TAMBO: Searching for Tau Neutrinos in the Peruvian Andes

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Abstract

TAMBO is a planned next-generation neutrino observatory sensitive to 1–100 PeV Earth-skimming tau neutrinos. This tau neutrino specificity will provide a high-purity sample of astrophysical neutrinos whose locations on the sky can then be used to improve the sensitivities of all-flavor neutrino observatories. The observatory will be located in a deep canyon and will comprise an array of water-Cherenkov and plastic scintillator air-shower detectors. In this proceeding, I will summarize the current status of the updated TAMBO simulation package, which is currently being used for detector optimization and reconstruction studies.

1 Introduction

It is now just over ten years since IceCube's discovery of a diffuse flux of astrophysical neutrinos [1], which proved that neutrinos can serve as a unique probe of the Universe's most energetic processes. Since then, IceCube has discovered a handful of point sources of neutrino emission [2, 3] and observed our own galaxy's neutrino signature [4]. At the same time, IceCube's observations have raised several urgent questions in the field of neutrino astrophysics. It is unknown if extragalactic neutrino sources continue to accelerate particles to energies above a few PeV due to IceCube's low statistics at these energies. Additionally, through IceCube has been operating for over a decade, only a handful of neutrino sources have been identified. Where are the remaining point sources that comprise the observed diffuse neutrino flux? Answering these questions is the goal of next-generation neutrino telescopes.

Given IceCube's successes, it is no surprise that there are several water-Cherenkov neutrino telescopes either in development [5] or under construction [6, 7]. These IceCube-like observatories will increase both the sky coverage of neutrino telescopes, as well as the total number of observed astrophysical neutrinos at energies up to a few PeV. These experiments are often referred to as high-energy (HE) neutrino observatories. In addition, there are several next-generation neutrino telescopes under development that aim to observe the radio signal produced by neutrinos. This approach is most sensitive to neutrinos with energies $\gtrsim$100 PeV, and are thus termed ultra-high-energy (UHE) neutrino observatories. Interestingly, the fact that ice- and water-Cherenkov neutrino telescopes are most sensitive below a few PeV, coupled with the fact that radio telescopes are most sensitive above $\sim$100 PeV leads to a gap in sensitivity from roughly 1–100 PeV. Bridging this gap requires the development of a new detection technique.

TAMBO, the Tau Air Shower Mountain-Based Observatory, is a planned next-generation neutrino telescope that aims to bridge the gap between HE and UHE neutrino observatories by detecting Earth-skimming tau neutrinos with energies in the range of 1–100 PeV. This will be achieved by detecting the air-shower signature unique to tau neutrinos. Additionally, this tau-neutrino specificity enables a low-background observation of astrophysical tau neutrinos, enhancing the sensitivity of all-flavor neutrino telescopes to point sources. In this proceeding, we present an overview of the TAMBO observatory and give an update on its current status.

2 Observatory Design

TAMBO is a deep-valley neutrino detector similar to that first proposed by Fargion *et al.* in Ref. [8]. TAMBO's principle of operation relies on observing the air shower produced upon the decay of a tau lepton, which itself is produced by the charged current interaction of a tau neutrino with rock surrounding the canyon. This process is outlined in Fig. 1. The fact that Earth is opaque to neutrinos with energies in the 1–100 PeV energy range necessitates searching for Earth-skimming neutrinos. Previously, the Piere Auger observatory performed a search for such showers produced by Earth-skimming tau neutrinos [9]; however, the sensitivity of this search was limited by the fact that the plane of the air shower array was relatively orthogonal to the shower front of the incoming tau-induced shower. Other air shower arrays designed to observe cosmic ray air showers face similar difficulties.

