Benefits of Looking for Coincident Events, Taus, and Muons with the Askaryan Radio Array

Authors: Abby Bishop, Austin Cummings, Ryan Krebs, William Luszczak for the ARA Collaboration

ASKARYAN RADIO ARRAY

25% of ultra-high energy neutrino observations

simulated for our in-ice, neutrino detector aren't from initial neutrino cascades, they

are via cascades from secondary leptons, such as muon tracks and tau decays.

Motivation

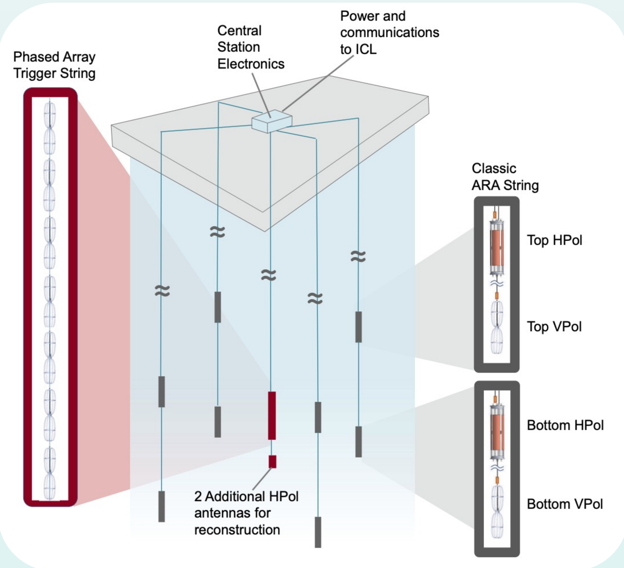
By not simulating outgoing muons and taus from ultra-high energy (energy ≥ 10^{16} eV) charged current neutrino interactions, **we have underestimated our detector's sensitivity**. Historically, muons and taus were thought to be rarely observed and were left out of simulations. Same for events that trigger more than one station.

But additional observations of one or more cascades leads to **improved event reconstruction**. This becomes especially important as in-ice ultra-high energy detectors grow in size and performance.

The Askaryan Radio Array (ARA)

South Pole detector with 5 Stations in a hexagonal grid and 2km spacing (purple squares, shown right), each with 8 horizontally and 8 vertically polarized radio antennas installed 100 or 200 meters in ice. Our fifth station has a Phased Array as well, made of 7 tightly-spaced vertically polarized radio antennas. [1]

ARA is analyzing 24 station-years of data taken from 2012 to 2022 and we want to know if we should look for muons and taus in our data set.



Using simulated effective areas and the 2010 Kotera et al Star Formation Rate flux model with an E_{max} of $10^{21.5}$ eV, **we expect to find 2.09 events in 25 station-years of data**. [2]

Common and interesting event topologies are described below and illustrated right.

1: Classic Neutrino Events

These are events where an initial cascade from a primary neutrino triggers ARA.

Expected Events in 25 st-yrs: 1.56 (75% of total)

2: Muon & Tau Events

These events involve triggered cascades from secondary muons and tau. The prevalence of these events supports similar results from a 2020 study [3].

Expected Events in 25 st-yrs: 0.52 (25% of total)

3: Multi-Cascade Events

Multi-cascade events occur when more than one cascade from a single event triggers ARA. Typically, due to charged lepton tracks or an initial cascade followed by a cascade from a muon or tau.

Expected Events in 25 st-yrs: 0.17 (8% of total)

4: Multi-station Events

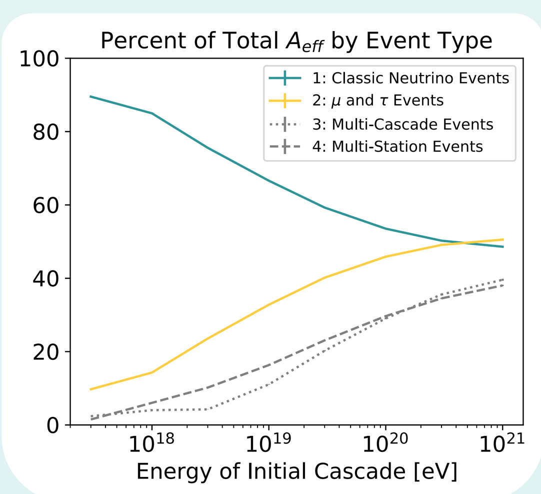
4a: Multi-station events where a single neutrino initial cascade triggers more than one detector.

Expected Events in 25 st-yrs: 0.16 (8% of total)

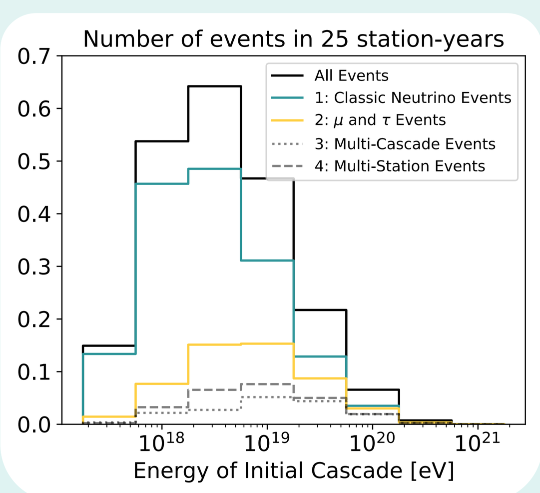
4b: Multi-station events where muon and tau cascades are involved. For example, a tau decay that triggers two stations, or multiple stochastic losses from a muon track that trigger two stations (illustrated, right).

