Neutrino Telescopes in Deep Sea

Marco Circella --- INFN Bari

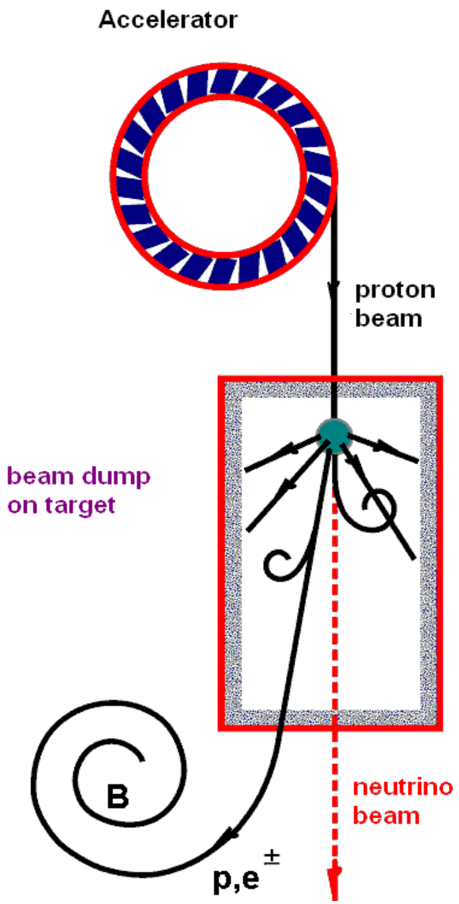
Contents

Contents

1. Motivation
2. Approach
3. Pros and cons of a sea water detector
4. Status and outlook

Neutrinos from cosmic sources

Accelerators	*Production mechanism*	Cosmic sources



Proton acceleration

- Fermi mechanism

Energy spectrum $dN_p/dE \sim E^{-2}$

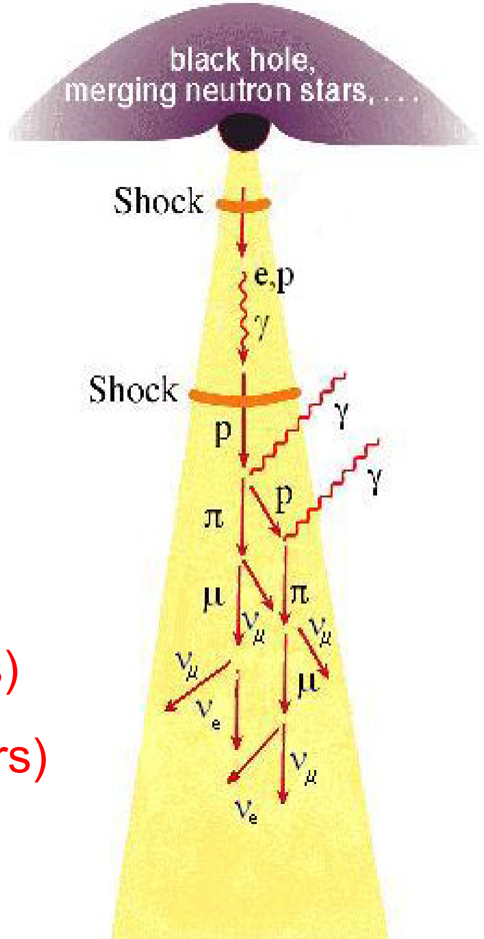
Neutrino production

- Proton interactions

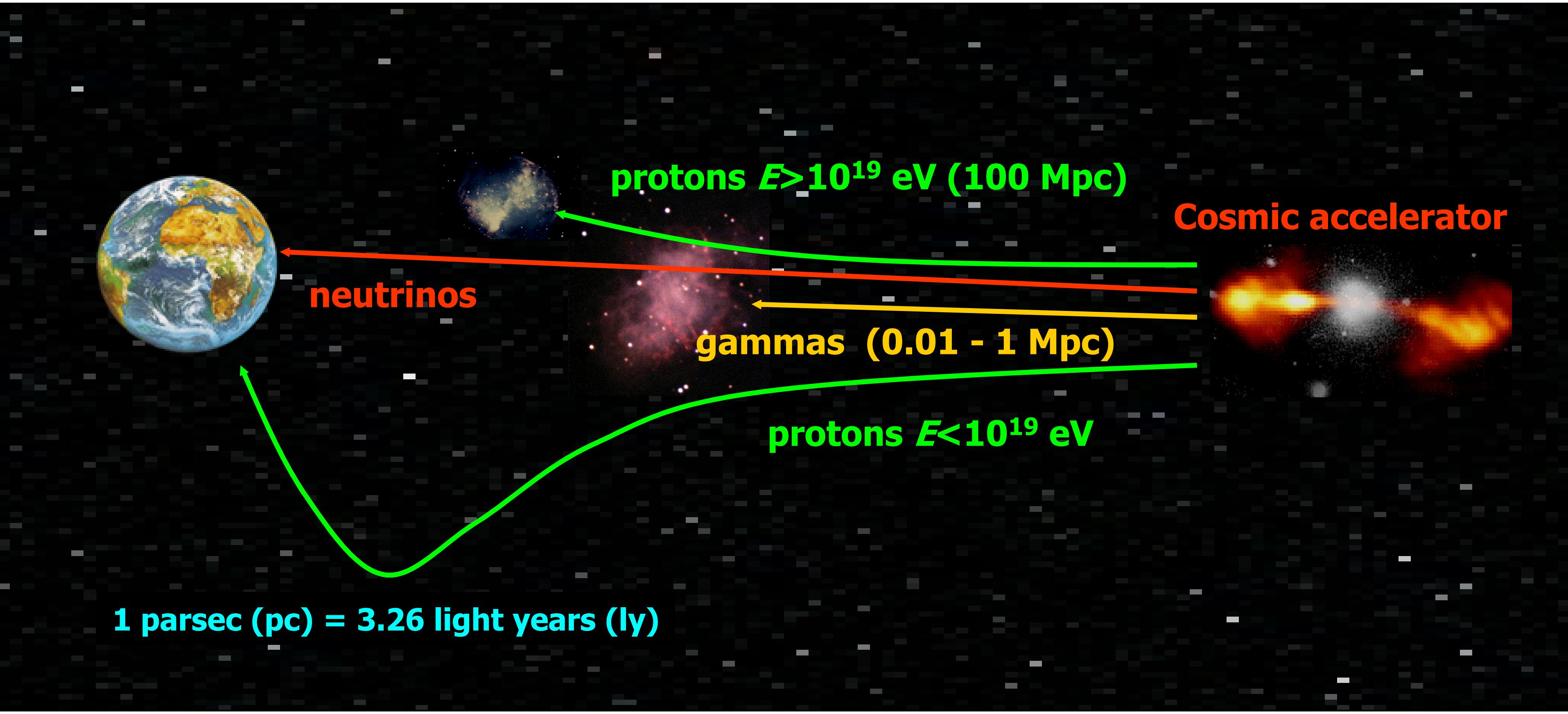
  p → *p* (SNR,X-Ray Binaries)

  p → γ (AGN, GRB, μQuasars)

- π/μ decays

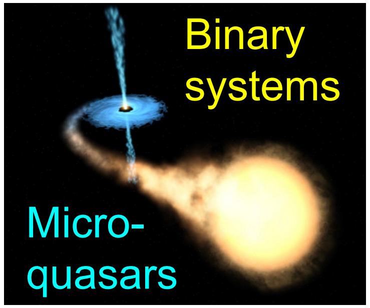


Cosmic probes



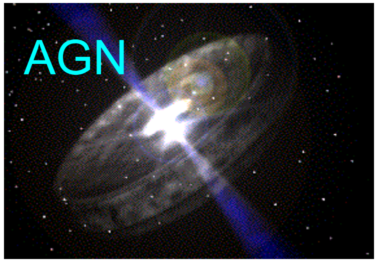
Photons: absorbed on dust and radiation;
Protons/nuclei: deviated by magnetic fields, reactions with radiation (CMB)

Potential Galactic sources



- The accelerators of cosmic rays
  - Supernova remnants
  - Pulsar wind nebulae
  - Micro-quasars
  - …
- Interaction of cosmic rays with interstellar matter
  - Possibly strong ν signal if CR spectrum harder in Galactic Centre than on Earth (supported by recent MILAGRO results)
- Unknown sources – what are the H.E.S.S. ”TeV gamma only” objects?

Potential extragalactic sources



- AGNs
  - Models are rather diverse and uncertain
  - The recent Auger results may provide an upper limit / a normalisation point at UHE

- Gamma ray bursts
  - Unique signature: coincidence with gamma observation in time and direction
  - Source stacking possible

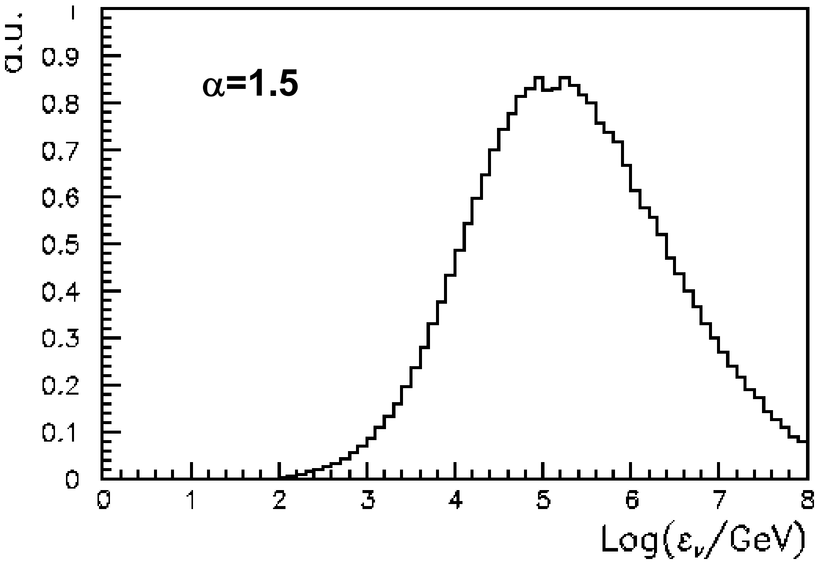
Additional goals:

- search for Dark matter (wimps)
- exotic (magnetic monopoles, nuclearites)

…

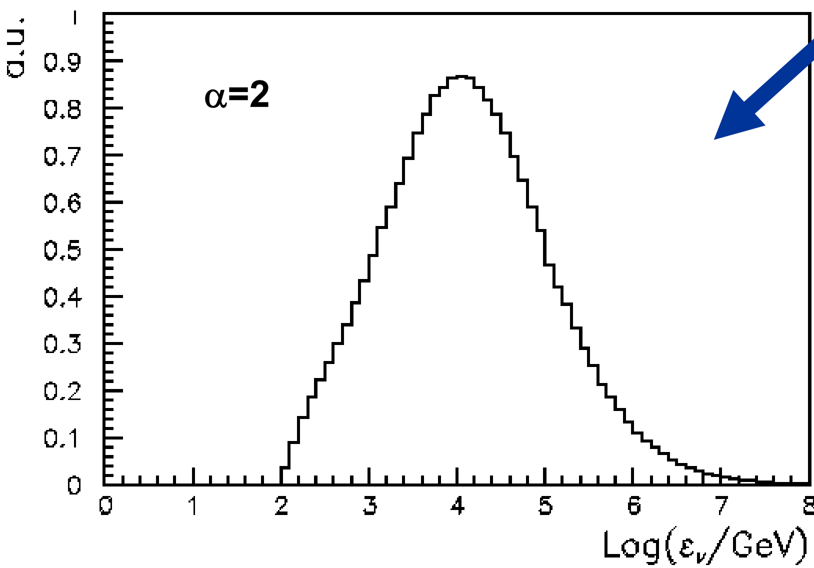
and be prepared to the unknown (or unexpected)!

