Summary of the NuMI Project

Version 5.1
November 20, 2000

The Fermilab NuMI Project Staff
and
The MINOS Collaboration
NuMI - 678

Fermilab is operated by the Universities Research Association for the U. S. Department of Energy

Contents

Table of Tables

Table of Figures

1. Introduction

This document provides a concise summary of the Neutrinos at the Main Injector (NuMI) Project. It is meant to provide an easily readable overview of all essential aspects of the project. The document is updated periodically to reflect the current state of the project and the information in this version supersedes that in all previous versions. Version 5.0 is up to date as of November 2000.

Each of the subjects in this summary is described in detail in other project documents, which are listed in the references. The three major subprojects, which together constitute the NuMI Project, are described in the following three sections.

The NuMI Facility

The purpose of the NuMI Facility subproject is to produce an intense beam of neutrinos to enable a new generation of experiments whose primary goal is to definitively detect and study neutrino oscillations. The neutrino beam will be of sufficient intensity and energy that experiments capable of identifying muon neutrino (ν_μ) to tau neutrino (ν_τ) oscillations are feasible. The first step in the production of the NuMI neutrino beam is to direct a beam of protons from Fermilab's Main Injector onto a production target. Interactions of the proton beam in the target produce mesons, which are focused toward the beam axis by two magnetic horns. The mesons then decay into muons and neutrinos during their flight through a long decay tunnel. A hadron absorber downstream of the decay tunnel removes the remaining protons and mesons from the beam. The muons are absorbed by the intervening earth shield, while the neutrinos continue through it to a "near" detector (in a new experimental hall at Fermilab) and beyond, to the "far" detector in Soudan, Minnesota. The Fermilab and Soudan experimental halls house massive detectors specially designed to detect the small fraction of the NuMI beam neutrinos that interact in them.

In addition to the underground construction at Fermilab, the NuMI Facility includes two service buildings located on the surface. The NuMI beamline and experimental facility at Fermilab are fully described in the NuMI Facility Technical Design Report.[1] Figure 1 depicts the NuMI Facility under construction at Fermilab.

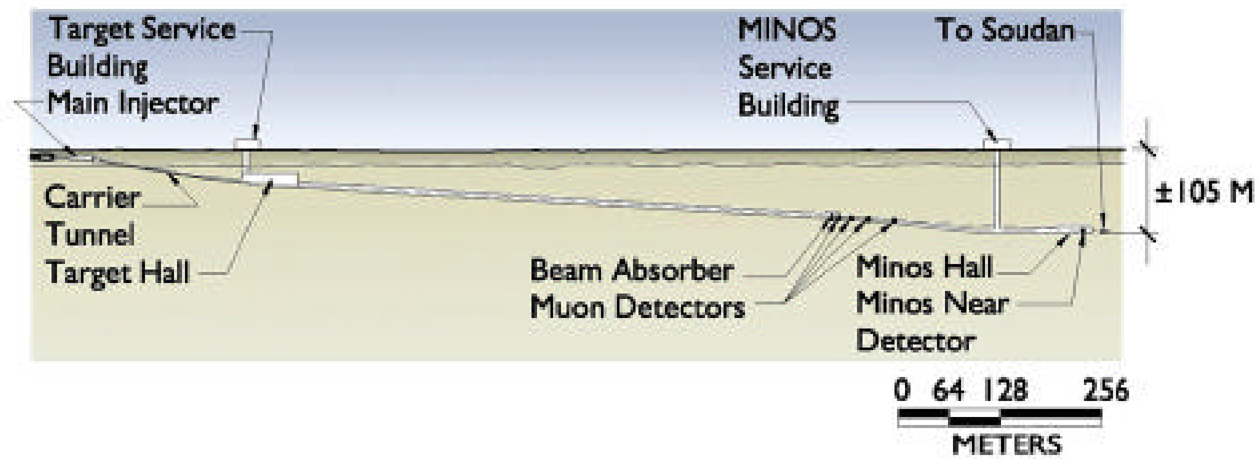

Figure 1. The NuMI Facility and beamline at Fermilab.

The MINOS Detectors

The MINOS Detectors subproject requires the construction of two massive calorimeter detectors. A near detector, located on the Fermilab site, provides a measurement of neutrino types, rates and energy spectra close to the point where the neutrinos are produced. A far detector, located in Soudan, Minnesota, repeats these same measurements 735 km downstream. We expect that the comparison of neutrino event types, interaction rates and energy spectra in the near and far detectors will provide conclusive measurements of neutrino oscillations.

The MINOS neutrino detectors are highly modular. The MINOS far detector consists of a sandwich structure with alternating octagonal planes of plastic scintillator and magnetized steel. The resulting detector is constructed in two "supermodules". Eventually, if funding allows, this detector may be supplemented with a third supermodule, an ancillary detector of a different type, or both. The near detector is of similar construction but smaller than the far detector. Details of the detector design and construction are given in the MINOS Detectors Technical Design Report.[2] A schematic diagram of the MINOS far detector is shown in Figure 2.

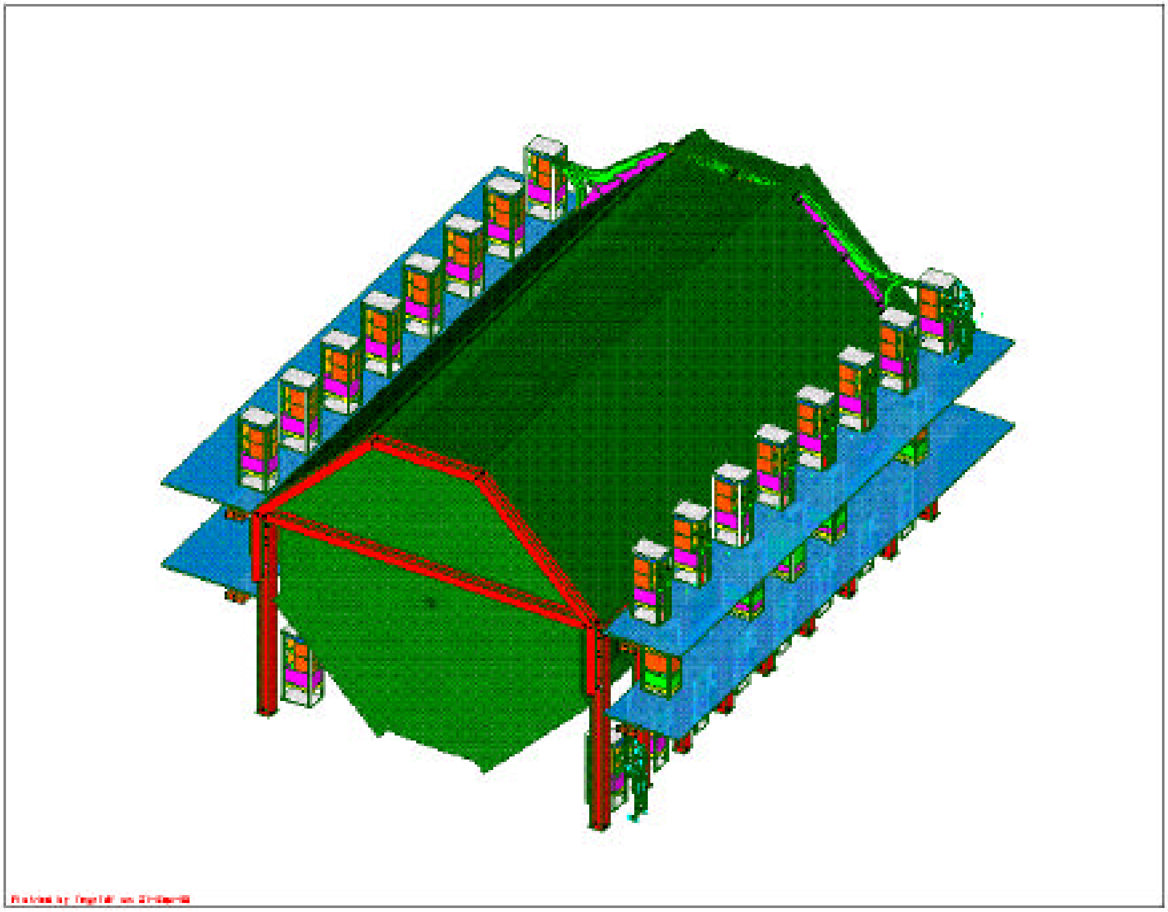

Figure 2 Schematic drawing of the baseline MINOS far detector, as it will be installed in the cavern at Soudan.

