



# The KM3NeT infrastructure: status, perspectives and preliminary results

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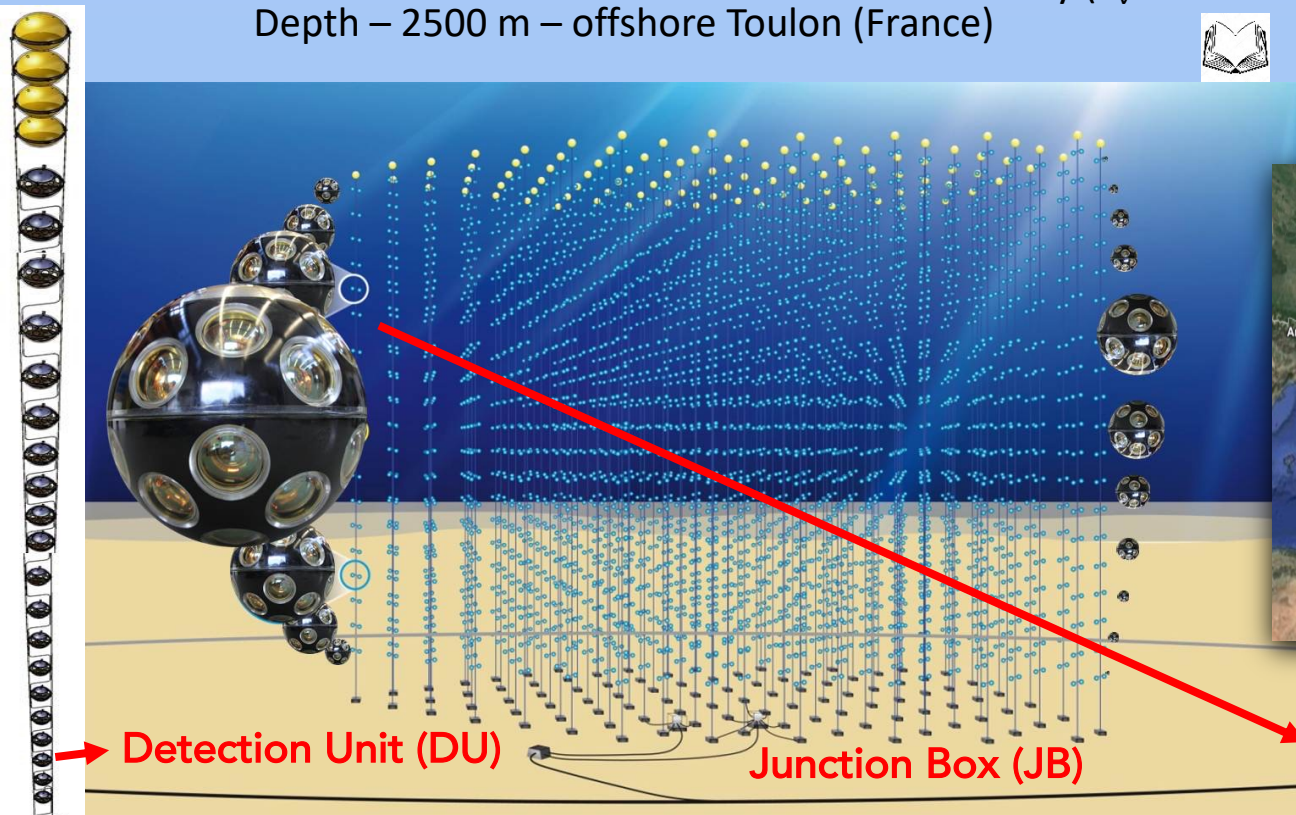
# The KM3NeT detectors

KM3NeT is a research infrastructure underwater in the Mediterranean Sea that will host a network of neutrino telescopes:

- KM3NeT/ARCA** (Astroparticle Research with Cosmics in the Abyss)
  - discovery and observation of high energy cosmic neutrino sources ( $E_\nu \sim \text{GeV-PeV}$ )
  - Depth – 3500 m – offshore Sicily (Italy)
- KM3NeT/ORCA** (Oscillation Research with Cosmics in the Abyss)
  - determination of the neutrino mass hierarchy ( $E_\nu \sim \text{MeV - GeV}$ )
  - Depth – 2500 m – offshore Toulon (France)



**KM3NeT 2.0 Letter of Intent:  
J.Phys. G43 (2016) 084001**



Detection Unit (DU)

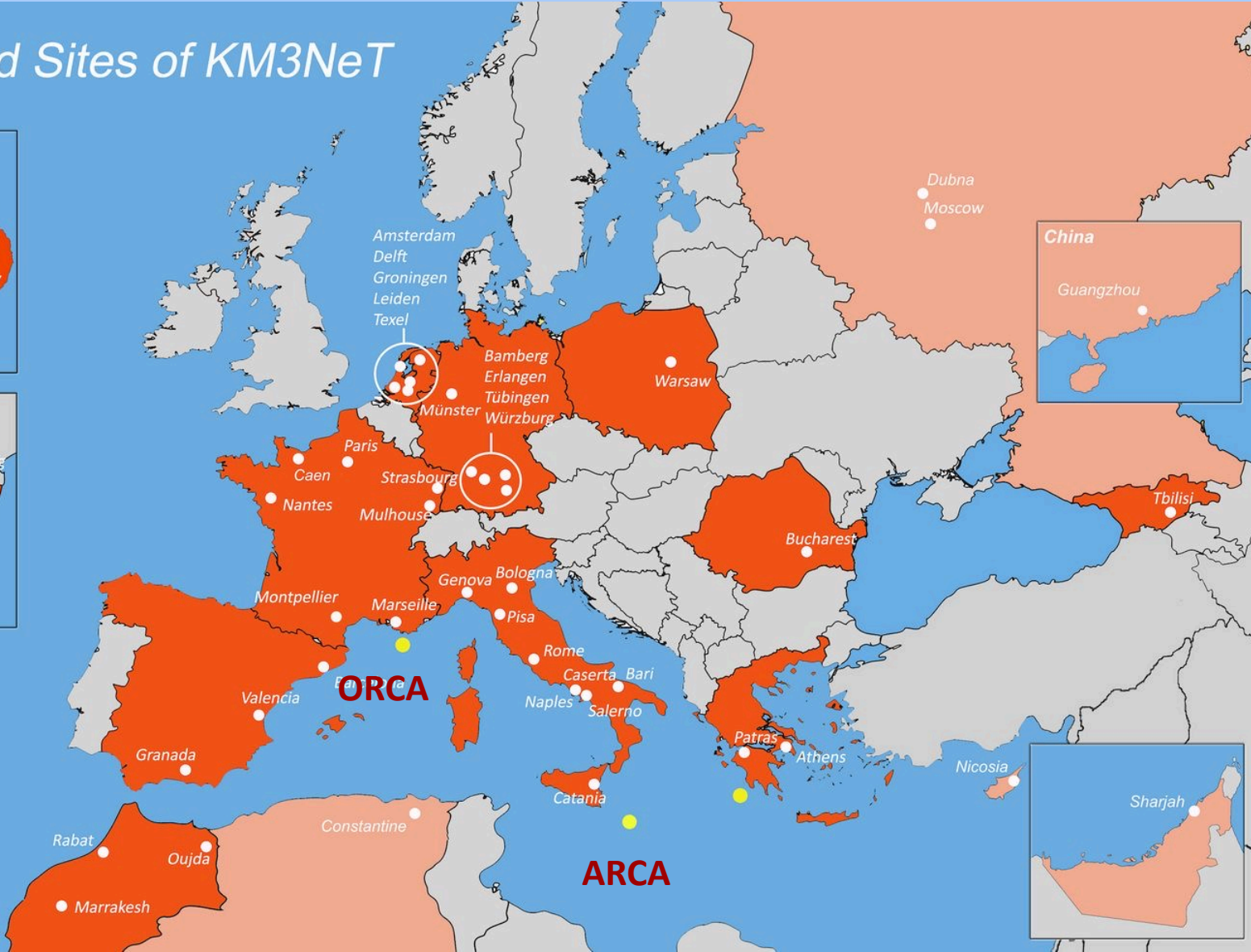
Junction Box (JB)