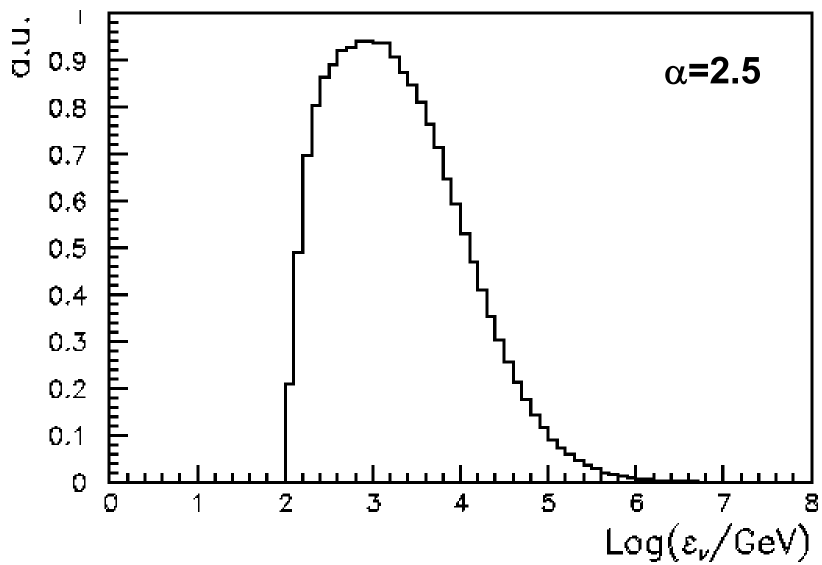
Neutrino energy range



Energy spectrum of detectable neutrinos

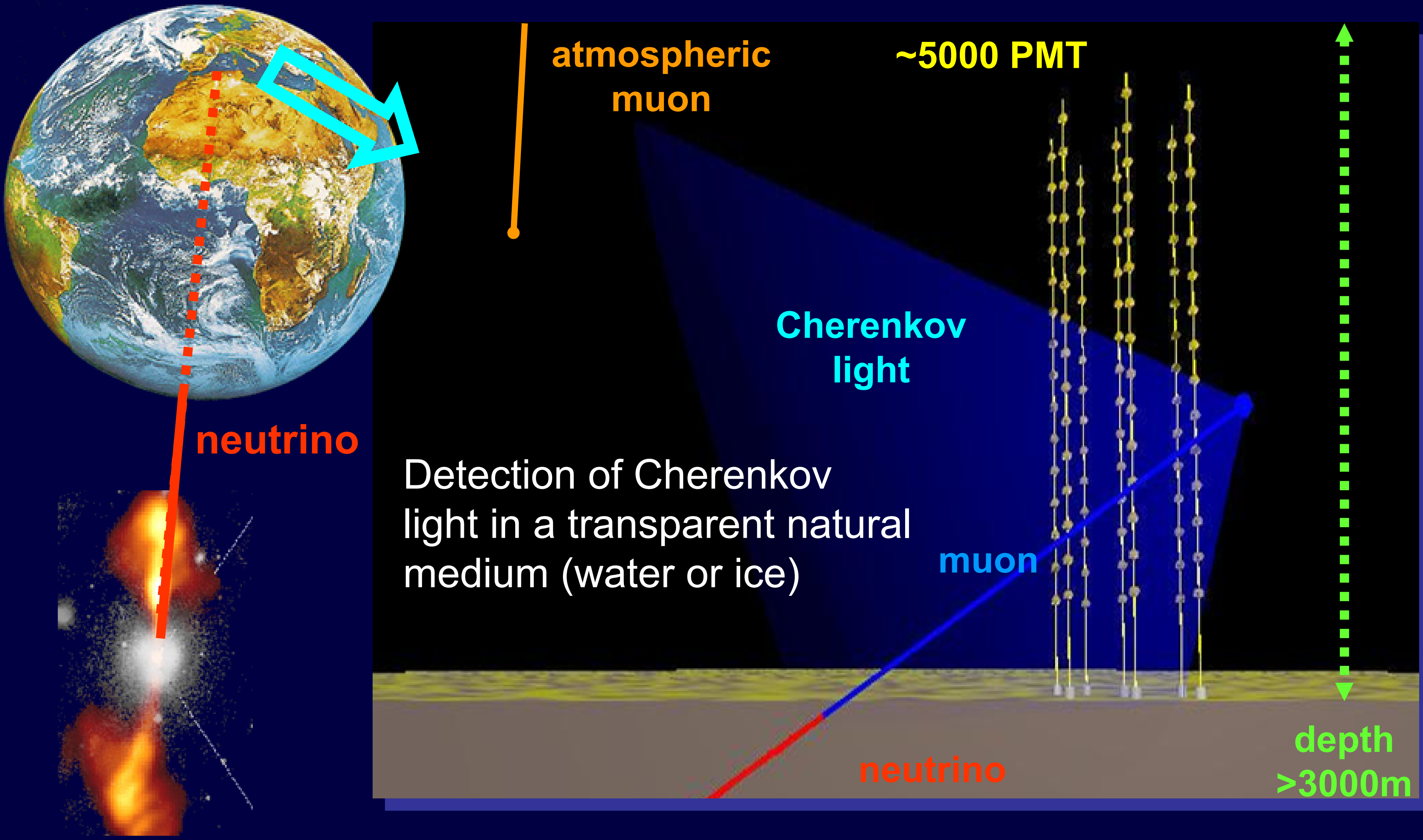
Energy range of (most) interest: 1-100 TeV





Contents

High energy neutrino detection principle

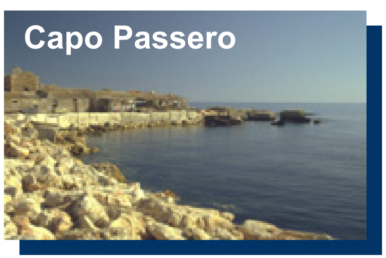


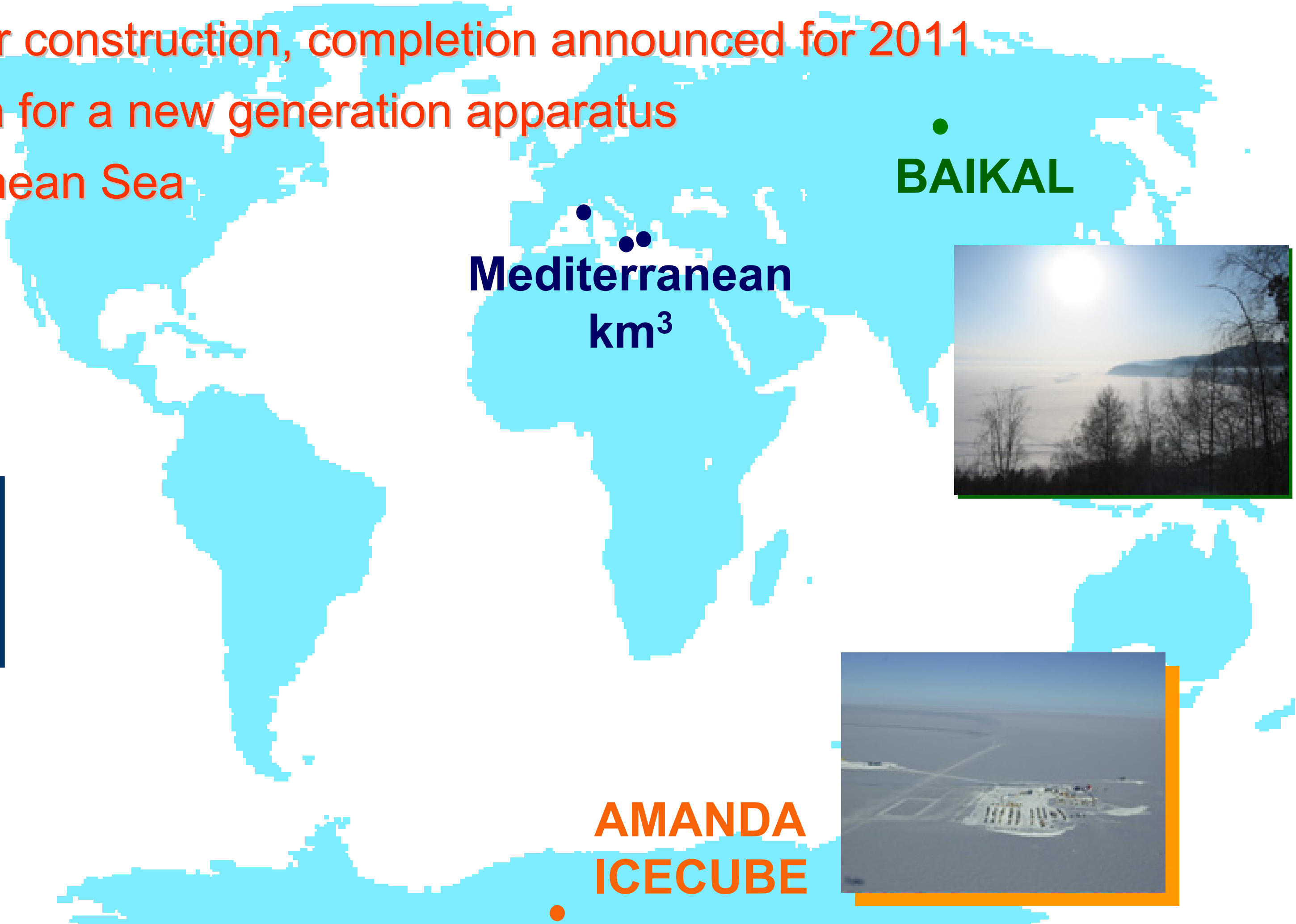
BAIKAL, AMANDA, ANTARES: data taking

NEMO, NESTOR: R&D

ICECUBE: under construction, completion announced for 2011

KM3NeT: design for a new generation apparatus in the Mediterranean Sea





Baikal Neutrino Project

Milestones:

>1983: site / water studies;

R&D: large area PMT, u-water techn.;

physics small setups (exotics search)

First generation Neutrino Telescope in Lake Baikal – NT200

1991: Proposal for NT200 detector in Lake Baikal submitted

1993: NT36 – the first underwater array operates

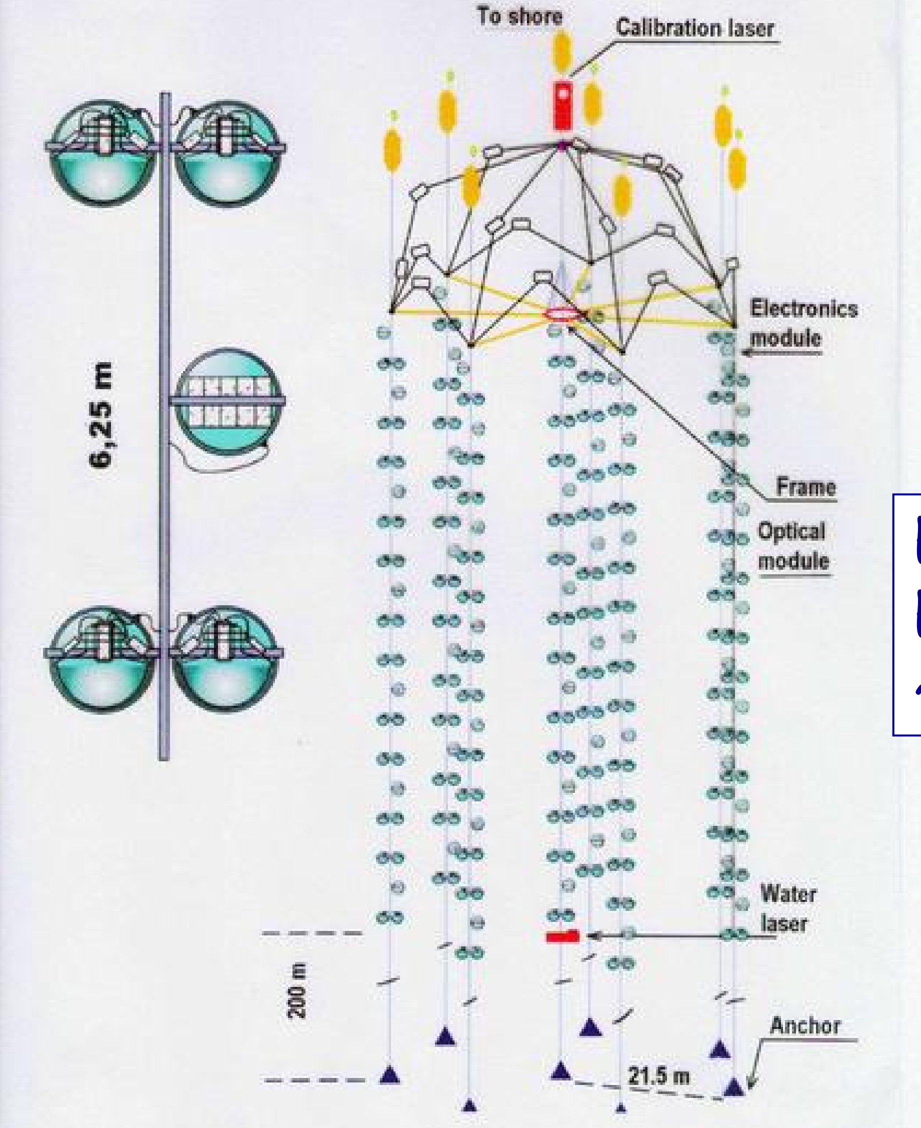
1998: NT200 commissioned

Second generation Neutrino Telescope – Gigaton Volume Detector (km3)

