Mediterranean Neutrino Telescopes

New Views of the Universe

Chicago, December 2005

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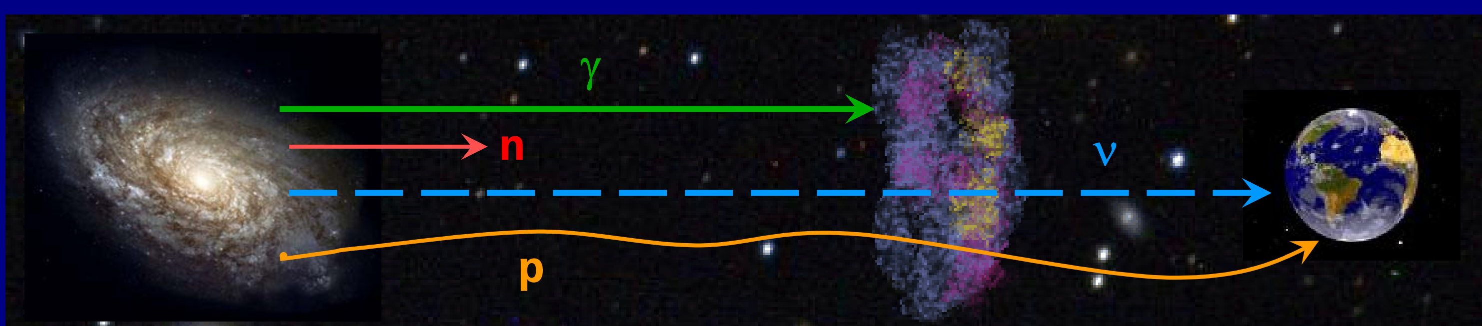
Neutrino Astronomy

- Neutrino Astronomy is a quite recent and very promising experimental field.
- Advantages:
  - Photons: interact with CMB and matter (r~10 kpc @100 TeV)
  - Protons: interact with CMB (r~10 Mpc @1011 GeV) and undergo magnetic fields (Δθ>1º, E<5·1010 GeV)
  - Neutrons: are not stable (r~10 kpc @109 GeV)
- Drawback: large detectors (~GTon) are needed.



Scientific Scopes

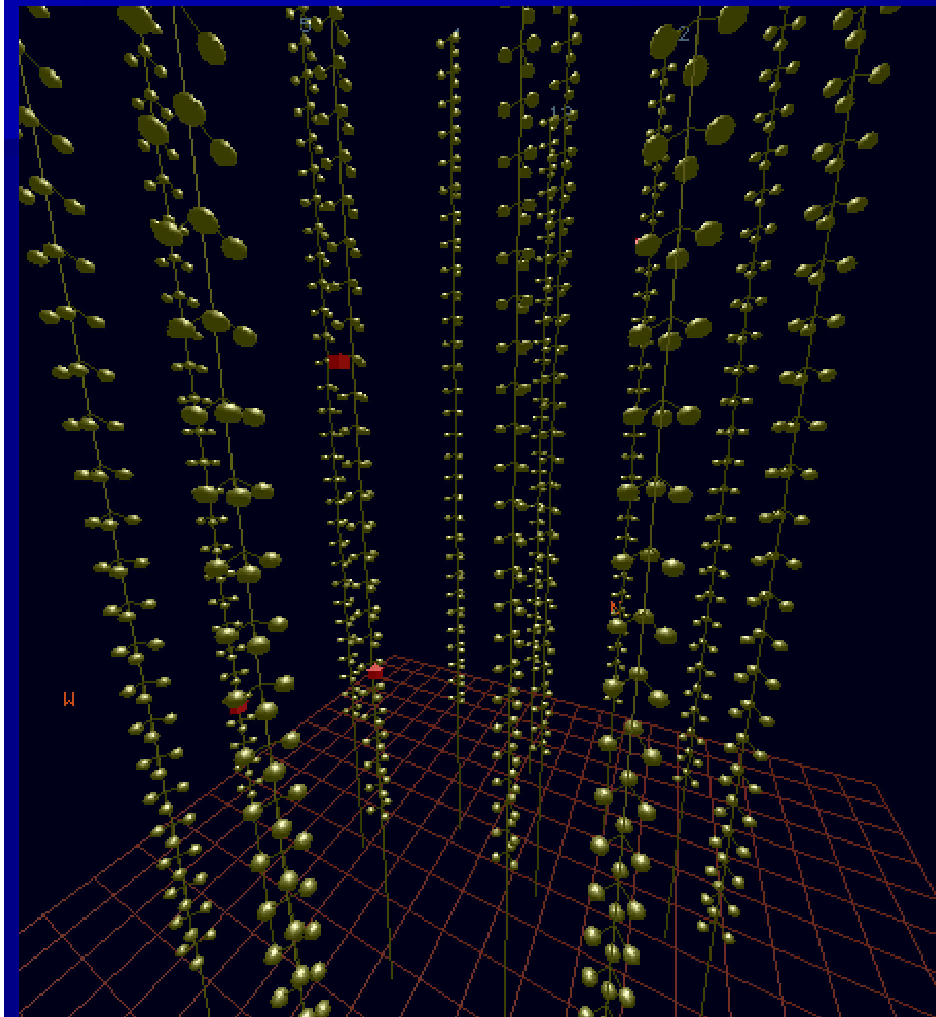
- Origin of cosmic rays
- Hadronic vs. leptonic signatures

Energy	~MeV	GeV-100 GeV	GeV-TeV	TeV-PeV	PeV-EeV	>EeV
Physics	Supernovae	Neutrino oscillation	Neutralino search	Astrophysical sources (AGNs, GRBs, MQs)	AGNs, TD, GZK neutrinos	?
Signature	Average increase in the PMT counting rate	Up-going muons	Up-going muons	Up-going muons and cascades	Almost horizontal tracks	Down-going tracks

not for telescopes in the ocean: ^{40}K

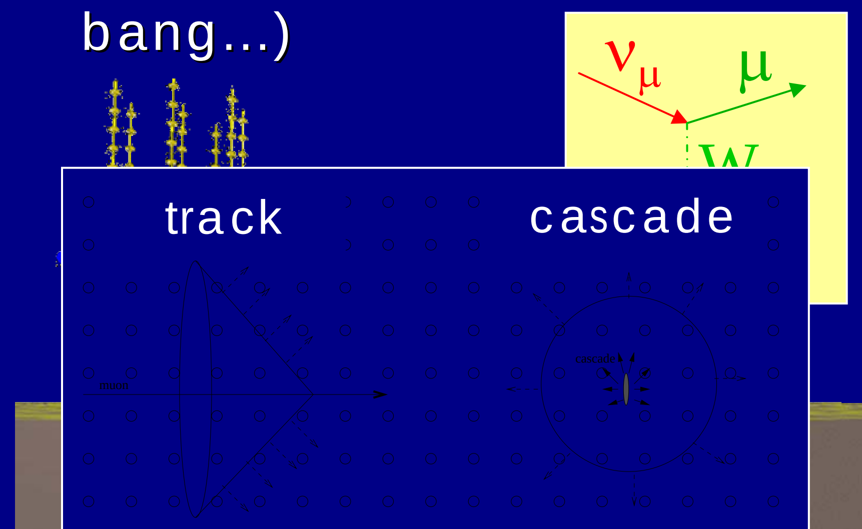
Other physics: monopoles, Lorentz invariance, super-massive DM , SUSY Q-balls, etc...

Detection Principle



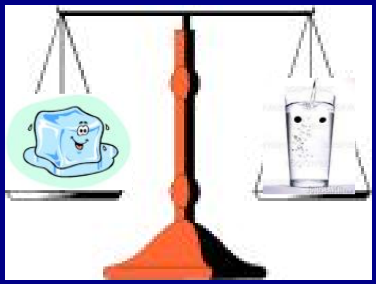
1.2 TeV muon traversing the detector.

