Status of the searches for high-energy neutrinos from the Milky Way

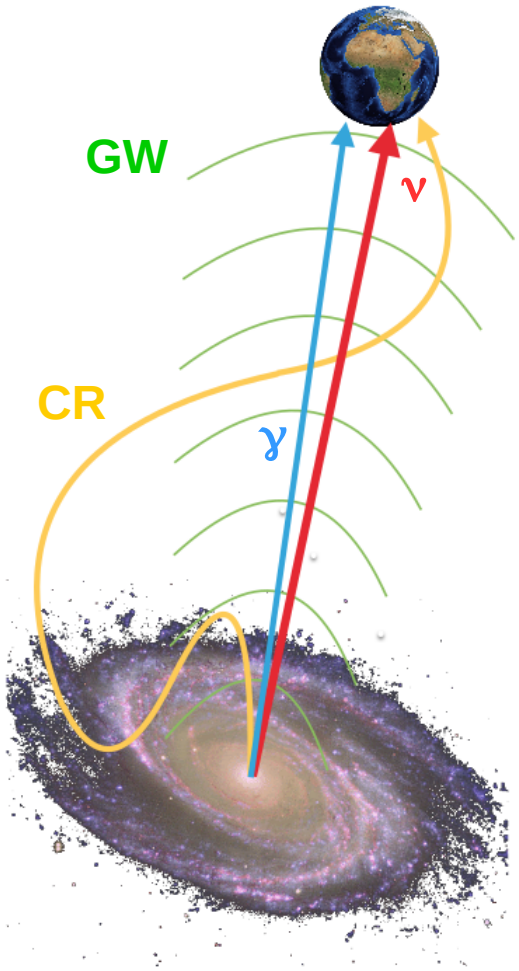
NOW2022 - Ostuni
4th - 11th September 2022

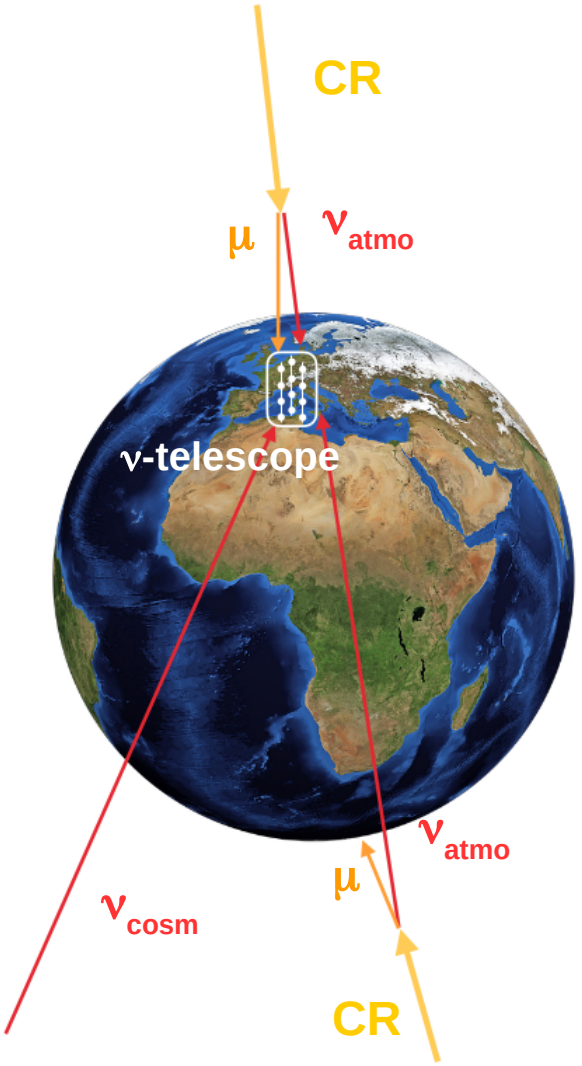
Luigi Antonio Fusco
Università di Salerno

