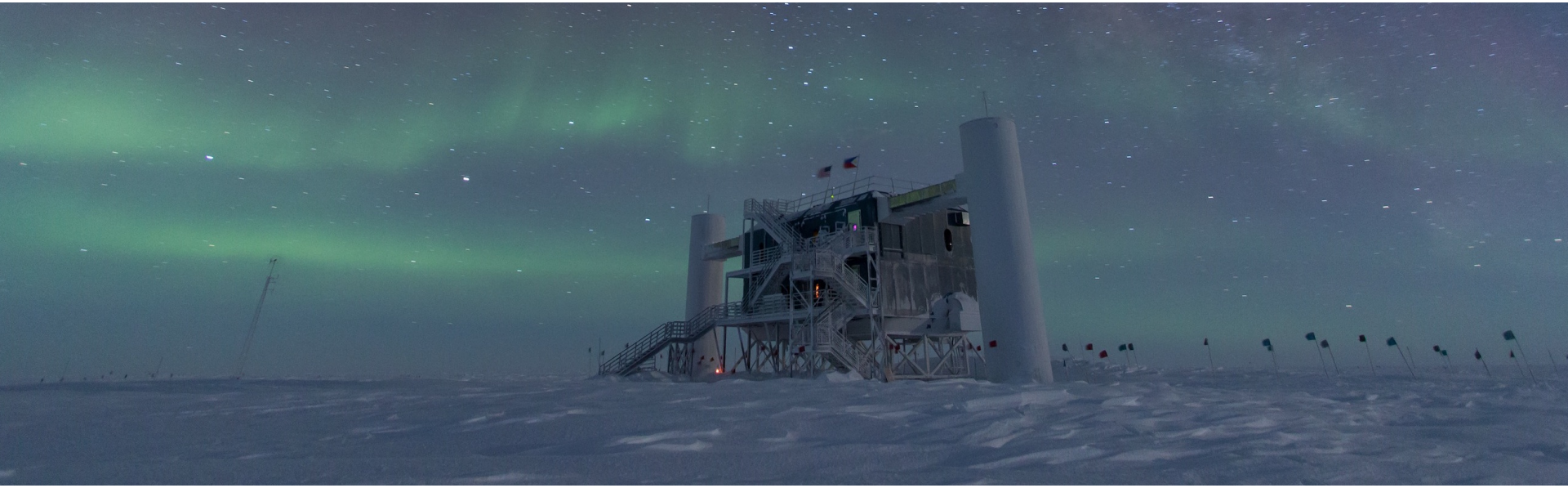

Searching for neutrino transients below 1 TeV with IceCube

Michael Larson, Jason Koskinen, Alex Pizzuto, and Justin Vandenbroucke

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

NSF

IceCube
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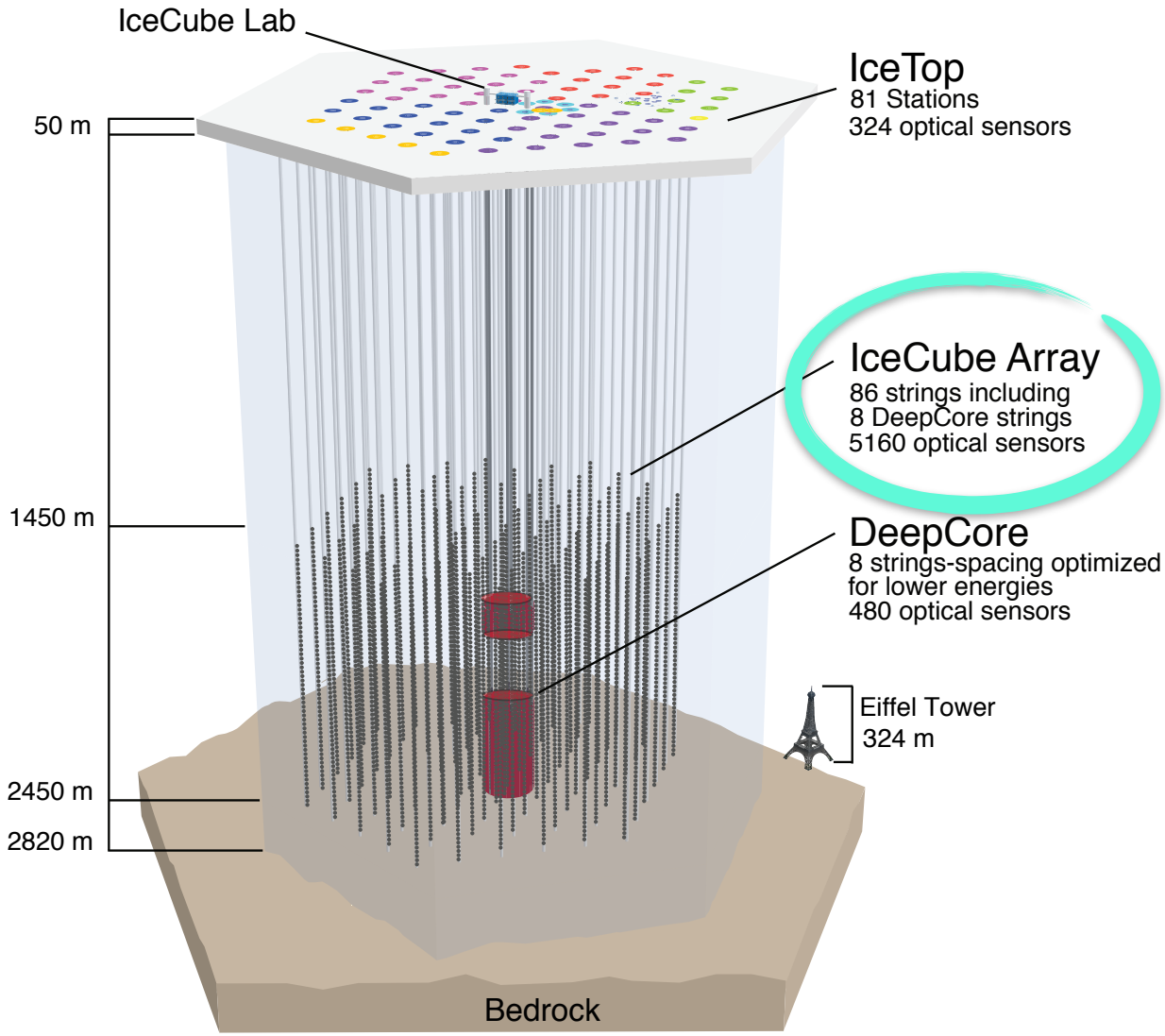
UNIVERSITY OF MARYLAND