- The neutrino is detected by the Cherenkov light emitted by the muon produced in the CC interaction.
- Other signatures are also possible (cascades, double bang…)



1 km at 300 GeV 25 km at 1 PeV	5-10 m long diameter ~ 10 cm

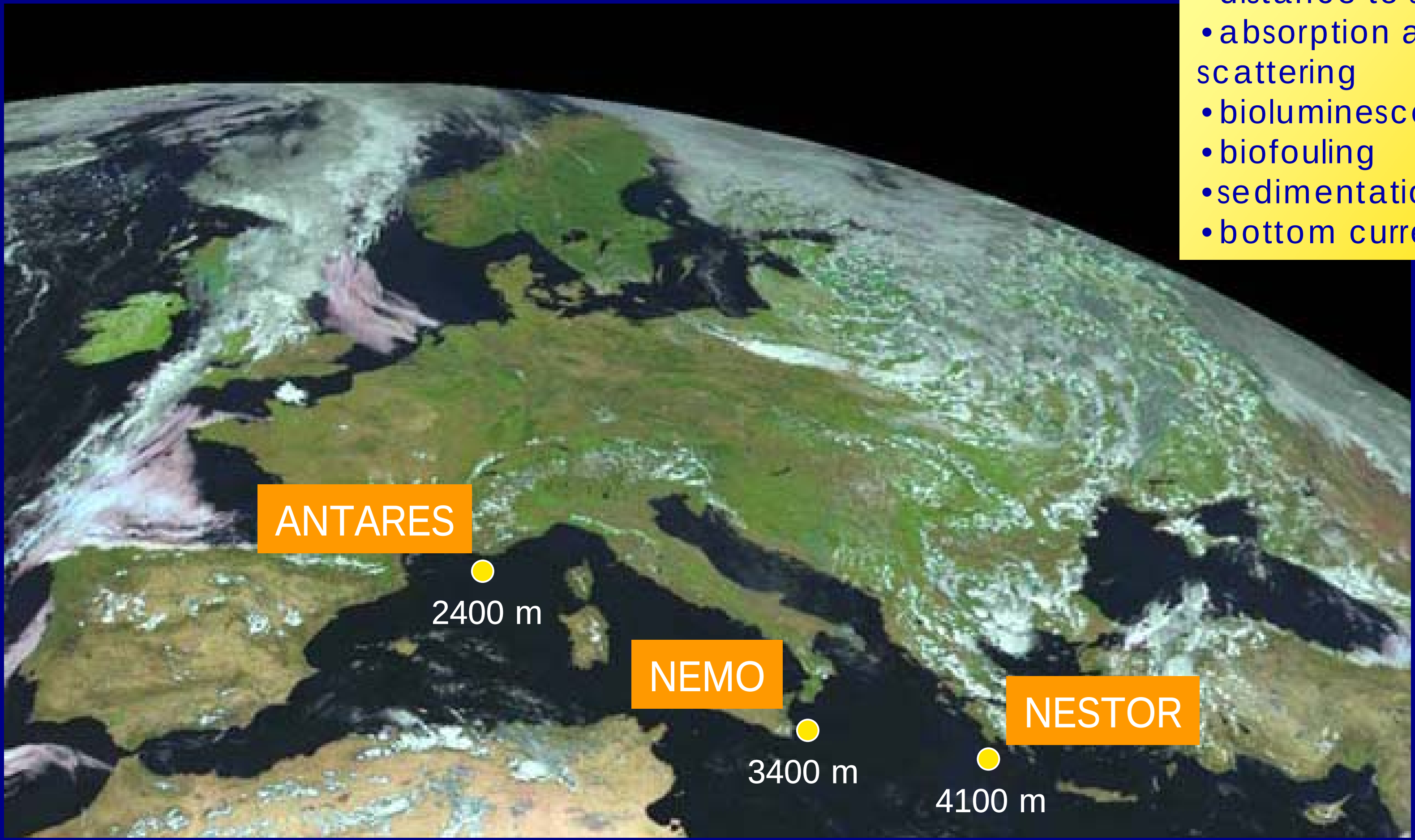
Sea vs. Ice



- Very large volumes of medium transparent to Cherenkov light are needed:
  - Ocean, lakes…
  - Antarctic ice
- Advantages of oceans:
  - Larger scattering length $\rightarrow$ better angular resolution
  - Weaker depth-dependence of optical parameters
  - Possibility of recovery
- Advantages of ice:
  - Larger absorption length
  - No bioluminescence, no ^{40}K background, no biofouling
  - Easier deployment
- Anyway, a detector in the Northern Hemisphere in necessary for complete sky coverage (Galactic Center!), and it is only feasible in the ocean.

Neutrino Telescopes in the World

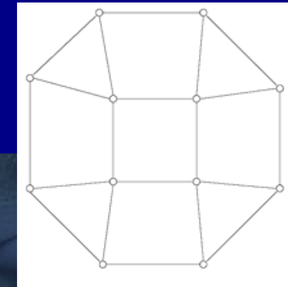
- Several projects are working/planned, both in ice and ocean and lakes.



important factors for the site selection

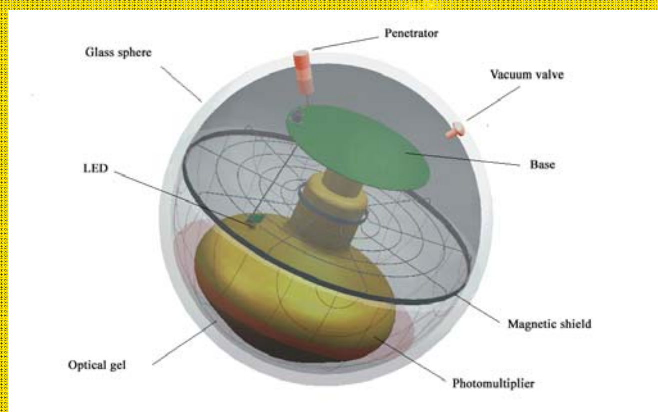
- depth
- distance to shore
- absorption and scattering
- bioluminescence
- biofouling
- sedimentation
- bottom currents

ANTARES: Layout


Horizontal layout

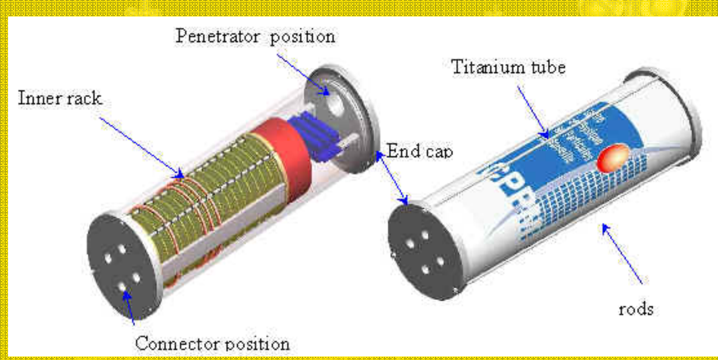
- 12 lines (900 PMTs)
- 25 storeys / line
- 3 PMT / storey

Buoy



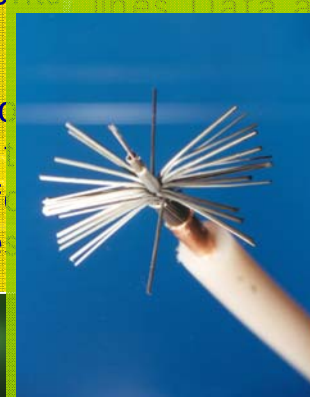
The Optical Module contains a 10" PMT electronics

The Optical Beacons will allow timing calibration and water properties measurements



The Local Co… Module cont… electronics f… signal proce…

It receives power from shore station and distributes it to the lines. Data and control signals … transmitted to the JB.



