Open H.E.S.S. Workshop, Heja Lodge Conference Center, Namibia:

Fishing for Neutrinos – Science, Technology and Politics

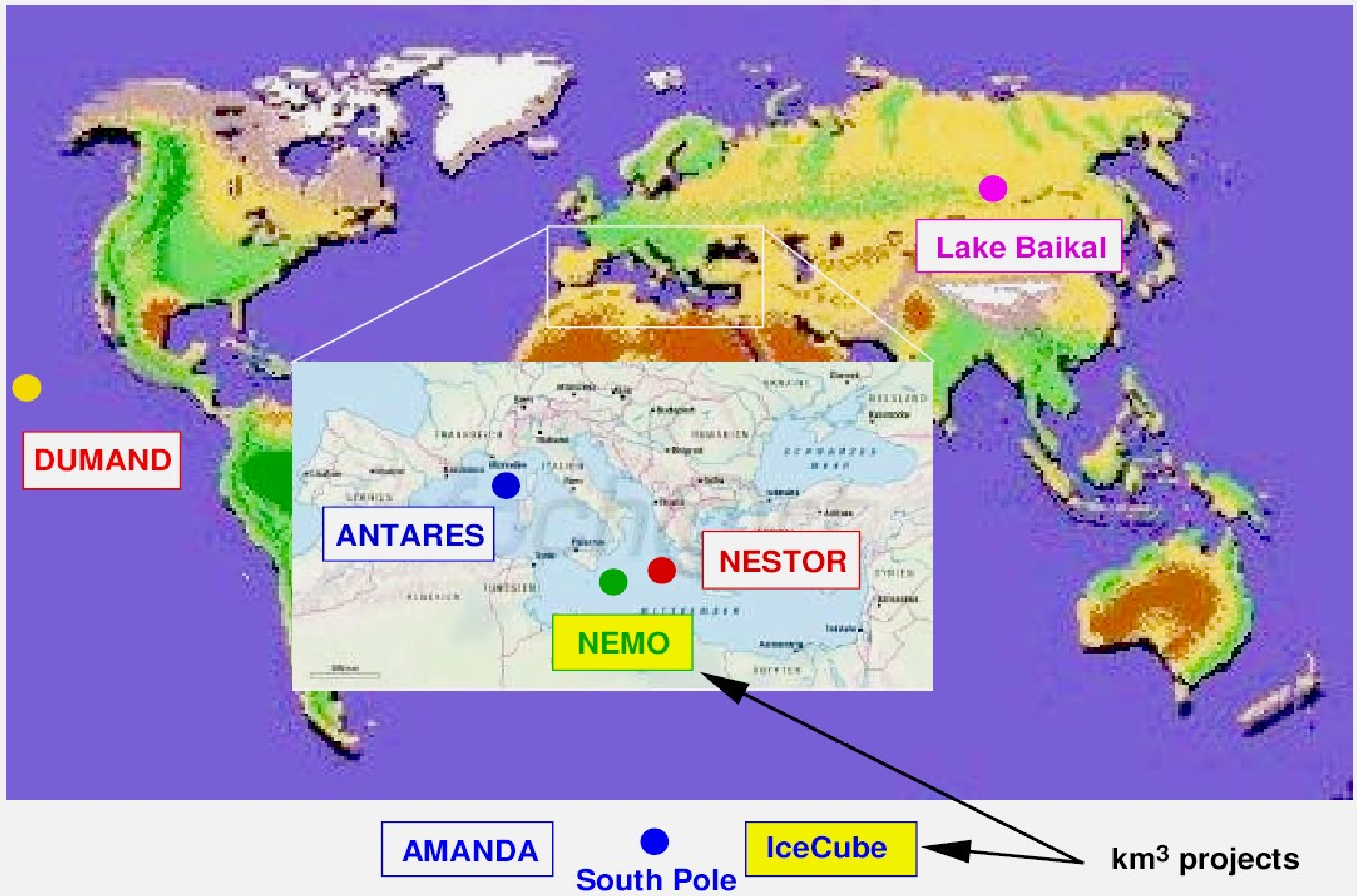
Uli Katz
Univ. Erlangen
27.09.2004

- Introduction
- Current Deep-Sea Projects
- Aiming at a km^3 Detector in the Mediterranean
- The KM3NeT Design Study
- Conclusions and Outlook

Why Neutrino Telescopes?

- Neutrinos traverse space without deflection or attenuation
  - they point back to their sources;
  - they allow a view into dense environments;
  - they allow to investigate the universe over cosmological distances.
- Neutrinos are produced in high-energy hadronic processes
  $\rightarrow$ distinction between electron and proton acceleration.
- Neutrinos could be produced in Dark Matter annihilation.
- Neutrino detection requires huge target masses
  $\rightarrow$ use naturally abundant materials (water, ice).

The Neutrino Telescope World Map



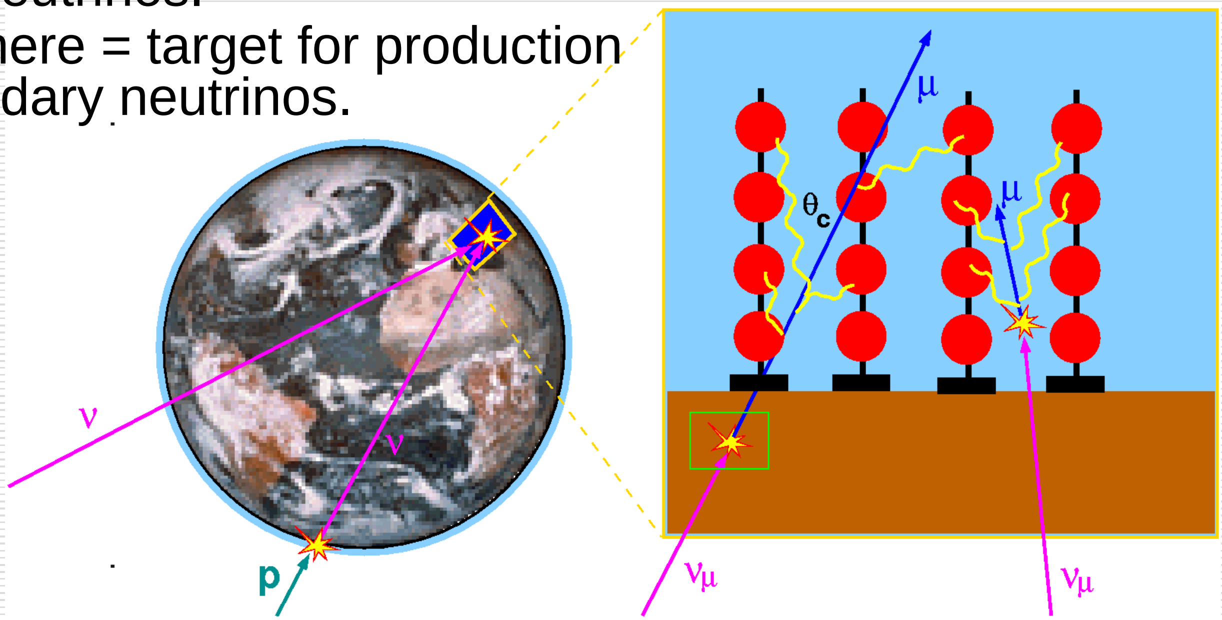
The Principle of Neutrino Telescopes

Role of the Earth:

- Screening against all particles except neutrinos.
- Atmosphere = target for production of secondary neutrinos.

Cherenkov light:

- In water: $\theta_C \approx 43°$
- Spectral range used: ~ 350-500nm.



Neutrino reactions (key reaction is $\nu_\mu N \rightarrow \mu X$):

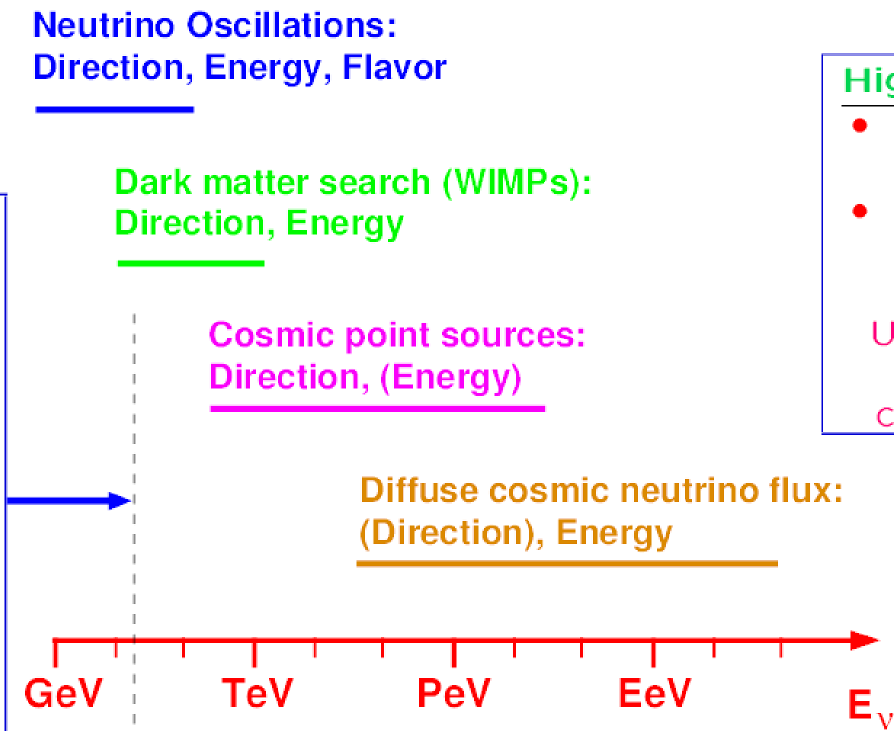
- Cross sections and reaction mechanisms known from accelerator experiments (in particular HERA).
- Extrapolation to highest energies (> 100 TeV) uncertain.

Particle and Astrophysics with ν Telescopes

Low-energy limit:

- short muon range;
- only few photo sensors give signal;
- in sea water: ^{40}K background prohibitive.

Intrinsic limit, can only be overcome with specialized, very densely instrumented detector.



High-energy limit:

- fluxes decrease as $E^{-2} \ldots E^{-3}$;
- large detection volume needed.

Ultimate volume (at least) one cubic kilometer.