Optical sensor (DOM)  
31 PMTs of 3 inches

# The collaboration

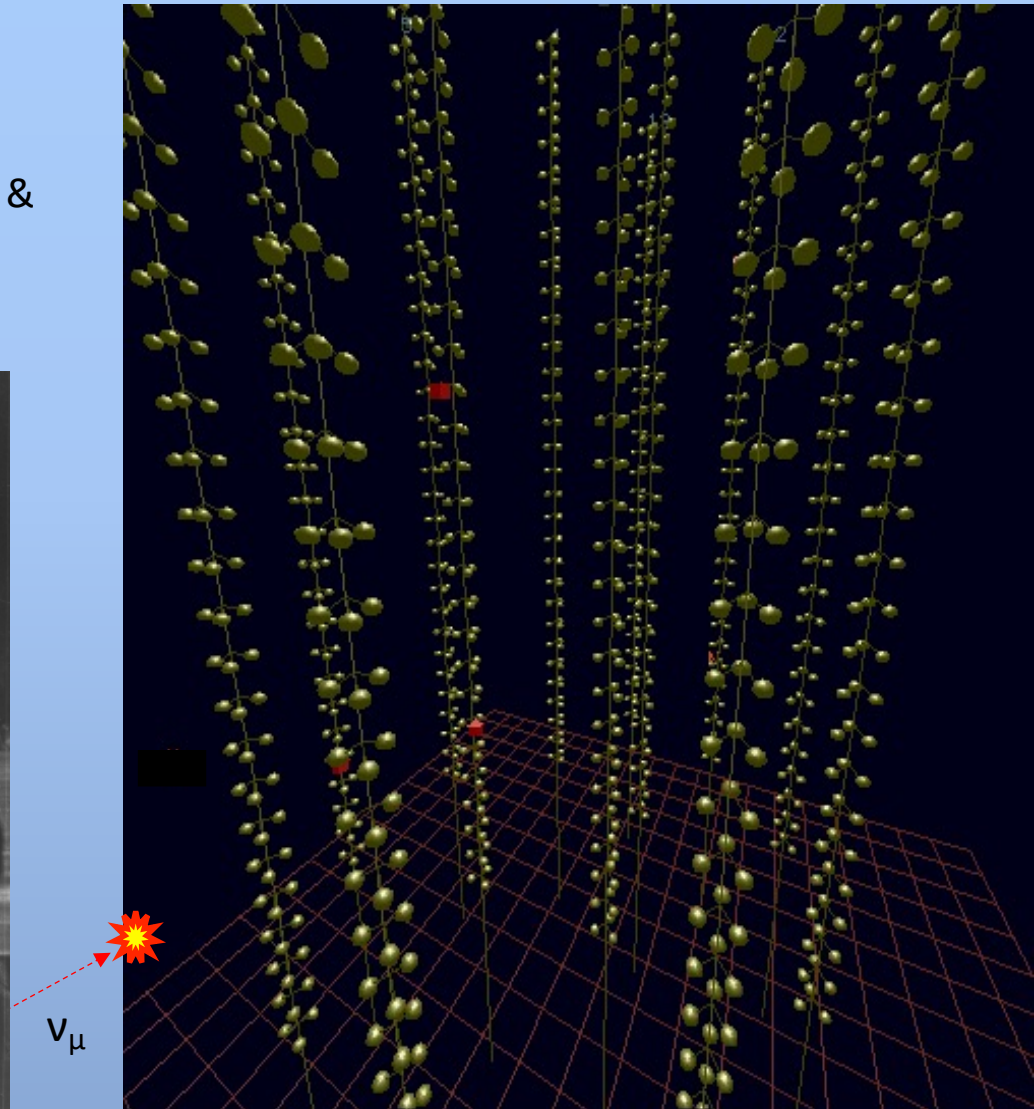


## Cities and Sites of KM3NeT



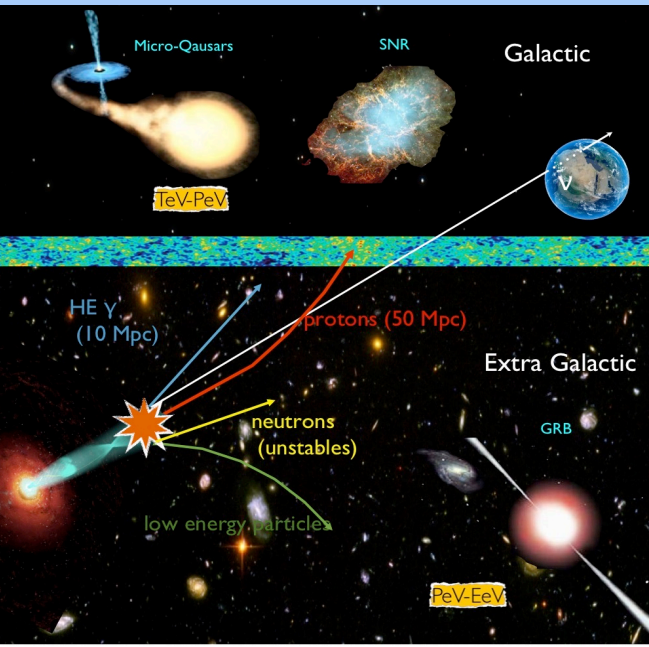
# The concept of Cherenkov neutrino telescopes

- 3D lattice of photomultipliers collecting Cherenkov photons due to relativistic charged particles from  $\nu$  interactions
- $\nu$  direction reconstructed using photon time & position





# The scientific case



**ASTROPHYSICS**

Perfect probes : undeflected and unabsorbed

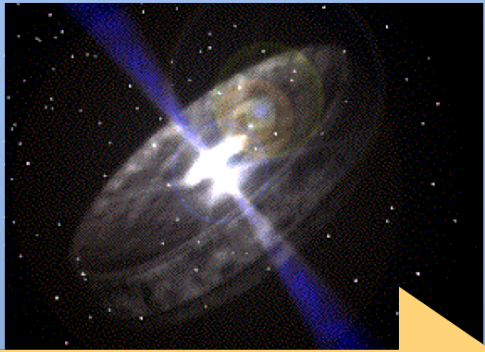
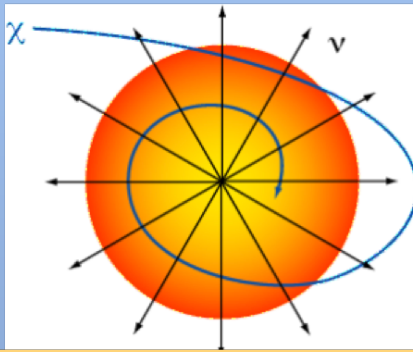
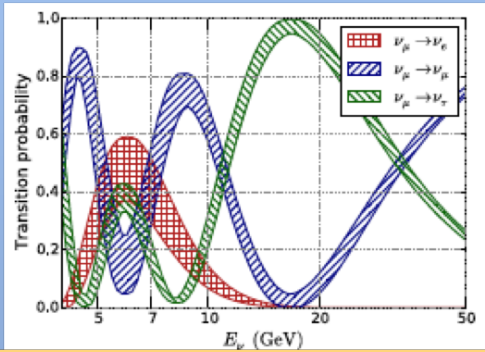
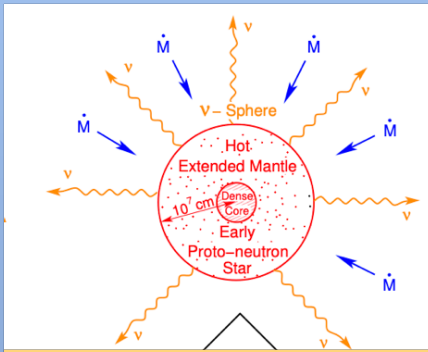
Multimessenger approach

**PARTICLE PHYSICS**

ATMOSPHERIC NEUTRINOS

- $\nu$  oscillations
- sterile neutrinos
- mass hierarchy
- tau appearance
- non-standard interactions

Super Novae explosion      Neutrino oscillation      Dark Matter      HE neutrinos Multi-messenger program



