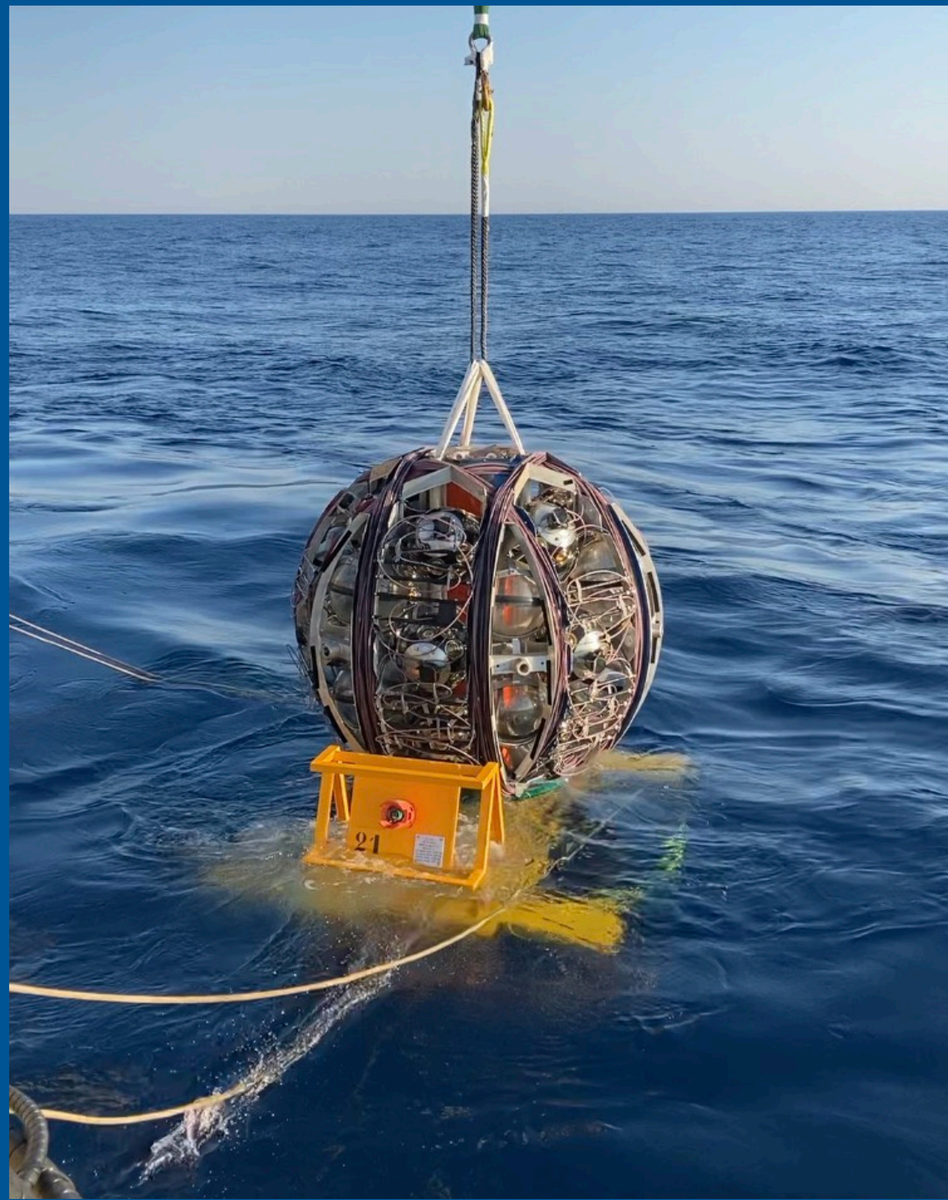
RICAP-24 Roma International Conference on AstroParticle Physics

Frascati 23-27 September 2024

KM3NET STATUS AND RECENT RESULTS

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

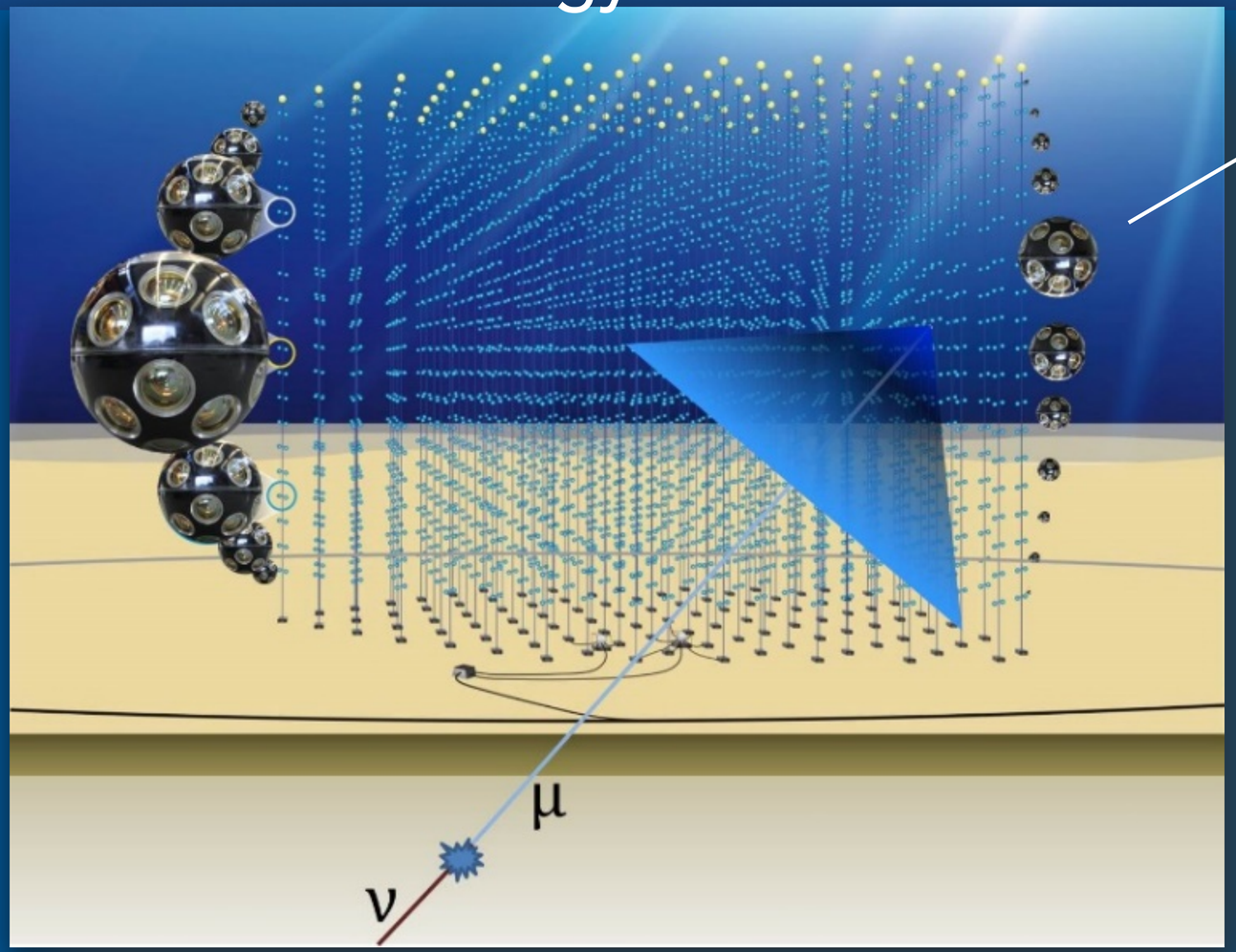
- KM3NeT/ARCA (Astroparticle Research with Cosmics in the Abyss)
  - observation of high energy (GeV ÷ PeV) neutrino sources 👉 a telescope offshore Capo Passero (Sicily-Italy) is under construction at a depth of 3500m

- 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 under construction at a depth of 2500m

1 collaboration 1 technology 👉 2 detectors

THE KM3NET DETECTORS

Same technology for the two detectors



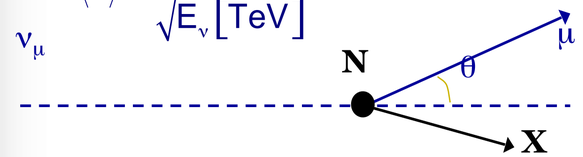
Digital Optical Module DOM)
31 PMTs of 3 inches

Detection Unit (DU)

Neutrino direction can be reconstructed from PMT positions and hit times

- Photomultipliers to detect the light
- Acoustic system to measure the PMT position each 10 minutes

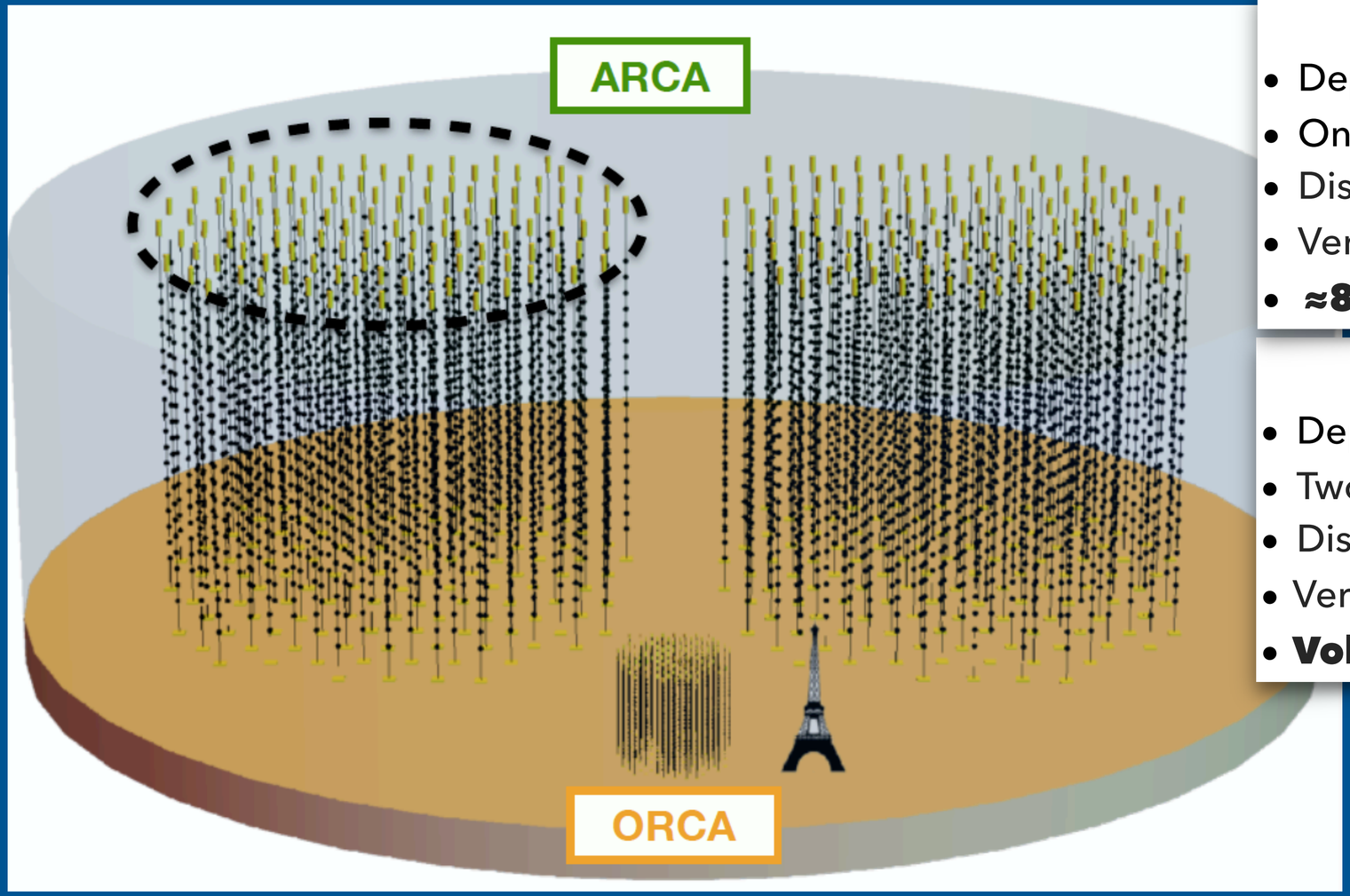
$$\langle\theta\rangle \approx \frac{1.5°}{\sqrt{E_\nu\,[\mathrm{TeV}]}}$$



For neutrino energies >TeV 👉 neutrino and muon collinear

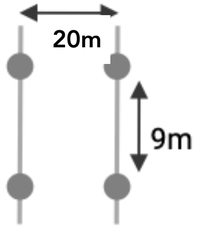
Detectors under construction and taking data

THE KM3NET DETECTORS



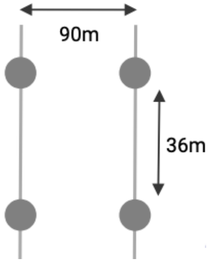
ORCA

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



ARCA

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



1 Building Block (BB) 👉115 Detection Units

ARCA 2 BB (230 DUs)

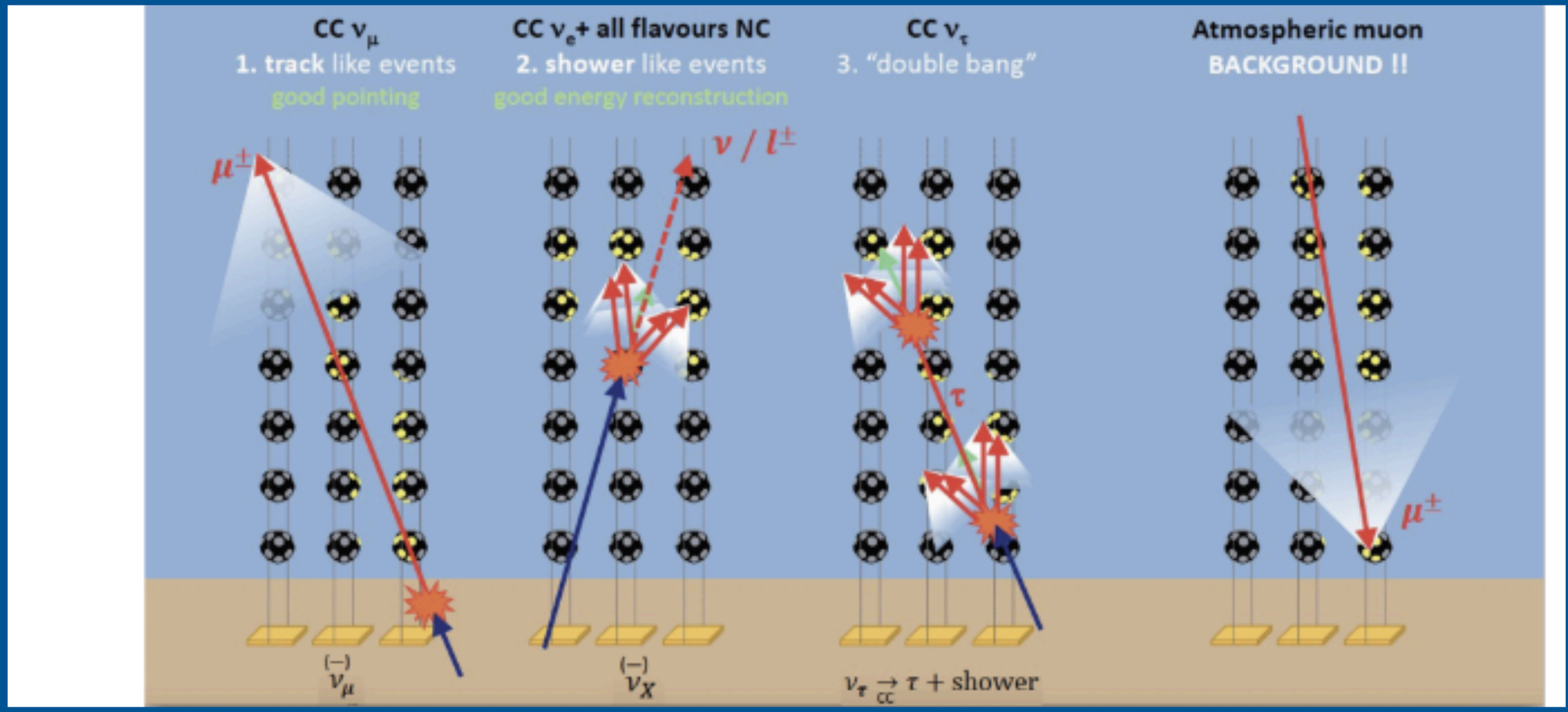
ORCA 1BB (115DUs)