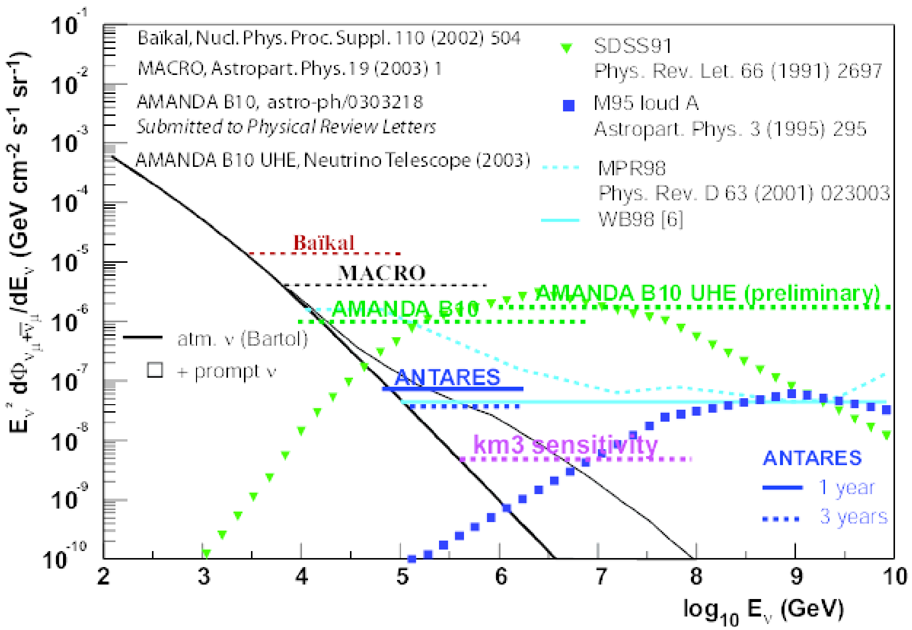
... and also:
- GZK–neutrinos
- Z bursts
- magnetic monopoles
- topological defects
- top–down scenarios
- supernova detection
- ...

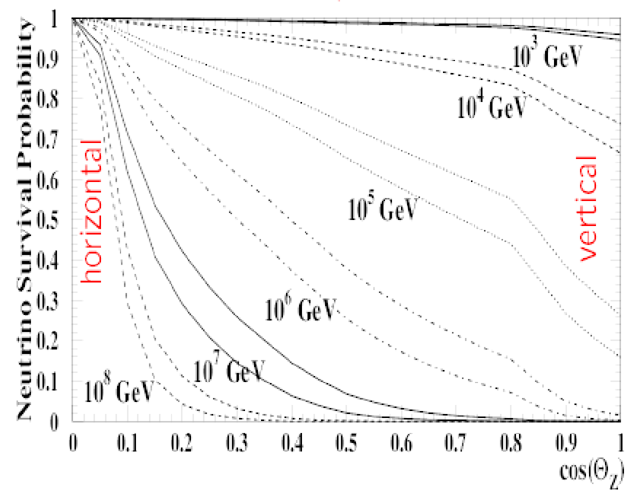
Neutrino Fluxes and Event numbers

Observed event numbers for diffuse fluxes:

$$\frac{dN_{\rm evt}}{dE_\nu\,dt} = \int_\Omega \underbrace{\frac{dN_\nu}{dE_\nu\,dt\,dA\,d\Omega}} \cdot \underbrace{\sigma(\nu_\mu N \to \mu X)} \cdot (\rho\,\underbrace{V_{\rm eff}}) \cdot T\,d\Omega + \underbrace{\frac{dN_{\rm evt}(\nu_e,\nu_\tau)}{dE_\nu\,dt} + \frac{dN_{\rm evt}({\rm NC})}{dE_\nu\,dt}}$$

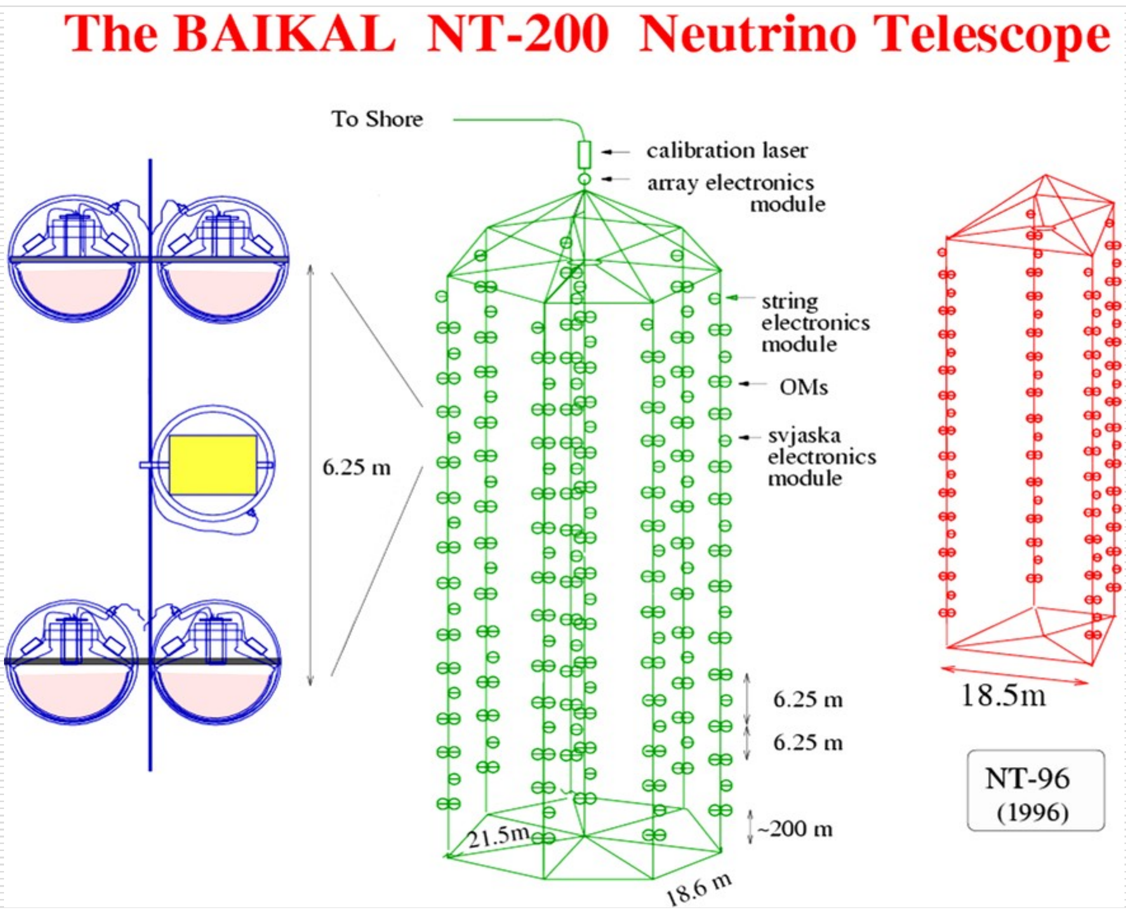
- Incoming cosmic flux $\Phi \propto E_\nu^{-2}$ (?)
- ν_μ CC cross section $\sigma \propto E_\nu$ (weaker rise at $E \gtrsim 10$ TeV)
- eff. volume, increases with range(μ). But: bad E_ν measurement
- contributions from other neutrino flavors and NC reactions

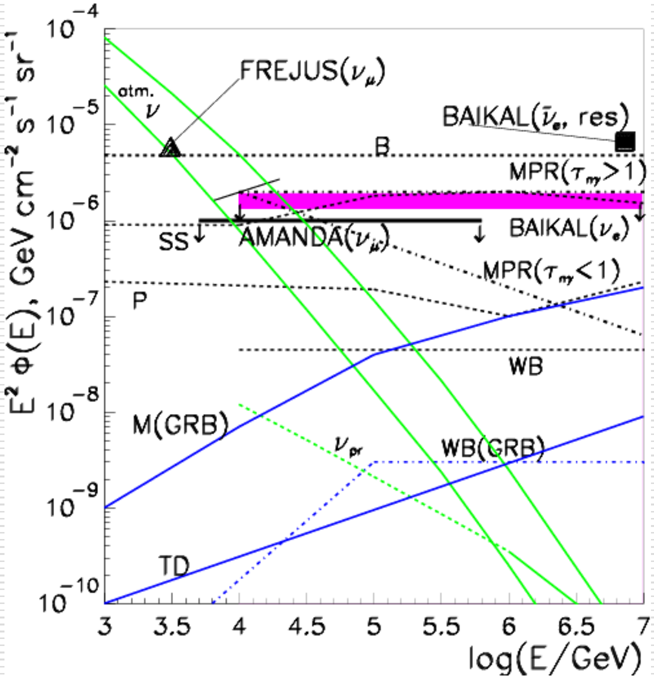


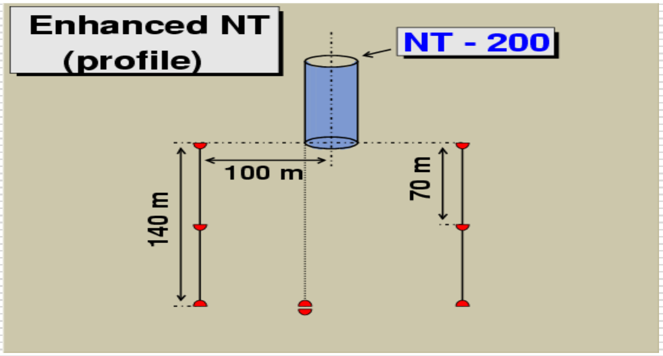


Lake Baikal: A Sweet-Water ν Telescope

- **Pioneers in under-water technology for ν telescopes.**
- **Many excellent physics results.**
- **Further upgrades planned, but km³ hardy reachable.**

