Neutrino Astronomy news from the Mediterranean Sea

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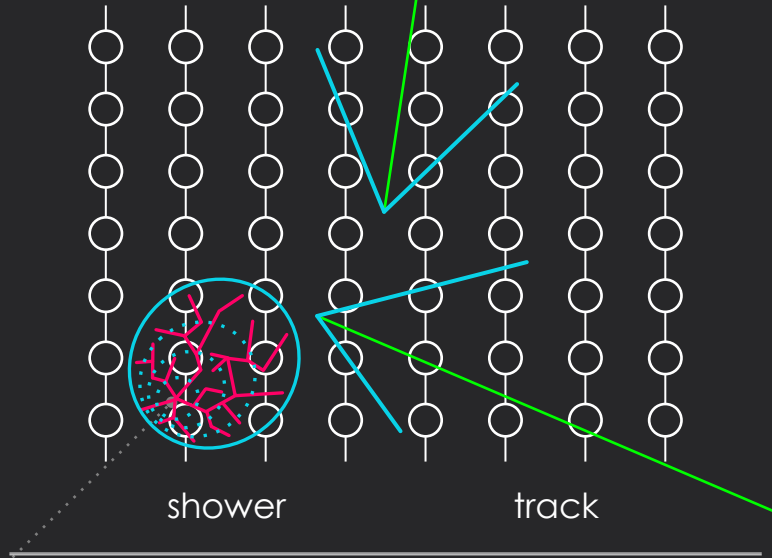
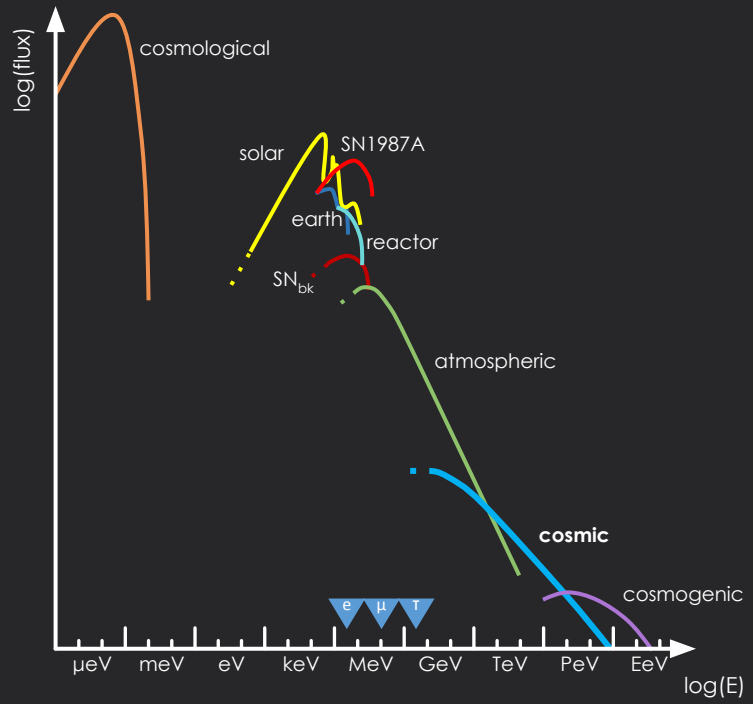
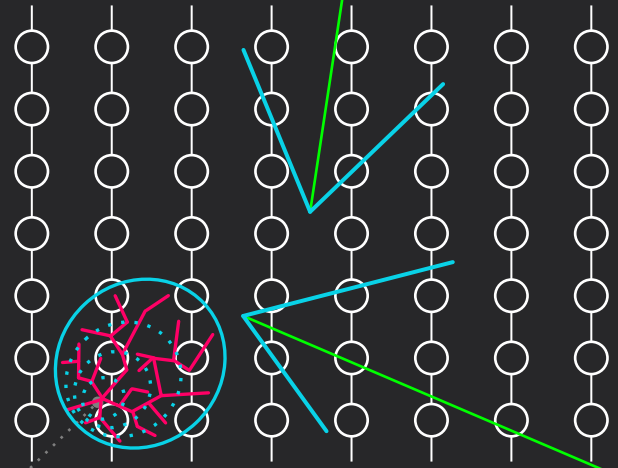
Valencia Experimental Group of Astroparticles