Expansion of the Soudan Underground Laboratory

The neutrino beam produced at Fermilab travels through the earth's crust to the Soudan Underground Laboratory, where its interactions are studied with the MINOS far detector. The MINOS Far Detector Laboratory subproject provides the underground experimental hall and infrastructure needed to construct and operate the MINOS far detector facility. The Soudan Underground Laboratory is a unique research site operated by the School of Physics and Astronomy of the University of Minnesota. It is located in the Soudan Underground Mine State Park, where the Minnesota Department of Natural Resources (DNR) preserves the oldest iron mine in Minnesota. Approximately 30,000 tourists visit the State Park underground attractions each summer. The laboratory is located 2341 feet below the surface, on the mine's 27^{th} level. The 1000-ton Soudan 2 proton decay experiment has been in operation since 1986 and the CDMS (Cryogenic Dark Matter Search) experiment is currently under construction in the existing Soudan 2 hall. The NuMI Project requires the expansion and operation of the existing research facility at the Soudan Underground Laboratory in order to accommodate assembly and operation of the MINOS far detector. This is shown in Figure 3. A building is being constructed on the surface near the mineshaft to support the work underground. Details of the Soudan Underground Laboratory design and construction are given in the MINOS Far Detector Laboratory Technical Design Report.[3] The underground trajectory of the NuMI beam is illustrated in Figure 4.

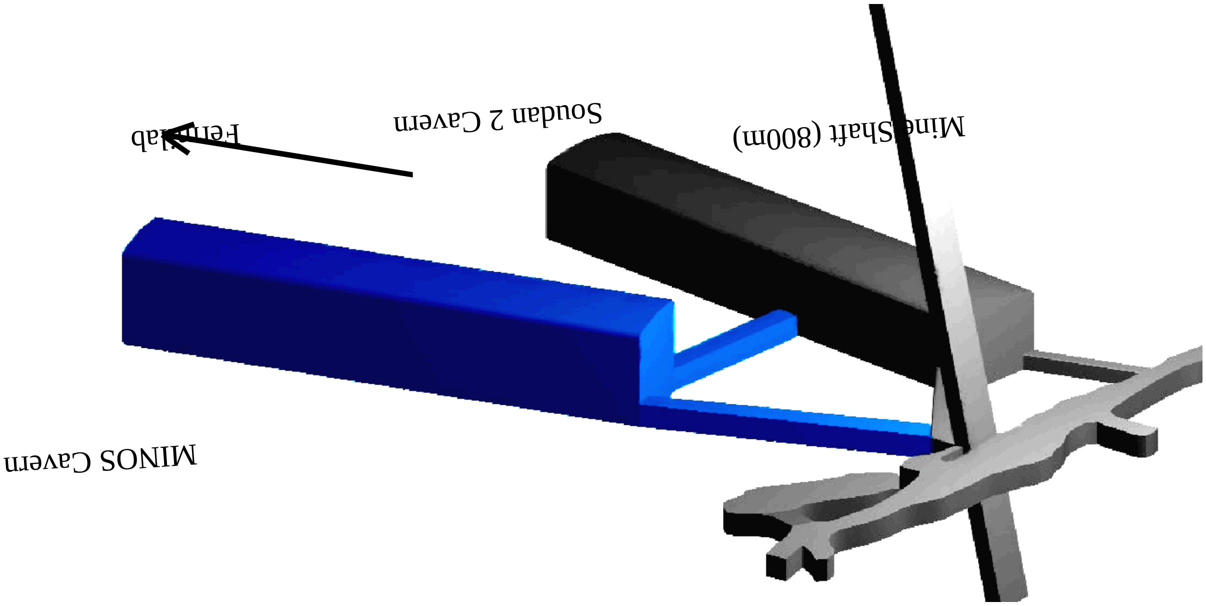

Figure 3 Layout of the Soudan Underground Laboratory with the MINOS cavern included.

In the next two chapters of this document we describe our physics goals and how they have led us to choose the key parameters and technology options for this project. Then Chapters 4, 5, and 6 summarize the technical scope, cost, schedule and management of the NuMI Project. Chapter 7 presents an overview of the MINOS Collaboration and Chapter 8 gives our present outlook and plan for the coming year.

Figure 4 Underground trajectory of the NuMI neutrino beam from Fermilab to Soudan.

2. Physics Goals

Neutrinos and the Standard Model

Neutrinos are the most enigmatic of the basic building blocks of the universe. The three species (or flavors) of neutrinos: electron, muon, and tau, account for three of the 12 fundamental constituents of matter. Neutrinos are hence fundamental. In addition, they are all around us as relics of the Big Bang; they are produced in the sun and in cosmic rays; they carry away the bulk of the energy released in a supernova explosion. They are far less well understood, however, than the other fundamental particles. We know that neutrinos interact only via the weak force and thus propagate through matter with only minimum attenuation. Their intrinsic angular momentum is determined to be 1/2 and is always left-handed with respect to the linear momentum. We do not know if neutrinos have mass and we do not know if they are stable; aside from the fact that they are electrically neutral, we know little about their electromagnetic properties.

The Standard Model requires that the masses of neutrinos be zero but that requirement is *ad hoc* and not based on any fundamental principle, as is, for example, the fact that the photon is massless. A nonzero neutrino mass is thus a theoretical possibility and its experimental demonstration would be the first known departure from the Standard Model, and might provide clues to a more complete theory that must exist beyond it.

As an added bonus, neutrinos with nonzero mass could contribute to the solution of a central question in the field of astrophysics. Observations of gravitational effects in galaxies indicate that they contain much more mass than can be seen directly. The nature of this dark matter, as it is called, is still unknown and massive neutrinos might account for at least part of it.

Neutrino Oscillations

Experimentally we know that neutrino masses are small, probably well below the masses of other elementary particles. Direct mass measurements are very difficult and probably cannot be pushed to much better sensitivity than currently achieved. Thus new techniques must be brought to bear on the question of neutrino mass; the most promising of these appears to be the search for neutrino oscillations.

The phenomenon of neutrino oscillations allows neutrinos of one species (flavor) to slowly transform into another flavor as they propagate through space or matter. Thus, if oscillations exist, a pure beam of muon neutrinos created at an accelerator can develop admixtures of electron neutrinos and tau neutrinos some distance away. This phenomenon is called oscillations rather than transmutation because the newly created flavors will later transform themselves back to muon neutrinos, a quantum-mechanical process repeated again and again in an ongoing cycle. A necessary condition for the existence of oscillations is that neutrinos have mass; thus observation of neutrino oscillations is a definitive proof that they are not massless. The following sections discuss how quantitative information about neutrino masses can be obtained from experiments.

Solar and Atmospheric Neutrinos

It is not only the theoretical possibility of massive neutrinos that provides the impetus to searches for neutrino oscillations. There exist now a number of strong experimental indications that neutrinos do indeed oscillate. The most convincing of these come from the studies of solar and atmospheric neutrinos. Our sun is a gigantic fusion reactor, which converts protons into helium via the proton-proton chain. In this process unstable nuclei are created, which disintegrate by β-decay to produce electron-type neutrinos.[4] In this process energy is released, some of it through the emission of neutrinos in the energy range of several Mega-electron volts (MeV) and below. The exact number of neutrinos that should reach our earth can be predicted from the total electromagnetic energy we receive from the sun. The energy spectrum of these neutrinos is also predictable but with a few *caveats*. Over the last three decades a number of very difficult but elegant experiments have been performed to observe solar neutrinos on earth.[5,6,7,8] The conclusion is that there is a deficit; that is, fewer neutrinos are observed than one would expect from the predictions. Furthermore, this deficit may be energy dependent. Oscillations are an attractive explanation because muon neutrinos or tau neutrinos in the MeV energy range would not have enough energy to create their corresponding charged leptons, muon or tau, and hence would not be detected directly. Thus an apparent deficit of interactions would be observed.

The other and presently stronger evidence comes from the study of neutrinos created in the atmosphere. Our earth is constantly bombarded by energetic particles (protons and heavier nuclei) coming from all directions. As they strike our atmosphere, they interact with the nuclei therein, creating showers of mesons, mainly pions. These quickly decay, typically into a muon and a muon neutrino. Many of the muons also decay, into an electron, an electron neutrino, and a muon neutrino. Thus each pion decay should result in two muon neutrinos and one electron neutrino striking the earth. During the last decade, a number of experiments have been constructed underground which can observe and measure properties of these neutrinos. Their results lead to the conclusion that there is a deficit of muon neutrinos. The magnitude of the deficit observed in the Super-Kamiokande (Super-K) experiment appears to depend on the original direction of the neutrinos and hence the path length over which they traveled. An attractive explanation, which explains all of the data within their uncertainties, is the oscillation of muon neutrinos into tau neutrinos. The energy of atmospheric neutrinos is typically too low to create a tau lepton and thus tau neutrinos produced through oscillations will not be seen directly. There is also evidence for neutrino oscillations from an accelerator experiment at Los Alamos. This evidence, however, is more controversial, and still awaits confirmation by other experiments.

If all three pieces of evidence hold up, then the Standard Model cannot be modified by merely giving neutrinos mass; another (fourth) species of neutrinos must exist. To be compatible with other experimental data, neutrinos of this species must be completely inert and hence are named sterile neutrinos. Sterile neutrinos would not be able to interact in any way regardless of their energy. Some of the solar or atmospheric neutrino oscillations could then be into sterile neutrinos. Accommodation of sterile neutrinos would require a substantial modification of the Standard Model.