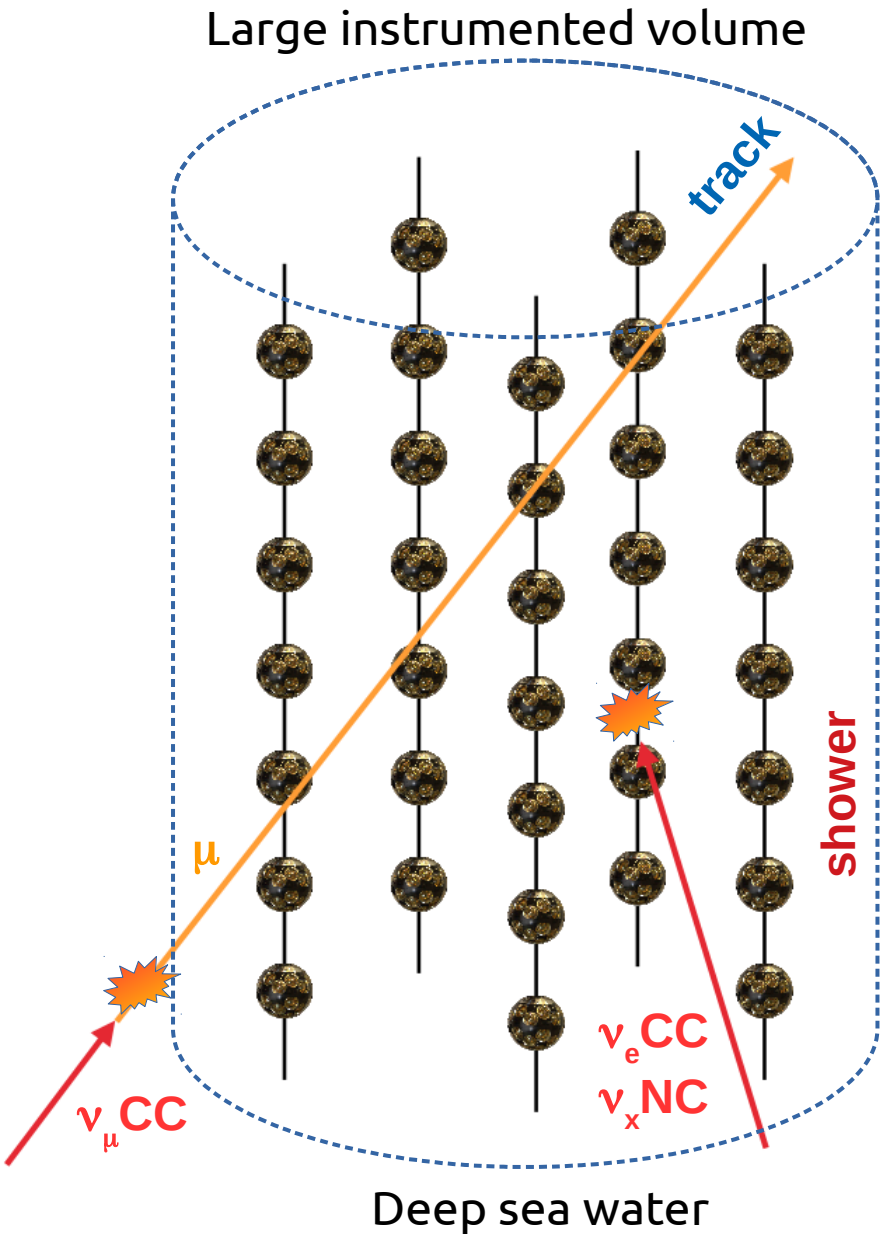
Outline

- Neutrino astronomy in our Galaxy?
- The detectors
- Recent results and outlook

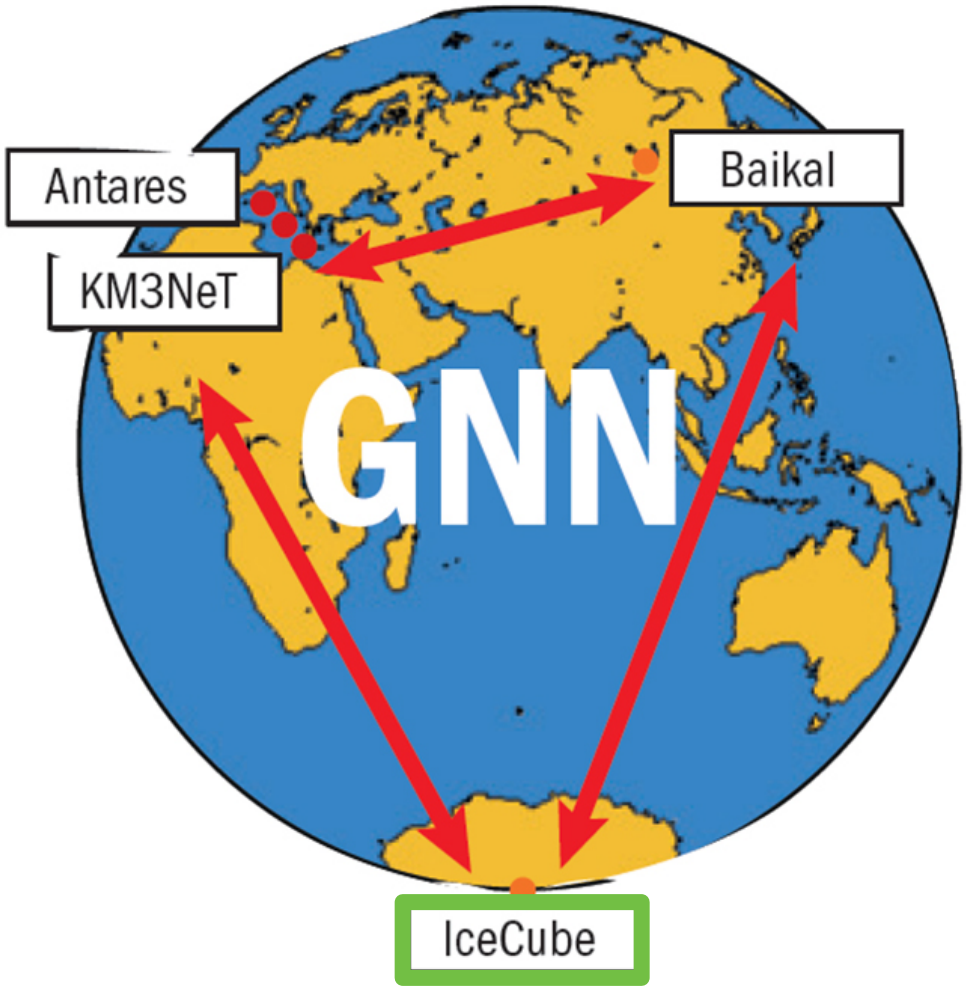
Neutrino astrophysics in a nutshell

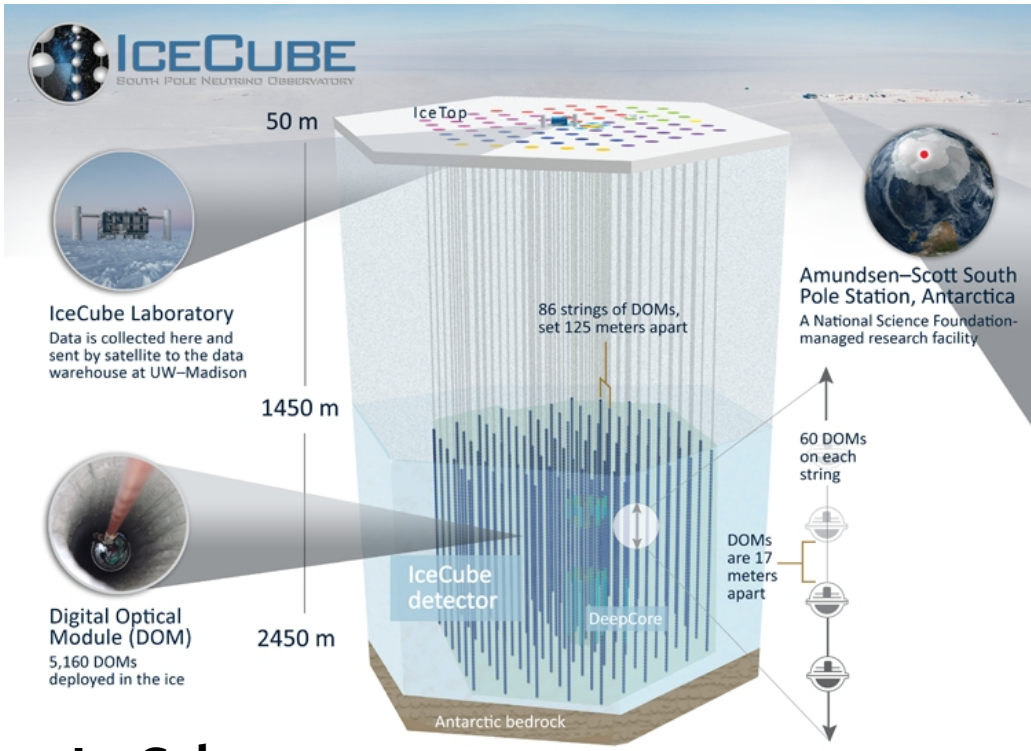






Neutrino telescopes



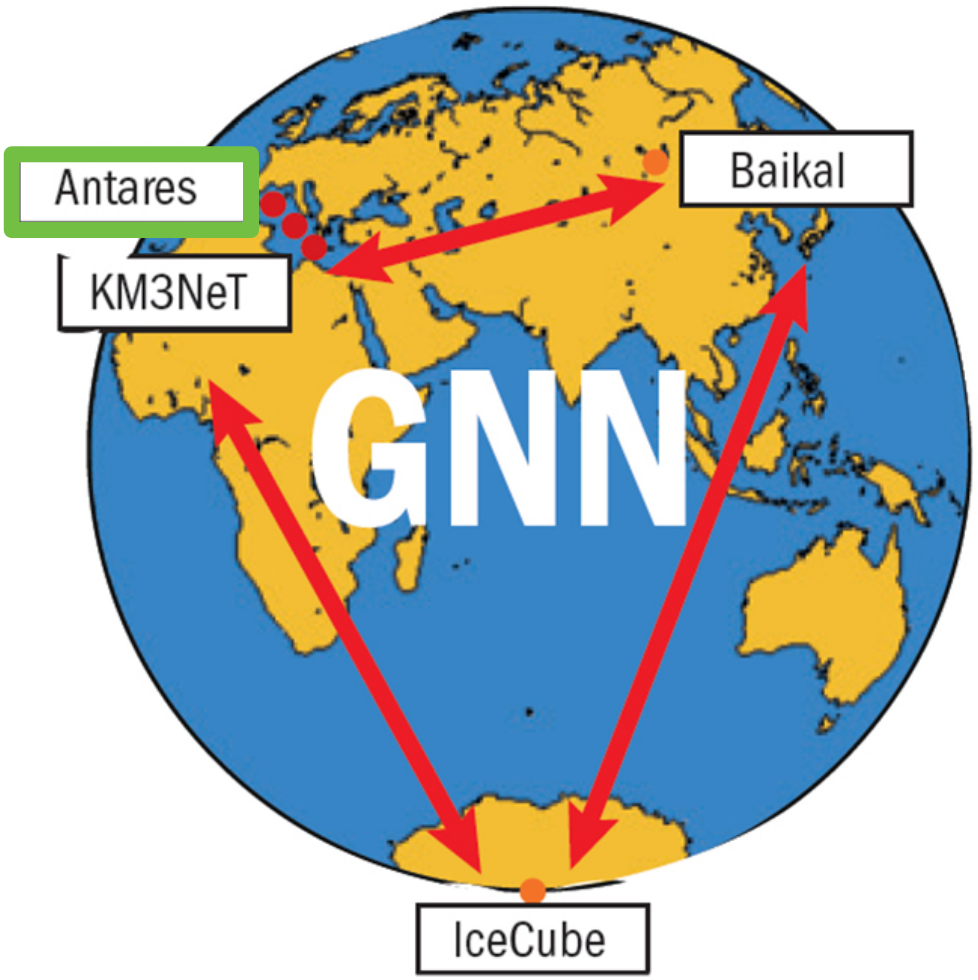


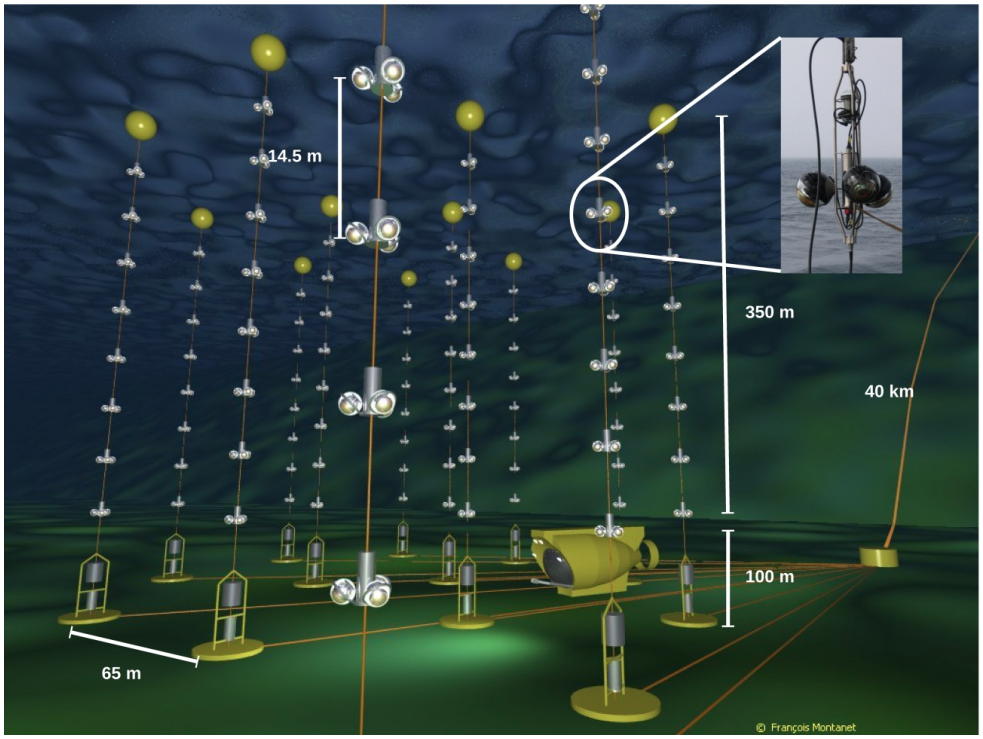
IceCube
km³ neutrino telescope

10+ years of data taking at the South Pole

Talk by S. Toscano this morning

Neutrino telescopes



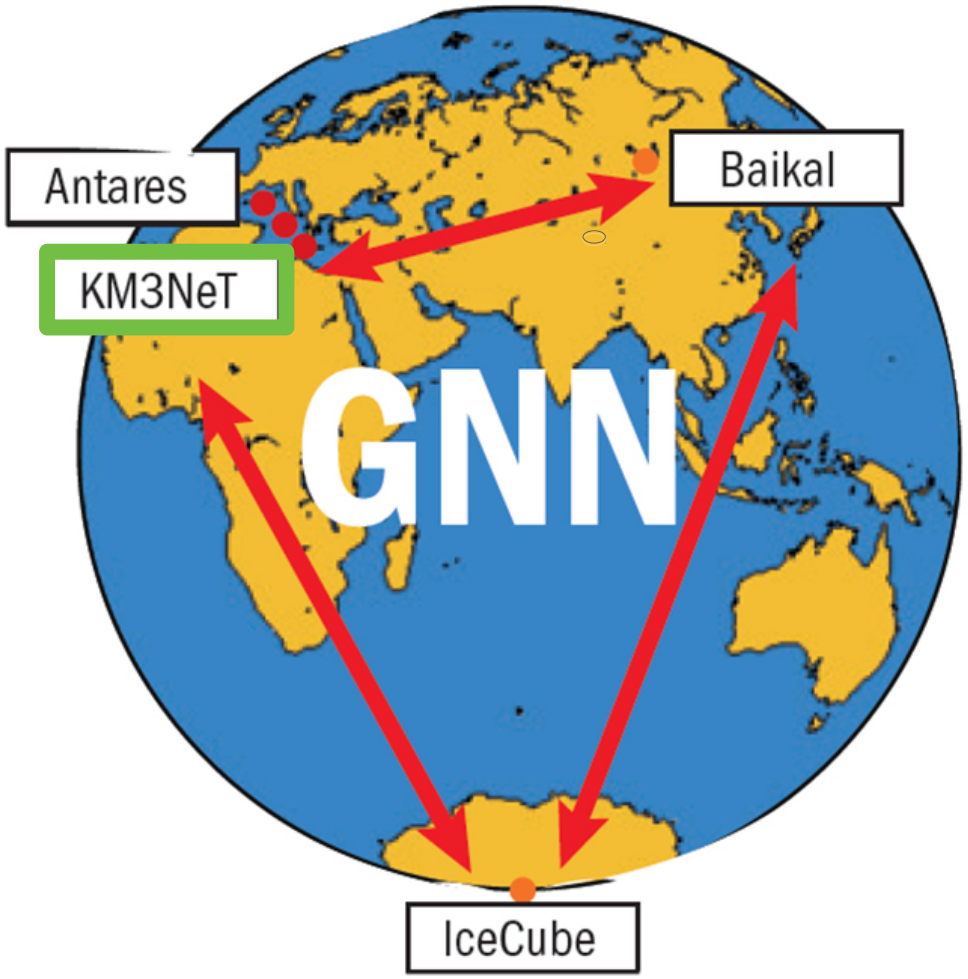


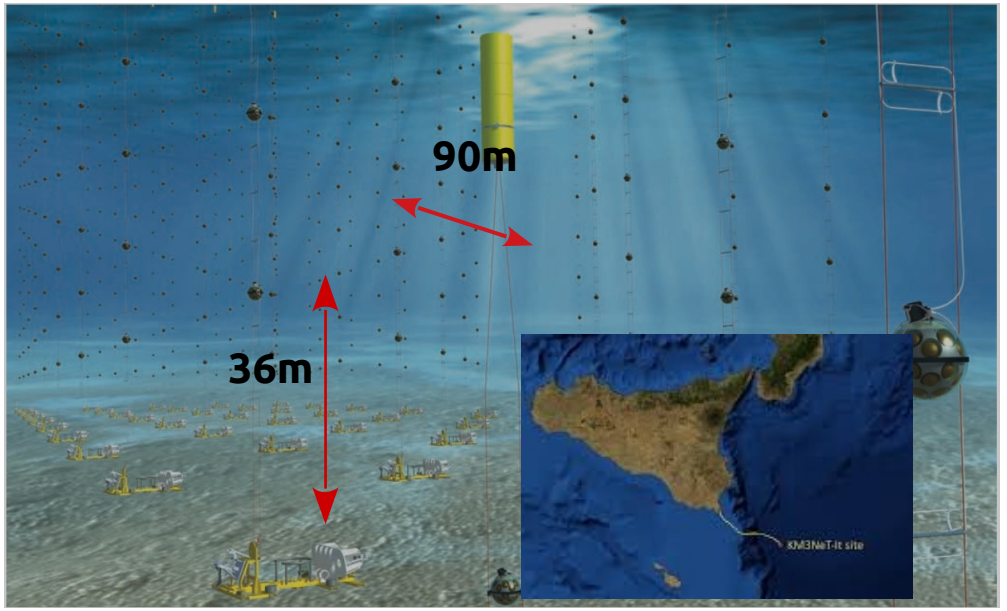
ANTARES
0.01 km³ neutrino telescope

15 years (2007-**2022**) of data taking in The Mediterranean Sea (France)

Talk by M. Spurio earlier this afternoon

Neutrino telescopes





KM3NeT ARCA (2016 -)
Goal: 2 Building blocks, 115 DU each → ~km³ volume

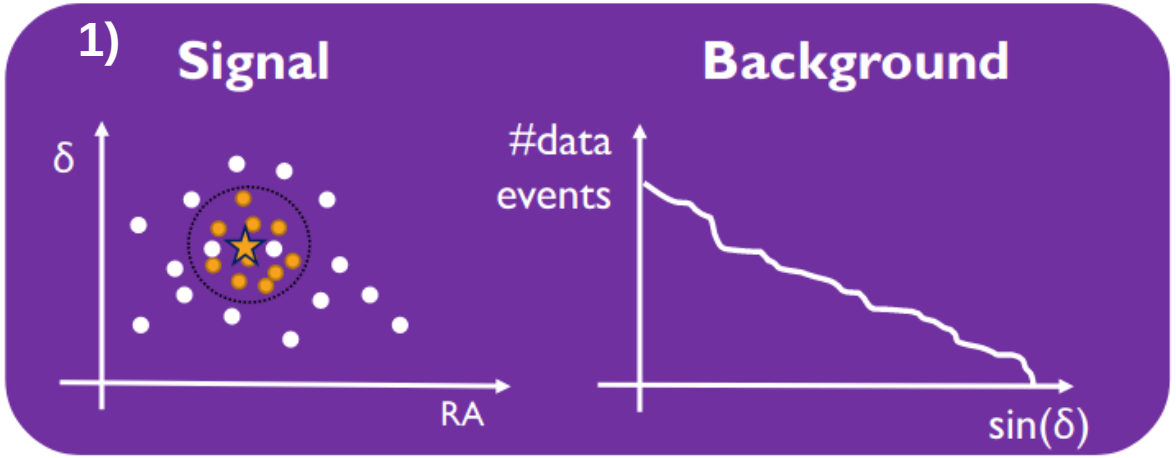
Under construction, currently 19 active DUs → ~3 x ANTARES

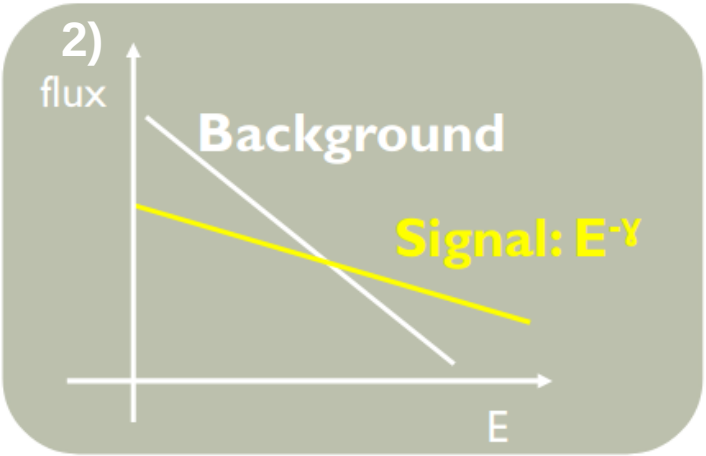
Searching for cosmic neutrinos

1) Search in data for spatial clustering of events with respect to atmospheric (~isotropic) Foregrounds

– Self-clustering of neutrinos
– Following templates for emission (point-source, extended, diffuse)

