IDM 2006, Rhodes Island, Greece – 11.-16. September 2006

KM3NeT: The Future km³-Scale ν Telescope in the Mediterranean Sea

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- Scientific motivation
- Current Projects: ANTARES, NEMO, NESTOR
- The KM3NeT Design Study and Beyond
- KM3NeT and Dark Matter
- Conclusions and Outlook

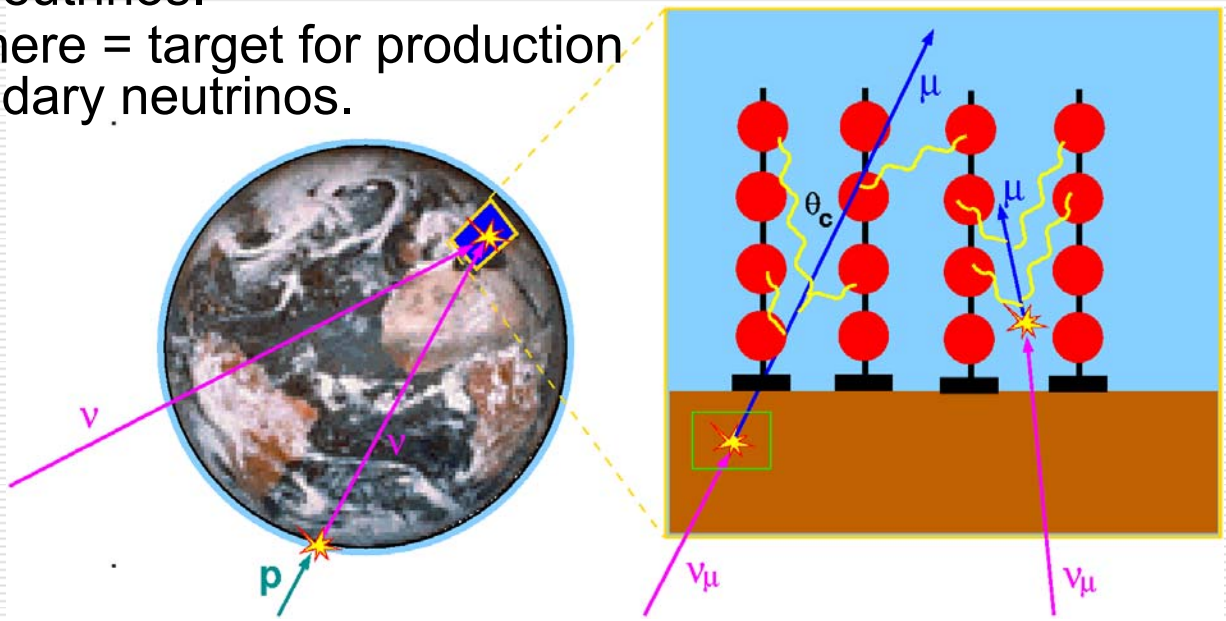
The Principle of Neutrino Telescopes

Role of the Earth:

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

Čerenkov light:

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



Angular resolution in water:

- Better than ~0.3° for neutrino energy above ~10 TeV, 0.1° at 100 TeV
- Dominated by angle(ν,μ) below ~10 TeV (~0.6° at 1 TeV)

Astro- and Particle Physics with ν Telescopes

Neutrino Oscillations:
Direction, Energy, Flavor

Low-energy limit:
- short muon range
- small number of photons detected
- background light from K40 decays

