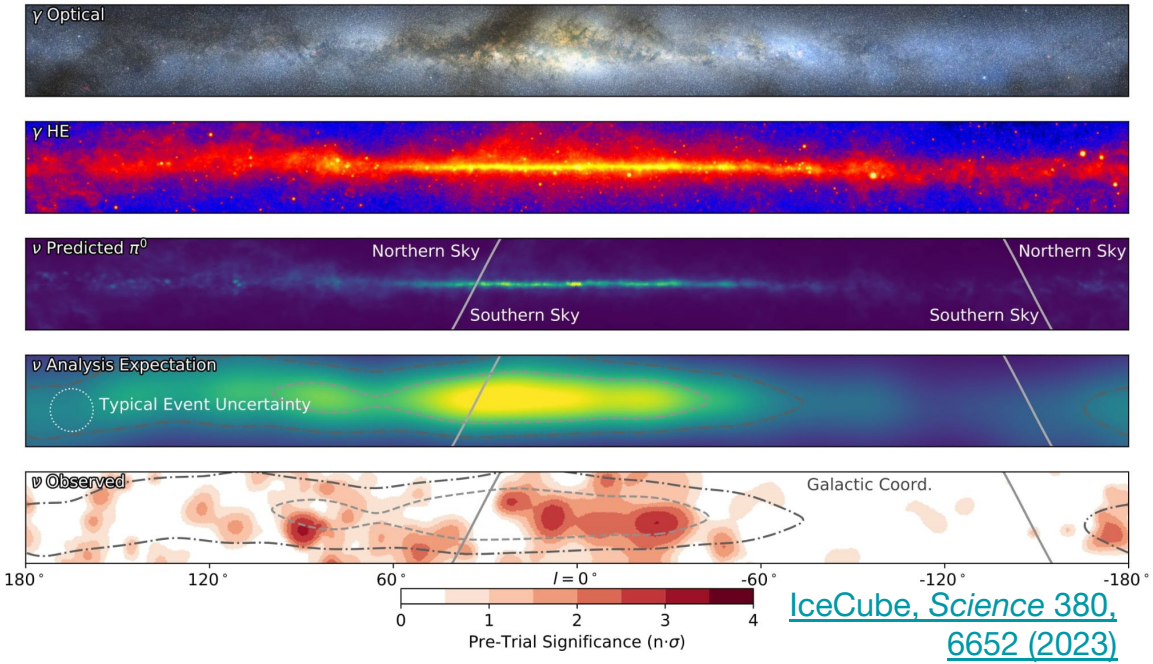
Neutrino astronomy latest results and prospects

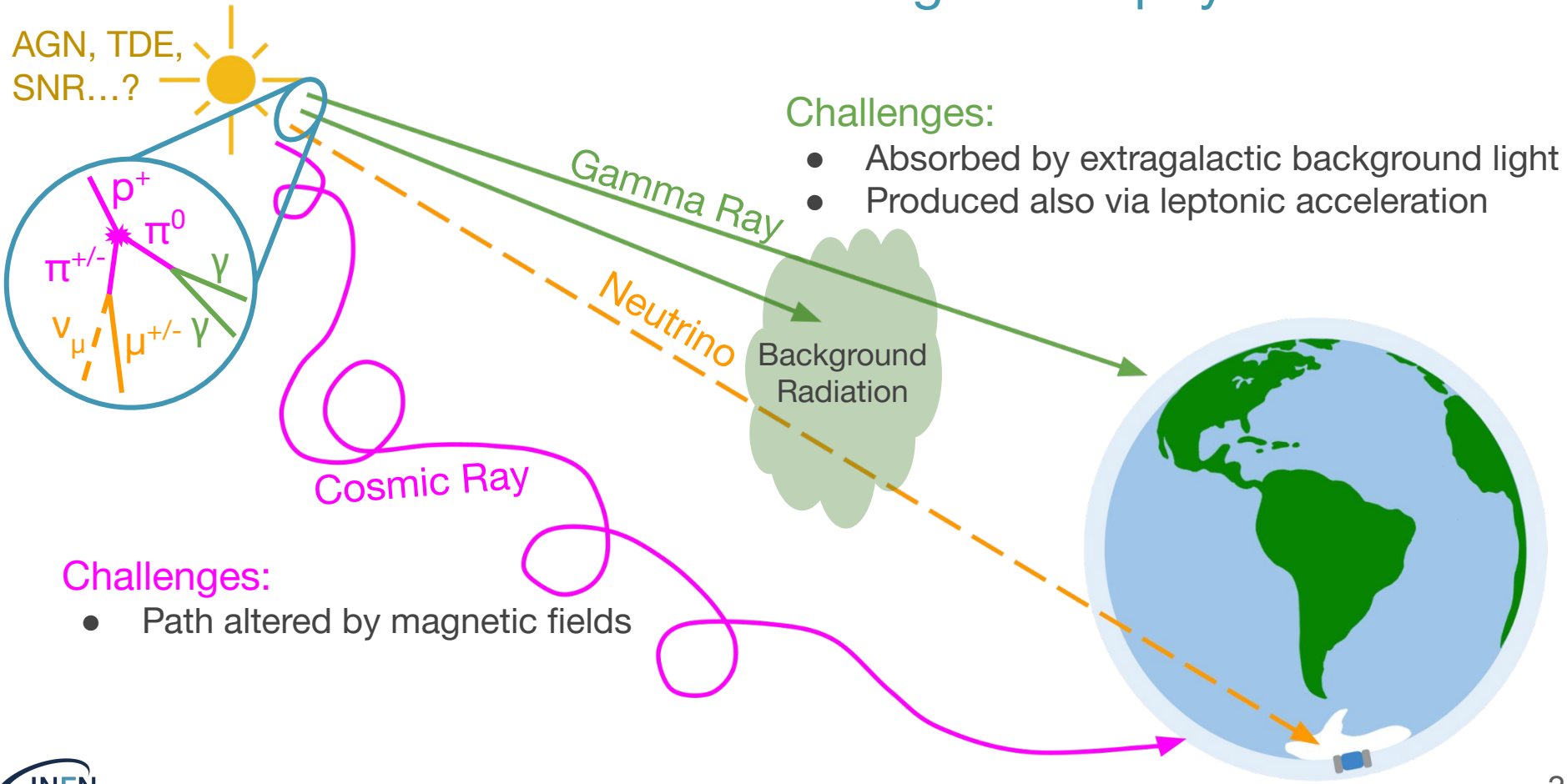
Sarah Mancina for the IceCube Collaboration

EPS-HEP 2025
Marseille, France
Astroparticles, Gravitation and Cosmology
July 8th, 2025



IceCube, *Science* 380, 6652 (2023)

Neutrinos in TeV-scale multi-messenger astrophysics



Challenges:

- Absorbed by extragalactic background light
- Produced also via leptonic acceleration

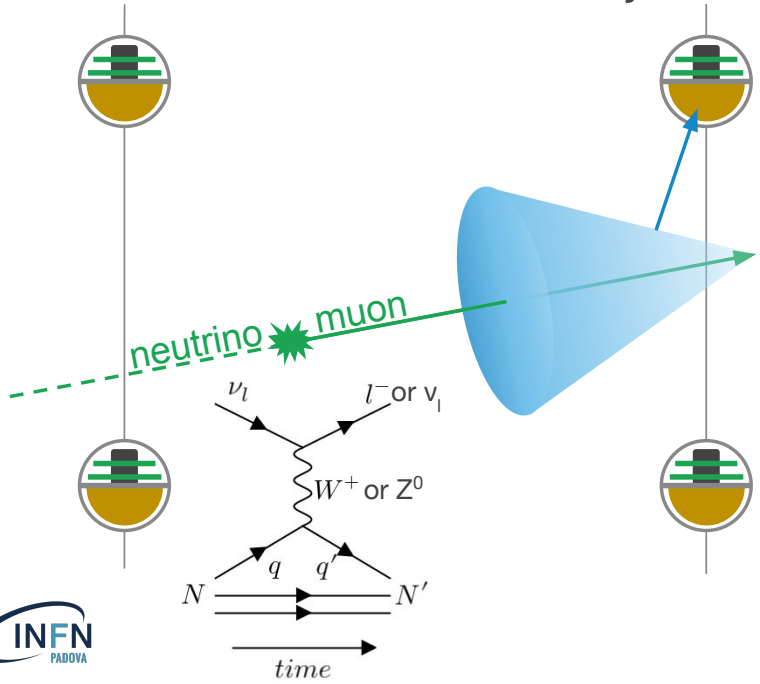
Challenges:

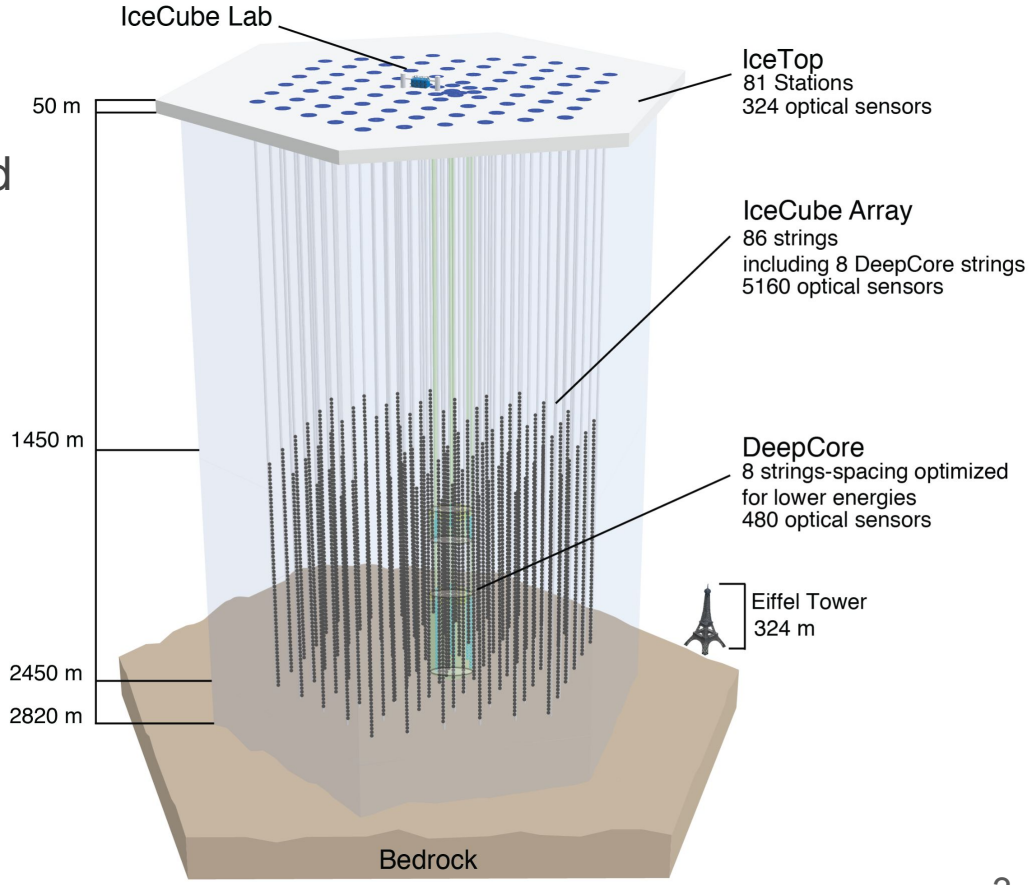
- Path altered by magnetic fields

Detecting neutrinos with Cherenkov light

Want to detect **TeV-PeV neutrinos from astrophysical sources**

Use naturally occurring water/ice to build **cubic-kilometer** detector arrays





Neutrino flavors and detector event morphologies

Muon Track

Angular Resolution: 0.6°

Log Energy Resolution: 20% of muon energy at detector entry

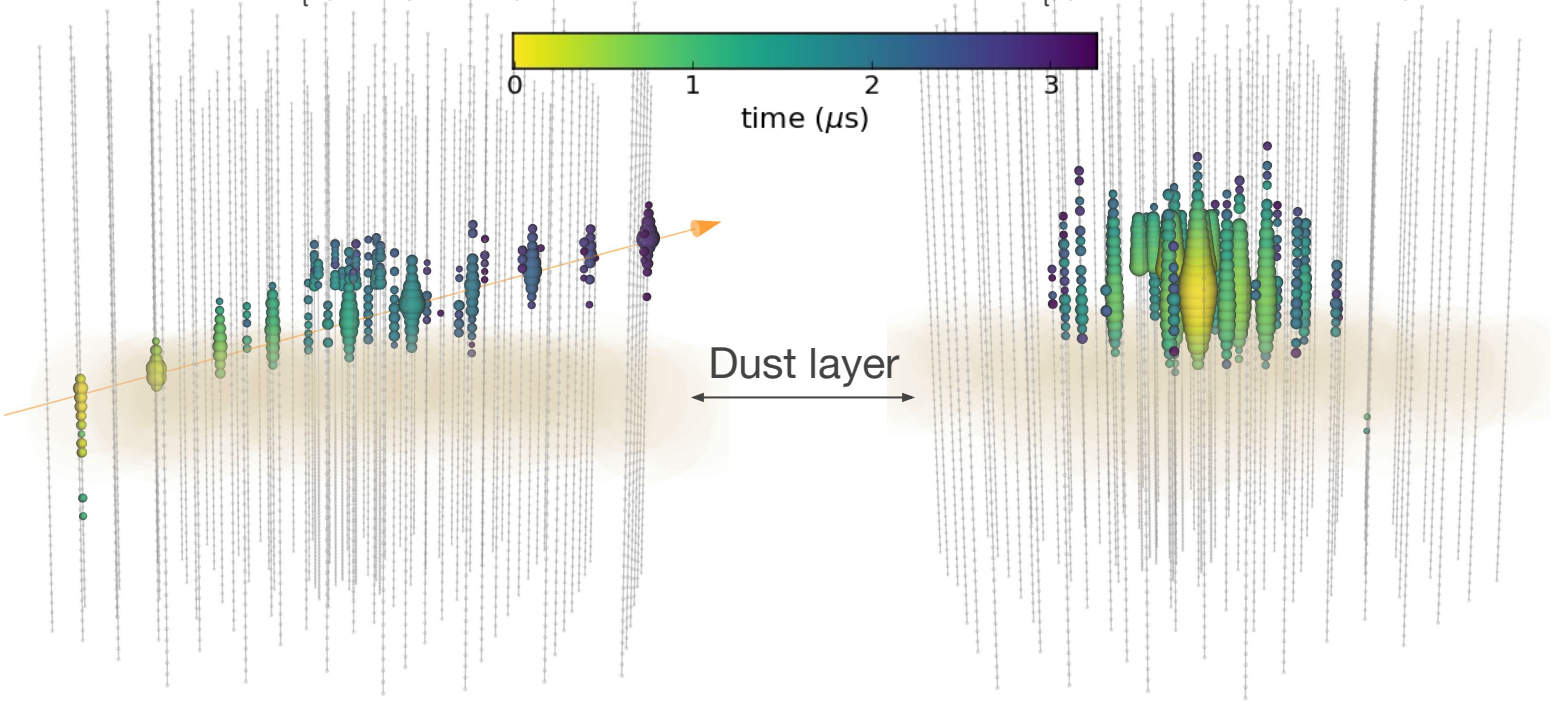
Atmospheric muons, charged current ν_μ and ν_τ ($\tau \rightarrow \mu + \nu$'s)

Electromagnetic/Hadronic Cascade

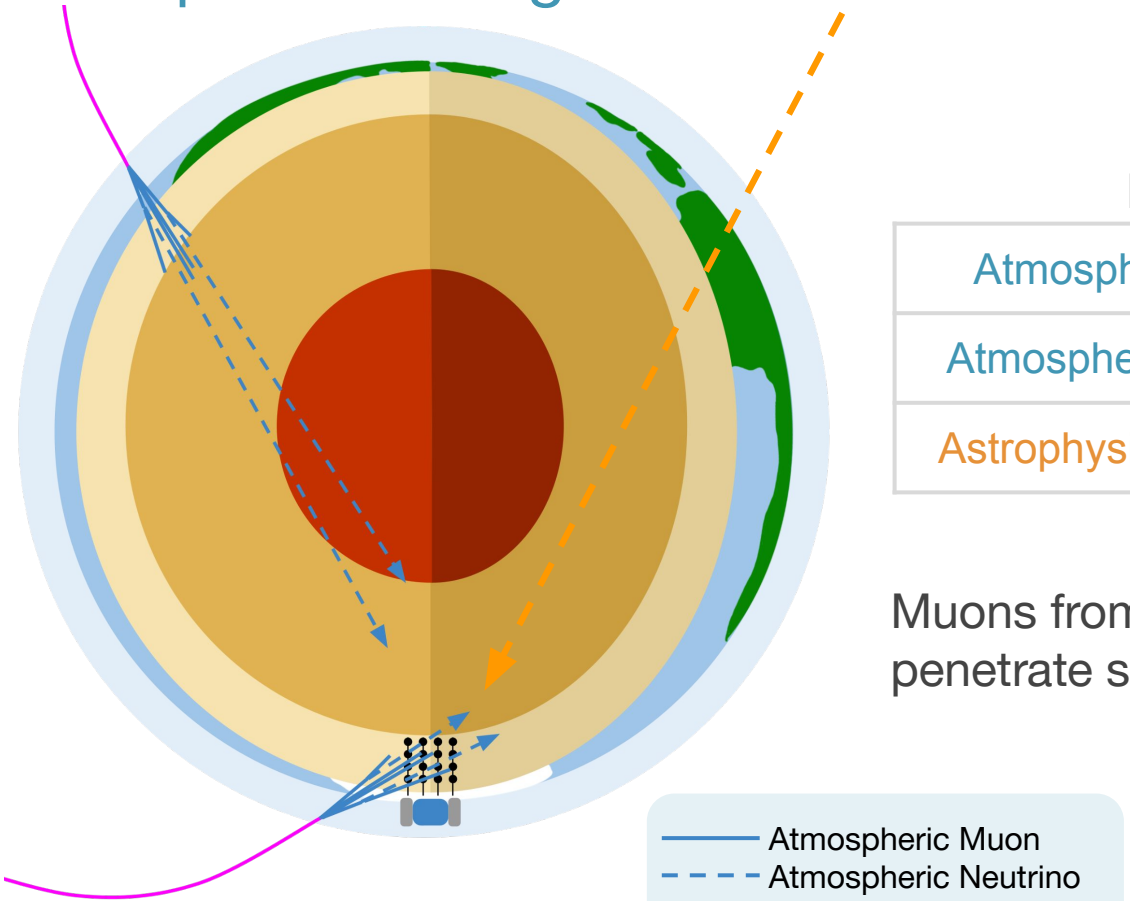
Angular Resolution: 5°-15°

Log Energy Resolution: 15% of neutrino energy

Neutral current ν, charged current ν_e and ν_τ ($\tau \rightarrow$ e/hadrons + ν's)



