PROCEEDINGS OF SCIENCE

TAMBO: Searching for Astrophysical Tau Neutrinos in the Andes

Pavel Zhelnin,[a,*] **Ibrahim Safa,**[b] **Andres Romero-Wolf**[c] **and Carlos A. Argüelles**[a]

[a] *Department of Physics & Laboratory for Particle Physics and Cosmology, Harvard University, 35 Oxford St., Cambridge, MA 02138, USA*

[b] *Department of Physics & Wisconsin IceCube Particle Astrophysics Center, University of Wisconsin-Madison, Madison, WI 53706, USA*

[c] *Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, USA*

E-mail: pzhelnin@g.harvard.edu

IceCube's discovery of astrophysical neutrinos, and subsequent characterization of their energy spectrum up to a few PeV, has provided a new window into the high-energy Universe. However, many opportunities for discovery remain; low sample sizes still plague measurements of astrophysical neutrinos above 1 PeV, and flavor measurements are challenging due to the difficulty in differentiating tau events from other flavors. A series of next-generation experiments aim to provide a novel aperture into the under-explored component of the high-energy neutrino spectrum. Among them is TAMBO (Tau Air-Shower Mountain-Based Observatory), a proposed water-Cherenkov detector set on a valley-side in the high Peruvian Andes. Utilizing the unique geometry of the Colca alley, TAMBO is situated to produce a high-purity sample of 1–100 PeV astrophysical tau neutrino events. In this contribution, I will discuss recent progress and highlight the prospects and challenges of astrophysical tau neutrino detection in the next generation of neutrino experiments.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

https://pos.sissa.it/

PoS(ICHEP2022)566

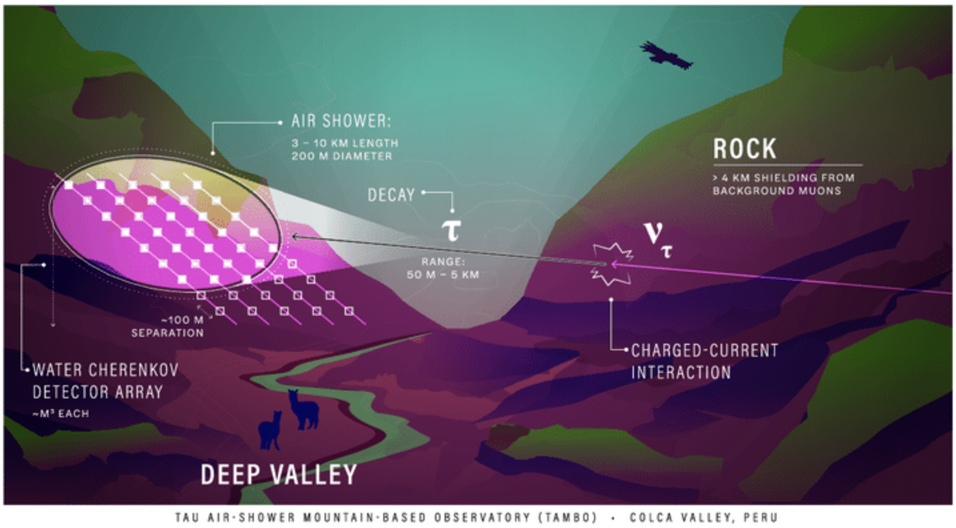

Figure 1: An artistic rendition of TAMBO which will be located in the Colca Valley, Peru to take advantage of the unique geography there. Courtesy of Jack Pairin.

1. Introduction

With the 2013 discovery of a neutrino astrophysical flux, neutrinos became the latest member of the multi-messenger astronomy family. The recent coincident observation of neutrinos from the TXS 0506+056 blazar provides some of the first evidence for an astrophysical neutrino source. While both these advancements mark significant contributions to neutrino astronomy much remains to be discovered. Our current energy spectrum characterization is limited at energies greater than several PeV and tau flavor identification remains challenging due to morphological similarities with electron neutrinos. To address these limitations, the Tau Air Shower Mountain-Based Observatory (TAMBO) has been proposed as a next-generation deep valley Earth-Skimming (EAS) experiment.

EAS experiments' main signal is lepton decay produced via EAS neutrino interactions with Earth. When a traversing neutrino interacts inside the Earth it can produce a charged lepton via a charged current interaction. For tau neutrinos in charged current interactions, the parent neutrino can transfer approximately 80% of its energy to its daughter tau lepton. In the 1 - 100 PeV regime, these tau leptons then have a corresponding decay length of 50 m - 5 km. If the original interaction occurs within this distance from an EAS experiment then detection of the decay products is possible. A deep valley with a separation between valley sides comparable to the length scale of 10 km would be highly sensitive to the extensive air showers produced by tau decay. Furthermore, the relative geometric acceptance of a valley is increased relative to flat ground experiment for EAS experiments. The Colca Valley in Peru was selected as the ideal location that was narrow enough to catch tau decay air showers while maximizing the depth to capture more EAS neutrinos.

