The IceCube Neutrino Telescope

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The IceCube Neutrino Telescope, a huge Neutrino Telescope with 1 cubic km instrumented volume, starts construction in 2004. The project status and the expected sensitivity and performance for detecting high energy cosmic neutrinos are reported. The capability of EHE neutrino detection is also briefly mentioned.

1. Introduction: IceCube Detector

It has been discussed that many of the proposed astrophysical models of ultra-high energy (UHE) neutrino production would require a scale of a cubic kilometer target volume to secure their detection. The IceCube detector [1] has been designed and will be constructed following this philosophy using the deep ice at the South Pole as an interaction target.

The instrumented volume where Cherenkov light from neutrino-induced charged leptons is detected contains an array of 4800 PMTs each enclosed in a transparent pressure sphere to comprise a Digital Optical module (DOM). Eighty strings are regularly spaced by 125 m over an area of approximately one square kilometer with DOMs at depths of 1.4 to 2.4 km below the ice surface. Each string, containing 60 DOMs spaced by 17m, will be deployed into a hole drilled with pressurized hot water. A complimentary air shower array on the ice surface called IceTop is also built for providing the background-veto capability as well as study of the cosmic ray origin in the knee region ($\sim 10^{16}$ eV).

The IceCube DOM is shown in Fig. 1. It contains a 10 inch diameter PMT supported by coupling gel, a signal processing electronics board, an LED flasher board for calibration, and the PMT base with high voltage supplier, all of which are housed in the spherical pressure glass.

Our PMT choice is the HAMAMATSU R7081 with 10 dynodes which has exhibited excellent charge resolution and low noise. The operation gain is planned to be $\sim 5 \times 10^7$. The PMT response has also been investigated in some detail such as two dimensional relative sensitivity on the photocathode surface. An example is shown in Fig. 2 where the sensitivity is plotted as a function of distance from the cathode center. These results are all implemented in the IceCube detector Monte Carlo simulation we are now developing. The overall noise for each individual DOM is targeted to be 500 Hz which can be realized due to the sterile and low temperature environment of the deep ice and an effort to use low activity materials.

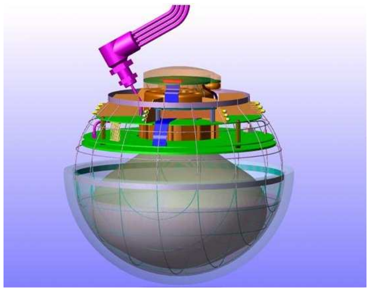

Figure 1. Schematic view of the IceCube Digital Optical Module.

2. The Basic Performance and Sensitivity to Astrophysical ν_μ

The backgrounds for searches for extraterrestrial neutrinos come from atmospheric muons and neutrinos produced by decay of mesons gener-

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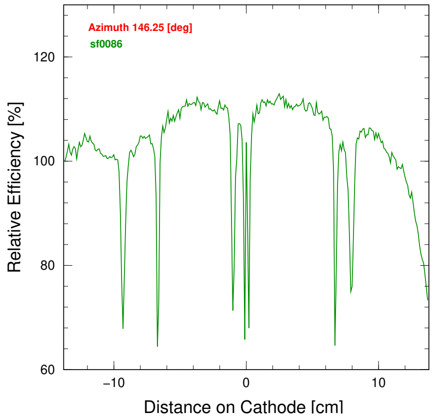

Figure 2. The relative PMT sensitivity as a function of distance from the photocathode center. The scanned data sliced by the horizontal axis with 146.25° from the dynode orientation is plotted here. The spikes are due to the deadspace of the shield of the geomagnetic field and not the real response of a PMT.

ated from cosmic ray (CR) interactions in the atmosphere. CR-interaction induced background events can be identified by the fact that they result mainly in down-going tracks in the instrumented volume of ice.

The discrimination of the astrophysical neutrino signals from the background is based on the geometrical parameters obtained by the various reconstruction algorithms, the reduced likelihood of the reconstruction, number of PMT channels receiving an unscattered Cherenkov photon, the track length and so on. The details are found in [2]. The initial results indicated that the atmospheric muon background can be reduced by more than factor of $\sim 10^6$. The effective area for upward moving neutrino-induced UHE muons is 1.2 km^2 at 1 PeV. The pointing resolution is better than 1.0°. As with the sensitivity, we found [2] diffuse flux of $E_\nu^2 dN_\nu/dE_\nu = 1 \times 10^{-8}$ cm^{-2} sec^{-1} sr^{-1} GeV is detectable in three years of observation. An angular search cone of 1° in one year of observation would reach a sensitivity of $E_\nu^2 dN_\nu/dE_\nu = 5.5 \times 10^{-8}$ cm^{-2} sec^{-1} GeV for point sources emissions. The best order-of-magnitude estimate from the W-B model on the GRB UHE neutrino emissions is about 1 event

