



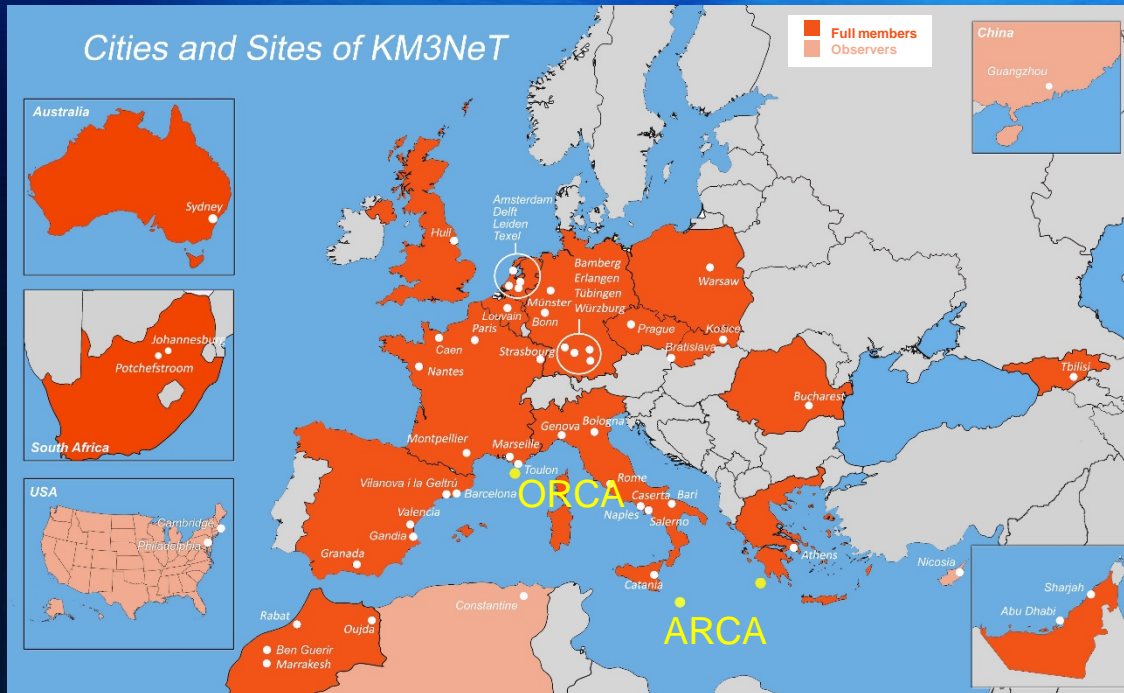
Results of KM3NeT and update on its construction

Marco Circella, INFN Bari – on behalf of the KM3NeT Collaboration



Note: this pdf version does not contain the animations of the live presentation

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



More than 65 institutes
in 22 countries in 5 continents



Same technology for:

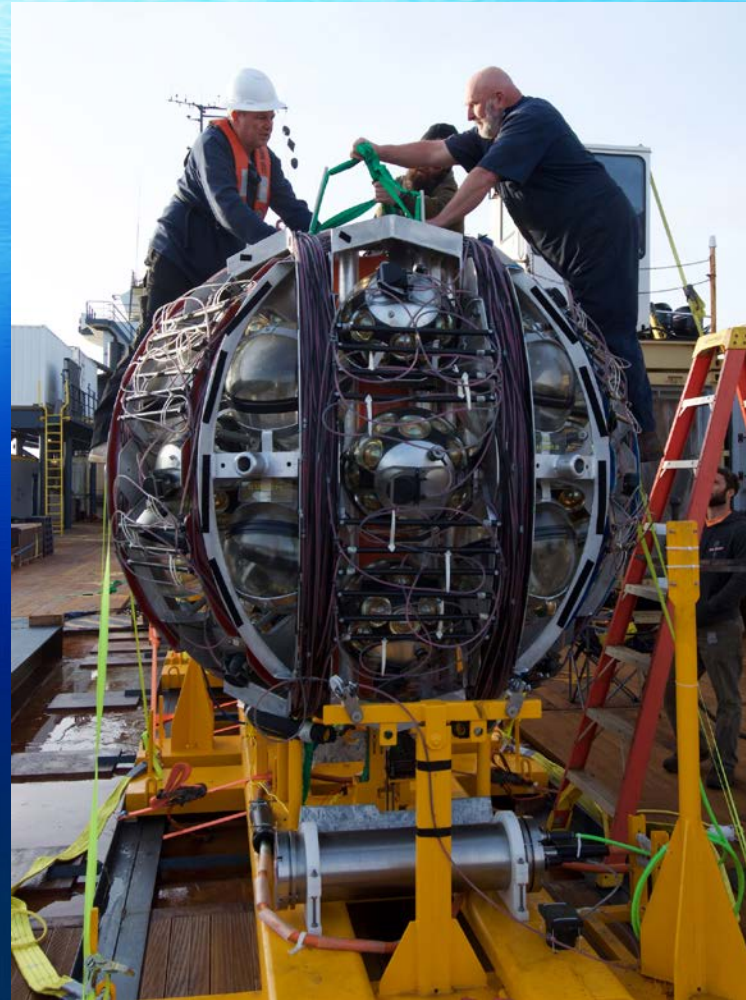
KM3NeT/ARCA (Astroparticle Research with Cosmics in the Abyss) - Observation of high energy (GeV ÷ PeV) neutrino sources with a telescope offshore Capo Passero (Sicily-Italy) at a depth of ~3500 m

KM3NeT/ORCA (Oscillation Research with Cosmics in the Abyss) - Determination of the neutrino mass hierarchy with a detector offshore Toulon (France) able to detect neutrinos of tens of GeV at a depth of ~ 2500 m

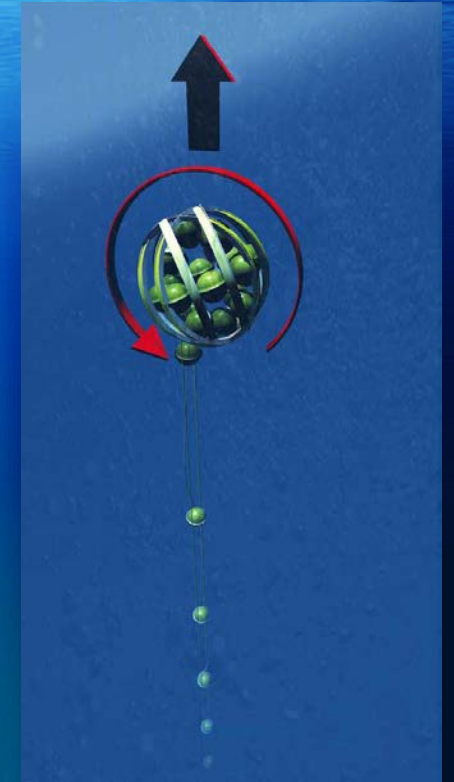


Multi-PMT DOM (Digital Optical Module)

- 31 PMTs (3" photocathode)
- Maximal sensor area
- Photon counting
- Directional sensitivity



18 DOMs are installed in a
DU (Detection Unit)

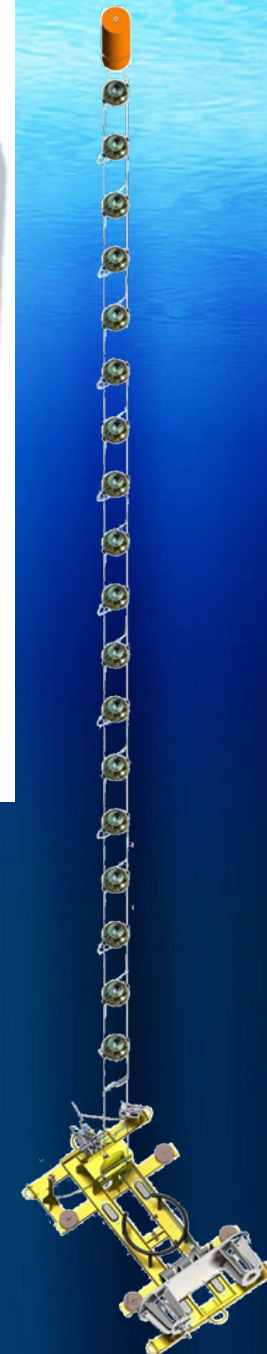
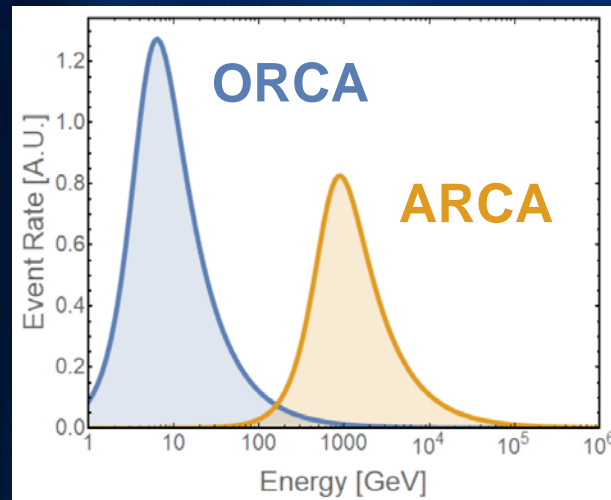
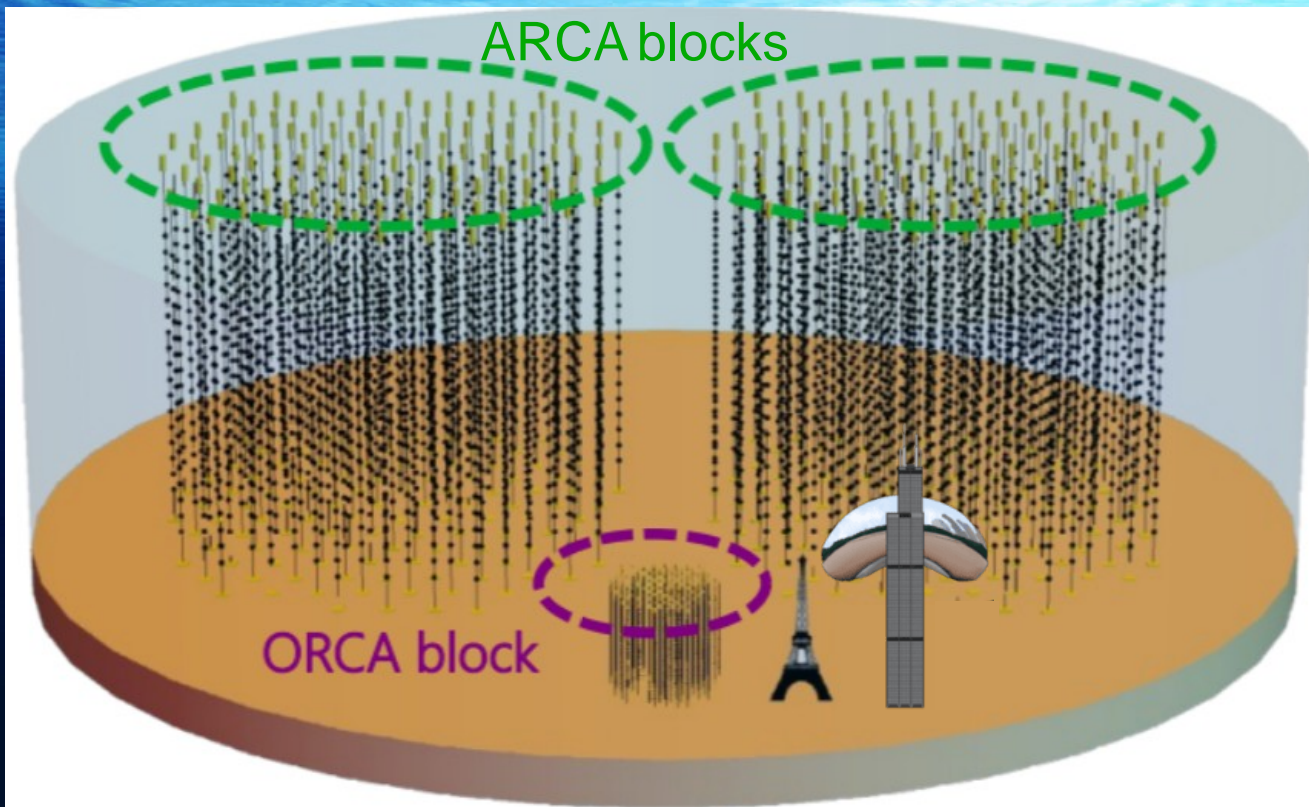


