Proposal for Tests of a Prototype Veto Shield for MINOS

The MINOS collaboration

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Abstract

The MINOS far detector offers a unique opportunity to measure whether atmospheric anti-neutrinos oscillate in the same way as neutrinos. Recently, enough of the far detector has been installed to permit work to start on neutrino analysis of the data. Preliminary analyses suggest that backgrounds for contained events may be unacceptably high for atmospheric neutrino analysis without a veto shield for downgoing muons. We are studying the possibility of construction of a veto shield around the far detector using either MINOS scintillator system components and/or re-use of Soudan 2 veto shield components. Here, we propose to install a prototype shield to study and understand the nature of potential backgrounds and verify the adequacy of the contemplated shield. We propose to borrow some scintillator system components for this test but to pay for all costs associated with the test using non-Fermilab, non-project funds.

1 Introduction

One of the reasons for location of the MINOS detector in the Soudan Underground Laboratory was to allow unique measurements on atmospheric neutrinos [1]. MINOS is the first large underground detector which has a magnetic field. This permits measurement of muon momentum and charge which extends measurement capabilities from any existing or previous detectors. In particular, it will be possible to make the first significant measurements on whether atmospheric anti-neutrinos oscillate in the same way as neutrinos. Of additional importance is that the data collection and analysis on this subject can begin almost immediately, providing analysis opportunities for young colleagues and students.

The MINOS detector installation is nearing 40% complete. The installation is proceeding very well and by July the first supermodule will be complete and the magnetic field in that section will be energized. Recently, enough data has been collected in the far detector to permit us to start to do neutrino analyses. An exciting event was the observation of the first atmospheric neutrino-induced upgoing muon on March 22. However, this muon was produced due to a neutrino interaction in the rock outside of the detector. These upgoing muons are certainly interesting but provide only a relatively small part of the complete analysis of atmospheric neutrino events which MINOS offers.

The most important class of events are those where the neutrino interaction vertex (and perhaps all of the products) is contained within the detector. In addition to studies on upgoing muons, we have recently started analyses to identify contained events. Unfortunately, those first analyses have identified apparently contained events at a rate which is at least 10 times higher than could result from the interaction of atmospheric neutrinos. In order to make precise measurements, we must limit the background to no more than about 10% of the signal and furthermore be able to characterize the remaining backgrounds. Hence, although these first analyses are just getting started, they already appear to demonstrate that a veto shield will be necessary to eliminate backgrounds induced by downgoing cosmic-ray muons.

The observation of the first upgoing muon event accentuates the fact that the MINOS detector will be ready for making measurements on atmospheric neutrinos as soon as the magnetic field in the first Supermodule is energized early in July. However, without a shield, those analyses will be severely hampered. Hence, we are seeking a path to install a veto shield as soon as possible. It is only now that we can clearly study this issue and responsibly propose a specific shield solution. One very attractive option is to build it with MINOS scintillator system components. However, this presents another urgent timescale for making a decision which is the fact that production of scintillator system components will start to ramp-down in August of this year (and production of fiber by July).

We plan to submit a proposal for construction of the shield for consideration by the PAC at their June meeting. For that, we wish to do the following things:

1. Document and clarify the physics case.
2. Provide clear evidence of the background problem.
3. Provide evidence that the proposed shield will solve the problem. This almost certainly requires data from a prototype.
4. Provide additional design detail and costs.

We request permission from Fermilab and NuMI Project Management to construct a prototype shield by borrowing some existing MINOS scintillator system components. We further request permission to install the shield above the detector, pending approval from a safety review. We propose to do this work with no cost to the project or Fermilab funds and with no delay in the ongoing installation of the detector planes at Soudan.

2 Atmospheric neutrino physics

MINOS is nominally able to study three classes of atmospheric neutrino-induced events:

1. Upgoing muons which enter the detector from below. These include both muons which stop in the detector and muons which pass completely through the detector and exit at some point above where they

enter. The typical ν energy which initiates these events is around 100 GeV. Because the rock target around the detector is relatively large compared to the detector itself these events (based on the rate of apparently oscillated events in other detectors) will comprise about 1/3 of the total number of observed ν-induced events.

2. Contained events. These include both ν_μ and ν_e CC and NC events with a vertex in the detector and all charged secondaries contained within the detector. The typical ν energy for these events is less than a few GeV. These will comprise about 1/3 of the total number of observed ν-induced events.

3. Contained vertex events where some particle (particularly the muon) exits the detector. These will include all of the same event types as the "contained events" but really only the ν_μ CC events will be of interest here since the muon momentum can be measured by curvature in the magnetic field. The typical ν energy for these events will be less than about 10 GeV. These will comprise the final 1/3 of the observed ν-induced events.

The total number of events which we expect per year of operation of full MINOS is about 300 (this takes account of the anticipated reduction in flux due to oscillations and the approximate threshold for observing events in MINOS which is 1 GeV). Hence, we expect nearly 1000 events before the beam for MINOS turns on and double that if one adds a minimum running time of 3 years with accelerator neutrinos. A very important feature of contained events and contained vertex events is that it will be possible to form an up/down ratio for a particular quantity of interest which eliminates the relatively large systematic errors which are intrinsic to the neutrino fluxes and cross-sections. The systematic uncertainty on the flux of upgoing muons is around 20% [2]. However, the systematic uncertainty on an up/down ratio is only about 3% [3]. The systematic error on the ratio between neutrinos and anti-neutrinos has not been carefully studied but is at least 10%. Given the event rates and the systematic uncertainties, we immediately see that the contained and contained-vertex events are of great importance to precision measurements both statistically and systematically. Although no measurements exist at this time, we expect that anti-neutrinos will comprise about 20-30% of the total number of events, if they oscillate in the same way as the neutrinos.

