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Italian Physical Society



# Neutrino astronomy in the Mediterranean and the KM3NeT/ARCA detector

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on behalf of the KM3NeT Collaboration

**presentato da:**

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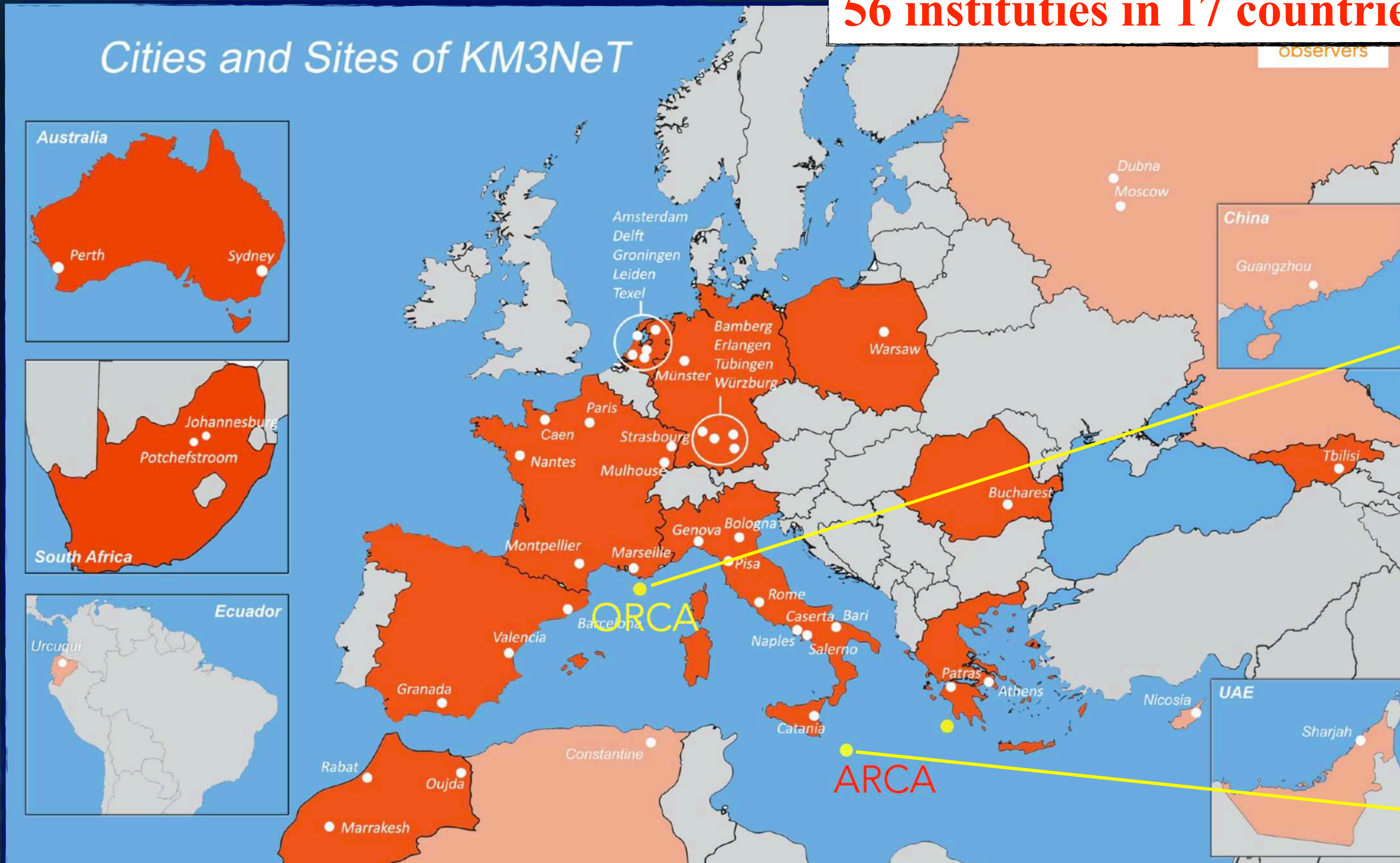
# Outline

- ▶ The KM3NeT project
  - Technology and infrastructure
  - Current status and plans
- ▶ Neutrino Astronomy at KM3NeT (ARCA)
  - Sensitivity to Cosmic Neutrino Flux
  - Core-Collapse Supernova Neutrinos
  - Real-time Multimessenger program
  - KM3NeT/ARCA Performances
- ▶ Summary and outlook



# The KM3NeT Collaboration

## 56 institutes in 17 countries



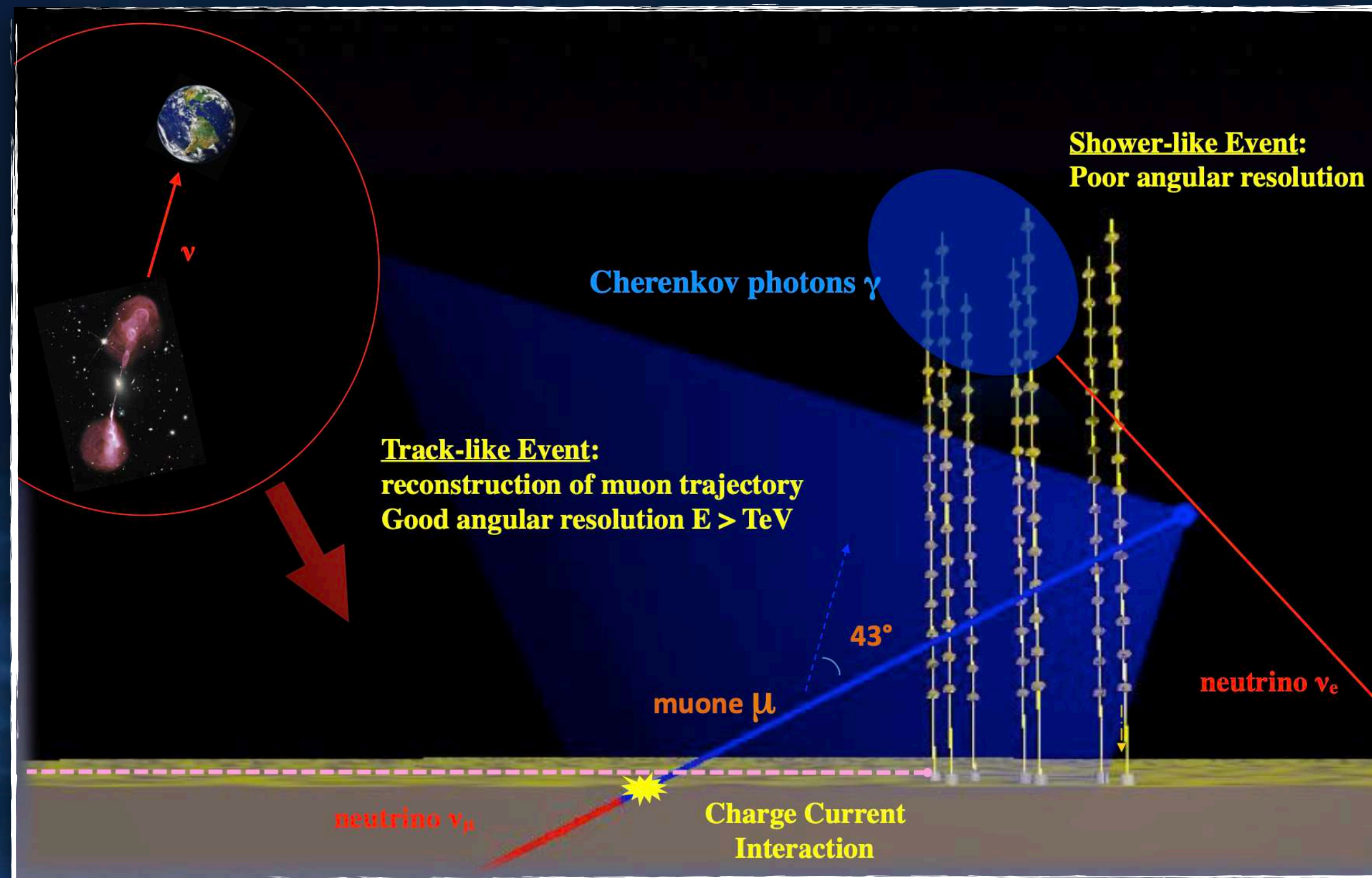
# ORCA (Oscillation Research with Cosmic in the Abyss)

# ARCA (Astroparticle Research with Cosmics in the Abyss)

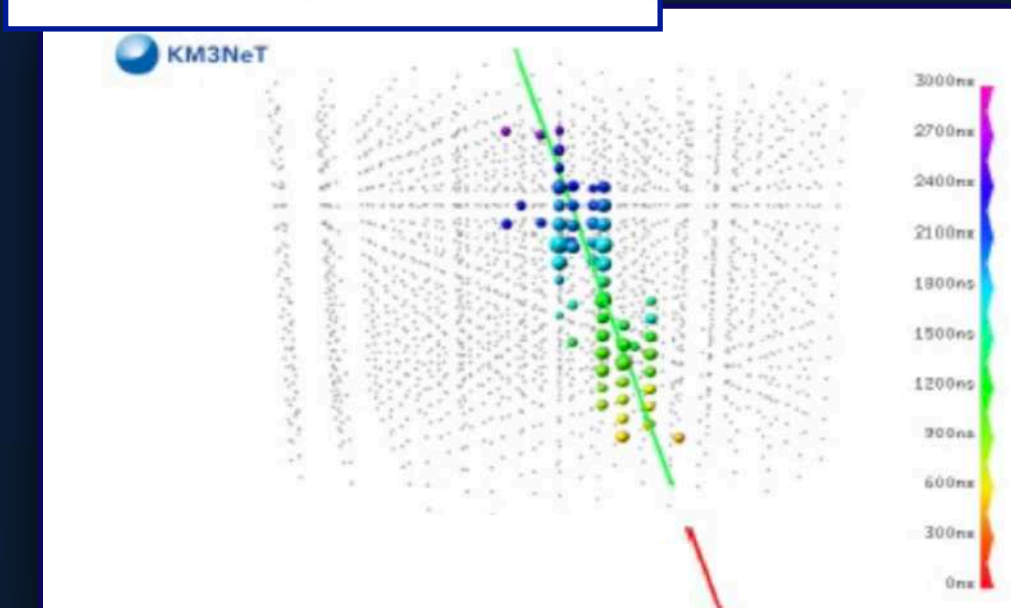


# Cosmic neutrino detection principle

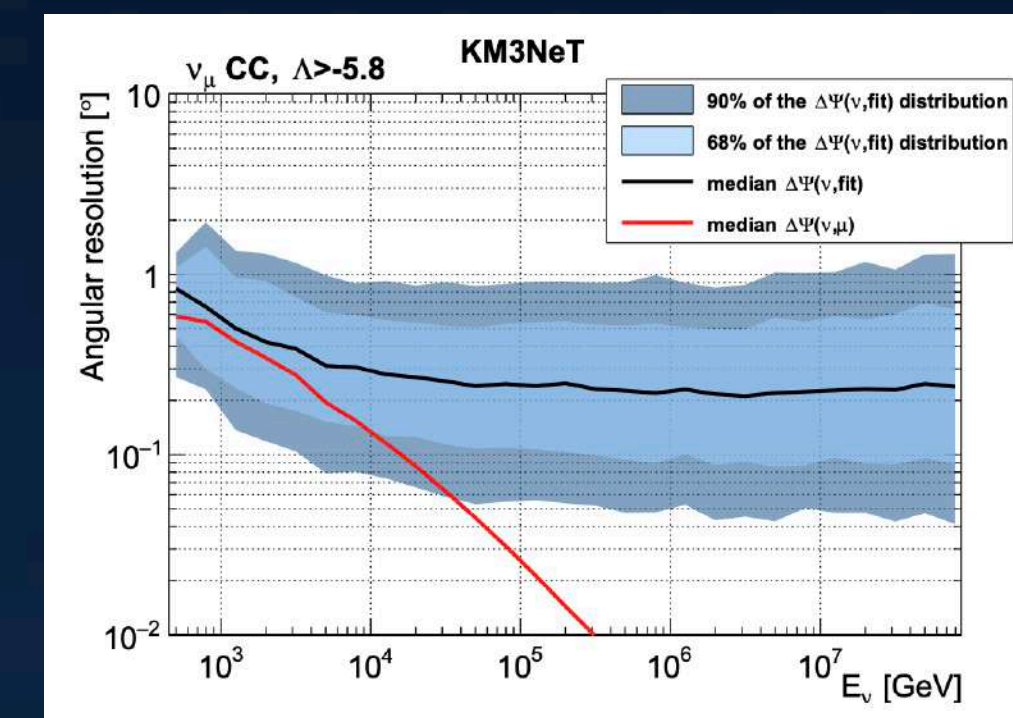
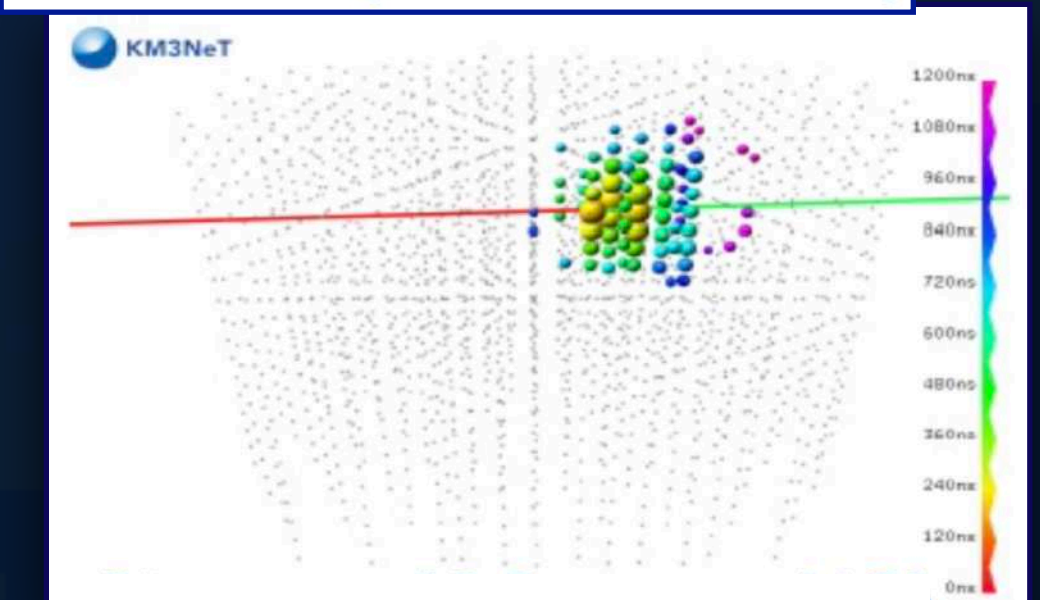
- ▶ Detection of Cherenkov photons induced by the neutrino interaction products using a 3D array of optical sensors
- ▶ Large volume of transparent medium to detect cosmic neutrinos —————> water/ice
- ▶ Time, position and amplitude of PMT pulses allow both direction and energy reconstruction