The MINOS Experiment

There is continuing experimental work going on in all three areas mentioned above, aiming to elucidate further these interesting observations. But those experiments, especially the ones on solar and atmospheric neutrinos, have basic limitations resulting from their limited ability to control experimental conditions. The flavors, intensities, and energy spectra of solar and atmospheric neutrinos are fixed by nature. They cannot be modified so as to optimize the investigations. To achieve such ideal and controllable conditions we need to perform accelerator experiments.

In a two-flavor approximation, the probability for a neutrino oscillation is given by the expression

$$P = \sin^2(2\theta)\sin^2\left(1.27\frac{\Delta m^2 L}{E}\right).$$

Here θ is the mixing angle between the two neutrino mass states, Δm^2 is the difference between the squares of the masses $(\mathrm{eV})^2$, L is the distance traveled (km) and E is the neutrino energy (GeV). The parameters $\sin^2(2\theta)$ and Δm^2 must be determined by experiment and the range of possible values for them is referred to as the parameter space for neutrino oscillations. The characteristic length scale over which the oscillations occur is inversely proportional to Δm^2. The oscillation parameters suggested by the solar neutrino deficit are such that extremely long distances are needed to observe oscillations. Thus it is difficult to investigate this problem through terrestrial experiments.

On the other hand, the atmospheric neutrino anomaly can be studied with suitably designed accelerator experiments, and the MINOS experiment focuses on this. *L* is firmly established by locating the MINOS far detector at Soudan and *E* is constrained to be within a certain range by the NuMI primary beam energy.

Currently the best and most extensive data on atmospheric neutrinos come from the Super-K experiment in Japan.[9] Because of the intrinsic limitations of such an experiment, it can only delineate roughly the possible values of oscillation parameters. Thus, for example, the suggested value of Δm^2 is only known within a factor of four at the 90% confidence level. Other experiments on atmospheric neutrinos (Soudan 2, Kamiokande) indicate values of Δm^2 somewhat higher but not incompatible with the Super-K result. Figure 5 shows the expected sensitivity in parameter space of the MINOS experiment for several energy configurations of the NuMI beam (adjustable beam energies for NuMI are described in Chapter 3).

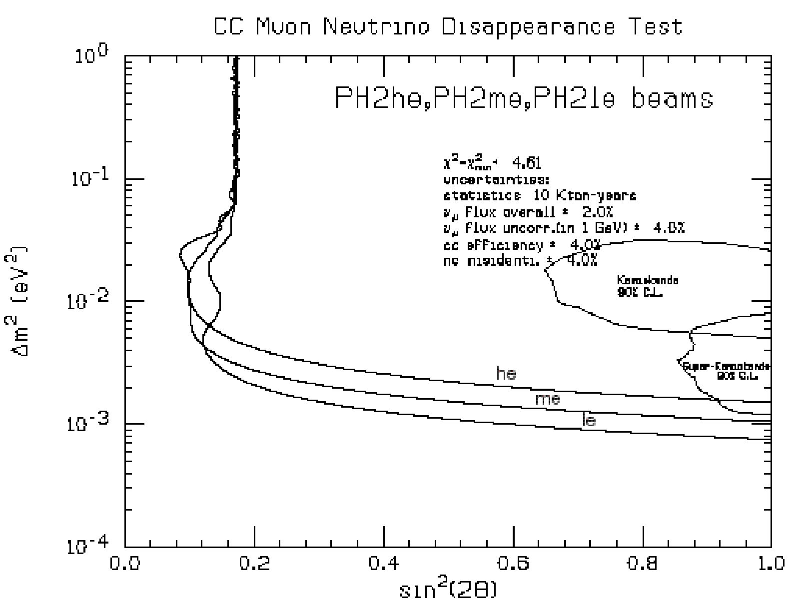

Figure 5 Search limits in neutrino oscillation parameter space. The three curves define the Monte Carlo exclusion regions for the NuMI high-energy, medium-energy and low-energy beams with two parabolic horns. The Super-Kamiokande region is based on results presented in April 1999.

It is the goal of the MINOS experiment to cover the full region of parameter space allowed by the experiments to date, as illustrated in Figure 5. MINOS is designed not only to be able to verify the existence of oscillations unequivocally (if indeed they exist) but also to perform a full set of relevant measurements. Thus MINOS will be able to determine the principal oscillation mode (e.g., $\nu_\mu \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_{sterile}$), the mass squared differences (Δm^2), and the strength of oscillations ($\sin^2 2\theta$) both for the principal as well as other minor modes. Furthermore, sufficient redundancy exists so that two or more alternative measurements can address the same question, thus reducing the impact of systematic errors. In addition, MINOS will be able to study the energy spectrum in some detail, allowing one to make a distinction between the oscillation hypothesis and other, more exotic, possibilities such as neutrino decay or extra dimensions.

Other Long Baseline Experiments

MINOS is not the only experimental effort to address the question of the atmospheric neutrino anomaly. Because of the importance of this issue, several other groups are also focusing on this question. Both the Super-K and Soudan 2 experiments will continue to take data on atmospheric neutrinos, increasing their statistics and refining their analyses. On the other hand, for reasons such as those mentioned above, there are intrinsic systematic limitations as to how well these kinds of experiments can pinpoint the oscillation parameters.

The Japanese high energy physics laboratory, KEK, is sending a neutrino beam from the KEK 12 GeV accelerator to the Super-K detector, some 250 km away, to see if neutrinos will have oscillated while traversing this path. This experiment, known as K2K, began taking data in March 1999 and plans to run for the next several years. Their operational goal is to achieve 10^{20} protons on target. Neutrinos originating at KEK have been observed in the Super-K detector, thus demonstrating the feasibility of long-baseline neutrino experiments.[10] However, K2K is limited relative to MINOS in two ways: its lower beam intensity limits K2K's statistical precision and its energy and baseline limit K2K's ability to explore small values of Δm^2. During the past year, K2K has observed 27 accelerator-produced neutrino interactions in their fiducial volume, with 40 expected under a hypothesis of no neutrino oscillations.

There is also an intensive planning effort in Europe for a neutrino oscillation program using a neutrino beam from CERN in Geneva to the Gran Sasso Laboratory in Italy, focusing on the detection of tau neutrinos. The 730 km distance is essentially the same as the MINOS neutrino flight path. The European experimental program is planned to start in 2005, more than a year after the anticipated start of the MINOS experiment.

3. Overview of the MINOS Experiment

The MINOS experiment has been designed to explore a large area in neutrino oscillation parameter space, as indicated in Figure 5. It is optimized for the range of oscillation parameters that are suggested by the current and past generations of underground experiments studying atmospheric neutrinos. Therefore, one must study the interactions of a neutrino beam after it has traversed a very long flight path. This in turn requires an intense neutrino beam and a massive detector.

A main design goal of MINOS is to explore the region suggested by the Super-K experiment. The characteristic length over which oscillations occur is proportional to the neutrino energy, E_ν, and inversely proportional to the mass squared difference, Δm^2. To have a sizable oscillation effect, the neutrino source to detector distance, L, should not be much less than this oscillation length. Since L cannot be changed once the detector is constructed and the Δm^2 range suggested by existing experiments is uncertain by about an order of magnitude, we must have the capability of varying the energy of the neutrino beam by the same factor in order to cover the full region of interest.

The site of the principal MINOS detector is the Soudan mine in northern Minnesota, about 735 km away from Fermilab. This site choice was dictated by a number of factors:

- the underground location reduces the spurious backgrounds and also allows the study of atmospheric neutrinos;
- the distance is fairly well matched to the oscillation parameters suggested by atmospheric neutrino experiments and the energy of neutrinos available from the Main Injector at Fermilab;
- there is now an established tradition of scientific cooperation with the Department of Natural Resources (DNR) of the State of Minnesota which operates the Soudan mine;
- the DNR is providing the infrastructure necessary to do the experiment in Soudan;
- the State of Minnesota is providing some of the financial resources to modify the existing underground facilities for MINOS;
- the existing Soudan 2 detector could provide additional measurements, complementary to those from the main MINOS detector.

The source of the neutrinos is the new Main Injector accelerator at Fermilab. The Main Injector is ideally suited for exploration of the neutrino oscillation parameters in the region of interest. The energy of the Main Injector is such as to be able to provide a large flux of neutrinos in the most interesting energy range: 1 to 16 GeV. This energy band, coupled with the Fermilab to Soudan distance, is well matched to the investigation of the indicated Δm^2 range.

The NuMI Facility

The Main Injector is a very high intensity proton accelerator that can provide an adequate neutrino event rate even in a detector 735 km away. Furthermore, the anticipated mode of operation of the Main Injector during the next decade is ideally suited to the NuMI Project. The accelerator will have to operate a significant fraction of the time to produce antiprotons for $\bar{p} - p$ collisions in the Tevatron. Only one of six bunches will be used for antiproton production, the other five being available for stationary target experiments such as MINOS. Furthermore, the Main Injector is a relatively conventional proton synchrotron so there is a high likelihood that its intensity will increase with time and thus experiments with higher statistics and better sensitivity will be possible in the future.

