"Direct" neutrino production and charmed particles

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(Submitted March 27, 1975)
Zh. Eksp. Teor. Fiz. **69**, 452–456 (August 1975)

"Direct" neutrino production, i.e., the production of neutrinos in processes other than pion and kaon decay, may be detected and studied in high energy neutrino experiments if there is no pion and kaon decay region present. In distinction from ordinary neutrino beams, where muonic neutrinos predominate, the neutrinos produced in charmed particle decays are characterized by equal numbers of ν_e and ν_μ. A feature of the proposed experiments is a relatively small expected background, but the intensity of the effect which is looked for is small. The neutrino detector should be capable of recording electron showers produced in the interactions of the electronic neutrinos with nuclei.

PACS numbers: 14.60.G, 14.80.D

In high energy nucleon collision one observes[1] so-called "direct" production of charged leptons, i.e., lepton production in processes other than pion, kaon (and muon) decays. By means of investigations of the "direct" production of single charged leptons it is hard to separate the contribution of the virtual photons and the contribution of electromagnetic decays of vector mesons ($\rho \to \mu^+\mu^-$, etc.) from the contribution of the (weak) decays of the new short-lived particles, say charmed particles. This difficulty disappears completely in the case of "directly" produced neutrinos, which here are defined as neutrinos which are not produced as a result of pionic, kaonic (and muonic) decays.

Thus the problem here is the inclusive production in nucleon-nucleon collisions of charmed particles which decay with the emission of a neutrino and the inclusive recording of these neutrinos

$$\underline{\text{proton}} + A \to 2\ \underline{\text{charmed particles}} + \ldots$$
$$\underline{\text{neutrino}} + \ldots$$

(by neutrino we understand here one of the following ν_e, ν_μ, $\bar{\nu}_e$, $\bar{\nu}_\mu$).

Appropriate experiments have already been discussed several years ago[2] from a purely phenomenological point of view, in relation to the problem whether there are sources of neutrinos other than pions and kaons, and have already been carried out at the Stanford electron accelerator[3], albeit with a sensitivity insufficient for solving the problems posed below. Such an experimental setup could be realized if one does not give the pions and kaons the possibility to decay in flight, by recording "directly" the produced neutrinos by means of the well-known effective high-energy neutrino detectors. This means that the proton beam must be incident directly on the shield behind which the neutrino detector is situated.

At the present time, when the scientific public opinion interprets the narrow boson resonances with masses 3.1 and 3.7 GeV[4–6] as particles with hidden charm, it is appropriate to specify more concretely the problem of "directly" produced neutrinos; in experiments one should record neutrinos from the decay of charmed particles (lifetime approximately $10^{-11}-10^{-14}$ s) in the presence of neutrinos from the decays of pions, kaons and muons[1)].

We assume that a high-energy proton beam impinges on condensed matter (of a thickness equal to a large number of nuclear interaction lengths, as is the case with the iron shielding used in high energy neutrino experiments). The background in these experiments arises from the decay in flight of pions and kaons "against our will"[2)], where obviously the length available for their decay is comparable to the nuclear length, although it is somewhat larger owing to multiple pion production. If we are interested in recording of high energy neutrinos, then the fraction of long-lived mesons (pions and kaons) with energy W, decaying with the emission of such neutrinos equals R/D(W), where R is the nuclear absorption length and D is the decay length of the corresponding mesons ($R/D \ll 1$). Since D(W) is proportional to W, this leads to a "softening" of the neutrino spectrum coming from pion and kaon decays relative to their spectra in known experiments, where there is a long "decay region." The charmed particles for which $R > D$, with obvious notations, will decay with probability one. The relatively short-lived particles like the K^0, for which $R \lesssim D$ will also be taken into account in the estimation of the background.

Let $(\nu_\mu)_{\text{charm}} \simeq (\nu_e)_{\text{charm}}$ denote the average number of muonic and electronic neutrinos produced in one decay of a charmed particle, multiplied by the cross section σ_{charm} for charmed-particle production in nucleon-nucleon collisions. Let $(\nu_\mu)_{\pi^+}$, $((\nu_\mu)_{K^+}$, $(\nu_e)_{K^+}$, $(\nu_e)_{K_L^0}$, and $(\nu_e)_{K_S^0})$ be the average number of neutrinos of the indicated kind produced in one decay of the particle in the subscript, multiplied by the probability $R/\tilde{D}$ of its decay under the conditions of the process under consideration, and by the cross section σ_{π^+} (σ_{K^+}, $1/2\sigma_{K^0}$) for the production of the indicated particle in nucleon-nucleon collisions. Let $\Gamma(\ldots)$ denote the widths of the corresponding processes. Whereas quantities like σ_π, σ_K, $\Gamma(\pi \to \mu\nu_\mu)$, $\Gamma(K \to \mu\nu_\mu)$, $(K^+ \to e^+\nu_e\pi^0)$ ...and the total widths of these particles are known, one cannot say anything definite in the case of the charmed particles. With moderate optimism we shall assume (cf., e.g.,[7])