The magnetic field of MINOS will enable several unique measurements compared to previous atmospheric neutrino experiments:

1. By measuring the curvature of muons in the magnetic field of MINOS, we will be able to identify the charge, and hence whether the muon was produced by a neutrino or anti-neutrino. No previous measurements exist which differentiate between the two. Differences in the disappearance rate of neutrinos and anti-neutrinos requires CPT violation. There have been several theoretical papers in the last year which have suggested that this may be the case [4, 5, 6]. Nobody really knows what levels of CPT violation are possible. With a shield we anticipate making an up/down ratio of ratios of neutrinos and antineutrinos which will provide an asymmetry measurement of

about 5% using the contained events. Using only the upgoing muons we can compare upgoing neutrinos to anti-neutrinos at the level of about 15-20%. An analysis of existing atmospheric neutrino data, along with results from K2K will permit some constraint on whether neutrinos and anti-neutrinos oscillate in the same way. Based on the statistics in K2K and systematic uncertainties in comparing the accelerator result to the atmospheric neutrino result the precision of this comparison will likely be limited to about 30%.

2. Again using the magnetic field, we will provide complete neutrino energy measurements up to relatively high energies for the contained-vertex interactions. Combined with the contained events this will provide a relatively good L/E measurement compared to existing detectors.
3. We will measure the muon momentum for most of the upgoing muons which may provide additional constraints on oscillation parameters compared to existing measurements and provide a high-energy sample of events (the muons will look straight) which accentuates sensitivity to astrophysical point sources of neutrinos.
4. We will use calorimetric response to search for very high energy muons (10 TeV and above). Even a single event of this type which points towards a known astrophysical accelerator may be very interesting. Because MINOS is a much better EM calorimeter than previous detectors we can offer new constraints on this type of event (and perhaps even different constraints than detectors like Amanda?)

The measurement which we believe really stands out here is the comparison of anti-neutrino oscillations to neutrino oscillations using the contained and contained vertex events. Hence, we are particularly interested in ensuring that we understand that sample of events very well and we wish to limit the level of background to no more than about 2% after all corrections are applied.

3 The need for a shield for contained-vertex events

Backgrounds to contained neutrino interactions may be generated when a downgoing muon (typical energy around 200 GeV) enters the detector through a gap between scintillator planes (moving fairly near to parallel with the detector planes) and then interacts in a plane of steel to produce an apparent contained event. The interacting muon may or may not be finally observed but if it is observed only following the interaction it could just as well have resulted from a neutrino interaction. Hence, in order to properly veto such background events it is important to observe the muon before it enters the detector, on its way down. An additional class of problematic events are low energy downgoing muons which again enter the detector through a gap and then scatter in the steel and thus appear to originate from a neutrino interaction inside of the detector. These can exactly mimic low-energy CC ν_μ interactions.

The rate of downgoing muons entering MINOS is about 10^5 times higher than the rate of neutrino interactions in MINOS. Because the planes of MINOS are erected vertically with a pitch of 6 cm while the scintillator is 1 cm thick, a relatively large solid angle is available for downgoing muons to slip into the detector without being observed. An additional problem is that the 8-fold multiplexing of the detector readout makes pattern recognition off of the central axis of the detector relatively difficult so that even if a hit is observed as muons enter the detector the final reconstruction of the event may place the hit near to the central collection of hits and this will then appear to be a contained interaction.

At this time, we have two pieces of evidence that a shield will be necessary for analysis of contained and contained vertex events.

1. Our initial attempts at identifying contained events yielded many more events than are possible from neutrino interactions. We observed roughly 100 times more showering events and 10 times more track-like events than expected from neutrino interactions with observed energies in the detector greater than 1 GeV. If we assume that a background of 10% is acceptable for our analyses (correctable down to 2% by adequate characterization of the backgrounds) then we are looking for something like a factor of 100 (with a factor of at least 2 uncertainty at this time) reduction in background events. It is possible that some of this reduction will come from improved analysis techniques. However, after studying some of the events it appears highly unlikely that we will achieve sufficient improvements just from analysis to make the contained events useful for precision studies.
2. The Soudan 2 detector required a veto shield with about a factor of 100 reduction. However, Soudan 2 also had relatively fewer cracks than MINOS (which viewed side-on is mostly cracks!). Offsetting the fact that MINOS has more cracks is the fact that we will only attempt to look at events which are relatively high energy compared to those observed in Soudan 2 and the average density is higher. An important class of background events in Soudan 2 were showers with energy less than 500 MeV which are not relevant in MINOS. However, Soudan 2 also observed relatively higher energy track-like events which needed to be vetoed with their shield.

4 Design requirements for a shield

We have set the following preliminary design requirements for a shield, based on our preliminary contained event analysis:

1. All downgoing muons which pass through the detector should pass through at least one layer of shield first.
2. The shield design should allow for two layers of detector in order to get very high efficiency.
3. Fast-timing is attractive as it may be useful for helping to keep the fiducial volume of the detector as large as possible by providing

an additional discriminant for containment based on time. It also simplifies construction by making it easier to match shield hits with central hits without concerns about random backgrounds creating inefficiency.

