June 2004 Update to the NOνA (P-929) Proposal

Appendix C.
R&D Plans for NOνA Liquid Scintillator Designs

C.1. Overview

Our R&D efforts are now totally focused on liquid scintillator designs for NOνA. We keep the RPC and Solid Scintillator versions described in the March 2004 NOνA proposal as backups only in case some show-stopping problem develops with the liquid scintillator designs. This is not yet an official "technology decision", but does indicate the collaboration's strong desire to pick a final design as soon as possible.

In this appendix we outline the R&D we are doing with FY04 funding, describe our progress to date on various issues, and describe the R&D steps we need to pursue during the next two years. A total of $1 M – $1.5 M of R&D funds would be required during the next two years to advance this proposal at its technically limited pace. In addition we assume contributions of effort from Fermilab and the NOνA collaborating institutions to accomplish the R&D.

C.2. Immediate Priorities

C.2.1. Overview: Given the funding we have available in FY04, we are restricting our immediate efforts to three topics. Our most important goal is to verify the light output level, light collection efficiency, photodetection efficiency and electronics design assumed for the baseline and TASD detectors. Measuring the actual number of photoelectrons detected from the far end of our long extrusions will be the crucial test for this technology.

Secondly, we are pursuing the Cosmic Ray Background Test described in Chapter 10, Section 8 of the NOνA proposal to directly measure the need for an active shield and/or an overburden for the detector. Both these items are large cost drivers. In the TASD design we believe the active shield will just be the outer parts of the basic neutrino interaction detector.

Finally we will continue simulations of the detector response to neutrino interactions and analyses of the detector structural properties.

C.2.2.Light Output, Collection, and Detection:

We have ordered a die for a 3 cell wide version of the PVC extrusion with a cell profile 4 cm wide and 2.5 cm deep. The order includes an extrusion run for about 3500 feet of extruded material with 12% TiO_2 loading. The profile is shown in Figure C.1. We ordered units with lengths of 48 ft, 10 ft, and 4 ft and expect delivery in 6 to 8 weeks.

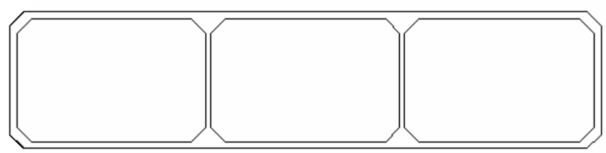

Figure C.1. 3-cell extrusion profile. The exterior wall material is 2 mm thick and the two interior walls are 1 mm thick.

We have also ordered 10 of the 16-channel Hamamatsu S8550 arrays for tests and expect delivery in 1 – 2 months. We still need to order some cooling systems for the APDs. We have some 0.8 mm and 0.6 mm WLS fiber on hand at various collaborating institutions but expect to order additional amounts.

C.2.3.Cosmic Ray Background Test:

Chapter 10, Section 8 of the NOνA proposal indicated that we would do this test with borrowed BELLE RPCs. Given that RPCs are not a favored technology choice, our Cosmic Ray Background Group (composed primarily of RPC enthusiasts) proposed that they change direction towards a scintillator design. It appears that doing this test with liquid scintillator would not be immediately possible since we have yet to establish the final construction techniques for sealing extrusions, building manifolds, or routing fibers, and we do not have in hand the APD readout chain.

It would be a close approximation to do this test with solid scintillator. To this end the NOνA collaboration has officially requested that the MINOS collaboration release their "Four Plane Prototype" detector built long ago in the New Muon Laboratory at Fermilab. We believe we can cut up these 8 meter long prototypes with readout at both ends into enough 3 – 3.5 meter bars with readout at one end. The counters are not useful to MINOS since they were earlier prototypes with low light yield. The light yield may be sufficient for the shorter NOνA application, but we would have to test a few to make sure.

An alternate plan proposed to MINOS is that they release the spare Near Detector and Far Detector modules to NOνA. These spares are made from the final high quality MINOS scintillator. Once all the scintillator has been installed in MINOS, there is no way to replace any part of it, so these spares may be available.