The DU is packed on a
spherical launcher vehicle
for installation

The KM3NeT technology: DOMs and DUs



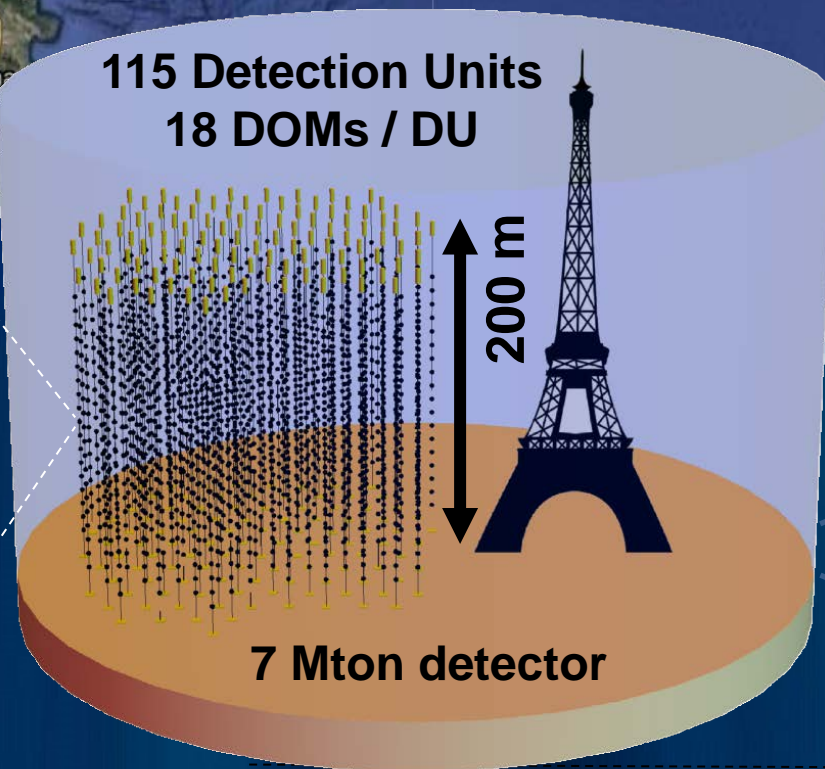
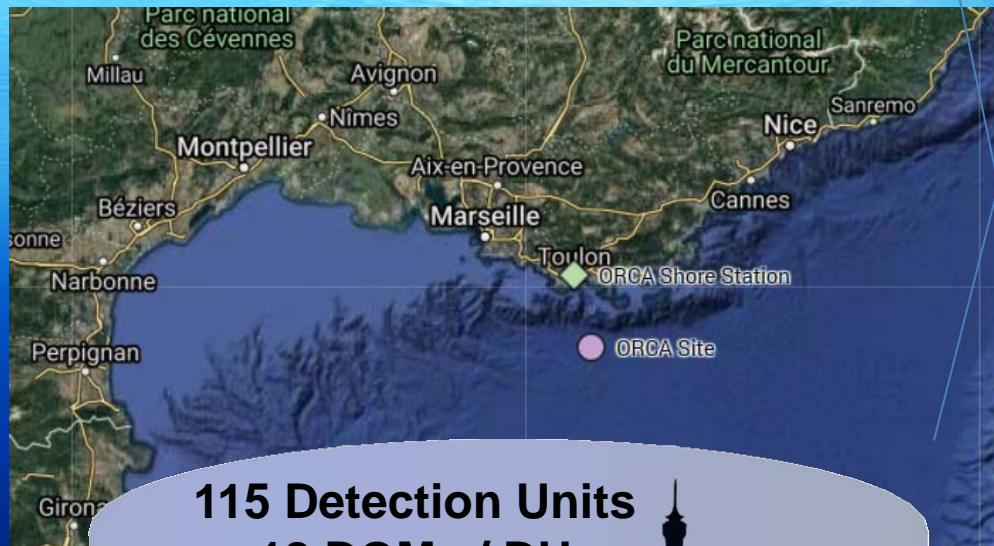
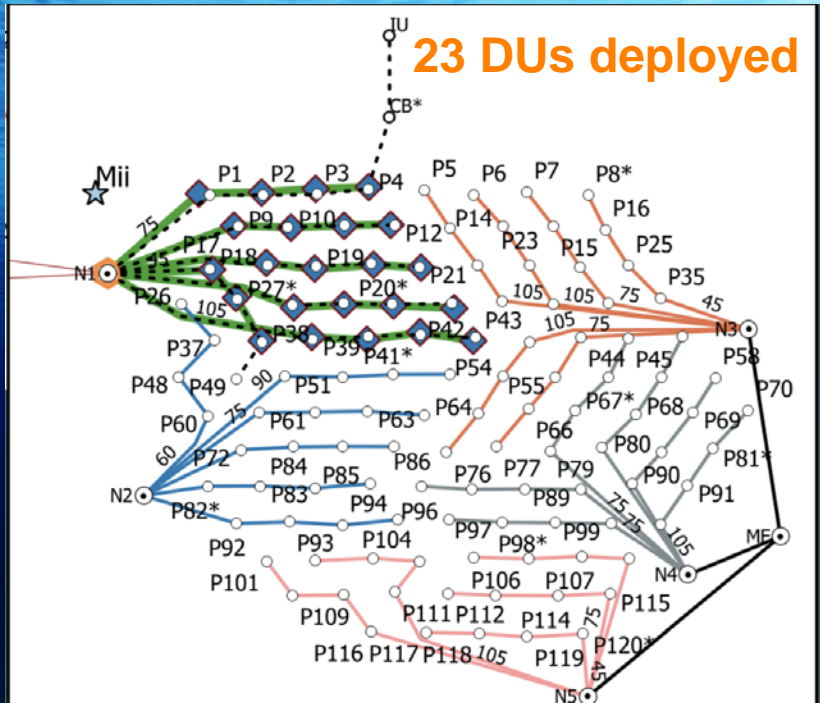
Multiple DU installation in the same campaign



	ARCA	ORCA
Location	Sicily (IT)	Toulon (FR)
Depth	3450m	2450m
No. of DUs	2 x 115	115
DU horizontal spacing	90 m	20 m
DOM Vertical Spacing	36 m	9 m
DOMs/DU	18	18
PMTs/DOM	31	31
Instrumented water mass	1 Gton	7 Mton
DUs deployed	28	23