Difference in the spatial distance of optical sensors

DETECTION PRINCIPLE

Two kinds of event:

- "Track-like" events mainly from ν_μ CC interactions
- "Cascade-like" events mainly from ν_e CC and NC interactions



Tracks 👉 @E_ν>100 TeV Ang. res. below 0.1° - Energy res. ~ factor 2

Shower 👉 @E_ν>100 TeV Ang. res. below 2° - Energy res. ~6%

THE HIGH ENERGY NEUTRINO DETECTORS

P-ONE
R&D phase

KM3NeT/ORCA
In construction (14%)
8Mton

ANTARES
(dismantled)
0.01 km³

KM3NeT/ARCA
In construction (12%)
1km³

Baikal-GVD
In construction
1km³

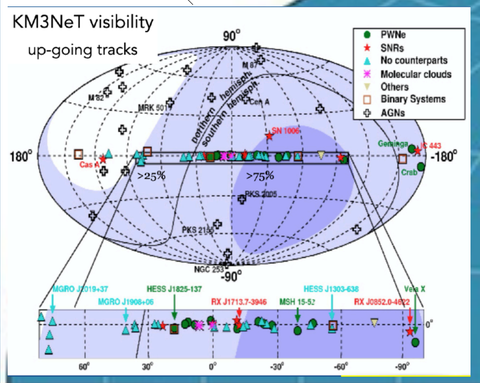
R&D phase
TRIDENT
~8 km³

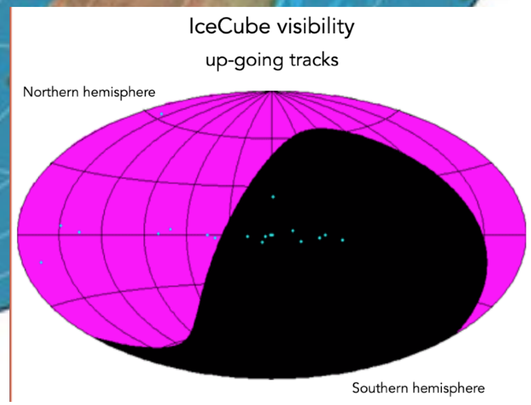
IceCube-Gen2
Planned
~8 km³

IceCube
1 km³

In China also:

- HUNT ~30 km³ in Lake Baikal or the South China Sea http://hunt.ihep.ac.cn/
- NEON ~10 km³ in the South China Sea https://arxiv.org/pdf/2408.05122





Aitoff Projection

THE TECHNOLOGY

The basic elements:

- Optical sensors 👉 DOMs
- Strings 👉 DU
- Seafloor network 👉 Electro-optical cables and JBs (Junction Boxes)

Sea talks of:
L. Morales Gallegos (technology and construction)
F. Benfenati (DAQ)
D. Real (electronics)
C. Lastoria (data quality)

The Digital Optical Module

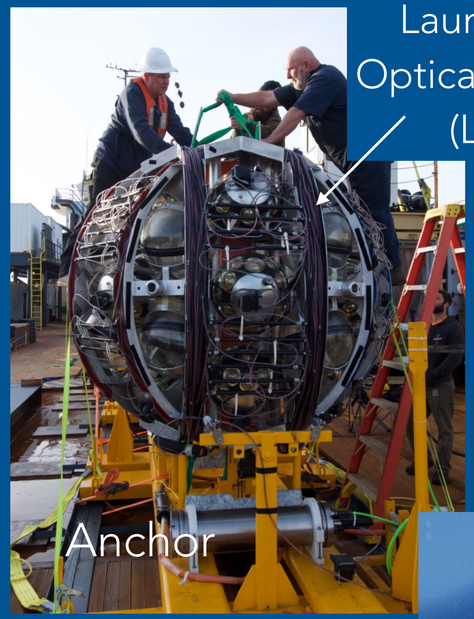
DOM

It is a 17” glass sphere containing:

- 31 3” PMTs (photocathode aerea ≃ 3 × 10” PMTs)
- LED and Piezo
- Front-end electronics -> FPGA

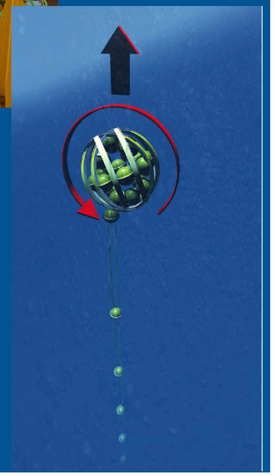
Video of the DOM integration

The Detection Unit



18 DOMs in a DU

DU



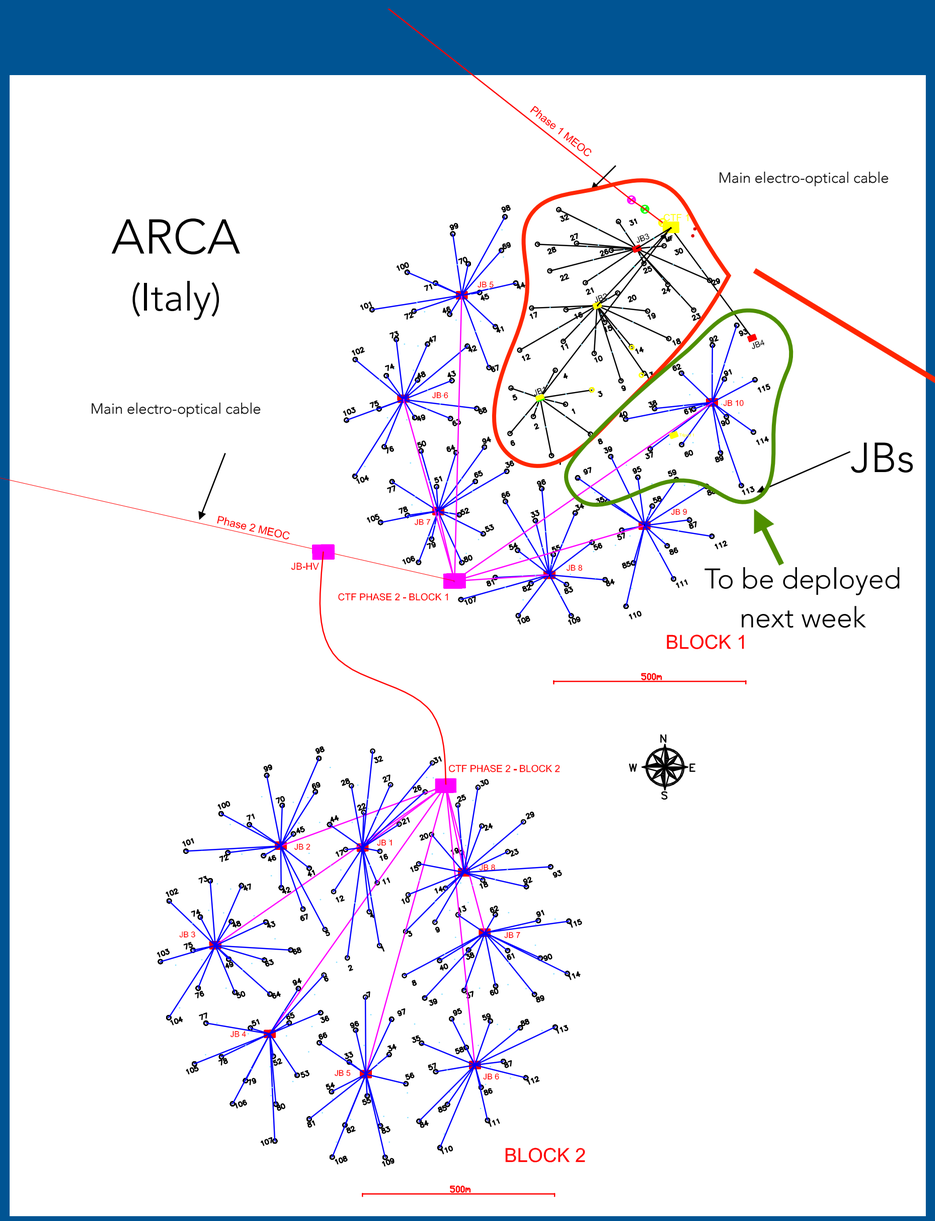
Video of a DU integration

The Sea floor network:

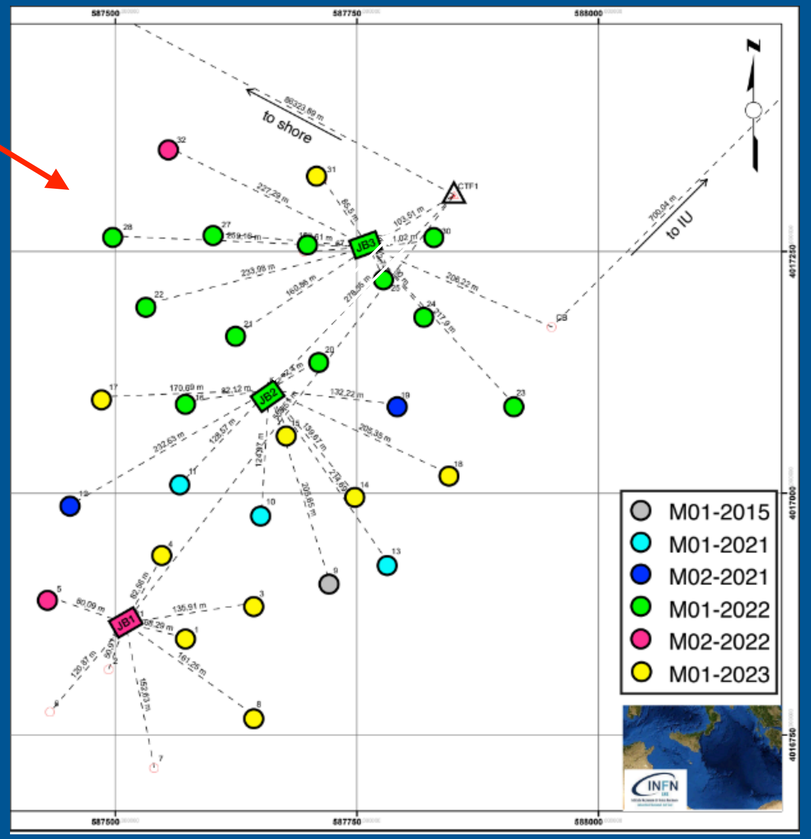
- Electro-optical cables from shore to the deep sea
- Junction boxes (JB)/nodes to distribute power and optical fibers
- In ARCA Cable Termination Frames (2 already installed)
- Interlink cables for connection of DU to JB and JB to the main cable

ARCA JB

THE KM3NET/ARCA STATUS



Current status 28 DUs deployed (26 taking data)
+ 3 JB



1 sea campaign per year

The next one in October 2024

To be deployed:

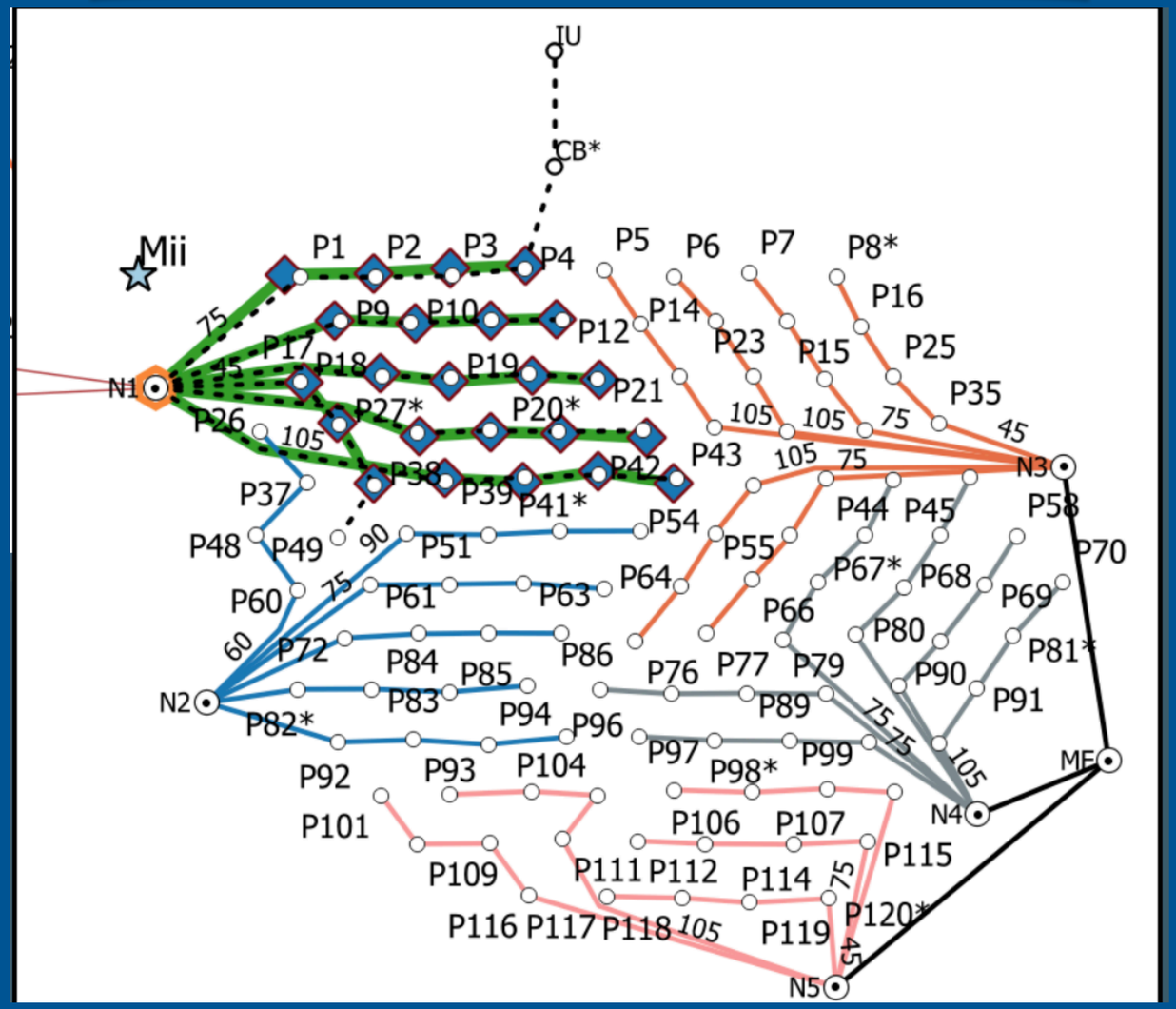
2 JB + 19DUs + Instrumentation Unit (IU)

