Status of the NuMI Project

URA Visiting Committee

Greg Bock
NuMI Project Manager
March 14, 2003

Outline

• Project overview
• Progress during the past year
• Schedule & Funding
• Plans for the coming year
• Summary and Outlook

NuMI (Neutrinos at the Main Injector)
MINOS (Main Injector Neutrino Oscillation Search)
NuMI Project

Construct Facilities and Equipment for a Two Detector Neutrino Oscillation Experiment with Variable Energy Neutrino Beam (Start 2005)

Obtain firm evidence for oscillations and measure oscillation parameters, $\Delta m^2$, $\sin^2 2\theta$. Probe for $\nu_\mu \rightarrow \nu_e$ appearance.

Near Detector: 980 tons
Far Detector: 5400 tons
MINOS Sensitivity
(8E20 Protons)

- From $\nu_\mu$ disappearance signal
  « Measure $\Delta m_{23}^2$ to $\sim$10%

- Probe for $\nu_\mu \rightarrow \nu_e$ appearance
  « Sensitivity at the level of
    $\sin^2 2\theta_{13} > 0.06$ @ 90%CL

\[ \approx \sin^2 \theta_{13} \]

\[ \approx \sin^2 \theta_{13} \]

Low Energy Beam

- [Graph showing $\Delta m^2$ vs. $\sin^2 2\theta$]
- [Graph showing $|U_{e3}|^2$ vs. $\sin^2 \theta_{13}$]

- [Super-K Kamiokande 90% CL (1144 days)]
- [MINOS 90% CL (10 kt-yr)]
- [CHOOZ 90%]
- [MINOS Expected (10 kt-yr)]
Possible result in 2005

Expected event spectrum

Observed event spectrum

Ratio: survival probability

Mixing angle

Δm²
Project Scope

- **TEC = WBS 1.0 NuMI Facility ($109M)**
  - Construction of beam line facility at Fermilab
  - Project scope includes
    * underground excavation and outfitting of tunnels and halls
    * construction of two surface buildings
    * design, construction and installation of technical components in NuMI beamline

- **OPC = WBS 2.0 MINOS Detector + WBS 3.0 Project Support ($62M)**
  - Construction of two detectors and Soudan Far detector cavern
  - Project scope includes
    * WBS 2.0: design, construction and installation of two detectors
    * WBS 3.0: early phase of R&D tasks for NuMI and MINOS excavation and outfitting and pre-operating of MINOS Far detector cavern at Soudan Underground Laboratory
Progress Since Last March

- **Conventional Construction**
  - Excavation completed!
  - Service Buildings and Outfitting under contract and well underway

- **Technical Components,**
  - Primary beam re-designed. Fabrication underway. Installation in progress. Starting to plan for commissioning and operations

- **MINOS Detectors**
  - First of 2 Far Detector SuperModules complete and recording atmospheric neutrino data. The second will be finished later this summer. Good progress on Near Detector. Calibration data taken.

- In the past year have accomplished a major amount of work—over $30M on the TPC. As of January 31, $34M to go.

- We remain on the plan--scope, cost, and schedule.
Management Meetings, Reports, Reviews

- Semi-annual DOE Review of the NuMI Project held in May and December
  - No action items
  - Typically 2 or 3 dozen recommendations
  - May 28-30
- Director’s 2nd Installation Review (followup from December)
  - Focus on summer shutdowns with overview of whole project.
- Numerous engineering safety reviews of technical components being convened by management.
Management Meetings, Reports, Reviews

- Semi-annual UK MINOS Management meetings between NuMI and UK
- PMG Meetings (progress reporting and change control board) chaired by Deputy Director held roughly monthly.
- Collaboration Meetings in Minneapolis and Sussex, UK, Fermilab, and South Carolina—emphasizing physics at far detector, calibration studies at CERN, and beam issues
- DOE visitors included: Robert Card, (DoE Undersecretary), David Stadler, (Deputy Assistant Secretary) DoE Inspector General Audit, Phil Debenham, Peter Rosen
Environment, Safety and Health

