Recent results from the ANTARES detector

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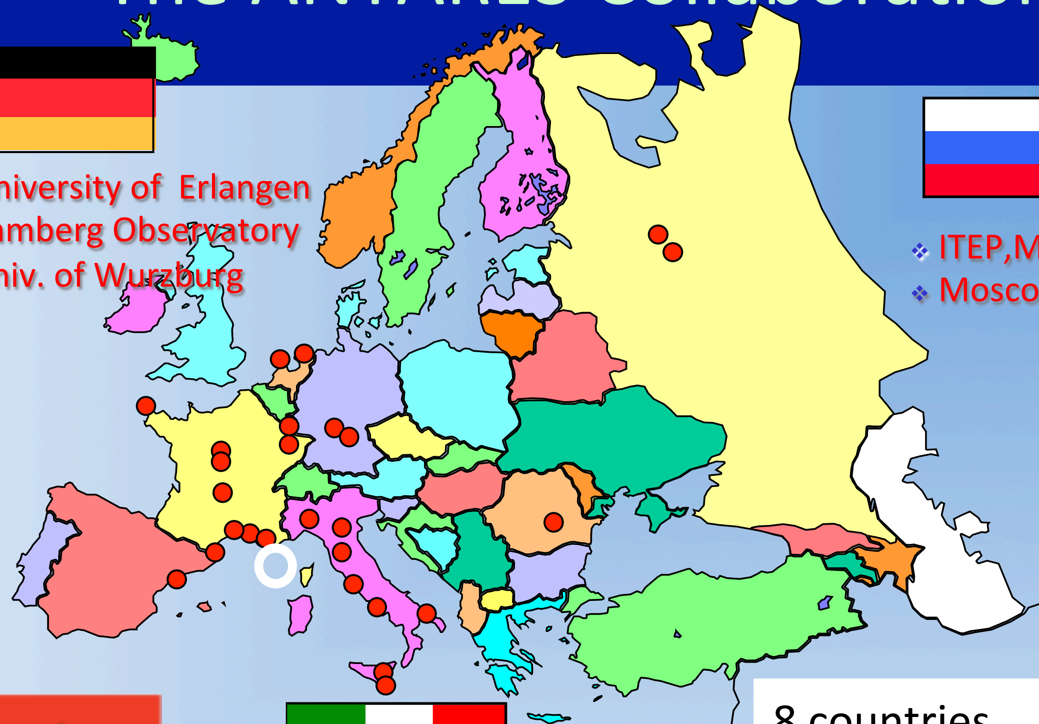
Università and INFN Bologna
on behalf of the ANTARES Collaboration

The ANTARES Collaboration



- NIKHEF,
- Amsterdam
- Utrecht
- KVI Groningen
- NIOZ Texel

- University of Erlangen
- Bamberg Observatory
- Univ. of Wurzburg

- ITEP,Moscow
- Moscow State Univ

- IFIC, Valencia
- UPV, Valencia
- UPC, Barcelona

- ISS, Bucarest

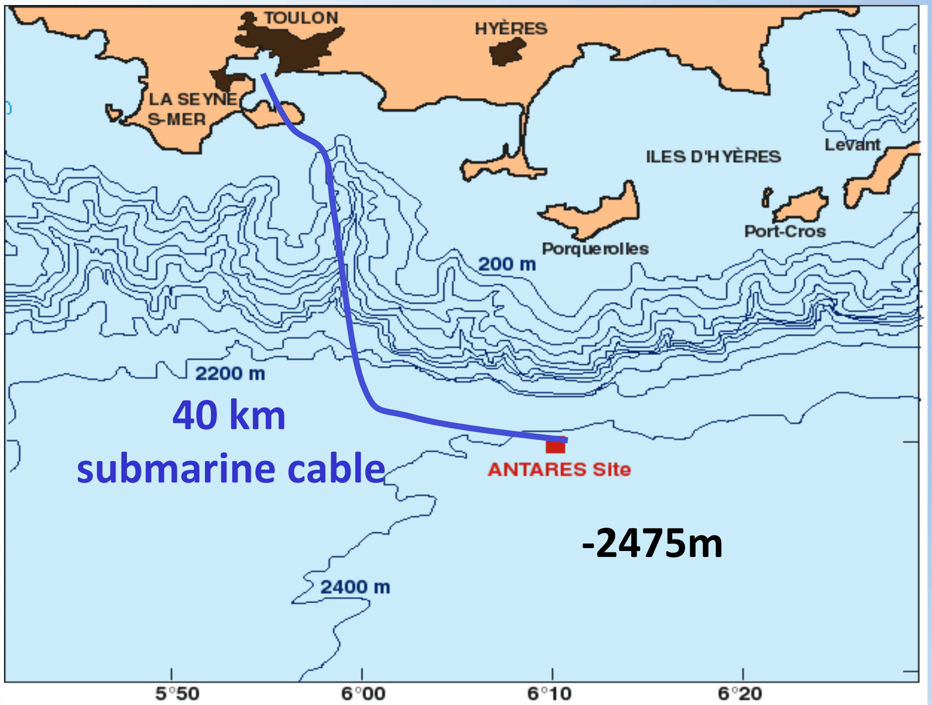
- CPPM, Marseille
- DSM/IRFU/CEA, Saclay
- APC, Paris
- LPC, Clermont-Ferrand
- IPHC, Strasbourg
- Univ. de H.-A., Mulhouse
- LAM, Marseille
- COM, Marseille
- GeoAzur Villefranche
- INSU-Division Technique