Dark matter search (WIMPs):
Direction, Energy

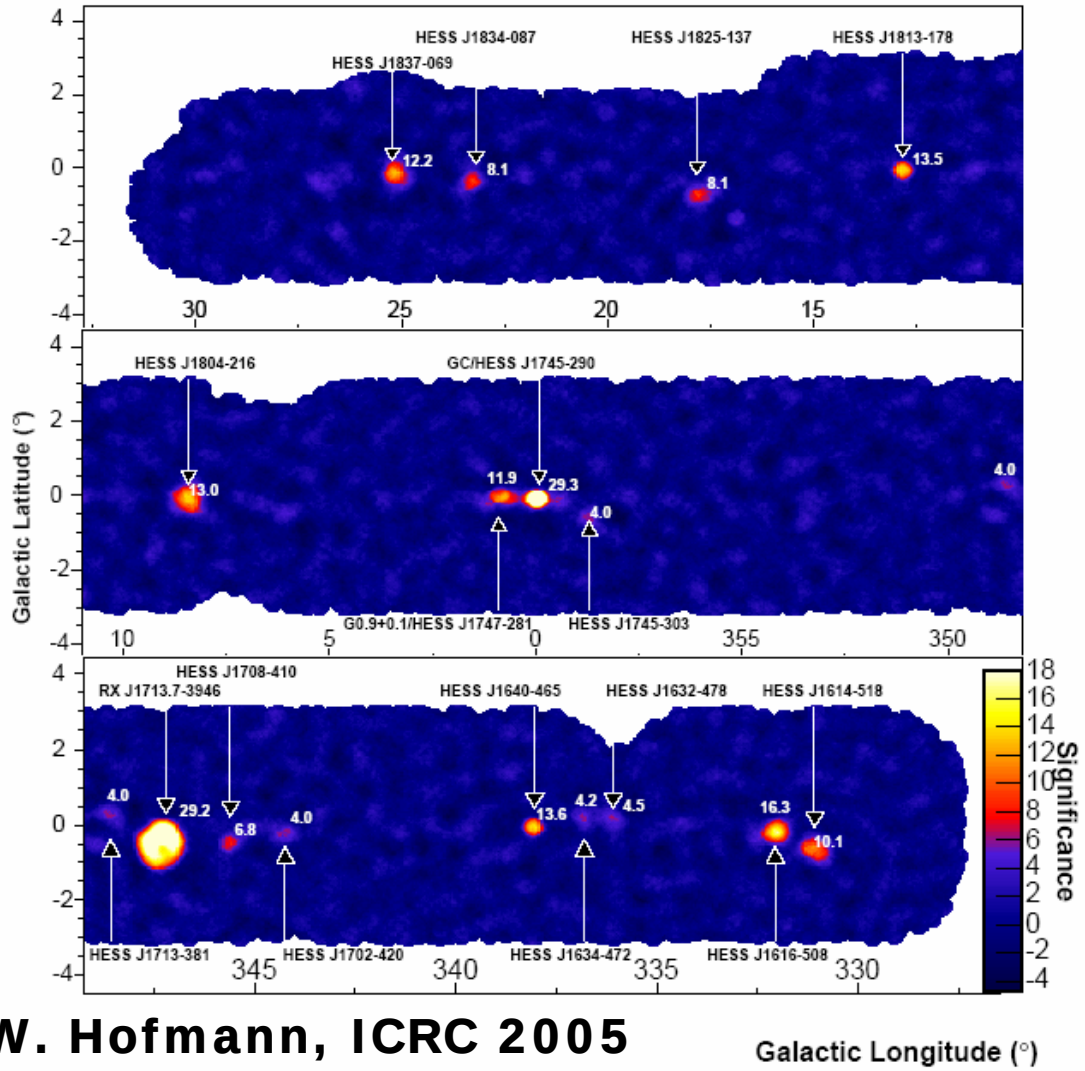
Astrophysical point sources:
Direction, (Energy), Time

