



# KM3NeT/ORCA

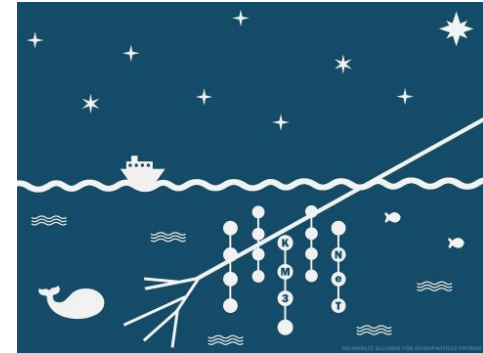
Conseil Scientifique de l'IN2P3  
26/10/2021

Mathieu PERRIN-TERRIN  
on behalf of the KM3NeT groups of  
APC, CPPM, IPHC, LPC, Subatech, LUPM



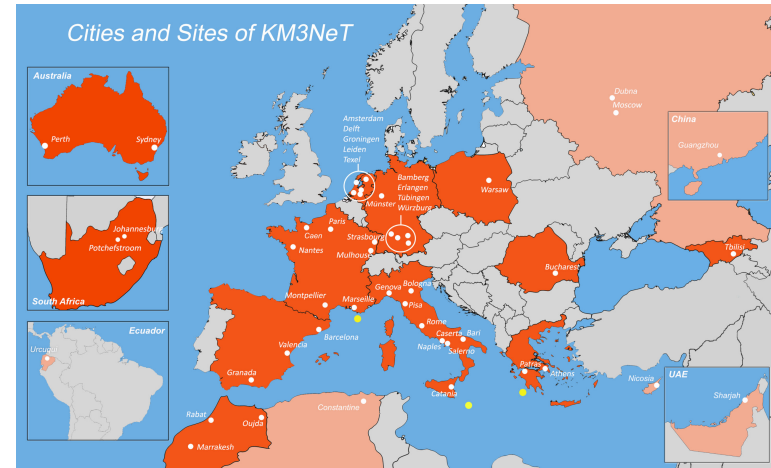
# Outline

- Introduction
  - KM3NeT Collaboration
  - KM3NeT Technology
  - French implication
- Status of the ORCA construction
  - Detectors construction
  - Deployments (past and future)
- Status of the Physics Analyses
  - Analysis of the first data
  - Expected sensitivities
  - Tag Neutrino Beam from Protvino



# Introduction

- KM3NeT Collaboration is building the next generation of  $\nu$  telescope
  - **56 institutes** distributed across **17 countries**
  - Successors of **ANTARES** which has been operational since 2007
- Two main scientific goals are addressed
  - determination of the  **$\nu$  mass ordering** (NMO)
  - discovery & observation of **high energy neutrino source** in the Universe
- Two detectors under construction
  - France: **ORCA** (**O**scillation Research with **C**osmics in the **A**byss) optimise for **GeV  $\nu$**
  - in Italy: **ARCA** (**A**stronomy Research with **C**osmics in the **A**byss) optimise for **TeV  $\nu$**
  - Both detectors use the **same technology**
- Selected on the [ESFRI roadmap](#)

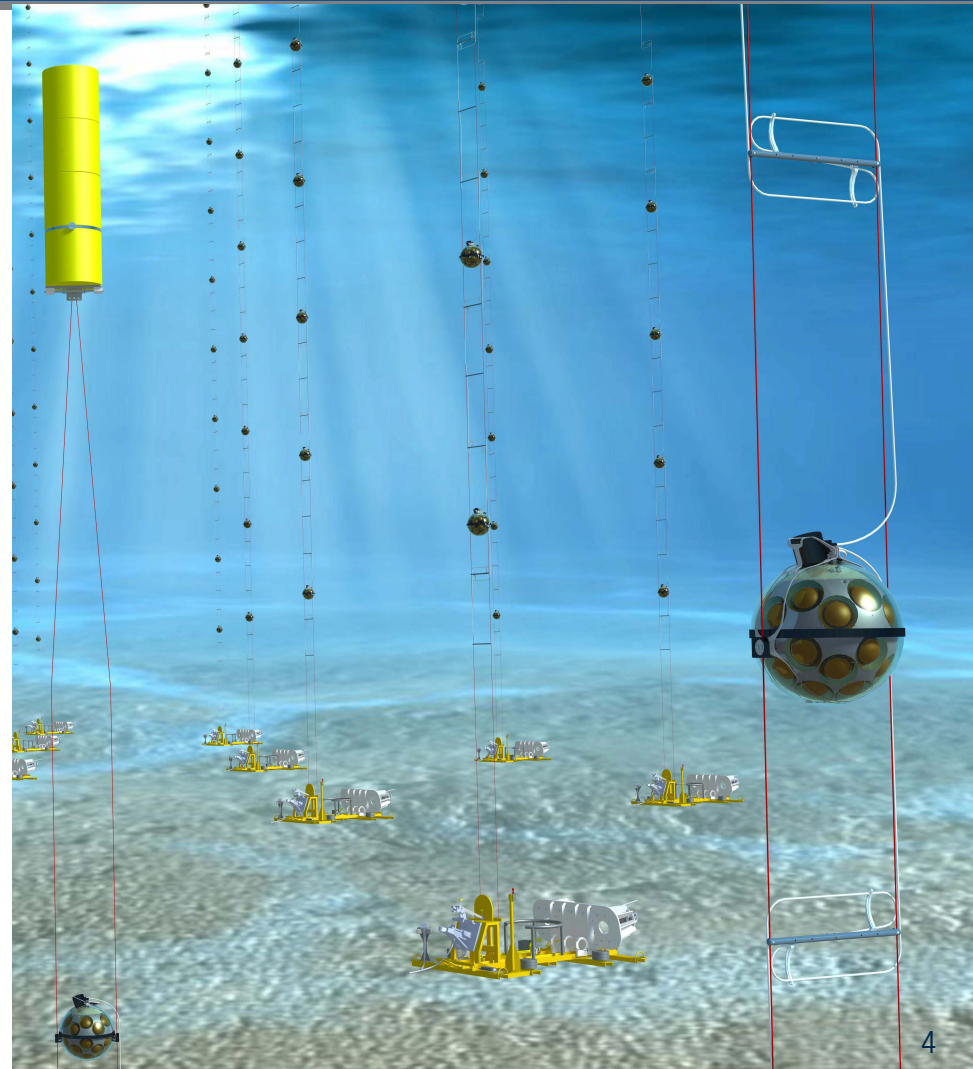
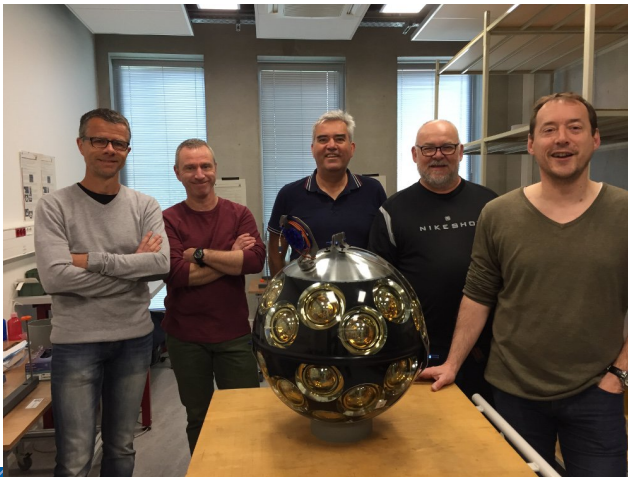


MONITORING OF ESFRI 2016 PROJECTS			
	<i>cientific Case</i>	<i>mplementation Case</i>	<i>Overall</i>
CTRIS	High	High	High
ANUBIUS	Medium/High	Medium	Medium
RIHS	Medium	Medium	Medium
ST	High	Medium	Medium/High
MPHASIS	Medium/High	Medium/High	Medium/High
KM3NeT	Very High	High	High/Very High