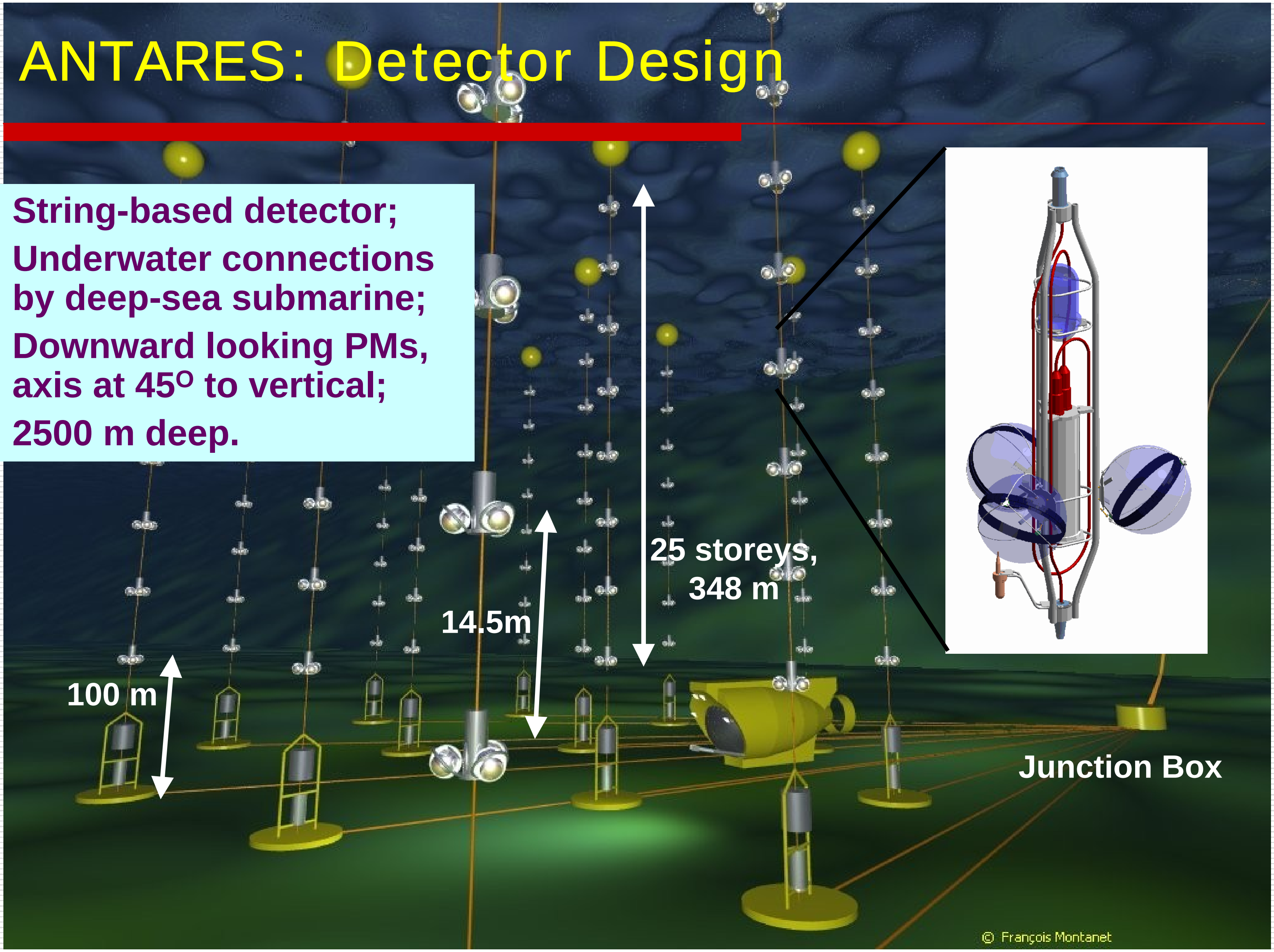






ANTARES: Detector Design

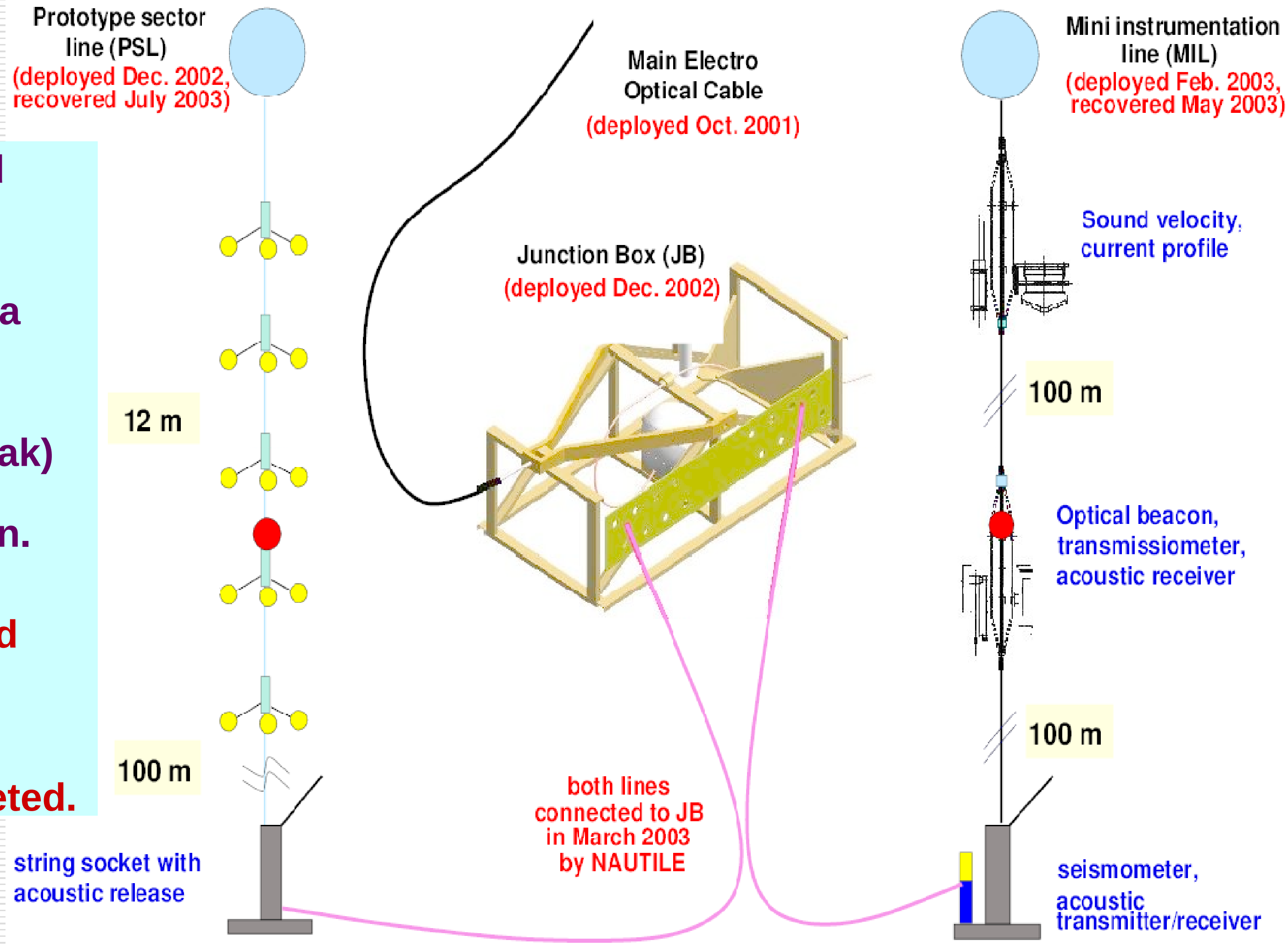
- **String-based detector;**
- **Underwater connections by deep-sea submarine;**
- **Downward looking PMs, axis at 45^{o} to vertical;**
- **2500 m deep.**



ANTARES: Status and Way to Completion

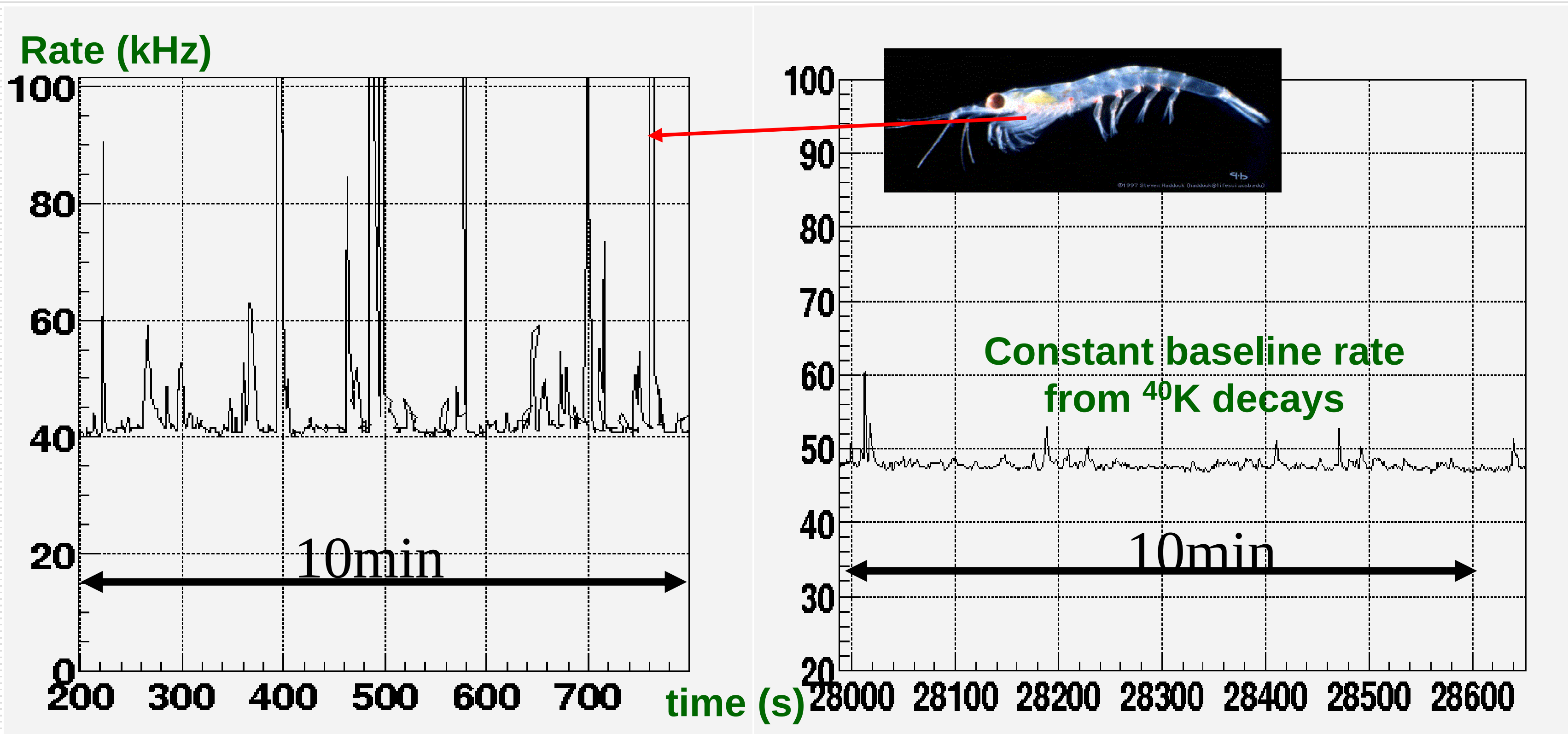
- **2003: Deployment and operation of two prototype lines.**
- **Several months of data taking.**
- **Technical problems (broken fiber, water leak)**
  → no precise timing,
  no μ reconstruction.

