Neutrino Oscillation Workshop 2008 (NOW 2008)
Conca Specchiulla / Otranto, Italy, 6-13 Sept. 2008

Underwater Neutrino Telescopes

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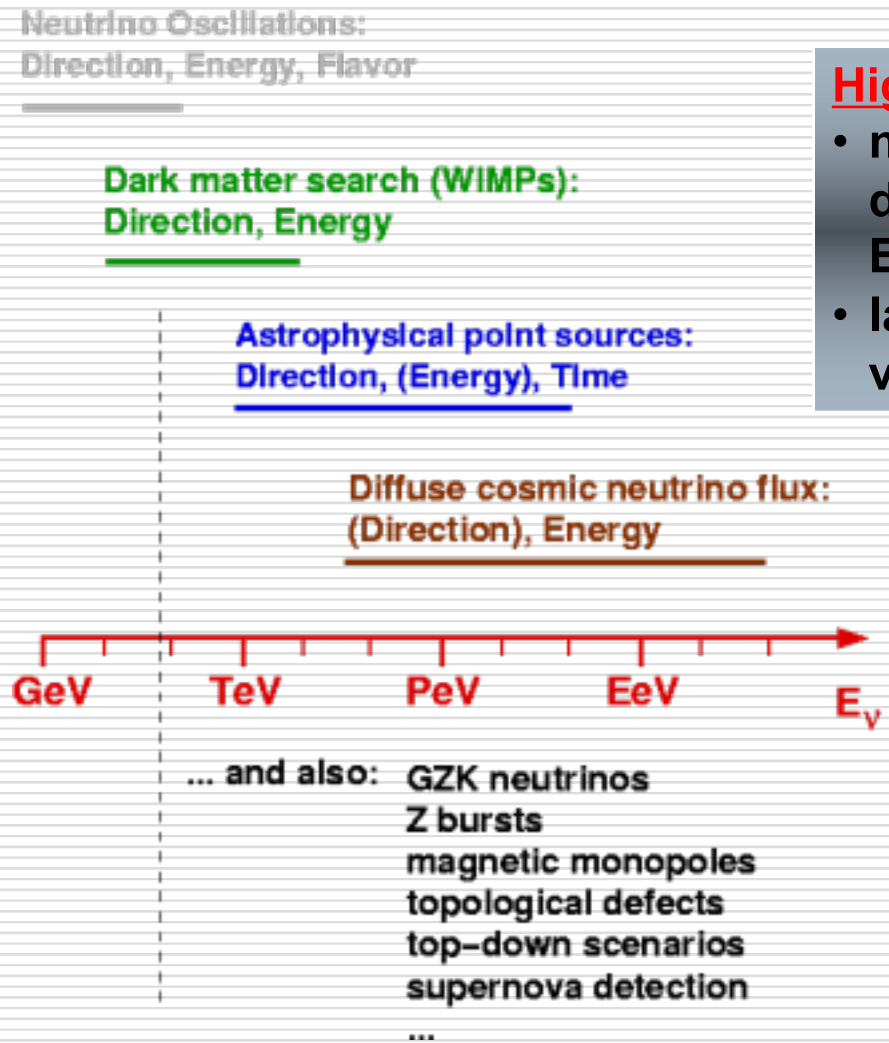
11.09.2008

- Introduction
- A few words on physics
- Current projects
- The future: KM3NeT

The Neutrino Telescope World Map

Astro- and Particle Physics with ν Telescopes

Low-energy limit:
- detector sensitivity
- background

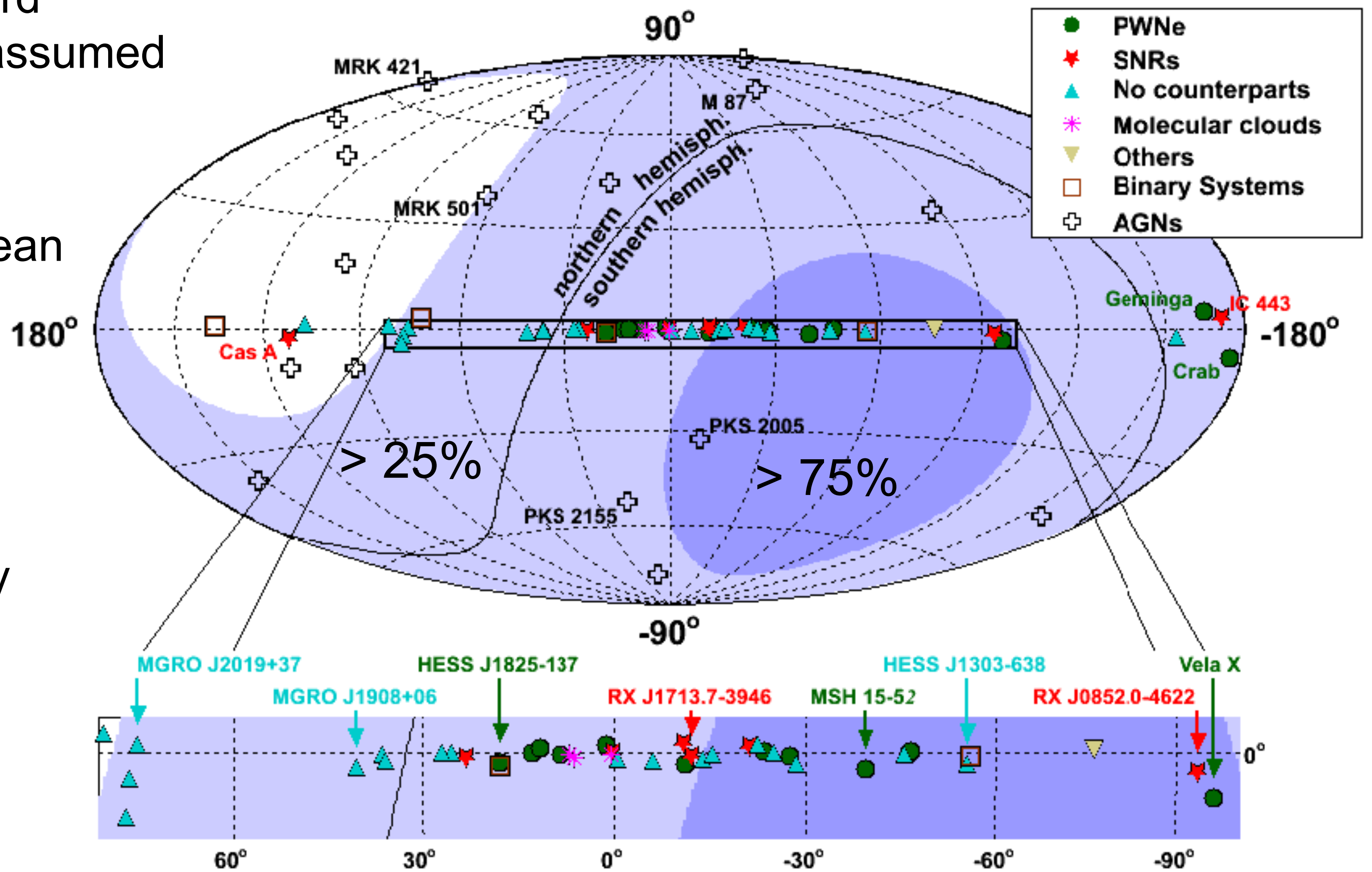


High-energy limit:
- neutrino flux decreases like E^{-n} ($n \approx 2$)
- large detection volume needed.

Fields of View: South Pole vs. Mediterranean

2π downward sensitivity assumed

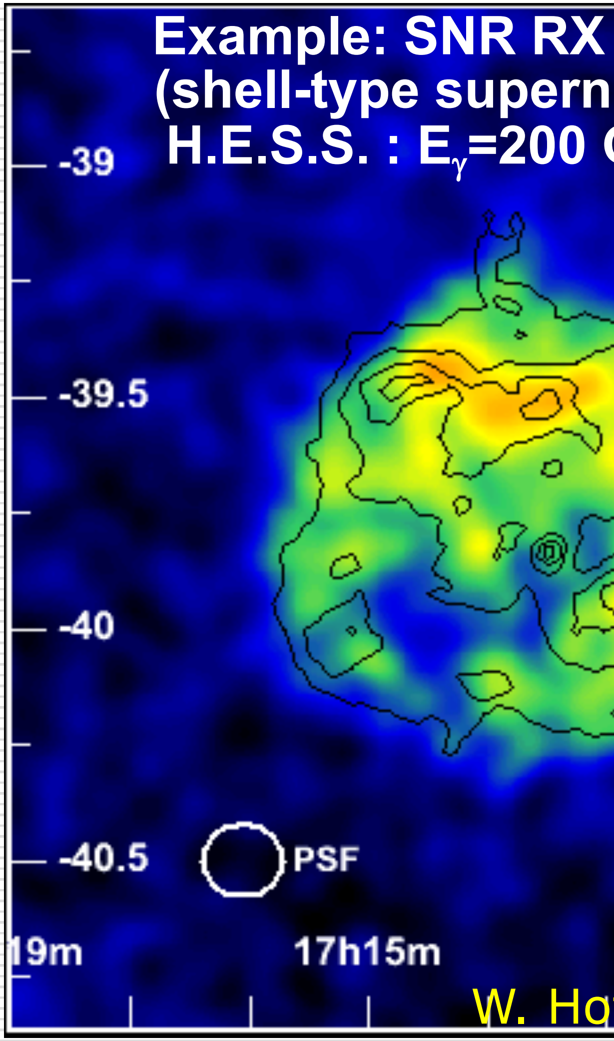
Located in Mediterranean → visibility of given source can be limited to less than 24h per day

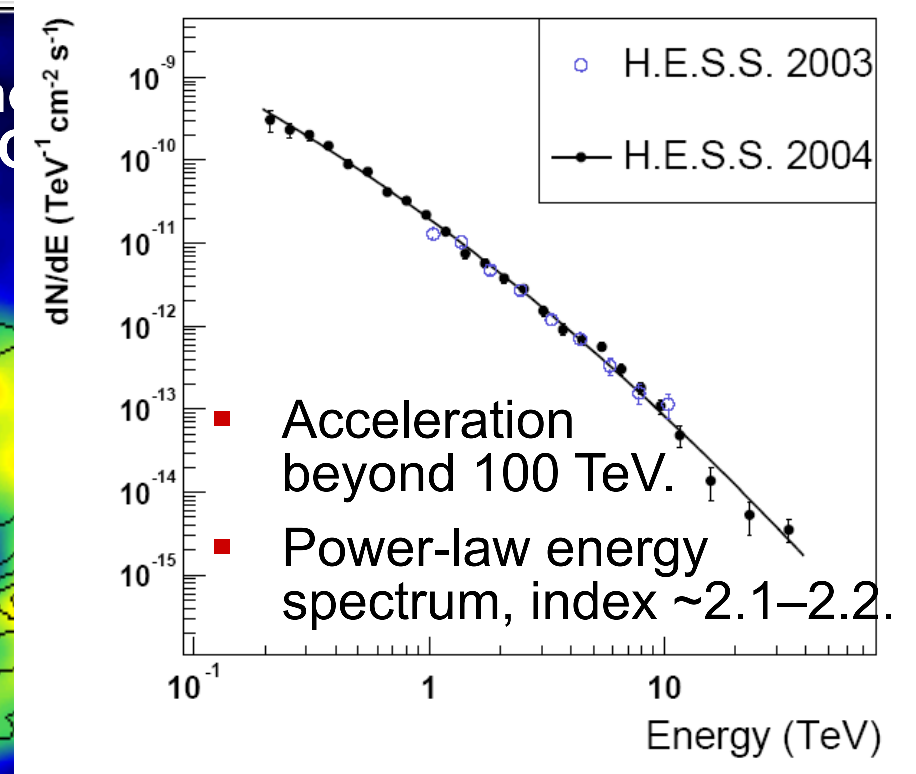


Potential Galactic Neutrino Sources

- 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?

Neutrinos from Supernova Remnants





- Acceleration beyond 100 TeV.
- Power-law energy spectrum, index ~2.1–2.2.

