Probing Secret Interactions of Astrophysical ν_τ in the High-Statistics Era

NuTau 2021

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Based on `arXiv:2107.13568`

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CENTER FOR COSMOLOGY AND ASTROPARTICLE PHYSICS

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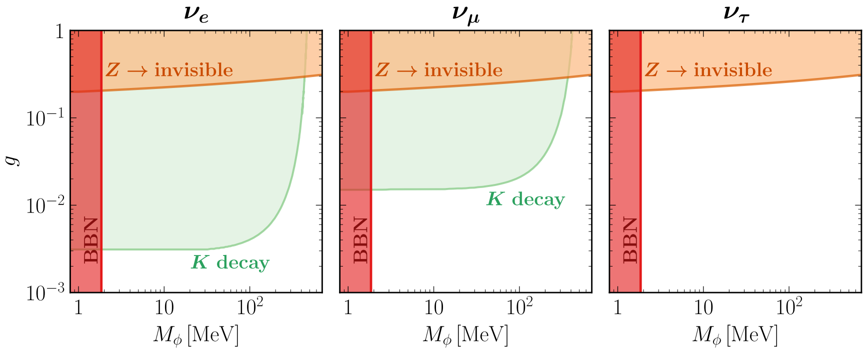
Neutrino self-interactions (νSI)

- Do neutrinos have sizable self-interactions?
  $\mathcal{L}_{\text{int}} \sim -g\bar{\nu}\nu\phi$

- Notoriously difficult to test



Blinov et. al., 1905.02727
Brdar et. al., 2003.05339

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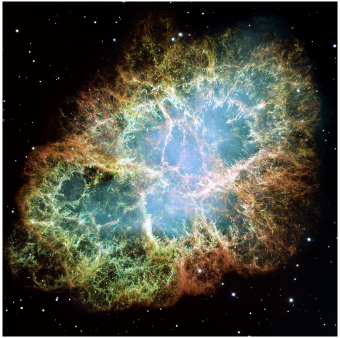
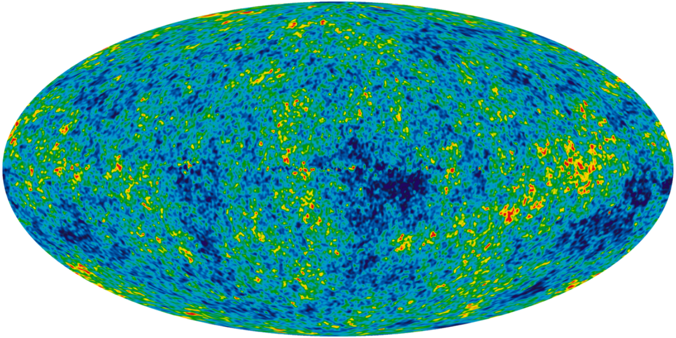
νSI: why do we care?

- It is a fundamental question that may shed light into the neutrino mass origin.
- Let's be practical: neutrinos are everywhere!





Shalgar, Tamborra, Bustamante, 1912.09115

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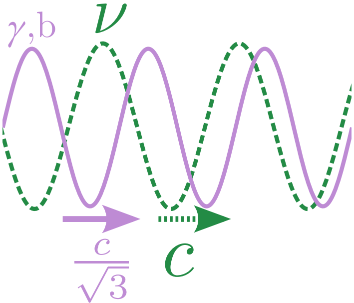
Why do we care?

- When the CMB is formed, neutrinos are $\sim 40\%$ of the energy density of the Universe!
- At those times
  - Photons and baryons **oscillate** (tightly-coupled acoustic waves, at $\boldsymbol{c/\sqrt{3}}$)
  - Neutrinos just **freely propagate** (free-stream, at $\boldsymbol{c}$)