2005 - 2006: NT200+ completed and currently is operating

>2006: Activity towards Gigaton Volume Detector in Lake Baikal

NEUTRINO TELESCOPE NT-200



- 8 strings: 72m height
- 192 optical modules
  = 96 pairs (coincidence)
- measure T, Charge
  - σ_T ~ 1 ns
  - dyn. range ~ 1000 p.e.

Effective area: 1 TeV ~2000 m^2
Eff. shower volume: 10TeV ~0.2Mt

Height × ∅ = 70m × 40m, $V_{inst}=10^5 m^3$

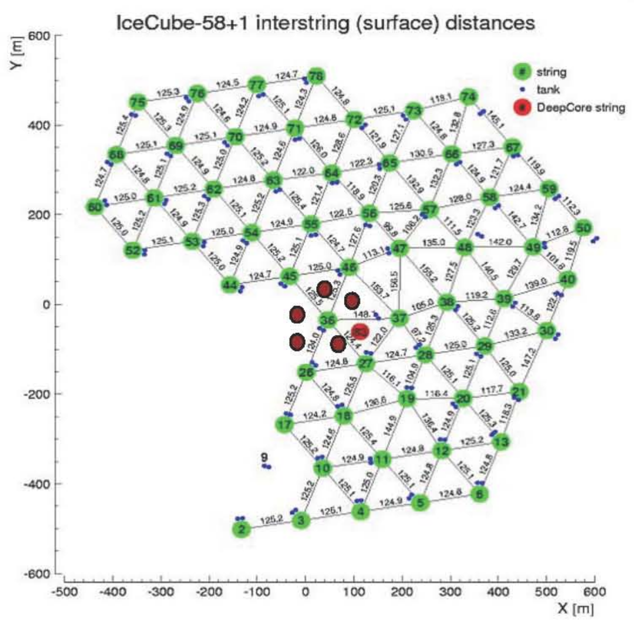
Quasar PM: d=37cm

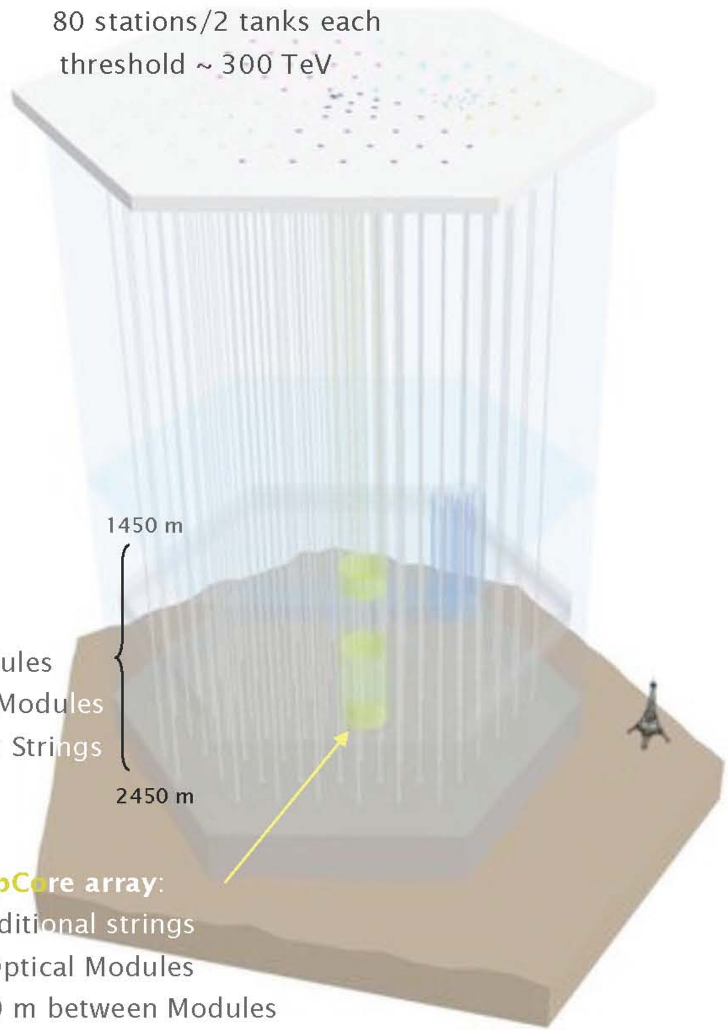
IceCube status

19 strings/stations installed during the 2008-2009 austral summer

Total of 59 strings and 118 IceTop tanks
→ over two thirds complete!

Integrated exposure reaching 1 km^3.year





Contents

Why the deep sea?

- Large volume (~km^3)
- Large depth (>2000 m)
- Good optical properties of the water (L_{abs} ~ 60 m)

  ➡ km^3 apparatus with 0.1° pointing resolution

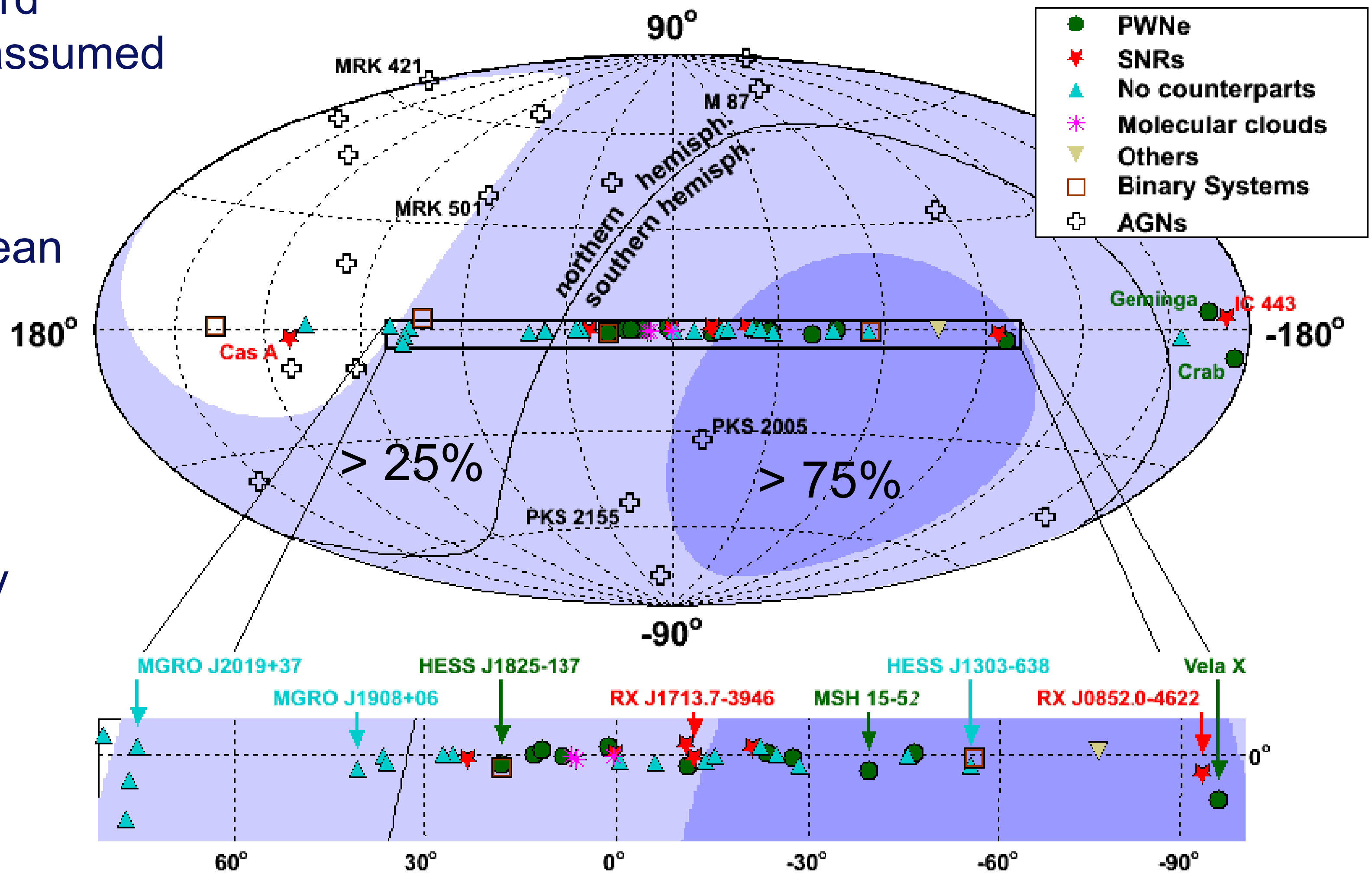
Hence, we have clear advantages, but also a long list of problems:

- Long distance (up to ~ 100 km) from shore
- High pressure
- Salted water may induce corrotion
- Detector installation may be very complicated
- Optical background due to ^{40}K and bioluminescence
- Mechanical structures may move due to sea currents => positioning system needed

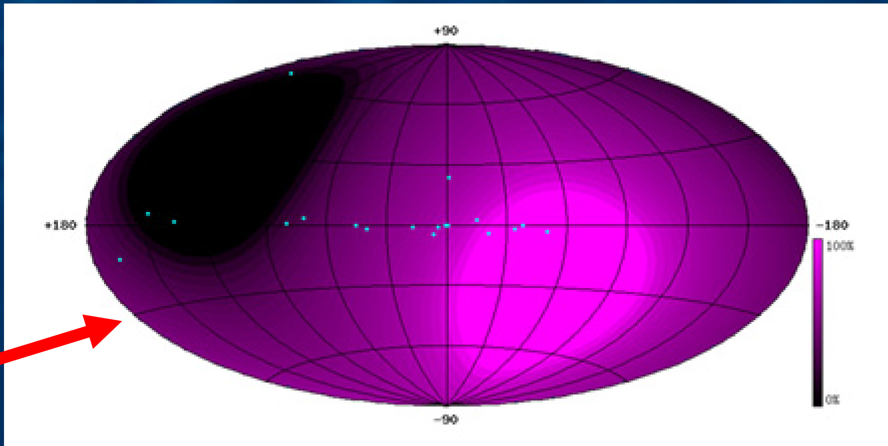
Mediterranean KM3 sky view

2π downward sensitivity assumed

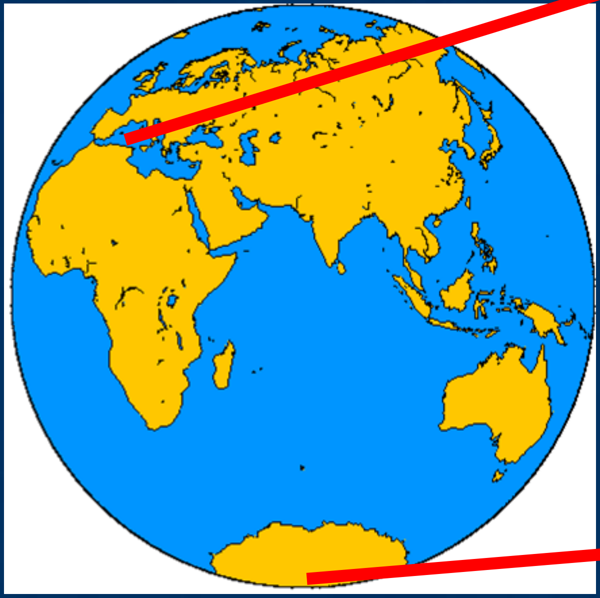
Located in Mediterranean → visibility of given source can be limited to less than 24h per day

