

Chapter 1

Introduction

1.1 Historical overview

From the time of the initial conception of the Main Injector it has been realized that the high proton intensity, coupled with the medium-high energy of this accelerator, could provide a source of neutrinos that would be unique in the world. This idea was first seriously discussed in a workshop on Fixed Target Physics with the New Main Injector held at Fermilab in May 1989. In the same time frame there was also a growing realization in the high energy physics community that the search for neutrino oscillations could be one of the most productive ways to test the hypothesis of neutrinos as dark matter and to look for departures from the Standard Model of particle physics. This model required massless neutrinos and thus could not accommodate neutrino oscillations. On the other hand the concept of nonzero mass neutrinos was quite attractive theoretically[1]. In addition there were experimental hints that neutrino oscillations might indeed be occurring in nature. Neutrino oscillations could explain both the solar neutrino deficit and the atmospheric neutrino anomaly.

In 1990 three proposals for Main Injector neutrino oscillation experiments were submitted to Fermilab: a short-baseline proposal, P-803 (COSMOS), to look at the mass region of cosmological interest, and two long-baseline proposals to look at the region suggested by the atmospheric anomaly; these were P-805, which proposed to send the neutrino beam 570 kilometers to the IMB water Cerenkov detector in Ohio, and P-822, which proposed to send it 730 kilometers to the 1 kiloton Soudan 2 detector in northern Minnesota. These ideas were further developed and elaborated on in a workshop on Neutrino Long-Baseline experiments held at Fermilab in November 1991[2]. Eventually P-805 was withdrawn because of the accident which caused the shutdown of the IMB detector. The PAC encouraged P-822 but made it clear that a more ambitious effort, involving an order of magnitude more massive detector, was required to make a statistically significant search.

It was in this environment that the Fermilab management issued a call for Letters of Intent (LOIs) for long-baseline neutrino experiments, with a deadline of May 16, 1994. Three LOIs were received in response to this call. The 1994 workshop on Particle and Nuclear Astrophysics and Cosmology in the Next Millennium[3] in Snowmass, Colorado, sponsored by the American Physical Society, provided a good forum for the proponents of these LOIs, as well as other interested parties, to meet and discuss issues of common interest.

As a result of these discussions, and of the recommendations from the summer 1994 Fermilab PAC meeting, a more focused meeting was held at Fermilab in late summer 1994 to consider forming a single collaboration to study long-baseline neutrino oscillations.

Such a Collaboration was indeed formed in the fall of 1994 and a decision was made to focus the effort on an experiment with a magnetic detector of roughly 10 to 15 metric kilotons (kt), to be located in the Soudan mine in Minnesota. At the first meeting of the Collaboration, a formal "constitution" was adopted and management and policy-setting groups were established. Stanley Wojcicki from Stanford University was chosen as the first Spokesperson of the Collaboration. The Collaboration adopted MINOS, an acronym for Main Injector Neutrino Oscillation Search, as the name for its experiment.

The Collaboration immediately initiated an effort on detector R&D with the goal of obtaining the information necessary to design an optimum detector, which could be built at reasonable cost, to characterize the interactions of neutrinos produced by the Main Injector. Unfortunately the level of the R&D had to be rather limited, both in 1995 and in the subsequent two years, because of serious funding constraints. In parallel, the Collaboration started work on a formal proposal to the Fermilab management which defined the scope of physics interest, the general method proposed to address this physics, and a "Reference Detector". The Reference Detector concept was devised by the Collaboration as a design which could address the relevant physics satisfactorily, did not require any new or unproven technology, and could be costed reliably. The Collaboration recognized from the beginning, however, that the results of the planned R&D program could lead eventually to an alternate design. The Collaboration chose the summer of 1997 as the deadline for specifying the basic parameters and technologies of the MINOS detectors.

The MINOS Proposal[4] was submitted to Fermilab management in early 1995 for consideration at its February 17-19, 1995, meeting. In response to specific questions formulated by the PAC at this meeting, the Collaboration prepared an Addendum[5] to elaborate on a number of physics and technical issues. At the next meeting of the Fermilab PAC, on April 28-30 of the same year, the Committee recommended that Stage I approval be granted to the Collaboration and Director John Peoples accepted this recommendation.

Fermilab was not the only location under consideration by the U.S. HEP community for a possible long-baseline neutrino oscillation experiment. Somewhat before the MINOS Proposal, another proposal was submitted to the Brookhaven National Laboratory management for an experiment utilizing the BNL AGS accelerator as the source of neutrinos. This proposal was approved by the BNL directorate and in subsequent months the proposal was further refined[6].

