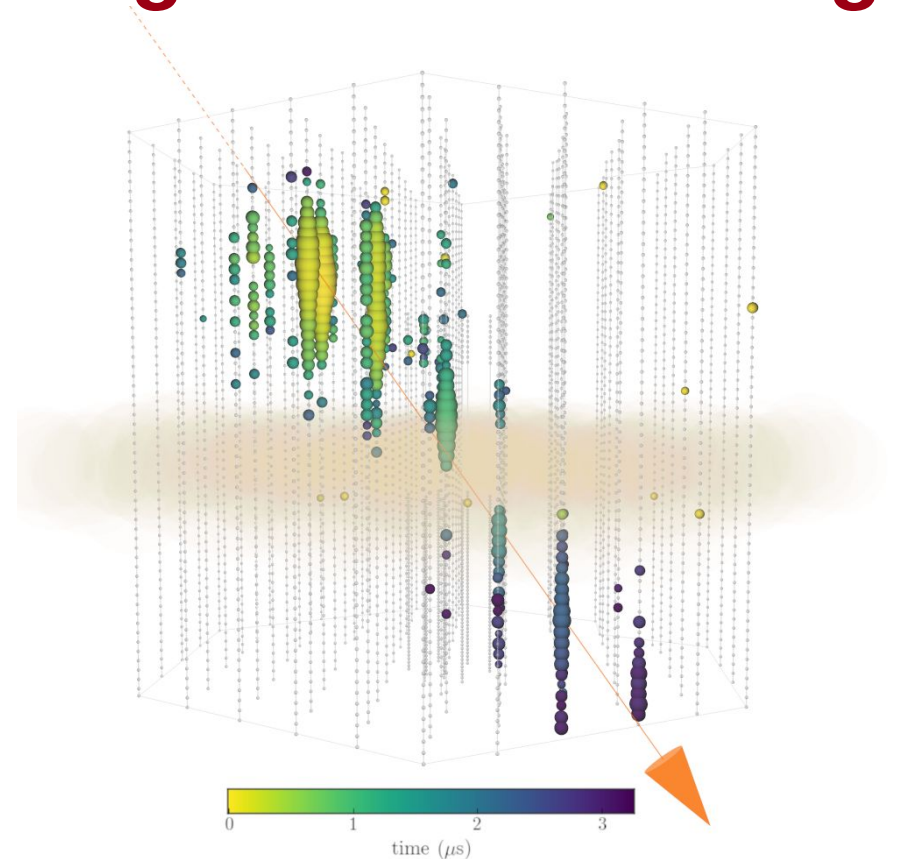


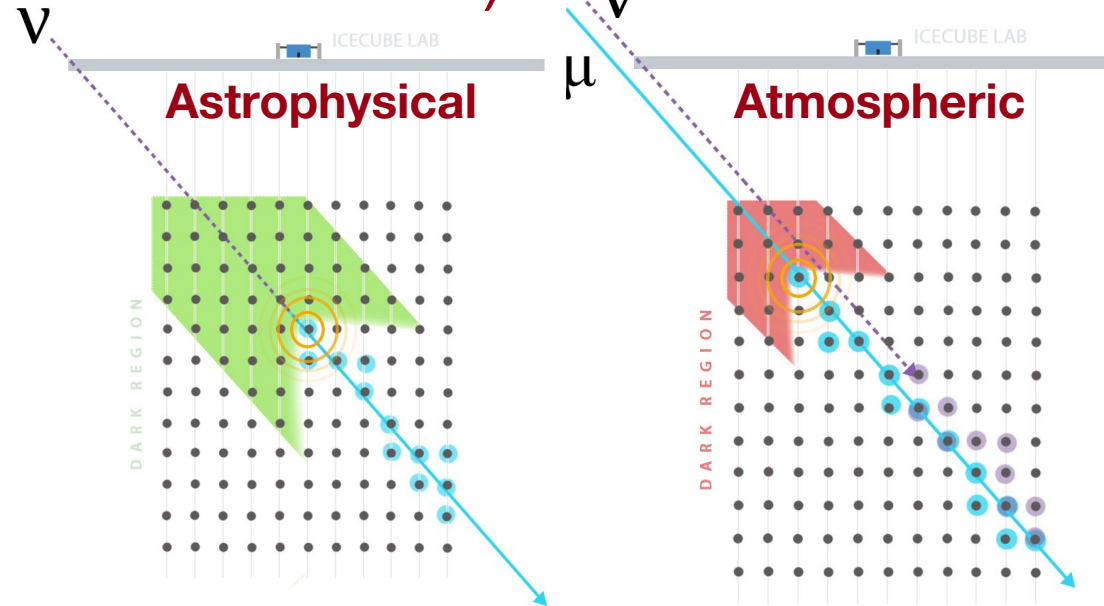
Creating a high purity astrophysical neutrino sample below 100 TeV using IceCube starting track events

Sarah Mancina and Manuel Silva
for the IceCube collaboration

NuTel 2023
Venice, Italy
October 26th, 2023



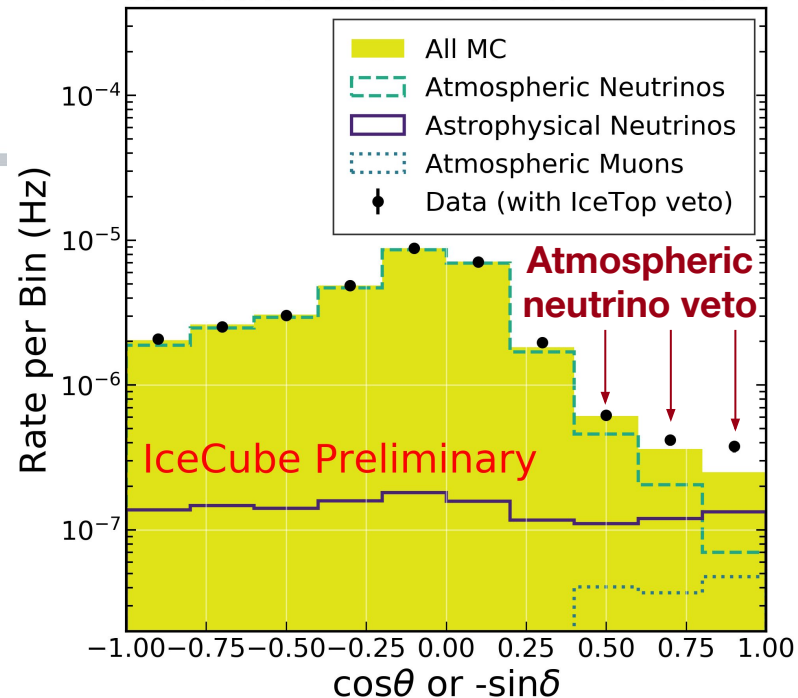
ESTES (Enhanced Starting Track Event Selection)



