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## Antares: A Deep-Sea 0.1 km<sup>2</sup> Neutrino Telescope

V. Bertin

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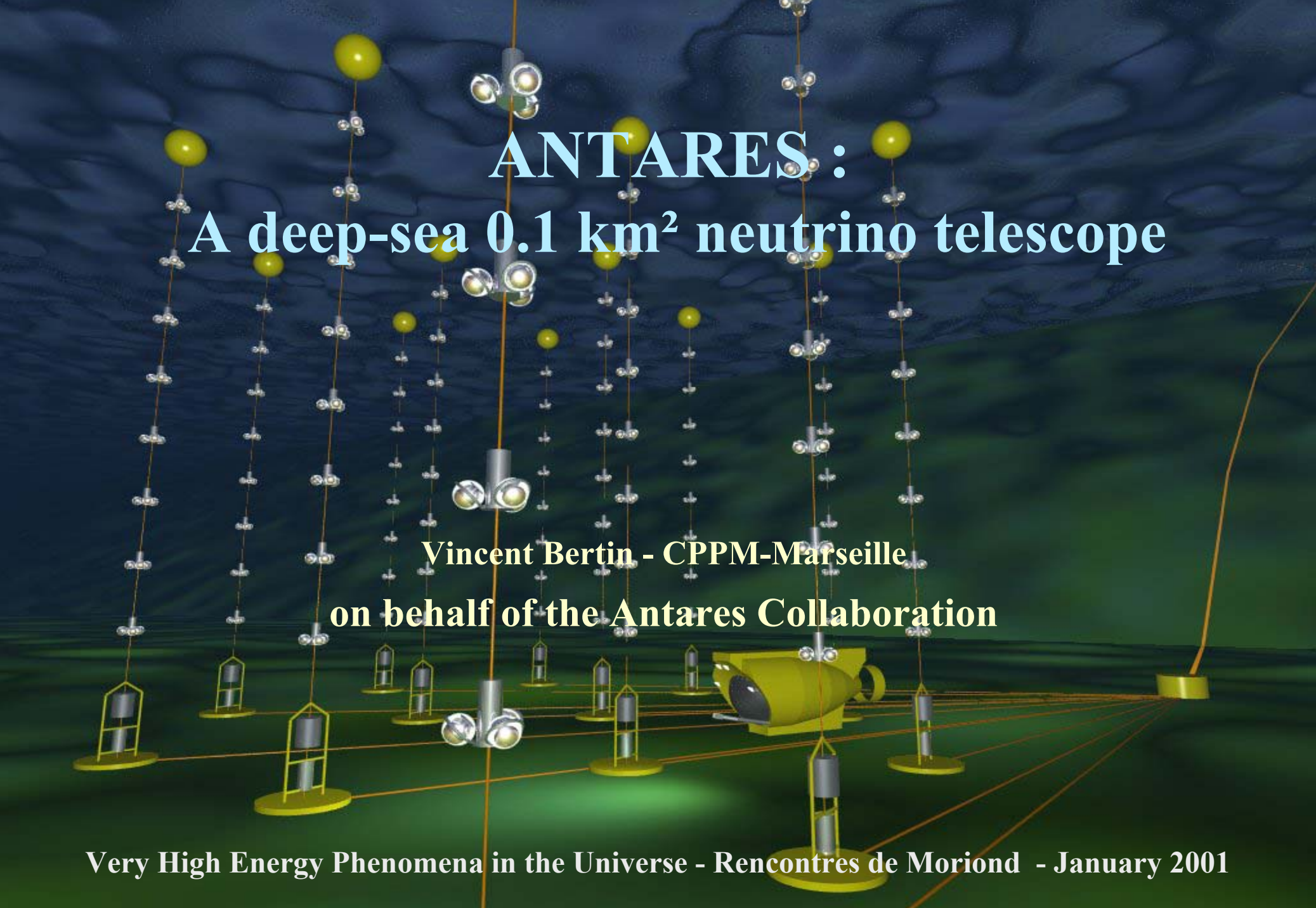
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A 3D computer-generated illustration of the ANTARES neutrino telescope. The structure consists of numerous vertical strings of optical modules (OMs) suspended in a dark blue, rippling deep-sea environment. Each string is anchored to a yellow circular base on the seafloor. The OMs are arranged in a grid pattern, with some strings having yellow spherical floats at the top. The overall scene is dimly lit, with a greenish glow emanating from the seafloor.

# ANTARES :

## A deep-sea 0.1 km<sup>2</sup> neutrino telescope

**Vincent Bertin - CPPM-Marseille**  
**on behalf of the Antares Collaboration**

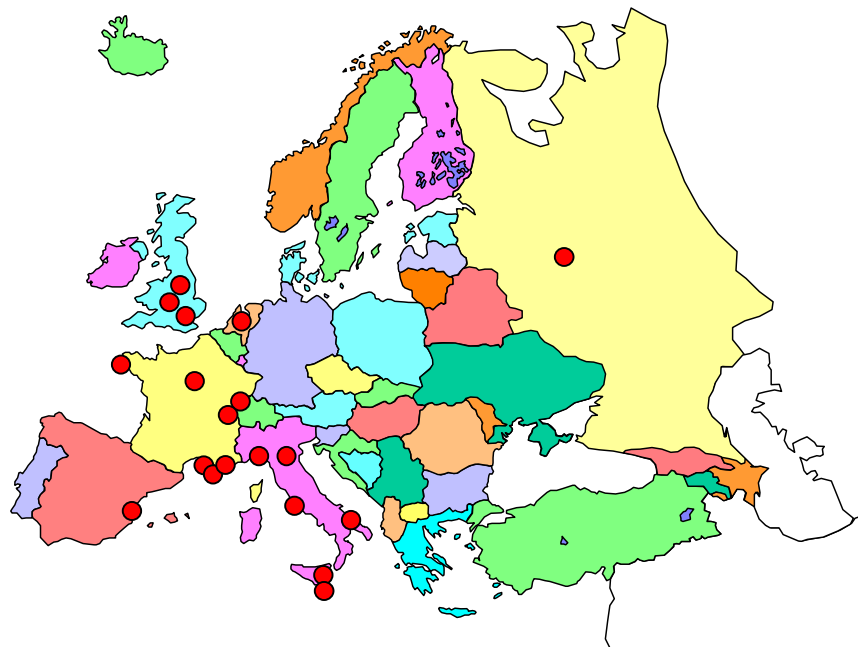
# The ANTARES Collaboration



- ❖ CPPM, Marseille (IN2P3)
- ❖ DSM/DAPNIA, Saclay (CEA)
- ❖ IReS, Strasbourg
- ❖ Univ. of H.-A., Mulhouse
- ❖ C.O.M. Marseille
- ❖ IFREMER, Marseille/Brest
- ❖ IGRAP (INSU), Provence



