Time calibration and functionality verification of the IceCube instrumentation

D. Chirkin[1], A. Goldschmidt[1], J. Jacobsen, A. Jones[3], S. Klein[1], D. Nygren[2], G. Przybylski[2], R. Stokstad[1],
and the IceCube Collaboration
[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*

The IceCube neutrino observatory at the South Pole will consist of 4800 optical sensors - digital optical modules (DOMs), installed on 80 strings between the depths of 1400 to 2500 meters in the antarctic ice, and 320 sensors deployed on the ice surface directly above the strings. Each of these sensors consists of a 10 in. photomultiplier tube, connected to a waveform-recording digital data acquisition circuit capable of resolving pulses with sub-nanosecond precision and having a dynamic range of at least 250 photoelectrons per 10 ns.

The photon hit events are time-stamped locally with an internal (to each sensor) clock, which has an estimated drift time of $\lesssim 1$ ns/s. All of the DOM clocks are time-calibrated with a special procedure, which involves sending an analog pulse from the surface to the DOM, where this pulse is received, digitized, and recorded. A similar pulse is sent back from the DOM to the surface, where it is, in turn, digitized, and analyzed together with the pulse recorded by the DOM (which is transmitted to the surface digitally after the main “round trip” calibration procedure finishes, fig. 1).

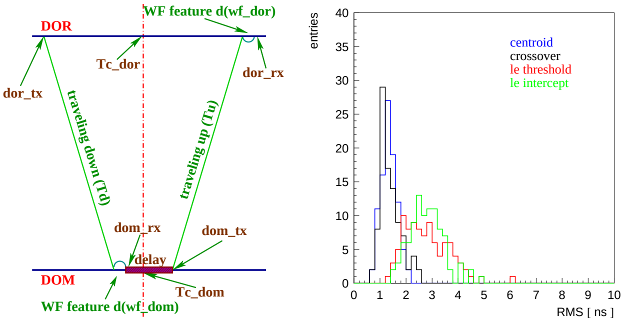

FIG. 1: Time calibration diagram (left). Roundtrip time resolution with four time calibration algorithms (right).

We analyzed data collected during the pre-deployment testing of the DOMs at facilities in Wisconsin, Germany, and Sweden. Several time calibration algorithms were developed and extensively tested. We also developed a suite of error-correction algorithms, which can recover from all error conditions that we observed (from temporary failure to acquire a valid GPS clock timestamp to mistakenly triggering on noise instead of a time calibration pulse).

IceCube DOMs are capable of recording detailed traces of photoelectrons and resolving multiple photons received within a window of 6.4 μs. A typical waveform captured by an IceCube DOM is shown in fig. 2. The waveforms are described very well by our waveform decomposition (feature-extraction) procedure, which yields single photon hit times.

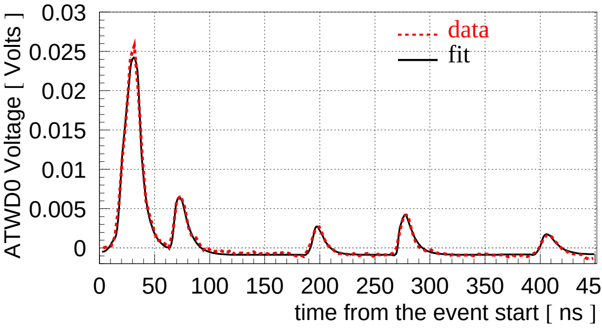

FIG. 2: Reconstruction of single photoelectron hits in the waveform data acquired by DOMs.

In laboratory tests, with the laser as a light source connected to large groups of DOMs (up to 92 DOMs) via optical fibers of equal length, we measured the arrival times of the photons recorded by the DOMs correlated with the laser signal. Using the developed time calibration and waveform reconstruction techniques we concluded that reaching a time resolution of ~ 2.0 ns was possible (fig. 3).

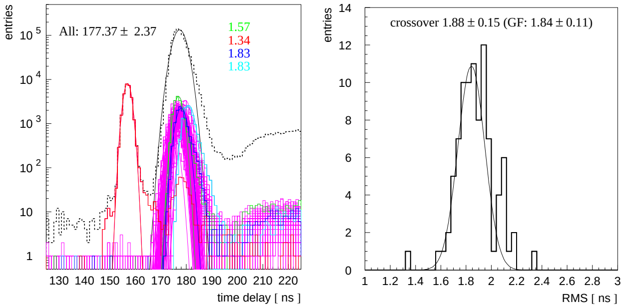

FIG. 3: Hit time distribution in 92 DOMs correlated with the laser pulse at t=0 (left). Laser time resolution with 92 DOMs (right).

Computer code was developed that reads event data, applies time and other types of calibrations (amplitude, charge, etc.), feature-extracts waveforms acquired by DOMs, and produces a time-sorted list of photon arrival times as the output. The code is available as a stand-alone software program, and as a suite of plug-in modules for the standard IceCube software.