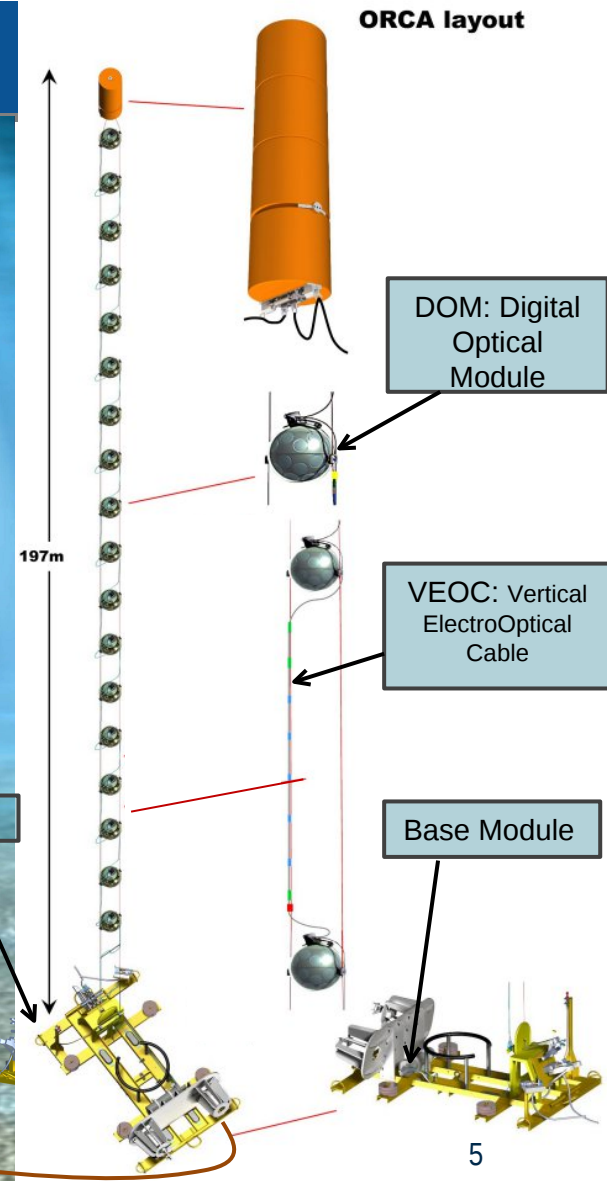
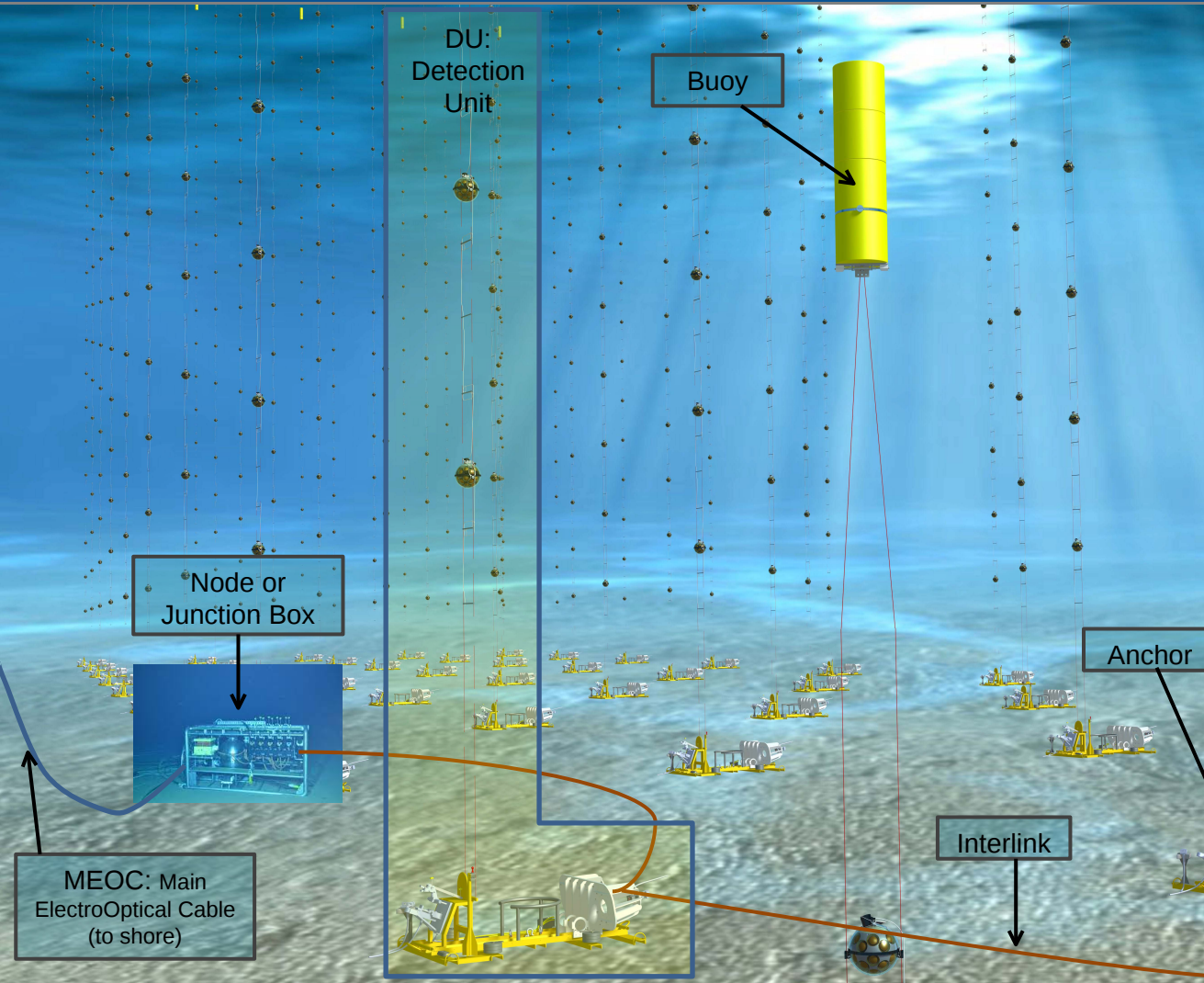
# KM3NeT Technology

## Array of Digital Optical Modules (DOM)

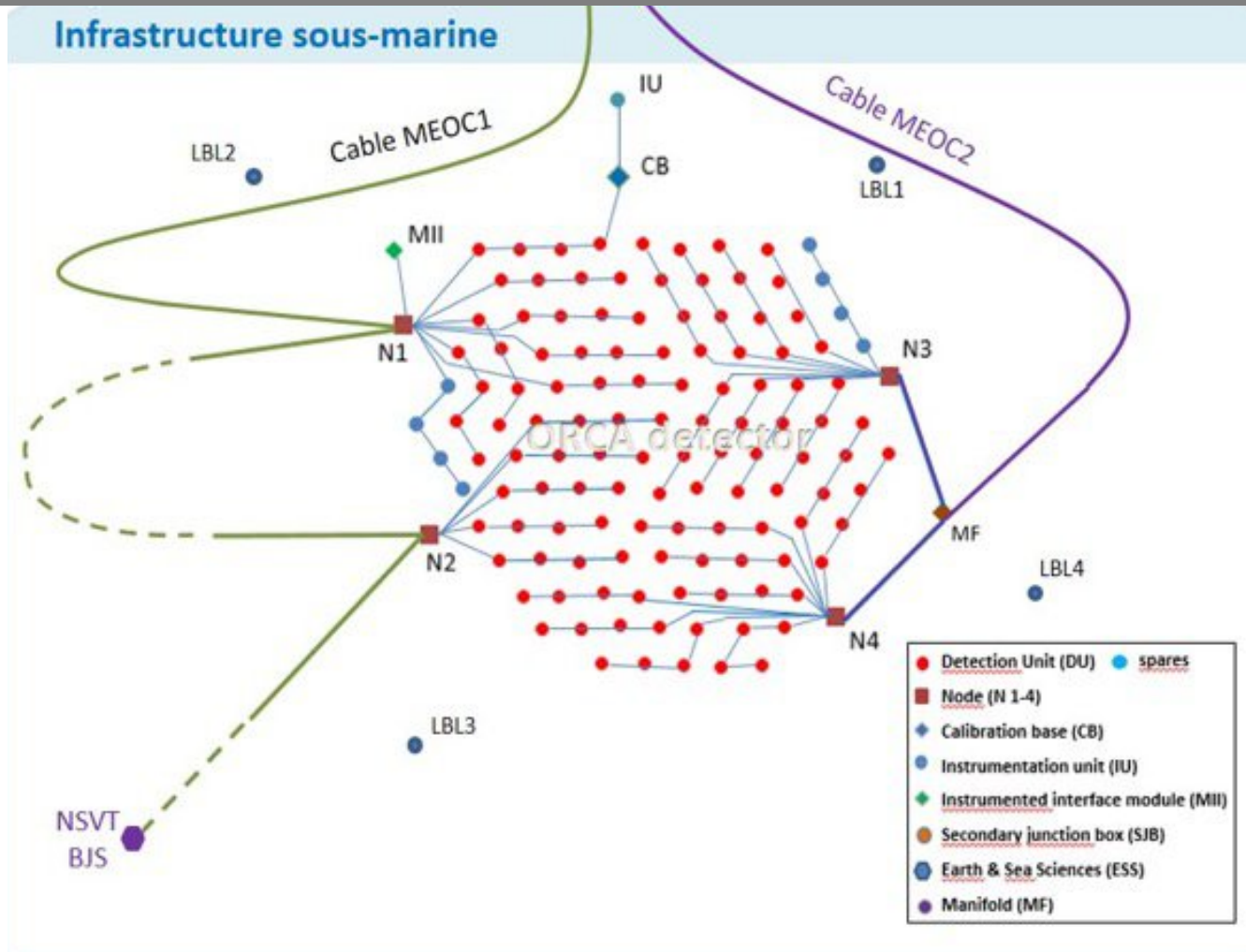
- Each **DOM** contains **31 PMTs** (3")
- **18 DOMs** form a **detection line**
- **ORCA** will consist of **115 lines**
- **ARCA** will consist of **2x115 lines**
- **Spacing** between DOM determines the detector **energy threshold**



# Nomenclature

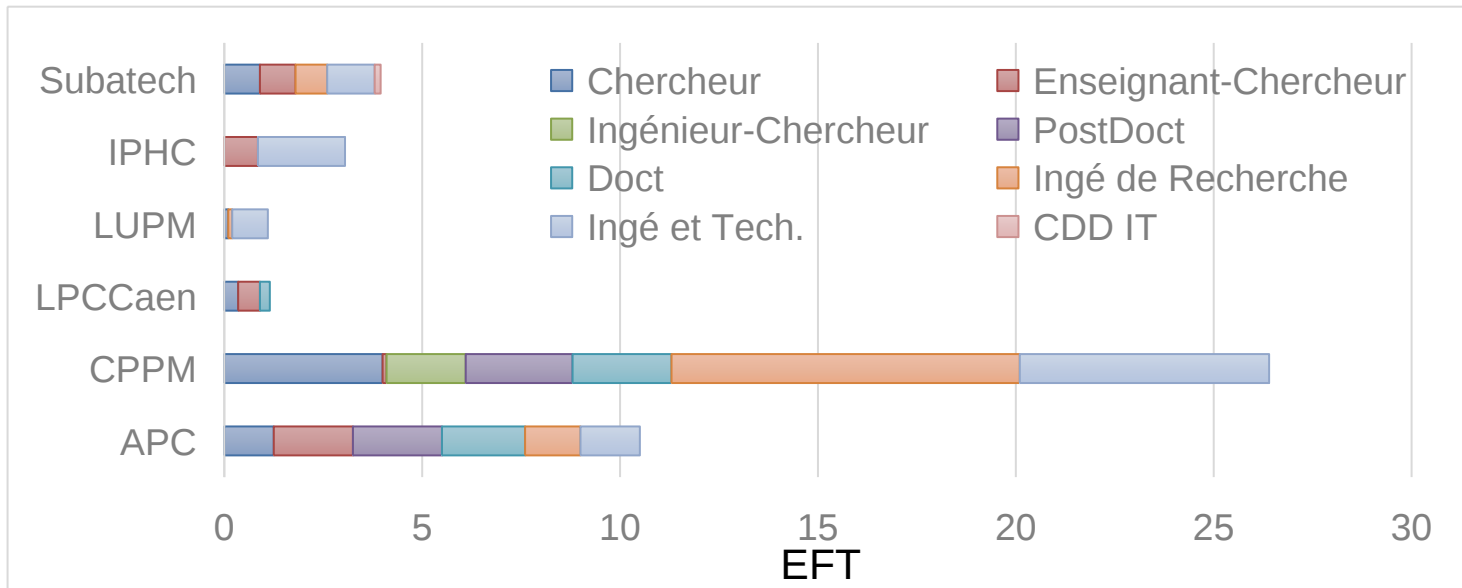


# ORCA Infrastructure



# French Implications

- Six IN2P3 Labs are members of KM3NeT
  - Two new members since 2017: LUPM and LPC-Caen