DU height is ~700 m in ARCA,
~200 m in ORCA

KM3NeT/ORCA



31x 3" PMTs

43 cm

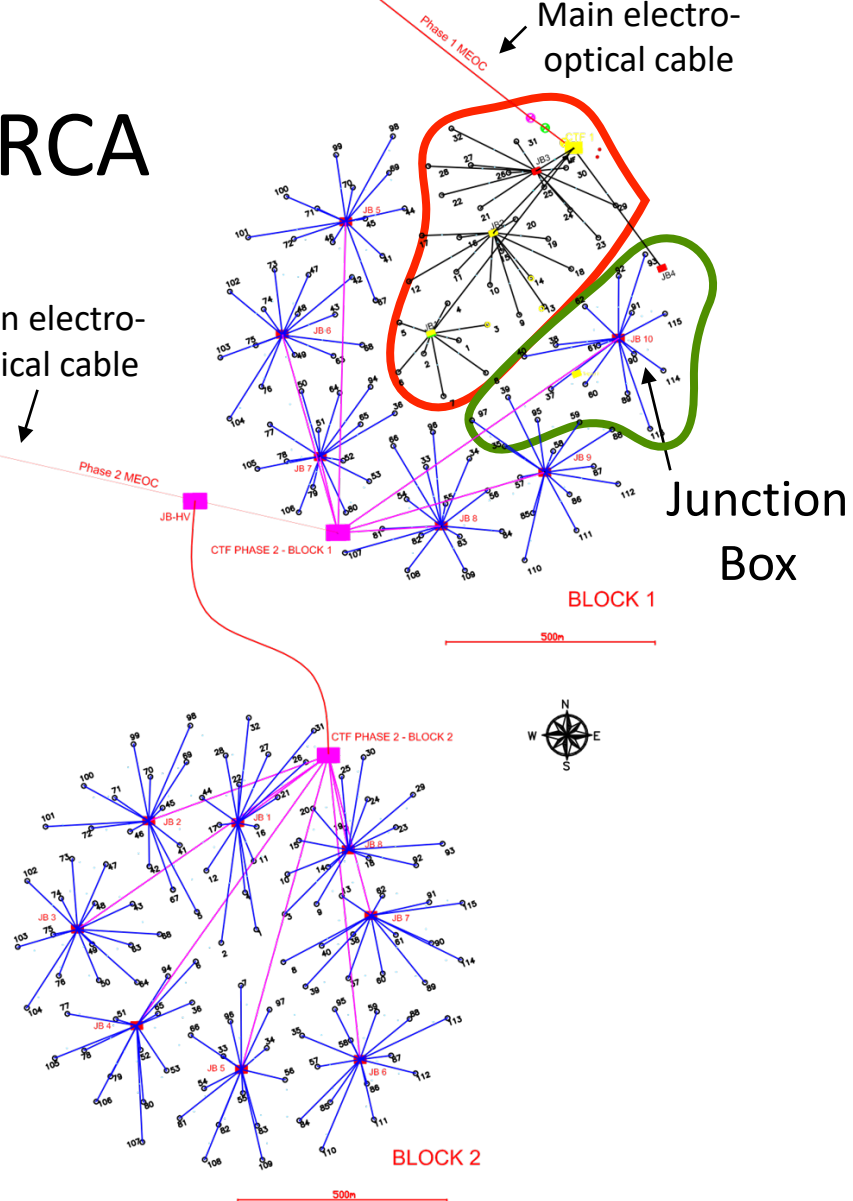
KM3NeT/ARCA

28 DUs deployed
19 DUs to be deployed this fall

ARCA

Main electro-optical cable

Main electro-optical cable



230 Detection Units
18 DOMs / DU

1 Gton detector

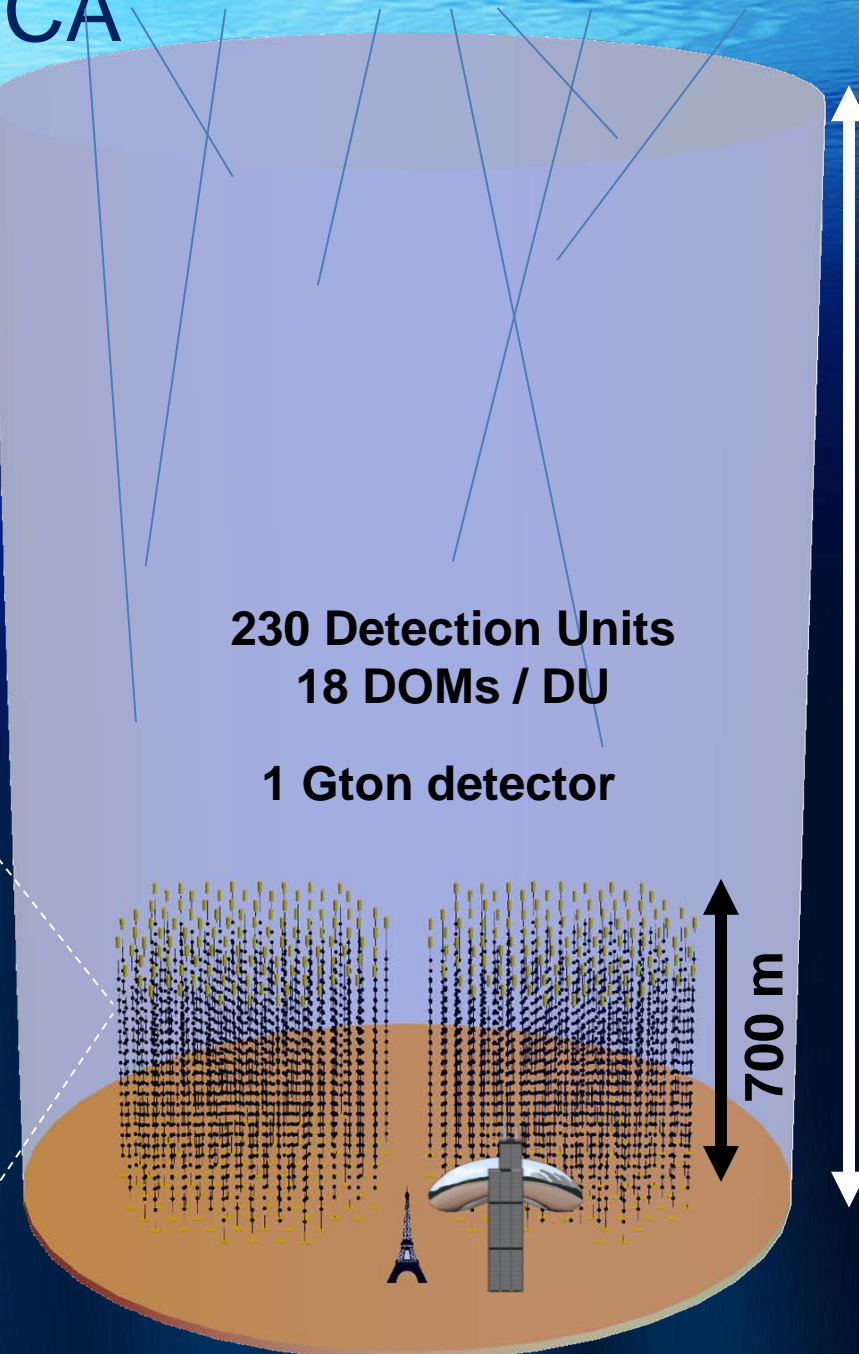
~3500 m

31x 3" PMTs

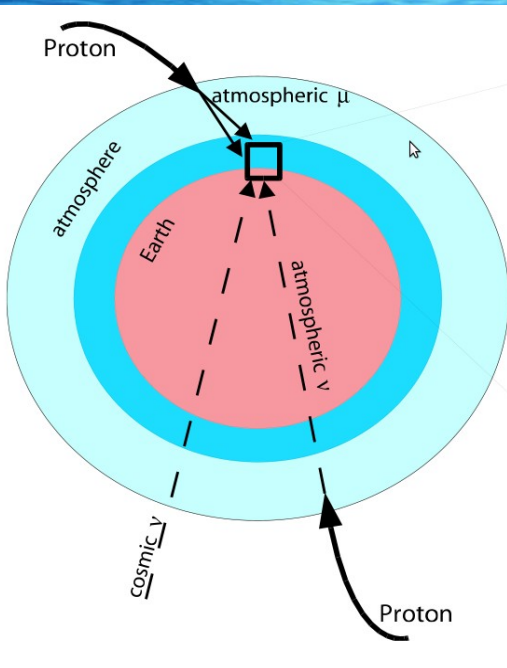


43 cm

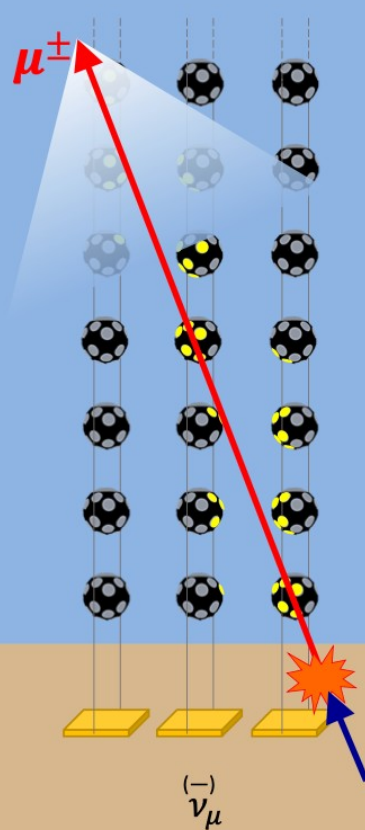
700 m



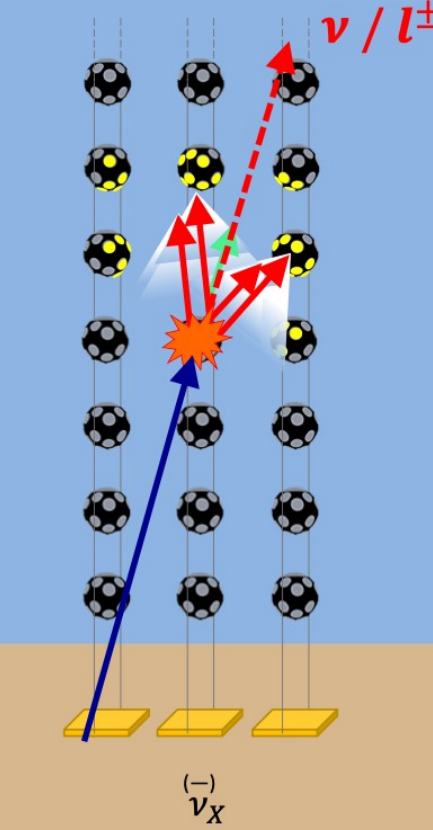
Equipped for detection of all neutrino flavours!



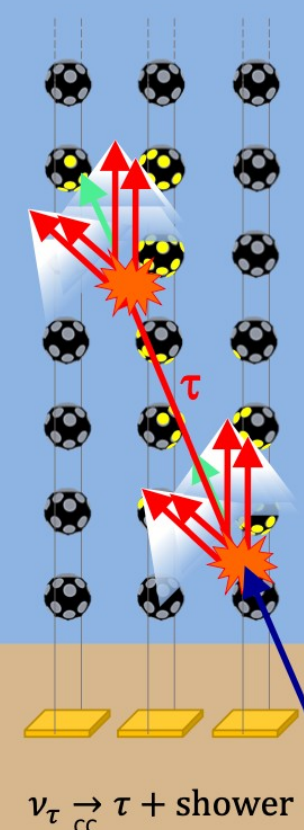
CC ν_μ
1. track like events
good pointing



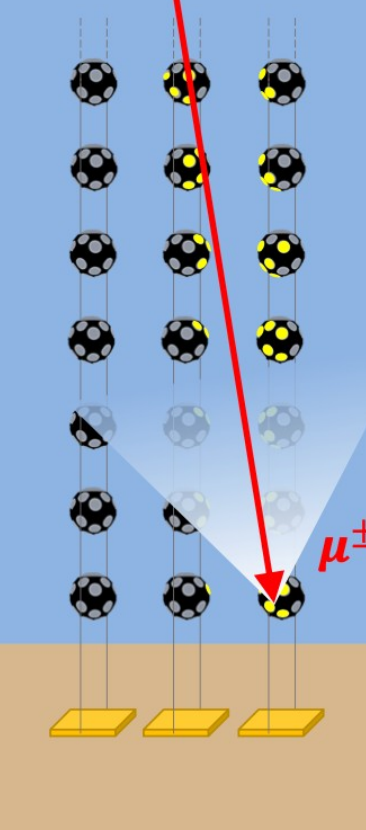
CC ν_e + all flavours NC
2. shower like events
good energy reconstruction



CC ν_τ
3. "double bang"



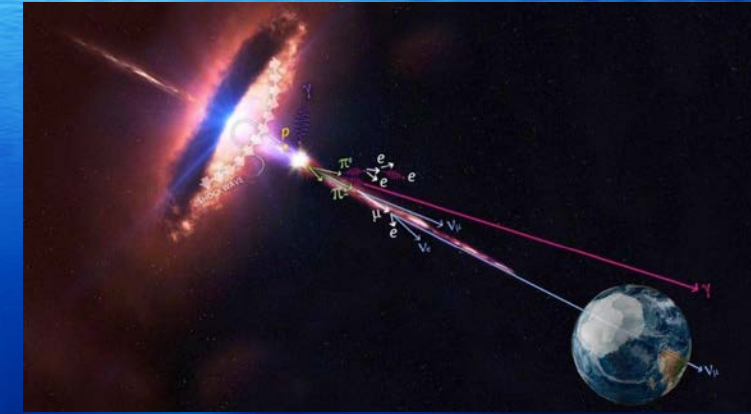
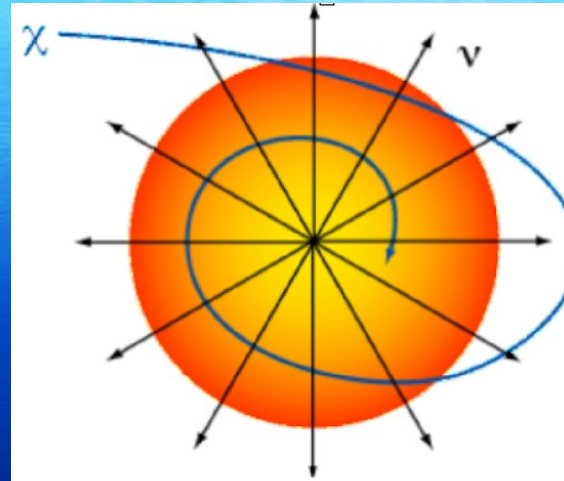
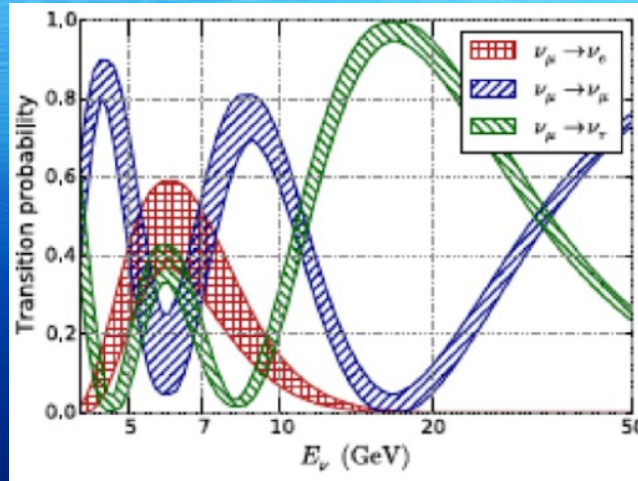
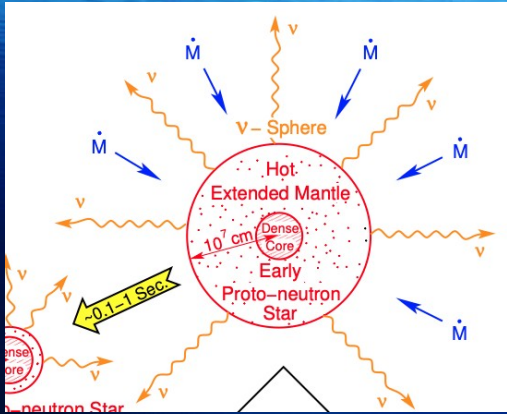
Atmospheric muon
BACKGROUND !!



