FOCUSING HORN SYSTEM FOR THE BNL VERY LONG BASELINE NEUTRINO OSCILLATION EXPERIMENT

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Abstract

This paper describes the focusing horn system for the proposed very long baseline neutrino oscillation experiment using a neutrino beam from BNL to an underground facility such as the Homestake Mine in South Dakota. The proposed experiment uses a 1 MW upgraded AGS. In order to achieve this performance the AGS will operate with a cycle time of 2.5 Hz and 8.9×10^{13} protons on target at 28 GeV. This paper discusses the design criteria of a horn system necessary to handle this intense beam and the optical geometry to achieve the desired flux distribution at the detector.

INTRODUCTION

Recent results show evidence for neutrino oscillations has kindled interest in experiments that can provide precise measurements of the neutrino mixing parameters. 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]. In order to provide a sufficient event rate at the far detector, an upgraded AGS would be required to provide the necessary proton intensity. The AGS upgrade would increase the repetition rate of the machine from the current 0.5 Hz to 2.5 Hz with 8.9×10^{13} protons per pulse providing an average beam power of 1 MW. The expected integrated intensity for a typical year of operation (10^7 sec) is expected to be 2.2×10^{21} 28 GeV protons on target. A description of the accelerator and target system design of the AGS Super Neutrino Beam Facility is given in a report [3]. The target and horn system must be designed to handle this intense proton beam. A solid target made of a low Z material is needed to survive a beam of this power. The target material selected is a woven carbon-carbon composite that has a very small coefficient of thermal expansion up to 1000°C. The expected temperature rise in the target from the deposited proton beam energy is 280°C. This extends the life of the target by reducing the thermo-mechanical stresses induced by the beam. The target itself is cooled by pumping helium gas into the space between the target and the inner surface of the horn. The description of the target system and its integration into the horn is discussed in another paper submitted to this conference [4]. Table 1 summarizes the important target parameters. In order to reach the Homestake mine, the neutrino beam must be directed into the earth with an 11.3° incline with respect to the ground level. To produce a sufficient flux of neutrinos a channel of 200 meters is needed to allow the secondary pions to decay. The target-horn ensemble must be located at an elevation of 38.5 meters to avoid possible contamination of the ground water. The neutrino beamline, target, horn and decay channel will be located on a 48 m high hill built for that purpose.

Table 1: Parameters that describe the proton target

Parameter	*Value*
Normalized X, Y Emittance	100 π mm-mrad
Target Radius	3.2 mm
Target Length	60 cm
Beam Radius	0.8 mm
Material Density	1.9 g/cm^3
Interaction Length	46 cm

HORN REQUIREMENTS

Table 2 shows the parameters that describe the horn system. The horn current is selected to produce a toroidal field, B_ϕ=5 T at the inner conductor of the first horn, which both captures and focuses the π and K mesons produced in the target. The second horn provides additional focusing for the higher energy component of the beam that is relatively forward. The starting point for the geometrical design of this horn system was that proposed by Palmer for horns that were designed for previous neutrino experiments at BNL[5, 6]. The first horn had to be elongated to contain the longer carbon-carbon target. Also additional modifications to the inner surface of the downstream part of the first horn were made to capture more of the higher energy part of the meson spectrum. The next section will describe the results of the simulation of the horn geometry. Figure 1 shows an illustration of the geometry of the first horn.

The following issues are important in the design of the horn:

- Heat generation in the horn and its removal.
- Irradiation and corrosion effects on the horn materials.
- Mechanical response and fatigue in the horn.
- The proper capture and focusing of π and K mesons to produce the desired neutrino beam.

The heat generation is a greater problem for the first horn than the second because of its proximity to the target. The two major contributions to the heat generation are the energy deposited in the horn from the secondary particles produced in the target and the Joule heating from the current in the horn conductor. The heat produced for both of these processes is maximal on the inner conductor of the horn of the first horn. The heat deposited from secondary particles on the inner conductor of the horn is estimated to be 8.39±1.9 kw. The contribution from the time averaged Joule heating on the first horn is 9.375 kw. An additional heat load due to heat radiation from the target is estimated at 1.36 kw. This heat load can be removed by spraying water onto the interior surface of the horn inner conductor. The material used for the horn conductor must have low resistivity, high yield strength and high resistance to corrosion. We have assumed that conductor material can be an aluminum alloy with resistivity of 3.7×10^{-8} Ω-m. The aluminum corrosion issue could be minimized by coating the surfaces with nickel in a manner similar to the NuMi horn.

