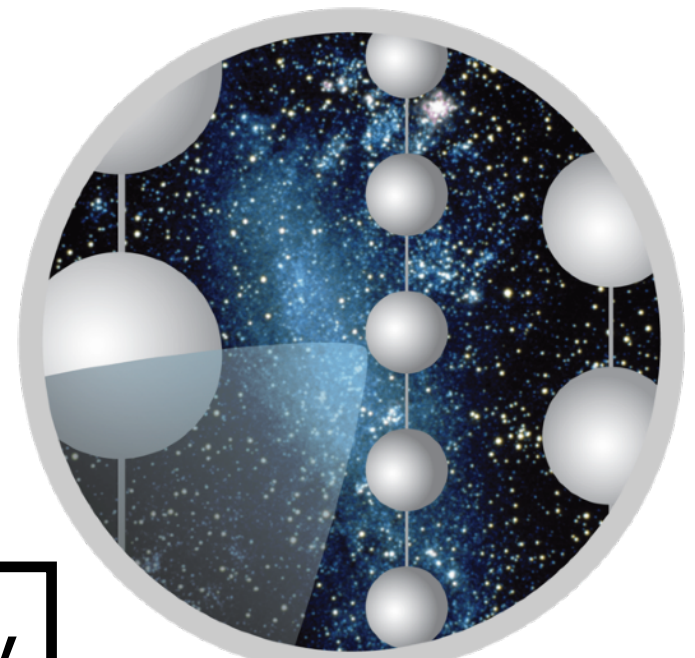




Search for Sterile Neutrinos with Cascades in IceCube

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Abstract: The introduction of a sterile neutrino is a common solution to short-baseline experiment anomalies looking for Standard Model neutrino (dis)appearance. IceCube is uniquely positioned to look for a sterile neutrino signal via the matter enhanced resonant oscillation of Standard Model neutrinos into the sterile state as they travel through the Earth. This search has been done with track events in IceCube before, with the most recent result consistent with the null hypothesis at 2.3σ . This poster introduces a parallel search using cascade events, which both opens sensitivity to additional sterile parameters, as well as provides an independent cross-check to the track results. To allow for this search, we investigate the sterile signal in cascade events of different ν flavors due to matter enhanced resonance, and begin exploring ML methods to separate tracks, cascades, and background.

Sterile Neutrinos

Anomalies in short-baseline experiments suggest that Standard Model 3 neutrino + oscillations may not be complete. A common solution to these anomalies is to introduce a **sterile** neutrino that does not interact via the weak force. Combined, these anomalies favor the sterile neutrino model at nearly 5σ , but with significant tension.