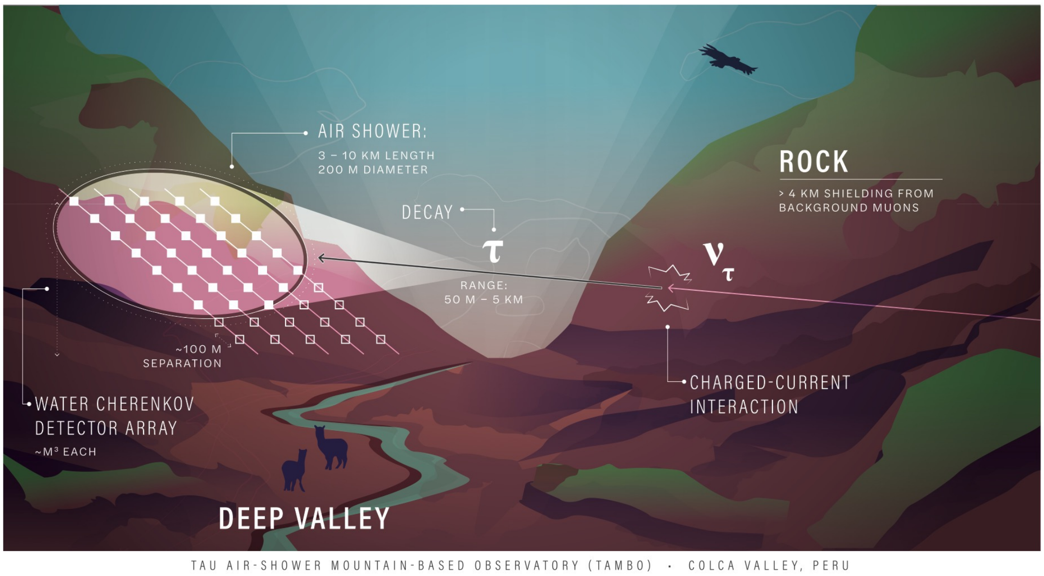


Figure 1: Visual overview of TAMBO's neutrino detection concept. Figure taken from Ref. [10].

Siting TAMBO in a deep canyon helps to overcome this challenge in two ways. First, because TAMBO will be located on a slanted surface, the array presents a relatively large solid angle to incoming showers from Earth-skimming tau neutrinos. Second, the opposite canyon face will also serve as a target for charged current tau neutrino interactions, enabling the observation of neutrinos several degrees above the horizon. This increased acceptance not only increases the number of neutrinos TAMBO will observe, but also increases its sky coverage.

3 Simulation Development

The initial investigation into the TAMBO observatory discussed in Ref. [11] utilized a preliminary version of the TAMBO simulation software package. While this enabled an initial study of the expected event rates along with detector optimization studies, a number of simplifying assumptions were made in this simulation. These included not accounting for the effects of tau regeneration, a parameterized approximation of the air shower physics, and a simplified canyon geometry. Here, we briefly describe how our updated simulation removes these simplifications to achieve a more physically precise picture.

As the Earth is relatively opaque to neutrinos in the 1–100 PeV energy range, it is common for neutrinos to undergo charged current interactions within the Earth, creating charged leptons. While electrons and muons at these energies quickly lose energy within the Earth, the timescale of tau energy losses is relatively large compared with the lifetime of the tau. Thus, tau neutrinos that undergo charged current interactions in the Earth are still able to reach our detector with an appreciable fraction of their initial energy [12]. This process, known as tau regeneration, is accounted for in our updated simulation via the TauRunner [13] package, and its impact can be seen in Fig. 2. Broadly speaking, the inclusion of tau neutrinos created from tau regeneration increases TAMBO's expected event rate compared with predictions from our preliminary simulation.

