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An Expression of Interest: MiniBooNE, Phase II

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Chapter 1

Introduction

This document is an expression of interest for further running of the MiniBooNE experiment, after Phase I is complete. On the basis of this, we request that the lab commit to maintaining the capability to run the MiniBooNE neutrino line through the end of the decade.

The MiniBooNE collaboration expects to pursue further running of the experiment, after Phase I [1] is complete. The projected time period for this program is late 2005 through 2009. This is the period prior to a two-detector BooNE run, which is unlikely to be constructed before 2009. This is also before a new Proton Driver is likely to be commissioned.

Two open questions make it difficult to present a clear vision for this period. First, what is the most compelling physics? We believe that all of the modes we present in this EOI are compelling, but the *best* choice of running mode depends on the outcome of MiniBooNE Phase I, and the MINOS atmospheric run. Second, what is the the number of protons on target that can be delivered? This depends upon how the protons must be shared among MiniBooNE and the other users in the Fermilab program, the details of which are not yet settled.

At present, we believe that there is enough information for an Expression of Interest, but insufficient information to put forward a program. In this EOI, we ask that the PAC endorse the following:

- The directorate and the beams division plan to maintain the capability of running the MiniBooNE neutrino line, at some level, throughout the decade.
- The Proton Source Study [2] be followed-up with an in-depth cost-benefit analysis of upgrades and proton delivery milestones for an 8 GeV program. We ask the PAC to recommend that this information be available by spring, 2004.
- On the basis of this information, that MiniBooNE be asked to present a Phase II plan to the PAC.

- As the Lab develops short and long term plans, that MiniBooNE Phase II be included as an integral part of the discussion.

All four of our requests may already be planned by Laboratory management. If so, this EOI serves as a way to formalize the goals.

In the following text, we begin by reviewing the case that protons can be made available to MiniBooNE during the Phase II period. As per the Proton Source Study [2], we do not present costs for upgrades, because these are yet to be determined. We follow this by the possible scenarios for MiniBooNE running. Lastly, we present a tentative plan. This plan is likely to change as answers to questions of physics and running become clearer, but it demonstrates that compelling and sensible programs can be developed. Our goal has been to keep this EOI brief, while providing sufficient motivation for the PAC to endorse our four requests above.

This EOI is an addendum to the MiniBooNE Phase I Run Plan. One should see that text for the main physics motivations of MiniBooNE, the Phase I running conditions of the experiment, and the Booster capability for the near term.

Chapter 2

Expectations for Protons on Target

This is a review of the expectations for protons on target during MiniBooNE Phase II, as drawn from the Proton Source Study. It is possible to run the 8-GeV line simultaneously with NuMI through the end of the decade with substantial intensity for MiniBooNE.

2.1 The Booster Neutrino Beam

The Booster Neutrino Beamline presently serves the MiniBooNE experiment, and is expected to do so throughout the duration of Phase II. The FINeSSE experiment may also be placed in this beamline during Phase II.

2.1.1 Booster Operation and Intensity

The entire history of the Booster Neutrino Beam is summarized in Fig. 2.1, which shows the number of protons per week delivered to the MiniBooNE experiment during its first year of running. During this period, the Booster performance was limited by beam loss on equipment in the Booster tunnel. In the beginning, the weekly protons on target per week (p.o.t./wk) leveled off at about 0.02×10^{20} p.o.t./wk by the Winter of 2002- 2003. By the spring of 2003 various improvements to the Booster led to a level of about 0.05×10^{20} p.o.t./wk. The major improvement was the identification and partial reduction of large non-linearities in the magnetic fields of the "dogleg" systems, which are used to extract the beam from the Booster. The non-linear fields caused distortions in the lattice, which led to unusually large beam sizes, and consequent beam losses, in various parts of the Booster. Near the end of May 2003 a shutdown of the entire accelerator complex took place to replace one of the poles holding up the high power lines delivering electricity to Fermilab. After this shutdown, the stability of the Linac became a problem and contributed to limiting the Booster performance. Subsequently, the weekly intensity was only 0.04×10^{20} p.o.t./wk.

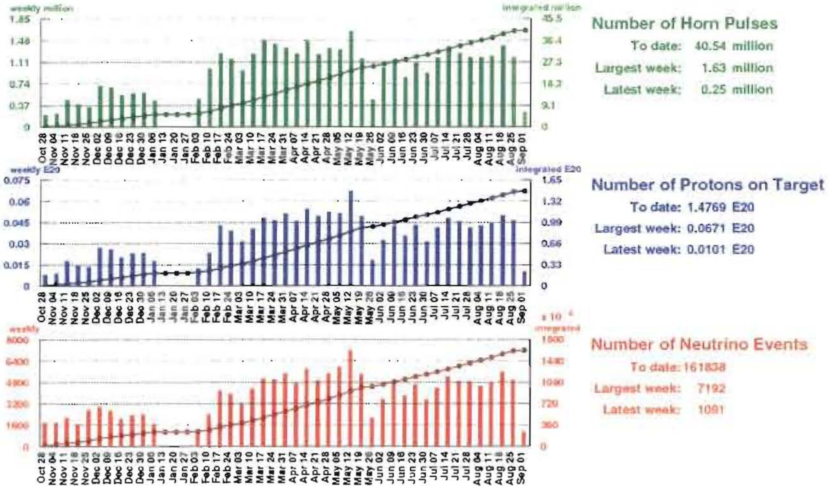

Figure 2.1: The number of horn pulses per week, the number of protons on target per week, and the number of neutrino events per week collected by the MiniBooNE experiment. Also shown are the total p.o.t., the total number of horn pulses, and the total number of neutrino events obtained during the first year of data collection.

During the second half of MiniBooNE's first year, the batch intensity (the number of protons per pulse) was in the range 3 to 4×10^{12} per batch, and the batch repetition rate (the average number of batches per second) was in the range 2 to 4 Hz. If the Booster had delivered this intensity and rate for an entire hour, the rate would be in the range 2.16×10^{16} to 5.76×10^{16} per hr. In fact the average hourly rate was in the range 2 to 5 $\times10^{16}$ per hr.

