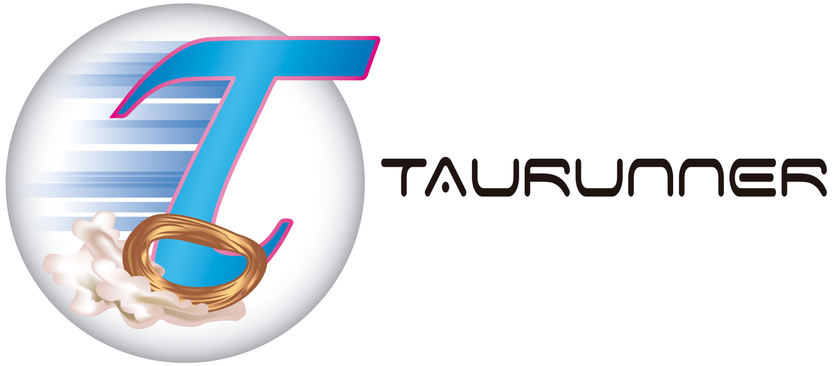




# TauRunner: A Monte Carlo for Very-High-Energy Tau Neutrino Propagation

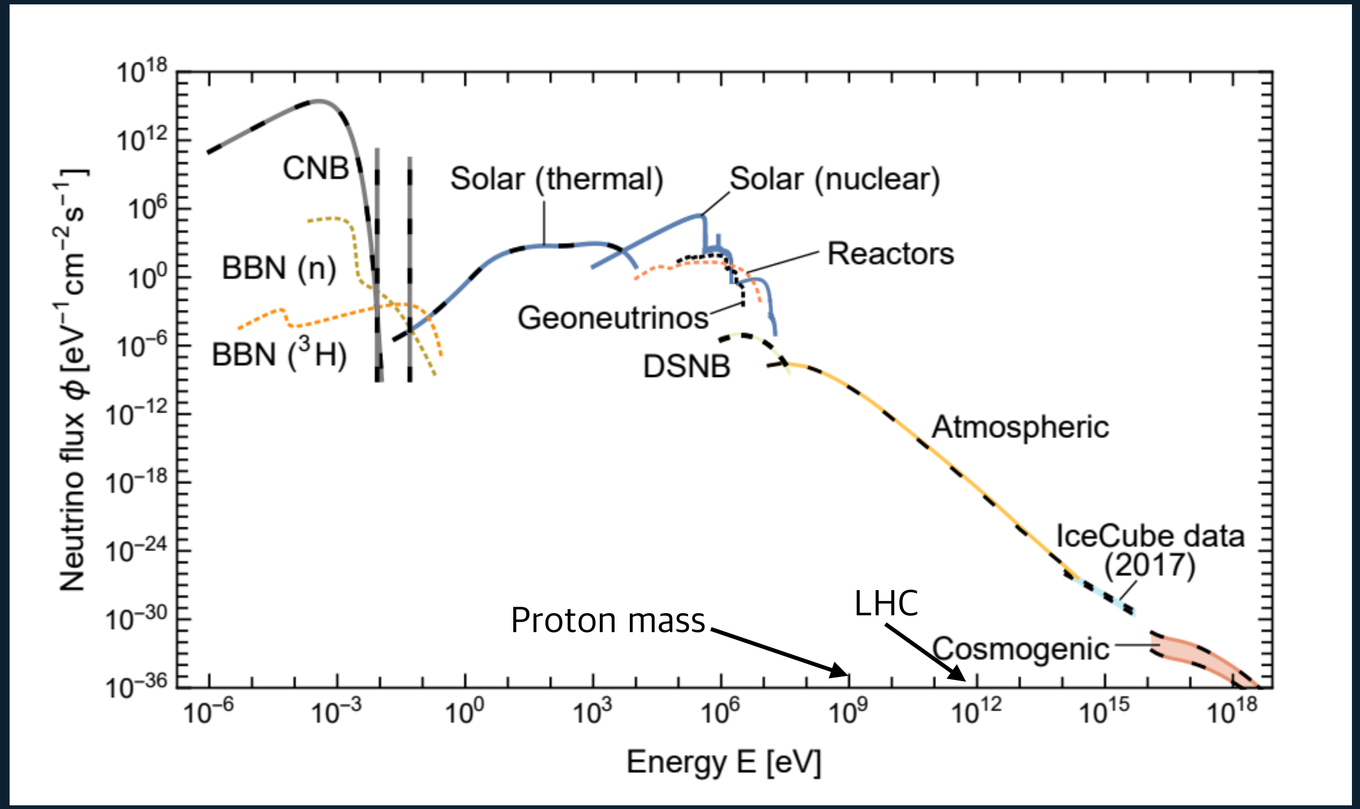
Oswaldo Vazquez




https://github.com/icecube/TauRunner

# Searching for Cosmogenic Neutrinos

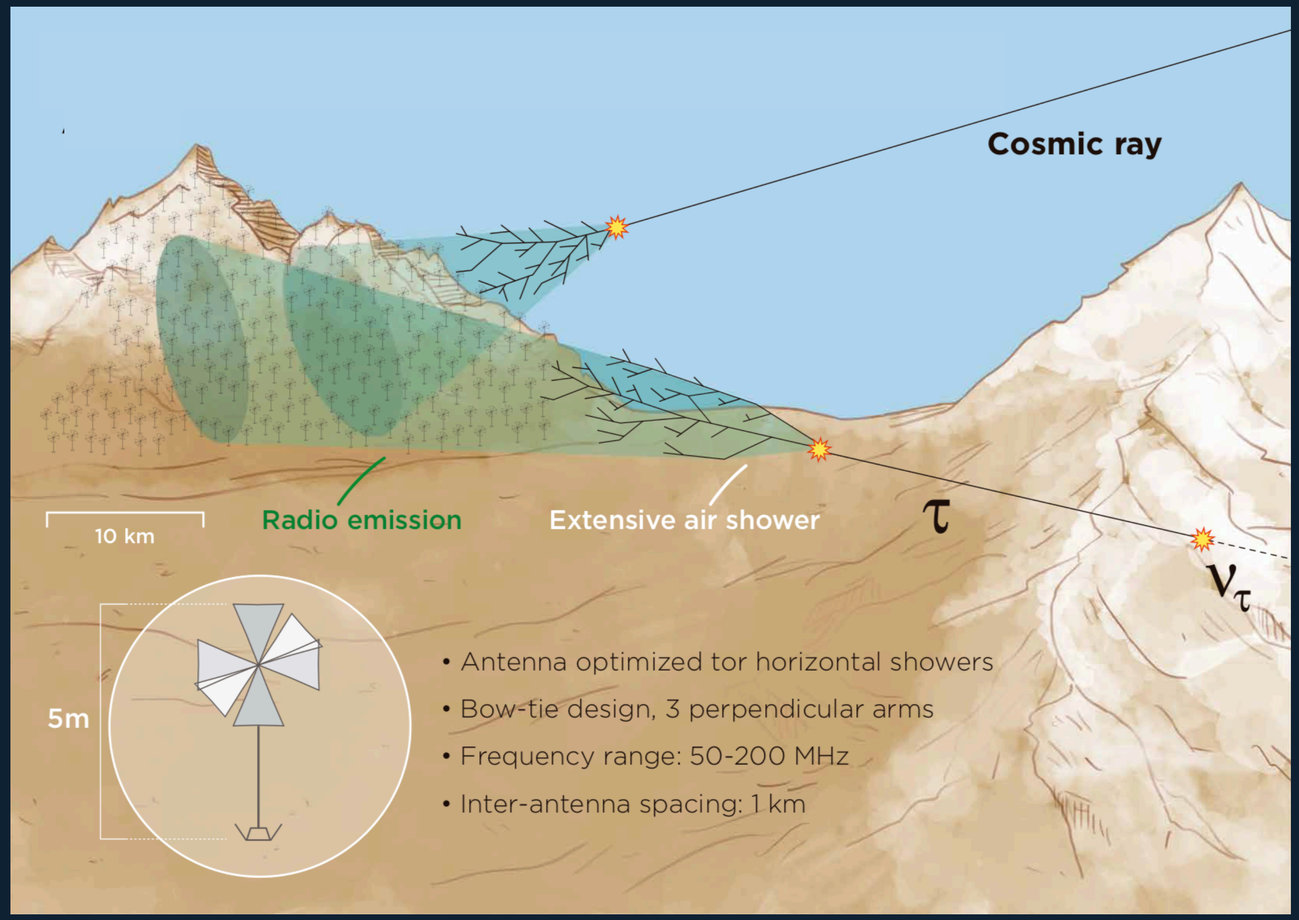
- Extremely-High-Energy (EHE) $\nu_{e,\mu}$s expected to be produced by cosmic-ray interactions with the CMB.
- Cross section at above $10^{18}$ eV reduces interaction length of neutrinos to $\mathcal{O}(100)$ km in rock.
- Cosmogenic flux is the target of IceCube-Gen2, TAMBO, RNO, GRAND, POEMMA, and CHANT.