4. Some localization of readout should be provided to assist in characterizing backgrounds. A 30-40 cm wide readout running transverse to the detector planes is acceptable.

5. Rapid deployment should be possible. This means keeping engineering and development very simple and using existing components as much as possible.

6. Costs need to be kept very low. A mono-layer shield has equivalent area as 13 MINOS detector planes. Although this is only 2.7% of the MINOS far detector that is comparable to the entire area of scintillator in most big collider scintillator-based hadron calorimeters.

5 Technology options

We think there are only two technology options which can meet the design criteria described above: MINOS scintillator system components and/or re-use of Soudan 2 shield components. We comment briefly on some of the relevant issues which will be used in the evaluation:

- MINOS scintillator components
  1. Fast timing: The MINOS scintillator shield provides a time resolution of about 4 ns per layer for a muon crossing. This may prove quite useful in helping to characterize backgrounds and in maximizing the fiducial volume by inclusion of time as part of decision to veto.
  2. Cost: We know the production cost for MINOS scintillator components very well and incremental cost of production of these components presents excellent value given the investment which already exists for production of MINOS planes. However, the ability to produce at good costs lasts only a few more months before current purchase contracts are completed and before we begin to ramp-down production. We already know that MINOS scintillator planes provide excellent value for large area coverage, regardless of technology.
  3. Use of MINOS scintillator components "as is" avoids the time and expense of any significant engineering design for detector components. The modules themselves are mechanically very strong and light and require only a modest support frame.
  4. Use of MINOS scintillator modules permits us to completely integrate the entire readout system with the existing detector trivially. We continue to have only one technology to maintain so once it is built the ongoing costs compared to the existing detector are negligible.
- Soudan 2 shield components

1. The Soudan 2 shield consists of aluminum proportional tubes. These have been used reliably for many years. For use in MINOS, they would need to be dismounted from their current location. It may be necessary to build new electronics for extended use in MINOS. Finally, the existing gas system may require refurbishment for use in MINOS. The cost for these items are the the effective "production costs" for this system.
2. The efficiency of this system as a veto shield is already well understood from Soudan 2 experience.
3. The proportional tubes would likely need to be installed transverse to the hall axis in order to keep local veto rates sufficiently low. This is somewhat less optimal than is possible using the MINOS scintillators.
4. We would need to maintain a gas system and separate electronics readout system and then match those events with the MINOS electronics.
5. The relative efficiency per plane will be less. This may require more planes of detector at all locations with more total readout.

A final possibility is to use a hybrid approach where a layer of MINOS scintillator provides fast timing but a layer of Soudan 2 tubes provide additional veto efficiency.

6 A reference shield design

Here, we present a reference design for the veto shield. We choose MINOS scintillator components only for this purpose but we plan to fully evaluate the proportional tube option as well.

The reference design consists of the following:

1. The Top Shield: The top of the detector will be covered with two layers of MINOS scintillator modules. The modules will be supported on an iron-tube structure which will be supported in turn by the support structure for the MINOS planes and in part by the planes themselves. The supports will be installed transverse to the axis of the hall and above the top of the detector. The top layer will be shaped so that the existing access bridge which runs on rails over the top of the detector may continue to be used. It will be used for installation of the shield. Figure 1 shows a drawing of the detector with the proposed locations for shield components. The scintillator modules will run parallel to the axis of the detector hall. A total length of two 8 meter modules is required to cover the length of each half of the detector. We will study whether one or two layers is necessary in this location. A single layer requires the equivalent of 6 planes of scintillator detector components or 1.2% of the far detector. Hence, a double layer is equivalent to 12 planes or 2.4%.
2. The Upper Side Shield: The shields on the sides of the detector are split into an upper section and a lower section. This is necessary due to the support structure and walkways along the sides of the

Item	Cost ($k)	Comments
Scintillator Modules	208	Includes scintillator and WLS fiber
Readout Components	172	Clear fiber cables, PMTs, electronics
Support structure and installation	80	(includes 50% contingency)
Total	460	

Table 1: Costs for the reference design shield.

detectors. The solid angle coverage, fractional detector coverage and associated muon flux are smaller for the side shields than for the top shield. Hence, the side shields will be only a single layer (subject to confirmation that this is adequate). Like the top shield, the length of 2 8 m scintillator modules will provide coverage for each supermodule. The upper side shield is located near the cavern walls above the upper catwalk. This is equivalent to 6.5 planes or 1.3% of the far detector.

3. The Lower Side Shield: The lower side shields are located between the detector and the support structure below the support ears of the steel. Like the upper shield, it is a single layer two module in length and 4 modules high for each side for each supermodule. This is equivalent to 6.5 planes or 1.3% of the far detector.

7 Cost for the reference design

Based on actual production costs, we have estimated the full cost of the reference veto shield. These are shown in table 1. The cost for components is about 1/2 for scintillator modules and 1/2 for all of the readout components (clear fiber cables, PMTs, PMT boxes, electronics). The costs presented here include all overheads and are estimated based on well-known production costs. These costs do not include contingency which for production of known parts should not be substantially different than the current estimate of necessary contingency on the estimate-to-complete.

