

# **R&D on Future Accelerators**

Steve Holmes

DOE Program Review

March 19, 2003

# Outline

---

- Goals and Strategy
- Accelerator R&D Program
  - Linear Collider
  - Proton Driver
  - Superconducting RF
  - Muon Facilities
  - Superconducting Magnets
- Resources/Budgets

Note: This presentation does not cover the significant accelerator R&D program operating in support of Collider Run II.

# Goals

---

- To develop the technologies that will provide the next round of opportunities in accelerator-based HEP.
  - Establish capabilities that will allow Fermilab participation as a leading partner in, and a credible host for, the construction and operations of a linear collider as the next forefront HEP facility.
  - Develop new accelerator technologies to support Fermilab's long-term accelerator-based HEP mission.

⇒ Close alignment with the vision of the Office of Science/HEP Facilities Committee
- To advance knowledge in fundamental accelerator R&D and to partner with universities in the training of new students.

# Strategy

---

- Priority is given to R&D aimed at supporting U.S. linear collider design efforts and establishing Fermilab as a credible host/construction partner.
- Pursuit of other options for Fermilab aligned with developing Office of Science vision.
- Once a direction has been established through the variety of planning exercises in place we anticipate consolidating resources.
- We continue to nurture accelerator R&D initiatives in the local universities via this process.
  - FNPL/NICADD
  - LC/University R&D program
  - Muon R&D/ICAR

# Accelerator R&D Program

## Elements of the Program

---

- Linear Collider
  - X-band (NLC collaboration)
  - Superconducting (TESLA collaboration)
- Proton Driver
- Superconducting RF
  - Fermilab NICADD Photoinjector Laboratory (FNPL)
  - CKM
  - SC linac (Proton Driver)
- Muon Facilities
- Superconducting Magnets

### Office of Science Facilities

Linear Collider

$\nu$  Superbeam

CKM, LC,  $\nu$  Superbeam

Neutrino Factory

LHC upgrades

# Linear Collider

**The U.S. community has now endorsed a linear electron-positron collider, constructed as an international endeavor and based on the optimum technology, as the next forefront facility in support of High Energy Physics. This sentiment has also been expressed by the our European and Asian colleagues.**

## Goals

- Complete NLC R&D work leading up to a technology demonstration (late 2003/early 2004).
- Contribute to the technology decision (mid-2004)
- Understand the ramifications of building a linear collider at Fermilab
- Be prepared to host/participate (2006/7)

# Linear Collider

## NLC

---

- The scope of work that Fermilab is undertaking has been severely constrained by the budgets of FY02-FY03, and more recently by the redirection of resources onto Collider Run II.
  - Budget stagnant since FY01 (\$2.5M) at level less than half of that anticipated when we started this program.
  - Strategy is to focus effort in areas where we have momentum, capabilities, and available people.
    - **Emphasis on cavity development and civil/siting studies**
    - RF development activities, including creation of an x-band power facility on-site, have been suspended.
    - The very successful permanent magnet development activity has been dramatically reduced following transfer of lead scientist to Tevatron Dept.
    - Accelerator Physics group has been redirected onto Run II.

# Linear Collider

## NLC

---

- Primary responsibilities within the NLC Collaboration include:
  - NLC Structures
    - Structures fabrication for 8-pack test
    - Development of a fabrication/industrialization methodology
    - Development of girder designs
  - Site Studies
    - Preliminary studies of potential northern Illinois sites
    - Providing overall coordination (Vic Kuchler) of all NLC civil activities including Illinois and California

# Linear Collider

## NLC Structures

---

- We have produced three 20 cm long traveling wave structures: FXA-001, FXA-002, and FXA-003.
  - These were used to learn how to fabricate and assemble structures, and to work out most of the bugs in the RF factory.
- We have produced two 60 cm long high gradient test structures: FXB-002 and FXB-003.
  - FXB-002 was the first Fermilab X-Band structure to undergo high power RF testing (in the NLCTA at SLAC). It performed better than some, not as good as others. It was made without hydrogen cleaning.
  - FXB-003 was received at SLAC on 3/6. It underwent hydrogen cleaning, as will FXB-002 upon its return from SLAC.
  - FXB-004, 005, 006 should be at SLAC in June.