Vitagliano et al. arXiv:1910.11878

# Direct Measurement

- Earth- and space-based detectors looking for EM showers (ANITA/GRAND/RNO/ POEMMA).
- Use a sliver of the planet (atmosphere, mountains, volcanoes) as target.
- Detection of Earth-skimming shower is a proxy for neutrino interactions.




Álvarez-Muñiz et al. arXiv:1810.09994

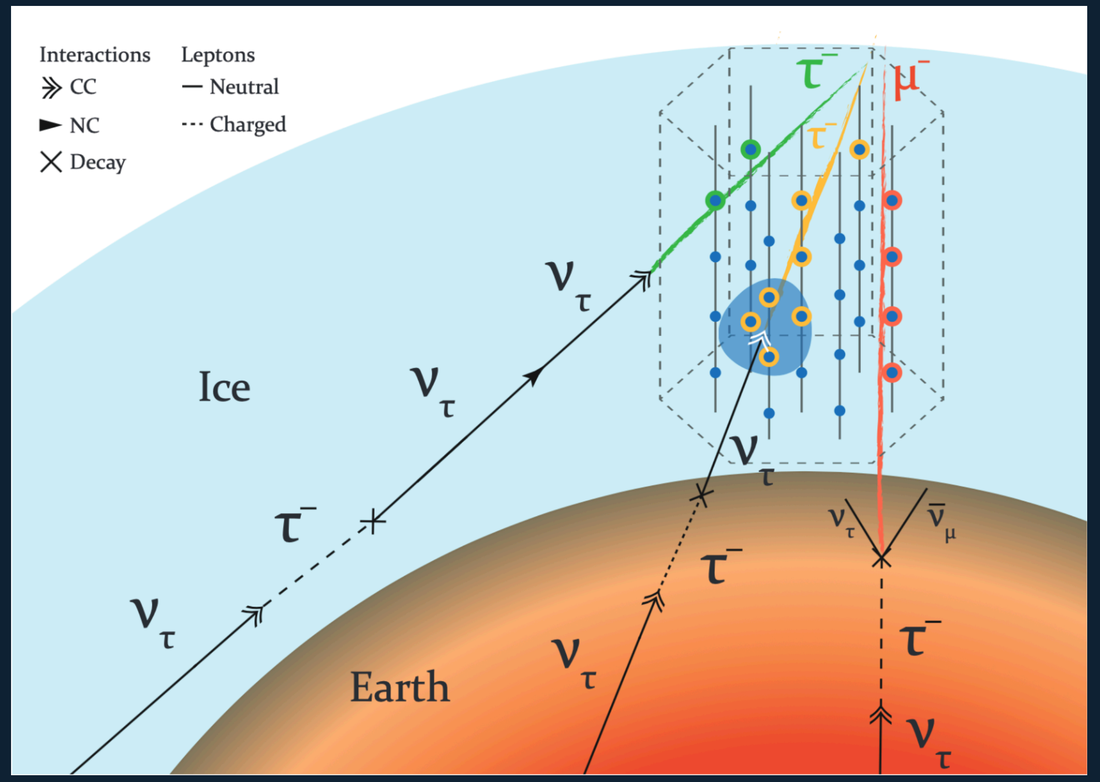
# Indirect Measurement

- Tau neutrino regeneration: $\nu_\tau \xrightarrow[CC]{} \tau^- \rightarrow \nu_\tau$

- Flux measurement can be done indirectly by observing Earth-throughgoing $\nu_\tau$s. Both fluxes are related by:

$$\frac{d\Phi(E,x)}{dx} = -\sigma(E)\Phi(E,x) + \int_E^\infty d\tilde{E}\, f(\tilde{E},E)\Phi(\tilde{E},x)$$