2) Search for high-energy excess of harder cosmic signal

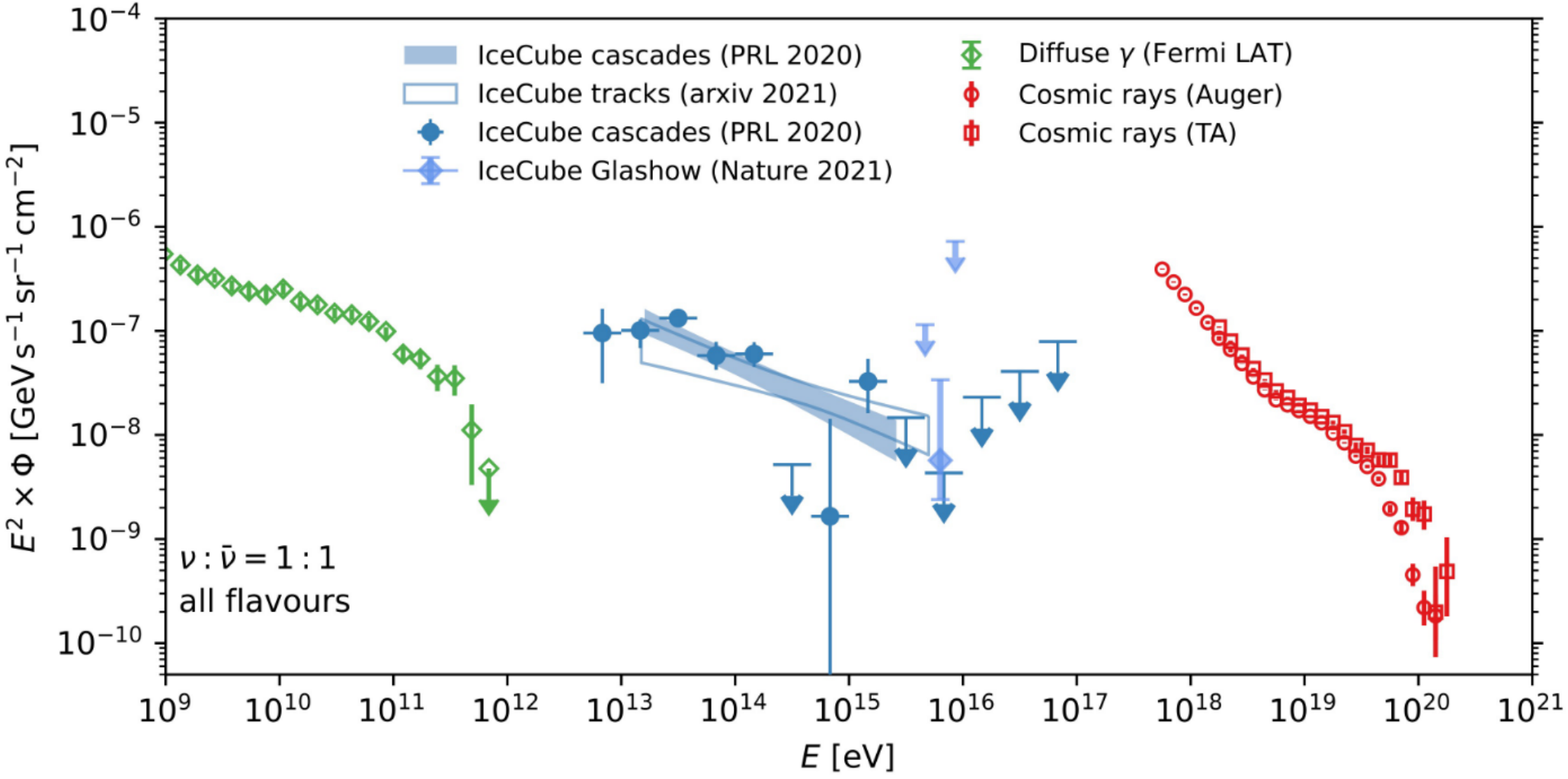




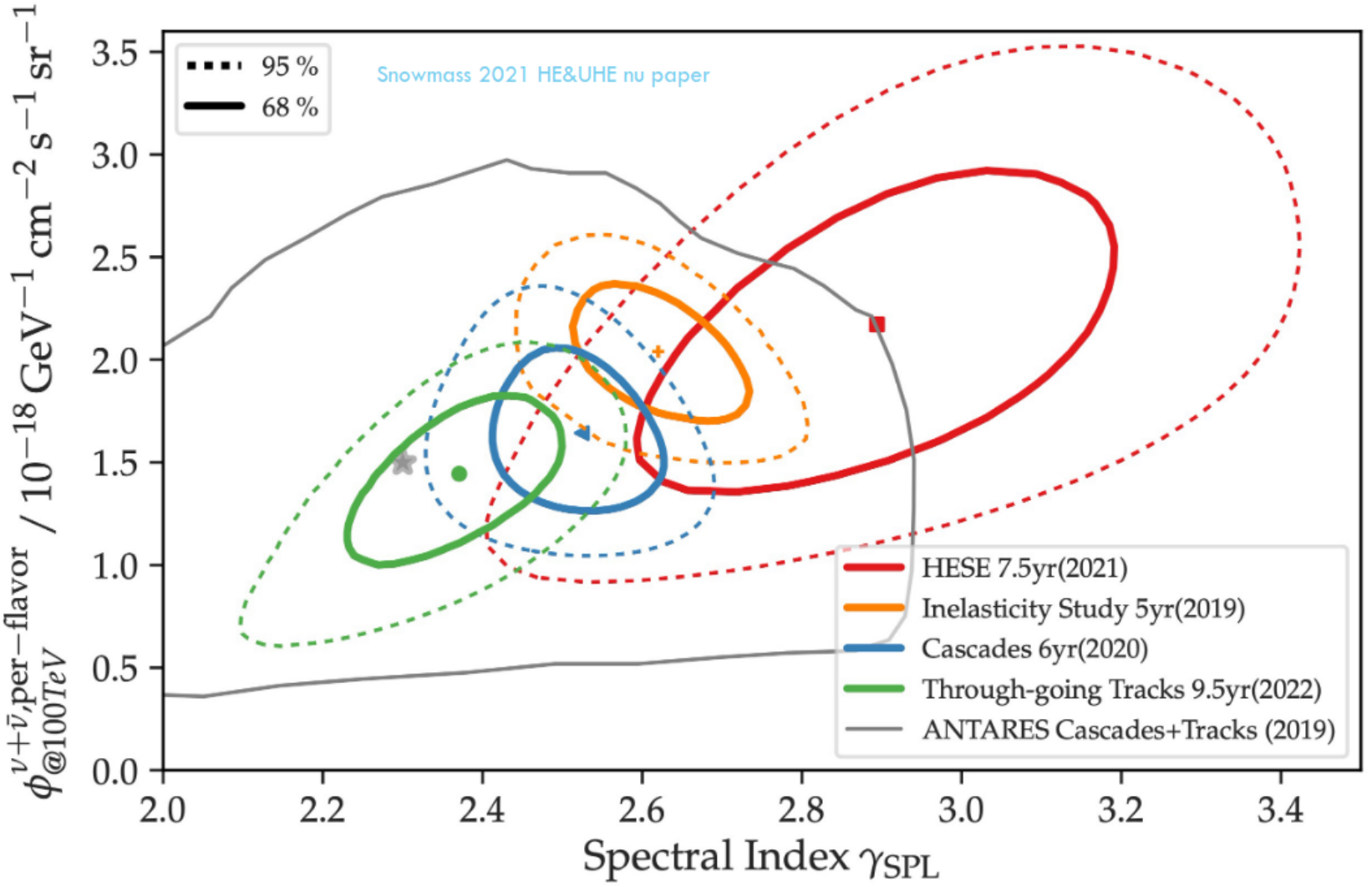
Also 3) transients. Not here

… and a mix of 1) and 2)

The cosmic diffuse flux



The cosmic diffuse flux



The cosmic diffuse flux

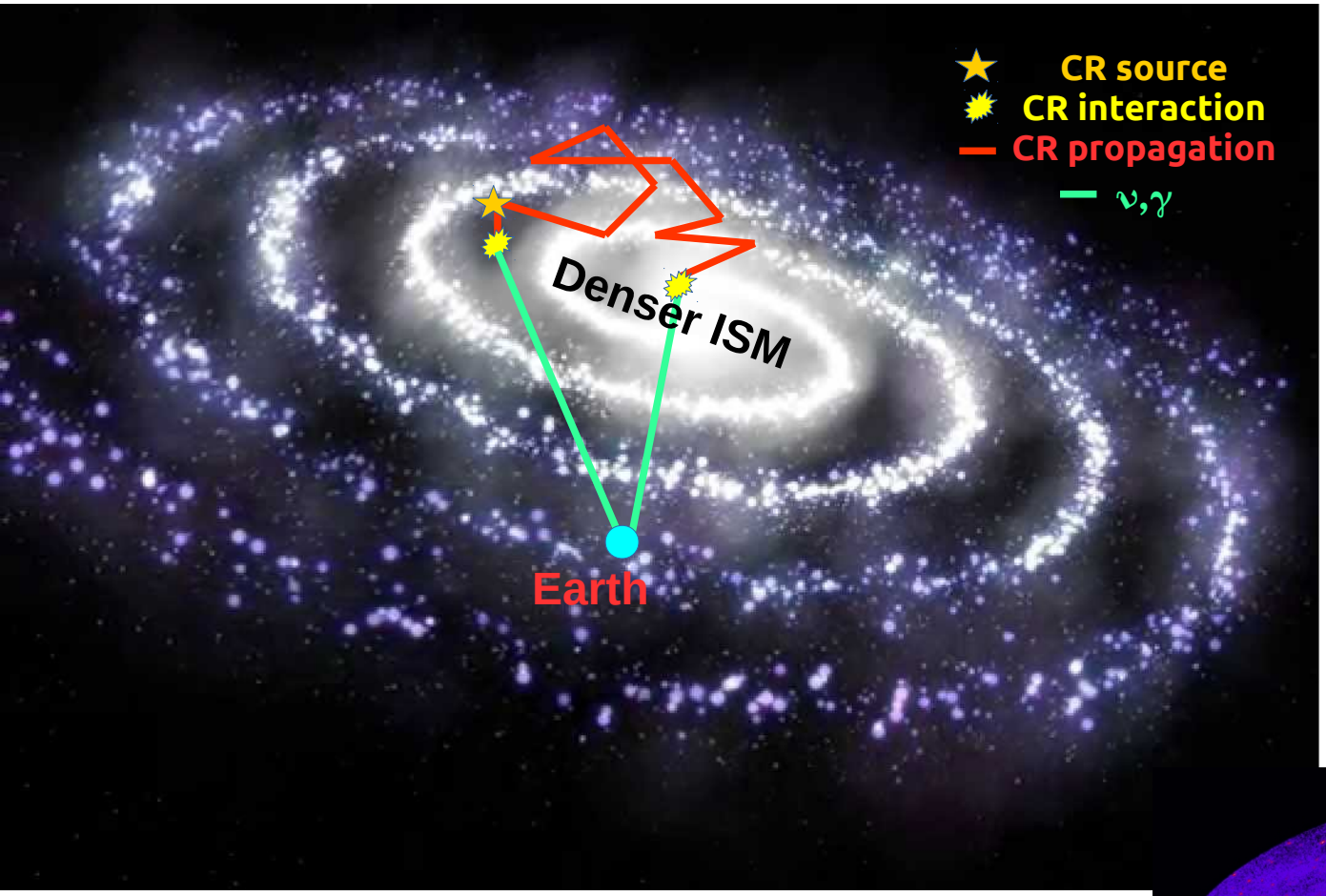
- Single power-law hypotheses can be challenged by IceCube data themselves
- North/Hard vs South/Soft

  → multiple components often invoked to explain the different spectra

  + some Galactic neutrinos from CR propagation must be there

- *More in the backup*

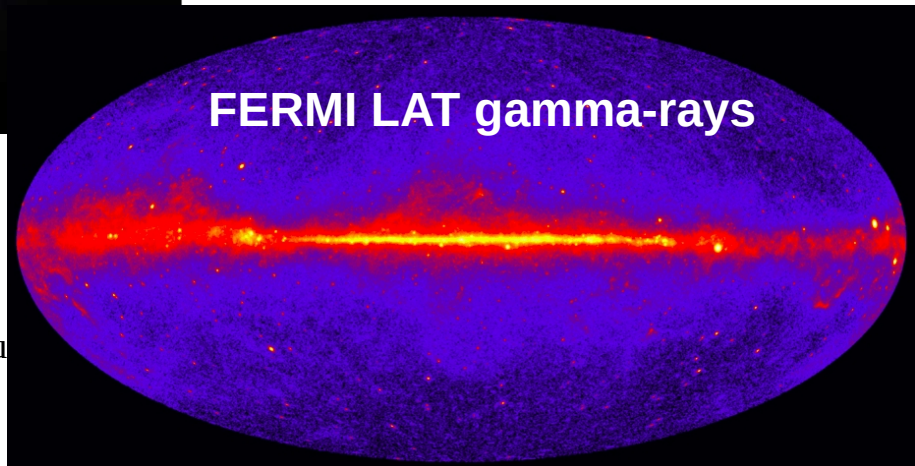
Galactic plane searches



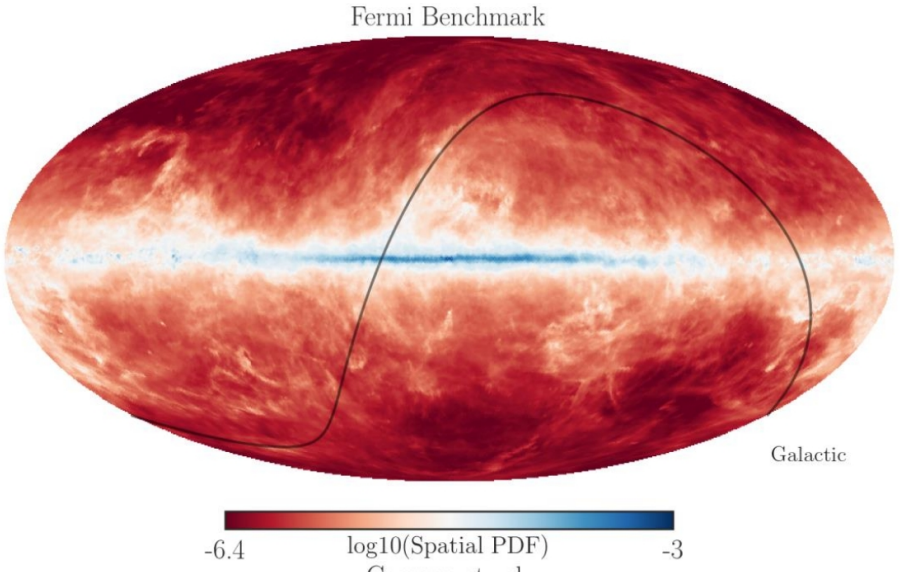
Neutrinos carry direct information on **CR propagation**. e.g.:

- Non-homogeneous diffusion can enhance γ and ν emission

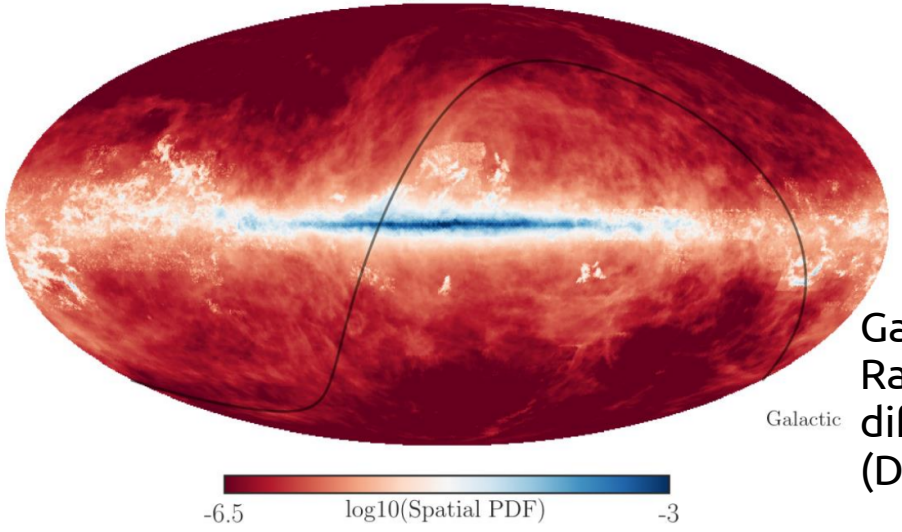
- Molecular clouds/dense environments boost γ and ν fluxes



Galactic plane template searches

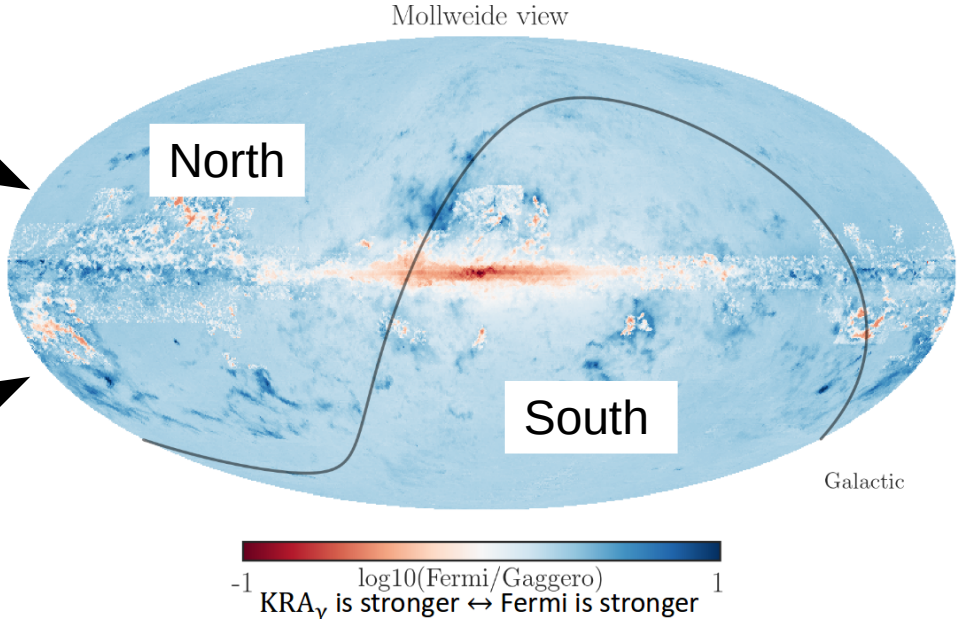


Standard model from Fermi (GALPROP)



Gaggero et al. Radially dependent diffusion – data tuned (DRAGON) KRAγ

Ratio of the two



Harder/stronger in the centre
Softer/lower in the periphery
→ different fields of view can test the model differently

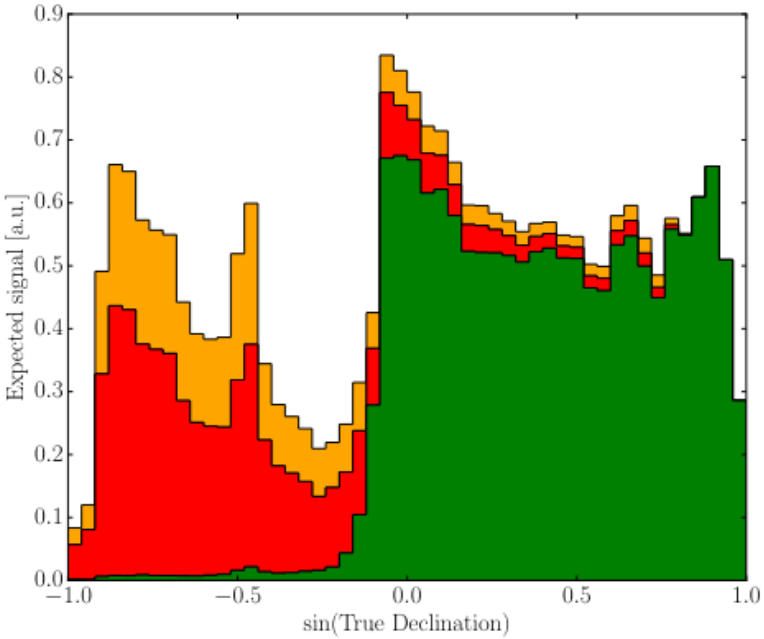
Plots by C.Haack, for the IceCube Collaboration

