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Study of TeV neutrinos with upward showering muons in Super-Kamiokande

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Abstract

A subset of neutrino-induced upward through-going muons in the Super-Kamiokande detector consists of high-energy muons which lose energy through radiative processes such as bremsstrahlung, e^+e^- pair production and photonuclear interactions. These "upward showering muons" comprise an event sample whose mean parent neutrino energy is approximately 1 TeV. We show that the zenith angle distribution of upward showering muons is consistent with negligible distortion due to neutrino oscillations, as expected of such a high-energy neutrino sample. We present astronomical searches using these high-energy events, such as those from WIMP annihilations in the Sun, Earth and Galactic Center, some suspected point sources, as well as searches for diffuse flux from the interstellar medium.

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Keywords: High-energy neutrinos; Muon energy losses; Astrophysics

1. Introduction

In order to select neutrino events with the highest energies, we consider muon neutrino interactions in the rock around the detector, because the effective target volume is very much increased [1]. To separate neutrino-induced muons from cosmic ray muons, we select only upward-going muons, since the background from downward going cosmic ray muons overwhelms any neutrino-induced muons from above. Muons penetrating the detector have energies of at least several GeV and point along the neutrino direction within a few degrees, allowing astrophysical studies. Neutrinos originating from cosmic point sources are expected to have harder energy spectra than the background of atmospheric neutrinos. Some of these high-energy neutrino-induced muons undergo radiative energy loss. We identify these muons as "showering muons". High-energy muons are correlated with high-energy neutrinos, which allow us to statistically select an extremely high-energy parent neutrino sample from the Super-Kamiokande data. Our aim is to extract this sample for physics and astronomy studies.

The Super-Kamiokande (Super-K) experiment [2] has previously analyzed two topologically distinct categories of upward muons caused by neutrino interactions in the rock below the detector: muons which exit the detector (called "through-going") and those which stop inside the detector (called "stopping") [3]. The parent neutrino energy of upward stopping and through-going muons for atmospheric neutrinos is peaked at $\simeq$10 GeV and $\simeq$100 GeV, respectively. In 1646 days of data, Super-Kamiokande detected 1856 upward through-going and 458 upward stopping muons. Oscillation results using only upward through-going muons and stopping muons have