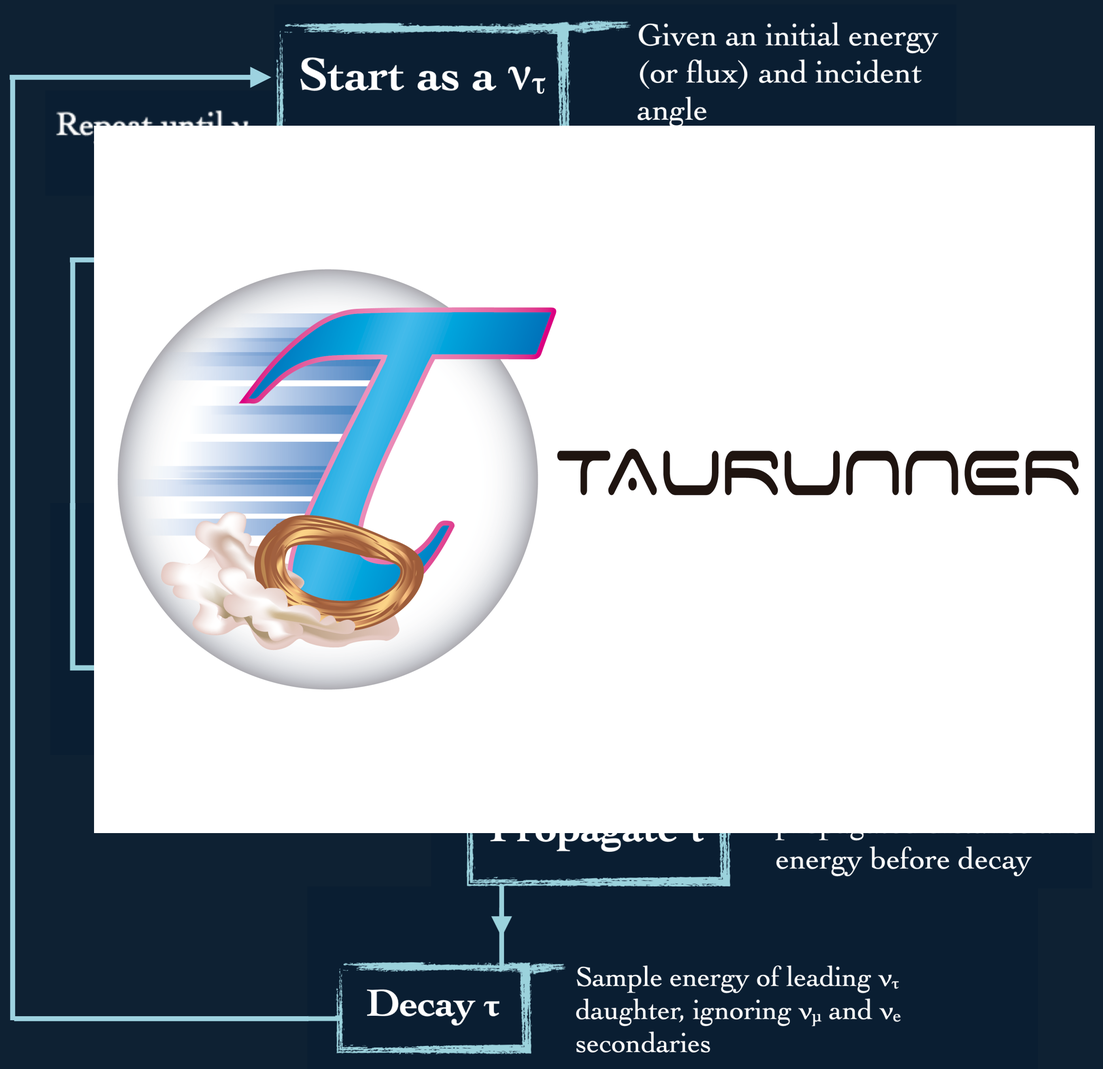
- Regeneration process creates $\bar{\nu}_{e,\mu}$ secondaries, each accounting for relatively large fluxes.




