

NO ν A detector technology with initial performance from the surface prototype

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Abstract. NO ν A, the NuMI Off-Axis ν_e Appearance experiment, will study $\nu_\mu \rightarrow \nu_e$ oscillations characterized by the mixing angle θ_{13} . Provided θ_{13} is large enough, NO ν A may ultimately determine the ordering of the neutrino masses and measure CP violation in neutrino oscillations. A complementary pair of detectors will be constructed ~ 14 mrad off beam axis to optimize the energy profile of the neutrinos. This system consists of a surface based 14 kTon liquid scintillator tracking volume located 810 km from the main injector source (NuMI) in Ash River, Minnesota and a smaller underground 222 Ton near detector at the Fermilab. The first neutrino signals at the Ash River Site are expected prior to the 2012 accelerator shutdown. In the meantime, a near detector surface prototype has been completed and neutrinos from two Fermilab sources have been observed using the same highly segmented PVC and liquid scintillator detector system that will be deployed in the full scale experiment. Design and initial performance characteristics of this prototype system are being fed back into the design for the full NO ν A program.

1. Introduction

NO ν A, the NuMI Off-Axis ν_e Appearance experiment will study $\nu_\mu \rightarrow \nu_e$ oscillations at a baseline of 810 km (L/E of 400 km/GeV). Provided θ_{13} is as large as early indications from the T2K experiment [1], NO ν A will have the reach to determine the ordering of the neutrino masses and constrain the CP violating phase, δ [2]. Additionally, NO ν A will study the differences in oscillations of neutrinos and antineutrinos, as well as make a precision measurement of θ_{23} by observing the muon neutrino disappearance.

Achieving these goals requires a detector with 14 kTons of material capable of suppressing ν_μ charge current (CC) and neutral current (NC) backgrounds at the 99% level. Additionally, good ν_e detector efficiencies and energy resolution less than 8% of the expected signal width for ν_e CC event are required [2].

2. Experimental design

2.1. Beam

To achieve the goal of the NO ν A project, two detectors will be placed 14 mrad off-axis to the primary direction of the NuMI (Neutrinos from the Main Injector) source. As shown in Figure 1, the ν_μ flux near the first $\nu_\mu \rightarrow \nu_e$ oscillation maximum at around 2 GeV is optimized at this

angle [2]. The off-axis beam also reduces high energy neutral current background events. To accommodate the needs of the experiment, the NuMI beam power will be upgraded to 700 kW during the shutdown of the accelerator from March to December 2012.

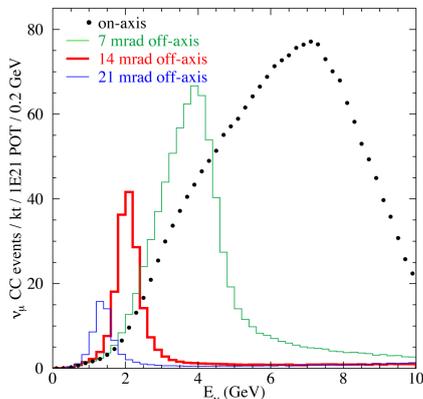


Figure 1. ν_μ CC energy distribution for off-axis angles with medium energy tune [2].



Figure 2. Photograph of the NO ν A Near Detector On the Surface.

2.2. Detectors

The NO ν A detector system consists of a complementary pair of detectors constructed 14 mrad off-axis to the NuMI source. Both detectors will be highly segmented tracking calorimeters built entirely from low Z (~ 0.15 radiation lengths per layer) PVC, glue, and mineral oil based liquid scintillator with a 65% active volume [2]. The far detector will be a surface based 14 kTon volume located 810 km from NuMI in Ash River, Minnesota. A smaller 222 Ton unit will be built 1.1 km from the source at Fermilab in a 105 meters deep underground cavern.

3. Near and far detector status

Beneficial occupancy of the far detector facility was obtained in April 2011. Construction of the far detector at Ash River is scheduled to begin in the first quarter of 2012 with a goal to have a detector segment in place before the Fermilab accelerator shutdown. The full detector is on track for completion in the first half of 2014.

Excavation of the underground cavern for the near detector will also begin following the beam shutdown. In the meantime, a near detector surface prototype (NDOS) has been completed and neutrinos from both the NuMI and Booster sources at Fermilab have been observed using the same highly segmented PVC and liquid scintillator detector system that will be deployed in the full scale experiment. This prototype has been taking data since October 2010. The initial performance characteristics of this prototype system are highlighted in the text below.

3.1. PVC cells

The NO ν A detector is built up from extruded TiO₂ loaded PVC cells [2]. Each cell is 3.8 cm by 5.9 cm in cross section with 90% reflectivity for light at 430 nm. Extrusions are joined together to produce a sealed module of 32 cells. In NDOS, the modules are either 4.2 m (vertical orientation) or 2.9 m (horizontal) long while far detector modules are 15.6 m long. These modules are glued together into alternating planes of horizontal or vertical orientation to create self-supporting 32 layer blocks. $\sim 360,000$ cells make up the 14 kTon far detector.

Six blocks were constructed along with a 1.7 m muon ranger (Fig. 2) for NDOS. Building the NDOS fully exercised the quality assurance/quality control (QA/QC) techniques in preparation for full production running for the far detector. This process revealed cracks in $\sim 20\%$ of the manifold covers. These covers have been repaired and a new more robust design will be used for future production. 1200 far detector sized sized extrusion have been produced to date.

3.2. Liquid scintillator

PVC blocks are filled in place with a “home brew” of mineral oil containing 5% pseudocumene and wavelength shifters to produce 400-450 nm light. The liquid scintillator makes up 65% of the total detector mass [2]. The scintillator is required to have 80% of the light output of commercial Bicron BC517P at 1 meter. NDOS required $\sim 30,000$ gallons of scintillator while the 14 kTon far detector will use over 3 million gallons.