Neutrinos will gravitationally pull! Bashinsky, Seljak, astro-ph/0310198



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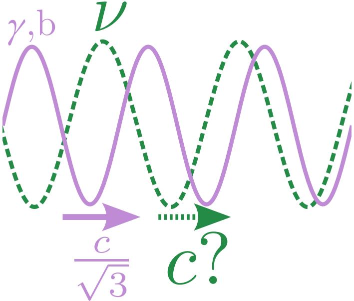
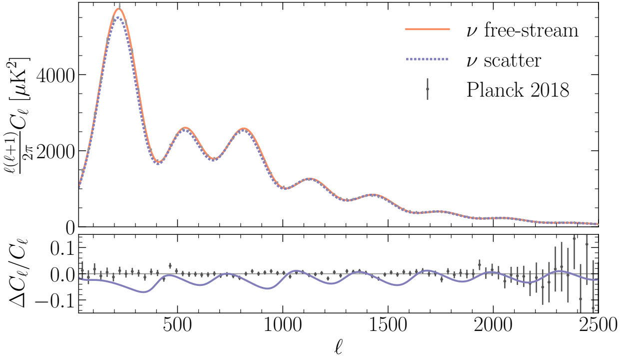
Or, will they? νSI can make neutrinos a tightly-coupled fluid too.





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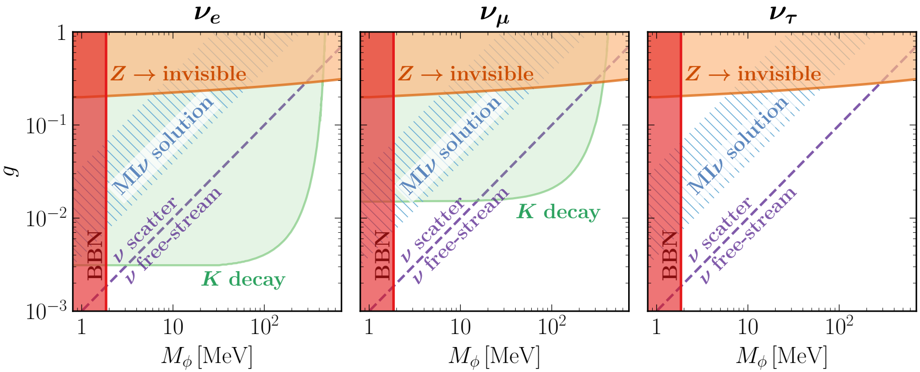
The Moderately Interacting Neutrino (MIν) solution



Cyr-Racine, Sigurdson, 1306.1536; Lancaster, Cyr-Racine, Knox, Pan, 1704.06657; Oldengott, Tram, Rampf, Wong, 1706.02123; Kreisch, Cir-Racine, Dor, 1902.00534; Barenboim, Denton, Oldengott, 1903.02036; ...

Non-free-streaming neutrinos may affect how we infer cosmological parameters from CMB anisotropies!

Most notably H_0, σ_8, and inflationary parameters N.B.: beware of polarization data, though

νSI in the ν_τ sector

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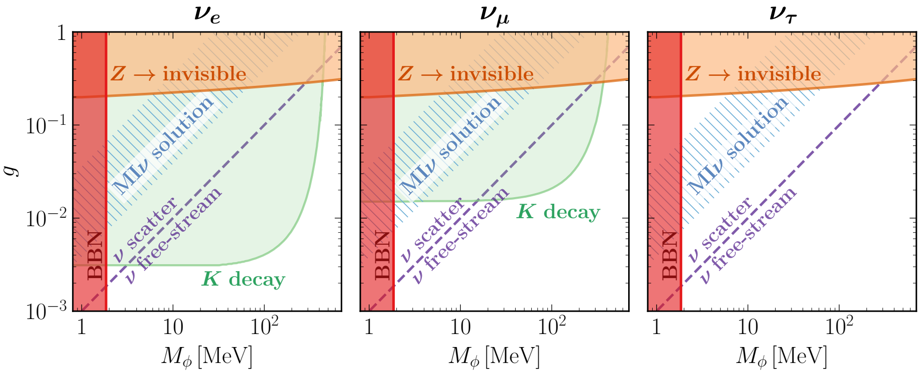

An opportunity opens to explore ν_τ self-interactions. As we show in our paper, we can catch it!
ν_τ are hard to *directly* produce, but oscillations can help us.