- **Early 2005: 2 upgraded prototype lines;**
- **Mid-2005: Line 1;**
- **2007: Detector completed.**



ANTARES: First Deep-Sea Data

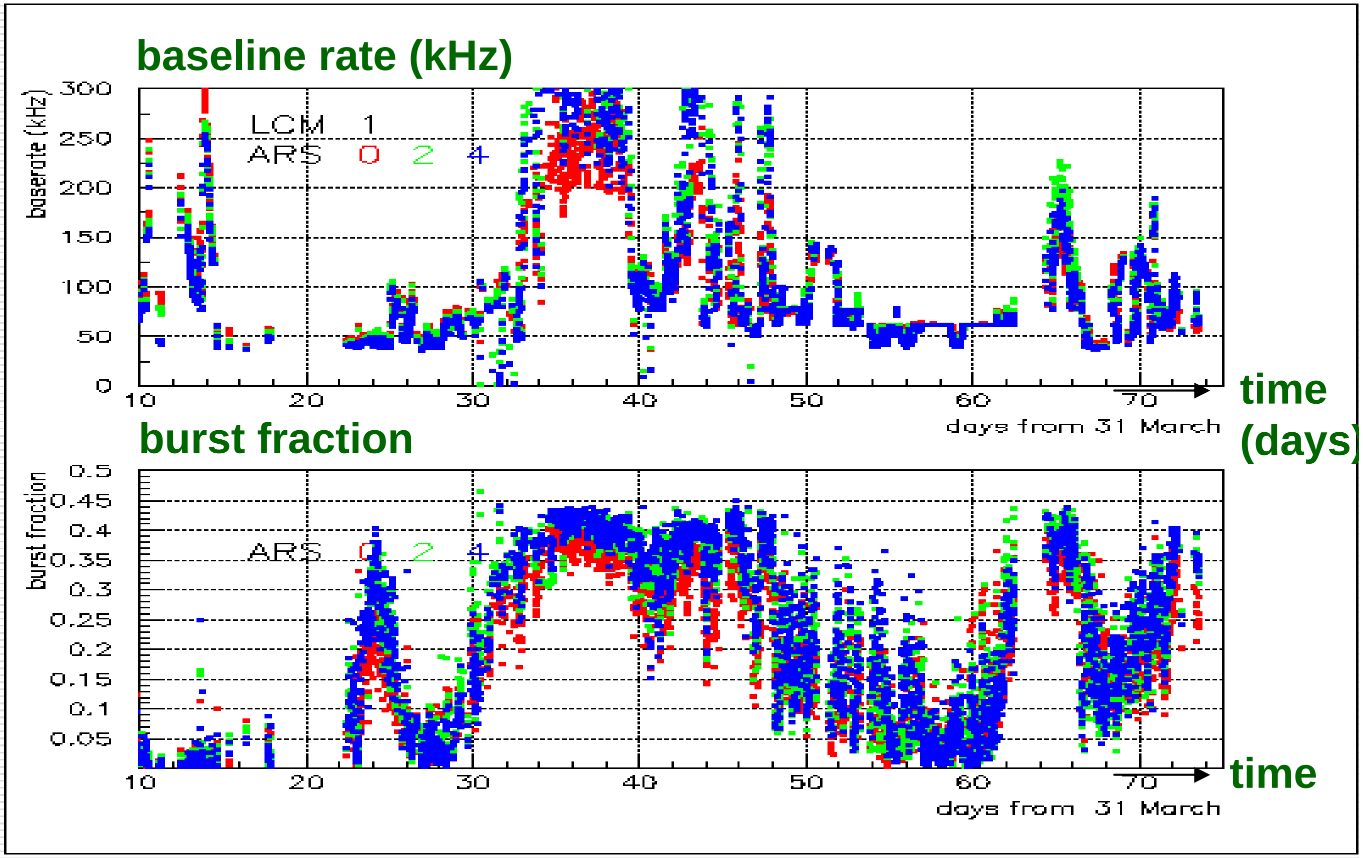
- Rate measurements: Strong fluctuation of bioluminescence background observed



ANTARES: Long-term Measurements

baseline rate =
15-minute average

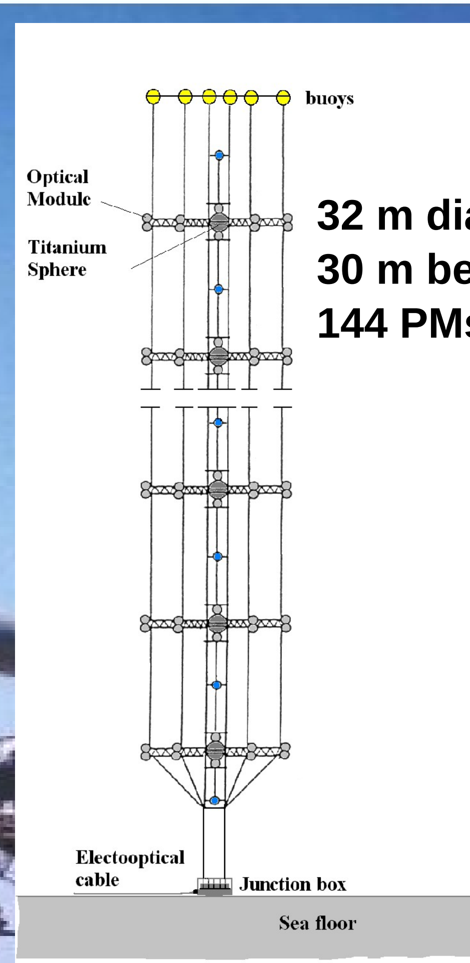
burst fraction =
time fraction above
1.2 x baseline rate



- Also measured: current velocity and direction, line heading and shape, temperatures, humidities, ...
- Important input for preparation & optimization of ANTARES operation.

NESTOR: Rigid Structures Forming Towers

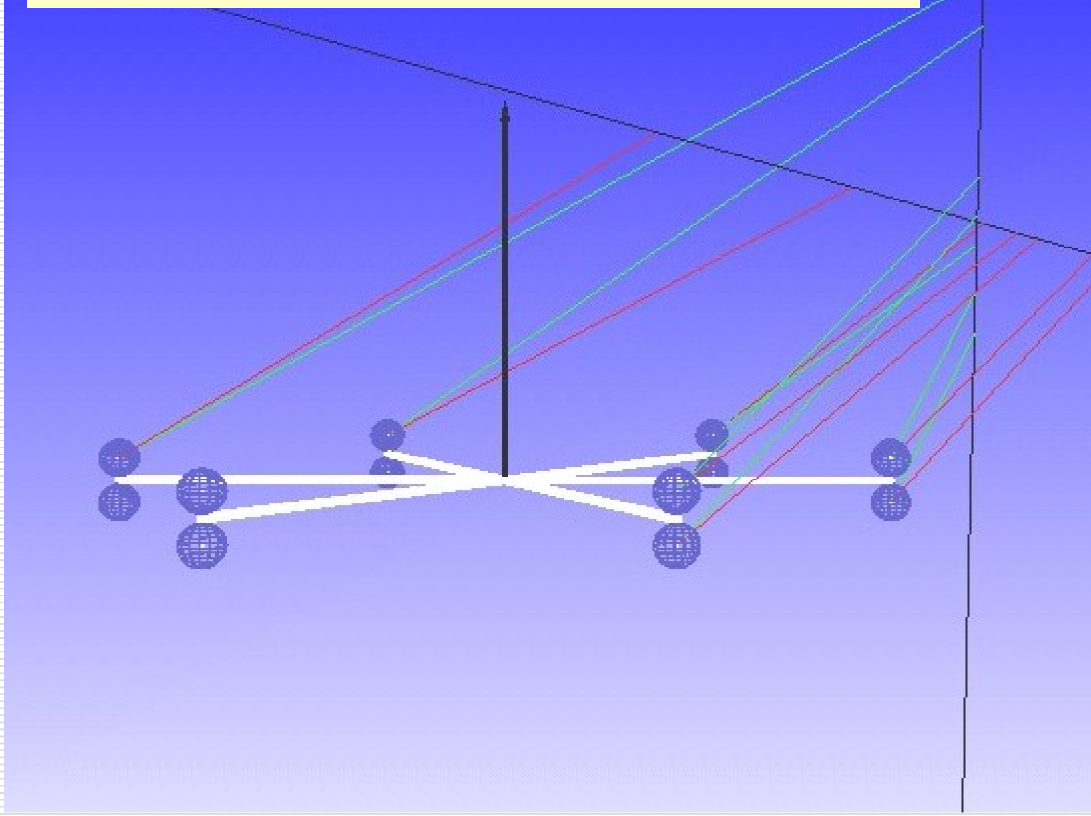
- Tower based detector (titanium structures).
- Dry connections (recover - connect - redeploy).
- Up- and downward looking PMs.
- 3800 m deep.
- First floor (reduced size) deployed & operated in 2003.