- ❖ University of Bari
- ❖ University of Bologna
- ❖ University of Catania
- ❖ LNS – Catania
- ❖ University of Rome
- ❖ University of Genova



- ❖ University of Oxford
- ❖ University of Sheffield



- ❖ ITEP, Moscow



- ❖ IFIC, Valencia



- ❖ NIKHEF, Amsterdam

# Detection Principle

Lattice of Photomultipliers : “Optical Modules”

Muon track direction from arrival time of light

Neutrino direction:  $\bar{\Delta} (\theta_\nu - \theta_\mu) \approx 0.7^\circ / E^{0.6}(\text{TeV})$

Muon energy from energy loss and range

Cherenkov  
light cone

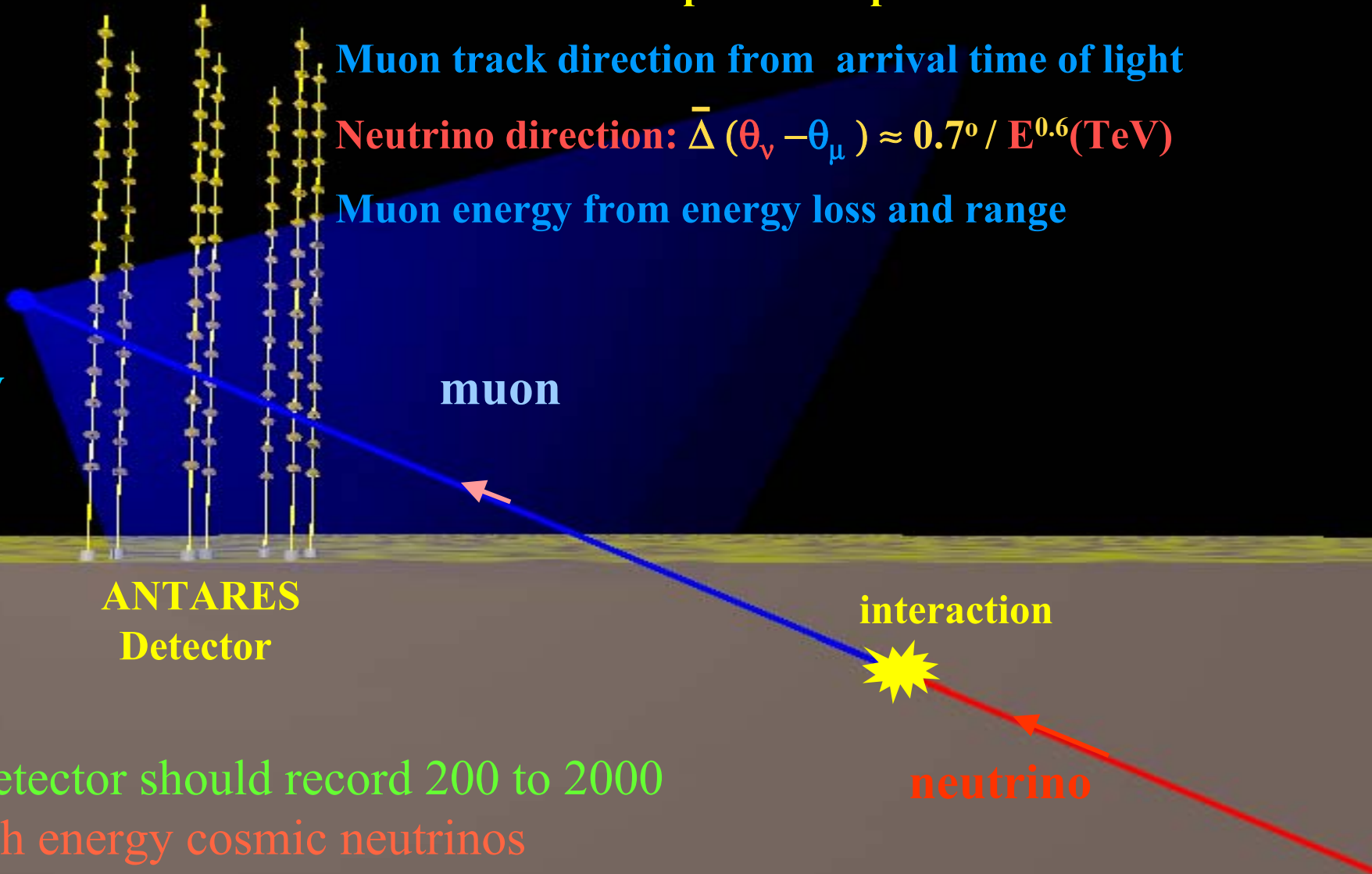
muon

ANTARES  
Detector

interaction

neutrino

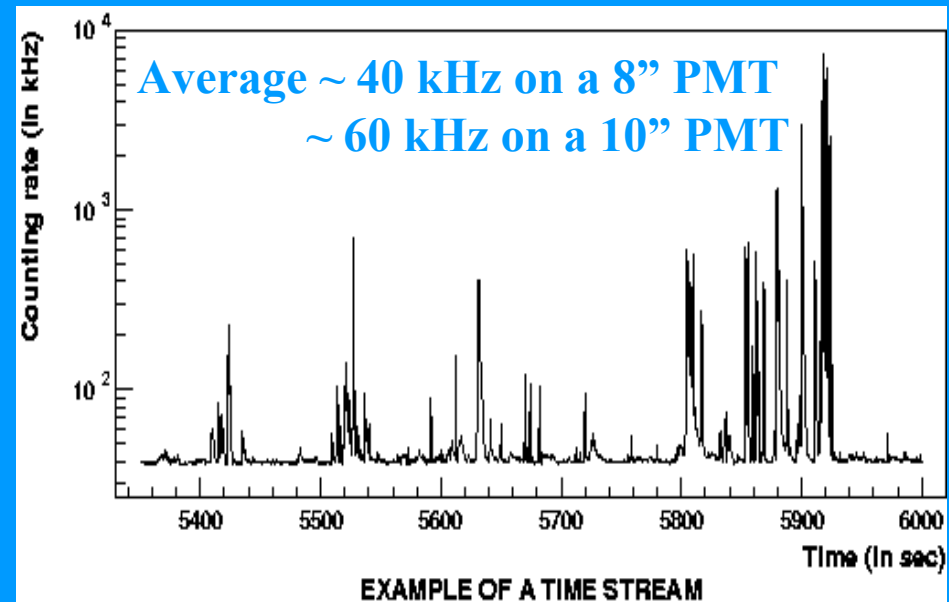
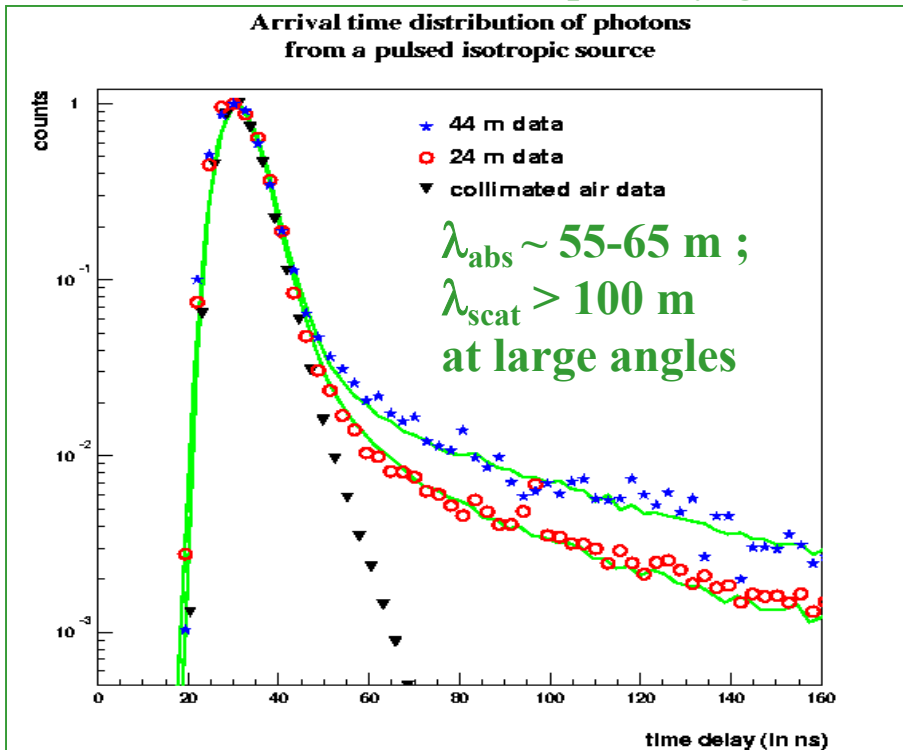
