Workshop on QCD at Cosmic Energies
Erice, August 29 - September 5, 2004

The ANTARES experiment: past, present and future

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on behalf of the ANTARES collaboration

ANTARES

Outline

- Introduction
  - Scientific motivation
  - Detection technique
  - Pre-history
- The ANTARES experiment: general issues
  - Collaboration
  - Site of experiment
- ANTARES milestones
  - Preparatory phase
  - 12-string detector: design and present status
- Physics performance
- Summary

Introduction

Introduction-I (motivation)

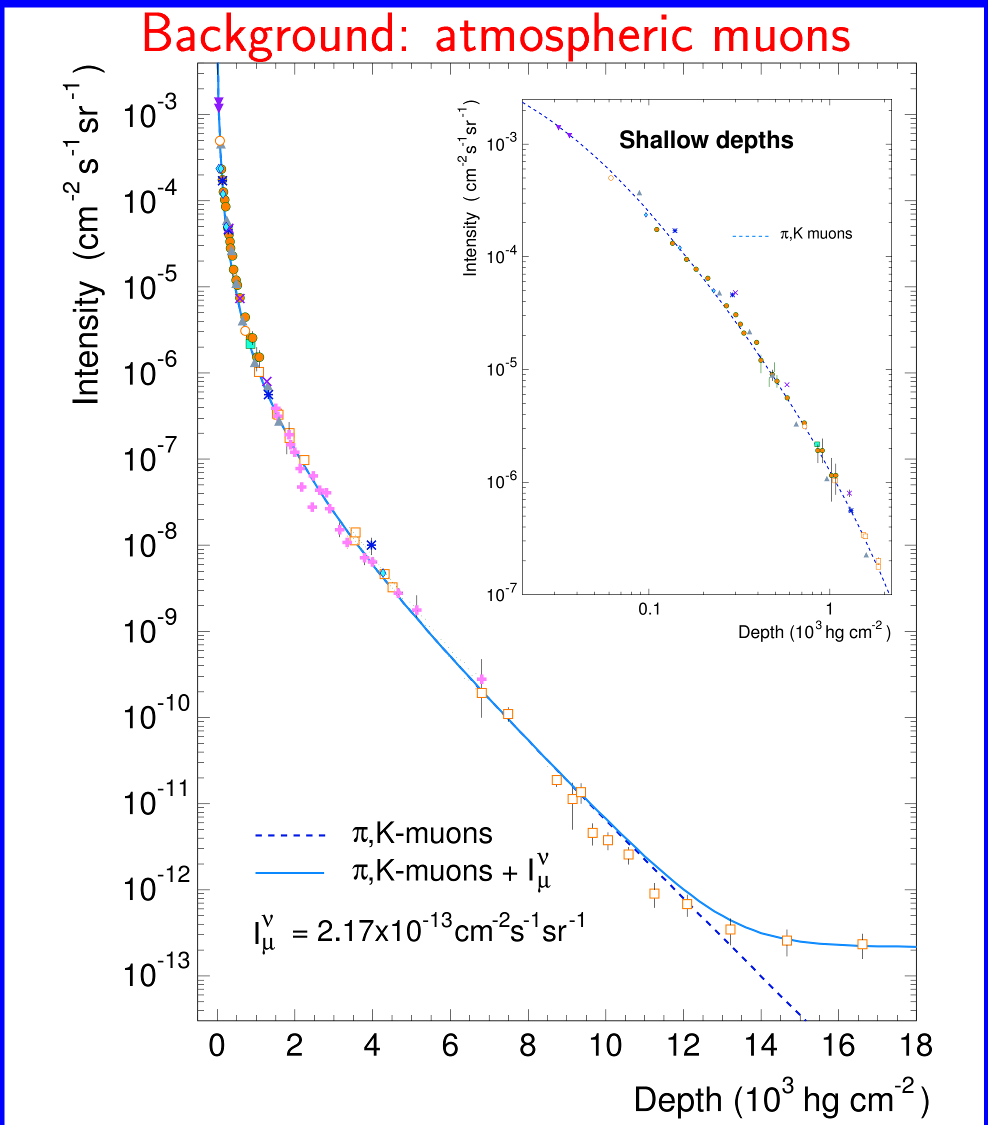
We need to study natural fluxes of high energy neutrinos

- What is the origin of high energy cosmic rays?
  - proton arrival direction is scrambled by magnetic fields below EeV energy range. Above ∼60 EeV protons interact with CMW background (GZK cut-off);
  - the Universe is opaque for γ's above ∼10 TeV;
  - the only particle that can reach the Earth from cosmological distances pointing back to the source of its origin is the neutrino
- Neutrinos from WIMP annihilation in Earth, Sun, Galactic Center...
- Atmospheric neutrinos
  - oscillations (10-100 GeV range)
  - prompt neutrino - charm production (TeV and PeV range)
- Other issues (including possible new physics)

Introduction-II (technique)

HE neutrinos can be detected by means of charged lepton (CC interactions): $\nu_l\, N \xrightarrow{CC} l\, X$

or hadronic shower (NC interactions): $\nu_l\, N \xrightarrow{NC} \nu_l\, X$

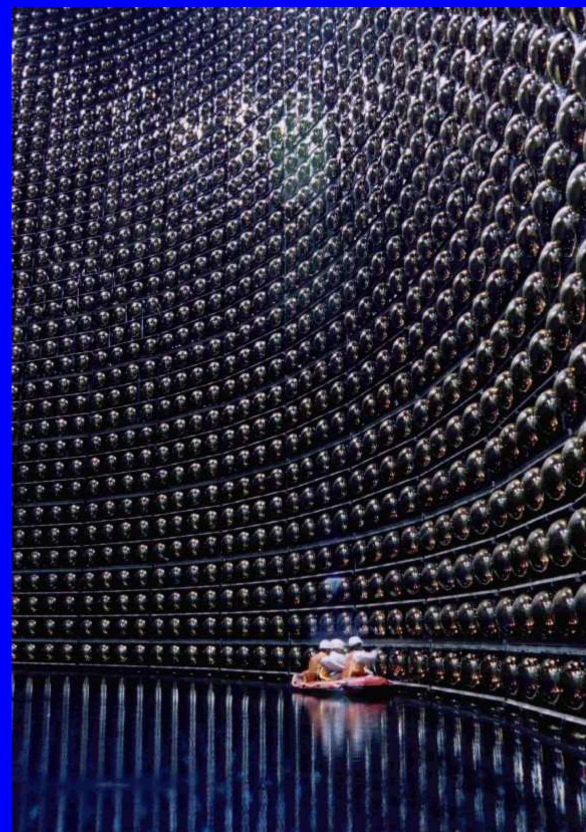


Taken from E.V. Bugaev *et al.*, Phys. Rev. **D58** (1998) 054001 [hp-ph/9803488]

- One needs a km-scale layer of matter above the detector to absorb μ_{atm} background
- Fluxes are low and one needs very large detectors

Introduction-III (pre-history)

Underground neutrino telescopes are located in old mines or tunnels. The history of underground telescopes culminated with giant detectors like MACRO and SuperKamiokande ($\sim 10^4$ m^3)



BUT one needs significantly larger scales to detect neutrinos from cosmic accelerators which goes beyond the construction possibilities of underground technique.

M.Markov (1960): idea to construct large deep underwater Cherenkov detectors for neutrino astrophysics using water masses of natural basins.

Era of underwater neutrino telescopes started

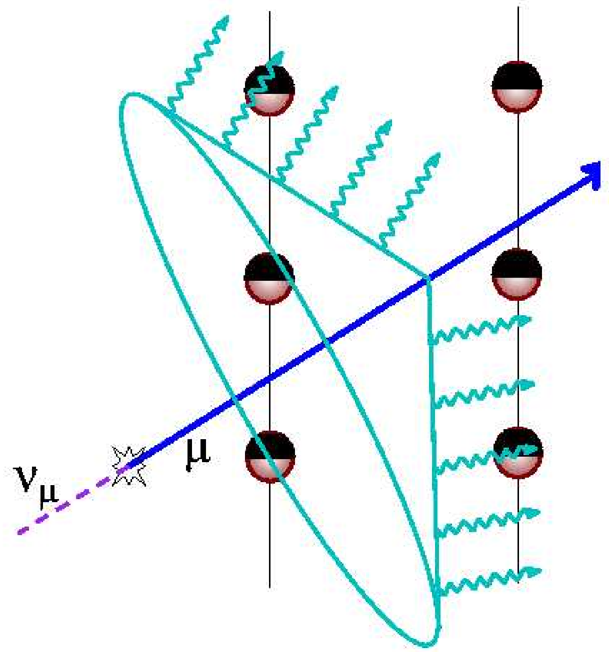
The original Markov idea :

detection of Cherenkov light emitted by ν induced muon

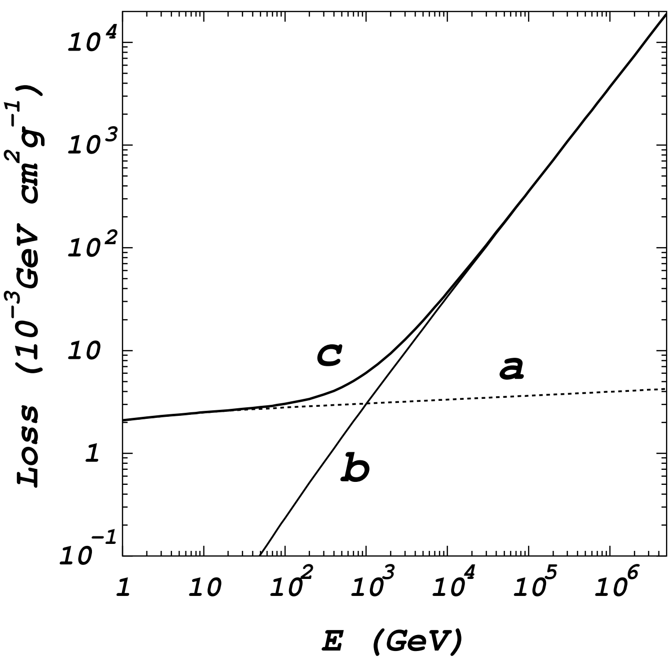
$$\nu_\mu N \xrightarrow{CC} \mu X$$

by means of 3D PMT array immersed in ocean or lake

$t_i, x_i, y_i, z_i \rightarrow$ track reconstruction $\quad A_i \rightarrow$ energy reconstruction