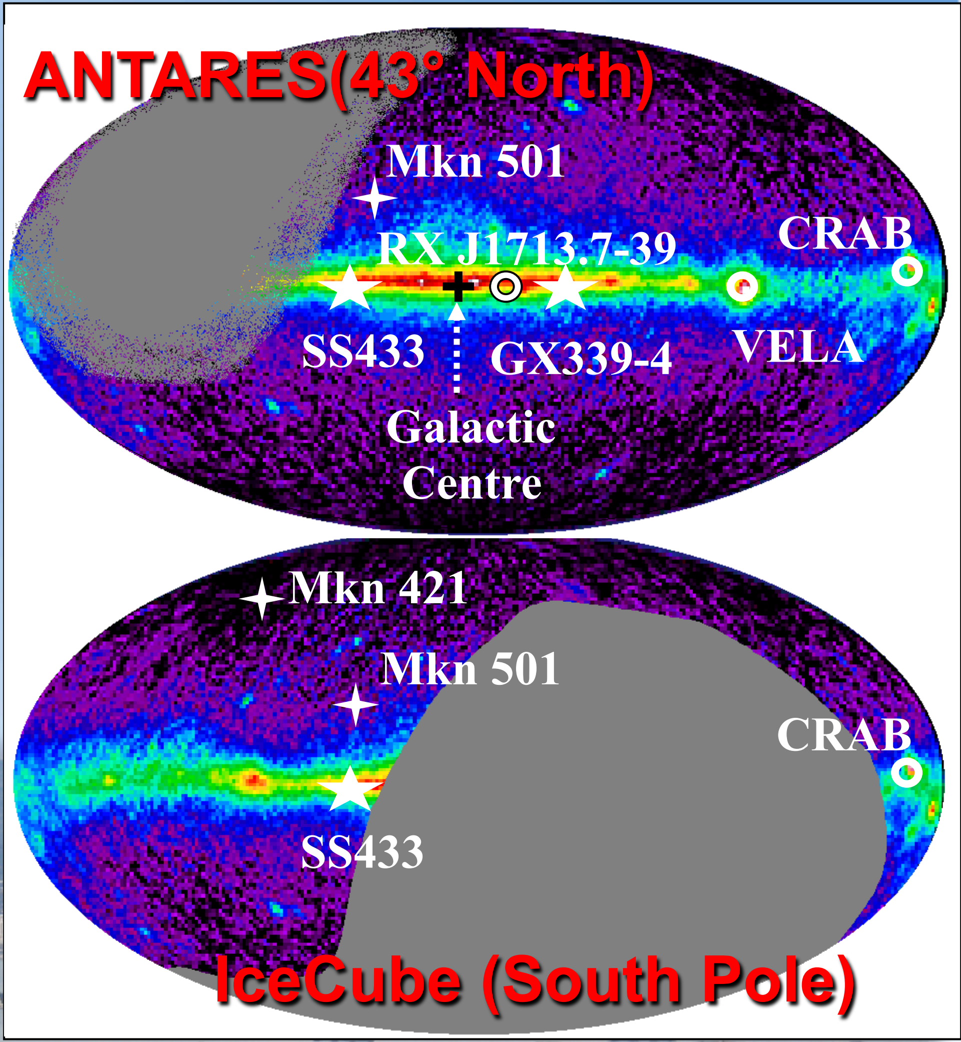
- LPRM, Oujda

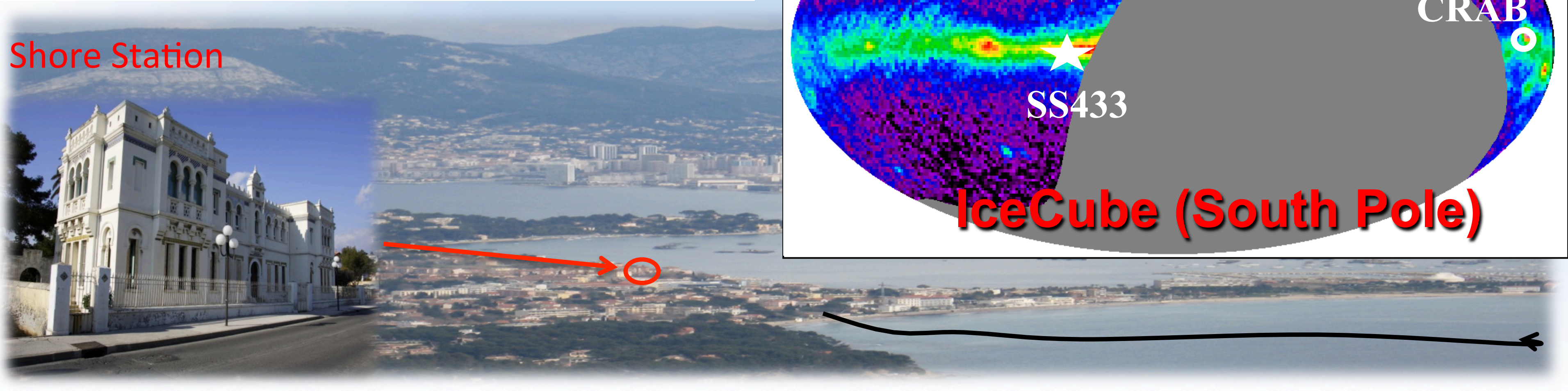
- Univ./INFN of Bari
- Univ./INFN of Bologna
- Univ./INFN of Catania
- LNS–Catania
- Univ./INFN of Pisa
- Univ./INFN of Rome
- Univ./INFN of Genova
- Univ./INFN of Napoli