- Safety across the project remains uppermost on all our minds.
- Re-emphasizing throughout the project taking time to plan ahead, identify hazards, put controls in place, monitor, assess.
- Added ES&H staff to cover increase in activities for FY03
- Increased consideration to ES&H in SB&O package as well as incorporating our experiences of the past years.
- Take action when violations occur. Four workers removed from SBO job for violations of safety procedures. Investigate incidents and implement appropriate corrective actions.
- To date, no injuries on the SBO job.
- Beamline component ES&H reviews continue. Walkthroughs of Fermilab sites instituted.
- Continuing to monitor Environmental compliance of our contractors. New water treatment plan in place.
Construction Safety

NuMI Tunnel & Halls Lost Workday Case Rates

Lost Workday Case Rates CY2000
Lost Workday Case Rates CY2001
Lost Workday Case Rates CY2002
Lost Workday Case Rates CY2003
NuMI Conventional Facilities

• Tunnels and Halls work completed providing underground spaces for the facility and the large decay pipe and shielding. High quality. Two shafts, two large underground caverns, 675m 2m diameter concrete encased decay pipe. Now into contract closeout phase.

• Service Buildings and Outfitting contract (SBO) Two surface buildings and underground outfitting of the tunnels. Incorporated much of what we learned over the last couple years managing the tunneling contract Office staffing contract language, ES&H expectations, and scheduling requirements. Full NTP issued on November 22.
NuMI Tunnels and Halls

- Product is complete and of high quality. It was a tough job with a good finish.
- Contract Closeout team established by the project replacing the Tunnels and Halls Construction Management Office. Charged with closing out the Healy contract equitably, so that only costs that are due and allowed are incurred. Team lead by Procurement Manager and Underground Construction Manager includes a negotiator, claims strategy advisors, geotechnical experts, cost estimators, auditors, and potentially litigators.
- Significant costs accompanying both the schedule delays and the preparation for defense of claims:
  - Our Geo-technical Baseline characterization was sound
  - Some potential claims already settled
  - Disputes Resolution Board Process underway
  - Our increased management costs were large—field and office and consultants. We intend to seek damages as a result
  - We have enough to pay what we will owe, but not what the contractor will seek. Lab provides claims/litigation support.
Service Buildings and Outfitting

- Last large contract on project—4 bids, all came in higher than expected. Led to a project-wide effort over the summer. Implemented a risk mitigation exercise we conducted last spring in preparation for such an event, and implemented $1M savings in Technical Components. Reviewed Technical Components and MINOS contingency and risk analyses. Determined we could afford it. Got concurrence from Laboratory and DOE management in a series of reviews. Contract awarded to Ragnar Benson, Inc of Park Ridge, IL for $17.9M.

- Off to a good start. Approximately 30% complete. Noticing some schedule concern (~3 weeks); contractor agrees: has promised a “workaround schedule” which could make use of more hours/day, days/week or more staff. We have had to work hard with RBI to instill our safety culture. Watching this job very carefully.
Underground Enclosures in November

Pre-target area, looking into decay pipe

MINOS Hall
Underground Enclosures in January

Pre-target area, looking into decay pipe

MINOS Hall
NuMI: Flexible Neutrino Beam

Expected CC Events Rates in MINOS Far detector

- High: 8,000 ev/2E20 p
- Medium: 3,600 ev/2E20 p
- Low: 1,400 ev/2E20 p
• Beam energy defined by the detector position
• Narrow energy range (minimize NC-induced background)
• Simultaneous operation (with MINOS and/or other detectors)
• ~2 GeV energy:
  • Below tau threshold
  • Relatively high rates per proton, especially for antineutrinos
• Matter effects to amplify to differentiate mass hierarchies
• Baselines 700 – 1000 km
• Significant technical progress being made in all areas and on goals. Engineering levels OK. Designs essentially 100%. Significant cost savings during the engineering, even with the primary beam upgrade. Costs holding constant since 2001.

• Work progressing well on Primary Beam. Good team, which continues to grow. Good communication/interaction with accelerator people. Design (Beamsheet) accepted by Main Injector.

• Much progress on installation activity and planning.

• Technical Components Handbook V2.0 released.

• Internal assessment reviews continue.

• Fabrication of Neutrino Beam components on schedule with float and reasonable staffing. No changes being discussed.