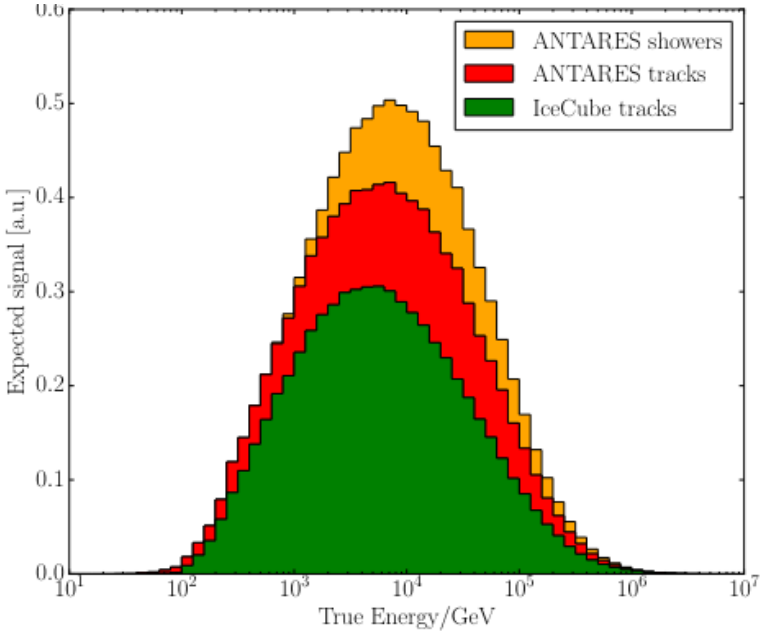
Astrophys.J. 868 (2018) no.2, L20

Galactic plane searches

ANTARES (tracks + showers)
+ IceCube (tracks)
joint dataset

Different exposure, different spectral sensitivities
→ cover the full galactic plane emission





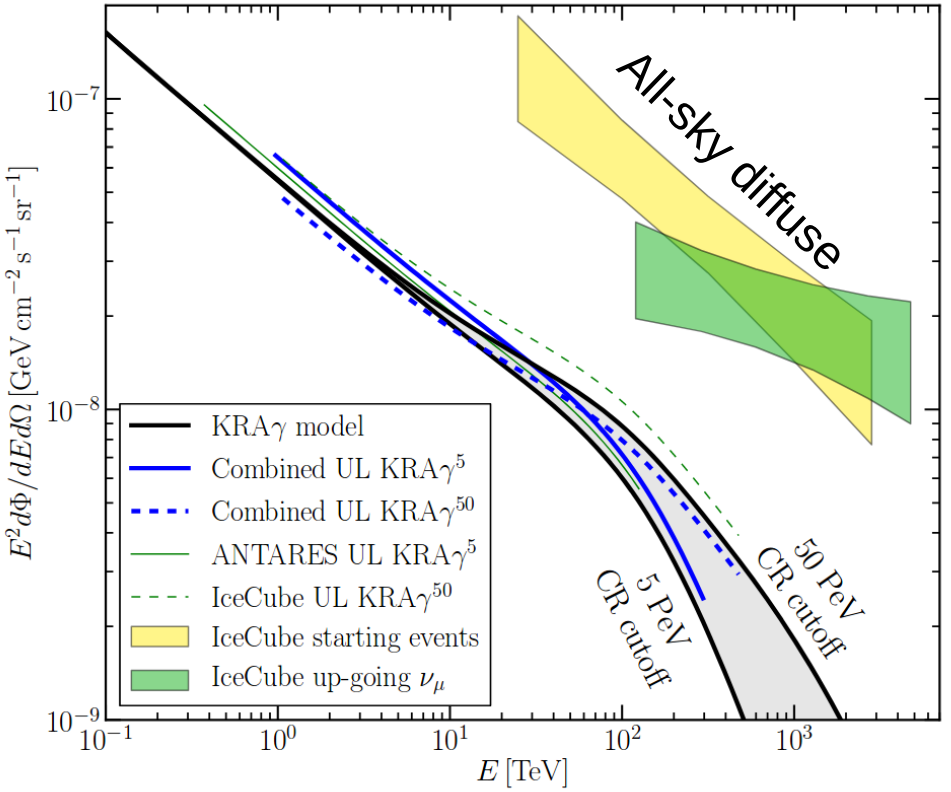
Astrophys.J. 868 (2018) no.2, L20

Galactic plane searches

ANTARES + IceCube
No significant excess found
→ upper limits

Low latitude Galactic contribution constrained to 8-10% of the all-sky flux

No significant excess observed



More data being analysed by both ANTARES and IceCube

Where is it going from here?

ANTARES+IceCube sensitivities are at the edge of discovery for the diffuse Galactic signal

(also, diverse claims of the presence of a signal in public IceCube datasets, already – in the backup)

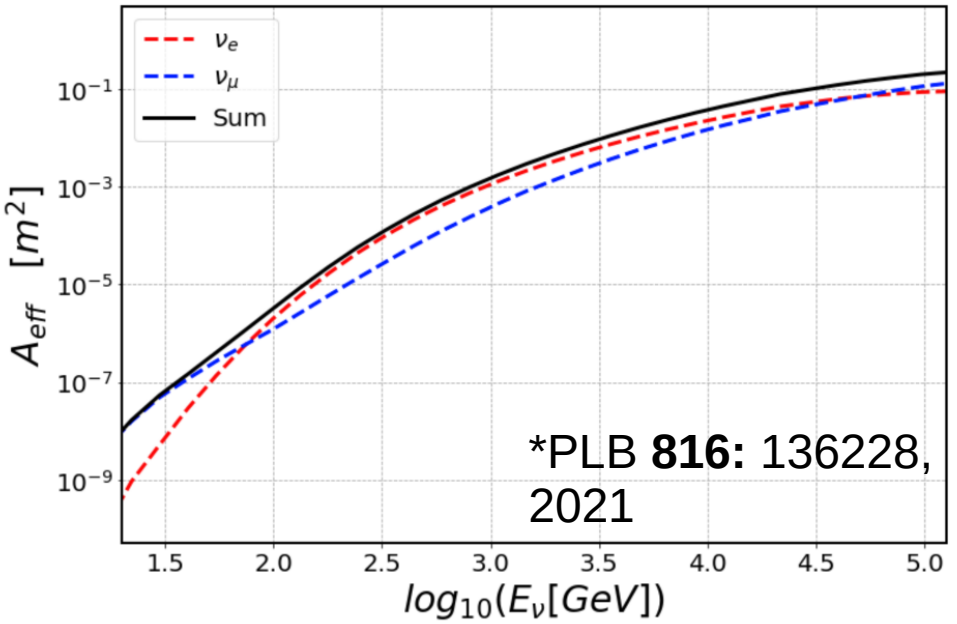
Maybe just more statistics is needed?

Where to get a larger sample?

- **ANTARES** has already included showers in their analysis
  - Showers have limited angular accuracy (few degrees) but lower foregrounds and better energy reconstruction
- However, new analysis* increases the shower event sample

→ New ANTARES shower sample, depending on the energy, increases the effective area by a factor **2 to 10**

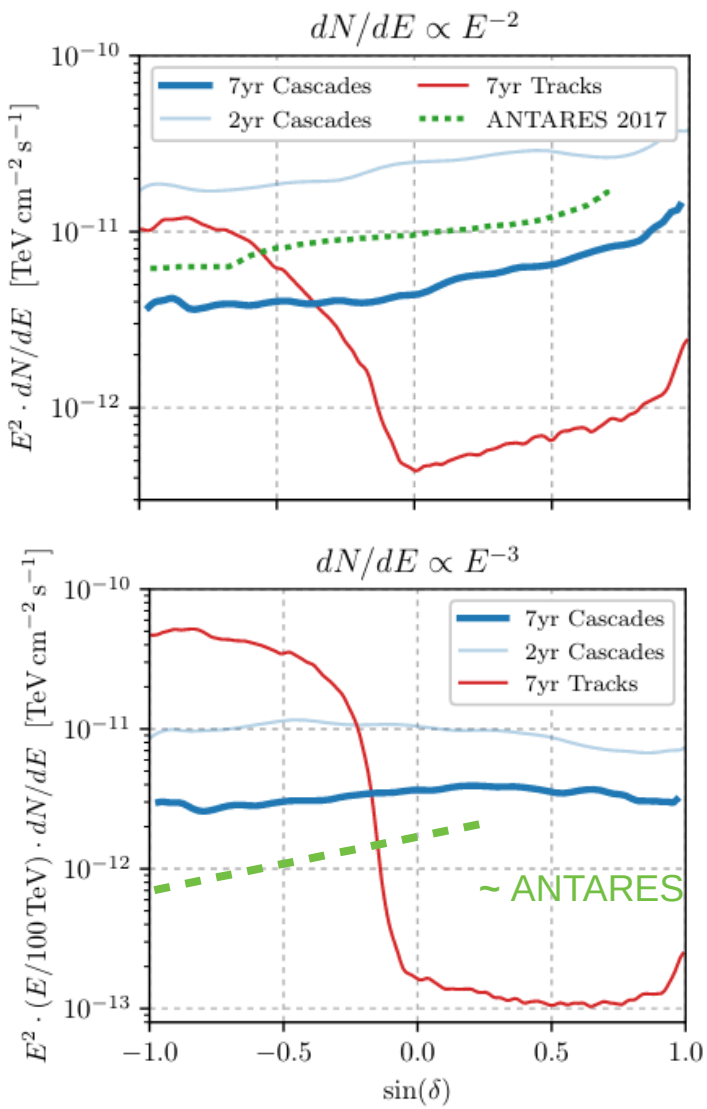
Data being analysed, non neglible improvements are expected



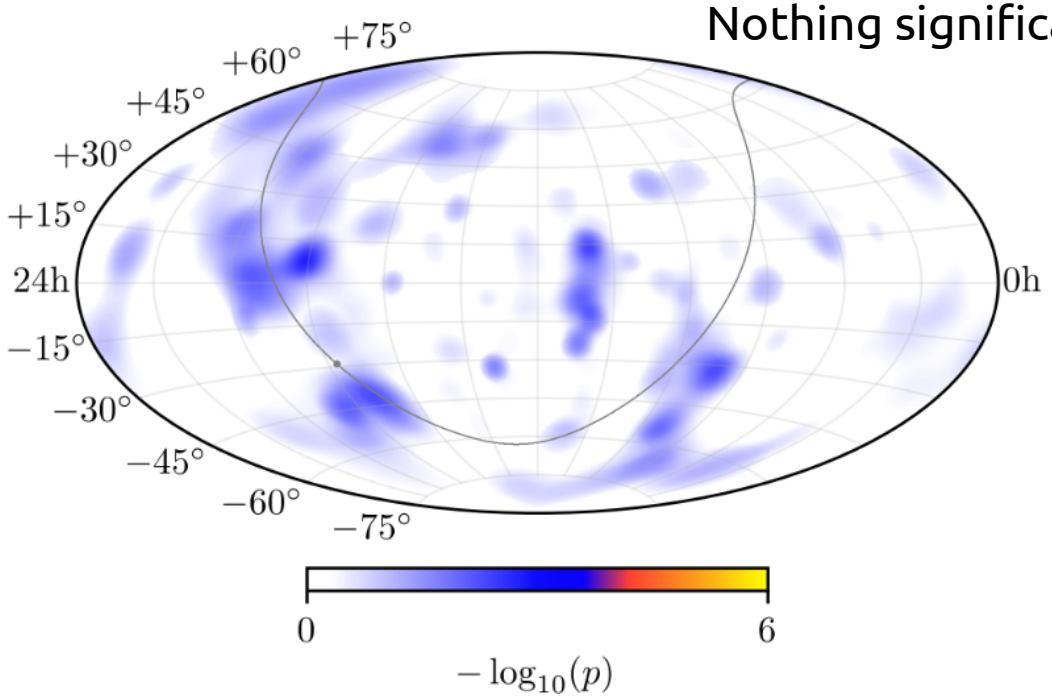
*PLB **816:** 136228, 2021

Where to get a larger sample?

- IceCube has produced a first result with showers from the Galactic plane (~5 x worse angular resolution than ANTARES)



Nothing significant



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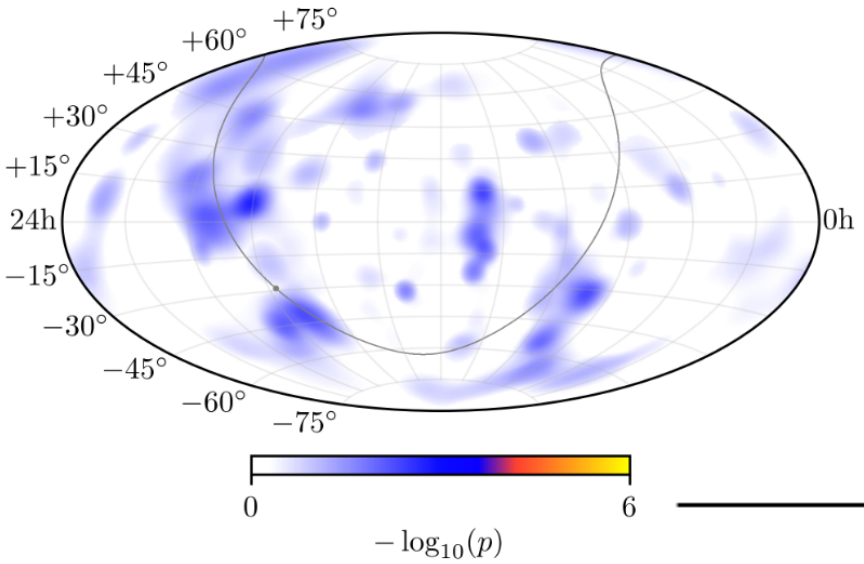