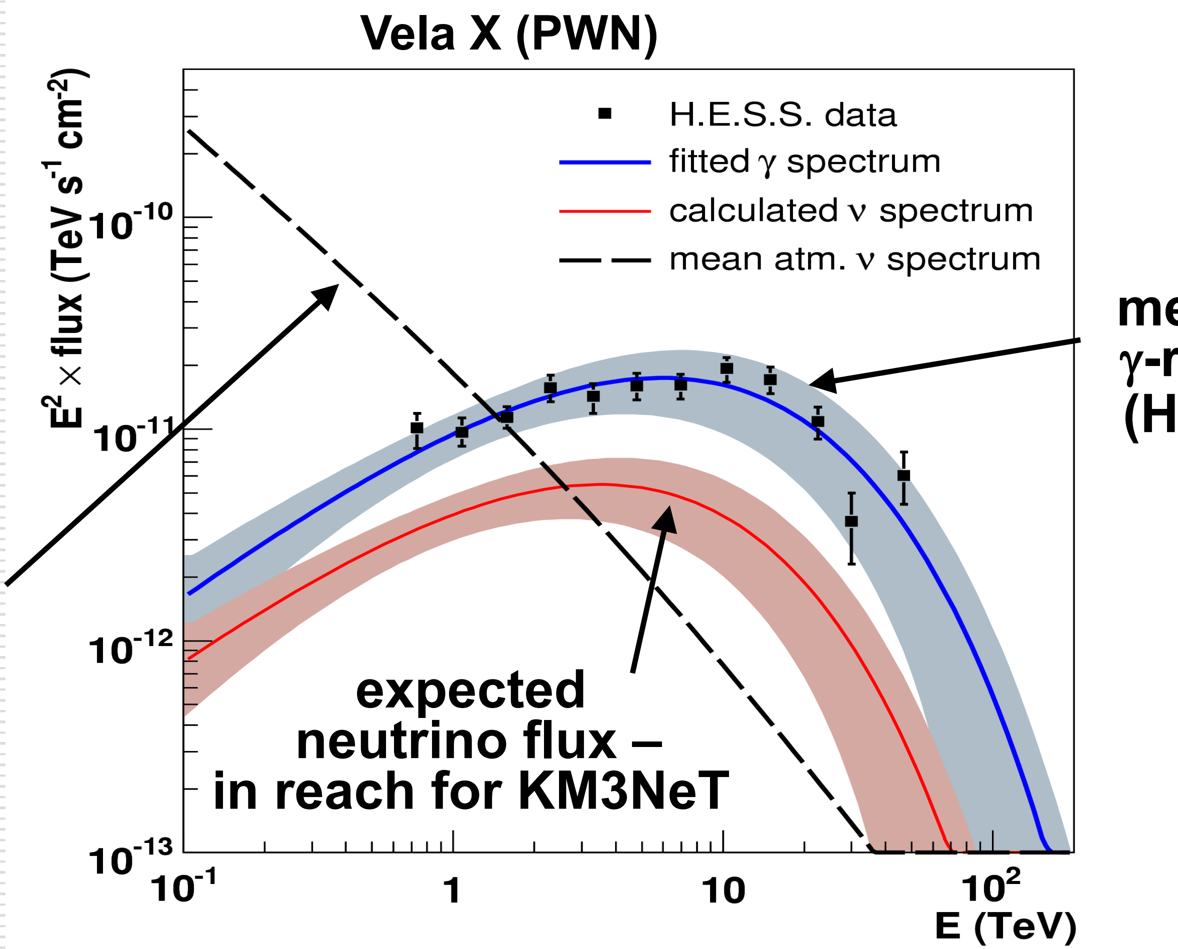
- Spectrum points to hadron acceleration → ν flux ~ γ flux
- Typical ν energies: few TeV

ν Flux Predictions from γ Measurements

A.Kappes et al., astro-ph 0607286

Note: hadronic nature of Vela X not clear!

mean atm. flux
(Volkova, 1980, Sov.J.Nucl.Phys., 31(6), 784)



measured γ-ray flux (H.E.S.S.)

- 1 σ error bands include systematic errors (20% norm., 10% index & cut-off)

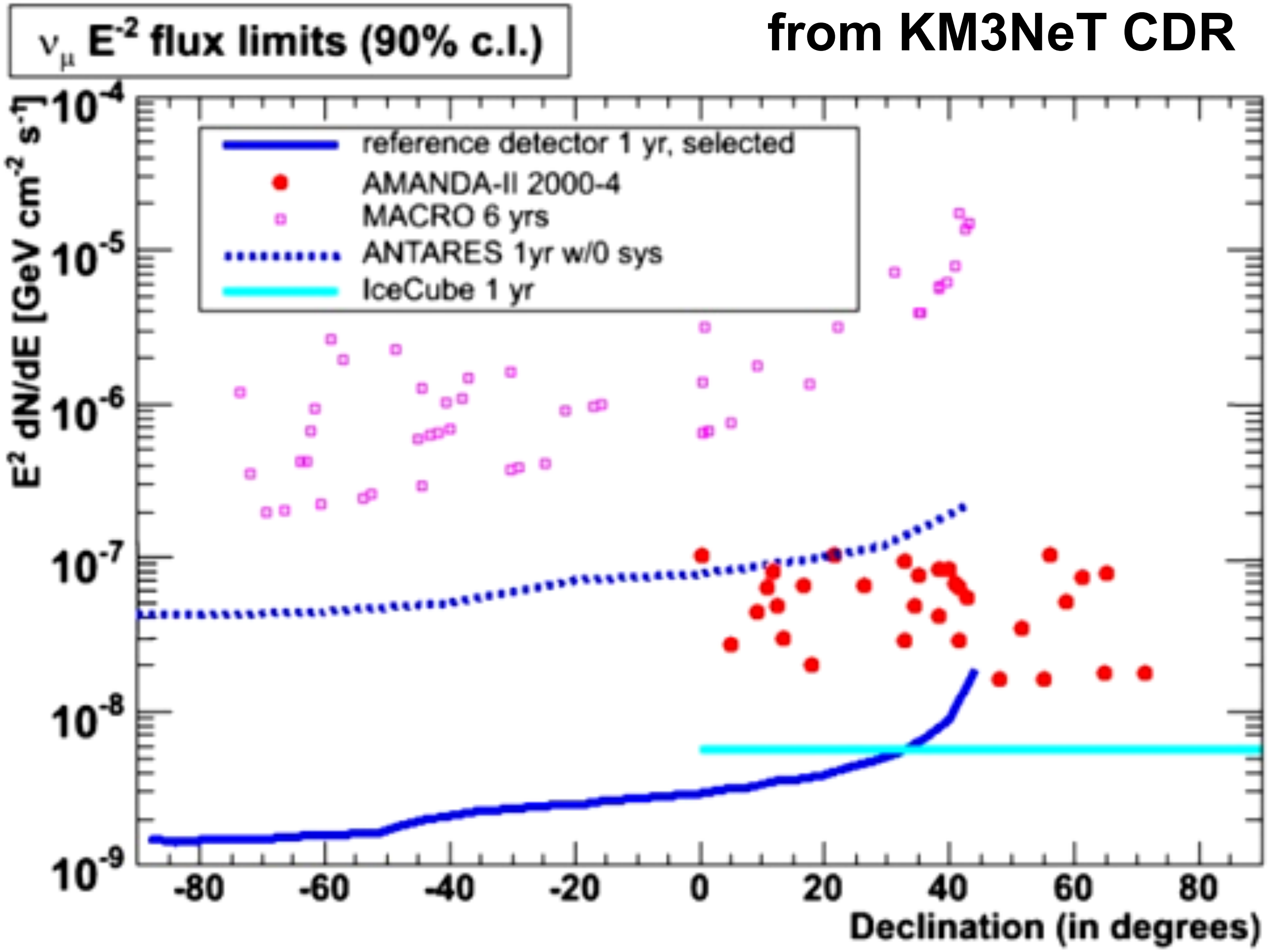
Potential Extragalactic Neutrino Sources

- AGNs
  - Models are rather diverse and uncertain
  - The recent Auger results may provide an upper limit / a normalisation point at UHE
  - Note : At about 100 TeV the neutrino telescope field of view is restricted downwards (ν absorption), but sensitivity starts to be significant upwards.
- Gamma ray bursts
  - Unique signature: Coincidence with gamma observation in time and direction
  - Source stacking possible

Point Source Sensitivity

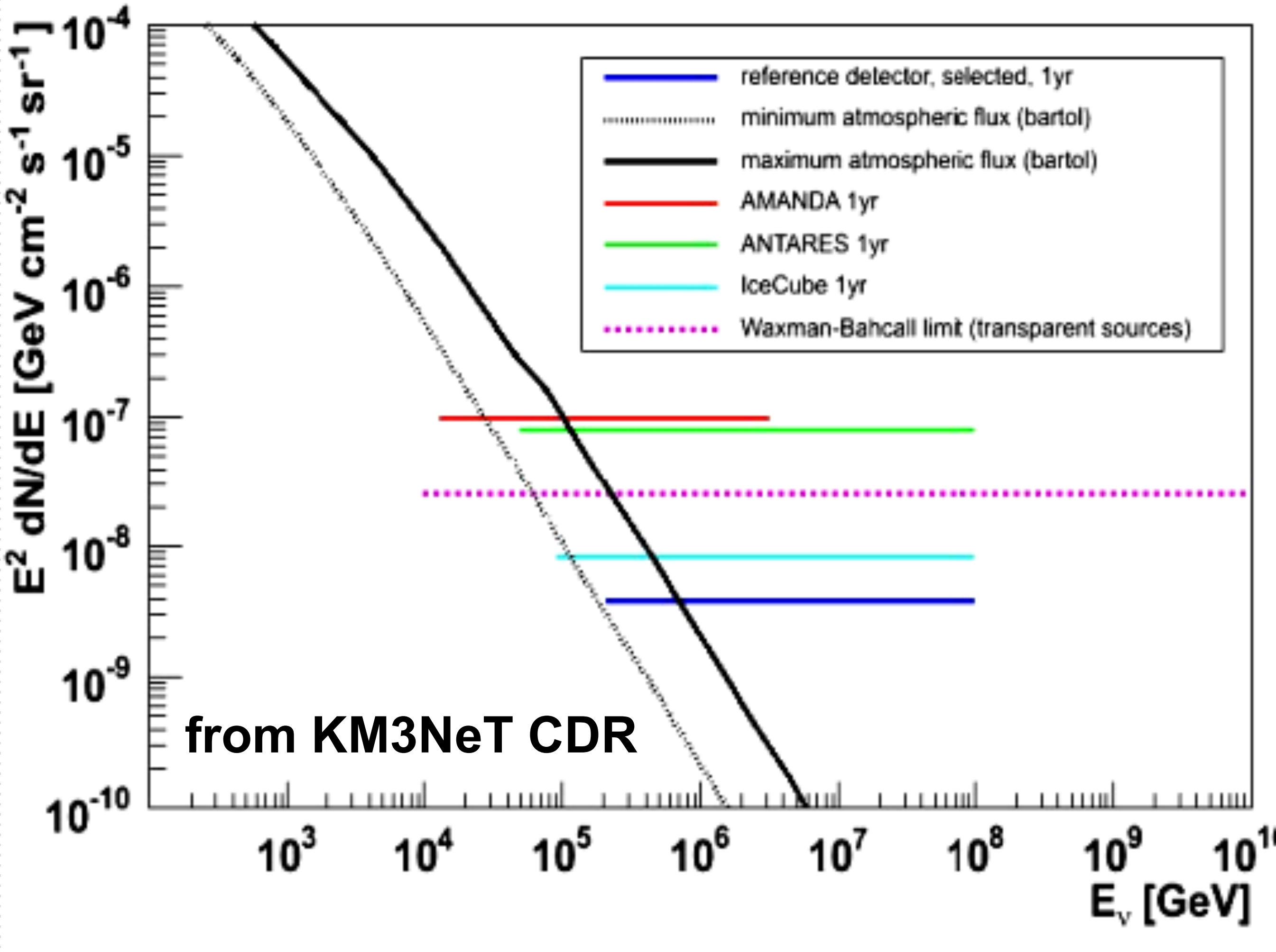
- Based on muon detection
- Why factor ~3 more sensitive than IceCube?
  - larger photo-cathode area
  - better direction resolution
- Study still needs refinements