It provides power and data link between the shore station and the detector (40 km long)

Junction box

100 m

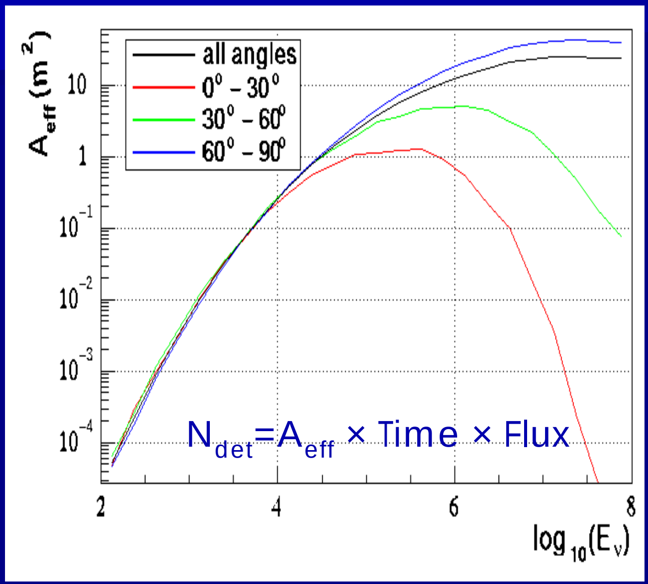
Readout cables

~60-75 m

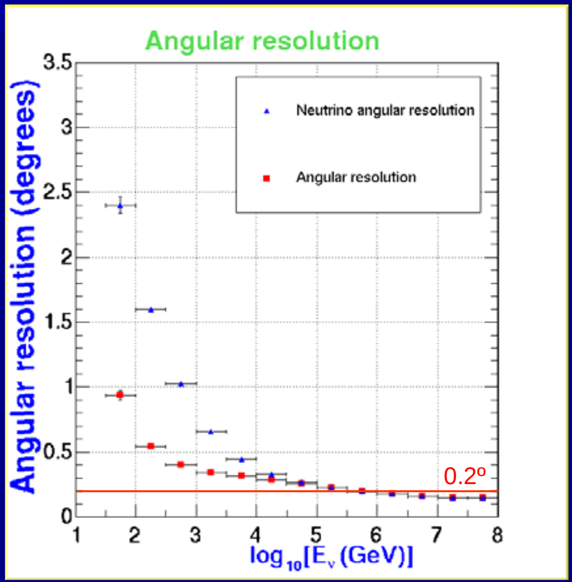
Electro-optical cable

ANTARES: Performance

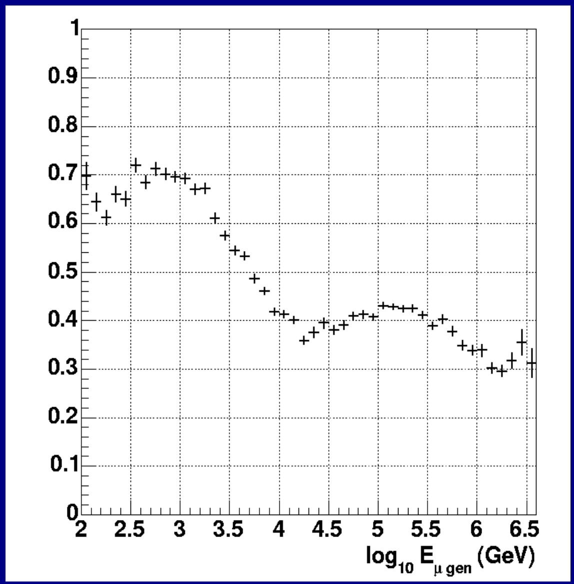
Neutrino effective area



Angular resolution



Energy resolution

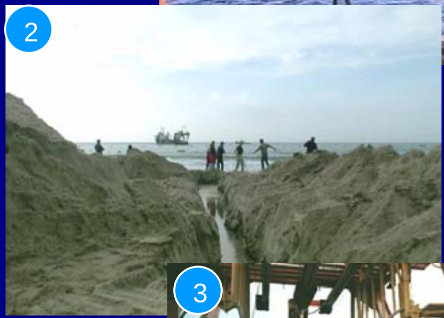


- For E_ν<10 PeV, A_{eff} grows with energy due to the increase of the interaction cross section and the muon range.
- For E_ν>10 PeV the Earth becomes opaque to neutrinos.

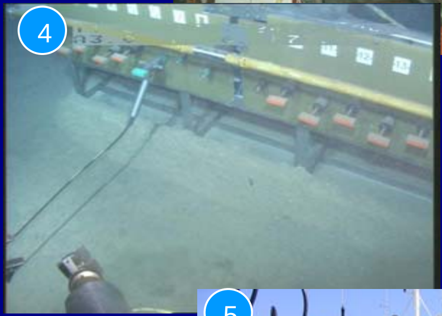
- For E_ν < 10 TeV, the angular resolution is dominated by the ν-μ angle.
- For E_ν > 10 TeV, the resolution is limited by track reconstruction errors.

- Energy reconstruction is within a factor 2.5 above 10 TeV .
- The energy reconstruction is key the diffuse flux analysis.

ANTARES: Milestones



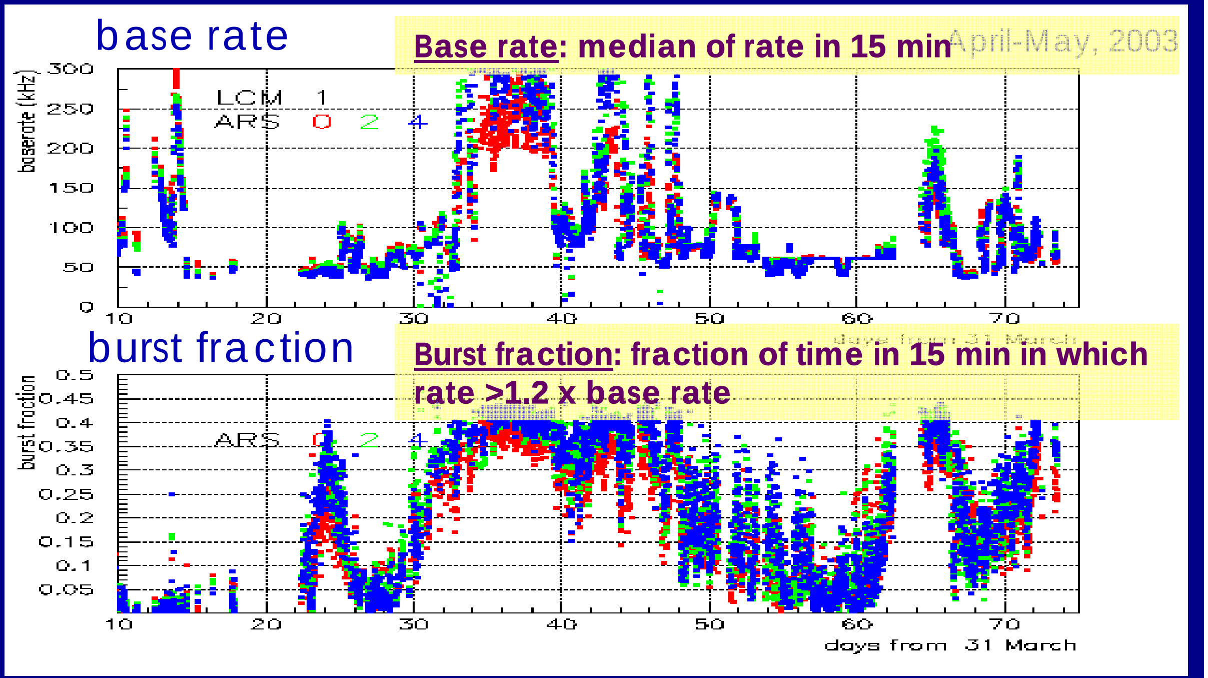
- 1996-1999:R&D and site evaluation programs.
- Nov 99 – Jun 00: Demonstrator line tests. 1
- Oct 01: Electro Optical cable deployment. 2
- Dec 02: Junction Box (JB) deployed. 3
- Dec 02: Prototype Sector Line (PSL) deployed.
- Feb 03: Mini Instrumentation Line deployed.
- Mar 03: PSL and MIL connected to JB by submarine. 4
- Mar 05: Deployment of Line-0 (full-length line with cables and mechanical structure) and MILOM (mini-instrumentation line with OMs). 5
- May 05: Line-0 recovered.
- 2006-2007: Deployment of 12 lines.