The production of the neutrino beam occurs in two stages. First the 120 GeV proton beam from the Main Injector is directed, by either single-turn or resonant (100 turn) extraction, into the NuMI beamline. There it is focused onto a segmented target, producing secondary mesons, both pions and kaons. Because we want to aim the neutrino beam at the Soudan Underground Laboratory, the proton beam will be directed downward at 58 mrad before it strikes the target. Subsequently, forward-going particles of interest (mesons) are focused and allowed to decay, producing neutrinos. The focusing is performed by a set of two magnetic horns. These devices are shaped in such a way that, when a pulse of current passes through them, a magnetic field is generated which focuses particles in the desired momentum range over a wide range of production angles. The average meson energy is selected by adjusting electrical currents in the horns and the horn and target locations along the beamline. Thus, this “zoom” beam design allows the energy of the meson beam (and therefore of the neutrino beam) to be varied during the course of the experiment.

The particles selected by the focusing horns (mainly pions with a residue of the uninteracted protons) are then allowed to propagate down an evacuated beam pipe (decay tunnel), 1 m in radius and 675 m long, placed in a tunnel, also pointing downward towards Soudan. While traversing the beam pipe, a significant fraction of pions decay, yielding forward-going neutrinos with energy equal to approximately 40% that of the parent pion. Studies on a method to improve the beam’s focus by means of a current-carrying wire (“hadronic hose”) have been completed.[11] By adjusting the energy of the parent pion beam, a neutrino beam in the desired energy range can be obtained. As mentioned above, this feature is crucial to our ability to explore experimentally a wide range of possible oscillation parameters. A hadron absorber is placed at the end of the decay pipe to remove the residual flux of protons and mesons.

The MINOS Detectors

To reduce systematic errors as much as possible, MINOS compares the types, rates and energy spectra of neutrinos which interact in two detectors: one located at Fermilab, the other one at Soudan. As shown in Figure 1, the Fermilab detector location is about 290 m downstream of the hadron absorber in a newly excavated experimental hall. This location is far enough downstream so that all the muons produced from pion decays in the beam pipe are stopped in the intermediate rock. The detector at Fermilab measures the properties of the neutrino beam before there is any significant probability of oscillations occurring. The two detectors are made as similar as practicable in order to minimize signal differences due to spurious instrumental effects.

The MINOS detectors are iron/scintillator sampling calorimeters, significantly larger and more fine-grained than detectors used in previous neutrino calorimetry experiments. The MINOS far detector has a total mass of 5,400 metric tons, equally divided between two supermodules. Each supermodule is composed of 243 octagonal steel plates, 8 m wide and 2.54 cm thick, interspersed with layers of plastic scintillator. A current carrying coil is provided for each supermodule to generate a toroidal magnetic field of about 1.3 Tesla at a radius of 2 m.

Mounted on each steel plate is a plane of 192 scintillator strips, each one 4 cm wide and up to 8 m in length. The orientation of the arrays of parallel strips is rotated by 90° in successive planes to provide two coordinate measurements. The scintillator is produced by a commercial extrusion process, during which a thin reflective layer is co-extruded on the surface of each strip. The readout is performed via wavelength shifting fibers, glued in a groove on the surface of each strip. As a charged particle passes through scintillator it causes the emission of ultraviolet and blue light. Some of this light enters the wavelength shifting fibers where it is absorbed and re-emitted as green light. A fraction of the green light in turn is trapped through internal reflection in the fiber and propagates to the two ends where it is detected by segmented, position-sensitive photodetectors.

The currently existing detector, Soudan 2, may also be used to record the interactions of neutrinos from the NuMI beam. Its mass is about 1 kiloton and its fine granularity would allow us to make some measurements that are difficult in the coarser-grained MINOS detectors.

The MINOS near detector at Fermilab has a mass of about 1 kiloton, and to a good approximation is a less massive version of the far detector. Only interactions of the very central part of the beam (about 25 cm radius) are used for the near/far comparison of neutrino interaction rates and types, because that part of the beam has an energy spectrum very similar to that expected at the far detector if neutrino oscillations do not occur. The geometric center of the near detector is offset about 1.5 m from the beam centerline to keep the central part of the neutrino beam away from the magnet coil region.

In addition to accelerator-produced neutrinos, the MINOS far detector also will be able to detect atmospheric neutrinos. Although the MINOS far detector is considerably smaller than the Super-K detector, it has the capability to measure muon charge and momentum, which allows it to make some complementary (and unique) measurements of atmospheric neutrinos. If Δm^2 should be at the very low end of the currently allowed range, the atmospheric neutrino measurements in MINOS will have comparable sensitivity to the accelerator measurements.

Future Options

In designing the NuMI Project, we have tried to maintain maximum flexibility so as to be able to react to new developments in the rapidly developing fields of neutrino physics and detector technology. The "zoom" neutrino beam design, which allows us to choose the optimum neutrino beam energy to match a given Δm^2 value, is one example of such flexibility. Another possible beam improvement is the hadronic hose, which would make the beam energy spectrum more similar at the near and far detectors.

The new cavern at Soudan is larger than is required for the two supermodules. The extra space will be used initially to facilitate the detector assembly but could be used subsequently to enlarge the detector by adding another supermodule or ancillary detector, should the physics warrant it and the financial situation allow it.

4. Technical Scope

In this Chapter we define the technical scope of the NuMI Project in terms of its principal Work Breakdown Structure (WBS) elements, which are described in tabular form to Level 3. Where appropriate, Level 3 Project Managers are listed in the tables. Figure 9 shows an overview of the NuMI Project WBS at Level 2. It includes the names of the Level 2 Project Managers.

Additional tables in this Chapter give the most important parameters of the major elements of the project. The considerations that have gone into choosing these parameters have been discussed in the previous two chapters. In general, the values of the technical parameters represent real-world tradeoffs between higher performance and budget constraints.

The NuMI Facility at Fermilab (WBS 1.0) – D. Bogert

This subproject is comprised of two Level 2 components. These are the technical components of the neutrino beamline and the civil construction of the facilities to house and support it.

Neutrino Beamline Technical Components (WBS 1.1) - J. Hylen

The technical scope of this component of the project is laid out in Table 1. In the event that the hadronic hose option[12] is approved, it will be added as WBS element 1.1.9. Key parameters of the beamline are listed in Table 2.

WBS	Subtask	Description	Manager
1.1.1	Primary Beam	Extraction and transport of 120 GeV proton beam from the Main Injector to the NuMI Target	P. Lucas
1.1.2	Neutrino Beam Devices	Production and focusing the secondary beam from the NuMI target through the focusing horns	K. Anderson
1.1.3	Power Supply Systems	Power supplies, cables and connections for NuMI beamline elements	N. Grossman
1.1.4	Decay Region & Hadron Absorber	Decay pipe for neutrino-producing decays of mesons, absorber for non-decaying particles, and associated radiation shielding	A. Wehmann
1.1.5	Neutrino Beam Monitoring	Measurement of flux and profiles of secondary beam and muons	D. Harris
1.1.6	Survey, Alignment & Geodesy	Accurate determination of the neutrino beam centerline at Fermilab and Soudan	W. Smart
1.1.7	Beamline Utilities	Water, vacuum and gas systems	D. Pushka
1.1.8	Systems Integration & Installation	Technical integration, installation coordination, and provision of common services	S. Childress

Table 1 Technical components of the NuMI beamline (WBS 1.1)

Downward slope of ν beam		58 mrad (3.3°)
Proton intensity		4×10^{13} p/1.9 sec
Spill length		1 msec or 8 μsec
Protons per year		3.7×10^{20}
Target material		Graphite
Pion focusing		Wide band, 2 horn
Neutrino Energy Options		
Baseline	Low Energy	2 -4 GeV
Option 1	Medium energy	4 -8 GeV
Option 2	High energy	8 - 16 GeV
Decay pipe		1 m radius × 675 m long
Muon absorber for MINOS		240 m of dolomite
Muon monitoring		Ion chambers installed in 3 alcoves in the dolomite shield

Table 2 Parameters for the NuMI beamline.

Civil construction at Fermilab (WBS 1.2) - C. Laughton

The major elements of the civil construction at Fermilab (WBS 1.2) are listed in Table 3. The excavation described is being performed by the S. A. Healy Company of Lombard, Illinois.