Fig. 2.1 shows that 1.48×10^{20} were actually delivered during the first year of MiniBooNE operation. This includes the startup period, which is shown in the beginning of the figure, and since MiniBooNE was shut off for September and October 2003, this number also represents the actual p.o.t. for a twelve month period. Fig. 2.1 also shows that approximately 162K neutrino events were collected during the first year of data taking.

2.1.2 Beam Intensity Requirements

During the shutdown in the fall of 2003, several improvements in the Booster were made that are expected to provide routine peak operation with 5×10^{12} protons/batch and 5 Hz for the Booster Neutrino Beamline. The efficacy of these improvements will be understood well before Phase II begins running, and there should also be sufficient time to implement additional improvements if the goals are not met by the end of 2004.

By the summer of 2003, the Booster was routinely delivering more than 5×10^{12} protons/batch for Stacking for Run II, so the Booster can achieve the batch intensity required for Phase II. The issues are reduction and control of losses with this intensity, and required repetition rate. The principal improvements during the fall of 2003 were modifications to the doglegs to reduce losses, installation of two large aperture RF cavities to reduce losses at these two locations, the installation of collimators to control losses, and modifications to the RF and magnet systems to allow an increase of the equipment repetition rate to 7.5 Hz. Once these improvements are operational, it could be that the above-ground radiation shielding assessment of 1.8×10^{18} protons per hour will be the limit on Booster operation, but this is well above what would limit operation during Phase II. In addition, in 2004 Columbia University is expected to develop a robot for measuring the losses in the Booster during beam operation. Once operational, this robot can help to understand in detail the losses in the Booster.

Although the Booster equipment will be able to achieve 7.5 Hz, the MiniBooNE horn imposes a limit of 5 Hz. If the Booster would achieve 5×10^{12} protons/batch at 5 Hz for an hour, the MiniBooNE target would receive 9×10^{16} protons per hour. However, this is considered a nominal maximum performance level, and it is not expected to persist for an entire week, or much less for an entire year.

In order to relate this nominal hourly performance to the number of protons delivered per year, one can define an annual efficiency. This annual efficiency must include factors to account for the number of weeks actually scheduled for beam operation in a year, the reliability of the Proton Source (Linac, Booster, and beam transfer lines) during those scheduled weeks, and the operational efficiency for actually achieving 5×10^{12} protons/batch and 5 Hz. The number of weeks scheduled per year is determined by the Director's Office and is taken to be in the range 42 to 44 weeks. The reliability of the Proton Source has been measured by MiniBooNE and is in the range 0.90 to 0.94, while the operational efficiency is estimated to be 0.90. Combining these factors, one obtains an annual efficiency of 0.65 to 0.72.

However, by the time Phase II would run, NuMI will also be running. NuMI is expected to use five Booster batches per Main Injector cycle. NuMI is expected to share the same Main Injector cycle as Stacking for Run II, and Stacking is expected to take two Booster batches per Main Injector cycle. The Main Injector cycle time is expected to be about two seconds. With these assumptions, NuMI plus Stacking will require seven batches every two seconds, which is an average rate of 3.5 Hz. At the moment, some of the Booster equipment requires two "prepulses" with no beam, or 1 Hz. Thus, the bandwidth required by NuMI, Stacking and the prepulses is 4.5 Hz. This leaves 3 Hz for delivering beam to the MiniBooNE target, assuming a total Booster bandwidth of 7.5 Hz. This is 60% of the maximum 5 Hz, which MiniBooNE should be receiving in 2004.

However, if NuMI is not taking beam when Run II is not stacking, then MiniBooNE can run at 5 Hz during these periods. The Proton Source Report [2] found that the fraction of the year that stacking takes place is 0.59, and the fraction of the year that stacking is not taking place is 0.19. If a repetition rate of 5 Hz is assumed for 0.19 of the year, and 3 Hz for 0.59 of the year, one calculates an effective repetition rate of 3.5 Hz. Also, if the Booster repetition rate can be raised from 7.5 Hz to 10 Hz, then 2.5 Hz can be added to the Booster Neutrino Beam. This proposal assumes some combination of these factors will become reality, and result in a repetition rate between 3.5 and 5 Hz.

Thus, one expects a nominal performance of the Booster Neutrino Beam for Phase II of 5×10^{12} protons/batch with a repetition rate between 3.5 Hz to 5 Hz. With the range for annual efficiency above, one calculates a range for p.o.t./yr for Phase II as $5\times10^{12}\times$ (3.5 to 5 Hz) x 3.15×10^{7} sec/yr x (0.62 to 0.72) = (3.42 to 5.68) $\times10^{20}$ p.o.t./yr, giving an average of 4.55×10^{20} p.o.t./yr.

Chapter 3

Run-Modes for MiniBooNE Phase II

This chapter discusses the three Run-Modes for MiniBooNE Phase II: Antineutrino Running, Running with a 25m Decay Length, and Running with FINeSSE. The final chapter describes how these three Run Modes might be sequenced.

3.1 Antineutrino Running

The primary physics motivation for running the BooNE beamline in antineutrino mode is the LSND signal for $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations. While this goal is sufficient to motivate antineutrino running, there are several other crucial reasons to include antineutrino running in the near-term and long-term run program. These other reasons for running in antineutrino mode include: CPT violation searches in $\bar{\nu}_\mu$ disappearance and $\bar{\nu}_e$ appearance, the elimination of nuclear potential effects such as effective mass and shadowing from systematic errors in MiniBooNE measurements, and a strong cross check on the charged kaon production rate at the neutrino source.

3.1.1 CPT violation

The MiniBooNE $\nu_\mu \to \nu_e$ oscillation search, while statistically powerful, will not be able to exclude in all models the possibility that LSND observed oscillations. LSND was actually a search for $\bar{\nu}_\mu \to \bar{\nu}_e$, so if one does not assume CPT invariance in the mass matrix then MiniBooNE's neutrino-mode search is not sufficient. CPT violation at this scale in the neutrino sector is not necessarily excluded by kaon-sector measurements [3], and has been invoked in three- and four-neutrino models [4, 5, 6] to bring the LSND results into compatibility with atmospheric and solar data.

