PROCEEDINGS OF SCIENCE

The NOvA Experiment

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NOvA is an off-axis long-baseline neutrino experiment, looking for ν_e appearance in an upgraded NuMI beam of ν_μ to precisely measure the recently discovered θ_{13} acting in subdominant $\nu_\mu \to \nu_e$ transitions. As an appearance experiment, NOvA might also be sensitive to CP-violating δ and the neutrino mass hierarchy. To maximize sensitivity to the resulting $\sim$GeV electromagnetic showers, the 14 kton Far Detector is "totally active", comprised of liquid scintillator contained in 15.7 m long extruded PVC cells, with the scintillation light piped out in wavelength shifting fibers then digitized by avalanche photodiodes. Both near and far detectors were fully completed last fall and have been taking ever more intense NuMI beam data. This talk will highlight progress towards the first NOvA results.

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1. Overview

NOvA is an experiment using Fermilab's NuMI neutrino beam to study neutrino oscillations and interactions [1]. It consists of two similar detectors, a near detector at Fermilab and a far detector 810 km away in Ash River, Minnesota. The detectors are situated 14 mrad (0.84°) off the focusing axis of the NuMI beam: while this comes at the cost of beam intensity, it results in a narrow-band beam of ν_μ centered on the first oscillation minimum near 2 GeV. The NuMI beam has operated routinely with powers up to 500 kW, and upgrades are in place to reach the target power of 700 kW in 2016. The first year's operation has seen 1.7×10^{20} protons-on-target ("pot") delivered to a completed NOvA far detector, part of 5.4×10^{20} in total, part of which was creating neutrinos while the detector was partially built and undergoing commissioning. 90% of this exposure was recorded at the far detector and 96% at the near detector, even while detector construction and commissioning was underway.

2. Goals

NOvA's primary goal is to observe ν_e appearance in the predominantly ν_μ NuMI beam by comparing the neutrino spectra observed at the near and far detectors. Although the primary parameter associated with this oscillation (θ_{13}) is now well measured [2], the fact that it is comparatively large means that the phase of CP violation in the neutrino sector δ_{CP} and the hierarchy of the neutrino mass states are accessible by comparing the oscillations observed in a neutrino beam with those seen in an anti-neutrino beam. These effects are proportional to the number of electrons in the path of the beam, and NOvA has the longest baseline of any accelerator neutrino experiment, giving sensitivity to part of the range of possible parameters. Furthermore, the fact that the baseline and energy differs from that of the T2K experiment in Japan [3] means that comparing the results of the two experiments will result in more sensitivity than either experiment alone. To do this, the plan is to run for three years each with a neutrino then an anti-neutrino beam and compare the differences. If neutrino mass states are arranged in a "Normal Hierarchy" where the solar doublet of mass eigenstates is larger than the third state, there would be an enhancement of the $\nu_\mu \to \nu_e$ appearance caused by coherent forward scattering of $\nu - e$ on electrons in the earth. The "Inverted Hierarchy" would behave in the opposite fashion.

3. The Detectors

The NOvA detectors are constructed to be as similar as possible aside from size: the far detector is 14 kt to maximize statistics while the near detector is 222 t. Both are constructed out of extruded PVC cells 3.9×6.6 cm in cross section filled with liquid scintillator, 15.5 m long at the far detector and 3.8 m long at the near detector. Light is piped out of the cell by a length of wavelength shifting fiber looped to the end of each cell and back, allowing avalanche photo-diodes to digitize the light and record when a charged particle has traversed a cell. The cells alternate between vertically and horizontally oriented to allow for a stereo readout. 60% of the mass of the detector is active, and the low-Z nature of the components allow for a long radiation length of 38 cm, meaning electromagnetic showers can be well resolved from potential neutral current background.

Unlike other long baseline neutrino experiments, the NOvA far detector is on the surface with minimal overburden. Its large size means that the cosmic ray rate is 10's of kHz, producing a 900 MB/s volume of data. To sort out the rare neutrino interactions, the time of the 12 μs beam spill at Fermilab is sent to the far detector and a window of data surrounding that time is saved (see Fig. 1). This results in a greater than 50 million to one reduction in cosmic ray background. For non-beam physics, a trigger farm examines the data real time to save interesting data [4].