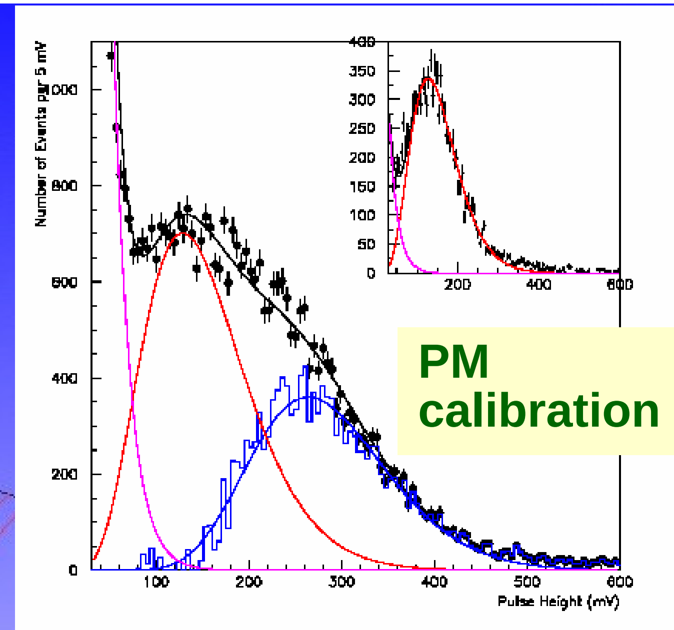


32 m diameter
30 m between floors
144 PMs

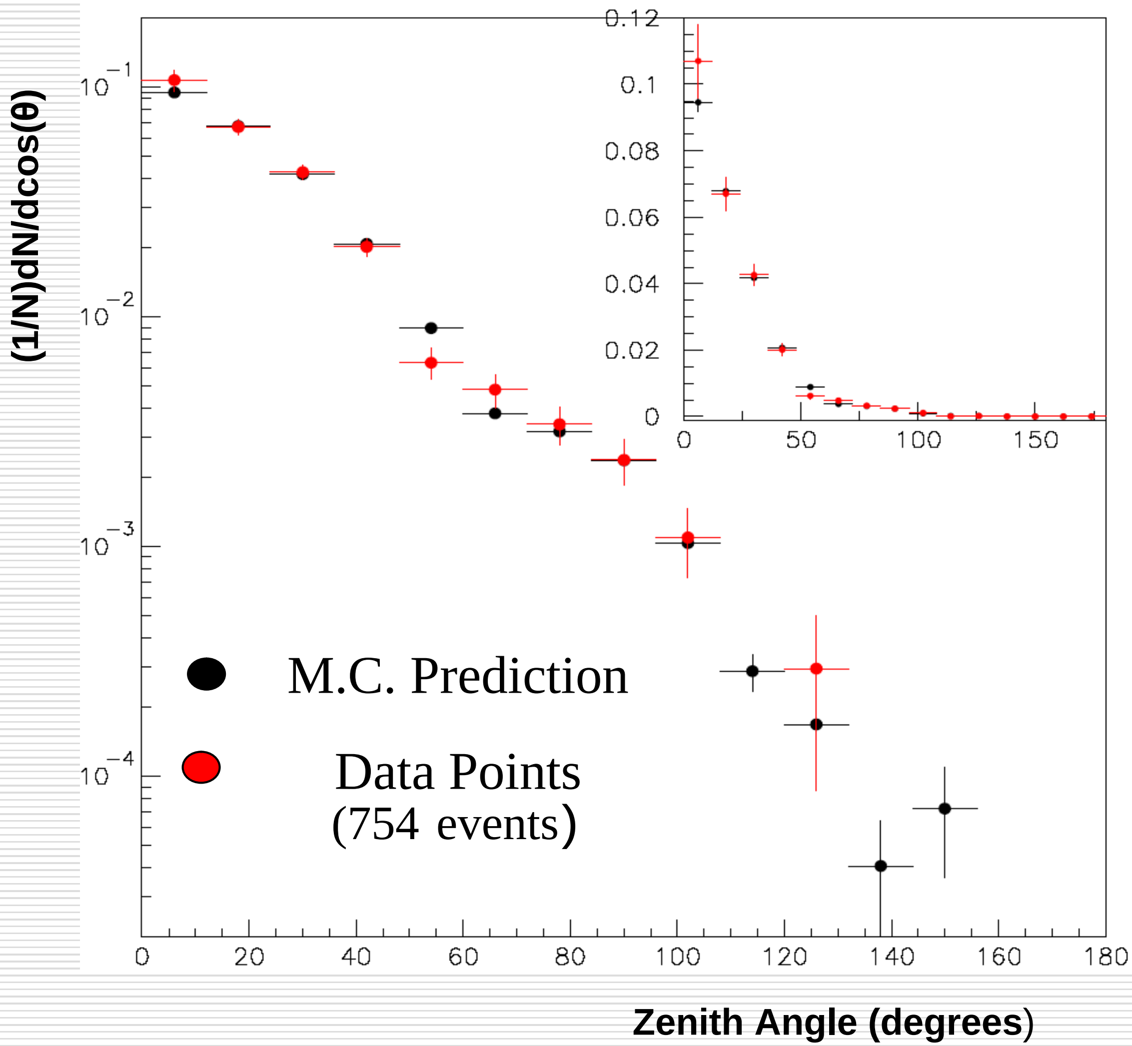
NESTOR: Reconstruction of Muon Tracks

- **Track reconstruction using arrival times of light at PMs.**
- **Ambiguities resolved using signal amplitudes in up/down PM pairs.**





NESTOR: Measurement of the Muon Flux



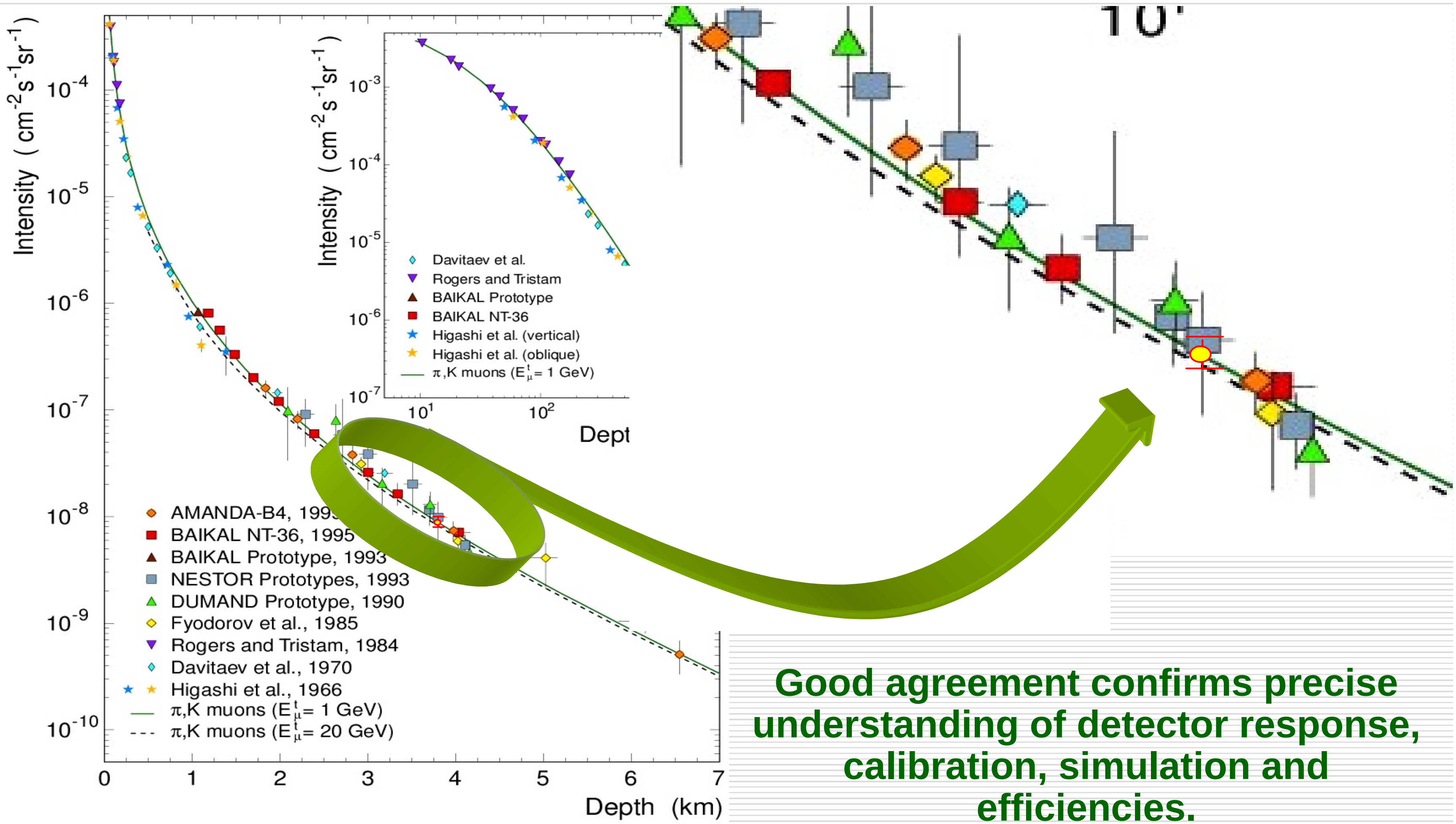
Atmospheric muon flux determination by reweighting MC simulation to observed raw zenith distribution using

$$\frac{dN}{d\Omega \cdot dt \cdot dS} = I_o \cos^{\alpha} \theta$$

Result:

α = 4.7
± 0.5 (stat.)
± 0.2 (syst.)
I_0 = [9.0×10^{-9}
± 0.7×10^{-9} (stat.)
± 0.4×10^{-9} (syst.)]
$cm^{-2}\, s^{-1}\, sr^{-1}$

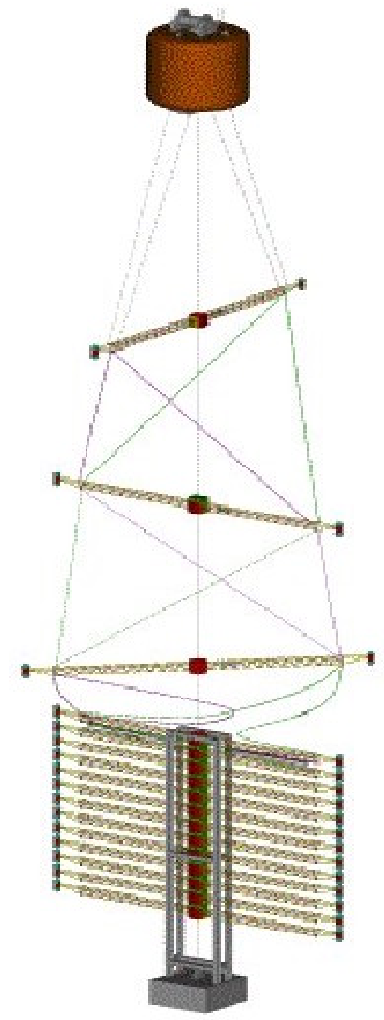
... and Comparison to Other Measurements



Good agreement confirms precise understanding of detector response, calibration, simulation and efficiencies.

The NEMO Project

- Extensive site exploration (Capo Passero near Catania, depth 3340 m)
- R&D towards km^3: architecture, mechanical structures, readout, electronics, cables ...
- Simulation