# French Responsibilities

- Strong implication of the French groups
  - Cristal Collectif du CNRS for CPPM Team

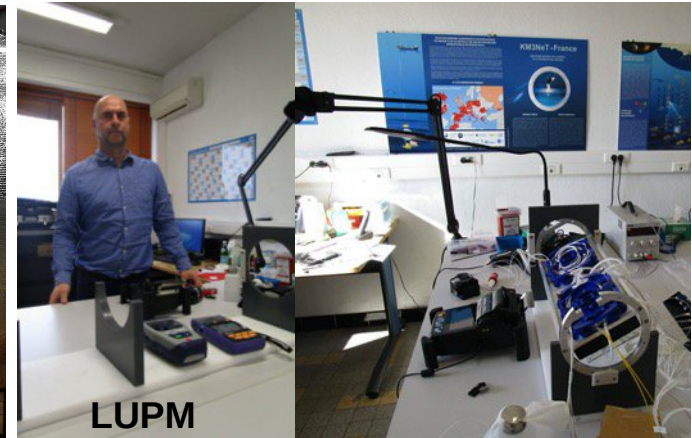
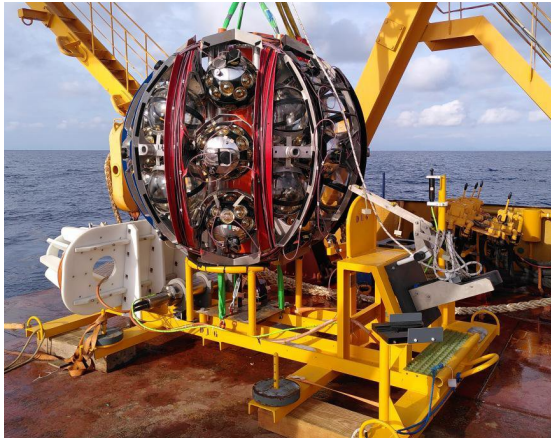
Labo	Technical Responsabilites	Management Responsabilites
APC	Calibration Unit	KM3NeT Technical Manager ANTARES Spokeperson Chair Conf. Committee Co-coord Oscillation Physics
CPPM	DU Integration Anchor Integration Sea Operations Control Room / Power System Instrumentation Unit Junction Boxes	KM3NeT Spokeperson Co-coord Oscillation Physics Co-coord Data Taking Co-coord Neutrino Astronomy Coord KM3NeT Outreach ORCA Site Manager
LPCCaen	DOM on VEOC Anchor integration	
LUPM	Base Module Integration	
IPHC	DOM Integration	
Subatech	DOM Integration	





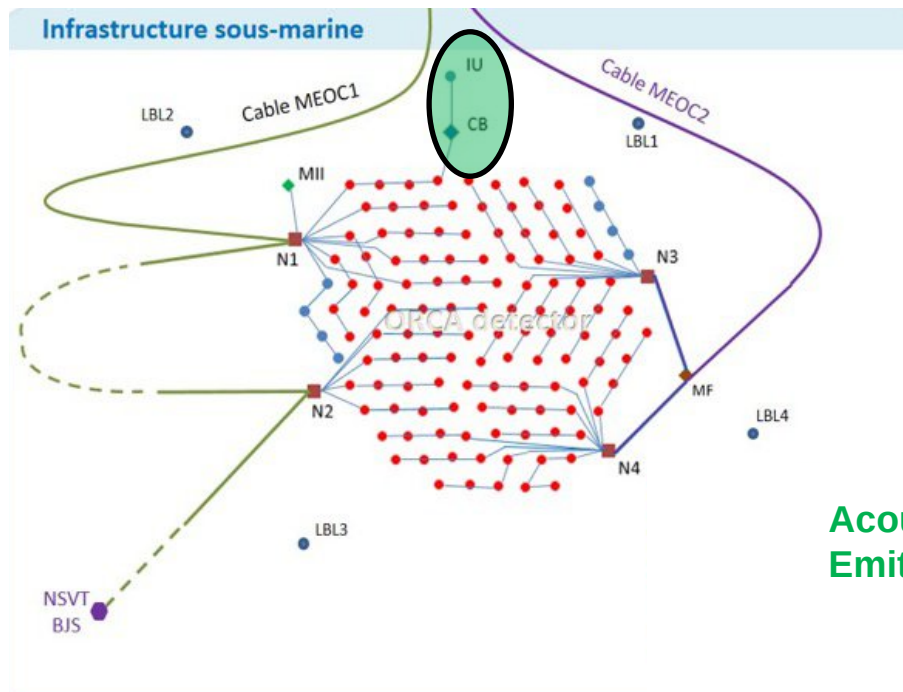
# Technical Realization — DU Construction

- Constructions since 2017
  - 76 DOMs [Subatech and IPHC]
  - 13 base modules [CPPM]
  - 16 DUs [CPPM]



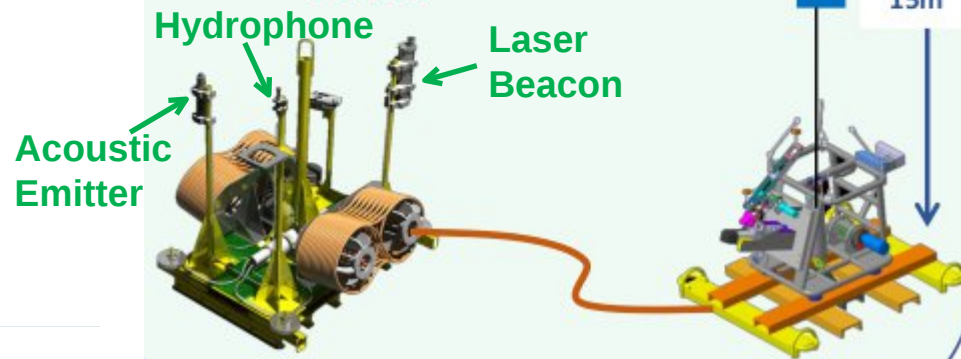
# Technical Realization — Calibration Instruments

- Instrumentation Line & Calibration Base (CPPM & APC)



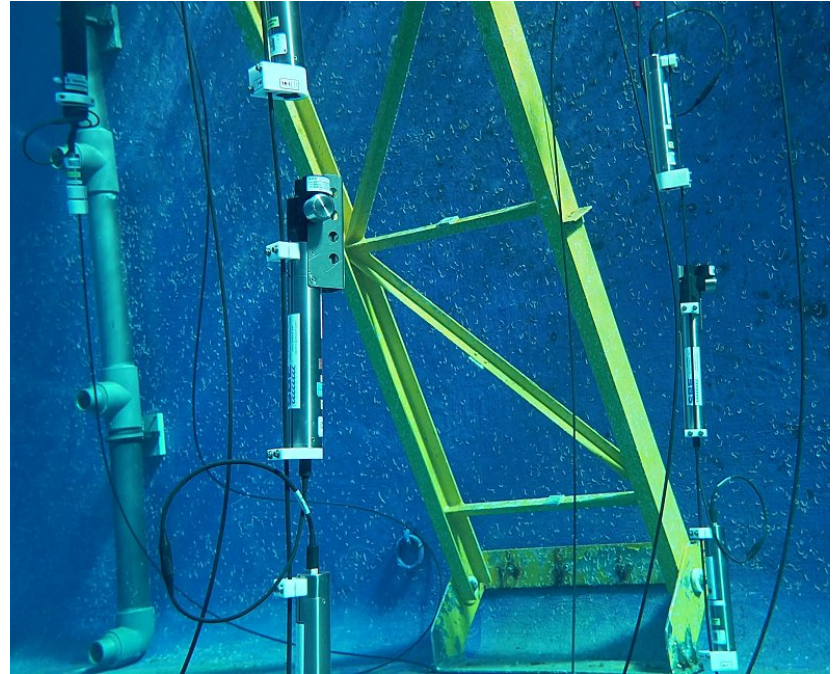
- Instrumented line**

- ADCP: Curent Profiler
- CTD: Conductivity, Temperature and Pressure sensor
- SV: Sound velocity sensor



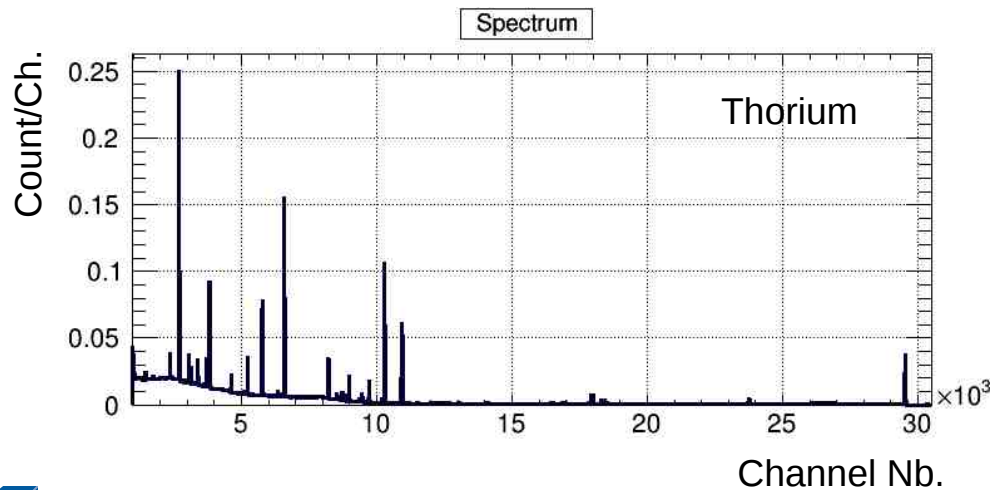
# Technical Realization — Calibration Instruments

- Instrumentation Line & Calibration Base



# Technical Realization — Earth and Sea Science

- Gamma spectrometer (CPPM)
  - High purity Germanium (HPGe): excellent resolution
  - Cryogenic detector (70°K) marinized to operate at 2500m depth
  - Excellent  $\gamma$  energy resolution
  - Spectrum will be measured live !

