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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-5-19. On High Energy Neutrino Physics in Cosmic Rays

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1. The problem of detection of high energy neutrino beams in cosmic rays has many interesting aspects[1)2)]. Its development can make in particular a great contribution to a new branch of experimental physics arising now-high energy neutrino physics. It is not excluded that the results obtained in this new branch may prove to be fundamental in the elementary particle theory in general. That is why at present possibilities are being intensively searched for solving the problems of high energy neutrino physics (*e.g.* on the accelerators).

The proflems emerging in high energy neutrino physics may be listed as follows:

1. a magnitude of the cut off momentum of weak interactions both for neutrino-lepton interactions,
2. intermediate boson,
3. muon neutrino ν_μ and electron neutrino ν_e,
4. (νe) (νe) interaction.

In this paper we evaluated some possibilities of neutrino physics in cosmic rays.

2. Neutrino flux in cosmic rays consists, in principle, of two components different in their origin. The first part presents the flux of "true" cosmic neutrinos, the other is the flux of neutrinos generated by cosmic rays in the earth's atmosphere. It is natural to suppose that the high energy true cosmic neutrinos are due to the cosmic rays solely. In this case the intensity of cosmic neutrino flux is about 10^3 times less than intensity of the atmosphere neutrino flux, as calculated in the reference 3. That is why it is possible to think that in cosmic neutrino experiments we shall deal with the atmospheric neutrinos.

Atmospheric neutrinos are convenient for the experiments, since their energy spectrum and angular distributions in the atmosphere can be calculated with the sufficient accuracy. Hence, it makes possible to calculate the energy and angular distributions of the products (for example μ-mesons) of the neutrino reactions with substances. Any deviations from the predictions can be observed and interpreted. Unfortunately small intensity of the neutrino flux is a defect of cosmic rays as the neutrino source. That is why the installations of large area are needed and the requirements to the experimental conditions are severe. Because of the large cosmic-ray background, one has to carry out experiment deep underground. A small neutrino flux absorption and symmetry with respect to a horizontal plane makes it possible to record the neutrinos coming from the lower hemisphere, *i.e.* passing through the earth. The directly recorded particles are μ-meson (and electrons).

The experimental arrangement may have the following design. The detection of μ-mesons is carried out by three layers of scintillators, placed one above another at the distances sufficient for time resolution of the pulses and switched on to the delaying coincidences. Between the layers of the scintillators an absorber is placed in order to record μ-mesons with the energy greater than threshold. The change of the threshold and also the analysis of the angular distribution of recorded μ-mesons make it possible to obtain an extremely important information for the choice between different theoretical variants. It is possible to carry out registration with two different threshold at the same time, if we add the fourth layer of scintillators. The scattered μ-mesons of cosmic rays can imitate the studied processes. This effect however decreases rapidly with increases of earth depth and of threshold of μ-meson registration. Therefore it is always possible to provide sufficiently pure experimental conditions.

3. In the framework of the available experimental data and theoretical concepts, the following reactions for neutrino and

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antineutrino from the π-meson and μ-meson decays can be envisaged (we do not distinguish muon and electron neutrinos)

a) $\nu+n\rightarrow p+\mu^-(e^-)$
b) $\bar{\nu}+p\rightarrow n+\mu^+(e^+)$
c) $\bar{\nu}+n\rightarrow \Sigma^-+\mu^+(e^+)$ (1)
d) $\bar{\nu}+p\rightarrow \Sigma^0+\mu^+(e^+)$
e) $\bar{\nu}+p\rightarrow \Lambda^0+\mu^+(e^+)$

It seems worthwhile to investigate the behaviour of cross-sections of the reactions (1) with increase of energy. In the case of local interaction the cross-section for the type

(a) is $\sigma_\nu\approx 1{,}5\cdot 10^{-38}\ E_\nu \mathrm{cm}^2$ (E in Gev)
and for the other reactions

$$\sigma_{\bar{\nu}}\approx 0{,}5\cdot 10^{-38}\ E_{\bar{\nu}}\ \mathrm{cm}^2$$

At neutrino and antineutrino energies of the order of several Gev, the cross-sections of the effects (1) become of the order of 10^{-38} cm^2. At higher energies a further growth of the cross-section with energy can only be said to be essentially modified by the form-factor.

It is possible that the four-fermion interactions involving baryons in the vector variant (" week electrodynamics ") are cut off by the Hofstadter form-factors. It is possible that total interaction ($V-A$) is cut off by the same formfactors as well (though it is not obvious *á priori* and it may be that $F_A\neq F_\nu$).

In this case weak interactions can be a source of an information about electromagnetic form-factors of the nucleon. Both long and short lengths equally make contribution into the total cross-section of weak interactions. Therefore, the measurement of the total cross-section of weak interaction can compete with the measurement of the electrodynamic cross-sections on the large angles for the definition of the form-factors.

