The KM3NeT underwater neutrino telescope: status and future perspective

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on behalf of the KM3NeT Collaboration

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KM3NeT

Outline

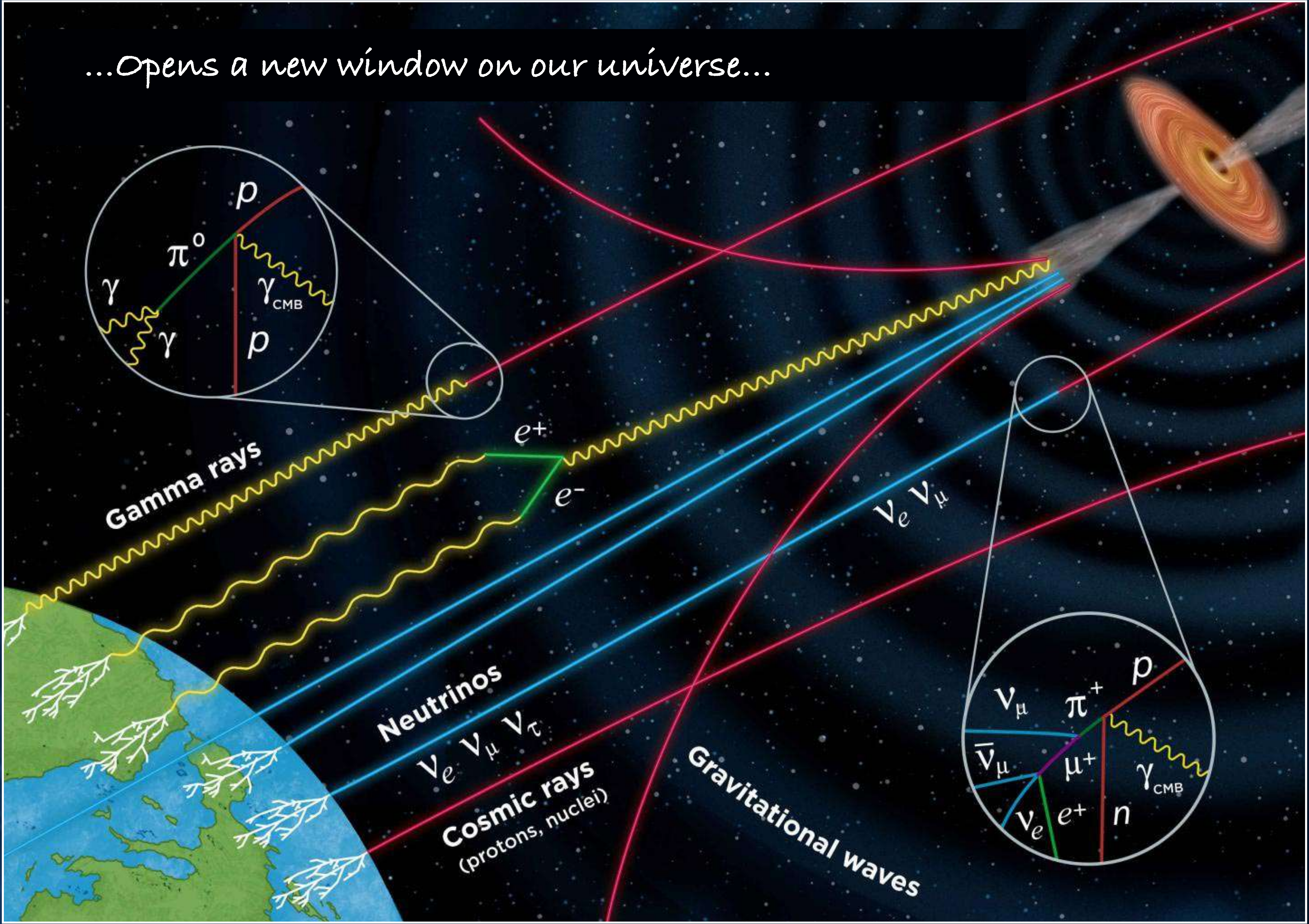
- Neutrino Astronomy and the KM3NeT project
  - Technology and infrastructure
  - Current status and plans

- Search for cosmic neutrino sources with ARCA
  - Sensitivity to Cosmic Neutrino Fluxes
  - Real time Multi-messenger program

- Oscillation research with ORCA

- Summary and outlook

Neutrino Astronomy



- Neutrinos: neutral, stable, weakly interacting

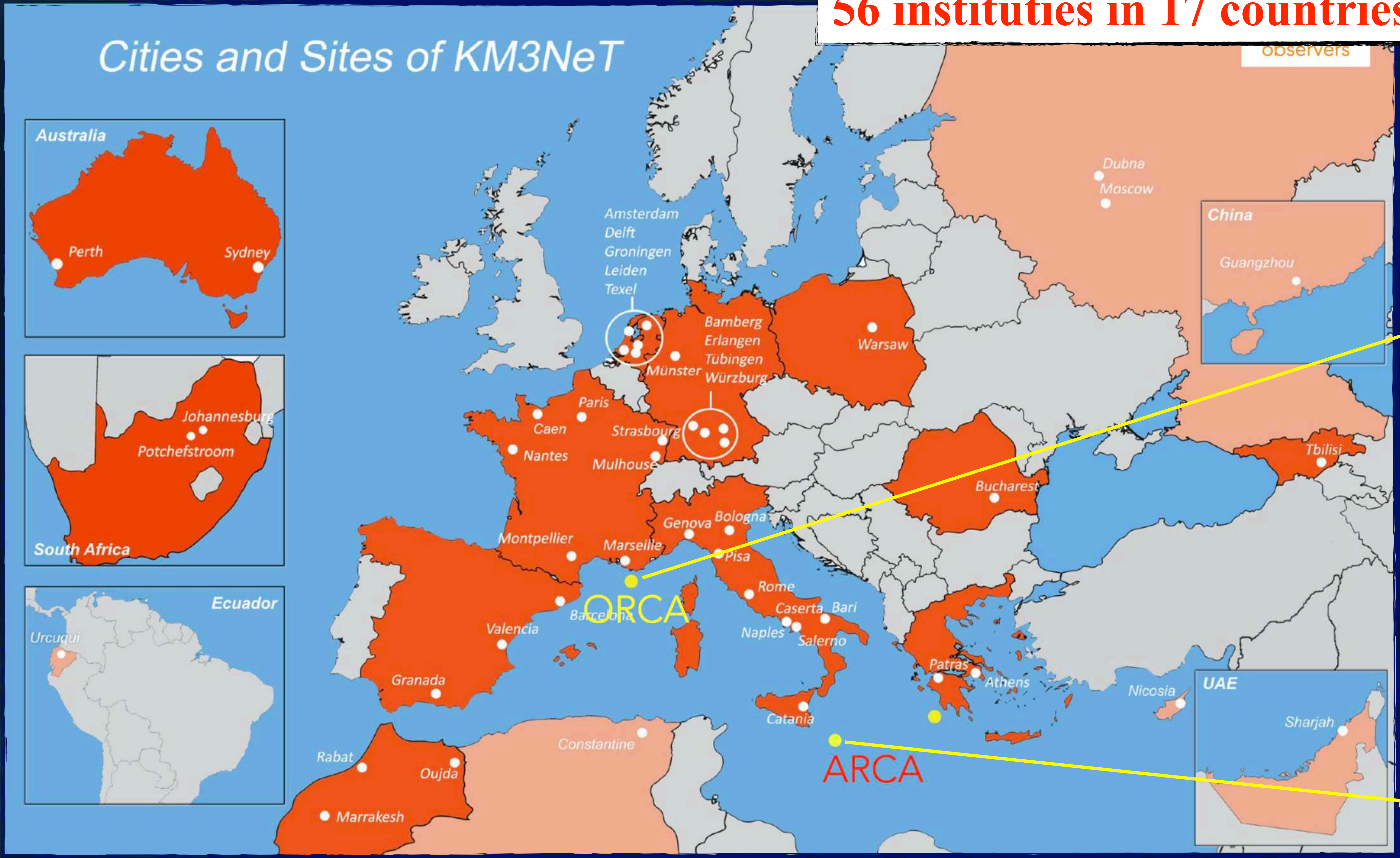
  - not absorbed by background light/CMB (access to cosmological distances)
  - not absorbed by matter (access to dense environments)
  - not deviated by magnetic fields (astronomy over a wide energy range)

- 'Smoking gun' signature for hadronic processes

- Correlated in time/direction with electromagnetic and gravitational waves: Multi Messenger Astronomy

The KM3NeT Collaboration

56 instituties in 17 countries

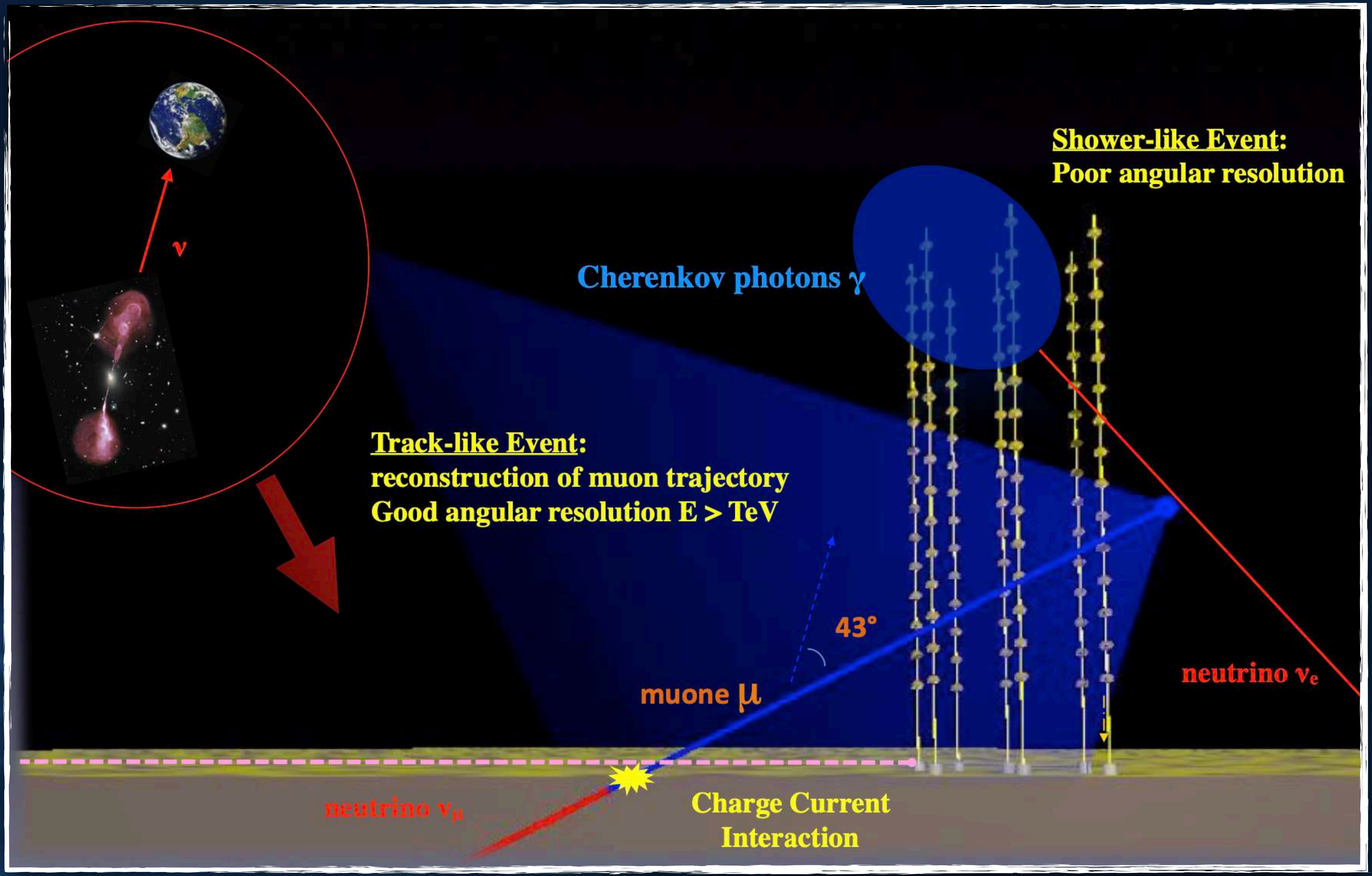


ORCA (Oscillation Research with Cosmic in the Abyss)

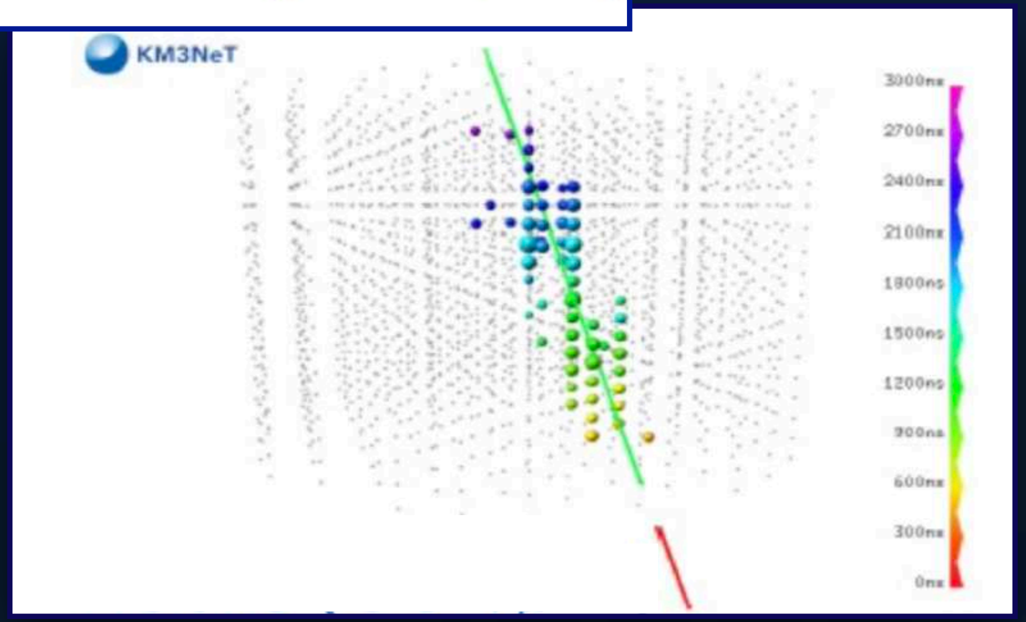
ARCA (Astroparticle Research with Cosmics in the Abyss)

Cosmic neutrino detection principle

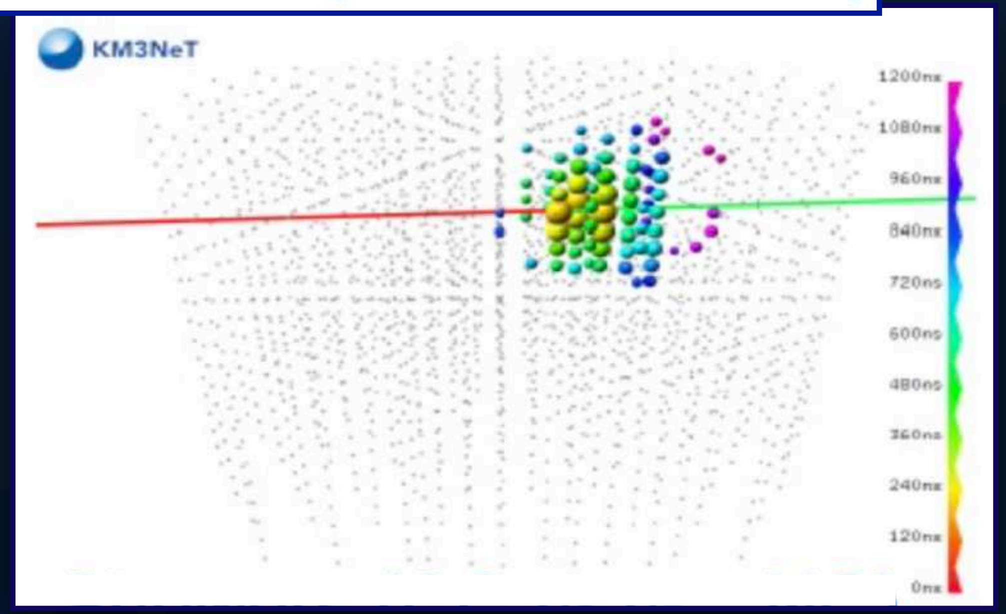
- Detection of Cherenkov photons induced by the neutrino interaction products using a 3D array of optical sensors
- Large volume of transparent medium to detect cosmic neutrinos ⟶ water/ice
- Time, position and amplitude of PMT pulses (hits) allow both direction and energy reconstruction

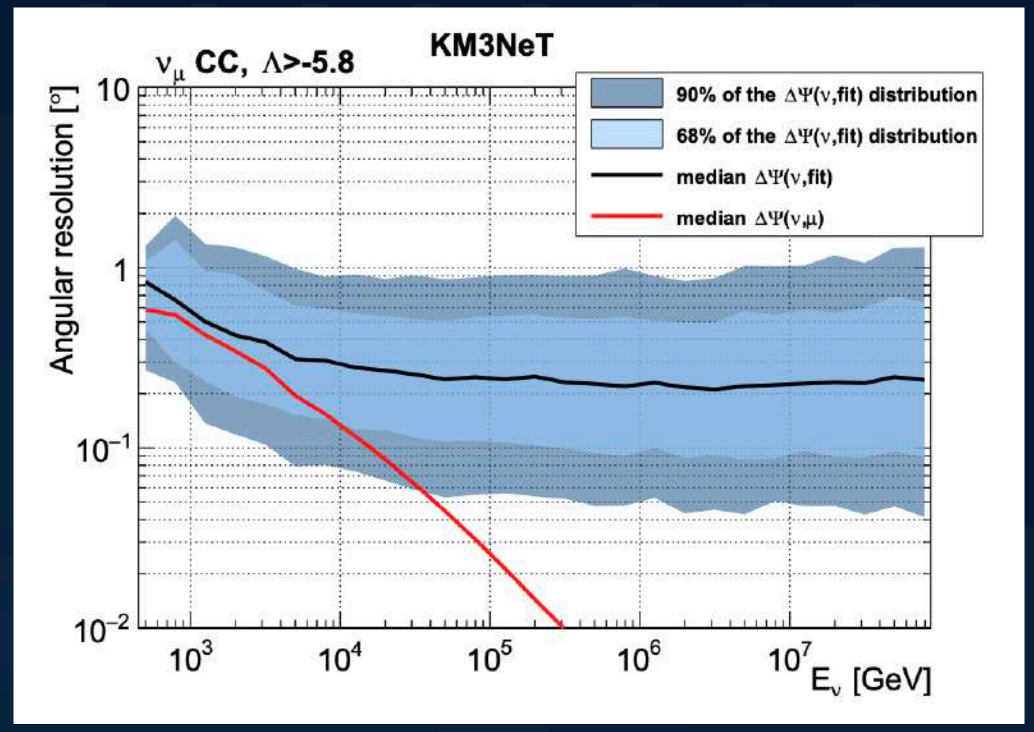


Tracks (CC ν_μ ν_τ)