The large scale of these proposed efforts implied that the U.S. HEP program could not afford to mount both experiments. Accordingly, the Director of DOE's Office of Energy Research, Dr. Martha Krebs, requested the High Energy Physics Advisory Panel (HEPAP) to form a Subpanel with the following charge[7]:

Evaluate the existing evidence for neutrino oscillations, and consider the feasibility of testing this phenomenon in experiments at U.S. accelerator facilities. Review the status and discovery potential of ongoing and proposed experiments at accelerators in the U.S. and abroad. Conduct an indepth review of the neutrino oscillation experiments proposed at U.S. accelerators, and compare them on the

basis of scientific merit, discovery potential, and likelihood of achieving a definitive result. Also, for each of these proposals, comment on the reliability of its cost and schedule estimates, and the impact on the host laboratory. Consider the priority of these experiments in the context of the U.S. accelerator-based High Energy Physics Program. If appropriate, recommend to the Department of Energy a cost-effective plan for pursuing this physics.

The creation of a Subpanel with such a charge was unprecedented in the history of U.S. high energy physics and its peer review process. Never before had there been conducted a national level peer review of experiments approved at two different laboratories with a goal of performing only the one with a higher physics potential.

Stanley Wojcicki, chair of HEPAP at that time, being one of the principals in the MINOS effort at Fermilab, recused himself from all deliberations on this issue including the discussions on Subpanel formation. Dr. Piermaria Oddone, from Lawrence Berkeley National Laboratory, was designated by DOE to be the Acting HEPAP Chair for the Consideration of Neutrino Oscillation Experiments. He acted as chair in the activities of HEPAP connected with the Subpanel formation, its deliberations, and the eventual consideration of the Subpanel's recommendations by HEPAP. Prof. Frank Sciulli from Columbia University was selected as the chair of the Subpanel. There were also appointed eleven additional members of the Subpanel, all of them active members of the U.S. HEP community with extensive knowledge of neutrino physics.

The Subpanel held a number of meetings, the first one on March 22-24, 1995 in Bethesda, Maryland. Separate three day meetings were held at the two proponent laboratories: at Fermilab on June 13-15, 1995, and at Brookhaven on June 20-22, 1995. Together with the evaluation of the physics capability of each experiment, a parallel review was conducted of their estimated costs with the help of a specially appointed Cost Review Subcommittee. The Subpanel generated a list of additional questions to the proponents and the two laboratories, answers to which were provided to the Subpanel before its last meeting[8].

The Subpanel concluded its deliberations, formulated recommendations, and wrote its report at its final meeting held in Denver, Colorado on July 24-28, 1995. The Subpanel stated in its report[9]:

The discovery of neutrino oscillations, and consequently the discovery of neutrino mass, would constitute a major breakthrough in particle physics and the first evidence of physics beyond the minimal Standard Model.

Its four recommendations were:

- 1. The search for neutrino oscillations with accelerator experiments, including a single long-baseline beam, should form an important segment of the U.S. high energy physics program.*
- 2. The MINOS experiment at Fermilab should be supported; the E-889 experiment at Brookhaven should not be supported.*
- 3. The COSMOS experiment at Fermilab should be supported.*
- 4. The Fermilab program should remain flexible to react to new information.*

Subsequently, at its September 18-19, 1995 meeting in Washington, D.C., the full HEPAP considered the Subpanel report. After extensive discussion, HEPAP unanimously supported the report. In its transmittal letter to Dr. Martha Krebs, Acting HEPAP Chair Oddone wrote[10]:

We believe that the program of neutrino oscillations, to be carried out at FNAL as recommended by the subpanel, is an important component of the future national program Discovery of neutrino oscillations accessible to accelerator experiments would revolutionize particle physics.

In the time since the HEPAP recommendations, the MINOS Collaboration grew in size by attracting additional collaborating institutions: Dubna and IHEP-Protvino from Russia, IHEP-Beijing from China, University College London from Great Britain, and the University of Texas at Austin and Harvard University from the U.S. During that same period, Oak Ridge National Laboratory and Columbia University have withdrawn from the MINOS Collaboration. The detector-oriented R&D program during that time focused on the simulations of physics reactions of interest and the development of associated software, the experimental investigation of different active detector technologies, and the examination of different methods of constructing the large steel absorber planes. Four different active detector technologies were investigated: resistive plate counters, proportional gas chambers, liquid scintillator and solid scintillator. Considerations in the ultimate selection were based on cost estimates, simulations of physics performance, laboratory bench tests, test beam results, and experience of HEP experimental groups around the world.

A specific steel plane design was chosen in the fall of 1996. In September 1997 the Collaboration decided on solid scintillator as the active detector technology. These choices form the basis for the design of the detector described in this Technical Design Report.