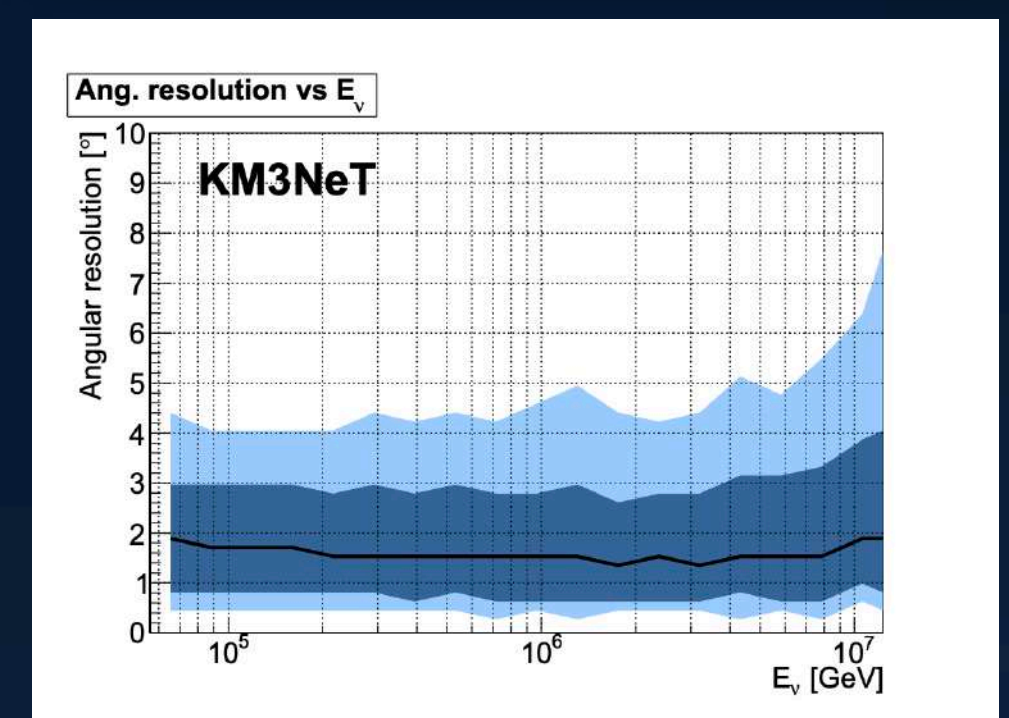
Tracks (CC  $\nu_\mu \nu_\tau$ )



Showers (CC  $\nu_e \nu_\tau$  – NC)



Angular  $\sim 0.1^\circ$  at 100 TeV



Angular  $\sim 1^\circ$  at 100 TeV



# The KM3NeT technology and infrastructure

The basic elements:

- ▶ DOM (Digital Optical Module)
- ▶ DU (Detection Unit)
- ▶ Seafloor network: electro-optical cables and JBs (Junction Boxes)

## DOM

- ▶ 17" glass sphere with 31 3" PMTs
- ▶ LED and Piezo
- ▶ Front-end electronics



## DU

- ▶ ~ 250/750 m (ORCA/ARCA)
- ▶ 18 DOMs (~9/36 m btw DOMs)
- ▶ Anchor
- ▶ Buoy



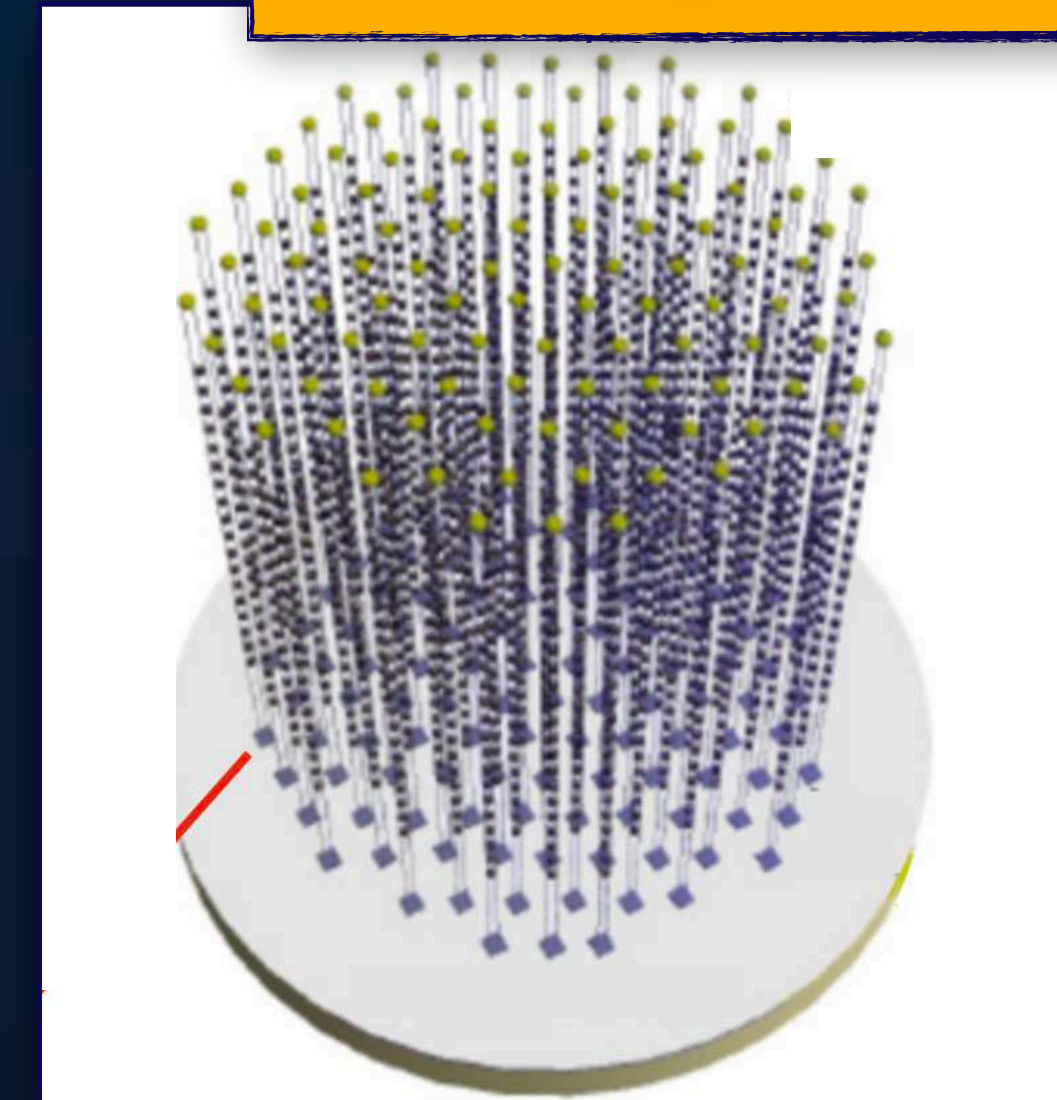
## JB





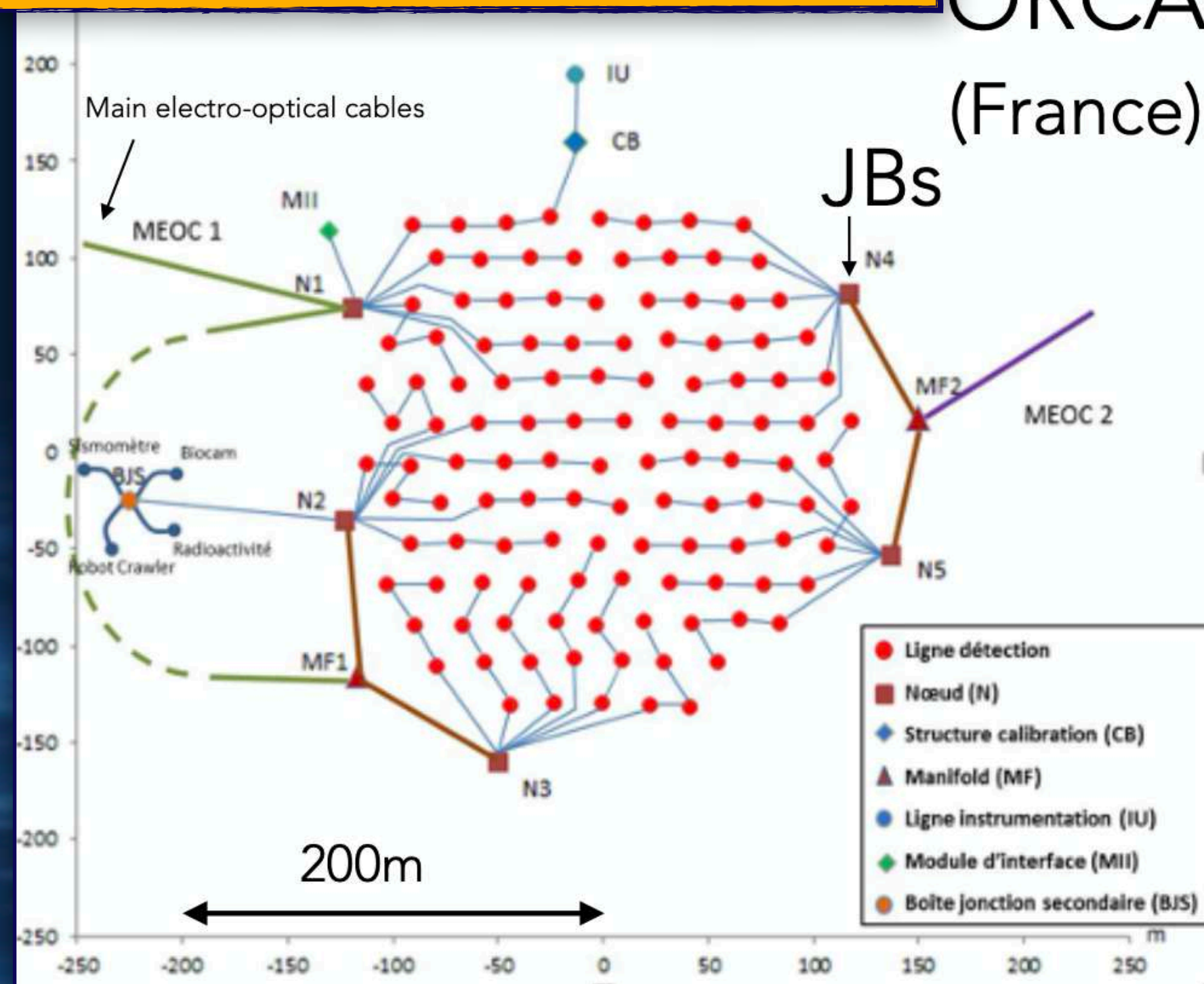
# The KM3NeT technology and infrastructure

