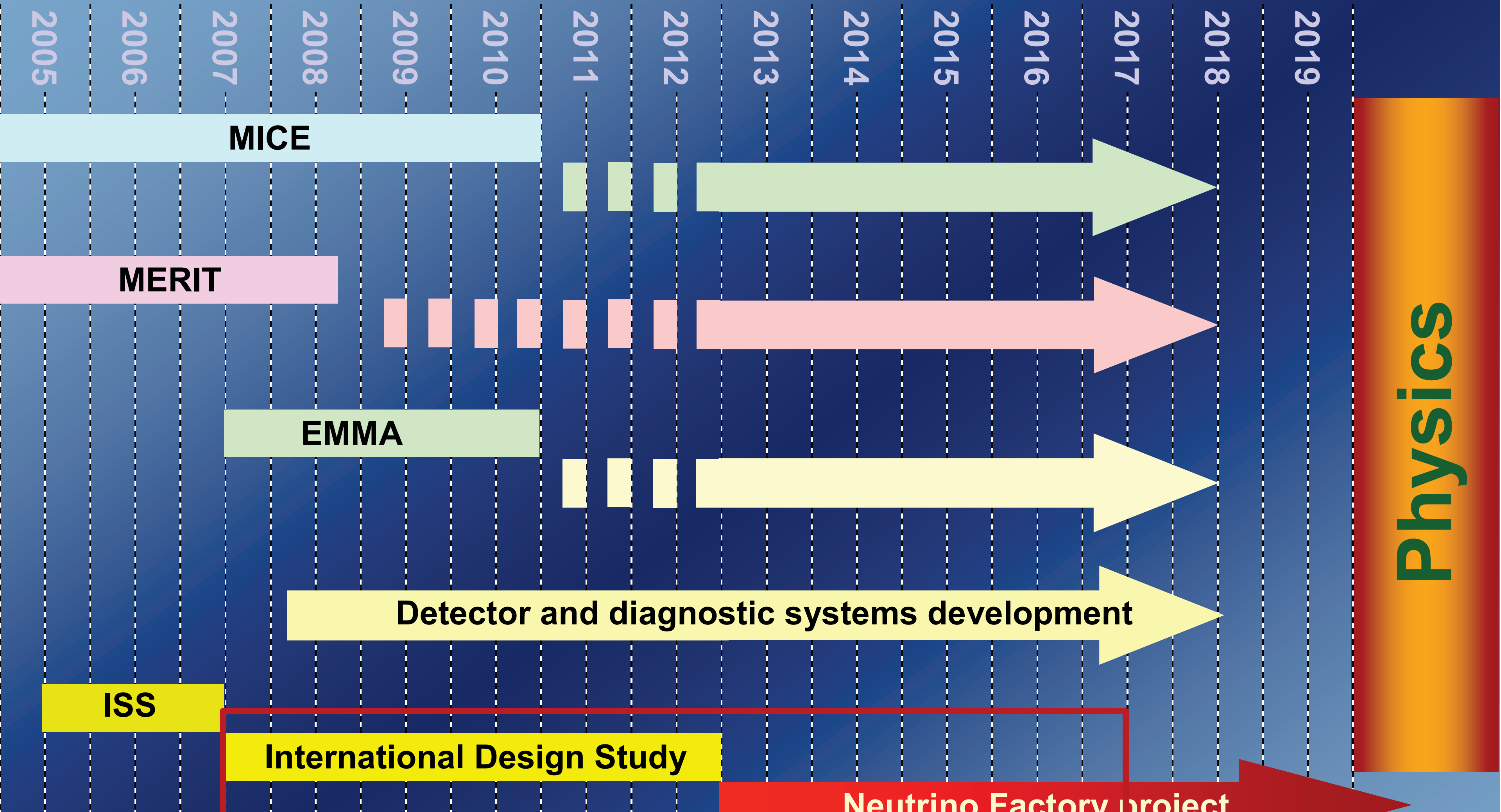
Detector

Detector 'type'	R&D task	Coordinators
MIND	Photosensor/electronics development to reduce channel cost Scintillating fibre development to produce long active length (~20 m) and to reduce channel cost Evaluation of alternative active media (scintillator vs RPCs)	Being approached
TASD	Photosensor/electronics development to reduce channel cost Scintillating fibre development to reduce channel cost Development of large volume magnet	Begin approached
Liquid Argon	Charge detection: demonstration of long drift length; development of charge detection electronics; comparison of operation in gas and liquid phases. Optical detection: development and test of prototype position sensitive optical readout, for example based on LEMs. Verification of pattern recognition for large volumes Development of large volume magnet	
Emulsion	Development of rapid scanning techniques.	Being approached
Near Detector	Baseline design(s)	Being approached
Beam Monitoring	Prototypes of BCT, muon polarimeter and Cherenkov beam divergence device	Being approached



