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NEUTRINO PRODUCTION FROM THE SOLAR ATMOSPHERE

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ABSTRACT

When the high energy primary cosmic rays enter near the solar surface, they pass through a thick matter but having a low density. If the density and path length satisfy an appropriate condition, the primaries collide with the constituents near the solar sphere (almost protons) and produce pions and kaons, most of which decay into $\mu+\nu_\mu$ without successive hadron collisions. Muons also decay into ν_μ and ν_e before reaching the earth. The neutrino flux of which the producer is matter near the solar surface is computed by solving cascade diffusion equations. The calculated differential flux of muon neutrino at 1 TeV is 1×10^{-13} $(GeV.cm^2.s.ster)^{-1}$ which is rather difficult to be observed in the present apparatuses or DUMAND.

1. Introduction.

Recently, the production mechanisms of cosmic ray neutrino with high energies are considered other than conventional ones which are decay products of pions and kaons in the primary - air nucleus collisions. One is the neutrino emission from the matter surrounding a source of very high energy cosmic ray protons (1, 2). The other is the neutrinos produced by the collisions of the primary and 3K background radiation (3) and so on. Besides these the following mechanism is treated here. As the high energy primary cosmic rays collide with nulei in terrestrial atmosphere and produce pions and kaons which decay into neutrinos (conventional neutrino), we expect that the primaries can produce high energy neutrinos from the solar atmosphere (we call this neutrino the solar neutrino, hereafter). Though the solar atmosphere takes a part of producer, the solar neutrinos at high energies (nearly equal to or more than 1 TeV) originate from the Sun. In this paper, the flux of the solar neutrino is estimated and its observation is discussed. The flux is so sensitive to the densities near the solar surface that the observation, if possible, gives informations the density which will be helpful for searching the solar models.

2. A Critical density and the density near the solar surface.

Firstly, let us introduce a critical density with which produced pions (or kaons) decay into $\mu\nu$ or trigger a succesive collision with same probability. The critical density can be written by

$$\rho_{cr}(i) = m_i Br_i c/N_A E_i \tau_i \sigma_i \ , \tag{1}$$

where N_A is Avogadro's number, the suffix i means π or K and m, Br, E, τ, σ are the mass, the branching ratio to $\mu\nu$, the energy, the mean life and the inelastic cross section, respectively. For σ_π = 30 mb and σ_K = 20 mb, we have

$$\rho_{cr}(\pi) = (2.11/E_\nu)\ 10^{-6}\ \ g/cm^3\ , \qquad (2)$$

$$\rho_{cr}(K) = (2.23/E_\nu)\ 10^{-5}\ \ g/cm^3\ , \qquad (3)$$

where the relation of E_i and the neutrino energy E_ν on the average is used and E_ν in the unit of TeV. When the target matter is the terrestial atmosphere, the relation of $z/\rho(z) = H$ (constant), where z is a hight in g/cm², holds in the upper part and decay constants defined by $m_i H/c\tau_i$ make the diffusion equations for pions and kaons simple. However the present problem is not the case.

Up to now, the density ρ near the solar surface is seemed not to be well confirmed. But referring to (4, 5), we express ρ for the quiet Sun as an approximate analytical form as follows:

$$\rho = 1.05\times10^{-11}\ (300-h)^{1.78}\ \ g/cm^3 \text{ for } h<100\ , \qquad (4)$$

$$\rho = 3.29\times10^{-7}\ \exp\ (-h/107)\ \ g/cm^3 \text{ for } h>100\ , \qquad (5)$$

where h in km is a height measured from the surface of the photosphere, which is $R = 6.96\times10^5$ km distant from the center of the Sun. For $h = 0$, $\rho = 2.7\times10^{-7}$ g/cm² which nearly corresponds to $\rho_{cr}(\pi)$ with $E_\nu = 10$ TeV. so the region of $h<0$, i.e. the inside of the photosphere, as well as $h>0$, i.e. the solar atmosphere, should be taken into account.