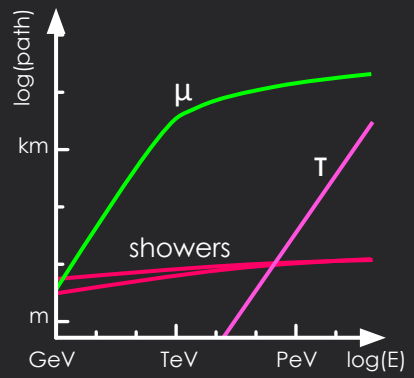
A Neutrino Telescope

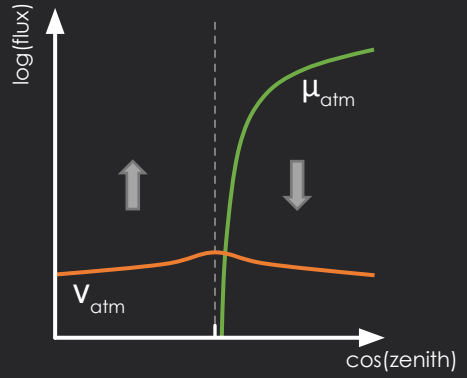


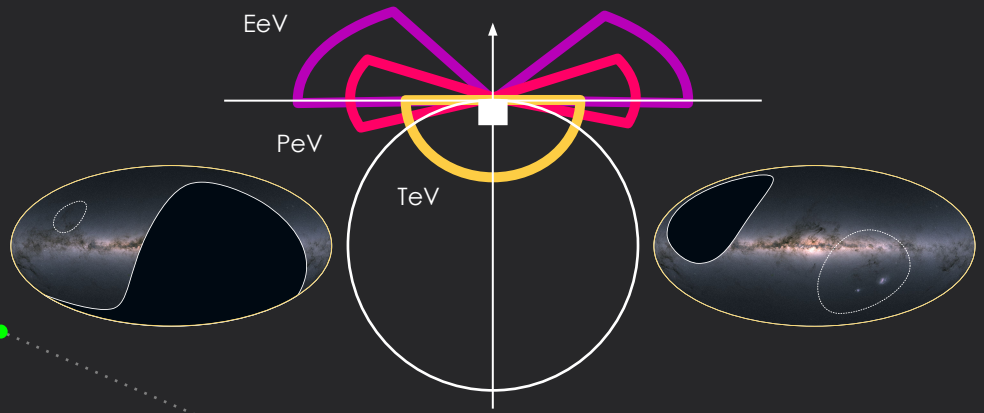


A Neutrino Telescope





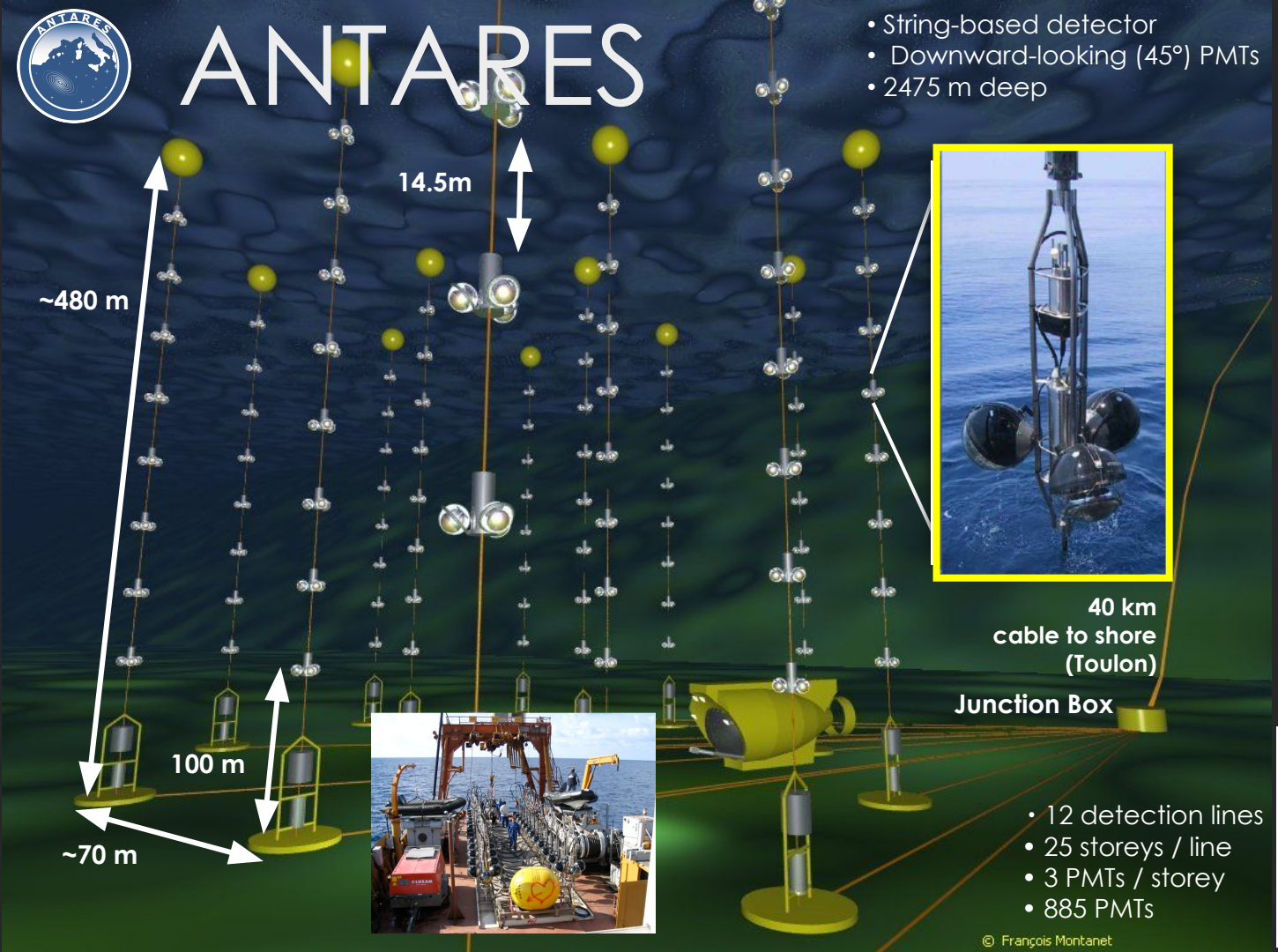




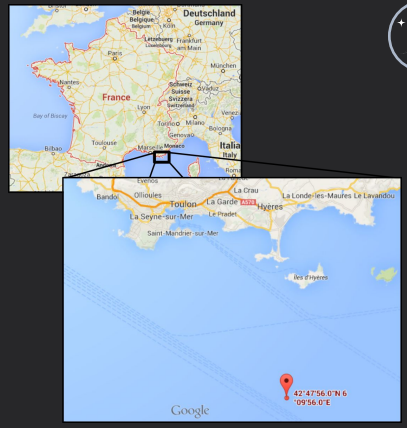
The Mediterranean Sea

ANTARES

- String-based detector
- Downward-looking (45°) PMTs
- 2475 m deep



- 12 detection lines
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

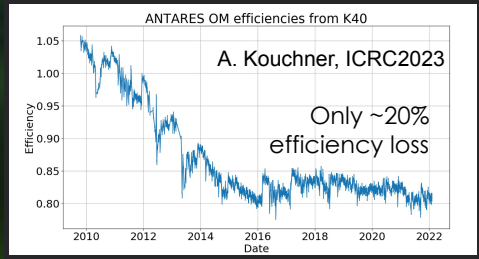


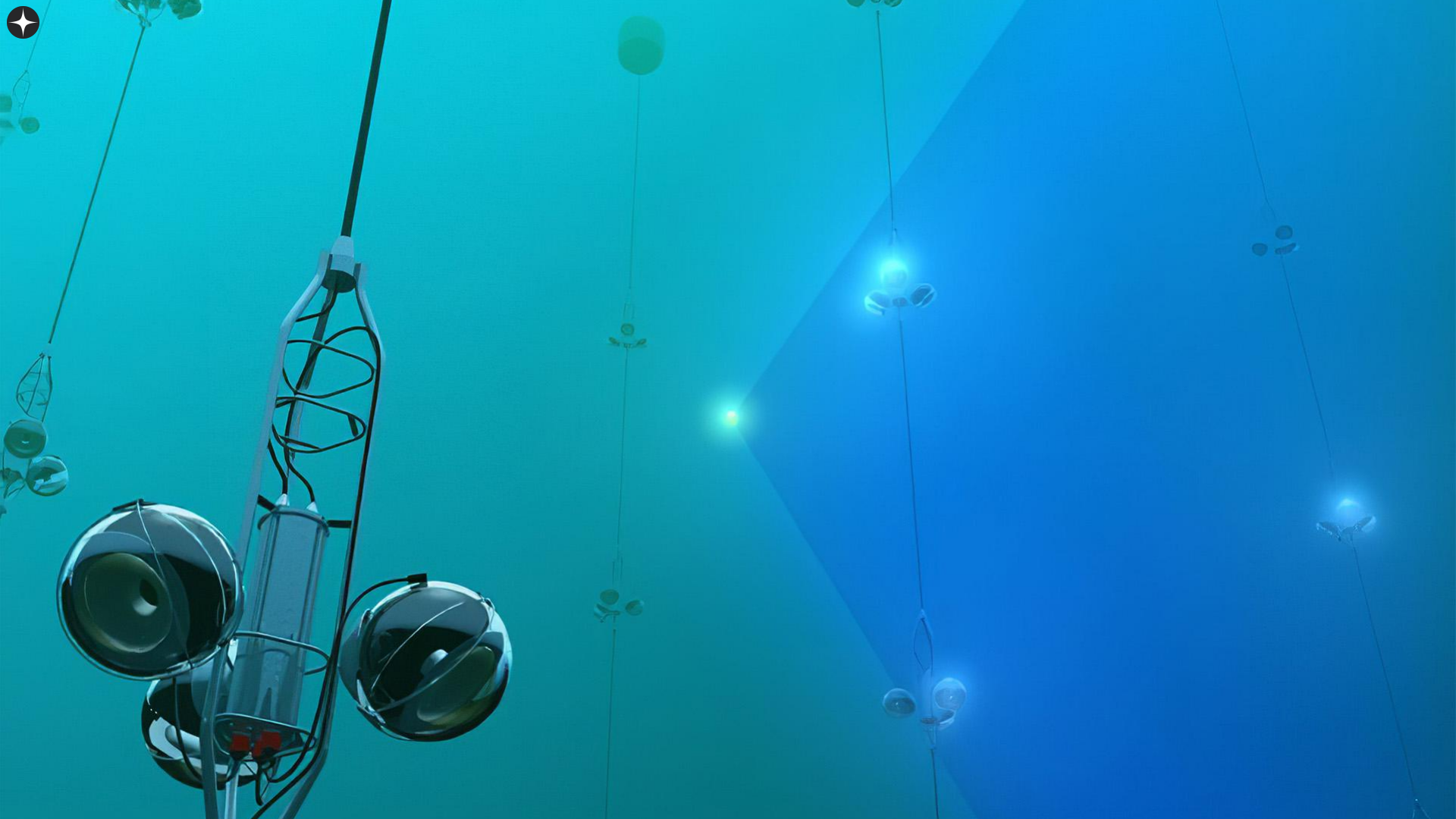
More than 15 years taking data (2006-2022)

~0.01 km^3
Largest NT on North Hemisphere for years

Medium angular resolution
tracks: < 0.4° @ E > 10 TeV
showers: ~ 2°

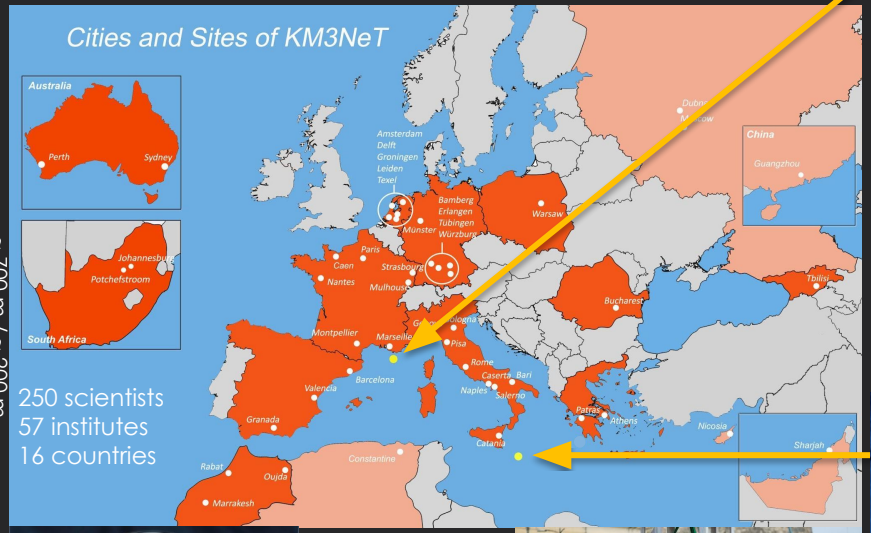
Hundreds of GeV to PeV range

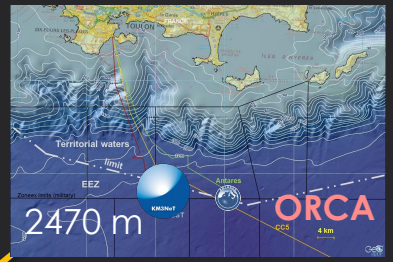




KM3NeT

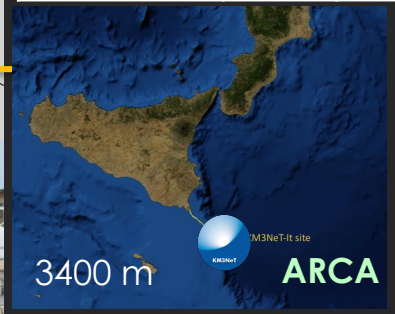
Multi-site, deep-sea infrastructure
Single collaboration, Single technology
Two outstanding physics cases



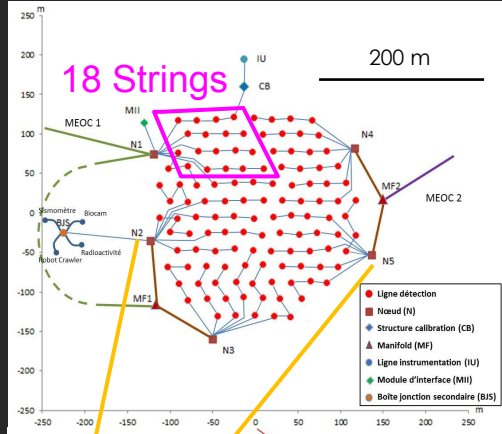


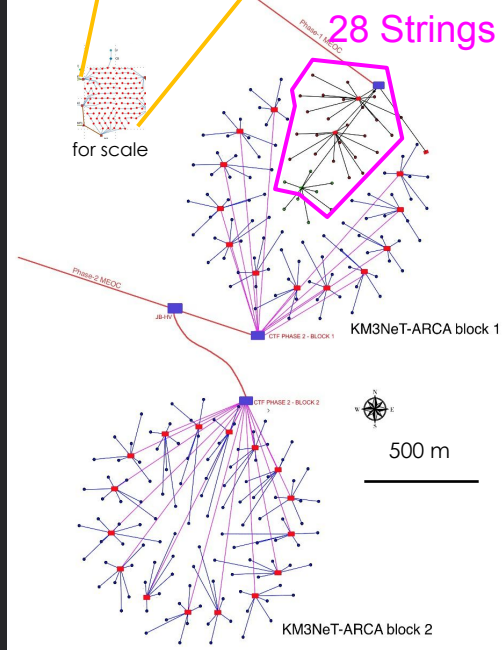
Oscillation Research with Cosmics in the Abyss

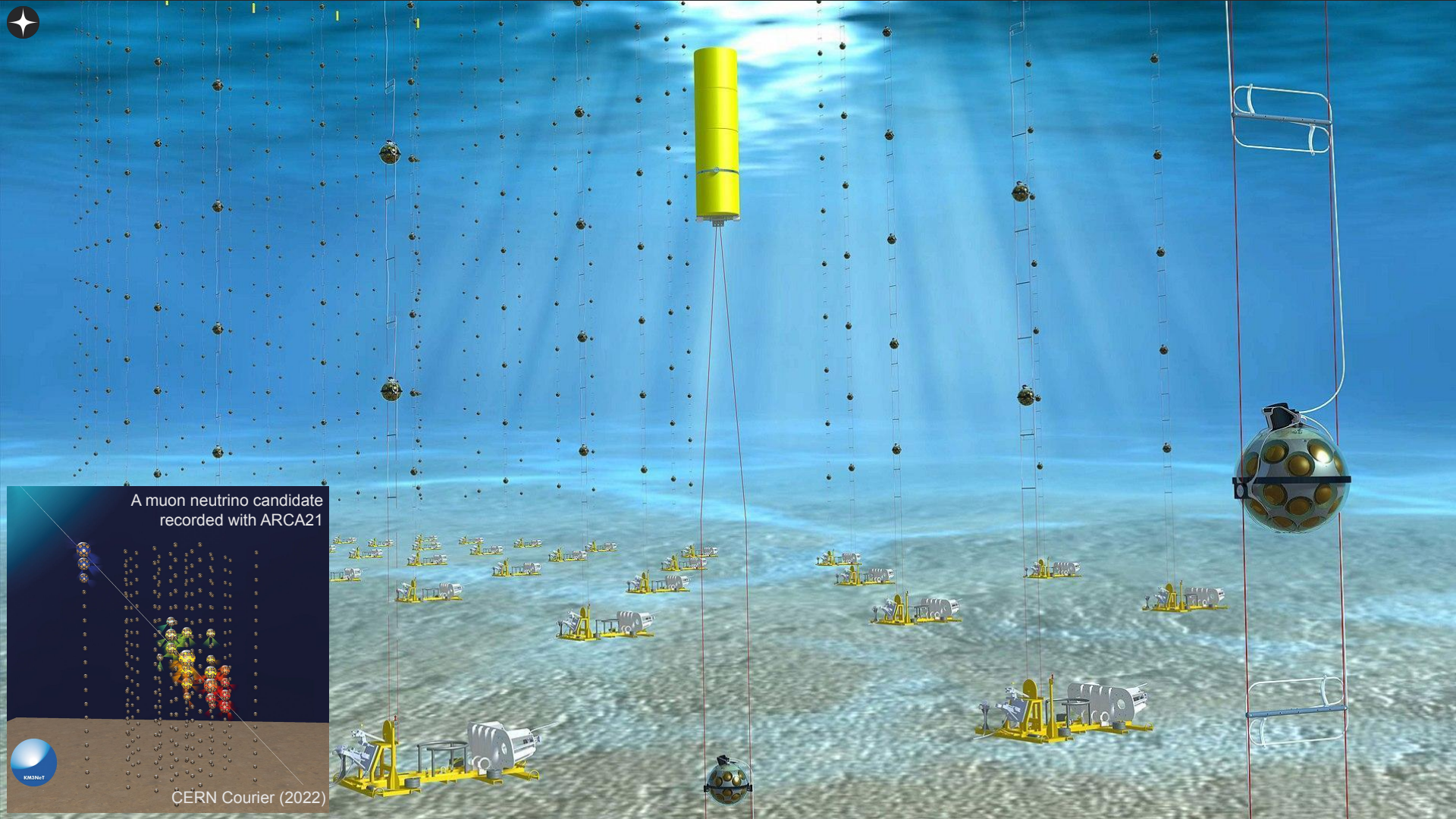
	ORCA	ARCA
Strings	115	115 × 2
String spacing	20 m	90 m
DOM spacing	9 m	36 m
Instrumented mass	7 Mton	500 × 2 Mton
Energy range	GeV	TeV – PeV



