Probing Neutrino Decay Using the First Steady-State Source of High-Energy Astrophysical Neutrinos, NGC 1068

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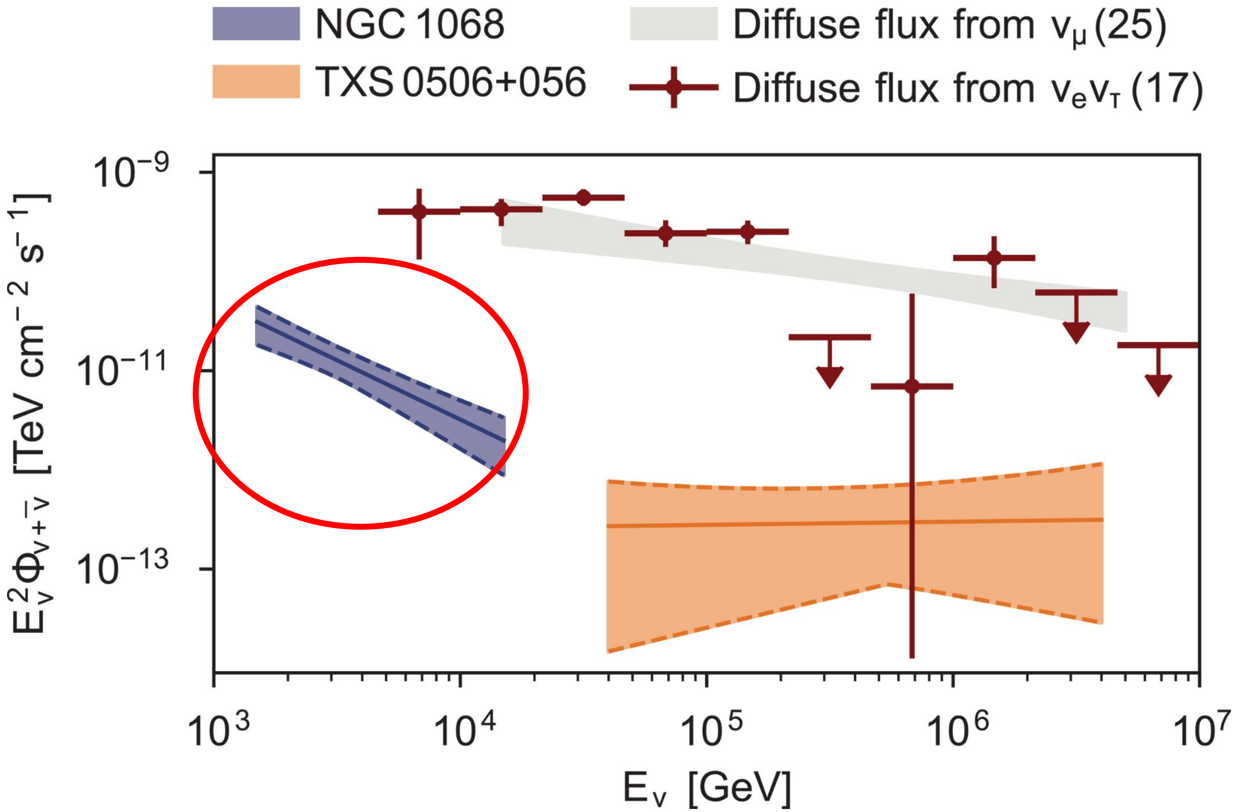
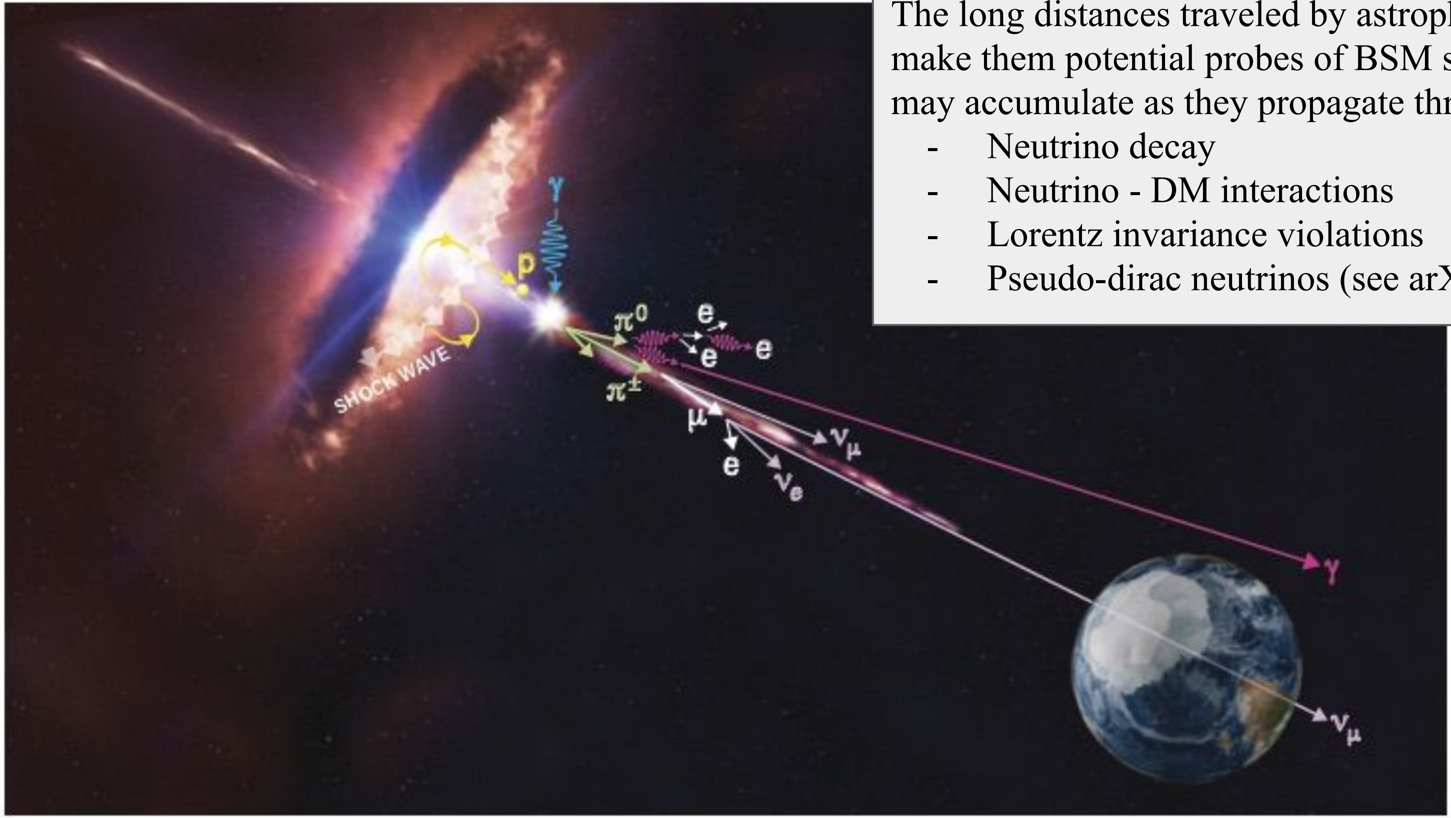
Based on ongoing work with Damiano Fiorillo, Ivan Esteban, and Mauricio Bustamante

The astrophysical neutrino landscape so far



Using NGC 1068 to probe BSM signatures



The long distances traveled by astrophysical neutrinos make them potential probes of BSM signatures, which may accumulate as they propagate through the Universe

- Neutrino decay
- Neutrino - DM interactions
- Lorentz invariance violations
- Pseudo-dirac neutrinos (see arXiv: 2212.00737)