Rasa Muller

Tracks: @ $E_\nu > 100$ TeV Angular resolution below 0.1° - Energy resolution \sim factor 2
Shower: @ $E_\nu > 100$ TeV Angular resolution below 2° - Energy resolution $\sim 6\%$

Physics of KM3NeT



Supernova explosions
ARCA&ORCA

Neutrino Oscillation
Main Topic of ORCA

Dark Matter
ARCA&ORCA

High Energy Neutrino Astronomy
Multi-Messenger Program
Main Topic of ARCA

From MeV...

...to PeV (and beyond!)

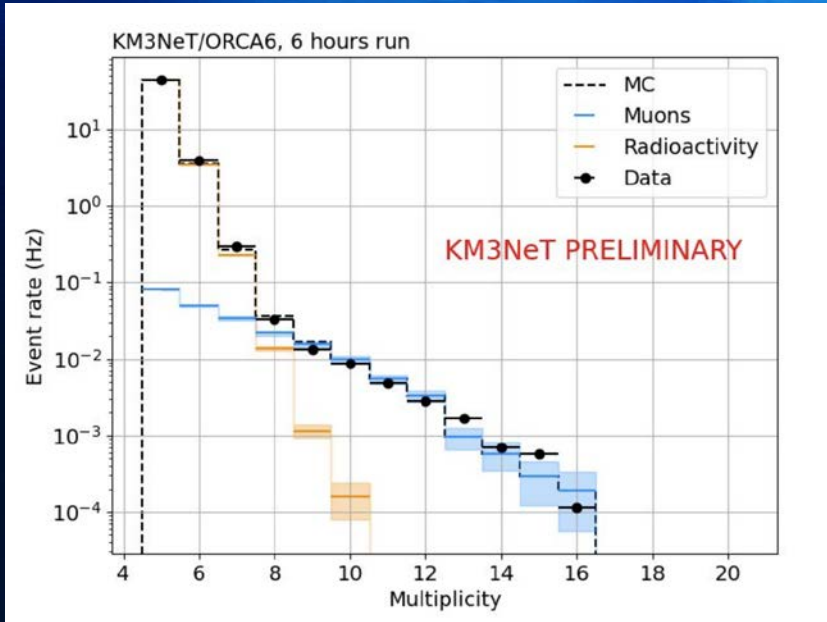
+ oceanology, biology, seismology

Selected results follow

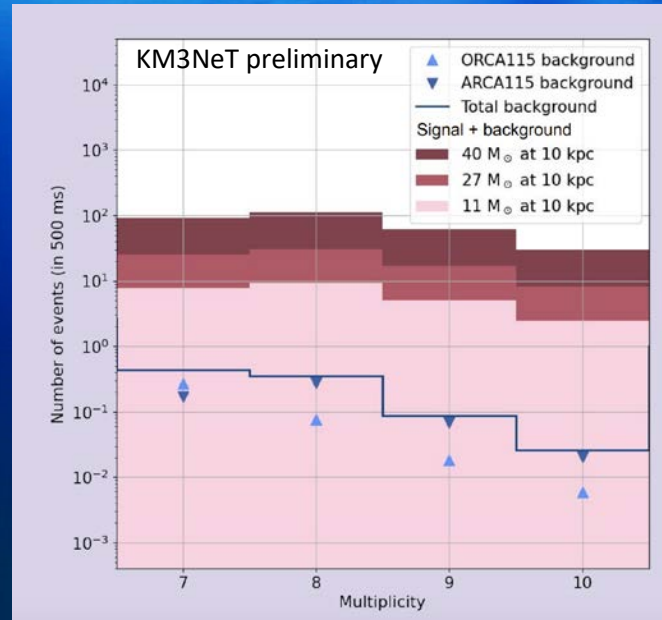
Supernova explosions

A DOM as a single detector, with powerful muon background rejection

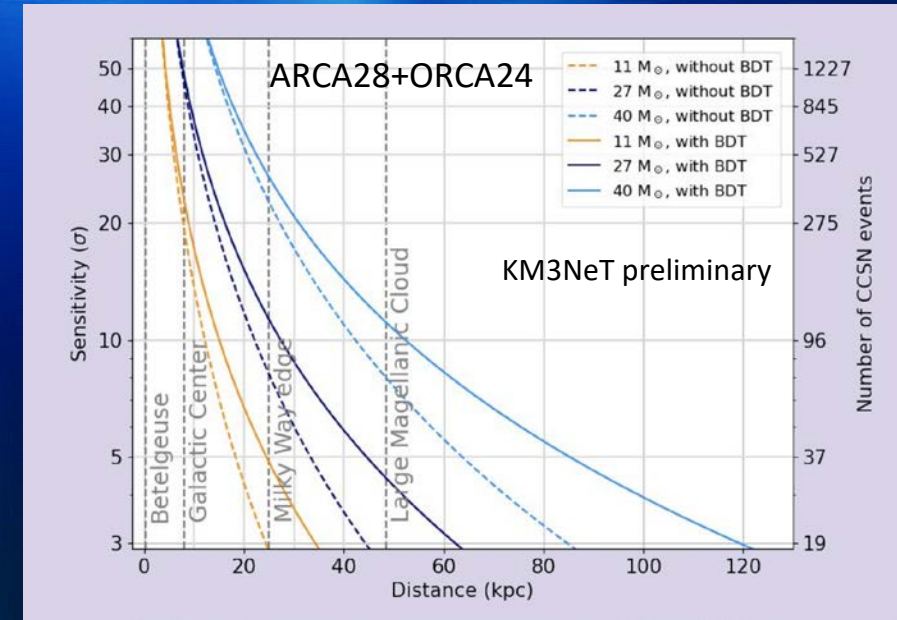
PMT multiplicity plot



Expected signal



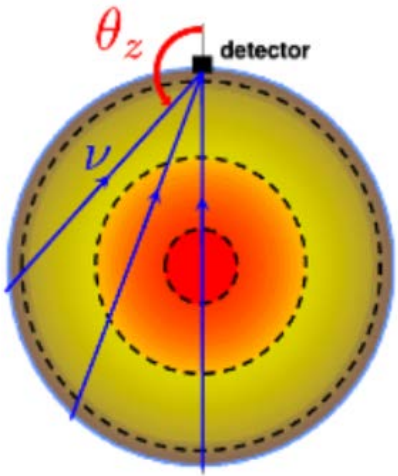
Significance



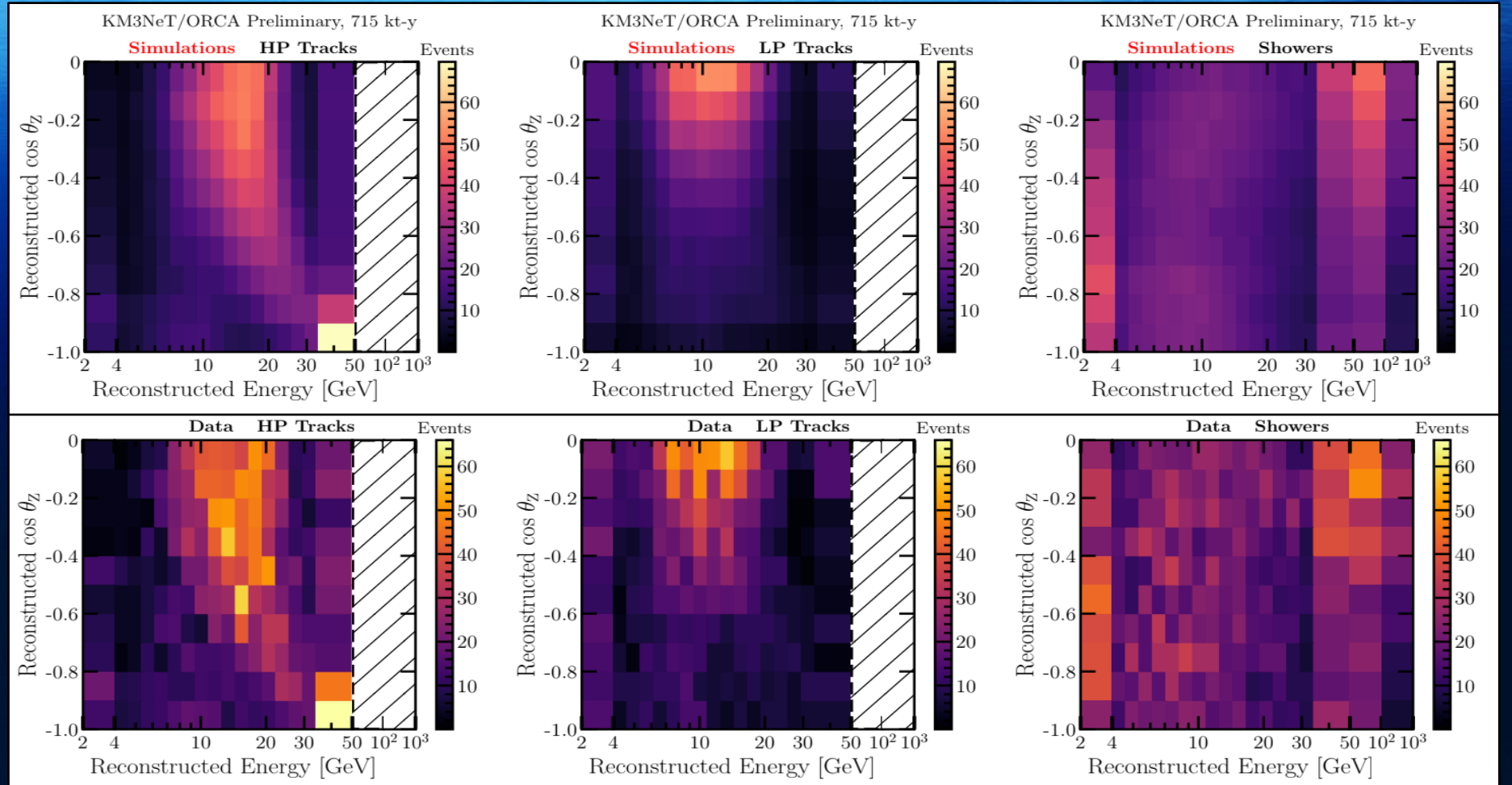
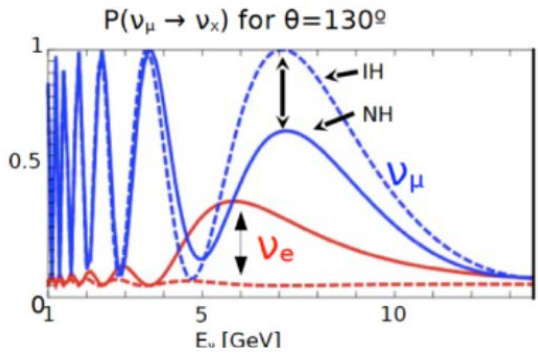
On-line alert system for CCSN already implemented
Integrated in SNEWS