ANTARES: PSL and MIL

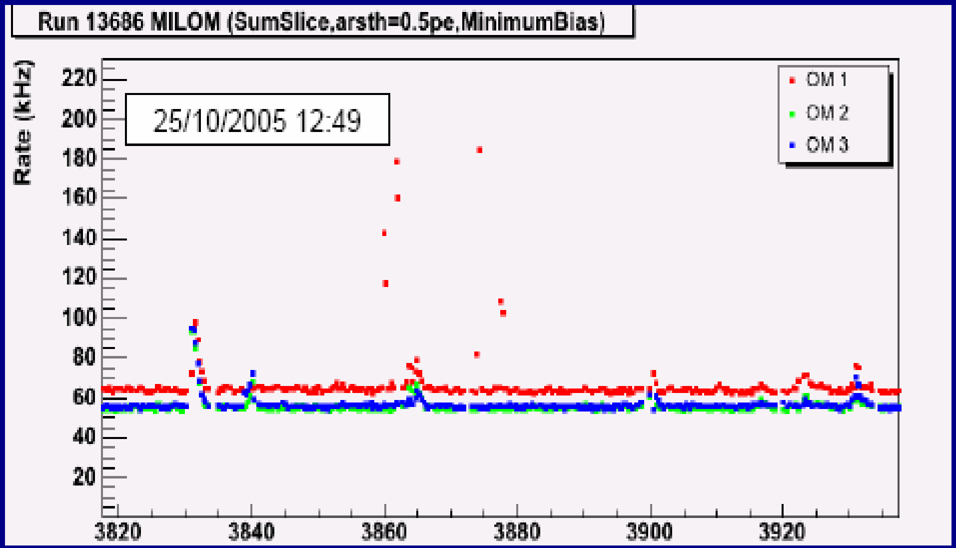
- The Prototype Sector Line (PSL) is a 1/5 of a complete line.
- The Mini Instrumentation Line (MIL) contains devices for calibration and environmental parameter monitoring.

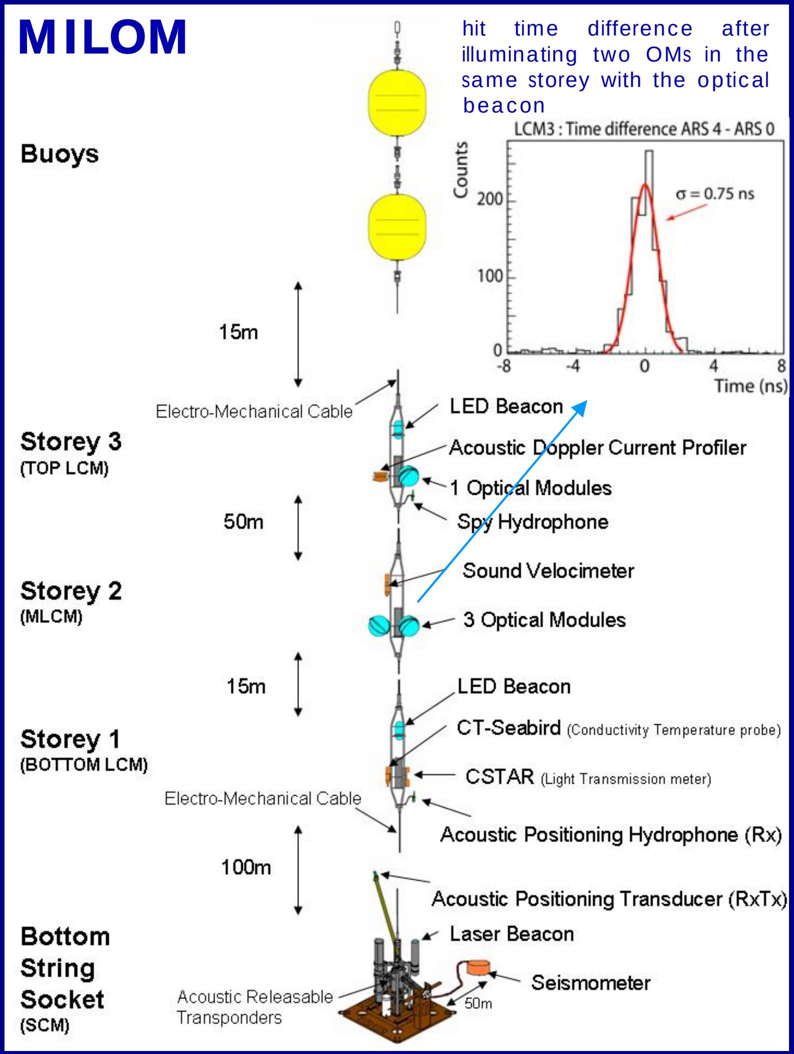
- These lines allowed to test a "mini-detector" in realistic conditions.
- The deployment, connection and recovery operations were <u>successful</u>.
- Some technical problems were also discovered and have been solved:
  - –Water leak in one of the Ti containers of the MIL
  - –Optical fibers broken



ANTARES: MILOM

- It allowed to the final test of electronics and the acoustic positioning system.
- The time calibration was checked to be under control (<1 ns)
- Many environmental parameters (baser rate, salinity, temperature…) have been monitored.





ANTARES: Line 0

- Line-0 allowed the validation of mechanical and cable structure of a complete line (no PMTs).
- It checked the absence of water leaks.
- Optical transmission losses were detected. A solution is being tested.

ANTARES: Line 1

- First line of the detector calibrated and fully tested.
- Ready for deployment next month!

