The NEMO Project

Neutrino Mediterranean Observatory

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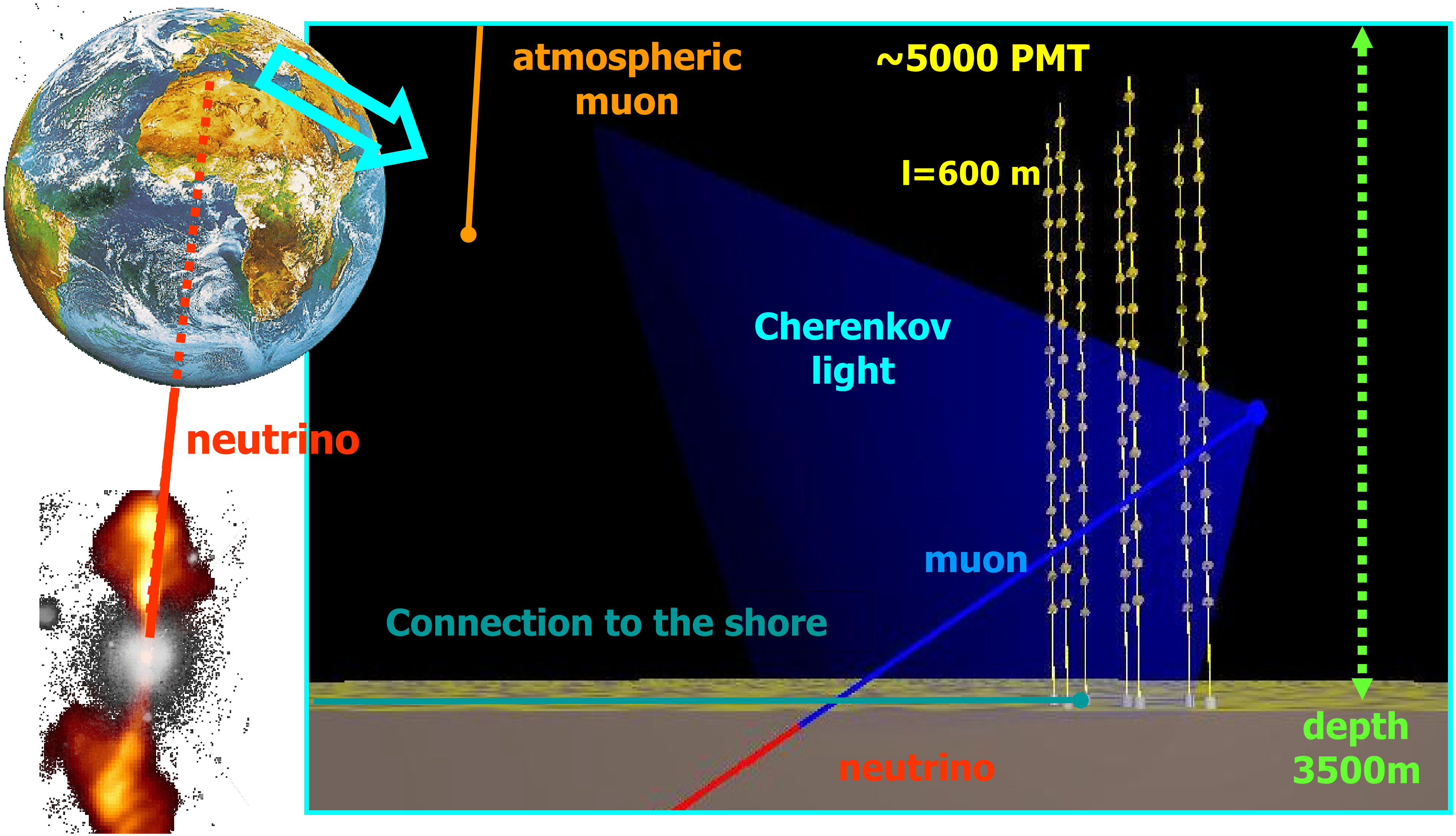
CRIS 2004
Catania, may 31 - june 4 2004

Neutrino telescopes: the physics case

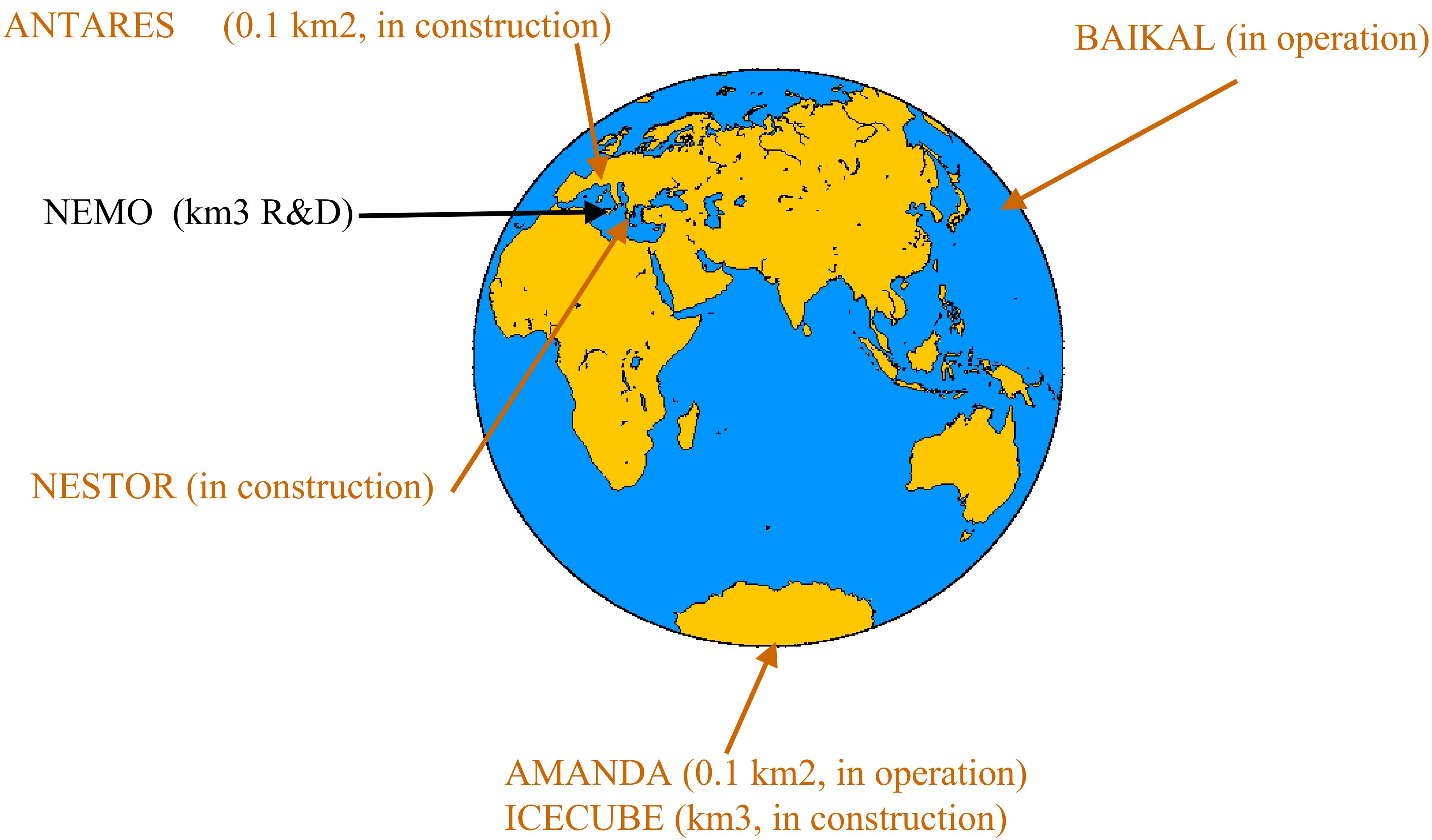
- Astrophysical sources of neutrinos
  - Galactic (Supernova Remnants, MicroQuasars, interaction of cosmic rays with interstellar medium)
  - Extragalactic (Active Galactic Nuclei, Gamma Ray Bursts)
  - Unknown objects
- Origin of cosmic rays
- Indirect search for dark matter
- Deep sea sciences
  - Monitoring of oceanographic parameters
  - Biology

Principles of neutrino astronomy

Flux estimate ➨ need km3 scale detectors



Underwater neutrino telescope projects



Towards the km3 detector

- **R&D phase (1999 - 2002)**
  - ***Site selection and characterization***
    Several sites close to the italian coasts have been studied. A site close to Capo Passero (Sicily) at 3500 m with optimal water characteristics has been identified for the installation
  - ***R&D activities***
    Development of specific ASICS for the underwater front end electronics
    Large area hybrid photomultipliers
  - ***Feasibility study of the km3 detector***
    A complete feasibility study has examined all the detector critical components and the deployment procedures
    A preliminary project for the km3 has been developed
- **Phase 1: Advanced R&D and prototyping (2002 - 2006)**
  - ***Realization of a detector subsystem including all critical components***
    The system under realization at the Underwater Test Site of the LNS at 2000 m
- **Km3 detector realization (2007 ? - …)**

The NEMO Collaboration

INFN

Bari, Bologna, Cagliari, Catania, Genova, LNF, LNS, Messina, 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:

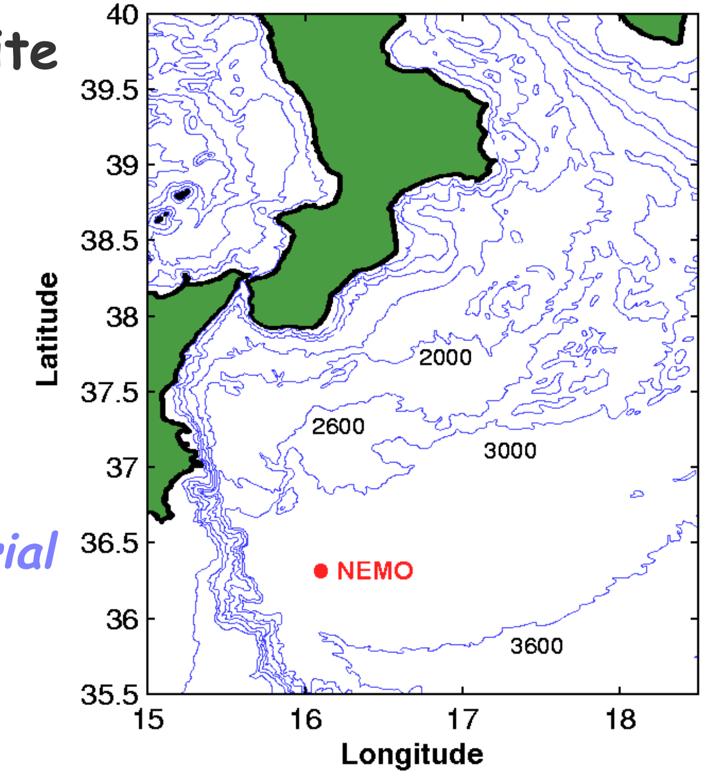
Bari, Bologna, Cagliari, Catania, Genova, Messina, Roma *"La Sapienza"*

