Progress and latest results from Baikal, Nestor, NEMO and KM3NeT

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Outline

- Status of the under-water high energy neutrino experiments in the northern hemisphere
  - Baikal
  - NESTOR
  - NEMO
  - ANTARES activities reported in the talk by J. Carr
- KM3NeT: towards a km3 scale detector in the Mediterranean Sea
- Conclusions and outlook

Baikal

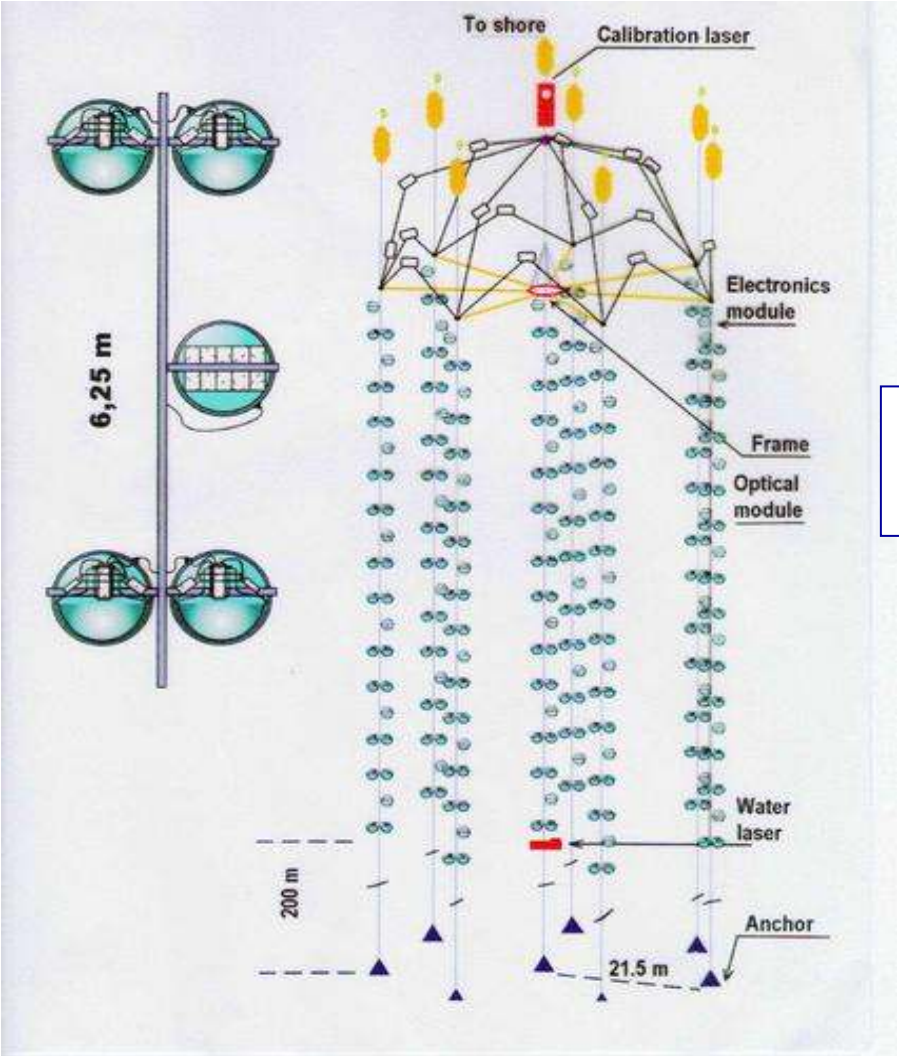
Collaboration

- Institute for Nuclear Research, Moscow, Russia.
- Irkutsk State University, Russia.
- Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia.
- DESY-Zeuthen, Zeuthen, Germany.
- Joint Institute for Nuclear Research, Dubna, Russia.
- Nizhny Novgorod State Technical University, Russia.
- St.Petersburg State Marine University, Russia.
- Kurchatov Institute, Moscow, Russia.

“history”

- Since 1980 Site tests and early R&D started
- 1989/90 Proposal NT200 detector in lake Baikal submitted
- 1993 NT36 started 13.4.93 (36 PMTs at 3 strings)
  The First Underwater Array
  First Neutrino Candidates
- 1998 NT200 commissioned 06.04.98
  Start full Physics program
- 2005 NT200+ commissioned 09.04.05
- 2006/7 R&D for Gigaton (km3-scale) Volume Detector (GVD)
- 2008 April 2008 - prototype string for GVD was installed

Baikal NT-200



-8 strings: 192 optical modules
→ 96 measuring channels
→ T, Q measure
*Timing ~ 1 nsec
*Dyn. Range ~ 10^3 ph.e.

Effective area: 1 TeV~2000m^2
Eff. shower volume: 10TeV~ 0.2Mt

Quasar : d = 37cm

Height x ∅ = 70m x 40m, $V_{inst}=10^5 m^3$

Diffuse neutrino flux limits

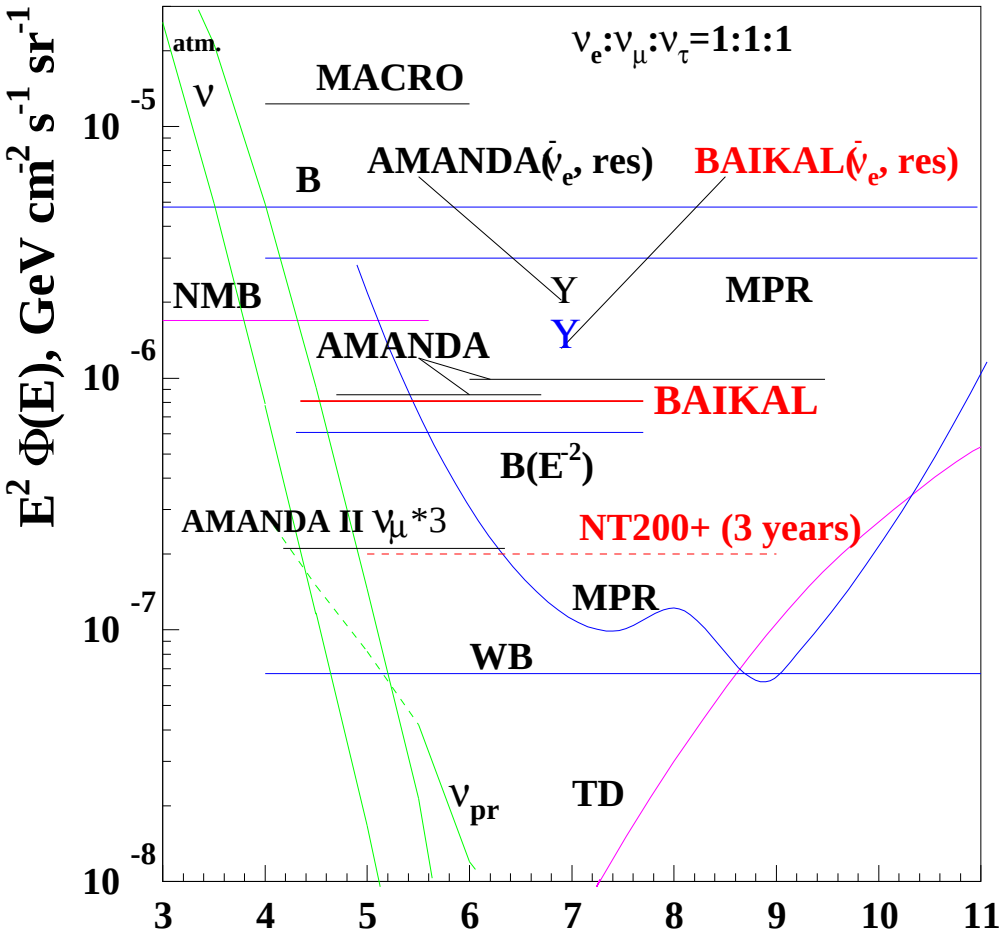
372 Neutrinos in 1038 Days (1998-2003)
385 events from Monte-Carlo

NT200 (1038 days)
no statistically significant excess above the background from atmospheric muons has been observed

The 90% C.L. "all flavour" limit (1038 days) for a $\gamma=2$ spectrum $\Phi_\nu \sim E^{-2}$ (20 TeV < E < 50 PeV), and assuming $\nu_e:\nu_\mu:\nu_\tau$ = 1 : 1 : 1 at Earth (1 : 2 : 0 at source)

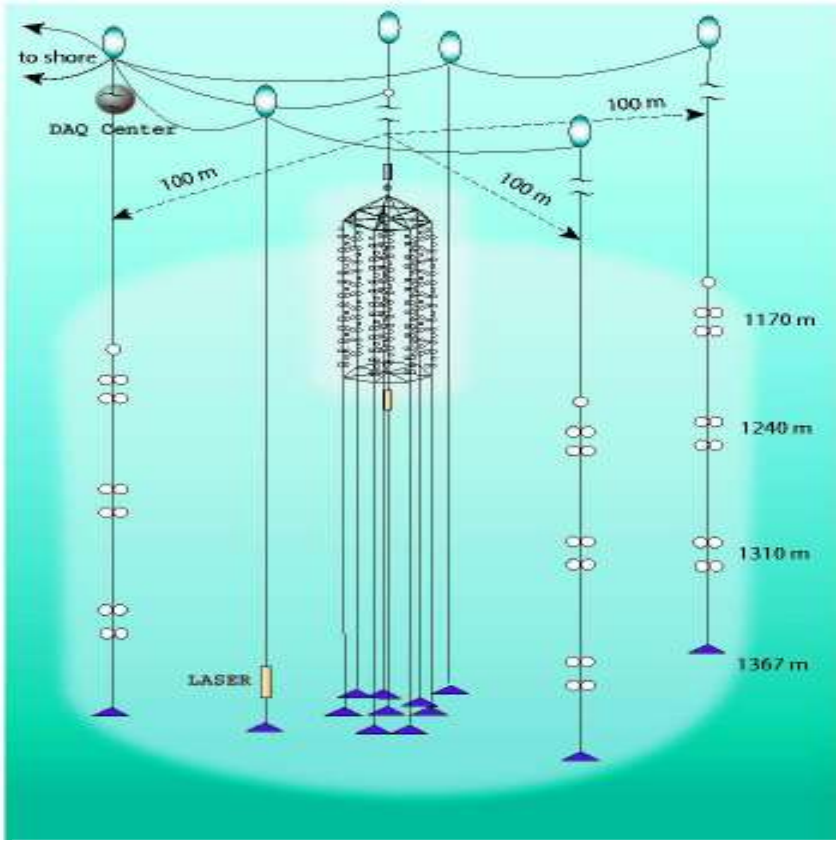
$E^2\,\Phi_\nu < 8.1\cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1} (Baikal 2006)

Experimental limits + bounds/ predictions



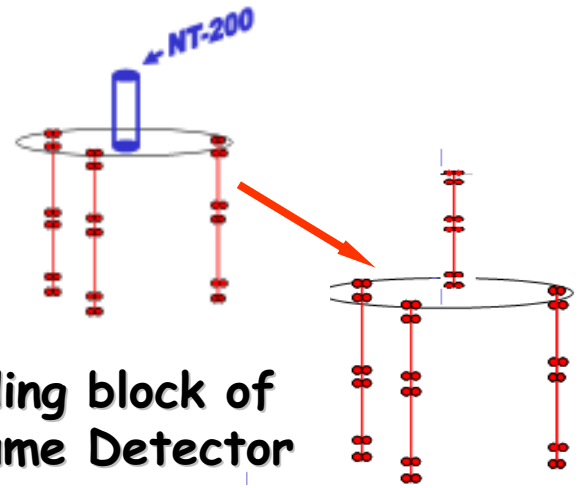
V. Aynutdinov, VLVnT08

Upgrade to Baikal NT-200+



NT200+ = NT200 + 3 outer strings

- **Height = 210m**
- **∅ = 200m**
- **Volume ~ 5 Mton**



Basic building block of Gigaton Volume Detector

36 additional PMTs on 3 far 'strings'

→ 4 times better sensitivity

→ Improve cascade reconstruction

Vgeom ~ $4 \cdot 10^6$ m^3

Eff. shower volume: 10^4 TeV ~ 10 Mton

Expected ν-sensitivity (3 yrs NT200+)

$E^2 \Phi_\nu < 2 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

Proposal for a Gigaton Volume Detector at Baikal

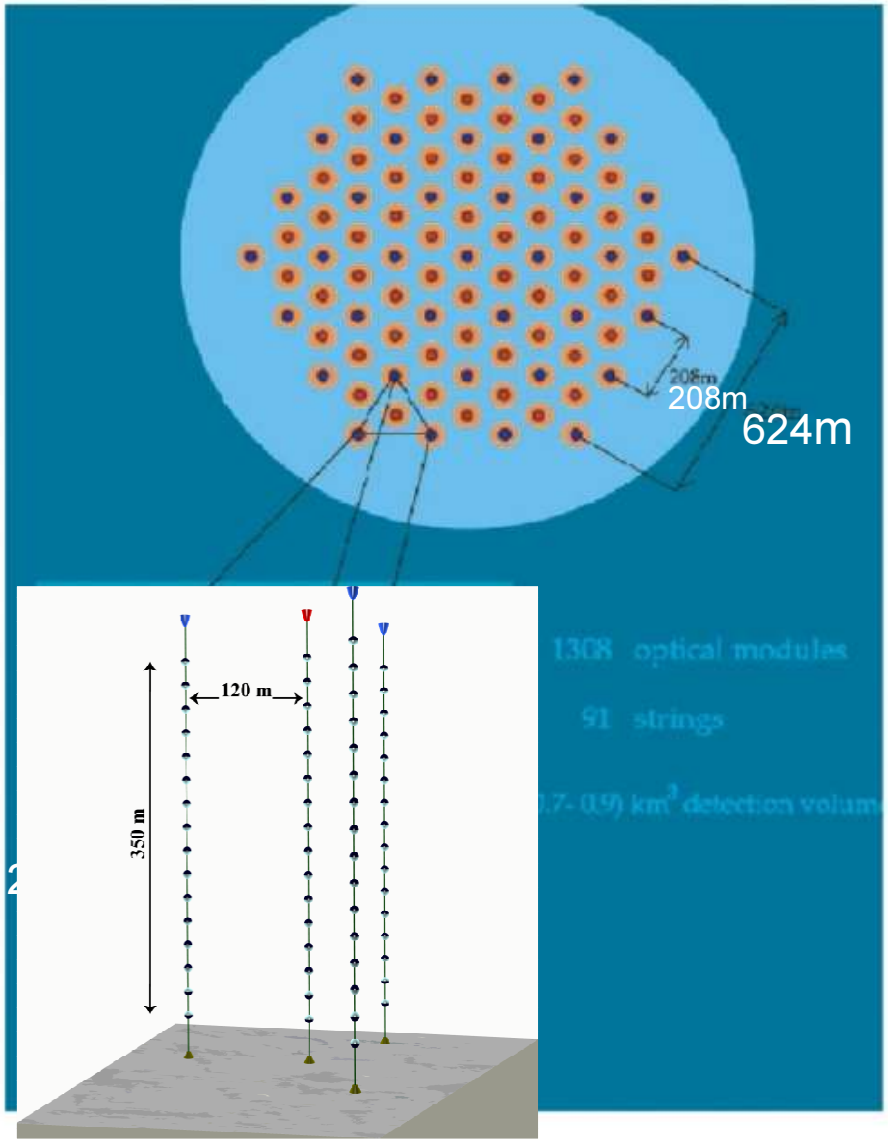
Sparse instrumentation:

91 – 100 strings with 12 – 16 OMs
(1300 – 1700 OMs)

- effective volume for >100 TeV cascades: ~ 0.5 -1.0 km^3
  $\delta lg(E) \sim 0.1$, $\delta\theta_{med} < 5^o$

- detects muons with energy > 10 - 30TeV

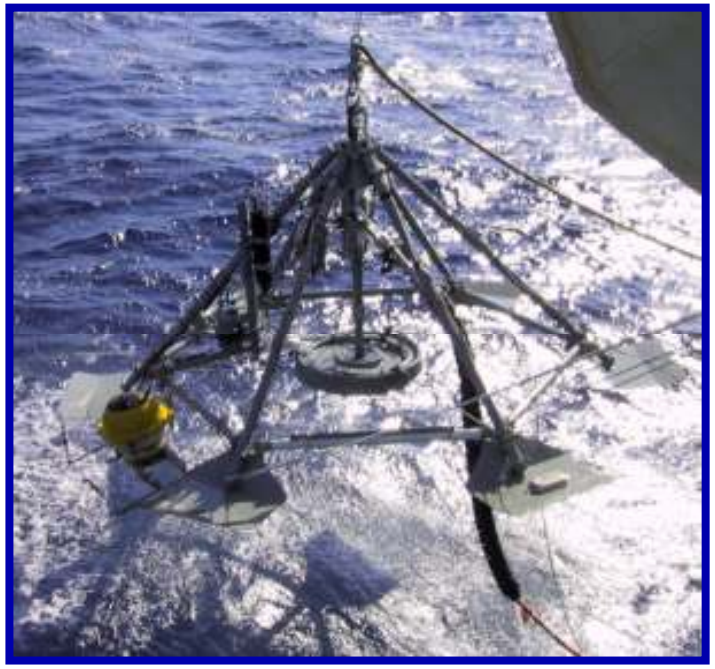
- prototype string as a part of NT200+ (8 April 2008)

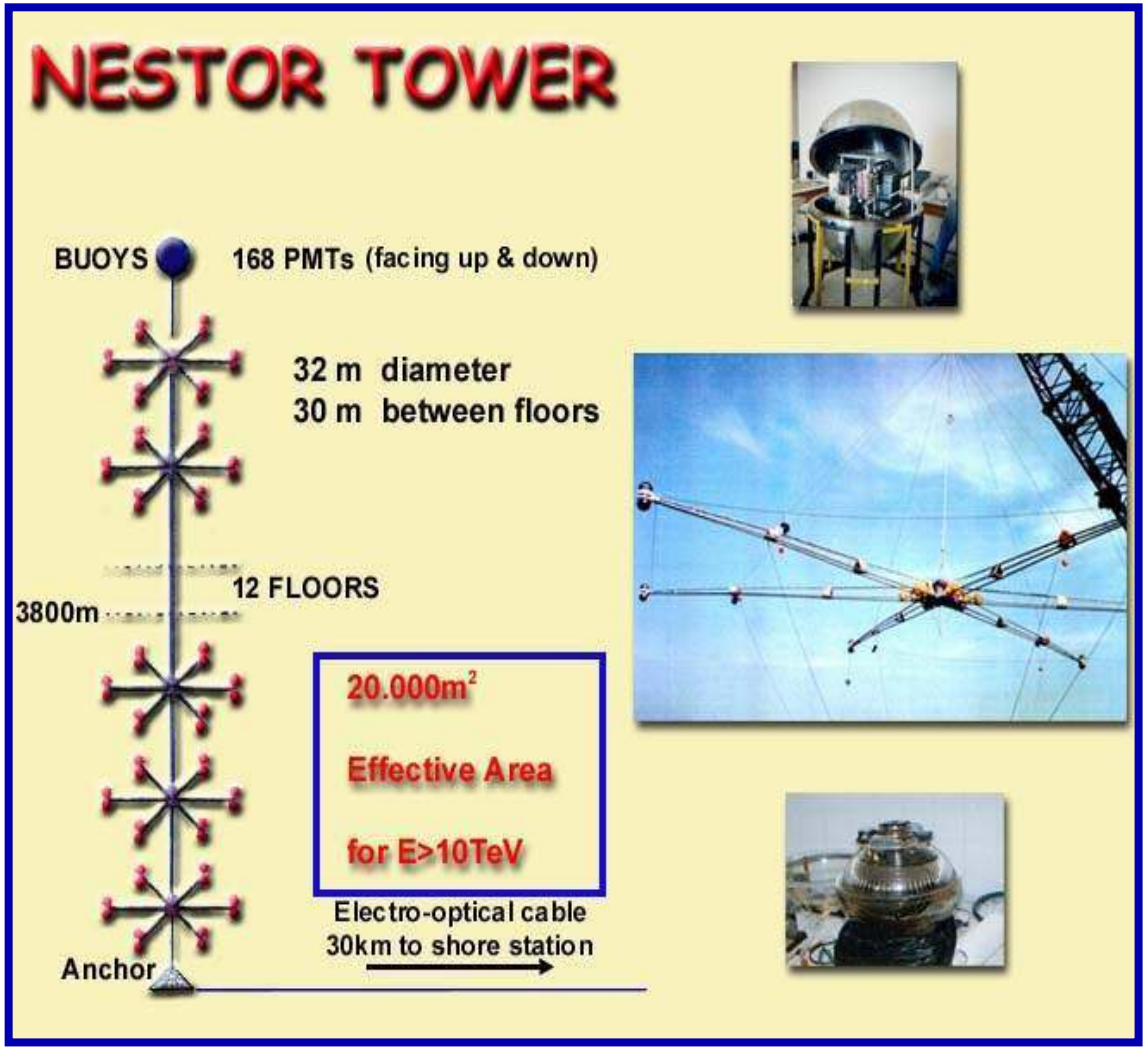


- Three experiments in the Mediterranean Sea
  - ANTARES
  - NEMO
  - NESTOR
- Common effort towards the km3-scale detector inside the KM3NeT european consortium

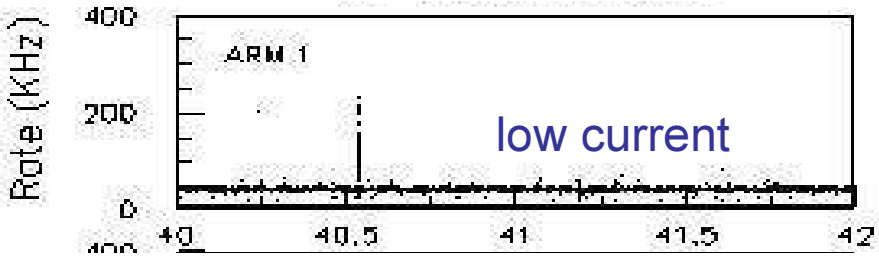
NESTOR

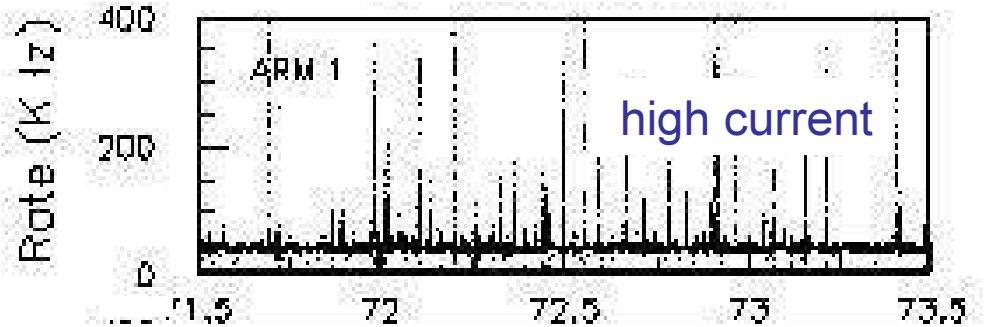
- Tower based detector
- Up- and downward looking PMTs
- 4000 m deep
- Dry connections
- Test floor (reduced size, 12 m) with 12 PMTs deployed and operated in 2003

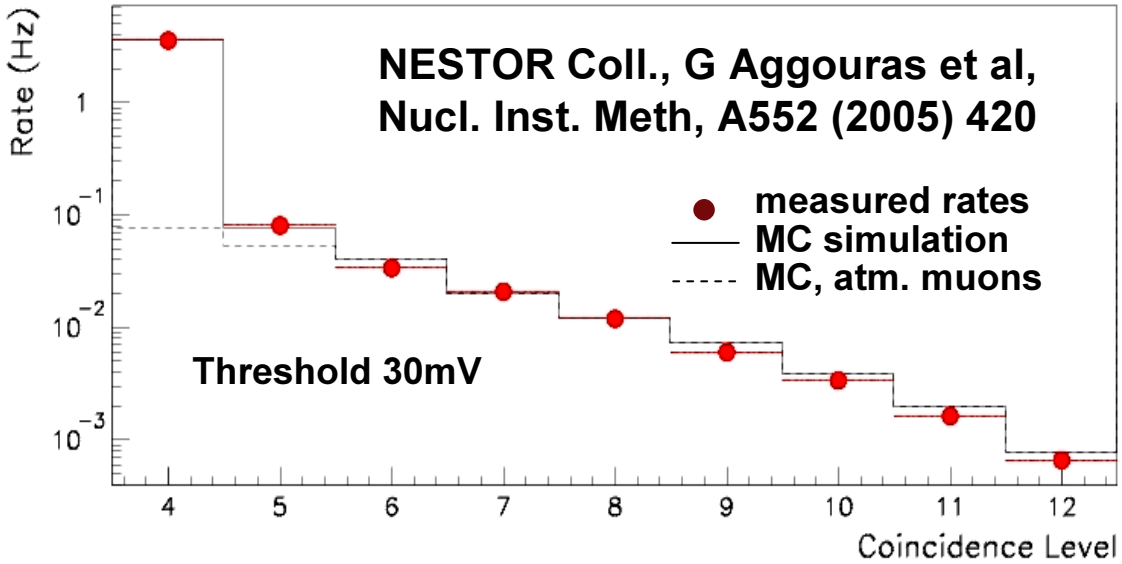




NESTOR



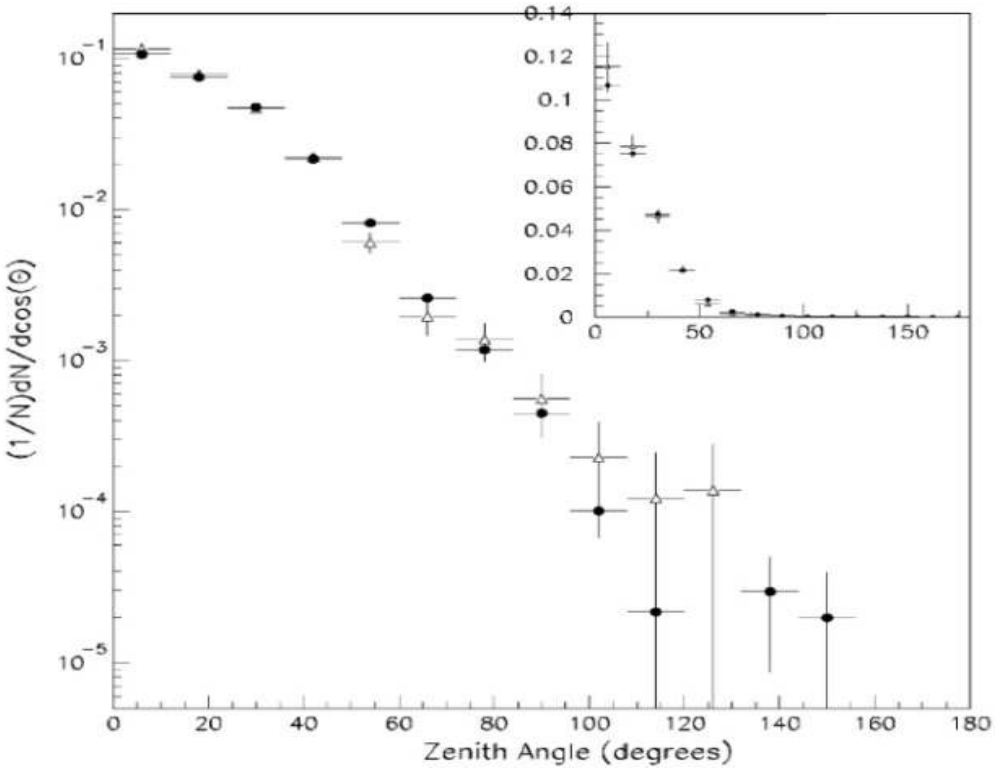




- Background baseline rate of 45-50 kHz per PM
- Bioluminescence bursts correlated with water current, on average 1.1% of the time.

- Trigger rates agree with simulation including background light.
- For 5-fold and higher coincidences, the trigger rate is dominated by atmospheric muons.