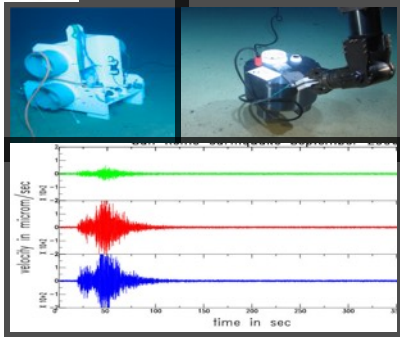


Intrinsic Bkg Measurement at CENBG (PRISNA)

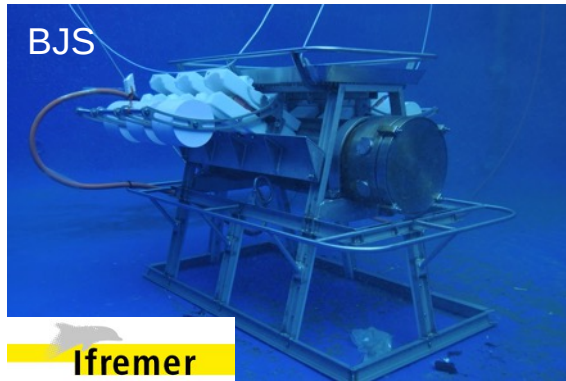


# More Earth and Sea Science

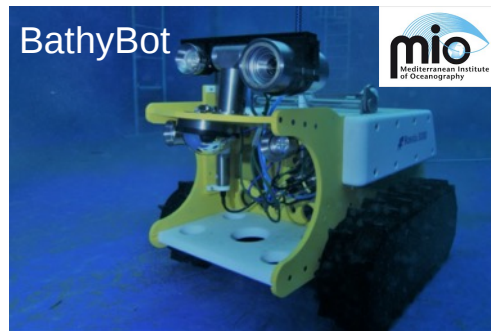
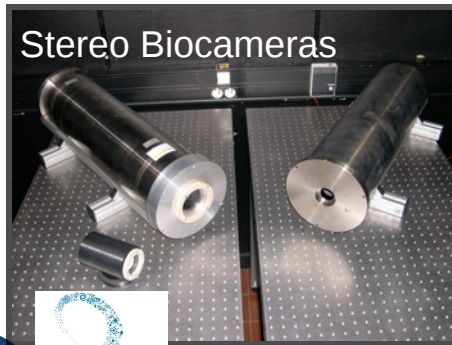
- Infrastructure is now a platform:
  - Laboratoire Sous Marin Provence Méditerranée



Seismometer



Ifremer

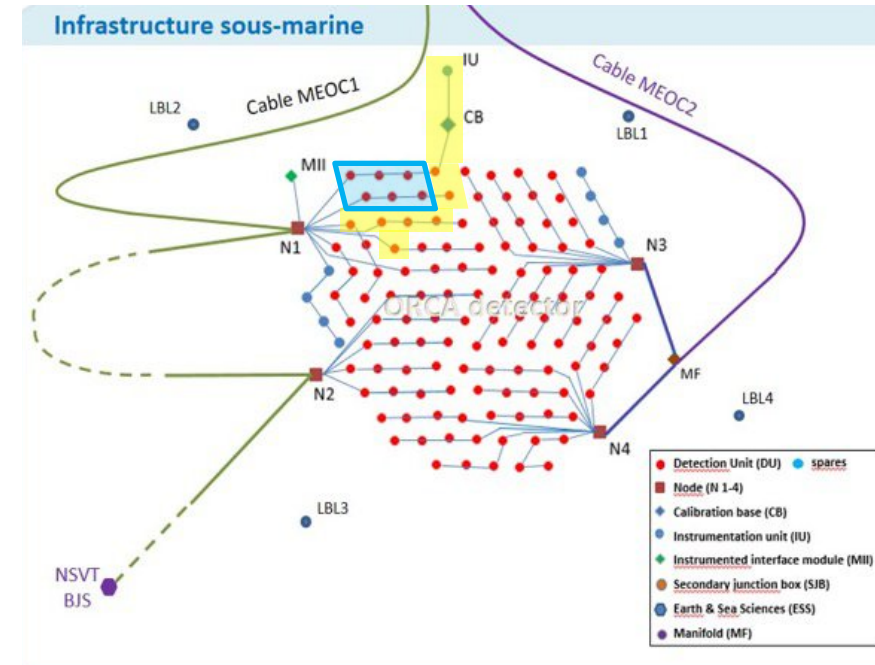


BathyBot



# Sea Operations

- Activities on the Infrastructure
  - MEOC1 & Node 1 repaired
  - 6 DUs [May19-Jan20]
  - Node 2 [Oct 20] up to 50DUs
  - To Be Deployed: 7 DUs + IU + CB

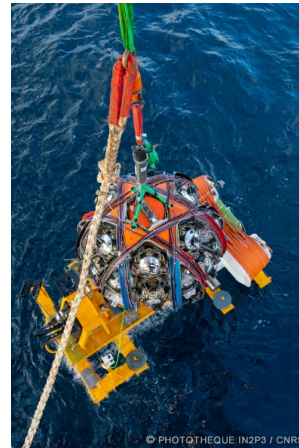


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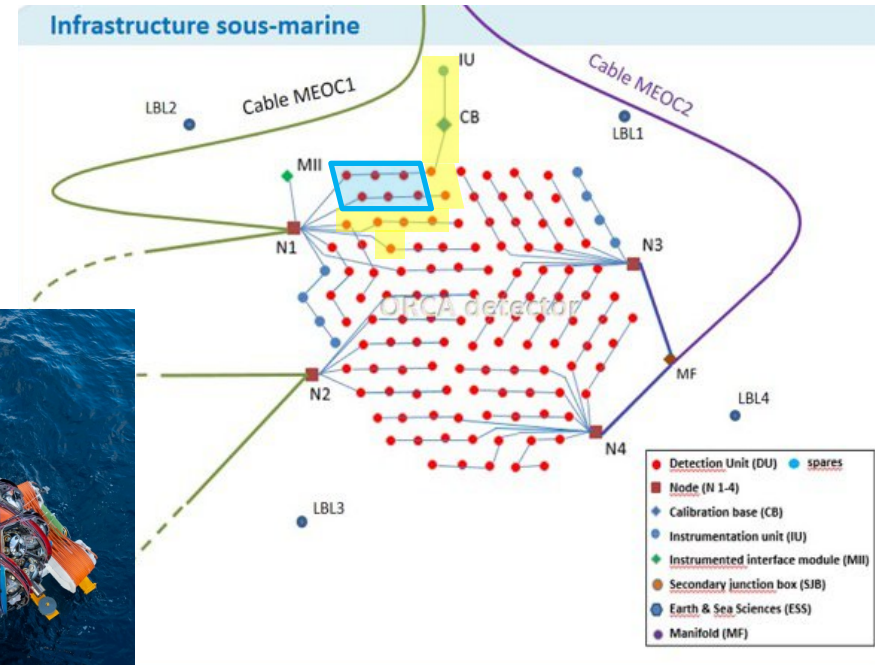
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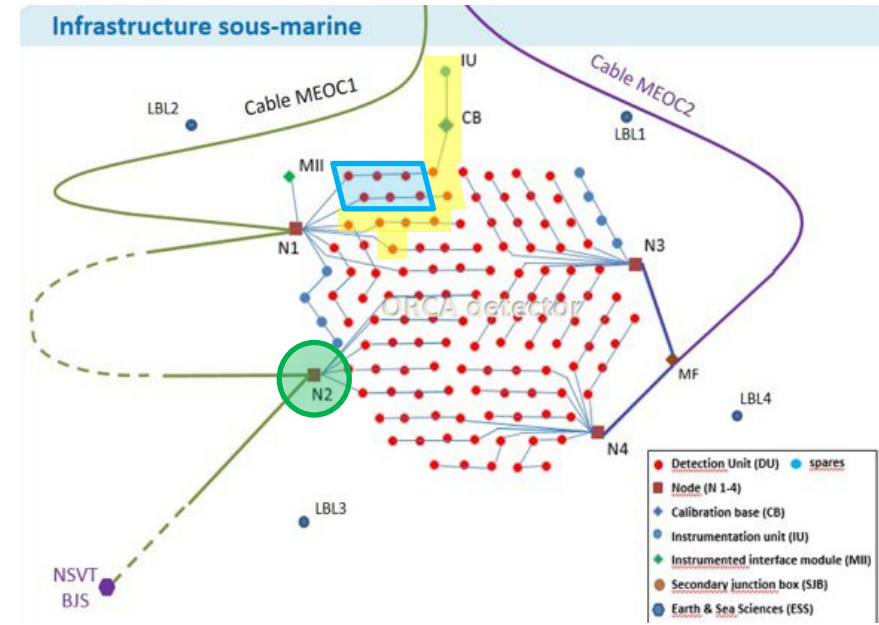