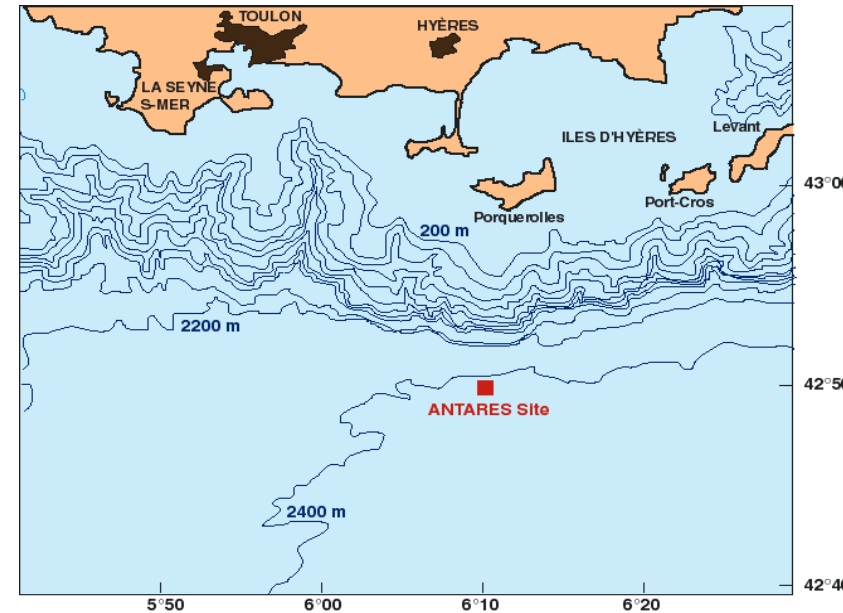
A 1km<sup>3</sup> detector should record 200 to 2000  
high energy cosmic neutrinos  
per year ( $E_\nu > 10\text{-}100 \text{ TeV}$ ).



# Phase I : Water properties measurements

■ Perform precise measurements of crucial environmental parameters :

- ◆ In situ measurements on Antares site (2400 m depth off French Mediterranean coast)
- ◆ Long term measurements of optical background ( $^{40}\text{K}$  decays, bioluminescence) and biofouling of Optical Modules
- ◆ Measurement of water transparency @ 466 nm :

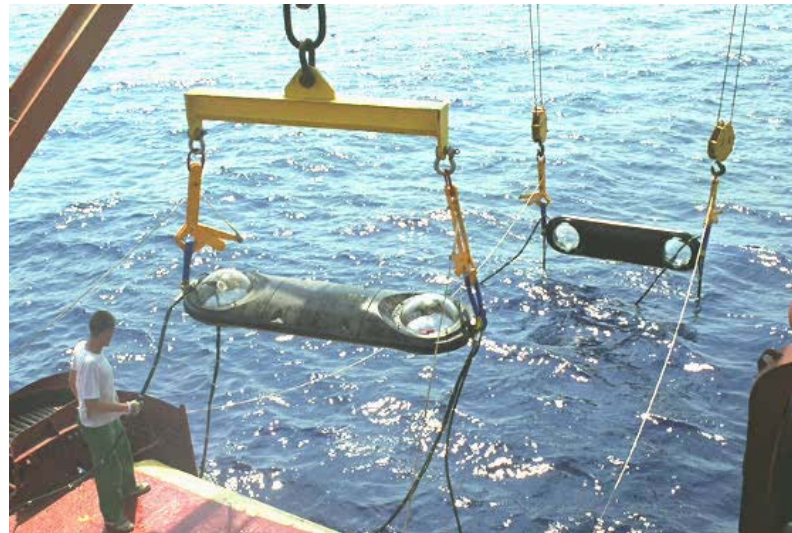


# ANTARES Phase I : Demonstrator

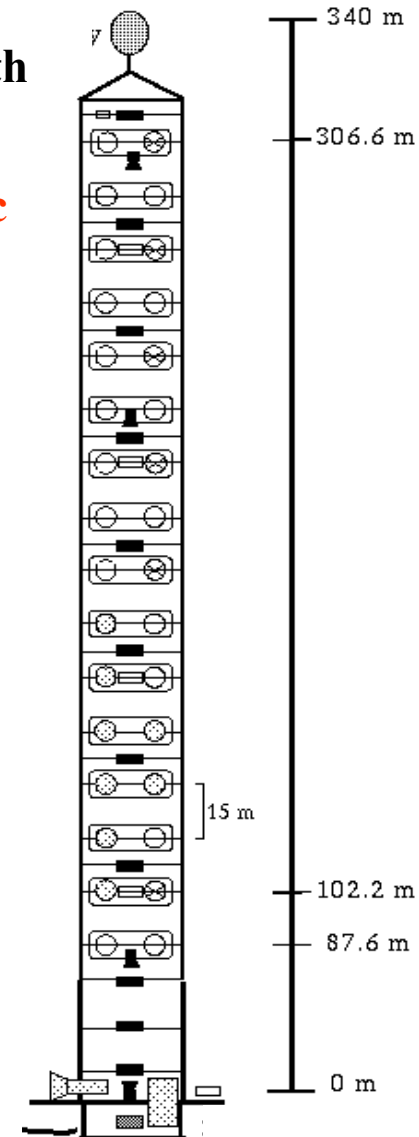
## ■ First line of 350m high equipped with 16 pairs of Optical Modules