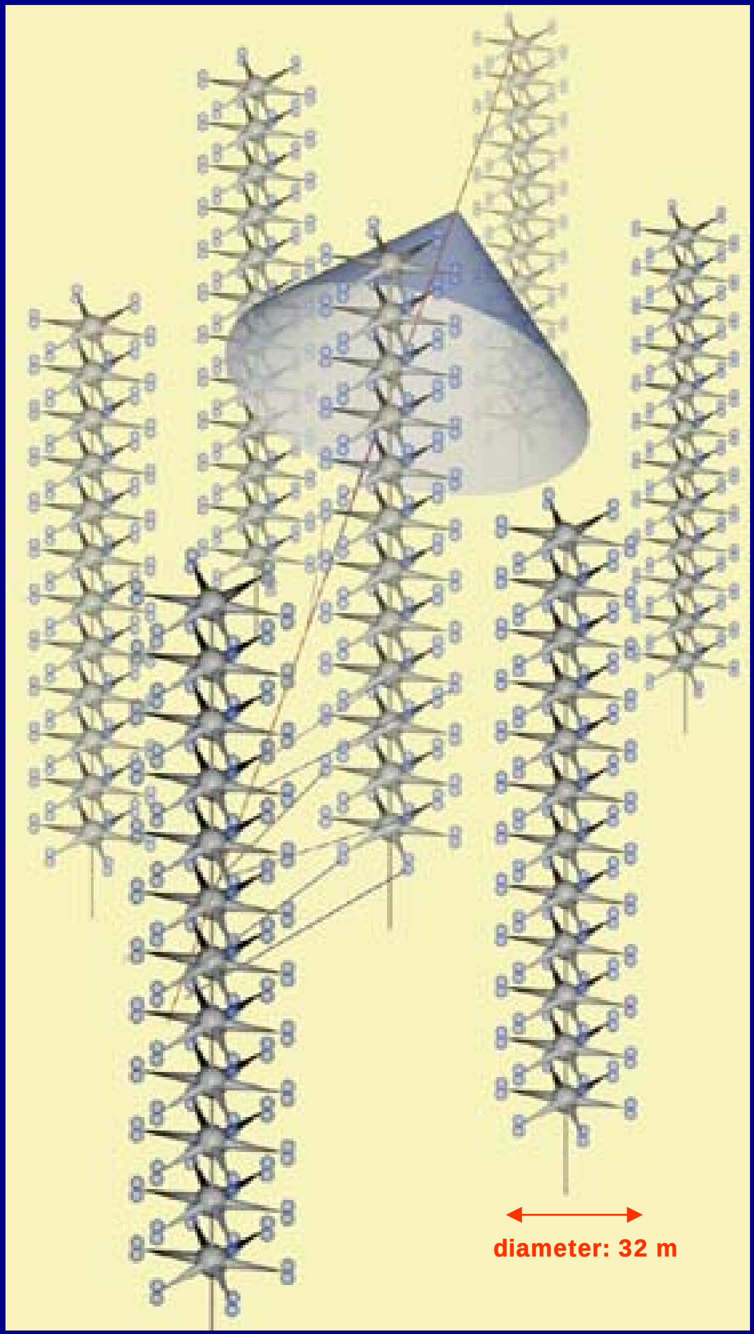
NESTOR: Site

- Large depths (4100 m) relatively close to shore (15 km).
- Good attenuation length: 55 m
- Extremely low rate of sedimentation and bio-fouling which allows up-going OMs.
- Low ^{40}K background: 50 Hz
- Low bio-luminescence: 1% of dead time)

broad plateau: 8x9 km2

NESTOR: layout

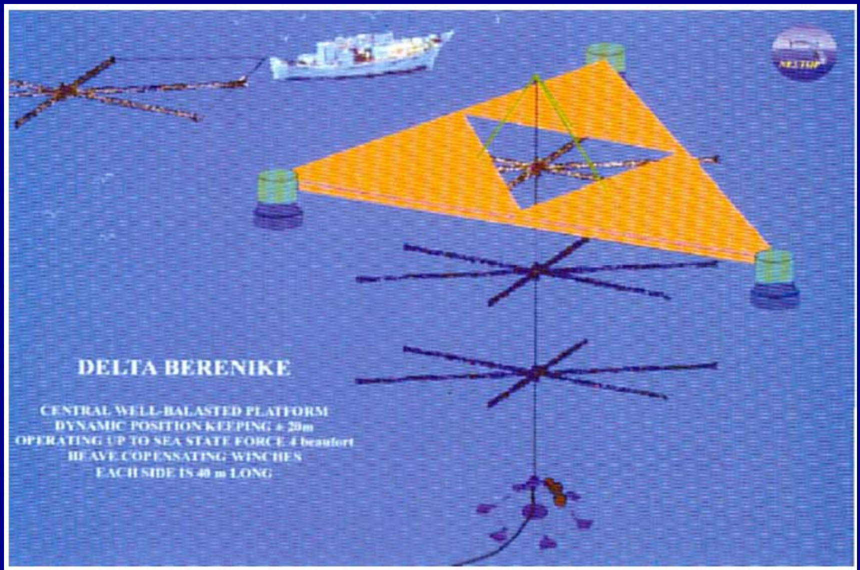
- Array of towers (360 m high)
- 144 PMT/tower
- 12 floors/tower in the form of 6-pointed stars.
- Two PMTs in each arm: one looking up and the other down.
- Electronics container in the center of each floor
- Effective area (one tower): 20,000 m^2
- Energy threshold: 4 GeV



NESTOR: Deployment Operations

- Cable deployed in Jun 00, but was damaged during the lay.
- In Jan 02, the cable was deployed again and also the junction box and several instruments for the monitoring of the environment.
- In Mar 03, the first floor detector was deployed: measurement of atmospheric muons.
- End of 2006, a full tower will be deployed
- Dry connection at surface:
  - less expensive connectors
  - no need of ROV or manned submarine
- A platform is being building for the deployment of the towers.
- This triangular structure is self-propelled and can maintain its position within several meters.

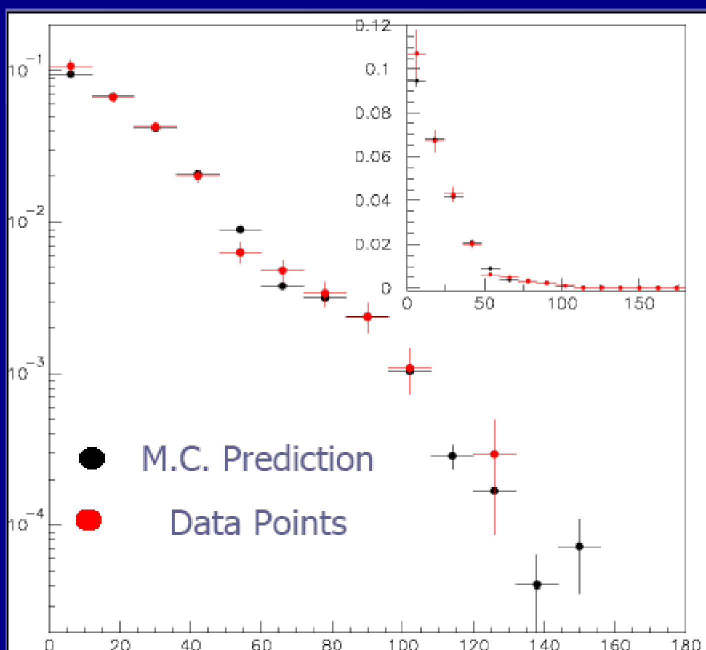
Deployment of first floor of NESTOR.



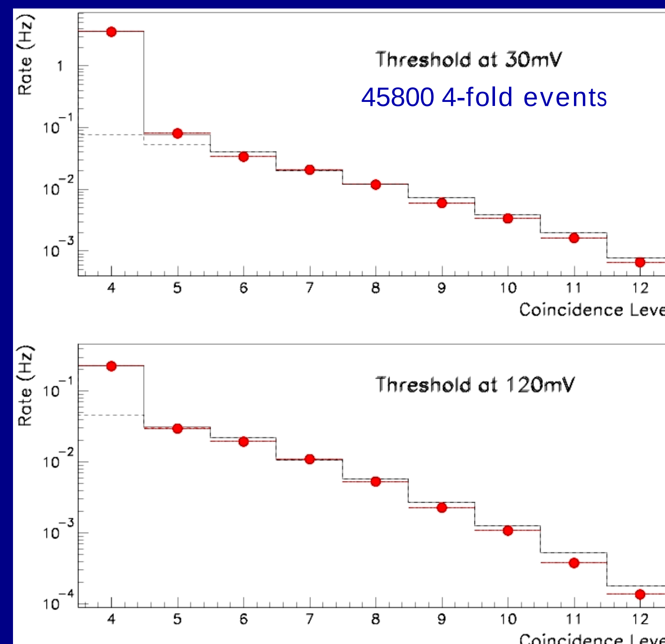
NESTOR: first data

- Data from the first floor have been used to reconstruct atmospheric muons
- Results agree with the MC prediction
- Trigger rates also agree with simulation

1/N dN/d(cosθ)



