A km^3 detector in the Mediterranean: status of NEMO

- **Motivation for a km^3 detector in the Mediterranean**

  (why, where, how and when)

- **NEMO objectives**

•***site selection and survey***

•***feasibility study for underwater km^3***

- **Status of NEMO phase 1**

- **KM3-NeT**

- **Conclusions and perspectives**

Neutrino telescopes brief history

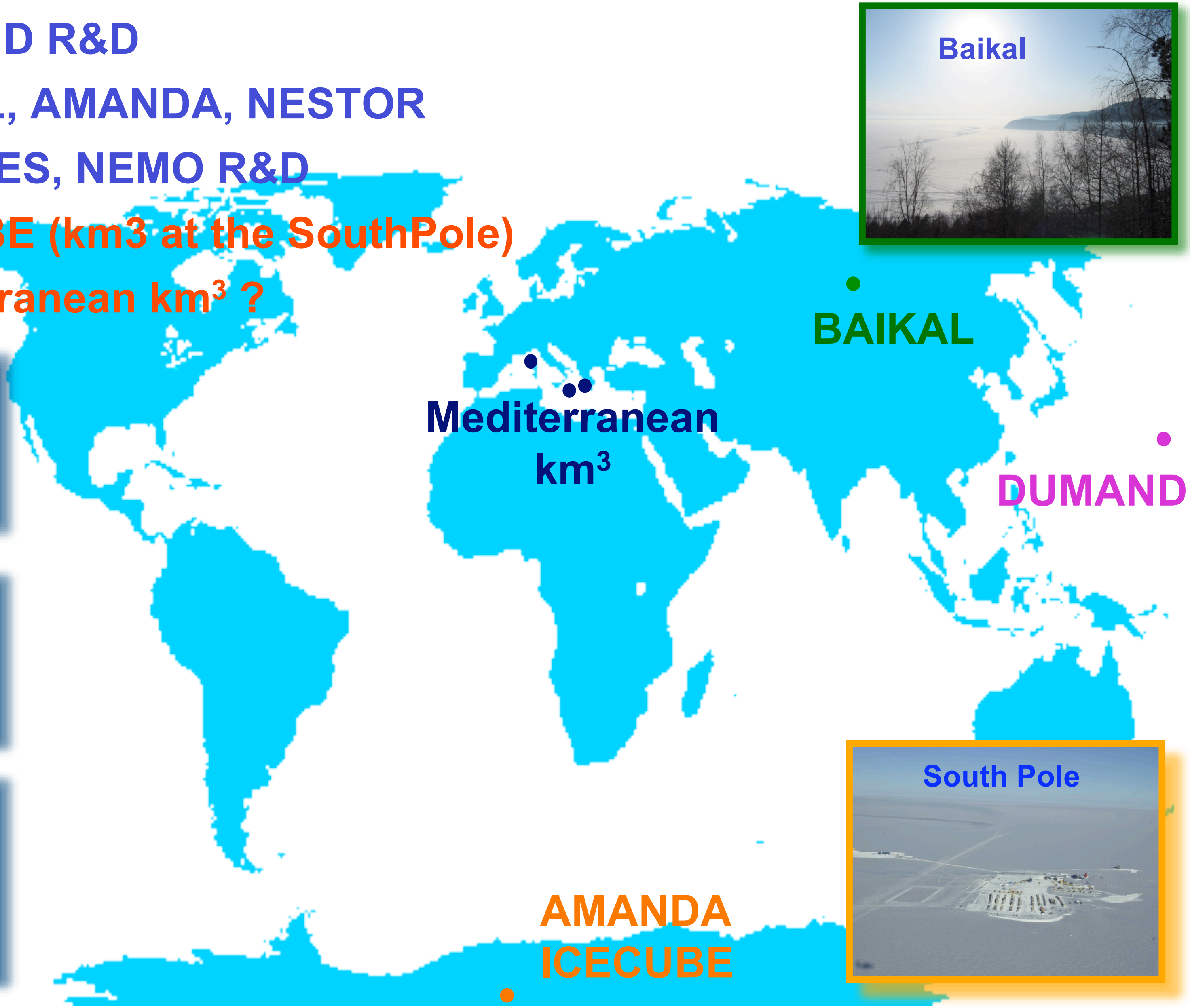
80’s: DUMAND R&D

90’s: BAIKAL, AMANDA, NESTOR

2k’s: ANTARES, NEMO R&D

2010: ICECUBE (km3 at the SouthPole)

……? Mediterranean km^3 ?



WHY? - Scientific objectives for a km^3 ν telescope

Km^3 underwater/ice ν telescopes field of research:

→ *point source search (steady and transient sources)*
→ *diffuse flux (upgoing + downgoing) measurement*
→ *indirect DM search*
→ *...*

Detector has to be optmised w.r.t.:

→ *effective area ($A_{eff}^{\mu} \geq 1$ km^2)*
→ *pointing resolution and accuracy*
→ ν_μ *energy threshold of a few hundreds of GeV*
→ *all ν flavor detection*
→ *…*

Constraints arise from technologies and costs

WHY? - Scientific motivations for two km^3 detectors

There are strong scientific motivations that suggest to install a neutrino telescope in the Northern hemisphere:

- **Complementarity with ICECUBE**
- **Full sky coverage**
- **Galactic Center only observable from the Northern Hemisphere**

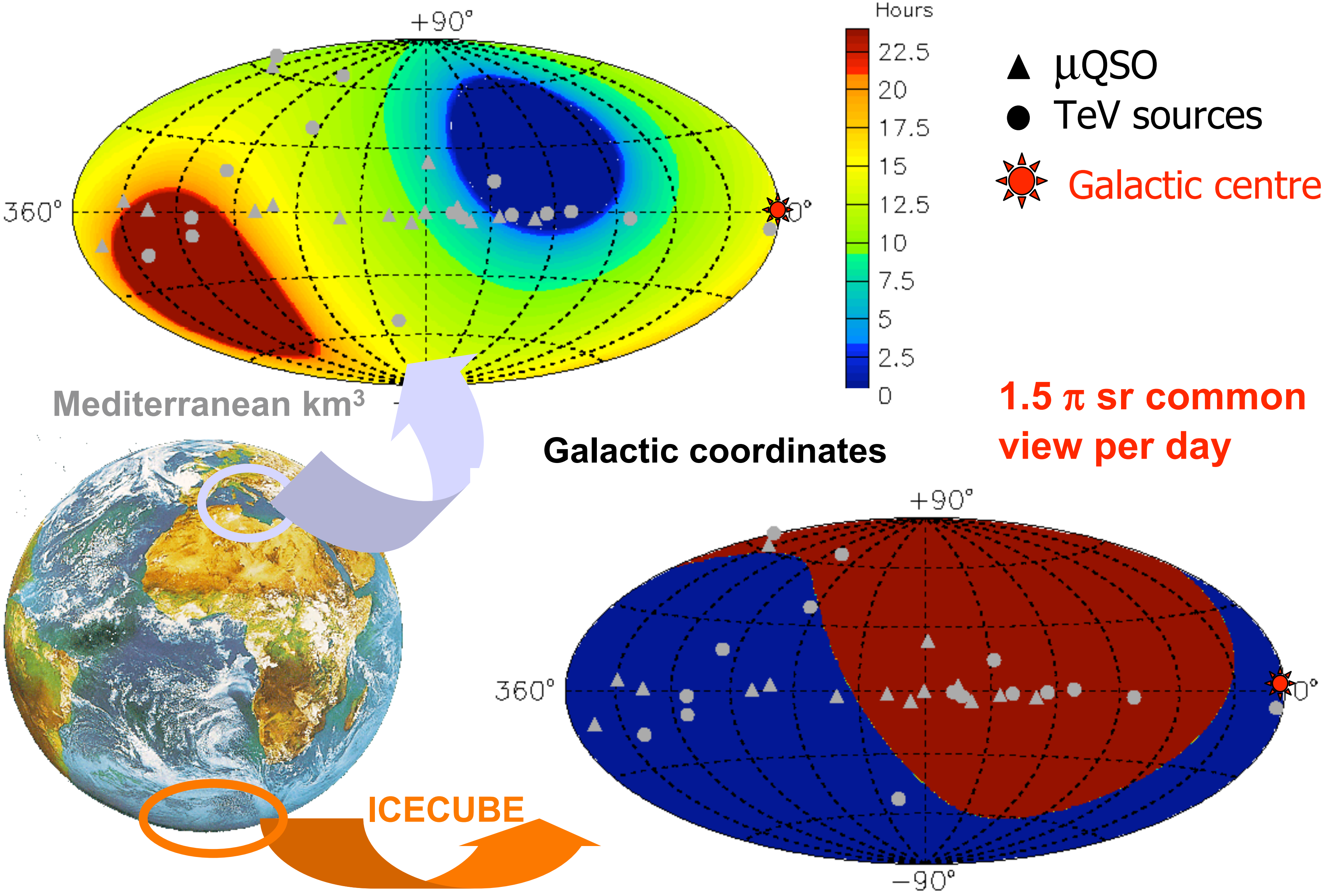
The most convenient location for the Northern km^3 detector is the Mediterranean Sea:

vicinity to infrastructures

good water quality

good weather conditions for sea operations

WHERE? - Observation time



▲ μQSO

● TeV sources

✹ Galactic centre

Galactic coordinates

1.5 π sr common view per day

WHERE? - The Mediterranean km^3 detector: potentials and payoffs

☺ **Structures can be recovered:**

- **The detector can be maintained**
- **The detector geometry can be reconfigured**

