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(Presented by N. Kondakis)

Abstract

We present results of calculations of ν_μ fluxes in the AGS neutrino beam with the new dichromatic horn. The wide band beam ν_μ, as well as the ν_e backgrounds, are discussed. The ν_e/ν_μ ratio is about 8 x 10^{-3}. The possible sources and magnitudes of uncertainties are discussed. Finally, the calculated fluxes are compared with beam measurements.

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1. The Beam line

To produce the Narrow Band Beam (NBB), the 28 GeV proton beam is transported through the AGS U-line, and focused down to 2 mm before impacting on a 5-mm diameter, 12 cm-long copper target. The secondary particles produced in the target pass through a magnetic horn system (Fig. 1), which uses two magnetic horns, and a series of collimators and beam dumps for focusing and momentum selection. The total length of the horn system is about 10 meters. The focused charged particle beam is allowed to decay over a distance of 80 meters in the decay tunnel. A 30-m steel beam dump (muon shield), at the downstream end of the decay tunnel, is used to absorb all particles except, of course, the neutrinos.

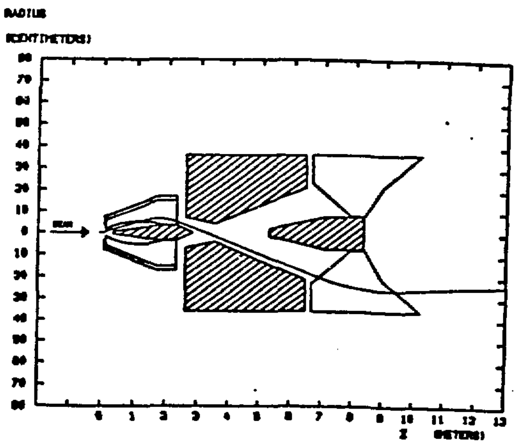

Fig. 1. Schematic of the Narrow Band Horn system.

Two segmented ionization chambers (pion monitors) were placed at 40 m and 60 m downstream from the end of the dichromatic horn system. The role of these detectors was to measure and monitor the charged beam profiles and fluxes.

2. Flux Calculations

All neutrino fluxes discussed below are assumed for a distance of 1 km from the target, along the beam line, where the E776 detector is located. At this distance, the detector subtends about 2.5 mrads. The calculation was done with a Monte Carlo program that simulates the particle production in the target, the transport through the focusing system, and the subsequent decays.

a. Particle production. The Monte Carlo program generated particles in the target according to the production model of Sanford and Wang[1]. This model gives the pion, kaon, and antiproton production from semiempirical formulae obtained by fitting the experimental particle production data in p - Be collisions between 10 and 35 GeV/c. The model dependency of the calculation has been estimated by repeating the calculation, assuming a different production model, namely that of Grote, Hagedorn, and Ranft[2], which uses particle production data in tabular form.

b. Transport and decay. Each particle is transported through the beam elements (Fig. 1), and is allowed to decay along its path. The daughter particles from each decay are also transported until the decay chain is exhausted. All charged particles are allowed to undergo multiple Coulomb scattering and absorption, while they traverse the walls of the magnetic horns. The chain of transport-decay is terminated when a particle encounters a collimator, a beam dump, or the tunnel walls. Reinteraction in the target or the horn walls was not taken into account. Instead, a single exponential was used to account for the secondary beam loss due to interactions in the materials of the beam elements. We are currently in the process of implementing particle interaction, energy loss, and decays, inside the various materials.

c. Results. The angular divergence of the focused charged particle beam in the decay tunnel is about 4 mrad. The momentum is 3 GeV/c at a horn current of 240 kA (3.5 GeV/c at 280 kA) with a momentum bite of 15 % . At these energies, about 30 % of the focused pions and almost all kaons decay before they reach the beam dump. The ratio of muon to pion decay is about 0.3 %. Table I shows the dominant sources of neutrinos and antineutrinos. The $\pi_{\mu 2}$ decay and the $K_{\mu 2}$ decays constitute the primary sources of the muon neutrino dichromatic beam. A small fraction (few percent) of WBB ν_μ and ν_μ background is expected from pion and kaon decays occurring before momentum selection, while the muon decay and the various K_{e3} decays are responsible for the ν_e background.

Table I. Dominant ν, $\bar{\nu}$ sources.

