International Journal of Modern Physics A

STATUS OF THE ICECUBE NEUTRINO TELESCOPE

T. DEYOUNG*

Department of Physics, University of Maryland
College Park, Maryland 20742, U.S.A.

For the IceCube Collaboration

Received (Day Month Year)
Revised (Day Month Year)

IceCube is a kilometer-scale deep-ice neutrino telescope, to be constructed at the South Pole beginning in January 2005. The concept and design of IceCube, its science goals, present status, and expected performance will be discussed.

Keywords: keyword1; keyword2; keyword3.

1. Introduction

The IceCube neutrino telescope[1] is designed to detect very high energy (TeV – EeV) neutrinos from astrophysical sources. Such neutrinos may originate from the sources of the highest energy cosmic rays; from interactions of ultrahigh energy cosmic rays with the cosmic microwave background; from astrophysical sources of very high energy gamma rays such as active galactic nuclei, supernova remnants, or gamma ray bursts; from the annihilation of dark matter trapped in gravitational wells such as the Sun; or in 'top-down' scenarios as the decay products of massive cosmological relic particles. Other science goals of IceCube include studies of cosmic ray composition above the knee; searches for exotic particles such as magnetic monopoles, nuclearites, Q-balls, or long-lived sleptons; searches for evidence of TeV-scale extra dimensions; and searches for neutrinos from galactic supernovae.

Extragalactic background radiation severely attenuates photons traveling over cosmological distances above roughly the TeV scale.[2] Neutrino astronomy therefore allows us to observe astrophysical objects in an energy regime which is inaccessible to conventional photon-based astronomy, even with the new generation of air Cherenkov gamma ray telescopes.

*deyoung@icecube.umd.edu

2. The IceCube Detector

IceCube consists of two components: the deep detector, consisting of 4800 digital optical modules (DOMs) on 80 strings buried in the extremely transparent ice below the South Pole at depths of 1450–2450 m; and the IceTop detector, comprising 80 pairs of ice Cherenkov tanks on the surface above the strings. Each string holds 60 DOMs at a spacing of 17 m, and each IceTop station consists of two tanks, each containing two DOMs. The strings (and associated stations) will be deployed on a hexagonal grid of 125 m spacing, covering an area of approximately 1 km^2 on the surface and a volume of 1 km^3 in the ice.

The deep detector observes the interactions of very high energy neutrinos with the ice surrounding the detector. These interactions produce ultrarelativistic charged leptons, which are detected through their Cherenkov emission by photomultiplier tubes (PMTs) inside the DOMs. With timing resolution of a few nanoseconds and sensitivity to single photons, the trajectory and energy deposition of the lepton can be reconstructed from the observed Cherenkov light. Inferences about the original neutrino can then be drawn from the lepton information; for instance, above the TeV scale the lepton is aligned with the neutrino's direction to within a degree, with the misalignment angle decreasing at higher energies.

The surface detector, IceTop, will detect cosmic ray air showers above the "knee" in the cosmic ray spectrum. In conjunction with the deep detector, this will allow us to study the composition of cosmic rays in this energy range. In addition, penetrating muons from air showers observed by IceTop will act as a calibration beam for IceCube, and IceTop can be used as a veto to separate downgoing neutrino induced events from penetrating muons produced by the cosmic rays.

The DOMs used in both IceCube and IceTop consist of a 10" PMT inside a spherical glass pressure vessel. Each DOM also houses electronics which perform the initial data acquisition (DAQ) functions, digitizing PMT signals locally and transmitting them asynchronously to surface DAQ components. The DOM provides 40 MHz samples over a 6.4 μs window, as well as 300 MHz samples at three different gains for the first 300 ns of the readout, where the most physically interesting data is expected. Instantaneous dynamic range is approximately 200 photoelectrons, and two sets of digitization electronics operated in a 'ping-pong' fashion will reduce deadtime to less than 1%.

3. Detector Performance

IceCube will be sensitive to all lepton flavors over a wide energy range. Muons produce long tracks through the detector, and can be reconstructed above a (muon) energy of a few hundred GeV.[3] Cascades from ν_e, ν_τ, and neutral current interactions produce roughly spherical events, and can be reconstructed above several TeV. Above PeV energies, τ lepton events are distinguishable from other types of cascades through their characteristic "double bang" topology: a cascade from the initial νN interaction followed by a second cascade from the τ decay in flight, separated by approximately 50 m/PeV.[4]

At low energies, a substantial flux of muons produced in atmospheric cosmic ray showers above the detector masks any possible downgoing neutrino-induced muon events. Low energy muon neutrino events are identified by searching for upgoing events, which have passed through the Earth en route to the detector. Expected astrophysical neutrino fluxes are predicted to have much harder spectra than cosmic ray muons, however, so at high (PeV) energies we will be able to observe sources in the Southern Hemisphere by restricting our attention to high energy events. On the other hand, at high energies the neutrino cross section rises to the point that the Earth becomes opaque, so the Northern Hemisphere can only be observed at lower energies.

Cascade events from ν_e and neutral current interactions may be detected from all directions (barring effects of the Earth's opacity), if they can be separated from a background of hard stochastic emission produced by penetrating cosmic ray muons. This will be possible in IceCube by using IceTop and the outer layers of the deep detector as a veto. Cascade events offer better energy information, but poorer directional information, than muon events.

In both channels, there is also a background of neutrino events produced in atmospheric cosmic ray showers along with the penetrating muons. This flux is roughly isotropic, and like the cosmic ray muon flux it follows a soft spectrum. Astrophysical neutrino events can thus be isolated from this background by demanding high energies. Events from individual astrophysical sources can also be identified by their position on the sky and, for transient or variable sources, by their timing.

Finally, it should be noted that tau neutrino events are a reliable indicator of astrophysical neutrinos. Neutrinos propagating over cosmological distances will oscillate, so that a significant fraction of such a signal will be detected as tau events. In atmospheric cosmic ray showers, however, no appreciable tau flux is produced at the relevant (PeV) energies either through the prompt channel[5] or through oscillation over terrestrial baselines. Moreover, τ lepton decay in flight implies that ν_τ can traverse the Earth even at ultrahigh energies, due to neutrino regeneration from the lepton decay. The cross section is such that upgoing ν_τ are detected primarily around the PeV scale at which the double bang topology becomes useful for lepton identification.[6] The tau channel will thus be uniquely useful for detecting astrophysical neutrino events.

References

1. http://icecube.wisc.edu
2. J. G. Learned and K. Mannheim, *Ann. Rev. Nucl. Part. Sci.*, **50**, 679 (2000).
3. J. Ahrens *et al.*, *Astropart. Phys.* **20**, 507 (2004).
4. J. G. Learned and S. Pakvasa, *Astropart. Phys.* **3**, 267 (1995).
5. L. Pasquali, M. H. Reno, and I. Sarcevic, hep-ph/9905389.
6. F. Halzen and D. Saltzberg, *Phys. Rev. Lett.* **81**, 4305 (1998).