AstroDark-2021

Intrinsic Backgrounds in High-Energy Astrophysical Tau-Neutrino Searches

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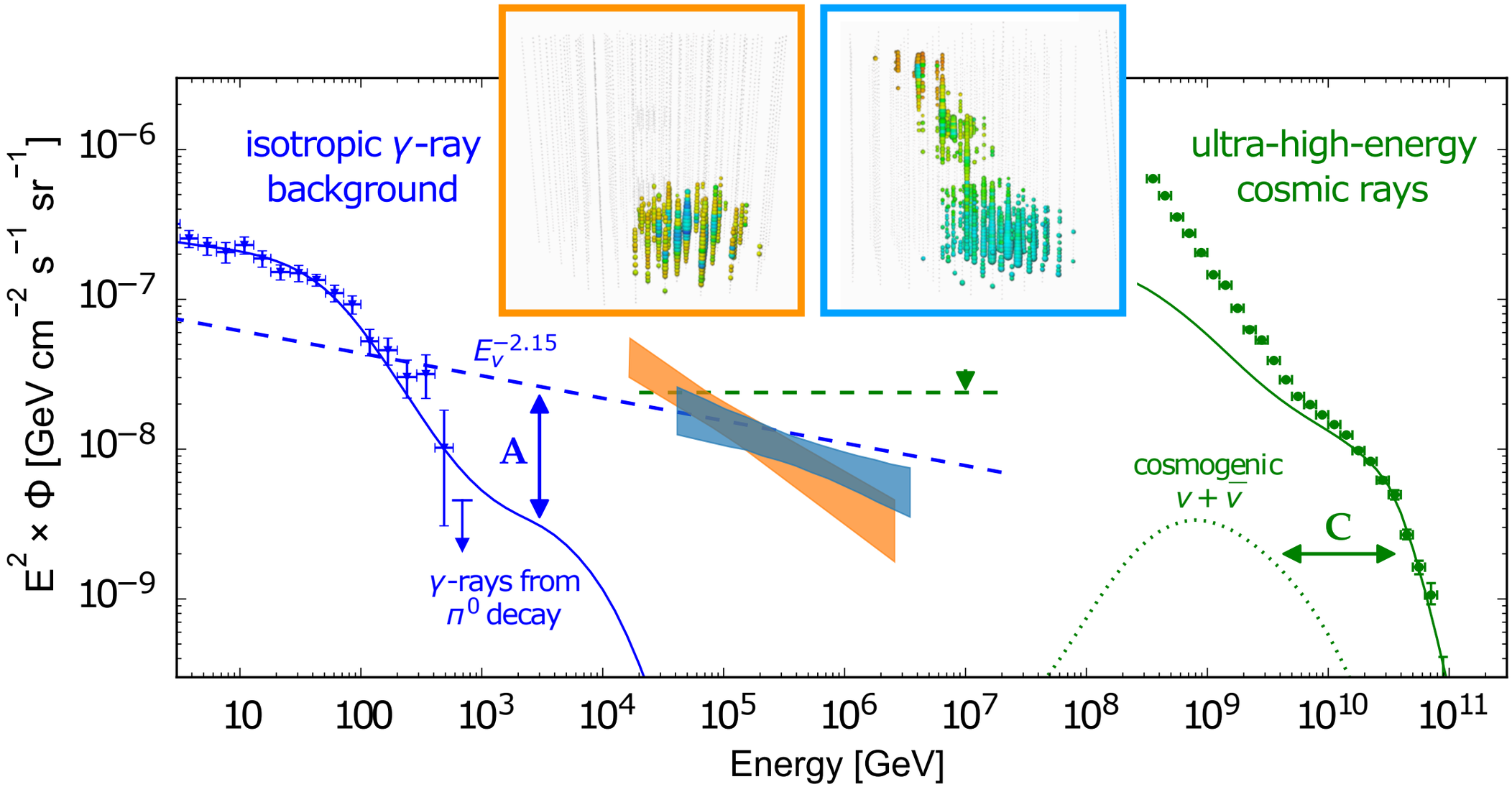
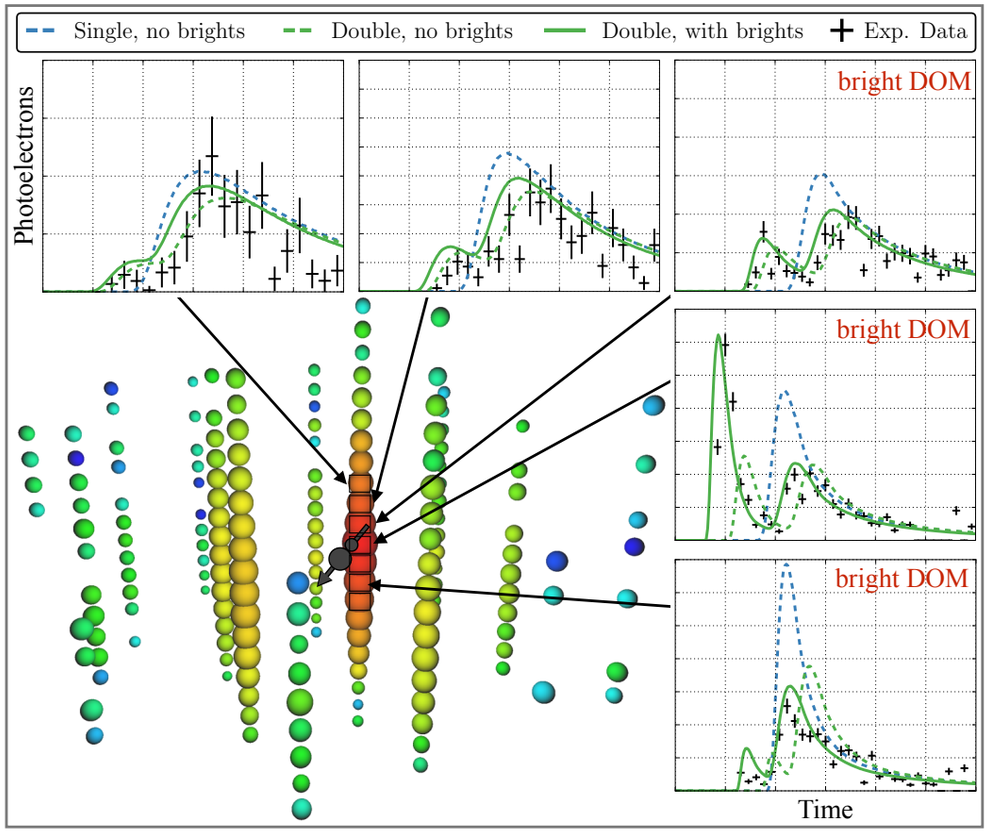
Astrophysical neutrinos:

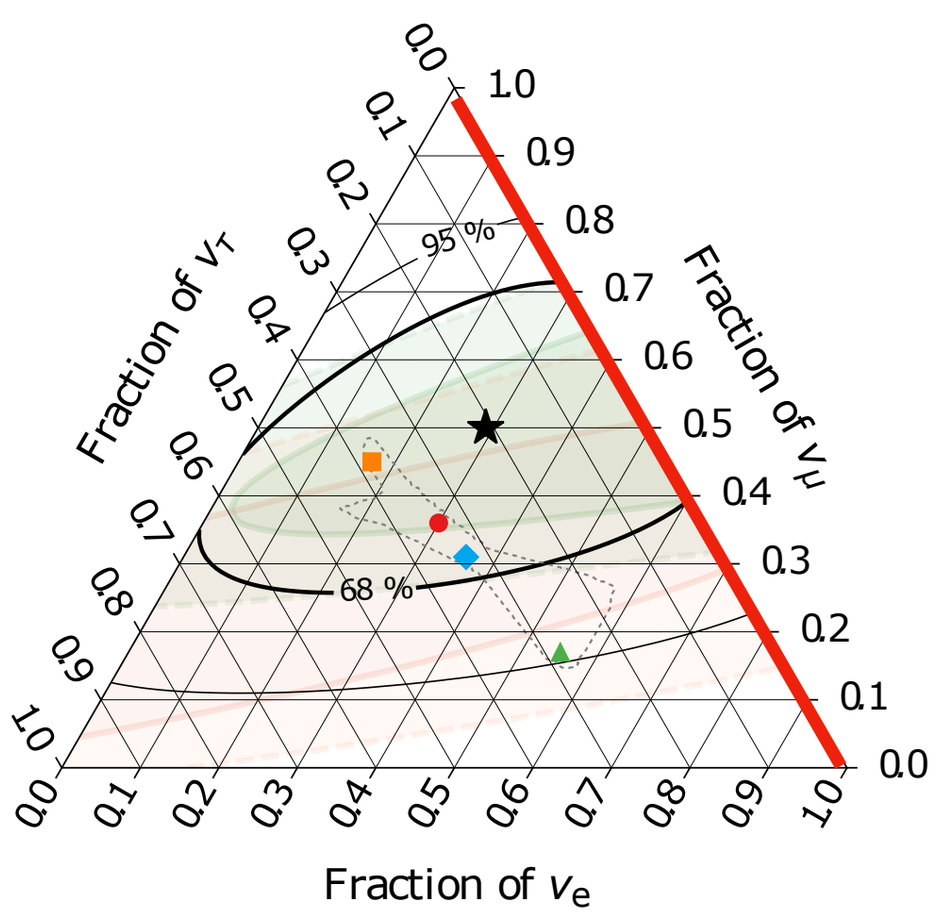
- Origin of cosmic neutrinos remain unclear -> diffuse flux.
- Several IceCube measurements of the spectrum of astrophysical neutrinos.
  - HESE -> High energy showers contained in the detector.
  - Northern tacks -> Long track patterns coming below the horizon.



Why tau neutrinos?

- Assuming standard neutrino oscillation -> ~same $\nu_e:\nu_\mu:\nu_\tau$ at Earth.
- No compelling evidences of a tau component in the diffuse flux:
  - IceCube has identified two tau neutrino candidates (97.5%, 76%).
- Several BSM scenarios can explain 'lack of taunnes'.





