

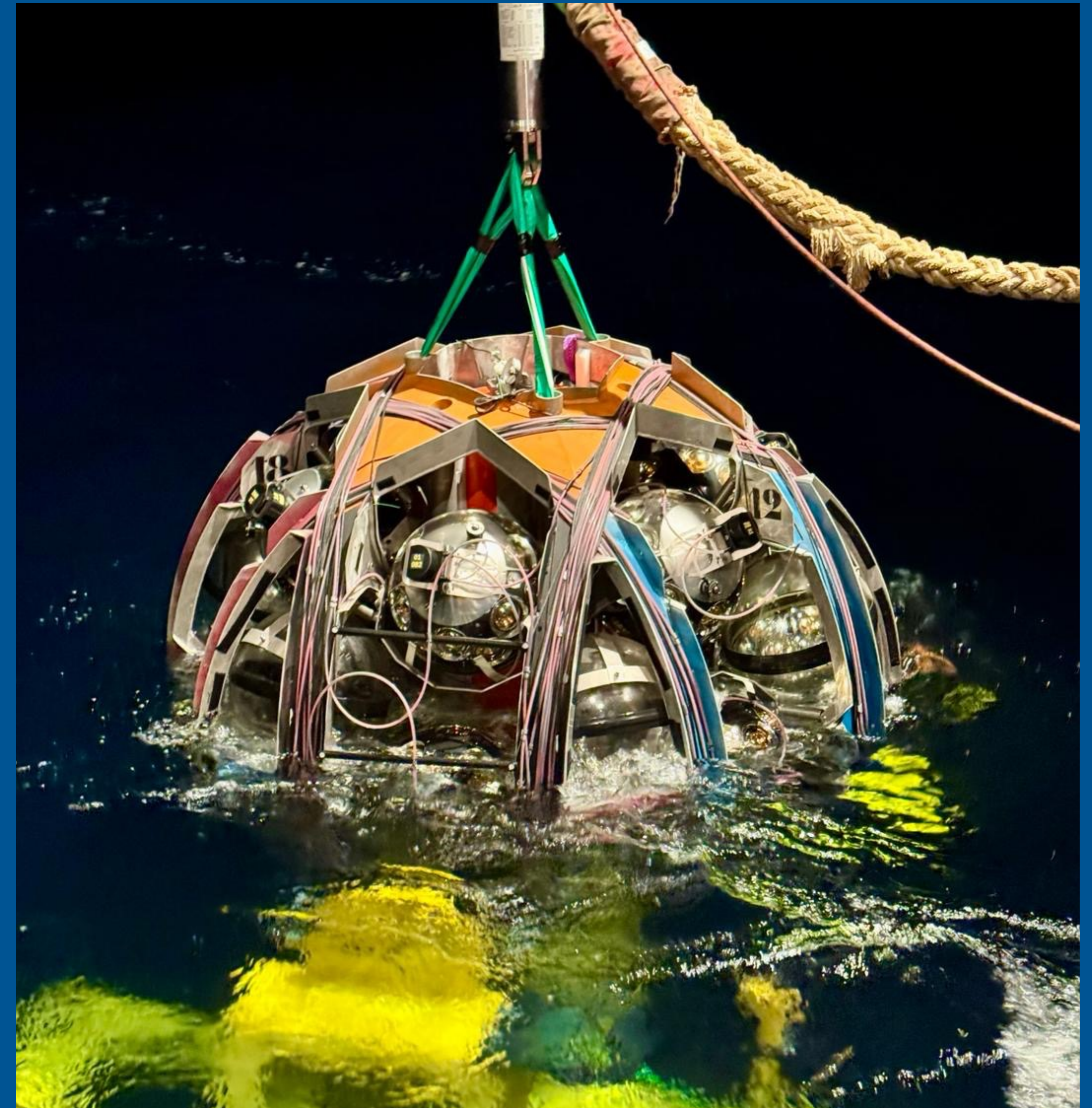


13th Cosmic-Ray International Studies and Multi-messenger Astroparticle Conference

Trapani 17-21 June 2024

HIGHLIGHTS ON KM3NET

ROSA CONIGLIONE ON BEHALF OF THE KM3NET
COLLABORATION
INFN - LABORATORI NAZIONALI DEL SUD
(ITALY)



KM3NeT is a Mediterranean research infrastructure hosting two neutrino detectors and instrumentations for earth and sea sciences

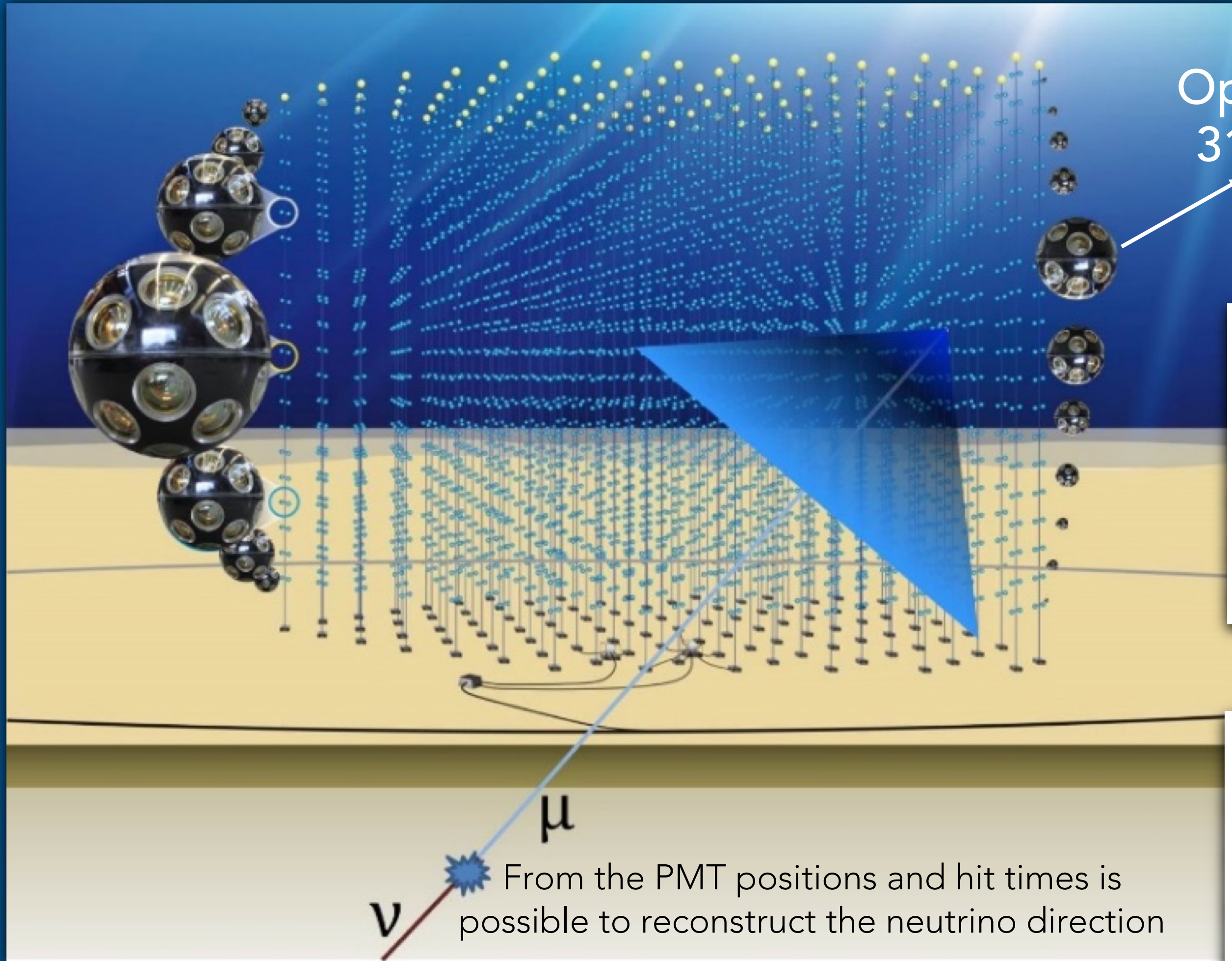
- **KM3NeT/ARCA** (Astroparticle Research with Cosmics in the Abyss)
 - observation of high energy (GeV ÷ PeV) neutrino sources 🙌 a telescope offshore Capo Passero (Sicily-Italy) is in construction at a depth of 3500m
- **KM3NeT/ORCA** (Oscillation Research with Cosmics in the Abyss)
 - determination of the neutrino mass hierarchy 🙌 a detector offshore Toulon (France) able to detect neutrinos of tens of GeV is in construction at a depth of 2500m

1 collaboration 1 technology 🙌 2 detectors

THE KM3NET DETECTORS

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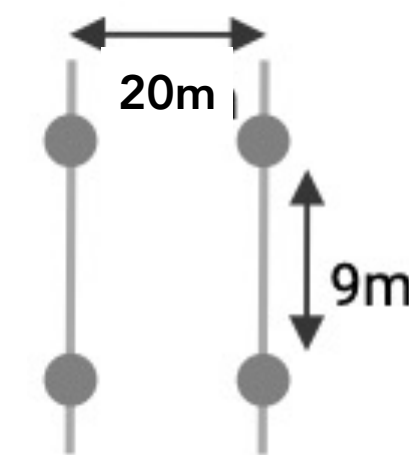
Same technology for the two detectors



Optical sensor (DOM)
31 PMTs of 3 inches

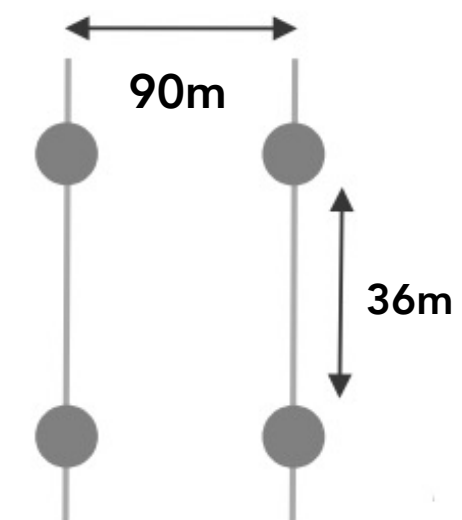
ORCA

- Depth ~2500 m
- One block of 115 Detection Units
- Distance between Detection Units ~20 m
- Vertical distance between DOMs ~9 m
- **≈8 Mton**



ARCA

- Depth ~3500 m
- Two blocks of 115 Detection Units each
- Distance between Detection Units ~90 m
- Vertical distance between DOMs ~36 m
- **Volume (0.5 × 2) km³**

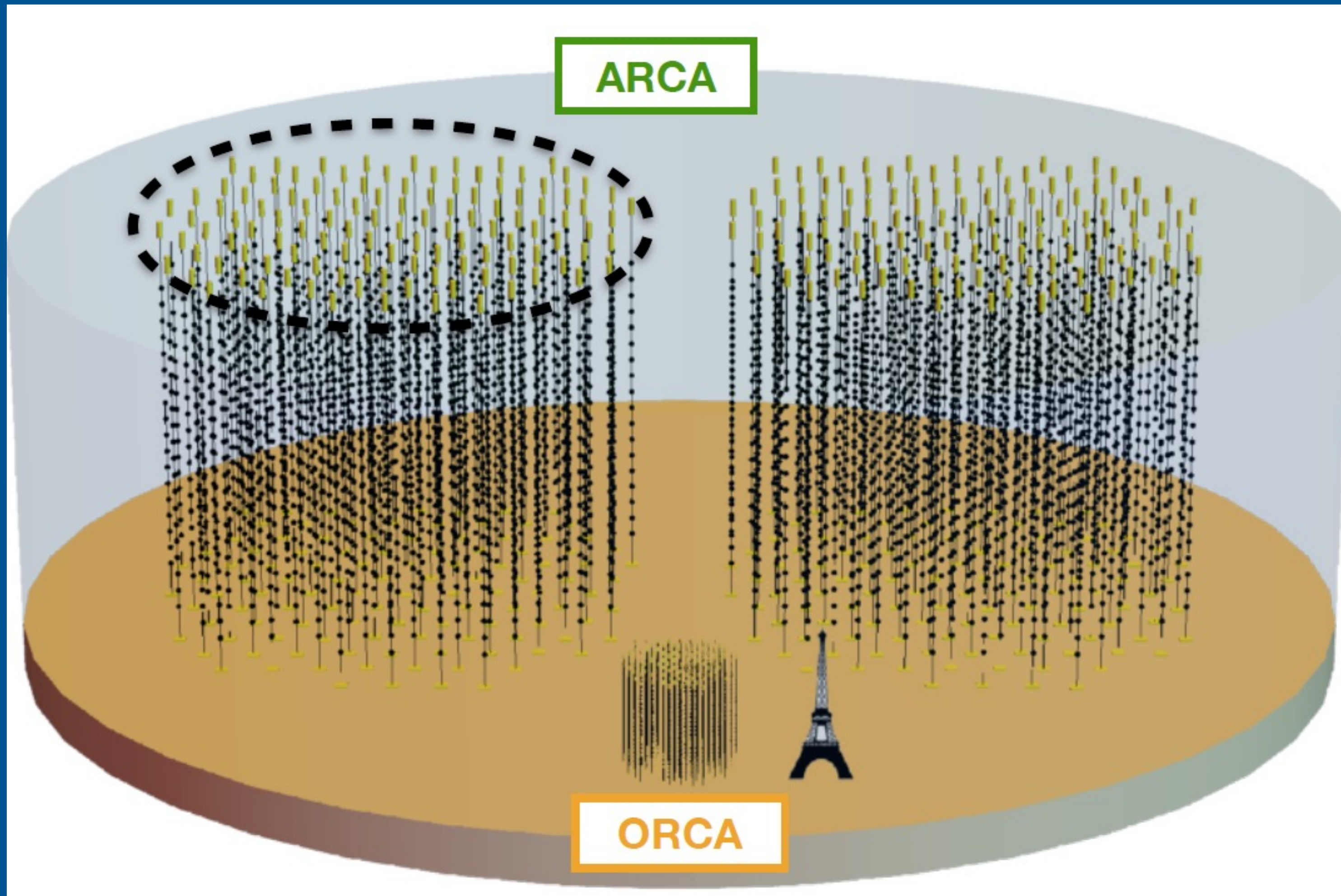


Detection Unit (DU)

Detectors in construction and taking data

THE KM3NET DETECTORS

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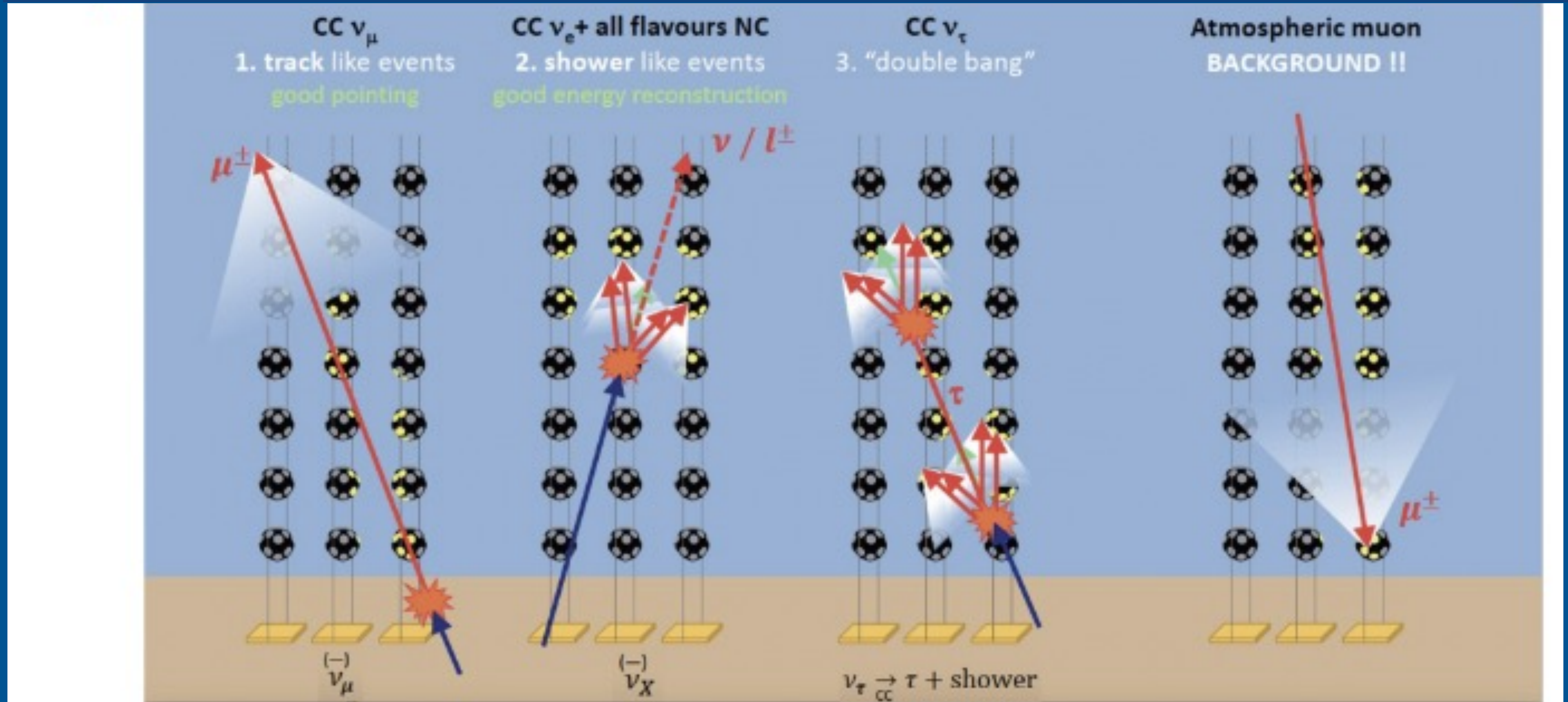


1 Building Block (BB) → 115 Detection Units
ARCA 2 BB (230 DUs)
ORCA 1BB (115DUs)

Difference in the spatial distance of optical sensors

DETECTION PRINCIPLE

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Tracks 🙌 @ $E_\nu > 100$ TeV Ang. res. below 0.1° - Energy res. \sim factor 2
Shower 🙌 @ $E_\nu > 100$ TeV Ang. res. below 2° - Energy res. $\sim 6\%$

THE TECHNOLOGY

6 The basic elements:

- Optical sensors 📍 DOMs (Digital Optical Module)
- Strings 📍 DU (Detection Unit)
- Seafloor network 📍 Electro-optical cables and JBs (Junction Boxes)

The Digital Optical Module



DOM

It is a 17" glass sphere containing:

- 31 3" PMTs (photocathode area $\approx 3 \times 10$ " PMTs)
- LED and Piezo
- Front-end electronics -> FPGA

[Video of the DOM integration](#)

The Detection Unit



18 DOMs in a DU

DU

[Video of a DU integration](#)

The Sea floor network:

- Electro-optical cables from shore to the deep sea
- Junction boxes/nodes to distribute power and optical fibers
- In ARCA Cable Termination Frames (2 already installed)
- Interlink cables for connection of DU to JB and JB to the main cable



