Search for New Particles at the Alternating-Gradient - Synchrotron Beam Dump

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This paper presents results of a beam-dump experiment performed at the Brookhaven alternating-gradient synchrotron to search for prompt sources of neutrinos and axionlike particles. We observe no excess of ν_e or $\bar{\nu}_\mu$ events, and no excess in neutral-current events over that expected from neutrinos from π and K decays. We report on limits of prompt particle-production cross sections and lifetimes.

We report on a beam-dump experiment performed at the Brookhaven National Laboratory (BNL) alternating-gradient synchrotron (AGS) neutrino beam to search for prompt sources of neutrinos and new penetrating neutral particles. Prompt sources of electron neutrinos have been observed at the CERN Super Proton Synchrotron.[1]

The detector consisted of 22 6-ft×6-ft thin-plate optical spark chambers interspersed with twenty planes of plastic scintillator (Fig. 1). The fiducial volume was five tons. The fiducial volume was followed by a muon identifier consisting of magnetized toroids and 8-ft×8-ft aluminum spark chambers.

The BNL neutrino beam was run in two configurations. In the first (bare target) configuration, protons impinged on a 6-in.×12-in.×12-in. copper target. Pions and kaons produced in the target decayed in a 200-ft drift space behind the target. Remaining charged particles were then attenuated by a 100-ft iron shield. In the second (beam dump) configuration, protons were transported to a 24-in.×12-in.×12-in. copper target immediately in front of the iron shield. The strong suppression of neutrinos from π and K decays in this configuration increases sensitivity to new sources of neutrinos or other neutral penetrating particles. The bare-target run allows a direct comparison of interactions observed in the beam-dump run with neutrino interactions from π and K decays. We report on data for 1.9×10^{17} protons on target in the bare-target configuration and 4.7×10^{18} protons on target in the beam-dump configuration. The two exposures were adjusted to yield approximately equal numbers of charged-current neutrino interactions from π and K decays. The calculated energy spectra of neutrinos was similar in the two configurations. We compare the beam-dump data to the bare-target data for anomalous ν_μ and $\bar{\nu}_\mu$ charged-current rate,

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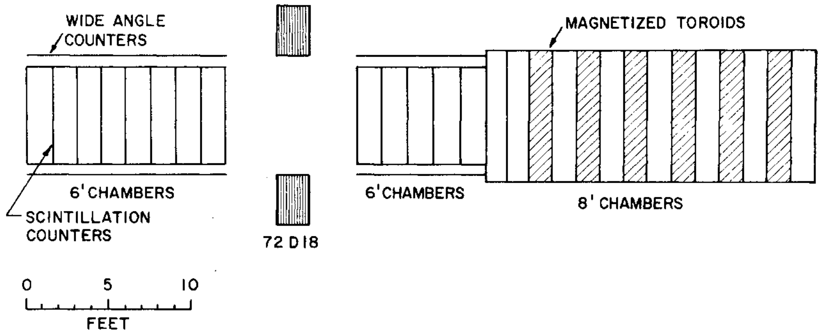

FIG. 1. Detector configuration.

neutral-current rate, and electron-neutrino rate. We also examine the beam-dump data for evidence of the axion decay $a \rightarrow \gamma\gamma$,[2] in a 50-ft drift space in front of the apparatus.

We first examine the charged-current and neutral-current rates. Events were selected with three of any five adjacent counters firing in coincidence. These events were scanned by physicists for vertex events. The minimum track length was 1 in. of Al; the minimum shower energy was 100 MeV. Events with a muon were called charged current (CC); events without, neutral current (NC). A muon was defined as a track either exiting from the detector or stopping with a minimum range of 18 in. of Al. The time of each event was measured by the counters relative to the beam arrival at the iron shield. Protons from the AGS were delivered in 50-ns buckets separated by 220 ns. The times for NC and CC events in the beam dump are shown in Figs. 2(a) and 2(b) (modulo 220 ns). The 50-ns bucket is clearly seen, along with some out-of-time background. We attribute this background to neutrons. After a flat neutron subtraction, the number of events we find is, for bare target, 53 CC and 9 NC; for beam dump, 49 CC and 14 NC. We have not selected single-track NC topologies (νp, $\nu n \pi^+$, etc.). Limiting ourselves to NC with ≥ 2 tracks and CC with ≥ 3 tracks (where one is the muon), we find for bare target, 24 CC and 9 NC; for beam dump, 29 CC and 14 NC. We also select π^0 events with at least one shower with $E_{\text{shower}} \geq 100$ MeV. We then find for bare target, 14 CC (π^0) and 7 NC (π^0); for beam dump, 14 CC (π^0) and 7 NC (π^0). There is no evidence for a significant increase of NC events in the beam dump for these topologies. The multiplicity, angle, and range distributions of NC and CC events are similar in the two configurations.