Subtask	Description
Stub Extension w/Carrier Pipe Tunnel	Enclosure for pipe to bring protons from the Main Injector to the NuMI primary beam elements
Pre-Target Tunnel	Tunnel enclosure to house NuMI primary beam elements
Target Enclosure	Underground hall to house neutrino beam elements (target, horns & upstream hadron monitor)
Upstream Service Building	Building on surface to provide access and services to upstream areas
Upstream Access Shaft	Shaft to access Target Hall; includes power supply room and connector tunnel
Decay Tunnel	Underground tunnel to allow secondary mesons to decay in flight, producing neutrinos
Absorber Enclosure	Underground enclosure for the hadron absorber, downstream hadron monitor, and 1st muon monitor
Downstream Service Building	Building on surface to provide access and services to downstream areas

Downstream Access Shaft	Shaft near hadron absorber to access downstream NuMI areas, including the muon alcoves and the experimental hall
MINOS Access Tunnel	Underground corridor (offset from neutrino/muon flight path) from the downstream shaft to the experimental hall housing the MINOS near detector
Muon Alcoves	Three short tunnels transverse to the beamline from the MINOS Access Tunnel into the neutrino/muon beam to house beam monitoring devices
Experimental Hall	Underground hall to house the MINOS near detector

Table 3 Civil construction of the NuMI Project at Fermilab.

MINOS Detectors (WBS 2.0) – A. Byon-Wagner

The detectors for the MINOS experiment (Fermilab E875) are included in the baseline for the NuMI Project as element 2.0 of the WBS. The following sections describe to Level 3 the technical scope of this subproject.

Magnets: Steel and Coils (WBS 2.1) - J. Kilmer, J. Nelson

Most of the mass of the MINOS detectors is comprised of steel plates that are suspended vertically and are toroidally magnetized. These provide mechanical support for the scintillator planes as well as a massive target for neutrino interactions. The scope of this subtask is defined in Table 4.

WBS	Subtask	Description
2.1.1	Steel Plane Fabrication	Purchase of steel plates for far and near detectors
2.1.2	Steel Handling Fixtures	Design and fabrication of strongbacks for steel plane assembly
2.1.3	Near Detector Support Structure	Design and fabrication of structure to support and access the near detector and ancillary equipment
2.1.4	Magnet Coils	Design and fabrication of near and far detector magnet coils
2.1.5	Detector Plane Prototypes	Fabrication and study of prototype steel and detector planes to validate design, check installation time estimates, and train assembly crews

Table 4 Subtasks for the manufacture of the steel and magnet coils for the MINOS detectors.

Scintillator Detector Fabrication (WBS 2.2) - D. Michael

The active portions of the MINOS detectors will consist of planes of plastic scintillator coupled to photodetectors and readout electronics. The scope of this subtask is defined in Table 5. B. Baller and J. Thomas are deputy managers for this subtask.

WBS	Subtask	Description	Manager
2.2.1	Scintillator Strips	Scintillator extruded in long strips	A. Pla-Dalmau
2.2.2	Fibers	Wavelength-shifting fibers and clear optical fibers for light collection	B. Choudhary
2.2.3	Scintillator Modules	Assembly of scintillator panels (scintillator, fibers & manifold)	T. Chase
2.2.4	Photodetector Systems	Detectors which transform scintillator light to electronic signals	K. Lang
2.2.5	MUX Boxes & Connectors	Optical multiplexing boxes and fiber optics connectors	S. Mufson
2.2.6	Calibration Systems	Systems to calibrate responses of near and far detectors	P. Harris
2.2.7	Assembly and Testing Equipment	Machines for preparing scintillator module components for assembly	V. Guarino
2.2.8	Module Factories	Facilities for scintillator module assembly	J. Grudzinski
2.2.9	Management	Salary support for WBS Level 3 Manager engineers, and travel support for Level 2 and Level 3 Managers	D. Michael
2.2.10	Scintillator Installation	Facilitate organization of scintillator installation effort	R. Webb

Table 5 Subtasks for the scintillator detector fabrication.

Electronics and Data Acquisition (WBS 2.3) – G. Pearce, J. Thron

The electronics and data acquisition (DAQ) systems digitize the electronic signals from the photodetectors (PMTs) and select data of interest for mass storage and physics analysis. The database that maintains permanent records of the construction, installation, calibration and history of the MINOS experiment is also included in this subtask. The technical scope of this subtask is defined in Table 6.

WBS	Subtask	Description	Manager
2.3.1	Near Front Ends	Electronics assemblies to control and digitize data from PMTs for Near Detector	G. Drake
2.3.2	Far Front Ends	Electronics assemblies to control and digitize data from PMTs for Far Detector	J. Oliver
2.3.3	Data Routing, Central System and Triggering	Electronics to collect data from front ends and route it to the processor farm for data selection through software triggers	S. Madani
2.3.4	Data Acquisition	Electronics to collect data from trigger farm processors for offline storage	G. Pearce
2.3.5	Database	Software system to maintain a record of the construction, operation and calibration of the detectors for use in offline data analysis	P. Border
2.3.6	Clock & Distribution System	Systems to provide absolute timing via GPS, internal clock system	A. Weber
2.3.7	Management	Travel support for L2 & L3 Managers	J. Thron
2.3.8	Slow Control and Monitoring	Systems to provide monitoring and control for nonelectronic detector components	M. Marshak
2.3.9	HV System	System to provide high voltage for PMTs	R. Webb

Table 6 Subtasks for the MINOS electronics and DAQ systems.

Far Detector Installation (WBS 2.4) - D. Ayres, W. Miller

This subtask includes the installation of the MINOS far detector and its associated infrastructure in the new underground laboratory at Soudan. The WBS is outlined in Table 7.

WBS	Subtask	Description
2.4.1	Completed Design Tasks	Completed tasks in FY98 - FY00
2.4.2	Minecrew Management	Salary for Soudan Coordinator and administrative assistant
2.4.3	MINOS Construction Oversight	Salary for mine crew coordinators during the Soudan facility construction
2.4.4	Soudan Lab Infrastructure	M&S and labor needed for infrastructure setup of detector installation

2.4.5	Detector Installation	Labor for detector installation, including handling and detector assembly and testing
2.4.6	DNR Costs	Hoist charges and hoist operator labor
2.4.7	Survey & Alignment	Measurement and recording of the location of the detector and the internal positions of its components

Table 7 Subtasks of the installation of the MINOS far detector.

Near Detector Installation (WBS 2.5) - C. James, R. Plunkett

This subtask includes the installation of the MINOS near detector and its associated infrastructure in the new underground experimental hall at Fermilab. The WBS is outlined in Table 8. Key parameters of the MINOS detectors are listed in Table 9 - Table 11.

WBS	Subtask	Description
2.5.1	Infrastructure	Installation of near detector support structure, magnet power supply and DAQ room; Coordination with construction of experimental hall at Fermilab
2.5.2	Plane Assembly	Management and transport of detector materials; Assembly and mounting of steel and scintillator planes above ground
2.5.3	Detector Installation	Management and transport of assembled detector planes to Near Detector Hall; Installation of planes and electronics; Survey and alignment of detector underground

Table 8 Subtasks of the installation of the MINOS near detector.

The following tables list key parameters of the baseline MINOS detectors.

Total mass	5400 tons
Fiducial mass	3300 tons
Cross section	8 m octagon
Total number of steel plates	486
Number of Supermodules	2
Photodetector	Hamamatsu 16 pixel R5900 u

Table 9 Parameters of the MINOS Far Detector.

Total mass	980 tons
Target mass	100 tons
Cross section	4.8 m W × 3.8 m H
Number of steel plates	282
Photodetector	Hamamatsu 64 pixel R5900 u

Table 10 Parameters of the MINOS Near Detector.

Steel composition	Low carbon AISI 1006
Steel plate thickness	2.54 cm
Typical steel magnetization	1.3 Tesla
Scintillator plastic	Extruded polystyrene
Scintillator thickness	1.0 cm
WLS fiber diameter	1.2 mm

Table 11 Parameters common to the MINOS Near and Far Detectors

Project Support (WBS 3.0) – D. Bogert

This section addresses WBS elements 3.1 – 3.4 of the NuMI Project. WBS 3.1, the conceptual design, is now complete. It provided support for Fermilab to develop the NuMI conceptual designs.[13,14] WBS 3.2, Detector Research and Development, is also complete. It supported the work by the MINOS Collaboration that formed the basis of certain detector technology choices, particularly those concerning the active detectors and the steel planes. WBS 3.3 includes the construction and outfitting of the MINOS Far Detector Laboratory and is fully described in the MINOS Far Detector Laboratory Technical Design Report[3]. This subproject is summarized in Table 12. Element 3.4 includes certain operating costs at the Soudan Underground Laboratory. Earl Peterson is the Soudan Laboratory Manager and serves in this capacity as manager of both the WBS 3.3 and 3.4 tasks.

WBS	Subtask	Description
3.3.1	Cavern Construction	Construction of new cavern at Soudan to house the MINOS far detector
3.3.2	Cavern Outfitting	Ventilation, utilities and ancillary rooms for MINOS cavern
3.3.3	Detector Outfitting	Utilities and materials handling systems for MINOS far detector

Table 12 Subtasks for construction and outfitting at the Soudan Underground Laboratory.

WBS	Subtask	Description
3.4.1	Soudan Minecrew Support	Operation of base facility at Soudan Underground Lab
3.4.2	Breitung Township Building	Surface facility for materials handling

Table 13 Subtasks for facility operations at the Soudan Underground Laboratory.