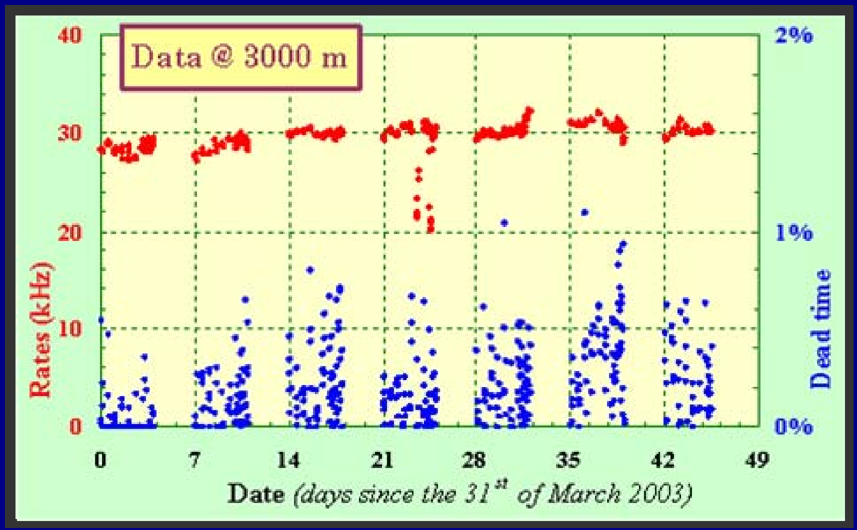
zenith angle (deg)



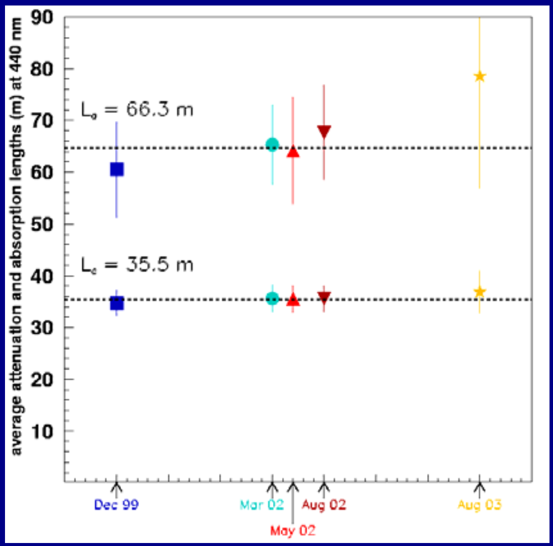
Trigger rate: data (red point), MC atm. muons+ ^{40}K (solid line) and MC atm. muons (dashed line)

NEMO: Site Evaluation

- Capo Passaro, 100 km from Sicily shore has been selected by the NEMO collaboration as optimal location for the detector.
- The depth at chosen location is >3400 m.
- The absorption length is ~65 m @ λ=440 nm.
- Very low bioluminescence.
- Water currents are low (3 cm/s on average).
- Stable water properties.