Goal: select muon neutrino events with interaction vertex contained inside detector

Reject atmospheric muons and neutrinos with light from incoming muons (for neutrinos > 1 TeV)

Neutrino Source Event Selection



Suppresses atmospheric background in southern sky

~1,000 unique southern sky events in 10.3 years

Flux assumed from [PoS\(ICRC2023\)1008](#)



Galactic Plane Neutrino Source Searches with ESTES

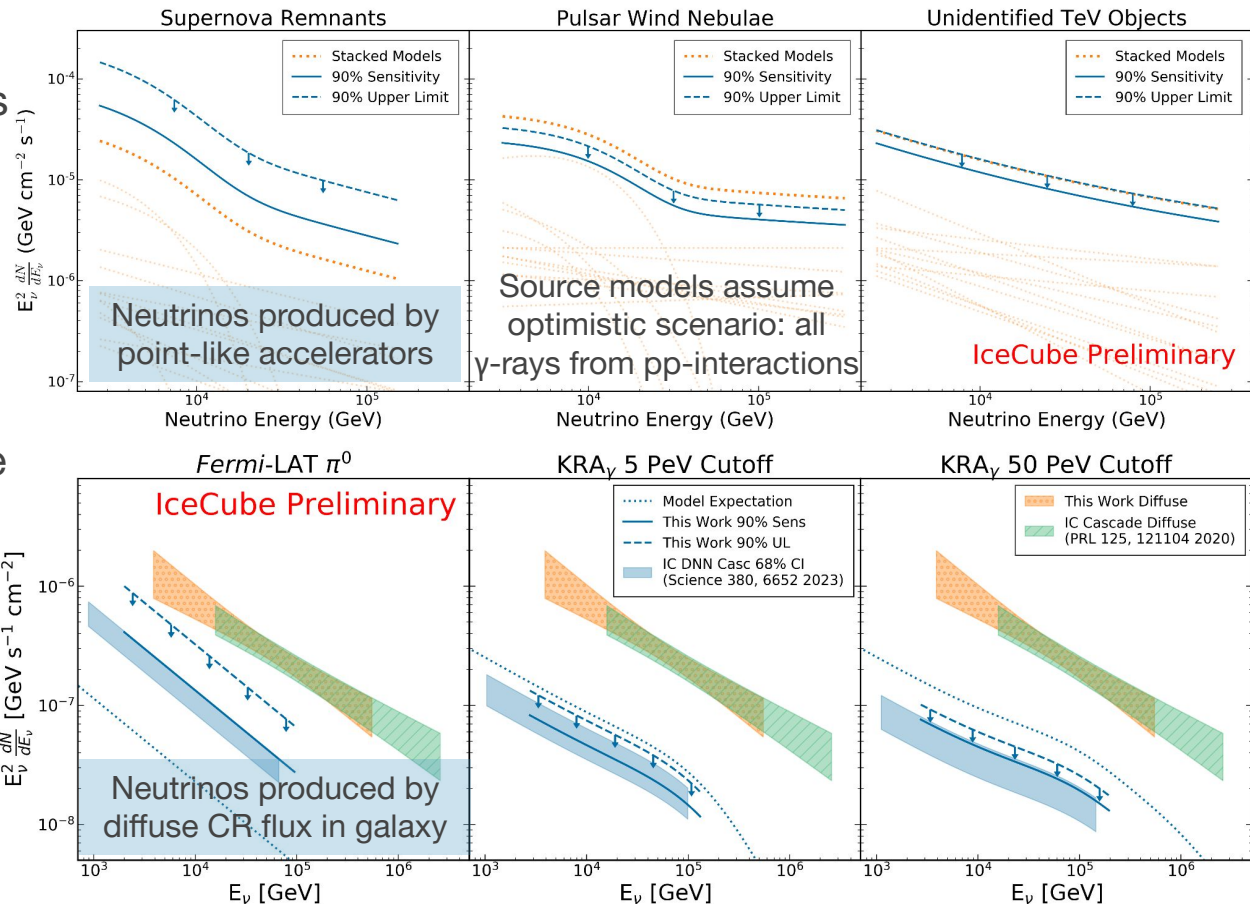
Better pointing but lower statistics than cascades analysis (Science 380, 6652 2023)

ESTES Result: **1.58 σ** post-trial significance for **SNR** catalog

ESTES Result: **1.58 σ** post-trial significance for **Fermi π^0** template

Cannot reject null hypothesis

Motivates further research into diffuse + accelerator models for origin of galactic plane neutrinos

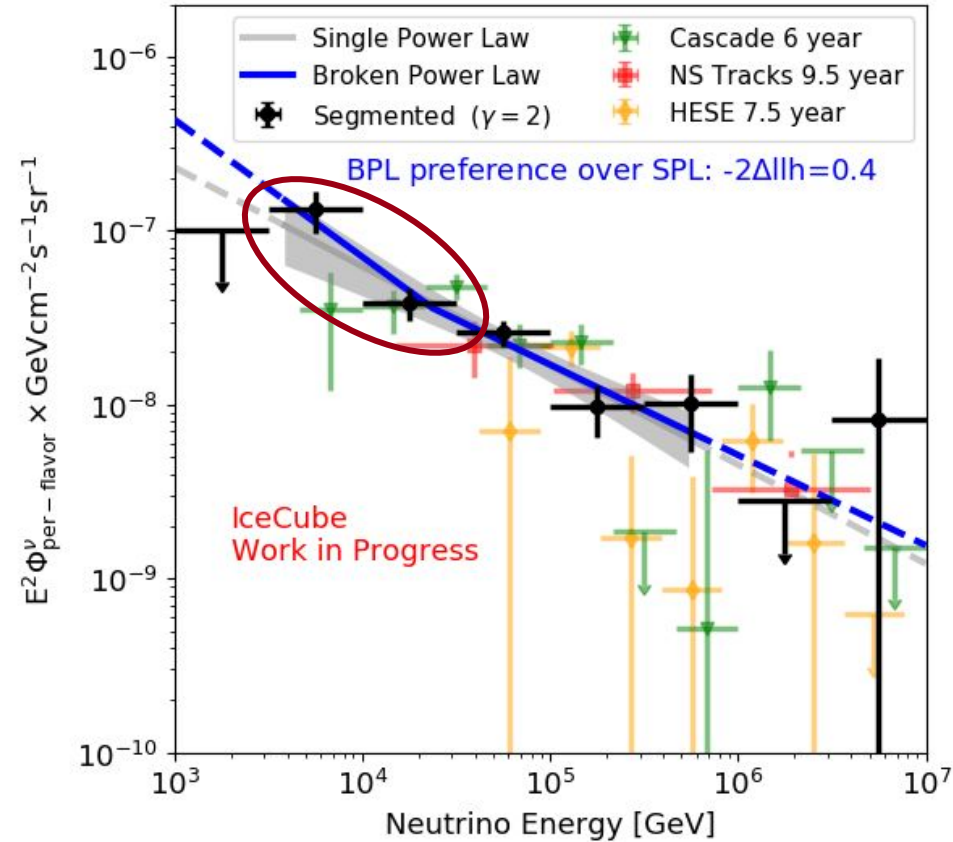


Source Models: Nahee Park

Fermi π^0 : [ApJ 750 \(2012\) 3](#)