MiniBooNE can address certain CPT-violating models by searching for $\bar{\nu}_\mu$ disappearance in a relatively short antineutrino run. To address definitively the possibility of CPT-violating oscillations (or, indeed, any oscillations at all) in the LSND data, MiniBooNE will have to run for an extended period and search for $\bar{\nu}_e$ appearance.

Comparison to MINOS atmospheric running

MINOS has already begun collecting atmospheric neutrino data, and is the first large atmospheric neutrino detector sensitive to muon charge. If CPT violation exists in the three-neutrino model suggested in Ref. [5], then large ($\sim 10\%$) differences between ν_μ and $\bar{\nu}_\mu$ disappearance effects could reasonably be expected in atmospheric neutrinos. MINOS expects to observe approximately 120 upward μ^+ in five years [7], so their sensitivity to such an effect would be at the 1-2σ level.

Electron antineutrino appearance at MiniBooNE

The MiniBooNE beam has the capability to switch horn polarities, from the current positive charged particle (neutrino) focus to a negative charged particle focus. This switch will enhance strongly the antineutrino component of the beam and strongly suppress the neutrino component. One can imagine performing an electron antineutrino appearance measurement under these circumstances.

There are several features, besides antineutrino enhancement, encountered when operating with negative polarity. Negative kaon production is much smaller (around a factor of 20) than positive kaon production. The background from neutrinos in the antineutrino beam is much higher than in the opposite case. Also, the antineutrino cross section is much smaller ($\sim$ 3 times) than the neutrino cross section in the neutrino energy region 200 MeV to 1000 MeV. These effects tend to cancel each other somewhat, so that the sensitivity is not a factor of 3 to 4 worse, but rather a factor of 1.5-2.5 worse depending on what specific hadron production models are used in the estimate.

Even in the worst case, the possibility of testing CPT violating models of neutrino mass is extremely intriguing. An observation of this effect would be revolutionary in particle physics.

3.1.2 Bound nucleon studies

One of the dominant uncertainties in MiniBooNE's physics program is direct knowledge of the neutrino (antineutrino) nuclear cross sections. This problem is compounded by the difficulty of predicting the neutrino (antineutrino) fluxes. There is a way, however, by using both neutrino and antineutrino reactions, to measure these effects, and hence to determine the neutrino fluxes.

Antineutrino running offers the unique possibility of differentiating the effects of quasi-elastic scattering from nuclei and scattering from free nucleons. This is due to the presence of hydrogen atoms in the mineral oil. Antineutrinos will undergo charged current quasi-elastic scattering with protons, while neutrinos will not.

This difference can be used to discriminate between free proton and nuclear scattering. In general, the presence of the other nucleons in the nucleus will suppress low Q^2 reactions, while the free proton cross section will peak at a Q^2 of zero. By comparing the Q^2 dependence of neutrino scattering versus antineutrino scattering, the energy dependent rate for free proton scattering can be extracted.

Once the free proton rate is known as a function of energy, it can be translated directly into a measurement of the antineutrino flux versus energy. Once this is done, the nuclear part of the cross section can be completely determined.

3.1.3 Charged Kaon Background Validation

Another aspect of running with negative horn focus is the ability to check the charged kaon production rate at the neutrino source. The rate of positive kaon production is much larger than negative kaons by about a factor of 20 at Booster proton energies. This is due to the different production threshold for the two kaon charge states. By comparing directly the LMC rates between positive and negative focus, a unique verification of the LMC rates can be obtained, and hence, a verification of the kaon backgrounds in the positive focus beam.

3.2 Running with a 25 m Decay Length

As part of the design of MiniBooNE, the capability to reduce the length of the decay pipe by a factor of two (from 50 m to 25 m) has been included through the option to lower a secondary dump at the 25 m location. The motivation for this capability is multi-faceted, and gives MiniBooNE the option to measure *in situ* how various background and signal components change with this length. The physics driving these cross-checks and measurements is associated with the lifetimes and decay distributions of the various sources of neutrinos in the beamline. For example, the ν_μ's from pion decay will have a much different energy distribution, since the low energy pions decay rapidly before the 25 m dump and the high energy pions decay relatively uniformly throughout the 50 m decay region. The MiniBooNE detector subtends a very small solid angle in the forward direction for pion decays, giving the ν_μ spectrum a very close tie with the pion spectrum. (In fact, as shown in the original MiniBooNE proposal, the relation between the pion and neutrino energy is almost exactly $E_\pi = 2.5E_\nu$.) One of the major backgrounds to the ν_e oscillation search is neutral current π^0 production, which is much higher for the higher energy incident ν_μ's. Thus, the relative background from this source will be much less with the 25 m absorber in place.

Combinations of results from both 25 m and 50 m running can be used in several ways to check systematics and improve measurements. Possibilities include checking the components of the neutrino flux from various sources, constraining the neutrino rate from charged kaons, separating the ν_e background from muon versus kaon decay, and isolating the backgrounds from NC π^0 production.

Some initial investigations have been made to quantify the changes between running with a 50 m and 25 m absorber. The relative flux distributions are shown in Figs. 3.1 and 3.2 as a function of generated neutrino energy. One sees that the ν_μ flux ratio drops with generated energy until a little over 1 GeV, where the ratio starts to rise toward one. The initial falloff is due to the increase of decay length for pions as they become higher in energy; the rise happens as the ν_μ's from kaon decay starts to dominate.

Table 3.1 gives the estimated event samples for 50m versus 25m running after the standard final selection cuts. The energy distributions of events passing these selection cuts as a function of the reconstructed energy is also shown in Figs. 3.3 and 3.4. One sees that at 0.4 eV^2, the backgrounds drop off by about 40% and the oscillation signal by 30%.

The point of the analysis is that the various backgrounds and signal should go down by the predicted ratio if one understands their sources. Any anomaly will indicate a problem. The 25 m absorber running can be used to investigate the backgrounds, by seeing how the various components of the energy distribution change from 50 m to 25 m running. Table 3.2 shows results for various 25 m and 50 m running scenarios. A combined energy dependent oscillation fit is done for each scenario and the error in determining $\sin^2 2\theta$ is listed in the last column. As this table shows, the sensitivity to oscillations is comparable for all combinations and basically only dependent on the number of protons on target. Therefore, running with the 25 m absorber does not compromise the oscillation search, but rather gives another handle on studying the backgrounds and their uncertainties.

