14th Pisa Meeting on Advanced Detectors

# KM3NeT : next-generation neutrino telescope under the Mediterranean Sea

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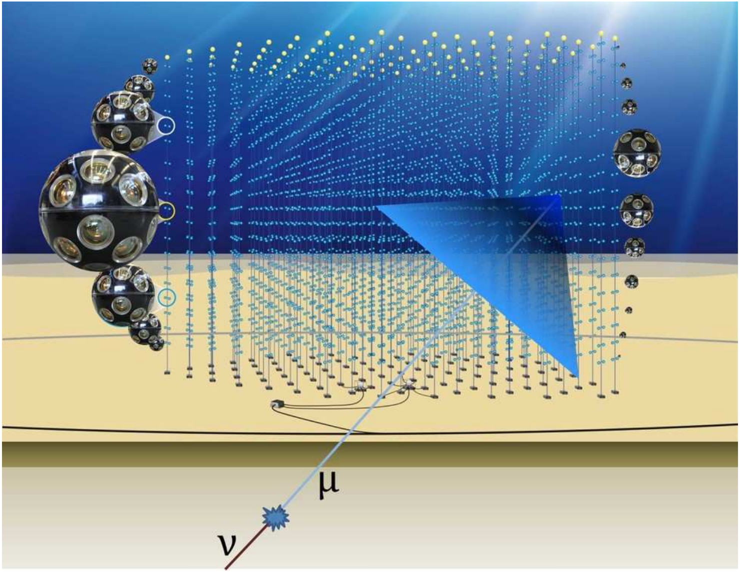
# Introduction : Deep Sea Neutrino telescopes

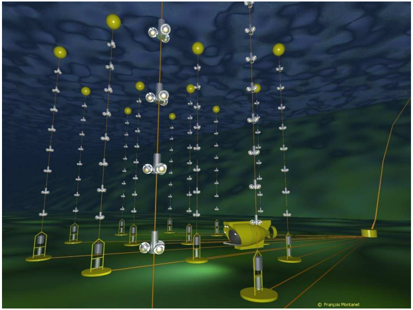



**Concept : Detection of Čerenkov light**

# Introduction : Deep Sea Neutrino telescopes

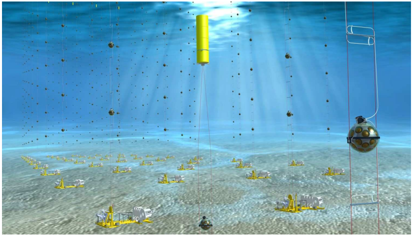
**ANTARES Neutrino Telescope :**

- Feasability of deep sea neutrino telescopes
- Multidisciplinary (Earth and Sea Science)
- Lines : 12
- PMTs : 885

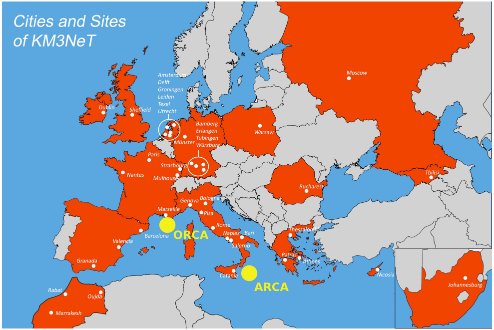



**Next Generation : KM3NeT**

- S. Adrian- Martines et al., Letter of Intent for KM3NeT 2.0, J. Phys. G 43 (2016) 084001
- Lines : 115 + 230
- PMTs : 64170 + 128340
- Improved Technology
- Multi-site