- ◆ Summer 98 : successful deployment test at 2300m depth performed with Dynamical Positioning ship
- ◆ December 99-June 00 : demonstrator equipped with 7 PMTs + acoustic positioning system linked to shore station by electro-optical cable

*NAUTILE*



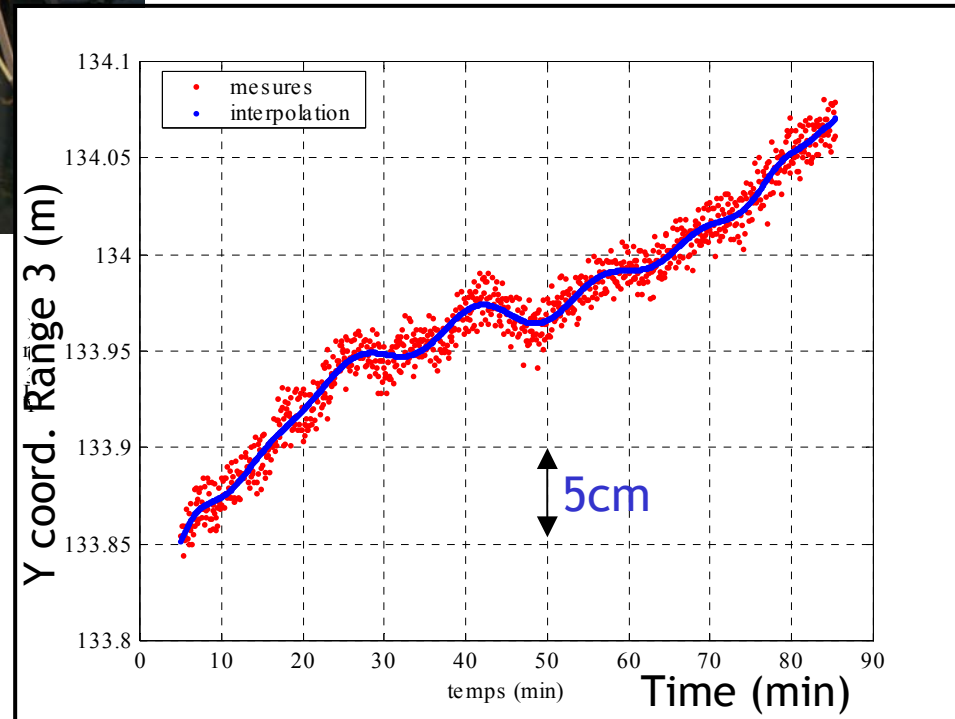
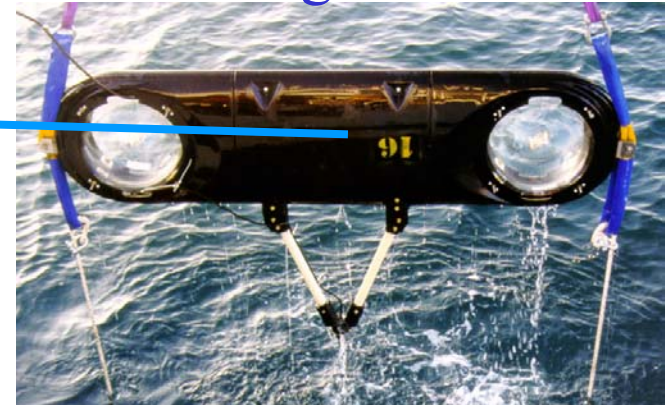
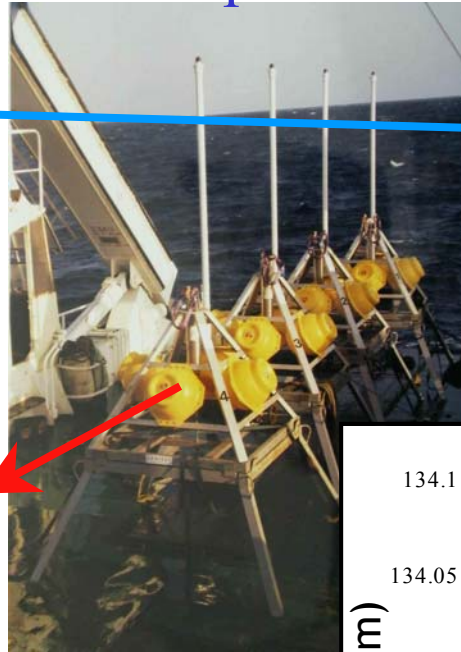
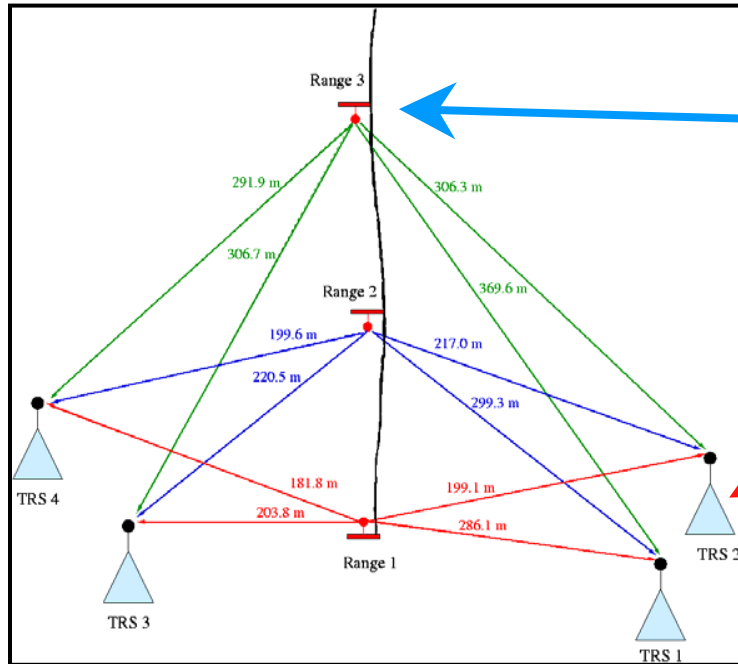
- December 98 : successful undersea electrical connection test of detector anchor performed at 2400m depth by IFREMER submarine vehicle *Nautilie*