Building Block

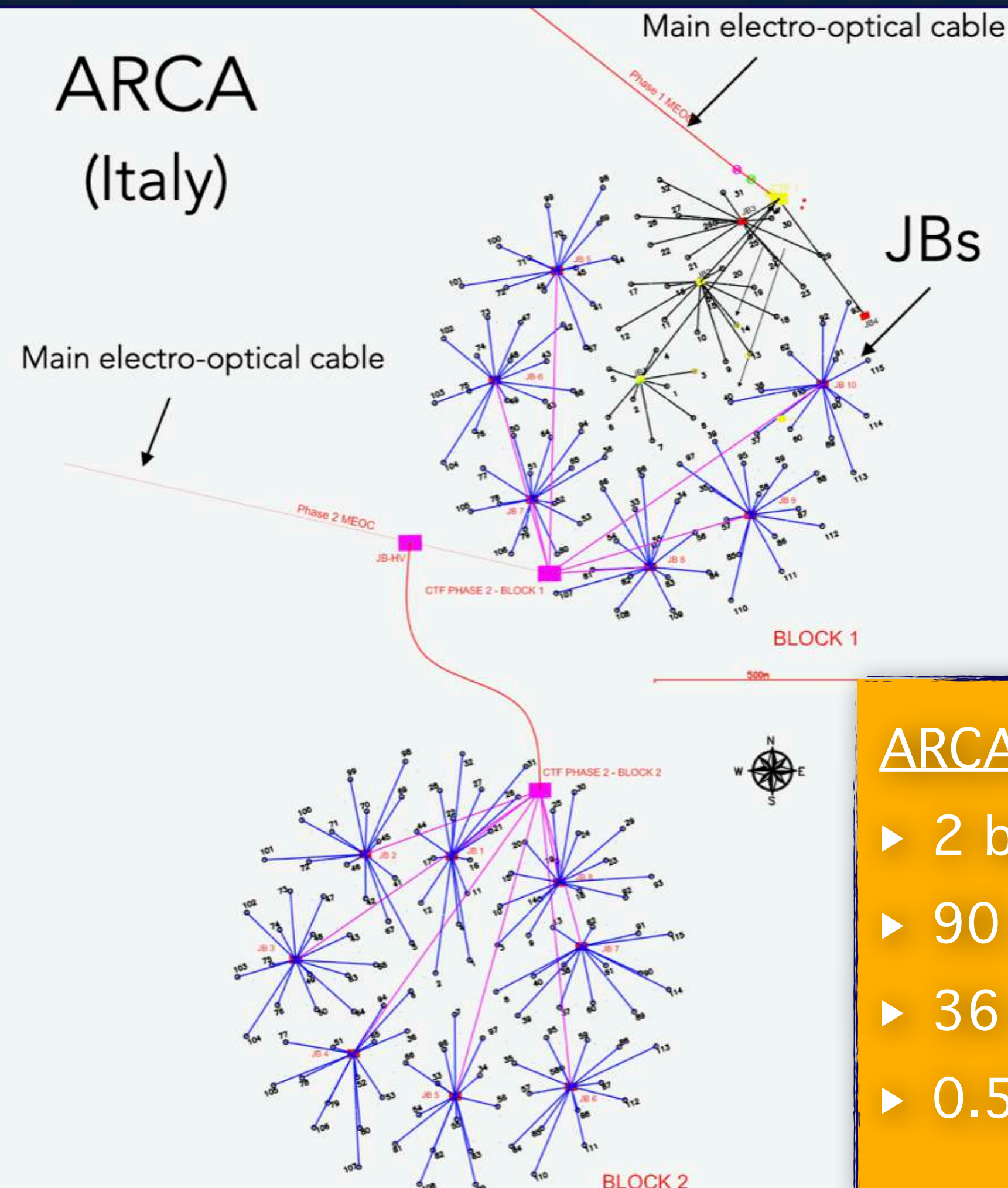


## ORCA:

- ▶ 1 building block (BB) of 115 DUs
- ▶ 20 m DU interspacing
- ▶ 9 m inter DOM spacing (7 Mton)



## ARCA (Italy)



## ARCA:

- ▶ 2 building blocks of 115 DUs
- ▶ 90 m DU interspacing
- ▶ 36 m inter DOM spacing
- ▶ 0.5 km<sup>3</sup>=500Mton/block



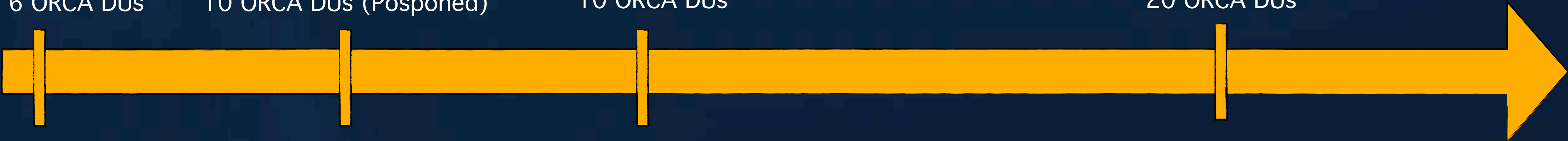
# Current status and next sea campaigns

April 2021  
6 ARCA DUs  
6 ORCA DUs

June 2021  
6 ARCA DUs  
10 ORCA DUs (Posponed)

Set/Oct 2021  
11 ARCA DUs (ongoing!)  
10 ORCA DUs

Spring 2022  
23 ARCA DUs  
20 ORCA DUs



September - October 2021  
5 DUs at ARCA site  
3 DUs + CU (Calibration Unit) at ORCA site

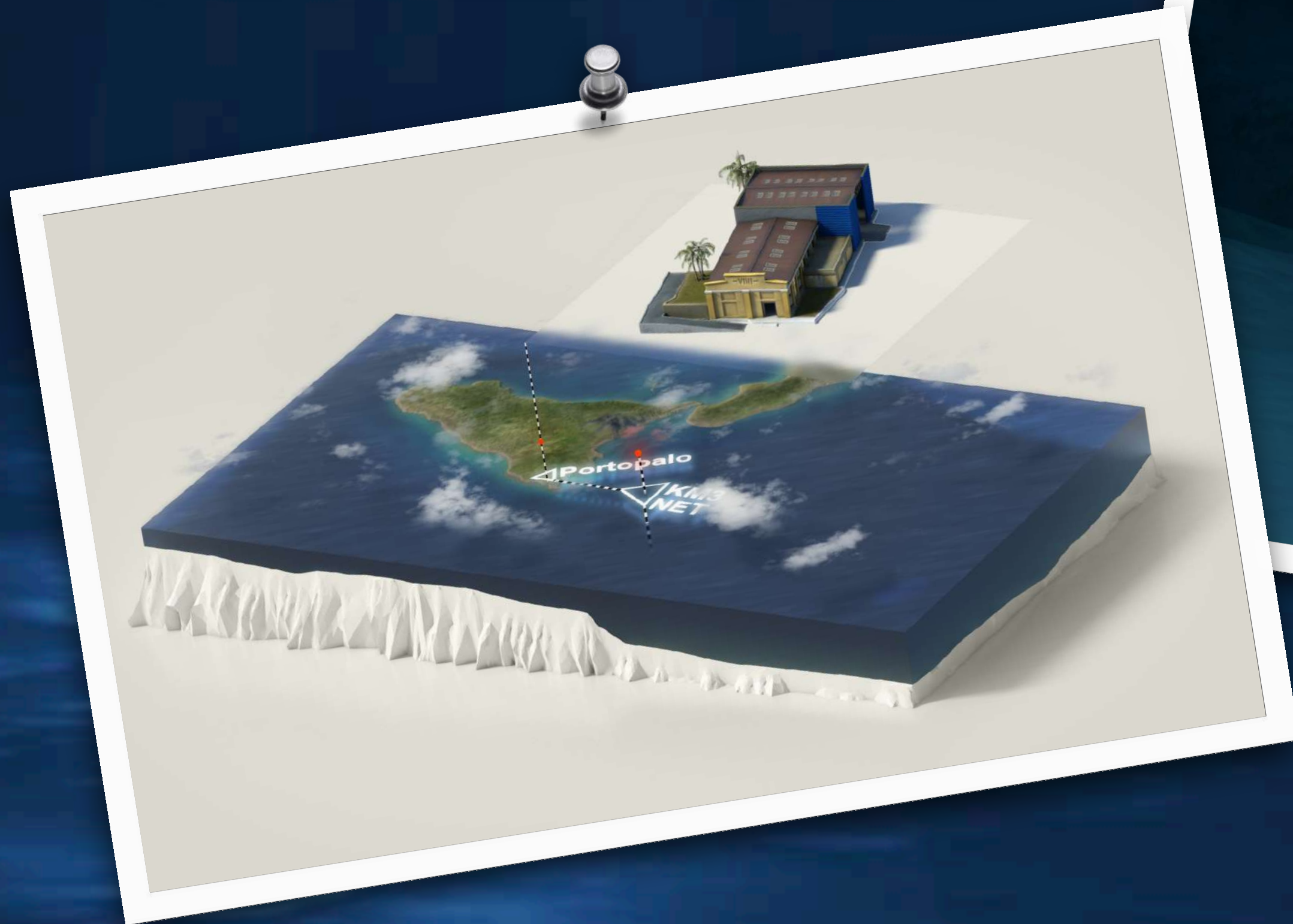


Spring 2022  
12 DUs + 1JB +1 CB (Calibration Base) +  
1 IU (Instrumentation Unit) at ARCA site  
7 DUs at ORCA site