ARCA JB

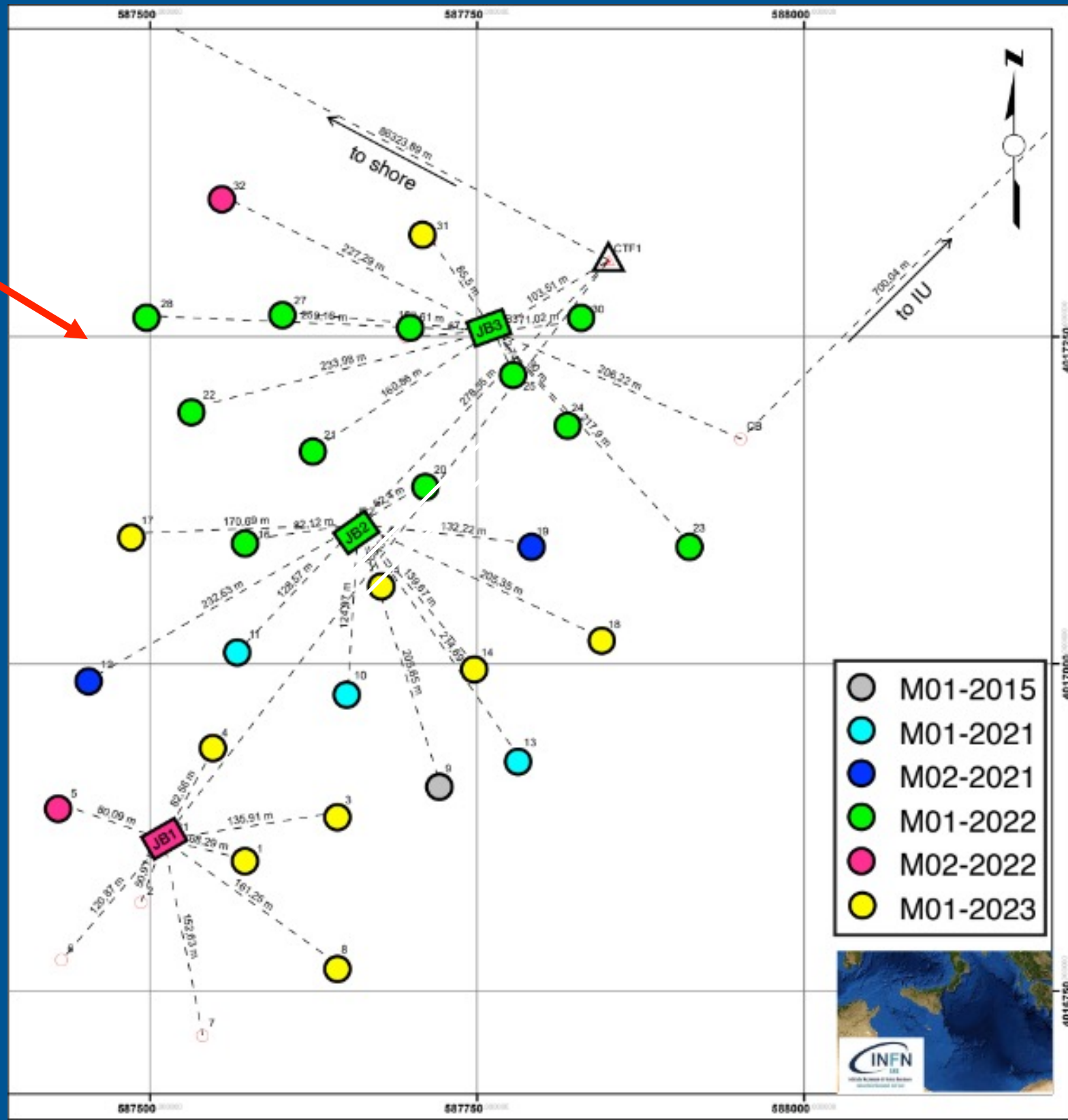
THE KM3NET/ARCA STATUS

Current status 28 DUs deployed
+ 3 JB

1 sea campaigns per year

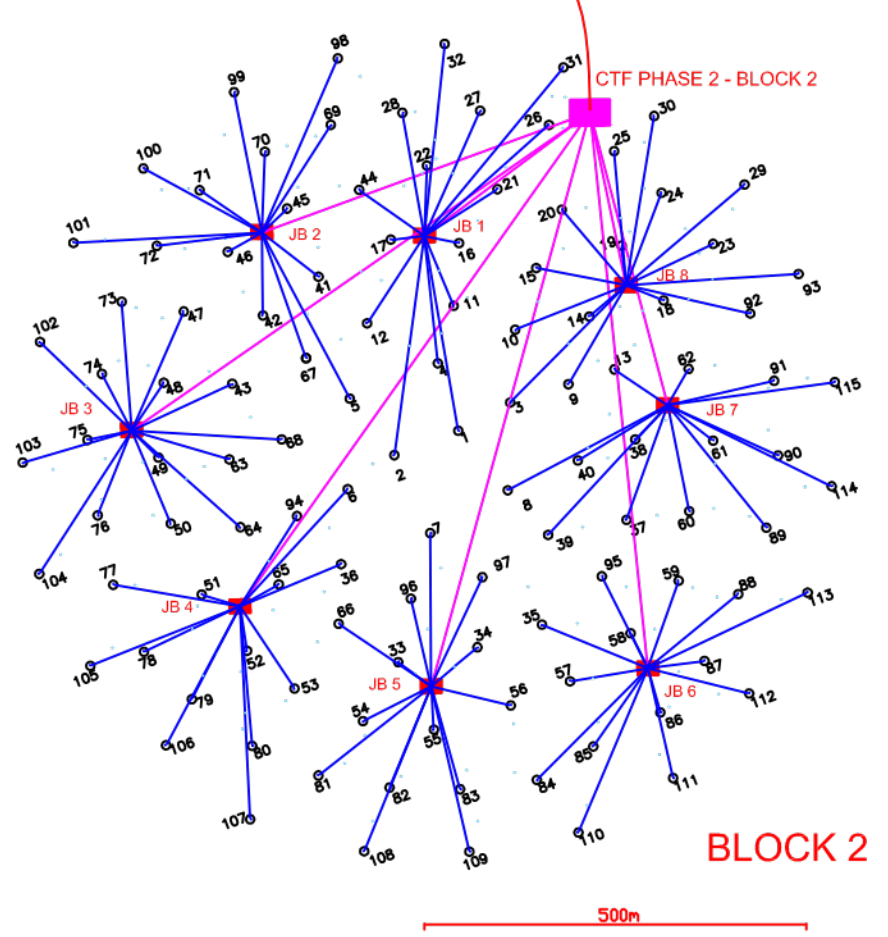
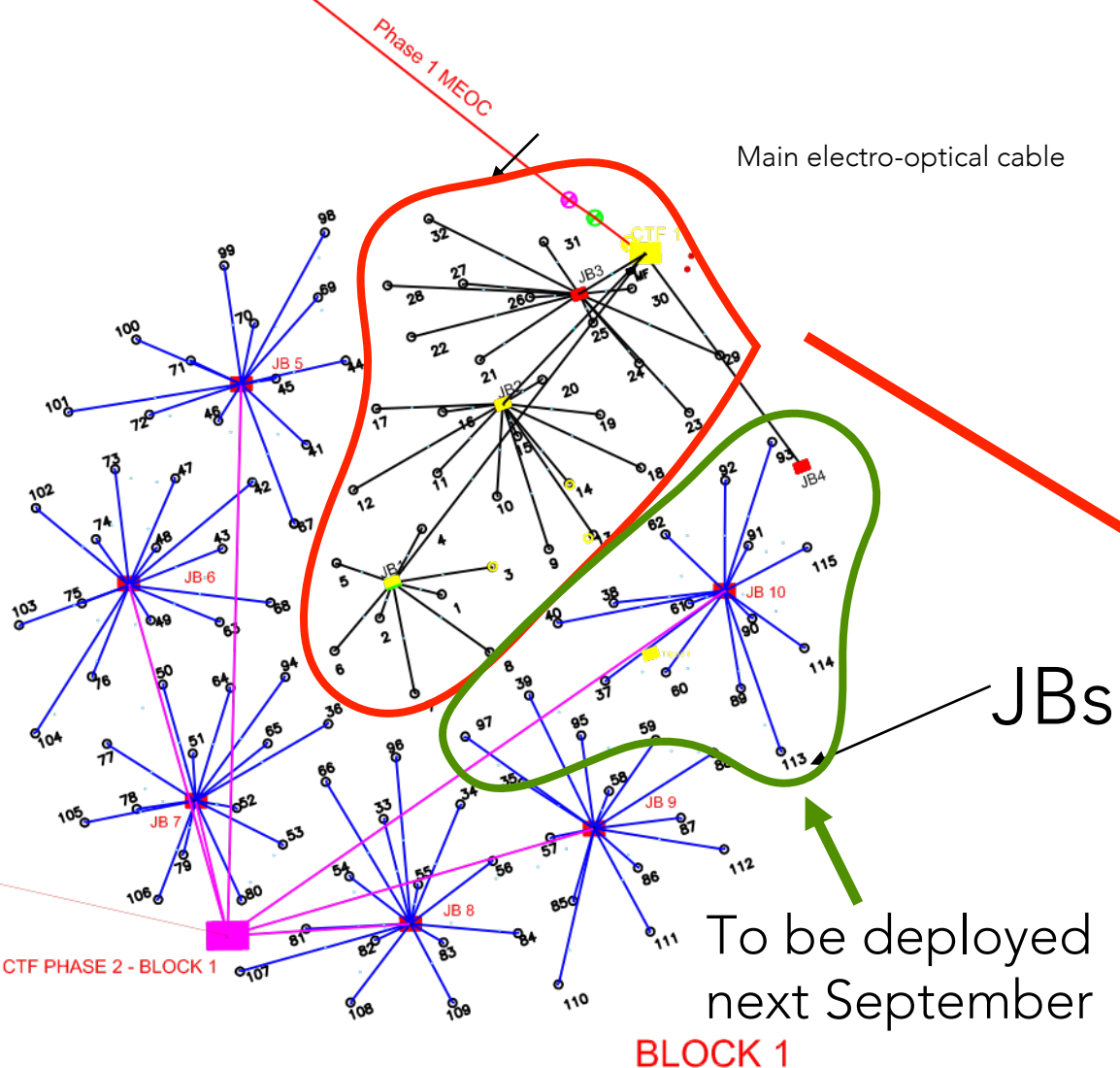
The next one in September 2024
To be deployed:
2 JB + ~19DUs + Instrumentation
Unit (IU)

~47 DUs at the end of this year
(~40% of the first block)



ARCA
(Italy)

Main electro-optical cable



THE KM3NET/ORCA STATUS

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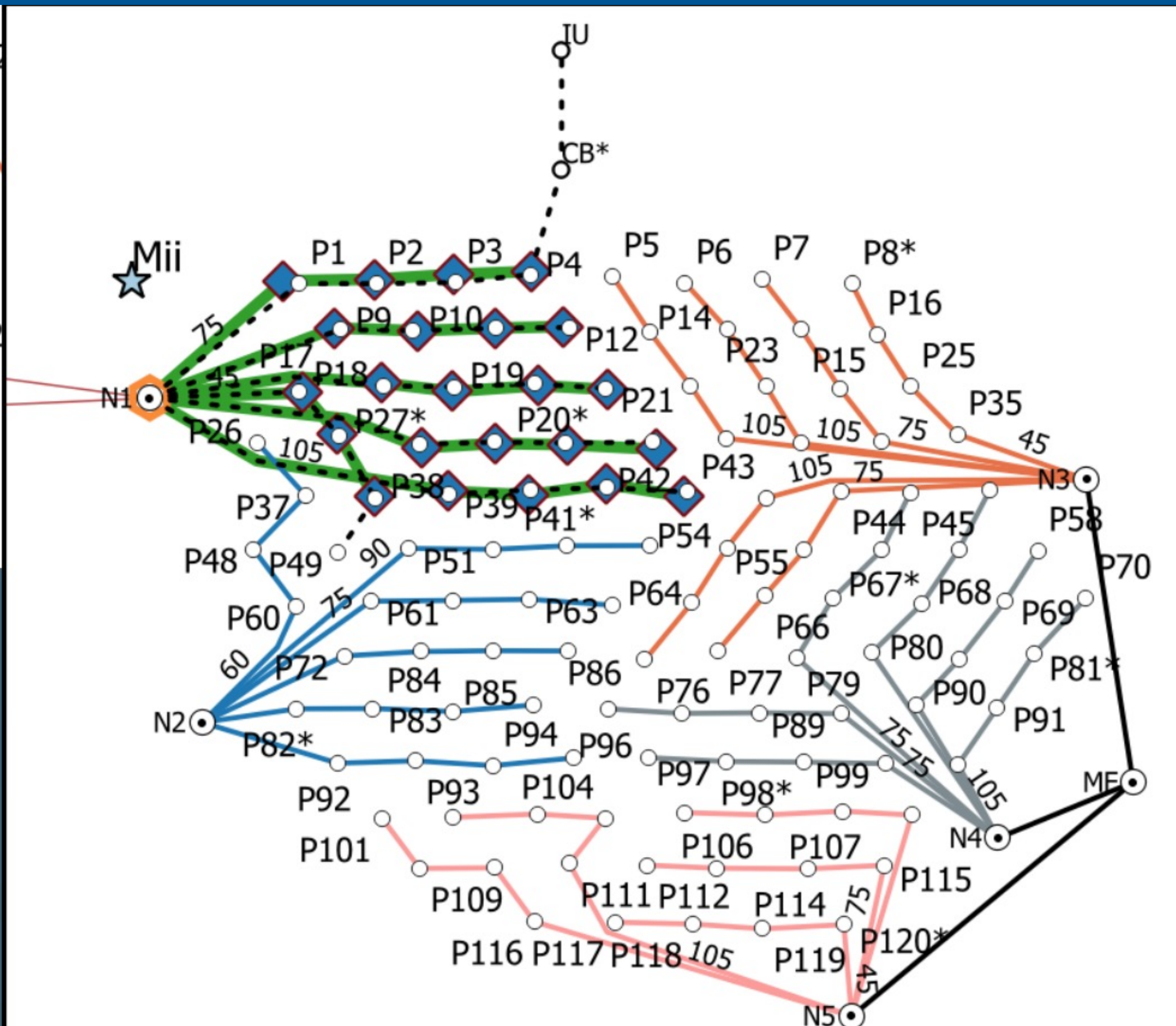
Current status 23 DUs deployed

Many sea campaigns/year

Next one foreseen before the end of the year 🙌 complete the DUs of node1 and deploy the node2 & 4-5 DUs

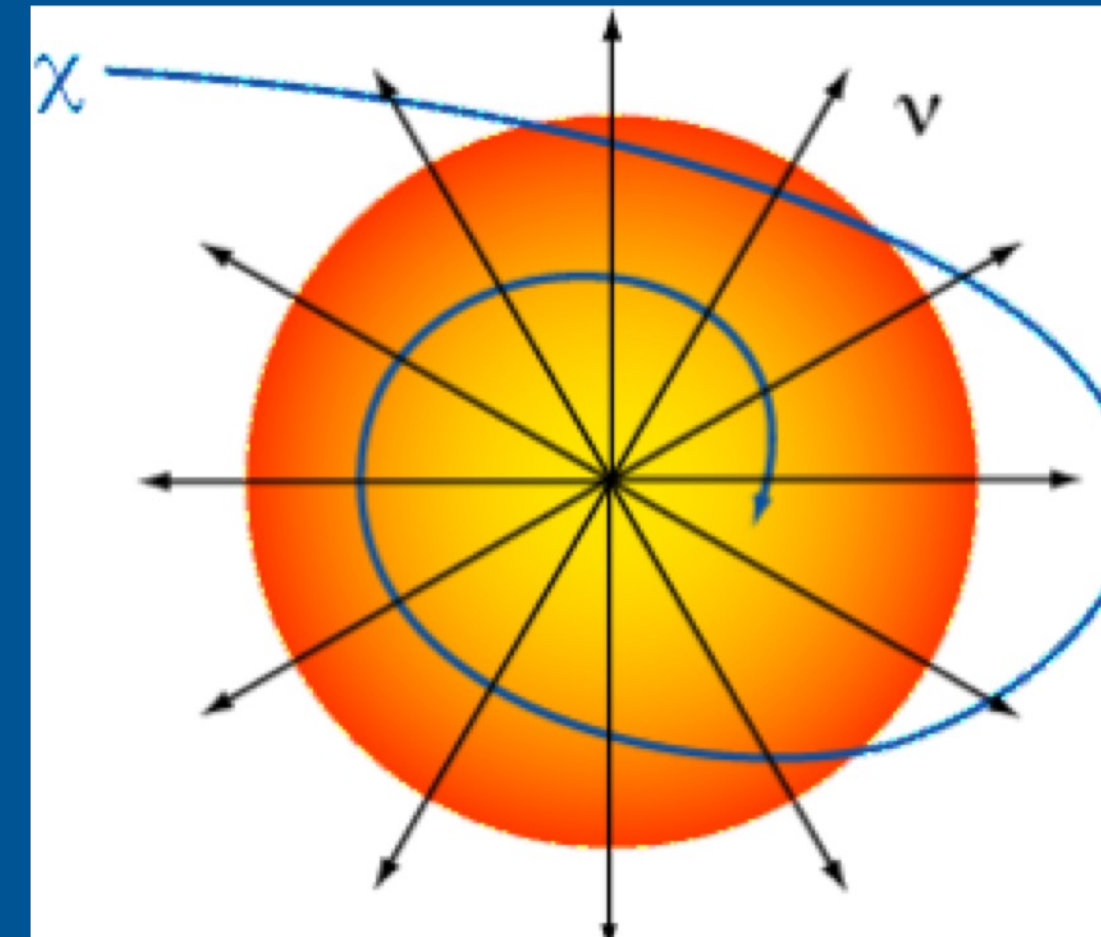
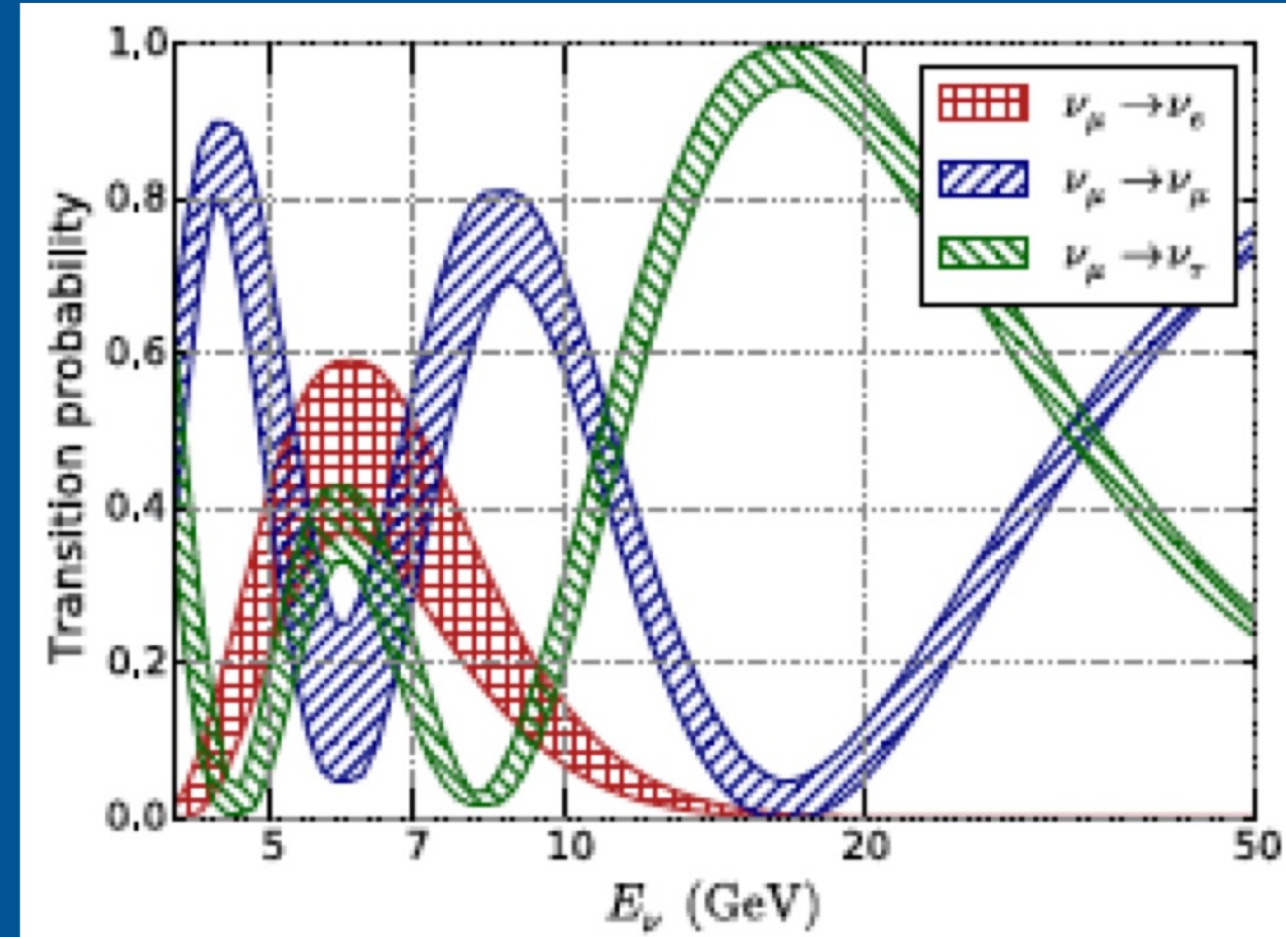
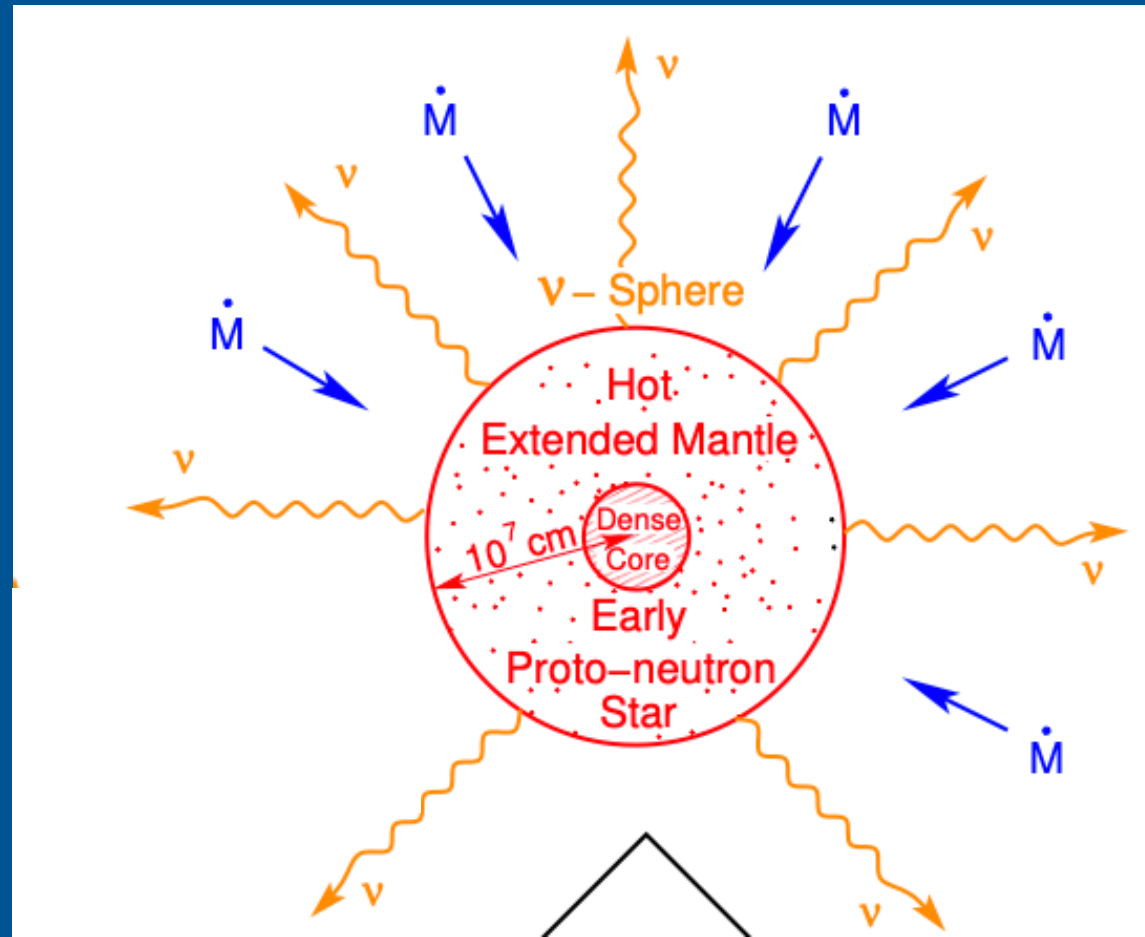
Almost completed the first node 🙌

20% of the full detector in water



THE PHYSICS

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Supernova explosions
Single DOMs as detectors
ARCA&ORCA

Neutrino oscillation
Main topic of ORCA

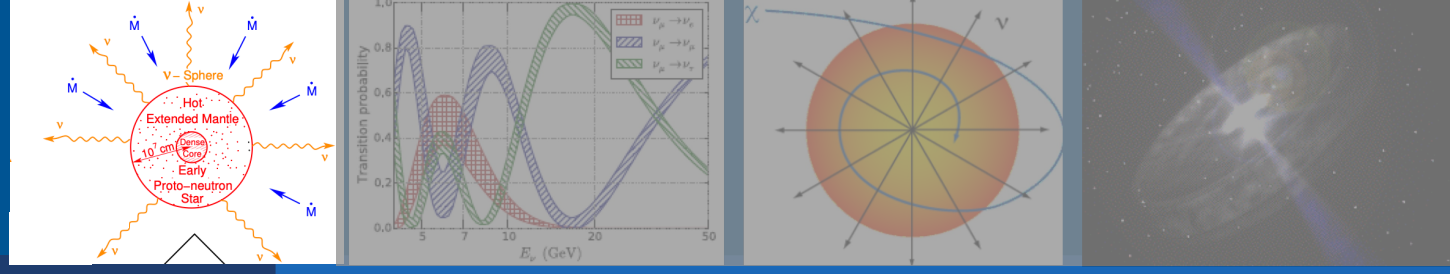
Dark Matter
ORCA & ARCA

HE neutrinos
Multi-messenger program
Main topic of ARCA

From MeV ...

