Direction Reconstruction of IceCube Neutrino Events with Millipede

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Abstract

To conduct neutrino astronomy with the IceCube detector at the South Pole, the direction of the incoming neutrino must be known accurately to within one degree. When a muon neutrino interacts in the ice at the South Pole, it produces a muon which produces Cherenkov light as it travels through the detector. Using the direction of the muon, the direction of the original neutrino can be determined and used for astronomy. Millipede is an algorithm used to numerically determine the properties of the muon track by making predictions about the light signal seen in the detector and checking how this compares to the observed signal using a likelihood maximisation.

With this algorithm, the muon track direction is expected to be resolved to within one degree. However, problems have been encountered with simulated muons where millipede finds a direction which is very different from the true direction or millipede fails to reconstruct the event. After analysis of the likelihood grid scans of some of these events, the problems with millipede seem to be due to the minimiser finding a local minimum in the likelihood surface rather than the desired global minimum. These local minima arise from fluctuations in the likelihood surface. These fluctuations were observed in all dimensions including track position.

The source of these fluctuations was investigated in simulations by first using millipede's predictions as the input waveforms. Poisson fluctuations were then added and produced a less accurate likelihood scan with more fluctuations. Finally, the effect of photomultiplier after-pulses was investigated by removing all signal more than 3μs after the median time. Removing this signal dramatically improves some of the likelihood scans but many show no change.

After this analysis, the main factors causing these fluctuations in the likelihood surface seem to be a combination of bin-wise fluctuations in the waveform and the presence of after-pulses which are not taken into account by millipede. The after-pulses and other late light seem to be the dominant cause across a range of energies, though generally high energy events, while the fluctuations are the dominant cause for the low energy events.

Declaration of Originality

I, Alexander Wallace, certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Contents