Antonio Capone, Dipartimento di Fisica
Università "La Sapienza" & INFN, Roma

Il progetto NEMO e le prospettive per l'astronomia con neutrini nel Mediterraneo

NEMO
NEUTRINO MEDITERRANEAN OBSERVATORY

ANTARES

νONE - Observatory of Neutrino Events

KM3NeT

Outlook

•Physics with deep under-water/ice Neutrino Telescopes

•Current projects in Mediterranean Sea:
- ANTARES (Rome group is contributing to it)
- NEMO (Rome group is contributing to it)
- NESTOR

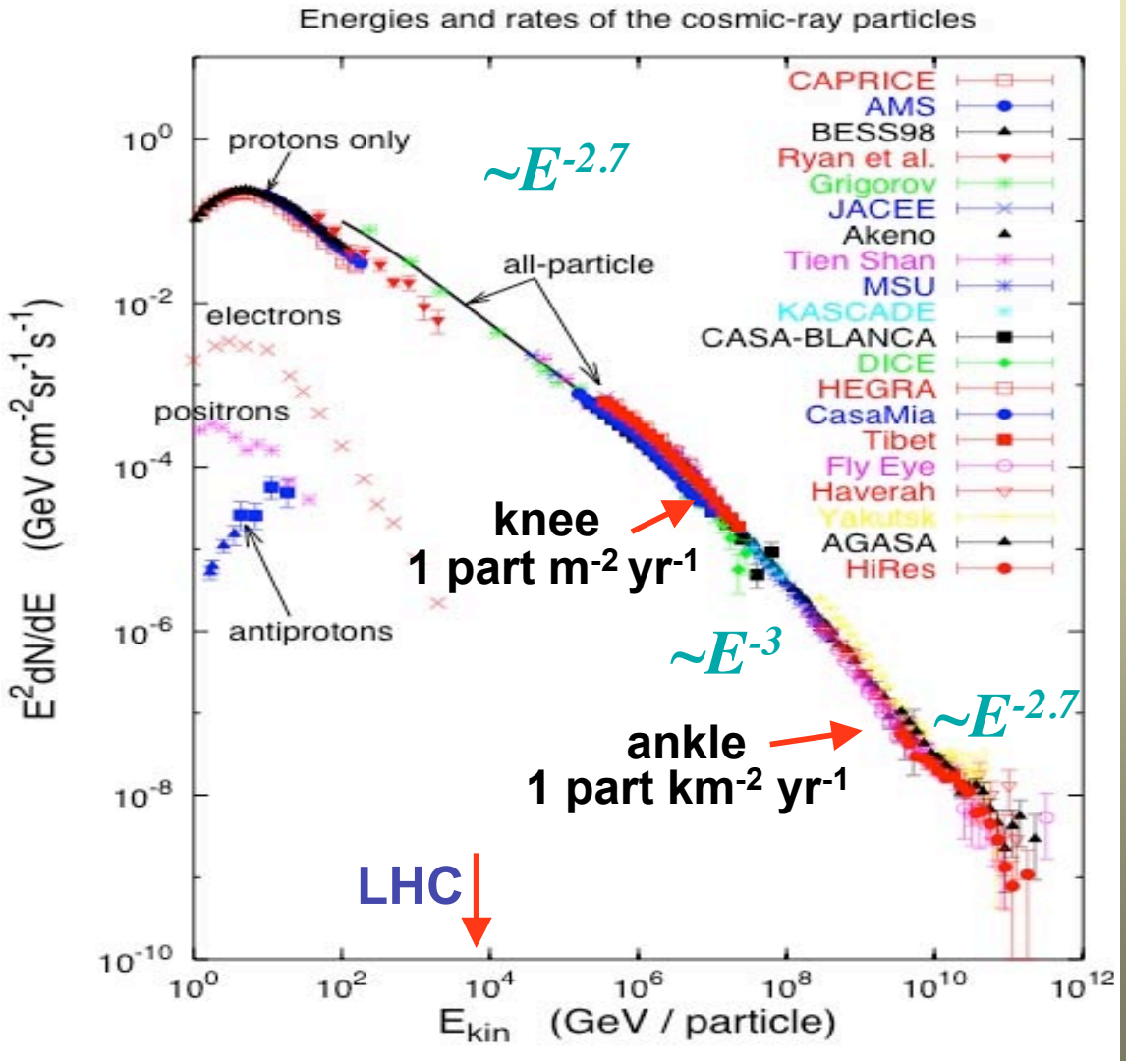
•Aiming at a Km^3 Neutrino Telescope in Mediterranean Sea:
- KM3NeT Design Study (Rome group is contributing to it)

  Joining efforts, design and technologies towards a common project

  Pan-European coordination of funding agencies and research Institutions

•Status and perspectives

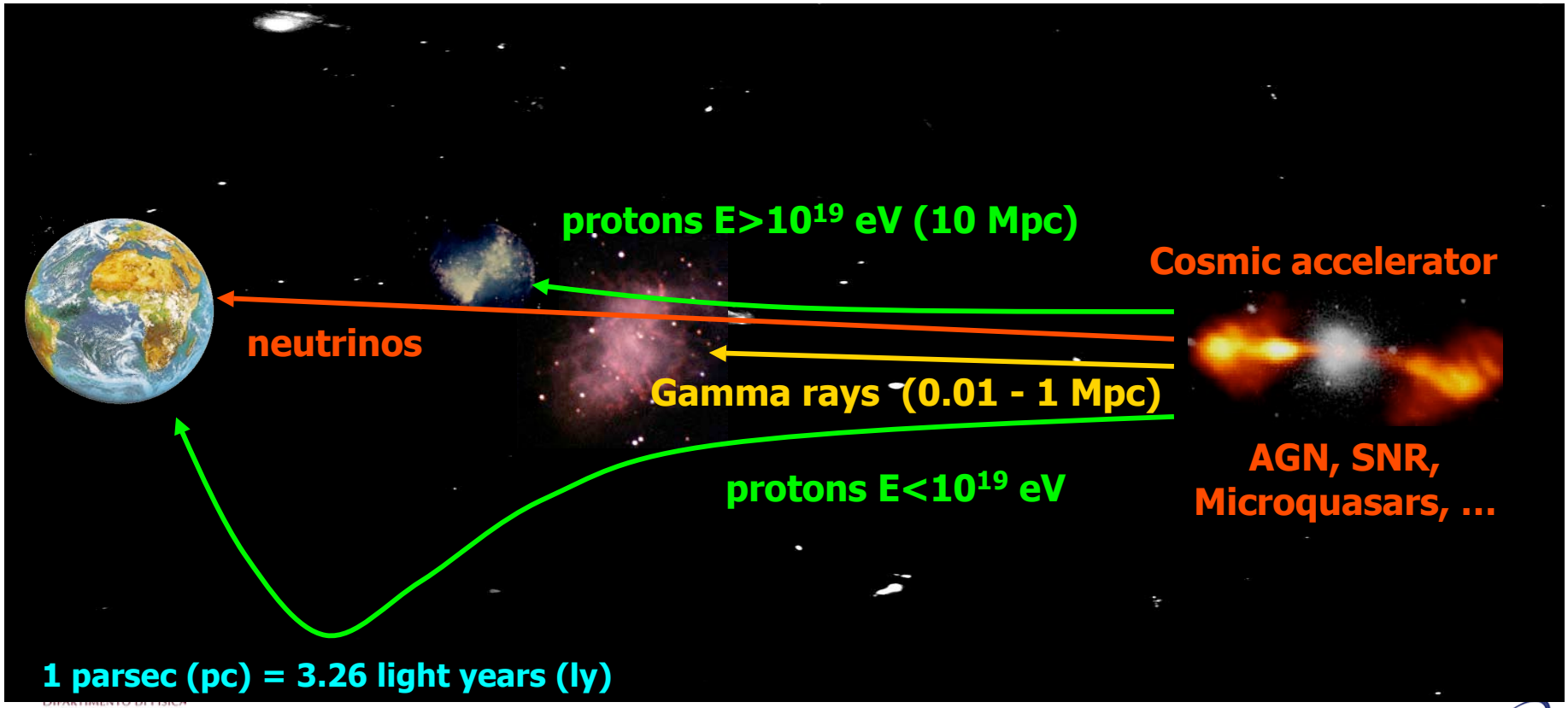
What do we know about Cosmic Rays?



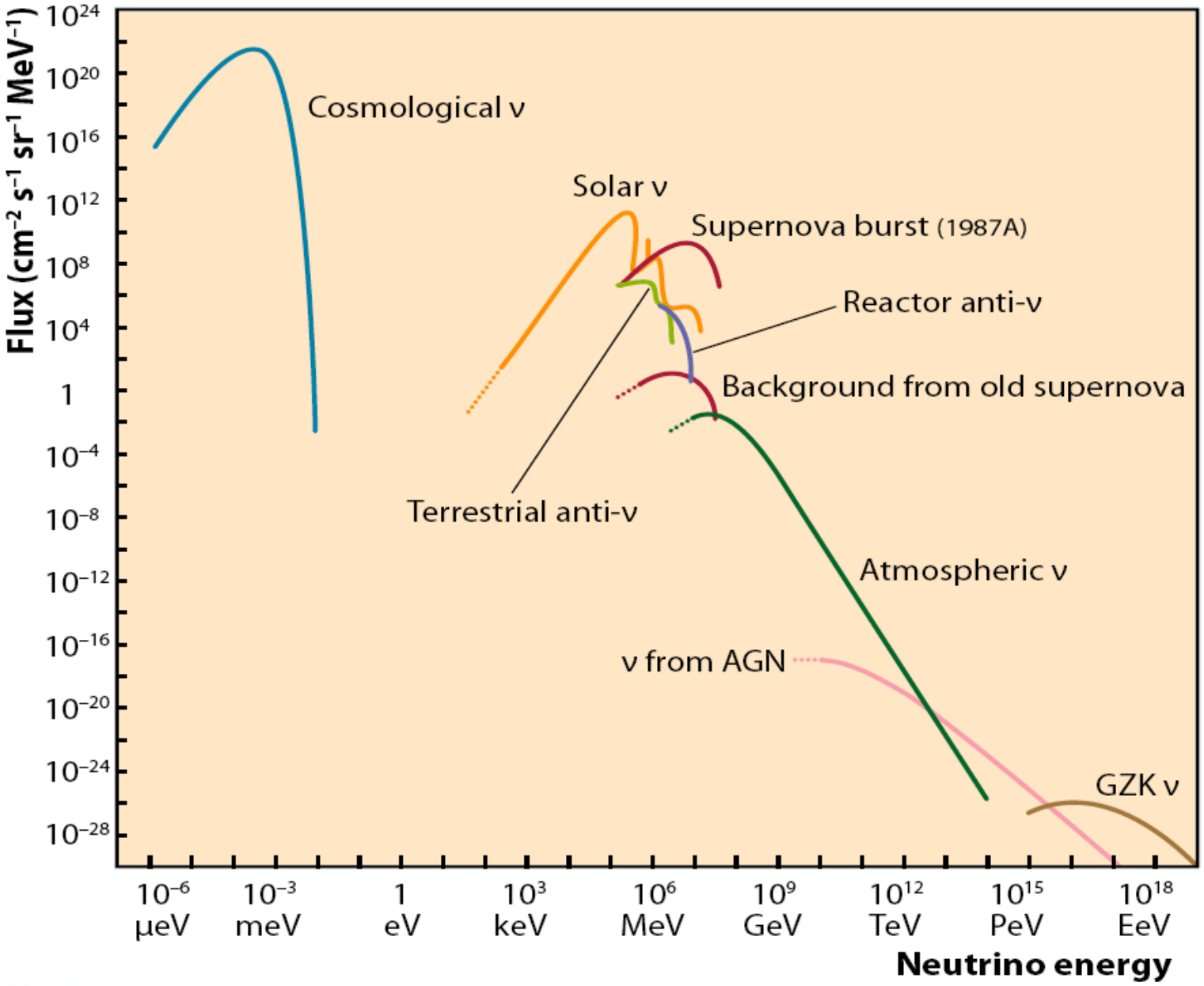
- Elementary particles or nuclei carrying a kinetic energy up to 10^{21} eV (like a 100g object moving at ~150km/h)
- Many open questions:
  - Where they come from ?
  - Which acceleration mechanism ?
  - …
  - are neutrinos produced in astrophysical sources ?
- Multi - messengers astronomy (γ , p , ν , GW, …) will provide, we hope, a lot of answers
- UHE astrophysical neutrinos will extend the limits of the "visible" Universe.

The Universe is transparent for UHE neutrinos !

- γ and p / nuclei astronomy is limited by:
  - the interaction of photons on intergalactic dust and radiation (IR, CMB)
  - the interaction of protons and nuclei with
    - magnetic field
    - dust and radiation
- Only neutrinos will allow to map the sources of UHE Cosmic Rays in the close and far Universe

