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The NOνA Experiment at FNAL, status and perspectives

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The NOνA experiment is a new long baseline neutrino experiment designed to measure θ_{13} through the appearance of ν_e in a ν_μ beam, at an off-axis angle of 14 mrad. The NOνA experiment has constructed and instrumented their near detector and has begun taking data in a surface location that places the detector in both the Neutrinos at the Main Injector (NuMI) neutrino beam and booster neutrino beam at Fermilab. This location provides significant neutrino fluxes for studies of both ν_e and ν_μ interactions and for understanding of the detector response to both types of interactions.

1. Introduction

The NuMI Offaxis ν_e Appearance (NOνA) Experiment is a new experiment at Fermi National Accelerator Laboratory to measure parameters crucial to our understand of neutrinos and neutrino mixing. The primary goals of the NOνA experiment are to make measurements of the mixing angle θ_{13} through the appearance of ν_e in a ν_μ beam, and then through comparison of ν and $\bar{\nu}$ oscillation probabilities, access information on the CP violating phase δ and determine the the sign of Δm^2_{13} to resolve the neutrino mass hierarchy. In addition, NOνA will perform a higher precision measurement of θ_{23} and address other topics in neutrino physics at accelerator energies.

2. Detector Designs

The NOνA experiment utilizes a two detector design with a small (220 ton) near detector 14 mrad off of the primary beam axis 1002 meter from the production target, and a large (15 kton) far detector located 14 mrad off-axis at 810 km from the production target. The far and near detectors use identical detector geometries and detection technologies in order to cancel systematic effects in the near/far flux comparisons.

The detectors have been designed as highly segmented, low Z calorimeter/range stacks. Each plane of the detector is constructed as a series of polyvinyl chloride (PVC) extrusions which serve as the thin walls of the rectangular 4×6.6×1500 cm detector cells. Each detector cell is filled with a mineral oil based liquid scintillator and strung with a 31 m long wave-shifting optical fiber which is looped down the detector cell to allow for both ends to be readout on a single edge of the module. The optical fibers are readout using an avalanche photo diode (APD) pixel array with both ends of a given fiber being readout by a single APD pixel and associated front end electronics.

The experiment is designed to take advantage of the kinematics of pion and kaon decay, by placing the near and far detectors off the primary beam axis at an angle θ such that the resulting ν_μ energy from either a parent π or K can be expressed as:

$$E_\nu = \frac{\left(1 - \frac{m_\mu^2}{m_{\pi,K}^2}\right) E_{\pi,K}}{1 + \gamma^2\theta^2} \tag{1}$$

In a θ=14 mrad off-axis configuration, the ν_μ flux arising from pion decay is projected into a narrow energy band centered around 2 GeV. For the NuMI, medium energy beam tune configuration this results in an expected energy spectrum at the far site detector that is shown in Fig. 1. The key aspect of this configuration is that the narrow band beam centered around 2 GeV, allows for stringent suppression of most of the backgrounds of the ν_e appearance channel. This is accomplished by restriction of the

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signal event energy window which suppresses contamination from ν_μ neutral current interactions with single π^0 production, and through the reduction of systematic uncertainties related to the pion and kaon energy spectra. The off-axis configuration also significantly suppresses contamination of the signal sample from beam intrinsic ν_e which arise from kaon decay, by kinematically projecting them into a higher energy band. In this configuration the intrinsic ν_e contamination, estimated from the flux times cross section and projected to the far detector, is less than 5% at $E_{\nu_e} = 2$ GeV.

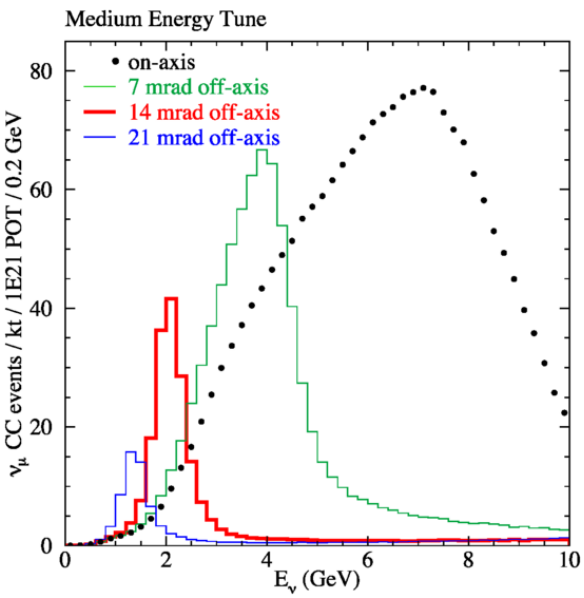

Figure 1. Expected event rates at the NOνA far detector, determined from calculations of the neutrino flux × energy dependent cross section.

2.1. Near Detector on the Surface

In addition to the far detector, the NOνA experiment has constructed a smaller (220 ton) near detector which is being operated at a newly constructed surface building site at FNAL, where the detector can be exposed to both the NuMI beam at 112 mrad off-axis, and also to the Booster neutrino beam in an on-axis configuration. The site is unique in that it allows the significant exploration of the detector response characteristics of the NOνA detector technology with high intensity neutrino beams that have energy spectra that are similar to the final run parameters. The key aspect of the test beam site is that by being at 112 mrad off the NuMI beam axis, a very narrow peak in the neutrino energy spectrum is formed at 2 GeV. In contrast however to the normal 14 mrad off-axis configuration, the peak corresponds to ν_μ's from a parent kaon instead of parent pion. A second narrow peak at 300 MeV is also present, which corresponds to the neutrinos arising from pion decays. These spectra are shown in Fig. 2.

