united nations educational, scientific and cultural organization

international atomic energy agency

the
abdus salam
international centre for theoretical physics

40th anniversary 1964 2004

H4.SMR/1574-21

"VII School on Non-Accelerator Astroparticle Physics"

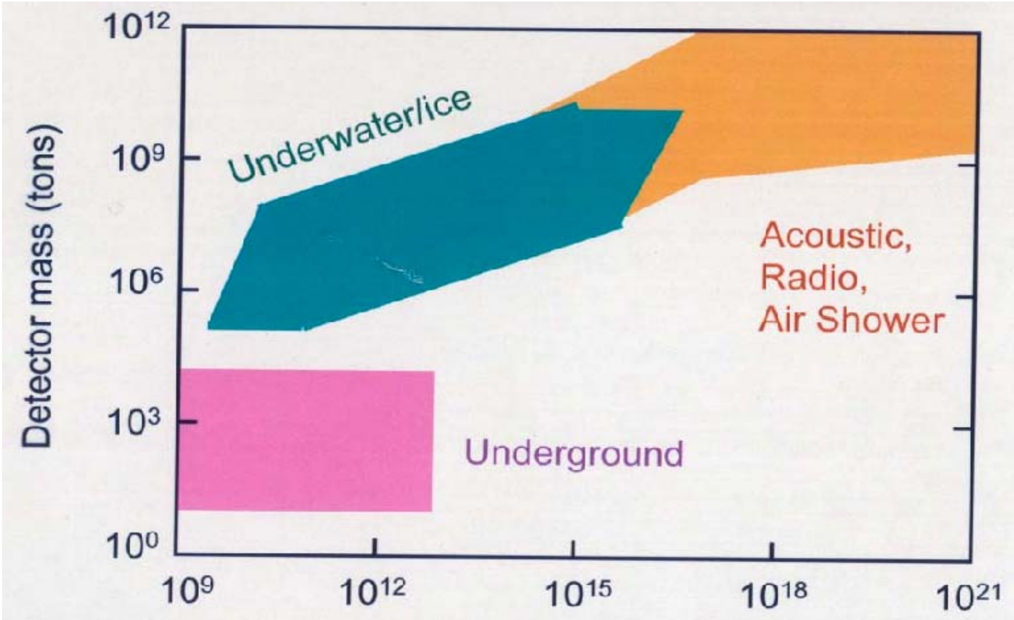
26 July - 6 August 2004

Neutrino Telescopes - II

John Carr

Centre de Physique des Particules de Marseille / IN2P3 / CNRS
France

Neutrino Telescope Techniques



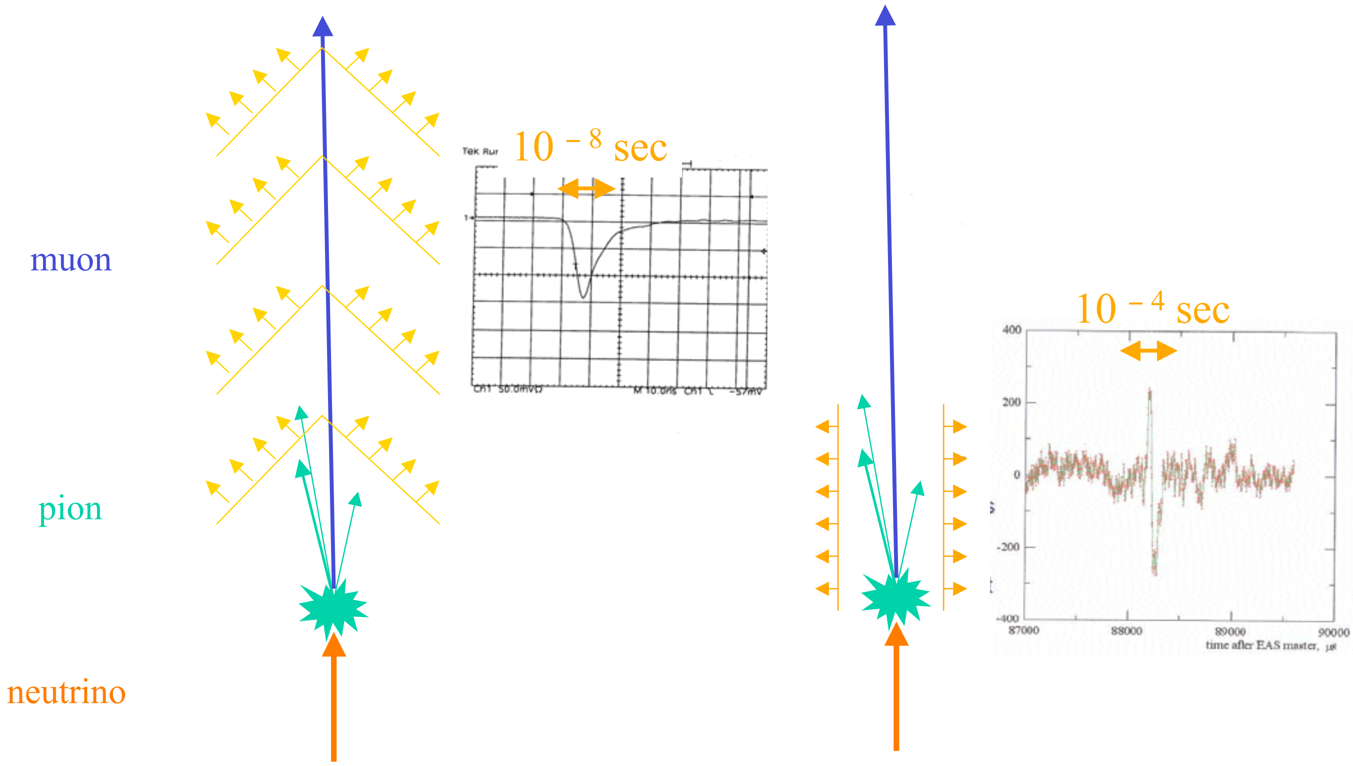
E_ν eV

Flux of neutrinos decreases with energy
so need increasing mass for detector

Detection of neutrinos: Light and Sound

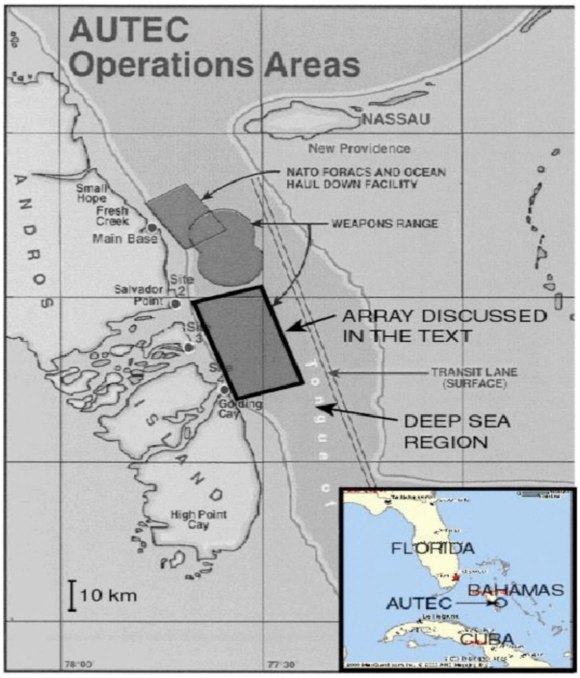
Cherenkov light

Sound

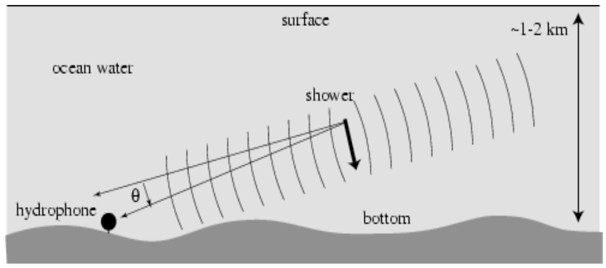


Ocean Acoustic Detection

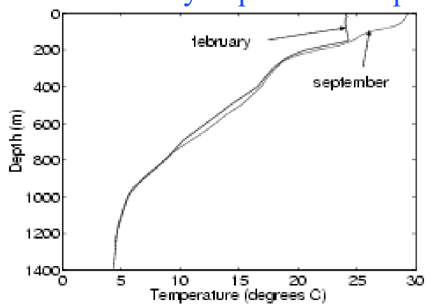
Stanford project to use US Navy array in Atlantic



pancake beam pattern



sound velocity depends on depth

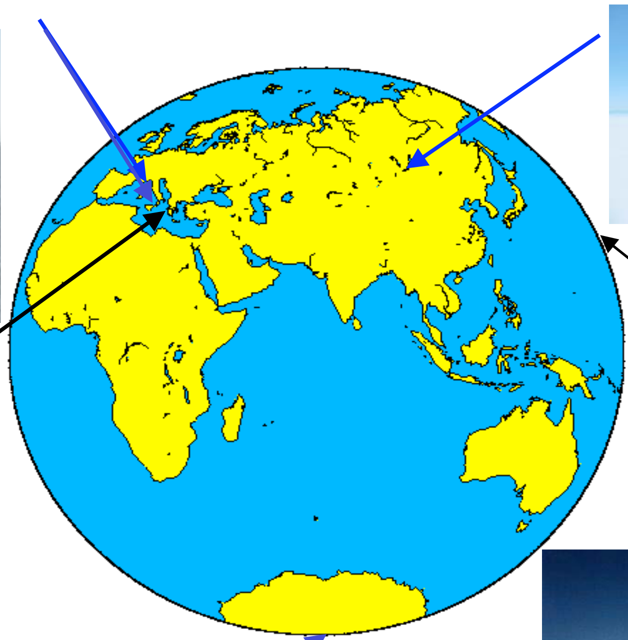


G.Gratta, atro-ph/0104033

H_2O Neutrino Telescope Projects

ANTARES La-Seyne-sur-Mer, France
(NEMO Catania, Italy)

BAIKAL: Lake Baikal, Siberia



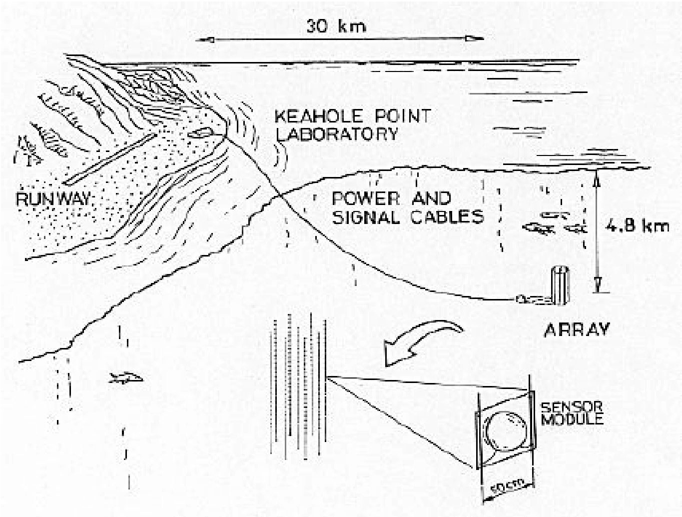
NESTOR : Pylos, Greece

DUMAND, Hawaii
(cancelled 1995)