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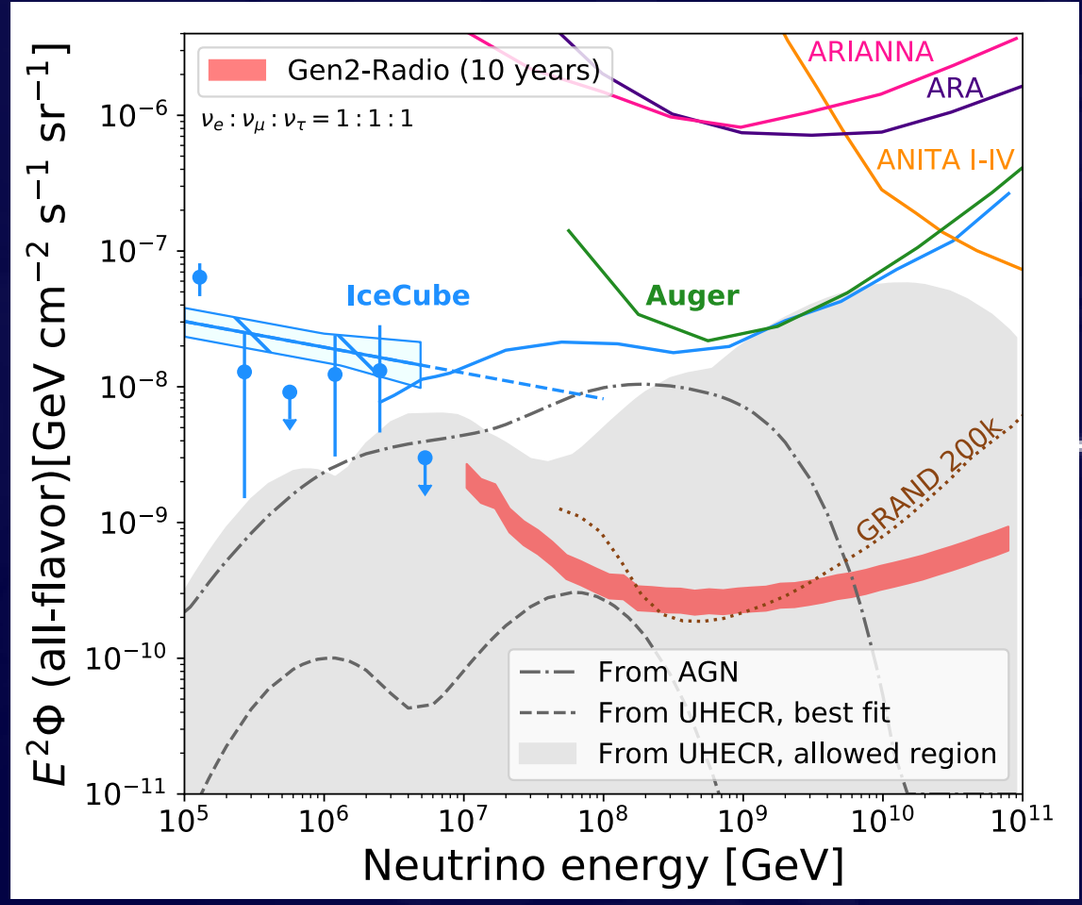
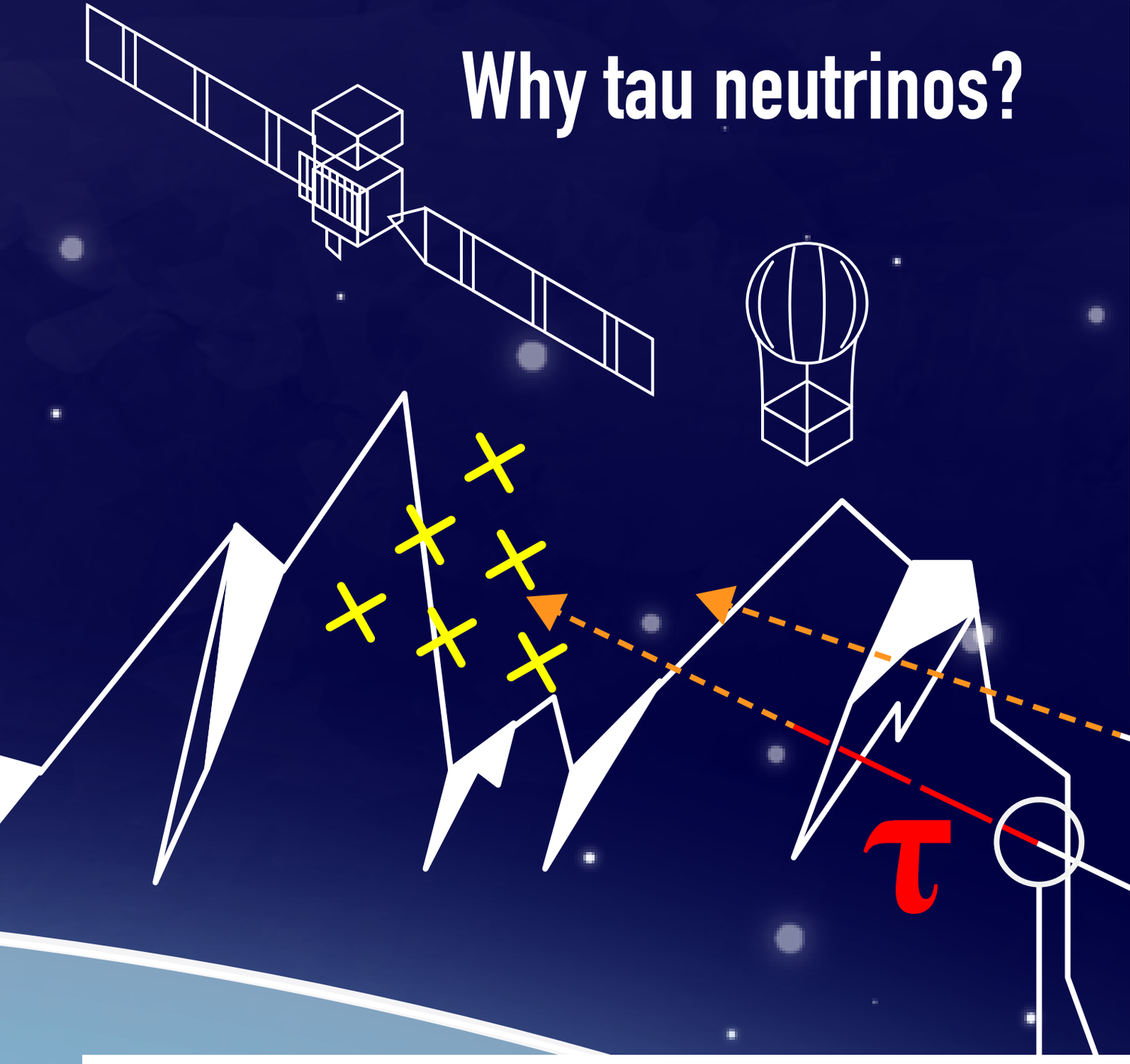
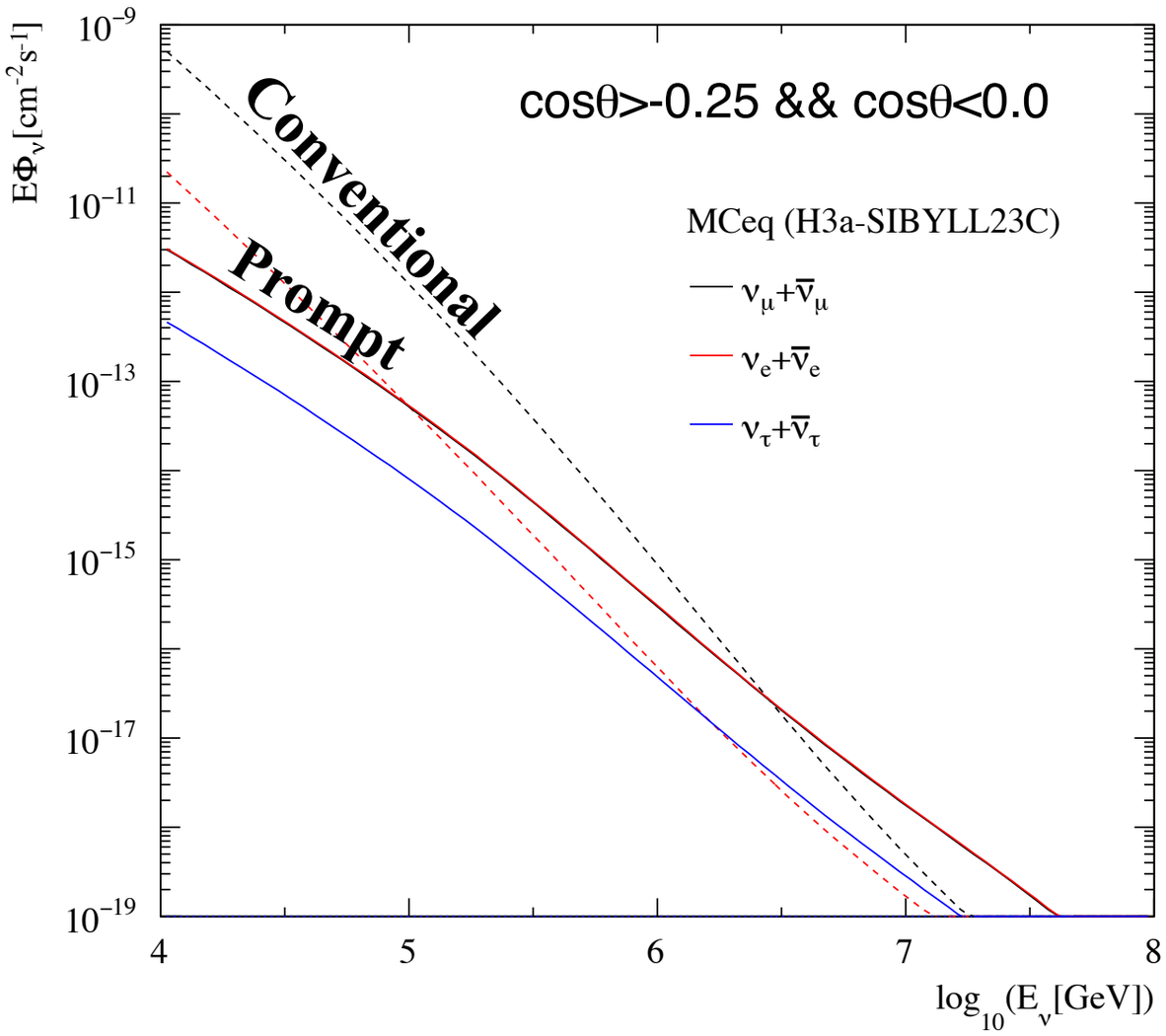




- Earth-skimming experiments can open the EeV window.
- Look for tau leptons emerging from the surface and decaying in the atmosphere.
- Constrain the origin of cosmogenic neutrinos.

Tau-neutrino backgrounds

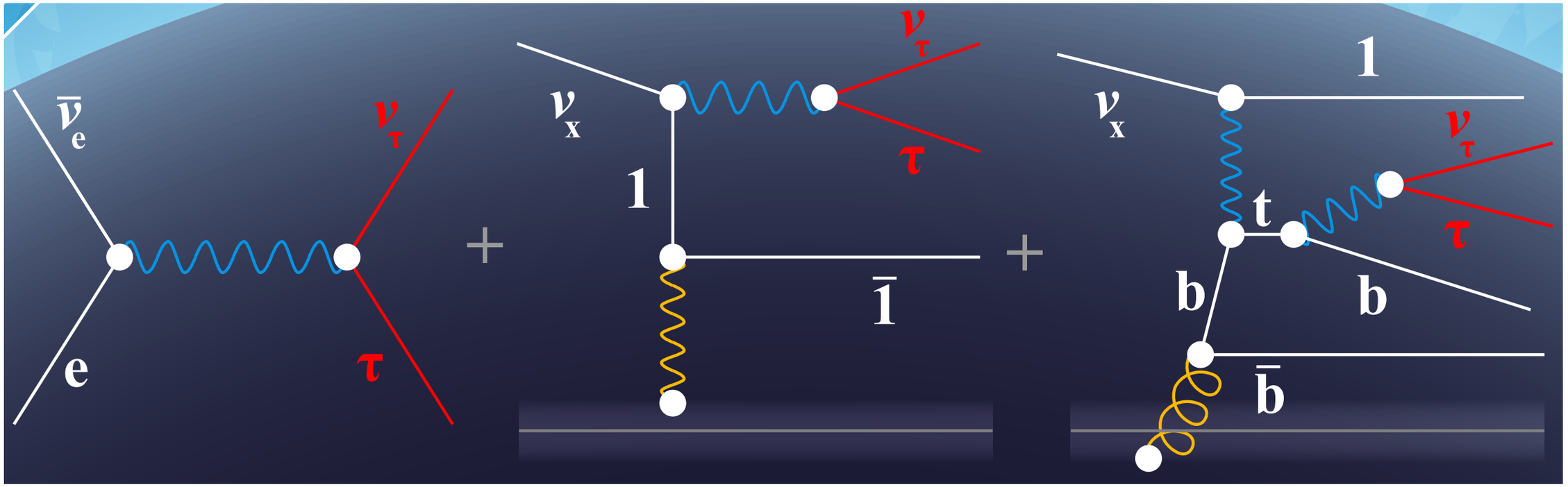
- Apart from the astrophysical tau neutrinos, are there other sources?
  - ν_X->ν_τ standard oscillations are suppressed at E>100 GeV.
  - Tau neutrinos are rarely produced in the atmosphere.
    - Prompt component: D_s^+-> $\tau\nu_\tau$ (1-5% BR)
    - Tau pair production by atmospheric muons -> O(-4) prompt.