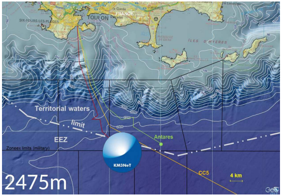
# The KM3NeT Collaboration



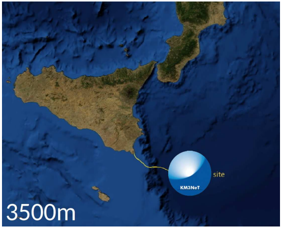

- 51 institutes and groups
- 41 cities
- 15 countries
- 250 people

**Two detectors ⇔ Same Technology**

**ORCA** : **Oscillation Research with Cosmics in the Abyss (KM3NeT-Fr)**




**ARCA** : **Astroparticule Research with Cosmics in the Abyss (KM3NeT-It)**



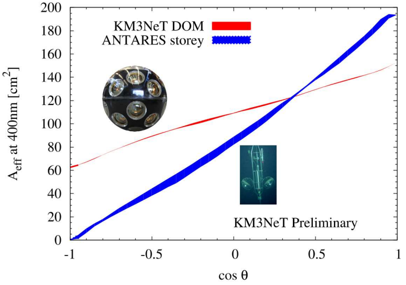
# Digital Optical Module (DOM)

**DOM :**

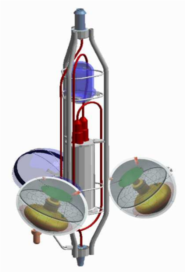
- 43 cm of diameter
- 31 x 3" PMTs
- Directional Information
- $4\pi$ sr coverage
- Main background : $^{40}$K
- All data to shore ($1$ Gb.$s^{-1}$ / DOM)

**PMT :**

- Digital Photon Counting
- Light concentrator ring
- Time-over-Threshold measurements

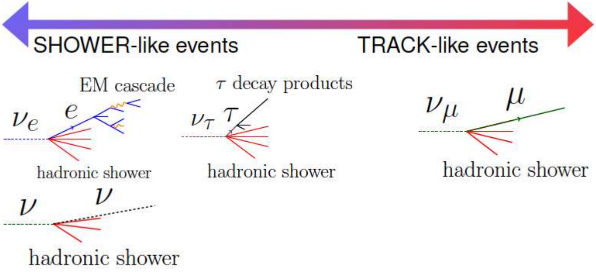


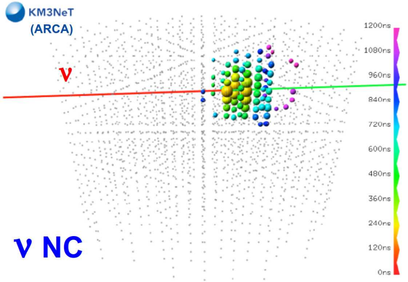

**KM3NeT**

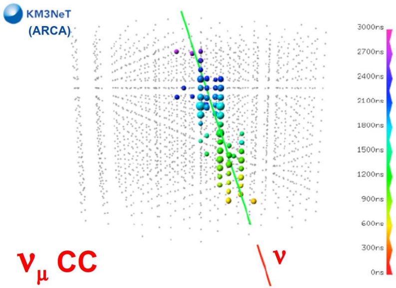


**ANTARES**

# Event topologies in a neutrino telescope



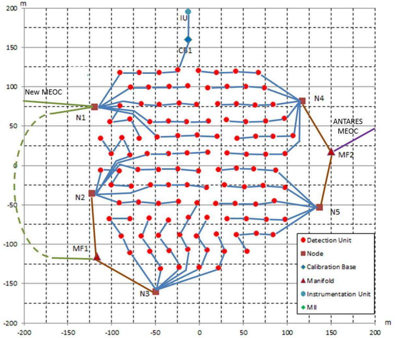



**KM3NeT-Fr Site : offshore Toulon (France)**

- Main research : neutrino mass hierarchy
  - $\Rightarrow$ More details in the following
- Few to hundreds of GeV neutrinos
- Depth of 2500 m

**ORCA block :**

- 115 lines
- 23 m horizontal spacing
- 18 floors
- 9 m vertical spacing
- 8 Mton instrumented