Matter Enhanced Resonance

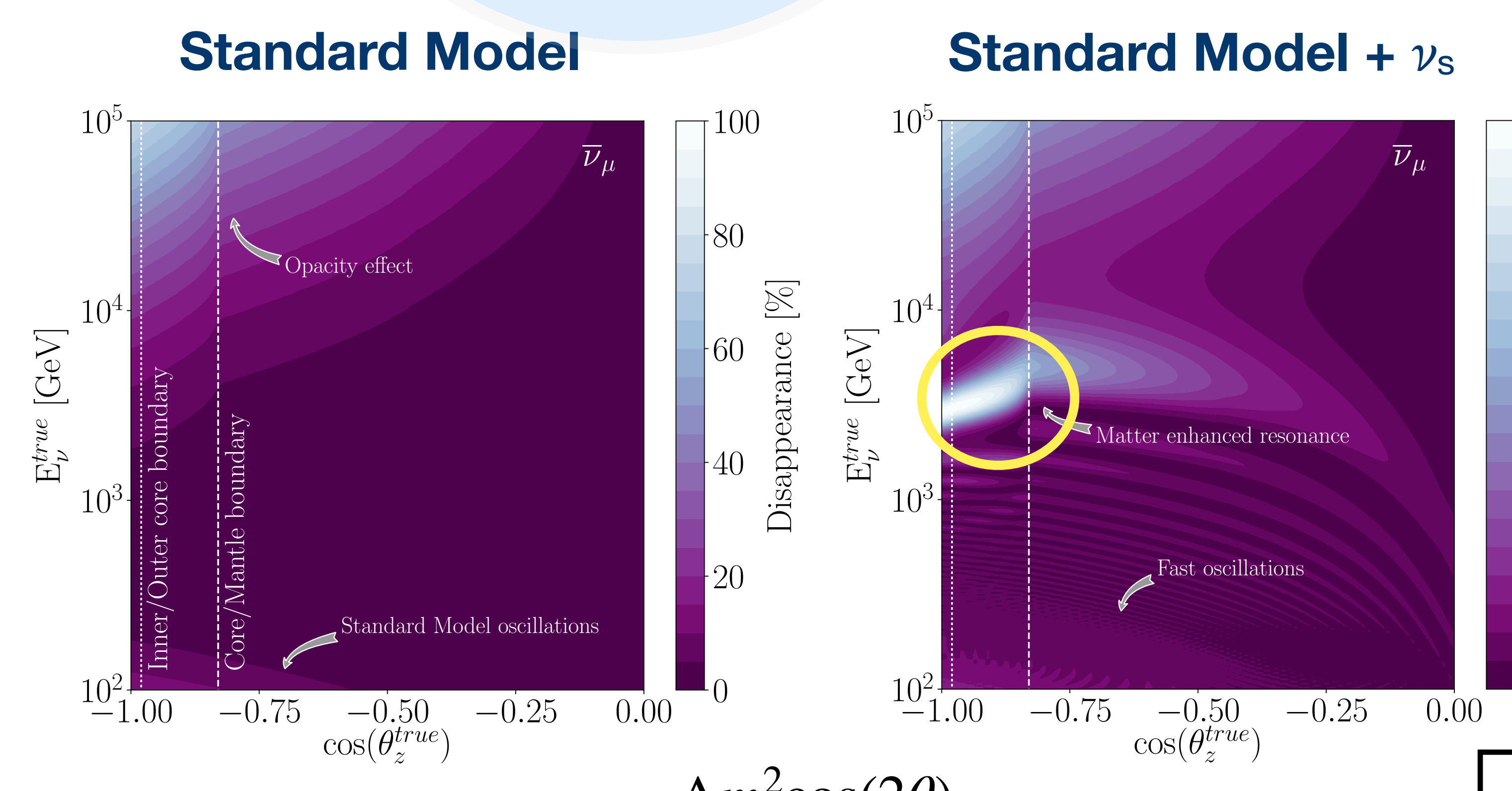
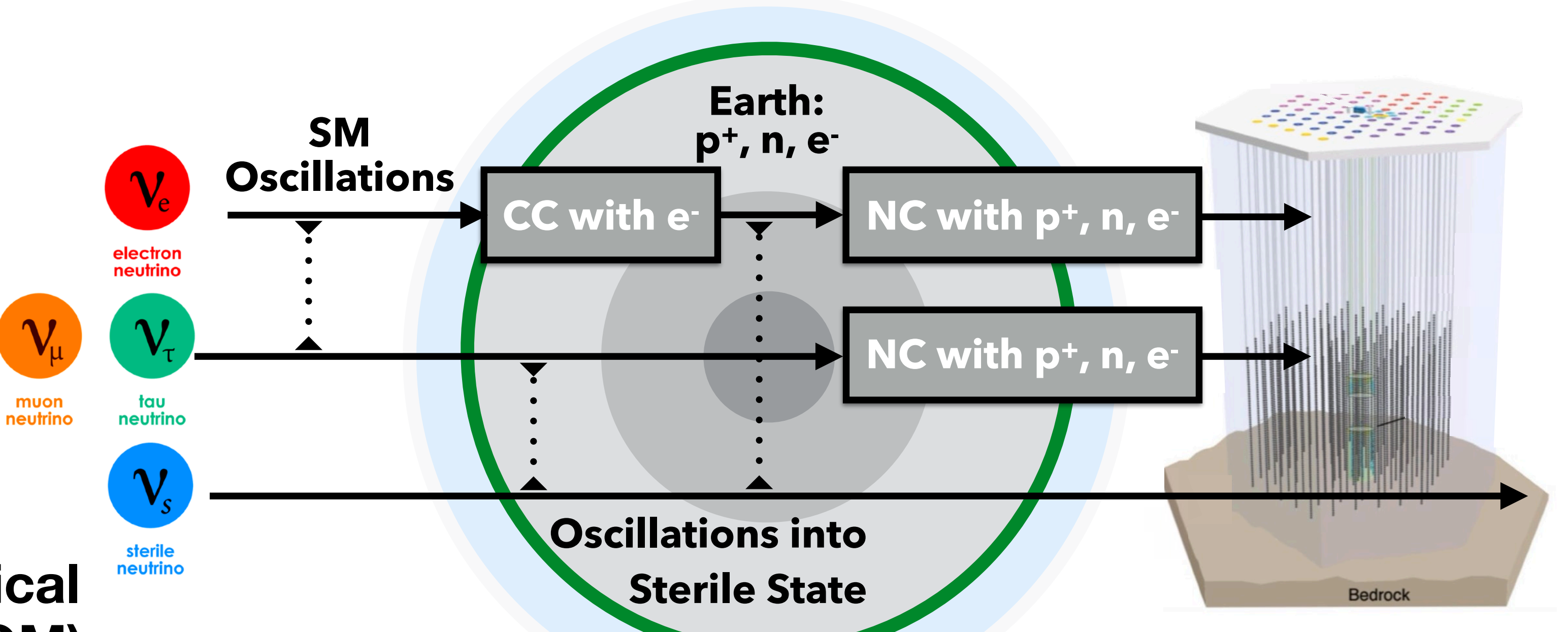
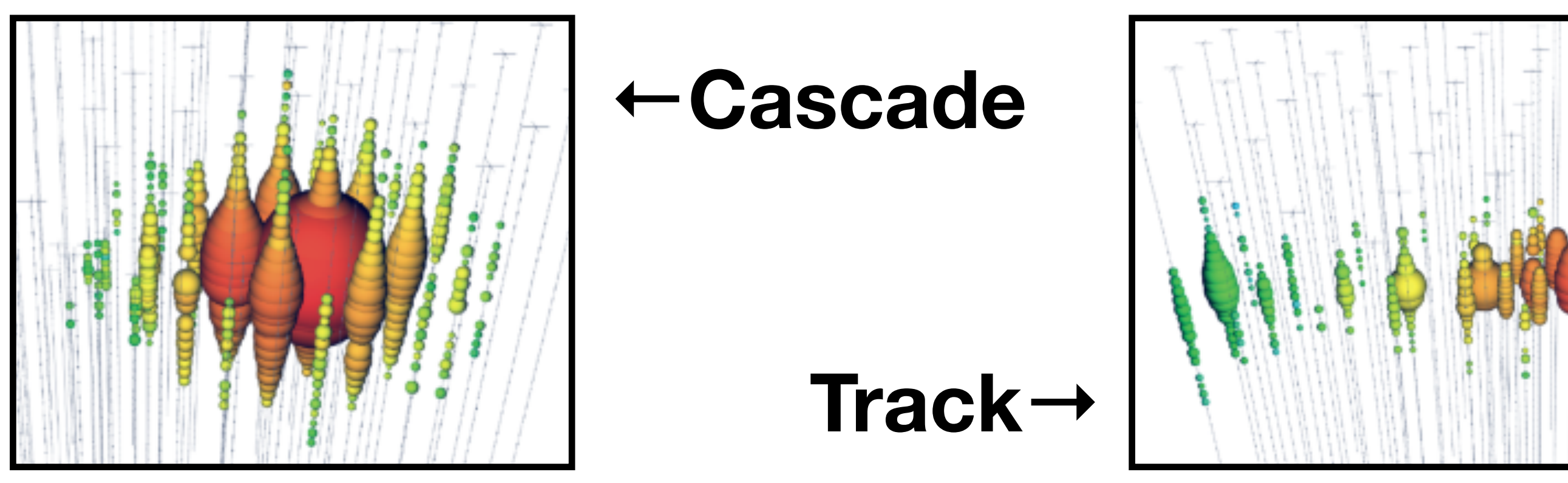
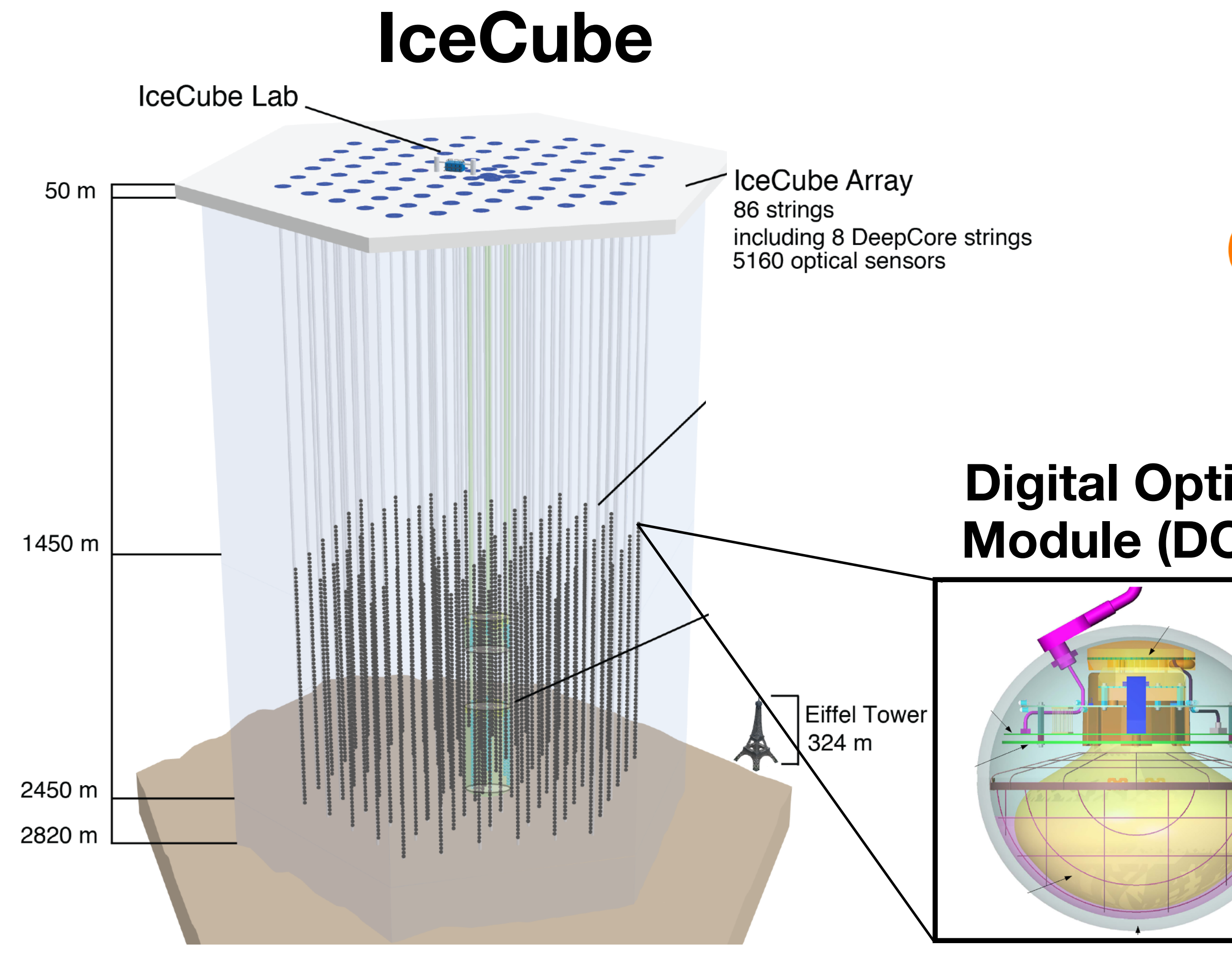
IceCube is able to look for a sterile neutrino signal in a unique way. When neutrinos pass through matter, their oscillations are modified due to the MSW effect. In the case of a sterile neutrino, given the right density of matter and neutrino energy, there is a **resonant oscillation** into the sterile state. IceCube can look for this effect in a deficit of Standard Model neutrinos.