from KM3NeT CDR



Diffuse Fluxes

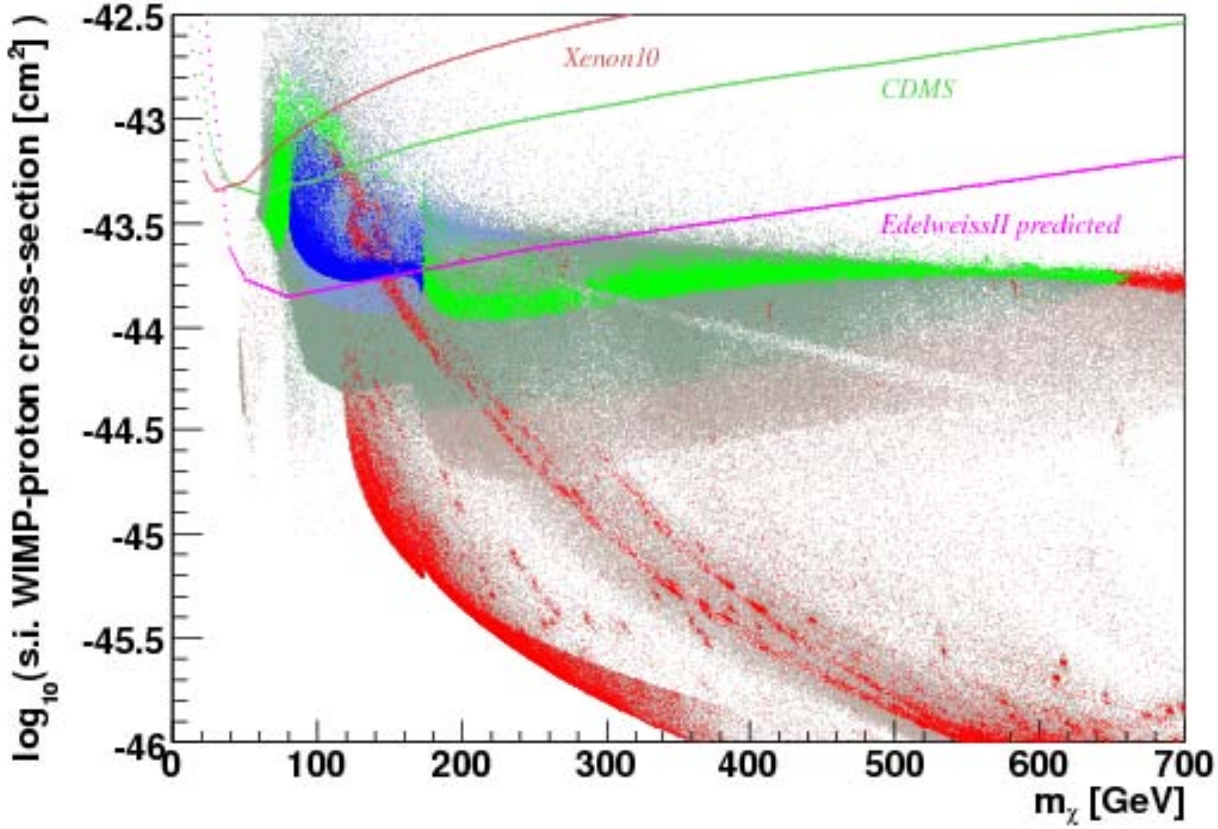
- Assuming E^{-2} neutrino energy spectrum
- Only muons studied
- Energy reconstruction not yet included



Dark Matter Sensitivity

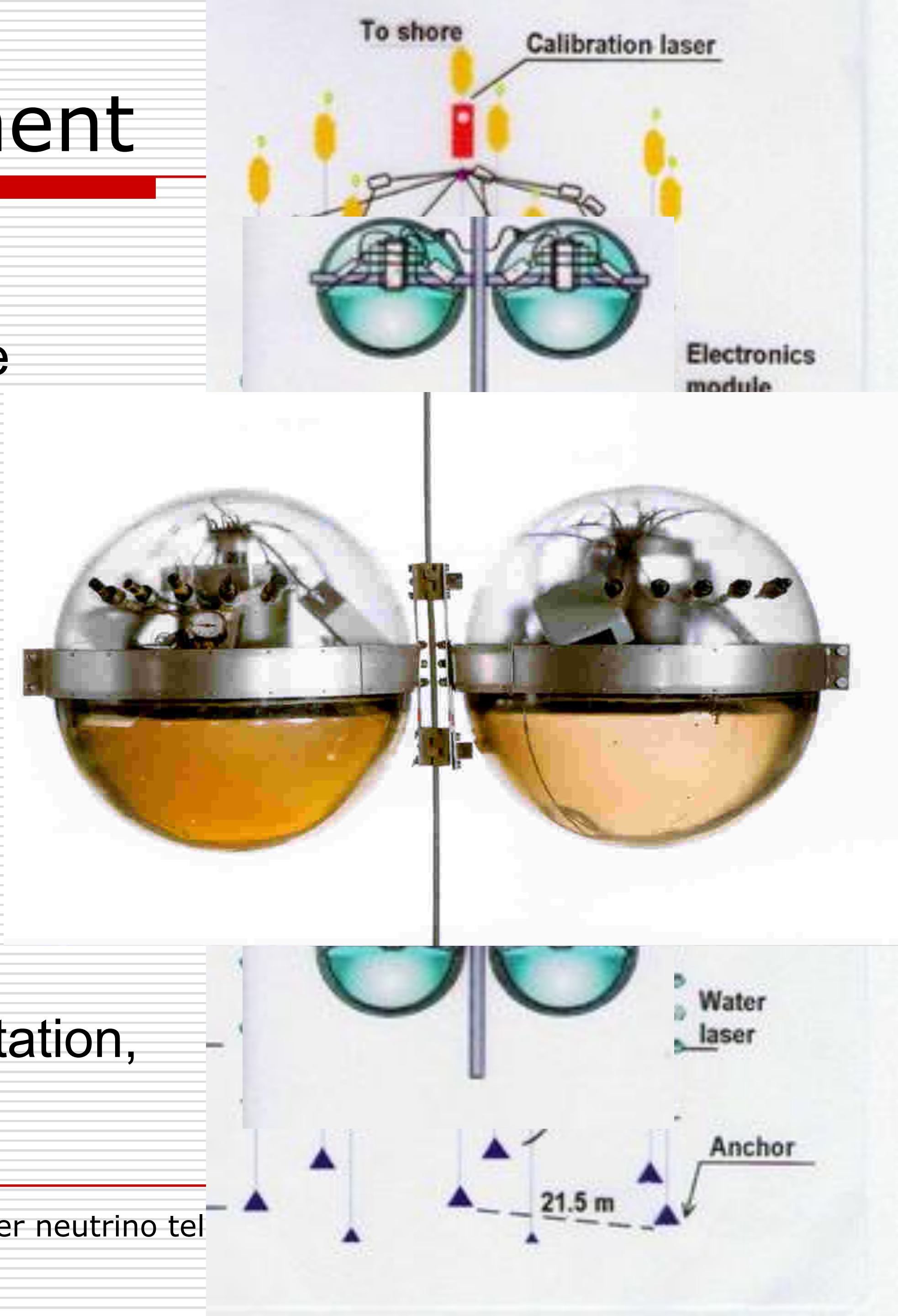
- Scan mSUGRA parameter space and calculate neutrino flux for each point
- Focus on points compatible with WMAP data
- Detectability:
  - Blue: ANTARES
  - Green: KM3NeT
  - Red: None of them

from KM3NeT CDR



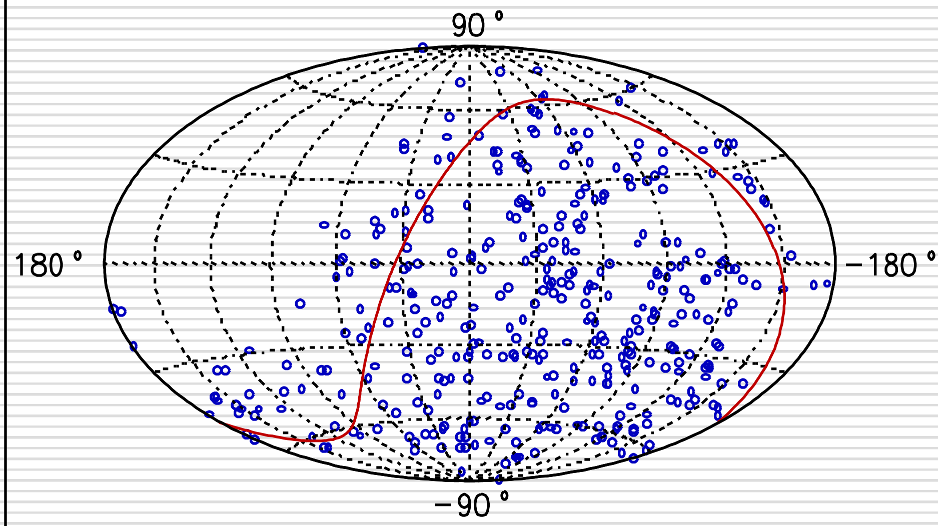
The Baikal Experiment

- In Lake Baikal, Siberia
- Deployment and maintenance from frozen lake surface
- Several development stages, first data 1993
- 1998-2003: NT200 (8 strings, 192 OMs, 10^5m^3)
- Since 2005: NT200+ (4 additional “far strings”, 12 OMs each)
- R&D for future large-volume instrument (sparse instrumentation, threshold 10-30 TeV)



Baikal Results

- Many physics results
- NT200: 372 neutrino candidates in 1038 days (MC: 385 expected from atmospheric neutrinos)
- Limits on
  - point sources (GRBs)
  - diffuse flux (μ's, cascades)
  - WIMP annihilation in Earth
  - magnetic monopoles
  - …



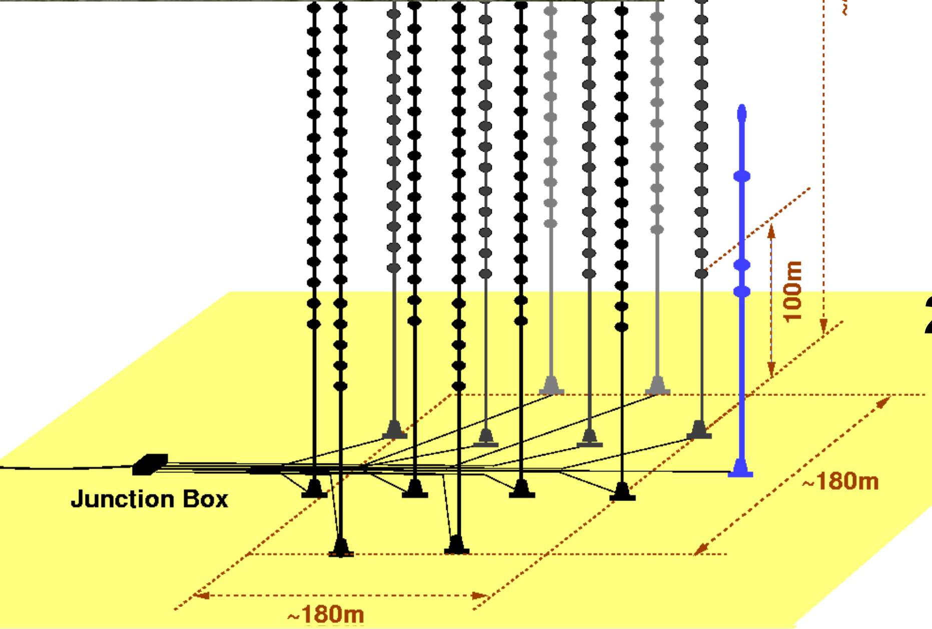
E_{THR} 15-20 GeV

ANTARES: Detector Design

- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking photomultipliers (PMs), axis at 45° to vertical;
- 2500 m deep;
- First deep-sea neutrino telescope in operation!

For more details see Eleonora Presani's talk on Sunday

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 – April 2007:

- Mini Instrumentation Line with OMs (MILOM) operated ~4 months in 2005
- Lines 1-5 running (connected between March 2006 and Jan. 2007)
- Lines 6+7 deployed March/April 2007

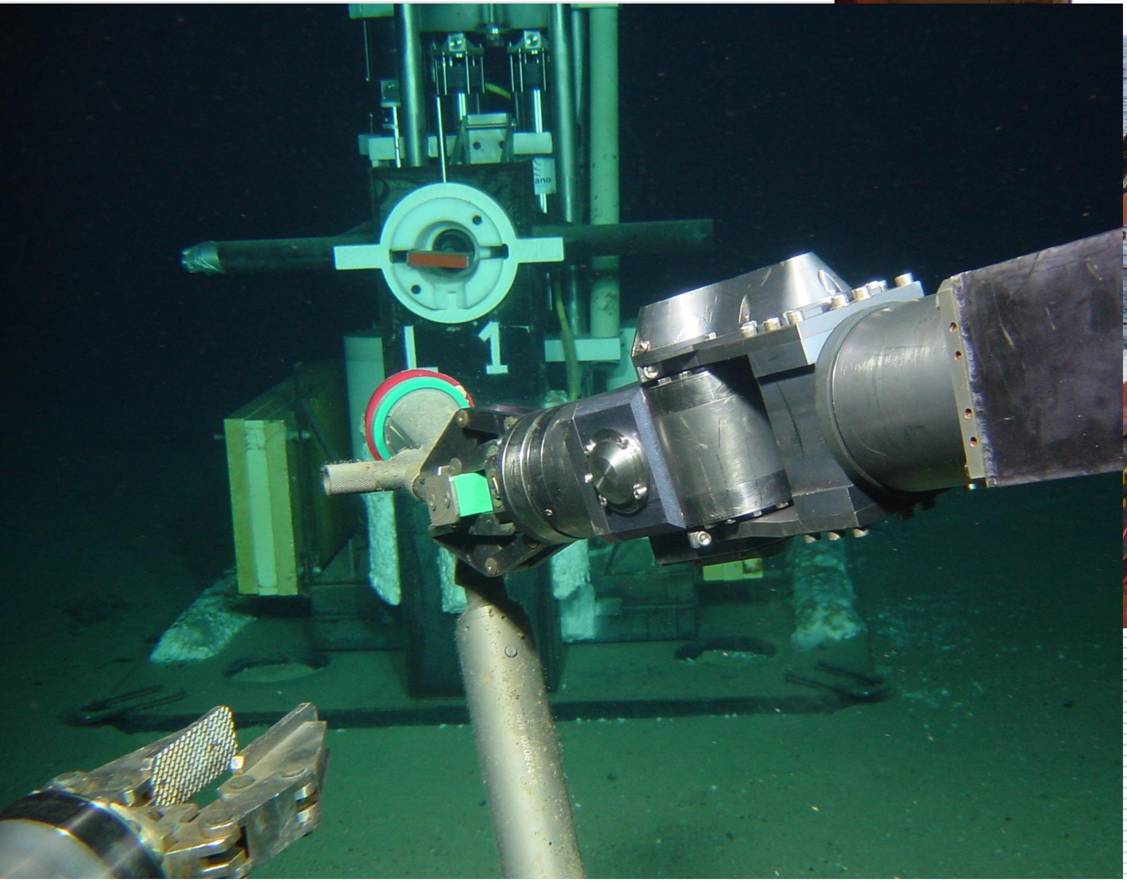
2007 – now:

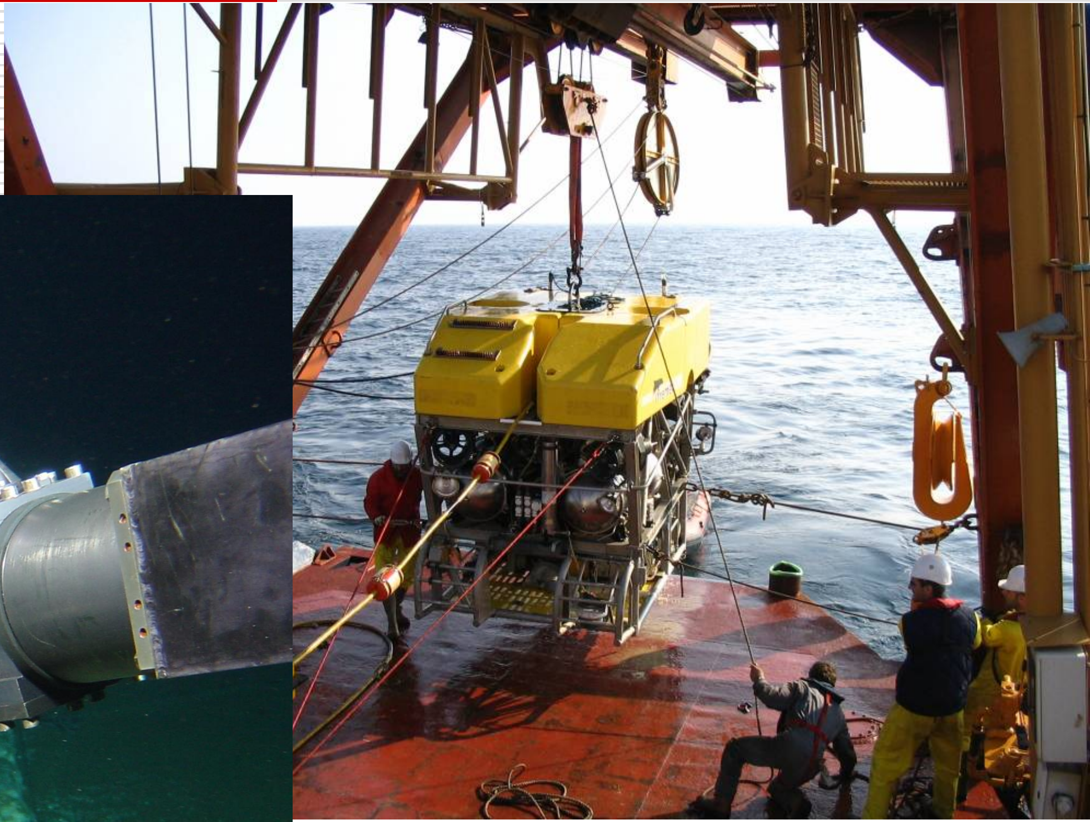
- Deployment / connection of remaining lines completed in May 2008
- Replacement of MILOM by full instrumentation line (IL)
- **Physics with full detector !**

ANTARES: First Detector line installed …

14. Feb. 2006

… and connected by ROV Victor!



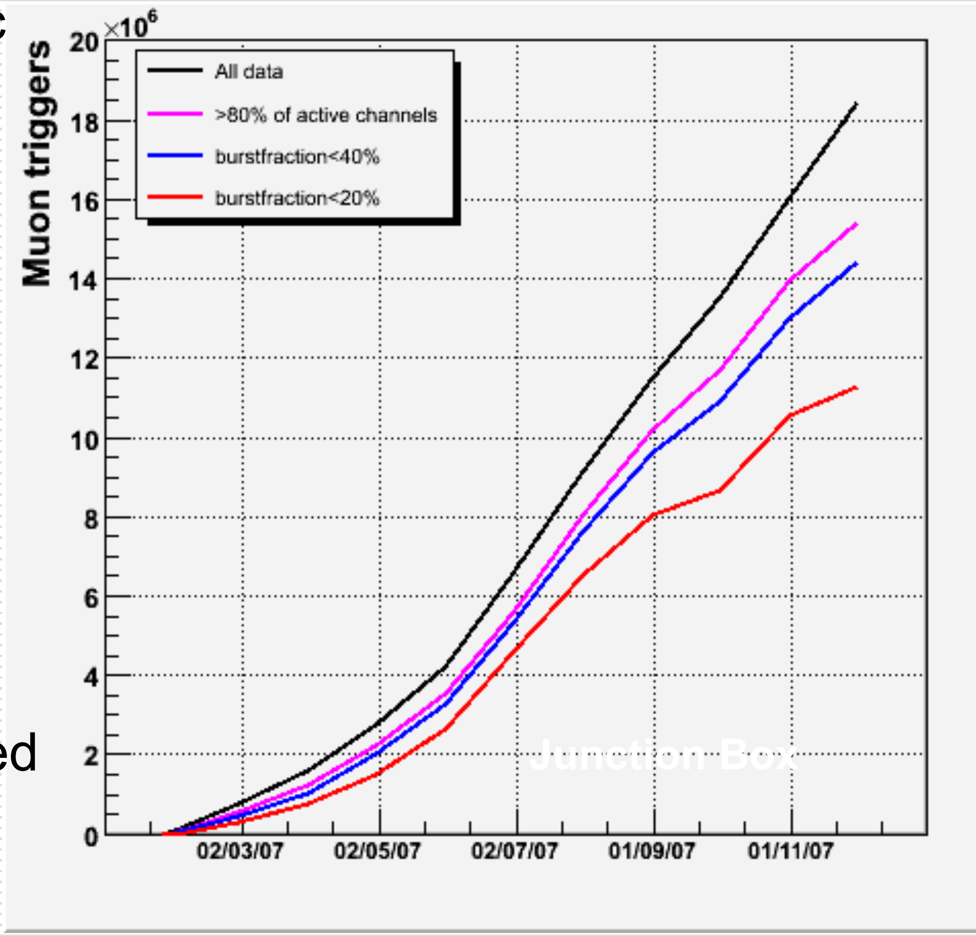


2. March 2006

(ROV = Remotely operated submersible)

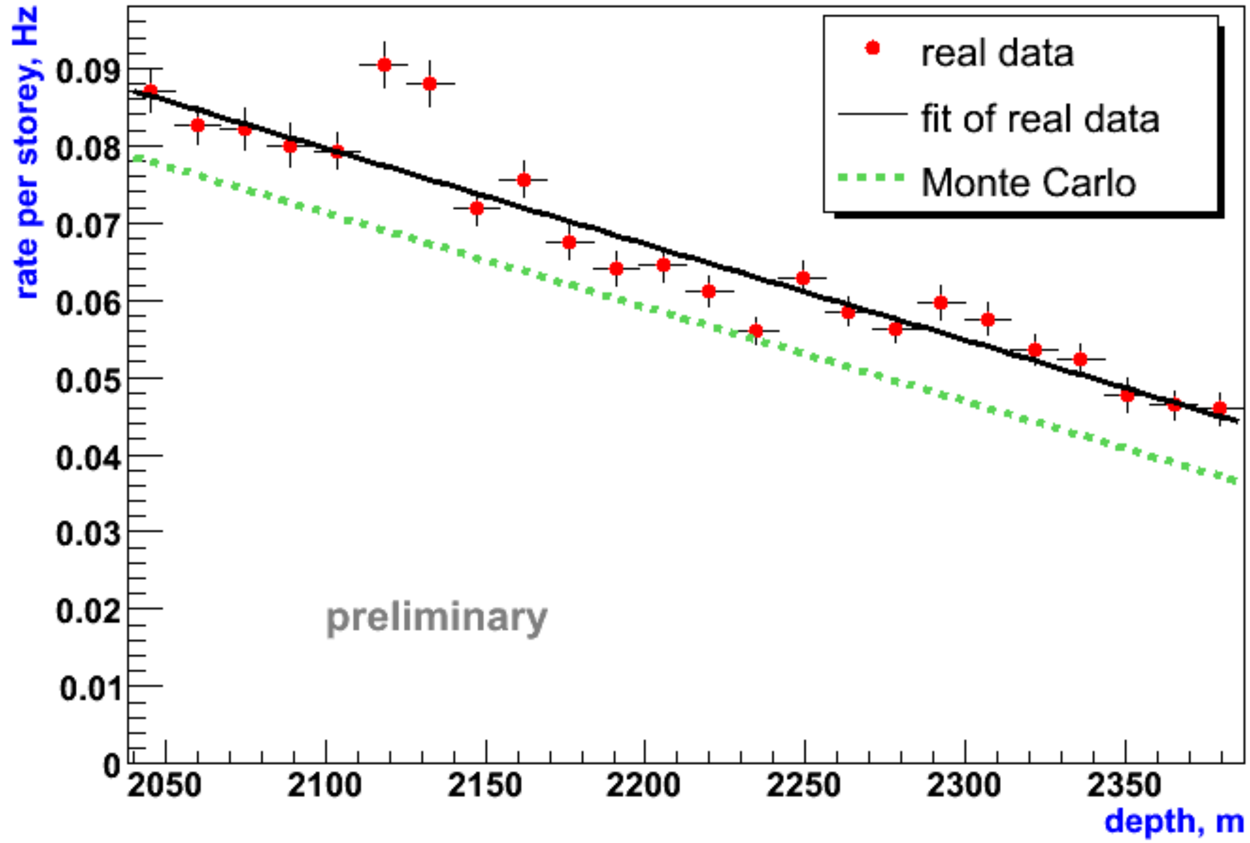
ANTARES: Calibration and Data Taking

- Position reconstruction with acoustic triangulation, direction and tilt measurements
  → Accuracy ~10cm
- Timing resolution:
  – 0.5ns from electronics/calibration
  – 1.3ns transit time spread (PMs)
  – 2.0ns chromatic dispersion/ scattering in water
- Angular resolution for μ's: 0.2°-0.3°
- Data taking:
  – 2 x 10^7 μ triggers in 2007 (5 lines)
  – 10- and 12-line data being analysed
  – break in July/August 2008 (cable problem, meanwhile repaired)