Oil work at NDOS gained us experience in the filling process. Some internal module obstructions were observed during filling; the causes of these has been resolved. $\text{NO}\nu\text{A}$ has currently taken possession of around 100,000 gallons of the oil that will be used for the far site.

3.3. Fiber

Internal to each cell is a 0.7 mm diameter looped fiber. The fiber shifts the light collected in the scintillator to 490-550 nm [2]. The fiber ends are routed through the manifold covered to an optical connector where they are available for single sided readout. ~ 113 km of fiber is used in the near detector design with 13,000 km needed for the far detector.

NDOS fiber handling allowed us to overcome tangling problems related to spooling techniques. We have also learned to measure the fiber performance in real-time as modules are strung. We have received nearly 50% of the required fiber.

3.4. Avalanche photodiodes

The light from the fiber ends is incident on Hamamatsu avalanche photodiodes (APD) which have 85% quantum efficiency for 520-550 nm light [2]. The devices are operated at -15°C with a gain of 100. For $\text{NO}\nu\text{A}$ a 20 photoelectron (pe) signal from a minimum ionizing particle at the far end of a far detector sized module is required with a 10-15 pe threshold applied. Based on initial system verification, we expect 38 pe for such a signal, well above the requirement. 496 APD arrays are required for the near detector and about 12,000 are used in the far detector design.

Surface cleanliness and sealing issues have led to many of the NDOS APDs becoming unusably noisy. 274 installed unit have been removed from the detector for cleaning and study. New surface coatings and installation techniques are under study.

3.5. DAQ

The signals from the APDs are processed by front-end electronics (FEBs) which operate in continuous baseline subtraction digitization mode while sampling each channel every 500 ns [2]. 64 FEBs are fed to a Data Concentrator Module which packages and passes the data in 50 μs blocks to a processing farm. The data is then buffered at the farm for several seconds at which point a software trigger may be issued to record available data in a specified window.

For the near detector, a 500 μs trigger window was used with three separate trigger sources; the 0.4 Hz NuMI spill signal, the 1.2 Hz Booster beam signal, and a 10 Hz cosmic pulser. Real throughput capabilities of the DAQ have doubled since initial running. During stress tests of the system, stable running was achieved with a 96% duty factor (80 ms trigger windows at 12 Hz).

4. Results from the prototype near detector on the surface (NDOS)

Analysis of the data from NDOS is in progress. A full suite of available Monte Carlo (masked to behave like our prototype) together with tracking on real data has allowed us to begin to calibrate and reconstruct.

NDOS has collected 5.6×10^{19} protons on target (POT) worth of data in reverse horn current beam and 8.4×10^{18} POT in forward horn mode from NuMI. Analysis of this sample has yielded 1254 candidate neutrino events with 108 expected cosmic background events. Figure 3(a) shows an excess of tracks pointing back to the NuMI source over the out-of-time cosmic background [4]. Similar distributions have been seen in a Booster neutrino sample of 222 event (with 92 expected background events) from 3×10^{19} POT [5].

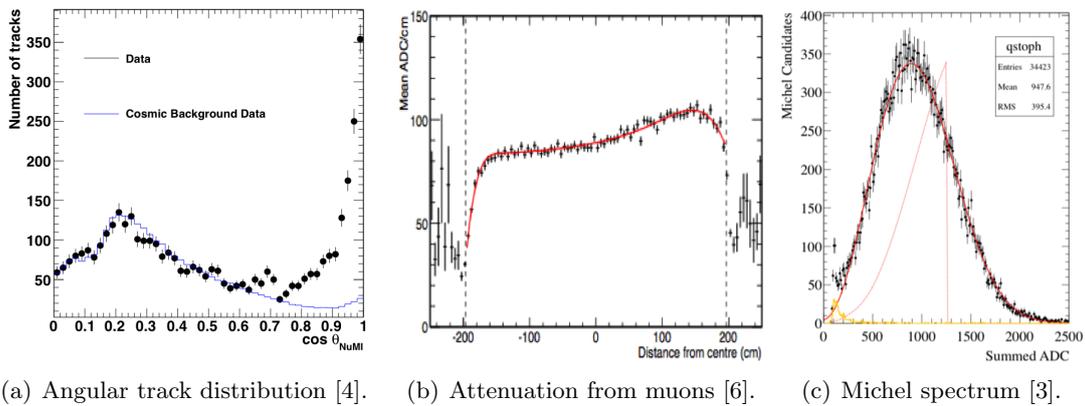


Figure 3. Preliminary analysis of events from the NuMI source and cosmic data in NDOS.

Additional studies have been performed to understand the energy deposited in the detector and its cell by cell calibrations. Figure 3(b) shows the mean ADC value as a function of the distance from the center of the cell from a cosmic muon sample [6]. A sample fit which could be used to calibrate the detector response is shown. Figure 3(c) shows a sample Michel electron distribution which can be compared against expectation from simulation to provide an electromagnetic energy calibration [3].

5. Conclusion

The $\text{NO}\nu\text{A}$ NDOS is taking and analyzing data now. This surface prototype has proved invaluable to all aspects of the experimental program, providing critical feedback for design enhancements and operational experience. Recent results from T2K which hint at a large value for θ_{13} , are very encouraging for the long term physics reach of $\text{NO}\nu\text{A}$ and open the opportunity to make real contributions in understanding the neutrino. The far detector is on track to begin data taking in 2012, with the detector hall construction nearly complete and expected beam upgrades running on time. The support for $\text{NO}\nu\text{A}$ continues to grow with the collaboration now consisting of 110 physicists from 24 institutions in 4 different countries.

References

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