An Algorithm for Reconstruction of Cascade-like Events in IceCube

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The IceCube experiment [1, 2] will provide a cubic kilometer of instrumented ice volume at the South Pole for the detection and study of high energy astrophysical neutrinos. This instrumentation will be accomplished by deployment of 80 kilometer-length strings, each containing 60 digital optical modules (DOMs). Each DOM contains a photomultiplier tube (PMT) that detects the Cherenkov light generated in the ice by muons and electrons produced by neutrino interactions that manifest in two interaction channels: tracks and cascades. Tracks come from muons produced in ν_μ charged-current interactions as well as by cosmic ray (atmospheric) muons. Cascades are produced by all flavor neutral-current interactions as well as by ν_e and ν_τ charged-current interactions. A cascade is characterized by nearly isotropic emission of light as distinguished from light emitted at a Cherekov angle along a track.

In IceCube the DOMs, using the analog transient waveform digitizers (ATWDs), provide full waveform sampling and capture up to 4 μs and with a dynamic range over signals produced by 1 to $\sim$ 500 single photoelectrons (SPEs). Longer duration signals (up to 6.4 μs) are sampled at 40 MHz by a fast analog-to-digital converter (FADC). The "Renew" (Reconstruction of Nu E's with Waveforms) is an attempt to reconstruct the position, energy, and direction of the cascade on a DOM-by-DOM basis using this full waveform information.

The idea behind the algorithm as applied to reconstruction of the position of the cascade is straightforward. In the region where the distance between the cascade and a string is greater than the scattering length of light in ice, the width of the waveform is expected to increase linearly with the distance from the cascade (due to scattering) [3]. Once this linear relation is characterized for each DOM from the measured width one can determine the distance to the cascade. Assuming an isotropic emission of light from the cascade, these distances can be used to determine the cascade position $\vec{X}_c$ by minimizing

$$\chi^2 = \sum_{i=1}^{N} \frac{((\vec{X}_i - \vec{X}_c) - R_i)^2}{(\sigma_{R_i})^2} \qquad (1)$$

where the sum is over N doms, $\vec{X}_i$ is the DOM position, R_i is the distance to the cascade as determined from the waveform width, and σ_{R_i} is the uncertainty in this determination.

Development of the algorithm has proceeded using the LED flashers that are contained in each deployed DOM. Twelve flashers are positioned around the circumference of the DOM; each flasher has adjustable brightness and pulse duration. These flashers can provide a cascade "simulation" using real data. The RMS width of the waveforms from the ATWD as a function of distance from the flasher can be seen in Fig. 1.

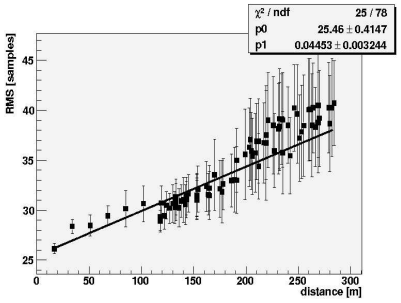

FIG. 1: RMS width of the ATWD waveform as a function of distance from the flashing DOM.

The distribution of reconstructed Z-positions of the flasher from the χ^2 minimization over many flasher runs can be seen in Fig. 2. The true position of the flashing DOM is at 92.0 m, compared with the reconstructed position of 99.0 m. The X and Y positions are reconstructed with similar accuracy and precision. These initial results are encouraging; however much work is still to be done, including use of the FADCs, testing the algorithm with cascade simulation, and development of energy and directional reconstruction.

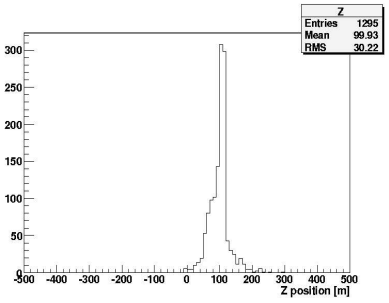

FIG. 2: Reconstructed Z position of the flashing DOM. The true position is 92.0 m.

[1] `http://icecube.wisc.edu`
[2] A. Achterberg *et al.* [IceCube Collaboration], arXiv:astro-ph/0604450.
[3] A. Karle *et al.*, "A Simulation of Photomultiplier Pulses by Electron- and Tau-Neutrino interactions in AMANDA and IceCube," IceCube internal note.