Under-H_2O ν experiments

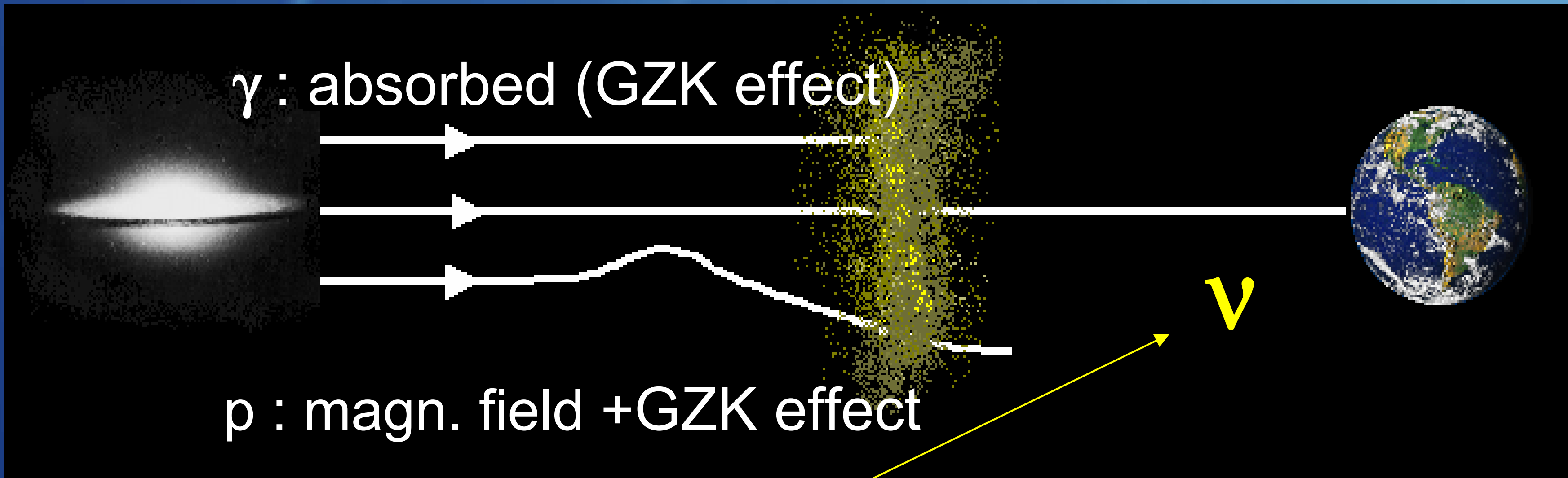
Chantal RACCA

IReS Strasbourg

Outline of the talk

- ν : a cosmic messenger
- Why under H_2O detectors ?
- Detection principle
- Physics goals
- Detectors : status and results
- Conclusions

ν : a cosmic messenger



Neutrino

- Source exploration on cosmologic distances
- In the heart of sources…
- Weakly interacting $\rightarrow$ large detection volume

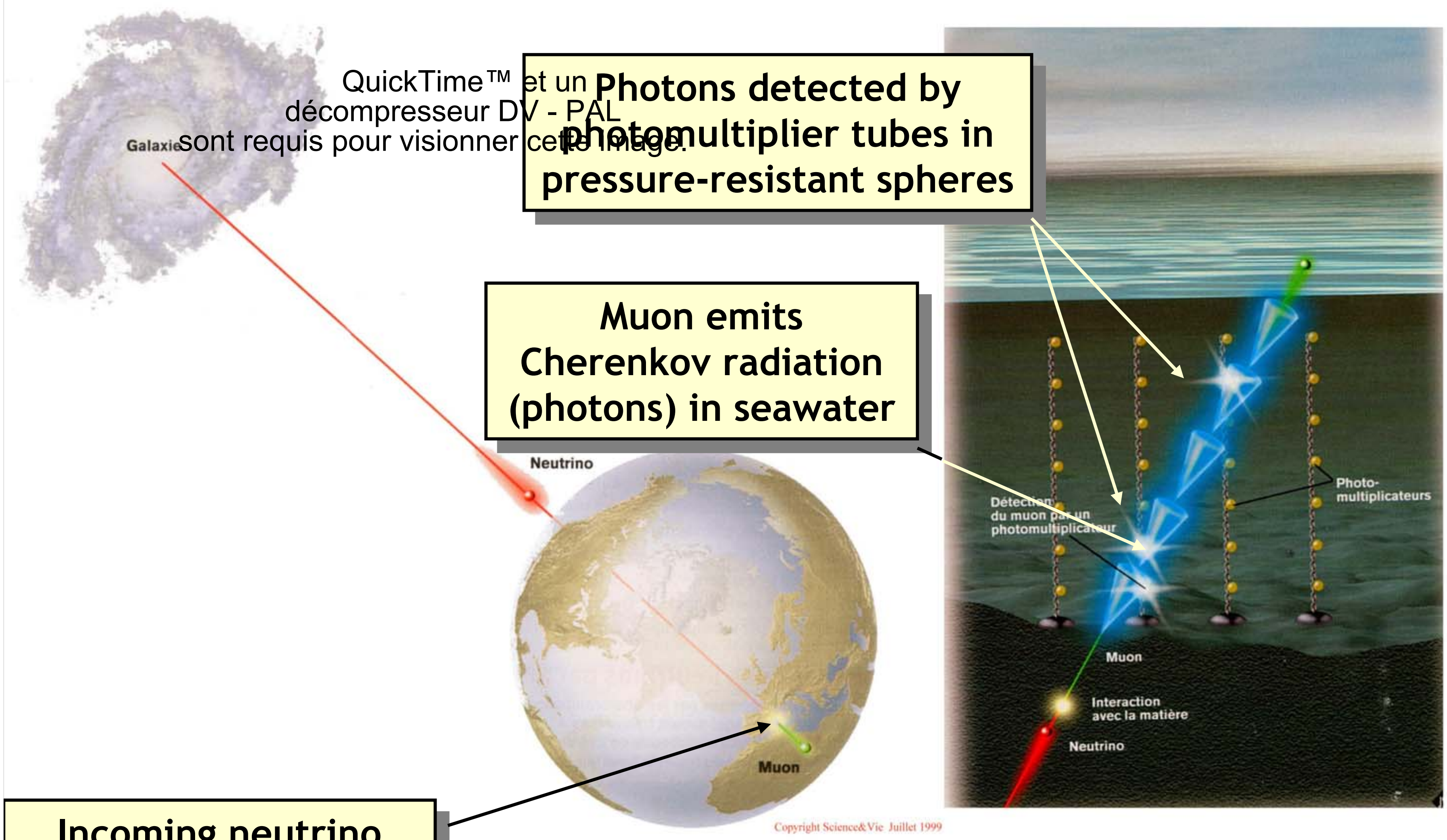
Why under-H_2O detectors ?

Detection of HE ν requires a **km scale** detector

Construction of such detectors possible only using natural transparent media: **polar ice** or **sea/lake water**

Difficult technological challenge

Detecting Neutrinos

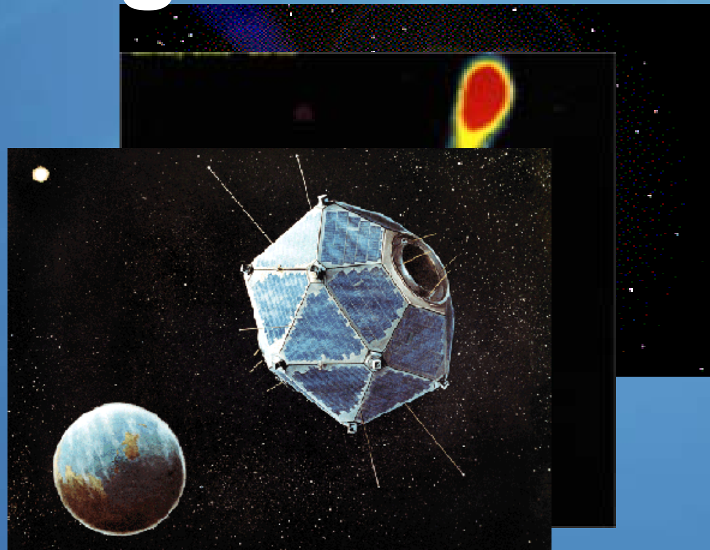


Photons detected by photomultiplier tubes in pressure-resistant spheres

Muon emits Cherenkov radiation (photons) in seawater

Incoming neutrino interacts to produce a muon

What are we looking for?



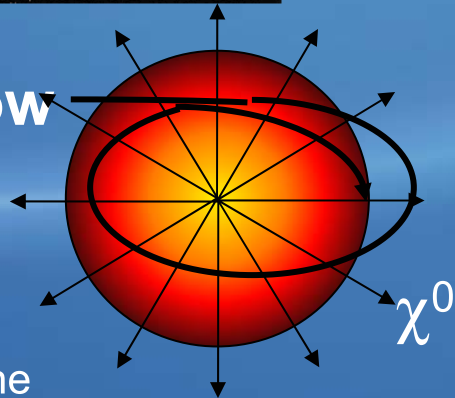
Neutrinos from galactic sources

- –Pulsars
- –Young Supernova Remnants (up to 100 ev/year/km^2
- –Micro quasars (SS433: up to 250 ev/year/km^2)

Neutrinos from extragalactic sources

- –Active Galactic Nuclei (AGN) steady
- –Gamma Ray Bursts (GRBs) transient (1-100 s)

Neutrino astrophysics could open a new window on the Universe



Dark Matter

neutrinos from the annihilation of neutralinos in the Sun, the Earth or the Galactic Centre (10 GeV < E_ν < 1 TeV)

+ oceanography, biology, seismology …

Needed performances

Good angular resolution

Ghost fighting

Good energy estimation

High reliability

Detectors : status and results

DUMAND : stopped in 1996

BAIKAL : takes data (http://www.ifh.de/baikalhome.html)

AMANDA : takes data (http://amanda.uci.edu)

ICECUBE : project (http://icecube.wisc.edu)

ANTARES : project (http://antares.in3p3.fr)

NEMO : project (http://nemoweb.lns.infn.it)

NESTOR : project (http://www.nestor.org.gr)

KM3 : proposal (http://www.vlvnt.nl)

The Baikal Experiment

Institute for Nuclear Research, Moscow, Russia.

Irkutsk State University, Irkutsk, Russia.

Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia.

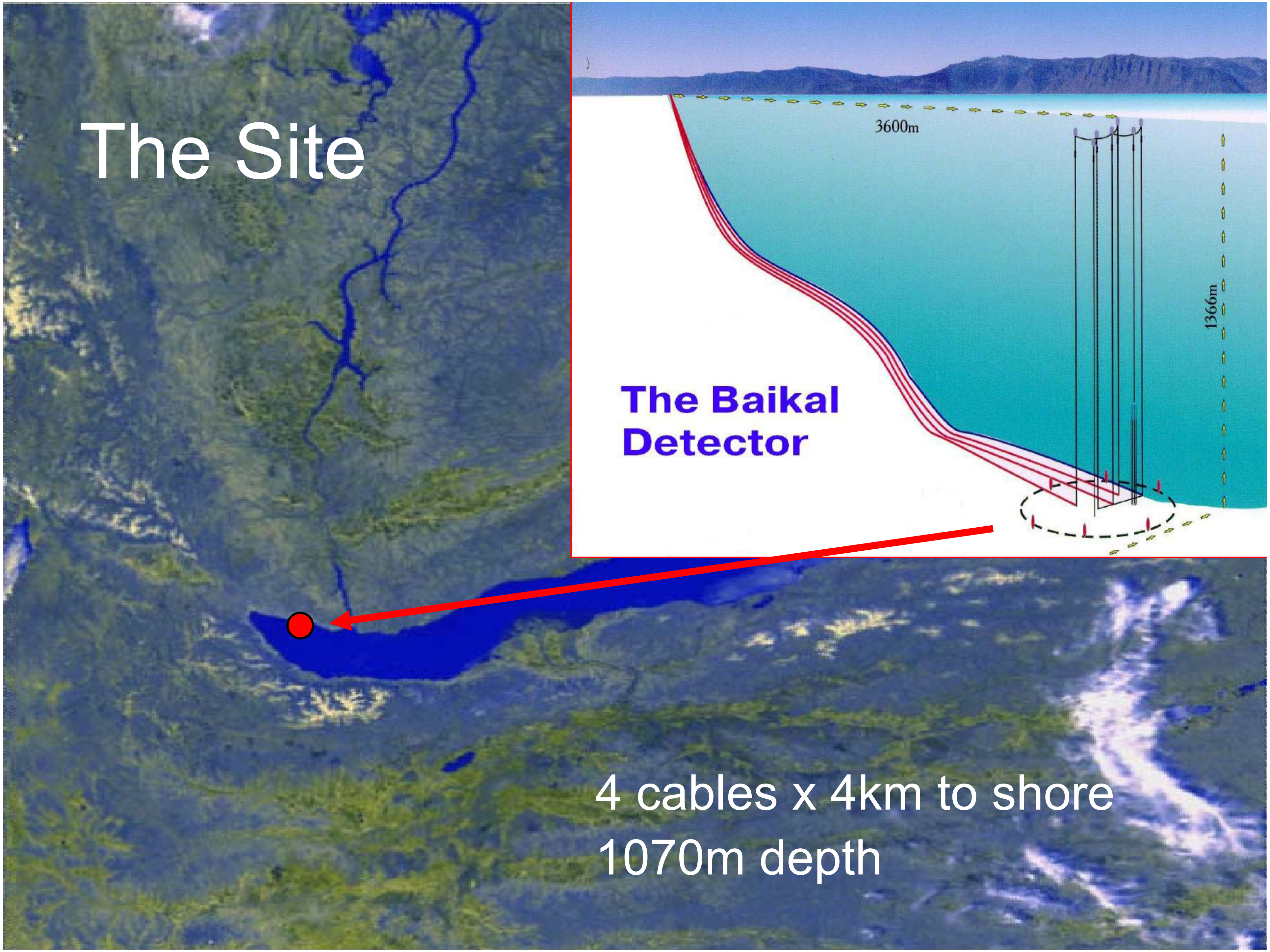
DESY-Zeuthen, Zeuthen, Germany.