# Linear Collider

## NLC Structures



FXB-002 at SLAC prior to high power testing, November 2002.  
N. Solyak, C. Boffo, D. Finley, G. Romanov, T. Arkan and H. Carter.

# Linear Collider

## NLC Structures



**FXB-002 Bead pull tuning**

- We are continuing to improve our fabrication methods and processes.
- We are working to broaden our base of vendors capable of producing high precision machined parts for structures (2 for disks and 3 for couplers).
- We have improved our in-house RF design capabilities through the purchase of more powerful software and hardware, and through collaboration with our SLAC and KEK colleagues. We now design our own couplers.

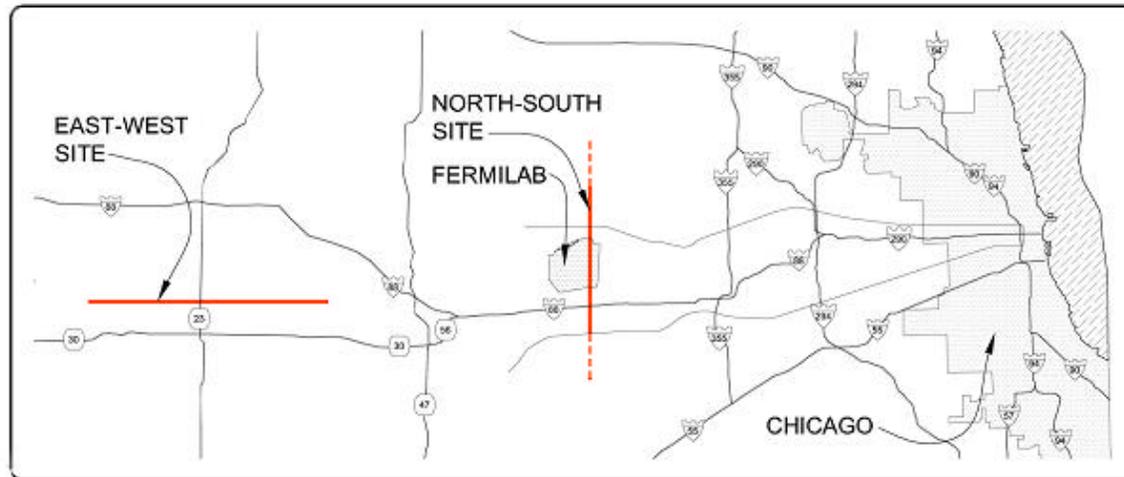
# Linear Collider NLC Support Girders

- We are just beginning to conduct girder tests, initially using a SLAC supplied test assembly.



SLAC Thermal Stability Test Girder in the MP8 Enclosure at Fermilab

# Linear Collider Site Studies



- Preliminary analyses of N-S and E-W sites completed over FY2001-02.
- FY2003 siting activities are being conducted under the auspices of the USLCSG sponsored warm/cold evaluation:
  - SC linac in a deep site near DeKalb, IL
  - Warm linac in a bored tunnel SE of Livermore, CA (Copper Mtn.)
  - Analysis of incremental changes/costs for the alternatives.