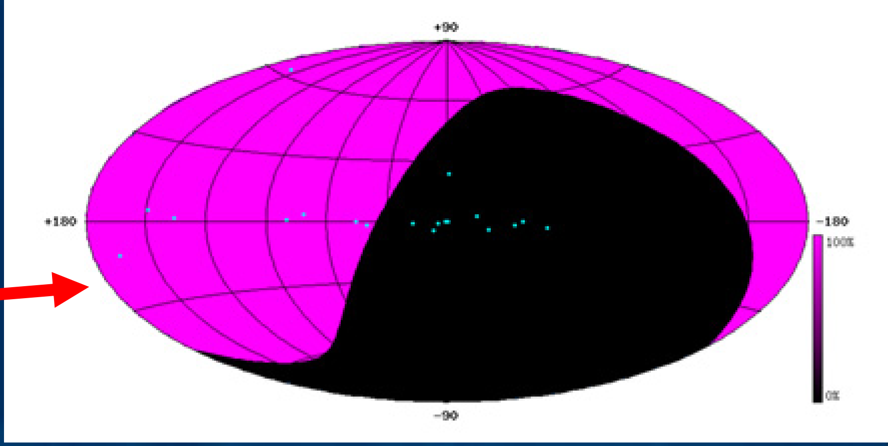


Field of view of ν-telescopes



Mediterranean Sea, 43° North





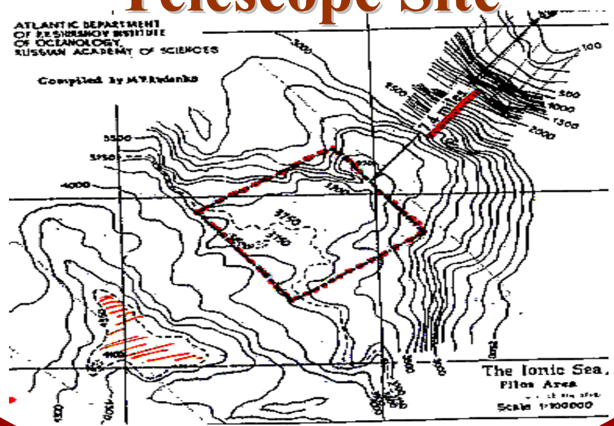
AMANDA/IceCube, South Pole

0.5 π sr instantaneous common view
1.5 π sr common view per day

From Mediterranean: Galactic Center visible for ~75% of the time

Contents

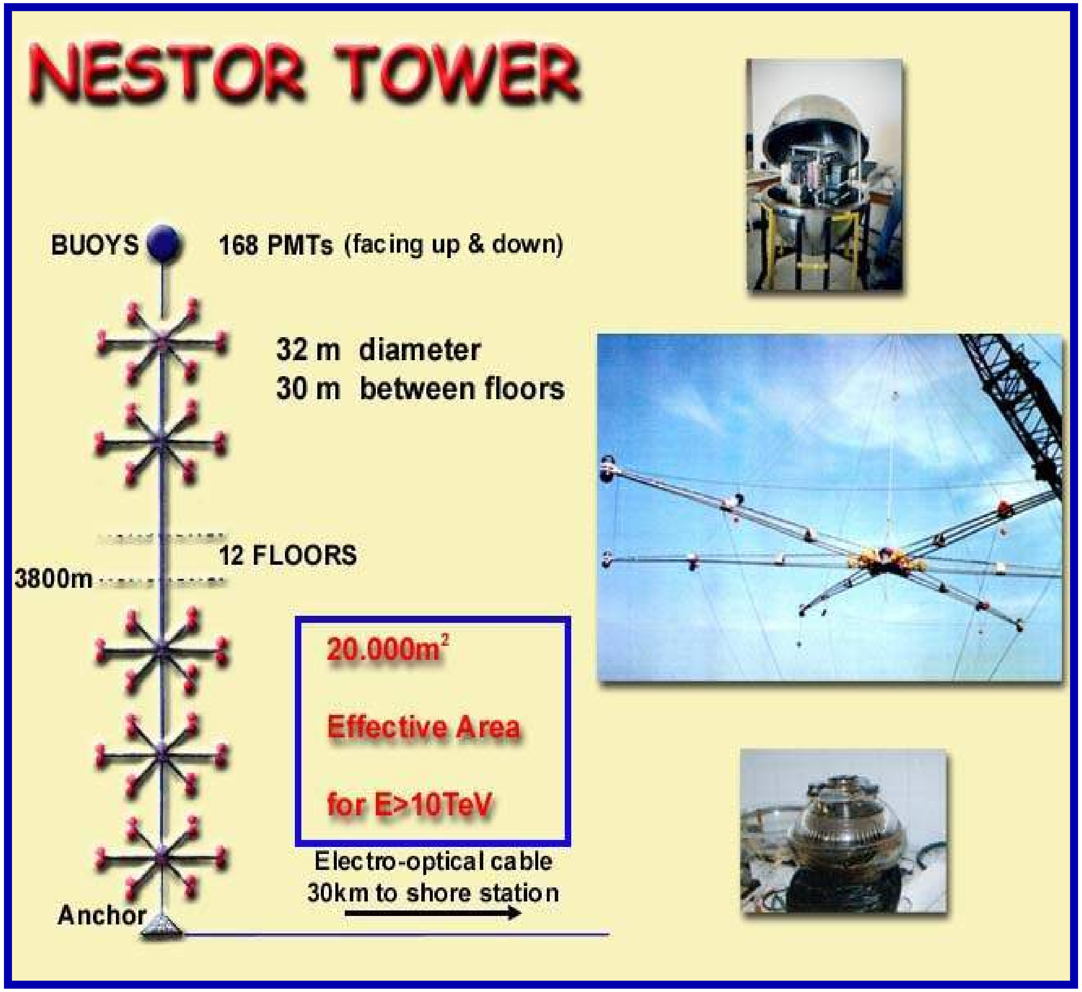
The NESTOR Neutrino Telescope Site



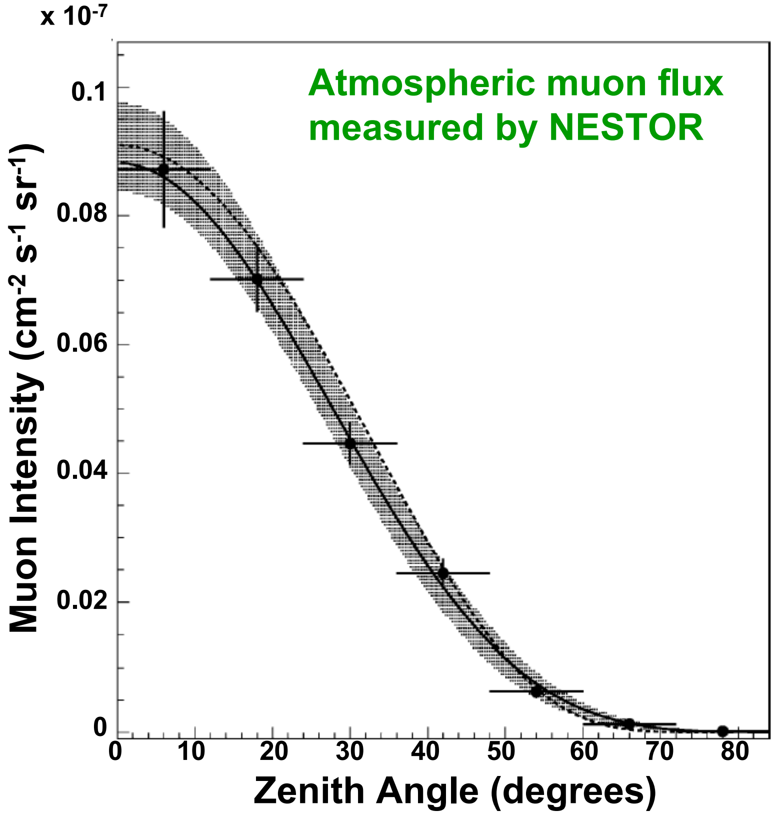
Site characteristics

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

NESTOR

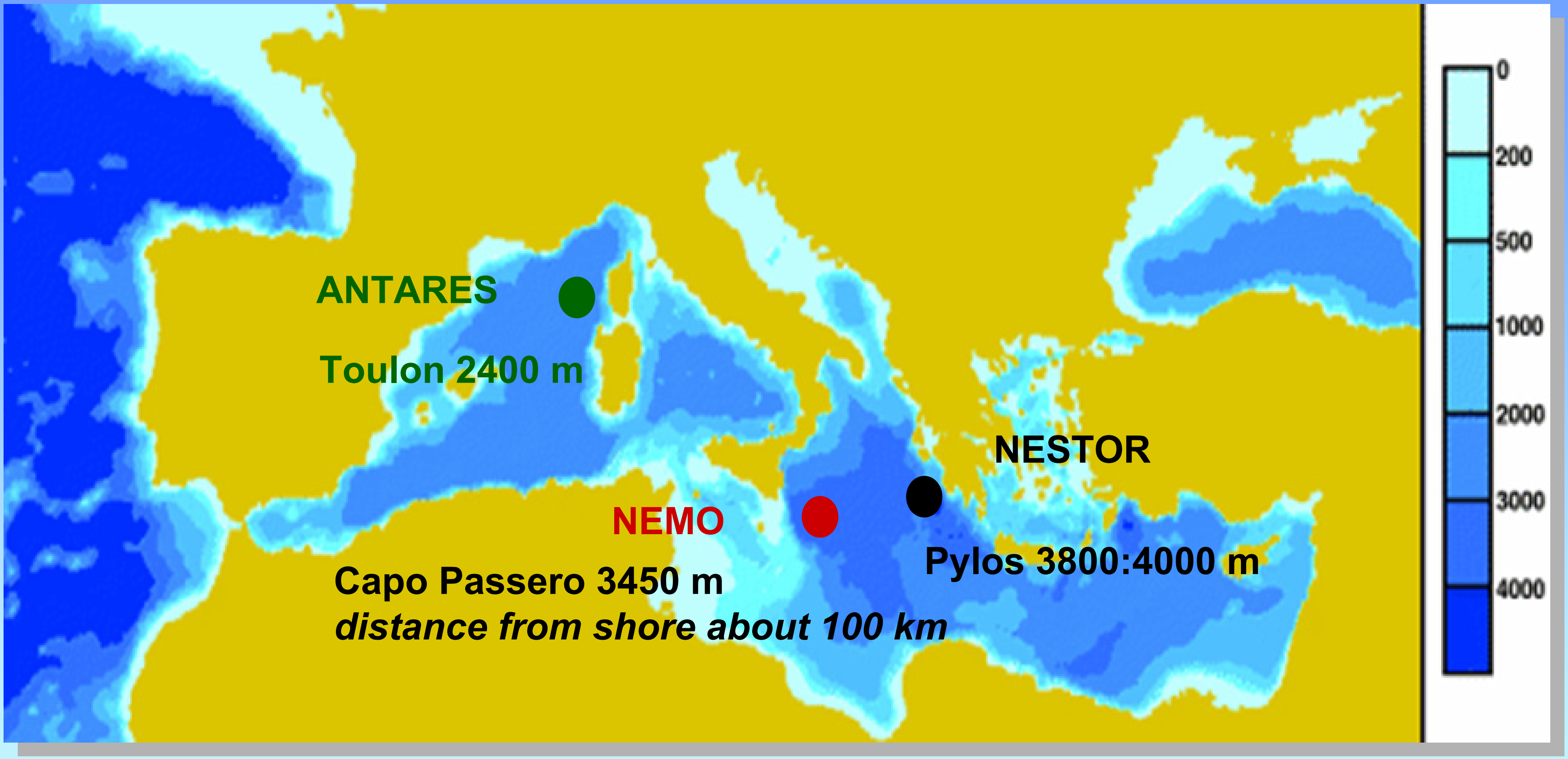


1 floor of 12 m diameter equipped with 12 PMTs deployed at 3800 m depth in March 2003