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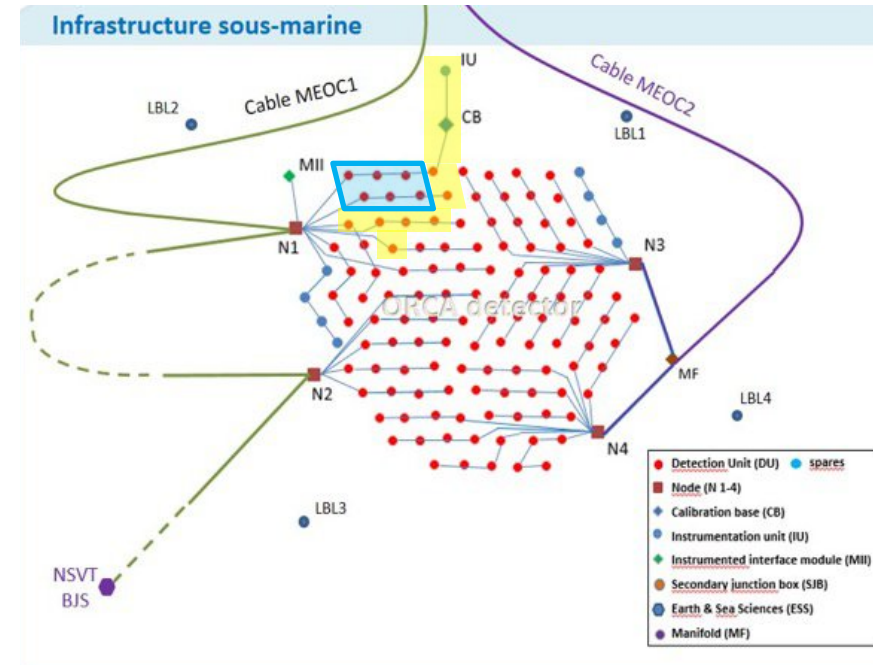
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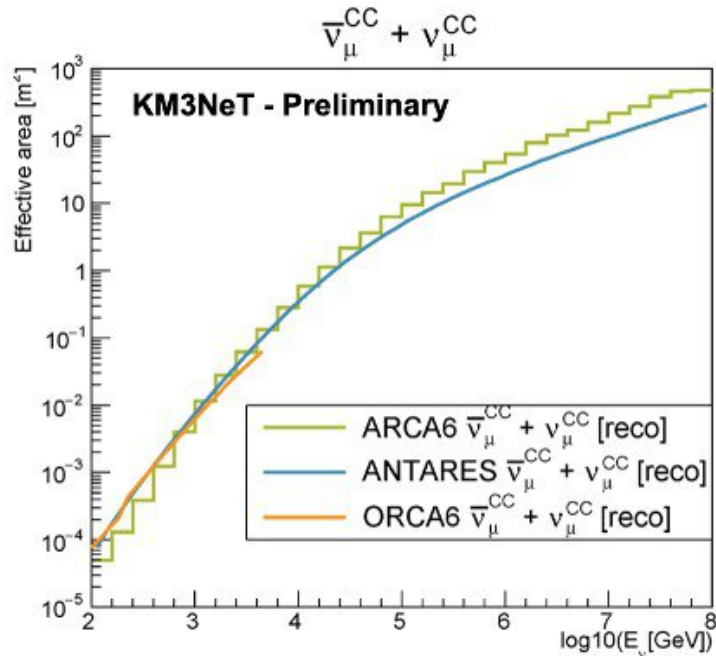
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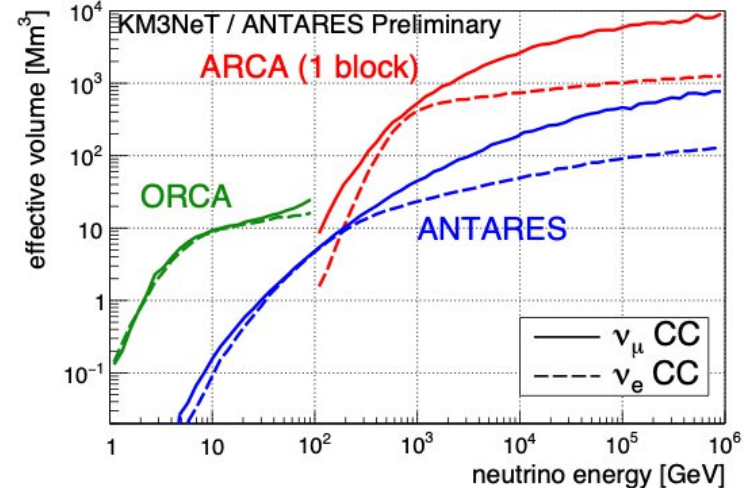


# ORCA6 ARCA6 and ANTARES

- Current Status
  - 6 lines at ORCA
  - 6 (+2) lines at ARCA (+15 next April)

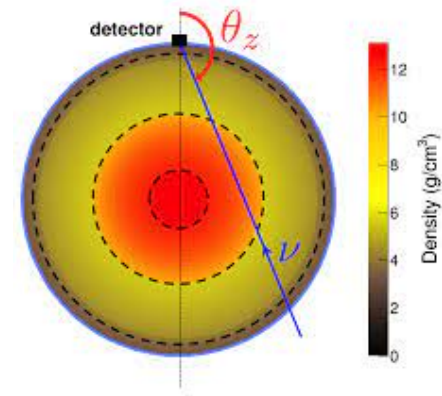
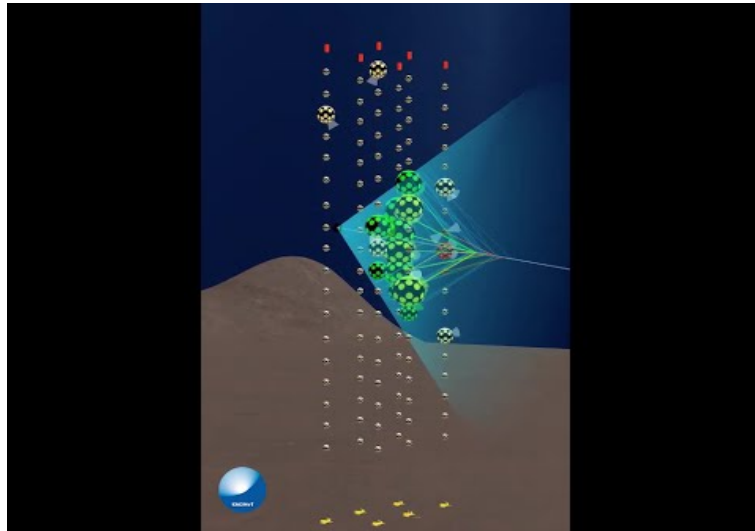


- Effective Area (i.e. efficiency)
  - larger than ANTARES on the whole energy range
  - ANTARES can be dismantled
- Full Detectors
  - nice overlap of the energy ranges



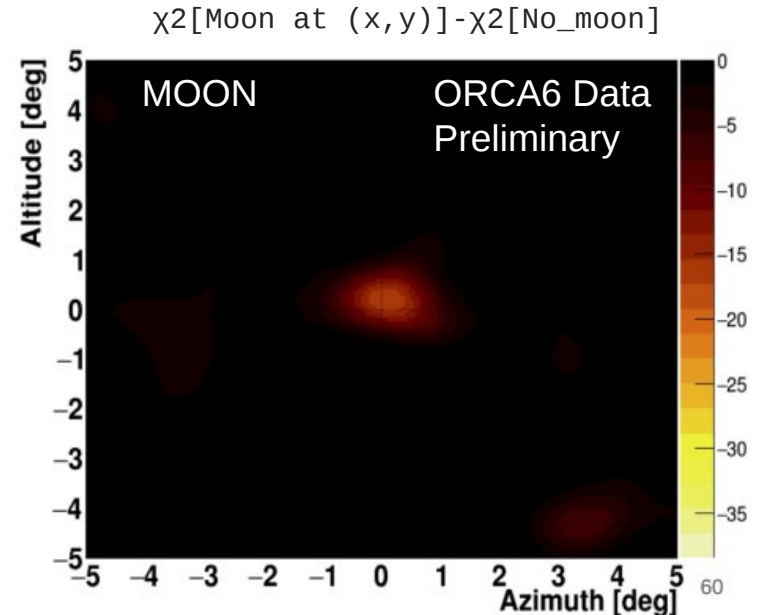
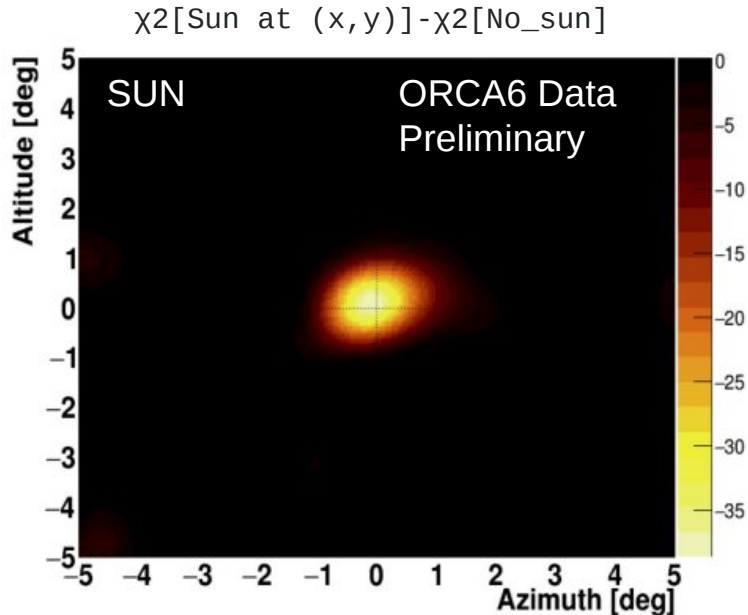
# Neutrino Events