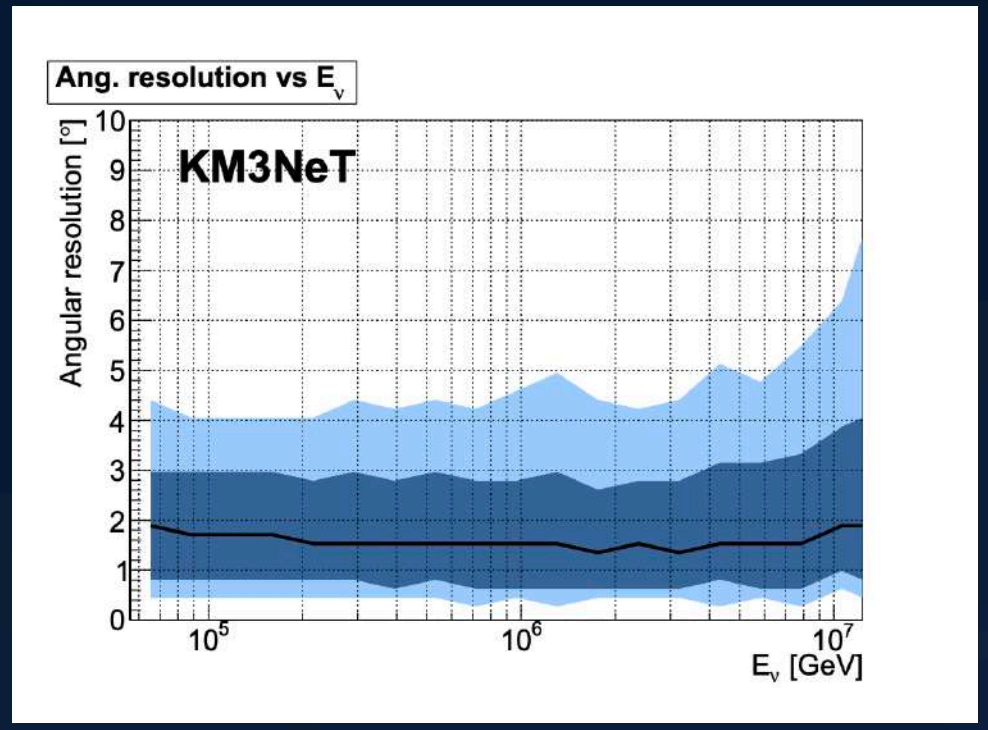


Showers (CC ν_e ν_τ – NC)





Angular ~0.1° at 100 TeV



Angular ~1° at 100 TeV

The KM3NeT technology and infrastructure

The basic elements:

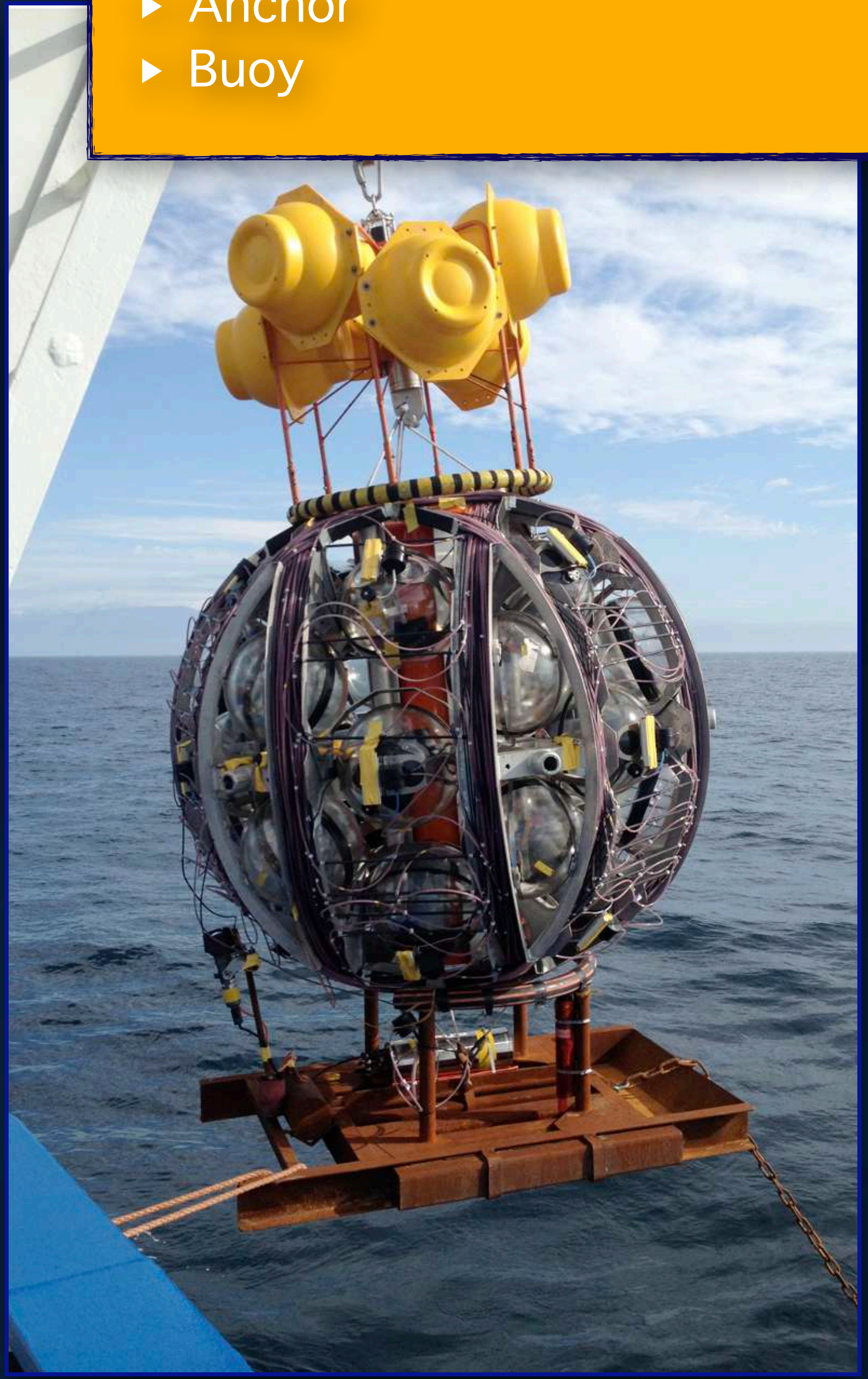
- DOM (Digital Optical Module)
- DU (Detection Unit)
- Seafloor network: electro-optical cables and JBs (Junction Boxes)

DOM

- 17” glass sphere with 31 3” PMTs
- LED and Piezo
- Front-end electronics

DU

- ~ 250/750 m (ORCA/ARCA)
- 18 DOMs (~9/36 m btw DOMs)
- Anchor
- Buoy

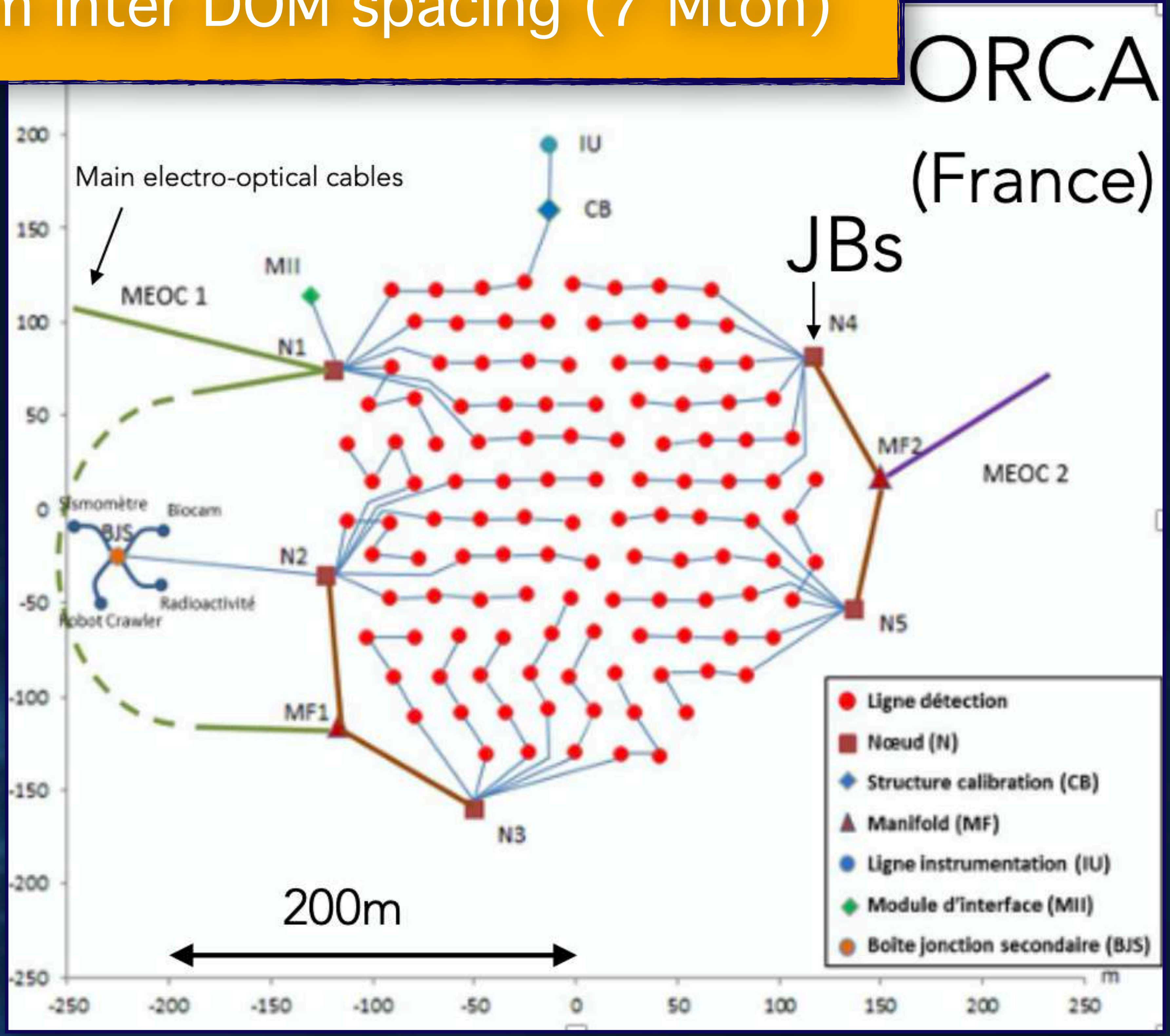


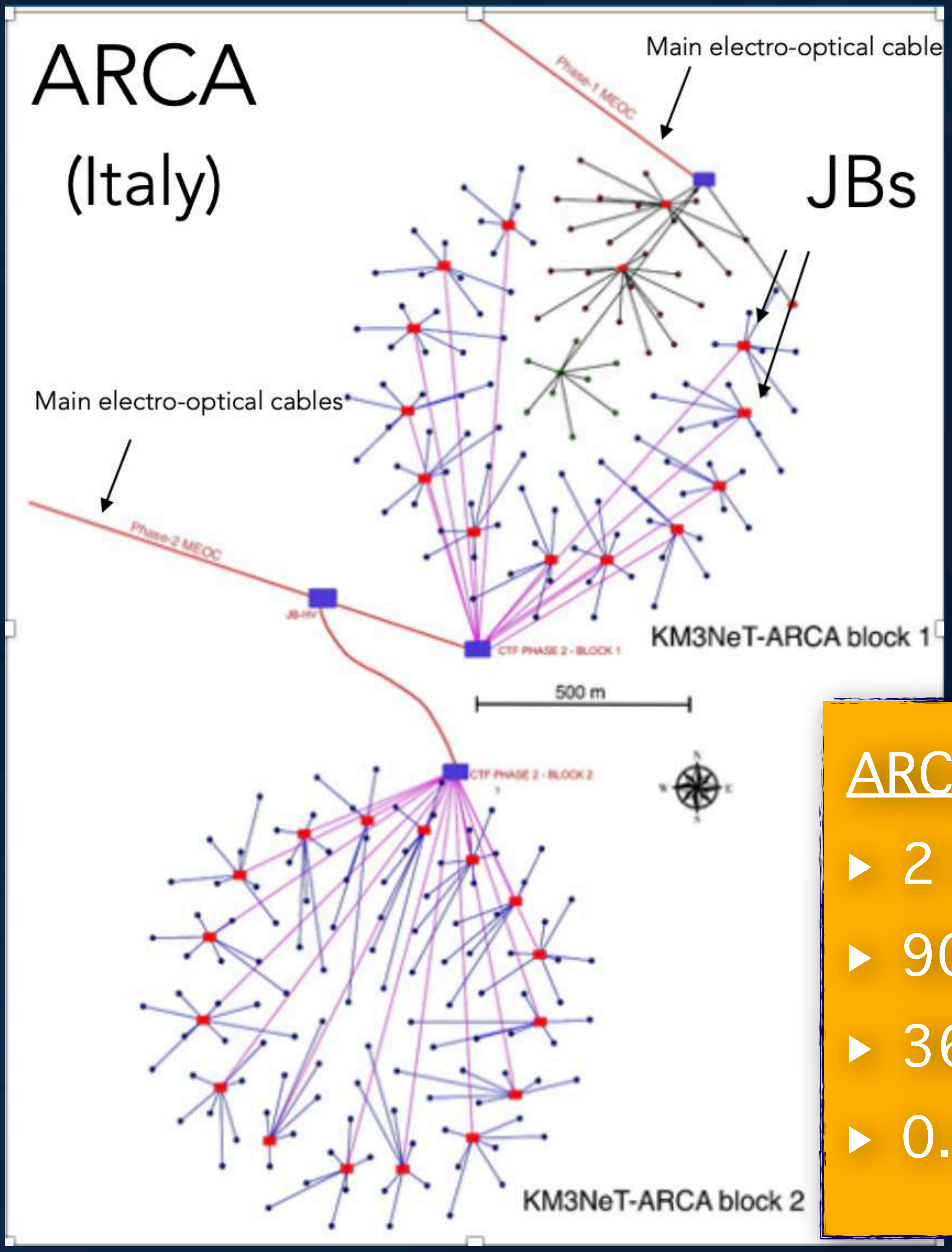
JB

The KM3NeT technology and infrastructure

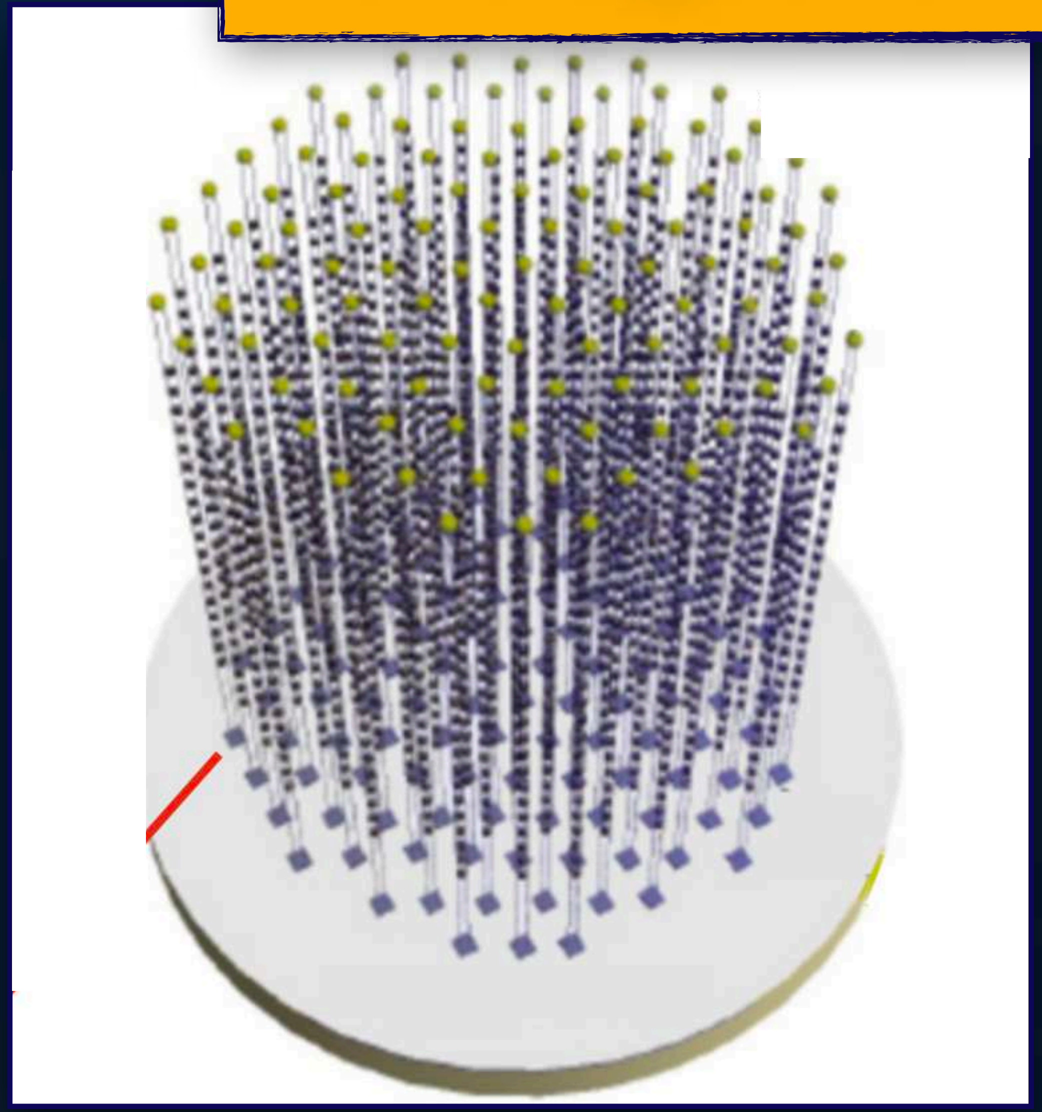
All data to shore

<u>ORCA</u>:
- 1 building block (BB) of 115 DUs
- 20 m DU interspacing
- 9 m inter DOM spacing (7 Mton)



