

The KM3NeT neutrino telescope: first results and perspectives



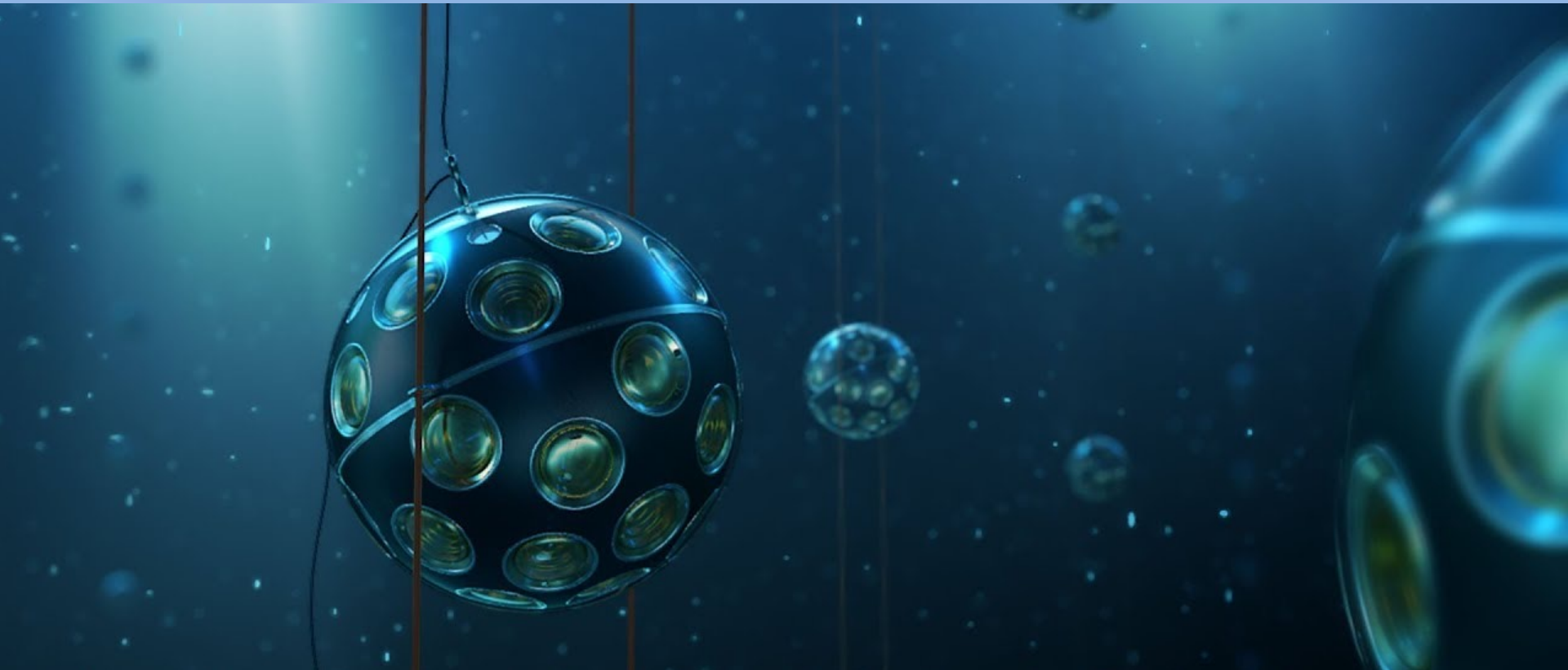
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UNIVERSIDAD
DE GRANADA

On behalf of the KM3NeT Collaboration

34th Rencontres de Blois on "Particle Physics and Cosmology", May 14–19, 2023

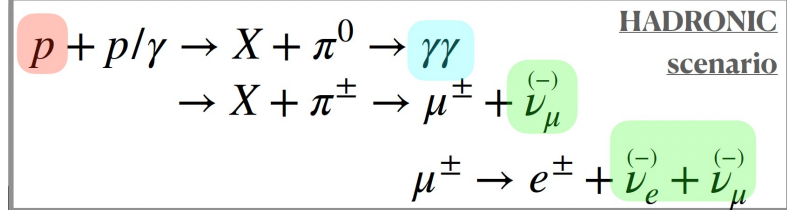
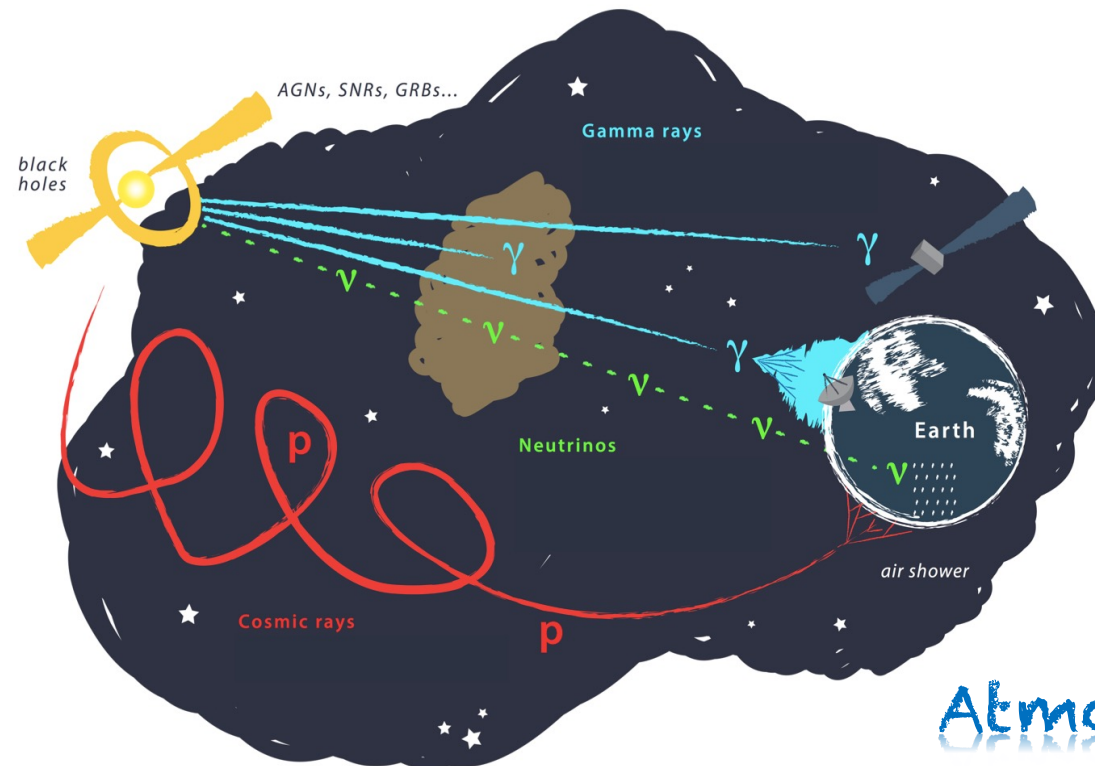


Neutrino telescopes: neutrino Astrophysics and Atmospheric neutrinos

Neutrinos are **ideal messengers** in the search for distant astrophysical objects

Unique properties of neutrinos: electrically neutral, stable, and weakly interacting particles

- ★ No deflection in magnetic field (**unlike cosmic rays**) → point back to their sources
- ★ No absorption in cosmic backgrounds, as Extragalactic Background Light (**unlike gamma-rays**)



ν Astrophysics:

- Search for **individual sources**
- Study the “**diffuse flux**”
- **Multimessenger** approach

Atmospheric ν beam:

- Broad Energy and Baseline range (L/E) to be explored
- ν properties (**Oscillations, NMO, NSI ...**)

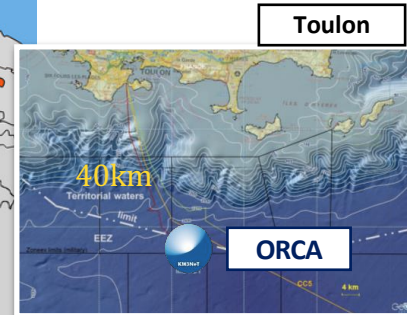
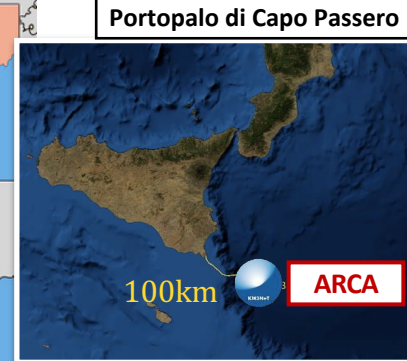
The KM3NeT Collaboration

KM3NeT : **Water Cherenkov detectors** for HE neutrinos in the Mediterranean Sea, under construction

Distributed research infrastructure with **2 sites, 2 main physics topics, 1 technology**

Cities and Sites of KM3NeT

~250 people
42+8 Institutes
15+5 Countries



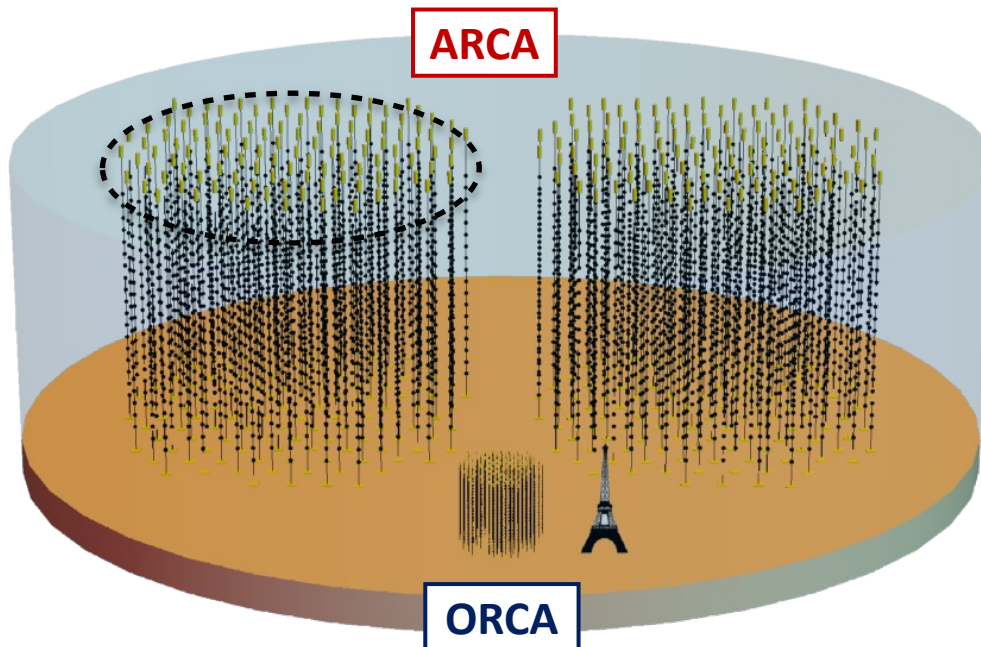
ORCA : Low-energy (\sim GeV)
studies of atmospheric neutrinos

