The IceCube High Energy Neutrino Telescope

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Abstract

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.

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 has been designed and will be constructed following this philosophy. It is the result of further technological development of the basic ideas of the AMANDA telescope [1], which has demonstrated the deep ice at the Soth Pole indeed provides an excellent interaction target for UHE neutrino detection, which validated the idea of having a much larger neutrino telescope in Antarctica. It will be realized as the IceCube detector [2].

The configuration of the IceCube detector is shown in Fig. 1. The instrumented volume where Cherenkov lights 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 is described separately [3]

The IceCube DOM is shown in Fig. 2. 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. It contains its own processor, memory flash file system, and real-time operating system. Its new digital technology enables it to schedule background communication while acquiring data, to invoke

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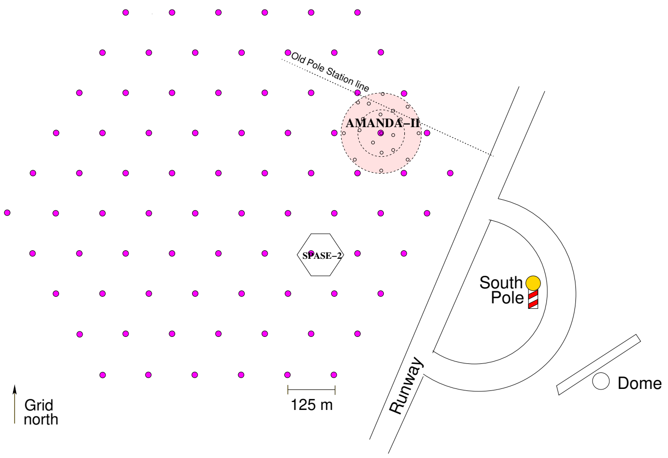

Fig. 1. Schematic top view of the string arrangement of the IceCube detector at the South Pole station.

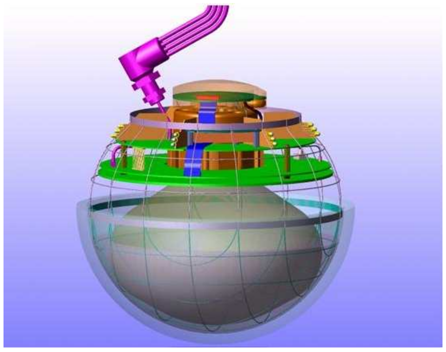

Fig. 2. Schematic view of the IceCube Digital Optical Module.

all calibration functions under software control, and most notably, to digitize the PMT pulse and store the full waveform information.

Our current 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 $\sim 5 \times 10^7$ with dynamic range of ~ 200 photo-electrons per 15 ns. 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.

2. Analysis Chain and the Basic Performance

The backgrounds for searches for extraterrestrial neutrinos come from atmospheric muons and neutrinos produced by decay of mesons generated from cosmic ray (CR) interactions in the atmosphere. CR-interactions induced background events can be identified by the fact that they result mainly in down-going tracks in the instrumented volume of ice. Our search for cosmic neutrinos will be performed, therefore, by excluding the vast backgrounds caused by atmospheric muons (and eventually atmospheric neutrinos also), which requires extensive simulations. The main sequence of the simulation and the analysis procedures are:

1. Neutrino and muon generation in the atmosphere by CR is simulated by the full Monte Carlo Package. Astrophysical UHE neutrinos are assumed to follow an E_ν^{-2} energy spectrum as a benchmark.

2. Propagation of neutrinos and induced muons in the earth is simulated. These simulations give the intensity of neutrinos and muons entering into our detector volume after propagation through the earth.

3. The Cherenkov light generation and propagation in the deep ice, taking account of scattering and absorption, is simulated. Then the detector response of the PMT array is modeled by the detector simulation. Initially [4] We used the software package primarily for AMANDA for this purpose.

4. The triggered events are filtered and reconstructed.

Here we only report on the case of ν_μ inducing high energy muons since their long range results in a larger detection volume than do the other charged leptons. Note that the complete reconstruction technique is based on the AMANDA experience, which implies that the results are reliable, but also conservative as we did not use the full pulse shape information available by the IceCube DOMs which will improve the sensitivity*.

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 [4]. The initial results indicated that the atmospheric muon background can be reduced by more than factor of $\sim 10^6$. The atmospheric neutrino background remains significant, but applying a channel multiplicity cut can exclude the background completely since the energy spectrum of astrophysical neutrinos ($\sim E^{-2}$) is much harder than that of the background neutrinos ($\sim E^{-3.7}$). 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°.

3. Sensitivity to Astrophysical ν_μ

The sensitivity obtained for a diffuse neutrino flux is summarized in Fig. 3. $E_\nu^2 dN_\nu/dE_\nu = 1 \times 10^{-8}$ cm^{-2} sec^{-1} sr^{-1} GeV is detectable in five years of observation. The GRB flux appears to be below the IceCube sensitivity, but coincident

*The reconstruction used here relies only on the information carried by the first photon arriving at the PMT assuming the original AMANDA read-out system.

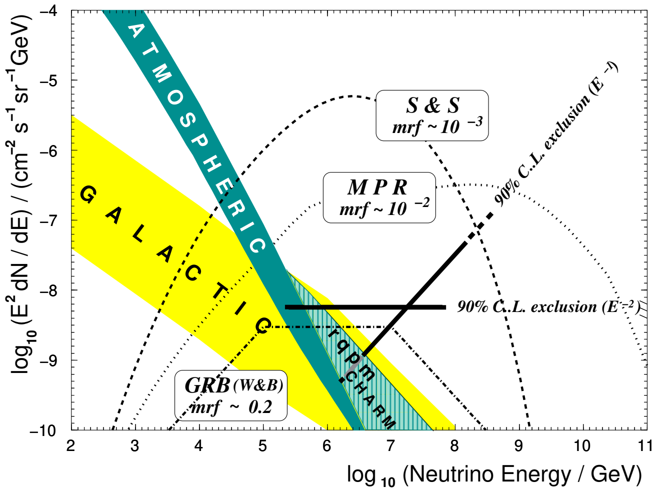

Fig. 3. Expected sensitivity of the IceCube detector.The various neutrino production models in AGNs/GRBs are shown for comparison [5-8]. The *mrf* implies the "Model Rejection Factor" which is described in [4] for details.

search in direction and burst timing leads to 5σ detection of the GRB neutrinos with 200 observed bursts which can be achieved in less than 1 year detector operation. An angular search cone of $1°$ would constrain models of point sources to those that produce flux less than $E_\nu^2 dN_\nu/dE_\nu = 2 \times 10^{-8}$ cm^{-2} sec^{-1} GeV.

4. Project Status

The project has been approved by the U.S. National Science Board and its total cost noted in the U.S. president's FY2004 budget request for the NSF, the source of the major fraction of the cost. 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 150 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.

5. References

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