Assessing and Installing Avalanche Photodiodes on the NOνA Near Detector

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Abstract

As of today, scientists suspect that neutrinos played a vital role in the evolution of the universe, contributing to all existing matter in the cosmos. How that evolution occurred still remains a mystery due to our lack of understanding of the puzzling properties of neutrinos. The NuMI Off-Axis ν_e Appearance (NOνA) experiment will seek to find some answers by studying neutrinos in order to understand matters as flavor state oscillation, mass hierarchy, and symmetry between matter and antimatter. Two massive detectors are being used: a 300-ton near detector at Fermi National Accelerator Laboratory (Fermilab) and a 14 kiloton far detector in Minnesota located 810 km away. To actually discern the presence of neutrinos, thousands of avalanche photodiodes (APDs) are utilized to detect light as neutrinos interact with atoms of liquid scintillator. The scintillator light that is emitted will be transferred by wavelength-shifting (WLS) fibers to the photodetectors. Afterwards, the light is then converted into electrical pulses and recorded digitally.

Main Features of NOνA

NuMI (Neutrinos at the Main Injector) Neutrino Beam

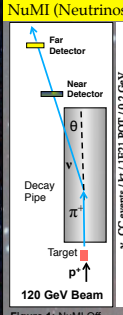


Figure 1: NuMI Off-Axis Beam

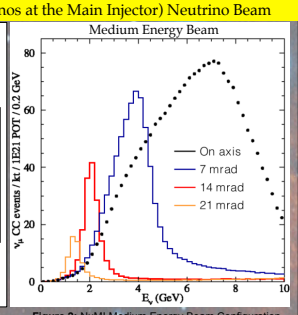


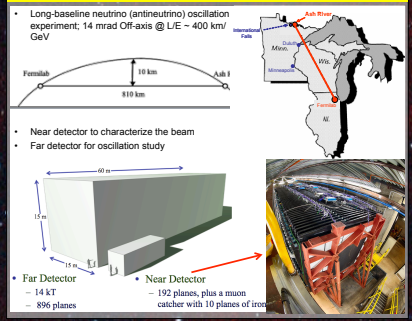
Figure 2: NuMI Medium Energy Beam Configuration

Benefits of Near Detector being 14 mrad off-axis from:

- *Helps create a narrow band beam*
- *Increases flux near oscillation maximum*
- *Reduces high-energy neutral current background events*

The Two Detectors

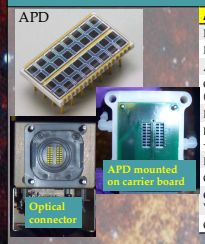
- Long-baseline neutrino (antineutrino) oscillation experiment; 14 mrad Off-axis @ L/E ~ 400 km/GeV



- Near detector to characterize the beam
- Far detector for oscillation study

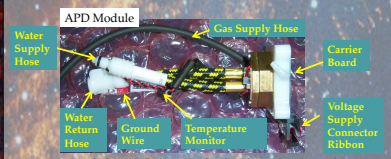
- Far Detector
  - 14 kT
  - 896 planes
- Near Detector
  - 192 planes, plus a muon catcher with 10 planes of iron

The Photodetector



APD Parameters	
Manufacturer	Hamamatsu
Pixel Size	2.3 mm
Array Size	32 pixels
Quantum Efficiency (>525 nm light)	85%
Pixel Capacitance	10pF
Bulk Dark Current (I_B) at -15 °C	0.15 pA
Peak Sensitivity	600 nm
Operating Voltage	400 ± 50 V
Gain at Operating Voltage	100
Operating Temperature	-15 °C

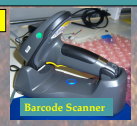
An array of 32 pixels is mated to an optical connector so that each pixel combines with a WLS fiber.

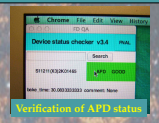


An APD module combines multiple elements in order to maintain a constant temperature of -15 °C, provide dry air to prevent condensation on the pixels, and power up the APD.