To examine the inclusive electron-neutrino rates, $\nu_e + N \rightarrow e +$ anything, we define an electron as a shower starting at the vertex with $E_{\text{electron}} > 500$ MeV. We observe one candidate in the bare-target data and one candidate in the beam-dump data. We conclude that there is no excess of electron candidates in the beam-dump run.

The film was also scanned for events originating in the 6-ft chambers with muons entering the magnetized toroids. The sign of the curvature of muons traversing at least two toroids was determined. We then find for bare target, four μ^+ and nineteen μ^-; for beam dump, six μ^+ and nineteen μ^-. There is no evidence for an increase in the $\bar{\nu}_\mu/\nu_\mu$ ratio for the beam-dump configuration.

We finally examine single-shower events. Axions decaying in a 50-ft drift space in front of the detector could result in an in-time signal for single showers observed in the detector. We select

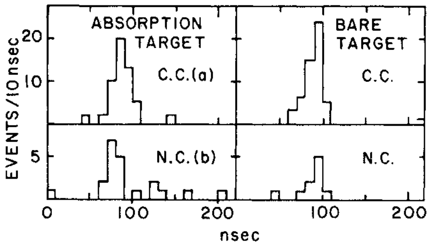

FIG. 2. Folded time of flight of CC and NC events for absorption-target and bare-target configurations.

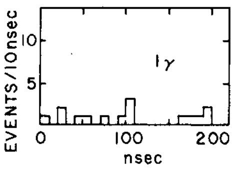

FIG. 3. Folded time of flight for single showers entering the detector in the absorption-target run.

single-shower events with $E_{\text{shower}} > 250$ MeV. The time-of-flight distribution is shown in Fig. 3. We observe no clear in-time signal.

We have performed a Monte Carlo calculation using the Sanford-Wang formula to compare CC rates for the beam dump and bare target. Since π and K secondary interactions in targets may be important, we calculate rates using an effective π, K absorption length of 30 cm for the beam dump. We assume two cases for the bare target. First, all inelastic pion scatterings remove pions from the beam; and second, there are no pion interactions. In the first case, we are in reasonable agreement with measured yields. In the second case we calculate a beam-dump–to–bare-target event ratio a factor of 2 below what we observe. However, even if one assumes that that discrepancy is due to prompt sources, we can rule out two possibilities. Prompt sources such as charm are expected to yield equal excess of ν_μ ($\bar{\nu}_\mu$) and ν_e ($\bar{\nu}_e$) events. We observe no excess ν_e ($\bar{\nu}_e$) events over those expected from K decays and no excess $\bar{\nu}_\mu$ events over those observed in the bare-target configuration. Neutral penetrating particles interacting in the detector would yield muonless events. We observe no excess NC events for any of the topologies studied.

We use our electron-neutrino rate to set a 90%-confidence-level limit on charm production. Assuming that the invariant cross section for $D\bar{D}$ production is proportional to $(1 - |X_{\text{F}}|)^{N} e^{-bp_\perp}$, we calculate an upper limit for the product $\sigma_{pp \to D\bar{D}}B$ (cross section times branching ratio to ν_e) of 20 μb for $N = 3$ and $b = 0.5$; and 12 μb for $N = 3$ and $b = 2$. Here we assume the A dependence for D production and π production to be the same. The limit is quite independent of the value of N, since we are sensitive to the low-$|X_{\text{F}}|$ region.

We have used our observed NC rate to set an upper limit on new penetrating particles interacting in our detector. Assuming a production spectrum given by that of the π, we set an upper limit of $\sigma_{\text{prod}}\sigma_{\text{int}} \leqslant 5 \times 10^{-68}$ cm^4 at the 90% confidence level.

If we assume $\sigma_{\text{int}}{}^a = \sigma_{\text{prod}}{}^a = 2.2 \times 10^{-34}$ cm^2, we find that $R = \sigma_{\text{prod}}{}^a/\sigma_\pi = 1 \times 10^{-8}$. Using this limit we can calculate the number of in-time single showers expected from the axion decay $a \to \gamma\gamma$ in the 50-ft decay space in front of our apparatus as a function of $c\gamma\tau$. Assuming an upper limit of three in-time events, we set the limits $c\gamma\tau > 1 \times 10^9$ ft or $c\gamma\tau < 12$ ft.

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[1] P. Alibran *et al.*, Phys. Lett. 74B, 134 (1978); T. Hansl *et al.*, Phys. Lett. 74B, 139 (1978); P. C. Bosetti *et al.*, Phys. Lett. 74B, 143 (1978).

[2] S. Weinberg, Phys. Rev. Lett. 40, 223 (1978); F. Wilczek, Phys. Rev. Lett. 40, 279 (1978).