Table 2: Table of Horn System Parameters

Parameter	*Value*
Material	Aluminum
Horn Current	250 kA
Horn 1 Inner Radius	7 mm
Horn 1 Inner Conductor Thickness	2.5 mm
Horn 1 Length	217 cm
Horn 1 Inductance	779 nH
Horn 1 Resistance	248 μΩ
Horn 2 Inner Radius	58.4 mm
Horn 2 Inner Conductor Thickness	1.6 mm
Horn 2 Length	150 cm
Horn 2 Inductance	287 nH
Horn 2 Resistance	30 μΩ
Stripline Inductance	480 mH
Stripline Resistance	30 μΩ
Pulse Width	1.2 ms
Repetition Rate	2.5 Hz
Distance Betw. Horn Fronts Plates	8.17 m

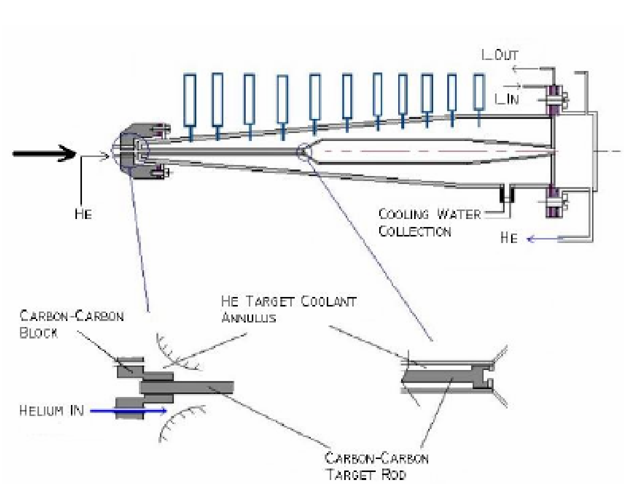

Figure 1: Sketch of First Horn with target inserted.

SIMULATIONS

The focusing performance of the horn can be examined by simulating the particle production in the target, tracking those particles through the horn field and allowing them to decay using the GEANT program. In this study a 28 GeV proton beam with a transverse profile of σ_r=0.8 mm and $\sigma_{r'}$=0 is incident on a carbon target with 3.2 mm radius, 60 cm length (1.1 interaction lengths) and ρ=1.6g/cm^3 (in this calculation). Because of its length the target is not a point source. The GEANT program has several options available for production of hadrons. We have compared pion production rates using GFluka, Gheisha and MARS [7, 8]. Table 3 shows the particle production rate from the target for these different hadron shower programs. Figure 2

Table 2: Particle production rate from carbon target. Rates are particles per proton on target.

Particle	*Gfluka*	*Gheisha*	*Mars*
π^+	1.72	2.17	1.68
π^-	1.39	1.73	1.34
K^+	0.083	0.072	0.105
K^-	0.037	0.022	0.001
K°	0.058	0.044	

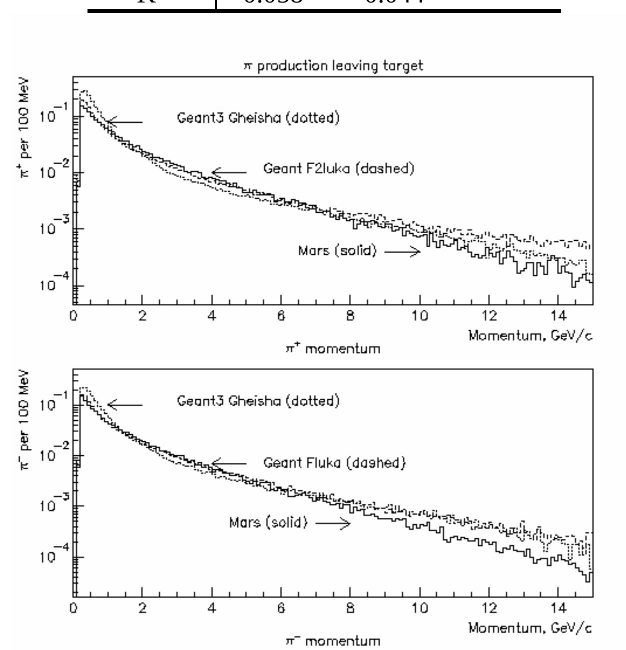

Figure 2: π^+ (upper) and π^- (lower) production from carbon target. Rates are per 100 MeV per 10^5 protons on target.