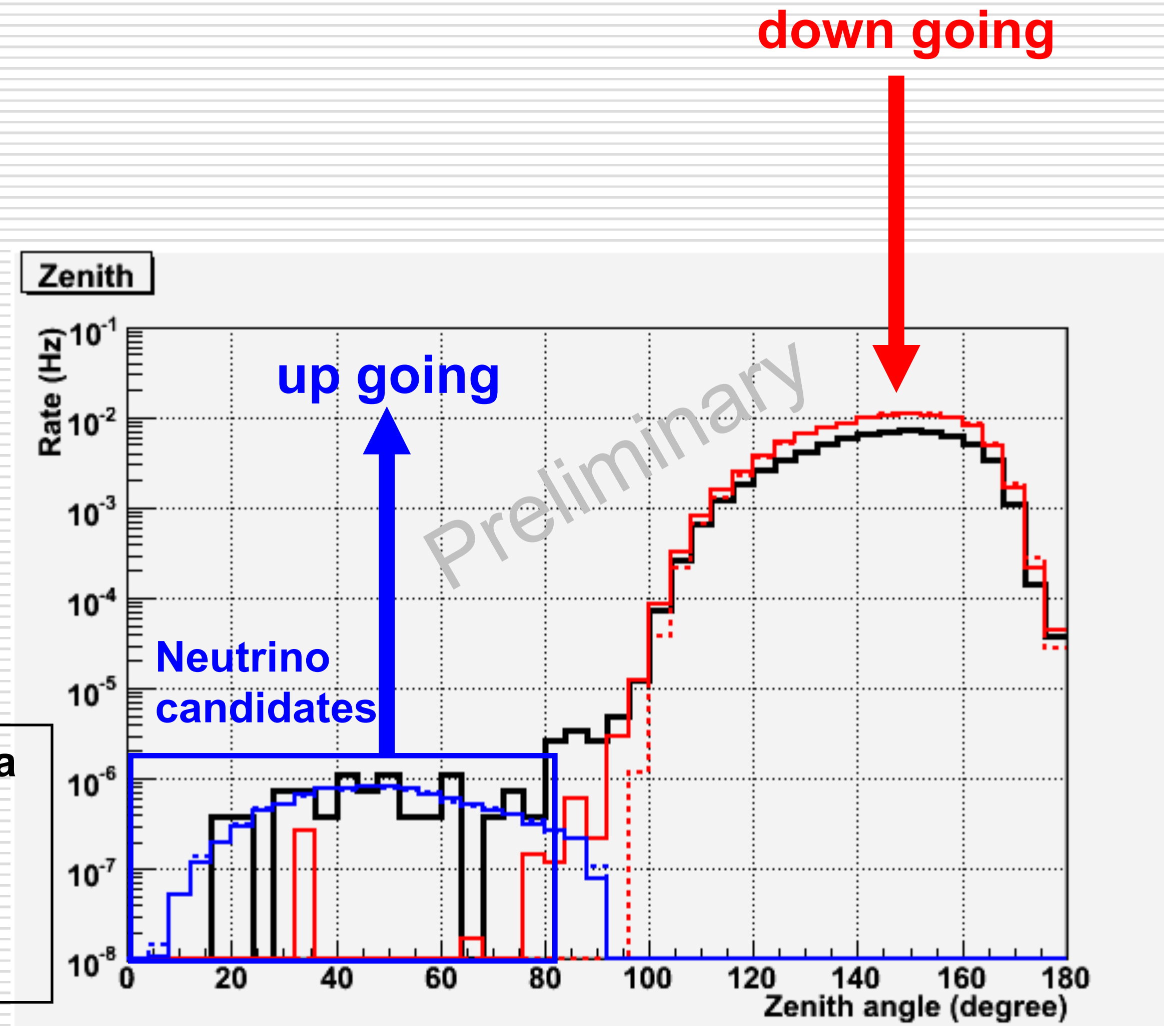
ANTARES: Atmospheric μ Flux

- Rate of atmospheric μ's per storey
  → depth dependence of μ flux
- Good agreement of ANTARES data with simulation
- Provides major cross-check of detector calibration and online filter efficiency



ANTARES: Atmospheric neutrinos

- ~5×10^6 triggers (Feb.-May 2007, 5 lines)
- Reconstruction tuned for upgoing tracks
- Rate of downward tracks:
  ~ 0.1 Hz
- Rate of neutrino candidates:
  ~ 1.4 events/day



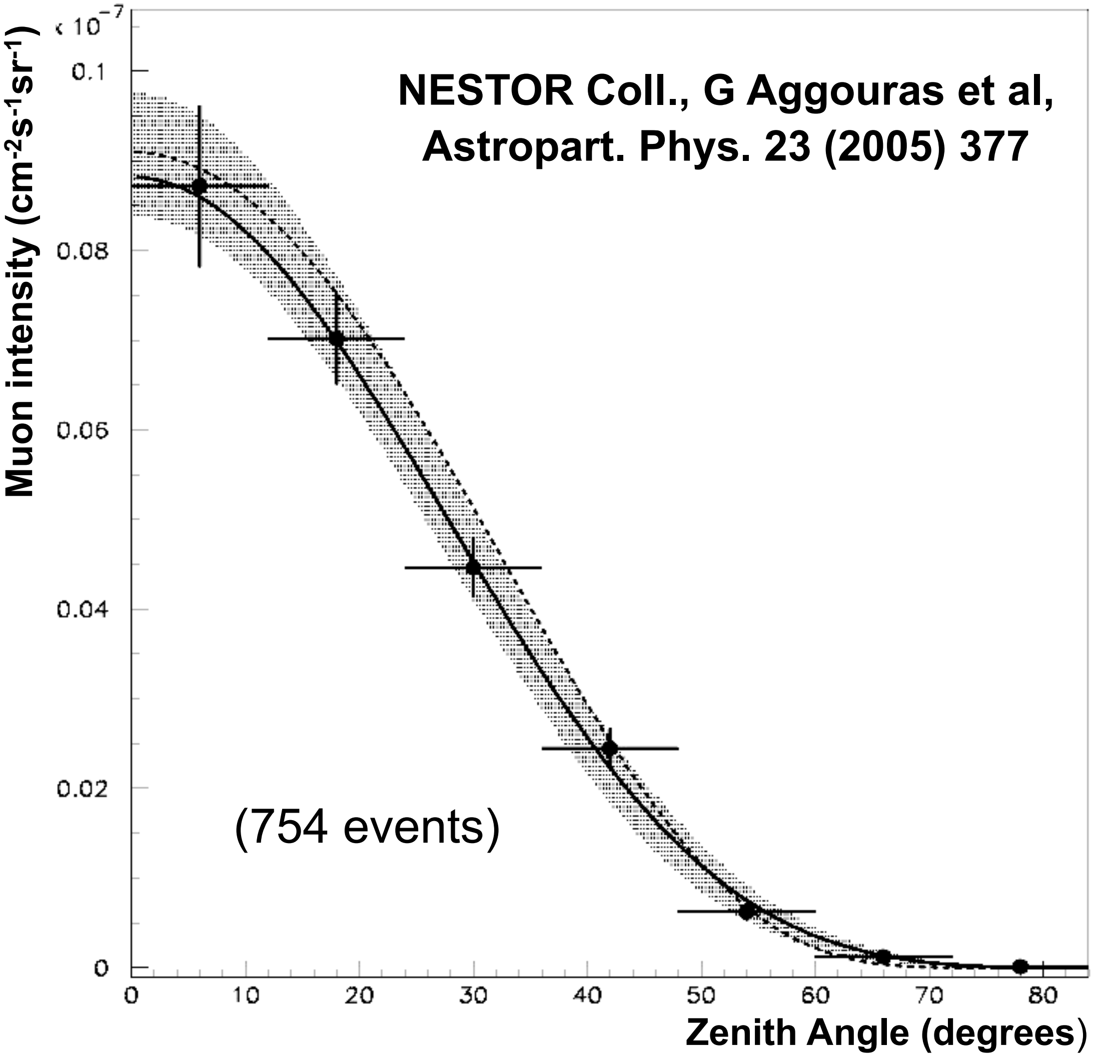
Reconstructed events from data
MC Muons
(dashed: true; solid: reconstr.)
MC neutrinos
(dashed: true; solid: reconstr.)

NESTOR: Rigid Structures Forming Towers

- Tower based detector (titanium structures).
- Dry connections (recover − connect − redeploy).
- Up- and downward looking PMs (15’’).
- 4000-5200 m deep.
- Test floor (reduced size) deployed & operated in 2003.
- Deployment of 4 floors planned in 2009

Vision: Tower(s) with12 floors
→ **32 m diameter**
→ **30 m between floors**
→ **144 PMs per tower**

NESTOR: Measurement of the Muon Flux



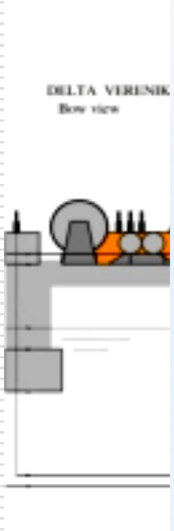
Atmospheric muon flux determination and parameterisation by

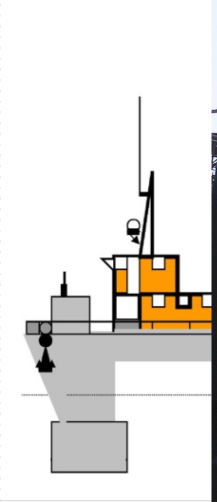
$$\boxed{\frac{dN}{d\Omega\ dt\ ds} = I_0\ \cos^{\alpha}\theta}$$

α **= 4.7 ± 0.5(stat.) ± 0.2(syst.)**
I_0 = 9.0 ± 0.7(stat.) ± 0.4(syst.)
x 10^{-9} cm^{-2} s^{-1} sr^{-1}

Results agree nicely with previous measurements and with simulations.

NESTOR: The Delta-Berenike Platform





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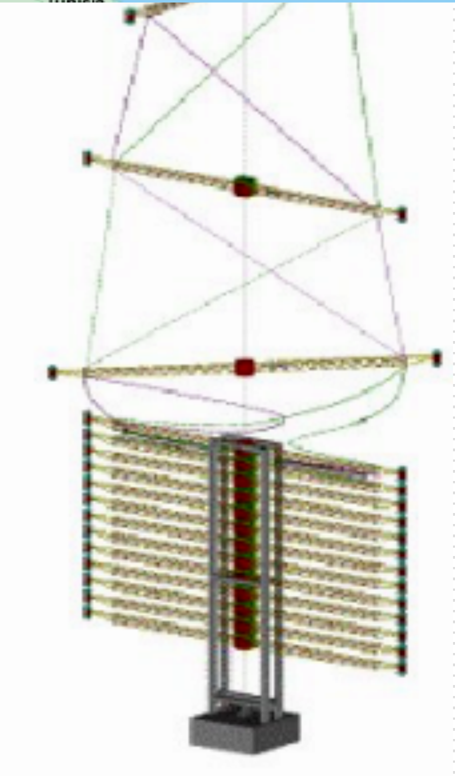
The NEMO Project

- Extensive site exploration (Capo Passero near Catania, depth 3500 m);
- R&D towards km³: architecture, mechanical structures, readout, electronics, cables ...;
- Simulation.



Example: Flexible tower

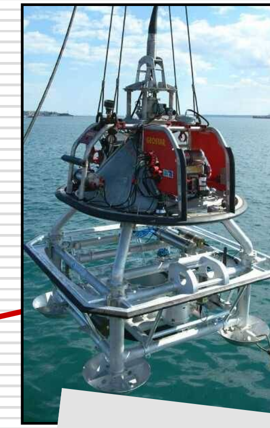
- 16 arms per tower, 20 m arm length, arms 40 m apart;
- 64 PMs per tower;
- Underwater connections;
- Up- and downward-looking PMs.

NEMO Phase I: First steps

Shore station

- Test site at 2000 m depth operational.
- Funding ok.

Geoseismic station SN-1 (INGV)



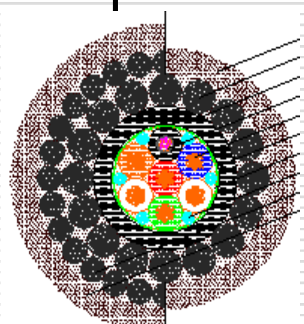
5 km e.o. cable

21 km e.o. Cable with single steel shield

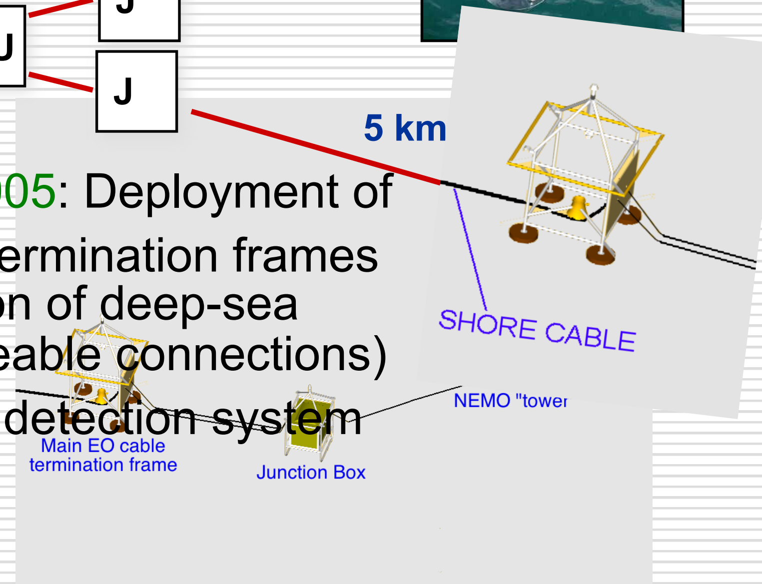
J — **BU** — **J** / **J**

5 km

2.5 km e.o. Cable with double steel shield



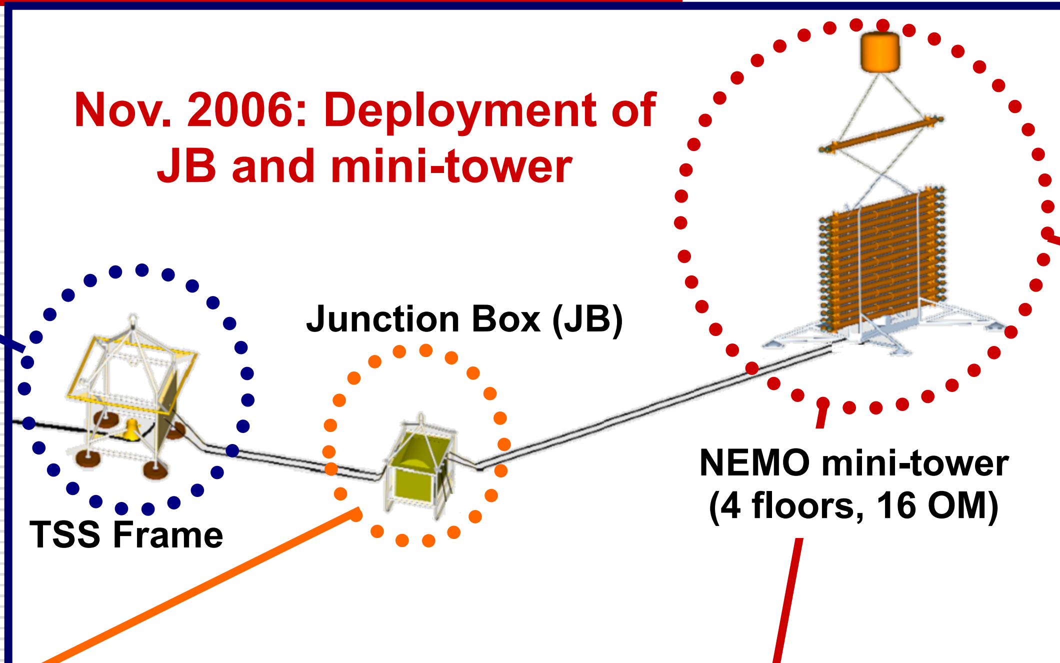
January 2005: Deployment of
- 2 cable termination frames (validation of deep-sea wet-mateable connections)
- acoustic detection system (OνDE).