Distance from neutrino source	735 km
Depth below surface	710 m
Laboratory dimensions	82 m L × 15 m W × 14 m H
Detector space	For 3 supermodules plus possible ancillary detector

Table 14 Technical parameters of the MINOS far detector hall.

5. Cost and Schedule

Table 15 shows the planned DOE and Fermilab funding profiles for the entire NuMI Project as of April 2000. The Total Estimated Cost (TEC) includes the technical components (WBS 1.1) and civil construction (WBS 1.2) for the NuMI beamline, but not the construction of MINOS detectors (WBS 2.0) or the civil construction work at Soudan (WBS 3.3). These last two subprojects are funded as Other Project Costs (OPC).

	Prior Fys (actual)	FY 98 (actual)	FY 99 (actual)	FY 00 (actual)	FY 01 (current)	FY 02 (plan)	FY 03 (plan)	Total
TEC	0	5,500	14,300	22,000	23,000	11,400	0	76,200
OPC	1,417	2,348	4,114	11,324	14,062	14,885	15,092*	63,242*
Total	1,417	7,848	18,414	32,386	38,000	26,285	15,092	139,442

Table 15 DOE funding profile by fiscal year (in thousands of then-year dollars).

* As first reported in the March 2000 Monthly Report, this includes "standing army effect" to account for inefficiencies in staff utilization. Numbers also include impact of inflation addition of Project Management for FY03 and two quarters in FY04.

Figure 6 shows a cost breakdown for the major WBS elements of the project. Note that Figure 6 also shows funding for the NuMI Project that is being provided by the State of Minnesota and by the United Kingdom.

Figure 7 summarizes the schedule that corresponds to the funding profile in Table 15. A key feature of this schedule was the early emphasis on civil construction work in FY 1999 and FY 2000. In FY 2001 and FY 2002, our emphasis will shift to the fabrication and installation of technical components. Our target date for the first NuMI neutrino events to be detected is October 2003.

During the later years of the project, we may propose an upgrade of the far detector (by adding a third supermodule and/or an ancillary detector) or possibly of the neutrino beam (by building the components for a narrow band beam). The possibility of upgrading the beam by using the hadronic hose is presently under consideration. Our upgrade plans will depend upon developments in neutrino oscillation physics during the next two years, as well as upon the availability of funds.

NuMI COST ESTIMATE ($000's Omitted)

WBS	System or Item	Cost In
	Total Project Cost (TPC)	**$136,100**
1.0	**Total Estimated Cost (TEC)**	**$76,200**

	Contingency (on 1.1, 1.2, 1.3)		$2,863
1.1		**Technical Components**	**$18,541**
	1.1.1	Extraction and Primary Beam	$2,390
	1.1.2	Neutrino Beam Devices	$7,036
	1.1.3	Power Supply System	$2,750
	1.1.4	Hadron Decay and Absorber	$925
	1.1.5	Neutrino Beam Monitoring	$535
	1.1.6	Alignment Systems	$582
	1.1.7	Water, Vacuum and Gas System	$1,539
	1.1.8	Installation and Integration	$2,784
1.2		Facility	$51,971
	1.2.2	Facility Construction Title I	$1,774
	1.2.3	Facility Construction Title II	$3,597
	1.2.4	Facility Construction Phase	$46,600
1.3		**Project Management**	**$2,825**
		Total U.S. Other Project Costs (OPC)-2.0&3.0	$59,900
	Contingency on 2.0&3.0		$7,373
2.0		**MINOS Detector Cost (U.S.)**	**$37,401**
2.1		Magnet: Steel & Coils	$7,497
2.2		Scintillator Detector Fabrication	$18,665
2.3		Electronics & DAQ	$7,016
2.4		Far Detector Installation	$5,574
2.5		Near Detector Installation	$2,389
2.6		Project Management	$1,532
		UK In-Kind Contributions (w/o Contingency)	($5,272)
3.0		**Project Support**	**$15,126**
3.1		NuMI Conceptual Design (Complete)	$1,869
3.2		Detector R&D (Complete)	$1,780
3.3		Soudan Laboratory Construction	$9,928
	3.3.0	Preconstruction Work (3.3.0.1 to 3.3.0.5)	$758
	Minnesota funds for Pre-Constr. (applied to 3.3.0)		($758)
	3.3.1	Cavern Construction	$6,714
	3.3.2	Cavern Outfitting	$2,812
	3.3.3	Detector Outfitting	$3,288
	3.3.4	Breitung Township Building	$114
	Minnesota FY99 Fund (applied to 3.3.1)		($3,000)
3.4		Soudan/MINOS Operating	$1,550

Figure 6 Baseline costs by WBS element in then-year dollars as of September 30, 2000.

Figure 7 Project master schedule for September 2000

6. Management

This chapter provides a summary of the NuMI Project management process that is defined in both the NuMI Project Execution Plan[15] (PEP) and the NuMI Project Management Plan (PMP).[16] The PEP describes the DOE management structure, resource plan and baselines against which DOE measures execution of the project. The PMP describes the organizational structure and management systems that Fermilab employs in execution of the project.

Project Management Overview

The multi-faceted nature of the NuMI Project dictates a management structure that is flexible enough to meet the requirements of the different subtasks. The project management responsibilities also reflect the project's budget structure (both TEC and OPC), which is described in the preceding chapter.

Specific roles of collaborating institutions are detailed in Memoranda of Understanding (MOU). Civil construction at the Soudan Underground Laboratory site is being performed by the University of Minnesota under an MOU agreement. The principal lines of responsibility for Fermilab's management of the NuMI Project, including tasks carried out by MINOS collaborators are shown in Figure 8.

Figure 9 shows the WBS structure of the NuMI Project to level 2. Work covered by the TEC (WBS 1.0) will be accomplished mainly by Fermilab personnel and subcontractors, with a relatively small amount of the work performed by other research institutions. By contrast, much of the work on the MINOS Subproject (WBS 2.0 and 3.0) will be accomplished by the various institutions of the MINOS Collaboration.

Another special MOU covers the UK-funded work to be carried out at UK institutions.

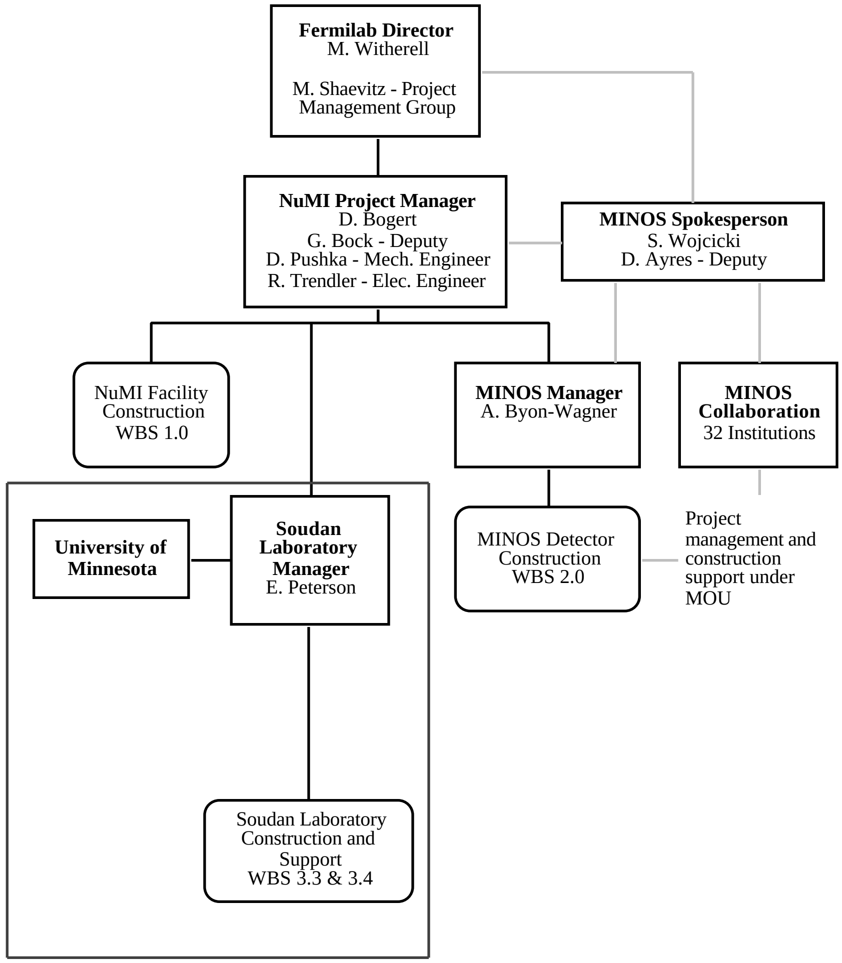

Figure 8 NuMI Project management structure. Solid lines indicate direct responsibility. Dotted lines indicate advisory functions. The boxes enclosed in the large square are the direct responsibility of the University of Minnesota. The round-edged boxes denote the three major subprojects.