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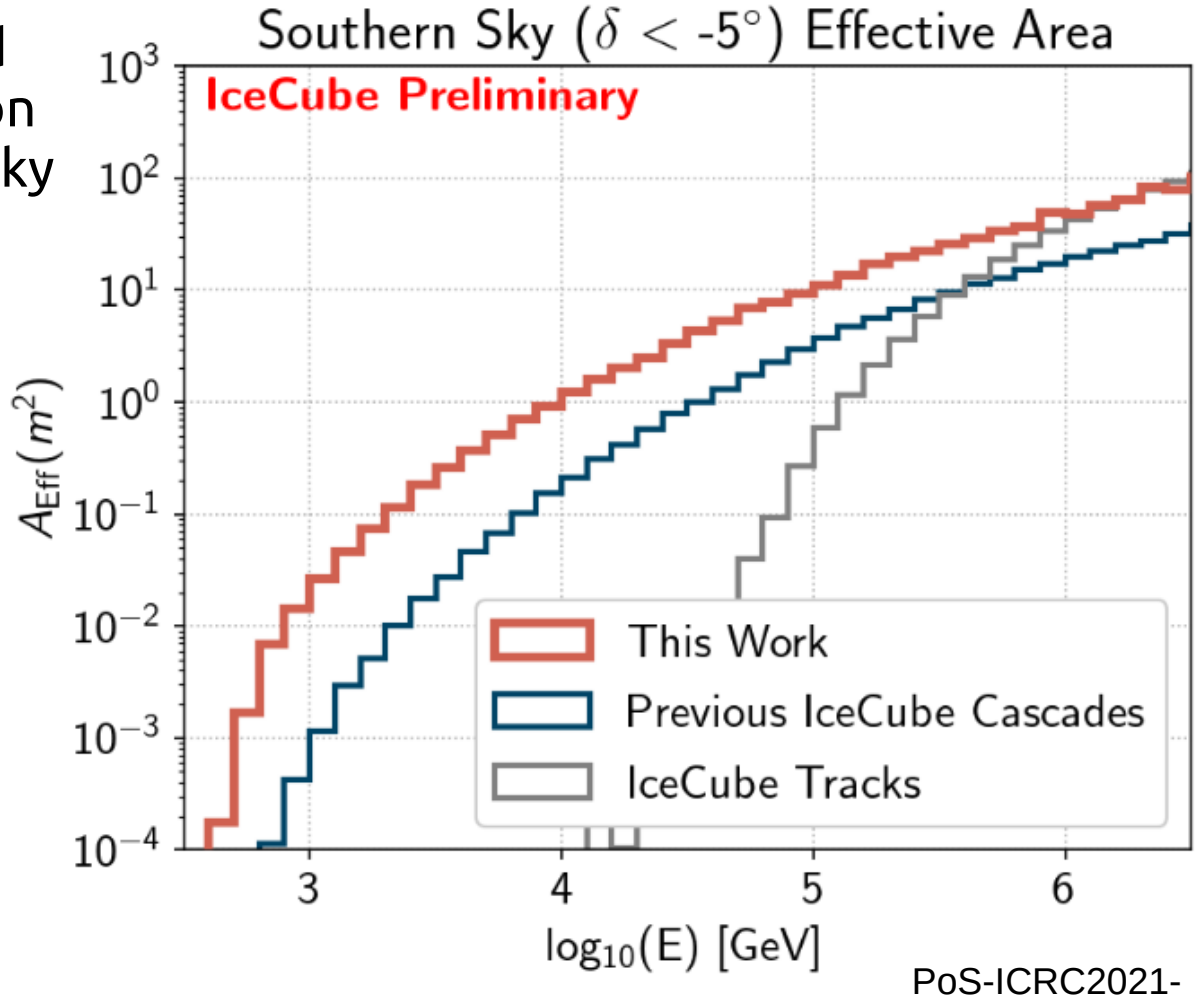
Galactic plane template search

	7yr Cascades			
Template	p-value	Sensitivity	Fitted Flux	UL
KRA_γ^5	0.021	0.58	0.85	1.7
KRA_γ^{50}	0.022	0.35	0.65	0.97
Fermi-LAT π^0	0.030	2.5	3.3	6.6

Is there more?

New IceCube sample obtained using Neural Network selection to expand towards Southern sky

→ **5x** more stat. with similar foregrounds and improved direction reconstruction

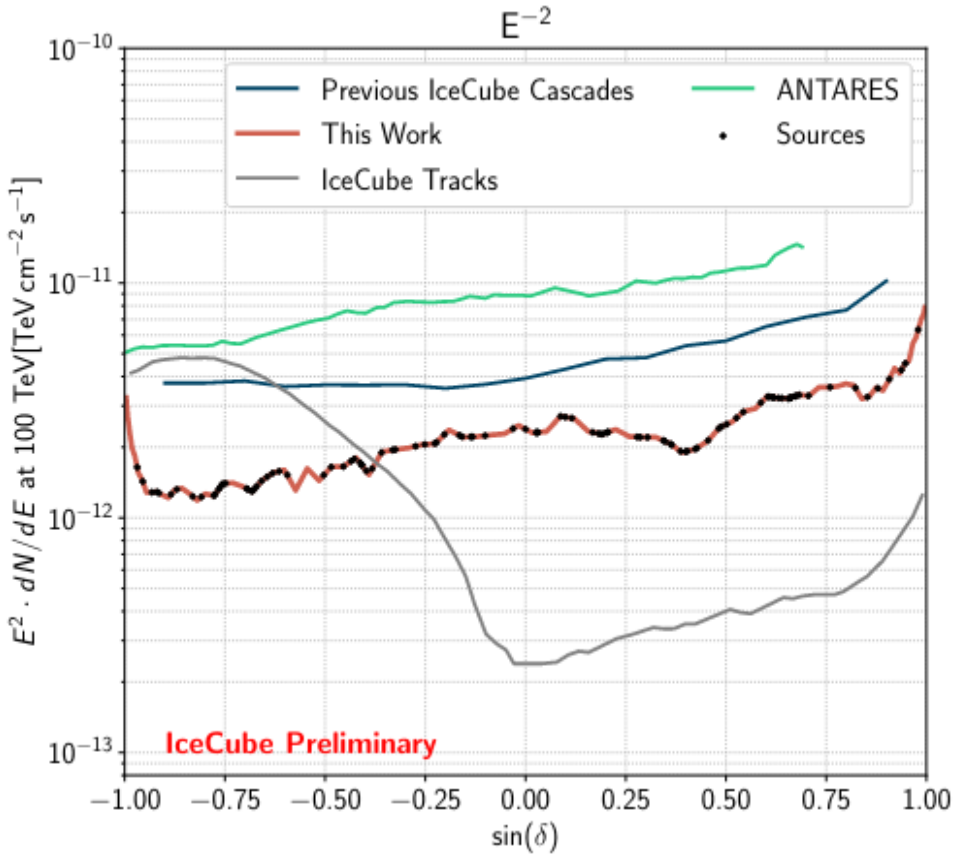


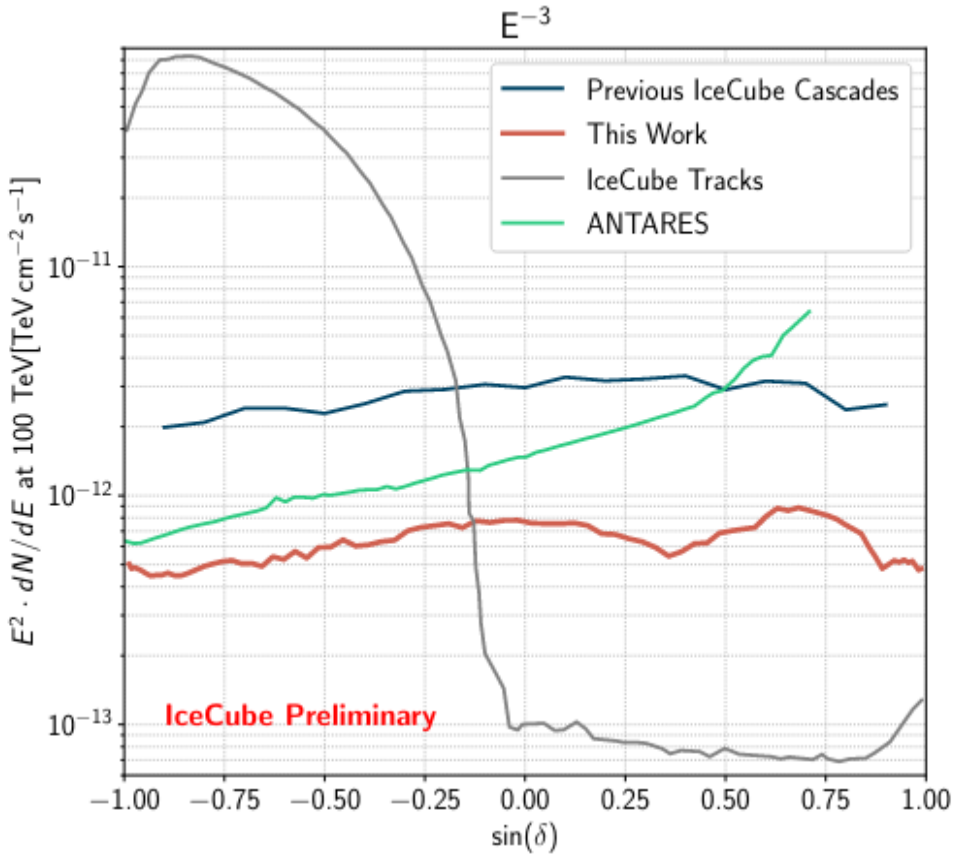
PoS-ICRC2021-1150

Is there more?

New IceCube sample obtained using Neural Network selection

→ **5x** more stat. with similar foregrounds and improved direction reconstruction



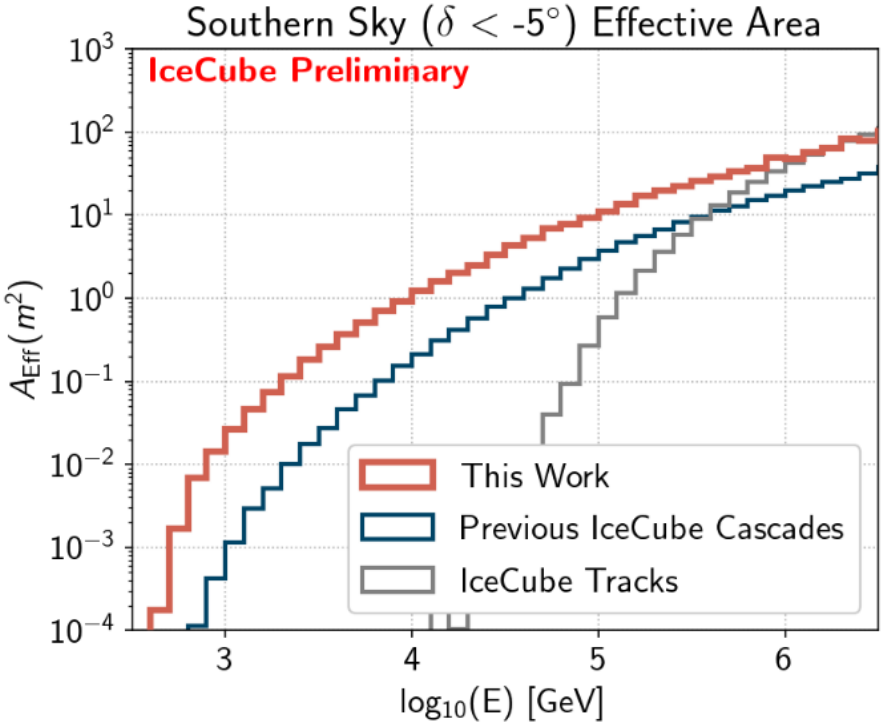


Is there more?

New IceCube sample obtained using Neural Network selection

→ **5x** more stat. with similar foregrounds and improved direction reconstruction

→ sensitivity to challenge (and discover) Model Fluxes



Galactic Plane Model	**This Work**	IceCube / ANTARES	Previous IceCube Cascades
KRA-γ 5 PeV	0.17	0.81	0.58
KRA-γ 50 PeV	0.12	0.57	0.35
Fermi π^0	0.82×10^{-18}	–	2.2×10^{-18}