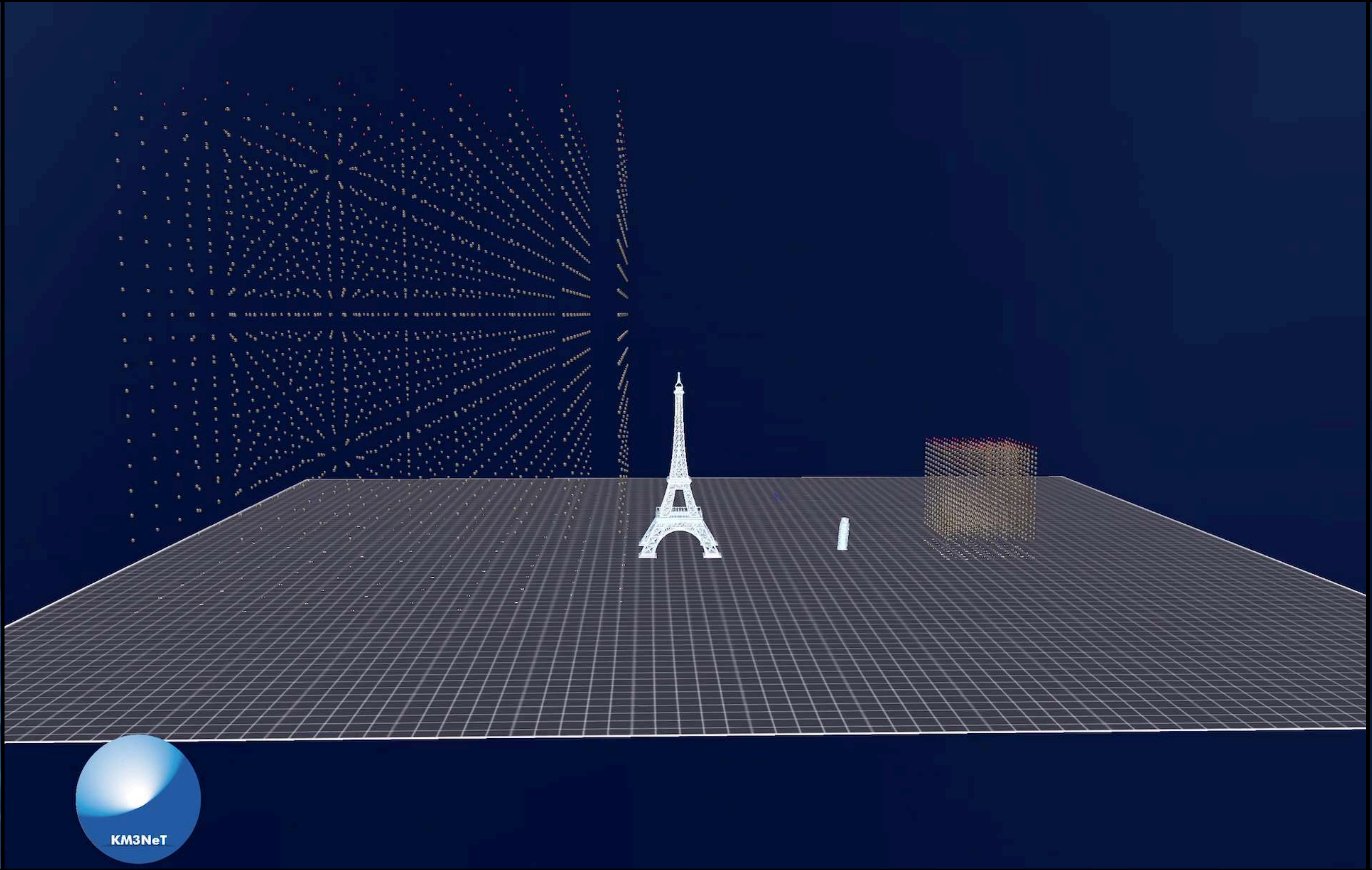


Building Block

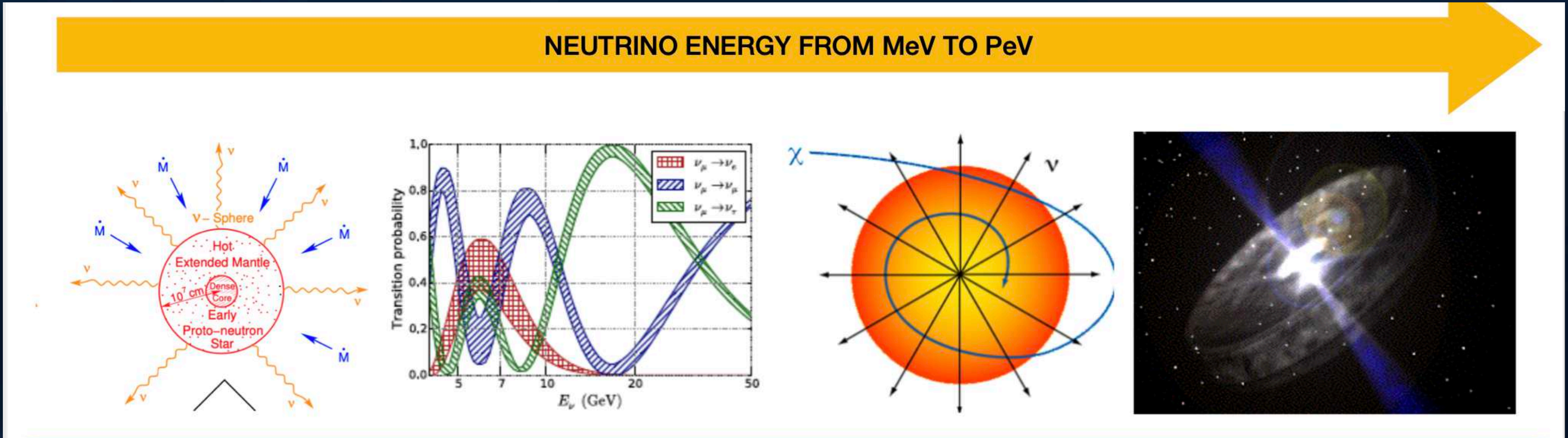


<u>ARCA</u>:
- 2 building blocks of 115 DUs
- 90 m DU interspacing
- 36 m inter DOM spacing
- 0.5 km3=500Mton/block

KM3NeT: ARCA and ORCA



Neutrino telescopes: science with a multi-energy scale



Super Novae explosion
MeV

Neutrino oscillation
GeV

Dark Matter (*)
TeV

HE neutrinos
Multi-messenger program
PeV

ARCA

ARCA

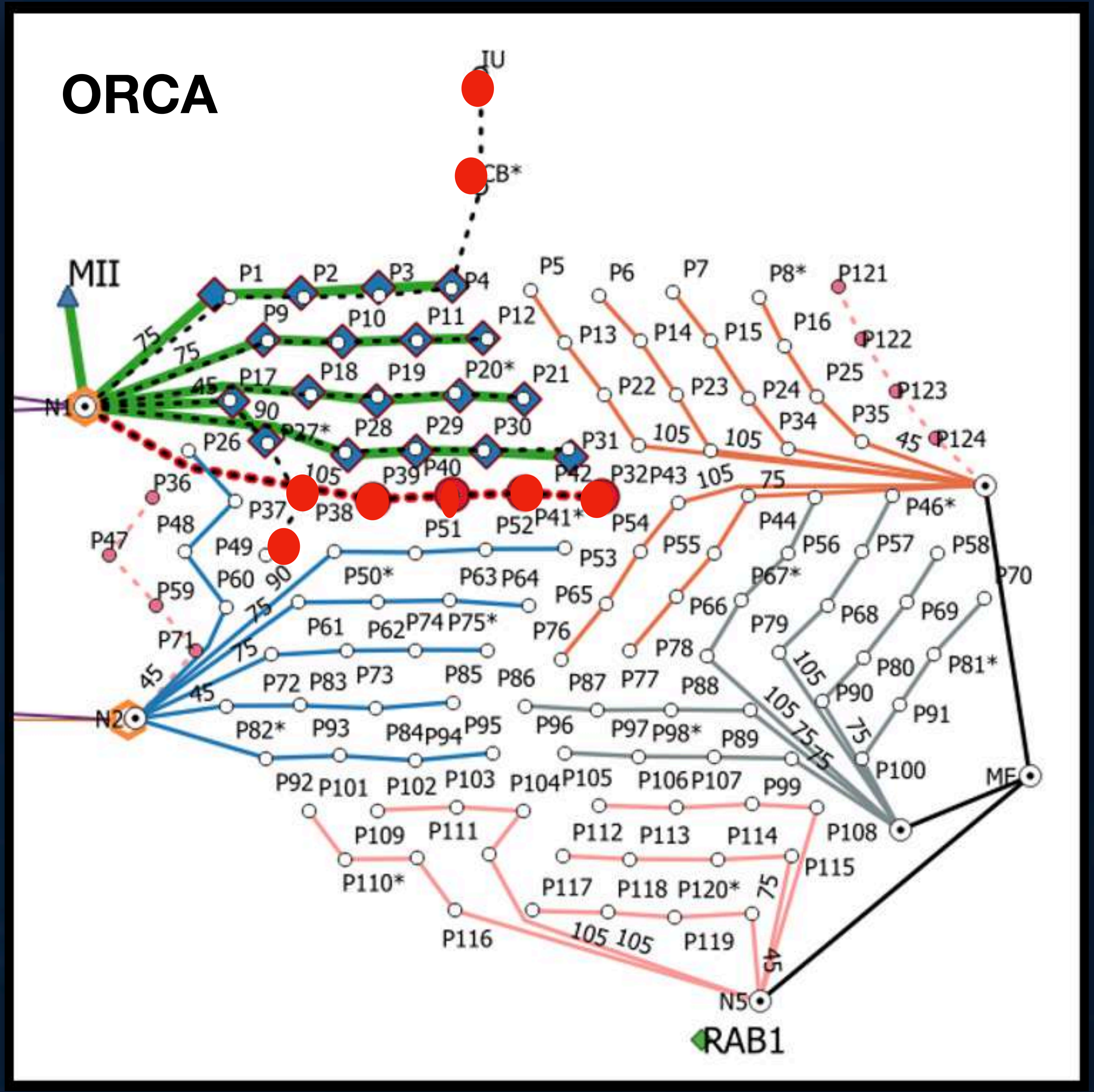
ORCA

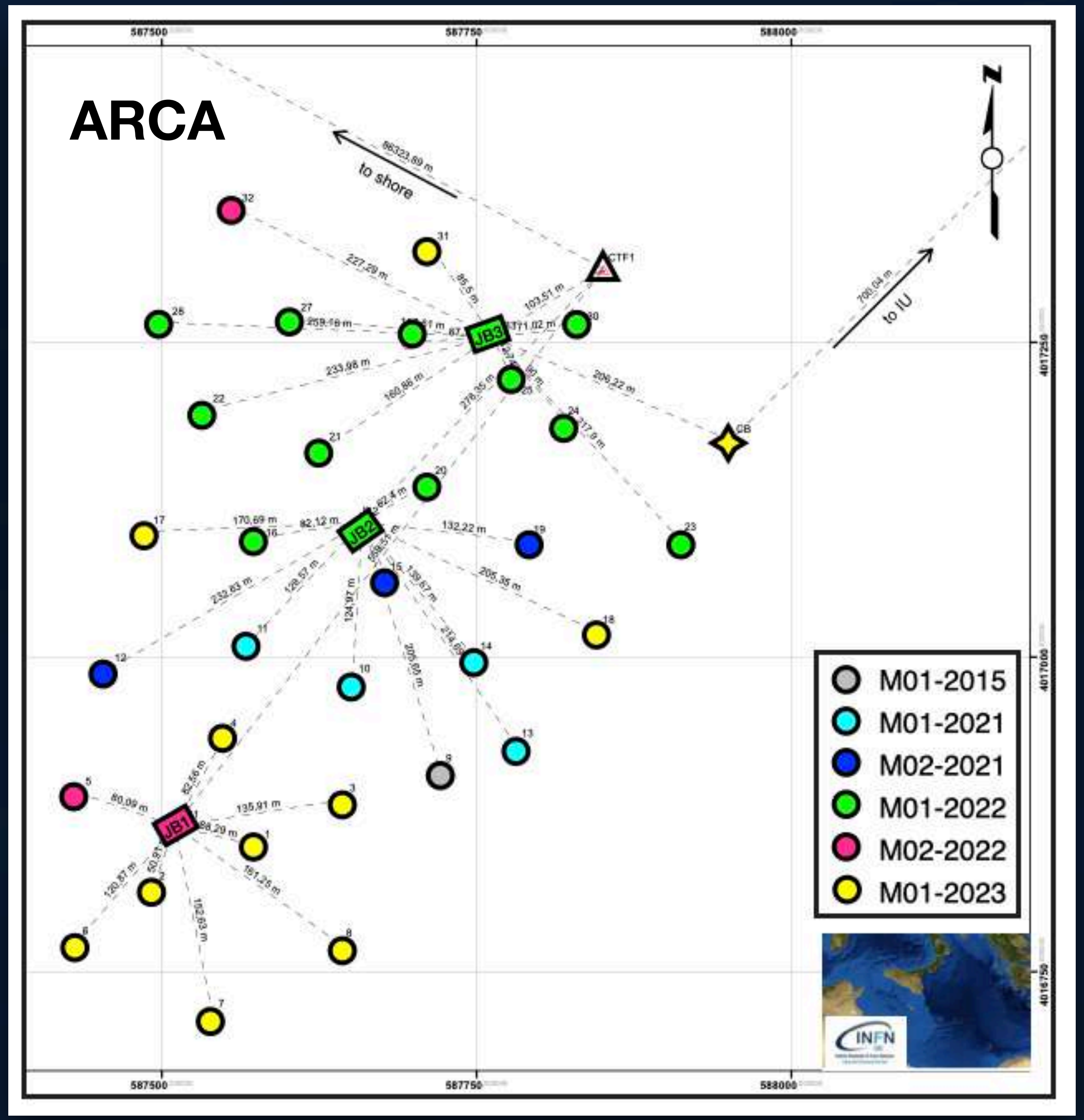
Current status and next sea campaigns

Current Staus: 21 ARCA DUs & 20 ORCA DUs

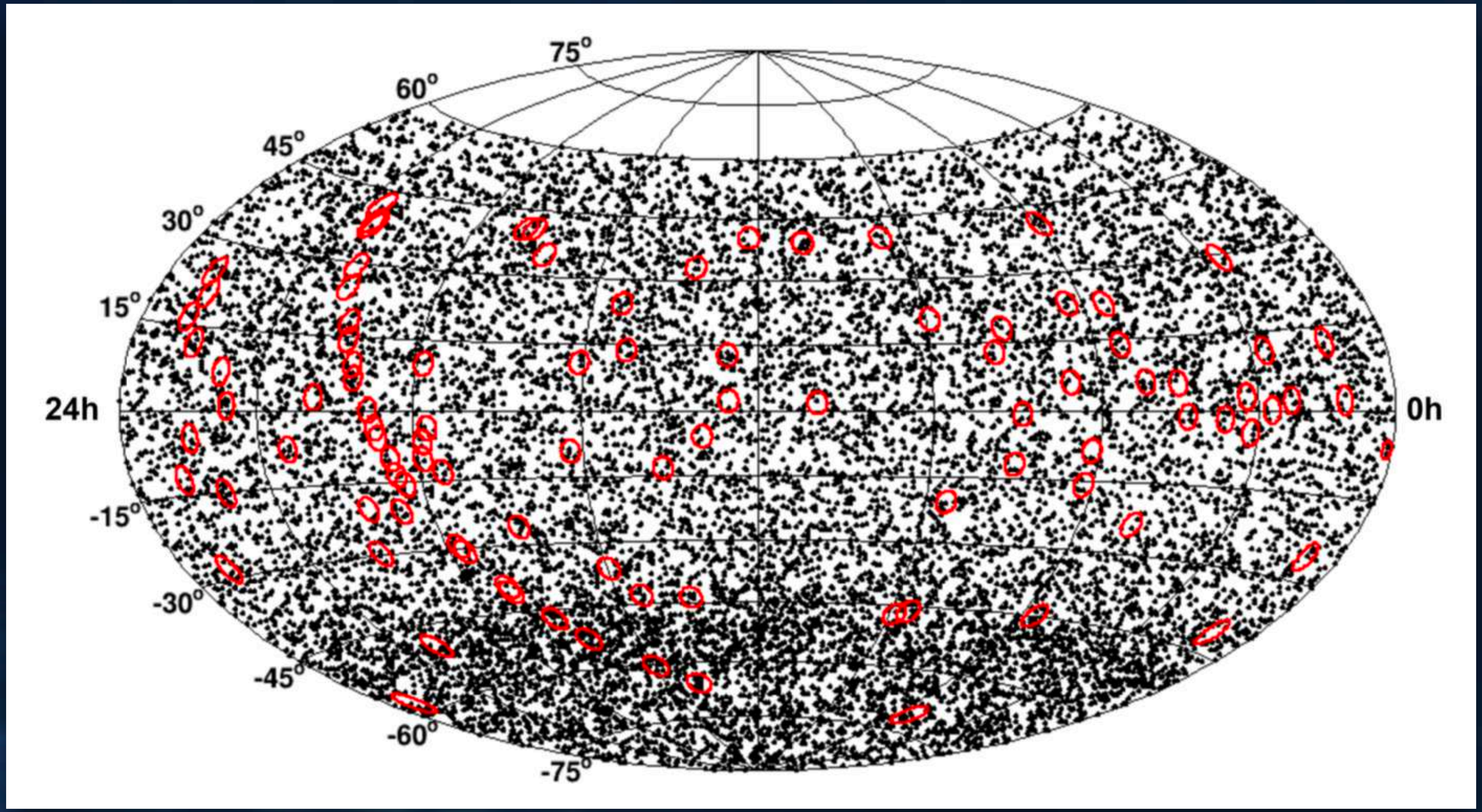
Next sea campaigns:

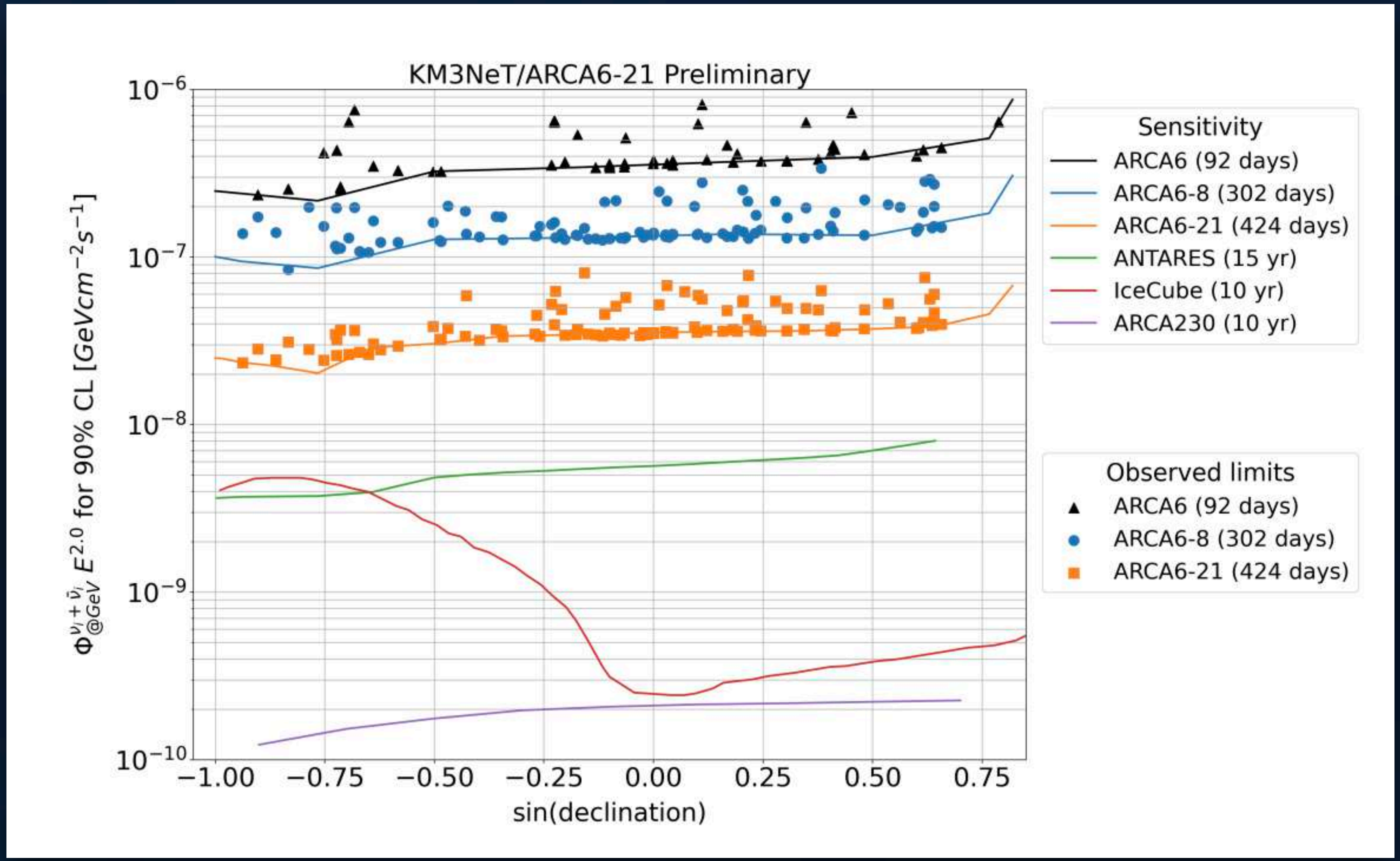
From September to Dicember 2023:
ARCA: 10 DUs
ORCA: 6 DUs + 1 Instrumentation Unit + 1 Calibration Base





Sensitivity to point-like and extended neutrino sources with ARCA





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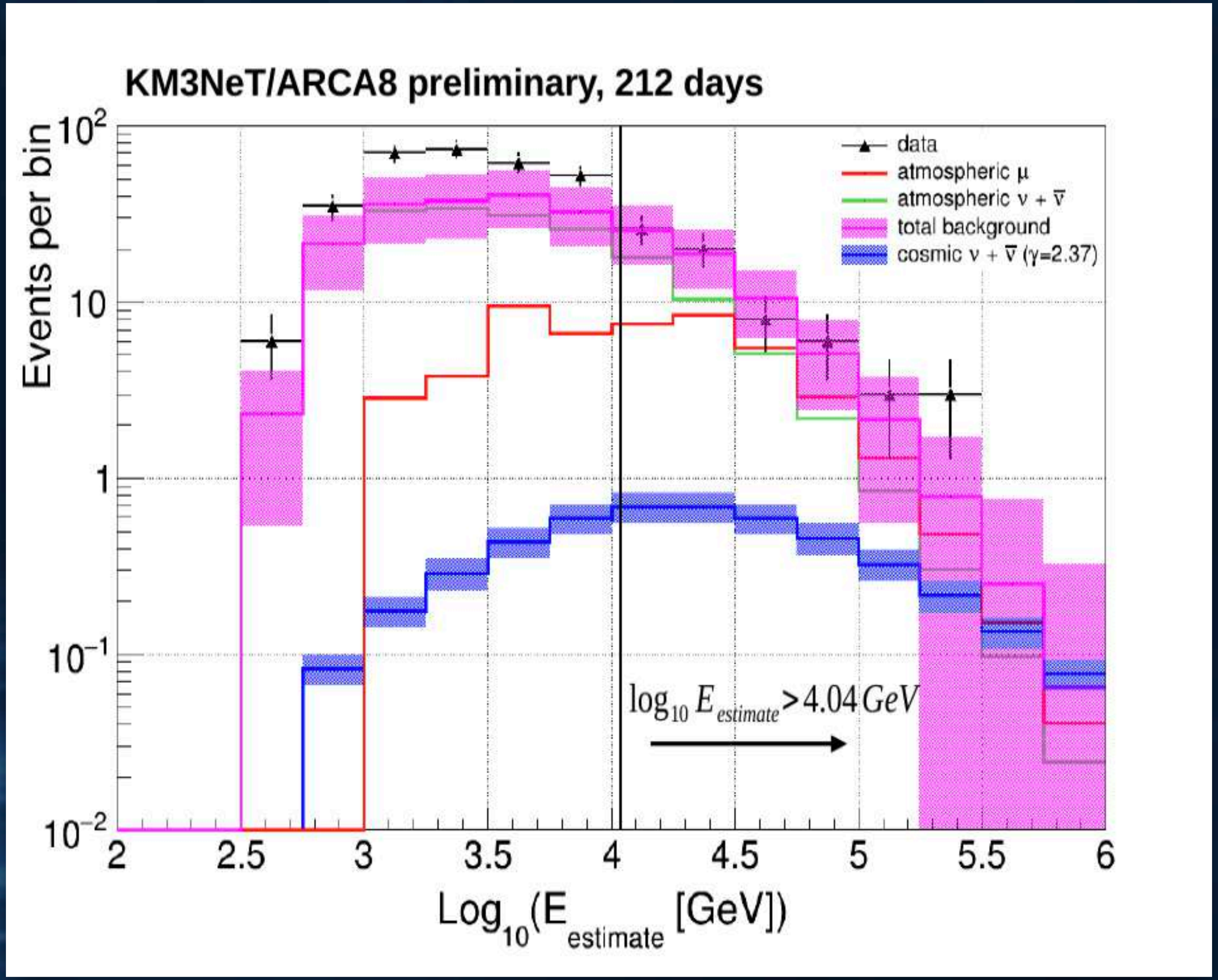
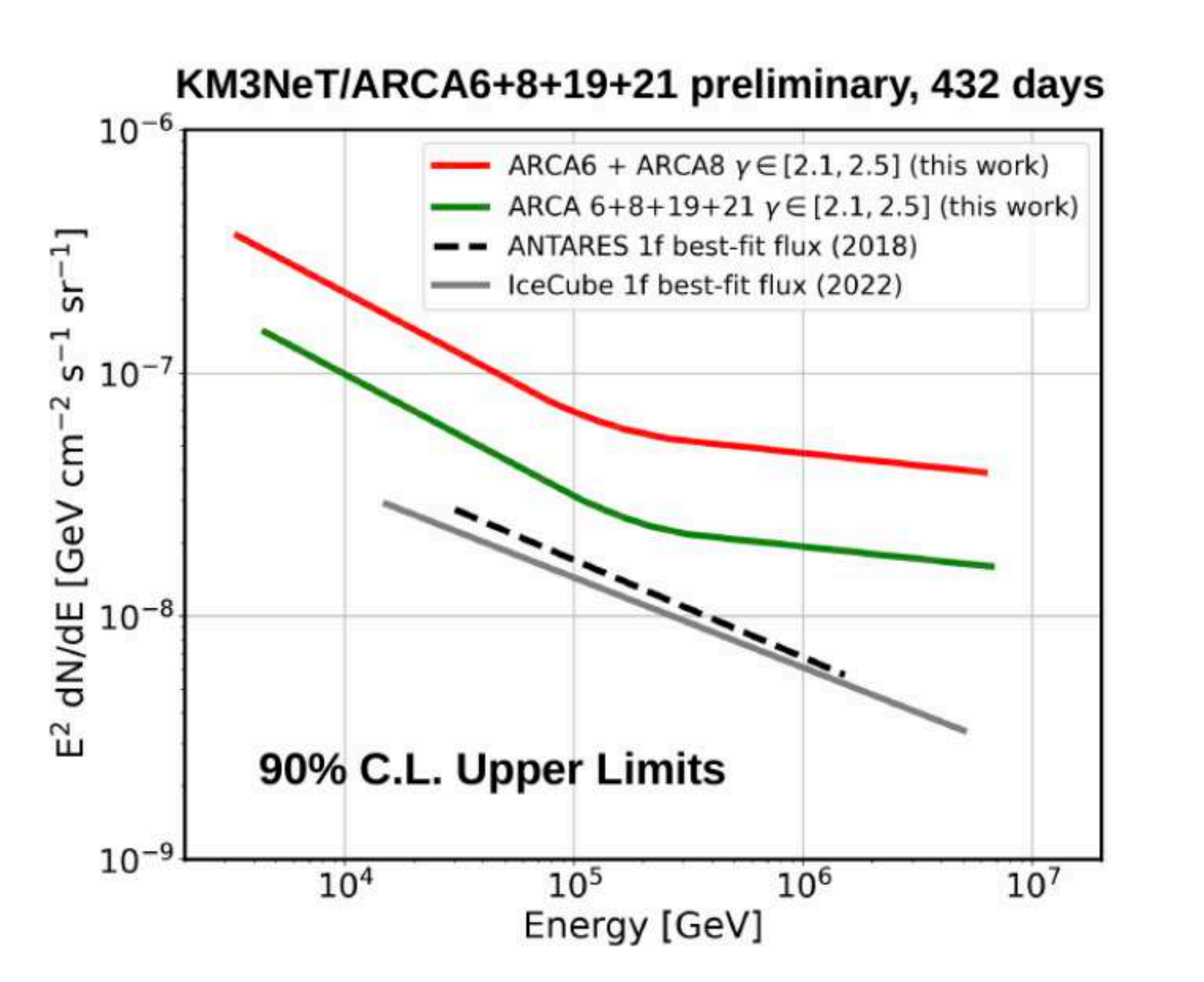
Sensitivity to diffuse astrophysical neutrino fluxes

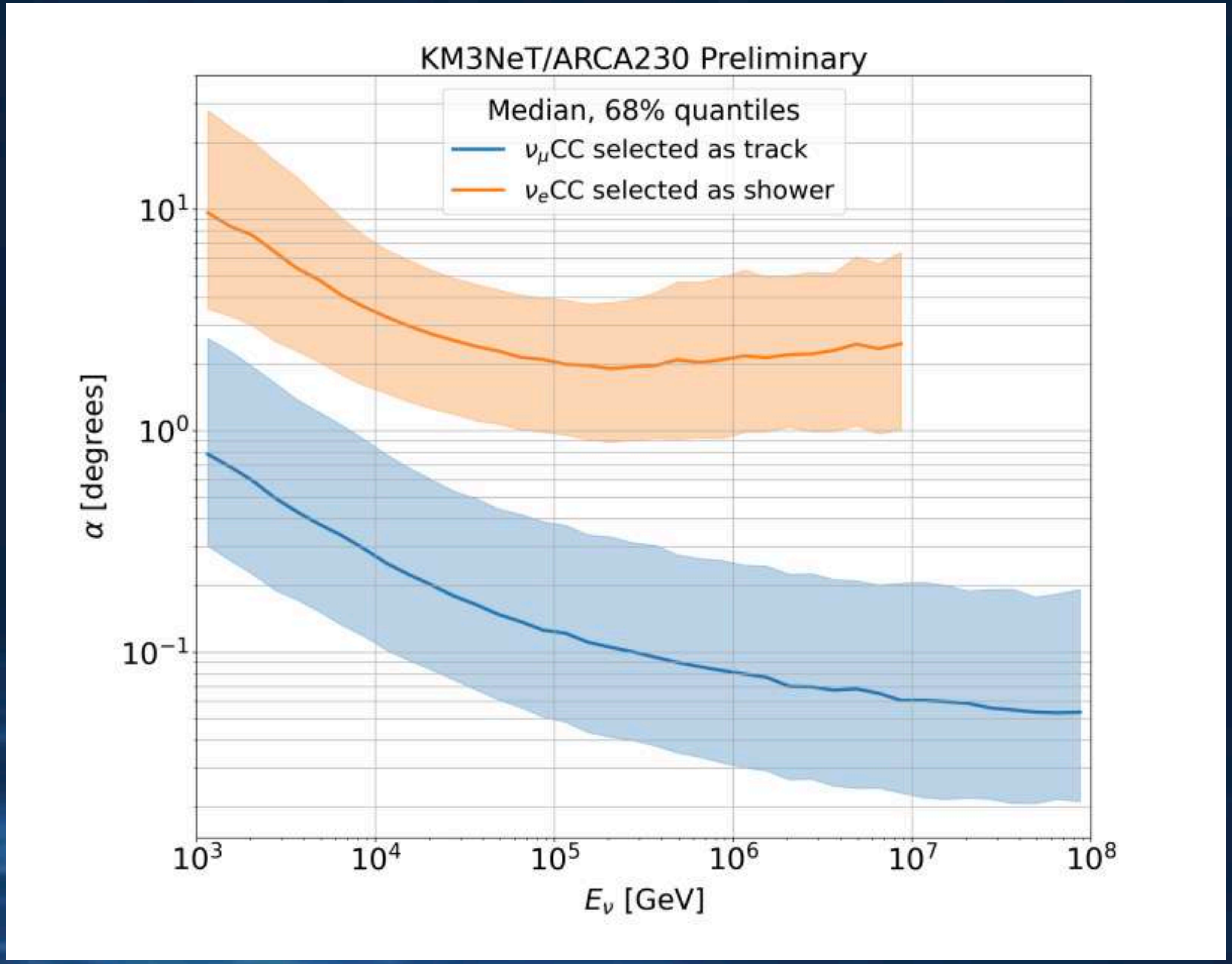
Upper limits to diffuse flux of astrophysical neutrinos assuming IceCube best fit γ = 2.37 and Φ_0= 3.06

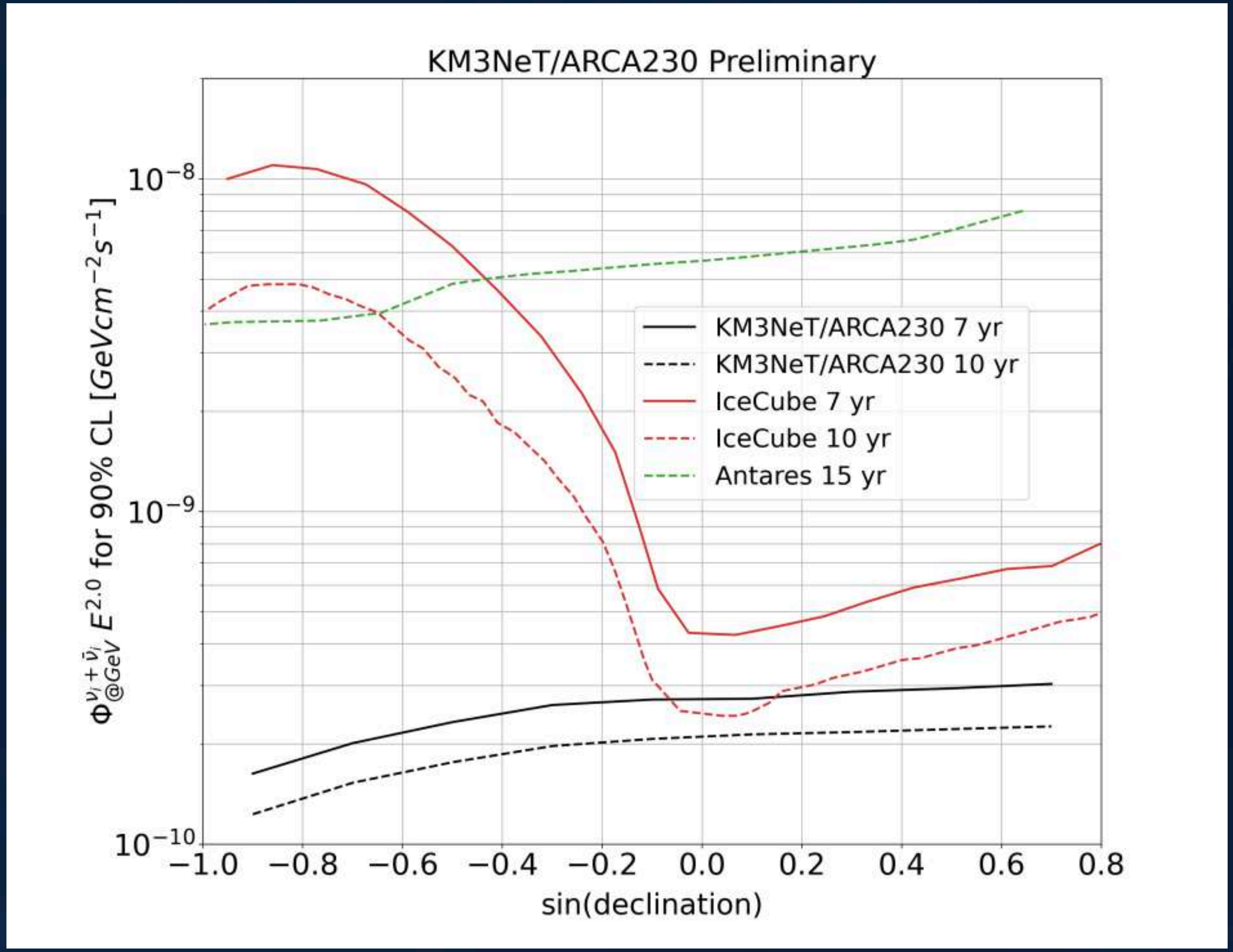
$$\Phi_{\nu+\bar{\nu}}(E) = \frac{dN}{dE} = \phi_0 \cdot 10^{-18} \cdot \left(\frac{E}{100\ \mathrm{TeV}}\right)^{-\gamma} [\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}]$$