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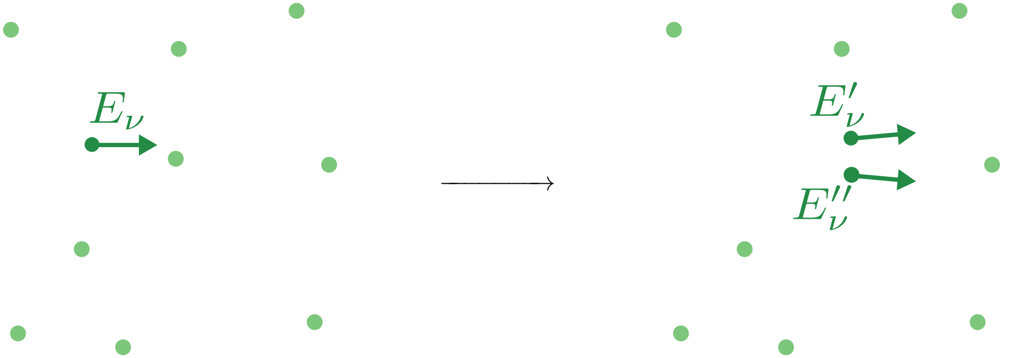
Astrophysical νSI: the basic idea

Kolb & Turner, 1987



Resonantly enhanced when $E_{\text{center-of-mass}} \equiv \sqrt{s} = \sqrt{2E_\nu m_\nu} = M_\phi$.

For $M_\phi \sim 10\,\mathrm{MeV}$, $E_\nu \sim 10^5\,\mathrm{GeV}$: **astrophysical neutrinos at IceCube!**

νSI in astrophysical neutrinos

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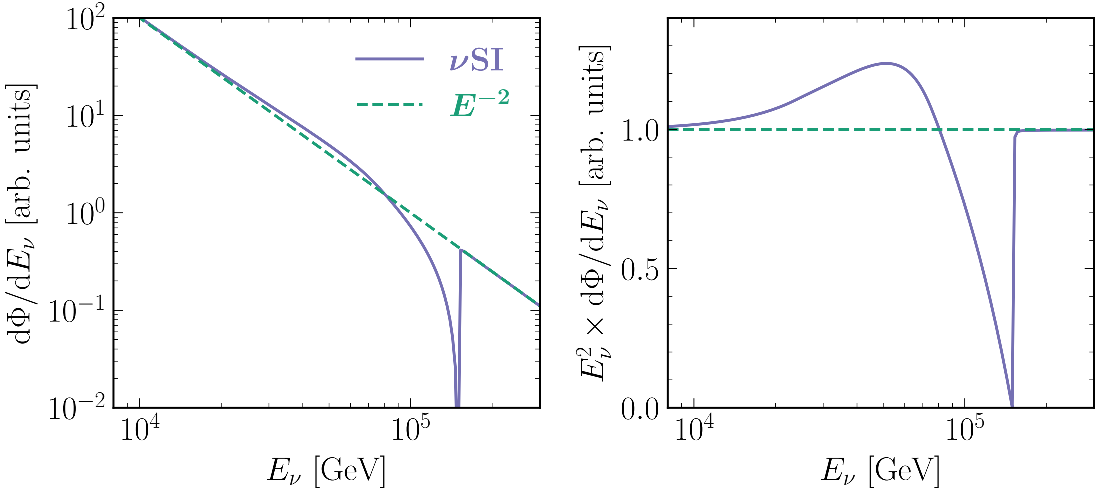
Hooper, hep-ph/0701194; Ng, Beacom, 1404.2288; Ioka, Murase, 1404.2279; ... $E_\nu^{\rm res} = \frac{M_\phi^2}{2m_\nu}$



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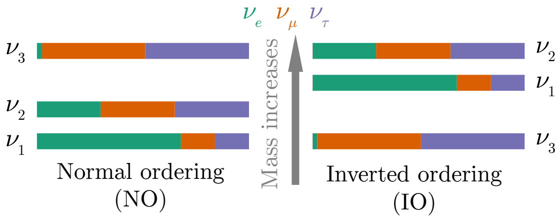
Focusing on ν_τ + 2021

What do we know about the neutrino spectrum?