Sensitivities – no data results yet

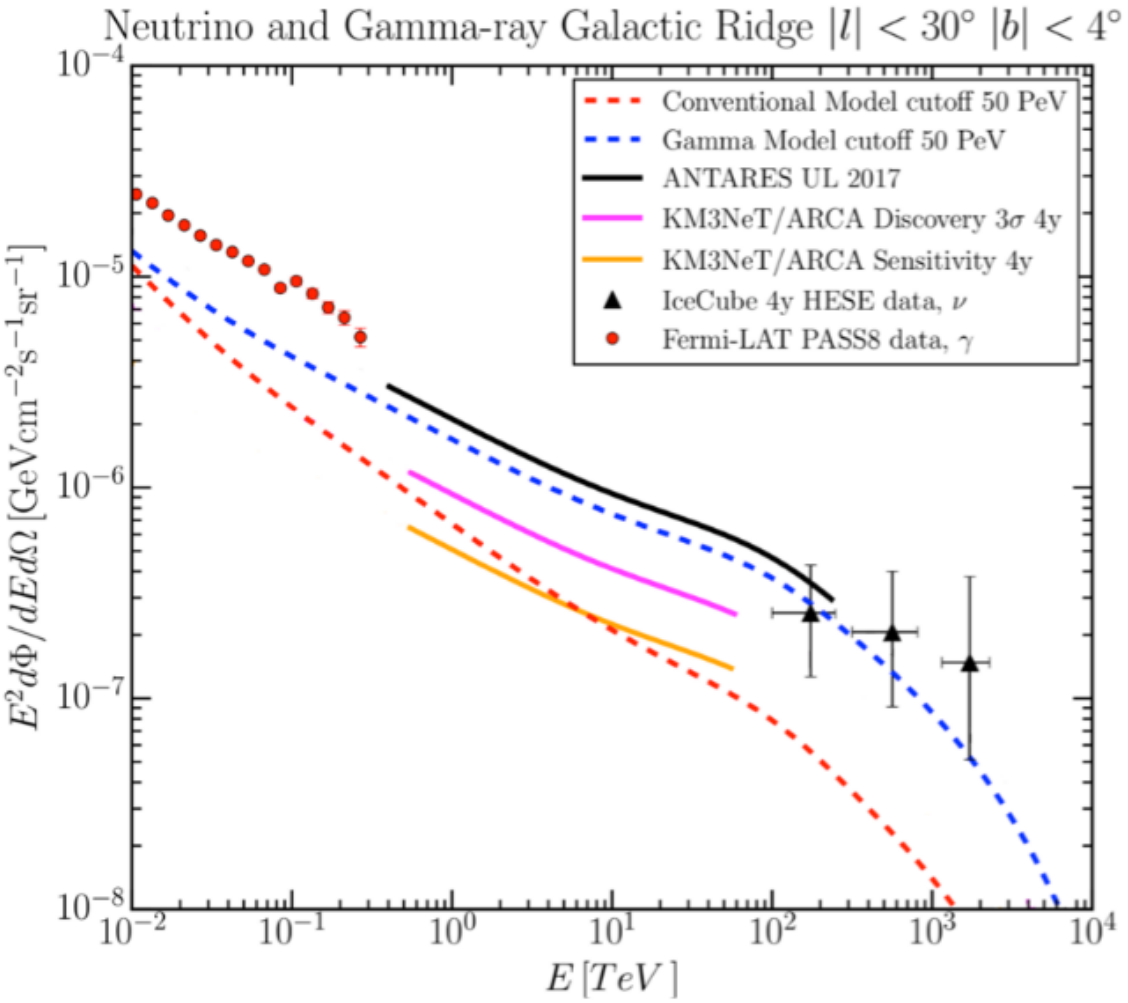
PoS-ICRC2021-1150

The future with KM3NeT

Using upgoing tracks

→ better angular precision and good rejection of foregrounds

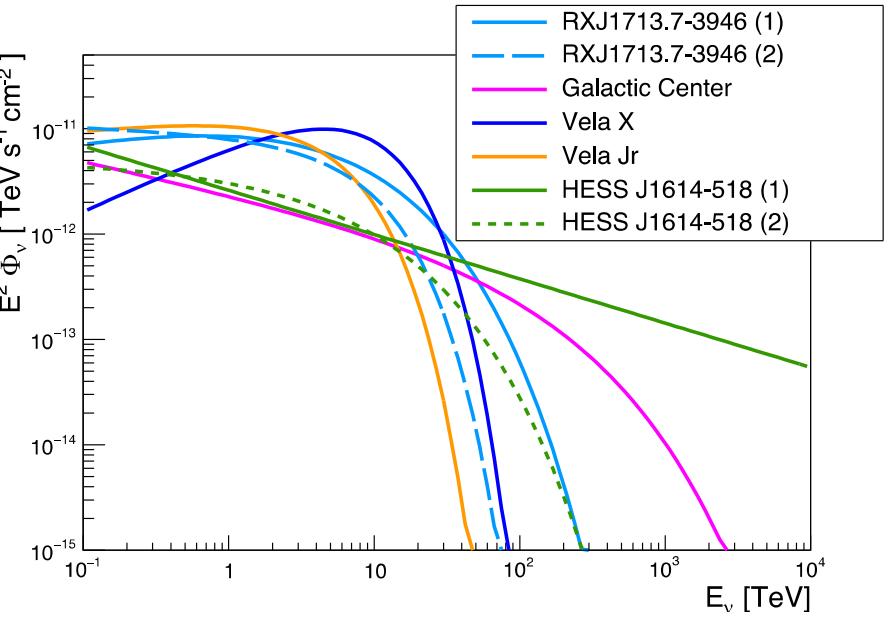
Discovery and characterisation

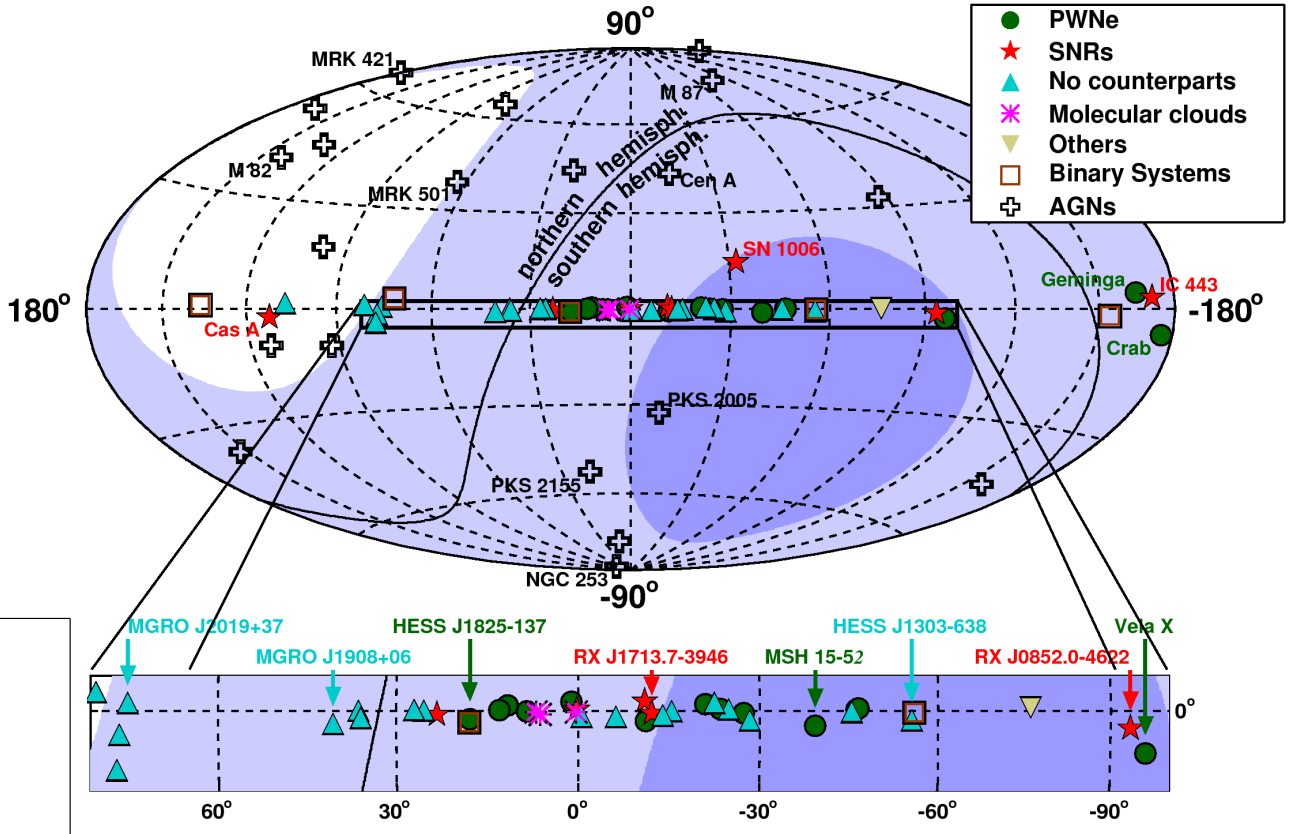


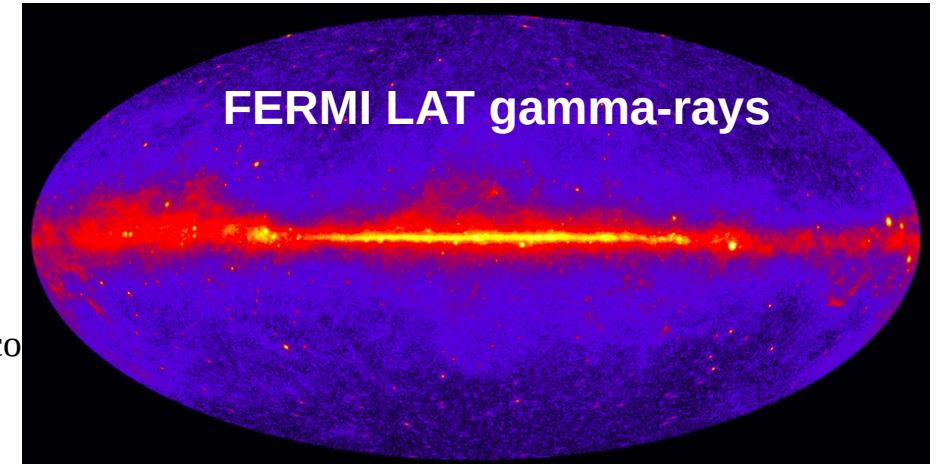
Where to look for individual sources?

Galactic gamma ray sources mostly in the Southern Sky
→ best pointing from a N-hemisphere telescope

Rather soft spectra
→ low detection threshold

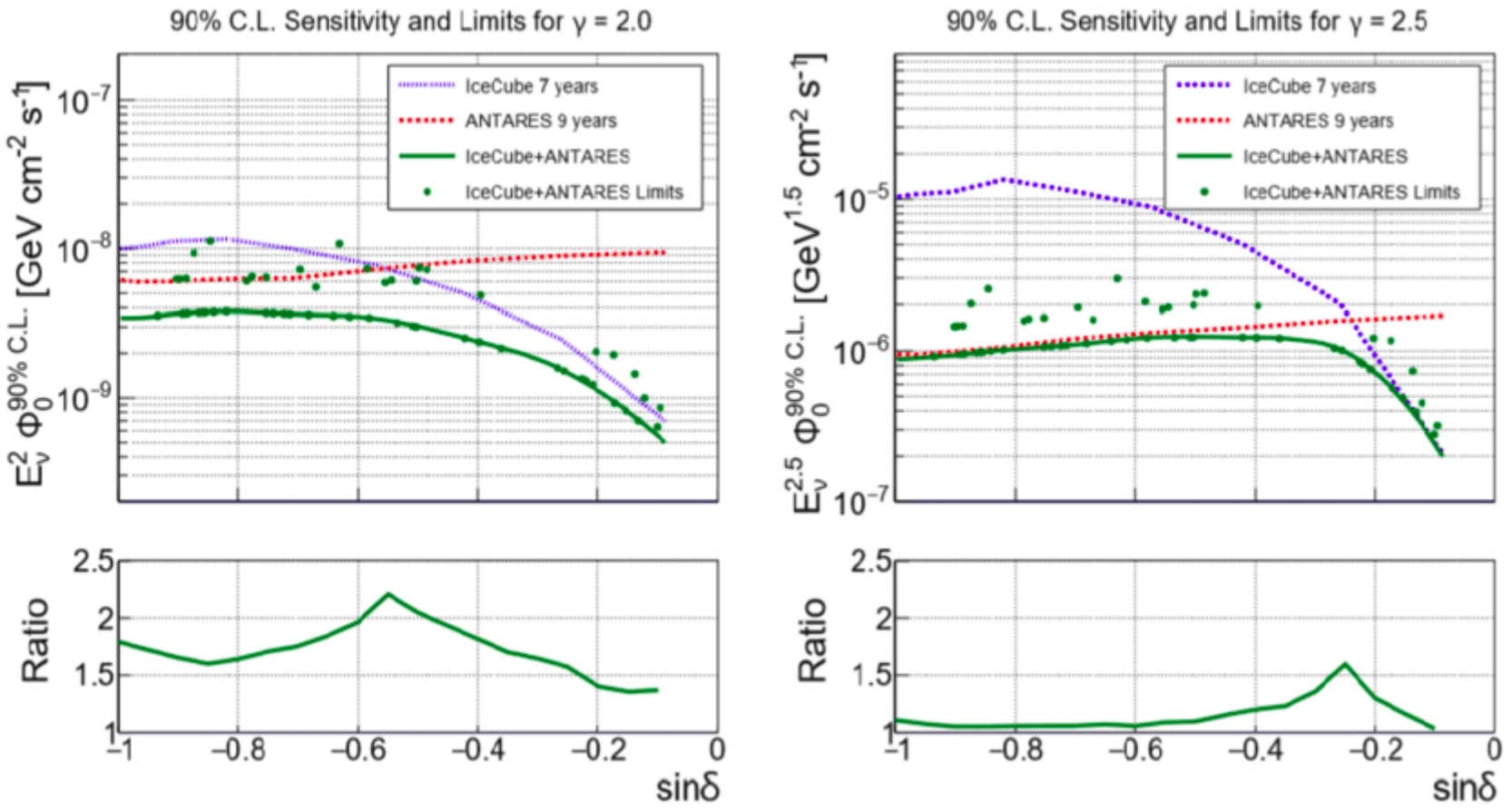






Searches for point-like sources

ANTARES + IceCube point sources from the Southern Sky



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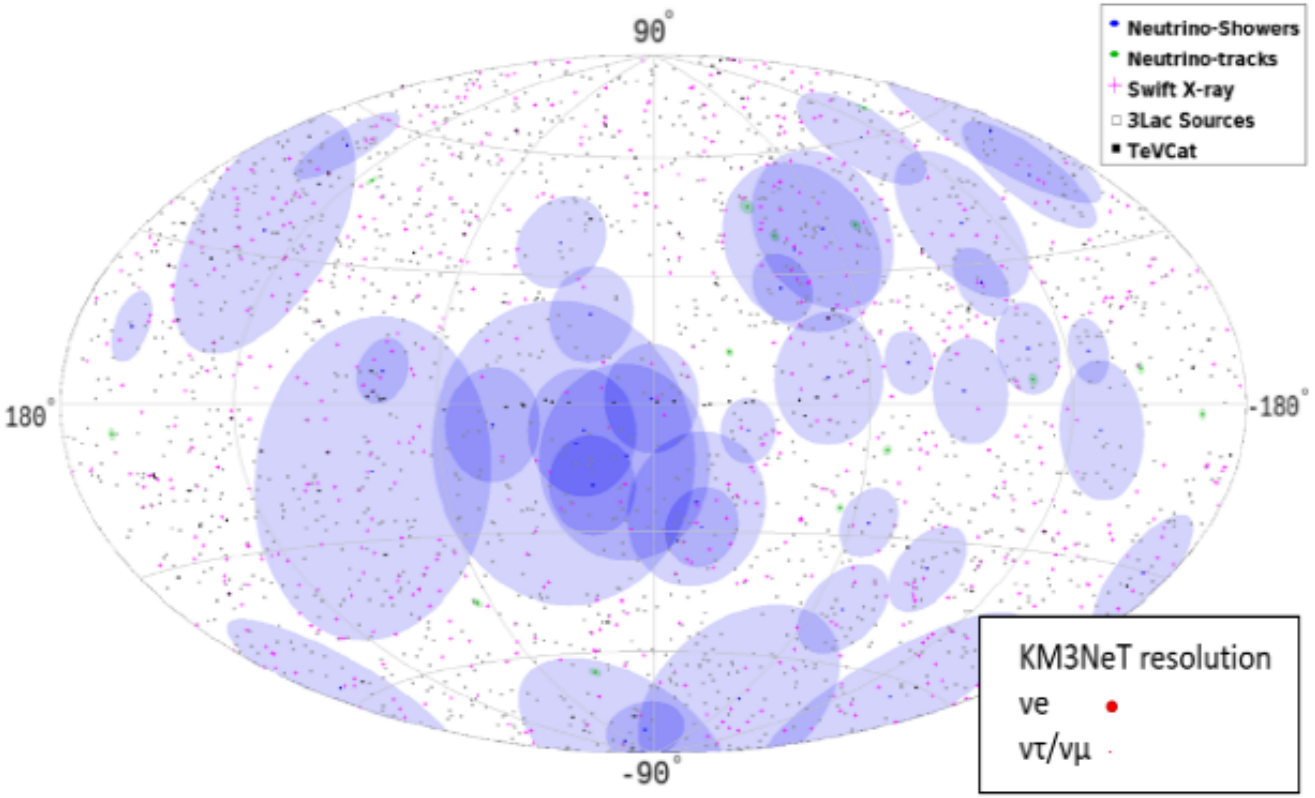
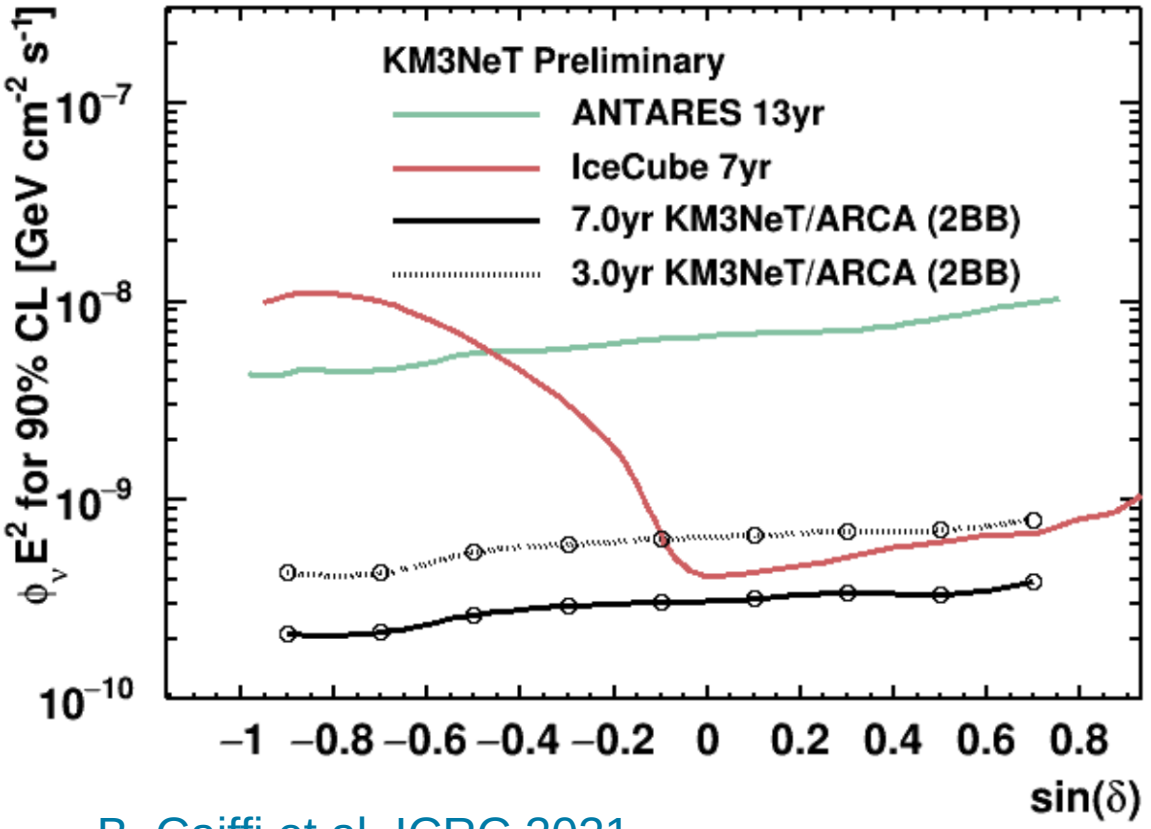
Searches for point-like sources