Astronomy potential for the full ARCA detector





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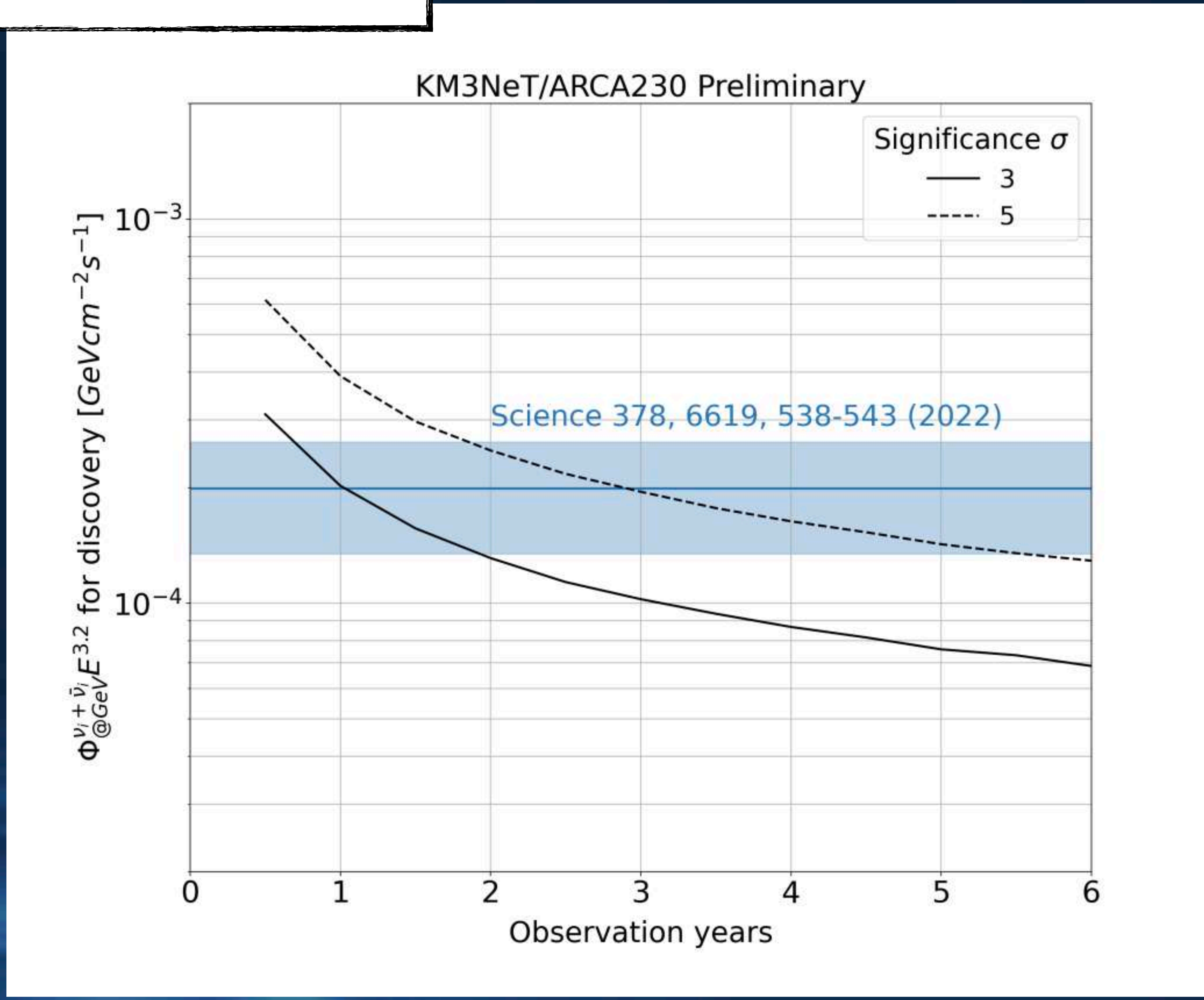
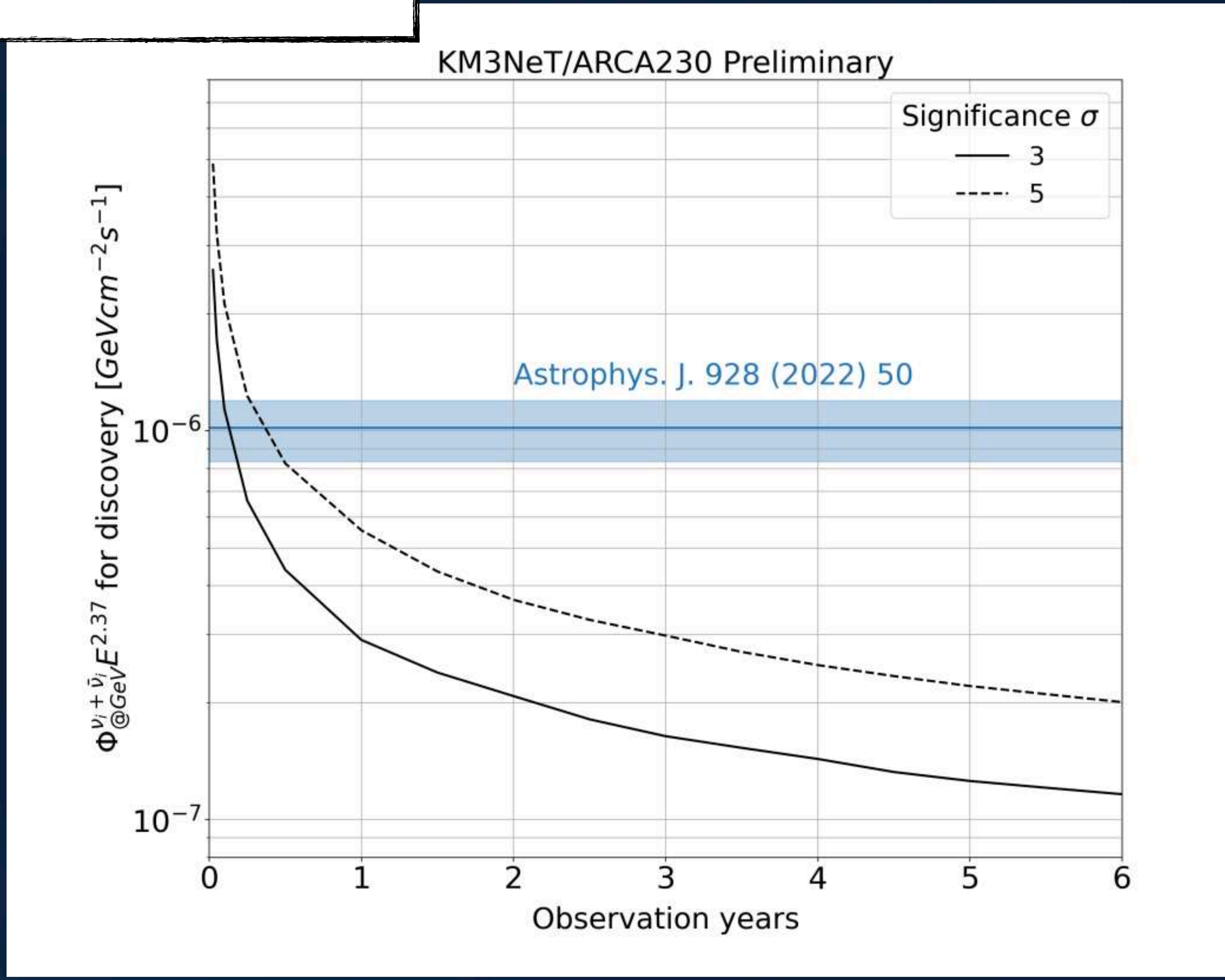
Astronomy potential for the full ARCA detector

NGC 1068



Diffuse flux



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Real time Multi-messenger program

Goals:

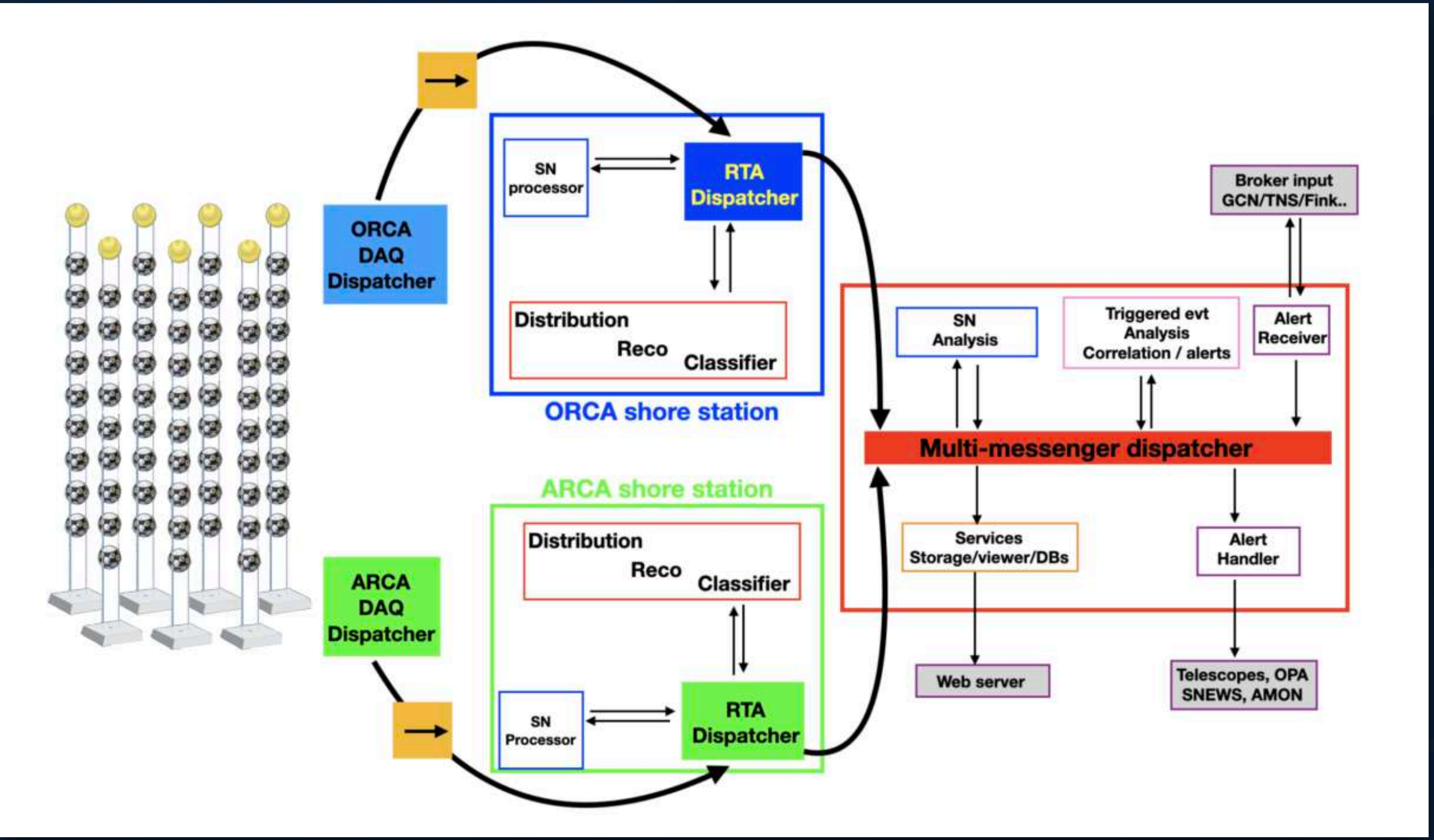
- Trigger neutrino alerts to the astronomy community
- look for time/space coincidence around external electromagnetic and multi-messenger triggers

Based on:

- Fast online reconstruction
- Fast selection of high-purity neutrino sample

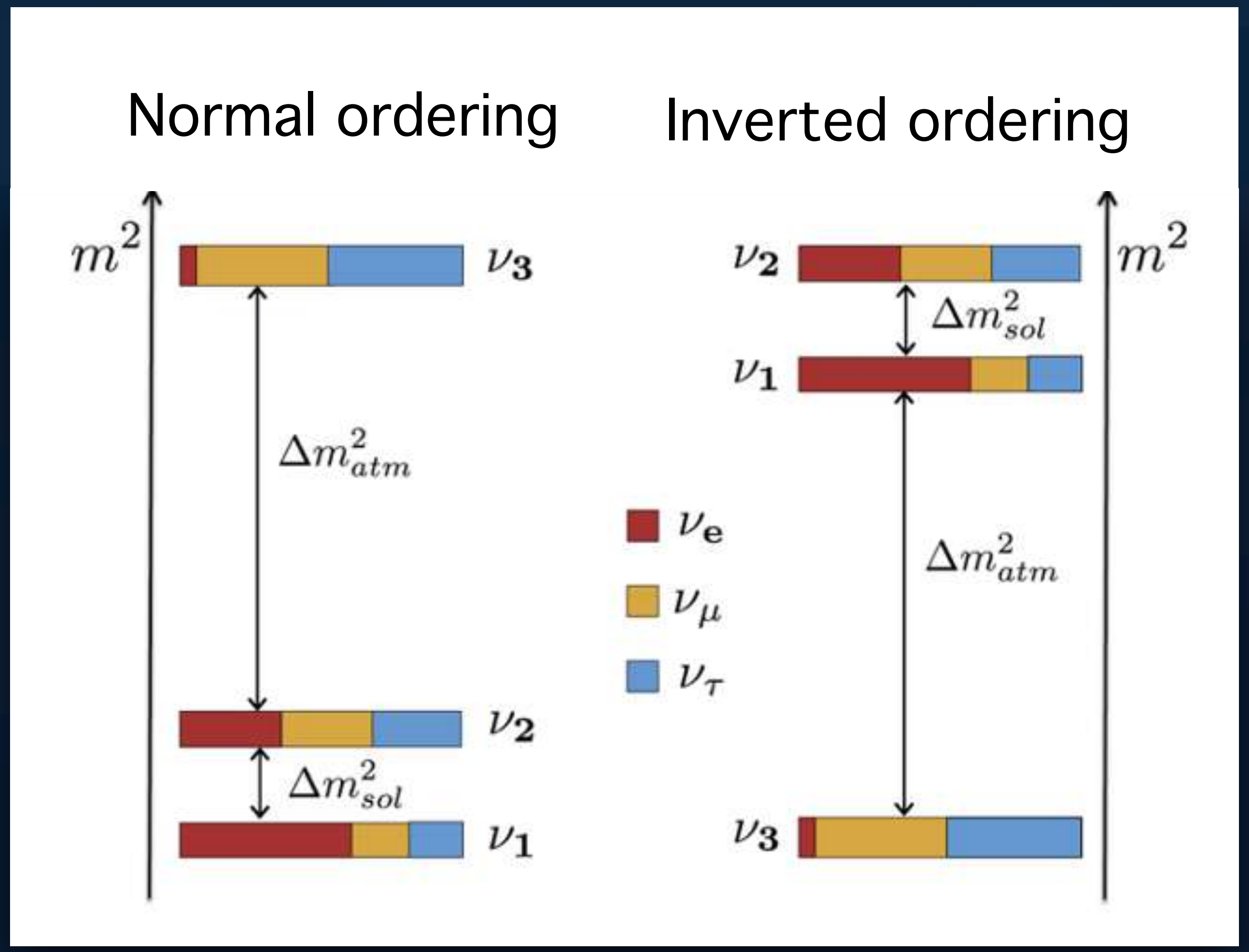
The program is based on two pipelines:

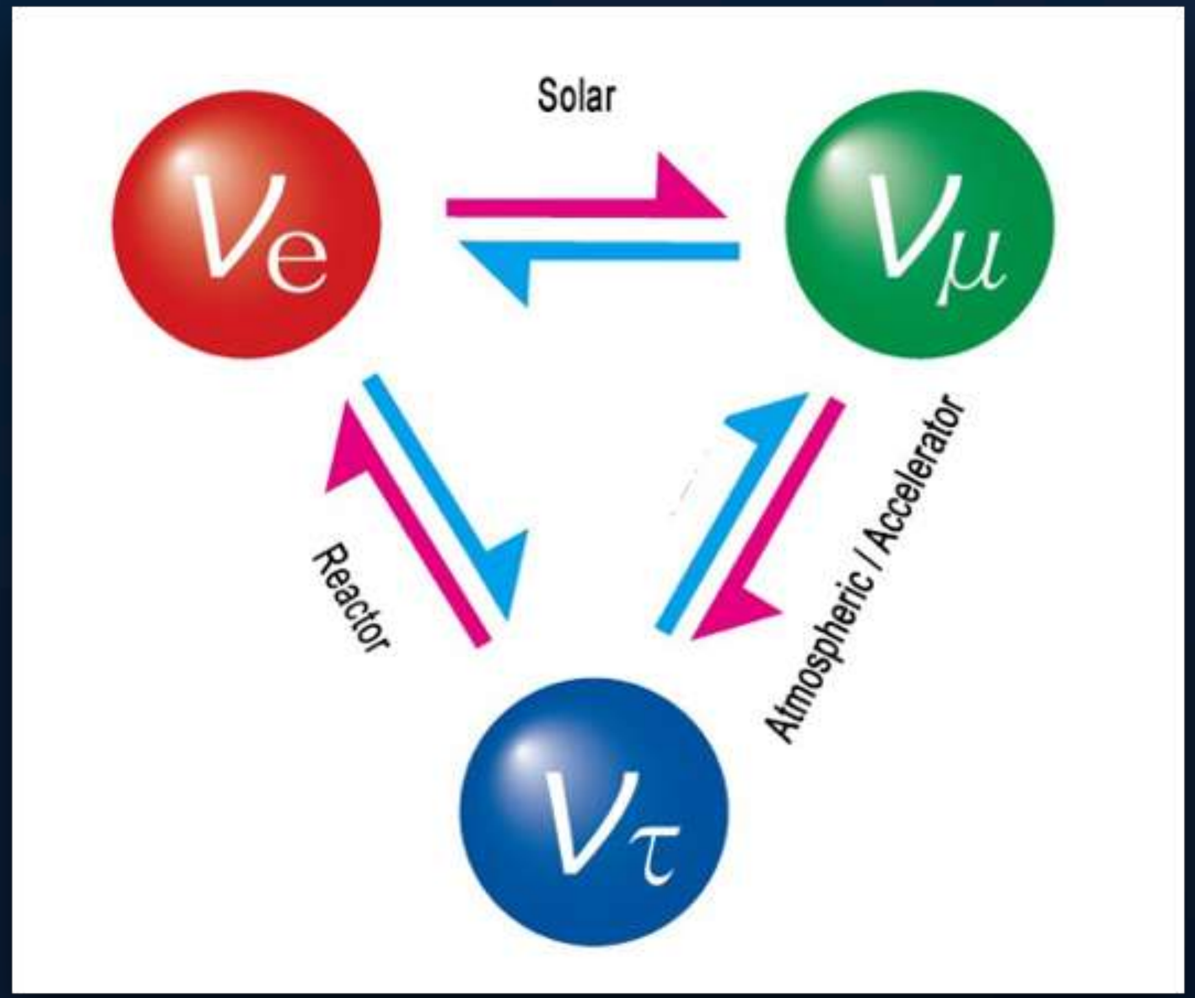
1. The MeV CCSN monitoring pipeline (ORCA)
2. The GeV-PeV neutrino alert pipeline (ARCA)