Of course, the weak interaction form-factors and electromagnetic form-factors can have a considerably different nature (intermediate meson, ν_μ and ν_μ—neutrino). Therefore the measurement of the weak interactions form-factors is of independent importance as well. The underground experiments to approach the investigation of the lengths much less than 10^{-14} cm.

The installation of 300 m^2 makes it possible to observe the following number of interesting events during a year:

1) If the cross-section of the reaction of the type (1) is not cut off up at the neutrino energy in the laboratory system E_ν=300 Gev we have:
70 μ-mesons, if the threshold equals to 0,5 Gev,
50 μ-mesons, if the threshold equals to 1 Gev,
30 μ-mesons, if the threshold equals to 3 Gev,
2) if the cross-section of the above reaction is cut off by the Hofstadter form-factor, we have
12 μ-mesons, if the threshold equals to 0,5 Gev,
9 μ-mesons, if the threshold equals to 1,0 Gev,
3,5 μ-mesons, if threshold equals to 3 Gev.

Fig. 1 shows the relative contributions of different energy neutrino to the total number of recorded events for two energy dependences of the cross-section of reactions:

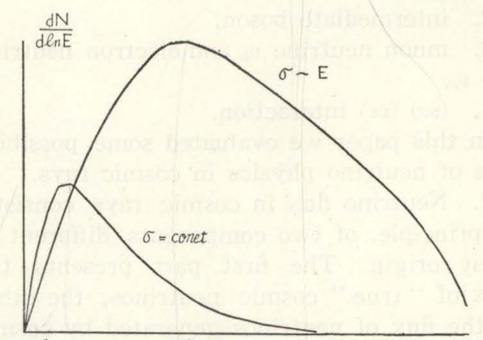

Fig. 1.

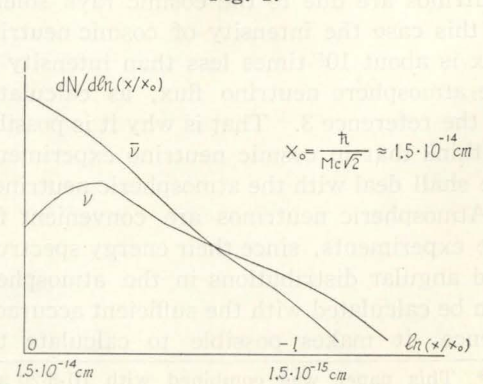

Fig. 2.

A rough estimate allows to evaluate in the following manner a contribution of different wavelengths to the total number of events in the case of linear increase of the interaction cross-section with energy (for example for the reaction (fa)):

$$\frac{dN}{dx}=A\cdot\frac{1}{x^3}\int_{1/x^2}^{E_\nu^{\max}} R(E)P_\nu(E)dE\,, \quad x=\frac{M\sqrt{2}}{\Delta g}\,, \tag{2}$$

where R—path of muons, $P_\nu(E)$—neutrinos energy spectrum.

Fig. 2 shows these relative contributions for ν and $\bar{\nu}$.

The neutrino fluxes in the atmosphere are distributed anisotropically[3]. Fig. 3 shows the energy spectra of neutrino plus antineutrino in the horizontal ($\theta=\pi/2$) and vertical fluxes ($\theta=0$).

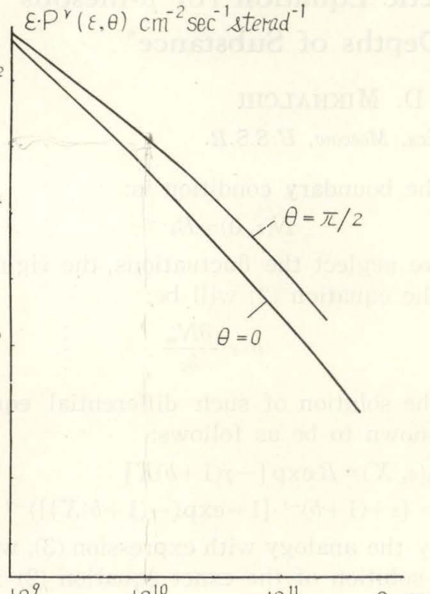

Fig. 3.

4. One of the main problems of the theory of weak interactions, whether these interactions are local or of the Yukawa type, is not solved yet. The great attention has been paid recently to the problem of an intermediate boson, which desintegrates according to

$$\begin{aligned} &W^\pm\to\mu^\pm+\nu(\bar{\nu})\,,\\ &W^\pm\to e^\pm+\nu(\bar{\nu})\,. \end{aligned} \tag{3}$$

From this point of view it seems to be of interest to consider, besides the reactions (1), the reactions of the Lee-Yang type[4].

$$\begin{aligned} &\nu+Z\to W+\mu(e)+Z'\,,\\ &\bar{\nu}+Z\to W+\mu(e)+Z'\,. \end{aligned} \tag{4}$$

2) Glashow type[5]

$$\bar{\nu}+e\to W\to\mu+\bar{\nu} \tag{5}$$

3) and also of Kinoshita type[6]

$$\begin{aligned} &\nu+n\to W'\to p+\mu\,,\\ &\bar{\nu}+p\to W'\to n+\mu\,, \end{aligned} \tag{6}$$

if one assumes that the intermediate boson with the baryon charge exists.