☺ **The underwater telescope can be installed at depth around 3500 m**

Muon background reduction and higher efficiency for downgoing ν

☺ **Light effective scattering length (>100 m) is much longer than in ice (20 m)**

Cherenkov photons directionality preserved

☹ **Light absorption length in water (70 m) is smaller than in ice (>=100 m)**

Less Cherenkov photons detected

☹ **^{40}K decay in water + bioluminescence**

Optical background and dead time increased

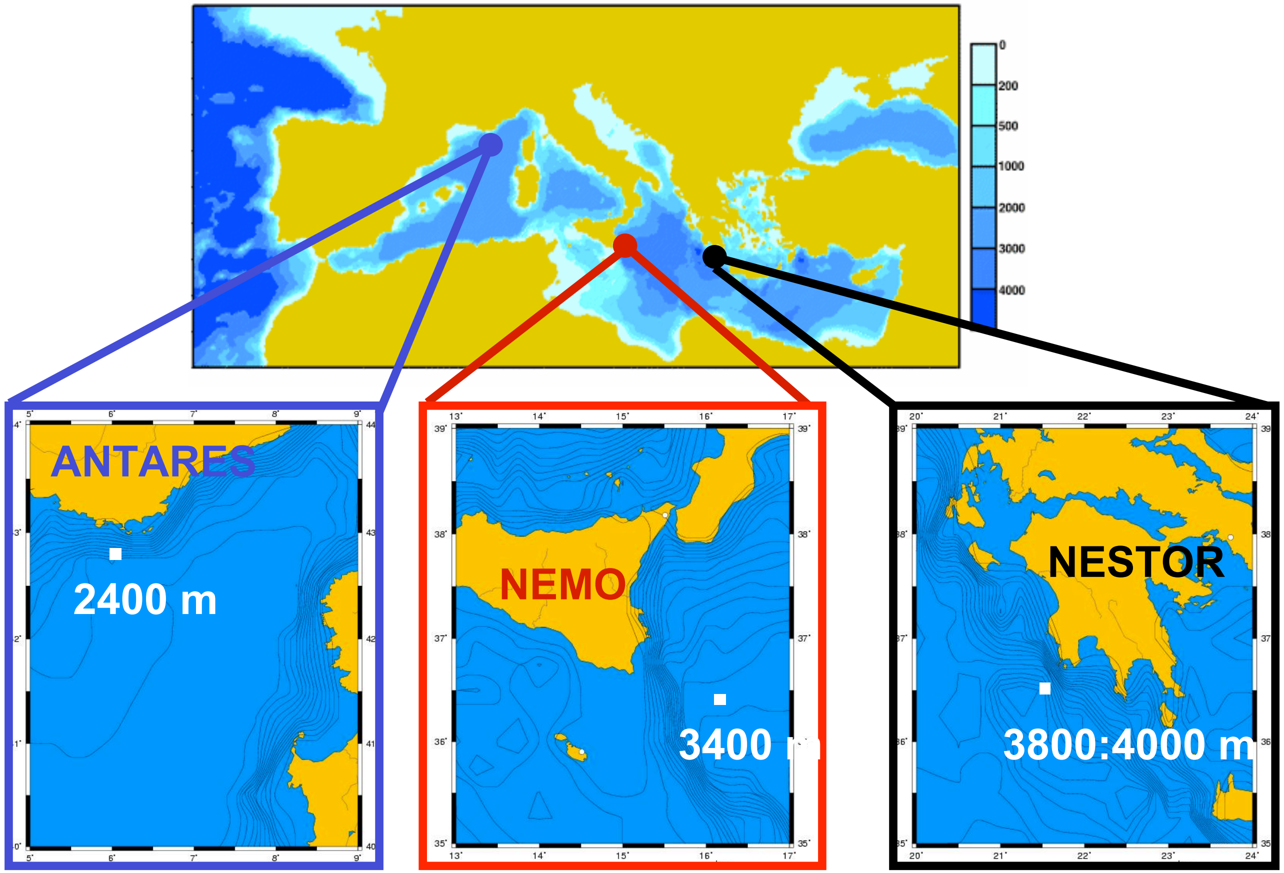
☹ **Sediments and fouling**

Optical modules obscuration → maintenance

WHERE? - Candidate sites for the km^3

There are 3 collaborations active in the Mediterranean Sea: ANTARES, NEMO and NESTOR and each of them proposes a site for km^3

APpEC Meeting, January 2003



NEMO Collaboration

INFN
Bari, Bologna, Cagliari, Catania, Genova, LNF, LNS, Messina, Pisa, Roma

CNR
Istituto di Oceanografia Fisica, La Spezia
Istituto di Biologia del Mare, Venezia
Istituto Sperimentale Talassografico, Messina

Istituto Nazionale di Geofisica e Vulcanologia

Istituto Nazionale di Oceanografia e Geofisica Sperimentale

Universities:
Bari, Bologna, Cagliari, Catania, Genova, Messina, Pisa, Roma *“La Sapienza”*

NEMO objectives

The NEMO Collaboration aims at:

1. Search, characterization and monitoring of a deep sea site adequate for the installation of the Mediterranean km^3

depth, optical and oceanographic features, …

2. Development of technologies for the km^3 finalized to the construction of a technological demonstrator including the main critical components for an underwater km^3 (NEMO phase 1)

submarine technology R&D

construction:improve reliability, reduce costs

deployment: define strategies taking profit of the newest technological break-through

connections:improve reliability, reduce costs

NEMO objectives

electronics technology R&D

• *readout:*	*reduce power consumption*
• *transmission:*	*increase bandwidth, reduce power consumption*

…

NEMO phase 1 will allow to validate procedures for technological solutions for underwater km^3

Capo Passero site features

The results of more than 20 sea campaigns support the candidature of Capo Passero as optimal site for km3 installation in the Mediterranean Sea

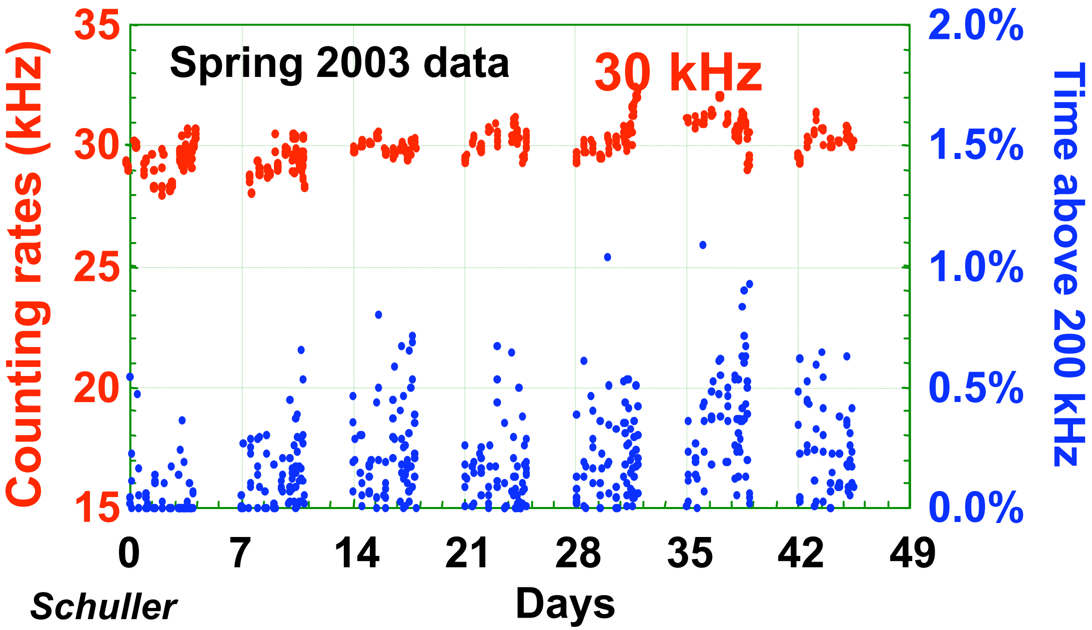
- Absorption lengths close to optically pure sea water values (λ_a ~70 m @440 nm)
- Measured optical background is low (<= 30 kHz ^{40}K background with rare bioluminescence bursts <= 1%)
- Measured values are stable troughout the years
- The site location is optimal (close to the coast, flat seabed, far from the shelf break and from canyons, far from important rivers)
- Measured currents are low and regular

