Tau appearance from high-energy neutrino interactions

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Kingston, Ontario Canada

Pavel Zhelnin

Alfonso Garcia Soto

Ibrahim Safa

Carlos Argüelles Delgado

Overview

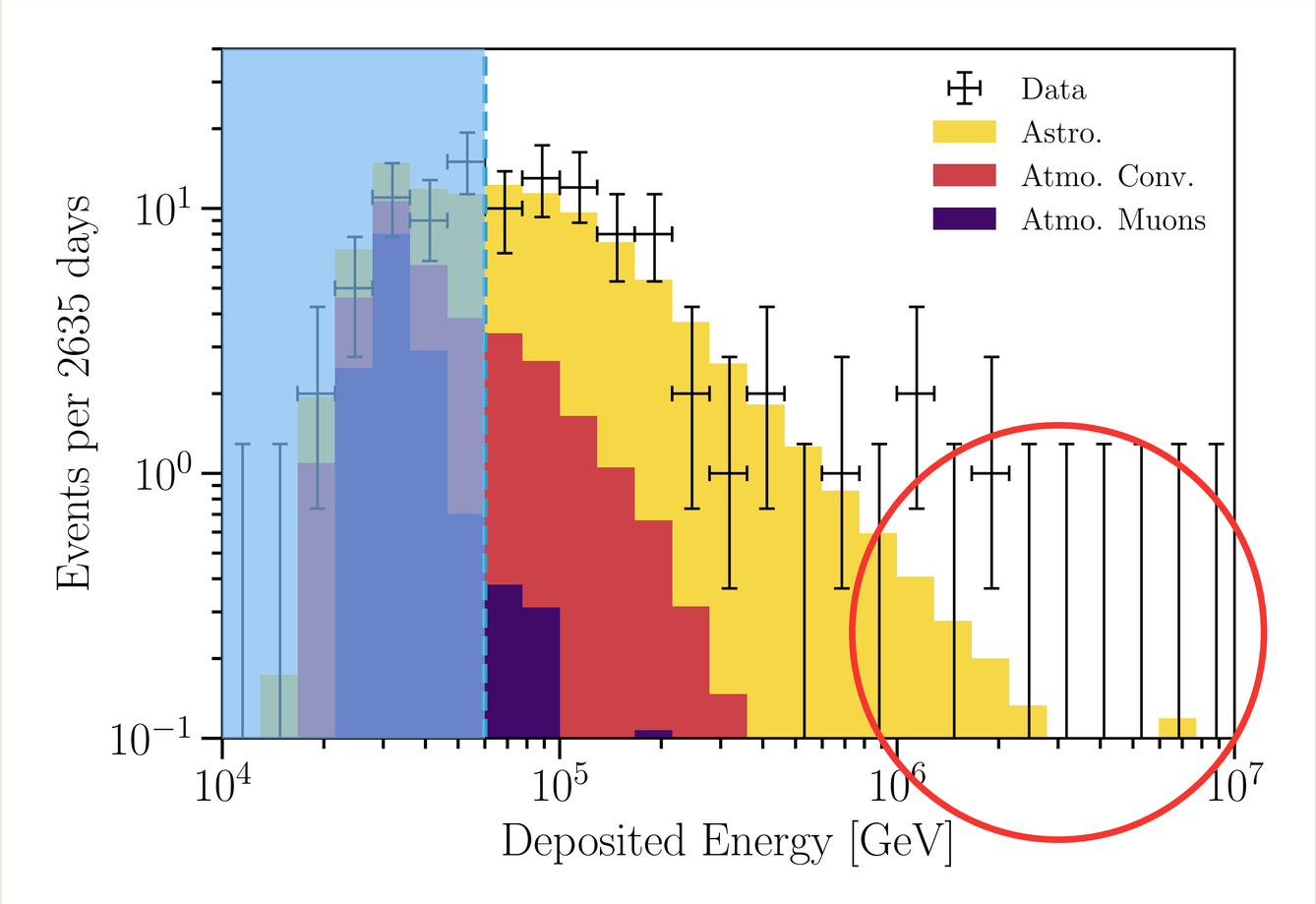
- Main Takeaway
- Motivation
- Why tau neutrinos?
- Tau neutrino backgrounds
- Tau appearance
- Conclusion

Main Takeaway:

Earth-going high-energy electron and muon neutrinos have a non-negligible probability of producing tau neutrinos

Astrophysical neutrinos

- IceCube has observed an astrophysical flux through HESE sample
- Some evidence of astrophysical sources
- However we're plagued by low event counts at high energies
- Only two tau neutrino candidates