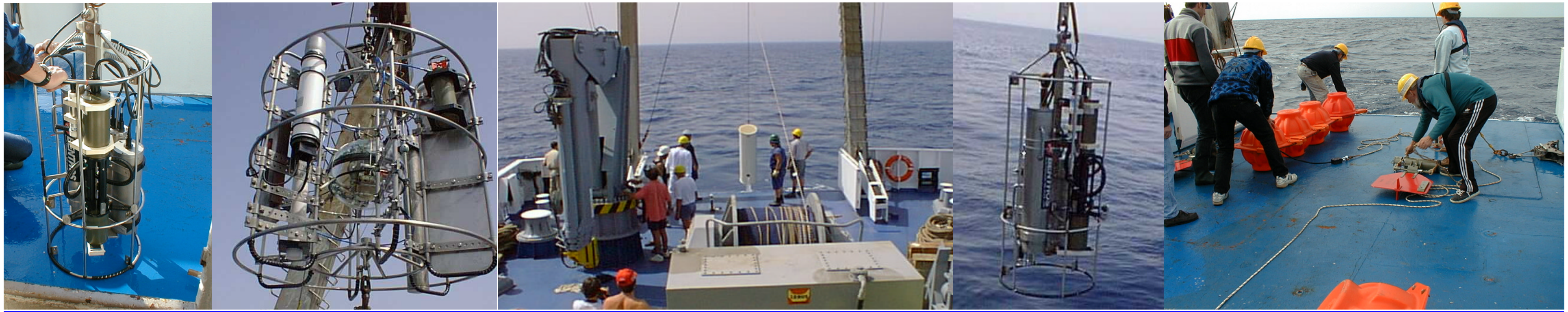
Site selection criteria

- **Depth**
  Reduction of atmospheric muon flux
- **Water optical transparency**
  Optimisation of detector performances (efficiency and angular resolution)
- **Weak and stable deep sea currents**
  Reduce stresses on mechanical structures
  Reduce stimulation of bioluminescent organisms
- **Low biological activity**
  Low optical background (bioluminescence) ⇒ detector performances
  Low biofouling and sedimentation on OM
- **Distance from the shelf break and from canyons**
  Installation safety
- **Proximity to the coast and to existing infrastructures**
  Easy access for sea operations
  Reduction of costs for installation and maintenance

Site exploration activities

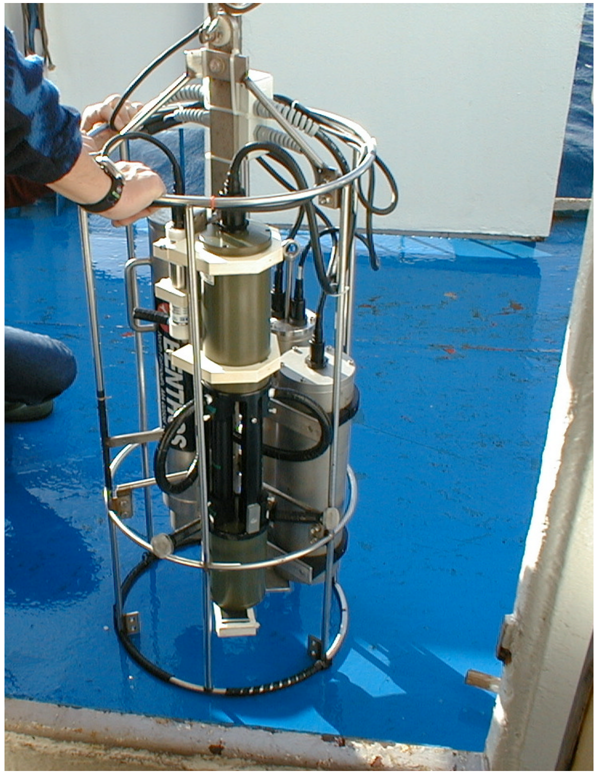
- Since 1998 continuous monitoring of a site close (≈80 km) to the coast of Sicily (Capo Passero)
- More than 20 sea campaigns on the site to measure
  - *water optical properties*
  - *optical background*
  - *deep sea currents*
  - *nature and quantity of sedimenting material*

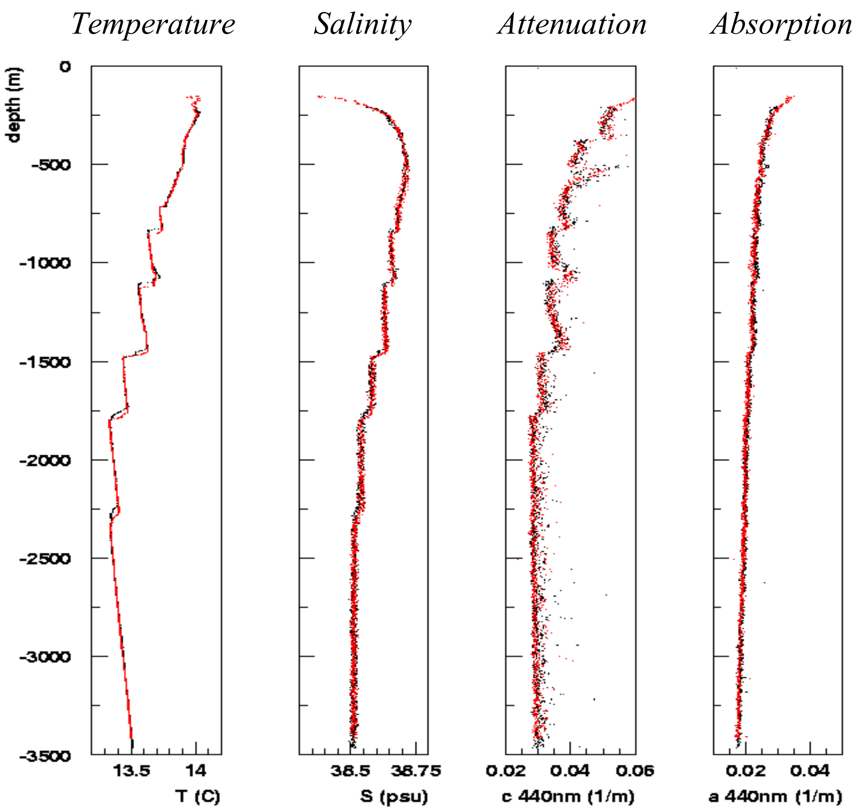




Water optical properties

Measure of profiles of water optical properties





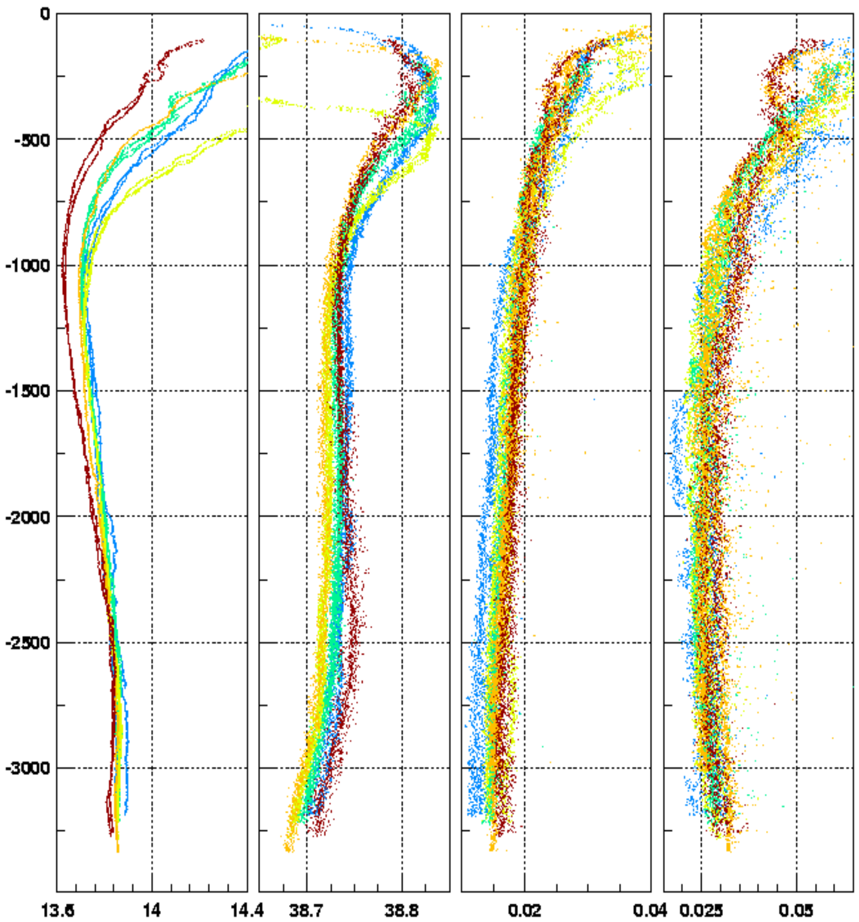
Data taken in the South Thyrrenian Sea (Alicudi)

Strong layering of waters

The setup used (AC9+CTD) measures oceanographical (temperature, salinity, pressure) and optical (absorption and attenuation coefficients at 9 wavelengths) parameters along the whole water column

Water optical properties

Seasonal dependence of optical parameters in Capo Passero



Seasonal dependence of oceanographical (Temperature and Salinity) and optical (absorption and attenuation) properties has been studied

Variations are only observed in shallow water layers

Data taken in:

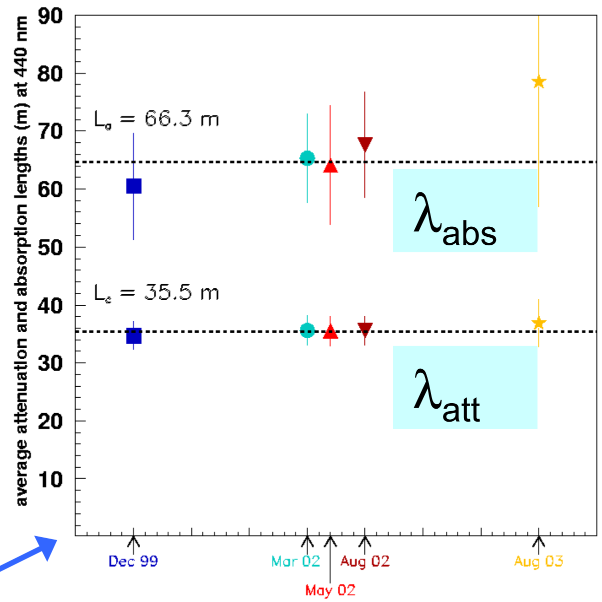
Aug 03 (2)