Hints of neutrino decay

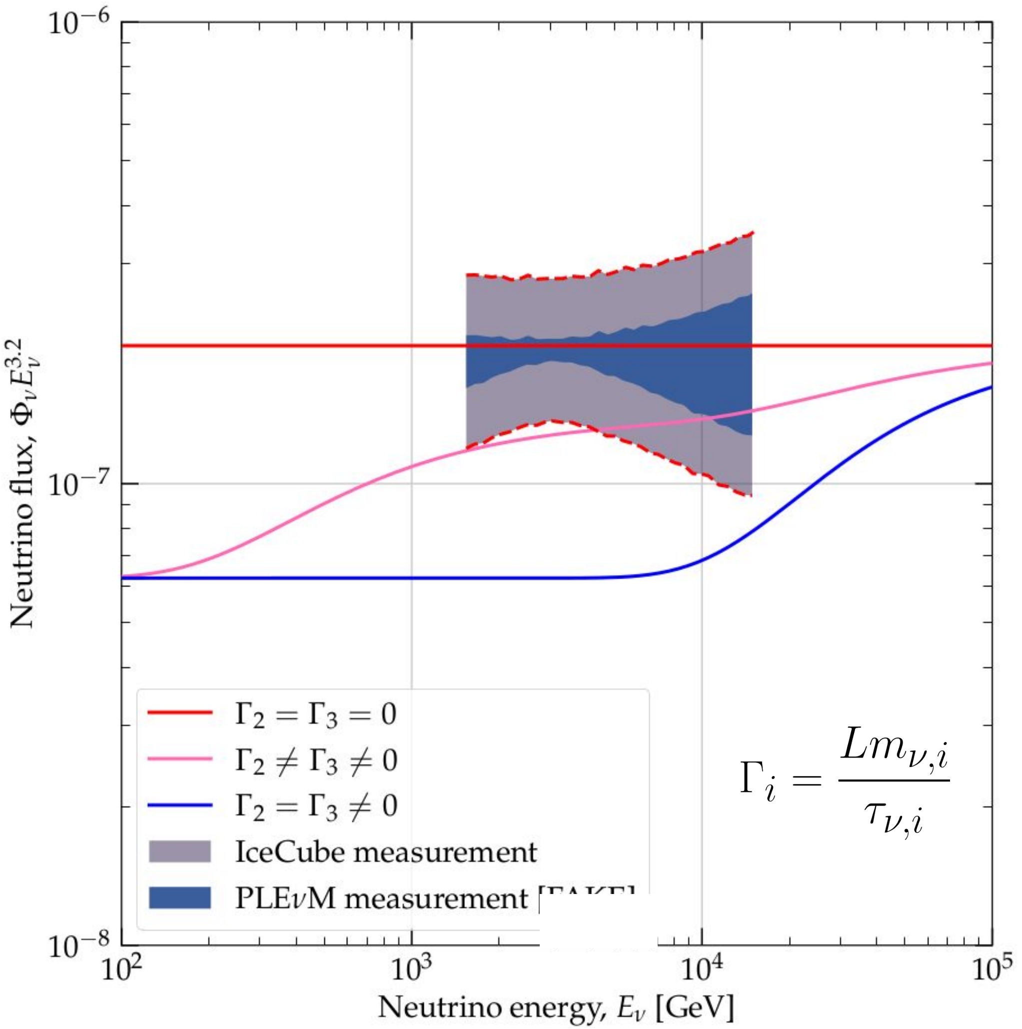
We consider invisible decay of ν_2, ν_3

$$\Phi_\beta(E) = \sum_{\alpha,i} |U_{\alpha i}|^2 |U_{\beta i}|^2 \frac{1}{4\pi r^2} \frac{dN_\alpha}{dE_\nu dt} \exp\left[-\frac{L m_i}{E_\nu \tau_i}\right]$$

Se we expect a sizable number of neutrinos to decay if

$$\frac{L}{\tau_\nu} \frac{m_\nu}{E_\nu} \gtrsim 1$$

Even though it seems like the jump feature could be visible, when including nuisance parameters, the sensitivity is washed out.



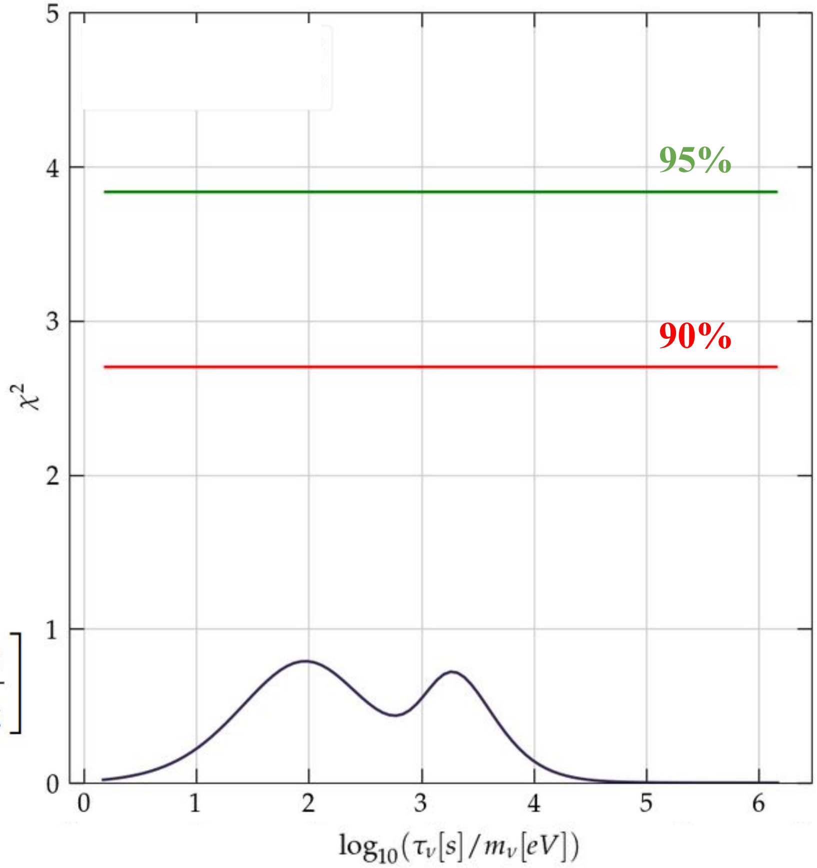
$$\Gamma_i = \frac{L m_{\nu,i}}{\tau_{\nu,i}}$$

IceCube alone has not sensitivity to neutrino decay features

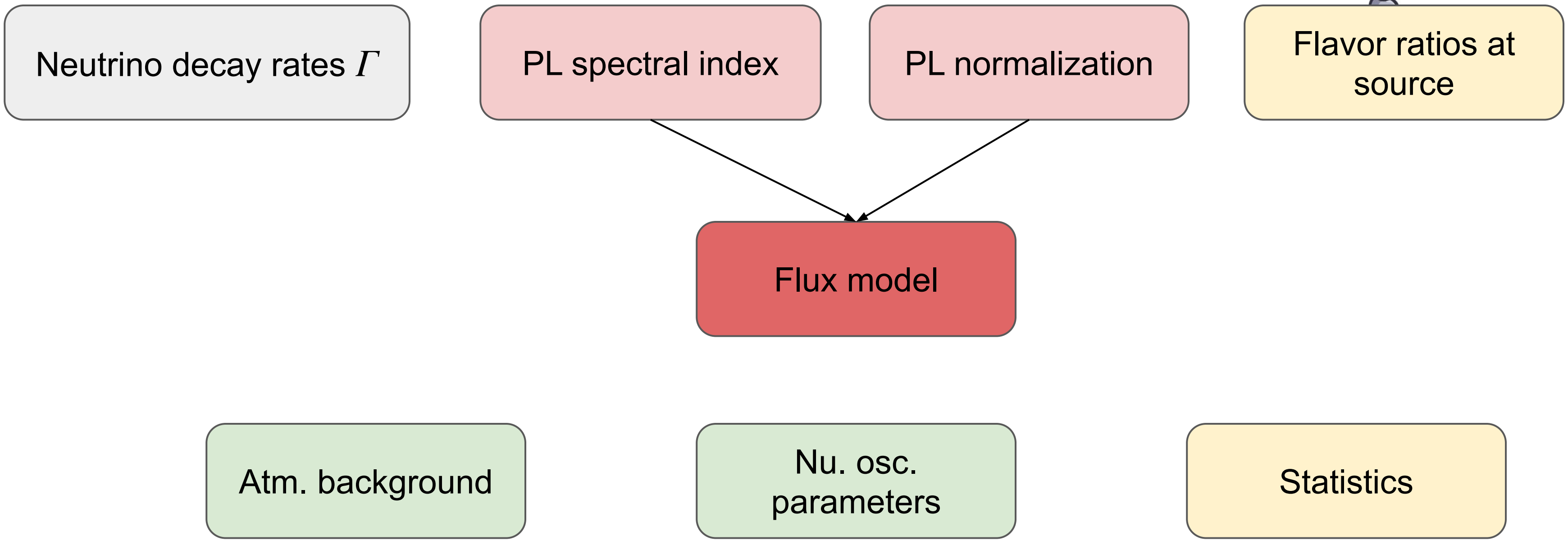
Parameters of the model:

- Neutrino decay rates Γ
- Power law spectral index
- Power law normalization
- Atmospheric background normalization
- Oscillation parameters (NuFit 5.2)
- Flavor ratios at the source

$$\Phi_\beta(E) = \sum_{\alpha,i} |U_{\alpha i}|^2 |U_{\beta i}|^2 \frac{1}{4\pi r^2} \frac{dN_\alpha}{dE_\nu dt} \exp\left[-\frac{Lm_i}{E_\nu \tau_i}\right]$$



How can we improve this situation?
Can we improve this situation?