745 atmospheric muon events reconstructed

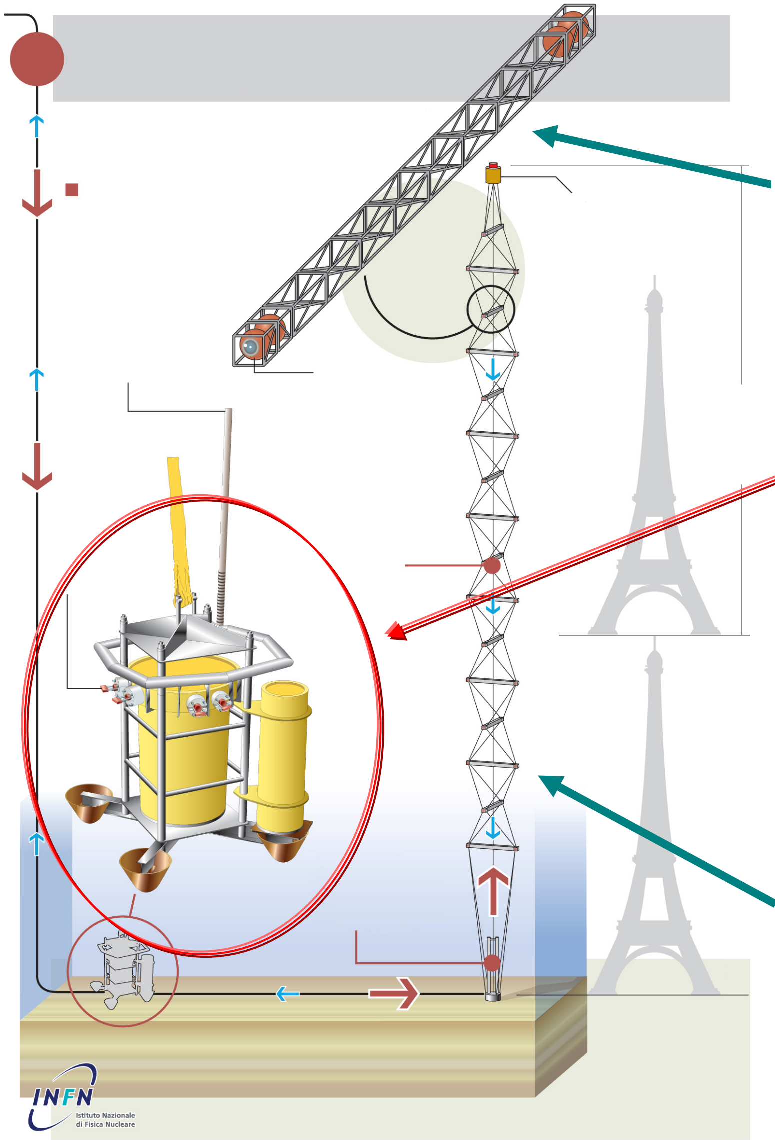
NEMO



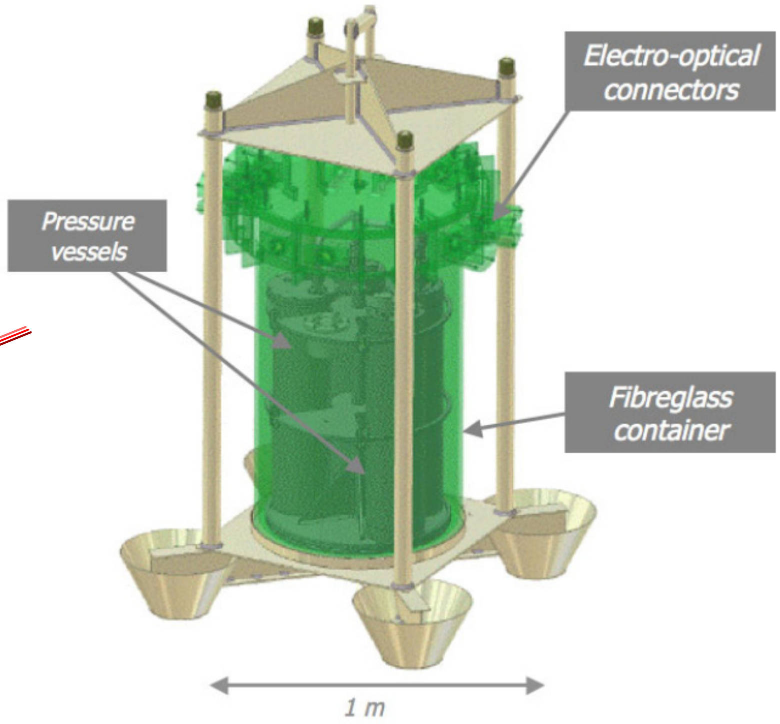
NEMO

- **Phase-1** → **Test of prototypes in deep sea**
  Near Catania at 2000 m depth
- **Phase-2** → **Construction of an infrastructure for km^3**
  Off Capo Passero at about 3500 m depth

km3 architecture: the NEMO proposal



A closer look at the junction box



Apparatus based on 'towers':
- **up to 18 floors on each tower**
- **4-6 optical modules on each floor**
- **40 m distance between consecutive floors**
- **first floor is at 100 m above sea bottom**

NEMO Phase-1

Shore laboratory, Port of Catania

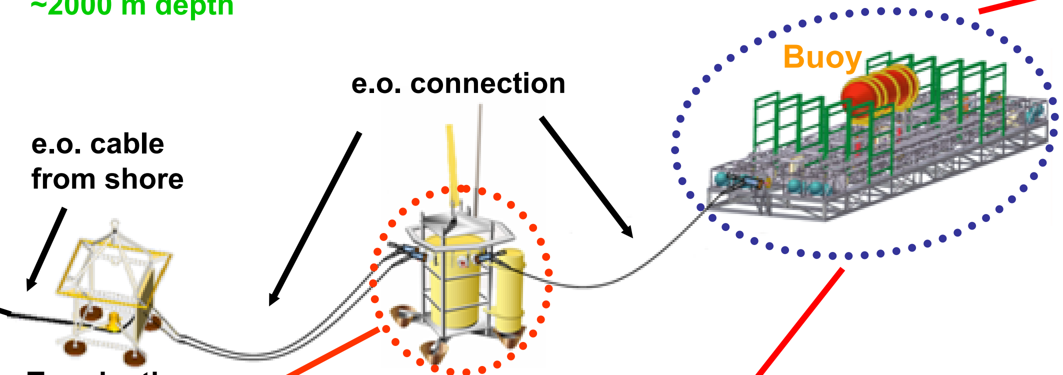
25 km East offshore Catania
~2000 m depth

e.o. cable
10 optical fibres, 6 conductors

e.o. cable from shore

e.o. connection

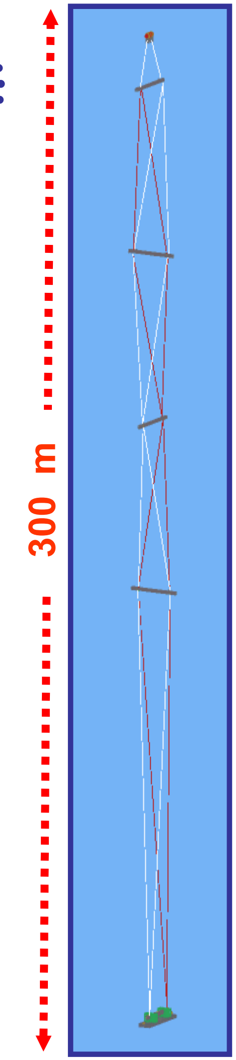
NEMO mini-tower (4 floors, 16 OM)