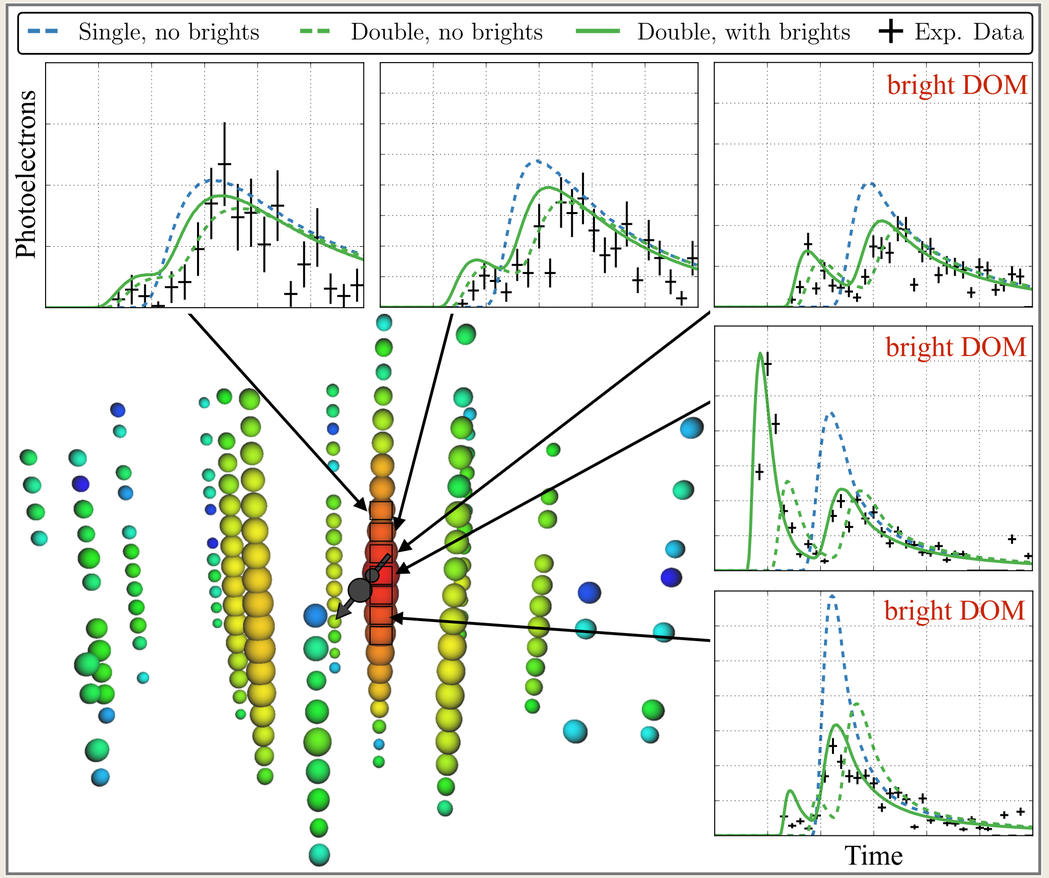


IceCube Collaboration, PhysRevD.104.022002

High Energy Starting Event sample (HESE):
Vetos events that start outside specified volume and with reconstructed energy about 60 TeV

Why can't we see tau neutrinos that well?

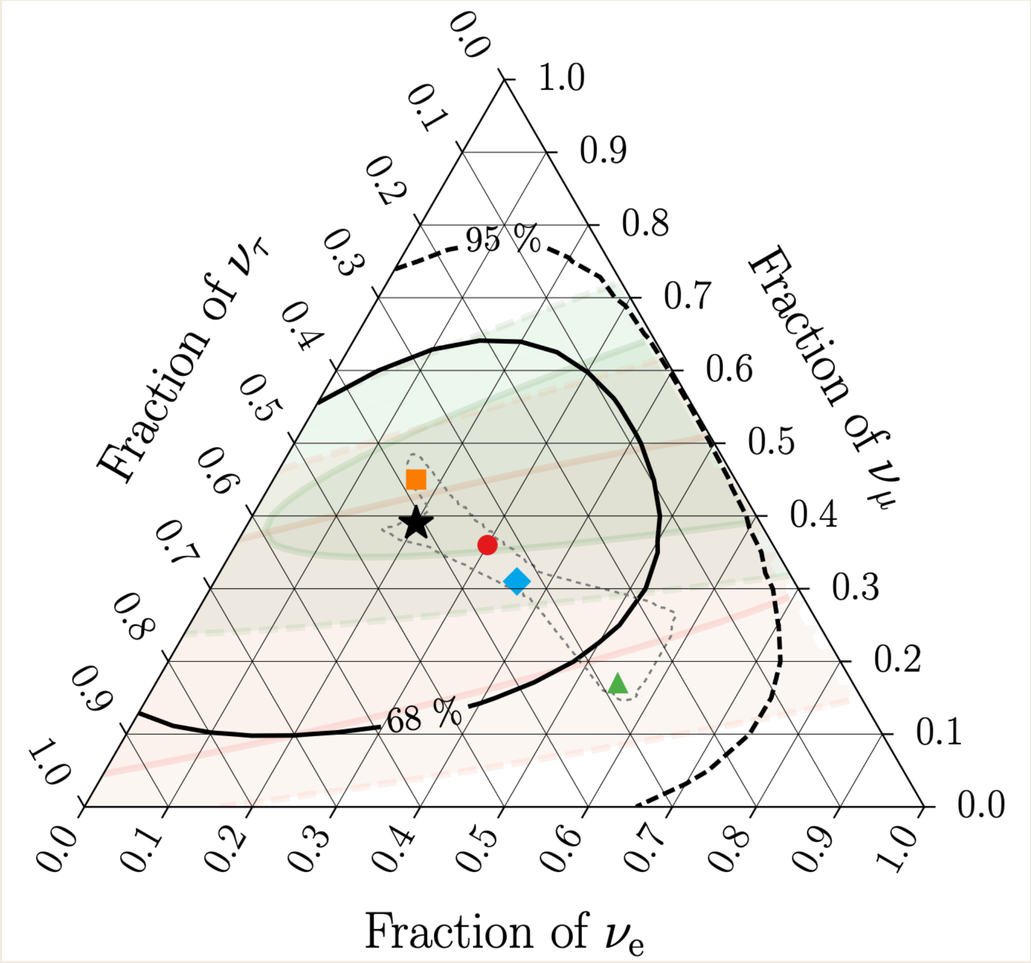
- Crash course in IceCube morphology
  - Muons produce tracks
  - Electrons/taus = cascades
  - Taus also = "double bangs"
    - Only resolvable in IceCube if tau is energetic enough
  - *For the most part, electron and tau events are degenerate!*