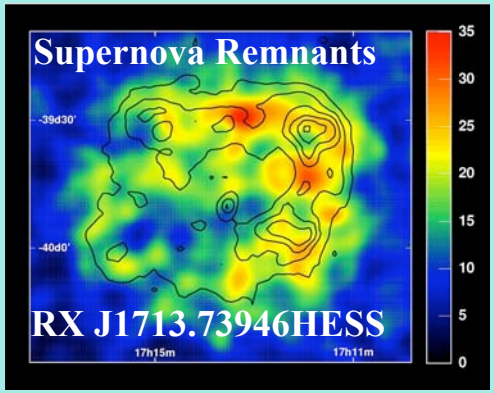


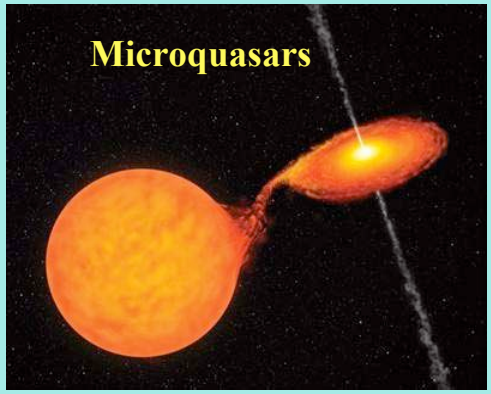
A synoptic view of neutrino fluxes



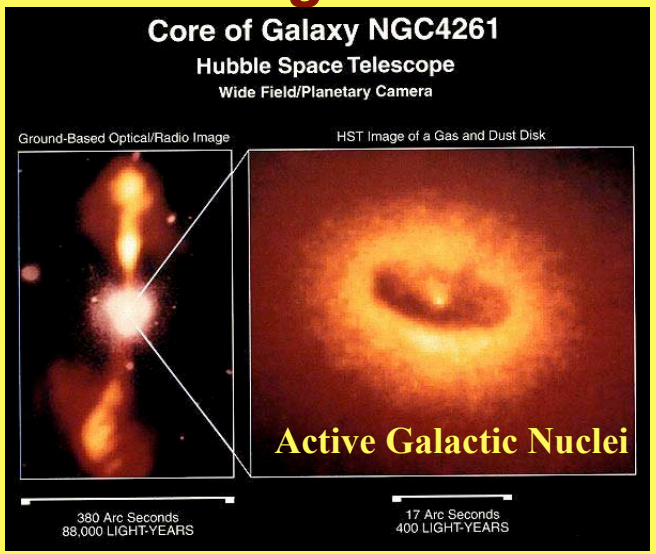
Point like cosmic Neutrino Sources

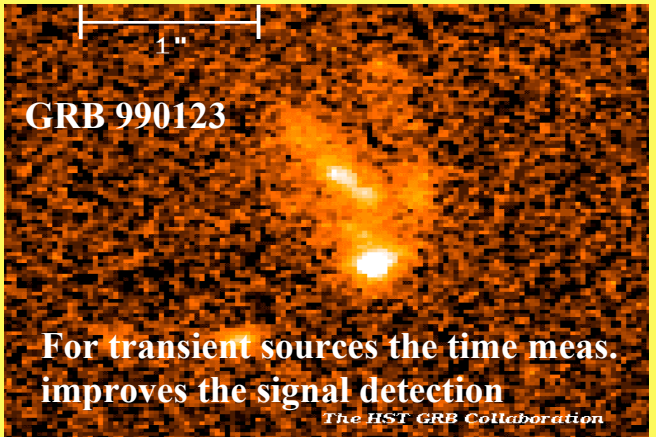
Galactic





Extragalactic



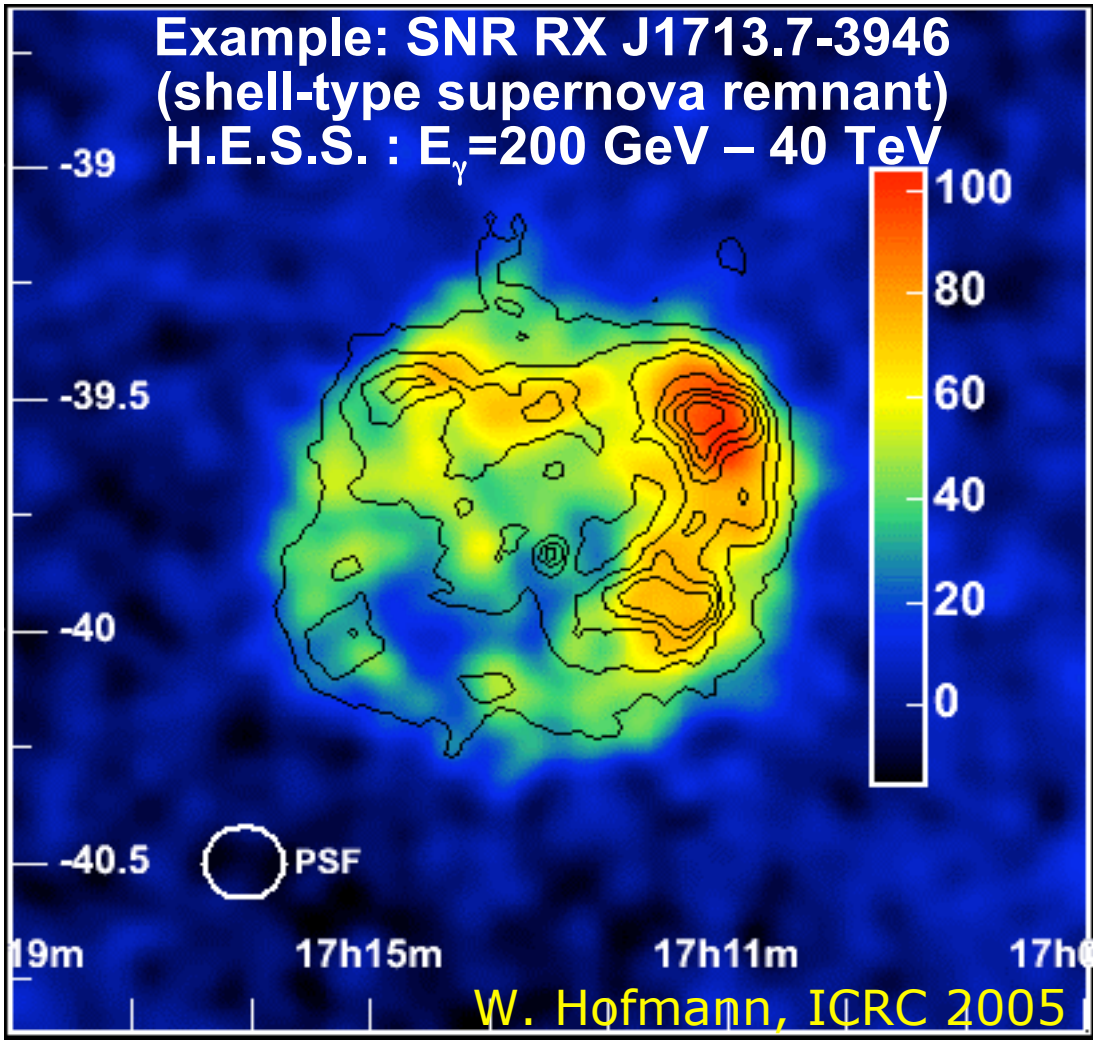


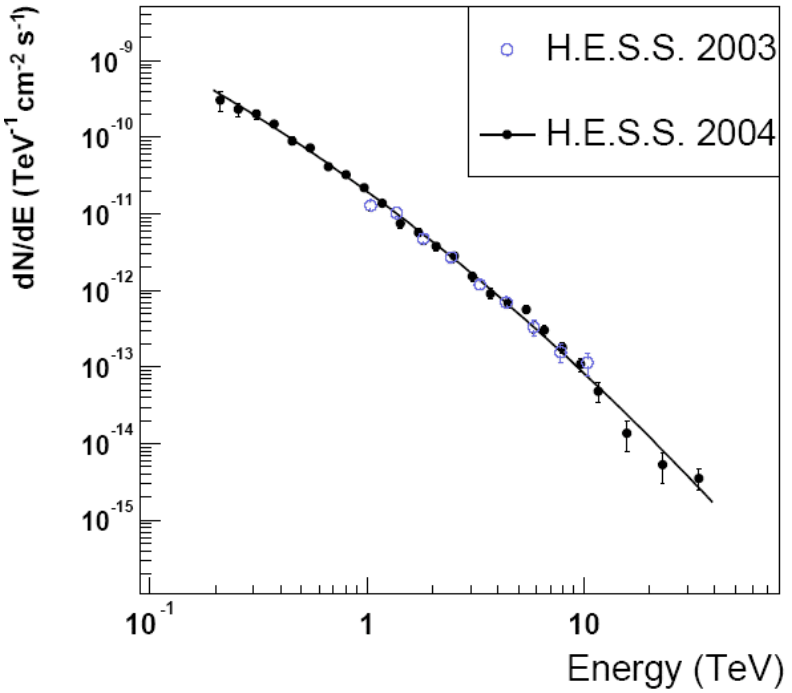
Their identification requires a detector with accurate angular reconstruction

$$\sigma(\vartheta) \leq 0.5^{\circ} \text{ for } E_{\nu} \geq 1 TeV$$

Experimental signal : statistical evidence of an excess of events coming from the same direction

Do we expect ν's from Supernova Remnants ?





Acceleration beyond 100 TeV.

Power-law energy spectrum ~ $E^{-(2.1\div2.2)}$

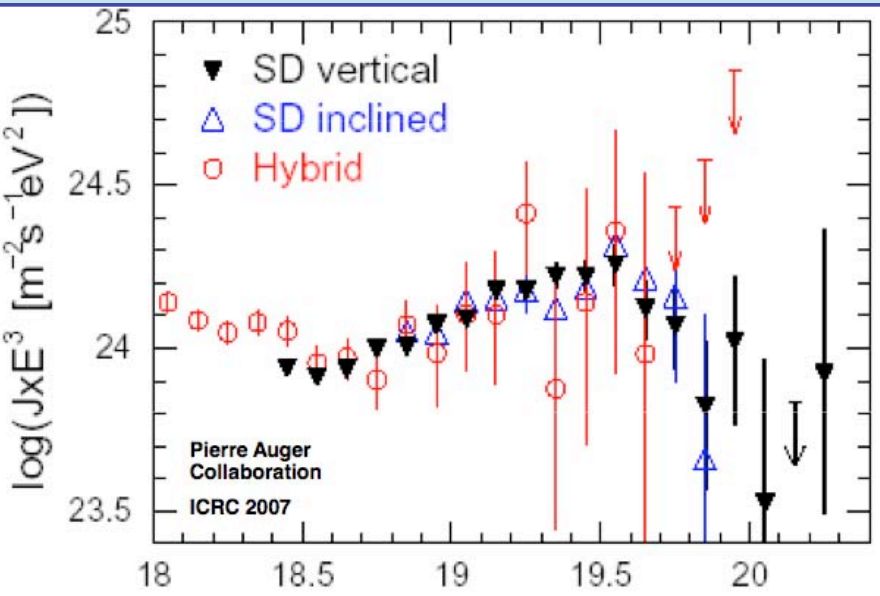
- **The observed γ spectrum seems to indicate hadron acceleration in the Source. In this case** $p+\gamma \rightarrow \Delta^{+} \rightarrow \pi^{+} n$ or $\Delta^{+} \rightarrow \pi^{0} p$ **we do expect ν flux ~ γ flux**
- **Typical ν energies: few TeV**

Diffuse Cosmic Neutrino Sources

- Unresolved AGN
- Neutrinos from "Z-bursts"
- Neutrinos from "GZK like" protons-CMB interactions
- Neutrinos foreseen by Top-Down models
- ….

Their identification out of the more intense background of atmospheric neutrinos (and muons) is possible at very high energies (E_μ > TeV) and implies accurate energy reconstruction.

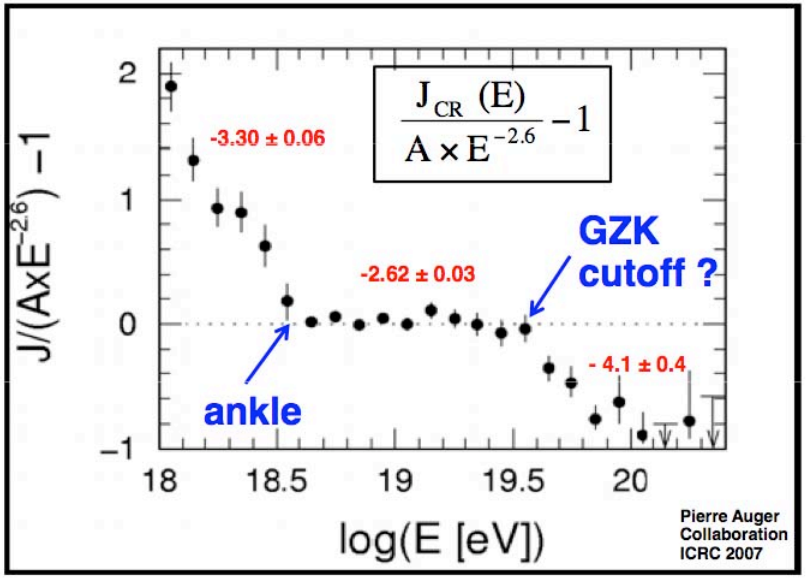
Does AUGER observe the GZK cut-off ?



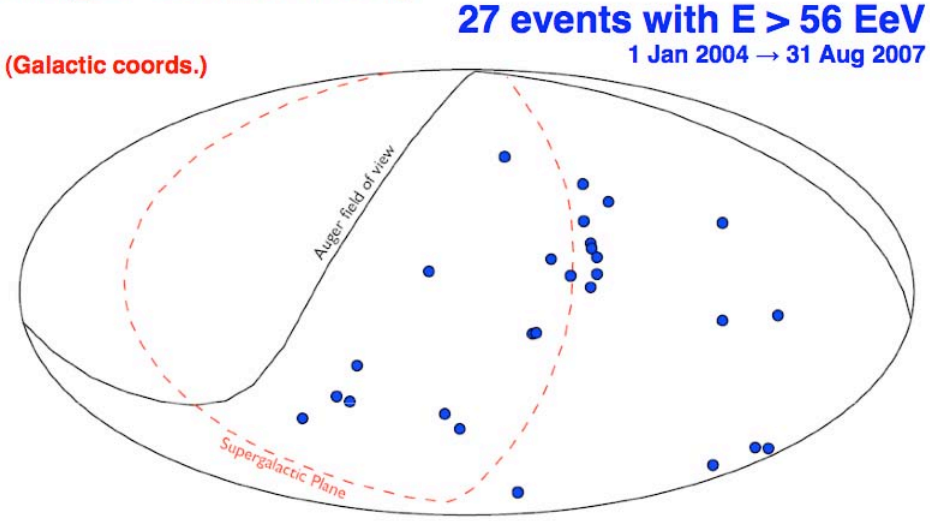
GZK: $p + \gamma_{CMBR} \rightarrow \Delta^+ \rightarrow \pi^+ n$ or $\Delta^+ \rightarrow \pi^0 p$

- Less than 2% of UHE events due to γ
- Protons do not dominate UHE events
- The arrival directions of UHE events are not distributed isotropically: extragalactic origin
- E_{min} = 57 EeV and D_{max} = 75 Mpc consistent with GZK

Residuals w.r.t. a "standard" spectrum



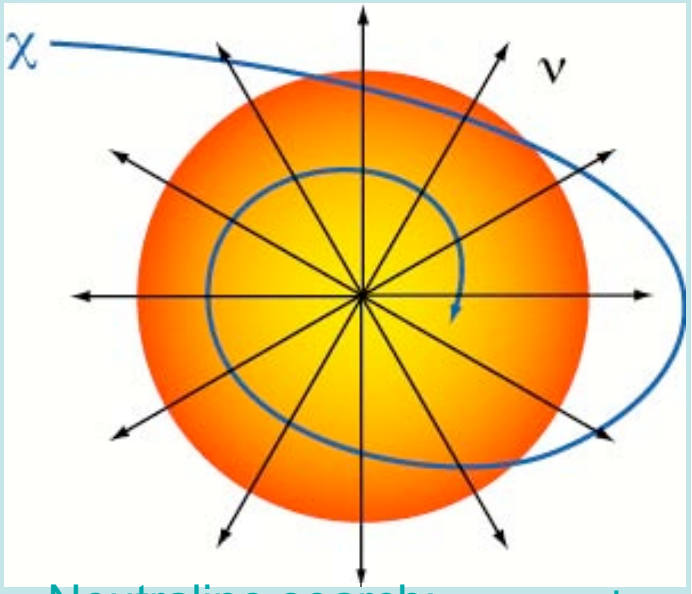
Auger UHECR sky



… not only neutrino astrophysics…

… also open problems in particle physics …

- Dark Matter searches:
  - Neutralinos annichilating in:
    - Sun,
    - Earth
    - Galactic Center
- Monopoles, Nuclearites
- Atmospheric neutrino oscillations
- Acceleration mechanisms
- Neutrino interactions Cross sections
- …