The IceCube Neutrino Observatory



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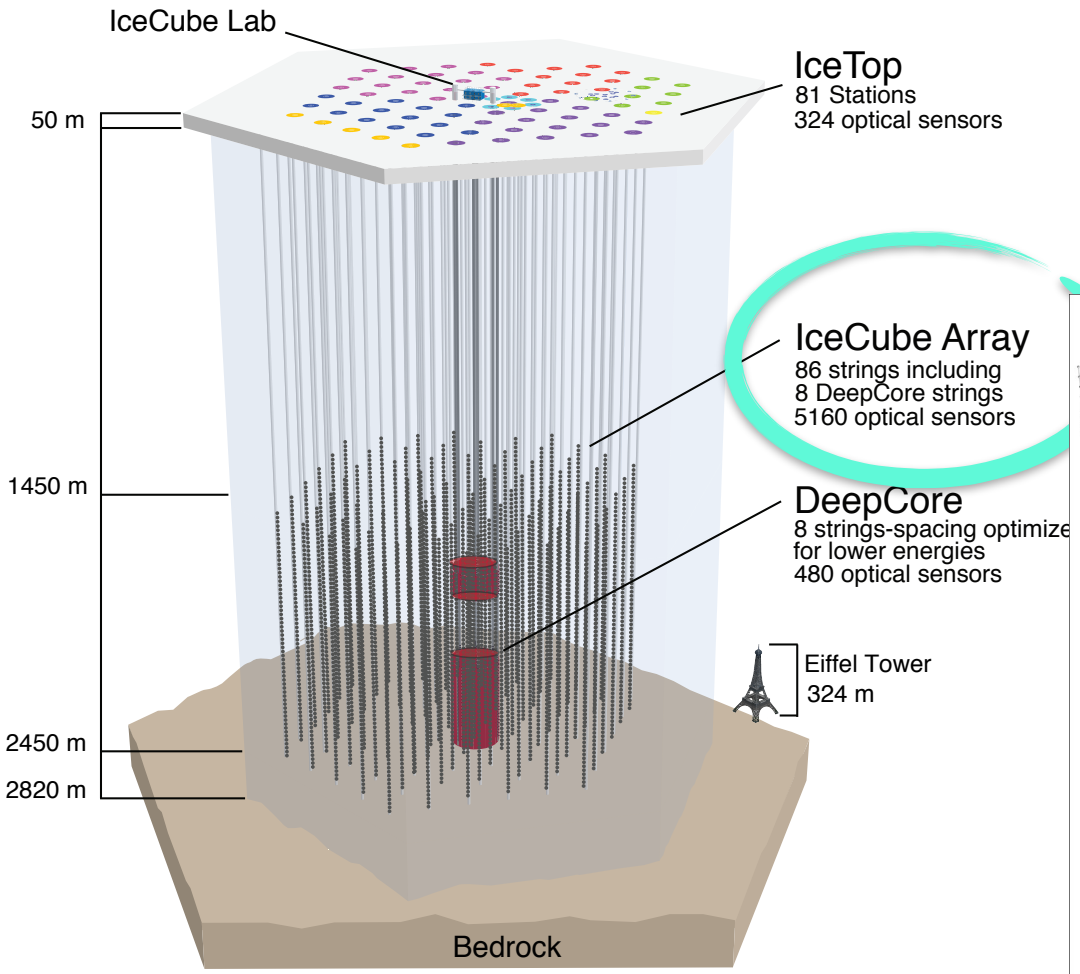
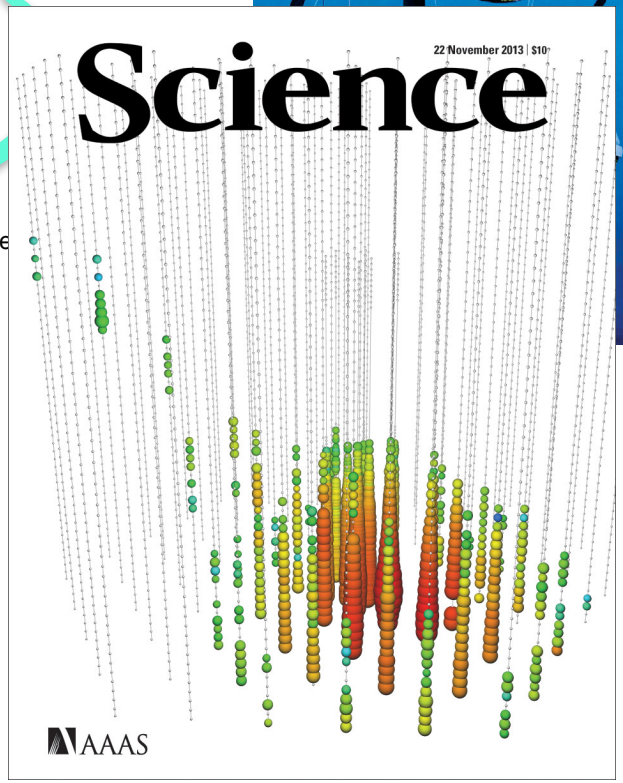
The IceCube Neutrino Observatory





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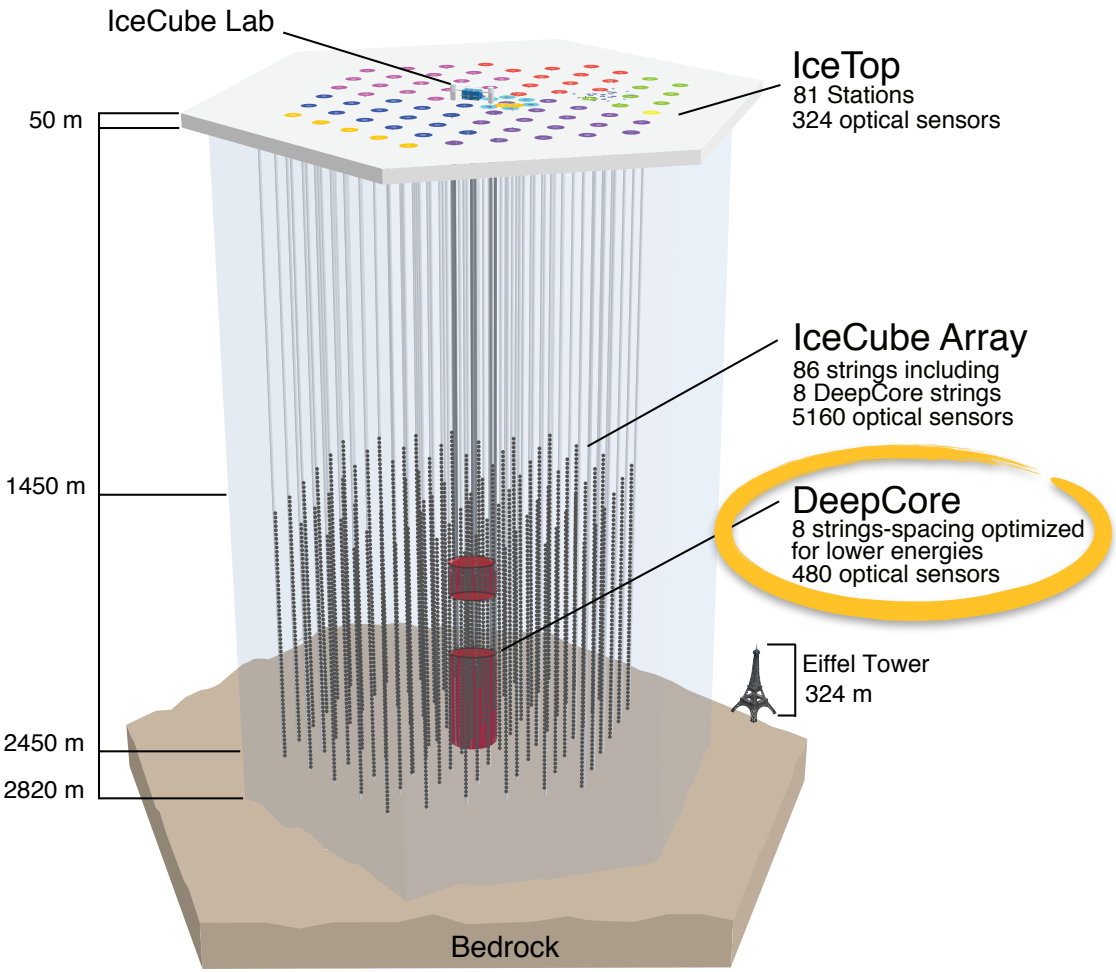
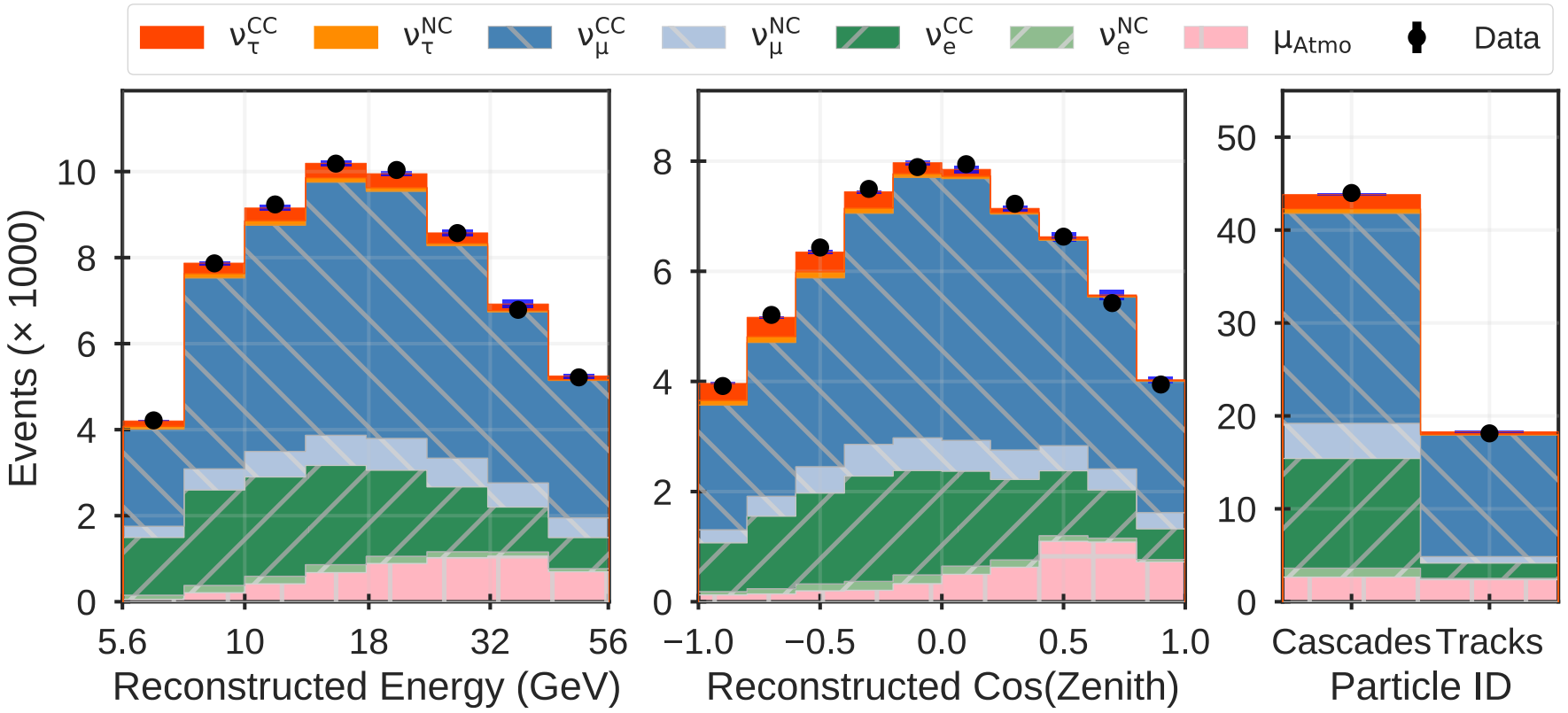
The DeepCore Subarray