Halzen, Saltzberg arXiv:9804354
Safa et al. arXiv:1909.10487

***An alternative way of seeing GZK neutrinos***

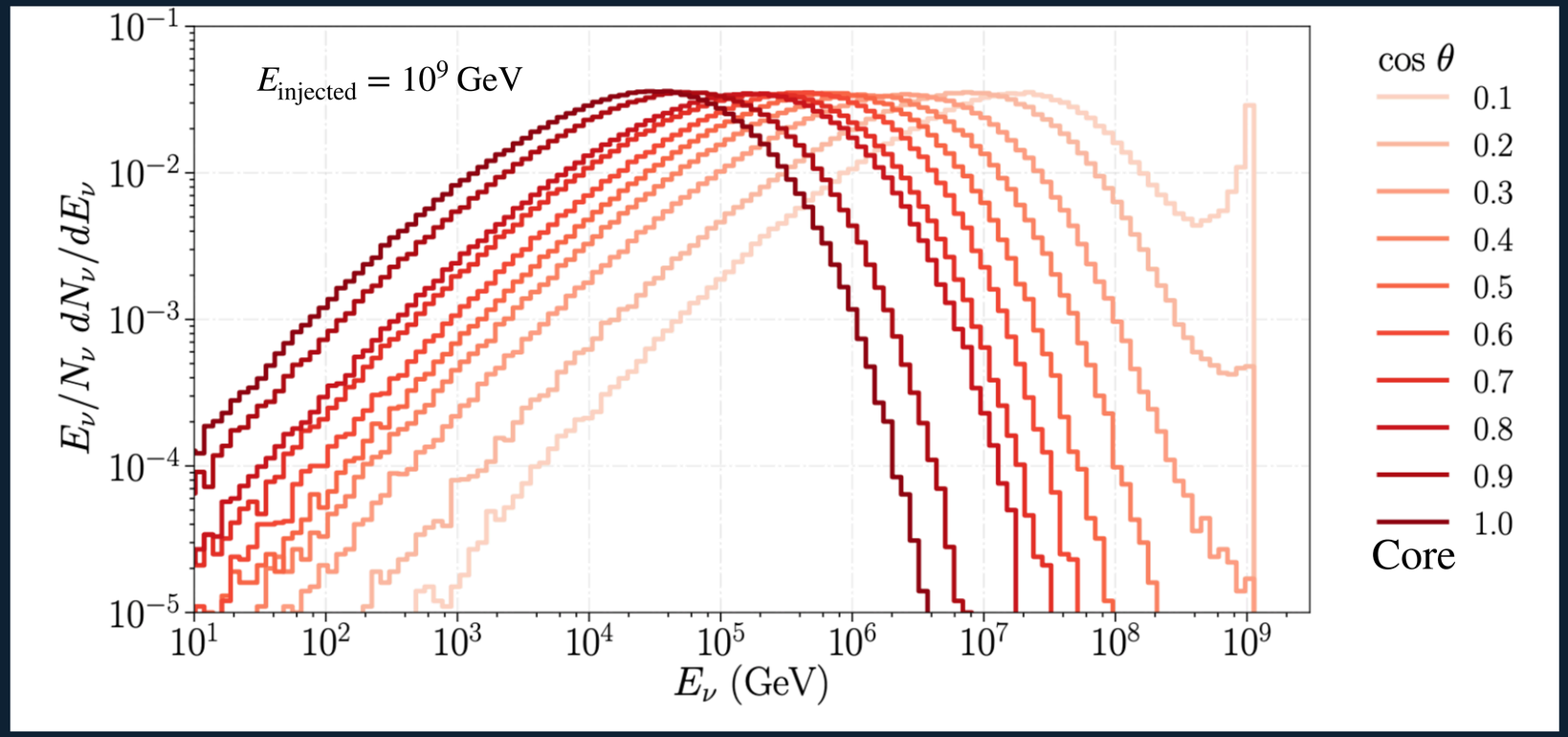
# TauRunner Algorithm




- Python package originally intended to propagate VHE tau neutrinos through a medium.
- Exploits tau neutrino regeneration process.
- Access TauRunner at **https://github.com/icecube/TauRunner**.

# 1 EeV $\nu_\tau$ Monochromatic Flux

- Core at $\cos\theta = 1.0$ and horizon at $\cos\theta = 0.0$.
- Neutrinos undergo ~2-3 CC interactions, on average.
- Peak energy ∝ 1 / column depth.