NESTOR measurement of the atmospheric muon flux

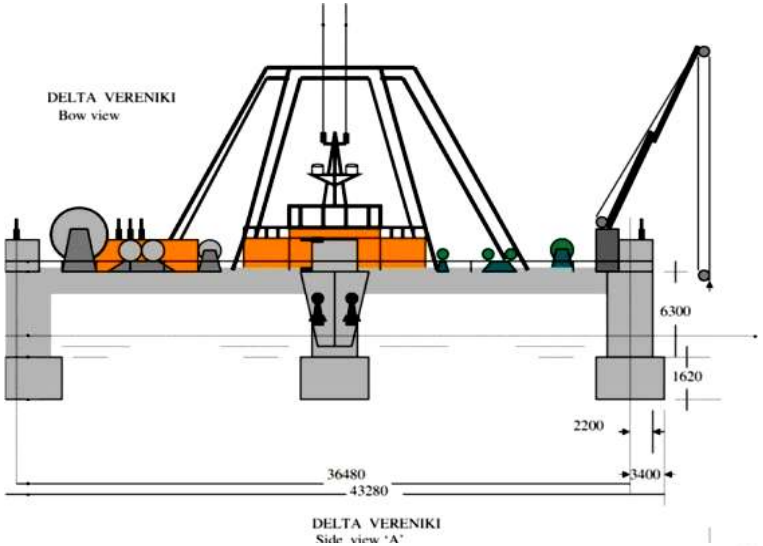


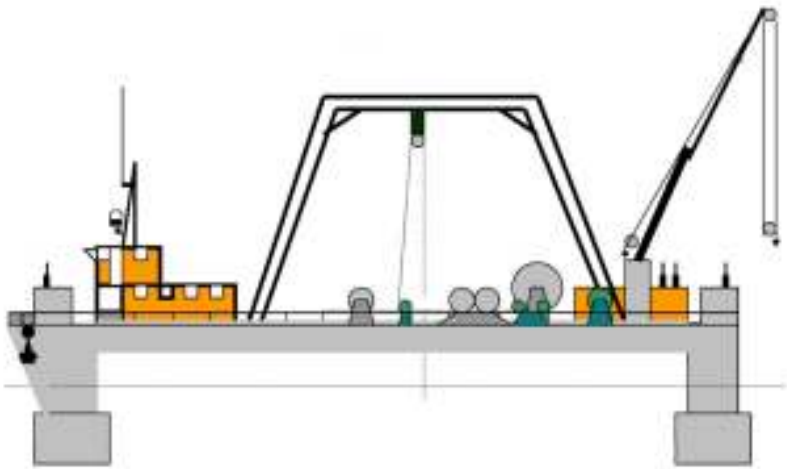
The measured vertical muon intensity I_0
and the index α, at a depth of 3800 m water equivalent, are

$$I = I_0 \cos^{\alpha}(\theta) \qquad \alpha = 4.7 \pm 0.5\ (stat) \pm 0.2\ (syst)$$

$$I_0 = (9.0 \pm 0.7\ (stat) \pm 0.4\ (syst)) \times 10^{-9}\ cm^{-2} s^{-1} sr^{-1}$$

Delta-Bereniki deployment platform



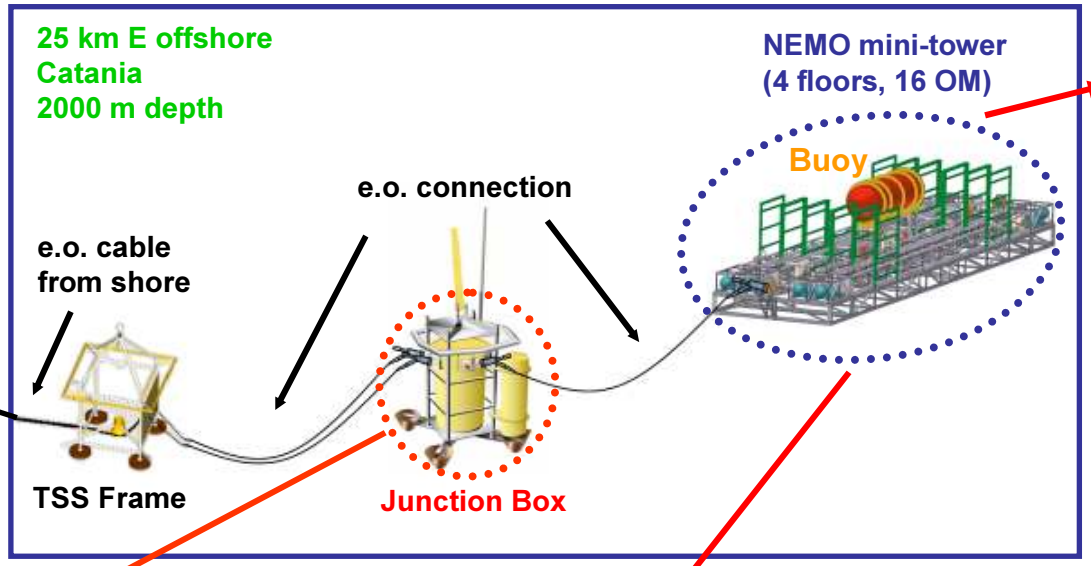


A versatile dedicated vessel

Almost completed

- The NEMO R&D activities
  - Site exploration - Capo Passero site properties
  - Realization of a techonological demostrator including all the key elements of the km^3
- NEMO Phase-1 (2003-2007) @ *the LNS Test Site (2000 m depth)*
  - Deployment of the mini-tower
  - Achievements and lessons learned
- NEMO Phase-2 (2006-2009) @ *the Capo Passero Site (3500 m depth)*
  - Realization of the on-shore and off-shore infrastructure
  - Full tower prototype (750 m height) deployment and operation (end 2008-2009)

NEMO Phase 1

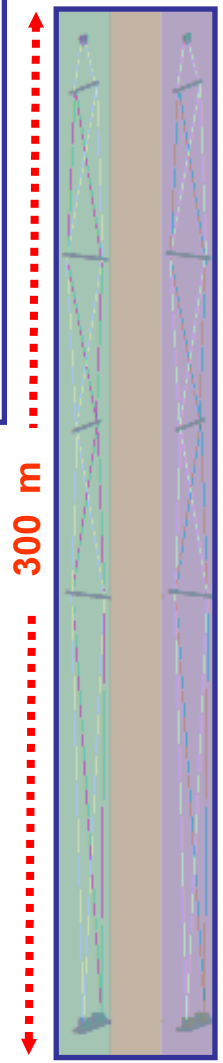


e.o. cable
10 optical fibre,
6 conductors

Junction Box

Mini-Tower compacted

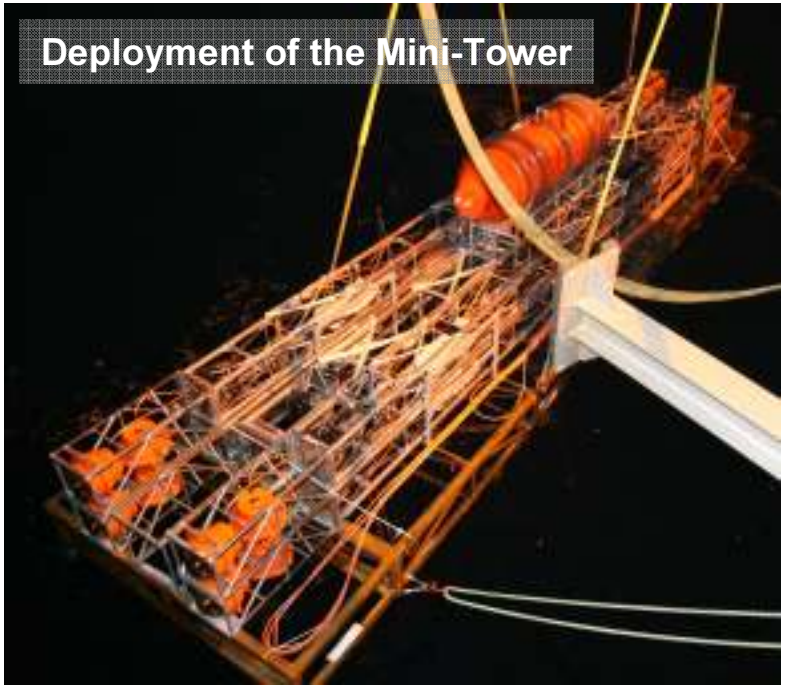
Mini-Tower unfurled

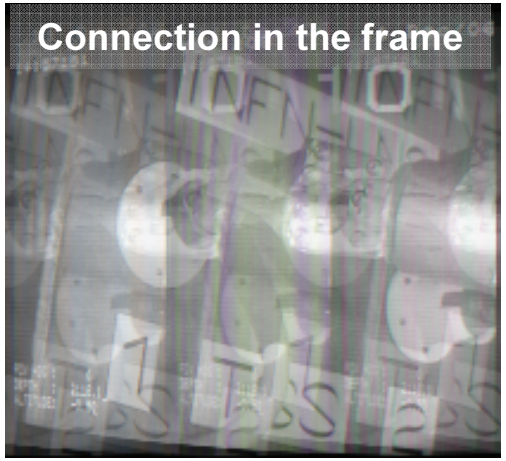


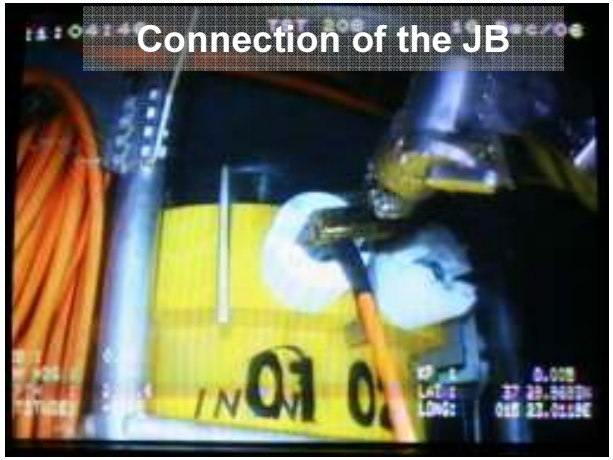
NEMO Phase 1 Deployment

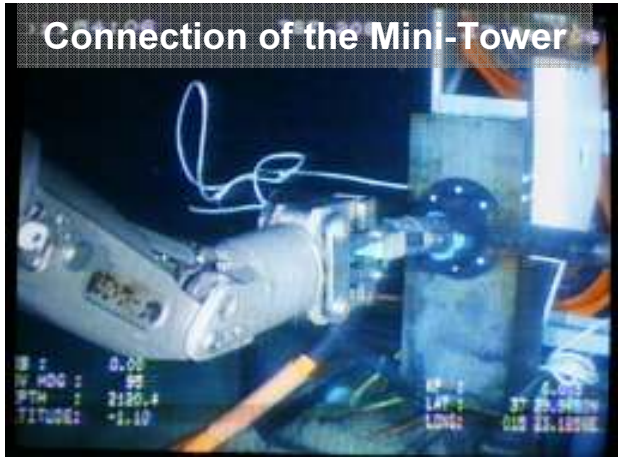
December 2006


Deployment of the JB


Deployment of the Mini-Tower


Connection in the frame


Connection of the JB

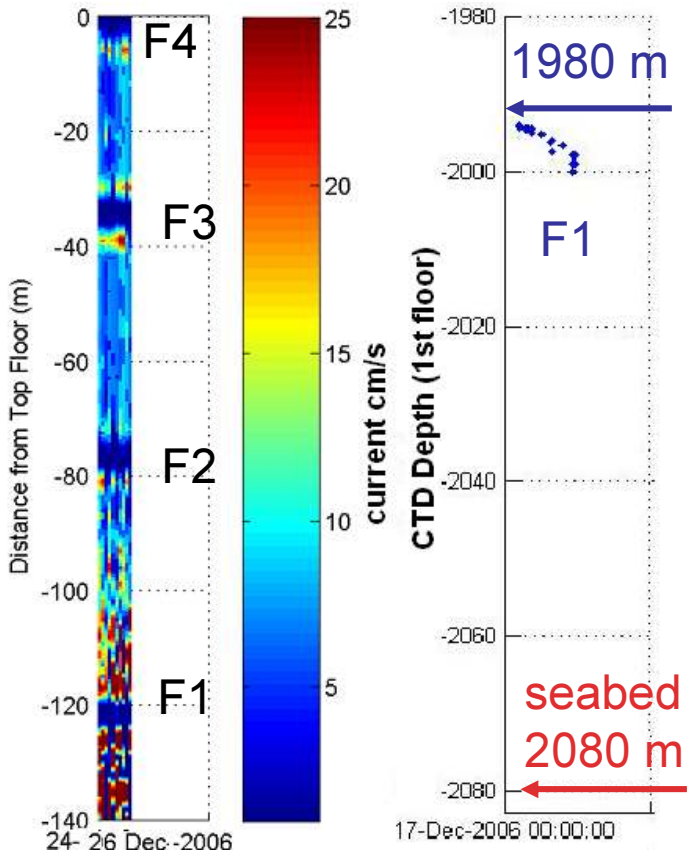

Connection of the Mini-Tower

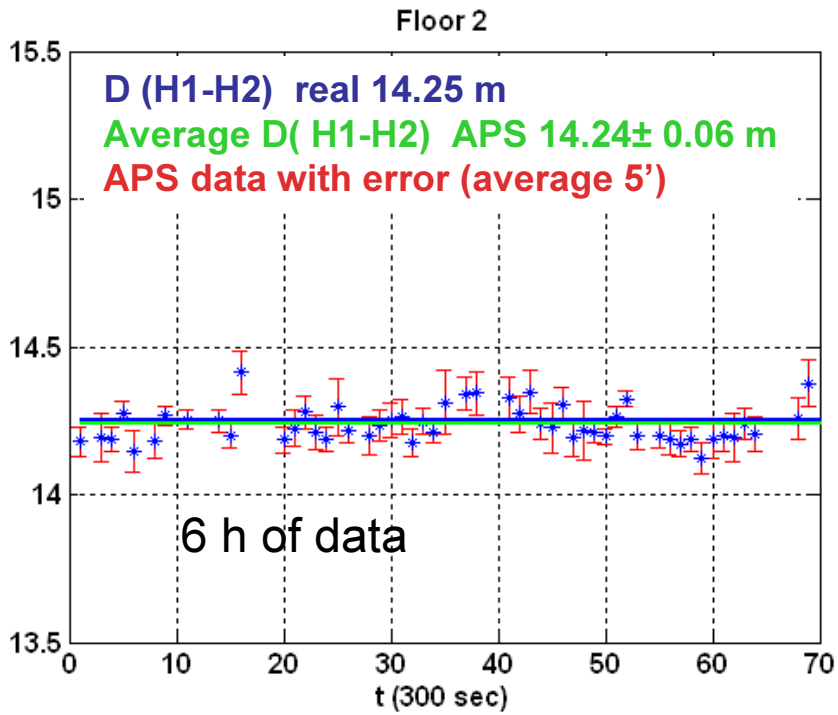
NEMO phase-1: operation

- After deployment the mini-tower was unfurled and assumed the expected configuration
- Acoustic positioning system, electronics, data transmission and data acquisition worked properly