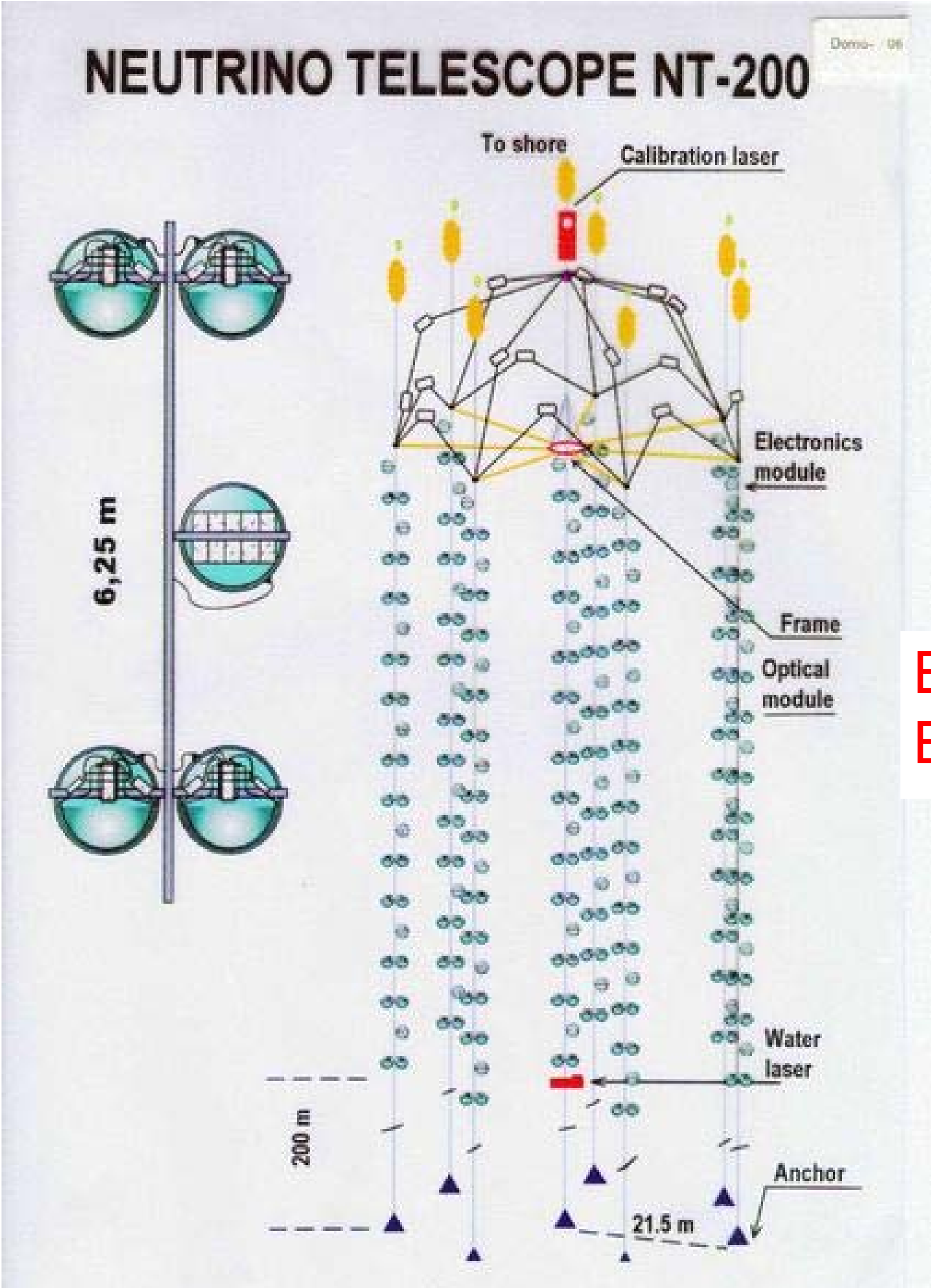
Joint Institute for Nuclear Research, Dubna, Russia.

Nizhny Novgorod State Technical University, Nizhny Novgorod, Russia.

St.Petersburg State Marine University, St.Petersburg, Russia.

Kurchatov Institute, Moscow, Russia.


The Site
3600m
1366m
The Baikal
Detector
4 cables x 4km to shore
1070m depth



- 8 strings: 72m height
- 192 optical modules
- pairwise coincidence
  □ 96 space points
- calibration with N-lasers
- timing ~ 1 nsec
- Dyn. Range ~ 1000 pe

Effective area: 1 TeV ~2000 m^2

Eff. shower volume: 10TeV ~0.2Mt

Height x = 70m x 40m, $V=10^5 m^3$

Water properties :

Abs. Length: 22 ± 2 m   Scatt. Length ~ 30-50 m

Ice as a natural deployment platform

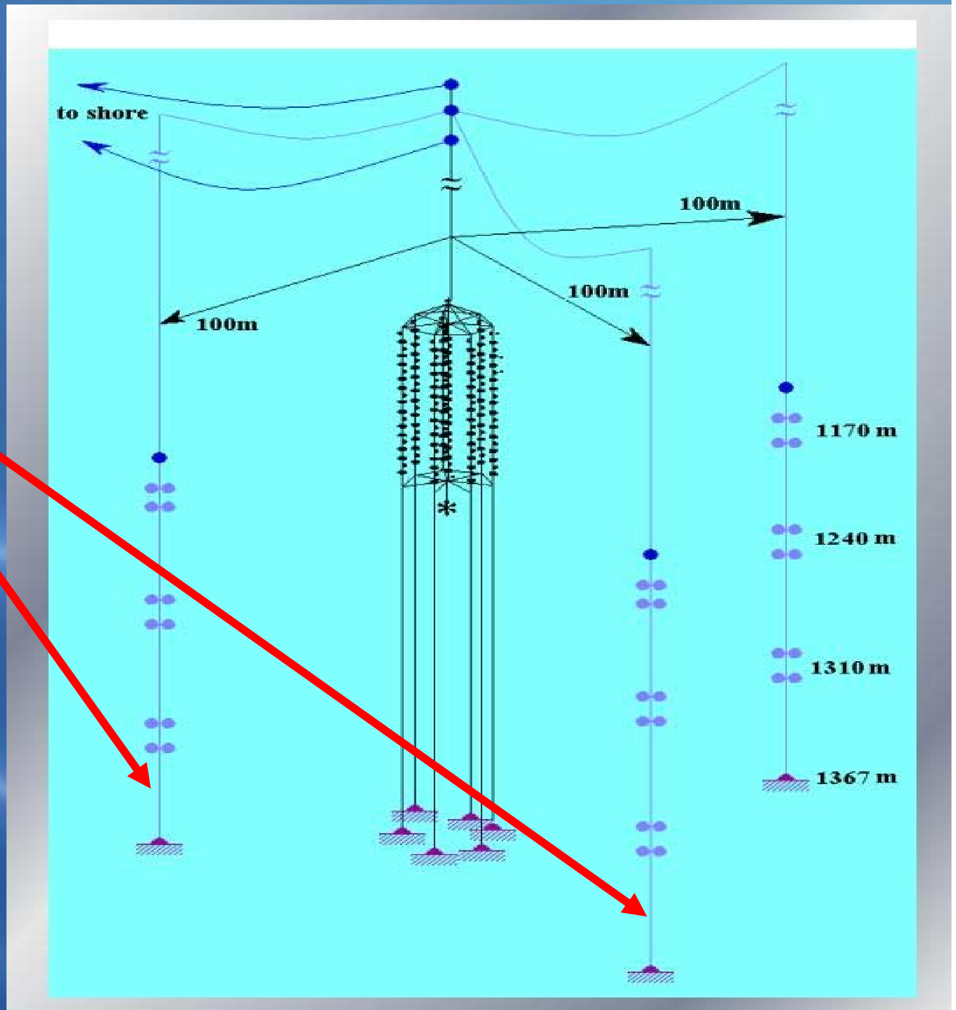
- Ice stable for 6-8 weeks/year:
  - Maintenance & upgrades
  - Test & installation of new equipment
  - Operation of surface detectors (EAS, acoustics,…)

Optical Module – Pair

Few upward pointing pairs get „hats“ against sedimentation

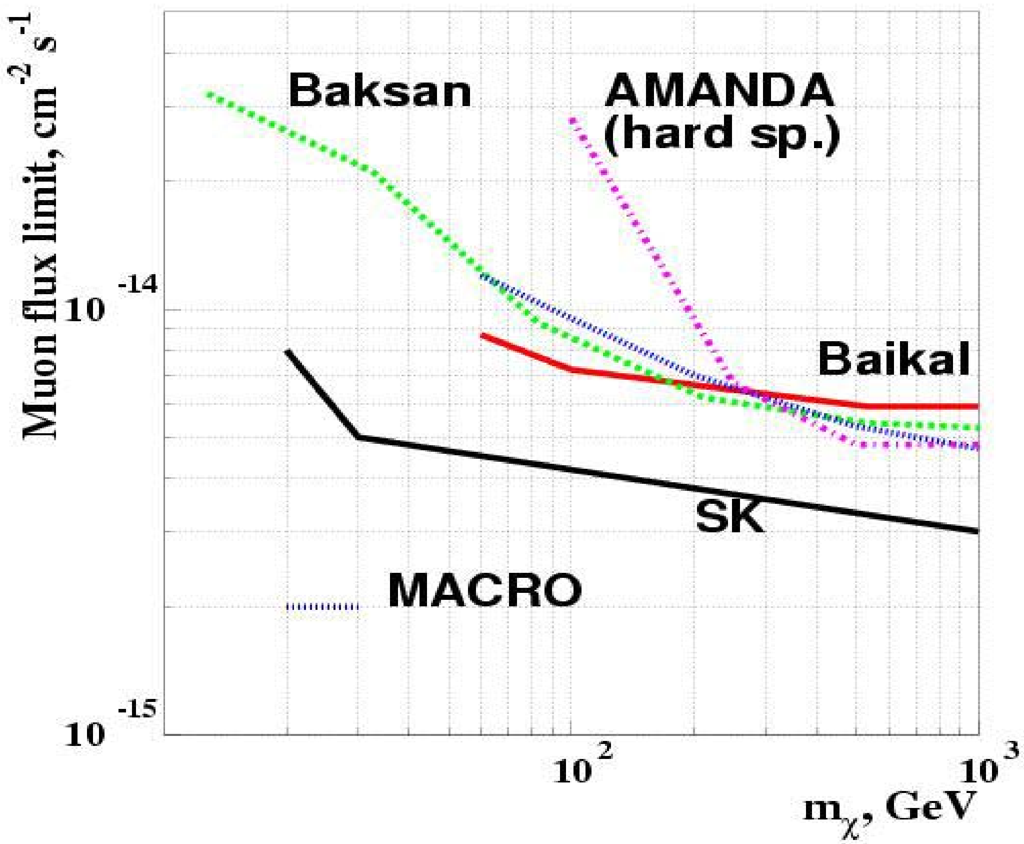
NT-200+ status

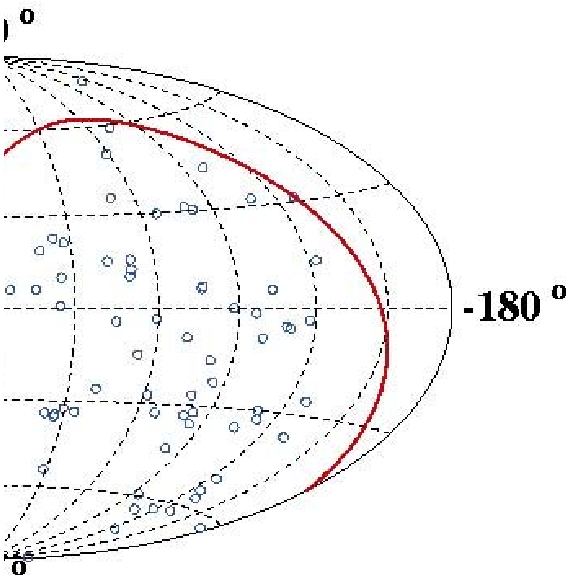
2004:
- new cable to shore
- DAQ system has been improved
- two of three outer strings are installed



2.3 10^4 common events are taken during 364 hours life time (0.017 Hz)

36 additional PMTs on 3 far ‘strings‘
→ 4 times better sensitivity !

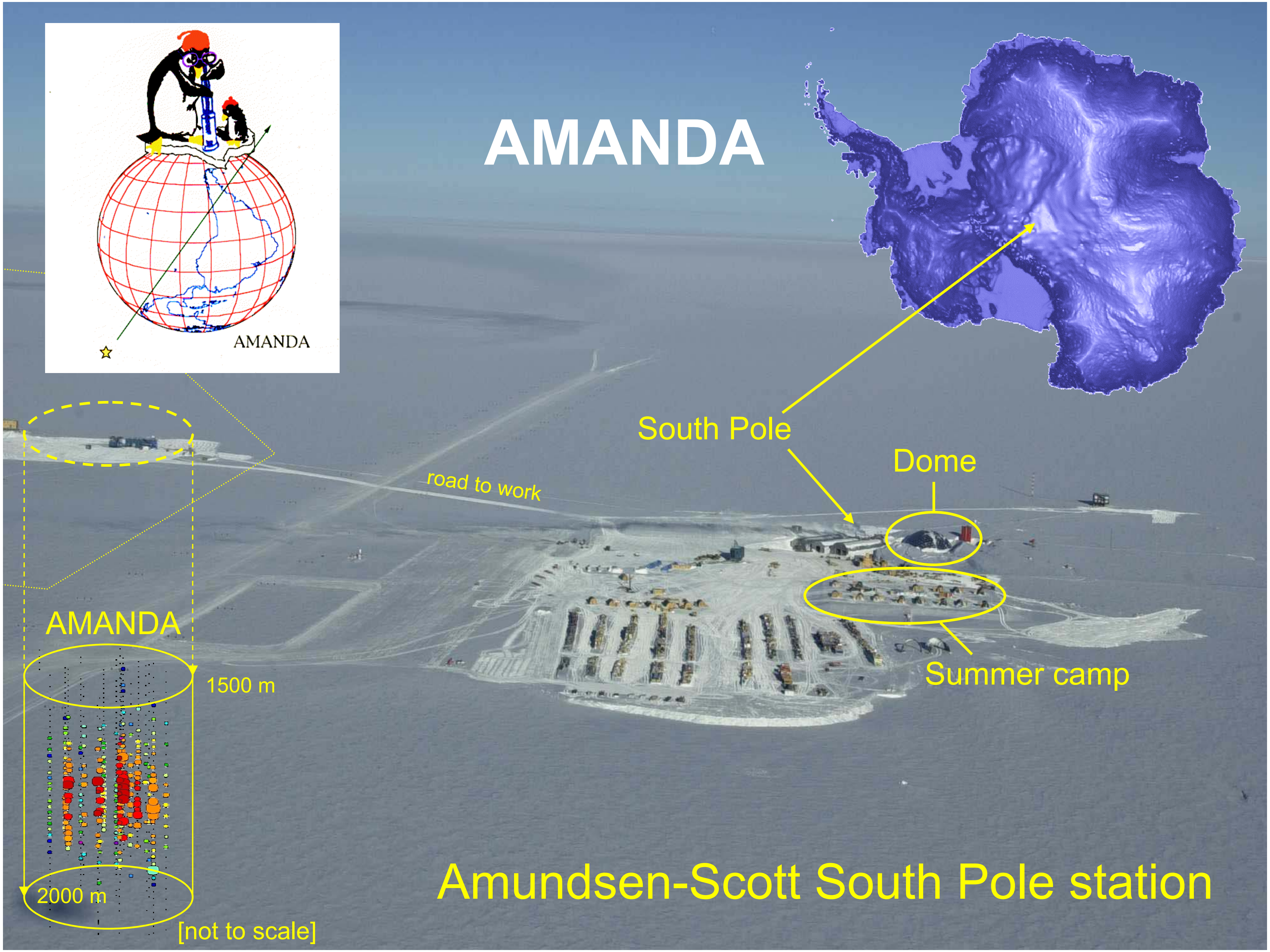




MP

005

tector (km^3)


AMANDA
AMANDA
South Pole
Dome
road to work
Summer camp
AMANDA
1500 m
2000 m
[not to scale]
Amundsen-Scott South Pole station

Aerial View of the Amundsen-Scott Research Station

going there …

and landing

The AMANDA Collaboration

United States

Bartol Research Institute
UC Berkeley
UC Irvine
Pennsylvania State
UW Madison
UW River Falls
LBNL Berkeley

South America

U. Simón Bolivar, Caracas

Europe

VUB-IIHE, Brussel
ULB-IIHE, Bruxelles
Université de Mons-Hainaut
Imperial College, London
DESY, Zeuthen