Cosmic tau neutrinos ~background free

Tau-neutrino backgrounds

- Muon and electron neutrinos can produce $\tau\nu_\tau$ as they propagate through Earth.
- We investigate three channels:
  - W boson production.
  - Glashow resonance.
  - Top production.



arXiv:1905.03792 arXiv:1910.08090 arXiv:1908.10077

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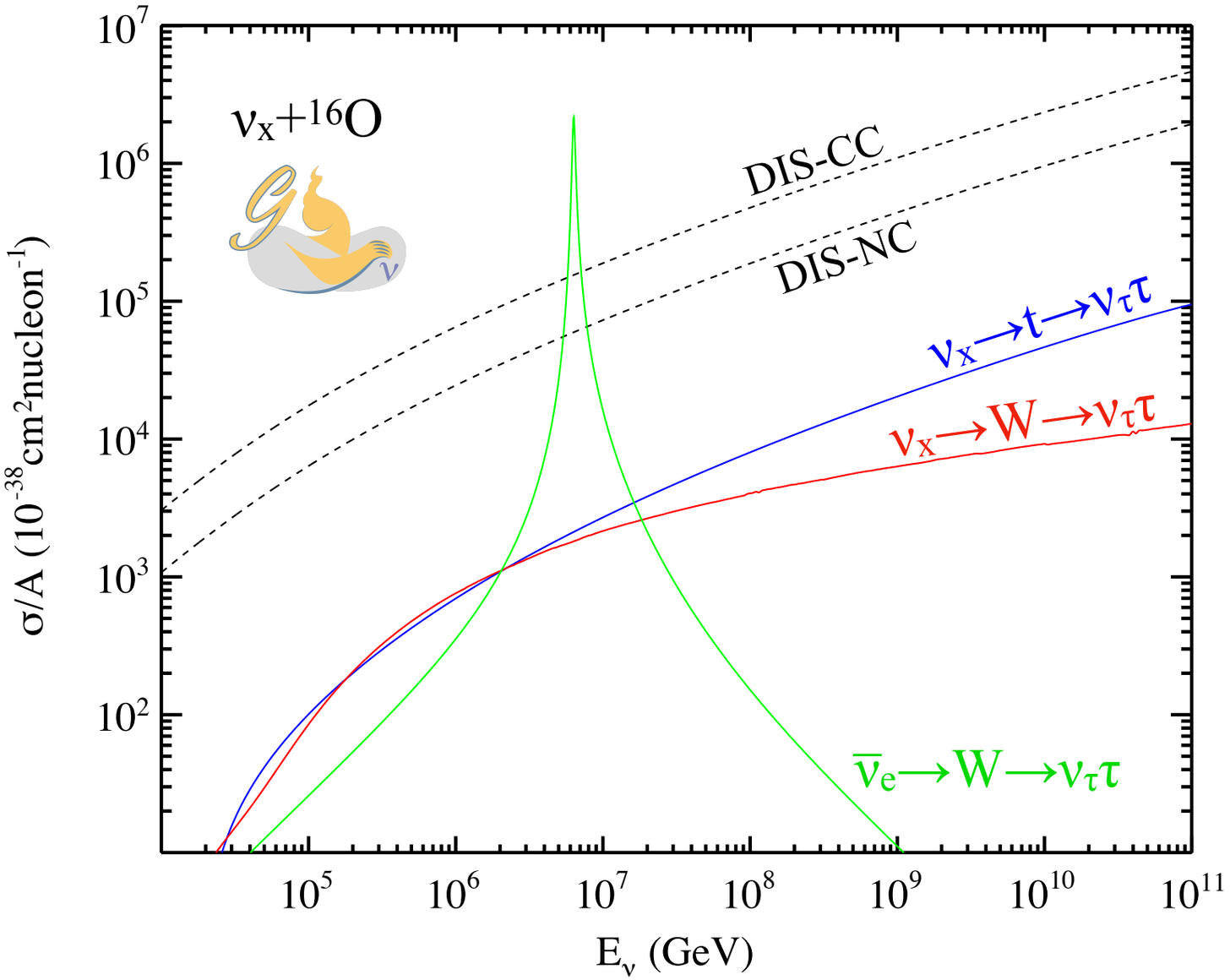
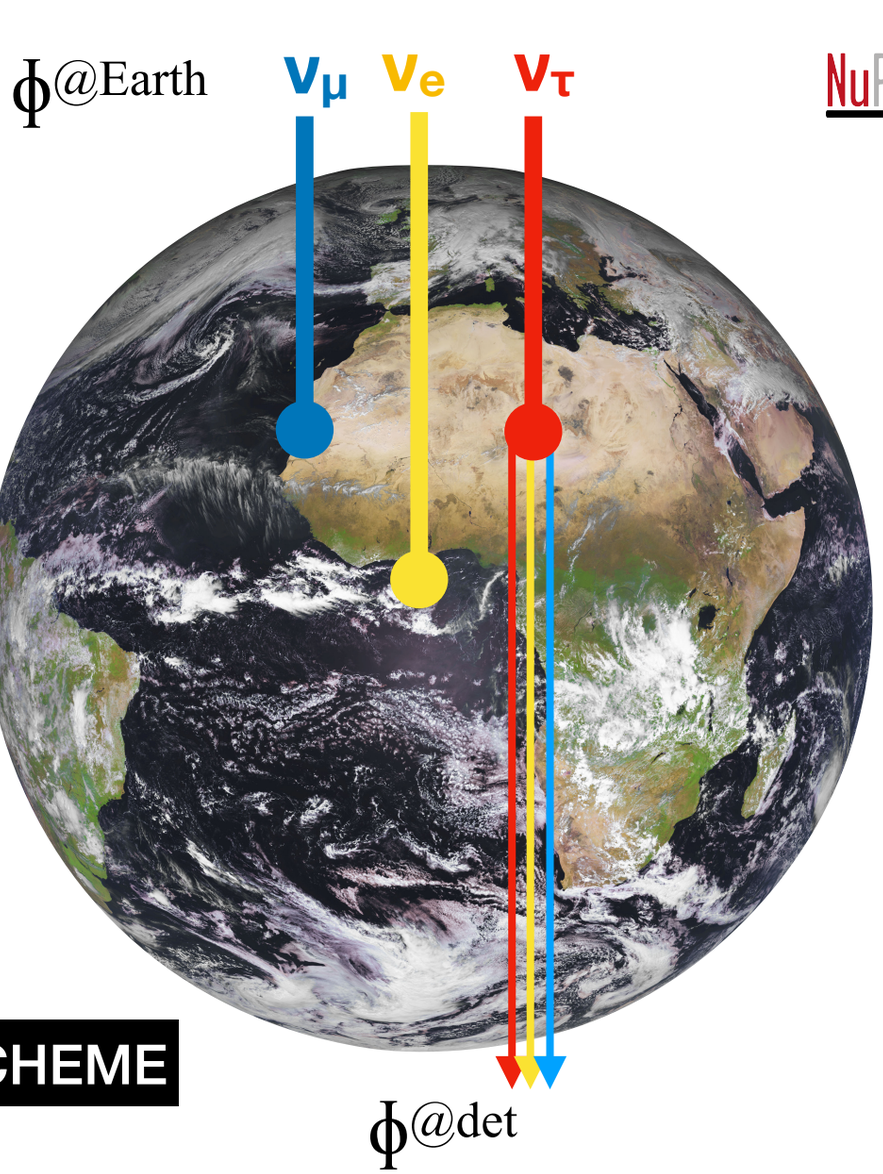
1-10% contribution at PeV-EeV energies