Reflections of ADCP beams on floors: 40 m between floors

CTD on first floor Depth: 1980 m 100 m above seabed





Atmospheric muons: comparison with simulations

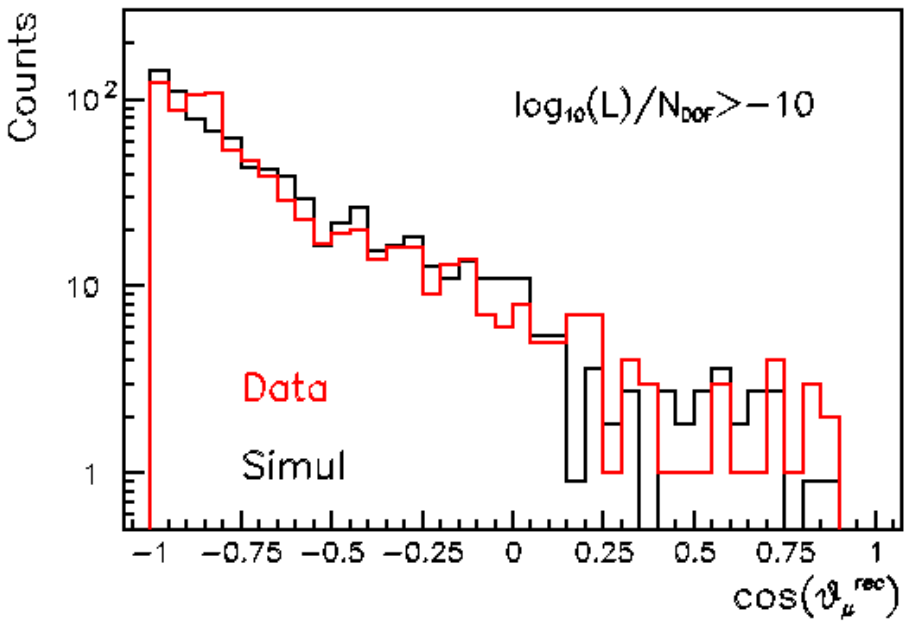
experimental reconstructed rate = 0.047 ± 0.001 Hz

first analysed data set (23th-24th Jan 2007)

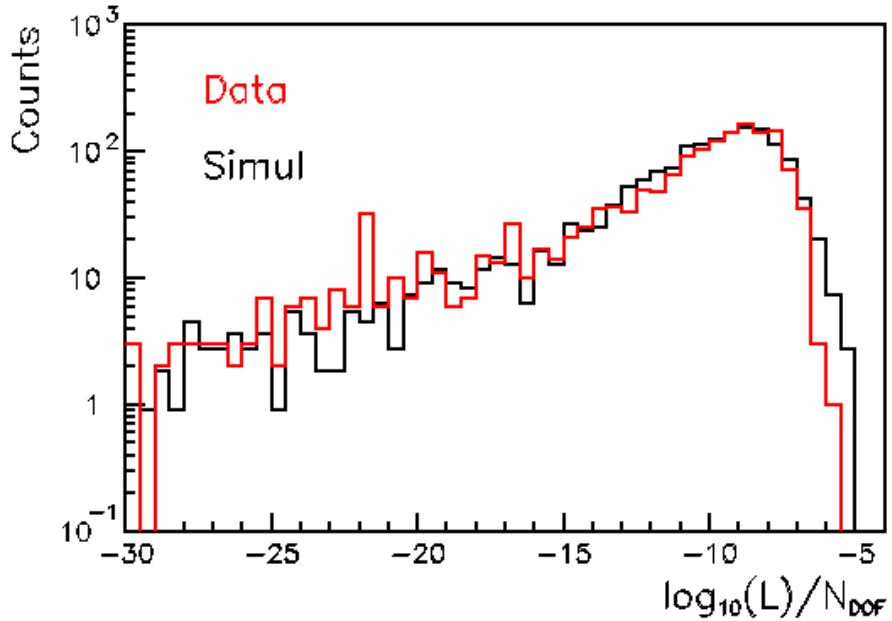
full data currently under analysis

simulated reconstructed rate = 0.044 ± 0.001 Hz

Atmospheric muon angular distribution

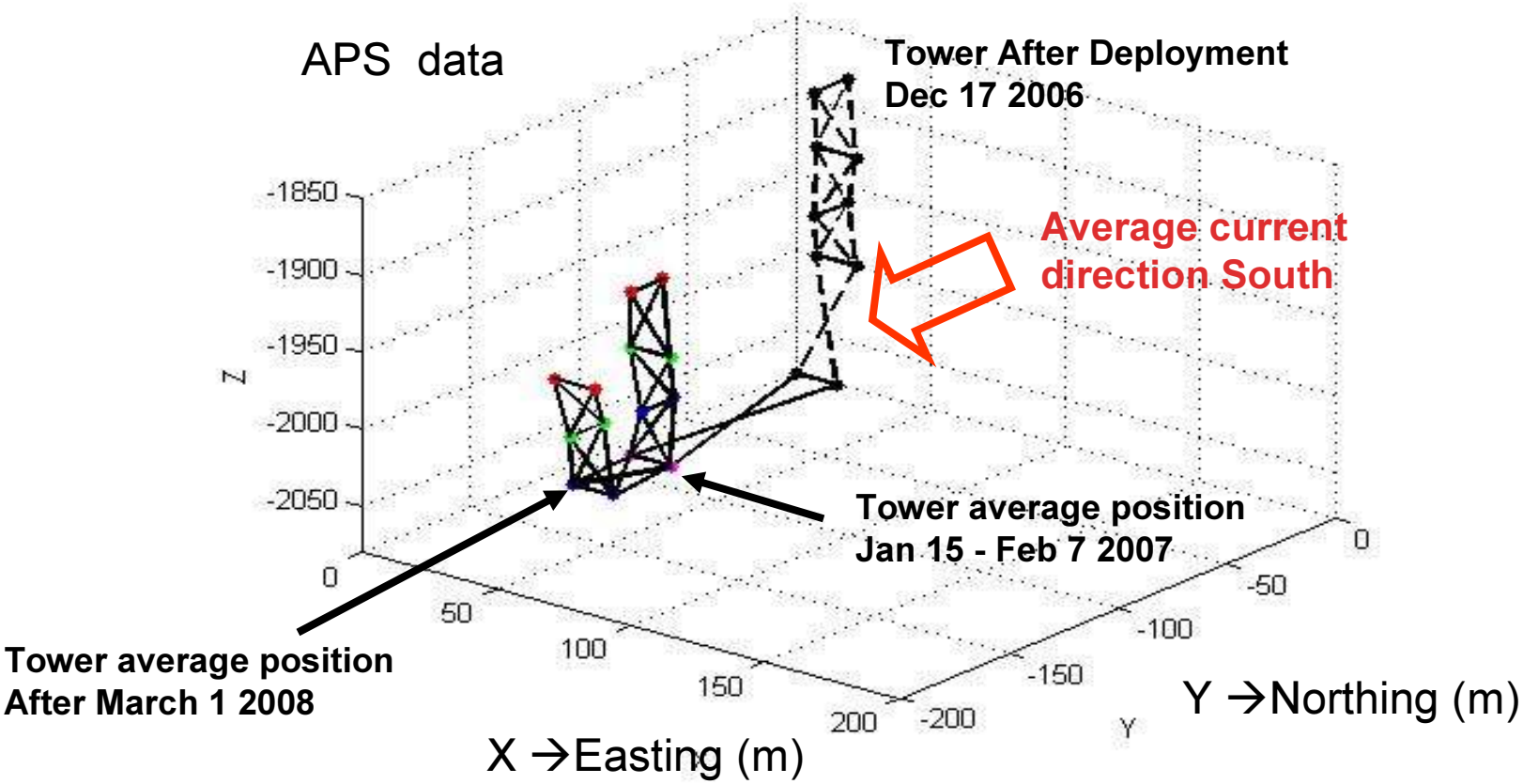


Likelihood Distribution

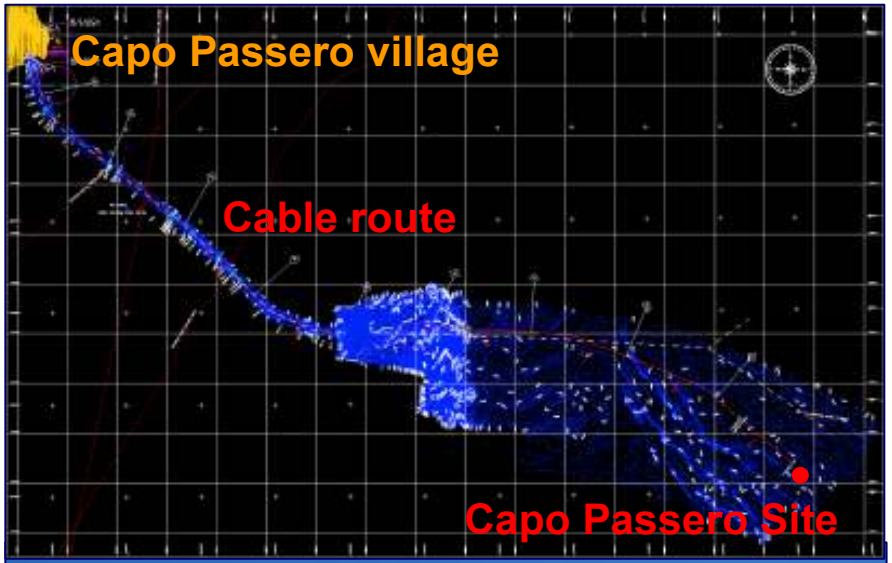


But also some problems …

- Loss of buoyancy due to deterioration of the buoy material under pressure. After some months the two first storeys of the mini-tower were laying on the sea bed.



NEMO Phase-2



STATUS

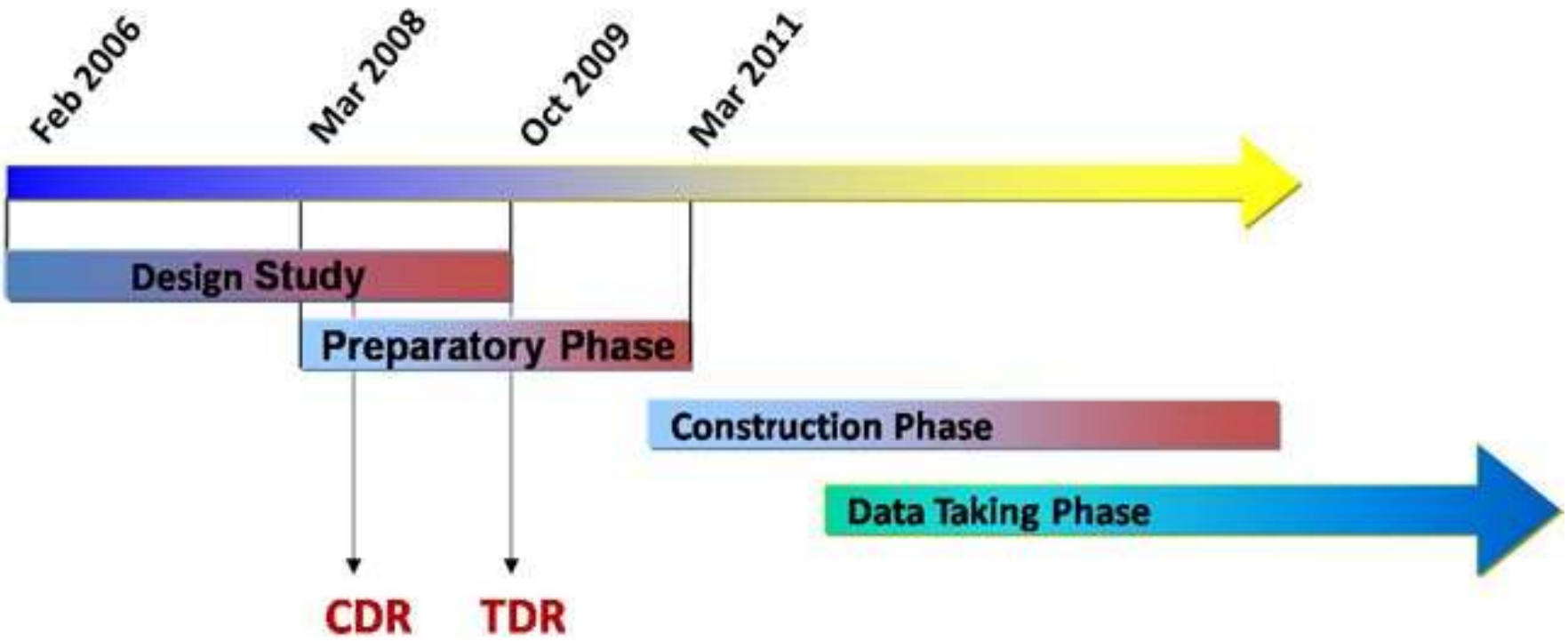
- 100 km electro-optical cable (>50 kW, 20 fibres) deployed in July 2007
- On-shore laboratory (1000 m^2) inside the harbour area of Portopalo completed
- Installation of Alcatel DC power supply system with DC/DC converter in October 2008
- Construction of a complete 16 storey tower under way
- Project completion planned beginning 2009

KM3NeT: towards a km3-scale neutrino telescope in the Mediterranean Sea

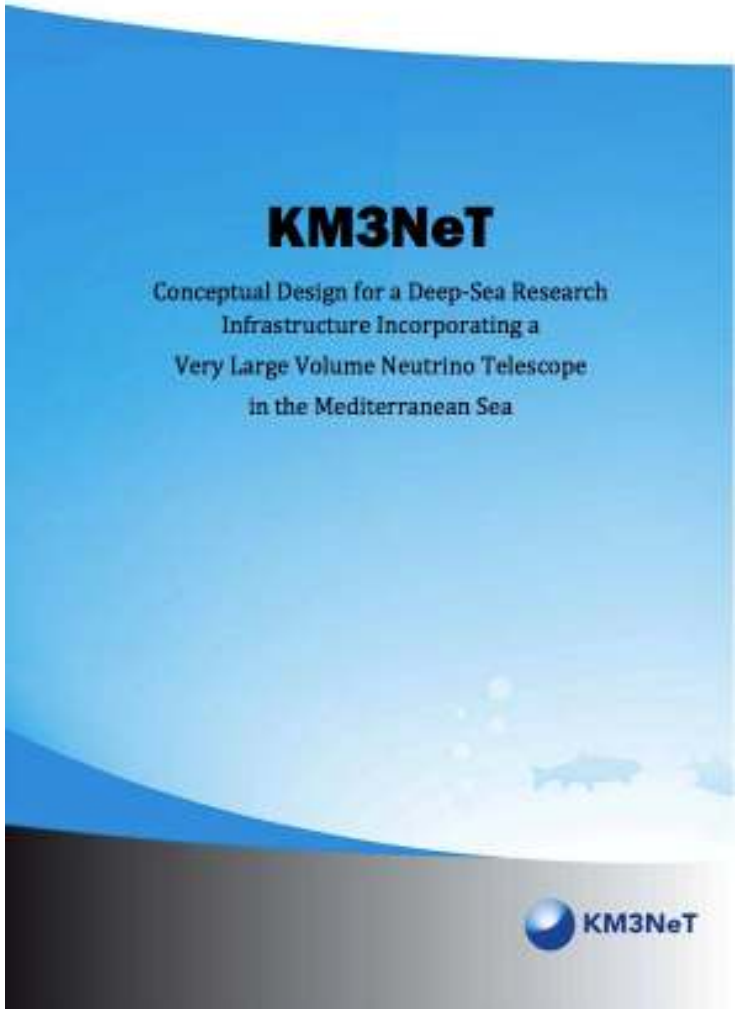
What is KM3NeT ?