Atmospheric background dominates astrophysical signal

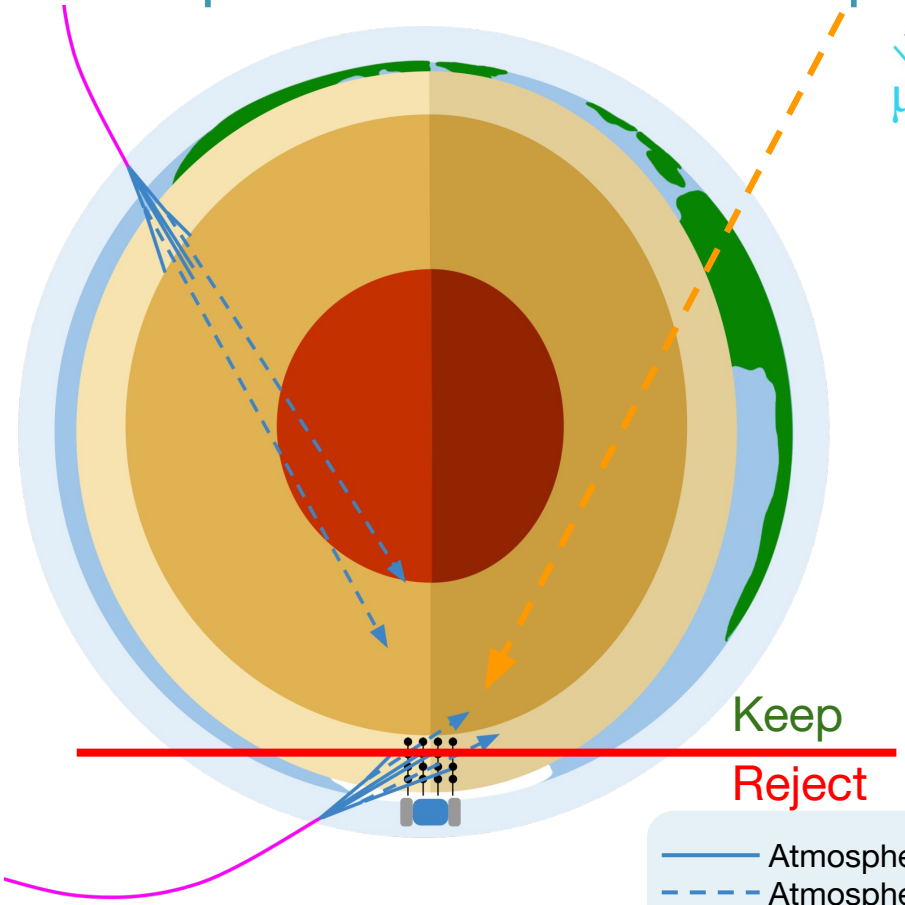


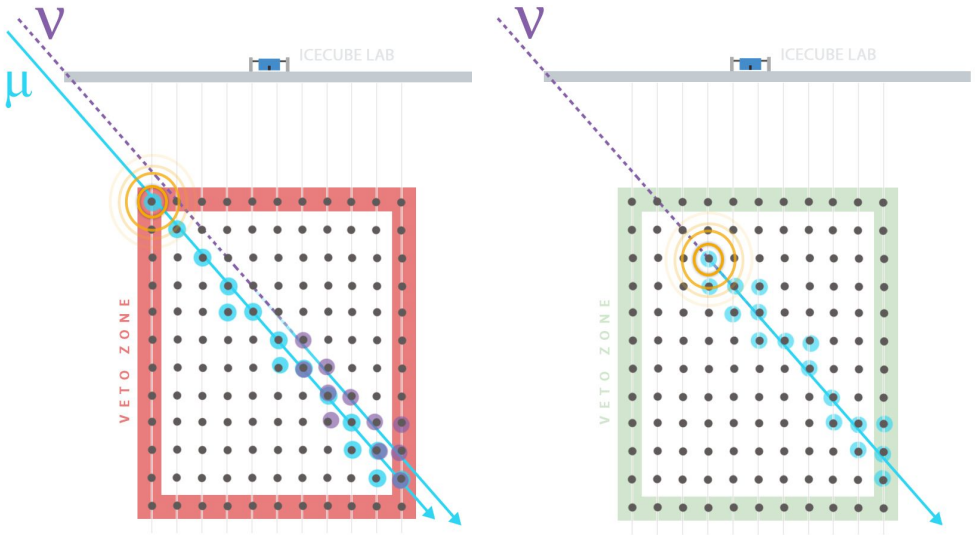
For a 1 km^3 detector

Atmospheric Muons	3000 per second
Atmospheric Neutrinos	~1 per second
Astrophysical Neutrinos	~1 per day

Muons from cosmic-ray air showers can penetrate several kilometers underground

Techniques to remove atmospheric background



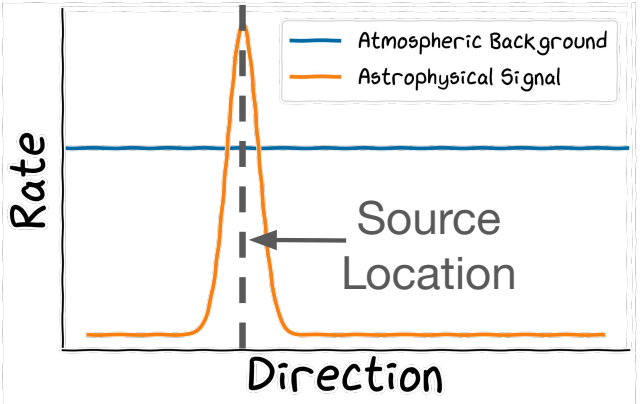


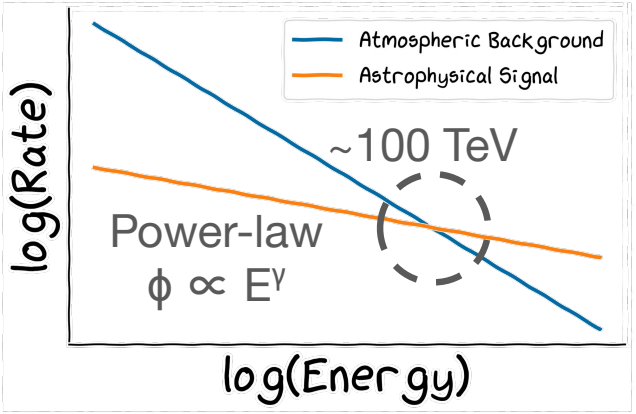
Can use earth to remove muons, but neutrinos from air showers still exist

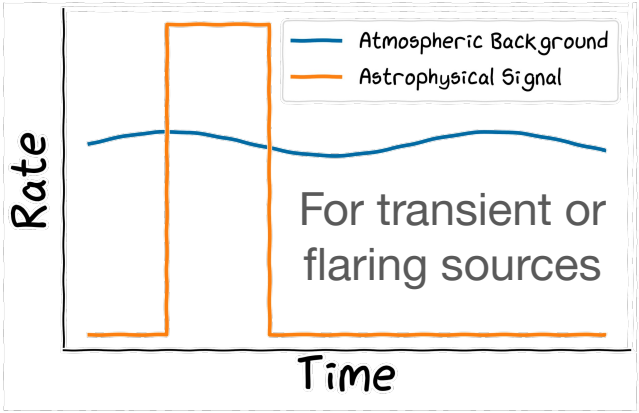
Selecting “starting” events reduces both backgrounds in southern sky

Atmospheric Muon
Atmospheric Neutrino
Astrophysical Neutrino

Techniques to distinguish astrophysical neutrino signatures





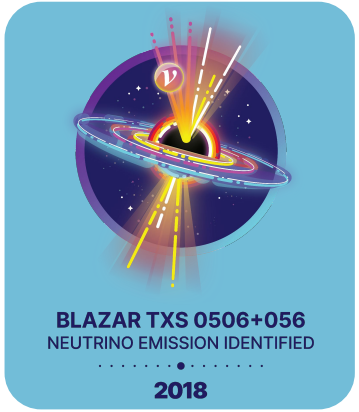


Overview of neutrino astronomy milestones

Properties of the astrophysical neutrino flux

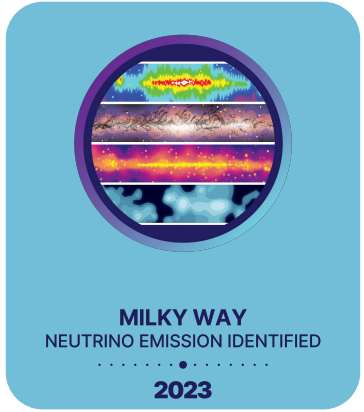
IceCube, Science 342, 6161 (2013)

Identification of sources of astrophysical neutrinos



IceCube, *et. al*, *Science* 361, 6398 (2018)

IceCube, *Science* 378, 6619 (2022)



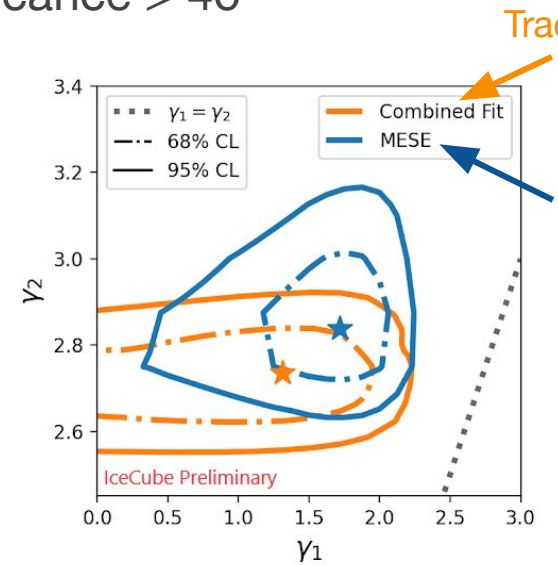
IceCube, *Science* 380, 6652 (2023)

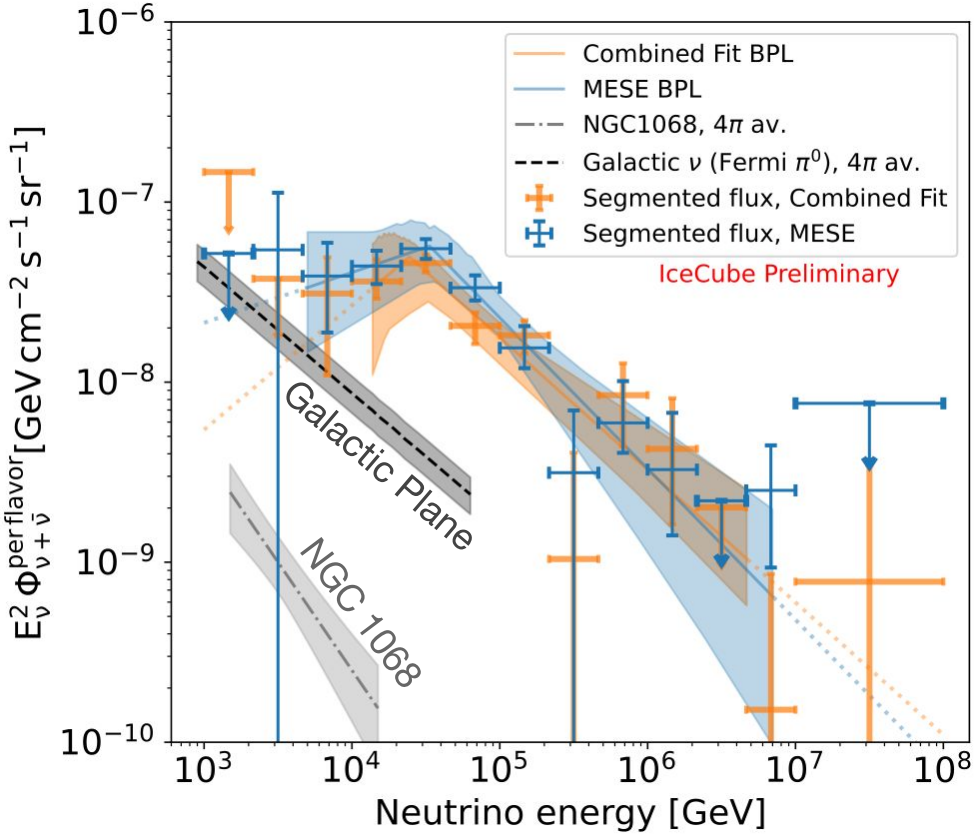
Recent improvements to the astrophysical flux measurements