# Acoustic positioning system

4 transponders

3 rangemeters

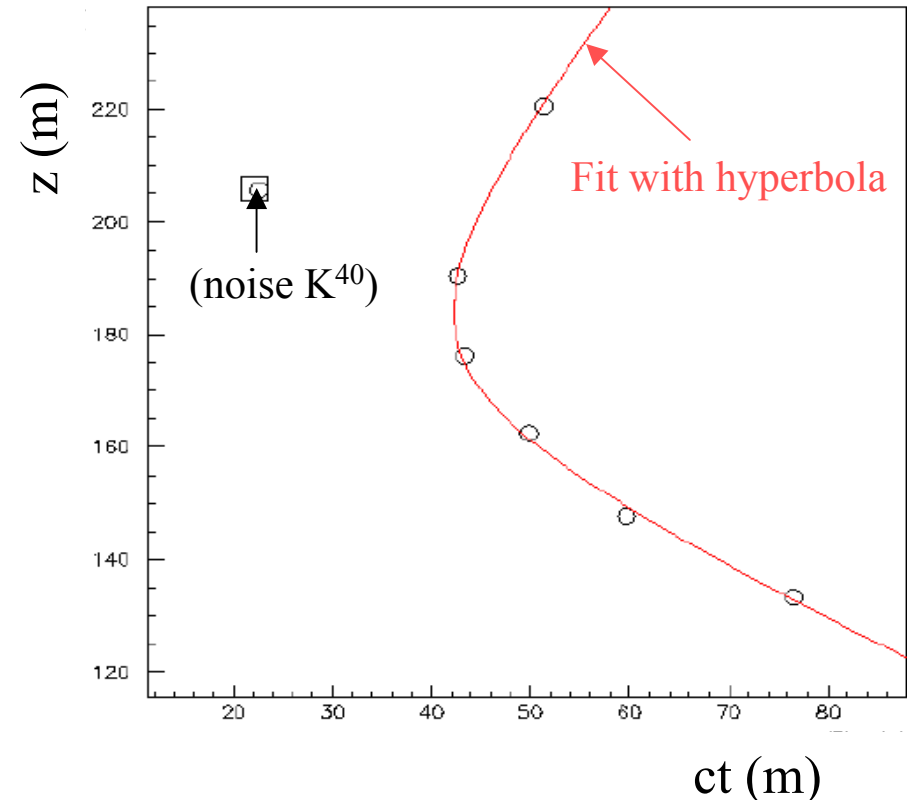
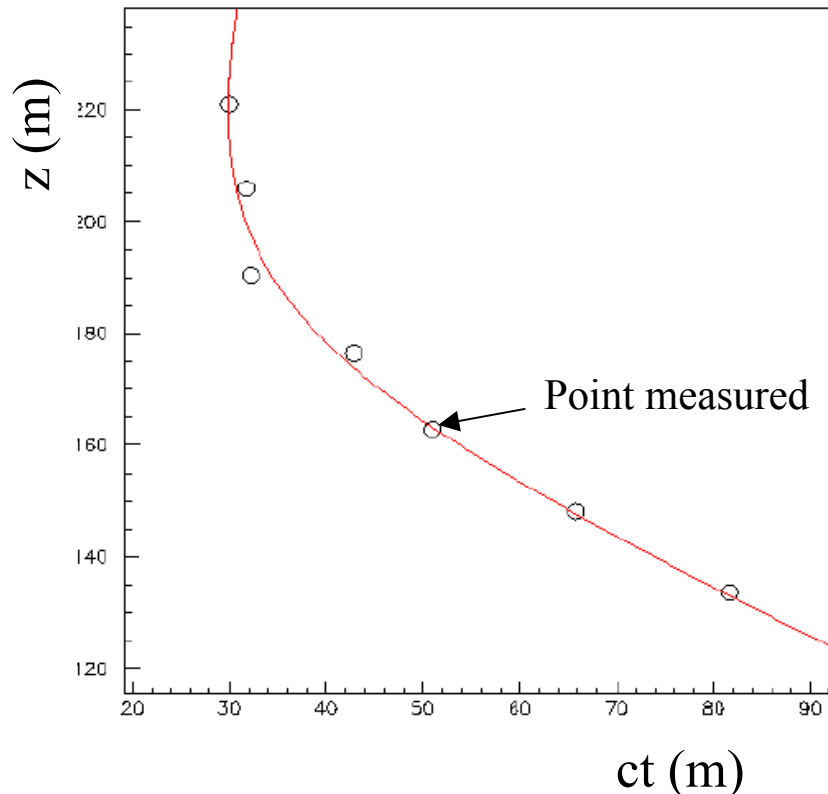


Devices	Accuracy ( $\sigma$ )
Inter-rangemeter	~ 1 cm
Inter-transponder	~ 1 cm
Rang.-Transpond.	$\leq 3$ cm

Triangulation allows  $\leq 5$  cm accuracy

# Reconstruction of Atmospheric Muons

- More than  $5 \times 10^4$  coincidences in all 7 PMTs have been recorded.
- Polar angle of down-going muons deduced from depth vs. time pattern.
- Hyperbolic fit (including multimuons).
- $^{40}\text{K}$  filtered out by the reconstruction software (see boxed hit in example).