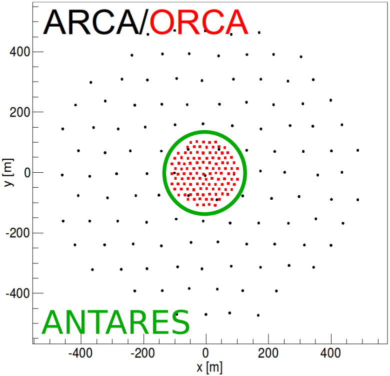

# Astroparticle Research with Cosmics in the Abyss (ARCA)

**KM3NeT-It Site : offshore Capo Passero (Sicily-Italy)**

- Main research : high energy neutrino astronomy
  - ⇒ More details in the following
- GeV to PeV neutrinos sources
- Depth of 3500 m

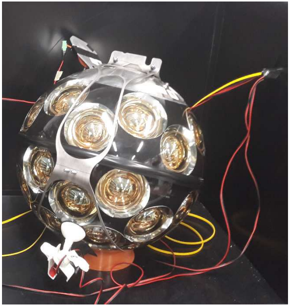
**ARCA block (x2) :**

- 115 lines
- 90 m horizontal
- 36 m vertical
- 0.5 Gton instrumented
  - ⇒ ORCA : 8 Mton
  - ⇒ ANTARES : 15 Mton



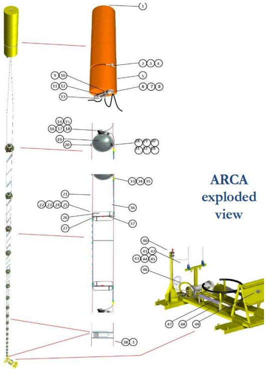

# Production Chain : DOM and line integration

**DOM Integration :**



- 8 DOM integration sites (in Netherland, Italy, Germany, Greece, France and Marocco)
- Assembling of all components (PMTs, electronics, PMTs 3D support, glass sphere, optical gel)
- QA/QC tests

**Line Integration :**




- 6 line integration sites (in Italy, Germany, and France)
- Assembling of all components (DOM, line base, cables, line structure, buoy)
- QA/QC tests

# Deployment of a Line

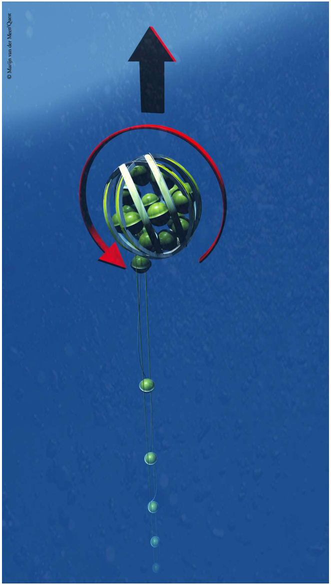
**Line furled around spherical frame | Position accuracy : $\sim$ 1 m**

# Inspection on the seabed (ROV)

## Connection to the Network (ROV)

# Unfurling of the Line

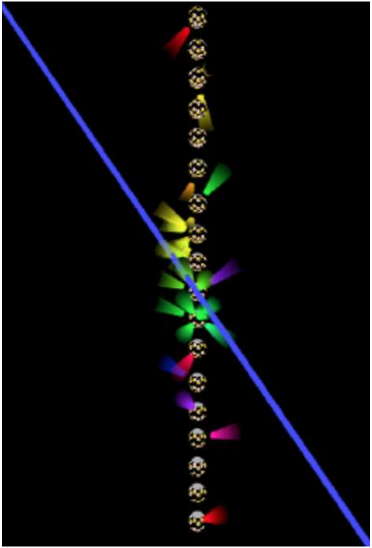
**Acoustic signal emitted after connection to the network checked**