Using the formula for the cross-section[4] of the reactions (4) at the neutrino (energies of (10–300) Gev, we obtain the following Counting rates per year at the threshold equal to 0,5 Gev:

170 events if the W-meson mass is equal to K-mass

25 events if the above mass is equal to I Gev.

It must be emphasized that application of the formula[4] at the neutrino energy less or of the order of 10 Gev give only a rough estimate of the cross-section.

The reactions (5) and (6) can also make a contribution to the number of events in the underground experiment. In this case one must take into account that the Glashow estimates[5] should be corrected in our case when the neutrino flux passing through the whole earth is investigated.

5. If the muon and electron neutrinos are of different nature the reaction (5) may take place only due to ν_e-neutrinos from the μ-decays ($\mu\to e+\nu_e+\nu_\mu$). The energy spectrum of the electron neutrinos falls off more rapidly than the total spectrum of the muon neutrinos (namely by a factor of $(E+1)^{-1}$, E in Gev). Therefore the Barton's experiment results[7] do not yet give evidence that the intermediate boson having the mass equal to K-mass does not exist.

6. Up to now we were speaking only about recording of μ-meson. But in the reactions (1), (4), (5), (6), electrons as the products of the reactions are possible as well (apparently, in equal quantatives with μ-mesons if there is no difference between ν_e and ν_μ). However, the recording of electrons is considerably more complicated than that matter of μ-mesons. For example, electrons have a small path in matter, while the path

of μ-mesons is proportional to their energy in a wide range of energies of μ-mesons. Therefore, at recording μ-mesons the "detector mass" is considerably greater than in the case of recording electrons. Besides, it is difficult to determine the light direction of the produced electron.

That is why we have to assume that at the beginning in the underground experiment the neutrino reactions with the production of a μ-meson will be investigated.

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III-5-20. The Solution of the Kinetic Equation for μ-mesons Passing through the Great Depths of Substance*

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The kinetic equation for μ-mesons passing through the dense substance is:

$$\frac{\partial N}{\partial X'}-\beta(E)\frac{\partial N}{\partial E}=\int_0^1 W(v,E)\times\left\{N\left(\frac{E}{1-v},X'\right)-N(E,X')\right\}dv \quad (1)$$

where $N(E,X')$ number of μ-mesons at the depth X' with the energy more than E: $W(v,E)dv$ probability that a meson with energy E loses a part of its energy $v, v+dv$ per path unit, $\beta(E)$ the value of continuous energy losses per path unit. Supposing

$$\beta(E)=\beta_0+aE\,,$$

$$W(v,E)=\frac{W_0}{v}$$

and introducing dimensionless parameters

$$\varepsilon=\frac{aE}{\beta_0}\,,\quad X=aX'\,,\quad b=\frac{W_0}{a}\,,$$

we have:

$$\frac{\partial N}{\partial X}-(\varepsilon+1)\frac{\partial N}{\partial\varepsilon}=b\int_0^1\frac{dv}{v}\left\{N\left(\frac{\varepsilon}{1-v},X\right)-N(\varepsilon,X)\right\}. \quad (2)$$

The boundary condition is:

$$N(\varepsilon,0)=B\varepsilon^{-\gamma}\,.$$

If we neglect the fluctuations, the right part of the equation (2) will be:

$$b\cdot\varepsilon\cdot\frac{\partial N_m}{\partial\varepsilon}\,.$$

The solution of such differential equation is known to be as follows:

$$N_m(\varepsilon,X)=B\exp\left[-\gamma(1+b)X\right]\times\{\varepsilon+(1+b)^{-1}\cdot[1-\exp\{-(1+b)X\}]\}^{-\gamma}. \quad (3)$$

By the analogy with expression (3), we take the solution of the exact equation (2) in the form:

$$N(\varepsilon,X)=B\exp\left[-A(\gamma)X\right]\times\{\varepsilon+\kappa^{-1}[1-\exp(-\kappa X)]\}^{-\gamma}\cdot\exp\varphi(\varepsilon,X). \quad (4)$$

This expression provides

$$\varphi(\varepsilon,0)\equiv 0\,.$$

The constant $A(\gamma)$ is determined from the condition that $\varphi(\infty,X)\equiv 0$, this gives

$$A(\gamma)=\gamma+b\int_0^1\frac{u^\gamma-1}{u-1}du\,.$$

For the determination of the constant κ we order $\varphi(0,\infty)=0$. This condition gives the equation for κ:

* This paper was combined with III-5-19 and presented by G. T. Zatsepin.