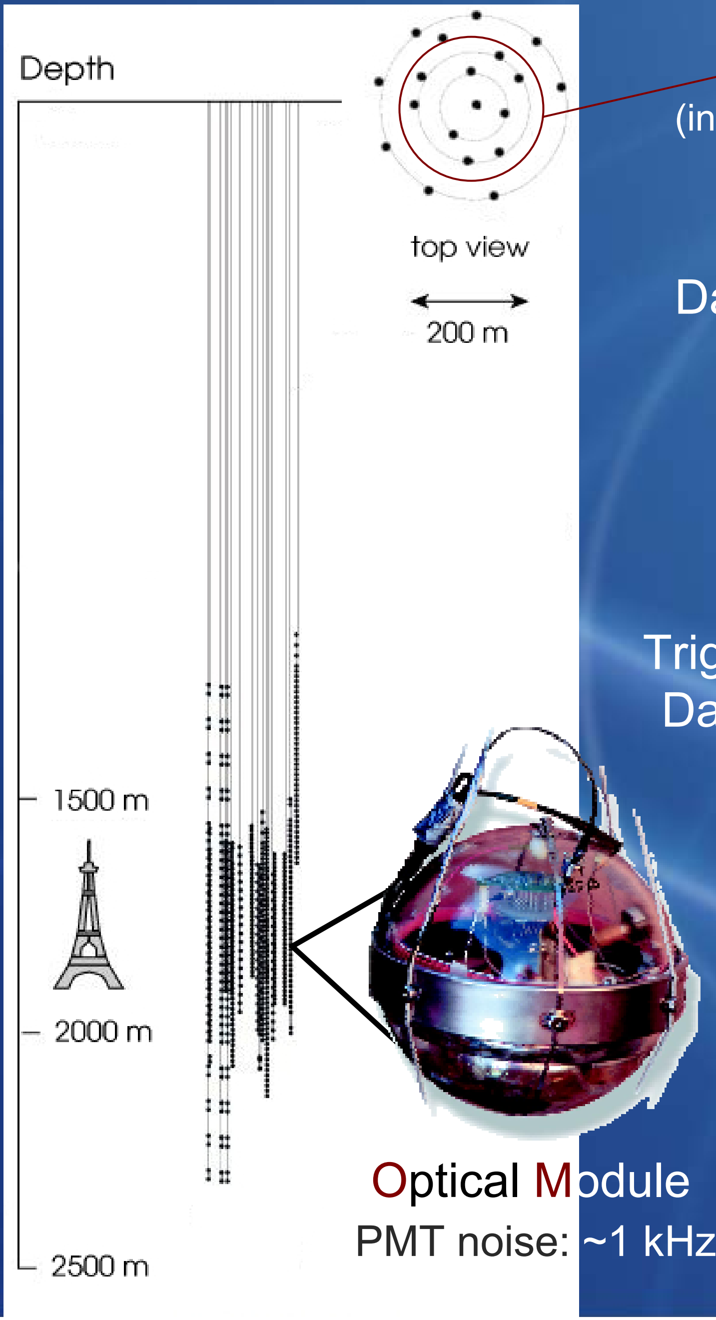
Mainz Universität
Wuppertal Universität
Stockholms Universitet
Uppsala Universitet
Kalmar Universitet

Antarctica

South Pole Station

~150 members

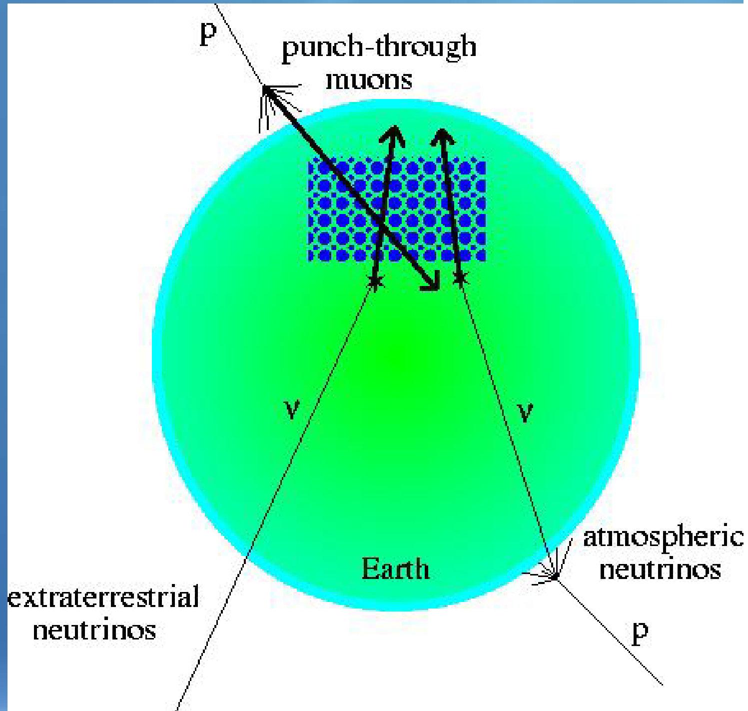
The Antarctic Muon and Neutrino Detector Array



AMANDA-B10
(inner core of AMANDA-II)
10 strings
302 OMs
Data years: 1997-99

AMANDA-II
19 strings
677 OMs
Trigger rate: 80 Hz
Data years: 2000-

Optical Module
PMT noise: ~1 kHz



"Up-going"
(from Northern sky)

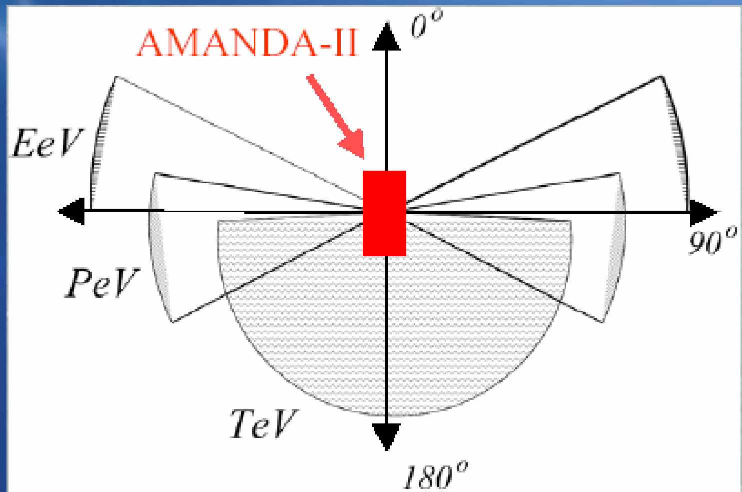
"Down-going"
(from Southern sky)

Reconstruction handles

	Up/Down	Energy	Source direction	Arrival time	Count rates
Atmospheric μ	+				
Diffuse μ, Cascades, UHE events	+	+			
Point sources: AGN, WIMPs	+	+	+		
GRB	+	+	+	+	
Supernovae					+

AMANDA energy coverage

Energy range	Analysis	Production site(s)
~MeV	SN	Supernovae
GeV - TeV	Atmospheric μ Dark matter	Atmosphere Earth, Sun
TeV - PeV	Diffuse Cascades Point sources	AGN, GRB, …
PeV - EeV	UHE	AGN, TD, …
> EeV	EHE	?

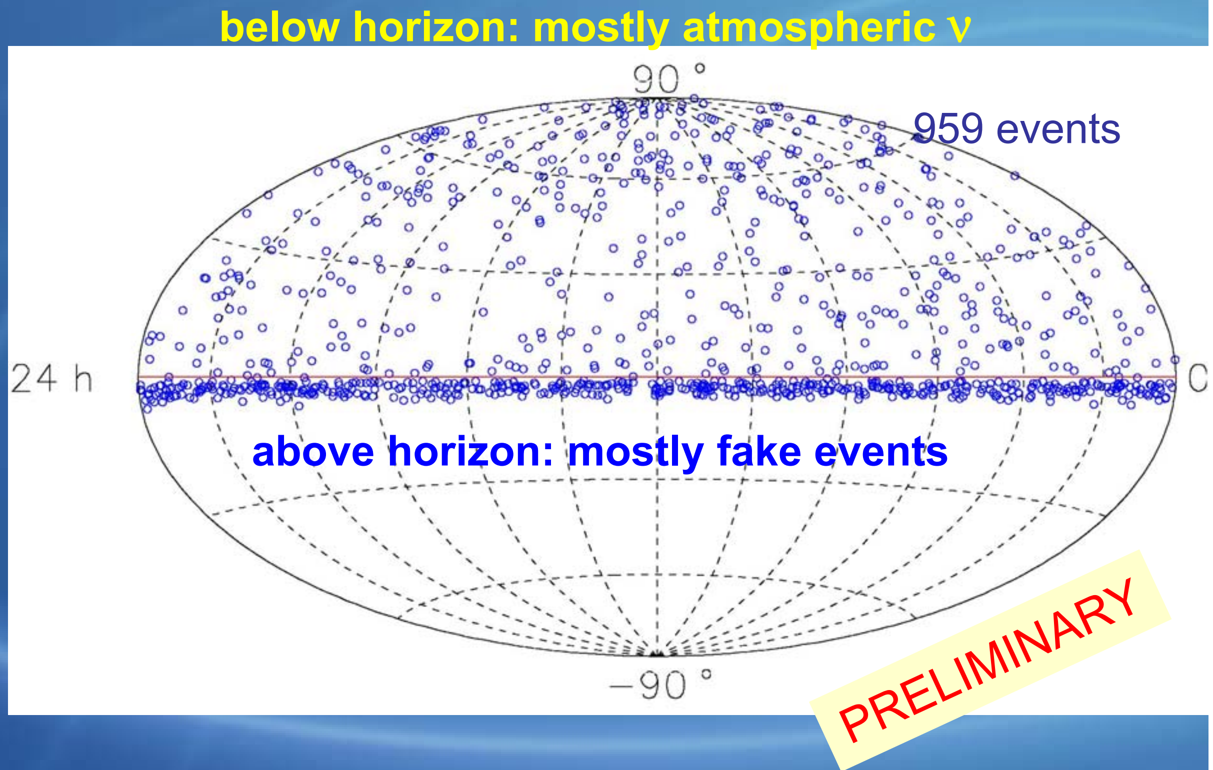


angular range for ν_μ detection

Search for HE neutrino point sources

Livetime
2000: 197 days
2001: 194 days
2000+2001: 959 events
465 below horizon

Step 1:
Select up-going events:
Maximize upgoing ν &
minimize downgoing μ



Step 2:
Search for clustering in
Northern sky:

No evidence for point sources
with an E^{-2} energy spectrum
based on first 2 years of AMANDA-II data

Consistent with atmospheric ν

WIMP annihilations in the center of Earth

Sensitivity to muon flux from neutralino annihilations in the center of the Earth:

$$xx \rightarrow q\bar{q}, l^+l^-, W, Z, H \rightarrow \nu_\mu$$

PRELIMINARY

Look for vertically upgoing tracks

NN optimized (on 20% data) to
- remove misreconstructed atm. μ
- suppress atmospheric ν
- maximize sensitivity to WIMP signal

Combine 3 years: 1997-99

Total livetime (80%): 422 days

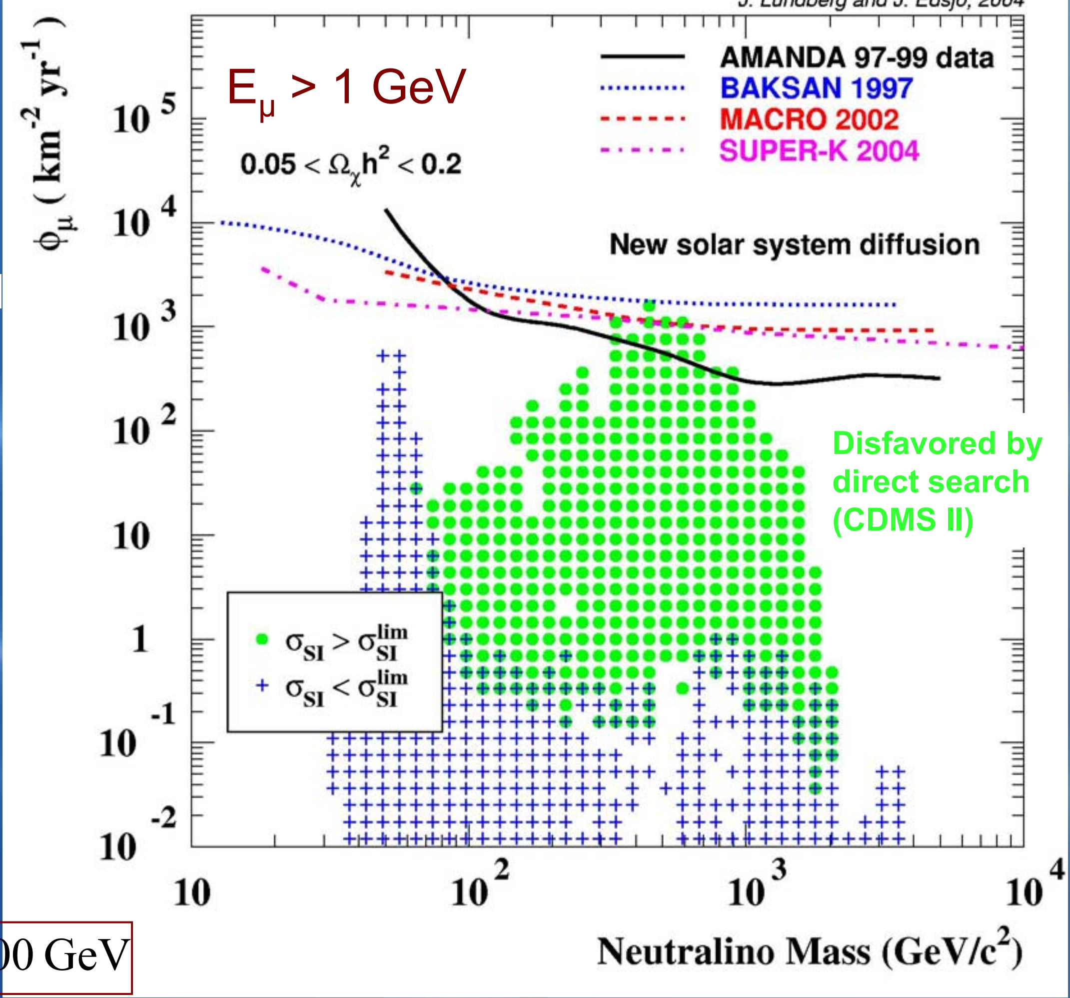
No WIMP signal found

Limit for "hardest" channel:

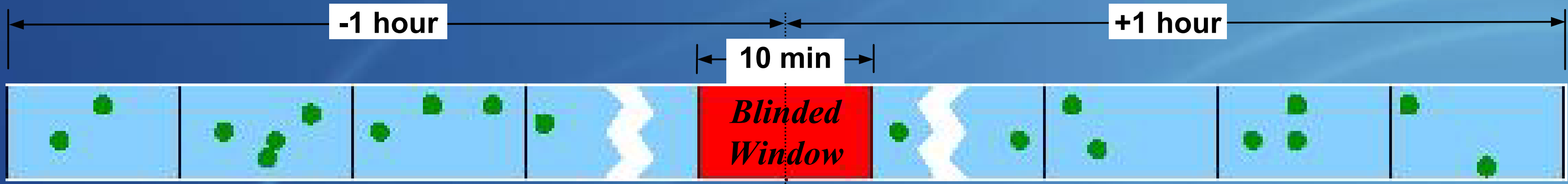
$$xx \rightarrow \tau^+\tau^- \rightarrow \nu_\mu \quad \boxed{M_x = 50\ \text{GeV}}$$

$$xx \rightarrow W^+W^- \rightarrow \nu_\mu \quad \boxed{M_x = 100\text{-}5000\ \text{GeV}}$$

Muon flux limits



Search for ν_μ correlated with GRBs



Background determined on-source/off-time | *Background determined on-source/off-time*

Time of GRB
(Start of T_{90})

Low background analysis due to space <u>and</u> time coincidence!