Taken from S.Barwick, Proc. of SSI-2000



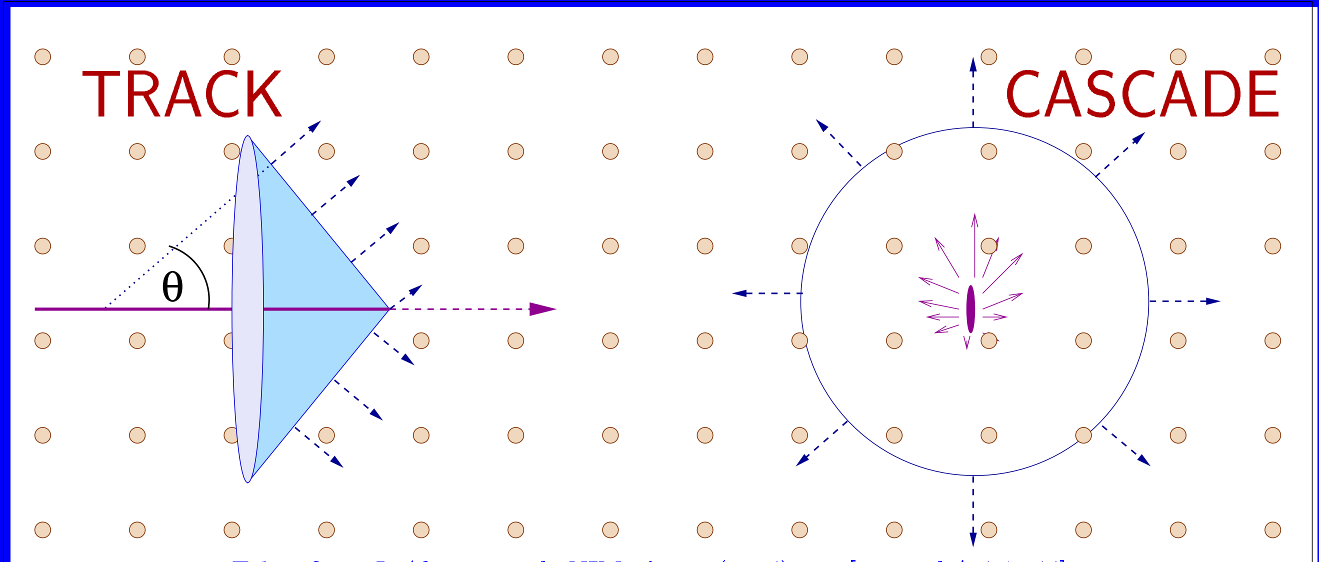
Water is used as:

- shield to protect from atmospheric muons
- target in which neutrino interaction occurs
- detection medium where the Cherenkov light is emitted

Water is not <u>an artificial medium</u> but rather <u>a natural environment</u>, the properties of which must be constantly monitored

- optical properties: absorption, scattering, biofouling and sedimentation
- water luminescence: intensity, time and spatial structure
- water currents: velocity, variations

Introduction-IV (topologies)

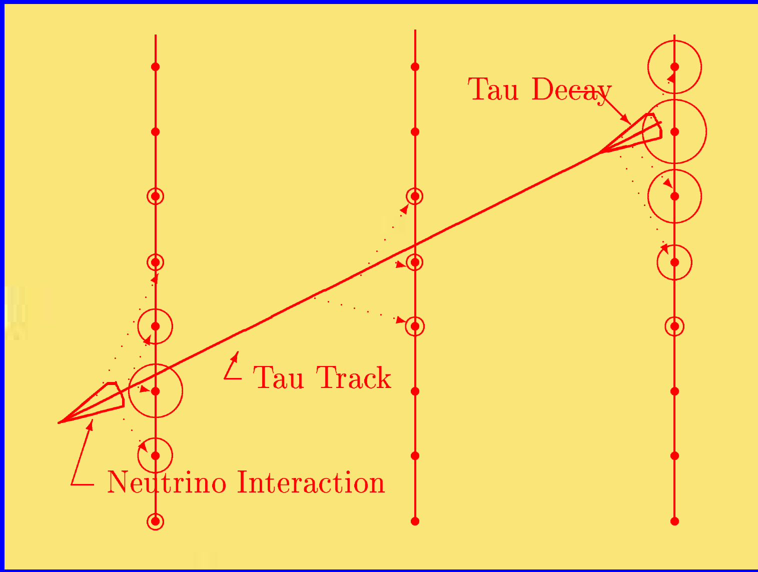


Taken from J. Ahrens *et al.*, NIM, **A524** (2004) 169 [astro-ph/0407044]

Muons and τ-leptons ($E_\tau > 2\cdot10^{15}$ eV)

Electrons and τ-leptons ($E_\tau < 2\cdot10^{15}$ eV), ν_e, ν_μ, ν_τ NC/CC interactions

Variety of topologies with both track and cascade(s): neutrino CC interaction (shower) with subsequent muon track; muon track with showers from secondaries; 'double bang' (τ-lepton), ...



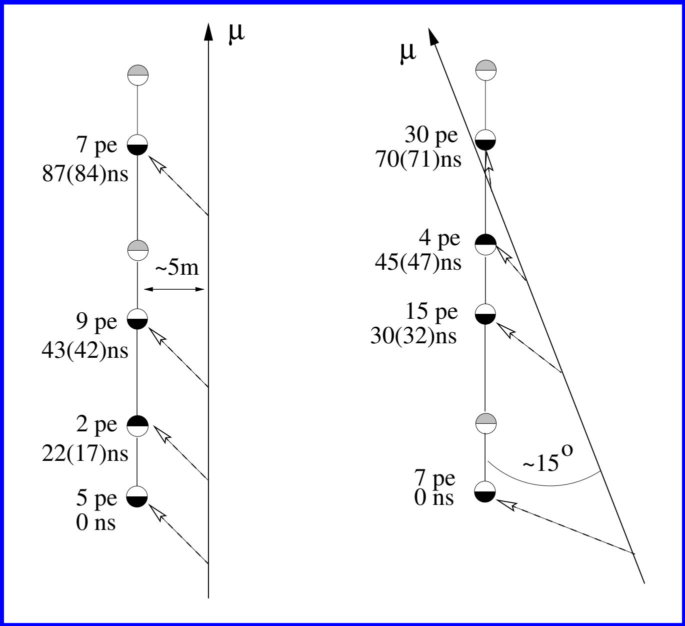
Detection of showers outside instrumented volume...

Introduction-V (starting point)

The ANTARES experiment started in 1996

By that time:

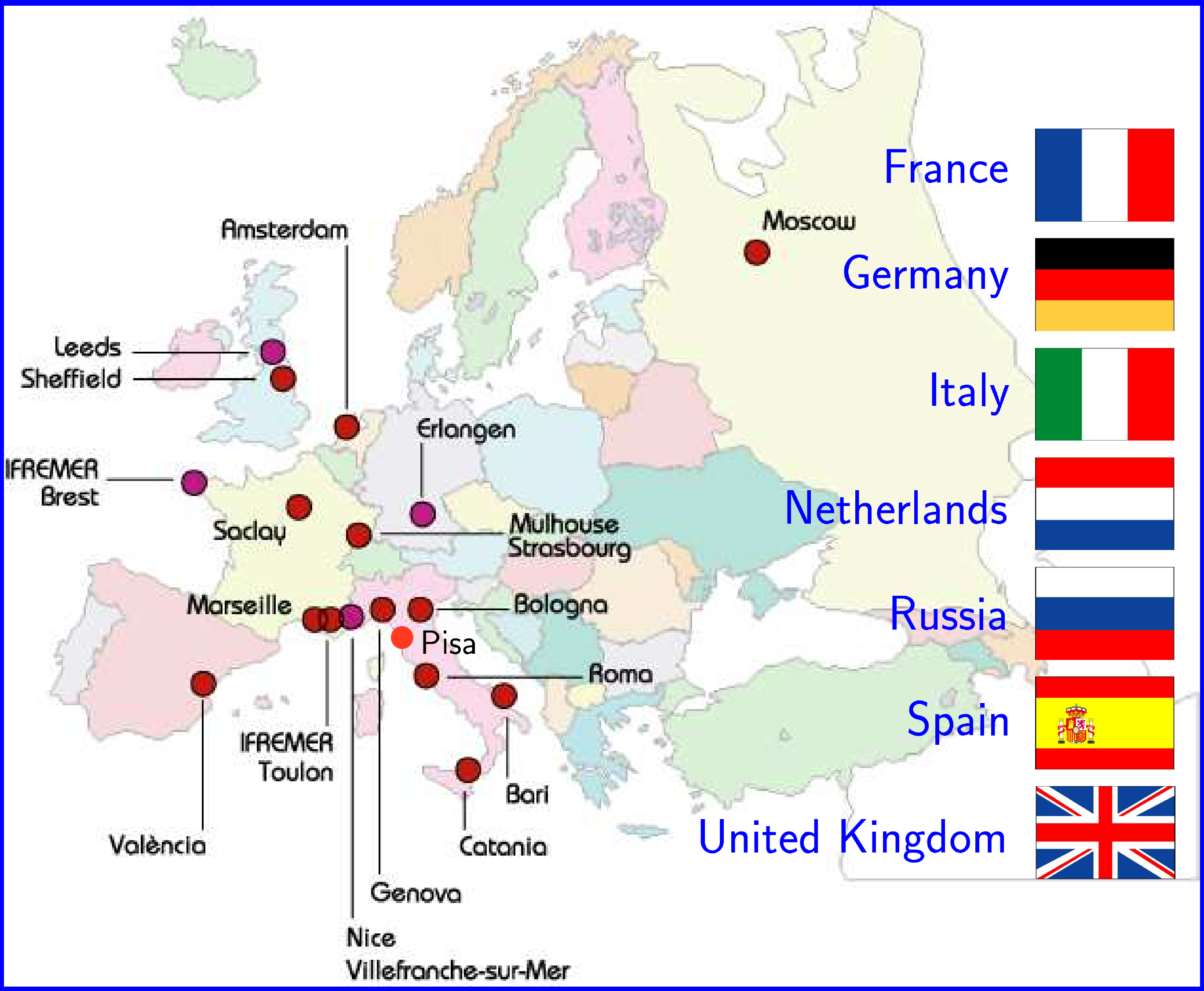
- The DUMAND project in Pacific ocean (1976-1995) cancelled
- The BAIKAL experiment in Siberian lake Baikal (started in 1981) reported the first underwater neutrinos; the neutrino telescope NT-200 (192 PMTs on 8 strings) under construction