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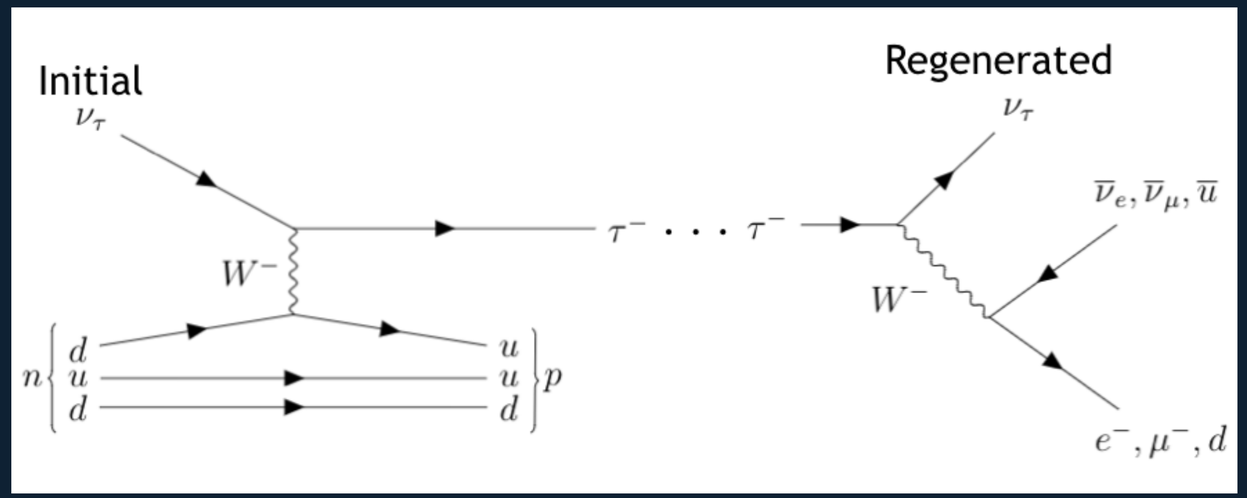
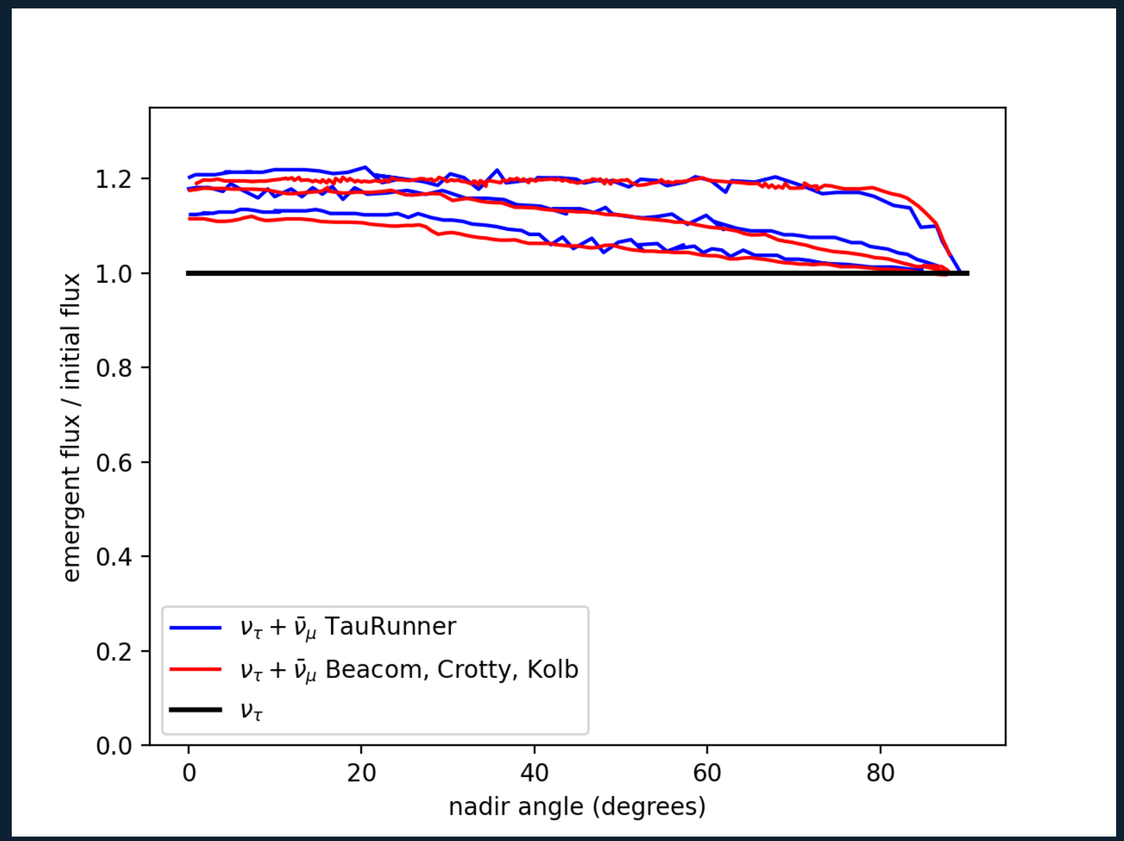
# Addition of $\bar{\nu}_{e,\mu}$ Secondaries




- $\bar{\nu}_{e,\mu}$ are created in some $\tau$ decay channels. These are now followed by the MC.
- Energies sampled using inversion method.
- Secondaries will boost the yield of events by a factor of 2.