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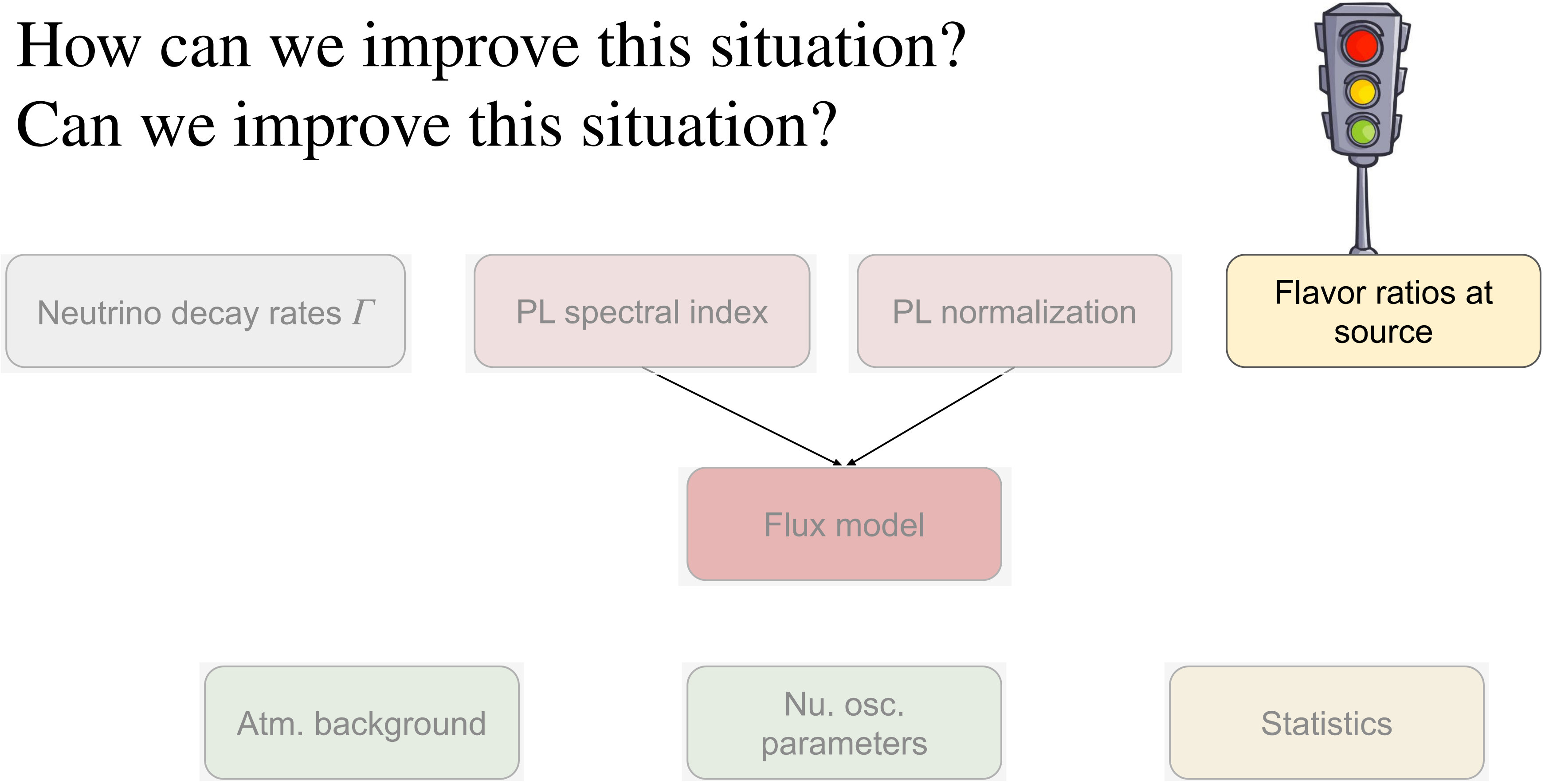
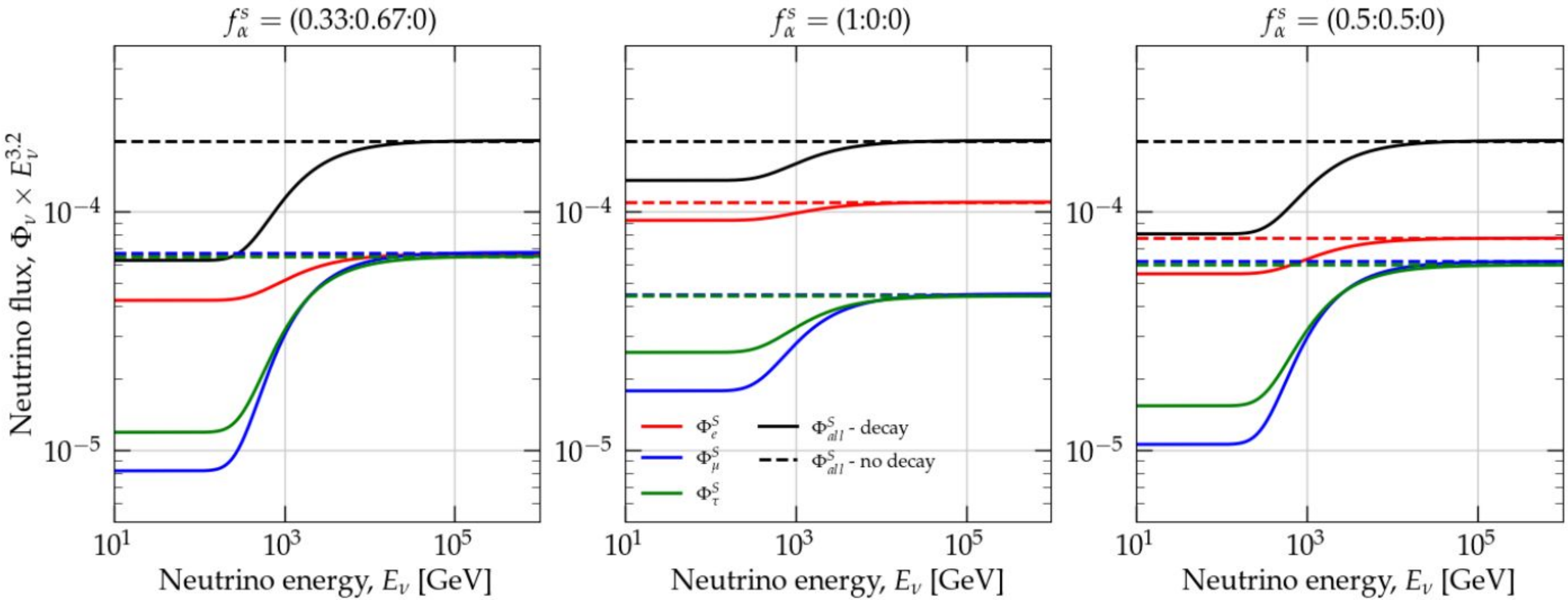


Brief comment of flavor composition at source

When using “tracks”, IceCube sees muon neutrinos (CC interactions) + 17% of tau neutrinos (CC interactions)

Photo-hadronic production | Beta decay (neutron decay) | Leptonic production **(2305.06375)**