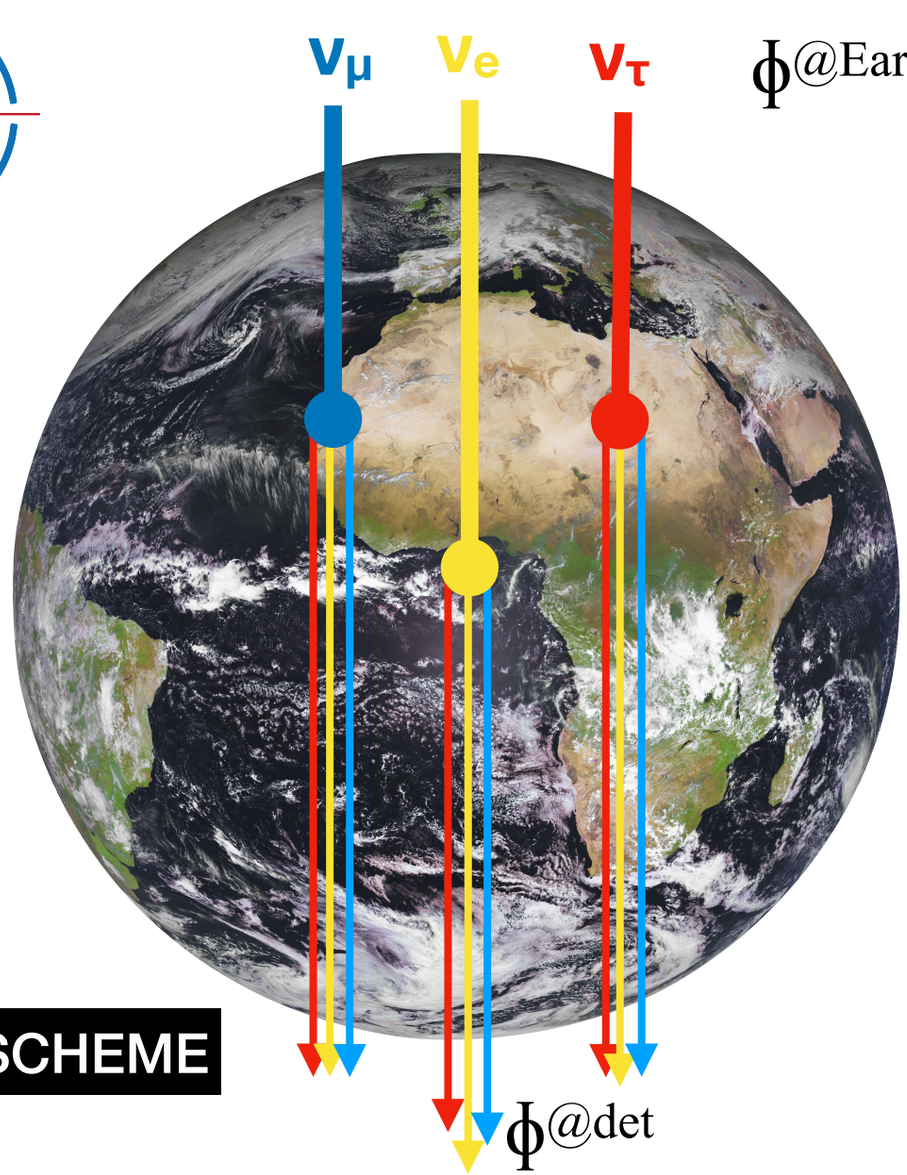
Neutrino-Earth propagation

- Use NuPropEarth to simulate the propagation of neutrinos through the Earth.
- Keep track of all neutrinos that exit including these new interactions.



