Neutrino Super-Beam Facility for a Long Baseline Experiment from BNL to Homestake

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Abstract. An upgrade to the BNL Alternate Gradient Synchrotron (AGS) could produce a very intense proton source at a relatively low cost. Such a proton beam could be used to generate a conventional neutrino beam with a significant flux at large distances from the laboratory. This provides the possibility of a very long baseline neutrino experiment at the Homestake mine. The construction of this facility would allow a program of experiments to study many of the aspects of neutrino oscillations including CP violation. This study examines a 1 MW proton source at BNL and a 1 megaton detector positioned at the Homestake Mine as the ultimate goal of a staged program to study neutrino oscillations.

1. Introduction

Recent results showing evidence of oscillations in atmospheric neutrinos [2] have created interest in understanding the fundamental aspects of neutrino oscillations. To explore the physics of neutrino masses and mixing angles new facilities with intense proton beams will be required. This paper summarizes a study by a working group at Brookhaven National Laboratory to examine the feasibility of upgrading the AGS to a 1 MW proton source and using it to create an intense conventional neutrino beam capable of producing significant flux at a large distance from BNL. A letter of intent [1] to build such a facility has been submitted to BNL. In addition to the upgrade of the AGS to a proton driver, a new neutrino beam line and targeting station capable of handling this intense beam will have to be constructed. It is likely that a graphite target will be able to handle up to 1 MW of power, however to go beyond that will require special materials. Also a horn would have to be designed to handle the high intensity and to capture more of the high end of the spectrum. The study group has considered detectors at a number of locations. In this paper two specific locations are considered so that estimates of the physics potential can be made. A very long baseline experiment with an extremely large water Cherenkov detector (1 megaton) placed at the Homestake Mine in South Dakota is being studied. The other baseline considered would be a large detector placed "off-axis" at a distance of 400 km from BNL. This detector is a 25 kton liquid argon detector with a magnetic field. Expected estimates of the number of events at these locations are calculated.

2. Flux Distributions and Event Estimates

A GEANT simulation of the proposed neutrino beamline was used to calculate the flux at the detector locations. Because of the 11.5^o incline of the neutrino beam necessary

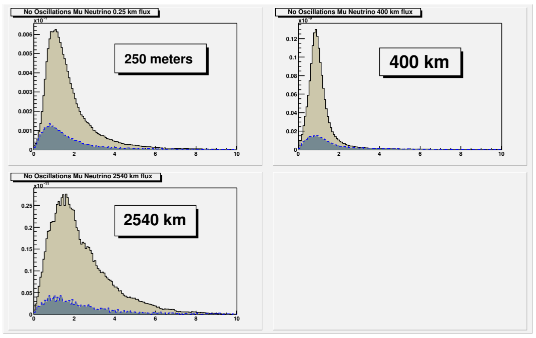

Figure 1. The figures show the ν_μ flux distribution with ν_e contamination (scaled by 20) superimposed. The plots show the flux distribution in units of ν per m^2 per GeV per proton on target.

Table 1. Estimates of the number of non-oscillated events in the quasi-elastic and charge current inclusive channels. Events in water Cherenkov detectors with $E_\nu > 2GeV$ are also shown.

Detector Position	Detector Mass	$\nu_\mu n \to \mu^- p$	$\nu_e n \to e^- p$	$\nu_\mu N \to \mu^- X$	$\nu_e N \to e^- X$
250 m	0.33 kton	1.33×10^9	1.69×10^7	4.16×10^9	5.37×10^7
400 *km Ar*	25 kton	10518	143	24700	441
Homestake	1000 kton	26601	232	107706	953
Homestake $E_\nu > 2GeV$	1000 kton	12416	108	76973	702