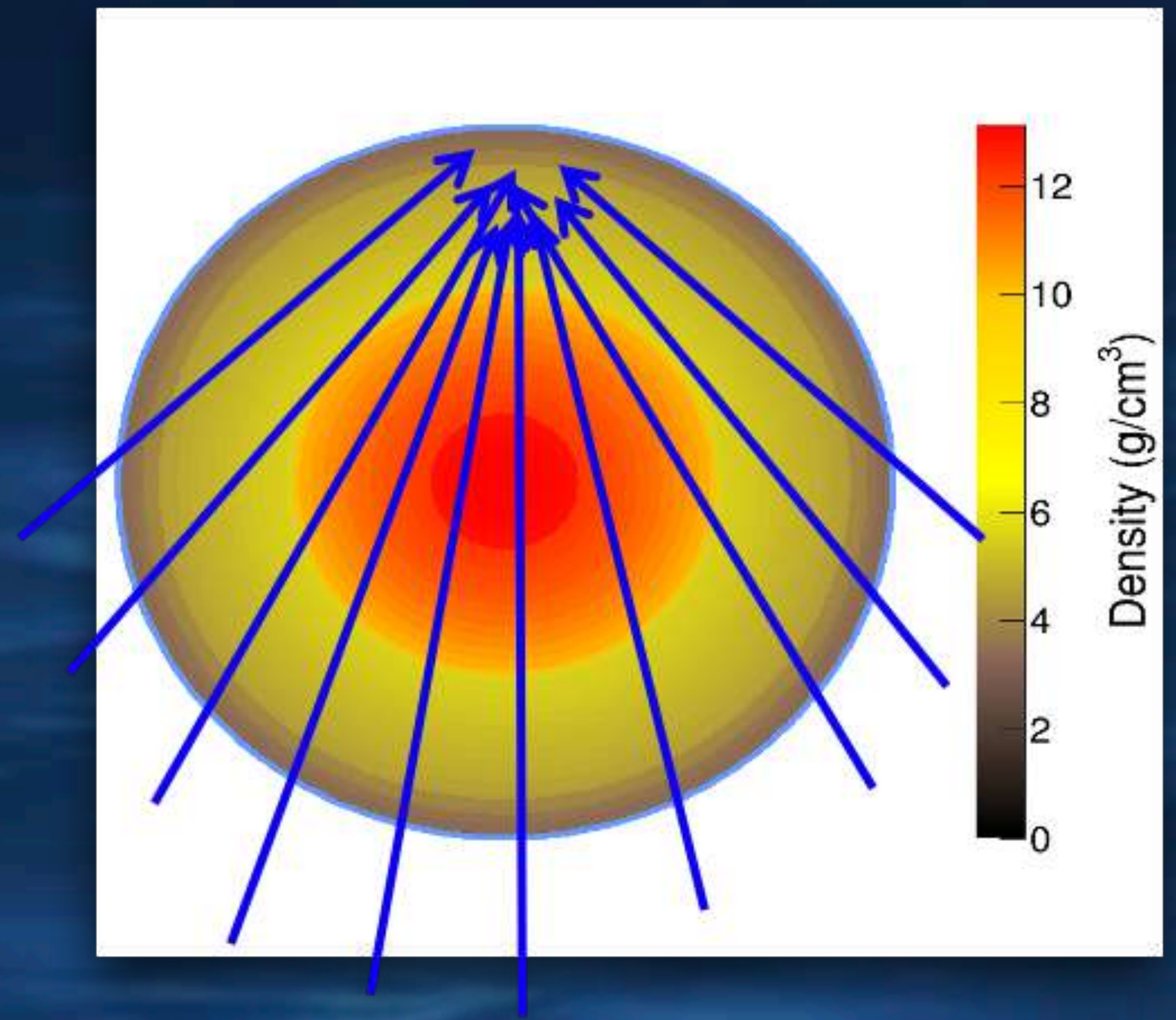
ORCA: neutrino oscillation with atmospheric neutrinos

- Goals: determine the neutrino mass ordering and measuring atmospheric neutrino oscillations

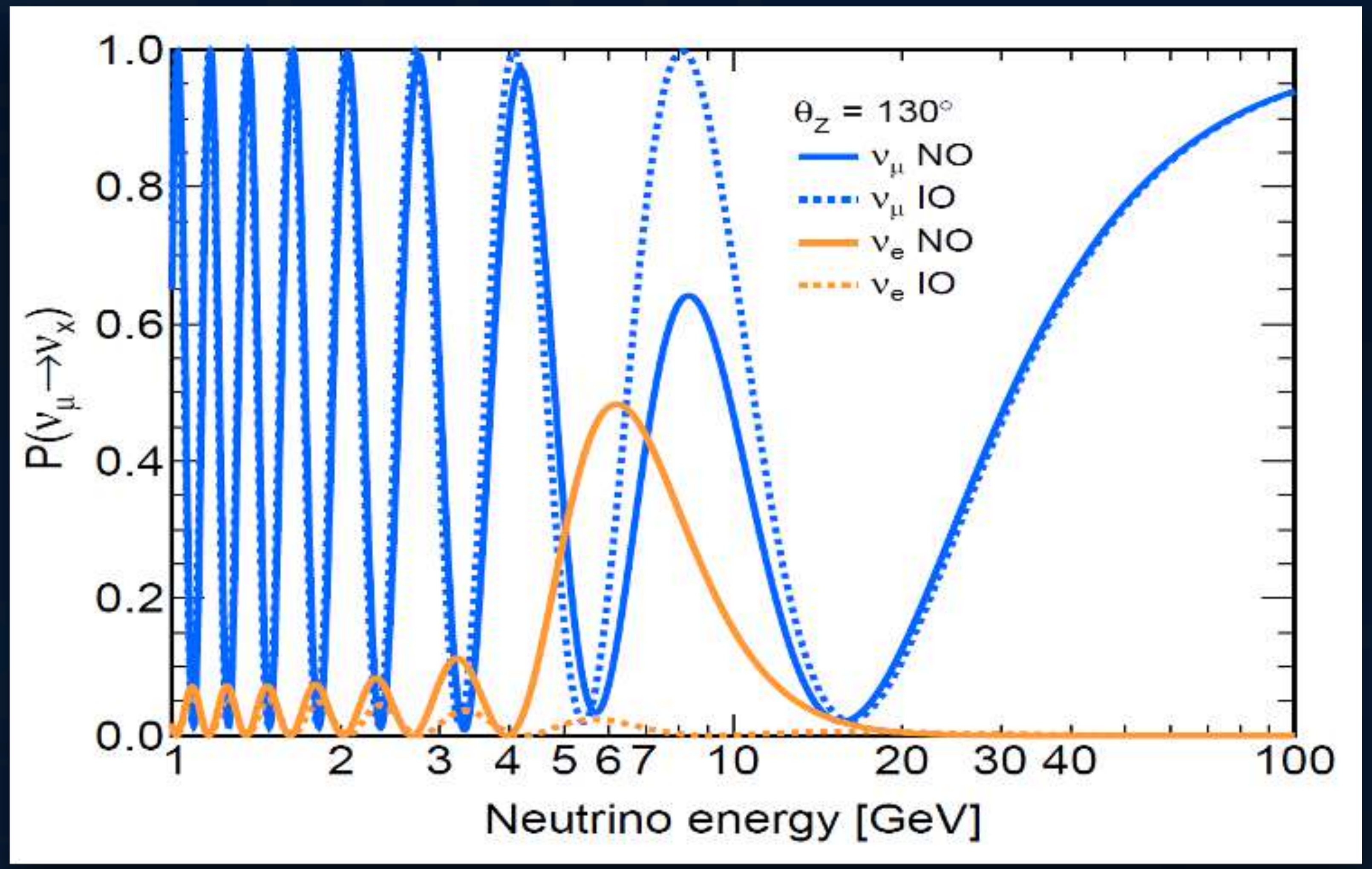




- The experiment focuses on the measurement of the energy- and zenith-angle-dependent oscillation patterns of cosmic-ray-induced neutrinos with a few-GeV energy that originate in the atmosphere and traverse the Earth

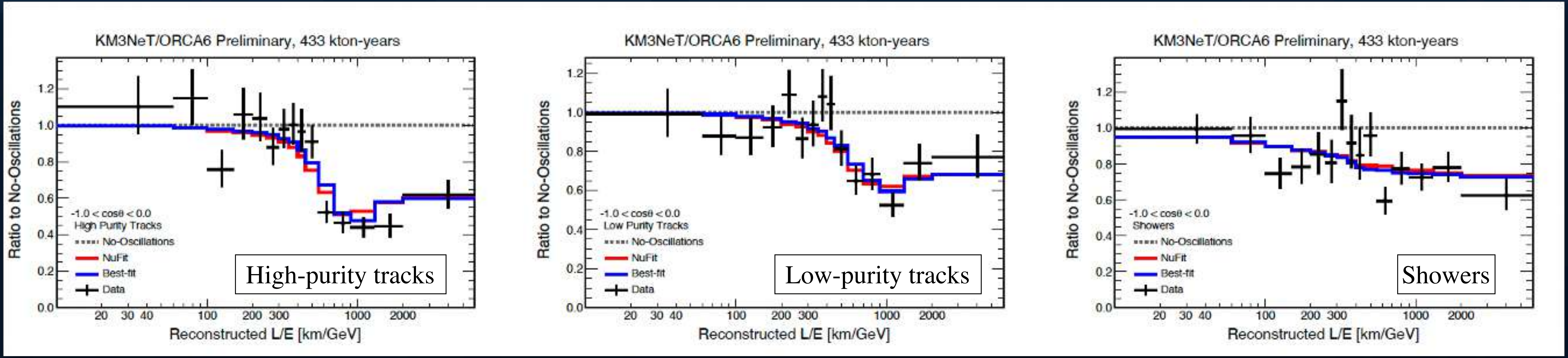


- The power to distinguish between the two different mass orderings is linked to the detection of an excess or deficit of neutrino events in different regions of these oscillation patterns.



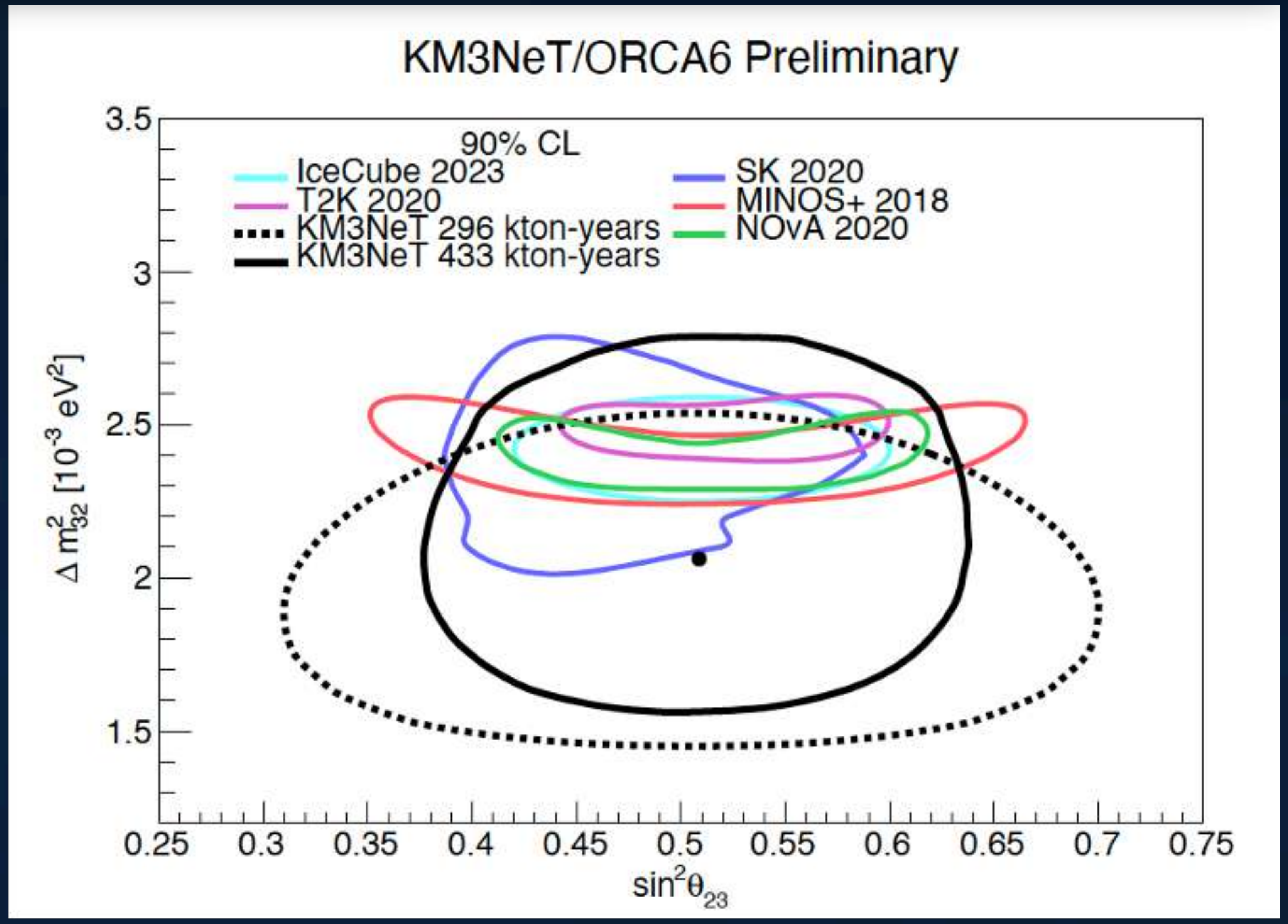
ORCA6: neutrino oscillation with atmospheric neutrinos

Oscillations are seen with significance > 6σ in L/E distributions

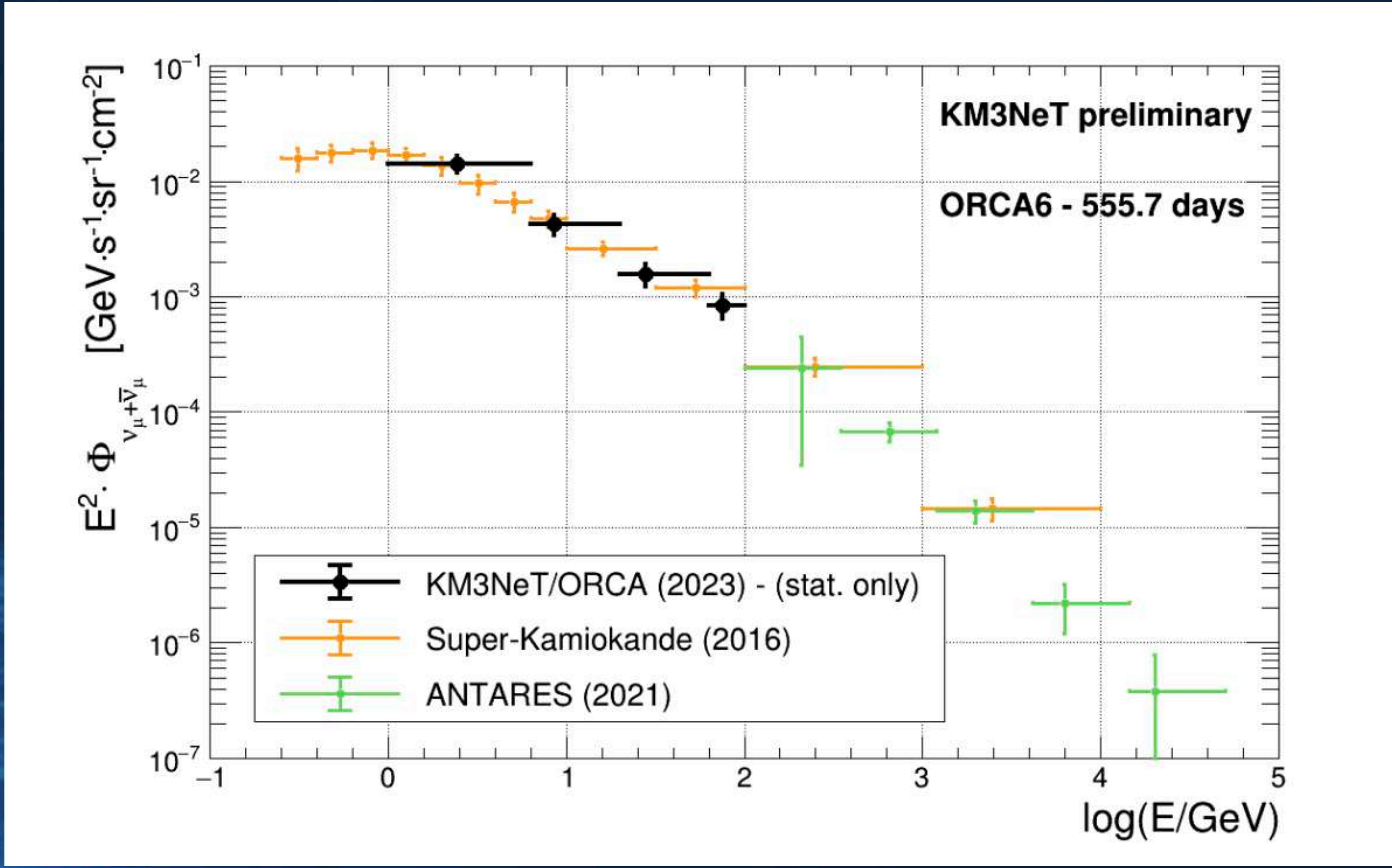


Best fit: $\sin^2\theta_{23} = 0.51^{+0.06}_{-0.07}$ $\Delta m^2_{23} = 2.14^{+0.36}_{-0.25} \cdot 10^{-3}\mathrm{eV}^2$

Normal ordering is preferred



Measurement of the atmospheric muon neutrino flux with ORCA6



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Summary & Outlook

KM3NeT/ARCA: current status 21 DUs, effective area already better than ANTARES

The good angular resolution will let KM3NeT/ARCA to contribute to the neutrino astronomy

- detection of the diffuse flux observed by IceCube with 5σ significance in less than a year
- sensitivity to astrophysical sources in the Southern Hemisphere improves by almost 2 orders of magnitude with respect to IceCube
- multi-messenger program