- Water is optimal for light
  - Limited scattering → direct photons
  - Homogeneous medium → easy to simulate, less systematic effects

→ 0.1 degree angular reconstruction accuracy

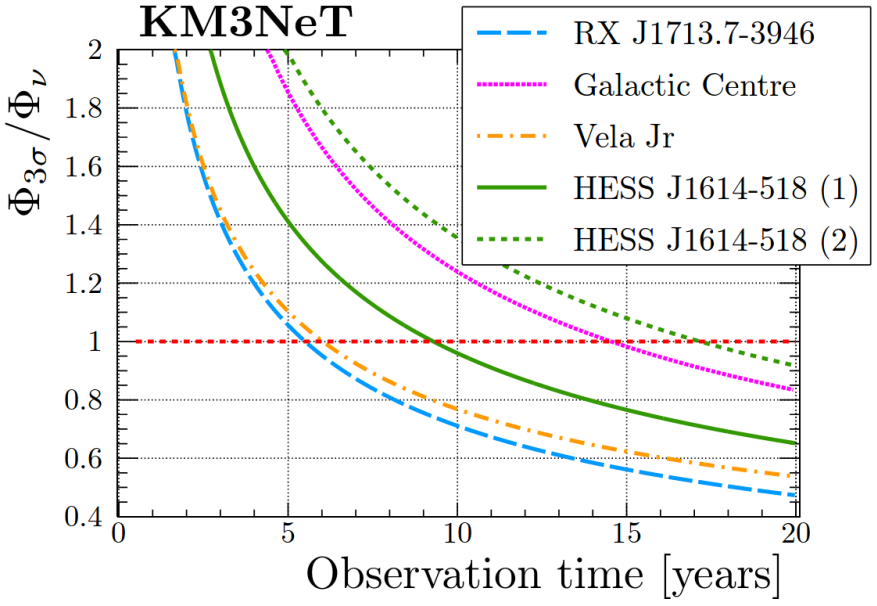


The future with KM3NeT



B. Caiffi et al, ICRC 2021

Discovery potential for possible Galactic targets



Astrop. Phys.
111: 100-110, 2019

Conclusions

- Very lively field, with both ANTARES and IceCube showing potential for discovery

  We are very close to the signal!

  - Once discovery is done, need to characterise it
  - Combine all the available information (including e-m + theory)

- Galactic neutrino sources will also be there
  - Point-source vs diffuse contributions?
  - Characterise the whole emission

Backup

Galactic plane templates recipe

Gaggero et al. 2015

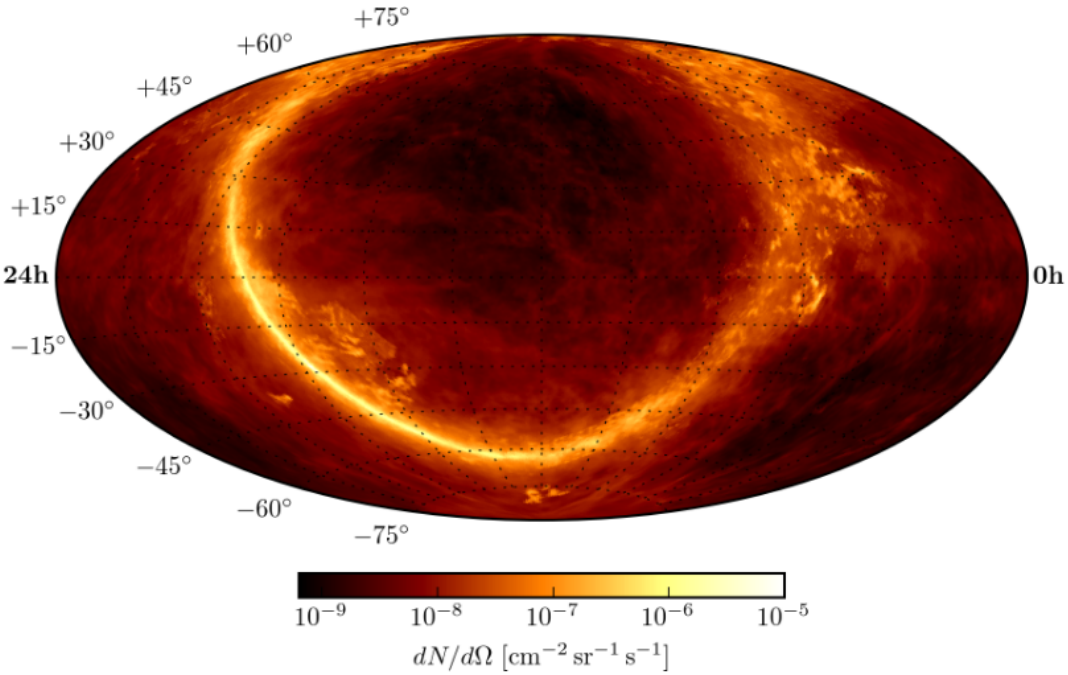
From e-m observations
- matter distribution
- gamma-ray flux

Add model for CR propagation

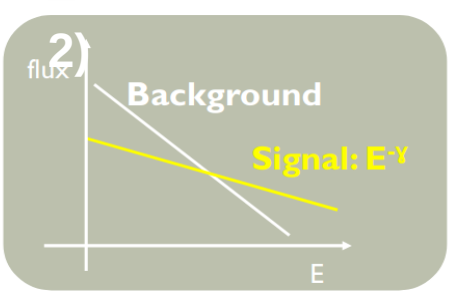
→ obtain neutrino flux

Convolute with detector simulation

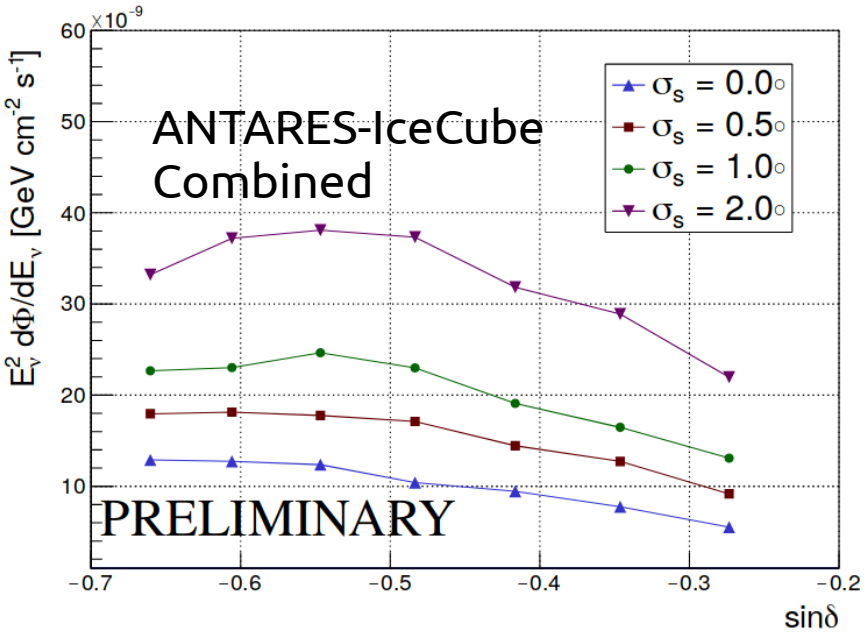
→ obtain neutrino expected PDF
(in space and energy)

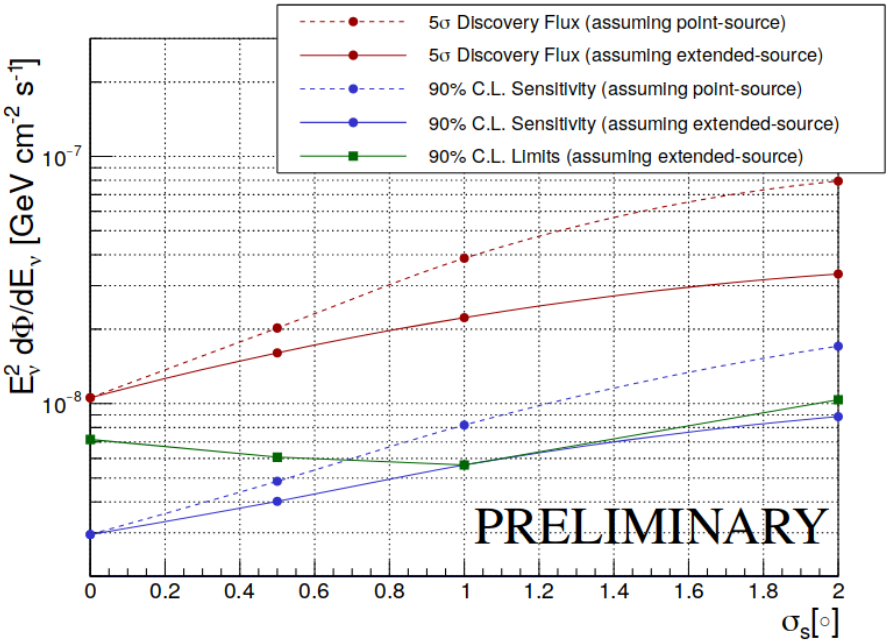


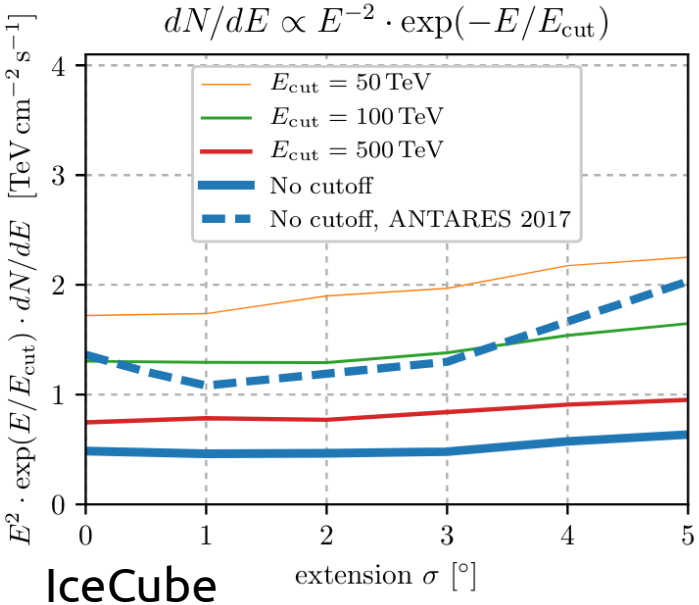
Then search for clustering of neutrinos according to PDF



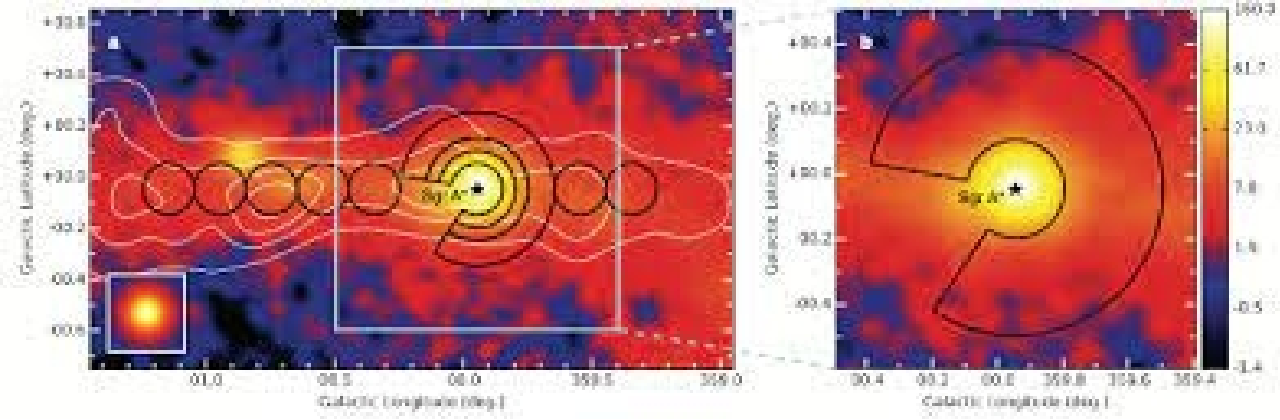
The Galactic centre







IceCube Cascade



H.E.S.S. PeVatron?

Is there already a signal?

- Various claims already since the first annoucement of the IceCube discovery
  - M. Spurio Phys. Rev. D 90, 103004, 2014
  - A. Neronov, D. Semikoz, and C. Tchernin, Phys. Rev. D 89, 103002, 2014
  - A. Palladino, F. Vissani, ApJ **826:** 185, 2016
  - A. Palladino, W. Winter, A&A **615**: A168 (2018)
  - …
  - *Y. Kovalev, A. Plavin, S. Troitsky arxiv:2208.08423, 2022*

Definitely a non-exhausting list

Is there already a signal?

- Just as an example*: Y. Kovalev, A. Plavin, S. Troitsky arxiv:2208.08423, 2022*

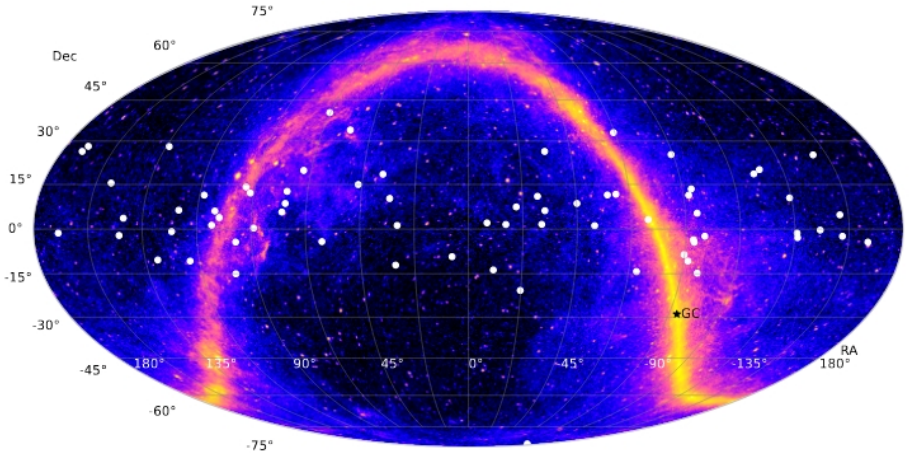


Fig. 1. Arrival directions (white dots) of the 70 IceCube events studied in the present work superimposed on the all-sky gamma-ray map, equatorial coordinates. The black star denotes the Galactic center. The color in the map reflects the intensity of the gamma-ray flux with energies above 1 GeV observed by *Fermi* LAT (https://svs.gsfc.nasa.gov/14090), with the emission from the Galactic plane clearly seen.
Fermi sky map credit: NASA/DOE/Fermi LAT Collaboration.

