The IceCube Project at LBNL

D. Chirkin[1], A. Goldschmidt[1] , D. Hays[1], K. Helbing[1], S. Klein[1], H. Matis[1], T. McCauley[1], R. Stokstad[1], W. Chinowsky[2], D. Nygren[2], G. Przybylski[2], B. Bingham[3], H. Chen[3], W. Edwards[3], A. Jones[3], J. Johnson[3], J. Joseph[3], E. Kujawski[3], R. Minor[3], T. Stezelberger[3], C. Vu[3], C. Day[4], A. Moktarani[4], S. Patton[4], K. Beattie, C. McParland[5], M. Stoufer[5], and S. Mandel[6]

[1] Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720
[2] Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720
[3] Engineering Division, , Lawrence Berkeley National Laboratory, Berkeley, California 94720
[4] National Energy Research Supercomputer Center, Lawrence Berkeley National Laboratory, Berkeley, California 94720
[5] Computational Research Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720
[6] Physics Department, University of California, Berkeley, California 94720

IceCube will be a kilometer-scale neutrino telescope that will explore new territory – the high energy neutrino sky in the TeV to PeV range. Its main purpose is to detect high energy neutrinos that may be generated at Active Galactic Nuclei, Gamma-Ray Bursters, Supernova Remnants, and possibly other high energy-density sites in the cosmos. It will be sensitive to all three neutrino flavors. The completed Observatory will instrument a cubic kilometer of deep ice with at least 70 new strings plus the existing 19 AMANDA strings.

Construction of the IceCube Neutrino Observatory reached a milestone in January 2005 with the deployment of the first deep-ice string of IceCube sensors and the first elements of the surface air-shower array, IceTop, located directly above IceCube. Since then, the 60 modules deployed in the ice and the 16 on the surface have been sending data back data that we have used to verify the performance of the system. The results indicate that the Digital Optical Modules and the DAQ system meet or exceed performance requirements.

Cosmic ray muons associated with air showers are used to test and verify the system. Fig. 1 shows a particularly spectacular event in which all 76 modules recorded a "hit." The times of arrival of Cherenkov photons at each of the modules enable the reconstruction of muon tracks. The crucial characteristics of the detector system - timing calibration and resolution, dynamic range, dead time, etc. have been determined from these data.

Each DOM contains a stable oscillator, free-running at 20 MHz, which is used to "time-stamp" the arrival of a photon. This clock is calibrated by sending analog pulses between the DAQ front end and the DOM. The (round-trip) time resolution for calibration for the 60 DOMs is <4 ns, rms. (Fig. 2) and typically 1.5 ns.

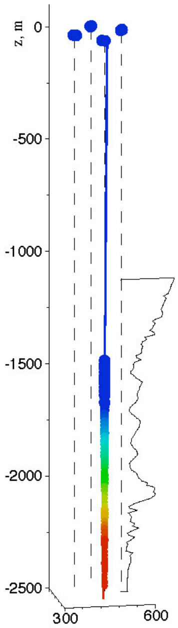

FIG. 1 An IceCube event in which all modules received a hit. The curve denotes the effective scattering coefficient of the ice.

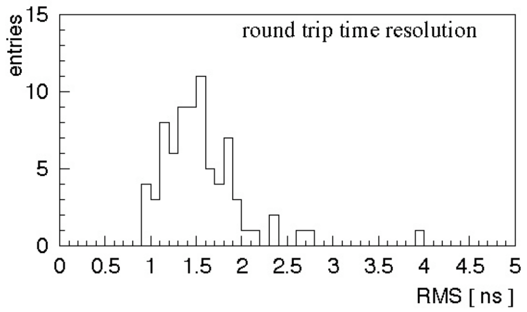

Fig. 2 The round-trip time resolutions for calibrating 76 local oscillators.

In order to measure the absolute accuracy for time-stamping the arrival of a photon, we reconstruct the tracks of muons using all DOMs but the nth. The predicted arrival times for unscattered photons are then compared with the actual arrival times for the nth DOM. The analysis is then repeated 60 times, for 0<n<61. The residuals of predicted and measured times are shown in Fig. 3.

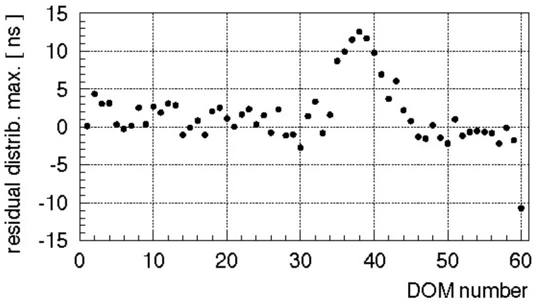

Fig. 3 Distribution of direct hit time residuals for all DOMs on the string

The larger residuals (indicating delayed arrival) for DOMs 30-45 arise from the increased optical scattering in the ice at their depth, a feature which is visible in the curve in Fig. 1. These results indicate that systematic errors in the time calibration are less than 3 ns. The deviation for OM 60 is under investigation.

In summary, the first IceCube DOMs are performing well.

IceCube is funded by the National Science Foundation, and our work is performed under subcontract to the University of Wisconsin.