Using starting events allows insight into lower energy range

See evidence of a spectral break around 30 TeV

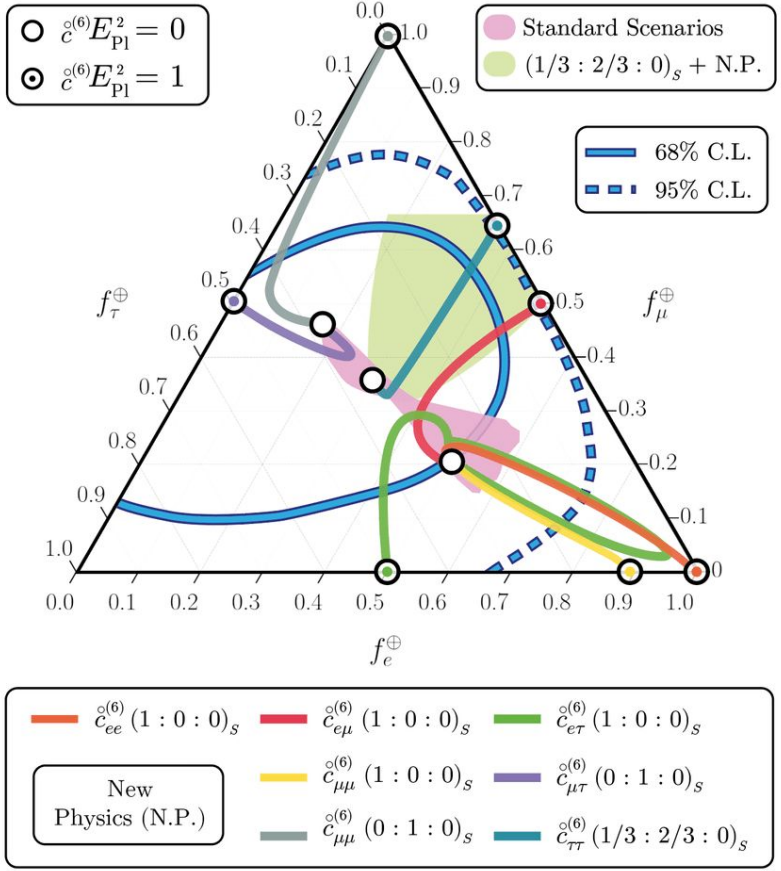
Reject single power-law flux with significance > 4σ





IceCube, TeVPA 2024
IceCube, POS(ICRC2023)1064

Neutrino flavor ratio measurements

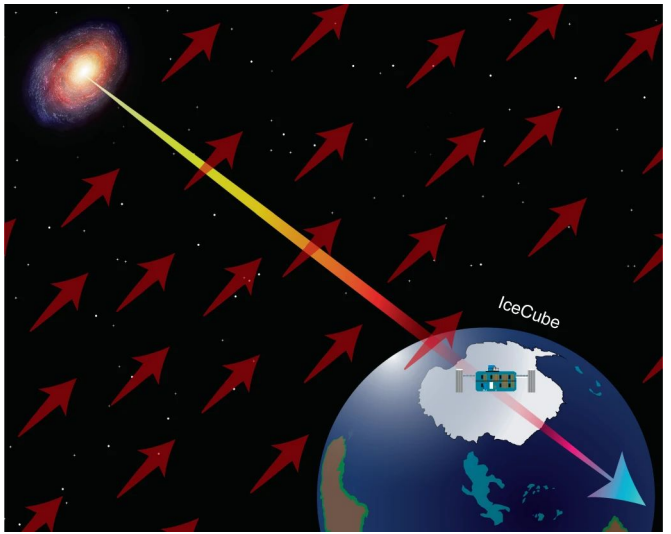


IceCube, Nature Physics 18, 1287-1292 (2022)

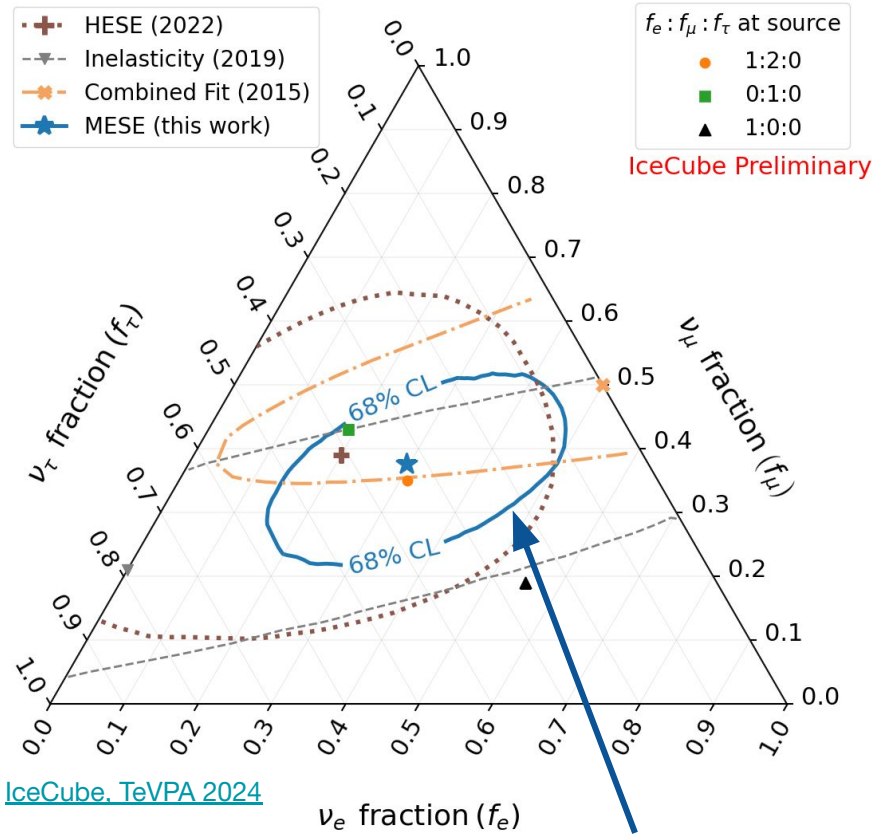
Neutrinos oscillate from their generation point to Earth

Flavor ratio at Earth gives insight into production mechanisms

Deviations can signal new physics



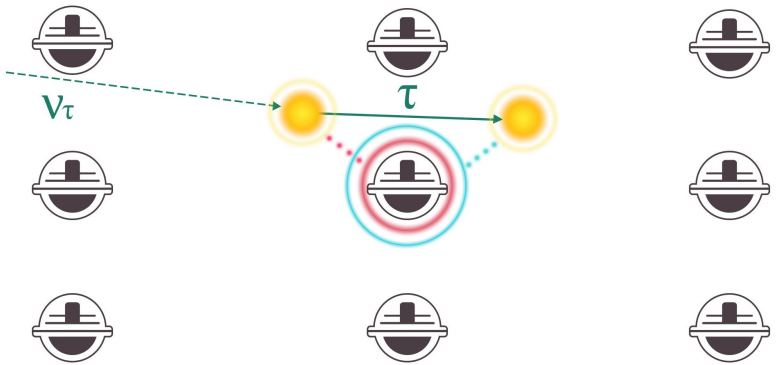
Neutrino flavor ratio measurements



IceCube, TeVPA 2024

New improvements to the flavor ratio measurement with starting events

Tau neutrino candidates can be identified by looking for signature of Tau decay

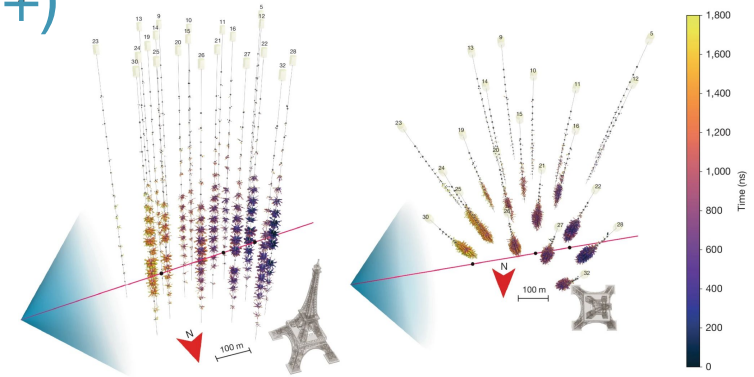


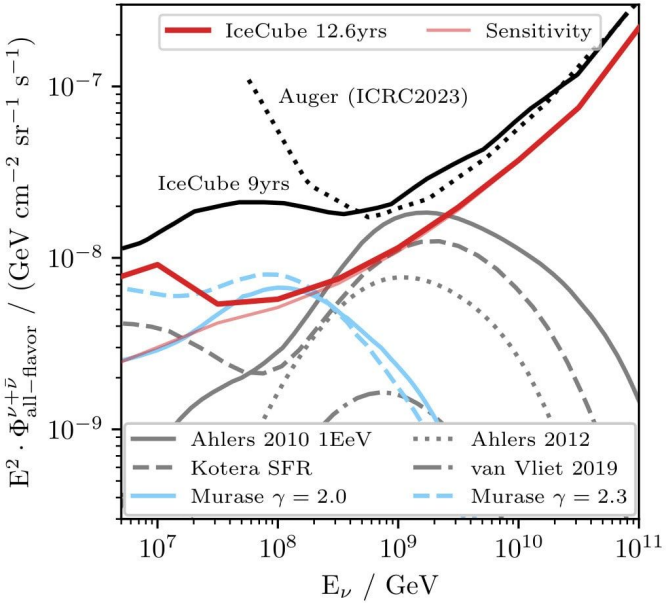
Source: IceCube/NSF

Ultra-high energy neutrinos (10 PeV+)

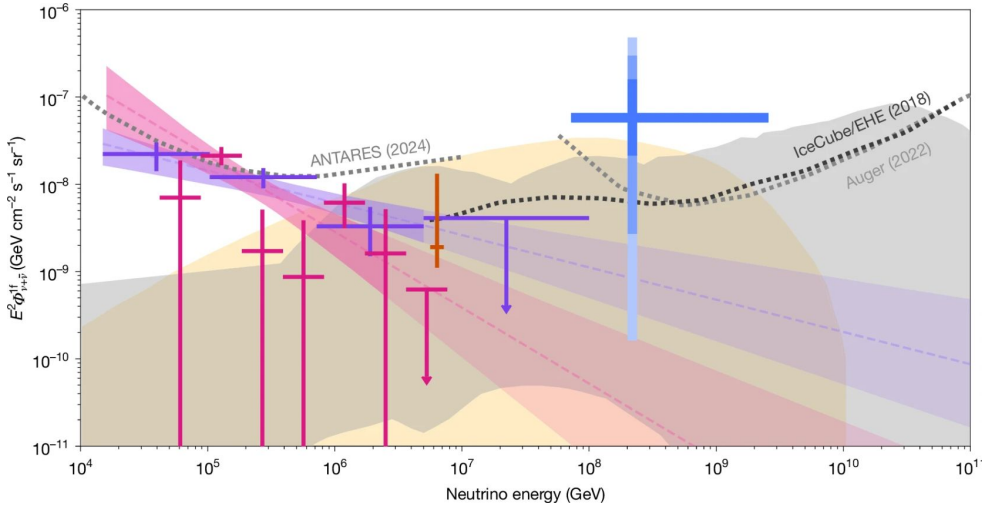
Highest energy cosmic rays interact with background radiation, producing pions