Neutrino Energy from MeV to PeV

ARCA + ORCA

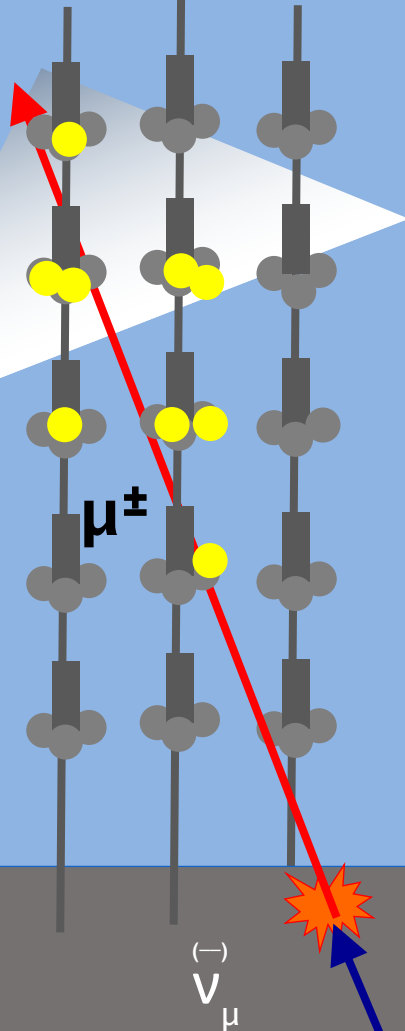
ORCA

ARCA

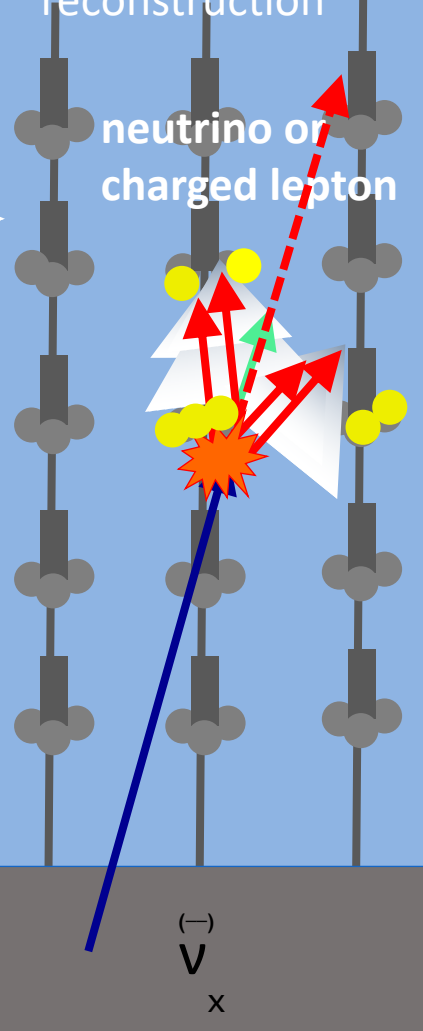


# Events in a neutrino telescope

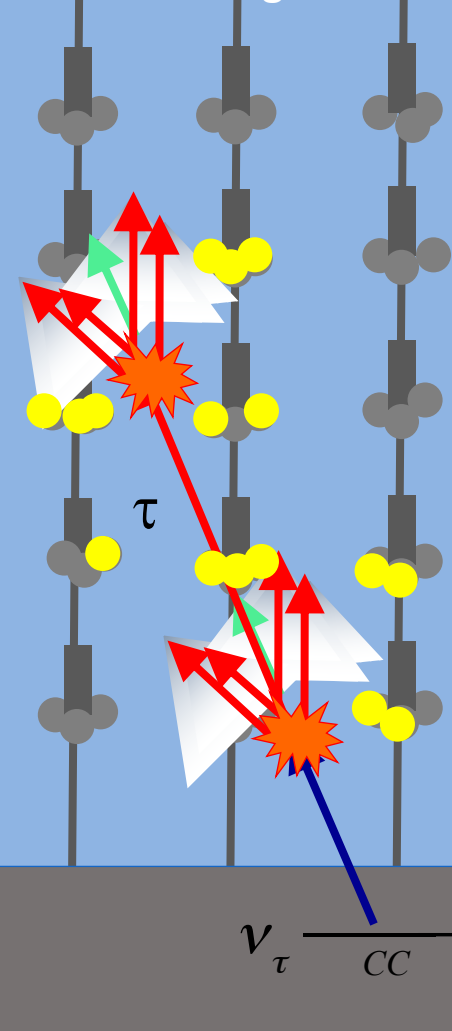
**CC  $\nu_\mu$**   
**track** like events  
good pointing



**CC  $\nu_e$  + all flavours NC**  
**shower** like events –  
good energy  
reconstruction

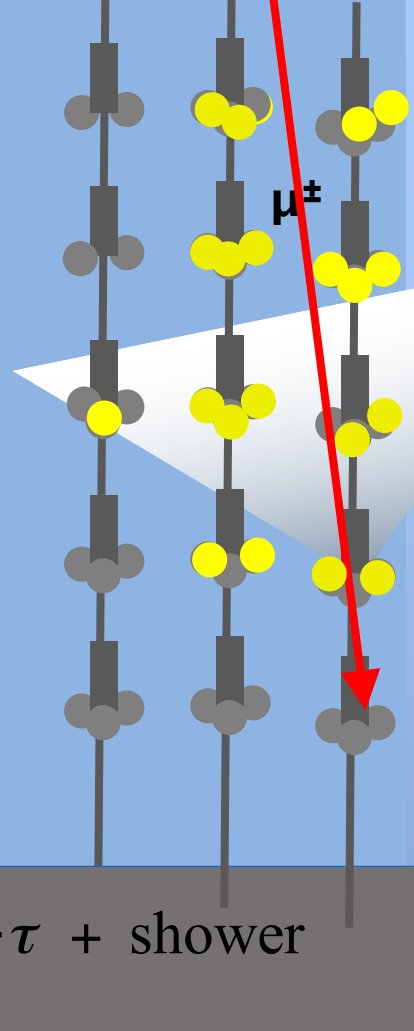


**CC  $\nu_\tau$**   
"double bang"



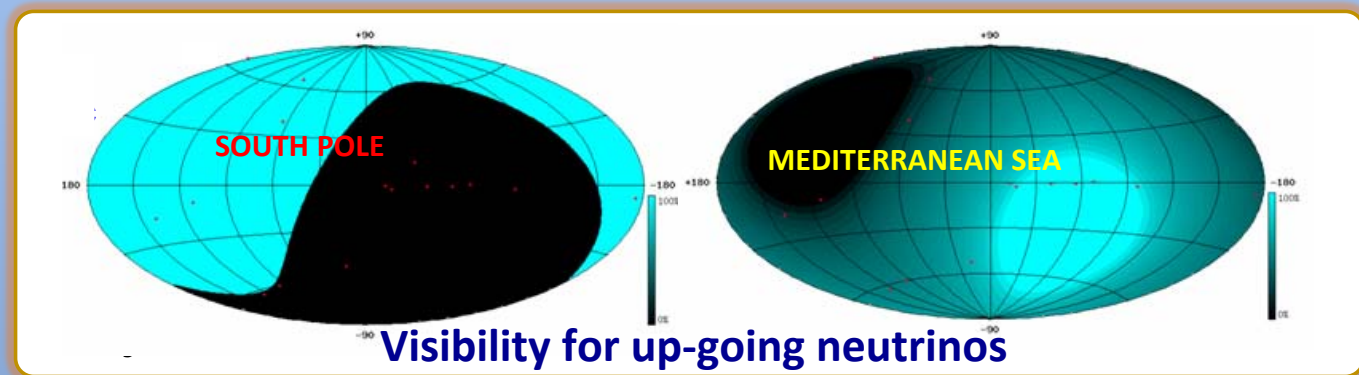
**BACKGROUND !!**

**atmospheric muon**



# Why the Mediterranean Sea

- Optical properties of water → Mapping the **Southern sky** with unprecedented angular resolution
  - tracks:  $< 0.2^\circ$  @ 10TeV -  $\nu_\mu$  CC (neutrino astronomy)
  - showers:  $< 2^\circ$   $E_\nu > 50$  TeV  $\nu_e$  CC +  $\nu_x$  NC ( $\sim$ calorimetric measurement)
- Visibility of the Galactic region →  $\sim 70\%$  for the Galactic Centre



# The KM3NeT detectors - Design

31 PMTs x 3" PMTs

The optical sensor:  
the **D**igital **O**ptical **M**odule (DOM)

a 3D array of optical sensors

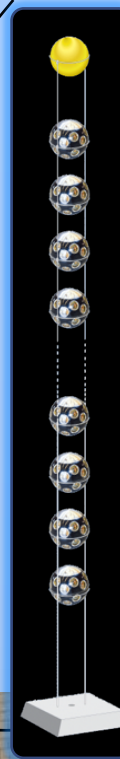
Seafloor Network

~ 40 cm

The **D**etection **U**nit (DU)

**String:**

- 1 Buoy
- 2 Dyneema ropes
- 18 DOMs
- 1 Anchor
- Electro-optical backbone:
  - Flexible hose 7mm
  - Oil-filled
  - 18 fibres
  - 2 copper wires

