Particle Physics in ASHRA

K. Kohri[1], Y. Aita[2], T. Aoki[2], Y. Arai[3], Y. Asaoka[2], T. Browder[4], C. Fukunaga[5], T. Hayashino[6], Y. Higashi[3], J. Hisano[2], W. S. Hou[7], Y. B. Hsiung[7], M. Ieiri[3], M. Jobashi[2], C. Jui[8], J. Learned[4], E. Loh[8], N. Manago[2], S. Matsuno[4], J. Matthew[8], K. Nakai[9], S. Nakamura[1]0, S. Ogawa[11], A. Okumura[2], S. Olsen[4], K. Sakurazawa[12], M. Sasaki[2], N. Sugiyama[13], Y. Tanaka[14], V. Vladimir[8], M. Z. Wang[7], Y. Watanabe[12], S. Yamada[2], and K. Yoshimura[3]

(1) Osaka University, Japan (2) Institute for Cosmic Ray Research, University of Tokyo, Japan, (3) High Energy Accelerator Research Organization, Japan, (4) University of Hawaii, USA, (5) Tokyo Metropolitan University, Japan, (6) Tohoku University, Japan, (7) National Taiwan University, Taiwan, (8) University of Utah, USA, (9) Tokyo University of Science, Japan, (10) Yokohama National University, Japan, (11) Toho University, Japan, (12) Tokyo Institute of Technology, Japan, (13) National Astronomical Observatory, Japan, (14) Nagasaki Institute of Applied Science, Japan

Abstract

Here we consider detectability of high-energy ν_τ whose energy is larger than 10^{16}eV by All-sky Survey High Resolution Air-shower telescope project (ASHRA). Furthermore, we discuss impacts on particle physics and astrophysics to detect such high-energy neutrinos.

1. Observation of high energy ν_τ

We have never observed a high-energy neutrino whose energy is larger than 10^{16}eV. Detecting such high-energy neutrinos has following four important implications [1].

1. We can explore the frontiers of particle physics, e.g., the effects by the extra dimensions.
2. We can obtain informations about the source of the high-energy cosmic rays, even if it is optically thick, and we cannot observe it.
3. Comparing the composition of high-energy cosmic rays, i.e., gamma-rays, nuclei and neutrinos, we can obtain informations about the mechanism of the acceleration.

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4. We can explore the neutrino oscillation and obtain new informations about the mixing angles and the mass of neutrinos.

In this section, we mainly explain about the 4th implication, "informations about neutrino oscillation", i.e., about the detectability of high-energy cosmic ray ν_τ as the key point. This plan is important because it is not only we can obtain informations about parameters in particle physics but also we can independently verify new physics beyond the standard model. We also explain that such detections of high-energy ν_τ provide informations about the source of high-energy cosmic rays in itself, and by using the observational data we can compare the theoretical models of the acceleration.

From the recent results of neutrino oscillation experiments in Super Kamiokande (Super-K), it has been reported that the atmospheric neutrino data favor the Large Mixing Angle solution, i.e., $\sin^2 2\theta_{\rm atm} \geq 0.85$, between ν_μ and ν_τ, and their mass difference is $1.1 \times 10^{-3}{\rm eV}^2 \leq \Delta m^2_{\rm atm} \leq 5.0 \times 10^{-3}{\rm eV}^2$ [2]. To confirm the evidence of the oscillation hypothesis further, it is important for us to directly detect ν_τ produced by the oscillation from ν_μ (ν_τ-appearance experiment). It means that we should detect secondary τ-leptons through the ν_τ-nucleon scattering [3]. So far no one has achieved such an appearance experiment of ν_τ. However, if we utilize the high-energy cosmic ray neutrinos, it is possible for us to verify the appearance of ν_τ.