Astroparticle Research with Cosmics in the Abyss

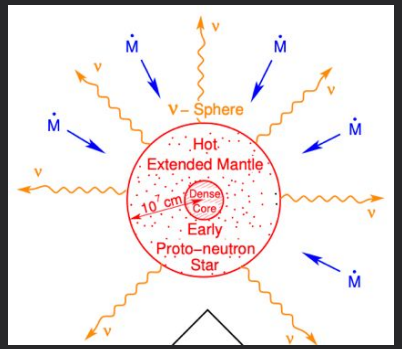




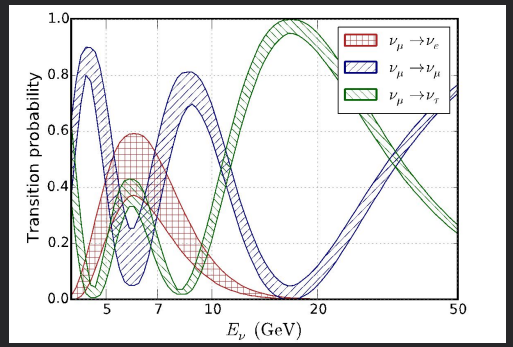

A muon neutrino candidate
recorded with ARCA21
KM3NeT
CERN Courier (2022)

Neutrinos on Neutrino Telescopes

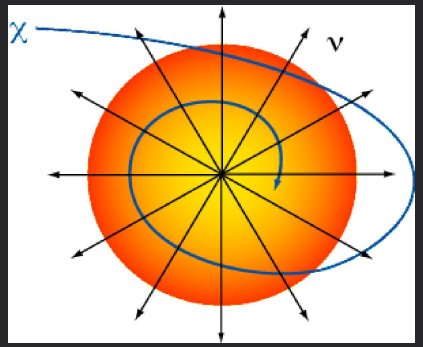
Low Energy
~ MeV



Low Energy
> 10 GeV



Medium Energy
10 GeV < E_ν < 10 TeV



High Energy
E_ν > 1 TeV

E

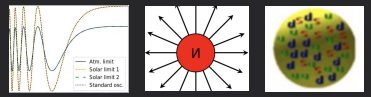
CCSN detection

ν oscillations

dark matter search

ν from extra-terrestrial sources
origin and production
mechanism of HE CR

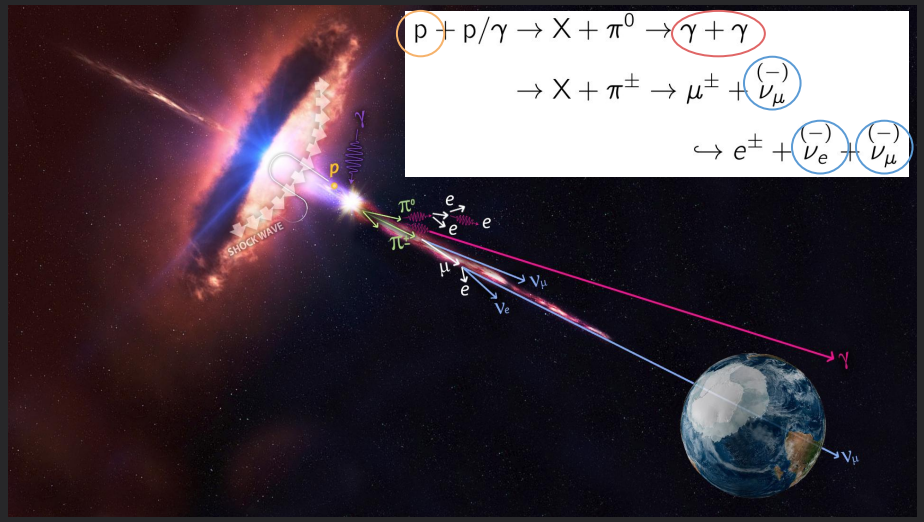
…and exotic searches



The Multi-Messenger Connection

- Cosmic accelerators can produce different *messengers*: **CRs**, **gamma rays**, **neutrinos**, and **gravitational waves**.
- **Common origin**: **CR** accelerators produce both γ and ν through hadronic processes: **pγ** and **pp** interactions.
- **Gamma rays** can also be produced in leptonic processes: synchrotron, inverse Compton.
- **Neutrinos can unambiguously reveal the CR sources.**

- They all have **pros and cons** when doing astronomy:
  - **Cosmic rays:** can reach UHE (>EeV) but deflected by the magnetic fields.
  - **Gamma rays:** very abundant, but absorbed at VHE (>TeV).
  - **Neutrinos:** neutral and unabsorbed can probe long distances, but small cross-section require huge detectors.
  - **Gravitational waves:** come from long distances and point back to the source, but poor localization and for now only few types of mergers (BH, NS).

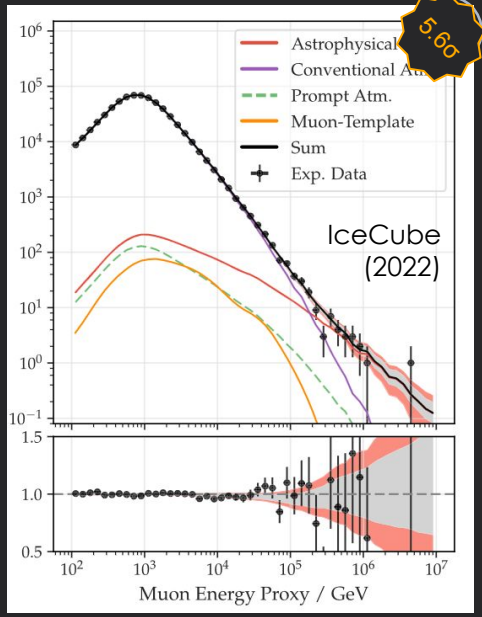


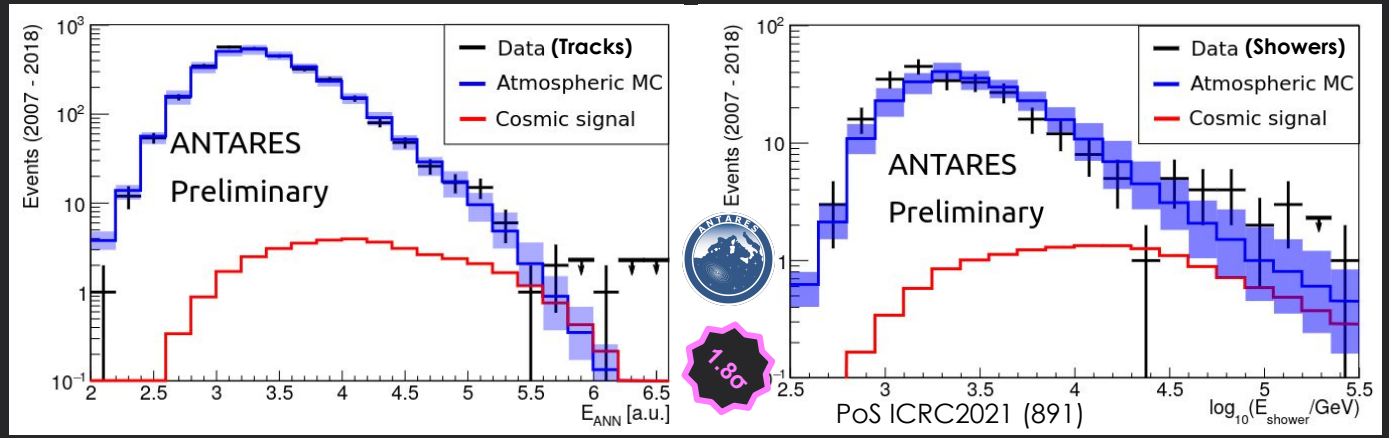
Multi-messenger astronomy concept: Combination of two or more messengers in spatial and/or temporal coincidence enhancing the discovery potential of a source.

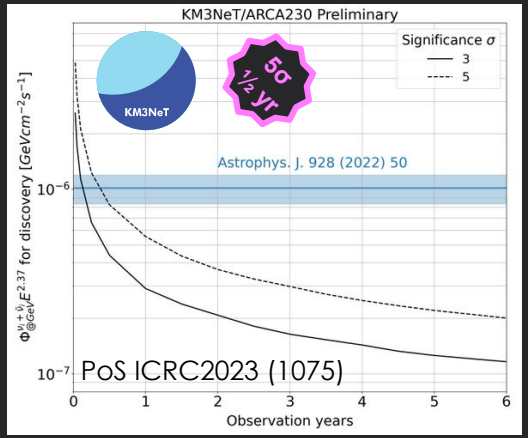
nu+γ/radio **GW nu** follow-ups
nu+nu **nu-CR**

Cosmic Diffuse Emission

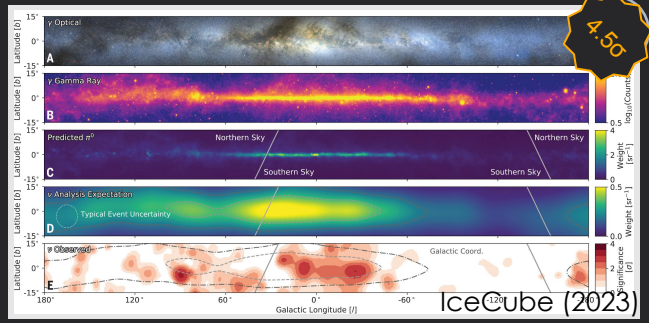
- High-energy cosmic neutrinos confirmed by the IceCube collaboration in 2013.
- ANTARES: mild 1.8 σ excess with 3330 days of data (2007-2018).
- 50 events (27 tr + 23 sh) observed vs 36.1 ± 8.7 (19.9 tr + 16.2 sh) expected from background.
- The last ~4 years of data will be added soon with analysis improvements (e.g. new shower selection, improved energy estimation).
- KM3NeT/ARCA6+8+18+21: 432 days, no excess, PoS(IRC2023)1195.
- The fitted flux normalisation of IceCube can be discovered with 5 σ within a half year of full KM3NeT/ARCA operation.