OLD SCHEME

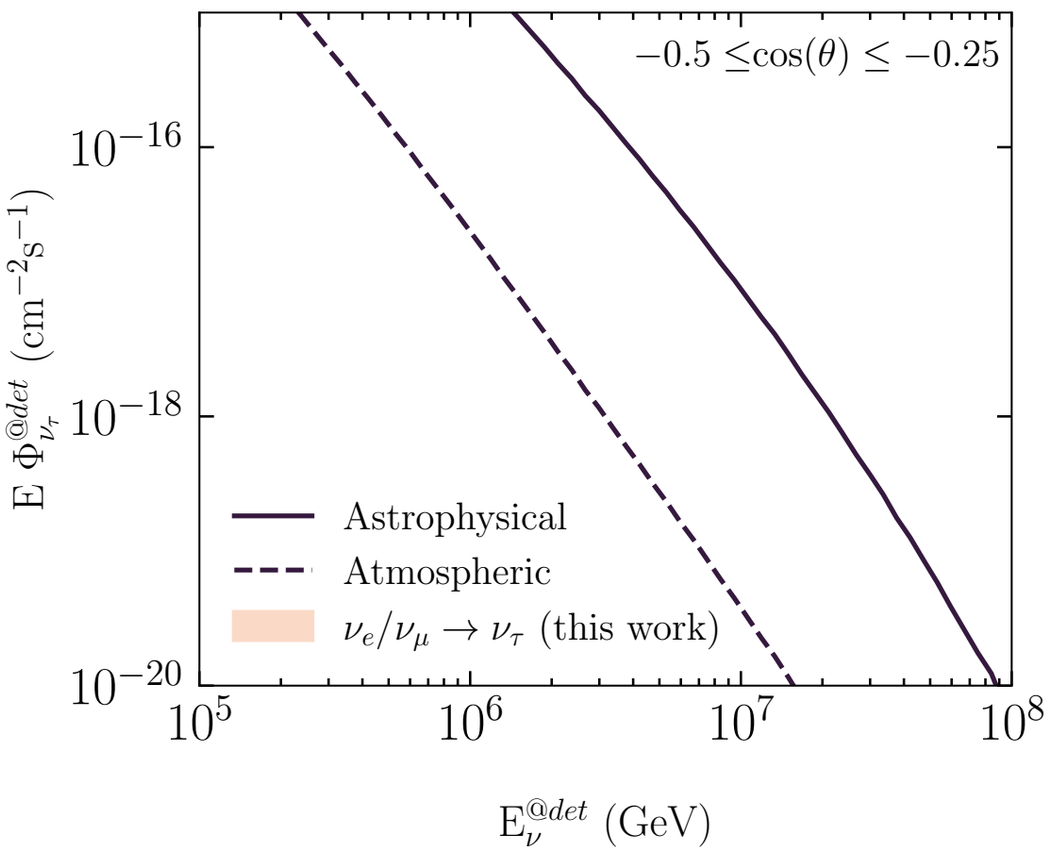
NuPropEarth

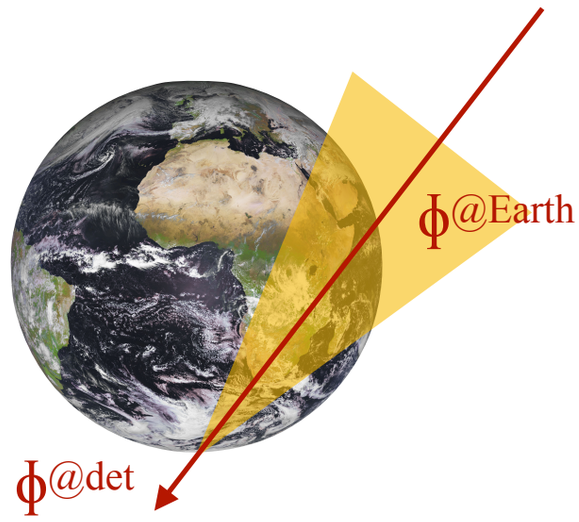


NEW SCHEME

TeV–PeV fluxes

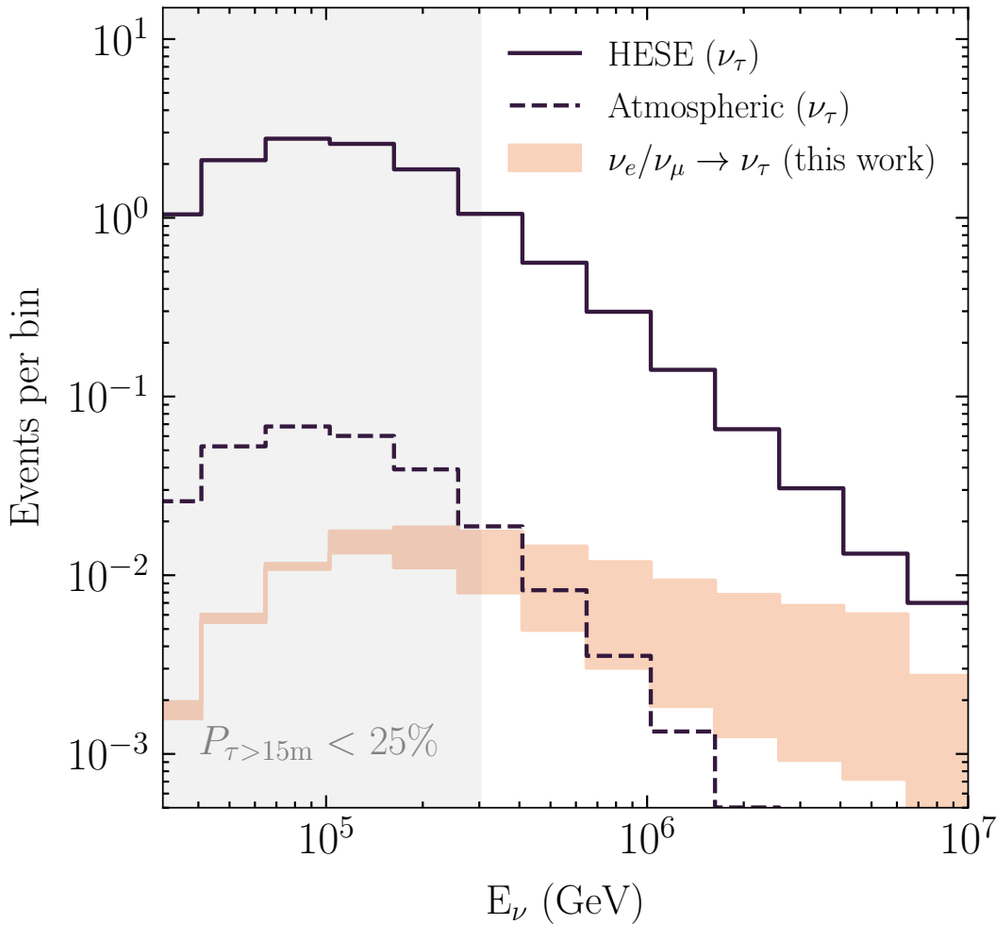
- Expected tau-neutrino flux at the detector for different components.
  - Astrophysical (best fit HESE assuming a 1:1:1 composition).
  - Atmospheric (prompt).
  - Secondary taus -> best fits from HESE&NT with different ν_e/ν_μ fractions.
- **Non primary tau flux > prompt above 300-500TeV.**
  - Relative contribution mainly depends on shape of primary ν_e/ν_μ cosmic flux.





TeV–PeV fluxes

- What is the effect of this additional contribution in IceCube?
  - Rates -> convolute these fluxes with HESE effective area.



Number of up-going tau neutrinos with 10 years of IC86*

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	10%	3.00	0.05 (4.3)	0.03-0.09 (4.1-3.7)
300 TeV	23%	1.57	0.02 (3.2)	0.02-0.07 (2.9-2.5)
400 TeV	34%	1.12	0.01 (2.7)	0.01-0.06 (2.4-2.1)

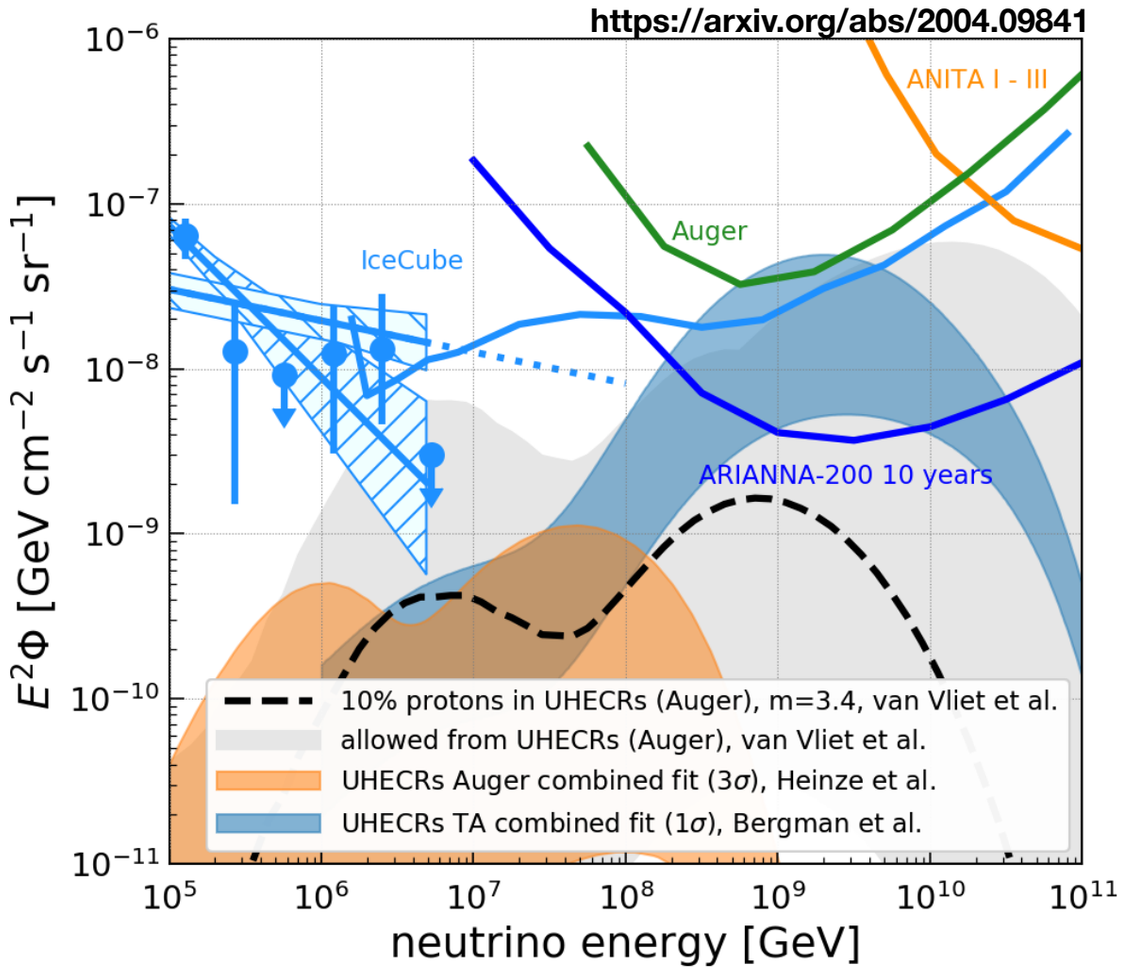
***assuming ideal ν_τ ID**

- Main background for cosmic tau searches using up-going events.
  - Capability to reject non-tau cosmic component is reduced when including this contribution.

