Event reconstruction in IceCube based on direct event re-simulation

The IceCube collaboration

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Introduction

IceCube is a cubic-kilometer neutrino detector installed in the ice at the geographic South Pole between depths of 1450 m and 2450 m. The ice surrounding the detector does not have the azimuthal symmetry previously ascribed to it (see [1], [2]), which significantly complicates tabulation of the probability density function (PDF) needed for likelihood-based event reconstructions. On the other hand it is relatively easy to add a description of almost any conceivable detail to the detector simulation. We present a new method of event reconstruction in IceCube that searches through an extensive set of re-simulated events to find the best match to data. Several search methods, including the stochastic approximation [4] and localized random search, were tried. We demonstrate the capability of the new method to reconstruct cascade-like as well as track-like events. While significantly slower than the parametrized PDF-based reconstructions, the new method is able to take into account all of the nuances present in the simulation that are sometimes omitted from the PDF-based description of data.

Cascade reconstruction

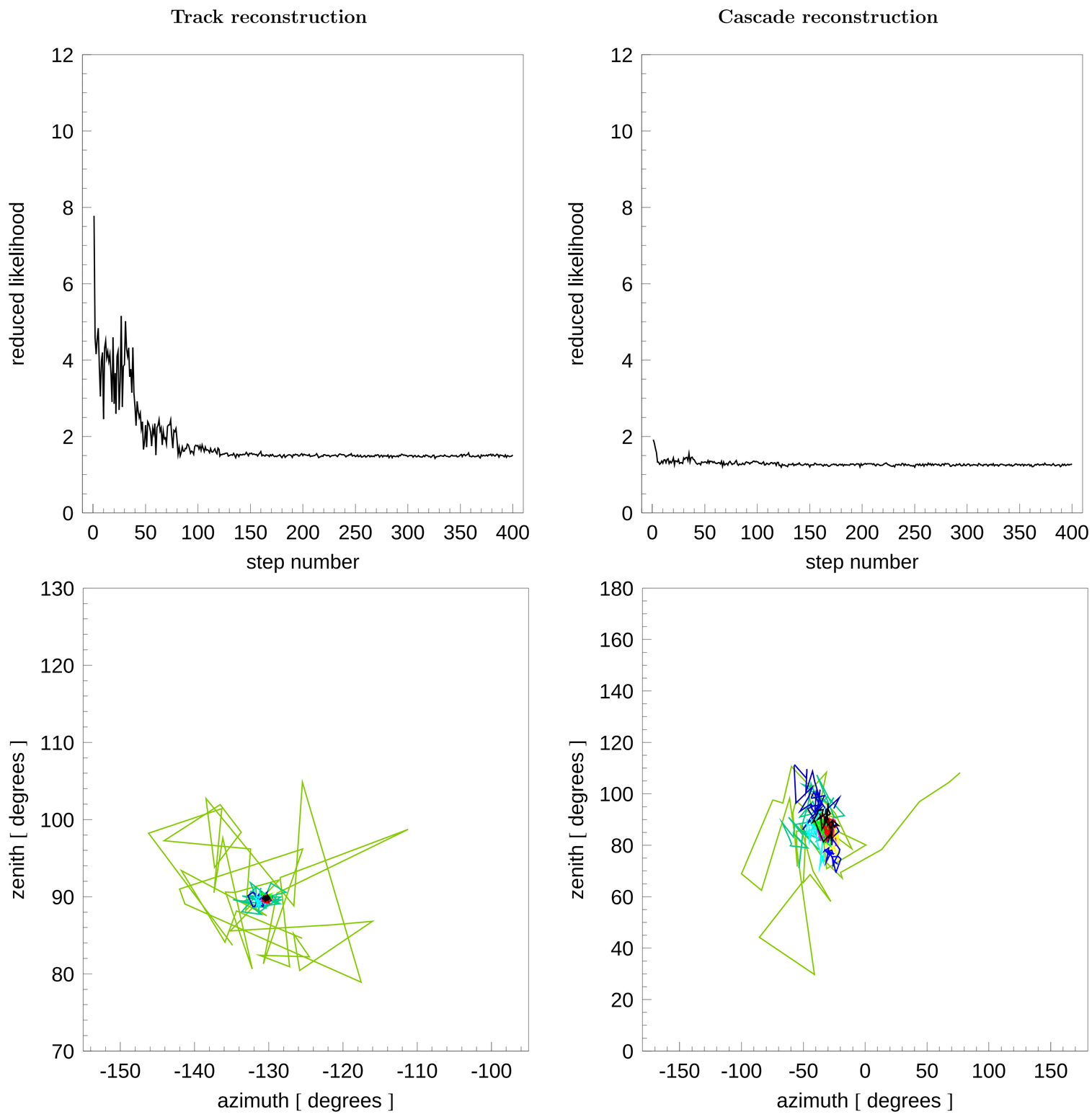
1. Start with some cascade parameters: energy (E), time and position (t_0, x, y, z), and direction (θ, ϕ).
2. Propose new parameters: x', y', z', θ', ϕ' (in the vicinity of x, y, z, θ, ϕ). Simulate cascade with energy E at time t_0 at these coordinates. Scale energy and shift around in time to get the best match to data: this yields new E' and t_0'.
3. Simulate cascade with parameters E', t_0', x', y', z', θ', ϕ' and compare to data.
4. Repeat steps 2 and 3 a few times and pick the cascade parameters that result in simulation that is closest to data. The comparison is performed with a method described in [3] using the individual waveforms in the DOMs.
5. Every few iterations of steps 1 through 4 update the parameters of the proposal distribution that best describe the last few iterations.