AMANDA, South Pole, Antarctica

DUMAND

1976 – 1995 : Developed techniques and discovered problems

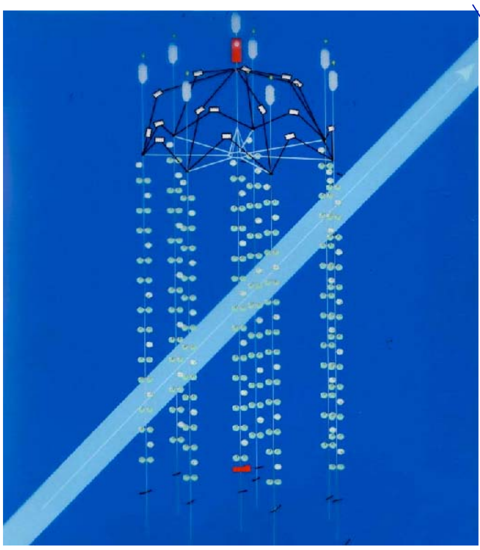


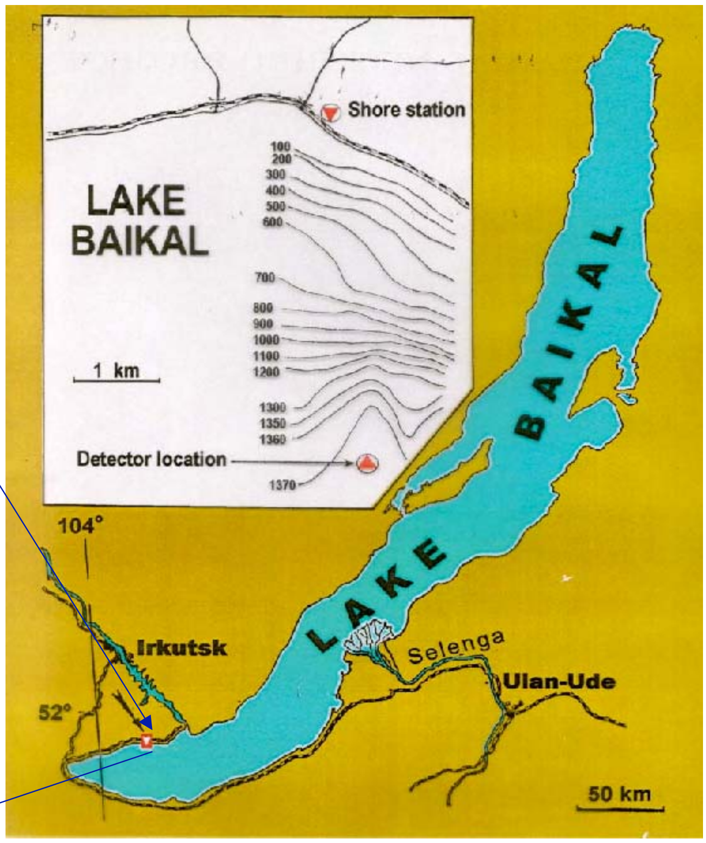
BAIKAL

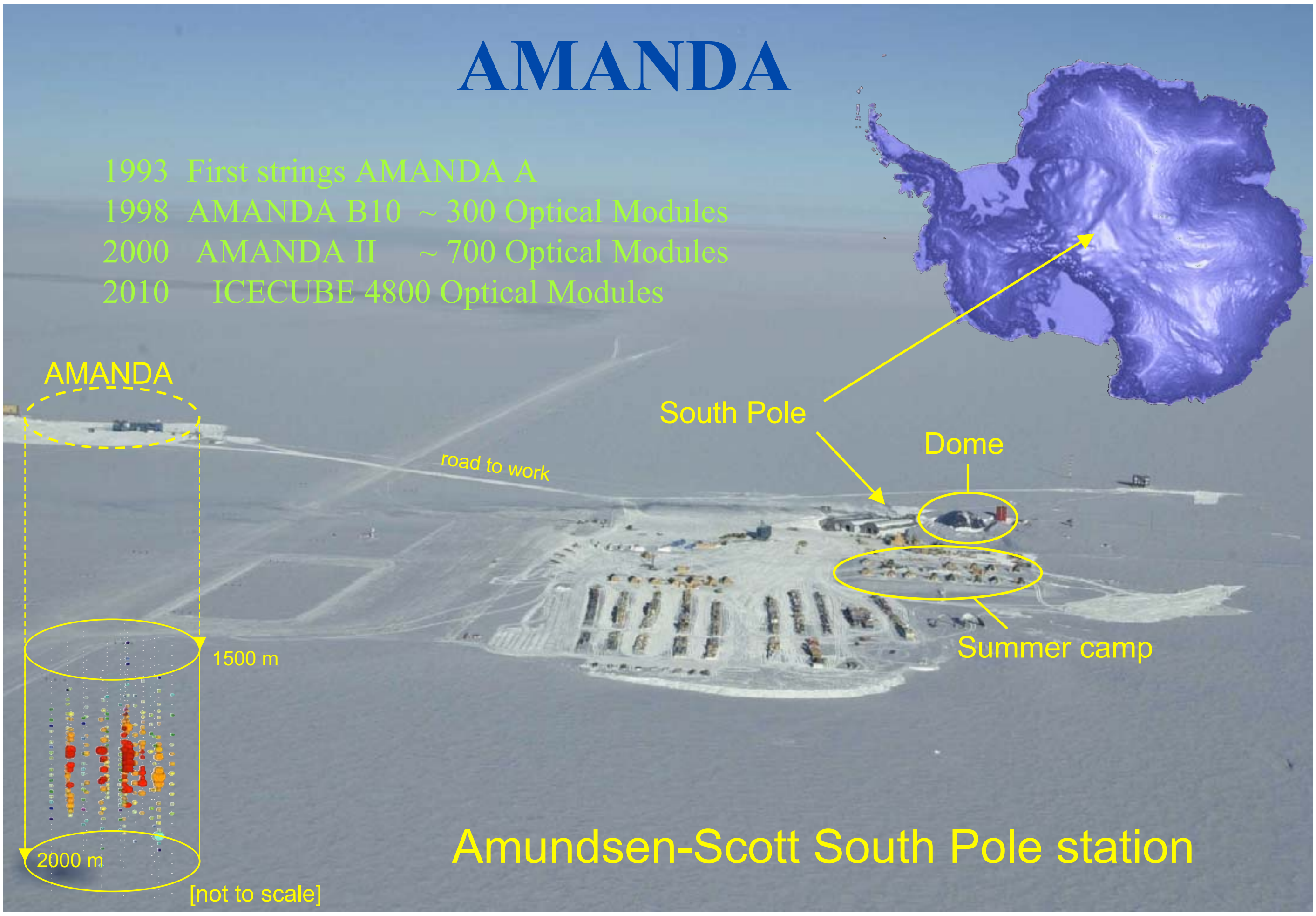
Lake Baikal, Siberia

Surface frozen in winter

1993 36 Optical Modules
1998 192 Optical Modules

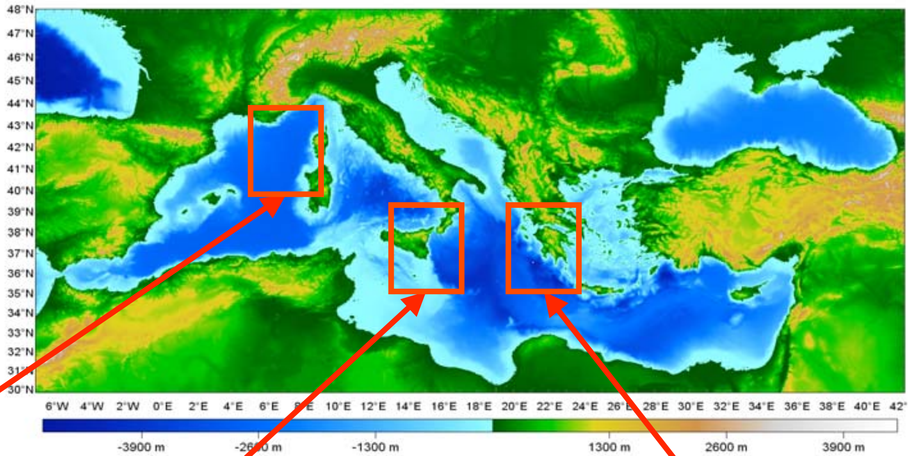


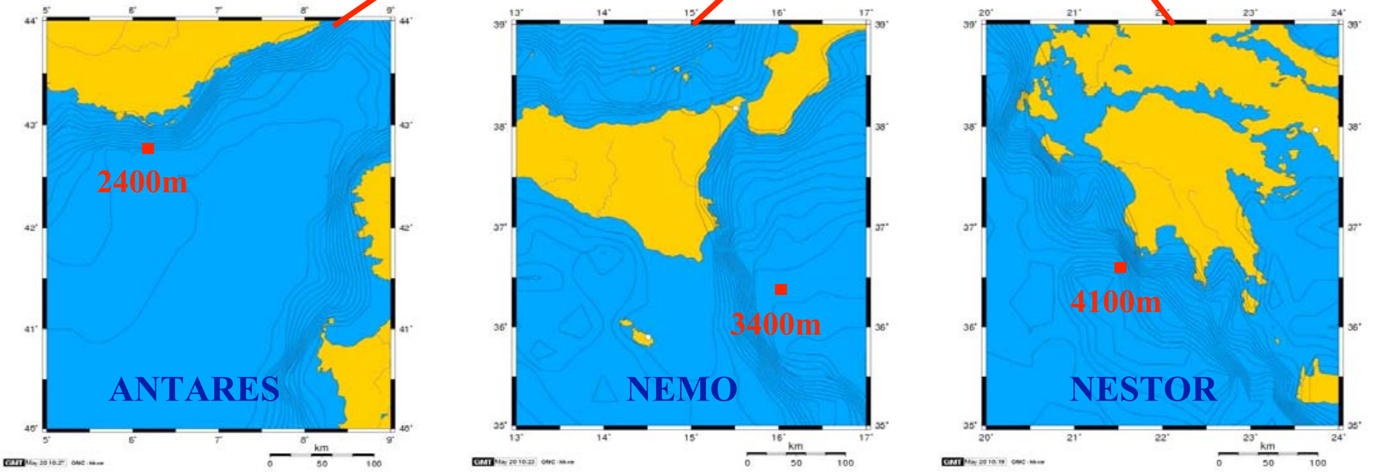




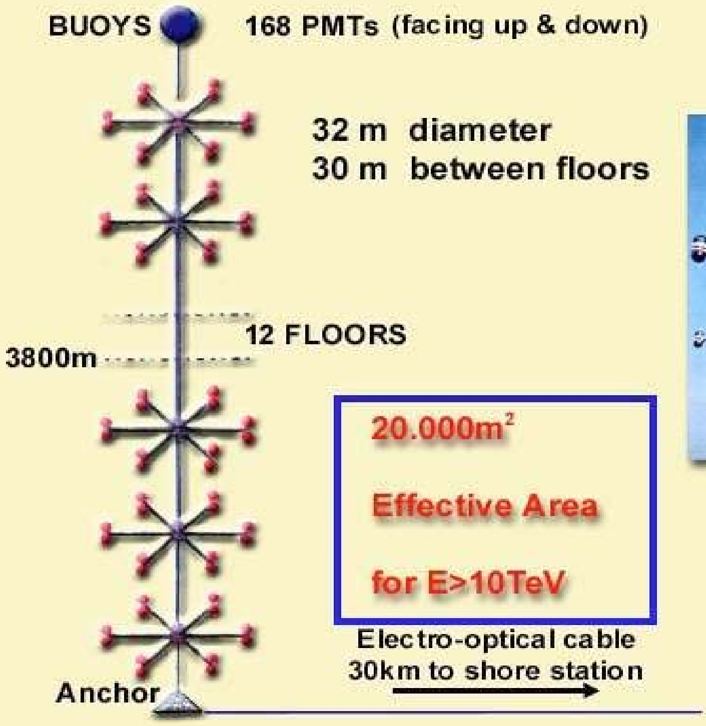
Mediterranean Sites

Collaboration for KM3NET Design Study



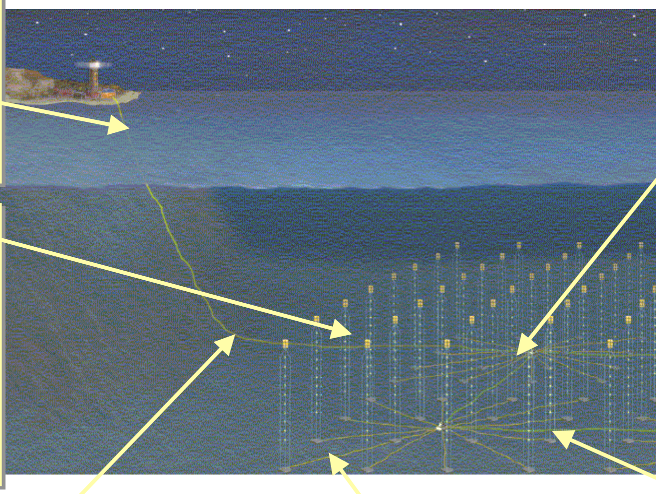


NESTOR

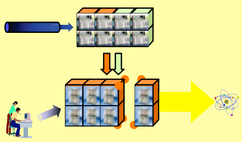


NEMO

The technological challenges

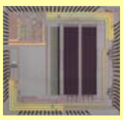


Data transmission



High bandtwidth data transmission

Electronics



Low power microelectronics for underwater applications

Underwater cable network

High power load electro-optical cables for deep sea applications

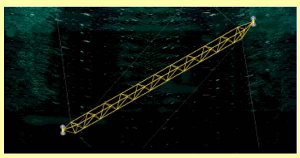
Connections

Underwater electro-optical connections

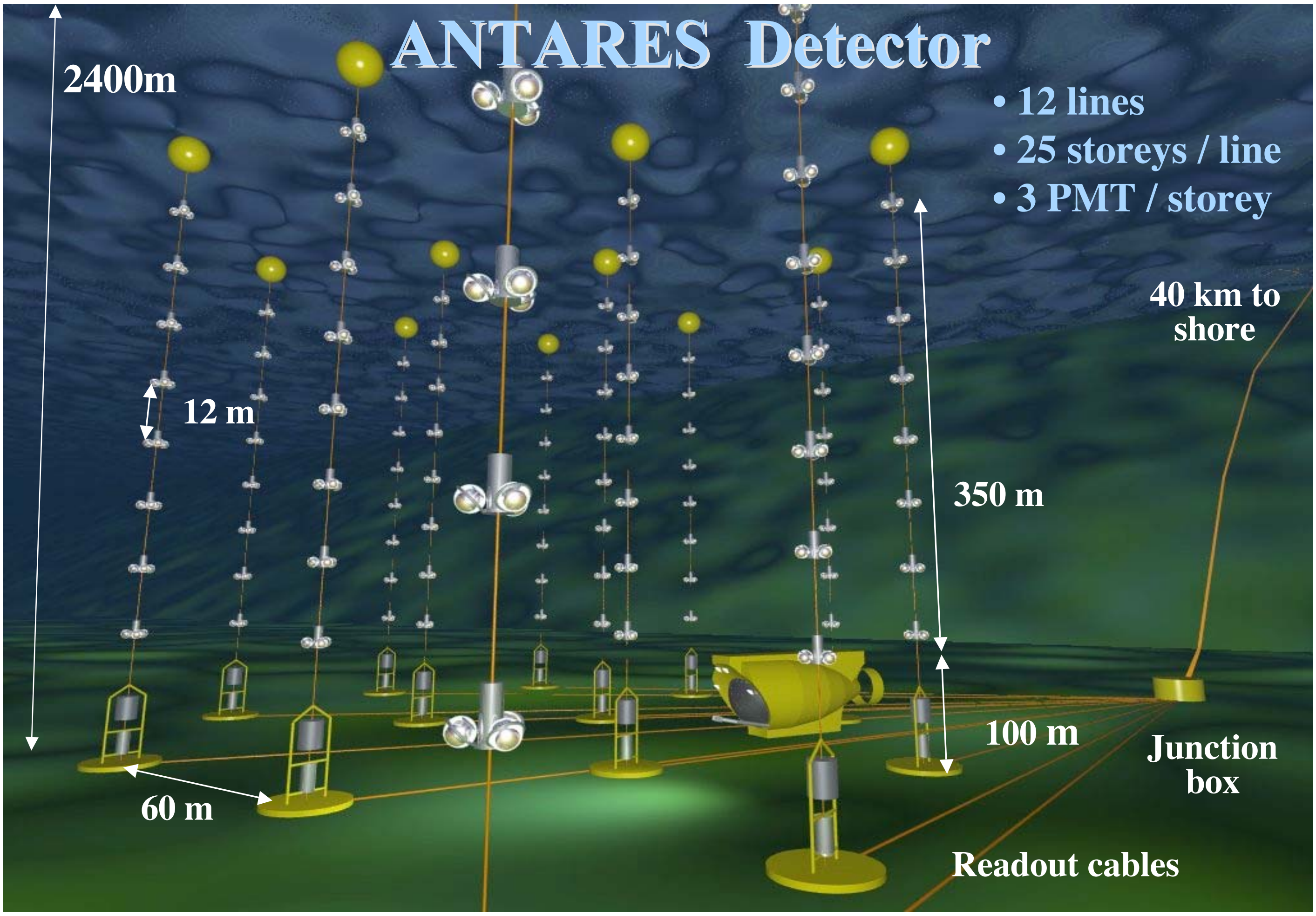
Deployment

Deployment and connection of the structures with underwater vehicles

Mechanical structures



Innovative materials for deep sea applications



Water versus Ice

Deployment

Ice gives solid platform to install detector
Sea experiments need boats/ platforms
Ice detectors worked first (Baikal deploys from ice)