Aug 02 (3)

Mar 02 (4)

May 02 (2)

Dec 99 (2)

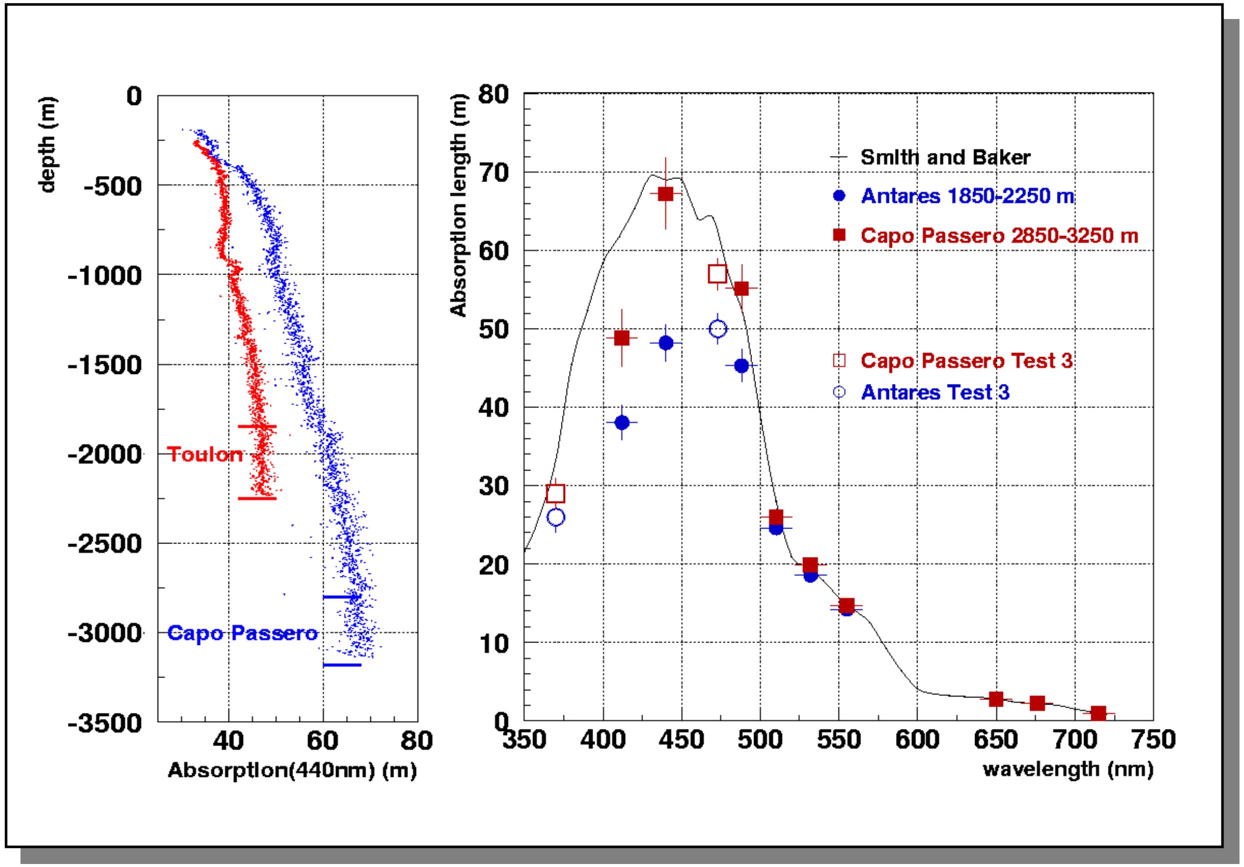


Average values 2850÷3250 m

Water optical properties

Comparison of NEMO and Antares data

Optical water properties have been mesured in the summer 2002 in Capo Passero and Toulon in two joint NEMO-ANTARES campaigns



Absorption lengths measured in Capo Passero are compatible with optically pure sea water data

Large differences between Toulon and Capo Passero are observed in the blue region

Values measured with the Antares Test 3' setup are in good agreement with the AC9 data

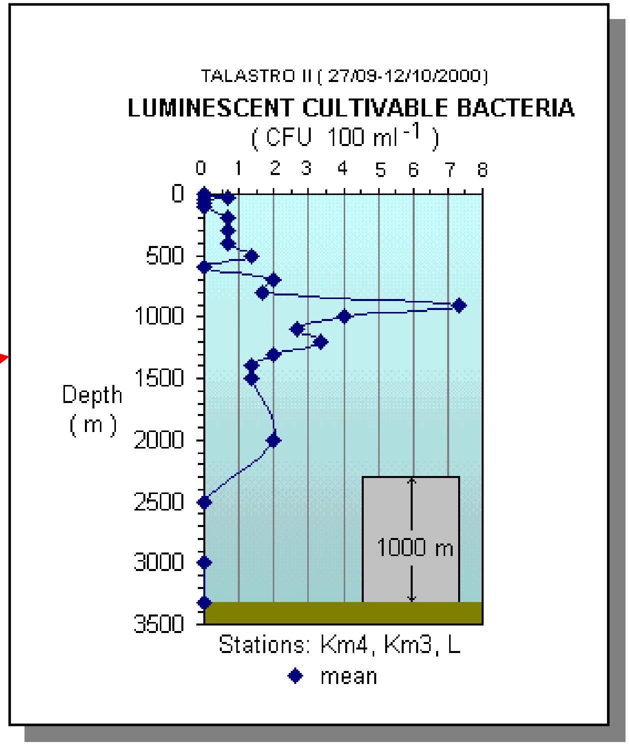
Optical background

Sources of optical background

- Decay of radioactive elements (mainly ^{40}K) → stable frequency noise (≈30 kHz on a 8" PMT at 0.3 p.e. threshold)
- Light produced by biological entities (bioluminescence) → random bursts with very high counting rate

No luminescent bacteria have been observed in Capo Passero below 2500 m

Data taken by Istituto Sperimentale Talassografico, CNR, Messina

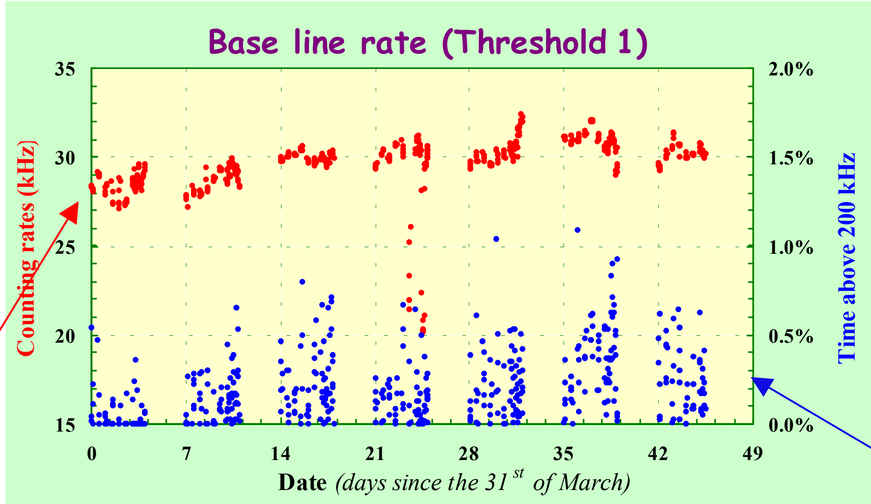


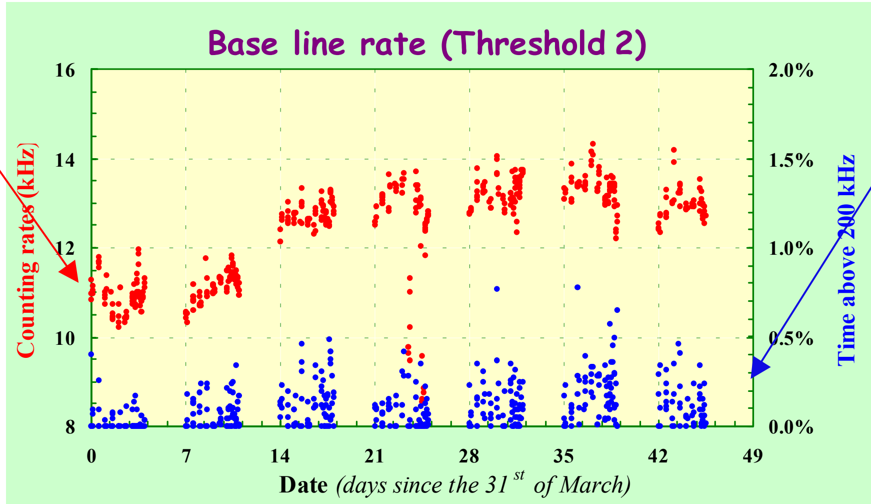
Optical background

Long period measurements in Capo Passero

Baseline rate

- 28÷31 kHz
- 11÷13.5 kHz





Burst fraction

- 0.2 %
- 0.1 %

Data taken in spring 2003 with the Antares setup

The Capo Passero site

Site optical and oceanographical characteristics

- Absorption lengths (~70 m @440 nm) are compatible with optically pure sea water values
- Measured values are stable troughout the years *(important: variations on La and Lc will directly reflect in changes of the detector effective area)*
- Optical background is low (consistent with ^{40}K background with only rare occurrences of bioluminescence bursts)
- 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)

Feasibility study for the km3 detector

Aim: *demonstrate that an underwater Cherenkov detector with effective area of more than 1 km^2 is technically feasible and can be constructed with a "reasonable" budget*

Aspects that have been analysed in detail

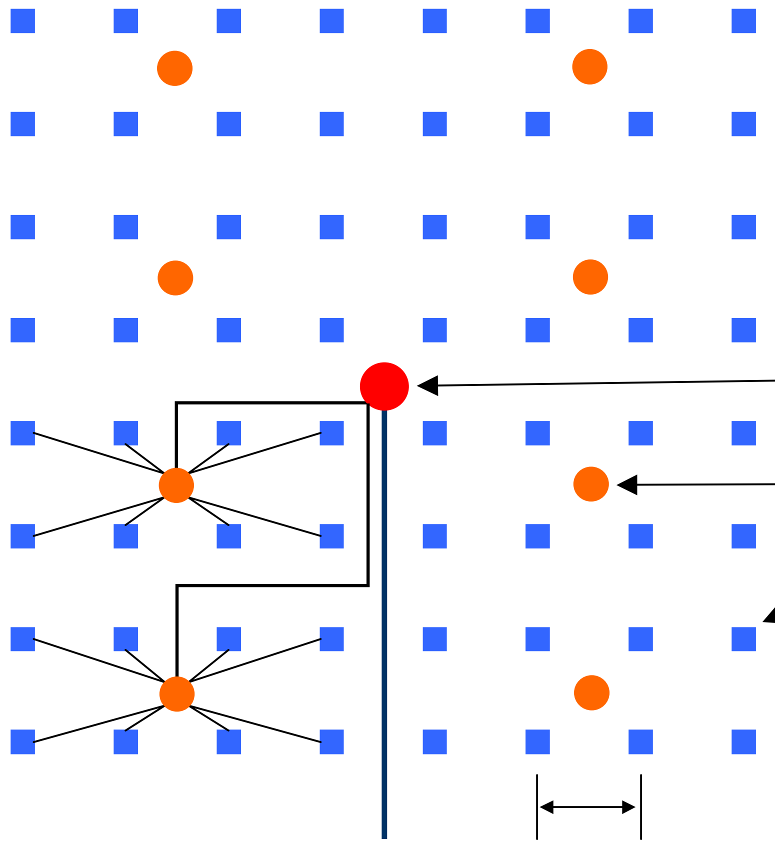
- Mechanical structures
- Power distribution
- Front end electronics
- Data transmission to shore
- Cable network (submarine cables and connectors)
- Deployment of the structures and cables