- A future deep-sea Research Infrastructure hosting a km3 scale neutrino telescope and facilities for associate marine and earth sciences
  - Included in the European Roadmap for Research Infrastructures of the ESFRI
- A Consortium of 40 institutes from 10 european countries including all the groups that have developed the pilot neutrino telescope projects in the Mediterranean Sea (Antares, Nemo, Nestor)
  - Two projects funded by the EU
  - Design Study (2006-2009): aims at developing a cost-effective design for the construction of a 1 km3 neutrino telescope
  - Preparatory Phase (2008-2010): preparing for the construction by defining the legal, financial ad governance issues as well as the production plans of the telescope components

Timeline towards construction



KM3NeT Conceptual Design Report



Describes the
scientific objectives, and the concepts behind the design, construction, and operation of the KM3NeT Research Infrastructure

Downloadable from the KM3NeT web site

http://www.km3net.org/CDR/CDR-KM3NeT.pdf

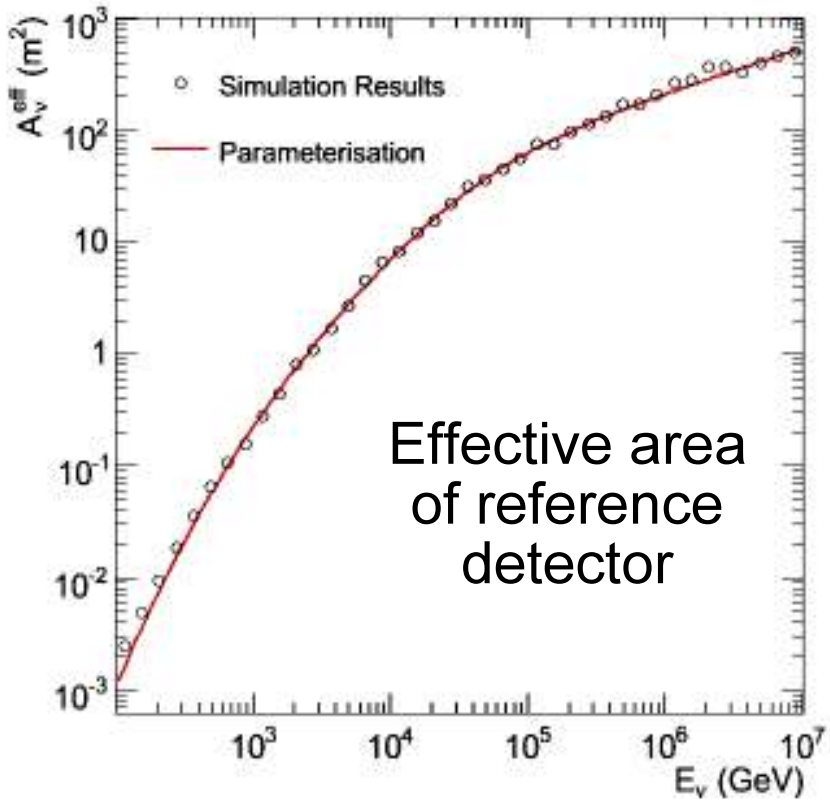
Design goals

- Core process:
  $\nu_\mu + N \rightarrow \mu + X$ at neutrino energies beyond 100 GeV
- Lifetime > 10 years without major maintenance, construction and deployment < 4 years
- **Sensitivity optimized in the TeV-PeV range**
- **Angular resolution 0.1° (for ν energies above 100 TeV)**
- Sensitivity to exceed IceCube by "substantial factor"
- Some technical specifications:
  - time resolution better than 2 ns
  - position of OMs to better than 40 cm accuracy
  - two-hit separation better than 25 ns
  - …

Reference detector

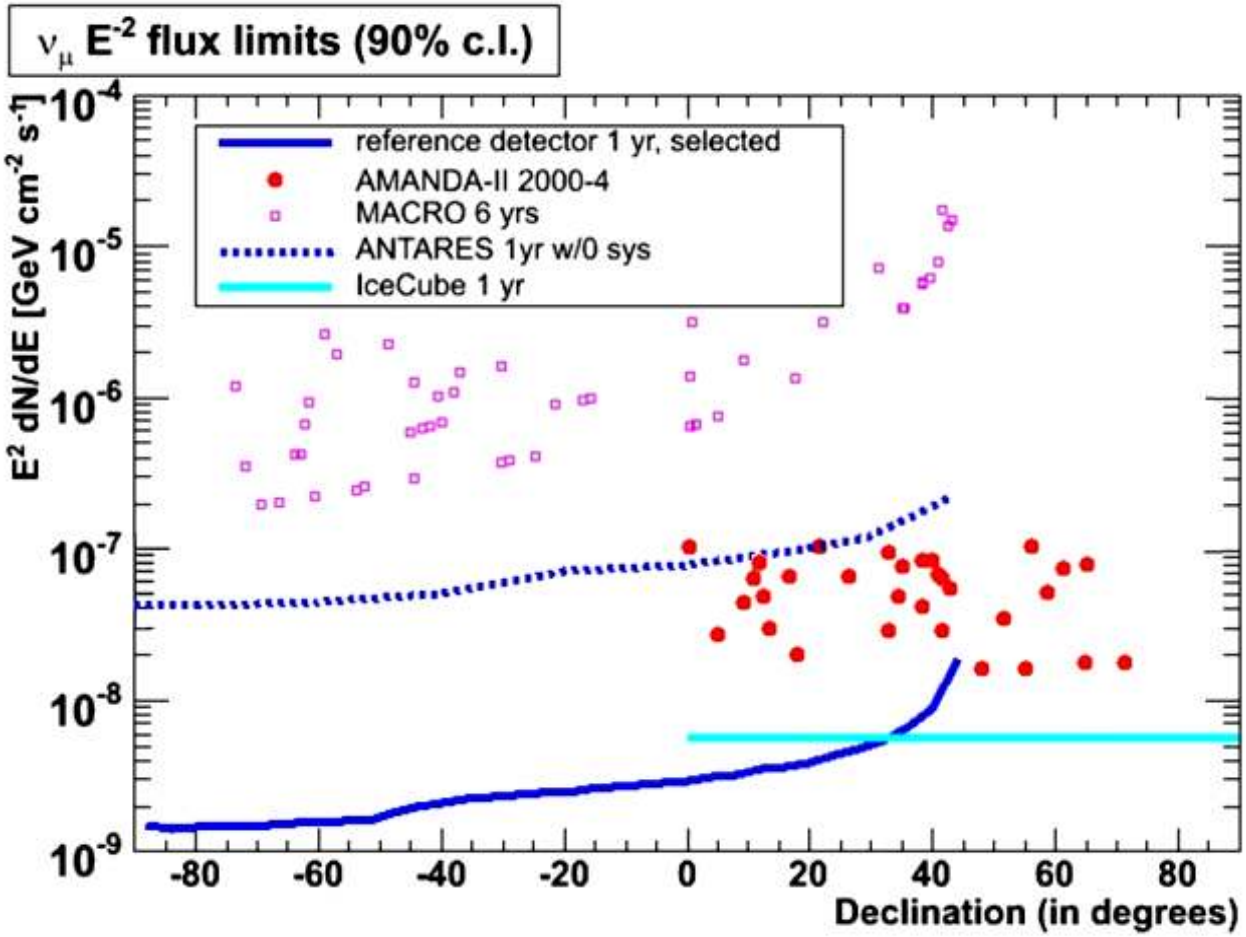
- Sensitivity studies with a reference detector layout
- Geometry:
  - 15 x 15 vertical detection units on rectangular grid, horizontal distances 95 m
  - each carries 37 OMs, vertical distances 15.5 m
  - each OM with 21 3'' PMTs

NOT the final KM3NeT design!

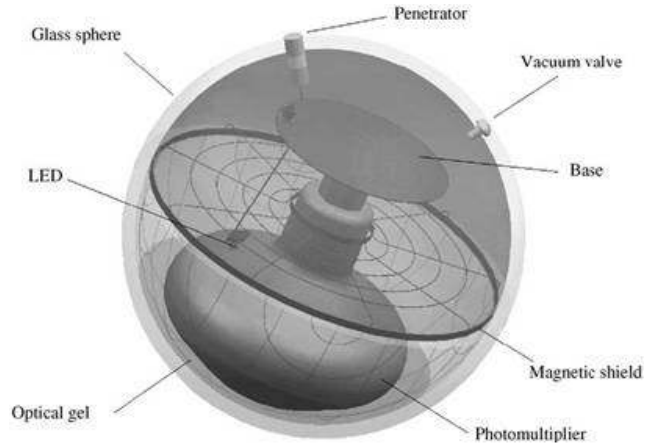


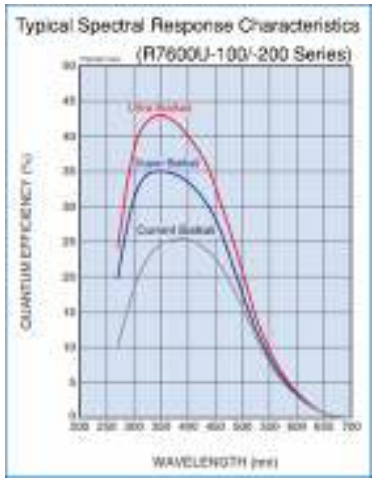
Point source sensitivity

- Based on muon detection
- Factor ~3 more sensitive than IceCube
  - larger photo-cathode area
  - better direction resolution
- Study still needs refinements



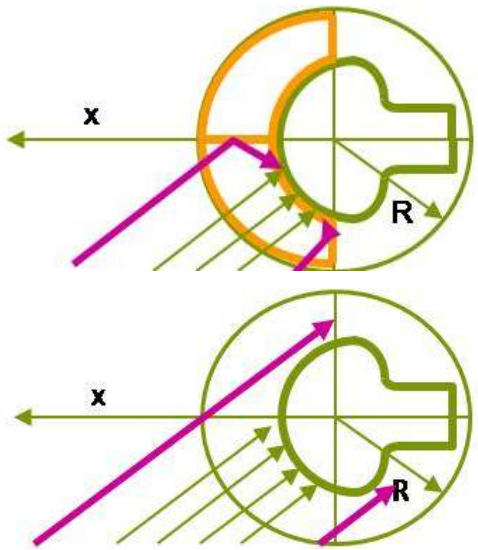
Optical Modules

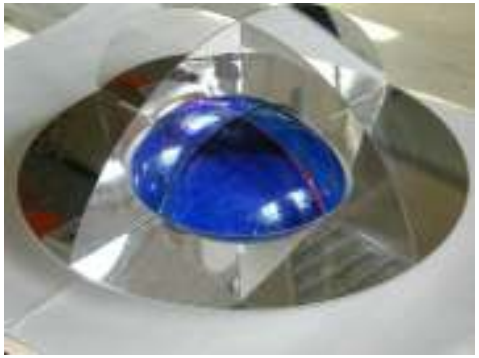




With improved photocatode QE

Standard





One large area PMT with segmented photocatode

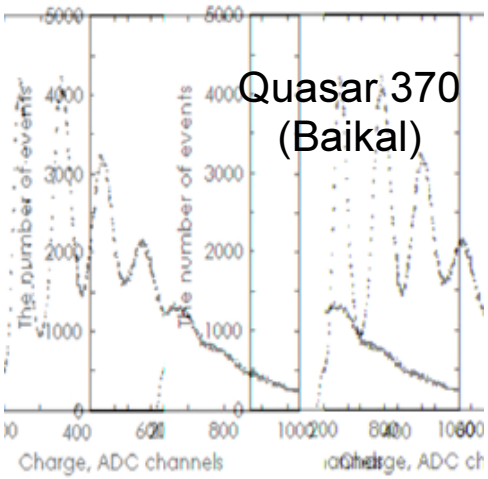
Directional

Optical Modules

Many small (3'' or 3.5'') PMTs in standard glass sphere

Multi PMT

Use high voltage (~20kV) and send photo electrons on scintillator;
detect scintillator light with small standard PMT



Hybrid

Mechanical structures

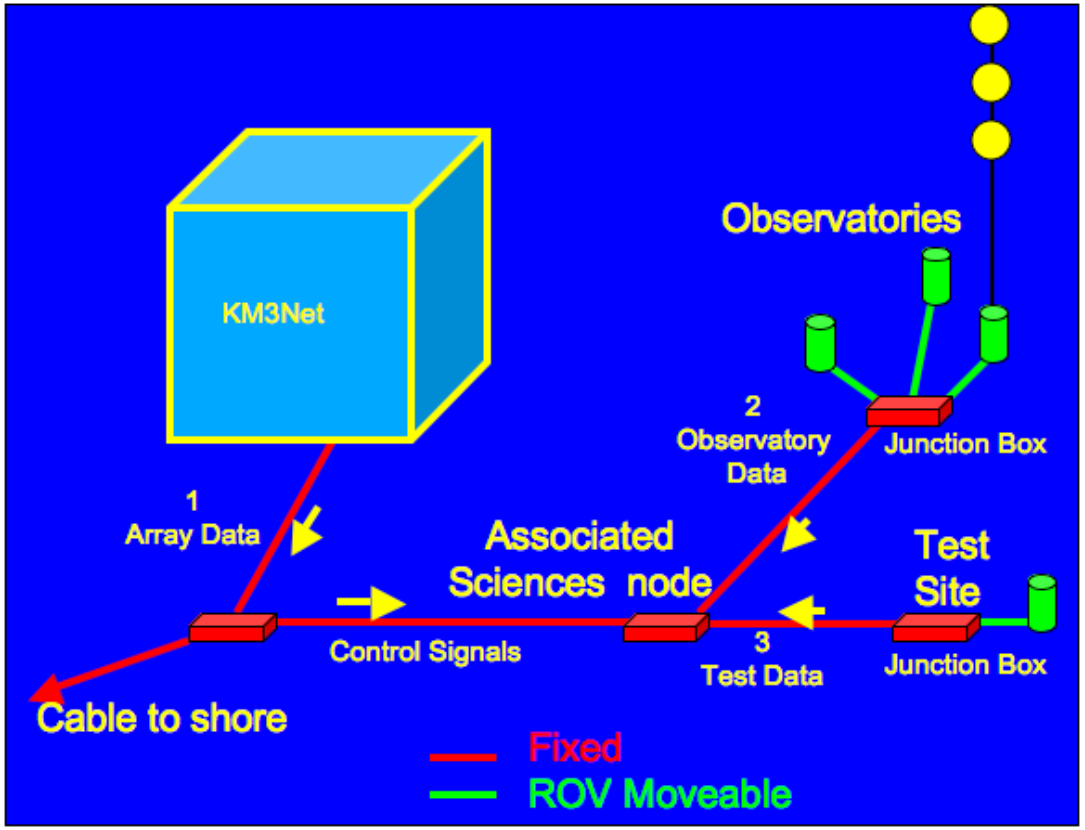
Tower like

String like

- Extended tower structure: NESTOR like, arm length up to 60 m
- Flexible tower structure: NEMO like, tower deployed in compactified “package” and unfurls thereafter
- String structure: Compactified at deployment, unfolding on sea bed
- Cable based concept: one (large) OM per storey, separate mechanical and electro-optical function of cable, compactified deployment