# Linear Collider

## TESLA

---

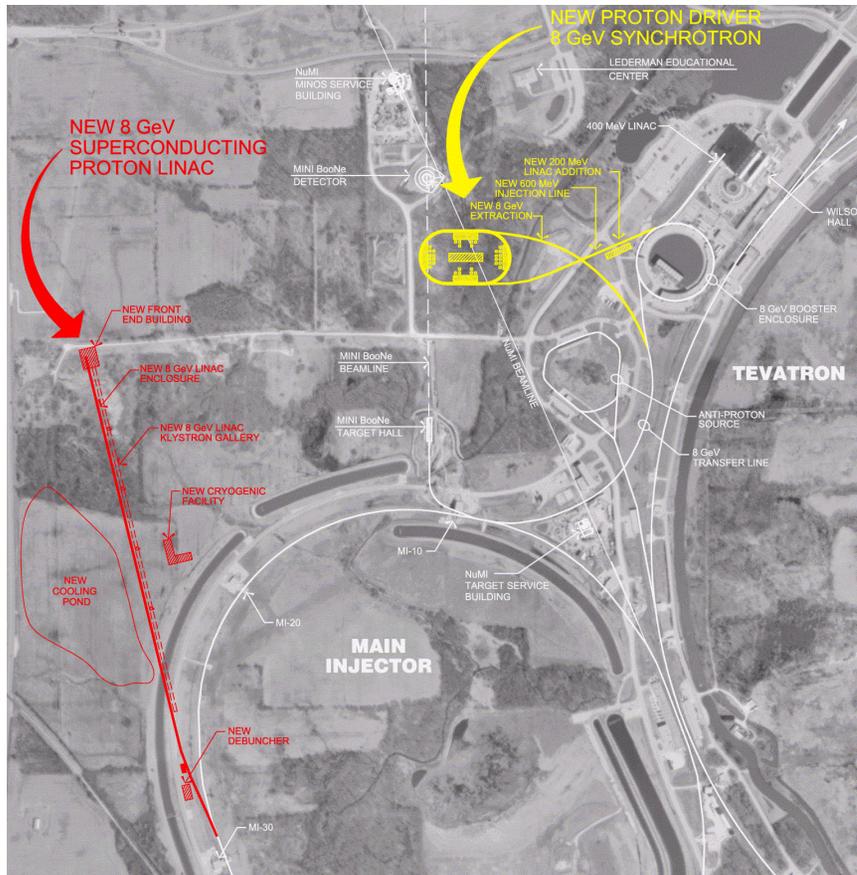
- Fermilab remains a member of the TESLA collaboration (and the only institution affiliated with both NLC and TESLA collaborations) although effort at this point is minimal.
  - Modest continuing consultation support for TTF
  - Engineering/cost study of the TESLA proposal completed in July 2002. (TM-2179)
  - Global Accelerator Network (GAN) activities at FNPL
- The most significant involvement of Fermilab relative to a superconducting linear collider is now occurring via the USLCSG sponsored evaluation.
  - Fermilab is providing leadership/support in the accelerator technology, site development, and cost estimating task forces. All of these draw on our considerable past experience in these areas, including the TESLA engineering/cost study.

# Linear Collider Goals through FY05

---

- Deliver 5.4 meters of X-Band structures for the 8-Pack Test. (CY2003)
  - Mix of FXB test structures, and 75 cm “full feature” structures (FXC’s) with damping manifolds.
- Develop girders for the Main Linac structures.
  - We are beginning to develop a design design with a kinematic support system and multi-axis positioning capability.
- Significantly ramp up the Linear Collider R&D effort in FY05.
  - Main Linac Beam Line Components
    - Structure industrialization
    - Linac girders
  - Siting and civil construction
- Significant contribution to the “warm and cold” evaluation of linear colliders commissioned by the USLCSG.

# Proton Driver



- Two concepts identified for a new 8 GeV proton facility at Fermilab
    - 0.5 (synchrotron) to 2.0 (linac) MW beam power at 8 GeV.
    - Both enable up to 2 MW at 120 GeV from MI (with upgrades)
    - \$0.25-\$0.5M price tag
  - Study completed in May 2002 (no work since)
  - Plan to reinstate R&D in FY05
- ⇒ Would create multiple opportunities for long-term leadership in hadron based HEP.