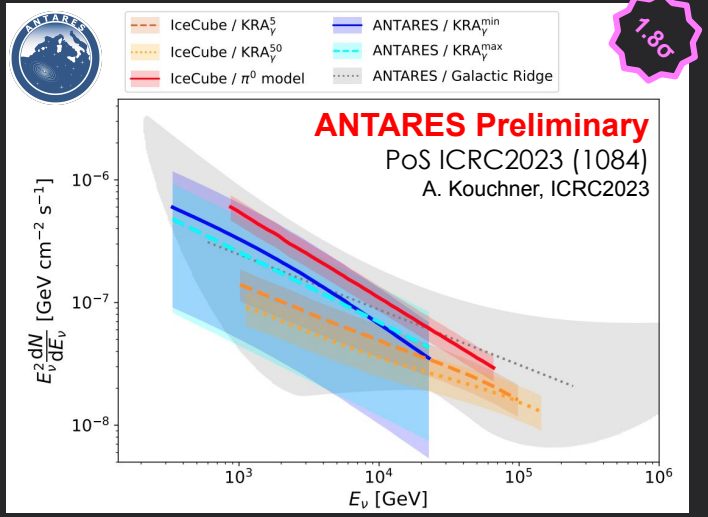


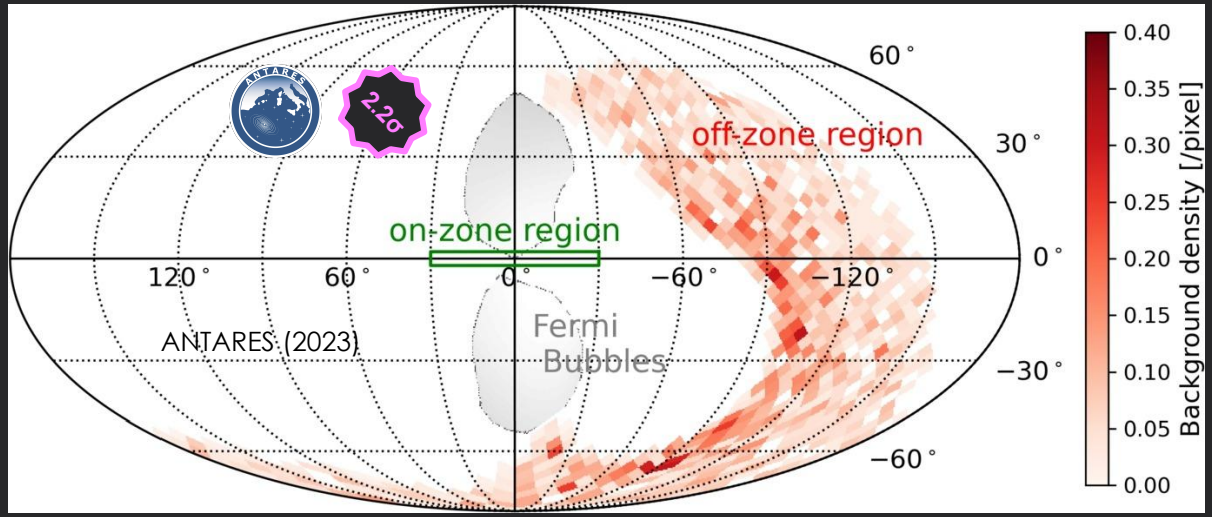


Galactic Diffuse Emission



- A Galactic component contributing to the cosmic neutrino diffuse flux was announced this year by ANTARES (**~2 σ**) and IceCube (**~4.5 σ**).
- ANTARES ON/OFF analysis at E>1 TeV detects 21 (13) track (shower) events while 11.7 ± 0.6 (11.2 ± 0.9) track (shower) events are expected, **2.2 (0.2) σ** excess.
- ANTARES template analysis using the most recent KRAγ models shows a **1.5-1.8 σ** excess.
- KM3NeT/ARCA6+8+18+21: short lifetime (432 days), so far no excess, PoS(IRC2023)1190.

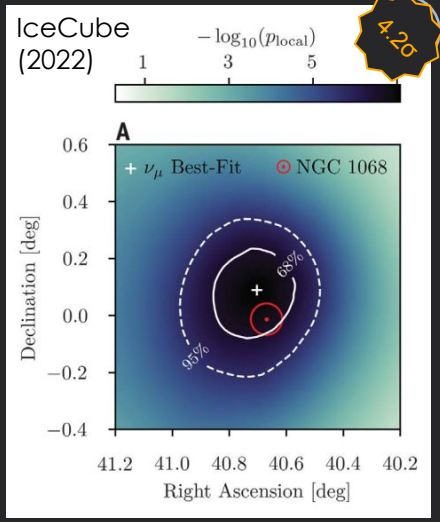


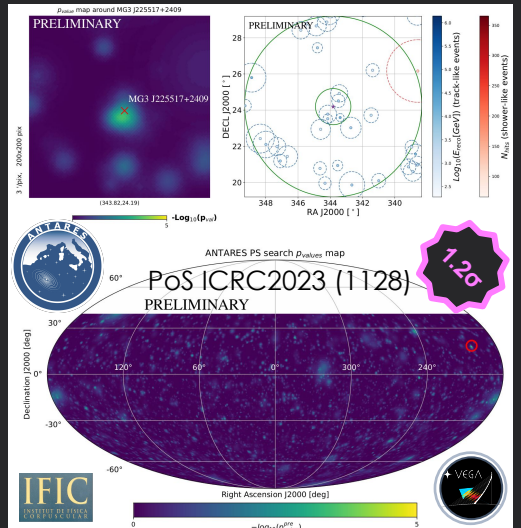


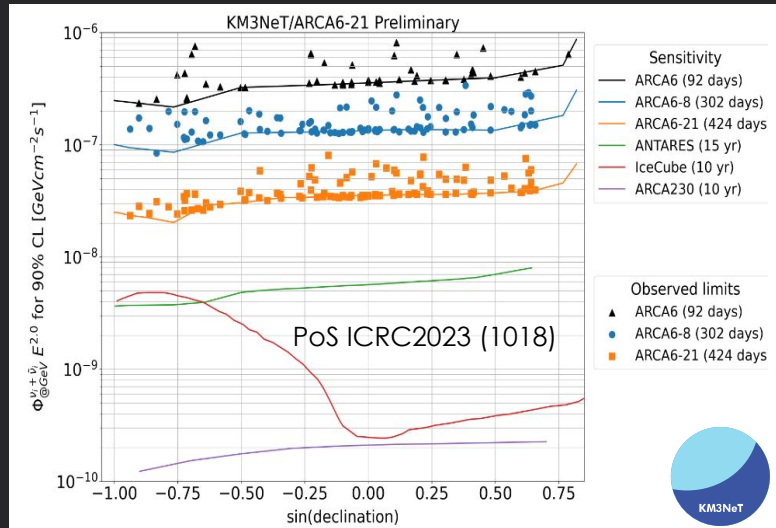
Neutrino Source Searches

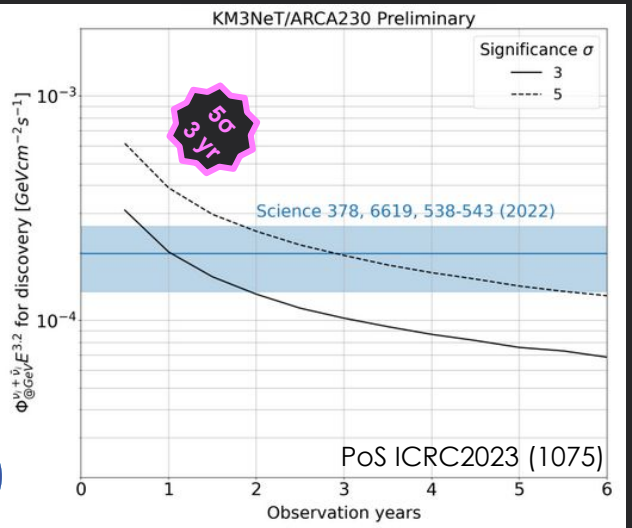
- Several searches: time-dependent, time-integrated, all-sky search, candidate list search, catalog-stacked, etc.
- ANTARES All-sky time-integrated search: most significant spot, (RA, dec) = (200.5, 17.7)°, pre(post)-trial significance of **4.0(1.2) σ**, no evident association (closest source is 1° away).
- A list of 163 candidate sources was tested. No significant excess observed but some sources show interesting upper fluctuations: MG3 J225517+2409 and 3C403 with **3.4(1.7) σ** pre(post)-trial significance.
- Combined searches (ANTARES & KM3NeT) ongoing.

1.7σ

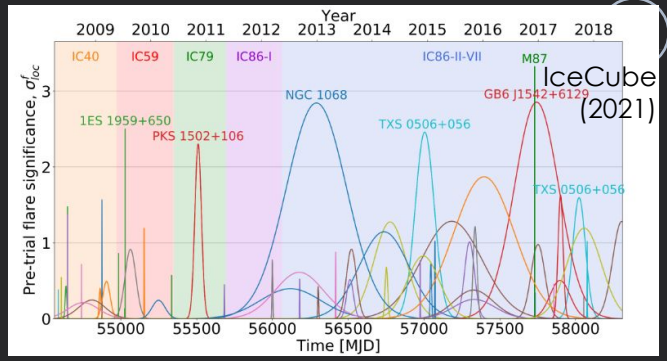




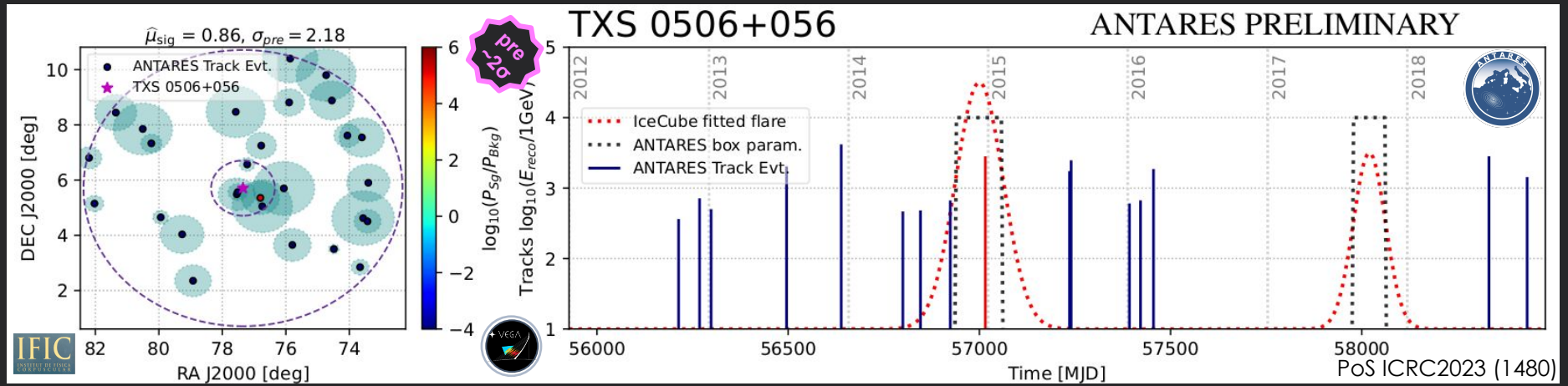




Time Dependent Searches



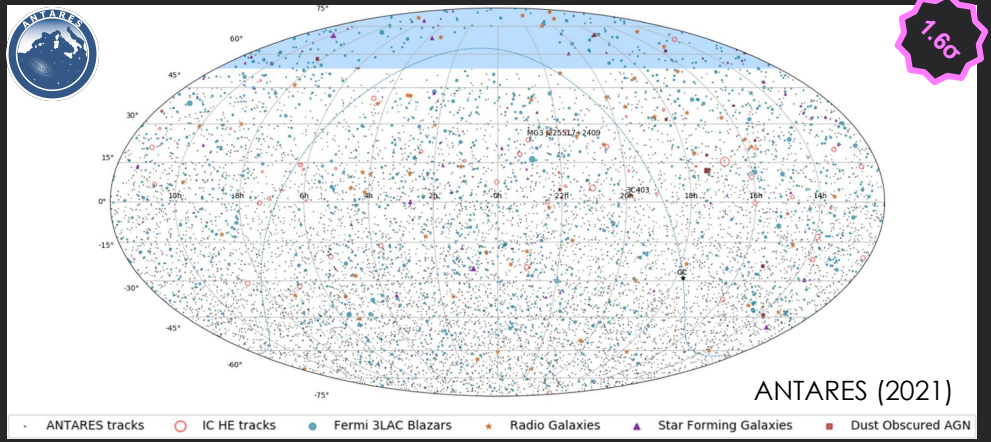
- Search for neutrinos using the temporal information from external observatories (triggered).
- Overall significance comparable to time-integrated search, with 3 times less signal.
- Tested potential neutrino flares by IceCube with ANTARES data.
- 4 (of 34) sources have fitted signal (pre-trial ~2 σ): TXS 0506+056 has 1 event compatible with the “orphan” neutrino flare (2014-2015).
- Searches based on EM observatories ongoing with both ANTARES & KM3NeT, PoS ICRC2023 (1505).