  (2-3 cm/s average; 12 cm/s peak)
- Sedimentation rate is low (about 60 mg m^{-2} day^{-1})
- No evidence of turbidity events (from core analysis)

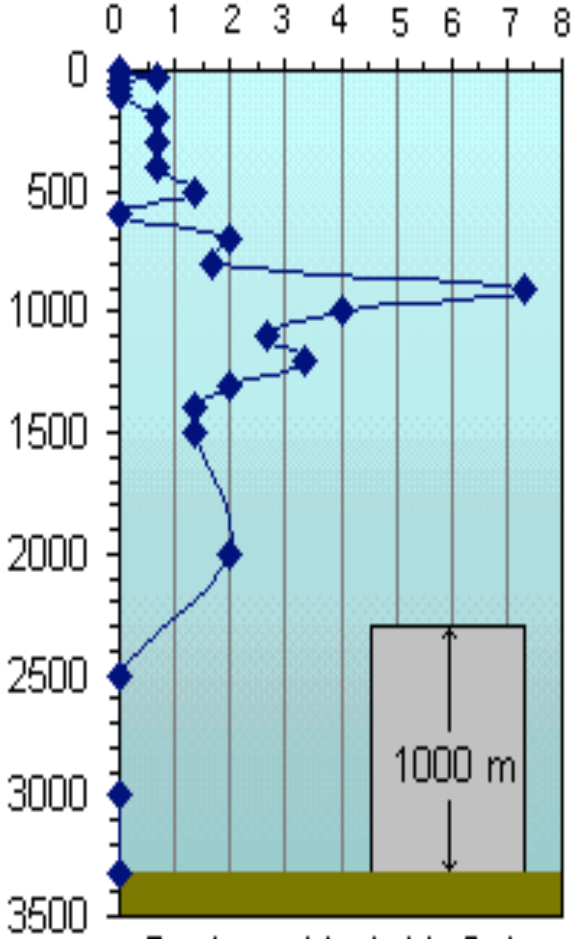
NEMO - Capo Passero: Optical background

Optical background was measured in Capo Passero with different devices.

Data are consistent with ^{40}K decay rate with very low bioluminescence.



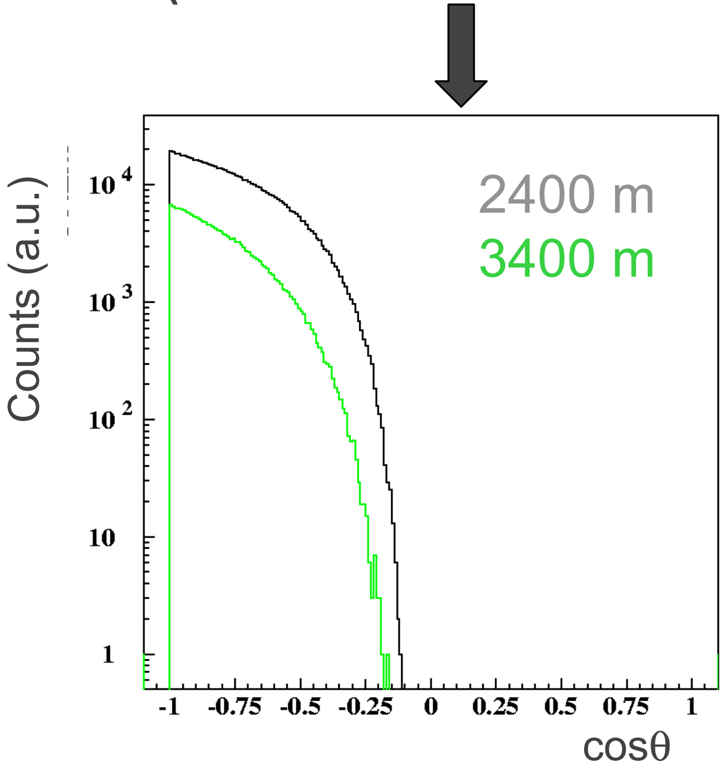
Bioluminescent bacteria concentration 100 ml^{-1}



Optical data are consistent with biological measurements:
No luminescent bacteria have been observed in Capo Passero below 2500 m

Effect of depth on detector performances

Atmospheric μ flux at the horizon of km^3 detector
(HEMAS + MUSIC simulations)

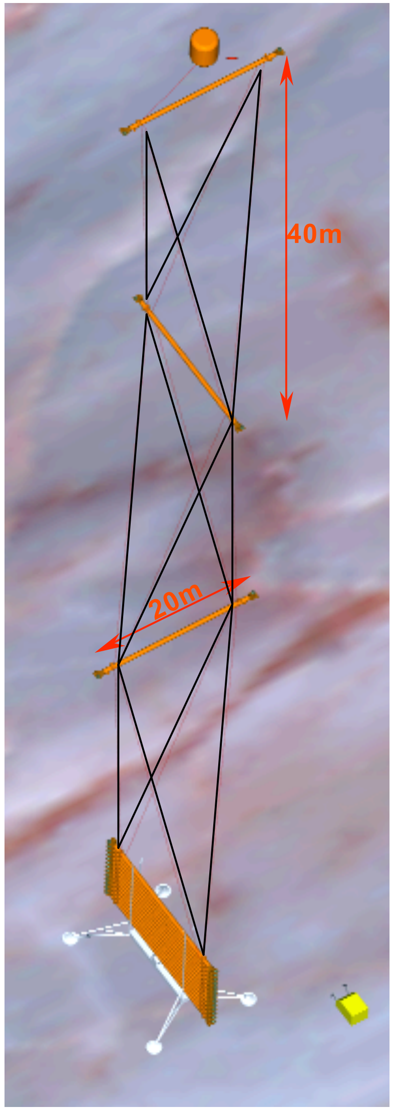


Downgoing muon background is reduced as a function of detector installation depth

effect on detector performance has to be investigated into more details

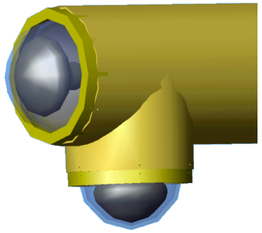
Depth in Capo Passero is about 3400 m (equivalent to Gran Sasso, Kamioka,..)

km^3 architecture: the NEMO proposal

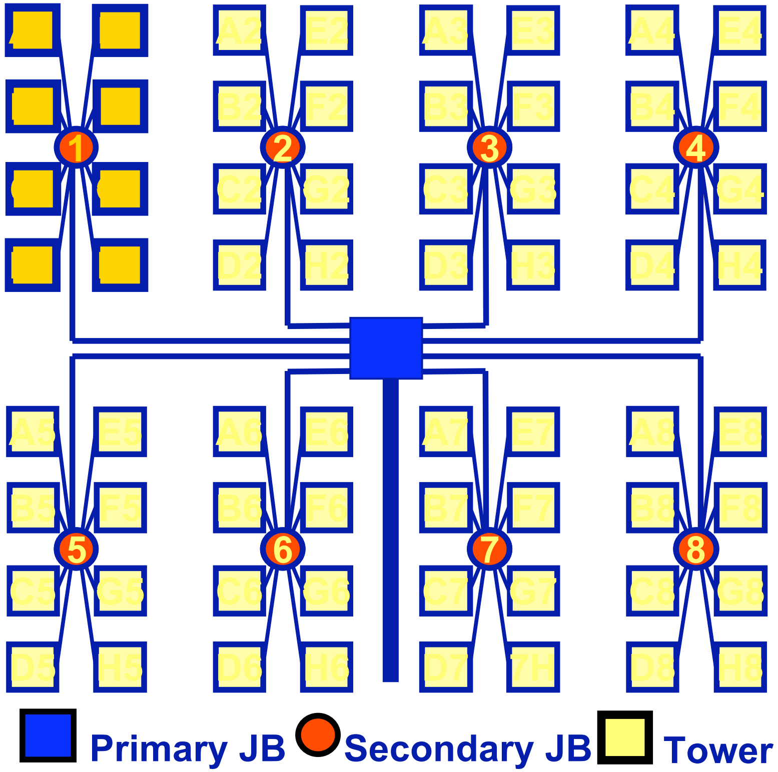


Strings, rigid towers, …
NEMO: towers made of a sequence of storeys rotated by 90° w.r.t. to the up and down adjacent ones

4 OM at each storey edge with a down-horizontal PMT arrangement (different arrangements possible)



Schematic detector layout



The NEMO tower

The NEMO tower is a semi-rigid 3D structure designed to allow an easier deployment and recovery.