2. A special note on astrophysical tau neutrino backgrounds

Astrophysical tau neutrinos were long thought to be background-less. Atmospheric production of tau neutrinos is negligible and standard oscillations from muon neutrino to tau neutrino at energies greater than 100 GeV are heavily suppressed. Therefore, if a tau neutrino is observed then dogma said it is astrophysical. However, a new irreducible background has recently been unveiled relating to tau appearance from muon and electron neutrino interactions inside the Earth. Using production mechanisms outlined in figure 1, secondary tau neutrinos can be produced. At energies of 1 PeV and greater this background contributes 1-10% to the astrophysical tau neutrino signal.

3. Backgrounds for TAMBO

We have considered four main background sources. Random coincidences of small showers and vertical muons mimicking tau air showers is the first background considered. We expect a rate of about kHz for the proposed TAMBO array size of these coincident showers/vertical muons. Strategies to mitigate this background include investigating trigger designs to create a summed signal requirement. This trigger will activate only when multiple detectors register hits thereby ideally cutting smaller showers.

Another background source comes from directional reconstruction uncertainty of cosmic ray showers near the sky-mountain boundary. Air showers can be mis-classified as coming from the mountain if the angular uncertainty is great enough. To eliminate this a zenith cut will be made so that any signal coming from 8 degrees above the sky-mountain boundary is cut.

A third background source comes from high-energy muons produced by cosmic ray air showers at an angle similar to EAS neutrinos. These muons can propagate through rock and emerge producing an air shower that would be difficult to distinguish from a tau decay air shower. However this background is suppressed by the previous cosmic ray air shower cut as high-energy muons experience large stochastic losses as they traverse rock.

The final source comes from muons produced in muon neutrino interactions in rock. The range of the muon is orders of magnitude larger than the tau meaning that the rate of muons leaving the mountainside is greater than that of tau particles. However, muon decay is very unlikely due to it's long lifetime relative to the tau particle. Yet there is still a small probability that an energetic muon can produce an air shower mimicking a tau air shower. Bounds on this background are currently being studied with detailed simulations.

4. Observatory Design

The approach was to identify a deep valley that would allow for the measurement of EAS neutrinos and then optimize array design to achieve desired sensitivity while minimizing number of detectors. TAMBO plans on using an array of 22,000 1 meter-cubed water-Cherenkov tanks spaced 150 meters apart arranged in a grid fashion. The 150 meter spacing optimizes detector density while maintaining the pointing resolution requirement of less than 1°. A co-requirement of these detectors to achieve this pointing resolution is that they have order nanosecond time uncertainty. Fortunately, modern photo-multiplier tubes (PMTs) have the necessary resolution and are commercially available.

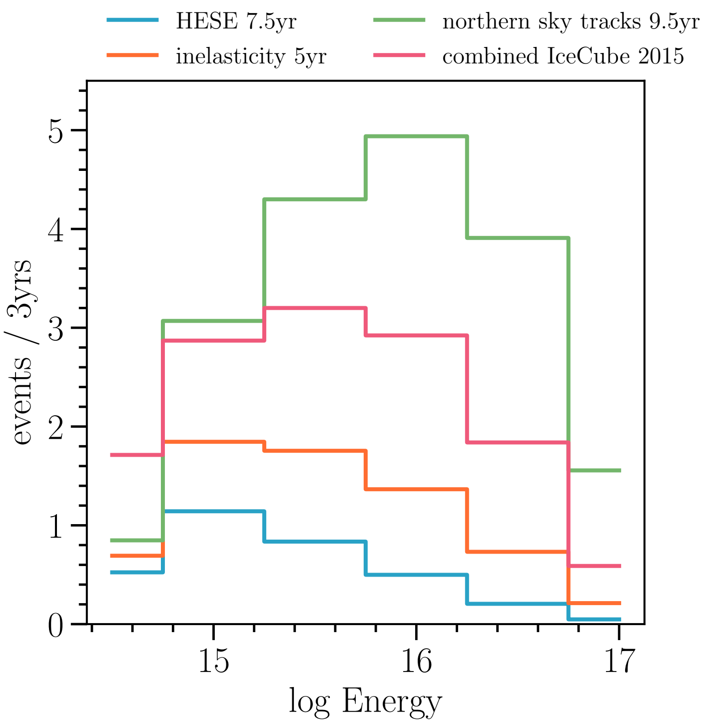

Figure 2: The expected number of astrophysical tau neutrinos in 3 years given several different astrophysical flux assumptions. The combined flux assumption predicts 13 events per 3 years of operation with a peak at 3 PeV.

TAMBO has the advantage that no new technologies need to be developed for its implementation. Water tank detectors with PMTs have been in operation since the 1960s. Also, the Colca Valley location has a major advantage in that it is well populated and has good access to the necessary infrastructure to sustain TAMBO.

5. Current Work

Current work is focusing on finishing a full TAMBO MC package, with updated geometry. Previous estimates of expected tau neutrino counts and astrophysical fluxes have been generated using a simple linear approximation of the Colca Valley, as seen in figure 3. We plan to update expected number of tau neutrinos and run simulations on backgrounds.