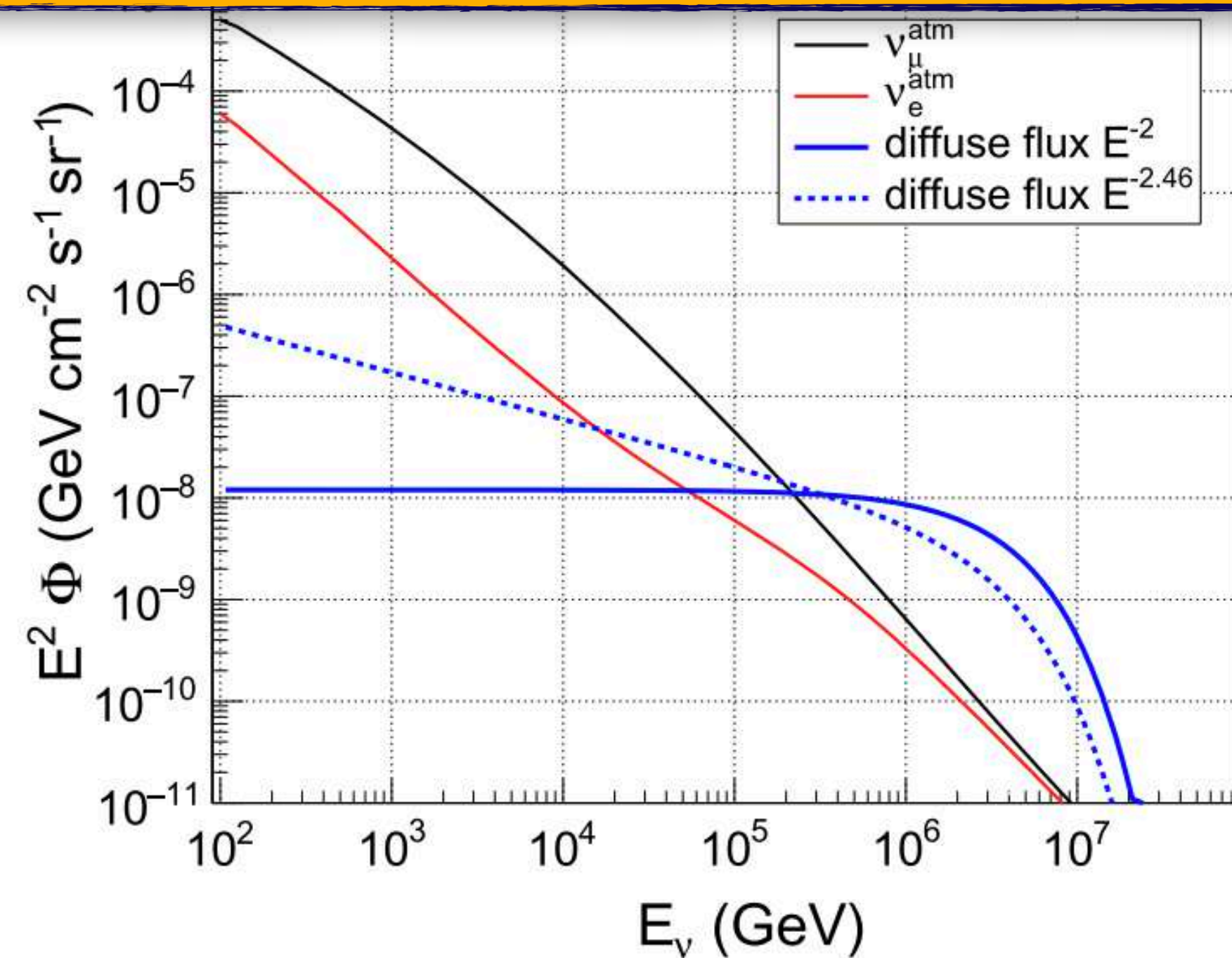
# Neutrino Astronomy at KM3NeT/ARCA





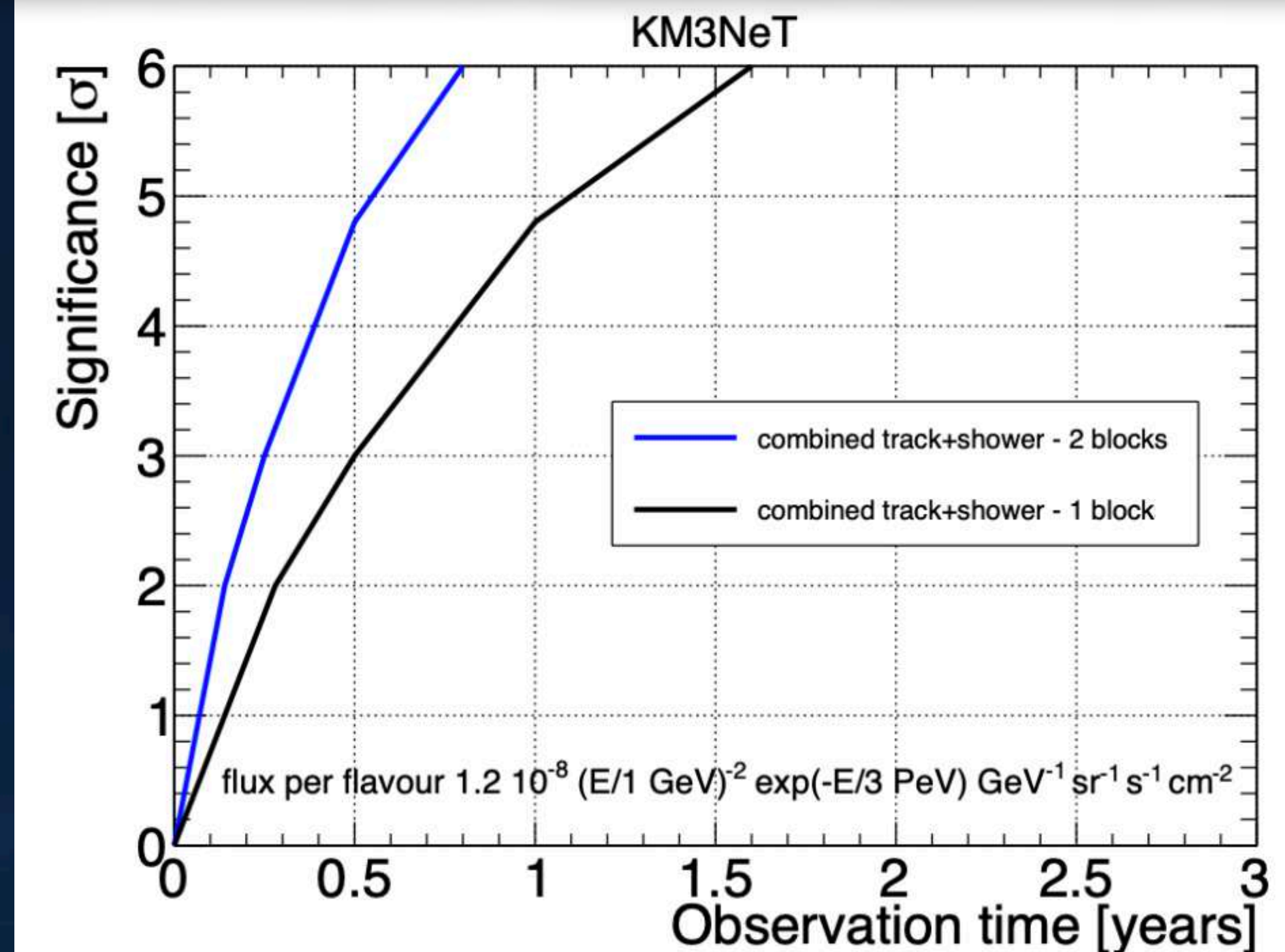
# Sensitivity to Diffuse Cosmic Neutrino Flux

- ▶ Goal: detection and detailed investigation of the Isotropic diffuse neutrino flux detected by IceCube (flavour-symmetric neutrino flux following a power law spectrum with a cut-off at a few PeV)
- ▶ Track + shower combined selection



Sensitivity:

- ▶ 5 $\sigma$  ~ 1 year with 1 block of ARCA (115 DUs)
- ▶ 5 $\sigma$  in ~ 0.5 year with 2 blocks of ARCA (2 x 115 DUs)

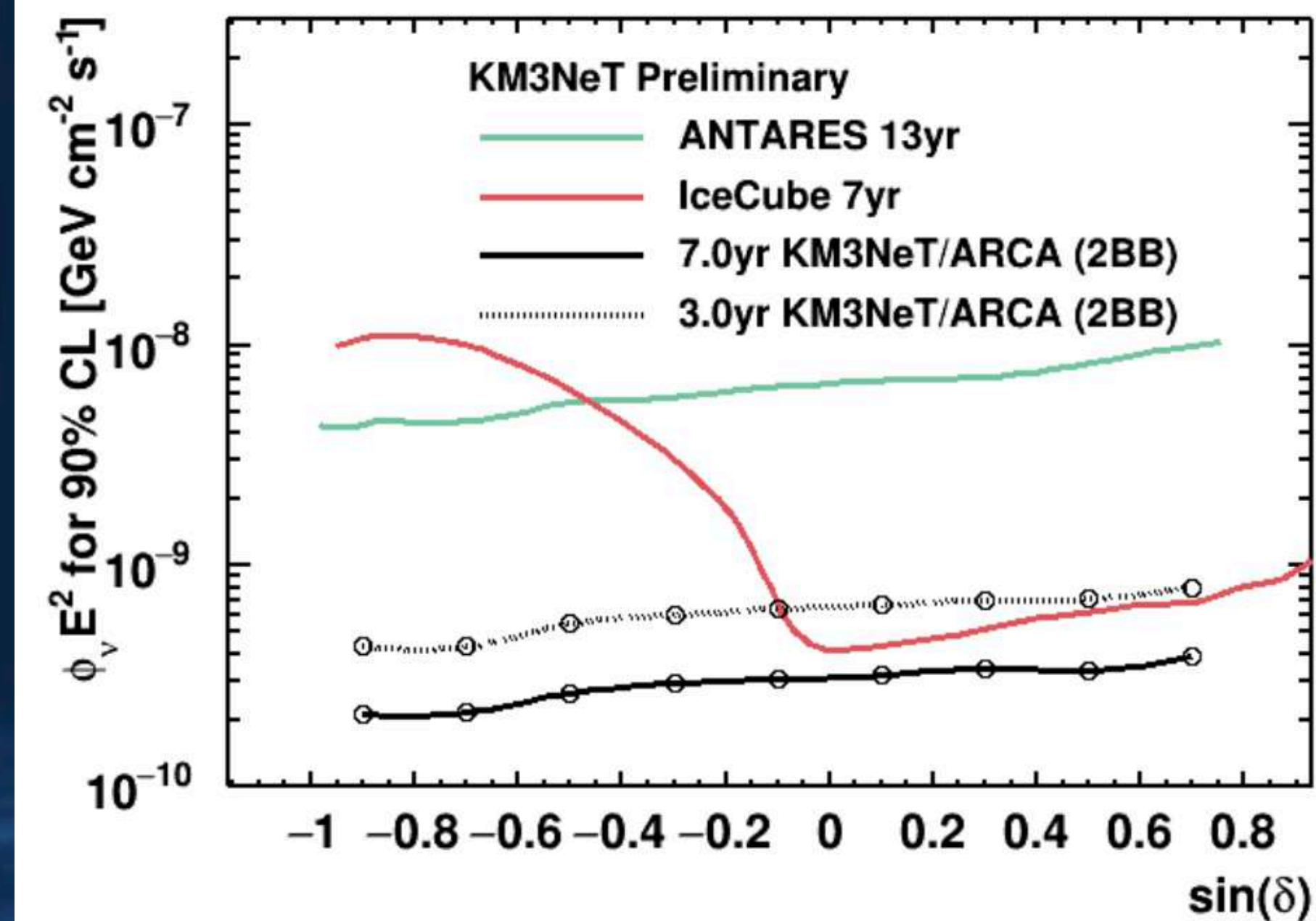




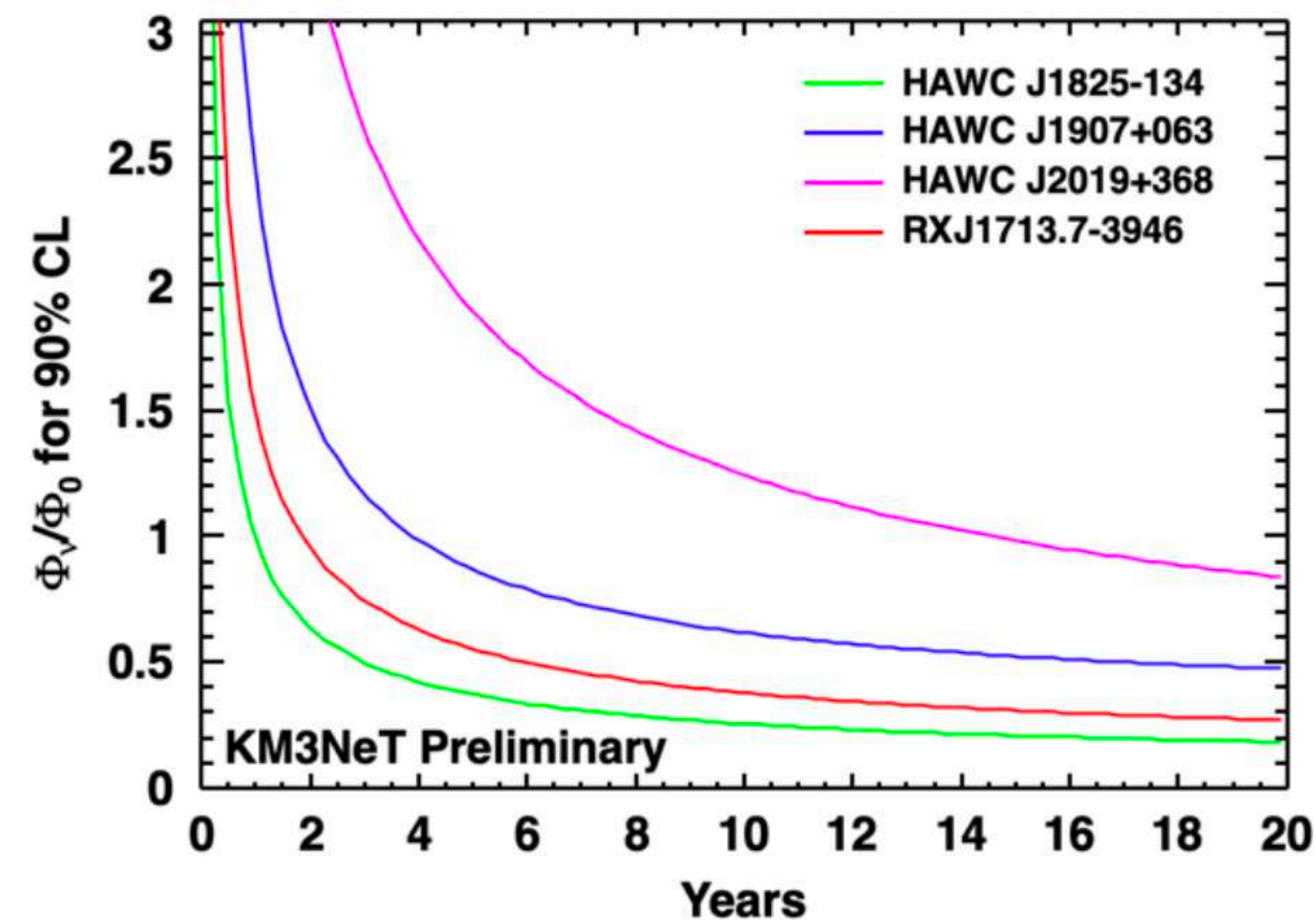
# Sensitivity to Point-like and Extended Neutrino Sources

Tracks reconstructed as horizontal or upward going ( $\theta < 100^\circ$ )

Sensitivity to point sources with an  $E^{-2}$  flux



Sensitivity to extended sources



Muller et al. [KM3NeT Coll.], PoS (ICRC2021) 1077

90% CL sensitivity to extended sources in less than 4 years. For the most promising source (HAWC J1825-134) achieved approximately in 1 year.



# Core-Collapse Supernovae Neutrinos

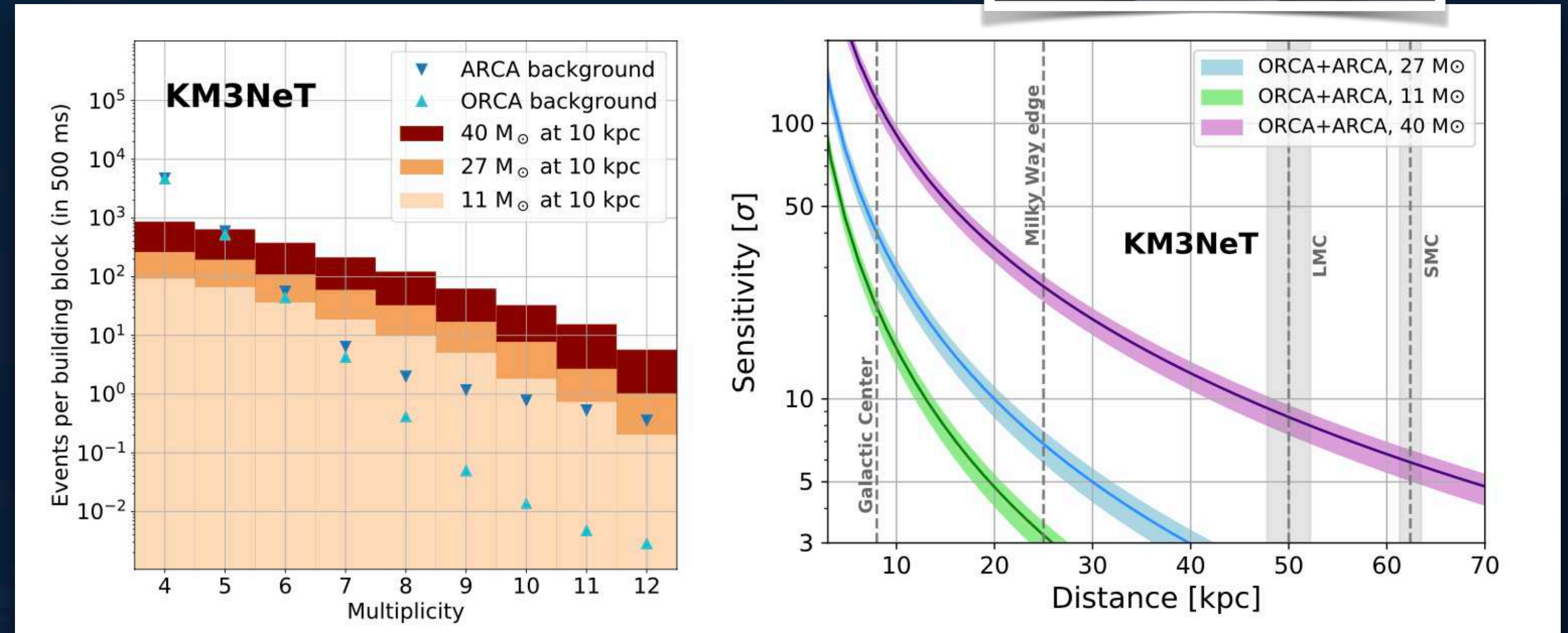
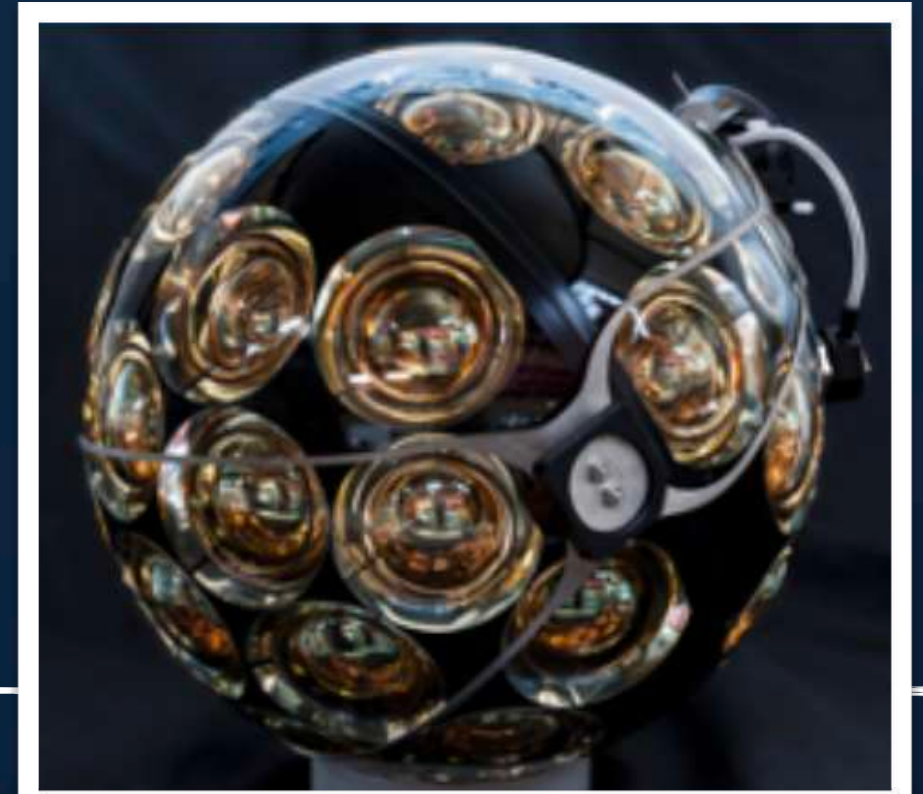
Neutrinos produced when a star's core collapse at the end of its evolution.

