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NEUTRINOS FROM DECAYS OF INTERMEDIATE $W^{\pm}$ AND Z° BOSONS

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1. THE $W^{\pm}$-NATURE OF ORDINARY NEUTRINOS

Intermediate bosons $W^{\pm}$ and Z^{o} have been observed for the first time in 1983 /1,2/. After such great discoveries, we may state with assurance that W and Z bosons are the only known sources of neutrinos at present*. More exactly we may state that either real or virtual W, Z bosons are responsible for all processes in which neutrinos either are generated or interact with matter.

When real W's and Z's are produced, and this happens only in extraordinary high energy collisions such as in collider experiments /1,2/, the decays of (real) W's and Z's are more or less on the same foot, in the sense which will be obvious below. In processes in which neutrinos interact with matter (charged and neutral current processes) the intermediate bosons are virtual; here again W's and Z's are more or less on the same foot.

However, in relatively low energy processes in which virtual W and Z bosons are generated and decay, W's and Z's cease to be on the same foot as neutrino sources. This is so because the processes due to the emission and decay of a virtual W (β-decay, π-μ-decay, etc.) have no competing processes. On the contrary processes due to emission and decay of a virtual Z (such as the neutrino radioactivity /3/ - the emission of a neutrino-antineutrino pair by an excited nucleus) have overwhelming competing processes due to electromagnetic interactions at characteristic energies $\ll M_Z$.

Thus all neutrinos with which we work in Laboratories (from β-decay of fission fragments in nuclear reactors, from decays of mesons in accelerator facilities, from thermonuclear reactions in the Sun, ...) originate in processes with participation of W's. Neutrinos from decay of virtual Z's, for the reasons mentioned above, have never been investigated. Practically there are no "reasonable" Z sources of neutrinos, the only Z sources of neutrinos we know of being quite exotic. We are

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*Here we are not considering the possible decays of Higgs particles with emission of neutrinos, the baryon nonconserving decays of nucleons with emission of neutrinos, etc.

not going to talk now in detail about neutrinos from decays of real Z's produced in $p-\bar{p}$ [1,2] (or e^+-e^- colliders) and in the hot Universe [4] at temperature $\geq M_Z$. Rather we shall briefly discuss the production of neutrinos in decays of virtual Z's. Because of the electromagnetic competition mentioned above it is not obvious that corresponding neutrino sources can be named. Tentatively we may think of large astrophysical objects [5], i.e., stars in some phases of their evolution. In such stars the emission through decays of virtual Z's of (very long mean free path) neutrinos will globally compete with the (frequent) electromagnetic processes in which photons (of very short mean free path) are emitted. This type of stars, as a source of neutrinos which one would like to detect, is of course extremely exotic but it may help to visualize "thought of experiments" in which neutrinos originate only from virtual Z-decay. Naturally the sources of neutrinos from decay of virtual Z's (neutrino radioactivity) may coexist with sources of neutrinos from decay of virtual W's (β-decay).

A final consideration. In high temperature stars neutrinos might arise through processes of annihilation of virtual [5] and real [6] positron-electron pairs. Let us remind here that to the amplitude of the processes $e^+ + e^- \to \nu_e + \bar{\nu}_e$ there are contributions from Z-exchange as well as W-exchange*. In principle one should not confuse this last source of neutrinos whereby interference of charged and neutral currents plays an important role with the previously discussed sources where neutrinos from Z and W coexist.

2. NEUTRINOS FROM Z DECAYS IN NON-STANDARD THEORIES?

In view of what was said above we could like to stress here that the left-handed nature of neutrinos has been directly tested for neutrinos (electron, muon and tauon types) from decays of W's. However, it is not excluded a priori that the Z decay may include channels with the emission of right-handed (sterile) neutrinos. Of course, the existence of such channels is not possible within the framework of the very successful standard model, but from a phenomenological point of view the question at issue is not entirely meaningless.