- The NESTOR project in Mediterranean Sea (near Pylos, Greece): R&D stage, site study
- The AMANDA experiment at South Pole: AMANDA-A (80 PMTs on 4 strings frozen in antarctic ice) are in operation since 1994, 72 PMTs on 4 strings were deployed and put into operation in 1995-96 (AMANDA-B)

The ANTARES experiment: general issues

ANTARES Collaboration



180 PHYSICISTS, ENGINEERS AND TECHNICIANS

- COM, Marseille
- CPPM, Marseille
- DSM/DAPNIA/CEA, Saclay
- University of Bari & INFN/Bari
- University of Bologna & INFN/Bologna
- University of Catania & INFN/Catania
- University of Genova & INFN/Genova
- Univ. "La Sapienza" & INFN/Roma
- Univ. de H. A., Mulhouse
- University of Valencia
- IFREMER, Brest/Toulon
- LNS/INFN, Catania
- IReS, Strasbourg
- ITEP, Moscow
- LAM, Marseille
- NIKHEF, Amsterdam
- LOV, Villefranche
- University of Erlangen
- University of Leeds
- University of Sheffield
- University of Pisa & INFN/Pisa

ANTARES Site

Shore station: Institut Michel Pacha, La Seyne sur Mer

Coordinates: $42^\circ\,50'$ N, $6^\circ\,10'$ E

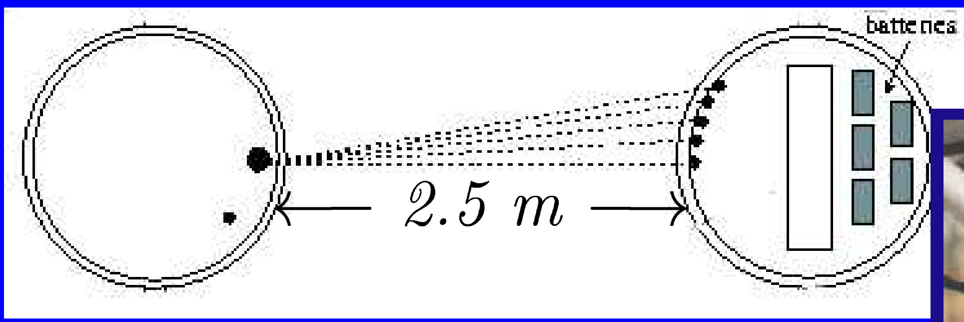
Depth: 2500 m

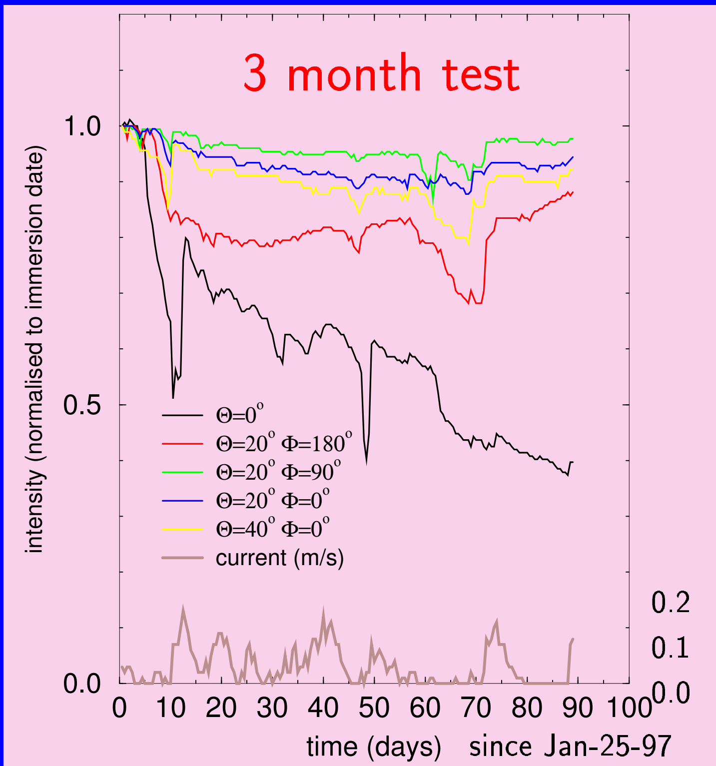
Distance to shore (cable length): 40 km

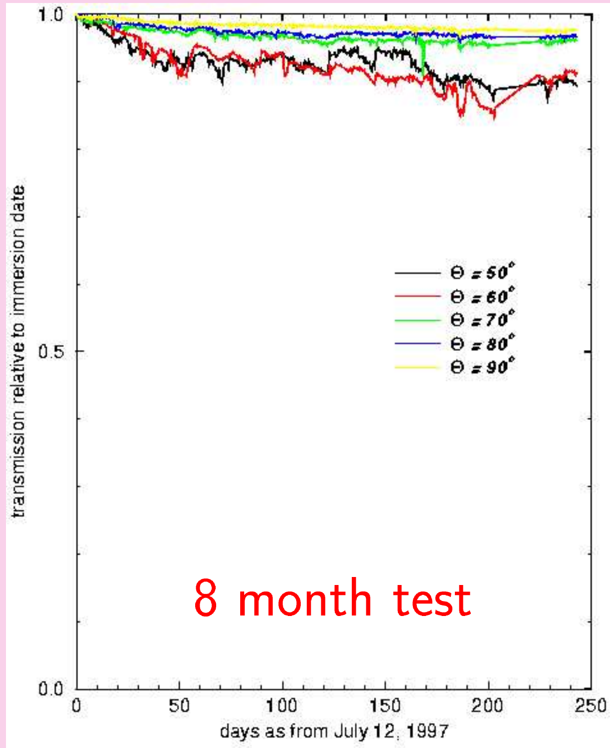
Biofouling

Sphere with blue LED

Sphere with photodiodes

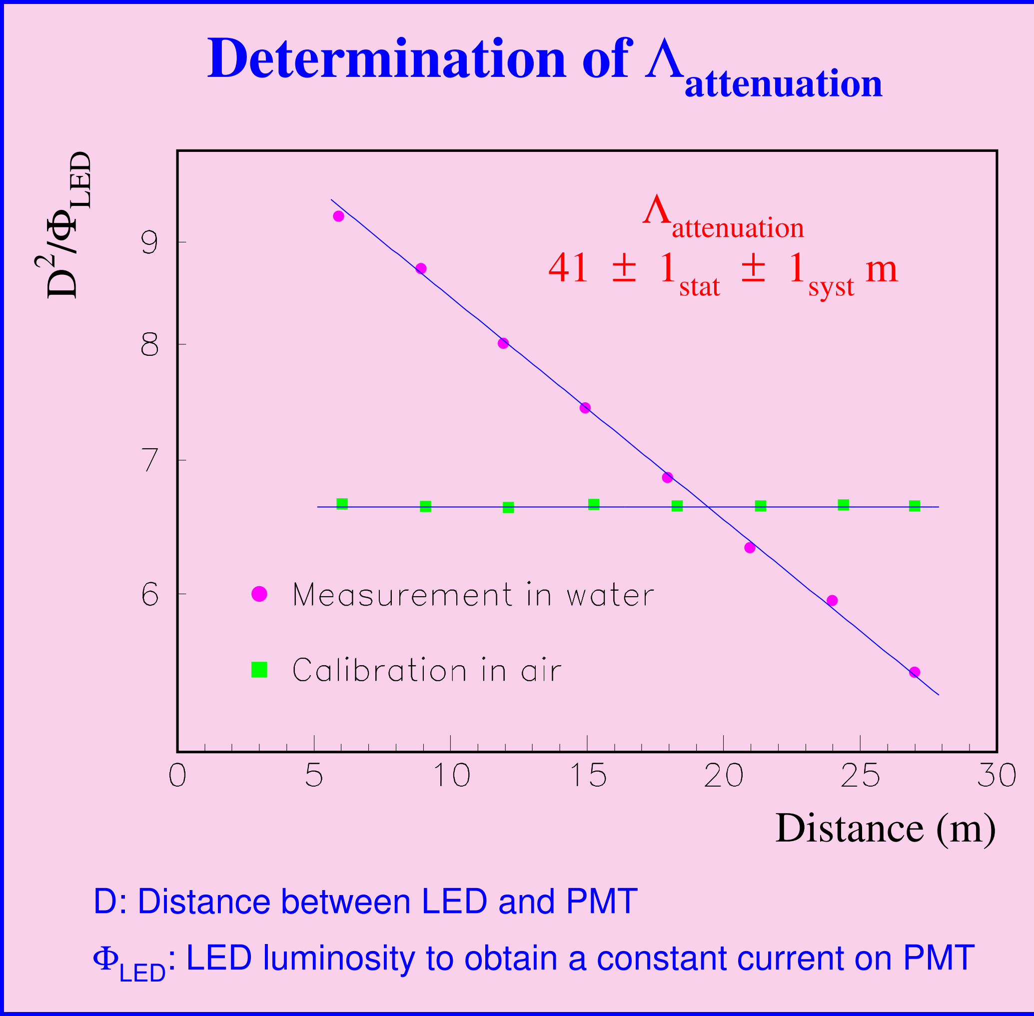






Loss <2% after 1 year at equator due to biofouling and sedimentation, saturates with time

Optical properties of the water



$\lambda_{abs} \approx 55$ m (466 nm); $\frac{\lambda_{scatt}}{1-\langle\cos\theta\rangle} > 100$ m

