Status of NuMI and MINOS

URA Visiting Committee

Greg Bock
NuMI Project Manager
March 12, 2004

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)
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, $\Delta m^2$, $\sin^22\theta$. Probe for $\nu_\mu \rightarrow \nu_e$ appearance.

Near Detector: 980 tons

Far Detector: 5400 tons
For $\Delta m^2 = 0.0025$ eV$^2$, $\sin^2 2\theta = 1.0$

Oscillated/unoscillated ratio of number of $\nu_\mu$ CC events in the far detector vs $E_{\text{observed}}$

MINOS 90% and 99% CL allowed oscillation parameter space.
Appearance of Electrons

90% CL Exclusion

MINOS with: 25, 16, 7.4 x10^{20} pot

ICARUS
(5 years, 3kt)

90% CL Exclusion Limits

\[ \Delta m^2 = 0.0025 \text{ eV}^2 \]

3 \sigma Contours

MINOS, with 25, 16, 7.4 x10^{20} pot

CHOOZ 90% CL

\[ \Delta m^2 = 0.0025 \text{ eV}^2 \]

- MINOS sensitivities based on varying numbers of protons on target
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 March 2003

- Installation underway at Target and MINOS sites
- Installation in Main Injector enclosures underway—magnets, crane, instrumentation, and more.
- Finished Service Buildings and Outfitting
- ES&H program carried over into installation
- Far Detector complete and taking physics quality atmospheric neutrino data
- Primary Beam studies underway
- Preparing for “readiness reviews” including SAD
- Continued on cost and schedule plan
NuMI Conventional Facilities at Fermilab

- **Major, complicated conventional construction**

- **3 major technical installations in three different areas:**
  - Several hundred feet of accelerator enclosure—half of which is between two operating machines
  - Downstream end of carrier tunnel, Pre-Target and Target Areas—primary beam focus, 8KT neutrino beam target station
  - MINOS area—beam monitoring, ~1 KT hadron absorber and ~1 KT neutrino detector

![Diagram showing NuMI Conventional Facilities at Fermilab with labeled areas and completions dates:](image-url)
NuMI Service Buildings

MI-65

MINOS
MINOS Underground 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

(Off-Axis Beams come for free)
NuMI Extraction Channel  
(In the Main Injector)

- Lambertsons and C-mag installed
- MI Instrumentation relocated
- 7 quads (one RR stand adjustment)
- 5 dipoles
- 9/13 rough aligned
- Displaced utilities replaced
- (Not fun to be the 3rd Beamline installed along 10’ high wall)

Outstanding work and cooperation with other groups!
NuMI Pre-target
(Upstream end of new NuMI Facility)
Recent Progress
Production Horns

Horn 1 and Horn 2 both assembled, test pulsed, magnetic fields mapped.
*Ready for installation.*
CD4 Commissioning and the Transition to Operations

- **Commissioning Plan for Project Completion (“CD4”)**
  - Demonstrate a functioning Far Detector (atmospheric neutrinos and muons)
  - Demonstrate a functioning Beamline and Near Detector (with beam neutrinos)

- **April 15 Commissioning Workshop**
  - CD4 preparations
  - Main Injector
  - Near Detector
  - Commissioning for physics

- **Planning for evolution to initial operational intensity**
  - 2.5E13 protons, 5/6 batches, 5E12 in Booster, 1.9s cycle
  - Integrated into BD/HQ planning: tasks, people, studies
  - Multi-batch studies, dampers, beam loading compensation, booster shielding, booster notch and timing
Main Injector Commissioning
Multi-batch w/wo transverse dampers

*without dampers*

1 to 11 Booster turns

@ 8.9 GeV/c:
\[ \nu_X = 26.43, \nu_Y = 25.42, \xi_X = -20, \xi_Y = -16 \]

*with dampers*

9 Booster turns

@ 8.9 GeV/c:
\[ \nu_X = 26.44, \nu_Y = 25.47, \xi_X = -5, \xi_Y = -5 \]
MI Commissioning Status

• Team of Fermilab accelerator physicists and MINOS collaborators in place and planned studies ongoing
• A beam intensity of $2.3 \times 10^{13}$ protons/cycle is now operationally achievable in MI
• Good performance of MI transverse dampers
  • achieved an intensity of $3.3 \times 10^{13}$ protons in MI at 8 GeV in MI
  • both transverse and longitudinal dampers planned to be fully operational in May 2004
• Progress on Booster cogging
• Operational and instrumentation issues have been identified
  • a plan has been developed to address the issues
• By October 2004 we expect to meet intensity and beam quality goals
The MINOS Detectors

- Far Detector (Soudan Lab)
  - 8m Octagonal Tracking Calorimeter
  - 2 sections, 15m each
  - 486 planes of steel & scintillator
  - 95,000 scintillator strips
  - **5.4 kT total mass**

- Near Detector (MINOS Hall - FNAL)
  - 3.8 x 4.8m “octagonal” steel & scintillator tracking calorimeter
  - Same basic construction, sampling & response as the far detector
  - 282 planes of steel
  - 153 planes of scintillator