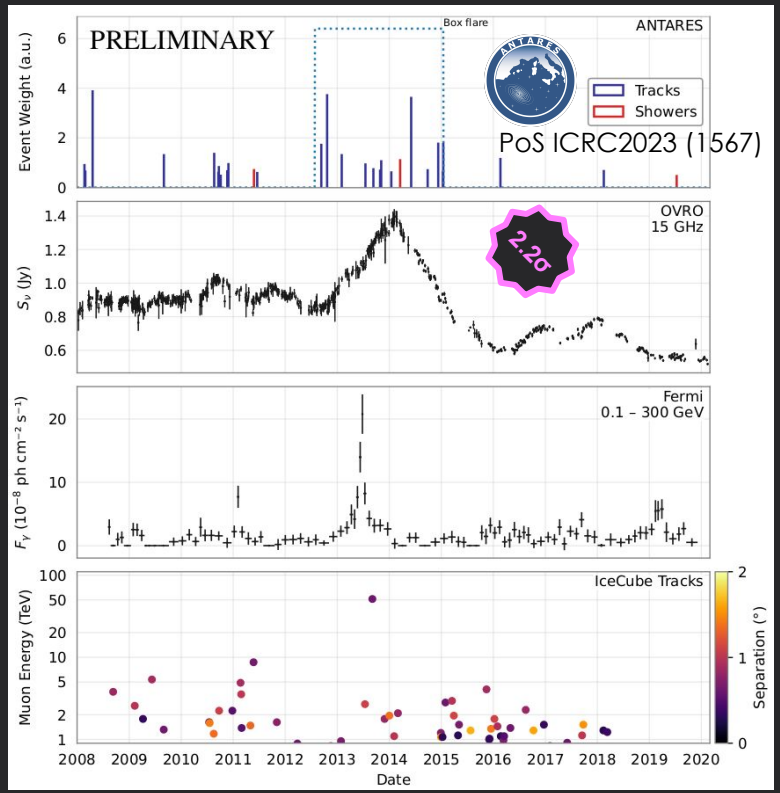


Catalogue Searches

- Different catalogues tested in ANTARES (11 years). The most significant: Radio Galaxies pre(post)-trial **2.8 (1.6) σ** excess.
- New analysis: updated radio-bright (VLBI) blazars catalog +2 yr data. Counting and likelihood analyses consistent (**2.2 σ**).
- Additional search for neutrino flares (untriggered) show 18 sources (out of 2744 tested) with pre-trial significance **>3 σ** pre-trial (background probability of this 1.4%, **2.5 σ**).
- **Both time-integrated and time-dependent analyses hint that some blazars might emit neutrinos.**
- Interesting case of J0242+1101, showing temporal coincidence with gamma and radio flares and also coincident with a high-energy IceCube track. Chance coincidence probability 0.5% (caveat: coincidence found a posteriori, assumptions made in this estimation).

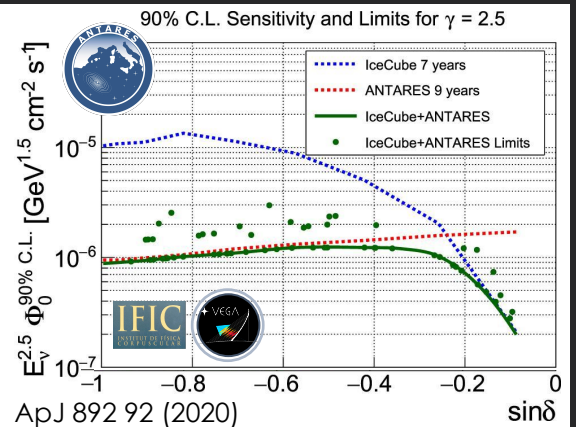
2.5σ



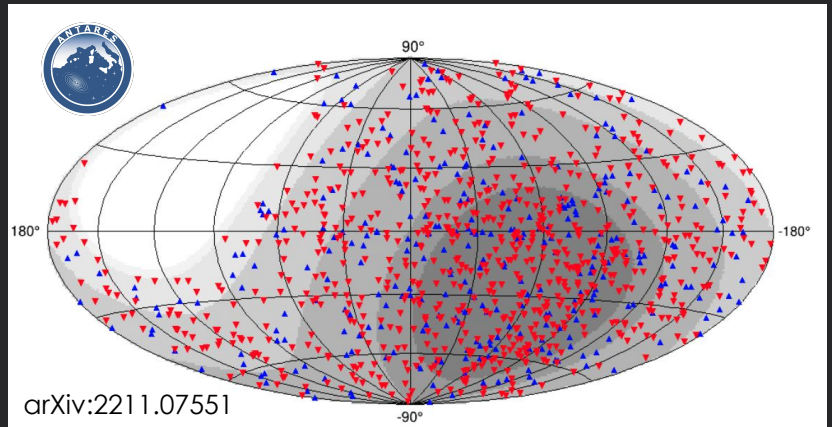


More Astrophysic Analyses

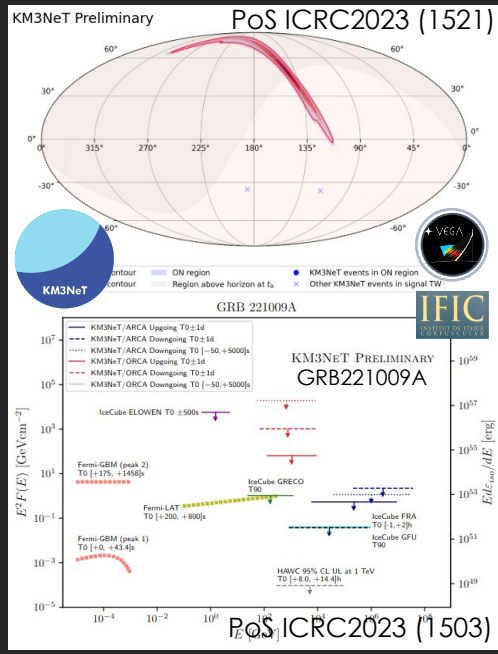
- A rich multi-messenger program with MoUs with different observatories.
- Combined analyses with IceCube (Southern sky): searches for sources, Galactic diffuse emission, dark matter, gravitational waves, etc.
- Correlations of neutrinos (ANTARES & IceCube) with UHE Cosmic Rays (Auger & Telescope Array) [ApJ 934(2022)164].
- Multi-messenger searches with HAWC through AMON [ApJ 944(2023)166].
- Alerts & transients follow-ups + alert generation programs (e.g. TAToO)
- Legacy of all the ANTARES follow-up online searches [arXiv:2211.07551]
- Search for neutrinos from transients (offline): GWs [JCA P04(2023)004, PoS ICRC2023(1521)], GRBs [JCAP03(2021)092, PoS ICRC2023(1503)].
- Also CCSN: DOM coincidences with events below reconstruction threshold.



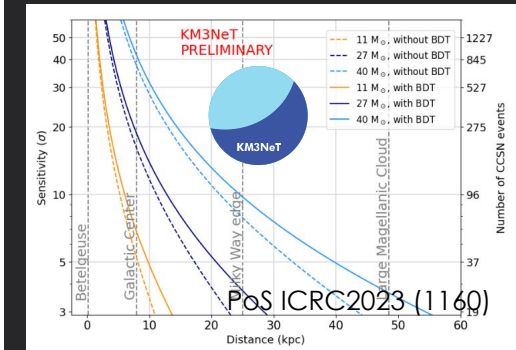
ApJ 892 92 (2020)



arXiv:2211.07551



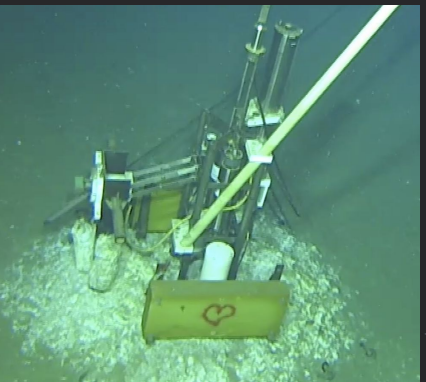
PoS ICRC2023 (1503)



PoS ICRC2023 (1160)

…exciting times ahead!

- Feasibility & reliability of operating a **neutrino telescope** underwater.
- **ANTARES** was relatively small, although relevant results were produced including hints compatible with the IceCube discoveries (cosmic & Galactic diffuse flux, TXS 0506).
- ANTARES legacy papers expected to be published by 2024.
- The next generation neutrino telescope **KM3NeT** is already taking data with a partial configuration whose size already exceeds that of ANTARES: improved design, two detectors (ARCA & ORCA) sensitive from MeV to PeV energies.
- Expected to become fully operational by 2028, KM3NeT will be a **discovery instrument.**
- More neutrino telescopes needed: complete sky coverage, independent cross-checks.
- **Multi-messenger astronomy**: cooperation with other observatories is key.
- **Abundant hints of a diverse neutrino astronomy!**



ANTARES

KM3NeT

VEGA

KM3NeT Neutrino @km3net · Sep 21

The sea campaign is over and we're happy to announce:

Our #astroparticle #cosmic #neutrino #detector ARCA now has 28 detection units successfully installed!

Congratulations to all who made it possible: from the integration of optical modules to the #deployment in the deep sea💙

LNS and INFN

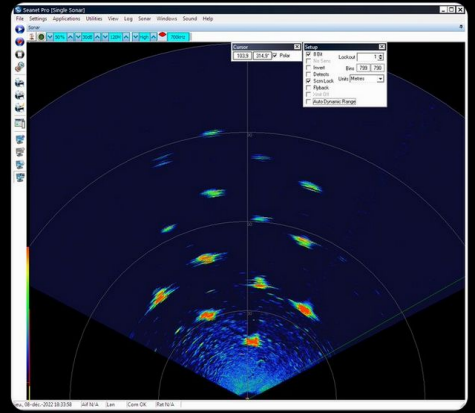
1 · 17 · 62 · 4,537

KM3NeT Neutrino reposted

KM3NeT Neutrino @km3net · Dec 12, 2022

During a sea campaign performed last week, KM3NeT/ORCA has been enlarged by 4 new detection lines. This brings the total of detection units deployed in ORCA to 15!