**Beacom et al. arXiv:0111482**

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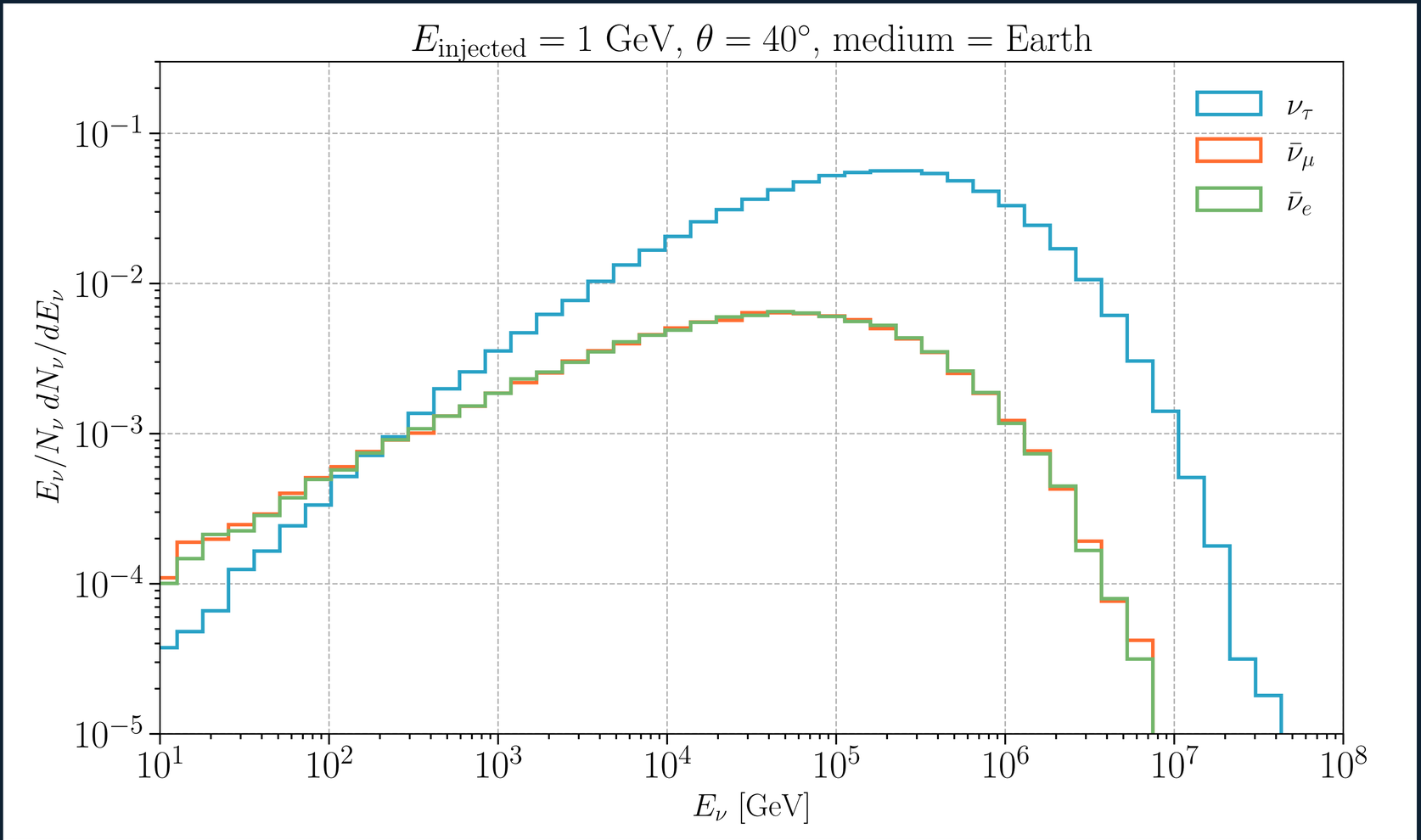
# Energy spectra for all neutrinos