Pions decay to produce “cosmogenic” neutrinos at high energies



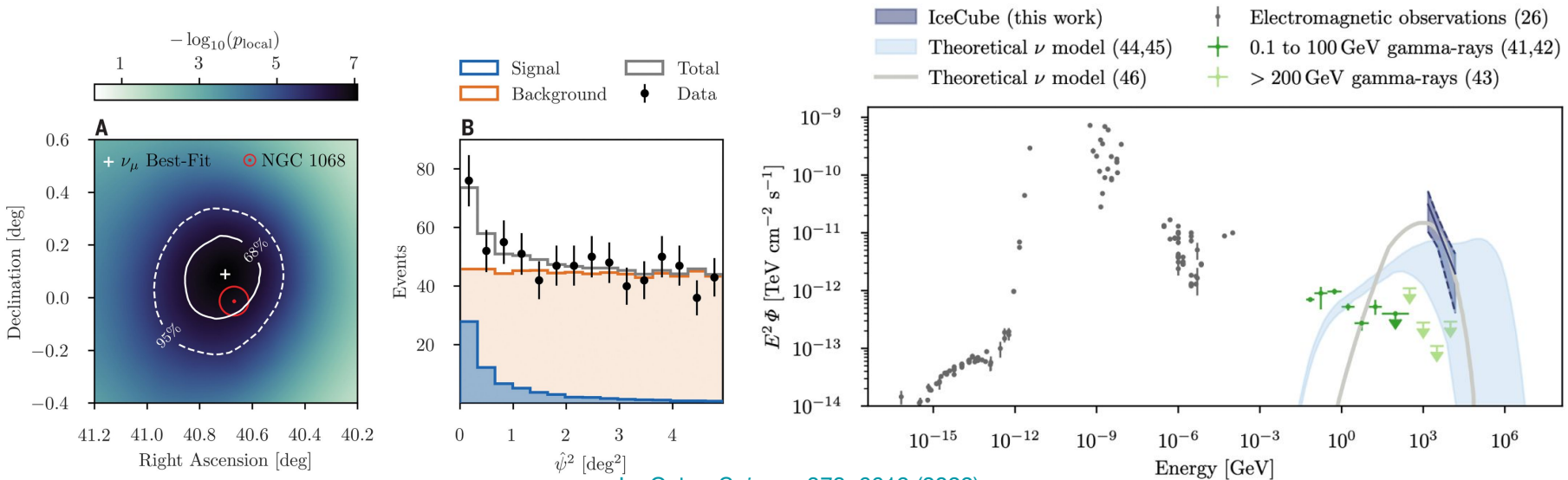


IceCube, arxiv:2502.01963



KM3NeT, *Nature* volume 638, pages 376–382 (2025)

NGC 1068 observations and the X-ray connection

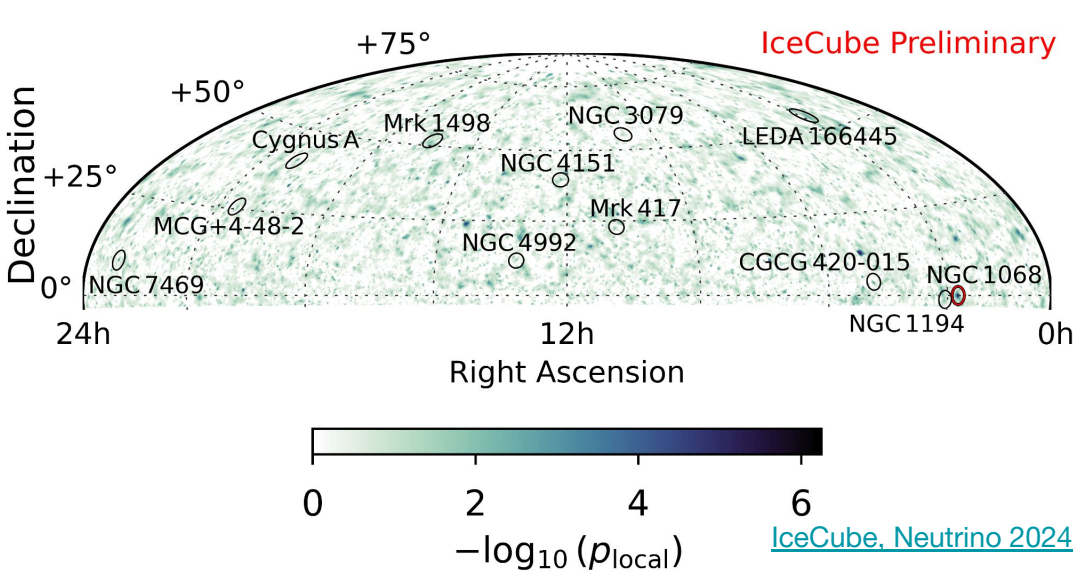


IceCube, *Science* 378, 6619 (2022)

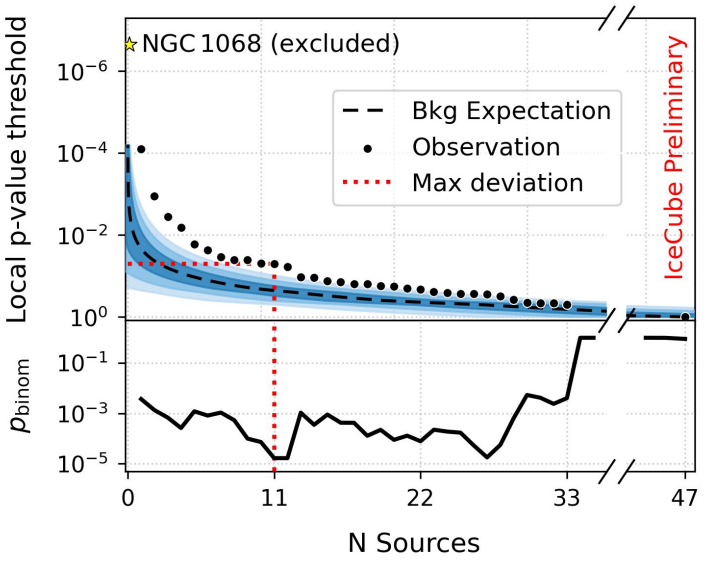
IceCube observes neutrino emission from NGC 1068 with global significance of 4.2σ

Neutrinos may be produced in matter/radiation dense environments which down-scatter gamma-rays to X-rays

X-ray bright Seyfert galaxies as a class of neutrino emitters



IceCube, Neutrino 2024



Multiple ~3σ correlation analyses between X-ray bright Seyferts and IceCube data:

- IceCube, Neutrino 2024 (X-ray bright non-bazar AGN)
- IceCube, arXiv:2406.07601 (X-ray bright Seyferts)
- IceCube, ApJ 981 131 (2025) (Hard X-ray AGN)
- Yu, S. NuFact 2024 (southern sky X-ray bright Seyferts)

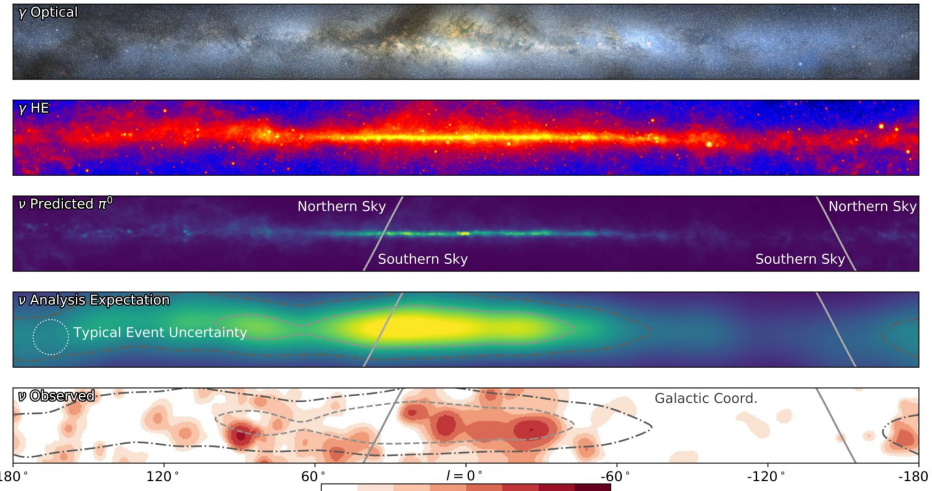
Neutrino excess from the Galactic plane

Neutrinos expected in Galactic plane from:

- Cosmic ray accelerators (point-like sources)
- Cosmic ray flux interacting with ISM (diffuse source)

IceCube sees 4.5σ excess from GP with cascade events using diffuse template

Data Set	Template Significance
IC Cascades	4.5σ
IC Northern Tracks	2.7σ
IC Starting Tracks	1.6σ
ANTARES	1.7σ

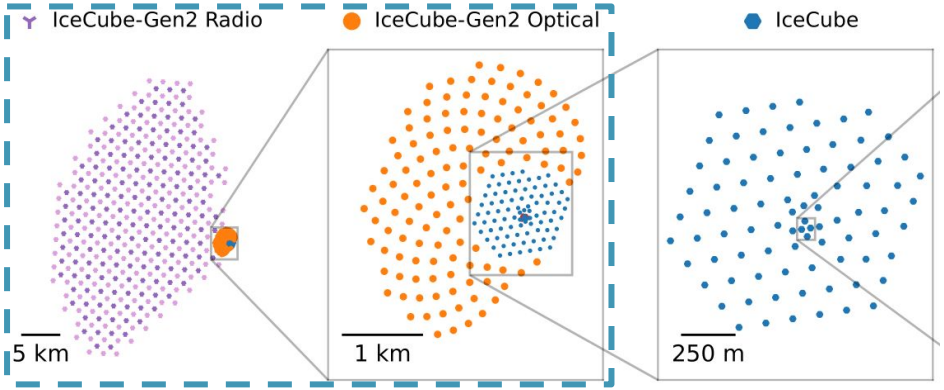


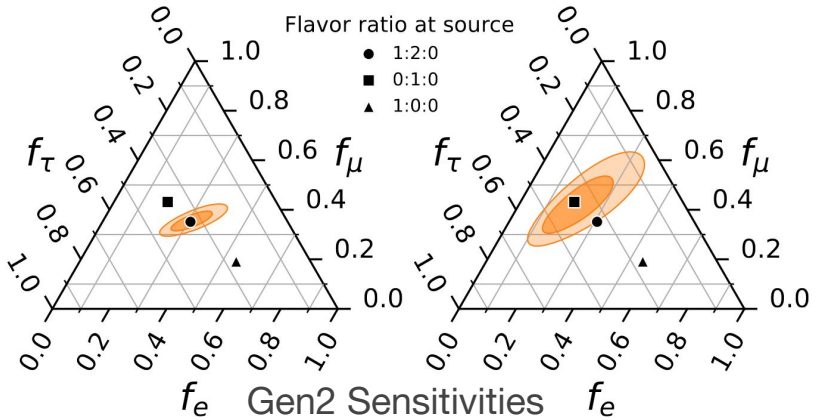
Diffuse emission model: *Fermi-LAT, ApJ 750 (2012) 3*