In addition we have recognized that the spare PMTs and electronics for the MINOS Far Detector are the best available readout chain for the NOνA test. This is because the MINOS electronics are designed for the kind of high live time fraction we need in this test to integrate the backgrounds expected in NOνA with a small detector operating for only a few months (see Chapter 10). We have asked MINOS to allow a substantial fraction of their spares to be in hot standby in the NOνA test in Lab E at Fermilab. It is likely that NOνA will have to purchase of order $25 K of additional items for those parts in short supply where the existing spares for MINOS must be kept at the Soudan Mine.

Using MINOS scintillator and readout also exploits the substantial overlap between collaborators on the two experiments and should get the Cosmic Ray Background Test operating earlier. Both groups realize that the MINOS turn-on with beam will have priority.

C.2.4. Simulations:

We plan a simulation effort to understand the physics impact of different choices for the cell widths and in the case of TASD for the cell depth along the beam. We optimized our 4 cm wide cell for the digital RPC design and have not reoptimized for liquid scintillator designs where the pulse height may change the optimization.

We need to further develop our conceptual designs for the support structures for the baseline and TASD detectors. We also need to develop our designs for access to the top and sides of both versions.

C.3. Progress and Longer Range R&D on APDs and Associated Electronics

C.3.1. Progress: We now have a second generation MASDA prototype board with a new low noise voltage regulator and with additional filtering and bypassing in the design. See Figure C.2. Tests of this board with an APD operating at a gain of 100 and at a temperature of -15^0C have demonstrated a reduced noise level of about 360 electrons (rms). This is very encouraging since it meets the level assumed in Chapter 7 of the NOνA proposal.

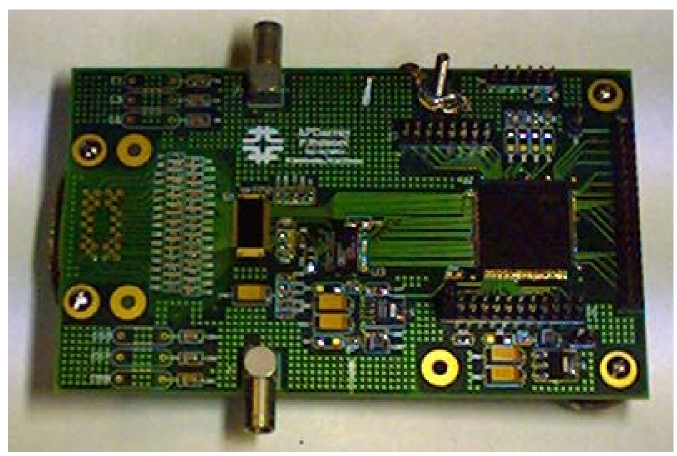

Figure C.2. The second generation APD + MASDA prototype board. The APD is on the back side of this picture on the far left hand side. The MASDA chip is just below the Fermilab logo.

C.3.2. Longer Range R&D: The MASDA chip does a dual-correlated sample. There is now an expectation that multiple correlated sampling as shown in Figure C.3 could reduce the noise level further to as little as 200 electrons with a 10 pf APD. Multiple sampling would simplify the design of the MASDA replacement ASIC being designed by the Fermilab ASIC group. Figure C.4 shows some of the current thinking.

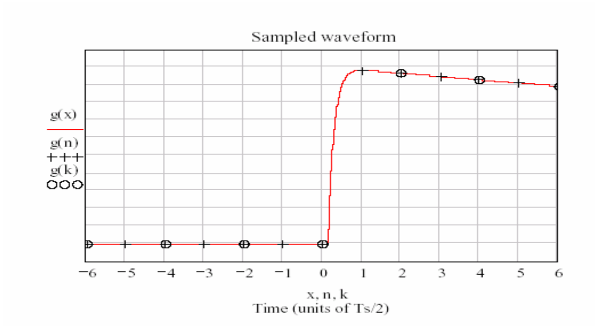

Figure C.3. Multiple correlated sampling scheme.

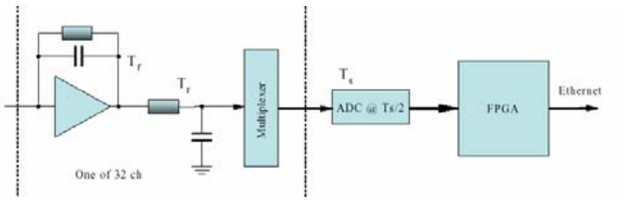

Figure C.4. Multiple correlated concept with the ASIC chip on the left side (between the dotted lines) and the board components on the right side.