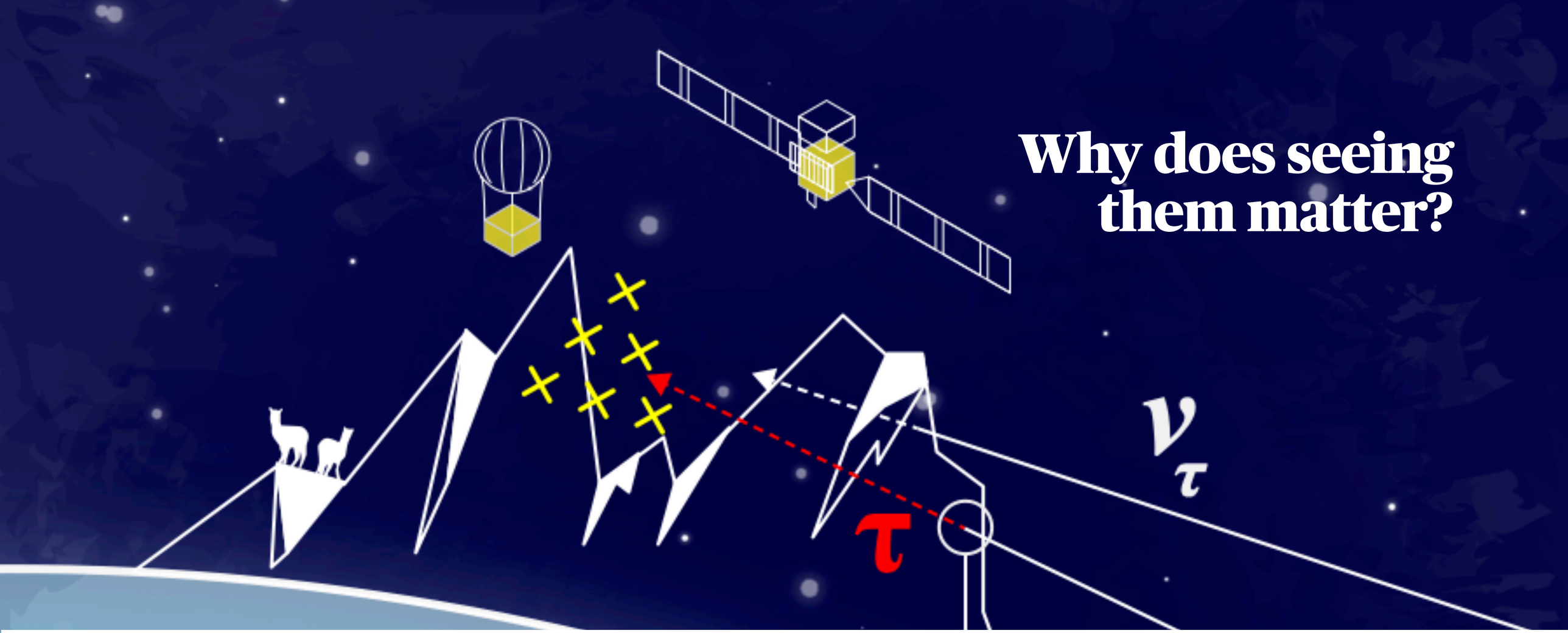
IceCube et al., arXiv:2011.03561

But why does seeing them matter?

- Assuming standard oscillations we should expect 1:1:1 ($\nu_e : \nu_\mu : \nu_\tau$)
- Yet, no bonafide evidence of tau component (only two tau neutrino candidates)
- This leaves room for possible BSM scenarios



IceCube Collaboration, arXiv:2011.03561

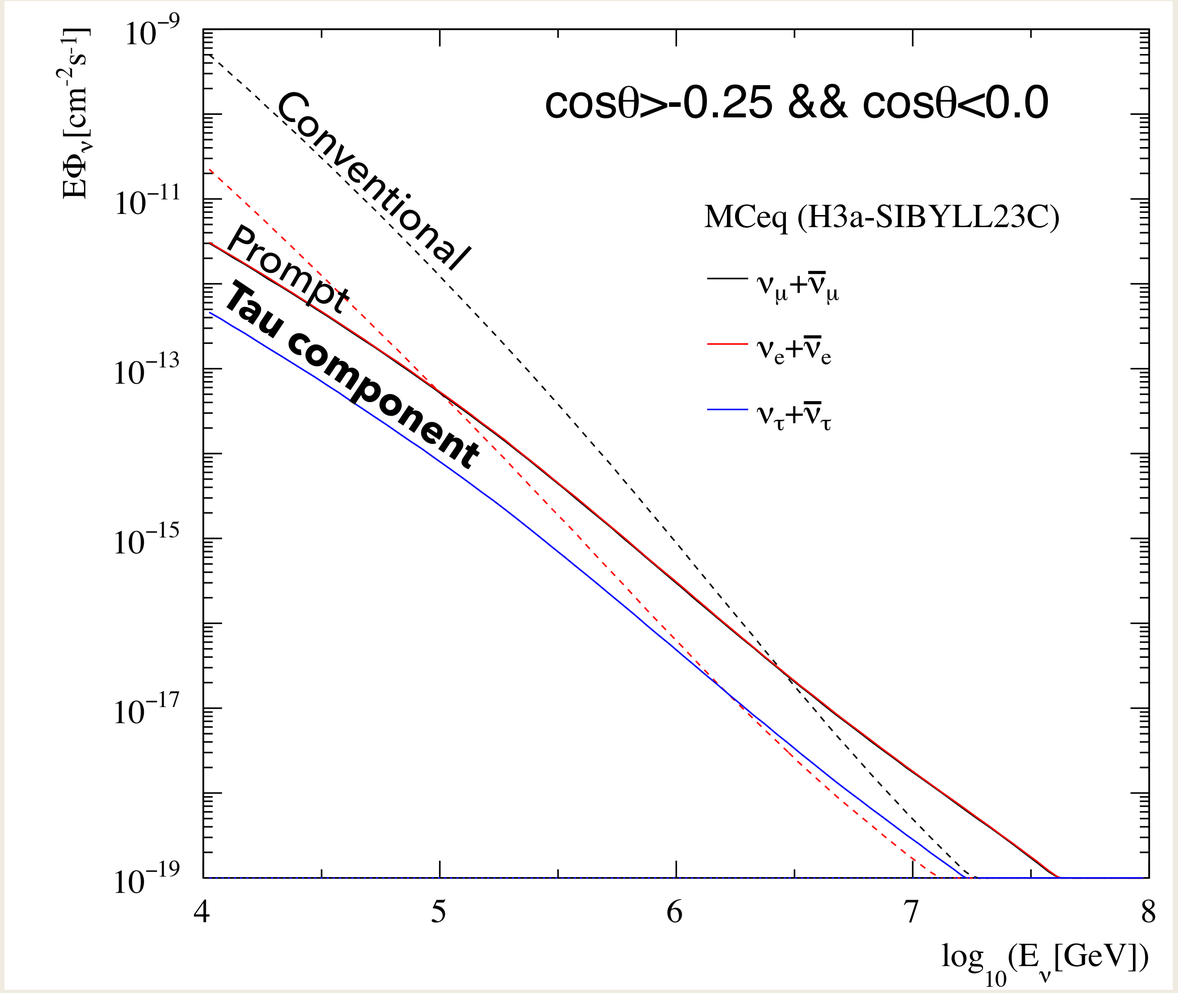


Why does seeing them matter?

