

# HNL Searches in IceCube

Current status and future opportunities

NBIA Summer School on Neutrinos

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Julia Book



# Summary

- ❖ Motivation
- ❖ The IceCube Detector
- ❖ HNL Search - current status
- ❖ HNL Search - future opportunities



# Motivation: Theoretical

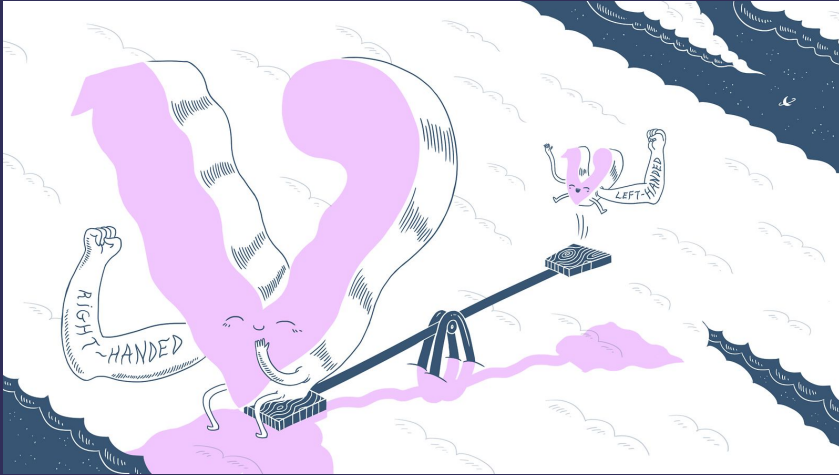


Image credit: Symmetry Magazine

Neutrino oscillations = neutrinos have mass

Neutrinos have mass + smallness of the mass = something funny going on

Seesaw mechanism could explain small mass via HNL

HNLs could then explain other issues, like matter antimatter asymmetry, Dark matter, oscillation anomalies

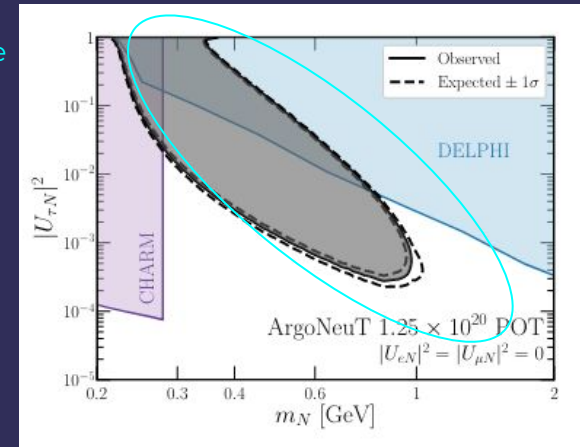
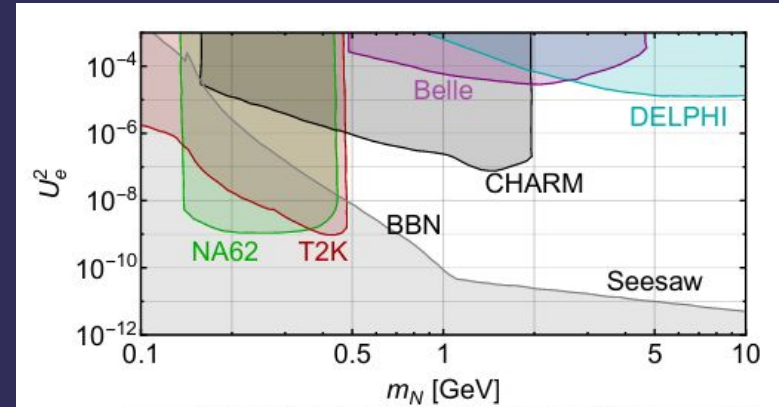
# Motivation: Experimental

Other experiments have placed strong upper limits on the potential HNL mixing with the electron and muon neutrinos

Limits are weaker when it comes to the nutau mixing

Icecube is capable of pushing the HNL - nutau mixing limits in the 1-2 GeV region

Approximate IceCube sensitivity region (work in progress)

