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B.Pontecorvo

"DIRECT" NEUTRINO PRODUCTION AND CHARMED PARTICLES

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It is well known that in high energy collisions of protons with nuclei the "direct" production/1/ of charged leptons is observed, that is the production of charged leptons in processes other than π, K (and μ) decays. By investigating single charged leptons it is impossible to separate the contributions of virtual photons and of electromagnetic decays of vector mesons ($\rho' \to \mu^+ + \mu^-$,etc.) from the contribution of (weak) decays of new short living particles, say, charmed particles. Obviously, there are no such difficulties in the case of "directly" produced neutrinos which are defined here as neutrinos generated in processes other than pion, kaon (and muon) decays.

Thus, the question here is raised about the inclusive production in nucleon-nucleon collisions of charmed particles decaying with the emission of neutrinos and the inclusive detection of such neutrinos:

$$\begin{array}{l} p + A \text{ -- } 2 \text{ charmed particles} + \ldots \\ \qquad\qquad\qquad\qquad\qquad\quad \hookrightarrow \text{neutrinos} + \ldots \end{array}$$

(here the word neutrino means ν_e , ν_μ, $\tilde{\nu}_e$, $\tilde{\nu}_\mu$) .

A type of experiment capable, in principle, of solving the question has already been discussed several years ago/2/ from the purely phenomenological point of view of searching for possible neutrino sources other than K and π decays and was actually performed at the Stanford electron accelerator/3/. The idea is to detect "direct" neutrinos by efficient, more or less conventional, high energy neutrino detectors, while pions and kaons are not allowed to decay in flight. This means that the proton beam must fall directly upon the "shield" behind which the neutrino detector is located.

At the moment when the narrow resonances of masses 3.1 and 3.7 GeV /4,5,6/ are widely interpreted as particles with hidden charm, it is time to discuss the idea mentioned above in terms of "charmed" particles. In the experiments one must detect neutrinos from charmed particle decays (the mean life being 10^{-11}-10^{-14} sec) in the presence of a neutrino background from π, K and μ decays*. Let us then suppose that a high energy proton beam impinge upon condensed matter (of thickness equal to a very large number of nuclear lengths, as in the case of the iron shield in high energy neutrino experiments). The neutrino background originates from those pions and kaons** which decay in flight "against our will", the length available for their decay being evidently of the order of a typical nuclear inelastic length, though somewhat larger. If we are interested in the detection of high energy neutrinos, the fraction of pions and kaons of energy W decaying with emission of neutrinos is R/D(W), where R is the proton nuclear absorption length and D(W) is the decay length of the corresponding mesons ($R/D(W) \ll 1$). Since D(W) is proportional to W, in the experiment being considered there arises a marked softening of the neutrino spectrum from π and K decays with respect to the neutrino spectrum from π and K decays obtained in the usual high energy neutrino experiments, where a long decay region is available. The charmed particles, for which $R \gg D$ (the notation is self-explanatory), will decay with probability 1. Relatively short-living particles as K_S^0, for which $R \lesssim D$, should be considered also in the evaluation of the background.

Let $(\nu_\mu)_{ch.} \sim (\nu_e)_{ch.}$ be the average number of electron and muon neutrinos emitted per decay of a charmed particle, multiplied by the cross section $\sigma_{ch.}$ for the production of charmed particles in nucleon-nucleon collisions. Let $(\nu_\mu)_{\pi^+}$, $[(\nu_\mu)_{K^+}, (\nu_e)_{K^+}, (\nu_e)_{K_L^0}, (\nu_e)_{K_S^0}]$ be the average number of neutrinos of the noted type emitted per decay of the indicated particle multiplied by its decay probability $R/\bar{D}$ under the conditions considered and by the cross section $\sigma_{\pi^+} (\sigma_{K^+}, \frac{1}{2}\sigma_{K^0})$ for the production of such a particle in nucleon-nucleon collisions.

Let Γ stand for the width of the process indicated below. While such values as τ_π, τ_K, $\Gamma_{\pi\to\mu\nu_\mu}$, $\Gamma_{K\to\mu\nu_\mu}$, $\Gamma_{K\to e\nu_e\pi}$

(and the total widths) are known, nothing definite can be stated about charmed particles. With moderate optimism I shall assume that

$$\Gamma_{ch.\to\nu_\mu+\dots}/(\Gamma_{ch.})_{total} = \Gamma_{ch.\to\nu_e+\dots}/(\Gamma_{ch.})_{total} \approx 0.1$$

and that for 400 BeV protons $\sigma_{ch.} \approx 10^{-29}$ cm^2 /7/. Then we obtain the following figures which have only a rough indicative value and refer to neutrinos with energy $\gtrsim$ 15 GeV produced by protons of energy $\sim$ 400 GeV in the type of experiments considered here.

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[*] Neutrino production by the intermediate vector meson decay is not discussed here, since the production of such meson is a semiweak process, while the production of charmed particles in nucleon-nucleon collisions is a strong, although somewhat suppressed, process.