One Supermodule of the Far Detector
MINOS Far Detector

- Two Magnetized Supermodules began routine operation August 2003
- All project components associated with Far Detector fully closed out
- Cosmic Ray Veto shield constructed from spare components installed to enhance atmospheric neutrino analysis
Atmospheric $\nu$'s in MINOS Far Detector

- Analyzed Exposure to date
  - SM1
    * 131 live days
    * Sept 02 - May 03
  - SM1+SM2
    * 92 live days
    * Jul 03 - Nov 03

- Analysis of Candidates continues
  - Upwardgoing muons
  - Contained Events

Expected Events in 24 kT years for $\Delta m^2 = 0.003$ eV$^2$, $\sin^2 2\theta = 1.0$

<table>
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<tr>
<th>Event Type</th>
<th>Neutrino</th>
<th>Antineutrino</th>
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<tr>
<td>Reco'd contained vertex with muon</td>
<td>440</td>
<td>260</td>
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<tr>
<td>Reco'd upward going muon</td>
<td>280</td>
<td>120</td>
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</table>
MINOS Calibration Detector (Caldet)

• Three runs in CERN T7 and T11 beams
  « 2001 June, July, Oct
    * FD electronics shake down
  « 2002 Summer
    * Far Detector calibration
    * Near Detector Shakedown
  « 2003 Summer, October
    * Near Detector calibration
    * Near/Far Comparison

60 planes
Same segmentation and sampling and Near and Far Detectors
MINOS Near Detector

- All components ready for installation
  - Planes & electronics (New Muon) (Install April-Oct)
  - Magnet Coil (D0)
9 - Plane Commissioning (New Muon Lab)

- **Accomplished since November**
  - Cabled up last 9 planes (first to be installed)
  - Commissioned all Front End Electronics
  - Established read-out through DAQ
  - Analyzed cosmics with off-line software

- **Ongoing (through end of March)**
  - Trigger software
  - Light injection
  - Operational Readiness Clearance Reviews
### MC

#### U view

<table>
<thead>
<tr>
<th>Event (even)</th>
<th>Entries</th>
<th>Mean x</th>
<th>Mean y</th>
<th>RMS x</th>
<th>RMS y</th>
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<tbody>
<tr>
<td></td>
<td>36</td>
<td>262.4</td>
<td>27.73</td>
<td>11.44</td>
<td>17.93</td>
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#### V view

<table>
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<th>Mean y</th>
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<th>RMS y</th>
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<tr>
<td></td>
<td>36</td>
<td>264.2</td>
<td>50.34</td>
<td>13.39</td>
<td>26.72</td>
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### Data

#### Event (even)

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<th>Mean y</th>
<th>RMS x</th>
<th>RMS y</th>
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<tr>
<td>75</td>
<td>75</td>
<td>264.2</td>
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#### Event (odd)

<table>
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<th>Mean x</th>
<th>Mean y</th>
<th>RMS x</th>
<th>RMS y</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>75</td>
<td>264.2</td>
<td>50.34</td>
<td>13.39</td>
<td>26.72</td>
</tr>
</tbody>
</table>
Environment, Safety and Health

- Safety across the project remains uppermost on all our minds. Deep underground facility unique at Fermilab.
- Our safety plan emphasizes Fermilab’s safe work policies. Throughout the project we are taking time to plan ahead, identify hazards, put controls in place, monitor, assess, and correct.
- Take action when necessary. Investigate incidents and implement appropriate corrective actions including stand-downs and disciplinary actions.
- Added ES&H staff to cover increase in activities for FY03. Maintaining dedicated ES&H staff for installation.
- Documentation team formed: gather and finalize and post documents.
- ES&H reviews continue. Joint BD/PPD Safety Committee provides oversight.
- Continuing to monitor Environmental compliance.
- Working on Shielding Assessment and SAD preparation for some time already. Goal is to be ready for approval in Summer 2004.
Management Meetings, Reports, Reviews

- Comprehensive financial, schedule, and narrative monthly report to DoE Project Manager. Supplemental weekly reporting to DOE.
- PMG Meetings chaired by Deputy Director held roughly monthly. Project progress and change control advisory board for the director and an important forum for reporting and discussing Fermilab resources used by NuMI. Weekly meeting with DoE Project Manager. Monthly video meetings with Headquarters.
- Collaboration Meetings every few months.
- UK MINOS Management meetings bi-annually
- Lehman reviews held in May and November 2003; next one, May.
- Director’s Reviews in April 2003 and February 2004
- Several miscellaneous reviews and visits from DOE HQ per year continue.
### Doe Milestones FY2002-2005