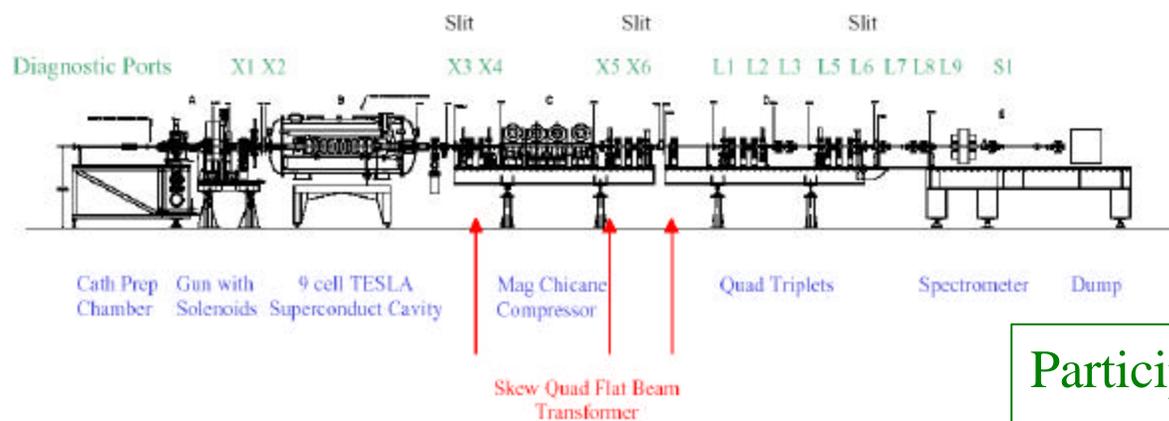
# Proton Driver Parameter Table

	Present Booster	Proton Driver/ Synchrotron	Proton Driver/ SC Linac	
Output Energy	8.0	8.0	8.0	GeV
Protons per pulse	$5 \times 10^{12}$	$2.5 \times 10^{13}$	$1.5 \times 10^{14}$	
Repetition Rate	15	15	10	Hz
Pulse Length	1.6	1.6	1000	$\mu\text{sec}$
Transverse emittance	$15\pi$	$40\pi$	$10\pi$	mm-mr
Average beam current	12*	60	240	$\mu\text{A}$
Average beam power	0.1	0.5	2.0	MW

(\*) Although originally designed for 15 Hz operations, the present Booster has never delivered beam at 15 Hz continuously. It is designed to operate in the near future at 7.5 Hz for MiniBooNE operations.

# Superconducting RF

## Fermilab NICADD Photoinjector Laboratory (FNPL)



- 15 MeV, laser-driven electron beam facility.
- Copy of the TTF injector
  - 8 nC/pulse
  - 30 psec (rms) bunch length
- Jointly supported by Fermilab and NIU

### Participating institutions:

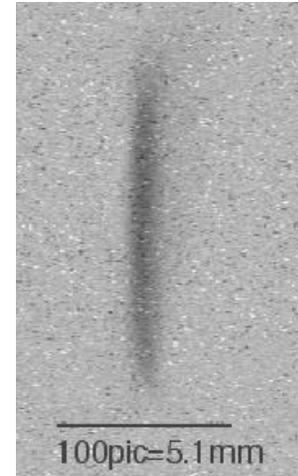
- Fermilab
- NIU
- UCLA
- Chicago
- Rochester
- DESY
- LBNL

# FNPL

## Current Program

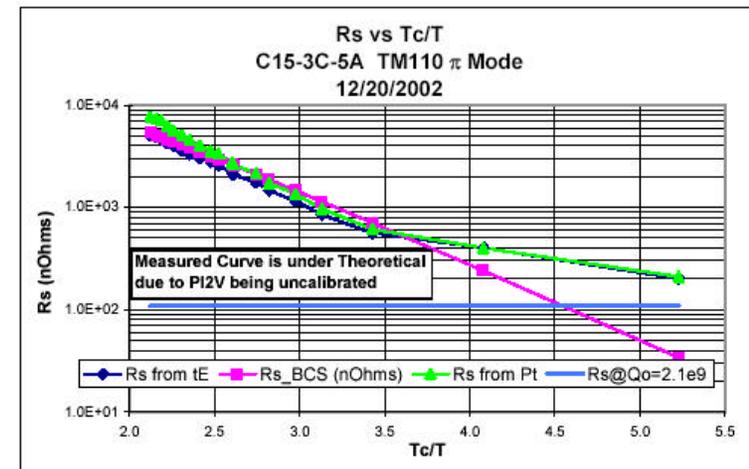
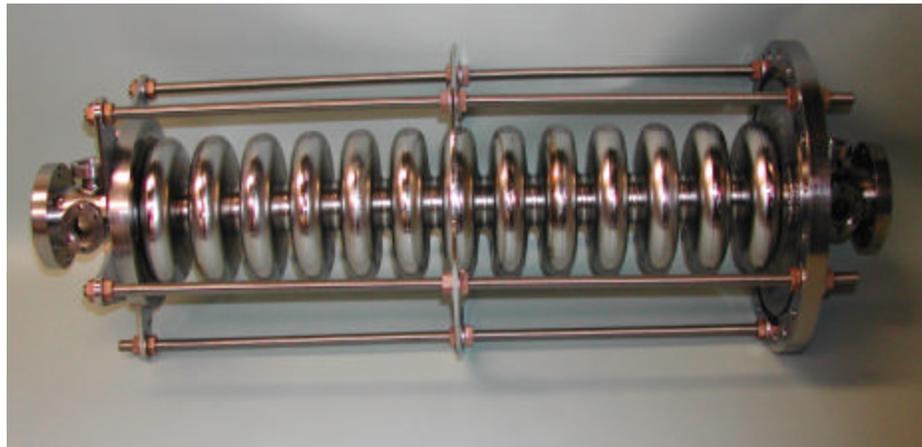
---

