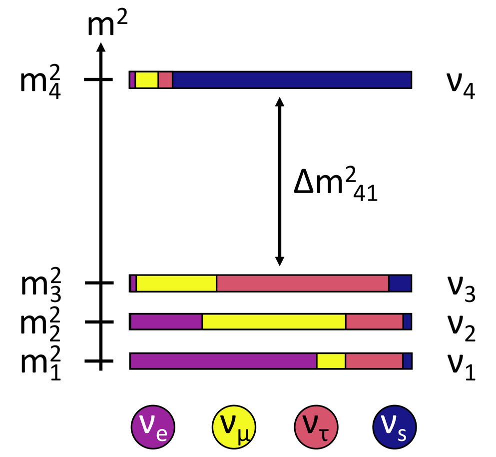
Light Unstable Sterile Neutrino Search in IceCube

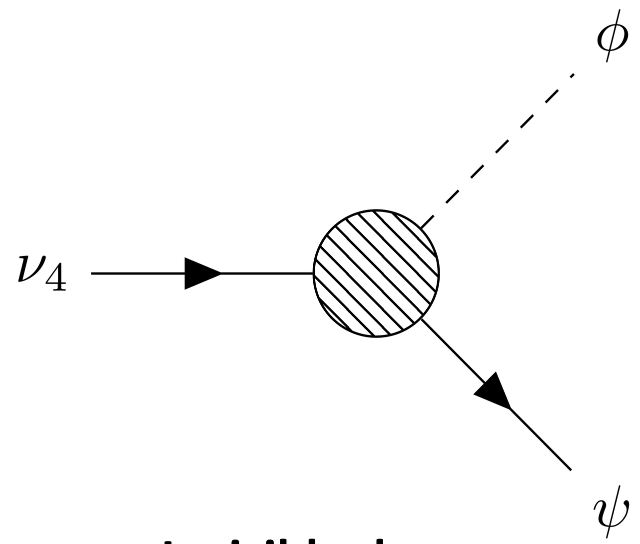
Marjon Moulai (MIT) for the IceCube Collaboration

Motivation for Unstable Sterile Neutrinos

- Anomalies in short-baseline (SBL) experiments suggest the existence of an eV-scale sterile neutrino [1-3].
- Recent fits to the relevant neutrino data find preference for a 3+1 model where ν_4 can decay, with lifetime τ [4-6].
- This unstable sterile neutrino model reduces tension between datasets in the global fits [5-7].



3+1 model
Assuming Normal Ordering



Invisible decay
ϕ and ψ are BSM particles that are invisible to the detector

Global fit results for unstable sterile neutrinos (3+1+decay)