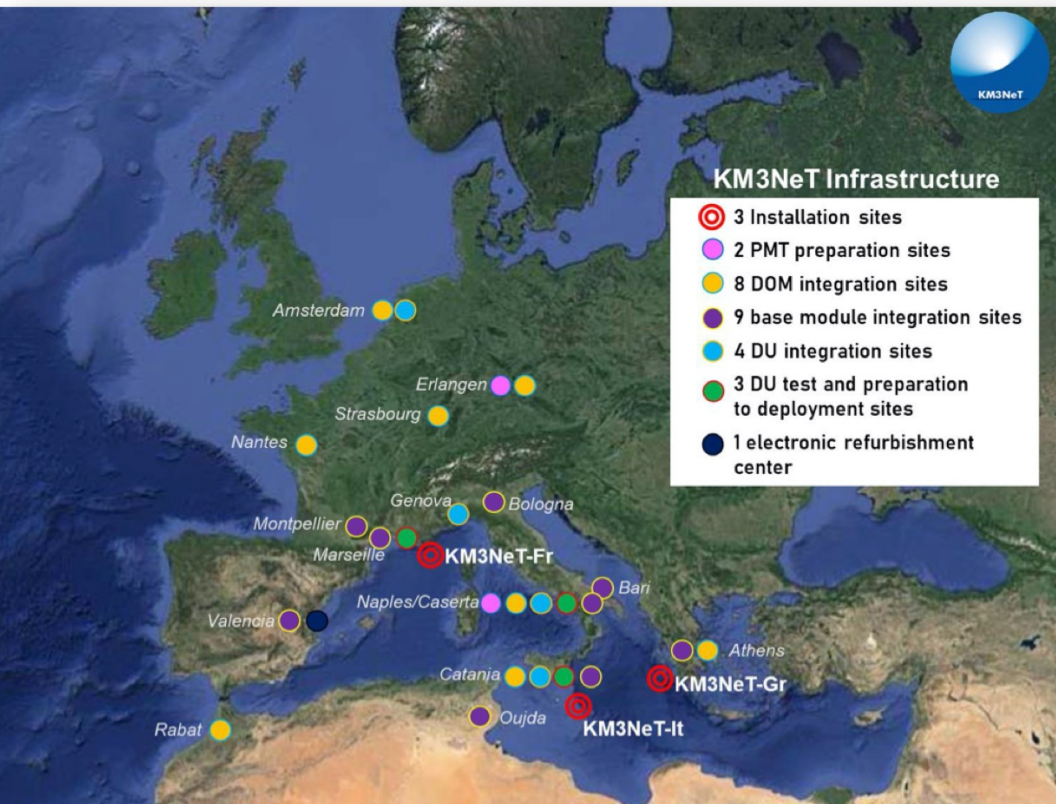


Improved background rejection  
Compact and cost effective design:  
photocathode area  $\approx 3 \times 10''$  PMTs

1 Building Block (BB) = 115 DUs  
ARCA= 2 BB = 230 DUs  
ORCA= 1 BB



# Several integration sites



## DOMs:

- 8 integration sites
- 640 DOM produced (400 ARCA, 240 ORCA)
- 100 currently in progress

## BMs:

- 9 integration sites
- 27 BMs produced
- 6 currently in progress

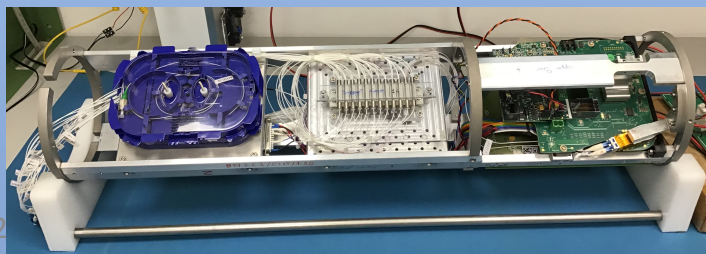
## DUs:

- 5 integration sites
- 13 DUs produced
- 8 currently in progress

**Total: 22 integration sites!**  
(last year: 15)



### Base Modules



### Digital Optical Modules

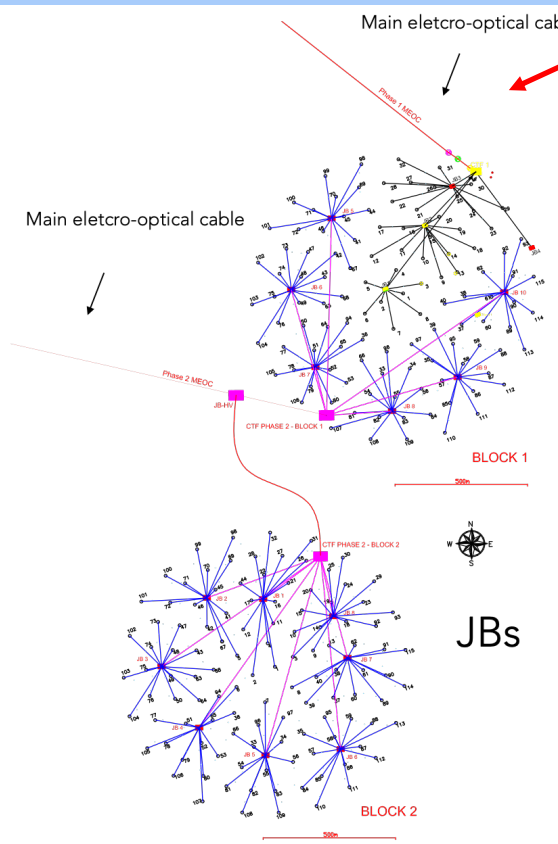


### Detection Units

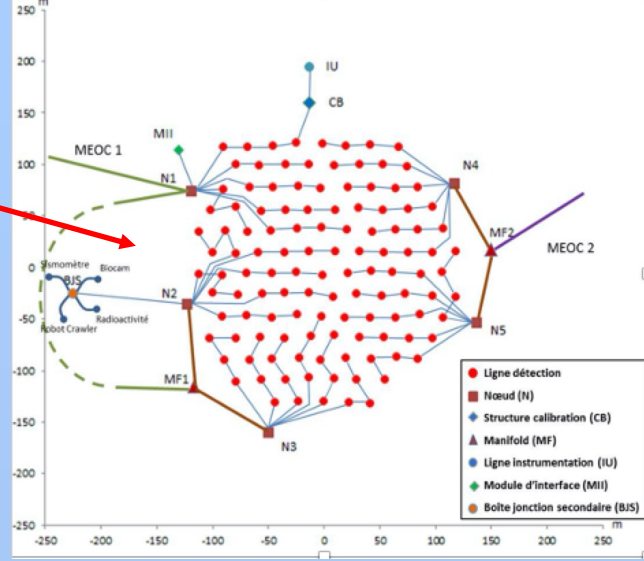


# KM3NeT/ARCA (KM3NeT-It site)

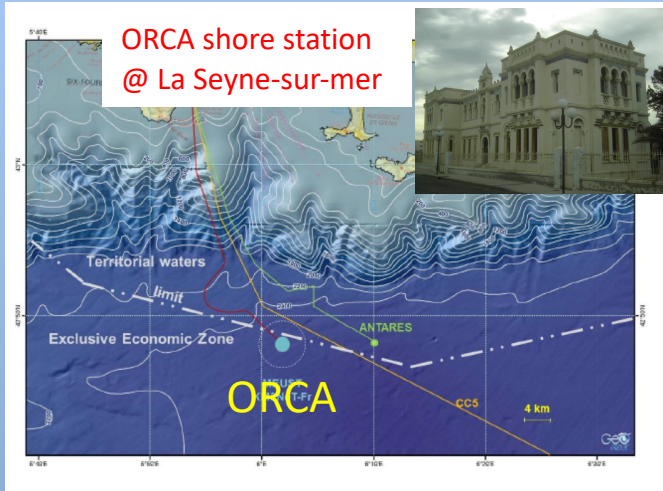
## Footprint of the two telescopes



- same technology
- same design
- different density of active sensors
- modular design
- power and data distribution with a single backbone cable
- breakouts at DOMs
- network of submarine cables + Junction Boxes
- connection to shore via a main e/o cable
- all-data-to-shore