ν oscillation patterns in ORCA

Baseline from 50 to 12800 km



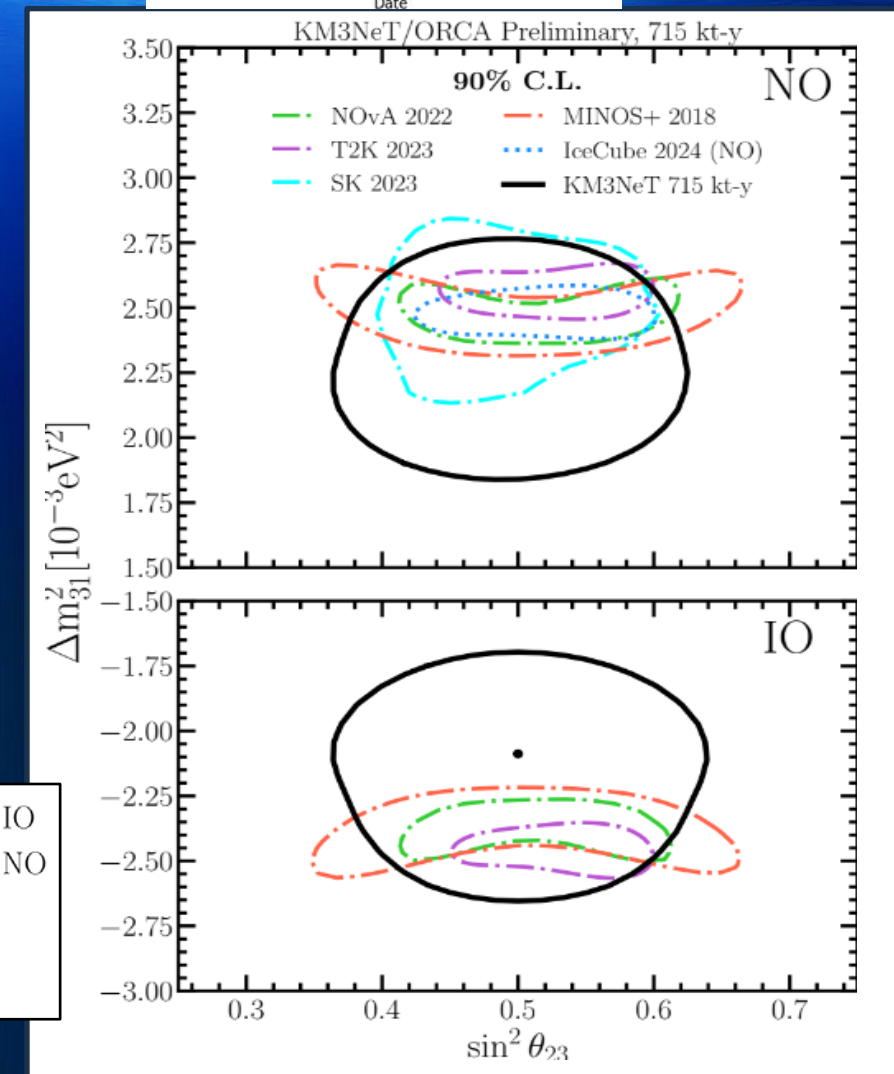
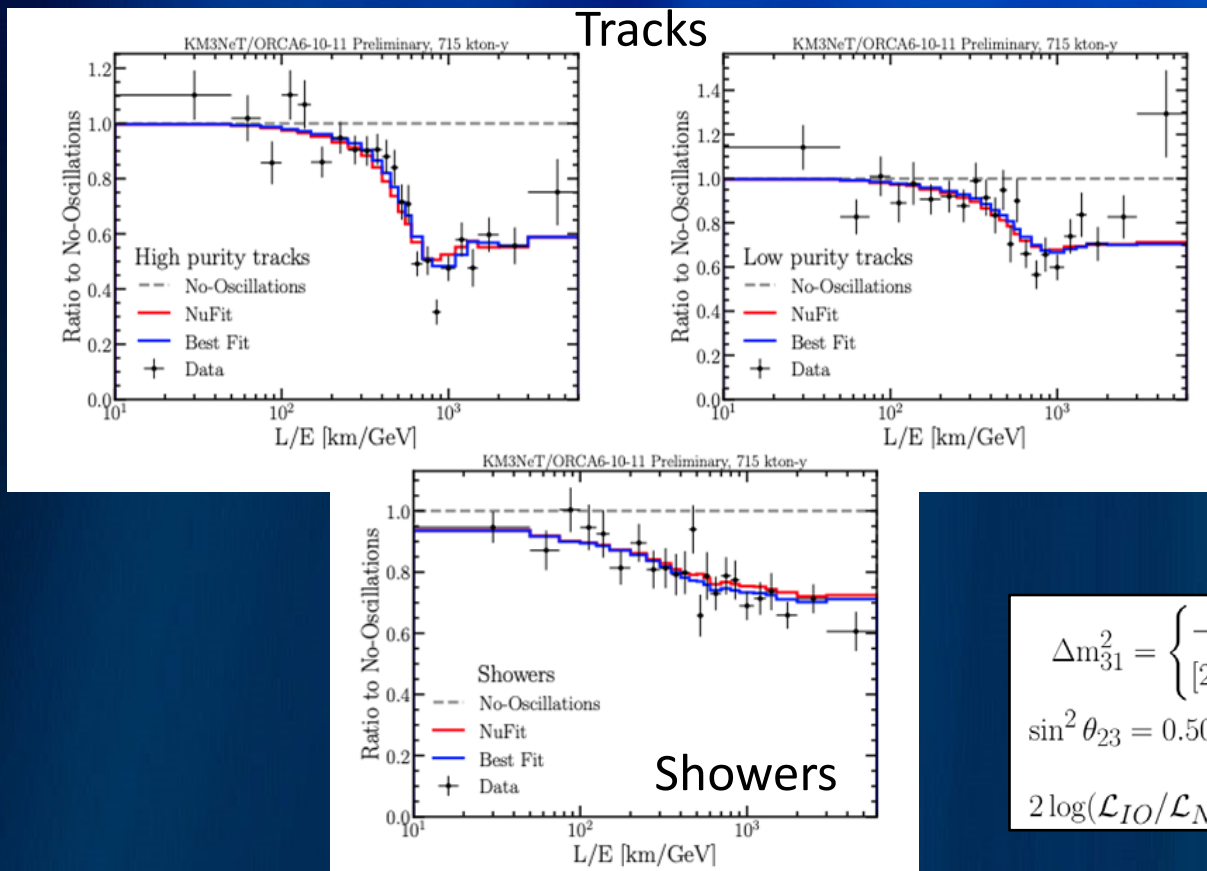
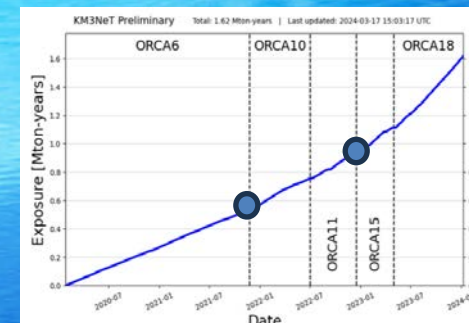
Energy range of interest 5-15 GeV



3 classes of events

Neutrino oscillation results

- Already providing relevant information with exposure equivalent to only 37 days of full ORCA detector
- Fully consistent with world data
- Results from analysis of ORCA6 (433 kton-yr) available in <https://arxiv.org/pdf/2408.07015>

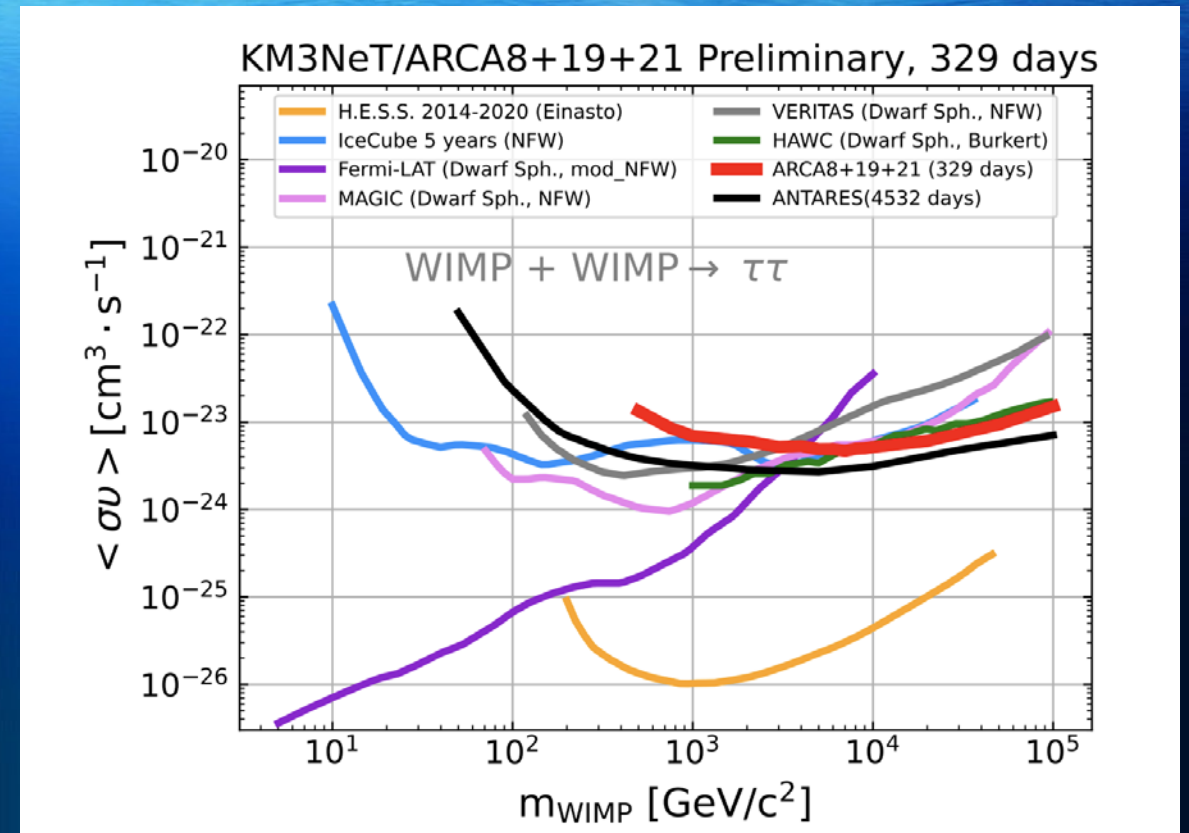
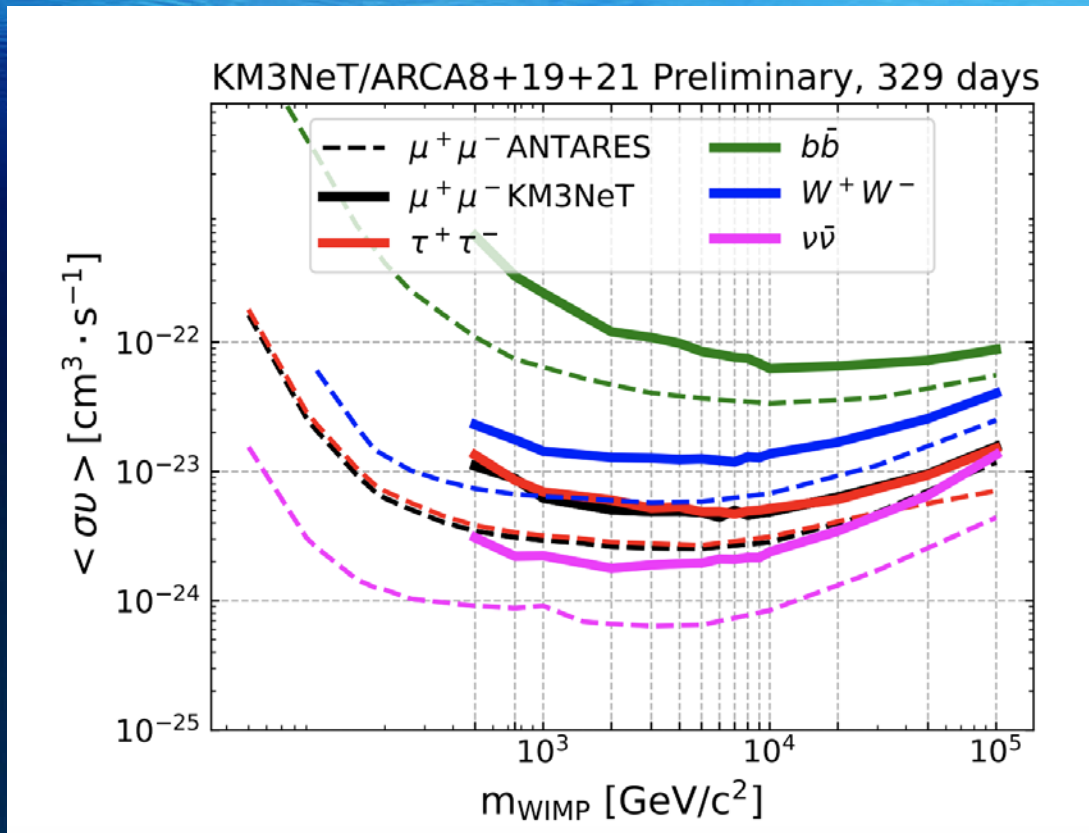


$$\Delta m_{31}^2 = \begin{cases} -2.09^{+0.17}_{-0.21} \times 10^{-3} \text{eV}^2, & \text{IO} \\ [2.10, 2.37] \times 10^{-3} \text{eV}^2, & \text{NO} \end{cases}$$