Termination Frame

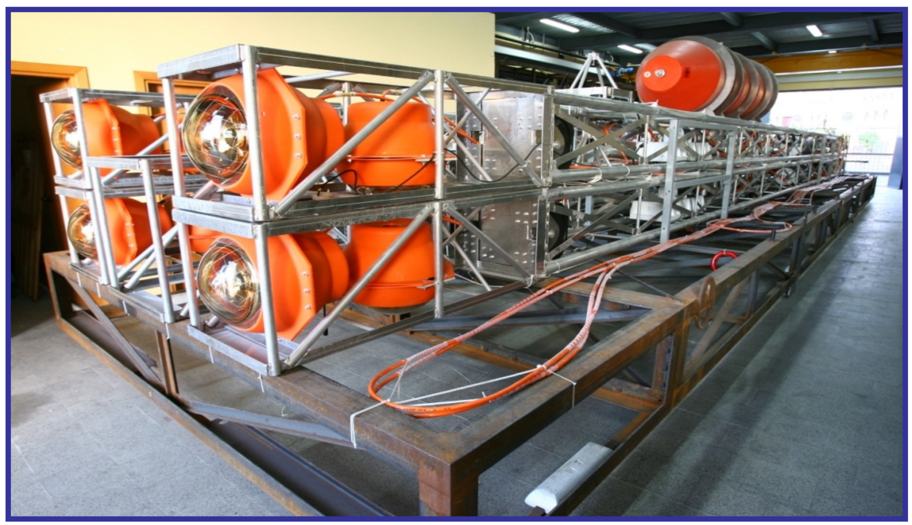
Junction Box

Mini-Tower unfurled



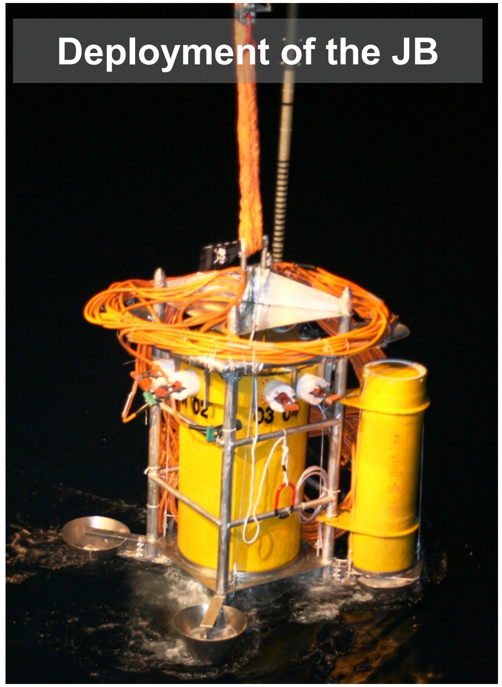
Junction Box

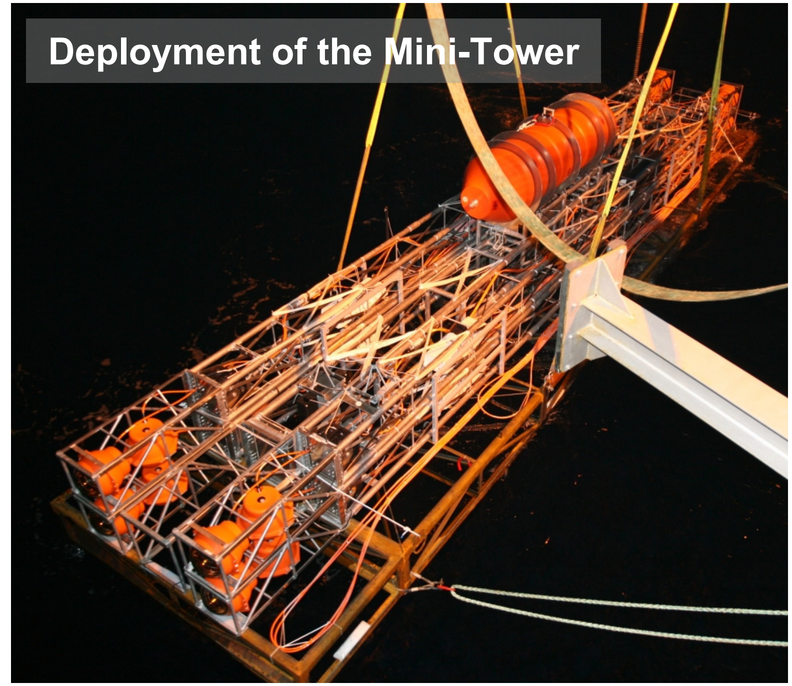
Mini-Tower compacted

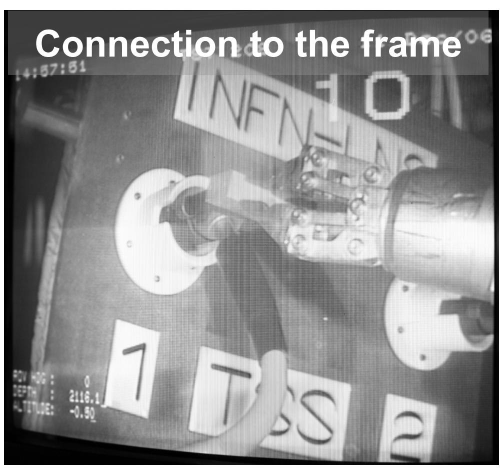


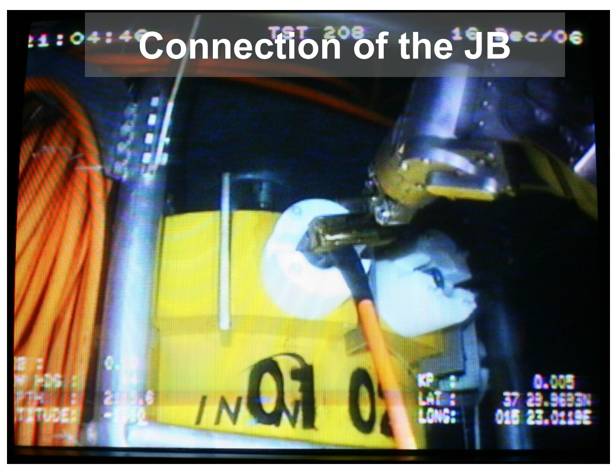
NEMO Phase-1: deployment and connection

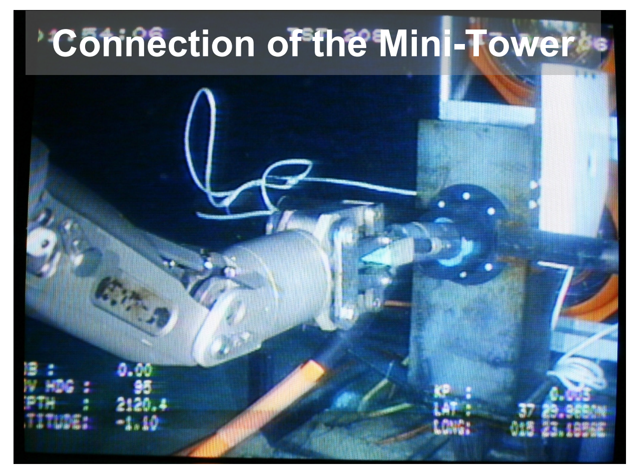
December 2006


Deployment of the JB


Deployment of the Mini-Tower


Connection to the frame


Connection of the JB


Connection of the Mini-Tower

NEMO Phase-2

STATUS

- 100 km electro-optical cable (>50 kW, 20 optical fibres) deployed in July 2007
- Installation of Alcatel DC power supply system with DC/DC converter scheduled in October 2009
- On-shore laboratory (1000 m^2) inside the harbour area of Portopalo under completion

NEMO Phase-2 Tower

- Electro-optical cable laid in july 2007
- Construction of a fully equipped 16 storey tower under way

The tower design has been revised taking into account the experience of Phase-1

- A mechanical model of the mini-tower is ready for deployment

Main modifications/upgrades of the new tower

- New power system to comply with the feeding system provided by Alcatel
- Optimization of the electronics and data transmission
- New segmented electro-optical cable backbone
- Integration of a new acoustic station in the tower

The ANTARES Collaboration

- NIKHEF,
- Amsterdam
- Utrecht
- KVI Groningen
- NIOZ Texel

- University of Erlangen
  Bamberg Observatory

- ITEP,Moscow
- Moscow State Univ

- ISS, Bucarest

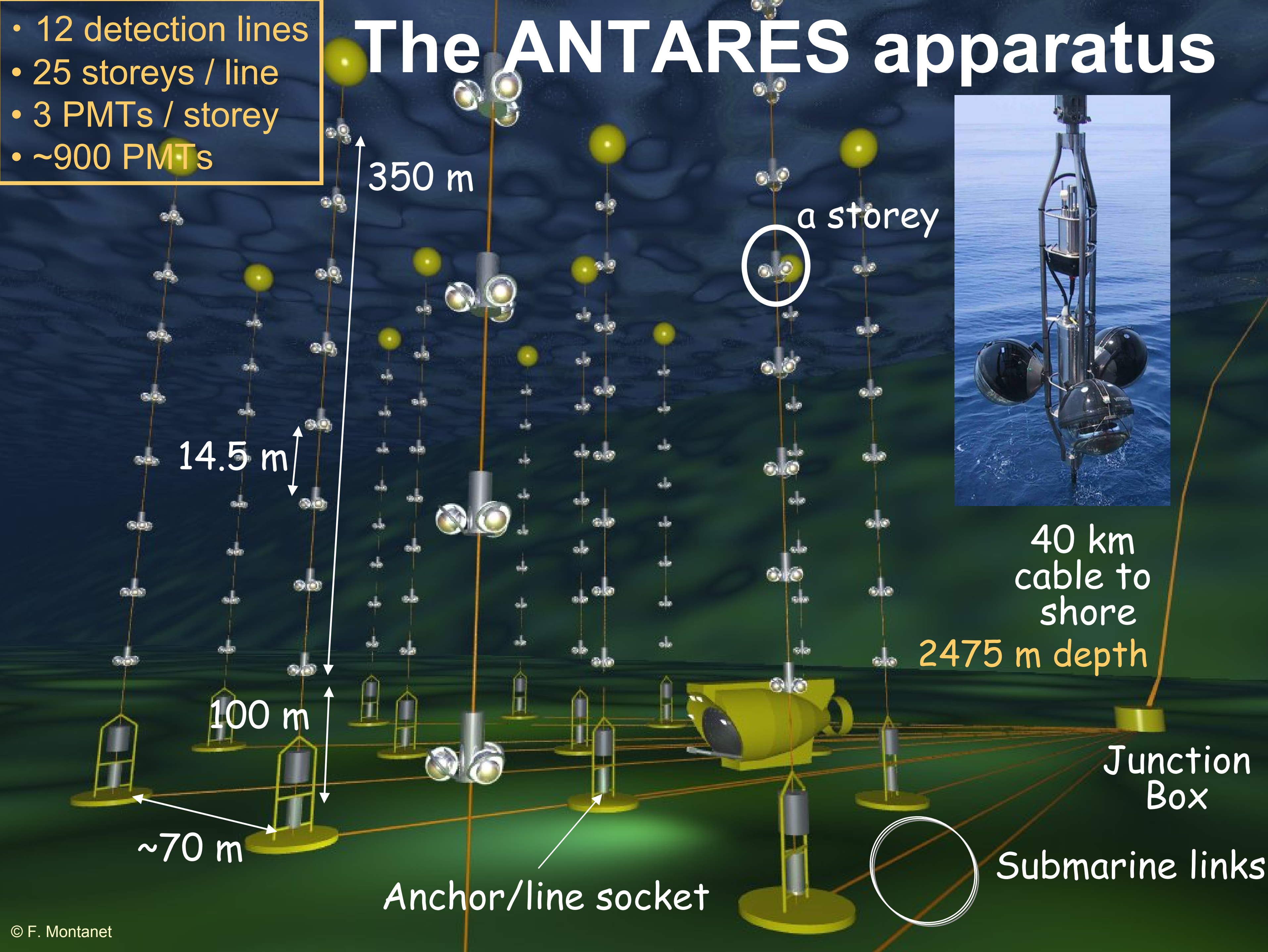
- IFIC, Valencia
- UPV, Valencia
- UPC, Barcelona

- CPPM, Marseille
- DSM/IRFU/CEA, Saclay
- APC, Paris
- LPC, Clermont-Ferrand
- IPHC (IReS), Strasbourg
- Univ. de H.-A., Mulhouse
- IFREMER, Toulon/Brest
- C.O.M. Marseille
- LAM, Marseille
- GeoAzur Villefranche

- University/INFN of Bari
- University/INFN of Bologna
- University/INFN of Catania
- LNS – Catania
- University/INFN of Pisa
- University/INFN of Rome
- University/INFN of Genova

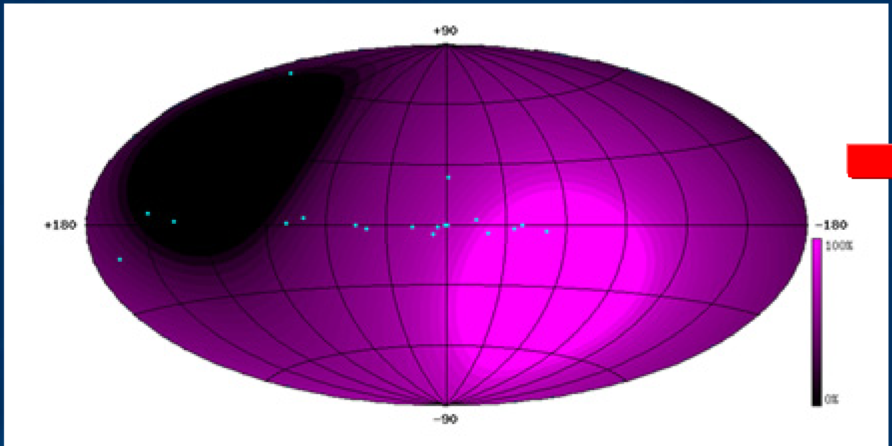
7 countries
29 institutes
~150 scientists+engineers

The ANTARES apparatus

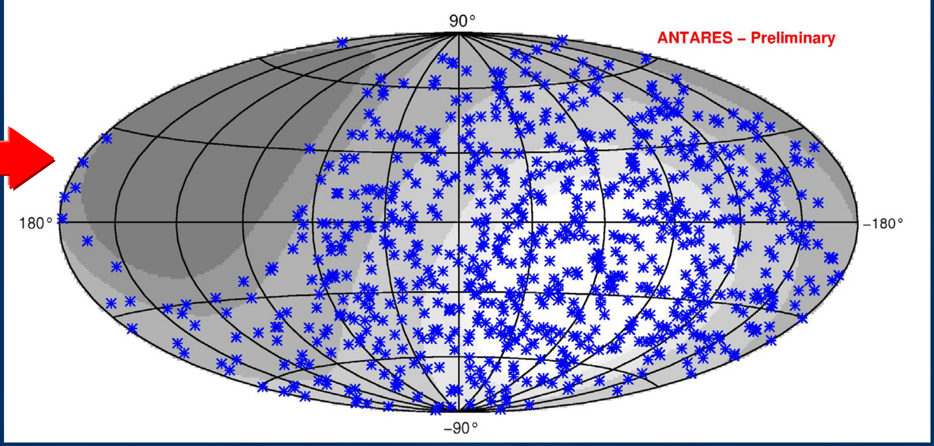


ANTARES status

- First line installed in Spring 2006
- Detector completed in May 2008
- (almost 10 years 1996-2006 for site survey, R&D, preparation)
- Routine maintenance ongoing
- Analyses ongoing, first results published



ANTARES field of view (calculated)



ANTARES ν sky-map (measured): 750 events from 2007-2008 runs, smeared angles (blinded data)

KM3NeT

KM3NeT will be a very large volume (> km^3) Neutrino Telescope, to be deployed in the Mediterranean Sea, after 2012.