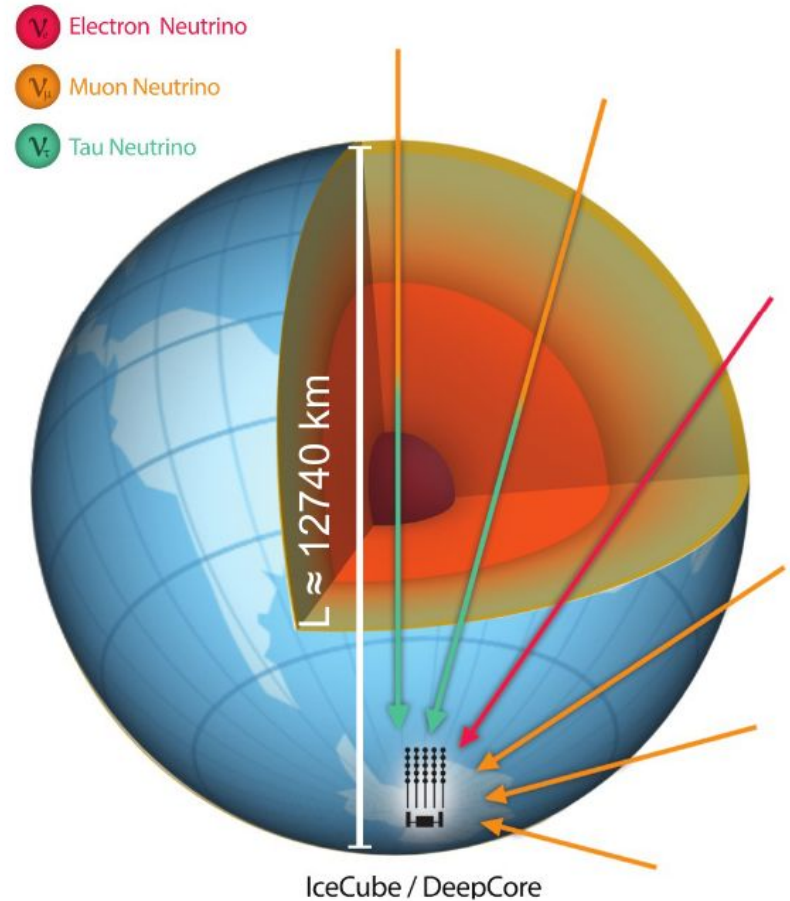


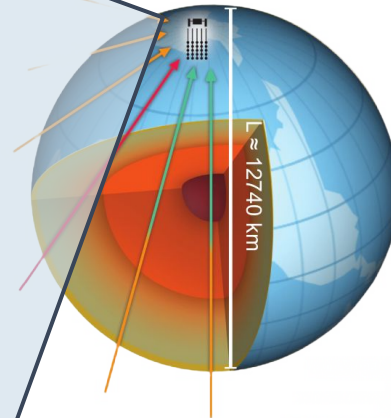
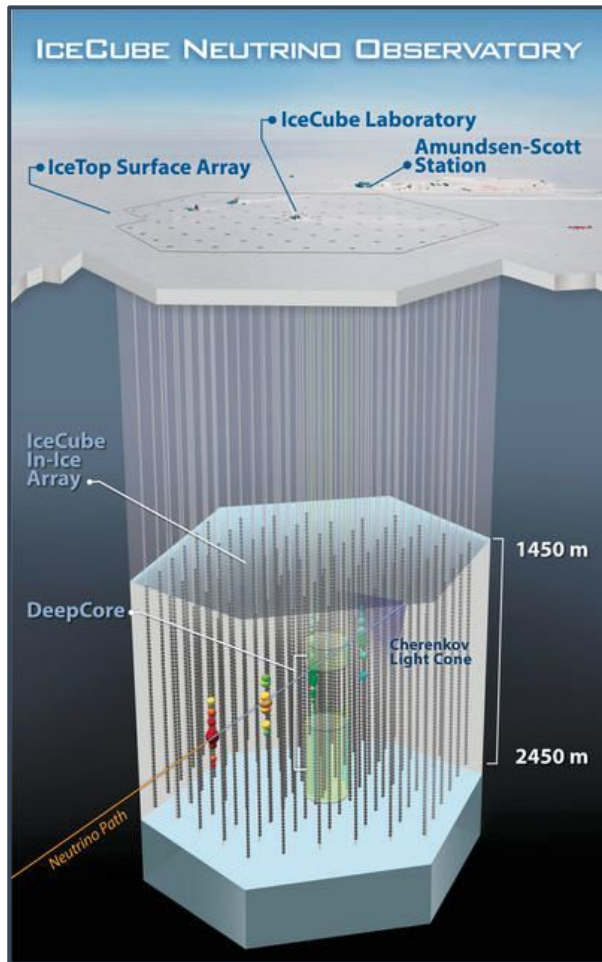
<https://arxiv.org/pdf/2107.14685.pdf> (top)  
<https://arxiv.org/pdf/2106.13684.pdf> (bottom)

# The IceCube Detector

Or, why are we do we see more tau neutrinos?

(About 2.5k in 10 years)

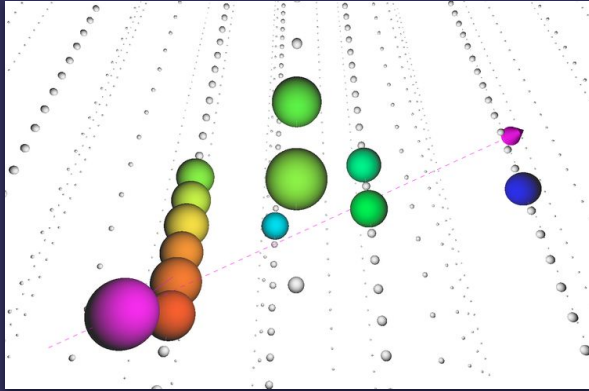




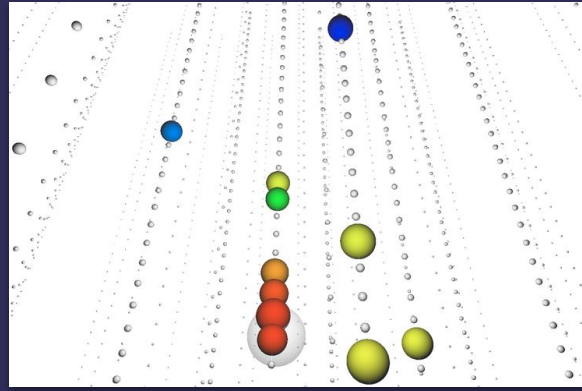
Event energies range from GeV to high TeV scales

- Neutrinos enter the detector and interact with the ice
- Charged secondary particles from the interaction release Cherenkov radiation, detectable by the Digital Optical Modules (DOMs) that make up the IceCube detector
- In DeepCore, the DOMs are more densely spaced, giving greater sensitivity for BSM searches

