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FEASIBILITY OF USING HIGH-ENERGY NEUTRINOS TO STUDY THE WEAK INTERACTIONS

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For many years, the question to how to investigate the behavior of the weak interactions at high energies has been one of considerable interest. It is the purpose of this note to show that experiments pointed in this direction, though not quite feasible with presently existing equipment, are within the capabilities of present technology and should be possible within the next decade.

We propose the use of high-energy neutrinos as a probe to investigate the weak interactions.

A natural source of high-energy neutrinos are high-energy pions. Such pions will produce neutrinos whose laboratory energy will range with equal probability from zero to 45% of the pion energy, and whose direction will tend very much toward the pion direction. For example, 1-Bev/c pions will emit neutrinos with an average energy of ~220 Mev in such a way that ~$\frac{1}{2}$ of the neutrinos will fall within a cone of half-angle 7°. For orientation purposes, the mean decay distance for such a pion would be 50 meters.

The best known source of pions is a proton accelerator where the beam is allowed to impinge on a target. Let us assume that we have available a 3-Bev proton beam and 10 000 kilograms of material for sensing a neutrino interaction. We may then estimate the proton flux necessary to produce one interaction per hour with a cross section of σ cm^2. To do this, let us consider the simple setup shown in Fig. 1.

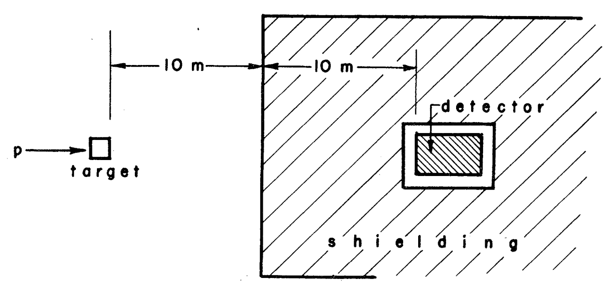

FIG. 1. Proposed experimental arrangement.

Let I be the number of incident protons per unit time, and let, say, $I/10$ charged pions with energy $\geqq 2$ Bev be produced at the target. These pions emerge in a cone of about 45° half-angle, or in about 2 steradians of solid angle. We now let them travel for a distance of 10 meters before hitting a 10-meter shielding wall in front of the detector. Approximately 10% of the pions will decay with an average neutrino energy of about 400 Mev. Each square centimeter of detector subtends a solid angle of $\frac{1}{4}\times10^{-6}$ steradian. Hence, the high-energy neutrino flux at the detector is $(\frac{1}{10}I)(\frac{1}{4}\times10^{-6})(\frac{1}{10})(\frac{1}{2})\cong1\times10^{-9}I$. If there are 10 000 kilograms of detector present, the number of events per unit time is given by

$$N\sim(10^7)(6\times10^{23})(10^{-9}I)\sigma=6\times10^{21}I\sigma.$$

For an intensity of $I=5\times10^{12}$ protons/sec $=1.8\times10^{16}$

protons/hr, the high-energy neutrino flux is ~ 5000 neutrinos sec^{-1} cm^{-2}. With a cross section $\sigma \sim 10^{-38}$ cm^2, the number of counts is $N \sim 1$ per hour in 10 000 kg of detector. The estimate here given is for neutrinos from high-energy pions. There is, as a matter of fact, a much greater flux of lower energy neutrinos from lower energy pions. However, because the neutrino cross section decreases rapidly with decreasing energy, the rate is not likely to be improved by more than a factor of two.

This estimate places the experiment outside the capabilities of existing machines by one or two orders of magnitude. Optimistic estimates for accelerators which are currently under construction, namely the 3-Bev machine at Princeton and the 10-Bev machine at Argonne, indicate that the experiments may be barely feasible in the near future. However, for really quantitative experiments it will be necessary to use high-intensity machines such as the FFAG machine proposed by MURA or the 10-Bev linear proton accelerator discussed by Blewett at Brookhaven. In these machines, one hopes to attain a beam intensity of the order of 10^{15} protons/sec at an energy of about 10 Bev.

The higher energy of the primary beam of protons makes the experiment easier because of the increased multiplicity of pions, the more concentrated forward distribution of the pions, and the increased cross section for neutrino reactions. Balanced against these is the fact that the percentage of higher energy pions that decay in 10 meters is smaller. The net result is likely to give a counting rate per primary proton that probably increases more than linearly with the primary proton energy.

Thus, a high-intensity 10-Bev proton machine with a beam intensity $\sim 10^{15}$ protons/sec may give a counting rate of more than 10^3 per hour, using the experimental setup described above. If that proves to be the case, it is perhaps desirable to have magnetic lenses to analyze and focus the pions so as to obtain more monoenergetic neutrino beams.

I would like to express my gratitude to Dr. T. D. Lee and Dr. C. N. Yang for many stimulating discussions which led to the above proposal.

Note added in proof. The author's attention has been called to a somewhat related paper which has just appeared: B. Pontecorvo, J. Exptl. Theoret. Phys. (U.S.S.R.) 37, 1751 (1959).

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THEORETICAL DISCUSSIONS ON POSSIBLE HIGH-ENERGY NEUTRINO EXPERIMENTS*

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The weak interaction so far most extensively studied is β decay, in which the momentum transfer is of the order of a few Mev. In μ decay and μ capture, momentum transfers of the order of 100 Mev are involved. In the theory of these processes, because of the limited region of momentum transfer studied, the phenomena can be described by a few parameters usually called coupling constants. For larger momentum transfers it is obvious that the weak interactions cannot continue to be described by these constants, because of the clothed structure of the nucleons due to the strong interaction, and also because of the reasonable expectation that the weak interactions, even without the interference of the strong interactions, may not be of the simple four-spinor product form in Fermi's theory.

In the preceding Letter,[1] Schwartz points out that the neutrinos from the decay of high-energy mesons can be used to study weak interactions. We have investigated the theoretical implication of such possible experiments. Efforts are made to separate and dissociate the inferences that can be drawn from different assumptions concerning the weak interactions. In this Letter we report briefly on this work.

1. The identity of the neutrinos. In the processes

$$\pi^+ \to \mu^+ + \nu_1, \qquad (\pi \text{ decay}) \qquad (1)$$

$$\mu^- + p \to n + \nu_2, \qquad (\mu \text{ capture}) \qquad (2)$$

$$Z \to (Z-1) + e^+ + \nu_3, \qquad (\beta^+ \text{ decay}) \qquad (3)$$

it is easy to see that ν_1 and ν_2 are the same par-