- Current experiments are limited by their effective volumes to detect EeV ν
- Earth-skimming (EAS) experiments have been designed to probe GZK flux
- ν_τ interacts in Earth, produces τ, decays in air
- Projected performance shows they'll be able to detect cosmogenic ν

Backgrounds as previously understood

- Astrophysical taus basically were thought to be background-less
  - Rarely produced in atmosphere
    - Prompt -> 1-5% Branching Ratio
    - Conventional -> 10^{-4}
  - Standard oscillations are suppressed at energies greater than 100 GeV
- So if tau observed = astrophysical



Our analysis

Electron and muon neutrinos produce $\tau\nu_\tau$ as they propagate through Earth.
How?

Glashow Resonance | W Boson Production | Top Production

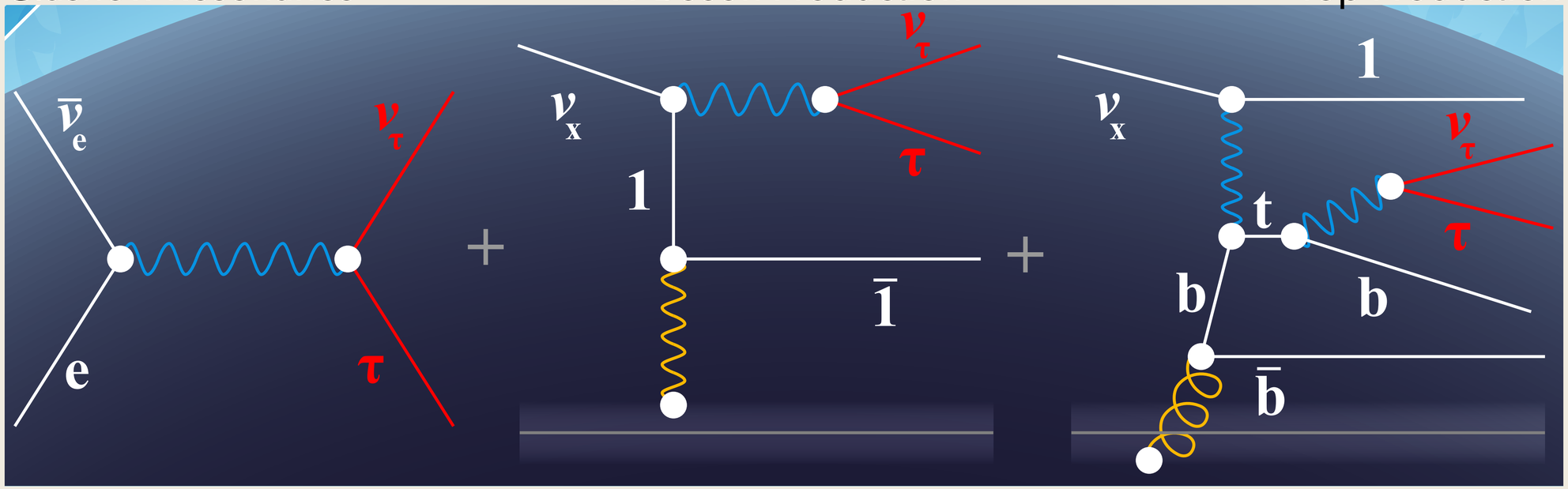
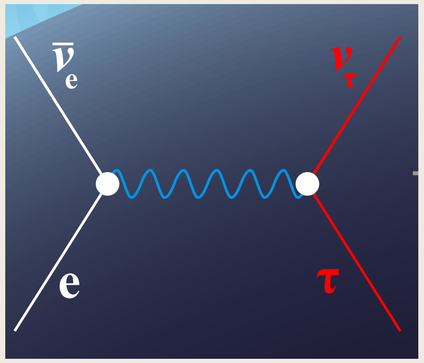