ARCA : High-energy (TeV-PeV)
neutrino astrophysics

The KM3NeT: a 3D array of Optical Sensors

Digital Optical Module

31 × 3" PMTs

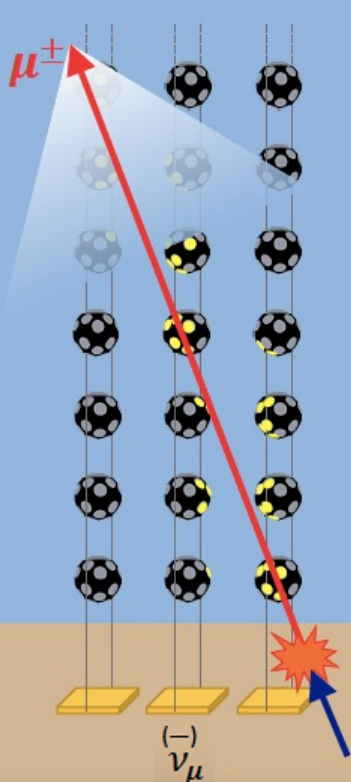


	ARCA	ORCA
Location	Italy (Sicily)	France (Toulon)
Depth	3450 m	2450 m
Distance from shore	100 km	40 km
Number of DUs	115 x 2 (2 BB)	115 (1 BB)
DU horizontal spacing	90 m	20 m
DOM vertical spacing	36 m	9 m
#DOMs/DU	18	18
#PMTs/DOM	31	31
Instrumented volume	~ 1 Gton	~ 7 Mton
> 1km³ neutrino telescope		
Deployed DUs	21	18

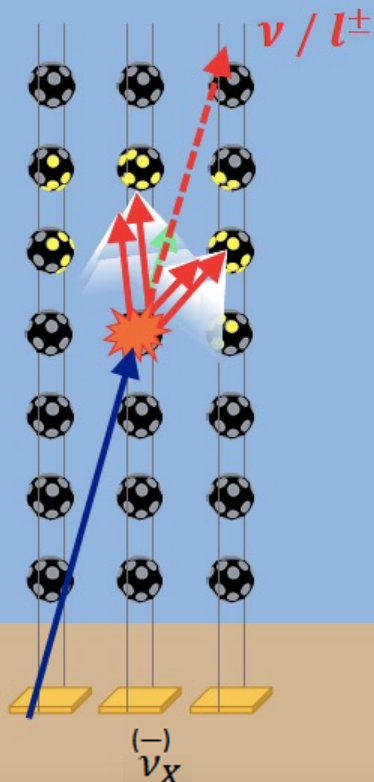
1 Building Block (BB) = 115 Detection Units (DU)

Event Topologies

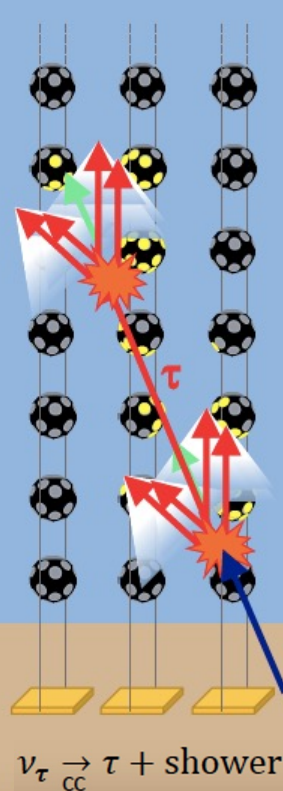
CC ν_μ
1. track like events
good pointing



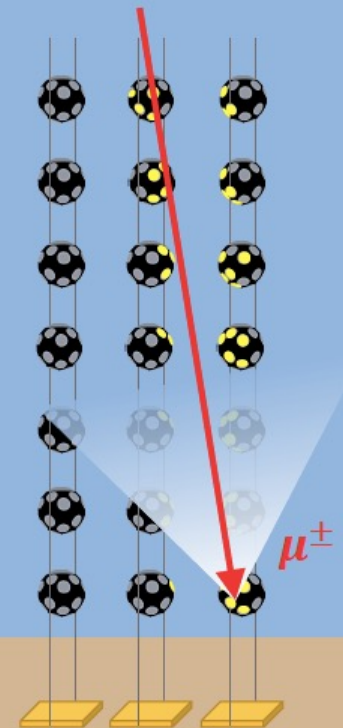
CC ν_e + all flavours NC
2. shower like events
good energy reconstruction



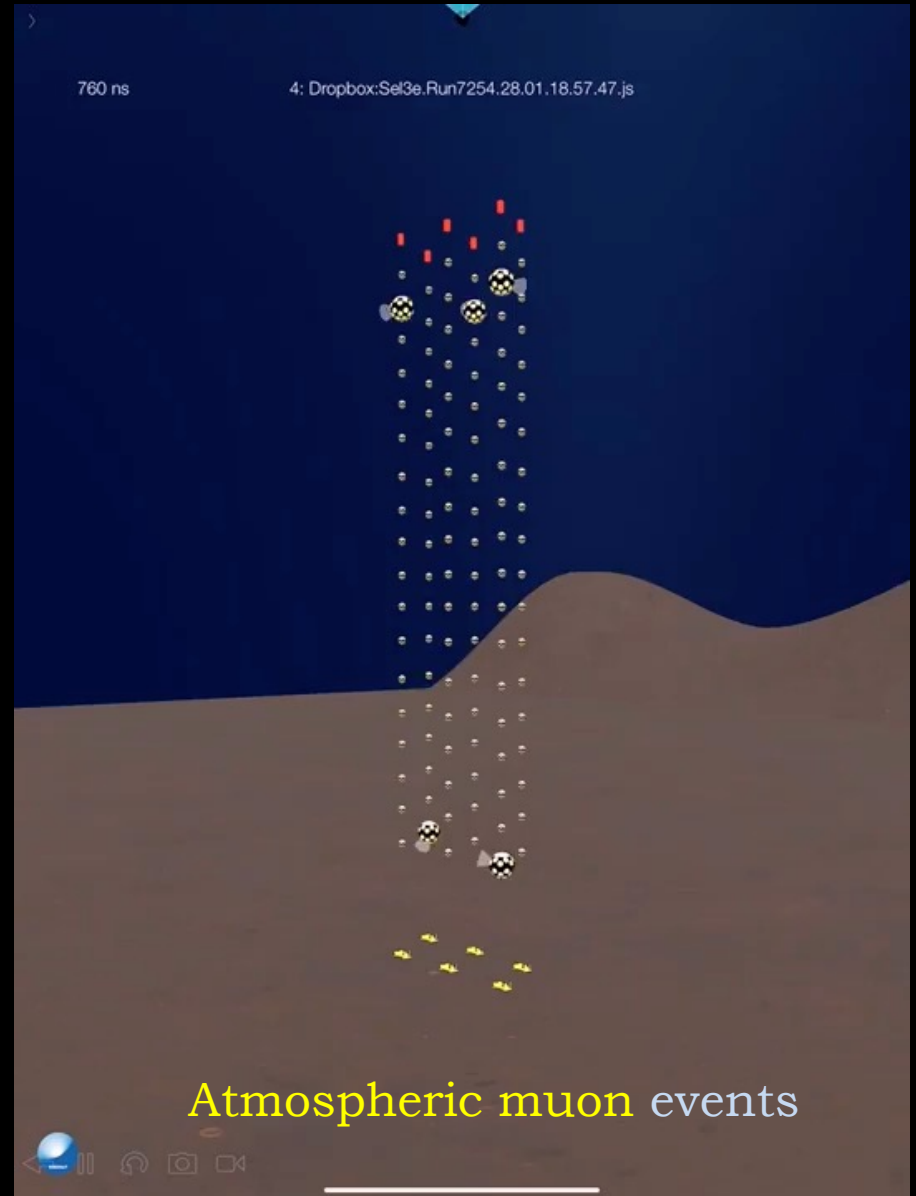
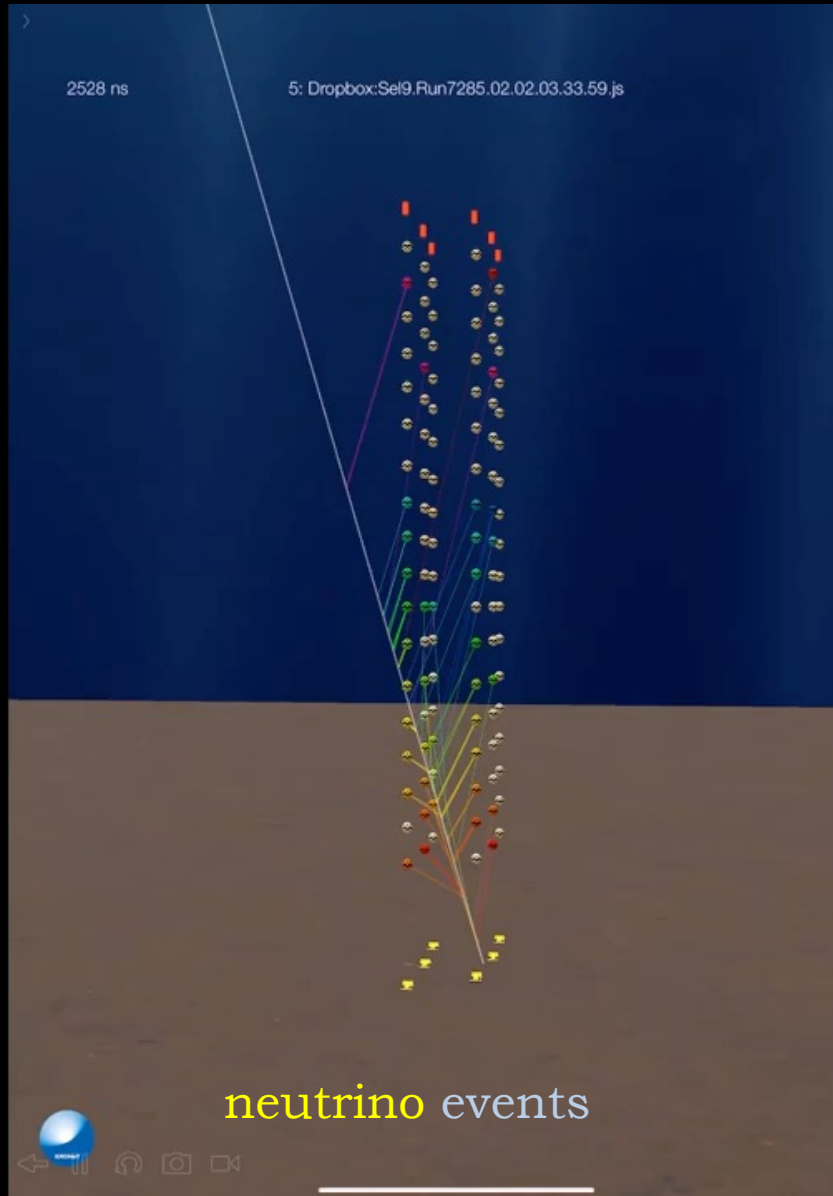
CC ν_τ
3. "double bang"



Atmospheric muon
BACKGROUND !!