High local PMT density is designed to perform local trigger.

Deployment and unfurling technique tested in shallow waters with a 1:5 scale 4 storey model of the tower (april 2004).

Tower height:

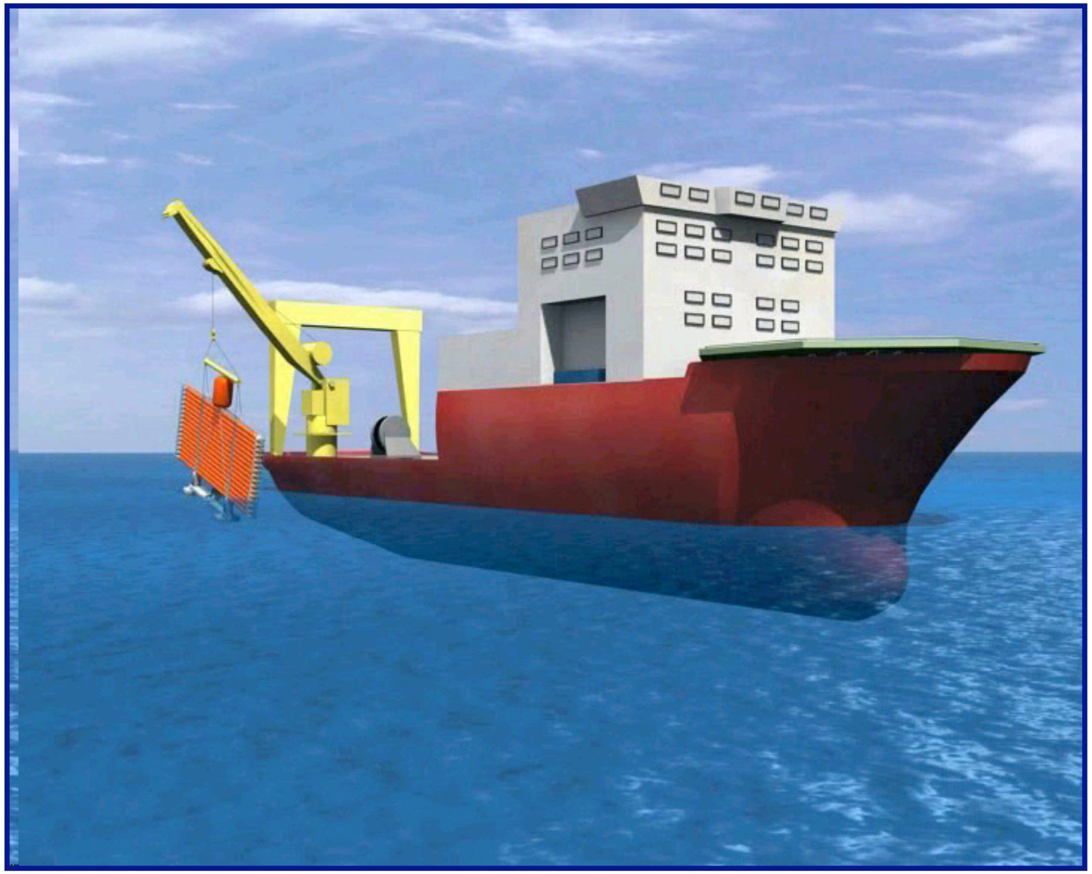
•compacted	15:20 m
•total	750 m
•instrumented	600 m

storeys:

n. storeys	16:20
n. PMT/storey	4
•length	15:20m
•spacing	40 m

PMT arrangement:

down-horizontal at the storey edges



Detector performances: effect of water properties

Effective areas and medians as a function of optical background rates after quality cuts (simulations performed with the ANTARES simulation package)

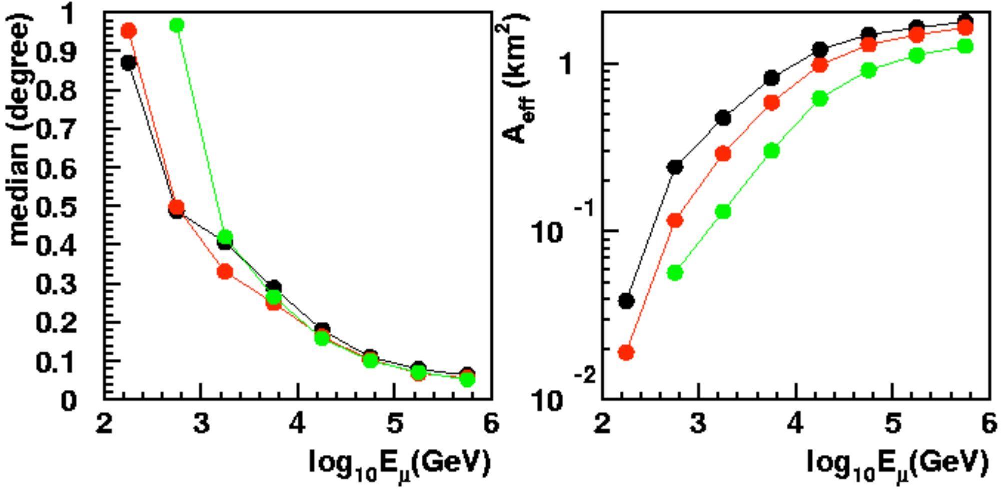
Detector geometry:

- *5832 PMTs*
- *81 towers arranged in 9x9 lattice*
- *140 m between towers*
- *20 m storey length*
- *40 m vertical spacing*
- *4 down-horizontal PMT/storey*

E^{-1} upgoing μ generated at the can surface

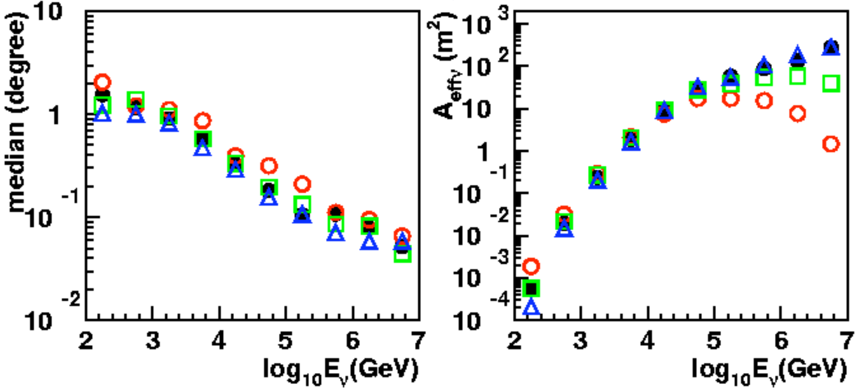
trigger 2/4 OR 2.5 p.e. (q.c. –9)
trigger ¾ OR 2.5 p.e. (q.c. –7.8)
trigger ¾ OR 2.5 p.e. (q.c. –7.4)