The study shows that a km3 detector is presently technologically feasible

Preliminary project for a km^3 detector

Schematic detector layout

Reference layout used for the feasibility study

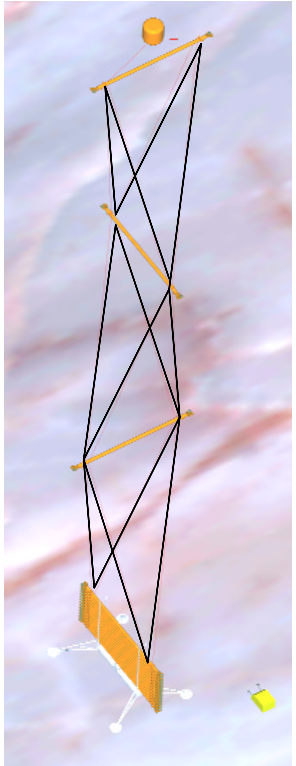


Detector architecture

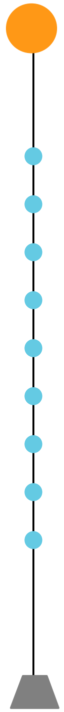
- *Reduce number of structures to reduce connections and allow underwater operations with a ROV ⇒ non homogeneous sensor distribution*
- *Modularity*

Total instrumented volume ≈1 km^3

Comparison of different km3 architectures



Simulations have been performed with the ANTARES simulation package



Tower architecture (5832 OM)

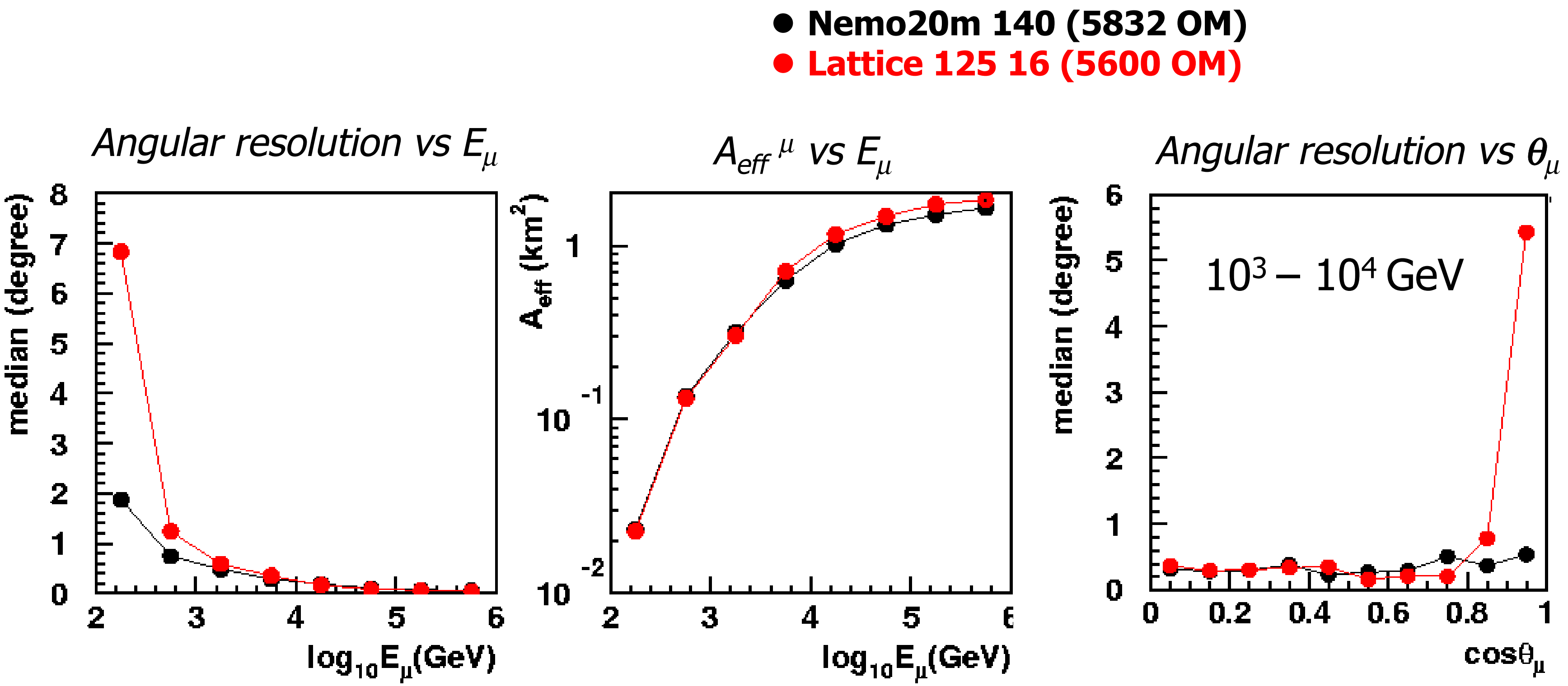
18 storey towers with 4 OM per storey
20 m storey length
40 m spacing between storeys
81 towers arranged in a 9x9 square lattice
140 m spacing between towers
≈ 0.9 km3 instrumented volume

Lattice architecture (5600 OM)

Strings with 58 downlooking OM spaced by 16 m
100 strings arranged in a 10x10 lattice
125 m spacing between string
≈ 1.2 km3 instrumented volume

Comparison of string and tower geometries

- ✓ Up-going muons with E^{-1} spectrum
- ✓ 60 kHz background
- ✓ Reconstruction + Quality Cuts



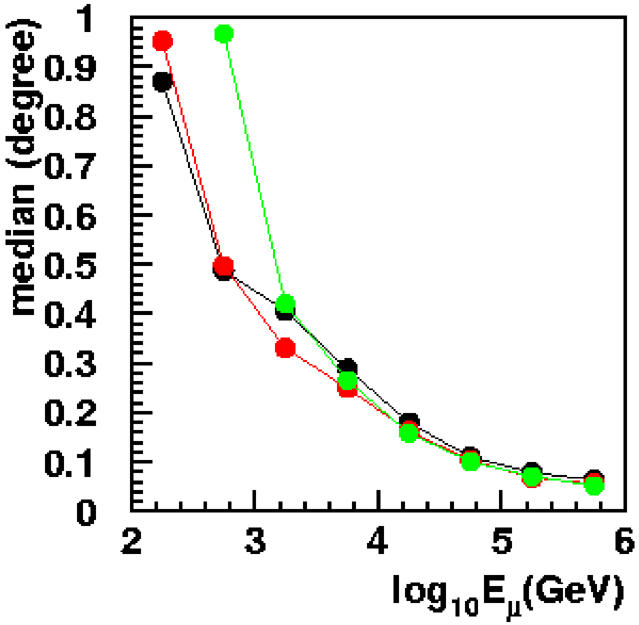
Comparison of different background rates

- ✓ Up-going muons with E^{-1} spectrum
- ✓ Tower architecture (5832 OM)
- ✓ Reconstruction + Quality Cuts

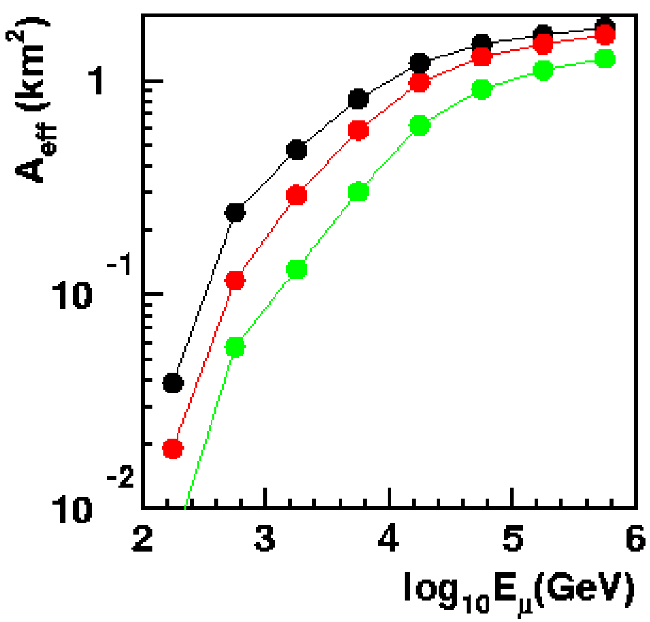
Optical background rate

- ● 20 kHz
- ● 60 kHz
- ● 120 kHz

Angular resolution vs E_μ



$A_{eff}{}^{\mu}$ vs E_μ



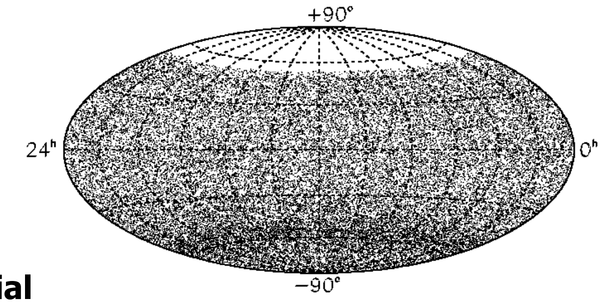
Sensitivity to point like sources

- Simulation of the km3 response to high energy neutrino fluxes from microquasars
- Simulation of background
  - *Atmospheric muon background*
  - *Atmospheric neutrino background*
- Background rejection
- Detector angular resolution