- Denser low-energy infill array targeting neutrino oscillations and BSM physics
- Larger IceCube array acts as an active veto to reduce backgrounds
- Extends IceCube's energy reach from 100 GeV down to ~5 GeV
- High atmospheric background rates, but existing oscillation event selections can be repurposed for low energy astrophysics

The GRECO Oscillation Selection



- Previously published* all flavor full-sky three-year dataset used to fit muon neutrino disappearance and tau neutrino appearance
- Very good data/simulation agreement
- Total atmospheric event rates of 0.87 mHz

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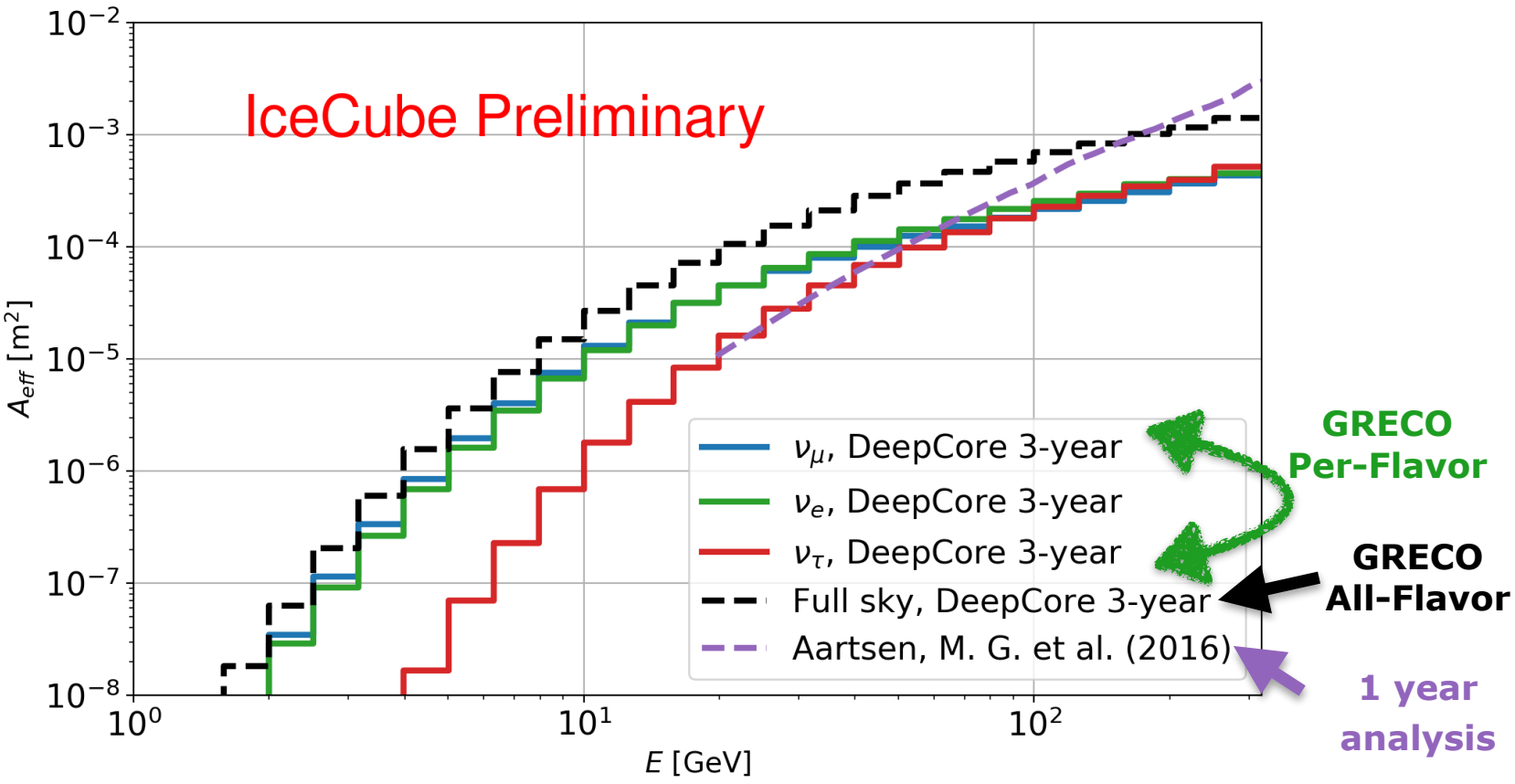
* Phys. Rev. D 99 no. 3, (2019) 032007.

Effective Areas for GRECO Oscillation Selection



- Effective area is significantly larger than previous one-year muon neutrino charged-current selection used for low energy transients*