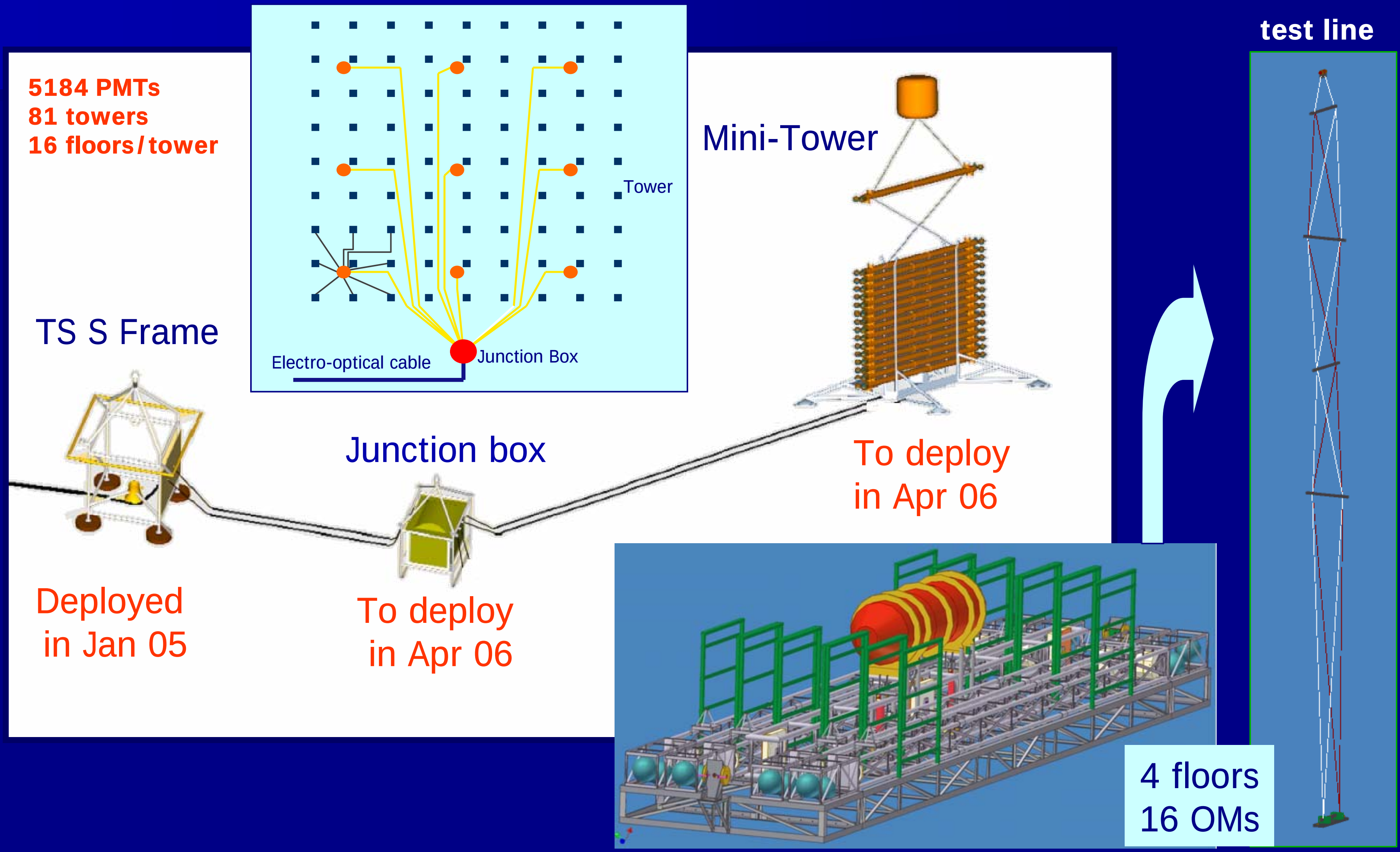


Rate and dead time due to optical background



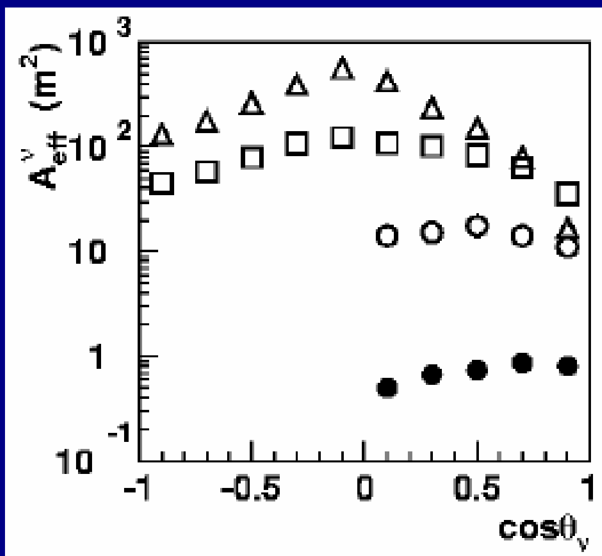
Seasonal behavior of λ_{abs}

NEMO: Deployment schedule

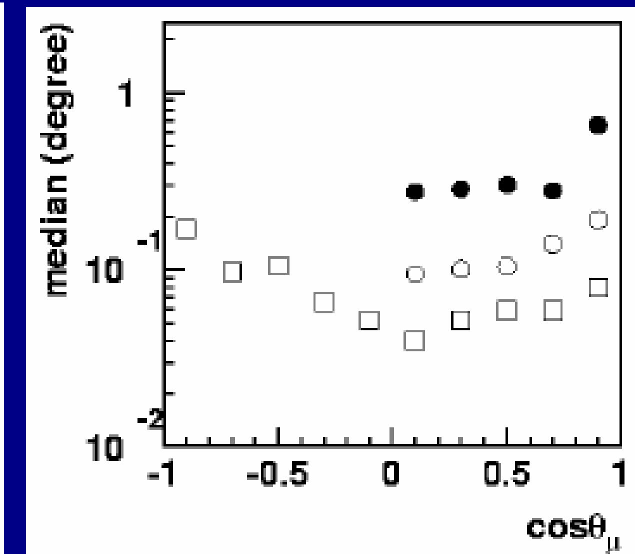


NEMO: Performance

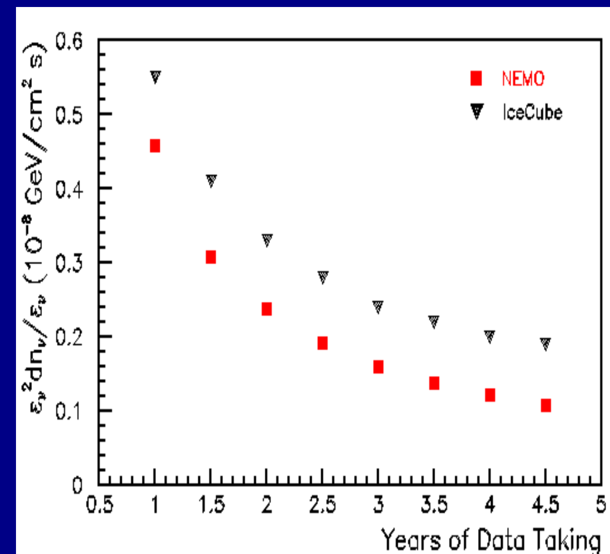
Effective Area



Angular resolution



Sensitivity to
Point-like Sources



full circles: 10^3 -10^4 GeV
open circles: 10^4 – 10^5 GeV
squares: 10^5 - 10^6 GeV
triangles: 10^6 – 10^7 GeV

Energy spectrum: E^{-2}
NEMO: 5832 PMTs
IceCube: 4800 PMTs

NEMO: Status and schedule

- Characterization and selection of the optimum site has been done.
- NEMO phase I: intermediate stage to validate the technical aspects of the project:
  - In Jan 2005:
    - electro-optical cable at 2000 m depth
    - submarine termination panels
    - station for acoustic background measurements
  - End of 2006:
    - test tower (4 floors)
- NEMO phase II:
  - End of 2007:
    - underwater infrastructure at 3500 m depth
    - 16-floor tower
    - long-term environment monitoring

KM3Net

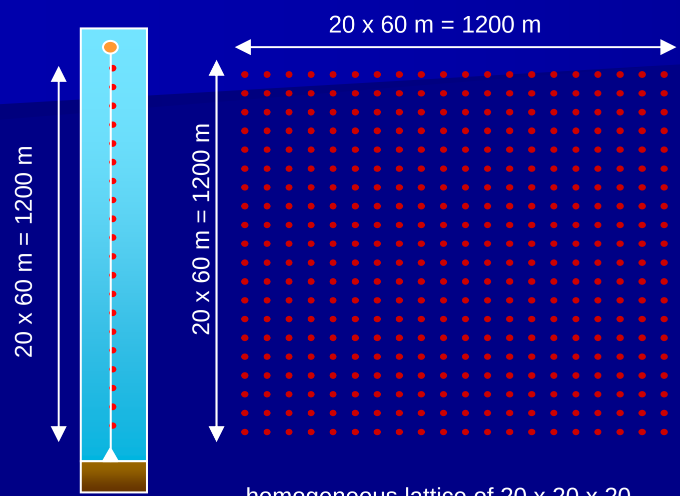
- KM3Net us the project of joint effort for the construction of a cubic kilometer neutrino detector in the Mediterranean Sea.
- The first step is R&D phase, in which the experience of present projects will be an important input.
- The expansion from 0.1 km^2 to 1 km^3 is not straight-forward.
- Parallel contributions to marine biology, geophysics, oceanography, etc. will be important.

KM3Net: Key issues

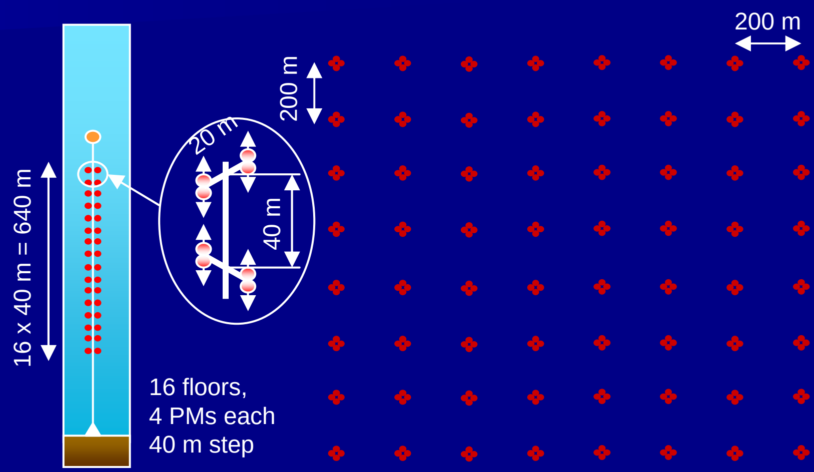
- Several issues are under study:
  - Layout: strings, towers…
  - Deployment procedure: Submarine (ANTARES) or surface connections (NESTOR)
  - Photo-sensors: large PMTs, small PMTs, others…
  - Site: France, Italy or Greece

KM3Net: Layouts

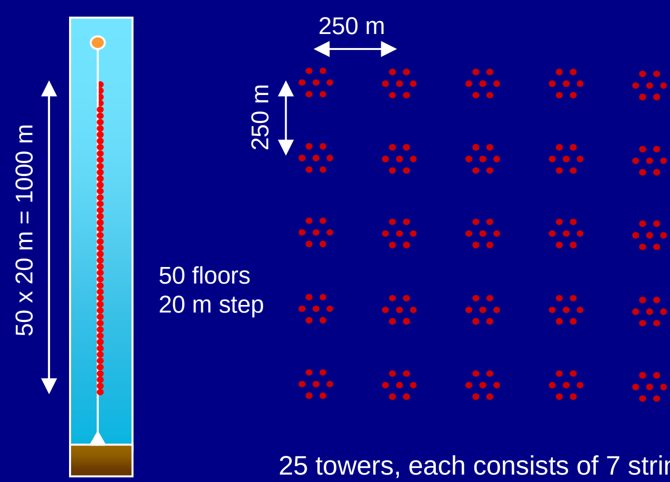
Zaborov, VLnT05



homogeneous lattice of 20 x 20 x 20
downward-looking
10-inch photomultiplier tubes



64 towers



25 towers, each consists of 7 strings
PMs are directed downwards

KM3Net: Schedule

Sep 2002	First initiative
Nov 2003	ApPEC review
Mar 2004	Proposal submission to FP6 program
Sep 2004	Proposal approved by the EU
01.02.2006	Start of Design Study (9 M€ funding for 3y)
Mid-2007	Conceptual Design Report
Feb 2009	Technical Design Report
2009-2010	Preparation Phase
2010-2012	Construction
2011-20xx	Data taking