GRB catalogs:
BATSE, IPN3 & GUSBAD

Analysis is blind:
finalized off-source (± 5 min) with MC simulated signal

BG stability required within ± 1 hour

Muon effective area *(averaged over zenith angle)* ≈ 50,000 m² @ PeV

PRELIMINARY

Year	Detector	N_{Bursts}	$N_{BG, Pred}$	N_{Obs}	Event U.L.
1997	B-10	78 (BT)	0.06	0	2.41
1998	B-10	94 (BT)	0.20	0	2.24
1999	B-10	96 (BT)	0.20	0	2.24
2000	A-II (2 analyses)	44 (BT)	0.83/0.40	0/0	1.72/2.05
97-00	B-10/A-II	312 (BT)	1.29	0	1.45
2000	A-II	24 (BNT)	0.24	0	2.19
2000	A-II	46 (New)	0.60	0	1.88
2000	A-II	114 (All)	1.24	0	1.47

(BT = BATSE Triggered BNT = BATSE Non-Triggered New = IPN & GUSBAD)

97-00 Flux Limit at Earth*: $E^2\Phi_\nu \leq 4\cdot10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

*For 312 bursts w/ WB Broken Power-Law Spectrum (E_{break}= 100 TeV, Γ_{Bulk}= 300)

~15× WB flux

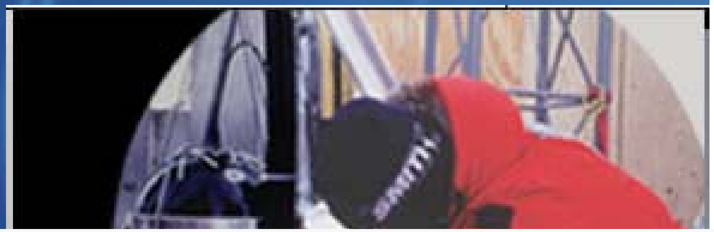
Conclusion and Outlook

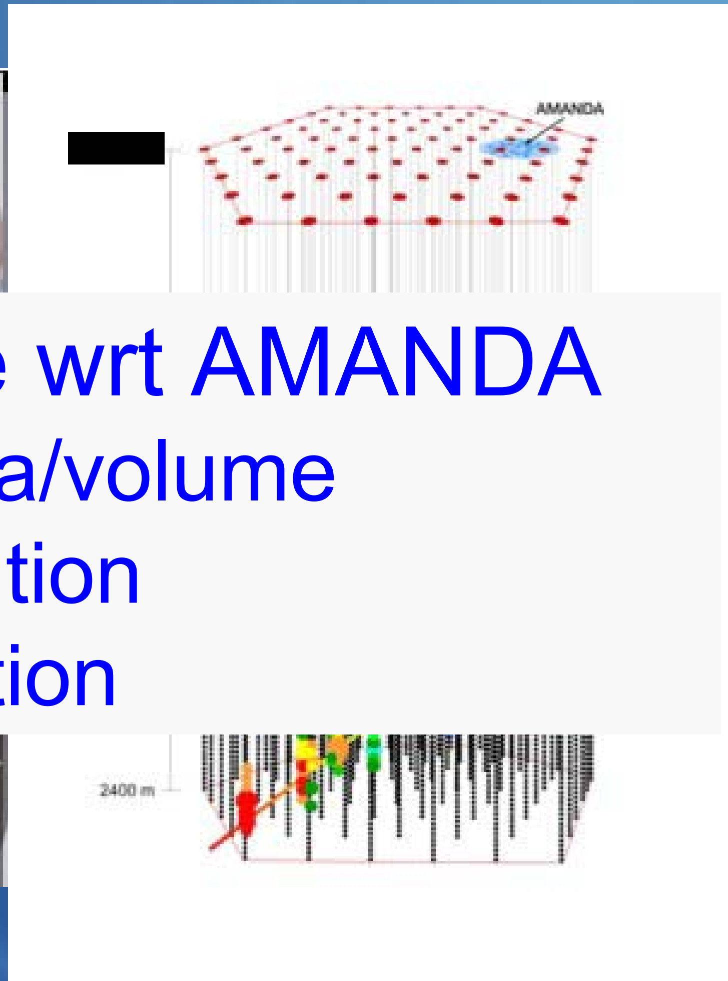
No extraterrestrial ν signal observed…yet

- Limits (TeV-EeV) on diffuse ET neutrino flux
- First results from AMANDA-II published:
  - point source search in 2000 data
- Combined analysis (2000-03) in progress
- Papers on 1997-2000+ data in progress
- Ice description mature
- Digitized waveform readout since 2003
- Will soon contribute to SNEWS

Next Generation: IceCube…(first strings in Jan 2005)

IceCube a kilometer-scale deep-ice ν observatory in Antarctica





Expected performance wrt AMANDA

- ✓ increased effective area/volume
- ✓ superior angular resolution
- ✓ superior energy resolution

IceCube concept

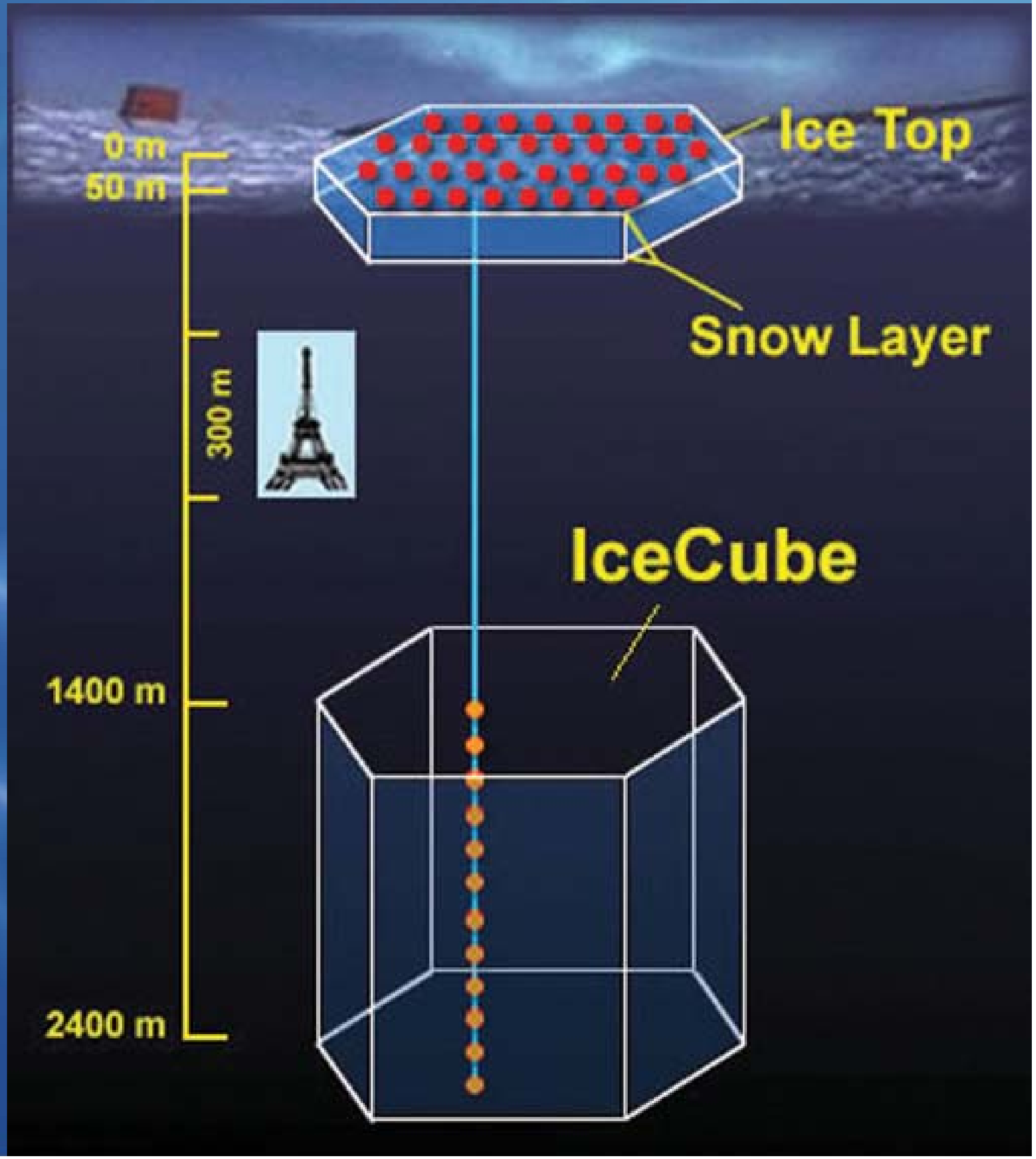
Deep ice array

- 80 strings / 60 OM's each
- 17 m OM spacing
- 125 m between strings
- hexagonal pattern over 1 km²

- geometry optimized for detection of TeV – PeV (EeV) ν's
- based on measured absorption & scattering properties of Antarctic ice for UV – blue Cherenkov light

Surface array IceTop

- 2 frozen-water tanks (2 OM's each) on top of every string



Status of IceCube project

- many reviews – international and within the U.S. - strongly emphasize the exciting science which can be performed with IceCube

- in Jan 2004, the U.S. Congress approved the NSF budget including the full IceCube MRE
- significant funding approved also in Belgium, Germany and Sweden

- in Feb 2004, NSF conducted a baseline review $\Rightarrow$ “go ahead”

- deployment over 6 years

IceCube strings	IceTop tanks	
4	8	Jan 2005
16	32	Jan 2006
32	64	Jan 2007
50	100	Jan 2008
68	136	Jan 2009
80	160	Jan 2010

The NEMO Project

Neutrino Mediterranean Observatory

The 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

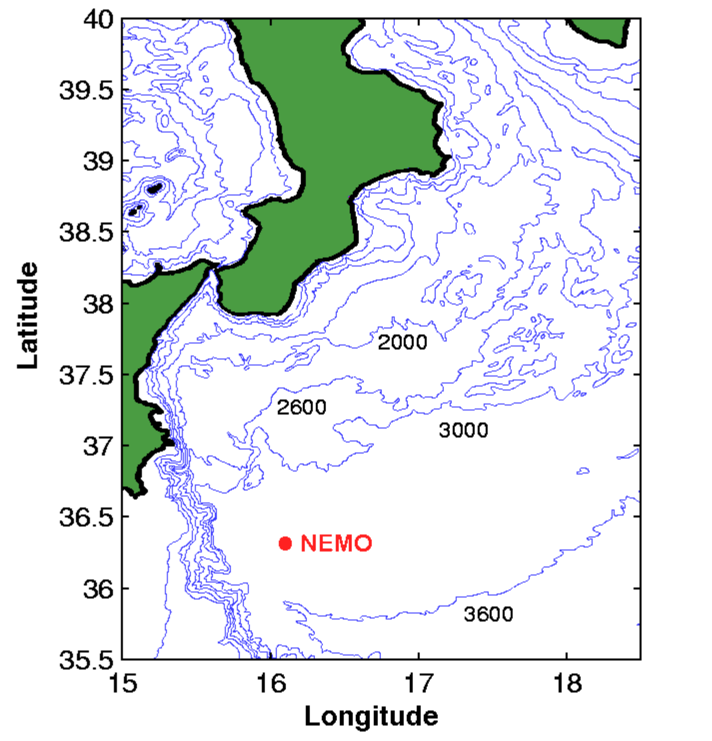
Istituto Nazionale di Oceanografia e Geofisica Sperimentale

Universities:

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

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

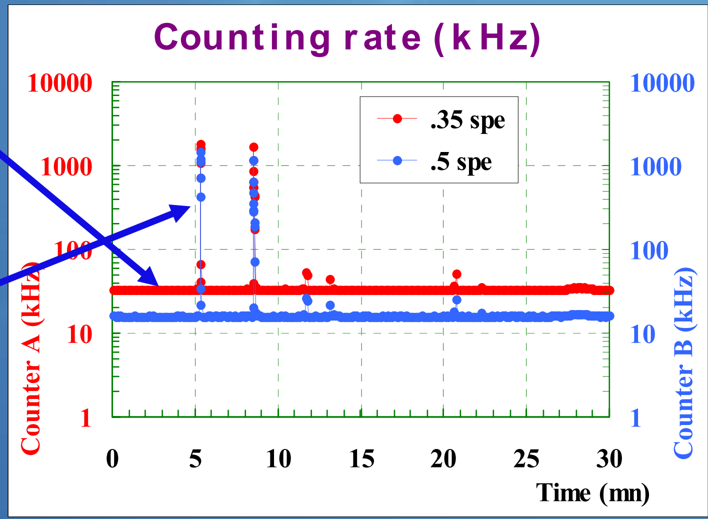


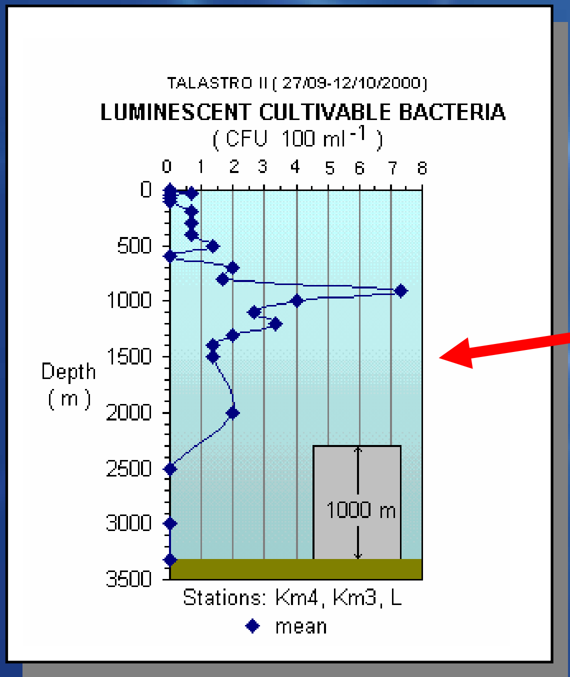
Optical background

Sources of optical background

Decay of radioactive elements (mainly ^{40}K) $\rightarrow$ stable frequency noise ($\approx$30 kHz on a 8" PMT at 0.3 p.e. threshold)

Light produced by biological entities (bioluminescence) $\rightarrow$ random bursts with very high counting rate