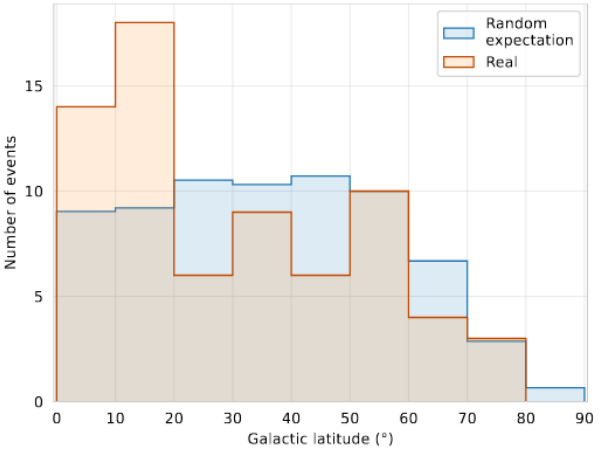
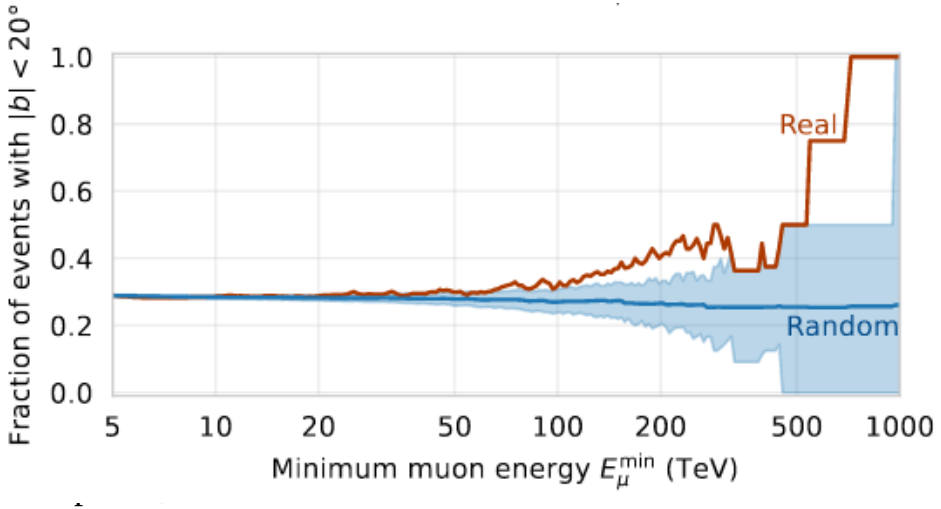


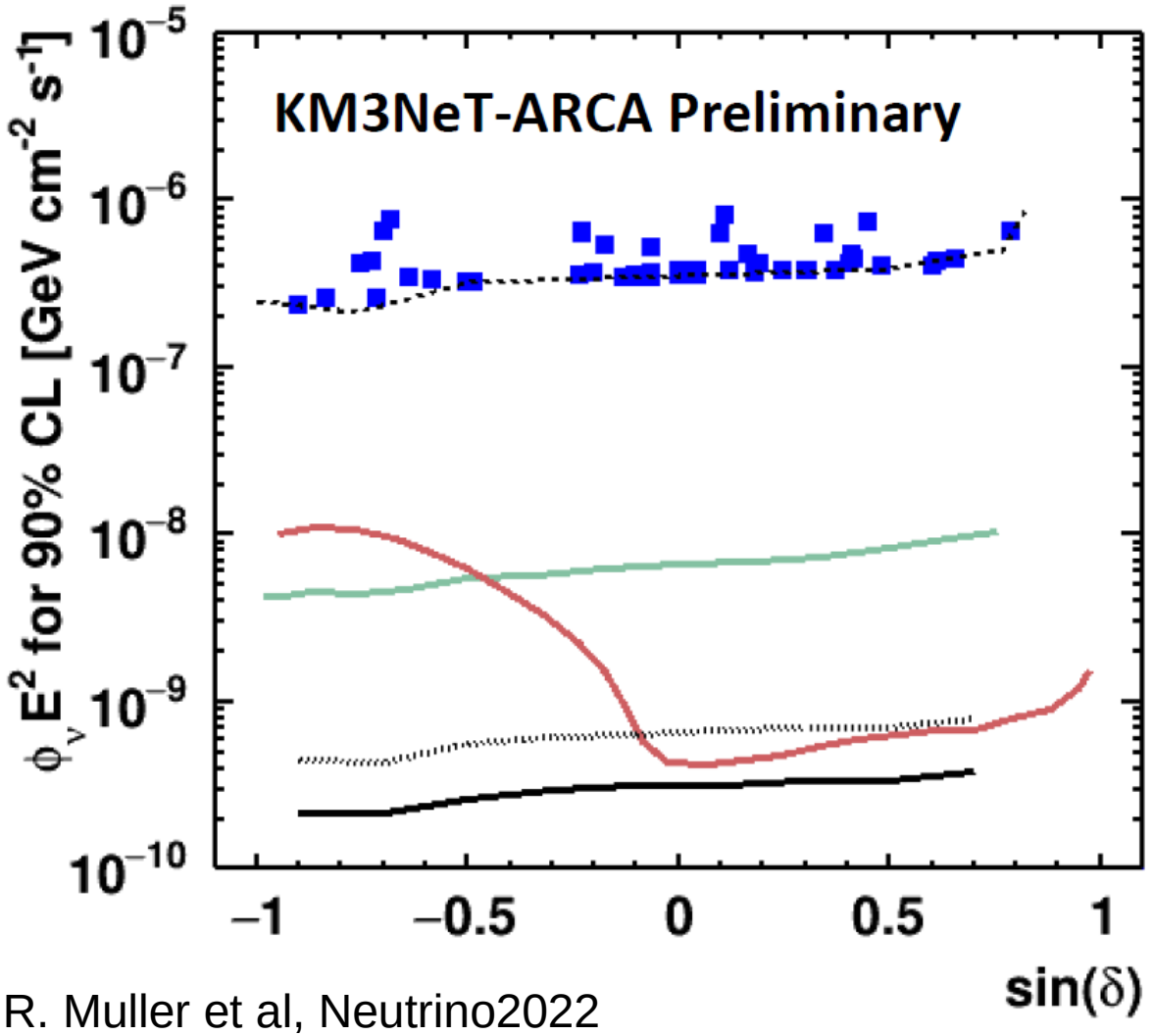
Fig. 3. Distributions of real (orange) and simulated (blue) events in the Galactic latitude of their arrival directions. The expected number of scrambled events in each bin is estimated by averaging 10^5 random samples.

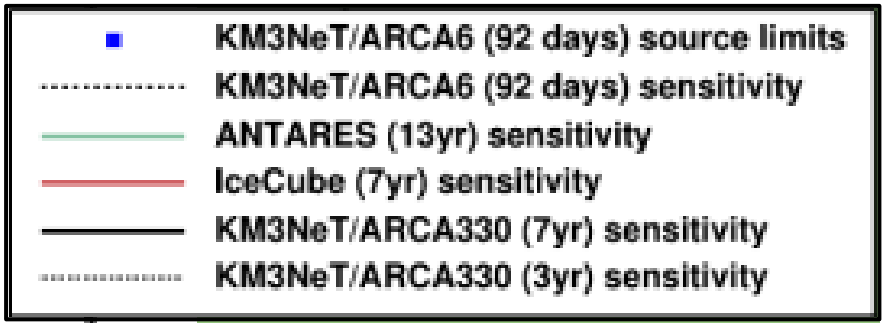


~4 sigmas claim

But:
– why at these very high energies?
– why it peaks at 20 degrees?

Status of KM3NeT



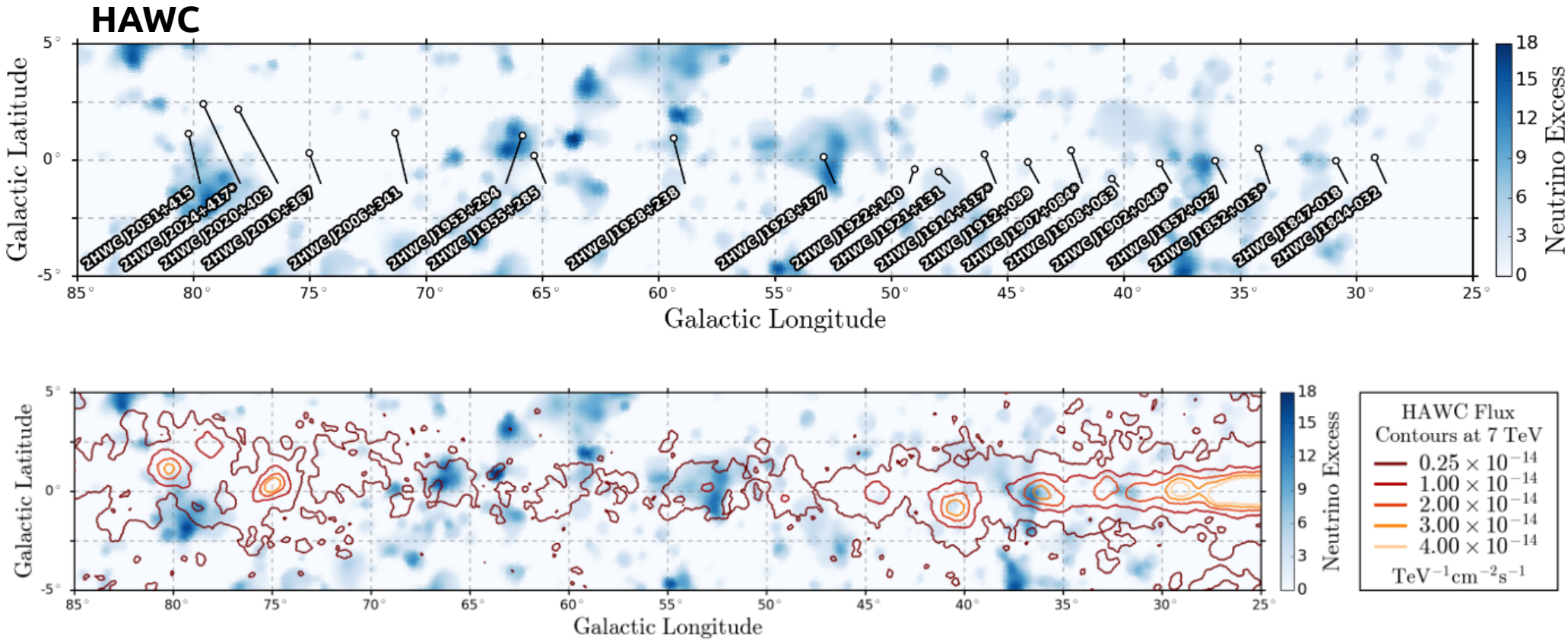


6DUs for ~100 days
First point-like source search results

No significant excess observed from the 46 cataloged sources that were tested

R. Muller et al, Neutrino2022

Very high-energy gamma-rays



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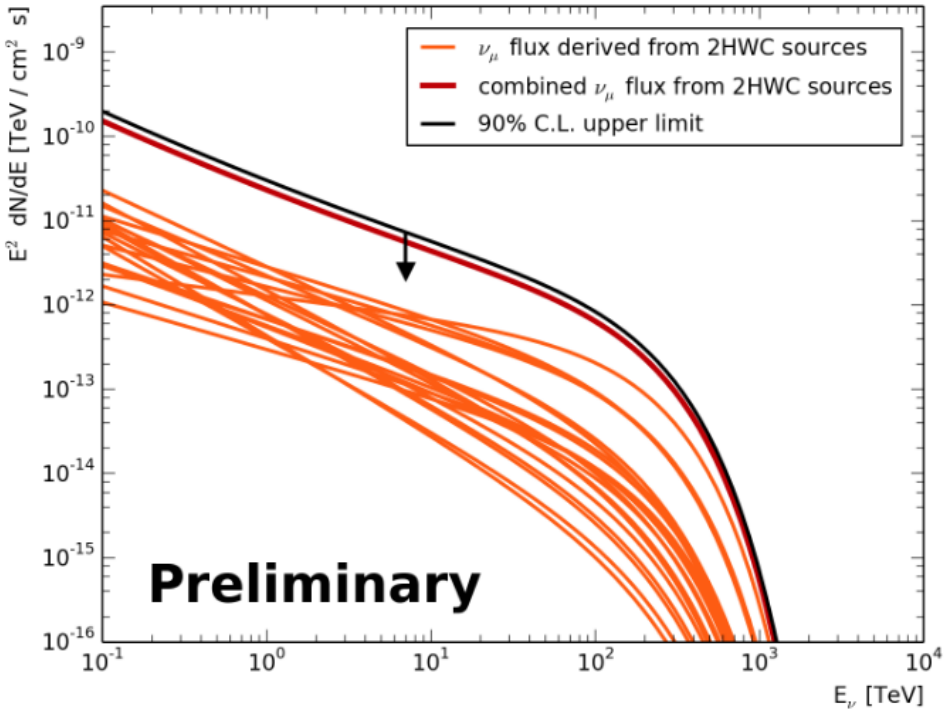
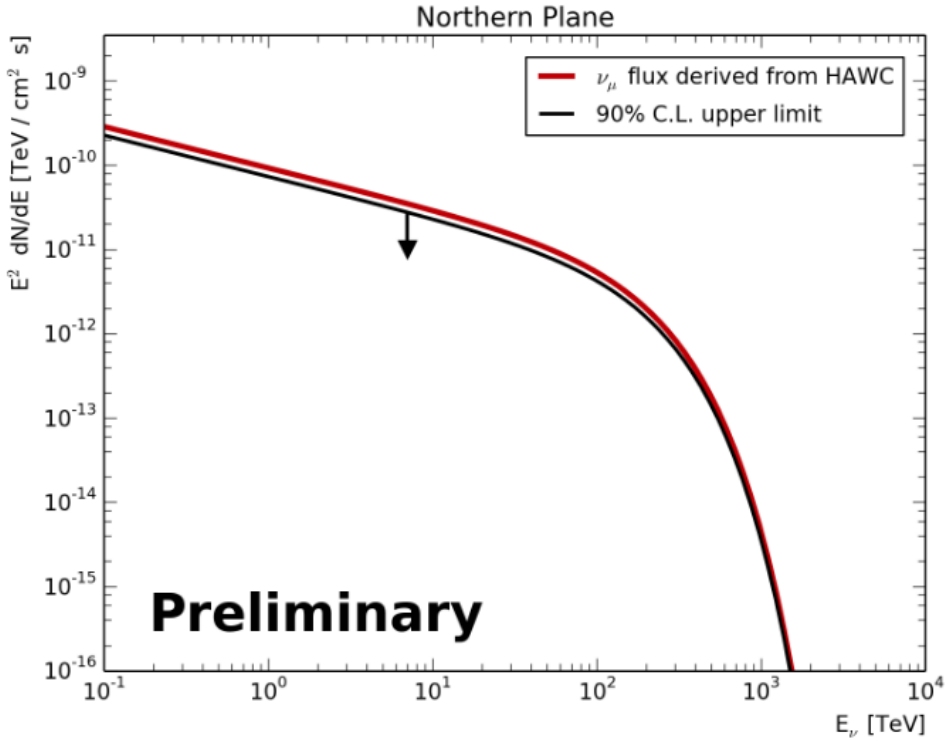
Very high-energy gamma-rays





Search	Best Fit n_s	Sensitivity 10^{-13} [TeV^{-1}cm^{-2}s^{-1}]	Upper Limit (90% C.L.) 10^{-13} [TeV^{-1}cm^{-2}s^{-1}]	p-value
Stacking	15.4	0.7	1.5	0.09
Northern Plane	77.8	2.5	5.7	0.06
Cygnus Region	0.0	1.0	0.4	0.80
J1908+063 Region	12.0	0.7	1.3	0.14
J1857+027 Region	36.7	0.8	2.1	0.02