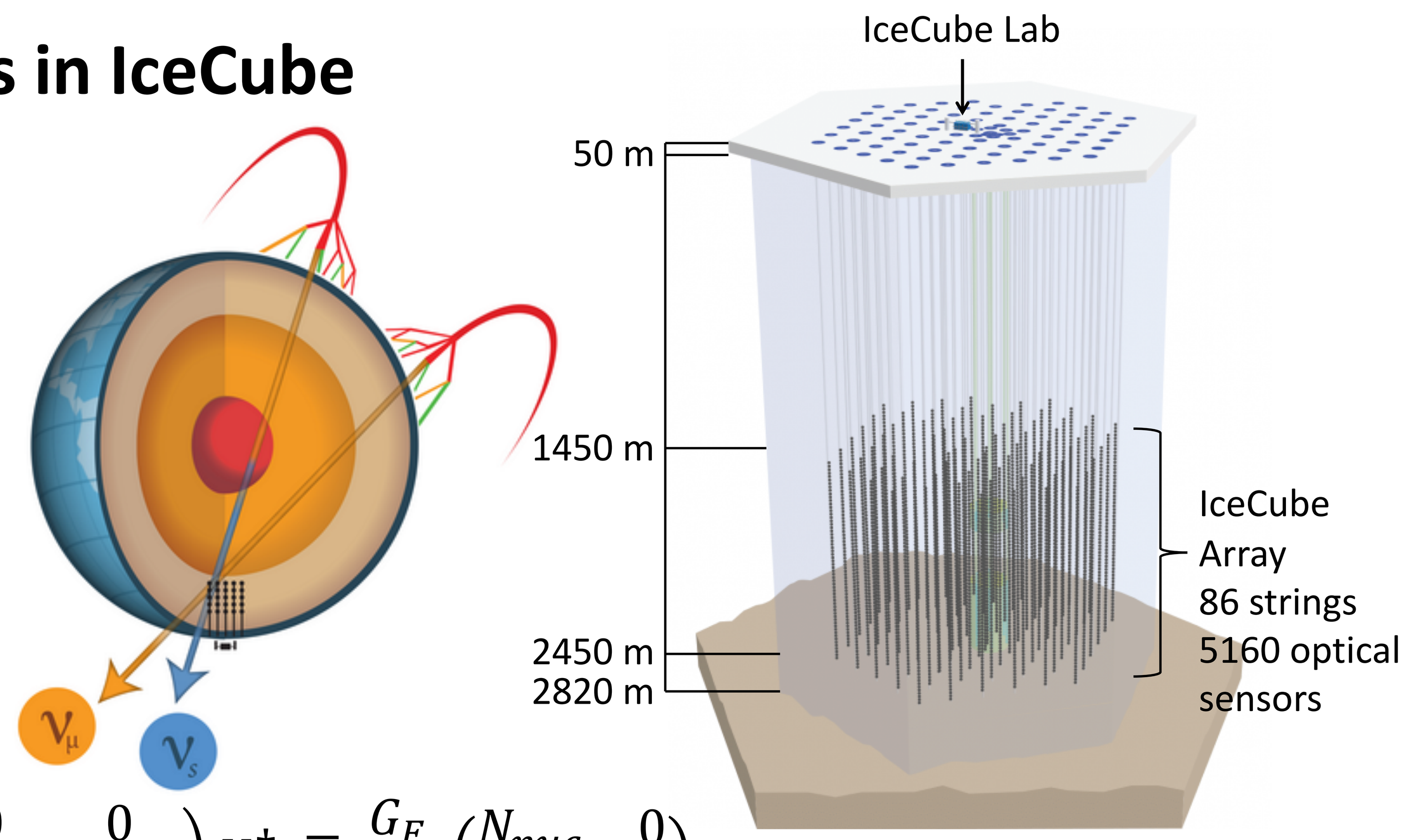
	Δm^2_{41} (eV^2)	τ (eV^{-1})	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	$\sin^2 2\theta_{24}$
SBL only [5]	0.21	1.96	0.49	0.18	0.15
SBL + 1 year of IceCube [6]	1.35	4.50	0.24	0.11	0.05

$$U_{4\times4} = \begin{pmatrix} 3\times3\ U_{PMNS} & \begin{matrix} U_{e4} \\ U_{\mu4} \\ U_{\tau4} \end{matrix} \\ U_{s1}\quad U_{s2}\quad U_{s3} & U_{s4} \end{pmatrix} = R_{34}R_{24}R_{14}\underbrace{R_{23}R_{13}R_{12}}_{U_{PMNS}}$$

$$\sin^2 2\theta_{24} \xrightarrow[U_{e4}=0]{\theta_{14}=0} 4\left(1-|U_{\mu4}|^2\right)|U_{\mu4}|^2$$

Sterile Neutrinos at TeV Energies in IceCube

- IceCube is a km³ ice-Cherenkov detector
- IceCube detects atmospheric and astrophysical ν_μ's and $\bar{\nu}_\mu$'s.
- Neutrinos traveling through the earth pass through a lot of matter
- ν_μ's ($\bar{\nu}_\mu$)'s scatter off quarks, while ν_s's do not.
- In a 2-flavor approximation, $\binom{\nu_\mu}{\nu_s}$, the Hamiltonian is:



$$H_0 = \frac{1}{2E}U\begin{pmatrix}0 & 0\\ 0 & \Delta m^2_{41}\end{pmatrix}U^\dagger \mp \frac{G_F}{\sqrt{2}}\begin{pmatrix}N_{nuc} & 0\\ 0 & 0\end{pmatrix}$$

where $-$ $(+)$ is for ν $(\bar{\nu})$

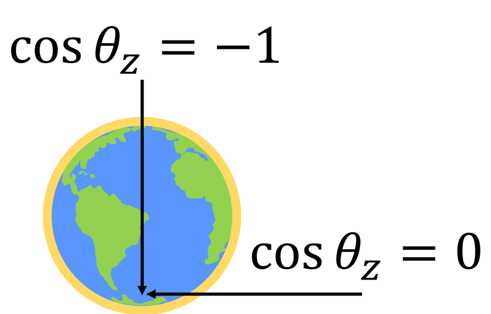
- The potential difference between the flavors causes a matter-effect, parametric resonance $\bar{\nu}_\mu \to \bar{\nu}_s$ transition at TeV energies, shown in oscillograms.
- Decay adds a term to the effective Hamiltonian:

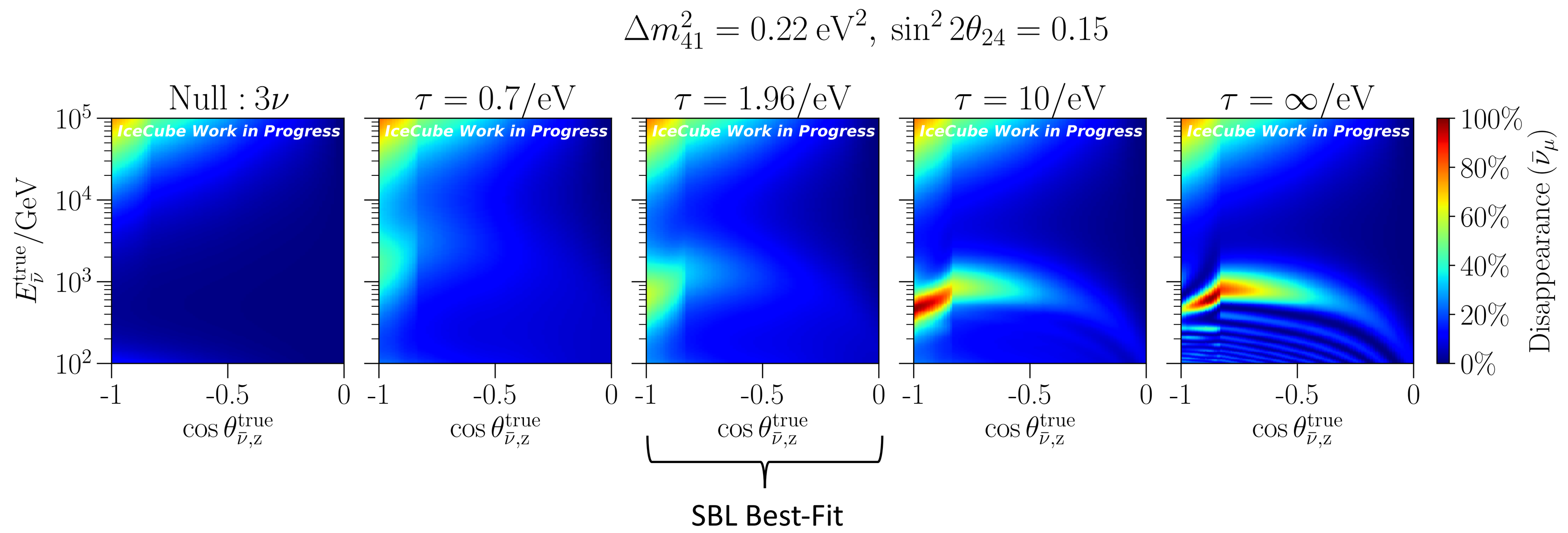
$$H = H_0 \ - i\frac{m_4}{2E}U\begin{pmatrix}0 & 0\\ 0 & 1/\tau\end{pmatrix}U^\dagger$$

where τ is the ν_4 lifetime

Oscillograms

- Oscillograms show $\bar{\nu}_\mu$ survival probability, accounting for oscillations, absorption by the Earth, and decay.
- ν_4 decay with lifetime τ modifies matter-effect resonance