Main interaction channels in water:

- ▶ inverse beta decay of electron anti-neutrinos on free protons
- ▶ elastic scattering on electrons
- ▶ interactions with oxygen nuclei

The sensitivity of KM3NeT to a CCSN neutrino burst is evaluated considering the variation of the multiplicity coincidence rate after the filter, in a 500 ms time window.

**Multiplicity:** number of PMT hits within coincidence window in a DOM.



Aiello et al. [KM3NeT Coll.], Eur. Phys. J. C 81 (2021) 445

ARCA6 and ORCA6 already participating to the SNEWS (SuperNovae Early Warning System) network aiming for the detection of supernovae in our Galaxy.

In the final configuration KM3NeT detectors will have a  $5\sigma$  sensitivity for more than 95% of the Galactic progenitors (11  $M_{\odot}$ ).



# Real-time Multimessenger program

Goals:

- ▶ Trigger neutrino alerts to the astronomy community
- ▶ look for time/space coincidence around external electromagnetic and multi-messenger triggers

Based on:

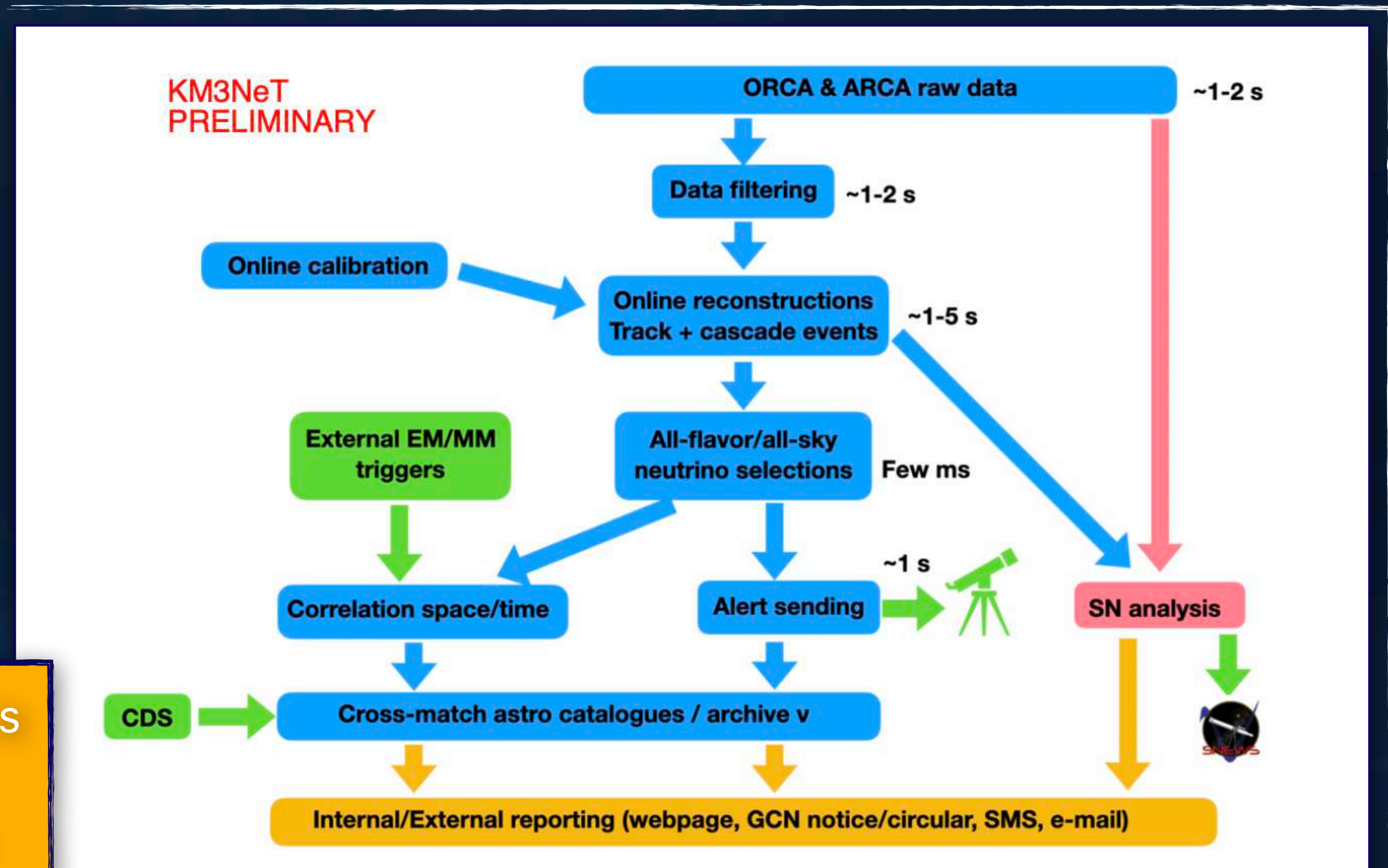
- ▶ Fast online reconstruction
- ▶ Fast selection of high-purity neutrino sample

The program is based on two pipelines:

1. The MeV CCSN monitoring pipeline (ORCA)
2. The GeV-PeV neutrino alert pipeline (ARCA)

The real-time multi-messenger framework is under active development.

Public KM3NeT multi-messenger alerts will start in 2022!





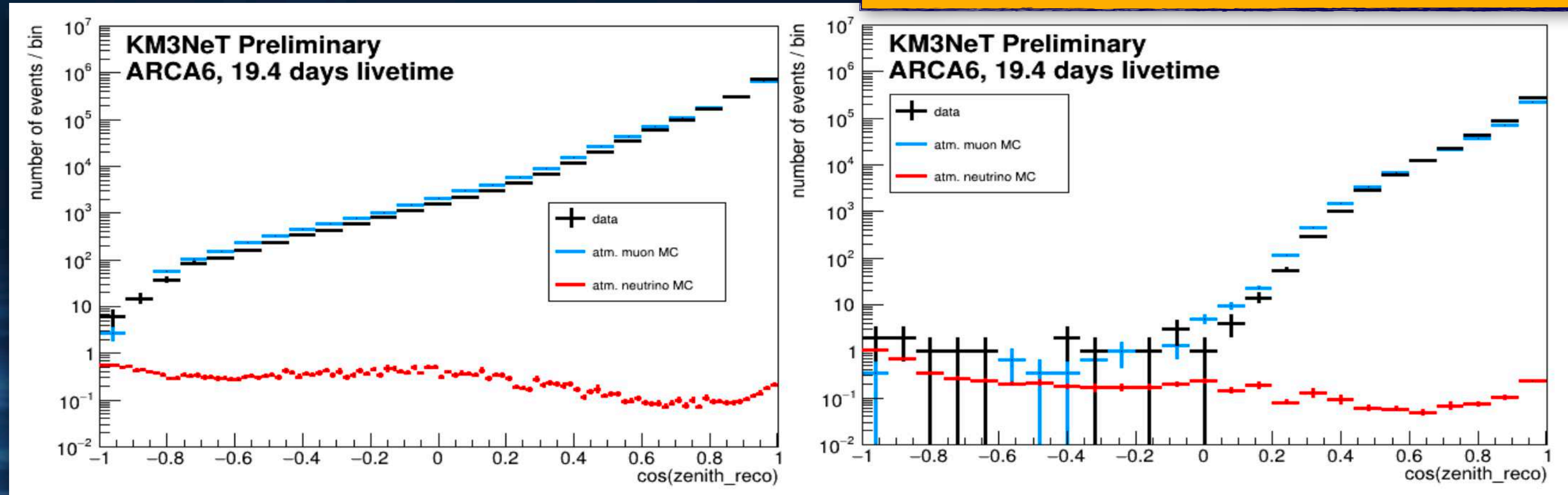
# Selection of atmospheric neutrino flux

For this analysis a total livetime of ARCA6 data of  $\sim 19$  days is used. Selection criteria applied to remove the atmospheric muon bkg:

- 15 events observed as upgoing
- 4  $\nu$ -events expected from MC
- 7  $\mu$ -events expected from MC

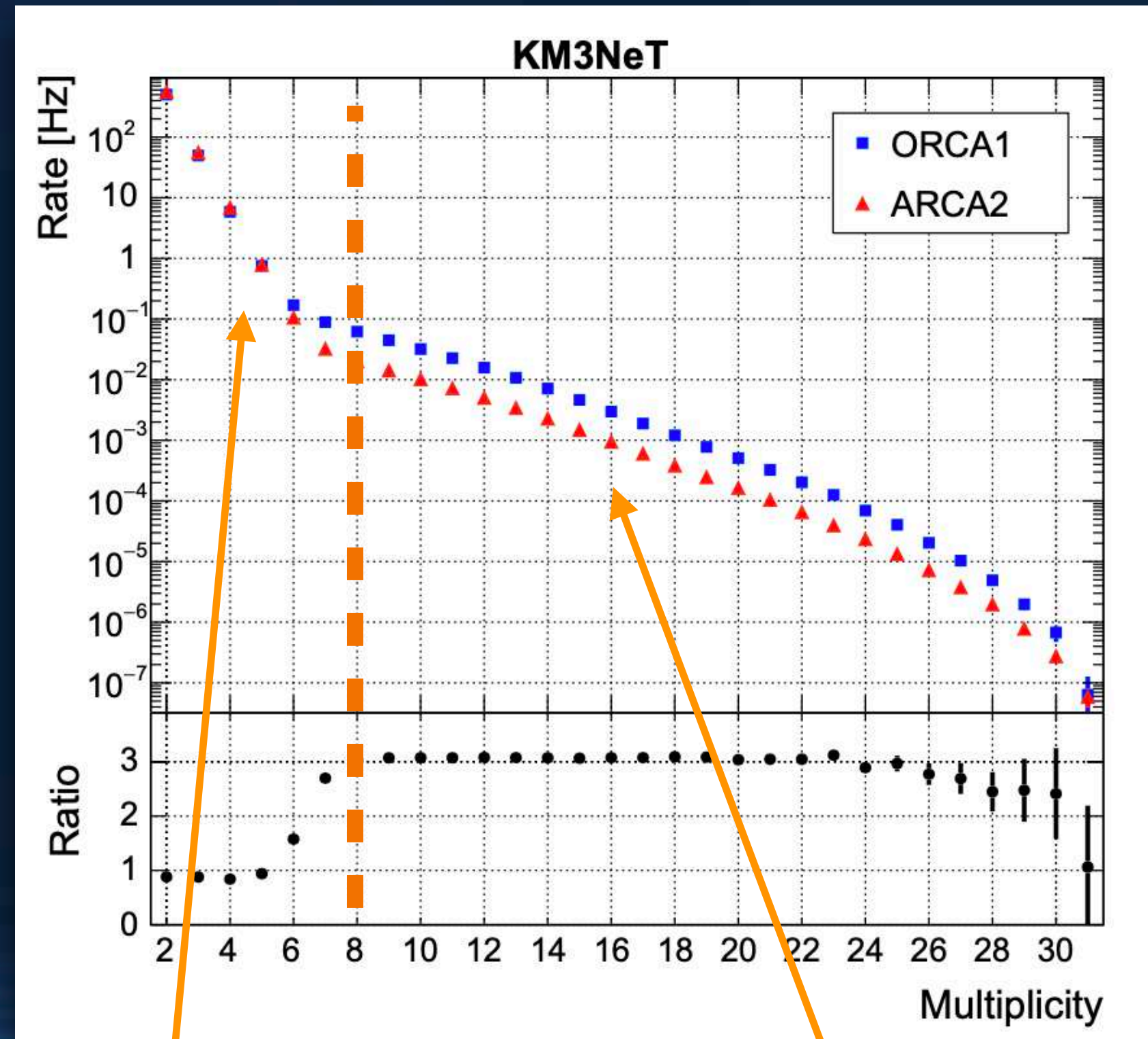
1-3% of the full ARCA volume:

- detection of atmospheric neutrinos
- powerful reduction of the atmospheric muon contribution





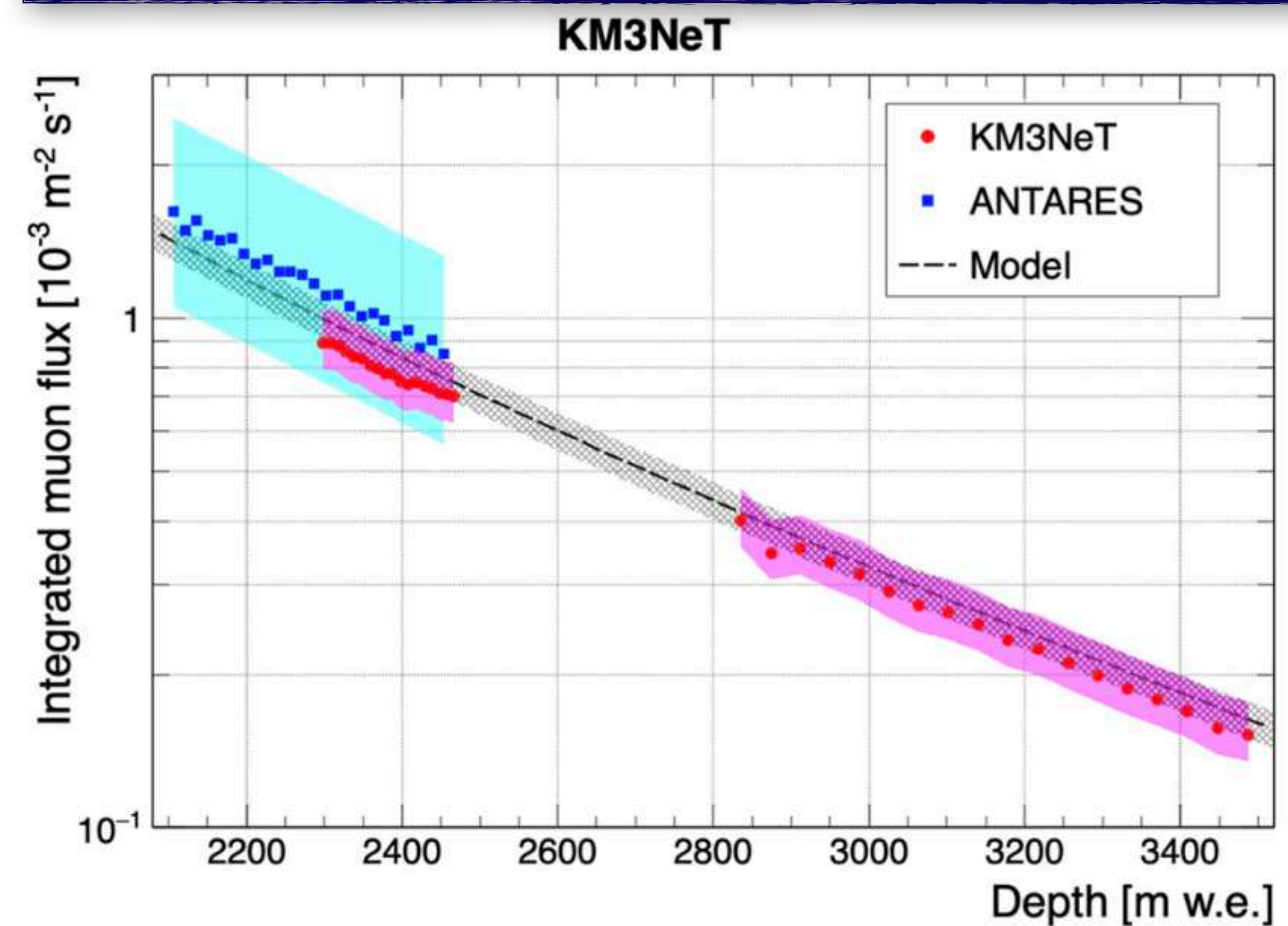
# Measurement of atmospheric muon flux



Optical background ( $^{40}\text{K}$ )

Atmospheric muons

- ▶ Measurement of single DOM coincidences
- ▶ Validation of the KM3NeT calibration procedure
- ▶ muon flux measurement compatible with Bugaev model and ANTARES data





# Sensitivity to transient sources

- ▶ The search method is based on a binned cut-and-count technique

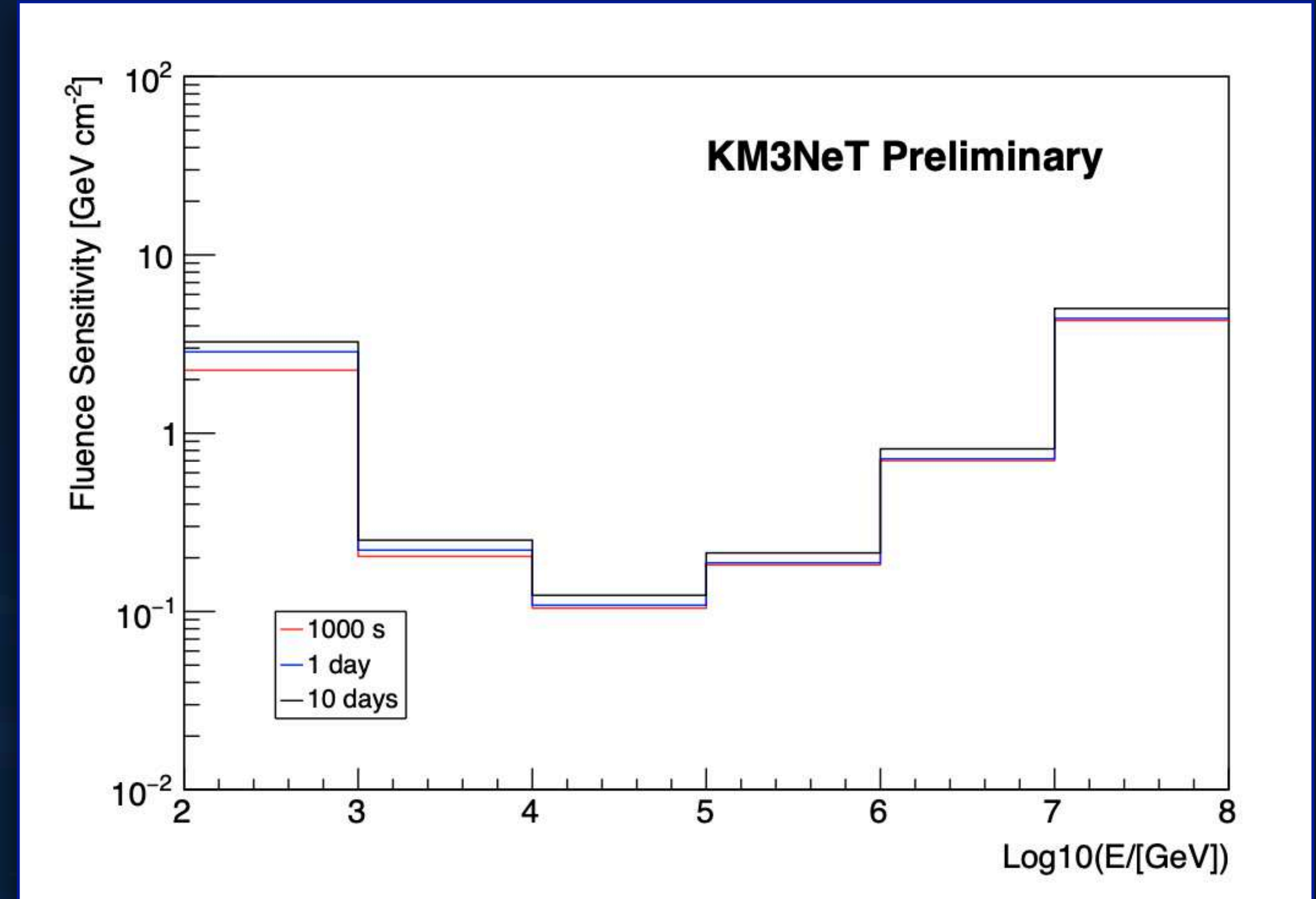
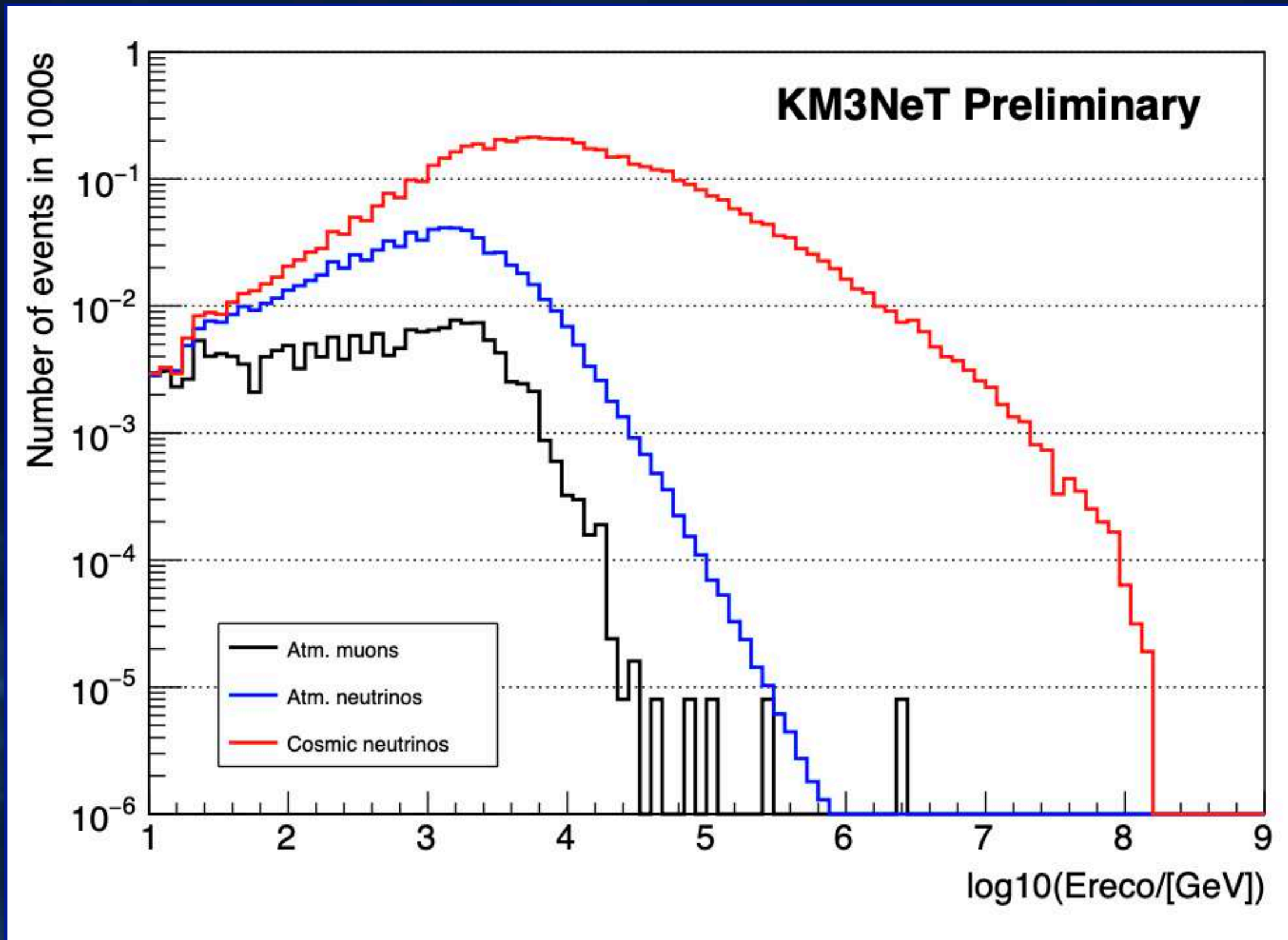
- ▶ Cosmic neutrinos spectrum:

$$\Phi = \Phi_0 E^{-\gamma}$$

$$\gamma = 2.0$$

$$\Phi_0 = 10^{-9} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

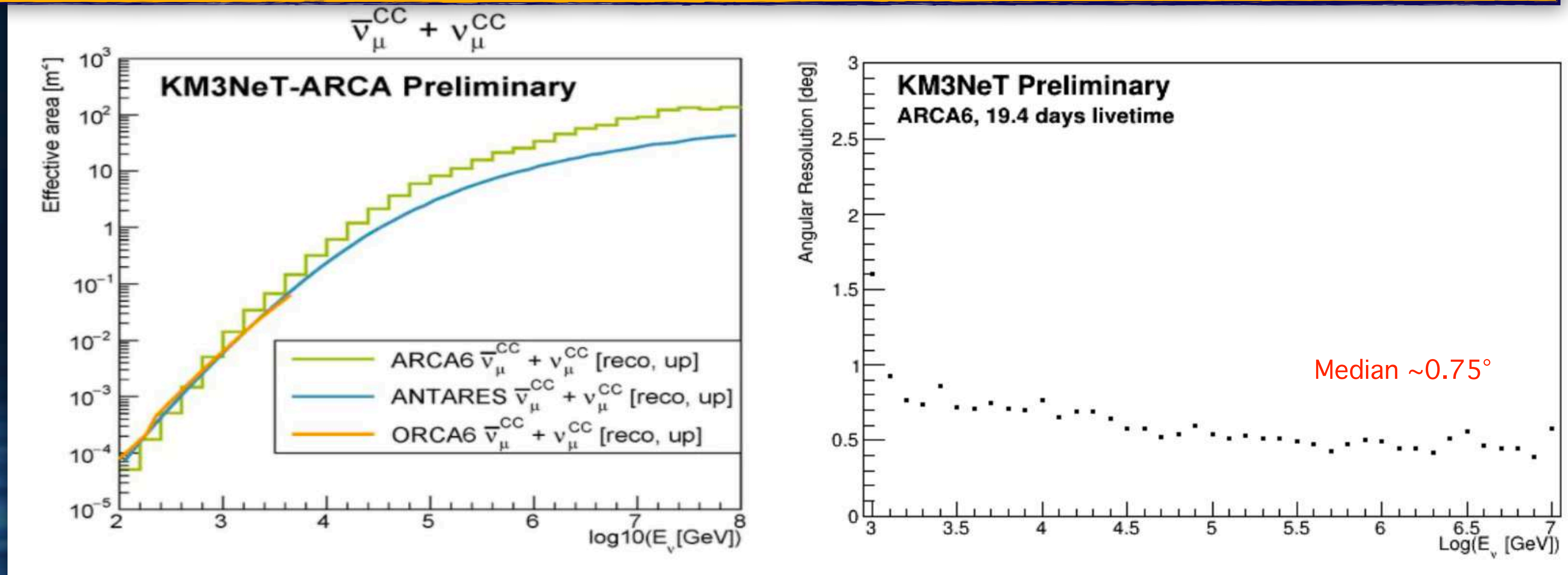
- ▶ Time window 1000s





# KM3NeT/ARCA6 Performances

- ▶ For  $E < 10$  TeV ARCA has comparable effective area to the current ORCA configuration (ORCA6) and to ANTARES
- ▶ For  $E > 100$  TeV ARCA6 is expected to perform significantly better than ANTARES



Sinopoulou et al. [KM3NeT Coll.], PoS (ICRC2021) 1134



# Summary & Outlook

- ▶ First KM3NeT/ARCA DU operating since 2015 + 5 more DUs in stable data taking since May 2021
- ▶ First 6 KM3NeT/ORCA DUs operating since 2019
- ▶ Well established underwater technology and calibration procedures
- ▶ The good Data/MC agreement reveals the good understanding of the detector
- ▶ KM3NeT/ARCA effective area already better than ANTARES
- ▶ The good angular resolution will let KM3NeT/ARCA to contribute enormously to the neutrino astronomy

The deployment of 5 KM3NeT/ARCA DUs is ongoing!!



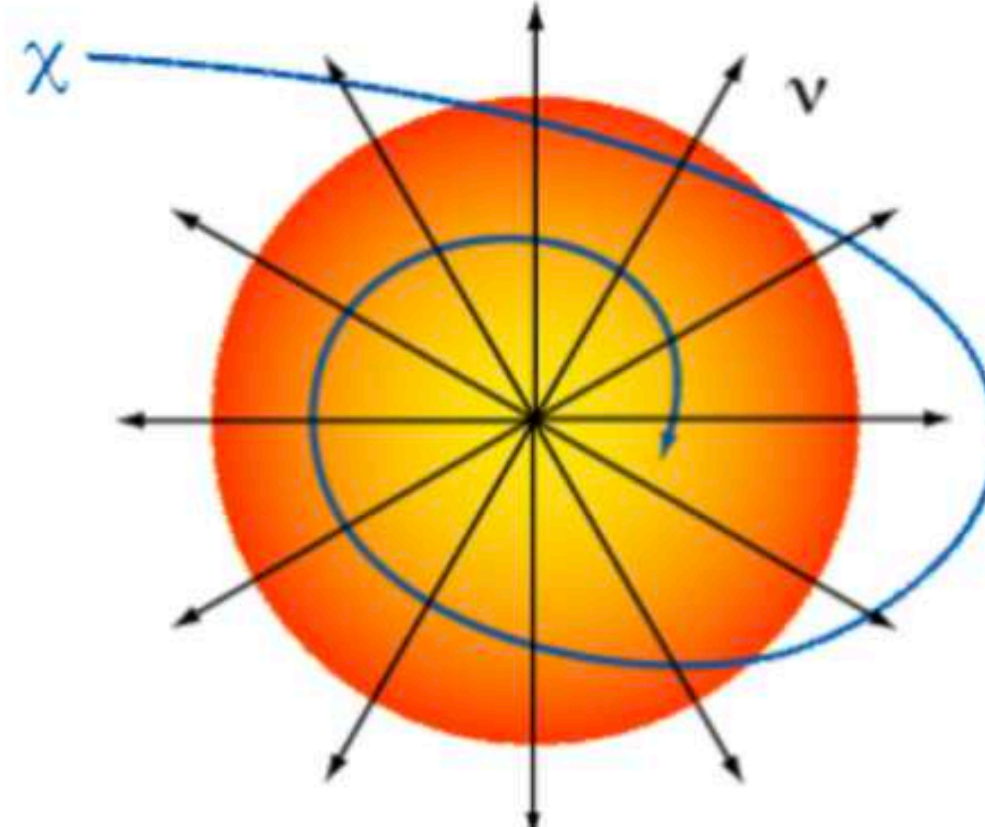
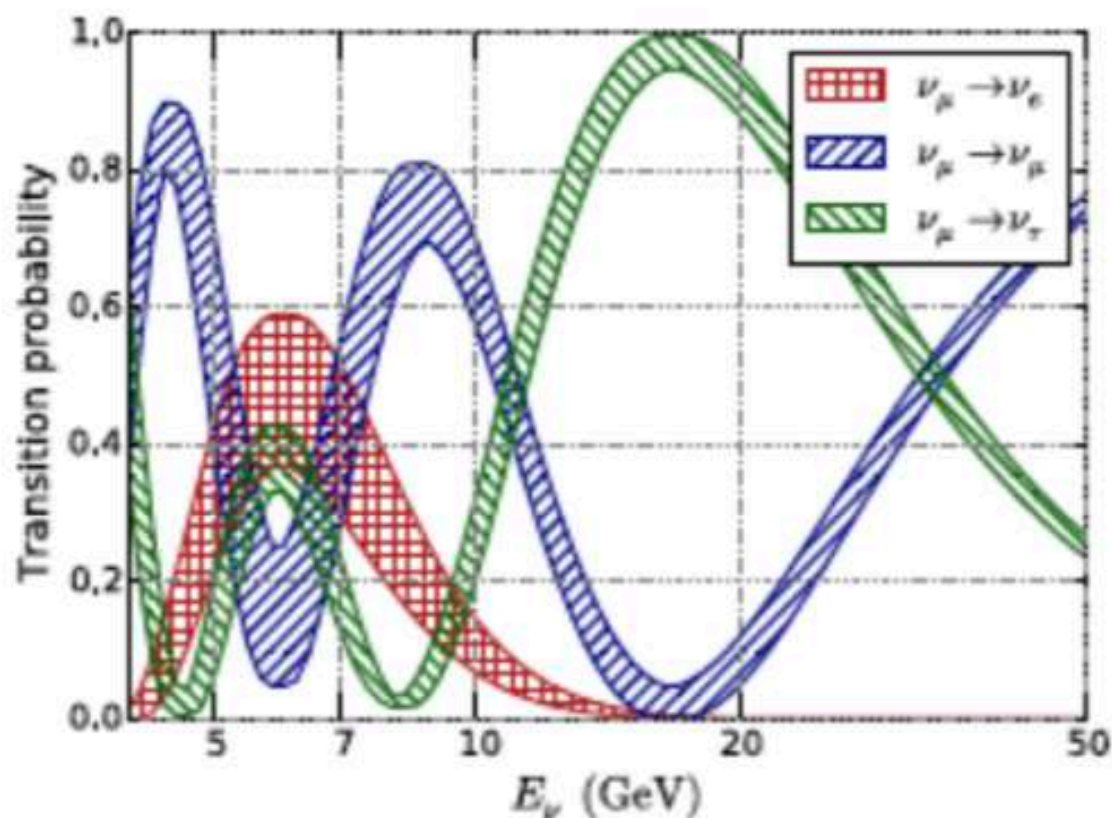
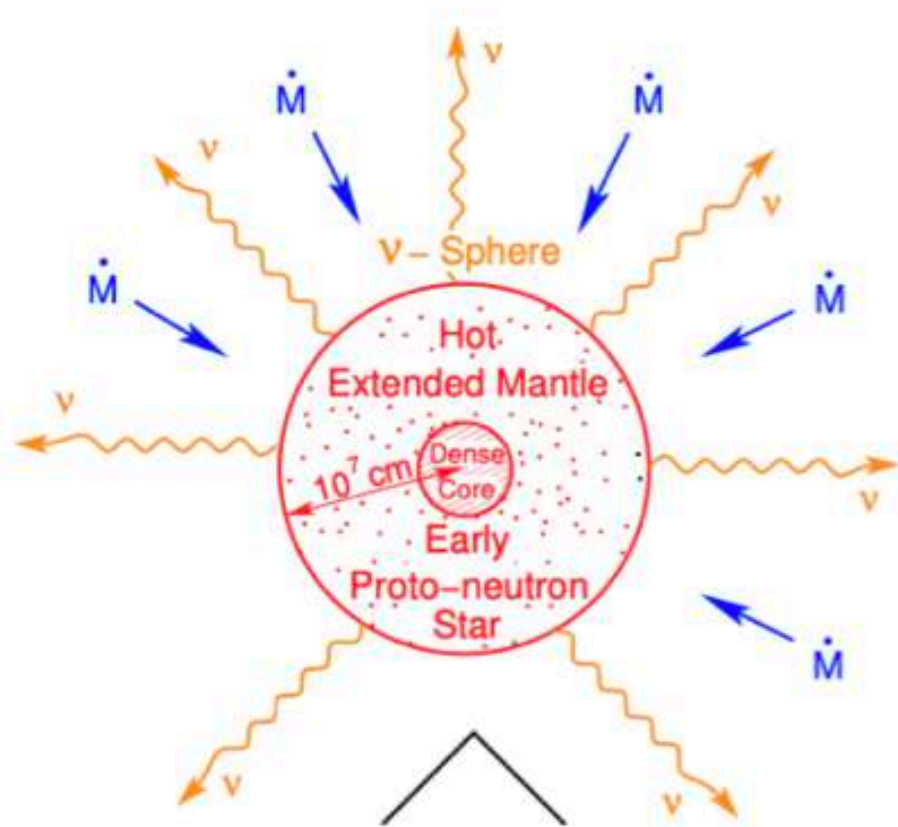
The background of the slide is a photograph of a sunset or sunrise over a body of water. The sky is a deep, dark blue, and the water in the foreground is a lighter, shimmering blue with gentle ripples. In the far distance, a city skyline is visible, with several tall buildings illuminated by lights, suggesting an urban setting at dusk or dawn. The overall mood is serene and contemplative.