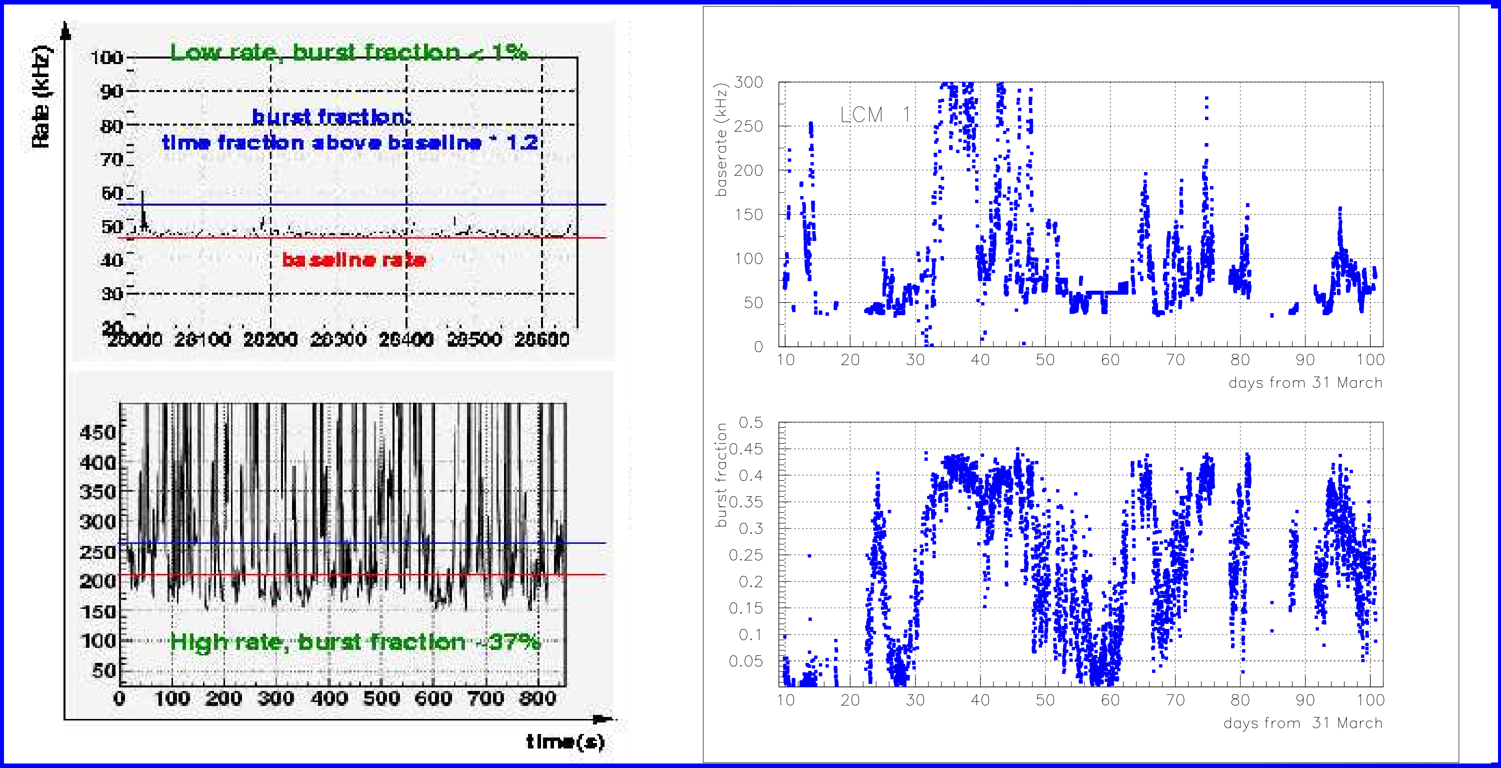
95% of photons emitted by 4π-source 24 m from a PMT are collected within 10 ns (466 nm)

Oceanological properties

Sea current: $\sim$6 cm/s (average); 19 cm/s (max)

Water temperature: 13.1°C

Water luminescence

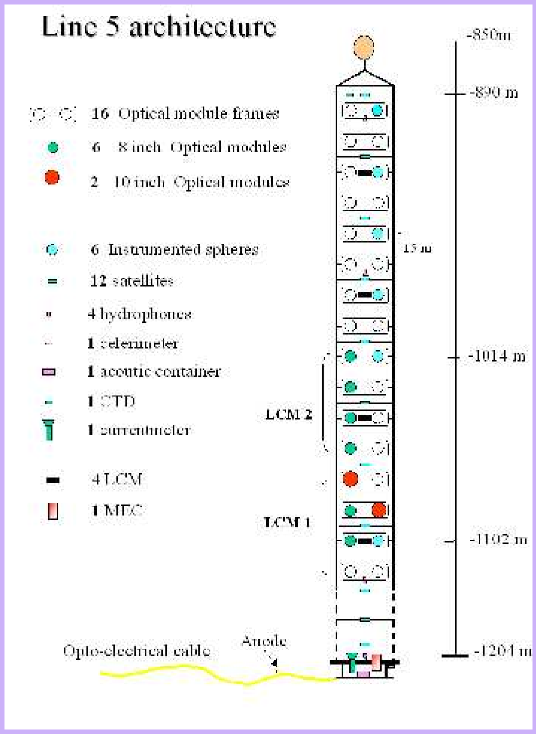


- Strong variability of rates: bursts and slow changes
- Some correlation between base line rate and burst fraction
- Mostly bioluminescence, ^{40}K rate ≈30 kHz (1 p.e.) per 10" PMT

The ANTARES milestones

The ANTARES milestones

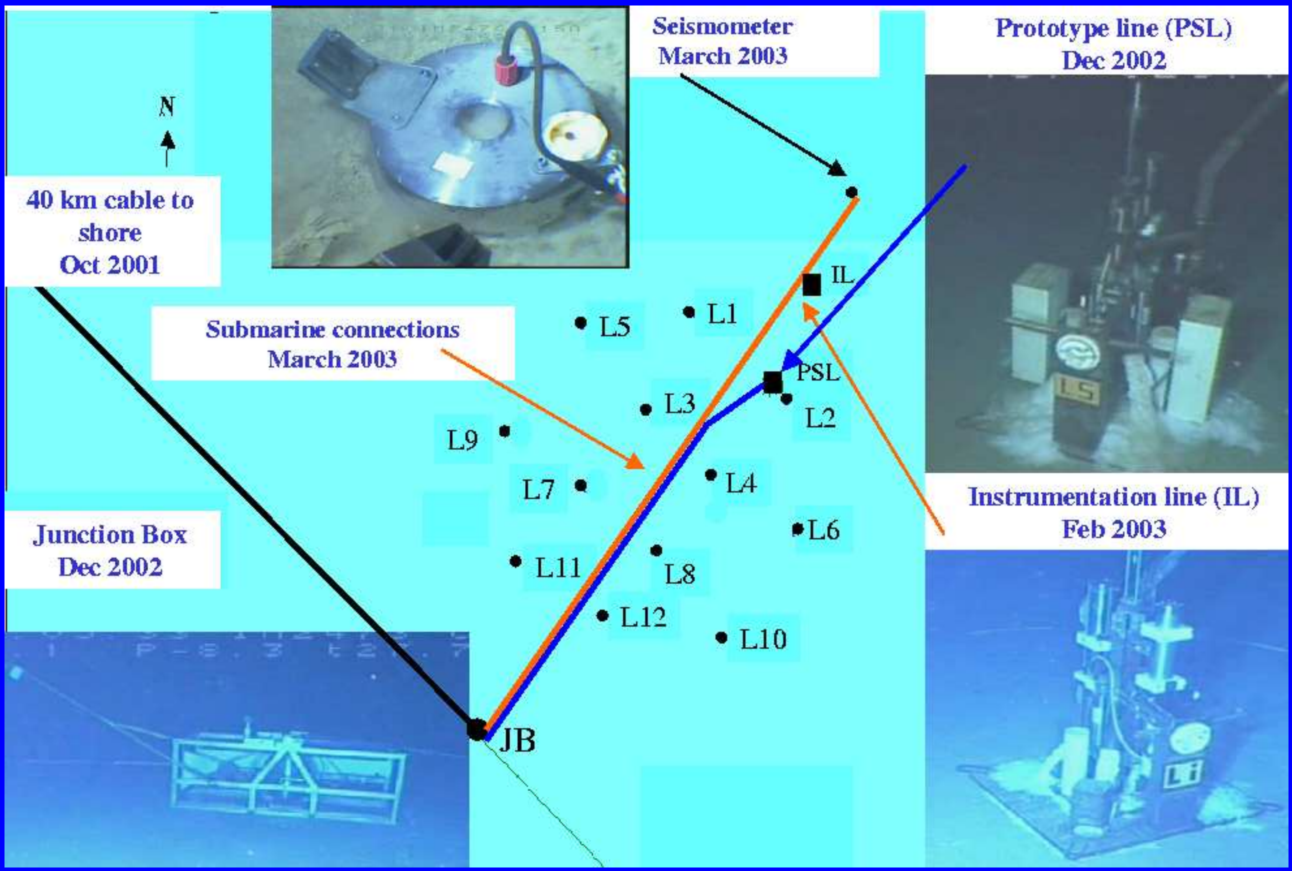
1996	ANTARES Project proposed, approved and started
1996–99	R&D program, site evaluation (stand-alone test lines)
1999	Project for large area telescope proposed, start of final design and construction
Nov 1999–Jun 2000	"Demonstrator string" (hydrological equipment + 7 OM), 1100 m depth, connection to shore with 37-km e/o cable, 50,000 atm. muons detected



- μ_{atm} zenith angle distribution reproduced reasonably well
- ~50% contribution of multiple muons - as expected
- Test of positioning (acoustic rangemeters, compasses, tiltmeters):
  - Precision of relative distances between 2 elements: 5 cm
  - Absolute positioning: ~1 m

2001 TDR (Technical design report) completed

Oct 2001	MEO cable deployed (48 fibers)
Apr 2002	Production of 900 OMs started (10" Hamamatsu R7081-20)
Dec 2002	Final-design prototype line (15 OM) deployed
Feb 2003	Instrumentation line deployed
Mar 2003	Prototype and instrumentation lines put into operation (connected to MEO cable by a manned submarine)
May, July 2003	Prototype and instrumentation lines recovered



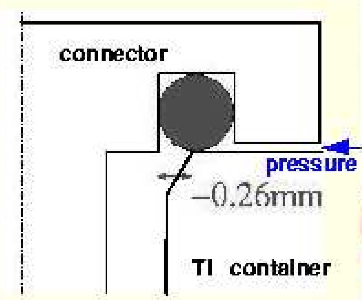
Two problems and solutions

The clock fiber failure

- **The symptom:**
  The clock signal did not arrive at the readout modules (both lines!)
- **The consequences:**
  → no data with ns time resolution;
  → no measurement of signal charges;
  → no acoustic positioning.
  However, we still were able to
  → measure PM rates;
  → control HV settings, thresholds;
  → take slow control data (compasses, tiltmeters etc.).
- The diagnostic:
  One plastic tube around the optical fiber for the clock signal collapsed.
  ⇒ Plastic material changed by manufacturer without notification.
  ⇒ Even worse: material not qualified for high-pressure applications!
- **The remedy:**
  Final cable design modified (use steel tubes now).