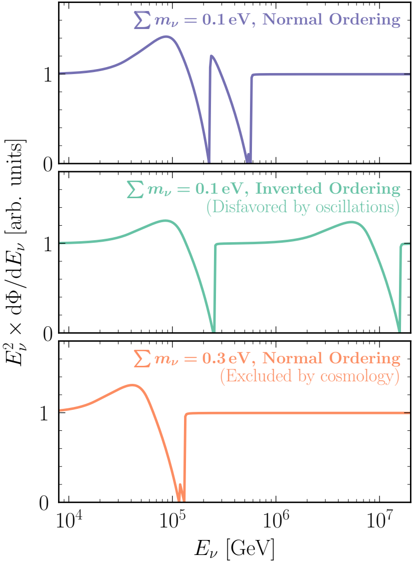
- Look for all flavors!

$\sum m_\nu < 0.12\,\text{eV}$, $\sqrt{\Delta m^2_{32}} \sim \sqrt{\Delta m^2_{31}} \sim 0.05\,\text{eV}$

$E_\nu^{\text{res,i}} = M_\phi^2/2m_i$

- Look for (close) double dips!

  And stay tuned on oscillations + cosmology!



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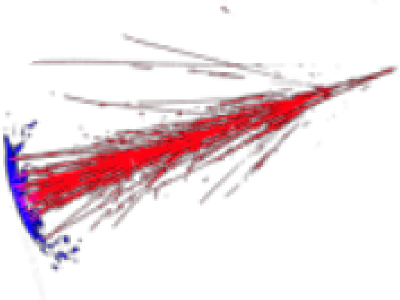
Focusing on ν_τ + 2021



What do we know about the neutrino spectrum?

- Look for all flavors!
- Look for (close) double dips!
  And stay tuned on oscillations + cosmology!

To compare with data, we need a realistic treatment

- Detector effects
- Proper theoretical ν-ν scattering calculation

ivan-esteban-phys/nuSIprop

νSI in astrophysical neutrinos

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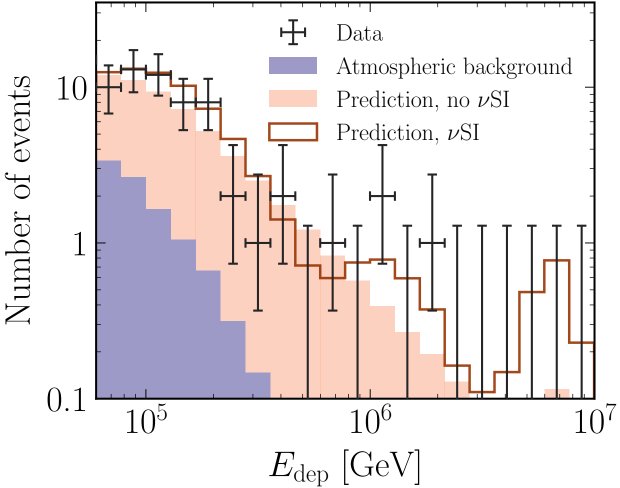
IceCube?

(HESE. Predictions generated with content in Abbasi et al, 2011.03545. We thank C. Arguelles & A. Schneider)



No νSI: $\phi \propto E^{-2.9}$

νSI: $\phi \propto E^{-2}$, $g = 0.1$, $M_\phi = 7$ MeV

Current IceCube data is not good because

- Low statistics $\Rightarrow$ fluctuations
- Small energy range $\Rightarrow$ degeneracy with unknown astrophysical neutrino flux