8 The prototype shield

The prototype shield is designed to demonstrate that the full shield will be able to reduce the rate of contained events to a level which is consistent with the rate of those induced by neutrino interactions. In addition, it will definitively answer the question whether the background to the contained event sample will be no more than 10%.

8.1 Description of the prototype

The principal component of the prototype shield will be a single layer of shield which will cover 1/2 of the first supermodule. This is the minimum amount of the full shield which can be implemented yet still provide

Item	Number required	Fraction of Fardet	Comments
Scintillator Modules	36	0.8%	Mix of 20 and 28-wide versions
Clear Fiber Cables	72	0.8%	Appropriate lengths for module
Hamamatsu M16 PMTs	14	1.0%	
PMT Boxes	6	1.2%	Special built boxes. Cost paid o
Front-end electronics	6	1.2%	boards and cables
Readout electronics	4	1.2%	VARC boards fit into existing V

Table 2: Components needed for the prototype shield.

complete coverage of the detector. The complete coverage is important to be able to adequately demonstrate that contained event backgrounds are reduced to an appropriate level. In addtion, a double-layer consisting of 5 scintillator modules will be installed on the top in order to test the correlated efficiency of two planes together.

We propose to borrow existing scintillator system components to implement the prototype. Table 2 lists the components which need to be borrowed for use in the prototype. All components will be used in a non-destructive way so that they can later be deployed in the main detector as planned. In order to provide the complete coverage of the detector, we therefore propose to install 1/4 of the support structure necessary for the reference shield.

The support structure on the top of the detector consists of a total of 5 tubular steel structures with appropriate cross-bracing as shown in the appendix, "Prototype Veto Shield Construction". The structures are supported by the top ears of steel planes in the detector and by vertical supports which hold it above the support structure at the sides of the detector. The support structures run transverse to the axis of the detector hall at a pitch of 2m. The modules simply sit directly on the support structure supported directly by the steel tubes every 2m. They are clamped at the ends and middle to keep them from moving.

The support structure on the sides of the detector consist of vertical steel channels which are located every 2 m along the length of the modules. The modules will be bolted to the channels using brackets which hold the module at the top and the bottom at each vertical support location.

Readout clear fiber cables will transmit signals from the module ends to PMT boxes located in racks near the ends of the modules. There is room in each of the PMT racks to add additional boxes. The PMT boxes will be specially "wired" inside to route the fibers from 8 contiguous scintillator strips to a single PMT pixel. Since these will be different than the normal PMT boxes, we will pay for their construction off-project. Many of the components in the box can be recovered for reconstruction as regular boxes in the future, but the routing of fibers from connectors to cookies would have to be completely redone. The electronics will be identical to the current readout electronics and will trivially fit into the existing systems by just adding additional modules.

8.2 Implementation and installation of the prototype

We plan to stage the implementation of the prototype veto shield in the following way:

1. Fabricate and install top support structure by May 6.
2. Install single top layer of scintillator modules by May 13.
3. Install upper sides by May 20.
4. Install lower sides and partial double layer by May 28.

None of the installation work will impact on the rate of the ongoing installation of scintillator planes. All technician manpower for shield fabrication and installation will be accounted separately from project work and paid for from various university funds. All special materials required will be purchased from university funds.

The fabrication of the steel tube structure will be done by the surface crew at Soudan. The underground mechanical installation will be done by a combination of mine-crew and university technicians. The hookup and testing of the readout will be done by physicists. We will schedule installation work using any minecrew as overtime activity if there is any interference with maintaining the installation schedule for the detector.

Additional details of some of the planning for installation of the prototype shield may be found in the accompanying construction document in the appendix.

8.3 Safety issues in the prototype

Other than safety concerns which are a part of the usual operations at the mine, we have identified the following issues which have some differences with the veto shield that are worth consideration:

- The support structure: We need to make sure that the support structure has appropriate strength and rigidity. The scintillator modules are quite light, only about 200 pounds per module and the corresponding support structure is quite simple. However, we are having the design reviewed by two sets of mechanical engineers to assure that nothing has been missed and it will be reviewed by the Soudan Safety committee. We welcome additional Fermilab safety review if that is deemed necessary.
- Possible damage during installation: It is possible that some clear fiber cables in the detector, or possible even protruding scintillator end manifold could be damaged during installation by being struck with a piece of support structure as it is being installed. Any such damage must be quite local. Clear cables can be replaced and are the most likely thing which might be damaged. Modules are actually quite robust and we anticipate nothing worse than a light leak which would need to be repaired. However, we will exercise particular care in this activity to avoid any damage. Installation of the modules also presents some possibility of damage, but probably only

Item	Cost ($k)	Comments
Parts for support structure	3	Steel tubing, brackets, bolts
Welder and labor for fabrication	7	surface and underground
Installation of support structure	6	After all welding is done
Installation of scintillator modules	7	Mine crew or university tech's
Fabrication of special PMT boxes	4	Most parts re-usable
Engineering and planning costs	4	
Total	28	

Table 3: Costs for the prototype shield.

to clear cables which can be replaced. Should any cables be damaged, we will pay for replacement cables and the manpower to make the replacement off-project.

- Installation of the shield above the detector covers the central detector from overhead water sprinklers. Because all of the scintillator is completely enclosed in aluminum casings it is our analysis that this does not present any additional fire hazard. Minnesota code officials have preliminarily concurred that this installation is acceptable.
- During the installation, there is a danger that a person working on the access bridge could fall. The danger is not different than if accessing the top of MINOS but the amount of time needed for such access is relatively large compared to normal work on planes. However, we do have such experience and a clear set of procedures have been implemented to ensure work in this area is done safely.