Challenging sea campaign 👉 new main cable+new Cable Termination Frame (CTF)+ new Wet White Rabbit System (WWRS) for time synchronization

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

THE KM3NET/ORCA STATUS

Current status 23 DUs deployed (22 taking data)



Many sea campaigns/year

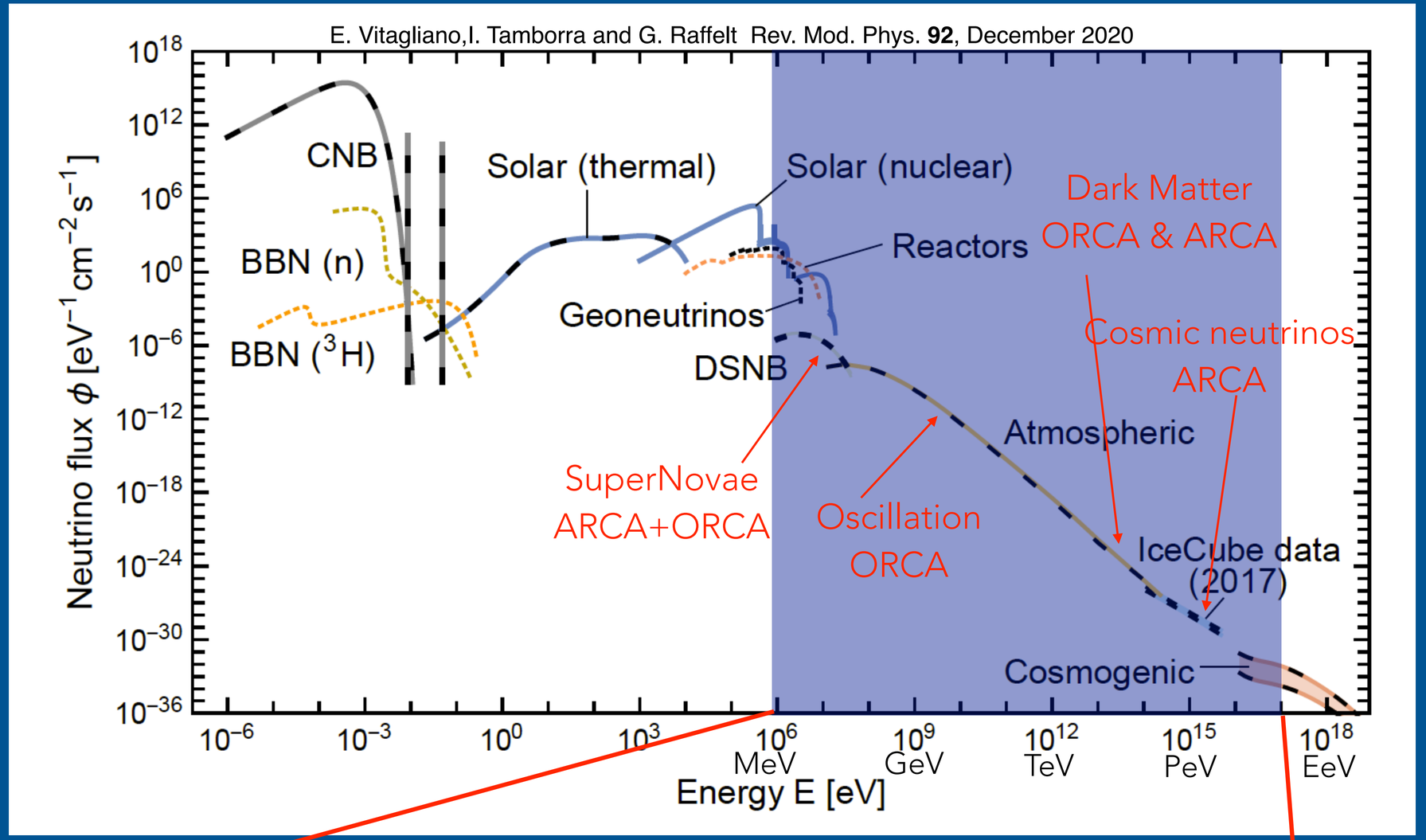
Next one foreseen before the end of the year 👉 complete the DUs of node1 (+2DUs) and deploy 4-5 DUs