Decay	Products
$\pi^+ \to \nu_\mu \mu^+$	ν_μ
$\mu^+ \to e^+ \bar{\nu}_\mu \nu_e$	$\bar{\nu}_\mu$, ν_e
$\pi^+ \to e^+ \nu_e$	ν_e
$K^+ \to \mu^+ \nu_\mu$	ν_μ
$K^+ \to \nu_\mu \mu^+$	ν_μ
$\mu^+ \to e^+ \bar{\nu}_\mu \nu_e$	$\bar{\nu}_\mu$, ν_e
$\pi^- \to \bar{\nu}_\mu \mu^-$	$\bar{\nu}_\mu$
$\mu^- \to e^- \nu_\mu \bar{\nu}_e$	ν_μ, $\bar{\nu}_e$
$\pi^- \to e^- \bar{\nu}_e$	$\bar{\nu}_e$
$K^- \to \bar{\nu}_\mu \mu^-$	$\bar{\nu}_\mu$
$\mu^- \to e^- \nu_\mu \bar{\nu}_e$	ν_μ, $\bar{\nu}_e$
$K^- \to \pi^0 e^- \bar{\nu}_e$	$\bar{\nu}_e$
$K_L^0 \to \pi^- e^+ \nu_e$	ν_e
$K_L^0 \to \pi^+ e^- \bar{\nu}_e$	$\bar{\nu}_e$

The resulting NBB ν_μ energy spectrum, calculated at a distance L = 1 km from the neutrino source, is plotted in Fig. 2. The contributions from pion and kaon decays are shown separately. The spectrum peaks at about 1.3 GeV at a horn current of 240 kA (1.5 GeV at 280 kA) with an energy spread σ_E/E = 15 %. The other component of the dichromatic beam (originating from the $K_{\mu 2}$ decays) peaks at 3 GeV (3.5 GeV at 280 kA). The ratio of the ν_μ fluxes from kaons and pions is about 0.04, as expected from the K^+/π^+ production ratio and the kinematics. Note that Fig. 2 includes also the WBB background contribution.

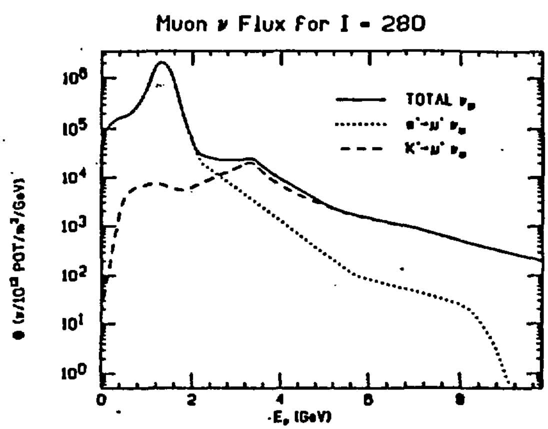

Fig. 2. Calculated ν_μ energy spectrum. It includes both NBB and WBB contributions.

The ν_e background energy spectra due to the four most dominant contributions are shown in Fig. 3, along with the total ν_e energy spectrum. It is clearly shown that the main contribution below 2.5 GeV comes from muon decay, whereas K^+ decays are responsible above 2.5 GeV.

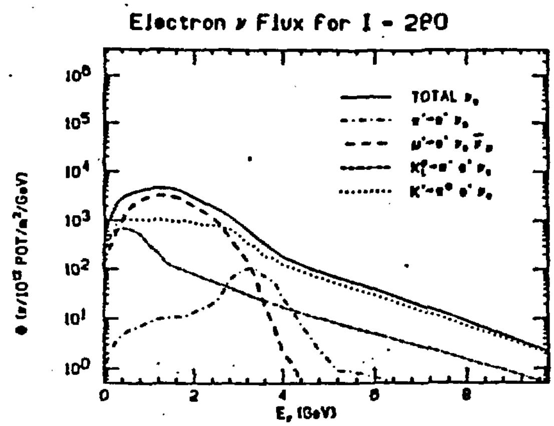

Fig. 3. Calculated energy spectra for the main sources of ν_e background.

The ν_μ and ν_e fluxes, integrated over the entire energy spectrum for a horn current of 280 KA, (expressed in ν's/10^{12} POT/m^2 at L = 1 km), are shown in Table II. The resulting ν_e/ν_μ ratio is calculated to be 7.8 x 10^{-3} at E_ν = 1.5 GeV (280 KA), and 8.3 x 10^{-3} at 1.3 GeV (240 KA).

