Neutrino Factory and Muon Collider Collaboration

R&D Program Plans

Michael S. Zisman
CENTER FOR BEAM PHYSICS

Muon Collaboration Project Manager

April 19, 2001
• Introduction

• Collaboration near-term R&D goals

• R&D plans

• R&D budget

• R&D timelines

• Summary
Introduction

- Since 1999, MC effort focused mainly on Neutrino Factory R&D topics
- Change in emphasis had one R&D implication
  - initial MUCOOL development based on 805-MHz components (RF cavity, power supply, solenoid)
    - work continued to learn about high-gradient performance in the presence of solenoid field
  - now need components sized for initial cooling channel parameters
    - 201 MHz RF cavity, power source, large-bore solenoid
  - R&D on these items is under way
- FNAL Feasibility Study taught us much about Neutrino Factory design
  - technical feasibility established (assuming component specs are met)
  - “cost drivers” were identified
    - R&D to produce cost-effective designs now included in program
• **MC** has 140 members from 30 institutions, including new NSF-sponsored University groups

• **We have the scientific personnel to carry out required R&D program in a timely way**

• **Committed to encouraging international cooperation for Neutrino Factory and Muon Collider R&D**
  
  — coordinate R&D between the various groups
    
    o Technical Board, Executive Board, NuFACT meetings
    
    o this is being encouraged from elsewhere also (Maiani letter)

  — **a cooling demonstration would be a natural topic for such collaboration**
    
    o there is interest in this in Europe and it will be discussed at NuFACT'01 in May
Introduction

- **MC** reorganized to improve R&D planning and monitoring
  - added the role of Project Manager (PM) with “line responsibility” for managing **MC** R&D program
  - **MC** member, appointed by—and reporting to—**MCOG** (with DOE-HEP concurrence)
**Collaboration Near-Term R&D Goals**

- Defined where we want to be in 2005 in all R&D areas, then determined what's needed to get there (funding and effort)

- By 2005 *(science/technology-driven schedule)*
  - all optics designs completed and self-consistent
  - validation experiments planned or under way
  - know what we want to build
  - know how to build “hard parts” (prototypes completed or designed)
  - ready to design and cost most components (⇒ ready to begin CDR)

- Aim for “ZDR-level” understanding of Neutrino Factory in 2003–2004

- Aim to begin CDR in 2005 (complete in 1–2 years)

- This aggressive schedule requires a reasonable funding level
  - which we not quite getting!  *(0.1 FTE × 10 years ≈ 0 FTE)*
R&D Plans

• Beam simulations
  — study alternative bunching and phase rotation schemes
  — continue error sensitivity studies
  — complete “interface” studies between cooling, acceleration, and storage ring sections
  — provide support for MUCOOL program
    ◦ especially, planning and analyzing cooling experiment
  — develop scheme(s) for longitudinal cooling (“emittance exchange”)

R&D Plans

• Targetry

  — **E951 program is proceeding on schedule**
    
    ◦ make neutron yield and pion yield measurements to benchmark codes (*MSU et al.*; Princeton, BNL)
    
    ◦ develop pulsed target solenoid for E951 tests (**MIT**, BNL)
      
      ◦ evaluate rad-hard materials and robust coil designs (**MSU**)
    
    — study “facility” issues (shielding, remote handling, radioactive storage) (**ORNL**, **BNL**)
    
    — explore other target options, e.g., “band” targets
    
    — evaluate target performance at 4 MW power level
    
    — tests of Hg jet in high magnetic field (13 T) started by **CERN** colleagues at Grenoble
R&D Plans

- Target mover and C target assembly in the A3 line at BNL
R&D Plans

- Target facility is a significant aspect of the project
**R&D Plans**

- **MU Colo**
  - complete high-power tests on 805-MHz cavities (*FNAL, LBNL*)
    - see what limits gradient; study multipactor and Be window behavior
  - build prototype LH$_2$ absorber and test with beam (*ICAR, FNAL*)
  - shift focus to 201-MHz RF development (*FNAL, LBNL*)
    - cavity design is under way (delivery and testing take 2-3 years)
    - Be window and/or grid design for large aperture cavity must be developed
  - design and fabricate solenoid to test cavity
R&D Plans

Open-cell cavity being tuned
(Fermilab)

Test solenoid in Lab G
(LBNL)
R&D Plans

- prepare string test (3 cells)
  
  ◦ assemble a single cell from the individual components (cavity, solenoids, absorber)

  - test it as a unit [FY02-FY04]

    ♦ expose to 400 MeV proton beam at FNAL

  ◦ design power source (MBK) during this period

  ◦ fabricate two more prototype cells and assemble with first cell for 3-cell string test [FY04-FY05]