8 countries
31 institutes
~150 scientists+engineers

The ANTARES Site & Sky

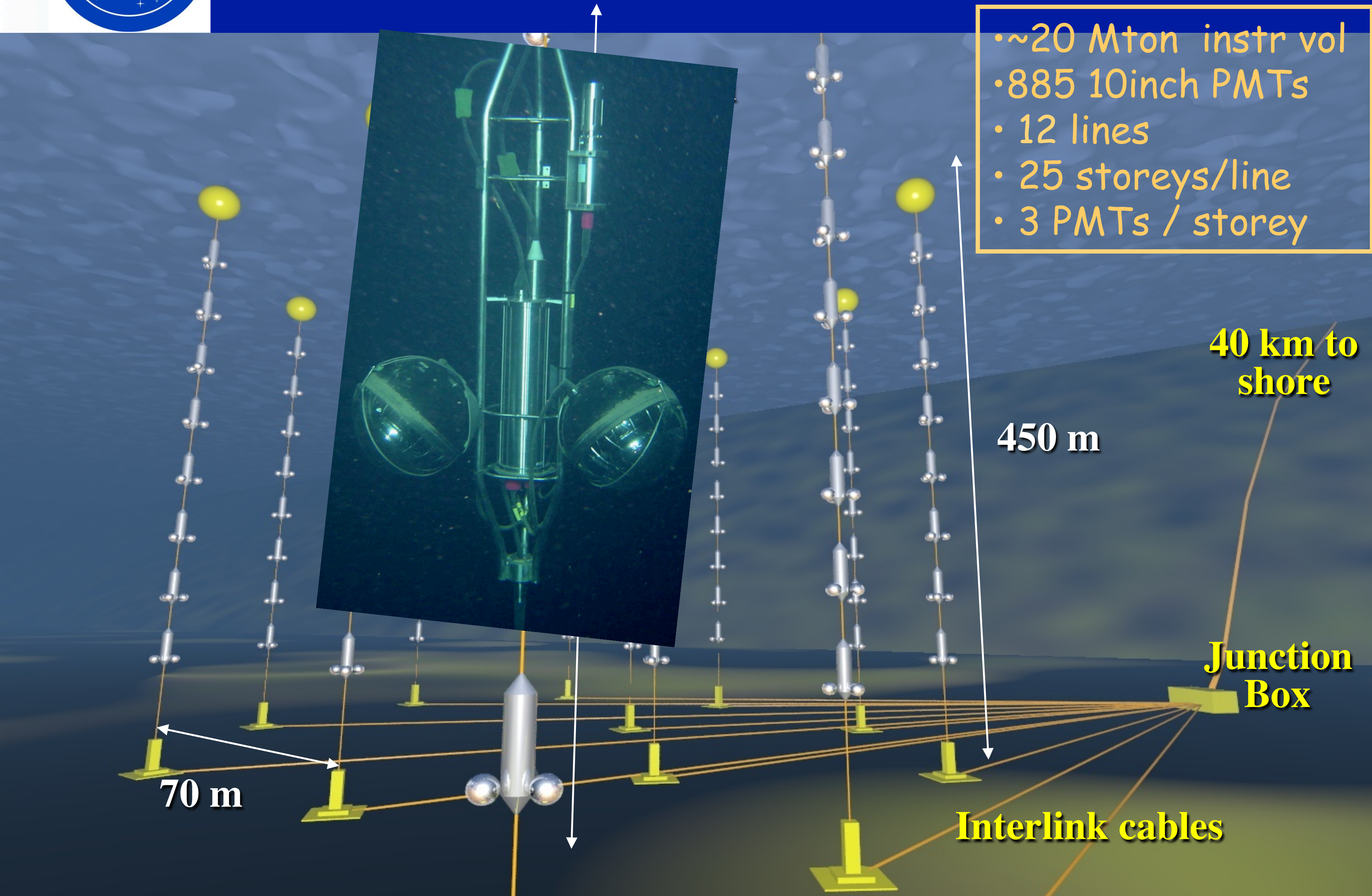




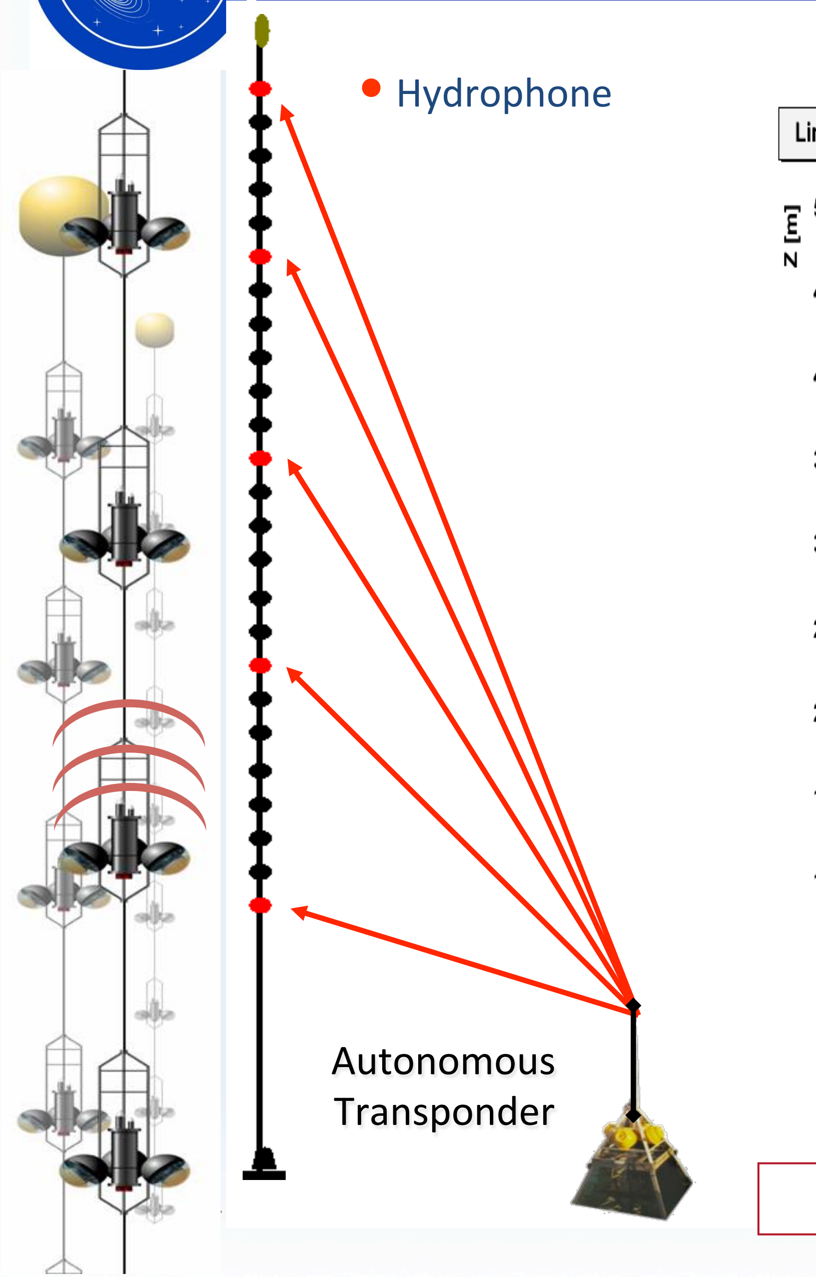


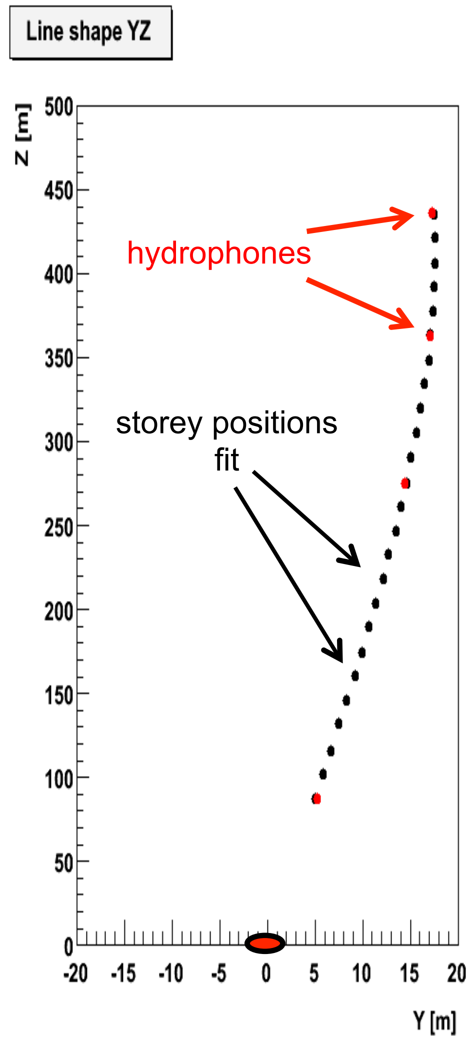
Overview

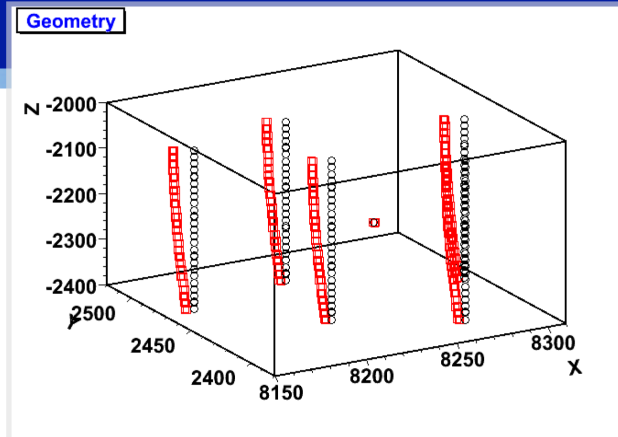
- ~20 Mton instr vol
- 885 10inch PMTs
- 12 lines
- 25 storeys/line
- 3 PMTs / storey



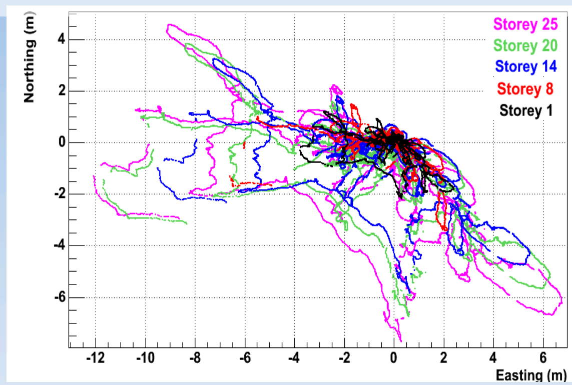
Detector calibration



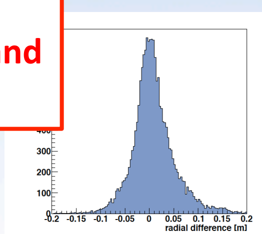