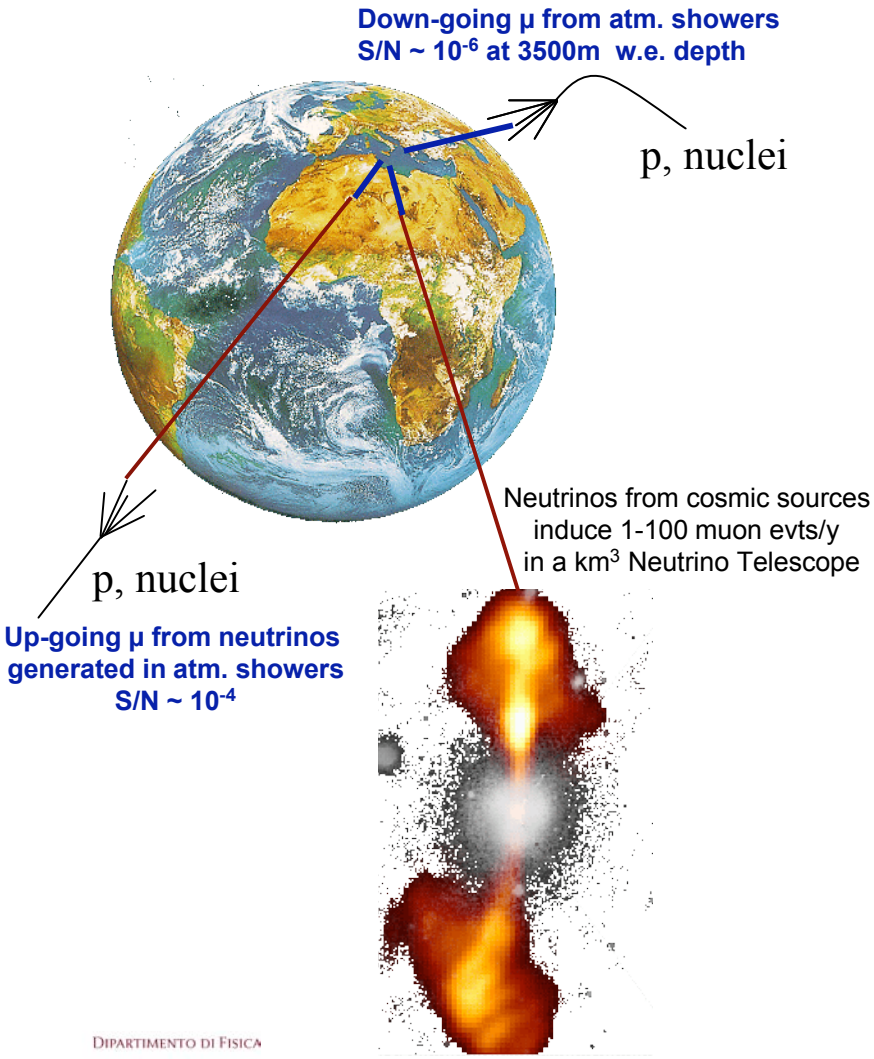


Neutralino search: $\chi\chi \rightarrow \nu$+…

Look for an excess of neutrinos coming from the Sun, with energy:
$E_\nu \sim 0.25\text{-}0.5\ m_\chi$

Detection principle

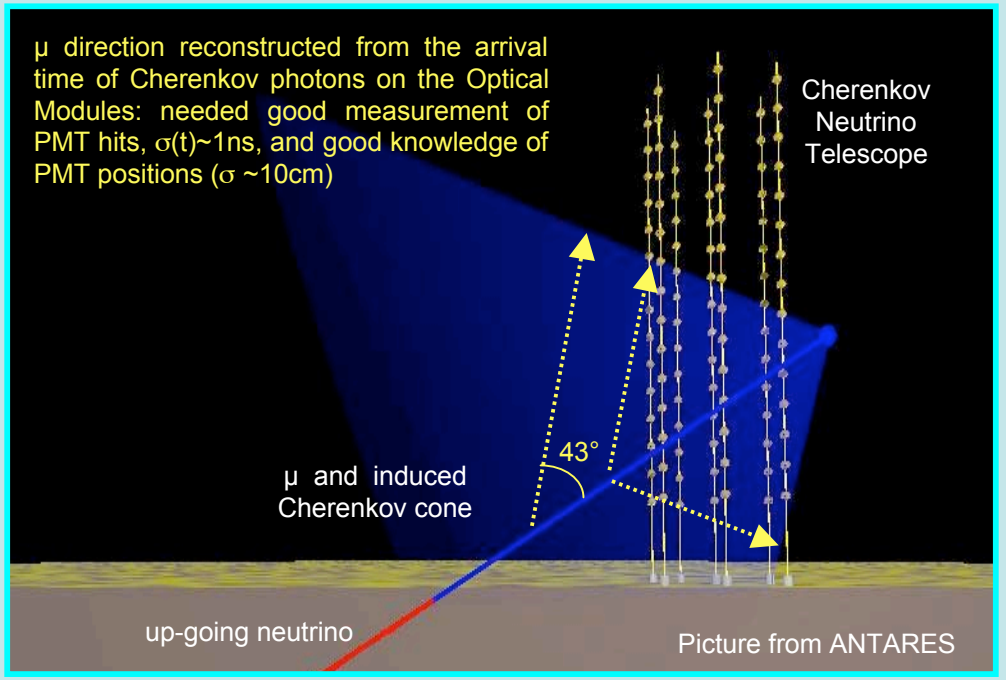
Search for neutrino induced events, mainly $\nu_\mu N \rightarrow \mu X$, deep underwater



- Atmospheric neutrino flux ~ E_ν^{-3}
- Neutrinos flux from cosmic sources ~ E_ν^{-2}
  - Search for neutrinos with E_ν>1÷10 TeV

- ~TeV muons propagate in water for several km before being stopped
  - go deep to reduce down-going atmospheric μ backg.
  - long μ tracks allow good angular reconstruction

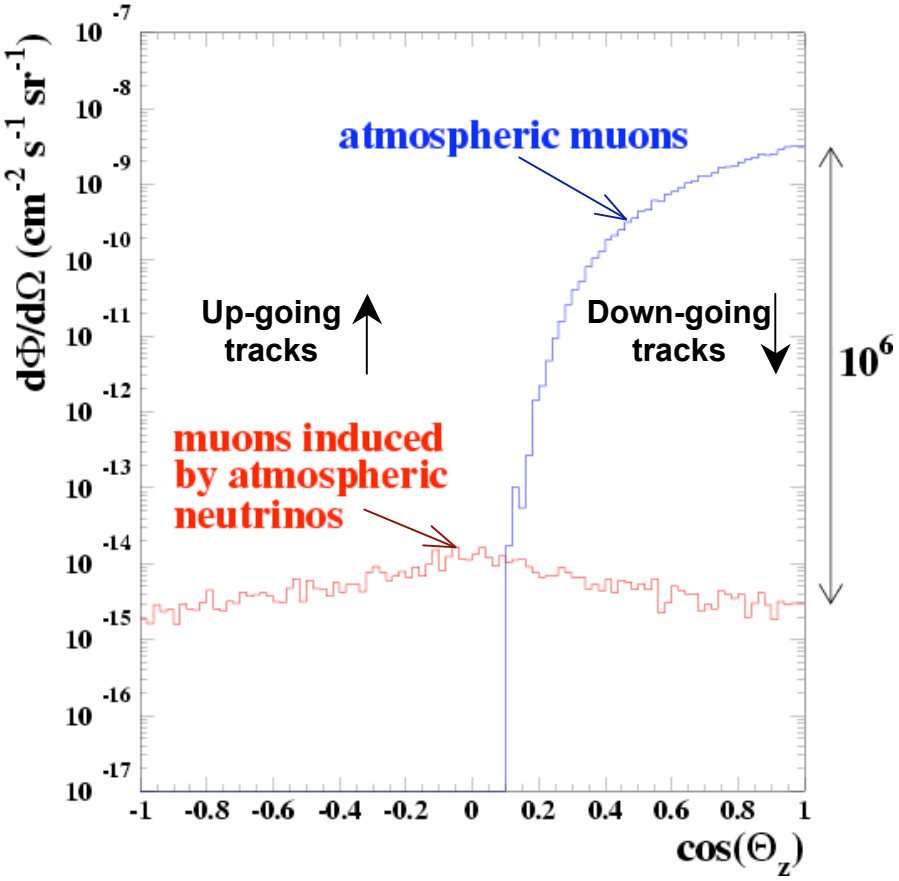
$$For\ E_\nu \geq 1TeV \quad \theta_{\mu\nu} \sim \frac{0.7^\circ}{\sqrt{E_\nu[TeV]}}$$

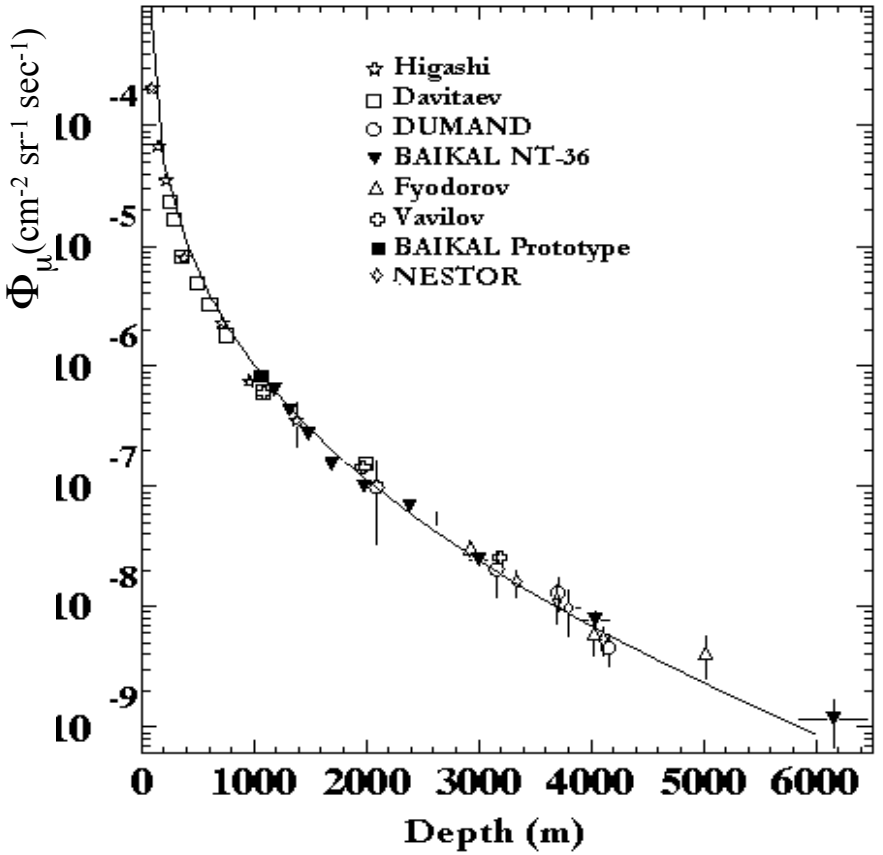


Down-going muons: the background

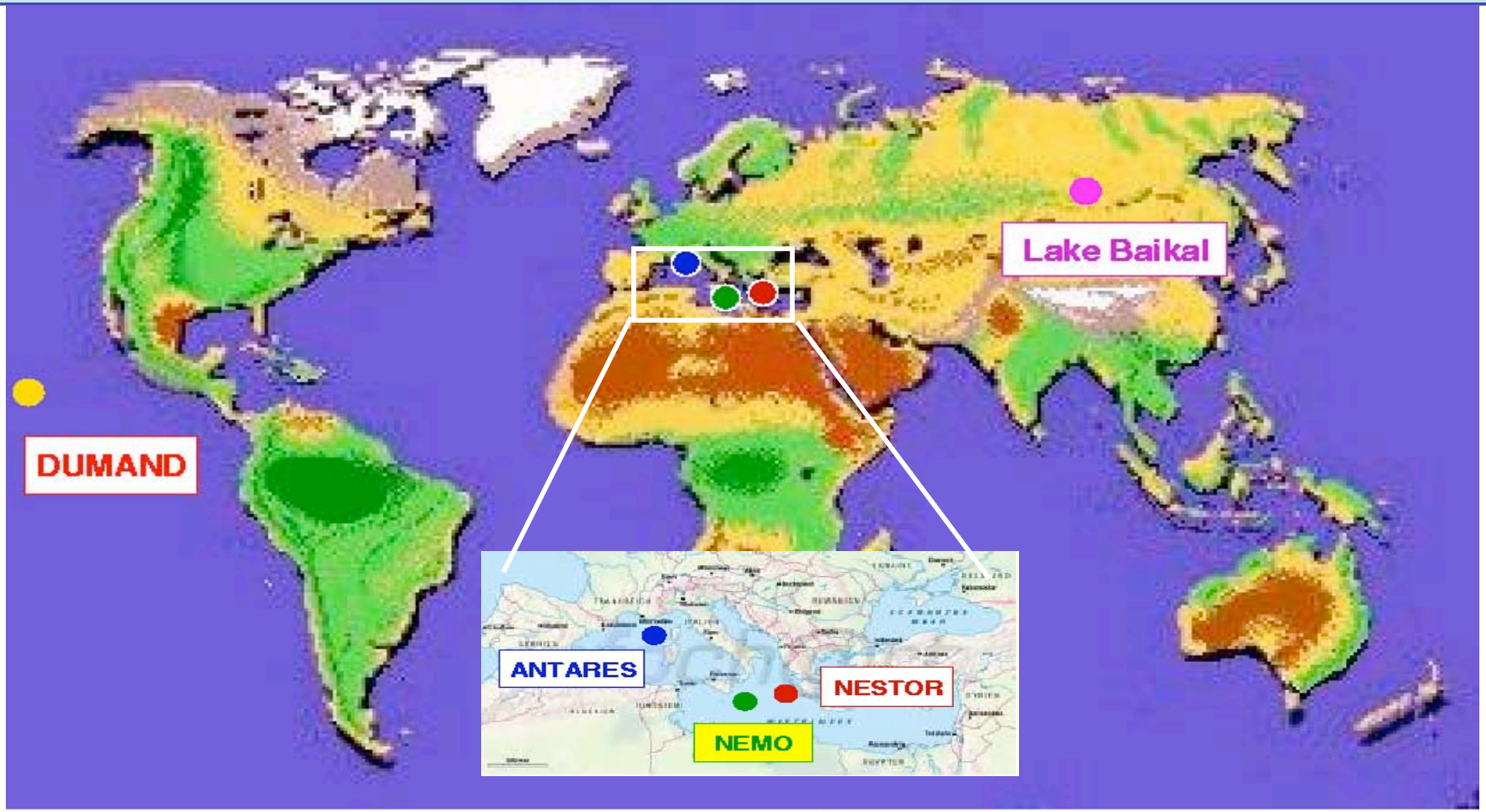
Muons can penetrate several km of water if E_μ > 1TeV;

Identification of cosmic ν's from above: needs showers or very high energies.