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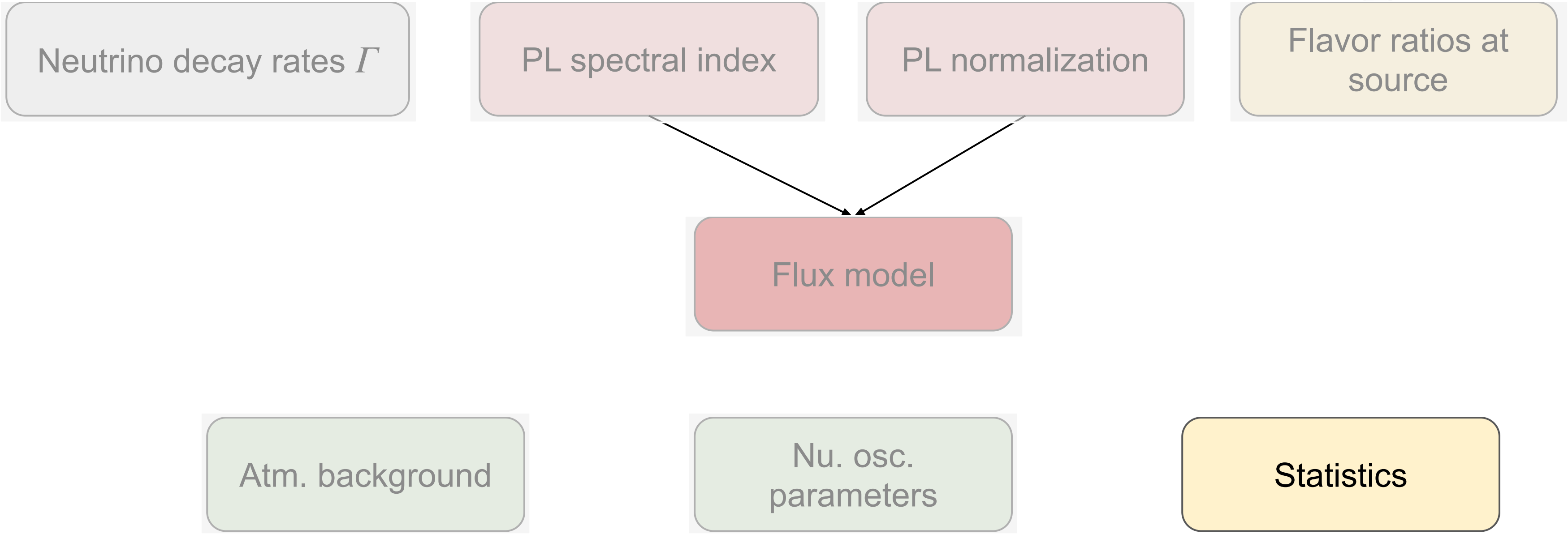
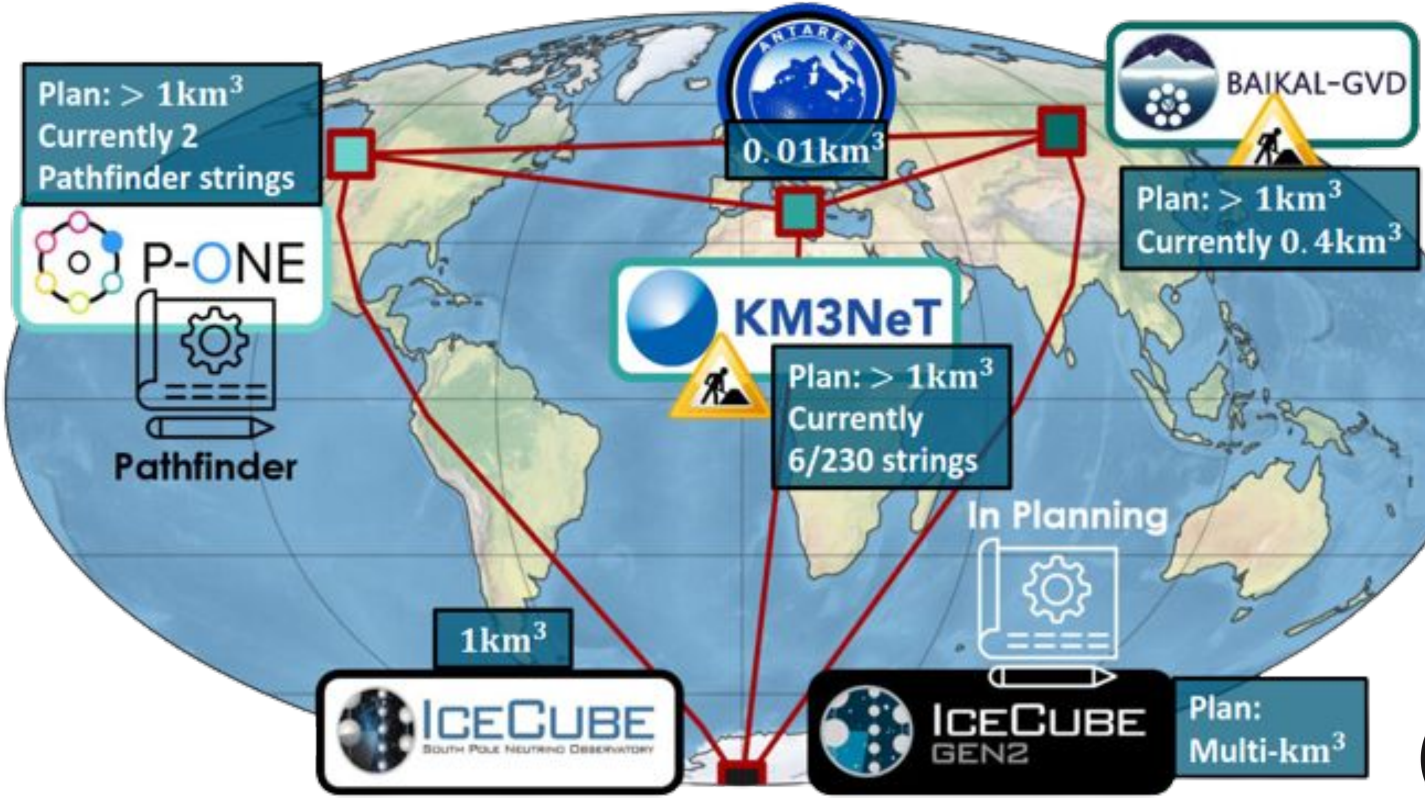


PLEνM: PLanEtary neutrino (ν) Monitoring system

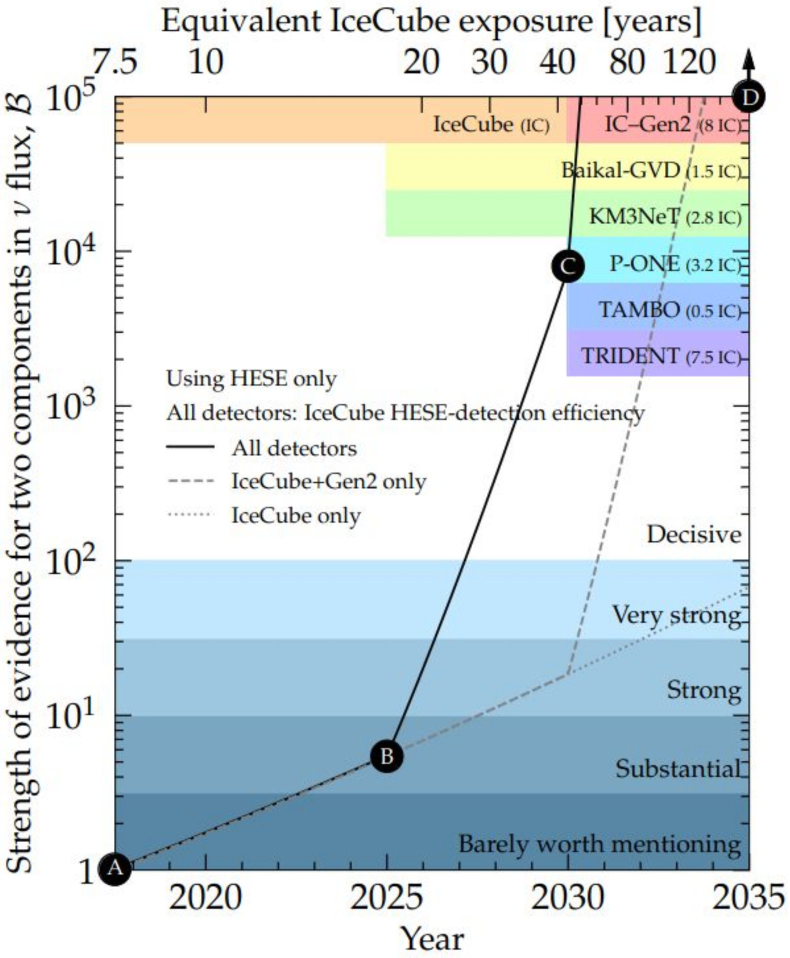


10 years of PLEνM are like 180 years of IceCube

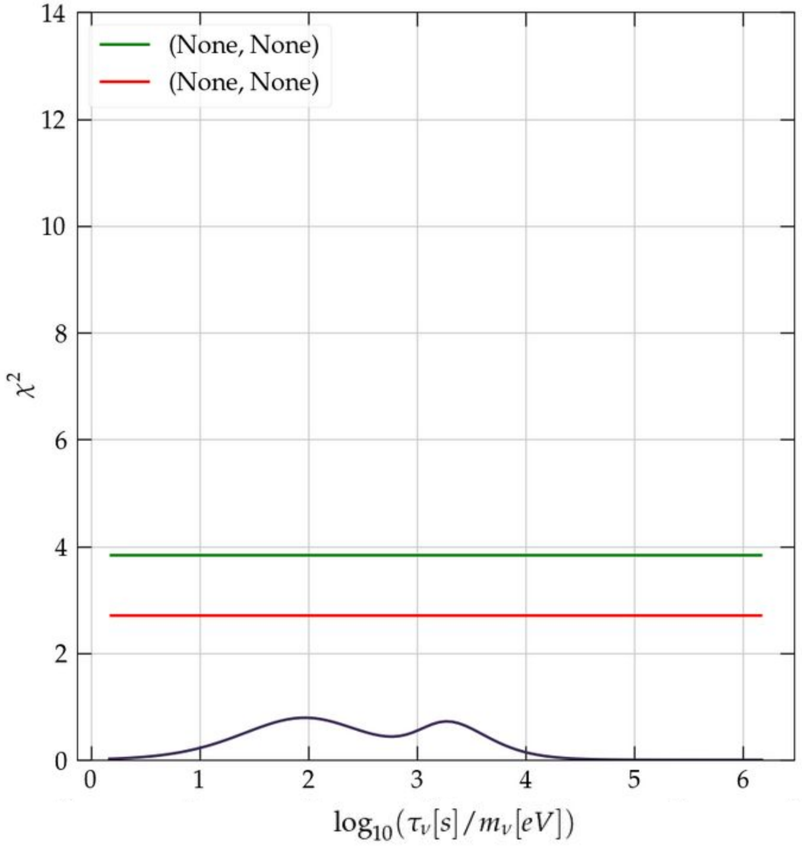
Lisa Schumacher
PLEnuM-group / **Plenum**

The power of PLEνM

In a different study led by Damiano Fiorillo, looking for spectral features beyond the single power law, he illustrates the power of PLEνM in this plot