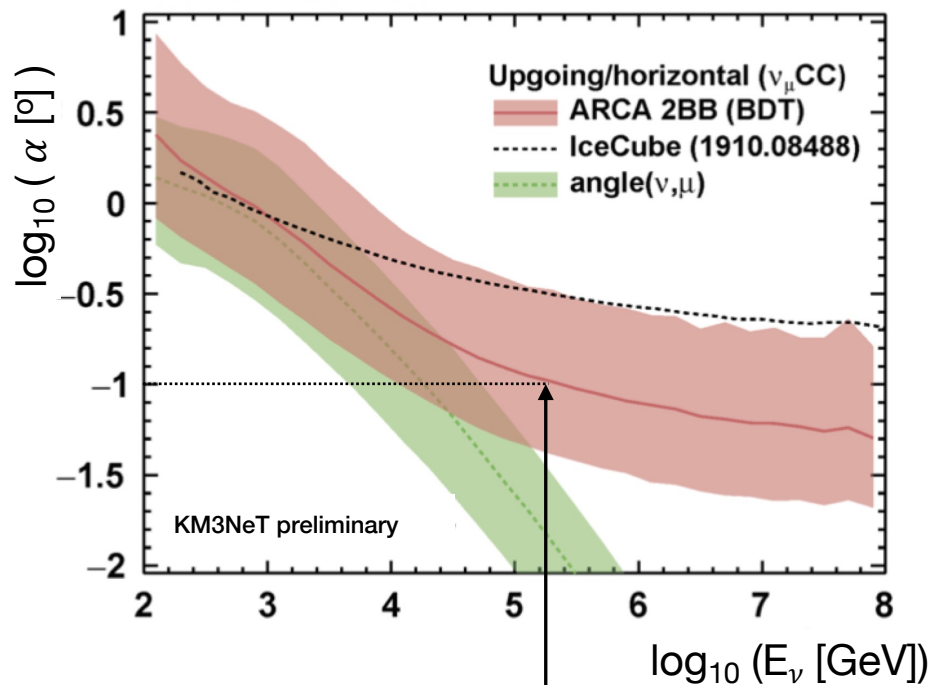


ORCA6: some data events



"tracks"

PoS(ICRC2021) 1077

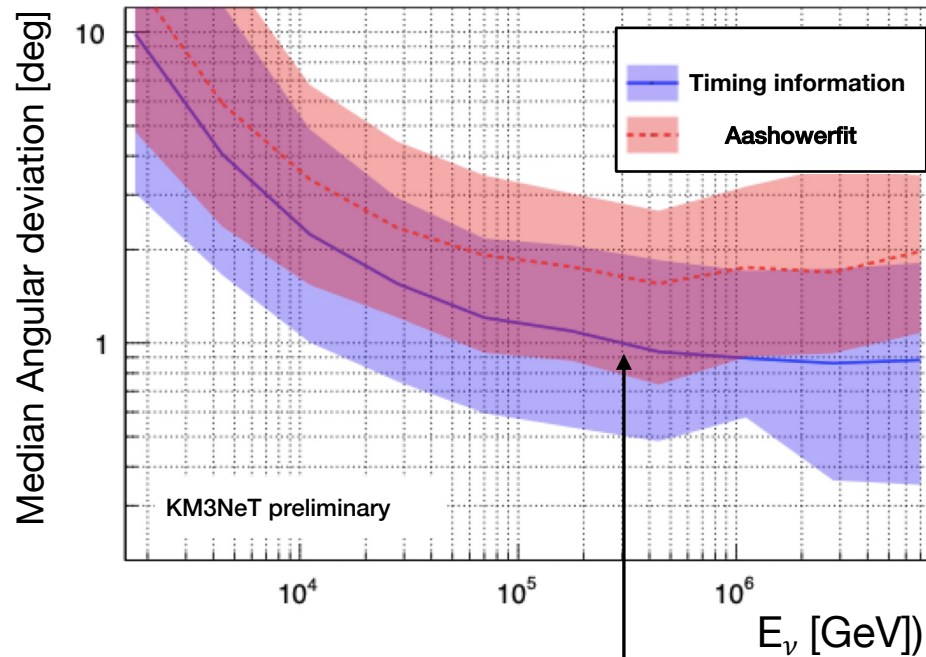


Better than 0.1° at 100 TeV

Energy Resolution ~ 0.27 in $\log_{10}(E_{\text{reco}}/E_\mu)$
(10 TeV $< E_\mu < 10$ PeV)

"showers"

PoS(ICRC2021) 1089

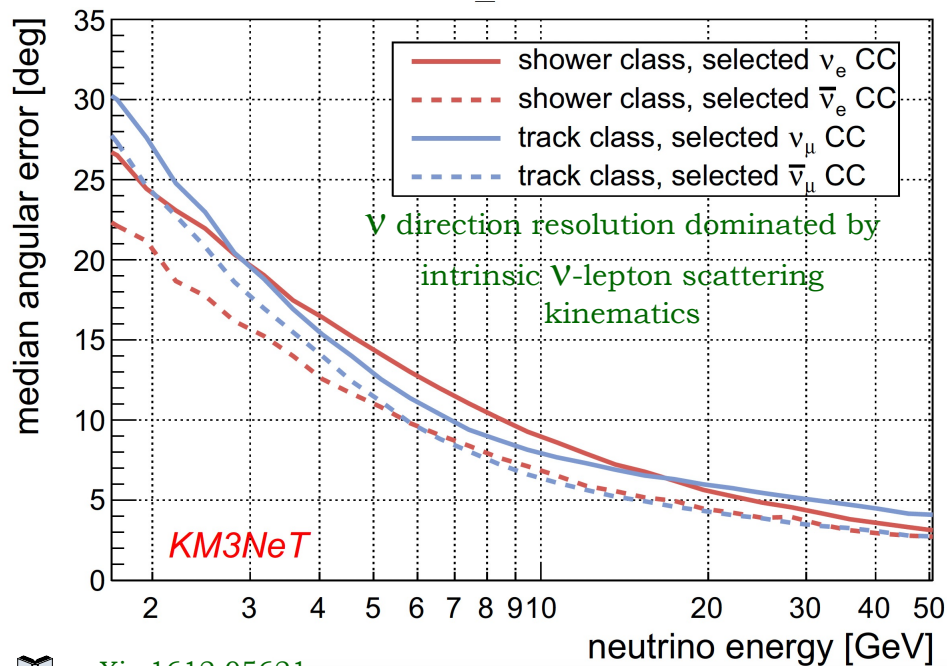


Better than 1° at 30 TeV

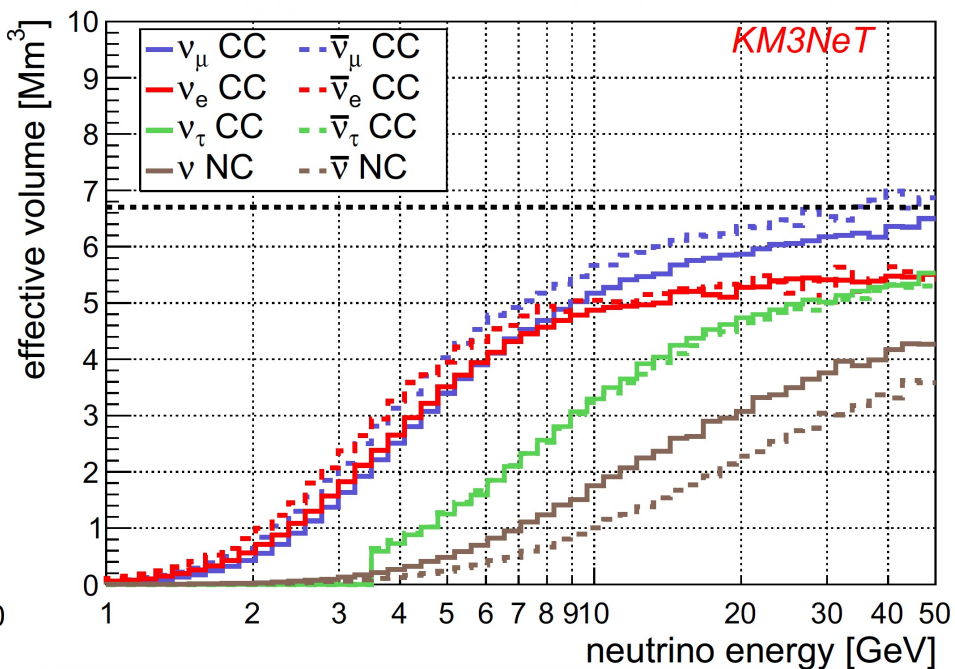
Energy Resolution $< 5\%$

Showers (ν_x NC + ν_e CC): **contained** events
Deposited energy strongly correlated with primary E_ν
Effective area smaller compared to "tracks"

"Angular resolution"



"Effective Volume"



 [arXiv:1612.05621](https://arxiv.org/abs/1612.05621)

Energy Resolution:

- $\Delta E/E \sim 25\%$ for ν_e CC events at $E=10$ GeV
(dominated by intrinsic light yield fluctuations in hadronic shower)
- $\Delta E/E \sim 35\%$ for ν_μ CC events
(outgoing muon often not fully contained)