$$\Gamma(\text{charm} \to \nu_\mu + \ldots)/\Gamma_{total}(\text{charm}) = \Gamma(\text{charm} \to \nu_e + \ldots)/\Gamma_{total}(\text{charm}) \approx 0.1$$

and that for protons of 400 GeV the cross section is $\sigma_{\text{charm}} \simeq 10^{-29}$ cm^2. Then we obtain the following estimates, which have a definitely approximate character, pertaining to the proposed experiment with 400 GeV protons and for production of neutrinos with energies in the region of 15 GeV:

$$(\nu_\mu)_{\text{charm}}/(\nu_\mu)_{\pi^+} \approx (\nu_\mu)_{\text{charm}}/(\nu_\mu)_{K^+} \approx 2, \quad (\nu_e)_{\text{charm}}/(\nu_e)_{K^+} \approx 60,$$
$$(\nu_e)_{\text{charm}}/(\nu_e)_{K_S^0} \approx 80, \quad (\nu_e)_{\text{charm}}/(\nu_e)_{K_L^0} \approx 120.$$

It turns out that the number of neutrinos (in particular of ν_e) from charmed particle decays will apparently exceed the number of neutrinos from kaon and pion decay under the conditions of the proposed experiment, so that there are no serious difficulties to be expected related to the background from noncharmed particles. One should note the important circumstance that there is an essential distinction between the "ordinary" neutrinos (from pionic and kaonic decays) and the "direct" neutrinos (of charmed parentage): among the latter the ν_e and ν_μ will have equal rights, whereas in beams of "ordinary" neutrinos the number of ν_e is considerably smaller than the number of ν_μ (since $\Gamma(\pi \to e\nu_e) \ll \Gamma(\pi \to \mu\nu_\mu)$ and $\Gamma(K \to e\nu_e) \ll \Gamma(K \to \mu\nu_\mu)$. This enhances the likelihodd of a clear picture of the events we are looking for.

In the case of leptons emitted under large angles (several degrees in the laboratory system) with respect to the beam of incident protons the conclusion reached above about a small background of "ordinary" neutrinos is confirmed not only in "direct" production experiments of charged leptons[1] carried out at Fermilab (E_p = 400 GeV) but also in the more difficult experiments on the same question, carried out at Serpukhov (E_p = 70 GeV). According to the result of the Serpukhov group[8], for instance, in collisions of 70-GeV protons with nuclei the measured number of muons from $K \to \mu\nu_\mu$ decay (kaons decaying over one nuclear interaction length) and the number of "direct" muons are comparable, where the muons with energies of 10–12 GeV have been emitted under 90° in the c.m.s. Of course, the number of "direct" muons observed is an upper limit for muons of charmed parentage, since muons can be produced "directly" in other ways, on account of electromagnetic interaction.

The searches for neutrinos of charmed parentage is apparently difficult on the Serpukhov accelerator, although the background of ν_e from kaon decays on this accelerator may turn out to be considerably smaller than the intensity of direct ν_e. One should take into account, however, that the absence of meson focusing in the proposed experiment, typical of experiments where neutrinos are produced by pions and kaons, is partially compensated by the better geometry of registration for "direct" neutrinos, related to the smaller distance between the source and neutrino detector. From this point of view the Serpukhov accelerator presents some interest, although in principle a higher proton energy has great advantages, since, first of all the charmed particle production cross section increases with the energy of the incident protons; second, the decay probability of pions and kaons decreases with their energy, and third, the cross section for neutrino interactions with nucleons increases with their energy.

Of course, the absolute intensity of neutrino events related to "directly" produced neutrinos is small: let us say, it is four orders of magnitude smaller than the intensity of "ordinary" neutrino events in known high-energy experiments.

Apparently, one has to take into account the possibility of carrying out experiments of the type under consideration in planning neutrino experiments on new accelerators. The main condition for this is the creation of a relatively compact shielding, possibly including magnetic deflection of the muons.