The consortium includes 40 Institutes or University groups from 10 European countries.

The research is financed trough 2 European projects: "KM3NeT-DS" and "KM3NeT-PP".

There will be room for *Earth and Ocean Sciences*.

One of the Magnificent Seven of the *ASPERA* Roadmap

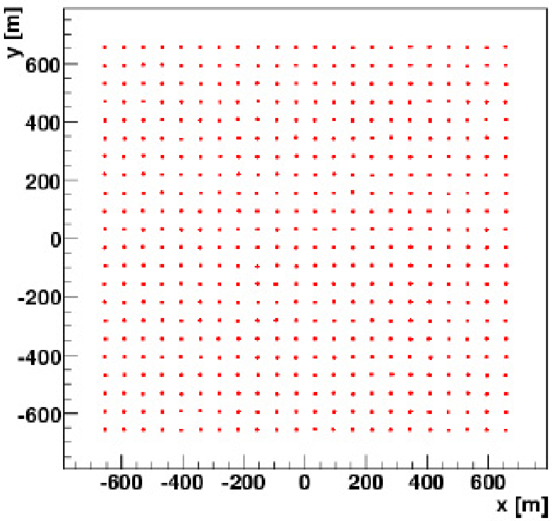
Official web page: *http://www.km3net.org*

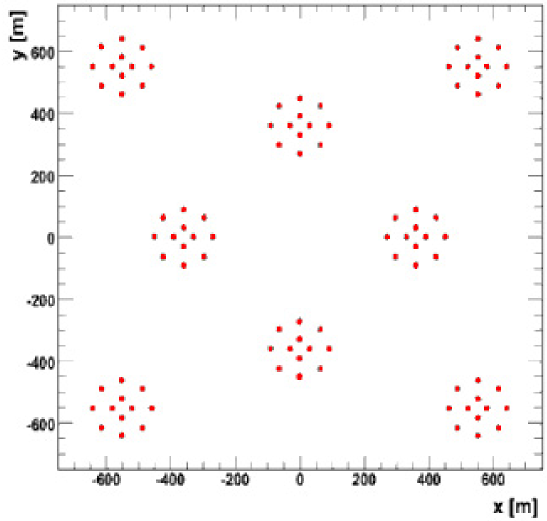
KM3NeT milestones and status

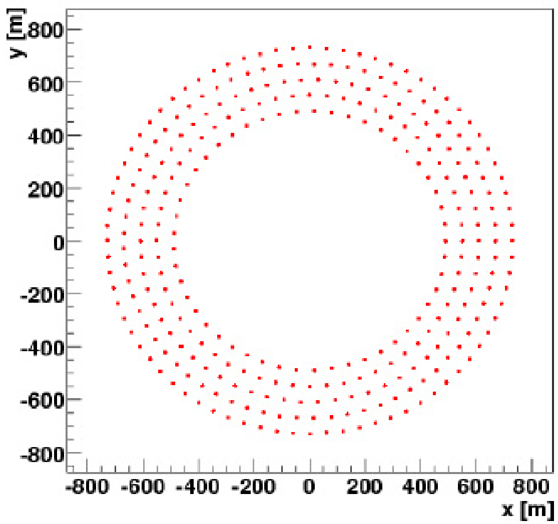
- Conceptual Design Report (CDR) delivered in Spring 2008 (available on http://www.km3net.org)
- Technical Design Report (TDR) under preparation
- A lot of activity ongoing on different subjects…

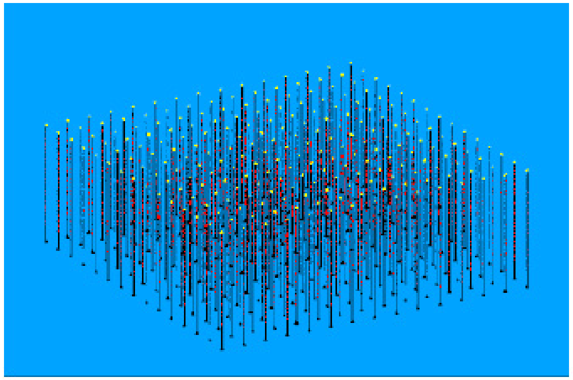
KM3NeT architecture

Several proposal scrutinized… (performance vs. cost)

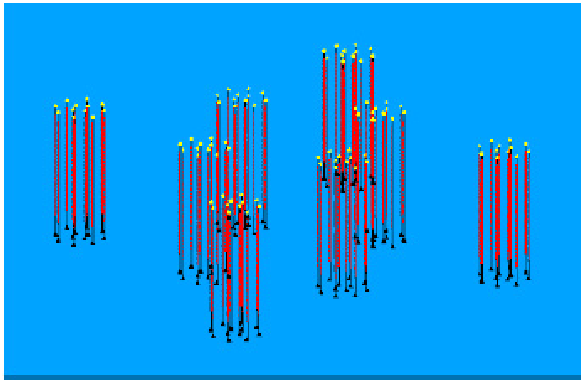




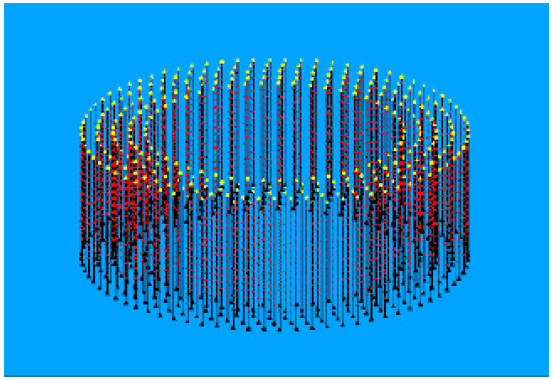




Homogeneous



Cluster

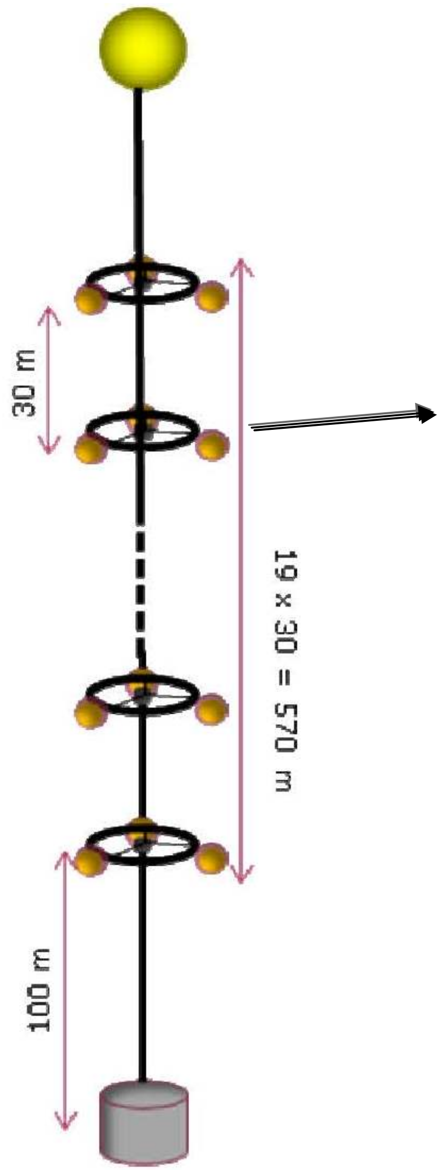


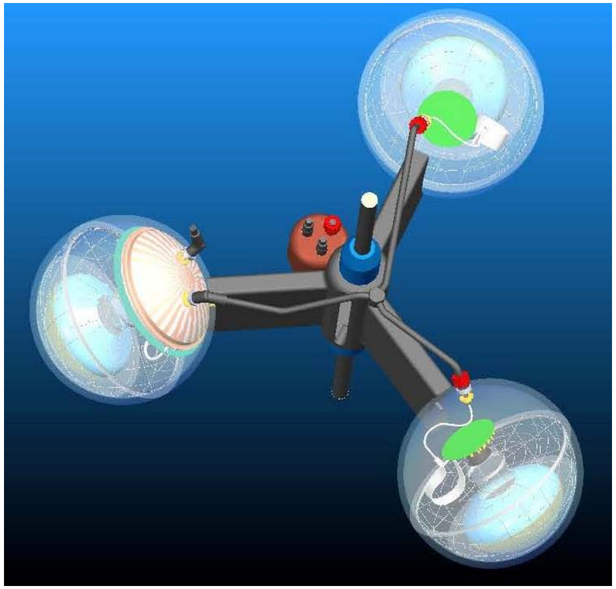
Ring

Remark: different configurations give different (but comparable) performance for different particle energies

KM3NeT structures I: lines…

Upgraded design based on the ANTARES experience

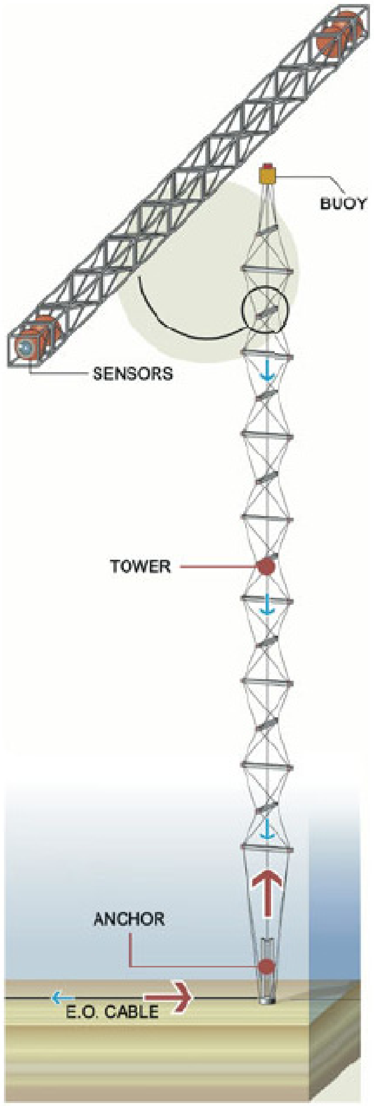




Triplet of optical modules

KM3NeT structures II: towers…

NEMO-inspired but with some improvements (bar length reduced, number of optical modules increased, etc.)

