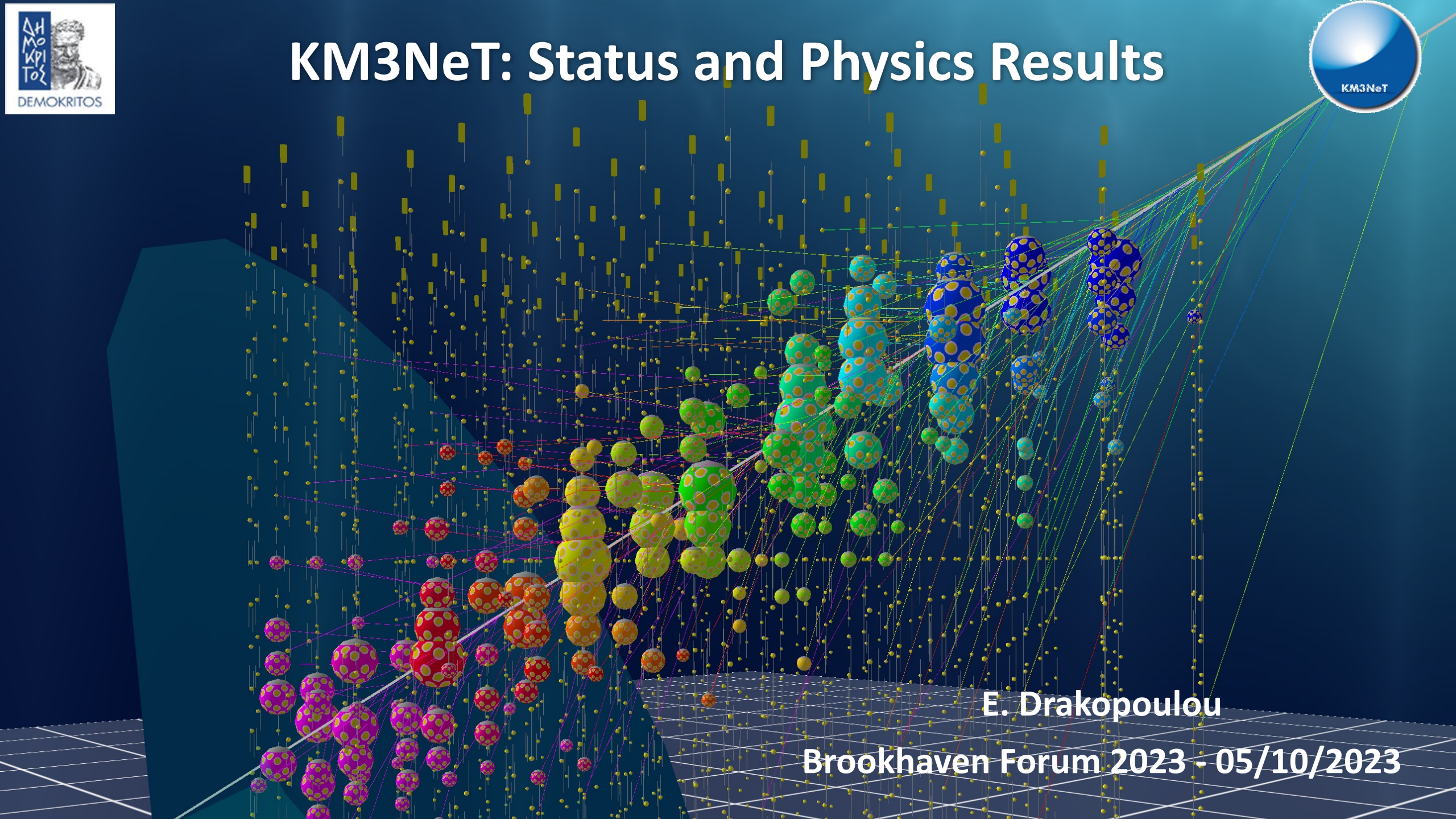
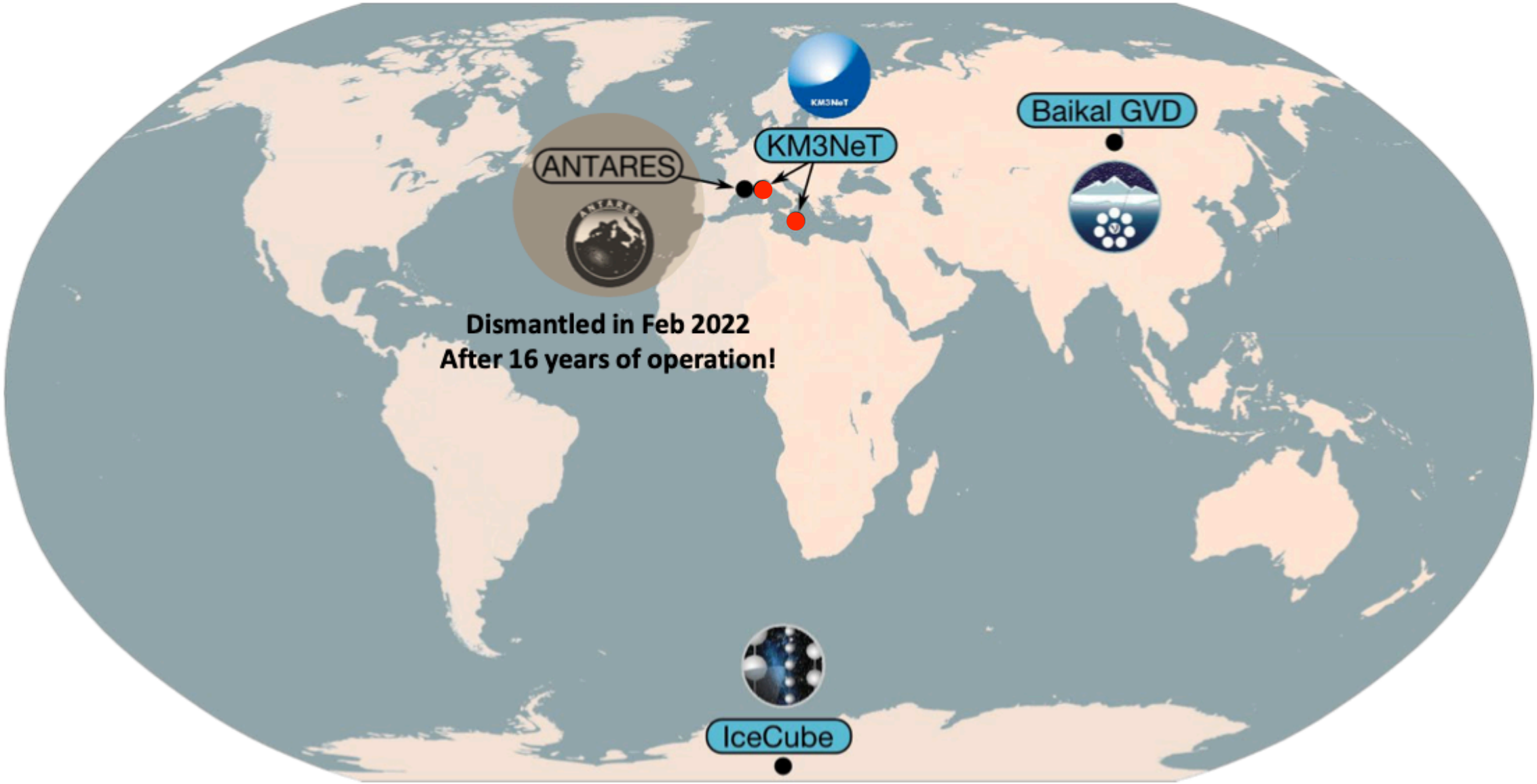
KM3NeT: Status and Physics Results



E. Drakopoulou

Brookhaven Forum 2023 - 05/10/2023

Global Neutrino Network (GNN)



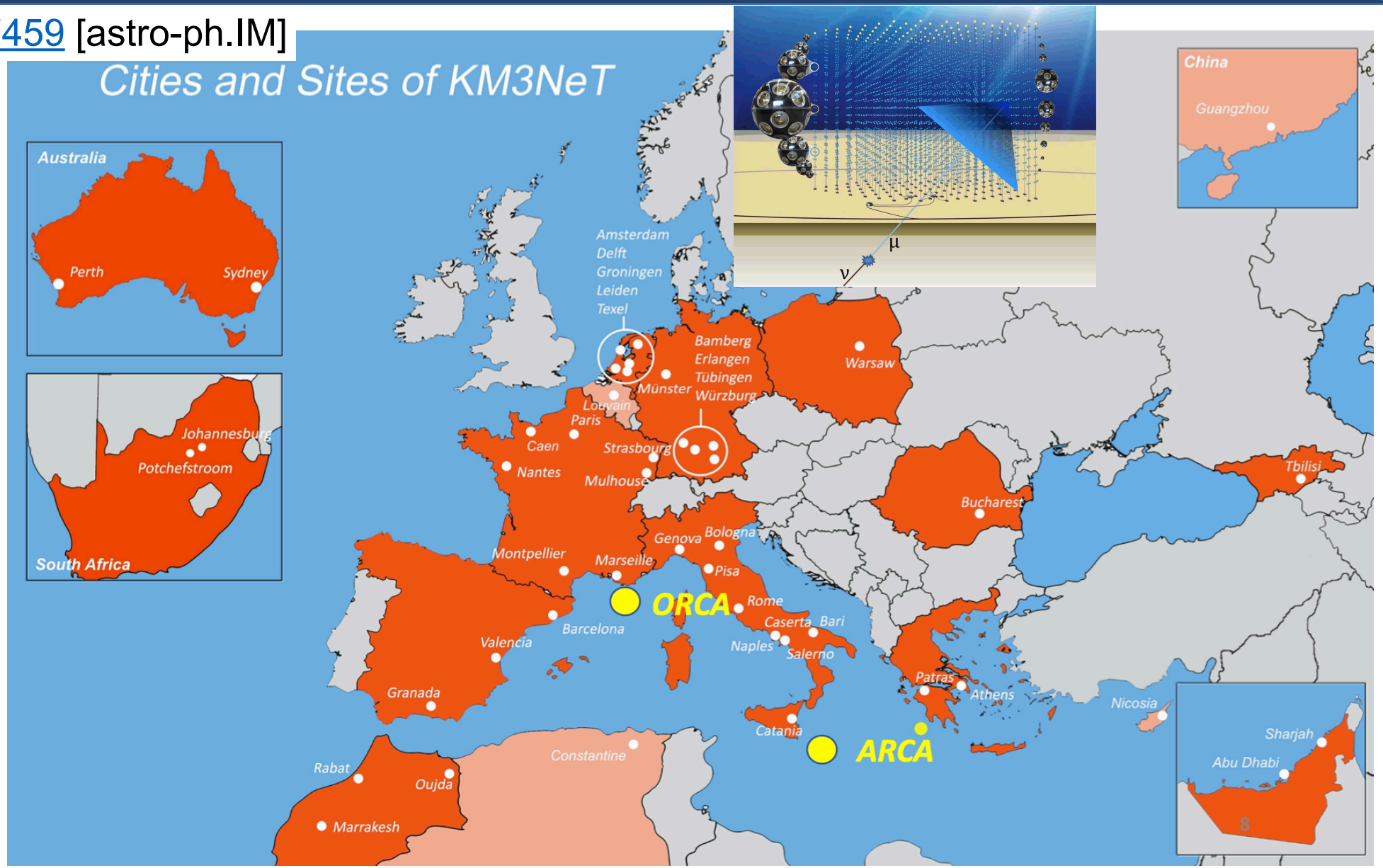
The KM3NeT collaboration

LoI: arXiv:1601.07459 [astro-ph.IM]

Numbers:

- 57 groups
- 21 countries
- 4 continents
- 2 detectors

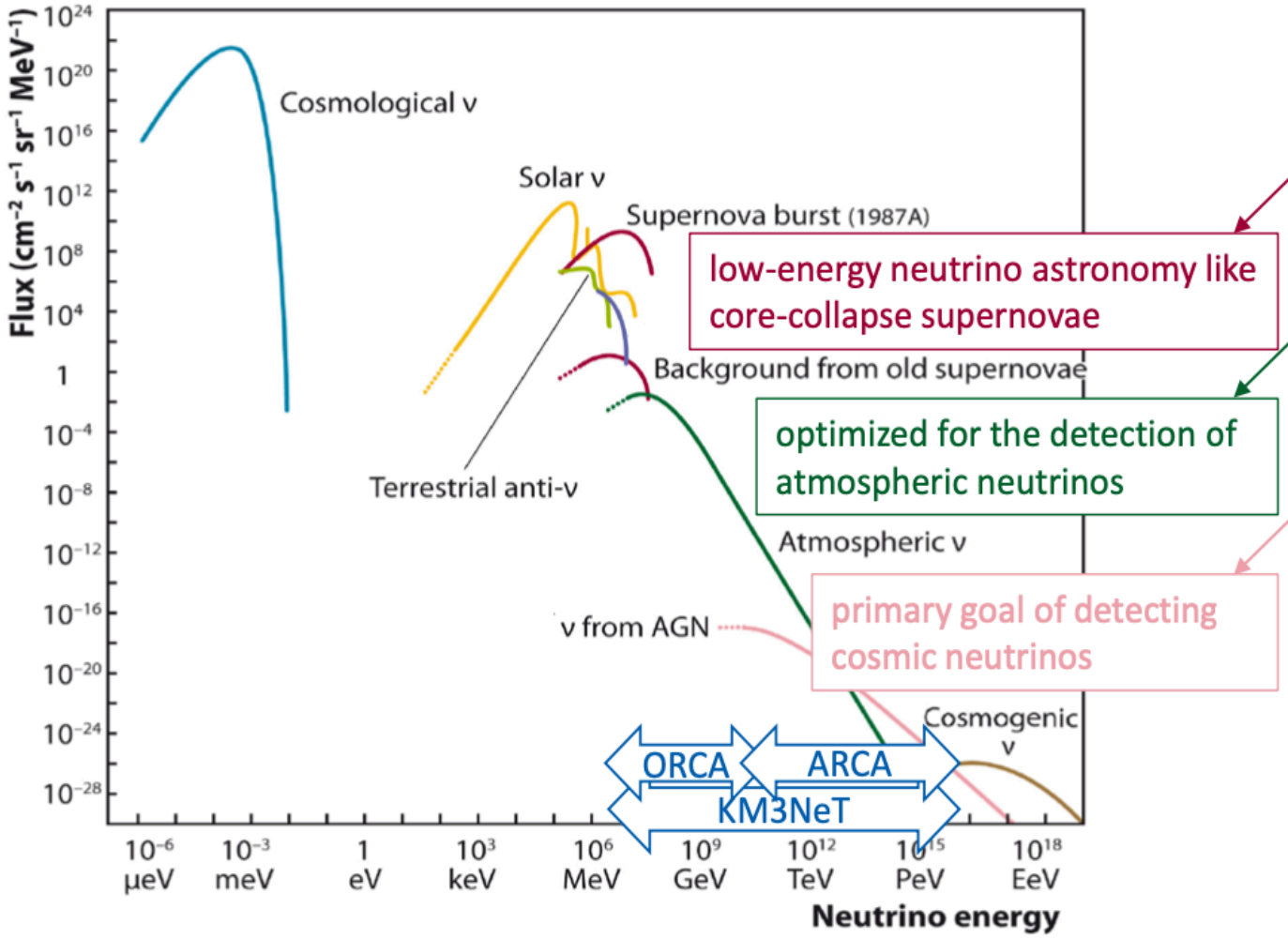
  ORCA/ARCA



Legend:

- group
- observer
- member

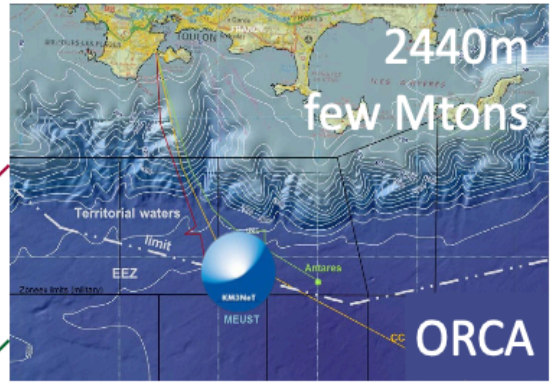
Neutrino Sources



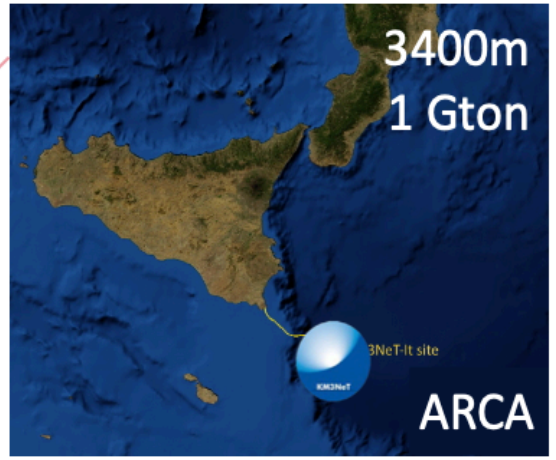
low-energy neutrino astronomy like core-collapse supernovae

optimized for the detection of atmospheric neutrinos

primary goal of detecting cosmic neutrinos



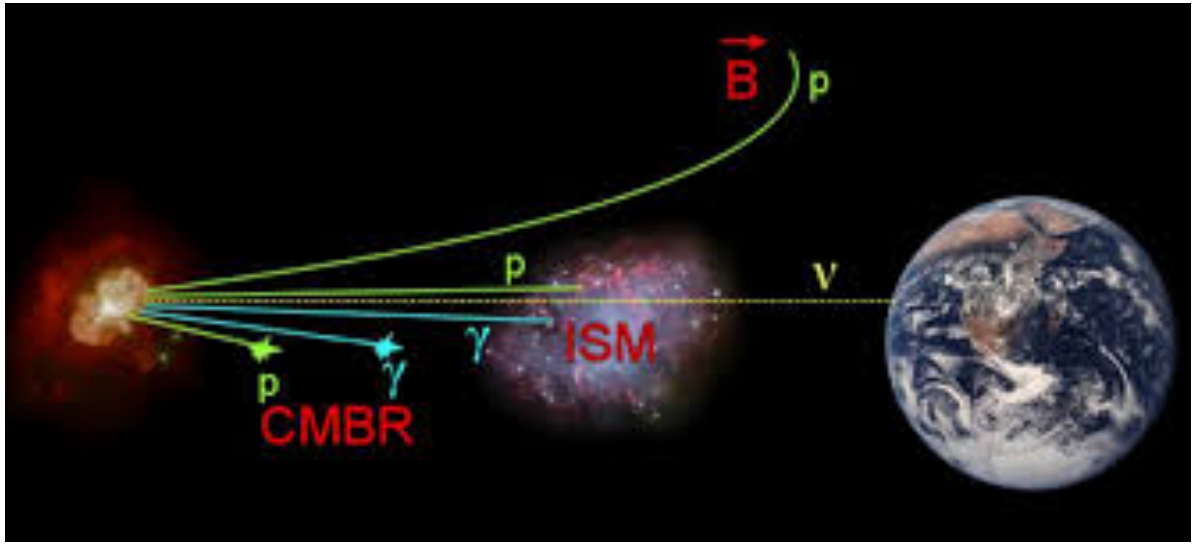
KM3NeT/ORCA
***O**scillation **R**esearch with **C**osmics In the **A**byss*



KM3NeT/ARCA
***A**stroparticle **R**esearch with **C**osmics In the **A**byss*

Position in the Northern Hemisphere: optimal view of the Southern sky, including the Galactic Center

Scientific Motivation- ARCA: Neutrino Astronomy

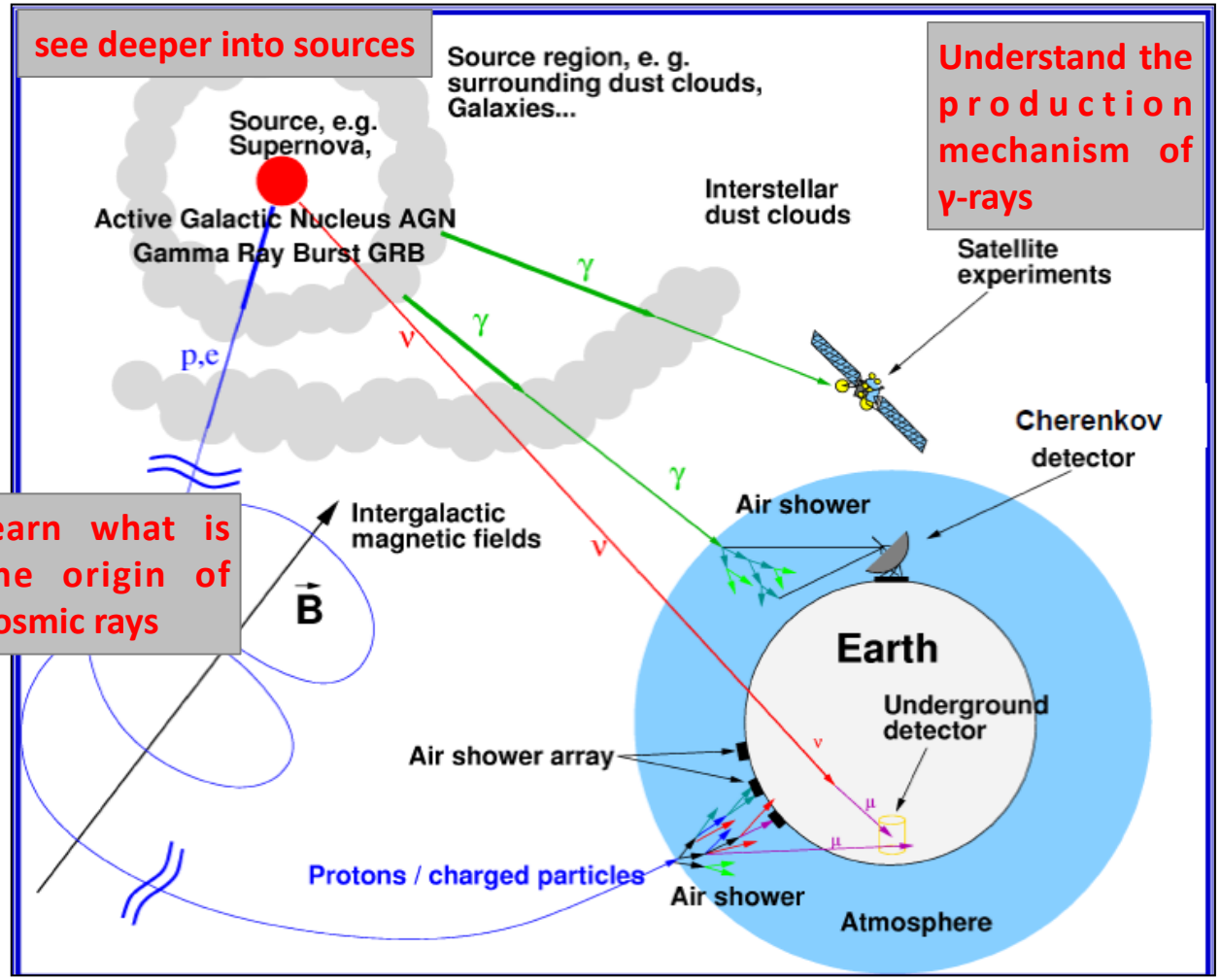


Neutrinos: straight trajectories, practically no absorption.

Sources: powerful cosmic hadronic accelerators

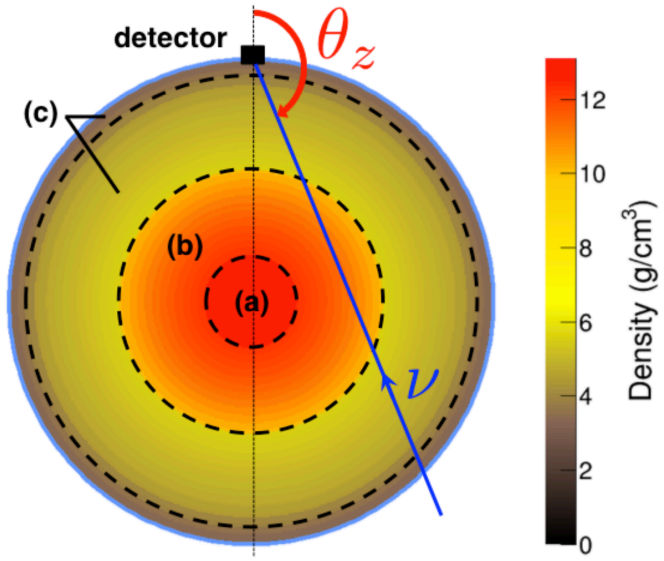
KM3NeT/ARCA: Exploring the High Energy Universe

- ➢ observe high energy (>TeV energy regime) neutrinos from astrophysical sources
- ➢ measure the diffuse flux of astrophysical neutrinos



Multi-messenger astronomy combine ν, γ-rays, other EM waves, gravitational waves, charged cosmic rays

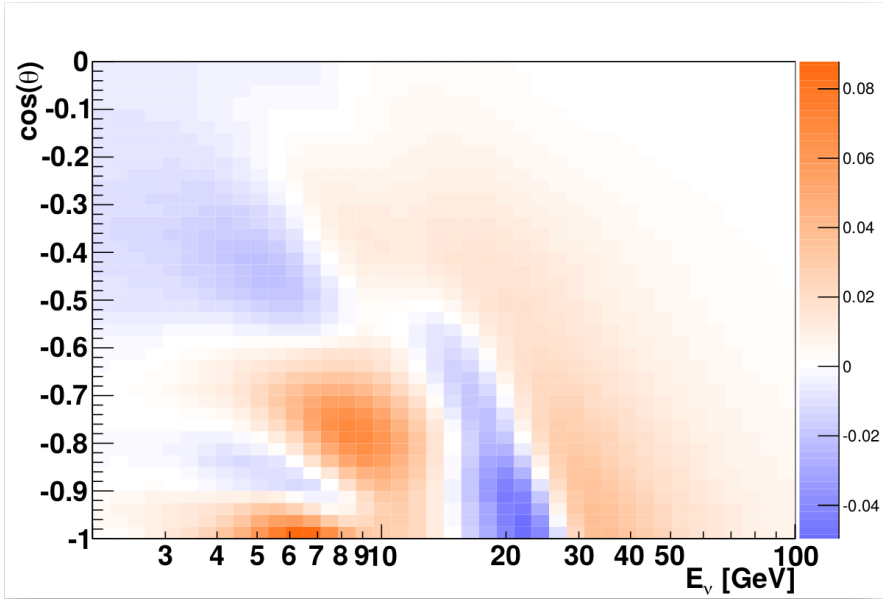
Scientific Motivation- ORCA: Neutrino Astronomy



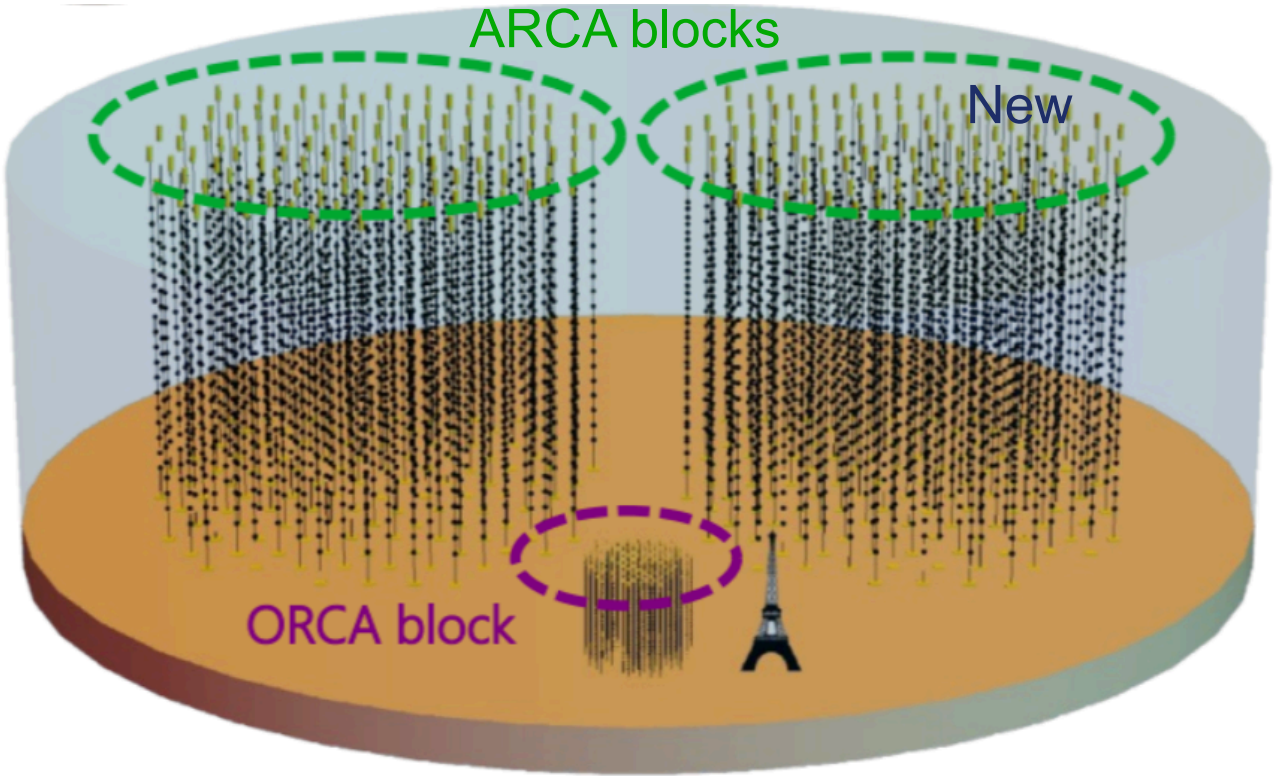
- Neutrino properties through oscillation studies
  - neutrino mass hierarchy
  - measure atm. mixing parameters
  - New physics (sterile neutrinos, NSI & other)
- Characteristic patterns of neutrino appearance/ disappearance at different energies/path length

KM3NeT/ORCA: Determine the neutrino mass ordering

- ➢ study atmospheric neutrino (~ few GeV energy regime) oscillations
- ➢ Oscillation pattern distorted by Earth matter effects. Allows for determination of mass ordering because of different behaviour of neutrinos/antineutrinos.
- ➢ KM3NeT: no event-by-event $\nu/\bar{\nu}$ separation, but differences in flux/kinematics/cross-section.