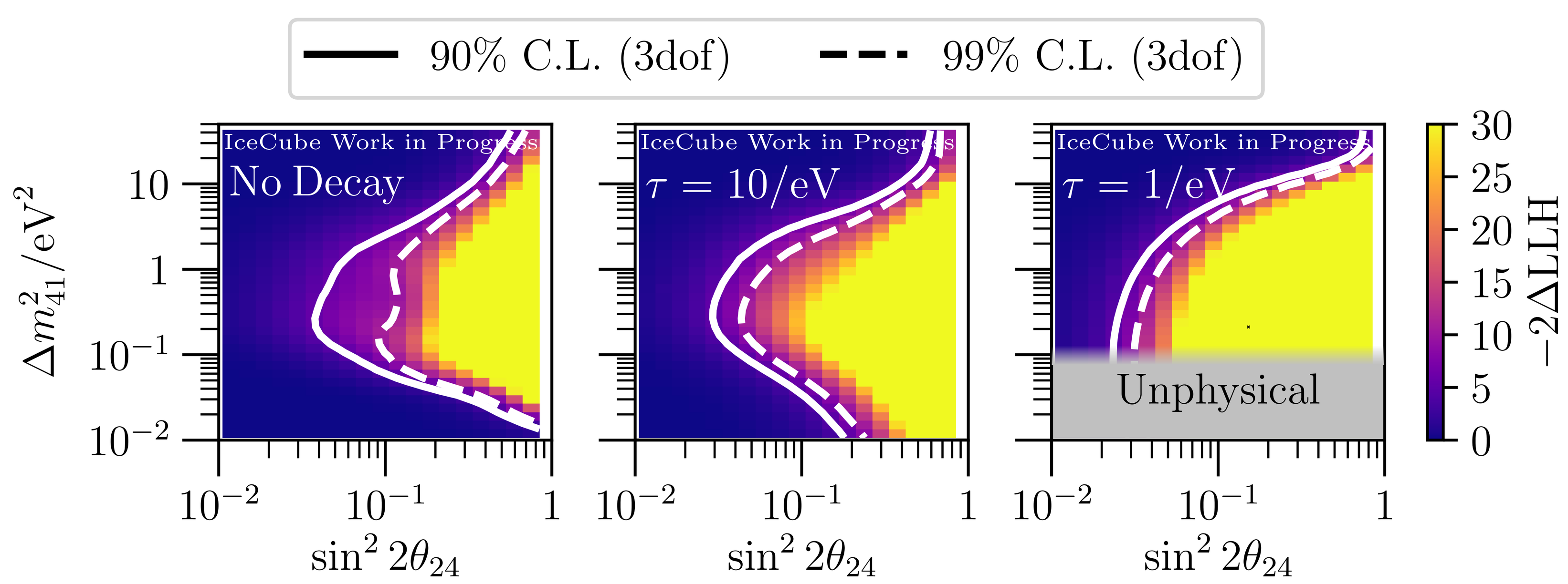


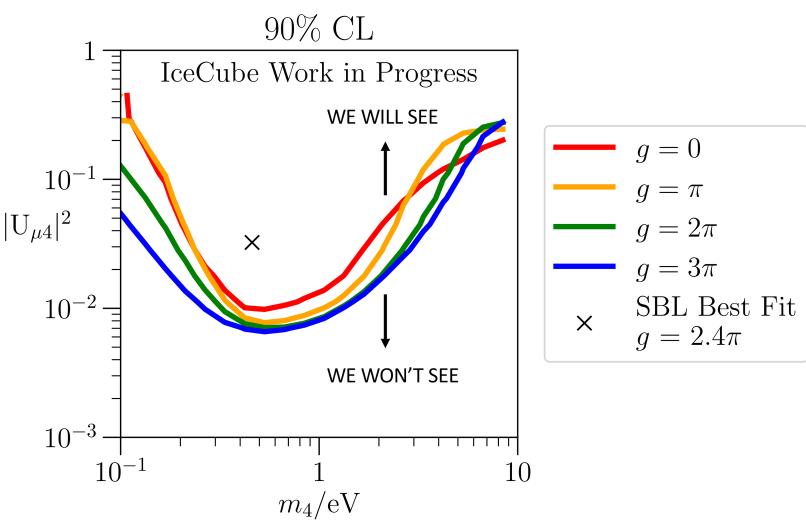


Sensitivity

- Eight years of data: 300,000 upward-going ν_μ's and $\bar{\nu}_\mu$'s
- 500 GeV – 10 TeV