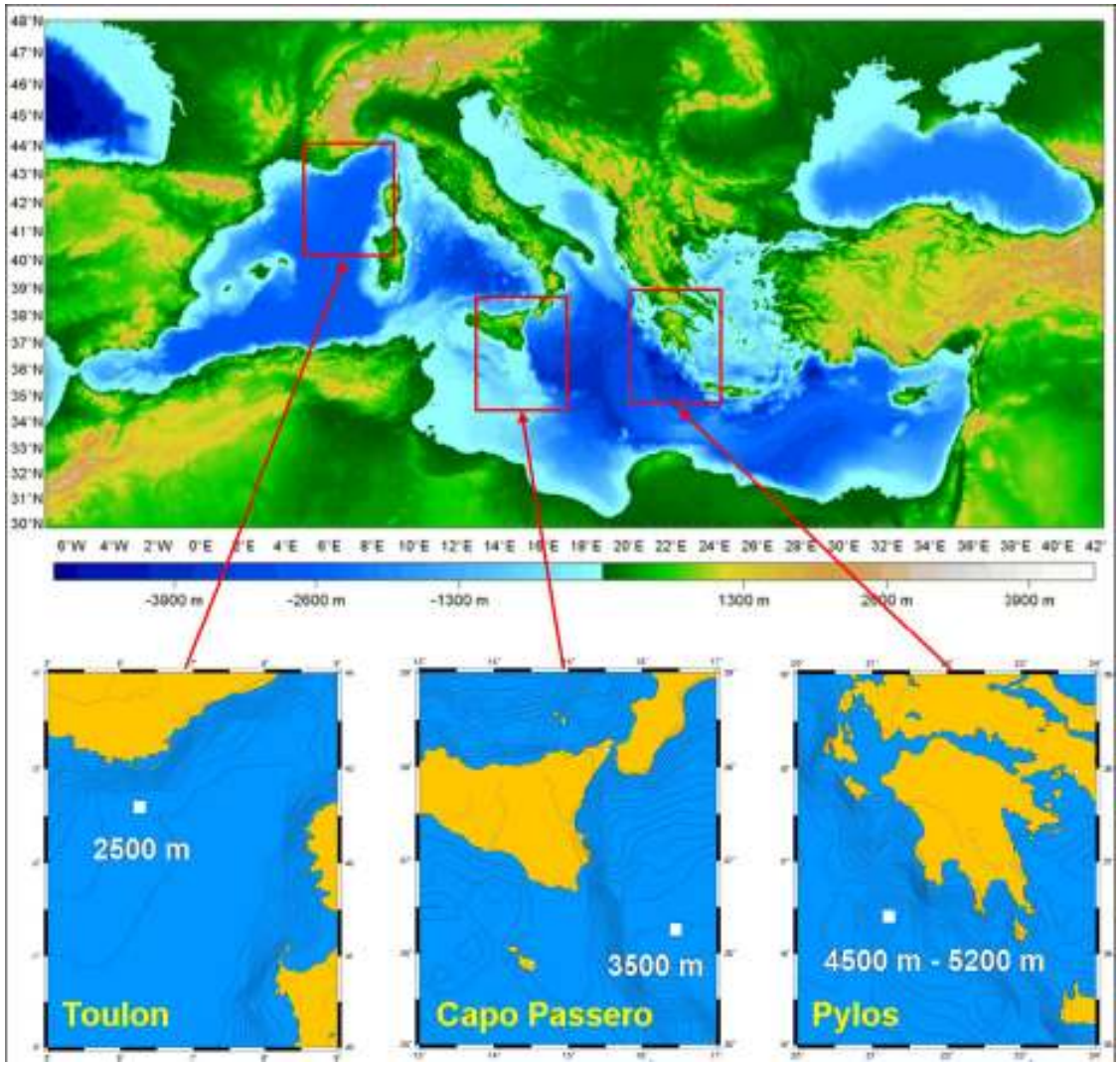
Associated sciences

- The KM3NeT infrastructure will serve as a platform for deep-sea and earth sciences
- Strong synergy with the deep-sea science community
- Associated science devices will be installed at various distances around neutrino telescope



- KM3NeT site in
  - **ESONET** (European Sea-floor Observatory NETwork)
  - **EMSO** (European Multi-disciplinary Sea-floor Observatory research infrastructure)

Candidate sites

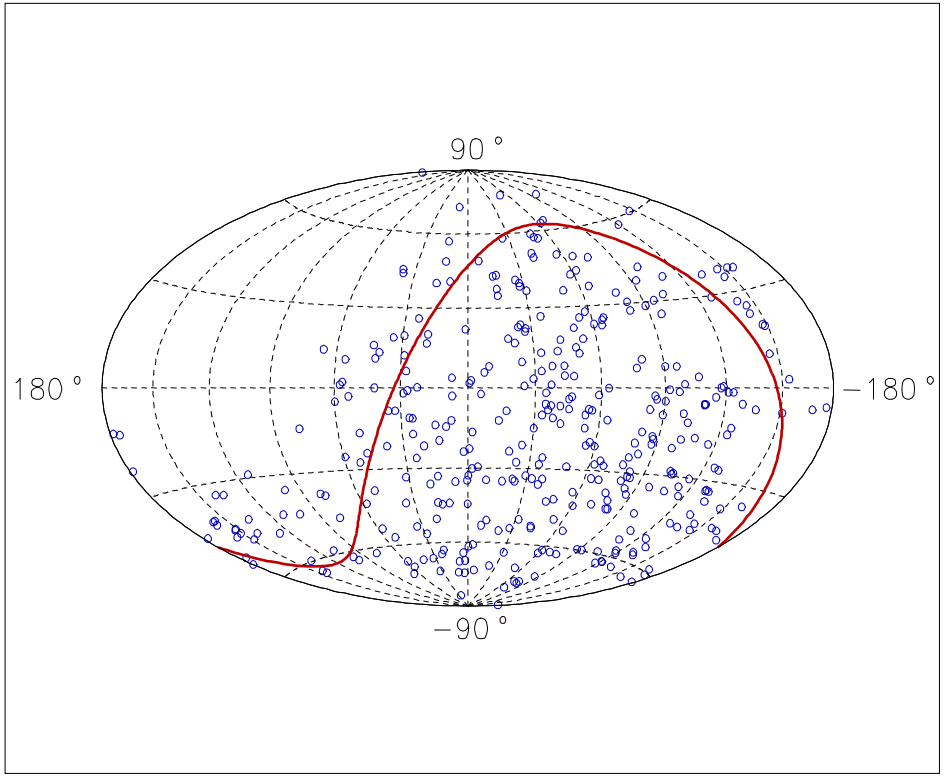


- Locations of the three pilot projects:
  - ANTARES: Toulon
  - NEMO: Capo Passero
  - NESTOR: Pylos
- All appear to be suitable
- Long-term site characterisation measurements performed and ongoing
- Final decision concerning location and single vs multi-site option requires scientific, technological and political input.

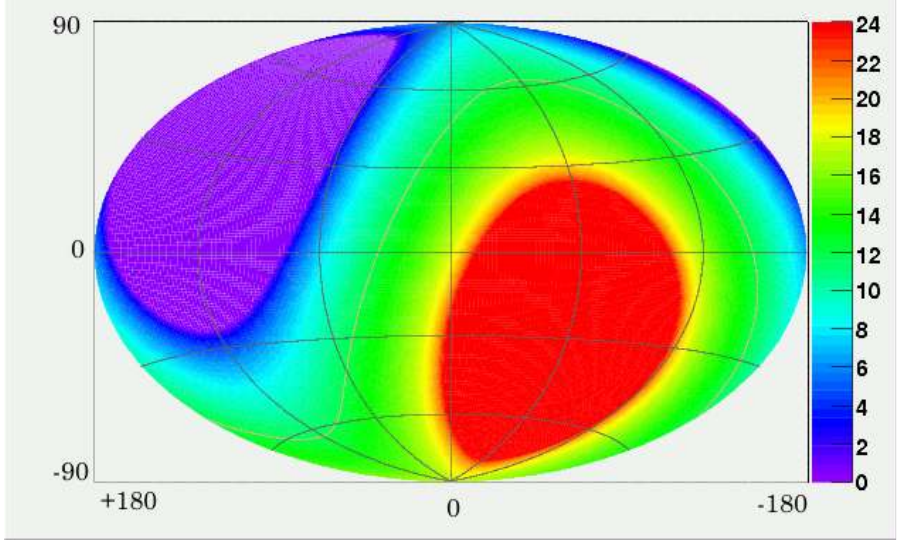
Summary and conclusions

- The successful experience of the pilot projects demonstrated the feasibility of the km3 underwater high energy neutrino telescope
- The KM3NeT consortium is progressing towards the completion of the Technical Design Report (2009) defining the technological solutions for the construction of a km3 ν telescope in the Mediterranean Sea
- The KM3NeT Preparation Phase started aiming at the definition of legal, financial and governance aspects

Atmospheric neutrinos in Baikal



E_{THR} 15-20 GeV



Skyplot of NT200 neutrino events for 5 years
(galactic coordinates)

372 Neutrinos in 1038 Days (1998-2003)
385 events from Monte-Carlo

V. Aynutdinov, VLVnT08

Baikal prototype string for the Gigaton detector

Installation of a "new technology" prototype string as a part of NT200+ (8 April 2008)

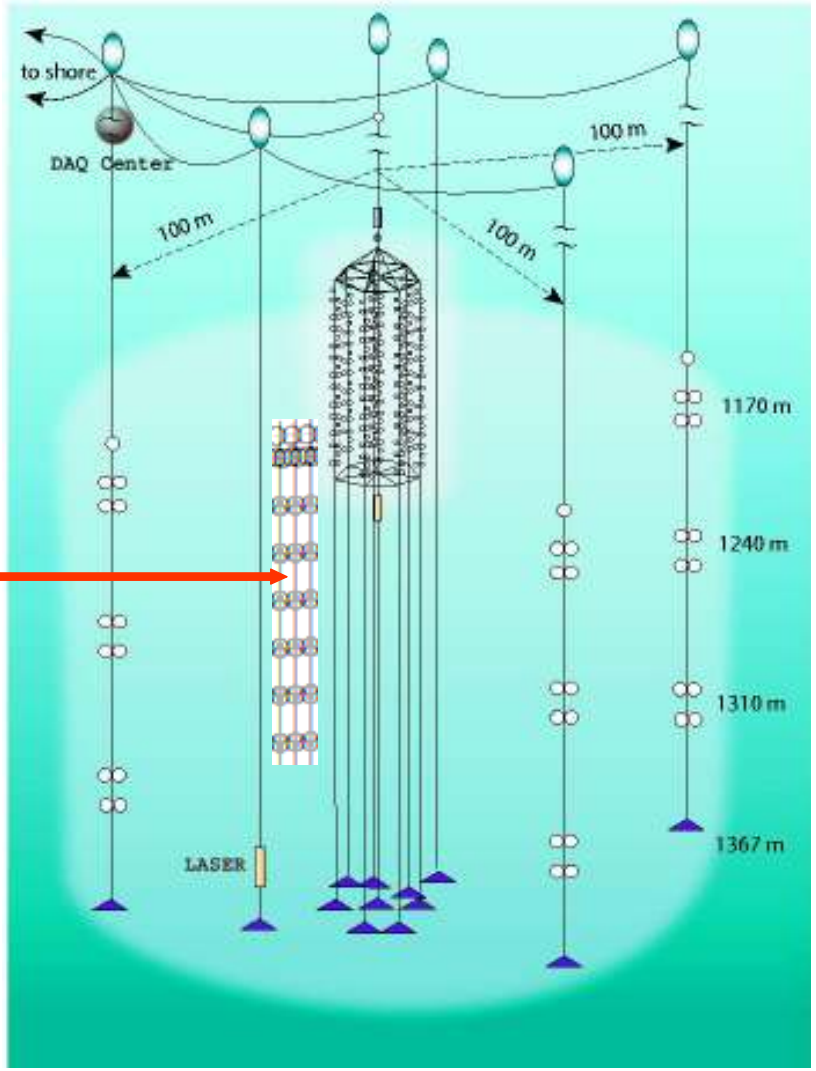
- Investigations and in-situ tests of basic elements of km3 detector: optical modules, DAQ system, new cable communications.

- Studies of basic DAQ/Triggering approach for the km3-detector.

- Confrontation of classical TDC/ADC approach with FADC readout.

