ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Лаборатория ядерных проблем

L.I.Lapidus

E – 1120

ON THE INTERPRETATION OF HIGH ENERGY NEUTRINO EXPERIMENTS

Дубна 1962

L.I.Lapidus

E – 1120

ON THE INTERPRETATION OF HIGH ENERGY NEUTRINO EXPERIMENTS

Submitted to JETP

Дубна 1962

Abstract

It is stressed that under some assumptions on the role of the induced pseudo-scalar in processes (1) and (2) within one-neutrino theory the predominance of the number of muons over electrons in the high energy neutrino experiments is possible.

Л.И. Лапидус

К ИНТЕРПРЕТАЦИИ ЭКСПЕРИМЕНТА С НЕЙТРИНО ВЫСОКИХ ЭНЕРГИЙ

Аннотация

Отмечается, что при некоторых предположениях о роли индуцированного псевдоскаляра в процессах (1) и (2) в рамках однонейтринной теории возможно преобладание числа мюонов над электронами в экспериментах с нейтрино высоких энергий. Обсуждается необходимость проведения дополнительных опытов с целью решения вопроса о существовании электронных и мюонных нейтрино.

At the 1962 International Conference on High-Energy Physics at CERN the results of the first experiment with the high energy neutrino carried out at the 32 BeV Brookhaven accelerator/1/ have been reported. The main results of this great experiment were the following:

1. The establishment of the fact that the number of muons produced by neutrinos due to $\pi^{\pm} \to \mu^{\pm} + \nu(\bar{\nu})$ decay is considerably larger than that of electrons*.

2. The approximated evaluation of the reaction cross sections induced by high energy neutrinos.

The predominance of the number of muons over the number of electrons evidenced to the existence of two kinds of neutrinos ν_e and ν_μ. In the discussion of ref./1/ and also of ref./2/ where the possibility of such an experi - ment was considered, it was assumed that in the framework of one-neutrino hypothesis in such an experiment the equal numbers of muons and electrons should be expected.

Below our attention is centered on the fact that within one-neutrino hypothesis it is possible for the number of muons to exceed the number of electrons and that supplementary experiments are necessary in order to solve more reliably the problems of muon and electron neutrinos.

Theoretically 'elastic' processes on free nucleons

$$\nu + n \to p + \ell^- \qquad (\ell = \mu, e) \tag{1}$$

$$\bar{\nu} + p \to n + \ell^+ \tag{2}$$

were considered earlier by Lee and Yang/4/, Cabibbo and Gatto/5/, Yamaguchi/6.7/. A serious uncertainty in the predictions is brought by strong interaction effects. As has been shown in ref./8/ the matrix elements of processes (1) and (2) in the framework of one-neutrino universal theory of weak interactions in the first approximation on the constant of the weak interaction are expressed (provided that CP invariance and the rule $/\Delta I\ / = 1$ /9/ are justifyable) by four form-factors $F_{1V}(q^2)$, $F_{2V}(q^2)$, $F_A(q^2)$ and $F_P(q^2)$ introduced in accordance with the general expression for the matrix element (of reaction (1))

$$\bar{u}_p [F_{1V}\gamma_a + \frac{\mu}{2M} F_{2V}(P-n)_\beta \sigma_{a\beta} + \lambda F_A \gamma_a \gamma_5 + i b F_p (P-n)_a \gamma_5] \ u_n \tag{3}$$

$$\bar{u}_e \gamma_a (1+\gamma_5)\ u_\nu .$$

where

$$q^2 = (P-n)^2 = (\ell - \nu)^2$$

determines the momentum transfer and the remaining notations are conventional.

---

* More rigorously, in the experiment with limited statistics there was found not a single event which definitely meant electron production.

With the help of the Dirac equation it may be easily seen that the contribution of the induced pseudo-scalar is proportional to the lepton mass.

In the case of the conserved vector current in weak interactions F_{1V} coincides with the isovector part of the Dirac electromagnetic nucleon form-factor and F_{2V} coincides with the Pauli one.* As to the axial form-factor λF_A, apart from general indications of dispersion relations only its value with $q^2 = 0$ is known. There is an evaluation /8,10/ of the pole contribution to the form-factor of the induced pseudo-scalar interaction $b F_p$... The estimations are made by the most part under the assumption that all the form-factors have identical dependences. It may easily be seen that then with neutrino energies about 1 BeV (what is close to Brookhaven experimental conditions) the contribution to the cross section, proportional to F_{1V}, F_{2V} and F_A, turns out to be approximately equal for electrons and muons in reactions (1) and (2), and the magnitude itself of the cross section for reaction (2) is about one third of the cross section of reaction (1). On the other hand the contribution of the pseudo-scalar F_p leads with great advantages to muon production, yielding electrons approximately in the same proportion in which the $\pi \to e + \nu$ and $\pi \to \mu + \nu$ decay probabilities are.

What is known at present about the effective constant of the pseudo-scalar interaction? What evaluations may be obtained for the pseudo-scalar contribution for the neutrino energy range about 1 BeV?

For the comparative evaluation of various form-factor contributions let us make use of Yamaguchi results /6,7/ obtained by him for form-factors of the kind

$$F_{1V} = F_{2V} = F_A = F_p = \left(1 + \frac{r^2 q^2}{12} \right)^{-2}$$

with $r_0 = 0.8 \cdot 10^{-13}$ cm.