Position of hydrophone relative to line base location



Difference between triangulation result and line fit for a storey



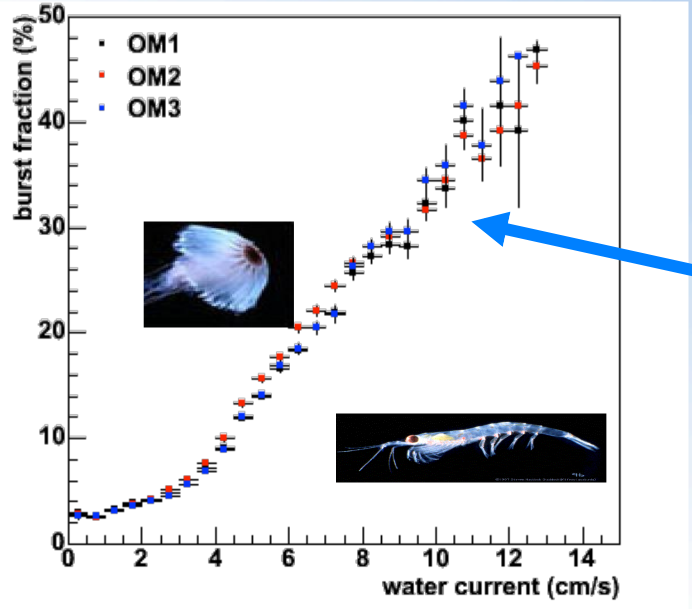
Positioning resolution < 10 cm

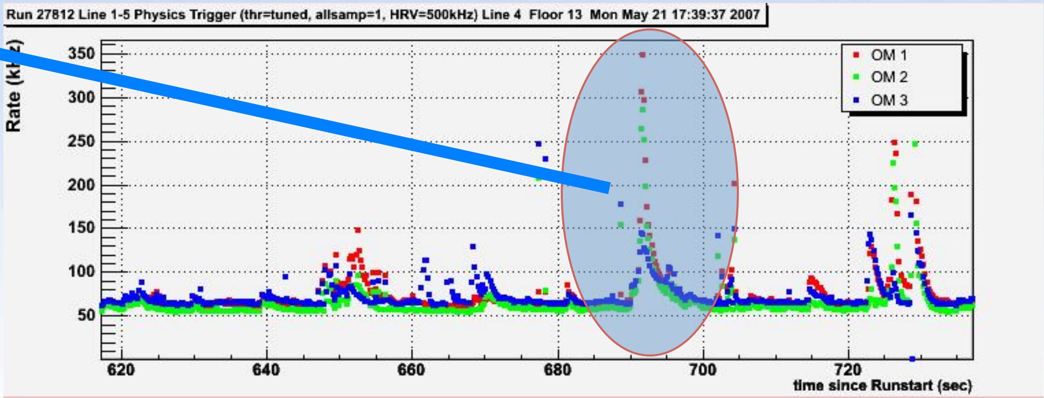
Background sources in ANTARES

NOT ONLY muons and atmospheric neutrinos

^{40}K decays and bioluminescence of micro-organisms (rate ~70 kHz)

Plus bursts from macro-organisms (strongly correlated to sea currents)