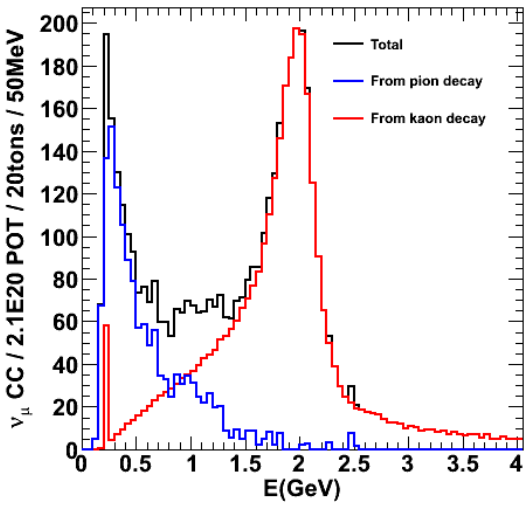

Figure 2. Expected event rate, expressed in terms of the flux × cross section, for ν_μ charged current events in the NOνA near detector in the surface test beam location, 112 mrad off the NuMI beam axis.

2.2. Detector Sensitivities

The 15 kTon far detector will have sensitivities to the θ_{13} mixing angle through the ν_e appearance channel. In the initial phase of NOνA

running with a 700 kW beam power, the detector will be able to probe a non-zero value of $\sin^2(2\theta_{13}) > 0.007$ at the 90% confidence level, over the full range of δ_{CP}. Additional running in the 1.2 MW or 2.3 MW beam power configurations have the ability to yield sensitivities below 0.005 in $\sin^2(2\theta_{13})$ in both the the normal and inverted hierarchies. These sensitivities are shown in Fig. 3. Depending on the measured value of θ_{13}, NOνA has the ability to resolve the neutrino mass hierarchy, and access the value of the CP violating phase δ_{CP}.

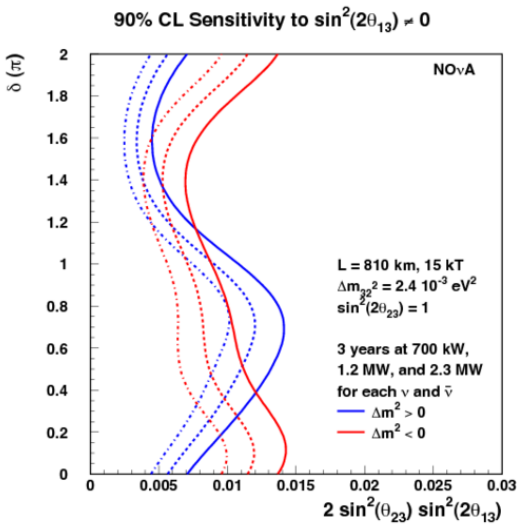

Figure 3. Sensitivity of the 15 kTon NOνA far detector to a non-zero mixing angle θ_{13}. Contours are shown for both normal and inverted mass hierarchies.

There has been recent interest regarding asymmetry in neutrino/anti-neutrino oscillation parameters that have been reported by the MINOS collaboration[1]. The NOνA experiment has the ability to address this asymmetry, with a sensitivity to a non-zero value of $(\Delta m^2_{23} - \Delta\bar{m}^2_{23})$ and $(\sin^2(\theta_{23}) - \sin^2(2\bar{\theta}_{23}))$ at 5σ after 1 year each of neutrino and anti-neutrino running. Full sensitivity is reached after 3 years each of neutrino/anti-neutrino running, and these sensitivity contours are shown in Fig. 4.

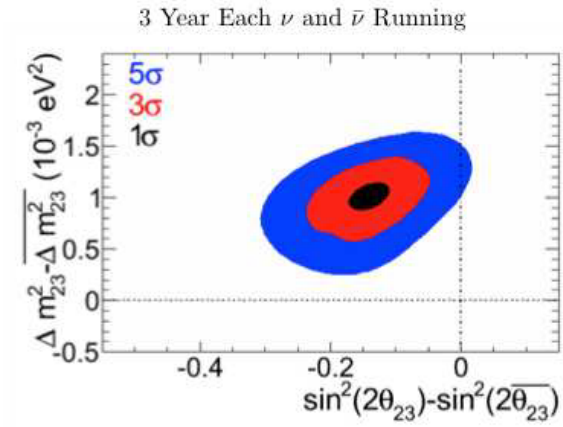

Figure 4. Sensitivity of NOνA to an asymmetery between ν_μ and $\bar{\nu}_\mu$ mixing.

2.3. Detector Progress and Outlook

The NOνA experiment began installation and commissioning of the near detector in in the surface configuration, in July of 2010. The near detector will continue operations until the 2012 shutdown of the accelerator complex. During this shutdown the near detector will be moved to the NuMI beam complex's underground caverns.

The far detector building will be completed in March of 2011, and construction of the far detector is scheduled to begin in the summer of 2011. The first far detector blocks will come online for operations in September 2011. The anticipated schedule bring 3-4 blocks online prior to the 2012 accelerator shutdown, and will have 10-12 kilotons of the far detector ready for operations when the accelerator resumes in 2013.

REFERENCES

1. P.Valhe, talk at 24th International Conference on Neutrino Physics and Astrophysics (Neutrino 2010), Athens, Greece, 14-19 June 2010.