KRAg: [10.5281/zenodo.7070823](#)

Diffuse Muon Neutrino Flux at Lower Energies



Sensitive to diffuse neutrino flux from 3 - 500 TeV

Energy threshold reduced by atmospheric neutrino rejection

Improved track energy resolution because neutrino interaction contained in detector

Previous southern sky measurements are cascade dominated

Previous track analyses are limited in energy by atmospheric background

Consistent with previous measurements

[M. Silva, ICRC 2023, 1008](#)



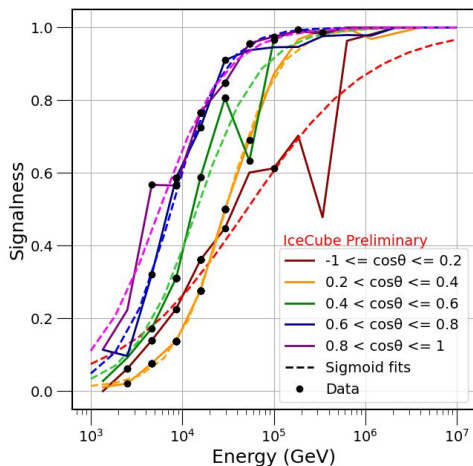
Future Projects using ESTES

Realtime alert stream

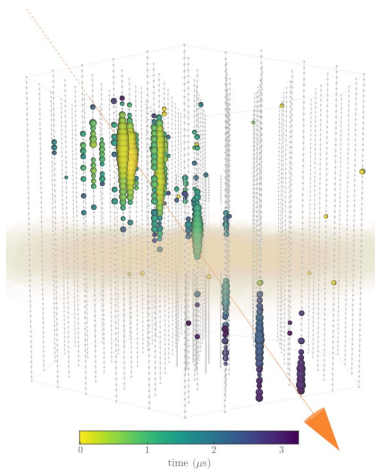
Sample of high astrophysical purity low-energy ν 's

Interesting for transient sources which cannot produce 100 TeV neutrinos

Produce **10.3 new alerts** per year with >50% average astrophysical purity



[J. Osborn, ICRC 2023, 1464](#)



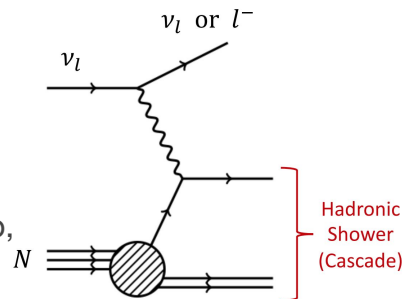
Inelasticity and other particle physics

10,000 events from full sky with contained interaction vertex

Inelasticity: $y = E_{\text{had}}/E_\nu$

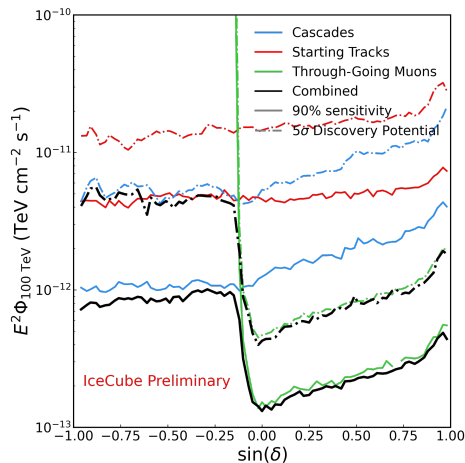
Measure inelasticity from 1-500 TeV

Also probe: ν flavor ratio, ν type ratio, charm production, +more



[M. Moulai and Y. Ashida, TeVPA 2023](#)

Combination with other IceCube selections



Most ESTES southern sky events are unique

More complete picture of galactic plane seen by IceCube

Include in global diffuse neutrino fit

[P. Savina, ICRC 2023, 1010](#)