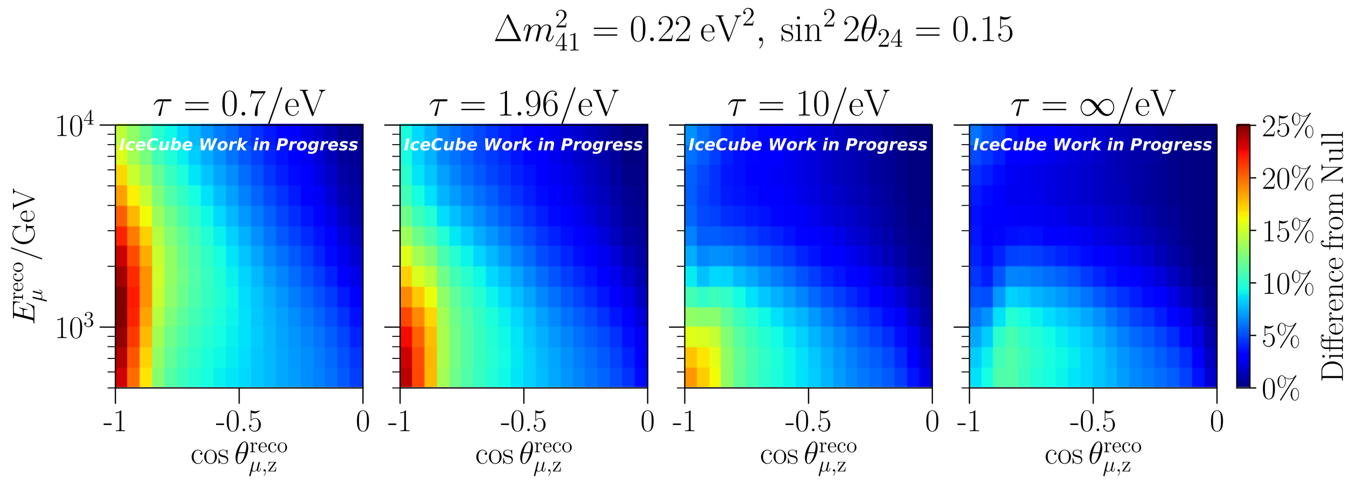
$$\frac{1}{\tau} = \frac{g^2 m_4}{16\,\pi}$$



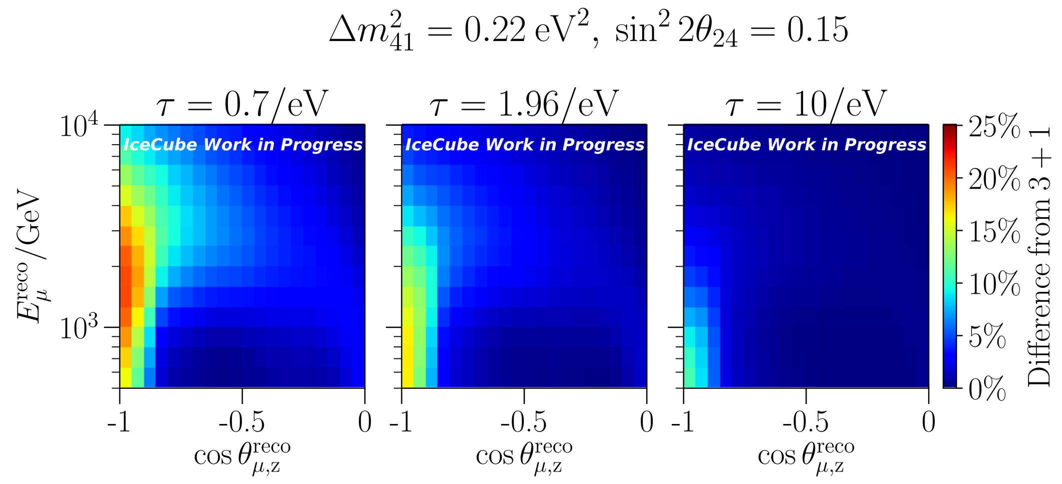


Event Distributions

Percent difference in event distributions compared to null (3ν)



Percent difference in event distributions compared to traditional 3+1



References

1) Aguilar-Arevalo, A. A. et al, (MiniBooNE Collaboration), Phys. Rev. Lett. 121, 221801 (2018) arXiv:1805.12028
2) Aguilar, A. et al (LSND Collaboration), Phys. Rev. D 64, 112007 (2001), arXiv:hep-ex/0104049
3) Mention, G. et al, Phys. Rev. D 83, 073006 (2011), arXiv:1101.2755
4) Berryman, J. M et al, Phys. Lett. B742 74 (2015), arXiv:1407.6631
5) Diaz, A. et al, arXiv:1906.00045
6) Moulai, M. H. et al, Phys. Rev. D. 101, 055020 (2020), arXiv:1910.13456
7) Dentler, M. et al JHEP 08, 010 (2018) arXiv:1803.10661