The KM3NeT Detectors

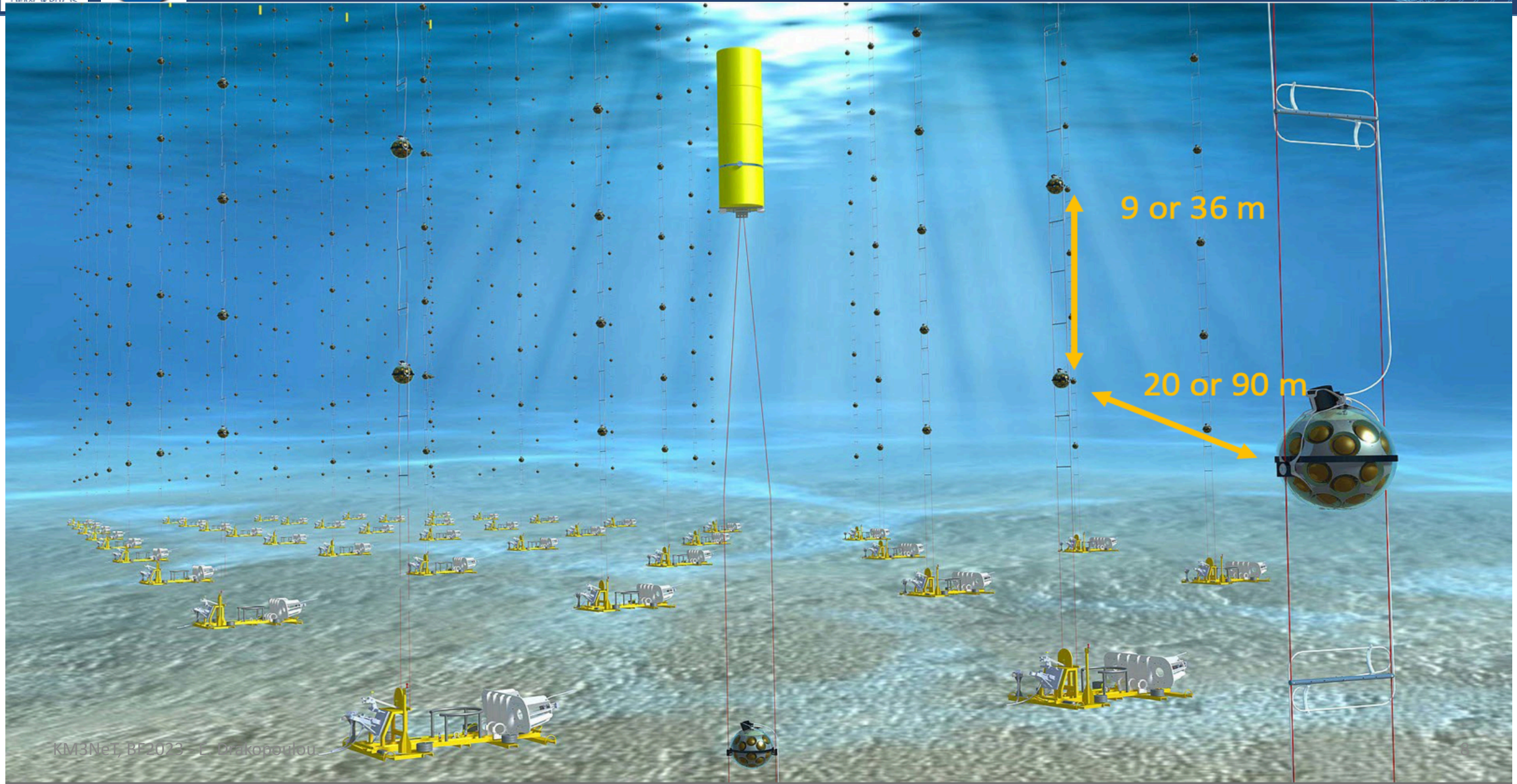


ARCA ✓ **Currently 28 DUs deployed**

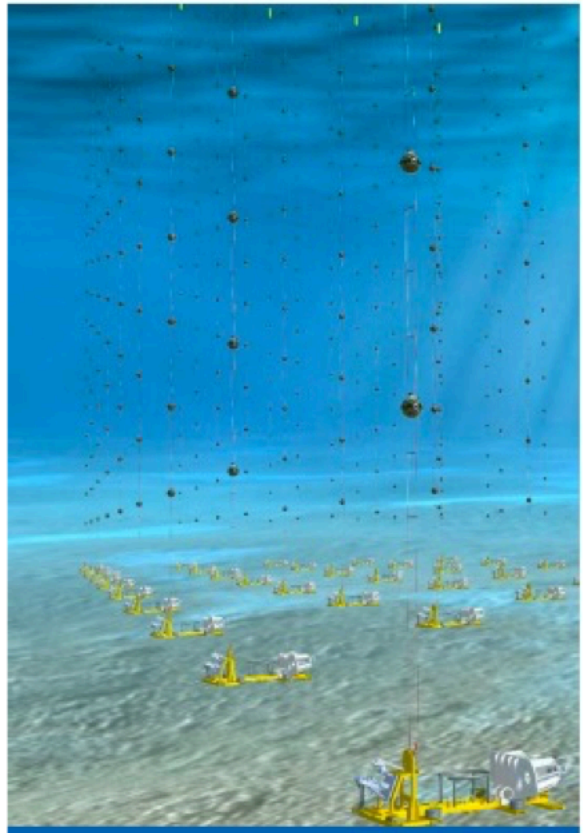
ORCA ✓ **Currently 18 DUs deployed**

	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	18

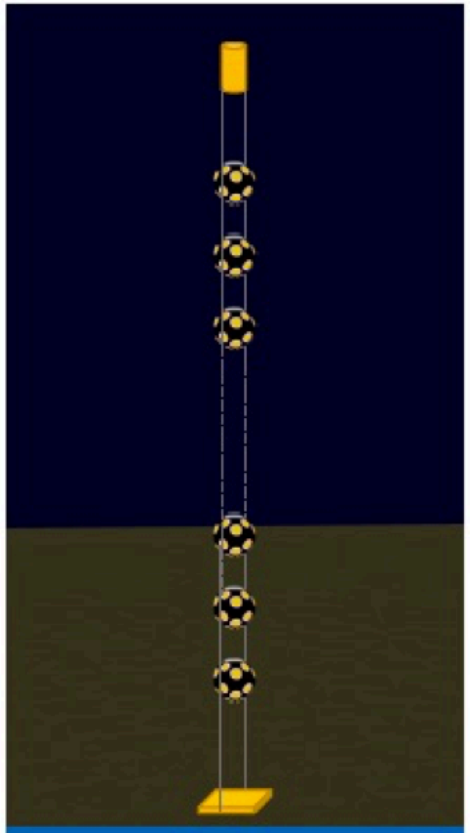
The KM3NeT Detectors



KM3NeT Components



1 building block =
115 lines



1 line =
18 optical modules

1 optical module =
31 photomultiplier tubes

71 unique components
(in solid or liquid phase)

Rasa Muller

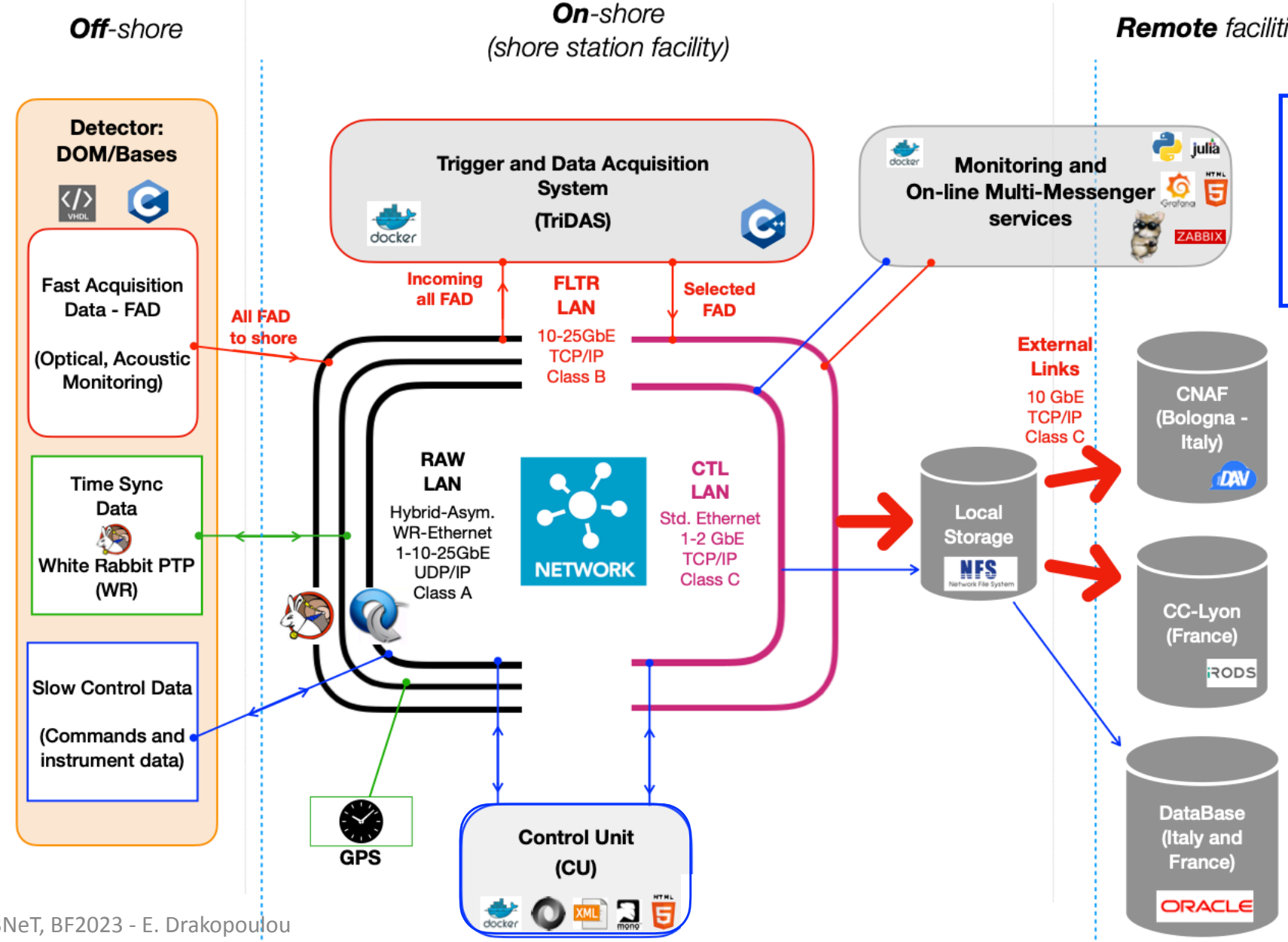
"detection unit (DU)"

"digital optical module (DOM)"
31 3'' photomultiplier tubes

JINST 17 (2022) 07, P07038

Identical for ARCA and ORCA

Data Acquisition in KM3NeT



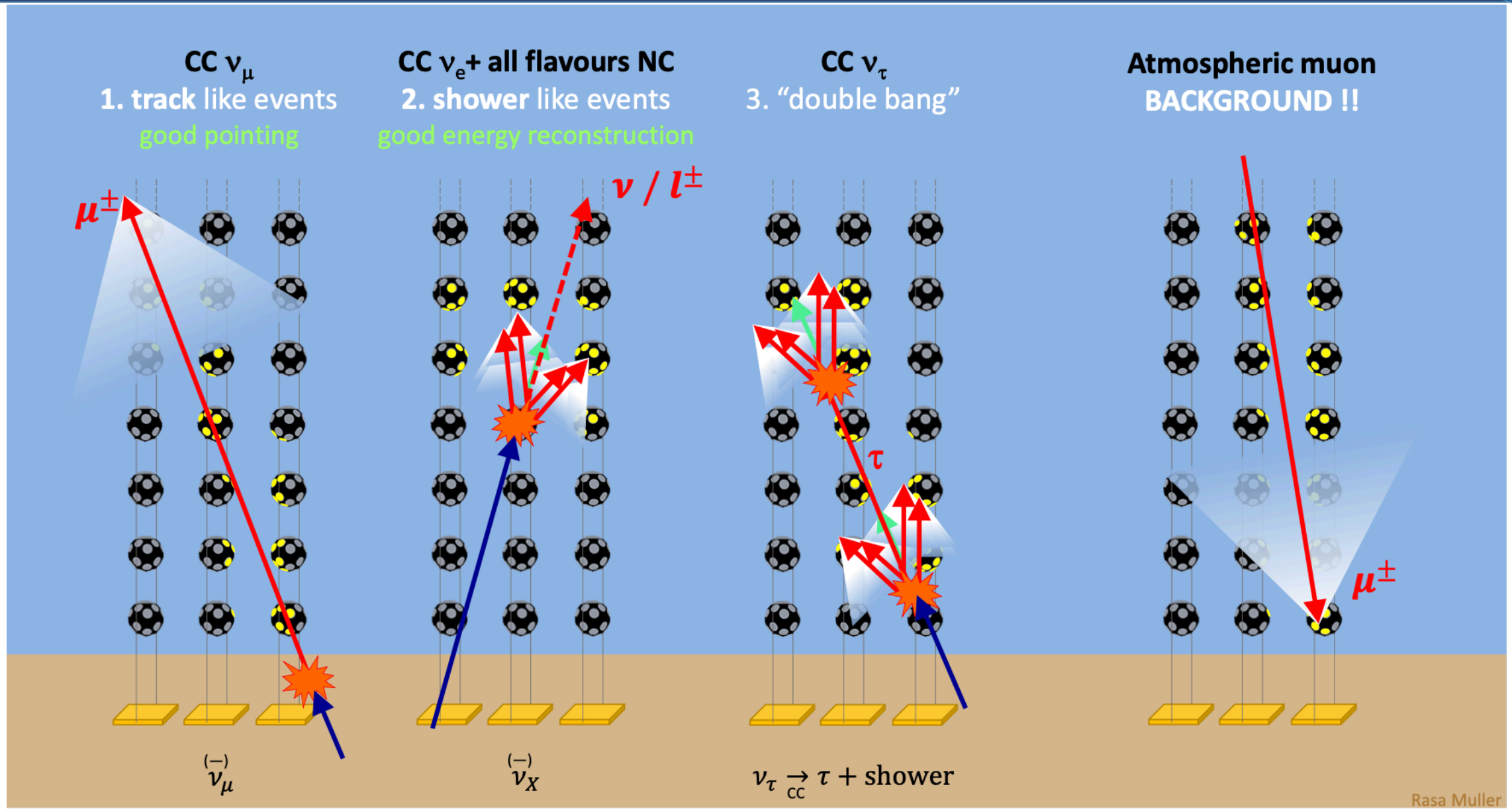
SCALABLE DAQ design

Many detection elements (# DOMs > O(1000)/km3) deployed in bunches

ALL DATA TO SHORE (trigger-less streaming readout) approach

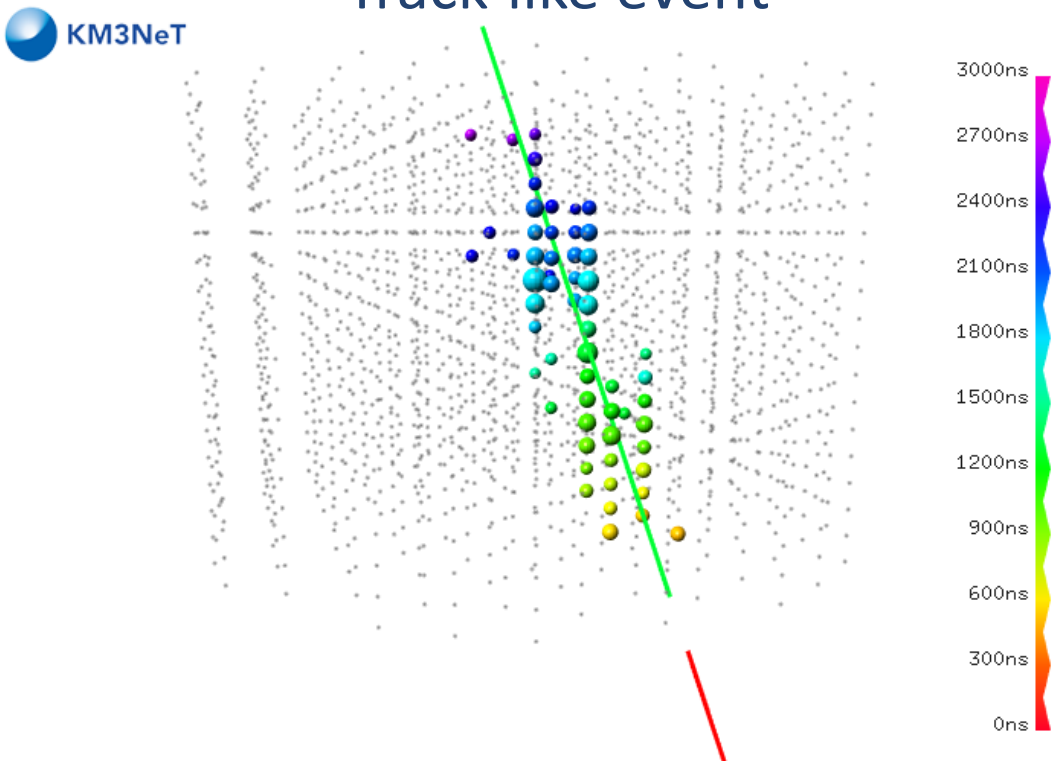
White Rabbit system to distribute the sub-nanosecond precision to all the DOMs via ethernet.