# KM3NeT/ORCA (KM3NeT-Fr site)

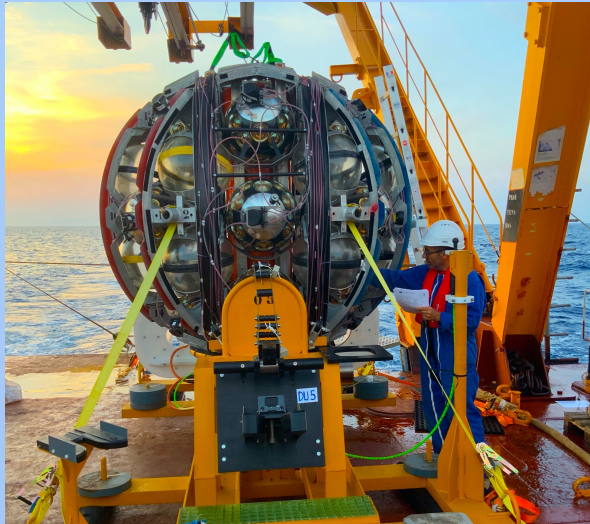


ARCA shore station @ Portopalo di Capo Passero

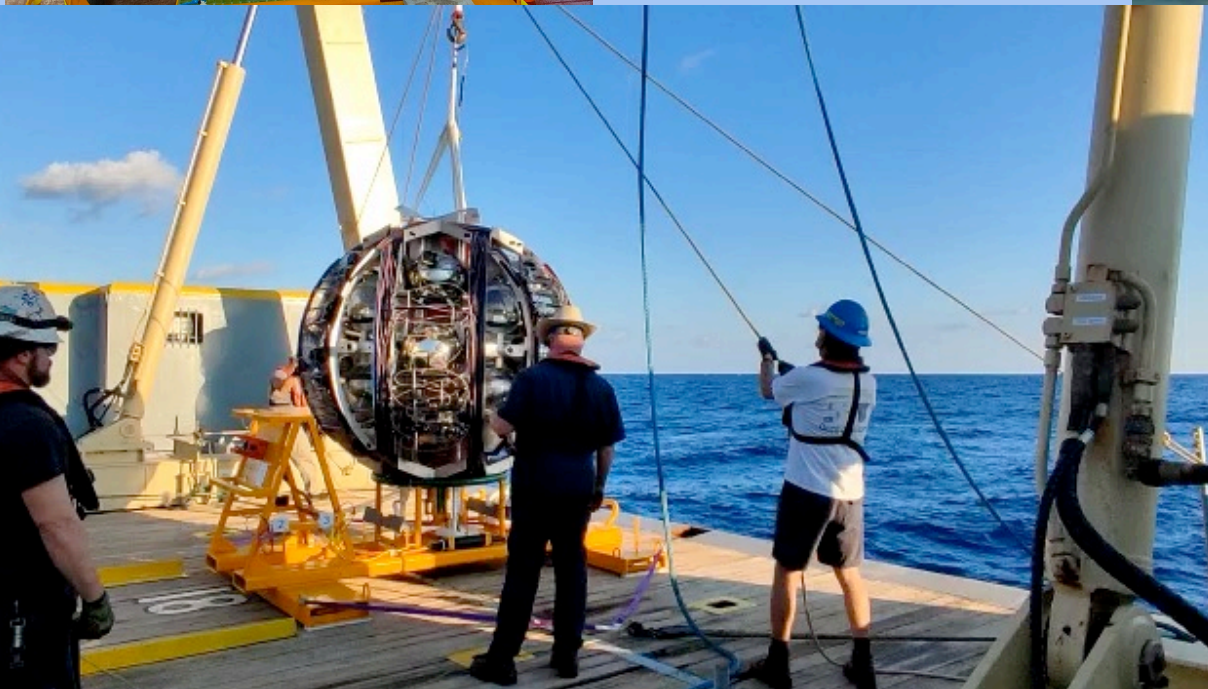
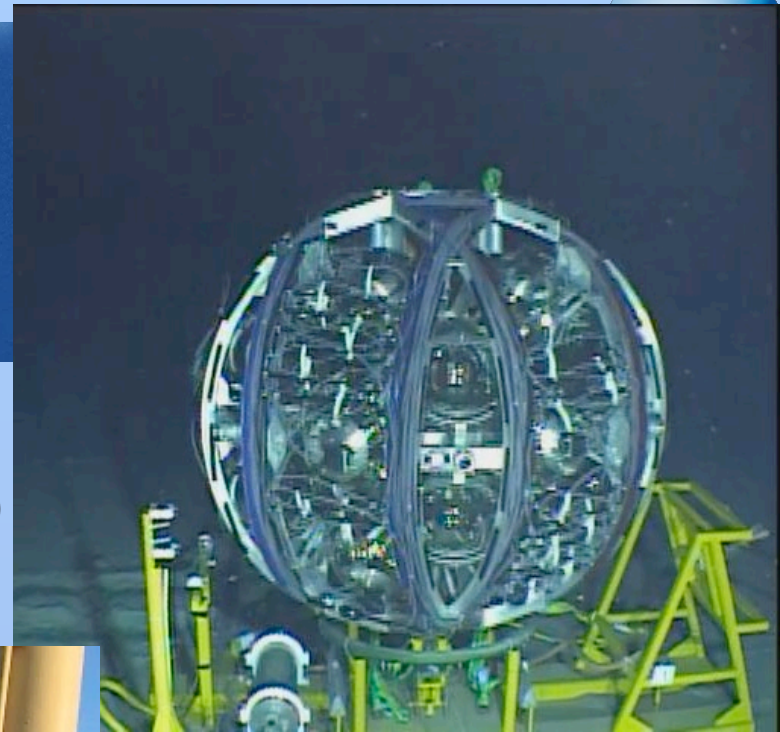


	ARCA	ORCA
Location	Italy	France
DU distance	90 m	20 m
DOM spacing	36 m	9 m
DU height	~ 800 m	~ 200 m
Instrumented mass	2*500 Mton	7 Mton
Depth	3500 m	2500 m

# KM3NeT Deployment



The LOM  
(Launcher of Optical Modules)

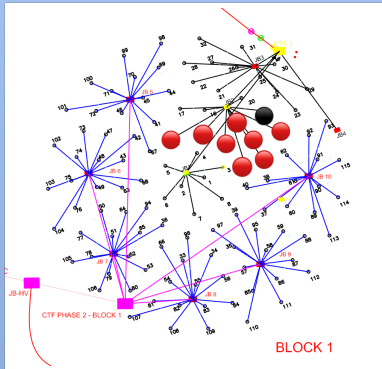


- Rapid deployment
- Multiple strings/sea campaign
- Autonomous/ROV unfurling
- Reusable

# Status of ARCA

December 2015 → First DU  
 April 2021 → + 5 DU & 1 JB  
 September 2021 → + 3 DU

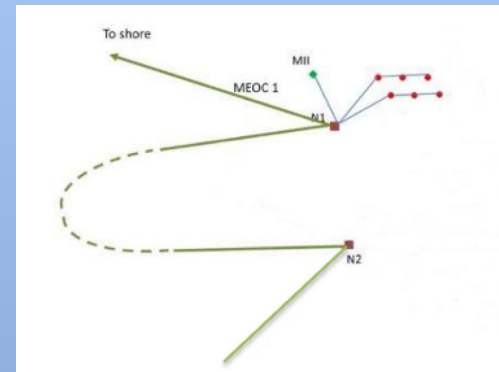
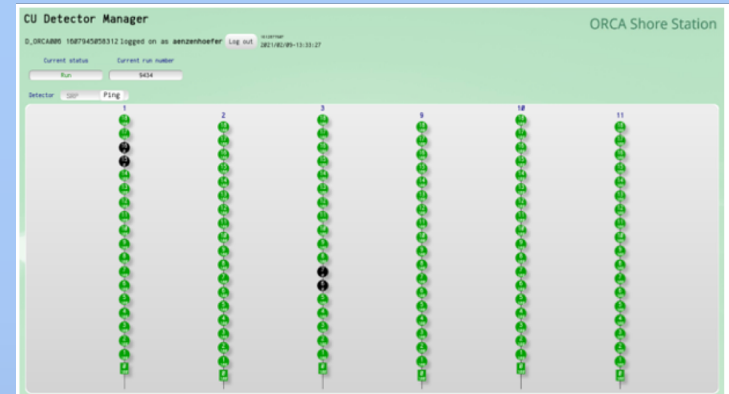
9 DU: **8 DU in data taking**



