Results from the Search for eV-Sterile Neutrinos with IceCube

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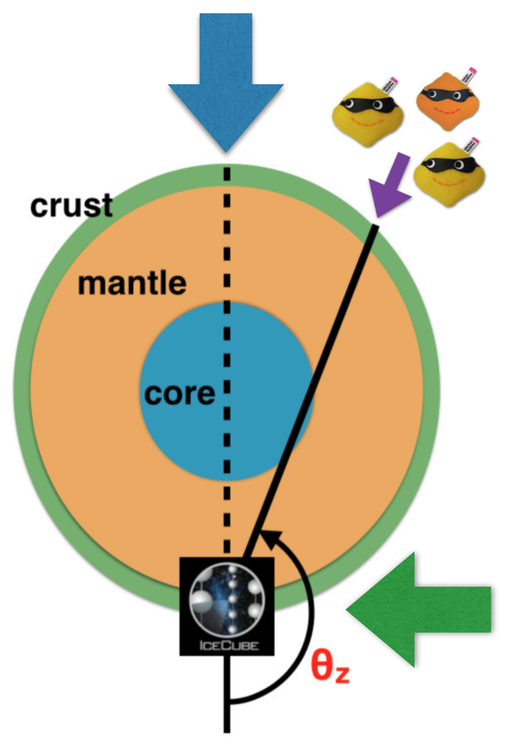
Abstract: The IceCube neutrino telescope at the South Pole has measured the atmospheric muon neutrino spectrum as a function of zenith angle and energy. Using IceCube's full detector configuration we have performed searches for eV- scale sterile neutrinos. Such a sterile neutrino, motivated by the anomalies in short-baseline experiments, is expected to have a significant effect on the $\overline{\nu}_\mu$ survival probability due to matter induced resonant effects for energies of order 1 TeV. This effect makes this search unique and sensitive to small sterile mixings. We will present results obtained using up-going muon neutrinos taken with one year of full detector and one year of partial detector configurations.

Atmospheric neutrino oscillations

Neutrinos are produced in cosmic rays showers throughout the Earth's atmosphere. They travel through the Earth layers on their way to IceCube they can experience flavors conversion.



In the presence of an eV scale sterile neutrino matter effects will induce large sterile to active transitions for antineutrinos at TeV energies.