Event Signatures

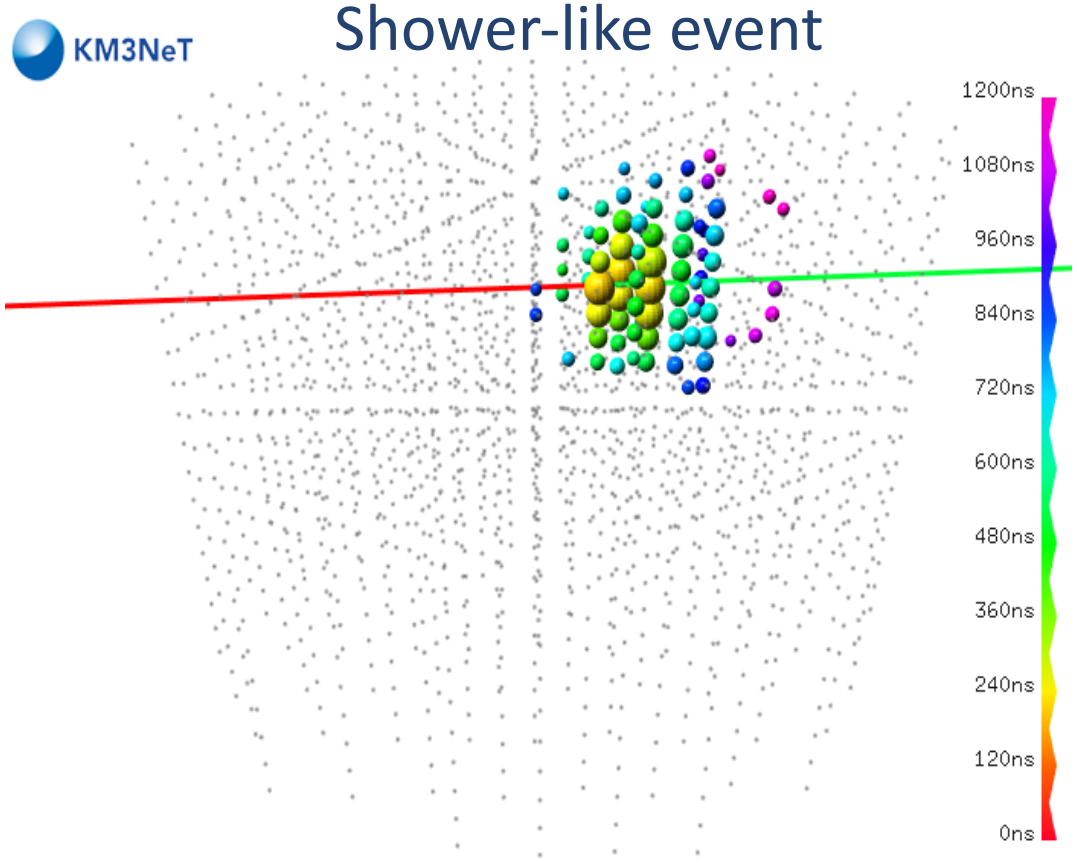


Event Signatures

Track-like event

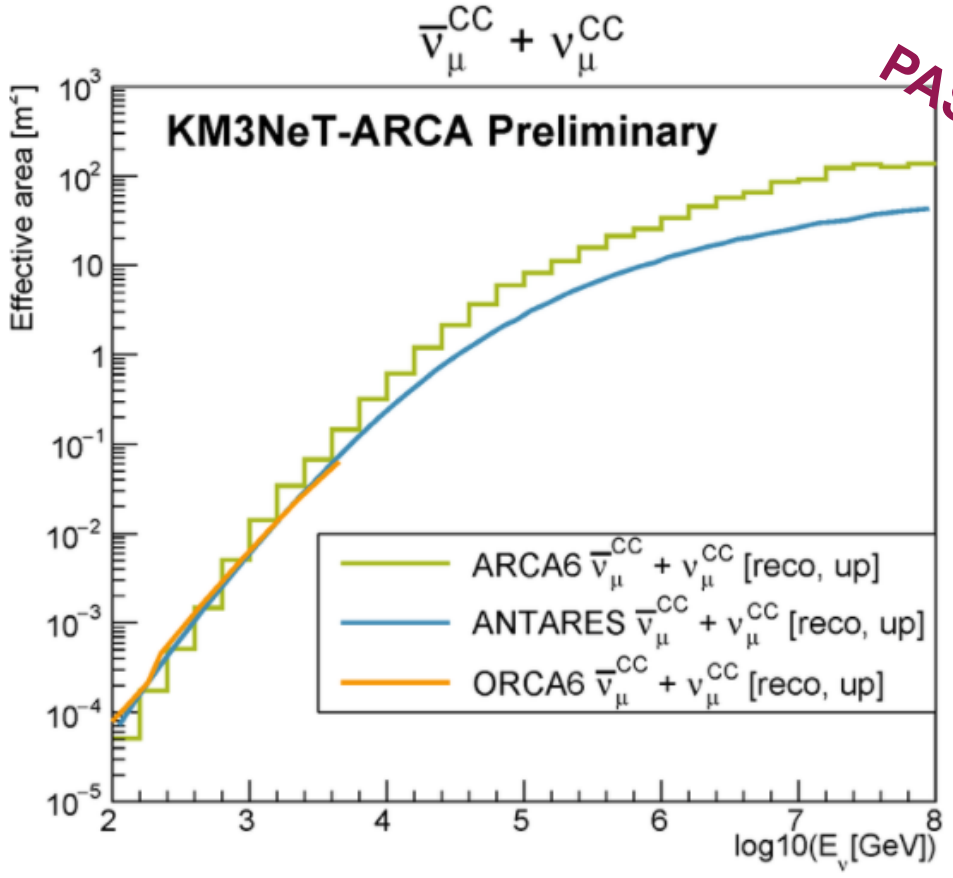


Shower-like event



Detector Capabilities

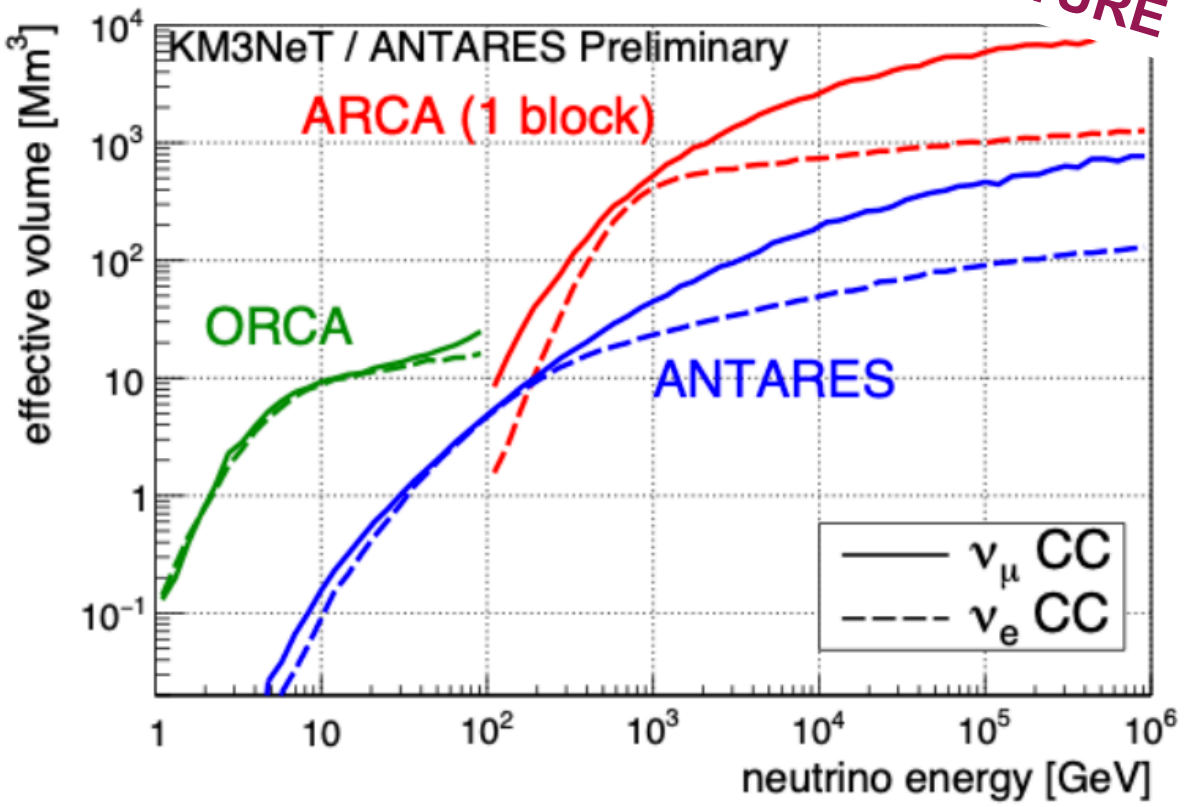
PAST



- ARCA6, ORCA6 and ANTARES have comparable effective areas for low energies.
- For E > 10 TeV, ARCA6 has significantly higher effective area.

JINST 16 C11015

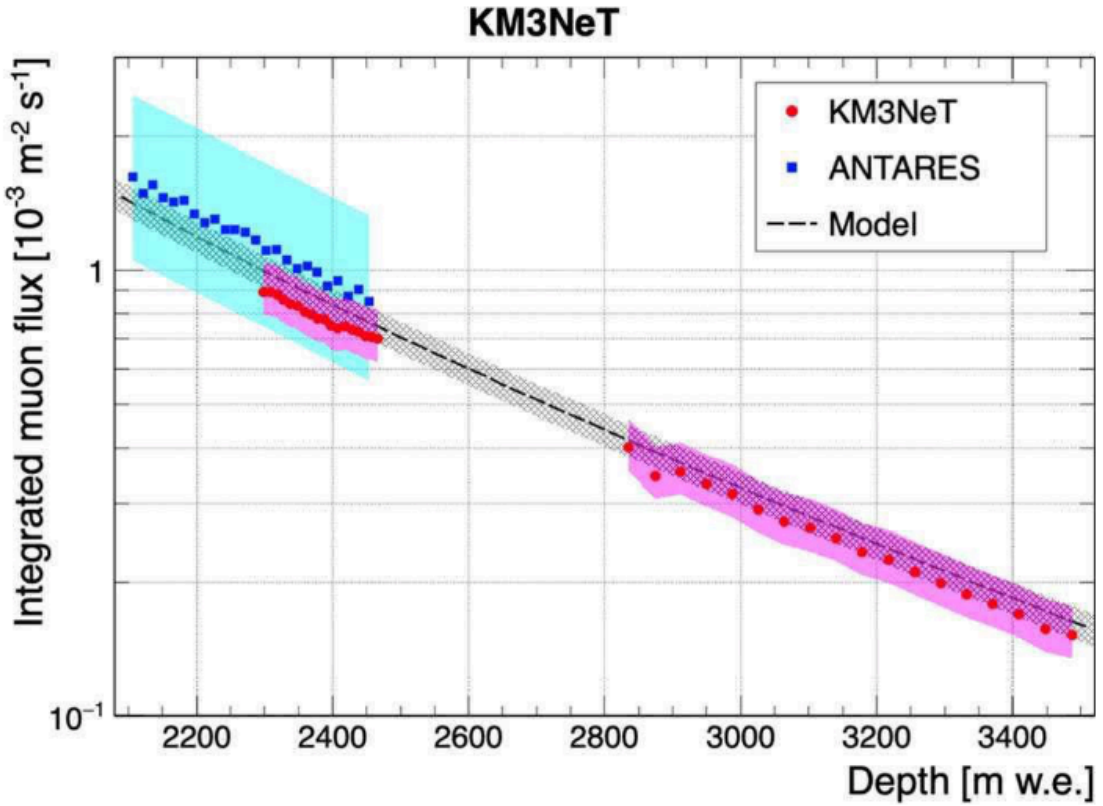
FUTURE



- Effective volume for ARCA (1BB) and ORCA compared to ANTARES.

ARCA6: ARCA with 6 DUs

Some basic measurements



- Underwater muon flux as a function of depth.
- ARCA2 and ORCA1
- Flux compared to ANTARES result and the Bugaev model

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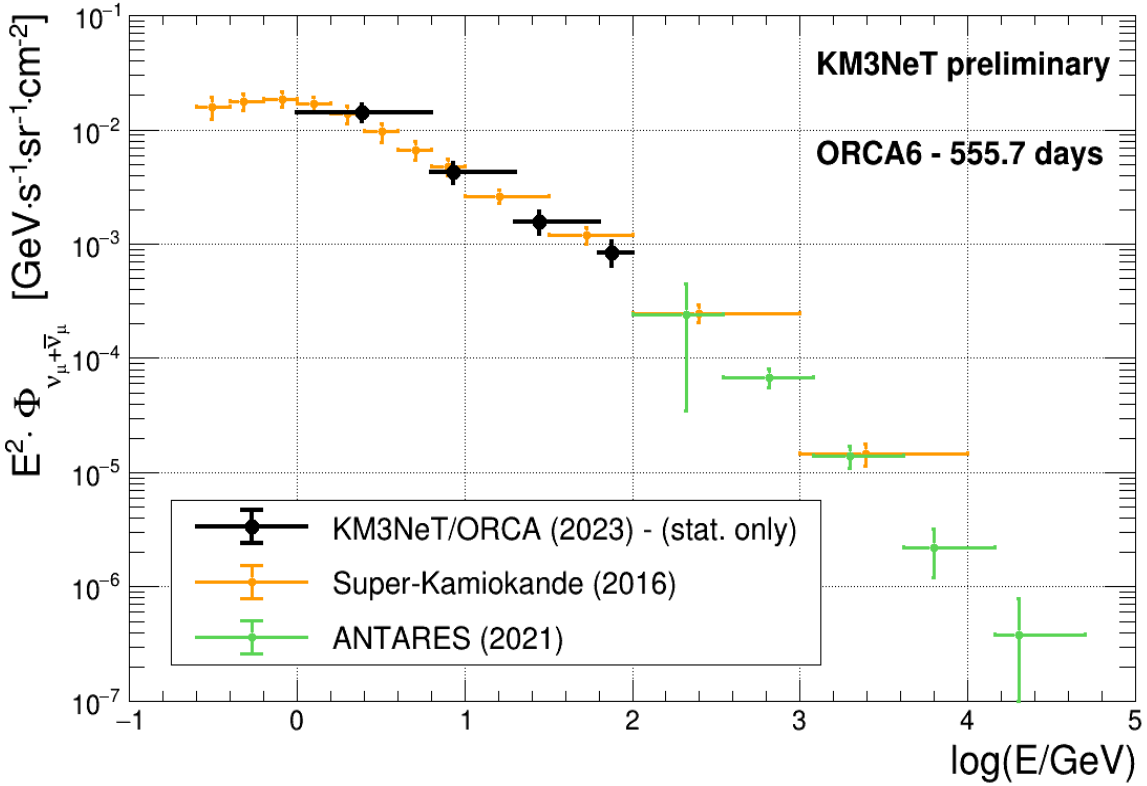


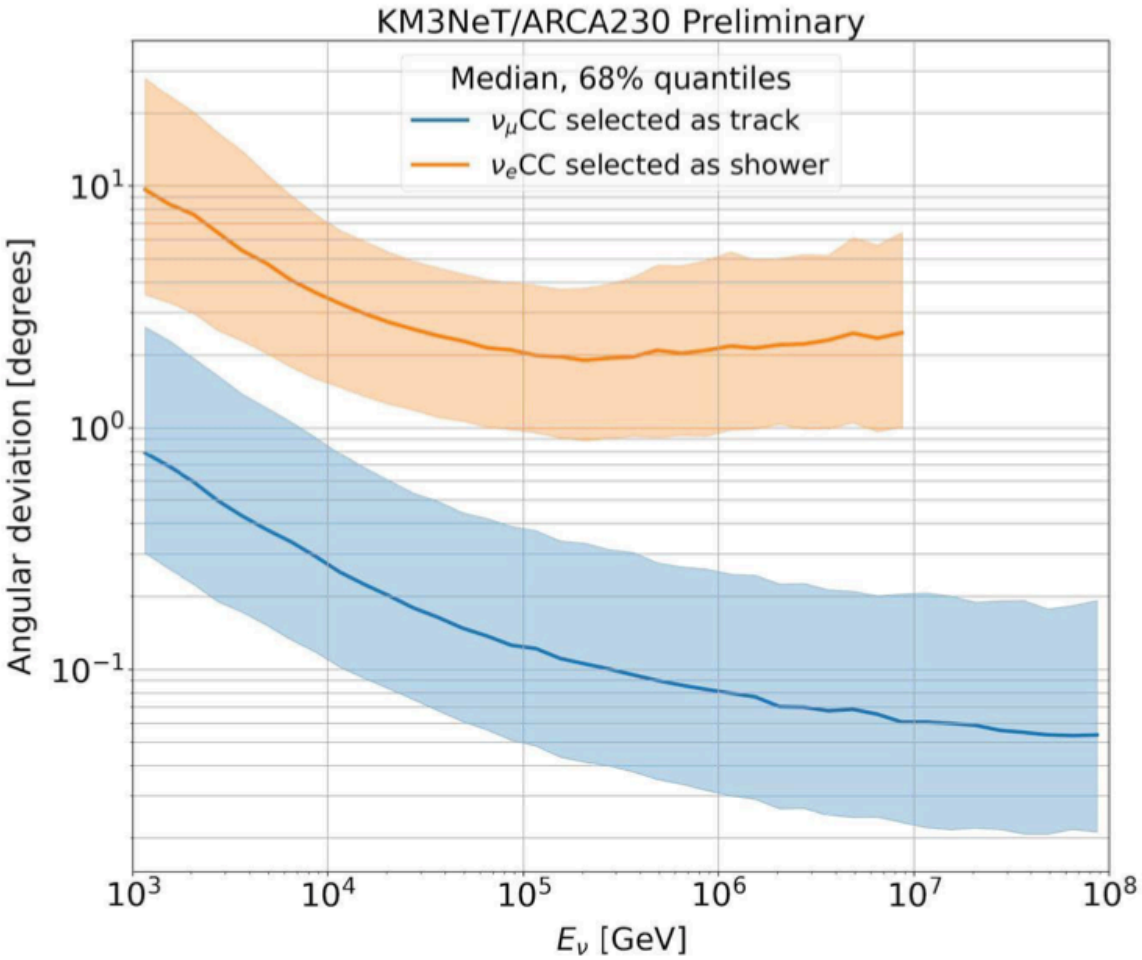
- Measurement of atmospheric ν_μ flux with ORCA6