- Event display of some up-going neutrinos

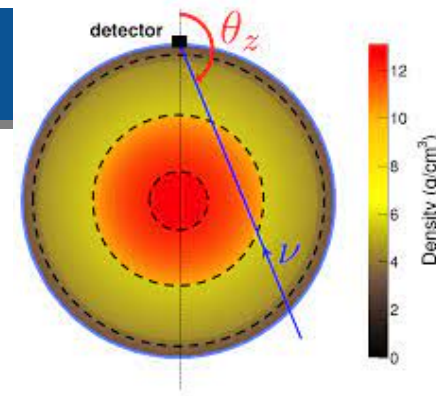


# Detector Absolute Pointing — Moon and Sun shadow

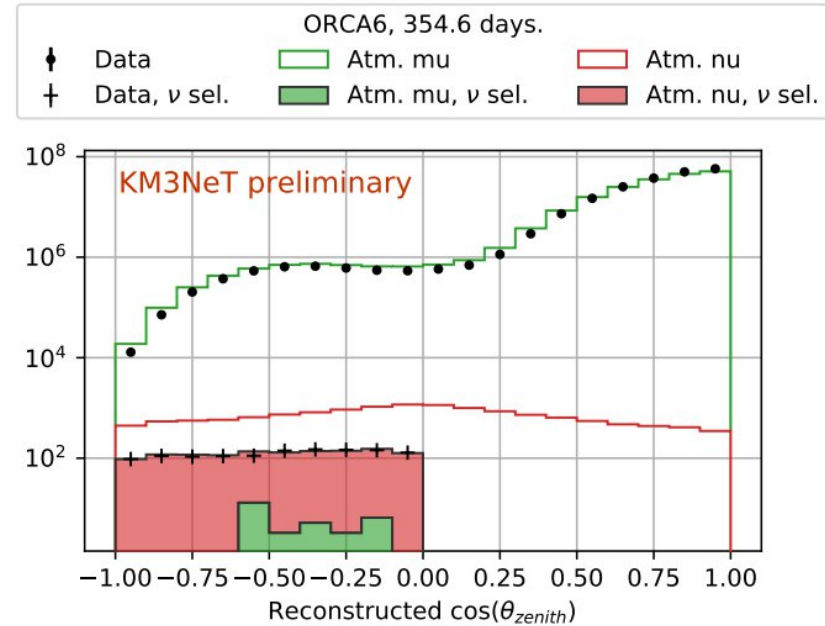
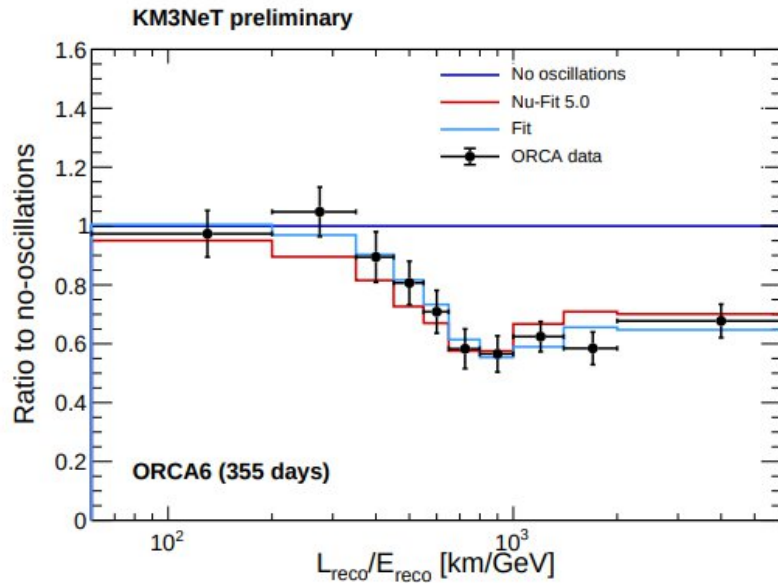
- Sun and moon are screening the cosmic rays
  - depletion in cosmic ray muon rate at the object position
  - allows to probe the detector pointing
  - ORCA-6 already sees the sun ( $6.1 \sigma$ ) and moon ( $4.0 \sigma$ ) with an angular reso of  $0.6^\circ$



# ORCA-6 Data: We see $\nu$ -Oscillation !



- Neutrino Oscillation
  - 355 days of data with ORCA-6
  - good matching between data and simulation
  - good suppression of the atm. muons
  - **no-oscillation hypothesis excluded at  $5.9\sigma$**

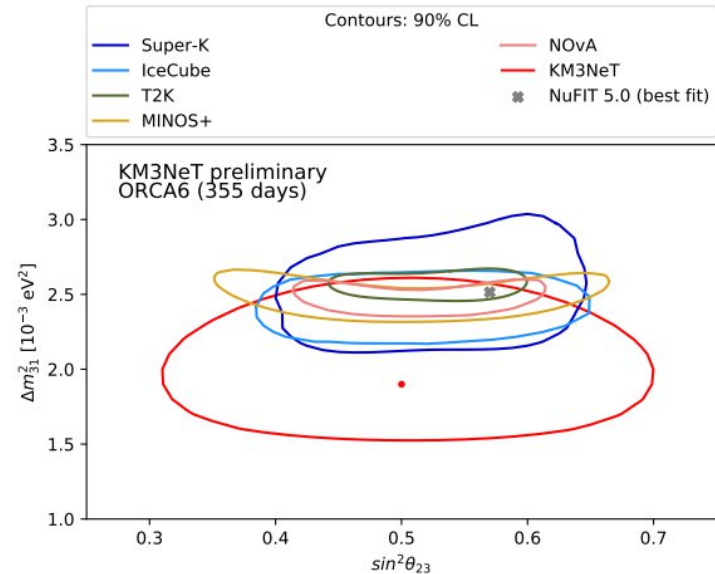
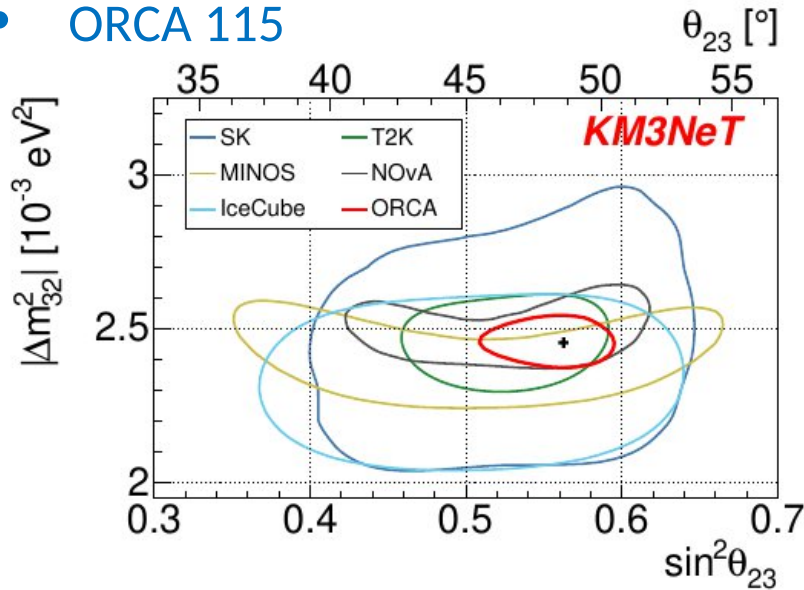


<https://pos.sissa.it/395/1123>

# We can measure $\nu$ -Oscillation parameters !

- Atmospheric oscillations parameters contour
  - getting competitive with other experiment
- Prospects
  - new analysis with improved reconstruction (energy)
  - more data with more DUs

- **ORCA 115**



<https://arxiv.org/abs/2103.09885>

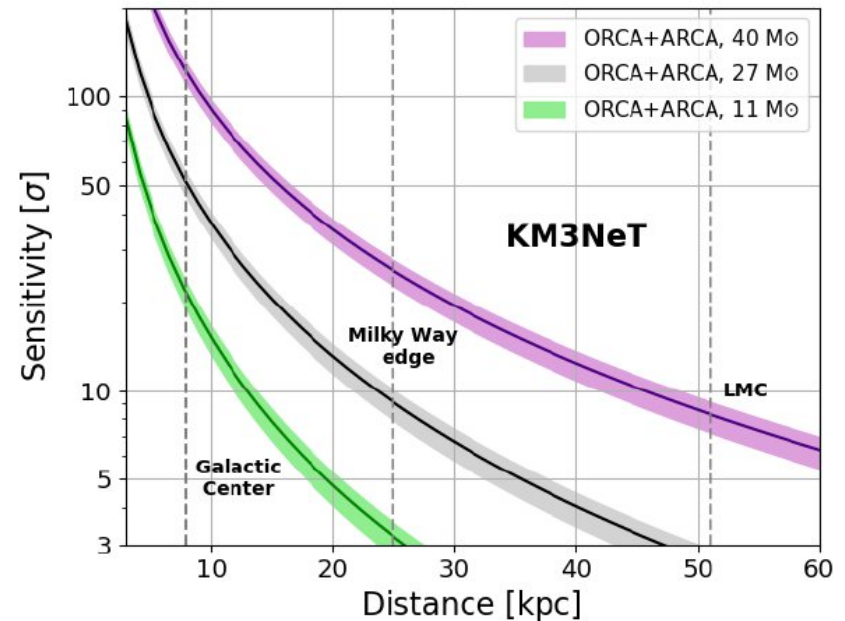
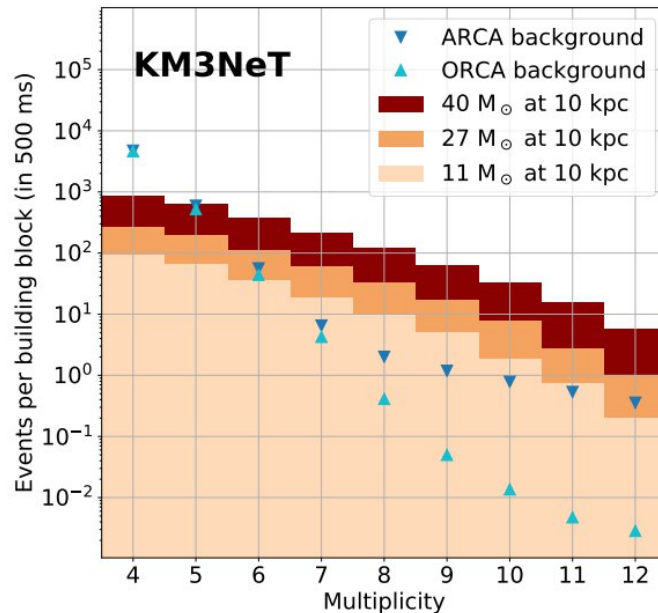
<https://pos.sissa.it/395/1123>

# Core Collapse Supernova

- Core Collapse SuperNova (CCSN)

Eur. Phys. J. C 81, 445 (2021)