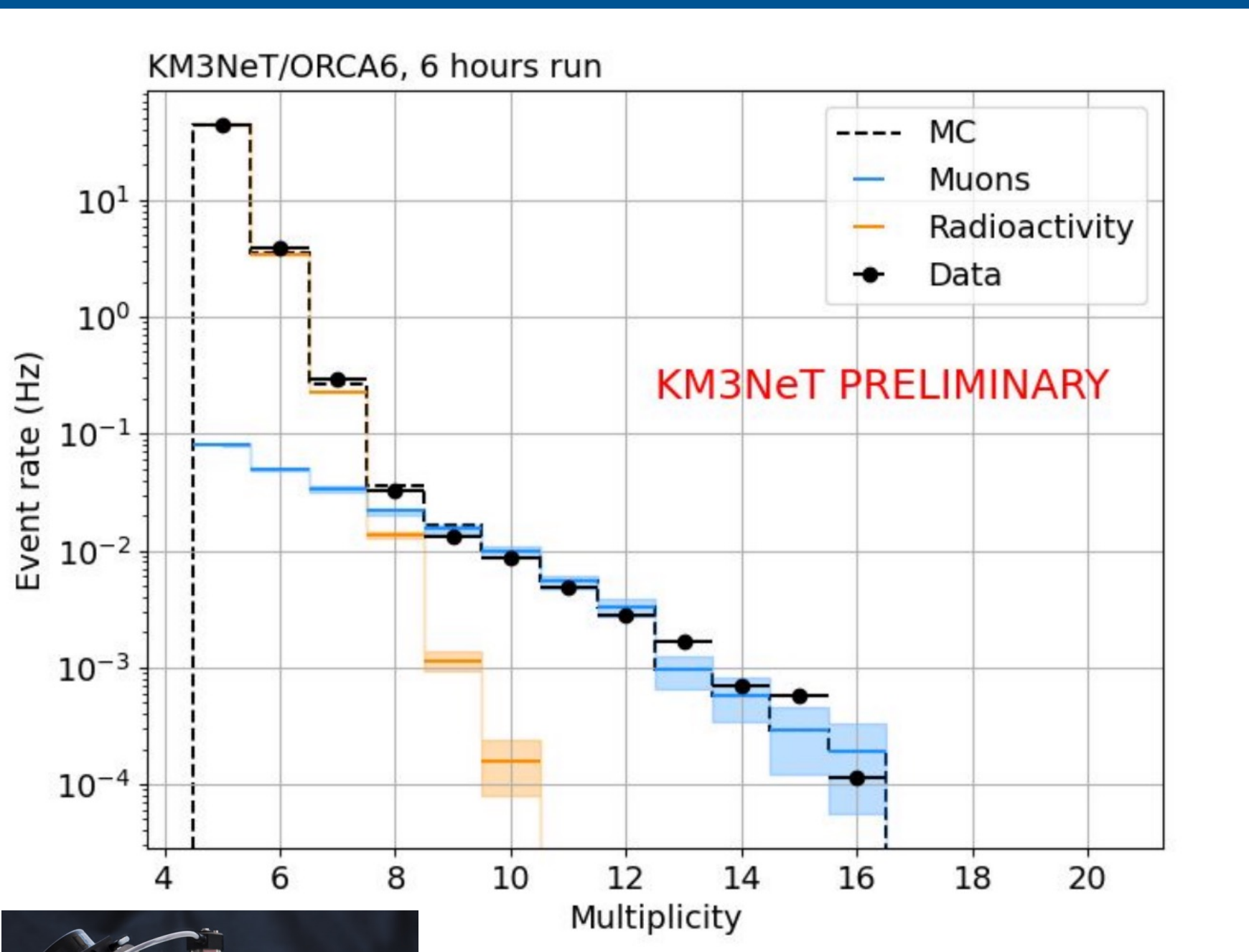
.... to PeV

SUPERNOVA EXPLOSION

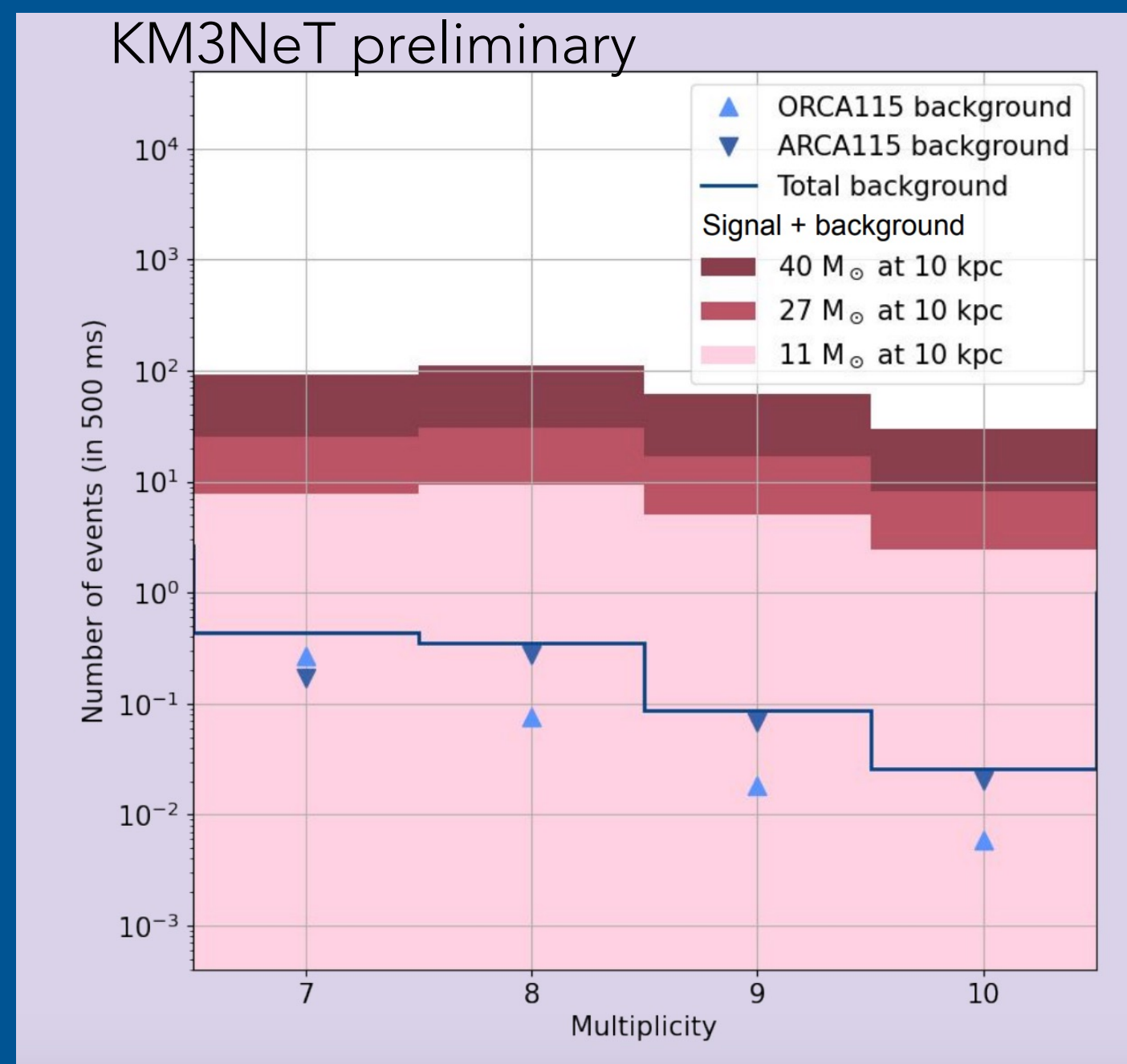


A DOM as a single detector
 Muon background rejection improved

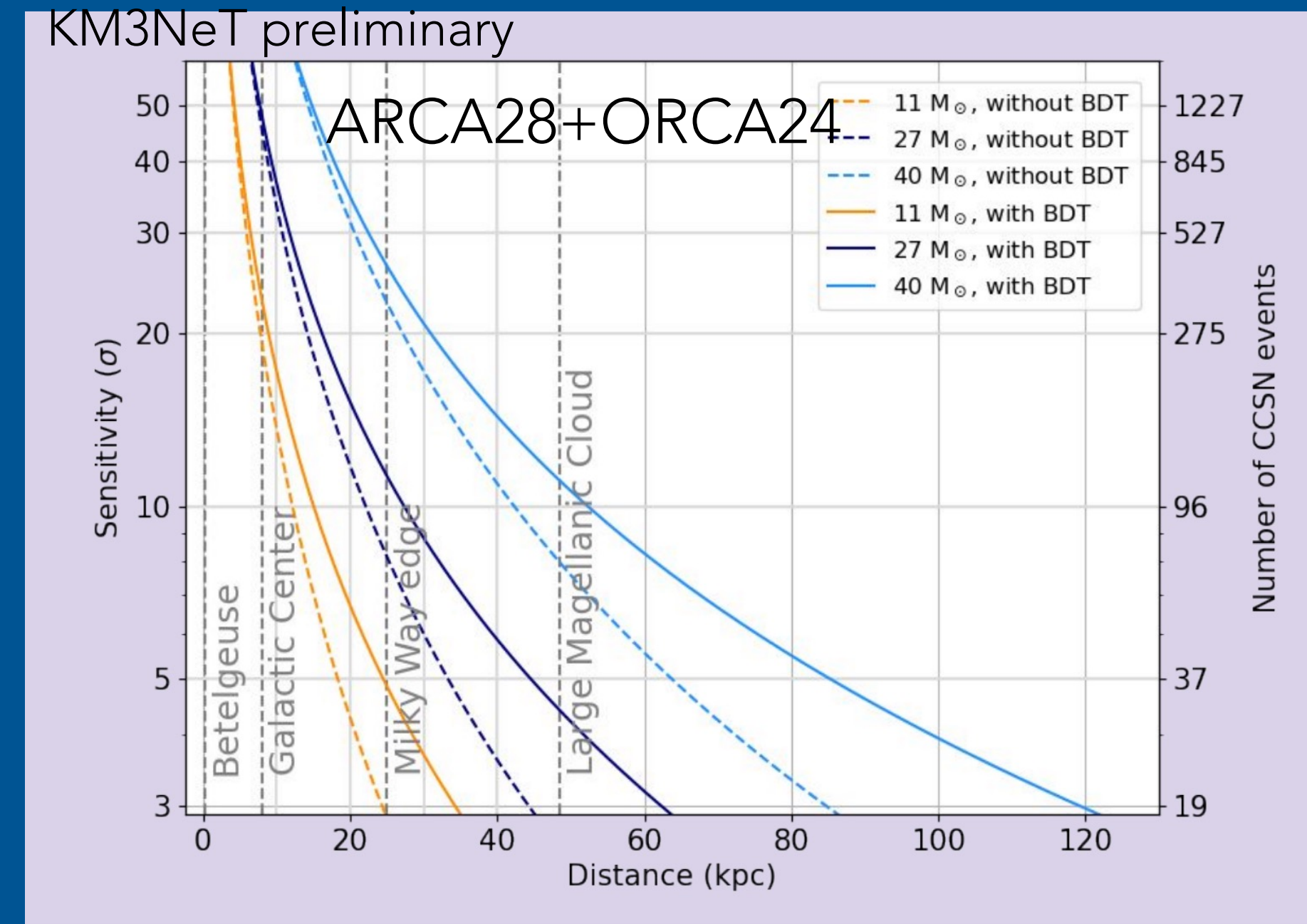
PMT multiplicity plot



Signal expected above background



Significance



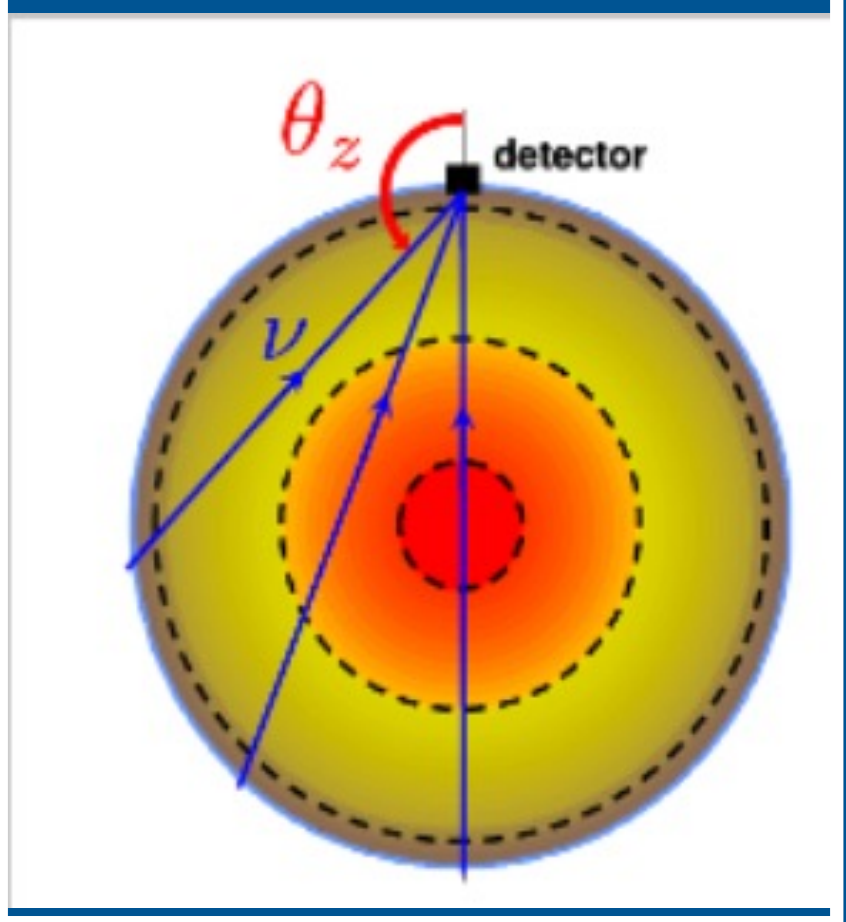
$>5\sigma$ for ARCA+ORCA for $27M_{\odot}$ at a distance $<50\text{kpc}$



An on-line alert system for CCSN already implemented
 Integrated in SNEWS

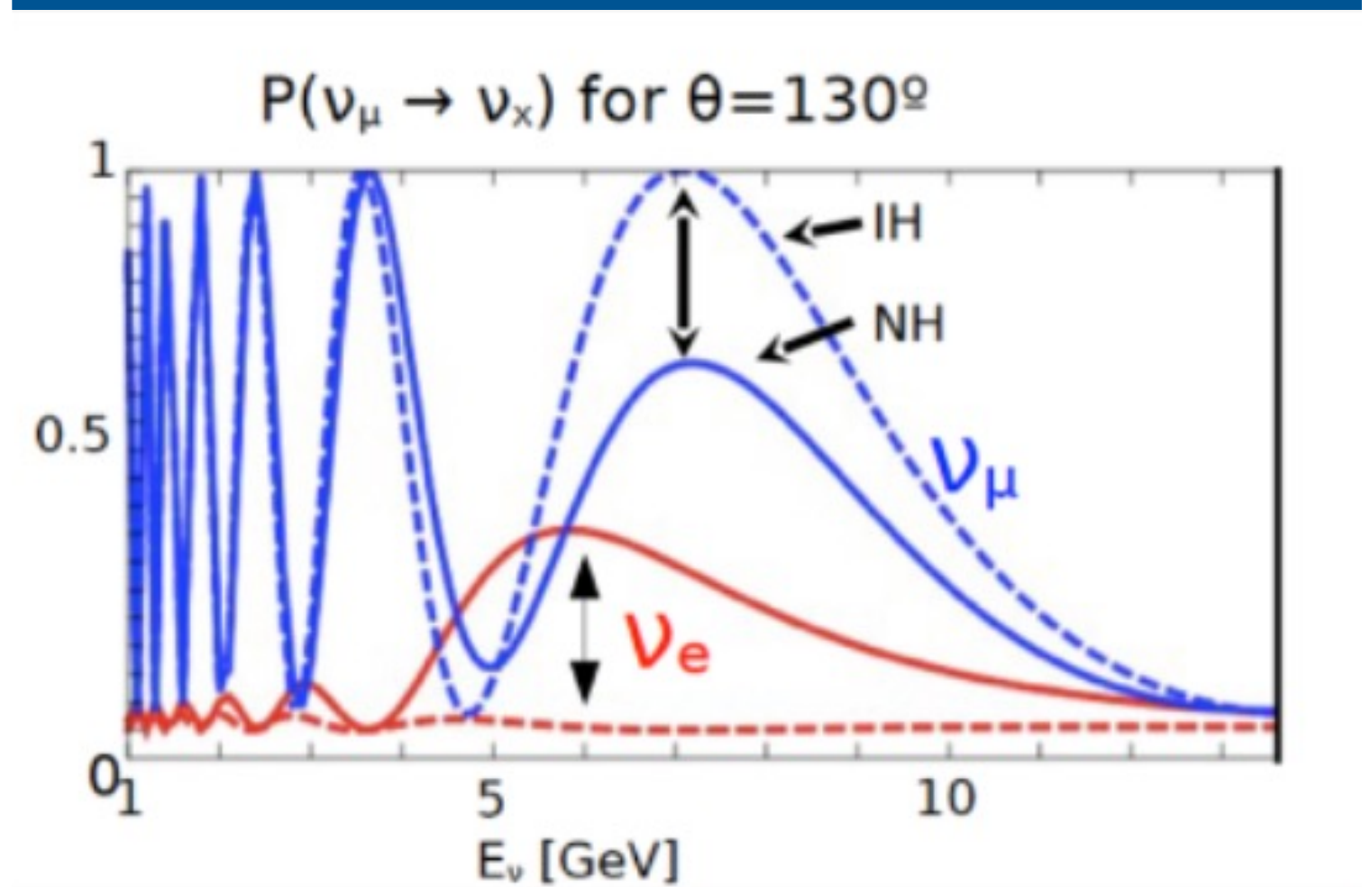
NEUTRINO OSCILLATION WITH ORCA

Baseline from 50 to 12800 km

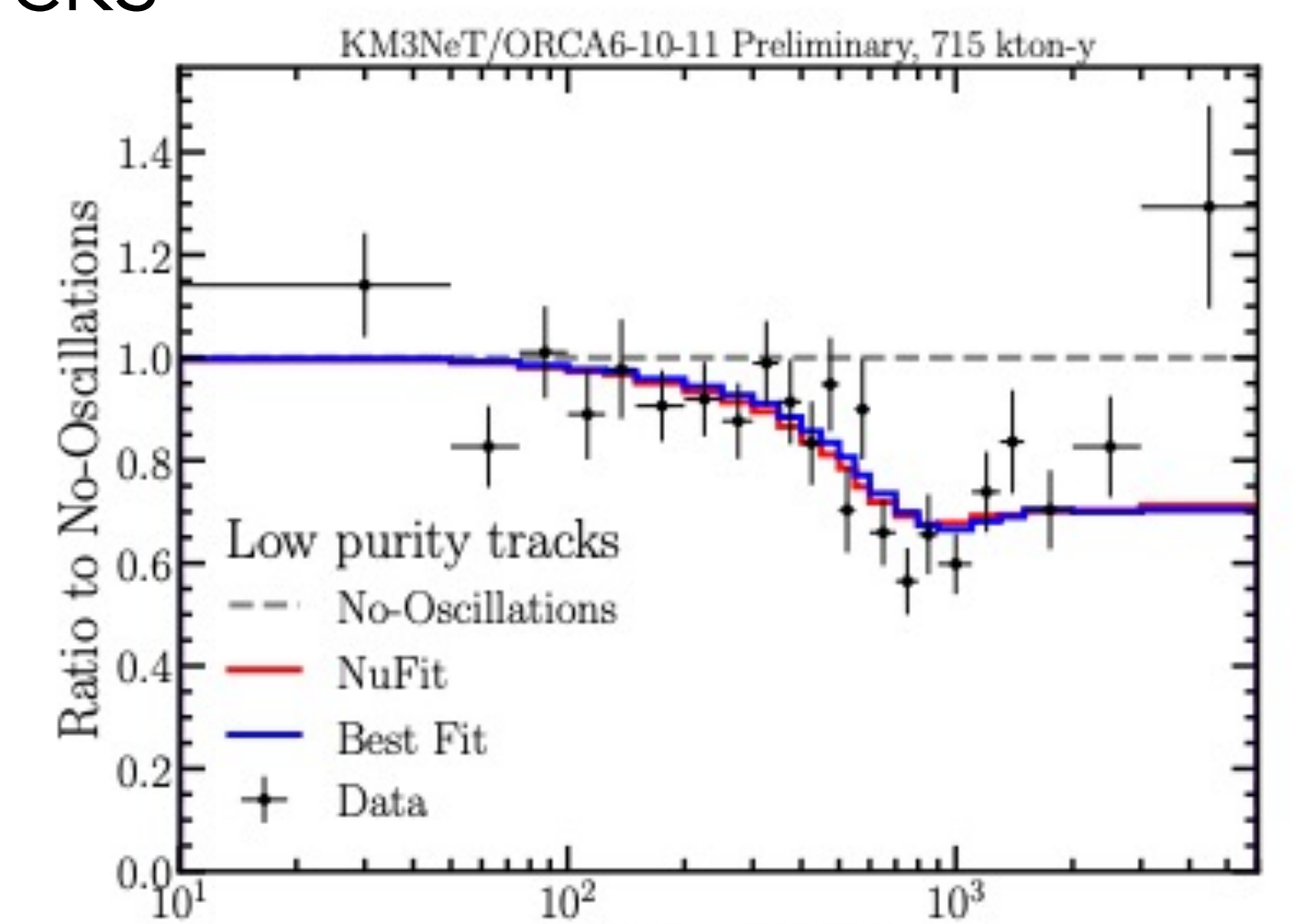
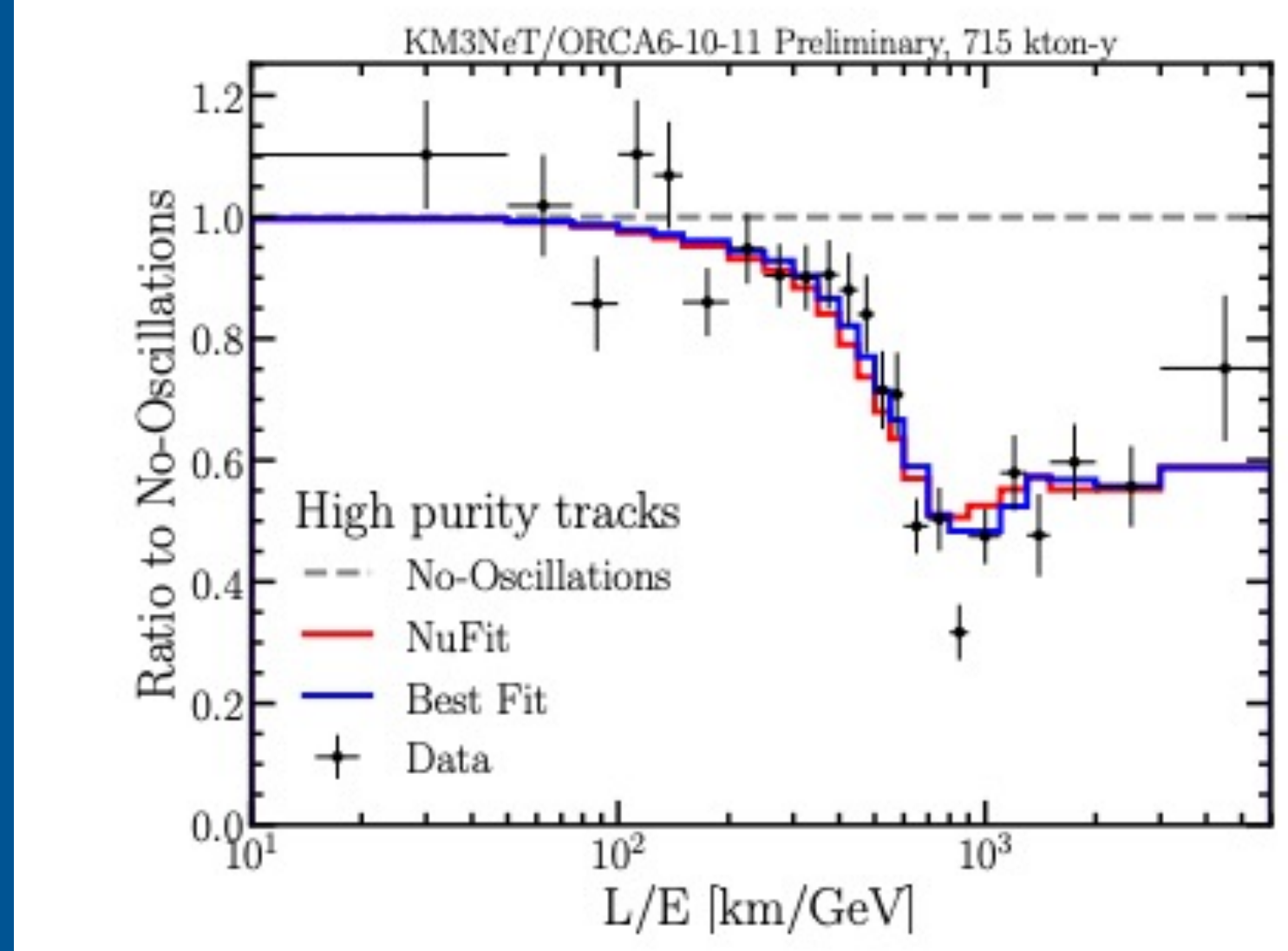