D. Stavropoulos talk

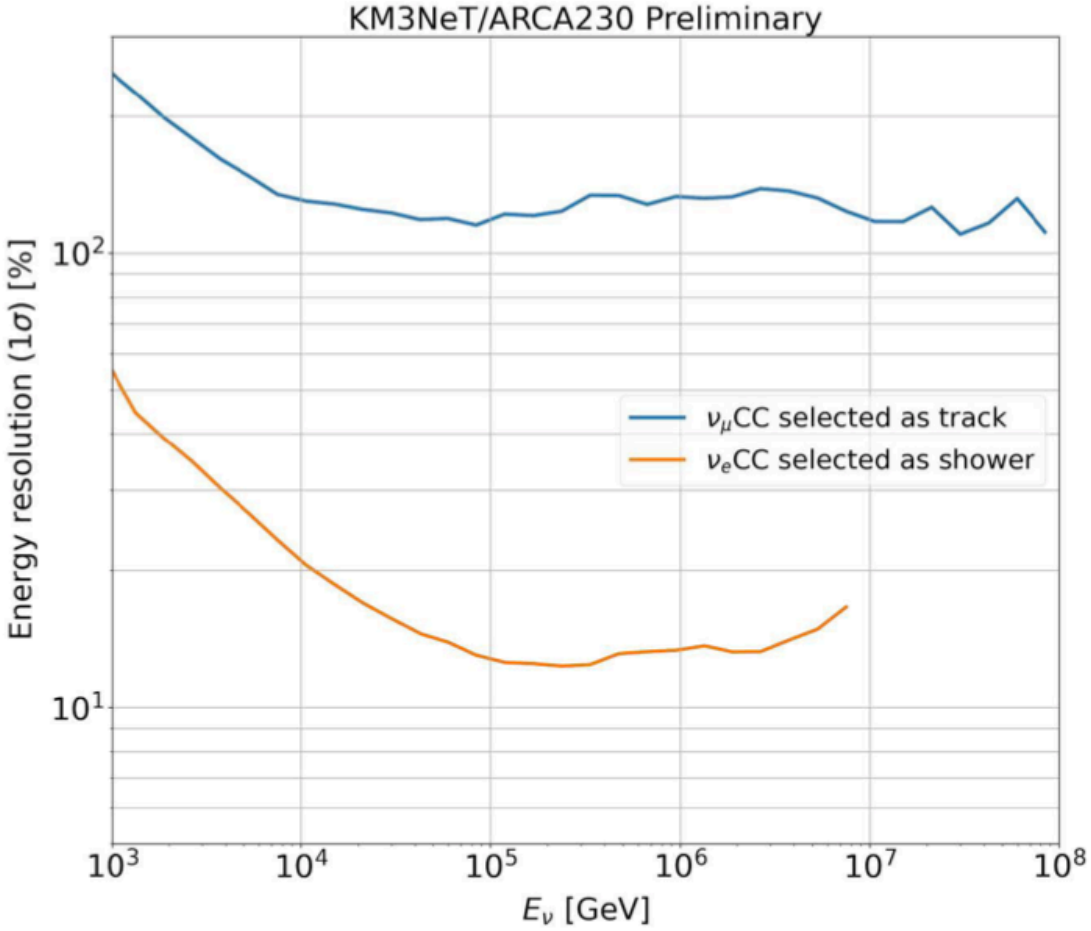
PoS ICRC2023 (2023) 1093

ARCA Performance

Full detector



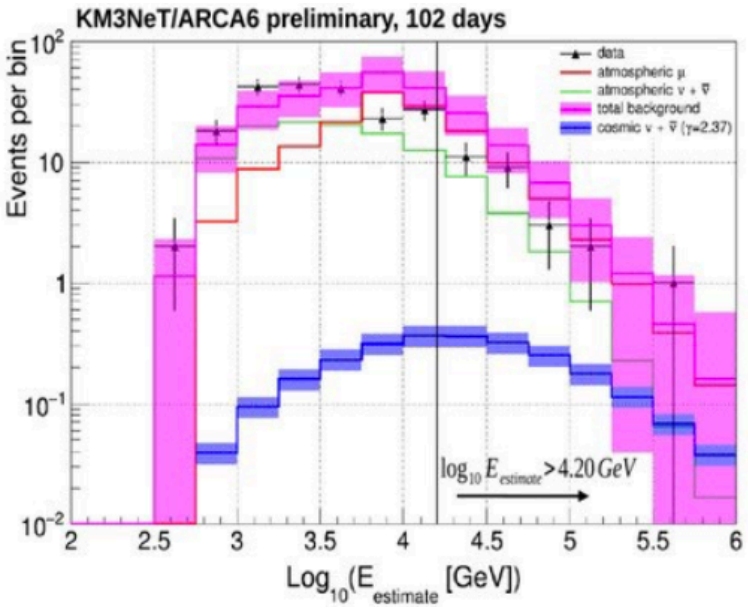
Pointing accuracy

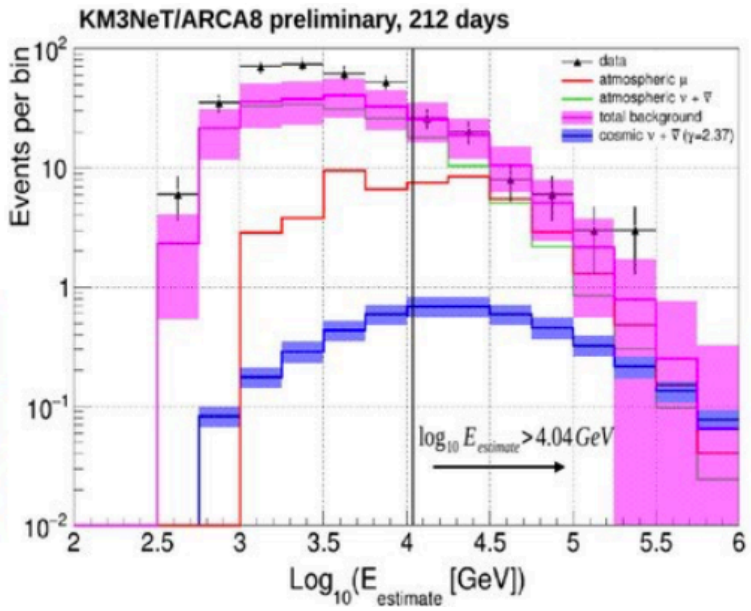


Energy resolution

PoS (ICRC2023)1074

ARCA: All-sky diffuse cosmic neutrino flux



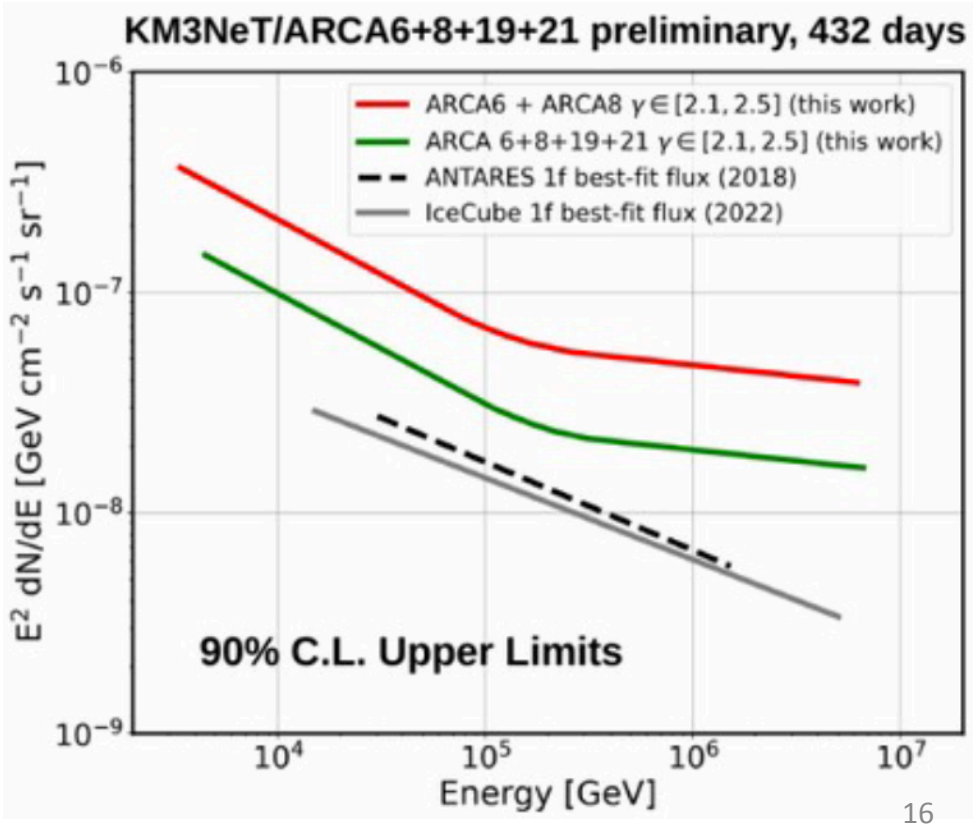


- No high-E excess due to neutrinos
- Results compatible with background

The detection of a diffuse flux of cosmic neutrinos provides:

- information on the production mechanisms composition and acceleration of Cosmic Rays
- Signal from faint sources that are difficult to detect individually

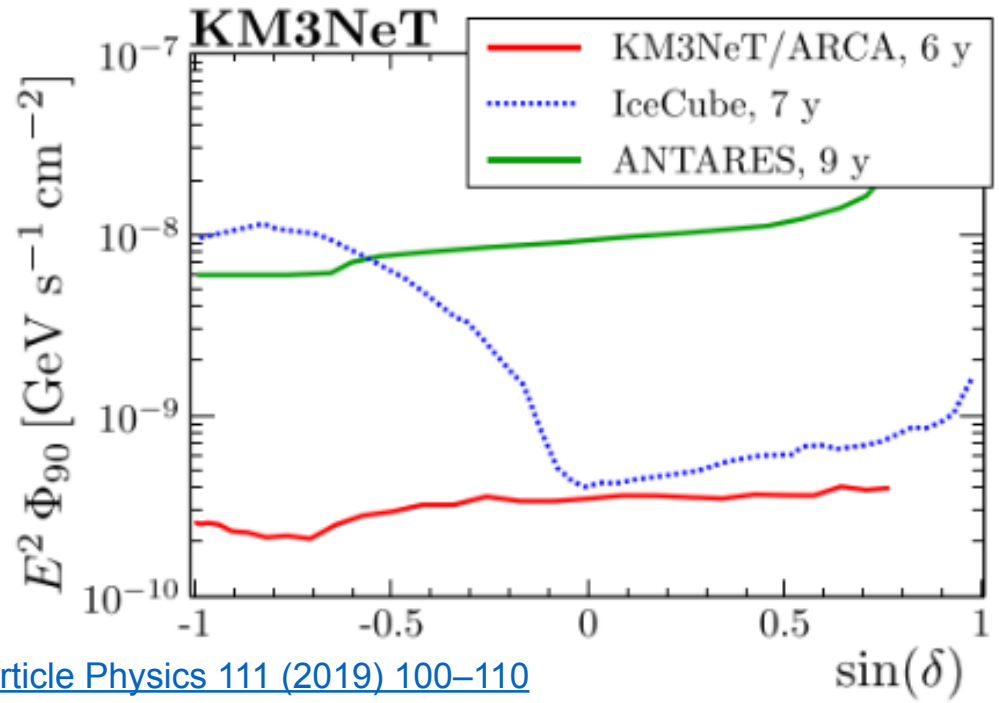
Simulated signal for $\nu_\mu = 1.44 \times 10^{-18}\,(E/100\ \mathrm{TeV})^{-2.37}$ (IceCube diffuse flux)



Neutrinos from Point Sources - Full ARCA

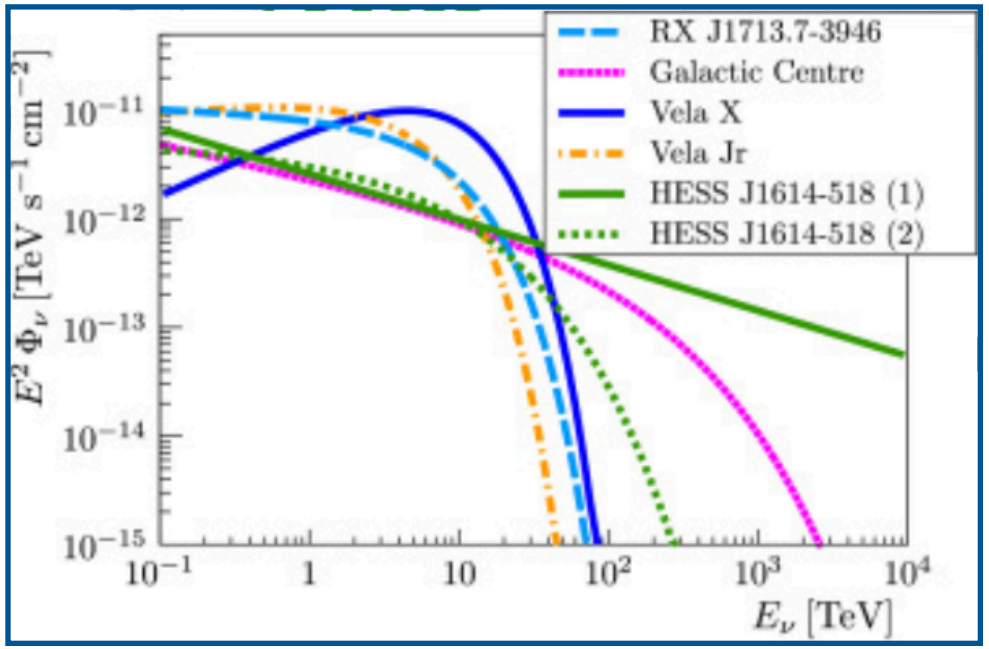
There are sources of High Energy Cosmic Rays in the galactic center; CR + interstellar medium → ν's!