Backup Slides

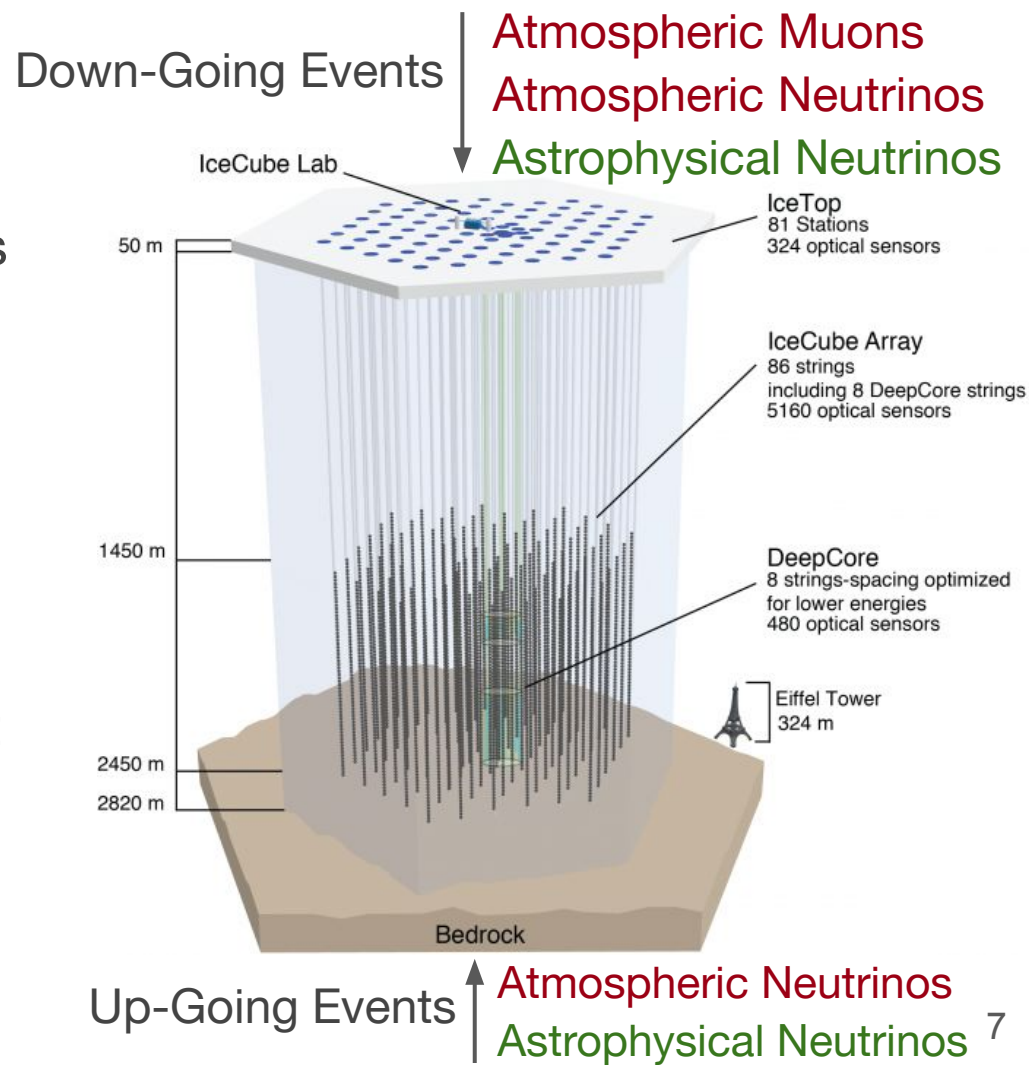
IceCube detector

Observe charged particles, neutrinos must interact to be observed

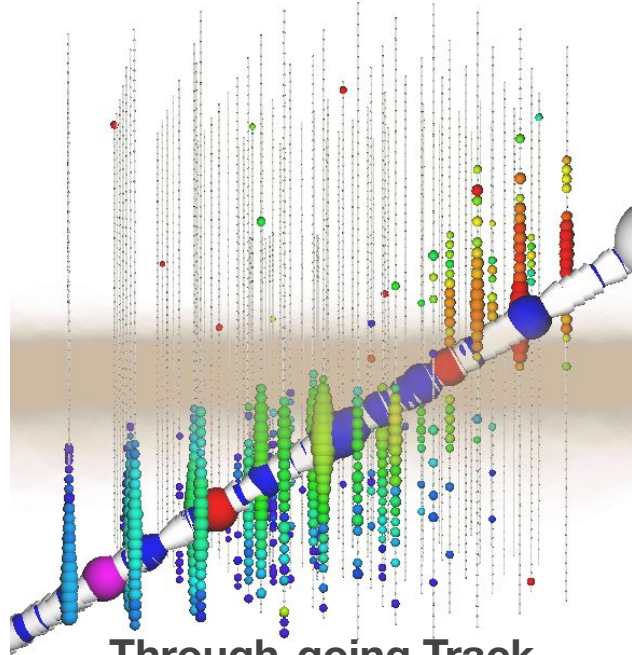
Look for signal of **astrophysical neutrinos**

Obscured by **atmospheric muon and neutrino** backgrounds

Can use direction, energy, and event morphology to distinguish signal



Neutrino event morphologies in IceCube

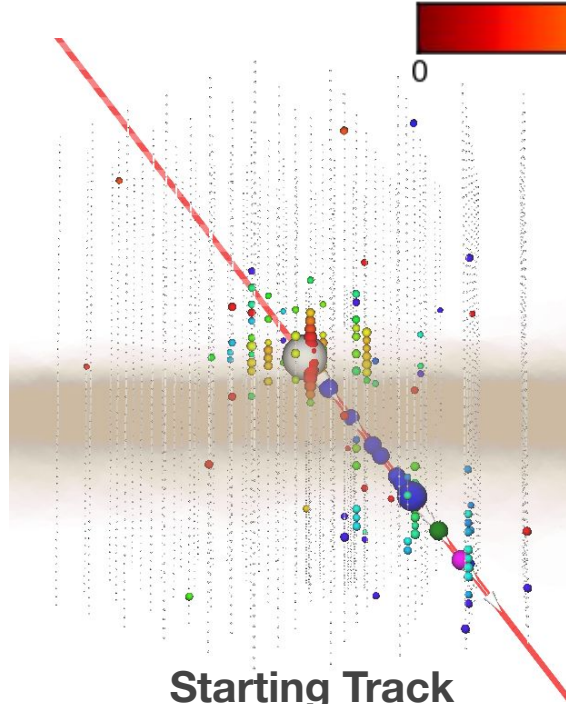


Through-going Track

Angular Resolution: 0.6°

Energy Resolution: $2 \times E_\nu$

Atmospheric μ , CC ν_μ , CC ν_τ
 $(\tau \rightarrow \mu + \nu's)$

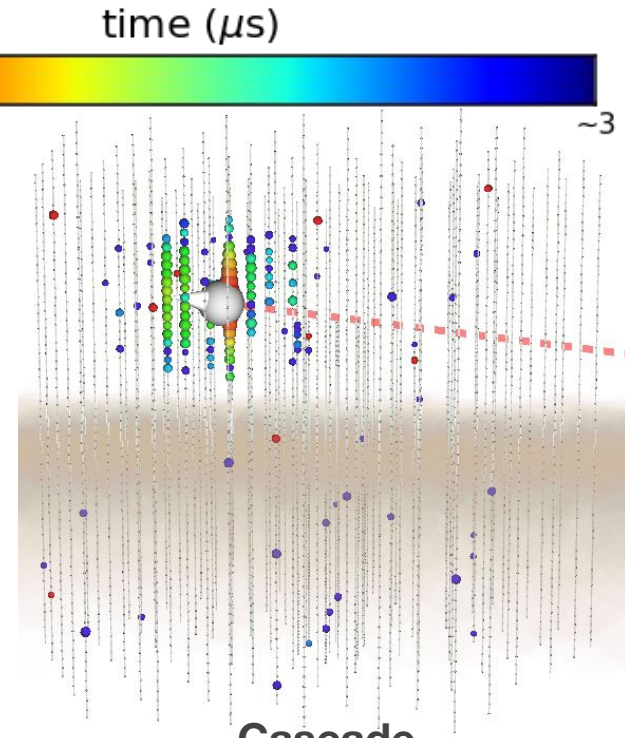


Starting Track

Angular Resolution: 1.0°

Energy Resolution: $.25 \times E_\nu$

CC ν_μ , CC ν_τ ($\tau \rightarrow \mu + \nu's$)