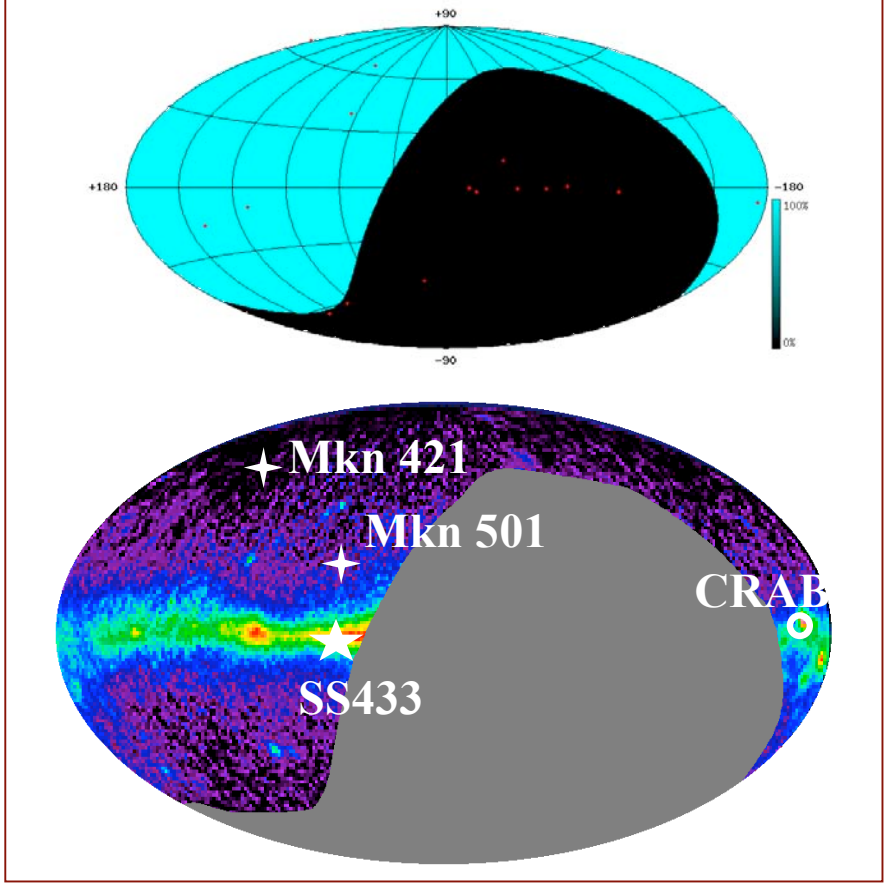
The Neutrino Telescopes World Map



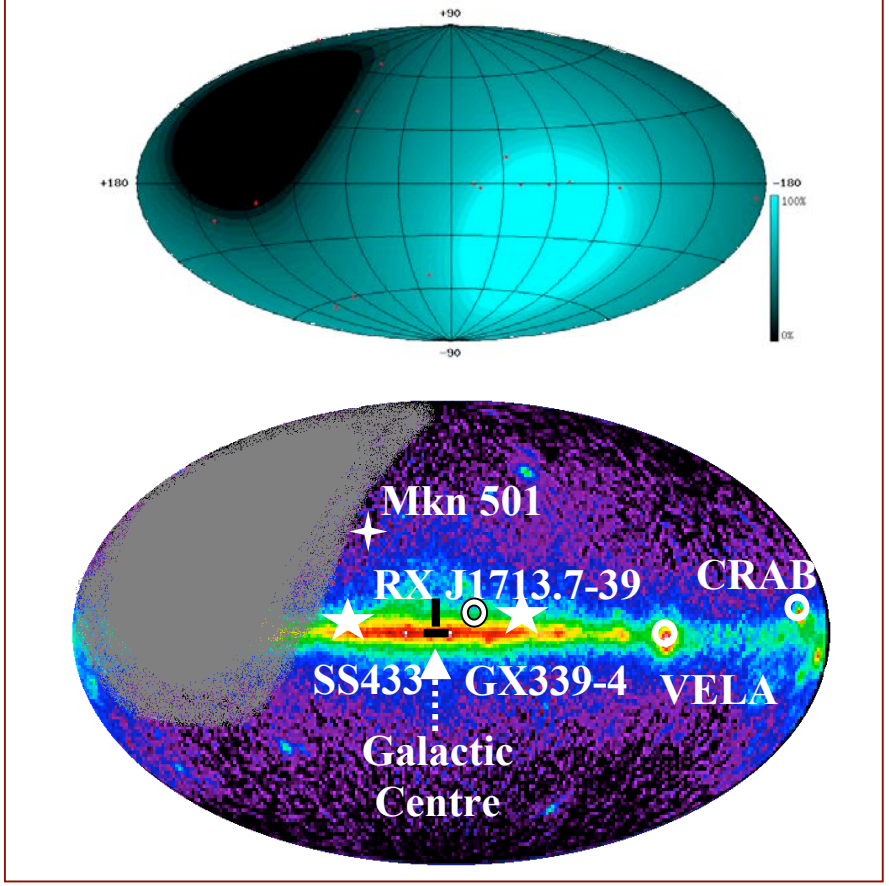
ANTARES + NEMO + NESTOR joined their efforts to prepare a km³-scale Cherenkov Neutrino Telescope in the Mediterranean → KM3NeT Design Study

Locations for Neutrino Astronomy

From Antartica



From Mediterranean Sea



Mediterranean location provides a 3π sr sky coverage, 0.5π sr instantaneous common view with IceCube, and about 1.5π sr common view per day. The Galactic centre is visible 2/3 of the time.

A Km^3 Neutrino Telescope in Mediterranean Sea will be complementary to IceCube and … will search for neutrino sources in the Galactic centre

KM3NeT, what is it ?

- A Consortium between the groups/Institutions that originated and support the pilot neutrino telescope projects in the Mediterranean Sea for:
  - *Design Study* for the construction of a Deep Sea Facility in the Mediterranean for Neutrino Astronomy and Associated Sciences
    - a next generation water Cherenkov neutrino telescope of 1 km^3 volume in the Mediterranean Sea
    - a future deep sea Research Infrastructure for ocean sciences:
      - Oceanology, Marine Biology, Environmental Science, Geology and Geophysics
  - Objective: develop cost-effective design for the construction of a 1 km^3 neutrino telescope (~ 200 M€)
  - *KM3NeT Design Study* funded by the European Community in the framework of "Frame Program 6" (FP6, 2002-2006)
- Participants from existing collaborations (ANTARES, NEMO, NESTOR):

+

+

+...

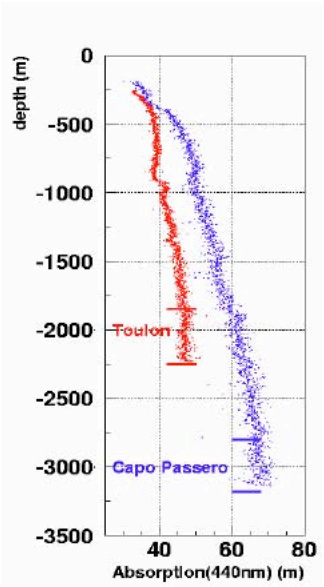
+ new collaborators + European Sea science and Technology Institutions (ESONET)

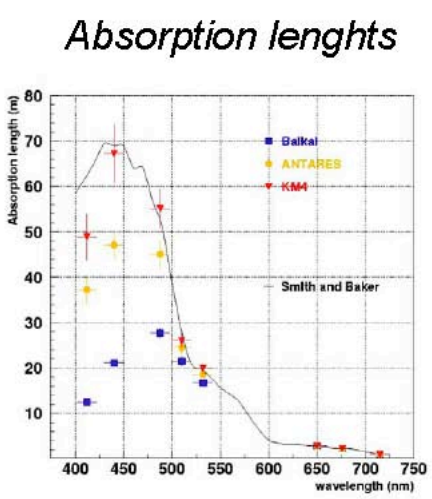
The NEMO Project: NEMO-RD

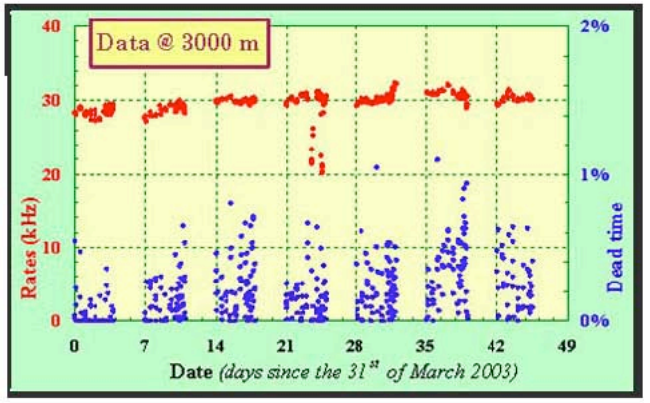
1998-2004 NEMO R&D and site selection

- **Extensive site exploration of Mediterranean Sea: selected Capo Passero site near Catania, depth 3500 m**
  - best optical properties out of studied sites L_a ~70m @ 440nm
  - No seasonal variations of water optical properties
  - extremely low background from bioluminescence
  - deep Sea water current are low (3cm/s avg.) and stable
  - Wide abyssal plain, far from the shelf break, allows for possible reconfigurations of the detector layout

- R&D towards km^3: detector architecture, mechanical structures, **electronics, readout**, cables …, junction box, all technological issues;
- **Simulation**







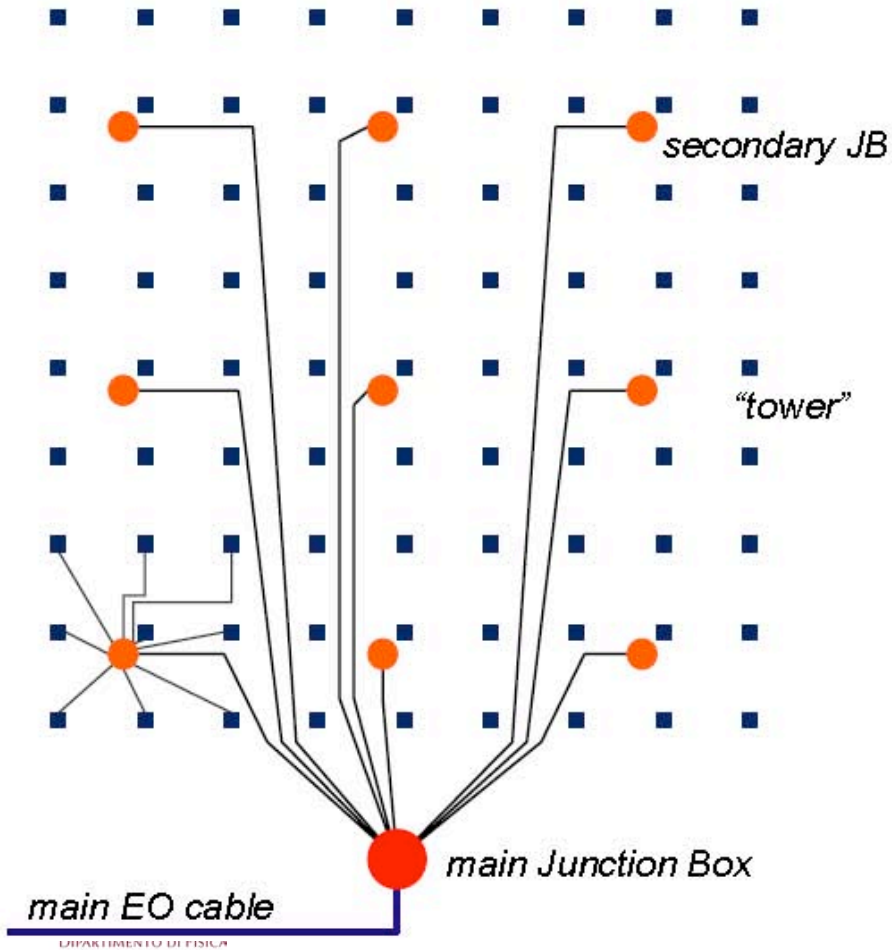
- PMT: 10"
- Thres: ~.5 SPE

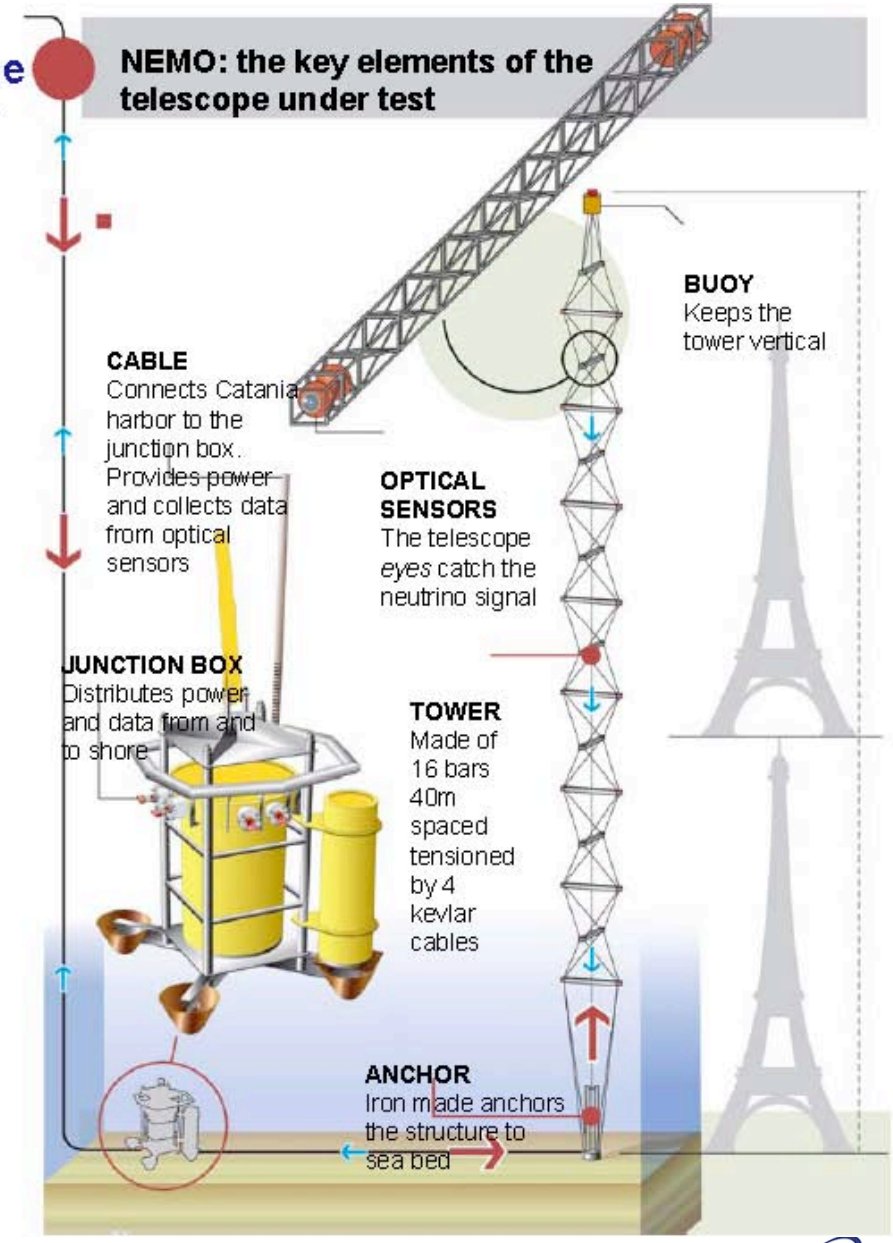
Fraction of time R > 200 kHz

NEMO-R&D technologies for the Neutrino Telescope

Reduce the number of structures to reduce the number of underwater connections and allow operation with a ROV