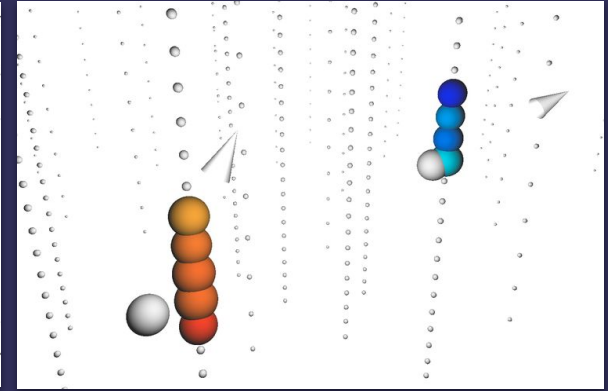
# Low-energy Event Topologies



Track



Cascade

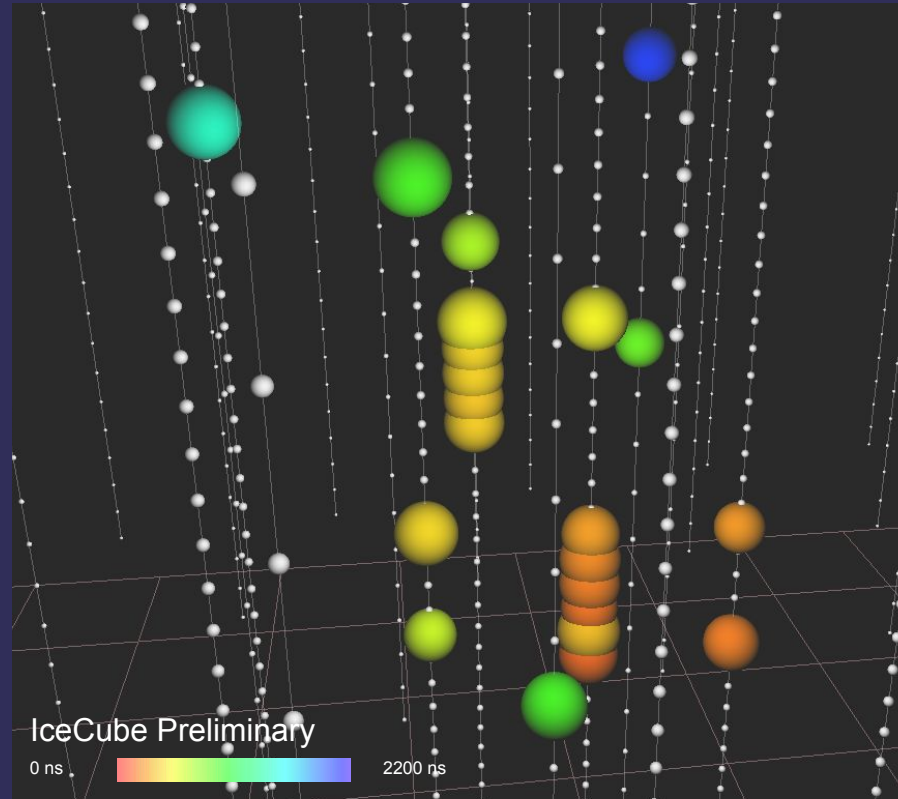


Double Cascade

The distinctive double-cascade shape has the potential to be a clear hallmark of an HNL signal

# Double Cascade HNL Production

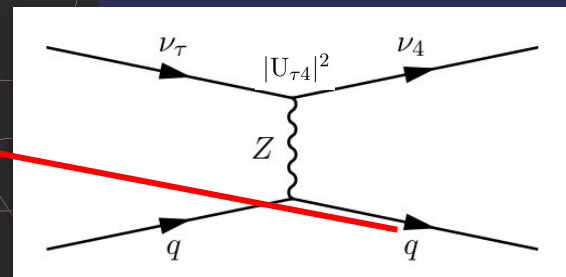
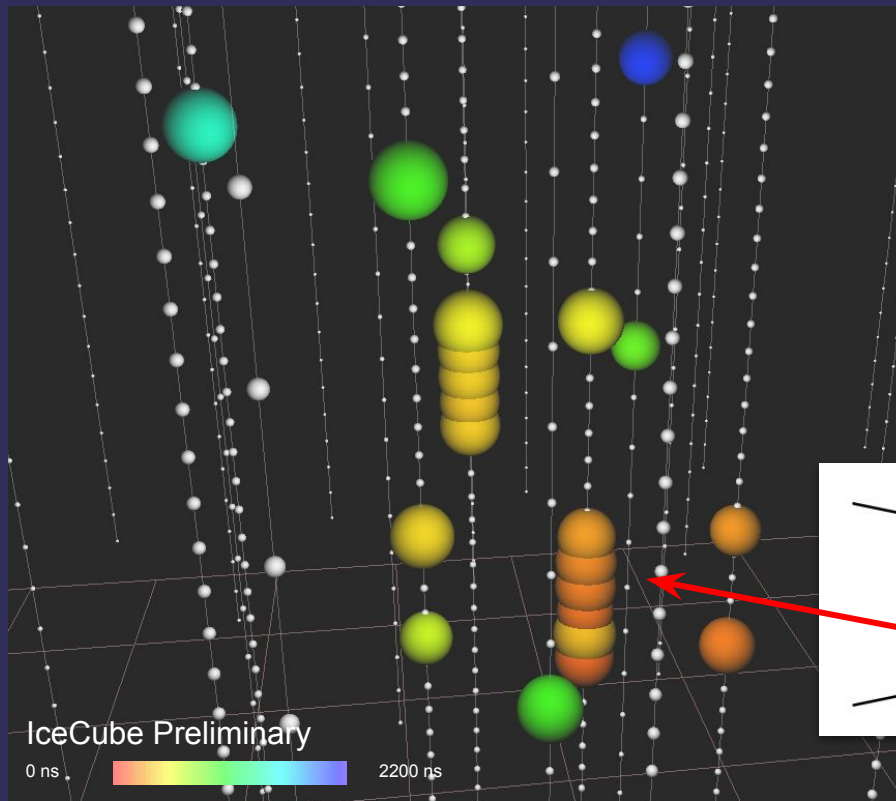
Tau neutrinos passing through the detector volume may scatter off ice nuclei, producing an HNL. HNLs then decay to leptonic or mesonic final states