Track reconstruction

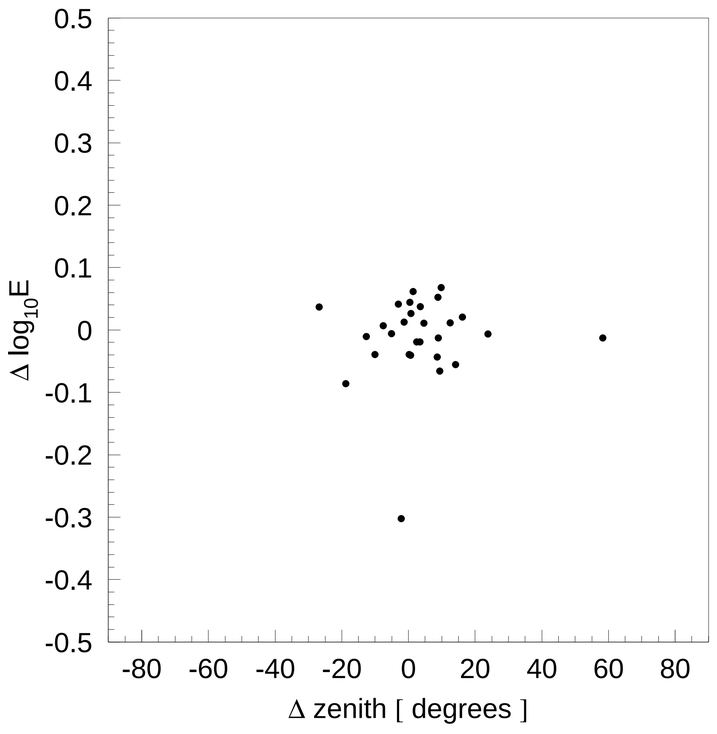
For track reconstruction instead of simulating a single cascade at coordinates x, y, z, θ, ϕ, several cascades are simulated at regular intervals along the line defined by these coordinates. These cascades are weighted and combined to get the best match to data, and the event is re-simulated with the best-fit values of weights.

Estimating uncertainties

Statistical uncertainties can be estimated from the "spread" of the reconstructed parameters, or, more rigorously, with an Approximate Bayesian Computation (ABC) method as in [5].



Top: Reduced log likelihood (log likelihood divided by the number of degrees of freedom) after each of the 400 iterations. Some stepping structure evident in the plot is related to the fact that the parameters of the proposal distribution are updated every 40 steps. Bottom: Convergence of the best fit direction: results of successive iterations are connected by line segments for visual clarity. Shown to the left is a reconstruction of a well-defined track, and results in the method wandering around in a very narrow range of zenith and azimuth. Shown to the right is a reconstruction of a cascade, with the method stepping through a wider range of zenith and azimuth. Each reconstruction takes about 2 days on a computer with 5 GPUs. Most of the calculation time is spent on the GPUs, which are used to run the photon propagation simulation.



Comparison between the results of the reconstruction method described in this report with the main reconstruction used in [6] for the 28 high energy events of [6].