What happens to our sensitivity when adding PLEνM



$\log_{10}(\tau_\nu[s]/m_\nu[eV])$

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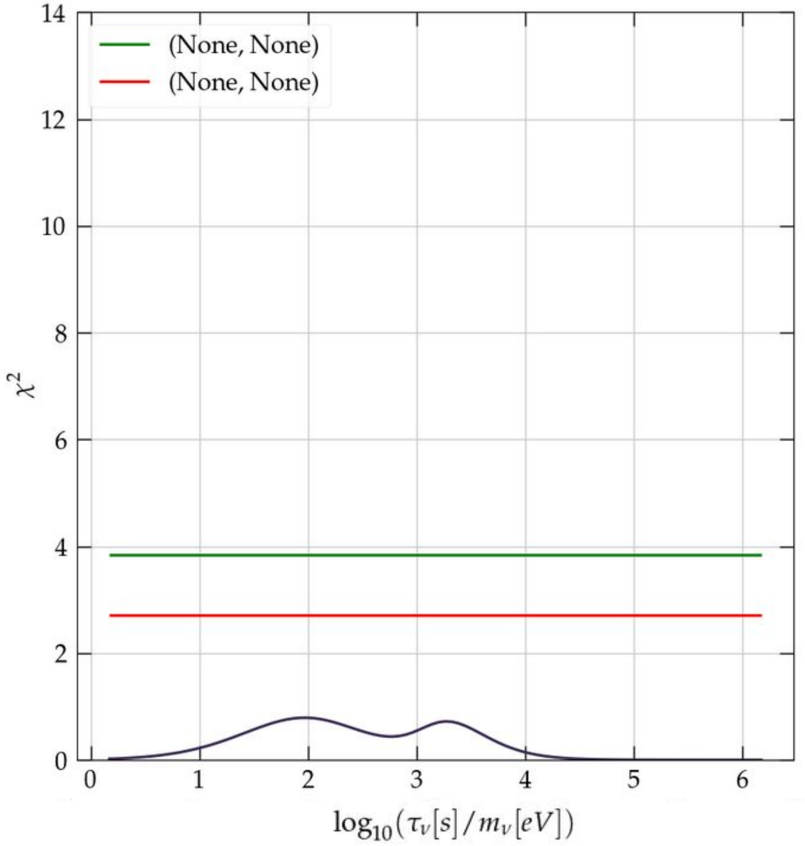
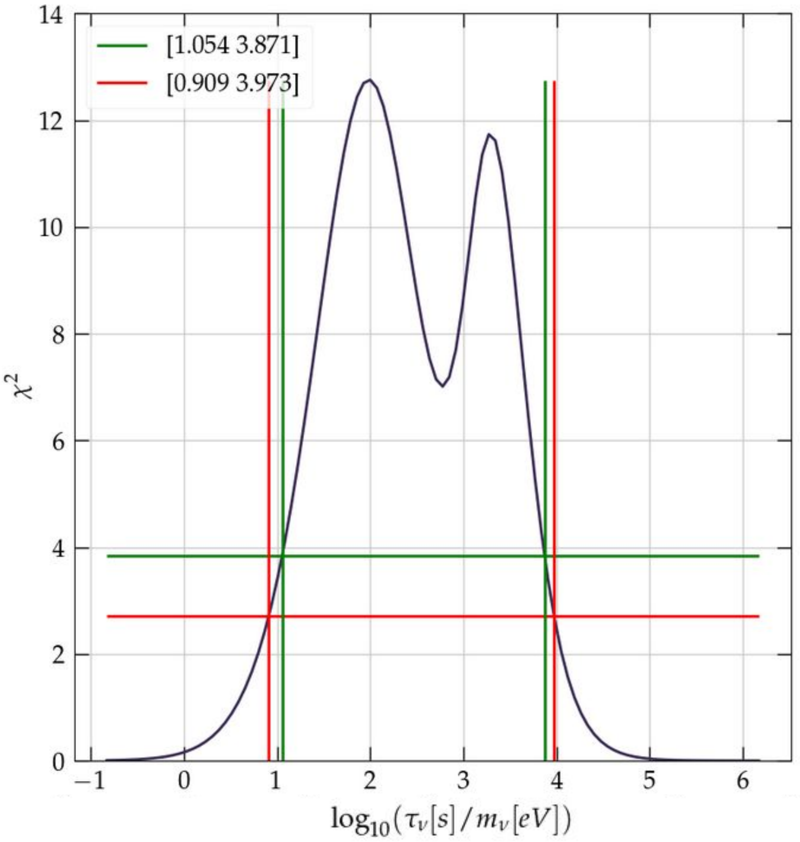
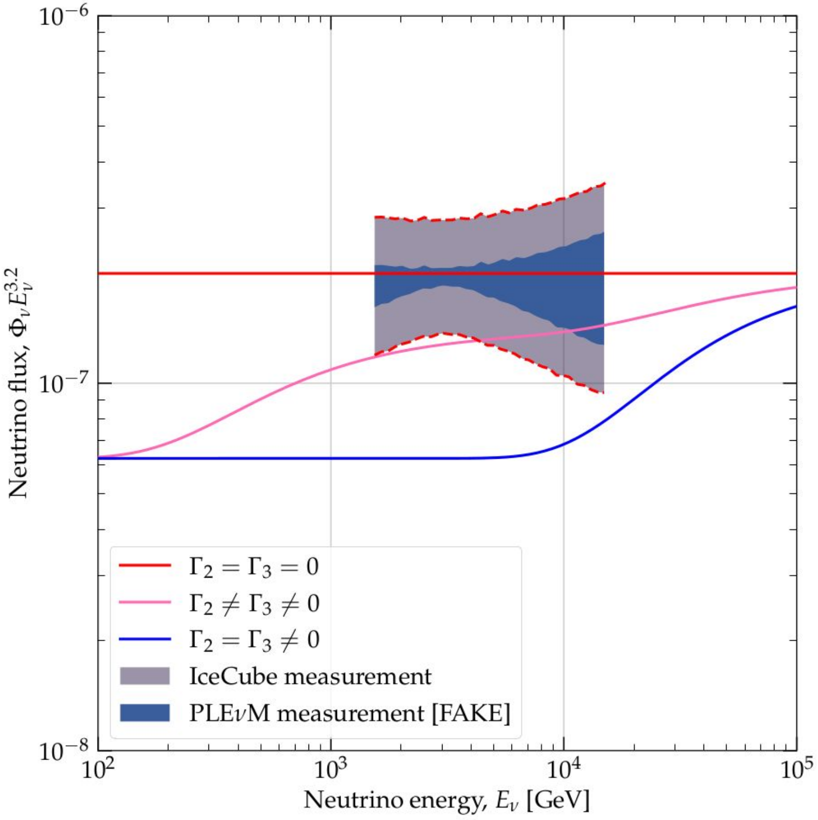
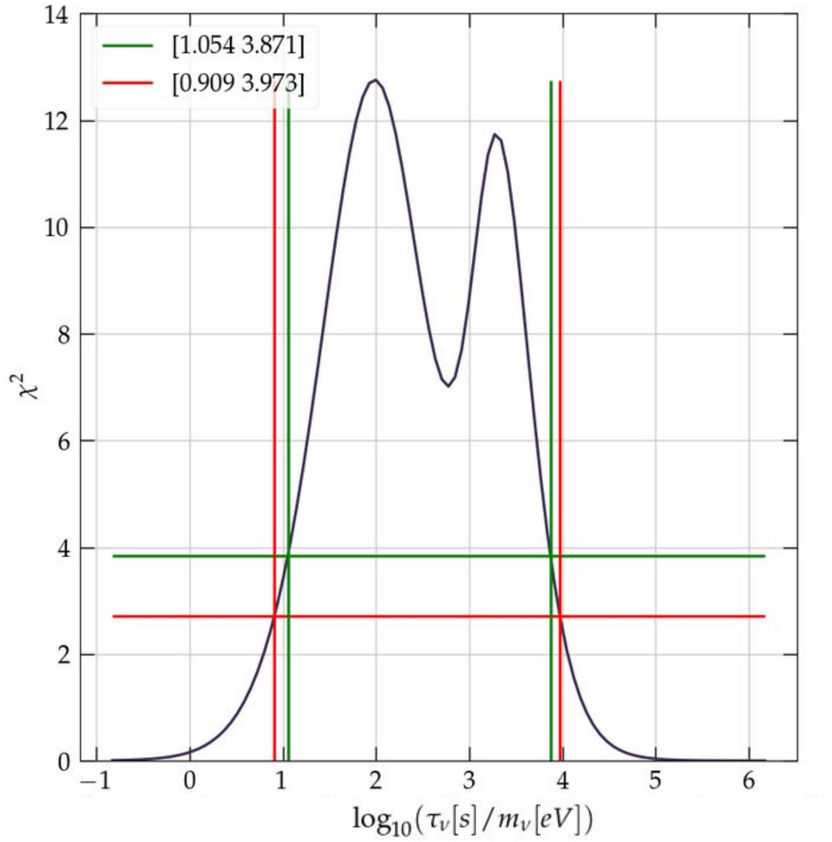