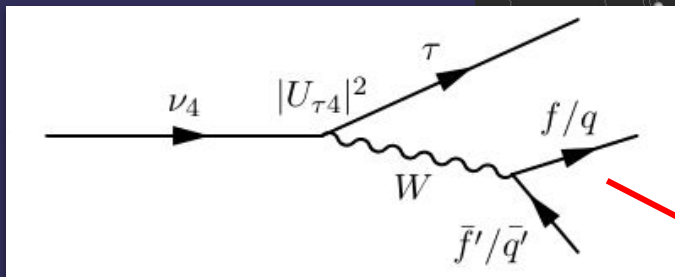


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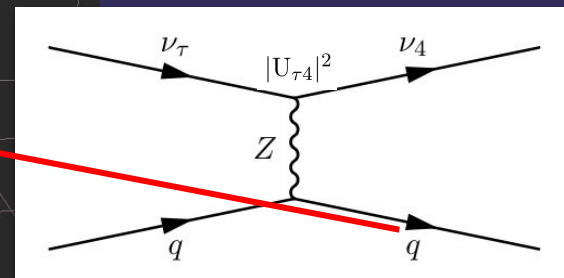
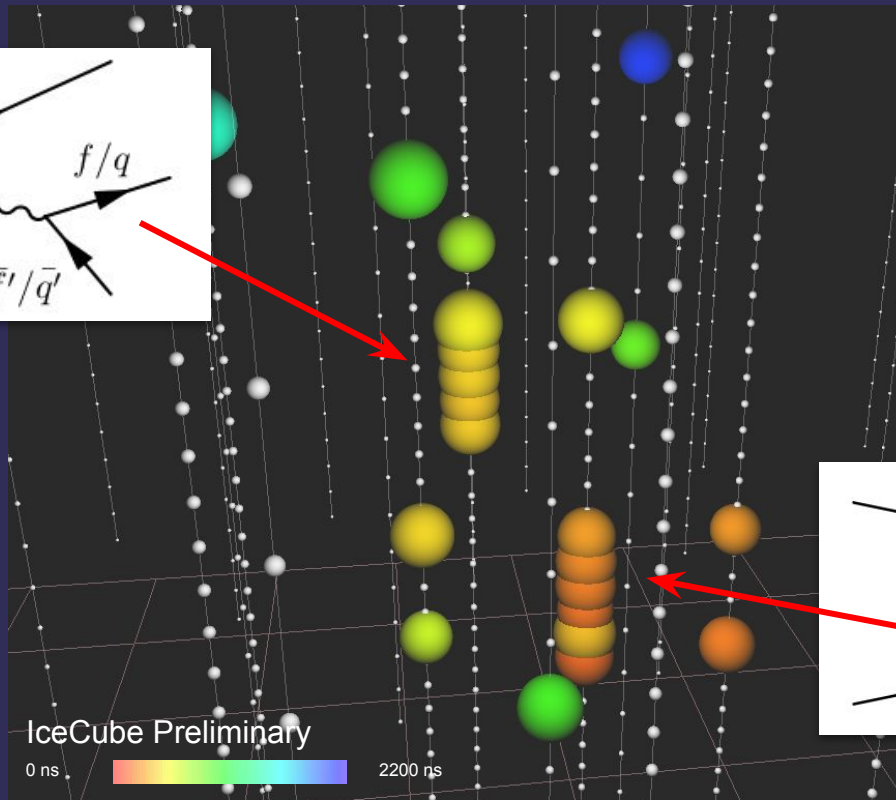
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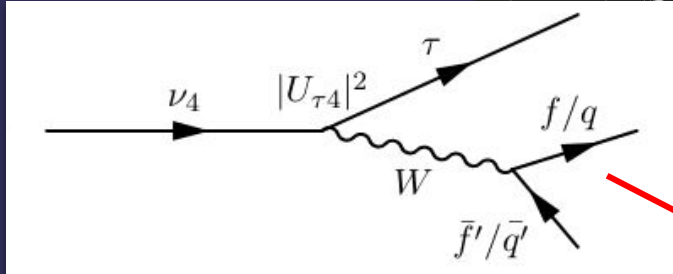
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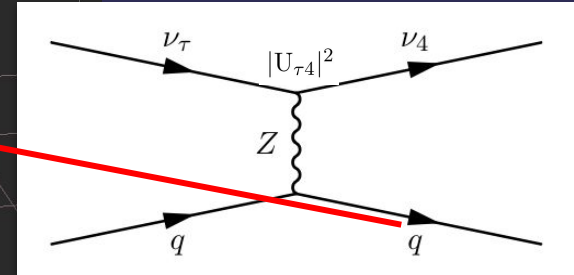
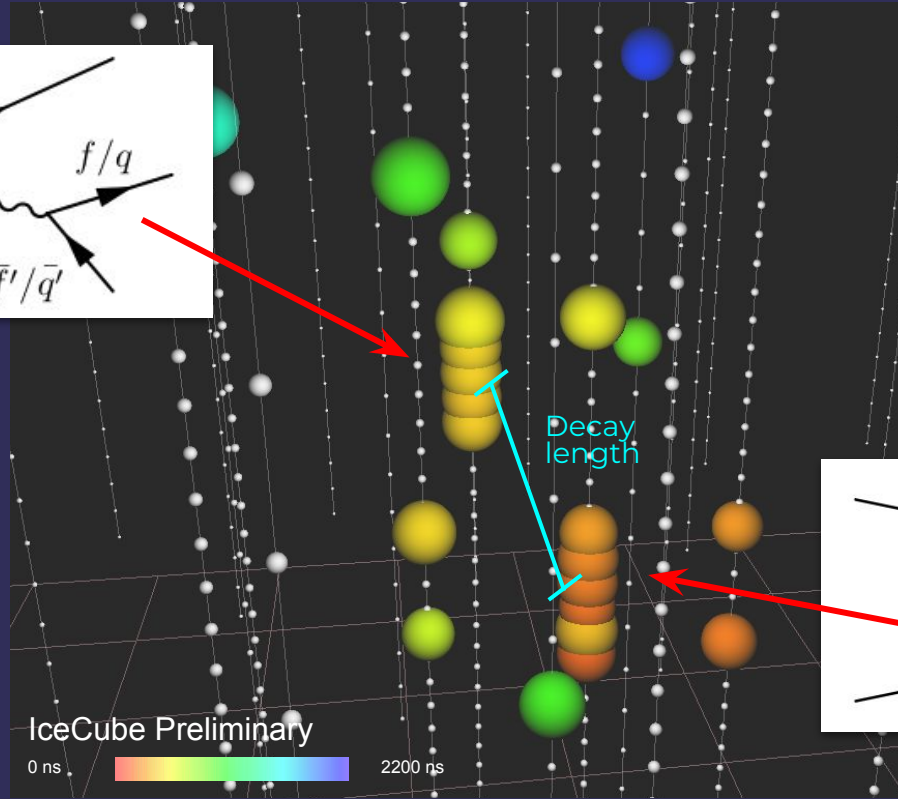
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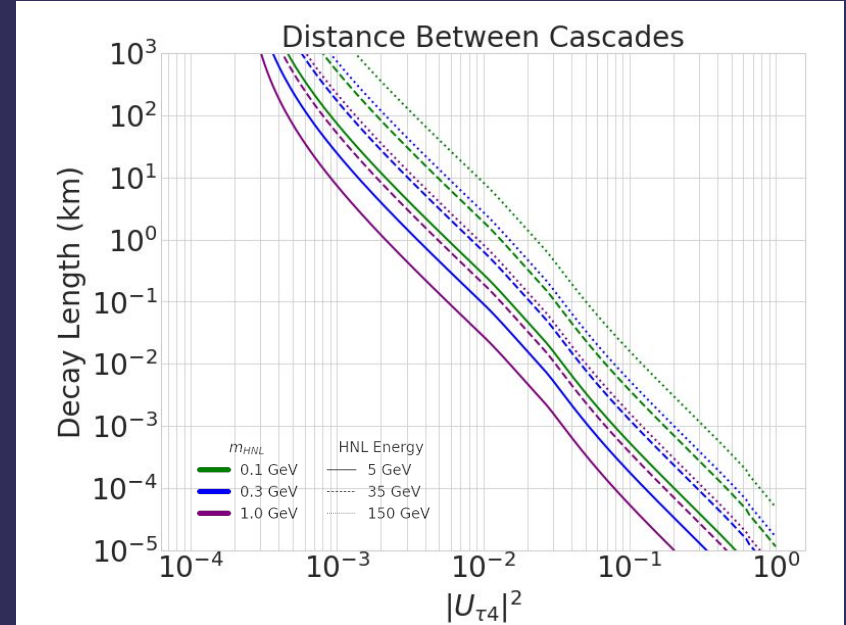