Almost completed the first node

👇

20% of the full detector in water

THE NEUTRINO SPECTRUM AT EARTH

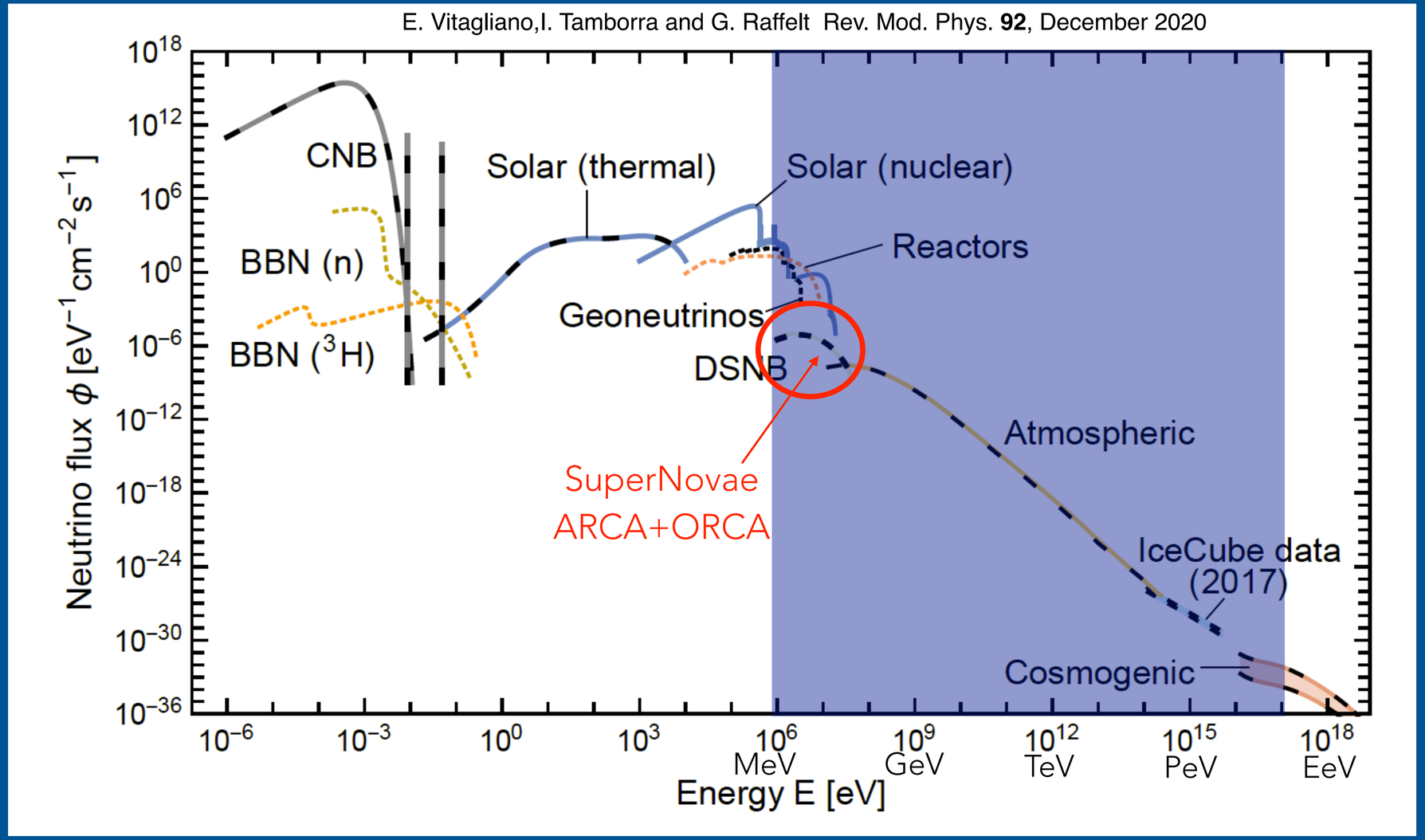


Dark Matter: talk of C. Gatius
GeV Neutrinos: talk of J. Mauro

GRB: talk of J. Palacios Gomez

KM3NeT detects neutrinos from MeV to PeV

SUPERNOVA EXPLOSION

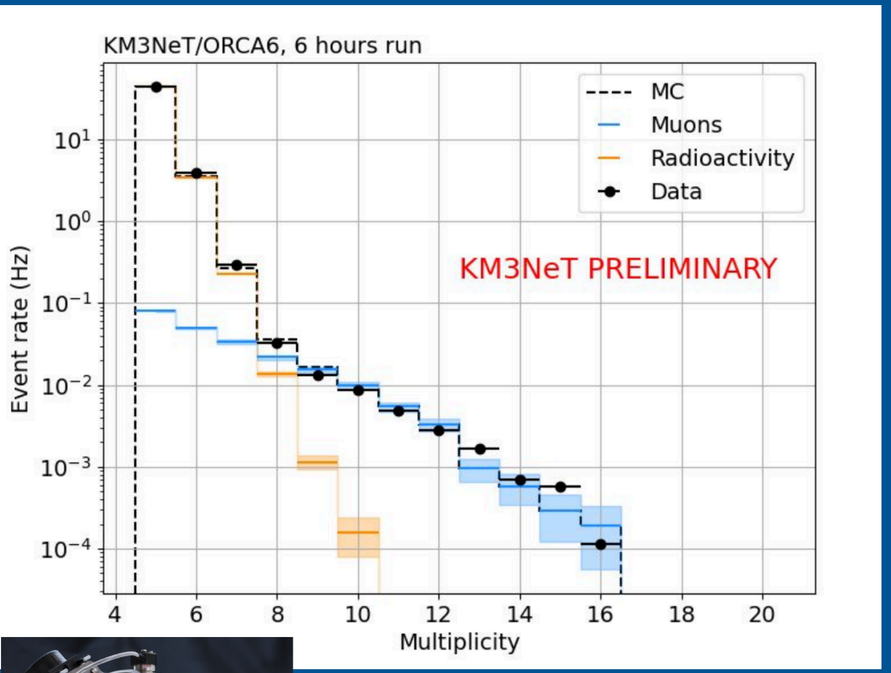


SUPERNOVA EXPLOSION

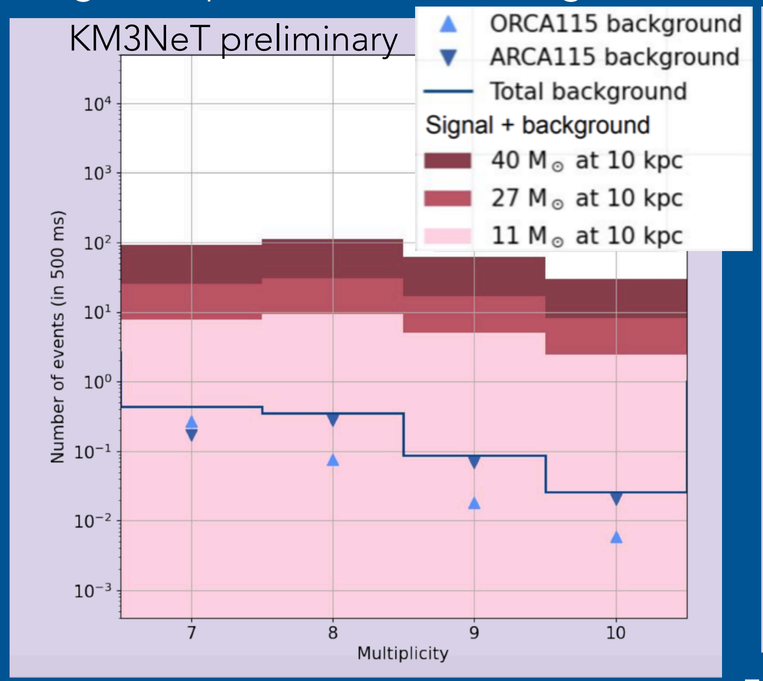
A DOM as a single detector

Muon background rejection improved

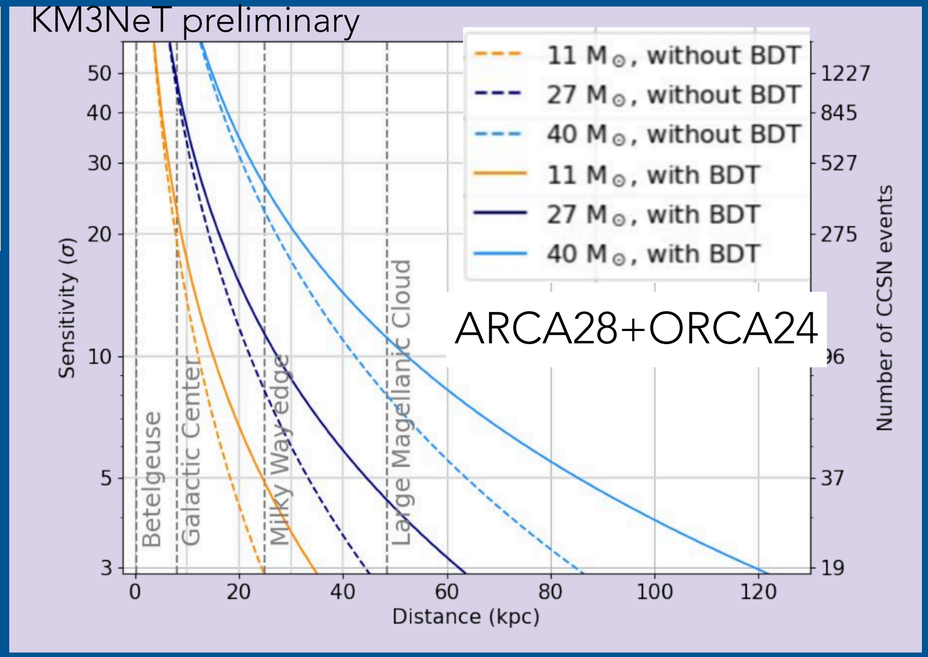
PMT multiplicity plot



Signal expected above background



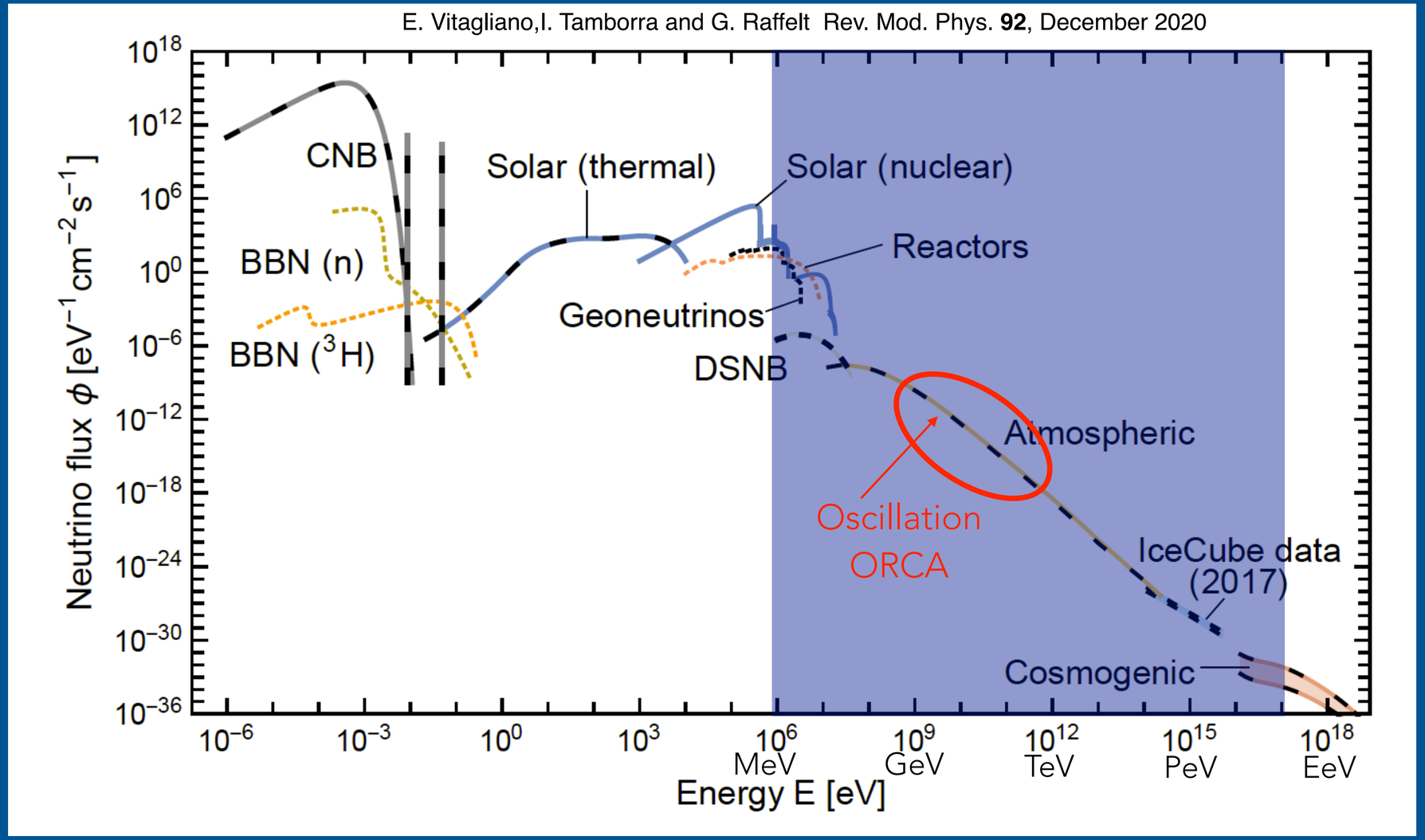
Significance



>5σ for ARCA+ORCA for 27M$_\odot$ at a distance <50kpc

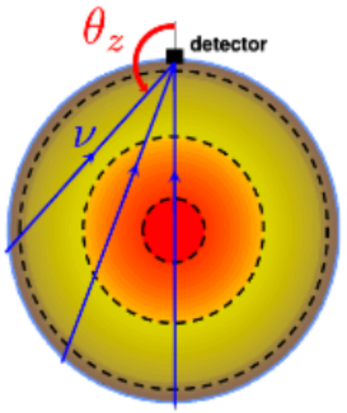
An on-line alert system for CCSN already implemented
Integrated in SuperNova Early Warning System (SNEWS)

ATMOSPHERIC NEUTRINOS AND OSCILLATION



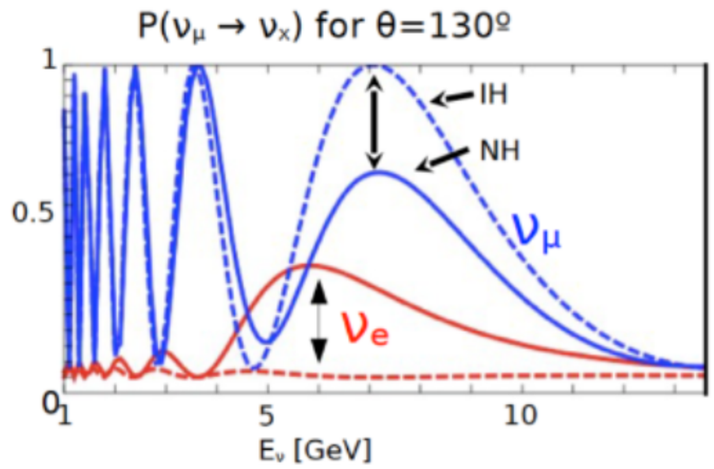
NEUTRINO OSCILLATION WITH ORCA

Baseline from 50 to 12800 km

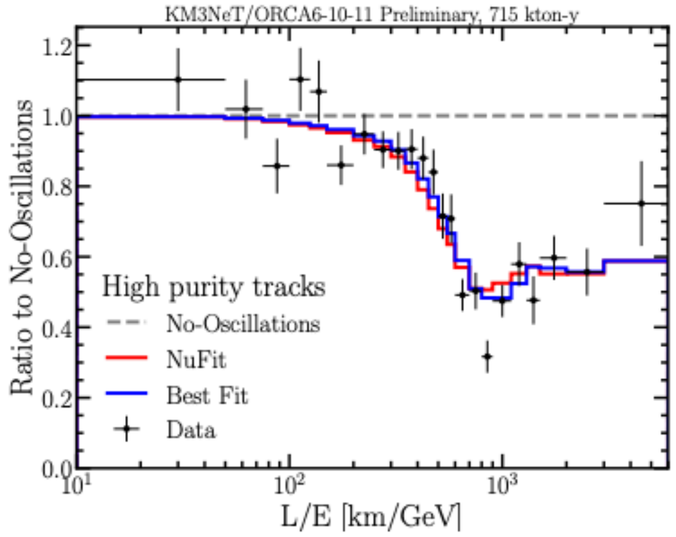


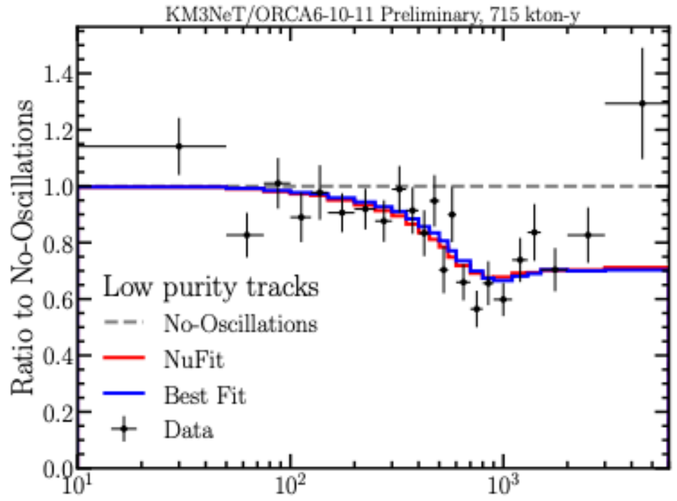
Neutrino Mass Ordering measuring atmospheric neutrinos crossing the Earth

Energy range of interest 5-15 GeV



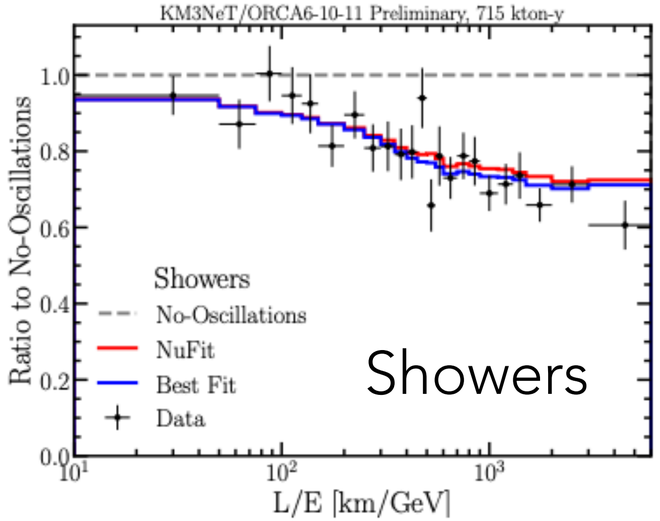
Tracks





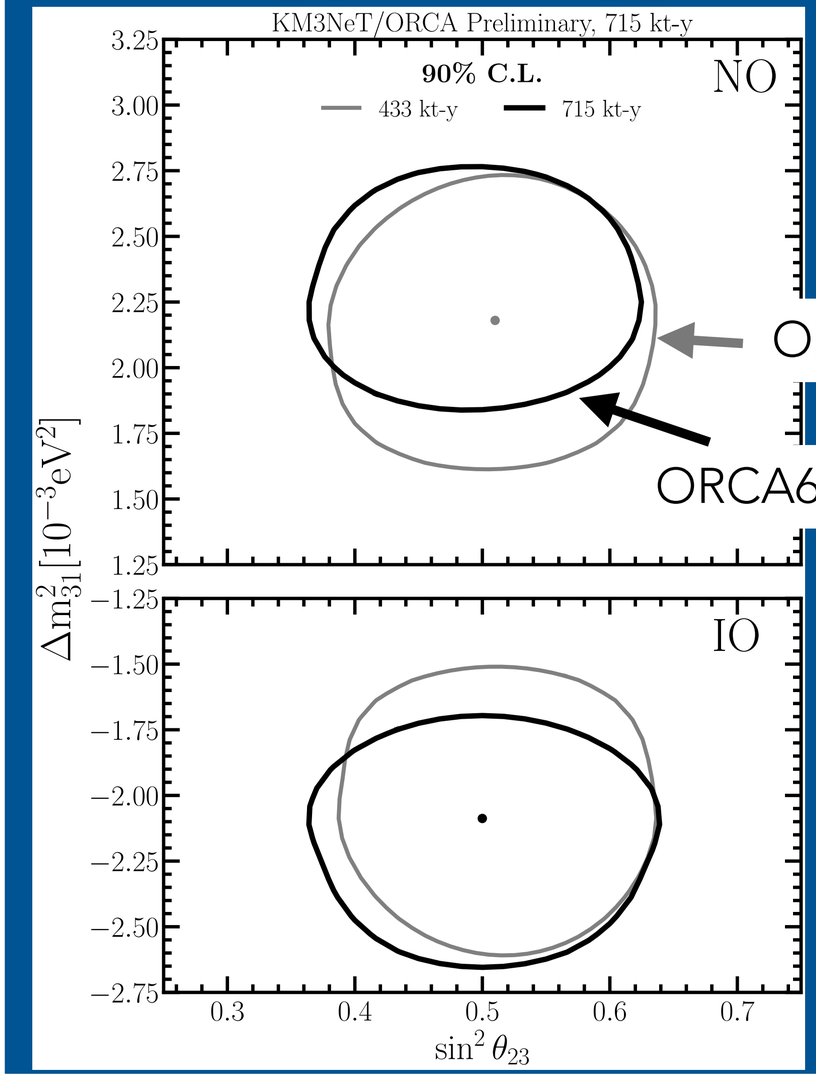
ORCA6-7-11 data

Oscillations clearly seen both in track and shower events



NEUTRINO OSCILLATION WITH ORCA

Δm^2_{32} vs $\sin^2\theta_{23}$



Same kind analysis as for ICRC2023 increased the exposure

👇

From 433kt-yr to 715 kt-yr

ORCA6 👉 433 kton-yr

ORCA6-10-11 👉 715 kton-yr

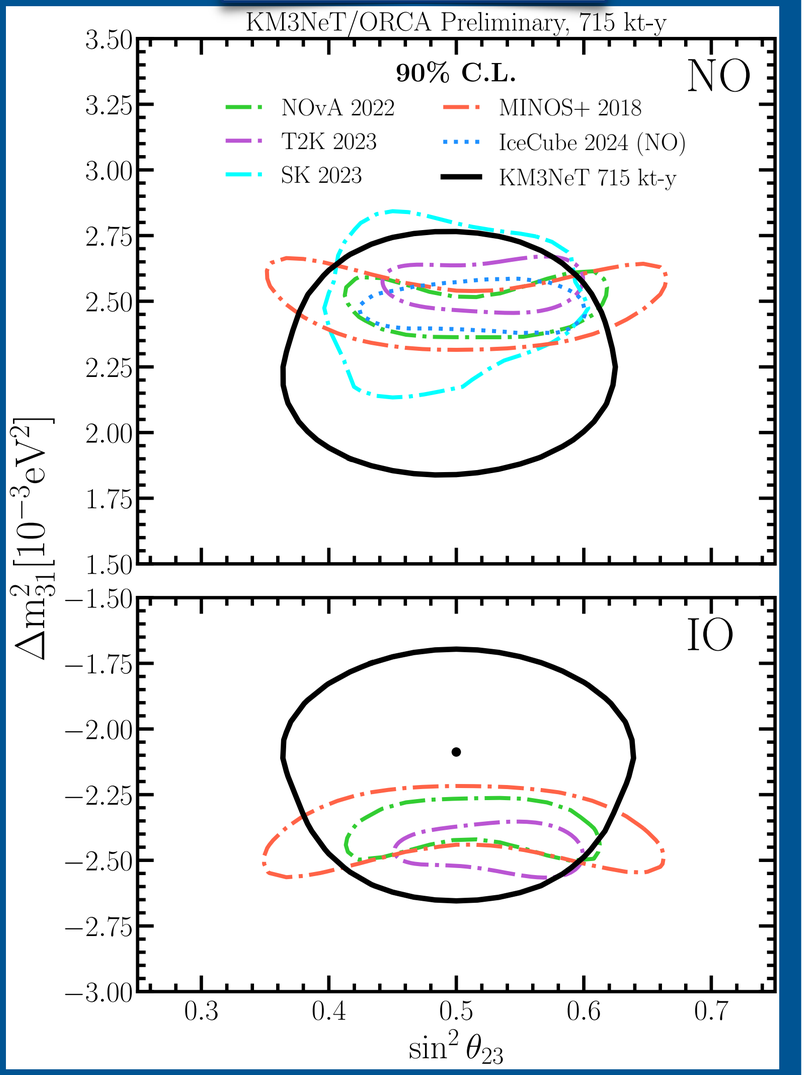
$$\Delta m^2_{31} = \begin{cases} -2.09^{+0.17}_{-0.21} \times 10^{-3}\mathrm{eV}^2, & \mathrm{IO} \\ [2.10, 2.37] \times 10^{-3}\mathrm{eV}^2, & \mathrm{NO} \end{cases}$$