Atmospheric muon background rejection

No QC

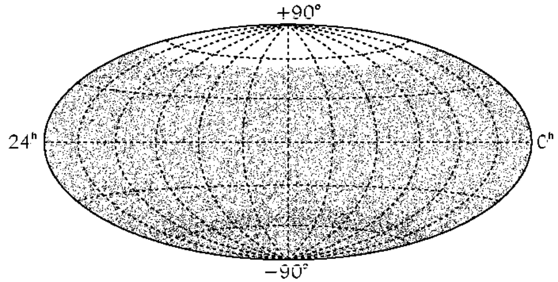
N_{μ}=41117



Misreconstructed muons in equatorial coordinates

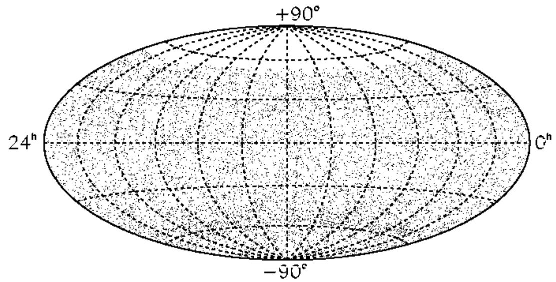
QC> −10

N_{μ}=20761



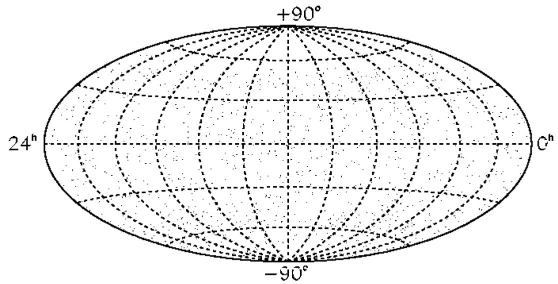
QC> −9

N_{μ}=11011



QC> −8

N_{μ}=1374



$1.8 \cdot 10^{7}$ downgoing muons simulated (Okada parameterization)

$1.1 \cdot 10^{6}$ reconstructed (using Antares code)

Rejection with quality cuts

The value of the logarithm of the likelihood function, at the fitted maximum, divided by the number of degrees of freedom:

$$QC = \log(L)/NDOF$$

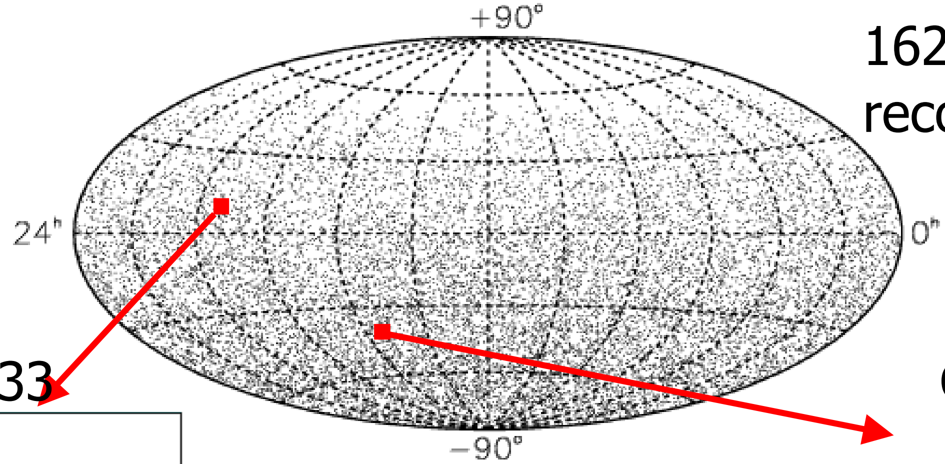
is used as a *goodness of fit criterion*.

Selection cuts increase the angular resolution but decrease effective area.

Sensitivity to point-like sources

Source and atmospheric neutrino background

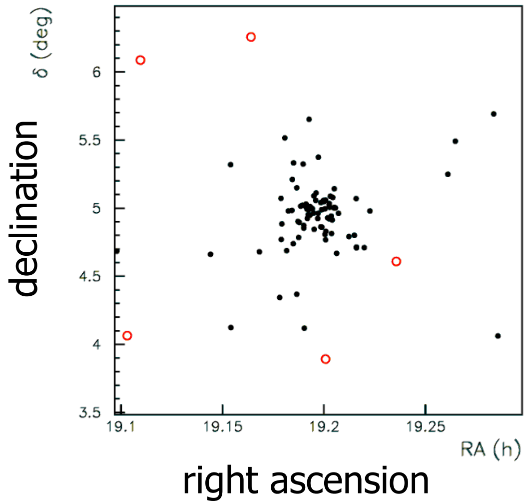
Equatorial coordinates



16204 atm. ν_μ events reconstructed in 1 year

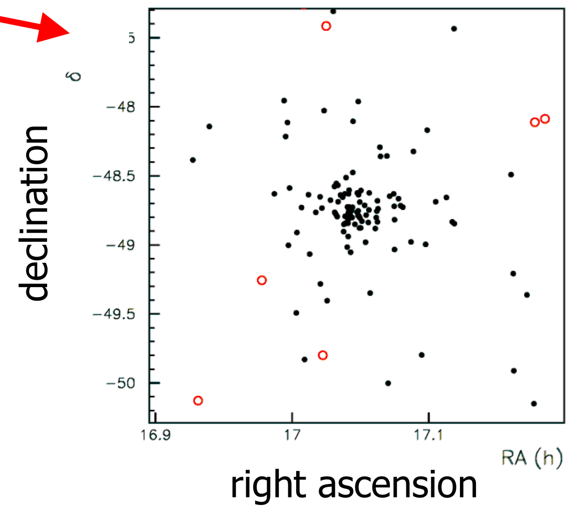
Simulated spectrum from Learned & Mannaheim, 2000

SS433



Simulated microquasars spectrum from Distefano et al., 2002

GX339-4



in the 3°x3° bin= 84+5

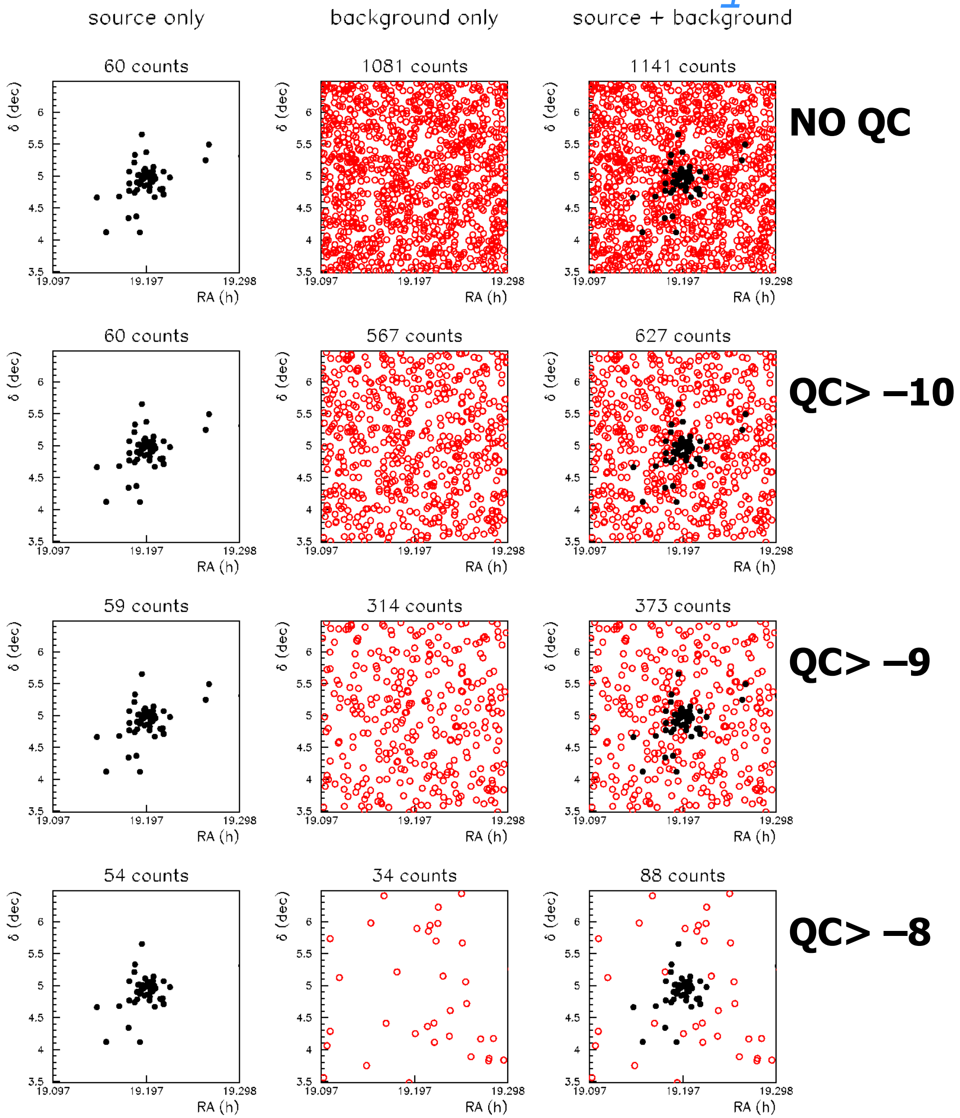
circular (r=1°) bin= 79+1

in the 3°x3° bin= 106+6

circular (r=1°) bin= 97+0

Sensitivity to point-like sources

The case of the SS433 microquasar



250 days time integration

counts 1° radius circular bin around the source

source	bkg	source+bkg	cut level
58	354	412	NO QC
58	195	253	QC –10
57	115	172	QC –9
53	15	68	QC –8