Angular Resolution

Light scattering much less in water
AMANDA : ~ 3° (real detector)
ANTARES : ~ 0.2 ° (simulations)

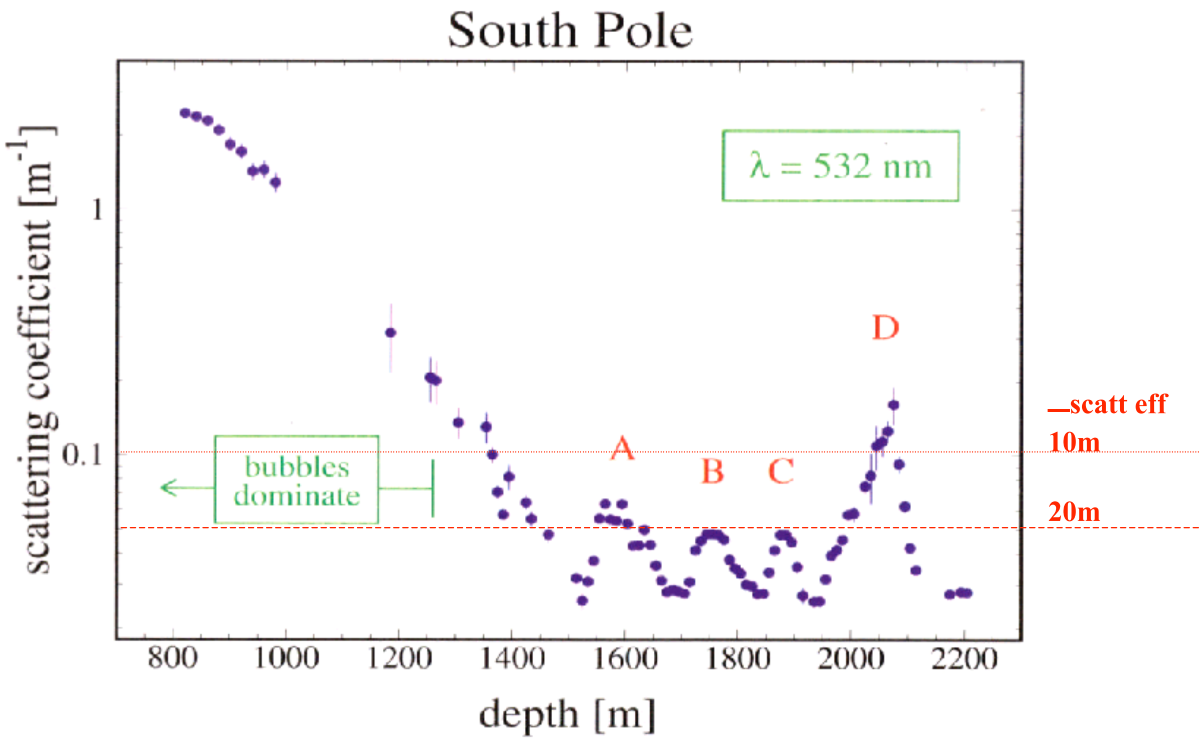
Uniformity of Detector response

Water homogeneous
Ice has dust layers, bubbles
Knowledge of efficiency simpler in water

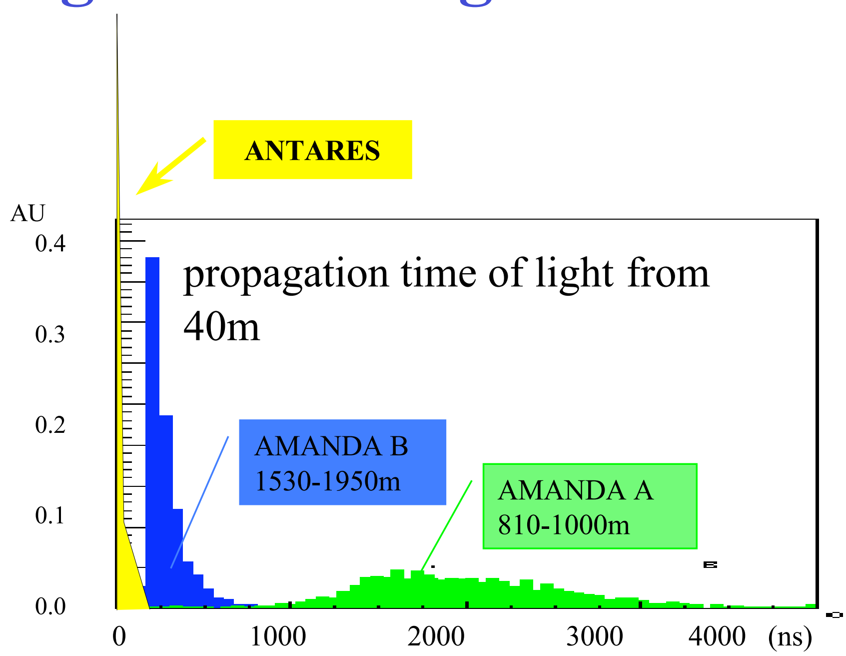
Noise Backgrounds

Water: ^{40}K /bioluminescence ~ 60kHz / PMT
Ice: only dark tube noise ~ 500Hz / PMT

AMANDA: effective scattering coefficient



Light Scattering: Sea Water and Ice



ANTARES

Absorption = 54 m

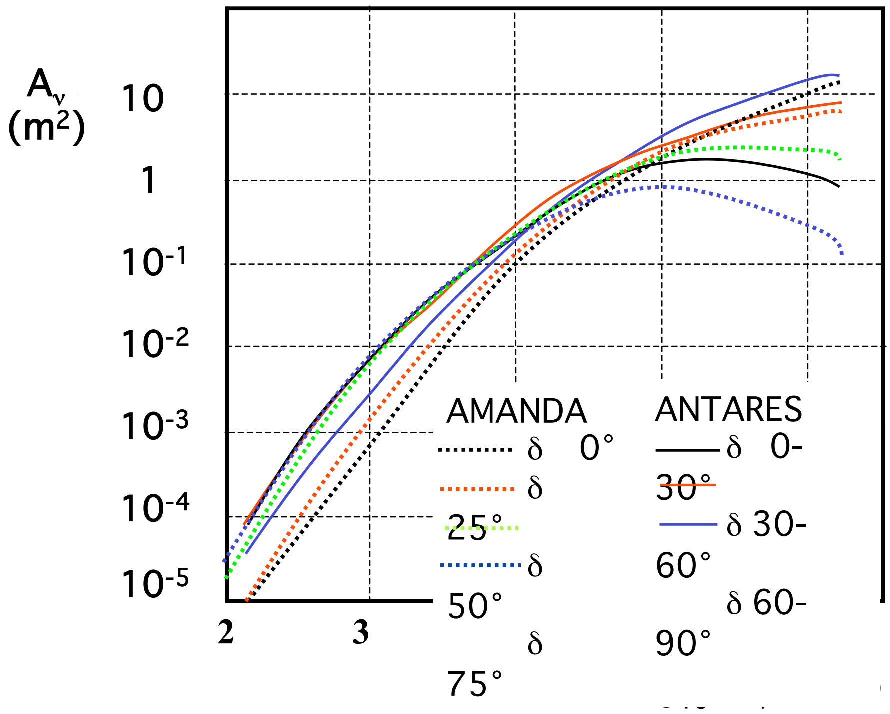
Scattering L_{eff} > 100 m

AMANDA B

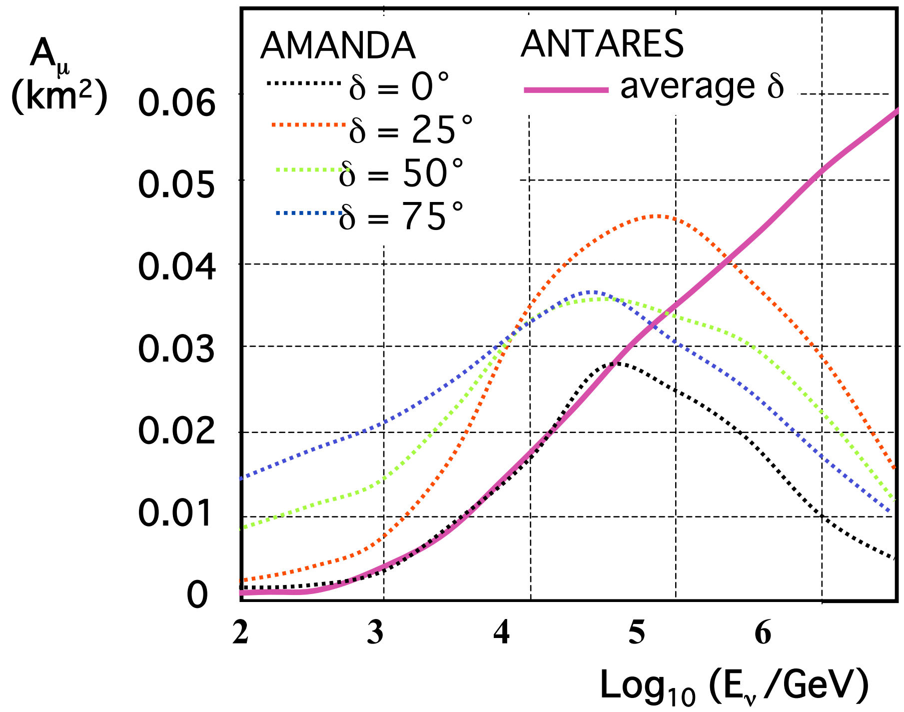
Absorption = 100 m

Scattering L_{eff} = 25 m

Effective Neutrino Area

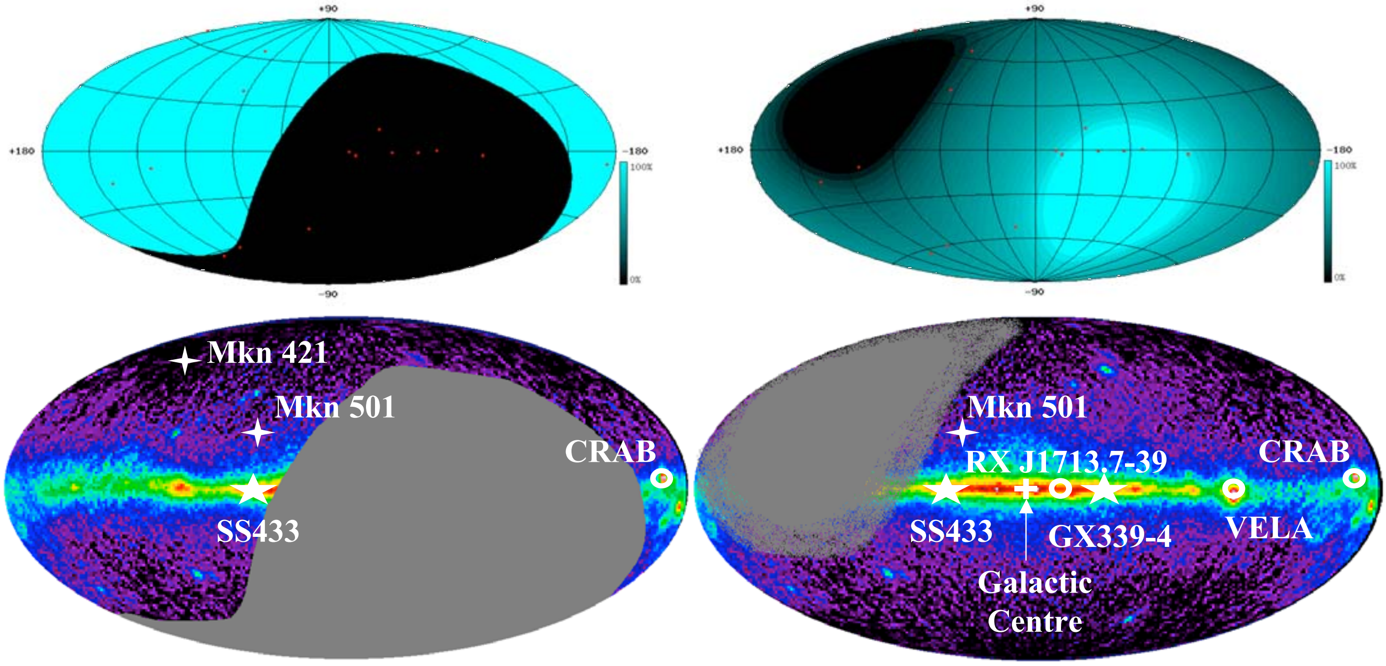


Effective Muon Area



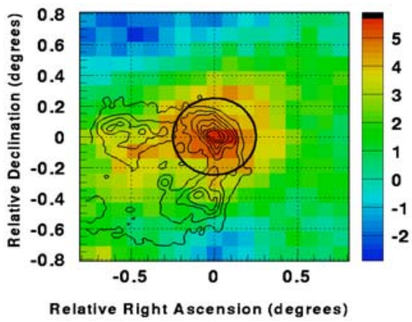
Region of sky observable by Neutrino Telescopes

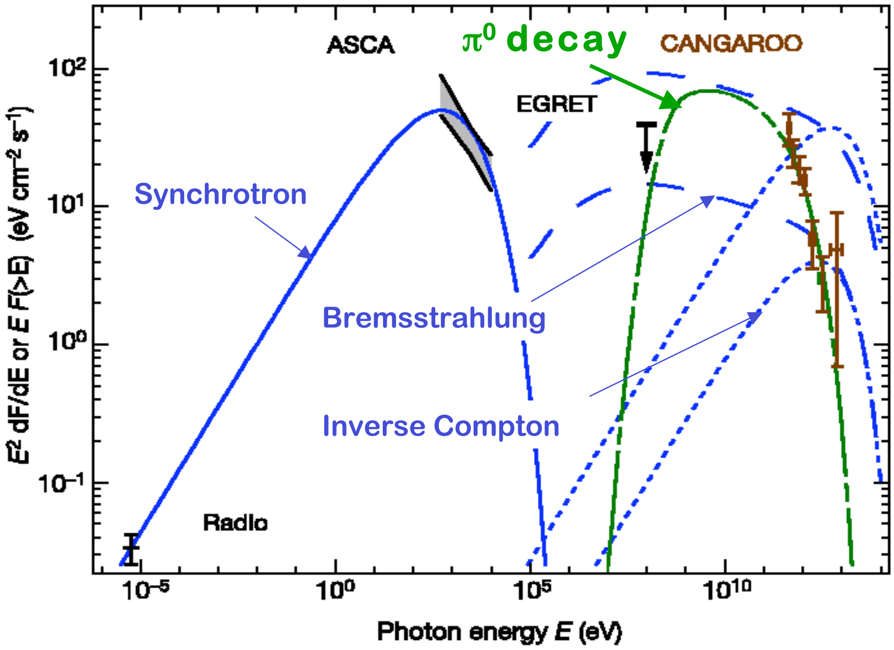
AMANDA (South Pole) | **ANTARES (43° North)**