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

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

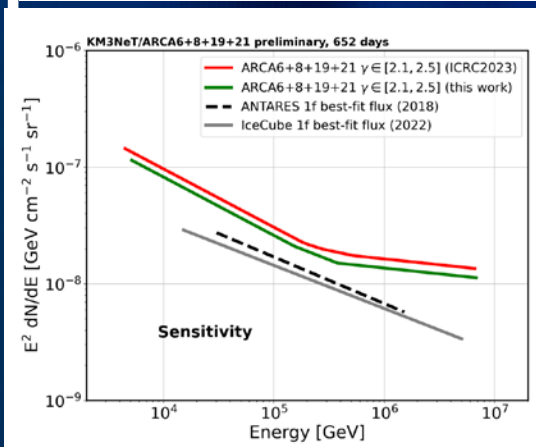
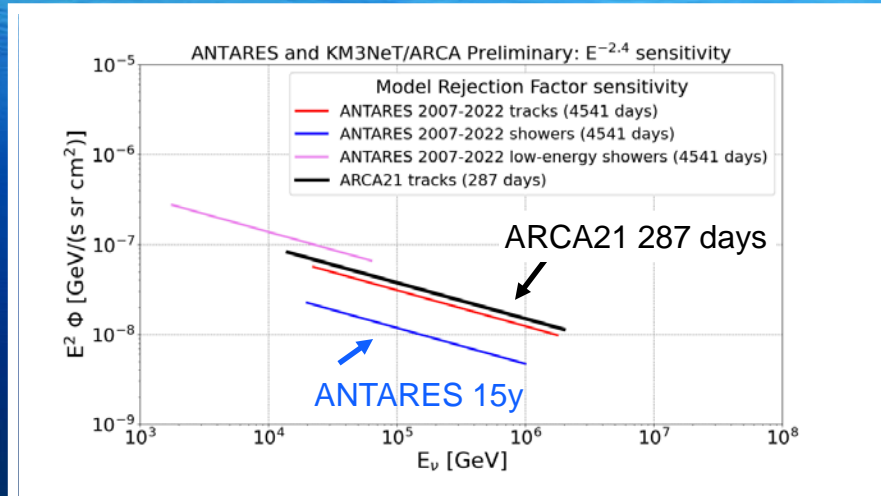
Dark matter from the Galactic Center



KM3NeT quickly reaching the ANTARES limits

Search for a cosmic diffuse neutrino flux

Full sky

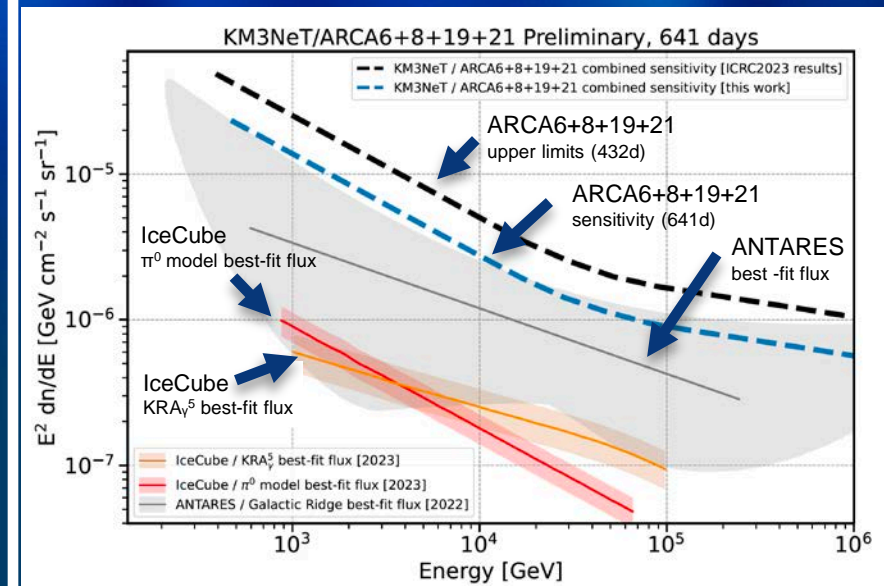


With the data collected until Sept. 2023 same sensitivity as ANTARES 15 years of data for track events

Galactic plane

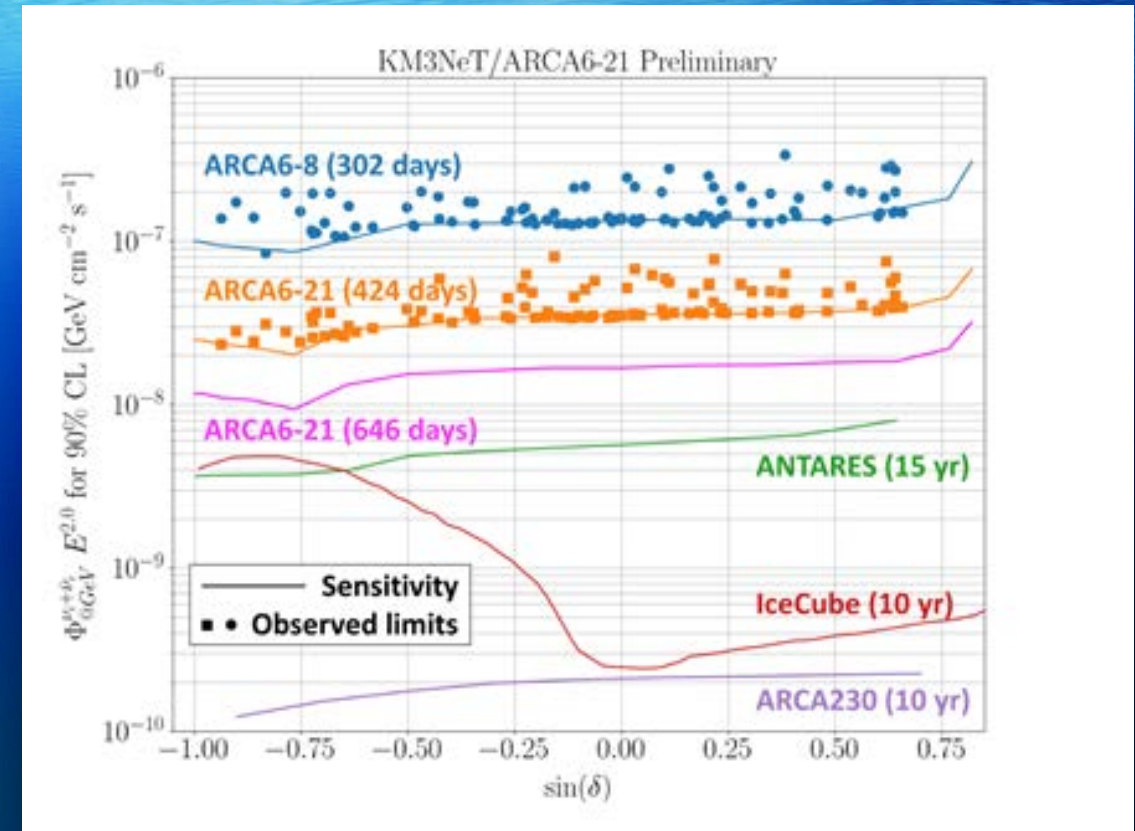
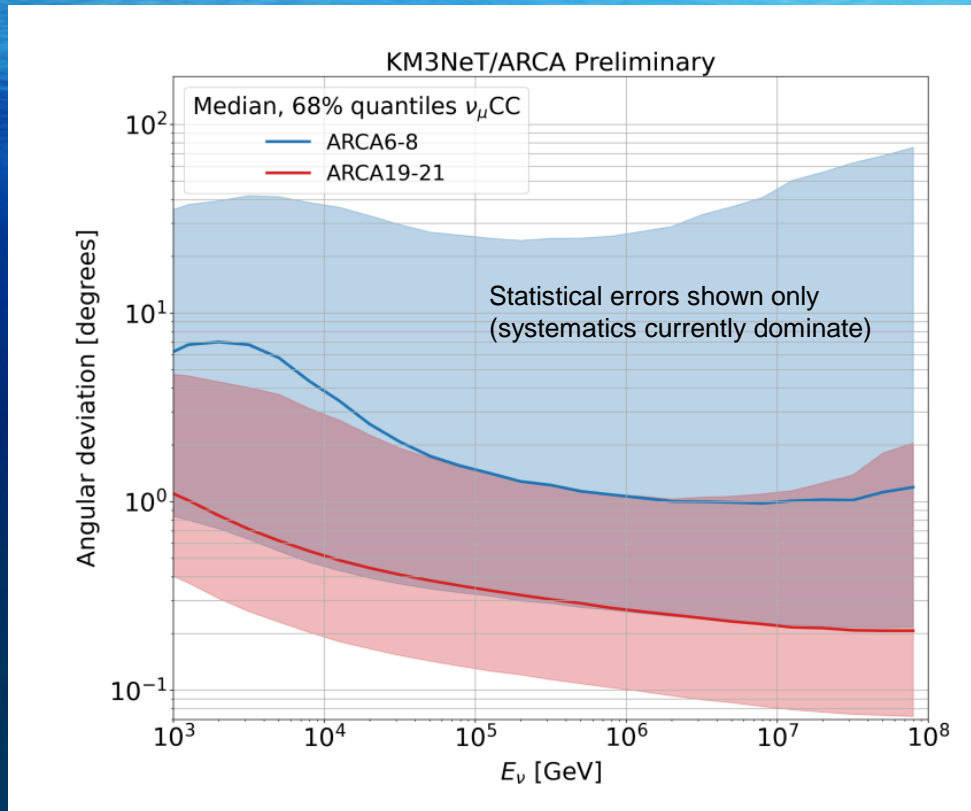
On-Off zone analysis