At QC > -8:

$$\frac{source}{\sqrt{source + bkg}} = \frac{53}{\sqrt{68}} = 6.4$$

Background is the sum of atmospheric μ and ν

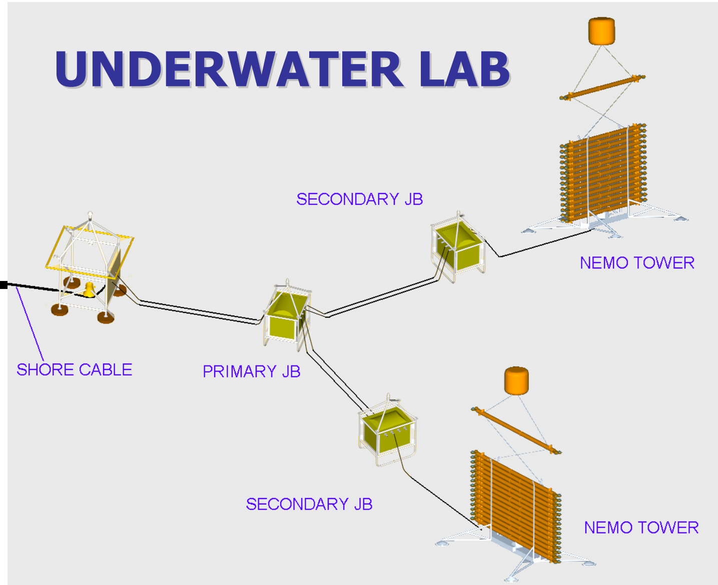
The NEMO Phase 1 project

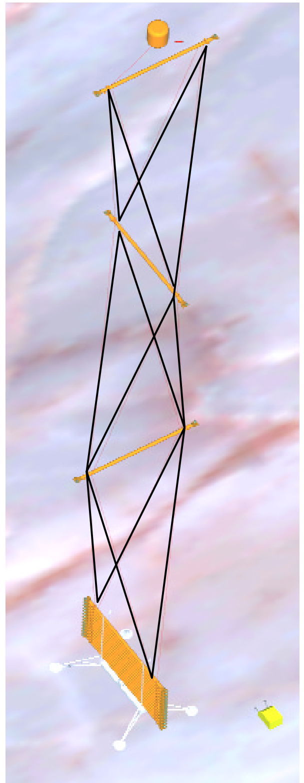
A step towards the km3 detector

Realization of a detector subsystem
including all critical components

EO CABLE

Length – 25 km
10 Optical Fibres ITU- T G-652
6 Electrical Conductors Φ 4 mm^2



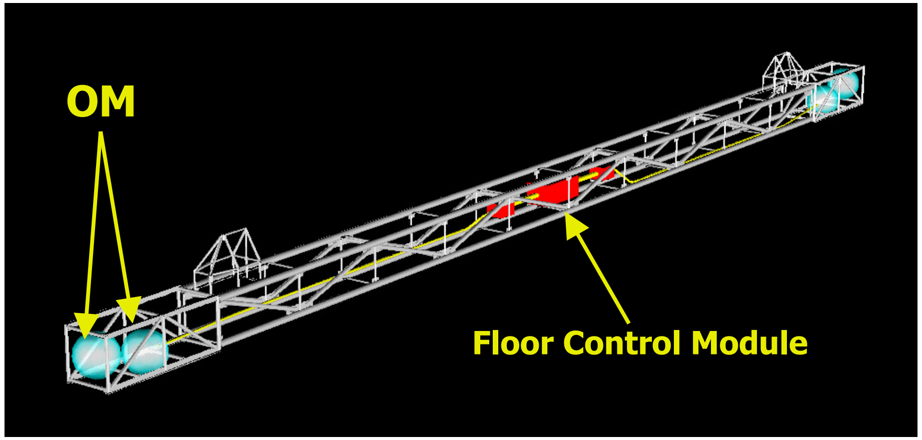


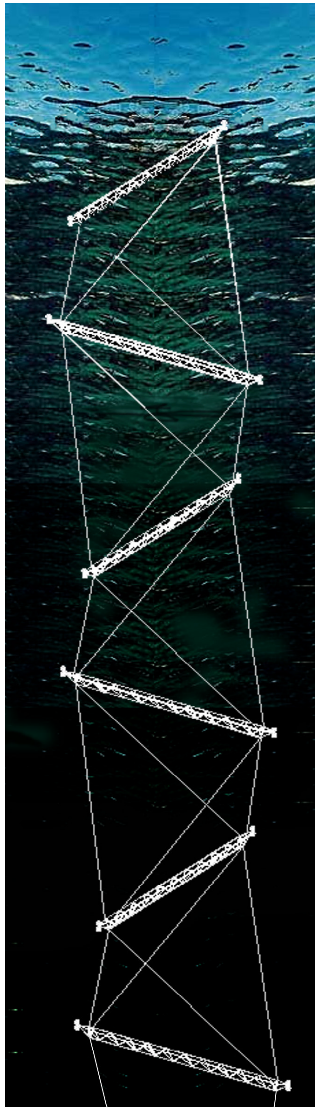
Project jointly funded by INFN and MIUR
Completion foreseen in 2006

The NEMO tower

"Tower" structure

Semi rigid structure
Tensioning and electro-optical cables are kept separated
The structure can be packed for transportation and deployment



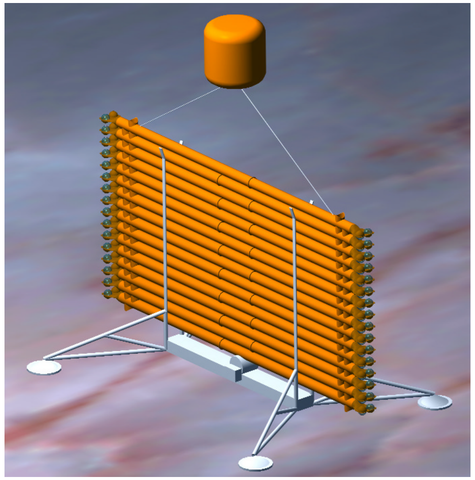


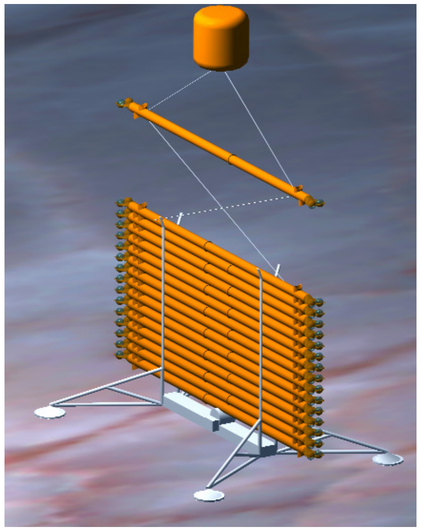
16 storeys spaced by 40 m
4 OM per storey
64 OM per tower
600 m active length

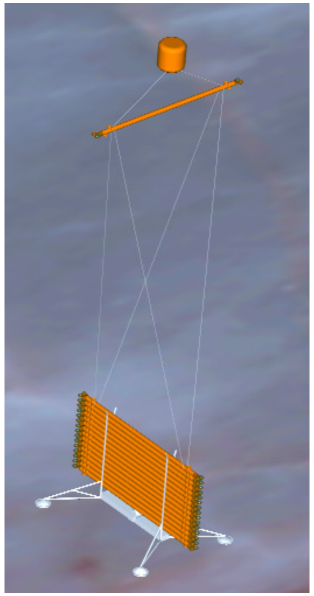
The NEMO tower

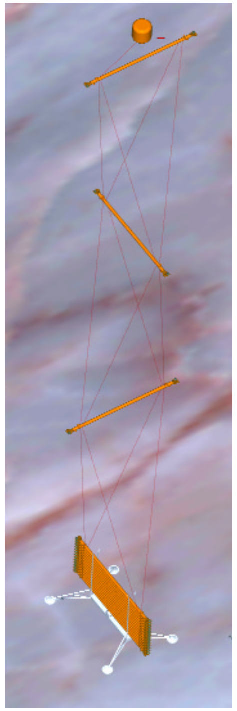
Deployment of the tower

Tested in shallow waters with a 1:5 scale model of the tower





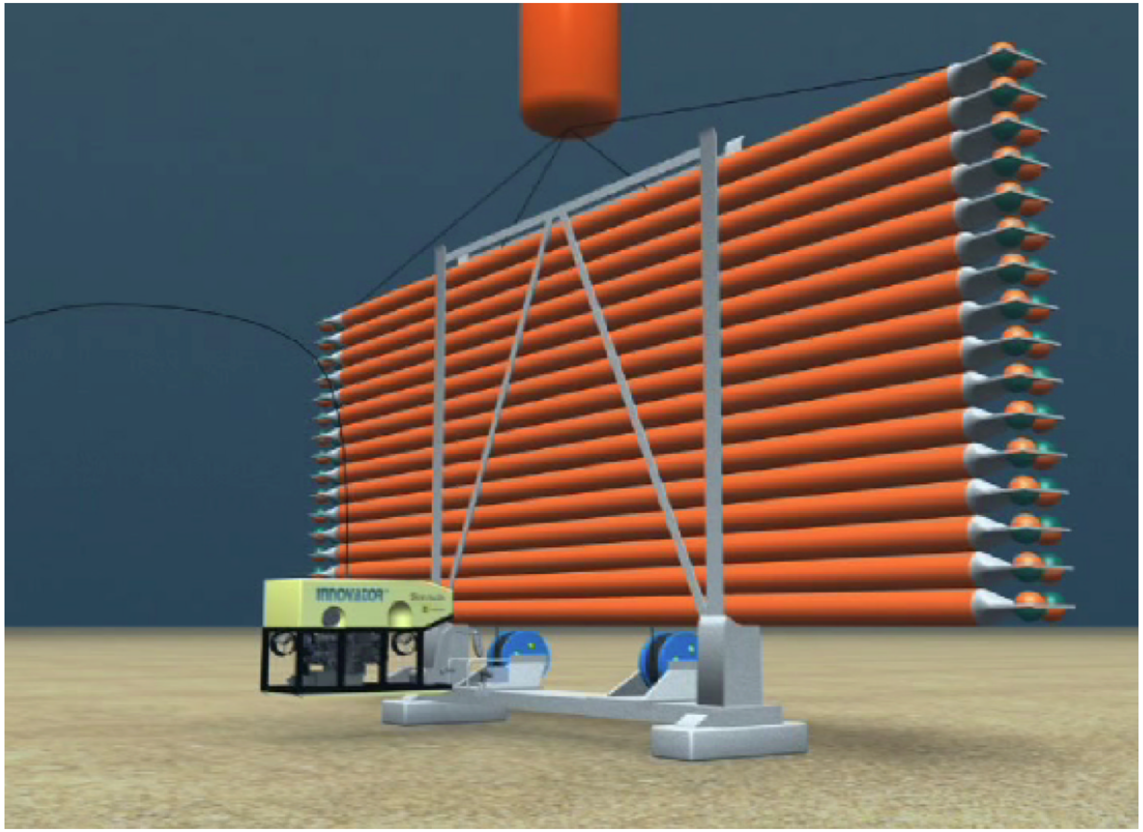




Deployment and submarine operations

Deployment will be performed by double positioning surface vessels

Unfurling of the tower and connections will be performed by means of submarine Remoted Operated Vehicles (ROV)