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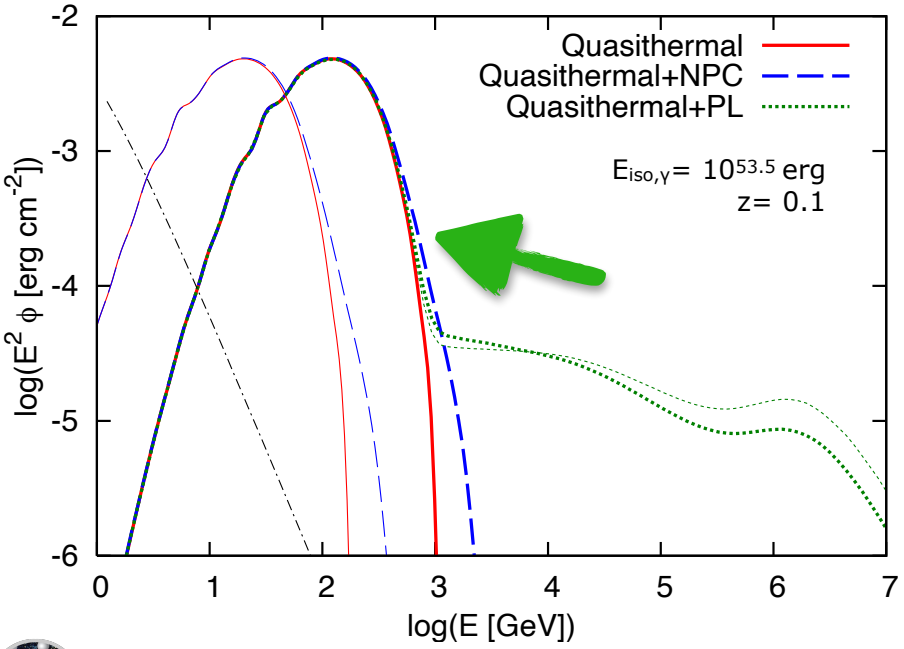
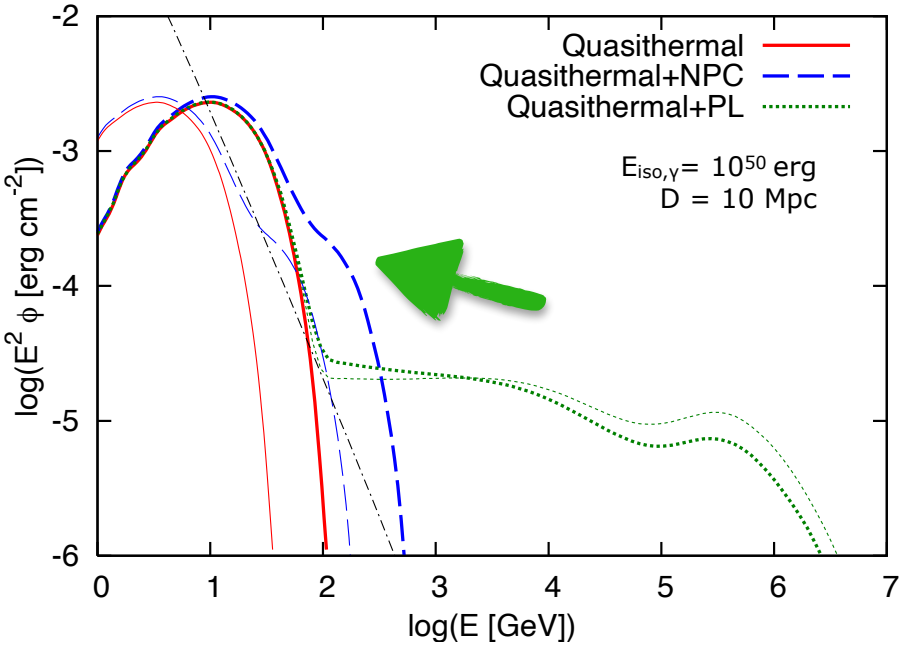
* Astrophys. J. 816 no. 2, (2016) 75.

Sub-TeV Neutrino Emission

- Assume a low energy neutrino spectrum approximating quasithermal emission shown in Murase, Kashiyama, and Meszaros*

$$\Phi(E) = \Phi_0 \left(\frac{E}{kT}\right)^2 / \left(e^{\frac{E}{kT}} + 1\right)$$





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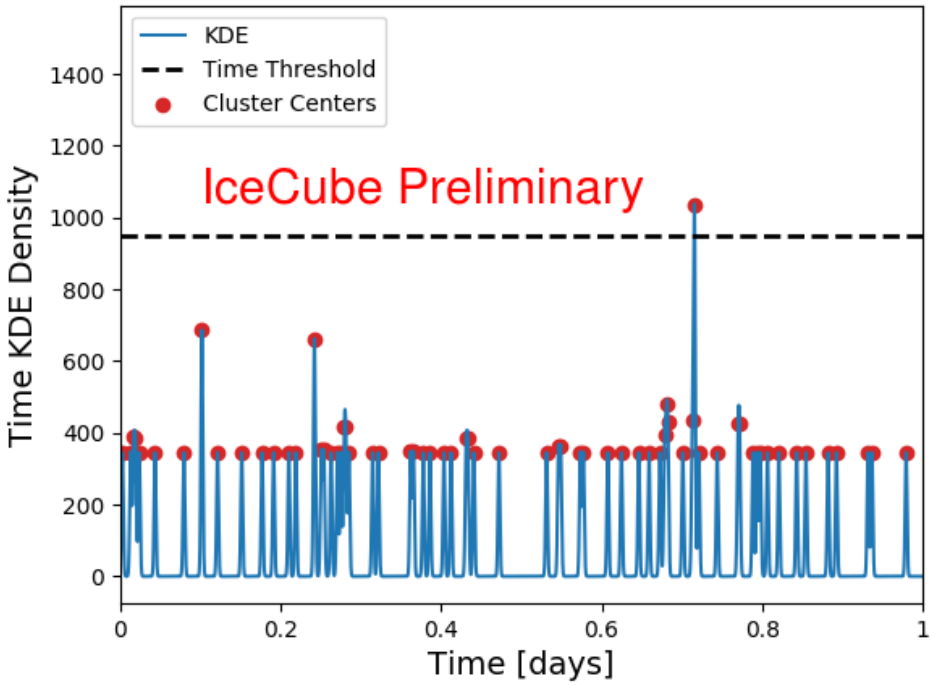
*Phys.Rev.Lett. 111 (2013) 131102

Search method and likelihood



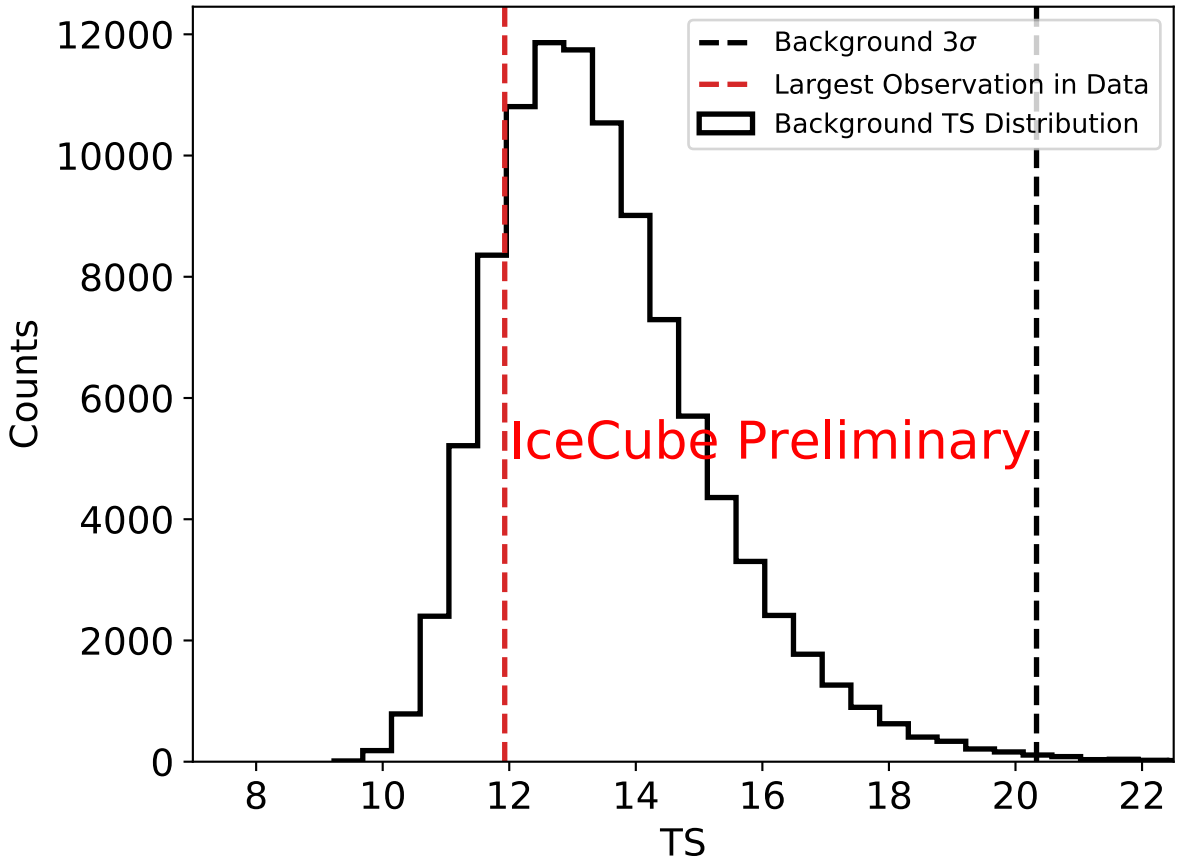
- Need to reduce possible search windows
- Assign Gaussian kernel (σ=100 seconds) to each event time (all sky)
- Sum Gaussian kernels and investigate 100 highest peaks/year
- Events within ±300 seconds of each peak fit with unbinned likelihood to obtain best-fit number of signal events n_s and test statistic

$$TS = \log \frac{\mathcal{L}(\hat{n}_s)}{\mathcal{L}(0)} = -\hat{n}_s + \sum_i^N \log\left(\frac{\hat{n}_s \mathcal{S}_i}{\langle n_b \rangle \mathcal{B}_i} + 1\right)$$