20 kHz 60 kHz 120 kHz



E^{-2} upgoing ν

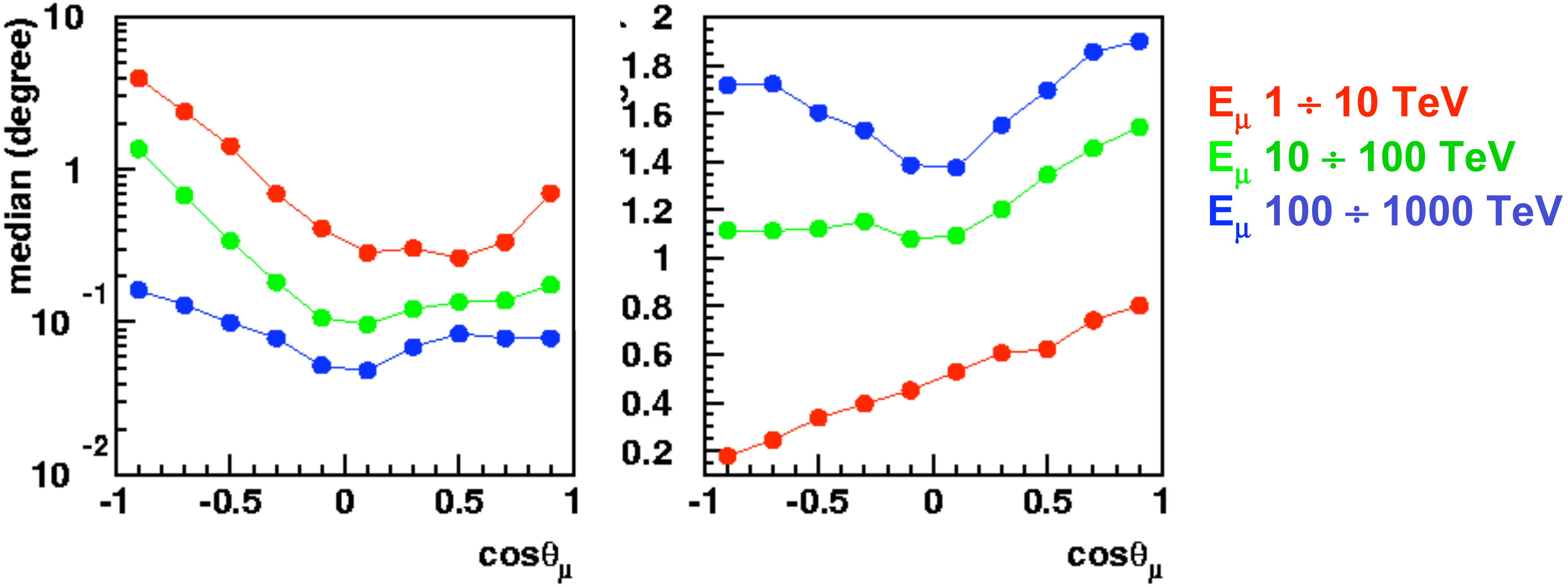
trigger 2/4 OR 2.5 p.e. (q.c –7.8)



● θ_ν = 0°-90° ○ θ_ν = 0°-30° θ_ν = 30°-60° ▲ θ_ν = 60°-90

NEMO tower detector performances

E^{-1} μ generated at the can surface (20 kHz trigger: 2/4 OR 2.5 p.e., q.c. –9)

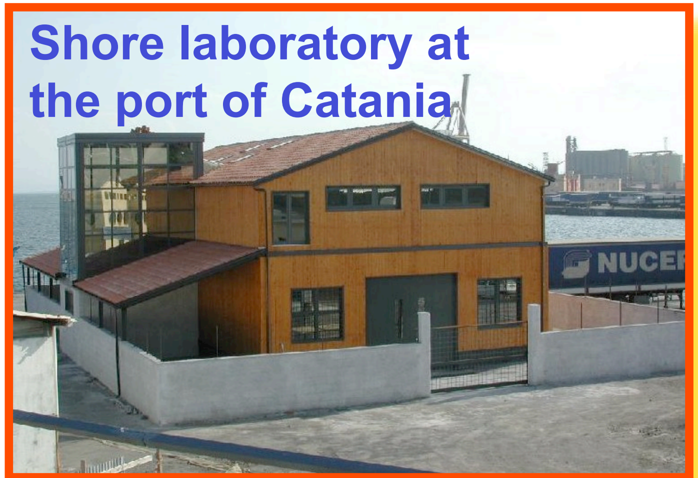


Median between the incident muon and the reconstructed one

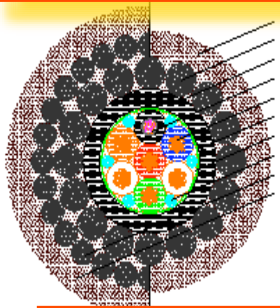
Muon effective area (km^2)

Rather good detector response for both upgoing and downgoing muon events
Downgoing muons => calibration, high energy ν, …

NEMO Phase 1

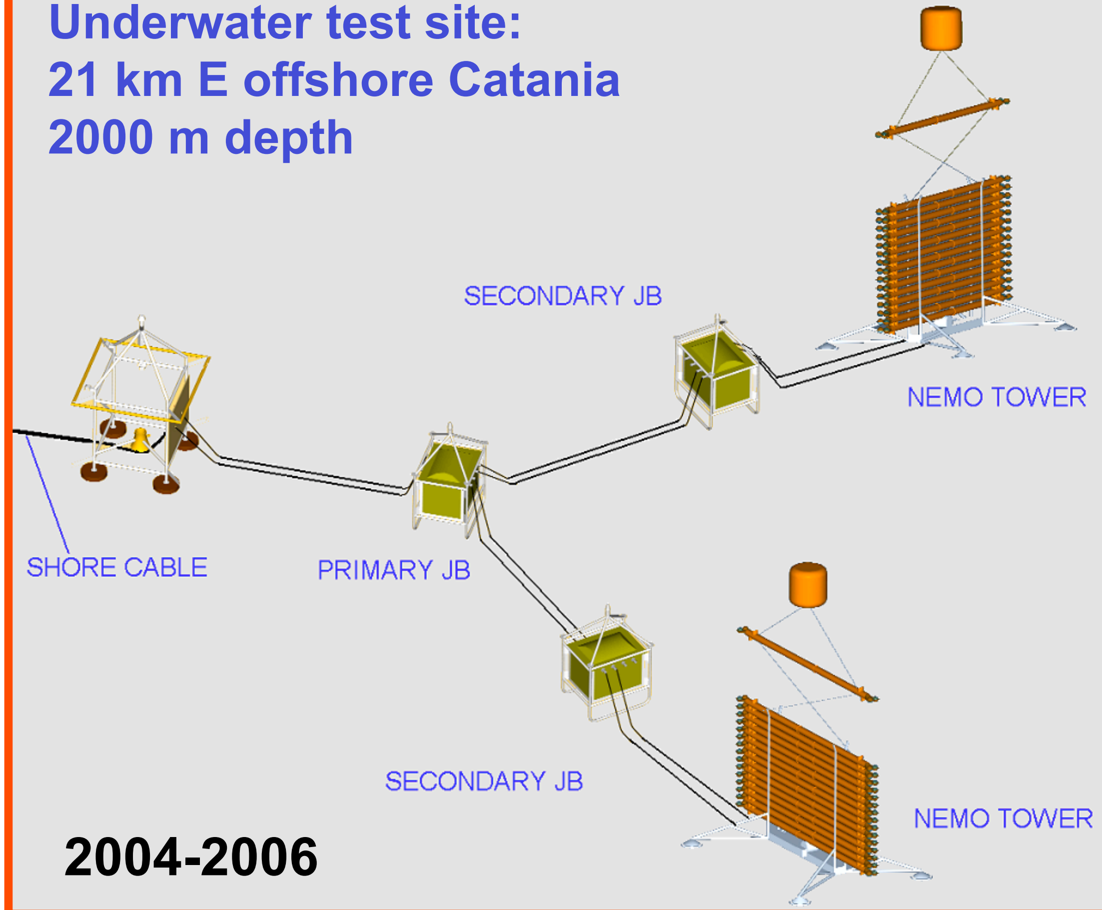

Shore laboratory at the port of Catania

A fully equipped facility to test and develop technologies for the Mediterranean km^3