Two 50 kT Magnetized Iron Detectors at baselines of 4000 and 7500 km

Neutrino Factory roadmap



MICE

MERIT

EMMA

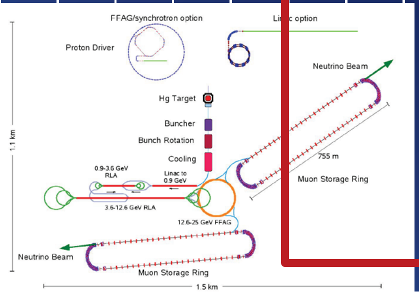
Detector and diagnostic systems development

ISS

International Design Study

Neutrino Factory project

Physics



Interim Design Report

Reference Design Report

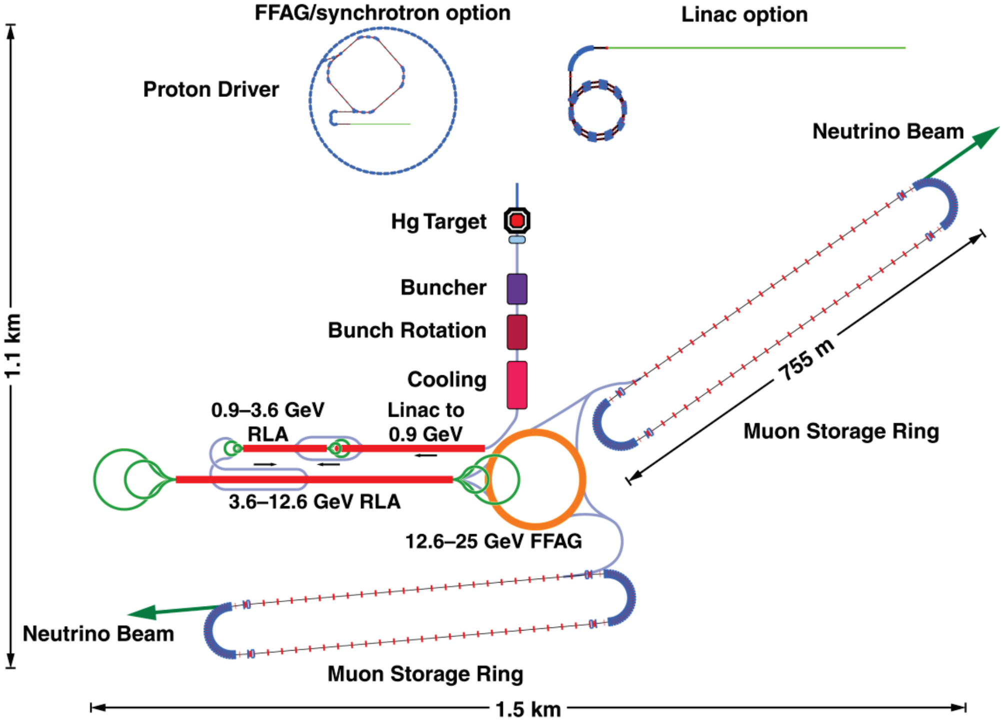
"Recent" IDS-NF Activities

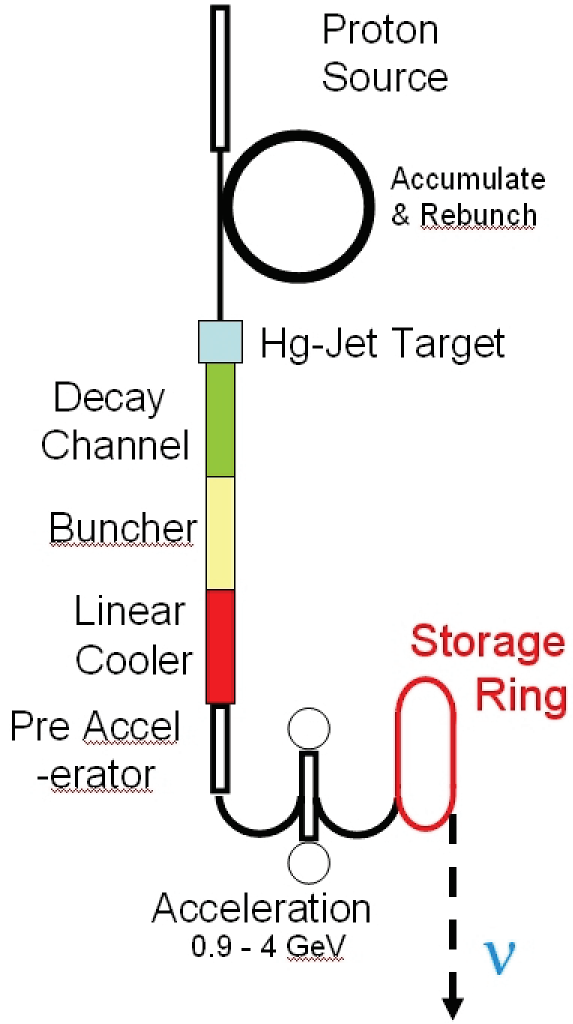
- First Plenary Meeting: March 29 – April 1, 2007 at CERN
- Second Plenary Meeting: June 10-12, 2008 at Fermilab
- Muon Front End and Acceleration Workshop, December 14-15, 2008 at TJNAF
- High-Power Target Workshop, November 6-7, 2008 at Princeton
    - 2nd Oxford-Princeton Workshop
- Targetry Workshop, December 15-17, 2008 at CERN
    - Part of EUROnu
- Third Plenary Meeting: March 23-27, 2009 at CERN