Acceleration of cosmic-ray protons in the supernova remnant RX J1713.7-3946

R. Enomoto et al., Nature, v416, p823,25 April 2002

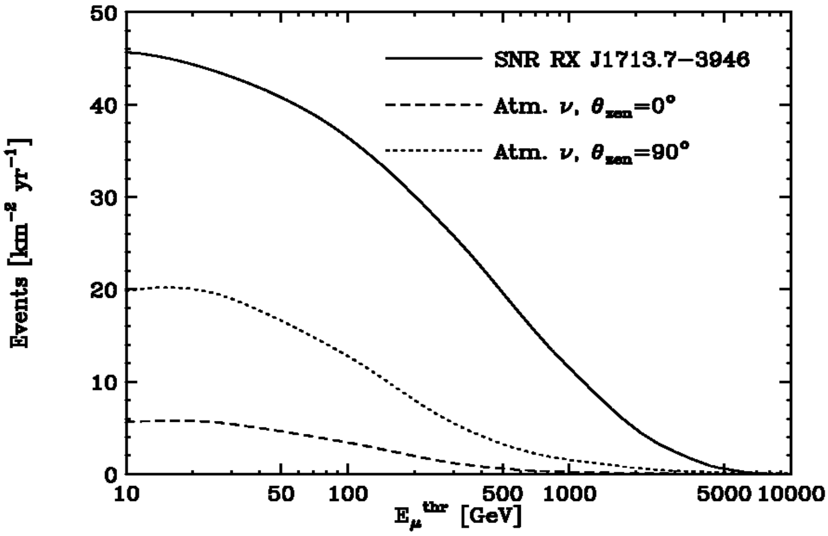




Recently confirmed by HESS

High Energy Neutrinos from RX J1713.7-3946

Assuming γ produced from π^0 decay then $N_\nu = N_\gamma$

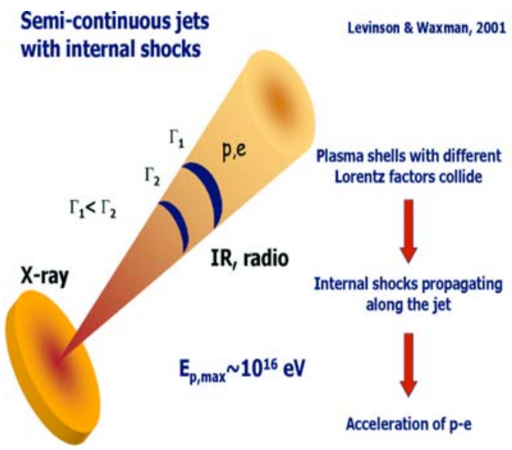


J. Alvarez-Mu_iz
and
F. Halzen
(astro-ph/0205408)

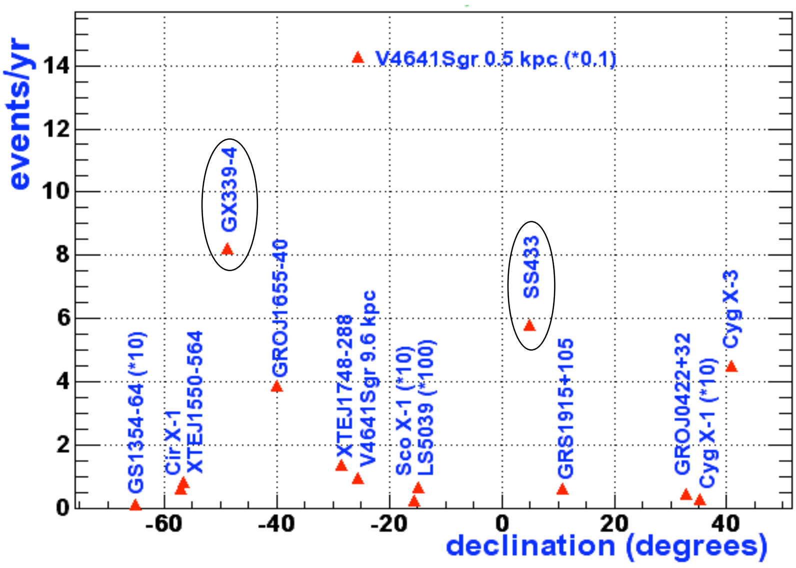
Clear signal for Northern Hemisphere Neutrino Telescopes
~3 events / year in ANTARES

Event rates from Microquasars in ANTARES

Model of Levisson and Waxman:
Proton interactions on synchrotron gamma from electrons
- assuming 10% of jet energy in protons



C. Distefano et al, ApJ 575, 378(2002)

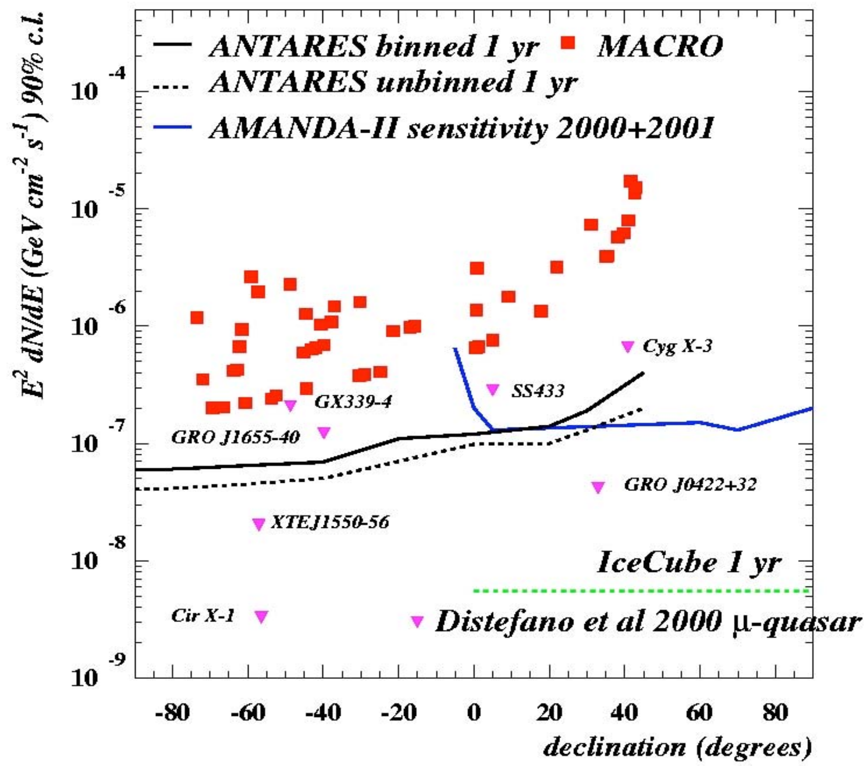


Predictions of rates for Galactic sources

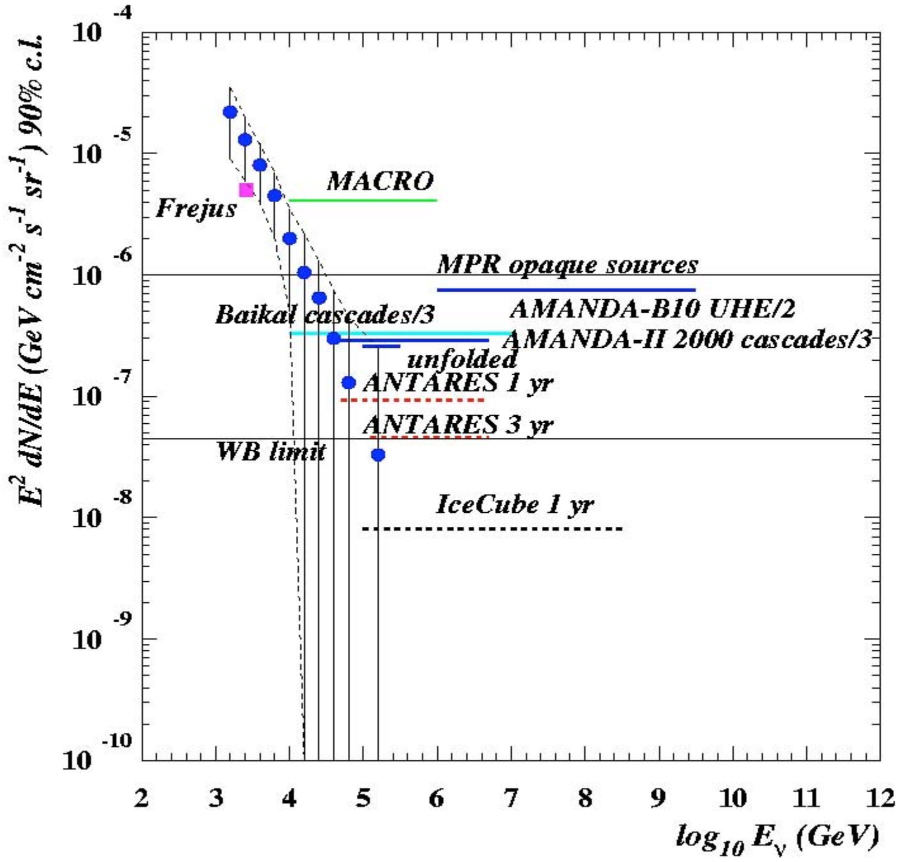
Source TypeA	Distance (kpc)	E_ν (GeV)	N_{ν} ($km^{-2}\ yr^{-1}$)	Ref.
Supernovae	10	<~ 10^3	~100	Waxman & Loeb 2001
Shocks		~ $10^2 - 10^6$	50 – 1000	Protheroe et al. 1998
pulsars		~ $10^5 - 10^8$	~ 100 – 1000	Beall & Bednarek 2002
		~ $10 - 10^8$	<~ 1000	Nagataki 2004
Plerions	0.5 – 4.4	< $10^3 - 10^5$	~ 1 – 12	Guetta & Amatto 2003
		~ $10^3 - 5\cdot10^5$	<~ 1	Bednarek 2003
Crab	2	~ $10^3 - 5\cdot10^5$	a few	Bednarek & Protheroe 1997
		~ $10^3 - 5\cdot10^5$	~ 1	Bednarek 2003
		$10 - 10^6$	~ 4 – 14	Amato et al. 2003
Shell SNRs				
SNR RX J1713.7	6	<~ 10^4	~ 40	Alvarez-Muñiz & Halzen 2002
Sgr A East	8	<~ 10^5	~ 140	
Pulsars + Clouds				
Galactic Centre	8	$10^4 - 10^7$	~ 2 – 30	Bednarek 2002
Cygnus OB2	1.7	>~ 10^3	a few	Torres et al. 2004
		$10^4 - 10^7$	~ 0.5	Bednarek 2003
		<~ 10^6	~4	Anchordoqui et al. 2003
Binary systems				
A0535+26	2.6	$3\cdot10^2 - 10^3$	a few	Anchordoqui et al. 2003
Microquasars	1 – 10	$10^3 - 10^5$	1 – 300	Distefano et al. 2002

(W. Bednarek, F. Burgio, T.Montaruli astro-ph/0404534)

Limits on point-like sources of neutrinos



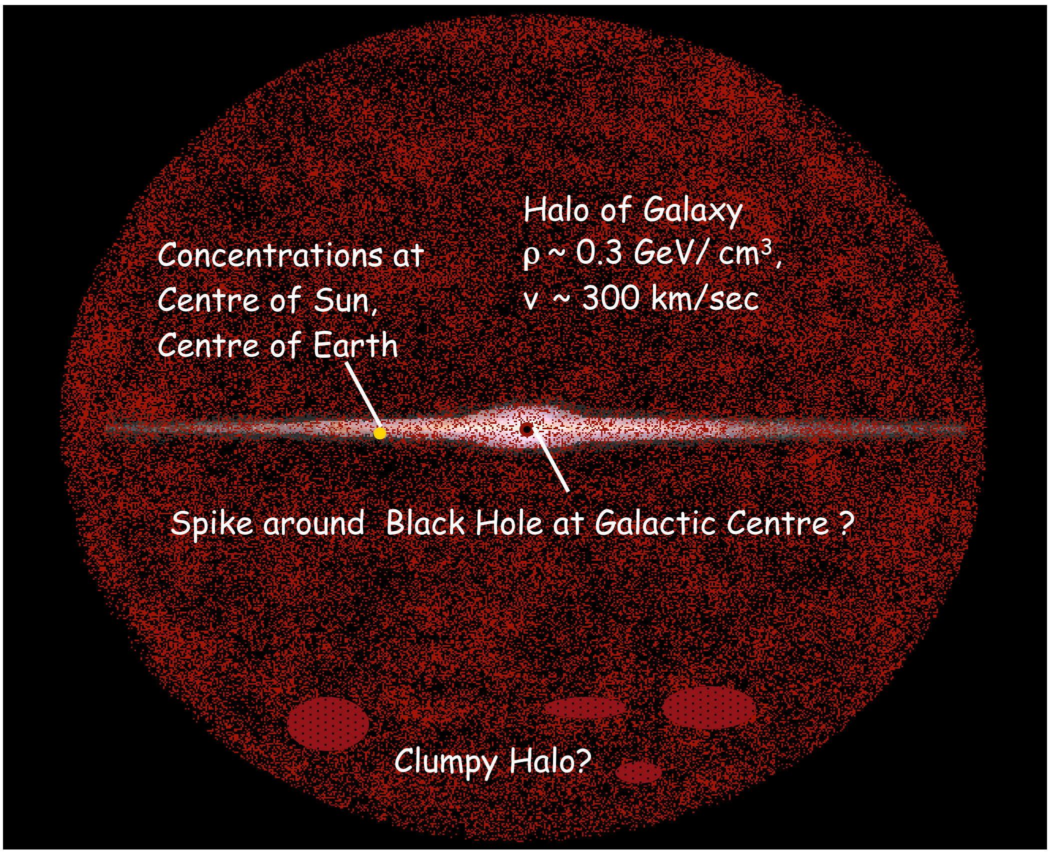
Limits on diffuse flux of muon neutrinos