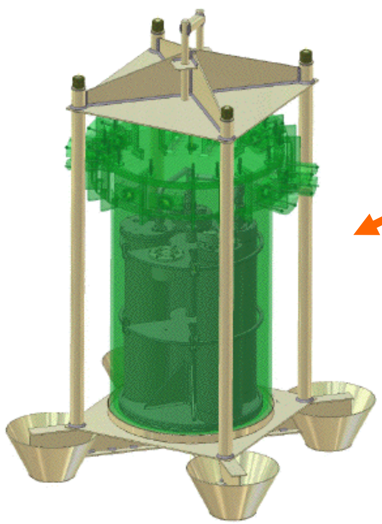


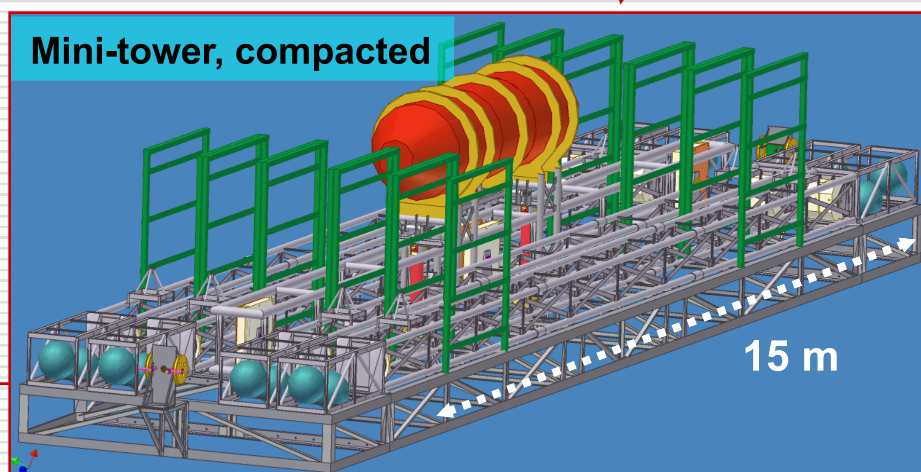
- **10 optical fibres standard ITU- T G-652**
- **6 electrical conductors Φ 4 mm²**

NEMO Phase-1: Current Status

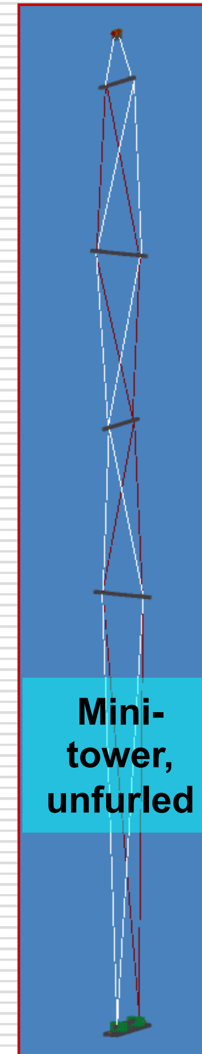
Deployed January 2005







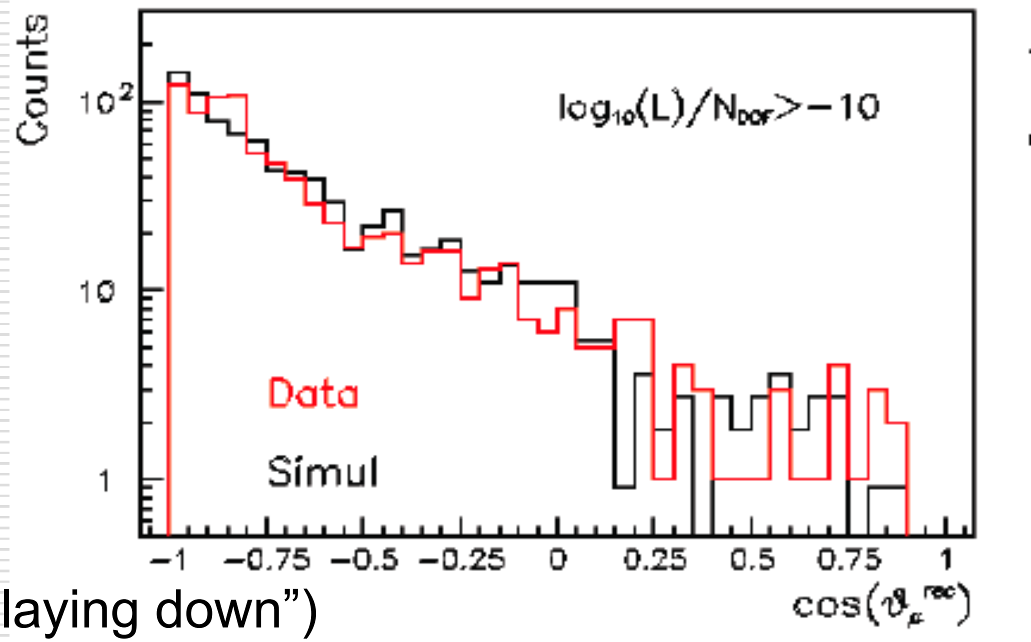
300 m



NEMO: Phase-1 Results

- Successful deployment and system test, all components functional
- Data being analysed (example: muon angular distribution)
- Some problems:
  - Missing buoyancy (tower “laying down”) traced back to buoy production error
  - Junction Box: Incident at deployment, data transmission problem after some weeks, short after ~5 months → recovery & analysis → some redesign for Phase-2

Atmospheric muon angular distribution



NEMO: Phase-2

- Objective: Operation of full NEMO tower (16 floors) and Junction Box at 3400 m depth (Capo Passero site)
- Some design modifications (cabling, calibration, power system, bar length 15 m → 12 m, …)
- Infrastructure:
  - Shore station in **Portopalo di Capo Passero** **(→ under renovation)**
  - **Shore power system** **(→ under construction)**
  - **100 km main electro-optical cable (50 kW, 20 fibres)** **(→ laid)**
  - **cable termination frame with DC/DC converter (Alcatel)**
    (→ some problems, installation expected Oct. 2008)
- Full installation by end 2008

What is KM3NeT – the Vision

- Future cubic-kilometre sized neutrino telescope in the Mediterranean Sea
- Exceeds Northern-hemisphere telescopes by factor ~50 in sensitivity
- Exceeds IceCube sensitivity by substantial factor
- Focus of scientific interest: Neutrino astronomy in the energy range 1 to 100 TeV
- Platform for deep-sea research (marine sciences)

KM3NeT: From the Idea to a Concept

- 11/2002: First consultations of ANTARES, NEMO and NESTOR
- 3/2004: Design Study proposal submitted
- 9/2005: KM3NeT on ESFRI List of Opportunities
- 2/2006: Begin of Design Study
- 9/2006: KM3NeT on ESFRI Roadmap
- 3/2008: Begin of KM3NeT Preparatory Phase
- 4/2008: The KM3NeT Conceptual Design Report

The KM3NeT Conceptual Design Report

- Presented to public at VLVnT0 workshop in Toulon, April 2008
- Summarises (a.o.)
  - Physics case
  - Generic requirements
  - Pilot projects
  - Site studies
  - Technical implementation
  - Development plan
  - Project implementation

available on www.km3net.org

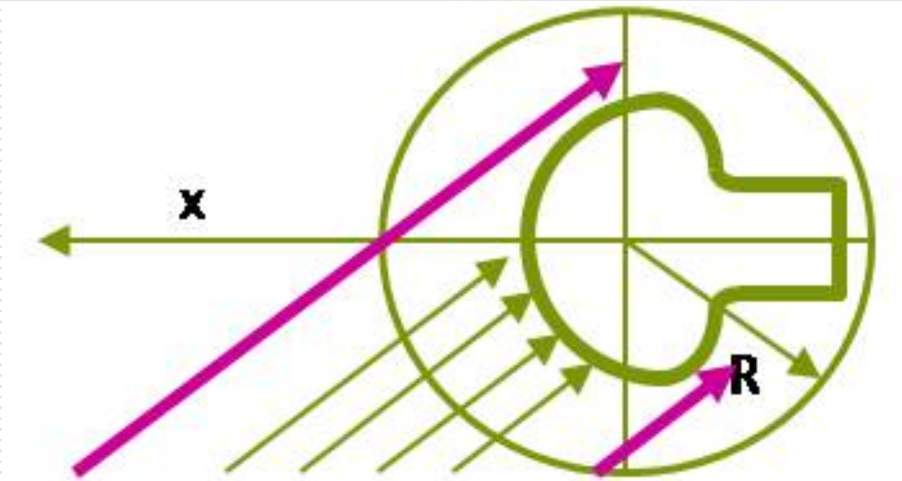
KM3NeT Design Goals

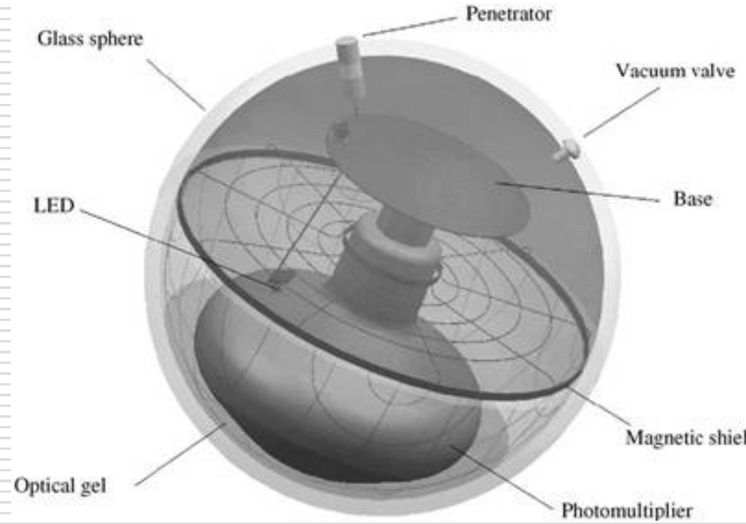
- Lifetime > 10 years without major maintenance, construction and deployment < 4 years
- Some technical specifications:
  - time resolution 2 ns
  - position of OMs to better than 40 cm accuracy
  - two-hit separation < 25 ns
  - false coincidences dominated by marine background
  - coincidence acceptance > 50%
  - PM dark rate < 20% of ^{40}K rate

