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Measurement of the diffuse neutrino flux by a global fit to multiple IceCube results

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Abstract

The IceCube Neutrino Observatory is the largest operating experiment searching for astrophysical neutrinos. Situated at the geographical South Pole, IceCube has been completed in 2010 and is entering its phase of discovery now. Several studies that have recently been performed in IceCube show an excess of events at high energies, indicating the presence of a non-atmospheric component in the diffuse neutrino flux.

The aim of this study is to characterize the diffuse neutrino flux as measured by IceCube. To this end, a global likelihood fit to the results of multiple IceCube analyses has been performed. These analyses include both main detection channels (track-like and shower-like events) and use data taken between 2008 and 2012 with four different IceCube configurations (featuring 40, 59, 79 and 86 strings, respectively). The fit method is introduced and first results are presented.

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1. Introduction

The maximum-likelihood analysis presented here combines the recent evidence for extraterrestrial neutrinos [1] with other IceCube analyses that have a lower energy threshold. The energy distributions measured by the analyses are combined and fit with distributions for background components and an astrophysical component. The analyses use data that have been collected between April 2008 and May 2012. The combined event selection features both main detection channels, track-like events induced by charged-current ν_μ interactions as well as shower-like events induced by charged-current ν_e and ν_τ interactions and all-flavor neutral-current interactions. The total energy range covered is between 2 TeV and 1 PeV.

One source of high-energy neutrinos is the atmosphere of the Earth. Neutrinos are produced in interactions of high-energy cosmic rays with atoms in the atmosphere and arrive at the detector from all directions. Neutrinos that are produced in decays of π and K mesons are called *conventional* atmospheric neutrinos, while neutrinos from the decay of charmed mesons are called *prompt* atmospheric neutrinos. Prompt atmospheric neutrinos follow a harder spectrum, due to the short lifetime of the parent mesons. They have not been observed yet, but are expected to dominate the total atmospheric neutrino flux above some 100 TeV.

It is expected that high-energy neutrinos are also produced in astrophysical candidate sources of cosmic rays such as active galactic nuclei (AGN) or gamma ray bursts (GRB), by essentially the same interaction

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mechanisms. Although these sources have not been identified yet, typically one expects an equal number of neutrinos per flavor ($\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$) for neutrinos produced in the decay of light mesons due to flavor oscillations during their propagation to Earth. A generic spectrum that is often used as a benchmark to evaluate the sensitivity to an astrophysical neutrino flux is a power-law $\phi \propto E^{-2}$. Such a spectrum is expected e.g. for neutrinos produced in the interaction of shock-accelerated protons and nuclei with the interstellar medium.

In reality, the neutrino spectrum depends on the dominant acceleration processes and regions, as well as on the properties of the interaction targets. Constraints on the shape of the astrophysical neutrino spectrum can help to identify the physical processes that generate the observed excess of neutrinos and narrow the range of source populations that might be responsible for the excess. Through the combination of several analyses on independent IceCube data sets that is presented here one obtains tighter constrains on the spectral parameters than the ones derived from individual analysis.

2. The IceCube Neutrino Observatory

The IceCube detector [2] is installed in the ice underneath the geographic South Pole, between 1450 and 2450 meters depth. It consists of 5160 optical modules, deployed on 86 strings with a spacing of approximately 125 meters. The vertical distance between two modules is approximately 17 meters. The instrumentation is more dense in a central part called DeepCore, IceCube's low energy extension. The optical modules contain 10″-photomultiplier tubes from Hamamatsu [3], together with digitization electronics [4]. The IceCube Observatory also includes IceTop, a cosmic-ray detector consisting of 81 stations that are installed on the surface of the ice above IceCube [5].

Neutrino interactions are detected by IceCube through the Cherenkov radiation that is emitted by the secondary particles created in the interaction. The topology of the detected events depends on the flavor of the incoming neutrino and the type of interaction. In charged-current ν_μ interactions a muon is produced, leading to *track-like* signatures that can be reconstructed with a good angular resolution. Because the muon track typically enters and/or leaves the detector, only a lower limit on the neutrino energy can be determined. So-called *shower-like* events stem from charged-current ν_e and ν_τ interactions and all-flavor neutral-current interactions. The dimensions of the particle shower produced in these interactions are much smaller than the detector spacing, resulting in a directional reconstruction that is worse than for track-like events, typically $10^\circ - 15^\circ$. The uncertainty on the energy deposited in the detector is approximately 15% [6].

The analyses considered here use data from the full IceCube detector with 86 strings (IC86, 2011/2012), but also data from partial configurations with fewer strings taken during the construction of IceCube (IC40, 2008/2009; IC59, 2009/2010; IC79, 2010/2011).

3. Searches for a diffuse neutrino flux in IceCube

Searches included in this analysis are targeted at the TeV-PeV energy range and are designed to search for an isotropic or *diffuse* flux of high-energy neutrinos. This flux is expected to manifest itself as an excess of events with respect to the high-energy tail of the atmospheric neutrino spectrum.

The first analysis included here [7] uses ν_μ-induced *tracks* from the Northern hemisphere. It has been performed with data taken with the 59-string configuration of IceCube. The analysis strategy consists of selecting high-quality upward-going tracks in order to suppress the overwhelming background of atmospheric muons. The selection includes events that have their interaction vertex outside of the instrumented volume, enlarging the active volume of IceCube. The large number of events selected in this sample yields good constraints on the atmospheric neutrino background.

Two analyses based on *shower-like* events are used, one using data from the 40-string configuration [8] and one using data from the 59-string configuration [9]. These analyses select events with a spherical topology and require the interaction vertex to be contained within the instrumented volume of IceCube, i.e. events in which light is first detected on the outermost layer of optical modules are rejected. While this selects events coming from both hemispheres, a sufficiently high probability to detect light from incoming