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

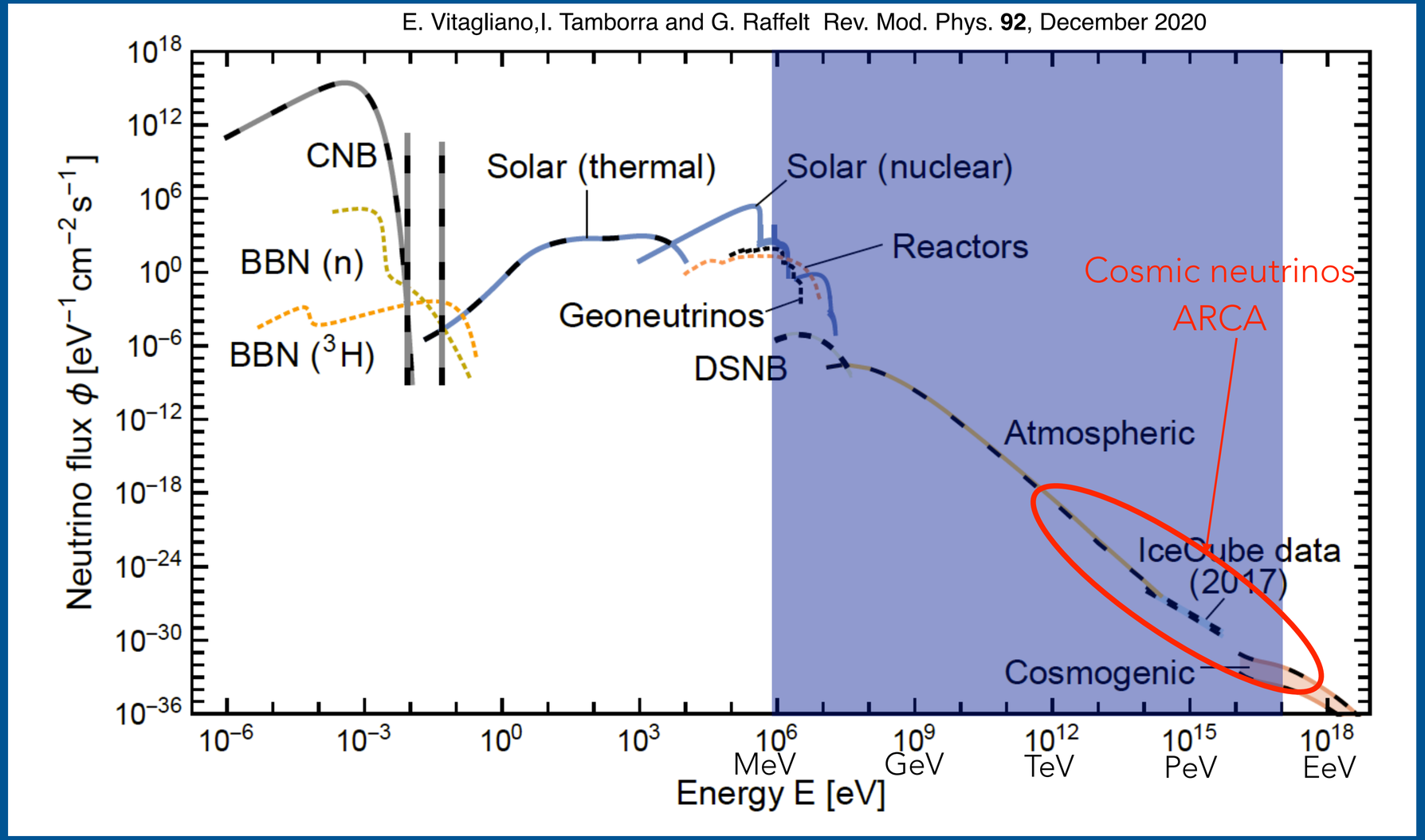
$$2\log(\mathcal{L}_{IO}/\mathcal{L}_{NO}) = 0.61$$

KM3NeT/ORCA competitive

Δm^2_{32} vs $\sin^2\theta_{23}$

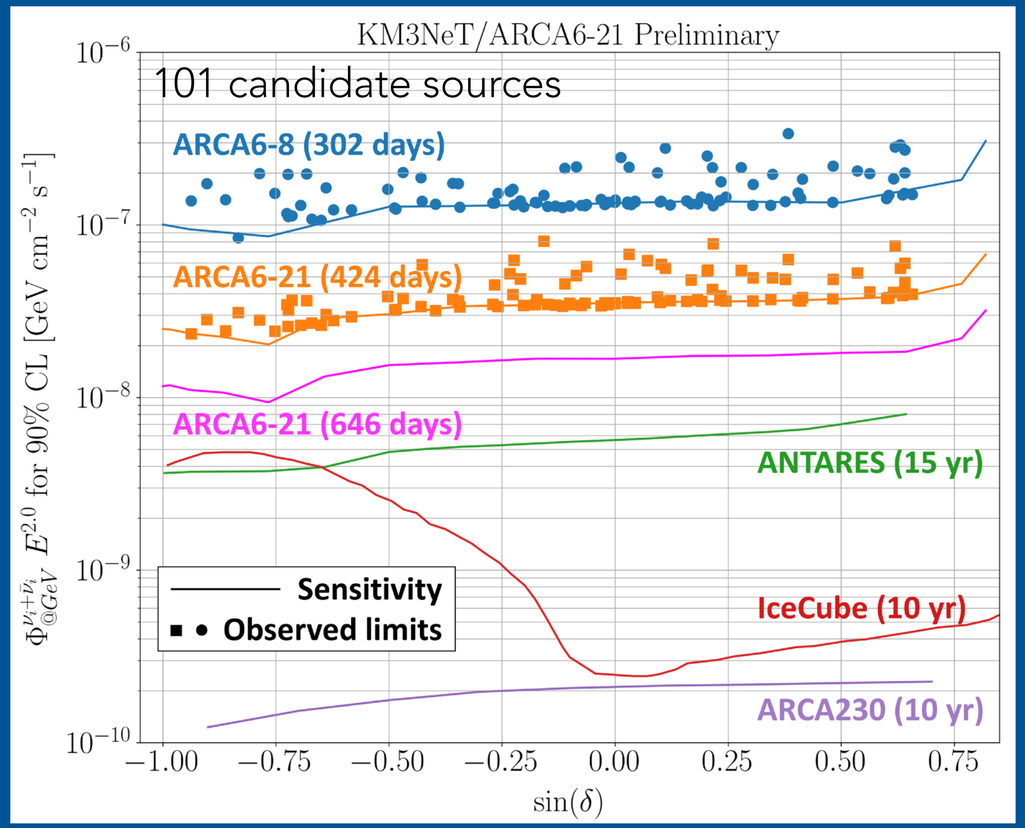


THE COSMIC HIGH-ENERGY NEUTRINOS



SEARCH FOR POINT-LIKE SOURCES

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

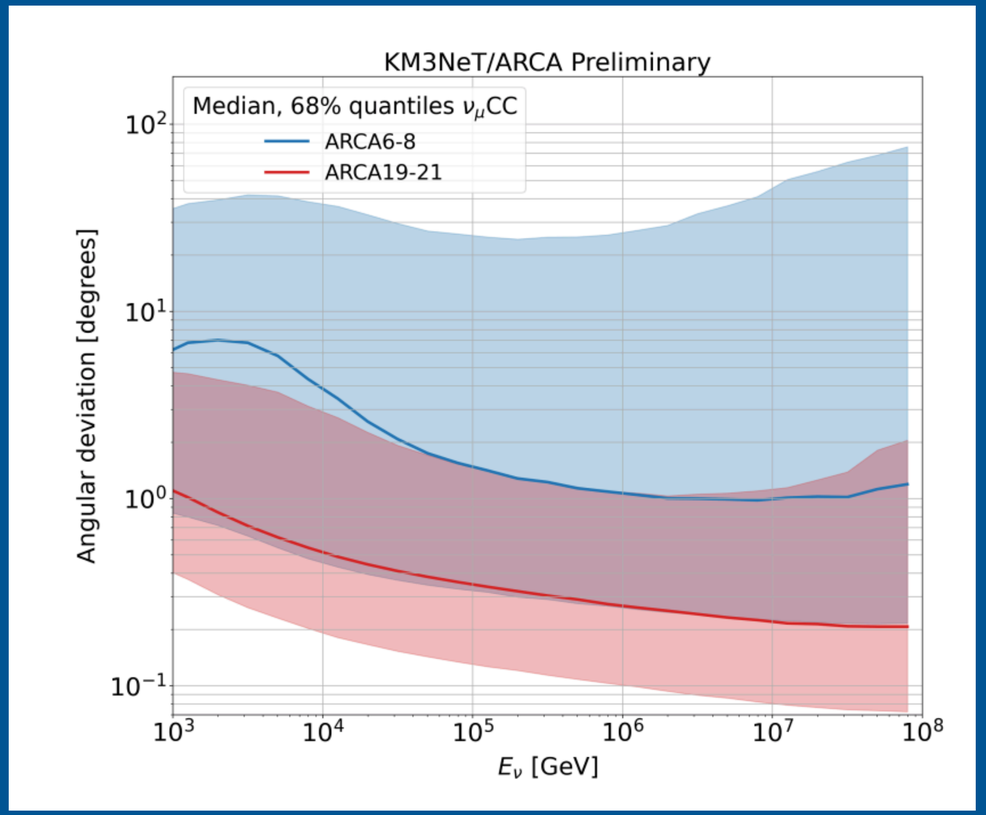


Large improvement in sensitivity is expected in the next year:
+ ARCA28 from sept 2023 + ARCA47 (?) from November 2024

KM3NeT upper limits are quickly reaching the ANTARES 15yr limits

Improvements also in angular resolution

Angular resolution



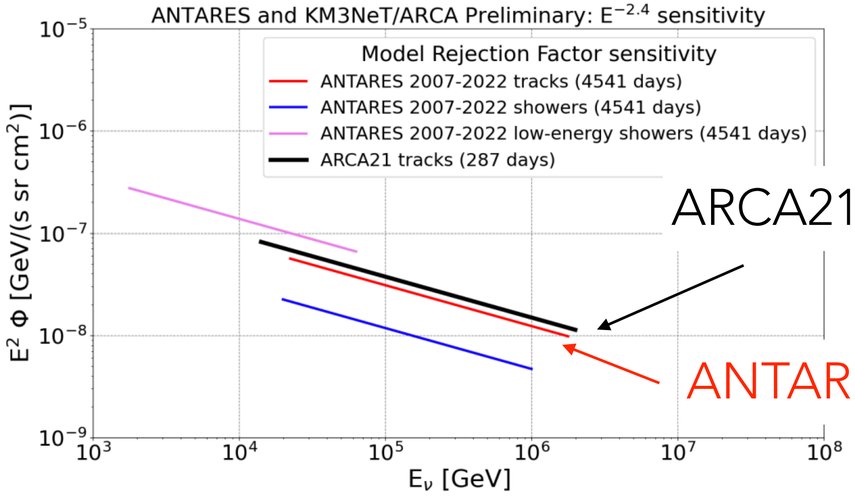
Joint ARCA-ANTARES point-like searches ongoing. ANTARES (15y) contributes most significantly, enhancement by 10% observed adding ARCA data (424d)

See Sandra Zavaterelli talk

SEARCH FOR DIFFUSE FLUXES

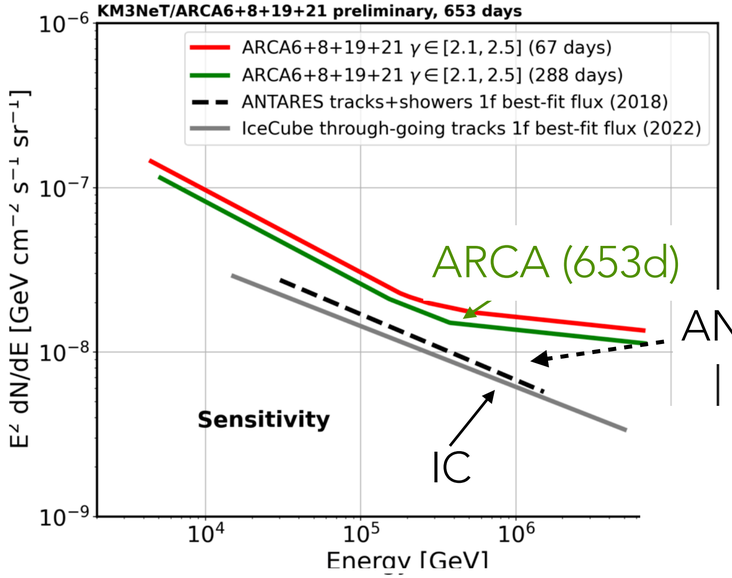
See for ANTARES diffuse talk of L. Fusco

From the full sky



ARCA21 287 days

ANTARES 15y



ARCA (653d)

ANTARES

IC

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

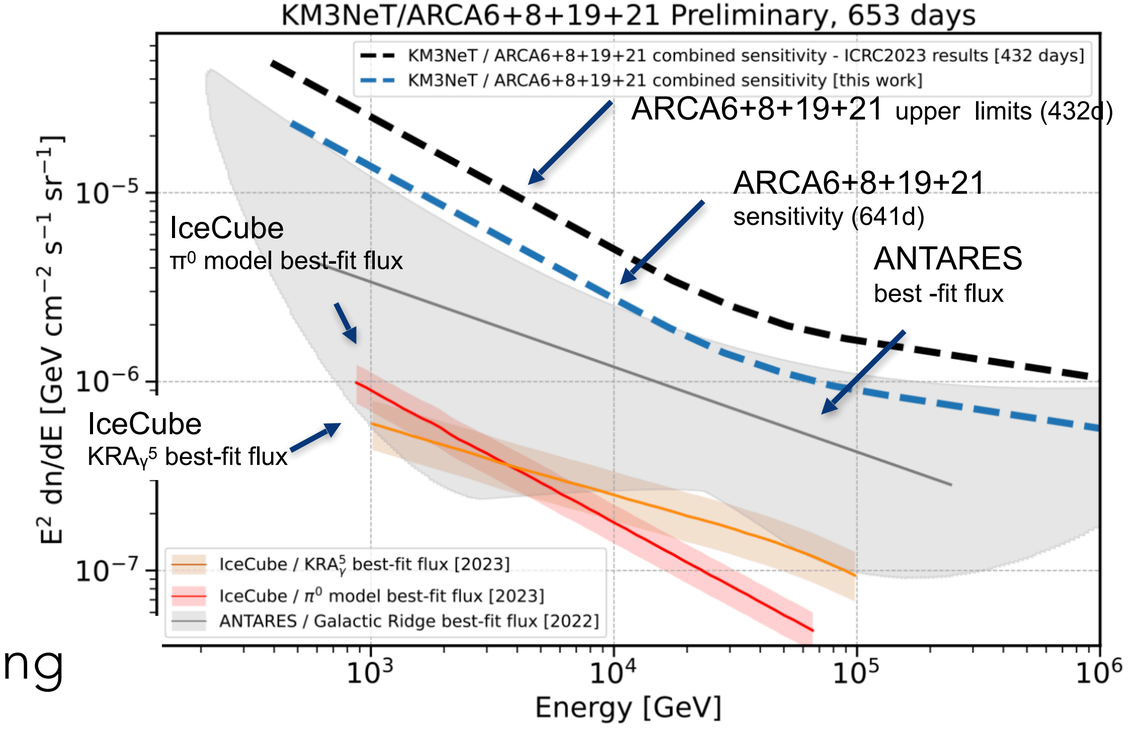
ARCA rapidly approaching ANTARES sensitivities