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>PEP Milestone #</th>
<th>DOE Milestones</th>
<th>January</th>
<th>Forecast</th>
<th>Float</th>
<th>Notes</th>
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<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>
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<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>
<td></td>
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<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>
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<tr>
<td>75% Scintillator Produced</td>
<td>L-2-19</td>
<td>8/30/2002</td>
<td>5/24/2002</td>
<td>98</td>
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<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>
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<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>
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<tr>
<td>Lambertson &amp; C-Magnets Assembled &amp; Tested</td>
<td>L-2-12</td>
<td>2/11/2003</td>
<td>10/31/2002</td>
<td>93</td>
<td>Complete</td>
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<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>
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<td></td>
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<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>6/17/2003</td>
<td>105</td>
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<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>
<td></td>
</tr>
<tr>
<td>Far Detector Complete &amp; Tested</td>
<td>L-1-8</td>
<td>4/25/2004</td>
<td>7/9/2003</td>
<td>291</td>
<td>Complete</td>
<td></td>
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<tr>
<td>Start Commissioning with Both Near and Far DAQ</td>
<td>L-2-21</td>
<td>8/30/2004</td>
<td>6/9/2004</td>
<td>82</td>
<td>Complete</td>
<td></td>
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<tr>
<td>Near Detector Complete &amp; Tested</td>
<td>L-2-14</td>
<td>3/31/2005</td>
<td>1/26/2005</td>
<td>64</td>
<td>Complete</td>
<td></td>
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</tbody>
</table>

Start commissioning with protons in December 2004
# Financial Summary as of January 31, 2004

<table>
<thead>
<tr>
<th>WBS</th>
<th>Amount</th>
<th>Estimated</th>
<th>ETC (BAC - BCWP)</th>
<th>% Complete</th>
<th>Obligated $</th>
<th>% Complete</th>
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<tr>
<td>TEC</td>
<td>109,242</td>
<td>101,051</td>
<td>7,477</td>
<td>93%</td>
<td>96,325</td>
<td>95%</td>
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<tr>
<td>1.1</td>
<td>28,328</td>
<td>5,499</td>
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<td>81%</td>
<td>24,231</td>
<td>86%</td>
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<tr>
<td>1.2</td>
<td>68,893</td>
<td>1,604</td>
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<td>69,266</td>
<td>101%</td>
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<tr>
<td>1.3</td>
<td>3,830</td>
<td>374</td>
<td></td>
<td>90%</td>
<td>2,828</td>
<td>74%</td>
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<tr>
<td>OPC</td>
<td>62,200</td>
<td>58,433</td>
<td>446</td>
<td>99%</td>
<td>57,484</td>
<td>98%</td>
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<tr>
<td>2.0</td>
<td>42,285</td>
<td>677</td>
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<td>98%</td>
<td>41,341</td>
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</tr>
<tr>
<td>3.0</td>
<td>16,148</td>
<td>(231)</td>
<td></td>
<td>101%</td>
<td>16,142</td>
<td>100%</td>
</tr>
<tr>
<td>TPC</td>
<td>171,442</td>
<td>159,484</td>
<td>7,923</td>
<td>95%</td>
<td>153,809</td>
<td>96%</td>
</tr>
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</table>

## Report Date

<table>
<thead>
<tr>
<th></th>
<th>% Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 2003</td>
<td>82% with $28M to go</td>
</tr>
<tr>
<td>September 2003</td>
<td>92% with $13M to go</td>
</tr>
<tr>
<td><strong>March 2004 (PROJECTION)</strong></td>
<td><strong>96% with $6M to go</strong></td>
</tr>
</tbody>
</table>
NuMI Project Status

NuMI Total Project Cost

- Est at Complete
- Contingency Usage
- Earned Value
- Remaining Contingency
- Jul-01 Estimate

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Expected Progress by March 2005

- Far Detector continuing to collect atmospheric neutrino data
- Target hall installation finishing over the summer
- Finish proton beam installation and commissioning
- Near Detector installation completing in Fall
- Project completion forecast for January 2005
- Beam Neutrino events in Far Detector
- Experiment taking data
Continuing Challenges/Risks

• Installation, especially in the area inside the Main Injector enclosures. This will be at least as hard as we thought going into it, but it isn’t any harder.

• Must maintain good progress on installation and commissioning activities.

• NuMI proton commissioning during Run II operations is difficult and needs to be carefully monitored.

• Keep focussed on working safely--we want no accidents/injuries anywhere on the project.

• Closeout completed project elements
Conclusion

• We are only months away from being ready to turn the beam and experiment on.
• All NuMI Facility conventional construction is completed!
• We are already doing physics with the Far Detector.
• Team succeeded with Fall 2003 installation during the Main Injector shutdown, now focusing on Summer 2004.
• Lots of oversight/scrutiny continuing. We remain on the schedule established in June 2001 and within budget.
• Last year was a good year. We are looking forward to the final next stages of the NuMI Project and the beginning of the MINOS experiment.
Supplemental slides
• Build a new ~50 kt fine-grained, low Z detector in northern Minnesota or Canada
• Beam energy defined by the detector position (~20 mR off-axis gives an optimum beam.
• Narrow energy range (minimizes NC-induced background)
• Simultaneous operation (with MINOS and/or other detectors)
• Improve on MINOS oscillation measurements due to lower energy, narrow-band beam with much higher statistics due to more protons on target and much bigger detector.
  • Discover or better measure $U_{e3}$ and other oscillation parameters
  • Matter effects can amplify oscillation probability and be used to determine mass heirarchy
  • Search for CP violation