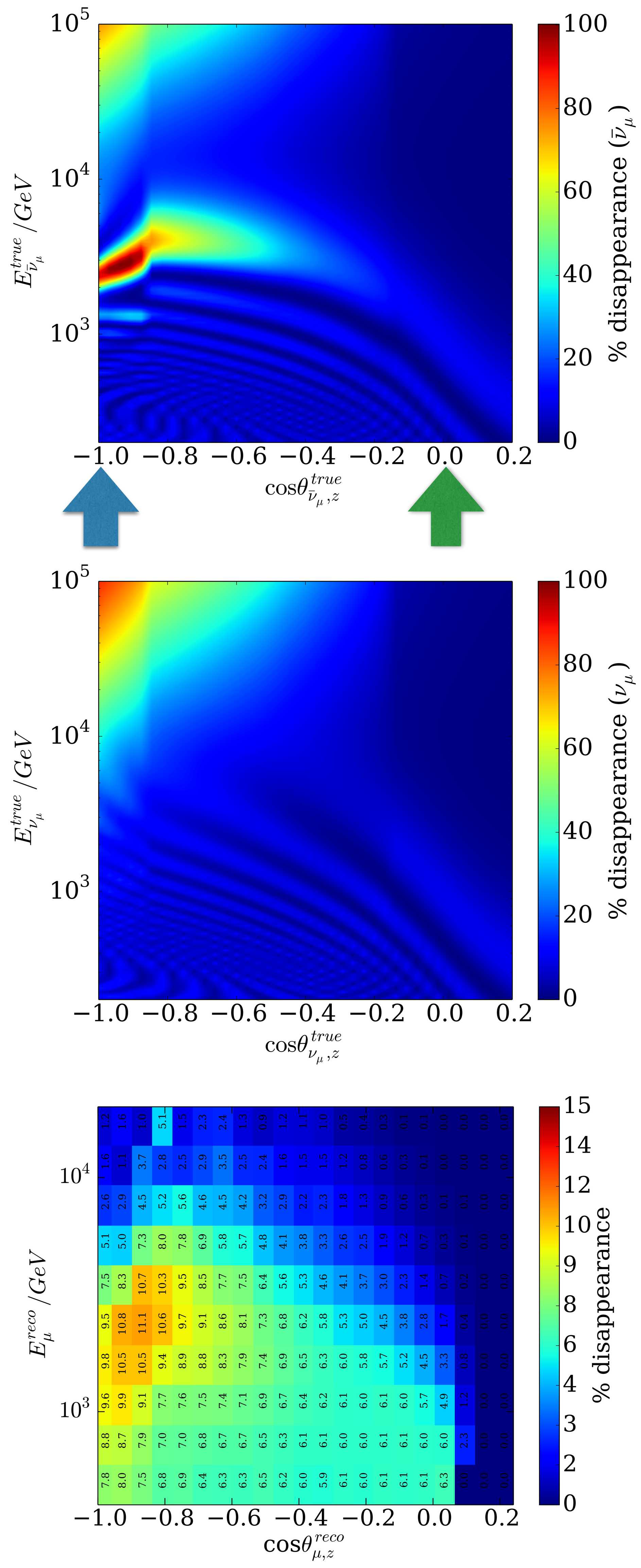


Figure 1: Upper (middle) panels shows the antineutrino (neutrino) disappearance probability for the best fit 3+1 model. Lower panel shows the effect in reconstructed observables when adding neutrino and antineutrino contributions.