Quality Assessment

1.





Visual Inspection and DevCheck: A device check (or "DevCheck") is the scanning of APD barcodes to ensure that APD details are cataloged in a database.

2.

Vacuum and Flow-Through Tests: Dry gas is pumped into the APD assembly so as to maintain low humidity and prevent buildup of moisture on the pixels. Tests are performed to see if APD assembly can maintain pressure and avoid gas leaks when mated to the optical connector. Next, we check to see if gas flows through the tubing to avoid blockages.

3.

Black Box Test: We measure the dark current of each APD to identify malfunctioning devices that draw too much current.

4.

TEC Test: The thermo electric cooler (TEC) cools the APD so as to limit noise on the electronic readouts. We apply power and measure the resistance of the photodetector to see if heat is being transferred from the APD to a heat sink.

Data

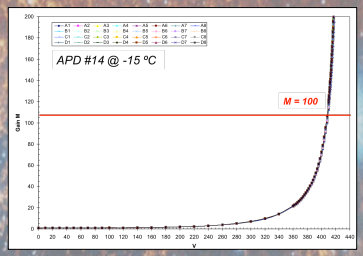


Figure 3: Gain vs. Applied Voltage

The operating voltage (400 ± 50V) produces the desired gain of 100 most efficiently at -15 °C.

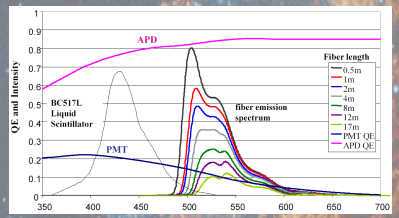


Figure 4: WLS emission spectra/Comparison of APD versus photomultiplier tube (PMT)

WLS fiber emission spectra measured at lengths of 0.5, 1, 2, 4, 8, 16 m, respectively illustrating the shift of the average detected wavelength as attenuation (fiber length) increases. Also shown are the quantum efficiencies (QE) of APD and PMT as a function of wavelength. The PMT is considered a standard and reliable photodetector, but the APD offers a better QE that is essential to the NOνA Project. The emission spectrum of the liquid scintillator is also shown.

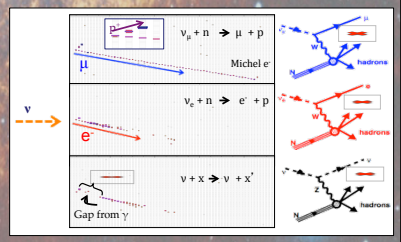
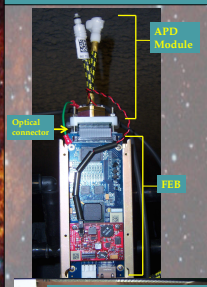
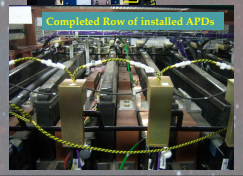


Figure 5: Event Topologies

The readout electronics on the near and far detectors take in signals from the APD, which are then processed and analyzed to produce event topology displays. The near detector almost entirely detects the interactions of muon neutrinos.

Installation





An APD is installed onto an optical connector attached to a front-end board (FEB), which provides a built-in 32-channel amplifier and the operating bias voltage for the APD. After installation, the APDs are turned on in batches and run "warm" to verify that they are operational on the detector. Eventually they will be operated in a cold mode, using the water to remove heat via the TE coolers, so that the signal can be better detected over background noise.

Conclusion

The QA process for 32 APDs can take a day. Installation of a single APD and checks for leaks can be completed within 10 to 15 minutes. Completion of one row from a section can take between four and five hours (32 APDs). Completion of the near detector is expected by the end of August 2014. Through the use of these photodetectors, NOνA will uphold the mission of Fermilab to advance the understanding of matter and energy to a greater degree as the team studies the nature of the neutrino.

References

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