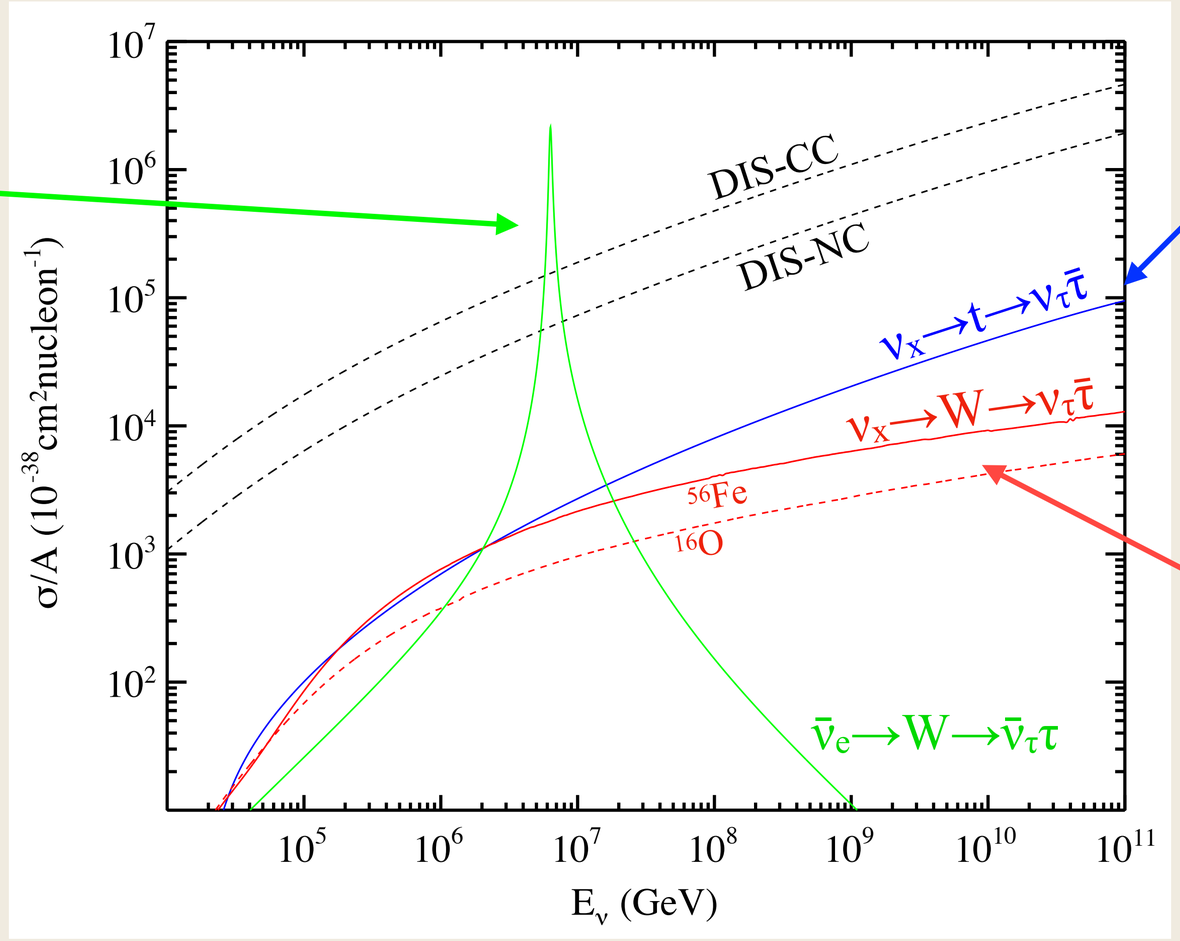
Image Credit: Jack Pairin

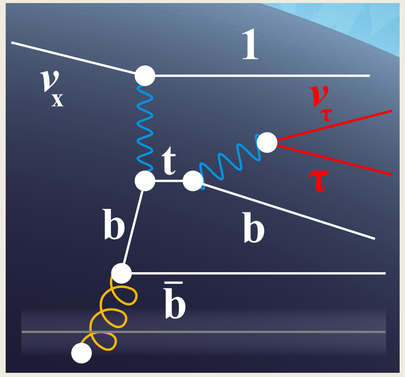
Contribution of these channels vs DIS

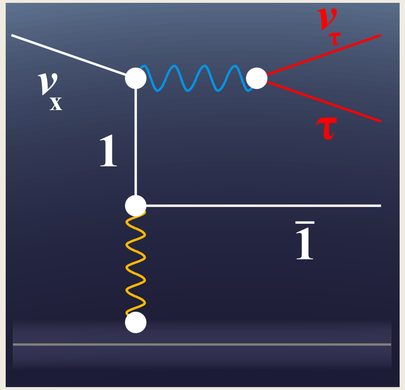
Deep Inelastic Scattering = DIS



- Secondaries are produced by on-shell W-bosons which decay to $\nu_\tau + \tau$ 10% of the time