3. Flux uncertainties

Several assumptions were made in the beam calculations: (i) The various particles were not allowed to interact or range out in the beam dumps. We do not know at this moment exactly the error (especially in the ν_e/ν_μ ratio) introduced by this assumption. (ii) The nuclear interactions in the materials and the target were approximated by a single exponential. We estimate that they can introduce an uncertainty as large as +30% to 40 %, depending on the effective absorption length used.

Table II. Integrated ν_μ and ν_e fluxes, in ν's/10^{12} POT/m^2, at L = 1 km.

ν-flavor	Reaction	Flux
ν_μ	$\pi^+ \to \mu^+\nu_\mu$	1.21 x 10^6
	$k^+ \to \nu^+\nu_\mu$	4.35 x 10^4
	Total	1.26 x 10^6
ν_e	$\mu^+ \to e^+\nu_e\bar{\nu}_\mu$	5.73 x 10^3
	$\pi^+ \to e^+\nu_e$	1.42 x 10^2
	$K^+ \to \pi^o e^+\nu_e$	3.21 x 10^3
	$K^o \to \pi^- e^+\nu_e$	8.25 x 10^2
	Total	9.91 x 10^3

(iii) In order to estimate the uncertainty from production we have compared the yields from several production models:
a. Sanford-Wang (SW) model, which was discussed previously.
b. Grote-Hagedorn-Ranft (GHR). The graphs in the atlas of particle spectra by Grote, Hagedorn and Ranft[2] are used to obtain the GHR values for the secondary particle production. c. A version of the GHR model (GHRW), modified to accomodate the proton reinteraction process in a "thick" target, which was used to fit the observed neutrino energy spectrum in the BNL WBB data[3], was also used for comparison. A comparison between the momentum spectra for the three models, for π^+ at $\theta = 3°$, is shown in Fig. 4. We are currently in the process of investigating the effects of the target size and the interaction of the beam in the horn plugs on the particle fluxes.(The latter effect was measured and was found to account for less than 5 % of the total charged particle flux.) Table III shows the values of the integrated production for the three models. The integration is performed over a wide range of momenta (0 - 17 GeV/c) and production angles(0 - 300 mrad). The difference in the absolute flux ranges from 30% to 40% (GHR over SW). Table IV shows the integrated production for the range of momenta

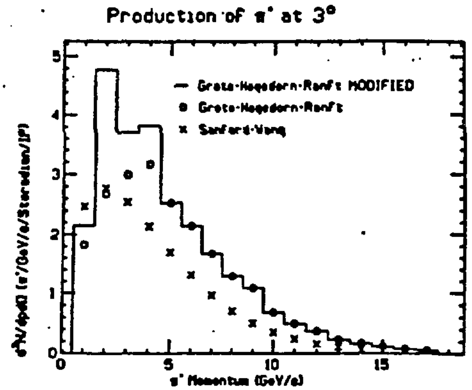

Fig. 4. π^+ momentum spectra at $\theta = 3°$ according to various production models.

Table III. Integrated production, in particles per interacting proton, for various models.

Particle	SW	GHR	GHRW
π^+	1.17	1.22	1.54
π^-	.895	.867	1.11
K^+	.135	.123	.153
K^-	.033	.044	.057

and production angles accepted by the horn system. The relative difference between the SW model and the GHR models in the high momentum range is twice as large as the difference in the whole momentum range. This affects directly the ratio of high energy to low energy ν_μ fluxes. Indeed, the energy spectrum calculated with the GHR model appears to have about 30 % higher flux above 2.5 Gev than the one calculated with the SW model. Thus, the uncertainty from production, estimated from the comparison of the various existing models, can be as high as +30 %. Finally, the statistical uncertainty is estimated to be less than ±10 %.

Table IV. Integrated production (particles per interacting proton) over the momentum and angle range of horn acceptance for various models.

Particle	SW	GHR	GHRW
π^+	.213	.203	.294
π^-	.161	.156	.218
K^+	.022	.018	.025
K^-	.007	.009	.012
p	-	.056	-

In summary, the absolute ν_μ flux is estimated to carry an uncertainty between +80%,-10%, the ν_e/ν_μ ratio between +30%,-30%, and the muon neutrino ratio ν_K/ν_π between +20%, -20%. These uncertainties are given here as possible upper limits for the quoted values and have no real statistical meaning. However, when we take into account the flux measurements with the pion monitors, we believe that we can narrow down these uncertainties, as we shall discuss in section 4.