8.4 Costs for the prototype

We note that the funding for implementation of the prototype will be completely off project. Since we plan only to borrow the scintillator system components, the costs are just for the support components, the manpower for fabrication of the support and the manpower for installation. Here, we identify the expected costs for the support fabrication and manpower for installation in order to provide a view that the total work involved is not large and hence we do not anticipate that it has a significant potential for distracting workers from the main task at hand. The estimated costs for the prototype are shown in table 3.

All work done by mine crew at Soudan will be accounted separately on University of Minnesota accounts which are not associated with the project. While some of the work may be accomplished during normal installation hours, all time spent on the shield work will be accounted separately from project installation work. Much of the work will be accomplished as overtime. Since the crew work a 4-day week, this is relatively easy to arrange.

Several of our university groups have pledged adequate funds to pay for the prototype shield costs.

9 Summary

Preliminary data show that a veto shield will be very important to analysis of contained atmospheric neutrino events in MINOS. The MINOS scintillator components present an attractive means for construction of this shield, but production is ending soon. Hence, if we wish to take this opportunity we must act quickly to decide to implement the shield. A prototype built with borrowed scintillator components can be installed on a short time-scale and at no cost to the NuMI project. We request permission from Fermilab and project management to borrow the necessary components and to make the installation above and around the detector.

References

[1] P875: A Long-baseline Neutrino Oscillation Experiment at Fermilab, The MINOS Collaboration, February 1995.

[2] Atmospheric Neutrino Flux Above 1 GeV, V. Agrawal, T. Gaisser, P. Lipari, T. Stanev, Phys.Rev.D53 (1996) 1314.

[3] Study of the Atmospheric Neutrino Flux in the Multi-GeV Energy Range, The Superkamiokande Collaboration (Y. Fukuda etal.), Phys.Lett.B436 (1998) 33.

[4] Neutrinos as the Messengers of CPT Violation, G. Barenboim, L. Borissov, J. Lykken, A. Smirnov, Submitted to Phys.Rev.Lett. hep-ph/0108199.

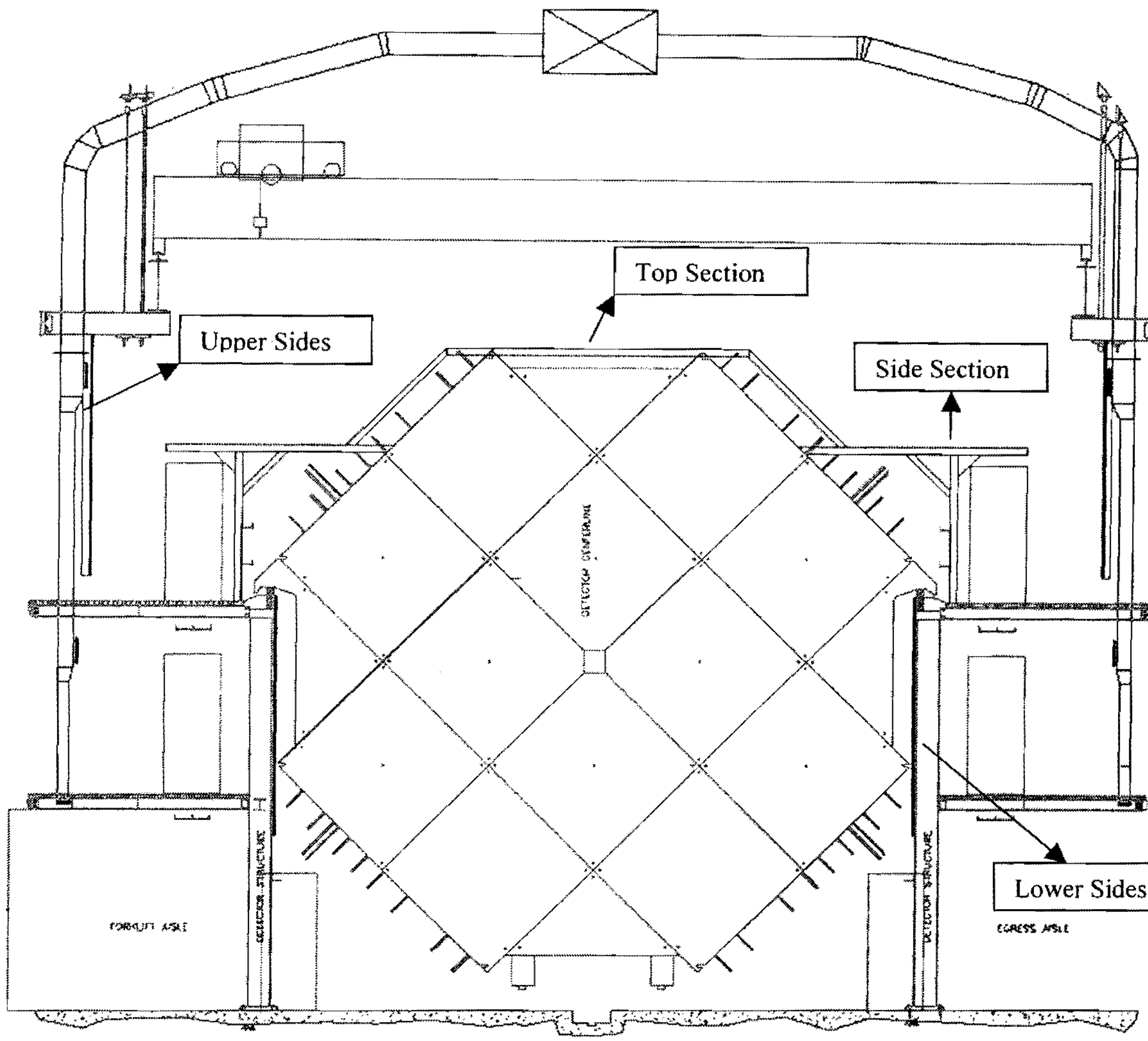
[5] Probing CPT Violation with Atmospheric Neutrinos, S. Skadhauge, hep-ph0112189.