From the galactic plane

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

KM3NeT On-Off zone analysis

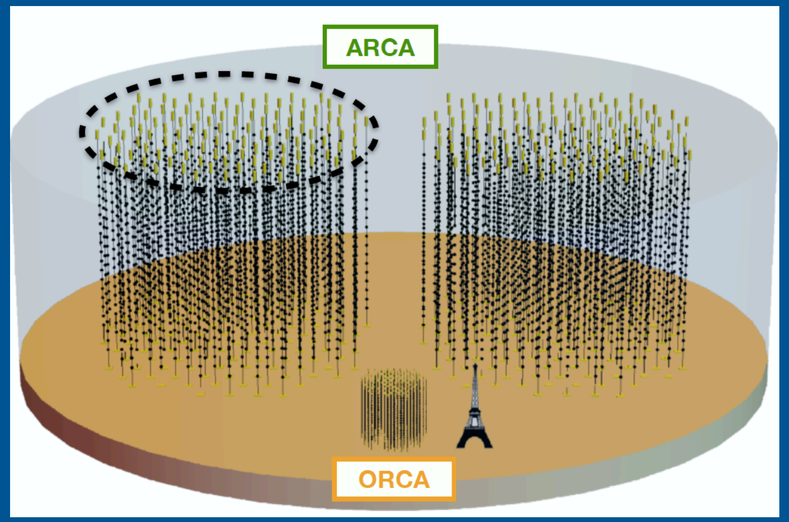
|l| < 31° and |b| < 5° for KM3NeT/ARCA6-8 and
|l| < 31° and |b| < 4° for KM3NeT/ARCA19-21



MULTI-MESSENGER PROGRAM

oS(ICRC2023)1125

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

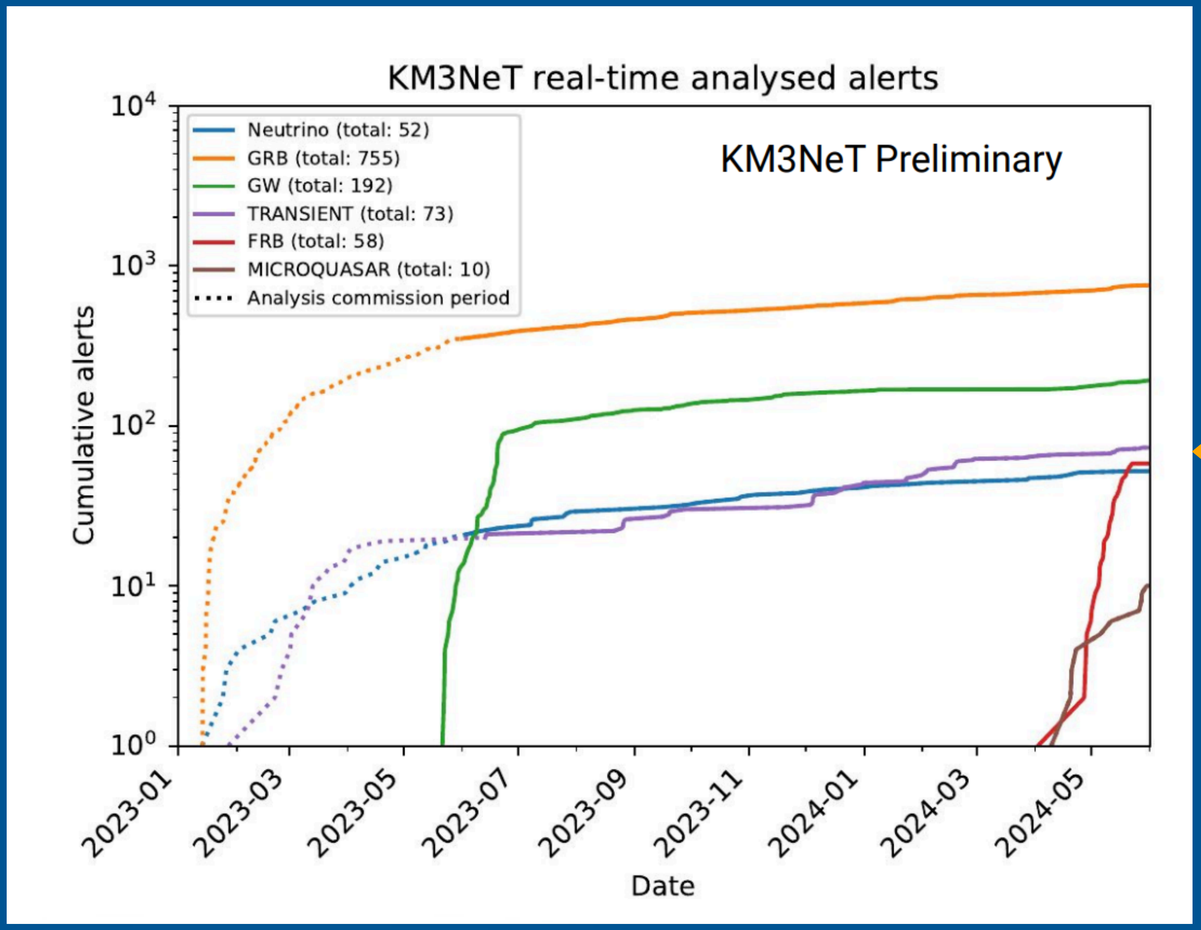
Receiving alert system operative 👉 RTA platform already active from November 2022 in ARCA and in ORCA detectors

Sending alert system 👉 High-energy neutrino alerts will be sent in real-time by end of 2024

MULTI-MESSENGER PROGRAM

oS(ICRC2023)1125

Talks of M. Mastrodicasa and and V. Cecchini

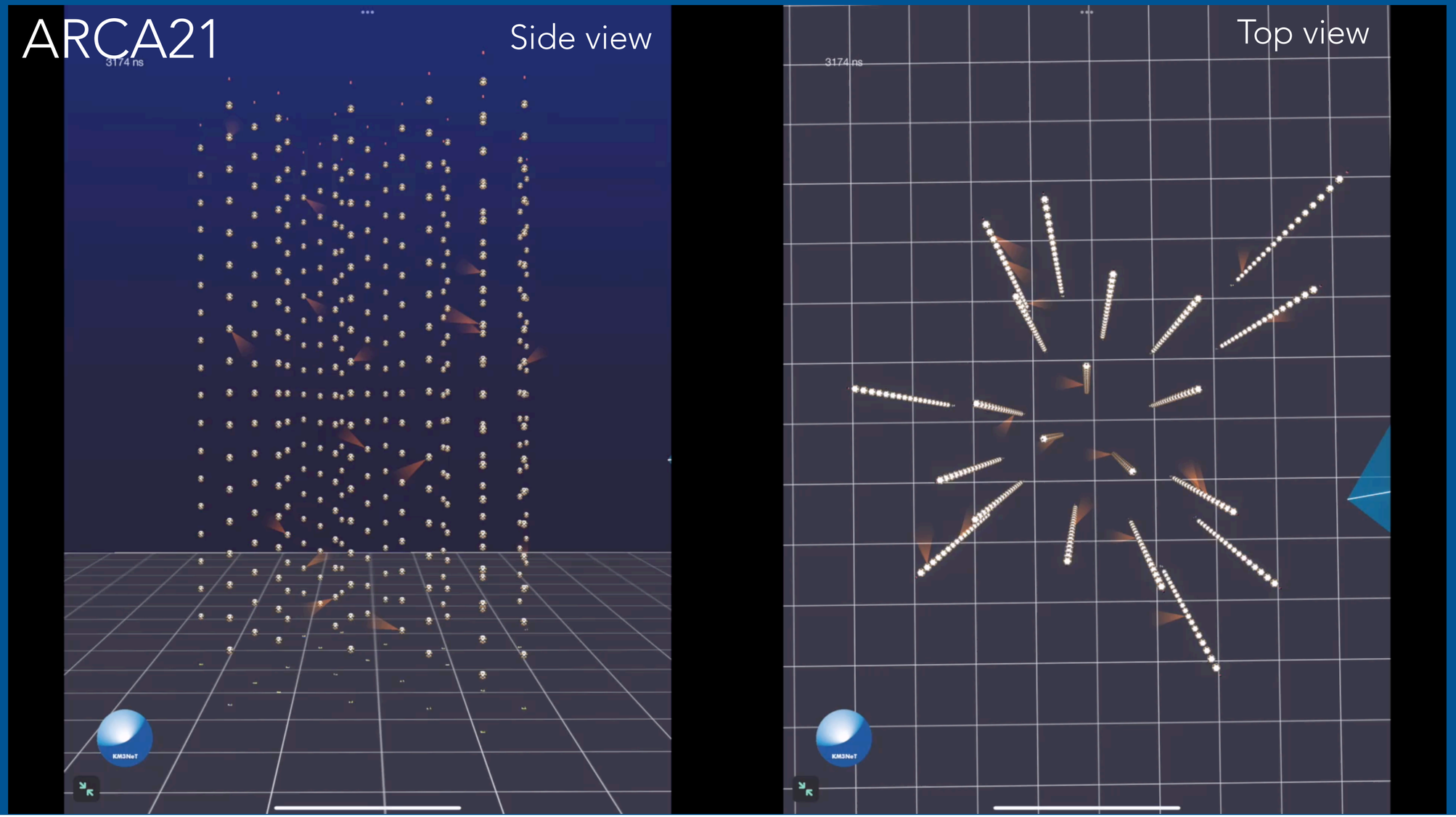


Several thousands of alert received and analyzed in real time 👉 so far no significant excess found in any of the observed alerts

THE EVENT WITH THE HIGHEST ENERGY

A very energetic cosmic event detected

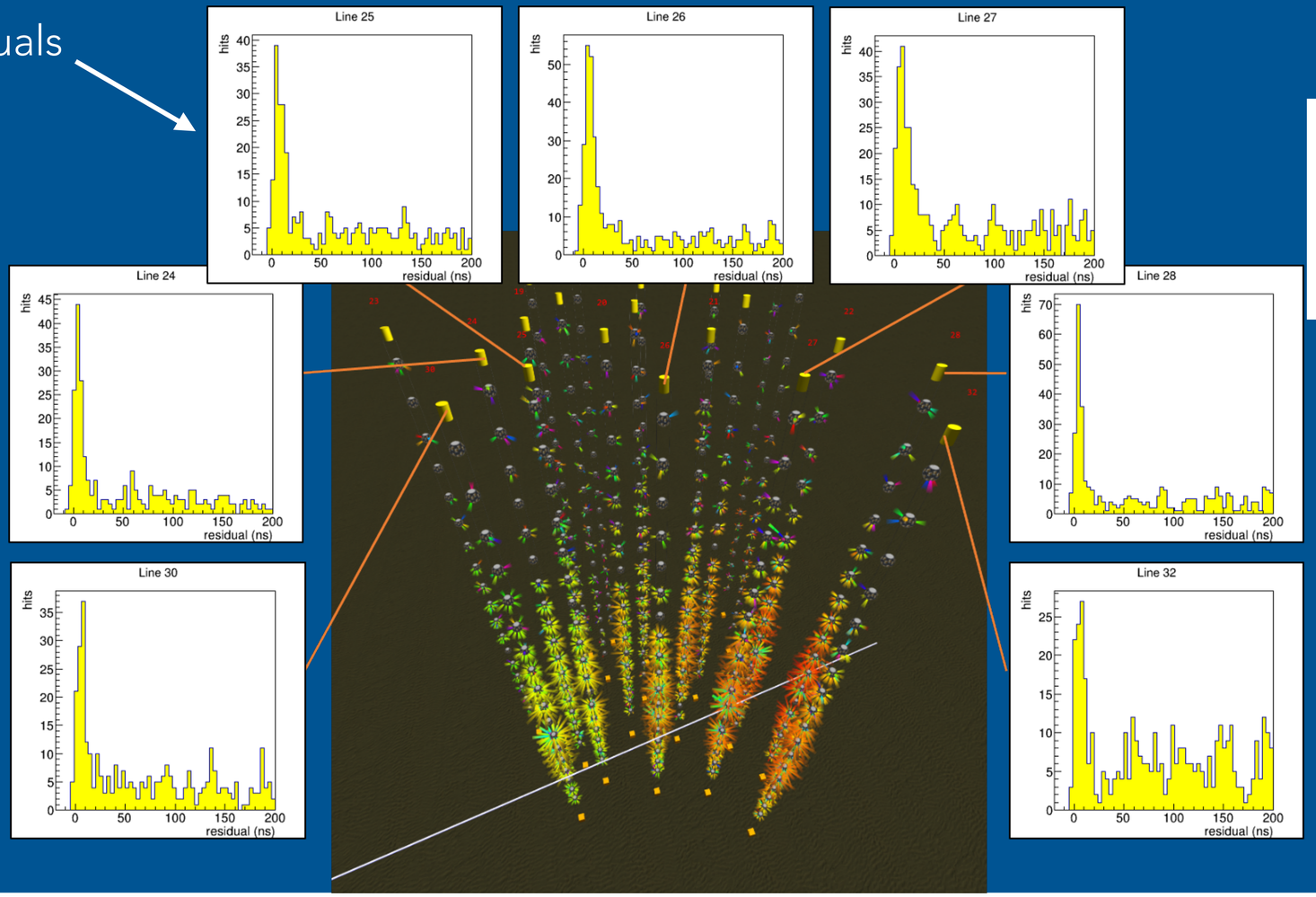
Huge amount of light detected 👉 35% of the total number of PMTs were triggered

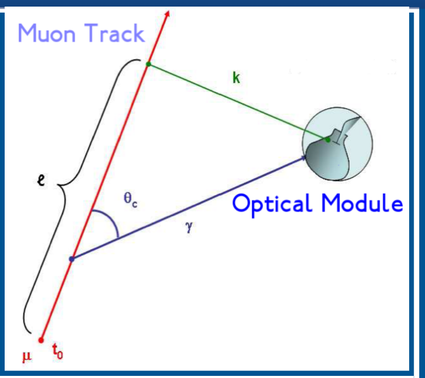


A very energetic cosmic event detected

The event is well reconstructed as a track

Time residuals





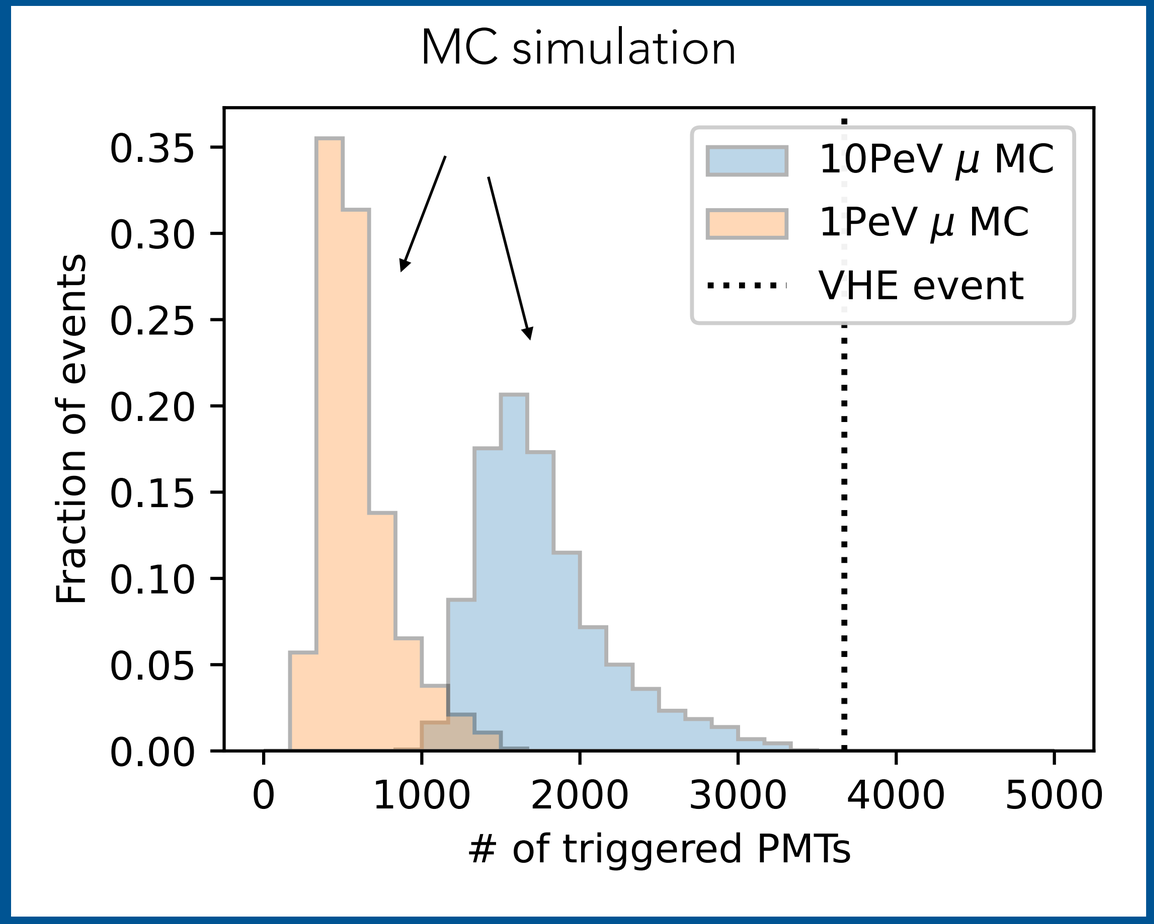
$$t_{teorico} = t_0 + \frac{1}{c}\left(l - \frac{k}{\tan\theta_c}\right) + \frac{1}{v_g}\left(\frac{k}{\sin\theta_c}\right)$$