- Von Mises likelihood assumed for signal events
- Background assumed only declination-dependent

Transients with the GRECO Oscillation Selection

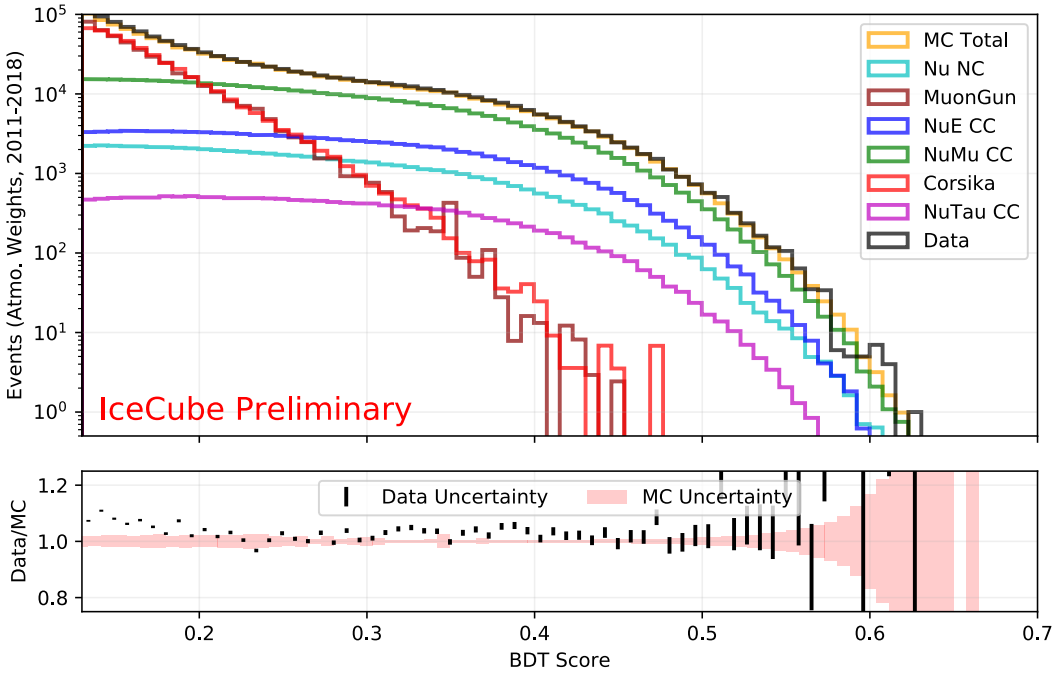
- Data unblinded from April 2012-May 2015
- Stacked test statistic from 300 time windows shows no measurable excess relative to background
- Draft paper available, arXiv:2011.05096 and submitted for publication



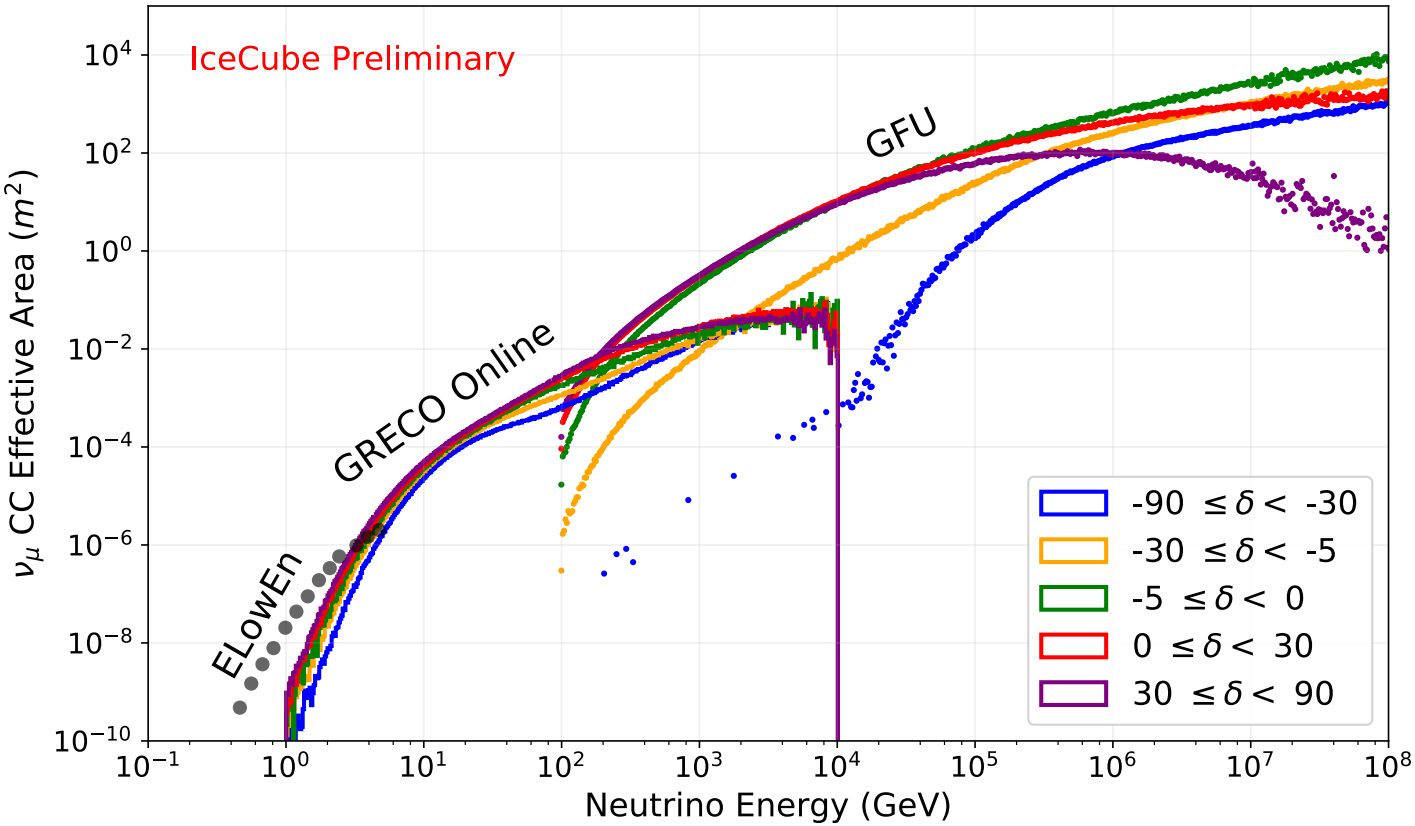
Re-optimizing the GRECO Selection

- Goals of oscillation and astrophysical transient analyses differ significantly
  - Short transient analyses resistant to atmospheric muon backgrounds
  - Dominant drivers of sensitivity are timescale + background rates and effective area

- We have re-optimized the GRECO oscillation selection to build the new GRECO astronomy selection
  - Upgraded simulation sets
  - New detector calibrations
  - Simplified BDT
  - 10x (100x) improved effective area at 100 GeV (1 TeV)
  - 8+ years of data with continuous updates planned