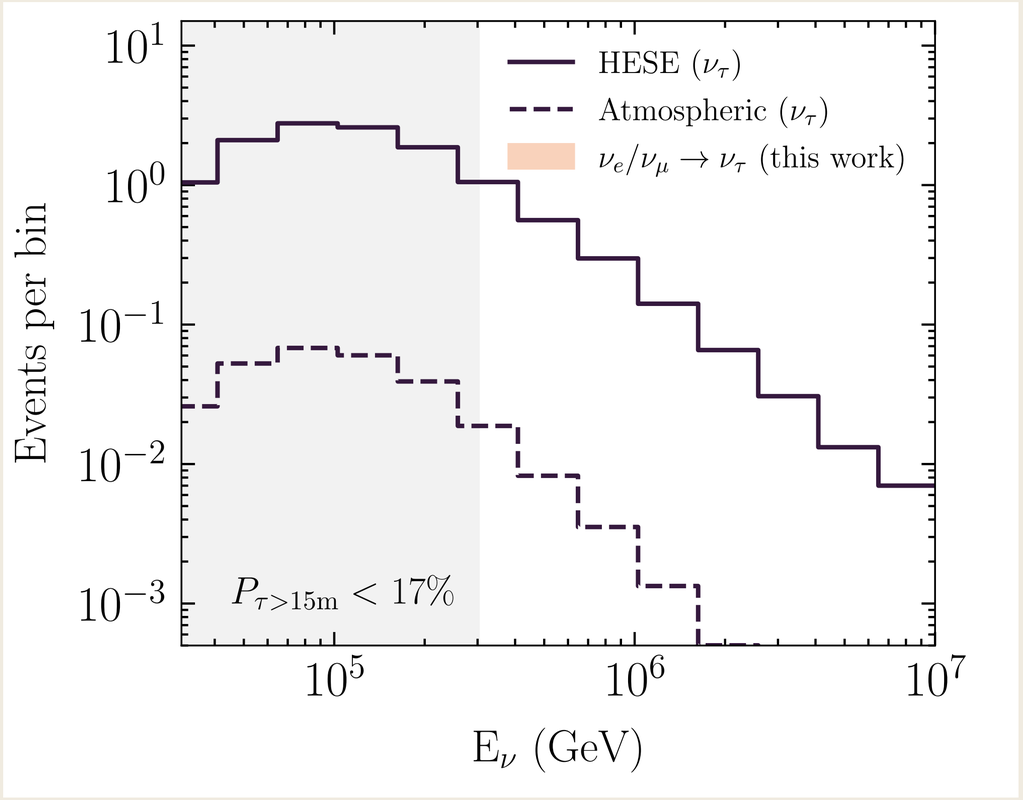


GENIE Coll., arXiv:2106.09381

Effects on IceCube's HESE sample

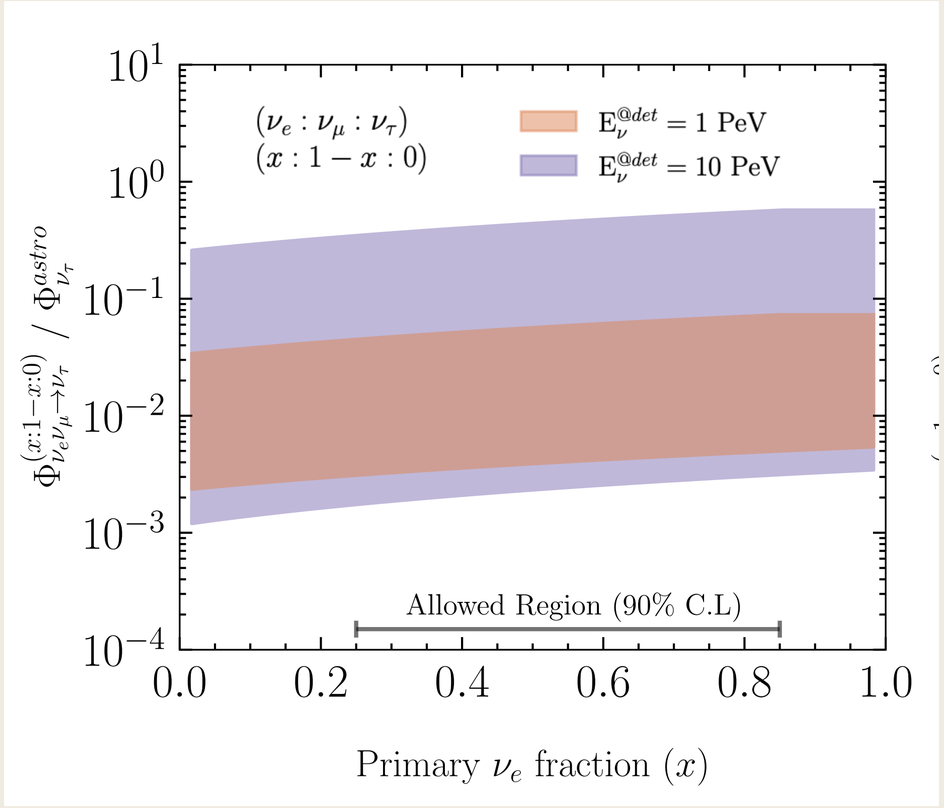
- 1-20% contribution above 1 PeV
- Becomes dominant background above 300 TeV
- Our capacity to reject non tau component is reduced given secondary taus

E_{th}	$P_{\tau>15\,\mathrm{m}}$	HESE	Atmos.	$\nu_\mu/\nu_e \to \nu_\tau$
100 TeV	1%	6.63	0.13 (6.3)	0.05-0.11 (6.0-5.7)
200 TeV	9%	3.00	0.05 (4.3)	0.03-0.09 (4.1-3.7)
300 TeV	17%	1.57	0.02 (3.2)	0.02-0.07 (2.9-2.5)
400 TeV	23%	1.12	0.01 (2.7)	0.01-0.06 (2.4-2.1)



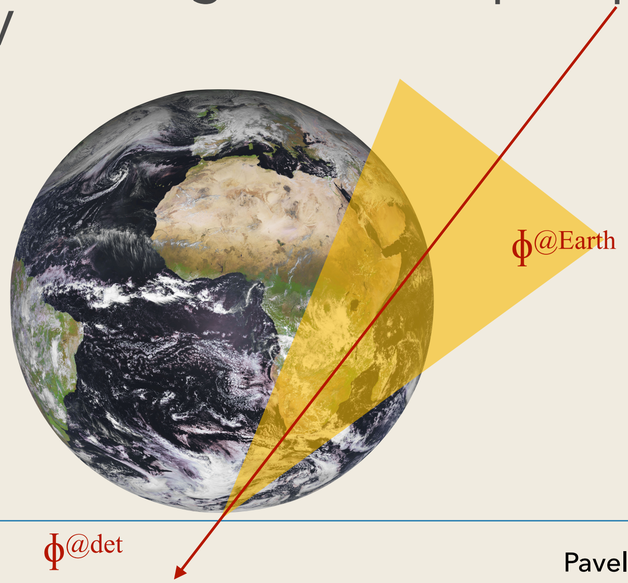
Varying the ratio x:1-x:0

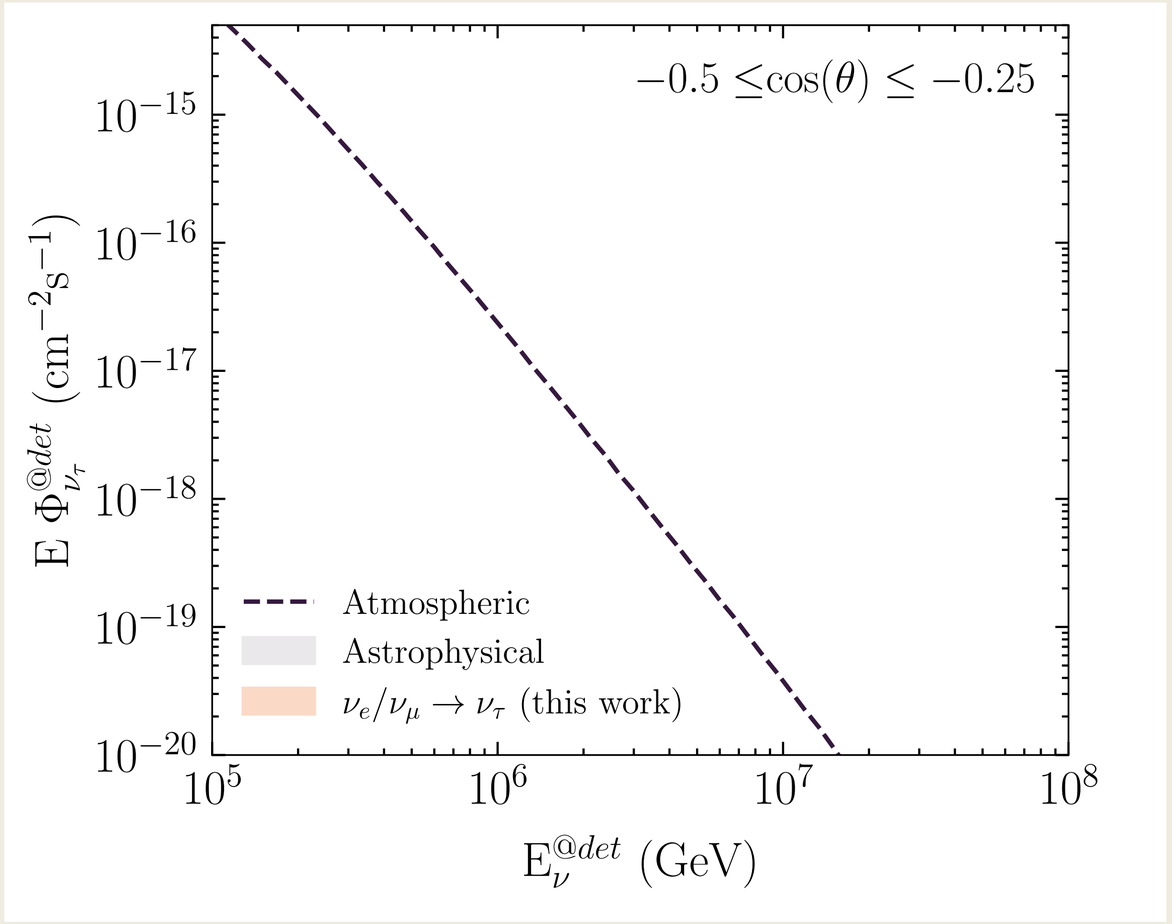
- ν_τ produced from ν_μ and ν_e alone can contribute as much as 5 - 50% for E > 10 PeV
- However this doesn't depend much on relative composition of ν_μ and ν_e
- The variation in primary spectrum plays a larger role



