Improving Astrophysical Tau Neutrino Identification with IceCube Waveforms

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ABSTRACT

IceCube has discovered a diffuse atmospheric neutrino flux. The significant number of tau neutrinos expected due to neutrino mixing from astronomical distances have yet to be observed. Since high-energy (>100 TeV) tau neutrino production in the Earth’s atmosphere is negligible, a tau neutrino detection confirms the astrophysical origin of the observed neutrino signal and helps improve the precise measurement of atmospheric neutrino flavor ratios. A tau neutrino undergoing charged current interaction in IceCube could produce double pulses in the sensor waveforms when the created tau reaches decay lengths of more than a few meters. Two methods improving the double pulse tau neutrino filter signal efficiency by 50%, while maintaining similar or lower background rates, are shown. The performance of these methods and the resulting sensitivity to the atmospheric tau neutrino flux with 8 years of IceCube data will be presented.

ICECUBE WAVEFORMS

- IceCube is a cubic-kilometer high energy neutrino observatory at the South Pole.
- It contains 5,160 digital optical modules (DOM) on 86 strings.
- Photomultiplier Tube (PMT) waveforms are digitized in ice [1].
- Analog Transient Waveform Digitizer (ATWD) waveform:
  - three channels with (16x, 2x, 0.25x) of nominal gain
  - time window: 128 samples with 3.3 ms/sample

SIGNAL: τv DOUBLE PULSE EVENT

- A high energy ντ charged current (CC) interaction in the ice produces two showers – one from the CC interaction vertex and the other from the tau lepton decay depicted in Fig. 2.
- To produce a second shower the t has to decay either into an electron or hadrons [2].
- Two showers might manifest themselves as double pulses (DP) in the waveforms of one or more DOMs, given sufficient time separation and suitable spatial orientation.

DOUBLE PULSE IDENTIFICATION

- A previous IceCube analysis created a double pulse identification method shown on the right [3].
- To separate ντ double pulse events and single pulse events such as ντ CC, shown in Fig. 3, large rising and falling edge thresholds were required.
- These large thresholds also reduced the observable ντ events, which yielded 0.32 expected events per year assuming the spectrum presented in [4].

MACHINE LEARNING

- Improve selection efficiency of ντ double pulse events with the application of machine learning.
- In addition, new features are added to characterize the statistical properties, smoothness, and consistence with a single pulse waveform.
- The performance of the random forest is shown in Fig. 5. Cutting at a classification score of 0.2 gives a purity of 97%, and an increase in signal rate by ~50%.

LOCAL COINCIDENCE

- The local coincidence (LC) method requires nearest or next-to-nearest DOM waveforms to both pass the DP threshold.
- Adding LC to the double pulse identification allows lower rising and falling edge thresholds, see table right for a comparison.
- The lowered LC thresholds keep a similar single pulse background as [3] and increases the signal rate by ~50%. Effective areas comparison shown in Fig. 4.

CONCLUSION AND OUTLOOK

The direct observation of a ντ interaction in IceCube will be another confirmation of atmospheric neutrinos and can shed light on potential new physics. IceCube has yet to identify a ντ interaction, but the chance increases with more observation time and improved methods as presented here. These improved double pulse identification methods use more sophisticated techniques and additional information than the previous method that allows IceCube to access double cascade ντ events at lower energies and previously unexplored phase spaces and thus increase the sensitivity to measure the flux of astrophysical ντ.

REFERENCES