Cascades/UHE sensitive to other flavours, so limits are divided by the number of flavours

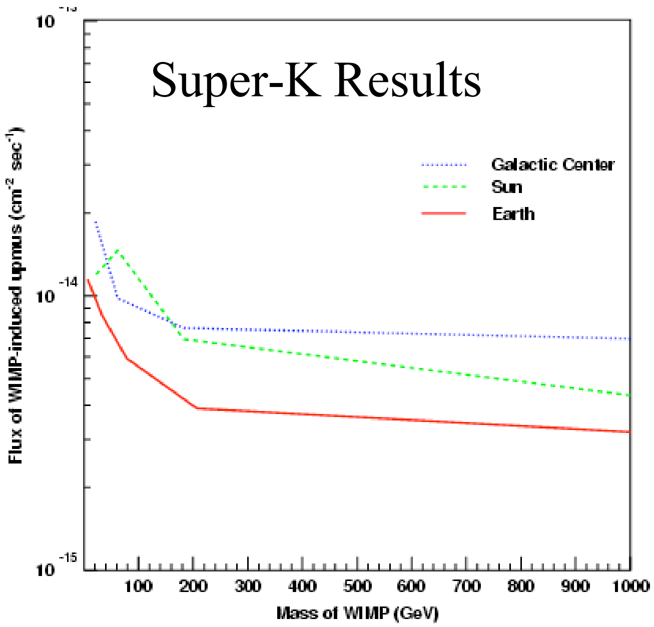
Compilation from T. Montaruli

WIMP Distributions in Galaxy

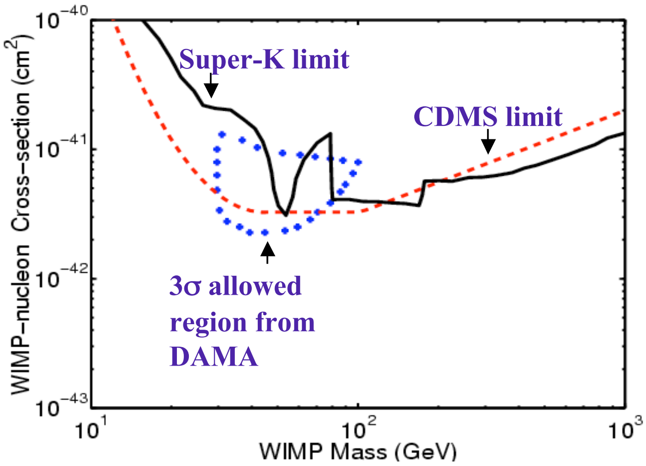


Search for WIMPS from centre of Earth, Sun and Galaxy

Limits on flux of muons from WIMPS

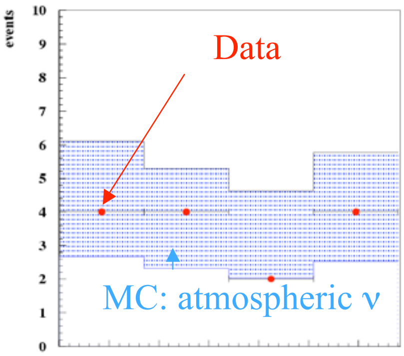


Compared to direct WIMP searches using Kamionkowski et al. (1995)

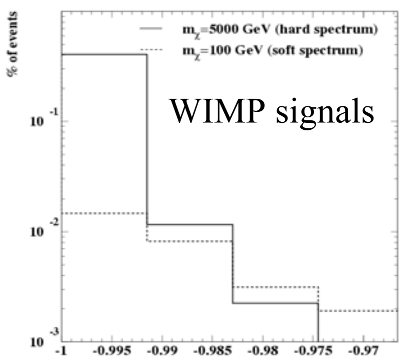


AMANDA Results

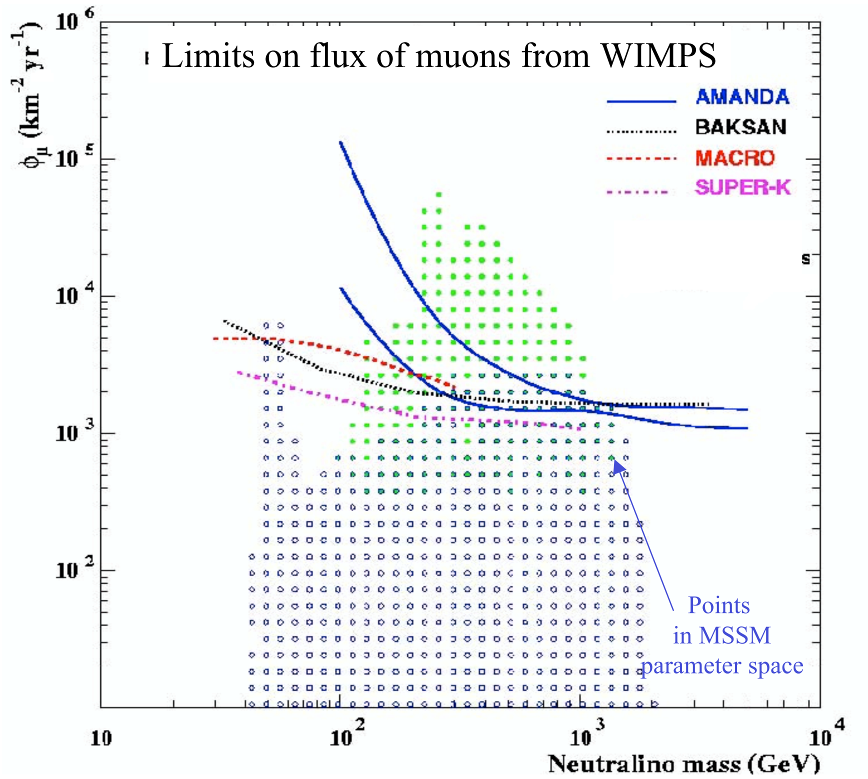
WIMPS from centre of Earth



Cos(angle to centre of Earth)



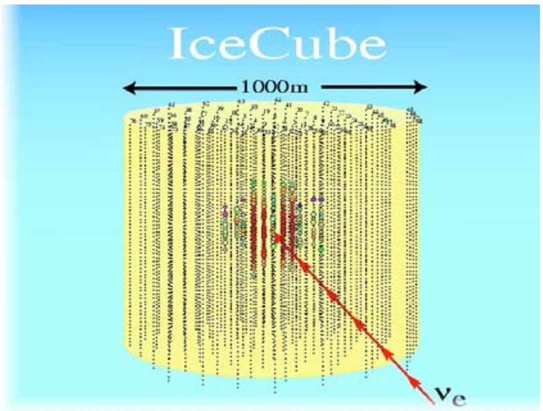
Cos(angle to centre of Earth)



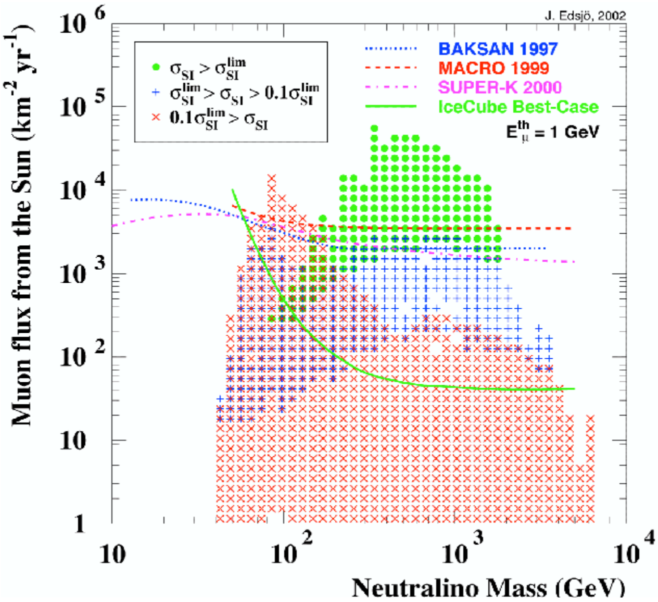
ICECUBE at South Pole

First Km³ Neutrino Detector, ~2010 ?

WIMPS sensitivity from sun



- **80 strings, 60 PM´s each; 4800 optical modules total**
- **V ≈ 1 km_, E_{th}~ 0.5-1TeV**



Sun always within 22° of horizon at pole

Comparison : ANTARES and Direct Detection

Using example of mSUGRA model

A_0=0, μ>0, tanβ=10,

$M_{1/2}$=0-800 GeV,

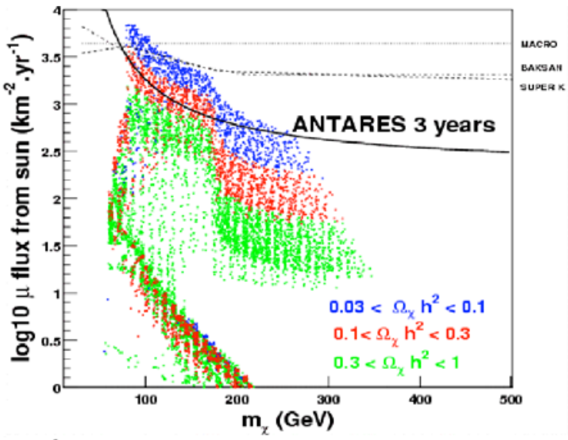
M_0=0-1000 GeV

+ $\Omega_{wimp}h^2 < 1$

+ LEP constraint

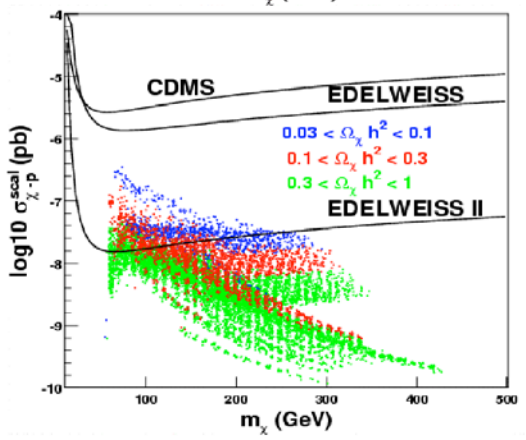
Neutrino telescope

ν flux from sun



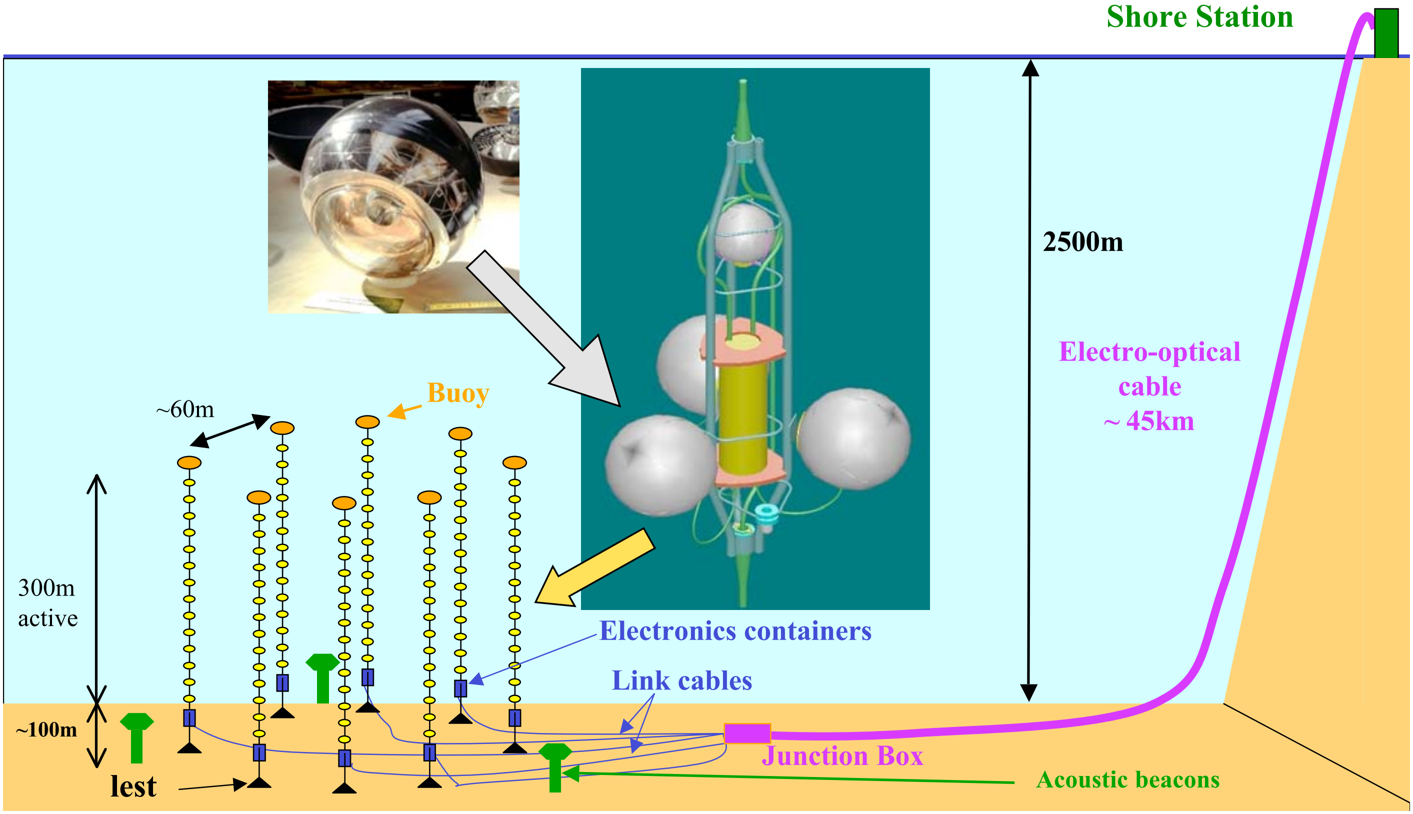
Direct Detection

spin-independent cross-section

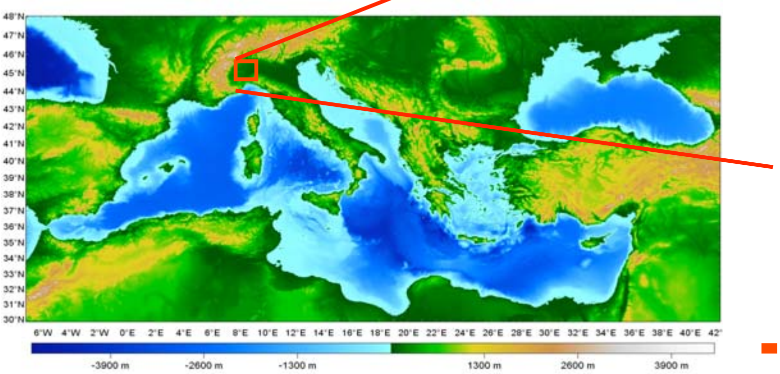


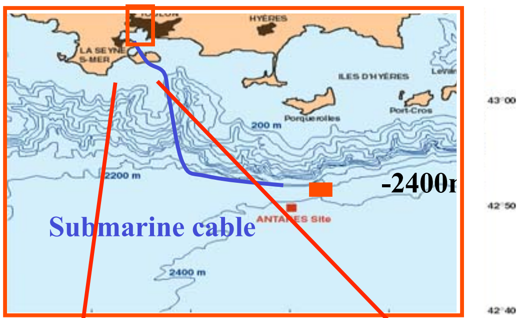
⇒ Neutrino Telescopes very competitive for some regions of MSSM phase space