In summary, 25 m absorber running will provide an important check for the MiniBooNE oscillation program. It also has the potential to give information on the high energy muon neutrinos from both pion and kaon decay. Such information may be very helpful in reducing uncertainties in the neutral current π^0 background and the intrinsic ν_e's from kaon decay. As an example, the simulated energy spectrum including simple cuts to isolate well measured ν_μ events is shown in Fig. 3.5. The simple cuts include tank hits > 100, veto hits < 6, one or two subevents, and reconstructed vertex < 500 cm. For 1×10^{21} p.o.t. split equally between 25 m and 50 m running, there are 1350 (1900) events with reconstructed energy greater than 2.0 GeV which are due primarily to charged kaon decay. The curves show that one can isolate the high energy ν_μ events that are due to charged kaon decay. The 25 m running removes the highest energy pion decay background component and, thus provides an important check and improvement for this measurement. These estimates indicate that it will, therefore, be possible to use these events to constrain charged kaon backgrounds at probably better than the 2% level. Future simulation studies are planned to investigate combined energy fits to both the ν_μ and ν_e distributions for 25 m and 50 m running. This technique holds the promise of providing better oscillation sensitivity and important controls on systematic uncertainties.

3.3 Running with FINeSSE

Phase II running is likely to include a coordinated run of the MiniBooNE and FINeSSE experiments, where the two experiments share data. The FINeSSE detector is a high resolution oil-based detector located 100 m from the 8 GeV neutrino tar-

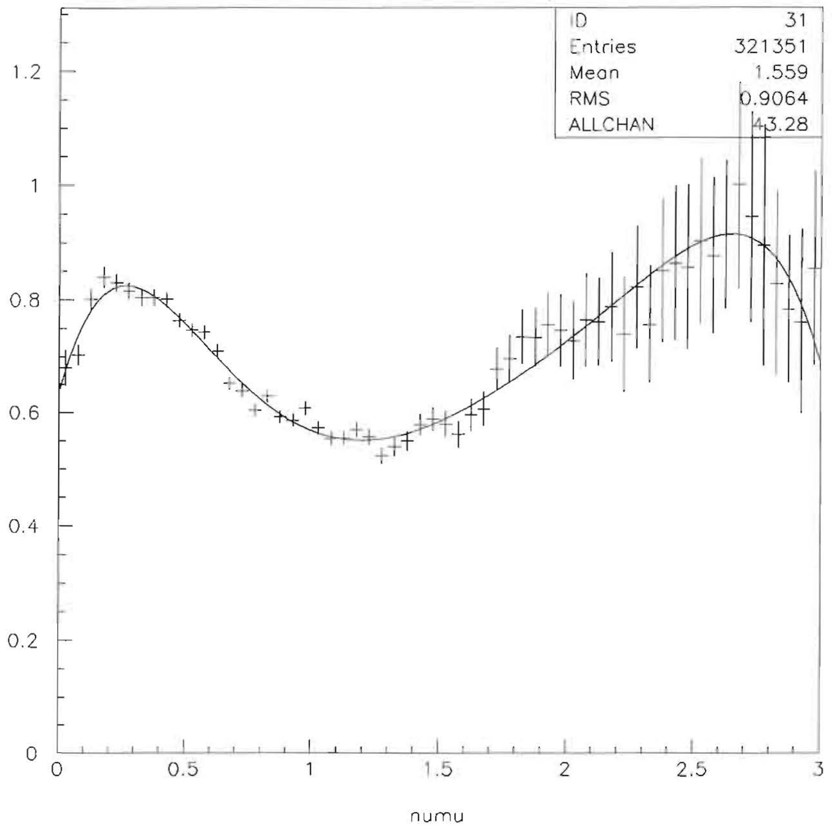

Figure 3.1: Ratio of the 25 m to 50 m ν_μ flux from all sources as a function of generated ν_μ energy.

Event Source	Events 50m	Events 25m	Ratio
ν_μ Mis-ID	400	253	0.63
Radiative $\Delta \rightarrow N\gamma$	81	50	0.62
ν_e from K^+ decay	186	114	0.61
ν_e from K^0 decay	52	31	0.60
ν_e from μ decay	215	124	0.58
Osc. 1.0 $eV^2/0.004$	279	187	0.67
Osc. 0.4 $eV^2/0.017$	336	240	0.71

Table 3.1: Event statistics for running with a 50 m and 25 m decay pipe length. (Numbers are for 1×10^{21} p.o.t. with the optimized selection cuts given in Chapter 5 of the MiniBooNE Run Plan.)

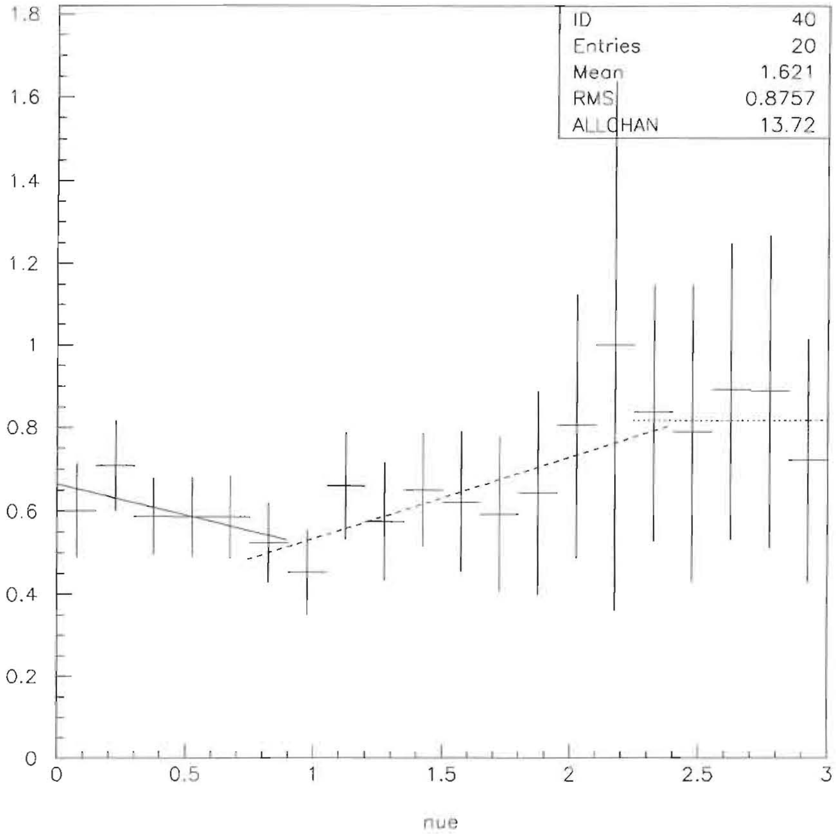

Figure 3.2: Ratio of the 25 m to 50 m ν_e flux from all sources as a function of generated ν_e energy.