# HNL Search: Current Status

The decay length is determined by the mass of the HNL, its mixing with the tau, and its overall energy

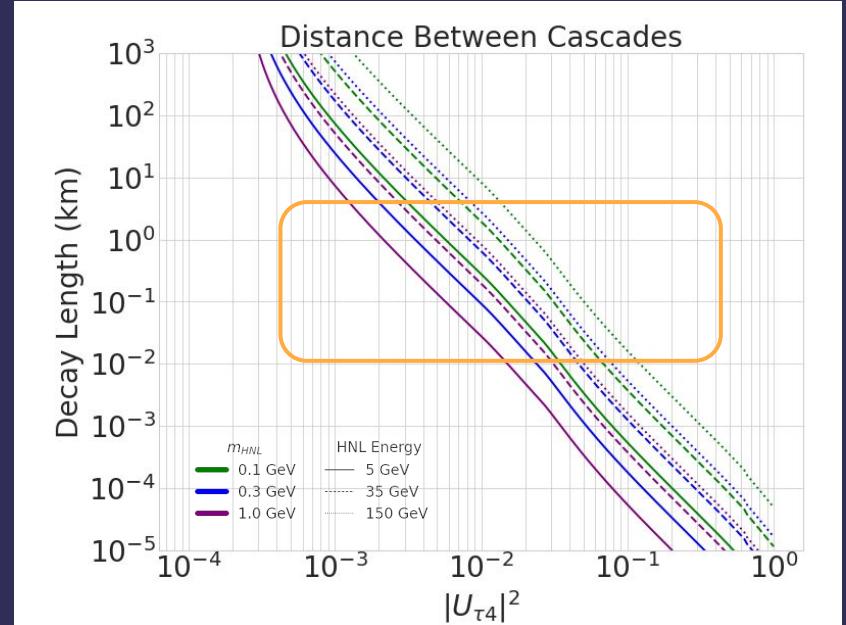
The construction of the IceCube Detector allows us to search only in a particular region of phase space

We tailor our simulation and reconstruction tools to decay lengths between cm and km scales - those resolvable in IceCube



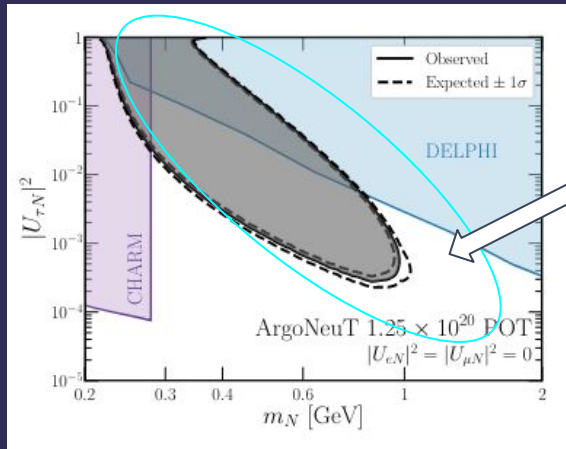
# HNL Search: Current Status

IceCube is most sensitive to mixings above  $10^{-4}$ , but is sensitive to lower mixings at higher HNL masses