Status of IDS-NF with Respect to θ_{13}

- Must Consider the case for a Neutrino Factory for the scenario where θ_{13} is measured before report is delivered
- Low-energy Neutrino Factory:
  - Interesting option, especially in this scenario and as a step in a possible staging scenario, but:
    - Physics reach for oscillation parameters for small θ_{13} not as competitive as for baseline

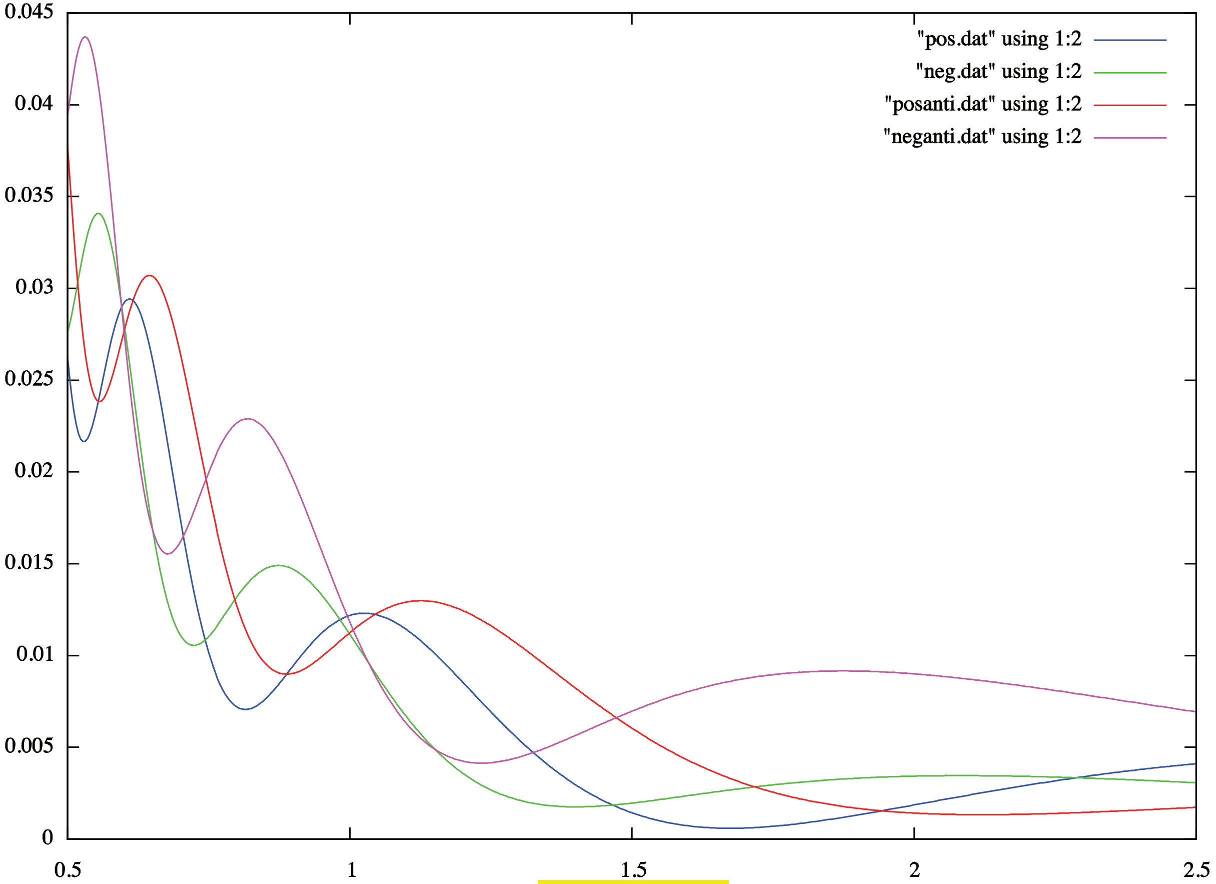
Low Energy Neutrino Factory Concept





Cost Savings of up to $500M

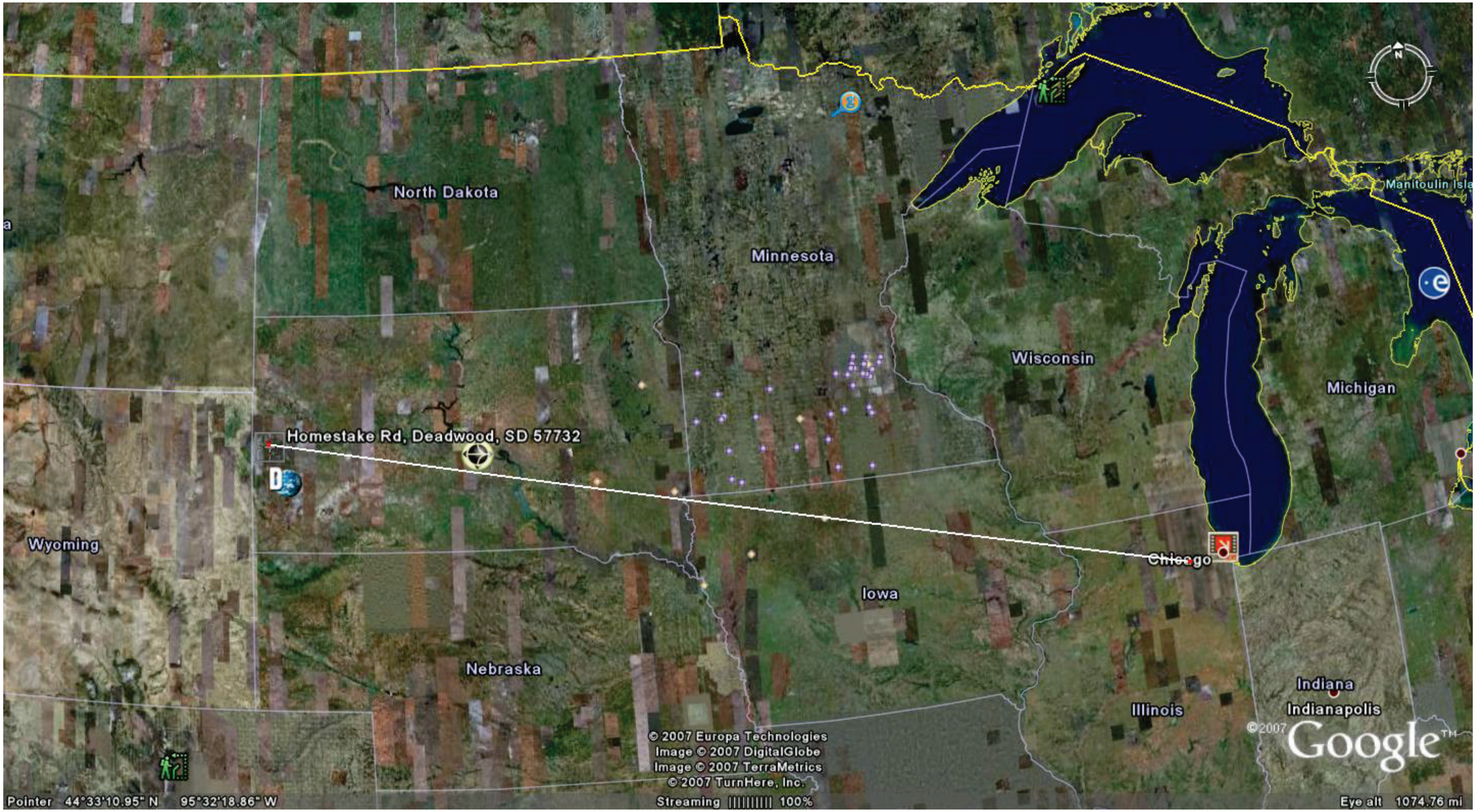
At Baseline of approximately 1300 km



E_ν GeV

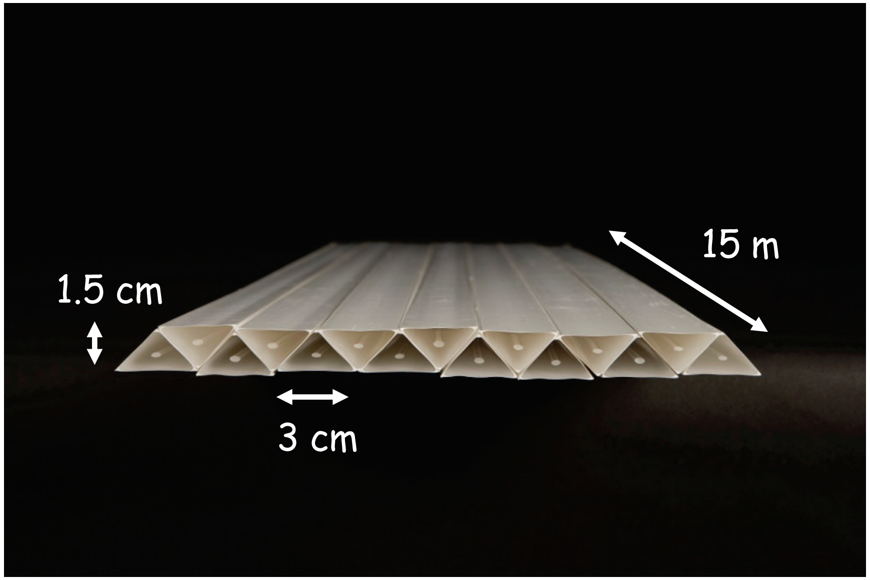
- Very rich oscillation pattern at low energy → 0.5 to 1.5 GeV

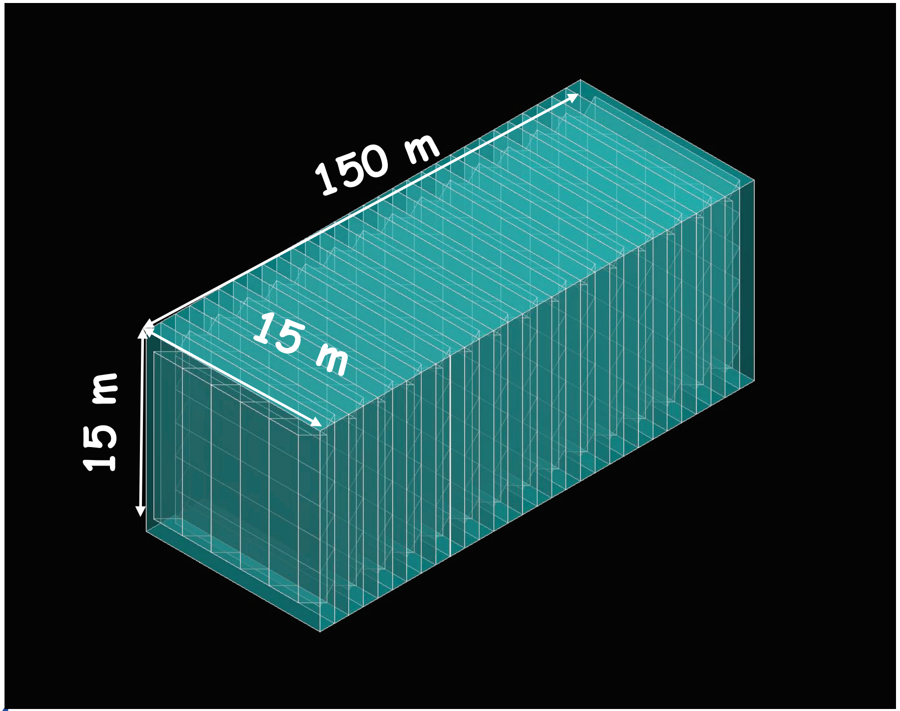