Ultra high energy neutrinos

- UHCRs interacting with CMB -> guaranteed neutrino flux.
  - Large uncertainties due to our limited knowledge on the origin of UHECRs.
    - Primary composition.
    - Redshift evolution of the sources.

- Strongest constraints come from: IceCube Auger ANITA.



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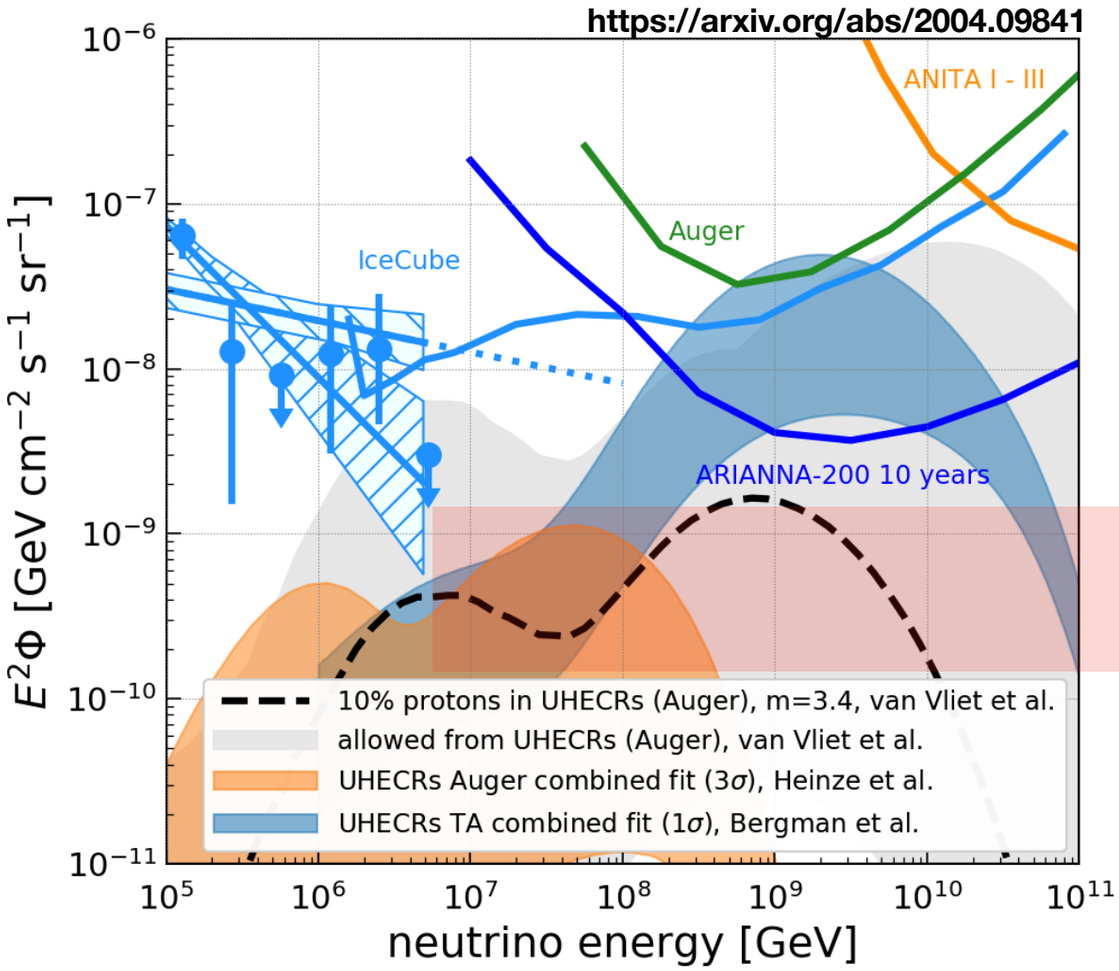


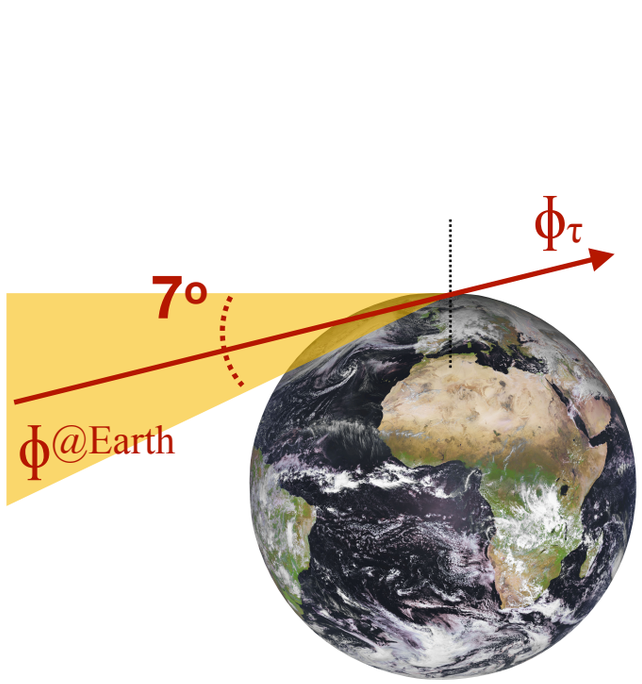
Earth-skiming technique is a game changer