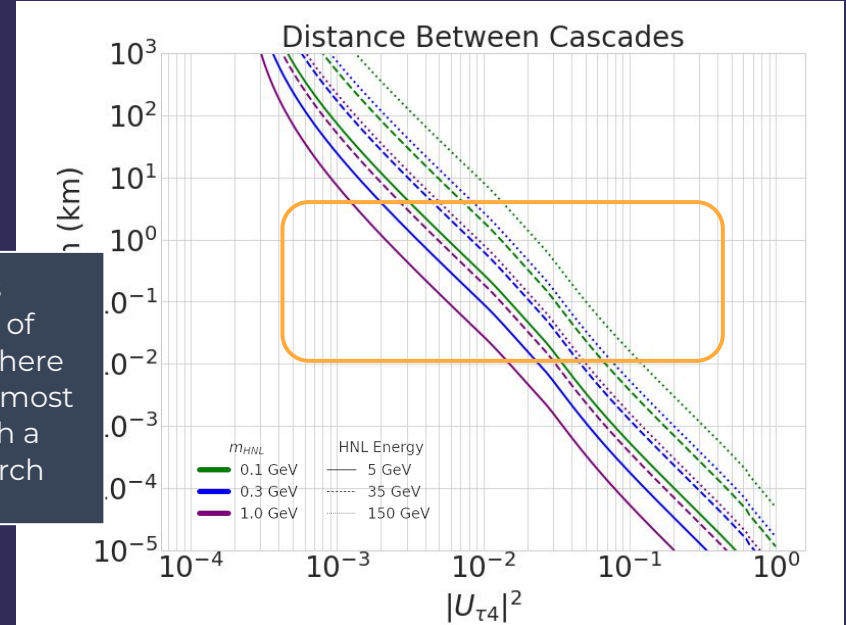


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This higher-mass higher-mixing area of parameter space is where IceCube can make its most singular impact with a double-cascade search



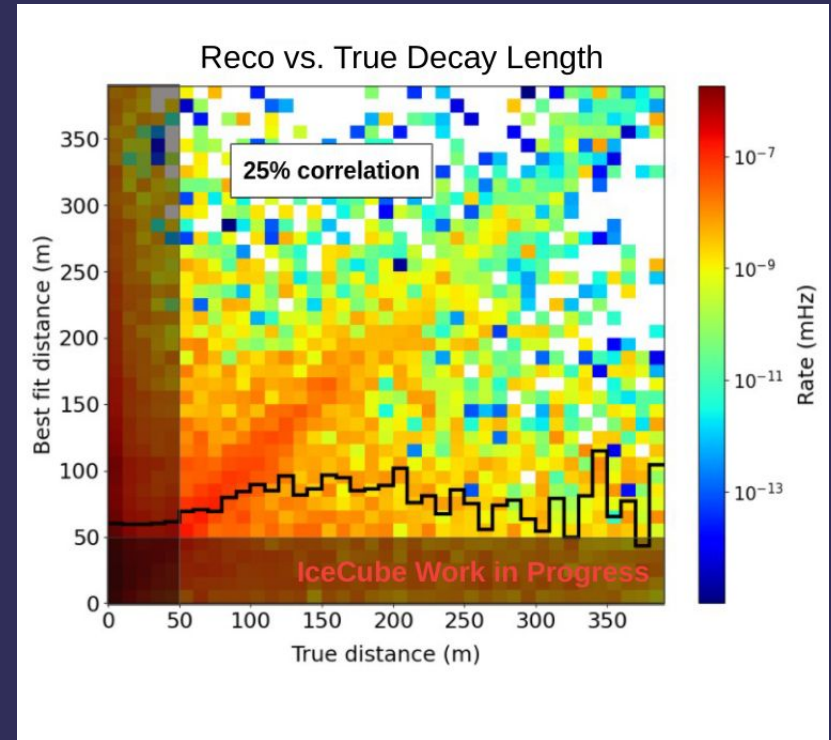
# HNL Search: Challenges

Few HNL events are resolvable as cascades

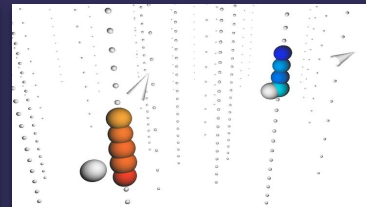
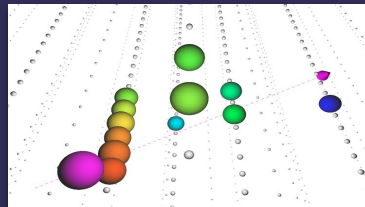
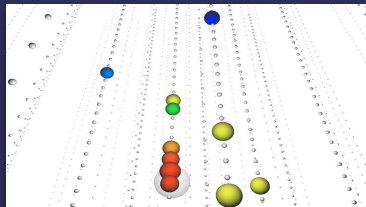
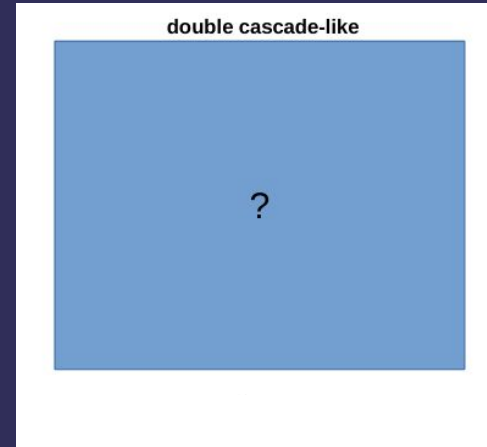
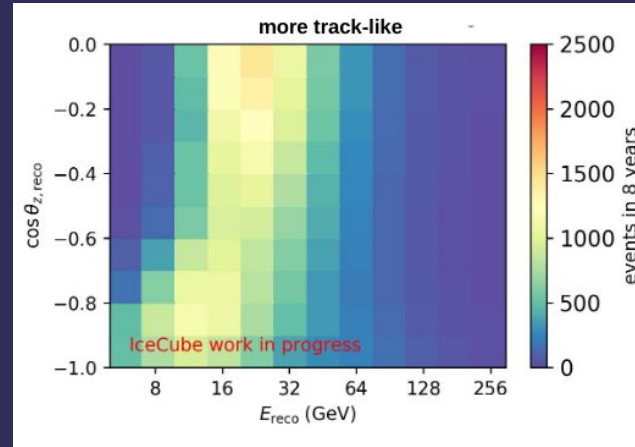
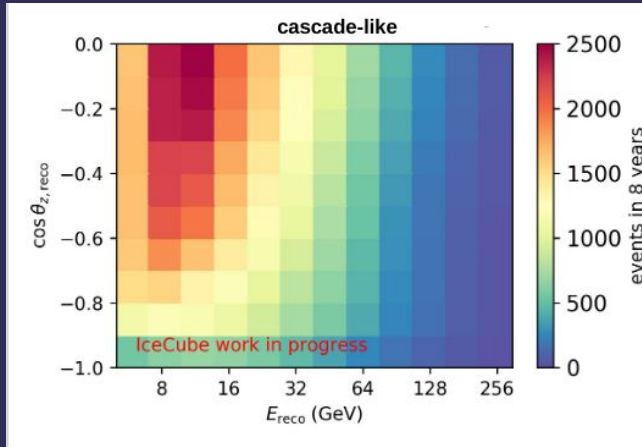
Background events can mimic signal due to detector sparsity