A water leak

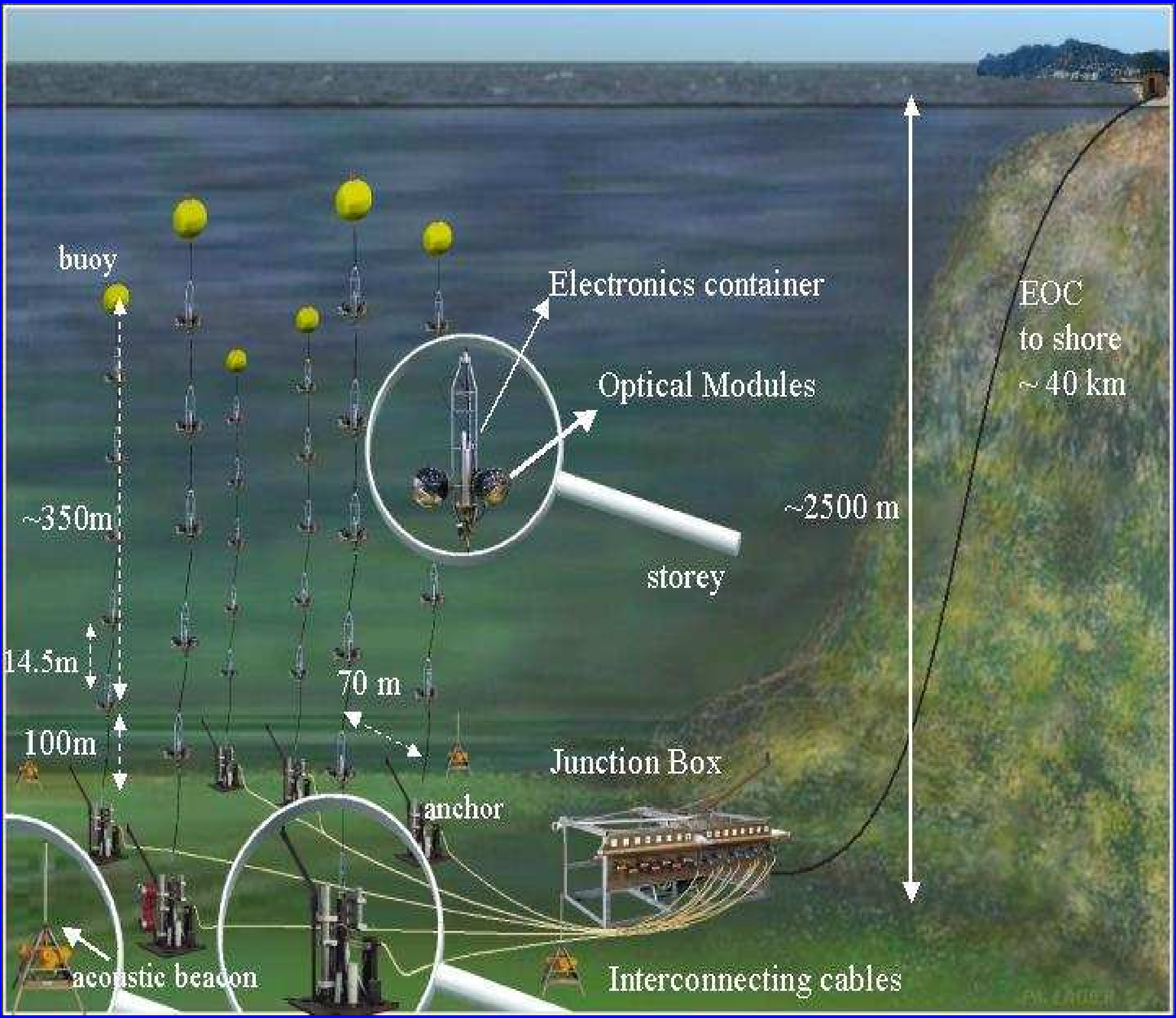
- **The symptom:**
  The mini instrumentation line stopped to work on April 11.
- **The consequence:**
  Immediate recovery of the line.
- The diagnostic:
  An o-ring secured connector had developed a leak.
  Specifications of hole diameter and tolerances by manufacturer were wrong.
  No problems seen in pressure tests!



- **The remedy:** different connectors.

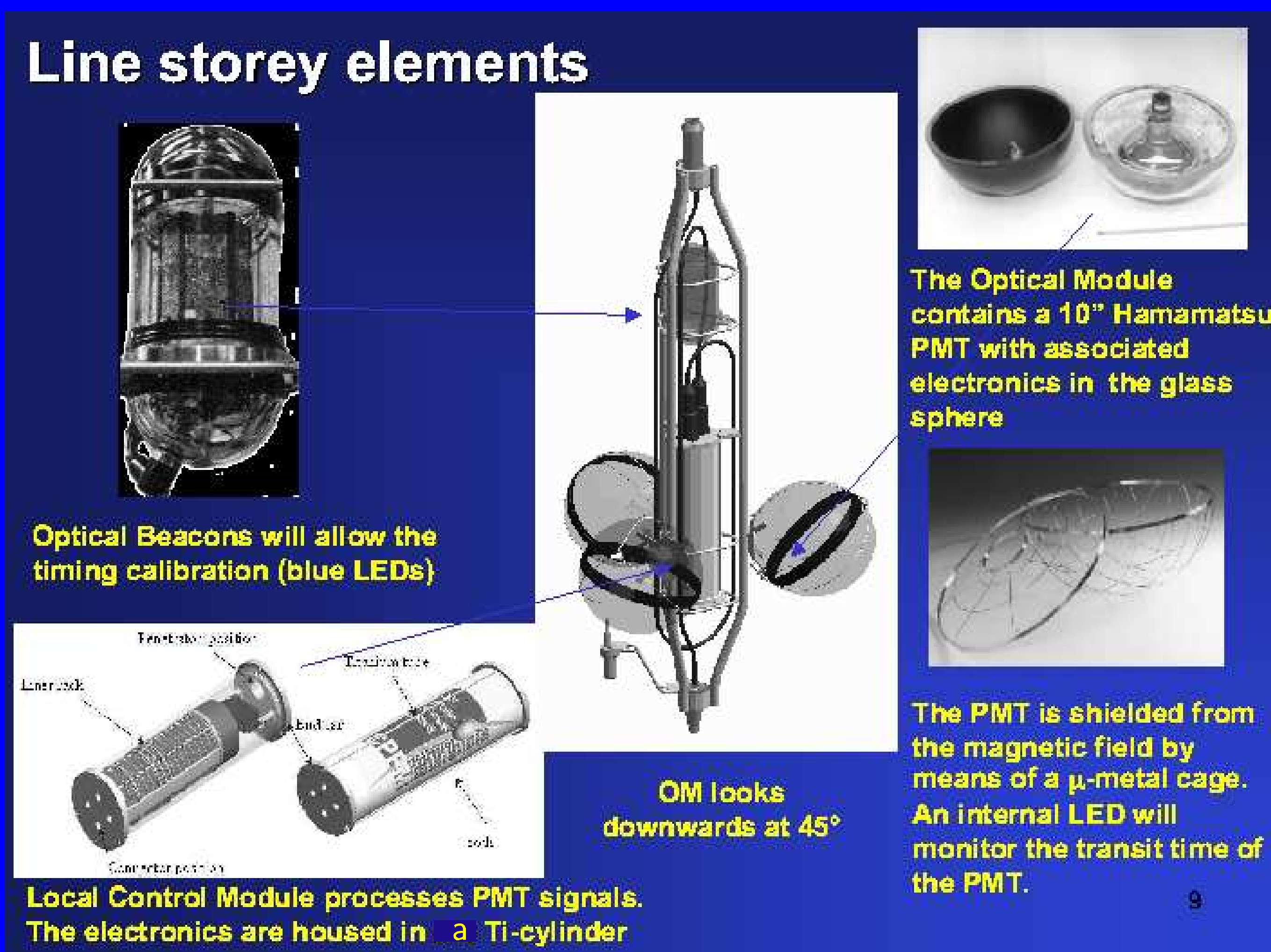
Prototype deployments confirmed successful sea operation procedures, junction box operation and data readout chain and helped in diagnosing the two problems described above.

Detector design



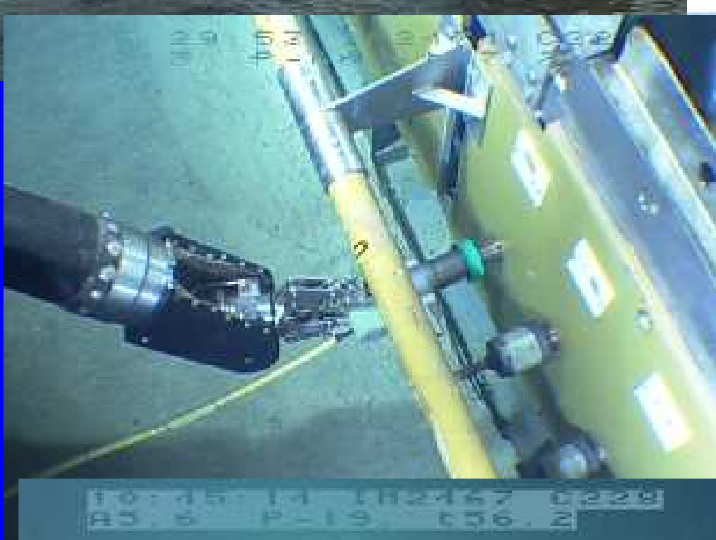
12 strings; 25 storeys/string;
3 OM/storey; 14.5 m between storeys;
~70m between strings, 900 PMTs

Hamamatsu 10" TTS=2.7ns QE>20%
(330 nm $< \lambda <$ 460 nm)