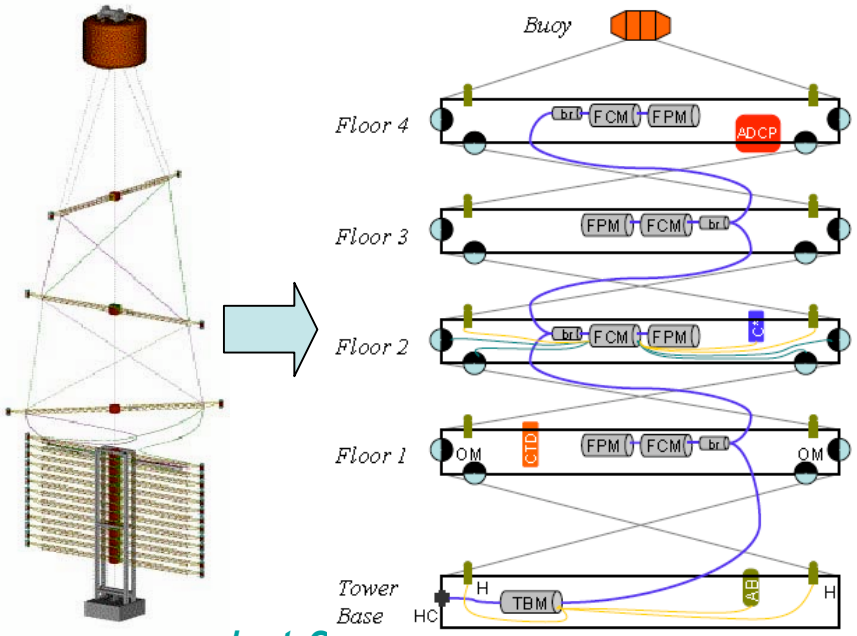
Detector modularity



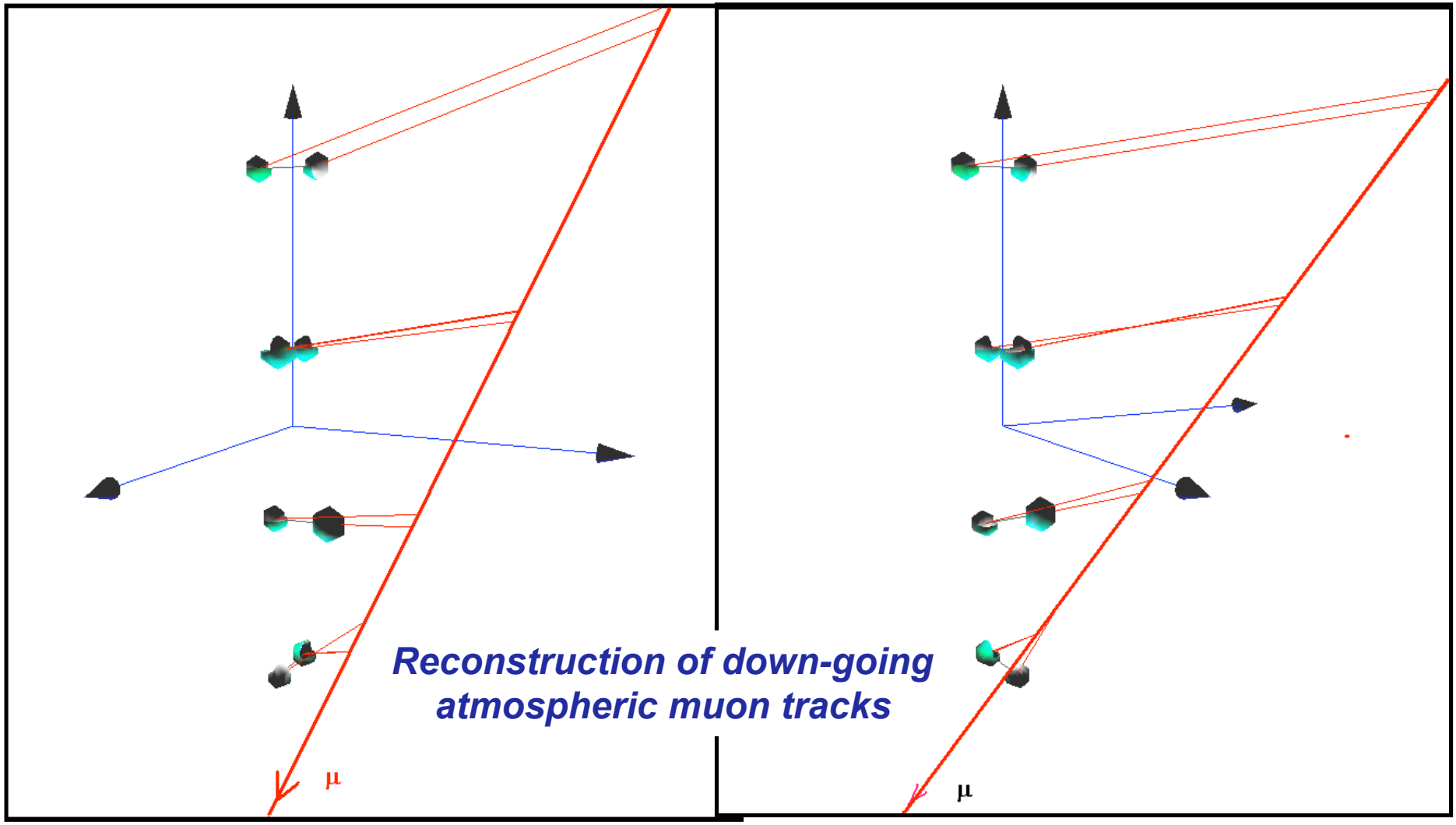


NEMO-Phase1 - 2004-2007

- Created a "Deep-Sea Test Site", 20 Km East of Catania at 2000m depth, connected with 25 km long EOC to the shore station of INFN-LNS
- Validation of the technological solution proposed for the realization and installation of the km^3 detector
- Realization of a technological demonstrator including all the key elements of the NEMO km^3 concept
  - *Mechanical structures*
  - *Optical and environmental sensors*
  - ***Readout electronics*** } **ROMA Group**
  - ***Data transmission system*** } **ROMA Group**
  - *Power distribution system*
  - *Acoustic positioning system*
  - *Time calibration system*
- Multidisciplinary activities
  - *Ovde (measurements of the acoustic background at 2100 m depth, dauphins and sperm whales)*
  - *SN-1 (first operative node of ESONET)*



NEMO-Phase1, some reconstructed down-going tracks



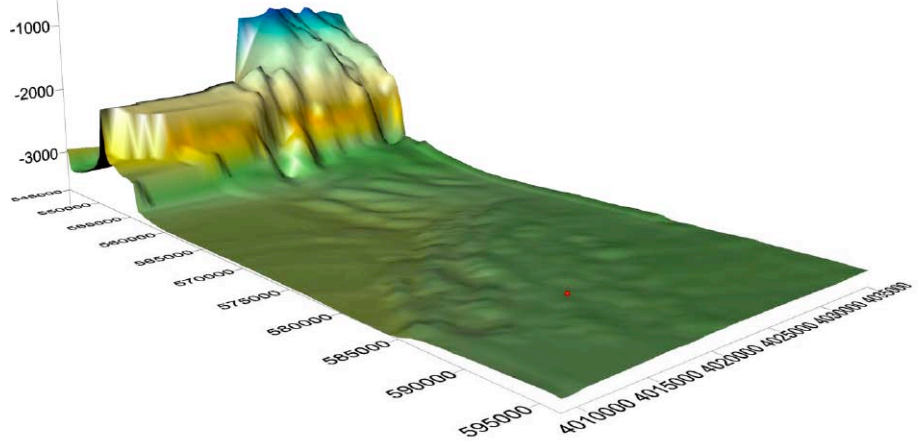
Reconstruction of down-going atmospheric muon tracks

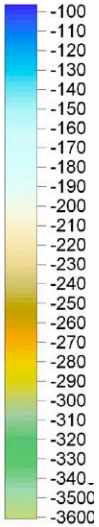
January 24 2007 - Run R17 file 1 Event # 366059 13 PMT hit

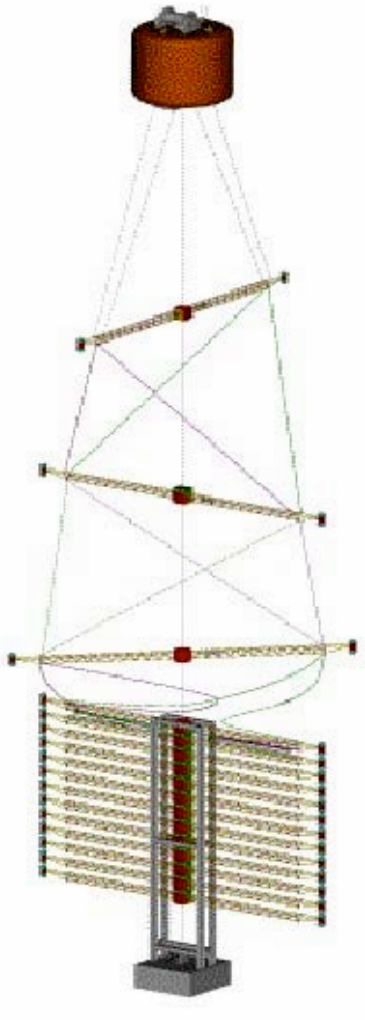
NEMO-Phase2, Capo Passero Site at 3500m depth

- On-shore infrastructure under construction (on-shore building completion at beginning 2008)
- 100 km Electro-Optical cable (>50 KW, 20 fibres) deployed (summer 2007)
- Power feeding system under construction, test December 2007
- Tower deployment foreseen middle 2008

The Capo Passero Site will also provide a very useful facility to test KM3NeT technologies







Portopalo Shore Station

An old building (a winery) has been acquired, to be used as shore laboratory and counting room. It is located at Portopalo (SR). At present is under restoration

Shore Power System installed!

Rooms designated to host the NEMO-Phase2 power system have been already renovated and are, already, at the disposal of the NEMO Collaboration

The ANTARES experiment

- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking photomultipliers (PMTs), axis at 45° to vertical;
- 2500 m deep.

25 storeys, 348 m

100 m

14.5m

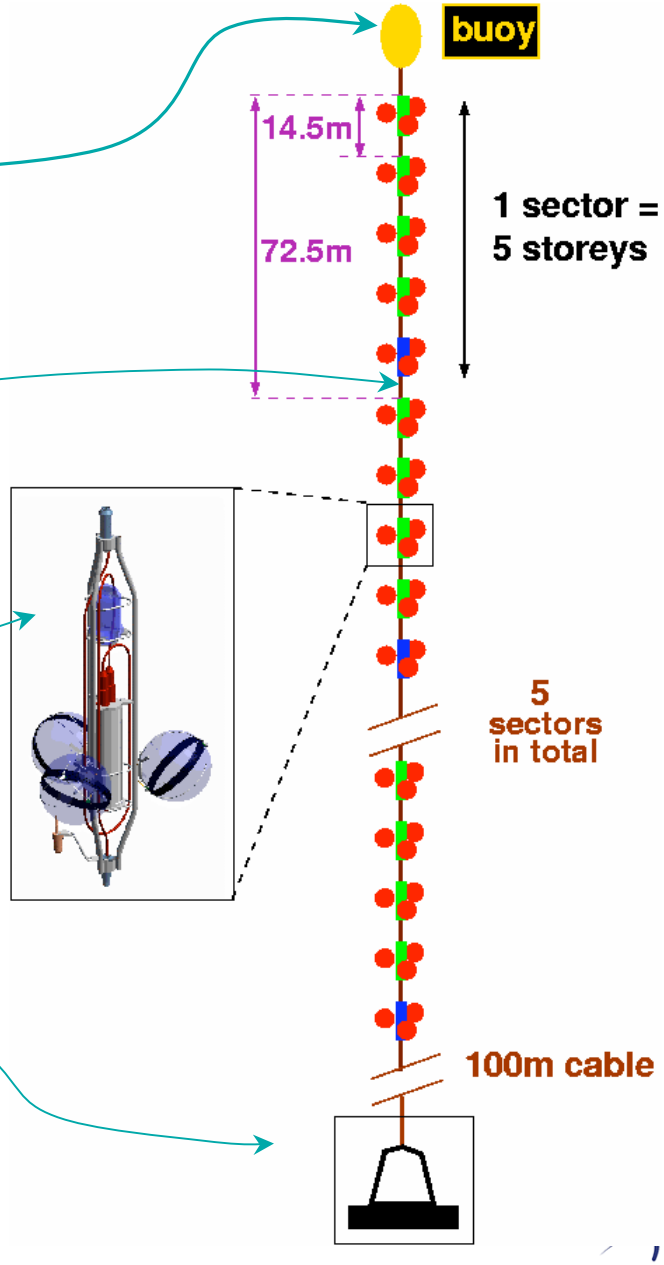
~70 m

Junction Box

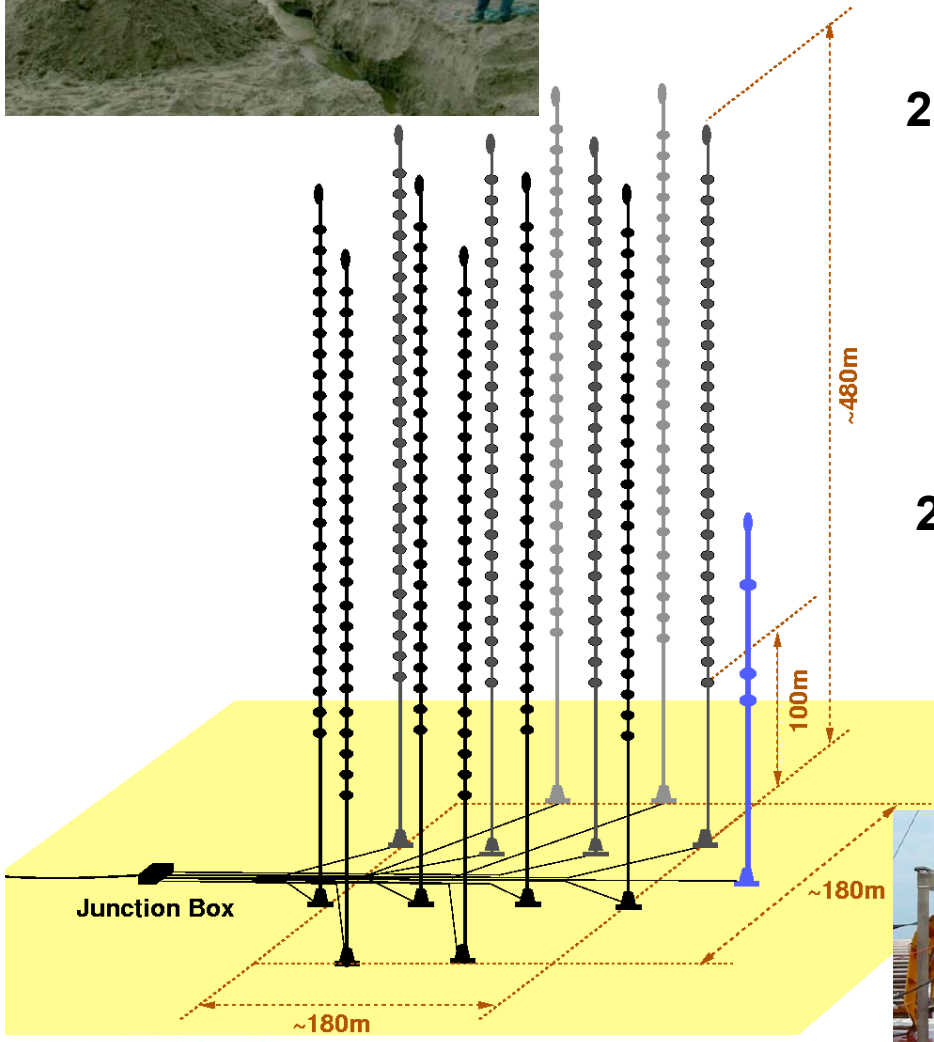
© François Montanet

ANTARES: Detector Strings

- Buoy:
  - buoyancy ~6400 N;
  - keeps string vertical to better than 20m displacement at top.
- Electro-optical-mechanical cable:
  - metal wires for power supply etc.;
  - optical fibers for data;
  - mechanical backbone of string.
- Storeys:
  - 3 optical modules per storey;
  - titanium cylinder for electronics;
  - calibration devices (light, acoustics).
- Anchor:
  - deadweight to keep string at bottom;
  - release mechanism operated by acoustic signal from surface.



