NOvA neutrino experiment status

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Abstract. The primary goal of the NOvA neutrino oscillation experiment is to study the probabilities of transformation of muonic-neutrinos into electron-neutrinos. The experiment is currently under construction and will use a 700 kW accelerator-based NuMI beam (Neutrinos at the Main Injector) and two detectors. The Near Detector (329 t at Fermi National Accelerator Laboratory, Illinois) and the Far Detector (14 kt, Ash River, Minnesota) are aligned to 14 mrad off-axis and separated by 810 km. They are made of active liquid scintillator and readout by avalanche photo-diodes. Recent results from world-wide neutrino experiments indicate that NOvA is in the position to determine the neutrino mass hierarchy as it is also searching for the first hints of CP violation in neutrino sector. The design, the goals and the current status of the NOvA experiment are presented here with the current estimates of its sensitivity to the mass hierarchy measurement.

1. Introduction

Neutrino physics, with many interesting topics and questions reaching beyond Standard Model, is being more and more appealing for particle physicists. Despite the huge progress made in recent years, there are still many open questions, regarding i.e. the mass ordering, the mixing angles and the CP violation in neutrino sector.

The NuMI Off-Axis \( \nu_e \) Appearance experiment (NOvA) was designed to answer some of these questions [1]. Being currently built in North America, it’s about to be one of the world’s leading neutrino experiments and the flagship of the Intensity Frontier – particle physics program of Fermi National Laboratory in Batavia, IL (USA).

NOvA is a long-baseline, two-detector neutrino oscillation experiment looking mostly for appearance of \( \nu_e \) in well-defined NuMI beam of \( \nu_\mu \). Both its detectors are being currently under construction and the beam was recently upgraded to be capable of delivering 700 kW of beam power, with optional change between neutrino and antineutrino beam.

Recent results from both long-baseline and reactor-based neutrino experiments confirm non-zero value of \( \theta_{13} \) [2-5] and non-maximal \( \sin^2 2\theta_{13} \) [6-8], which shows that NOvA is in a good position to measure precisely for the first time \( \Delta m^2_{23} \) (the mass ordering of three mass eigenstates); to get the first data on the CP violation delta phase; to accurately measure \( \theta_{13} \) mixing angle through probability of appearance of \( \nu_e \) in \( \nu_\mu \) beam and to determine the octant of \( \theta_{23} \).

1 On behalf of the NOvA collaboration
2. NOvA experiment

To carry out a measurement of accelerator neutrino oscillation, a so-called second generation experiment has to have an intense beam of neutrinos and a massive detector several hundreds of kilometers away. NOvA detects the NuMI beam (same as MINOS [8]) with Far Detector (FD) 810 km from the target and Near Detector (ND) 1 km from the target.

2.1. NuMI neutrino beam

The source of neutrinos to detect in NOvA detectors is the NuMI beam – Neutrinos at the Main Injector. The neutrinos are created by extracting 120 GeV protons from the Main Injector facility at Fermilab, and colliding them with a graphite target, which results in production of secondary mesons ($\pi^+$ particles can decay into $\mu^+$ and $\nu_\mu$). To meet the NOvA physics goals, the NuMI beam was upgraded from 300 kW to 700 kW of nominal beam power. This is achieved by reducing the 10 $\mu$s-pulse cycle time of the Main Injector from 2.2 s to 1.3 s via slip-stacking in the recycler ring; increasing the intensity per cycle with 12 Booster batches instead of 11 by installing new RF stations and a new injection kicker magnet; and upgrading the target and horns to accommodate the increased proton intensity.

As a result, there will be a 10 $\mu$s beam spill every 1.33 s in an intensity of $4.9 \times 10^{13}$ protons per pulse (corresponding to $6.0 \times 10^{20}$ protons on target per year of running). From pion decay kinematics, we know the neutrino energy will depend on the characteristic decay angle between the neutrino and the parent pion in the laboratory frame. For 14 mrad off-axis, most pion decays result in neutrinos with $E = 2$ GeV, some with energy smearing around that value. Therefore, the NOvA detectors placed 14 mrad off the NuMI beam axis will measure a narrow band beam peaked very near the $\nu_\mu$, $\nu_e$ oscillation maximum at 810 km ($E \sim 1.6$ GeV), as shown in Fig. 1. The narrow beam energy spectrum strongly reduces the background from feed-down of higher energy neutral-current (NC) neutrino events, the dominant background for $\nu_\mu$, $\nu_e$ oscillation searches with the detectors placed on-axis.

Figure 1. The energy spectra dependence on angle together with the $\nu$ oscillation probability profile.

Figure 2. NOvA Far and Near detectors with a cut-away of alternating extruded PVC planes.
2.2. NOvA detectors
The NOvA detectors are finely segmented, 64% active tracking calorimeters. The segmentation and the overall mechanical structure of the detectors are provided by a lattice of extruded PVC cells with cross sectional size $6 \text{ cm} \times 4 \text{ cm}$. Each cell extends the full width or height of the detector ($15.6 \text{ m}$ in the FD, $4.1 \text{ m}$ in the ND) and is filled with mineral oil mixed with liquid scintillator (pseudocumene). Secondary particles from neutrino interactions excite the scintillator and the light produced by the scintillator is collected and transported to the end of the cell by a wavelength-shifting fiber that terminates on a pixel of a 32-channel avalanche photodiode (APD). Figure 2 shows a sketch of the FD and ND along with a cut-away view of the PVC lattice.