Next sea campaign : Spring 2022  
**12-14 Detection Units + 2 Junction Boxes**

# Status of ORCA

**6 DU in data taking**  
 since February 2020



Next sea campaign : November 2021  
**+ 7 Detection Units**



# Some events in ARCA





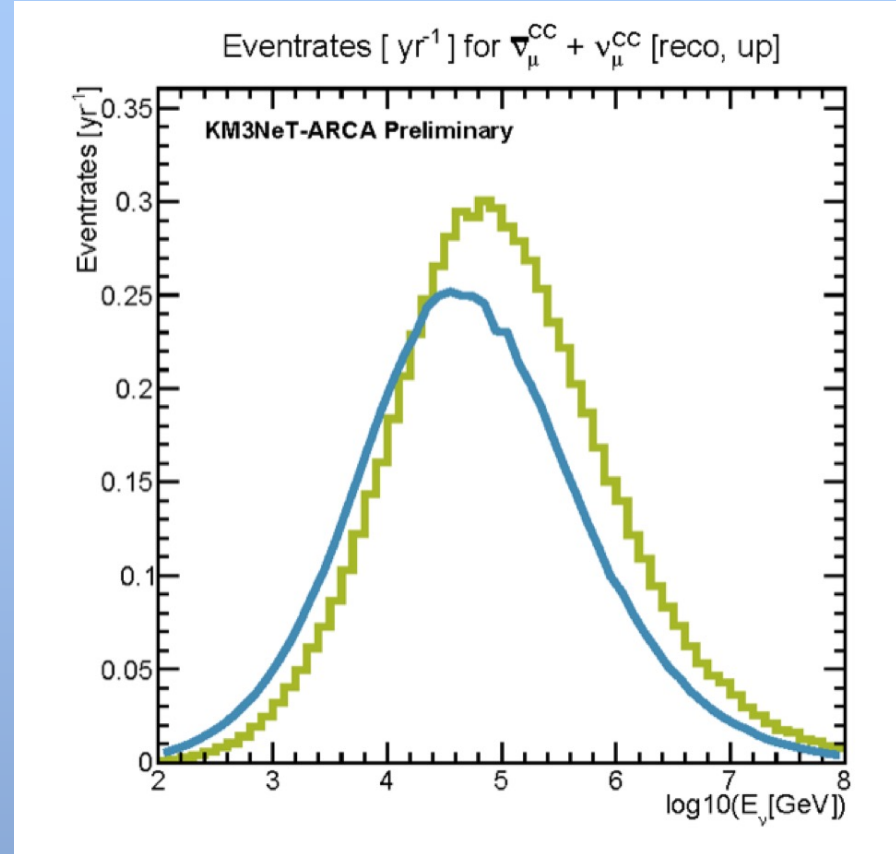
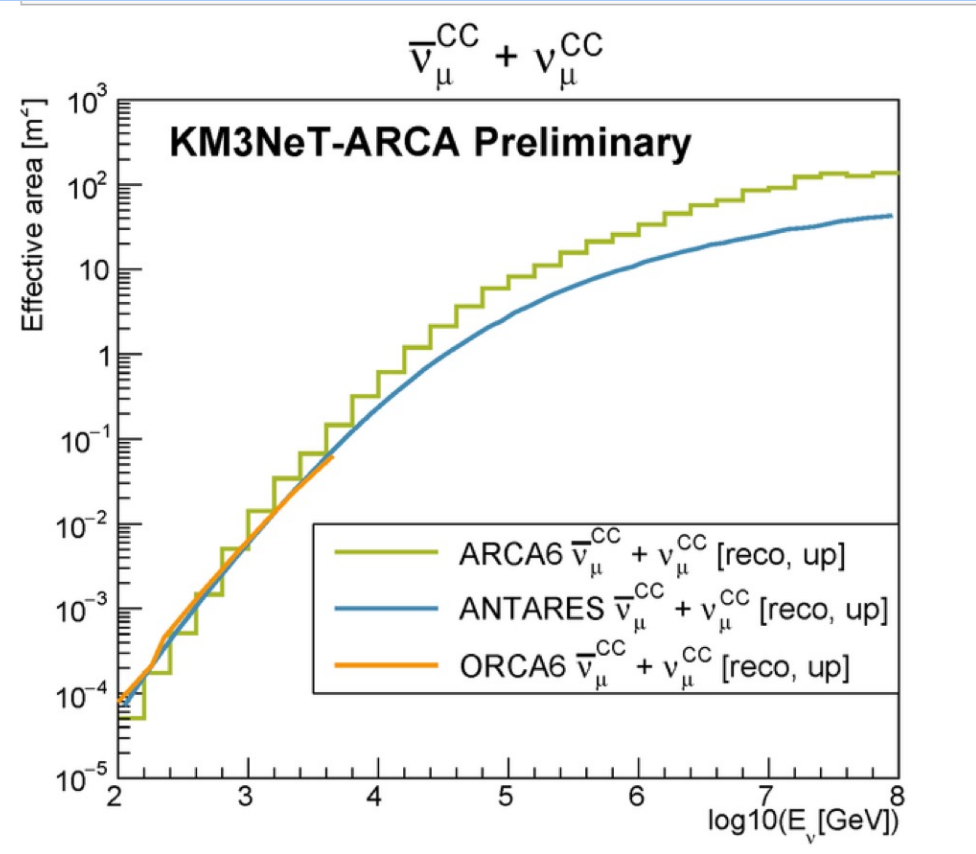
# KM3NeT effective area

Upgoing tracks selected

ARCA6 + ORCA6 area > ANTARES

Number of events per year for a cosmic diffuse flux

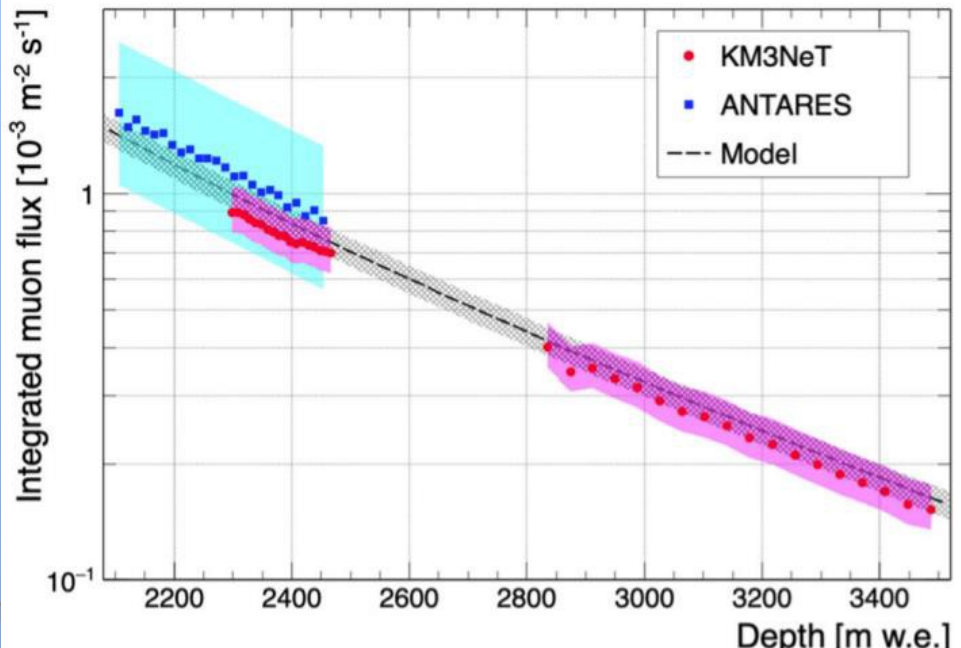
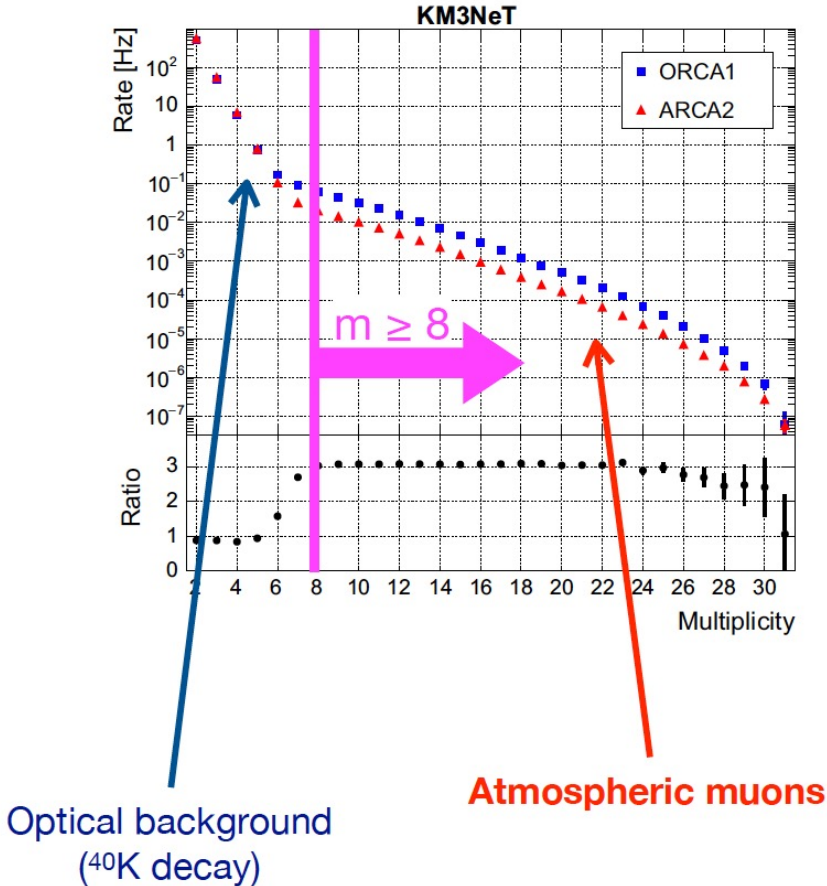
$$\Phi = 10^{-8} E^{-2} \text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$$



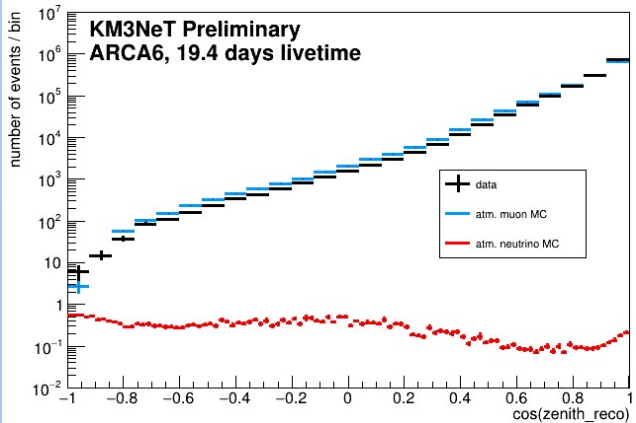
# Atmospheric muon flux vs depth

- Single-DOM measurement
- Useful calibration tool
- Good comparison with ANTARES and theoretical model