[6] CPT Violation and the Nature of Neutrinos, G. Barenboim, J. Beacom, L. Borissov, B. Kayser, hep-ph/0203261.

Figure 1: Please see figure 1 in the appendix. The locations of shield components around the MINOS detector. The shield consists of a top section, upper side sections and lower side sections. The top section consists of a central part, and wings on each side of the detector. The top shield is designed to continue to permit use of the access bridge to the top of the detector and shield.

WHM April 15,2002

Appendix: Prototype Veto Shield Construction



Cross section view of Prototype Veto Shield

Overview:

This design uses existing technology and materials used in the MINOS detector leaving little engineering costs. All materials being used in the support structure are readily available stock items. None of the support structure is permanently welded in place, so it can be removed if needed. All welding is done on the floor away from the detector to eliminate any potential damage. Limited drilling (mounting screws for scintillator and diagonal brackets) is needed in the detector area and metal chips can easily be caught.

All man-days are based on our standard 10-hour working day.

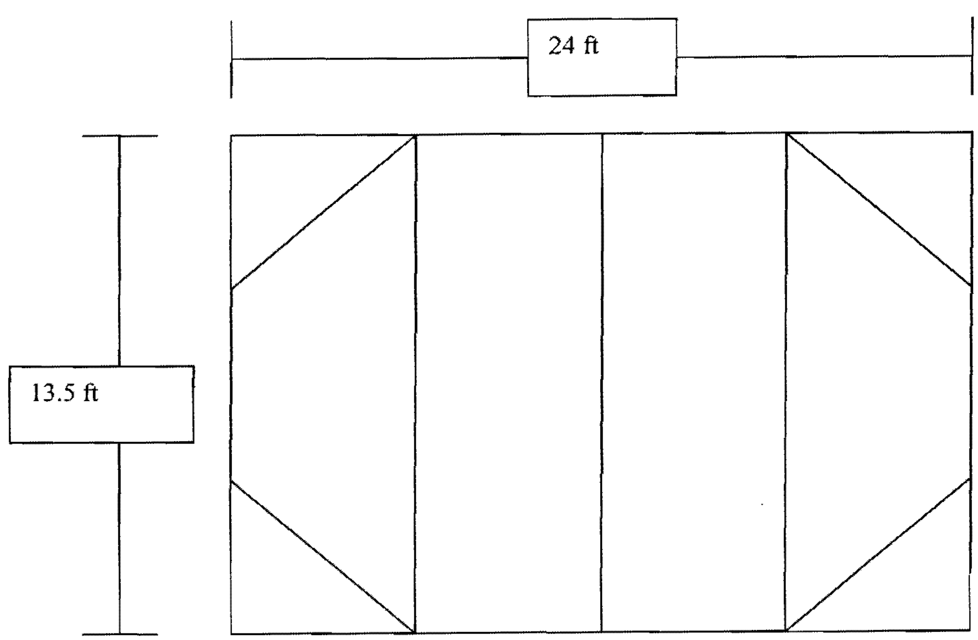
Top section support structure:

The construction of the top section uses 1 ½" x 4" x 1/8" structural tubing. It is a simple joist and rim joist design, which is welded together. The east/west running pieces must be custom fit to insure the raft remains level when completed. A welder and assistant do this work via our access bridge. One of the important features of this design allows the access bridge (which is adjustable vertically) to still allow access to the veto shield was well as the main detector if needed. Modules in the veto shield would be only clamped in place so could be moved if needed. So far after 168 planes access has not been needed at all once the planes are light tight. Scaffolding must be set up at the south end of the detector to allow access when final placement of the raft of steel tubes is put in place.

Each east/west joist has two 2 inch 45° notches welded into it at the proper location at the axial rod bolt ears just over 9 feet apart. These notches can be insulated from the detector steel if needed. This insures that the detector modules and cables can't be damaged and that nothing can move once it is in place. Once the five 60 lb joists have been fitted from the access bridge they are lowered to the floor and welded together. Diagonal braces are added to the corners to stiffen the raft up. Brackets are welded every 6 ft to attach the diagonal support tubes that attach the top and side support structures together.

Once the raft is completed it is hoisted into position with the 25-ton crane. It is lifted using 4 identical slings to insure that it is level when being put in place. 3 minecrew are needed for this task. Two will be stationed on the south scaffolding where it is their task to line everything up as it is slowly lowered into place. The 3rd minecrew is a crew boss that is experienced in the careful crane operation needed to make the lift. He is stationed in the man-lift on the north end of the detector. Since the detector is now 35 ft long he can't help guide the 24 ft long raft but has an excellent view of its movement. The total weight of the raft (700 lbs) and 10 modules (200 lbs each) is approximately 2700 lbs.