    - fabricate RF power source for cavity test during this period

  ◦ carry out proton beam tests with 3-cell string [FY05-FY06]
R&D Plans

— carry out cooling demonstration as an international effort
  ◦ finalize plans for muon beam demonstration test [FY03]
  ◦ begin experiment in collaboration with other groups [FY06-…]
    - could be based on “string” or other components
— in the longer term, plan for emittance-exchange test system
R&D Plans

• Component development
  
  – **SCRF cavity** program now under way at Cornell (NSF supported)
    
    o upgrade processing facilities; set up 201-MHz power source
    o explore cost-effective fabrication techniques
    o develop method to provide adequate mechanical stiffness
    o demonstrate high-power pulsed operation (at FNAL)
  
  – begin consideration of “operational” diagnostics (ANL, U-Miss, UCLA, Princeton, Northwestern, IIT)
    
    o what is needed to transport beam, characterize beam, maintain beam properties during storage
    o also must define and develop diagnostics for string test and/or cooling demo
R&D Plans

- induction linac prototype development
  - verify gradient performance, pulser design, internal SC solenoid

- engineering design of 201-MHz power source, e.g., multibeam klystron

Induction linac concept

TESLA 7-beam 1.3-GHz MBK
R&D Budget

- Funding was increasing, but now is decreasing
  - direct MC funds “leveraged” by base program funds
    - sponsoring Labs cover physics staff costs

<table>
<thead>
<tr>
<th>Year</th>
<th>DOE-base ($M)</th>
<th>DOE-MC ($M)</th>
<th>NSF ($M)</th>
<th>ICAR ($M)</th>
<th>TOTAL ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY99</td>
<td>2.8</td>
<td>2.2</td>
<td>--</td>
<td>--</td>
<td>5.0</td>
</tr>
<tr>
<td>FY00</td>
<td>3.3</td>
<td>4.7</td>
<td>1.2</td>
<td>--</td>
<td>9.2</td>
</tr>
<tr>
<td>FY01</td>
<td>2.1</td>
<td>3.2</td>
<td>1.2</td>
<td>2.1</td>
<td>8.6</td>
</tr>
<tr>
<td>FY02a</td>
<td>2.2</td>
<td>2.8</td>
<td>1.2</td>
<td>2.1</td>
<td>8.3</td>
</tr>
</tbody>
</table>

*Present guidance from funding agencies.

- We need increased funds to build components (NCRF cavity, target solenoid, absorber, klystron, induction linac module, SCRF cryomodule)
  - these are all expensive items
**R&D Budget**

- FY01 funding plan (only DOE-MC funds)<sup>†</sup>

<table>
<thead>
<tr>
<th>Institution</th>
<th>MUCOOL Expt. &amp; Generic Studies</th>
<th>TARGETRY Expt.</th>
<th>SALARY</th>
<th>RESERVE</th>
<th>TOTAL ($K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNL</td>
<td>130</td>
<td>880</td>
<td>50</td>
<td></td>
<td>1060</td>
</tr>
<tr>
<td>FNAL</td>
<td>845</td>
<td></td>
<td></td>
<td></td>
<td>845</td>
</tr>
<tr>
<td>LBNL</td>
<td>180</td>
<td>30</td>
<td></td>
<td>180</td>
<td>390</td>
</tr>
<tr>
<td>ANL</td>
<td></td>
<td>25</td>
<td>180</td>
<td></td>
<td>205</td>
</tr>
<tr>
<td>IIT</td>
<td></td>
<td></td>
<td>60</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>Mississippi</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Princeton</td>
<td></td>
<td>145</td>
<td></td>
<td></td>
<td>145</td>
</tr>
<tr>
<td>UCB</td>
<td></td>
<td></td>
<td>90</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>UCLA</td>
<td>65</td>
<td></td>
<td>30</td>
<td></td>
<td>95</td>
</tr>
<tr>
<td>ORNL</td>
<td>50</td>
<td>50</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>NHMFL</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>JLab</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Cornell</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Iowa</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td><strong>TOTAL ($K)</strong></td>
<td><strong>1450</strong></td>
<td><strong>1130</strong></td>
<td><strong>420</strong></td>
<td><strong>180</strong></td>
<td><strong>3180</strong></td>
</tr>
</tbody>
</table>

<sup>†</sup>NSF has provided $1.2M for muon R&D (mainly SCRF at Cornell) and ICAR has provided $2.1M for muon R&D (mainly cooling)
R&D Budget

- Budgets based on technology-limited schedule prepared (FY01–FY05)