Eur. Phys. J. C 80 (2020) 99



# Selection of atmospheric neutrinos



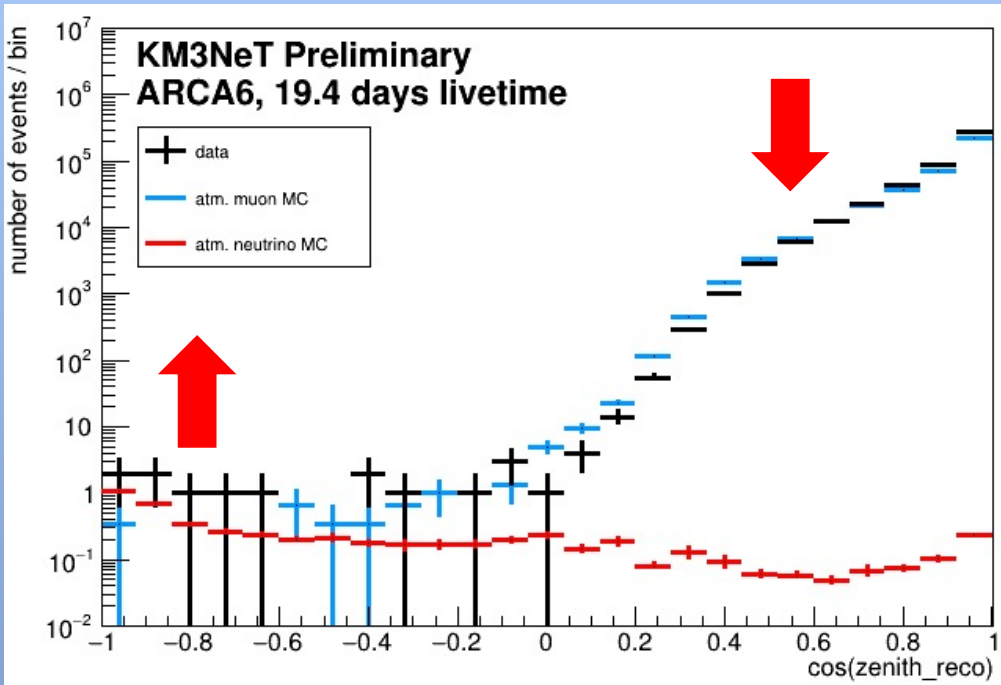
Only neutrinos can cross the Earth

Upgoing tracks = neutrino induced events  
 Downgoing tracks = dominated by atm muons

After reconstruction quality cuts

15 up-going tracks

MC expectations: 4 atm  $\nu$  + 7 atm  $\mu$





# Core Collapse SuperNovae (CCSN)

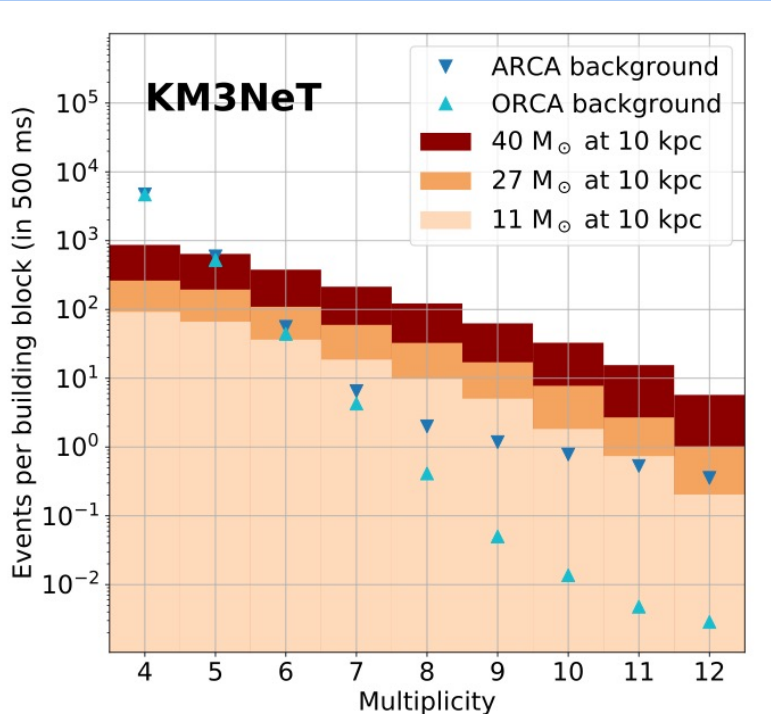


Eur. Phys. J. C81 (2021) 445

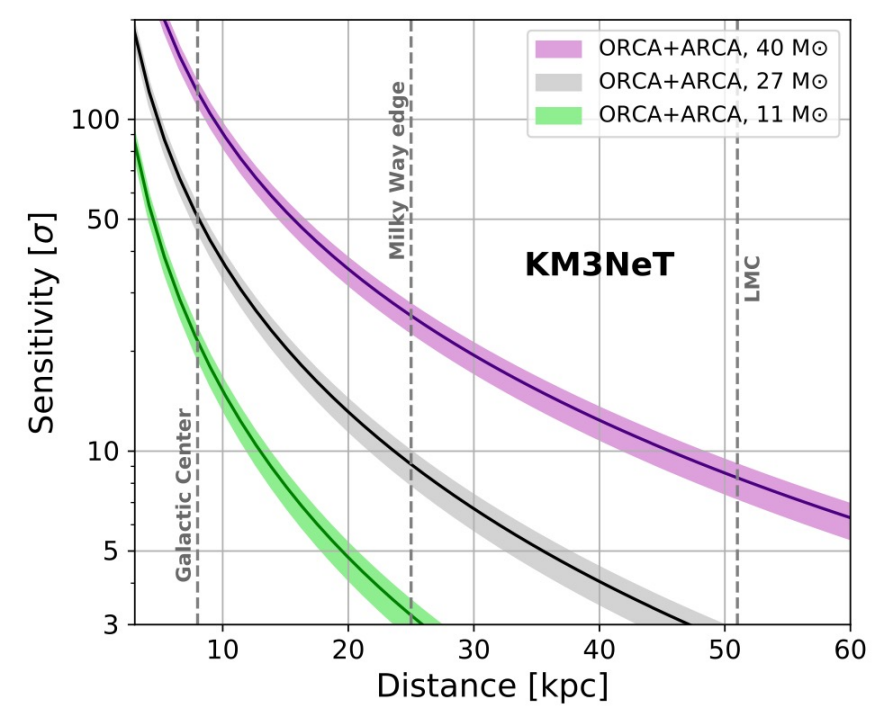
ARCA6+ORCA6 already sensitive to 60% of Galactic CCSNe (<11 kpc)  
real time trigger active in SNEWS since early 2019

> 5 $\sigma$  for ARCA+ORCA for 27M $\odot$  at a distance ~ 36 kpc

## ORCA 1 BB + ARCA 1BB



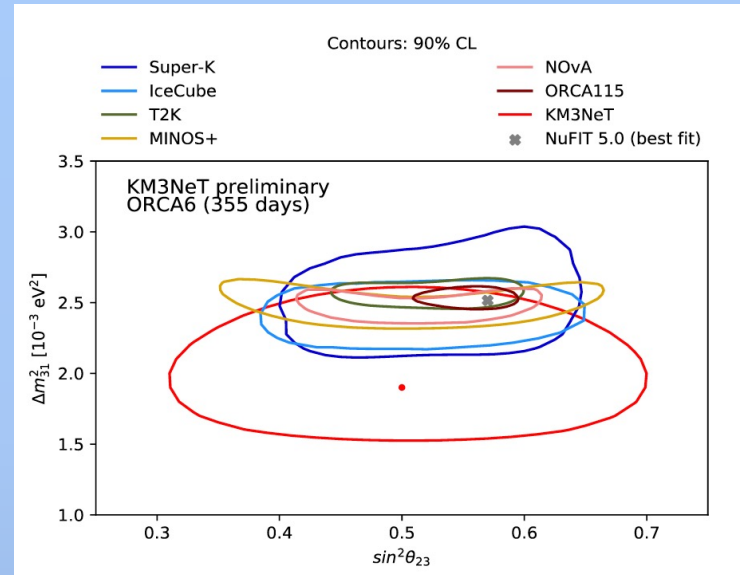
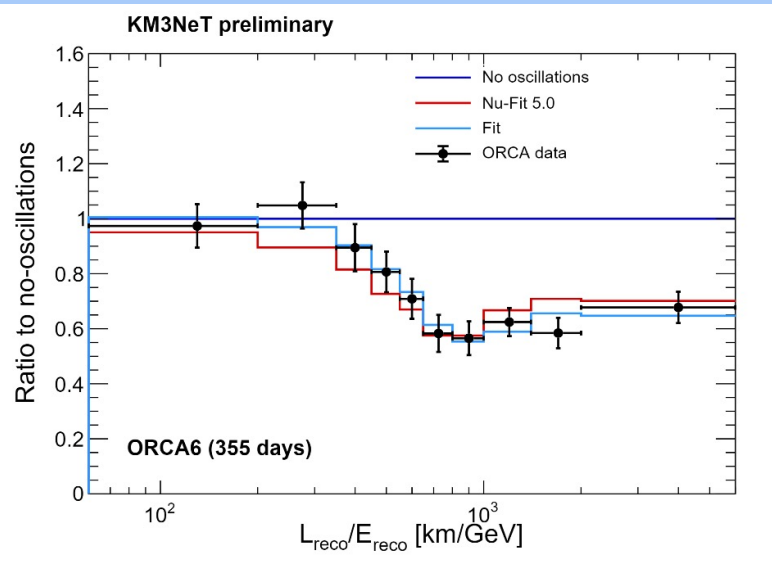
The KM3NeT