We shall consider 3 extreme (yes or no) cases:

a) there are no sterile neutrinos in nature and Z's decay into $\nu_e - \bar{\nu}_e$, $\nu_\mu - \bar{\nu}_\mu$, $\nu_\tau - \bar{\nu}_\tau$, ... in agreement with the standard model [7];

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*Of course the emission of $\nu_\mu \bar{\nu}_\mu$, $\nu_\tau \bar{\nu}_\tau$ pairs by high temperature stars is due only to decays of virtual Z's.

b) sterile neutrinos [8] do exist in nature, but Z's decays only into $\nu_e - \bar{\nu}_e$, $\nu_\mu - \bar{\nu}_\mu$, $\nu_\tau - \bar{\nu}_\tau$ ... in agreement with the standard model.

c) sterile neutrinos exist in nature and are emitted in the Z-decay with probabilities equal to that of other $\nu - \bar{\nu}$ channels (which is a quite "heretical" and not attractive point of view).

We wish to discuss here how, al least in principle and under favourable circumstances, some light could be thrown on the problem of the possible existence of sterile neutrinos, by combining information from $p-\bar{p}$ and e^+-e^- colliders with information from already performed [9] and future solar neutrino experiments.

As a matter of fact, on one side the number n' of neutrino types (ν_e, ν_μ, ν_τ ...) which are emitted in Z-decay will be measured in future in collider experiments involving real Z's [10]. On the other side it is known [11] that solar neutrino experiments may give information on the lower limit of neutrinos with definite masses. We have in mind experiments in which the flux I of solar neutrinos ν_e is measured at the Earth surface. Because of the possible presence of oscillations, it may turn out that I is smaller than the flux I° expected in the absence of oscillations: $I = \delta I°$, where $\delta \leq 1$. As is well known $n \geq 1/\delta$, where n is the number of neutrinos with definite masses. Similar relations can be obtained [12] in the case where information from neutrino oscillation reactor experiments is available in addition to the information from solar neutrino experiments. Suppose that n_{min} turns out to be larger than n': $n_{min} \geq n'$. Such a result would mean that there exists some sort of neutrinos which are not emitted in Z-decay. This would be, first, an indication in favour of the existence of sterile neutrinos and, second, a proof that Z bosons emit only "current" neutrinos, as it is usually assumed (point b). As was already mentioned, the question is not entirely devoided of meaning. As a matter of fact known data on parity violation in neutrino neutral current interactions do not exclude the purely phenomenological possibility that Z bosons emit sterile neutrinos [13], in addition to current neutrinos.

How about point c) above? The existence of sterile neutrinos in the Z decay would imply that sterile neutrinos undergo neutral current interactions. Such a circumstance, therefore, would make it possible to detect solar sterile neutrinos, the presence of which in solar neutrino oscillation experiments has been taken for a long time as a logical possibility [8] (these neutrinos would not be sterile anymore!). The discovery of the exotic situation c) mentioned above could be made directly through the contribution to neutral current interaction processes of solar sterile neutrinos of the type $\bar{\nu}_L + d \to \bar{\nu}_L + n + p$, $\bar{\nu}_{L'} + e \to \bar{\nu}_L + e$ ... Incidentally it may be noted that an experiment is being planned [14] in which (normally active) solar neutrinos will be detected with the help of the neutrino-electron scattering process.

Situation c) might under favourable circumstances be inferred also from the comparison of direct measurements of the Z°-width with measurements of the number of current neutrinos in the W-decay channels.

3. OSCILLATIONS OF NEUTRINOS FROM W AND Z DECAYS

In this section we shall at first assume the validity of the standard model and shall not consider sterile neutrinos. In the spirit of what was said in Sec. 1, we are considering now the generation of neutrinos in decays of <u>virtual</u> intermediate W^+, W^-, Z° bosons, that is, the generation of neutrinos in objects examples of which are correspondingly the Sun, a nuclear reactor and, as mentioned in Sec. 1, high temperature stars whereby the neutrino luminosity is much larger than the photon luminosity.

Clearly, if there is some kind of lepton mixing, neutrinos from decays of virtual W's do oscillate [15]. As for neutrinos from decays of virtual Z's, on the contrary, they do not oscillate, i.e., the composition of the neutrino beam at the place of generation happens to be equal to its composition at any distance from the source. The reason for the statement is simple. As is well known, in the standard model the probabilities of emission of various neutrino-antineutrino pairs are equal; thus at the place of generation the intensities of neutrinos of all types are the same, a situation under which clearly oscillations do not arise*.

In our terminology we call neutrinos neutral leptons having a mass, let us say, much less than the electron mass. Just because of the negligible masses of neutrinos, the probabilities of decay of a Z (either virtual or real) into neutrino-antineutrino pairs are equal, so that there are no oscillations. Instead, the decay of a virtual W naturally takes place with very different probabilities into various channels because of threshold effects (for example nuclei emit electrons in β-decay but cannot emit muons); thus neutrino from virtual W's may oscillate.