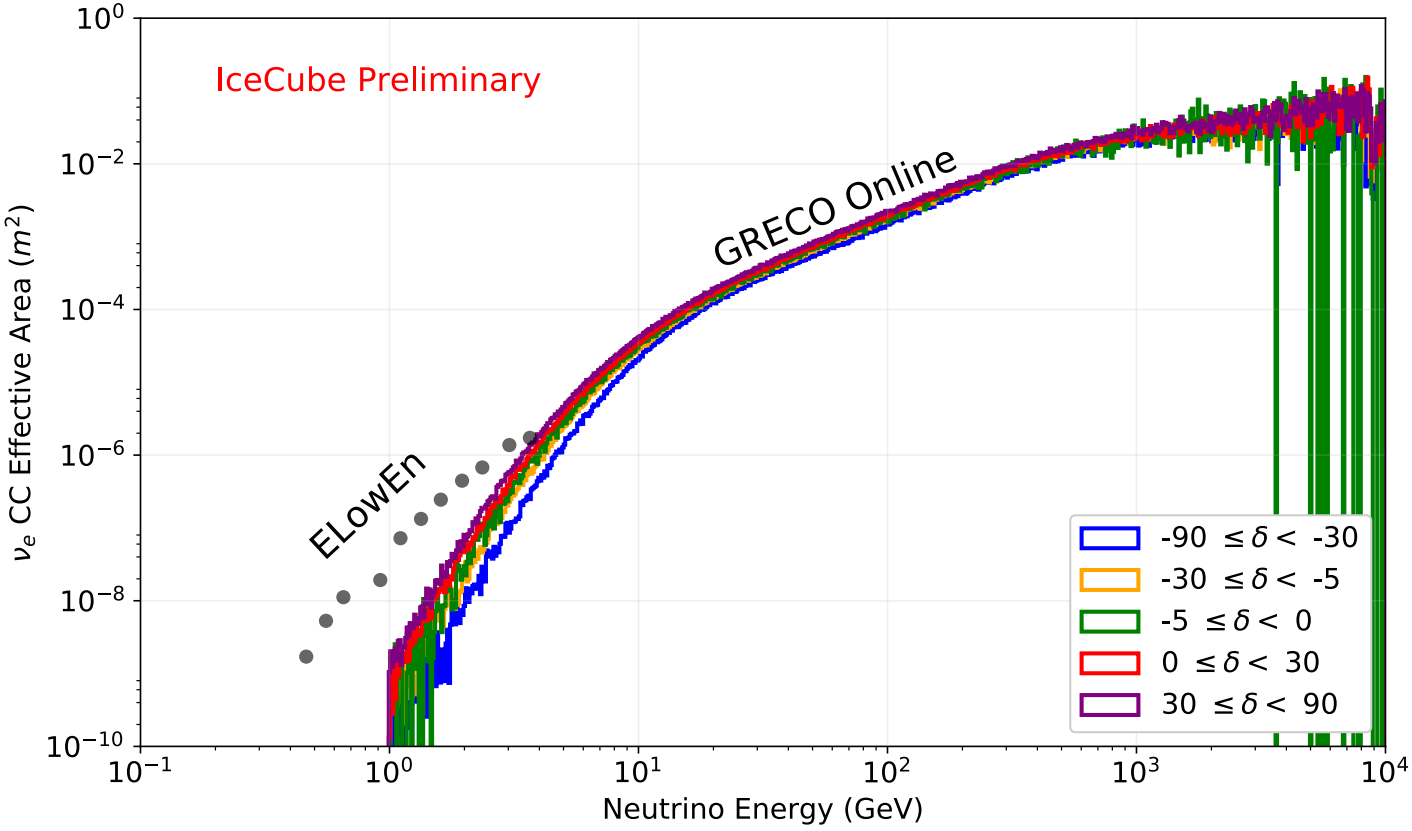


New Effective Areas (ν_μ)



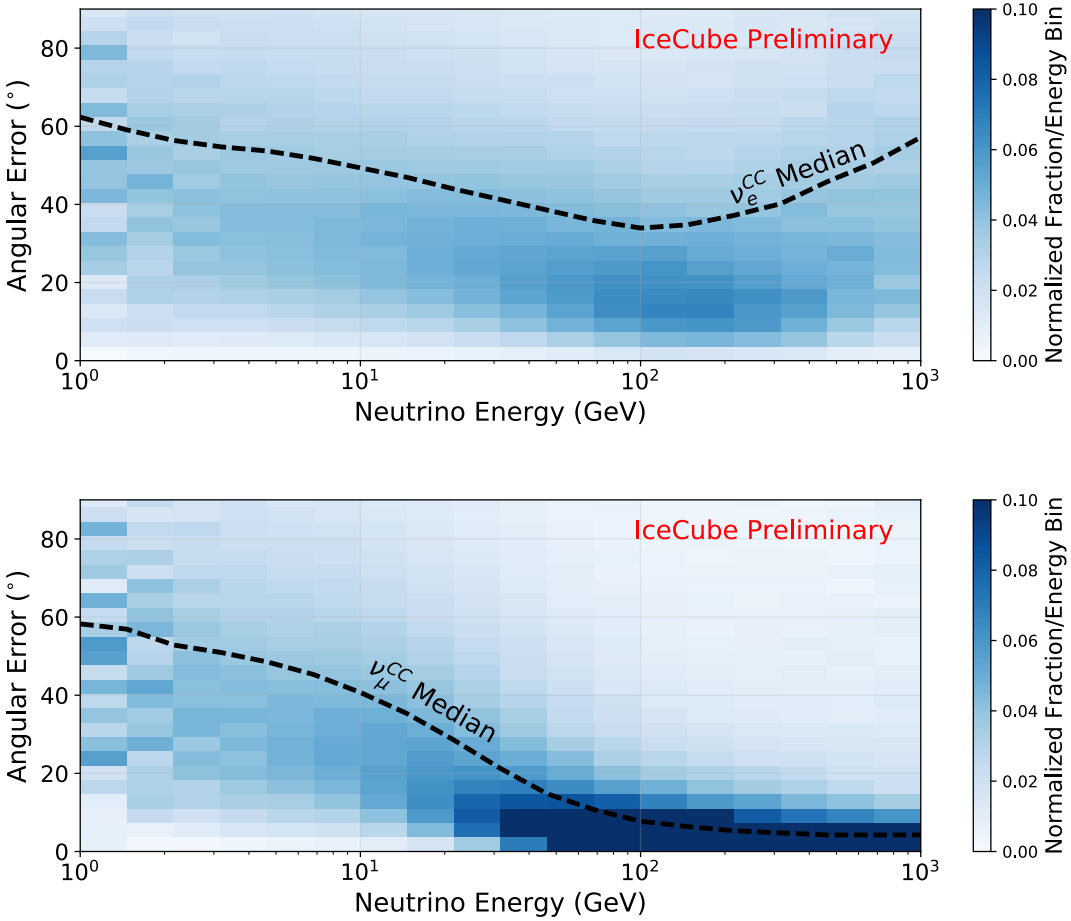
- Significant improvement at all declinations below 100 GeV
  - Southern hemisphere near horizon improves to ~few TeV
  - Improvements in far southern sky to 20 TeV

New Effective Areas (ν_e)



- All-flavor selection also includes contributions from cascade-like events
- Nearly declination-independent effective areas

Reconstruction Resolutions (Angular Error)

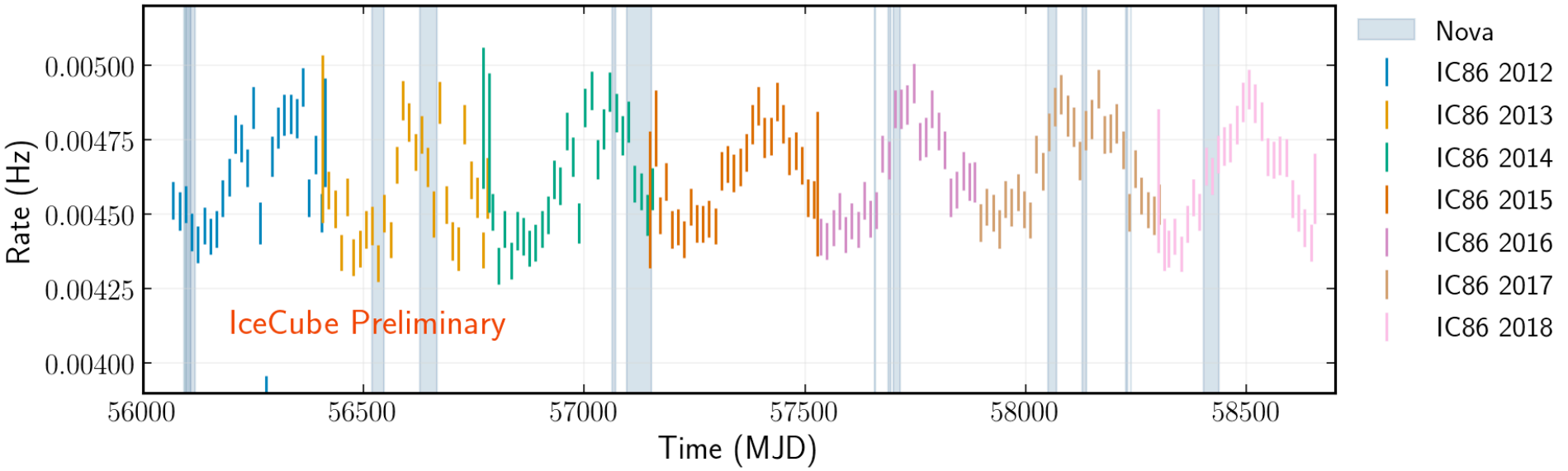


- Event information is fed to a random forest to estimate total per-event angular uncertainties
- Estimates include both reconstruction and kinematic effects
- Poor resolution due to low deposited energies, short muon tracks