- Flat Beam  $\epsilon_x \ll \epsilon_y$
- Plasma wakefield acceleration (PWFA)
- RF Gun Quantum efficiency measurements & breakdown studies
- 9 cell Superconducting cavity transfer matrix
- Gun & solenoid beam based alignment
- Injector emittance and beam size comparison with simulation
- Plasma density transition leading to electron trapping
- Laser acceleration with donut mode laser and open iris structure
- Interferometer bunch length measurement, compression & CSR studies



# Superconducting RF CKM Cavity Development

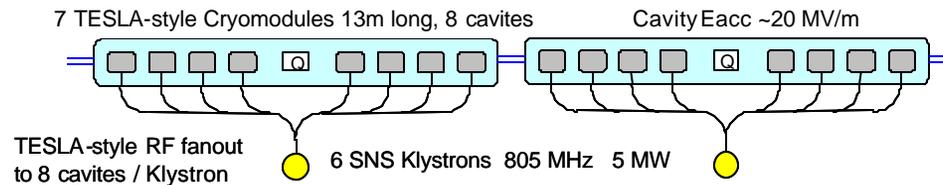
- 3.9GHz deflecting mode cavity for Kaon separated beam line
  - 5 MV/m transverse field
  - (Surface B field comparable to TESLA cells at 17 MV/m)
- Fabrication of full prototype (13 cell)
  - 12 units required
- Vertical dewar tests of 1& 3 cell (@ 5MV/m)
- Next- prototype Horizontal Cryostat
- Chemistry at Argonne



# Superconducting RF

## Future Goals

- FNPL (2003-05)
  - separate chicane and flat beam transformer
  - install laser acceleration and plasma density experiments
  - install/test superconducting CKM cavities
    - CKM deflecting mode cavity systems test and diagnostic for measurement of slice emittance
  - 3rd harmonic cavity for long (low space charge) bunches
  - Gun vacuum studies directed toward possibility of polarized beam.
- CKM (2003-05)
  - Move from R&D into cavity production
- Superconducting Proton Beta=0.81 Superconducting Linac **400 ® 1000 MeV** Linac
  - Initiate R&D on critical components (2005)



( 7 Cryomodules, 7 Klystrons, Length ~91m)

# Muon Storage Ring

---

Goal: Establish the technology base for an affordable, muon-storage-ring-based, neutrino factory.

- Fermilab is one of the three lead-laboratories for the Neutrino Factory and Muon Collider R&D.
- Fermilab is host to the MUCOOL sub-activity, which is the R&D program to develop the technologies required for a muon ionization cooling channel. Primary hardware activities:
  - Study of high-gradient NCRF cavities operating in high-field solenoids (one accelerator PhD to date another active).
  - Development of liquid hydrogen absorbers (led by ICAR).
  - 16 collaborating institutions from U.S., Europe, and Japan
- The Fermilab group is also instrumental in design & simulation studies focused on significantly reducing the cost of a neutrino factory. (One active PhD student)