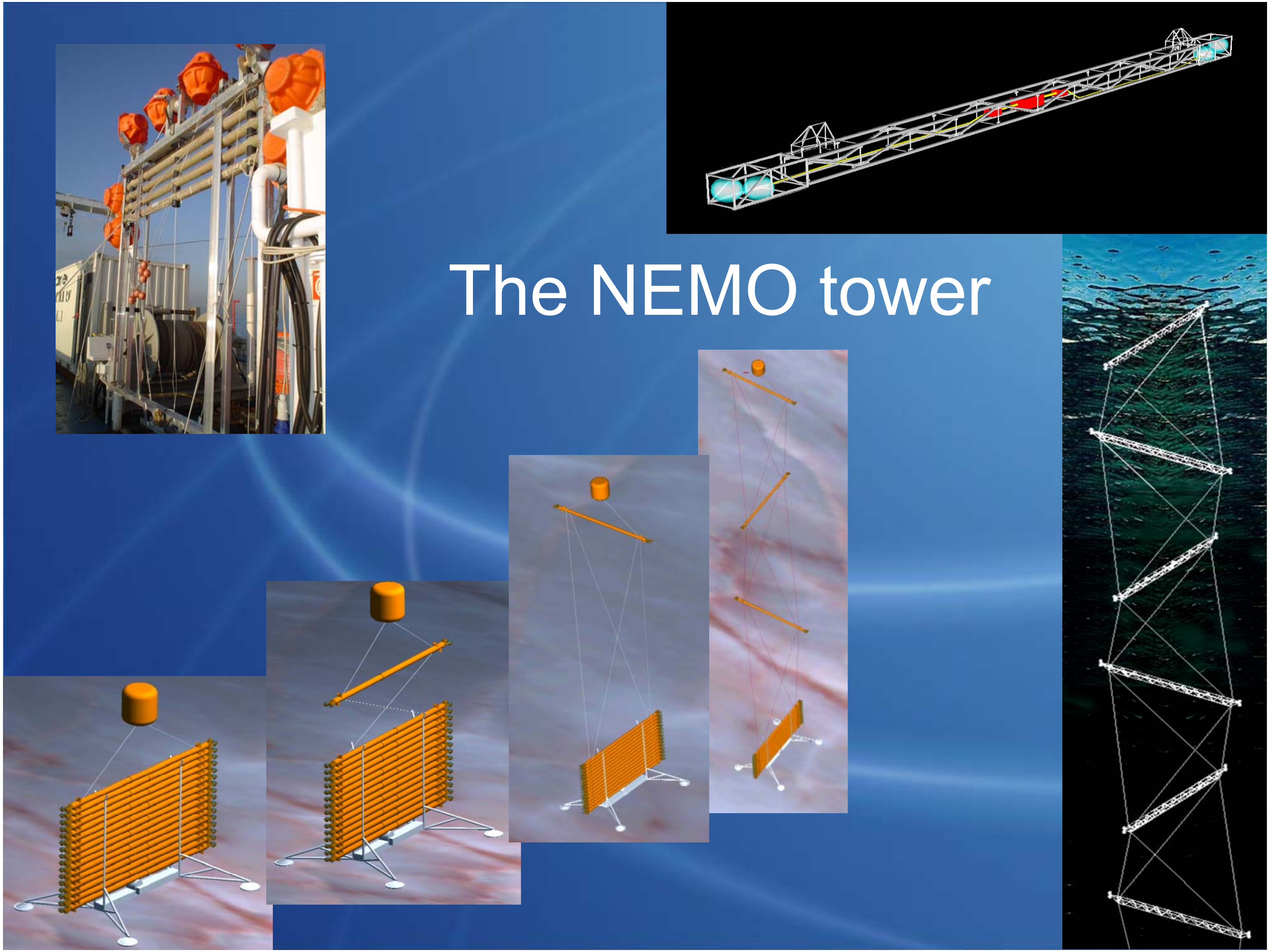




No luminescent bacteria have been observed in Capo Passero below 2500 m

Data taken by Istituto Sperimentale Talassografico, CNR, Messina

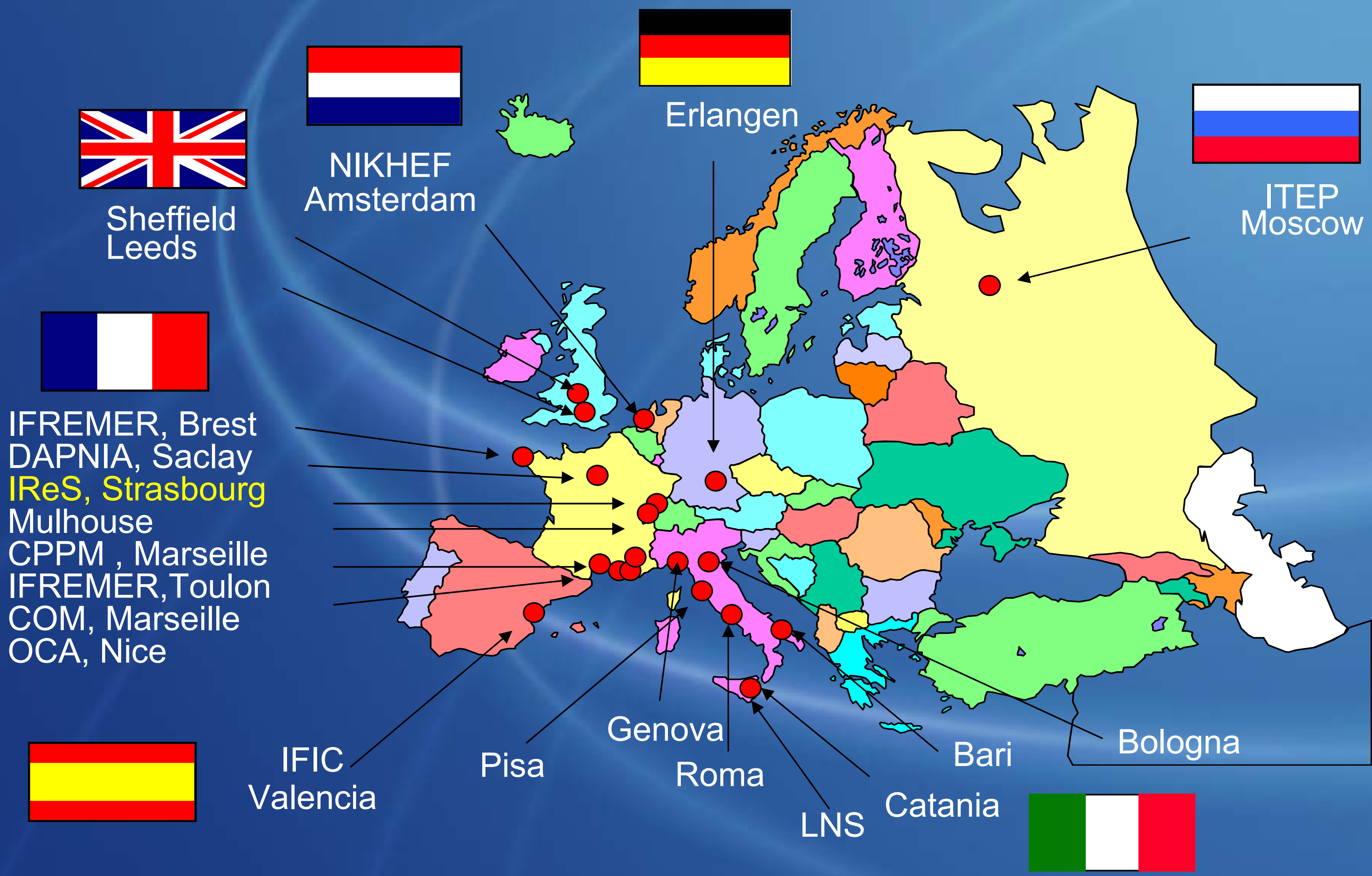
The NEMO tower



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

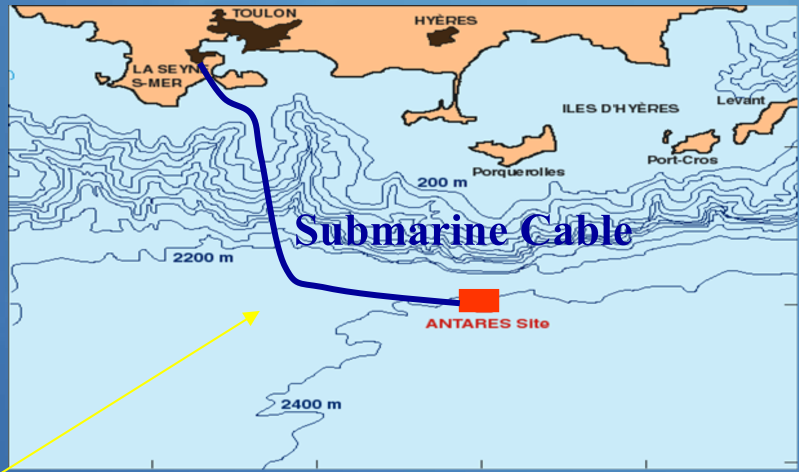
ANTARES

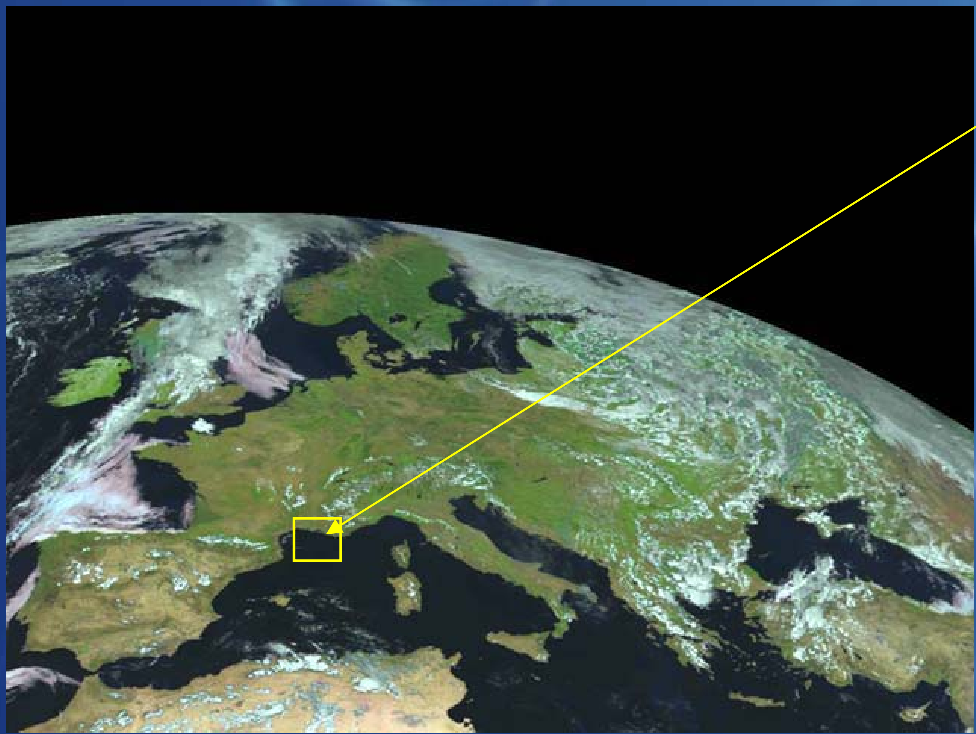

Erlangen
NIKHEF
Amsterdam
Sheffield
Leeds
ITEP
Moscow
IFREMER, Brest
DAPNIA, Saclay
IReS, Strasbourg
Mulhouse
CPPM , Marseille
IFREMER,Toulon
COM, Marseille
OCA, Nice
IFIC
Valencia
Pisa
Genova
Roma
LNS
Catania
Bari
Bologna

ANTARES Site

The detector will be located in the Mediterranean Sea (42º50'N, 6º10'E) at 2500 m depth, off the coast of Toulon (France).

This location benefits from IFREMER infrastructures.





The shore station is at La Seyne sur Mer, around 40 km NW of the ANTARES site.