Which is Quite Convenient
Fermilab ⇒ DUSEL



Fine-Resolution Totally Active Segmented Detector

3333 Modules (X and Y plane)
Each plane contains 1000 slabs
Total: 6.7M channels





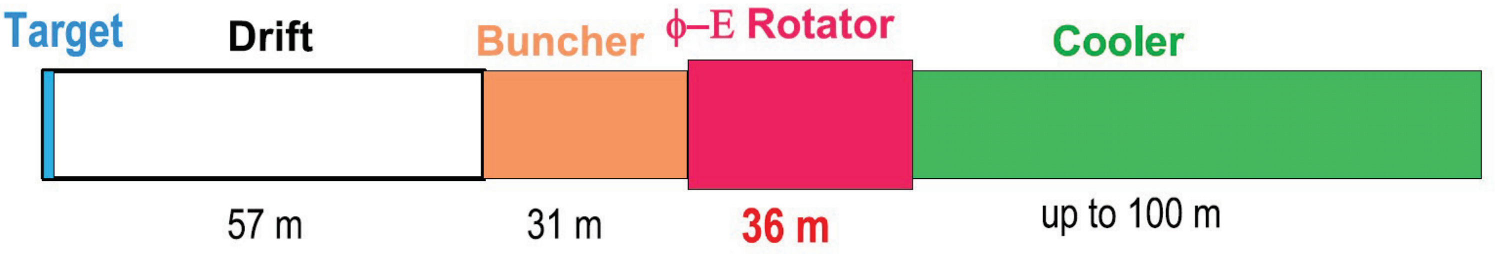
- Momenta between 100 MeV/c to 15 GeV/c
- Magnetic field considered: 0.5 T
- Reconstructed position resolution ~ 4.5 mm