shows π^+ and π^- production from the carbon target. The figure shows different curves corresponding to the different hadron production options. The Mars program shows a production rate similar to Gfluka for P_μ<7 GeV/c. At very large P_μ the Mars rates are significantly lower than that which Gfluka or Gheisha predict. These rates will affect the event estimates expected at the detector. The Gfluka program overestimates the π^+ production by 50% in comparison with Mars for P_μ>7 GeV/c.

NEUTRINO FLUXES

We have chosen to use the Gfluka program for hadron production in order to make the neutrino flux calculations. The π's and K's produced in the target are tracked through the magnetic field of the horns until they decay or interact.

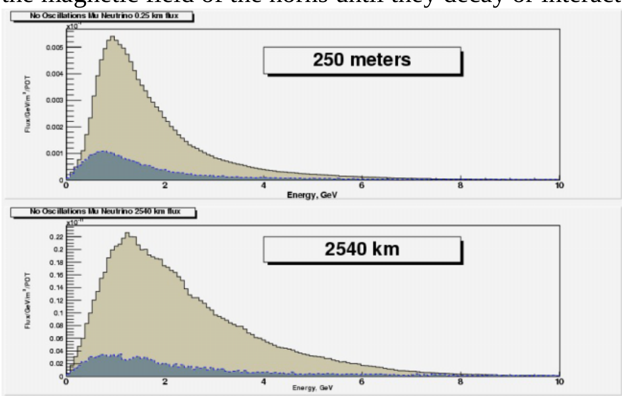

Figure 3: Neutrino Flux Distributions at the close (upper) and far (lower) detectors. Each plot shows the dominant ν_μ with the ν_e distribution superimposed in a darker color. The ν_e flux is scaled by a factor of 20 to be visible.

The horns are followed by a 200 meter (measured from the target) decay channel. Each meson is allowed to decay many times to obtain a reasonable number of neutrinos at the far detectors for a meaningful flux calculation. Each neutrino produced is weighted to account for these multiple decays. The various species of neutrinos from the decays of π, K and μ are counted as they pass the detectors. The location of the close detector, which is positioned at 250 m from the target, is constrained by the steep inclination of the neutrino beam line. The purpose of the near detector is to measure accurately the flux of the various neutrino species so that a prediction of the neutrino flux without oscillations can be made at the far detector. Figure 3 shows the expected flux at the near detector and at the far detector positioned at the Homestake mine. Since the distance to the close detector is comparable to the length of the decay tunnel the spectrum for that detector is different from the spectrum of the far detector which sees the neutrinos originating at a point source. Techniques will have to be developed to extract the predicted non-oscillated far detector spectrum from the observed near detector spectrum. Also, Figure 3 shows the ν_e flux spectrum expected at each location. (This spectrum is scaled by a factor of 20 in order to be visible on the same graph.) The ν_e contamination in the beam comes from the decay of K^+, K^0 and μ that are present. This is a background to the appearance signal of ν_e that come from oscillations of $\nu_\mu \rightarrow \nu_e$ and is ~1% of the non-oscillated ν_μ flux.

One can obtain an estimate of the number of non-oscillated events that would be seen at the near and far detectors by integrating the flux over the appropriate neutrino cross sections. To make these estimates it is assumed that the detector at BNL has a mass of 0.33 kton and that a water Cherenkov detector with a mass of 0.5 megatons would be built at the far location. Table 3 shows the number of events that would be seen after a five year running period (5×10^7 sec.)

Table 3: Estimates of the number of events that would be seen after a 5×10^7 sec running period if no oscillations occurred.

Channel	*Near Detector*	*Far Detector*
$\nu_\mu N \rightarrow \mu^- X$	3.5×10^9	51800
$\nu_\mu N \rightarrow \nu_\mu X$	1.1×10^9	16908
$\nu_e N \rightarrow e^- X$	4.5×10^7	380
$\nu_\mu n \rightarrow \mu^- p$	1.1×10^9	11767
$\nu_e n \rightarrow e^- p$	1.4×10^7	84

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