ANTARES Detector



Site location

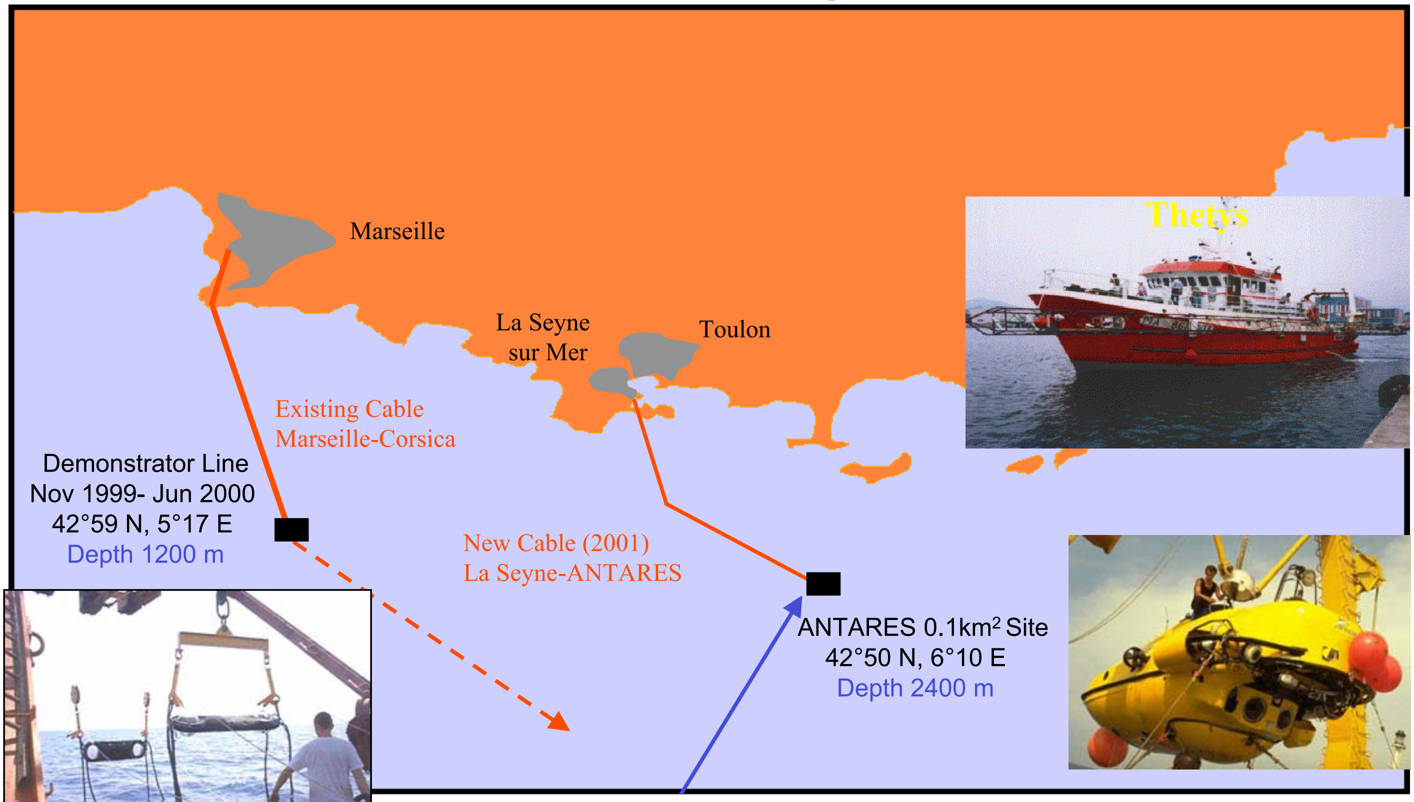




Shore Station

Institut Michel Pacha

ANTARES Programme



~ 40 deployments and recoveries of test lines for site exploration

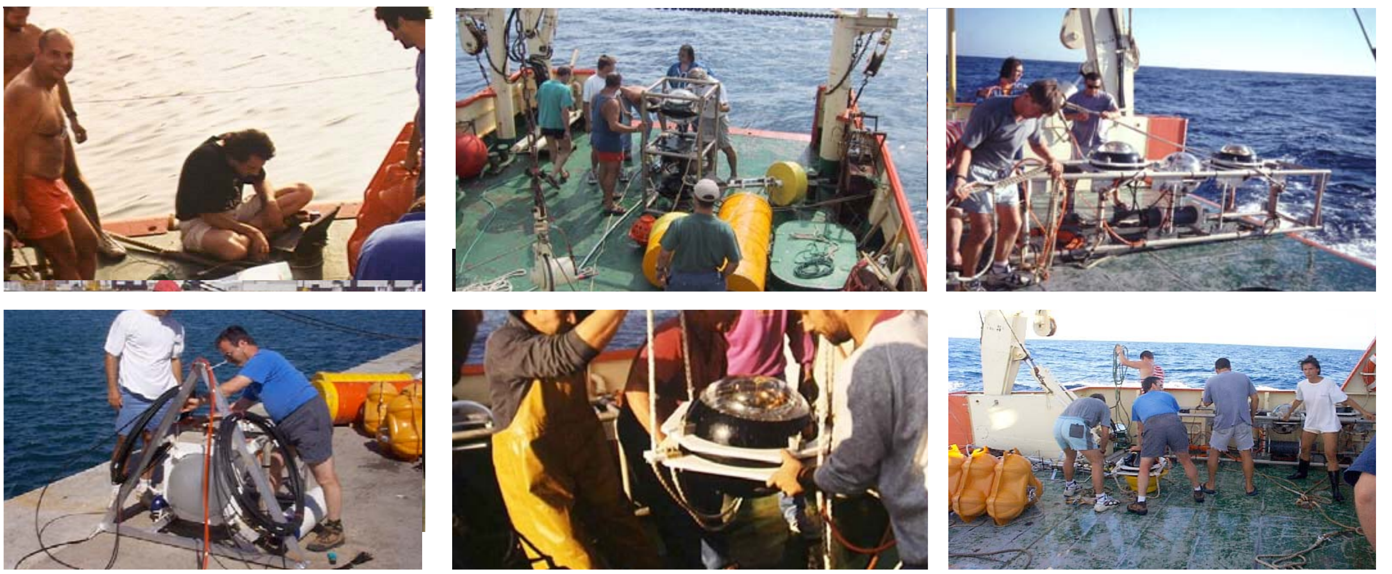
0.1 km^2 Detector with 900 Optical Modules , deployment 2004- 2007

Site Explorations

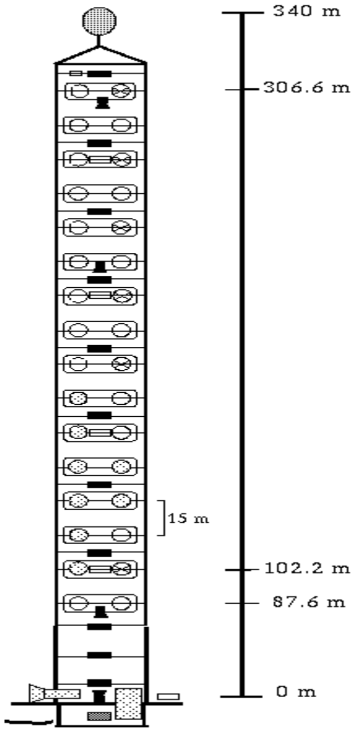
1) Optical background study: 15 deployments

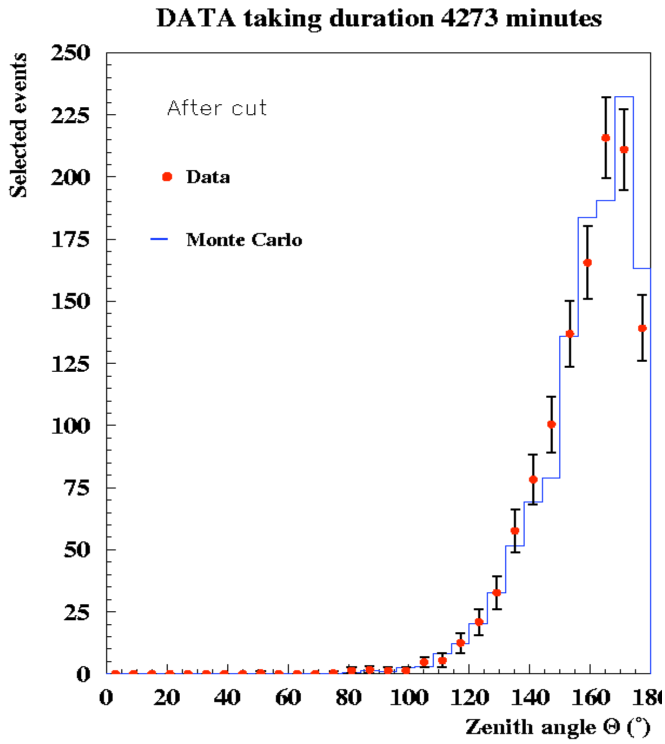
2) Biofouling-sedimentation study: 4 deployments

3) Optical properties study: 28 deployments



Muon Reconstruction with Demonstrator Line 1999





Sphere Implosion Test

Stored potential energy in sphere at 2600m: VΔP~ 1 mega Joule !!

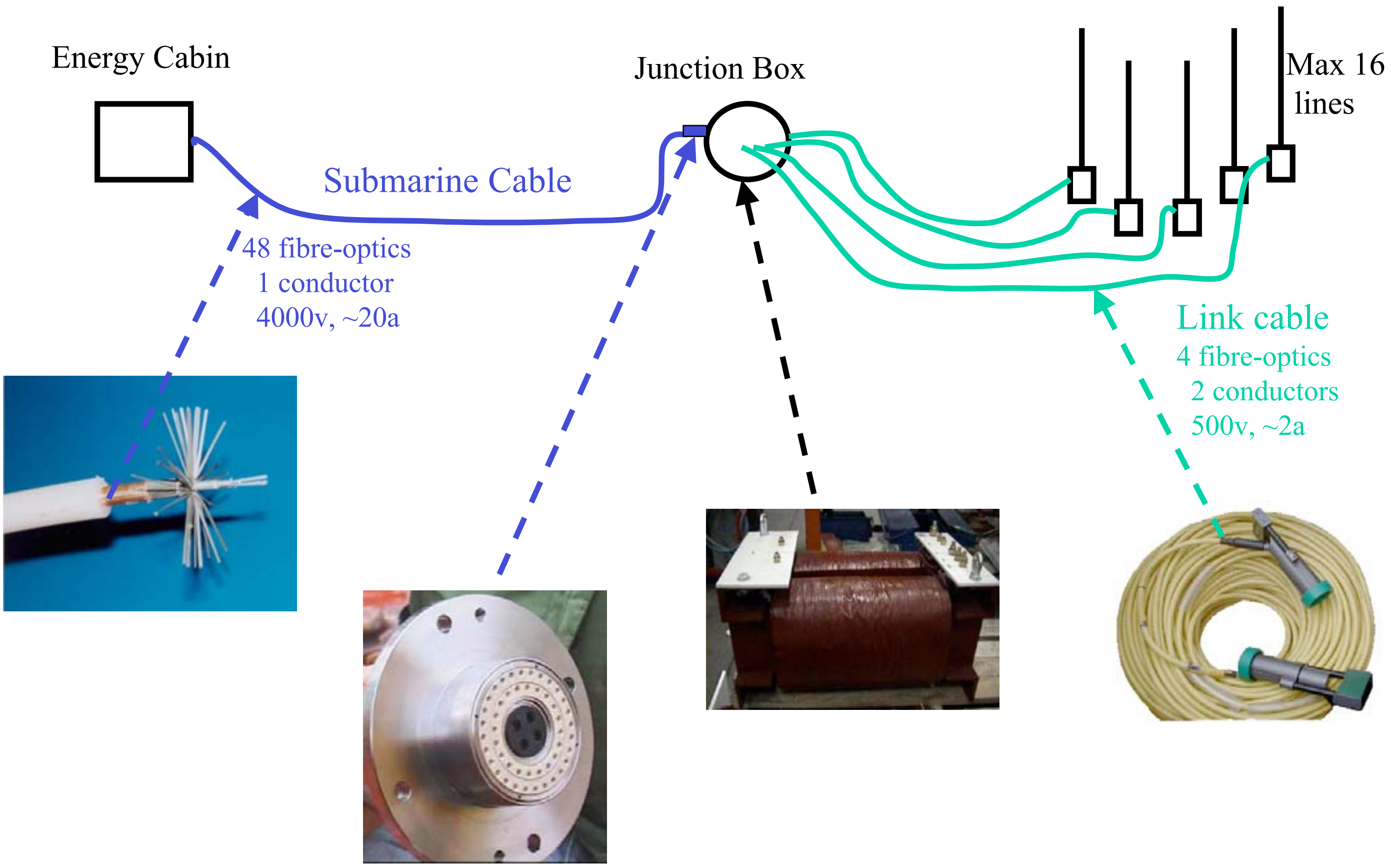
⇒ Risk of accidental implosion provoking a catastrophic chain reaction (cf. SuperKamiokande)