50m Running (p.o.t.)	25m Running (p.o.t.)	Intrinsic ν_e Events	ν_μ Mis-ID $+ \Delta \to N\gamma$	Osc. Events (1.0 eV^2/0.004)	$\delta(\sin^2 2\theta)$ (1.0 eV^2/0.004)
1×10^{21}	—	453	481	279	0.479E-03
5×10^{20}	5×10^{20}	361	392	233	0.492E-03
—	1×10^{21}	269	303	187	0.505E-03
1×10^{21}	5×10^{20}	587	632	373	0.422E-03
1.5×10^{21}	—	679	721	418	0.417E-03
1×10^{21}	1×10^{21}	722	784	466	0.385E-03

Table 3.2: Event statistics and oscillation sensitivity for various combinations of 25 m and 50 m running. $\delta(\sin^2 2\theta)$ is the error on measuring $\sin^2 2\theta$ with the given scenario and oscillation parameters.

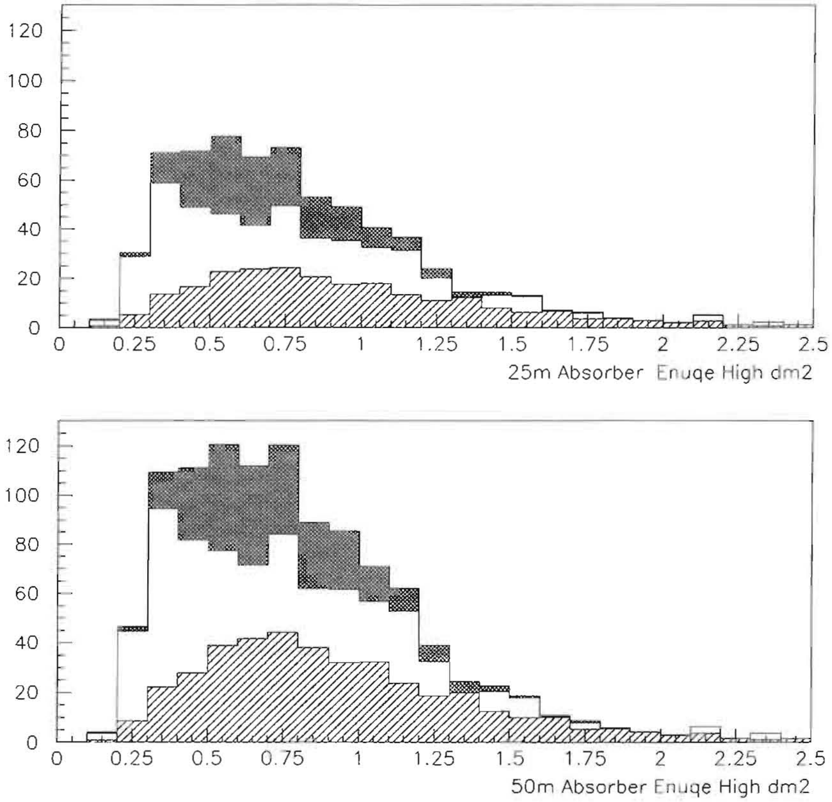

Figure 3.3: Event distribution after electron neutrino selection cuts versus quasi-elastic energy. Top dark area is the $\Delta m^2 = 1$ eV^2 oscillation events with $\sin^2 2\theta = 0.004$, the middle blank area is the ν_μ mis-id background, and the bottom hatched area is the intrinsic ν_e background.

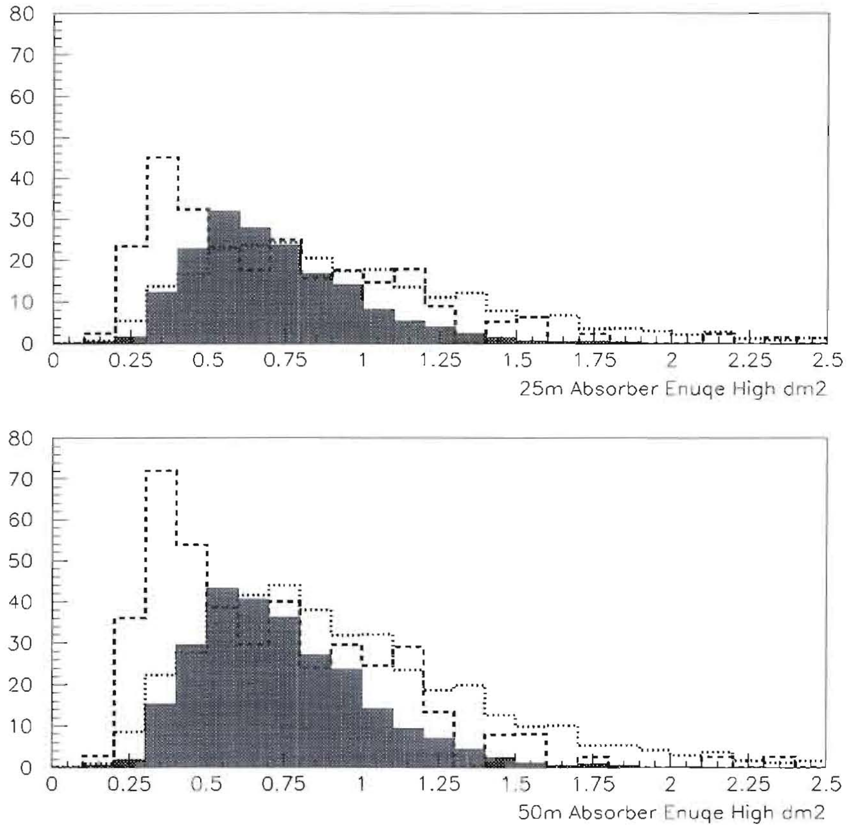

Figure 3.4: Event distribution after electron neutrino selection cuts versus quasi-elastic energy. Solid curve is the $\Delta m^2 = 1$ eV^2 oscillation events with $\sin^2 2\theta = 0.004$, the dashed curve is the ν_μ mis-id background, and the dotted curve is the intrinsic ν_e background.