IceCube-Gen2

νSI in astrophysical neutrinos

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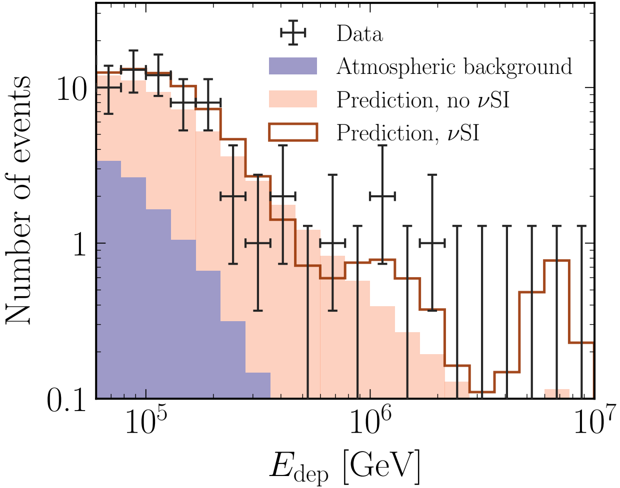

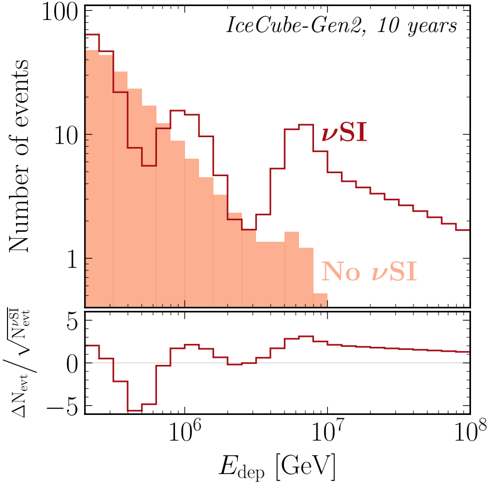

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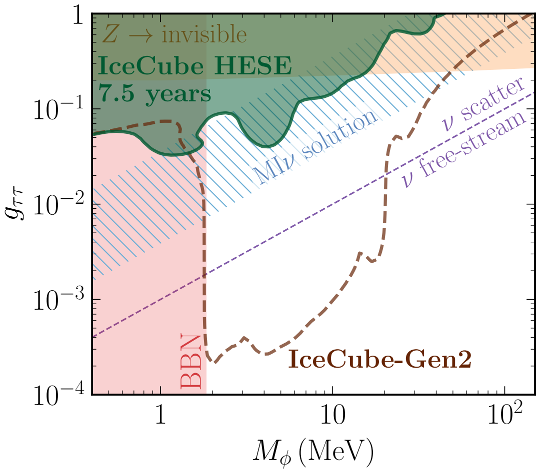
Present constraints and future sensitivity

(HESE analysis generated with content in Abbasi et al, 2011.03545. We thank C. Arguelles & A. Schneider)



- IceCube-Gen2 will be **very powerful**! Could even be sensitive to other νSI flavors!
- Gen2 will exploit **the full potential** of neutrino astronomy to probe νSI.

There is plenty of phenomenology to be explored: our code is publicly available to avoid unreliable approximations.

