NEUTRINO PHYSICS WITH THE ICECUBE DETECTOR

J. KIRYLUK FOR THE ICECUBE COLLABORATION

Lawrence Berkeley National Laboratory,
1 Cyclotron Rd, Berkeley, CA, 94720, USA
E-mail: JKiryluk@lbl.gov

IceCube is a cubic kilometer neutrino telescope under construction at the South Pole. The primary goal is to discover astrophysical sources of high energy neutrinos. We describe the detector and present results on atmospheric muon neutrinos from 2006 data collected with nine detector strings.

1. Introduction

The IceCube detector is a cubic kilometer neutrino telescope under construction at the South Pole[1]. The main goal of IceCube is to detect cosmic neutrinos of all flavors in a wide (100 GeV to 100 EeV) energy range[a]. IceCube will search for point sources of extra-terrestrial muon neutrinos and diffuse fluxes of extra-terrestrial neutrinos of all flavors. Possible high energy neutrino sources are active galactive nuclei (AGNs), gamma-ray bursters (GRBs) and supernova remnants (SNRs). Other IceCube physics topics include searches for WIMP anihilation in the Earth and Sun, signatures of supersymmetry in neutrino interactions, and exotica like magnetic monopoles or extra dimensions[1].

2. The IceCube detector

The IceCube detector is shown in Fig.1. When complete, the detector will cover an area of 1 km^2 at depths of 1.45 to 2.45 km below the surface. The $\sim$ 1km^3 detector volume is driven by the low extra-terrestrial neutrino flux expectations[4] and neutrino interaction cross sections. IceCube will be composed of $\sim$ 4800 in-ice Digital Optical Modules (DOMs), recording Cherenkov light from charged particles, on 80 strings spaced by 125 m.

[a]So far the only observed extra-terrestrial neutrinos are low energy neutrinos from the Sun[2] and SN1987A[3].

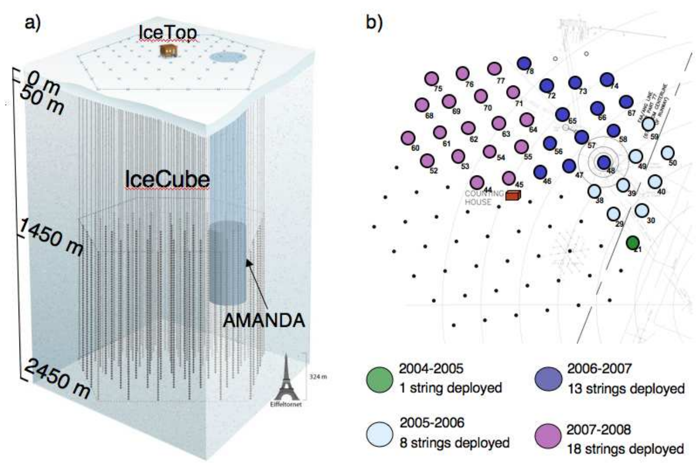

Figure 1. The IceCube detector: a) side view of the complete detector with 80 strings and b) top view of the detector showing the construction stages.

The data are digitized in the DOMs and sent to the surface, where filtering algorithms are used to reduce the data volume for satellite transmission off-site. A detailed detector description can be found in Ref.[5].

The construction of IceCube began in 2005 and proceeds in yearly stages as illustrated in Fig.1b). Currently 50% of the detector is installed and operational. Its completion is expected by 2011.

3. Neutrino detection

High energy neutrinos are detected by observing the Cherenkov radiation from secondary particles produced in neutrino interactions inside or near the detector. Muon neutrinos from charged current (CC) interactions are identified by the final state muon track [6]. Electron and tau neutrinos produced in CC interactions, as well as all neutrinos produced in neutral current (NC) interactions are identified by observing electromagnetic or hadronic showers (cascades). Track and cascade reconstruction algorithms are described in detail in Refs.[6,7].

The backgrounds to extra-terrestrial neutrinos of all flavors are down-going cosmic ray muons and atmospheric neutrinos (produced by the decay of π, K and charmed mesons in cosmic ray air showers in the Earth's atmosphere)[8].

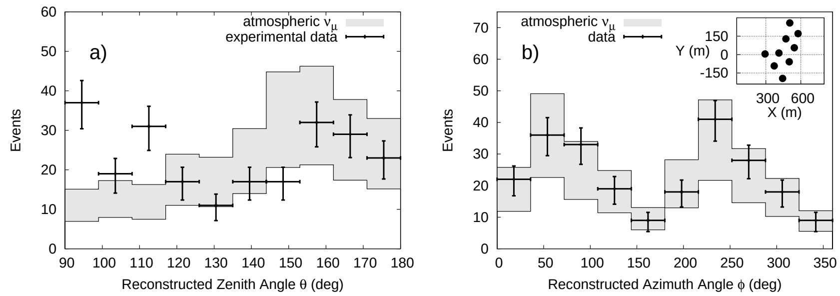

Figure 2. Distribution of the reconstructed: a) zenith angle θ and b) azimuth angle ϕ. The error bars on the experimental data are statistical. The band shows the range for the atmospheric neutrino simulation. The figure is from Ref.[9].