6. Conclusion

TAMBO aims to unambiguously achieve greater astrophysical tau neutrino sensitivity in the 1-100 PeV range. Flavor discrimination in the astrophysical regime allows for very fine tuning of Beyond the Standard Model (BSM) scenarios that could affect neutrinos over very long baselines.

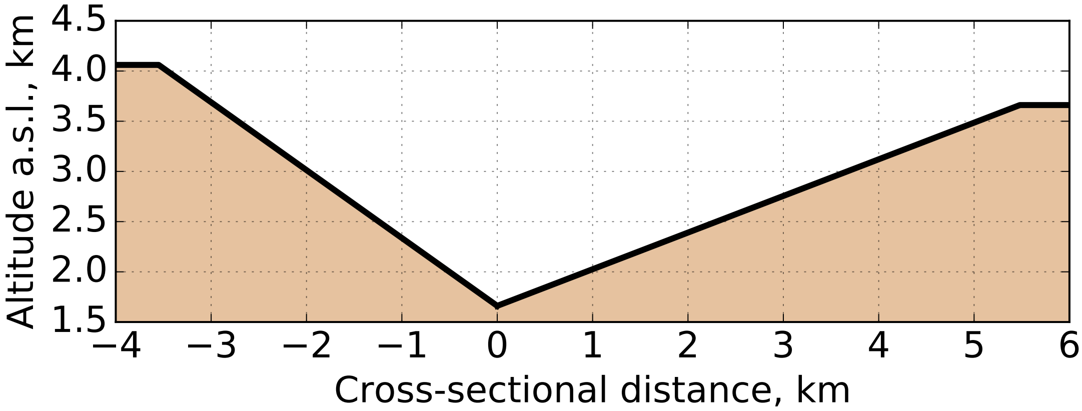

Figure 3: Geometrical model used to produce initial estimates for detector acceptance and expected tau neutrino count. Current work is being done on producing a more accurate geometrical model. Sourced from [1]

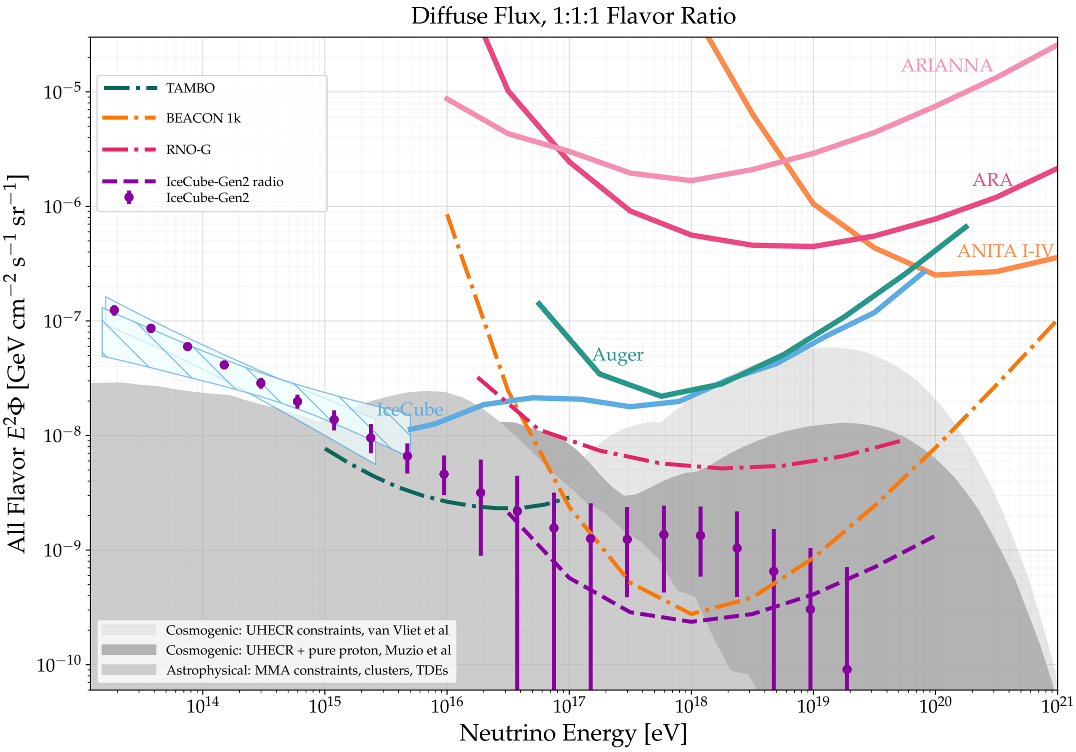

Figure 4: The expected differential 90% C.L. sensitivities for a variety of experiments to an all-flavor diffuse neutrino flux computed in decade-wide energy bins and assuming a ten-year integration. The measurements and sensitivities are compared with several astrophysical neutrino models. Sourced from [2]

References

[1] Romero-Wolf et al. An andean deep-valley detector for high-energy tau neutrinos, 2020.

[2] Ackermann et al. High-energy and ultra-high-energy neutrinos, 2022.