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



KM3NeT/ARCA rapidly approaching the ANTARES sensitivity

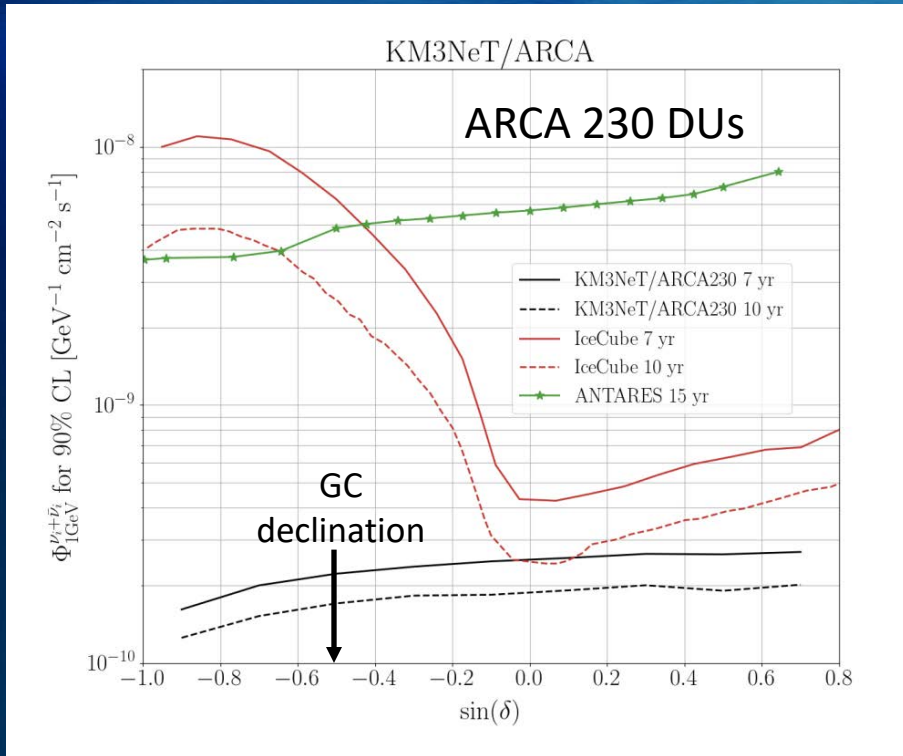
Search for cosmic (point) sources of neutrinos



- Accumulating more and more data
- Angular resolution improves as detector grows
- Dedicated system for improving pointing accuracy will be put in operation in fall
- The KM3NeT upper limits are quickly reaching the ANTARES 15yr limits

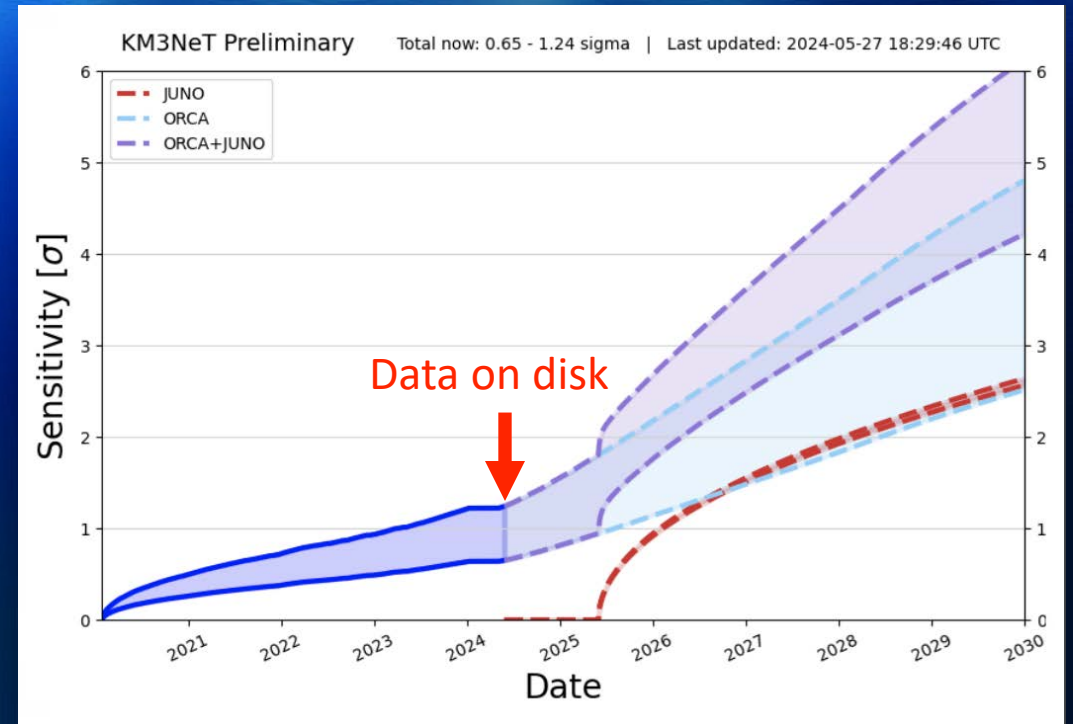
KM3NeT perspectives

ARCA - Sensitivity for point-like searches



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

ORCA - Neutrino mass ordering



2020 2021 2022 2023 2024 2025 2026 2027 2028 2029

ANTARES
decommissioning

ARCA 48 DUs
ORCA 24 DUs

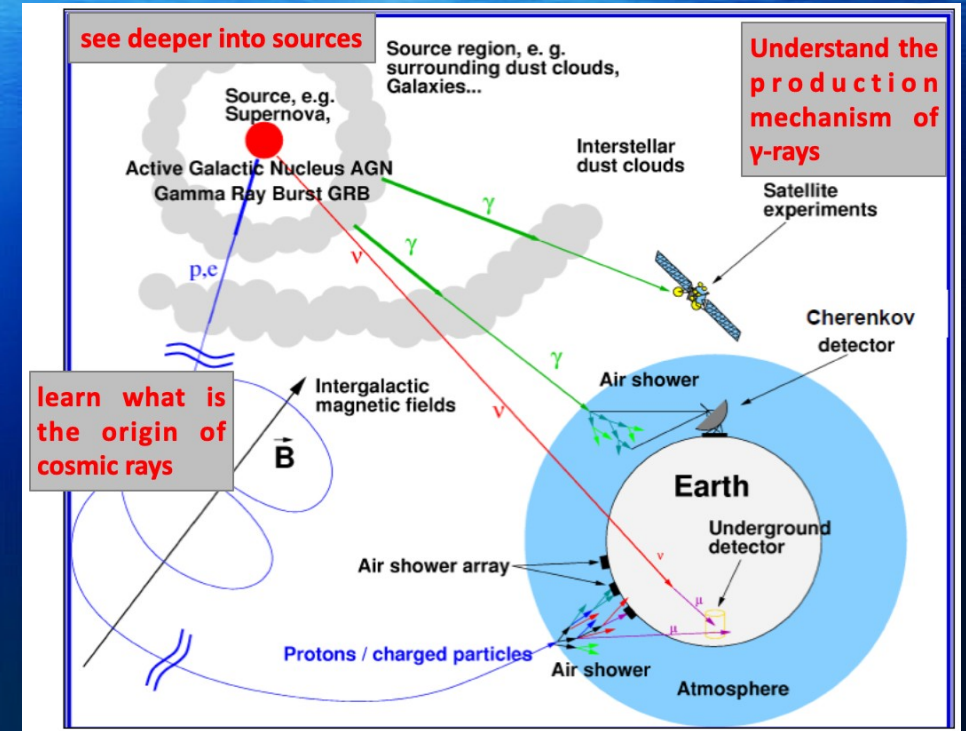
ARCA & ORCA
completion

Multi-messenger approach

Multi-messenger astronomy is becoming the most sensitive approach to astrophysical event detection, especially for transient events

Multi-messenger framework developed in KM3NeT

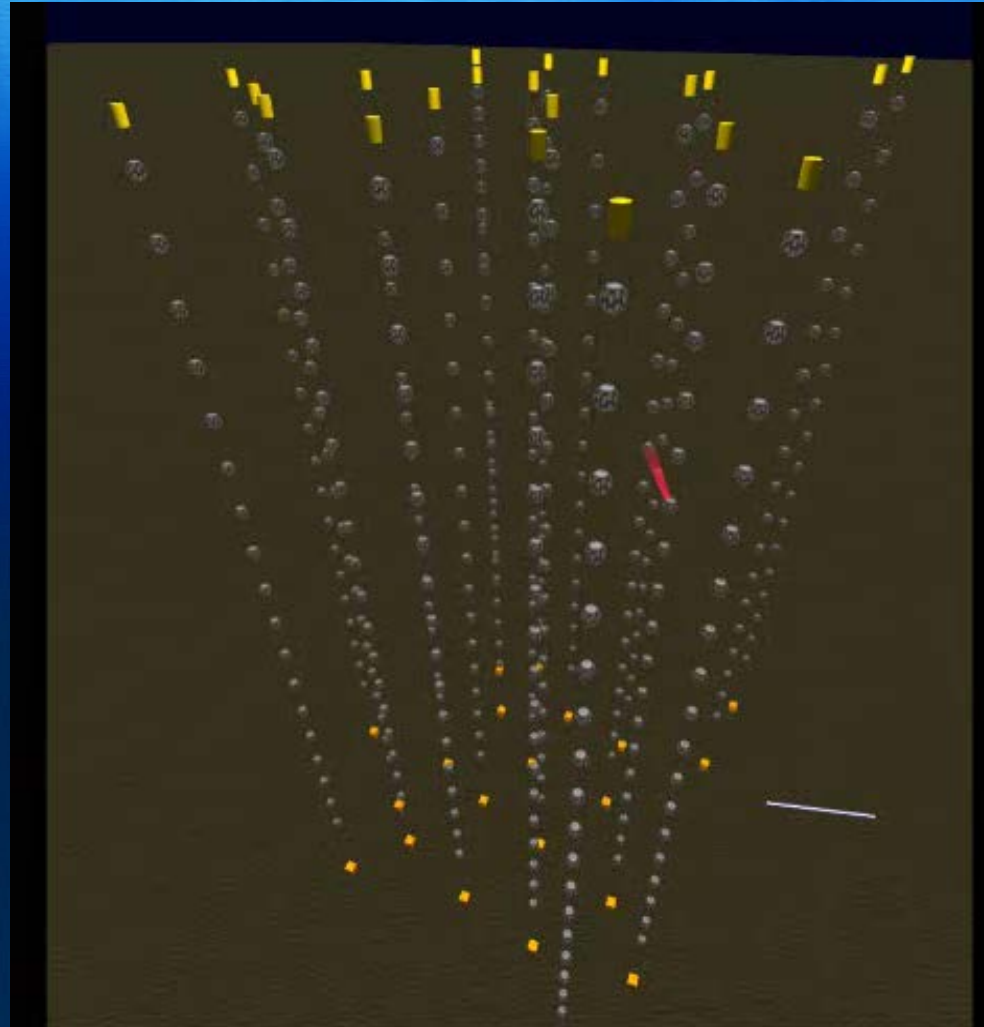
KM3NeT actively monitors and analyses a variety of external triggers in real-time, including alerts due to IceCube neutrinos, Fermi/Swift GRB, HAWC gamma-ray transients, LIGO-Virgo-KAGRA gravitational waves, SNEWS neutrino alerts, and others



- Receiving alert system operative → Real Time Analysis platform active since Nov. 2022 in ARCA & ORCA
- Several thousands of alert received and analyzed in real time → no significant excess found in any such alert so far
- Sending alert system being set up → High-energy neutrino alerts will be sent in real-time by end of 2024