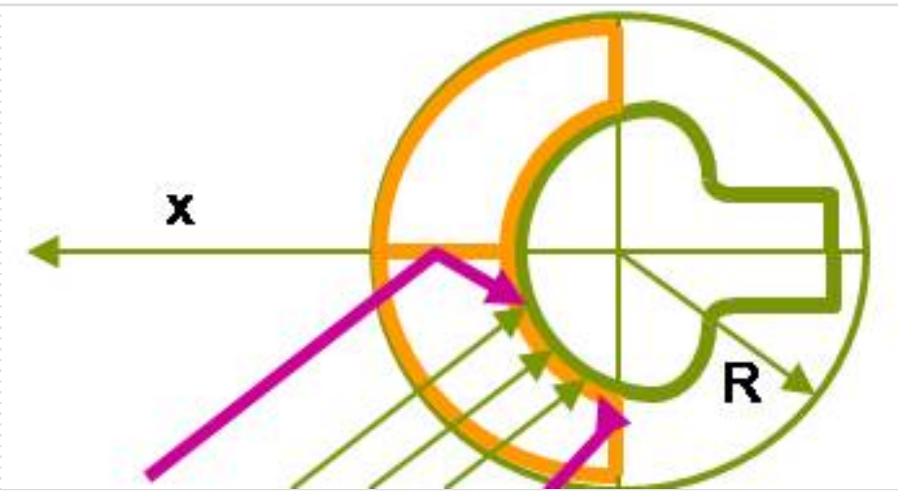
Technical Implementation

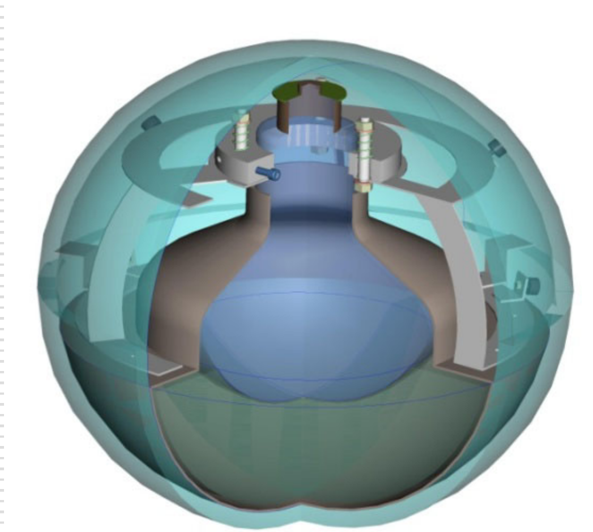
- Photo-sensors and optical modules
- Data acquisition, information technology and electronics
- Mechanical structures
- Deep-sea infrastructure
- Deployment
- Calibration
- Associated science infrastructure

Optical Modules: Standard or Directional



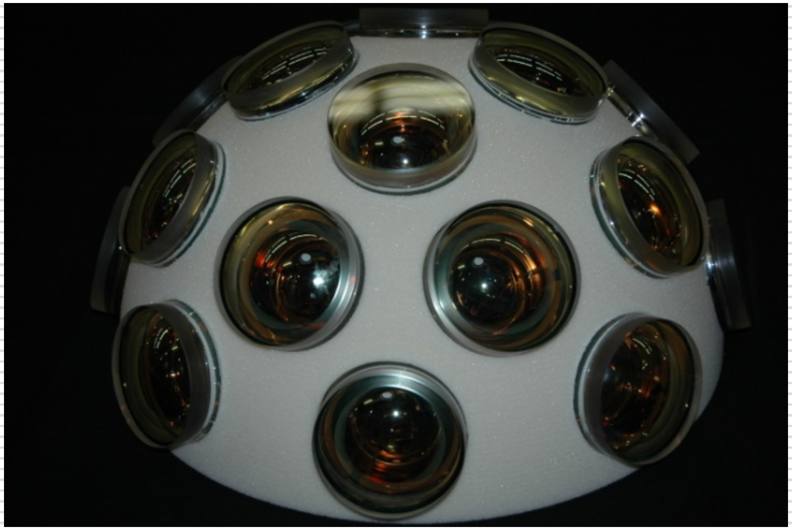






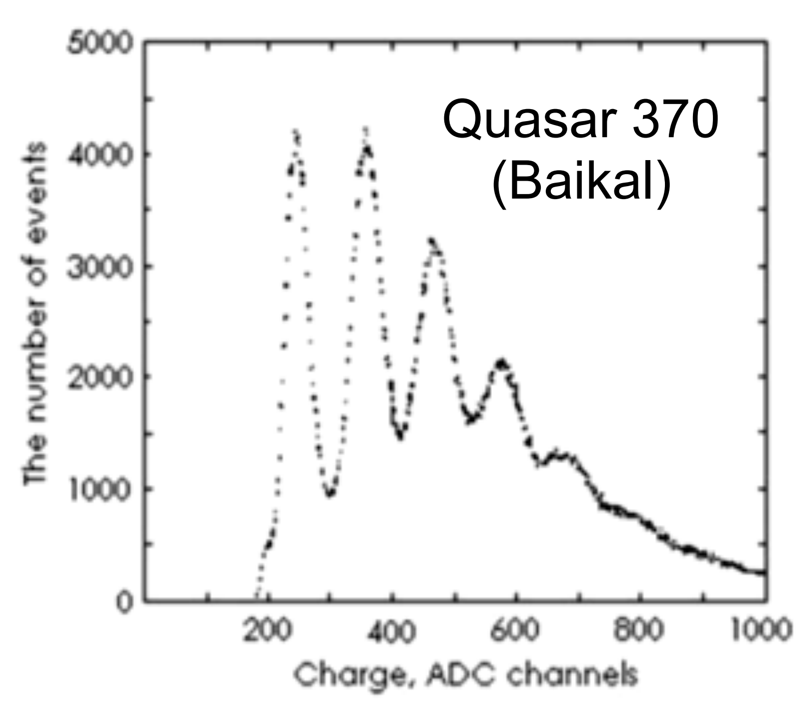
… or Many Small Photomultipliers …

- Basic idea: Use up to 30 small (3'' or 3.5'') PMTs in standard sphere
- Advantages:
  - increased photocathode area
  - improved 1-vs-2 photo-electron separation → better sensitivity to coincidences
  - directionality
- Prototype arrangements under study



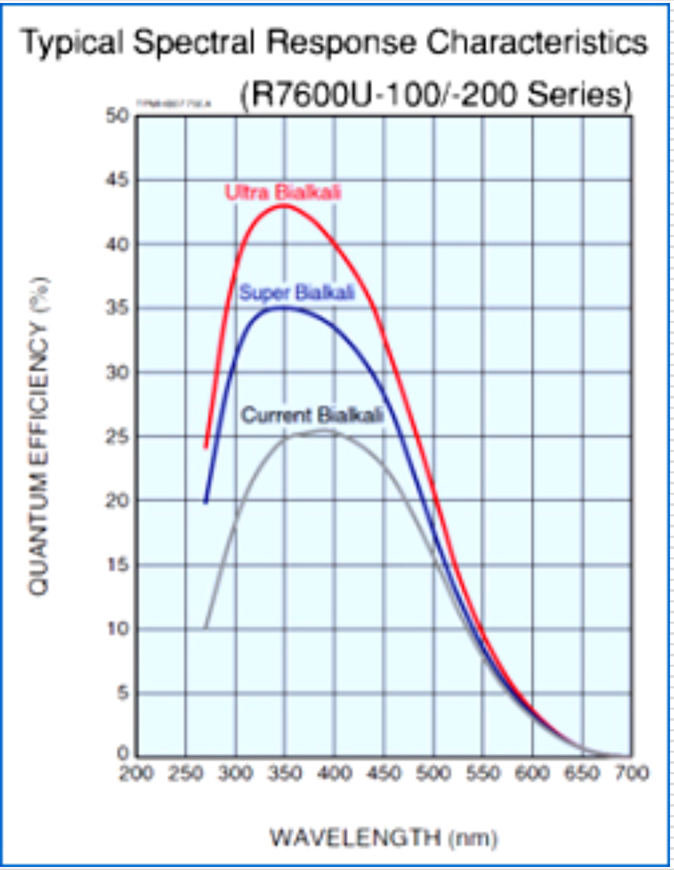
… or Hybrid Solutions

- Idea: Use high voltage (~20kV) and send photo electrons on scintillator; detect scintillator light with small standard PMT.
- Advantages:
  - Very good photo-electron counting, high quantum eff.
  - large angular sensitivity possible
- Prototype development in CERN/Photonis/CPPM collaboration

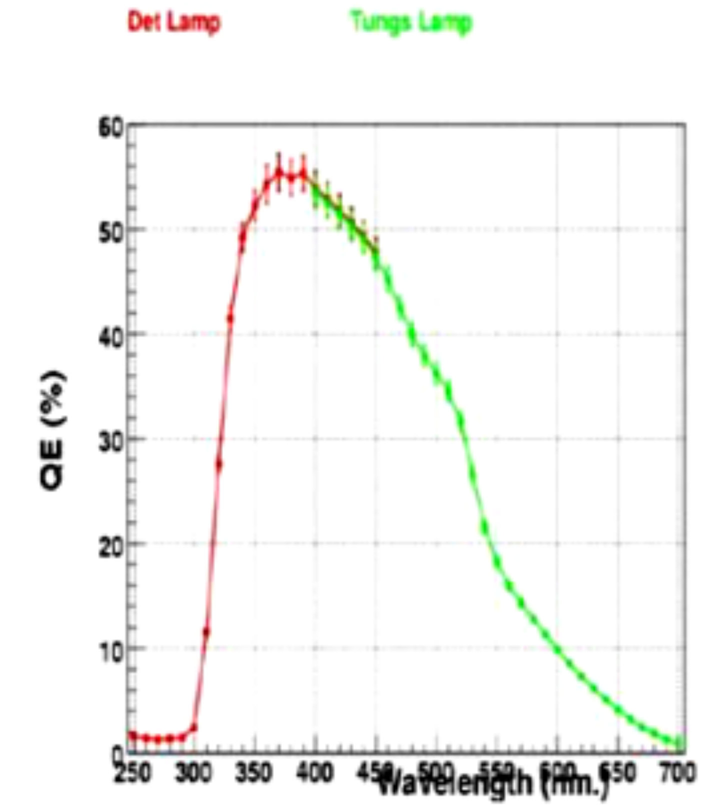


Photocathode News

Hamamatsu



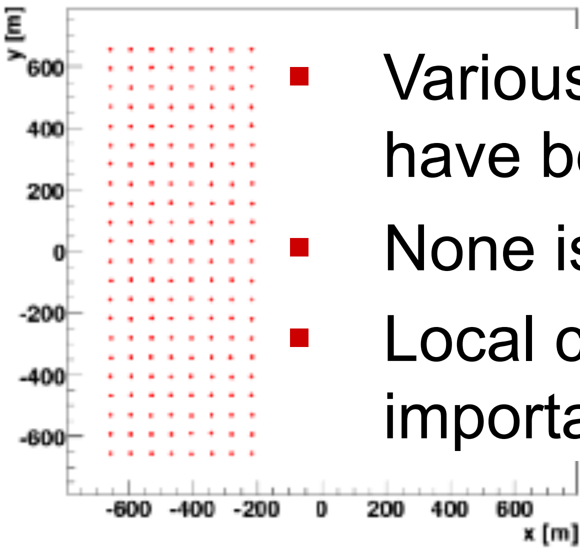
- New photocathode developments by two companies (Hamamatsu, Photonis)
- Factor 2 in quantum efficiency → factor 2 in effective photocathode area!
- Major gain in neutrino telescope sensitivity!

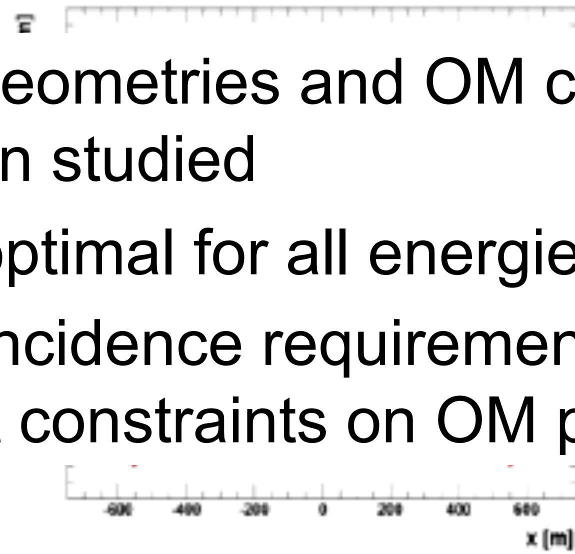


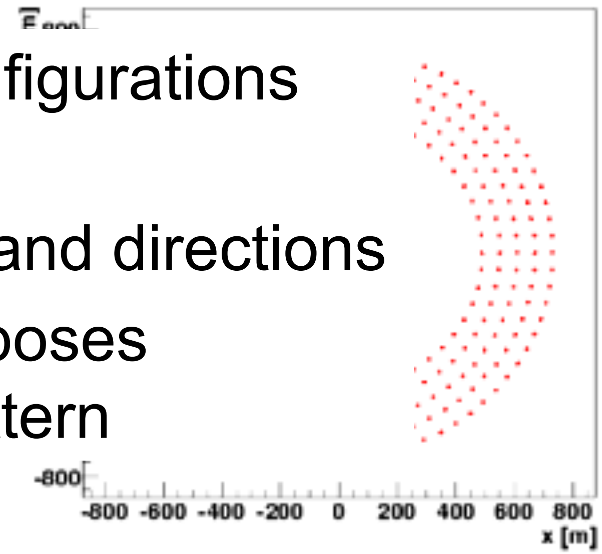
Photonis

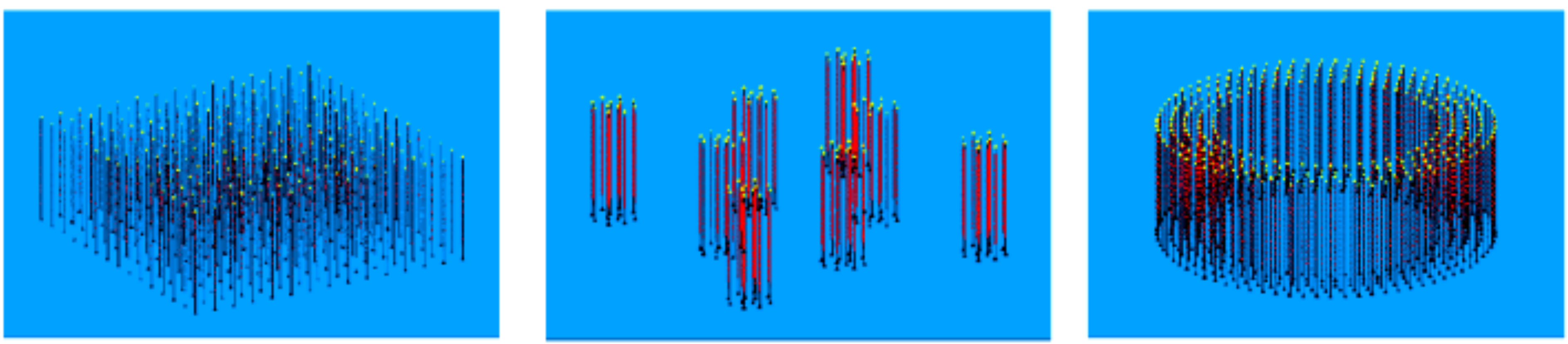
Configuration Studies

- Various geometries and OM configurations have been studied
- None is optimal for all energies and directions
- Local coincidence requirement poses important constraints on OM pattern