B = 0.5T

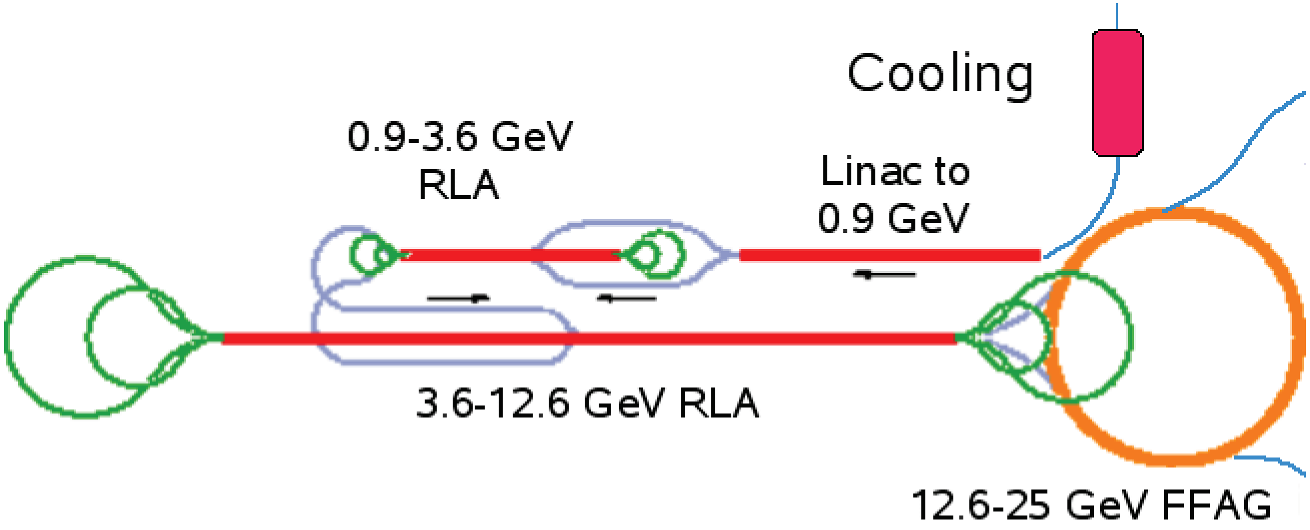
US Contributions to the IDS-NF

- The US contribution to the IDS-NF will focus on the following areas:
  - Proton driver
    - In the context of Project X
  - Targetry and Target Stations
    - MERIT and Hg Jet R&D
      - Continue and extend simulations of mercury flow in and out of the nozzle
      - Extend the engineering study from Study II
  - Pion capture and muon phase rotation
  - Muon Ionization Cooling
  - Accelerator Systems
  - Site-specific underground engineering issues associated with the muon storage rings
    - Fermilab Siting Studies
  - Magnetization concepts for neutrino detectors
    - Focus of Low-Energy Neutrino Factory Detector Concept

US IDS-NF Focus
Neutrino Factory Subsystems



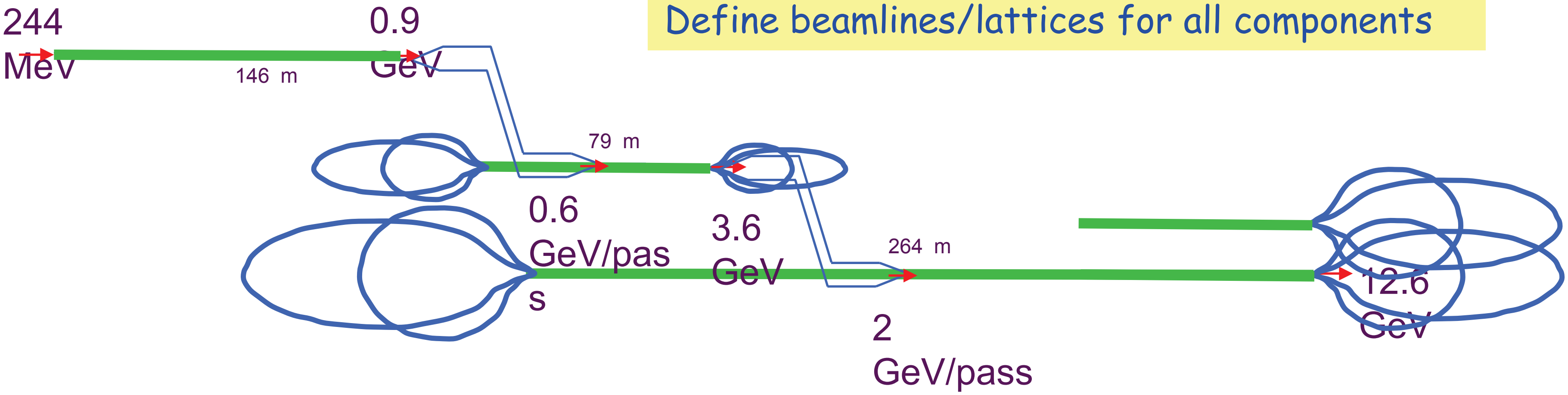
Optimization of the Front End
μ/p within reference acceptance = 0.085 at end of cooler (75m)