Physics Studies with Mediterranean ν telescopes

**Supernovae
Explosion**

ν **Oscillations**
 ν **Mass Ordering**

Dark Matter searches
+ Exotic searches

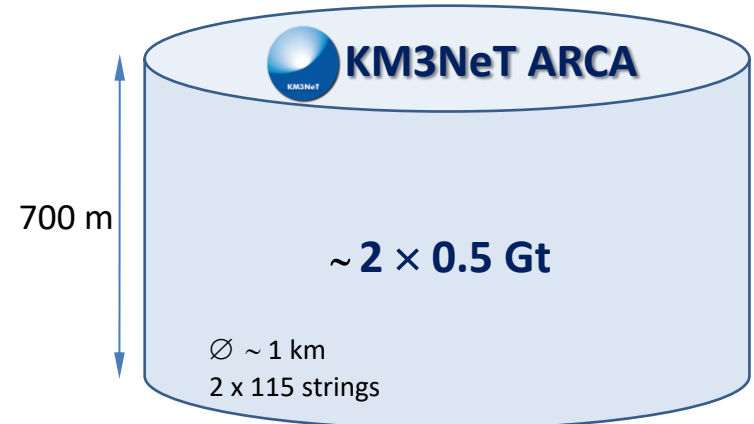
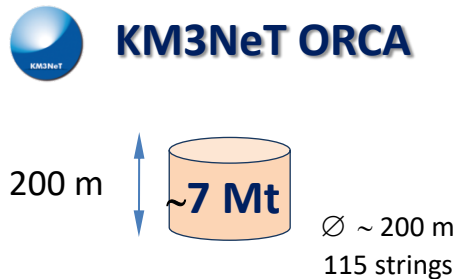
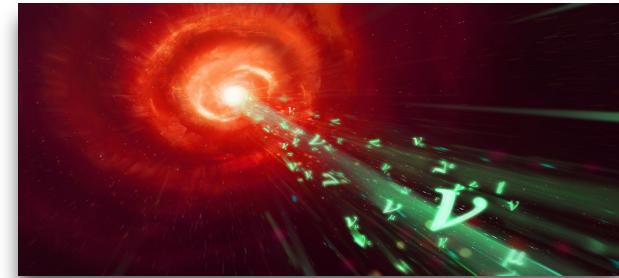
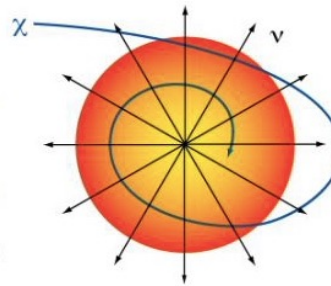
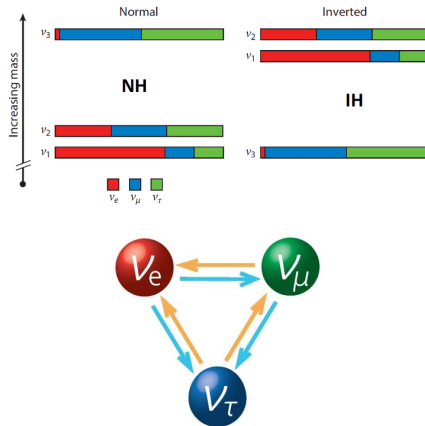
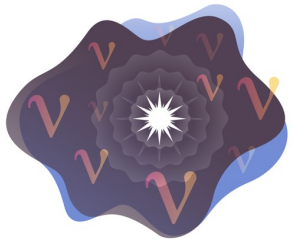
Cosmic neutrinos
Multi-messenger program

MeV

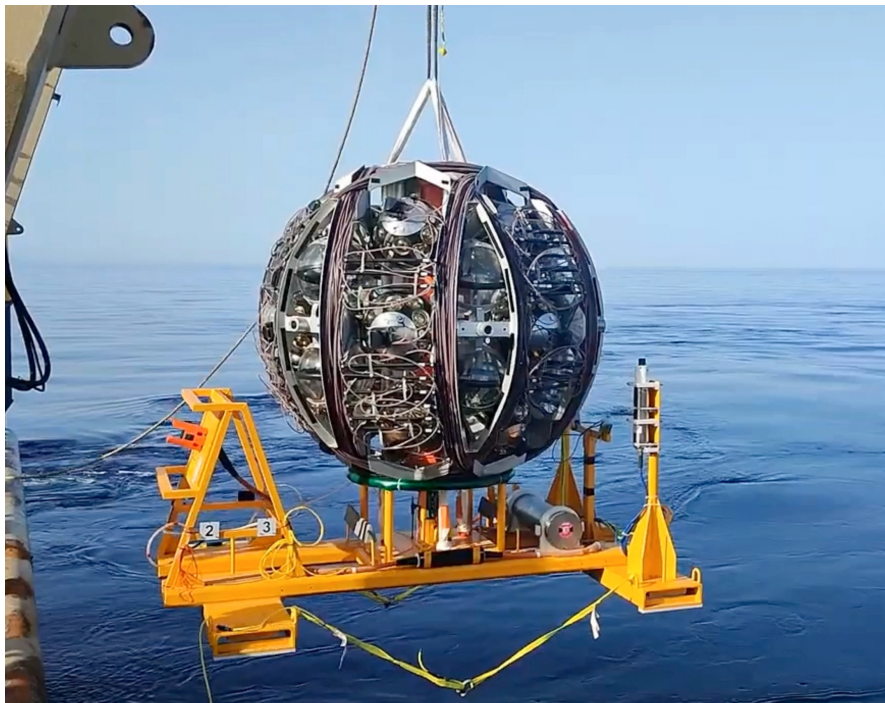
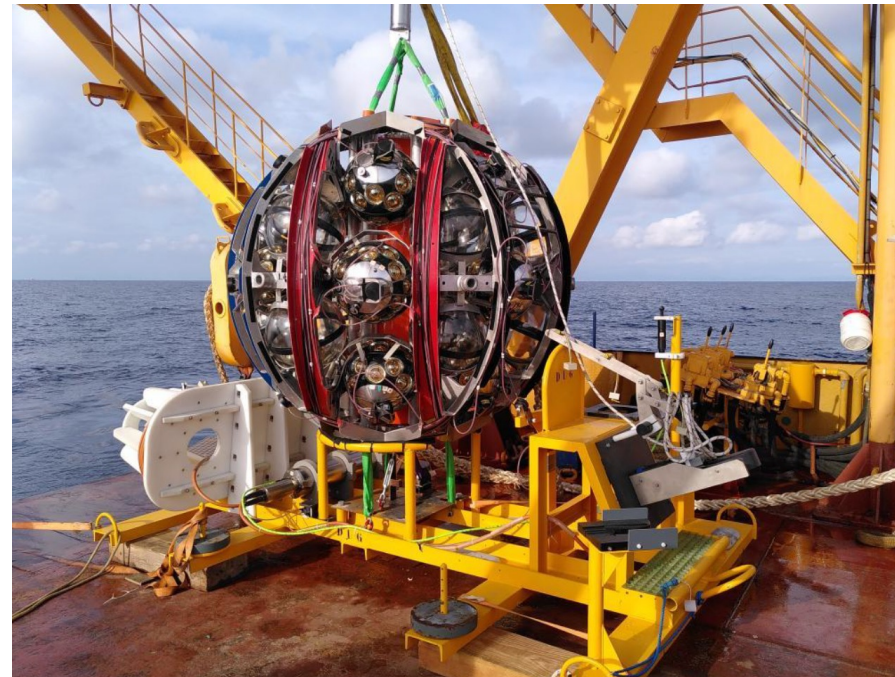
GeV

TeV

PeV



KM3NeT deployment of Detection Units



Deployment using **reusable launcher modules**:

- Deployment via ship crane
- Sink to Sea floor using anchor
- Submarine for inspection + release
- Self-unfurling through buoyancy

→ **Multiple strings per campaign**

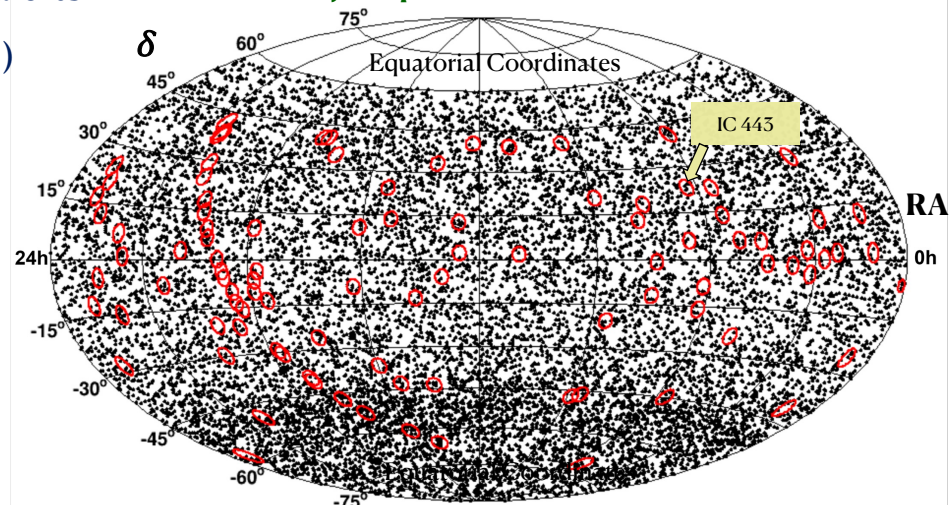
Currently deployed DUs: **21 (ARCA), 18 (ORCA)**

ARCA6+8: cosmic “point” & “extended” sources

Poster 0745, Neutrino2022

- ✓ 300 days of data with KM3NeT/ARCA 6 + ARCA 8 DUs
- ✓ Time integrated point-like search for neutrino excess (spectrum E^{-2})
 - 100 sources selected: ANTARES+IC searches/alerts + Galactic (TeVCat) + Extragalactic AGNs (VLI)
 - Track channel. Binned Likelihood search.
- ✓ **No strong neutrino emission observed.**

Skymap with unblinded data

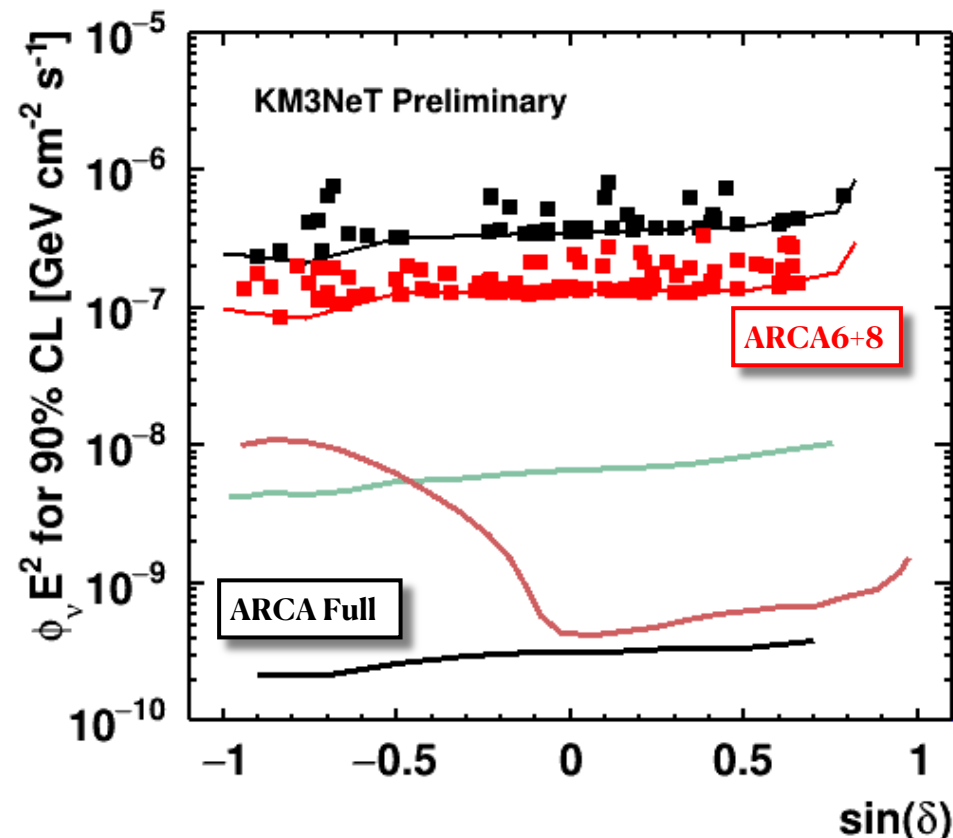


- KM3NeT/ARCA6 (92 days) source limits
- KM3NeT/ARCA6 (92 days) sensitivity
- KM3NeT/ARCA6-8 (~300 days) source limits
- KM3NeT/ARCA6-8 (~300 days) sensitivity
- ANTARES (13yr) sensitivity
- IceCube (7yr) sensitivity
- KM3NeT/ARCA230 (7yr) sensitivity