[**] It is easy to see that the neutrino background from muon decay is negligible in comparison with the other sources of background discussed below.

$$\frac{(\nu_\mu)_{ch}}{(\nu_\mu)_{\pi^+}} \approx \frac{(\nu_\mu)_{ch}}{(\nu_\mu)_{K^+}} \approx 2 \quad ; \quad \frac{(\nu_e)_{ch}}{(\nu_e)_{K^+}} \approx 60;$$

$$\frac{(\nu_e)_{ch}}{(\nu_e)_{K^0_S}} \approx 80 \quad , \quad \frac{(\nu_e)_{ch}}{(\nu_e)_{K^0_L}} \approx 120 \quad .$$

It is seen that in such experiment the number of neutrinos (especially ν_e) from charmed particle decays is larger than the number of neutrino from π and K decays, so that there are no very serious difficulties connected with the background from non-charmed particles. In fact, there is an important difference between "ordinary" neutrinos (from π and K decays) and "direct" neutrinos (from charmed parents):among these the numbers of ν_e and ν_μ are equal, while among "ordinary" neutrino there is a great majority of ν_μ (just becuase $\Gamma_{\pi\to e\nu_e} \ll \Gamma_{\pi\to\mu\nu_\mu}$ and $\Gamma_{K\to e\nu_e} \ll \Gamma_{K\to\mu\nu_\mu}$). This circumstance ensures a good signature of the events looked for.

For leptons emitted at large angles (few degrees in the lab. system) to the incoming proton beam, the above conclusion on the possibility of a low background of "ordinary" neutrinos does not contradict the results of the experiments on the direct production of charged leptons/1/. According to ref./8/, for example, in collisions of 70 GeV protons with nuclei the measured number of muons from K decay (the kaons decaying over a nuclear length) and the measured number of "direct" muons are comparable (10-12 GeV muons were emitted at a 90° angle in the c.m.s.). Of course,the number of observed "direct" muons is an upper limit for muons of charmed origin, since muons can be produced directly in some kind of electromagnetic interaction.

Search for neutrinos of charmed origin is difficult at 70 GeV, even though the ν_e background from pion and kaon decays at Serpukhov might be well below the flux of direct neutrinos. It should be noticed,however,that the absence of K and π focusing in the experiments at issue is somewhat compensated by the better geometry (the neutrino source and the detector are located at a relatively close distance). The Serpukhov accelerator has an advantage from this point of view, although higher energy protons are very desirable in experiments of the type considered here, because i) the production cross section of charmed particles increases with energy, ii) the pion and kaon decay probabilities over a nuclear length decrease with increasing energy and iii)the neutrino-nucleon cross section, and hence the neutrino detection efficiency, increases with energy.

Of course, the absolute rate of neutrino events due to "direct" neutrinos is quite small, say, 4 order of magnitude smaller than the intensity of "ordinary" neutrino events in conventional experiments at high energies.

It is perhaps important to consider the possibility of performing experiments of the type indicated while designing new accelerator facilities. The main point is to have a relative compact shield, with, perhaps, magnetic deflection of muons.

As far as the spectrum of neutrinos of charmed parents is concerned, I would like to make the following remark. It seems that such neutrinos,as a rule, should be emitted together with charged leptons, strange particles and pions. However, let us consider the vector mesons $F^*$and $\widetilde{F}^*$(of quark contents $\Lambda\tilde{\rho}'$ and $\tilde{\Lambda}\rho'$) ,the properties of which are of great interest. The point is that although the mass of the F* meson is expected to be somewhat larger than the mass of the pseudoscalar meson F of equal quark content, nevertheless one cannot exclude a closer degeneration or even a mass inversion. In such a case the processes $F^* \to F + \pi + \ldots$, $F^* \to F + \gamma$ might be suppressed to such an extent that weak decays

$$F^* \begin{cases} \mu^- \tilde{\nu}_\mu \\ e^- \tilde{\nu}_e \end{cases} \quad \text{and} \quad \tilde{F}^* \begin{cases} \mu^+ \nu_\mu \\ e^+ \nu_e \end{cases}$$

would take place noticeably. The presence of two-particle decays would then harden the neutrino spectrum (as this happens for the ν_μ spectrum from $K \to \mu \nu_\mu$ in usual ν_μ beams).

Independently of the above mentioned possibility, it is clear that the spectrum of "direct" neutrinos(from 3 particle decays of charmed parents) is enriched in high energy neutrinos relatively to the neutrino spectrum from π and K decays, which is naturally shifted to lower energies under the conditions of the experiment considered. Consequently, in such experiments one must look forward to detect high energy neutrinos.

Thus,a neutrino run "without" the π and K decay region" lasting several months at a high energy proton accelerator and making use of a massive detector capable of fixing electron showers might give in principle the possibility of

1) observing charmed particles through the observation of the neutrinos they are emitting,

2) verifying the assumption that among neutrinos of charmed origin the intensities of electron and muon neutrinos are equal,

3) getting interesting information on "direct" lepton production in nucleon-nucleon collisions by comparing the number of direct "neutrinos" and "direct" charged leptons,

4) obtaining information on the existence and the mass of the mesons F* and F .

5) observing unexpected processes connected with the possible existence of unknown particles (new types of neutrinos and new sources of neutrinos).

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