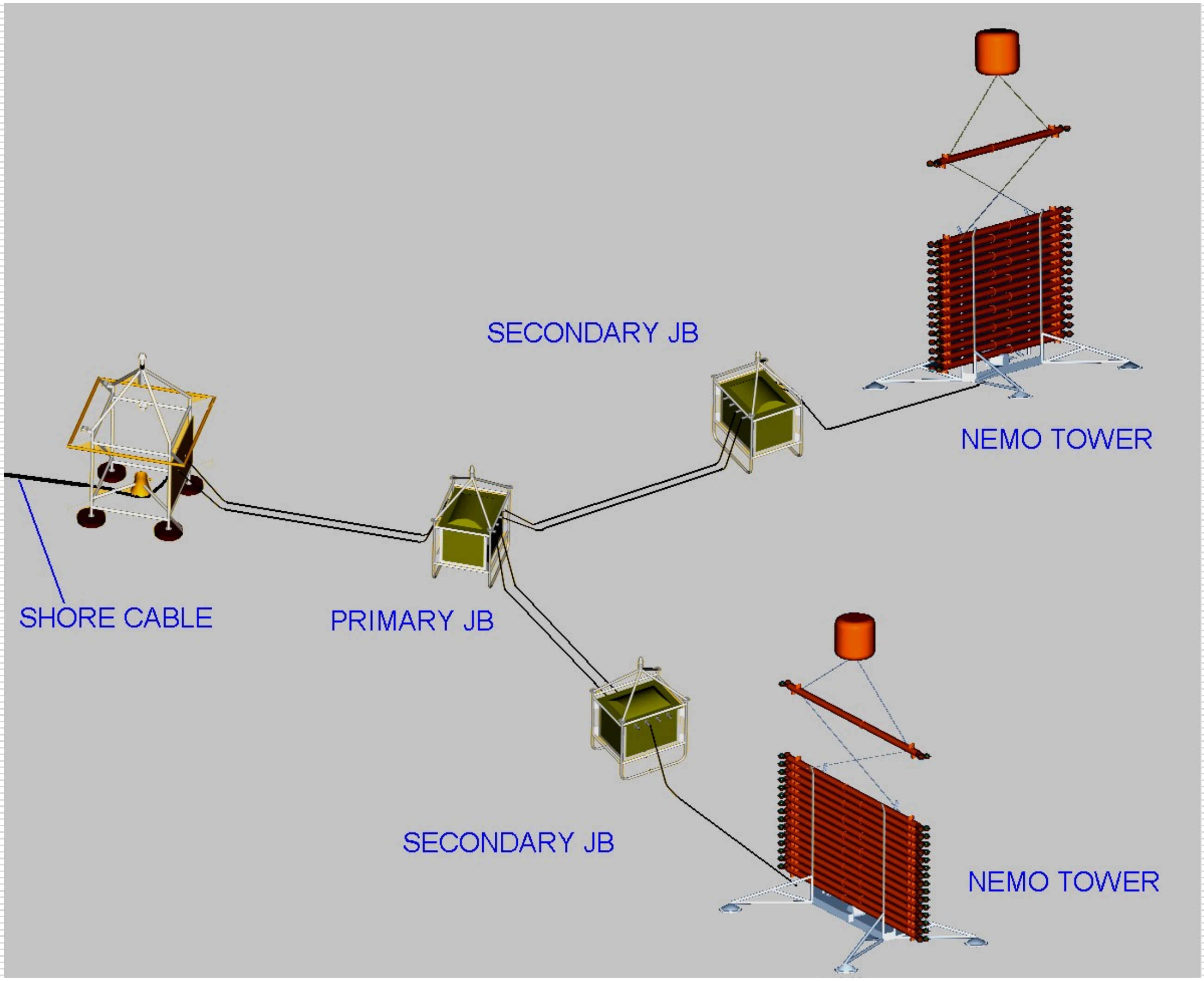


Example: Flexible tower

- **16 arms per tower, 20 m arm length, arms 40 m apart**
- **64 PMs per tower**
- **Underwater connections**
- **Up- and down-looking PMs**

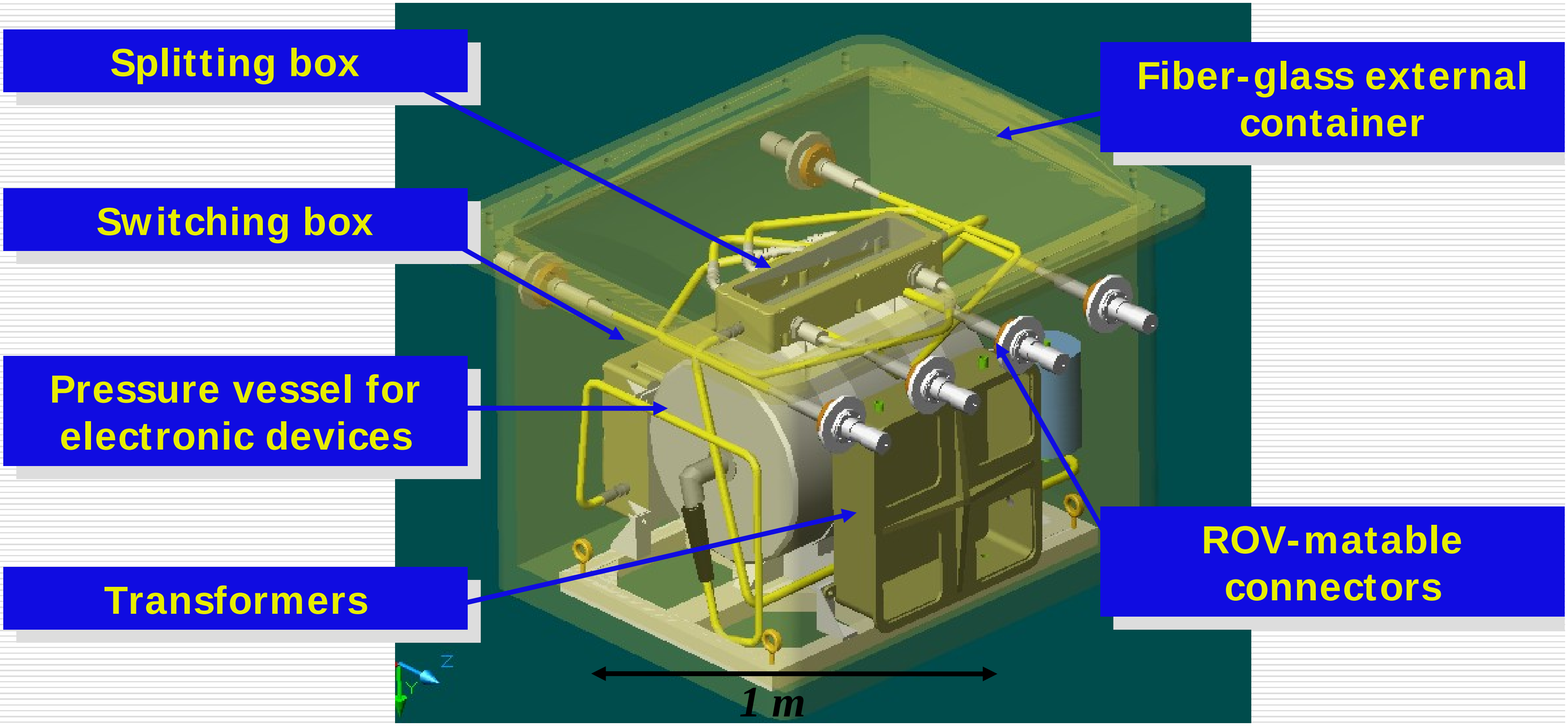
NEMO: Phase-1 Test

- Site at 2000 m depth identified.
- Test installation foreseen with all critical detector components.
- Funding ok.
- Completion expected by 2006.



NEMO: Junction Box R&D

Aim: Decouple the problems of pressure and corrosion resistance.



Aiming at a km^3-Detector in the Mediterranean

HENAP Report to PaNAGIC, July 2002:

- "The observation of cosmic neutrinos above 100 GeV is of great scientific importance. ..."
- "... a km^3-scale detector in the Northern hemisphere should be built to complement the IceCube detector being constructed at the South Pole."
- "The detector should be of km^3-scale, the construction of which is considered technically feasible."

Scientific Goals

- Astronomy via high-energy neutrino observation
  - Production of high-energy neutrinos in the universe (acceleration mechanisms, top-down scenarios, . . .);
  - Investigation of the nature of astrophysical objects;
  - Origin of cosmic rays;
  - No extraterrestric high-energy neutrinos observed so far $\rightarrow$ Predictions have large uncertainties.
- Indirect search for dark matter.
- New discoveries.
- Associated science.

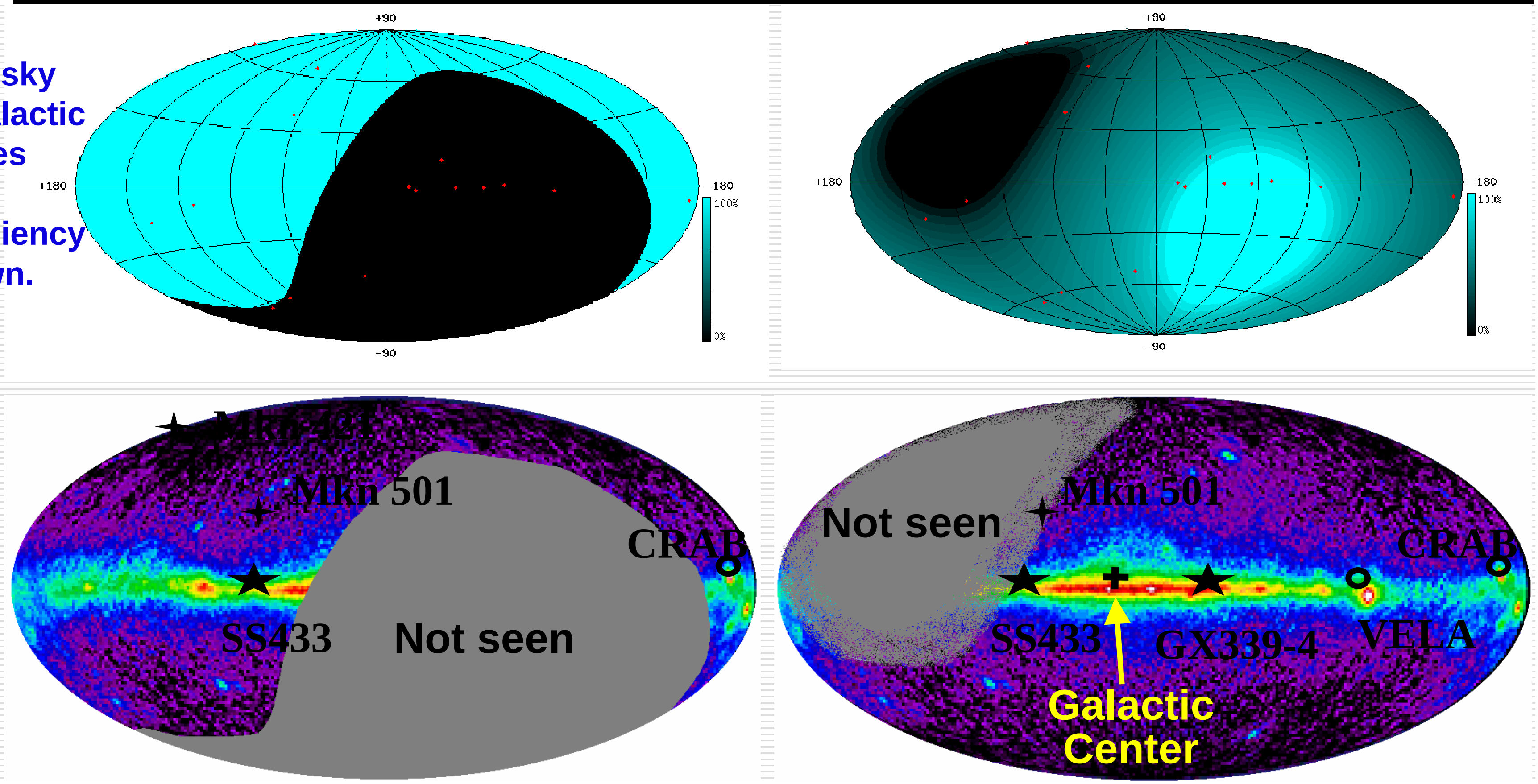
Point Sources

- Allows for association of neutrino flux to specific astrophysical objects.
- Energy spectrum, time structure and combination with multi-messenger observations provides insight into physical processes inside source.
- Searches profit from very good angular resolution of water Cherenkov telescopes.
- GRBs and other transient phenomena, if simultaneously observed by space-based experiments, allow for lower thresholds and larger efficiency.