○ Source from catalogue

Factor ~25 of difference between ARCA & ANTARES expected considering different **lifetime**

IC 443 with smallest p-value (~0.03) but still compatible with background

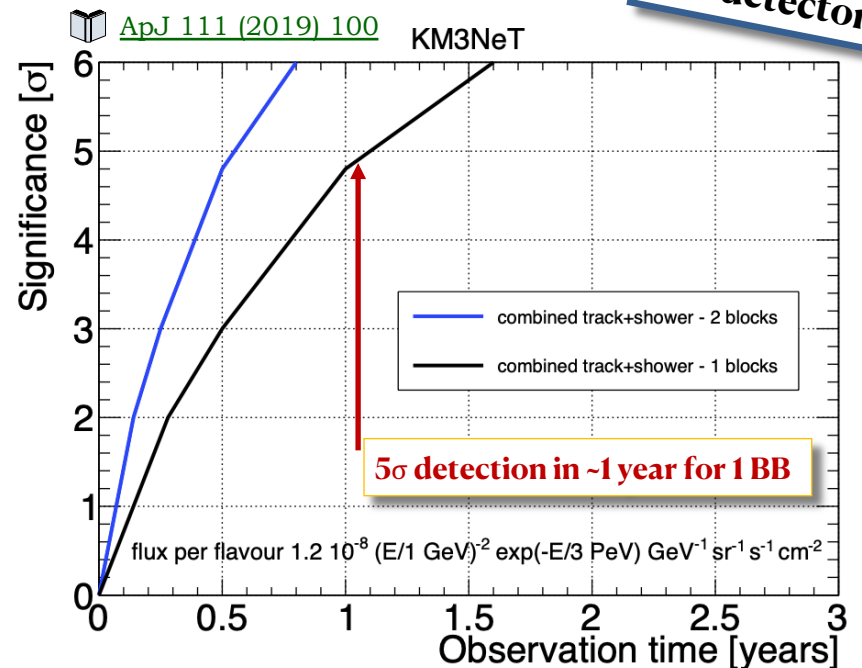
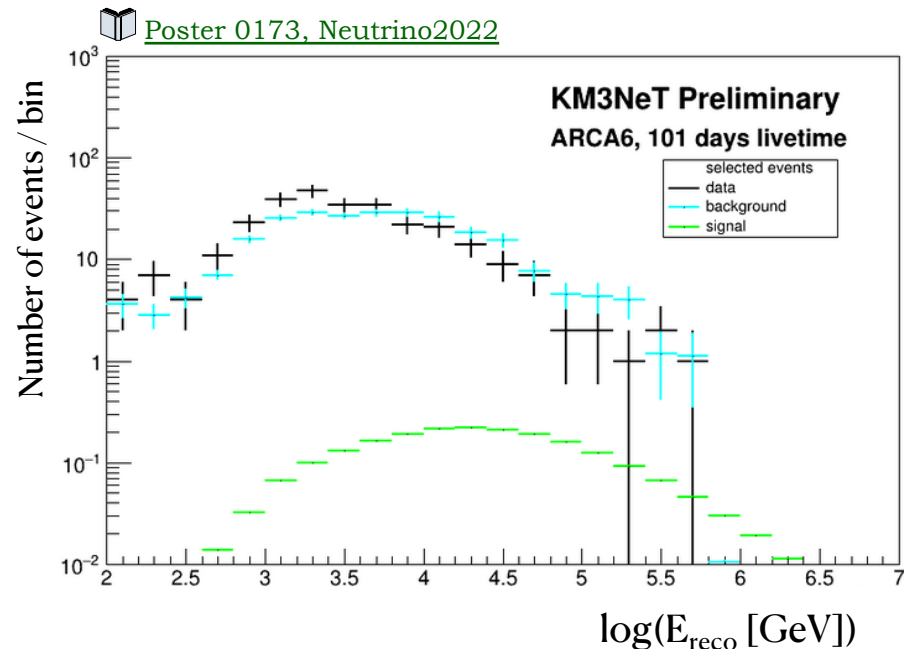


ARCA6: “all sky” emission (diffuse)

- ✓ 101 days of data KM3NeT/ARCA 6 DUs
- ✓ Background: atmospheric muons/neutrinos. Multi-variate (BDT) technique
- ✓ Simulated cosmic neutrino flux:
 - IceCube 10 y ν_μ spectrum (PoS(ICRC2019) 1017) $\phi = 1.44 \times 10^{-18} \left(\frac{E_{\nu_\mu}}{100 \text{ TeV}} \right)^{-2.28} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$
- ✓ **Obtained sensitivity:** Factor 12 more than the simulated signal flux

$$\phi_{90\%, \text{CL}} = 17.3 \times 10^{-18} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$$

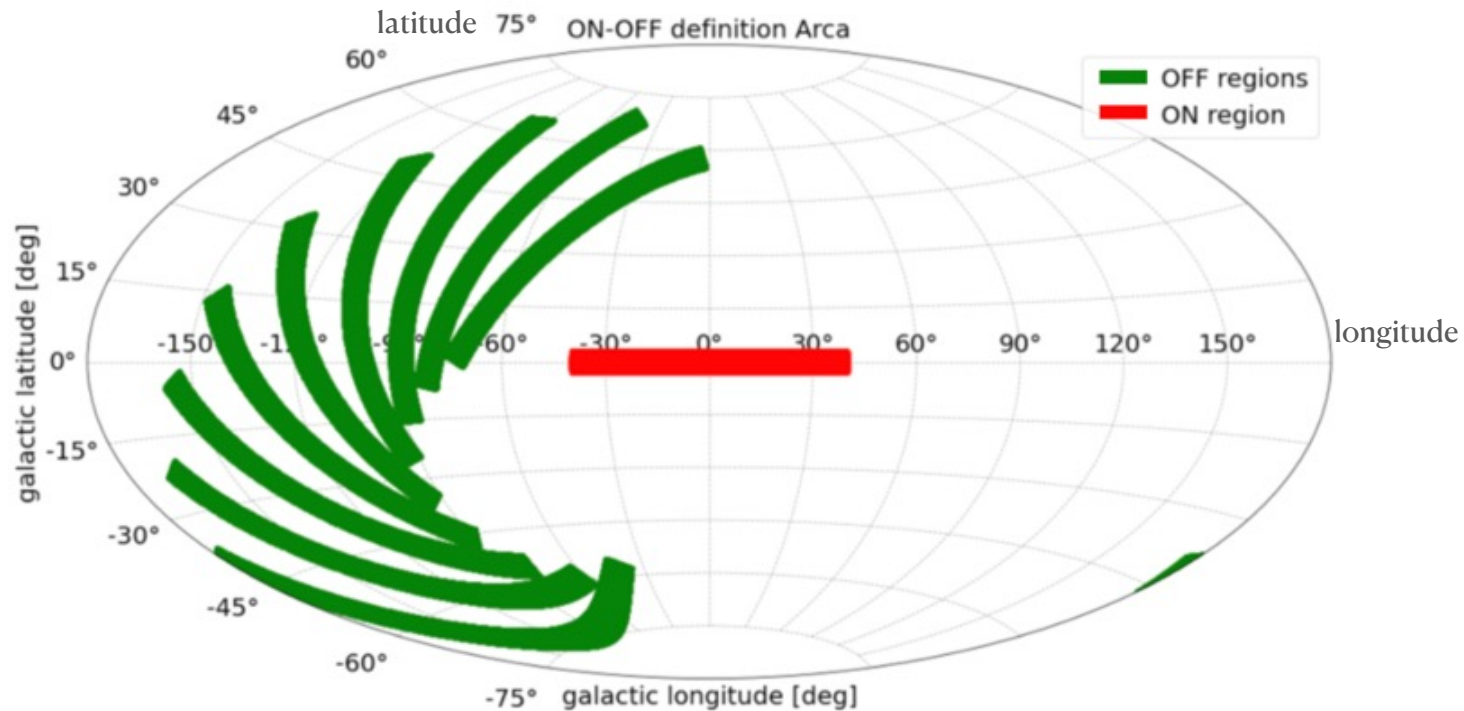
Full detector



ARCA6: “Galactic ridge” emission (diffuse)

 [Poster 0173, Neutrino2022](#)

- ✓ **101 days of data** KM3NeT/ARCA 6 DUs
- ✓ Simulated signal spectrum $\propto E^{-2.4}$: $\phi = 1.2 \times 10^{-8} \left(\frac{E}{\text{GeV}} \right)^{-2.4} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$
- ✓ **1 ON region**: Galactic Ridge, $|L_{\text{gal}}| < 40^\circ$, $|B_{\text{gal}}| < 3^\circ$
- ✓ **9 OFF regions**: shift in time of the **ON region**, avoiding the Fermi bubbles