ANTARES Construction Milestones



2001 – 2003:

- Main Electro-optical cable in 2001
- Junction Box in 2002
- Prototype Sector Line (PSL) & Mini Instrumentation Line (MIL) in 2003

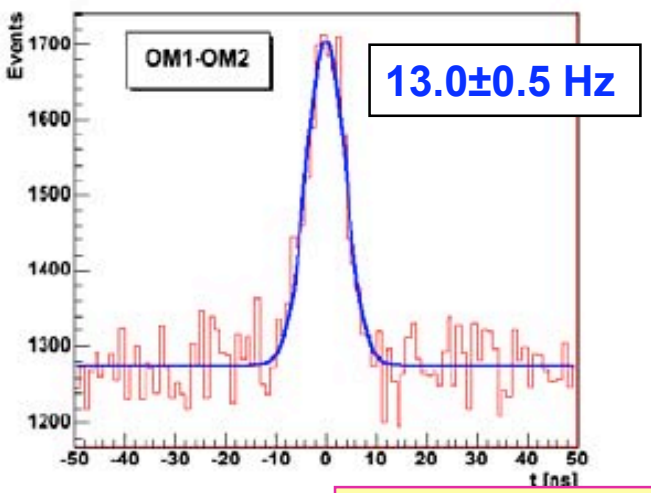
2005 – 2007:

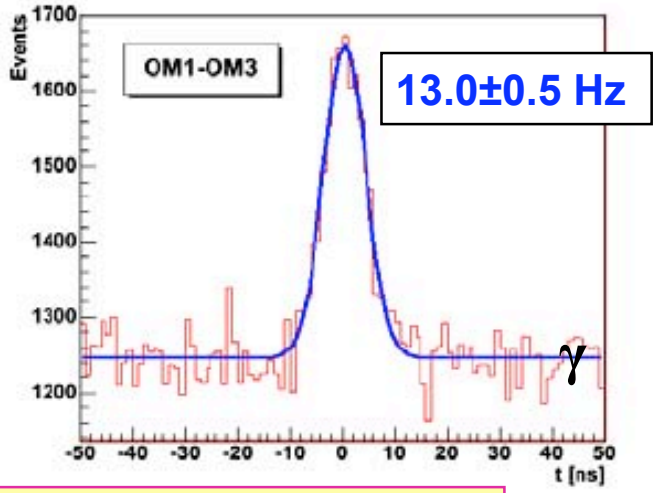
- Mini Instrumentation Line with OMs (MILOM) running spring 2005-spring 2007
- Lines 1-5 running (connected between March 2006 and Jan. 2007)
- MILOM recovery and replacement by full instrumentation line (IL)
- Lines 6+7+8+9+IL deployed

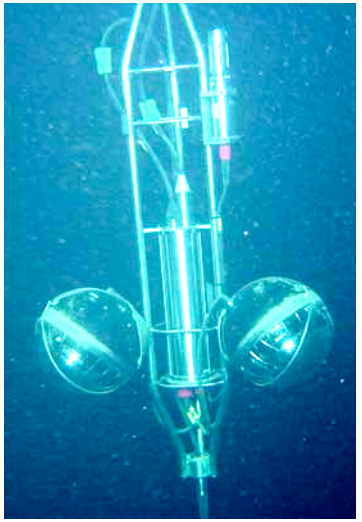
2008 - May

- **DETECTOR COMPLETE: Physics with full detector !**

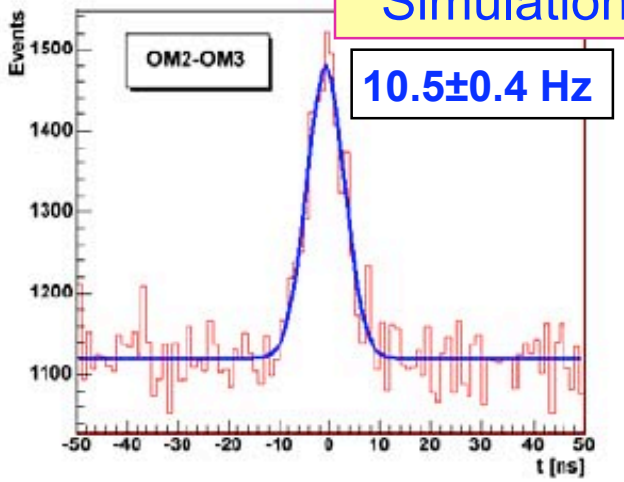
ANTARES: Coincidence rates from ^{40}K decays

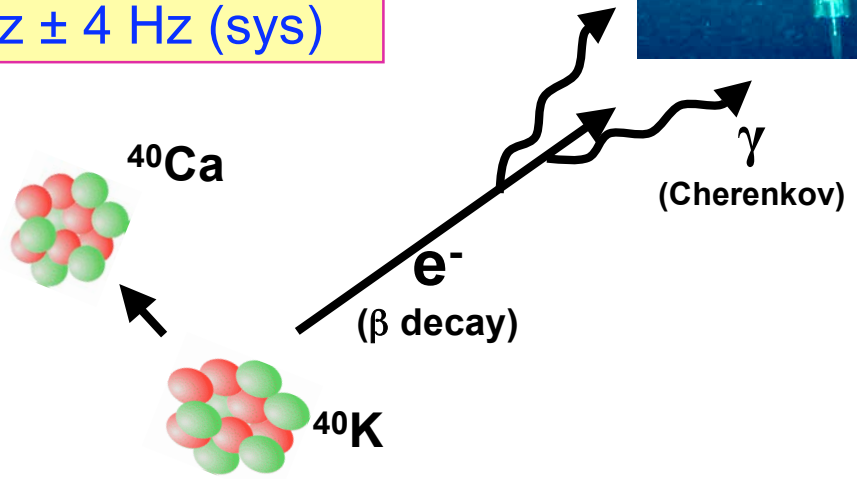




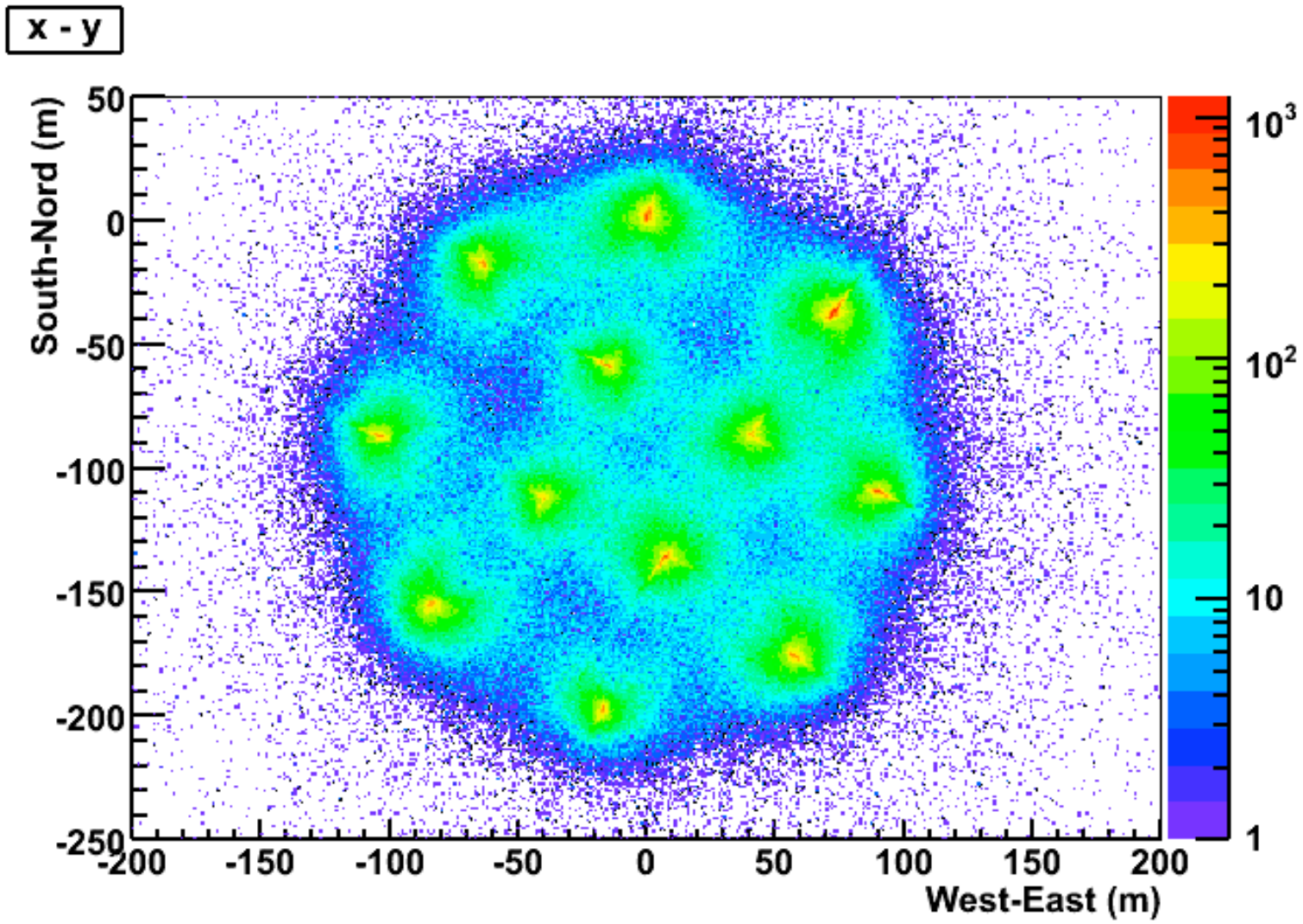


Simulation: 12 Hz ± 4 Hz (sys)



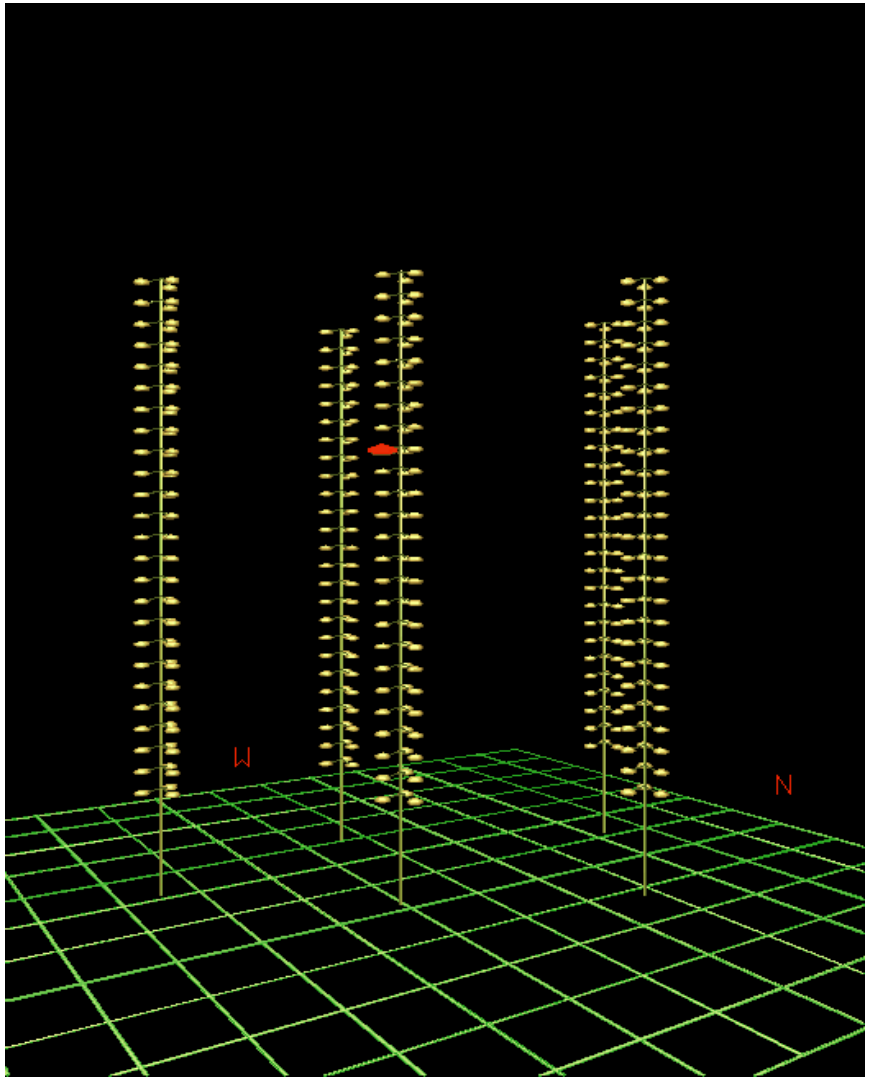


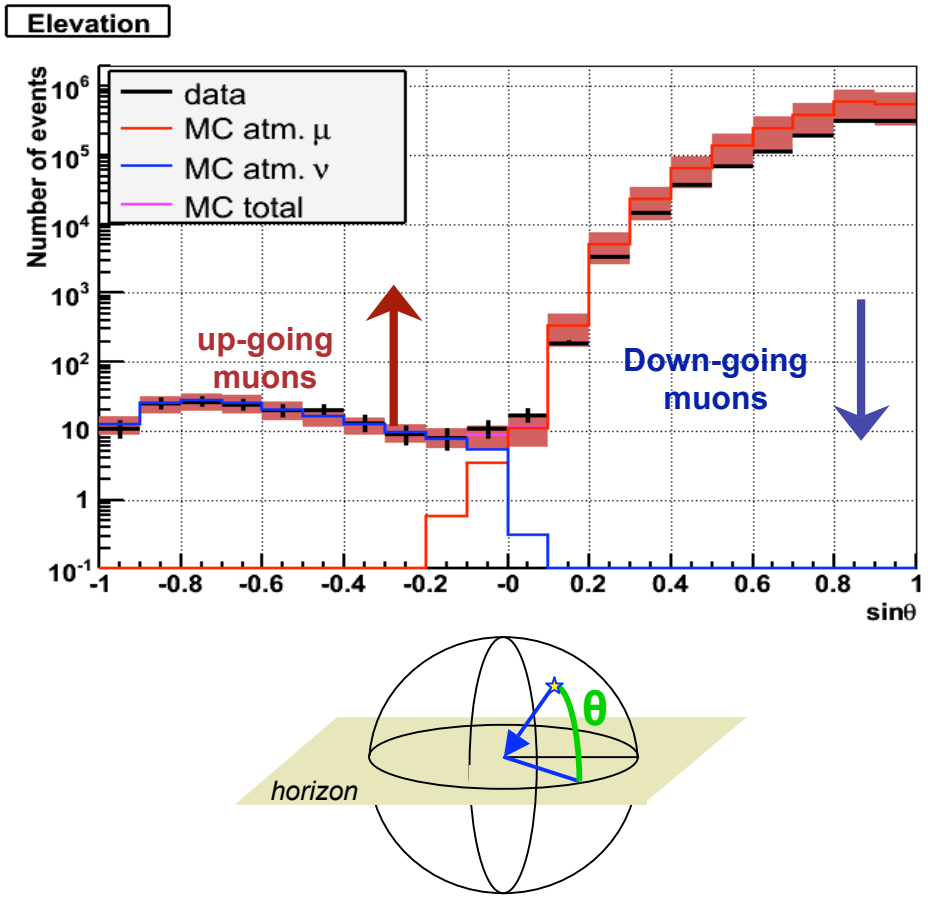
Footprint of the 12-line detector in atmospheric muons



The figure shows the x and y coordinates of track fits at the time of the first triggered hit.