14 are visible on this nice sonar map. The 15th is beyond the boundary. The bottom 4 are the new lines.



15 · 38

Thanks for your attention!

Backup

VEGA

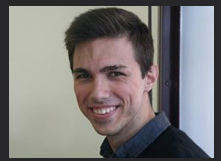
Valencia Experimental Group of Astroparticles

ANTARES & KM3NeT Neutrino Telescopes:

- **Cosmic neutrino searches (Astronomy)**
- Atmospheric neutrino oscillations
- Dark matter & exotic searches


Francisco Salesa


Agustín Sánchez


Sergio Alves


Juan Palacios


Emilio Pastor

VEGA “Astro” sub-group line of research:

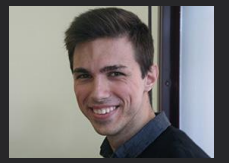
Cosmic Neutrino Searches

High energy cosmic neutrino searches in neutrino telescopes (ANTARES/KM3NeT) using assumptions from multimessenger inputs: looking for neutrinos from candidates defined by other messenger counterparts, often with a time constraint

- Gamma/X-ray/Radio:
  - Neutrinos from gamma ray flares in blazars (Fermi/IACTs), may be correlated with jet activity in radio (various)
  - Neutrinos from x-ray binaries during flares/outbursts (Swift/Rossi/MAXI/Fermi)
  - Neutrinos from gamma sources (HAWC)
- Neutrinos:
  - Neutrinos from untriggered neutrino flare candidates (IceCube)
  - Neutrinos from online remarkable events (IceCube/GVD)
- Gravitational waves:
  - Neutrinos from gravitational waves (LIGO-Virgo-KAGRA)

