SPECTRUM FROM THE PROPOSED BNL VERY LONG BASELINE NEUTRINO FACILITY

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Abstract

This paper calculates the neutrino flux that would be seen at the far detector location for the proposed BNL Very Long Baseline Neutrino Facility. The far detector is assumed to be located at an underground facility in South Dakota 2540 km from BNL. The neutrino beam facility uses a 1 MW upgraded AGS to provide an intense proton beam on the target and a magnetic horn to focus the secondary pion beam. This paper will examine the sensitivity of the neutrino flux at the far detector to the positioning of the horn and target so as to establish alignment tolerances for the neutrino system.

INTRODUCTION

A bold proposal to send a neutrino beam from Brookhaven National Laboratory to the Homestake Mine in South Dakota, a distance of 2540 km, could provide sensitivity to the mixing angles, mass splittings and CP violating phase that describe the neutrino oscillation matrix. The physics potential of this proposed long baseline experiment is described elsewhere [1, 2]. To provide a sufficient event rate at the far detector, an upgrade to the existing AGS facility would be required to provide the necessary proton intensity. The AGS upgrade would increase the machine repetition rate from the current 0.5 Hz to 2.5 Hz with 8.9×10^{13} protons per beam fill which would yield an average beam power of 1MW. The integrated intensity for a typical year of operation (10^7 sec) is expected to be 2.2×10^{21} protons on target. A description of the accelerator upgrades, neutrino beam line and target system design are given in the neutrino facility draft conceptual design report [3]. The target chosen must be able to handle this intense proton beam. The choice was to use a solid target with a low Z material. A woven carbon-carbon composite that has a very small coefficient of thermal expansion up to 1000º C was chosen to extend the life of the target by reducing thermo-mechanical stresses induced by the beam. The target is surrounded by a horn magnet, which it is mounted in. A description of the target and horn system is discussed in another paper submitted to this conference [4].

NEUTRINO BEAMLINE

In order to reach the detector at Homestake the neutrino beam at BNL must be directed into the ground with an incline of 11.3º with respect to the surface. The beam line is mounted on a 42 m high hill to accommodate the need for a 200 m decay tunnel and to avoid the possibility of contaminating the local ground water. The proton beam at BNL is transported to the U-line spur using the RHIC transport line. The beam is bent by 68º and then up the hill to a targeting station near the top. In order to obtain a broadband neutrino spectrum a two parabolic horn scheme similar to that which was employed for previous AGS neutrino beams was used. Each of the horns selects a different pion momentum range. In order to have two interaction lengths, the carbon-carbon target must be 80 cm long. The long length makes the design of the horn system difficult because the target does not act as a point source for pion secondaries. The horn geometry must be modified to account for the finite length of the target. Consequently the horn system cannot be viewed as a series of simple thin lenses. The upstream part of the first horn, which surrounds the target, captures the 1 to 3 GeV/c secondary particles produced from the target. The downstream part of the first horn has an approximately parabolic shape to collect particles in the 3-4 GeV/c momentum range from that part of the target. The second horn is placed 8.3 m from the upstream end of the first horn to collect particles with momentum greater than 3-4 GeV/c. The shape of the horn has been studied using the GEANT simulation program [5]. The important variables for the optimization of the first horn include (1) the opening angle after the target, (2) the thickness of the conductor on the inner wall of the horn, (3) the horn length, and (4) the shape of the parabolic lens at the downstream end.

Figure 1 and 2 show the neutrino and antineutrino flux, respectively, for 28 GeV protons using the carbon-carbon target, two horn system and 200 m long 4 m diameter decay tunnel. The figures also show the ν_e and $\bar{\nu}_e$ contamination, respectively, in the beam from K and μ decays.

The decay tunnel diameter was chosen to permit the option of operating the beam line to produce a 1º off-axis neutrino beam. Figure 3 shows a comparison of the off-axis beam with the on-axis beam. The off-axis beam suppresses the flux in the 3 to 8 GeV range of neutrino energy. This provides a narrow band neutrino beam, which is advantageous for observing the appearance oscillations into ν_e since the beam contamination in the narrow band range is greatly reduced.