Prototype string

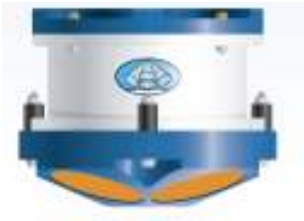
NT200+ current status



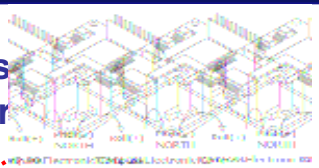
Mini-Tower Slow Control Instrumentation

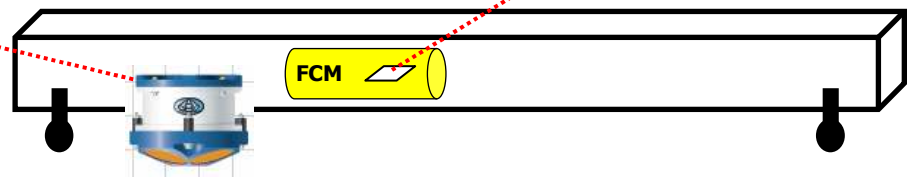
Acoustic Doppler Current Profile

→Sea Current

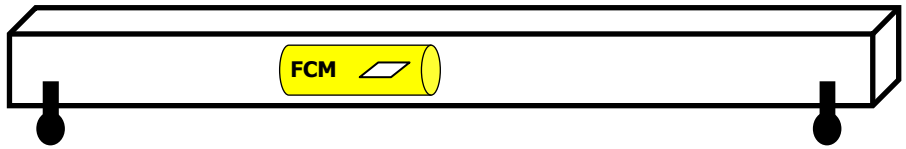


Compass
Tilt meter

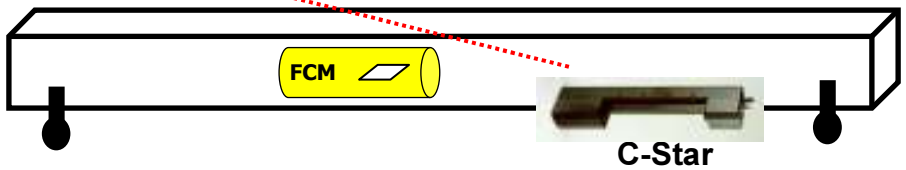




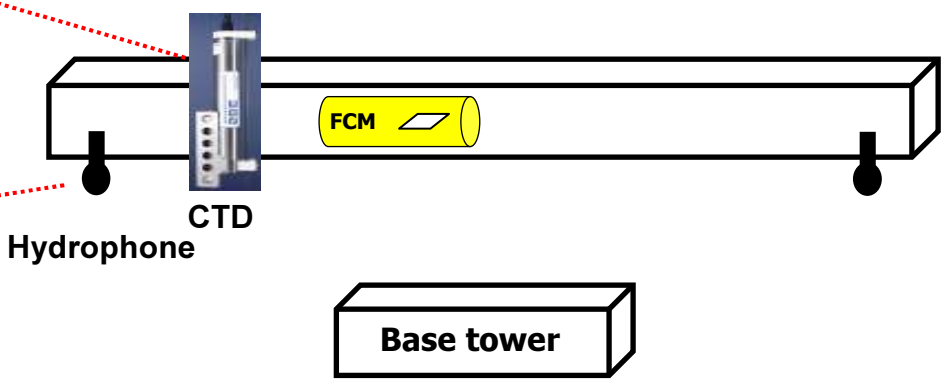
→Light Transmissivity in Water



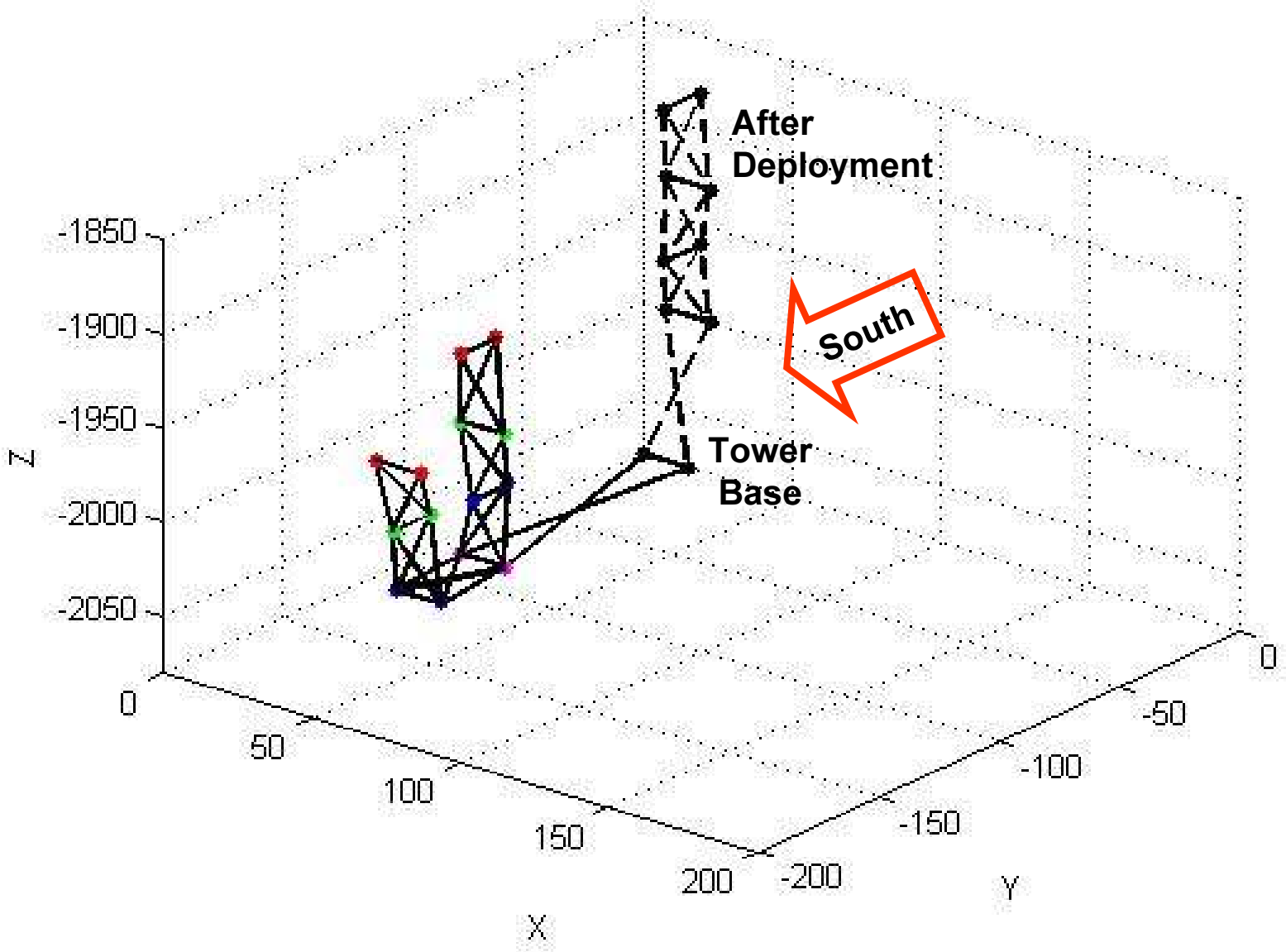
→ Conductivity Temperature Pressure



→ Acoustic Positioning



Acoustic Positioning Data



Reconstructed Atmospheric Muon Tracks

→1685 Tracks Reconstructed

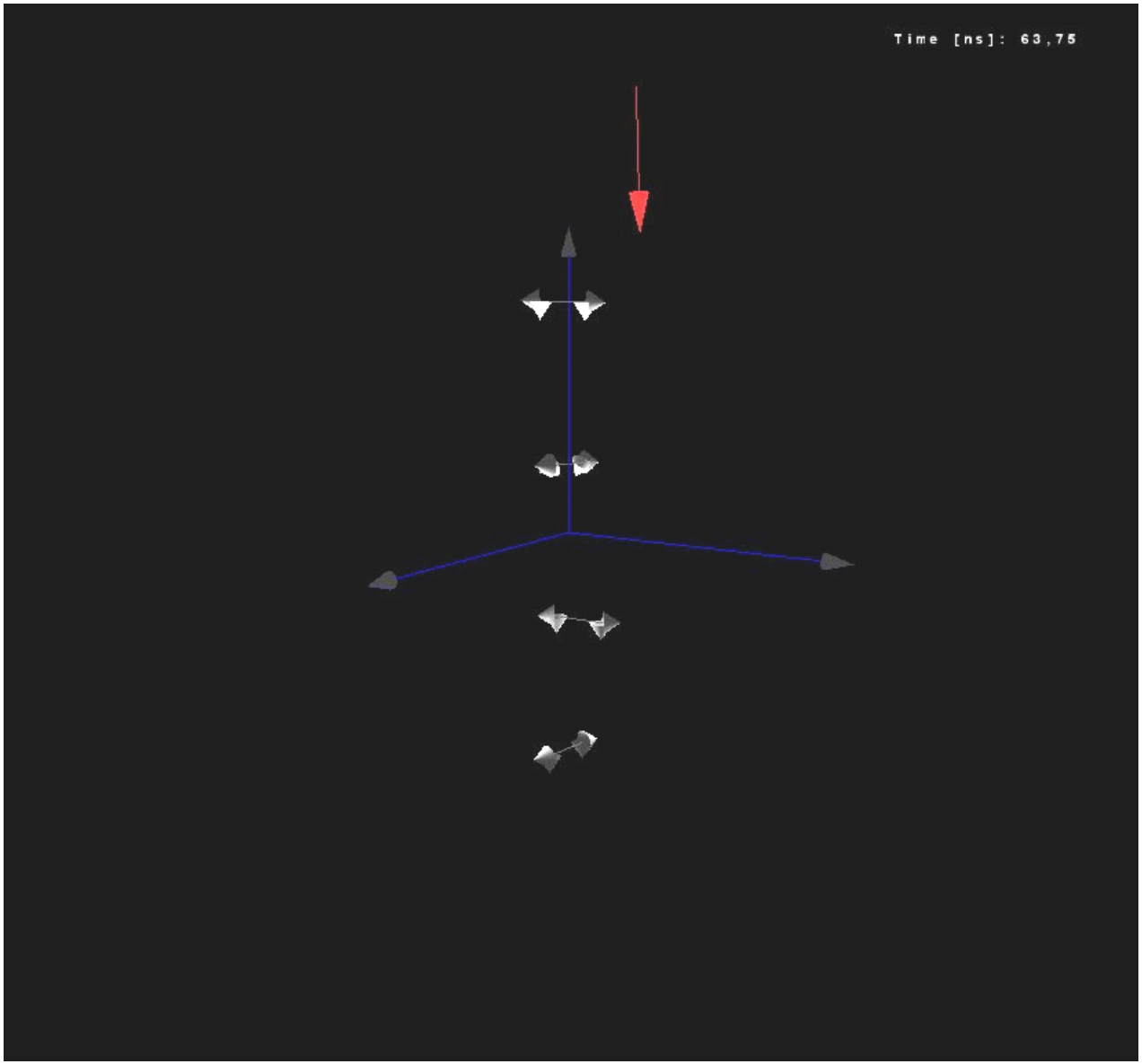
from the first analysed data set (23-24 Jan 2007)

Run 15 Event 11

Date 23 Jan 2007 20:21

θ= 168°

Likelihood$_{RED}$= - 8,3



Lessons learned: the junction box

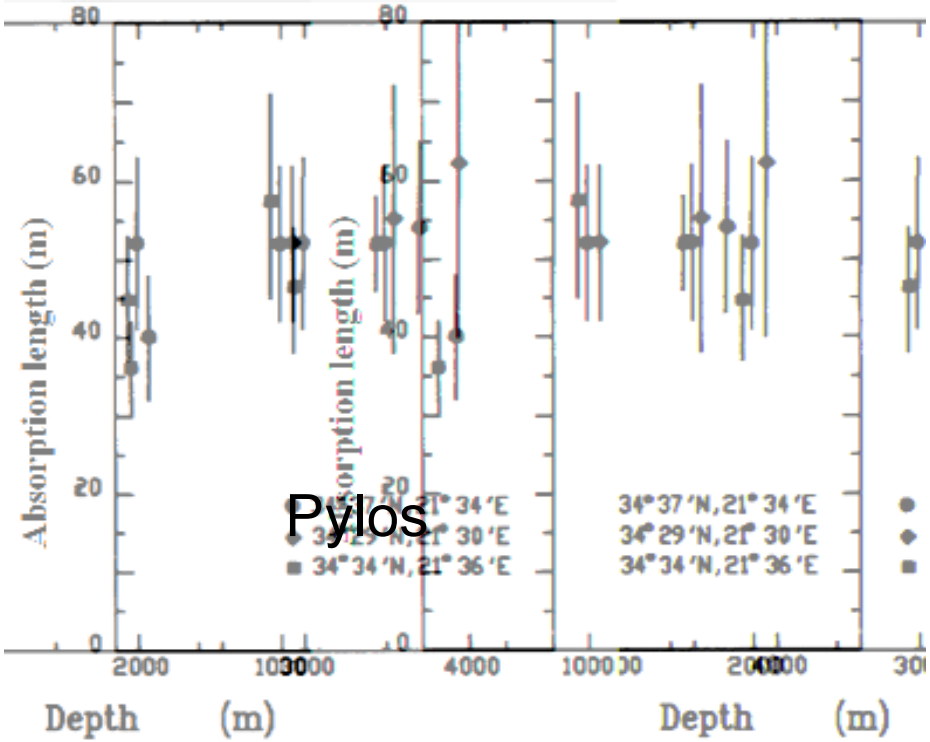
- Oil bath solution successful
  - Applied to the JB and the electronics containers of the tower
- Importance of redundancies
  - All control channels in the JB duplicated
  - Minor failures on some control boards overcome via redundant path

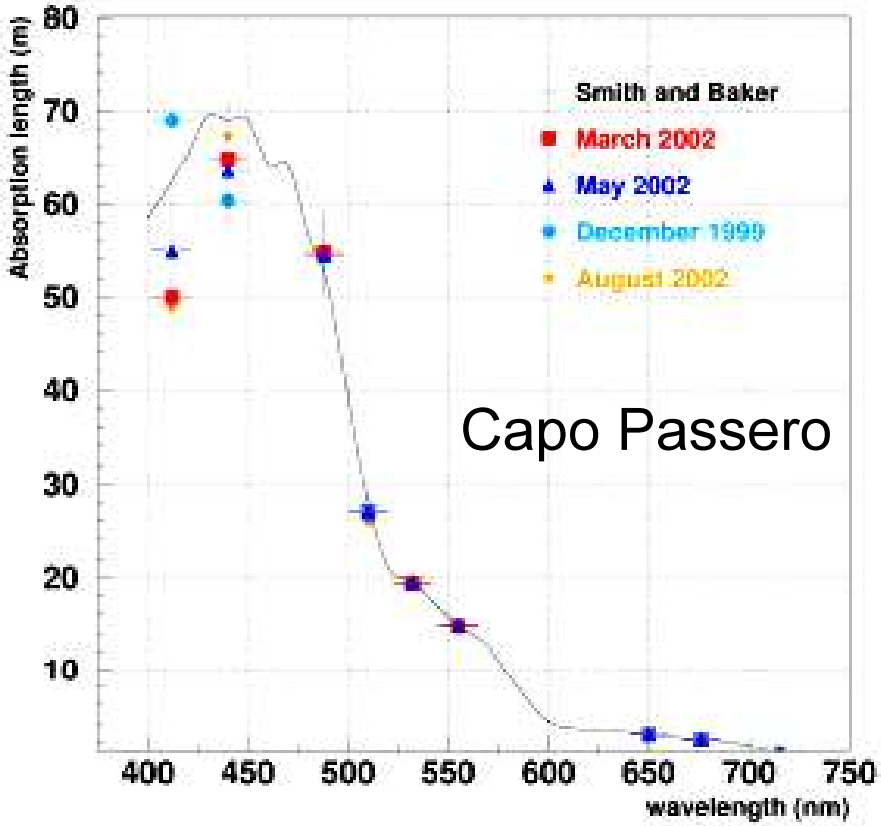
but …

- Malfunctions due to accidental crash
  - Recovery of the JB (June 16 2007)
  - Repair and redeployment (planned in autumn)

Site characterization

Water transparency





The NEMO Phase-2 project

- 100 km long electro-optical cable laid in july 2007
- Costruction of a fully equipped 16 storey tower started
  - The tower design has been revised taking into account the experience gained in Phase-1
  - Deployment foreseen end 2008

- Main modifications/upgrades of the new tower
  - New DC power system to comply with the feeding system provided by Alcatel
  - Optimization of the electronics and data transmission
  - New segmented electro-optical cable backbone
  - Integration of a new acoustic station in the tower