No statistically significant excess found

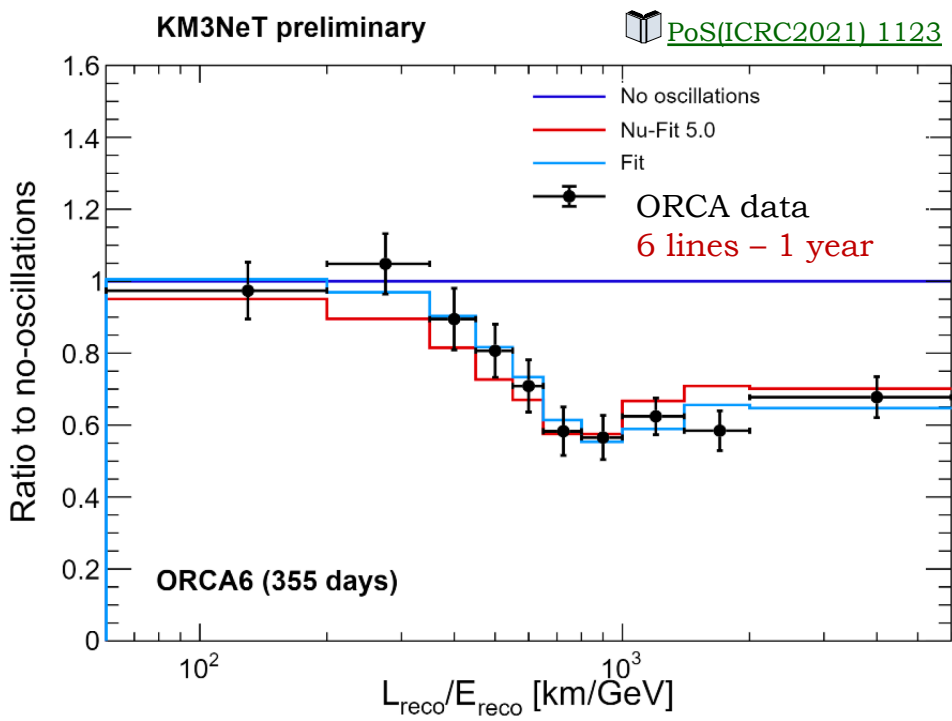
Upper limit : $6.2 \times 10^{-4} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$

ORCA6 : 1 year, neutrino oscillation results

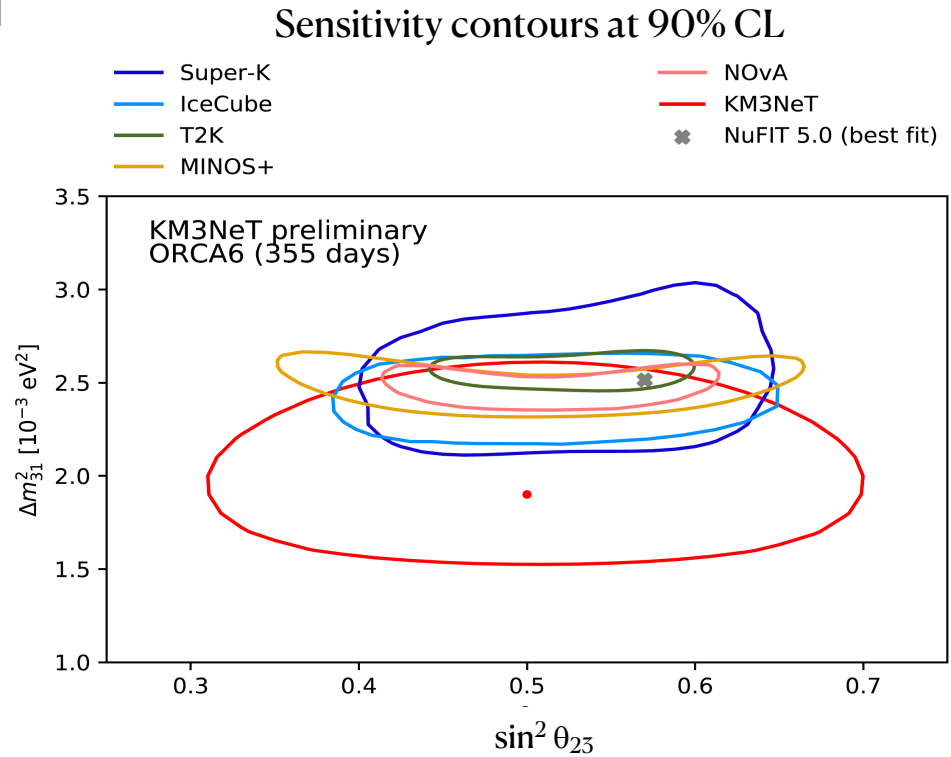


Atmospheric neutrinos traversing the Earth: sensitive to Δm_{31}^2 and θ_{23}

- ✓ **Clear effect of oscillations observed**
- ✓ First measurements of oscillation parameters: KM3NeT already in the game



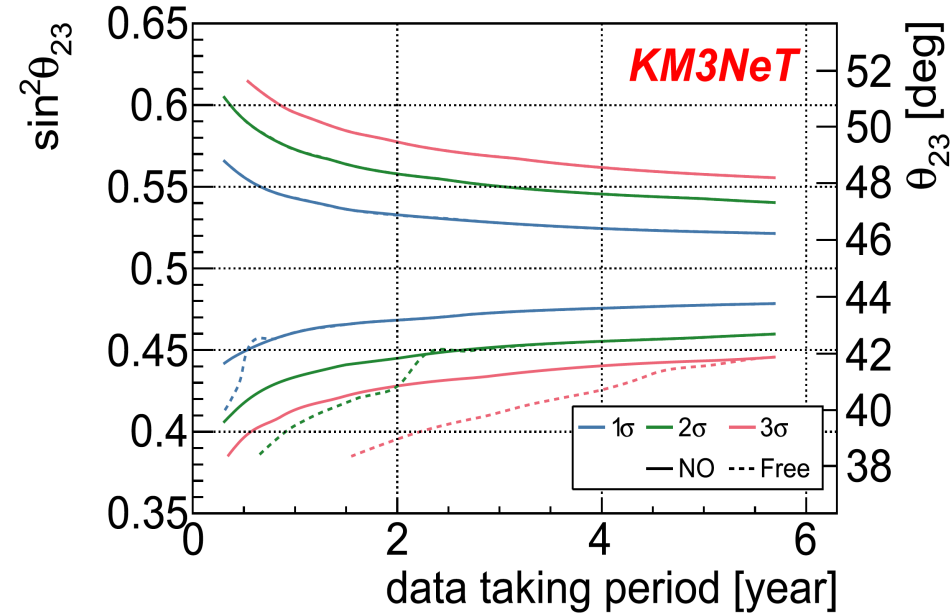
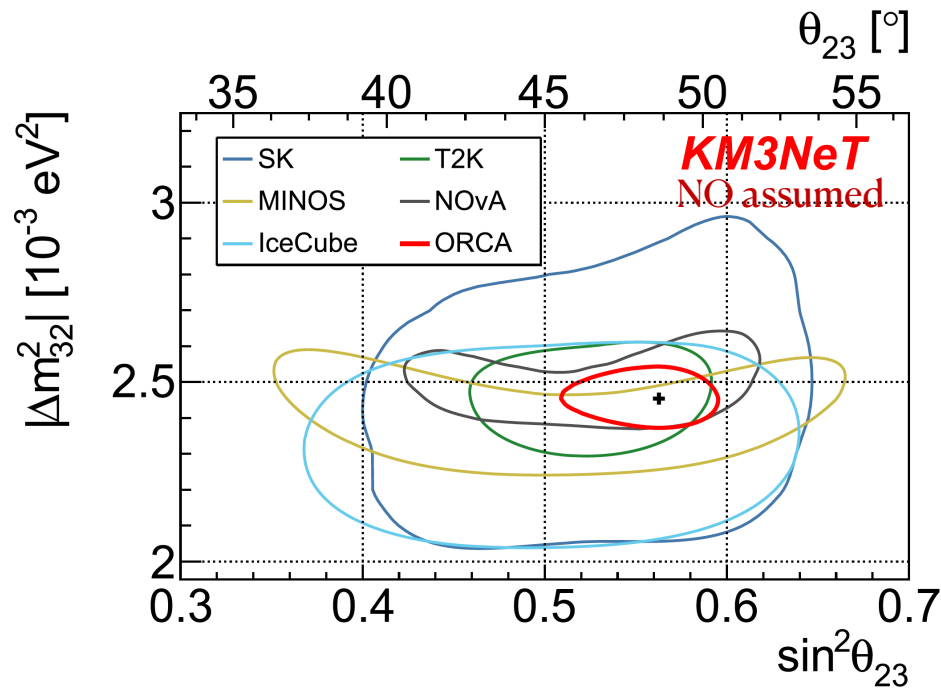
oscillations preferred with 5.9σ CL over "no oscillations"



Full detector

Full ORCA, 3 years

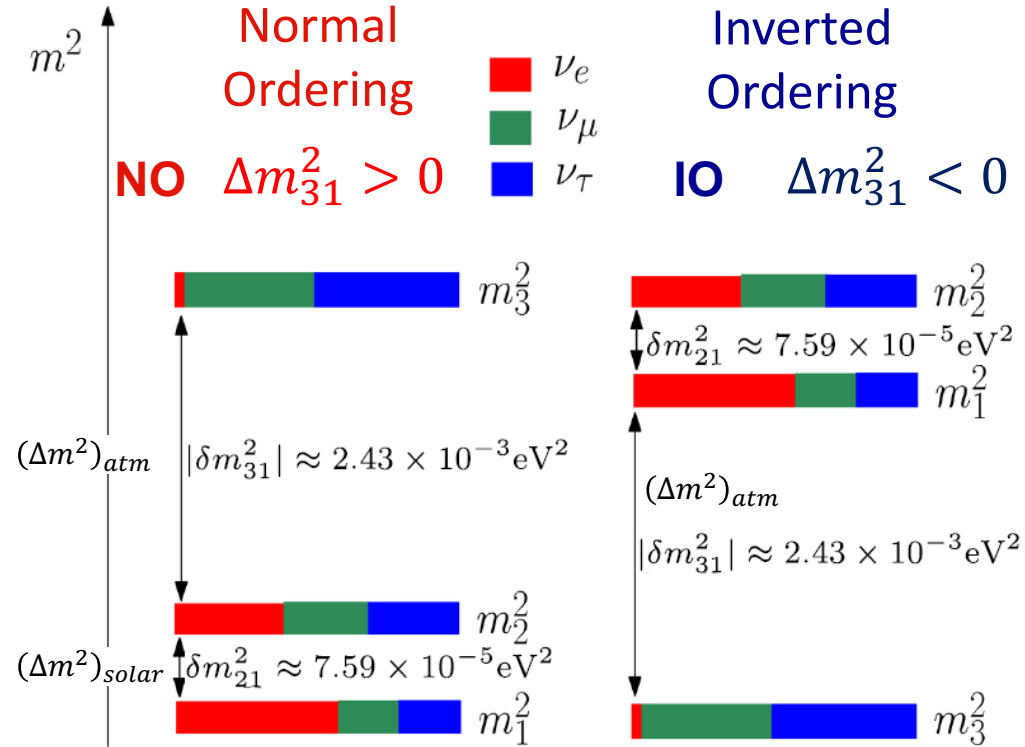
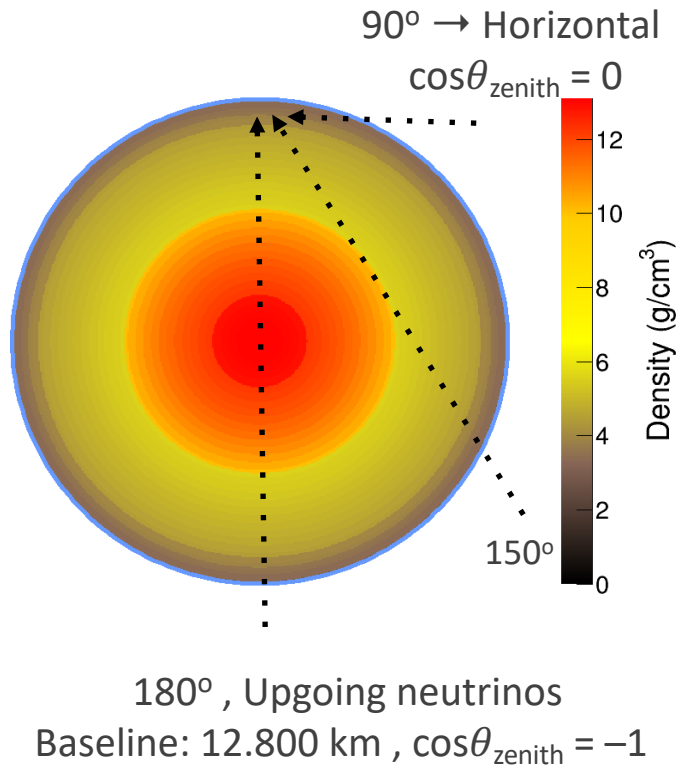
90% CL interval for Δm_{32}^2 and θ_{23}