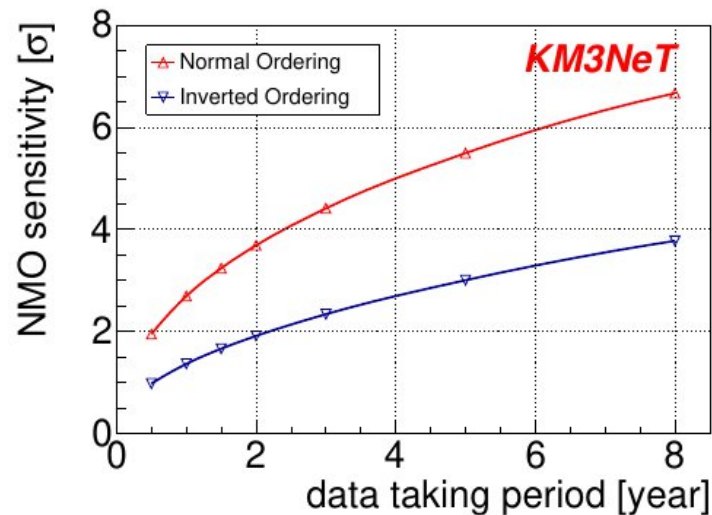
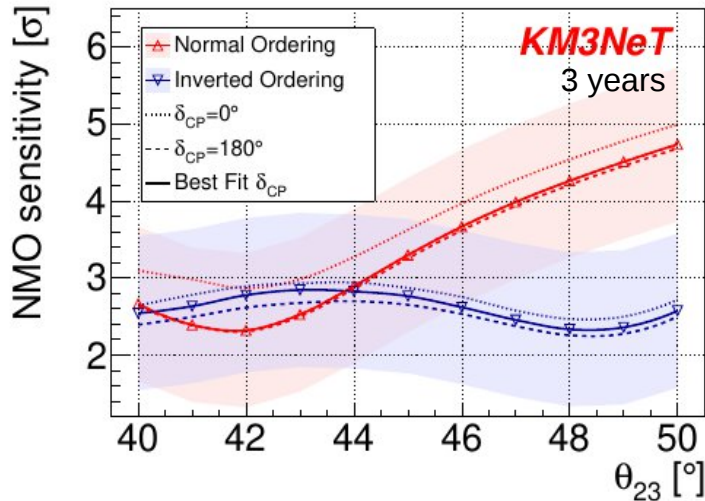
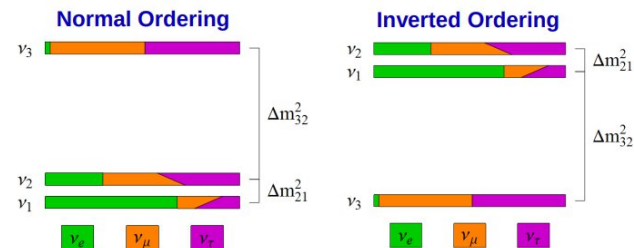
- O(10) MeV  $\nu$  detected from increased PMT coincidence rate
- CCSN analysis implemented real time since 2019 and deployed in SNEWS2.0
- with ORCA-6 and ARCA-6 the horizon for 11-27  $M_{\text{sun}}$  is 6-11kpc



# Physics with Full ORCA

<https://arxiv.org/abs/2103.09885>

- Update of the sensitivity to atmospheric oscillations
  - new trigger algorithm
  - new reconstruction method
  - additional systematic uncertainties

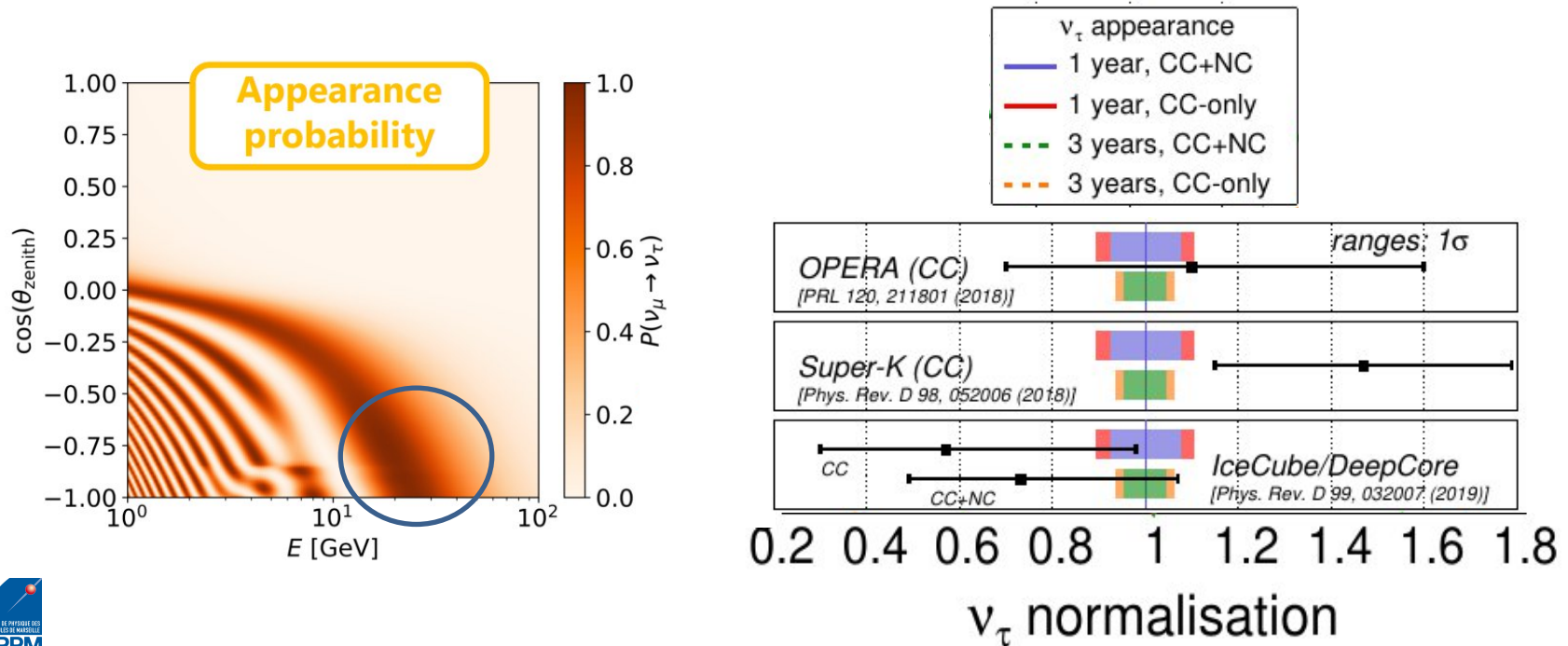




# $\nu\tau$ appearance

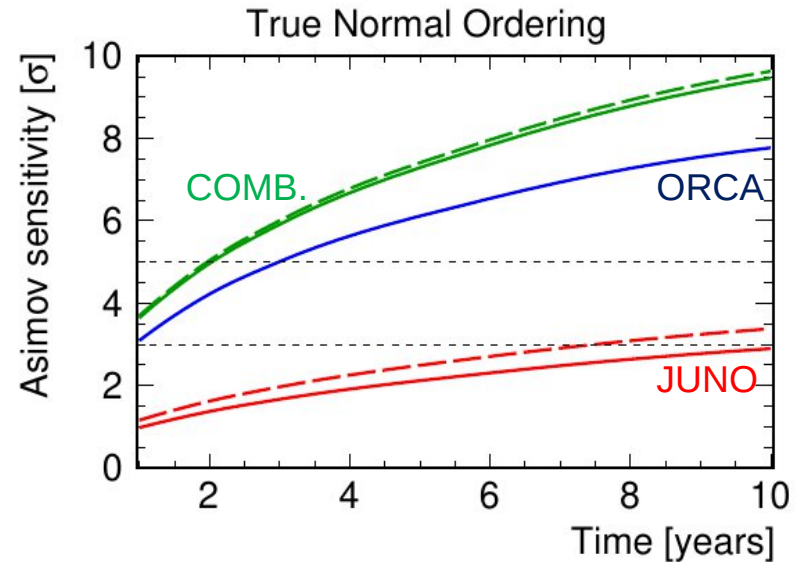
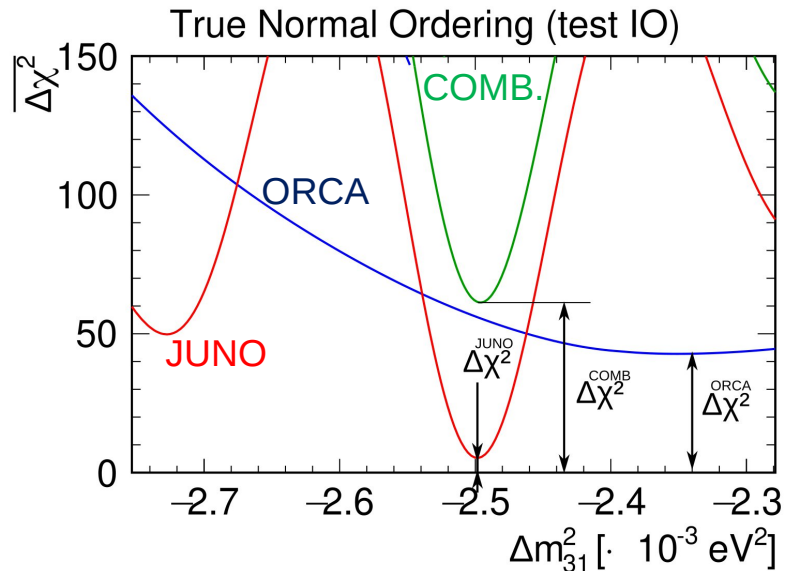
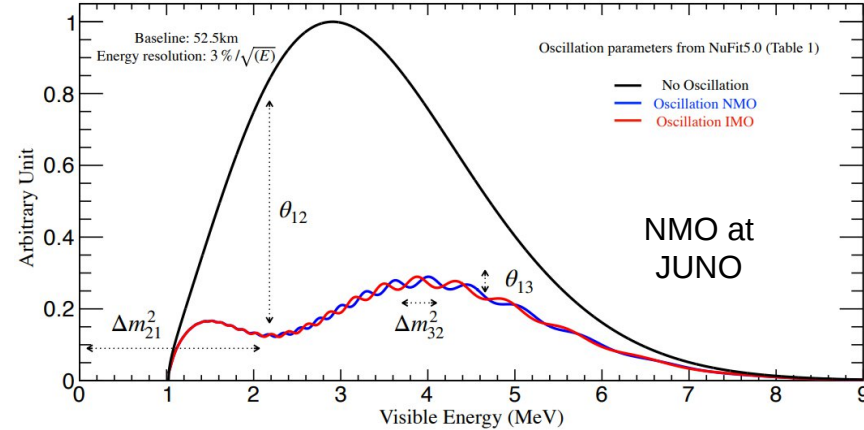
<https://arxiv.org/abs/2103.09885>

- Few experiments sensitive to  $\nu\tau$ :
  - $\nu\tau$  charge current interaction only possible if  $E\nu > 3.5$  GeV
  - dominant probability transition at 25 GeV
  - very important channel to constrain PMNS matrix unitarity (and indirectly sterile  $\nu$ )