The Fermilab PAC reviewed the project at its June 1997 meeting and made the following recommendations, which provide part of the motivation for the present baseline design with a 5.4 metric kt far detector:

- 1. The collaboration should proceed as quickly as possible with a smaller detector (e.g. 5 kton) focussing on the CC/Total method. The reduced mass would still allow the experiment to cover the atmospheric neutrino region and save a substantial portion of the requested funds.*
- 2. The collaboration should prepare for a future upgrade using the funds saved by reducing the detector mass. An upgrade might be vital in addressing future developments in the field, where improved electron or τ identification could be necessary.*

In February 1998 the HEPAP Subpanel on Planning for the Future of U.S. High Energy Physics (the Gilman Subpanel)[11] reiterated HEPAP's endorsement of the Fermilab long-baseline program, but noted that new experimental results on neutrino oscillations made this an appropriate time for Fermilab to reexamine the configuration of the NuMI-MINOS facility. Such a review is consistent with the fourth recommendation of the 1995 HEPAP Subpanel. In response to this, a special MINOS Subcommittee of the Fermilab PAC was appointed, with

Prof. Charles Baltay as chair, to review the physics goals and the scientific capability of the NuMI-MINOS project; the review was held in May 1998. The MINOS Collaboration input on the issues considered by the Subcommittee is discussed in detail in Reference [12]. The Subcommittee concluded[13] that “there now appears to be a respectable body of evidence indicating the existence of neutrino oscillations,” and expressed the feeling that “it is more desirable than it was even a few years ago to go ahead with a strong long-baseline neutrino oscillation program at Fermilab.” The Subcommittee’s report was strongly endorsed by the Fermilab PAC at its June 1998 meeting. The PAC added its own recommendations to those of the Subcommittee:

The compelling evidence for ν oscillations that has developed over the past year, primarily from the Super-Kamiokande experiment, makes a confirmation and study of this phenomenon an important and exciting area of research. Fermilab is well-positioned to take a leading role in this effort, and the NuMI/MINOS program should be pursued with high priority. The Committee believes the MINOS priority should be second only to Run II at this time. . . .

The high priority is based on the goals of observing the oscillation signal, ascertaining whether the observed oscillations are $\nu_\mu \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_s$, measuring precisely the values of Δm^2 and $\sin^2(2\theta)$ and measuring the $\nu_\mu \rightarrow \nu_e$ component of the oscillations.

1.2 Organization of the report

As the Technical Design Report for the MINOS detector, this document naturally emphasizes the technical descriptions of the design and construction methods we propose to use for the far and near MINOS detectors (located at Soudan, Minnesota and Fermilab, respectively). We want it to be, however, a relatively self-contained document and thus we have included, in abbreviated form, some additional material which provides the background for the experiment and its physics motivation.

The organization of the report is as follows. Following the brief historical introduction of the present Chapter, Chapter 2 presents the physics motivation for the experiment. Chapter 3 gives a general overview of the experiment: the experimental layout, the physics capabilities of the baseline design and possible future directions.

The next five chapters give technical descriptions of the components of the MINOS baseline detectors. Each of these chapters treats a Level 2 task of the MINOS Work Breakdown Structure (WBS). The first three, Chapters 4, 5 and 6, describe the three main technical components of MINOS: the magnet steel and coils, the active detector elements, and the electronics and data acquisition systems, respectively. The next two, Chapters 7 and 8, deal with the installation of the detectors and their associated infrastructure at the far (Soudan) and near (Fermilab) sites. All five of these Chapters follow the same general organization:

- an overview, intended as a self-contained summary of the task,
- a statement of the task's technical requirements and performance criteria,
- a definition of the scope of the task in terms of interfaces with other tasks,
- a detailed description of WBS elements, as a guide to the cost estimate[14],
- a brief description of the remaining optimization and engineering work.

The following three chapters deal with topics which are, strictly speaking, outside the scope of the formal NuMI/MINOS Project, in that they do not involve any Project costs. Chapter 9 discusses the existing software and its likely future evolution, as well as the computing and data storage requirements of the experiment. Chapter 10 gives a brief description of the existing Soudan 2 detector, which is an integral part of the Fermilab long-baseline neutrino oscillation program. Chapter 11 deals with a possible MINOS upgrade in the form of a hybrid emulsion detector, which appears today to be the most interesting option for expanding MINOS capabilities in the future.

Chapter 12 gives a brief description of the ES&H issues, on both the Fermilab and Minnesota sites. Chapter 13 summarizes the costs and schedules for the baseline near and far detectors, which are given in much greater detail in Reference [14]. Appendix A is a glossary of the specialized terms and acronyms used throughout this report.

Chapter 1 References

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