Building a Cascade Dataset

Novel searches using cascades include:

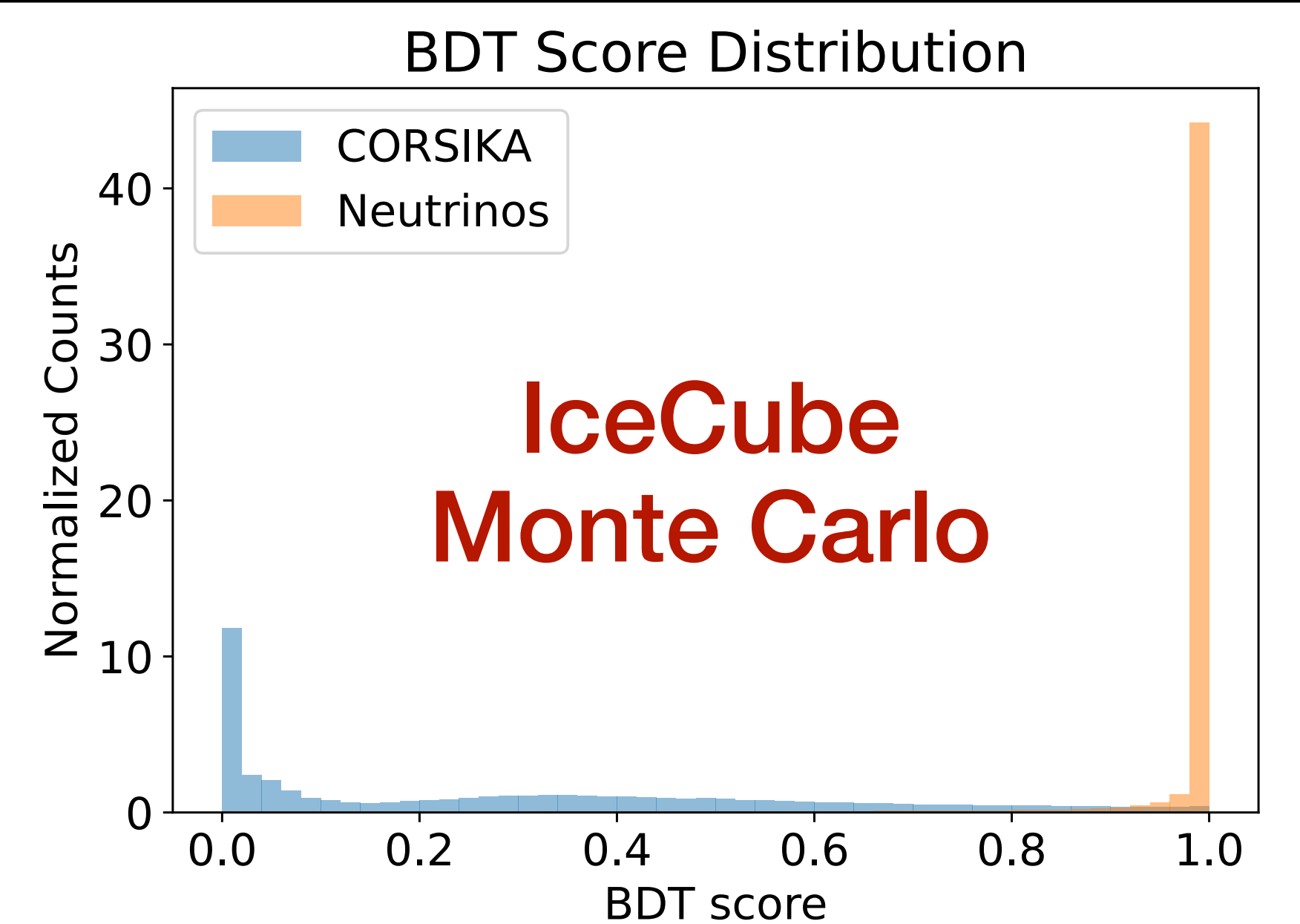
- Independent **cross-check of ν_μ (CC)** search with ν_μ NC events
- Constraining **additional sterile parameters** like θ_{34}
- Ability to test various additional BSM models

To achieve these goals, the background rejection and event selection will be updated to keep cascade events, and reconstructions will be trained specifically for cascades.



$$E_{crit}^M = \frac{\Delta m^2 \cos(2\theta)}{\sqrt{2} G_F N_n}$$

A BDT using fast event reconstructions and charge variables is able to effectively separate neutrinos from cosmic ray background. These events will then be split into tracks and cascades for better reconstruction.