Low light produced in the first cascade causes double-cascades to be mis-identified

Reconstruction of decay length is a work in progress

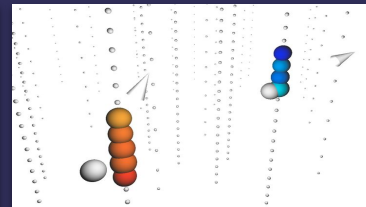
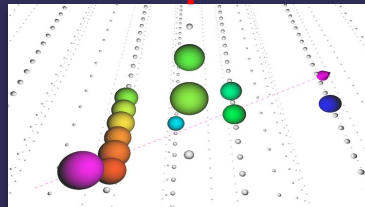
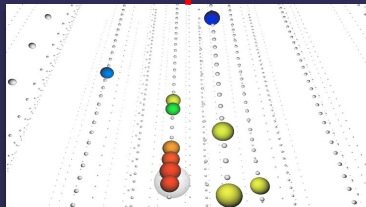
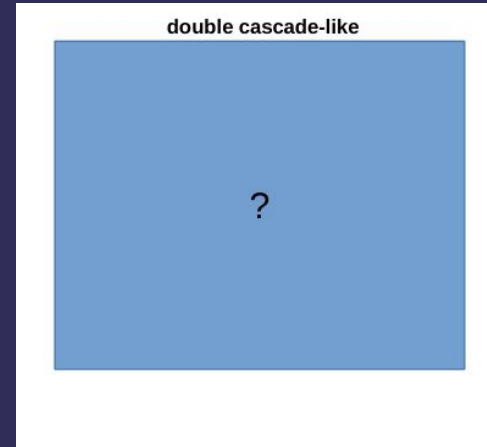
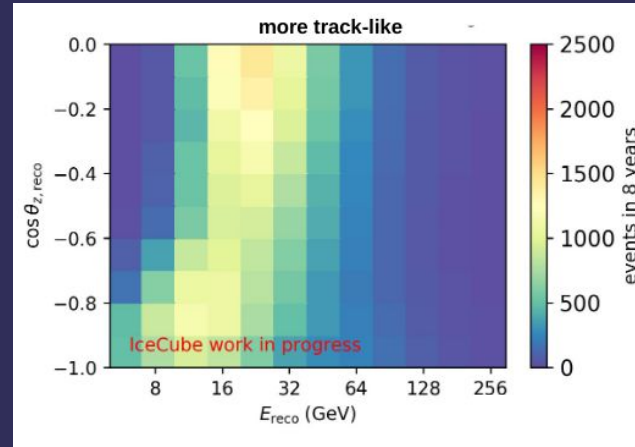
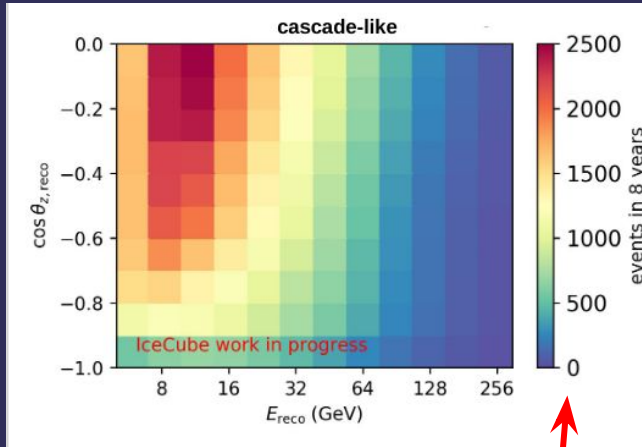