Francisco Salesa

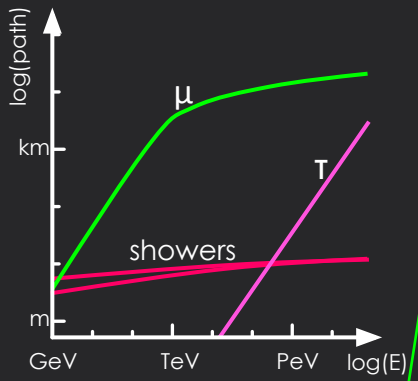
Agustín Sánchez

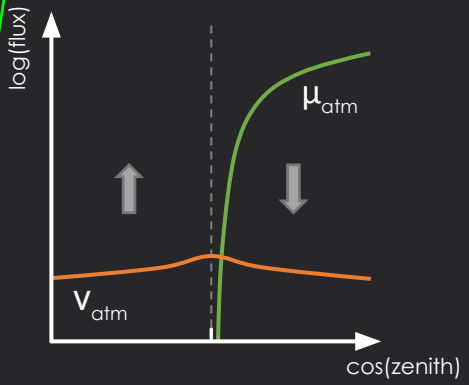


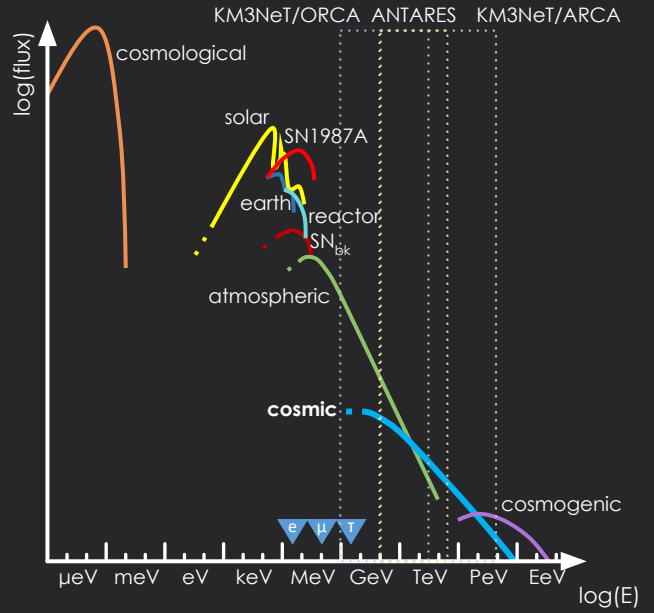
Sergio Alves

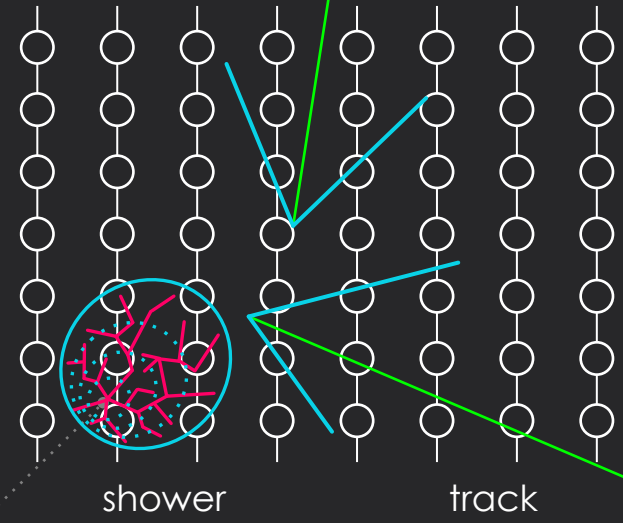
Juan Palacios

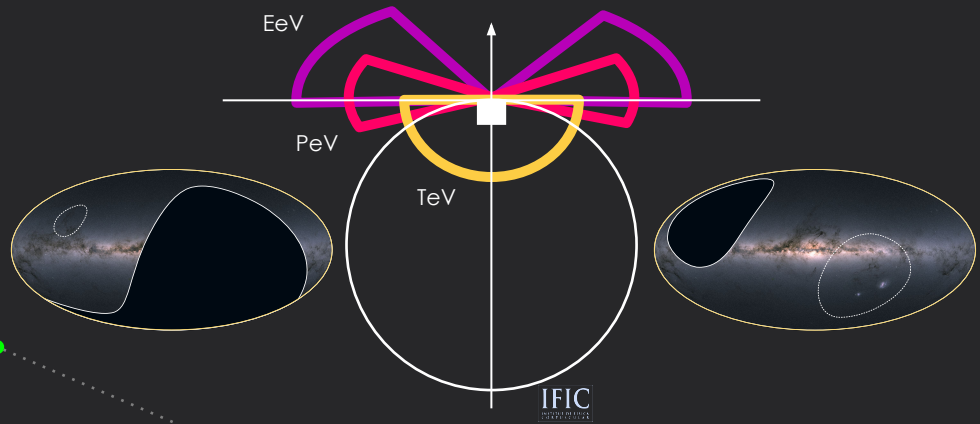
Emilio Pastor







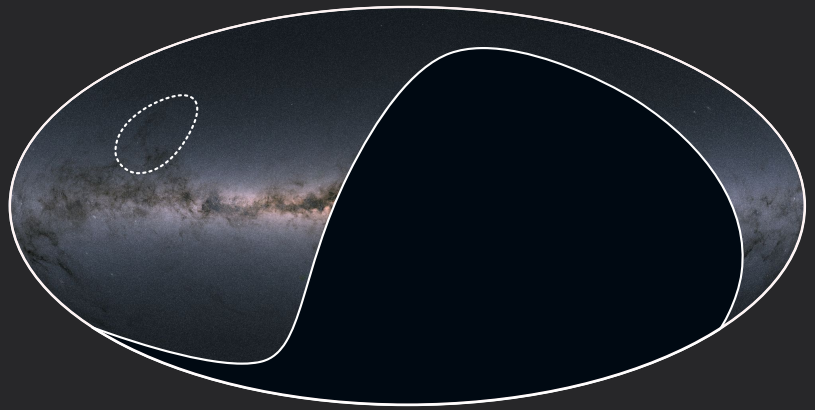


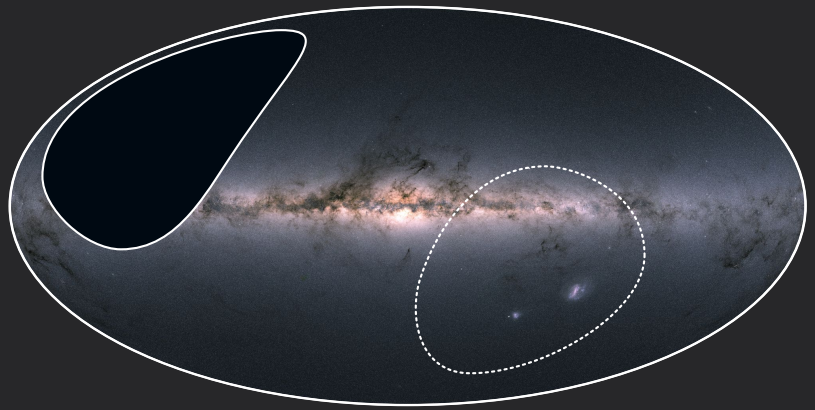


A Neutrino Telescope

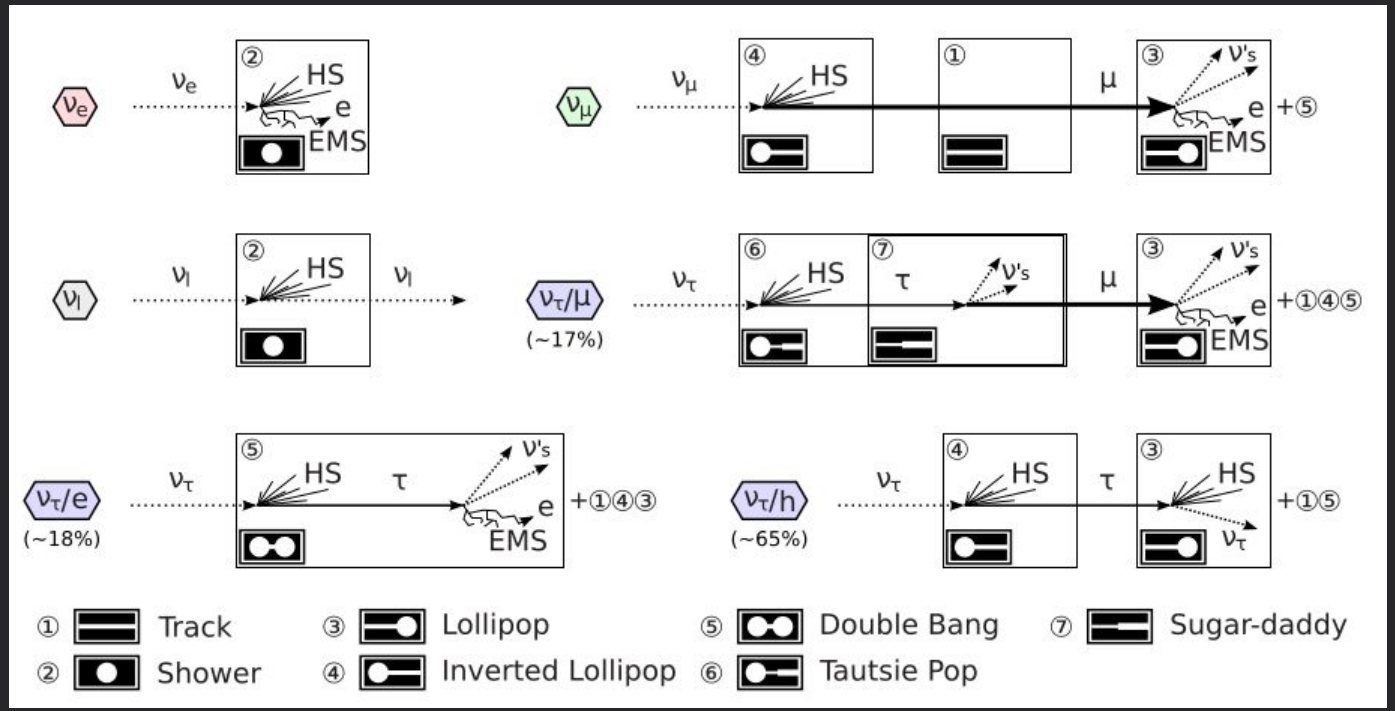
✦ VEGA

IFIC



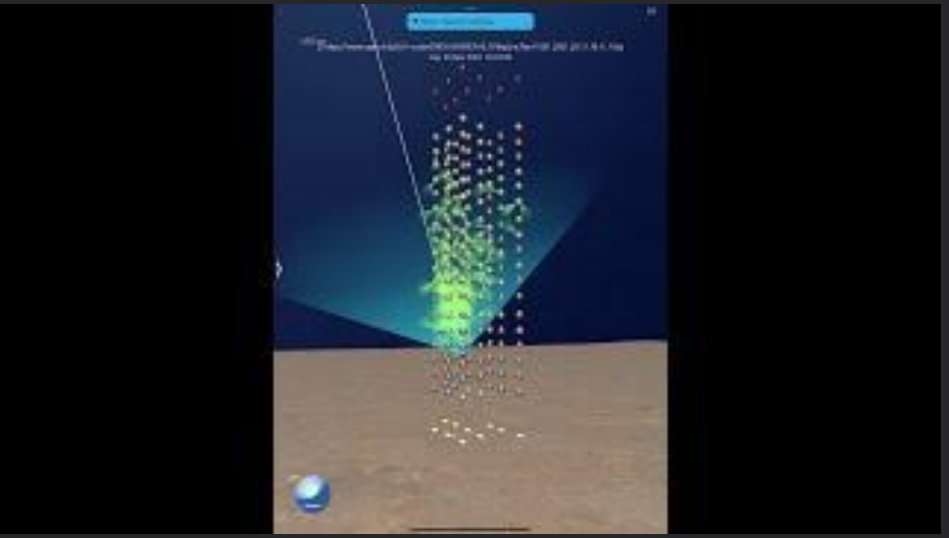


Neutrino Telescopes | Topologies



TRACK

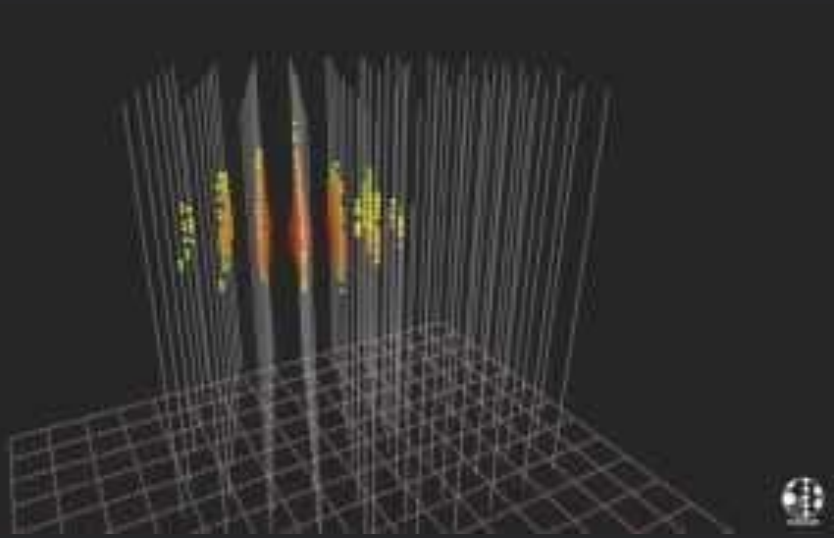
$\nu_{\mu/\tau\to\mu}$-CC



https://www.youtube.com/shorts/B7cbc7OHCbM

SHOWER

$\nu_{e/\mu/\tau}$-NC +
$\nu_{e/\tau\to e}$-CC



https://www.youtube.com/watch?v=y6cmY-ibqys

Neutrino Telescopes | Angular resolution

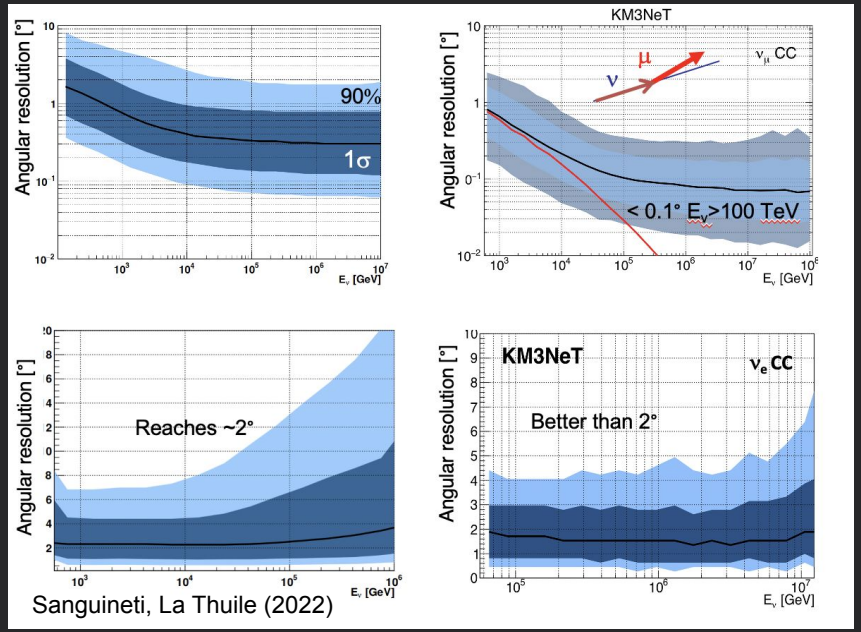
- Ang. res. depends strongly of energy (and data quality selection)
- Much better ang. res. for tracks than for showers... also beter in water than in ice
- Typically subdegree median ang. res. on tracks above TeV; not in showers, can worsen with energy
- Energy resolution better for showers (containment) while on tracks deposited energy: statistical use of energy estimators in analysis
- Reconstruction techniques still under improvements

ANTARES

KM3NeT/ARCA

TRACKS

SHOWERS

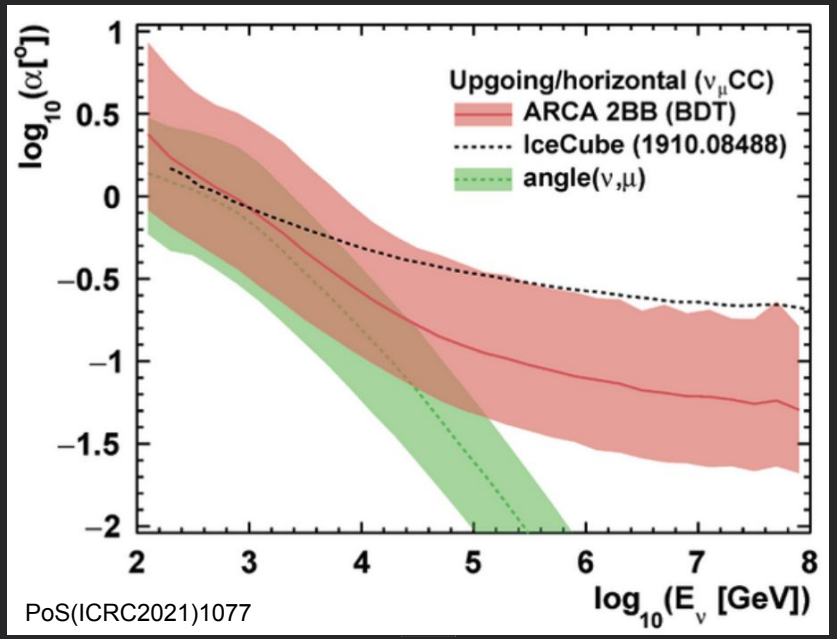


Sanguineti, La Thuile (2022)