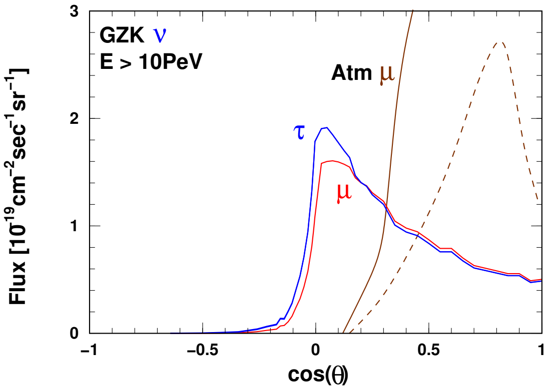

Figure 3. Dependence of the muon and tau fluxes originated in the cosmogenic neutrinos at the IceCube depth on the cosine of zenith angle. The integral flux above 10 PeV is plotted in linear scale. The atmospheric muon fluxes estimated by the two different methods [7] are also shown by the solid and dashed curves.

per 100 GRBs [3].

3. Some Remarks on the IceCube EHE Neutrino Sensitivity

It has been argued that underground neutrino telescopes being operated and/or planned to be built are capable of detecting Extremely-high Energy (EHE:$10^{17} \sim 10^{20}$ eV) neutrinos [4]. EHE neutrinos during the propagation do not penetrate the earth but are involved in charged/neutral current interactions that generate charged leptons and hadronic showers because their cross sections are expected to be enhanced in the ultra-high energy regime. Fig. 3 shows dependences of the secondary muon and tau fluxes on the zenith angles. The initial primary cosmogenic neutrino fluxes are taken from Ref. [5] in the GZK cosmogenic neutrino model [6]. Strong attenuation by the earth can be seen but the fluxes are more or less stable in the region of the "downward" events where $\cos\theta \geq 0$. Intensity of the downward going muons and taus are larger than the upward ones by an order of magnitude. One can also see that the muon background attenuates faster than the neutrino-induced EHE muons and taus, and there is a window where the signals

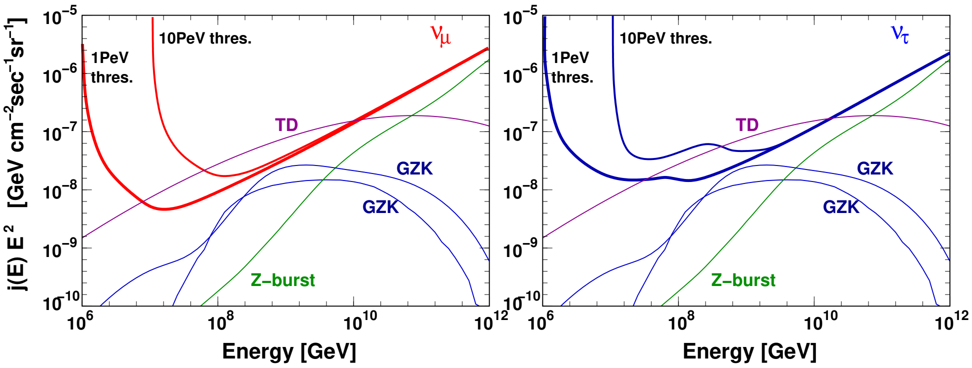

Figure 4. The IceCube sensitivities on the EHE neutrino fluxes. 90 % C.L. limits by a 1km^2 detection area with 10 years observation are drawn. The left panel shows the case of ν_μ and the right panel shows the ν_τ case. Labels refer to GZK ([5] for the lower curve, [8] for the upper curve), TD [9], and Z-burst [10].

dominate the muon background. The detail discussions are found in Ref. [7]. The event rate is found to be 0.27 $(\mu+\tau)/\mathrm{km}^2$ year for the cosmogenic neutrino fluxes with the moderate source evolution. Note that the downward event rate is 0.25 /km^2 year and dominates in the overall rate.

The IceCube sensitivity on EHE neutrinos can be evaluated by the secondary produced μ's and τ's event rate per energy decade $dN/dLogE$. Fig. 4 shows the resultant sensitivity with 1 km^2 detection area. The appropriate EHE downgoing event detection criteria was found to be energy deposit greater than 10 PeV in 1 km^3 volume of ice [7]. The various model predictions are also shown for comparison. The topological defects (TD) scenario would be severely constrained while the cosmogenic neutrino possibilities would not be ruled out by absence of signals.

4. Project Status

The project has been approved by the U.S. National Science Board and the N.S.F. is the major source of the project budget. Significant contributions for the cost of the detector are also being made by Germany, Sweden, and Belgium. The grants for the man power support and the detector calibration efforts has been approved by the Japanese agencies. Full construction will start in FY 2004 and take 6 years to complete. In this year, defined by project year 2, production and testing of $\sim$ 100 DOMs are scheduled in addition to shipping the new hot water drill to the South Pole. The detector verification, related software to utilize fully the DOM waveform information, and the efforts to expand the energy range (below TeV and above EeV) are under way.

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