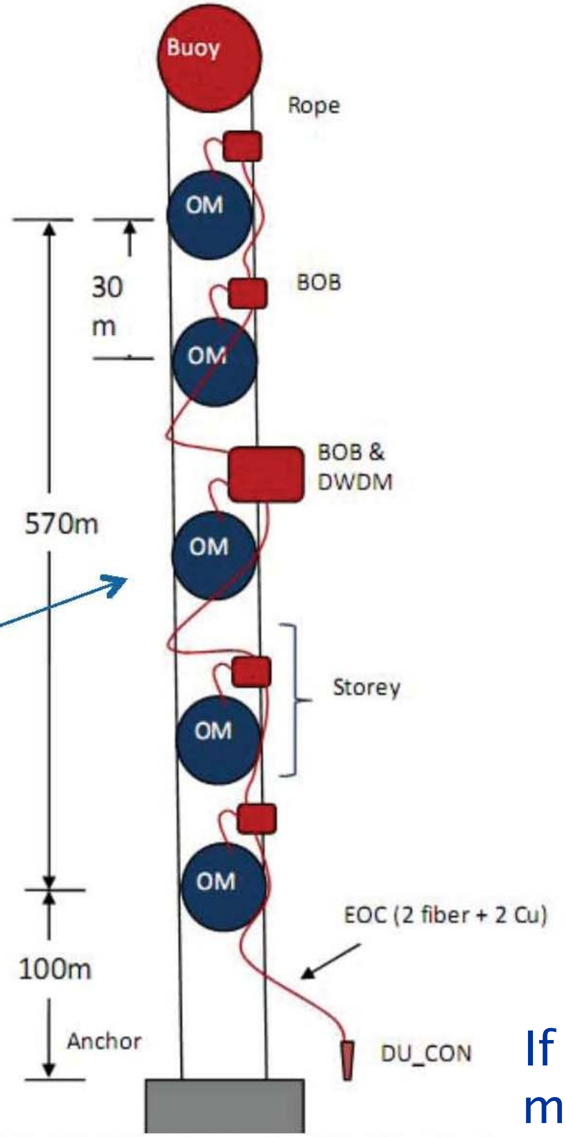


KM3NeT structures III: strings…

Brand-new concept

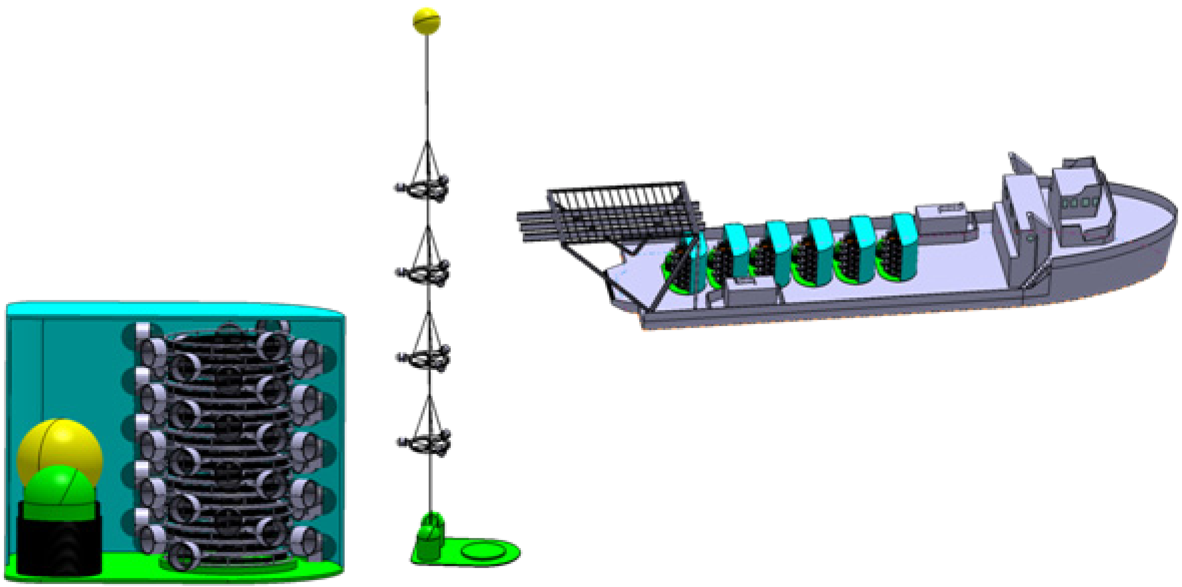
-Full readout to shore via fiber
-Optics

Self-sustained OMs

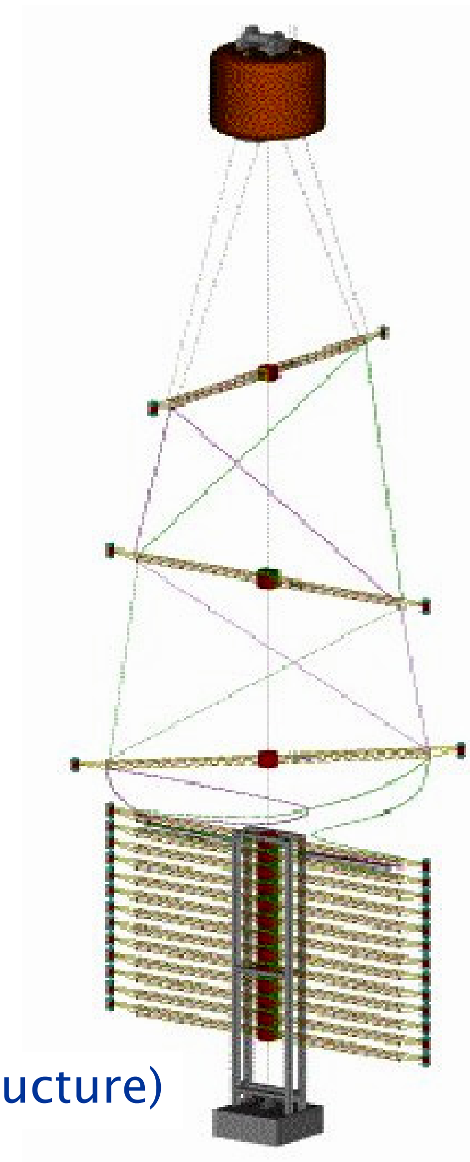


If the structures can be packed efficiently, many strings can be deployed in the same operation (under investigation)

Foldable structures for KM3NeT installation

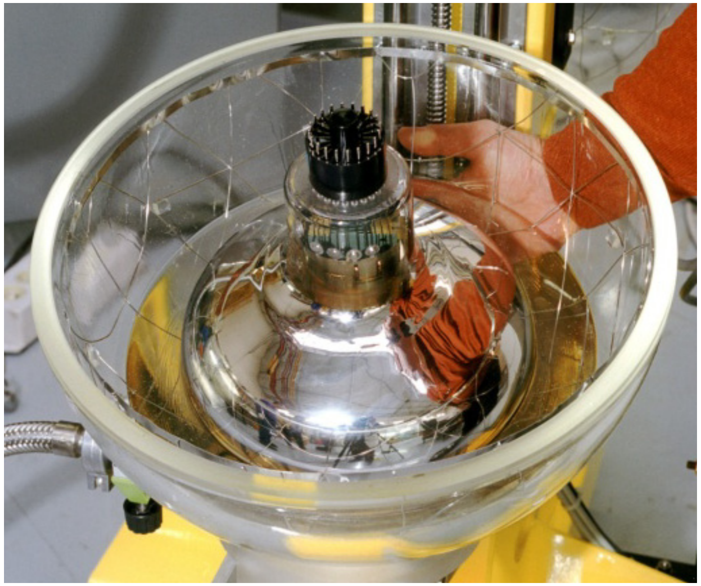


(Installation of a ‘line’ structure)



(Unfurling ‘tower’ structure)

KM3NeT detection units



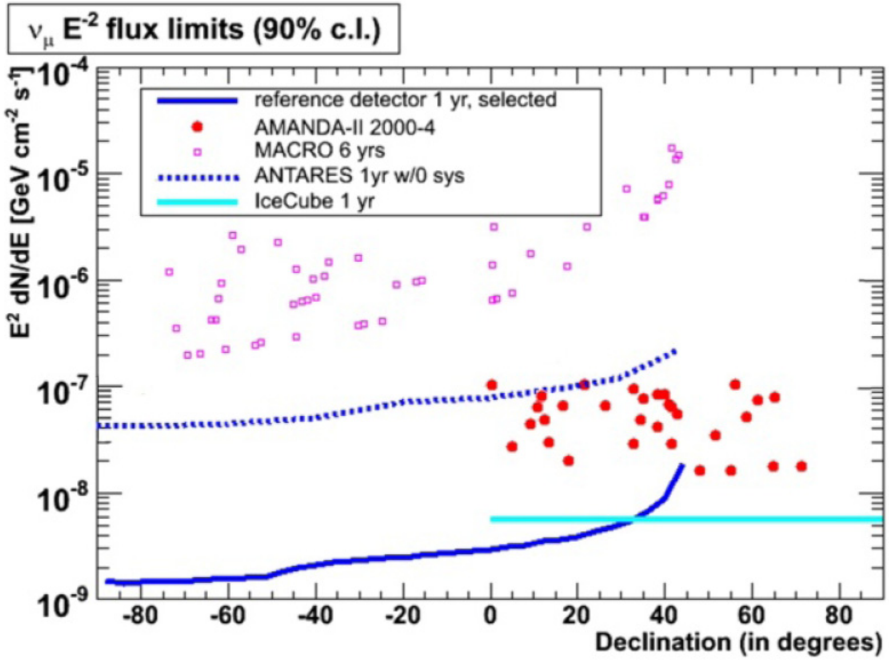
?

Traditional approach: single large-area (8”-10”) PMT inside a glass sphere

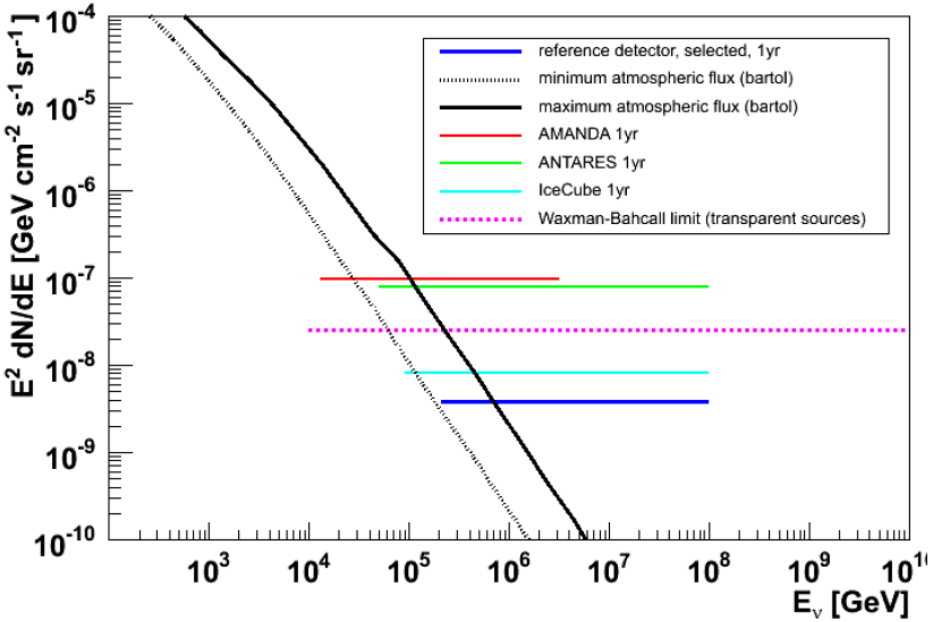
New concept: small-area PMTs densily packed in the glass spheres

+ further solutions also proposed (two large-area PMTs inside same glass sphere, multi-cathode PMTs, etc.)

KM3NeT (target) capabilities



Sensitivity to point-like sources



Sensitivity to diffuse ν-flux

Typical KM3NeT numbers:

- **up to 300 detection units**
- **600-800 m height**
- **~150 m distance between detection units**
- **several thousands (large-area) PMTs**

Conclusions

• With the positive experience of NESTOR and NEMO and the completion of ANTARES, a new phase has been opened for detection of cosmic neutrinos with telescopes under deep sea

• The KM3NeT consortium is working to define a second generation, km^3 apparatus to be installed in the Mediterranean Sea

• Multi-messenger observations (ANTARES-style) will be implemented

• Apparatus will also work as a long-term real-time platform for sea science and oceanographic observations

• Next workshop on Very Large Volume neutrino Telescopes (VLVnT09) is scheduled 13-15 October in Athens, Greece

(check http://www.nestor.noa.gr/vlvnt09)

...and...many thanks for your attention!