IceCube, *Science* 380, 6652 (2023)

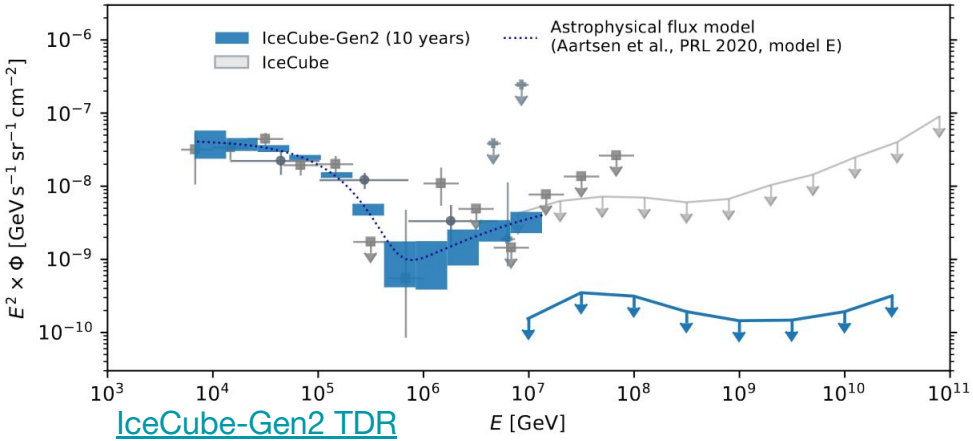
Northern sky neutrino telescopes will have better view of central Galactic region

The next generation of IceCube: IceCube-Gen2



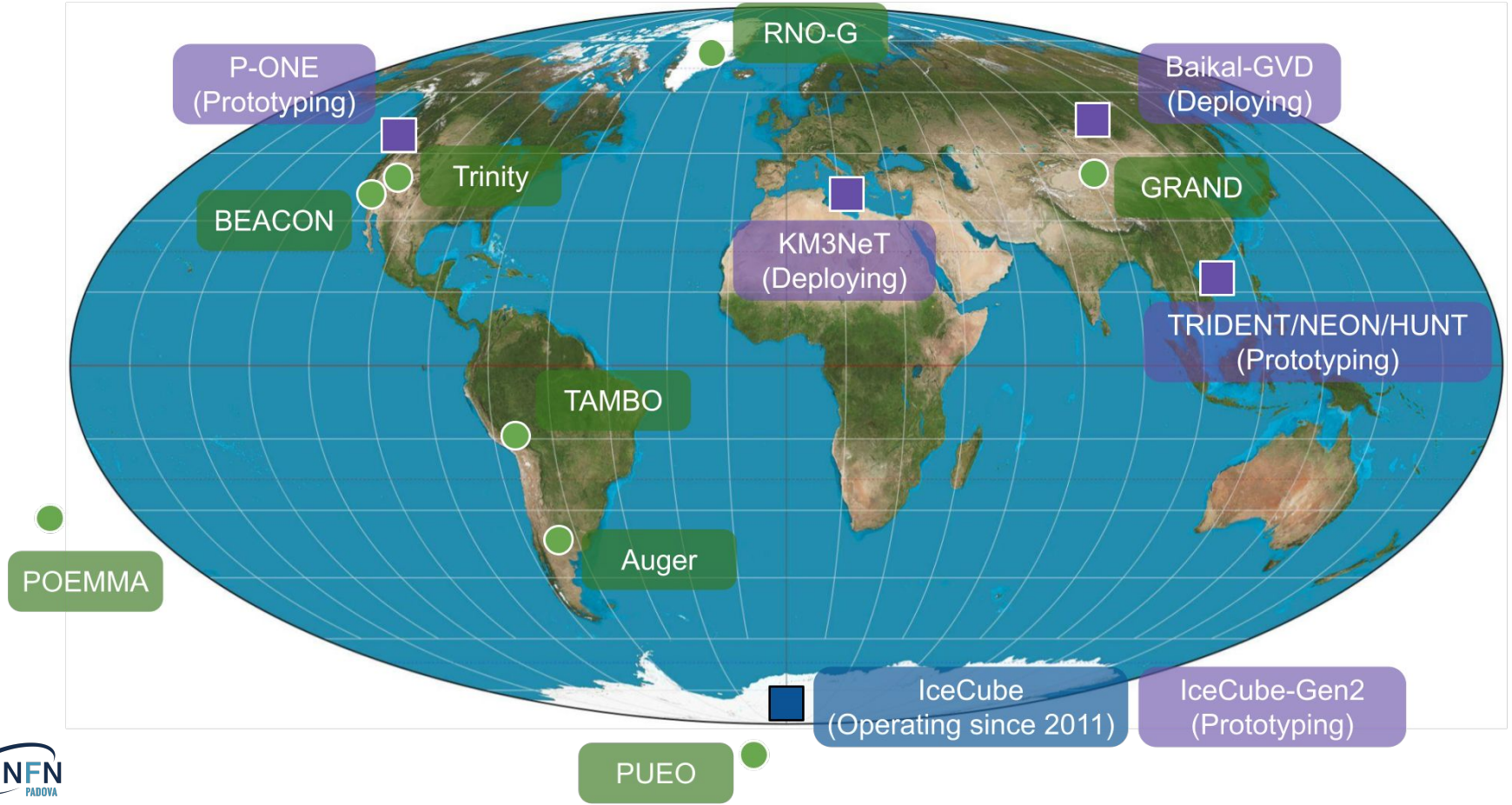


- Increase effective volume to 8 km^3
- Increase upper energy threshold
- Improve sensitivity to astrophysical neutrino sources by factor of ~5



IceCube-Gen2 TDR

Current and proposed astrophysical neutrino telescopes

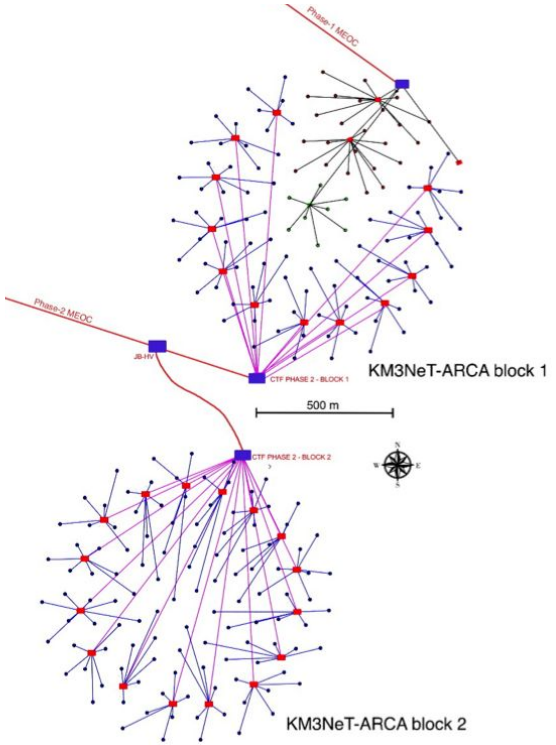


Northern hemisphere water cherenkov telescopes

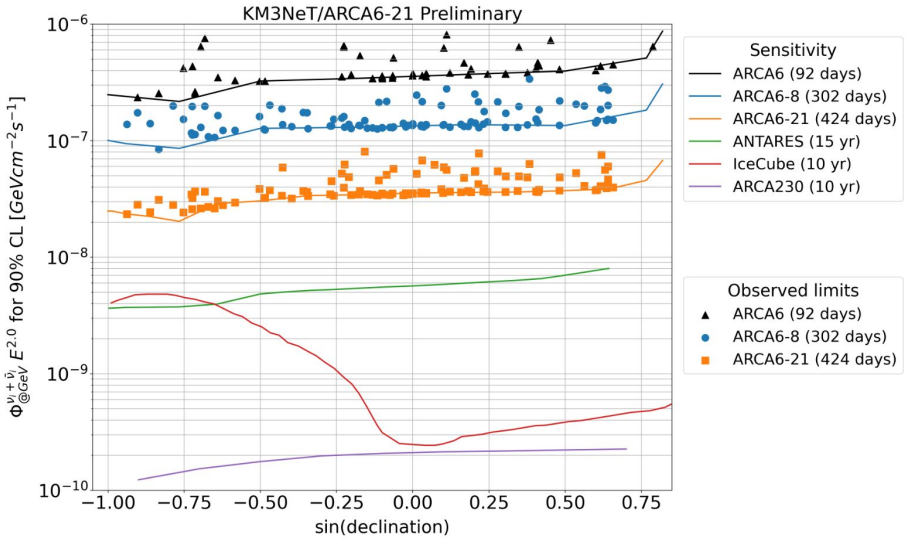
Water scatters light less than Antarctic ice ⇒ better directional reconstruction (~0.1°)