In the function of the neutrino energy the contribution of the pseudo-scalar proves to be maximum with $E_\nu \cong M$. With $E_\nu = M$ the contribution $F_{1V,\,2V}$, F_A (in units of 10^{-38} cm^2) is about 0.85 within these permissions for the cross section of process (1) and 0.33 for the cross section of process (2). The contribution F_p equal for both the processes with $G_p = 8\, G_A$ is 0.17. The three-fold increase of G_p comparing to the pole estimation increases the contribution of the pseudo-scalar interaction nearly 10 times (the interference of the pseudo-scalar contribution with the axial vector interaction is small) what causes the predominance of the number of muons over .electrons approximately 2.5 times for reaction (1) and 6-7 times for reaction (2) . From this point of view muon neutrino experiments are preferable over antineutrino ones.

Thus, in the Brookhaven conditions with approximately equal numbers of neutrinos and antineutrinos in the beam, in the framework of one-neutrino hypothesis without contradiction to available experimental data, it is possible to obtain five-fold predominance of the number of muons over electrons. Emphasize that these evaluations have been obtained only due to the increasing of the pseudo-scalar interaction constant under the assumption of equal dependences of all the form-factors.

At present, apparently, a possibility cannot be excluded that F_A decreases with increasing q^2 faster than other form-factors** .

---

* It is interesting to note that, in principle, from the point of view of the highest approximations, information on the asymptotic value of vector form-factors should be taken from high energy neutrino (lepton) experiments.

** It is of interest to remind that from the data on the $\pi \to \mu + \nu$ and $K \to \mu + \nu$ decay probabilities it follows that F_A^π and F_A^K axial form-factors of these particles are related as

$$| F_A^K (m_K) |^2 = 1/10\, | F_A^\pi (m_\pi) |^2$$

Different dependences of form-factors upon q^2 change the evaluation for the relation between the number of muons and electrons 2-3 times additionally without increasing the total cross section value.

It is worth nothing that in experiments with electromic neutrino when the efficiency of preudo-scalar interaction is sharply decreased, the equal numbers of electrons and muons arise within one-neutrino theory.

It is clear that the five-fold increase of muons due to the larger constant of the pseudo-scalar interaction gives rise to the corresponding increase of the absolute value of the cross section while a more precise determination of experimental data on the cross sections is very desirable.

In view of the fact that the experiment is carried out with nuclei, it appears necessary to make a more detailed consideration of nuclear effects, taking into account, for instance, correlation in Fermi-gas, the same as it has been performed by Glauber[11] for the scattering problem.

It is desirable that the experiments on the independent determination of the pseudo-scalar contribution to muon weak interaction at high energies be carried out. For this purpose use may be made of the fact that the pseudo-scalar contribution to the cross sections of reactions (1) and (2) is sharply decreased (vanishes in the approximation $v_\mu = 1$) for muons in forward direction. The value itself of the pseudo-scalar contribution is maximum about $E_\nu = M$ and is decreased with decreasing or increasing energy from both sides of this energy value. Therefore, an experiment with higher energy neutrinos would be desirable.

More precise information on the value of the pseudo-scalar in muon capture by nucleons at low energies would considerably clearify the problem.

From the point of view of this analysis it is obvious, that experiments with electronic neutrinos would be the most clear. The existence of electronic neutrino sources would be possible on increasing considerably the intensity of accelerator particles.

The two-neutrino hypothesis is attractive from the point of view of understanding the cause of prohibition of neutrinoless processes of the mode $\mu \to e + \gamma,\ 3e$. Stress, however, that the theory of weak interaction with symmetric neutral currents[12,13,14] also quarantees the prohibition of such processes, leaving room for considerable role of weak interactions in astro-physical phenomena due to direct neutrino-nucleon interaction.

The above discussion was based on the most frequently accepted expression on the general kind of nucleon current. The rule $|\Delta I| = 1$ being absent, along with the pseudo-scalar there arises a possibility of a induced scalar interaction, the contribution of which to the cross section of reaction of reactions (1) and (2) is also proportional to lepton mass. The induced scalar in (3) increases additionally the predominance of the number of muons over electrons.

Though some of the above considerations are speculative, the main task of the present note is to attract attention to a necessity of supplementary high energy neutrino experiments.

The author is very grateful to S.S.Gerstein, V.S.Yevseyev, L.B.Okun', B.Pontecorvo, A.P.Rudik, Ya. A.Smorodinsky, and R.M.Sulyayev for numerous and valuable discussions.

References

1. G.Danby, J.M.Gaillard, K.Goulianos, L.M.Lederman, N.Mistry, M.Schwartz, and J.Steinberger, Phys. Rev. Lett. 9, 36 (1962).
2. Б.Понтекорво. ЖЭТФ, 37, 1751 (1959).
   M.A.Markov. Hyperonen and K-mesonen, Berlin 1960.
3. M.Schwartz, Phys.Rev. Lett. 4, 306 (1960).
4. T.D.Lee, C.N.Yang, Phys. Rev. Lett. 4, 307 (1960).
5. N.Cabibbo and R.Gatto, Nuovo Cim. 15, 304 (1960).
6. Y.Yamaguchi, Prog, Theor. Phys. (Kyoto) 6, 111 (1960).
7. Y.Yamaguchi, Preprint CERN 61-2 (1961).
8. M.L.Goldberger, S.B.Treiman, Phys. Rev. 111, 354 (1958).
9. T.D.Lee and C.N.Yang, Phys.Rev. 126, 2239 (1962).
10. L.Wolfenstein, Nuovo Cim. 10, 882 (1958).
11. R.Glauber,Lectures in Theoretical Physics v1 p 315 Interscience Publish N.Y.1959.
12. S.Bludman, Nuovo Cimento 9, 433 (1958).
13. Б.Понтекорво. Препринт ОИЯИ, E-980, 1962.
14. R.A.Eramjan, S.S.Gerstein, Nguyen Van Hieu Preprint ОИЯИ E-1050, 1962.
    R.W.King Phys. Rev. 121, 1201,(1961).

Received by Publishing Department
on November 12, 1962.