KM3NeT/ORCA: current status 20 DUs

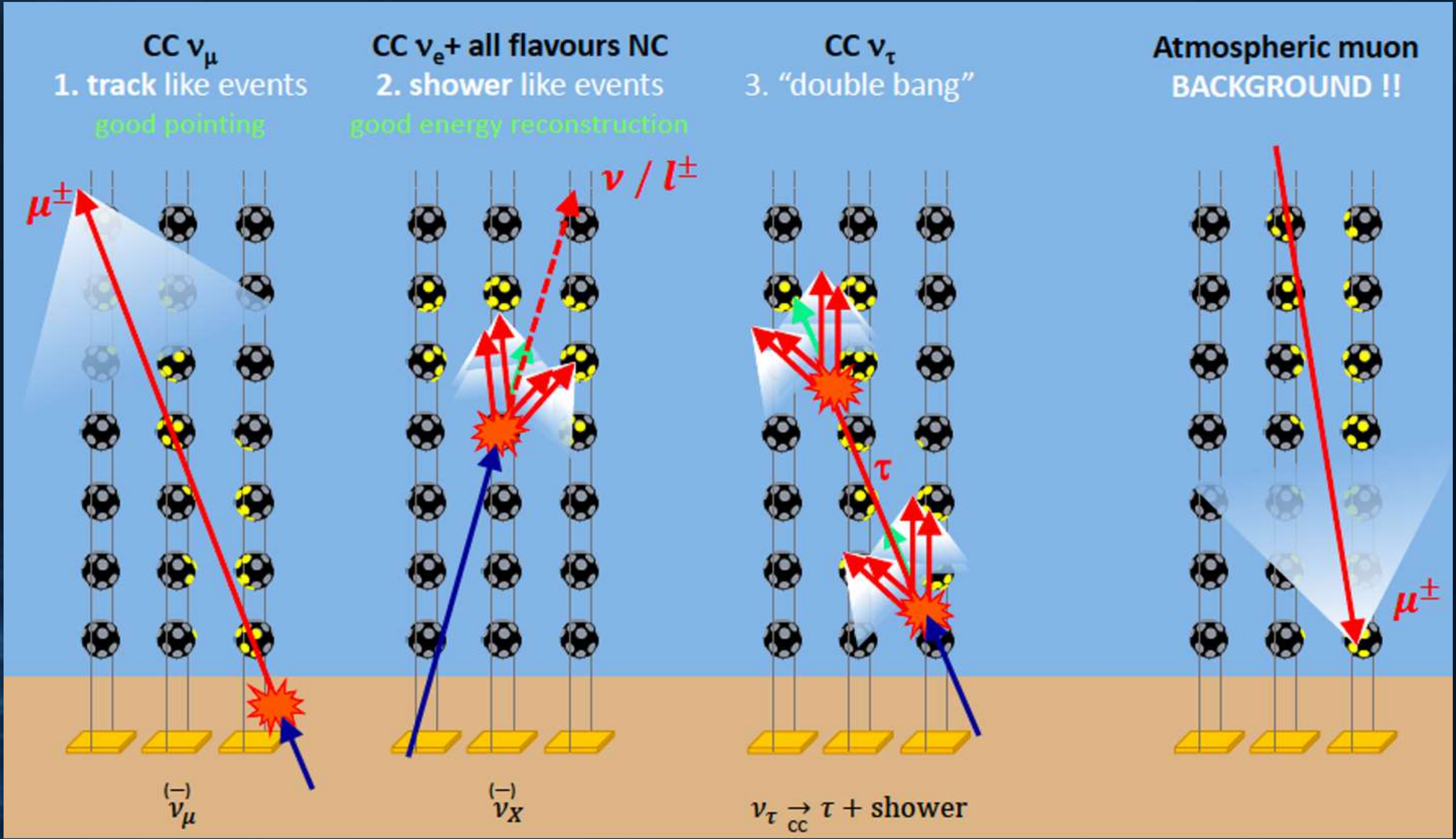
Measurement of neutrino oscillations and best fit of oscillation parameters
Search for new physics: physics beyond the Standard Model

KM3NeT infrastructure procurement and construction in progress

Funding assured for ~125 ARCA DUS and ~50 ORCA DUs ....improved results soon!!!

Backup slides

Event topologies

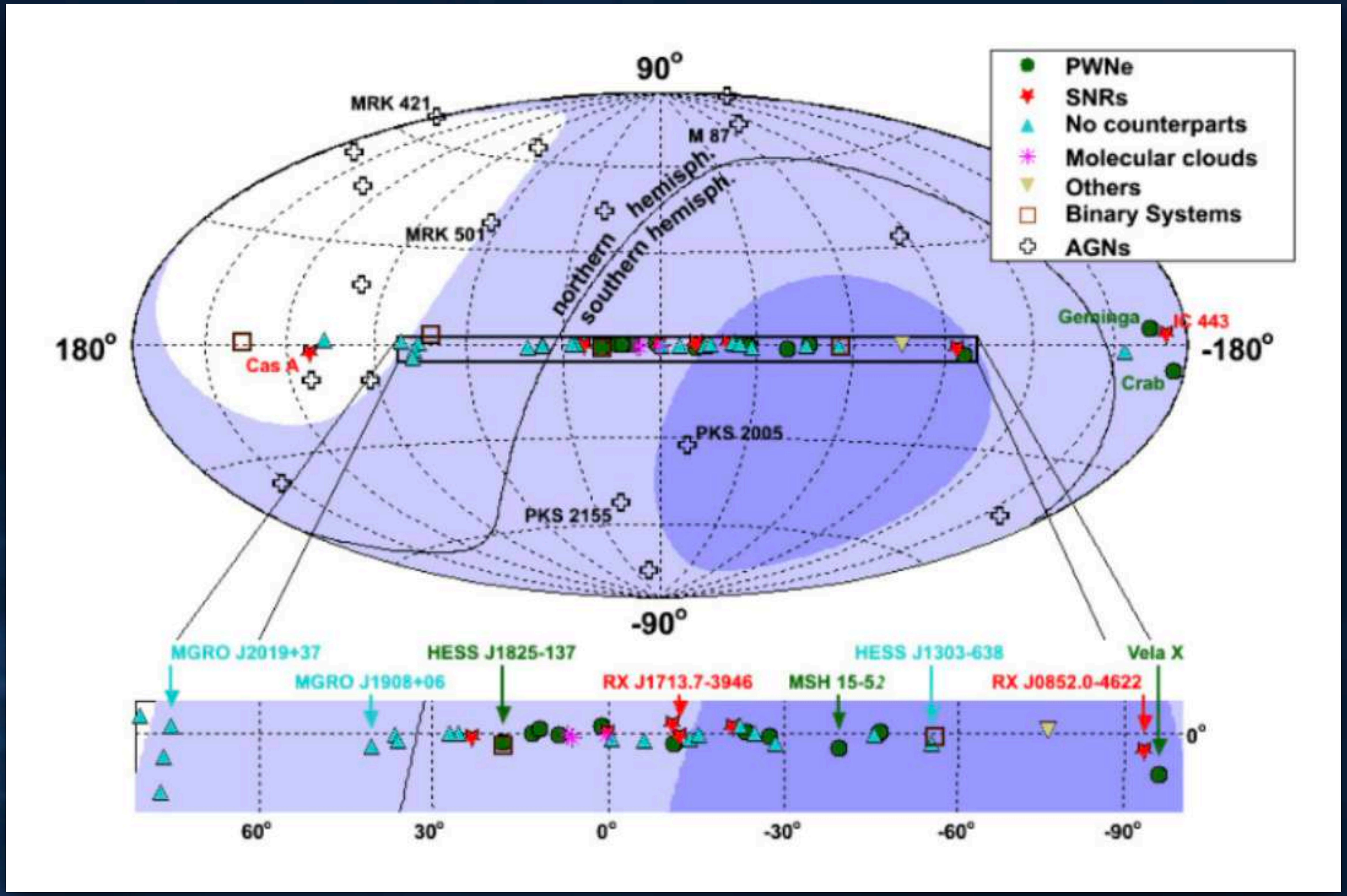


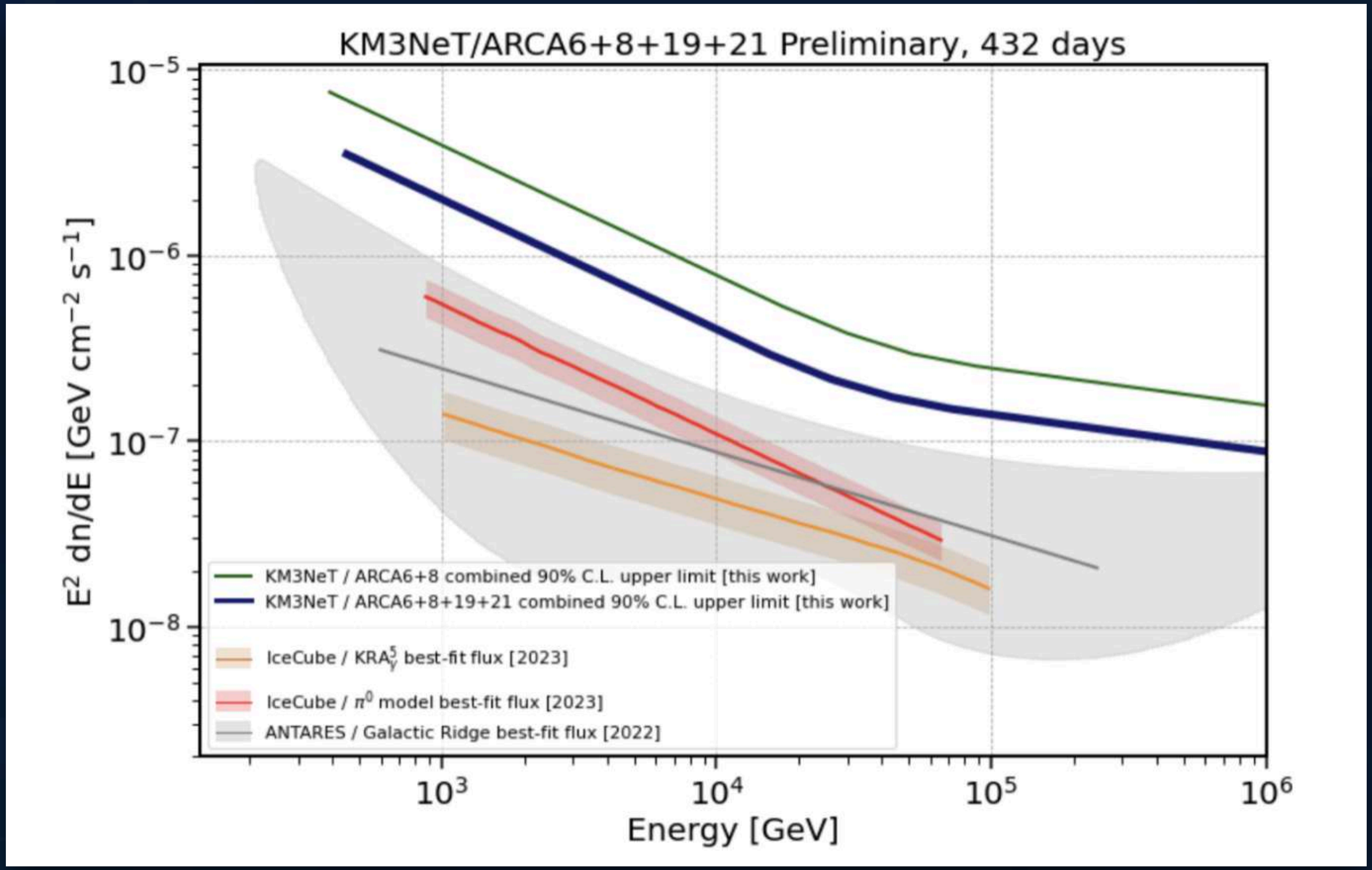
Search for diffuse astrophysical neutrino flux from the Galactic Ridge with ARCA

The methodology adopted for the analysis is an on-off technique

Neutrino signal follows a power-law energy spectrum with E0 = 40 TeV

$$\Phi_\nu(E) = \frac{dN_\nu}{dE_\nu} = \Phi_0 \times \left(\frac{E_\nu}{E_0}\right)^{-\Gamma_\nu}$$





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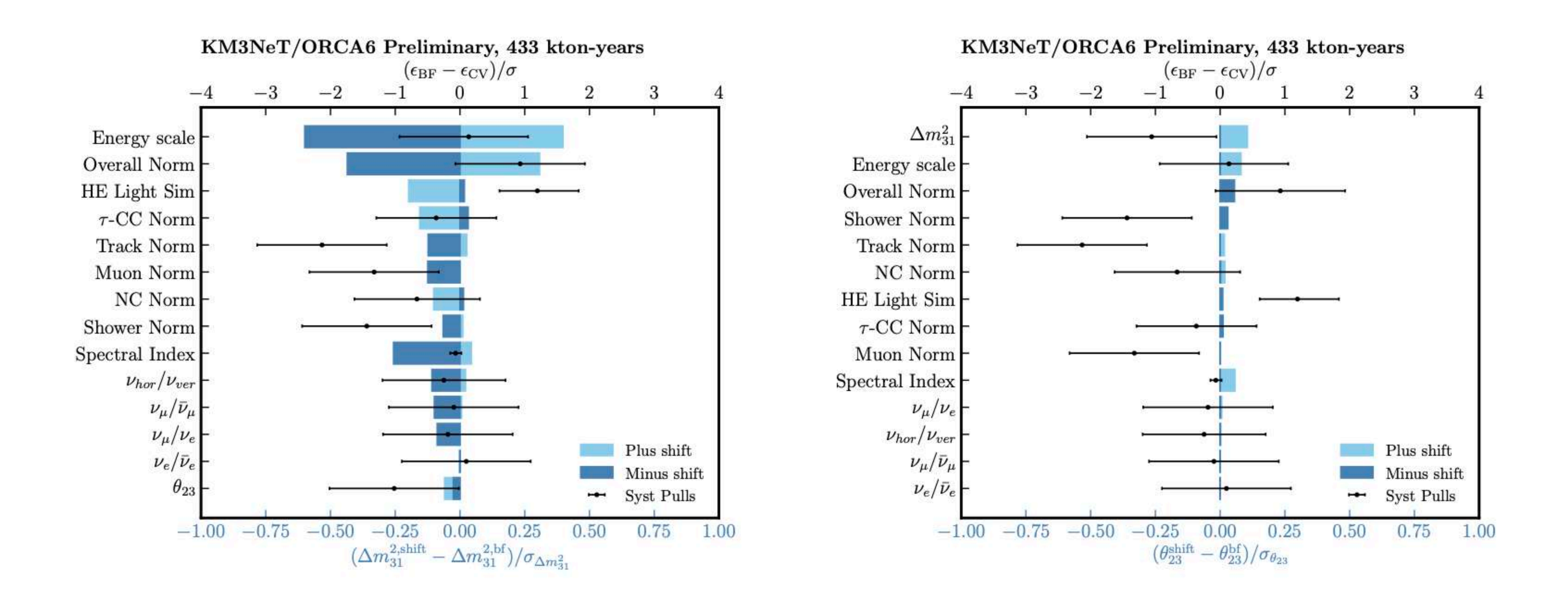
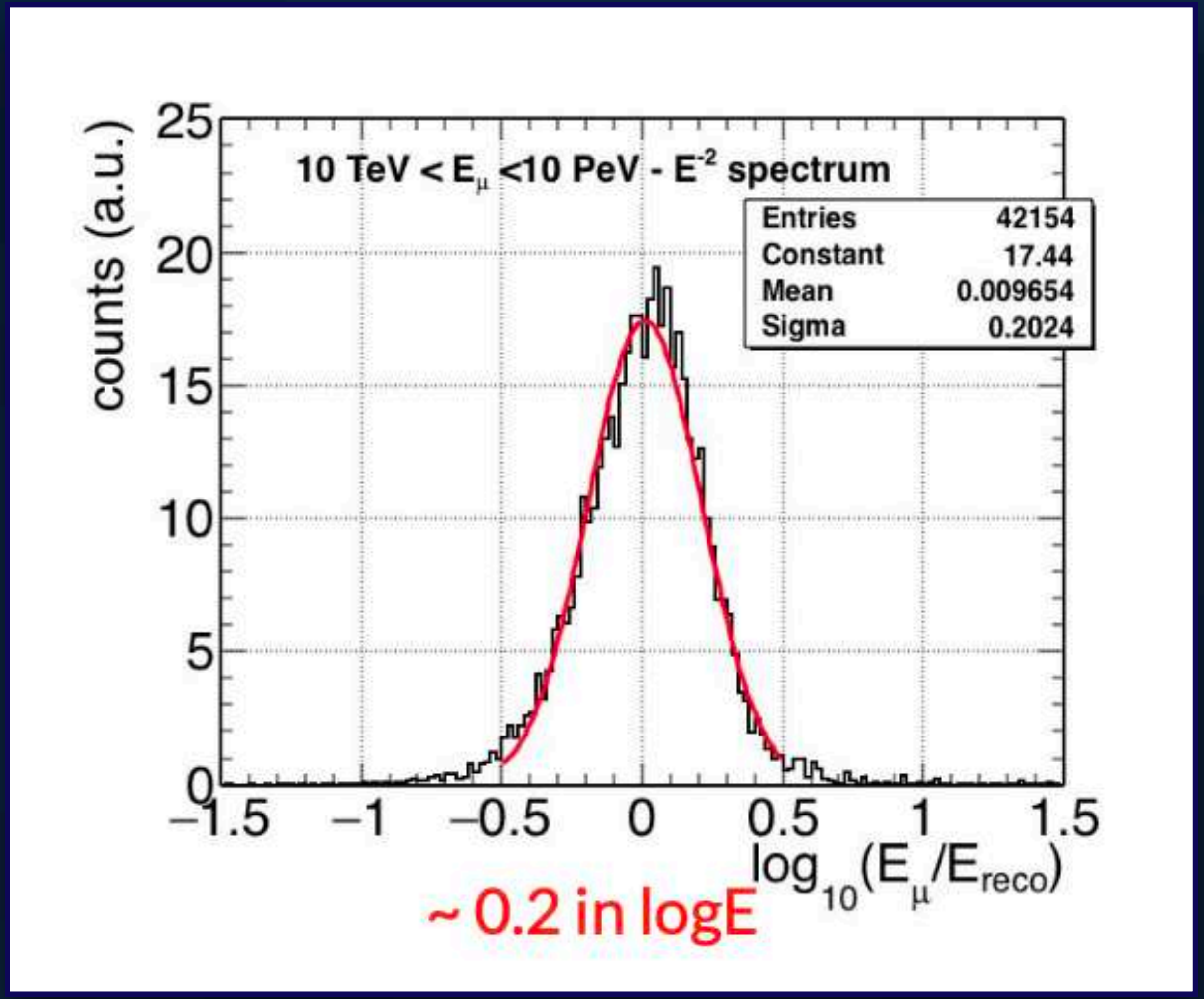
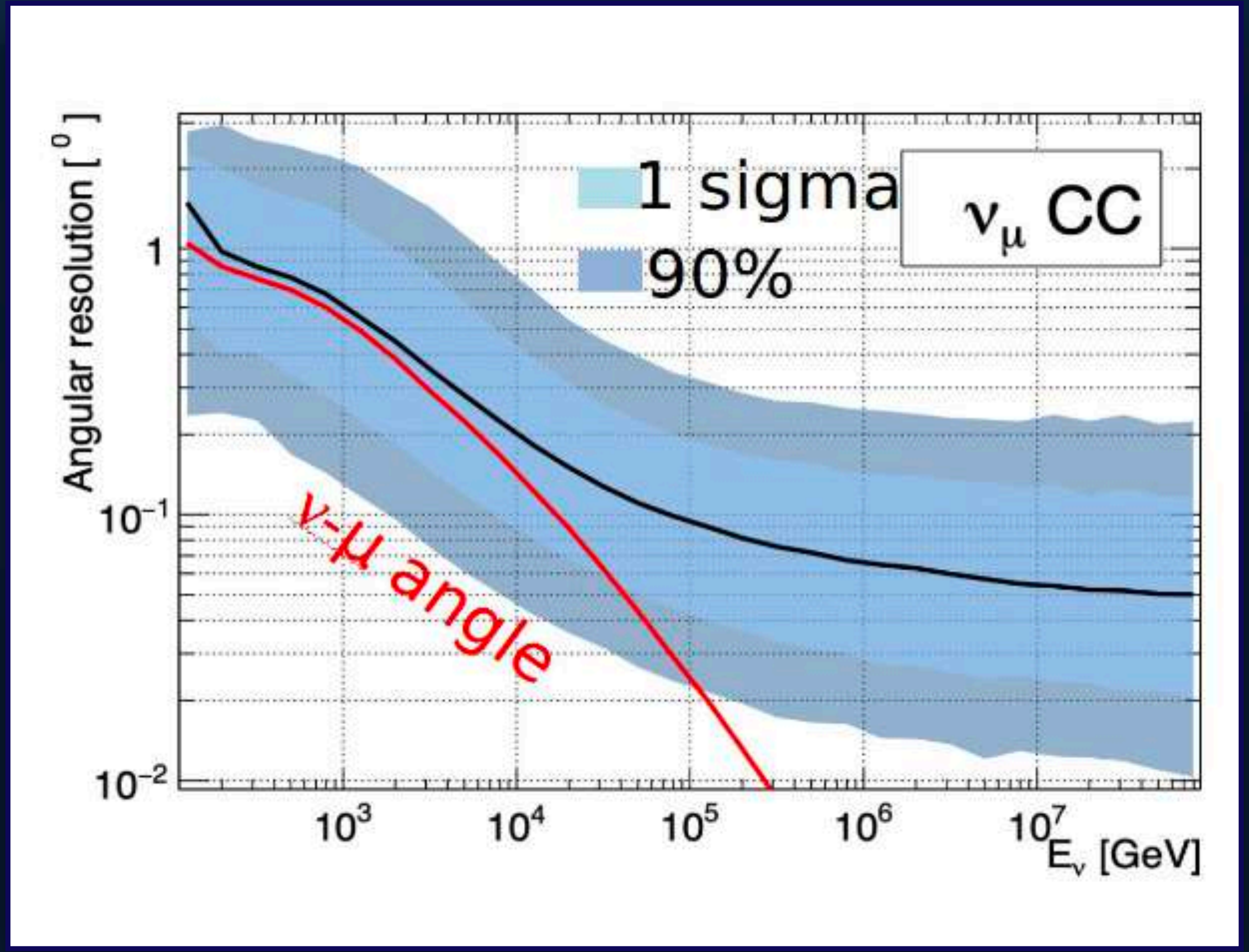
ORCA6: neutrino fit systematics uncertainties