Tests (June 2000) – Two storeys 12m apart, 1 sphere weakened, implosion occurred at a depth of 2600m

RESULT:
- Neighbouring spheres on same storey also imploded
- Electronics in LCM destroyed

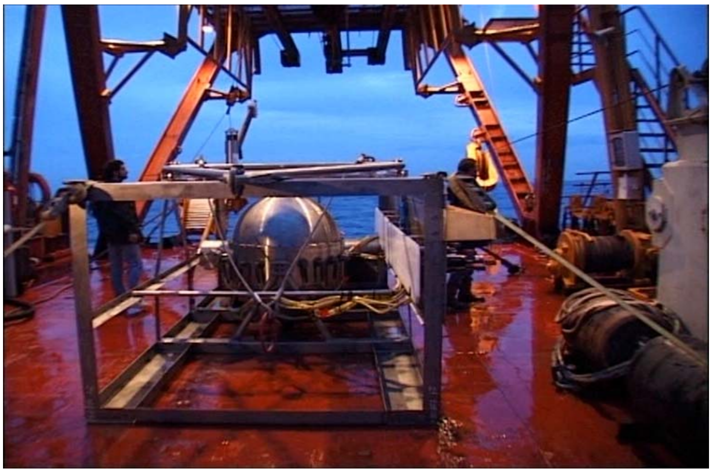
- Upper storey intact
- Mechanical cable unbroken

Connection of detector to shore

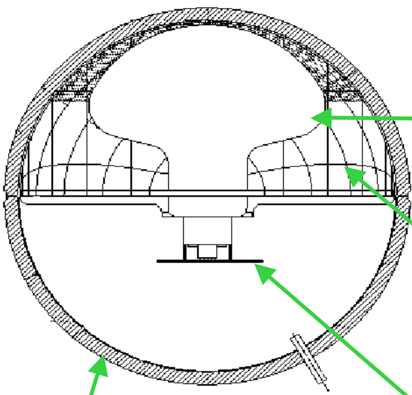


Deployment of Sea Cable, Nov 2001

Deployment of Junction Box, Dec 2002

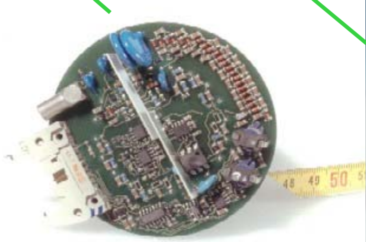


Light detectors : "optical module"



Photomultiplier: 10 inch Hamamatsu

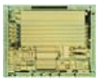
Glass sphere: Nautillus

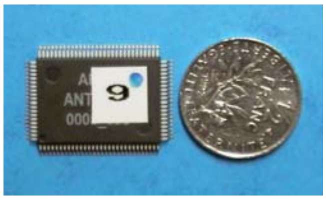


Active PMT base

Mu metal magnetic shield

Front-end electronics: ARS

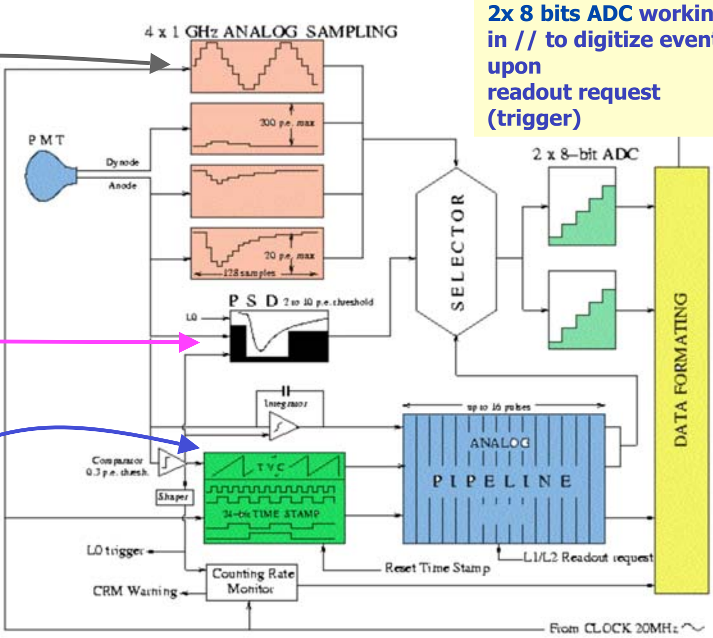




Constant 1GHz analog sampling of PMT's Anode, A/5, Dynode 11, and CLOCK signals
Dynamic: 4V (~60spe)

Configurable pulse-shape discrimination to tag complex shapes (Waveform) which will be fully digitized.

For simple pulses (SPE like) only Charge and Time information is measured.
σ_t ~400 ps



2x 8 bits ADC working in // to digitize events upon readout request (trigger)

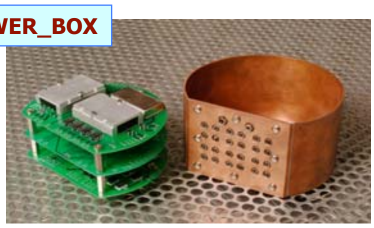
A high speed (20Mb/s) serial port is used to transfer digitized events to the central daq processor.

Electronics Crate

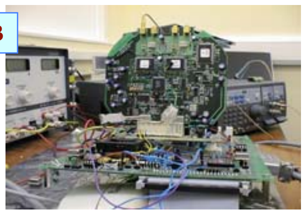
Inside a **L**ocal **C**ontrol **M**odule

LCM_DAQ

POWER_BOX

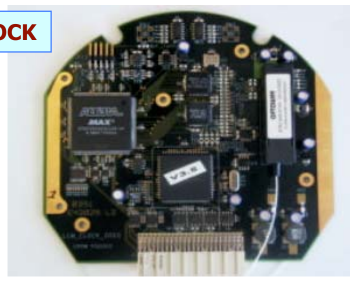


ARS_MB

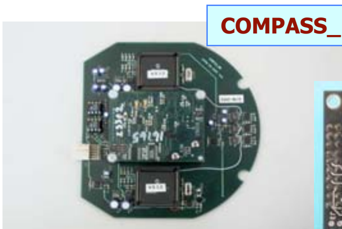


x 3
x 4 in case of LED beacon

LCM_CLOCK



COMPASS_MB



UNIV1

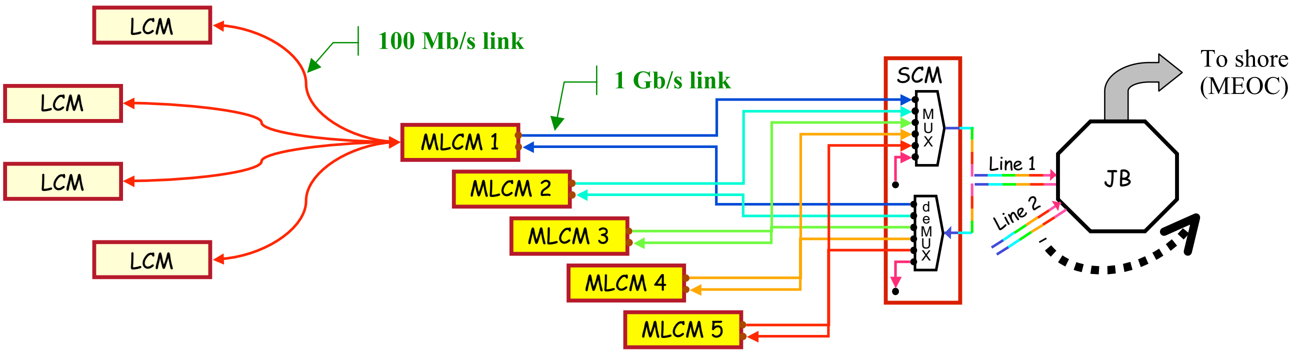
For some LCM's, additional cards for:

- LED beacon
- Hydrophone

Data Transmission

The main functions are:

- Readout and packing of the data produced by the ARS's.
- Transmission of the resulting data through the line network.
- Processing of slow control messages.
- Conversion to optical signals on 1 fiber (100 Mb/s)



Complete Prototype Line

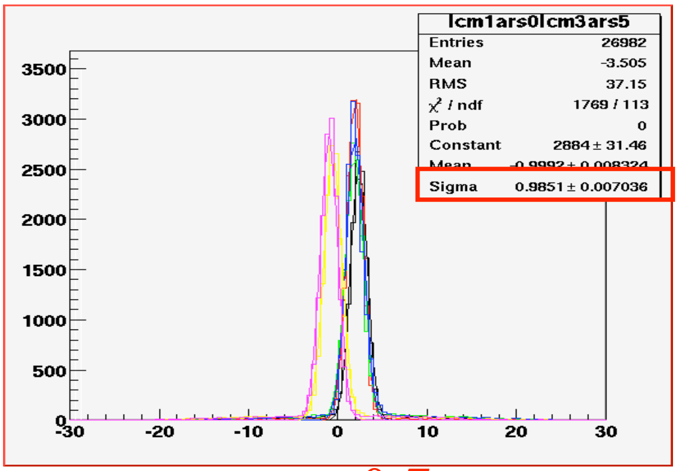
Time resolution

~0.34ns

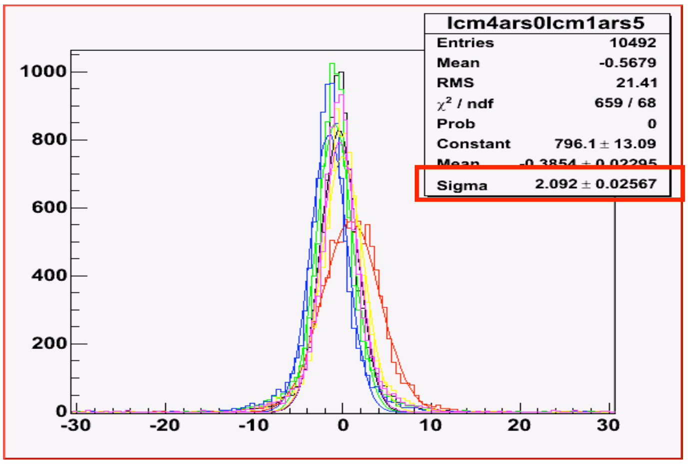
$$\sigma^2_{meas} = \sigma^2_{elec} + \frac{(\sigma^2_{TTS} + \sigma^2_{LASER})}{N_{phot}}$$