$$\Delta t_{res} = t_{teorico} - t_{\exp}$$

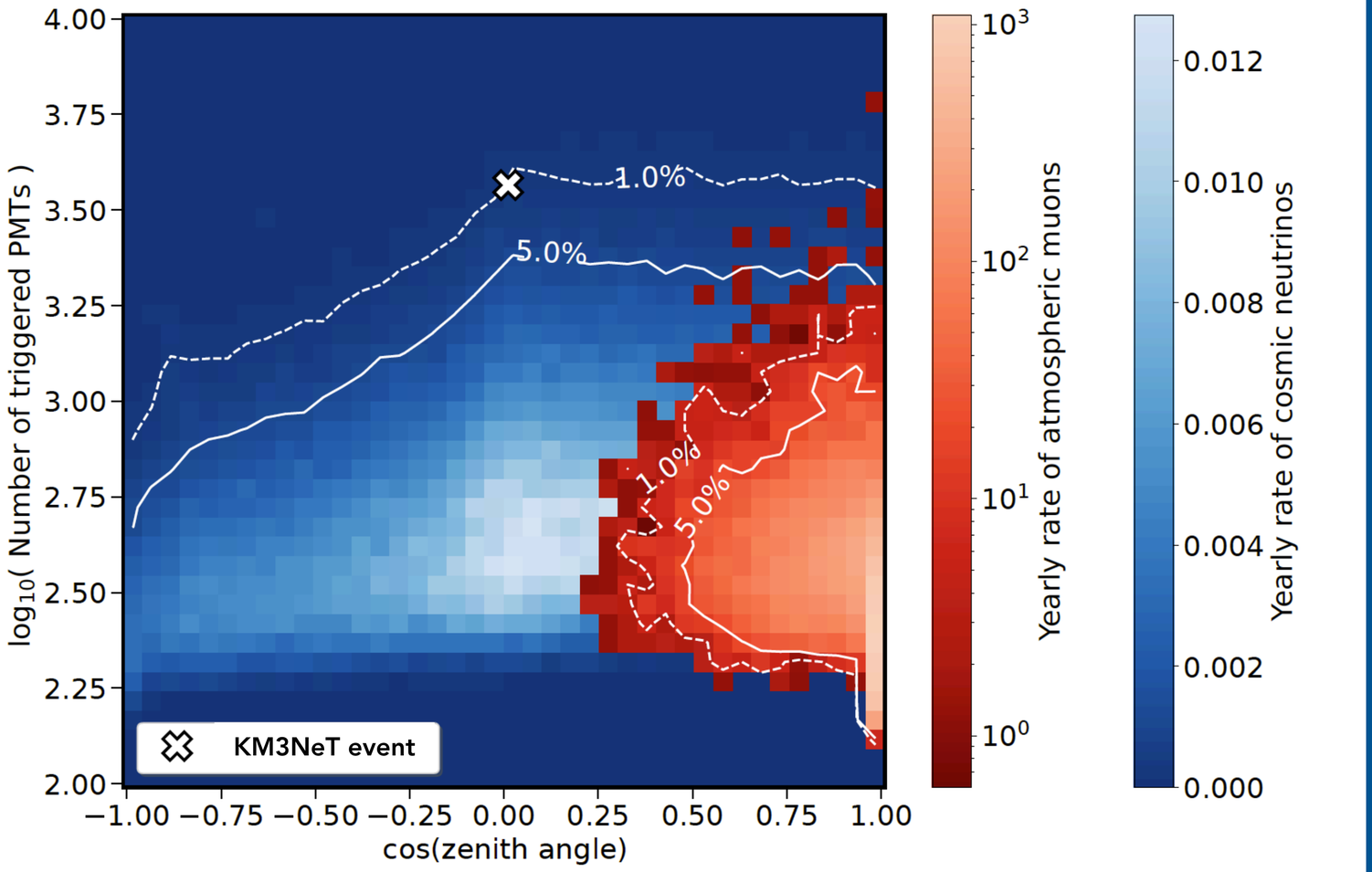
Time residual

A very energetic cosmic event detected

The event is a horizontal event (~0.6° above the horizon) with energy well above 10 PeV



Is it background ?

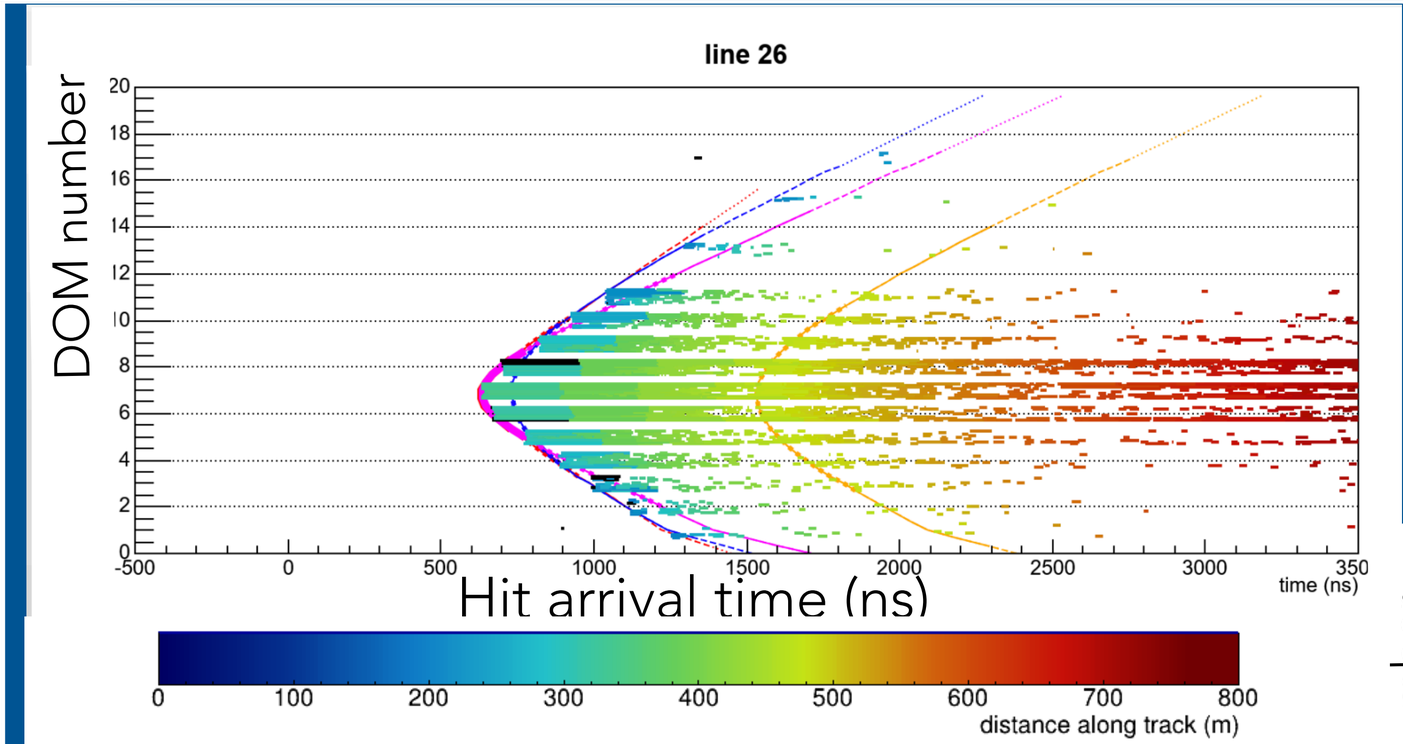


Given the detected energy and direction the expected rate of atmospheric muon reaching the detector is very low

- The amount of material traversed along the event direction is >100km of water equivalent (uncertainties included)

At this energies the expected rate of an atmospheric neutrino (prompt component) is about 10^{-5} events per year

