

# IceCube - First Results

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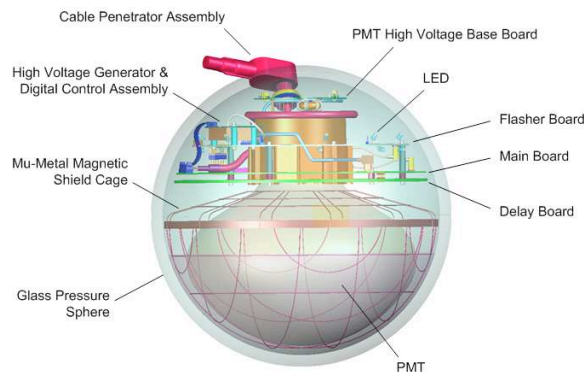
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**Abstract.** During the last two austral summers, the first sensors of the IceCube neutrino observatory were deployed in the deep Antarctic ice, along with a surface array. We will present first results obtained using the IceCube detector, demonstrating that the performance is within the design requirements, and showing the ability to reconstruct tracks, cascades and synchronizing times in the entire array to within 3 ns.

## 1. Introduction

The IceCube detector currently under construction at the South Pole, will consist of up to 4800 Digital Optical Modules (DOMs) covering a fiducial volume of 1 cubic km [?]. The DOMs will be equally spaced on up to 80 strings, at depth from 1.5 to 2.5 km in the deep, clear Antarctic ice. An array of surface stations, IceTop, enhance the ability to trigger on, or veto, down-going showers. Each IceTop station consisted of two clear ice tanks, each instrumented with 2 DOMs. An IceTop station is located roughly 10 meters from each bore hole of the In-Ice array.



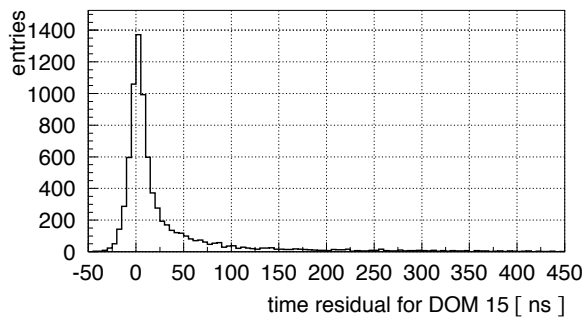
**Figure 1.** A schematic view of an IceCube Digital Optical Module (DOM)

IceCube is designed to detect Cherenkov radiation photons emitted by charged particles. The particles that are most likely to penetrate through the 1.5 km of ice on top of the detector are muons (from interaction of cosmic rays in the atmosphere), and neutrinos (atmospheric or from any other source). The rate of the muon background is about 6 orders of magnitude larger than

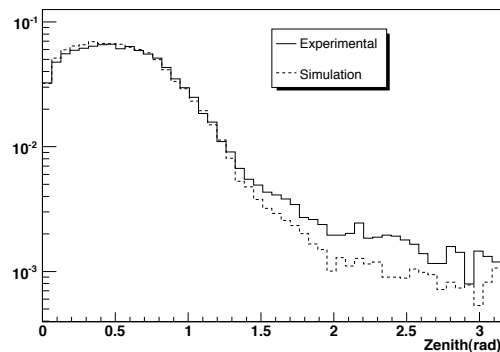
<sup>1</sup> A full list of collaboration members appears at the end of the proceedings

that of atmospheric neutrinos, and therefore neutrino searches are performed using up-going particles that traverse the entire earth, using the matter of our planet as a muon screen. Based on measurements of the number of photons arriving at different DOMs and their arrival times, a track or a cascade can be reconstructed. Each DOM is an autonomous data collecting and analyzing unit consisting of a 10" Hamamatsu PMT in a 12" pressure sphere (see figure ??). A main board inside the DOM can digitize up to 300 Mega Samples per Second (MSPS) for 400 ns and 40 MSPS for  $6.4\mu s$ . A flasher board, populated with 12 Light Emitting Diodes (LEDs), produces pulses used for optical and timing calibration. The DOMs can operate in a local coincidence mode, where a data recording will be triggered only if its neighbors were triggered within a certain time window.