$N_{phot} = \infty \Rightarrow \sigma_{meas} = \sigma_{elec}$

$N_{phot} = 1 \Rightarrow \sigma_{meas} \approx \sigma_{TTS}$

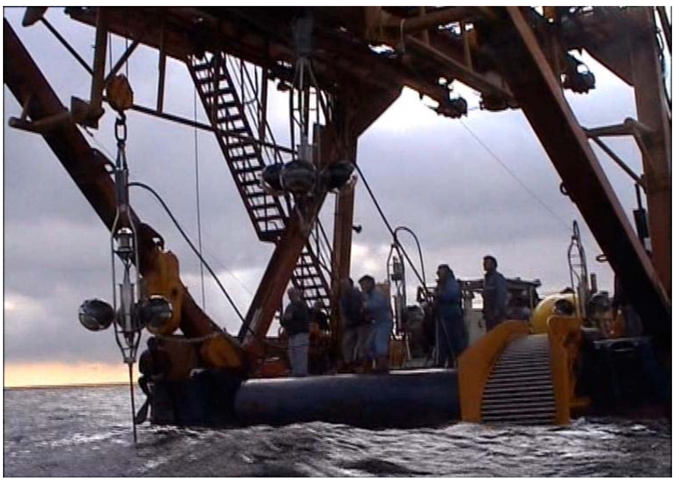


$\sigma_{elec} < 0.7$ns



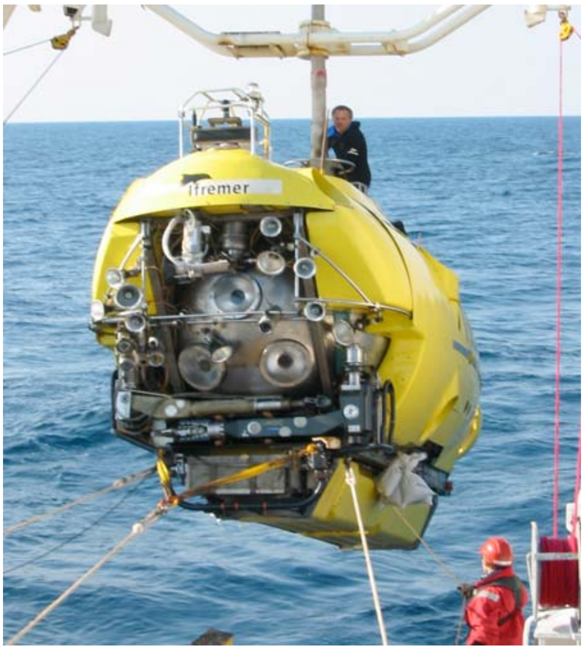
$\sigma_{TTS} \sim 1.5$ns

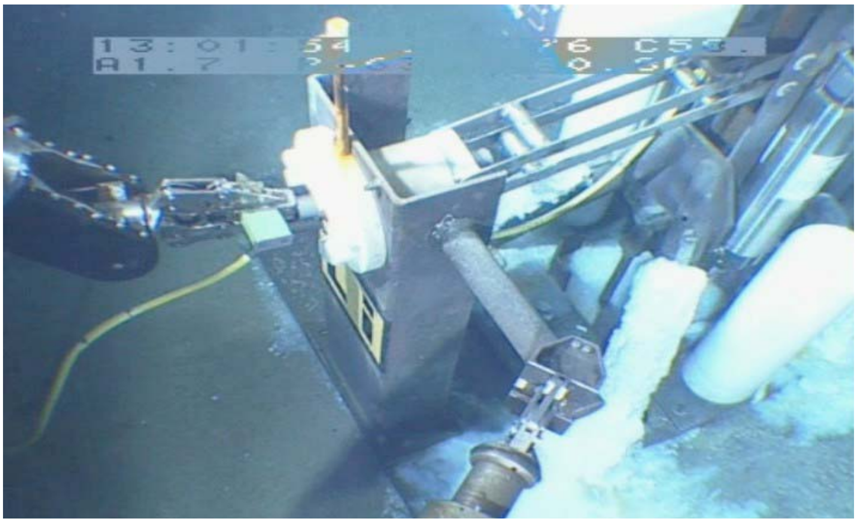
Prototype line deployment, Dec 2002

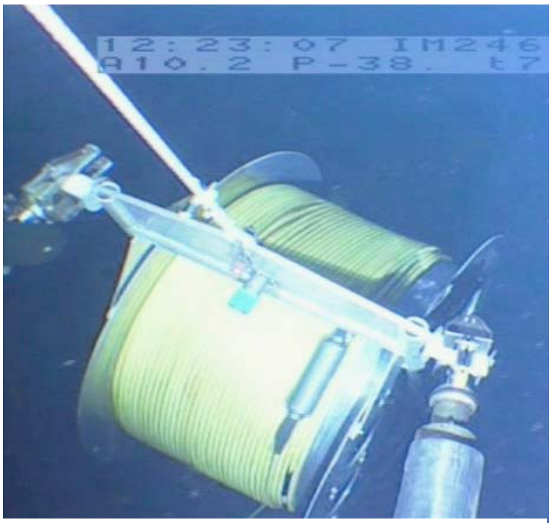


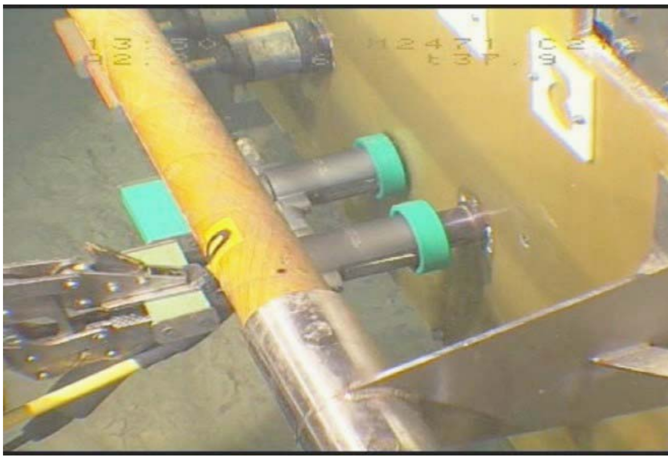
Submarine cable connection

Performed with Nautile in March 2003

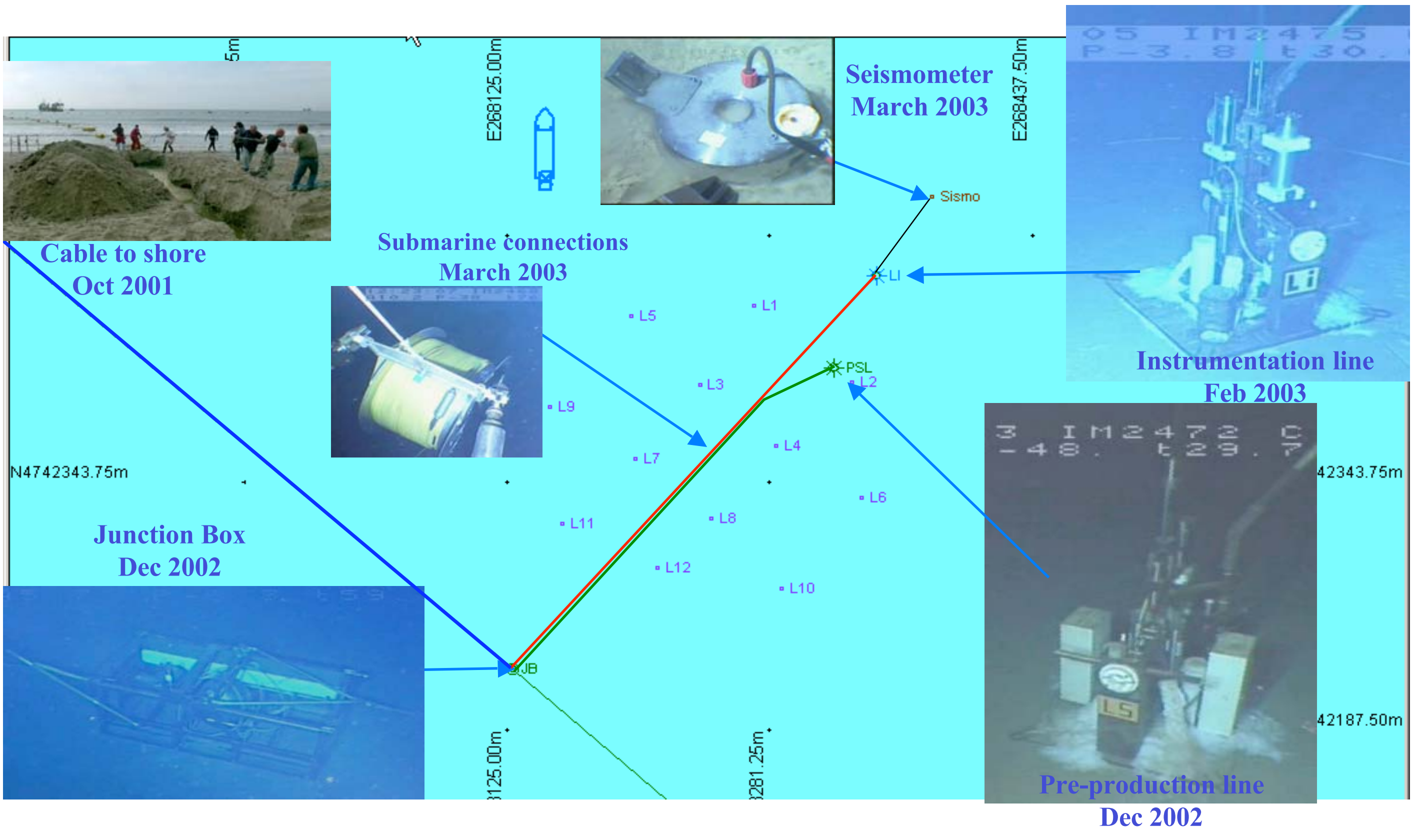




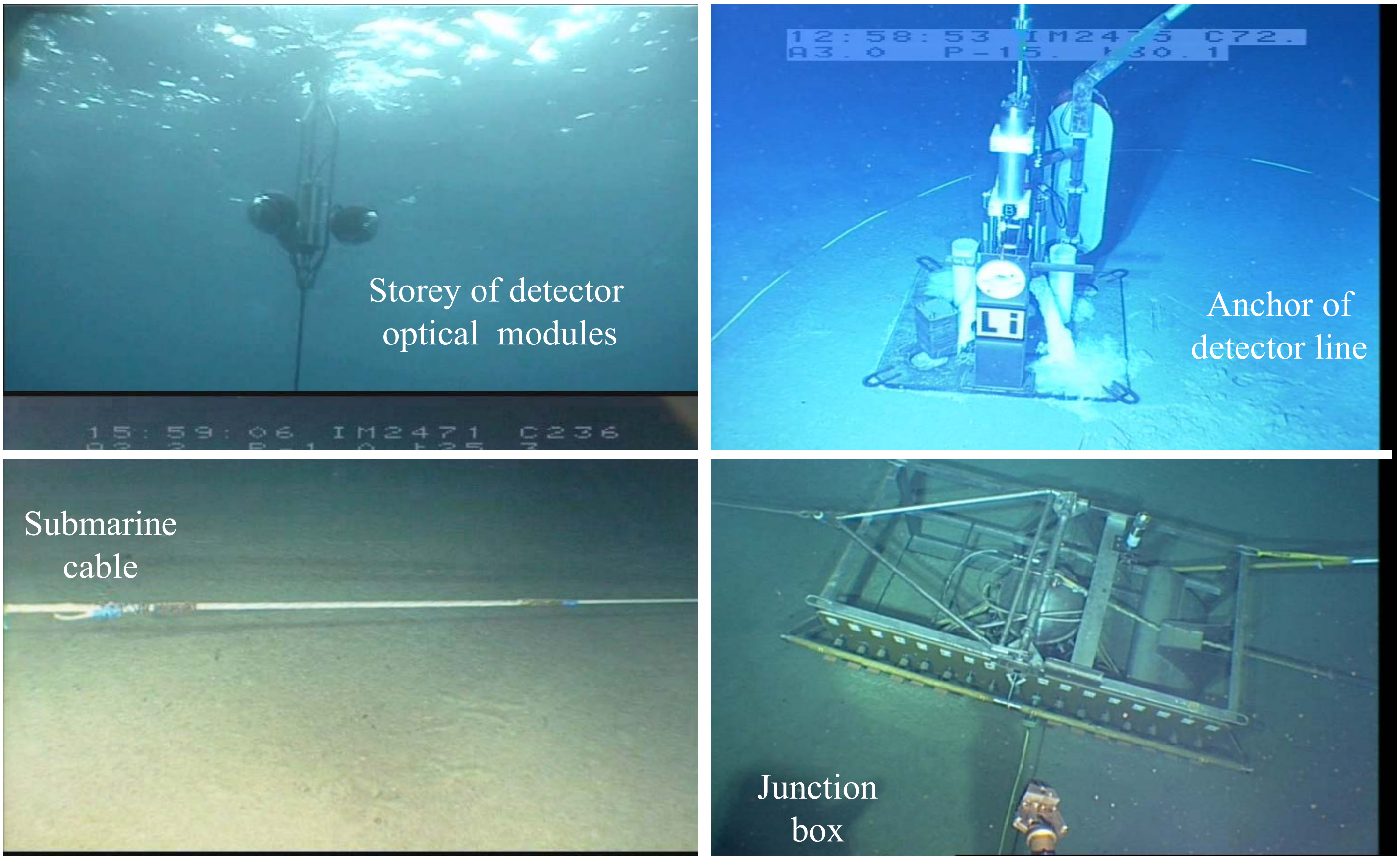




Layout of ANTARES site in Spring 2003

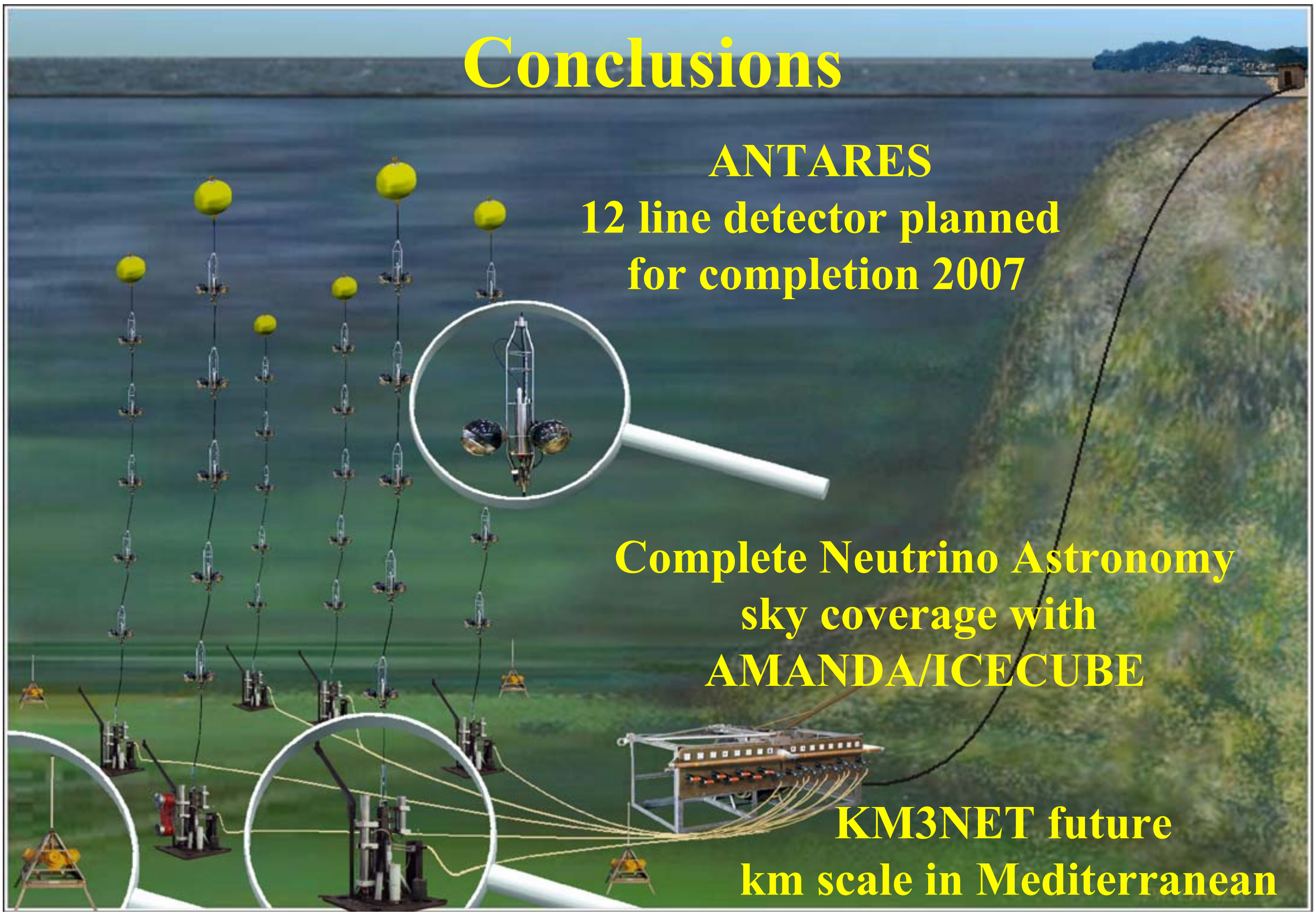


Undersea images of detector elements



Physics subjects left for ANTARES

Topic	Amanda	Antares
Diffuse flux	First	Confirmation
Extragalactic	Sky coverage	Sky coverage
Point sources		angular resolution
GRBs	Sky coverage	Sky coverage
Galactic sources	weak	strong
WIMPS sun	weak	strong
WIMPS Galaxy	No	Yes
Monopoles	First	Confirmation
SN bursts	Yes	No


Conclusions
ANTARES
12 line detector planned
for completion 2007
Complete Neutrino Astronomy
sky coverage with
AMANDA/ICECUBE
KM3NET future
km scale in Mediterranean