Better view of southern sky

https://www.km3net.org/



KM3NeT, PoS (EPS-HEP2019) 378

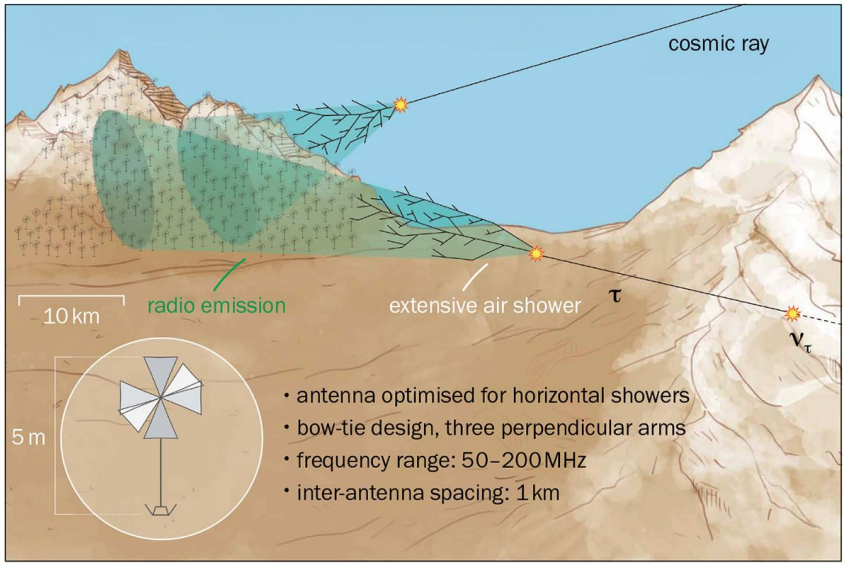


KM3NeT, PoS (ICRC 2023) 1018

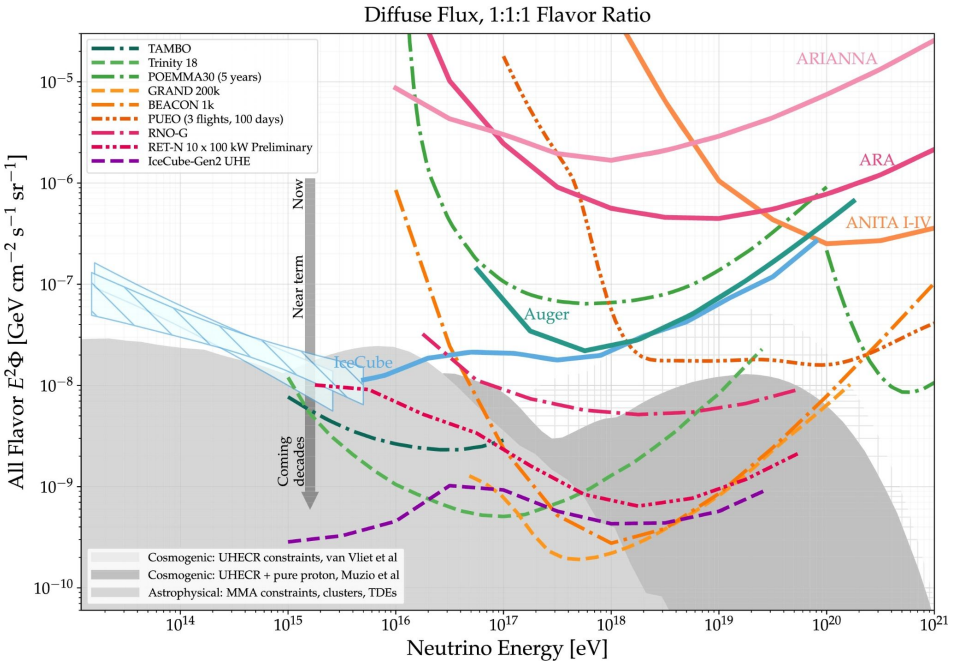
Many novel experiments to look for UHE Neutrinos

Increase detector volume by looking for earth “skimming” tau neutrino events

Many proposed detectors look for coherent radio emission from Askaryan effect



GRAND, https://doi.org/10.22323/1.340.0438



https://doi.org/10.1016/j.jheap.2022.08.001

Existing upper limit

Proposed sensitivity

Conclusions

Neutrino astronomy is a piece in the hadronic acceleration puzzle

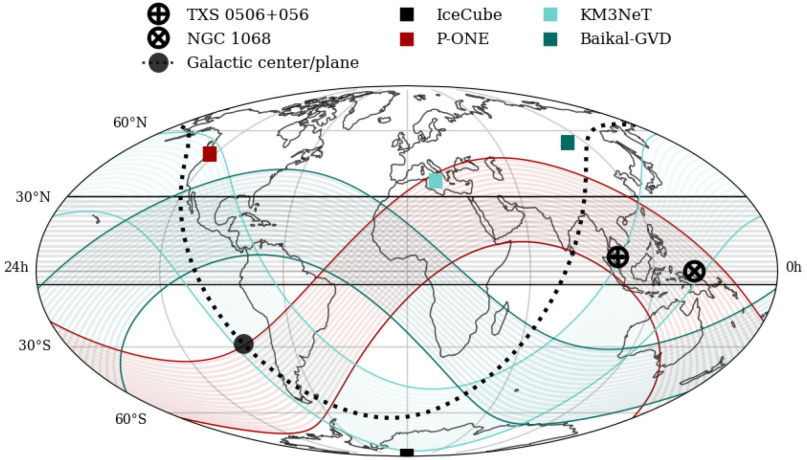
Atmospheric backgrounds obscure astrophysical neutrino signatures

IceCube has observed the astrophysical neutrino flux for over a decade

X-ray bright seyferts seem promising sources of neutrinos

An excess of neutrinos are seen from the Galactic plane

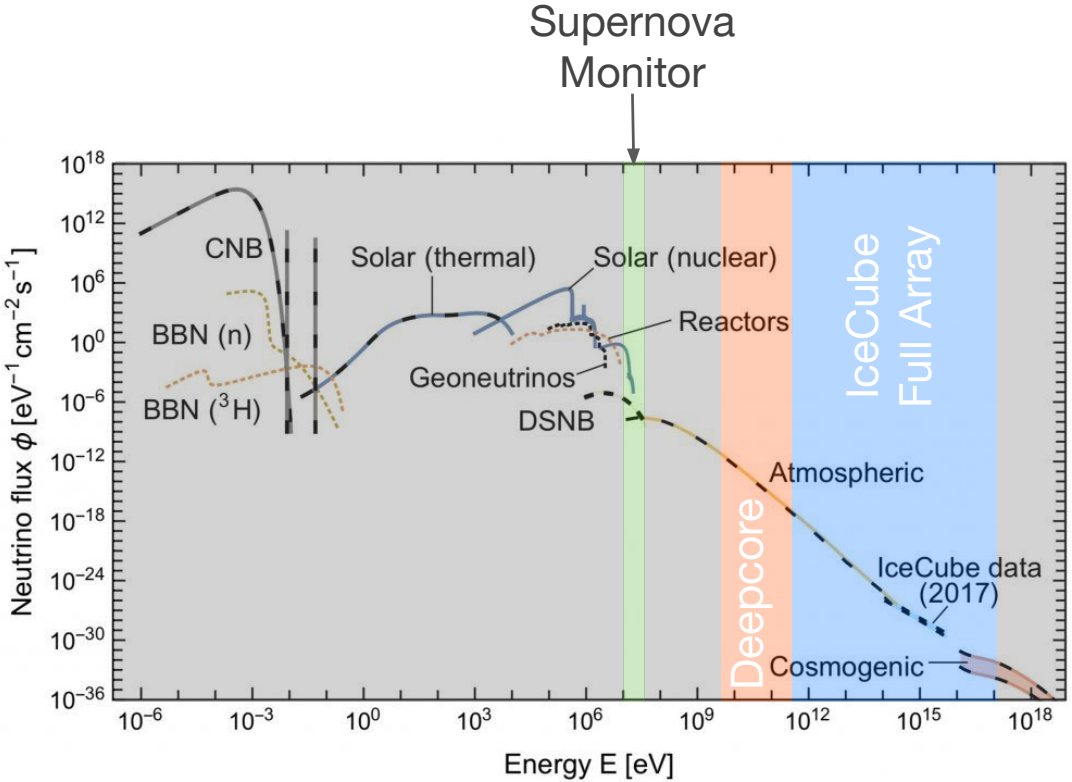
Many new neutrino telescopes on the way!



P-ONE Collaboration
DOI: 10.3390/universe10020053

Backup Slides

Astrophysical neutrinos relative to other neutrino sources



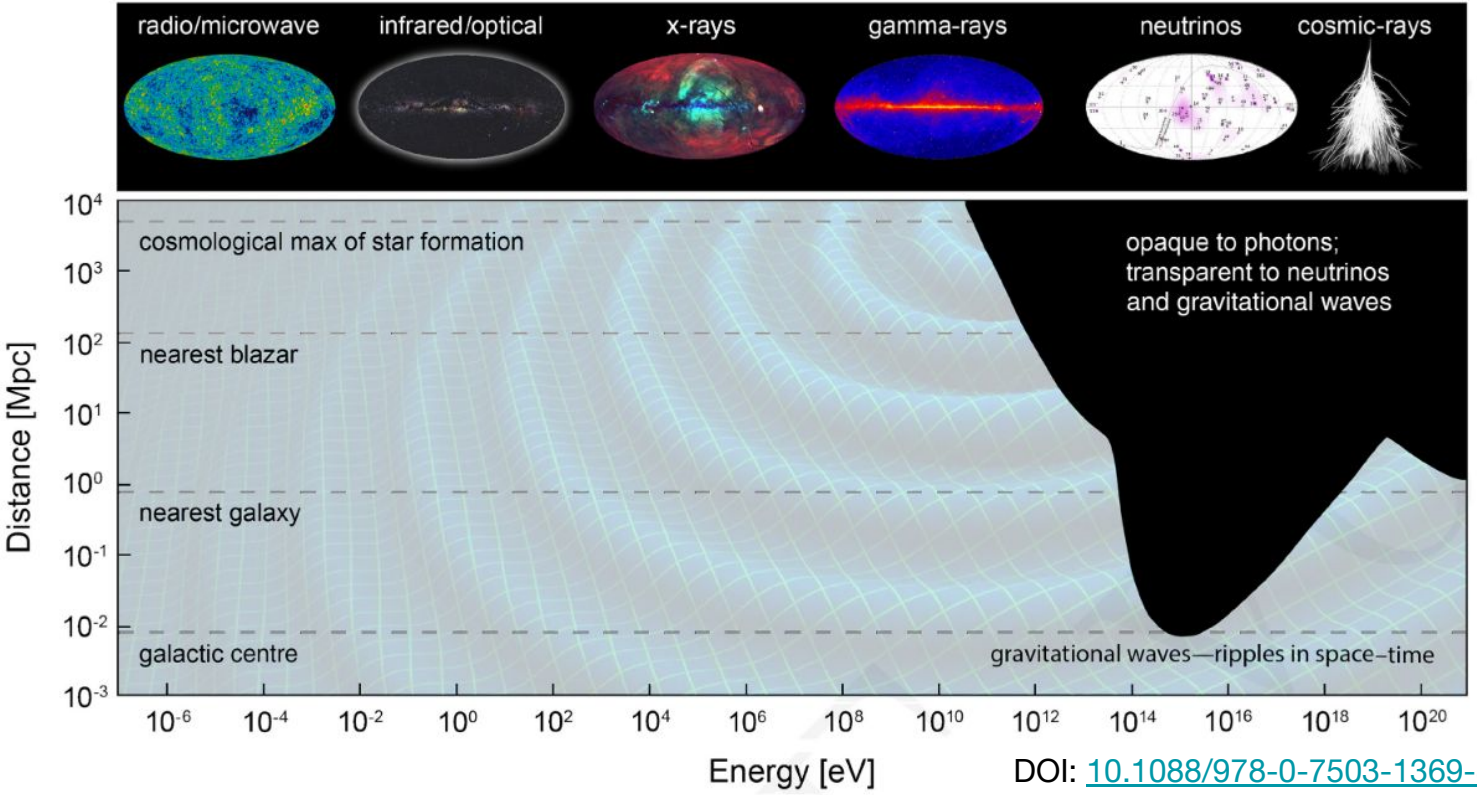
Neutrino fluxes across decades of energy