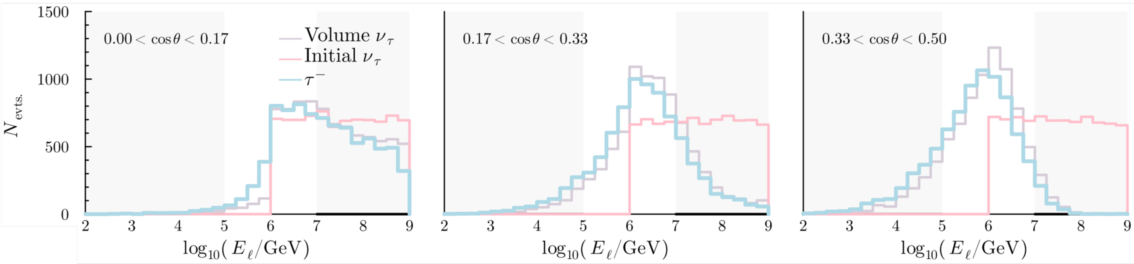
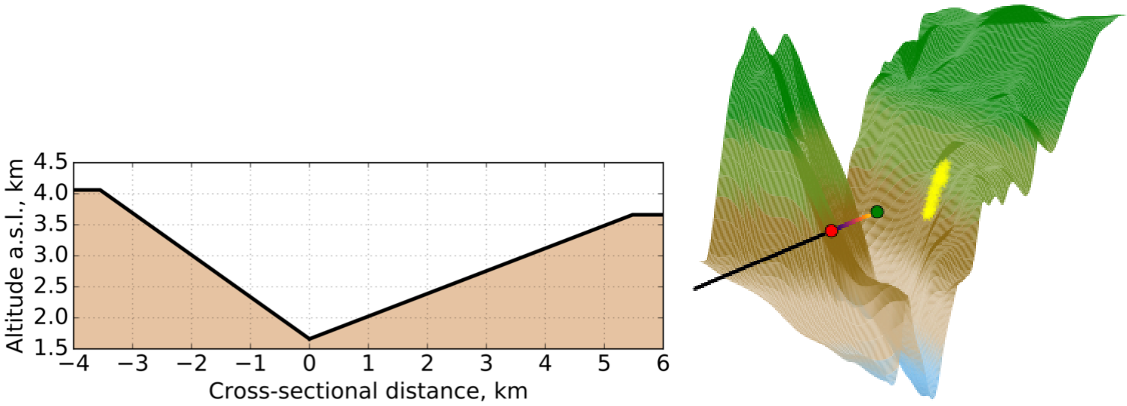


Figure 2: Impact of tau regeneration on energy distributions at various zenith angles. Initial ν_τ is the initial energy distribution of the astrophysical neutrinos, Volume ν_τ is the energy of the ν_τ when it arrives at a region of the Earth close enough to the canyon to produce a detectable shower, and τ^- is the energy of such a tau lepton. Tau regeneration has the greatest impact on the energy spectrum when the greatest amount of earth is traversed by the neutrino. Figure taken from Ref. [14].

While the preliminary version of our simulation made use of a parameterized air shower model for computational efficiency, our updated simulation performs a full air shower simulation using CORSIKA8. The resultant particle-level information allows us to perform more detailed detector optimization and energy reconstruction studies that are currently underway. Practically speaking, the use of CORSIKA8 was necessary because of the need to simulate showers that are both up-going and that intersect an inclined observation plane, which are not together supported by earlier versions of CORSIKA.

Lastly, the current version of our simulation includes a detailed geographic model of a candidate TAMBO site in the Colca Canyon. Previously, a simplified geometry was used that approximated the two canyon faces as smooth planes. The two simulation geometries are displayed in Fig. 3.

A more complete description of the TAMBO simulation software can be found in Ref. [14] and a full description will be presented in an upcoming publication.



(a) (b)

Figure 3: Simulated TAMBO canyon geometries. Left panel taken from Ref. [11].

4 Conclusion

TAMBO is a planned neutrino observatory that will bridge the gap between next-generation high-energy and ultra-high-energy neutrino telescopes. Additionally, by collecting a high-purity sample of astrophysical tau neutrinos, TAMBO will increase the sensitivity of all-flavor observatories to neutrino point sources. As a first step in realizing the observatory, we have made several improvements to the TAMBO simulation package, which have enabled more detailed detector optimization and energy reconstruction studies that are currently underway.

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