Note: True reconstruction errors shown

GRECO Astronomy Analyses

- Several analyses underway using GRECO astronomy sample
  - Gamma-ray detected novae during GRECO livetime
  - IceCube DeepCore for Gravitational Wave Follow-up using Low Energy Neutrinos (Aswathi Balagopal, see poster #939)
  - Search for Astrophysical Neutrino Transients with IceCube DeepCore (Chujie Chen, see poster #1143)



Conclusions

- IceCube has identified astrophysical neutrinos and several potential sources using high energy track-like events

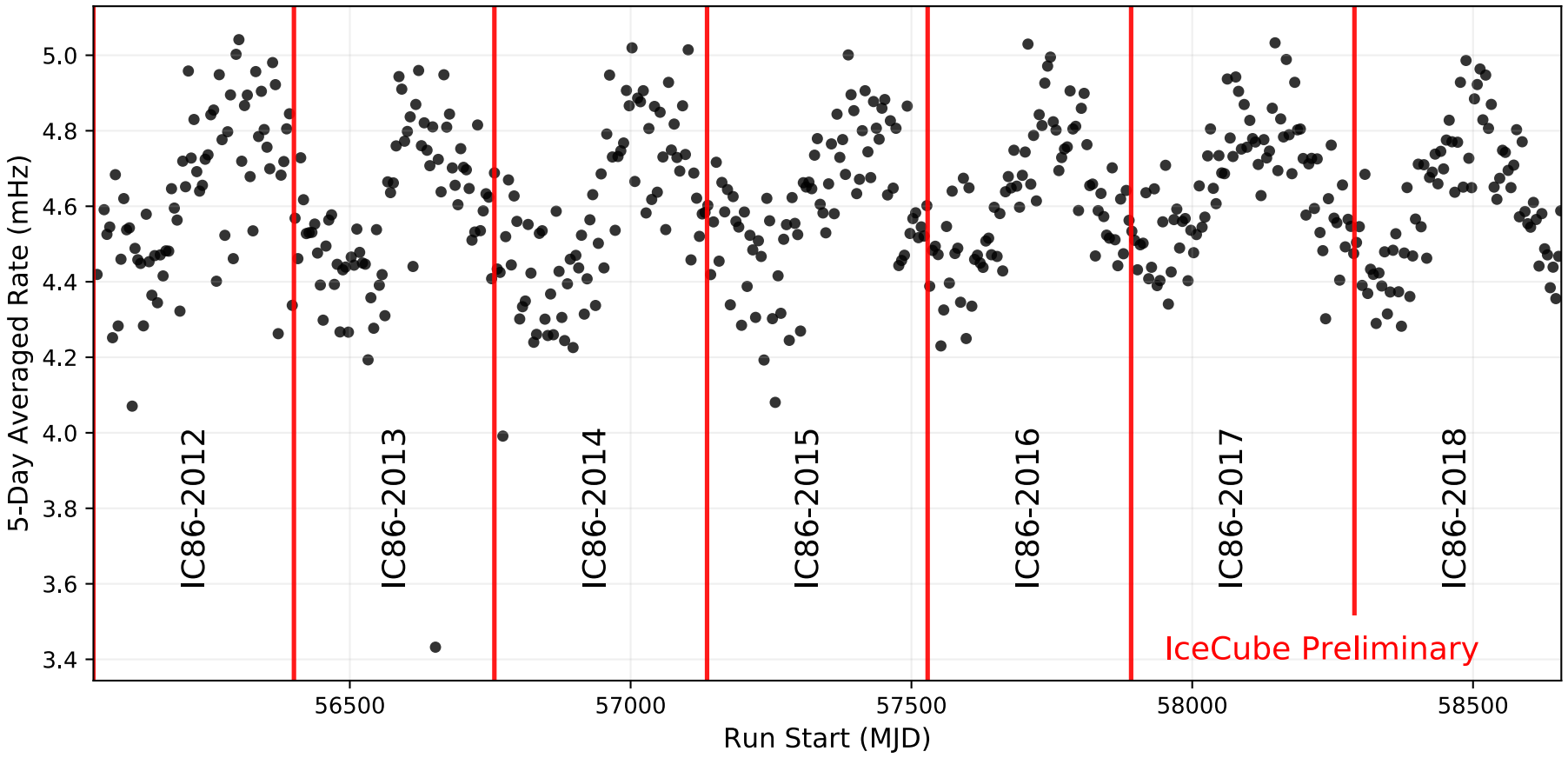
- Extension to energies from 1-1000 GeV is possible with DeepCore subarray
  - All-flavor full-sky analyses possible with good effective area
  - Large backgrounds and poor aiming limit analyses to short transients

- Three-year full sky performed using repurposed GRECO oscillation sample
  - No significant excess observed

- Newly tuned selection developed for new transient analyses
  - Improved effective area up to 100 GeV (north) to several TeV (south)
  - First analyses on the way!