Event distributions

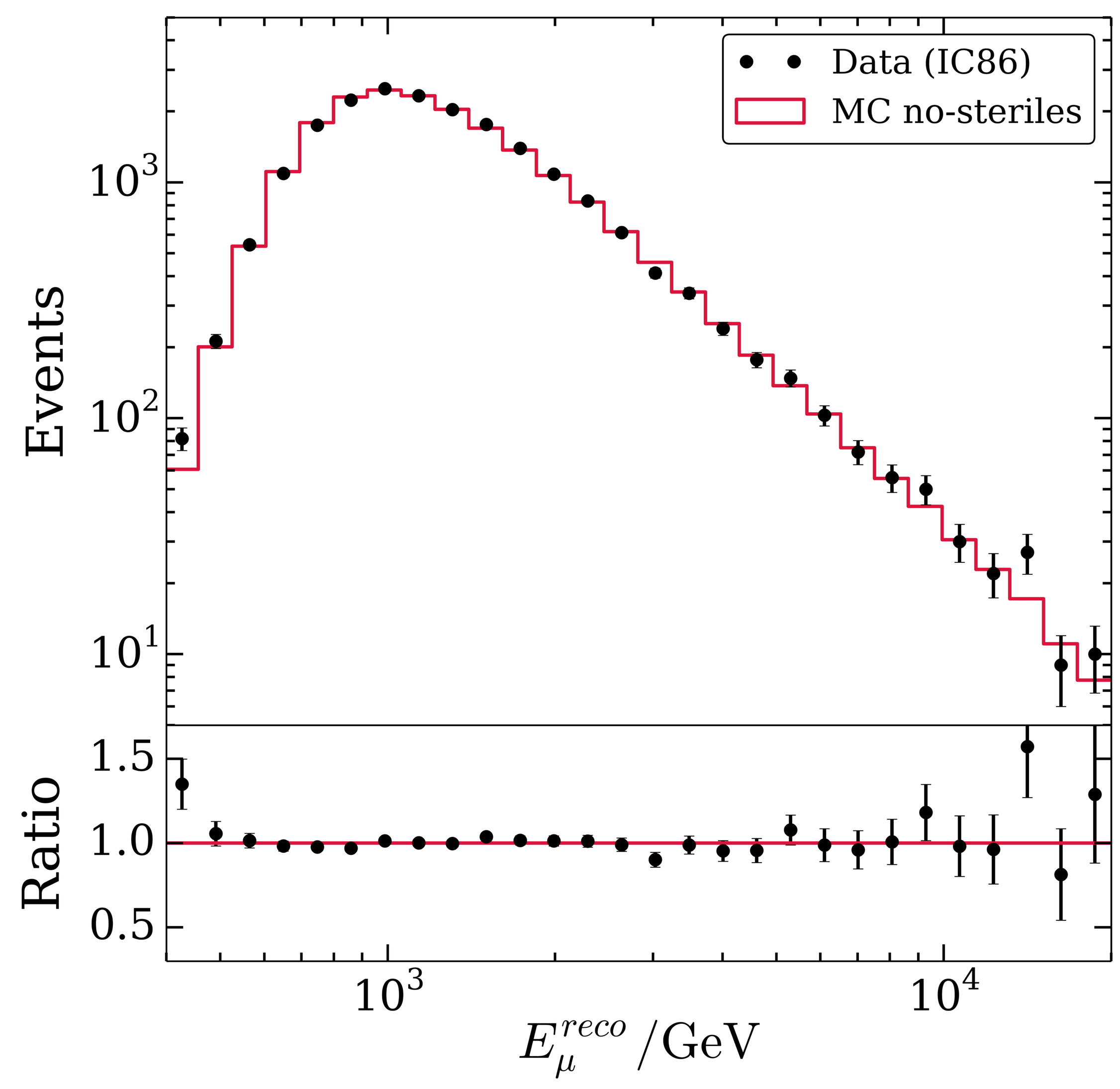


Figure 2: Reconstructed energy distribution of the sample compared to the no-sterile hypothesis.

The energy estimator uses the fact that at high energies the muon energy loss is proportional to the muon energy:

$$\frac{dE}{dX} = a + bE$$

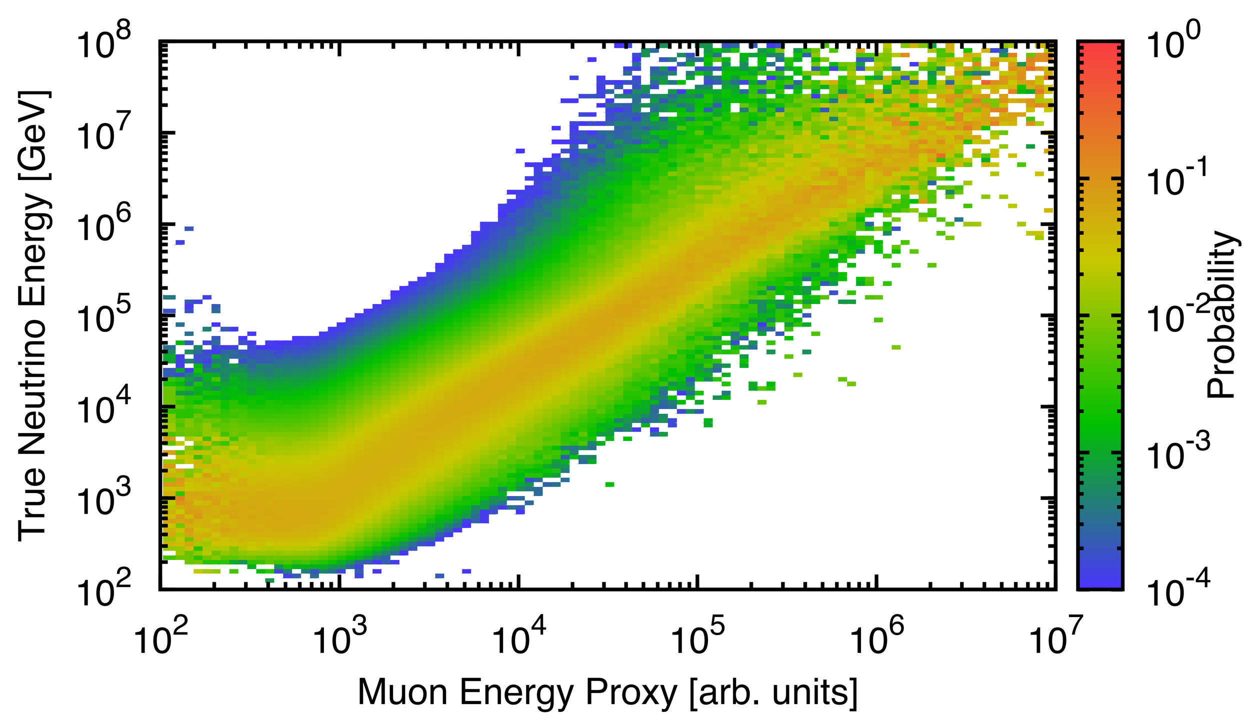


Figure 3: Relation between reconstructed energy and true neutrino energy.

Systematics

$$\phi_{\text{atm}}(\cos\theta) = N_0 \mathcal{F}(\delta)\left(\phi_\pi + R_{\pi/K}\phi_K\right)\left(\frac{E_\nu}{E_0}\right)^{-\Delta\gamma}$$

Atmospheric flux		
ν flux template	discrete (7)	
ν / $\overline{\nu}$ ratio	continuous	0.025
π / K ratio	continuous	0.1
Normalization	continuous	none[1]
Cosmic ray spectral index	continuous	0.05
Atmospheric temperature	continuous	model tuned
Detector and ice model		
DOM efficiency	continuous	
Ice properties	discrete (4)	
Hole ice effect on angular response	discrete (2)	
Neutrino propagation and interaction		
DIS cross section	discrete (6)	
Earth density	discrete (9)	

Table 1: Summary of systematic parameters considered in the analysis.