We would like to make a remark with regard to the spectrum of neutrinos of charmed parentage. Apparently such neutrinos will, as a rule, be emitted together with charged leptons and strange particles and pions. However, of special interest are the vector mesons F* and $\tilde{F}$* with the quark content ($\lambda\bar{p}'$) and ($\bar{\lambda}p'$). The reason is that although, as expected (cf. e.g.,[9]), the mass of the F* meson is very likely somewhat larger than the mass of the pseudoscalar meson F of the same quark content, nevertheless one cannot exclude a mass inversion. In this case the transitions $F^* \to F + \pi \ldots$ and $F^* \to F + \gamma$ are suppressed and then the two-particle weak decays

$$F^* \to \mu^-\tilde{\nu}_\mu,\ e^-\tilde{\nu}_e, \qquad F^* \to \mu^+\nu_\mu,\ e^+\nu_e$$

become competitive. At the same time the presence of two-particle decays leads to a characteristic hard neutrino spectrum for the (ν_μ, $\tilde{\nu}_\mu$, ν_e, $\tilde{\nu}_e$), as happens for the ν_μ spectrum from $K^+ \to \mu^+\nu_\mu$ in the usual neutrino experiments. Independently of the possible effect of two-particle decays, the neutrino spectrum from three-particle decays of charmed particles contains neutrinos of considerably higher energy than the neutrino spectrum from the decay of pions and kaons, which in the experiment under discussion is naturally depleted of "hard" neutrinos. Therefore in the experiment one must make an effort to record the energetic fraction of neutrinos.

Thus, a neutrino exposure "without a decay region for pions and kaons," over several months, on a high-energy proton accelerator, with a neutrino detector which effectively records electronic showers gives, in principle, the following possibilities:

1. To detect charmed particles by observing neutrinos coming from their decays.

2. On the basis of the general picture of neutrino events which differs from the picture in "ordinary" neutrino beams, to verify the hypothesis characteristic for charmed particles according to which in neutrino beams of charmed parentage the numbers of electronic and muonic neutrinos are comparable.

3. To obtain interesting information on "direct" lepton production in nucleon-nucleon collisions by comparing the number of "directly" produced neutrinos with the number of "directly" produced charged leptons.

4. To derive important consequences on the existence and on the mass of vector bosons with the quark content ($\lambda\bar{p}'$) and ($\bar{\lambda}p'$).

5. To observe unexpected phenomena, related to the possible existence of unknown particles (new types of neutrinos and new neutrino sources).

In conclusion I have the pleasure of thanking B. A. Arbuzov, S. M. Bilen'kiĭ, S. S. Gershteĭn, V. I. Zakharov, A. I. Mukhin, L. B. Okun', A. T. Fillipov and particularly B. A. Dolgoshein and R. M. Sulyaev for useful discussions.

1)We do not discuss neutrino production from intermediate vector bosons, since the production of the latter in nucleon-nucleon collisions is a semi-weak process, whereas the production of charmed particles is a strong, albeit suppressed, process.

2)It is easy to see that the background from muon decay in flight may be neglected.

1The Observation of Leptons of Large Transverse Momentum, CERN-Columbia-Rockefeller–Saclay collaboration, Columbia-FNAL collaboration, Princeton-Chicago collaboration, Wisconsin-Harvard-Chicago collaboration, Serpukhov contribution, Lederman summary, Proc. XVII Int. Conf. on High-Energy Physics, London, July

1974, V. 41–55.
[2]B. Pontecorvo, Proc. XV Int. Conf. on High Energy Physics, Kiev, August 1970; Usp. Fiz. Nauk 104, 3 (1971) [Sov. Phys. Uspekhi 14, 235 (1972)].
[3]M. Schwartz, Rep. on Progr. in Phys. 27, 75 (1965). D. Freyberger et al., Science News 100, 252 (1971).
[4]J. J. Aubert et al. Phys. Rev. Lett. 33, 1404 (1974).
[5]J. E. Augustin et al. Phys. Rev. Lett. 33, 1406 (1974); G. S. Abrams et al. Phys. Rev. Lett. 33, 1453 (1974).
[6]C. Bacci et al. Phys. Rev. Lett. 33, 1408 (1974).
[7]L. B. Okun', Adrony i kvarki (Hadrons and Quarks), Lectures at the Winter School of the ITEF, Zvenigorod, January 1974, MIFI Publ. House, 1974.
[8]G. B. Bondarenko et al. Proc. XVI Int. Conf. on High Energy Physics Batavia, September 1972, 2, 1973 p. 329. V. V. Abramov et al., Preprint, IFVE, SEF 74-83 Serpukhov, 1974.
[9]S. Okubo, V. S. Mathur and S. Borchardt, Phys. Rev. Lett. 34, 236 (1975).

Translated by M. E. Mayer
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