4. Muon neutrino results with IC9

After cuts, which selected well reconstructed up-going muon tracks, a total of 234 neutrino candidate events were identified in the first 137.4 days of livetime with the nine string detector (IC9)[9]. The zenith angle distribution of those events is shown in Fig. 2a). The small excess of events at low zenith angles (near the horizon) is most likely caused by misreconstructed down-going muons[b]. Events with larger zenith angles are consistent with the simulated atmospheric ν_μs. Figure 2b) shows the azimuth distribution of neutrino candidate events. The two peaks reflect the IC9 asymmetric geometry, shown as an inset, and are well reproduced by Monte Carlo background simulations[10]. The agreement of the detected atmospheric neutrinos with expectations established IceCube as a neutrino telescope[5,9]. The atmospheric muon neutrino event sample was used for the first extra-terrestrial neutrino point source searches with IceCube[11]. The sky-averaged point source sensitivity to a source with an E^{-2} spectrum is $E^2 d\Phi/dE = 1.2{\cdot}10^{-7}$ GeV cm^{-2} s^{-1}, comparable with the limit obtained from the AMANDA-II analysis of five years of data taking [12]. The results of the all-sky search are shown in Fig.3. The maximum deviation from background (3.35 σ at r.a. = 276.6 deg , dec= 20.4 deg) is consistent with random fluctuations. A search for neutrinos from 26 galactic and extragalactic sources was also performed. The most significant excess over background was 1.77σ for the Crab Nebula, consistent with random fluctuations. The 90% C.L. flux upper limit for the Crab Nebula is $E^2 d\Phi/dE = 2.2 \cdot 10^{-7}$ GeV cm^{-2}s^{-1}, Ref.[11].

[b]A zenith angle of 90 degrees indicates a horizontal event, and a zenith angle of 180 degrees is a directly up-going event.

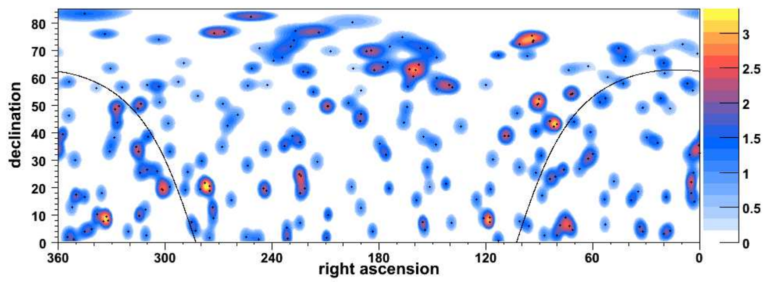

Figure 3. Sky map of the significance [σ] of deviations from background, estimated from the maximum likelihood point-source search. The figure is from Ref.[11].

5. Diffuse flux searches

If the neutrino fluxes from individual sources are too small to be visible as individual sources, but the number of sources is large, then these neutrinos will be detectable as a diffuse flux coming from the entire sky. The best known limit on the maximum diffuse neutrino flux was calculated by Waxmal and Bahcall[13](WB) to be $E^2 d\phi/dE < 7 \cdot 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}.

The experimental search method assumes that the signal has a harder energy spectrum than atmospheric neutrinos. When examining energy-related parameters, an excess of events over the expected atmospheric neutrino background would be indicative of an extraterrestrial neutrino flux. So far, no excess of events has been observed. For the IC9 data and 137 days livetime the expected sensitivity $E^2 d\phi/dE < 1.4 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1} is only a factor of 2 larger than the tightest AMANDA-II limit[14]. The summary of existing experimental limits on extra-terrestrial diffuse neutrino flux and WB flux limits are shown in Fig. 4.

6. Summary

The detection of atmospheric neutrinos with 9 string configuration established IceCube as a neutrino telescope[5,9]. A significant improvement of the sensitivity for both point-like neutrino sources as well as diffuse neutrino fluxes is expected from 2007 data taken with 22 strings. Analyses of these data are in progress. The IceCube detector continues to grow. We expect that an integrated exposure of 1km^3 $\cdot$ year will be reached in 2009 and the first extra-terrestrial neutrino signal may be detected. Stay tuned!

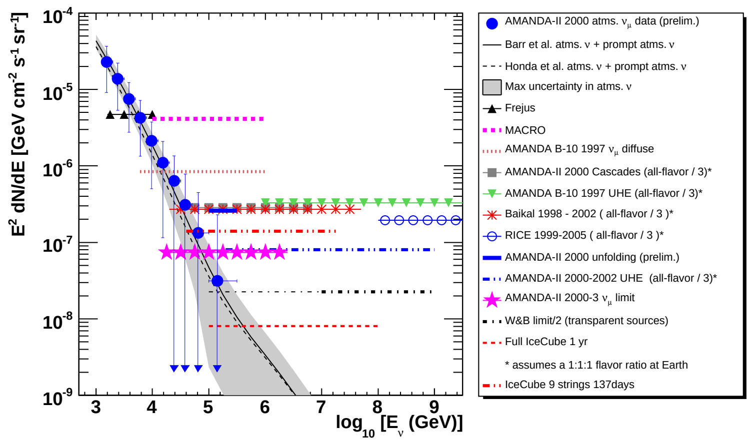

Figure 4. Summary of existing experimental limits on the diffuse neutrino flux versus the logarithm of neutrino energy. The figure is from Ref.[14].

Acknowledgments

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