ALIGNMENT REQUIREMENTS

In order to have confidence that the flux of neutrinos is known at the far detector site the beam, target and horns must be positioned and oriented within certain tolerances. The criterion that is being used for determining the tolerances is that the worst acceptable flux variation of the far detector should be less than 5% from alignment uncertainties. There are approximately twenty parameters that can be varied in positioning the beam, the target relative to the horn, and each of the horns. Since any of these variables can be randomly misaligned any single variable should have a 1.25% variation. We can allow

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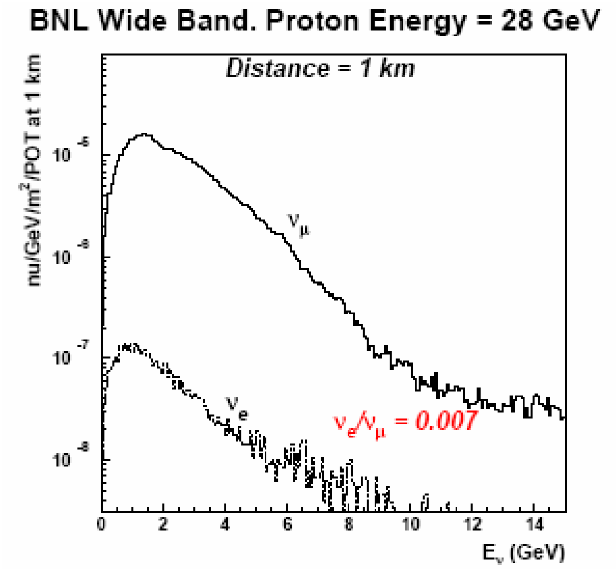

Figure 1: Wide band horn focused muon neutrino spectrum for 28 GeV protons on a carbon target.

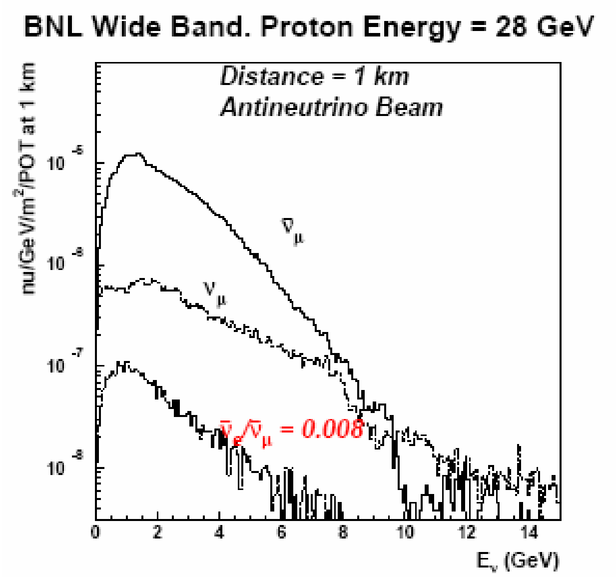

Figure 2: Wide band horn focused muon antineutrino spectrum for 28 GeV protons on a carbon target.

some of the variables to exceed this 1.25% variation since other parameters would come under this variation. We have set a maximum tolerance of 2.5% variation for each of the positioning parameters. This criterion is less stringent than that which has been used for the NuMI beam line at Fermilab. The NuMI criteria accepted a worst flux variation of 2% in any 1 GeV bin from 1-80 GeV of neutrino energy. The effective error of positioning the beam, target and horns for the NuMI beam line was approximately 0.5 mm. The necessity for precise knowledge of the neutrino flux at the far detector is to measure Δm_{23}^2 by the decrease in the number of neutrino events seen at the far detector from those expected if there were no oscillations of neutrino states. The BNL-

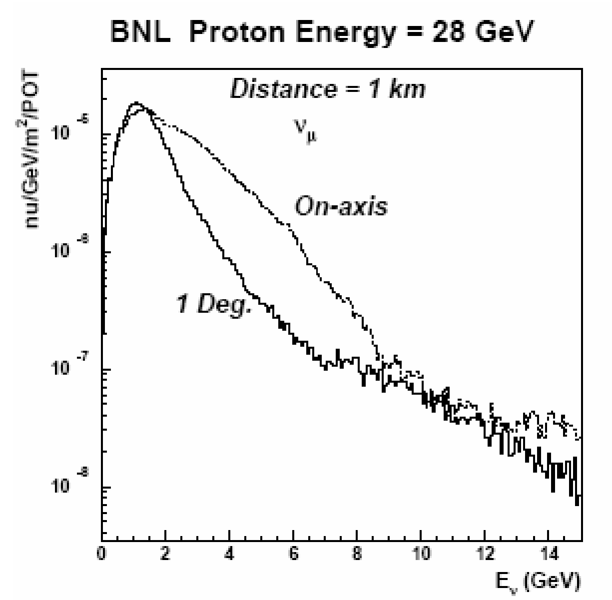

Figure 3: Comparison of the 1° off-axis muon neutrino spectrum with the on-axis neutrino beam for 28 GeV protons on a carbon target.

