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The NOνA Experiment

M. J. Frank[1]

University of Virginia, Charlottesville, Virginia

Abstract. The NOνA experiment aims to study the mixing behavior of neutrinos and will attempt to resolve the neutrino mass hierarchy. The experiment will rely on data collected at two detectors, one near Fermilab's NuMI (Neutrinos at the Main Injector) target and one 810 km north at Ash River, MN. The detectors are 14 mrad off the beam axis, which results in an almost monoenergetic beam of 2 GeV neutrinos. The construction of the far detector started early this year, the instrumentation will commence this fall, and we hope to take our first data in the beginning of next year. In this talk I will focus on the exciting possibilities of our detector in light of recent neutrino results and will discuss our plans to measure the neutrino mixing angle θ_{13} as well as to attempt to resolve the neutrino mass hierarchy and to understand the effects of the CP violating phase angle δ. I will also survey the rich physics program provided by our 14 kT fully active far detector, such as searches for magnetic monopoles and detection of supernova neutrinos.

Keywords: NOνA, neutrino oscillation, mass hierarchy, CP violation
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INTRODUCTION

The acronym NOνA stands for NuMI Off-Axis ν_e-Appearance, which summarizes our experiment [1]. The NuMI (Neutrinos at the Main Injector) facility provides the muon neutrino (ν_μ) source [2]. These neutrinos travel north through the earth to the Far Detector which is located 14 mrad off the beam axis where we expect an almost monoenergetic beam of 2 GeV neutrinos. During their 810 km journey to the Far Detector, the neutrinos oscillate in their flavor states and we detect the appearance of electron neutrinos (ν_e). From this we can measure the transition probability $P(\nu_\mu \to \nu_e)$ which is a function of the mixing angles θ_{13} and θ_{23}, the CP-violating phase angle δ_{CP}, and the neutrino mass hierarchy.

NEUTRINO DETECTION

The neutrino interaction cross section is very low, so we require a large detector mass. When an electron neutrino interacts with the detector an electron is produced that will in turn produce an electromagnetic (EM) shower. We therefore designed a "fully active" detector using low Z materials. We use PVC extrusions filled with liquid scintillator, which provides a radiation length of approximately 40 cm and a Molière radius of 11 cm. Each of the extrusions contains one wavelength-shifting fiber that is read out by

[1] On behalf of the NOνA collaboration.

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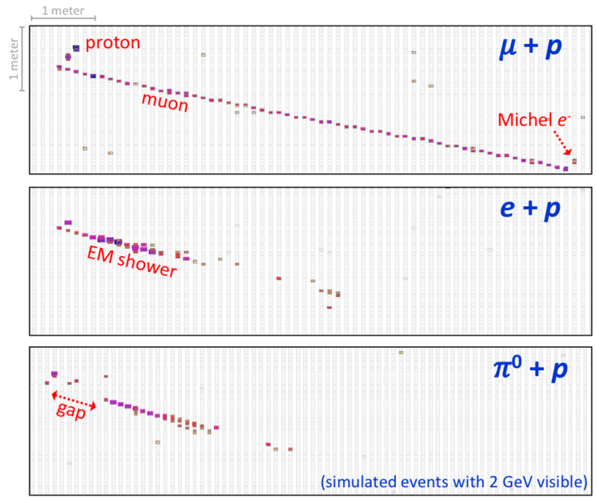

FIGURE 1. Simulated Near Detector event with a visible energy of 2 GeV. The top event shows a ν_μ charged-current interaction with the characteristically long muon track and short proton track with large energy deposition. The middle event shows a ν_e charged-current interaction that demonstrates the long EM shower in our "fully active" detector. The bottom event shows a hadronic interaction where the majority of the π^0 momentum is carried by one of the two decay photons, which in turn produces a displaced EM shower.

an avalanche photo-diode (APD). This detection technique is optimized to differentiate EM showers from hadronic showers as will be shown later.

THE EXPERIMENT

The neutrinos are created in the NuMI facility by colliding 120 GeV protons on a graphite target, which results in π^+ particles that are allowed to decay into μ^+ and ν_μ. The μ^+ particles are stopped by muon absorbers and the muon neutrinos travel onward to the Near Detector. The NuMI beam line is currently being upgraded to increase the beam power from 300 kW to 700 kW and reduce the cycle time from 2.2 s to 1.3 s.