Neutrino Mass Ordering measuring atmospheric neutrinos crossing the Earth

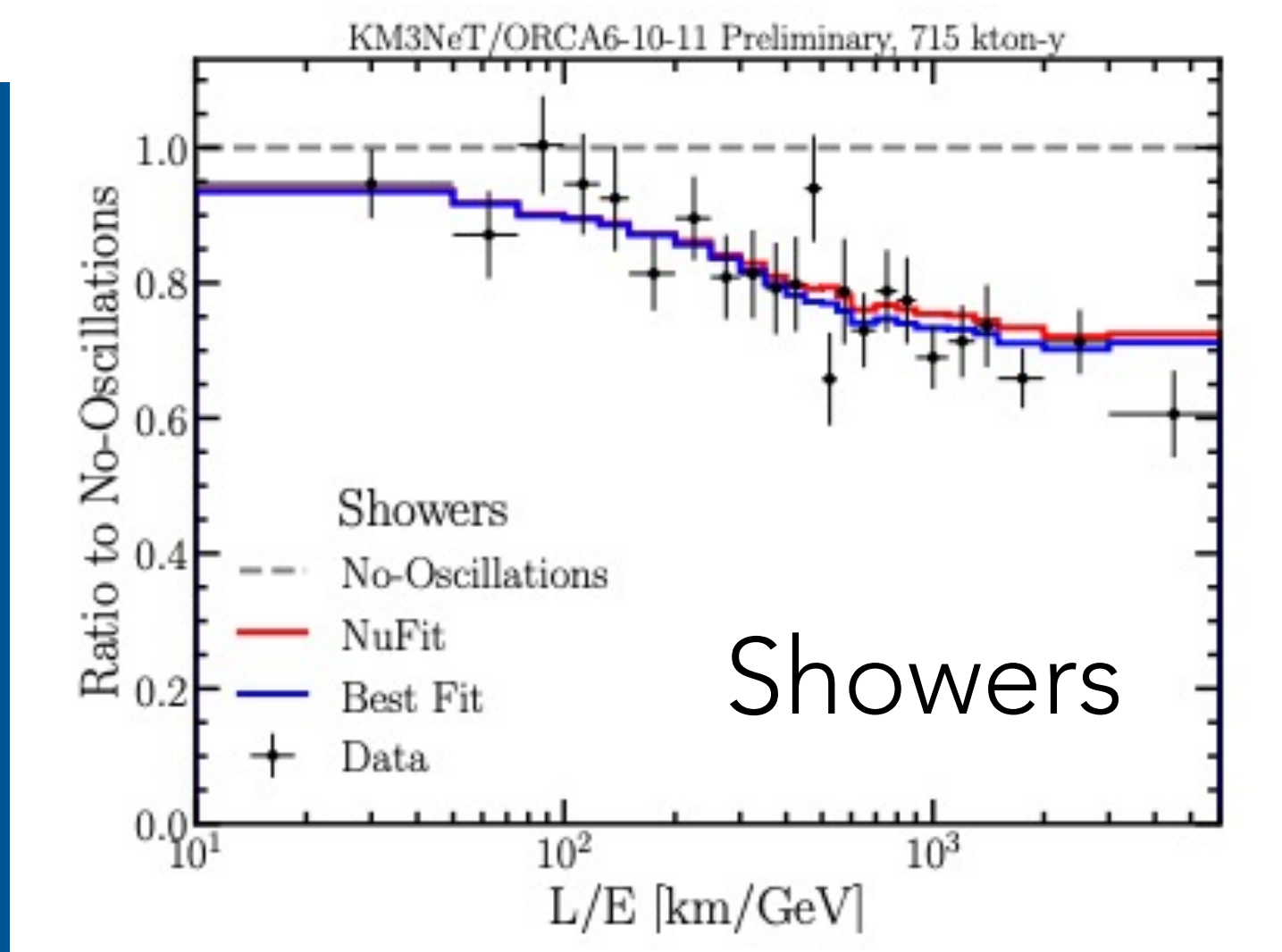
Energy range of interest 5-15 GeV



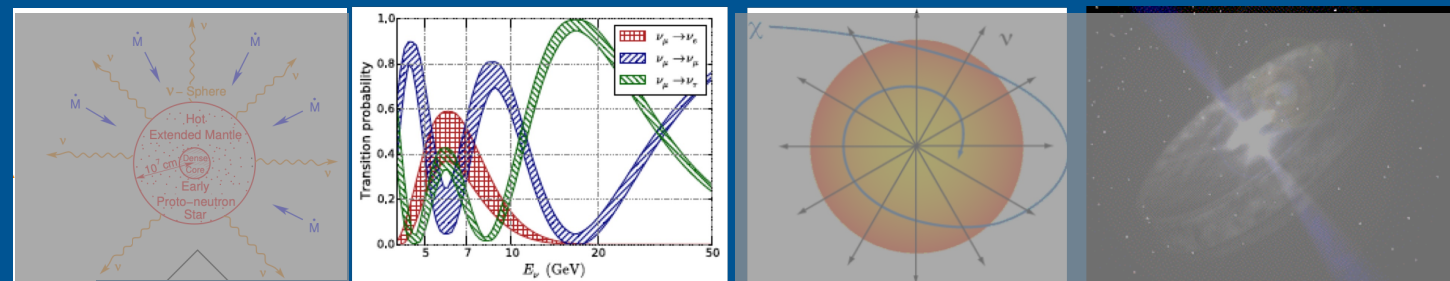
Tracks



ORCA6-7-11 data
Oscillations clearly seen both in track and shower events

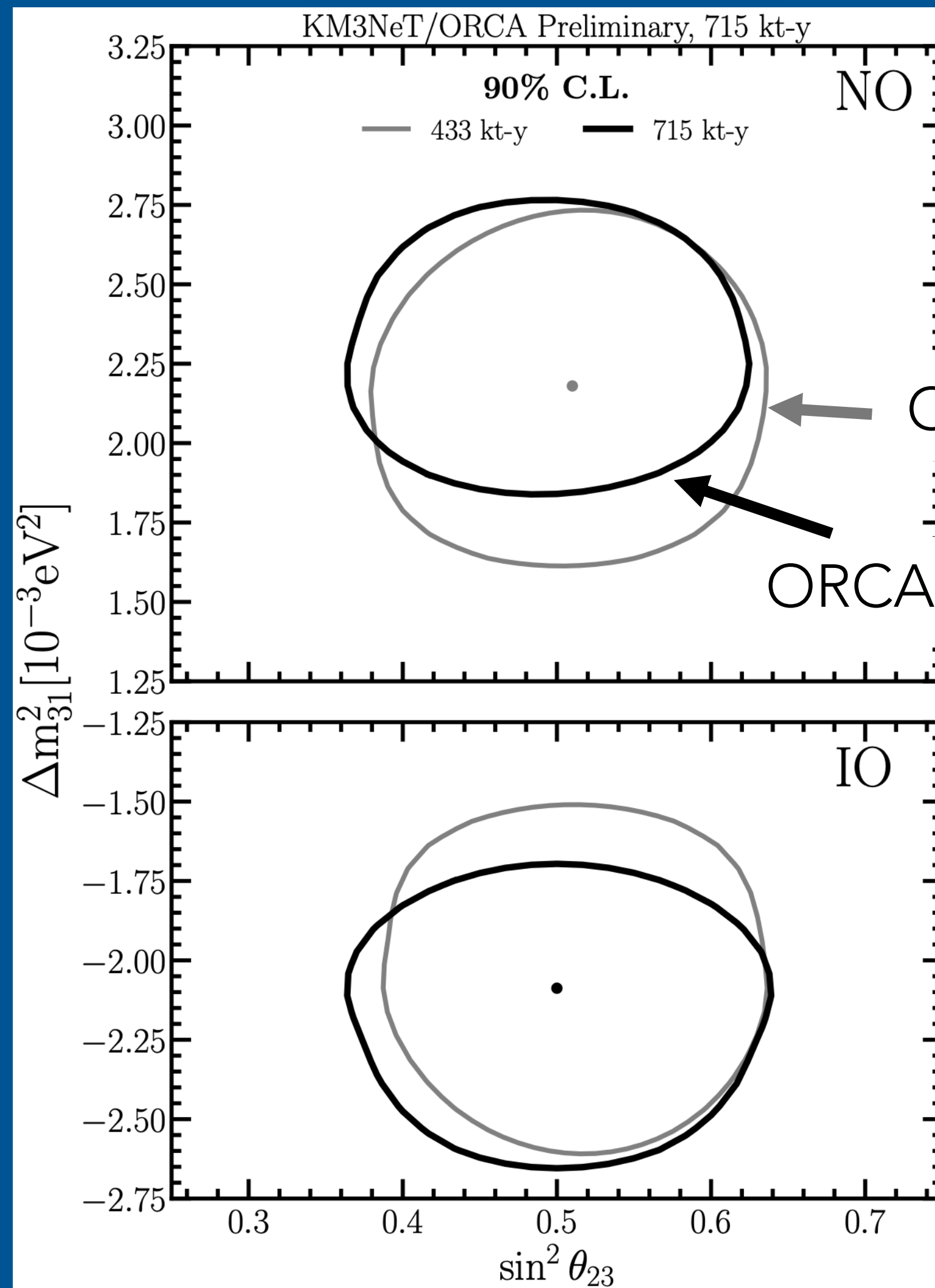


NEUTRINO OSCILLATION WITH ORCA



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Δm^2_{32} vs $\sin^2 \theta_{23}$



Same kind analysis of ICRC2023 increased the exposure

From 433kt-yr to 715 kt-yr

ORCA6 → 433 kton-yr

ORCA6-10-11 → 715 kton-yr

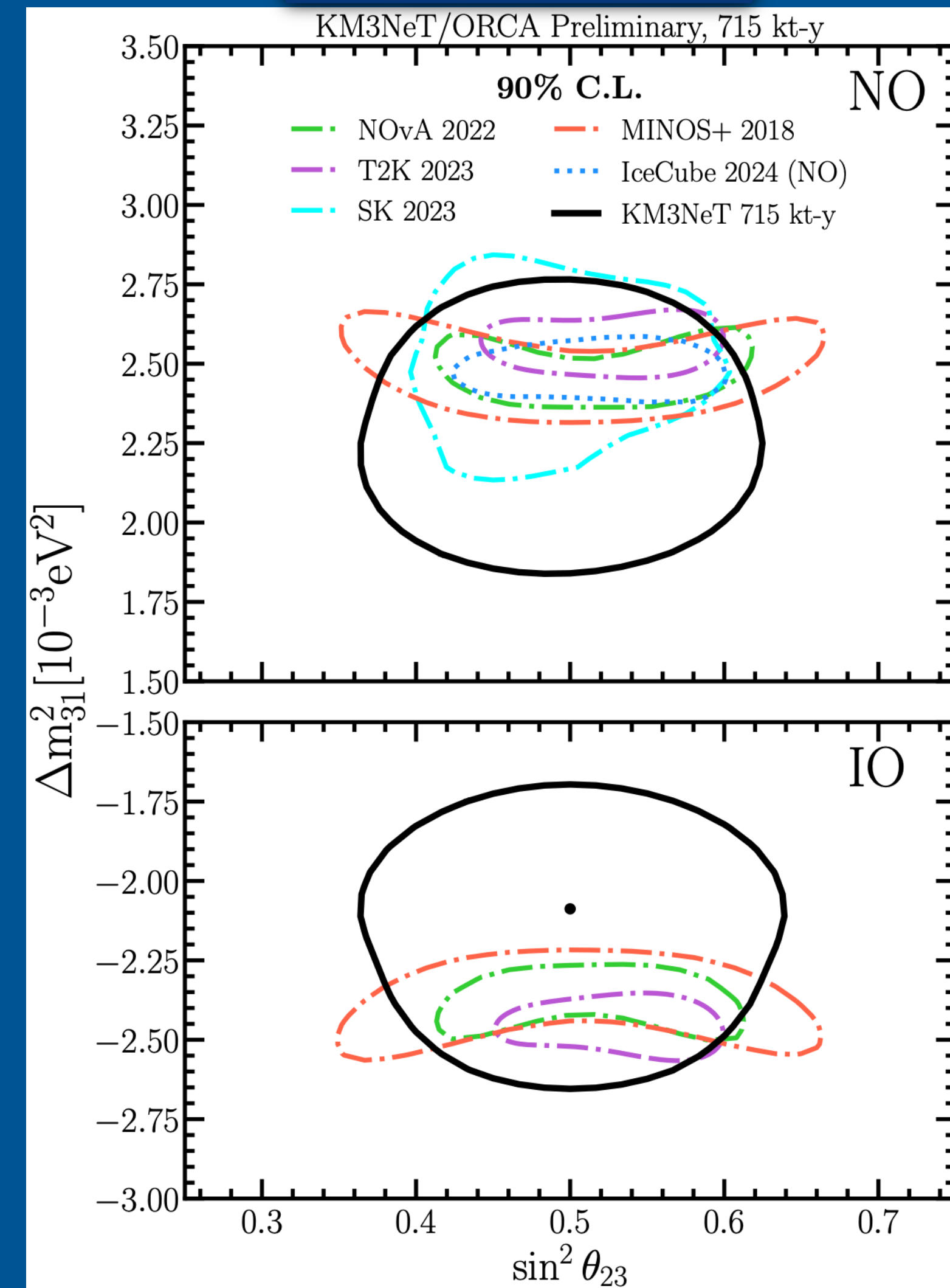
$$\Delta m^2_{31} = \begin{cases} -2.09^{+0.17}_{-0.21} \times 10^{-3} \text{eV}^2, & \text{IO} \\ [2.10, 2.37] \times 10^{-3} \text{eV}^2, & \text{NO} \end{cases}$$