• Integrating our plans for commissioning and initial high intensity running with the Beams Division
Installation Challenge: NuMI in the Main Injector Tunnel

MI ring on bottom, Recycler on top, NuMI in the middle
(fit between two accelerators)

NuMI Stub and Extension
(needs cranes, utilities etc.)
NuMI Target arrived from IHEP

Target encased, cooling lines

Target/baffle carrier drawings in drafting
NuMI Focussing System

(Spare) Horn 1 current distribution system

Assembly of inner and outer conductors of (production) Horn 2.
Installation, Commissioning and Transition to Operations

- Installation underway and continuing over next 20 months
  « January Shutdown: LCW piping, cable tray, cables
  « Summer Shutdowns: Lambertsons, Kickers, Instrumentation, magnets, cranes, etc
  « NuMI enclosures in Fall: Pre-target, Target Hall, Absorber hall, Muon monitoring alcoves, MINOS detector hall, and buildings
  « Director’s Reviews periodically

- Commissioning Plan developed
  « Technical Components L3 Managers led by Bruce Baller
  « Concentration on CD4 goals

- Evolution to initial operational intensity
  « 2.5E13 protons, 5/6 batches, 5E12 in Booster, 1.9s cycle
  « Integration into BD/HQ planning underway: tasks, people, studies
  « Multi-batch studies, dampers, beam loading compensation, booster shielding, booster notch and timing, possible RF upgrades
MINOS Far Detector

- 8m octagonal steel & scintillator tracking calorimeter
  - Sampling every 2.54 cm
  - 4cm wide strips of scintillator
  - 2 sections, 15m each
  - 5.4 kton total mass
  - $55\%/\sqrt{E}$ for hadrons
  - $23\%/\sqrt{E}$ for electrons
- Magnetized Iron (B~1.5T)
- 484 planes of scintillator
  - 26,000 m$^2$
Near Detector

- **3.8 x 4.8m** “octagonal” steel & scintillator tracking calorimeter
- Same basic construction, sampling and response as the far detector.
- No multiplexing in the main part of the detector due to small size and high rates.
  - Hamamatsu M64 PMT
  - Faster Electronics (QIE)
- **282 planes of steel**
- **153 planes of scintillator**
Detector Status

- We are past plane 426 (of 484).
- Installation end game being implemented. Factories shutting down.
  - The B field has been turned on for the 1st Super Module and data are being recorded. The current analysis is focusing on upward going $\mu$’s and $\nu$ interactions.
  - CALDET tests at CERN in 2002 (150 channels) and 2003 (1500 channels) testing electronics.
Atmospheric Neutrino Physics

• MINOS is the first large underground detector which has a magnetic field.
  «Measure charge/momentum of muons from ~0.5-70 GeV/c momentum.
  «Events with the neutrino interaction in the detector but where the muon exits still have complete \( E_\nu \) measurement: \( L/E \) measurements.

• Event direction reconstructed using timing and topology.

• Able to identify CC \( \nu_\mu \) and \( \bar{\nu}_\mu \) events from NC and CC \( \nu_e \) events over a very broad energy range as long as \( p_\mu > \sim 1 \text{ GeV/c} \).

• We can directly compare whether atmospheric \( \nu_\mu \) and \( \nu_\mu \) oscillate in the same way.

<table>
<thead>
<tr>
<th>Events in 24 kT years</th>
<th>Neutrino</th>
<th>Antineutrino</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contained vertex with muon</td>
<td>620</td>
<td>400</td>
</tr>
<tr>
<td>Upgoing muon</td>
<td>280</td>
<td>120</td>
</tr>
</tbody>
</table>
Atmospheric Neutrino Interaction

Run 8650, Snarl 42489. Planes Hit = 85, Track length = 6.43 m
$\beta^{-1} = -0.923$, $\chi^2 = 79.515$. vertex(x,y,z) = (3.145,-0.662,10.568)
$\cos(\theta) = -0.635$, $p_t = 6.207$ GeV/c, $\sigma_{\text{inel}} = 0.008$, $p_{\text{range}} = 4.329$ GeV/c
The critical path remains the completion of the civil construction at Fermilab and the subsequent installation of the NuMI technical components.

The schedule contains float. The schedule is integrated and resource loaded.

Re-estimates of critical activities are underway with the goal of accelerating the project.