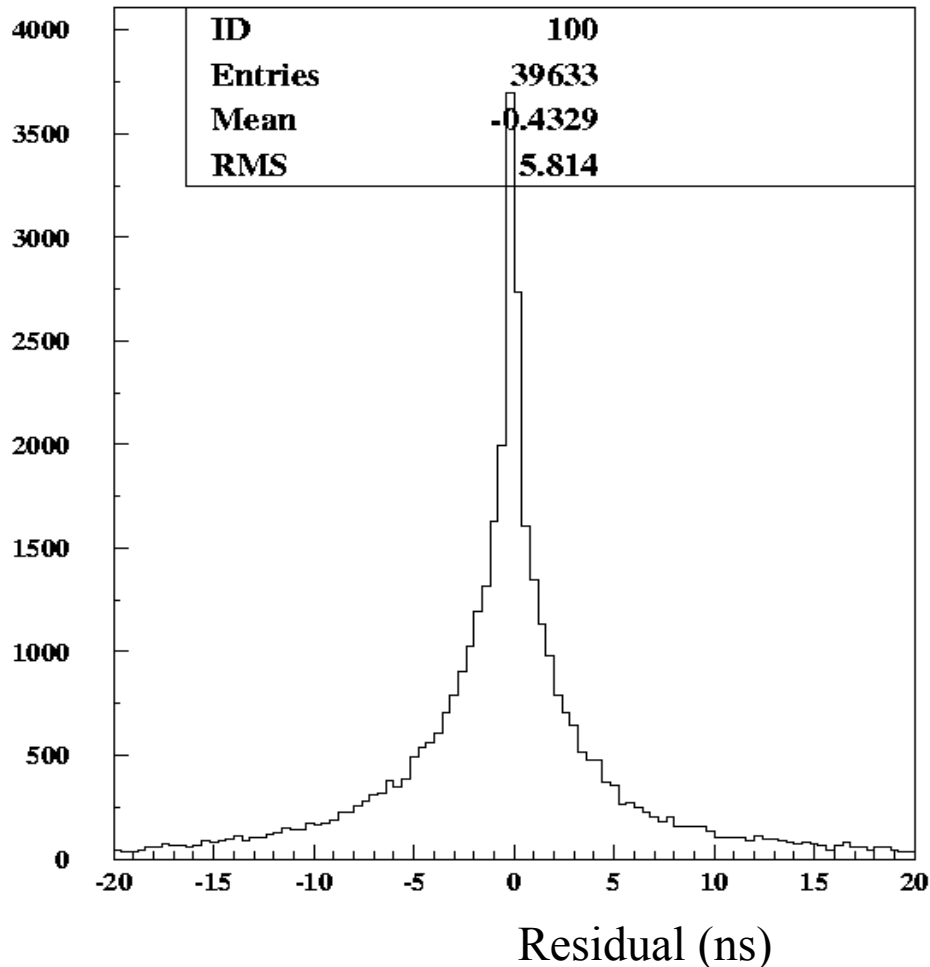


# Reconstruction of Atmospheric Muons

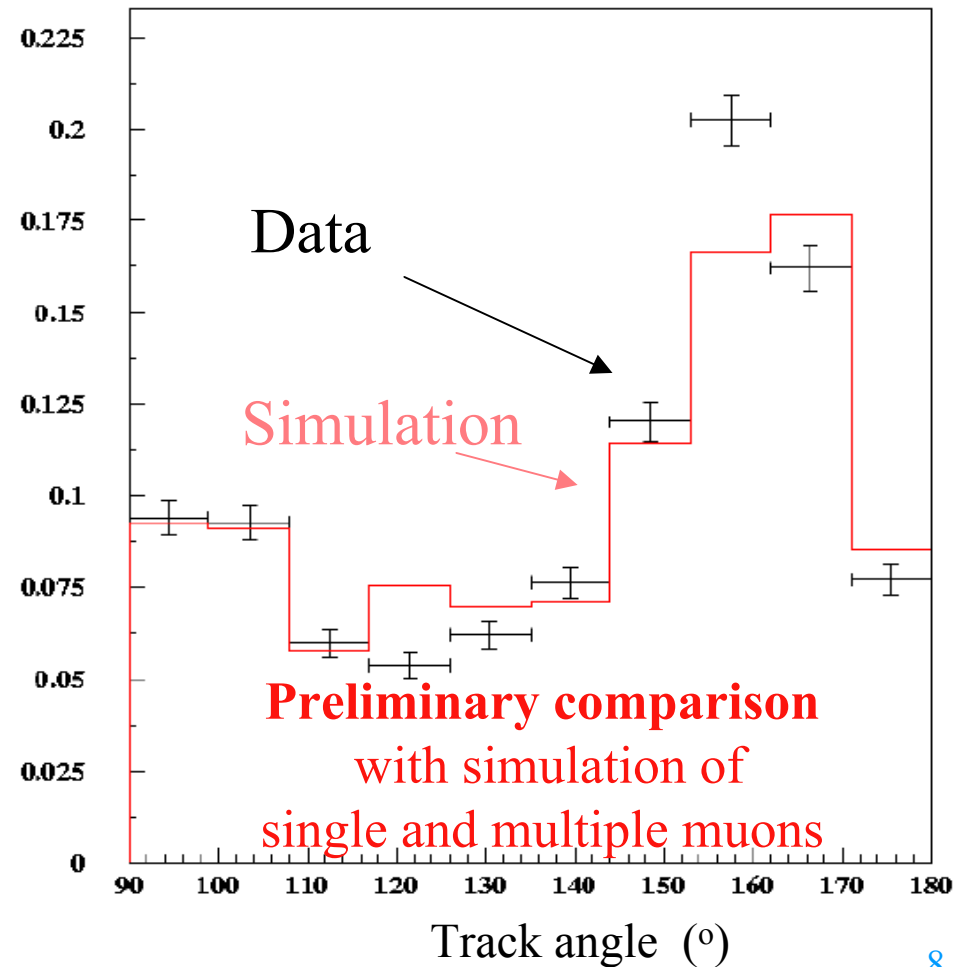
Over 50k 7-fold coincidences recorded

➡ more than **1350 reconstructed events per day**

$\Delta(\text{fit-point})$  in ns



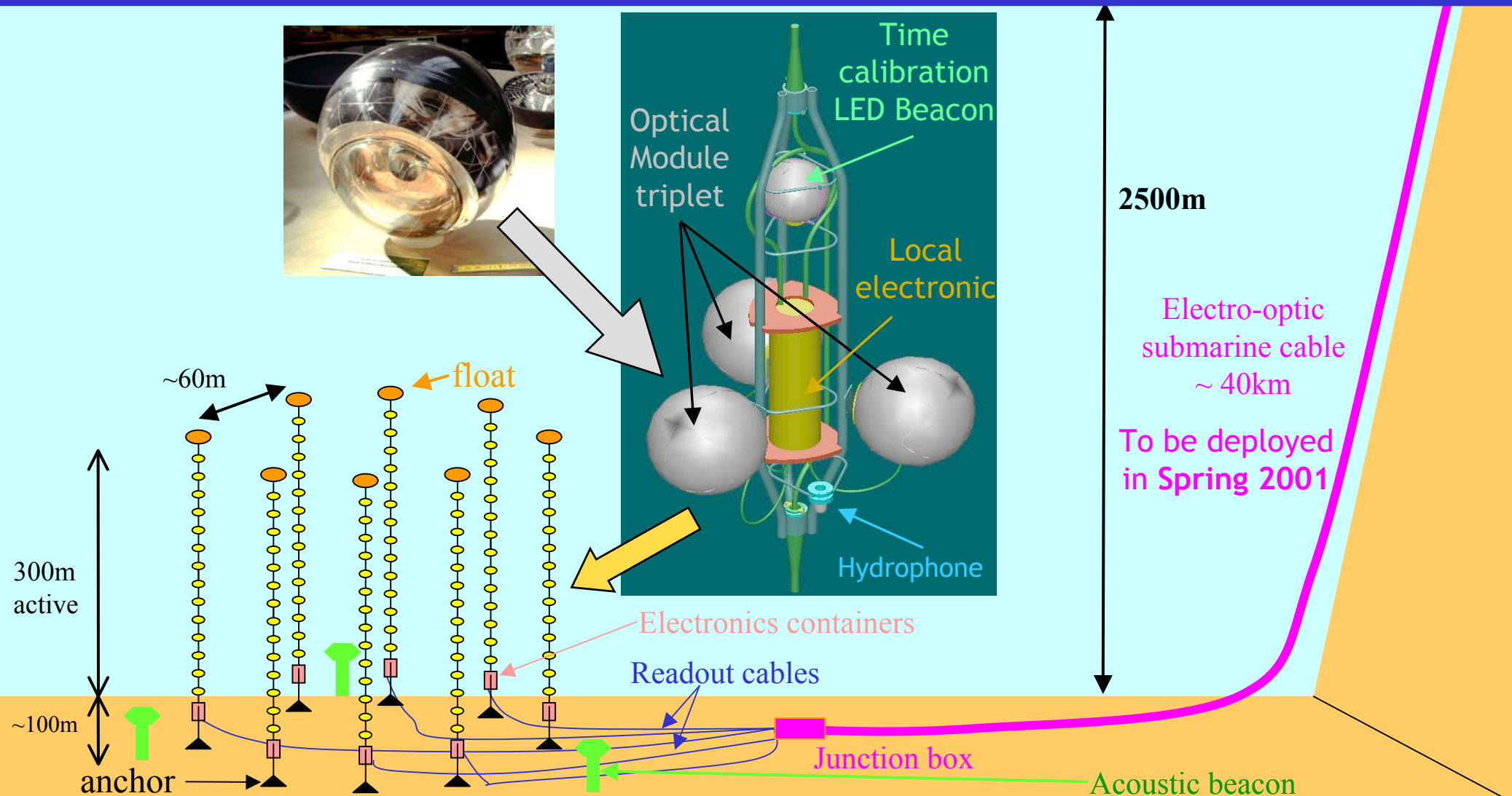
Angular Distribution



# ANTARES Phase II : 0.1 km<sup>2</sup> Detector

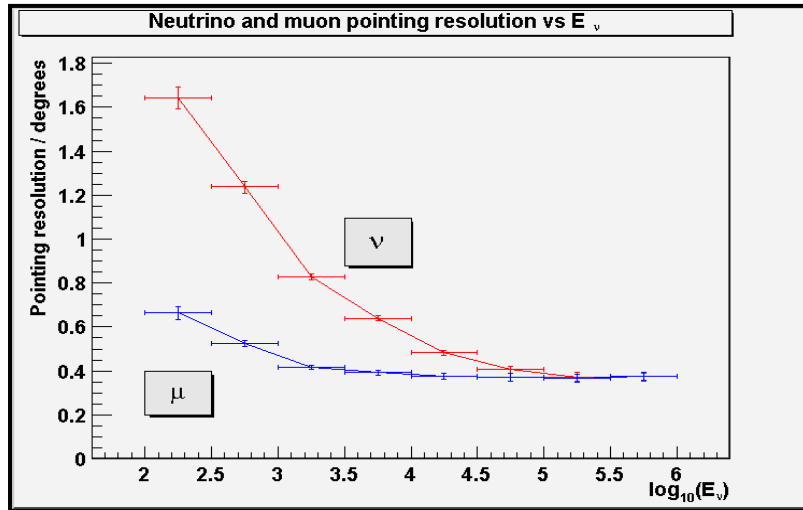
10 strings : 900 PMTs in total  
Detector to be deployed at ANTARES site by 2002 - 2004