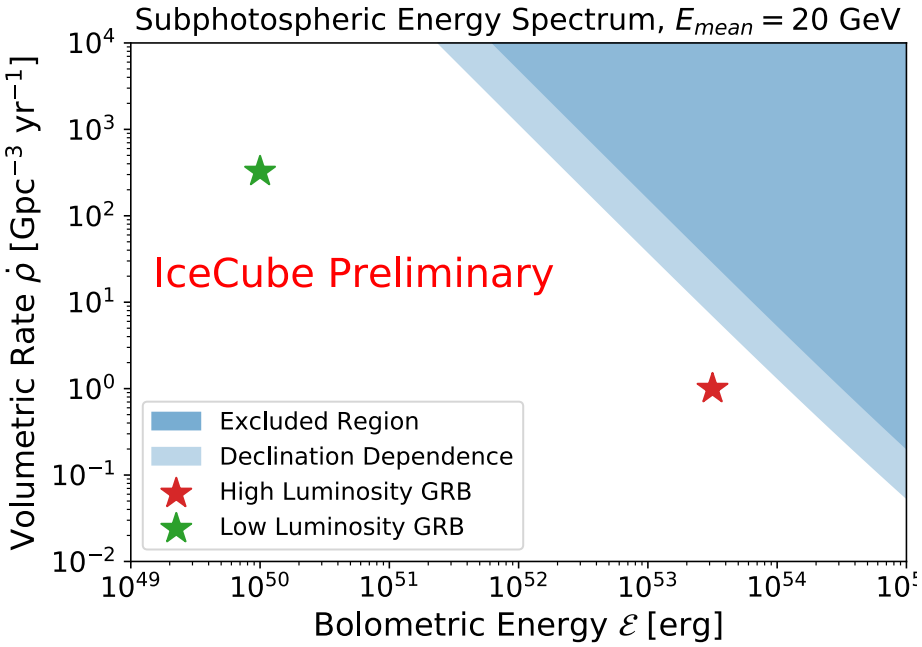
Backup

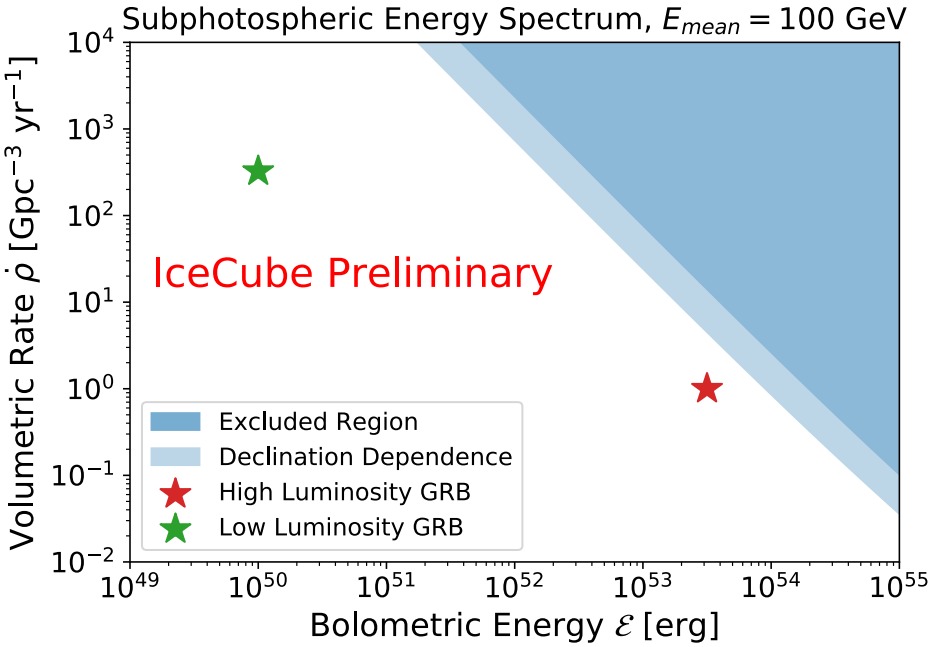
Atmospheric Backgrounds



Data is stable at 4.5 mHz with clear seasonal fluctuations from muons

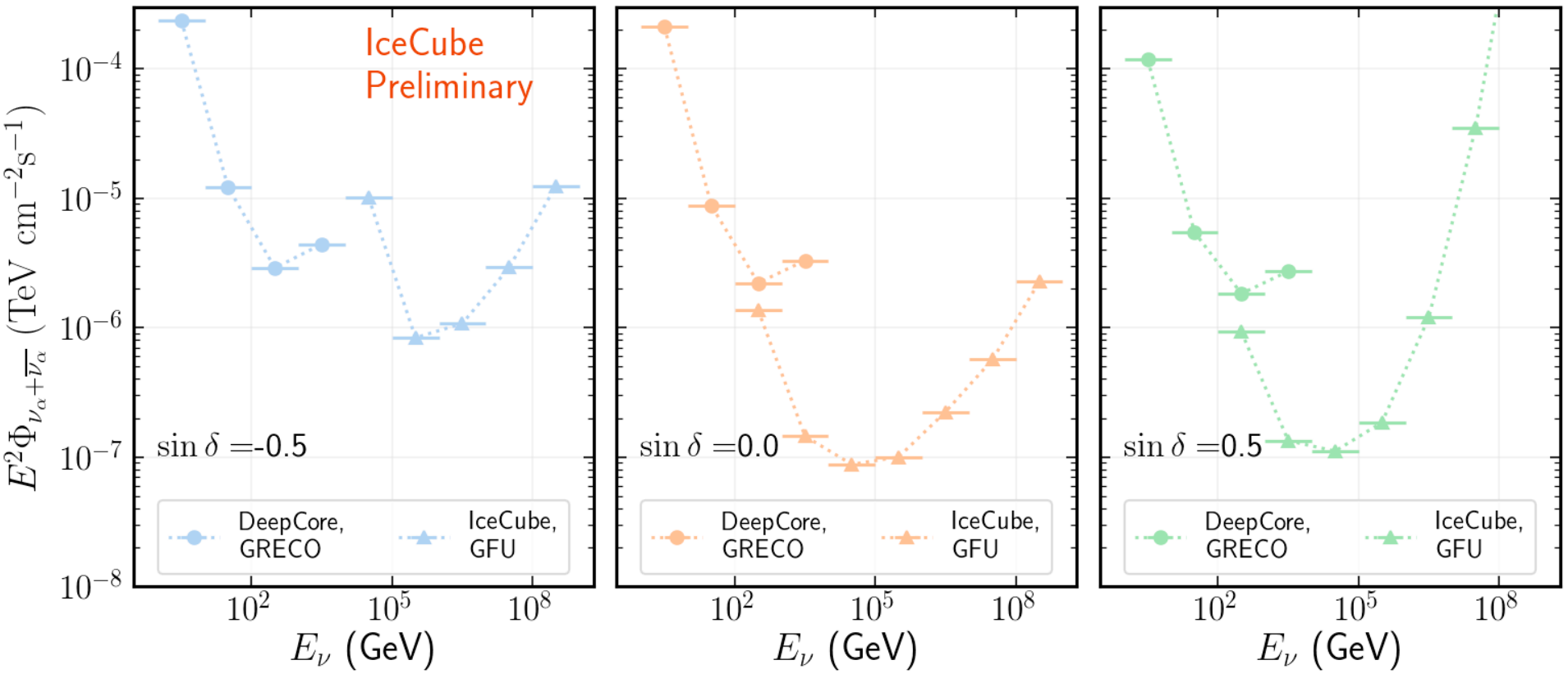
Transients with the GRECO Oscillation Selection





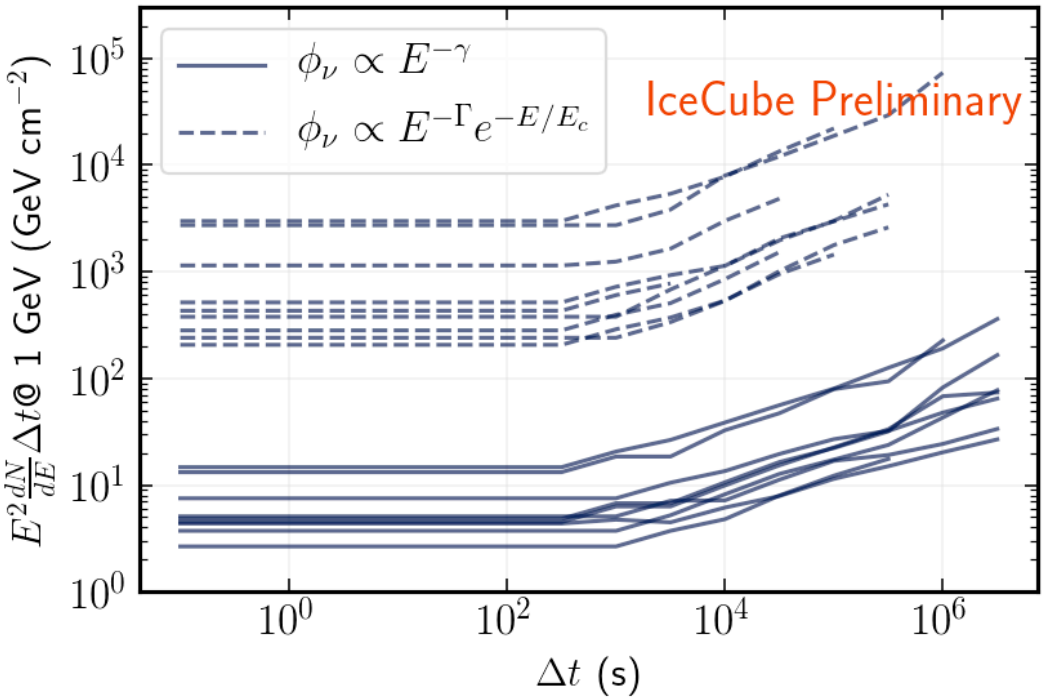
- Able to interpret null result as limits on populations of transient emitters

GRECO Astronomy Dataset Performance



- Differential sensitivity for 1000 s timescale transients comparing to a high-energy tracks sample assuming an E^{-2} in each bin
- Expect improvement relative to high-energy tracks for softer spectra

Novae with the GRECO Astronomy Sample



- Can use novae gamma-ray observations to estimate neutrino fluxes assuming simple or broken power law spectrum assuming 100% hadronic emission
- Sensitivity shown for selected novae in GRECO Astronomy selection
- Flat sensitivity out to O(100) seconds followed by background contributions degrading performance
- Work continuing on low energy novae analysis