$$\sin^2 \theta_{23} = 0.50 \pm 0.07$$

$$2 \log(\mathcal{L}_{IO}/\mathcal{L}_{NO}) = 0.61$$

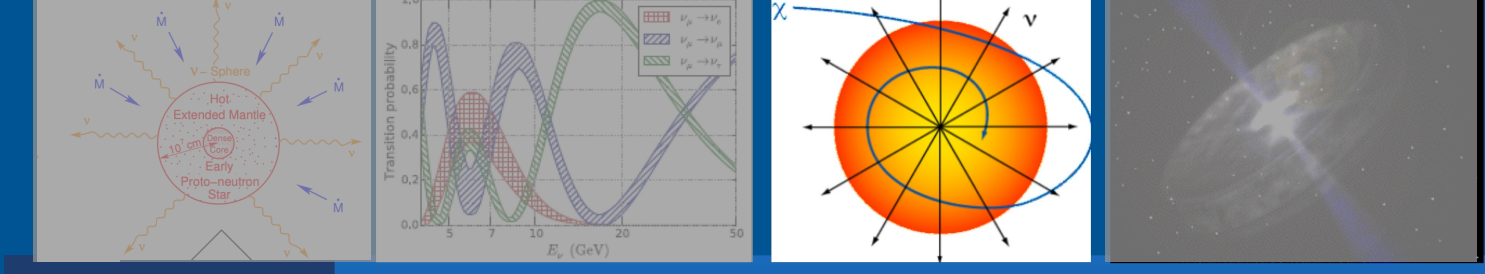
KM3NeT/ORCA competitive

Δm^2_{32} vs $\sin^2 \theta_{23}$

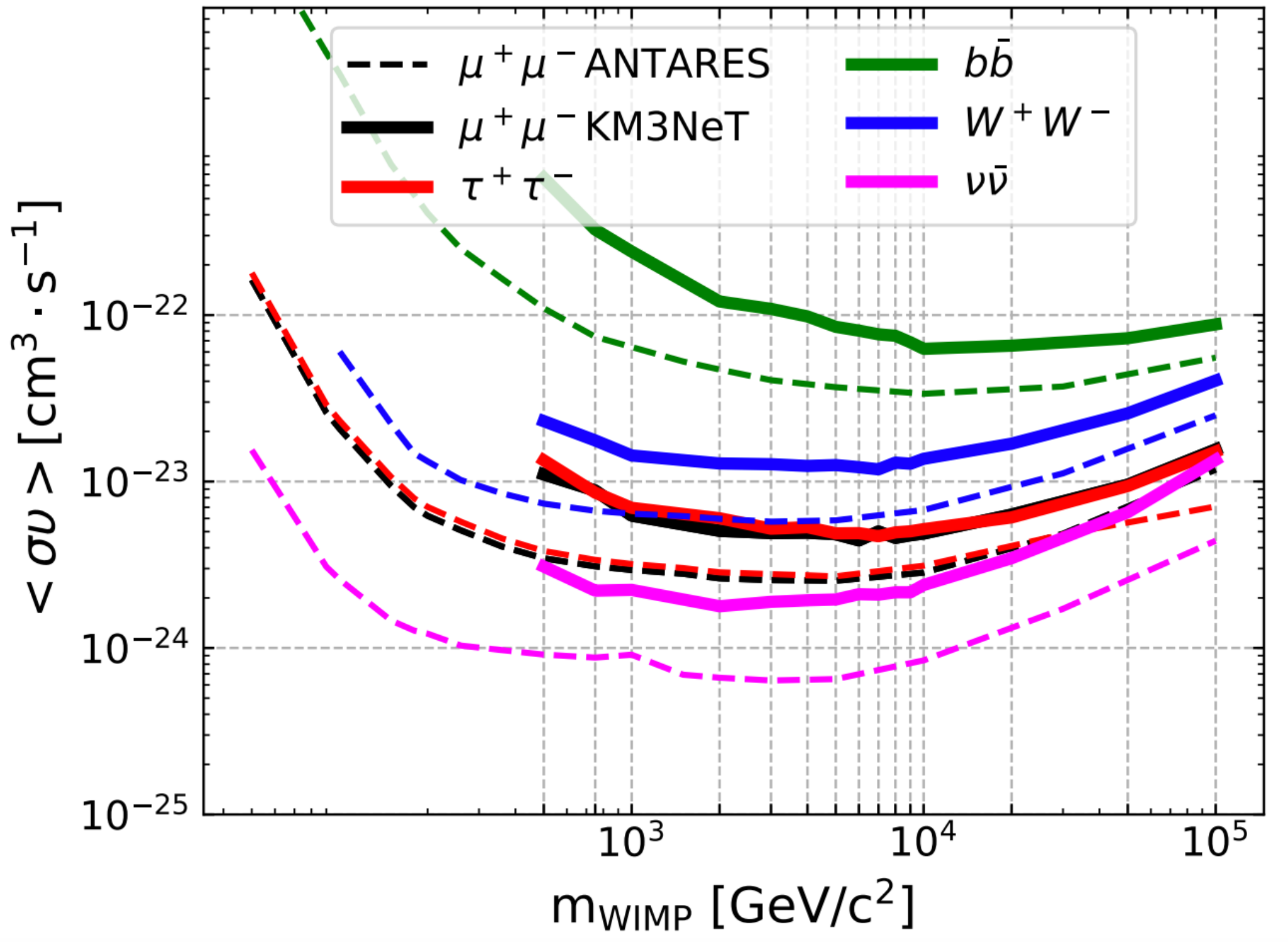


DARK MATTER

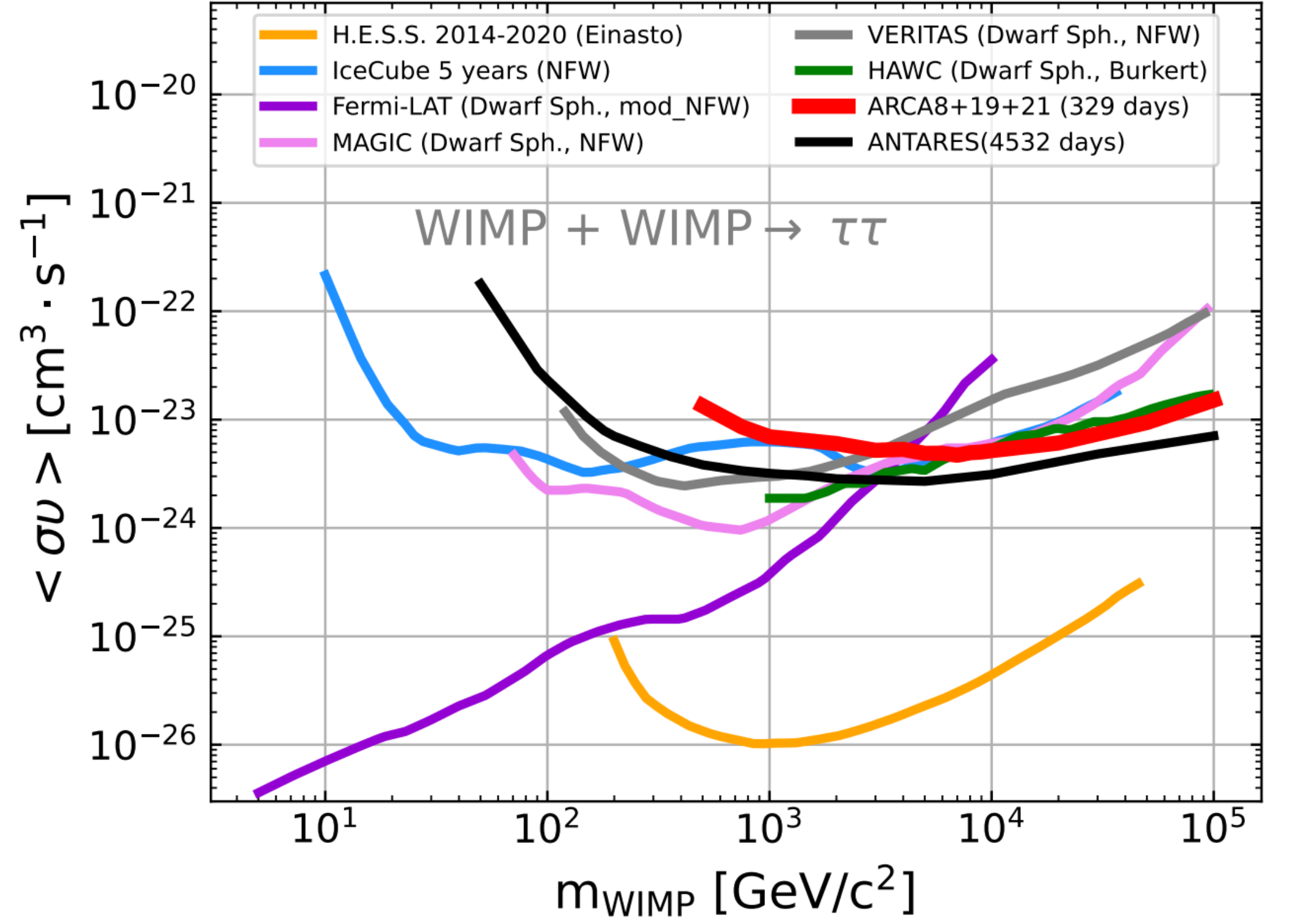
From the Galactic Center



KM3NeT/ARCA8+19+21 Preliminary, 329 days



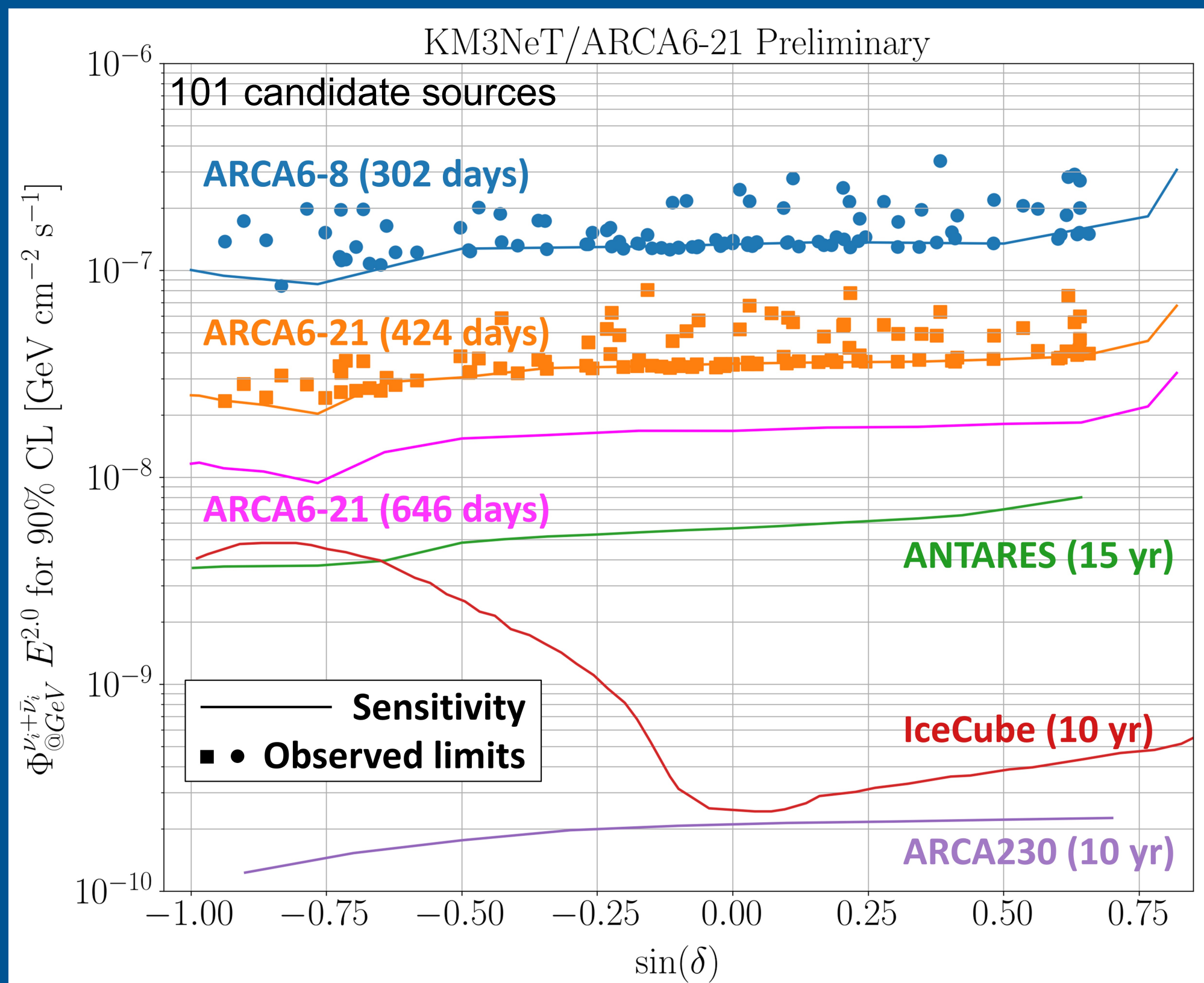
KM3NeT/ARCA8+19+21 Preliminary, 329 days



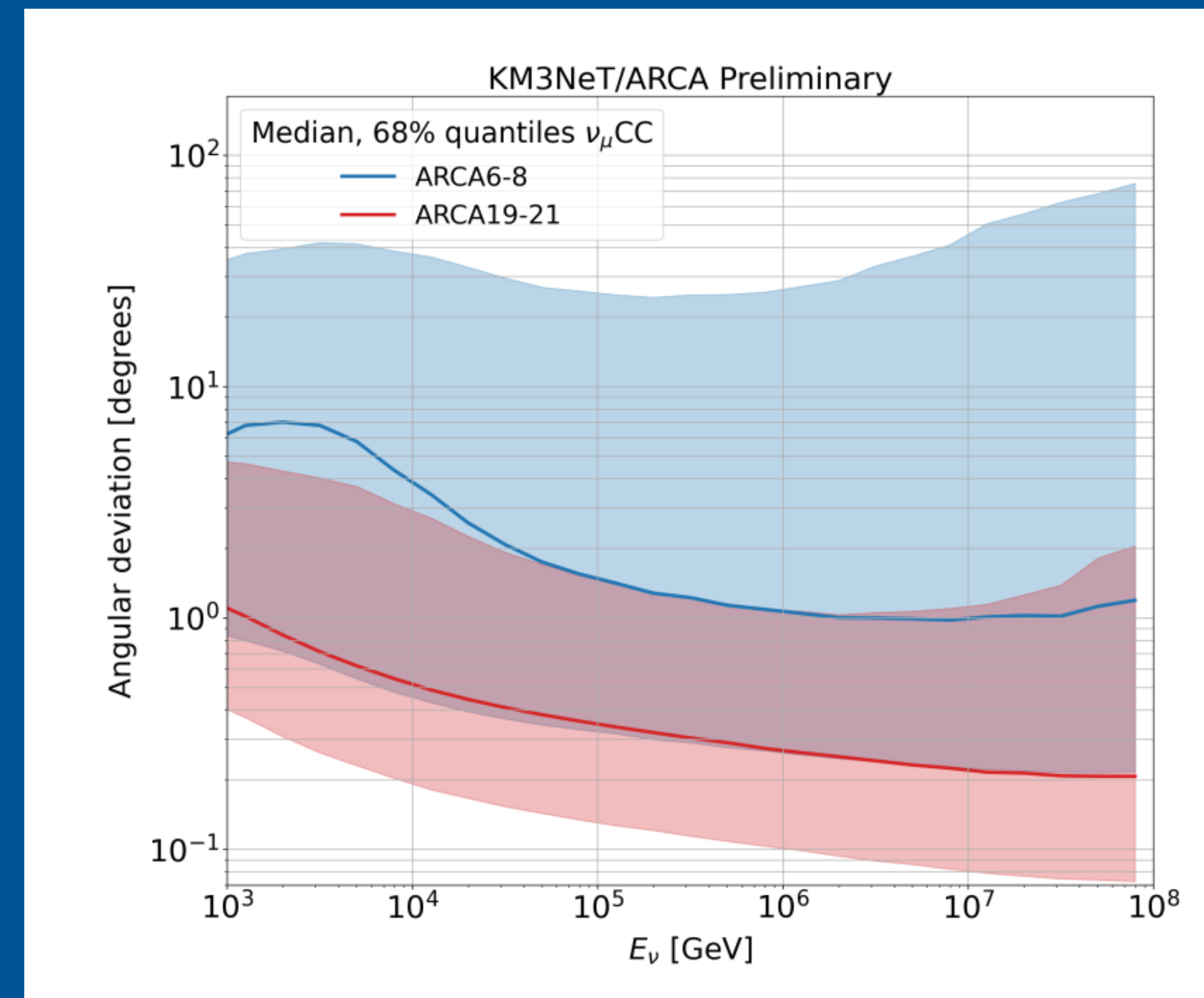
KM3NeT quickly reaching the ANTARES limits

SEARCH FOR POINT-LIKE SOURCES

ARCA21 unblinded until December 2022
 Unblinding of ARCA21 data full period expected very soon



Angular resolution



Large improvement in sensitivity is expected in the next year:
 + ARCA28 from sept 2023 + ARCA48 from sept 2024

KM3NeT upper limits are quickly reaching the ANTARES 15yr limits
 Improvements also in angular resolution

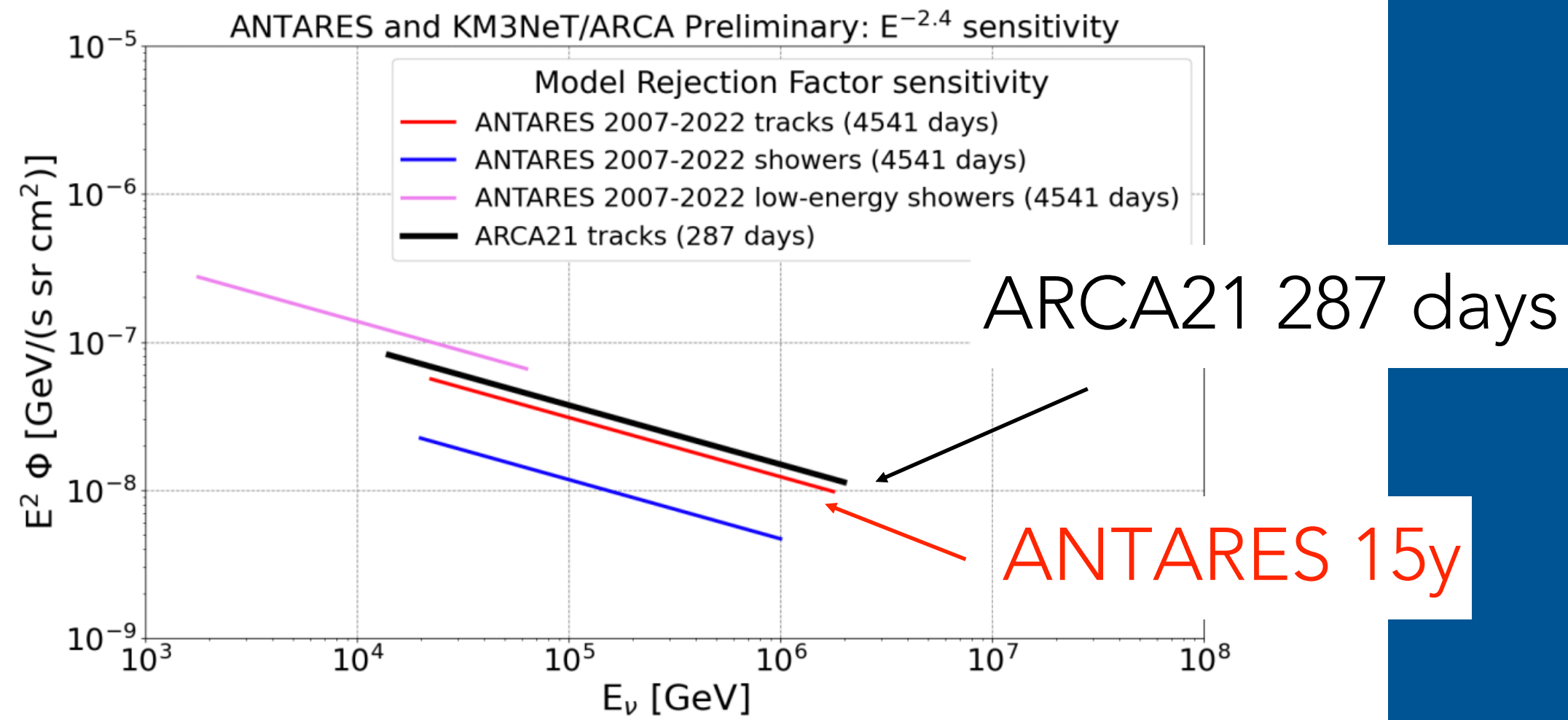
Joint ARCA-ANTARES point-like searches on going. ANTARES (15y) contributes most significantly, enhancement by 10% observed adding ARCA data (424d)

See M. Sanguineti flash talk

SEARCH FOR DIFFUSE FLUXES

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From the full sky

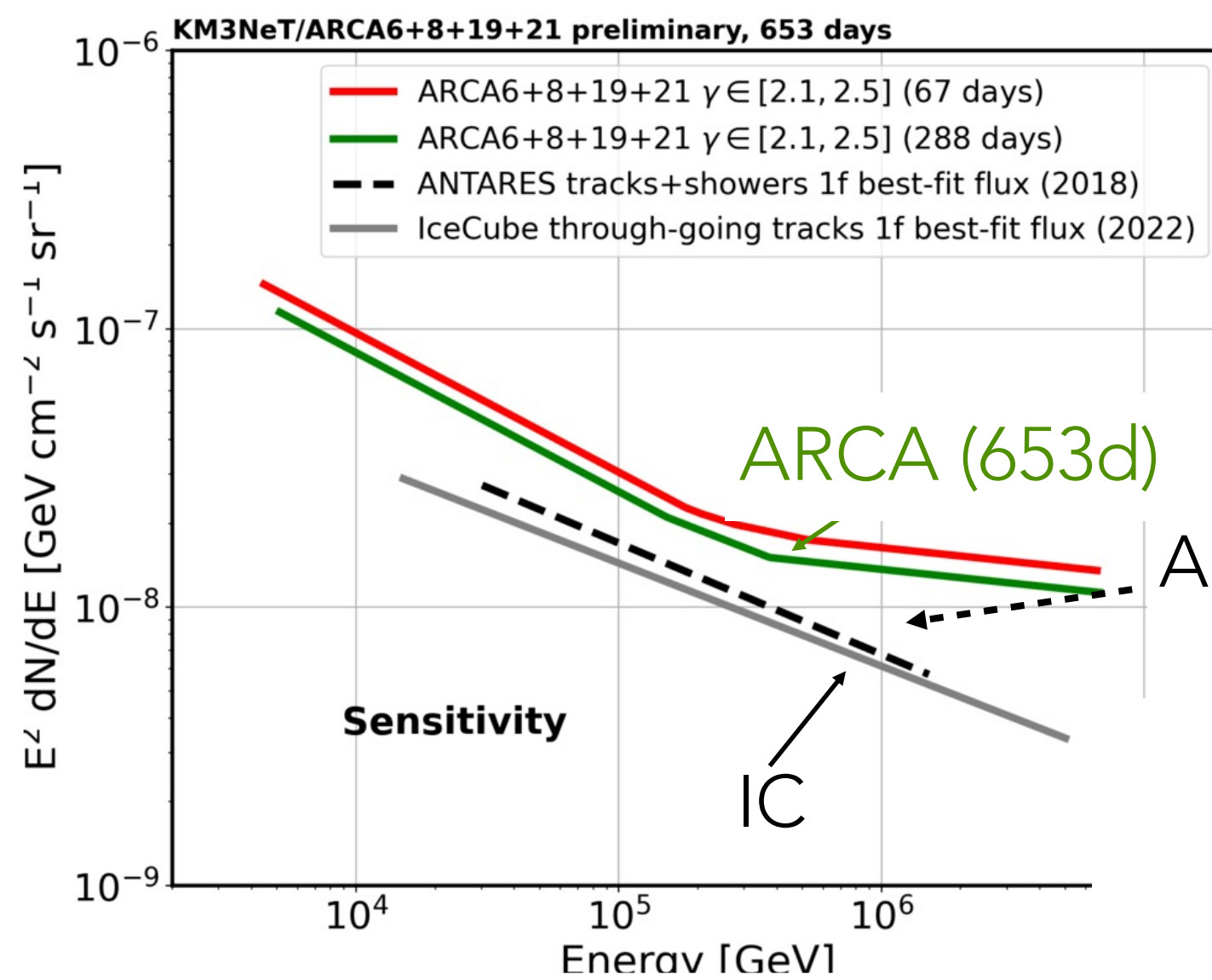


From the galactic plane

ARCA6 & ARCA8 & ARCA19 fully analyzed
 ARCA21 partially analyzed (until December 2022)

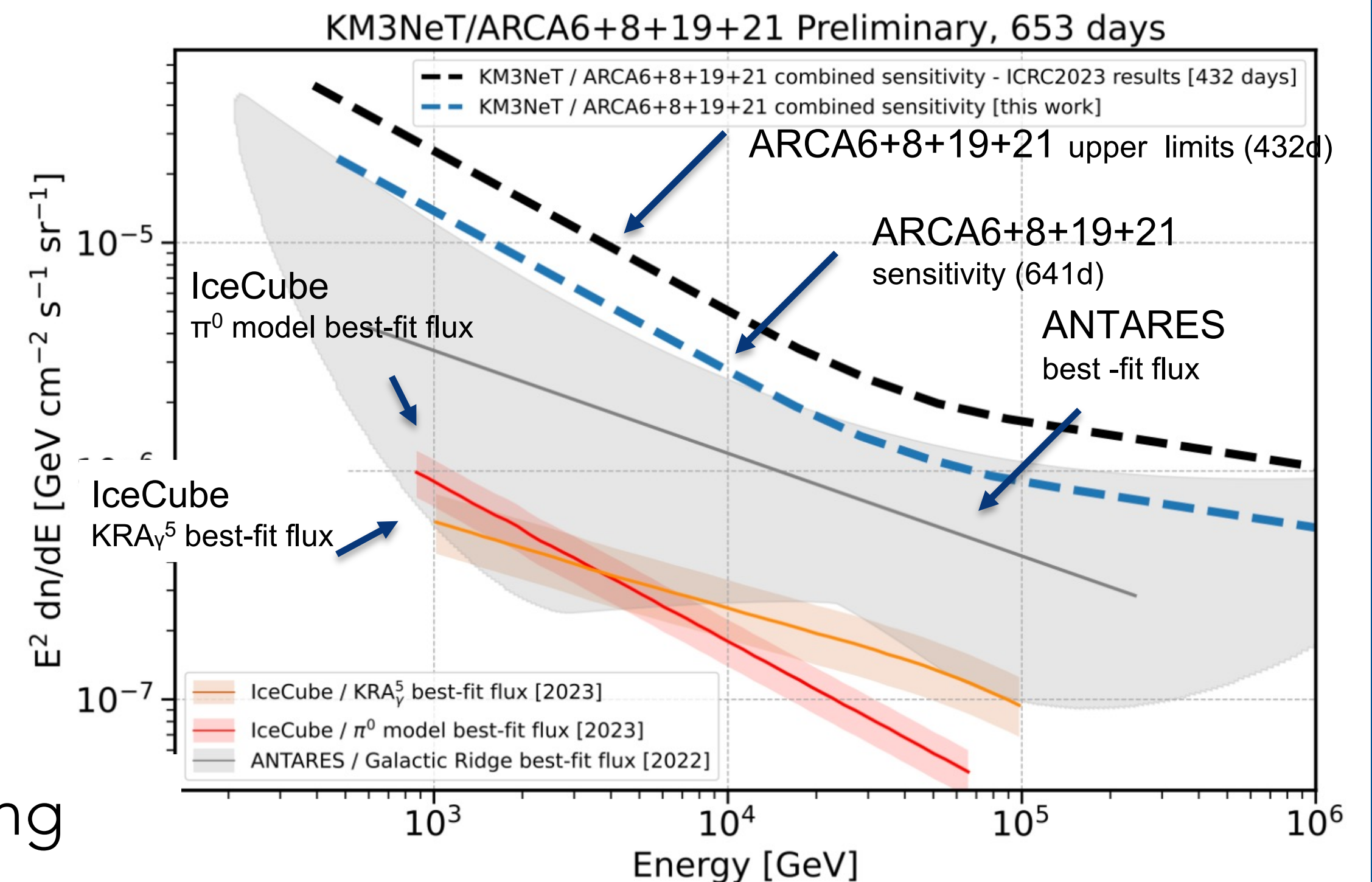
KM3NeT On-Off zone analysis

$|| < 31^\circ$ and $|b| < 5^\circ$ for KM3NeT/ARCA6-8 and
 $|| < 31^\circ$ and $|b| < 4^\circ$ for KM3NeT/ARCA19-21