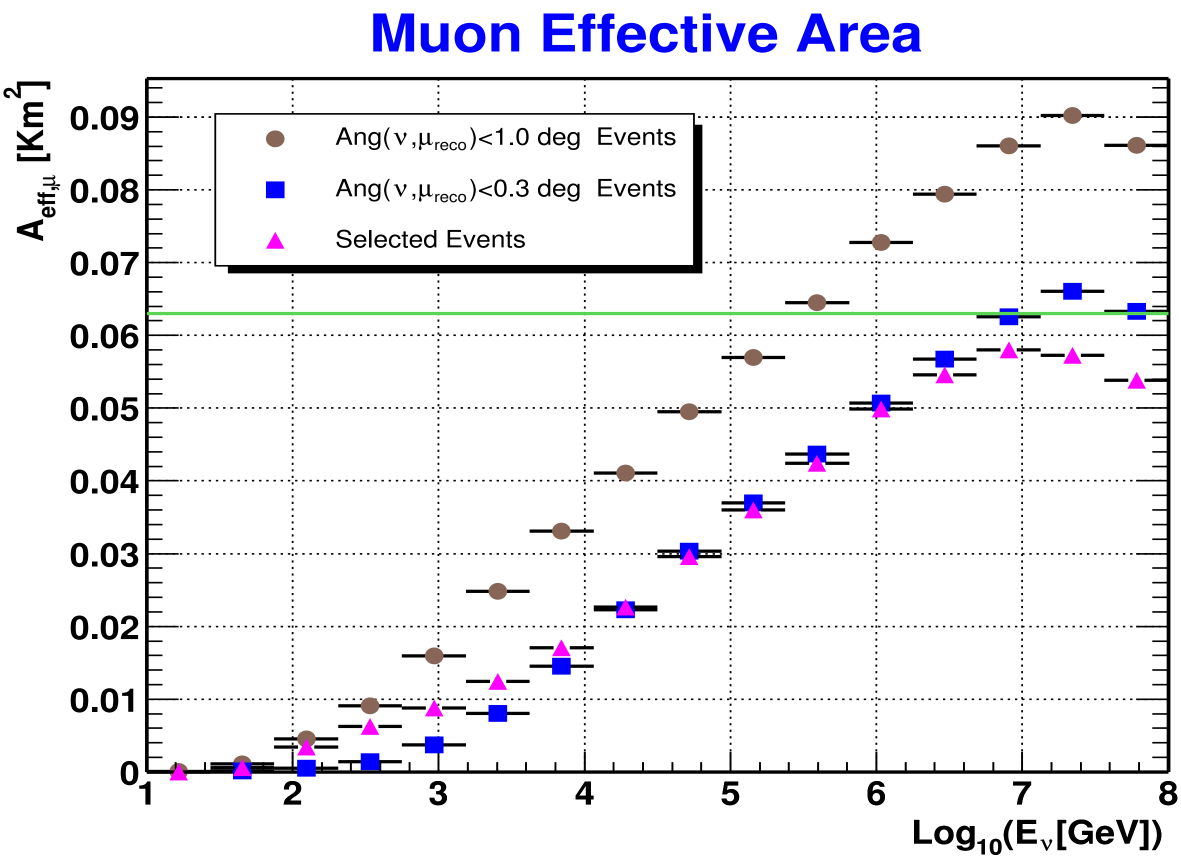
PMT readout: 2 Analog Ring Samplers - time and charge digitization. Wave form digitization for high amplitude pulses (~2%).
All data to shore (~1 MB/s/PMT, ~1 GB/s in total reduced down to ~1 MB/s by on-shore data filter).
100 PC farm on shore to process data.

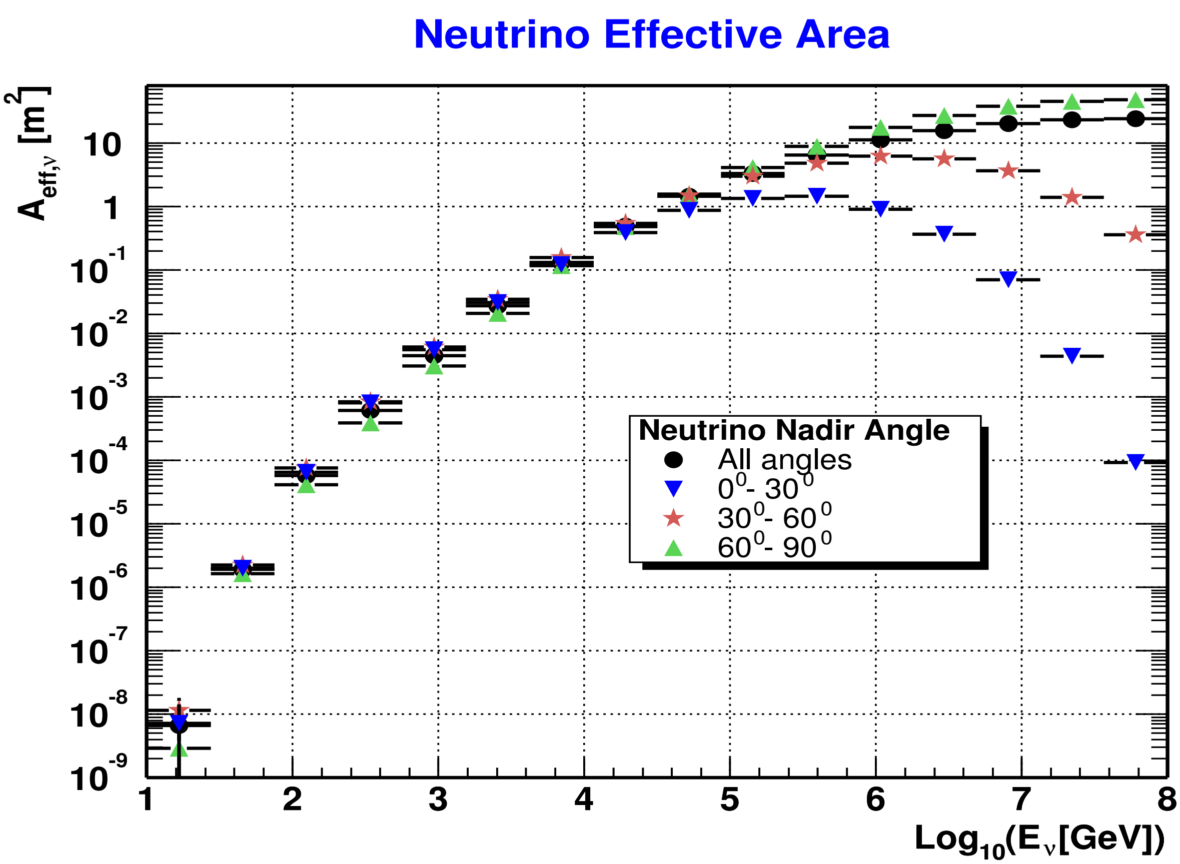
Sea operations



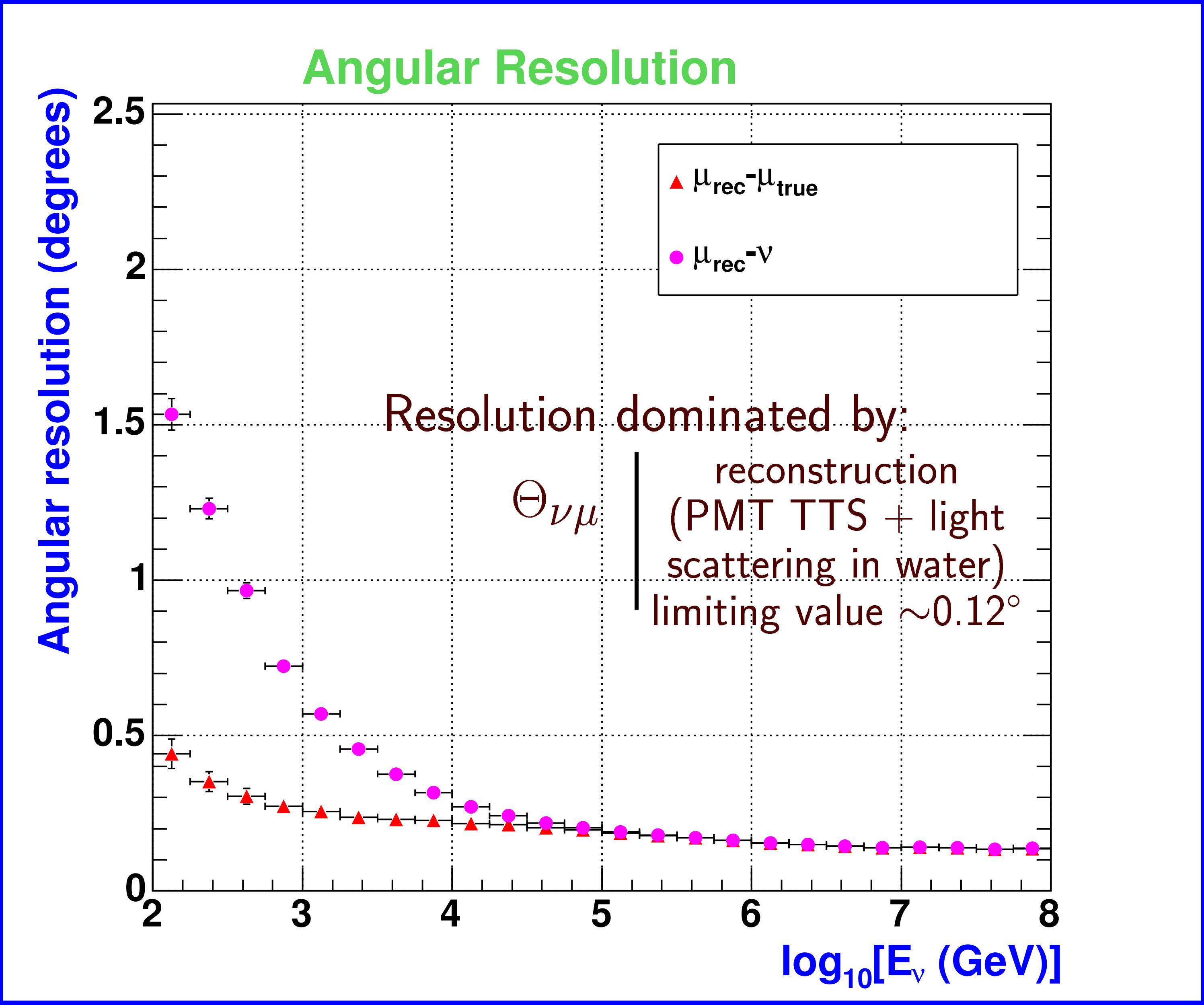

Physics performance

Effective areas





Angular resolution



Median angular reconstruction error vs E_ν

For a E^{-2} neutrino spectrum ~95% (~70%) of the events are reconstructed with an error <1° (<0.3°)