3. Derivation of the solar neutrino flux. We consider the production of the solar neutrinos at energies 1~100 TeV. The contribution of produced charmed particles is neglisible. The source of muon neutrinos is π (or K) $\longrightarrow \mu\nu_\mu$ and $\mu \longrightarrow e\nu_\mu\nu_e$. On the other hand, electron neutrinos originate only from muon decays. After the diffusion equations for π, K, μ, ν_μ and ν_e are written down, fluxes of ν_μ and ν_e are solved and can be expressed by some multi-integral forms. These forms contain the variable represented by

$$dz = \rho(b,x)\ dx\ \ , \qquad (6)$$

where z and x are path lengths in units of g/cm² and of cm, respectively and b means an impact parameter related to the center of the Sun. When b is fixed, the partial flux $f_\nu(E_\nu,z(b))$ can be obtained by multi-integration with respect to other variables including dx. In this procedure, the primary cosmic ray spectrum

$$I_0(E)dE = 1.8E^{-2.7}dE \qquad (7)$$

(E in GeV, $I_0(E)$ in $(cm^2 \cdot s \cdot sr \cdot GeV)^{-1}$) is used. The energy moments of π and k are taken as (6)

$$F_\pi = 0.0724\ , \quad F_k = 0.00959\ , \qquad (8)$$

and the average mass number is taken as 1.25 by considering the exsistence of He, C and O nuclei.

The partial flux $f_\nu(E_\nu,z(b))$ depends on the integrated path length given by

$$z(b) = \int^{a}_{-a} \rho(h)dx\ \ g/cm^2 \ \ \text{with } h = (b^2+x^2)^{1/2}-R\ , \qquad (9)$$

where as the origin of co-ordinate x is taken the closest point from the center of the Sun, namely $h = b-R$ at the origin. In eq.(9), since $\rho(h)$ is a steep decreasing function of h, $a \longrightarrow \infty$ may be allowed.

The observed differential flux of the solar neutrino on the earth can be expressed by

$$f_\nu(E_\nu) = \frac{1}{(S\Omega)_E}\int_{b_{min}}^{b_{max}} db\,\frac{d(S\Omega(b))}{db}\,f_\nu(E_\nu, z(b)) \quad , \tag{10}$$

where $(S\Omega)_E = 2\pi^2 R_E$, R_E is the radius of the earth and $S\Omega(b)$ is $S\Omega$ having a fixed b with respect to the center of the earth. In eq.(10), b_{max} and b_{min} are determined as follows: b_{min} is given by the condition

$$\rho(b_{min}-R) \approx 15\rho_{cr}(E\ ) \quad . \tag{11}$$

when a primary cosmic ray passes with impact parameter less than b_{min} most produced π and K give rise to a successive collision before decay. As far b_{max}, inserting eq.(5) into eq.(9), one has

$$z(b) \cong \rho(b-R)(2\pi \times 1.07 \times 10^7 R)^{1/2} \quad g/cm^2 \ . \tag{12}$$

Then b_{max} = R+1000km where $z(b_{max})$ is about 0.1 g/cm^2. In case E = 10 TeV, h corresponding to ρ_{cr}(10 TeV) is about zero, i.e. just the surface of photosphere, z(R) = 810 g/cm^2 and $h_{min} = b_{min} - R$ is about -400km. These numerical values may give us some ideas.

~~4. Result and discussion.~~ The derivation of the flux concerned with is necessary to carry out complex multi-integrations. In the present report, since the precision of numerical integrations is low, the following numerical values might more or less be modified. However our result say that $f_\nu(E_\nu)$ $(GeV\cdot cm^2\cdot s\cdot sr)^{-1}$ of $(\nu_\mu + \bar\nu_\mu)$ are 1.1×10^{-14}, 3.8×10^{-14} and 2.7×10^{-18} for E_ν = 1, 10 and 100 TeV, respectively. These values are compared with the conventional fluxes through terrestial atmosphere: 2.3×10^{-11}, 7.2×10^{-15} and 1.6×10^{-18} at the vertical direction (7). On the flux of $\nu_e + \bar\nu_e$, we have 5.4×10^{-13}, 1.1×10^{-14} and 6.5×10^{-19}, corresponding to conventional ones at the vertical direction: 1.1×10^{-12}, 3.3×10^{-16} and 7.4×10^{-20} (7) for E = 1, 10 and 100 TeV, respectively.

In our case, because most of muons decay into $e\,\nu_\mu\,\nu_e$, the flux of ν_e is enhanced compared with the conventional one. Around E_ν = 10 TeV, our flux is enhanced. The reason is that at these energies the main contribution come from the pass near the solar surface which has an appropriate low density and long pass length. We have the ratio of the solar flux to the conventional ones is from several tens % to comparable order. But the angular resolution of apparatus should be taken into consideration in order to detect the solar neutrino flux. Since DUMAND's minimum detectable flux, as an example, is 10^{-10} $(cm^2\cdot s)^{-1}$, the solar neutrino treated here is hard to be measured.

The flux of the solar neutrino is so sensitive to its density that the measurement of the flux in future may make clear the density or its change, say due to a violent solar flare, around the surface of the Sun.

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