Each of the 928 layers of the FD has 384 cells, for $\sim 344000$ total channels of readout. The ND has 206 layers each with 96 cells plus a muon range stack at the downstream end made by interleaving steel plates with standard detector layers, totalling 18000 channels.

There is also a 0.2 kton prototype Near Detector On Surface (NDOS) which served for DAQ, cooling, electronics and firmware tuning and as a proof of concept and still runs and provides valuable feedback for design enhancements and operational experience.

2.3. NOvA physics goals
NOvA will begin its oscillation data run in $\nu$ mode - that is with the NuMI horn configured to focus positive secondary hadrons. While FD construction and NuMI commissioning will still be underway during the first year of data taking, NOvA can nonetheless reach a $5\sigma$ C.L. observation of $\theta_{13}$-driven $\nu_{\mu}$ oscillations after one year, assuming the normal mass hierarchy. The baseline NOvA exposure is $3.6 \times 10^{21} \text{ POT}$, which can be accumulated in six years at design intensities, with a 14-kton FD. For the sensitivities shown below, this exposure is assumed divided evenly between $\nu$ and $\bar{\nu}$ running, a split that works well for many parameter scenarios but is nonetheless adjustable. The analysis techniques used here are those described in the NOvA Technical Design Report [1]. Updated analyses for use in the first NOvA results are under active development.

Outside of these primary goals, NOvA will also look for evidence of new physics through comparisons of $\nu_{\mu}$, $\nu_{\tau}$, and $\bar{\nu}_{\nu}$, provide constraints on sterile neutrino models by measuring the total flux of active neutrinos at its downstream detector, monitor for supernova neutrino activity, perform neutrino-nucleus cross section measurements with a narrow-band beam, and pursue a variety of non-neutrino topics including searches for magnetic monopoles and hidden sector particles.
3. Status of the NOvA experiment

The commissioning of the NOvA experiment is successfully approaching its completion. The FD laboratory currently holds 21 of 28 completed blocks, from which more than a half was filled with scintillator. Over 2 kt of detector (4.17 blocks) are equipped with APDs, read out and fully operational. The Near Detector cavern now accommodates the complete muon catcher and two regular blocks, which will continue being installed and should be completed in summer 2014.

The NuMI beam returned on September 4, 2013, with temporary capacity of 500 kW of beam power. After the Booster RF system upgrades, it will deliver the full 700 kW power in summer 2014. All reconstruction and analysis tools are in place and ready to be fed with data to produce early results on first runs from 2014.

4. Summary

NOvA is on track to make many important contributions to neutrino physics such as the measurement of the mixing angle $\theta_{13}$, determination of the neutrino mass hierarchy, search for neutrino CP violation, determination of $\theta_{23}$ octant and more precise measurements of $\Delta m^2_{23}$ and $\sin^2(2\theta_{23})$. Recent results from worldwide neutrino experiments are very encouraging for the NOvA goals as they provide evidence for a non-zero $\theta_{13}$ and non-maximal $\sin^2(2\theta_{23})$.

The Far detector block construction is being finished and more than 2 kt of its mass have been instrumented with APDs and are capable of particle detection. Construction of the full 14 kt is expected to be completed by early 2014. The upgraded NuMI is now back on and will deliver 500 kW of beam power before the recycler ring will be upgraded to handle 700 kW beam. The Near detector muon catcher is in place, the first blocks are being assembled and the detector should be ready before mid 2014. The NOvA NDOS prototype has been taking and analyzing data since October 2010 and continues to operate and provide critical feedback for design enhancements and operational experience.

References
[1] D. S. Ayres et al. “NOvA”, FERMILAB-DESIGN-2007-01 (2007)
[2] F. An et al. “DAYA-BAY”, Phys.Rev.Lett. 108, 171803 (2012), 1203.1669.
[3] J. Ahn et al. “RENO”, Phys.Rev.Lett. 108, 191802 (2012), 1204.0626.
[4] Y. Abe et al. “Double Chooz”, Phys.Rev. D86, 052008 (2012), 1207.6632.
[5] D. Dwyer “Daya Bay”, talk given at the Neutrino 2012 Conference, June 3-9, 2012, Kyoto, Japan, http://neu2012.kek.jp/.
[6] K. Abe et al., Phys.Rev.Lett. “T2K” 107, 041801 (2011), 1106.2822.
[7] R. Nichol “MINOS” (2012), talk given at the Neutrino 2012 Conference, June 3-9, 2012, Kyoto, Japan, http://neu2012.kek.jp/
[8] P. Adamson et al., “MINOS” Phys. Rev. Lett. 107, 181802 (2011), hep-ex/1108.0015v1.