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*As a matter of fact let neutrinos of all types have at generation an equal intensity I. The intensity of neutrinos at any distance from the place of generation of a given type ν_ℓ is the product of I by the sum of probabilities of the transition to ν_ℓ from all neutrino states (including ν_ℓ!). The sum is obviously equal to one, that is the intensity of ν_ℓ is equal to I.

Let us discuss, second, the generation of neutrinos from <u>real</u> W's and Z's. Not only Z's decay into $\nu_e - \bar{\nu}_e$, $\nu_\mu - \bar{\nu}_\mu$, $\nu_\tau - \bar{\nu}_\tau$ pairs with equal probabilities. The decay probabilities of real W's into $e - \nu_e$, $\mu - \nu_\mu$, $\tau - \nu_\tau$ are practically equal among themselves. Thus if the question is posed about oscillations in neutrino beams from real Z's and W's, we may conclude that generally speaking, sources of real Z's and W's generate neutrino beams which do not oscillate.

Let us notice that neutrinos from real W's (but not Z's) may oscillate under the following circumstance. Suppose that there exists one (or ≥ 1) charged lepton H, so heavy that the decay $W \to H + \nu_H$ is not possible (or has a probability much less than the probability of other lepton channels in the W decay). Clearly ν_H, which at generation is not present (or is produced with small intensity) may then appear as a result of oscillations.

We shall mention now the possibility of existence of sterile neutrinos. In this case neutrinos from decays of real W's will oscillate. This is so because at generation there are present practically equal quantities of active ν_e, ν_μ, ν_τ, ..., but not of sterile neutrinos. A similar situation will hold in the case of neutrinos from decays of virtual as well as real Z's: these neutrinos in the presence of sterile neutrinos will oscillate in case b) mentioned above (sterile neutrinos do exist but are not emitted in Z-decay). In the very exotic case c) (sterile neutrinos are emitted in Z-decay) there will be no oscillations.

Let us stress again that all sources of neutrinos from Z-decay we have been discussing are exotic indeed and consequently our considereations have been rather academic in character. Nevertheless such sources can be thought of and therefore the main conclusion of this section - that in absence of sterile particles neutrinos from Z decay do not oscillate*, whereas neutrinos from the decay of virtual W's do oscillate - is physical in character and, in our opinion, is instructive.

4. CONCLUSIONS

1. Practically all facts we know about neutrinos are based on experiments in which the neutrinos to be investigated arise from decays of (virtual) W intermediate bosons. Z bosons do not play any role as sources of "usual" neutrinos.

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*We can visualize "not oscillating" neutrinos as neutrinos described by stationary states, i.e., as a not coherent mixture of neutrinos with definite masses ν_1, ν_2, ν_3,... . The analogy with the neutral kaon case is obvious.

2. If there exist sterile neutrinos, the "heretical" question about the possibility of their "normal weak" interaction with Z is open from a phenomenological point of view. Solar neutrino experiments and experiments with colliders may help to get some information on this matter.

3. Only neutrinos from decays of virtual W's do oscillate, neutrinos from decays of virtual and real Z's and from decays of real W's do not oscillate (the statement holding if there are no sterile neutrinos).

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Биленький С.М., Понтекорво Б.М. E2-84-533
Нейтрино от распадов промежуточных $W^{\pm}$ и Z° бозонов

В настоящей заметке рассмотрены следующие вопросы: i) $W^{\pm}$ (но не Z°!) - природа пучков обычных нейтрино; ii) возможное существование "стерильных" нейтрино и чисто феноменологическая возможность того, что Z°-бозоны могут распадаться с испусканием стерильных нейтрино; iii) осцилляции нейтрино от распадов $W^{\pm}$ и Z°-бозонов.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Neutrino from Decays of Intermediate $W^{\pm}$ and Z° Bosons

In the present note we consider the following points: i) the $W^{\pm}$-decay (and not Z°-decay!) origin of usual neutrino beams; ii) the possible existence of "sterile" neutrinos and the purely phenomenological possibility (entirely out of the framework of the standard electroweak theory) that in Z°-decay there are channels in which sterile neutrino are emitted; iii) oscillations of neutrinos of $W^{\pm}$-decay and Z°-decay nature.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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