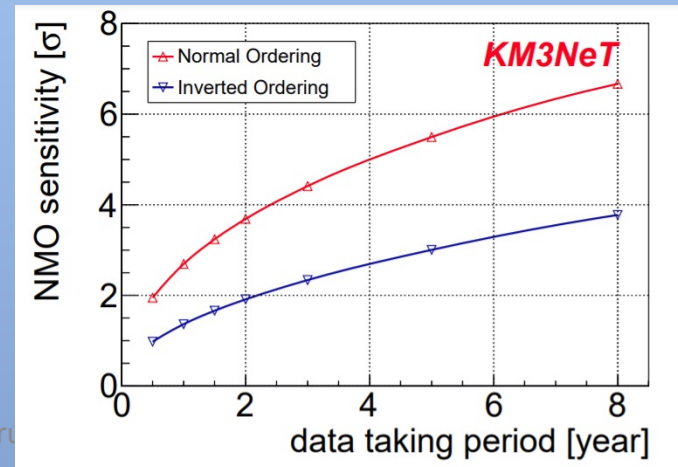
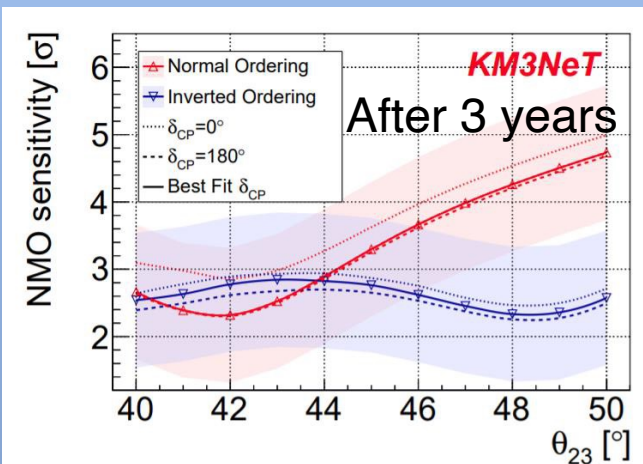
# Neutrino studies with KM3NeT/ORCA



## Oscillations – sensitivity after 3 y and Preliminary results



## Neutrino Mass Ordering





# Conclusions and perspectives

- KM3NeT is taking over the responsibility of neutrino astronomy in the Mediterranean Sea from ANTARES
- Technique fully validated
- First preliminary results confirm expectations
- Detectors are in construction
- 8 ARCA + 6 ORCA Detection Units are taking data
- Next sea campaigns:
  - ORCA : November 2021 → + 7 DUs  
February 2022 → + 3 DUs & Calibration Base & Instrumentation Unit
  - ARCA : Spring 2022 → 12 DUs & 1JB + & Calibration Base & Instrumentation Unit

# Backup slides





# Background

## Atmospheric muons

direction cut → upward going events

useful for detector calibration

## Atmospheric neutrinos

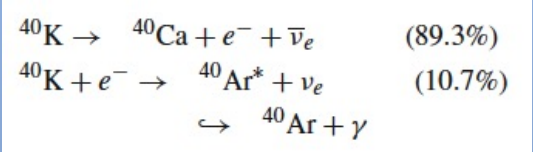
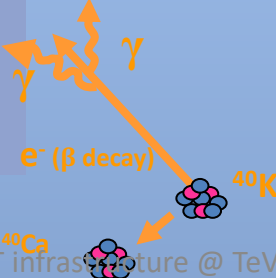
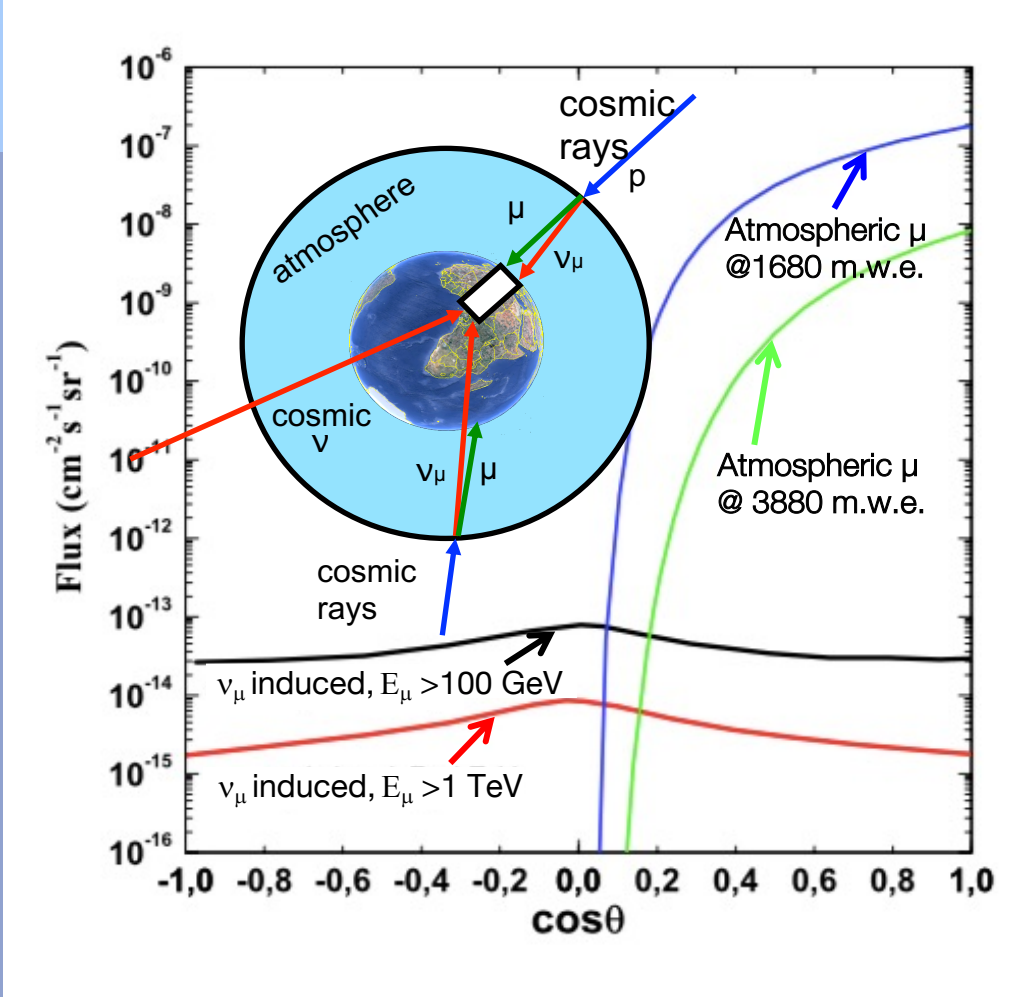
irreducible background

neutrino oscillations → mass hierarchy

## Environmental background

- $^{40}\text{K}$  decay
- bioluminescence
- 

rejection : causal correlation of the signals



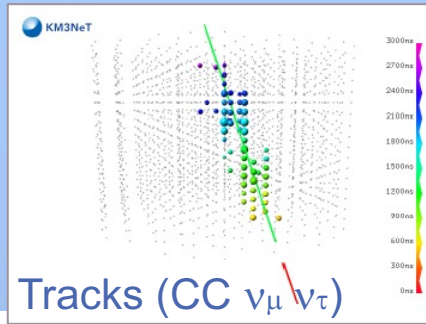
# Reconstruction performances

Excellent optical properties of sea water → good angular resolution

**Tracks** →  $\nu_\mu$  CC (neutrino astronomy)

Angular resolution  $< 0.2^\circ$  @10 TeV

Energy resolution  $\sim 30\%$



**Showers** →  $\nu_e$  CC +  $\nu_x$  NC

Angular resolution  $< 2^\circ$   $E_\nu > 50$  TeV

Energy resolution  $< 5\%$

Contained events, calorimetric meas.