Results

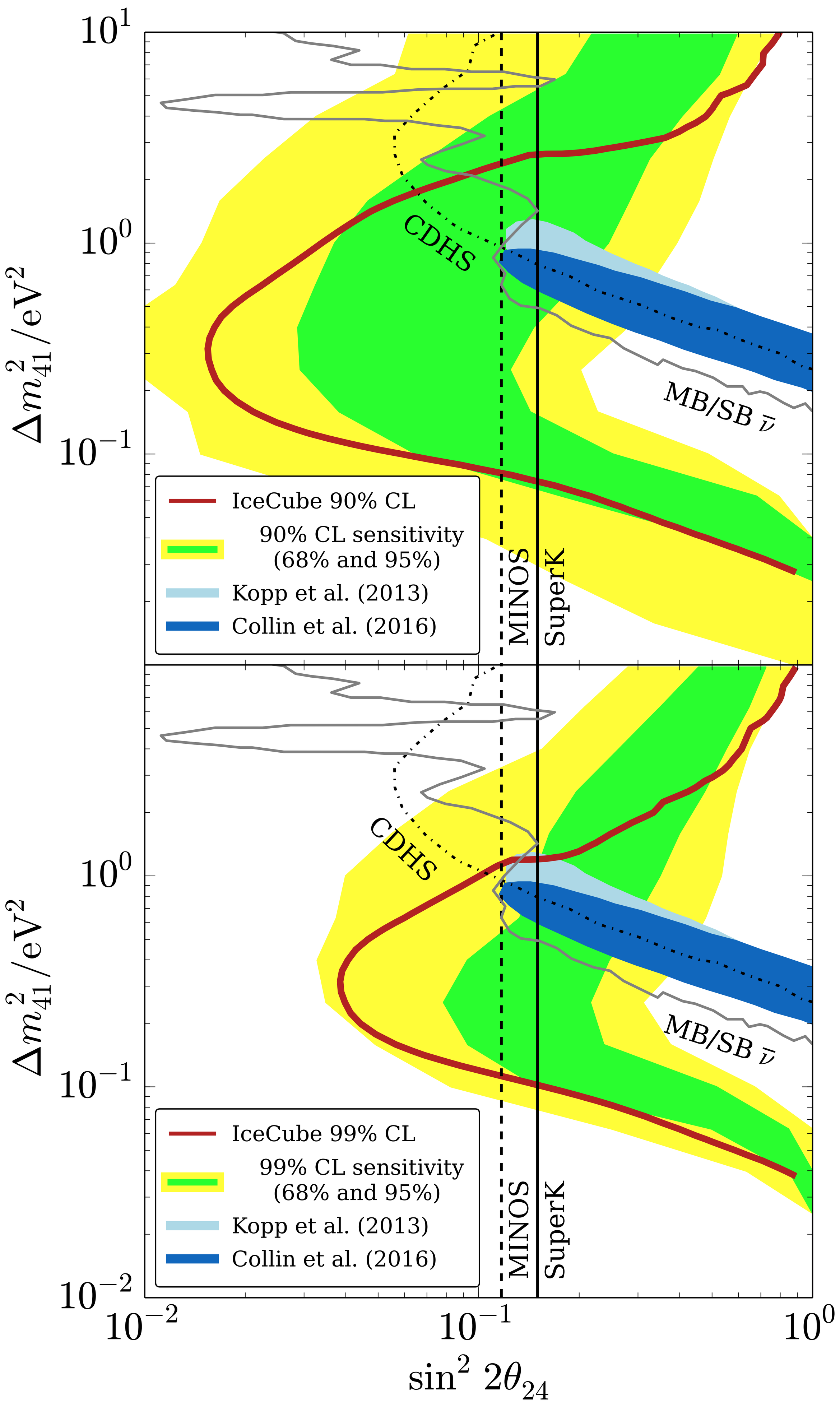


Figure 4: Results of the IC86 sterile neutrino analysis at 90% (99%) C.L. in the upper (lower) panel compared with other null disappearance results. Also, 99% C.L. allowed region from global fit to appearance experiments including MiniBooNE and LSND are shown. In Kopp et al. **$\sin^2 2\theta_{ee}$ = 0.092** and in Collin et al. | **$\sin^2 2\theta_{ee}$ = 0.106**.

Connection to the mixing angles: terms in **red** are constrained by this analysis, those in **green** by ν_e disappearance experiments, e.g. reactor, & **blue** is appearance, e.g. LSND/ MB:

$$\begin{aligned}
\sin^2 2\theta_{ee} &= \sin^2 2\theta_{14} \\
\sin^2 2\theta_{\mu\mu} &= 4\cos^2\theta_{14}\sin^2\theta_{24}(1-\cos^2\theta_{14}\sin^2\theta_{24}) \\
\sin^2 2\theta_{\mu e} &= \sin^2 2\theta_{14}\sin^2\theta_{24} \\
\sin^2 2\theta_{e\tau} &= \sin^2 2\theta_{14}\cos^2 2\theta_{24}\sin^2\theta_{34} \\
\sin^2 2\theta_{\mu\tau} &= \sin^2 2\theta_{24}\cos^4\theta_{14}\sin^2\theta_{34}
\end{aligned}$$

Outlook

IceCube has placed strong bounds on eV scale sterile neutrinos using one year of data, but we have several years of data already taken. Improved multiyear analysis results will come soon!

References:

- Searches for Sterile Neutrinos with the IceCube Detector - IceCube Collaboration (Aartsen, M.G. *et al.*) **arXiv:1605.01990**.
- Sterile Neutrino Oscillations: The Global Picture - Kopp, Joachim et al. JHEP 1305 (2013) 050 **arXiv:1303.3011**.
- Sterile Neutrino Fits to Short Baseline Data - Collin, G.H. et al. Nucl.Phys. B908 (2016) 354-365 Sterile Neutrino Fits to Short Baseline Data - Collin, G.H. et al. Nucl.Phys. B908 (2016) 354-365 **arXiv:1602.00671**.
- Evidence for Astrophysical Muon Neutrinos from the Northern Sky with IceCube - IceCube Collaboration (Aartsen, M.G. et al.) Phys.Rev.Lett. 115 (2015) no.8, 081102 **arXiv:1507.04005**.
- Energy Reconstruction Methods in the IceCube Neutrino Telescope - IceCube Collaboration (Aartsen, M.G. et al.) JINST 9 (2014) P03009 **arXiv:1311.4767**.

Get our paper here: **arXiv:1605.01990**