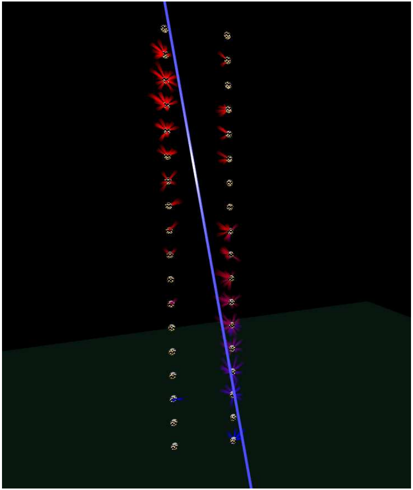


# Inspection of the Line (ROV)

# Data taking

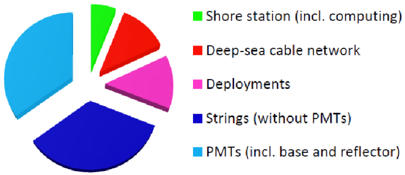
**Examples of recorded events for ORCA (left) and ARCA (right)**

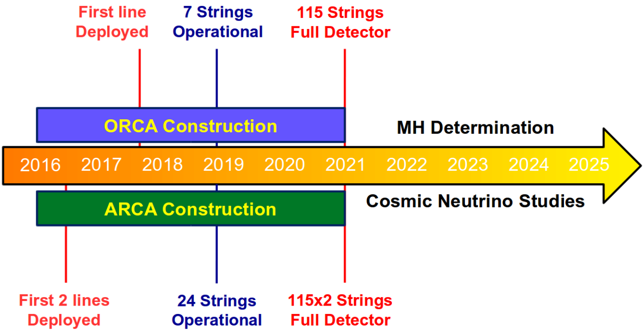




# Timeline and Costs

- Cost per line : $\sim$ 300k €



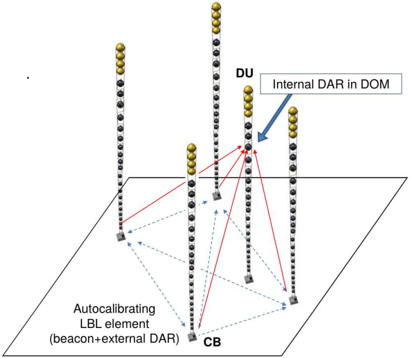
# Calibration Technics

- Thousands of Digital Optical Modules (DOM).
- Performance of KM3NeT : relies on precise timing and positioning of all detector elements.
- Complete set of instruments and tools :

  $\Rightarrow$ Calibration Base
  $\Rightarrow$ Instrumentation Line
  $\Rightarrow$ Muons
  $\Rightarrow$ $^{40}$K
  $\Rightarrow$ Nanobeacons
  $\Rightarrow$ Acoustics

# Acoustic Positioning System

- DOM position must be known to properly reconstruct tracks and showers
- Measurement accuracy : $\sim$ 10 cm




**The Long Base-Line :**

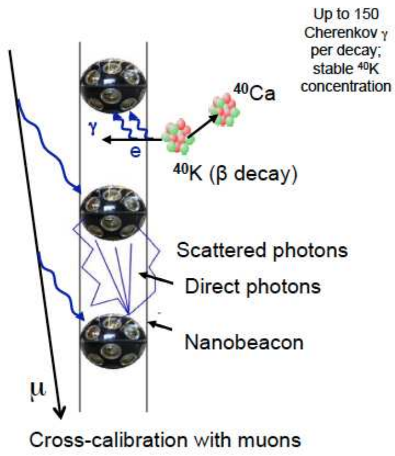
- Hydrophones on Calibration Base and Line Base
- Absolute positions known
- Reference system
- Acoustic Beacons on CB and LB

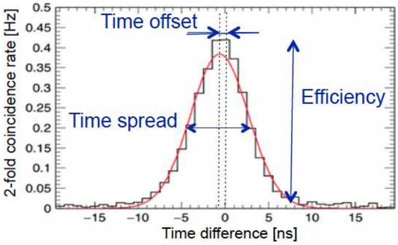
**On each DOM :**

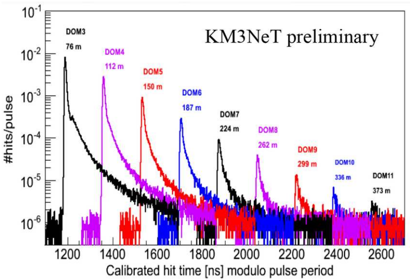
- Digital Acoustic Receiver

# Optical Backgrounds and Nanobeacons

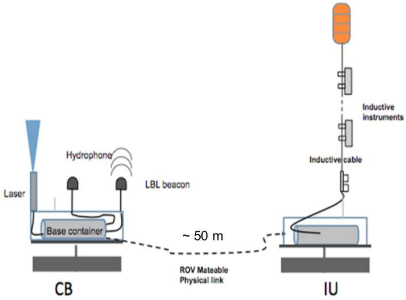
- DOM efficiency
- Internal DOM calibration