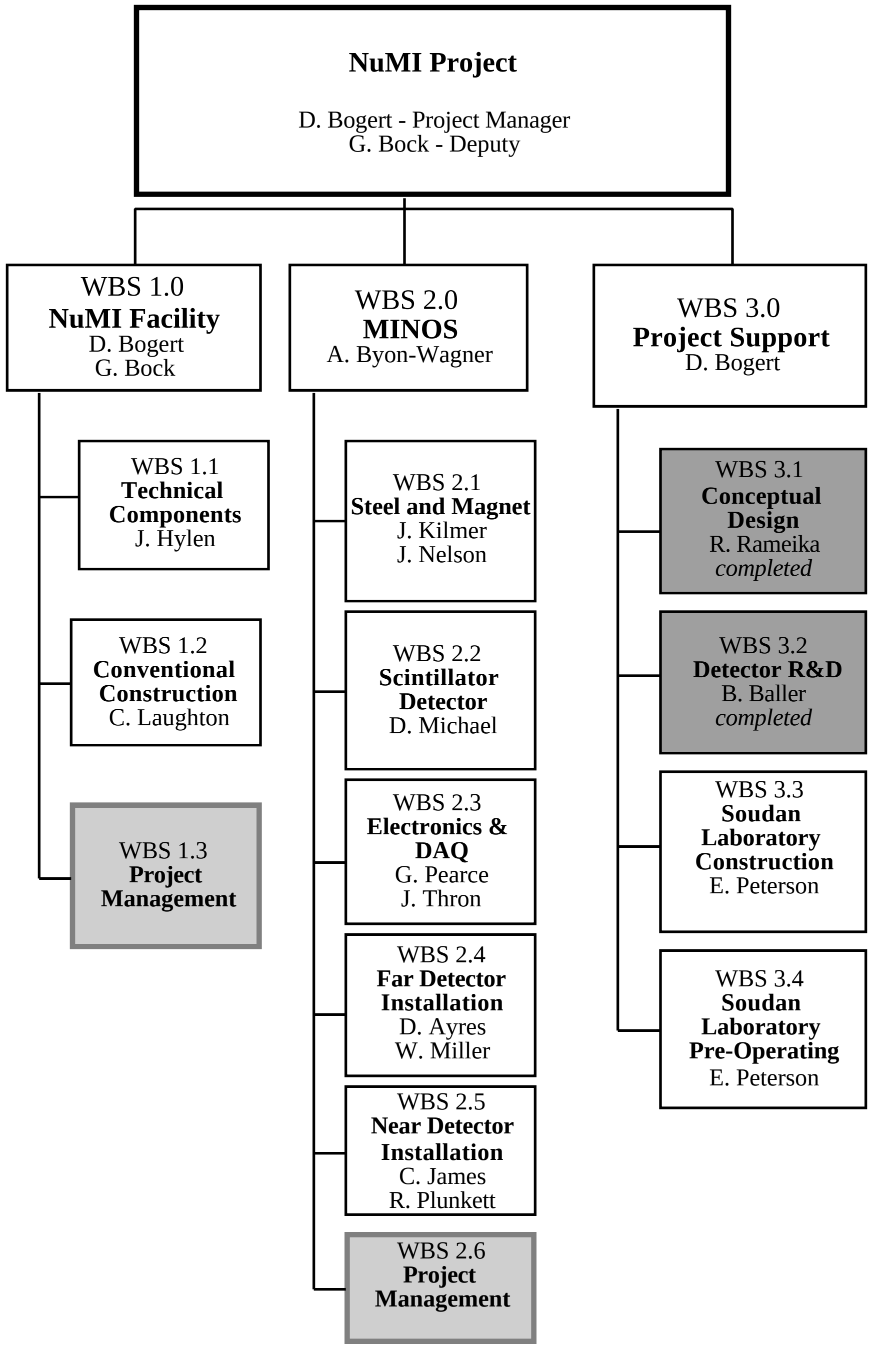

Figure 9 Work Breakdown Structure of the NuMI Project to Level 2.
Lightly shaded boxes indicate budget codes dedicated to management. Darkly shaded boxes indicate completed work.

Table 16 shows the current plan for the scintillator detector fabrication tasks to be carried out by MINOS collaborating institutions.

WBS	Task	Responsible Institutions
2.2.1	Scintillator Strips	Fermilab
2.2.2	Fiber	Caltech, Indiana, Texas-A&M, JMU, UK
2.2.3	Module design & prototype	Caltech, Minnesota, ANL, Fermilab, Tufts, Protvino
2.2.4	Photodetector Testing	Texas-Austin, UK, Athens
2.2.5	MUX boxes	Indiana, Tufts, UK, Texas-Austin, Protvino
2.2.6	Calibration systems	UK
2.2.7	Assembly & test equipment	ANL, Fermilab, Minnesota, Caltech
2.2.8	Module production	Caltech, Minnesota, ANL
2.2.10	Scintillator Installation	Texas A&M

Table 16 Current assignment of responsibilities for MINOS scintillator subsystems.

Project Controls

The major elements of the project controls system are baseline development, monitoring project performance and change control management.

Baseline development includes the actions necessary to define the scope of work, cost and schedule for the project. The scope of each Subproject is defined in the appropriate Technical Design Report. Each Subproject has a formal cost estimate and schedule, which is documented in the appropriate Cost and Schedule Plan. Baseline information is contained in the latest version of the approved documentation, databases and plans, which is regularly augmented by input from design reviews.

The official baseline for the NuMI Project was approved by the DOE Office of Science in February 1999. This approval followed a successful comprehensive peer review of the NuMI baseline in November 1998.

The principal functions of performance measurement are to identify, analyze and rectify significant deviations from the baseline as early as possible. A monthly earned value analysis is performed to assess the labor and fiscal resources expended and the work completed. This ensures that shortfalls that could lead to cost or schedule variances are identified so that appropriate actions can be taken.

The NuMI Project Management Group (PMG) is composed of key members of project and laboratory management, as described in the Project Management Plan, and serves as the baseline change control board. In this capacity, the PMG considers major changes to technical, cost and schedule baselines and recommends approval of them if appropriate. Changes are initiated through the submission of a Change Request by the task manager. As described in the NuMI PEP, DOE approval at an appropriate level is required for major baseline changes.

Fermilab provides monthly project reports to the DOE through the DOE Project Manager. Information in these reports includes:

- Project description
- Overview of project status
- Master schedule
- Funding summary
- Highlights of progress on major WBS elements
- ES&H highlights
- Cost reports
- Level 3 milestone status
- Variance analysis

Quality Assurance

Quality Assurance is an integral part of the design, procurement, fabrication, construction and installation of all aspects of the NuMI Project. The NuMI Quality Assurance Plan conforms to DOE guidance and Fermilab Director's Policy on Quality Assurance, issued in September 1999. Major acquisitions have specific QA plans, which may be included in Advance Acquisition Plans. These are included in the overall NuMI QA plan as attachments as they are developed.

Environment, Safety & Health

The design, construction, commissioning, operation, and de-commissioning of all NuMI systems is being done in compliance with the standards in the Fermilab ES&H Manual[17], and all applicable ES&H standards in the Laboratory's "Work Smart Standards". All related work is performed in compliance with applicable federal, state and local regulations.

There are three assigned NuMI Project staff positions for ES&H responsibilities. The NuMI ES&H Coordinator has the primary responsibility for preparing the NuMI Safety Assessment Document. The NuMI Radiation Safety Coordinator has the primary responsibility for preparing the shielding assessment. The NuMI Construction ES&H Coordinator is the primary interface between construction contractors and Fermilab for matters relating to ES&H in the construction of the NuMI Facilities at Fermilab. . The University of Minnesota is responsible for ES&H matters in the Soudan Laboratory. The current assignments to these positions are:

- NuMI ES&H Coordinator: D. Boehnlein
- NuMI Construction ES&H Coordinator: C. Laughton
- NuMI Radiation Safety Coordinator: N. Grossman
- Soudan Laboratory Safety Coordinator: J. Meier

The MINOS ES&H Review Committee, appointed by the Fermilab Particle Physics Division Head, conducts safety reviews of MINOS subsystems to ensure that they comply with Fermilab ES&H Standards. A similar committee, appointed by the Fermilab Beams Division, oversees safety reviews of work on NuMI beamline components

The NuMI Radiation Safety Advisory Committee is chaired by Kamran Vaziri of the Fermilab ES&H Section. In July 1999, the committee concluded that the NuMI project has identified all of the important radiological issues associated with the project and is using an acceptable methodology to mitigate them. The actual mitigation work is in progress. This committee will continue to meet on an as-needed basis to provide semi-formal reviews of NuMI radiation issues and shielding designs. The Fermilab ES&H Section is developing a plan for environmental monitoring during NuMI operations. Several key ES&H documents are listed in the references.[18,19,20,21]

7. The MINOS Collaboration

The MINOS Collaboration has grown substantially since its formation in 1994. The Collaboration currently consists of 32 institutions – 22 universities, 5 research institutes and 5 national laboratories – from China, Greece, Russia, the United Kingdom and the United States, with a membership of over 250 physicists, engineers, technical specialists and graduate students.