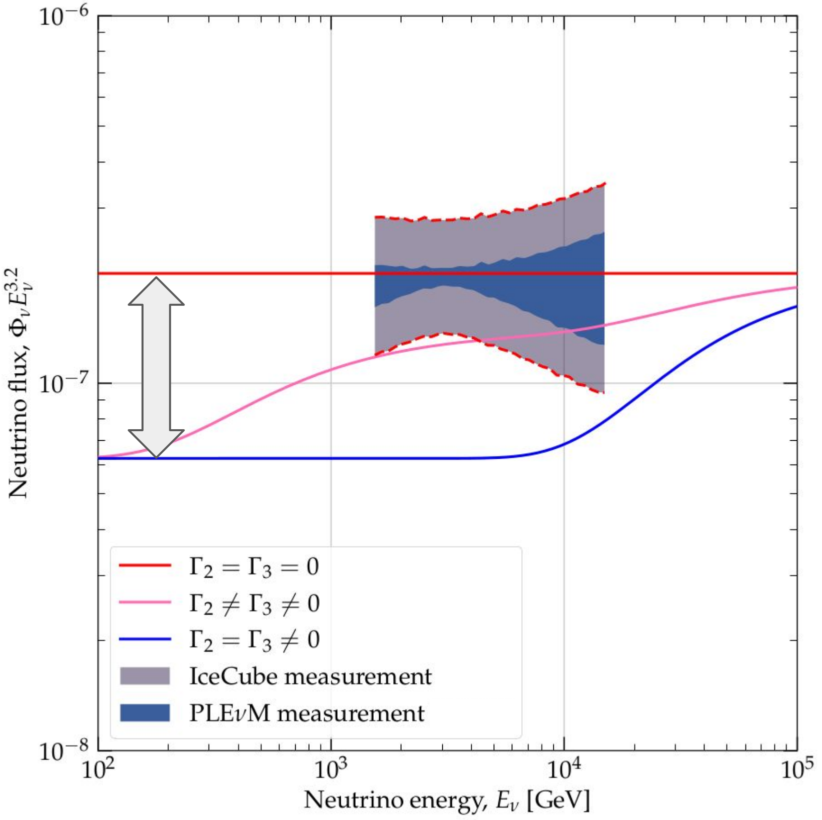


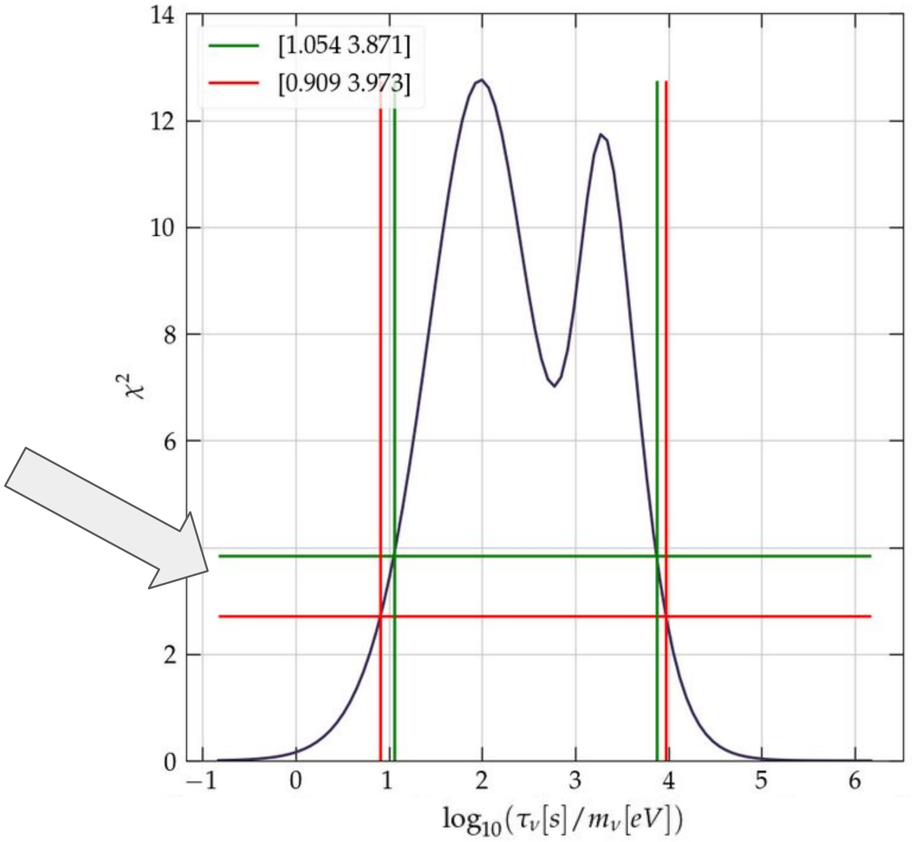
What extra information can we exploit?





Understanding the dynamics of the source to constrain the overall flux normalization