FULL ARCA: Observation with 3σ significance possible in about six years of operation for most intense sources



Astroparticle Physics 111 (2019) 100–110

Neutrino flux from potential astrophysical neutrino sources



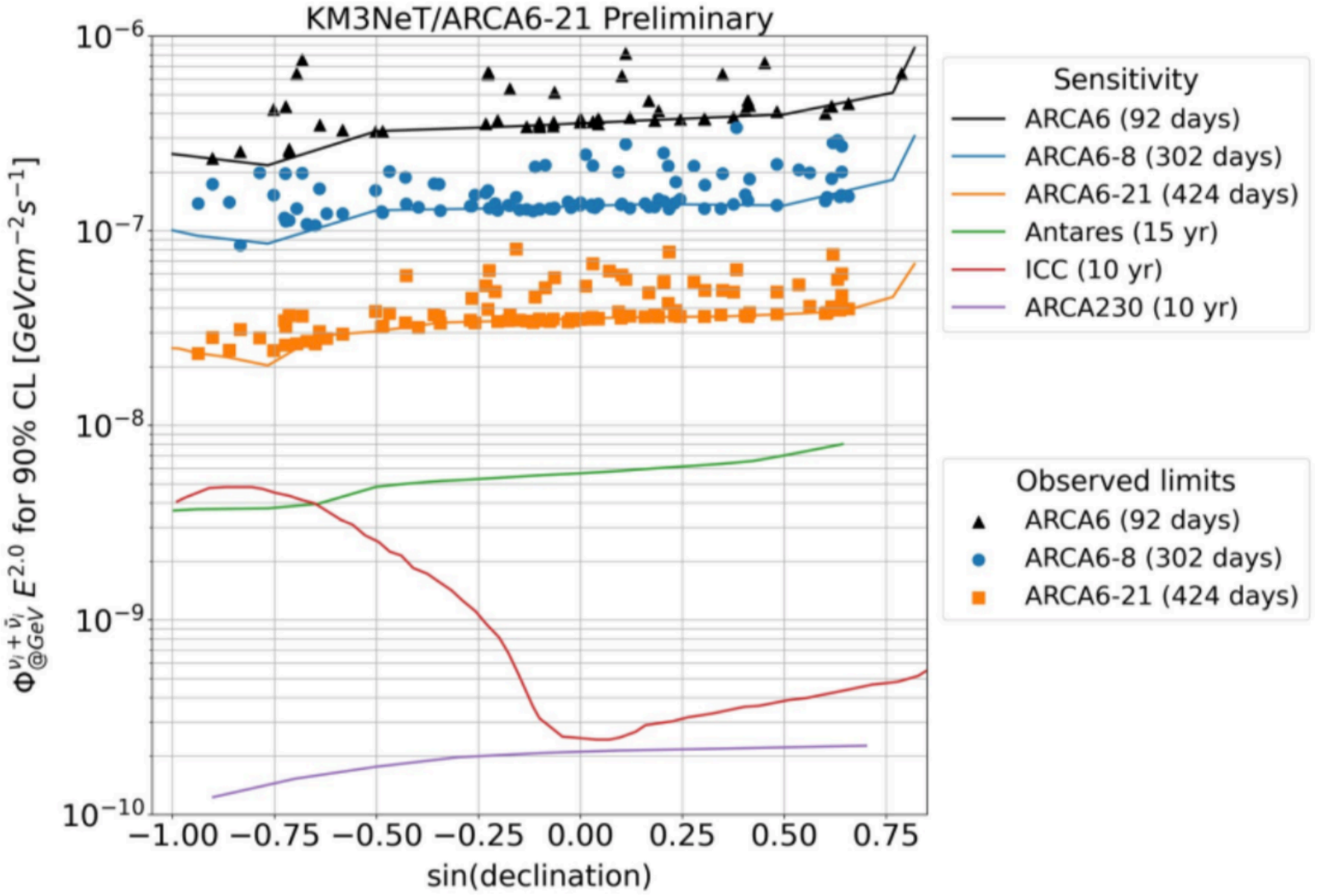
Astroparticle Physics 111 (2019) 100–110

Neutrinos from Point Sources

424 days of data with KM3NeT/ARCA 6 + ARCA 8 + ARCA 21

Time integrated point-like search for neutrino excess

101 sources selected: ANTARES+IC searches/alerts + Galactic (TeVCat - γ) + Extragalactic AGNs (VLI)



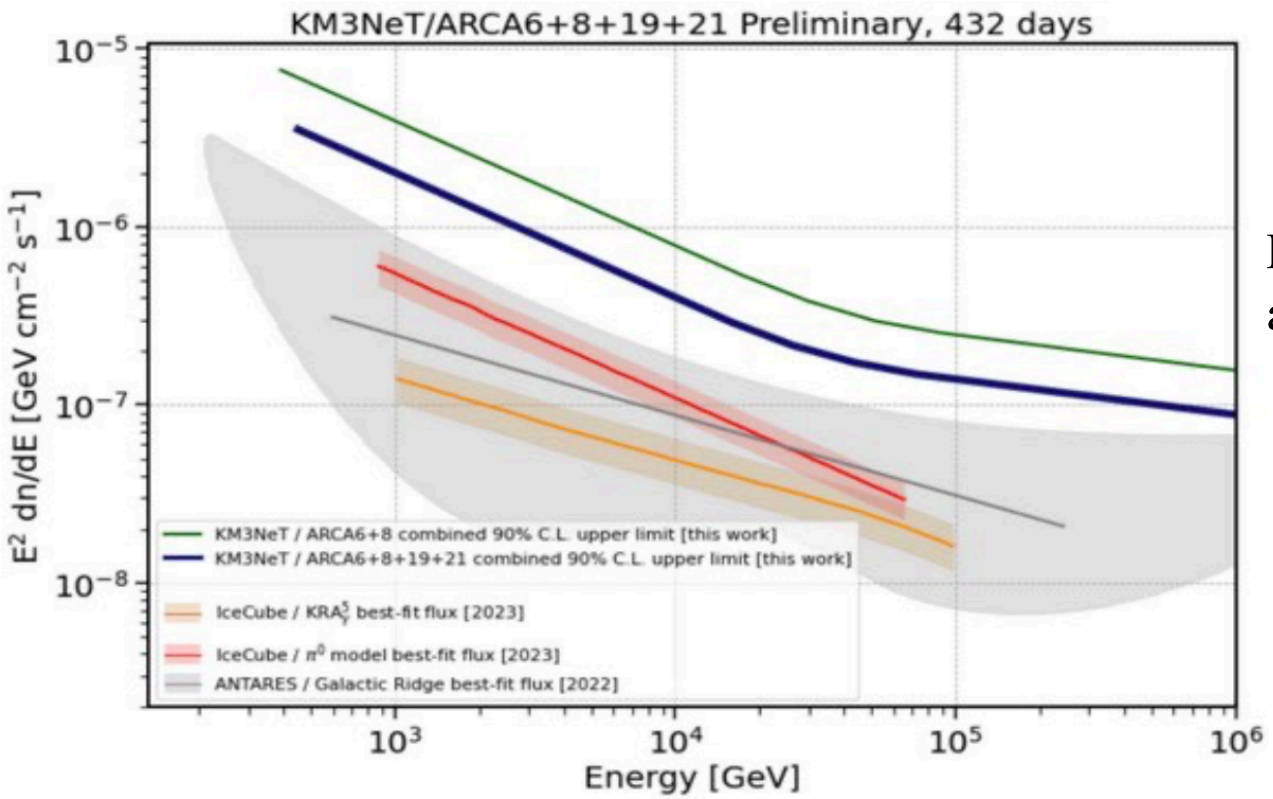
No source exceeding background yet

Background dominated by misreconstructed atmospheric μ

PoS ICRC2023 (2023) 1018

Neutrinos from the Galactic Ridge

- Multiple sources of high-energy Cosmic Rays in the centre of the Milky Way
- High-energy neutrinos should be produced via interaction of CR with the interstellar medium



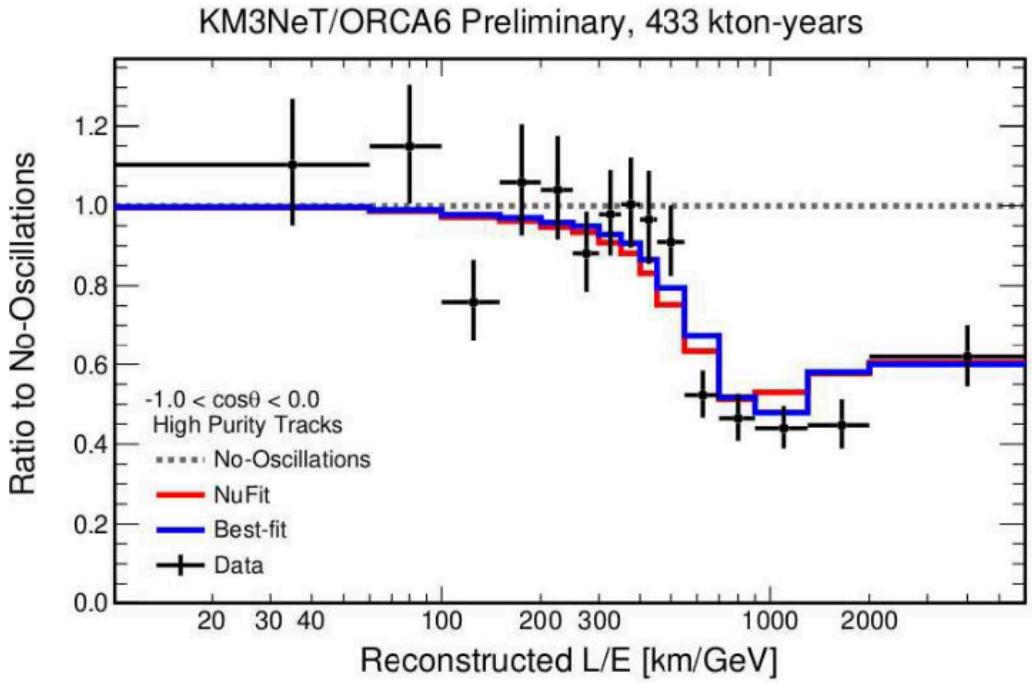
Flux upper limits for KM3NeT/ARCA 6-21 vs ICECUBE and ANTARES

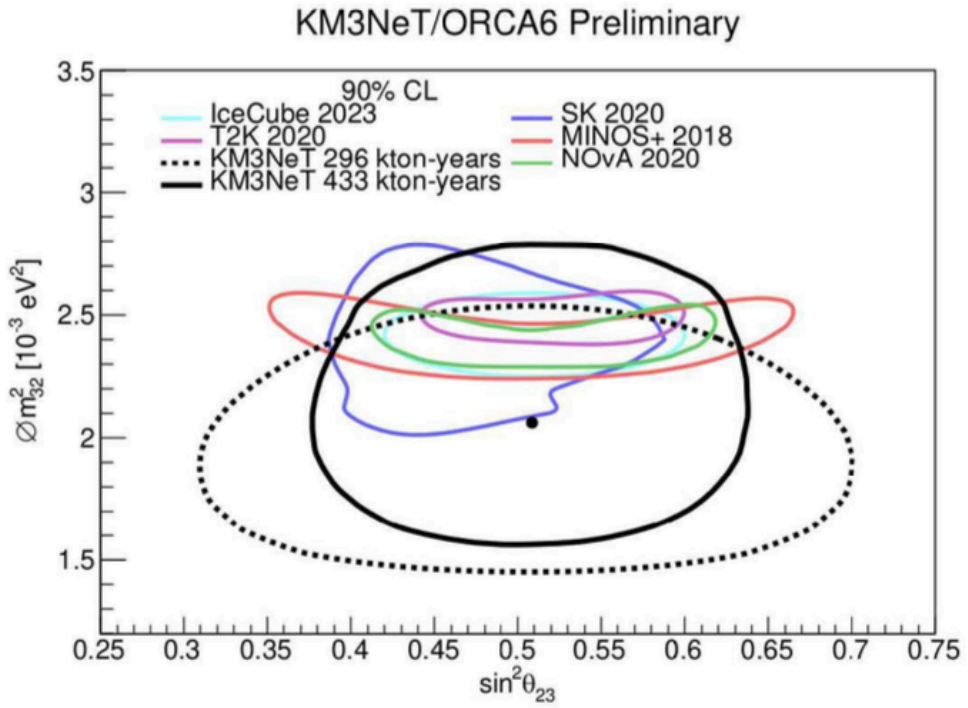
Unblinded 'pilot (on/off-zone) analysis', **432 days ARCA 6-21** → No statistically significant excess found

Neutrino Oscillations - ORCA6

The first KM3NeT/ORCA oscillation results with only 6 DUs!

Clear effect of oscillations observed





- Neutrino oscillations preferred with 5.9σ CL over the hypothesis of no oscillations
- Normal mass ordering preferred

Best fit

$$\Delta m^2_{31} = 2.14^{+0.36}_{-0.25} \cdot 10^{-3}\text{eV}^2$$

$$\sin^2\theta_{23} = 0.51^{+0.06}_{-0.07}$$

$$-2\log\left(\frac{L_{NO}}{L_{IO}}\right) = 0.9$$

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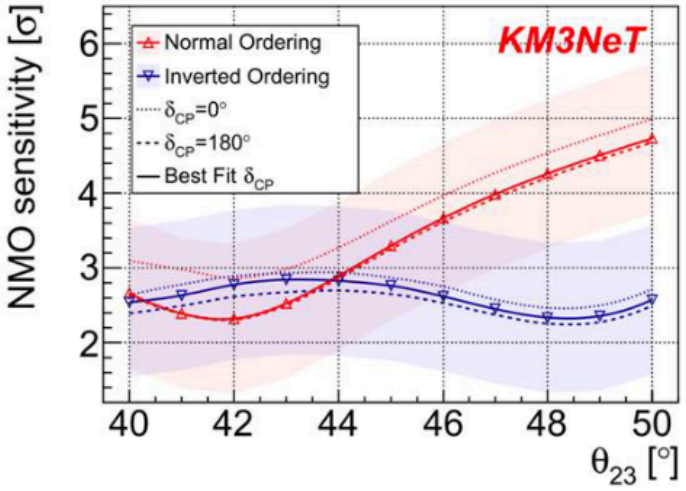
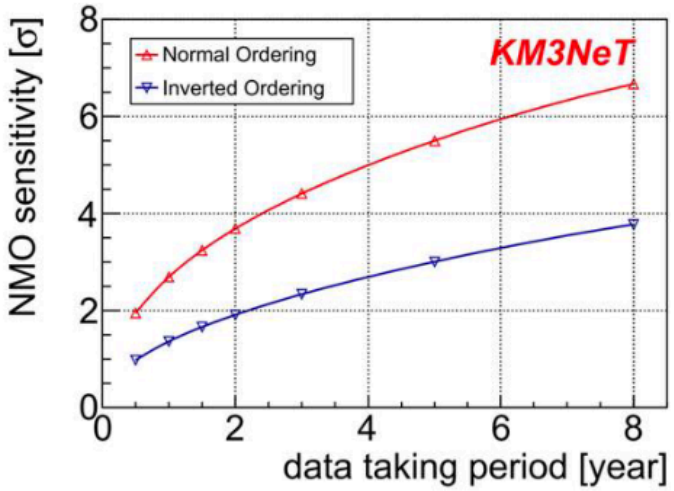
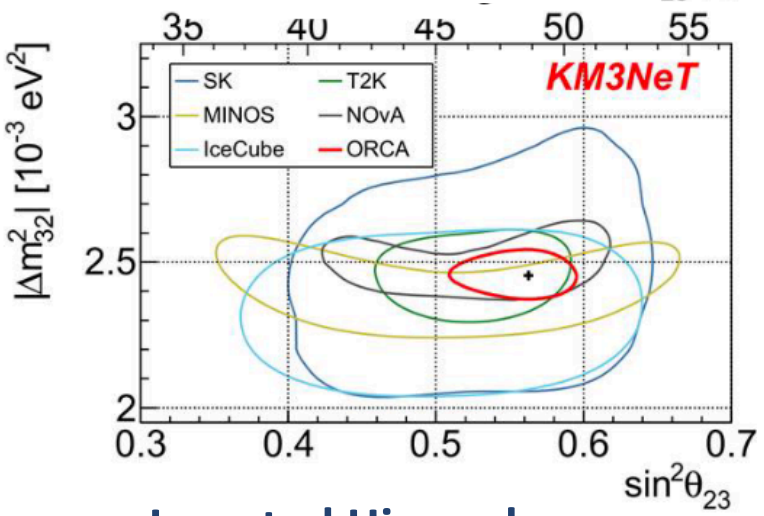
Neutrino Oscillations - Full ORCA

- The sensitivity to Neutrino Mass Ordering (NMO) after 3 years of data taking is 4.4σ (NO) and 2.3σ (IO).
- The NMO can be determined at 3σ level after 1.3 (5.0) years if the true NMO is normal (inverted).
- Competitive measurements for Δm^2_{32} and θ_{23}

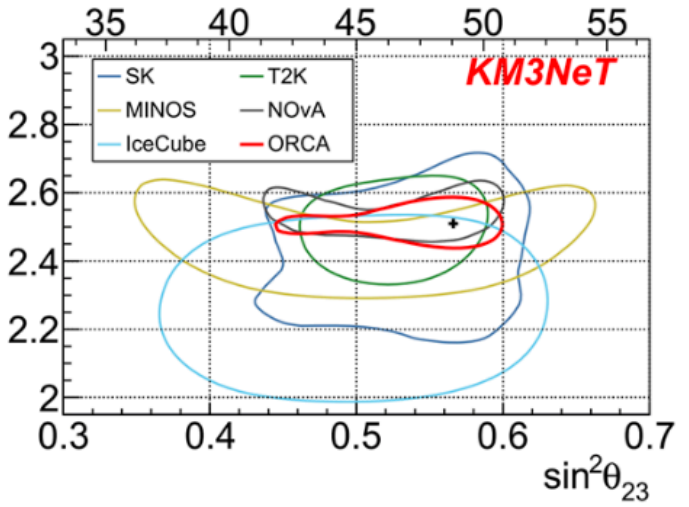




Normal Hierarchy



Inverted Hierarchy



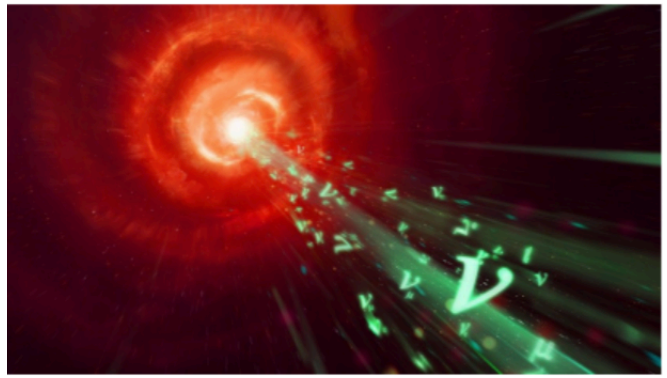
Eur. Phys. J. C **82**, 26 (2022)

zenodo.org/record/6785279

Multimessenger Analysis

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

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



KM3NeT has developed a framework to identify neutrino candidates in real-time.