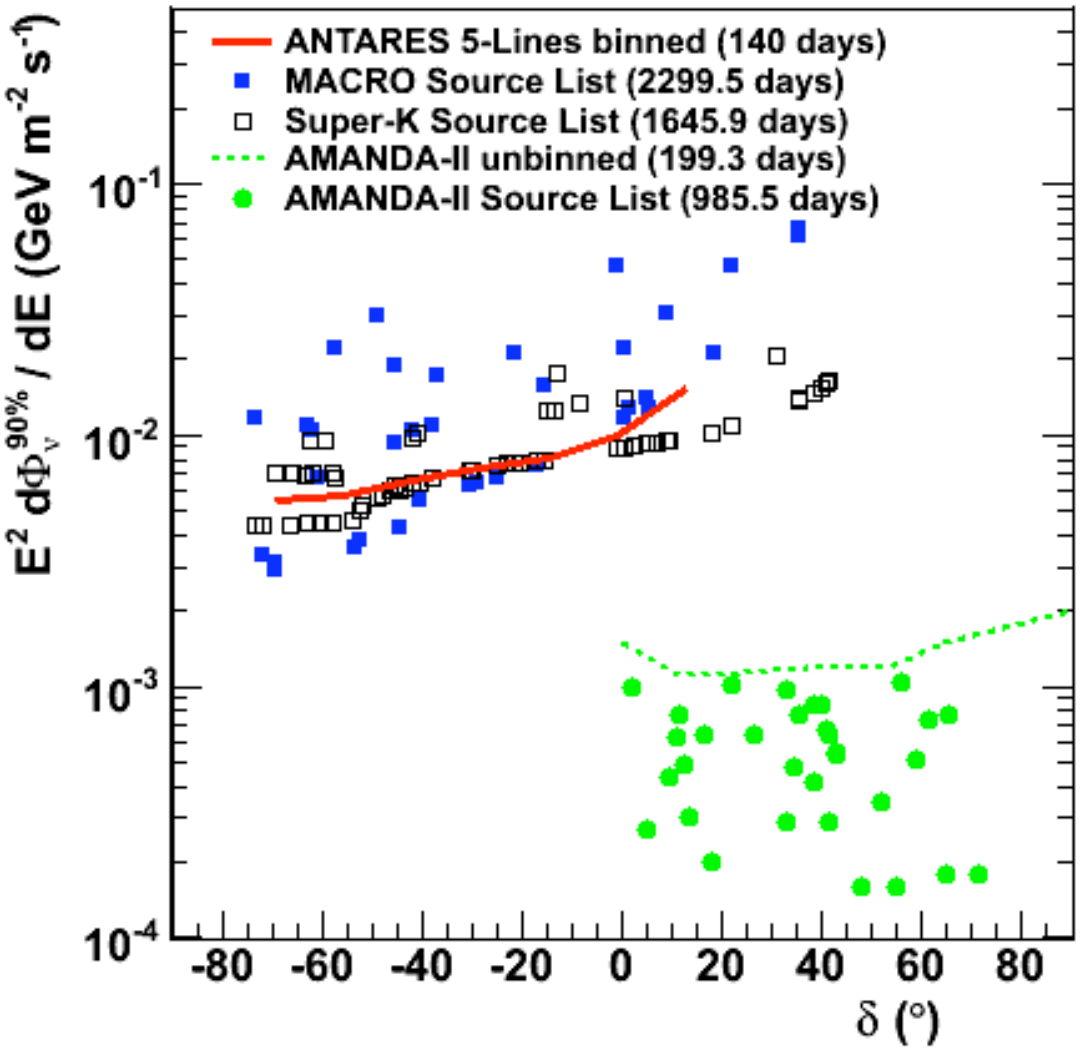
ANTARES: …and neutrinos with 5 Lines !





5 Line Detector
Feb - Dec 2007
140 active days

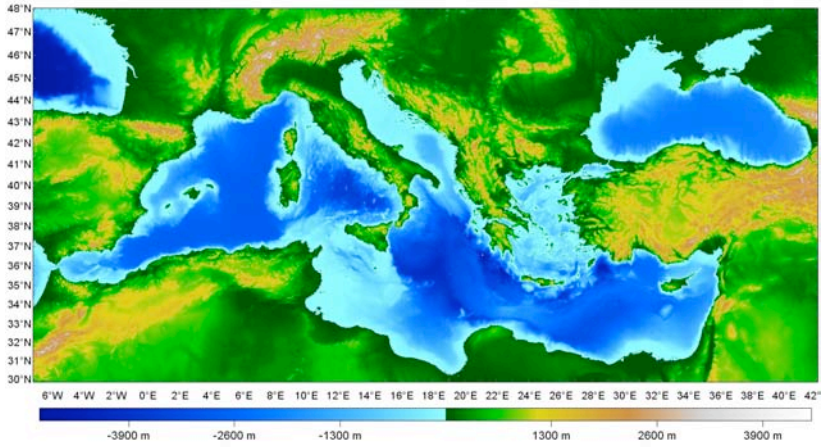
ANTARES 5-Line data: sensitivity to point-like neutrino sources



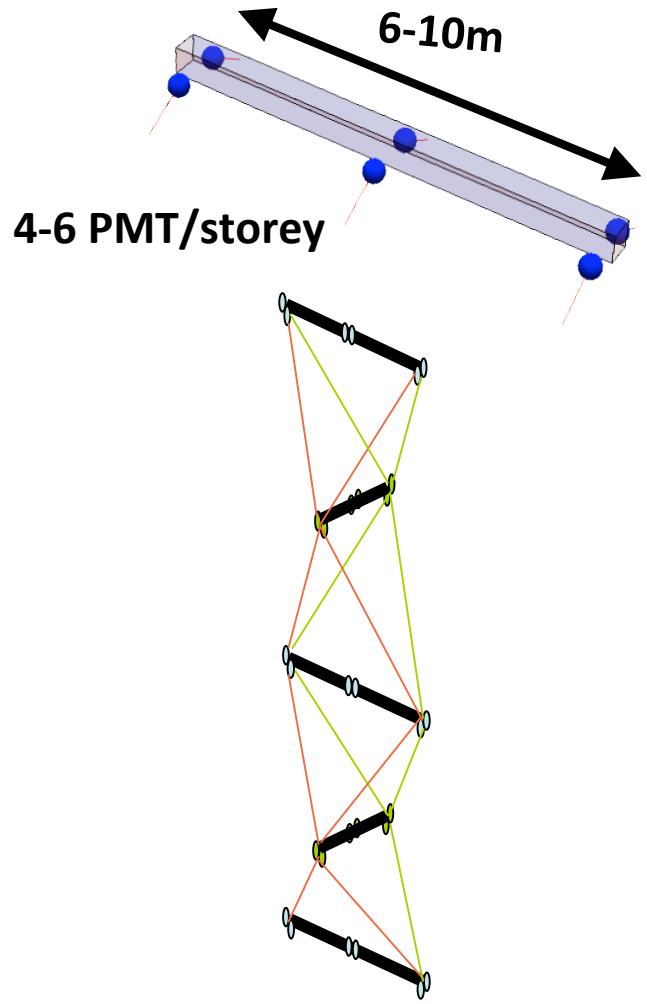
Where will be located the km^3 Telescope

Site selection

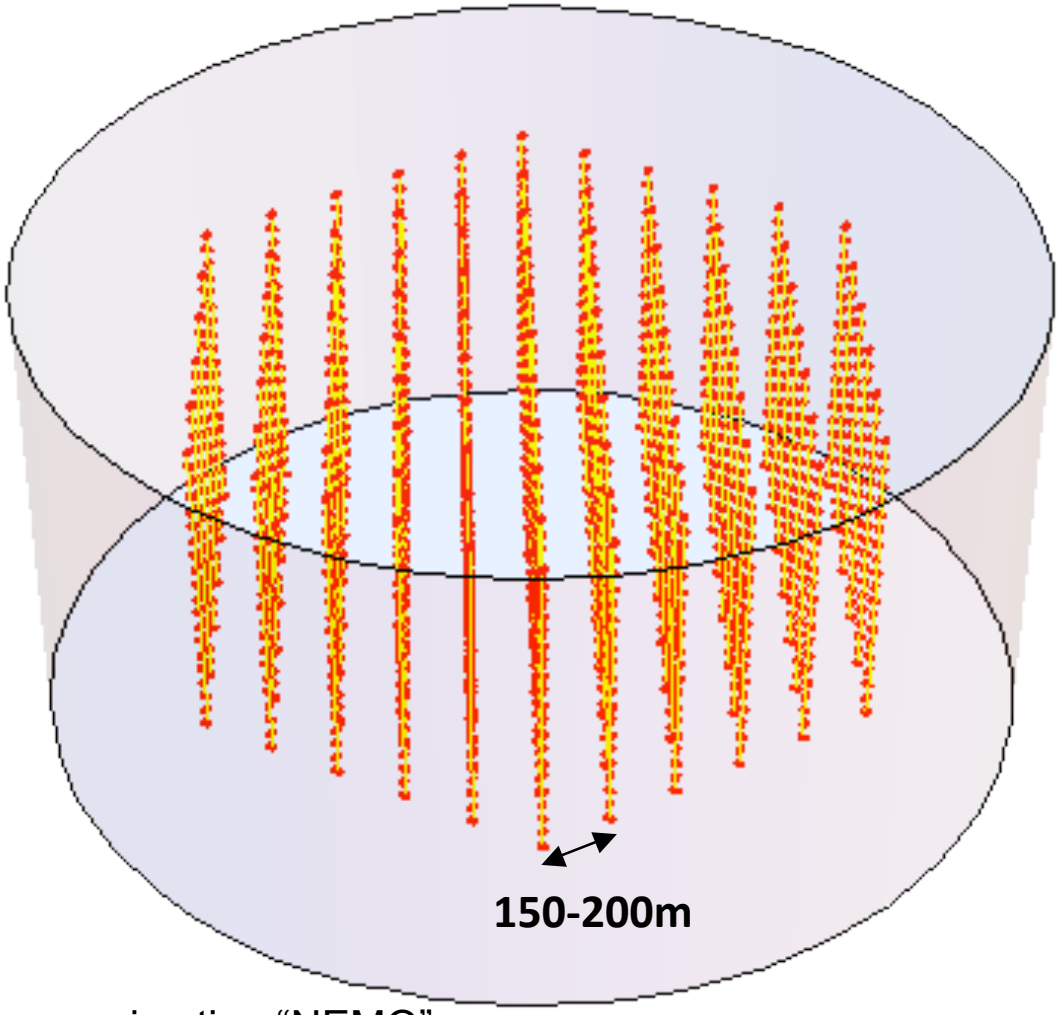
- Accurate collection of existing data about:
  - Oceanographic and environmental deep sea properties: currents, temperature salinity values and variations, light absorption and scattering, optical noise, fouling, sedimentation, Sea-bottom geology, seismicity, …
  - Good knowledge of sites properties exists !
- New measurements when direct comparison of sites properties non possible
- Final choice will depend on
  - Depth
  - Accessibility
  - Distance from shore
  - Bioluminescence rate
  - Sedimentation
  - Sea current
  - Access to high speed networks on shore
  - ……
  - **Socio-political/regional considerations**



Verso il rivelatore da 1km^3 : ν-one



ν-one : progetto condiviso da INFN-IN2P3



- meccanica tipo “NEMO”
- elettronica (front-end/trasmissione a riva) sviluppata da Roma, con modifiche da realizzare e provare nel 2009/10

Il gruppo NEMO/ANTARES/KM3NeT di Roma

- Senior Physicists
  - Maurizio Bonori
  - Antonio Capone
  - Piero Vicini
- Fellows
  - Fabrizio Ameli
  - Gabriele Giovanetti
  - Alessandro Lonardo
  - Fabrizio Lucarelli
  - Francesco Simeone
- PHD students
  - Manuela Vecchi
- Thesis students
  - Marco Innocenti
  - Valerio Paladino
  - Matteo Turisini
- Technical Staff
  - Rocco Masullo

and for oceanographyc studies:
  - Vanda Bouchè
  - Ettore Salusti

Tesi disponibili:

PHD= dottorato, TS=tesi specialistica, T3= dissertazione triennale

- Studio dell'efficienza di rivelazione di interazioni di corrente neutra in un Telescopio Cherenkov sottomarino per neutrini astrofisici (NEMO-ANTARES) (PHD, TS, T3)
- Rivelazione di neutrini da sorgenti astrofisiche note come sorgenti di fotoni (NEMO-ANTARES) (PHD, TS, T3)
- Studio della risoluzione angolare di un Telescopio Cherenkov sottomarino per neutrini astrofisici tramite “l'ombra della Luna" (NEMO-ANTARES) (TS)
- Ottimizzazione e calibrazione di un apparato acustico sottomarino per la rivelazione delle interazioni di neutrini astrofisici (NEMO-ANTARES) (TS)
- Definizione delle caratteristiche del "sistema di trigger" per un Telescopio Cherenkov sottomarino per neutrini astrofisici (NEMO) (TS, T3)
- Studio delle proprietà del sito sottomarino di ANTARES tramite l'analisi dei dati raccolti con la "Linea Instrumentata" (ANTARES) (TS)
- Calibrazione temporale di un Telescopio Cherenkov sottomarino per neutrini astrofisici (ANTARES, NEMO) tramite il tracciamento di muoni atmosferici (TS)
- Misura dei flussi di neutrini astrofisici da 'sorgenti diffuse e/o non identificate' (ANTARES, NEMO) (PHD, TS, T3)
- Studio della possible misura di 'Monopoli Magnetici' in un Telescopio Cherenkov sottomarino per neutrini astrofisici (ANTARES, NEMO) (TS, T3)