Top Section Structural Tube Layout



Manpower estimate top section: Total-6 10 hr. man-days

Welder	**1 ½ man-day**
Welder Assistant	**1 ½ man-day**
Crew Boss	**1 man-day**
2 Lab techs	**1 man-day each**

View looking north over detector top

Side section support structure:

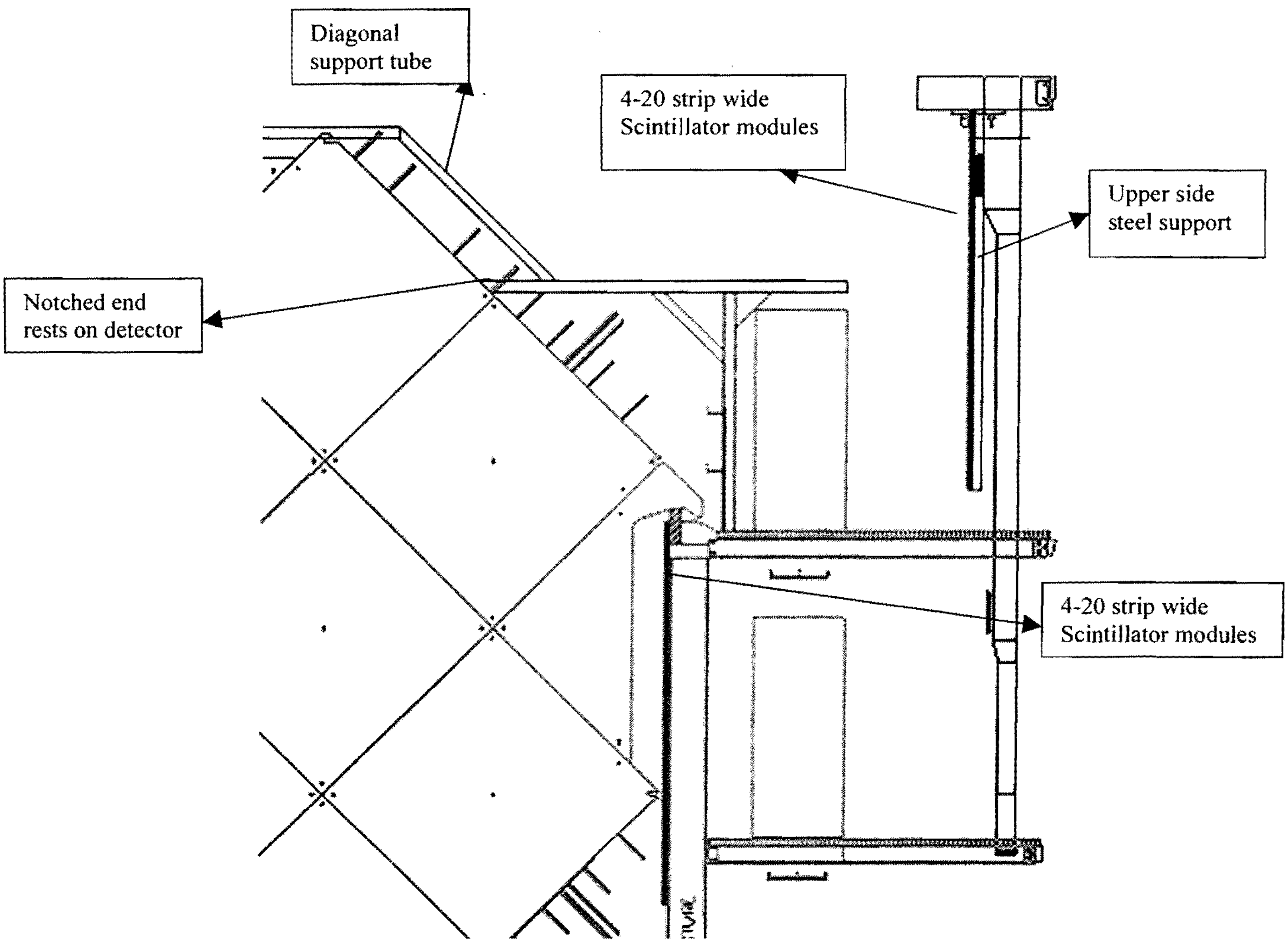
The side section is constructed from 2" x 4" x 1/8" structural tubing. The first of 10 post sections is custom fit and then the rest are duplicated. A bracket is welded on the end of the horizontal tube so a rim joist can be bolted in place once all the posts are installed. The base of the post is bolted directly to the floor. The support structure lines up with the existing handrail posts and is clamped to it at the top using a large u-bolt. The horizontal tube on the detector end has a special notch welded in the end that slips over the 1" thick detector plate steel. The notch will need to be adjusted so that it rests on the detector planes at each location. An non-magnetic layer can be added if needed to keep the magnetic flux of the detector running down the support.

It will require 3 minecrew to put each 105 lb support structure in place. Two crew guiding it in from the upper deck and 1 guiding the notch onto the detector from the access bridge.