to reach Homestake, a close-in detector for the determination of the flux composition can only be placed on the other side of the beam dump. The choice of technology for the close detector has not been determined. It would be desirable to have a magnetic field on that detector because there would be a component of the antineutrino in the neutrino beam that should be measured. Also there would be limited space available at that location. These two reasons suggest that a liquid argon detector would be preferable, however it may be desirable to have the same technology for the near detector as the far detector to eliminate systematic effects. Fig. 1 shows the ν_μ flux distributions at the three locations if there are no oscillations. Also shown in Fig. 1 is the ν_e contamination (scaled by 20) in the beam at the same three locations. The ν_e contamination in the beam is $\sim 1\%$ of the total. The off-axis ν_μ flux at 400 km has a narrow energy distribution centered at $\sim$1 GeV. The ν_e event contamination in the off-axis beam is reduced by a factor of $\frac{1}{2}$ if we consider only those events that are in the same energy range as the ν_μ distribution. Table 1 shows the number of events expected at each of the three detectors. The number of non-oscillating events are calculated for a running period of 5×10^7 seconds with a 1 MW source that produces 2.5×10^{21} protons on target during a 10^7 second year. These numbers can be scaled should it be necessary to consider smaller detectors for economical reasons. The table shows that significant event rates are expected at distances as far away as Homestake.

There are two backgrounds that have to be considered for observing oscillations in the ν_e appearance mode. The first is the ν_e contamination in the beam from K and μ decays. Estimates of the numbers of events from ν_e component of the beam are included in Table 1. The other source of background comes from single π^o neutral

Table 2. This table shows the expected number of events at the two far detector locations. The oscillation parameters are assumed to be $\Delta m^2_{32} = 0.0025 eV^2$, $sin^2(2\theta_{23}) = 1$ and $\Delta m^2_{12} = 5 \times 10^{-5} eV^2$. $sin^2(2\theta_{13})$ is given in the table for the cases.

Position	$sin^2(2\theta_{13})$	$\nu_\mu n \to \mu^- p$	$\nu_\mu N \to \mu^- X$	$\nu_e n \to e^- p$	$\nu_e N \to e^- X$
400 km	no osill	10518	24700	0	0
	0.04	2942	10031	172	330
	0.01	2941	10030	44	83
	background			143	209
2540 km	no oscill	26601	107706	0	0
	0.04	12555	45858	315	1249
	0.01	12554	45852	80	315
	background			232	953
2540 km	no oscill	12416	76973	0	0
$E_\nu > 2GeV$	0.04	6716	34155	132	845
	0.01	6716	34151	33	213
	background			108	702

current events where one of the γ from the π^o decay goes undetected. The size of the NC π^o background depends on the technology that is used for the detector. If a liquid argon detector is used this background is expected to be small because of the very good efficiency for the detection of γ. The NC π^o background is expected to be significant in a water Cherenkov detector below $E_\nu = 2$ GeV. Above $E_\nu = 2$ GeV this background becomes small, however 72% of the inclusive charge current events in the on-axis beam are produced above 2 GeV. One could cut these low energy events to remove this background.

3. Estimates of the Oscillation Signal

In order to estimate the number of events that will be seen at the far detectors one has to choose a set of oscillation parameters. The choice of $\Delta m^2_{12} = 5 \times 10^{-5}\ eV^2$, $sin^2(2\theta_{23}) = 1$ and $\Delta m^2_{32} = 2.5 \times 10^{-3}\ eV^2$ are consistent with our current knowledge of solar and atmospheric oscillations. The 90% C.L. upper limit of $sin^2(2\theta_{13})$ is currently 0.13. The two representative values of $sin^2(2\theta_{13})$ that have been used in this study for event estimates are 0.04 and 0.01. Table 2 shows event estimates at 400 km and 2540 km from BNL. The estimates shown require that $E_\nu > 2\ GeV$ so as to remove the background to ν_e appearance from the NC π^o channel. The table assumes a running period of 5×10^7 sec. The background shown in the table is just the remaining background from the ν_e component of the beam.

Acknowledgments

This work was supported by the US DOE under Contract No. DE-AC02-98CH10886.

References

[1] D. Beavis et al. Neutrino oscillation experiments for precise measurements of oscillation parameters and search for $\nu_m u \to \nu_e$ appearance and cp violation. hep-ex/0205040.

[2] Y. Fukuda et al. Evidence for oscillation of atmospheric neutrinos. *Phys. Rev. Lett.*, 81:1562, 1998.