Significant to determine Octant θ_{23} :

- NMO known (solid) / not known (dashed)
- Constrain octant in **6 years** with better than **95% CL** for $|\sin^2 \theta_{23} - 0.5| < 0.05$

ORCA: ν Oscillation properties & Mass Ordering



“matter effects” are sensitive to the Sign of Δm_{31}^2 in the oscillation patterns

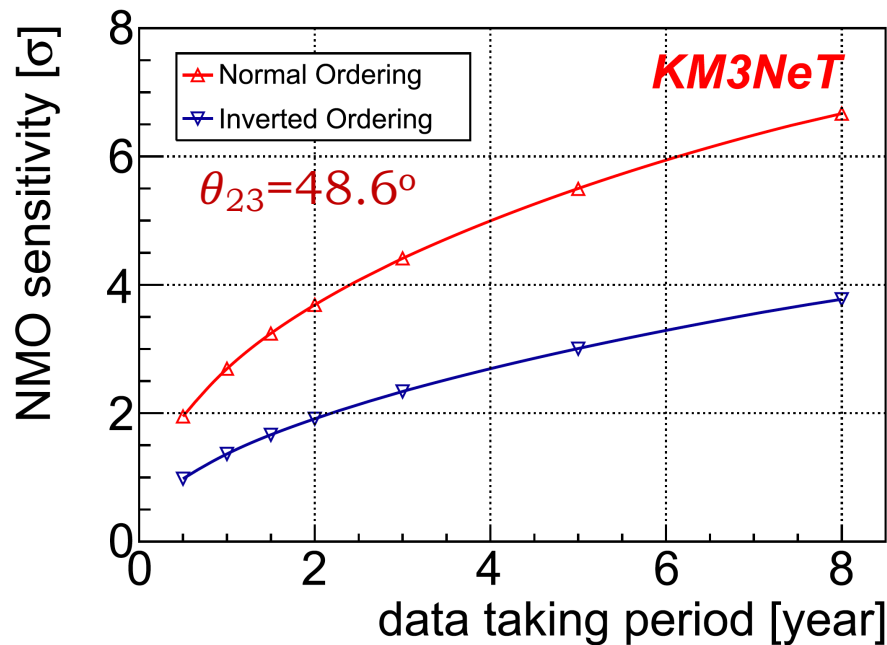
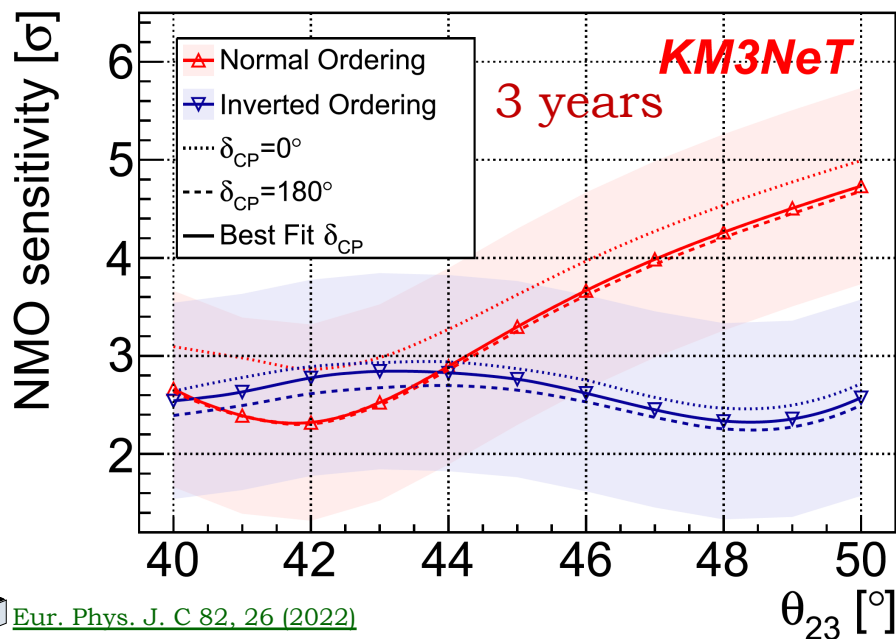
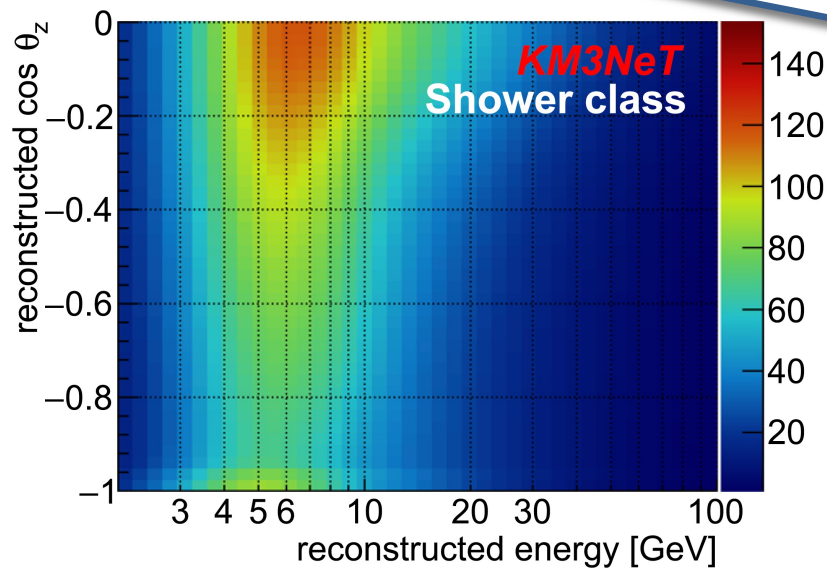
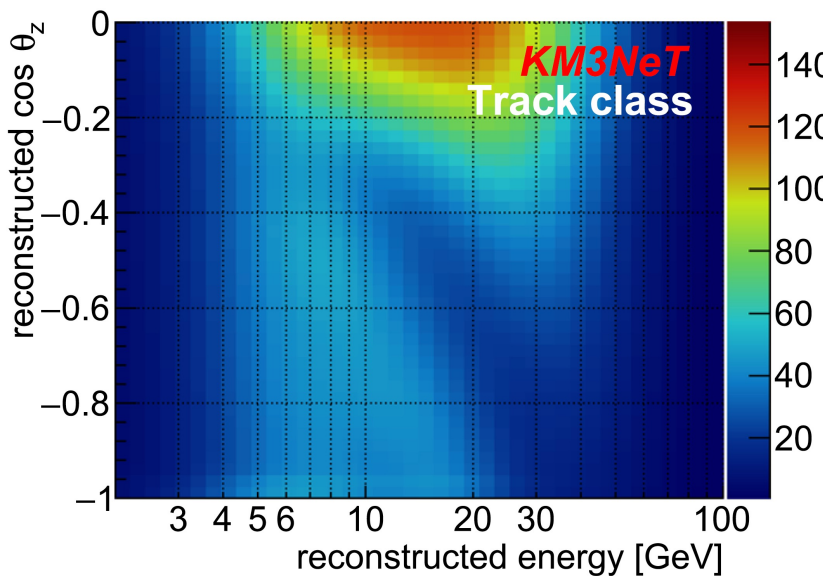
- ✓ NO (ν_e appear. \uparrow) \equiv IO (anti- ν_e appear. \uparrow)
- ✓ $E_{\text{res}} \sim 7 \text{ GeV}$ (3 GeV) in Mantle (Core)