Cascade

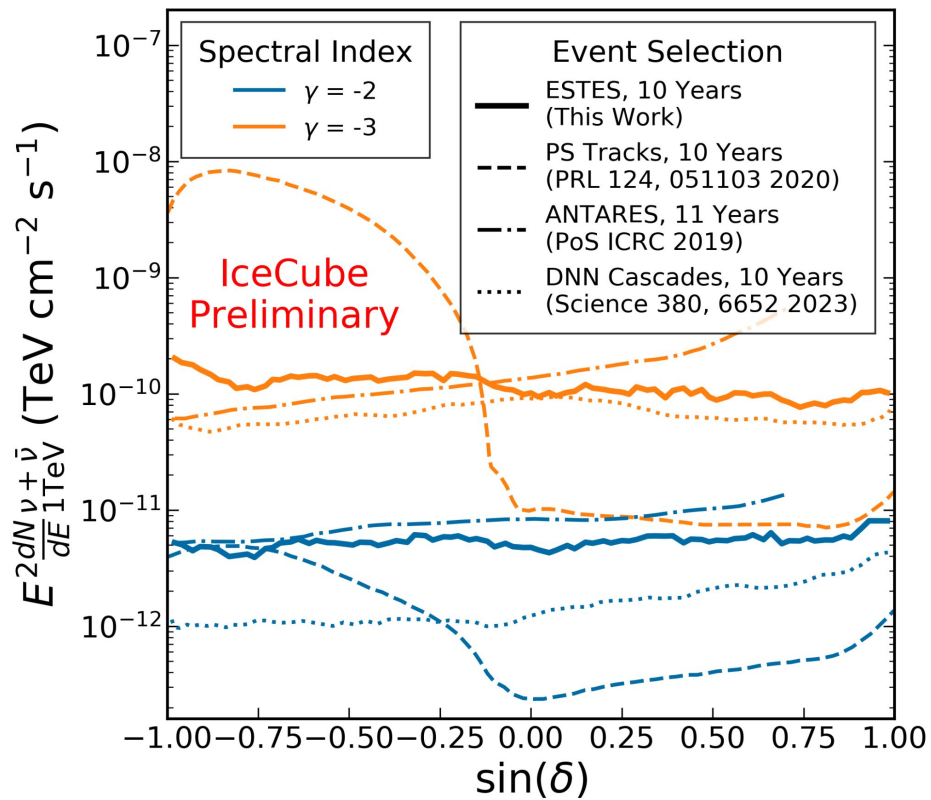
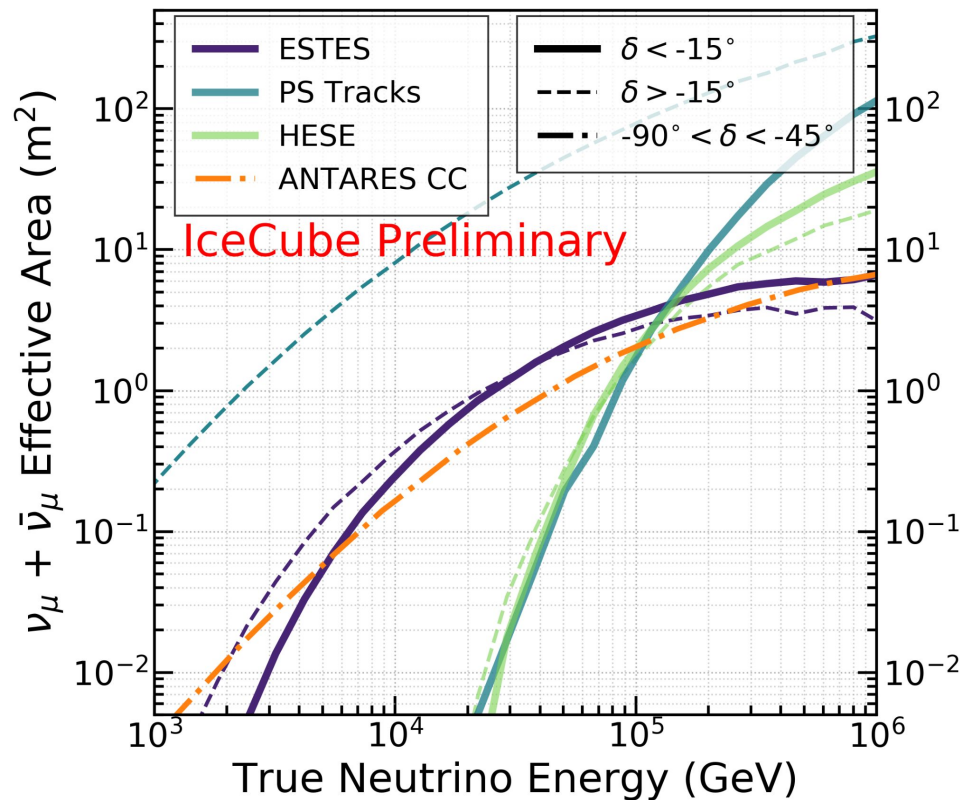
Angular Resolution: 5° - 15°

Energy Resolution: $.15 \times E_\nu$

NC ν , CC ν_e , CC ν_τ ($\tau \rightarrow e/h + \nu's$)

(+ more) ⁸

Comparison of ESTES to other astrophysical neutrino samples



Improve sensitivity in the southern sky with track events

Minimal overlap of events in the southern sky with other event selections (<2%)



Search for point sources with ESTES

Used standard IceCube maximum likelihood approach to search for sources

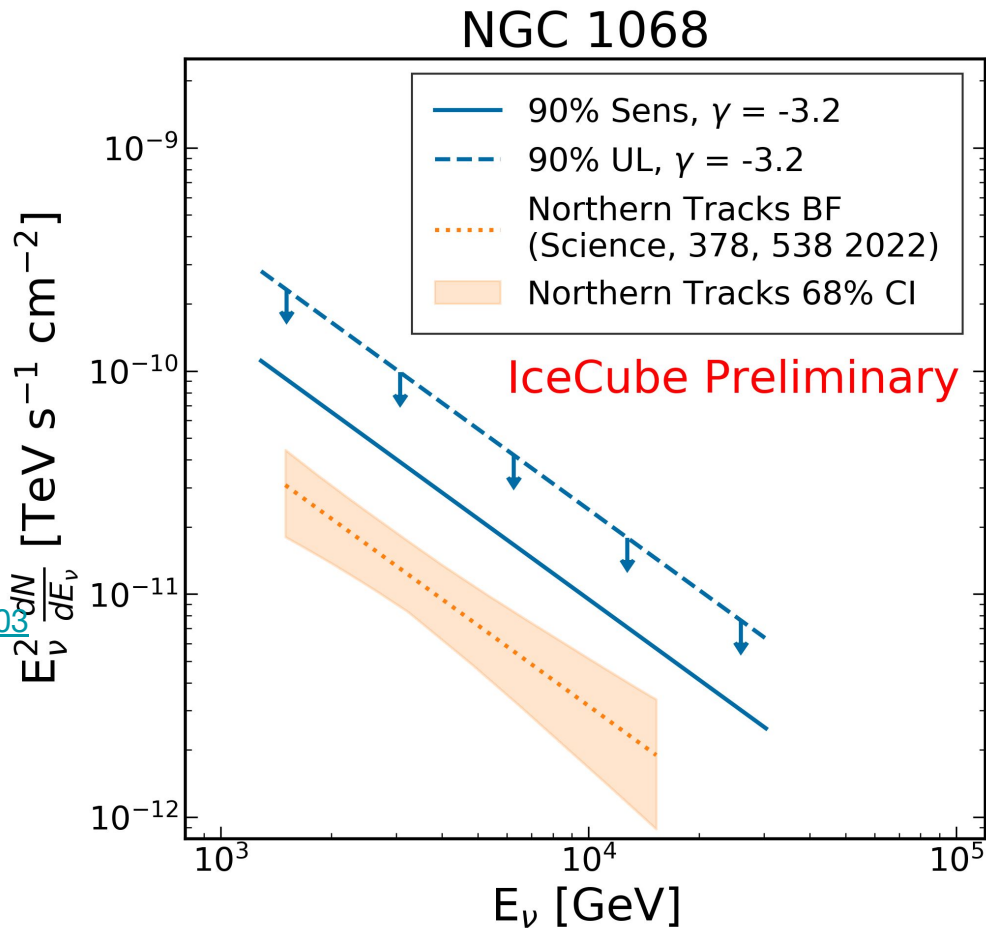
No statistically significant source found in all sky search after post-trials correction