Diagonal support structure:
Once the side structure work is completed the 32 lb diagonal supports that attach to the top and side sections may be put in place. The top end of the diagonal support bolts into the brackets on the to section. The bottom end rests on the side supports horizontal tube. It is bolted into place with a cleat so that it can't move. All of this work must be done from the access bridge and will require 2 minecrew.

Manpower Estimate: Total-10-10 hr. man-days

Welder	**2 man-days**
Welder Assistant	**2 man-days**
3 Lab techs	**2 man-days each**



Upper side support:

The upper side supports are 2" x 4"x 1/8" structural tubes that are bolted via bases at the floor and attached to the bottom of the large crane beam via beam clamp. (The upper side steel support shown goes all the way to the upper deck) The spacing of the tubes is the same as the spacing on the h-clips on the scintillator modules approximately 6 ft apart. At the appropriate level to hold 4-20 strip wide modules as close to the top crane supports as possible a 1 ½" x 4" x 1/8" x 24' tube is bolted. This supports the weight (800 lbs) of the 4 modules. At the top of the modules a small hole is drilled and tapped for a small flat-headed screw to hold each h-clip in place. The next module is then dropped into the interlocking h-clips and again attached at the top.

Lower side support:

The lower side support structure is more difficult to put in place due to the large number of cables and relay racks in place. Support is similar to the upper section with vertical tubes in the proper location so h-clips can be attached. Again a 1 ½" x 4" x 1/8" x 24' tube is used to support the weight of the modules. The frame is bolted in place piece by piece but can be made on the floor where access is easier. Modules are attached the same as the upper sides.

Manpower Estimate: Total-7 10 hr. man-days

Welder	**1 man-day**
Welder Assistant	**1 man-day**
Crew boss	**1 man-day**
2 Lab techs	**2 man-days each**

Installing scintillator modules:

Top section-10 modules, double layer:

The top section is the hardest since we only have access on the south end when modules are being lifted. We can place 3 ft long roller bars on the top section east/west tubes and a bracket supported from the scaffolding. We must use our clip style module mover attached to the 25-ton crane. Each module must slowly be lowered onto the roller bars from the south so that clips can be removed as the crane moves north. Once the module is resting on the top section it can slide into place using the access bridge and scaffolding. This will require a crane operator (as he can get another module while the last one is being put in place) two minecrew on the scaffolding and two on the access bridge. It will take about 30 min. per module to get into its final position. Once they are all in place the outside modules are clamped so that they can't move.

Side and diagonal sections-10 modules, single layer:

The sides are very easy as access is possible along the upper deck. The diagonal ones will be a little tricky as we only have access from the south end. We can't use the access bridge since there is not enough clearance to allow the module to go from horizontal to 45°. We can use ropes from the opposite side of the detector to help pull up and push poles from the deck to get them in place. It will take at least 5 minecrew for this task, but it is only 4 modules. Figure on 1 hour per tube for these hard ones. The horizontal will be very easy and should only take about 15 min each and use 3 minecrew.

Upper and lower sides-16 modules, single layer:

Both upper and lower modules will be placed using the same technique. Two 24 ft long double Uni-strut rails will be beam clamped into place. Roller hooks with pulleys and ropes will move in these channels. Once a module is lifted onto the upper deck 5 minecrew will lift it on edge and attach the ropes to each h-clip. The module is raised to the proper elevation and slowly rolled into position. One at a time the ropes are removed and the bolt that holds the module in place is added. This is slow work but easy, estimate 20 min. per module. On the upper sides and 30 min. on the lower. Including setup time assume that it takes one full day to position modules.

Manpower Estimate: Total-10 10 hr. man-days

Crew Boss	**2**	**man-days**
4 Lab techs	**2**	**man-days each**

Cabling and electronics:

Visiting physicists can do all cabling and electronics hookup with very little help needed from the minecrew. Simple safety instruction will allow them use the access bridge for the access needed. Light tightening the cable connections will be a hard slow task lying on the access bridge but we have done this task before and it is doable. Each connection on the top and side support sections will take about ½ hour and require a second person to help route the cable. There are 40 connections so this task will take several days.

Cost Summary:

Manpower is based on normal 10-hour working days and multiplied by 1 ½ to assume that all time is worked at OT. Manpower wage includes fringe, J & A and contingency are added in separately.

Manpower estimate:		**OT Wages**	**50% contingency**	**Total**
Welder/Crewboss	**\$25/hr**	**85 hrs x 1 ½ =\$3187.50**	**\$1594**	**\$ 4,782**
Welder Assistant	**\$23/hr**	**45 hrs x 1 ½ =\$1552.50**	**\$ 776**	**\$ 2,329**
Lab tech	**\$23/hr**	**200 hrs x 1 ½ =\$6900.00**	**\$3450**	**\$10,350**
Grand Total				**\$17,461**

Support structure materials:

		Each	
14-24 ft	**1 ½" x 4"x 1/8" tube**	**\$34.68**	**\$ 485.52**
16-24 ft	**2" x 4" x 1/8" tube**	**\$36.29**	**\$ 580.64**
1-24 ft	**4" x ¼" flat bar (bases)**	**\$28.50**	**\$ 28.50**
2-24 ft	**2" x 2" x ¼" angle iron (brackets)**	**\$26.90**	**\$ 53.80**
Misc. bolts and mounting hardware			**\$ 460.00**
Total			**\$1,608.46**
J&A			**\$ 418.20**
50% contingency			**\$1,013.33**
Grand total			**\$3,039.99**