1. INTRODUCTION

IceTop is the surface air shower array above the IceCube [1] neutrino detector. Its primary purpose is to complement the detection of high energy astrophysical neutrinos and support IceCube by identifying background events. To do that IceTop will [2]:

1) Tag a fraction of the small showers on the surface that are associated with the main atmospheric muon background in IceCube. Among the identified events will be a sample in which two independent single muons occur within the reconstruction time interval of IceCube at different locations. Study of such events, which have the potential of being misreconstructed as horizontal or upward going muons or showers, will be particularly valuable.

2) Veto events with large energy deposition inside IceCube when their associated air showers are detected at the surface. IceTop will be able to cover a large fraction of the upper hemisphere at energies approaching $10^{17}$ eV because there is no need to reconstruct fully the surface shower to veto an underground event.

3) Provide an independent measure of angular resolution and pointing of IceCube by use of independently reconstructed showers detected in coincidence with IceCube. This task has been already tested with SPASE2/AMANDA coincidences [3]. Analysis of coincident events can also provide independent information on ice quality.

In addition, IceTop together with IceCube constitutes a novel, three-dimensional air shower array with an aperture approaching 1 km$^2$-sr. As such it will be able to measure the primary cosmic-ray spectrum and composition from below the knee up to $10^{18}$ eV. The high elevation of the South Pole, equivalent to a vertical depth of 700 g/cm$^2$, has the advantage that the electromagnetic shower component is observed relatively near shower maximum, thus minimizing the effects of fluctuations in the relation between observed size and total energy. Sensitivity to primary mass comes from measurement of the ratio of the muon bundle in the deep detector to the shower size at the surface. In the process of analyzing SPASE2/AMANDA coincident events [4], Monte Carlo studies showed that the number of muons passing through the deep detector is well-correlated with the total amount of Cherenkov light observed, after accounting for the location of the trajectory of the shower core (muon bundle).

2. TESTING AT SOUTH POLE

After preliminary tests in 2000 and 2001 with frozen ice-Cherenkov tanks instrumented with AMANDA analog optical modules, two test tanks, each containing two early versions of the IceCube digital optical modules (DOMs) were deployed at the end of 2003. The two tanks have
a surface area of 3 m$^2$ and ice depths of 0.9 and 1.0 m respectively and are insulated with polyurethane foam. Their rates and the collected waveforms demonstrate a good ice quality inside the tanks.

At the time of deployment the DAQ system was in its early stages and the DOM readout was done with a preliminary code with slow transmission speed and large dead time. We nevertheless able to communicate with the DOMs, control their voltage, monitor their temperatures and collect waveforms. A fraction of these waveforms was taken with a muon telescope consisting of two 0.2 m$^2$ scintillator counters positioned vertically 90 cm apart from each other. The identification of the muon signals was made off-line using the GPS times of the muon telescope and the DOMs in the tank. Fig. 1 shows the amplitude distributions for all waveforms and for the muon telescope triggers. The amplitude and charge spectra of tank hits with its characteristic muon peak (as shown in Fig. 1) will be used to monitor and calibrate the IceTop detectors.

Another important test was the measurement of the temperature of the main board of the DOMs during the Antarctic winter. Although the DOMs were not always powered there was no failure of the system even when the air temperature dropped suddenly below -70°C. As a consequence of its thermal mass combined with the tank insulation, the ice temperature varied smoothly during the austral winter, reaching a low of -55°C in August 2004 and increasing gradually since then. The DOM main board typically runs 10°C higher than the ice temperature when the PMT is on.

3. IceTop DESIGN

IceTop will consist of 80 stations arranged in a triangular grid with average distance between the stations of 125 m. Each station is in the vicinity of an IceCube hole, and will share through a junction box power supply and communication cables with the under-ice detectors. SPASE 2 will be inside the IceTop perimeter and will be used in coincidence for at least the initial 3 years of the IceCube/IceTop deployment period. Each IceTop station will consist of two tanks filled with frozen water and viewed by standard IceCube DOMs. A DOM consists of 10 inch Hammamatsu R-7081PMT and boards on which electronics and testing equipment is mounted. Some of the main board firmware will be modified to suit the air shower detection. The two PMT in the same tank will be tuned to different gains to enlarge the dynamic range of the tank to about $10^6$.

Tanks are made of high-density polyethylene and have radius of 1 m. The two DOMs are positioned about 72 cm inward from the walls of the tank. The tanks are then filled with 90 cm of water. The walls of the tanks are covered with diffusely reflecting (e.g. tyvek) liners, while the inside tops of the tanks are not reflective. The ice quality in the tank has to be fairly good so the sensitivity to particle signals is uniform throughout the tank. A top-down freezing method was developed and tested in Delaware and at South Pole. To ensure clear, bubble-free ice the water below the freezing front is degassed with a small vacuum and pump system inside the tank operated by a freeze-control unit mounted on the side of the tank that also controls the ejection of the water produced by the expansion of the ice. The freezing control process is automatically monitored.