The ASIC design process at Fermilab will begin in August 2004 and end with a prototype ASIC submission in January 2005. The chips would be back in April 2005 for testing. The submission would most likely be in the 0.25 micron process and yield about 40 prototype chips for about $30 – 35 K. Additional chips could be obtained in the same submission for additional cost.

For the APDs themselves the next R&D step is to pursue our contacts with Hamamatsu to work in the direction of using their bare APD die in combination with the Fermilab ASIC inside one package.

C.4. Progress and Longer Range R&D on Wavelength Shifting Fiber

C.4.1. Progress: We have simulated various fiber and cell configurations using a program which traces the path of individual photons and takes into account their reflection, transmission, or absorption in the walls, fibers, and liquid. Figure C.5 shows some of the fiber positions studied. In all cases for the TASD cells (3.8 cm by 4.5 cm) and in most of the cases for the baseline cells (3.9 cm by 2.6 cm) the light collected from four 0.5 mm diameter fibers is slightly greater than or equal to the light collected from two 0.8 mm diameter fibers as assumed in our designs of Chapter 7 and Appendix B. Since the cost of fiber should scale as the volume of fiber, and therefore as the square of the diameter, there is a potential savings of about 20% here with the smaller fiber if we can confirm the simulation. Both 2 x 0.8 mm and 4 x 0.5 mm WLS fibers fit easily onto the 1.6 mm x 1.6 mm APD pixel.

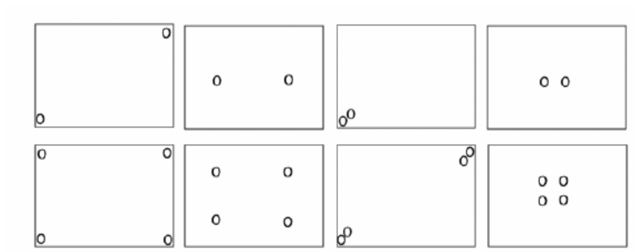

Figure C.5. Possible positions of WLS fibers as simulated inside a PVC extrusion cell. The top diagrams are configurations studied with two 0.8 mm diameter fibers, the bottom diagrams are equivalent positions studied with four 0.5 mm diameter fibers.

C.4.2. Longer Range R&D: Clearly we wish to study the four 0.5 mm fiber vs. two 0.8 mm fiber designs with real fibers in real extrusions. In addition we are just beginning studies of fiber aging in the liquid scintillator. The plan is to study multiple loops of different diameter fibers in high temperature tests and in tests with temperature cycling.

C.5. Progress and Longer Range R&D on Liquid Scintillator

C.5.1. Progress: Our baseline and TASD cost analyis assumes we use a liquid scintillator like Bicron 517L which is a mix of 10% pseudocumene (+ trace amounts of the waveshifters PPO and POPOP) and 90% mineral oil. We have recently understood [1] the Bicron specification for light output from their fluor mixes as shown in Figure C.6.

Previous experiments have used a wide range of pseudocumene concentrations, ranging from a low of 5% in MACRO [2] to a high of 36% in Palo Verde [3]. Since the cost of liquid scintillator is dominated by the cost of the fluor (pseudocumene) and waveshifters, sacrificing some light may result in a substantial cost savings.

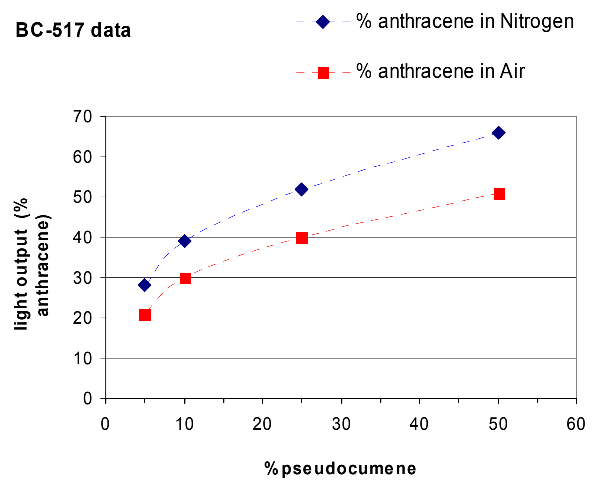

Figure C.6. Light output (% anthracene) as a function of % pseudocumene.