With the data collected until Sept. 2023 same sensitivity of ANTARES 15yr for track events

ARCA rapidly approaching ANTARES sensitivities



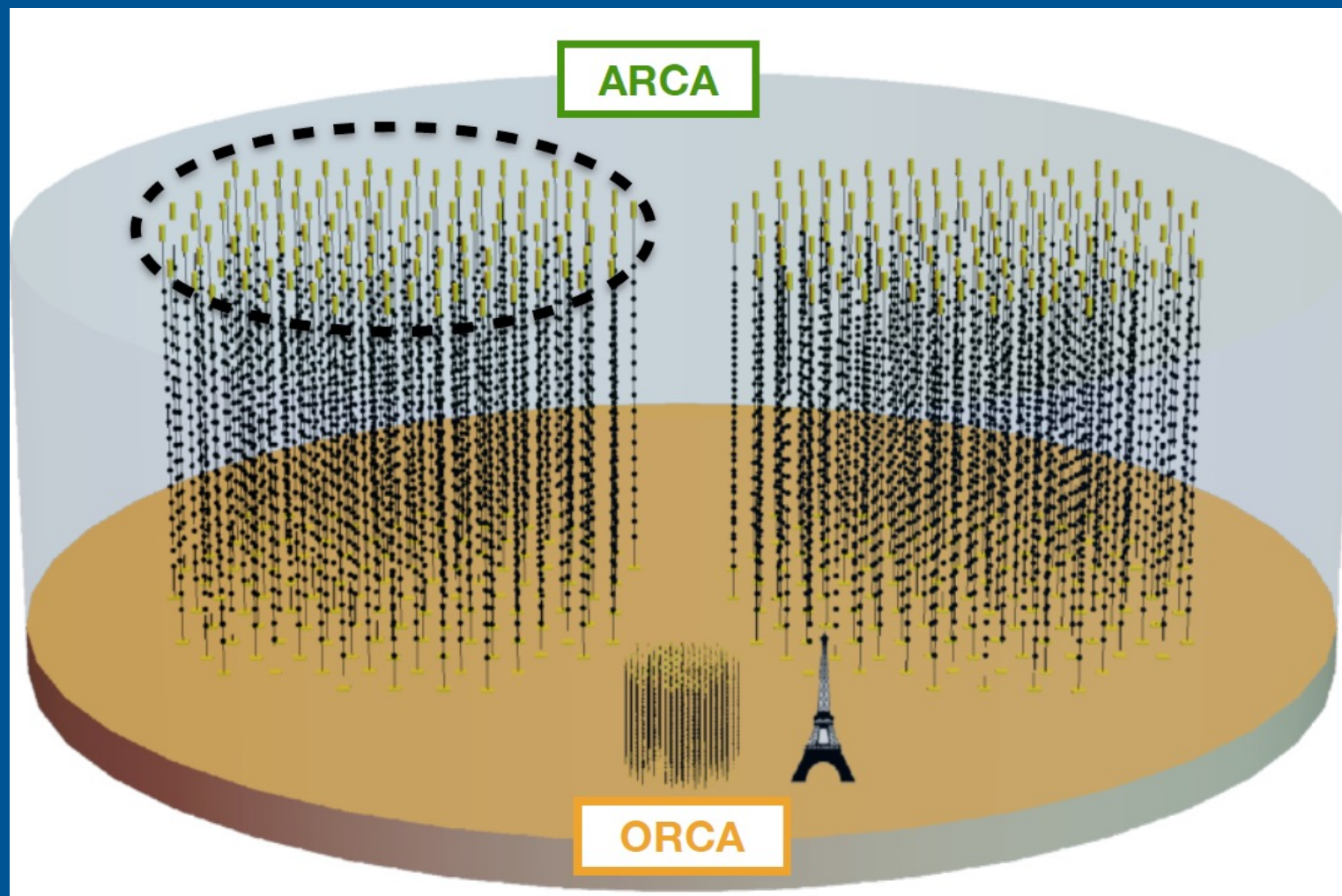
MULTI-MESSENGER PROGRAM

16

oS(ICRC2023)1125

ICRC2023 PoS_1125 ICRC2023 PoS_1521

A dedicated software is installed at the shore stations for Real-Time Analysis (RTA)



Sending alerts

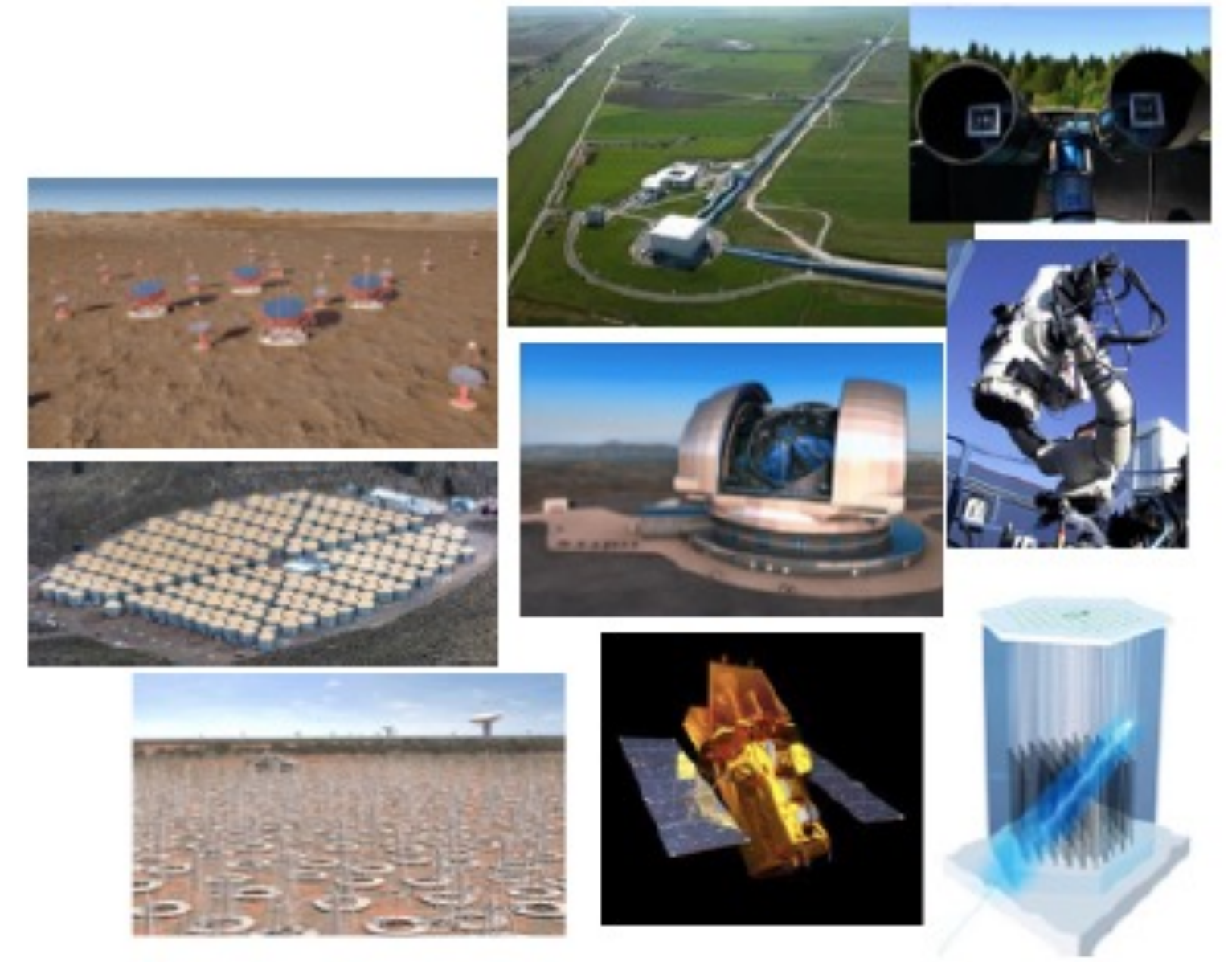
Send neutrino alert to external communities



Receiving alerts

Receive alert from external communities - on-line analysis and follows ups

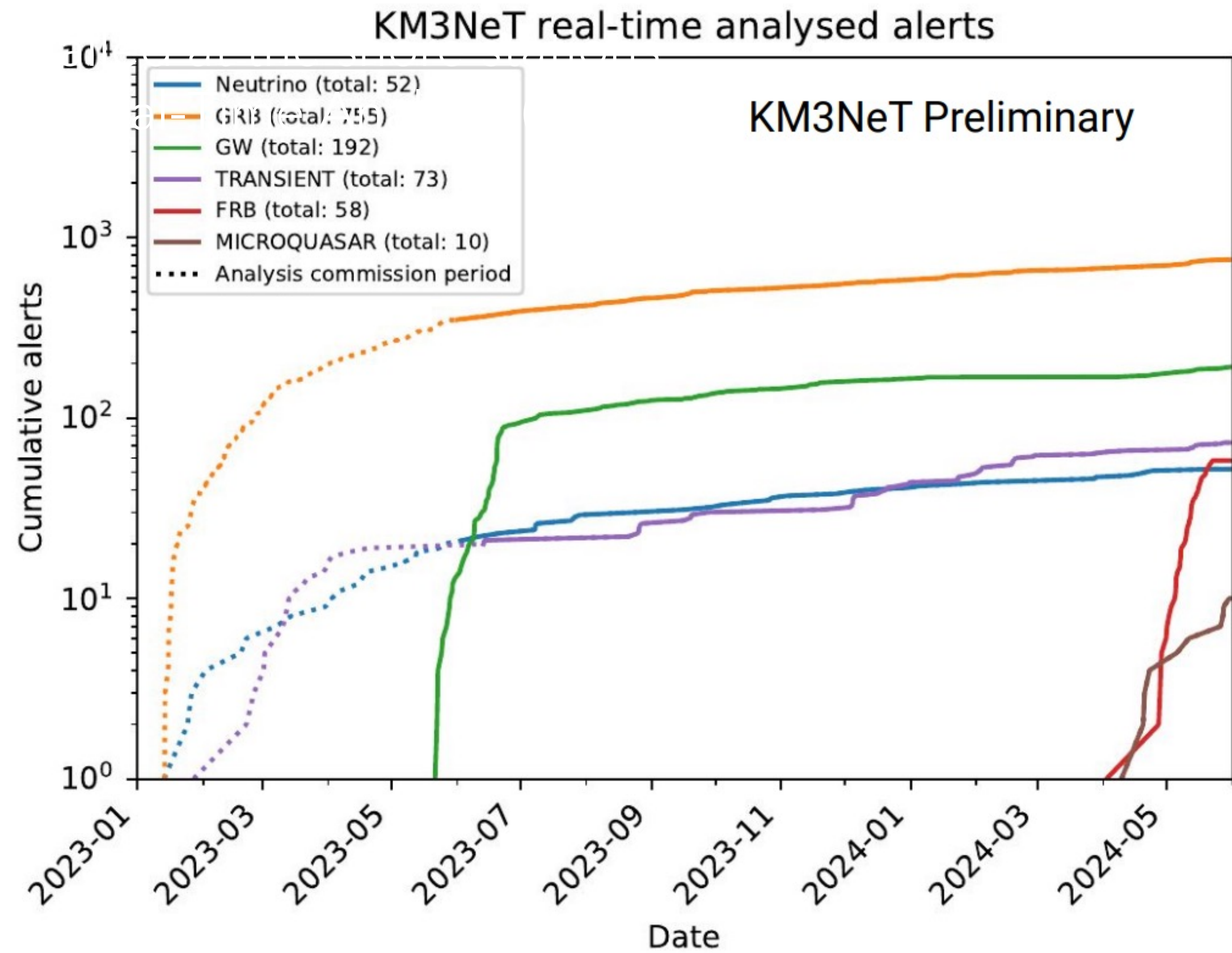
EM/MM external communities



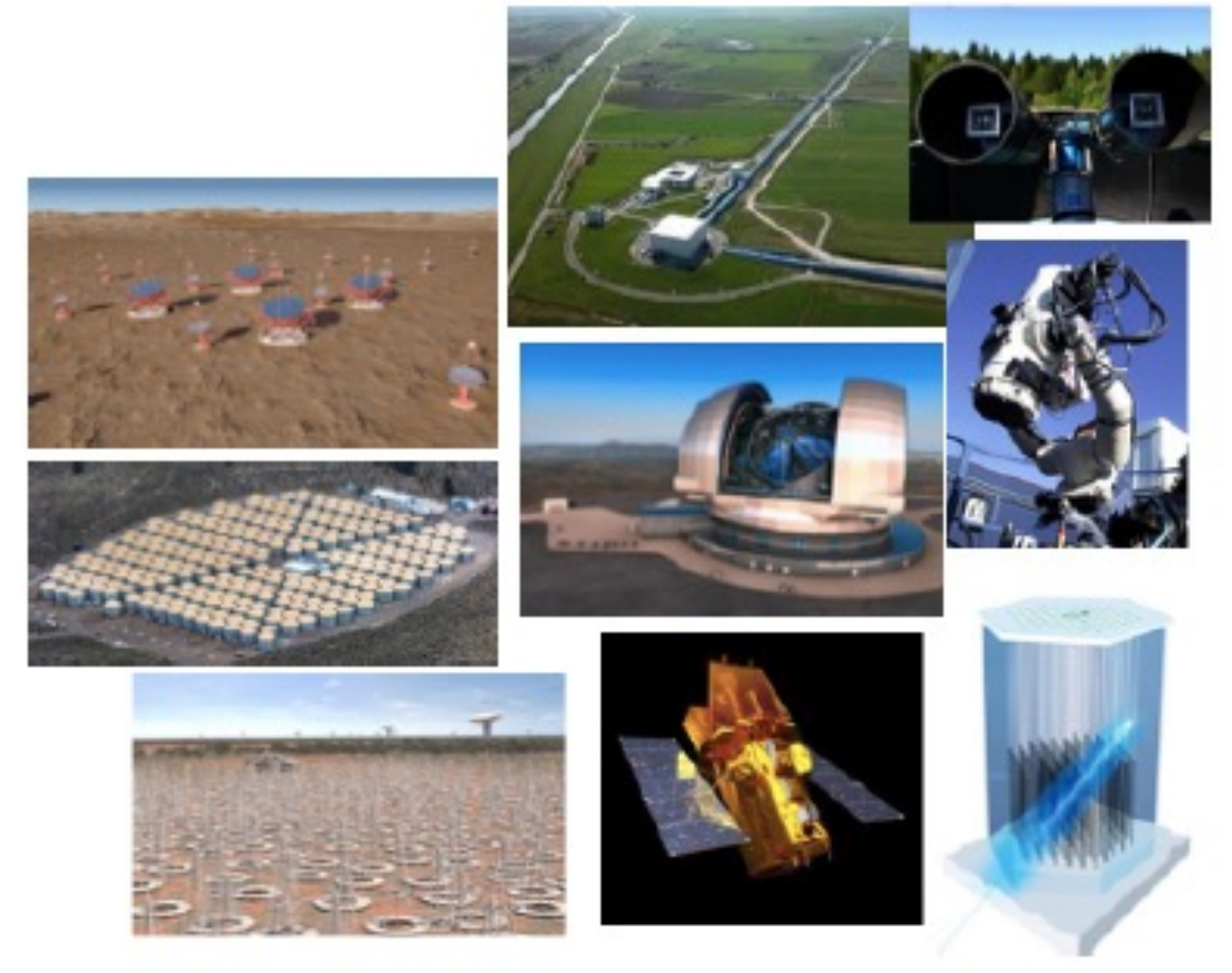
Receiving alert system operative 🖱️ RTA platform already active from November 2022 in ARCA and in ORCA detectors

Sending alert system on going 🖱️ High-energy neutrino alerts will be sent in real-time by end of 2024.

MULTI-MESSENGER PROGRAM



EM/MM external communities

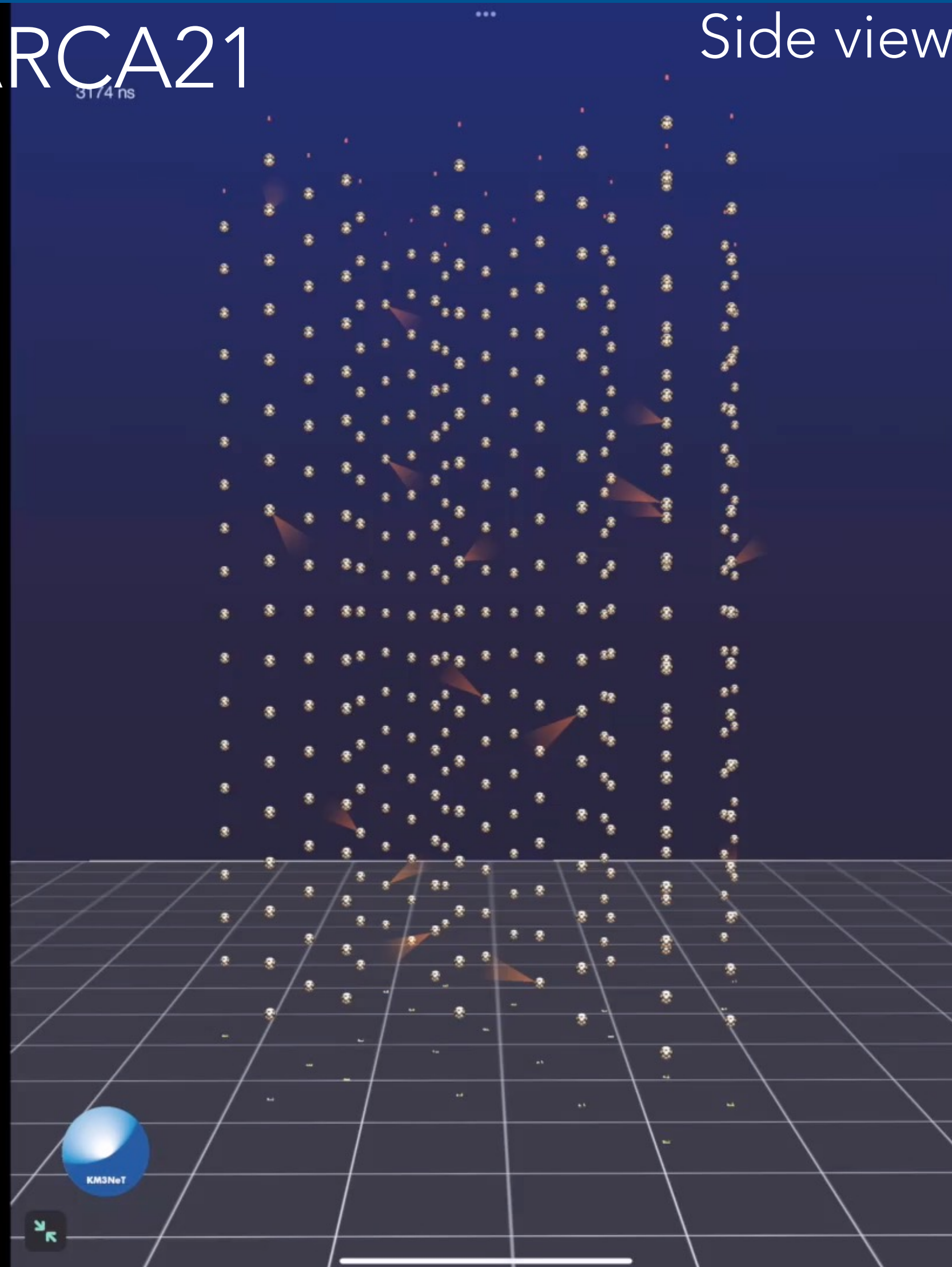


Several thousands of alert received and analyzed in real time 🙌 so far no significant excess found in any of the observed alerts