# Calibration Unit




**Calibration base :**

- Laser Beacon :
  - ⇒ Time calibration (<ns)
  - ⇒ Water optical properties.
- Hydrophone : position of the CB on the seafloor
- Acoustic Long Baseline emitter for DOM positioning

**Instrumentation line :**

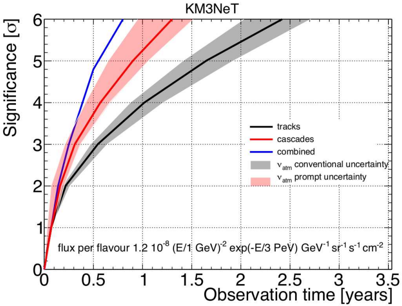
- Light and sound transmission
- Monitor full water column
- Measurement every 20 minutes
- Current meter
- Sound Velocimeter
- CTD probe : Conductivity, Temperature and Depth

# ARCA : science program

- Provide complementary measurement of IC flux
- All neutrino flavour astronomy
- Multimessenger (continous data taking over $4\pi$ sr)
- New unknown sources
- Galactic sources

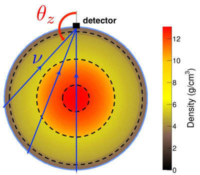
expected ARCA performances for a diffuse flux (from LoI)

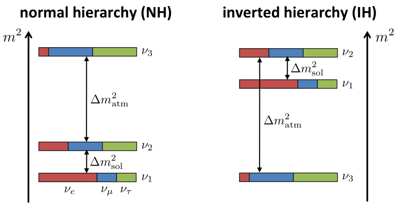
- Check neutrino emission from :
  - $\Rightarrow$ Galactic plane ($3\sigma$ in 1.3 years)
  - $\Rightarrow$ RXJ1713 ($3\sigma$ in 4 years)
  - $\Rightarrow$ VelaX ($3\sigma$ in 2.5 years)

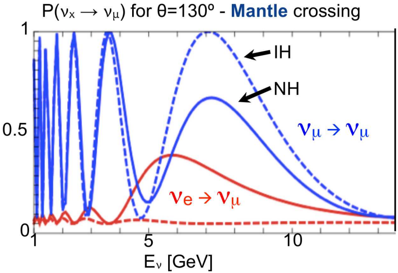


**Main goal : neutrino mass hierarchy (NMH)**

- Important for theory, cosmology, $0\nu\beta\beta$
  - $\Rightarrow$ Sensitivity better than $3\sigma$ in 4 years
- ORCA optimised for GeV atmospheric neutrinos
- Probe matter effect on $\nu$ survival and appearance probabilities with Up-Going muons

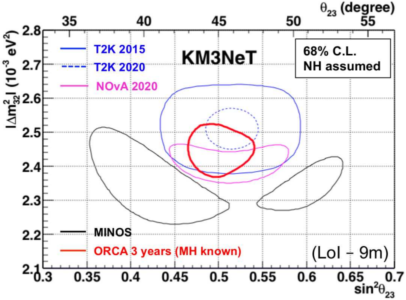


# ORCA : other science topics

- Improvement of measurement of $\Delta m^2_{32}$ and $\theta_{23}$
- Indirect search for low mass dark matter
- Supernovae monitoring
- Earth sciences : tomography, seismology
- Sea sciences : oceanography, bioacoustics, bioluminescence