Some MUCOOL Accomplishments local to Fermilab & ICAR



Dark current ring measurements on glass plate – ANL/FNAL/IIT



High-Gradient RF Tests in High Magnetic Field - FNAL



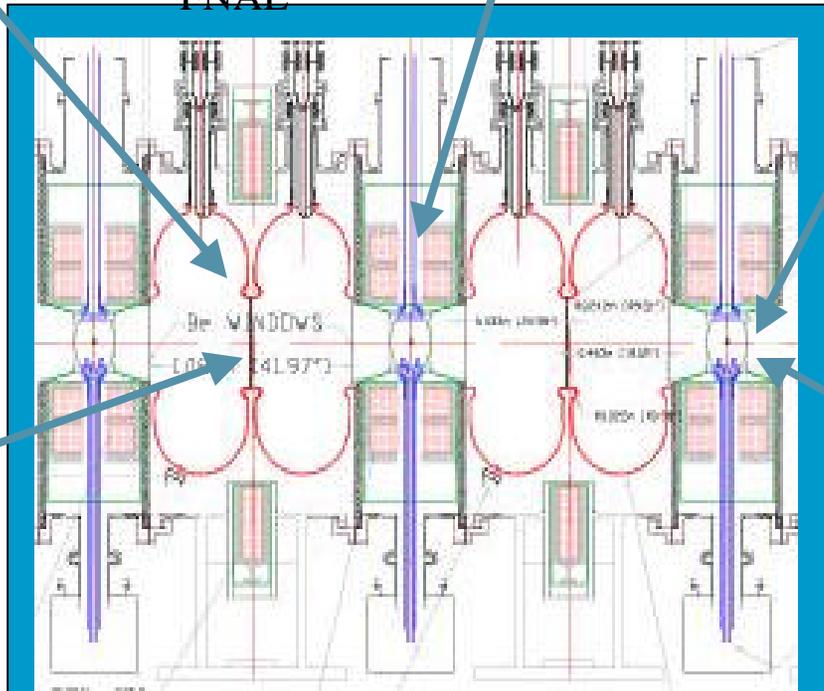
Lab G 805 MHz Test Setup



Bolometer detectors for Window Beam profile – cryogenic setup– U. Chicago



High pressure seal test for high-pressure RF studies – Muons Inc



Liq. H RF Liq. H RF Liq. H  
COOLING CHANNEL DESIGN



Window burst tests – ICAR Universities

# MuCool Test Facility



## **MUCOOL Test Facility at end of Fermilab 400 MeV Linac**

- Fill Liq. H absorbers: U.S. & Japanese prototypes
- High-Power tests of 201 MHz & 805 MHz Cavities
- Full engineering test of Absorber – Cavity – Solenoid system
- Development of new beam diagnostics
- Eventual engineering test in high-intensity Linac beam

**Longer term: Build cooling components for the international (US-Europe-Japan) Cooling experiment (MICE) at the Rutherford Lab.**

# Muon Storage Ring

## Future Plans

---

### FY04

- Complete/equip MUCOOL Test Area
- Continue 805 MHz studies at Lab G
- Fill first absorber with Liq. H<sub>2</sub>
- Continue preparation for Feasibility Study III

### FY05

- 201 MHz High Power Tests
- Fill absorber next to operating cavity
- Prepare 400 MeV beam capability
- Initiate Feasibility Study III

### FY06 and Beyond

- Complete Feasibility Study III
- Cooling component engineering tests with Linac beam
- Production of components for the MICE experiment

# Superconducting Magnet R&D

---

## Goals:

- Support for ongoing Tevatron collider operations.
- Development of high field superconducting accelerator magnets that could form the basis for a next generation hadron collider (LHC upgrade or VLHC).
  - The low-field superconducting magnet program at Fermilab is effectively over. Some modest (low priority) activities are aimed at documenting achievements.
  - We anticipate this program becoming integrated with the LHC Accelerator Research Program as it develops over the next few years.

# Superconducting Magnet R&D

## High Field Magnet Program

---

- Long-term goal is development of next generation superconducting magnets with the nominal field **above 10 T**, operating temperature of **4.5 K**, and **field quality/operating margin** appropriate for accelerator applications.