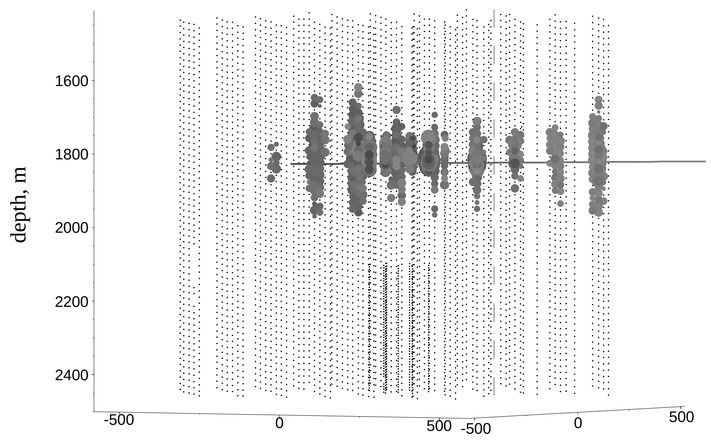
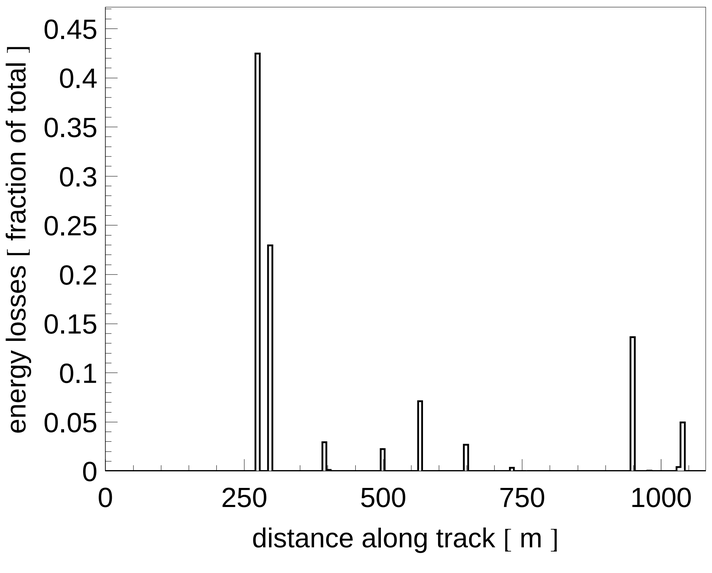


Illustration of a track-like event, one of the 28 high energy events of [6].



Reconstructed energy losses along the best-fit track of a track-like event shown above (one of the 28 high energy events of [6]). The losses are normalized to the total energy lost in the volume of the detector.

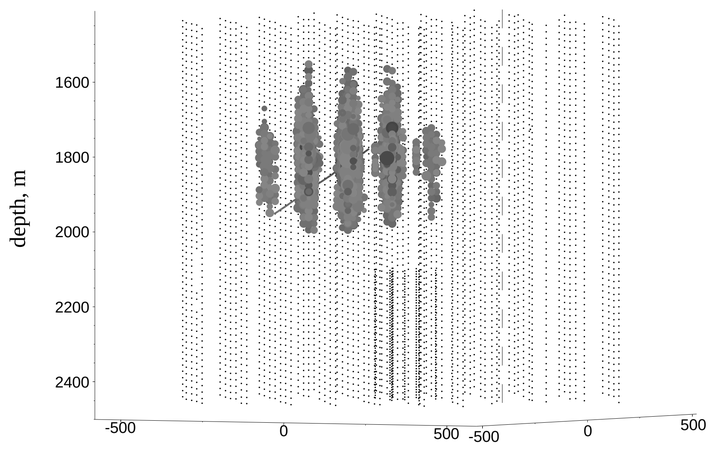
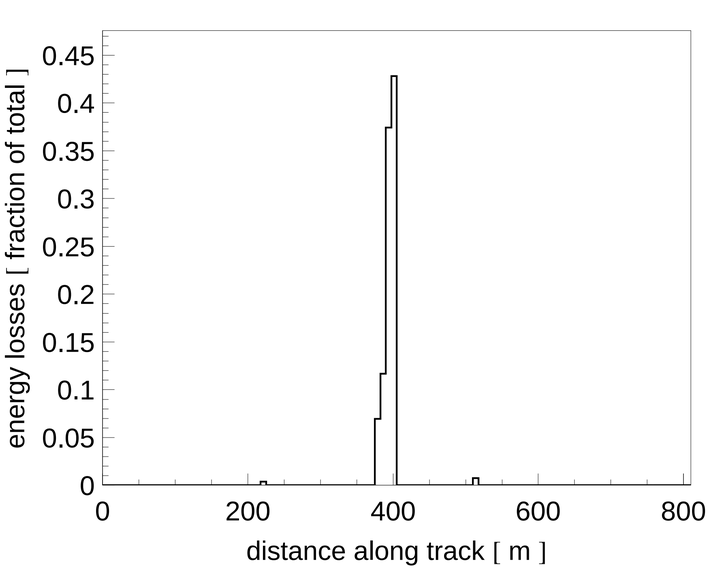


Illustration of a cascade-like event, one of the 28 high energy events of [6].



Reconstructed energy losses along the best-fit track of a cascade-like event shown above (one of the 28 high energy events of [6]). The losses are normalized to the total energy lost in the volume of the detector.

References

[1] M. Aartsen et al., NIM-A, 711 (2013) 73, arXiv:1301.5361.

[2] IceCube Coll., paper 0580 these proceedings.

[3] D. Chirkin, arXiv:1304.0735.

[4] http://en.wikipedia.org/wiki/Simultaneous_perturbation_stochastic_approximation

[5] P. Marjoram et al., PNAS, 100-26 (2003) 15324.

[6] IceCube Coll., paper 0650, these proceedings.