Angular Dependence

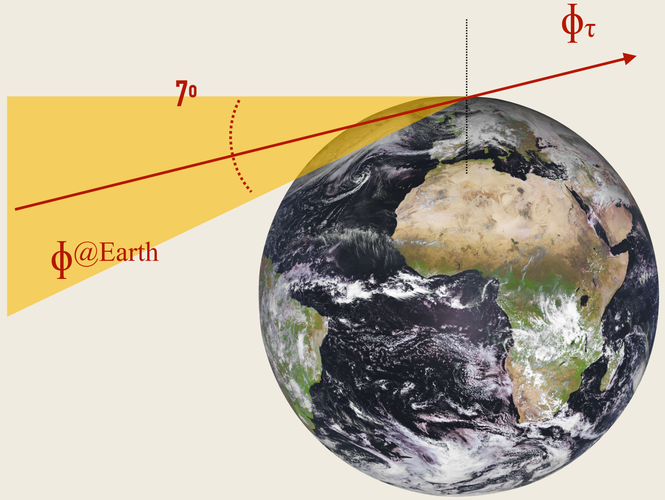
- Expected tau neutrinos @ detector for different fluxes
  - Astrophysical takes best fit from Northern Tracks (NT) and HESE (assuming 1:1:1)
  - Secondary taus assume different ratios of ν_e/ν_μ (also takes best fit from NT/HESE)
- Non primary tau flux is **greater than** prompt at 300-500 TeV

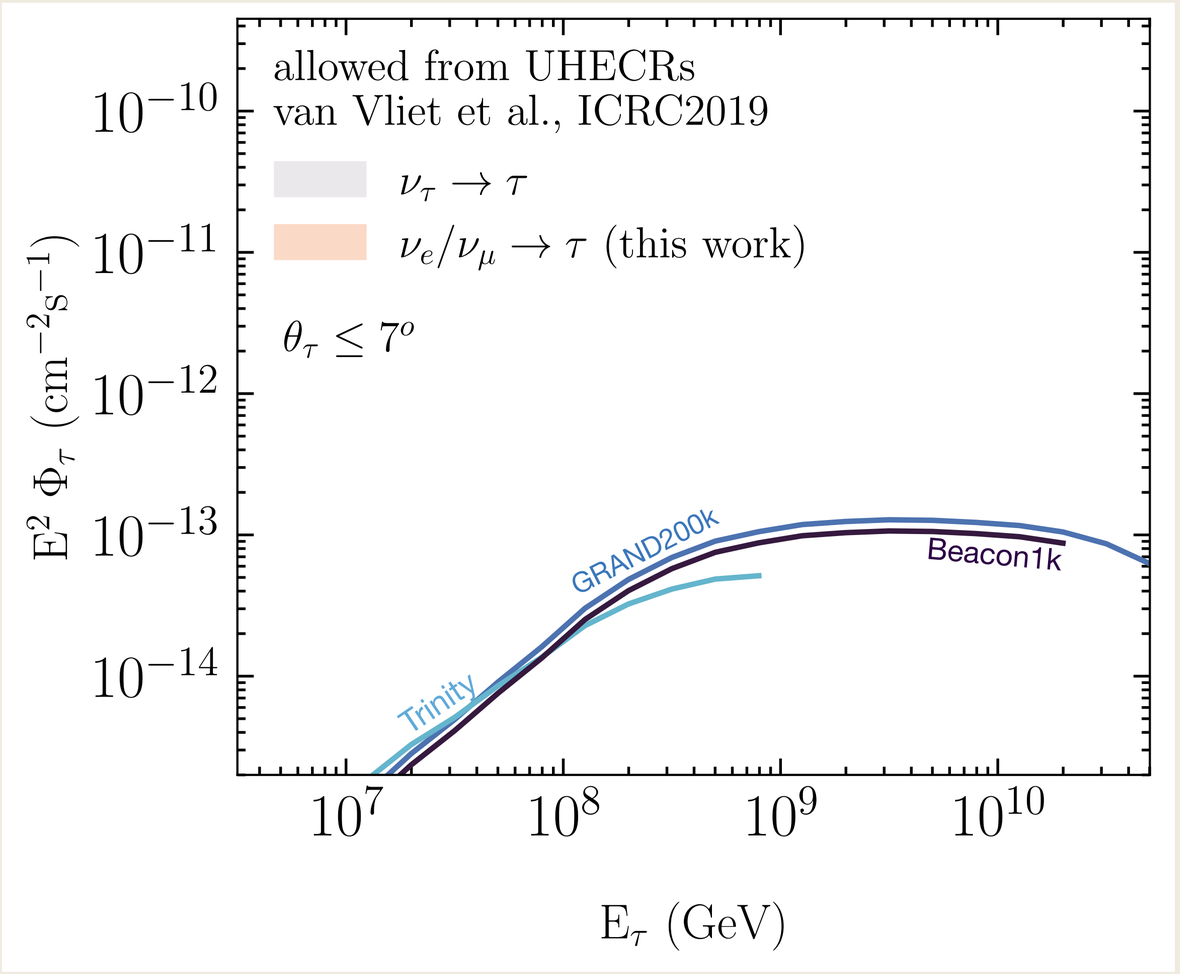




Flavor compositions: 1:1:1 vs 1:1:0?