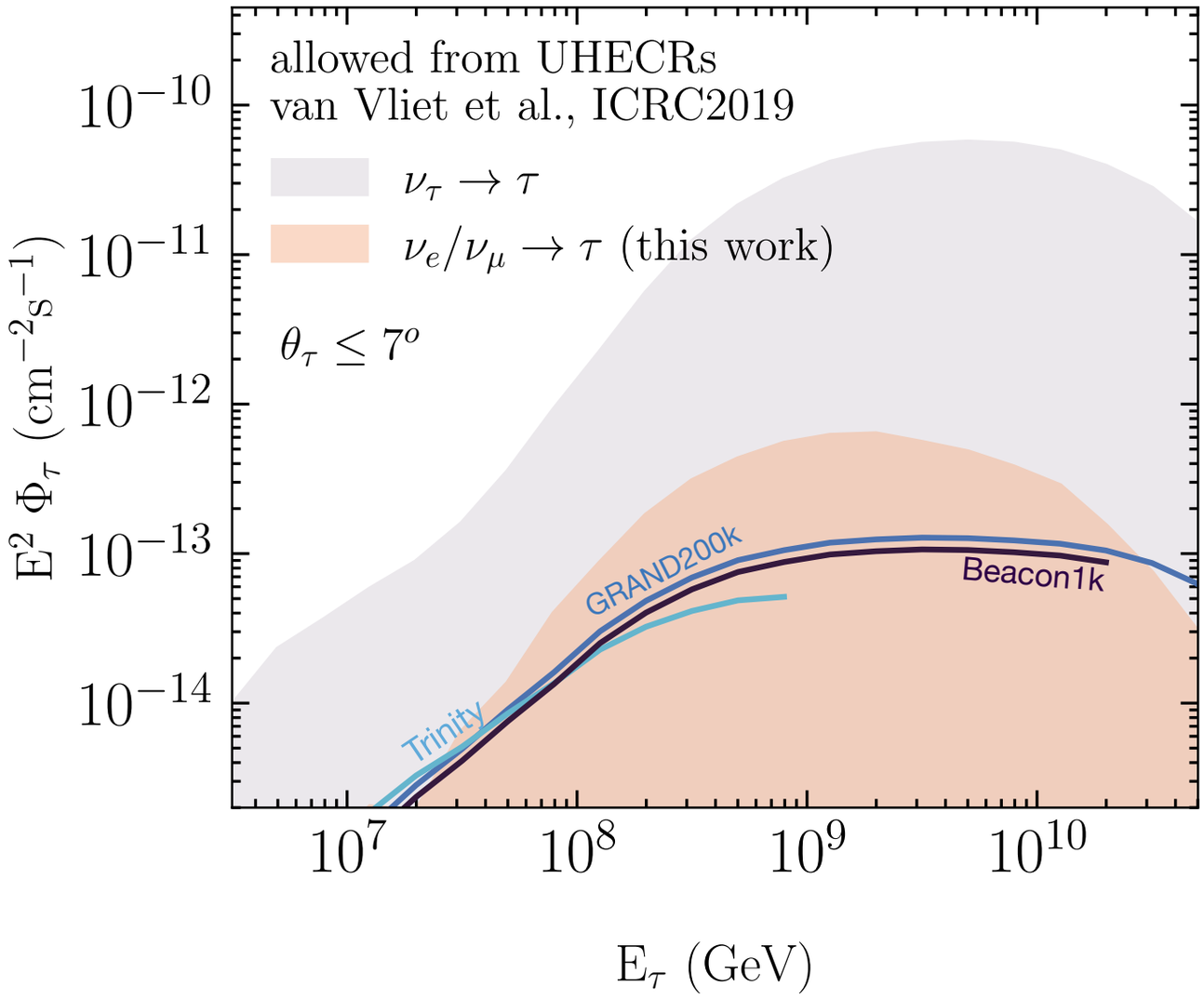
GRAND, Trinity, TAMBO, Beacon, POEMMA …

Ultra high energy neutrinos

- What if the cosmogenic flux have a zero tau-neutrino component?
  - Earth-skimming experiments could still observe tau neutrinos existing the Earth.
    - Measurement of GZK flux normalisation is degenerated.

      If taus are detected, do they come from a low (1:1:1) or a high (1:1:0) flux?





Conclusion

- The detection of high-energy tau neutrinos is one of the milestones for neutrino telescopes in the next decade.

- Estimation of novel tau-neutrino fluxes.
  - Numu/nue interactions in Earth yield a flux of up-going tau neutrinos.
  - Higher than prompt neutrino flux above few hundreds TeV.

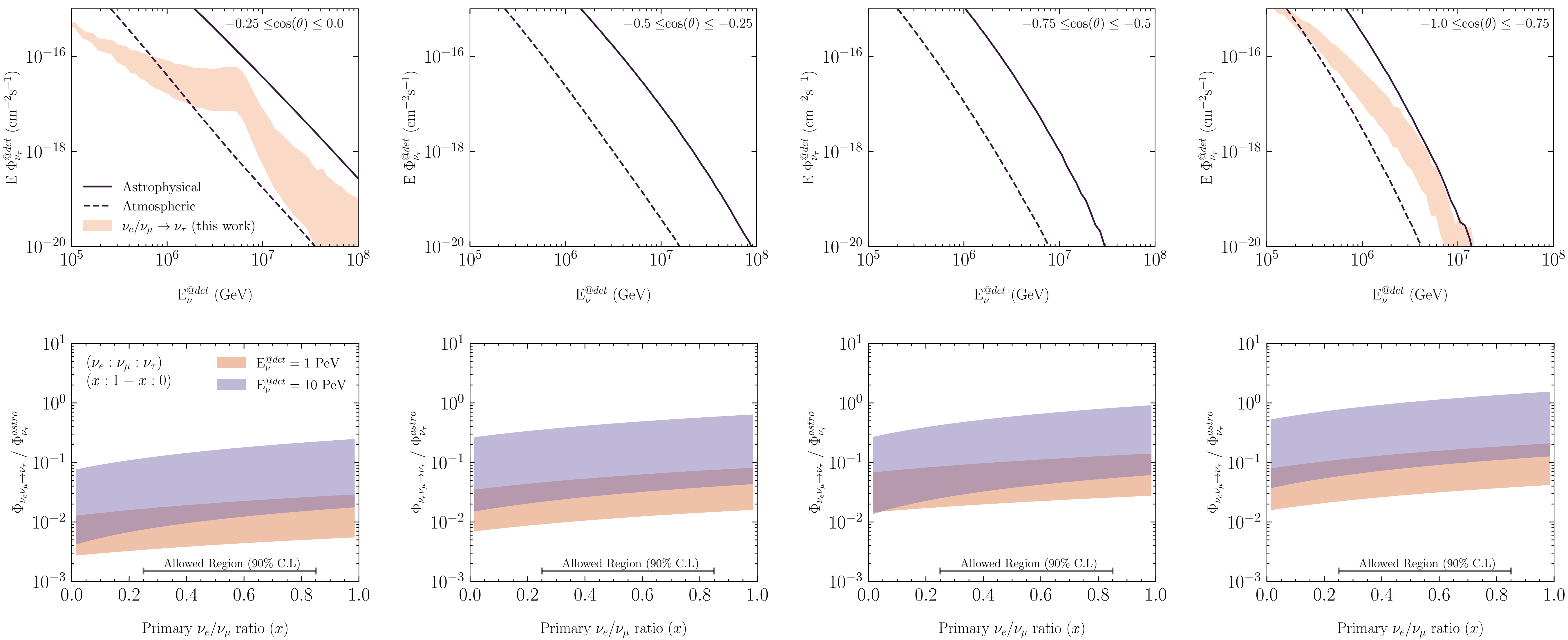
- Significant impact for tau neutrino measurements with neutrino telescopes:
  - @PeV -> alters capability to reject non tau cosmic component
  - @EeV -> Earth-skimming experiments would observe (1:1:0) cosmogenic fluxes.

References

NuPropEarth	https://github.com/pochoarus/NuPropEarth
GENIE	https://github.com/GENIE-MC/Generator
PROPOSAL	https://github.com/tudo-astroparticlephysics/PROPOSAL/tree/6.1.6
TAUOLA	https://tauolapp.web.cern.ch/tauolapp/
MCeq	https://github.com/afedynitch/MCEq
HESE 7.5y	https://github.com/icecube/HESE-7-year-data-release

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101025085.



$-0.25 \leq \cos(\theta) \leq 0.0$
$-0.5 \leq \cos(\theta) \leq -0.25$
$-0.75 \leq \cos(\theta) \leq -0.5$
$-1.0 \leq \cos(\theta) \leq -0.75$
$E\ \Phi^{@det}_{\nu_\tau}$ (cm^{-2}s^{-1})
$E^{@det}_{\nu}$ (GeV)
Astrophysical
Atmospheric
$\nu_e/\nu_\mu \rightarrow \nu_\tau$ (this work)
$(\nu_e : \nu_\mu : \nu_\tau)$
$(x : 1 - x : 0)$
$E^{@det}_{\nu} = 1$ PeV
$E^{@det}_{\nu} = 10$ PeV
$\Phi_{\nu_e\nu_\mu\rightarrow\nu_\tau} / \Phi^{astro}_{\nu_\tau}$
Allowed Region (90% C.L)
Primary ν_e/ν_μ ratio (x)