Energy resolution ~ 30%

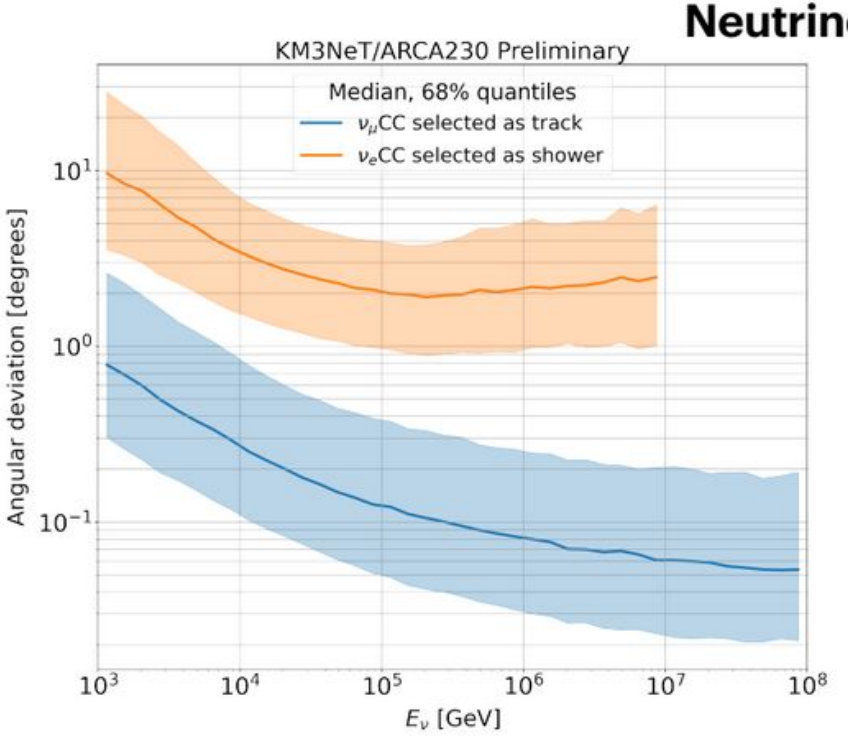
Energy resolution < 5%

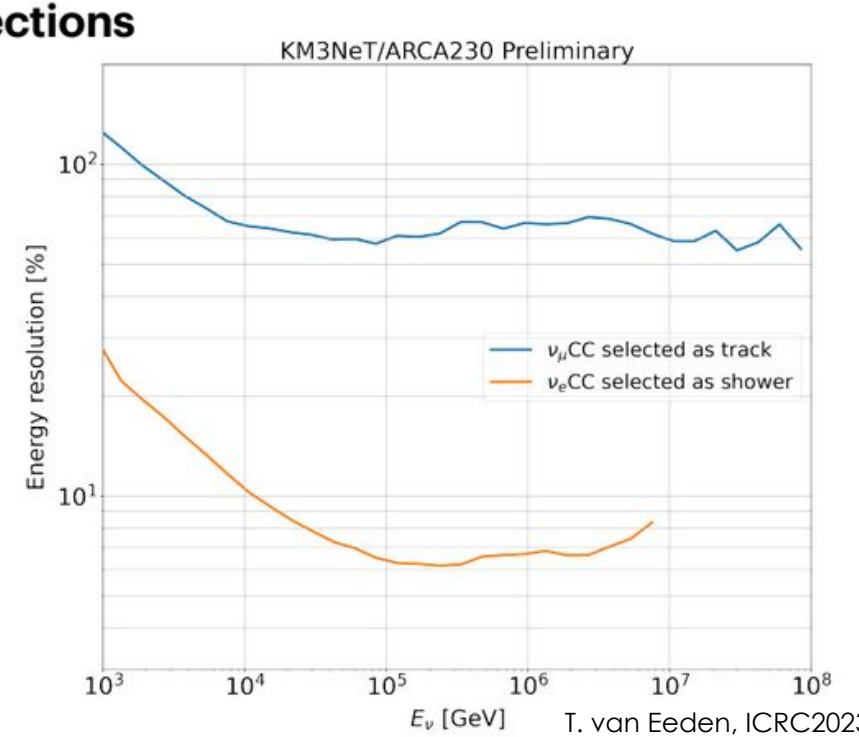
KM3NeT/ARCA vs IceCube



PoS(ICRC2021)1077

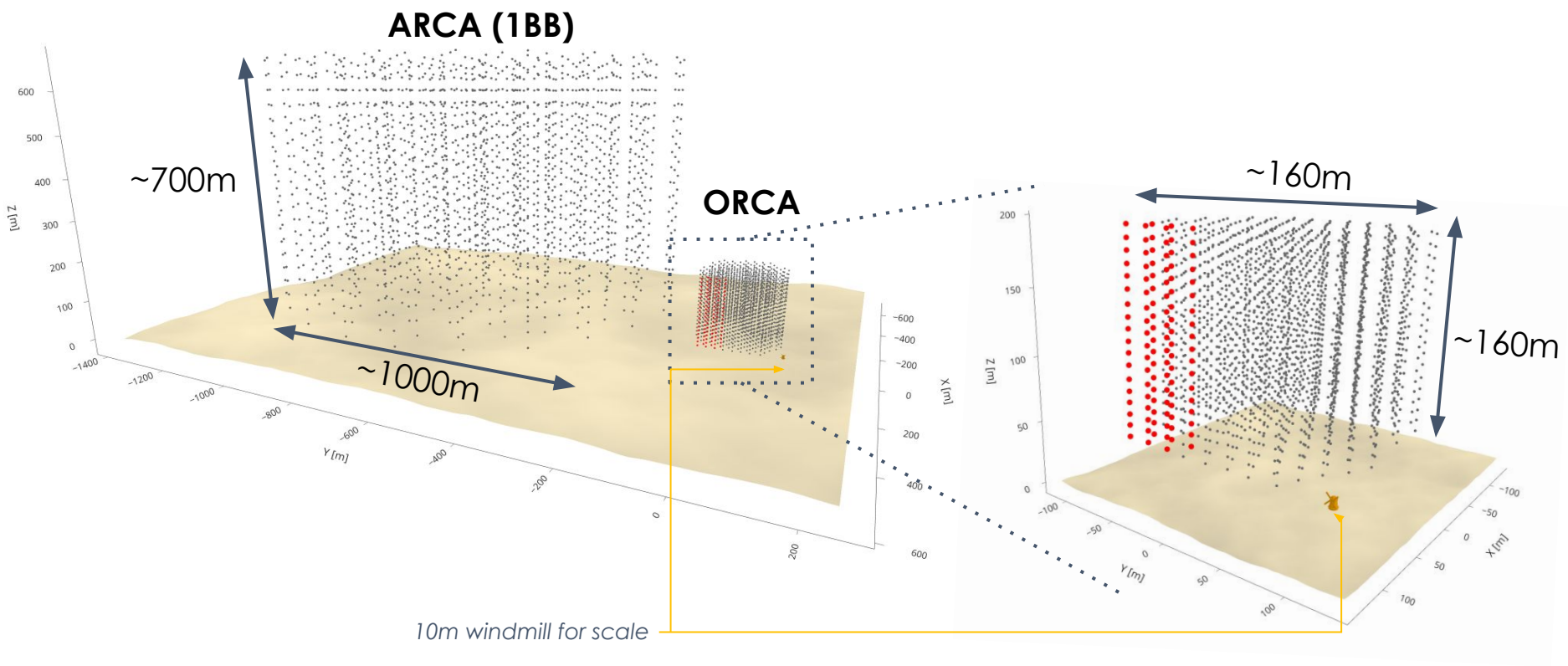
Neutrino selections



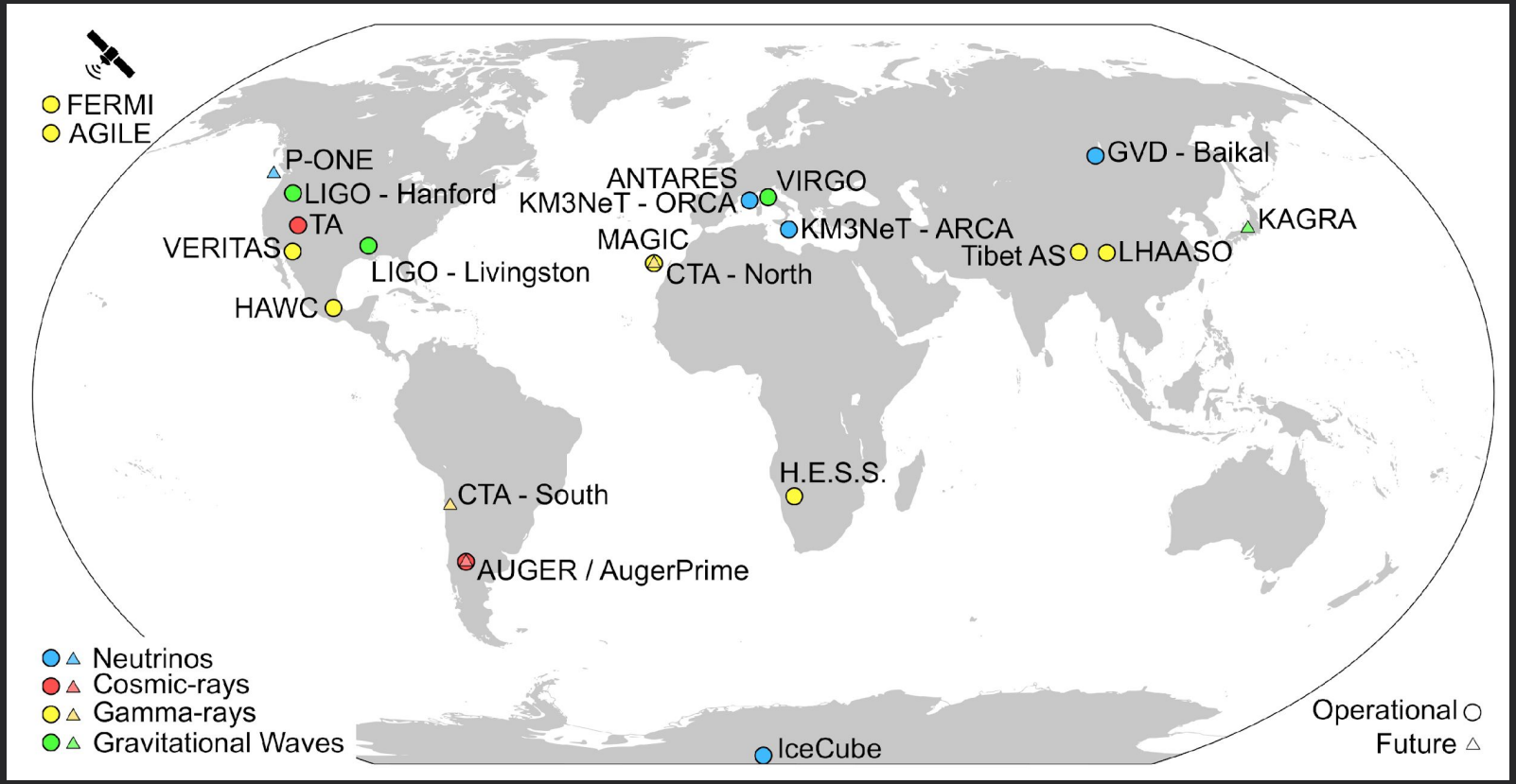


T. van Eeden, ICRC2023

KM3NeT: ARCA vs ORCA

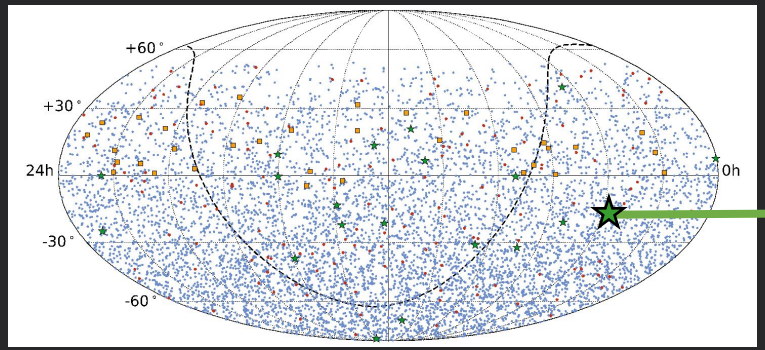


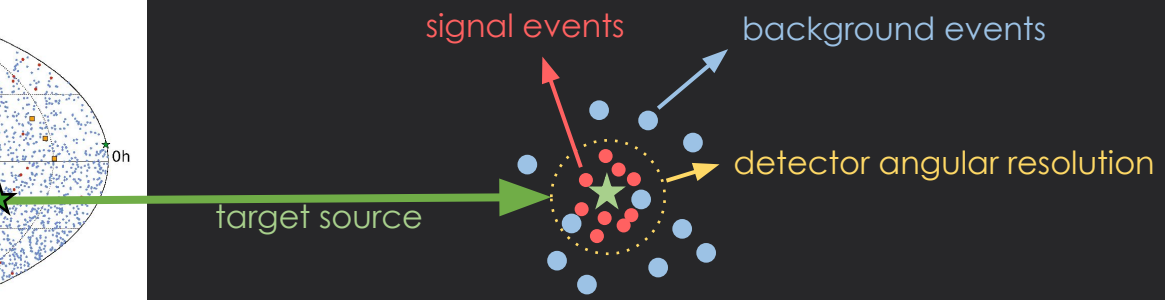
The Experiments | Worldwide coverage



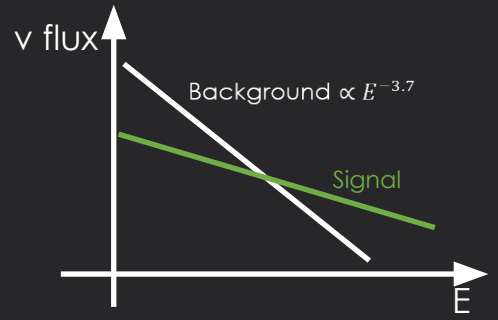
The Searches: Direction-Energy-Time

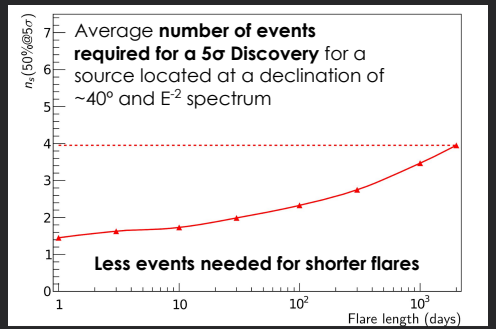
- **Spatial** distribution: compatible with point-like/extended sources?





- **Energy** spectrum: compatible with signal expectation?





- Arrival **time**: limited to a transient signal hypothesis?