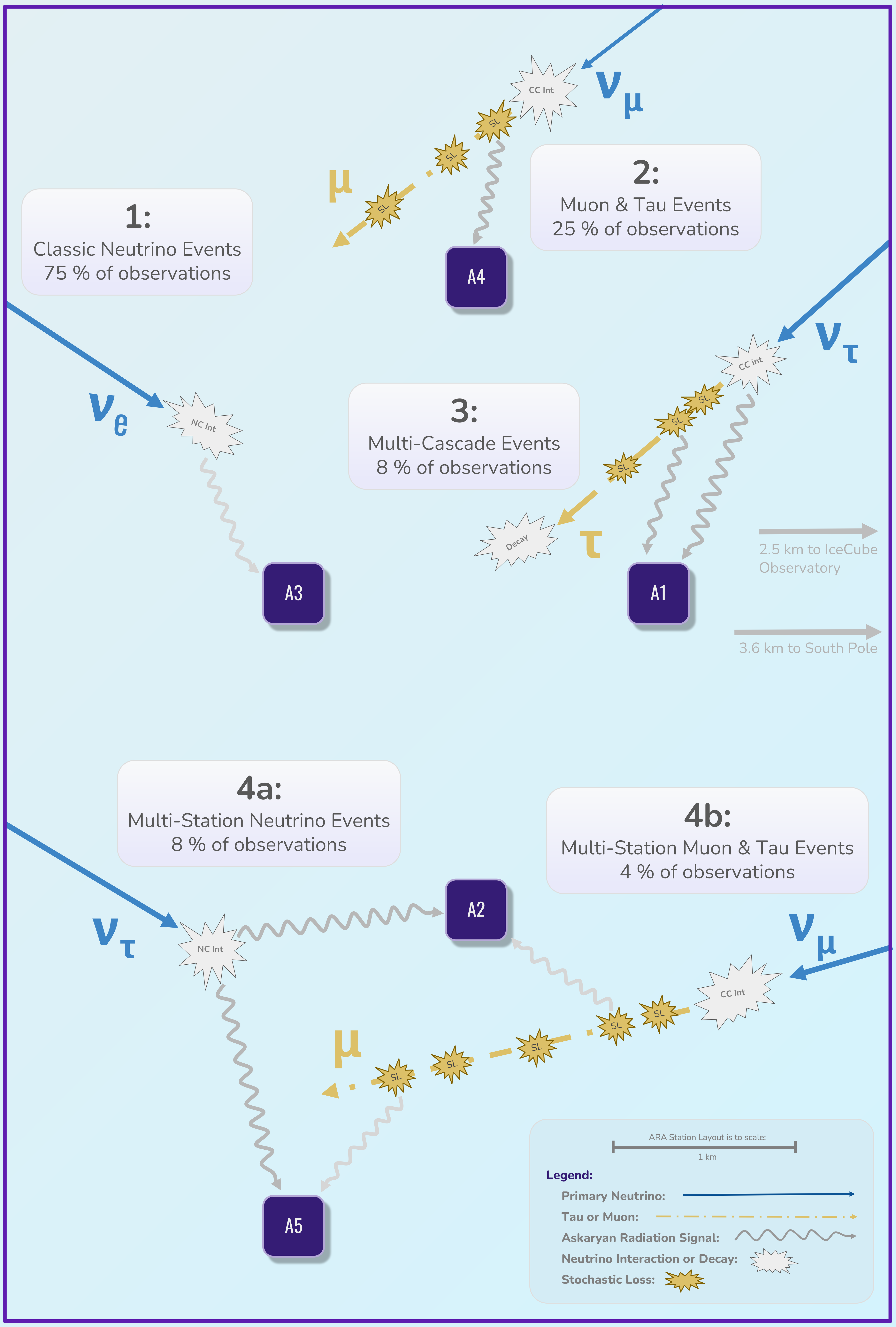
Expected Events in 25 st-yrs: 0.09 (4% of total)

Effective Area Breakdown



Event Rate Breakdown





Simulation

NuLeptonSim simulates primary neutrinos along trajectories that spread across Earth and intersect with ARA's viewing region. The outgoing muons, taus, and neutrinos from neutrino interactions are simulated as well as all particles from muon and tau decays until the particles fall below 10^{16} eV. [4]

Python for Radio Experiments (PyREx) simulates Askaryan Radiation from each nearby cascade, estimates the voltage waveforms ARA records, and calculates if ARA stations trigger on each cascade. [5]

Conclusion

Muon, tau, multi-station and multi-cascade events are increasingly likely for events with energy > 10^{19} eV. It is worthwhile to search for additional cascades when we observe such energetic events since the additional data could dramatically improve event reconstruction.

Proceedings

References

[1] **ARA** Collaboration, P. Allison *et al.* *Astroparticle Physics* 35 no. 7, (Feb., 2012) 457–477.

[2] K. Kotera, D. Allard, and A. V. Olinto *JCAP* 2010 no. 10, (Oct., 2010) 013.

[3] D. García-Fernández, A. Nelles, and C. Glaser *PRD* 102 no. 8, (Oct., 2020) 083011.

[4] **ARA** Collaboration, A. Cummings *et al.* *PoS* 424 (05, 2022) 014.

[5] "Python for radio experiments." https://github.com/abigailbishop/pyrex. Accessed: 2022.