- supernova monitoring for prompt alerts, generation latency < 20 s
- receive external EM/GW/ν alerts; search for correlated ν
- send all flavor, all-sky ν alerts (multiplets & HE (GeV - PeV)) to external observatories

zenodo.org/record/6805372

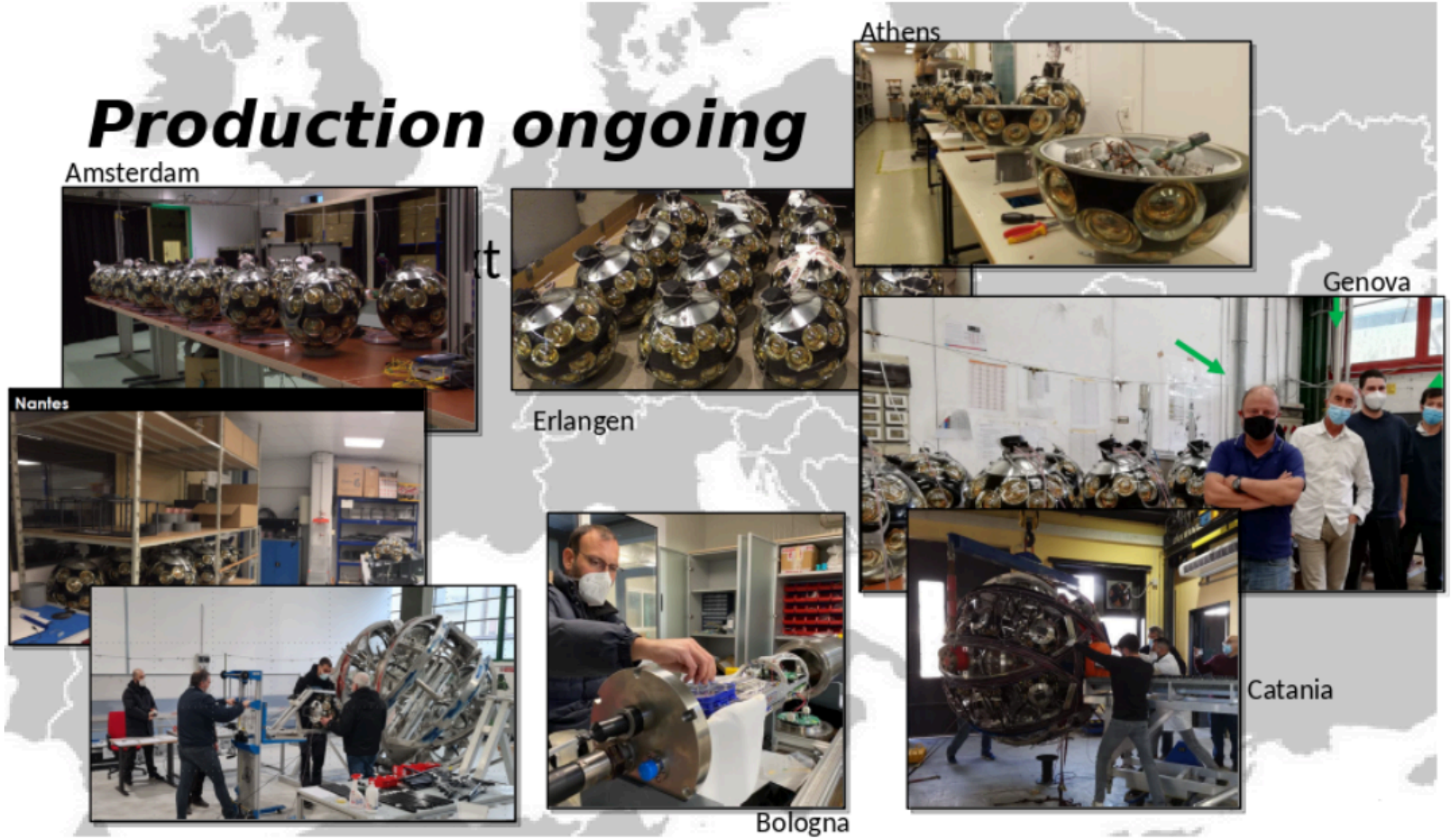
Follow-up of IceCube alerts with ARCA

IceCube alert	Potential blazar	Sky location (RA, DEC)	Optimum RoI	Expected background	Expected signal	Events in ON region
IC211208A	PKS 0735+17	(114.5°, +17.7°)	1.4°	$(4.7 \pm 0.7) \cdot 10^{-2}$	$8.9 \cdot 10^{-3}$	0
IC220205B	PKS 1741-03	(266.1°, −3.9°)	1.9°	$(4.9 \pm 0.9) \cdot 10^{-2}$	$9.7 \cdot 10^{-3}$	0
IC220225A	PKS 0215+15	(34.5°, +1.7°)	3.0°	$(2.9 \pm 0.4) \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$	0
IC220304A	TXS 0310+022	(48.3°, +2.5°)	2.9°	$(2.6 \pm 0.4) \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$	0

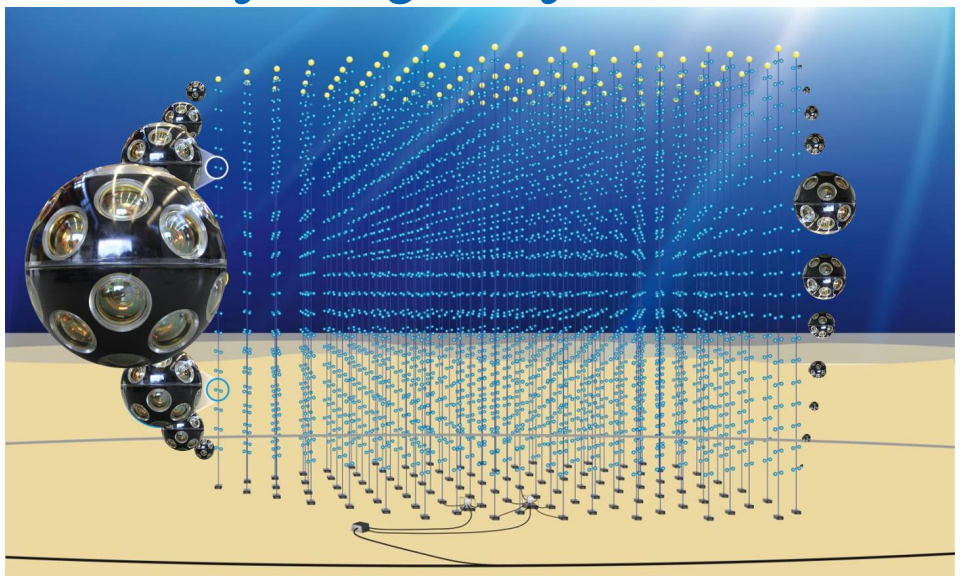
No confirmation yet.

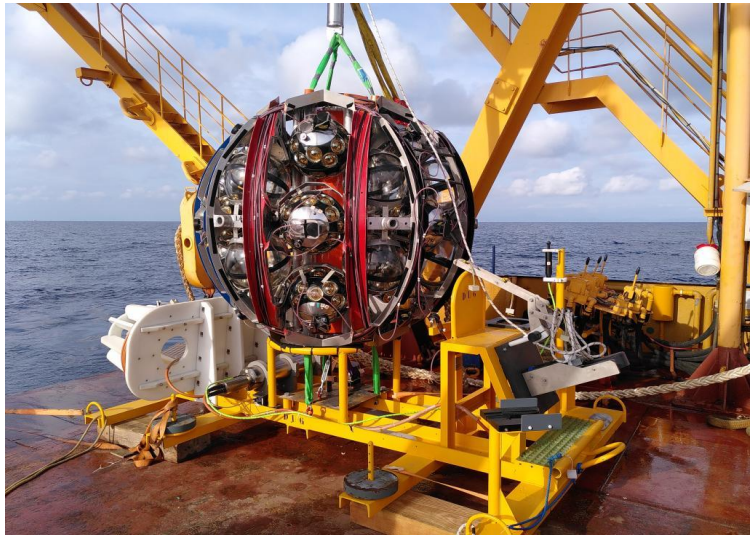
zenodo.org/record/6805417

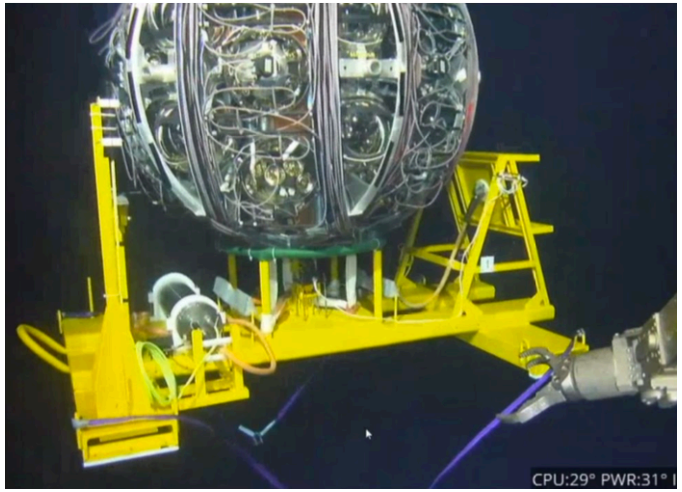
KM3NeT DOM & DU Production

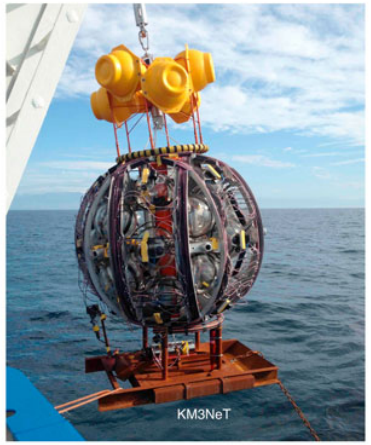


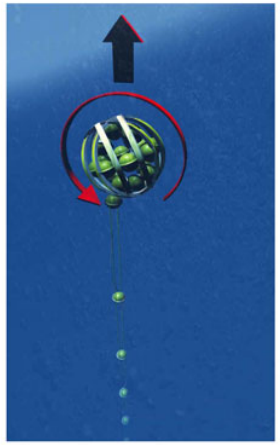
Thank you for your attention!









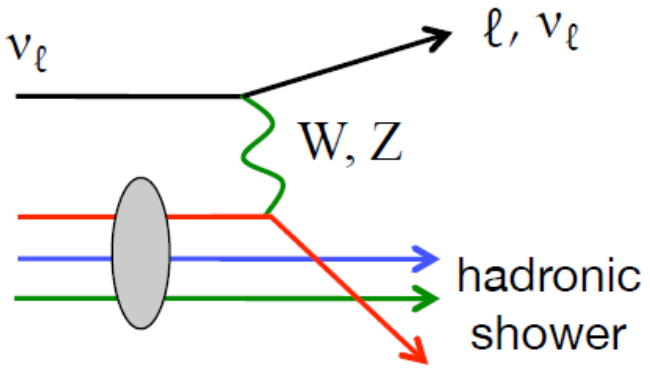


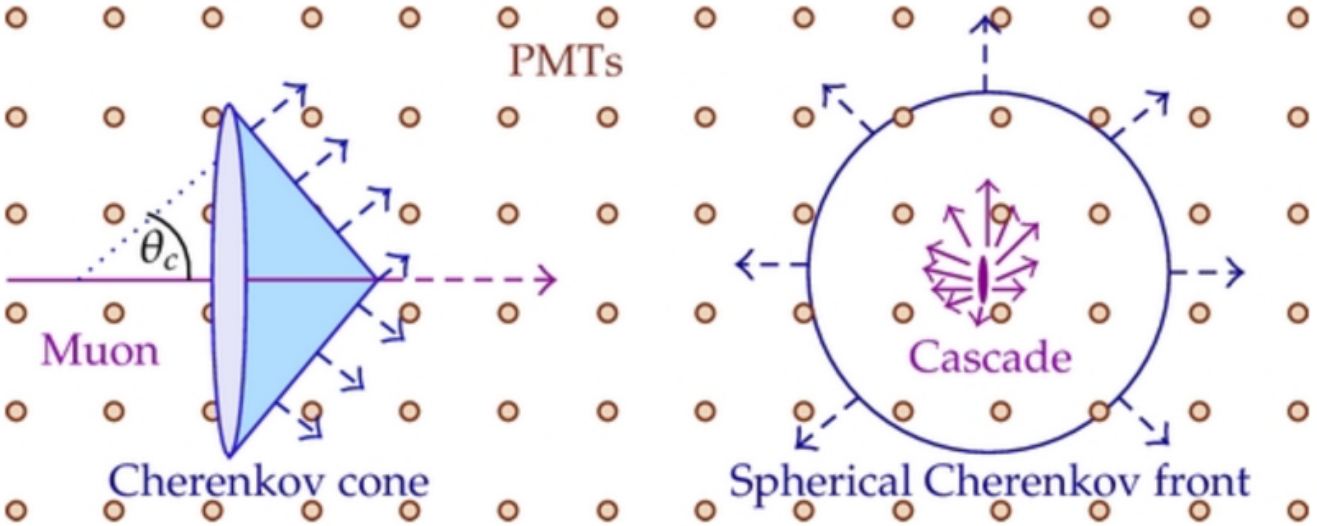
For more follow us at:
https://www.km3net.org

Backup

Detection Principle

Charged Current (CC) / Neutral Current (NC) interactions





Neutrino detection:

- Cherenkov radiation allows directional reconstruction
- radiative processes allows energy reconstruction

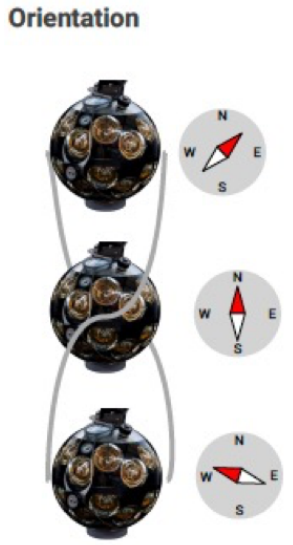
Detector properties:

- Transparent medium
- Deep underground to shield backgrounds (atmospheric muons)
- Huge detector volumes
- Direction Resolutions:
  - track channel: better than 0.1º for E>100TeV
  - cascade channel: better than 2º

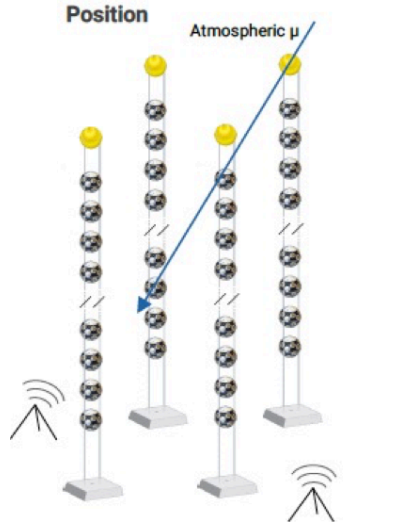
Detector Control and Calibrations

Timing Calibration:

- LED pulsers (nanobeacon) for inter-DOM calibration arXiv:2111.00223 [astro-ph.IM]
- < 1ns precision for relative timing between DOMs



compass in DOMs

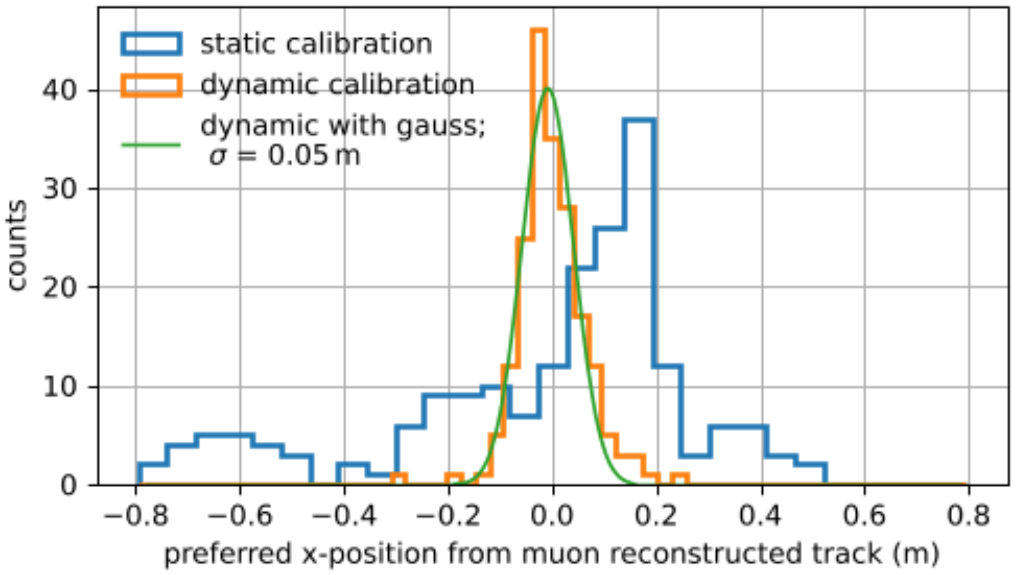


acoustic emitters, hydrophones, piezo sensors

Position Calibration:

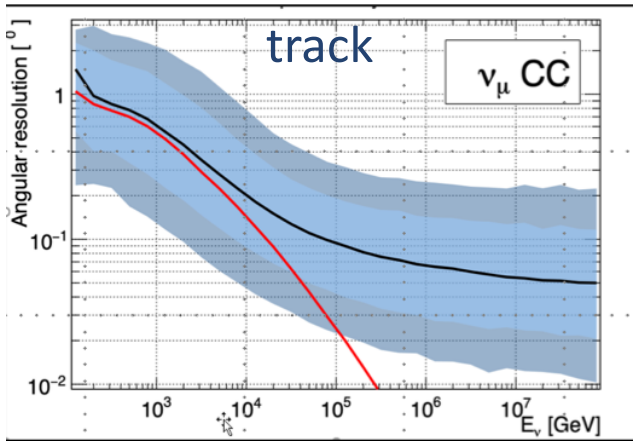
Lines move with the sea current. Needs dynamic position calibration.

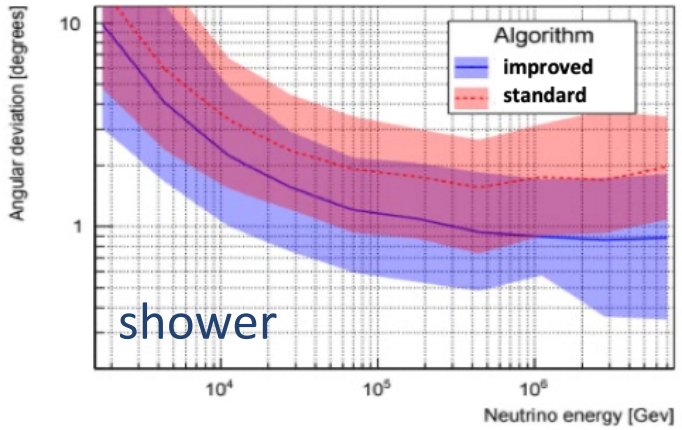
- Acoustic system for dynamic alignment
- Precision O(10 cm)
- Checked with atmospheric muons

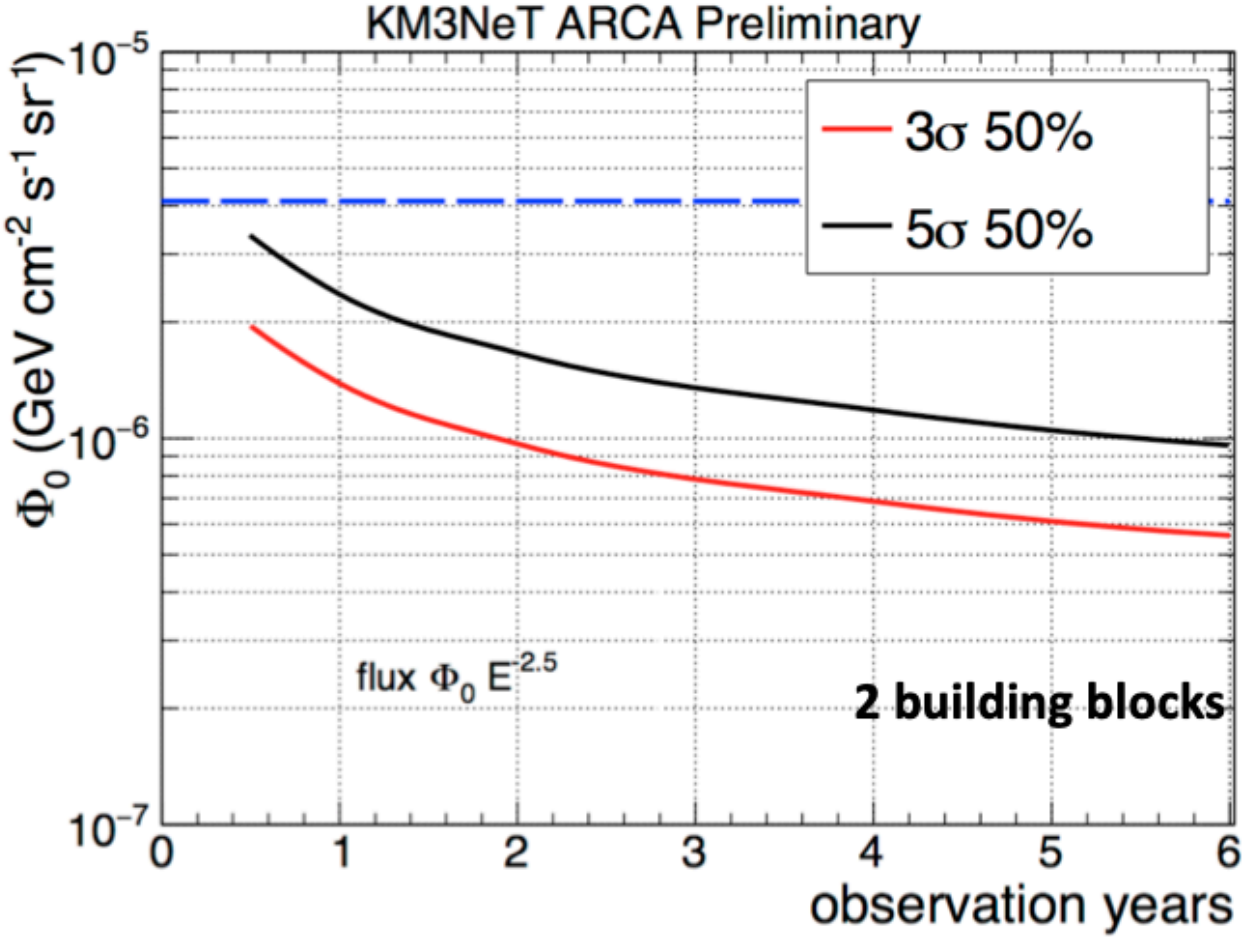


Cosmic neutrino flux - Full ARCA

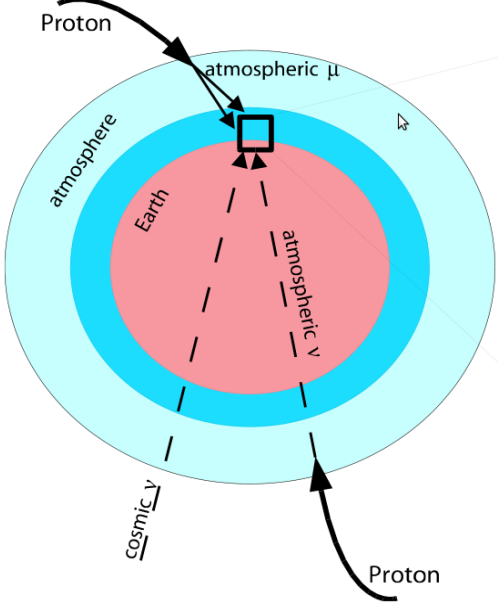
When ARCA is completed (2BB), it will be able to confirm the IceCube flux within within 1 year of data







Neutrino Astronomy: the reality!



- Signal: Neutrinos from astrophysical sources
- Background: atmospheric neutrinos
  atmospheric muons

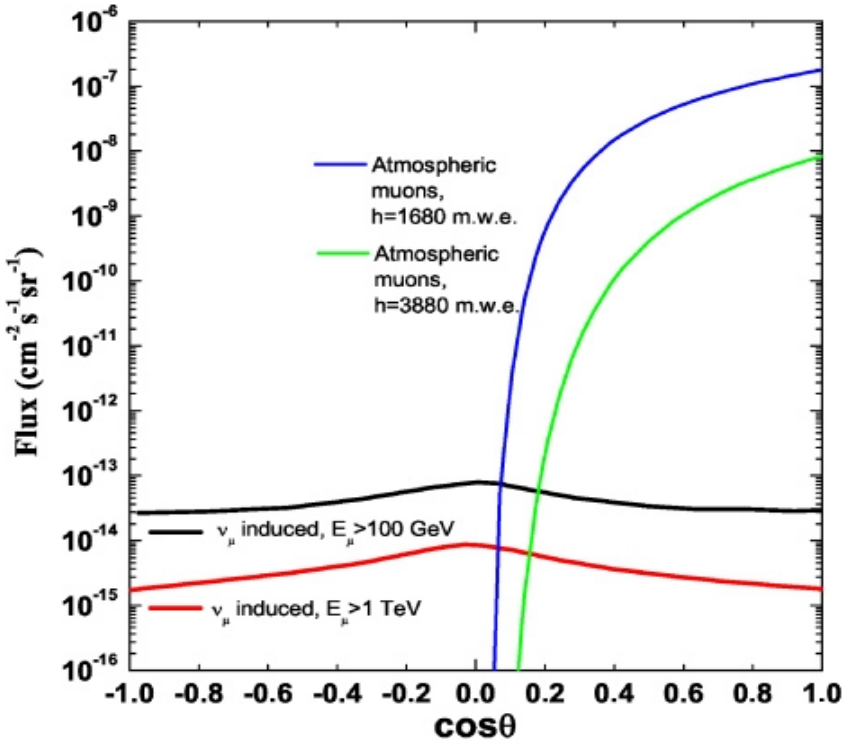
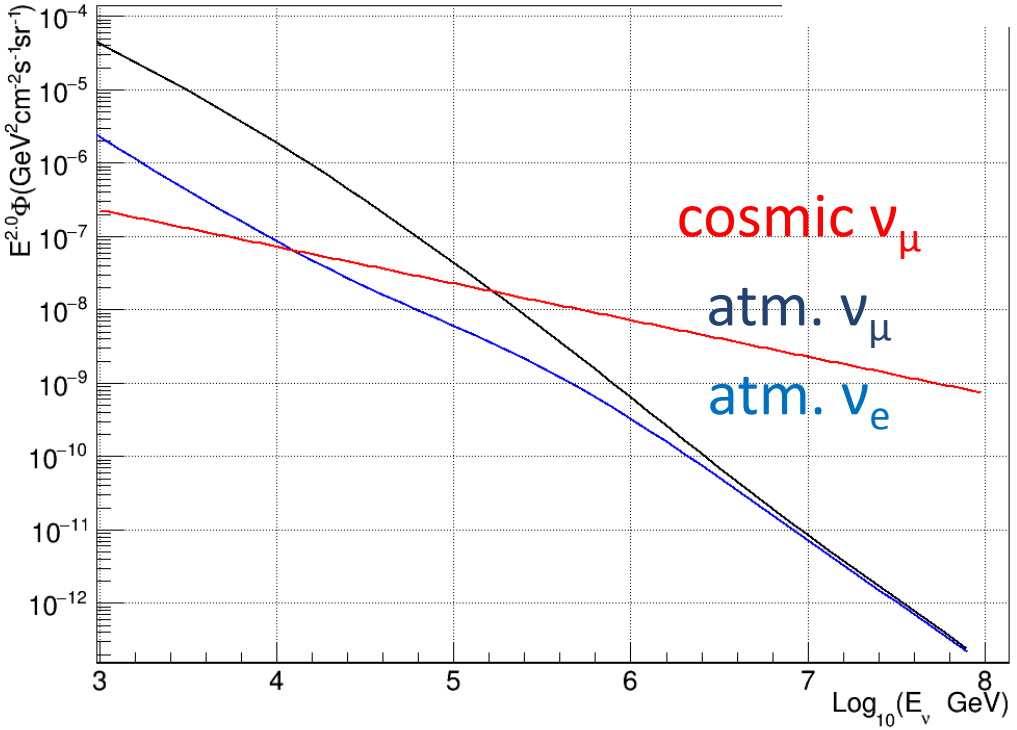
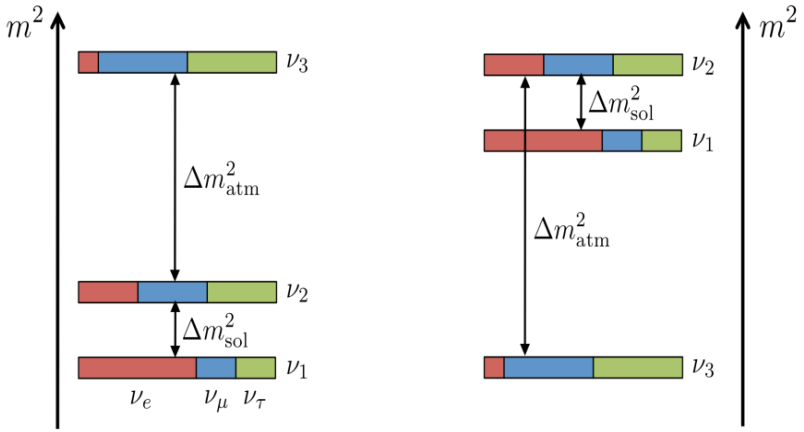


Figure 12 from High-energy neutrino astronomy: detection methods and first achievements B Baret and V Van Elewyck 2011 Rep. Prog. Phys. 74 046902



Science Objectives: Neutrino Physics

normal ordering (NO) inverted ordering (IO)

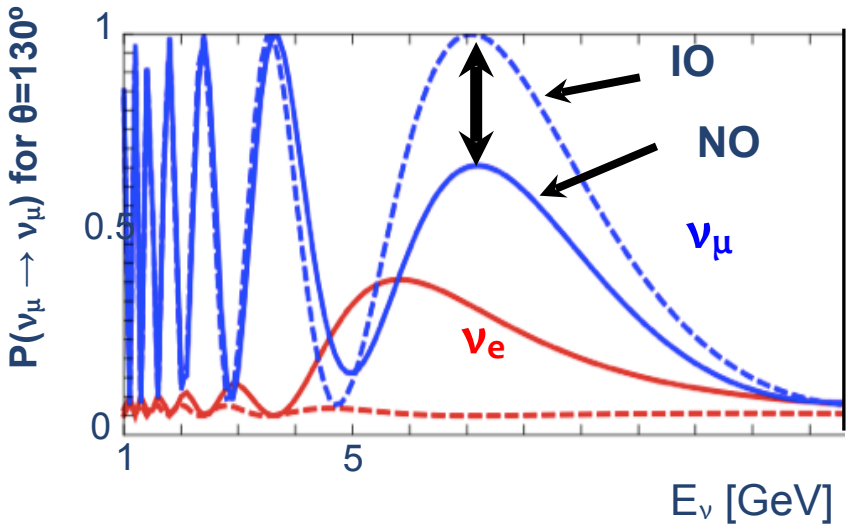


Atmospheric neutrinos:
"free beam" of known composition (ν_e, ν_μ)

Oscillation pattern distorted by Earth matter effects
maximum difference for θ=130° (7645 km) and E_ν = 7 GeV

KM3NeT-ORCA: Oscillation Research with Cosmics in the Abyss

measuring the neutrino mass ordering (MC Simulation)



Measure θ and E_ν for upgoing atmospheric neutrinos (GeV scale)

Treatment of systematics is important