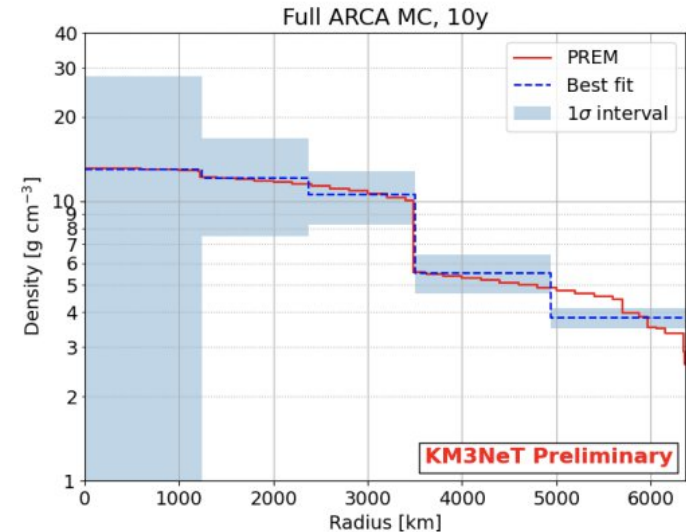
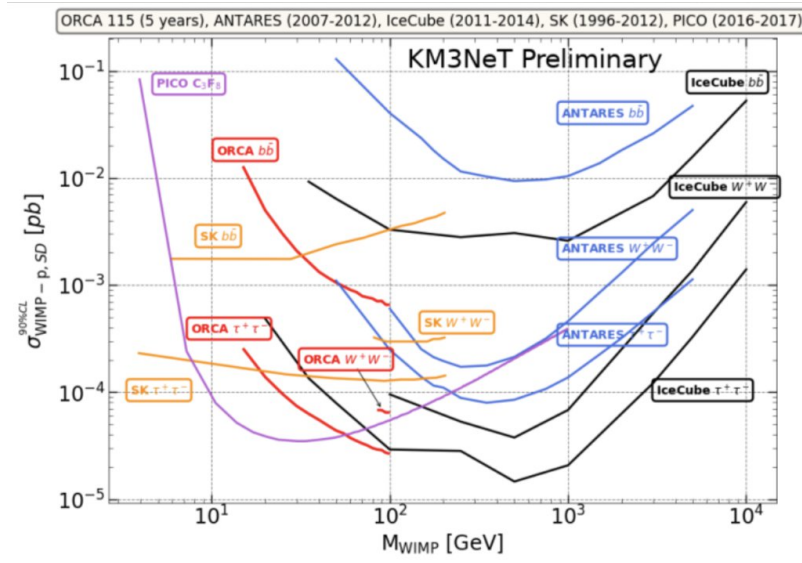
# Combination with JUNO

- Synergy between ORCA and JUNO
  - JUNO's precise determination of  $\Delta m^2_{31}$  boosts the ORCA NMO sensitivity
  - Joint paper being published: arXiv:2108.06293



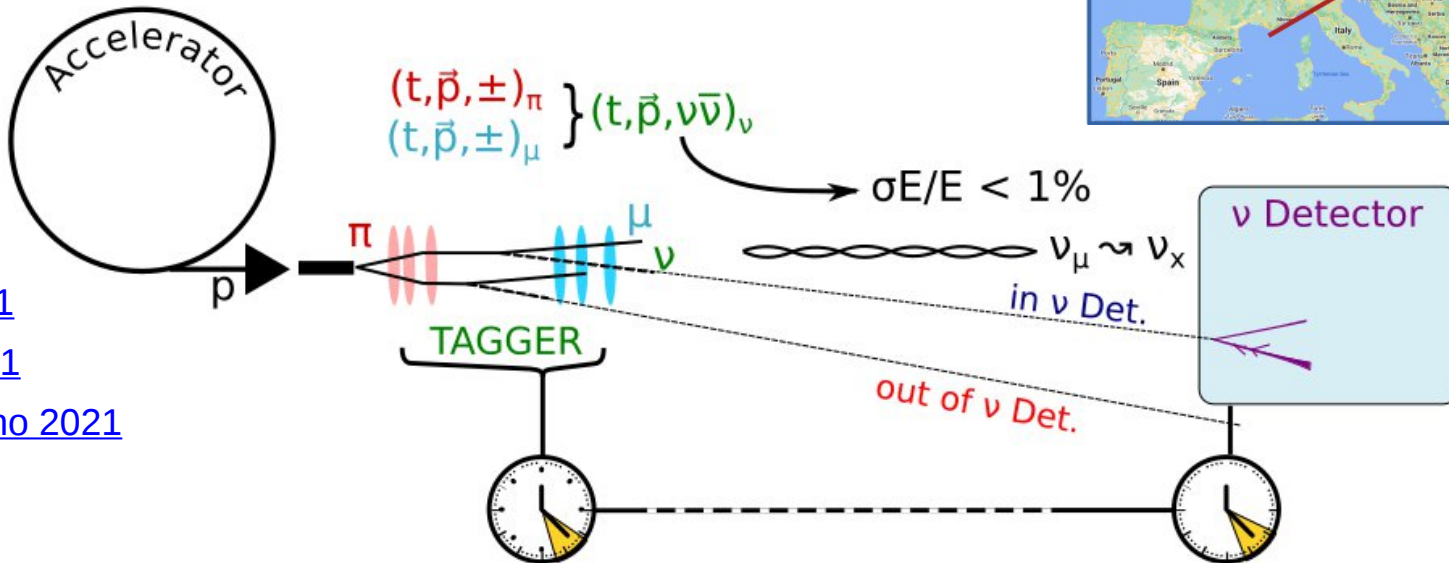
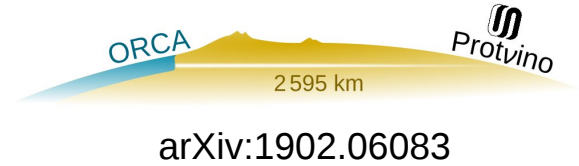
# Others main physics topics

- Several topics can also be addressed:
  - Indirect **dark matter** search from the Galactic Center and the Sun
  - **Earth tomography** via matter effect in the  $\nu$  oscillation / absorption of the  $\nu$  flux
  - $\nu$  astronomy at intermediate energies GeV - TeV from transient sources with ORCA:
    - choked GRB, Novae outburst, GW sources, flare of the Sun...
  - **Combined ORCA/ARCA (ANTARES)** analyses to increase the energy range with maximal sensitivities.



# Tagged P20

- Neutrino beam from Protvino to ORCA
  - Re-use the **same ORCA detector (no upgrade)**
  - **ORCA mass (6 Mton)** allows to operate at **lower beam intensity**
  - **Si detectors** in beam line to **track all  $\pi^\pm$  and  $\mu^\pm$**
  - $\nu$  produced by  $\pi \rightarrow \mu \nu$  can be precisely reconstructed: **tag- $\nu$**
  - **$\nu$  interacting** in ORCA matched individually with **tag  $\nu$**



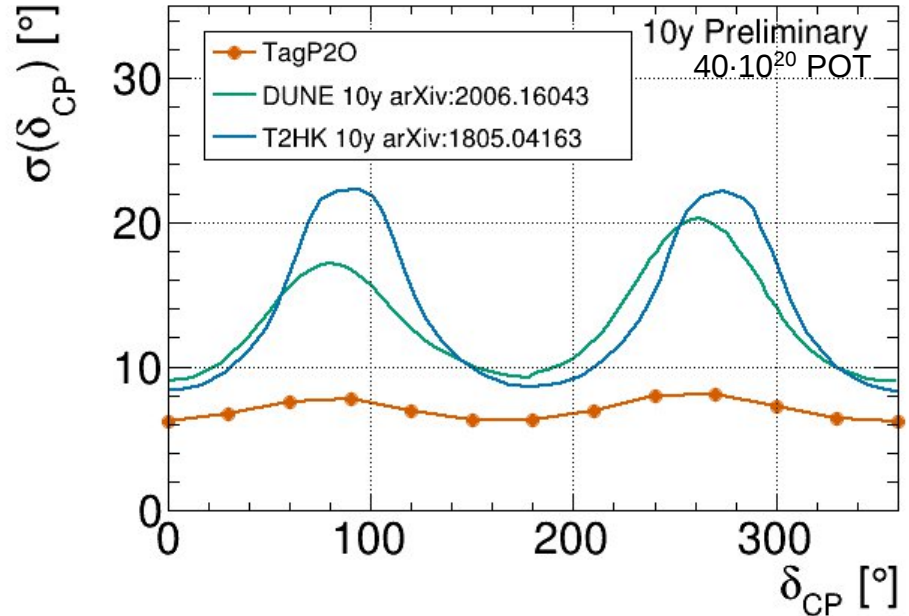
[Neutel 2021](#)

[VLVnT 2021](#)

[INR Neutrino 2021](#)

# Tagged P20 Status

- Tagging technique
  - ANR obtained to study the technique
  - **Experimental validation ongoing** at CERN-SPS with NA62: data being collected
  - **Beam line** being studied @ **CERN-PBC & IHEP Protvino**
  - **Trip to IHEP** Protvino in December
- Expected sensitivity
  - far detector: **ORCA-115** with the perf. as for atmospheric  $\nu$  (conservative)
  - exploit excellent **energy resolution** (resolve osc. pattern, reduce NC bkg)
  - **reduced systematic** uncertainties (beam composition, energy scales)



# Conclusions

- KM3NeT technology and analysis method are validated
  - **6 DU operational** for more than **1.5 year**
  - data collected already allows to **observed  $\nu$ -oscillations at  $5.9\sigma$**
  - **atmospheric osc. parameters** are measured
- Construction is progressing
  - 7 more DUs ready to be deployed
  - 13 more DUs under construction for the next year
- Physics Case
  - strong **opportunities** for **several world best/first** measurements [NMO, Tau, Sterile]
  - **Tag-P2O**: a new avenue for  $\nu$  physics which allows
    - unique opportunities (e.g. precise measurement of  $\Delta_{CP}$ )
    - to attract new collaborators in KM3NeT
    - a full exploitation in the longer term of money/efforts invested in ORCA