# Backup slides



# Neutrino telescopes: science with a multi-energy scale

NEUTRINO ENERGY FROM MeV TO PeV



Super Novae explosion  
MeV

Neutrino oscillation  
GeV

Dark Matter (\*)  
TeV

HE neutrinos  
Multi-messenger program  
PeV

ARCA

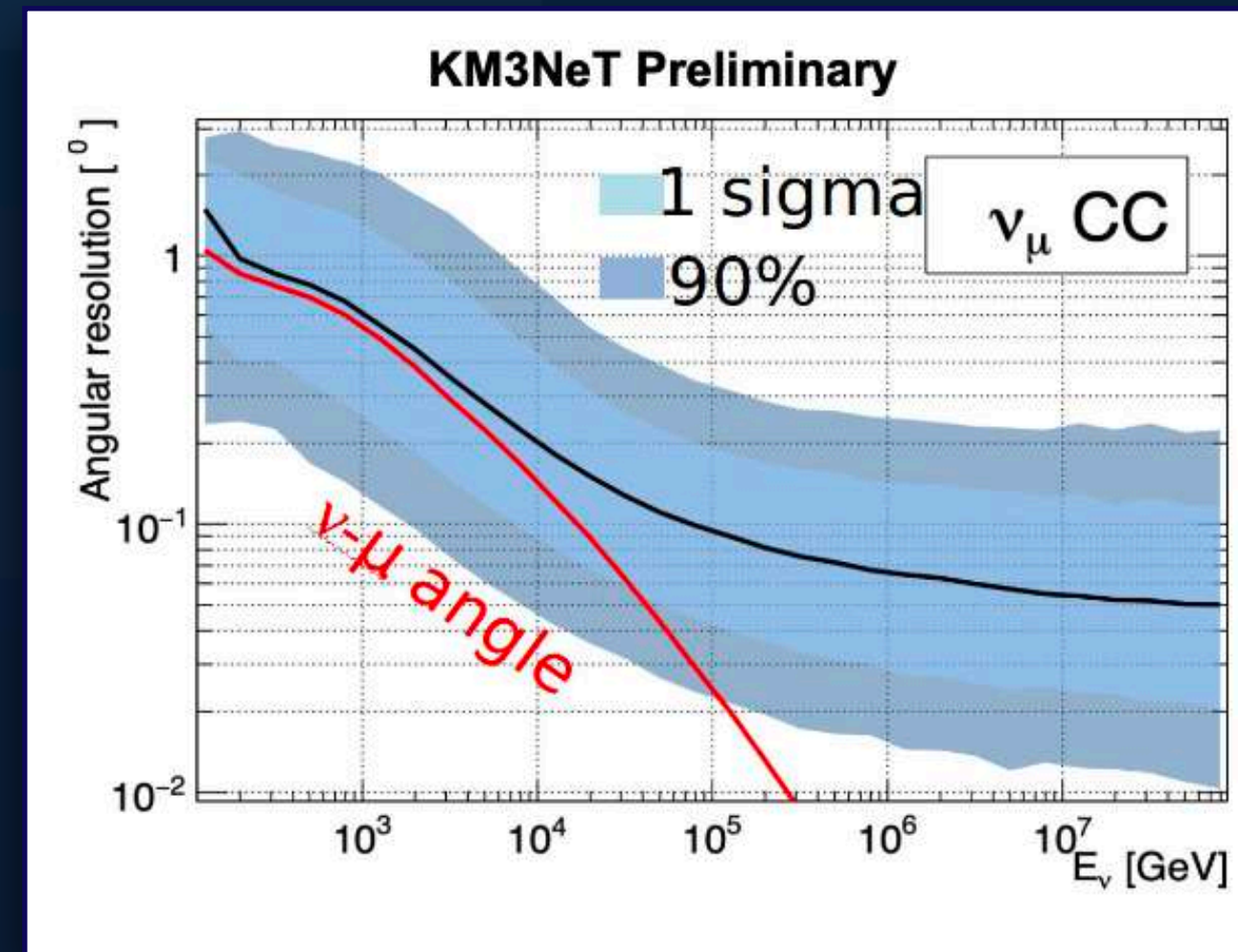
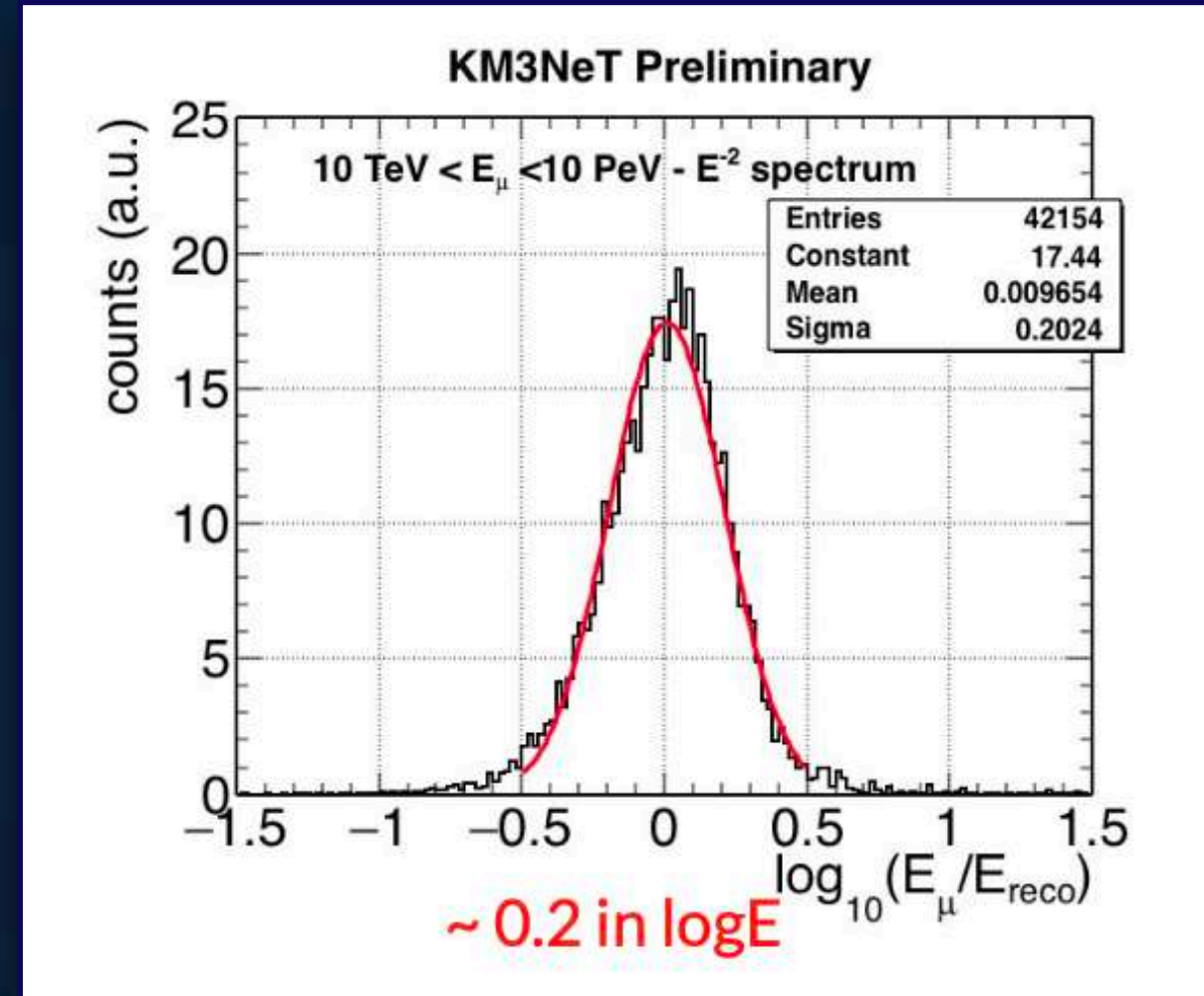
ARCA

ORCA



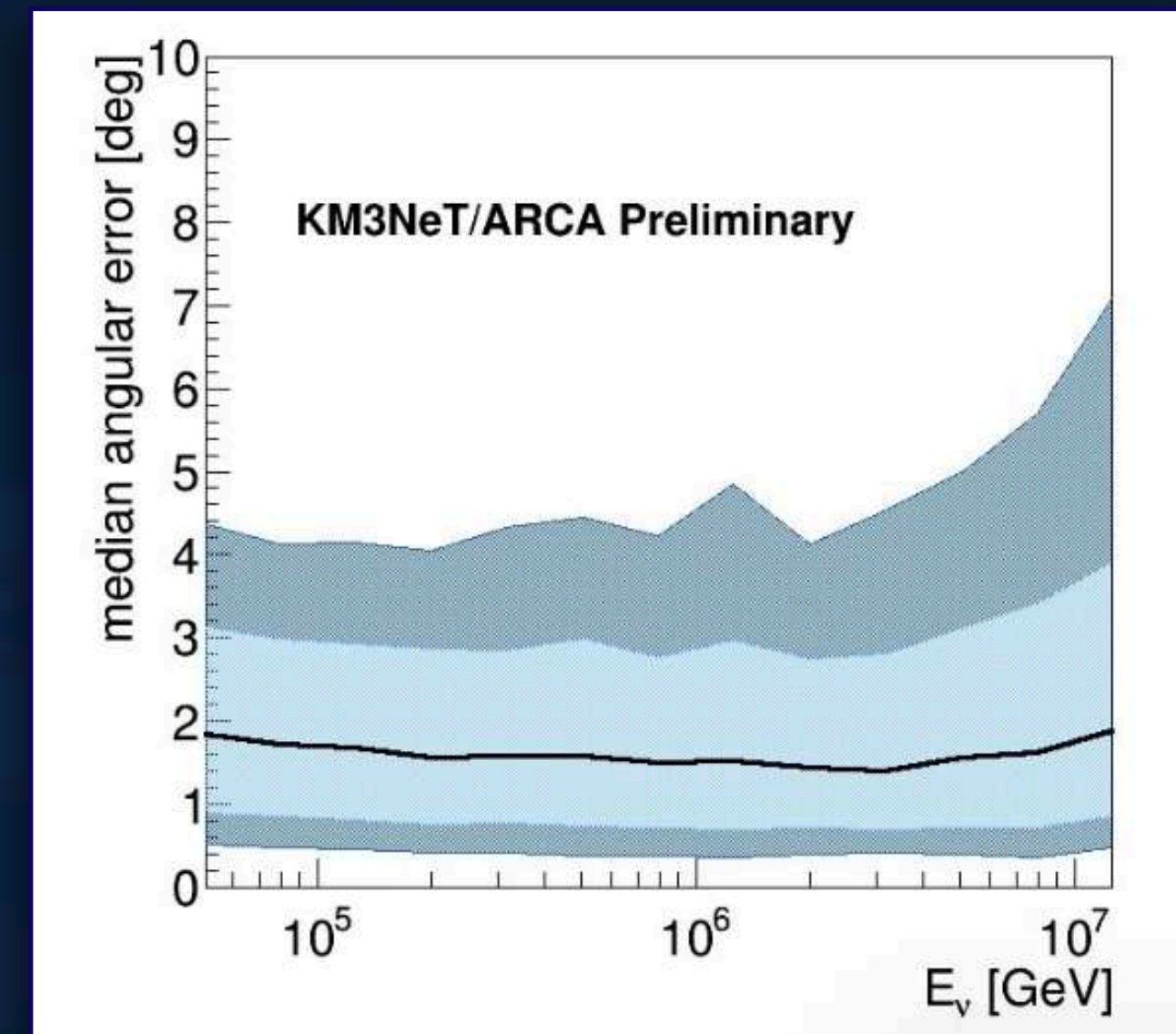
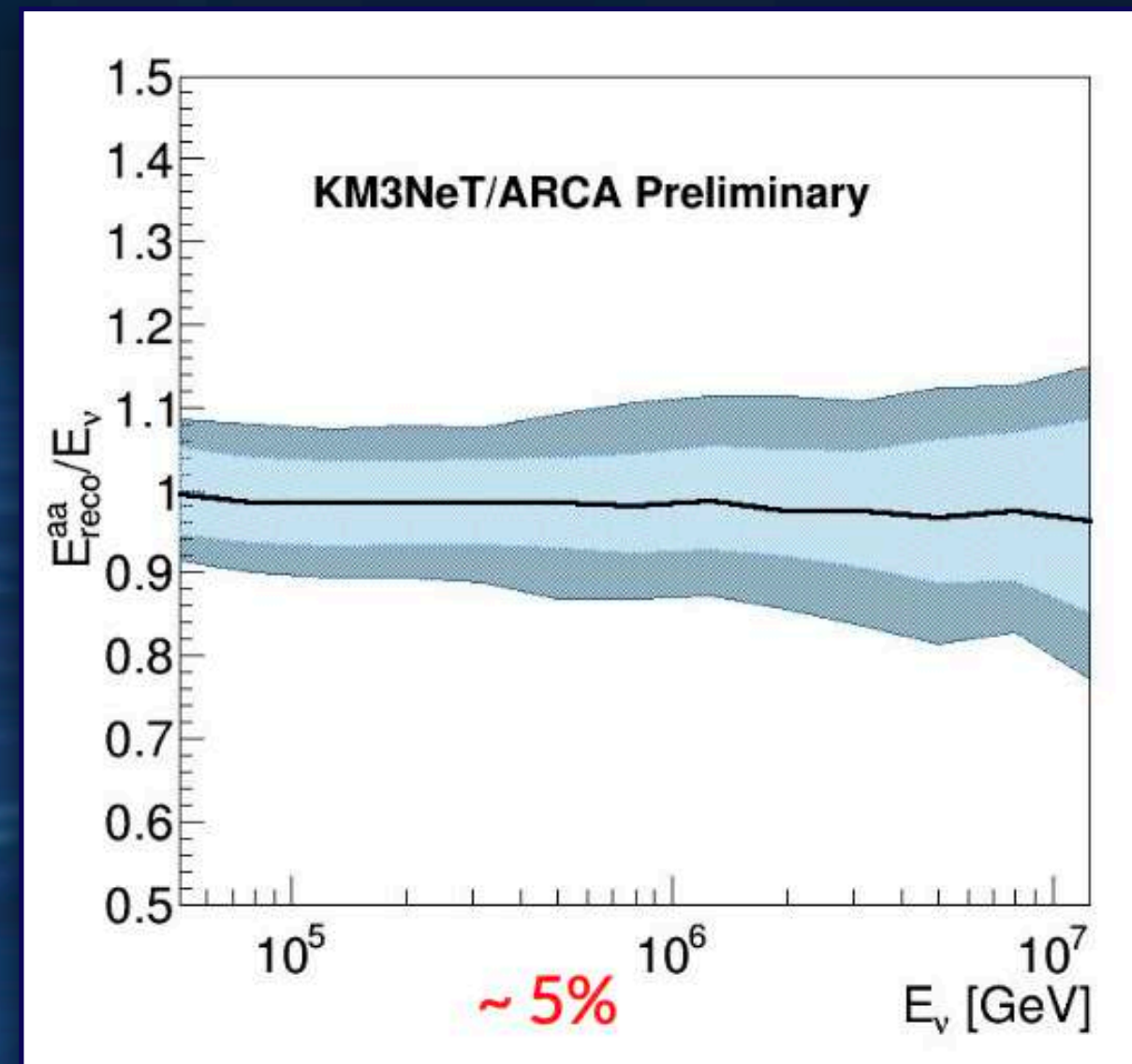
# ARCA reconstruction resolutions

## ► Track:



Track median angular resolution  
<  $0.1^\circ$  at  $E > 100$  TeV

## ► Shower:



Shower median angular  
resolution <  $2^\circ$