C.5.2. Longer Range R&D: We intend to explore these fluor + waveshifter mixtures in combination with the fiber diameter and extrusion cell cross section. Less light from a lower cost fluor can be compensated by different WLS fiber diameter and by the extrusion cell size and of course also by the extrusion cell length. Initially this is a search in multidimensions seeking a cost minimum.

In the longer run we intend to test the relative light output of fluors and waveshifters in mixes we contol. We are setting up a simple test cell and will scan the pseudocumene component in the range 3% to 15% along with the PPO component in the range 0.1 - 2.5 g/l and the POPOP component in the range 1/500 – 1/2000 of the PPO concentration.

We also will investigate liquid scintillator handling techniques. The extrusions on order will be used to investigate whether trapped bubbles in the horizontal cells could be a problem. We will explore filling techniques, local buffering of the liquid during the construction phase, and QA issues related to the large number of individual truckloads of liquid scintillator expected.

C.6. Progress and Longer Range R&D on Extrusions

C.6.1. Progress: As reported above, we have ordered 3-cell extrusions with the baseline detector profile. In addition to understanding the light detection in long extrusions, we will use these prototypes to design bottom seals, top manifolds, and connections between the extrusions panels. Figure C.7 shows a concept for using the outside of the chamfer for fill welding of the PVC using hot air machines that operate at 300^{0}C and stick weld with a PVC rod melted separately. Speeds of 2 feet per minute are normal. Skip welding along the groove is possible. Similarly adjacent vertical and horizontal extrusion panels could be tack welded to one another at the overlap of the exterior chamfers.

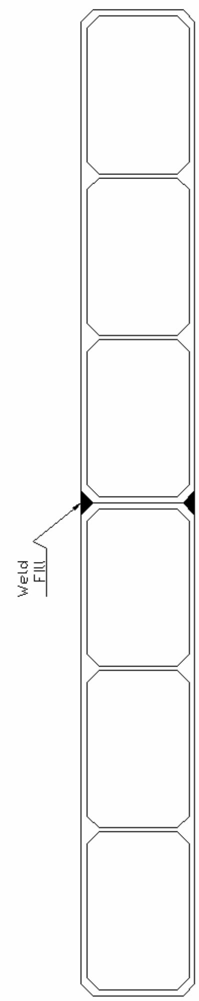

Figure C.7. Two 3-cell extrusions welded together.

C.6.2. Longer Range R&D: Our structural calculations have relied on the properties of rigid PVC which contains some TiO_2, but not in the concentrations we need for good reflectivity (10-15%). We plan to test the 3-cell extrusion material for its elastic properties with 12% TiO_2. We also need to learn about its long term creep under stress, if any. We particularly need to understand if the material suffers from creep rupture.

We also plan to investigate the thermal expansion properties of TiO_2 loaded PVC. Thermal expansion has an impact on the overall structure (do we need expansion joints?). We also must understand PVC thermal expansion relative to the thermal expansion of liquid scintillator.

Eventually we will need to take the next step in R&D and procure a 30 – 32 cell wide die with a second generation cell profile. These dies are expensive (estimated at about $250 K), but needed for bonding studies and for handling studies to finalize a construction scheme and understand the detector cost in more detail.

C.7. Progress and Longer Range R&D on the Detector Support Structure

So far our concept for the detector support structure includes a network of I-beams underneath the detector to allow access to the bottom (see Chapter 11, section 4). For TASD PVC this is a different structural question than those considered so far because the idea is to concentrate the load on less than the full bottom surface in order to allow access to other parts of the bottom surface. In the case of the baseline detector we believe we can support the weight on one-third of the bottom edges of particleboard. We need to understand if and how one can do this in the TASD case.

These support structure studies are really studies of how to gain access to the detector periphery. Studies are planned to develop concepts for personnel access to the top and sides of the detector where the electronics will reside and make connection to the WLS fibers.

Appendix C References

[1] Saint-Gobain Crystals and Detectors, Newbury, Ohio, private communications on BICRON products BC-517S, BC-517H, BC-517L, and BC-517P.

[2] R.M. Heinz et al., Nucl. Instrum. Meth. A281 (1989), 213-215.

[3] F. Boehm et al., Phys. Rev. D62, 072002 (2000).