Conclusions

- Major scientific interest for neutrino astronomy
- A neutrino telescope in the Northern Hemisphere is necessary for complete sky coverage: Galactic Center.
- ANTARES and NESTOR have made important progress in the installation of their ~0.1 km^2 projects.
- NEMO is actively preparing the field for the big telescope in the Mediterranean: KM3Net

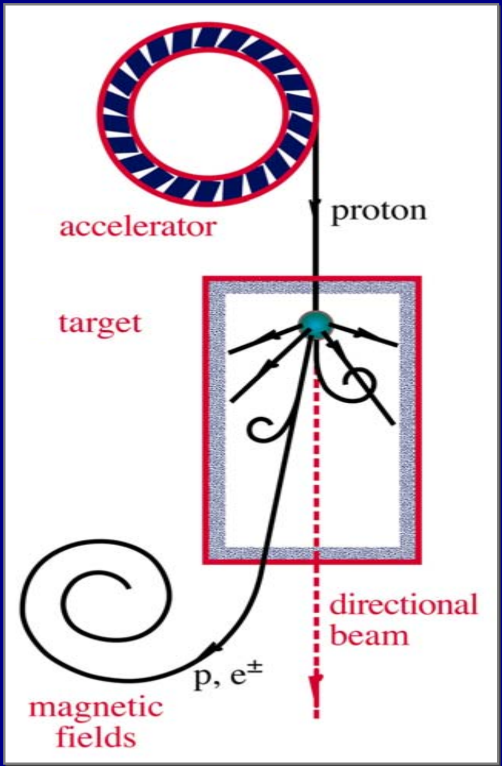
Back-up transparencies

Outline

- Neutrino astronomy
- Detection principle
- Sea vs. Ice
- Telescopes in the Mediterranean Sea
  - ANTARES
  - NESTOR
  - NEMO
  - KM3
- Conclusions

Production Mechanisms

- Neutrinos are expected to be produced in the interaction of high energy nucleons with matter or radiation:



$$N+X \rightarrow \pi^{\pm}(K^{\pm}...)+Y \rightarrow \mu^{\pm}+\nu_{\mu}(\bar{\nu}_{\mu})+Y$$

Cosmic rays

$$\downarrow$$

$$e^{\pm}+\bar{\nu}_{e}(\nu_{e})+\bar{\nu}_{\mu}(\nu_{\mu})$$

• In these scenarios, high energy photons would also be produced:

$$N+X \rightarrow \pi^{0}+Y \rightarrow \gamma\,\gamma+Y$$

Gamma ray astronomy

Astrophysical Candidates and Limits

- **Extra-galactic sources**: most powerful sources in the Universe
  - AGNs
  - GRBs

- **Galactic sources**: these are near objects (few kpc) so the luminosity requirements are much lower.
  - Micro-quasars
  - Supernova remnants
  - Magnetars

- **Limits on the diffuse fluxes:**

–Upper bounds from UHE cosmic rays and γ diffuse flux can be established.

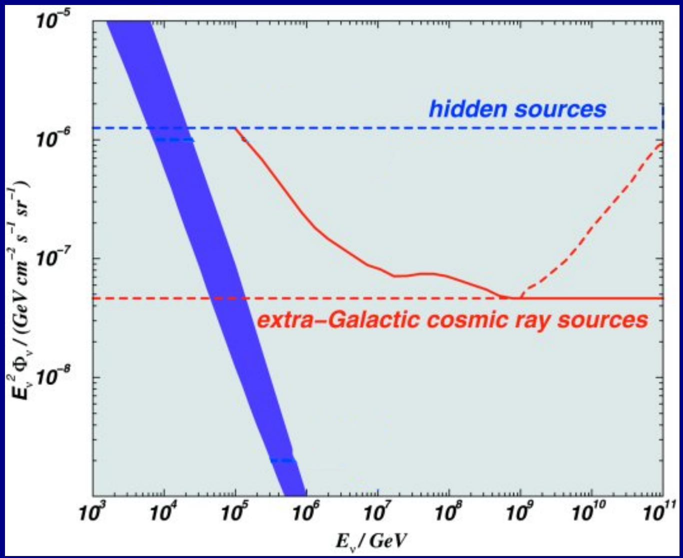
–The first limit comes from the isotropic gamma ray background.

$$E^2\, d\Phi/dE < 10^{-6}\ \text{GeV cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$$

–Concerning cosmic rays, the limit depends on the assumptions on the source*:

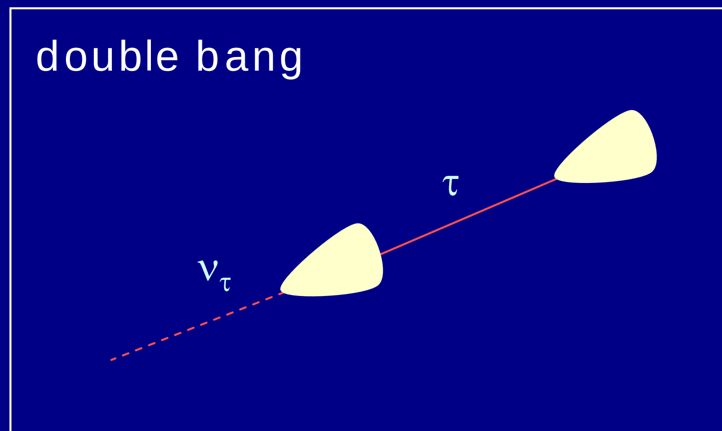
WB: $E^2\, d\Phi/dE < 4.5\times10^{-8}\ \text{GeV cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$

MPR: $E^2\, d\Phi/dE < 2\times10^{-6} - 4.5\times10^{-8}\ \text{GeV cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$



*Oscillations reduce these limits in a factor two: 1:2:0 → 1:1:1

Double bang



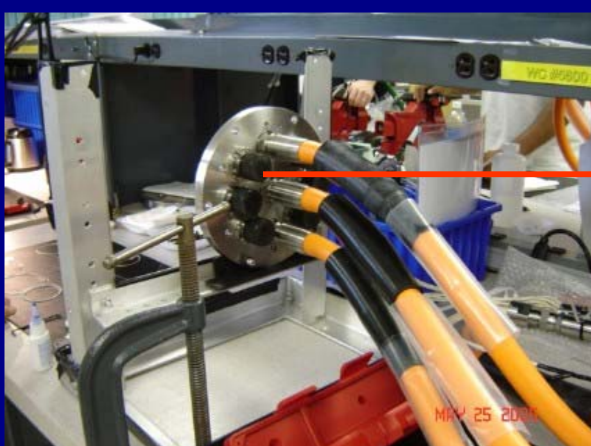
- ANTARES, NESTOR and & AMANDA are too small to detect double bang signature (they are too rare)
- However, cubic-kilometer telescopes could detect them.

NEMO: Elements of the detector

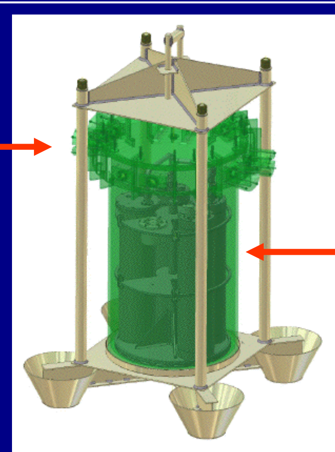
Two cable termination frames equipped with EO wet mateable connectors were deployed in Jan 05.

Marine aluminum floor for the mini-tower

The design of the decouples the problems of corrosion and pressure resistance (cheaper!).



Electro-optical cable



Pressure vessel for the JB

Some numbers