NH, $\delta_{CP} = 0$, maximal mixing assumed

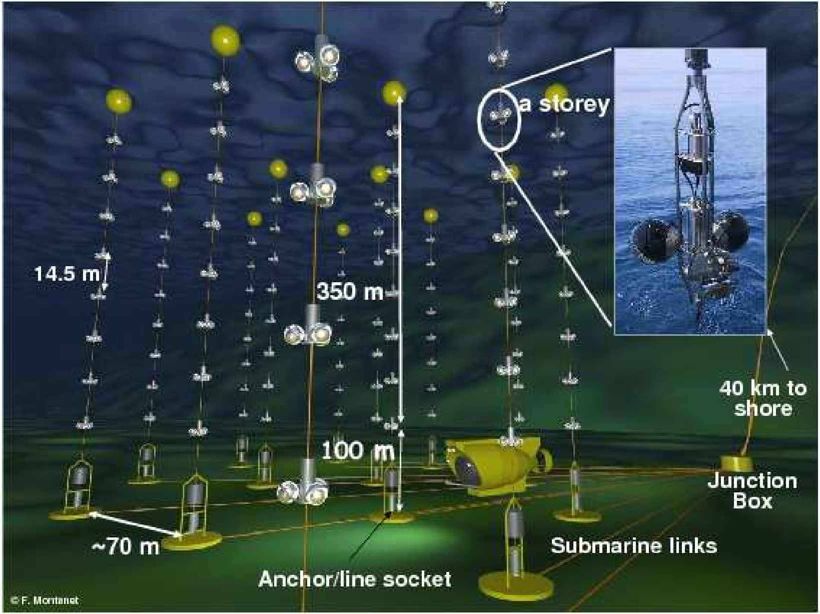
# Conclusion and outlooks

$\Rightarrow$ **Two next-generation neutrino telescopes in the Mediterranean sea**

- New innovative and effective design for the Digital Optical Module :
  - $\Rightarrow$ Increase in photo-cathode area
  - $\Rightarrow$ Directional Information and $4\pi$ sr coverage
- Complete set of precise calibration instruments
- KM3NeT/ARCA can observe high energy neutrino flux seen by IceCube at the South Pole with :
  - $\Rightarrow$ A different field of view
  - $\Rightarrow$ Different systematic uncertainties
- KM3NeT/ORCA oscillations with atmospheric neutrinos :
  - $\Rightarrow$ NMH with a sensitivity of $>3\sigma$ in 4 years of operation

# Backups

# ANTARES dimensions



# Specification of the PMTs

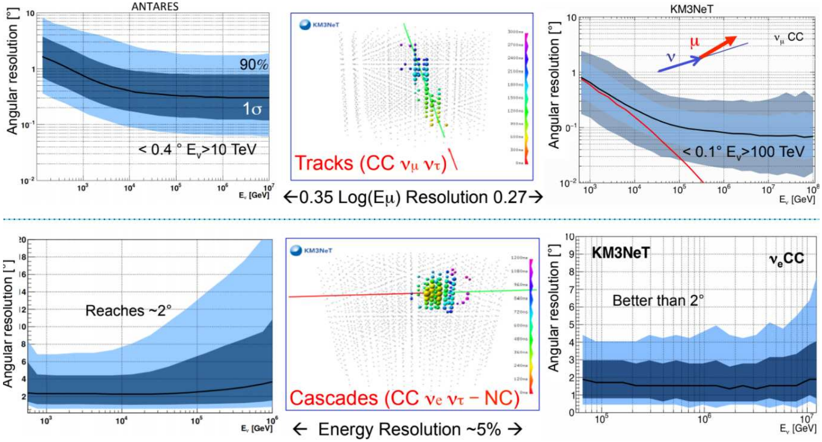
| | |
|---|---|
| Radiant blue sensitivity at 404 nm | 130 mA/W |
| Quantum efficiency (QE) | 20% @ 470 nm and 28% @ 404 nm |
| Inhomogeneity of cathode response | 10% |
| Supply voltage for a gain of $3 \times 10^6$ | 900–1300 V |
| Dark count at 15°C and 0.3 photo-electron threshold | 1.5 kHz |
| Transit time spread (TTS) | 4.5 ns (FWHM) |
| Peak to valley ratio | 2.5 |

Table 2: Specification of the PMTs.