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Neutrino decay rates Γ

PL spectral index

PL normalization

Flavor ratios at source

Flux model

Atm. background

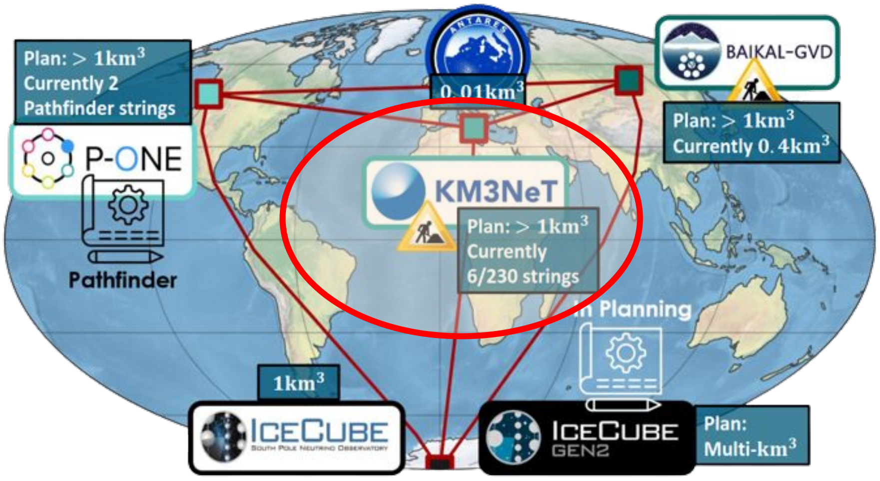
Nu. osc. parameters

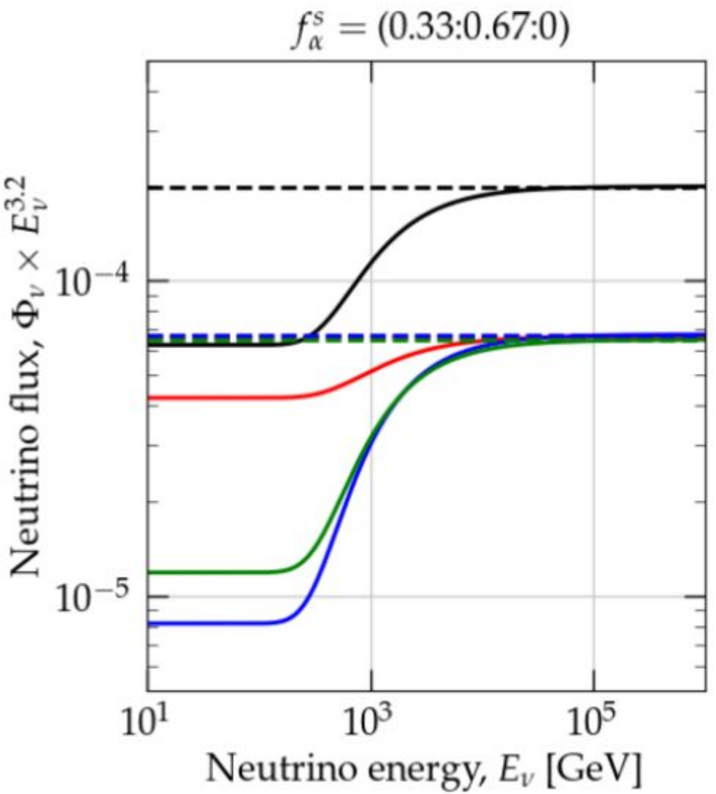
Statistics

KM3NeT could have the key for flavor explorations

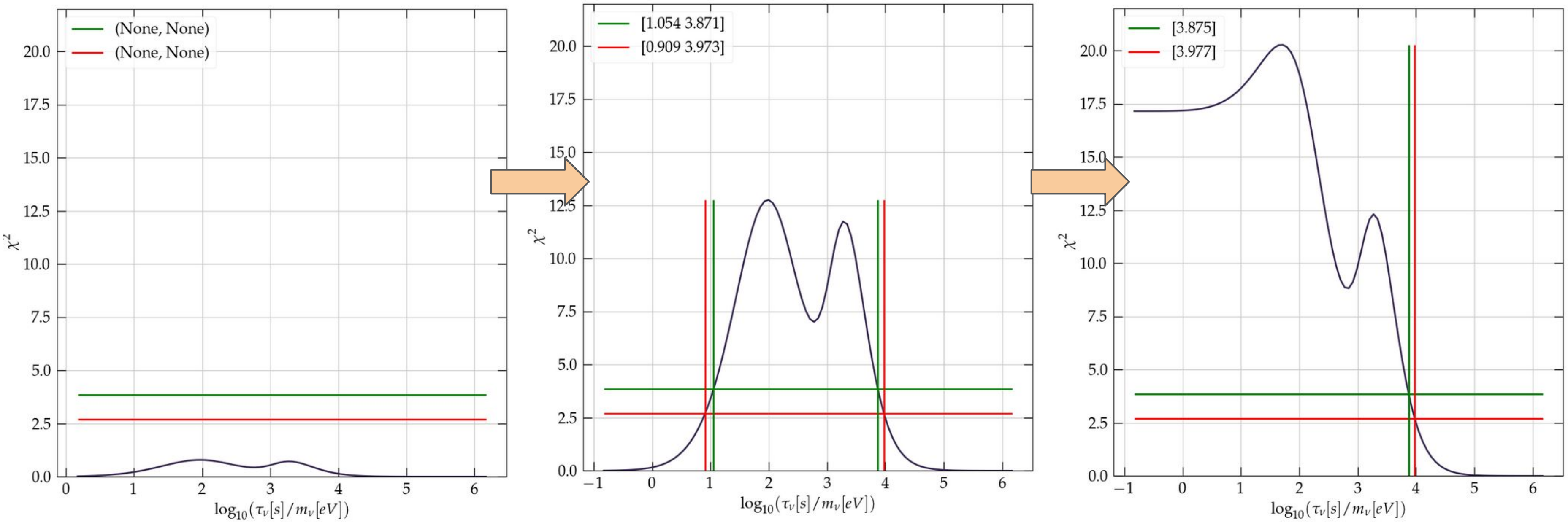
The renormalization jump to reconcile quick decays with the null hypothesis is different for muon neutrinos and electron neutrinos.

- Angular resolution is bad but not terrible (3° - 10°)
- Atmospheric background is smaller (~1/3)
- Comparable signal-to-noise ratio

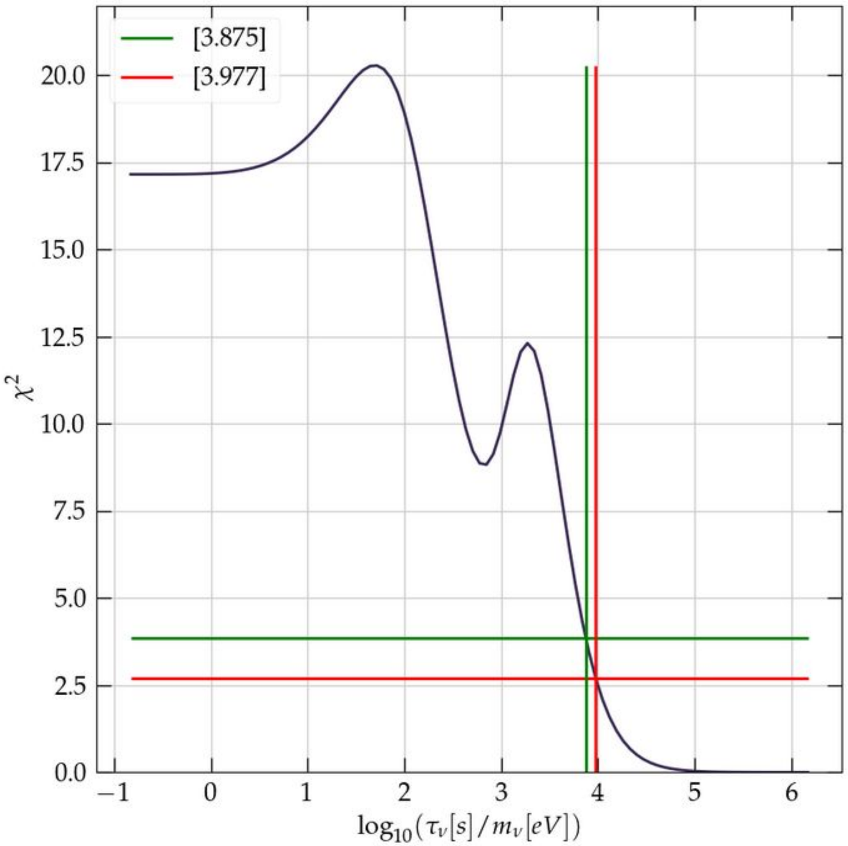


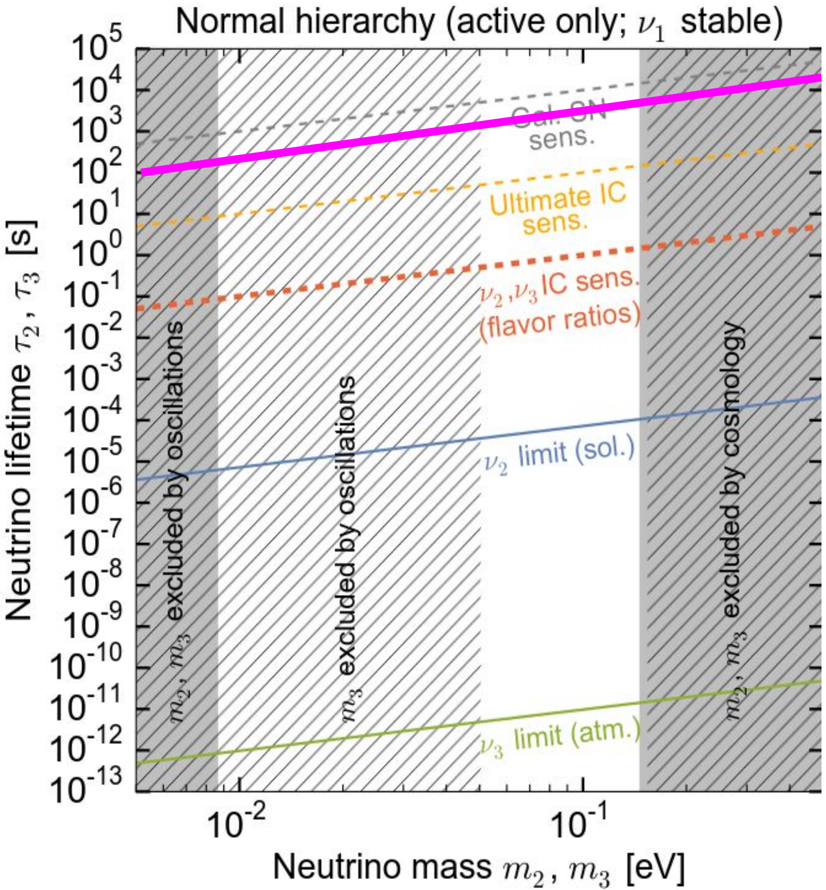


How this impact the results



Competitive results in the context of current and future bounds





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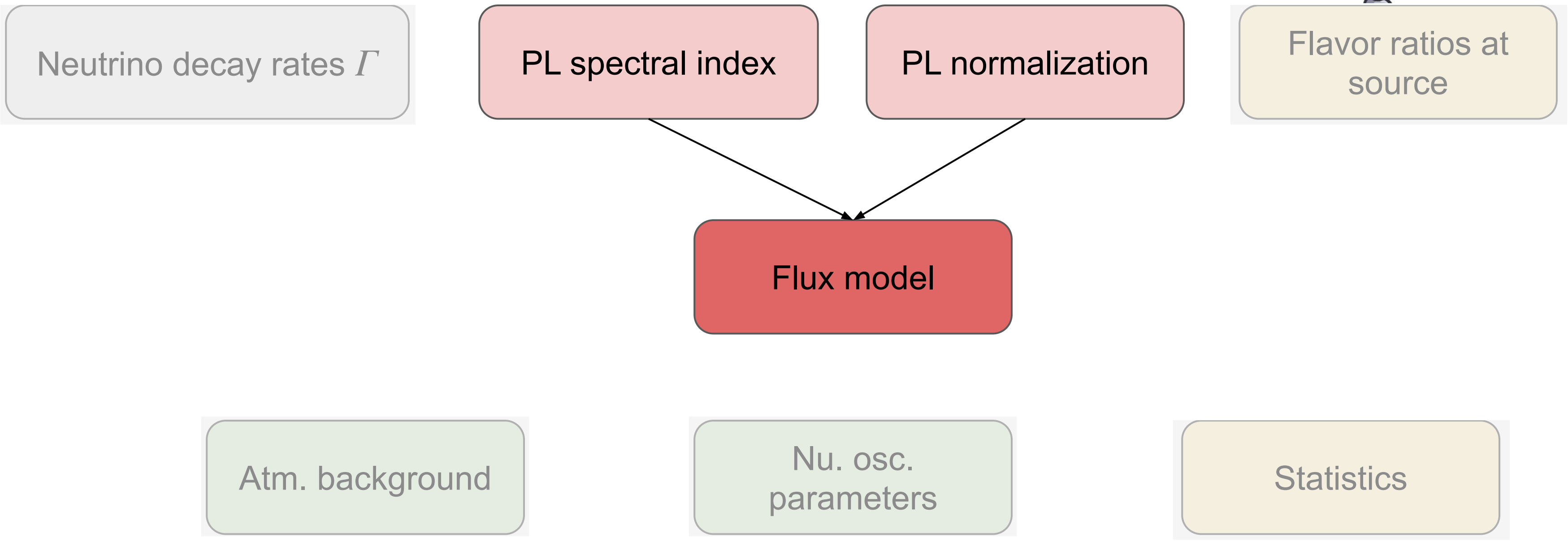