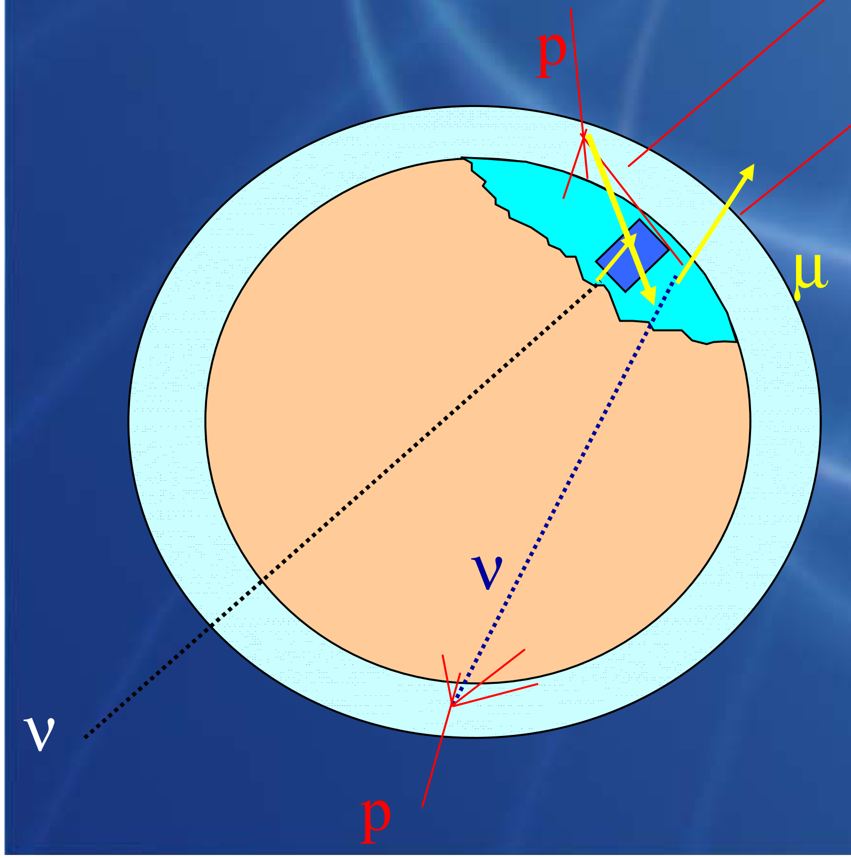
Institute Michel Pacha,

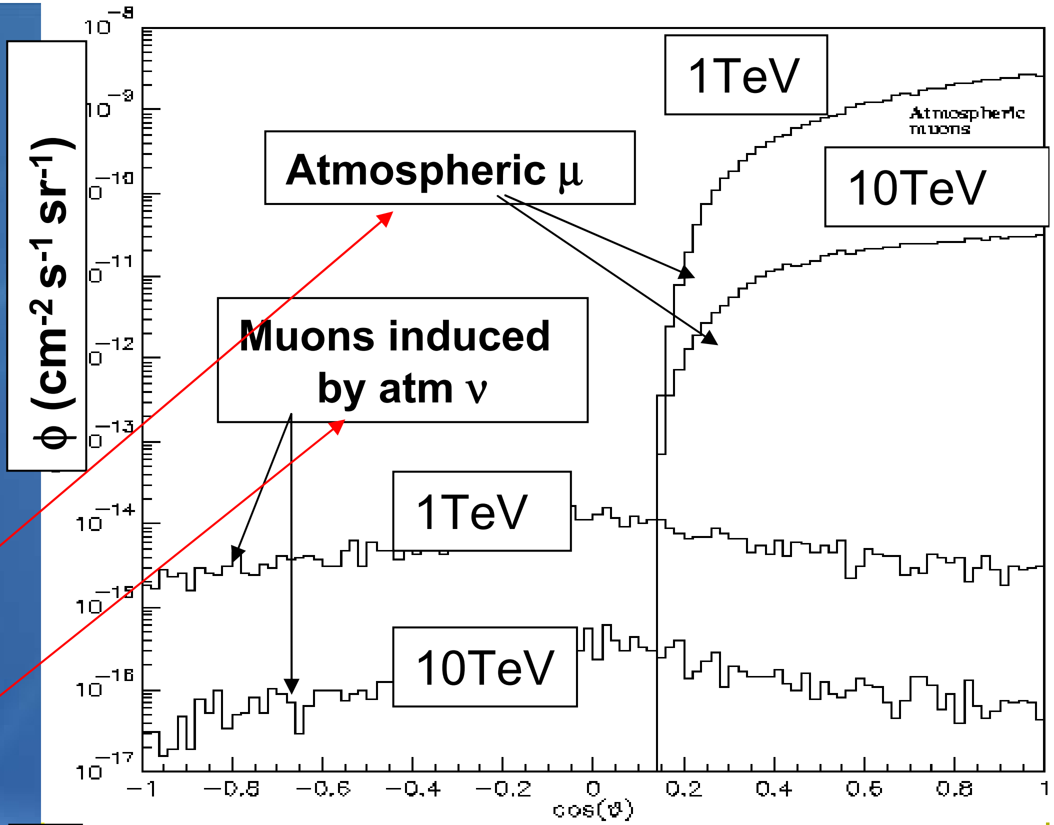
hosting the control room

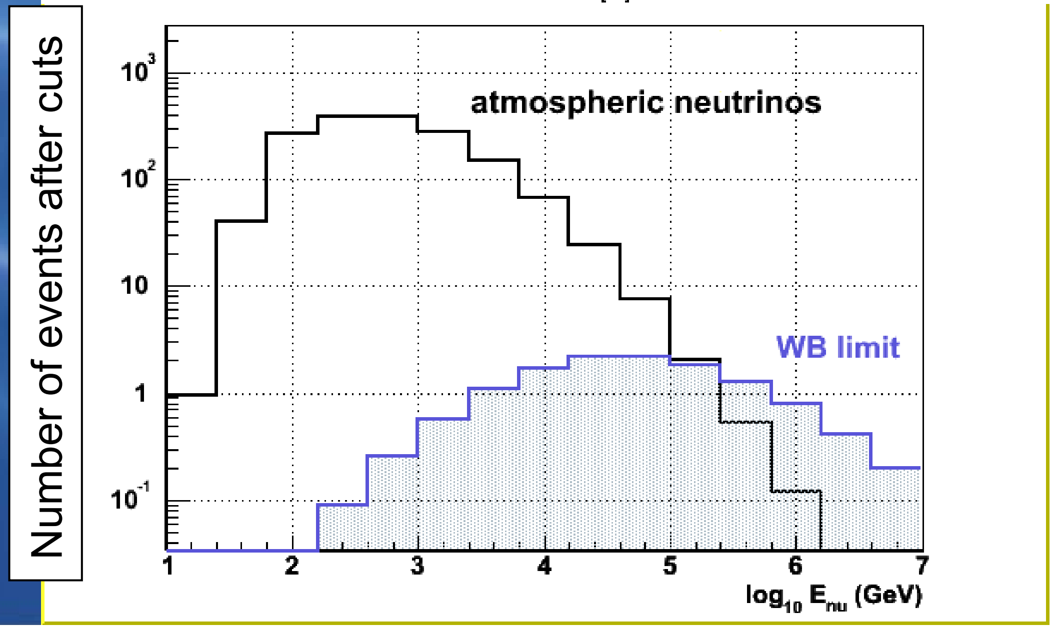
Background for cosmic neutrino searches

Muons produced by cosmic rays in the atmosphere (detector deep in the sea and selection of up-going events).

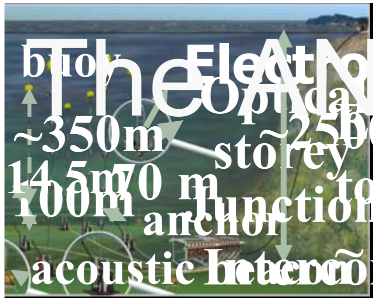
Atmospheric neutrinos (cut in energy).







The ANTARES detector



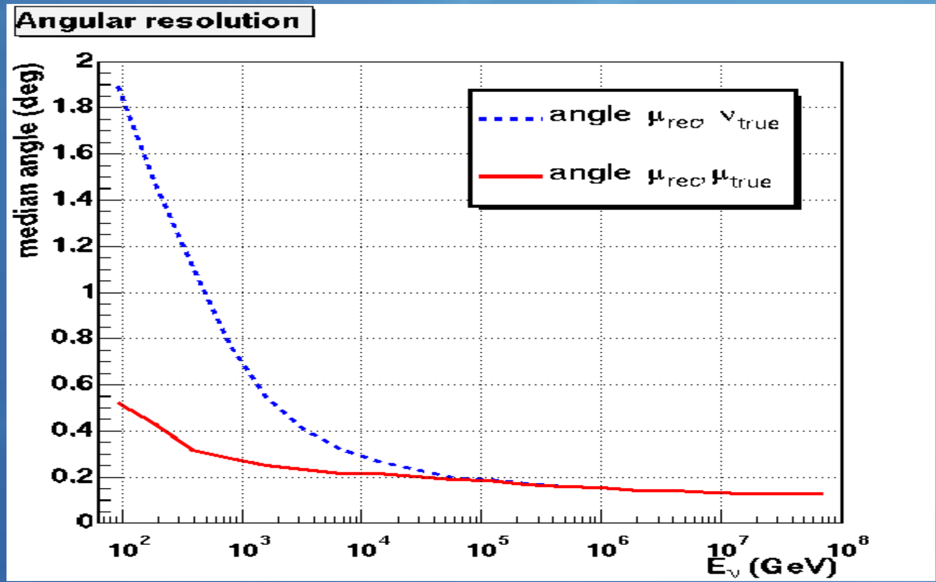
12 lines (900 PMTs)
25 storeys/line
3 PMTs/storey

HE expected performances

Angular resolution

E_μ > 10 TeV ⇒ ~ 0.2º

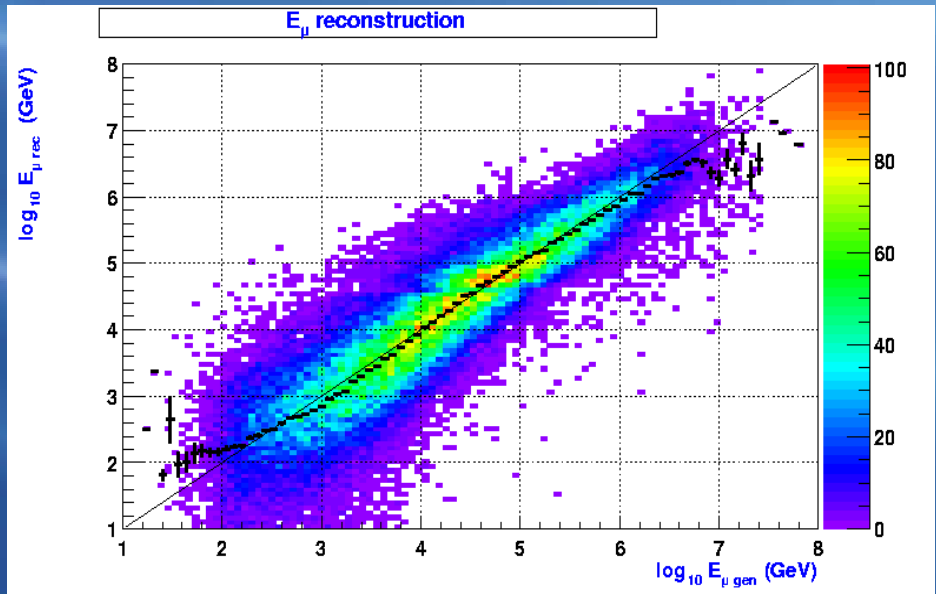
E_μ < 10 TeV ⇒ ν–μ scattering dominated



Spectral resolution

10 GeV < E_μ < 100 GeV muon path

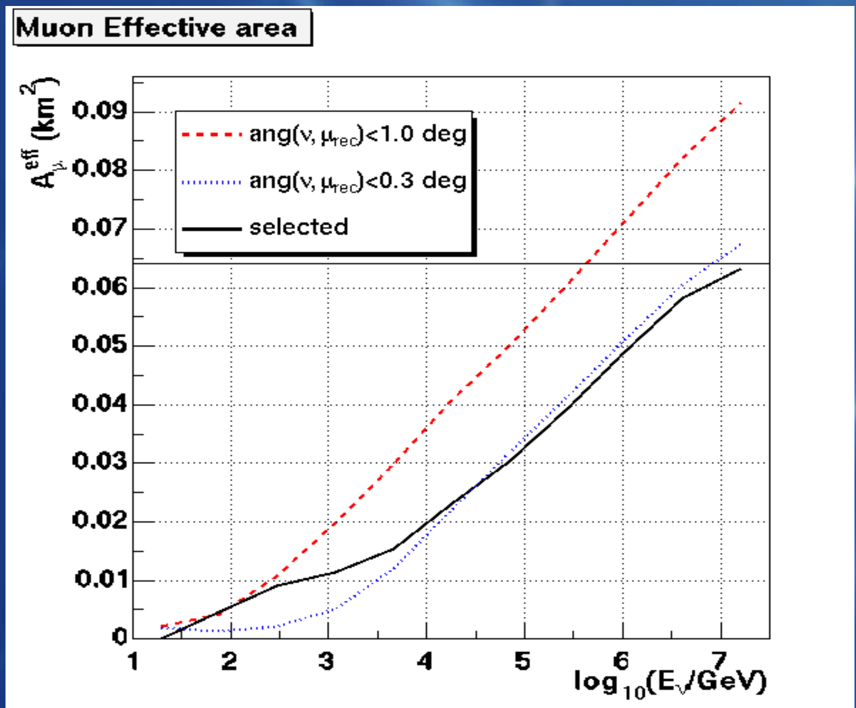
E_μ > 1 TeV ⇒ E estimated by a factor 2-3

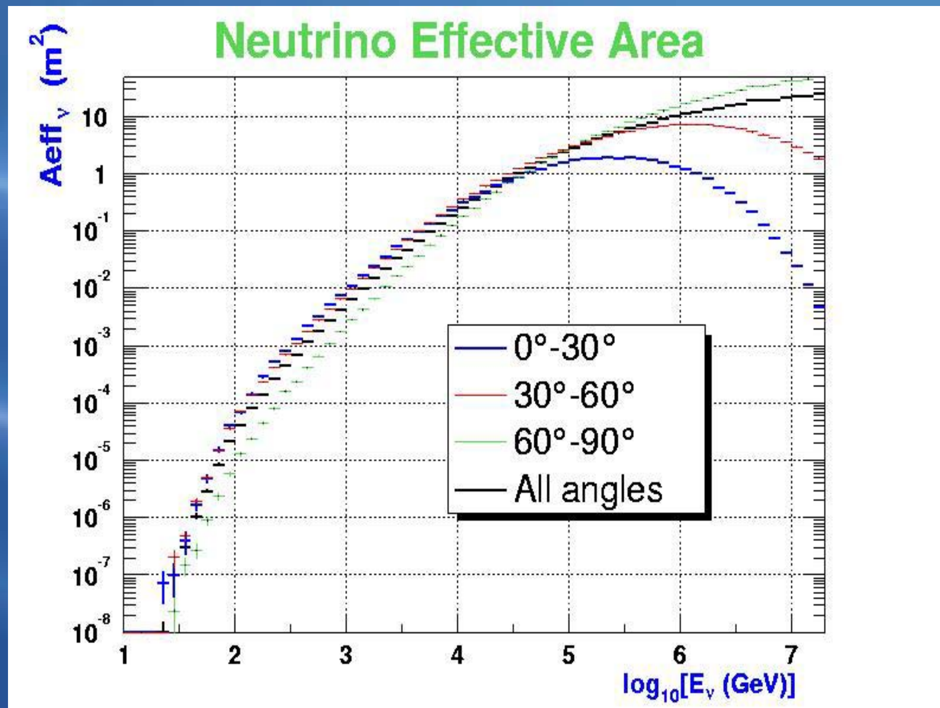


Effective areas (rate/flux)

For ν induced muons at the detector $0.01\text{-}0.07\ km^2$

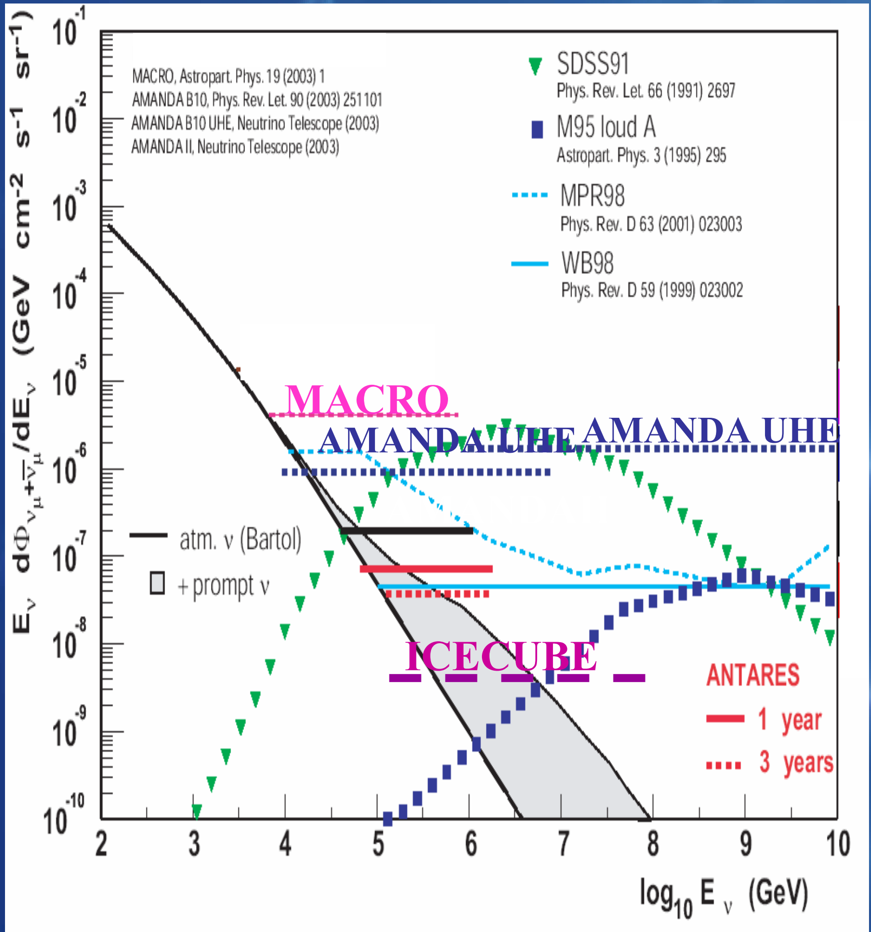
For neutrinos when entering earth $1\text{-}20\ m^2$



