

## Tau Neutrino Identification at IceCube for Unitary Violation Tests

*Friday, 11 February 2022 11:45 (15 minutes)*

The largest tau neutrino dataset to date is IceCube's atmospheric tau neutrino appearance dataset containing  $> 1,000$  tau neutrino and antineutrino events as determined by a fit to a standard three-flavor oscillation framework. On an event-by-event basis, however, it is impossible to know that any given event is a tau neutrino as they are identical to either an electron neutrino charged-current event or a neutral-current interaction of any active flavor. Nonetheless, we conclusively show that, using only the cascade sample even without knowledge of the oscillation parameters and without assuming that the lepton mixing matrix is unitary, tau neutrino identification is still possible and there is no viable scenario in which all of the tau neutrino candidates are actually electron neutrinos. This is primarily due to the matter effect and the tau lepton production threshold, as well as the fact that tau neutrinos are systematically reconstructed at a lower energy than electron neutrinos due to one or more outgoing neutrinos. This conclusively shows that it is possible for an atmospheric neutrino oscillation experiment to confirm that  $U_{\tau 1}$ ,  $U_{\tau 2}$ , and  $U_{\tau 3}$  are not all zero even with limited particle identification.

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**Session Classification:** Parallel Session 2: Astrophysical Neutrinos