<table>
<thead>
<tr>
<th>R&amp;D area</th>
<th>FY01 ($)</th>
<th>FY02 ($)</th>
<th>FY03 ($)</th>
<th>FY04 ($)</th>
<th>FY05 ($)</th>
<th>Sum ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MU COOL</td>
<td>4.9</td>
<td>3.8</td>
<td>4.3</td>
<td>11.3</td>
<td>11.2</td>
<td>35.4</td>
</tr>
<tr>
<td>Targetry</td>
<td>4.7</td>
<td>3.8</td>
<td>4.1</td>
<td>3.5</td>
<td>2.1</td>
<td>18.2</td>
</tr>
<tr>
<td>Beam Simulations</td>
<td>2.3</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>10.3</td>
</tr>
<tr>
<td>Acceleration/Storage Ring</td>
<td>1.0</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>3.6</td>
</tr>
<tr>
<td>Components</td>
<td>1.9</td>
<td>4.5</td>
<td>7.5</td>
<td>4.3</td>
<td>4.0</td>
<td>22.2</td>
</tr>
<tr>
<td>ZDR Preparation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>15</td>
<td>15</td>
<td>19</td>
<td>26</td>
<td>26</td>
<td>100</td>
</tr>
</tbody>
</table>

- reaching the CDR stage will require about $100M

- Difficult to sustain component development program at funding level well below $10M/yr

- below a certain threshold, R&D produces only “paper and plastic”
**R&D Budget**

- Budgets projected into the out-years (basis: SWAG)
  - actuals for FY01 (and expectations for FY02) are indicated
  - decrease in FY17 and beyond would be filled in with R&D effort for MC-II

...if I had the nerve to draw it!

---

### MC R&D Profile

<table>
<thead>
<tr>
<th>Year</th>
<th>Budget ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY01</td>
<td>0</td>
</tr>
<tr>
<td>FY02</td>
<td>5</td>
</tr>
<tr>
<td>FY03</td>
<td>10</td>
</tr>
<tr>
<td>FY04</td>
<td>15</td>
</tr>
<tr>
<td>FY05</td>
<td>20</td>
</tr>
<tr>
<td>FY06</td>
<td>25</td>
</tr>
<tr>
<td>FY07</td>
<td>30</td>
</tr>
<tr>
<td>FY08</td>
<td>35</td>
</tr>
<tr>
<td>FY09</td>
<td>40</td>
</tr>
<tr>
<td>FY10</td>
<td>45</td>
</tr>
<tr>
<td>FY11</td>
<td>50</td>
</tr>
<tr>
<td>FY12</td>
<td>55</td>
</tr>
<tr>
<td>FY13</td>
<td>60</td>
</tr>
<tr>
<td>FY14</td>
<td>65</td>
</tr>
<tr>
<td>FY15</td>
<td>70</td>
</tr>
<tr>
<td>FY16</td>
<td>75</td>
</tr>
<tr>
<td>FY17</td>
<td>80</td>
</tr>
<tr>
<td>FY18</td>
<td>85</td>
</tr>
<tr>
<td>FY19</td>
<td>90</td>
</tr>
<tr>
<td>FY20</td>
<td>95</td>
</tr>
<tr>
<td>FY21</td>
<td>100</td>
</tr>
<tr>
<td>FY22</td>
<td>105</td>
</tr>
<tr>
<td>FY23</td>
<td>110</td>
</tr>
</tbody>
</table>

- Beam Tests ZDR/CDR
- NF ($M)
- MC ($M)
- Sum ($M)
- Actuals ($M)
R&D Timelines

• The **technology-limited** schedule to start a Neutrino Factory physics program is expected to be:

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2003</td>
<td>R&amp;D activities (ongoing)</td>
</tr>
<tr>
<td>2003-2004</td>
<td>Prepare Zeroth-Order Design Report (ZDR); continue R&amp;D; cooling string tests begin</td>
</tr>
<tr>
<td>2007-2012</td>
<td>Construct Neutrino Factory (assume 6 years)</td>
</tr>
<tr>
<td>2013</td>
<td>Experiments begin</td>
</tr>
</tbody>
</table>
The schedule to start a Muon Collider physics program is expected to be much later:

- **2000-2006**: R&D activities (ongoing; mainly theory and simulation effort)
- **2007-2012**: Develop and bench test components for longitudinal cooling (bent solenoid, wedge absorber, diagnostics, ring cooler)
- **2010**: Feasibility Study for Muon Collider
- **2013-2015**: Beam tests of 6D cooling system
- **2013-2016**: Prepare Zeroth-order Design Report (ZDR), followed by Conceptual Design Report (CDR)
- **2017-2024**: Construct Muon Collider (assume 8 years)
- **2025**: Experiments begin
Summary

- **MC** R&D program has clear directions to proceed on all fronts
- Long-range planning of R&D program has been done
- **MC** membership provides sufficient manpower to carry out our program
- Subpanel endorsement of **MC** R&D plan is critical to increasing financial support from Labs (base program) and funding agencies (DOE, NSF)
  - strong R&D support is a prerequisite to having good technical options from which to choose