10 Optical Fibers
6 Conductors

Underwater test site:
21 km E offshore Catania
2000 m depth



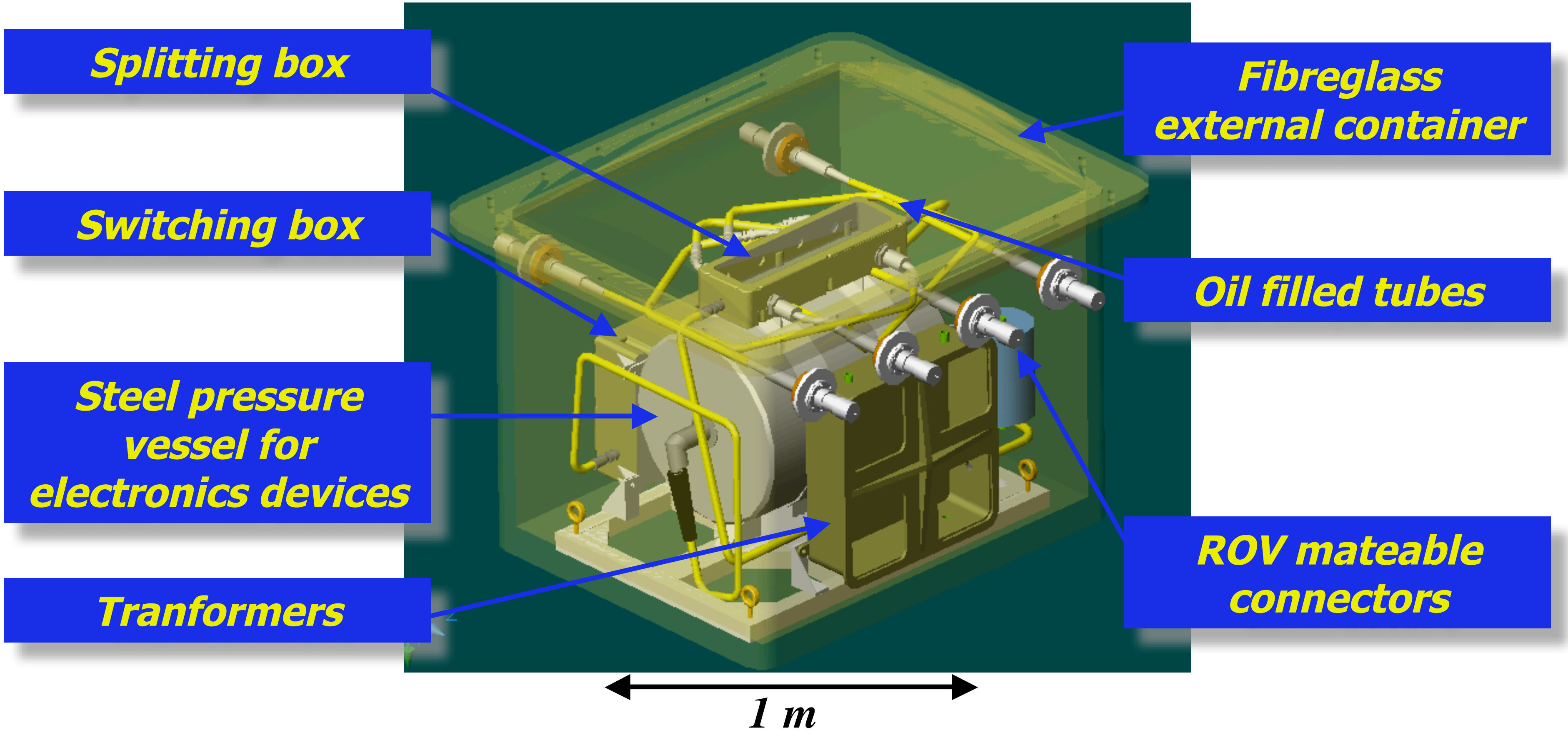
2004-2006

NEMO phase1 - Junction Boxes

Alternative design to the Titanium container (Antares-like)

Aim

Decouple the two problems of pressure and corrosion resistance



Splitting box

Switching box

Steel pressure vessel for electronics devices

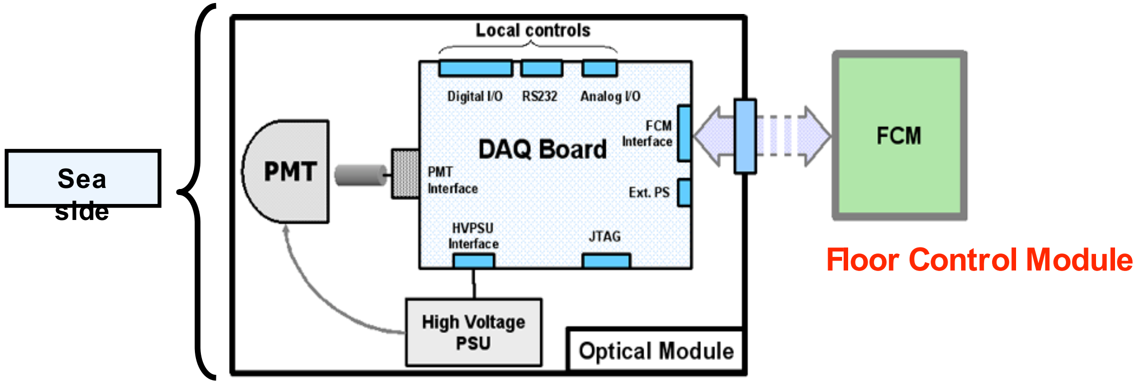
Tranformers

Fibreglass external container

Oil filled tubes

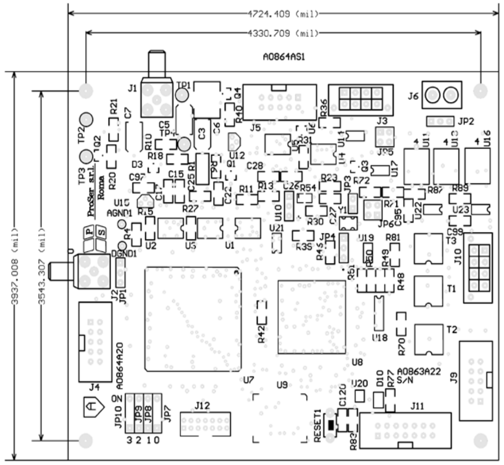
ROV mateable connectors

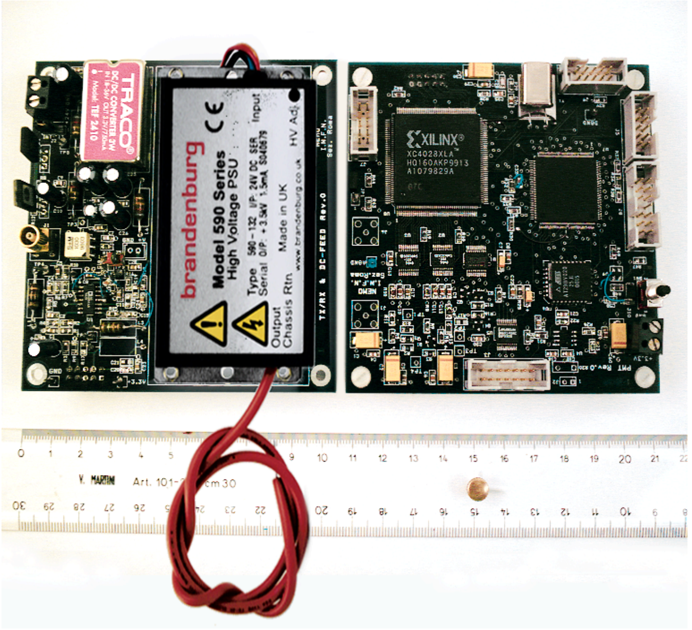
NEMO phase1 - Optical Module electronics

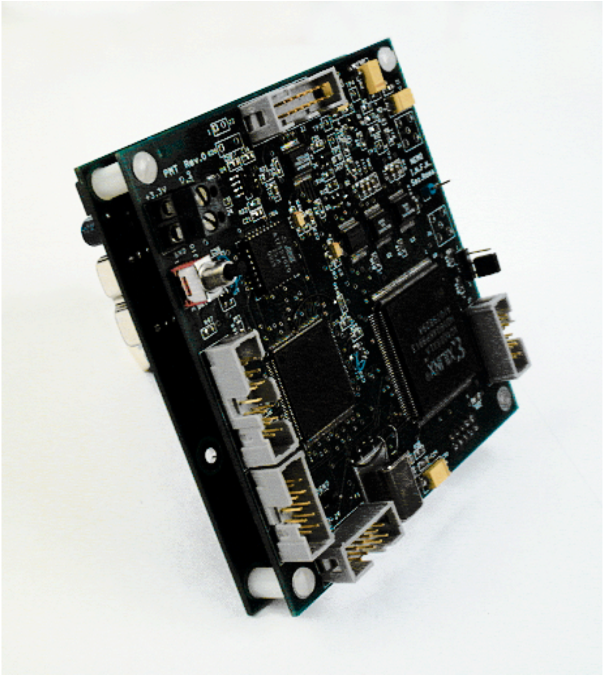


Data Acquisition:
- **200Msample/s**
- **8bit** (logarithmic compression)
- User programmable **digital threshold** level