Sky Coverage of Neutrino Telescopes

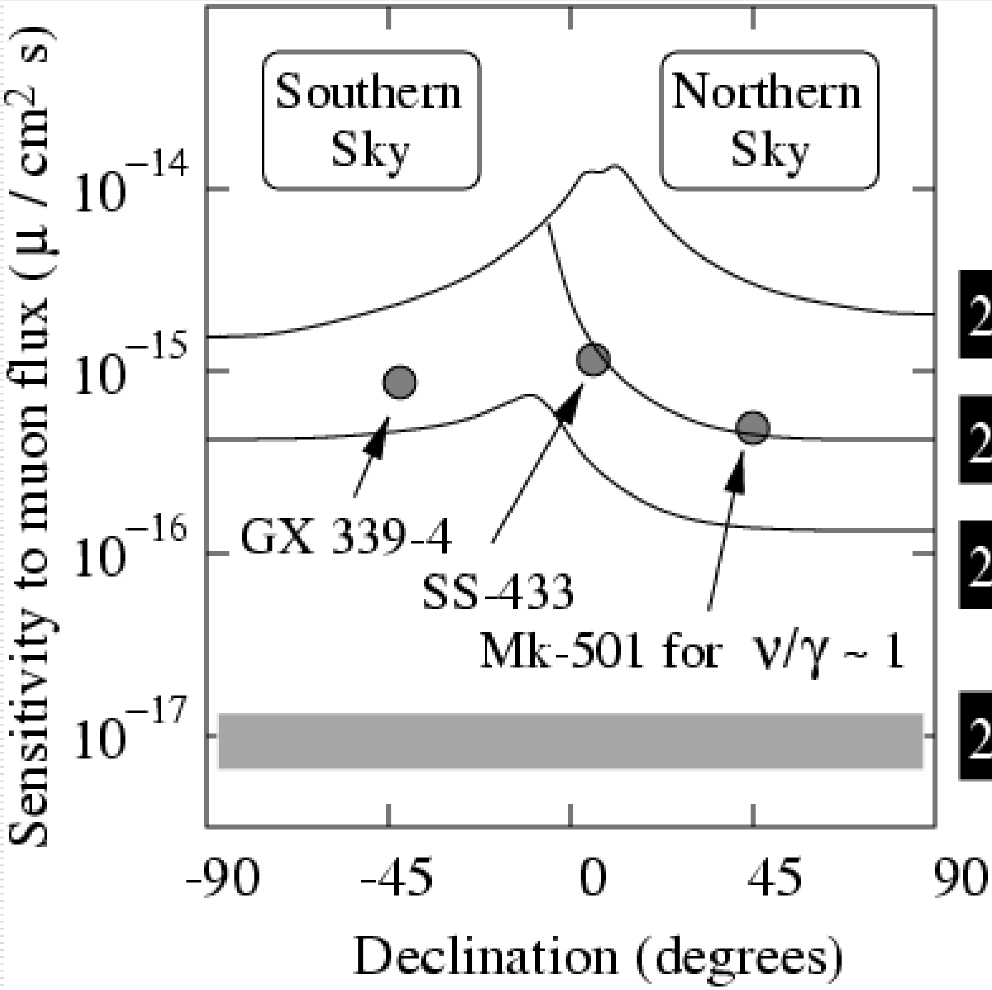
South Pole | **Mediterranean**

Region of sky seen in galactic coordinates assuming 100% efficiency for 2π down.



→ We need ν telescopes in both hemispheres to see the whole sky

Point Sources: Sensitivities



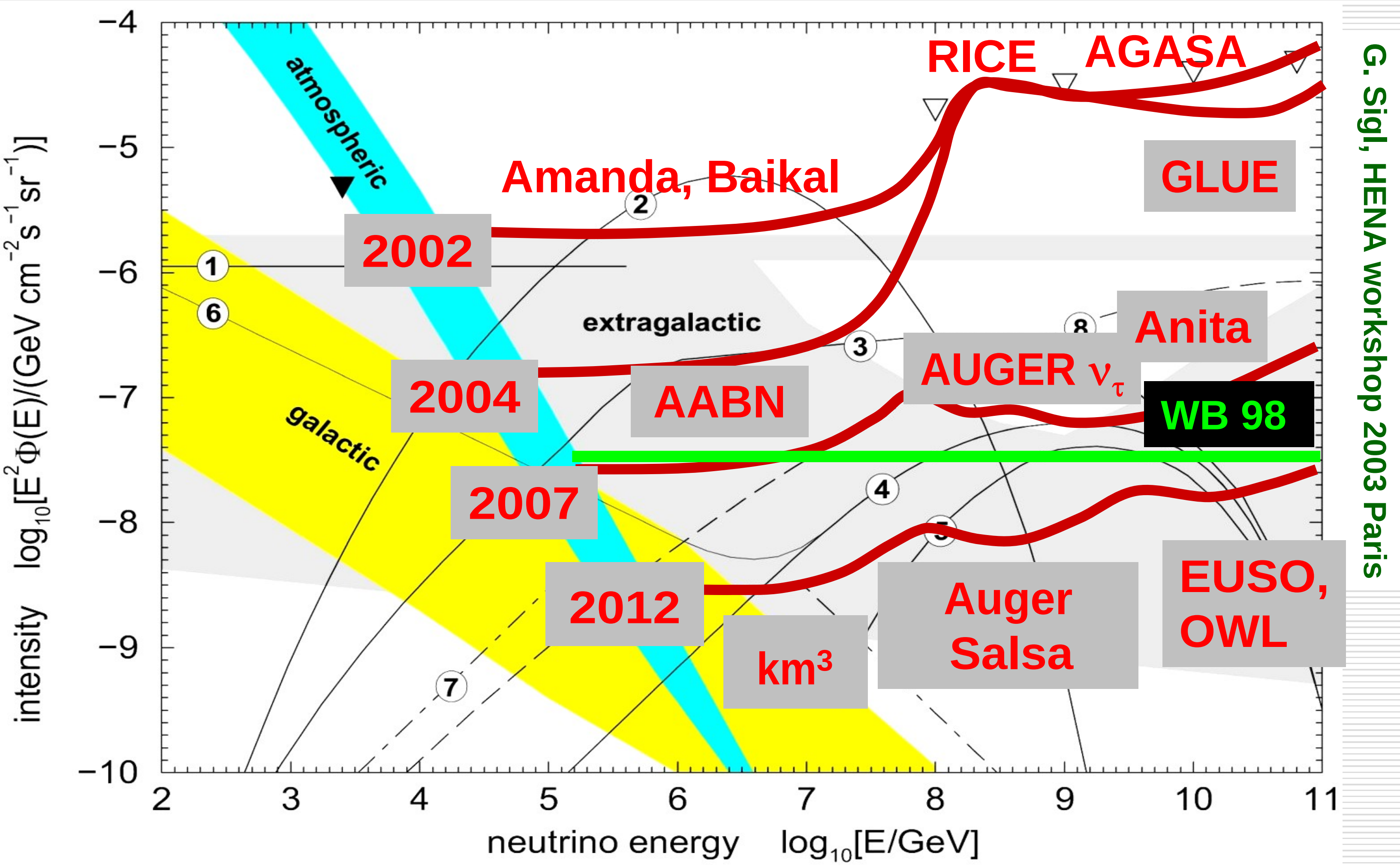
Ch. Spiering, astro-ph/0303068

- **2001** MACRO + SK + AMANDA-B10
- **2003** AMANDA
- **2007** AMANDA + IceCube + ANTARES + NESTOR
- **2012** IceCube + KM3NeT

Diffuse ν Flux

- Energy spectrum will provide important constraints on models of particle acceleration and energy budget at cosmological scales.
- Present theoretical upper limits are at the edge of current experiments' sensitivities
  → Precise flux measurement needs km^3-scale detector.
- Accessible energy range limited by atmospheric neutrino flux (~10^5 GeV) and detector size (~10^8 GeV).
- Measurements at these energies require sensitivity for neutrinos from above due to opacity of Earth.
- Cosmic neutrinos arrive in democratic flavour mix
  → Sensitivity to ν_e, ν_τ and NC reactions important.

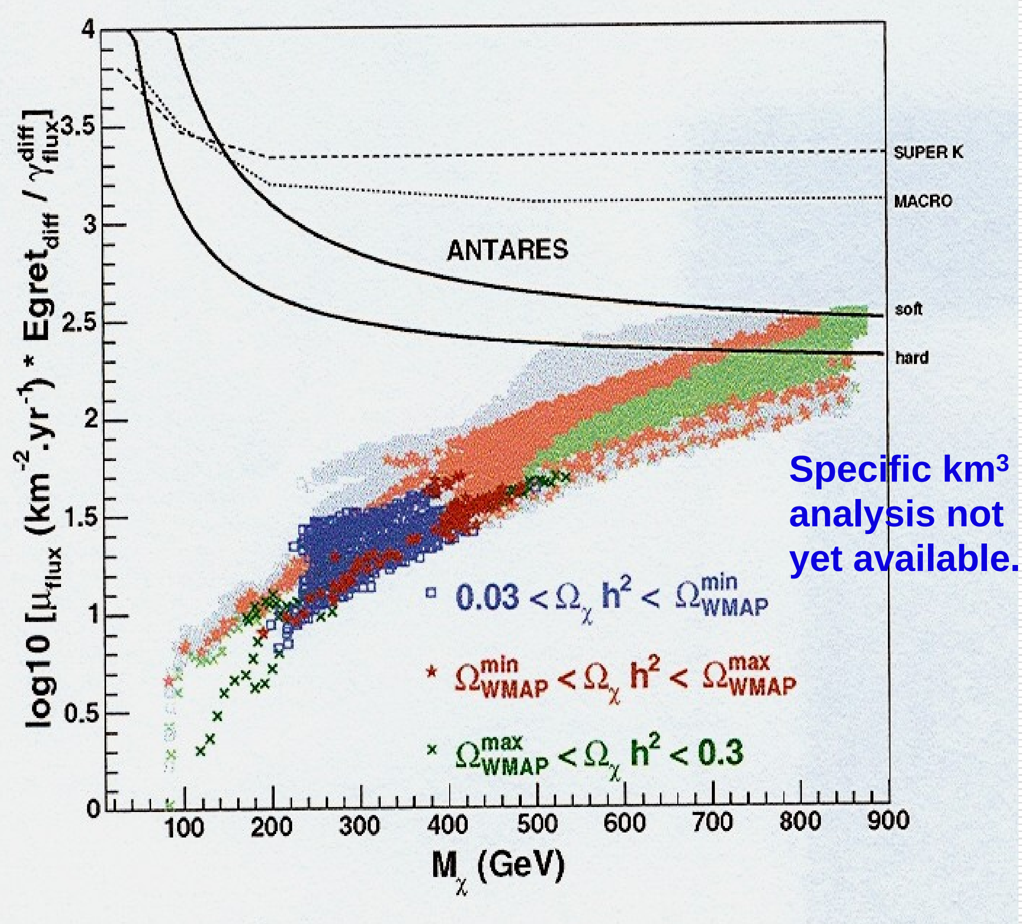
Diffuse ν Flux: Limits and Sensitivities