github.com/ivan-esteban-phys/nuSIprop

Conclusions

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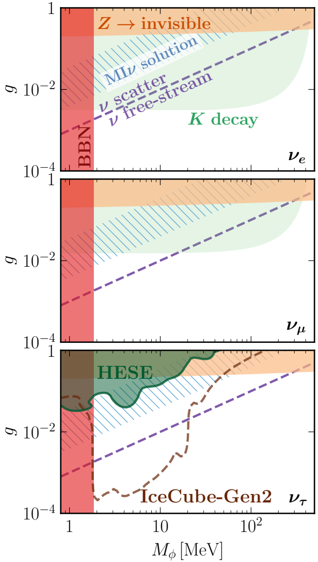
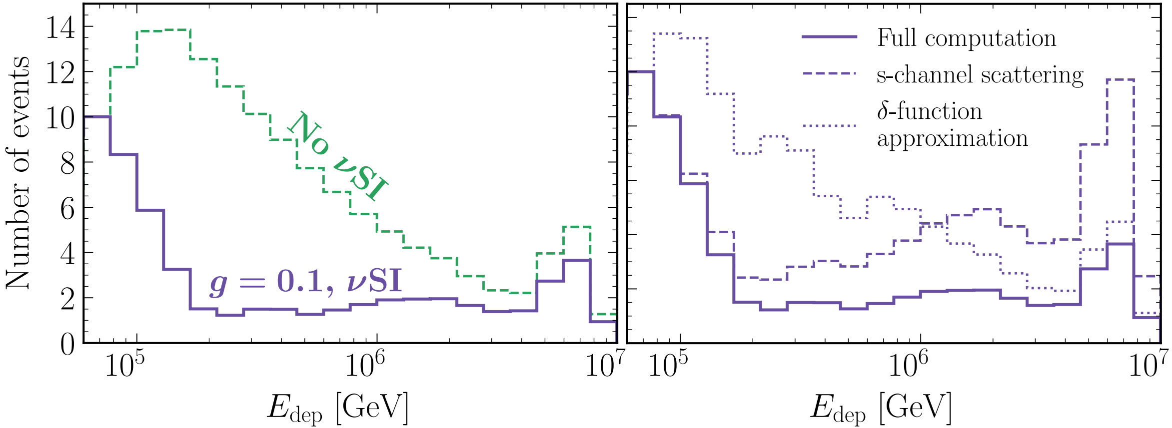


- Neutrino self-interactions are not only fundamentally interesting, **they affect our understanding of the Early Universe**.
- Unexplored ν_τ sector $\Rightarrow$ **opportunity for neutrino telescopes**.
- We define a roadmap for *making decisive progress*:
  - IceCube-Gen2
  - Improved theoretical treatment
  - Realistic treatment of detection effects
- *Gen2 will realize the full potential*. It can also probe ν_e, ν_μ!
- This is just the beginning: hints will be testable. Improvements in
  - Astrophysics, point sources, cosmology
  - Flavor
  - Ultra-High Energy neutrinos
  - ...

are welcome!

https://github.com/ivan-esteban-phys/nuSIprop

How does this look in IceCube? (Generated with content in Abbasi et al, 2011.03545. We thank C. Arguelles & A. Schneider)



Double-dips and non-resonant effects are relevant!

Backup

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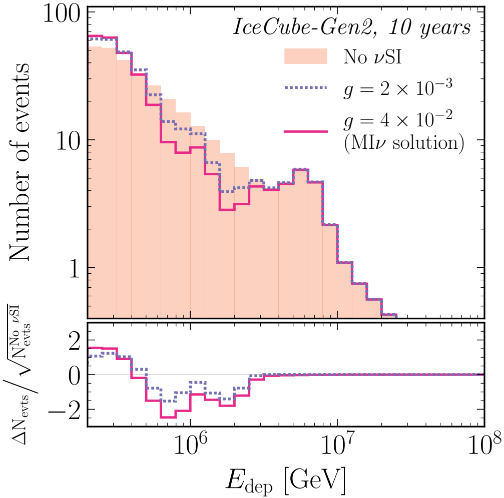
How does this look in Gen2?



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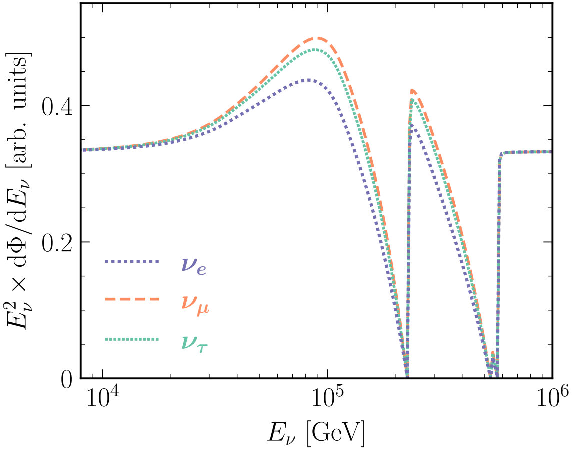
Flavor?



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Improve on Gen2?