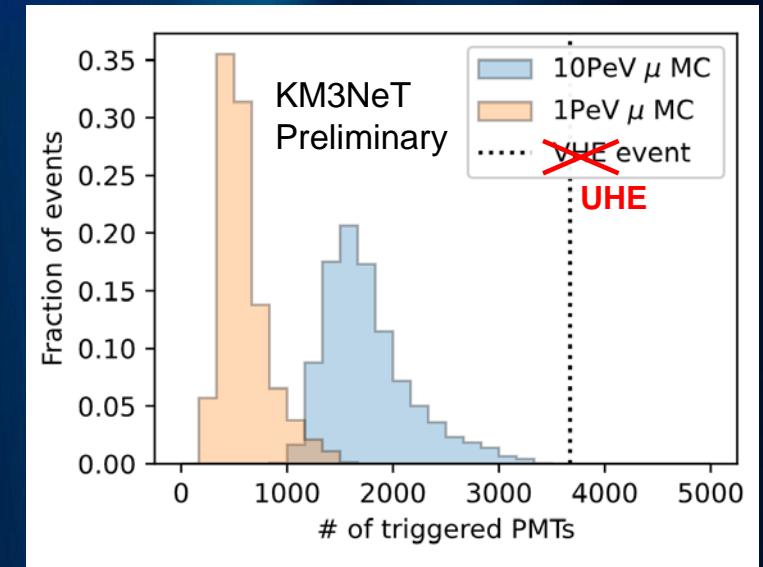
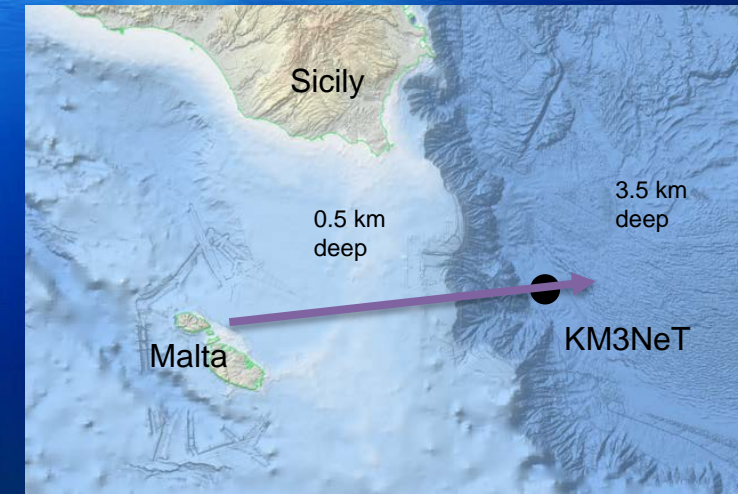
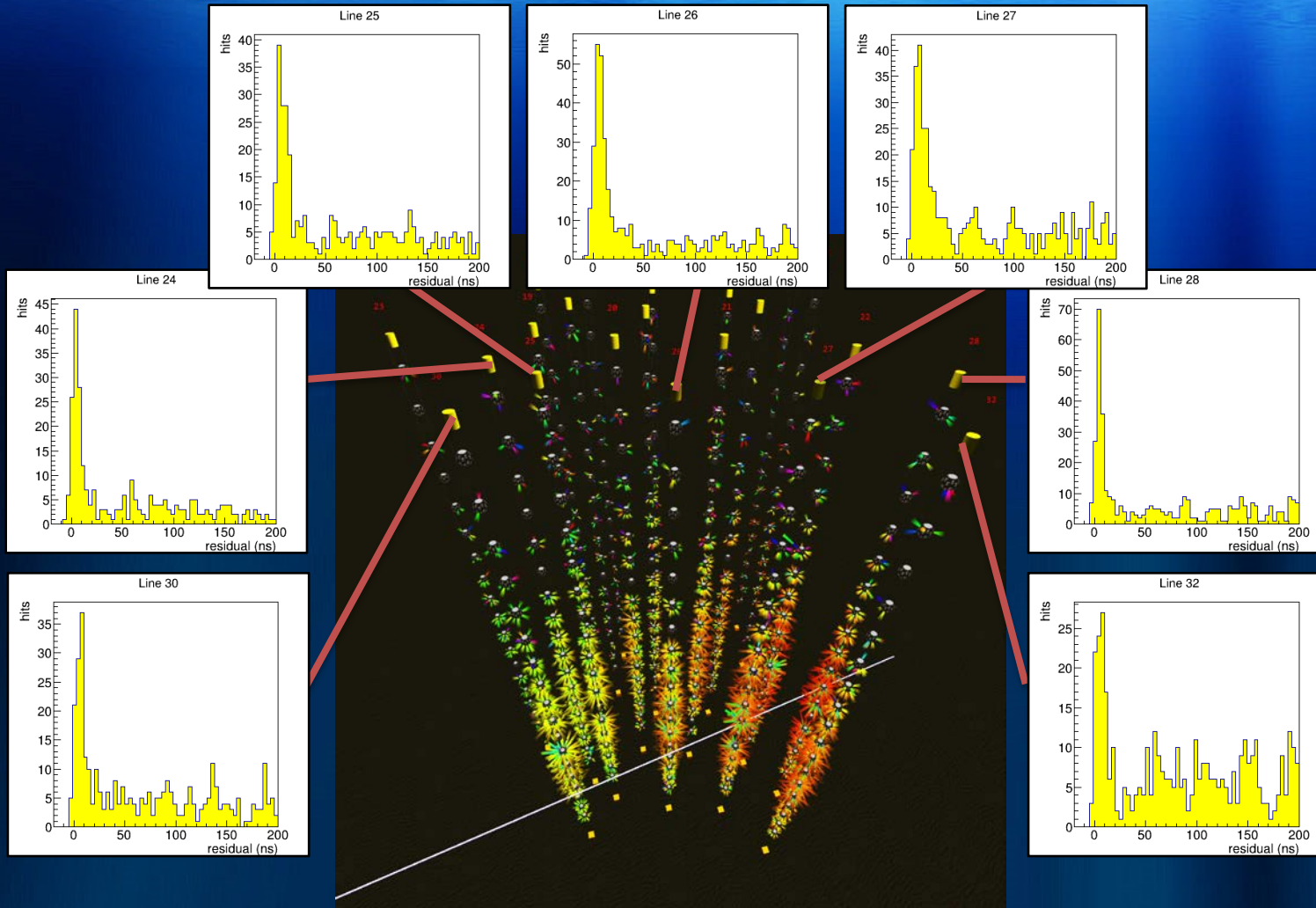
Message from the cosmos: the first UHE neutrino!

- Single muon crossing almost horizontally entire ARCA21 detector, releasing signal in 1/3 of the apparatus!



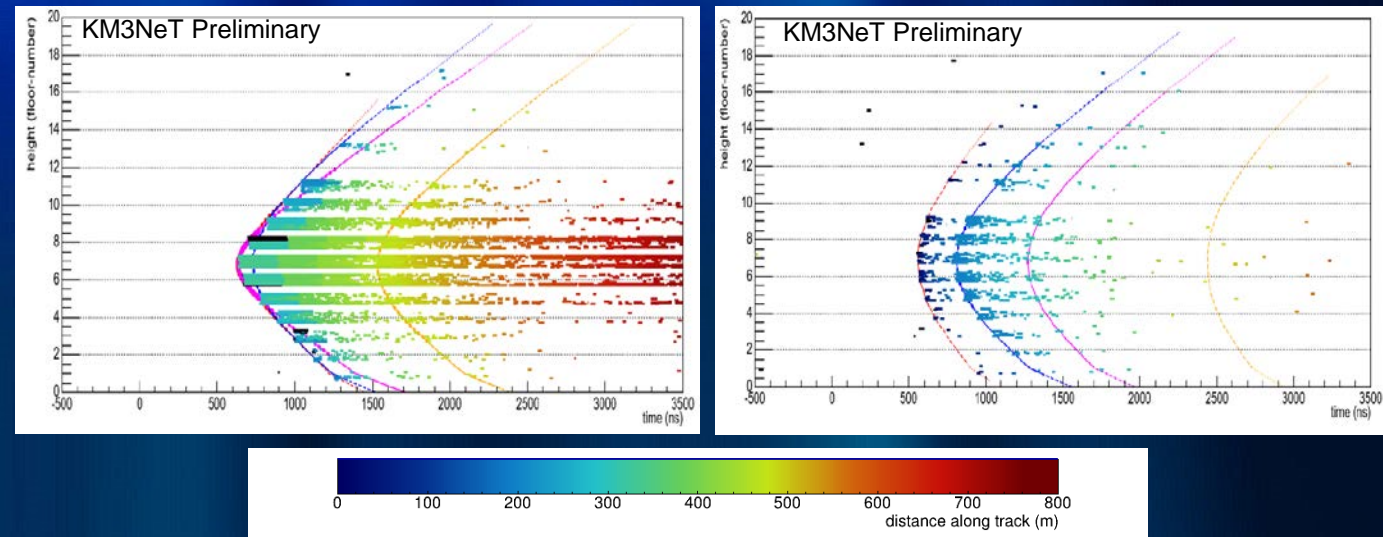
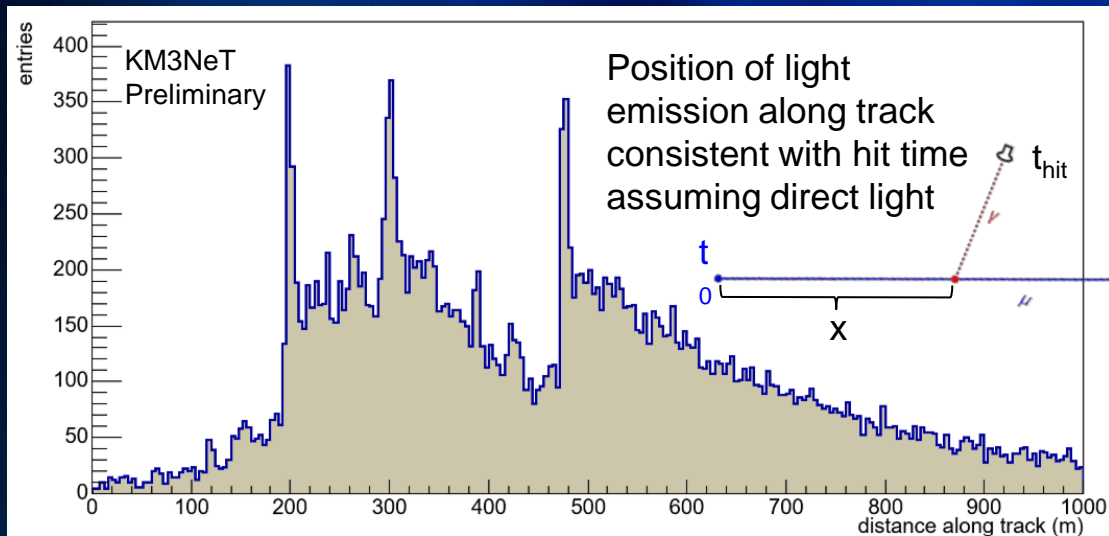
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- Exceedingly unlikely for an atmospheric muon to travel through that much water/column depth or for an atmospheric neutrino to provide such extreme energy → it's the evidence of a cosmic neutrino!



Message from the cosmos: the first UHE neutrino!

- Single muon crossing almost horizontally entire ARCA21 detector, releasing signal in 1/3 of the PMTs!
- Exceedingly unlikely for an atmospheric muon to travel through that much water/column depth or for an atmospheric neutrino to provide such extreme energy → it's the evidence of a cosmic neutrino!
- Light profile consistent with 3 large energy depositions along the muon track - characteristic of stochastic losses from very-high-energy muons
- (Low light scattering in sea water and good time resolution are instrumental to get such rich details)



Outlook and conclusions

The KM3NeT detectors ARCA and ORCA exploit a novel multi-PMT Optical Module design to explore from the deep sea the frontiers of the cosmos and to investigate the neutrino properties

KM3NeT has been taking high-quality data already during its construction phase

New results available about neutrino oscillations, search for cosmic neutrinos and a variety of other topics (atmospheric muons and neutrinos, search for new physics, etc.) – with much more to come!

An event with unprecedented energy has been observed in rich detail – a muon with energy $\gg 10$ PeV!

Detector construction is well proceeding:

- effective integration and deployment procedures are in place
- integration facilities are being further extended
- funding secured for $\sim 2/3$ ARCA and $\sim 1/2$ ORCA, new requests in preparation

Aiming at completing both ARCA and ORCA for 2028