$$\sigma_\nu \sim 2 \sigma_{\text{anti-}\nu}$$

$$\phi_\nu \sim 1.1 \phi_{\text{anti-}\nu}$$

NMO affects **oscillograms** : $(\cos\theta - E_{\text{reco}})$ plots

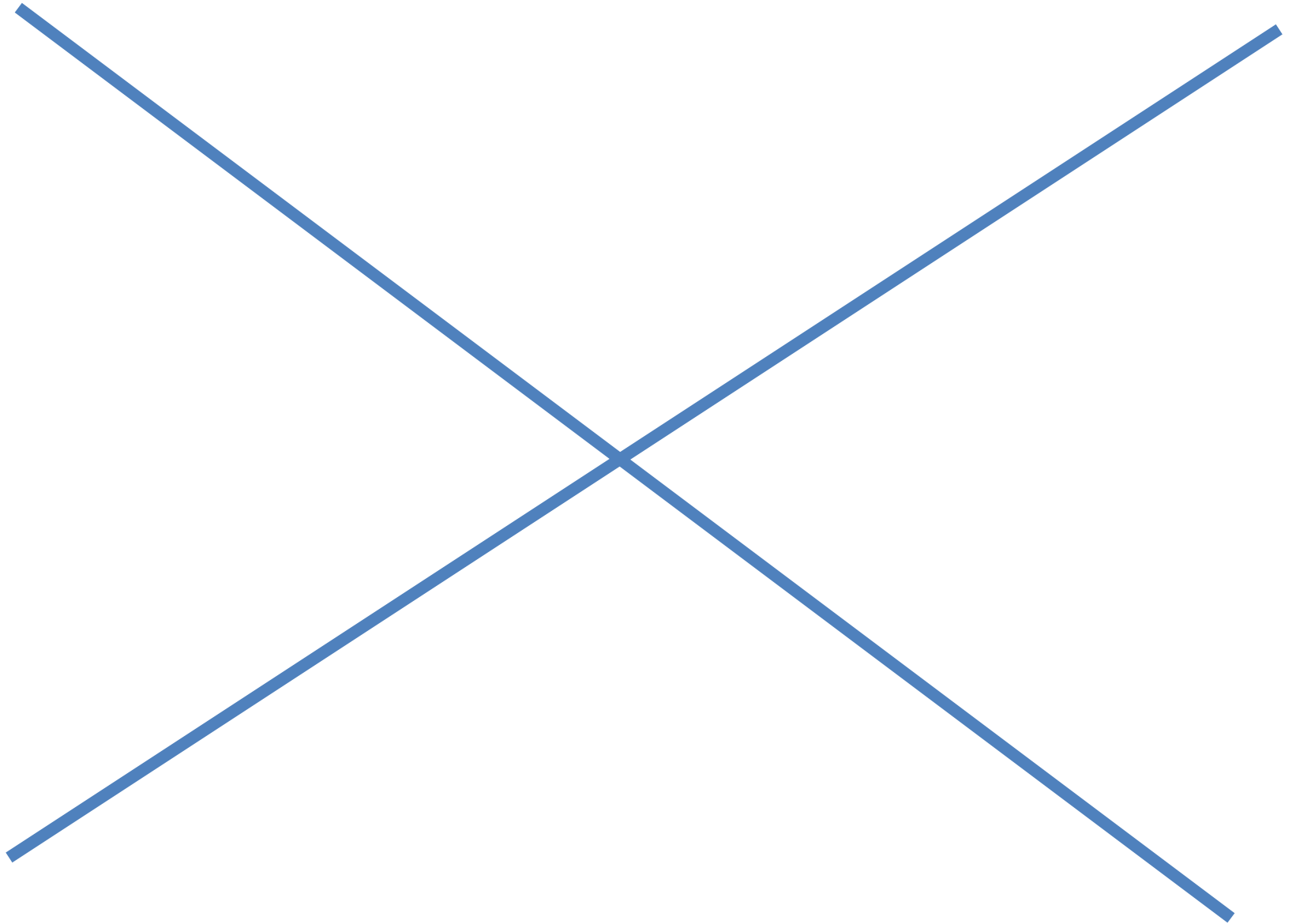
ORCA: Neutrino Mass Ordering



- ✓ KM3NeT is a next generation neutrino telescope under construction in the Mediterranean Sea : ORCA (Toulon, France) + ARCA(Capo Passero, Italy)
- ✓ Spanning 8 decades in energy: **oscillations** (ORCA) & **astronomy** (ARCA)
- ✓ To date, **21 ARCA DUs + 18 ORCA DUs have been deployed**
- ✓ Detector performance as good as expected
- ✓ **First science preliminary results from 8 ARCA + 6 ORCA DUs**
- ✓ **Broad Science Program** : competitive results thanks to excellent performance
- ✓ **Real-time multimessenger analysis framework** in progress and already operative
- ✓ **Construction ramping up on the way to the full detector!**



Backup



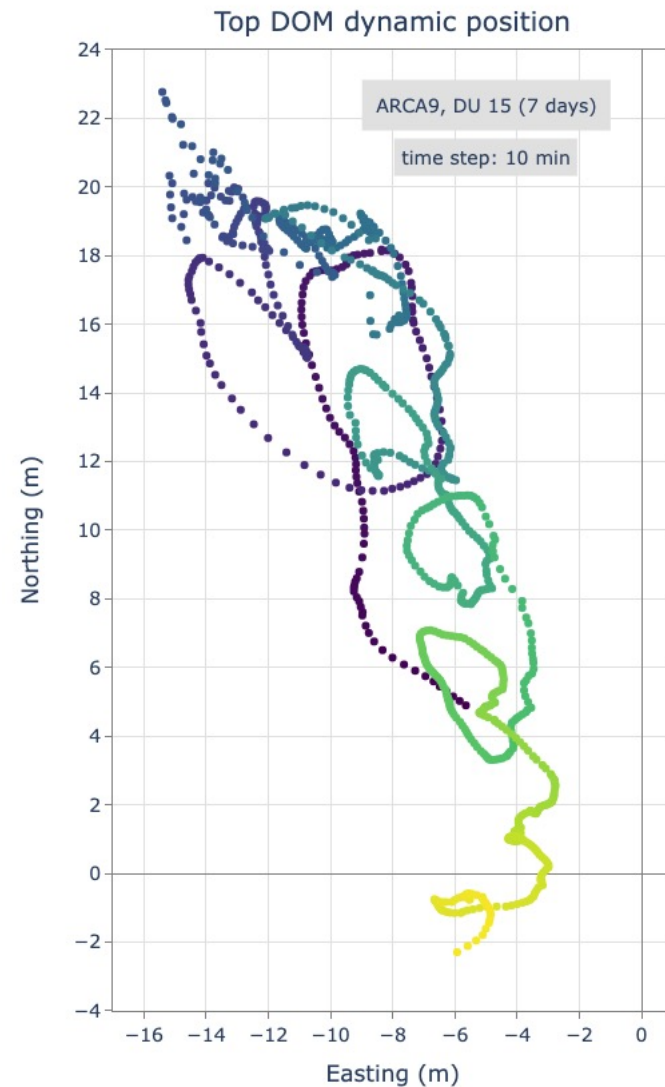
POSITION :

- **Tilt** and **heading** in each DOM :
- Deviation from vertical position due to **sea currents**
- **acoustic positioning** system
- precision down to around **10 cm**

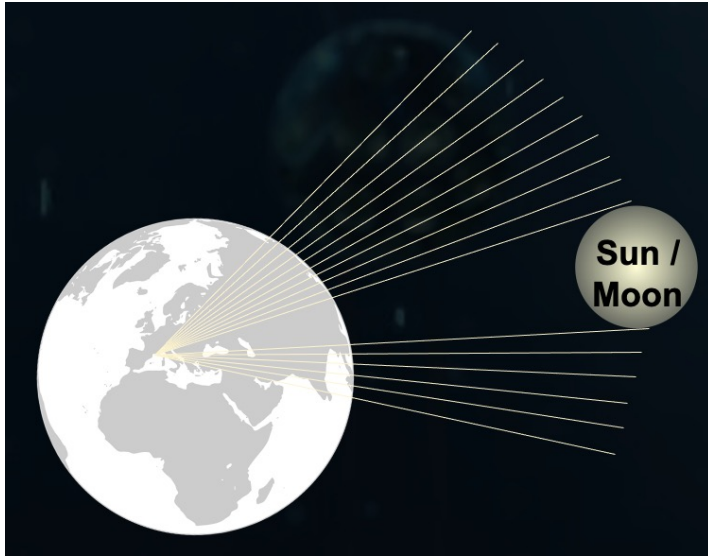
TIMING : arXiv:2111.00223

- LED pulsers (nanobeacon) for inter-DOM calib.
- **< 1ns precision** for relative timing **between DOMs**
- individual control for each DOM, each DU base and slow control for the junction boxes at the seabed

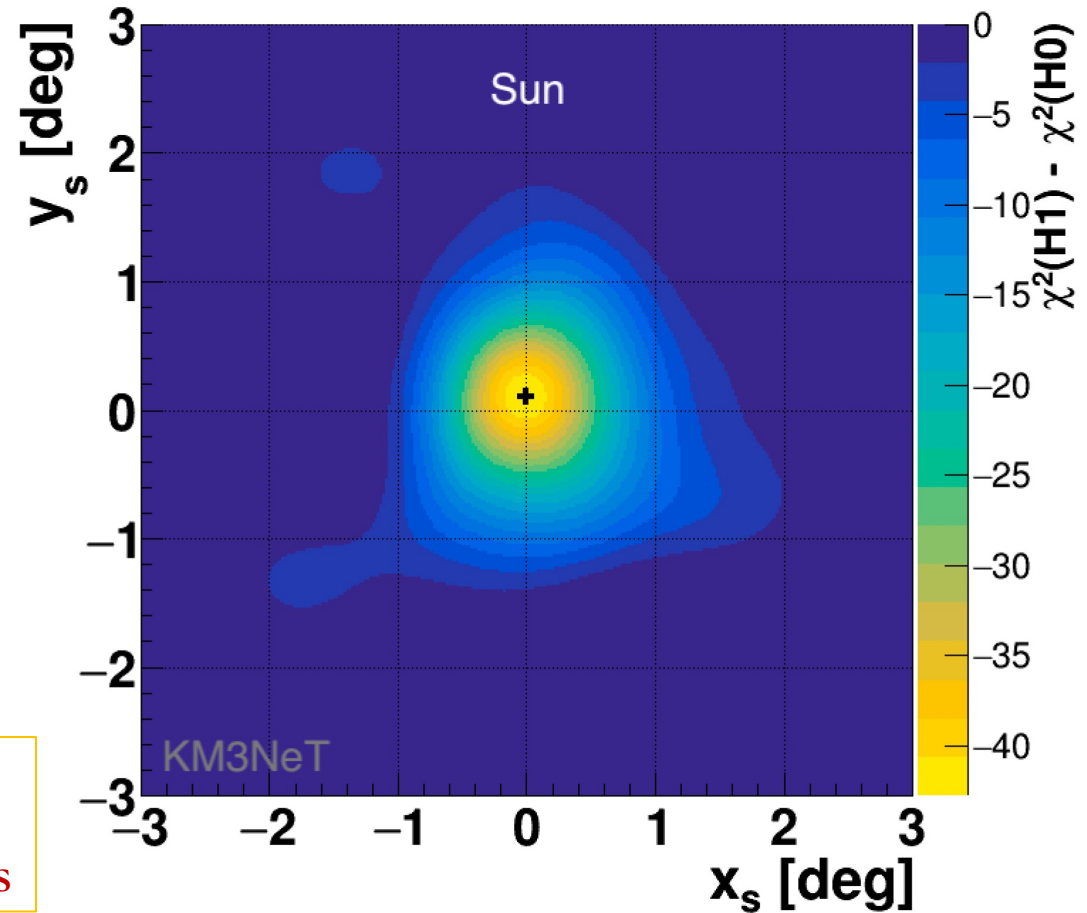
... results in **< 0.1° precision** for neutrino direction



ORCA6 Performance: pointing resolution



→ Deficit of the atmospheric muon flux from the direction of the Moon & Sun induced by the absorption of cosmic rays



ORCA6 (500 days) arXiv: 2211.08977	Sun	Moon
Statistical Significance	6.2 σ	4.2 σ
Resolution	0.65° ± 0.13°	0.49° ± 0.15°

KM3NeT : Core Collapse Supernovae



Supernova MeV neutrinos → collective excess of multi-fold coincidences on all DOMs Real Time monitoring activity

A trigger + Real Time Alert System for CCSN already implemented within SNEWS since 2019

EPJ C81 (2021) 445