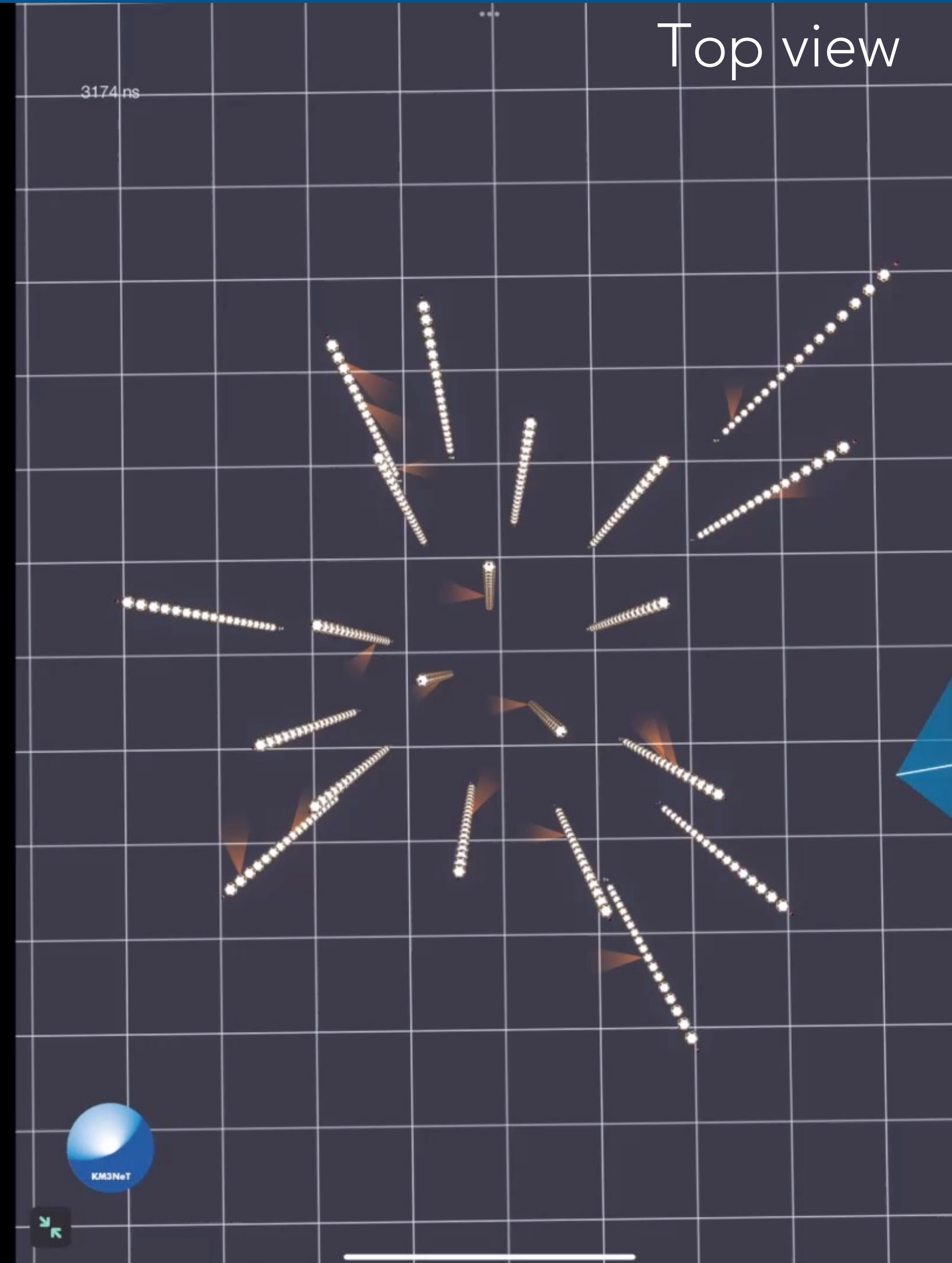
A very energetic cosmic event detected

ARCA21
3174 ns

Side view



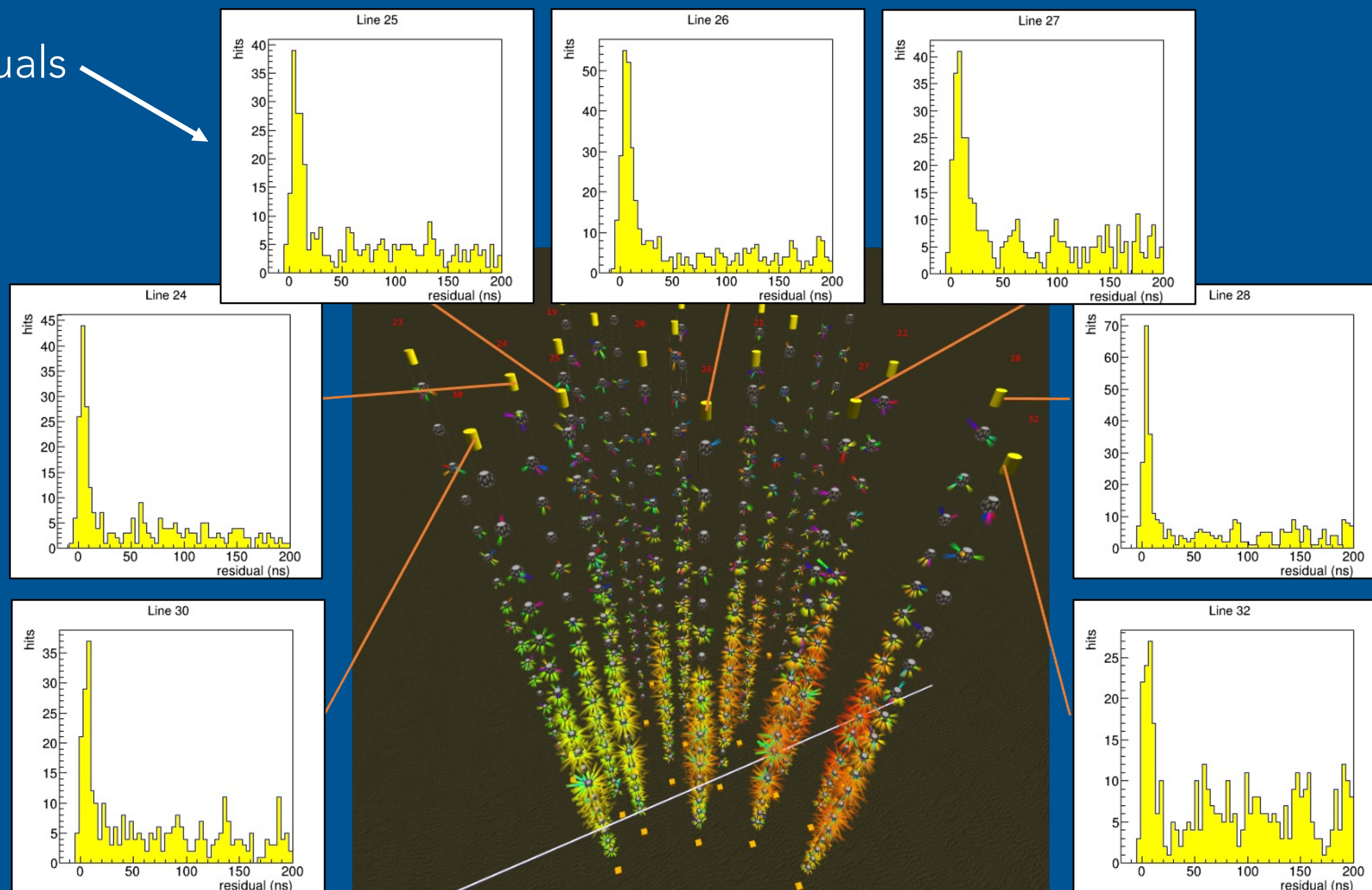
Top view



A very energetic cosmic event detected

The event is well reconstructed as a track

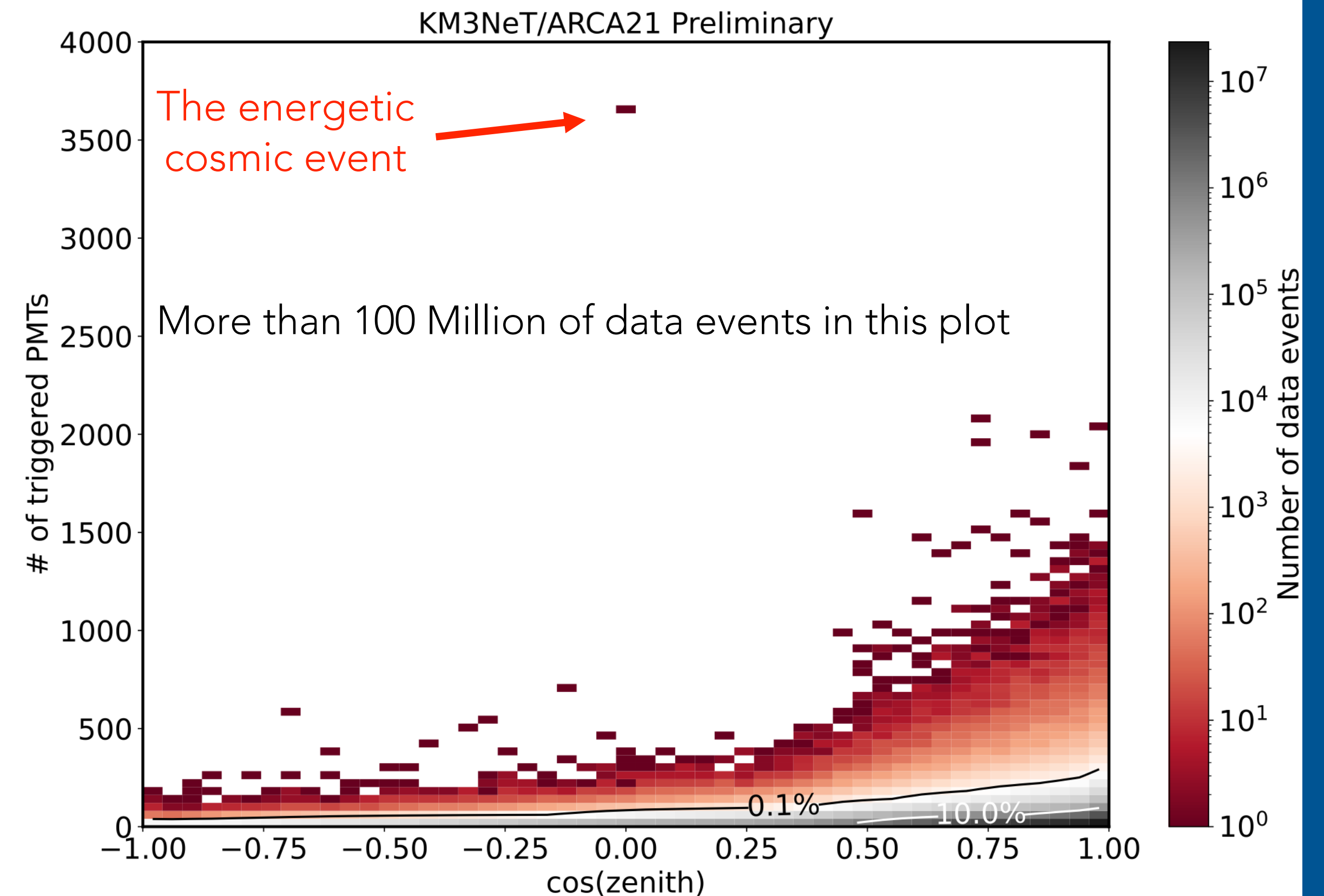
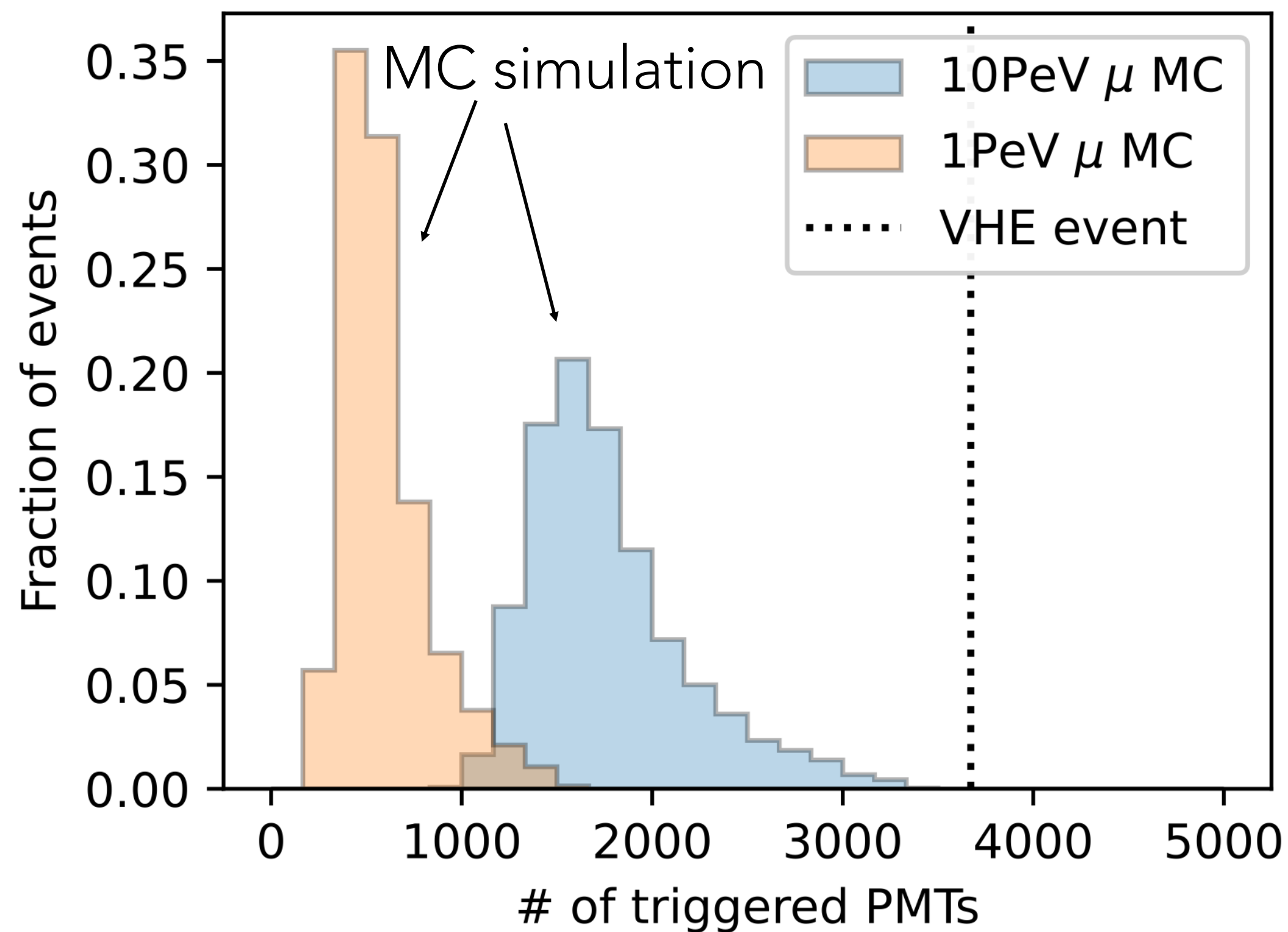
Time residuals



A very energetic cosmic event detected

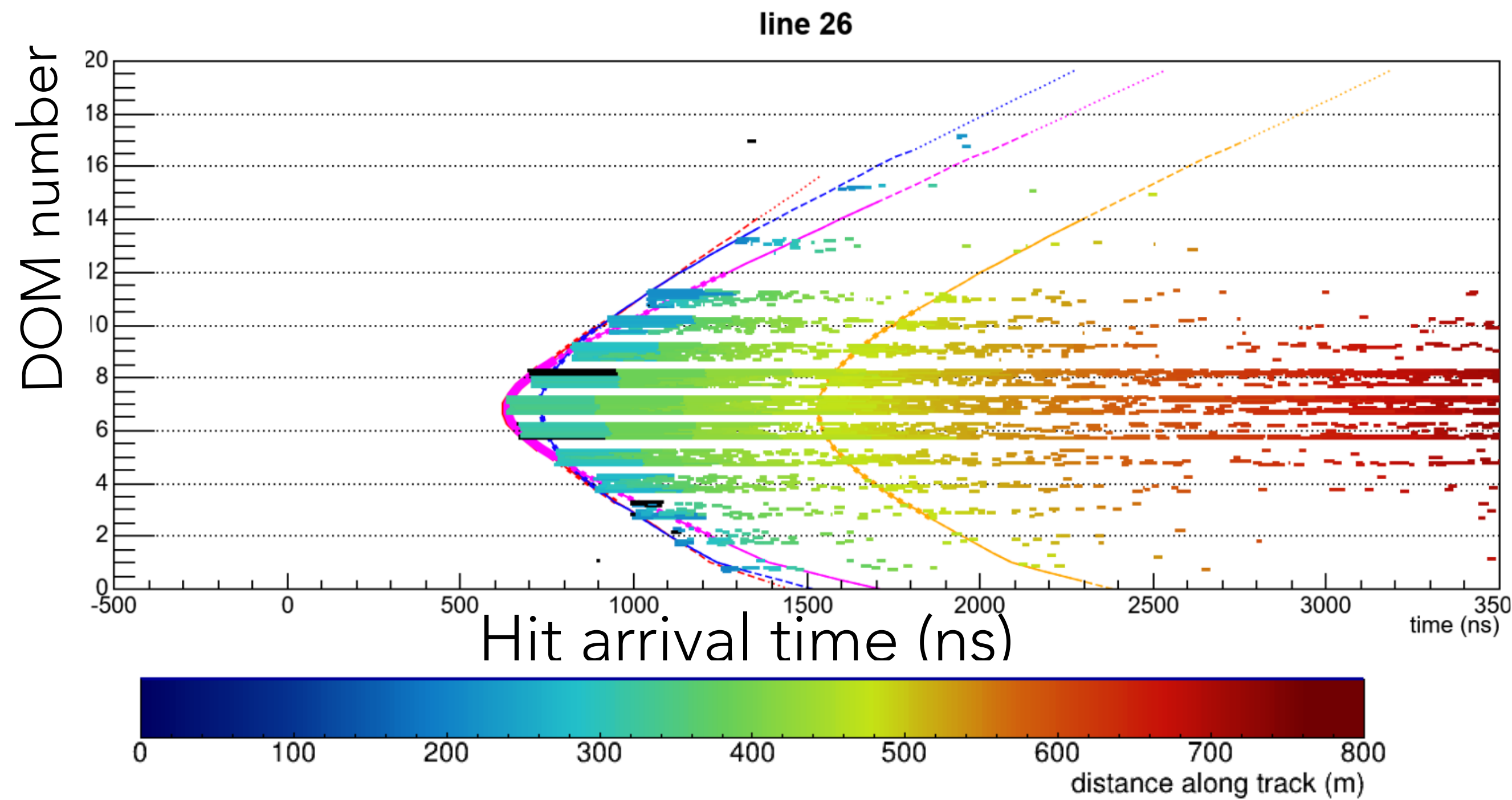
The event is a horizontal event (1° above the horizon) with energy above 10 PeV

Huge amount of light detected 🖱️ 35% of the total number of PMTs were triggered



THE EVENT WITH THE HIGHEST ENERGY

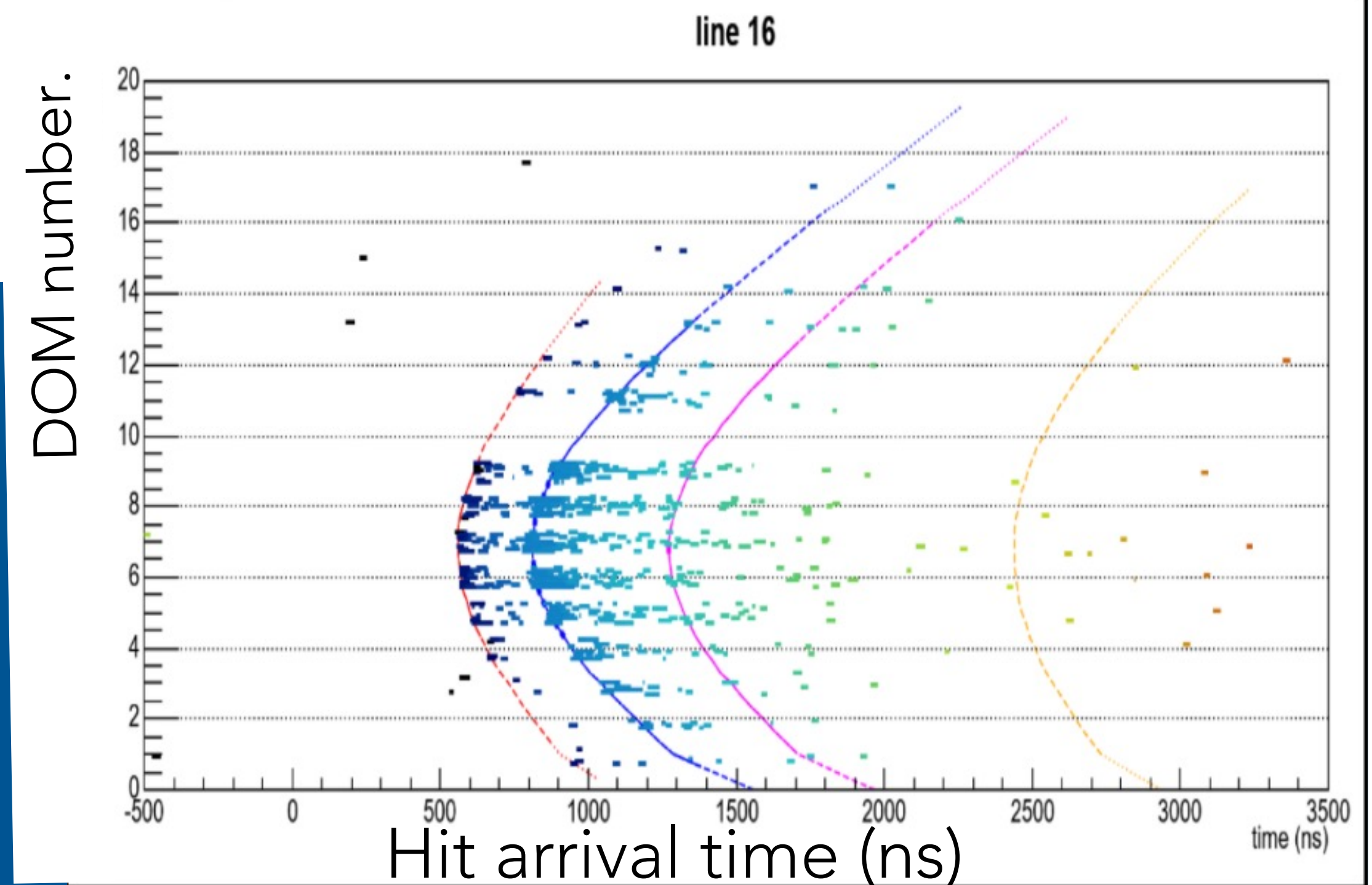
21



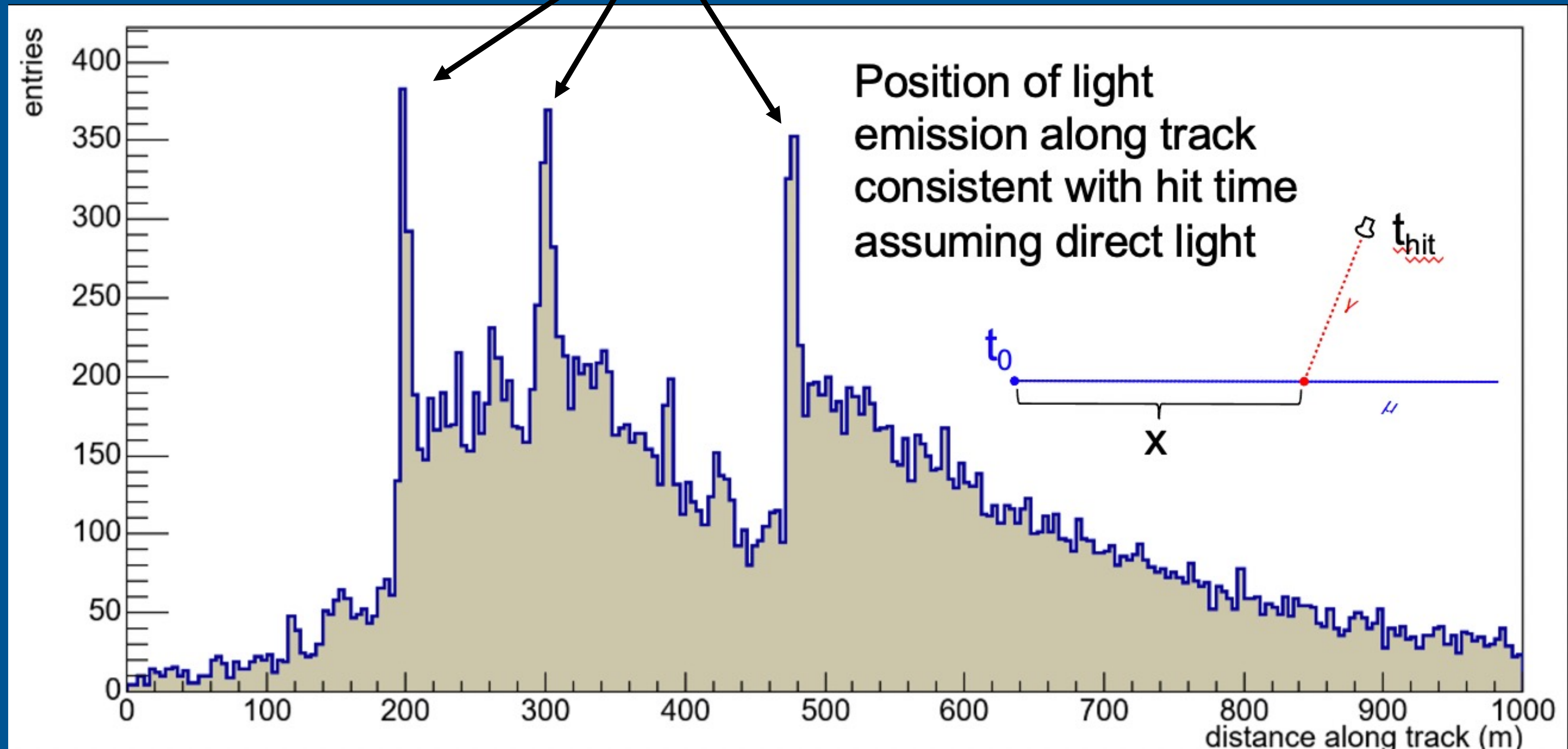
From the track and shower reconstructions