On-board sensors:
- Temperature
- Humidity

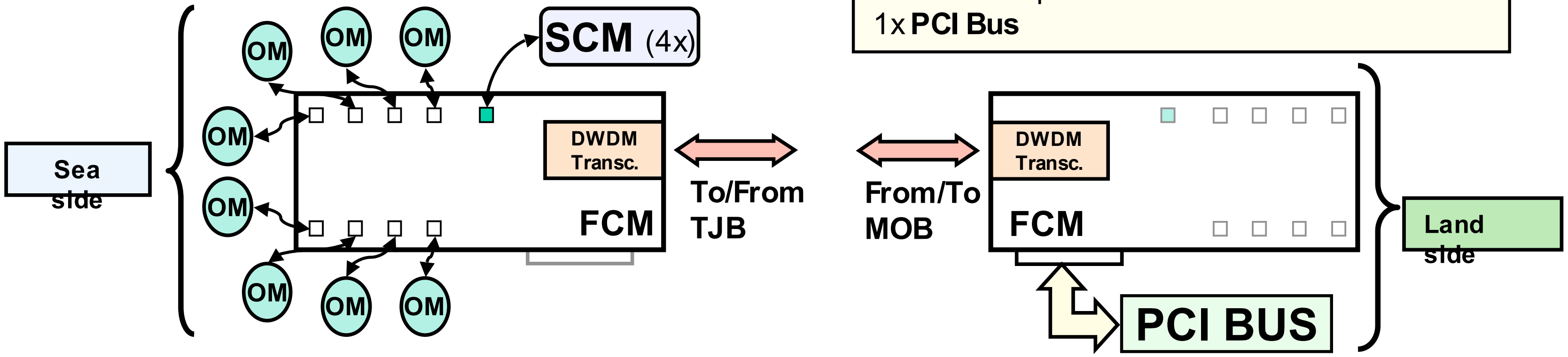


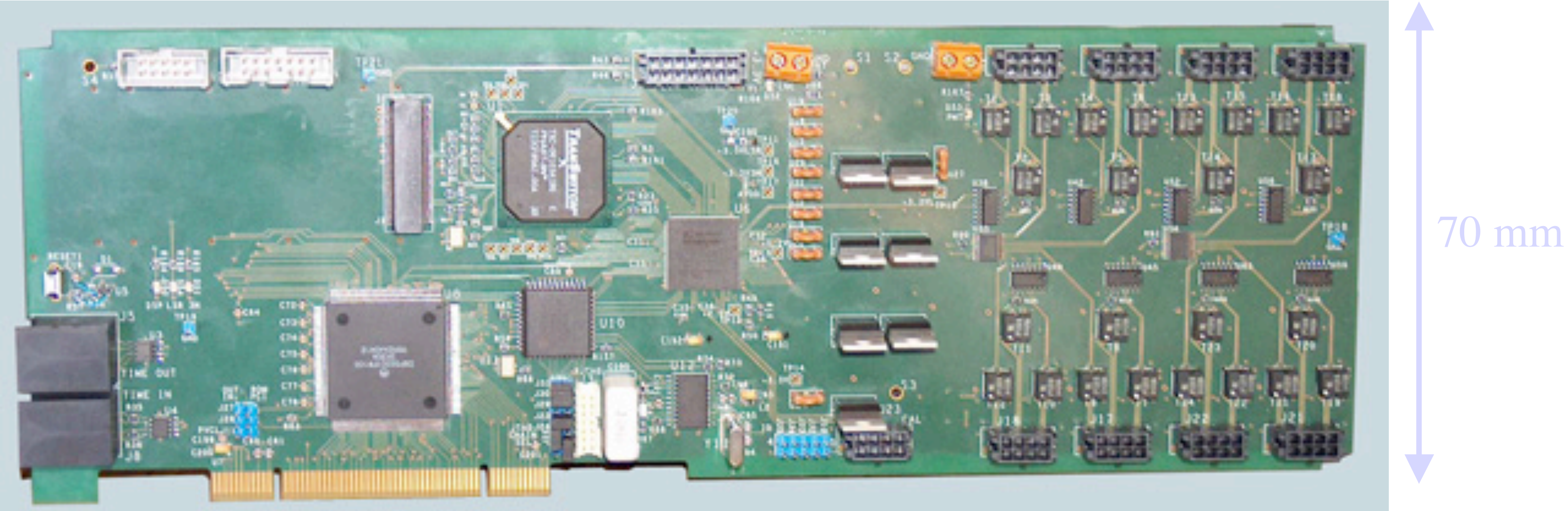




NEMO phase1 - Floor electronics

MAIN INTERFACES
8x **O**ptical **M**odule (LVDS)
4x **S**low **C**ontrol **M**odule (SPI bus)
1x **DWDM** Optical Transceiver
1x **PCI Bus**



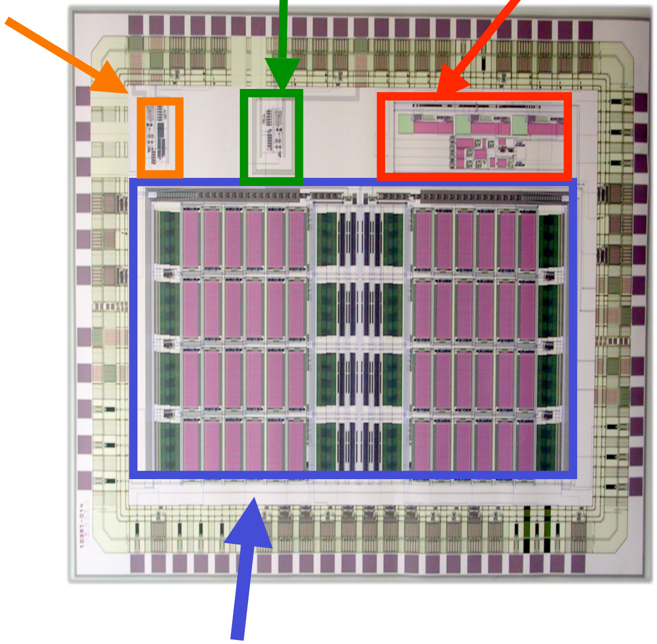


km^3 technological challenges: low power electronics

New full custom VLSI ASIC presently under laboratory test It will be tested in some OM in NEMO phase1

- trigger level remote controlled
- max Power dissipation <200 mW
- sampling frequency: 200MHz
- input dynamic range 10 bit
- dead time < 0.1%
- time resolution < 1 ns