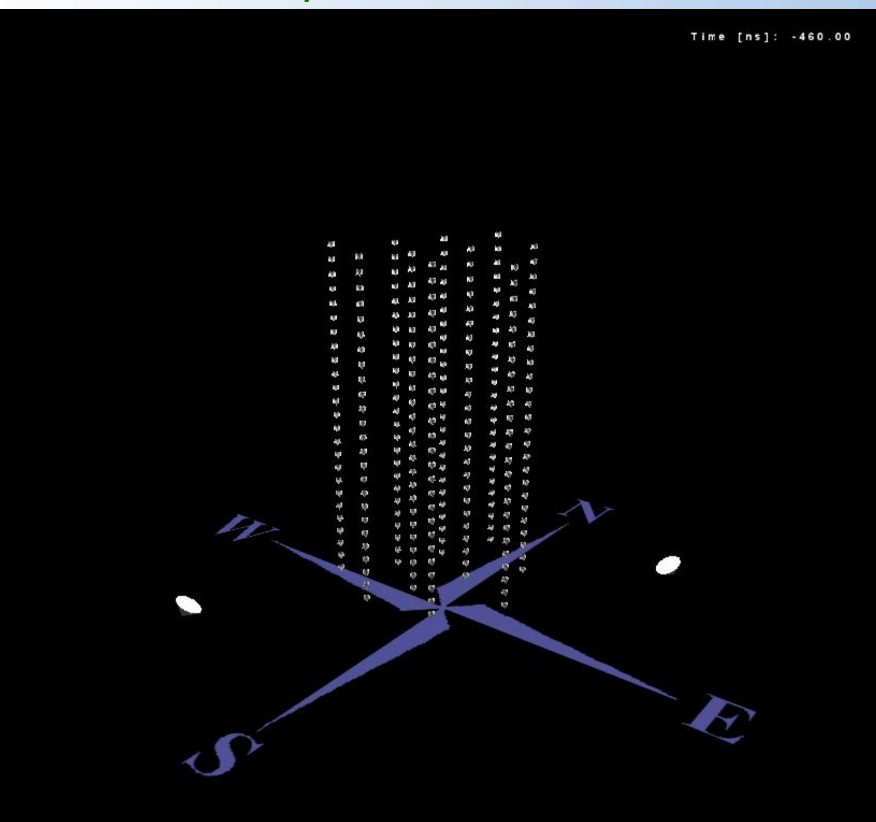




Events in ANTARES

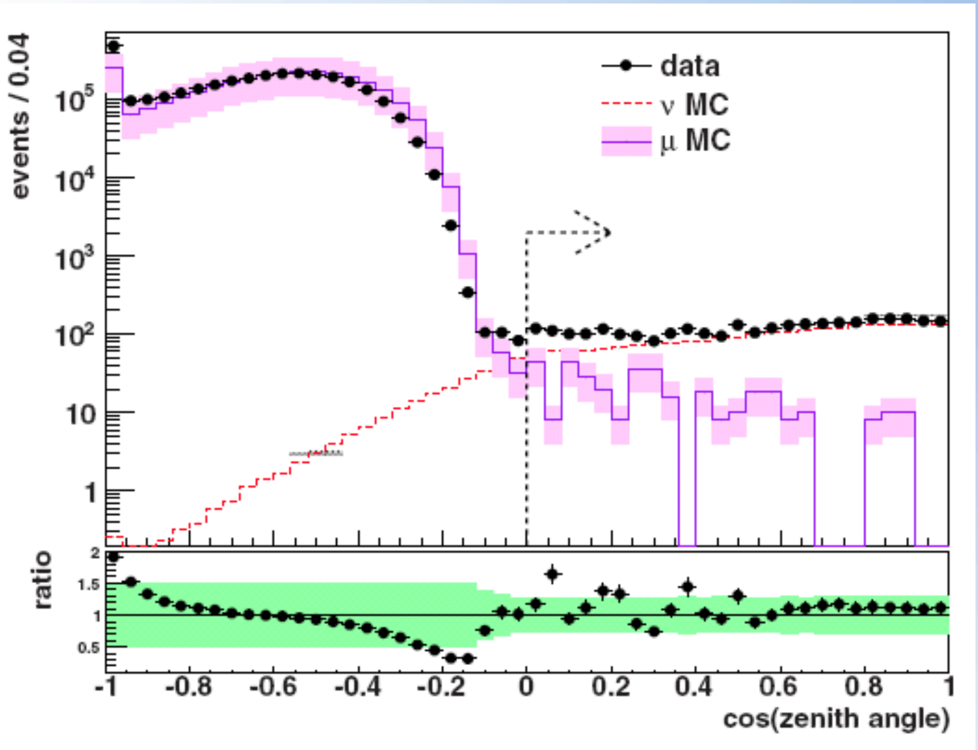
reconstruction of muon trajectory from **time, charge and position** of PMT hits assuming relativistic muon emitting **Cherenkov light**

reconstructed up-going neutrino detected in 6/12 detector lines:



reconstructed down-going muon detected in all 12 detector lines:

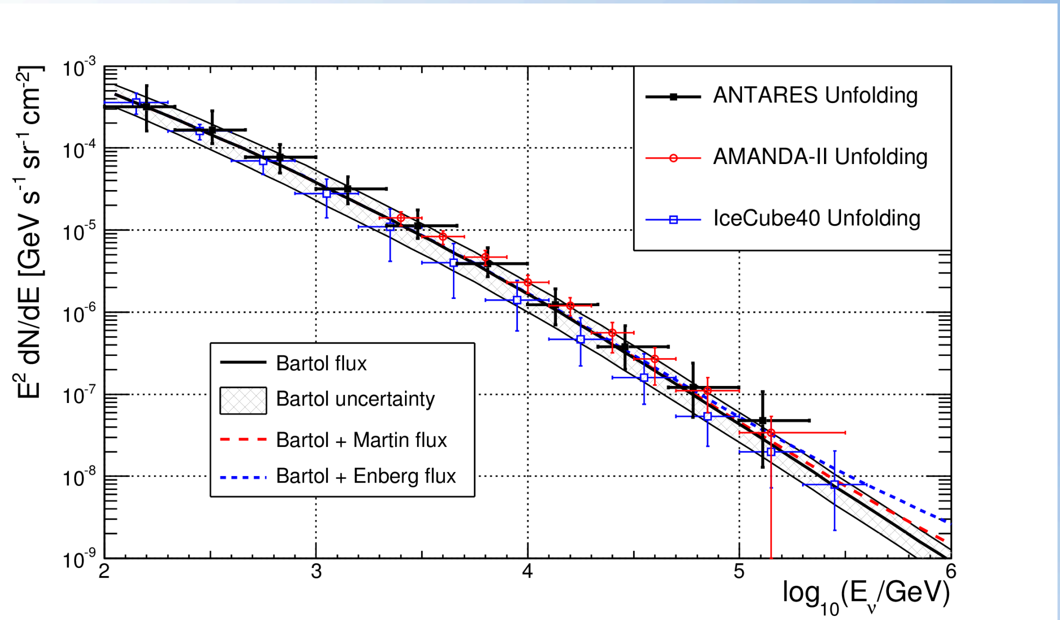
Reconstructed tracks



- ✧ ~3-10 reconstructed muons per second
- ✧ ~ 4 neutrinos per day
- ✧ > 7000 neutrinos so far
- ✧ Median angular resolution 0.3° – 0.4°
- ✧ Visibility:

3/4 of the sky, most of Galactic Plane including the Galactic Center

Atmospheric muon neutrinos spectrum



- Unfolding technique to account for the limited energy resolution
- response matrix of the detector observed estimator distribution

energy distribution at the detector

2008-2011 data set (855 days)

Two different energy estimators:

- dE/dX as evaluated from total collected charge

estimates muon energy loss per track length inside the sensitive volume

$$dE/dX \approx \rho = \frac{\sum^{\mathrm{nHits}} Q_i}{\varepsilon(\vec{x})} \cdot \frac{1}{L_\mu(\vec{x})}$$

L: length
e: efficiency

- Combined likelihood for hit/no-hit for all Oms

maximizes the agreement between the observed and expected amount of light on each OM.

$$\mathscr{L}(E_\mu) = \frac{1}{N_{OM}} \prod_i^{N_{OM}} \mathscr{L}_i(E_\mu).$$

free param

Measurement of atmospheric neutrino oscillations

➢ Two-flavour mixing approximation:

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2(2\theta_{32})\sin^2\left(\frac{1.27\Delta m_{32}^2 L}{E_\nu}\right) = 1 - \sin^2(2\theta_{32})\sin^2\left(\frac{1.27\Delta m_{32}^2 D_{Earth}\cos\Theta}{E_\nu}\right)$$

unknown
measurable

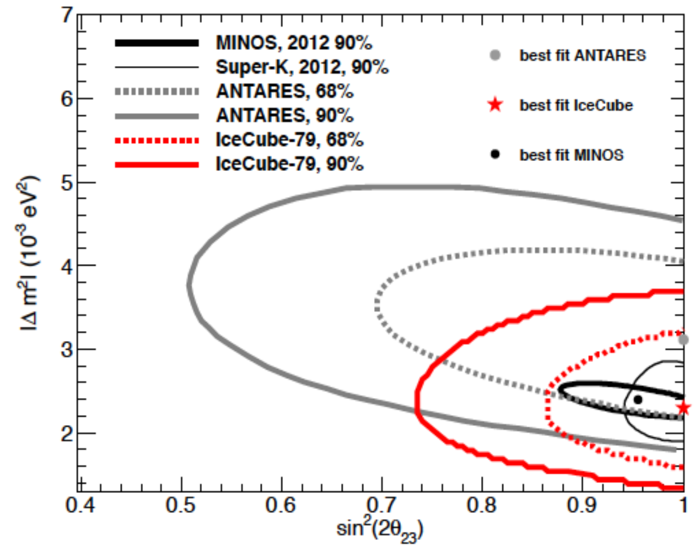
world data: first oscillation minimum at $\cos\Theta = 1$ → $E_\nu = 24$ GeV (typical μ range ≈ 120 m)

➢Dedicated low-energy data sample:

2007-2010 (863 active days)

20 GeV < E_ν < 100 GeV

median angular resolution 0.8° (multi-line) → 3° (single-line)



➢ First measurement of neutrino oscillation parameters by neutrino telescope !

📖 Phys. Lett.B 714 (2012) 224

Search for a diffuse cosmic ν_μ spectrum

❖ Updated search 2008-2011 data

➢ Updated analysis: 2008-2011 (855 days livetime)

Unblinded result: n_{obs}=8 n_{bkg}=8.4 n_{sig}=2.3
Muon contamination negligible (<0.4%)

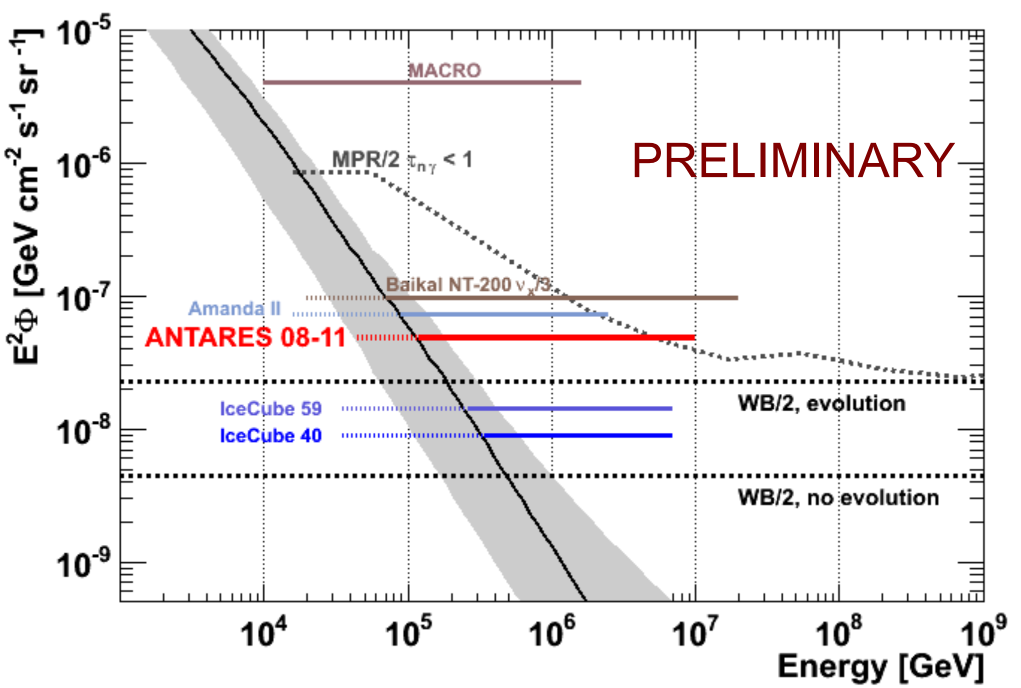
Main challenges:

Low contamination by atmospheric muons

- Upgoing tracks with strict quality cuts

Reliable neutrino energy proxy

- Improved energy estimate based on dE/dX



No significant improvement for upper limit:

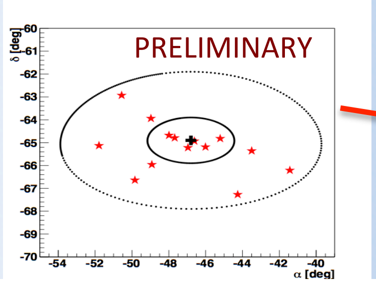
$$E^2\Phi_{90\%} = 4.8 \times 10^{-8}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$$