A muon track and three showers detected

Hit times are fully consistent with photons from Cherenkov emission



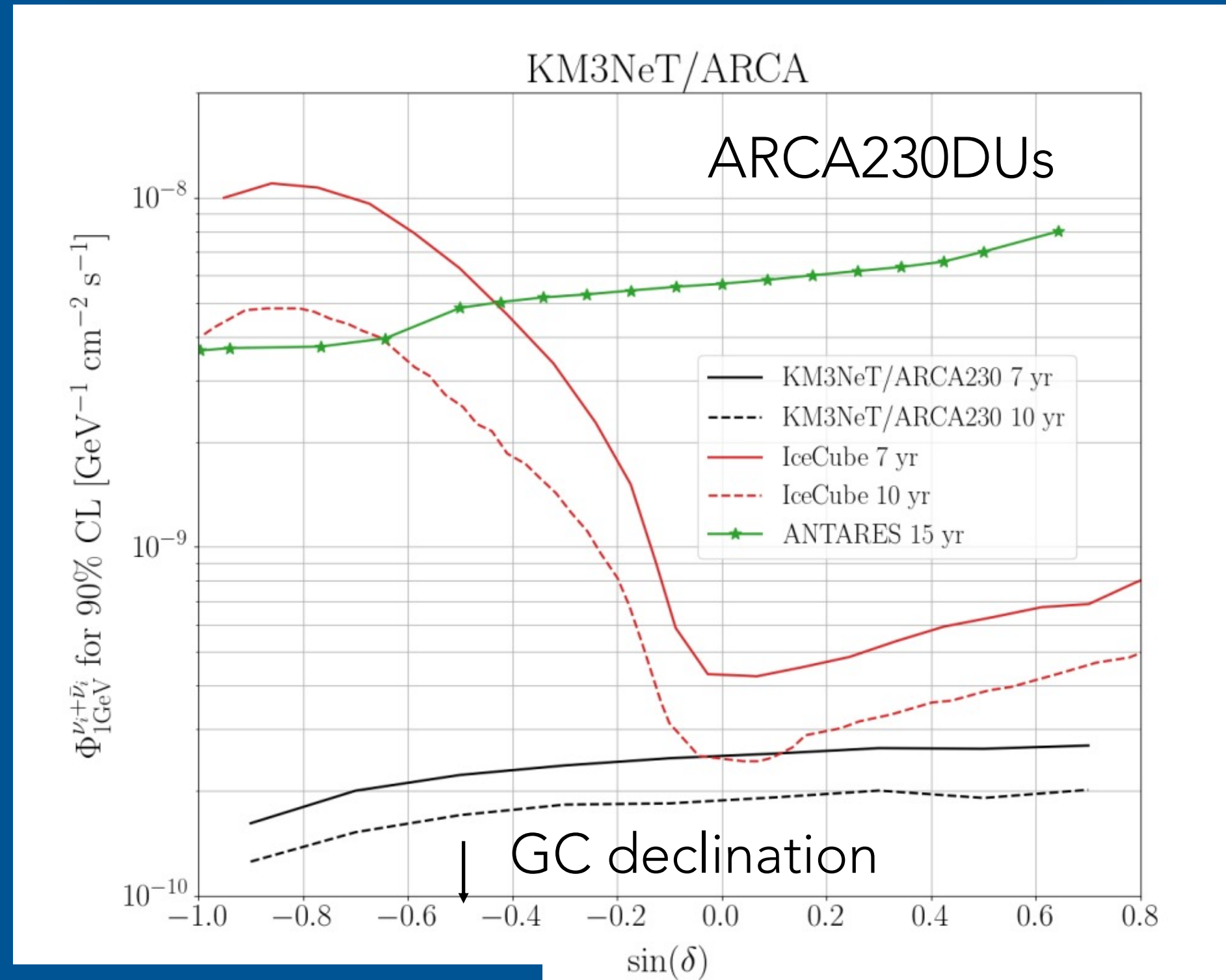
Hit times consistent with the emission from three points along the track 🙌 stochastic light emission



KM3NET PERSPECTIVES

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ARCA - Sensitivity for point-like searches

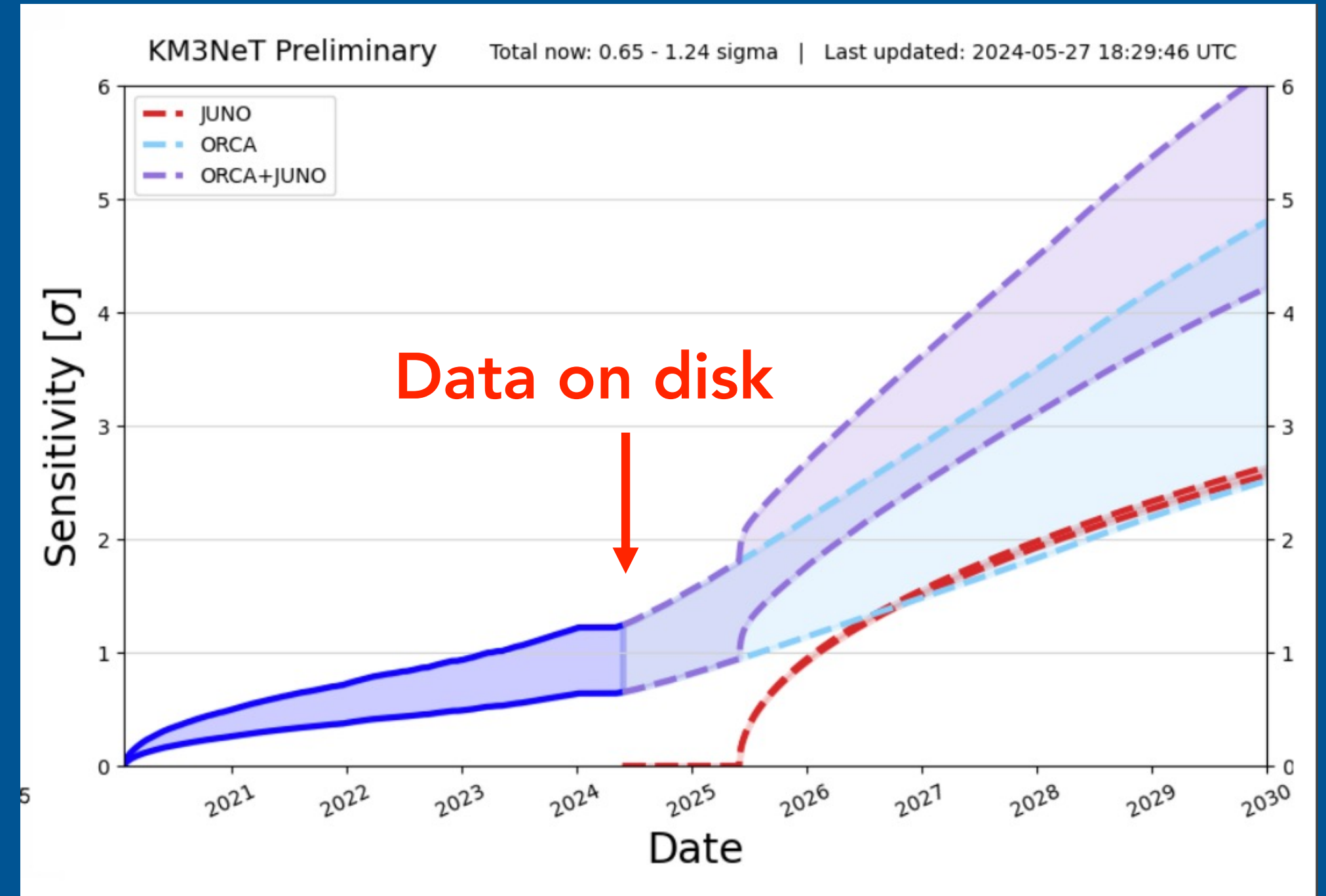


<https://arxiv.org/abs/2402.08363>

Big expectations for the southern sky

ORCA - Neutrino mass ordering

Predictions based on the current construction plan.



5σ can be reached in the next 5-6 years if combined with Juno

2020 2021 2022 2023 2024 2025 2026 2027 2028 2029

↑
ANTARES
decommissioning

↑
ARCA 48DUs
ORCA 24 DUs

↑
ARCA & ORCA
completion

SUMMARY

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KM3NeT under construction 🙌 present status: ARCA 28 DUs (12% of full detector) and ORCA 23 DUs (20% of the full detector)
Detectors in data taking from the first strings deployed

ARCA sensitivities quickly approaching the ANTARES ones

Exciting results expected in a few years especially in the exploration of the southern sky

Promising results also in the neutrino oscillation 🙌 KM3NeT/ORCA in the race for mass hierarchy

An exceptional high energy track event detected 🙌 a horizontal event with energy above 10 PeV 🙌 detailed event description

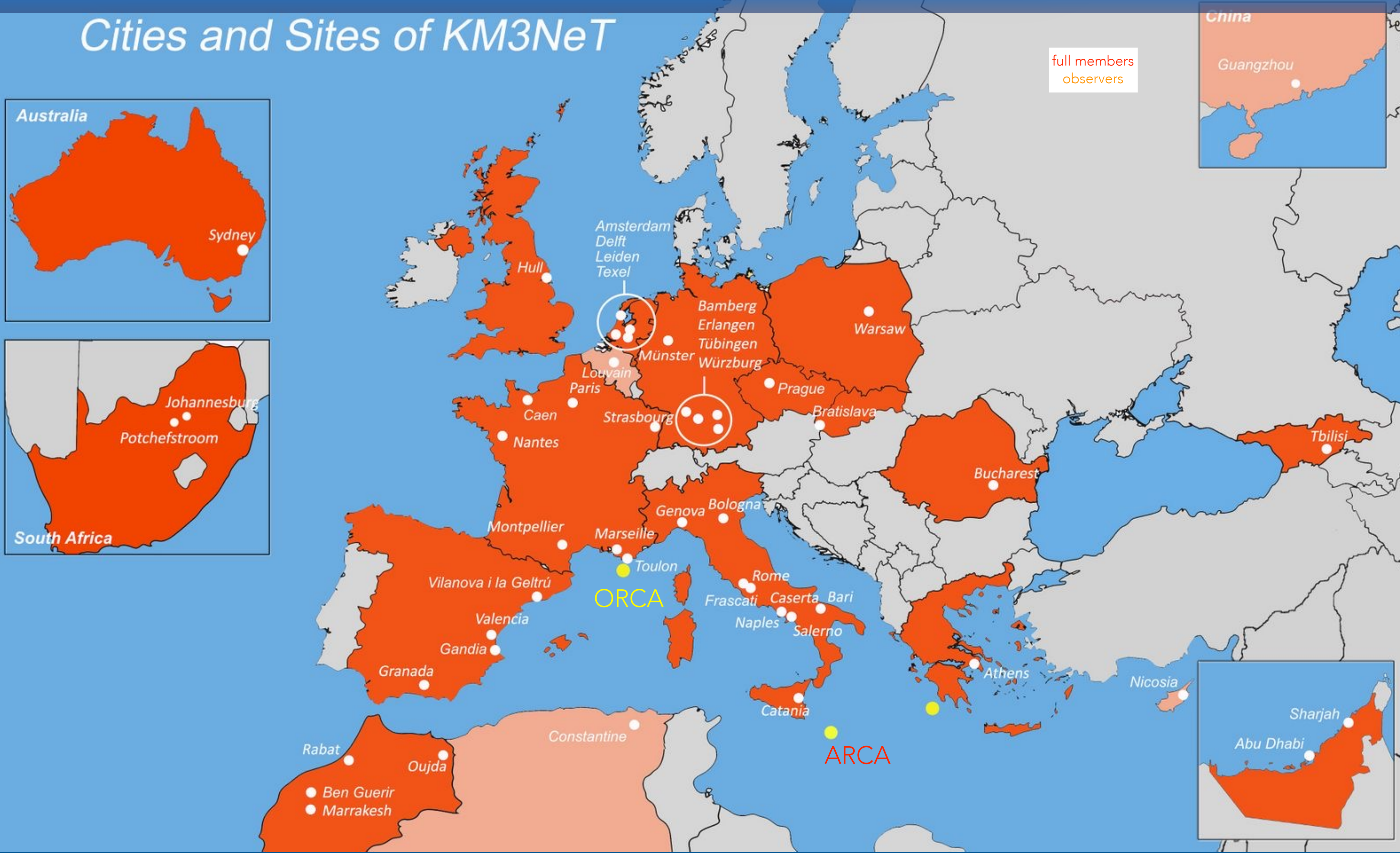
More information will follow soon

THE KM3NET COLLABORATION

63 institutes in 22 countries

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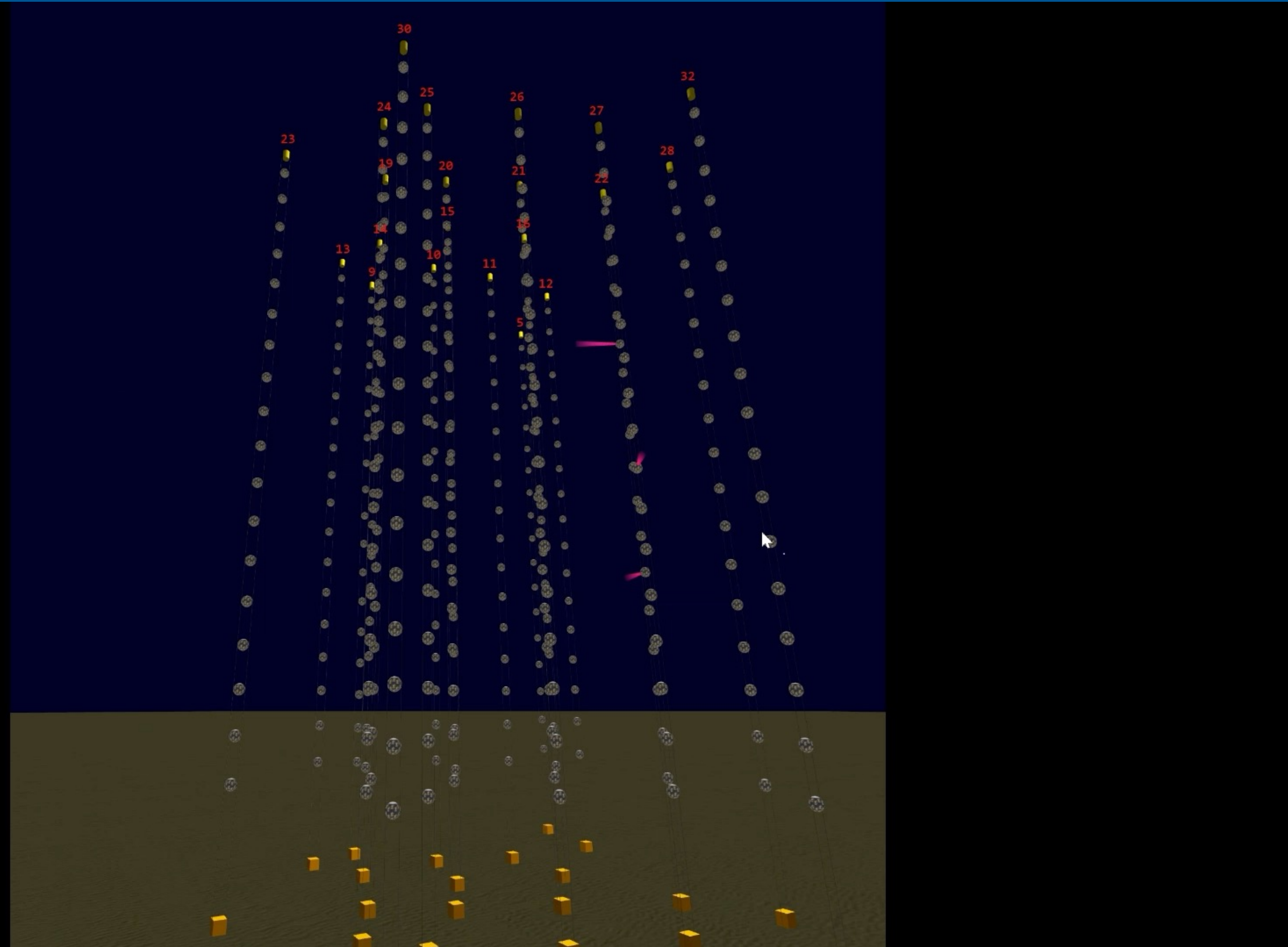
Cities and Sites of KM3NeT



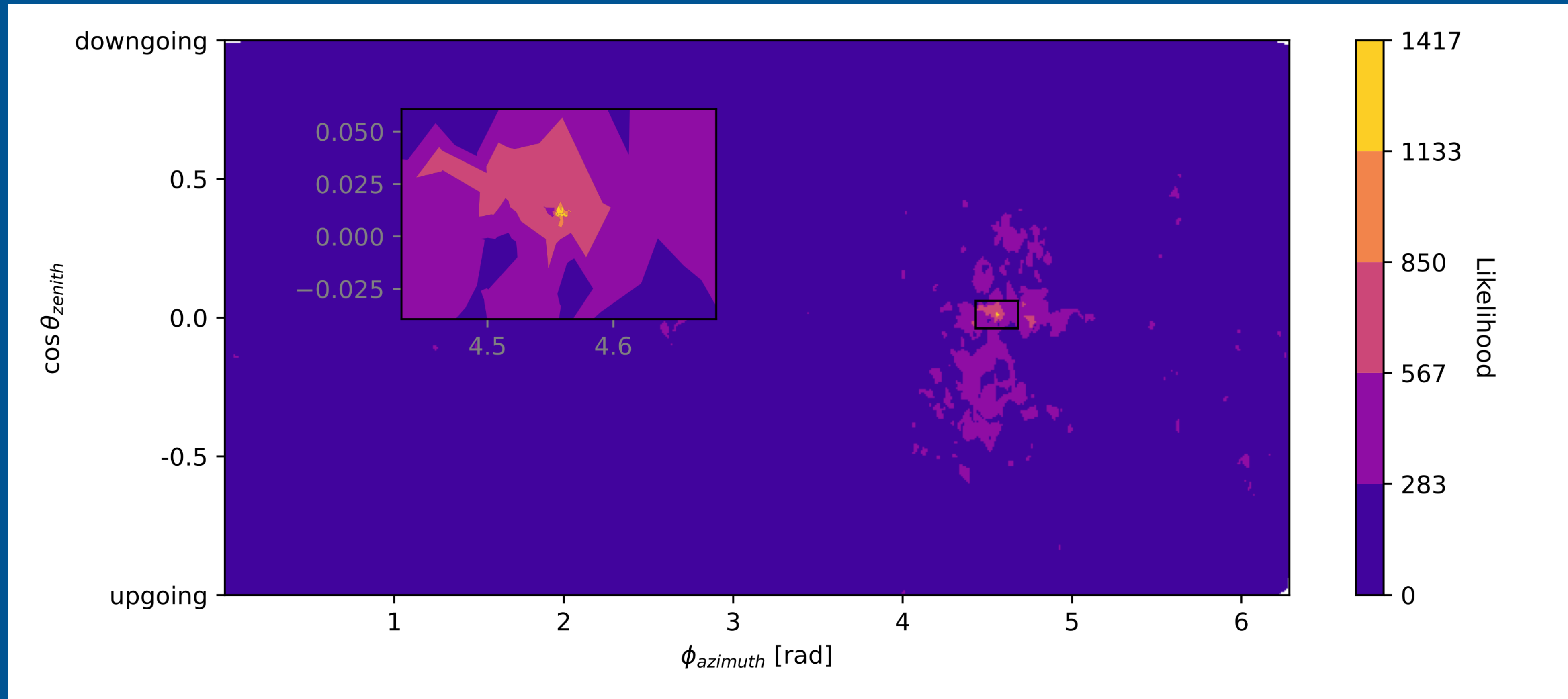
+ Harvard University (USA)

A very energetic cosmic event detected

ARCA21



From the track reconstruction the likelihood map



Very well defined minimum in local coordinates

THE HIGH ENERGY NEUTRINO DETECTORS