Shore station



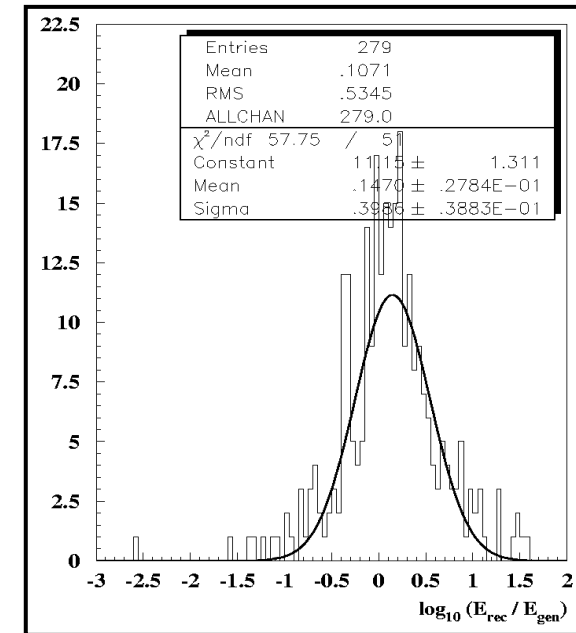
# 0.1 km<sup>2</sup> Detector : Expected performance

## Angular resolution



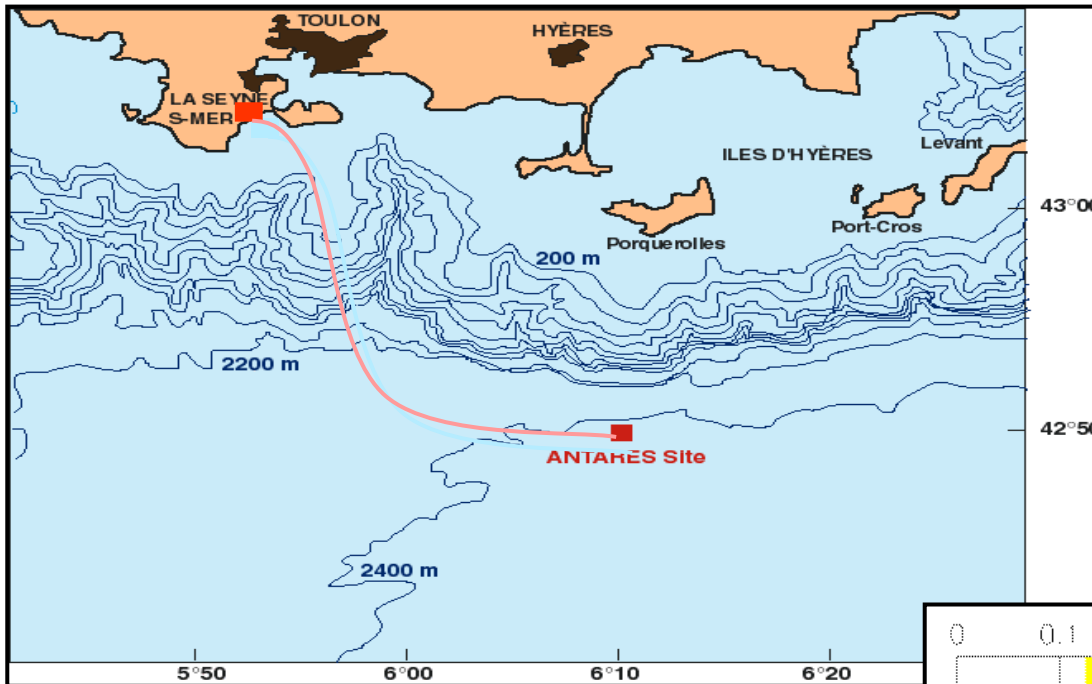
- ❖ Including effects of reconstruction and selection, PMT TTS, positioning, timing calibration accuracy and scattering.
- ❖ Below  $\sim 10$  TeV angular error is dominated by  $\nu$ - $\mu$  physical angle.
- ❖ Above  $\sim 10$  TeV angular accuracy is better than  $0.4^\circ$  (reconstruction error).