Dark Matter

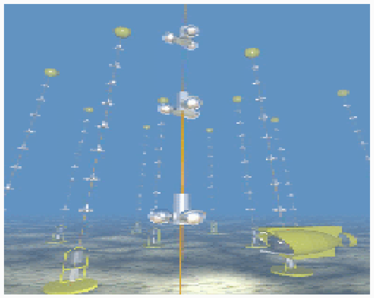
- **Neutrinos from co-annihilation of WIMPs gravitationally trapped in Earth, Sun or Galactic Center provide sensitivity of ν telescopes to Dark Matter.**
- **Detection requires low energy threshold (O(100GeV) or less).**
- **Could solve long-standing questions of both particle- and astrophysics.**
- **Flux from Galactic Centre may be enhanced if a Black Hole is present → exciting prospects (see e.g. P. Gondolo and J. Silk, PRL 83(1999)1719).**
- **But: model uncertainties are orders of magnitude!**

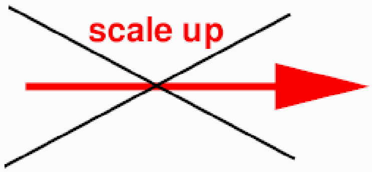
from G. Bertone et al., astro-ph/0403322



Specific km³ analysis not yet available.

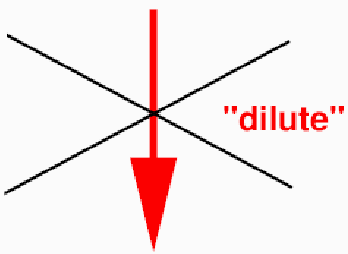
How to Design a km³ Deep-Sea ν Telescope





Existing νT's times 100–1000 ?

- **Too expensive:** ANTARES $\times$ 100 $= \mathcal{O}(2 \times 10^9)$ Euros.
- **Too complicated:** production/deployment take forever, maintenance impossible.
- **Not scalable:** e.g. readout bandwidth, online filter, power distribution, ...



km3 volume with ∼same number of PMs as in existing νT's ?

- **PM distance:** determined by light attenuation in water (+PM properties).
- **Efficiency loss:** Effective volume $\ll 1\,\mathrm{km}^3$ except maybe at highest E_ν.

Research and Development needed:

- **Cost-effective solutions:** Reduce price/volume by factor $\gtrsim 10$.
- **Increased stability:** Goal: maintenance-free detector.
- **"Fast" installation:** Time for construction & deployment less than detector life time.
- **Photo sensors:** High quantum efficiency, large area, low noise, directional sensitivity.
- . . .

A major R&D project is needed!

Some Key Questions

- Which architecture to use?
(strings vs. towers vs. new design)
- How to get the data to shore?
(optical vs. electric, electronics off-shore or on-shore)
- How to calibrate the detector?
(separation of calibration and detection units?)
- Design of photo-detection units?
(large vs. several small PMs, directionality, ...)
- Deployment technology?
(dry vs. wet by ROV/AUV vs. wet from surface)
- And finally: The site choice/recommendation!

The KM3NeT Design Study (EU FP6)

Design Study for a Deep-Sea Facility in the Mediterranean for Neutrino Astronomy and Associated Sciences

- Initial initiative Sept 2002 (ApPEC meeting, Paris).
- Intense discussions and coordination meetings from beginning of 2003 on.
- VLVνT Workshop, Amsterdam, Oct 2003.
- ApPEC review, Nov 2003.
- Inclusion of sea science/technology institutes (Jan 2004).
- Proposal submission 04.03.2004.
- Evaluation report received June 2004 (overall mark: 88%).
- Unofficial but reliable message a few days ago:

The KM3NeT Design Study will be funded !

KM3NeT Participants

- Cyprus: Univ. Cyprus
- France: CEA/Saclay, CNRS/IN2P3 (CPP Marseille, IreS Strasbourg), IFREMER
- Germany: Univ. Erlangen, Univ. Kiel
- Greece: HCMR, Hellenic Open Univ., NCSR Democritos, NOA/Nestor, Univ. Athens
- Italy: CNR/ISMAR, INFN (Univs. Bari, Bologna, Catania, Genova, Messina, Pisa, Roma-1, LNS Catania, LNF Frascati), INGV, Tecnomare SpA
- Netherlands: NIKHEF/FOM
- Spain: IFIC/CSIC Valencia, Univ. Valencia, UP Valencia
- UK: Univ. Aberdeen, Univ. Leeds, Univ. Liverpool, John Moores Univ. Liverpool, Univ. Sheffield

Particle/Astroparticle institutes – Sea science/technology institutes – Coordinator

Objectives and Scope of the KM3NeT DS

Establish path from current projects to KM3NeT:

- Critical review of current technical solutions;
- Thorough tests of new developments;
- Comparative study of sites and recommendation on site choice (figure of merit: physics sensitivity / €);
- Assessment of quality control and assurance;
- Exploration of possible cooperation with industry;
- Investigation of funding and governance models.

Envisaged time scale of design, construction and operation poses stringent conditions.

Design Study Target Values

- Detection principle: water Cherenkov.
- Location in Europe: in the Mediterranean Sea.
- Detection view:
  maximal angular acceptance for all possible detectable neutrino signals including down-going neutrinos at VHE.
- Angular resolution: close to the intrinsic resolution
  ($< 0.1°$ for muons with $E_\mu > 10$ TeV).
- Detection volume: 1 km^3, expandable.
- Lower energy threshold:
  a few 100 GeV for upward going neutrinos with the possibility to go lower for ν from known point sources.
- Energy reconstruction: within a factor of 2 for muon events.
- Reaction types: all neutrino flavors.
- Duty cycle: close to 100%.
- Operational lifetime: ≥ 10 years.
- Cost-effectiveness: < 200 M€ per km^3

All these parameters need optimisation !

Exploitation Model

Goal: facility exploited in multi-user and interdisciplinary environment.

- Reconstructed data will be made available to the whole community.
- Observation of specific objects with increased sensitivity will be offered
  (dedicated adjustment of filter algorithms).
- Close relation to space-based observatories will be established (alerts for GRBs, Supernovae etc.)
- "Plug-and-play" solutions for detectors of associated sciences.

Associated Sciences

- Great interest in long term deep-sea measurements in many different scientific communities:
  - Biology
  - Oceanography
  - Environmental sciences
  - Geology and geophysics
  - . . .
- Substantial cross-links to ESONET (The European Sea Floor Observatory Network).
- Plan: include the associated science communities in the design phase to understand and react to their needs and make use of their expertise (e.g. site exploration, bioluminescence).

Work Packages

- WP1: Management of the Design Study
- WP2: Astroparticle physics
  (benchmark ν fluxes, simulation, calibration, geometry optimization)
- WP3: Physics analysis
  (event selection, classification, reconstruction; physics sensitivity studies)
- WP4: System and product engineering
  (optical and calibration modules, mechanical components, readout implement'n, calibration devices, assembly/transport procedures, production lines)
- WP5: Information technology
  (signal detection/transmission, readout procedures, data handling & distribution)
- WP6: Shore & deep-sea infrastructure
  (site studies, deployment/recovery, cables, power distribution, shore station)
- WP7: Sea surface infrastructure
  (floating structures for deployment/recovery, surface calibration devices)
- WP8: Risk assessment and quality assurance
- WP9: Resource exploration
  (governance, legal and funding aspects for construction/operation of KM3NeT)
- WP10: Associated science
  (cooperation model, sensors & interfaces, input to KM3NeT design)

KM3NeT DS: Resources

- Suggested overall budget of the Design Study: 24 M€
  (mainly personnel, but also equipment, consumables, travel etc.)
- Amount requested from EU: 10 M€
- Estimated overall labor power: ~3500 FTEMs
  (FTEM = full-time equivalent person month)
  → 100 persons working full-time over 3 years!

Substantial resources (labor power) additional to those available in the current pilot projects will be required !

KM3NeT: Time Schedule

Time scale given by "community lifetime" and competition with ice detector

- Experience from current first generation water neutrino telescopes is a solid basis for the design of the KM3NeT detector.
- Interest fades away if KM3NeT comes much later than IceCube (ready by 2010).

Time schedule (optimistic):

01.01.2006	Start of Design Study
Mid-2007	Conceptual Design Report
End of 2008	Technical Design Report
2009-2013	Construction
2010-20XX	Operation

A few Remarks on EU Applications/Projects

- The EU applies rather stringent and formal rules.
  These rules are not laws of nature – so physicists tend to ignore them!
- Writing proposals:
  - Take the evaluation criteria serious; for DS's e.g.:

    European added value
    Scientific and technological excellence
    Relevance to the objectives of the scheme
    Quality of the management
  - Read all available EU documentation – learn "EUish":

    " Indirect costs are, for those working on the full cost model, all eligible costs determined by the contractor, in accordance with its usual practices, which are not directly attributable to the project but are incurred in relation to the direct costs of the project. "
- Evaluation process:
  - Well structured and transparent from inside . . .
  - . . . but completely opaque from outside!
  - It helps a lot to take part in EU evaluations.
- Next to come: Negotiations, consortium contract, ...

Conclusions and Outlook

- Neutrino astronomy opens a new window to the universe.
  To fully exploit it, we need 2 km^3–scale ν telescopes:
  - In the South, IceCube/AMANDA are on track.
  - In the North, the Mediterranean Sea offers optimal conditions for a ν telescope observing the Southern sky.
- Mediterranean projects ANTARES, NEMO, NESTOR:
  - ANTARES & NESTOR currently under construction, first data taken → feasibility proof and essential experience.
  - NEMO: Ongoing R&D efforts towards future, cost-effective solutions.
  - Common effort to realize next-generation ν telescope (KM3NeT).
- The EU KM3NeT Design Study (2006-2008) aims at laying the foundation for the construction of the detector.

We look forward to a world-wide multi-messenger cooperation!