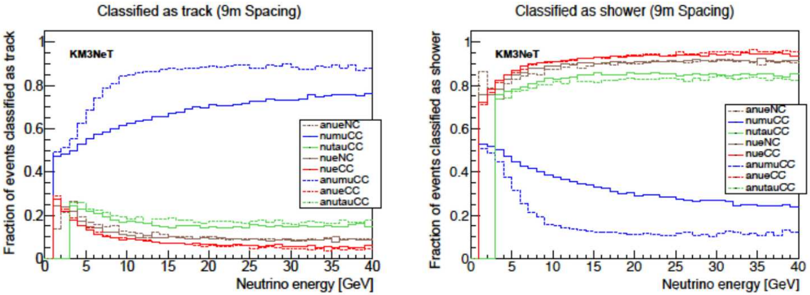
# PMTs

Figure 13: Photographs of the PMTs. ETEL D792KFL (left) and Hamamatsu R12199-02 (right).

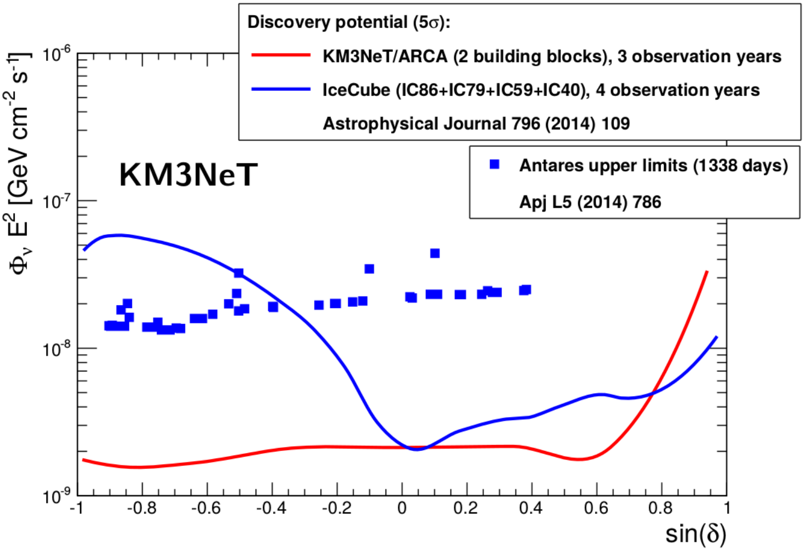
# ARCA/ANTARES angular resolution



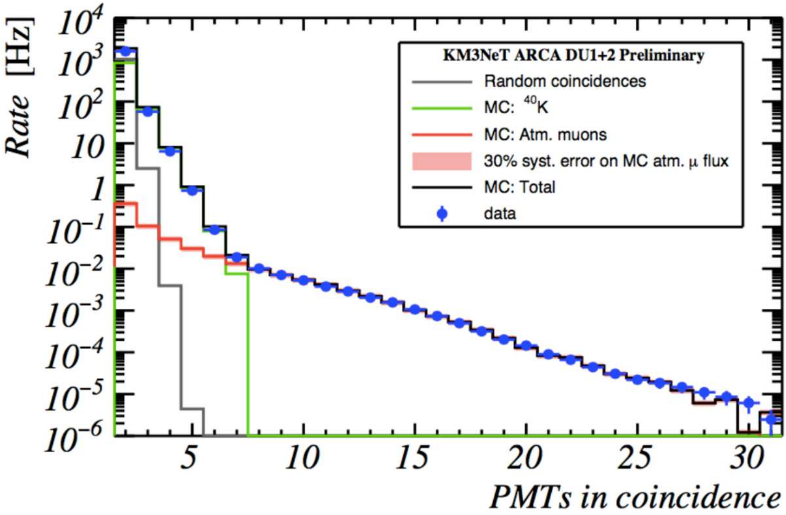
# ORCA tracks and shower identification



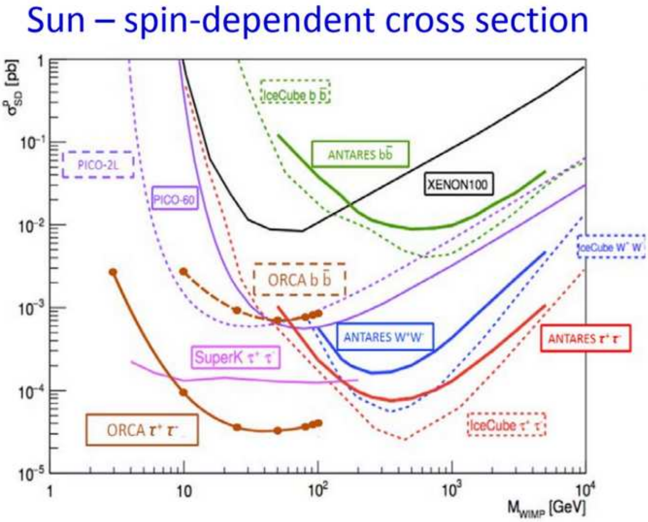
# ARCA point-like source ($\propto E^{-2}$ spectrum)



# PMT Coincidences Rates



# ORCA Dark Matter




Phys. Lett. B, 759, 2016, 69-74

# ORCA NMH sensitivity

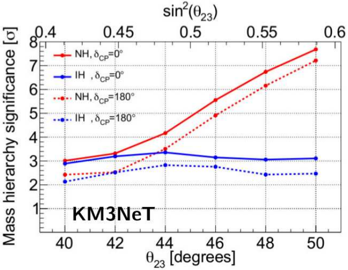
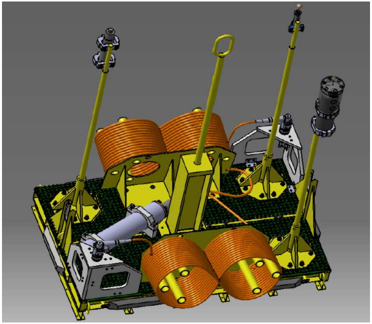
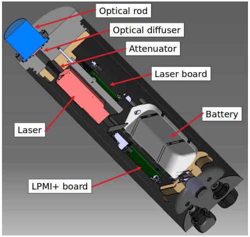



Figure 106: The mass hierarchy sensitivity for 9 m spacing, using the default settings. This includes a fit of $\theta_{23}$, $\Delta M^2$, $\delta_{CP}$ and the five systematics. The left plot shows its dependency on $\theta_{23}$ for two values $\delta_{CP}$ for three years of operation time whereas the right plot illustrates its improvement over time for two selected values of $\theta_{23}$ and $\delta_{CP} = 0°$.

# Calibration Base

- Laser Beacon :
  - ⇒ Time calibration (<ns)
  - ⇒ Water optical properties.
- Hydrophone : position of the CB on the seafloor
- Acoustic Long Baseline emitter for DOM positioning (+ acoustic receiver on each DOM)



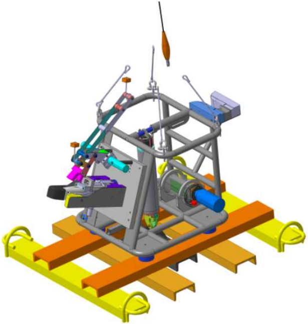




**To monitor environmental conditions :**

- Light and sound transmission affected
- Monitoring of the full water column
- Measurement every 20 minutes
- Height adapted to ARCA/ORCA
- Same instruments at different depths
- Current meter : Inclination of the lines
- Sound Velocimeter
- CTD probe : Conductivity, Temperature and Depth

  $\Rightarrow$ Infer sound velocity through seawater equation of state



Valeport Midas Mini SVS