Most significant source in list **1ES 0647+250** **1.71 σ** post-trial significance

Cannot reject null hypothesis

Source located in northern sky and upper limits set by previous analyses ([PRL 124, 051103 2020](#))

Results for NGC 1068 consistent with Northern Tracks measurement ([Science, 378, 538 2022](#))



Galactic plane source stacking analysis

Tested for correlations between locations of know TeV gamma-ray emitting galactic plane objects and our neutrinos

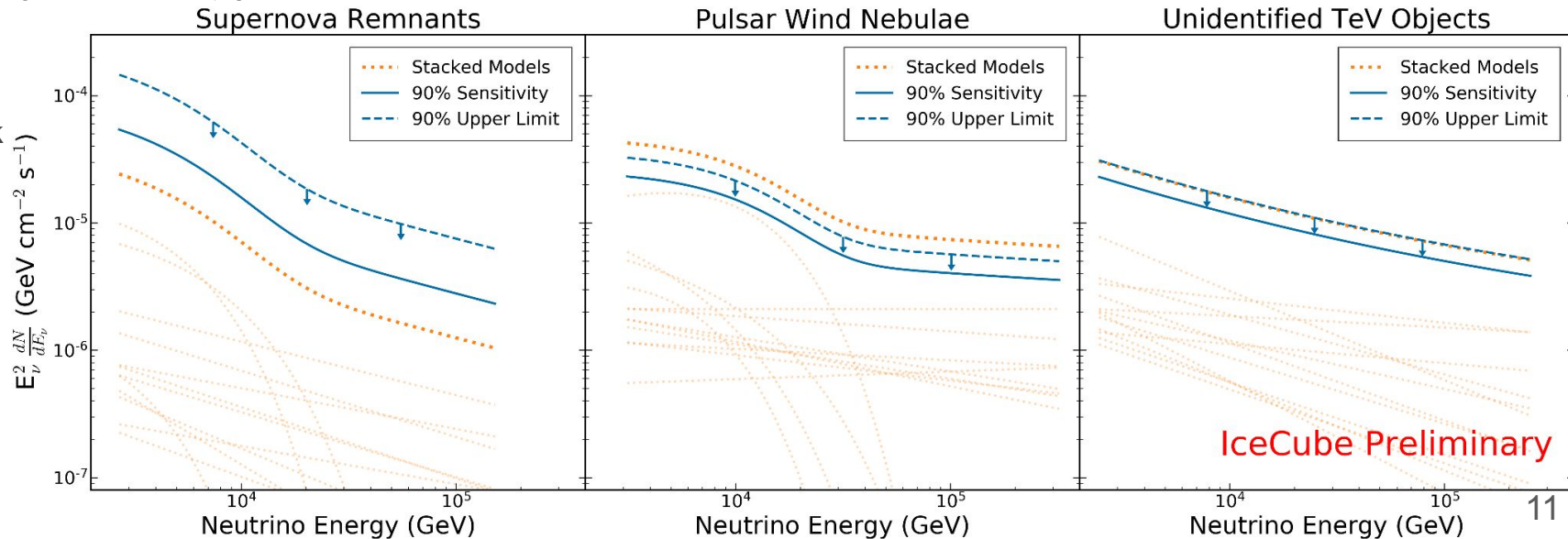
Tested four catalogs: Supernova Remnants, Pulsar Wind Nebulae, Unidentified TeV Objects, and TeV Binaries

Supernova Remnants had most significant result with **1.58σ post-trial** significance, cannot reject null hypothesis

Models
made by
Nahee Park

Use top 12
sources

Optimistic
scenario:
100% of
 γ -rays from
p-p int.



Diffuse neutrino emission from the galactic plane

Test for excess of neutrinos from cosmic ray interactions with the galactic plane material

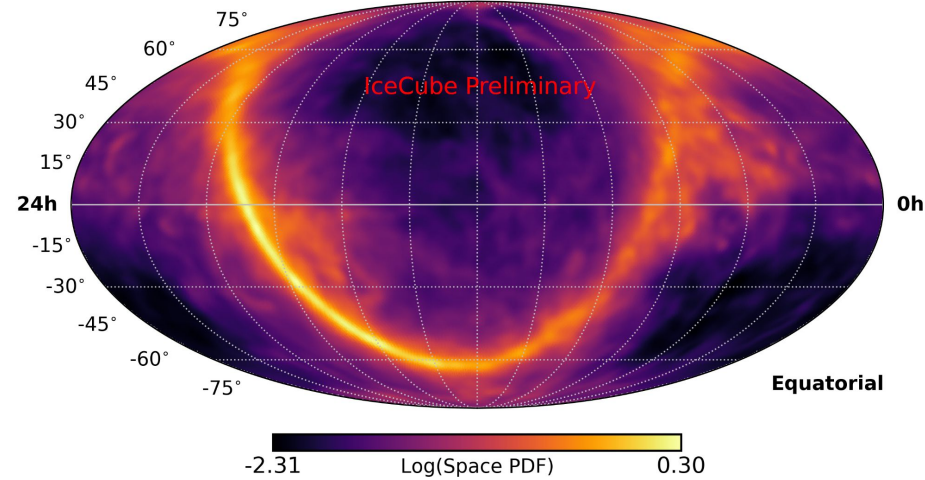
Two models: Fermi π^0 ([ApJ 750 2012 3](#)) and KRA γ ([10.5281/zenodo.7070823](#))