ARCA reconstruction resolutions

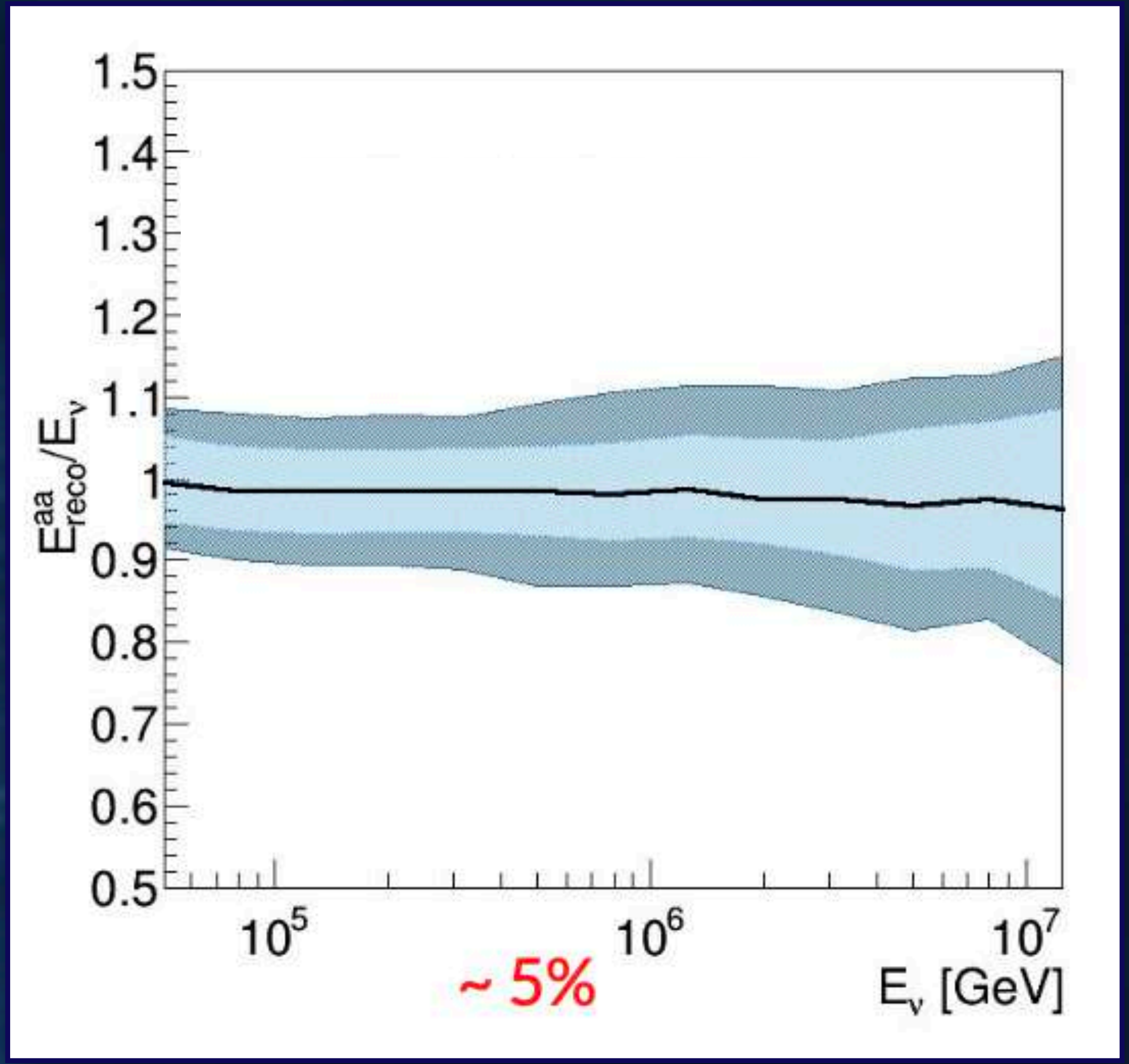
- Track:

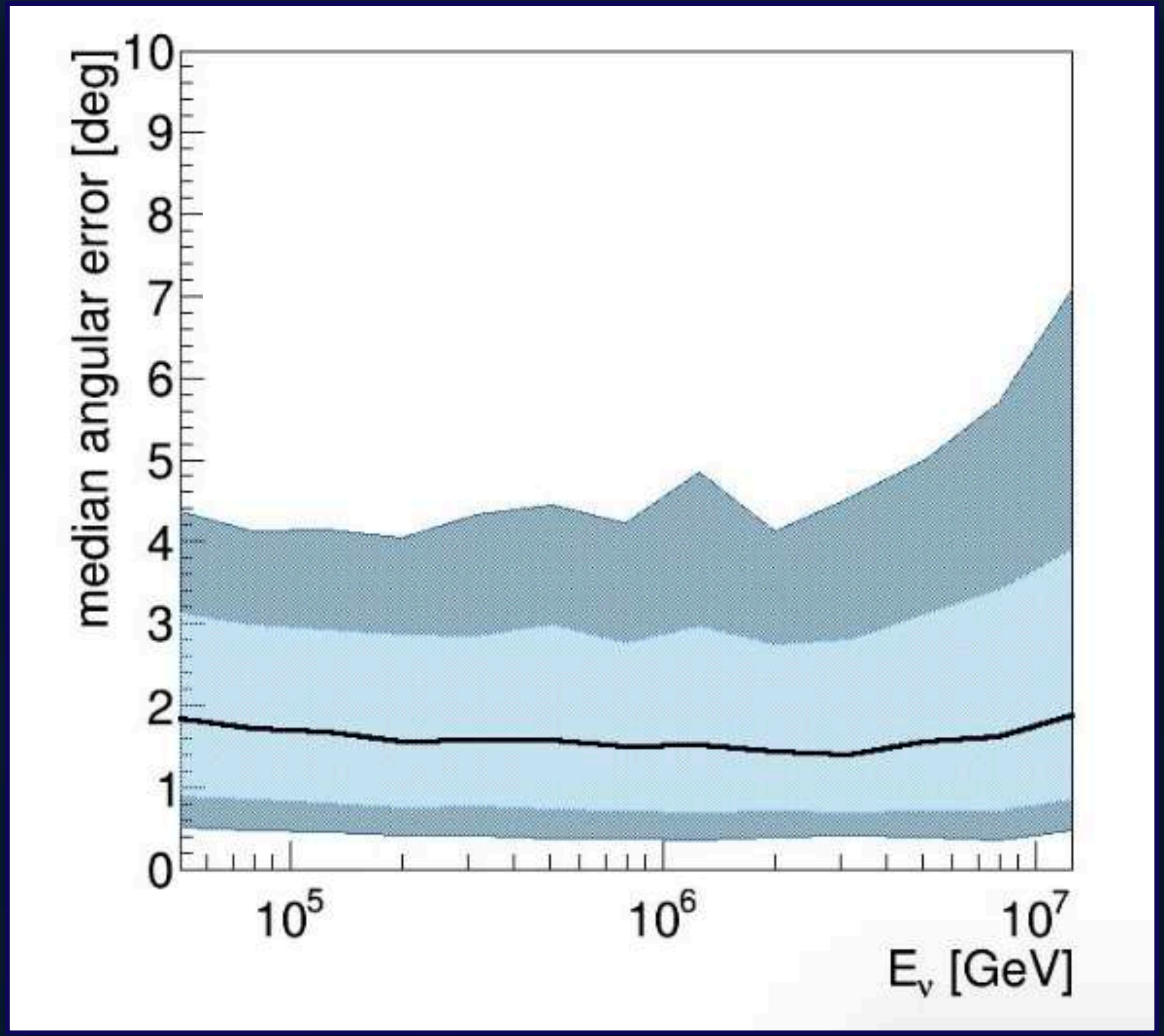




Track median angular resolution < 0.1º at E>100 TeV

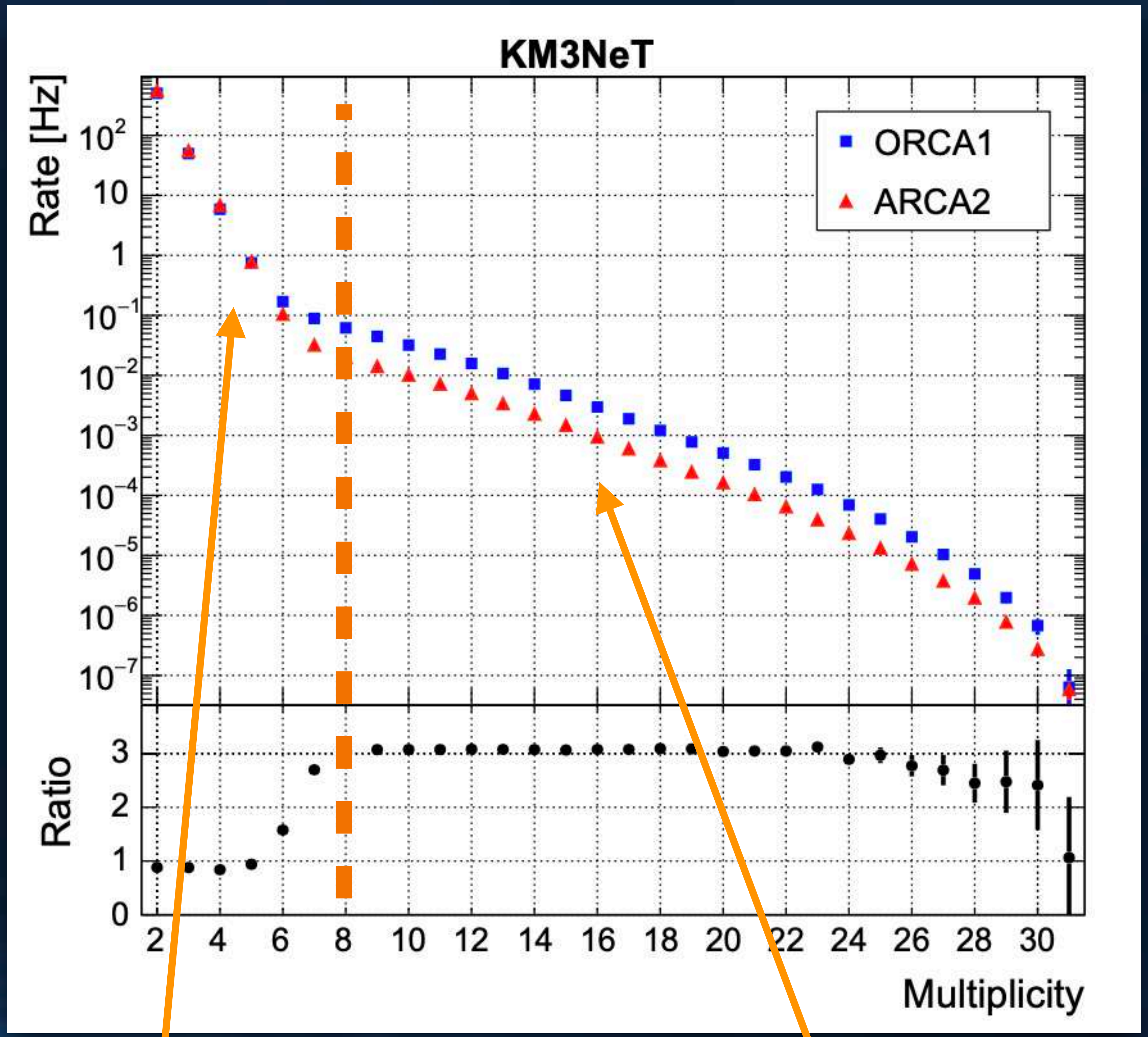
- Shower:





Shower median angular resolution < 2º

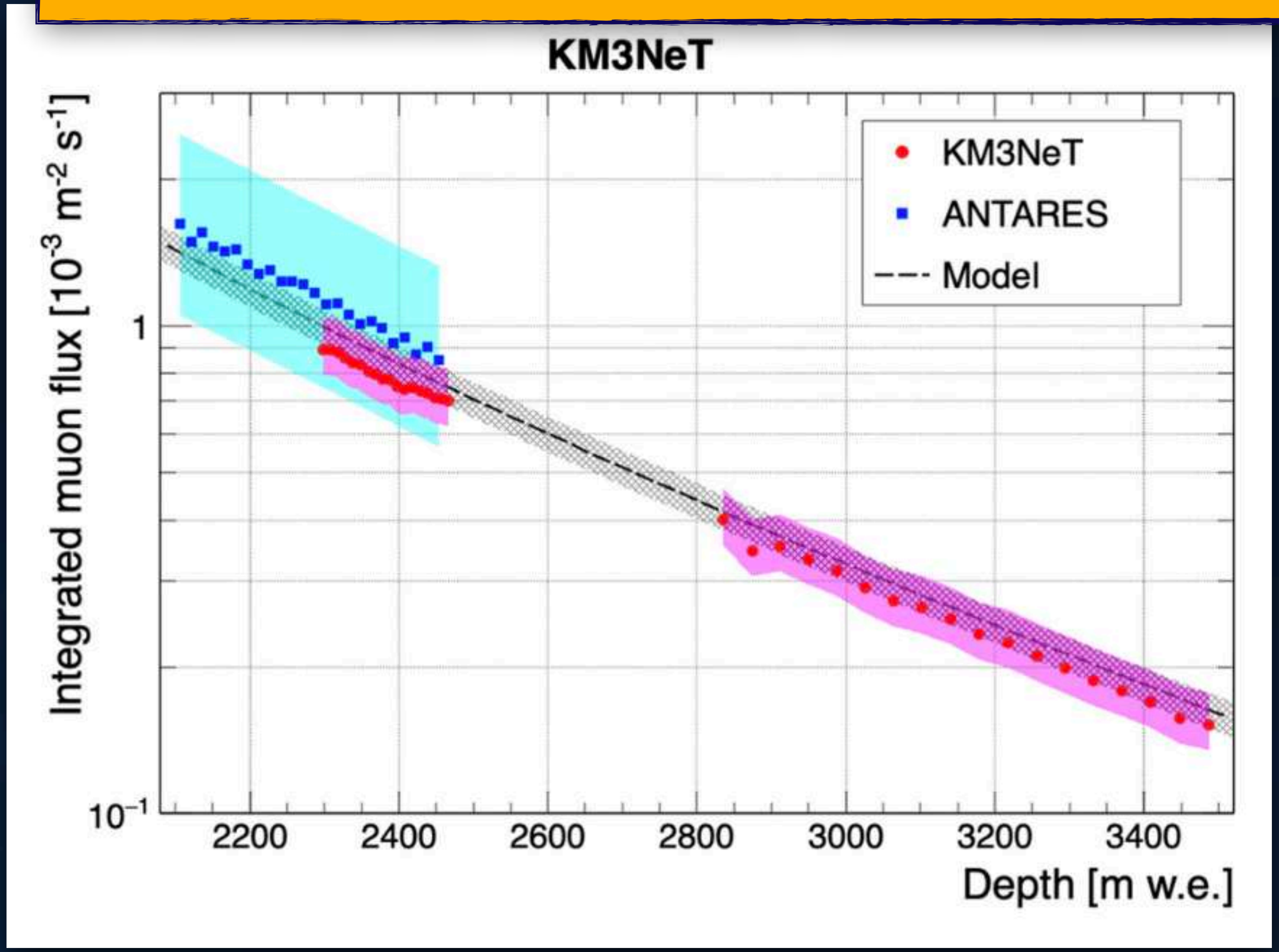
Measurement of atmospheric muon flux



Optical background (^{40}K)

Atmospheric muons

- Measurement of single DOM coincidences
- Validation of the KM3NeT calibration procedure
- muon flux measurement compatible with Bugaev model and ANTARES data



Ageron et al. [KM3NeT Coll.], Eur. Phys. J. C 80 (2020) 99