Figure 1. Amplitude distribution of the waveforms of all signals (shaded) and the muon signals.
4. DATA ACQUISITION

The signal rate at the surface is much higher than in ice. To manage the high data rate we distinguish between single particle hits and potential air shower signals by use of local coincidence between the two tanks at each station. A single tank hit is assumed to be a single particle: GeV $\mu$, $\gamma$, $e^+$, $e^-$. A coincidence between the two tanks in the station is a shower signal. On board firmware recognizes 2-tank station coincidences above a threshold of 30 MeV deposited energy. All such hits are transmitted to the counting house, where a shower trigger is constructed from four-fold station coincidences. This would correspond to a shower threshold energy of 300 TeV for proton induced showers and about 500 TeV for iron induced showers. We also keep isolated muons, recognized on board by a combination of amplitude and shape. These muons are used for calibration work and for identifying very large horizontal air showers by coincidence across the array. Periodically the hit threshold will be lowered to take single pe (photoelectrons) calibration data.

Figure 2 shows examples of waveforms extracted with early versions of the electronics from the test tanks at South Pole for different types of events. The waveform from each DOM is digitized at three different amplifications allowing for a dynamic range of $1 - 10^3$ pe with $\sim 6$ bits S/N. The sampling time for the waveforms is set to 3.3 ns. Overall timing accuracy of a hit is < 10ns including clock distribution to the DOMs. The multi-pe & muon waveform shapes are a convolution of single pe waveforms with photon arrival times at the DOM. For the 2003/04 test tanks the integrated signal from the low gain channels is 5-10% that of the high gain channels. The multi-pe waveform in the figure contains about 12 pe, and the muon $\sim 120$ pe.

The InIce and IceTop DAQs are being developed as an integrated IceCube experiment. Either an IceTop or InIce trigger will cause a read-out of the entire experiment to build common events for offline analysis. This will facilitate the collection of sub-threshold surface activity in coincidence with in-ice muons, tagging a fraction of those muons as atmospheric in origin. Such muons can be used to verify in-ice filter and reconstruction algorithms.

5. SIMULATIONS

The IceTop simulation code is an integral part of the IceCube simulation. Parts of the code are already well developed. Specific items include CORSIKA shower simulations and transfer of the simulation data in a format convenient for both IceTop and InIce devices. This is achieved by an object oriented approach which allows data exchange between the different simulation stages, similarly to the data exchange of real data [6].

We have done the first run to calculate the event rates in the test tanks. Systematic cosmic ray shower simulations are to start in the beginning of 2005.

We have constructed a tank simulation code

![Figure 2. Samples of different types of waveforms, from top to bottom: single pe, most likely a muon, and multi-pe, probably shower event.](image)
based on GEANT 4 that generates the number of PE in the DOMs. This code is complete and is currently used for verification by comparison with test tank signals. We are using the results of the GEANT 4 code to generate a set of photon tables for use in production simulations, suitable for treatment of the Corsika showers. Simulation of the electronics is also in progress. We have also created an initial reconstruction code for treatment of the simulation results and for analysis of data from the first season.

6. DEPLOYMENT

The first IceCube deployment season is the austral summer of 2004/2005. The plan is to deploy up to 4 strings and 4 IceTop stations for a total of 8 tanks. As of December 2004 all eight tanks are deployed, equipped with two DOMs each, filled with water and in the process of freezing. The tanks will be closed for DOM operation in mid-January. Freezing will be completed after the tanks are closed. The entire 80-string, 160-tank IceCube detector is scheduled for installation over the following five polar seasons.

Considering the first season as an engineering run, we expect to verify the operation by measuring coincidence rates between IceTop and deep detector. Spacing between the two tanks at a station is optimized to select small showers by requiring a coincidence between two tanks at the station with no hits in adjacent stations. Such showers correspond to primary cosmic rays with energies of order 10–100 TeV which typically produce single muons in the deep detector. With 4 strings and 8 tanks we expect a coincidence rate of approximately 0.3 Hz for such events. With only four stations, this event sample will be contaminated by large showers that fall outside the 4-station array. In future years, as the array grows, these will be removed and we expect to obtain a fairly clean sample of tagged single muon events which will permit study of the main background in the neutrino telescope. The trajectory will be determined by connecting the hit station with the center of gravity of the deep detector signal.

The threshold for triggering the full 4-station air shower array is approximately 300–500 TeV depending on the primary. With a four-station array we expect 4-station air shower triggers at a rate of approximately 0.2 Hz. The rate for 3-folds is approximately 0.3 Hz. Taking into account the geometry factor for 4 strings instrumented from 1.4 to 2.4 km and separated by 125 m, we expect a coincidence rate between 4-fold air showers and muon bundles inside the 4-string IceCube of approximately 20 per hour.

Acknowledgments I appreciate the contributions of T.K. Gaisser, P. Nießen, D. Seckel and S. Tilav to this presentation.

REFERENCES

1. J. Ahrens et al., New. Astr. Rev., 48, 519 (2004)
2. T.K. Gaisser for the IceCube Collaboration, Proc 28th ICRC (Tsukuba), (Universal Academy Press, T. Kajita & M. Teshima, eds.) p.1117 (2003)
3. J. Ahrens et al., NIM A522, 347 (2004)
4. J. Ahrens et al., Astropart. Phys., 21, 565 (2004)
5. see, e.g., C. Spiering for the IceCube Collaboration, astro-ph/0404090 for a more detailed description.
6. see the structure of data sharing at http://glacier.lbl.gov
7. S. Agostinelli et al., NIM A506, 250 (2003)