Test Fermi π^0 assuming energy spectrum is single power law with spectral index -2.7

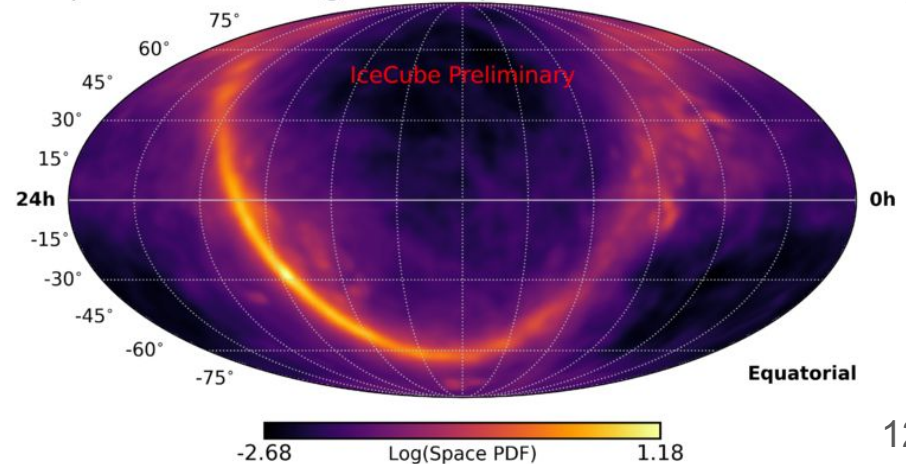
Test KRA γ using model energy spectrum and 5 PeV and 50 PeV exponential cutoff

Fermi π^0 returns 1.58σ post-trial significance, cannot reject null hypothesis

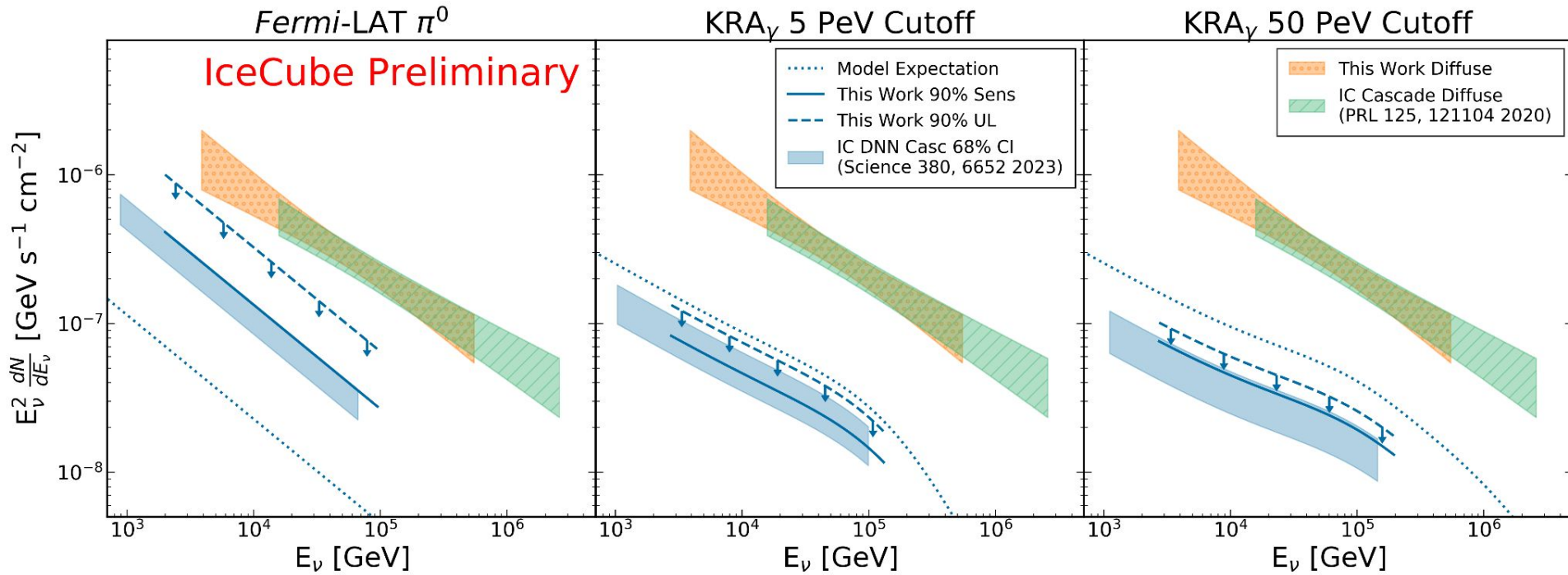
Fermi π^0 signal acceptance with 1.4° smoothing



KRA γ 5PeV Cutoff signal acceptance with 1.4° smoothing



Upper limits on diffuse galactic plane emission



Limits and sensitivity for ESTES relative to the Cascade result ([Science 380, 6652 2023](#)) and diffuse measurements

Upper limits and results **consistent** with Cascades results

ESTES diffuse flux from [PoS\(ICRC2023\)1008](#)



Conclusions and next steps

Introduce first neutrino source search results from ESTES, a starting track sample