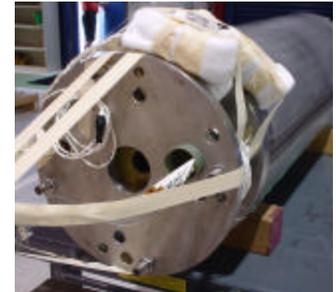
⊢ **Requirements exceed the capabilities of NbTi.**

- The R&D program is concentrated on:
  - **Development of 11-12 T accelerator magnets based on Nb<sub>3</sub>Sn**
    - Commercially available but difficult because of brittleness
    - ⊢ **Same technology as likely required for LHC luminosity upgrade.**
  - Two designs:
    - traditional shell-type ( $\cos\theta$ ) and common coil configurations
  - Two approaches
    - Wind-and-react/react-and-wind

# High Field Magnet Program Status

- Cos $\theta$

- Four 1 m models fabricated and 3 tested in FY2001-2002
  - Nb<sub>3</sub>Sn single bore dipoles, wind-and-react coils
  - Design: 12 T @ 4.5 K, accelerator quality field, 43.5 mm bore
  - Achieved field quality, but field @ 60% of short sample
- Currently studying quench performance using half-coils and magnetic mirror
- Next short model HFDA05 planned for fabrication/testing in 9/03



- Common coil

- Two 1 meter coils fabricated and tested in FY2001-2002.
  - Nb<sub>3</sub>Sn react-and-wind racetracks
  - Design: 11 T @ 4.5 K, accelerator quality field, 40.0 mm bore
  - 2nd racetrack tested in FY 2002 reached 78% short sample (world record for this approach)
  - 3rd racetrack to be tested in April, 2003
- 1st short model planned for fabrication/testing in 5/03



# Superconducting Magnet R&D

## Future Plans

---

- Produce/test 2-3 different model magnets per year. Goals:
  - Understand and improve magnet quench performance (FY2003-2004)
  - optimize field quality (FY2005-2006)
- Integration with the LARP effort.
- Once basic problems are understood possible directions within the high field dipole program include:
  - Increase the production and tests of HFM models of different types to ~6 per year.
  - Develop infrastructure and move to fabrication of long models starting in FY2005-2006 in collaboration with other national laboratories, universities and industry.
- Continue superconductor (materials) development within the national program

# Resources and Budgets

We have been saying for several year that the accelerator R&D program at Fermilab needs to expand significantly, particularly in the linear collider area. Despite our best efforts and intentions we have failed to do this due intense competition for resources within the laboratory.

## Funding Levels (Dollar amounts in millions, Direct costs only)

	<u>FY00</u>	<u>FY01</u>	<u>FY02</u>	<u>FY03</u>	<u>FY04</u>	<u>FY05</u>
Linear Collider/NLC (a)	\$1.2	\$2.5	\$2.5	\$2.4	\$2.5	\$5.0
SCRF (FNPL, CKM, TESLA)	\$0.7	\$0.8	\$2.3	\$2.6	\$2.0	\$4.3
SC Magnet (b)	\$3.0	\$3.1	\$3.6	\$3.2	\$3.5	\$4.4
Muons(c)	\$3.1	\$1.7	\$0.5	\$1.1	\$1.1	\$2.4
<b>TOTAL</b>	<b>\$8.0</b>	<b>\$8.1</b>	<b>\$8.9</b>	<b>\$9.3</b>	<b>\$9.1</b>	<b>\$16.1</b>

(a) Redistribution between x-band and SCRF will occur in FY05 assuming a LC technology decision comes in FY04.

(b) Includes initial buildup of LHC Accelerator Research Program at \$0.1, 0.3, 0.4, 0.9M over FY02-05

(c) Includes Muon Collaboration funding and Proton Driver.

# Summary

The future accelerator R&D program at Fermilab is striving to develop the technologies that will provide a future for Fermilab, and the U.S., in accelerator-based elementary particle physics.

- We believe this program is well-aligned with potential future initiatives identified within the Office of Science Facilities List
    - Priority is on R&D aimed at **establishing Fermilab as a credible host/construction partner to a second generation linear collider.**
    - Re-initiation of R&D aimed at a MW class hadron facility (FY2005).
    - Development of superconducting transverse deflecting cavities for CKM.
    - FNPL operations and improvements.
    - R&D on technologies for a muon storage ring based  $\nu$  factory.
    - R&D on superconducting magnets for future hadron colliders
- ⇒ There are numerous synergies between the above efforts.

# Summary

---

- Support for these activities is inadequate
  - This has led us to curtail efforts in some areas in order to support higher priority activities. However, one should not necessarily translate “higher priority” to mean “well supported”.

**Nonetheless, we believe we are making remarkable progress with the resources available and look forward to translating R&D into construction of a new facility in the near future.**