spectrum seen at the far detector. The Δm_{23}^2 measurement can be determined from the spacing of the Homestake wideband oscillation experiment expects to see more than one oscillation peak in the disappearancepeaks on the E_ν spectrum distribution, thus it is less sensitive to as precise knowledge of the neutrino flux as the NuMI experiments are.

The PBEAM program [6] program that was used for the NuMI alignment study was used to evaluate the flux at our far and near detector locations for slightly misaligned configurations of the beam, target and horn positions and orientations. The program produces $\pi^{\pm}$, $K^{\pm}$ and K^0 from the target and tracks these particles through the horn focusing system and decay tunnel. A weight is assigned to neutrinos produced from the meson decays corresponding to the branching ratio for that decay mode and the probability that the corresponding neutrino reaches the detector. The weighting process permits the generation of significantly larger statistics than can be reasonably obtained with GEANT. The PBEAM program does not handle cascading decays such as the $\pi \rightarrow \mu \rightarrow \nu_e$ decay, which is an important source of the ν_e background for the lower energy BNL spectrum. The meson production spectrum that is observed off the target with the PBEAM program is not consistent with that observed with GEANT. PBEAM does not produce as many high energy mesons as GEANT does, however this may not be critical in this study since the analysis looks at ratios of perturbed to unperturbed distributions. Table 1 shows the parameters that were used to describe the target-horn system for this study. These parameters vary slightly from the current baseline values.

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Table 1: Parameters used to describe the beam, target and horn for the alignment analysis.

Parameter	Value
Beam Momentum	28 GeV/c
Beam RMS Radial Size	1.0 mm
Target Material	Carbon
Target Density	1.7 g/cm^3
Target Length	80 cm
Target Radius	3 mm
Horn 1 Length	2.17 m
Horn 1 Inner Radius	7 mm
Horn 1 Upstream Position	0 m
Horn 2 Length	1.5 m
Horn 2 Inner Radius	32-44 cm
Horn 2 Upstream Position	8.5 m
Horn Current	250 kA

In the analysis each of the following variables was varied one at a time and the flux was calculated at the detector positions:

- x, y, θ_x, and θ_y of the beam position on the target.
- x, y, θ_x, and θ_y of the target relative to horn 1.
- x, y, θ_x, and θ_y of the position of the horn 1 plus target ensemble.
- x, y, θ_x, and θ_y of horn 2.
- the horn current.

The ratio of the perturbed distribution to the unperturbed is calculated and fitted to a polynomial to smooth out the distribution. The largest variation in the distribution is used to determine the tolerance of that variable. Table 2 shows the allowable tolerances for the positioning and orientation of the beam, target and horns.

Table 2: Proposed positioning tolerances for the neutrino beam elements.

Variable	Proposed Tolerance
Beam Position	1.5 mm
Beam Angle	3 mr
Target Position	1 mm
Target Angle	3.7 mr
Horn 1 Position	1.7 mm
Horn 1 Angle	3.5 mr
Horn 2 Position	3.5 mm
Horn 2 Angle	7.0 mr

The target position and angle tolerances are given with respect to the position and angle of horn 1, which surrounds it. The angle tolerances can be stated as tolerances of the relative positions of the downstream part with respect to the upstream part. The listed angular tolerances would be achieved if each end of the element were positioned with this respective positioning tolerance.

These tolerances should be achievable initially. There is concern as to whether the neutrino beam elements will stay within these tolerances over time since the hill on which the beam line is built might settle after the alignment is made. If the positioning of the beam elements is monitored during a running period, corrections to the determination of the flux at the far detector can be made. Active repositioning of the beam elements need not be made during a run. They can be repositioned during long shutdown periods. An optical system of measuring fiducial markers on both ends of the neutrino beam line elements during the run will be necessary.

ACKNOWLEDGEMENTS

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