Rev. Mod. Phys. 92, 45006 (2020)

Neutrino astronomy versus gamma ray astronomy

Gamma rays attenuated by CMB and other background light in the TeV energy ranges

Gamma rays also produced by cosmic ray electron acceleration, **leptonic acceleration**



DOI: 10.1088/978-0-7503-1369-8

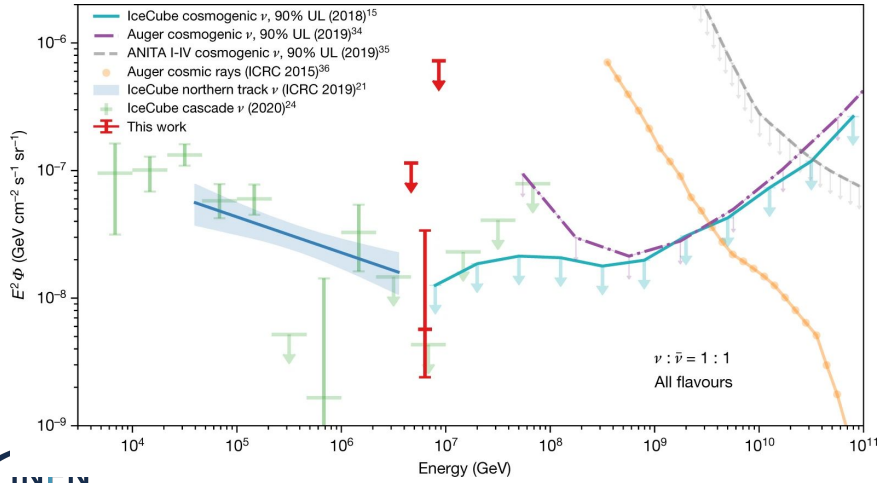
IceCube's Glashow event (2021)

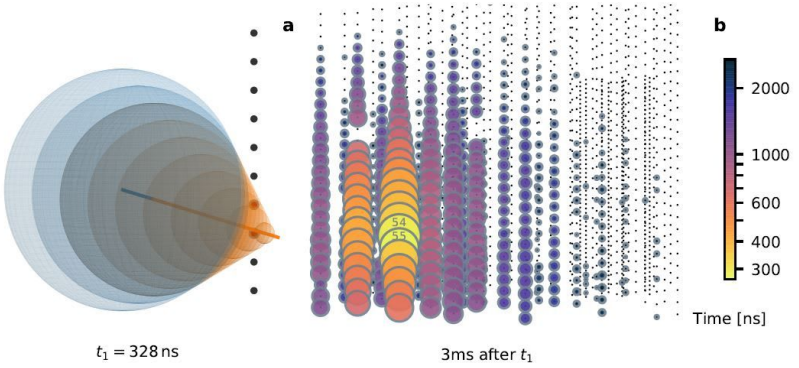
W resonance between electron and electron antineutrino

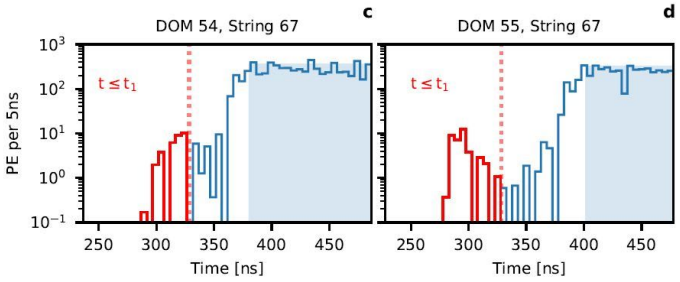
Partially contained cascade event with 6.3 PeV reconstructed energy

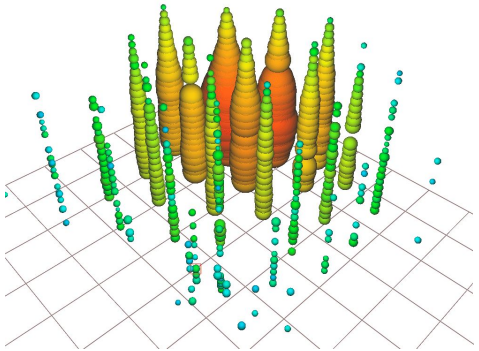
Secondary muons observed consistent with hadronic decay of boson

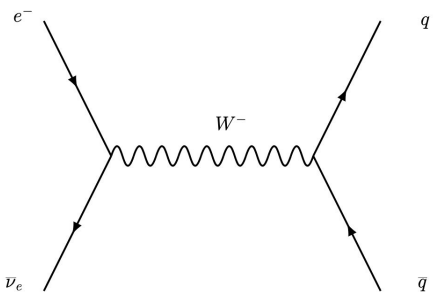
Insight into PeV neutrino flux





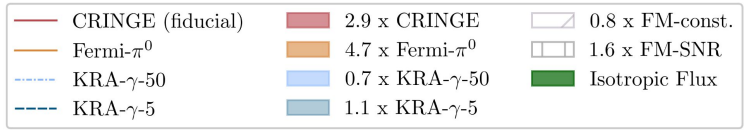


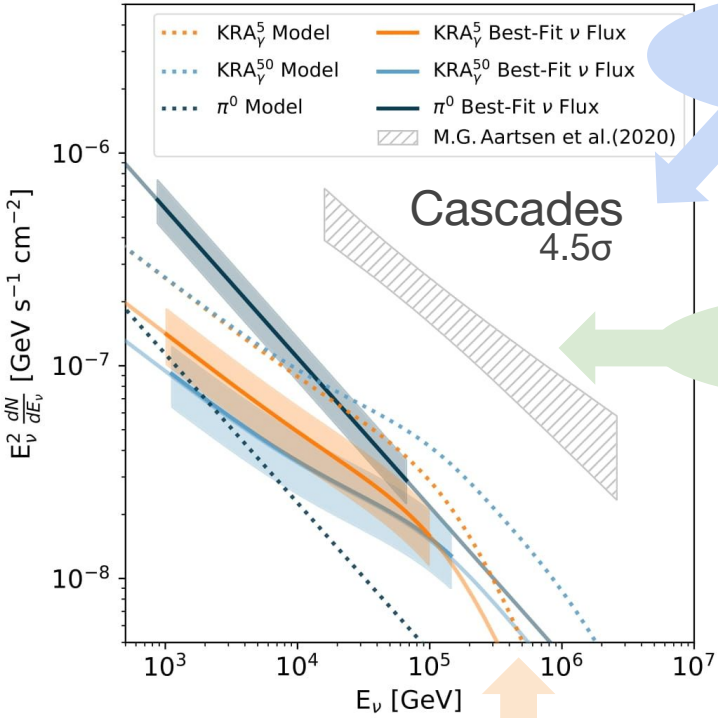




Nature 591, 220-224 (2021)

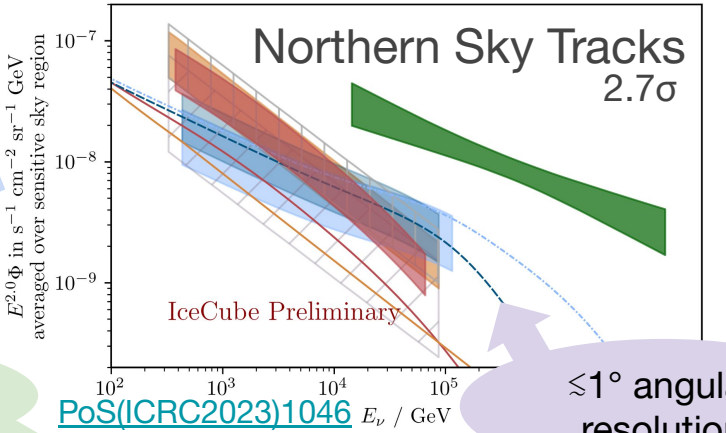
Measurements and upper limits of the galactic plane neutrino flux





DOI: 10.1126/science.adc9818

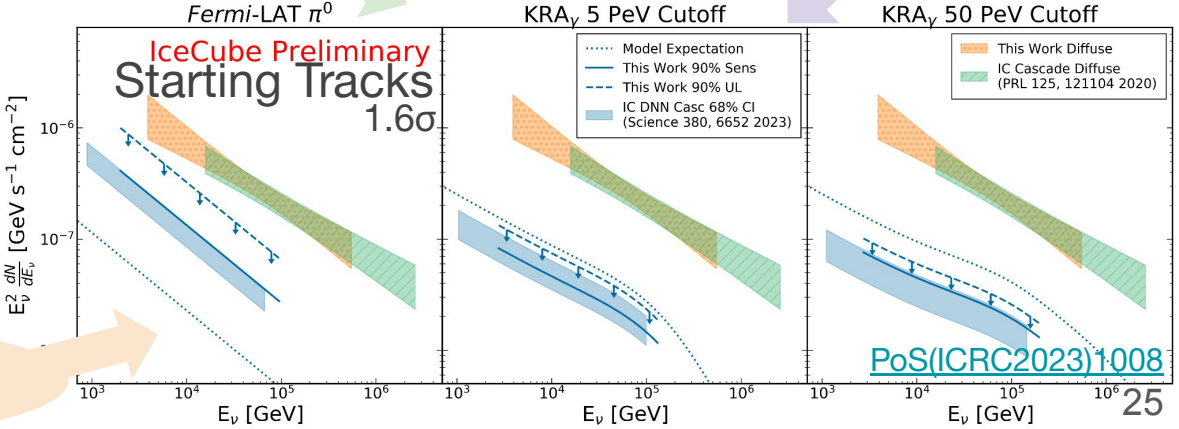
Larger rate of signal events



PoS(ICRC2023)1046

View of Galactic Center

≲1° angular resolution



PoS(ICRC2023)1008

Atmospheric ν Background Veto