1. Executive Summary

1.1 Introduction

Fermi National Accelerator Laboratory and the NOνA Collaboration composed of 181 scientists and engineers from 26 Universities and Laboratories have collaborated to create this preliminary design for a new study of neutrino oscillations using the existing Department of Energy investment in the NuMI neutrino beam at Fermilab. NOνA is designed to search for oscillations of muon neutrinos to electron neutrinos ($\nu_\mu \rightarrow \nu_e$) by comparing electron neutrino rates at Fermilab with electron neutrino rates observed 810 kilometers from Fermilab.

1.2 Project Components

This technical design for the NOνA Project consists of four main elements:

1. **An upgrade of the Fermilab accelerator complex from 400 kW to one capable of 700 kW of beam power.** The Recycler will be converted from an anti-proton to a proton 8 GeV storage ring. New proton injection and extraction lines will be built using five new kicker systems and recycled magnets. The Main Injector cycle time will be reduced from 2.20 seconds to 1.33 seconds via the addition of two new additional RF cavities. The NuMI neutrino line will be upgraded to handle the increased beam power with small changes to the primary beam line and upgrades to cooling systems. The NuMI Target Hall will be changed to the medium energy neutrino beam configuration, requiring a new target, and horn 2 will be moved downstream 13 meters with an extended strip line transmission line. Commissioning of the upgraded accelerator complex is not part of the project since the complex is used by other experiments and must be scheduled by the Fermilab Directorate.
2. **A 222 ton Near Detector.** This detector will be placed in a small new underground cavern adjacent to the existing NuMI tunnel on the Fermilab site and will measure the inherent NuMI beam backgrounds relevant to a search for electron neutrino appearance in the NuMI muon neutrino beam.
3. **A new building on a site near the US-Canadian border in Ash River, Minnesota.** This building will house a new NOνA Far Detector. This site is 810 kilometers from Fermilab. The new building is 20.4 meters wide by 113.8 meters long with the detector section sunk 16 meters below the existing grade into granite rock at the site. The excavated granite is used as a cosmic ray shield on the above grade sides of the building. The roof of the building over the detector is composed of 1.37 meters of concrete covered with 0.15 meters of barite (barium sulfate) to complete the cosmic ray shield.
4. **A 15,000 ton (15 kiloton) NOνA Far Detector.** This detector will be composed of 385,000 cells of extruded PVC plastic in a cellular structure. Each cell is 3.9 centimeters wide by 6.0 centimeters deep and is 15.5 meters long. The cells are filled with a total of 3.3 million gallons of liquid scintillator. The liquid scintillator comprises 70% of the total detector mass, making this a totally active tracking calorimeter detector optimized for identification of electron neutrino (ν_e) interactions. The detector is read out via 13,000 kilometers of 0.7 millimeter diameter optical wave-shifting fiber into 12,000 avalanche photodiodes with associated electronics. The 222 ton Near Detector will be constructed with components identical to the ones used in the Far Detector.

1.3 Use of Existing Facilities

The NuMI beam is used in a new way by placing the NOνA detector at an angle 14.6 milliradians off the beam axis to obtain a muon neutrino (ν_μ) beam sharply peaked at 2 GeV in

energy. Following some modifications for 700 kW of beam power, the Fermilab NuMI beam transport, target, focusing horns, vacuum decay pipe, and absorber will be utilized to provide the neutrino beam for NOνA. The NOνA Near detector will be accessed via the existing NuMI underground tunnel at a depth 105 meters below grade.

1.4 Capabilities

The Accelerator and NuMI Upgrades portion of the NOνA Project is designed to deliver 6×10^{20} protons per year to the NuMI Target. In a six year run with a total of 36×10^{20} protons delivered by the Fermilab Main Injector, NOνA would measure the probability for muon neutrino to electron neutrino oscillations ($\nu_\mu \rightarrow \nu_e$) down to a value ten times smaller than the existing experimental limit.

The existence of neutrino oscillations means that neutrinos have mass. In a six year run equally split between neutrino and anti-neutrino beams, NOνA can resolve the neutrino mass ordering in a significant portion of the available parameter space for these oscillations. This capability is a unique aspect of NOνA not duplicated by any other formally proposed experiment.

1.5 Scope, Cost, and Schedule

The technical scope of the NOνA Project includes the Fermilab accelerator complex upgraded for 700 kW capability, a 15 kiloton Far Detector in a new building at Ash River, Minnesota, and a 222 ton Near Detector at Fermilab.

The Total Project Cost (TPC) of the NOνA Project is $ 260 M. The TPC includes $ 54.6 M in costs in a DOE Cooperative Agreement with the University of Minnesota to construct the Far Detector Building.

The NOνA Project Schedule calls for 68 months of construction from May, 2007 through January, 2013.