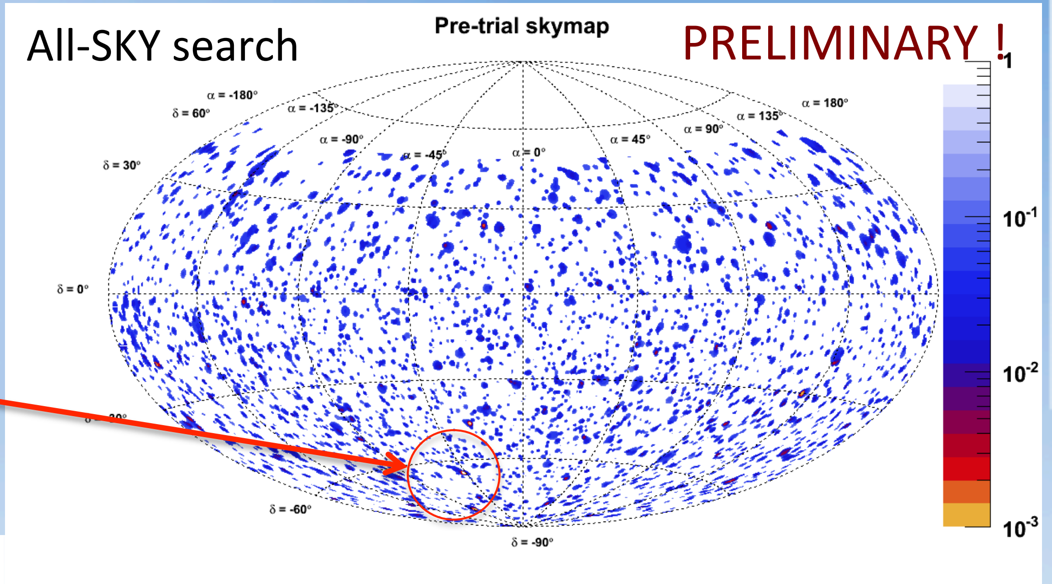
45 TeV< E < 10 PeV

Search for neutrino point sources

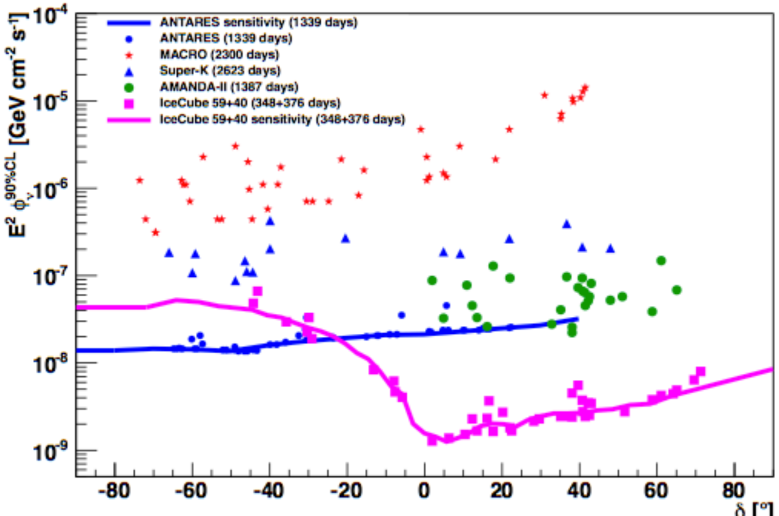
❖ New updated search 2007-2012 (1340 days)

- 5516 neutrino candidates (90 % of which being better reconstructed than 1º)
- Median of the angular resolution – 0.4°
- No significant excess
- Same most significant cluster with 6 additional events: p-value = 2.1% (2.3 σ) Compatible with background hypothesis





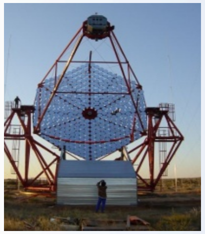
Equatorial coordinates



Most stringent limits for large part of Southern Sky in TeV region

Expect further improvement including showers (work in progress)

Multimessenger analyses



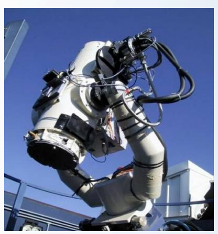
GeV-TeVγ-rays
Fermi / HESS…

UHECR
Auger

HE neutrinos

Optic / X-ray
TAROT, ROTSE /
Swift, ZADKO

Gravitational
Waves
Virgo / Ligo



- A way to better understand the sources and the related physics mechanisms
- A way to increase the detector sensitivities (uncorrelated backgrounds)

Multimessenger analyses – some examples

- GRB triggered searches → No event found within 10° window from GRB
  - Analysis of GRBs from late 2007 – 2011:
  - 296 long GRBs, total prompt emission duration: 6.6 hours
  - Multi-messenger information from FERMI/SWIFT/GCN
- Coincidences with Gravitational Waves
  - plausible common sources (GRB, SGR, microquasars)
  - discovery potential for hidden sources (e.g. failed GRB)

Effective collaboration (MoU) between LSC and ANTARES since Sept 2009

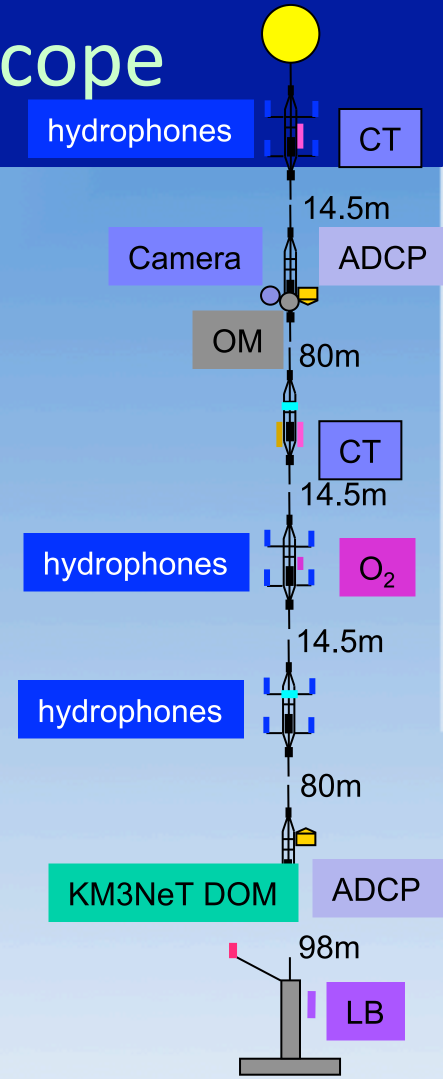
GW/HEN common challenge: faint signals on top of abundant noise/background