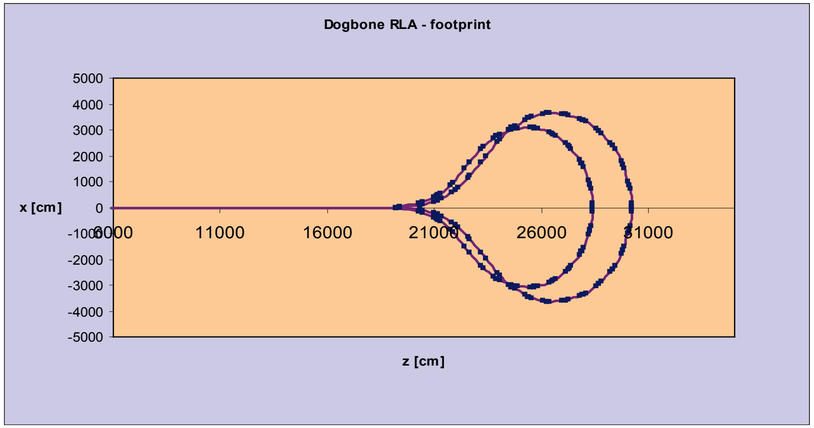


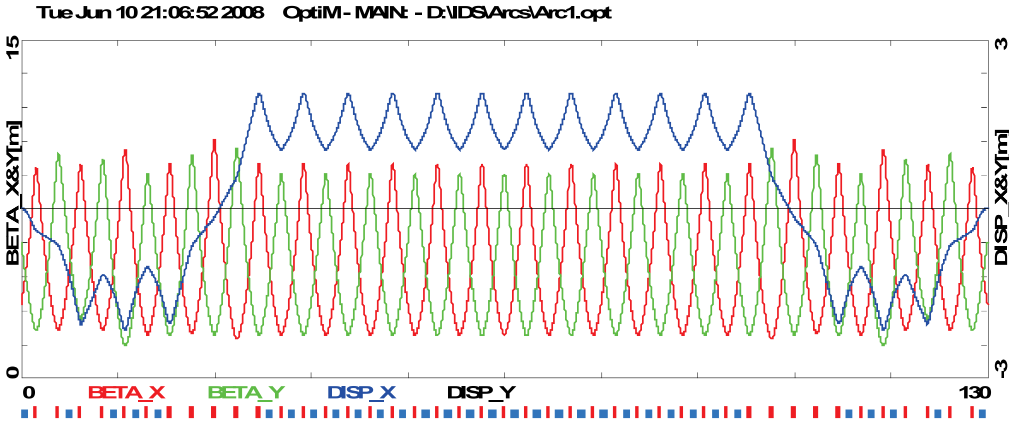
Acceleration Systems

Develop Engineering Design Foundation

Define beamlines/lattices for all components

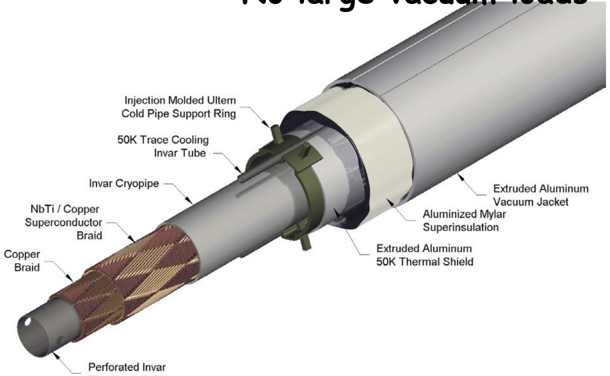






Very-Large-Magnetic Volume R&D

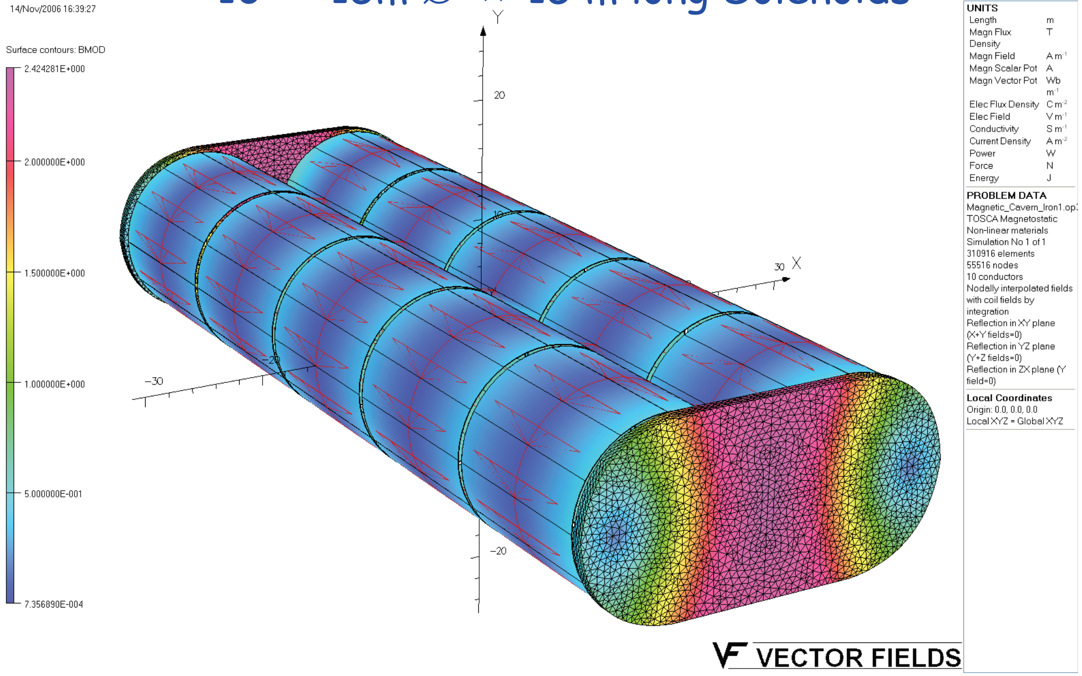
- Production of very large magnetic volumes – expensive using conventional technology
  - For SC magnets – cost driven by cryostat
  - Use VLHC SC Transmission Line Concept
    - Wind around mandrel
    - Carries its own cryostat
    - No large vacuum loads



•Scaling Factor:

•Cost ∝ r ?

10 - 15m ∅ × 15 m long Solenoids



UNITS	
Length	m
Magn Flux Density	T
Magn Field	$A\,m^{-1}$
Magn Scalar Pot	A
Magn Vector Pot	$Wb\,m^{-1}$
Elec Flux Density	$C\,m^{-2}$
Elec Field	$V\,m^{-1}$
Conductivity	$S\,m^{-1}$
Current Density	$A\,m^{-2}$
Power	W
Force	N
Energy	J

PROBLEM DATA
Magnetic_Cavern_Iron1.op
TOSCA Magnetostatic
Non-linear materials
Simulation No 1 of 1
310916 elements
55516 nodes
10 conductors
Nodally interpolated fields with coil fields by integration
Reflection in XY plane (X+Y fields=0)
Reflection in YZ plane (Y+Z fields=0)
Reflection in ZX plane (Y field=0)

Local Coordinates
Origin: 0.0, 0.0, 0.0