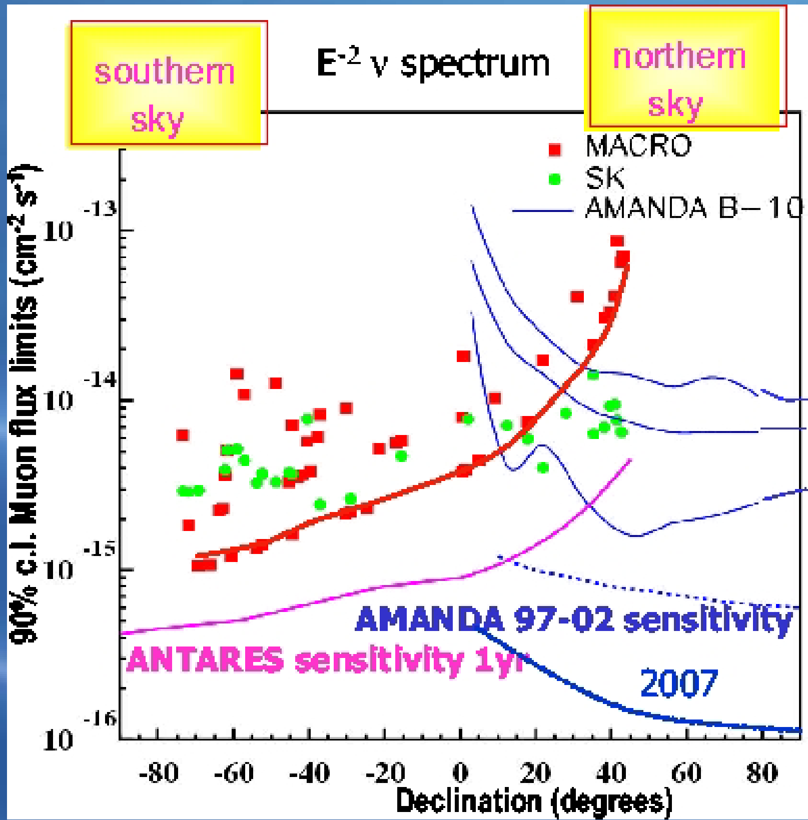


Sensitivities

Diffuse fluxes

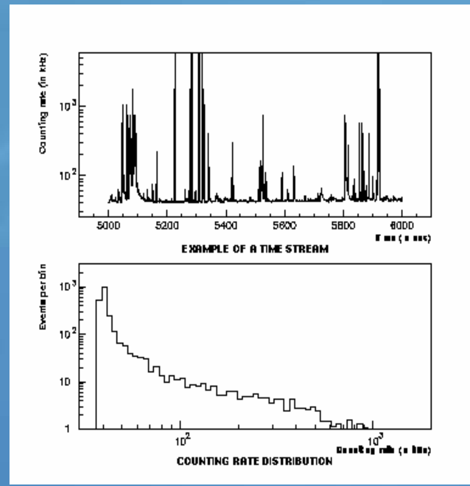


Point-like sources



Site properties

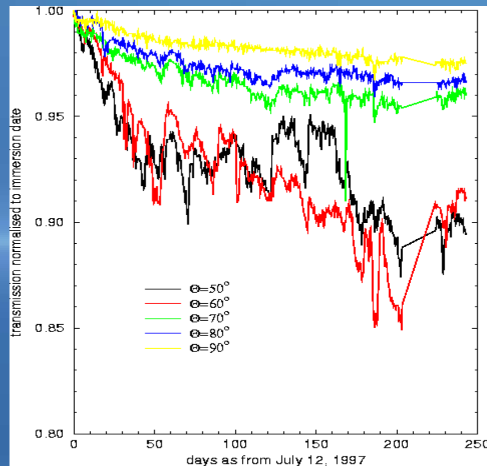
> 30 deployments of autonomous strings:

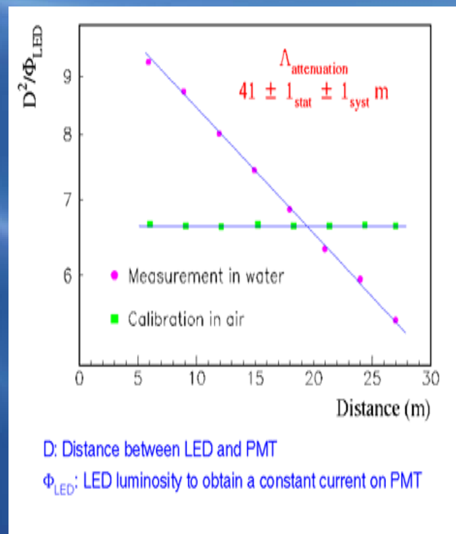


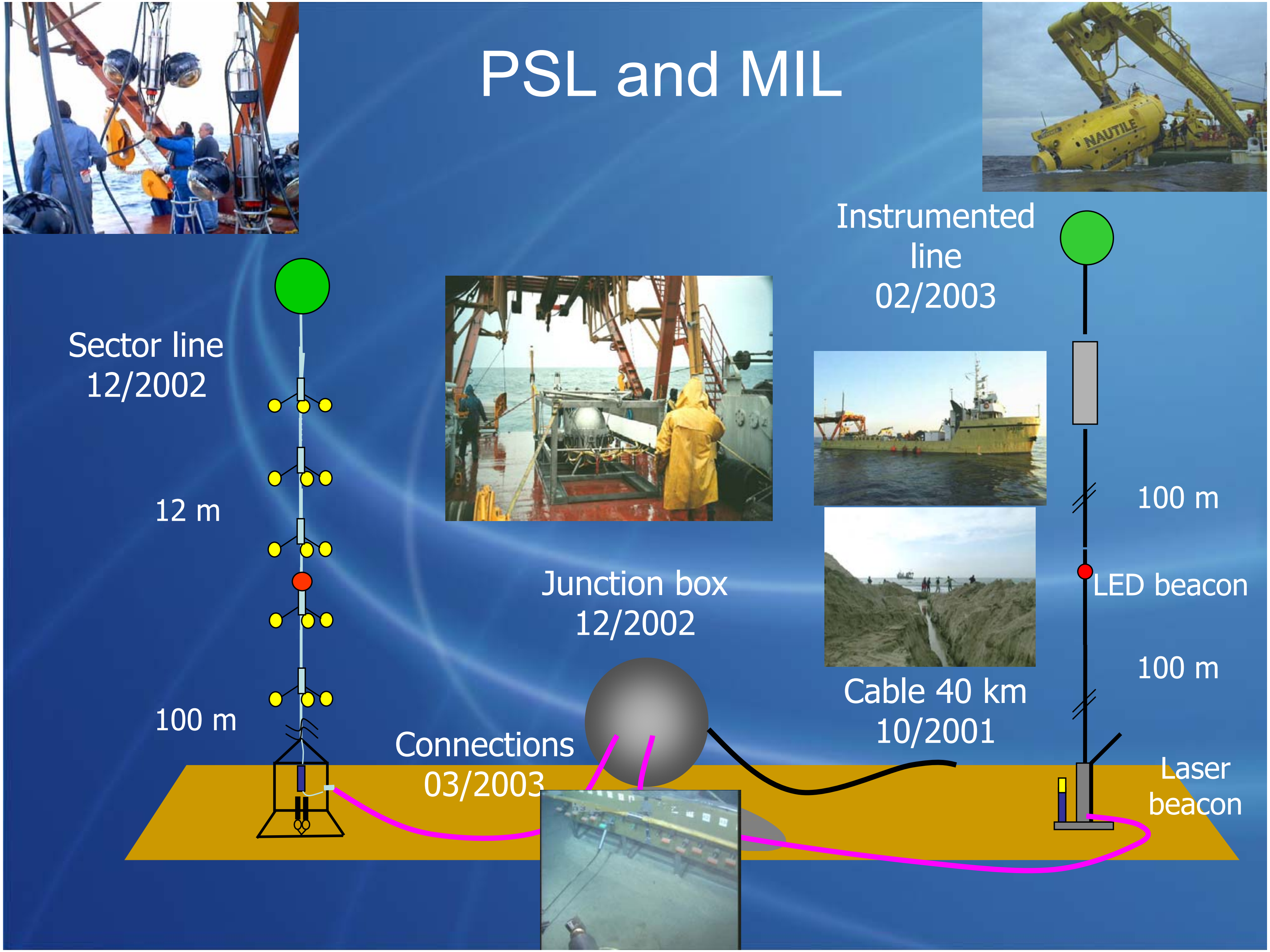
- Water transparency :

  λ_{abs} ~ **55-65 m,** λ_{att} **= 41 m**

- Biofouling: **transparency -2% yr** for PM surface
- Optical backgr: **Mean ~60 KHz for 10" PM**






PSL and MIL
Instrumented line 02/2003
Sector line 12/2002
12 m
100 m
100 m
LED beacon
100 m
Junction box 12/2002
Cable 40 km 10/2001
Connections 03/2003
Laser beacon
NAUTILE

Conclusions

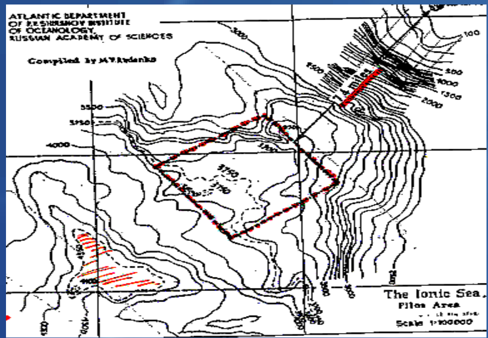
- The construction of the ANTARES neutrino telescope in the Mediterranean Sea has started.
- Intense R&D studies have been performed.
- The deployment and connection of the Junction Box, the Prototype Sector Line and the Mini Instrumentation Line has been successful.
- These tests have also been useful to detect some problems which are being corrected.
- The detector will be completely installed in 2006.
- First step towards a KM^3 detector

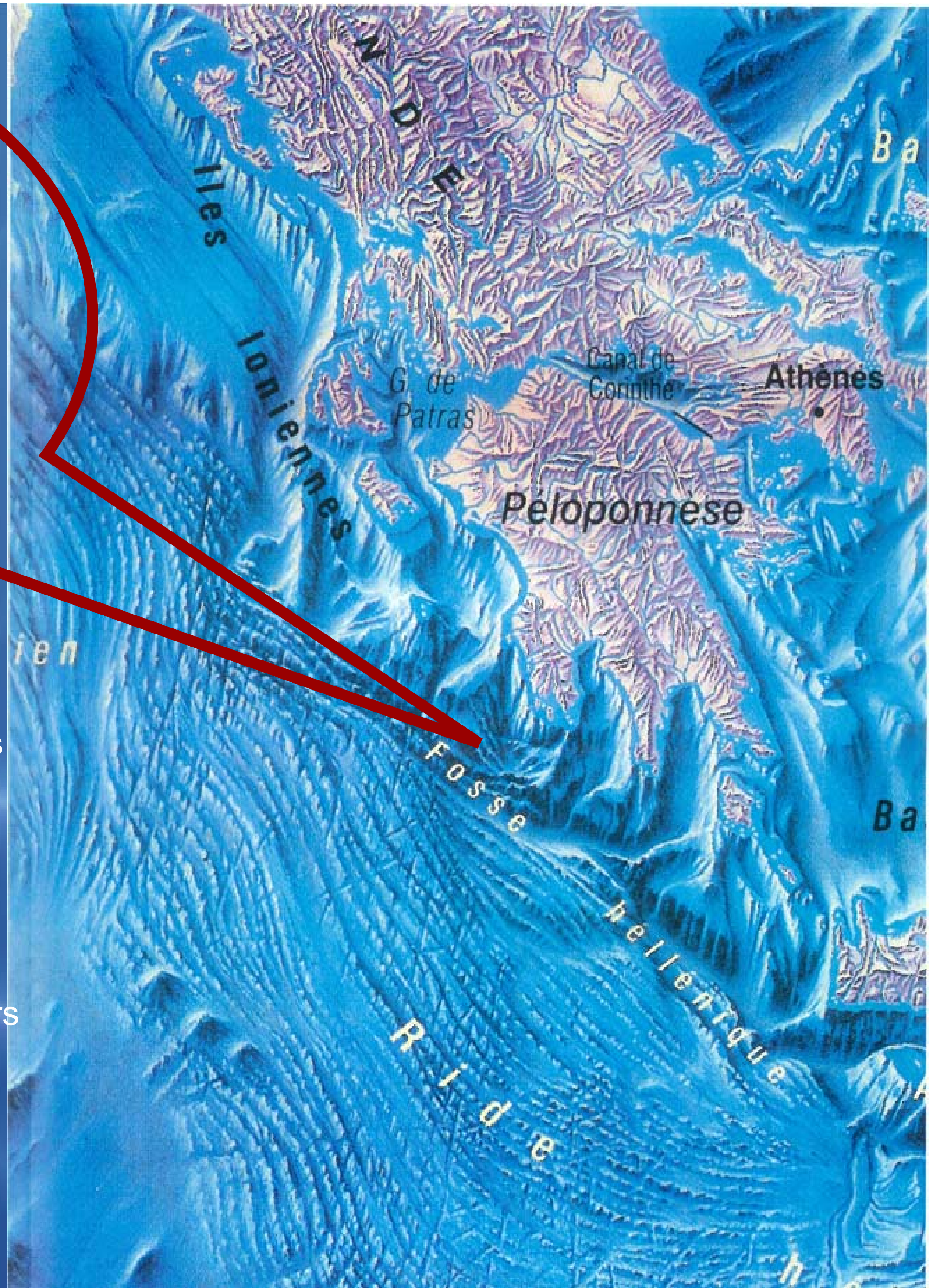
NESTOR

(NEUTRINO EXTENDED SUBMARINE TELESCOPE WITH OCEANOGRAPHIC RESEARCH)

Institute for Geodynamics, Athens Observatory
Physics Dept., University of Athens
Physics Dept, University of Bern
CERN
PhysicsDept., University of Crete
NRCPS DEMOKRITOS
Institute for Geophysics, University of Hamburg
Dept. of Physics and Astronomy,University of Hawaii
Institute of Experimental and Applied Physics, Center for Applied Marine Sciences
Research and Technology Center West Kueste (FTZ Buesum)
University of Kiel
NESTOR Institute for Deep Sea Research, Technology and Neutrino Astroparticle Physics
Physics and Astronomy Dept., University of Patras
School of Science and Technology, Hellenic Open University
Department of Physics, Aristotelian University of Thessaloniki
Experimental Design Bureau of Oceanological Engineering
AInstitute For Nuclear Research , Russian Academy of Sciences

The NESTOR Neutrino Telescope Site

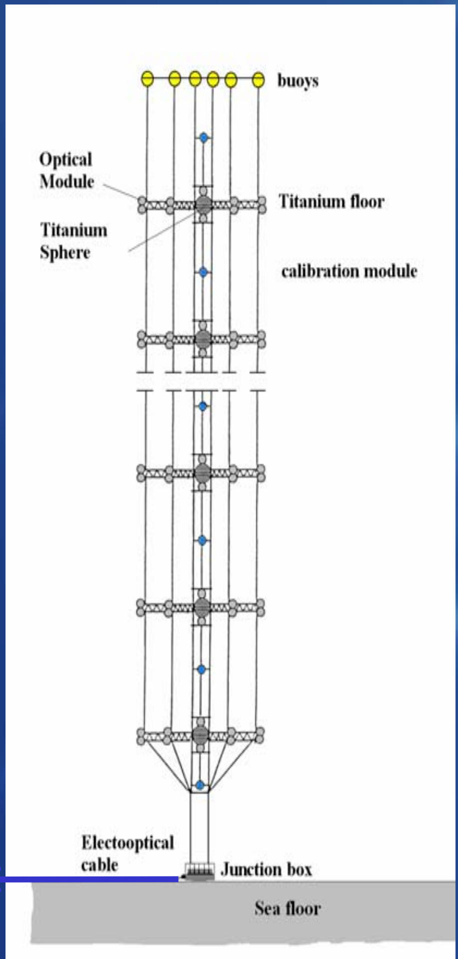




Site characteristics

- **a broad plateau:** 8x9 km^2 in area, 7.5 nautical miles from shore
- **depth:** ~4000m ($\rightarrow$5200m)
- **transmission length**: 55 $\underline{+}$ 10m at λ=460 nm
- **underwater currents:** <10 cm/s measured over the last 10 years
- **optical background:** ~50 kHz/OM due to K^{40} decay bioluminescence activity (1% of the experiment live time)
- **sedimentology tests:** flat clay surface on sea floor, good anchoring ground.