## Energy resolution



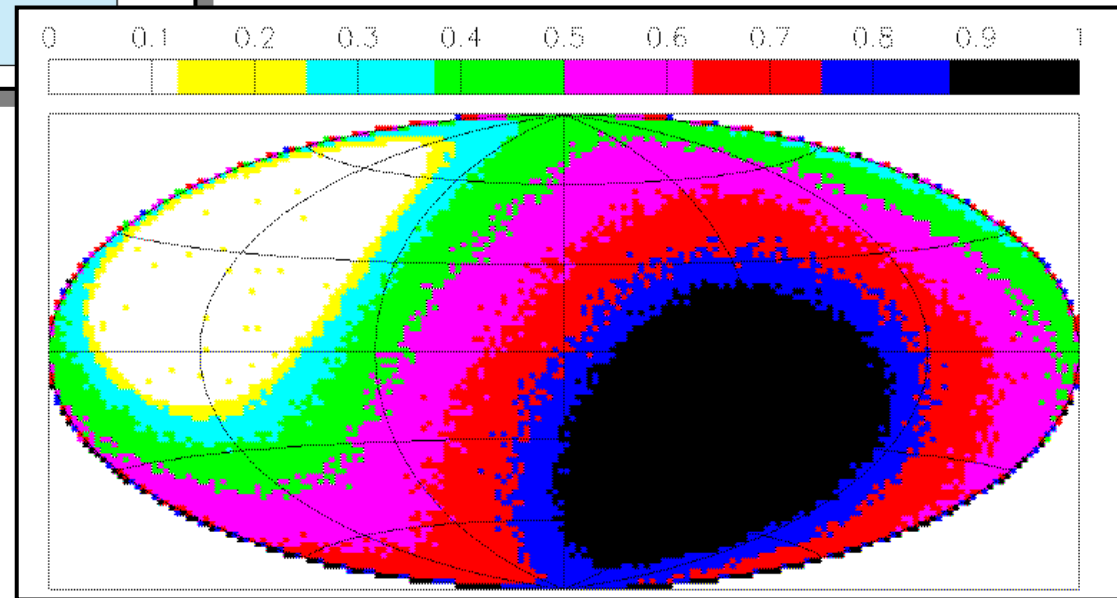
- ❖  $\sigma_E / E \approx 3$  ( $E > 1$  TeV)
- ❖ Below  $E \sim 100$  GeV energy estimation via muon range measurement.

# ANTARES 0.1 km<sup>2</sup> Detector Site



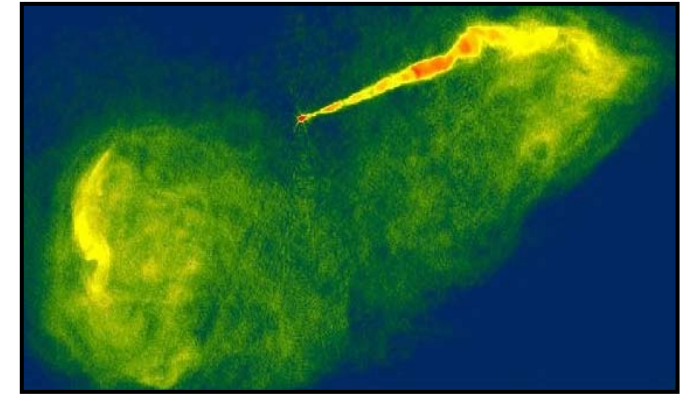
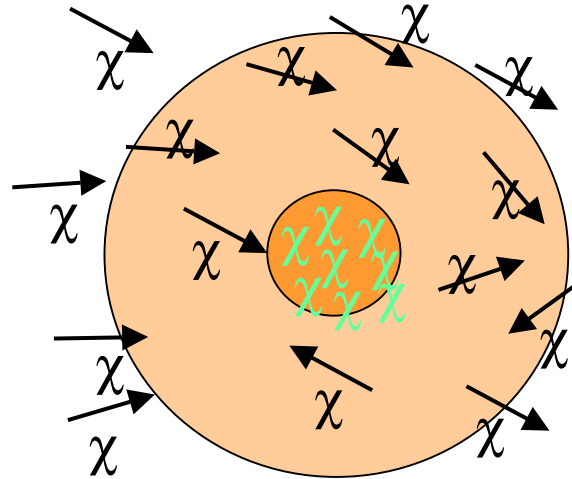
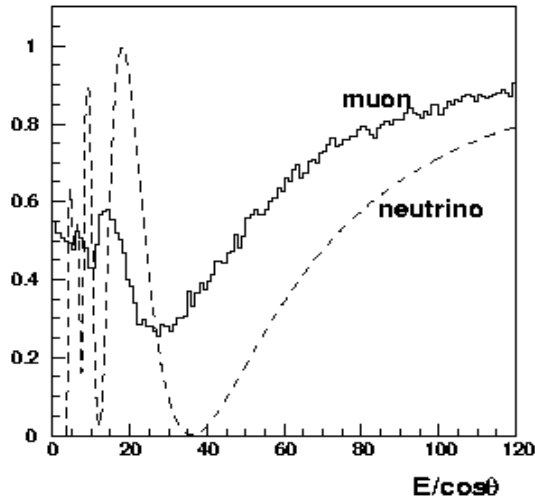
- ❖ 40 km SE of Toulon, Southern France (42° 50' N, 6° 10' E)
- ❖ Shore base at La Seyne-sur-Mer (excellent infrastructure)
- ❖ 2400 m below sea level

- ❖  $3.5\pi$  sr of the sky is covered
- ❖  $0.5\pi$  sr overlap with Amanda
- ❖ Galactic Centre surveyed



# Scientific Programme

# Energy



## Low energy

- **Neutrino oscillations** via the modification in the energy spectrum due to **observation of the first oscillation minimum**

## Medium Energy


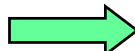
- **Search for neutralinos** via their **self-annihilation** to products containing **neutrinos at the centre of the Earth, Sun and Galaxy**

## High energy

- **Observation of neutrinos from (extra-)galactic sources** such as **GRB, AGN, Supernovae remnants, molecular clouds, etc.**

# Conclusions

ANTARES has made excellent progress over the past 4 years :

- ◆ Site environmental characterisation  **OK**
- ◆ Tests of marine technologies  **under control**
- ◆ Deployment and operation of Demonstrator String
- ◆ First down-going muons reconstructed
- ◆ Expanding Collaboration

ANTARES is well engaged in Phase II of its programme  
by the design, the installation and the running  
of a 10-strings 0.1 km<sup>2</sup> detector in 2002-2004

**Major step forward towards a km-scale  
neutrino telescope in the Mediterranean Sea**