Local XYZ = Global XYZ

1 m iron wall thickness.
~2.4 T peak field in the iron.
Good field uniformity

SCTL Parameters

PARAMETER	UNIT	DESIGN	
		No iron	With iron
$I_{solenoid}$	MA	7.5	
N_{turns}/solenoid		150	
I_{turn}	kA	50	
$\|B\|_{average}$ in XZ	T	0.562	0.579
W_{total}	GJ	3.83	3.95
L_{total}	H	3.06	3.16
F_r maximum	kN/m	15.66	15.67
F_x maximum	kN/m	48.05	39.57

100 kA op demonstrated

$1000/m ⇒ $50M

Resources

	Year 1	Year 2	Year 3	Year 4
Engineers	2.5	5	6	4.5
Technicians	1	4	3	2.5
Postdocs	2	2	2	2
Scientists	2	2	2	2
M&S	50	850	900	250

The M&S and some of the effort is on the large magnetic volume R&D and is not funded in the 5 Year Plan

BUT

Much of the effort required for our desired participation in the IDS-NF is actually captured within the 5 Year Plan in MC R&D since the front ends are the same

US Participation in the IDS-NF
Conclusions

- The US participation in the IDS-NF covers many areas, but the focus is on
  - Front End
  - Acceleration Systems
    - Defining beam lines and lattices
  - Costing Exercise
- Input with specific local emphasis
  - Project X as the proton driver
  - Site-specific underground engineering
    - Decay ring issues
  - Low-Energy Neutrino Factory
    - And Detector R&D