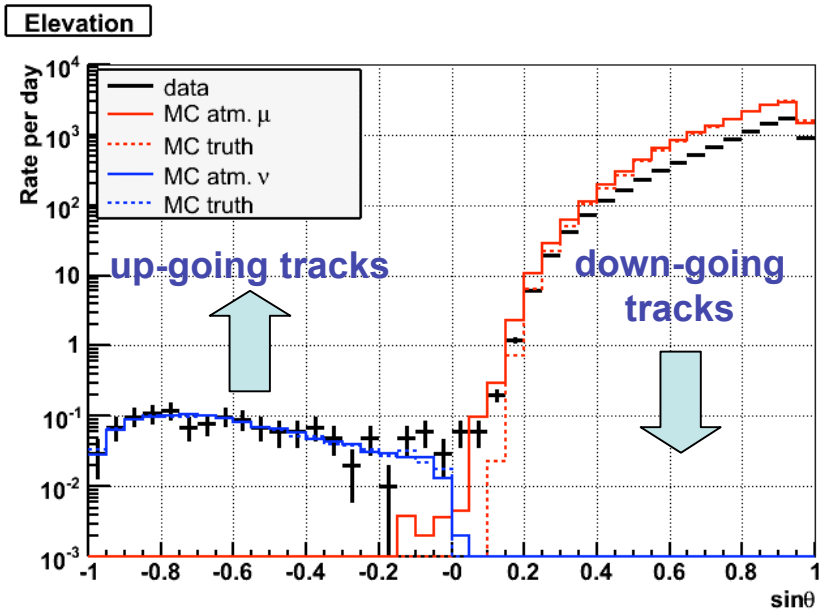
http://www.roma1.infn.it/exp/nemo/AHEN/index.html

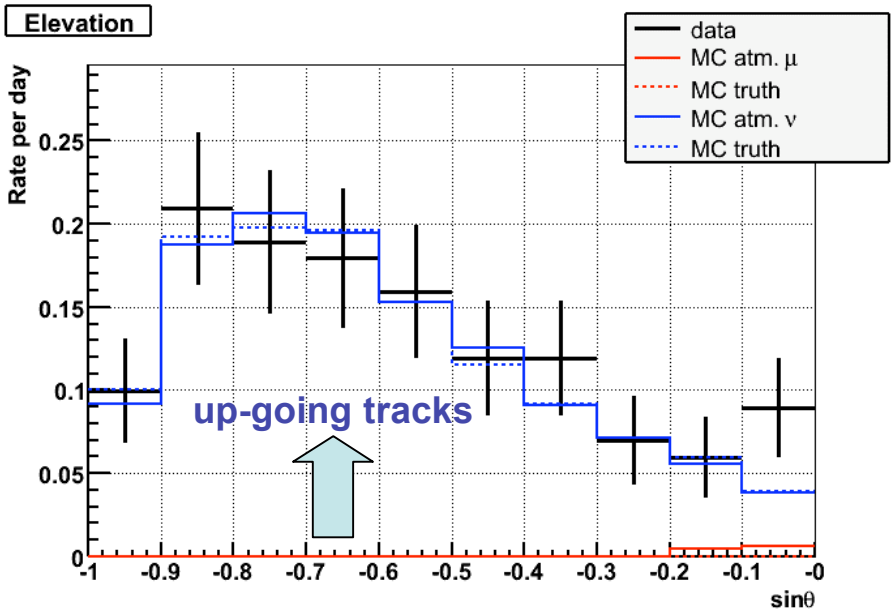
Summary

- **Compelling scientific argument for complementing IceCube with a km^3 scale detector in the Northern Hemisphere**
- The Mediterranean projects NESTOR, ANTARES and NEMO provide knowledge and experience for the deep sea Neutrino Telescope
- **The KM3NeT Design Study (2006-2009), funded by European Committee within FP6, endorses the common effort of the Mediterranean pilot projects ANTARES-NEMO-NESTOR (plus new collaborators) for the design of the km^3 Neutrino Telescope, the related deep-Sea infrastructures, and the solutions to technological challenges.**
- FP7 Preparatory Phase project (2008-2010) will allow to address, and solve hopefully, "strategic, legal and financial issues related to the construction of an European deep-sea infrastructure housing the km^3 Cherenkov Neutrino Telescope and providing access for deep-sea research".

Neutrino signal from 5 lines data in 2007 using a multiline fit

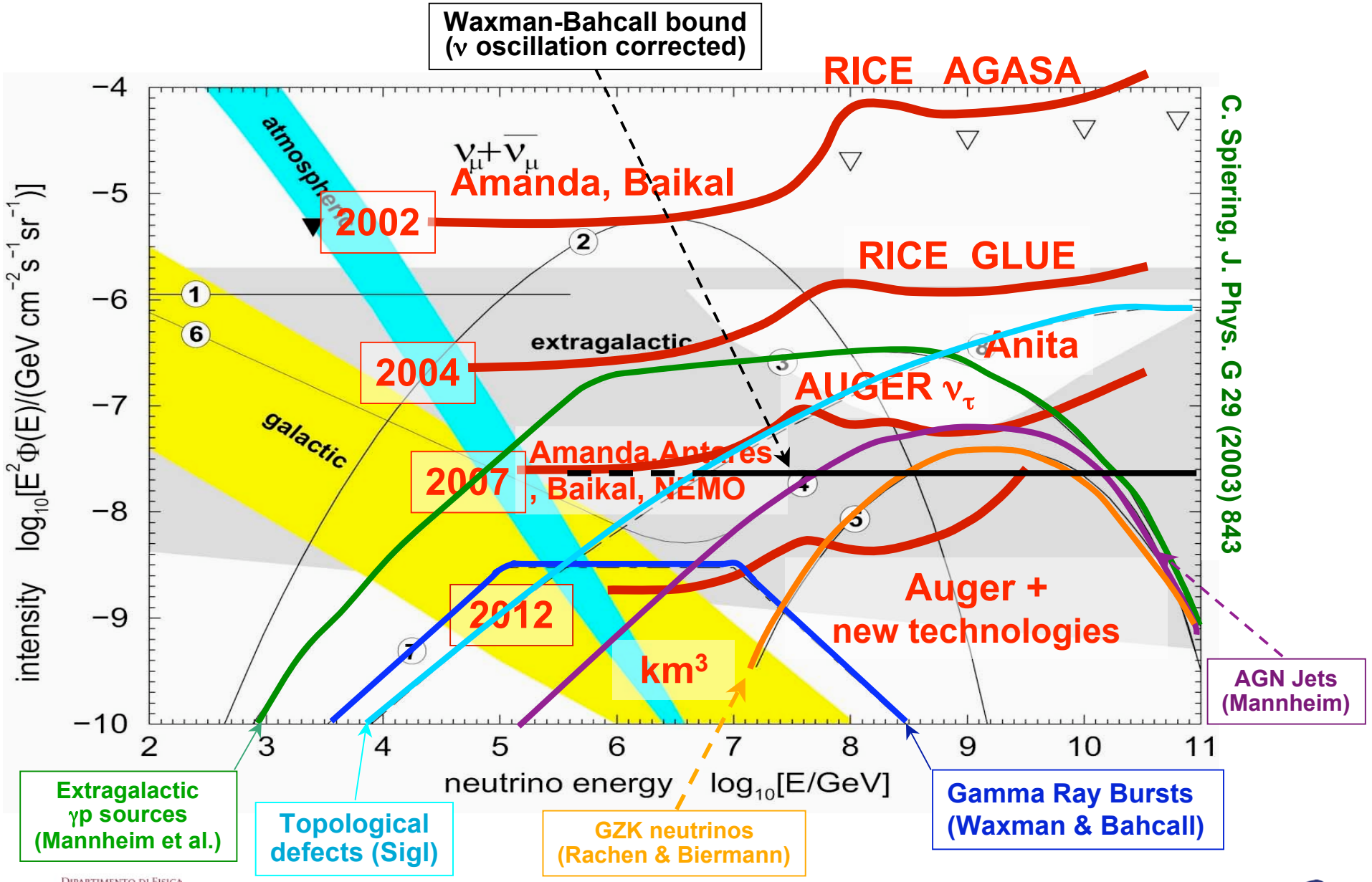
ANTARES





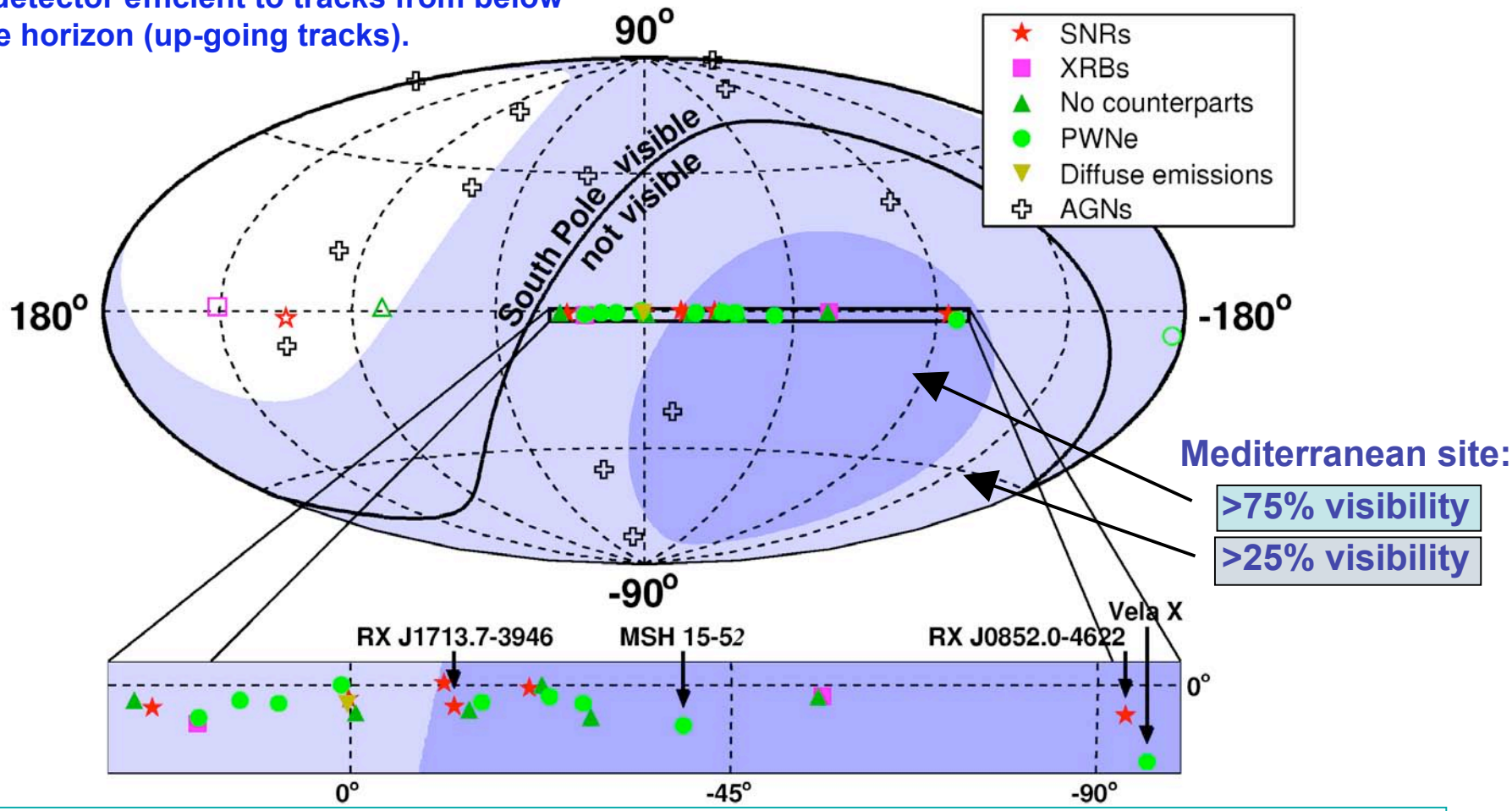
The data sample consists of all "silver runs" between 25/05/2007 and 04/12/2007. With this selection we observed 1.29 events atmospheric neutrino up-going events per day (130 events in 100 days).

Diffuse ν flux: models, limits and sensitivities



Mediterranean Sea ν Telescope Sky Coverage

Observed sky, in galactic coordinates, by a detector efficient to tracks from below the horizon (up-going tracks).



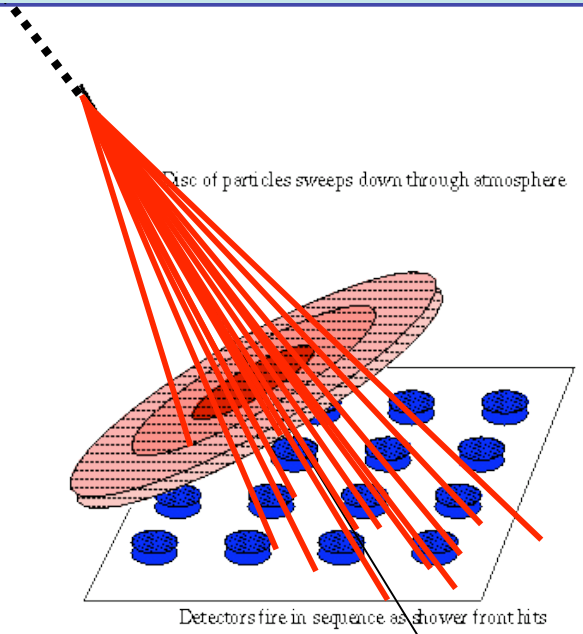
Mediterranean site:

>75% visibility

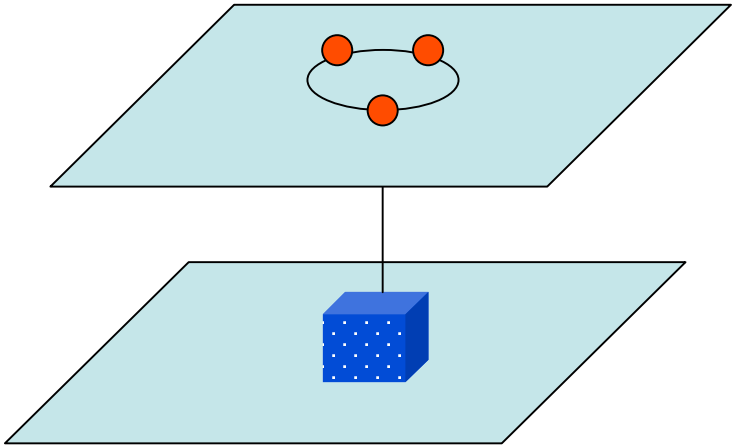
>25% visibility

→ We need a km^3 Northern ν Telescope to cover the Galactic Plane

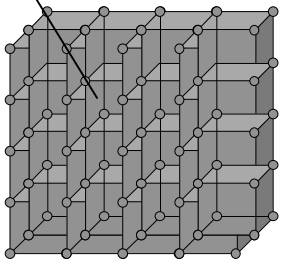
Possible use of a surface array for calibration: *SeaTop*



Three stations at 20 m distances with 16 m^2 scintillators each



Calibration:
- angular offset
- efficiency
- angular resolution
- absolute position



The new data transmission concept: the daisy chain

Roma/LNS project under development and test

The link is bidirectional with asymmetric data rates:

- Up-going link @163.84 Mb/s for timing and slow control
- Down-going link @1.18 Gb/s for physics data and control

Pros

Timing from Low Speed

Nodes are identical

Cons

Higher Power

Failure stops higher floors