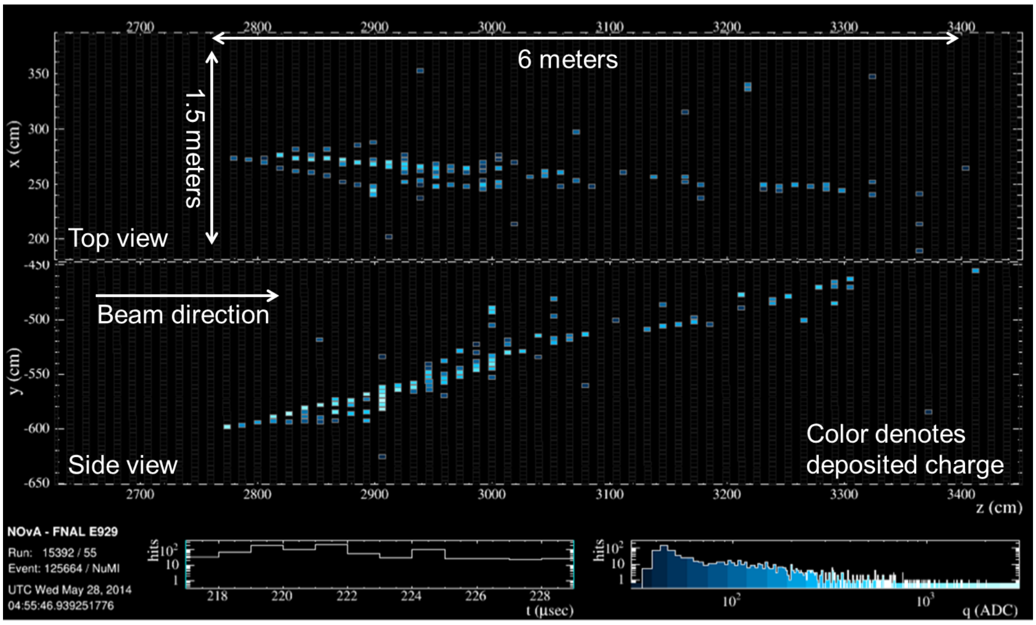

Figure 1: An event display of a candidate electron neutrino interaction seen in the NOvA far detector. The top rectangle is the view from above the detector, the bottom from the side. The NuMI beam enters the detector from the left. This image is zoomed in to show the details of the electromagnetic shower produced by an ∼2 GeV electron neutrino interacting in the detector. Each small colored box is one cell, coded by the charge digitized from the light in the cell.

The NuMI beam was operational as the far detector was constructed and commissioned, with physics data being recorded from February 2014. The modular nature of the detector allowed collecting of neutrino data with the partially built part of the detector. Both detectors were complete in August 2014 with the final commissioning at the far detector finished in November 2014. Scaling the exposure by mass, an equivalent of 2.5×10^{20} pot on a full 14 kt was collected before the Fermilab summer shutdown in June 2015. With this exposure and known oscillation parameters, 4.4 ν_e are expected to appear, compared to a background of less than 1.3. Additionally, 4.4 ν_μ are expected (compared to a background of 2.3), even with the location of the far detector being at the first oscillation minimum meaning that most ν_μ will having oscillated away.

4. Summary

The NOvA experiment is complete and has collected its first set of data. The detector is working well and low numbers of background events are anticipated when the signal is extracted for both ν_e and $\nu_m u$ disappearance. These results were released soon after this EPS-HEP talk (so they can't be in these proceedings) at the DPF meeting [5] August 4–8 2015 in Ann Arbor. A publication is pending.

References

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[3] K. Abe *et al.* [T2K Collaboration], "Measurements of neutrino oscillation in appearance and disappearance channels by the T2K experiment with 6.60^{20} protons on target," Phys. Rev. D **91**, no. 7, 072010 (2015) [arXiv:1502.01550 [hep-ex]].

[4] A. Norman, "Performance of the NOvA Data Acquisition and Trigger Systems for the full 14 kT Far Detector", proceedings of the 21st International Conference on Computing in High Energy Physics, April 13–17 2015, Okinawa, Japan. (2015)

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