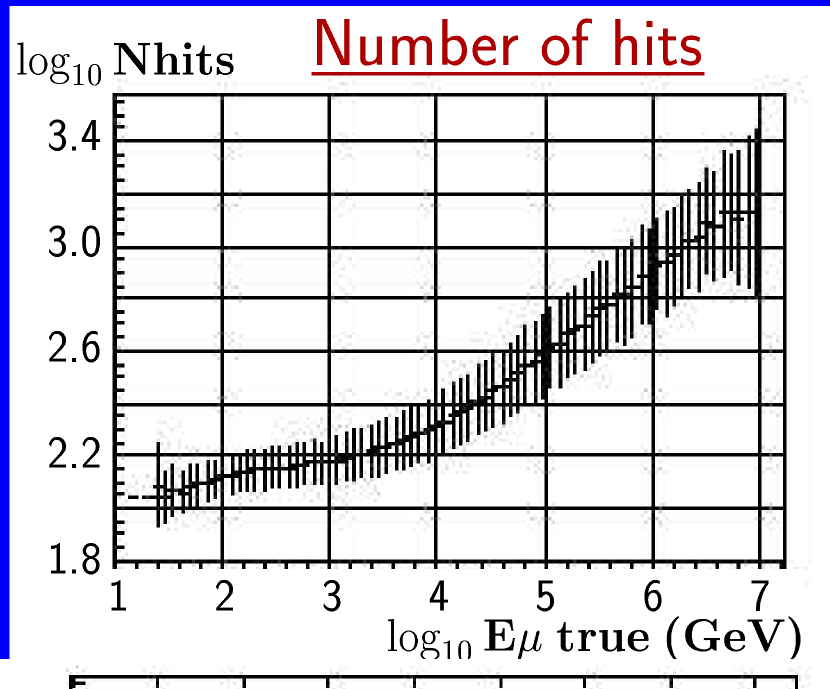
Energy resolution

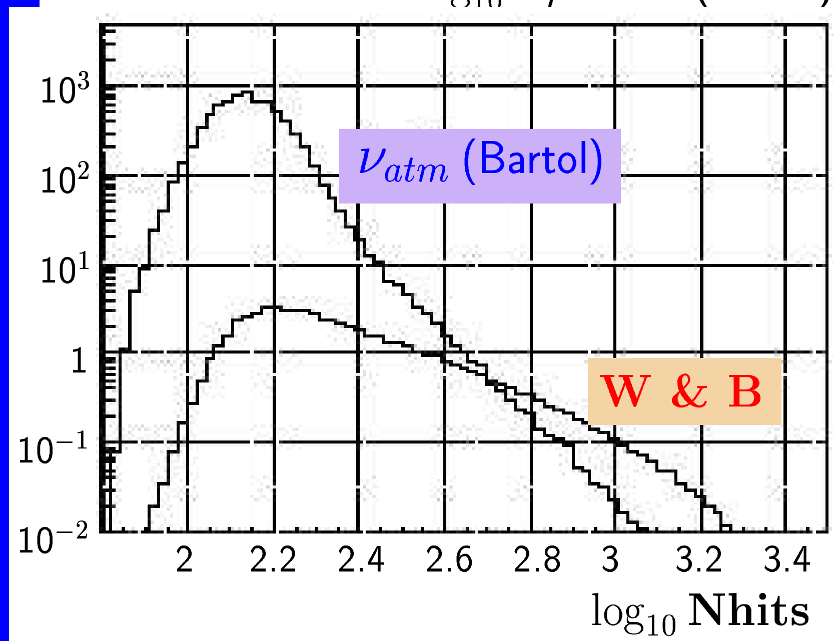
Energy estimated from the measurements of the light intensity along a muon track.

Various estimators:

- number of hits
- hit amplitudes
- $dE/dx =$ amplitude/track length

$\sigma(\log_{10} E_{rec}/E_{tr})$~0.3-0.4



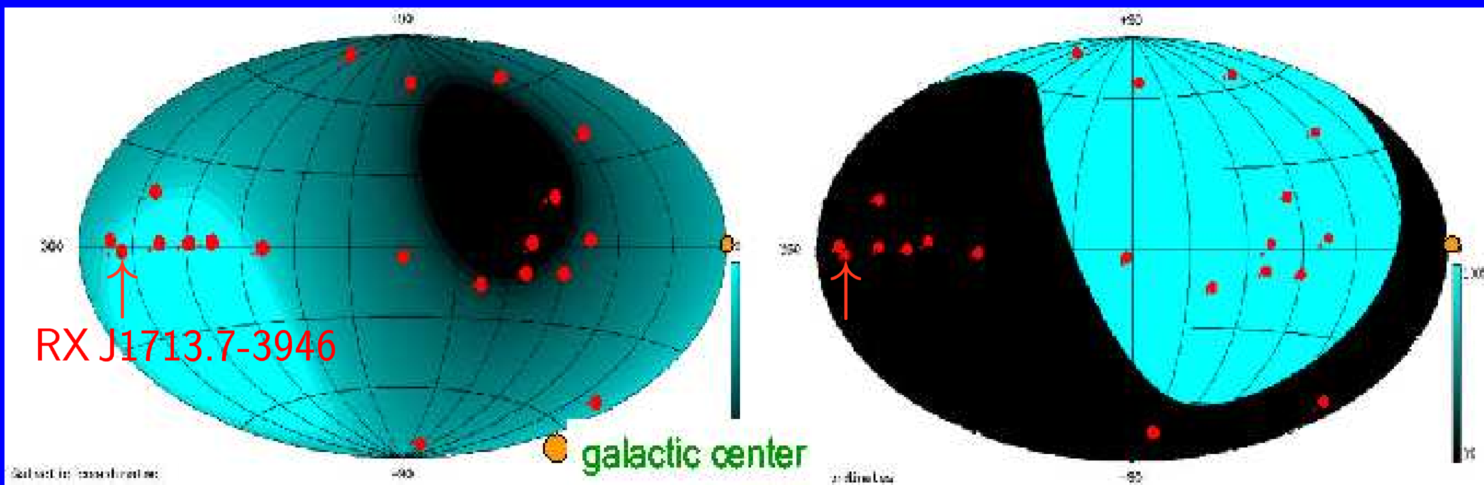


Energy resolution can be used to discriminate between atmospheric and cosmic neutrino spectra.

Sensitivity (90% CL) after 1 yr ($E_\mu >$50 TeV):
$9.34\times10^{-8}\,E^{-2}\,GeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}$

Sky coverage

TeV photon sources



ANTARES - 42° 50′ N

4 sources: 100% of the time
8 sources: >50% <100%
9 sources: >0% <50%
3 sources: never seen

AMANDA - South Pole

12 sources: 100% of the time
12 sources: never seen

8 'common' sources

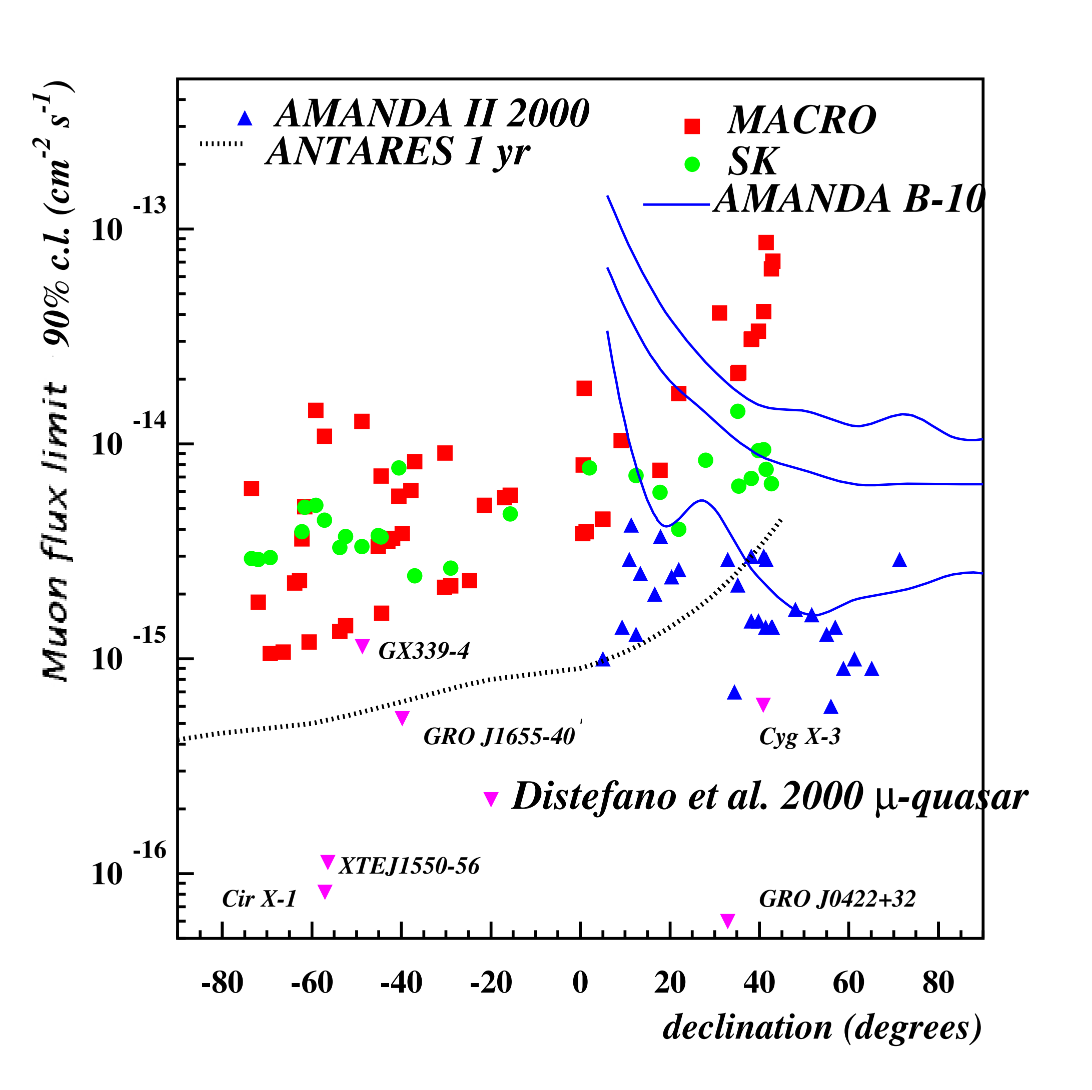
RX J1713.7-3946: supernova remnant, indication of π° decay spectrum $\rightarrow$ hadronic mechanism of CR production [CANGAROO, Nature 416 (2002) 823] though there is some debate [O.Reimer et al., Astron. Astrophys. 390 (2002) L43]

78% of tne time visible by ANTARES, never by AMANDA

- sky coverage 3.5 π sr
- whole Southern hemisphere
- significant fraction of Northern hemisphere
- Galactic centre seen 67% of the time
- Overlap with AMANDA: 0.5 π sr instantaneous common view, 1.5 π sr common view per day.