Search methodology: HEN selected events trigger the search for GW in time/space coincidence

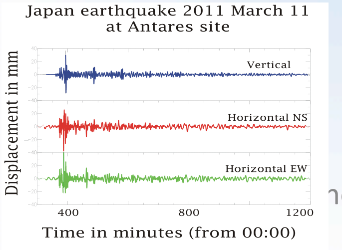
Beyond the neutrino telescope

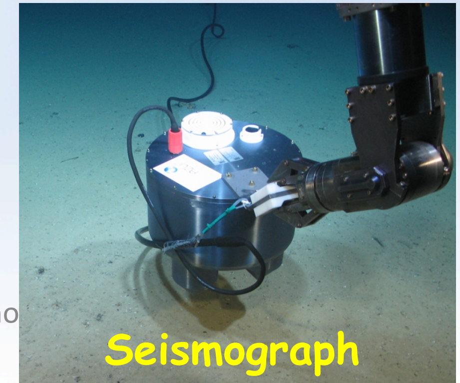
sea water is target, tracking medium, shield and background source

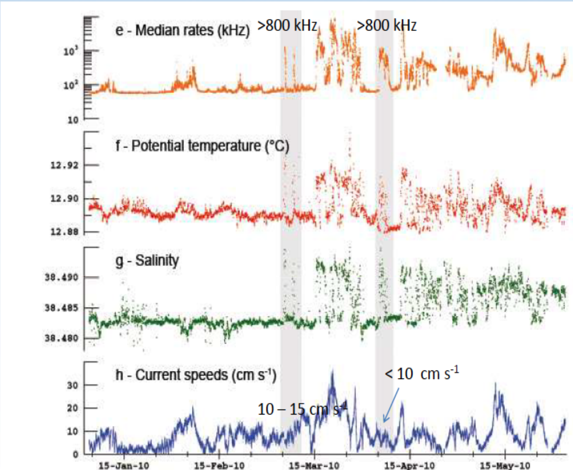
- A good knowledge of its characteristics and of the physics phenomena happening in deep water is essential.
- Fruitful interactions with oceanographers, biologists, seismologists.
- Cabled deep sea observatories are rare and costly
- Dedicated Instrumented Line in proximity of the ANTARES 12 lines
- acoustic system, Acoustic Doppler Current Profiler (ADCP)
- Salinity, temperature, O_2
- Seismograph, Bio-cameras



- H. van Haren et al. Acoustic and optical variations during rapid downward motion episodes in the deep north-western Med. Sea., Deep-Sea Research I 58 (2011) 875.
- C. Tamburini et al. (2013) Deep-Sea Bioluminescence Blooms after Dense Water Formation at the Ocean Surface. PLoS ONE 8(7) e67523.







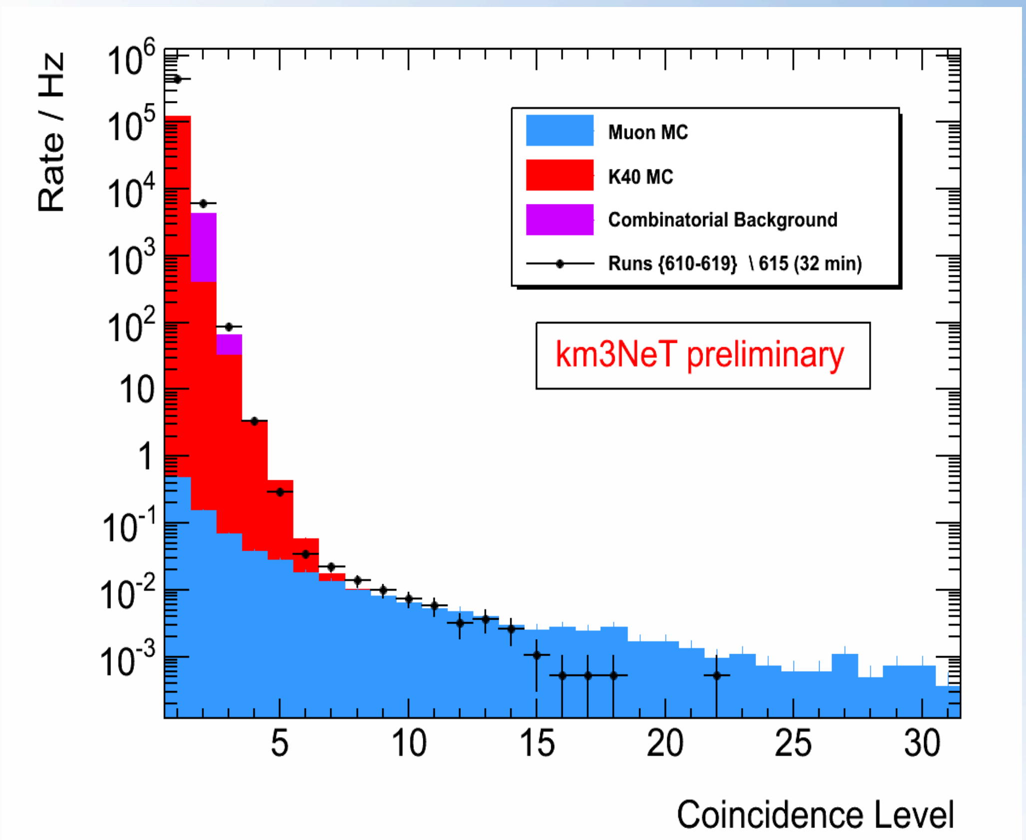
deep water formation: change in salinity and temperature

CONSEQUENCES

dramatic increase in optical rate important for climate studies

Reconnection of the Instrumentation Line

KM3NeT already taking data from an ANTARES line !



KM3NeT DOM – 31 3” PMTs works well

>5 coincidences within 20ns ⇒ reduces K40 contribution dominated by atmospheric muons

Summary

- ANTARES is the largest neutrino telescope in the Northern emisphere
- Not only a neutrino telescope → multi disciplinary observatory→ Earth & Sea Sciences
- Technological challenge → hostile sea environment → ANTARES has been working well
- **Important test bed for the KM3NeT detectory :**
  - **Feasibility of the sea neutrino telescope technique**
  - **Test for new KM3NeT technology**
- MANY OTHER ANALYSES in progress:
  - Atmospheric muon studies
  - Dark Matter
  - Magnetic Monopoles, nuclearites
  - ....