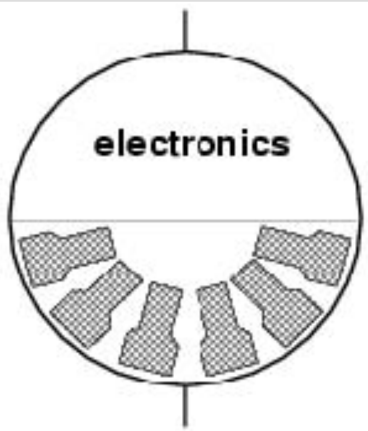


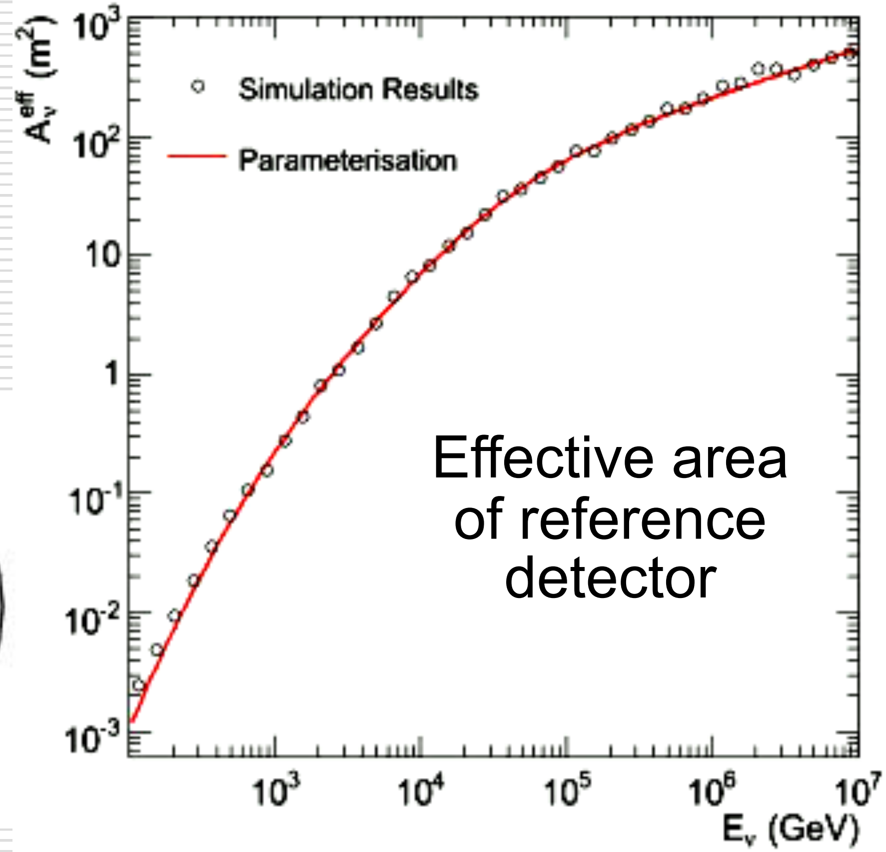




The KM3NeT Reference Detector

- Sensitivity studies with a common detector layout
- Geometry:
  - 15 x 15 vertical detection units on rectangular grid, horizontal distances 95 m
  - each carries 37 OMs, vertical distances 15.5 m
  - each OM with 21 3'' PMTs

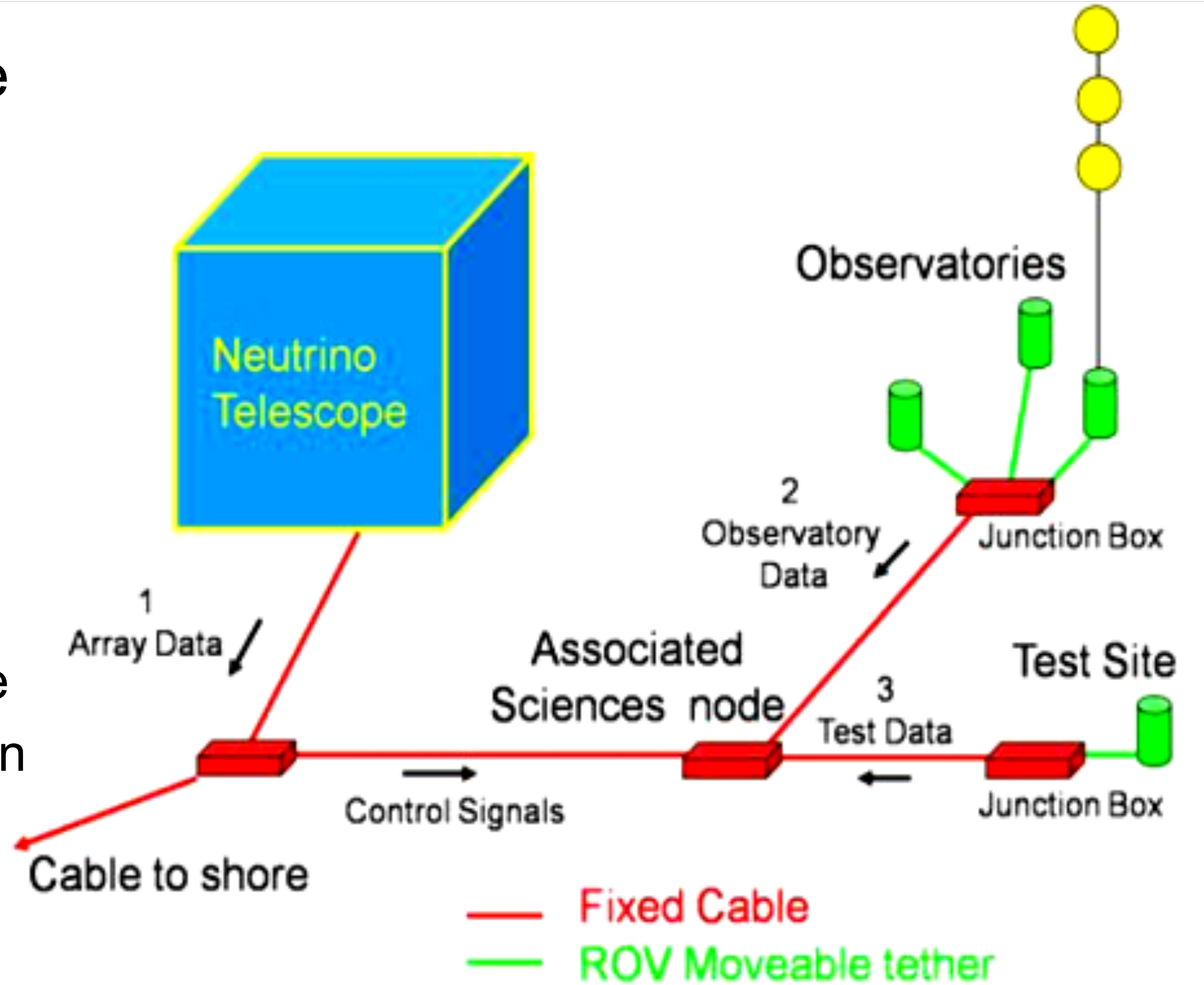




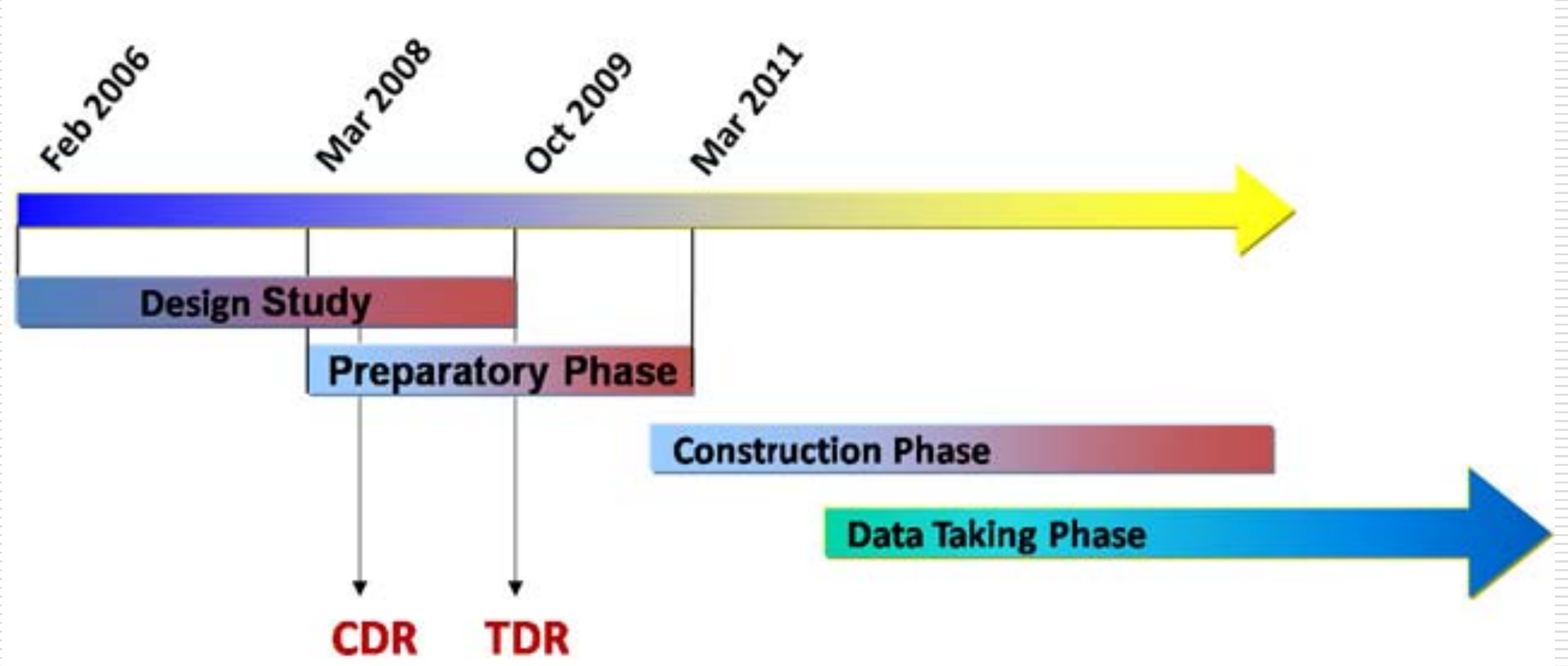
This is NOT the final KM3NeT design!

The Associated Science Installation

- Associated science devices will be installed at various distances around neutrino telescope
- Issues:
  - interfaces
  - operation without mutual interference
  - stability of operation and data sharing
- Synergy effects



Timeline Towards Construction



Note: “Construction” includes the final prototyping stage

Summary

- Neutrinos would (and will) provide very valuable astrophysical information, complementary to photons and charged cosmic rays
- The first generation of deep-sea/lake neutrino telescopes has provided the proof of feasibility of underwater neutrino astronomy and yields exciting data
- Exploiting the potential of neutrino astronomy requires cubic-kilometre scale neutrino telescopes providing full sky coverage
- The KM3NeT detector in the Mediterranean Sea will complement IceCube in its field of view and exceed its sensitivity by a substantial factor