The main scientific goal of IceCube is to map the neutrino sky [?]. IceCube will also look for high energy GZK neutrinos [?], study air showers, high energy atmospheric neutrinos [?] and look for supernovas in a special data acquisition mode [?]. IceCube measurements can be used, to some extent, also for neutrino mass hierarchy and CP phase measurements [?]. There are models predicting certain neutrino flux enhancements, which could be measured by IceCube. These sources include, but are not limited to, dark matter, super-symmetry, magnetic monopoles, quantum gravity [?].



**Figure 2.** Distribution of time residuals of photons arriving at a DOM from nearby tracks reconstructed with the rest of the string. Photons arriving from the track directly with no scattering will have time residual = 0



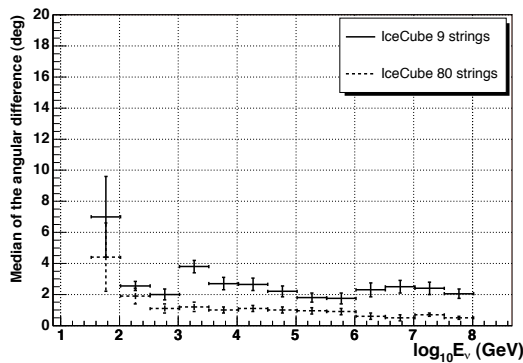
**Figure 3.** Distribution of reconstructed zenith angle for muon events

## 2. Current Status and Verification

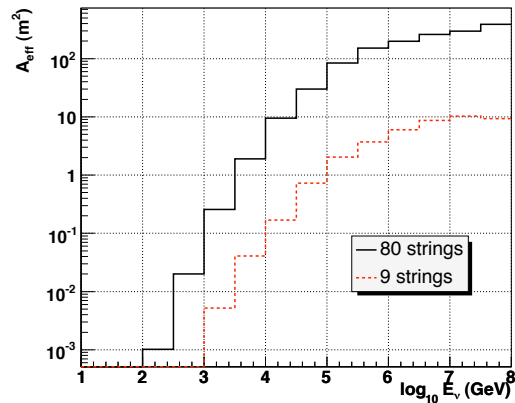
In the winter of 2004-2005 a single In-Ice string and 4 IceTop stations were deployed. At the end of the 2006 Austral summer IceCube consists of 9 In-Ice strings and 16 IceTop stations. A set of measurements were performed to confirm the design goal of the detector and check its performance [?]. In order to reconstruct and time tracks over the entire array, a timing resolution of a few nanoseconds is needed. The time resolution of each detector unit was estimated in two independent ways. In the first the flasher board was used. A LED on a DOM was flashed and adjacent DOMs triggered on it. The time delay between the flashing and the triggering was measured multiple times. This procedure was repeated for all DOMs, and the maximum time RMS resolution was found to be less than 2ns. A different way to estimate the time resolution is by reconstructing down-going muon tracks excluding one DOM, and calculating the time difference between the measured hit time and the expected hit time. Figure ?? shows the distribution of those time residuals for a single DOM using multiple events. The process is

repeated for all DOMs. The resolution was found to be less than 3 ns, after correcting for ice properties.

The distributions of different reconstruction parameters were compared to predicted rates and simulated Monte Carlo events. For both down-going atmospheric muon candidate events, and up-going neutrino candidates events the agreement between Monte Carlo and data was good, and in agreement with previous predictions [?]. A comparison of the zenith angle distributions is shown in figure ?? . In order to estimate signal and background behavior and check detector performance, a reliable neutrino interaction and detector simulation is needed. The IceCube simulation software is currently under active development.



**Figure 4.** The angular resolution for 9 Ice strings and for the full IceCube array as function of event energy (Preliminary). Shown here the differences between the true and reconstructed muon track.



**Figure 5.** The effective area calculated for 9 and 80 strings detector, for reconstructed muon tracks as function of the neutrino energy (Preliminary)

### 3. Future Sensitivity

Using simulation of the 9 and 80 string detector configurations, effective areas, angular resolutions and event rates were estimated. Likelihood reconstructions run on simulation are used to estimate the angular resolution of the detector, shown as a function of energy in figure ?? . Resolutions can also be characterized by energy spectral indices. For example, the angular resolution for reconstructed atmospheric muon tracks will be about  $2.2^\circ$  ( $2.7^\circ$ ) using 80 (9) strings, and  $0.8^\circ$  ( $1.3^\circ$ ) for an  $E^{-2}$  spectrum. The angular resolution results quoted are expected to improve when the DOM waveform information will be fully used. In figure ?? the estimated effective area for neutrino detection as function of energy is shown.

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