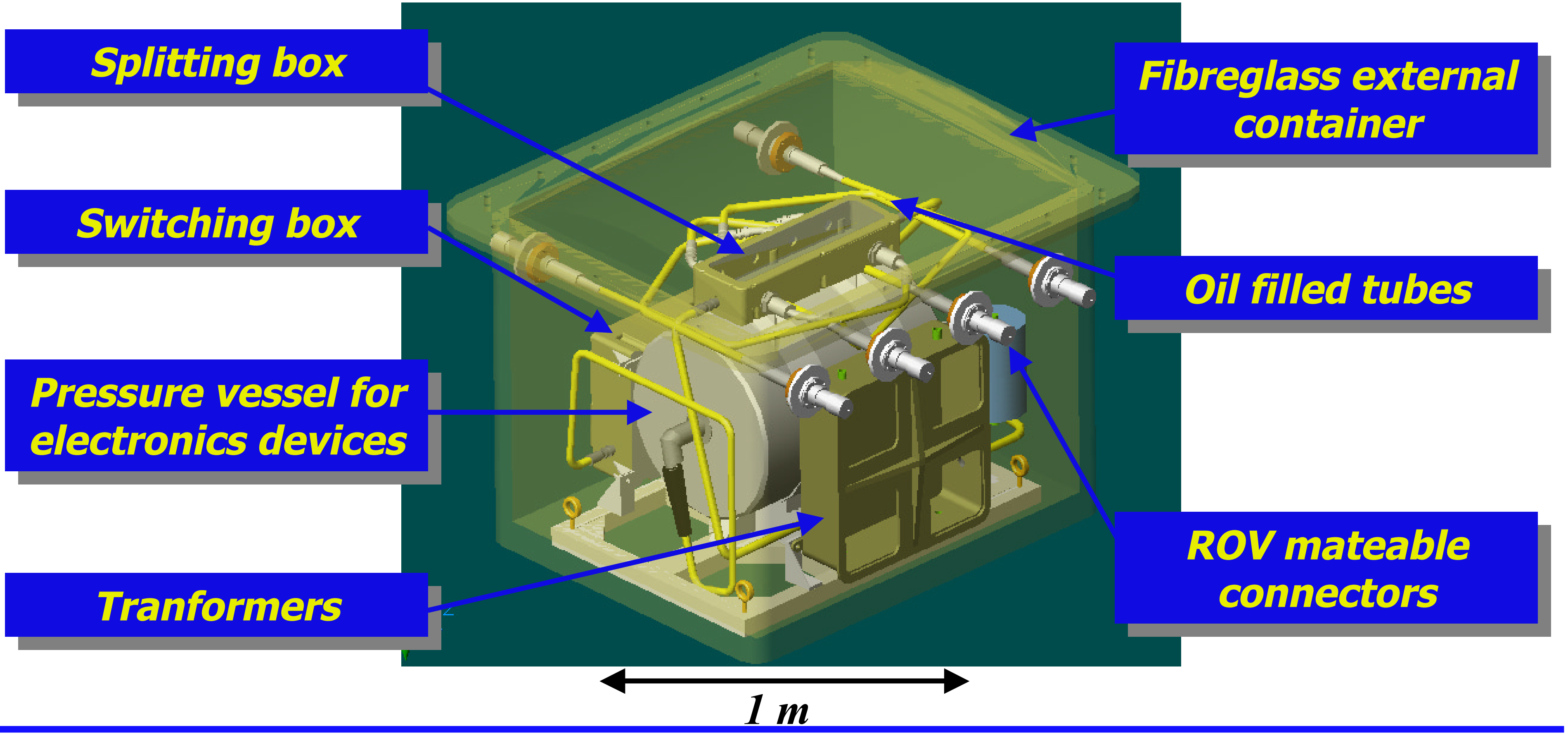


Junction Boxes

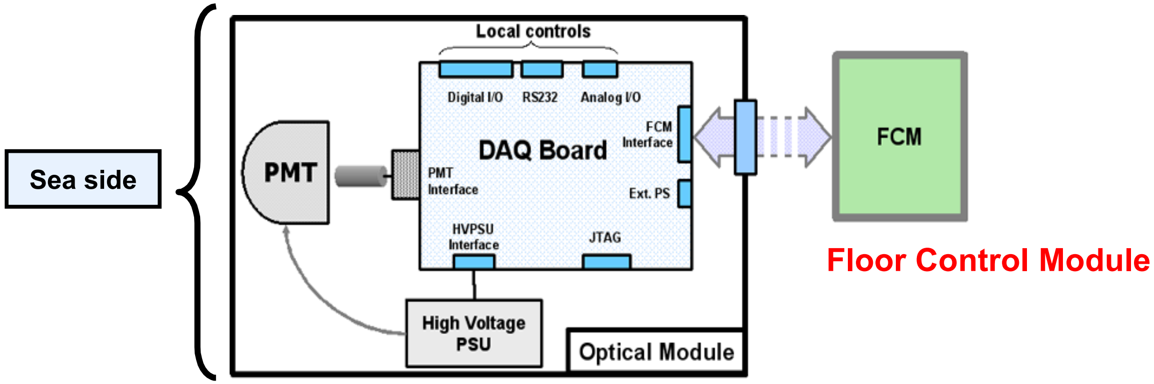
Alternative design to the Titanium container (Antares-like)

Aim

Decouple the two problems of pressure and corrosion resistance

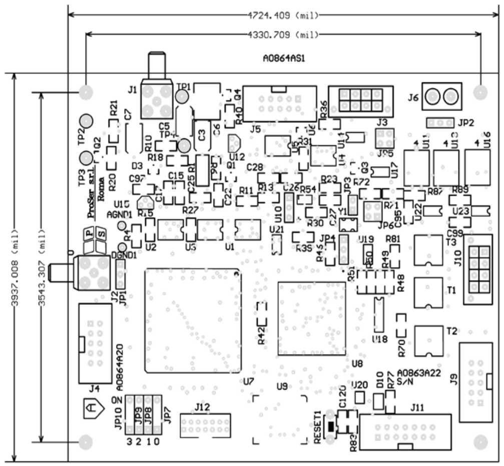


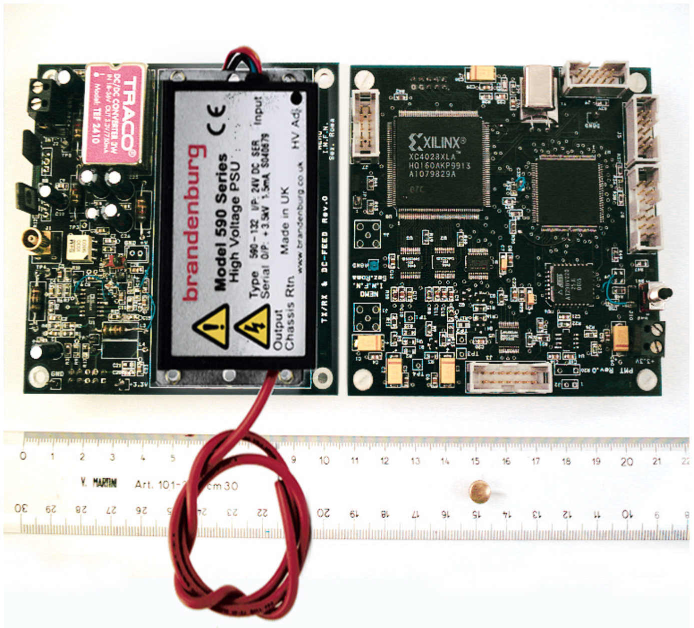
Optical module electronics

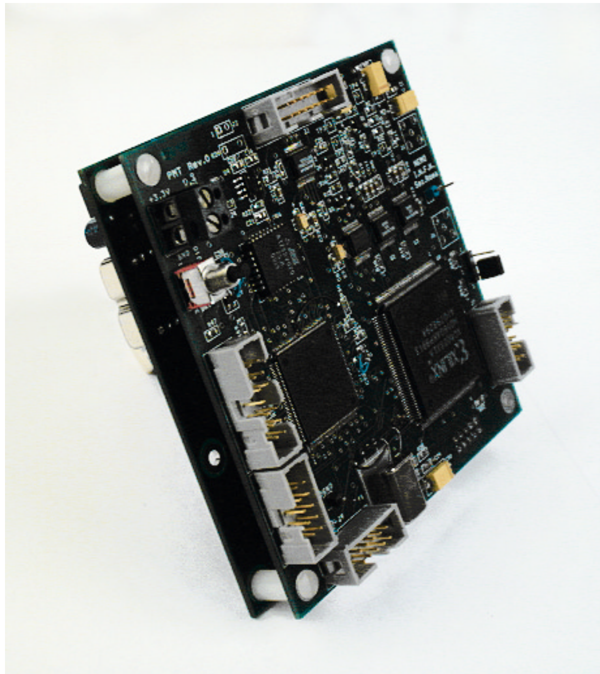


Data Acquisition:
- **200Msample/s**
- **8bit** (logarithmic compression)
- User programmable **digital threshold** level

On-board sensors:
- Temperature
- Humidity







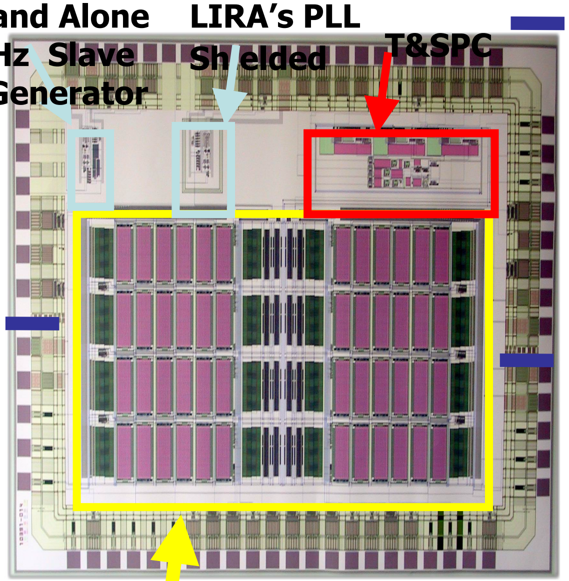
New low power electronics for the OM

- Sampl .Freq.: 200MHz
- Trigger level remote controlled;
- Max Power dissipation less than 200 mW
- Input dynamic range 10 bit
- Dead time < 0.1%.
- Time resolution < 1 ns