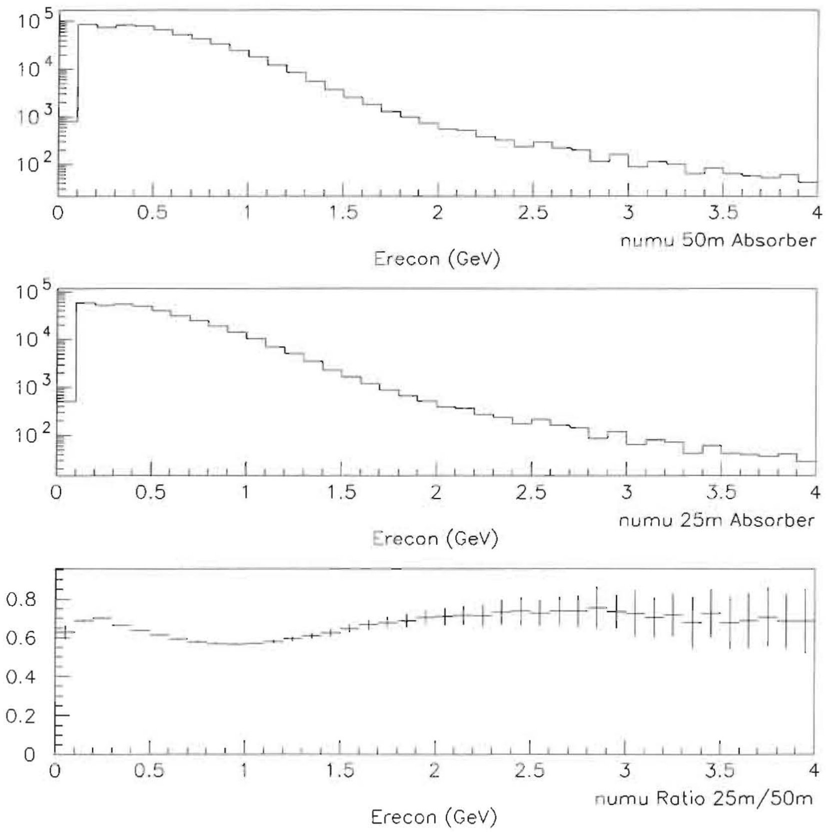

Figure 3.5: Event distribution after muon neutrino selection cuts versus quasi-elastic energy. The events are completely dominated by ν_μ events with negligible electron neutrino contamination. The top plot gives the distribution for 50 m running for 1×10^{21} p.o.t., the middle for 25 m running with 1×10^{21} p.o.t., and the bottom plot is the ratio.

get. The design is described in reference [8]. The detector will be aligned such that it eclipses the MiniBooNE detector. Thus a fiducial region can be selected where neutrinos traverse both detectors.

There are several physics motivations for coordinated running with FINeSSE. If MiniBooNE sees a signal, coordinated running provides a cross-check to the $\nu_\mu \rightarrow \nu_e$ search. However, more importantly, through the disappearance search, a MiniBooNE+FINeSSE run might limit the possible beyond-the-Standard-Model physics available to explain a MiniBooNE signal. Even if MiniBooNE does not see a signal, there is an interesting astrophysical motivation for a disappearance search through a coordinated run. These motivations are discussed below. For extensive details and justification of the claims of capability, see the FINeSSE proposal [8].

Once FINeSSE is constructed, organizing a coordinated run will be straightforward, since there is large overlaps between the collaboration. "Coordination" simply means that both experiments are up and running at the same time and that the groups agree to share data. At the end of this section, we address how "coordination" will be implemented.

Due to the time required to construct FINeSSE, we envision the coordinated run following the antineutrino run. Most likely, neutrino mode running would be selected, although we note that, at some point, FINeSSE may want an antineutrino run. Because the FINeSSE detector is located near the extended meson decay region, the beam at FINeSSE suffers from parallax when run with the 50m absorber. Therefore, when running with FINeSSE, the 25 m absorber configuration is optimal. (As discussed in the previous section, MiniBooNE plans a 25 m run during Phase II, therefore we do not expect a conflict with FINeSSE over this choice). While this is the default, we note that coordinated runs can be performed, and are valuable, in any beam mode.

3.3.1 $\nu_\mu \rightarrow \nu_e$

If MiniBooNE observes a signal, the combination of FINeSSE and MiniBooNE data can narrow the $\nu_\mu \rightarrow \nu_e$ parameter space. The initial FINeSSE request for 6×10^{20} p.o.t. is not sufficient to make a substantial impact on the $\nu_\mu \rightarrow \nu_e$ search. However, with continued running through the end of Phase II, FINeSSE can usefully constrain MiniBooNE systematic errors on the absolute ν_e content of the beam and on the decay of the Δ resonance.

The initial FINeSSE run of 6×10^{20} p.o.t. with the 25 m absorber installed, is statistics limited on the measurements addressing MiniBooNE systematics. About 250 fully-reconstructed intrinsic ν_e events are expected in the FINeSSE detector, which results in a worse than 10% statistical error on each source. This is about twice as large as the expected MiniBooNE errors. As a result, this measurement provides peace of mind if there is good agreement with the MiniBooNE predictions, but it cannot constrain the error. On the other hand, significant improvement can be obtained in the systematic error on decays of the Δ, even with these small statistics. Justification of FINeSSE reconstruction capability is left to the FINeSSE proposal [8], and we simply quote the expectations. With ~ 50 events during the 6×10^{20} p.o.t.