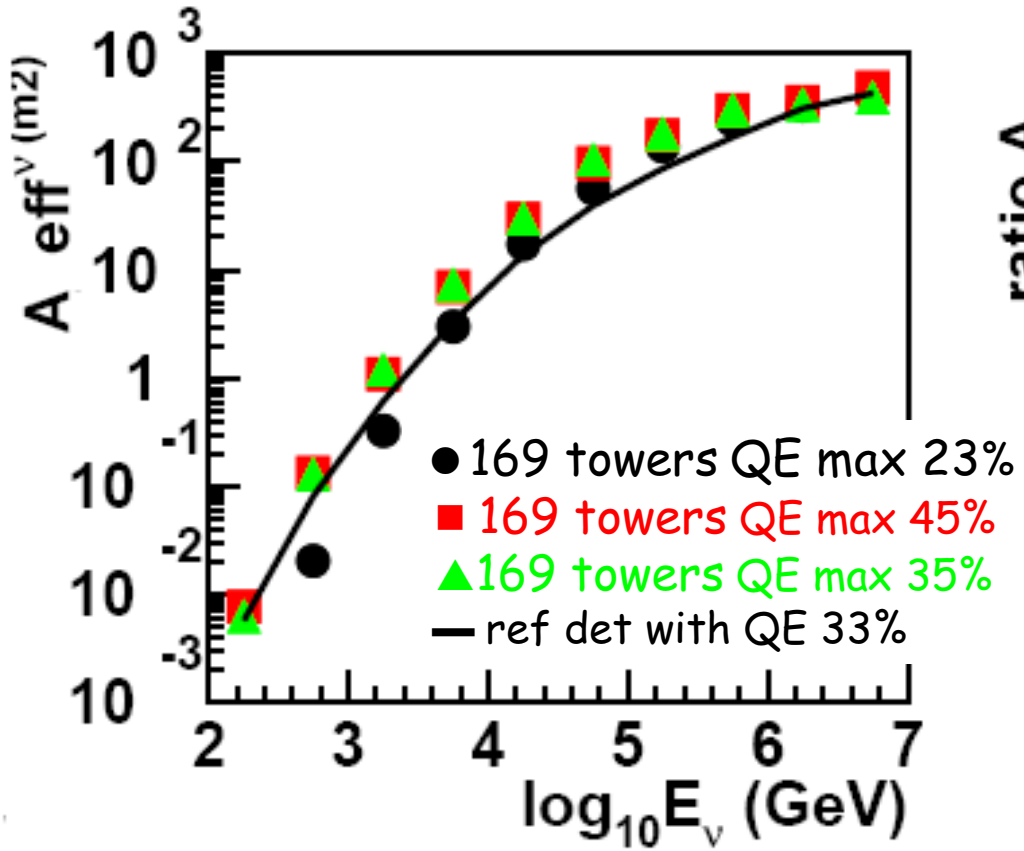
Quantum efficiency effect

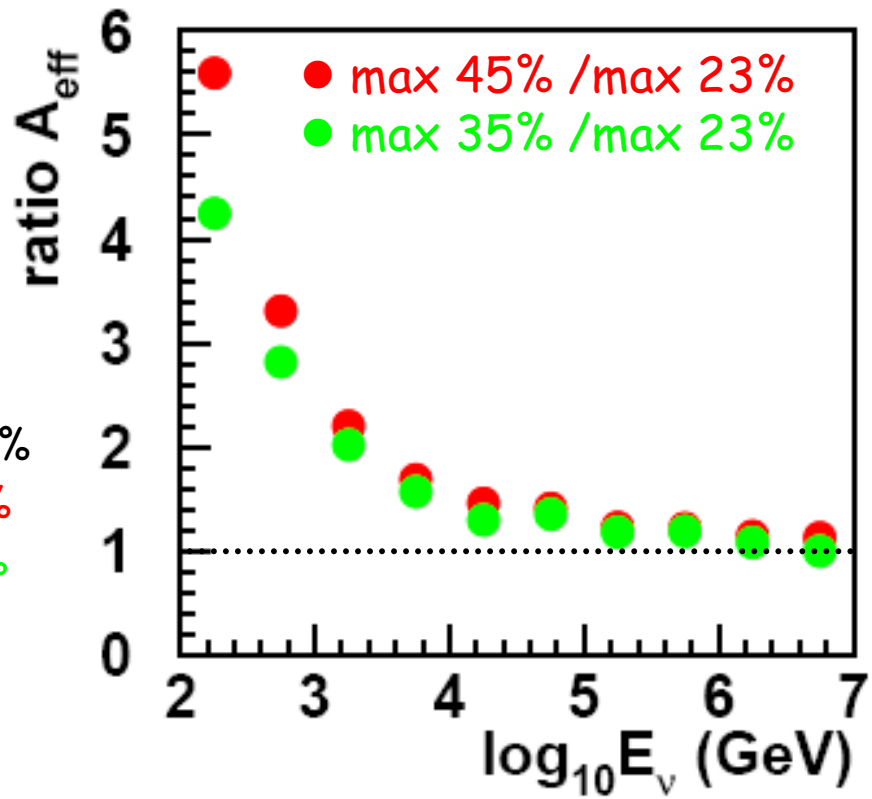
preliminary results

Neutrino effective areas

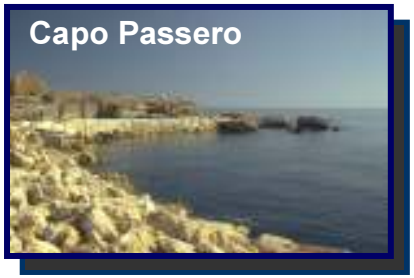
Ratio for 169 towers detector

Quality cuts applied (0.1°@30TeV)





High energy neutrino telescopes world map



BAIKAL

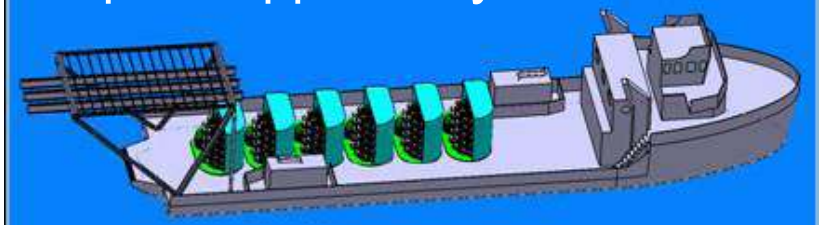
KM3NeT { **ANTARES** *(see J. Carr talk)*, **NEMO**, **NESTOR** }

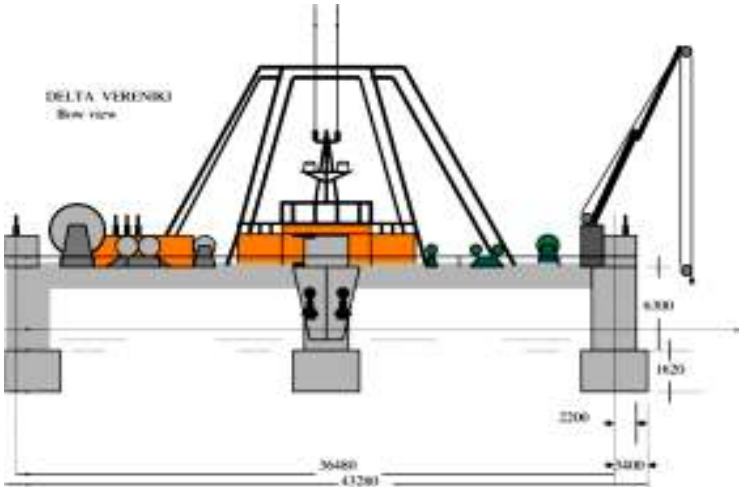
AMANDA
ICECUBE

Deployment

- On the surface, deployment operations require ships and/or dedicated platforms

Ships: Buy, charter or use ships of opportunity

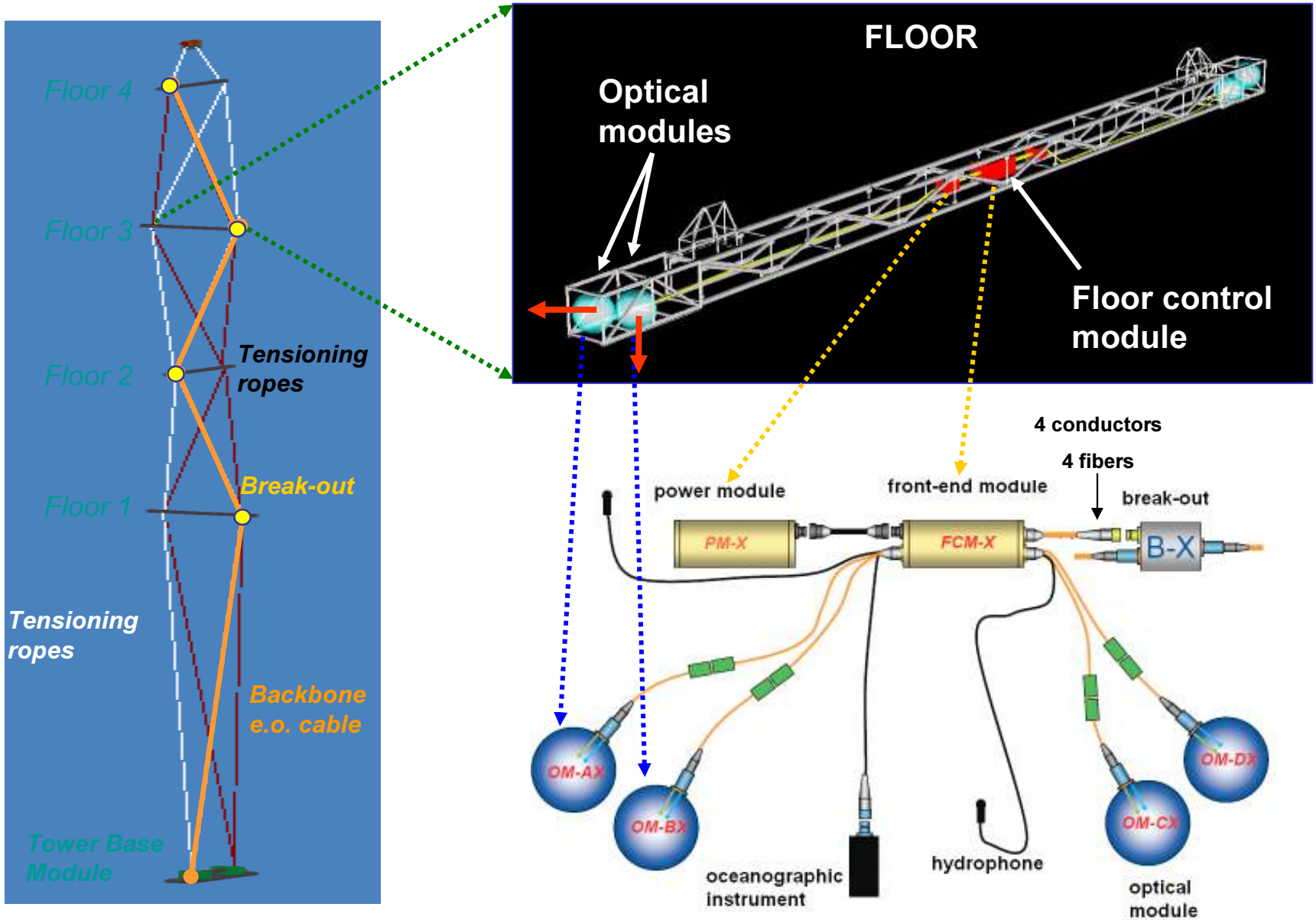




Platform: Delta-Berenike, under construction in Greece, ready summer 08

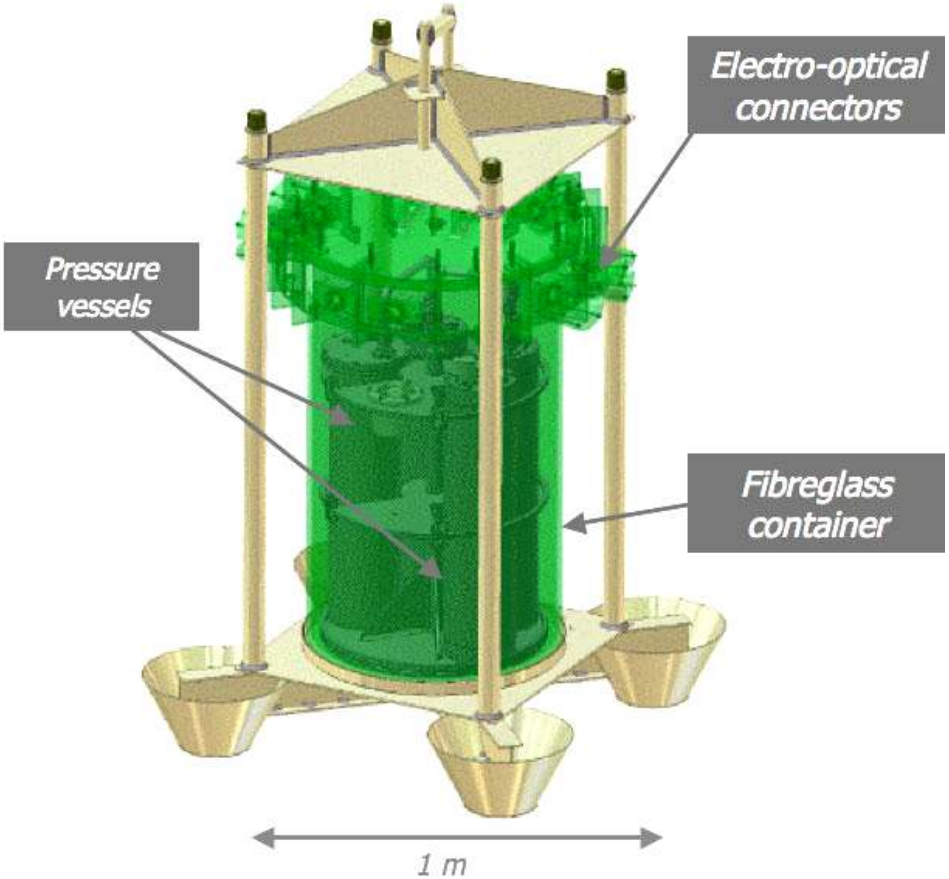
- In the deep-sea submersibles ROVs are likely needed for
  - laying out the deep-sea cable network
  - making connections to detection units
  - possibly maintenance and surveillance

The NEMO Mini-Tower



Deep-sea infrastructure

- Major components:
  - main cable & power transmission
  - network of secondary cables with junction boxes
  - connectors
- Design considerations:
  - cable selection likely to be driven by commercial availability
  - junction boxes: may be custom-designed
  - connectors: Expensive, reduce number and/or complexity



NEMO junction box design
Technology with double vessel system