We have been on schedule or slightly ahead for the past 21 months.
# Doe Milestones FY2002-2005
(Shaded milestones completed since March 2002)

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>PEP Milestone #</th>
<th>DOE Milestone (As of 12/2001)</th>
<th>Current Month's Forecast Milestone</th>
<th>DOE Milestone Variance (Cal Days)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic Rays Observed in Far Detector</td>
<td>L-2-10</td>
<td>3/22/2002</td>
<td>8/31/2001</td>
<td>203</td>
<td>Complete</td>
</tr>
<tr>
<td>Technology Choice Made for Muon Monitors</td>
<td>L-2-16</td>
<td>5/30/2002</td>
<td>12/10/2001</td>
<td>171</td>
<td>Complete</td>
</tr>
<tr>
<td>Service Building &amp; Outfitting Bid Package Out</td>
<td>L-1-10</td>
<td>7/30/2002</td>
<td>2/25/2002</td>
<td>155</td>
<td>Complete</td>
</tr>
<tr>
<td>75% Scintillator Produced</td>
<td>L-2-19</td>
<td>8/30/2002</td>
<td>5/24/2002</td>
<td>98</td>
<td>Complete</td>
</tr>
<tr>
<td>Near Detector Hall Excavation Complete</td>
<td>L-2-7</td>
<td>12/30/2002</td>
<td>8/30/2002</td>
<td>122</td>
<td>Complete</td>
</tr>
<tr>
<td>Target Hall Excavation Complete</td>
<td>L-1-5</td>
<td>12/30/2002</td>
<td>10/4/2002</td>
<td>87</td>
<td>Complete</td>
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<tr>
<td>Lambertson &amp; C-Magnets Assembled &amp; Tested</td>
<td>L-2-12</td>
<td>2/1/2003</td>
<td>10/31/2002</td>
<td>93</td>
<td>Complete</td>
</tr>
<tr>
<td>First Far Detector Super Mod Complete &amp; Tested</td>
<td>L-1-7</td>
<td>3/15/2003</td>
<td>7/24/2002</td>
<td>234</td>
<td>Complete</td>
</tr>
<tr>
<td>Inner &amp; Outer Conductors for First Production Horn Assembled</td>
<td>L-1-6</td>
<td>4/14/2003</td>
<td>2/5/2003</td>
<td>68</td>
<td>Complete</td>
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<tr>
<td>Target Service Building Shell Complete</td>
<td>L-2-18</td>
<td>9/30/2003</td>
<td>7/7/2003</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Near Plane Pre-assembly Complete</td>
<td>L-2-20</td>
<td>10/10/2003</td>
<td>12/17/2002</td>
<td>297</td>
<td>Complete</td>
</tr>
<tr>
<td>Far Detector Complete &amp; Tested</td>
<td>L-1-8</td>
<td>4/25/2004</td>
<td>9/10/2003</td>
<td>228</td>
<td></td>
</tr>
<tr>
<td>Beneficial Occupancy of Service Buildings at Fermilab</td>
<td>L-2-11</td>
<td>5/31/2004</td>
<td>12/12/2003</td>
<td>171</td>
<td></td>
</tr>
<tr>
<td>Start Commissioning with Both Near and Far DAQ</td>
<td>L-2-21</td>
<td>8/30/2004</td>
<td>4/1/2004</td>
<td>151</td>
<td></td>
</tr>
<tr>
<td>Complete Installation of Horn Power Supply</td>
<td>L-2-17</td>
<td>9/1/2004</td>
<td>9/18/2003</td>
<td>349</td>
<td></td>
</tr>
<tr>
<td>Near Detector Complete &amp; Tested</td>
<td>L-2-14</td>
<td>3/31/2005</td>
<td>9/24/2004</td>
<td>188</td>
<td></td>
</tr>
<tr>
<td>CD-4 Start Operations</td>
<td>L-0-3</td>
<td>9/30/2005</td>
<td>1/19/2005</td>
<td>254</td>
<td>End of Commission</td>
</tr>
</tbody>
</table>

Beam in 21 months
Project Schedule to Completion

- SBO Contract 28% Complete
- SBO Target area Complete (7 months)
- SBO MINOS area Complete (9 months)
- Proton on Target (13 months, Installation)
- Project Complete (1 month)
- DOE CD4 (8 months)
Financial Summary as of January 31, 2003