The Near Detector will be located 105 m underground and 14 mrad off the beam axis. It will have a mass of approximately 266 tons and a size of 4 m by 4 m by 14 m. The far detector is located on the surface a distance of 810 km away and also 14 mrad off the beam axis. Its construction began this year (2012) and it will have a mass of over 14,000 tons and a size of 16 m by 16 m by 64 m at its completion.

OSCILLATION PHYSICS

Figure 1 shows the simulated signatures of different particle interactions in the Near Detector. It shows that we are able to differentiate EM showers (center) from hadronic showers (bottom). With this particle identification we can measure the rate of $\nu_\mu \to \nu_e$

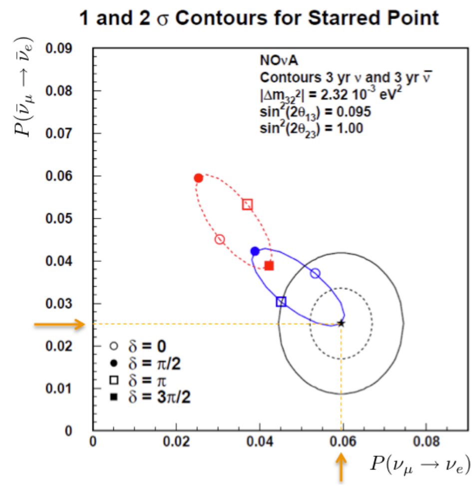

FIGURE 2. This plot shows the transition probabilities $P(\nu_\mu \to \nu_e)$ and $P(\bar{\nu}_\mu \to \bar{\nu}_e)$ for different values of $\delta_{\rm CP}$ for the normal (solid blue oval) and inverted (dashed red oval) mass hierarchies. If we measure the probabilities indicated by the orange arrows we could resolve the mass hierarchy and set limits on $\delta_{\rm CP}$ at different confidence levels indicated by the solid (2 σ) and dotted (1 σ) contours.

and $\bar{\nu}_\mu \to \bar{\nu}_e$ and then extract nature's parameters based on the following two equations:

$$\begin{aligned} P(\nu_\mu \to \nu_e) &\approx \sin^2(2\theta_{13})\sin^2(\theta_{23})f^+(L,E,\Delta m^2_{31}) \\ &+ \{\cos\delta_{\rm CP}\cos\frac{\Delta m^2_{31}L}{4E} - \sin\delta_{\rm CP}\sin\frac{\Delta m^2_{31}L}{4E}\} \\ &\times 2\frac{\Delta m^2_{21}}{\Delta m^2_{31}}\sin(\theta_{13})g^+(L,E,\Delta m^2_{31},\theta_{12},\theta_{23}) \end{aligned} \tag{1}$$

$$\begin{aligned} P(\bar{\nu}_\mu \to \bar{\nu}_e) &\approx \sin^2(2\theta_{13})\sin^2(\theta_{23})f^-(L,E,\Delta m^2_{31}) \\ &+ \{\cos\delta_{\rm CP}\cos\frac{\Delta m^2_{31}L}{4E} + \sin\delta_{\rm CP}\sin\frac{\Delta m^2_{31}L}{4E}\} \\ &\times 2\frac{\Delta m^2_{21}}{\Delta m^2_{31}}\sin(\theta_{13})g^-(L,E,\Delta m^2_{31},\theta_{12},\theta_{23}) \end{aligned} \tag{2}$$

L stands for the baseline (810 km) and E stands for the energy (2 GeV). The functions f and g are introduced to compact the full equation and illustrate the important terms [3]. θ_{13} has recently been measured to be large ($\approx 9°$) [4, 5, 6] which will enhance the above terms and give us a chance to measure the θ_{23} octant and $\delta_{\rm CP}$. By combining the results of the neutrino and anti-neutrino running, we can exploit the sign differences to extract the sign of Δm^2_{31} and resolve the neutrino mass hierarchy.

Figure 2 shows what NOνA can achieve by combining three years of neutrino running with three years of anti-neutrino running. If nature's parameters reside at the starred point, we would be able to resolve the neutrino mass hierarchy and set limits on $\delta_{\rm CP}$ at the two sigma level.

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