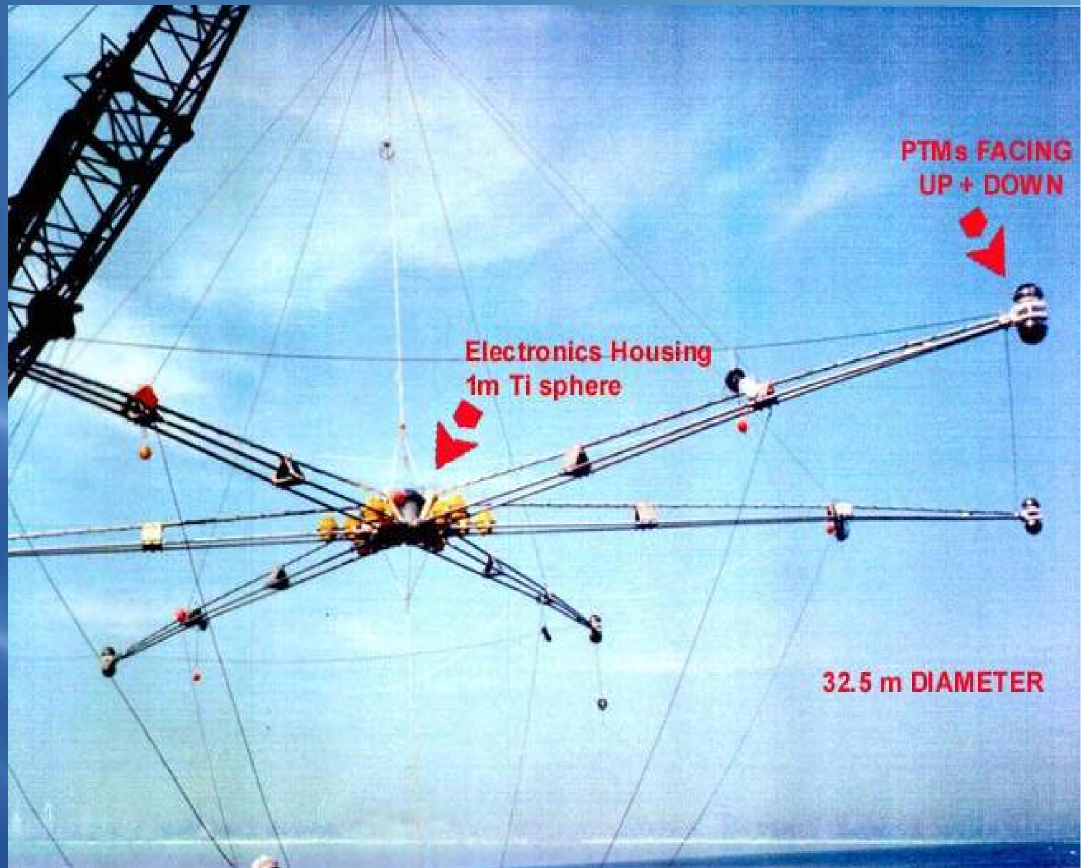
NESTOR DETECTOR



32 m diameter

30 m between floors

144 PMTs



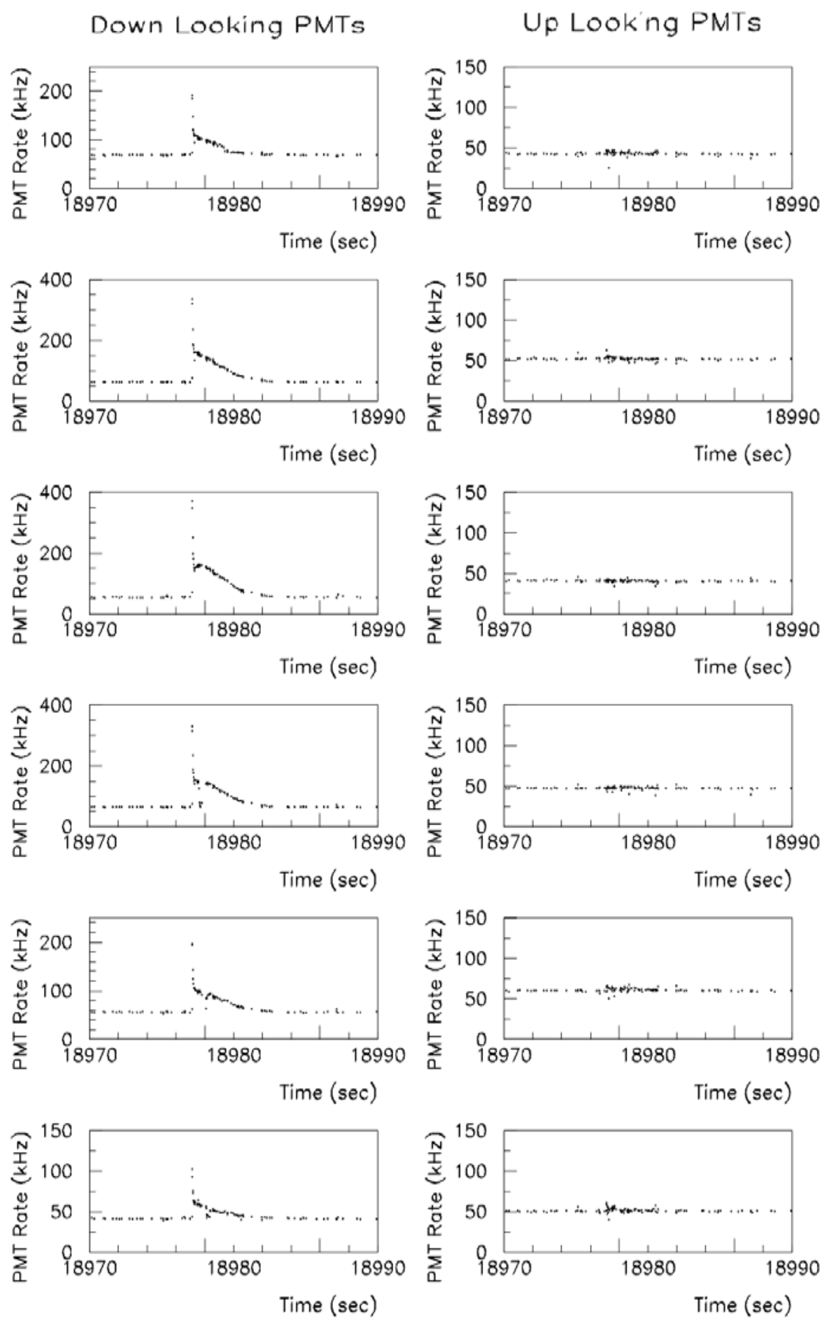
$20\ 000\ m^2$

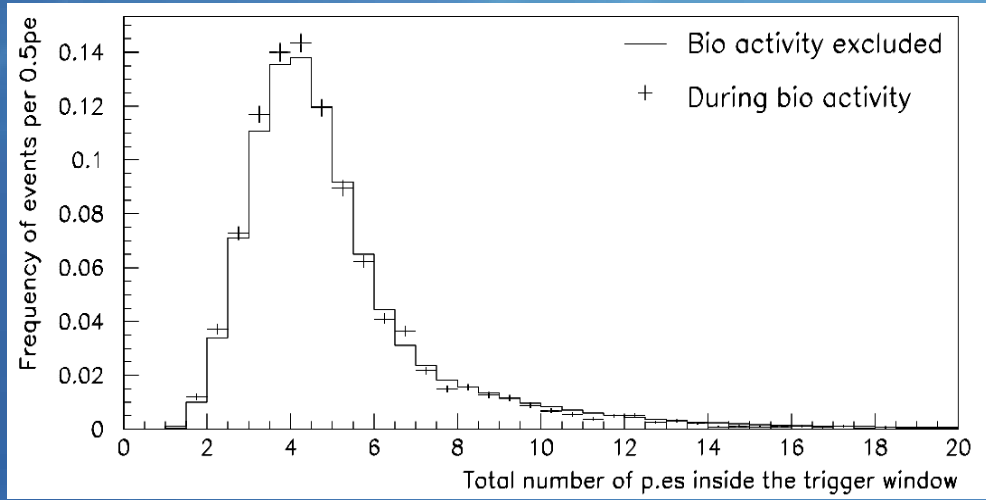
Effective Area

for E>10TeV

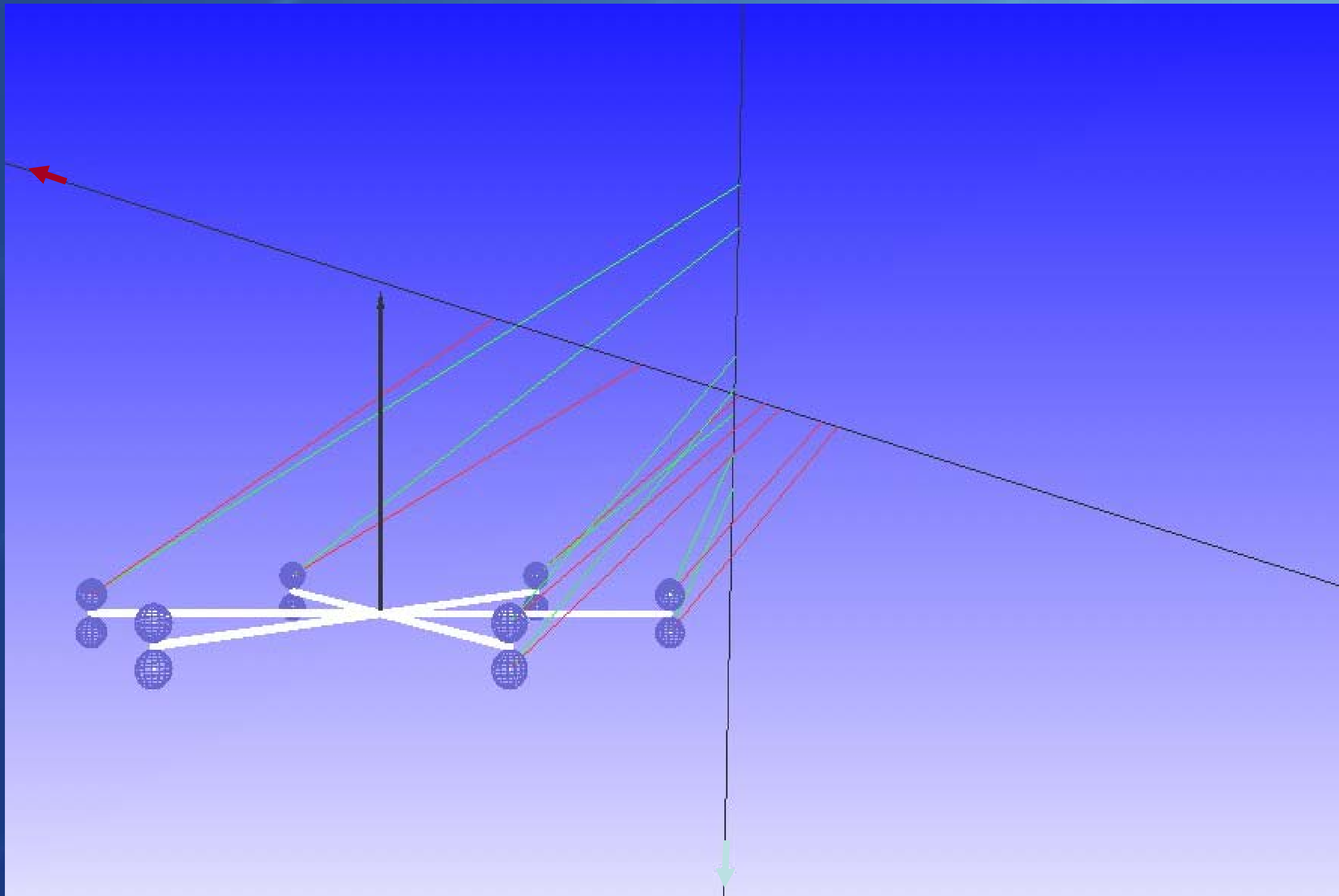
Energy threshold as low as 4 GeV

Data from a depth of 3800 m





Bioluminescence Occurs for the 1.1% ± 0.1% of the Active Experimental Time



c

Conclusions

The objectives for the deployment of the NESTOR test detector concerning:

- a thorough test of,
  - the electrical supply and distribution systems
  - the monitoring and control systems
  - the full data acquisition and transmission chain from the sea to the shore station
- the demonstration of the ability of the proposed neutrino telescope to reconstruct muon trajectories,
-

were met successfully.

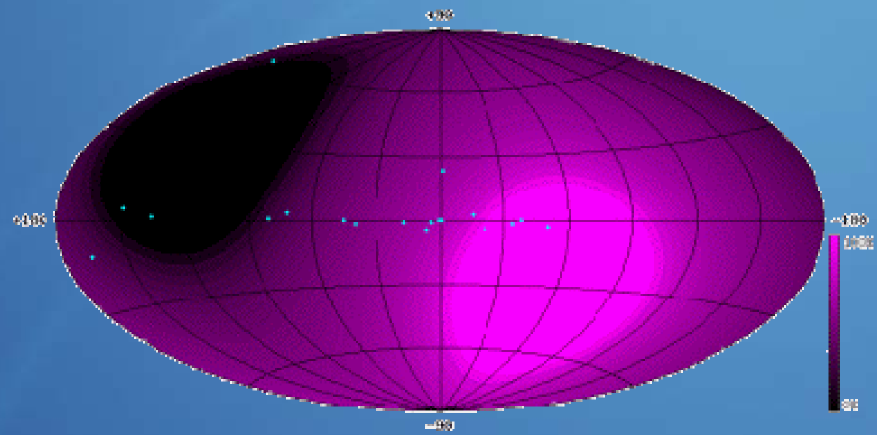
(Towards) a km^3 detector in the Mediterranean Sea

Why the Mediterranean?

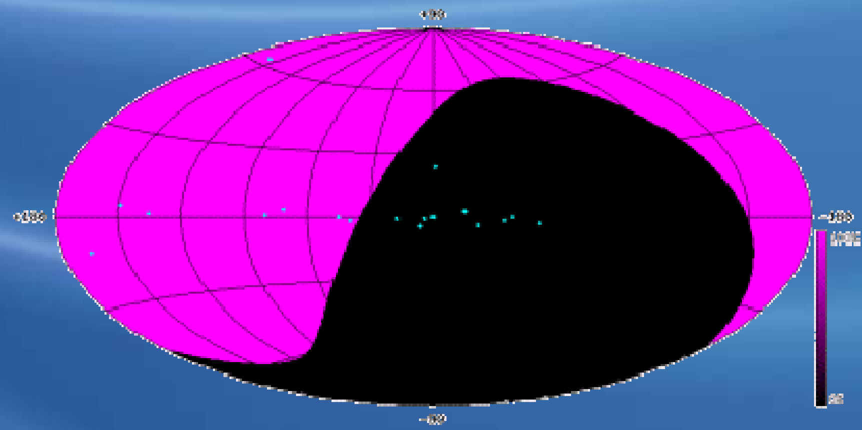
- Obvious complementarity to ICECUBE
- Availability of deep sites - up to ~5000m
- Candidate sites often close to shore

  - logistically attractive
- Long scattering length leads to excellent pointing accuracy
- Re-surfacing and re-deployment of faulty/damaged detector elements is feasible

ANTARES



AMANDA



EU FP6 Design Study: KM3NET

- 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 - end product will be a TDR for KM3 in the Med

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 TDR for a Cubic Kilometre Detector in the Mediterranean

Concluding remarks

- Fascinating domain
- Great experimental challenge
- Interdisciplinarity

Special thanks to…

- AMANDA web page for the film
- Speakers of NEUTRINO 2004 conf. for their slides :
  - ✓ Zh. Dzhilkibaev *(Moscow)* for BAIKAL
  - ✓ K. Woschnagg *(Berkeley)* for AMANDA
  - ✓ O. Botner *(Uppsala)* for ICECUBE
  - ✓ P. Piattelli *(Catania)* for NEMO
  - ✓ S.E.Tzamarias *(Patras)* for NESTOR
  - ✓ L. Thompson *(Sheffield)* for KM3NET