We expect that ultra-high energy cosmic rays (UHECR) are accelerated by gamma-ray bursts (GRB) or active galactic nuclei (AGN). The distance from the Earth to them would be $\mathcal{O}(10)$Mpc–$\mathcal{O}(1000)$Mpc at least. Detecting cosmic-ray neutrinos which are emitted by such compact objects means that we can measure the mass differences up to the sensitivity $\Delta m^2_{\rm atm} \sim 10^{-17}{\rm eV}^2$ if we consider the vacuum oscillation effect. In advance we know that the ratio of ν_e to ν_μ in cosmic rays is approximately $1/2$ because the cosmic-ray neutrinos are produced only by the decay of pions which are produced through the nucleon-nucleon scattering (NN') and/or the photo-pion processes ($N + \gamma \rightarrow N' + \pi^\pm$). The latter is called "Greisen neutrinos". In other words, we know that there are approximately no ν_τ's which are produced directly by the scattering of cosmic rays. As we mentioned above however, because the mixing angle between ν_μ and ν_τ is large, ν_τ's are produced through the vacuum oscillation effects from cosmic-ray neutrinos which come from a long distance. Therefore, the ratio of the averaged values of the flux approximately becomes $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$. Note that it does not depend on the mixing angle between ν_e and ν_μ. Therefore, as long as we believe the standard process of neutrino production, detecting the high-energy cosmic ray ν_τ means an independent verification of neutrino oscillation.

Recently a good idea to detect the high-energy ν_τ was proposed [4]. That is to observe high-energy cosmic ray ν_τ which skimmed the Earth. It is called "Earth-skimming ν_τ event", and the schematic figure is put in Fig. 1.. Such a high-energy ν_τ scatters off a proton or a neutron and produces a high-energy τ-lepton through the charged current interaction. Then the τ-lepton penetrates the Earth from the ground surface into the atmosphere and decays there. The decay of τ-lepton produces hadronic showers at a large hadronic branching ratio ($\sim 64\%$) and also produce fluorescent radiations [5]. In this case since the τ-lepton can fly only a short distance before its decay ($\sim 5\text{km}(E_\tau/10^{17}\text{eV})$), we can detect the shower only for the skimming ν_τ's. In particular, because ASHRA outperforms the other detectors in the detection of the fluorescent radiation, it will be best to detect such Earth-skimming ν_τ events. For Greisen neutrinos which are estimated by the spectrum of UHECR [6], we expect tens of Earth-skimming ν_τ events in ASHRA when we assume the duty cycle of 10% for three years [1][4].

On the other hand, as the other source of high-energy neutrinos, AGN [7], GRB [8], topological defects (TD) [9] and Z-burst [10] have been also studied, for the review see Refs. [1][4]. They reported that we expect $\mathcal{O}(10)$–$\mathcal{O}(100)$ Earth-skimming ν_τ events in ASHRA when we assume the duty cycle of 10% for three years. In addition, comparing the Earth-skimming ν_τ events with the Deeply-penetrating shower (DPS) events, we see that there are some features for each source [1]. In particular, we expect significantly larger Earth-skimming ν_τ events for top-down models like TD and Z-burst. Observing such differences clearly, we will also obtain informations about the source of the high-energy neutrinos in detail.

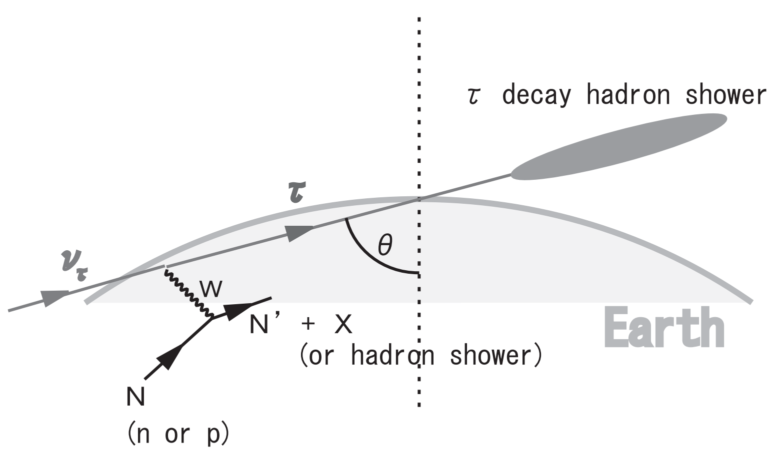

Fig. 1. Earth-skimming ν_τ event.

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