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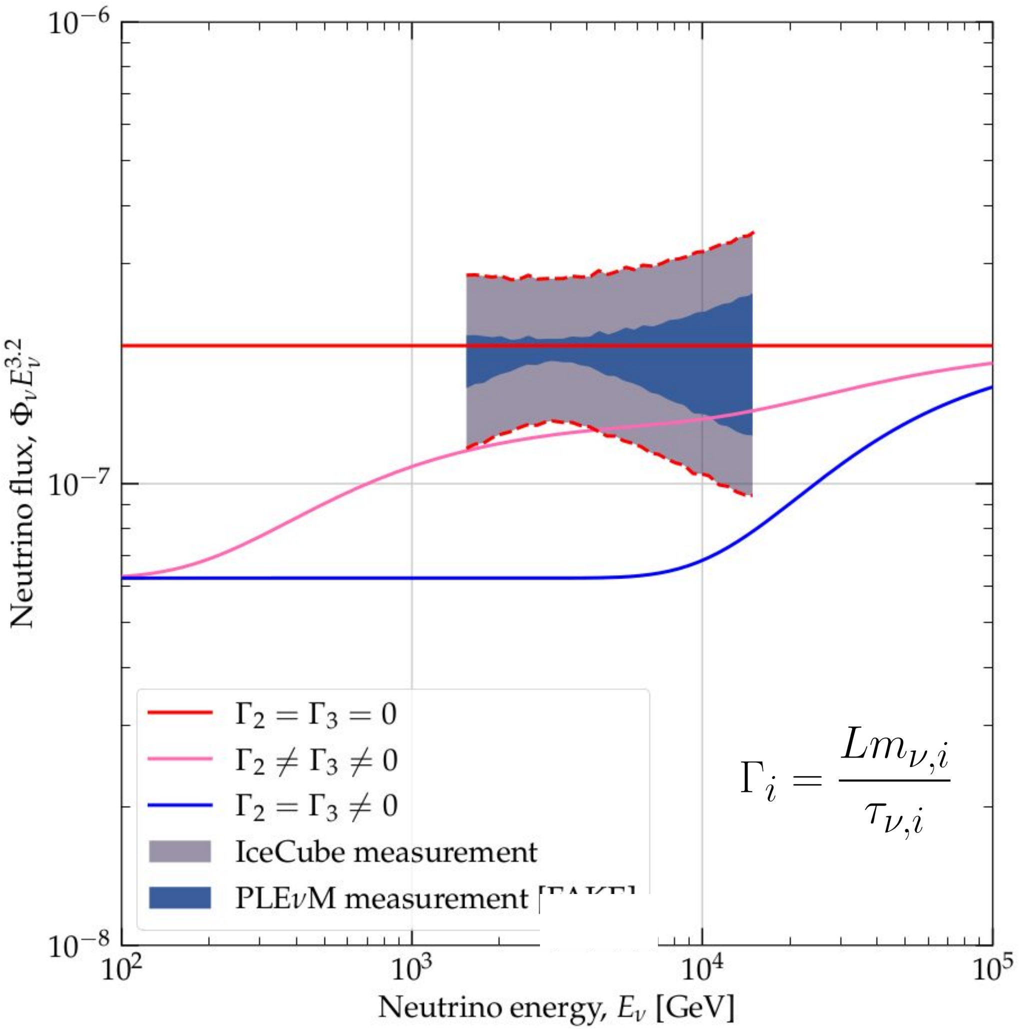
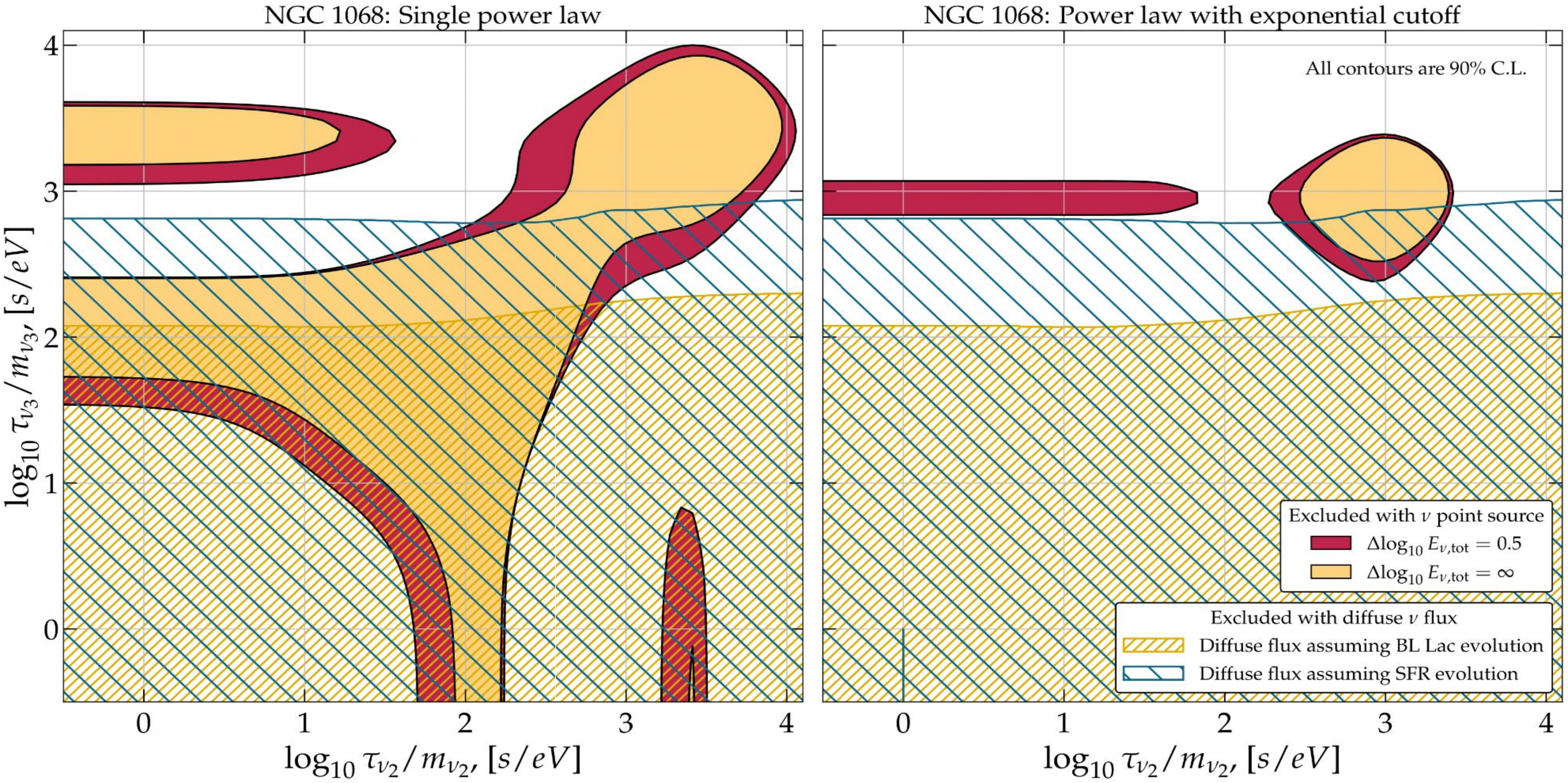


$$\Gamma_i = \frac{L m_{\nu,i}}{\tau_{\nu,i}}$$



NGC 1068: Single power law
NGC 1068: Power law with exponential cutoff
All contours are 90% C.L.
Excluded with ν point source
Δlog10 Eν,tot = 0.5
Δlog10 Eν,tot = ∞
Excluded with diffuse ν flux
Diffuse flux assuming BL Lac evolution
Diffuse flux assuming SFR evolution
log10 τν3/mν3, [s/eV]
log10 τν2/mν2, [s/eV]

In conclusion

A) The bad

- Studying BSM signatures with a single point source is not straightforward.
- Once all considerations are made, sensitivity drops sharply.
- Our limited knowledge about the source is a big problem.

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B) The good
- Neutrino astronomy at last.
- Multiple neutrino telescopes coming up soon (next decade)
- Flavor could be key! Keep an eye on in-water detectors (Baikal GVD, KM3NeT, Trident)