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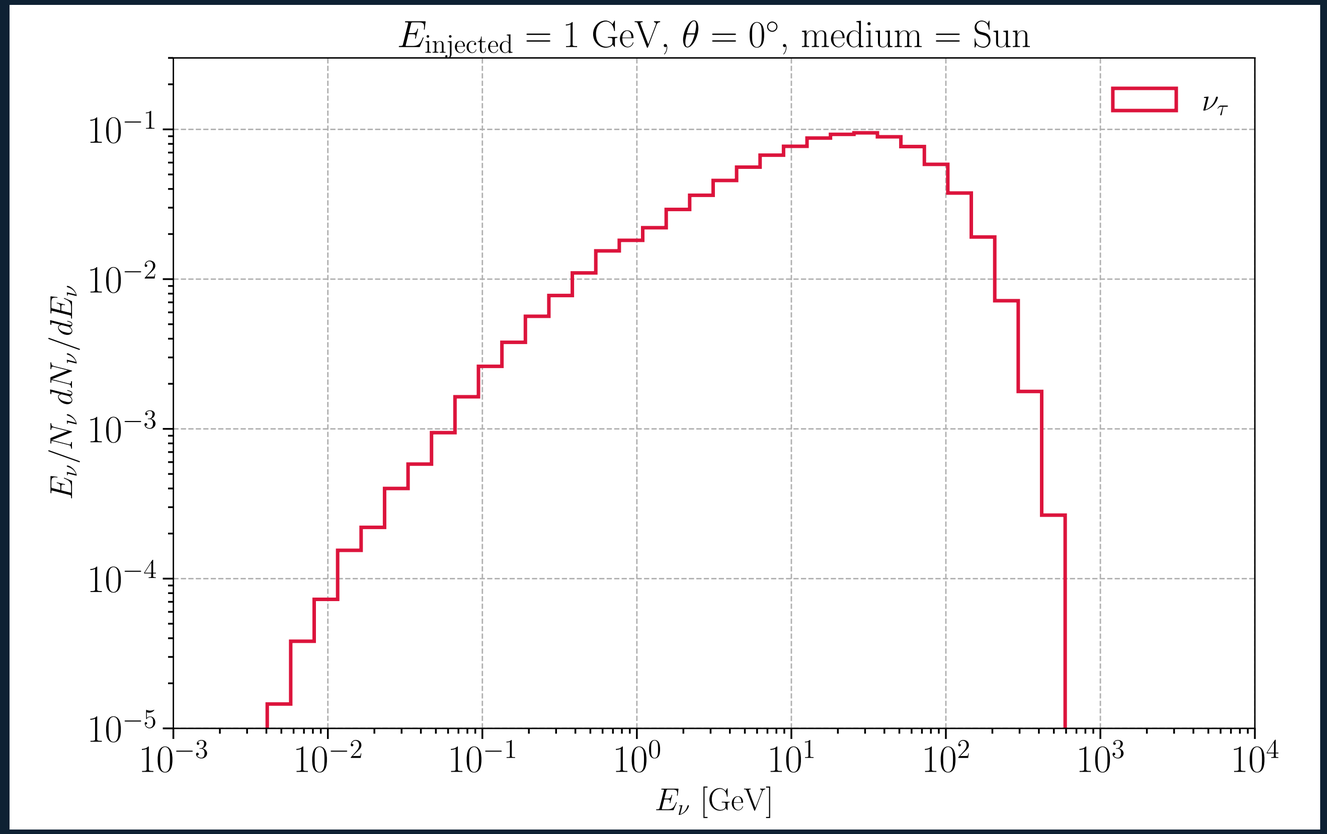
# Bodies

- TauRunner originally had the Earth as the only body.
- Now any medium can be used by specifying a density profile and radius.
- Sun has been added as a second physical medium.

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# Optimizations

- Reduced dependencies significantly.
- Automate installation via pip.
- Include continuous integration aiming for 100% coverage.
- Significant leap in code readability with the new TauRunner.
- All features will be described in an upcoming publication.


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# Conclusions

- Exciting time for cosmogenic neutrino searches.
- Continue to develop software to enable indirect detection of GZK neutrinos.
- Seek synergic efforts with NuTauSim (**https://github.com/harmscho/NuTauSim**), NuPropEarth (**https://github.com/pochoarus/NuPropEarth**).
- Please try our MC and give us feedback!


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