Key Considerations for Cascade Analysis

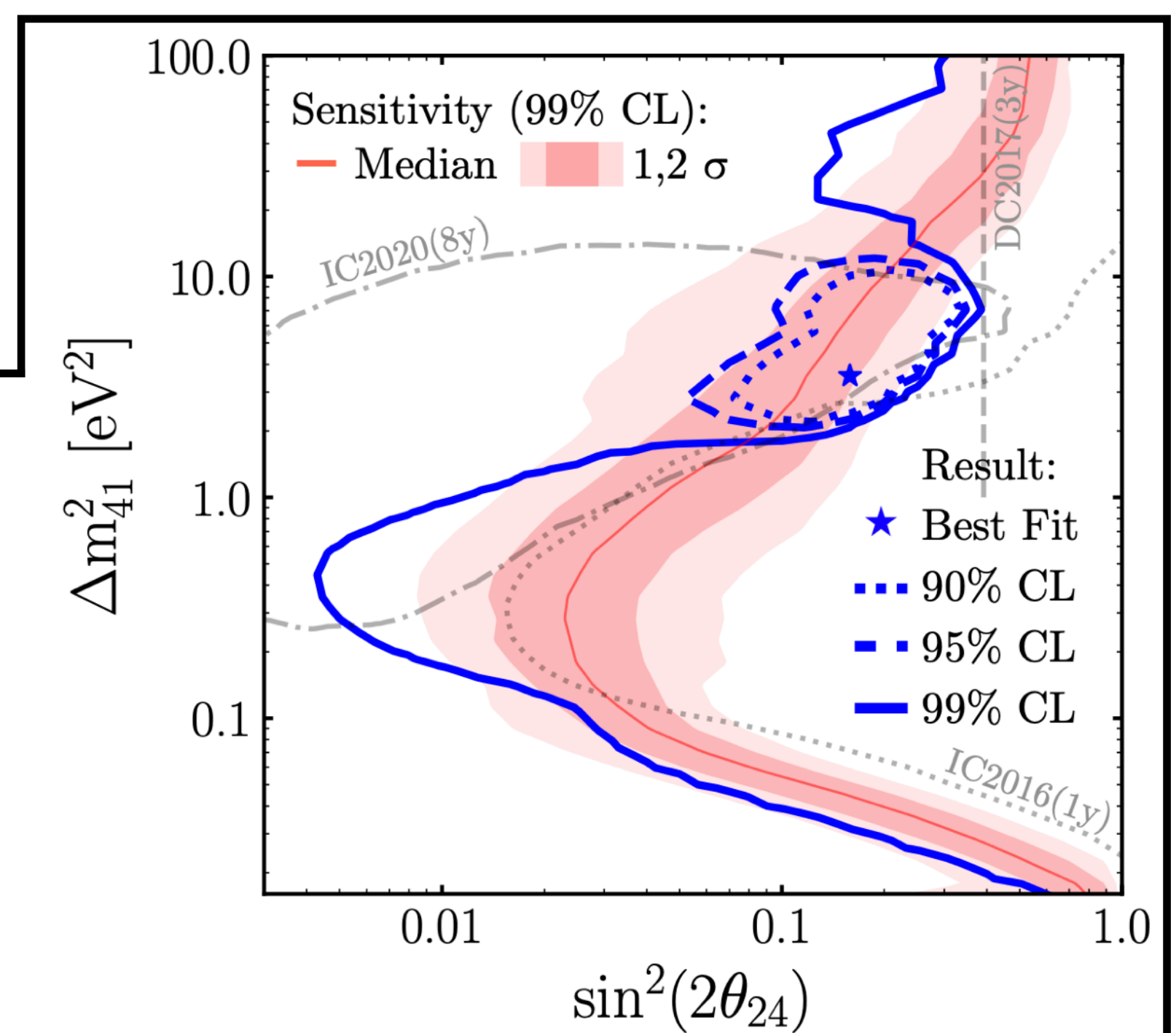
- Statistics:** IceCube sees fewer cascades than tracks at the relevant energies
- Flavor separation:** Cascades produced by different flavors of neutrinos look nearly identical in the detector. We can only separate them on a statistical basis.
- Directional Reconstruction** is more difficult with cascades compared to tracks, but energy reco is better.

Main Event Topologies in IceCube

- Cascades** from all-flavor NC and ν_e & ν_τ CC: good energy resolution due to the containment of the events inside the detector, but poor pointing due to the spherical event shape.
- Tracks** from ν_μ CC: excellent pointing due to their extended shape, but worse energy resolution as much of the event may lie outside the detector.

Previous Sterile Search (Tracks)

- Very (99.9%) pure track sample with 360,000 events in 11 years of data¹
- Result consistent with the null hypothesis at 2.3σ .
- Constrains two sterile parameters: the mixing angle θ_{24} , and the mass-squared splitting Δm^2_{14} .



Next Steps

- Development of ML-based methods for cascade/track separation and cascade reconstruction
 - Suite of different tools to do different reconstructions, trained specifically on cascades
- Sensitivity study for ν_μ cross-check with NC events
- Assessment of systematic uncertainties for cascades

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References: ¹ R. Abbasi et al., Phys. Rev. Lett. 133, 201804, 2024.