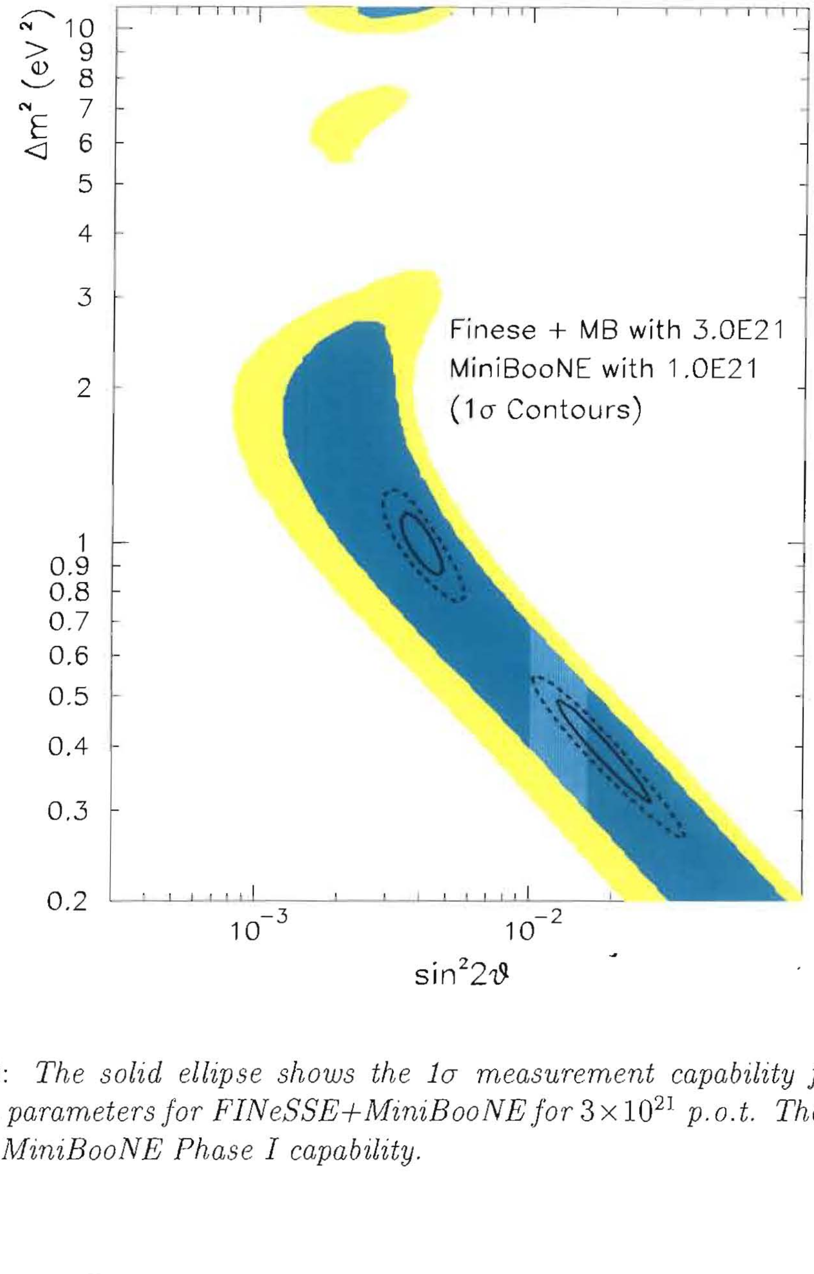

Figure 3.6: *The solid ellipse shows the 1σ measurement capability for two sets of oscillation parameters for FINeSSE+MiniBooNE for* 3×10^{21} *p.o.t. The dashed ellipse shows the MiniBooNE Phase I capability.*

run, there are sufficient statistics to reduce the error on the radiative decay from 20% to 15%. The statistical error on the π^0 is reduced to a negligible 1.5%, such that this is now dominated by the systematic error. The resulting total error is expected to be 3%. Combining these improvements gives, at 1σ, $\sin^2 2\theta = 4.2 \times 10^{-4}$. This is only 15% better than the MiniBooNE Phase I measurement.

However, with 3×10^{21} p.o.t., the errors on the MiniBooNE backgrounds, as measured by FINeSSE, are no longer statistics limited. The following goals are achievable:

NC π^0:	0.03
Radiative Δ Decay:	0.06
ν_e from μ:	0.04
ν_e from K^+:	0.04
ν_e from K^0:	0.06

Combining these systematics with the improved MiniBooNE statistics results in the measurement capability shown in Fig. 3.6. The LSND allowed band is indicated by the solid color. We show the 1σ allowed region for two example Δm^2 values by the solid ellipses. The dashed ellipses indicate the MiniBooNE Phase I allowed range.

To achieve delivery of 3×10^{21} p.o.t. between 2006 and 2010, the Booster will need to be upgraded to 15 Hz running and for higher per-pulse intensity. In the next six months, the second phase of the Proton Source Study is likely to address the practicality of attaining 15 Hz. It will also be necessary to increase the intensity beyond 5×10^{12} protons per pulse. It is unclear how to achieve this while staying within the radiation limits of the Booster. However, this goal is very important to NuMI as well as MiniBooNE. Therefore, we intend to work together and with Beams Division to address this problem.

3.3.2 ν_μ Disappearance

The search for ν_μ disappearance is the most important motivation for combining data from FINeSSE and MiniBooNE, because this addresses the existence of sterile neutrinos. This physics is both compelling and achievable with a 6×10^{20} p.o.t. run. This search is performed by looking for deviations between a predicted ν_μ event rate and the measured event rate. In MiniBooNE Phase I, with no near detector, this search has to rely on theoretical inputs to make the ν_μ flux prediction. If, instead, the prediction comes from a near detector, like FINeSSE, then near/far ratios substantially reduce errors, allowing a more sensitive search.

With the addition of data from FINeSSE, the reach for ν_μ disappearance is extended to cover all 3+1 allowed regions, as shown in Fig. 3.7. This has the following statistical and systematic assumptions, as justified in reference [8]: 6×10^{20} p.o.t., $\delta_{eff} = 2\%$, $\delta_{norm} = 20\%$, $\delta_{shape} = 10\%$, $\delta_{scale} = 5\%$, where the systematic errors are on detector efficiency, total normalization, relative shape of the neutrino flux and energy scale, respectively.