Power Budget:
ANTARES 900 PMTs: 16kW over 40km
NEMO 5000 PMTs: 30kW over 100km



PLL Stand Alone 200 MHz Slave Clock Generator

LIRA's PLL Shielded

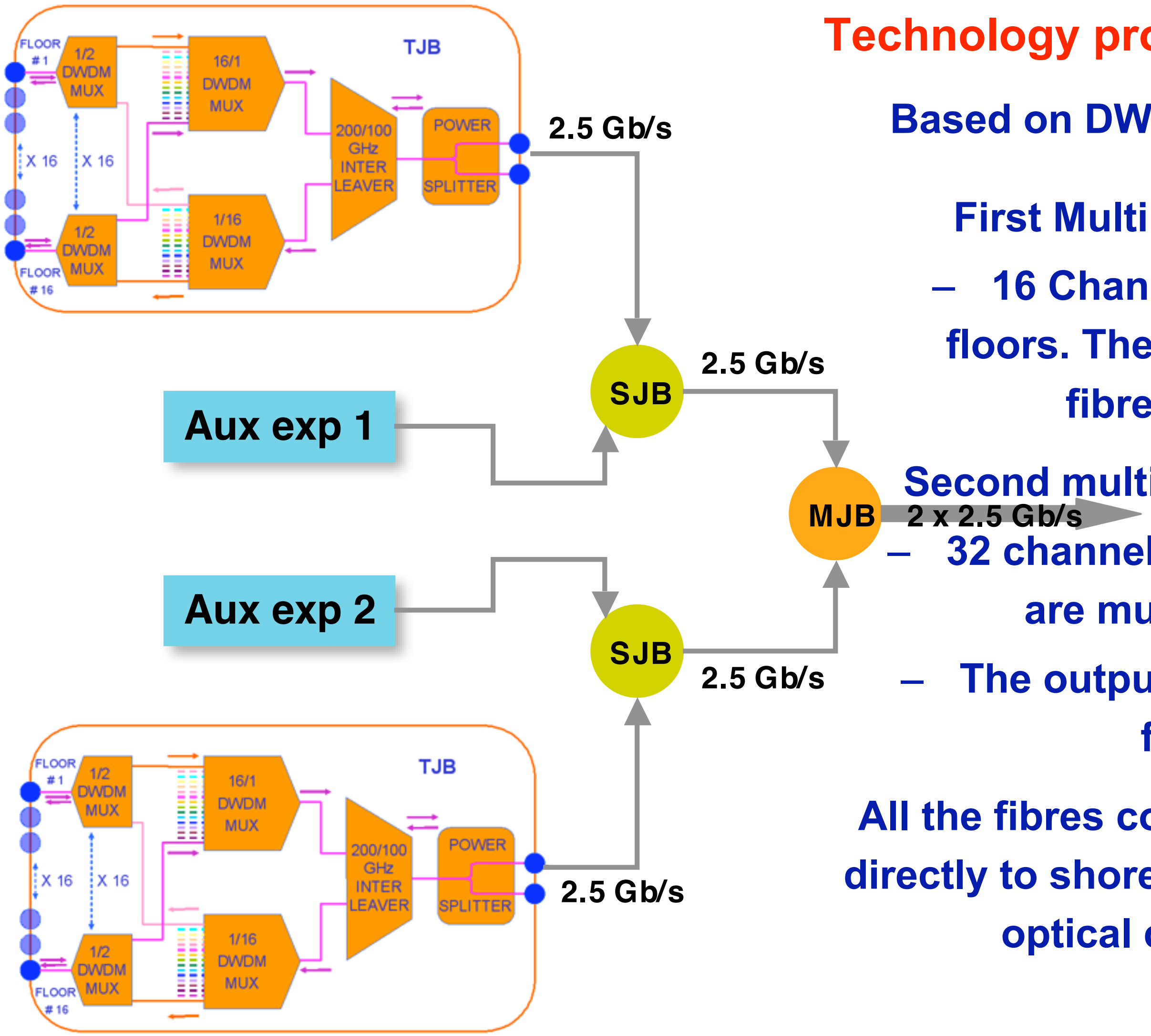
Trigger

LIRAX2 200 MHz Write 10 MHz Read

NEMO phase1 - Data transmission system

Mostly passive components

Very low power consumption



Technology provided by telecomunications

Based on DWDM and Interleaver techniques

First Multiplation Stage (Tower base):

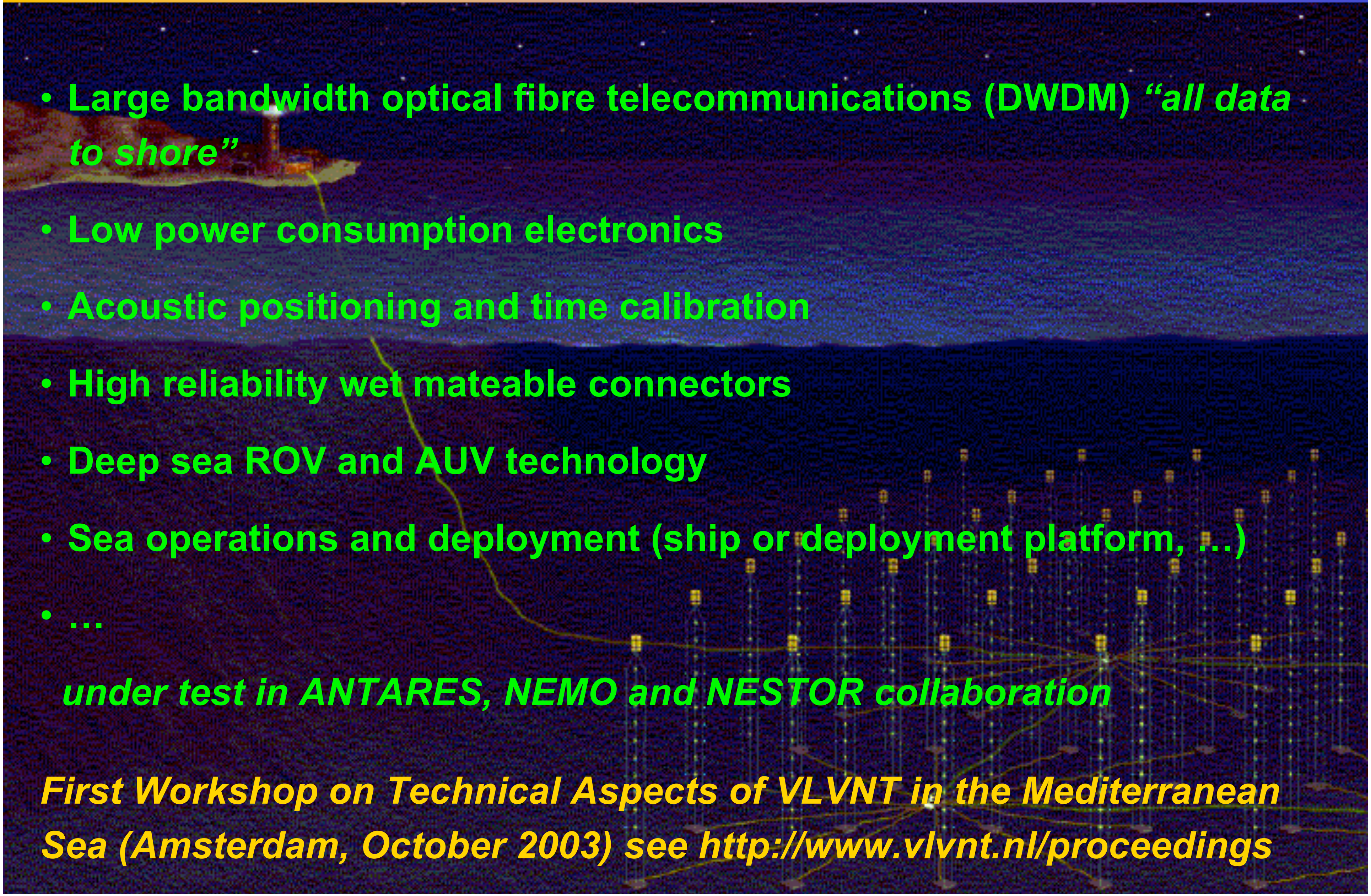
- 16 Channels coming from the 16 tower floors. The channels are multiplexed in one fibre at the base of each tower.

Second multiplation stage (secondary JB):

- 32 channels coming from a couple of tower are multiplexed with an interleaver;
- The output is a single fibre for each of the four couples of towers.

All the fibres coming from the secondary JB go directly to shore (connection to the main electro-optical cable inside the main JB)

HOW? - Mediterranean km^3: technological challenges



- Large bandwidth optical fibre telecommunications (DWDM) *"all data to shore"*
- Low power consumption electronics
- Acoustic positioning and time calibration
- High reliability wet mateable connectors
- Deep sea ROV and AUV technology
- Sea operations and deployment (ship or deployment platform, …)
- …

under test in ANTARES, NEMO and NESTOR collaboration

First Workshop on Technical Aspects of VLVNT in the Mediterranean Sea (Amsterdam, October 2003) see http://www.vlvnt.nl/proceedings

EU FP6 Design Study: KM3NET

The experience and know how of the three collaborations (ANTARES, NEMO and NESTOR) is merging in the KM3-NET activity

- Collaboration of 8 Countries, 34 Institutions
- Aim to design a deep-sea km^3-scale observatory for high energy neutrino astronomy and an associated platform for deep-sea science
- Request for funding for 3 years => TDR

WORK PACKAGES

- Astroparticle Physics
- Physics Analysis
- System and Product Engineering
- Information Technology
- Shore and deep-sea structure
- Sea surface infrastructure
- Risk Assessment Quality Assurance
- Resource Exploration
- Associated Science

A Technical Design Report (including site selection) for a Cubic kilometre Detector in the Mediterranean

Conclusions and perspectives

The forthcoming km^3 neutrino telescopes are “discovery” detectors with high potential to solve HE astrophysics basic questions:

UHECR sources
HE hadronic mechanisms
Dark matter
...

The underice km^3 ICECUBE is under way, following the AMANDA experience

The Mediterranean km^3 neutrino telescope, when optimized, will be an powerful astronomical observatory thanks to its excellent angular resolution

Conclusions and perspectives

The feasibility of an underwater km^3 detector at depth ≈ 3500 m is widely accepted also thanks to recent break-through in submarine technology

NEMO Phase 1 (realization 2004-2006) will validate key technologies for the underwater km^3

A proposal for a 3 year design study of the km^3 has been submitted to EU under the KM3-NeT => TDR including site selection