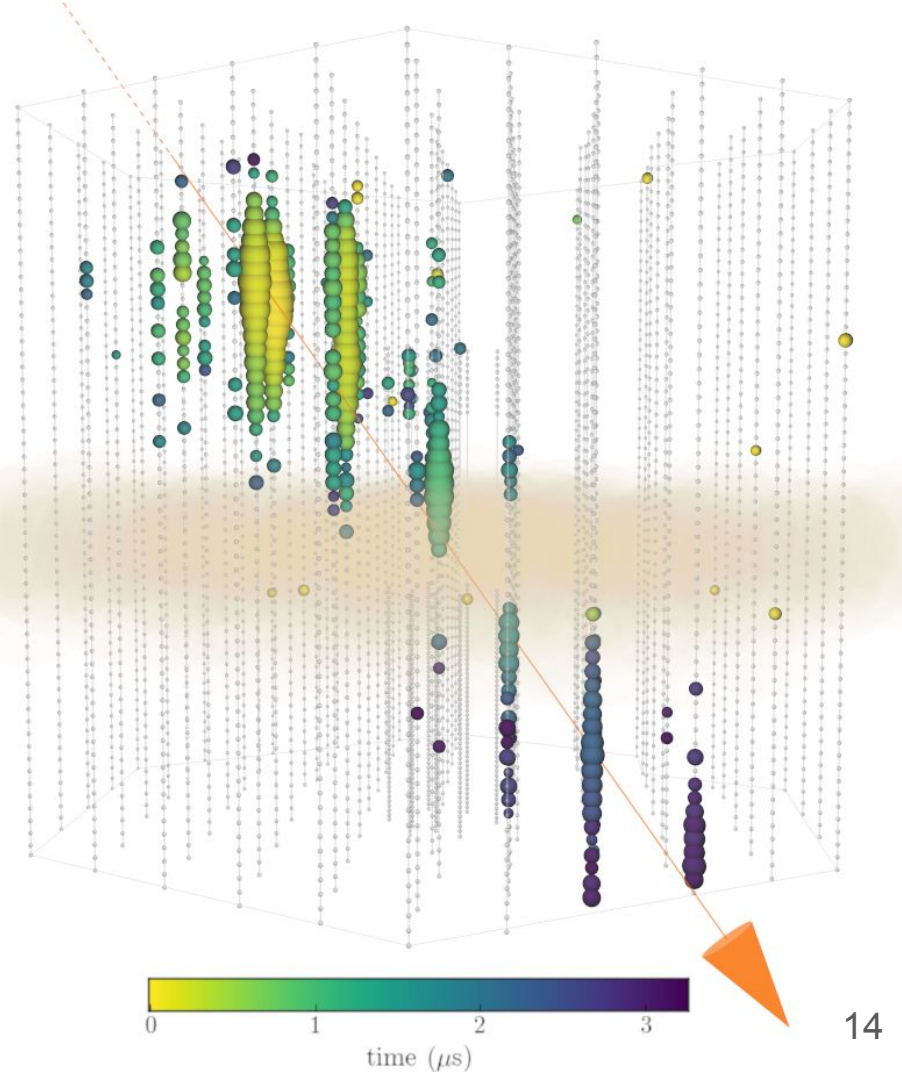
Can reject atmospheric neutrino background in southern sky

Increase sensitivity of IceCube to southern sky sources

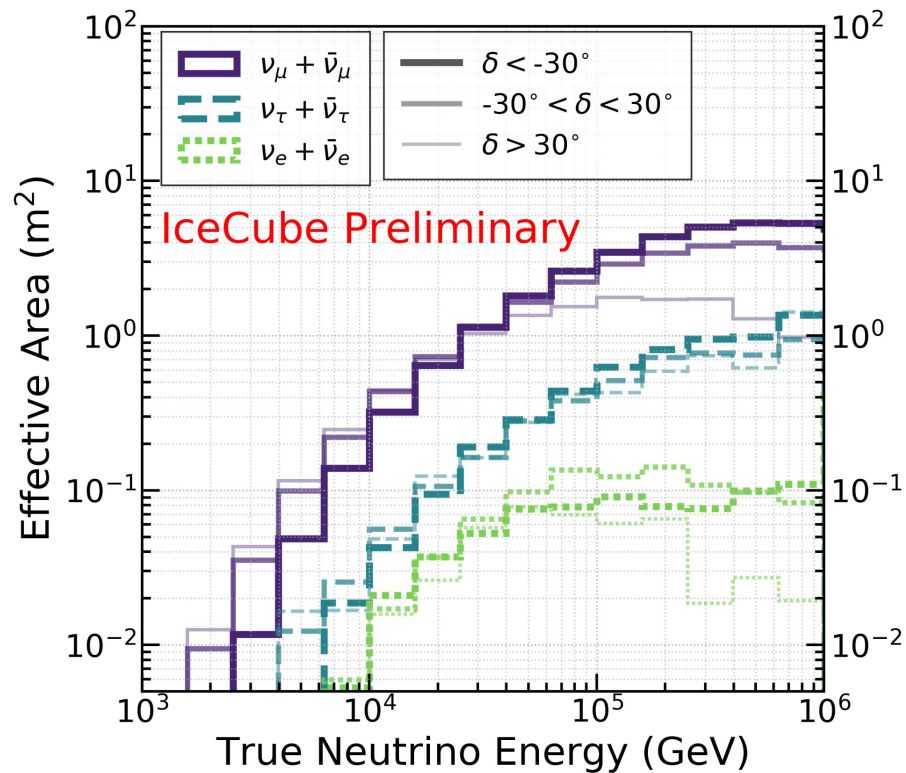
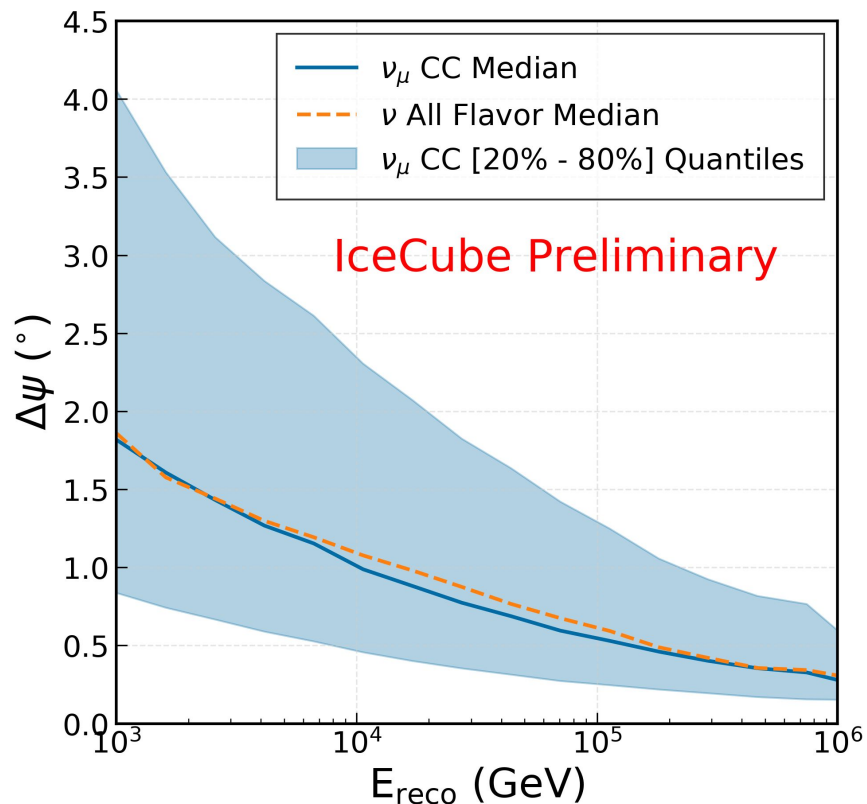
Cannot reject null hypotheses but **consistent with other IceCube measurements**

Can combine with other neutrino samples in future for source searches with all neutrino streams ([PoS\(ICRC2023\)1010](#))

Producing a high purity realtime alert stream with energies below 100 TeV with ESTES ([PoS\(ICRC2023\)1464](#))



More ESTES event selection properties



All-flavor effective area comparison