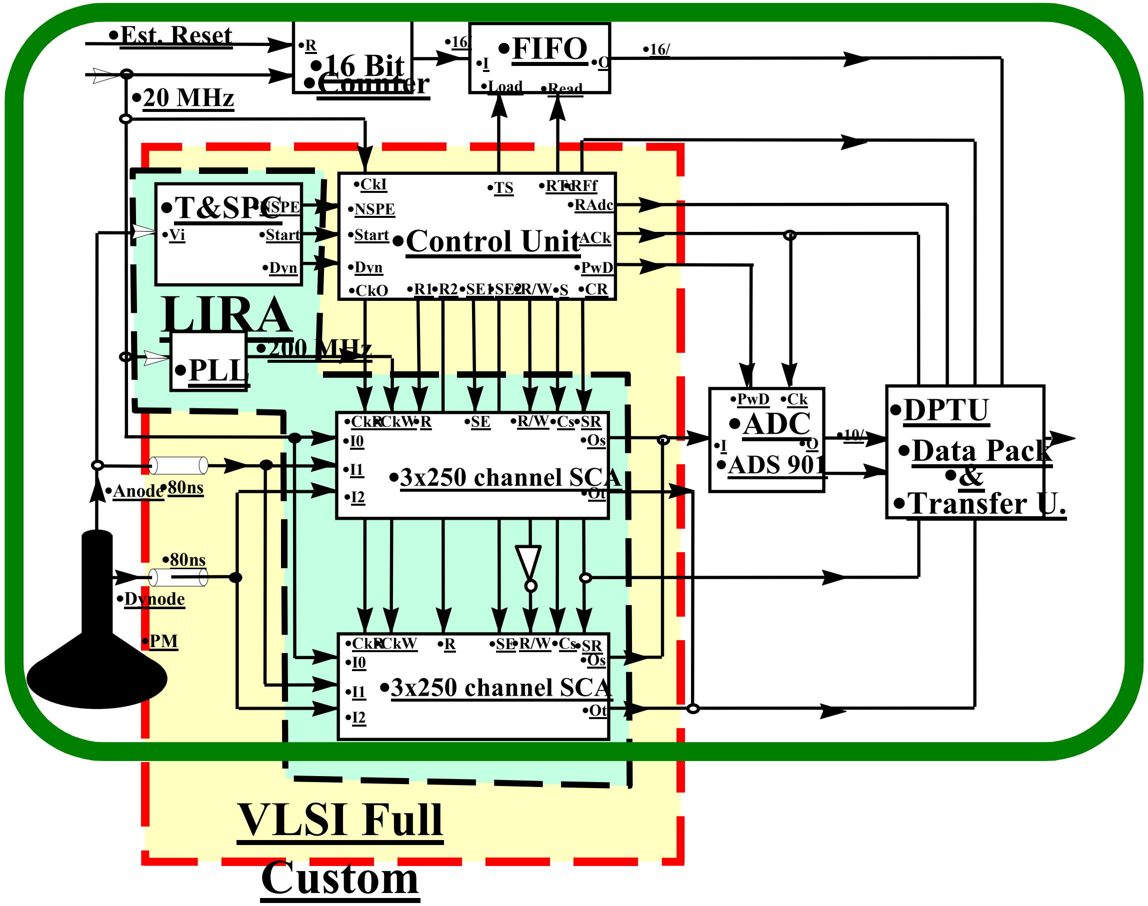
PLL Stand Alone
200 MHz Slave
Clock Generator

LIRA's PLL
Shielded

T&SPC



LIRAX2 200 MHz
Write 10 MHz Read



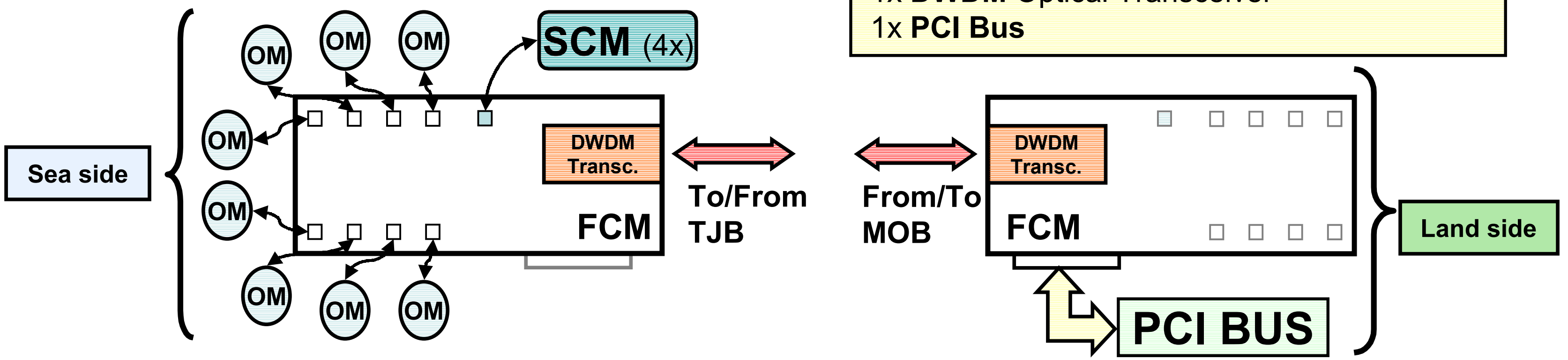
New full custom VLSI ASIC

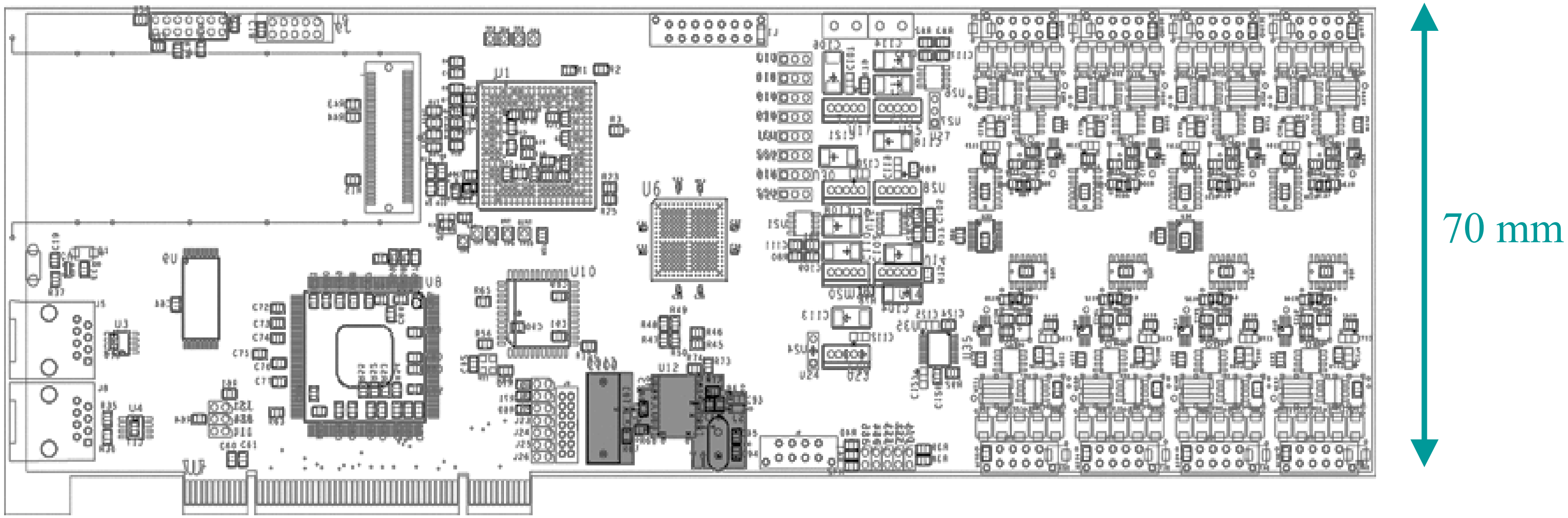
Presently under final laboratory testing

Will be tested in some optical modules in Phase 1

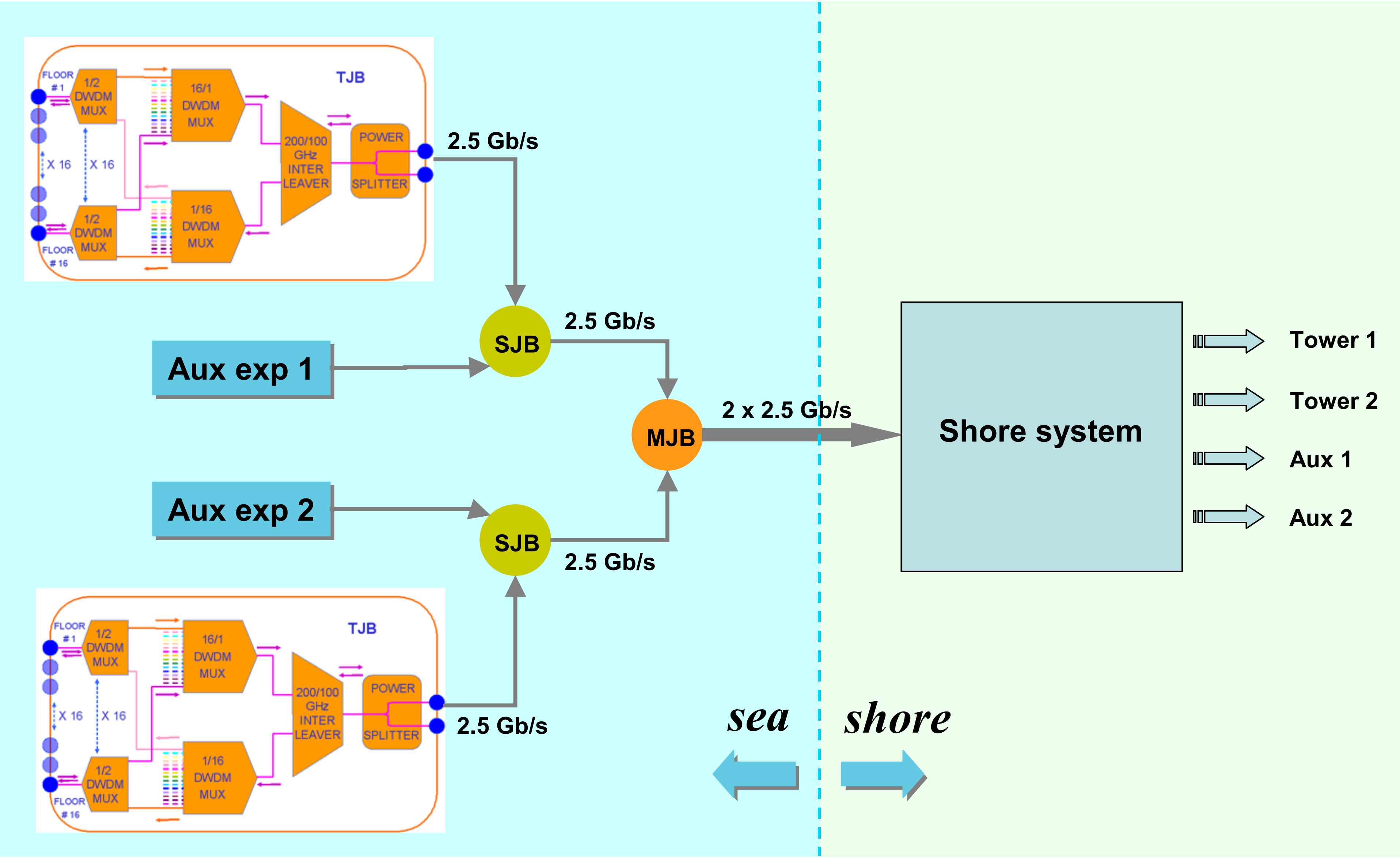
Floor electronics

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





Data transmission system



Summary and outlook

- Site selection
  - *The Capo Passero site close to the coast of Sicily has been deeply studied*
  - *The results show that it is an excellent location for the km3*
- Feasibility study
  - *All the critical detector components and their installation has been analysed in detail*
- Present activity
  - *Phase 1 project to realize a subset of the detector including all the critical components (completion in 2006)*
- Future plans
  - *Completion of R&D activities*
  - *Construction of the km3 within a large international collaboration*