# HNL Search: Opportunities

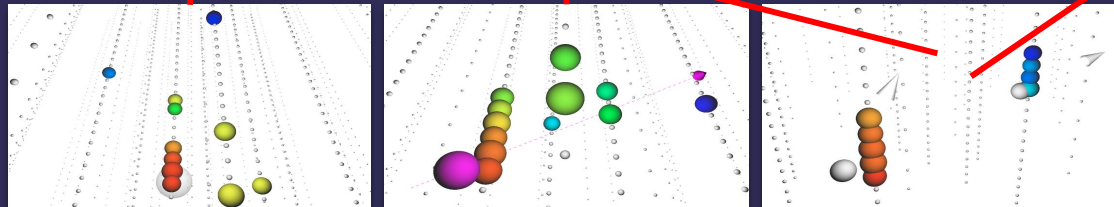
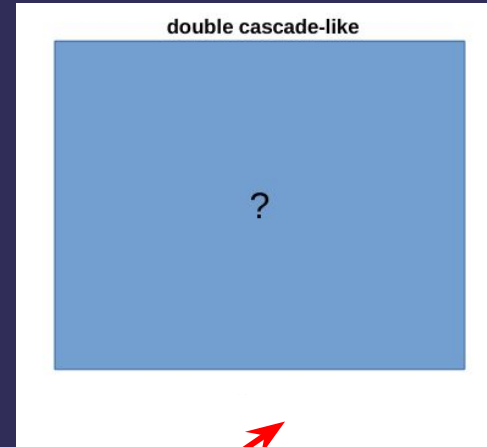
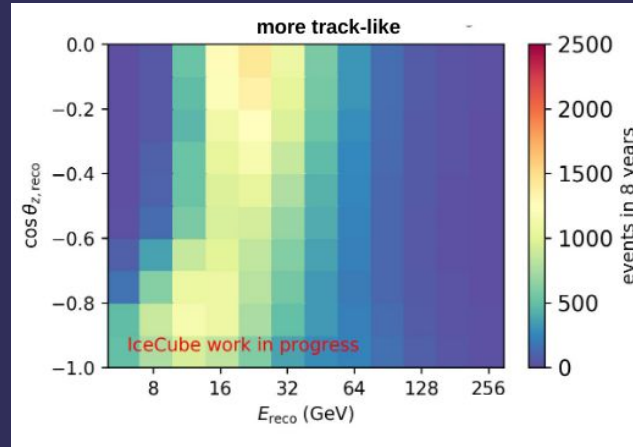
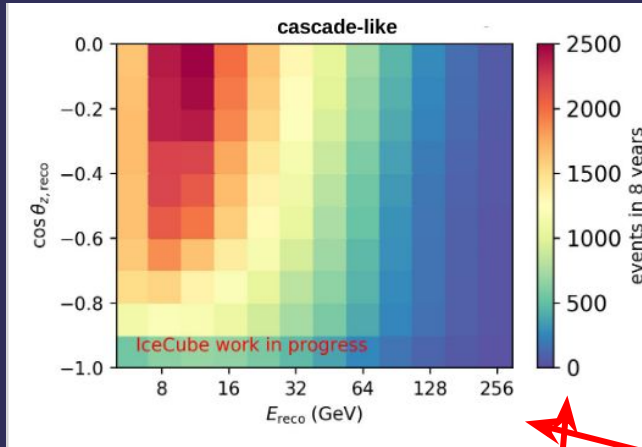




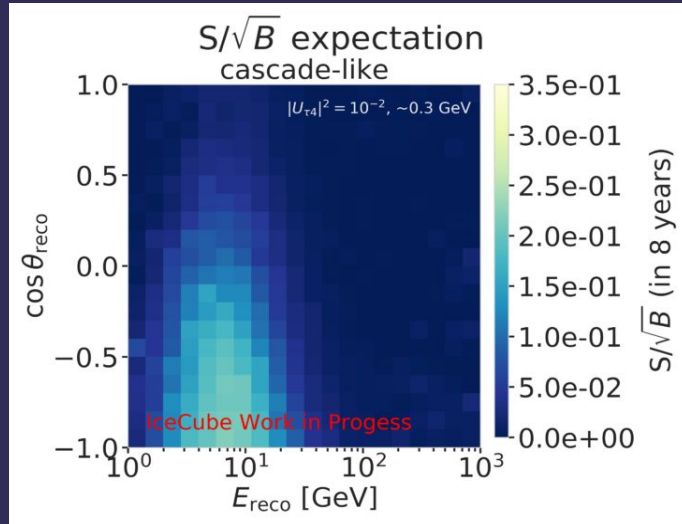
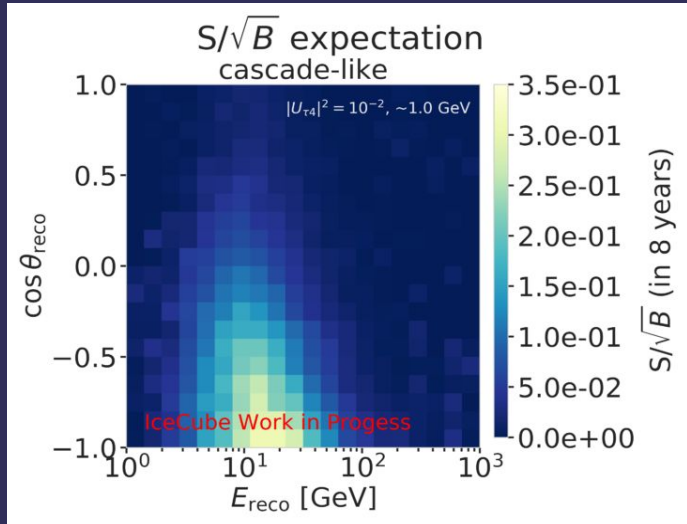
# HNL Search: Opportunities



# HNL Search: Opportunities



# Cascade-Like Sensitivity



The greater the tau mixing with the HNL, and the greater the HNL mass, the stronger our expected signal shape change

Signal (HNL) over square root of background ( $\nu_{\text{atm}}$ ,  $\mu_{\text{atm}}$ , Noise) for  $|U_{\tau 4}|^2 = 10^{-2}$  with  $m_{\text{HNL}} \sim 1.0$  GeV (left) and 0.3 GeV (right), for a fully processed MC sample.

# Double-Cascade Like Sensitivity

- Dedicated HNL simulation currently being refined
- Specialized low energy double-cascade reconstruction being developed

With tailored simulation and reconstruction, we'll be able to determine our sensitivity to double-cascade events.



Coming soon!



# Thank you for listening!

Further thanks to Leander Fischer, Summer Blot, and Carlos Arguelles-Delgado - the rest of the HNLs in IceCube team.