However, there is an interesting astrophysical motivation for searching for ν_μ disappearance at high Δm^2 even if no MiniBooNE signal is observed. Active-to-sterile neutrino oscillations in the late time post-core-bounce period of a supernova will affect the r-process, or rapid neutron capture process. This presents a mechanism for producing substantially more heavy elements ($A > 100$), solving the long-standing problem of the high abundance of uranium. A coordinated FINeSSE+MiniBooNE ν_μ disappearance analysis addresses allowed parameters for this solution.

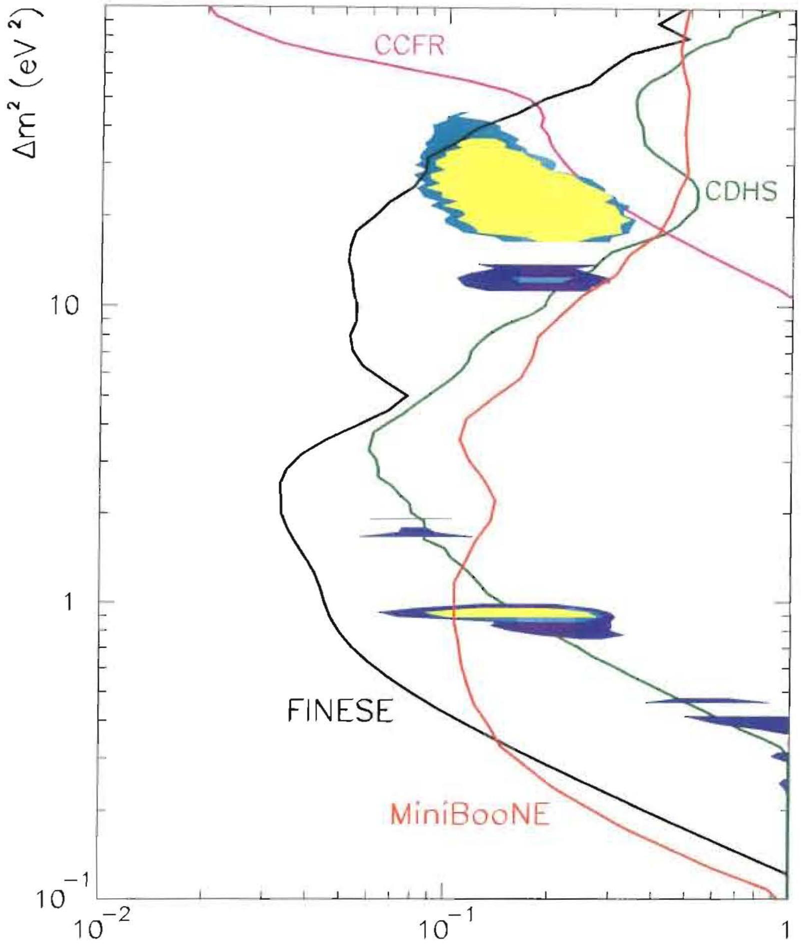

Figure 3.7: *The parameter space covered by FINeSSE+MiniBooNE for ν_μ disappearance (labeled "FINESSE"). Also shown: allowed regions in 3+1 models given the LSND signal (solid), existing exclusion regions from CDHS and CCFR, and expected exclusion region for MiniBooNE.*

3.3.3 Coordination of MiniBooNE and FINeSSE

Given the existence of the FINeSSE and MiniBooNE detectors, this physics comes with no extra construction investment by the lab. The two collaborations need to invest time for running and analysis, but there is sufficient interest in the physics that this commitment will be met. It also requires that the MiniBooNE and FINeSSE collaborations agree on the beamline configuration and on sharing data. After discussions, the collaborations have agreed to a Memorandum of Understanding, which appears in an appendix of reference [8], which is designed to prevent conflicts. In summary, conflicts regarding the beam configuration will be resolved by program planning and conflicts regarding data-sharing will be resolved by a committee consisting of the co-spokespersons of MiniBooNE and FINeSSE.

We expect this inter-group collaboration to proceed smoothly. First and foremost, both the FINeSSE and MiniBooNE collaborations regard the ν_μ disappearance search as a high priority, whether or not a signal is observed. Second, there is substantial overlap in membership between the two collaborations. Thus it will be possible for this bi-group analysis to be performed by members of both groups.

Chapter 4

A Possible Phase II Run Plan

A "srawperson" proposal for Phase II MiniBooNE running is presented that is reasonable and inexpensive, but allows Fermilab to react quickly and take full advantage of the physics opportunity in the eventuality that MiniBooNE confirms the LSND oscillation signal.

A "strawperson" proposal for Phase II MiniBooNE running is shown in Table 4.1. First, once MiniBooNE achieves its goal of 10^{21} p.o.t. for Phase I running in June 2005, the polarity of the focusing horn will be switched from positive to negative, to allow Phase II to begin with antineutrino running for testing CP violation and CPT violation in the neutrino sector. Second, the Phase I MiniBooNE neutrino oscillation results will be presented in August 2005. Third, the horn polarity will be switched back to positive in June 2006, as soon as the FINeSSE detector is completed, to allow neutrino running for both MiniBooNE and FINeSSE with the 25 m absorber. The Phase II MiniBooNE antineutrino oscillation results will then be presented in August 2006, and if the LSND oscillation signal is confirmed, then Fermilab can decide to begin construction of the second detector (BooNE) in October 2006.

This plan enables Fermilab to take full advantage of the exciting physics possibilities of the existing 8 GeV beamline and MiniBooNE detector. It is reasonable and inexpensive and has only a small impact on the rest of the Fermilab physics program. Therefore, it is a good physics investment.

Table 4.1: A "strawperson" proposal for Phase II MiniBooNE running.

Projected Dates	Milestone
present-6/05	Phase I Neutrino Running (10^{21} p.o.t.)
6/05/-6/06	Phase II Antineutrino Running (5×10^{20} p.o.t.)
8/05	Phase I MiniBooNE Neutrino Oscillation Results
6/06-10/09	Phase II Neutrino Running with 25 m Absorber for MiniBooNE & FINeSSE
8/06	Phase II MiniBooNE Antineutrino Oscillation Results

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