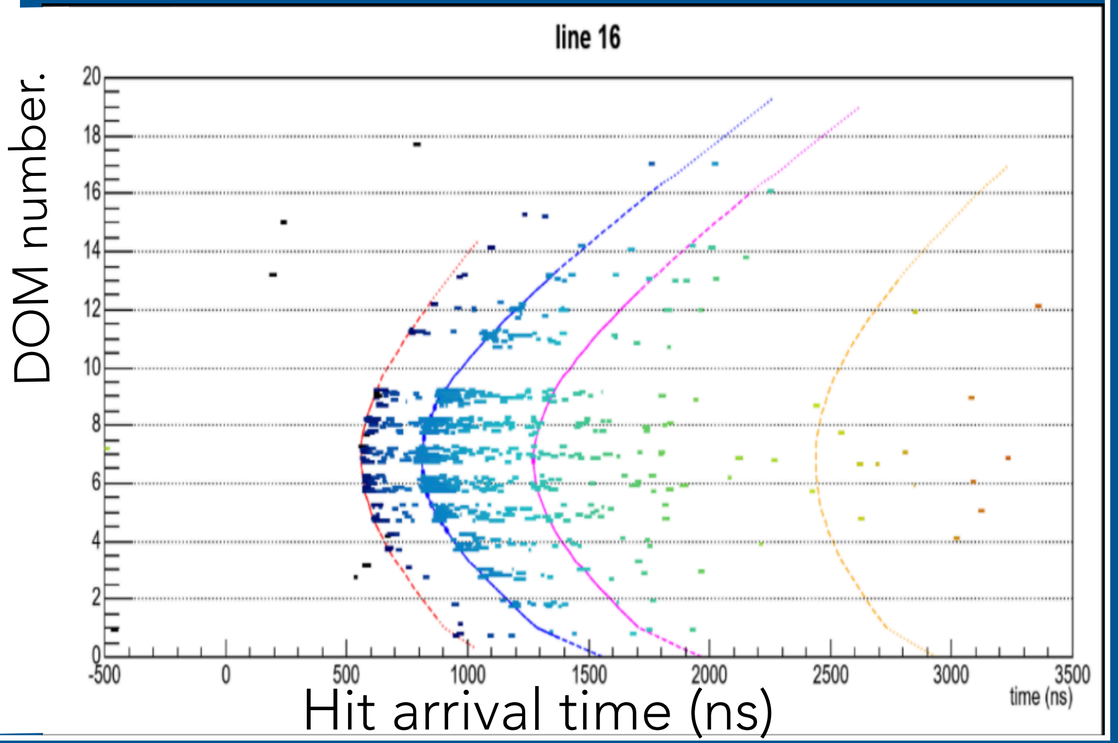
THE EVENT WITH THE HIGHEST ENERGY



From the track and shower reconstructions

👇

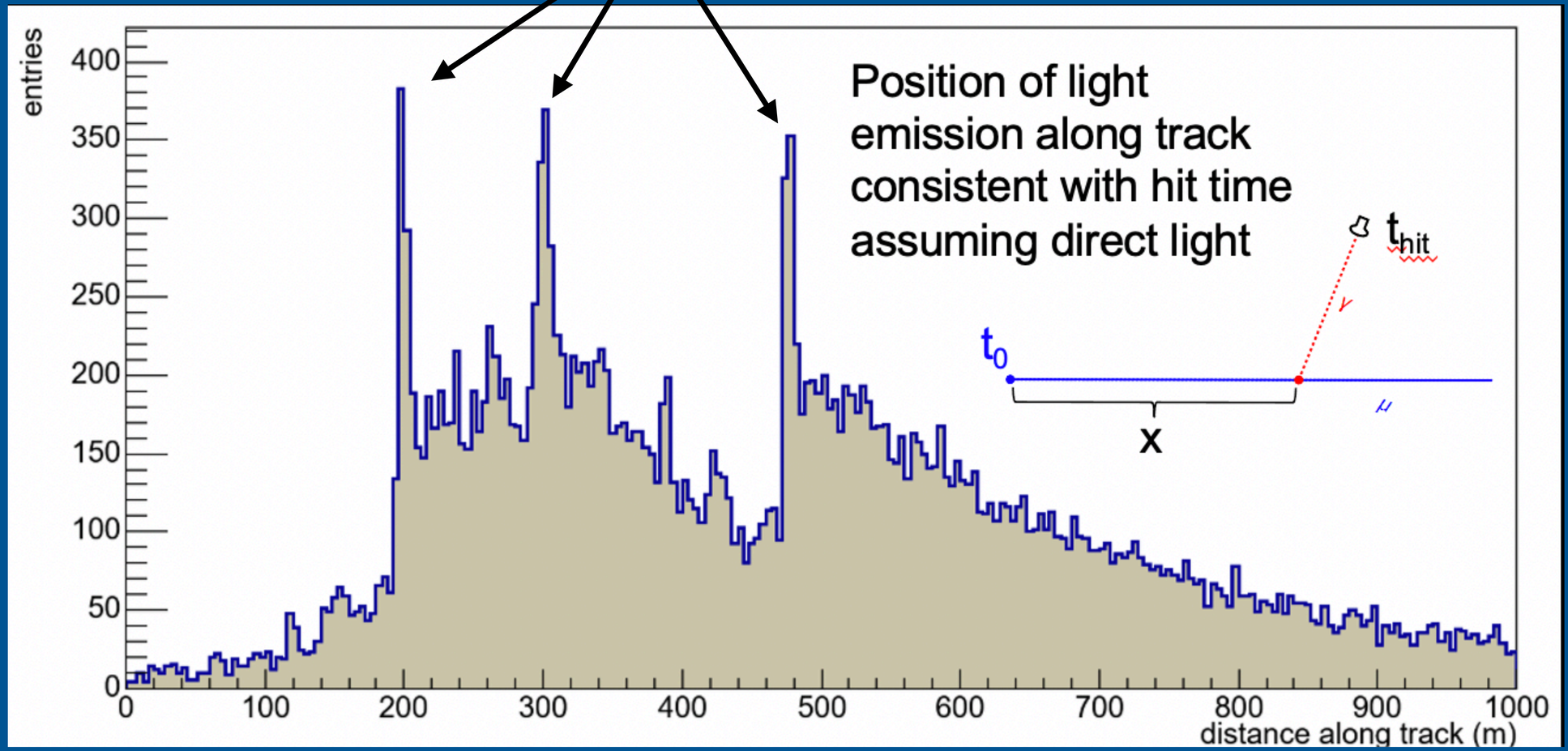
A muon track and three showers detected



Hit times are fully consistent with photons from Cherenkov emission

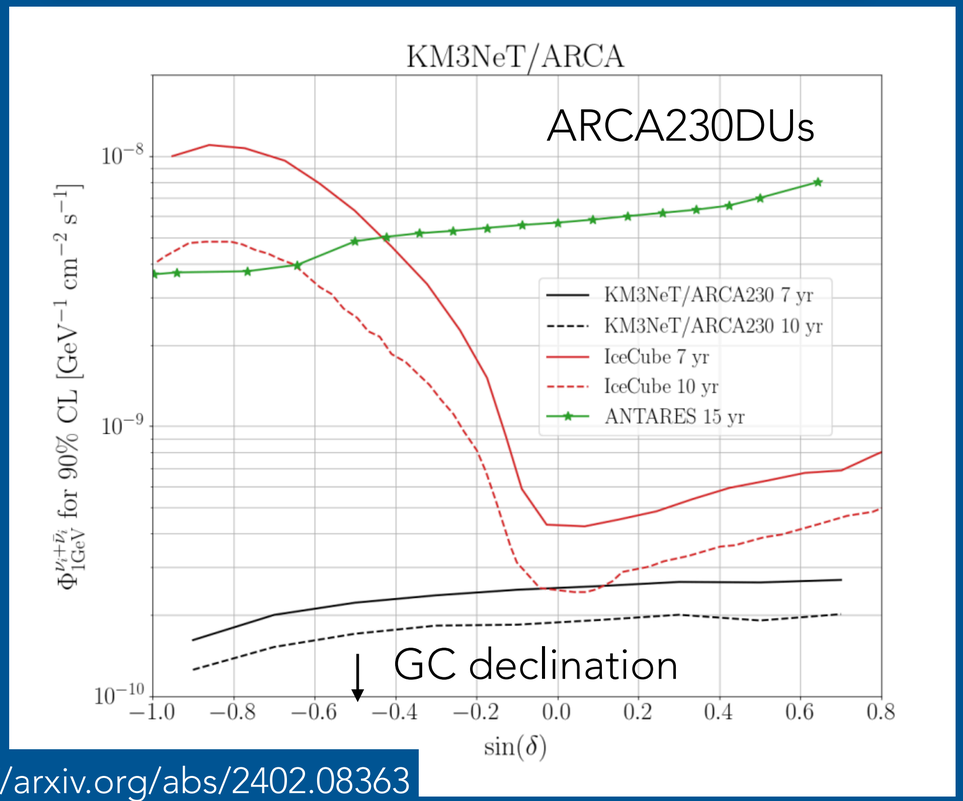
THE EVENT WITH THE HIGHEST ENERGY

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



KM3NET PERSPECTIVES

ARCA - Sensitivity for point-like searches

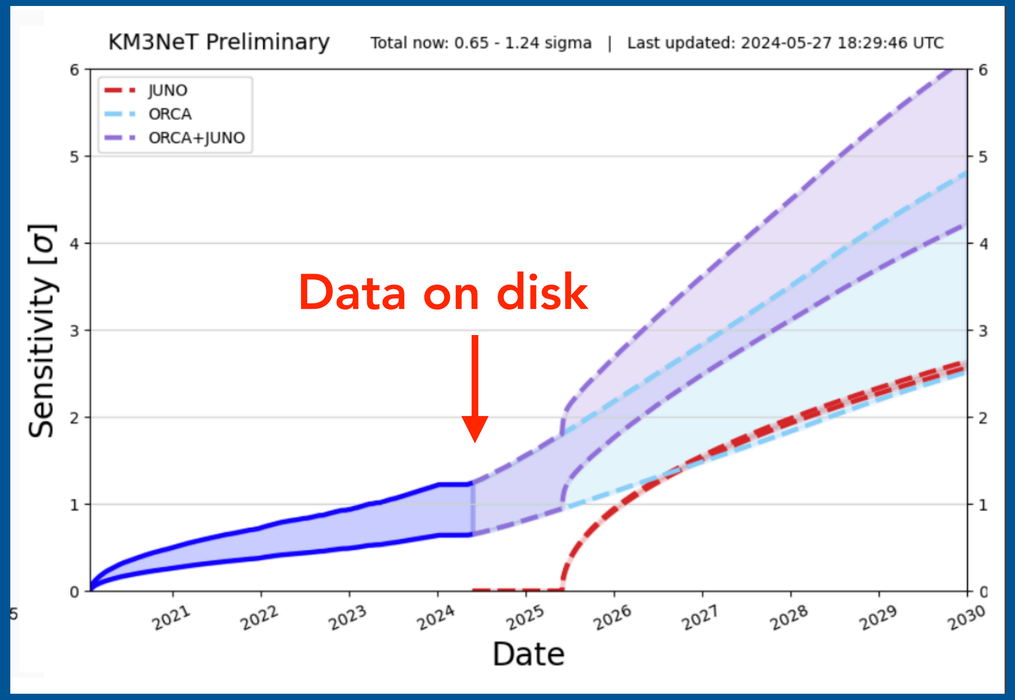


https://arxiv.org/abs/2402.08363

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

- 2022: ANTARES decommissioning
- 2024: ARCA 47DUs ORCA 24 DUs
- 2028: ARCA & ORCA completion

SUMMARY

KM3NeT under construction

present status:

- ARCA 28 DUs (12% of the full detector) 👉 next month + 19DUs 👉 ARCA47 (40% of the full detector)
- ORCA 23 DUs (20% of the full detector) 👉 end of the year +2DU 👉 ORCA25 (22% 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

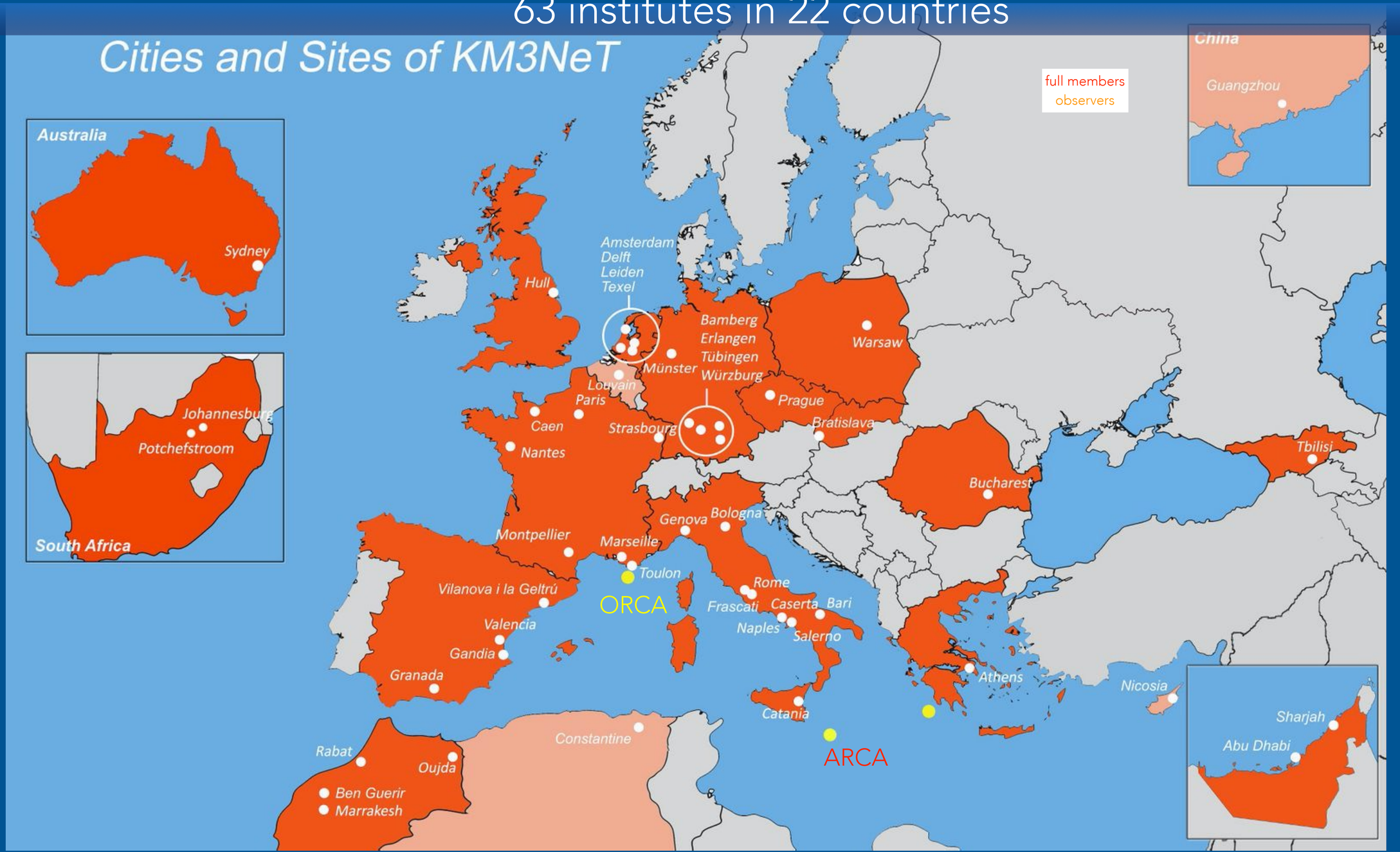
An exceptional high energy track event detected 👉 a horizontal event with energy well above 10 PeV 👉 detailed event description

More information will follow soon (paper submitted)

THE KM3NET COLLABORATION

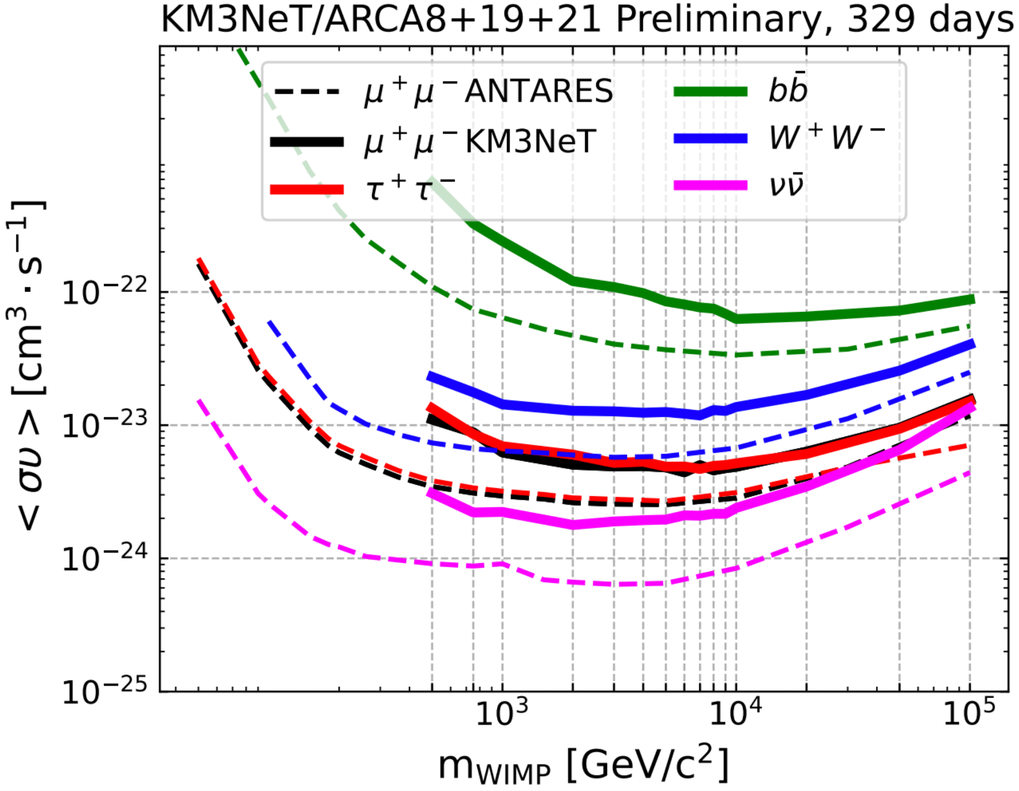
63 institutes in 22 countries

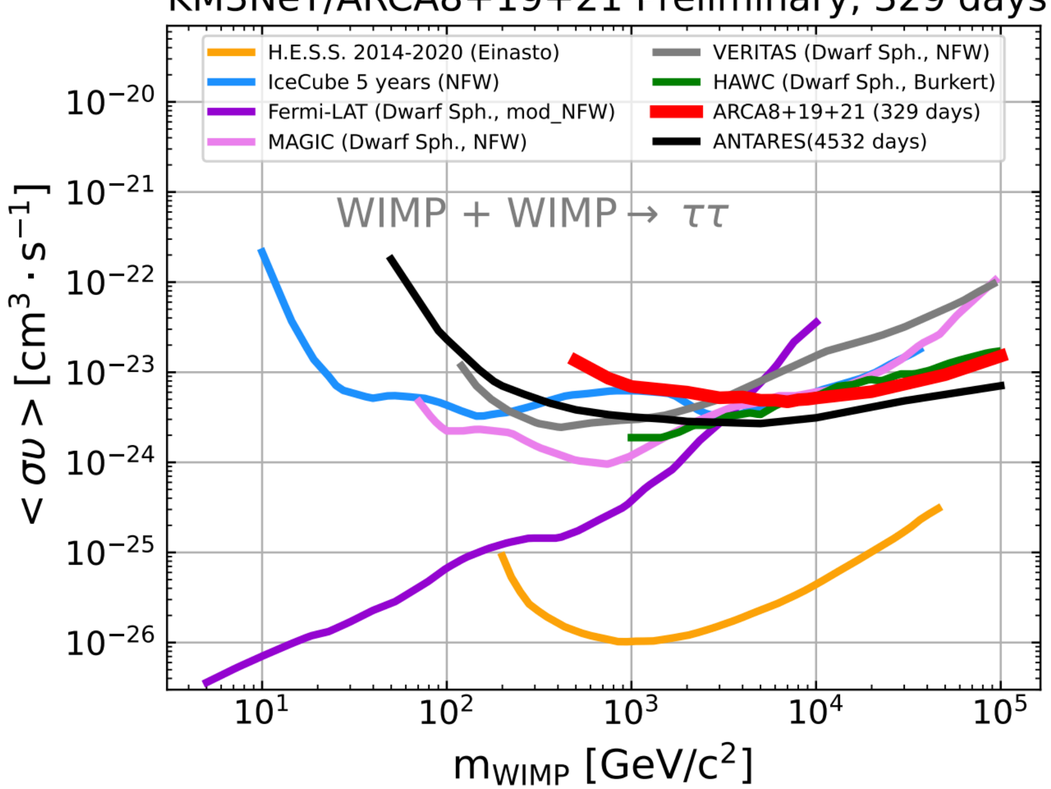
+ Harvard University (USA)



DARK MATTER

From the Galactic Center





KM3NeT quickly reaching the ANTARES limits