<table>
<thead>
<tr>
<th>WBS</th>
<th>Authorized Cost</th>
<th>ETC</th>
<th>% Complete</th>
<th>Obligated $</th>
<th>%</th>
<th>Contingency $</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEC</td>
<td>109,242</td>
<td>27,473</td>
<td>72%</td>
<td>84,092</td>
<td>86%</td>
<td>11,634</td>
<td>42%</td>
</tr>
<tr>
<td>1.1</td>
<td>26,311</td>
<td>12,372</td>
<td>53%</td>
<td>15,662</td>
<td>60%</td>
<td></td>
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</tr>
<tr>
<td>1.2</td>
<td>66,867</td>
<td>13,689</td>
<td>80%</td>
<td>66,103</td>
<td>99%</td>
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<td></td>
</tr>
<tr>
<td>1.3</td>
<td>4,430</td>
<td>1,411</td>
<td>68%</td>
<td>2,327</td>
<td>53%</td>
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<td></td>
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<tr>
<td>OPC</td>
<td>62,200</td>
<td>6,493</td>
<td>89%</td>
<td>54,053</td>
<td>92%</td>
<td>3,427</td>
<td>53%</td>
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<tr>
<td>2.0</td>
<td>42,554</td>
<td>6,477</td>
<td>85%</td>
<td>38,272</td>
<td>90%</td>
<td></td>
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<tr>
<td>3.0</td>
<td>16,218</td>
<td>16</td>
<td>100%</td>
<td>15,781</td>
<td>97%</td>
<td></td>
<td></td>
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<tr>
<td>TPC</td>
<td>171,442</td>
<td>33,966</td>
<td>78%</td>
<td>138,145</td>
<td>88%</td>
<td>15,061</td>
<td>44%</td>
</tr>
</tbody>
</table>

As of January 31, 2003

- **TEC**: 73% with $45M to go
- **September 2002**: 81% with $30M to go
- **March 2003 (PROJECTION)**: $2.5-3M/month
- **March 2002**: $30M progress in the last 10 mos

Report Date | % Complete
--- | ---
March 2002 | 62% with $64M to go
September 2002 | 73% with $45M to go
March 2003 (PROJECTION) | 81% with $30M to go

Remaining contingency OK
NuMI Project Status
Progress in “2002” (since last March)

• Underground excavation completed successfully and contract closeout underway.
• Outfitting underway and largely on schedule
• Installation schedule fully developed and more equipment installed in Main Injector enclosures
• Primary Beam re-design complete under construction
• First of the two Far Detector Super-Modules completed and taking physics data; the second on schedule for Summer 2003
• Full scale production of technical components underway. Designs complete.
• Near Detector Plane Pre-assembly complete. ND Electronics production underway.
• Successful CALDET run.
Expected Progress in 2003

- Summer Installation in Main Injector enclosure—magnets, crane, instrumentation, and more.
- Finish Service Buildings and Outfitting
- Fall Installations begin at Target and MINOS sites
- ES&H Performance continuing to improve
- Far Detector complete and taking physics quality atmospheric neutrino data
- Primary Beam studies underway
- Continue on cost and schedule plan
- Planning for “readiness reviews” including SAD
Continuing Challenges/Risks

- Finish conventional construction.
- Maintain technical component fabrication schedule. FY03 a crucial year
- Installation, especially in the area inside the Main Injector enclosures. This will be at least as hard as we thought.
- Continue to completion the excellent progress on Far Detector installation, and close out the construction efforts efficiently
- Maintain good progress on Near Detector Electronics
- We want no accidents/injuries anywhere on the project
- Underground construction contract closeout
- Accelerator studies need to be scheduled for later in FY03
- Manage cost and schedule challenges. Minimal contingency use.
Conclusion

• Remaining on schedule established in June 2001 within budget.
• Service Buildings & Outfitting contract well underway. Needs constant attention by the construction office staff; staff is up to the job. Complete in the Fall 2003.
• Technical components on track with a big spending year.
• Far Detector doing physics, finishing far construction, near electronics project underway, so far on schedule.
• Team succeeded with Jan. shutdown, now focusing on summer shutdowns (2003 and 2004).
• Lots of oversight/scrutiny.
• Last year was a good year, not easy, but good. We are looking forward to the next stages of the NuMI Project.