Collaboration institutions have laboratory facilities that are being used for the fabrication and assembly of MINOS detector components, as well as specialized software and equipment needed for mechanical and electronics engineering design and prototype construction. Collaboration members have extensive experience with the design and fabrication of the relevant types of instrumentation, including tracking calorimeters, scintillator detectors, photodetectors and electronics. Collaboration members have played important roles in past neutrino experiments at accelerators, including E594, CCFR, NuTeV and DONUT at Fermilab; CDHS, CHARM and NOMAD at CERN; and also in underground neutrino experiments, including MACRO, Soudan 2 and Super-K.

MINOS Organization

The MINOS Collaboration has adopted an organizational structure in which the ultimate authority rests with an Institutional Board (IB), consisting of one representative from each member institution. The IB admits new institutions to the collaboration, approves and maintains the MINOS Collaboration Bylaws,[22] and selects the MINOS Spokesperson. The Spokesperson is the executive manager of the Collaboration and serves a renewable three-year term. The Spokesperson is also the scientific representative of the Collaboration to Fermilab, to funding agencies and to the scientific community.

The MINOS Spokesperson provides the formal interface between the Collaboration and Fermilab through interactions with the Fermilab Director, the NuMI Project Manager and MINOS Manager. The NuMI Project Manager and MINOS Manager, who are usually members of the Collaboration, are appointed by the Fermilab management after consultation with the Collaboration. The MINOS Manager appoints the MINOS Detector WBS Level 2 Managers, who have formal responsibility for the procurement, fabrication, assembly and installation of detector subsystems. The MINOS detector WBS Level 2 Managers report to the Fermilab management through the MINOS Manager, and are usually members of the Collaboration.

The Executive Committee (EC) consists of the Spokesperson, Deputy Spokesperson, the NuMI and MINOS Project Managers and seven other members who are elected by the IB for staggered three-year terms. The EC sets scientific and technical policy for the experiment, and establishes procedures for making technical decisions, such as the formation of technical committees. The Spokesperson also appoints specialized committees to perform various advisory, oversight and planning functions. Advisory committees that are currently in existence are:

- The Computing Advisory Committee
- The Scintillator R&D Steering Committee
- The Four-Plane Prototype Task Force
- The Speakers' Advisory Committee
- The MINOS Physics Specifications for Electronics Advisory Group
- The MINOS Calibration Working Group
- The MINOS Integration Working Group
- Beam Monitoring Advisory Group
- Theseus Working Group
- The Coordinating Committee for Outreach Activities
- The MINOS Alignment Working Group

Members of the MINOS Collaboration

The following institutions are members of the MINOS Collaboration at this time:

<u>China</u>: Institute for High Energy Physics (Beijing).

<u>Greece</u>: University of Athens

<u>Russia</u>: Joint Institute for Nuclear Research (Dubna), Institute for High Energy Physics (Protvino), Institute for Theoretical and Experimental Physics (Moscow) and Lebedev Physical Institute.

<u>United Kingdom</u>: University of Cambridge, University College London, University of Oxford, Rutherford Appleton Laboratory and University of Sussex.

<u>United States</u>: Argonne National Laboratory, Brookhaven National Laboratory, California Institute of Technology, University of Chicago, Elmhurst College, Fermi National Accelerator Laboratory, Harvard University, Indiana University, James Madison University, Lawrence Livermore Laboratory, University of Minnesota-Duluth, University of Minnesota-Minneapolis, Northwestern University, University of Pittsburgh, University of South Carolina, Stanford University, Texas

A&M University, University of Texas at Austin, Tufts University, Western Washington University and University of Wisconsin.

Several other institutions are in various stages of applying for membership in the MINOS Collaboration.

8. Current Status and Outlook (November 2000)

In the past two years the evidence for neutrino oscillations has grown stronger. The Super-Kamiokande Collaboration has performed an analysis on their data that indicates the favored channel is $\nu_\mu \rightarrow \nu_\tau$ rather than $\nu_\mu \rightarrow \nu_s$. In addition, recent results from Super-Kamiokande favor values of Δm^2 which are above 10^{-3} eV^2, corresponding to L/E values that are well matched to the capabilities of the NuMI Project. Furthermore the long baseline experiment at KEK, K2K, is underway and has reported early results consistent with the atmospheric data. At Fermilab, work is proceeding on the Mini-BooNE experiment, the goal of which is to unambiguously confirm or deny the $\nu_\mu \rightarrow \nu_e$ signal claimed by the LSND Collaboration.

Since the previous DOE review of our project in May 2000, we have made good progress on several fronts. The excavation for the MINOS laboratory at the Soudan mine is complete and the outfitting of the laboratory is underway. The NuMI Tunnels and Halls excavation work at Fermilab is making good progress. The Title II design for the outfitting of the Fermilab tunnels and halls is complete. Installation of LCW piping for the NuMI primary beam magnets has begun in Main Injector tunnel. There has been successful initial testing on the prototype horn and associated power supply. MINOS has finalized all detector design parameters. The electronics designs for the detectors are completed and prototype studies are well underway. The production of the plastic scintillator and scintillator modules is well underway.

Our plans for the next 12 months include completing the engineering designs for beamline technical components and continuing their installation at Fermilab; accomplishing most of the underground construction at the Fermilab site; completion of the Far Detector Hall outfitting at Soudan and the start of detector installation there. Some important near term activities and dates are listed below.

Continued scintillator production and module fabrication	throughout 2001
Complete Excavation of the Decay Tunnel	5/00
Primary beam magnets ready for installation	7/01
Electronics under production	2/01
Complete Outfitting and Begin Installation at Soudan	7/01

References

[1] The Fermilab NuMI Group, *The NuMI Facility Technical Design Report*, NuMI-L-346, October 1998.

[2] The MINOS Collaboration, *The MINOS Detectors Technical Design Report*, NuMI-L-337, October 1998.

[3] University of Minnesota, CNA Consulting Engineers, Ericksen-Ellison Associates, Inc., Miller Dunwiddie, Inc., *MINOS Far Detector Laboratory Technical Design Report (Including Basis of Estimate & WBS) for Cavern Construction, Cavern Outfitting & Detector Outfitting*, NuMI-L-263, October 1998.

[4] See, e.g., R. L. Sears, *Astrophysical Journal*, **Vol. 140**, pp. 477-484 (1964).

[5] J. K. Rowley, B. T. Cleveland and R. Davis, AIP Conference Proceedings No. 126, Solar Neutrinos and Neutrino Astronomy, Eds. M. L. Cherry, W. A. Fowler and K. Lande, p.1, 1985.

[6] K. S. Hirata, *et al*., *Physical Review Letters*, **Vol. 65**, p. 1297, 1990.

[7] P. Anselmann *et al*., *Physics Letters*, **Vol. B327**, p. 377, 1994.

[8] J. N. Abdurashitov, *et al.*, *Physics Letters*, **Vol. B328**, p. 234, 1994.

[9] Y. Fukuda, *et al*., *Physical Review* , **Vol. 81**, p. 1562, 1998.

[10] T. Ishida (for the K2K collaboration), CIPANP2000 - 7th Conference on Intersections Between Particle and Nuclear Physics, Quebec, Canada, June 25-28, 2000

[11] J. Hylen *et al*., *NuMI Hadronic Hose Technical Design Report*, NuMI-B-610, April 2000.

[12] J. Hylen *et al*., *Proposal to Include Hadronic Hose in the NuMI Beam Line*, NuMI-B-542, October 1999.

[13] J. Hylen *et al.*, *Conceptual Design for the Technical Components of the Neutrino Beam for the Main Injector (NuMI)*, FERMILAB-TM-2018, September 1997.

[14] NuMI Project, LBL MI-60, *Civil Construction Conceptual Design Report*, June 1997.

[15] Department of Energy, *Neutrinos at the Main Injector Project Execution Plan*, February 1999.

[16] The Fermilab NuMI Project Staff, *NuMI Project Management Plan*, February 1999.

[17] Fermilab ES&H Staff, *Fermilab ES&H Manual*, current revision.

[18] Environmental Assessment, *Proposed Neutrino Beams At The Main Injector*, DOE/EA-1198, December 1997.

[19] NuMI Project Staff, *NuMI Project at Fermilab: Preliminary Safety Assessment Document*, December 1998.

[20] Gage-Babcock & Associates, Inc., *Fermi National Accelerator NuMI Project; Fire Protection/Life Safety Recommendations*, July 1998.

[21] University of Minnesota, CNA Consulting Engineers, Erickson-Ellison Associates, Inc. Miller-Dunwiddie, Inc., *MINOS Far Detector Laboratory Project Hazard Report and Safety Plan*, UM Project No. 896-95-1634, NuMI-L-419, November 1998.

---

[22] *The MINOS Collaboration Bylaws*, Rev. 3.4, September 2000.