- In general we assume 1:1:1 ratio
- EAS experiments are sensitive to this flux
- However if we assume 1:1:0 then EAS experiments will still observe taus due to our background
- Measurement of GZK flux is degenerated





Conclusions

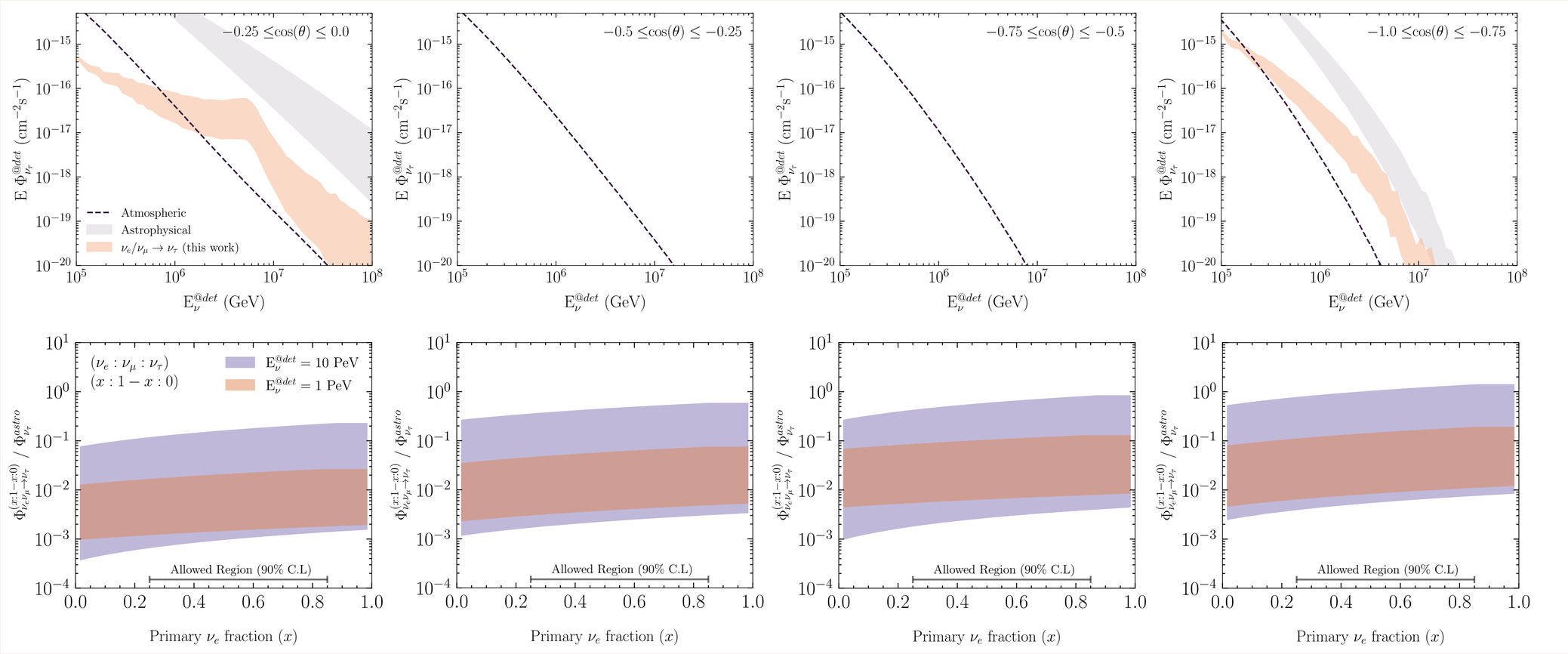
- HE ν_e and ν_μ produce ν_τ as they propagate through Earth
- Reduces our capability to reject non-tau astrophysical neutrinos
- EAS experiments, if they observe taus, will not be able to determine if they come from a 1:1:1 or 1:1:0 flux as a result of this new background

- Our paper: Garcia-Soto et al., PhysRevLett.128.171101

Thank you! Questions?

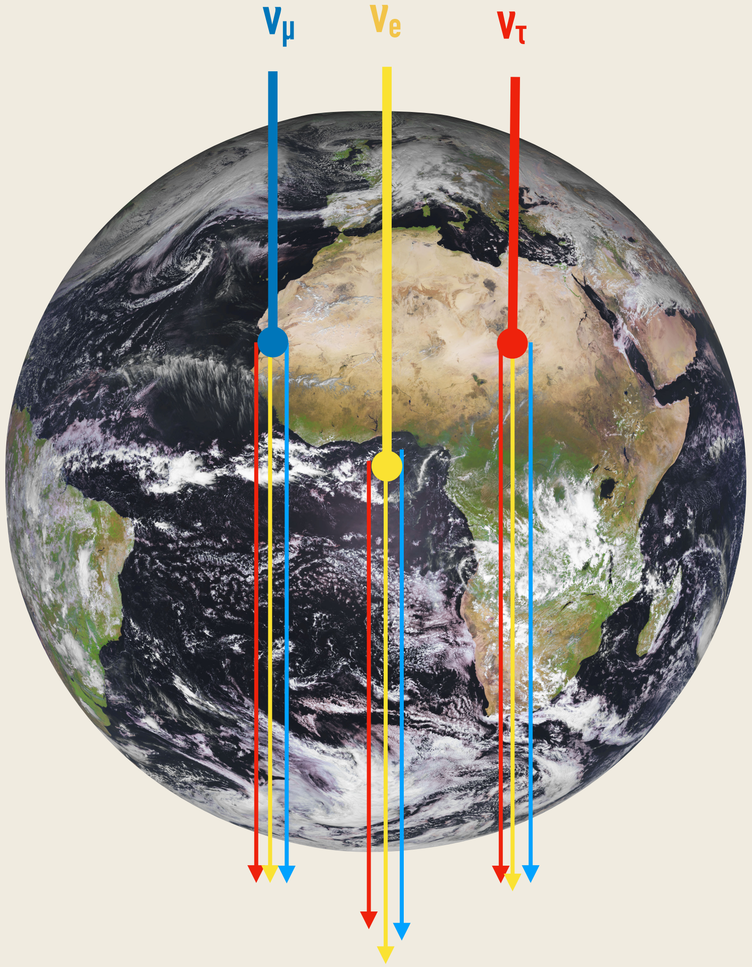
Backups

Tau appearance as a function of angle



MC chain

- NuPropEarth handles neutrino propagation through Earth
- GENIE calculates relevant neutrino cross sections
- Proposal calculates tau energy losses
- TAUOLA simulates tau decay



https://github.com/GENIE-MC/Generator

https://tauolapp.web.cern.ch/tauolapp/

https://github.com/tudo-astroparticlephysics/PROPOSAL/tree/6.1.6

https://github.com/pochoarus/NuPropEarth