Point-like neutrino sources

Upper limits on ν_μ induced μ flux (90%CL) vs declination for E^{-2} neutrino spectrum ($E_\nu \geq 10$ GeV)



The method: excess of events above ν_{atm} background

MACRO: 1338 ν_{atm}'s, 6 yrs, angular resolution $0.5°$.

SK: 2369 ν_{atm}'s, 4.6 yrs, angular resolution $2°$.

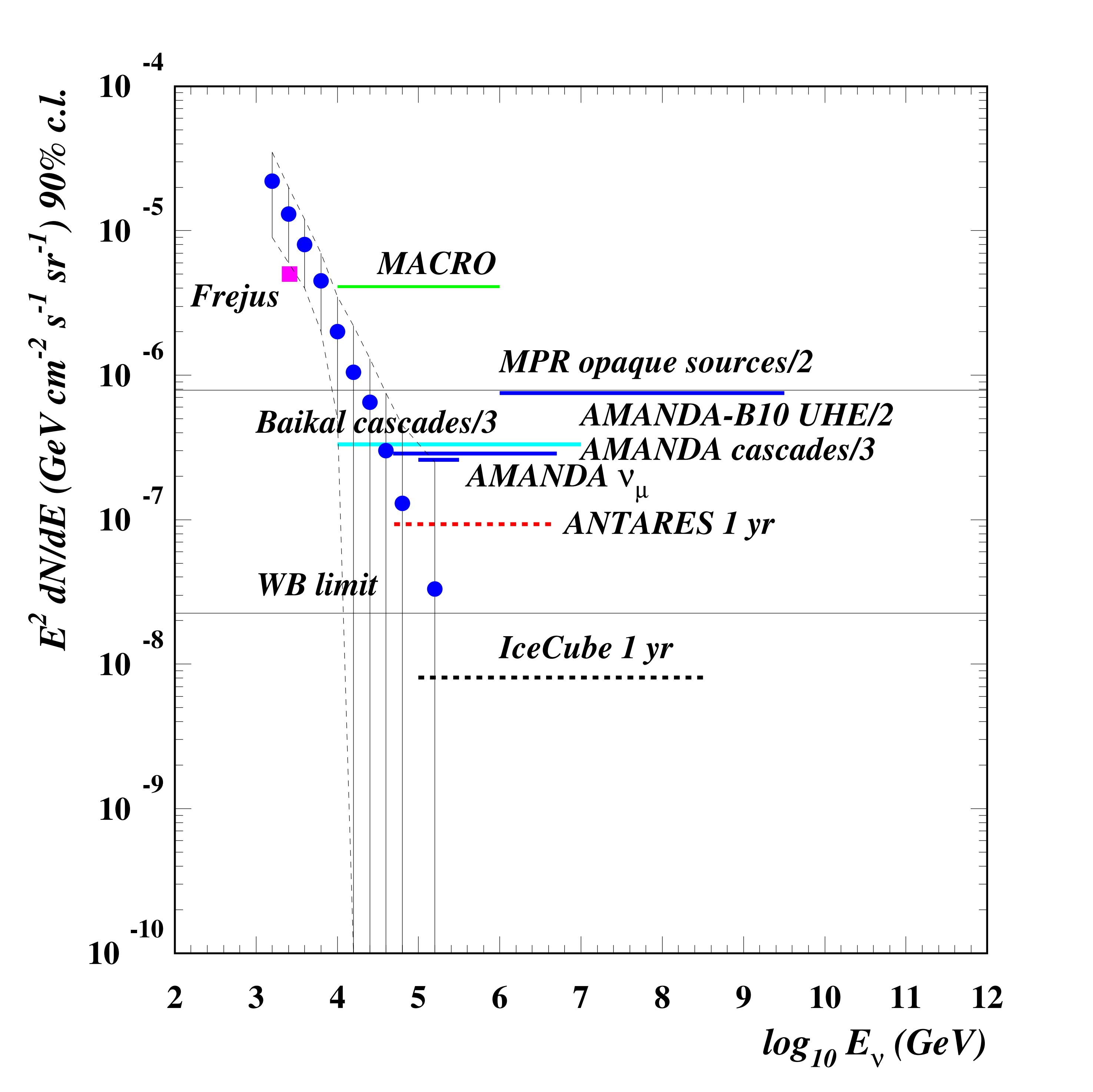
AMANDA B-10: 130 days, angular resolution $3.9°$.

AMANDA-II: 197 days.

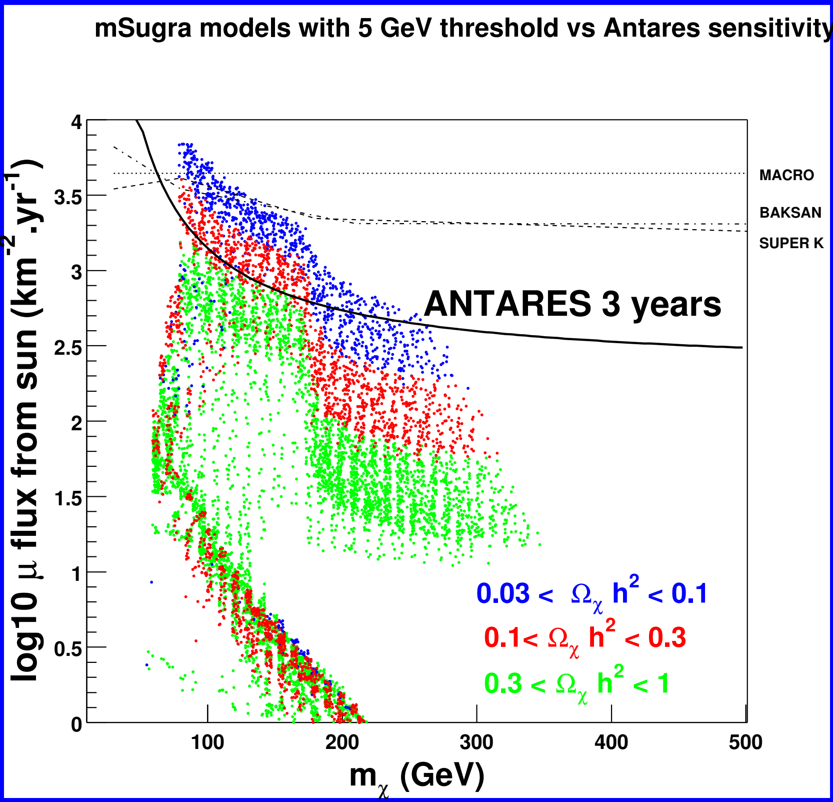
ANTARES: 1 yr, $\sim$2500 ν_{atm}'s, angular resolution $\sim 0.15°$ above 10 TeV.

Diffuse neutrino fluxes

Sensitivity to diffuse ν_μ fluxes, i.e. integrated over the full acceptance of the detector (E^{-2} spectrum assumed)

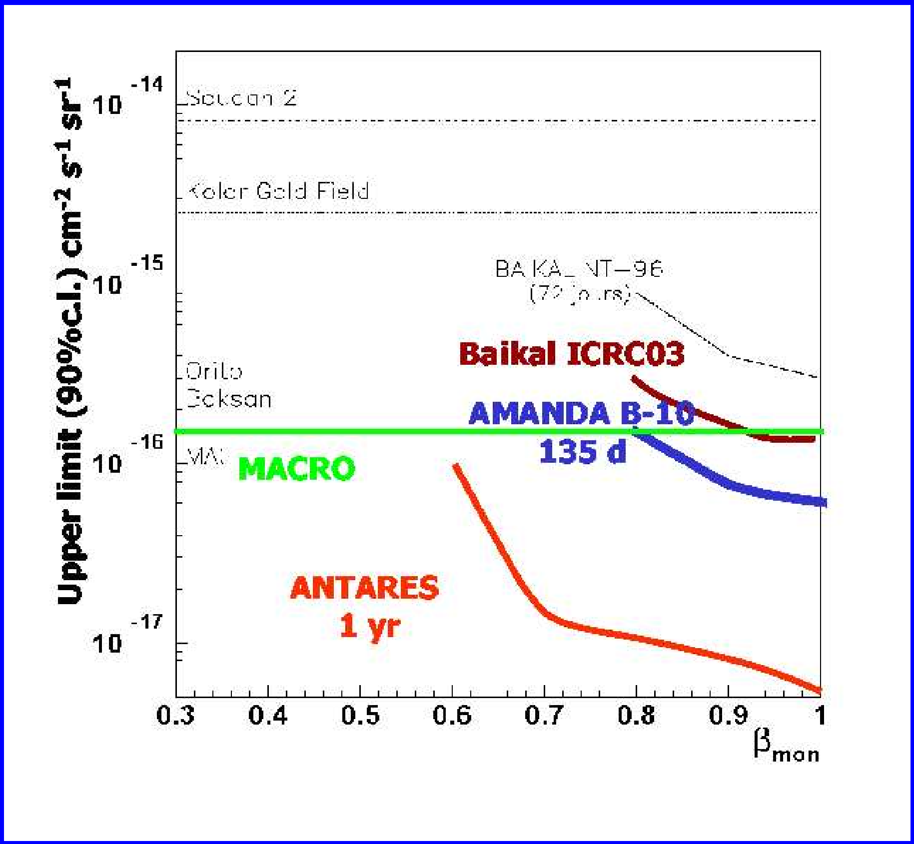


Dark matter



ANTARES sensitivity to μ's induced by ν's from χ annihilation in the core of the Sun

Experimental limits on magnetic monopole flux



New phenomena?..

???

"...because then we might find something that we weren't looking for, which might be just what we were looking for, really."

A. Milne, "Winnie-The-Pooh"

SUMMARY

- The construction of the ANTARES neutrino telescope in the Mediterranean has started
  - ◇ EOC and junction box permanently installed
  - ◇ mass production for the complete detector started
  - ◇ detector will be completed by 2007
- Experience from pre-production test lines: verification of the detector design and sea operations
- Technical problems have been understood and will be avoided in future
  - ◇ a new test with mini-line is needed and planned for the end of 2004
- Scientific programme includes neutrino astrophysics, dark matter searches and other exotica
- Common efforts between European groups (ANTARES, NEMO, NESTOR) toward a km3 detector in the Mediterranean