We are in the process of recalculating the ν_μ and $\bar{\nu}_\mu$ fluxes for both the narrow and the wide band beams. These calculations take into account (i) target effects, (ii) secondary particle production coming from interactions with the materials in the beam (horn walls, collimators, plugs, tunnel walls), and possible subsequent decays, and (iii) additional decay modes which contribute to both the NBB signal and WBB background.

4. Comparison with measurements

In order to check the calculations against measured quantities we performed the following tests: (i) We used the pion monitors to measure the radial profiles and absolute fluxes of charged particles in the decay tunnel, and (ii) we used the calculated ν_μ spectra to generate Monte Carlo events in the detector according to known cross sections. We then analysed these events in the same way as the data collected with the detector[4]. From this analysis we produced the ν_μ energy spectra and the neutrino rates for both the data and the Monte Carlo events.

Table V. Calculated and measured charged particle intensities (particles/10^{12} POT) in the pion monitors.

Pion Monitor	Calculated intensity	Observed intensity
1	1.3×10^{10}	1.7×10^{10}
2	1.7×10^{10}	2.3×10^{10}
1/2	0.77	0.74

From the comparison of the measurements with the calculations we can draw the following conclusions:

(i) The absolute charged particle flux, measured in the beam tunnel (see Table V), as well as the measured neutrino rate at the E776 detector, normalized to the number of protons on target(POT), are systematically higher from the calculated ones by about 30%.

(ii) If we normalize the

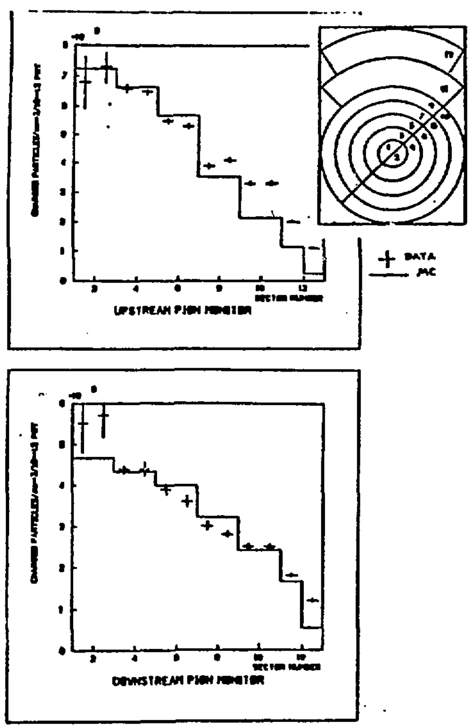

Fig. 5. Measured and calculated charged particle flux profiles in the beam tunnel.

calculated charged particle flux to the measured flux in the beam tunnel, then, with this normalization, the charged beam flux profiles measured with the pion monitors are in reasonable agreement with the calculated ones as shown in Fig. 5. With the same normalization the measured neutrino rates are consistent with the Monte Carlo.

(iii) As discussed in ref. 4, the measured ν_μ energy spectrum, normalized to the Monte Carlo below 2 GeV, has the expected shape; it peaks at 1.3 GeV for a horn current of 240 kA and it has a width of 23% (rms) consistent with the intrinsic beam width of 15% (rms) and the detector energy resolution. The measured spectrum tail above 2 GeV has about two times as many events as predicted with the Monte Carlo. The question of additional contributions to the WBB background is under investigation as a more sophisticated beam flux calculation is on the way.

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References

1. J.R. Sanford and C.L. Wang, "Empirical Formulas for Particle Production in p-Be Collisions between 10 and 35 BeV/c". AGS internal report, BNL # JRS/CLW-1, March 1, 1967. BNL report No. 11479, 1967, (unpublished).

   J.R. Sanford and C.L. Wang, "Empirical Formulas for Particle Production in p-Be Collisions between 10 and 35 BeV/c" (PART II). AGS internal report, BNL # JRS/CLW-2, May 1, 1967. BNL report No. 11479, 1967, (unpublished).

2. H. Grote, R. Hagedorn and J. Ranft, Atlas of Particle Production Spectra, CERN report, 1970 (unpublished)

3. L.A. Ahrens et al., "Determination of the Neutrino Fluxes in the Brookhaven Wide-Band Beams", Phys. Rev. D34, 75 (1986), and H.D. White, private communication.

4. G. Tzanakos, contribution to these Proceedings.