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

Diffuse cosmic neutrino flux:
(Direction), Energy

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

High-energy γ sources in the Galactic Disk



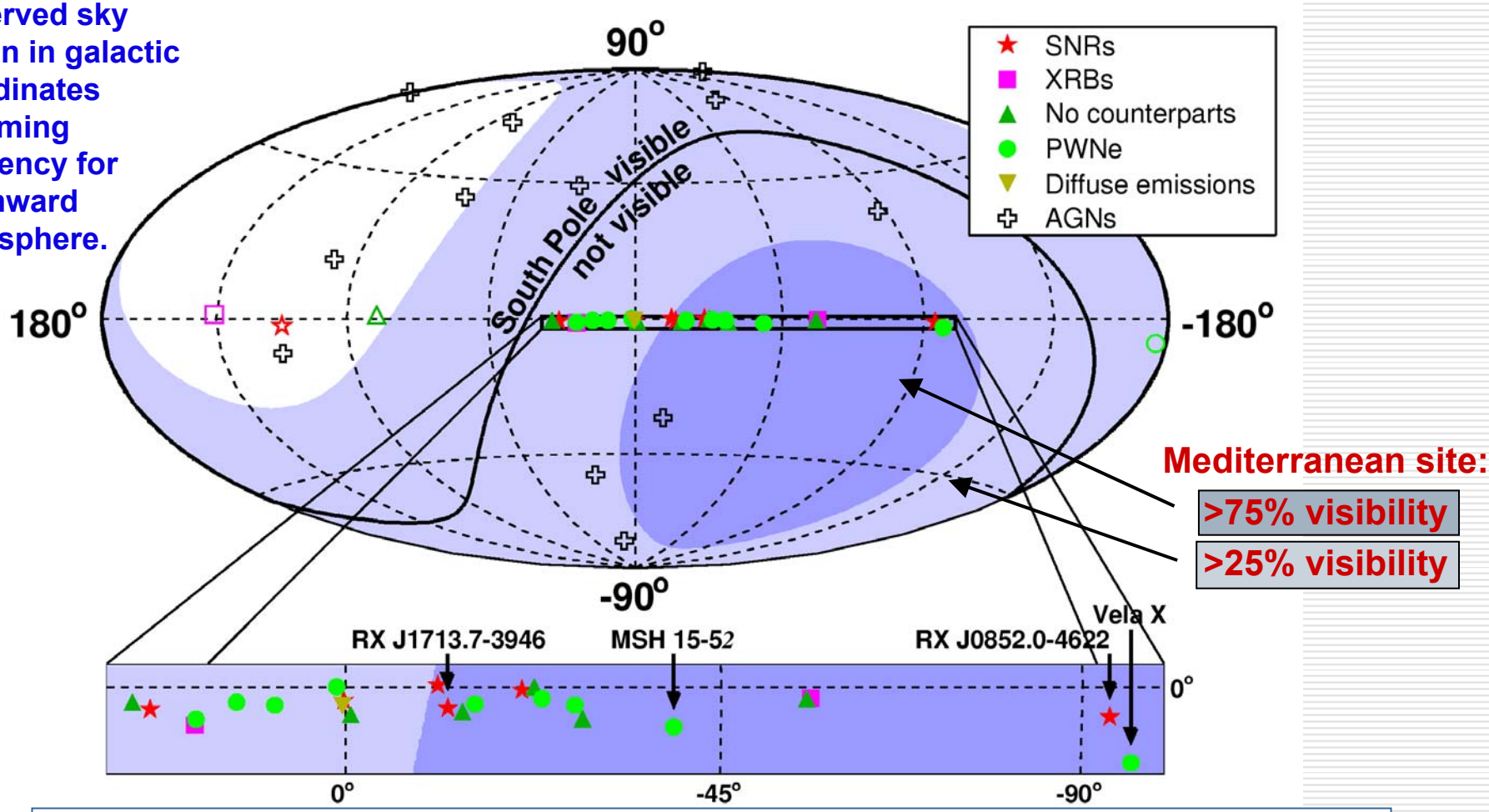
W. Hofmann, ICRC 2005

Update June 2006:

- 6 γ sources could be/are associated with SNR, e.g. RX J1713.7-3946;
- 9 are pulsar wind nebulae, typically displaced from the pulsar;
- 2 binary systems (1 H.E.S.S. / 1 MAGIC);
- 6 have no known counterparts.

Sky Coverage of Neutrino Telescopes

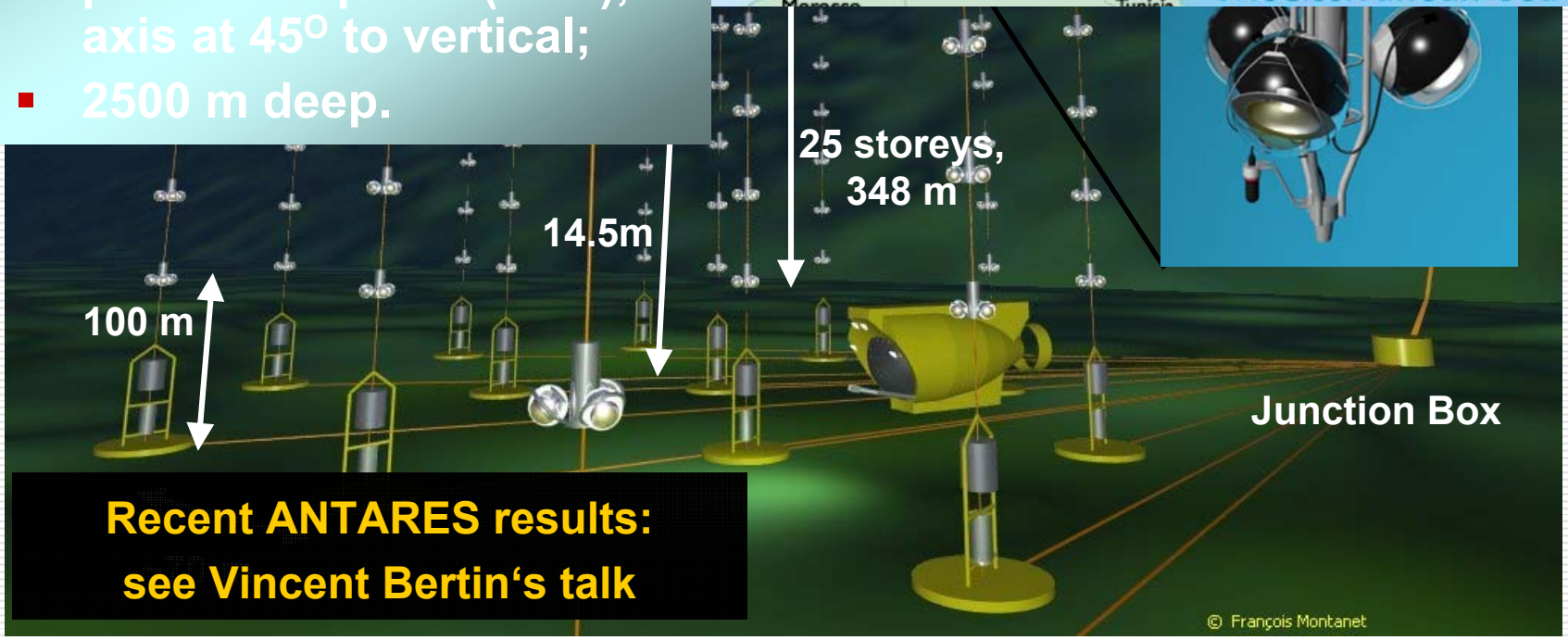
Observed sky region in galactic coordinates assuming efficiency for downward hemisphere.



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

ANTARES: Detector Design

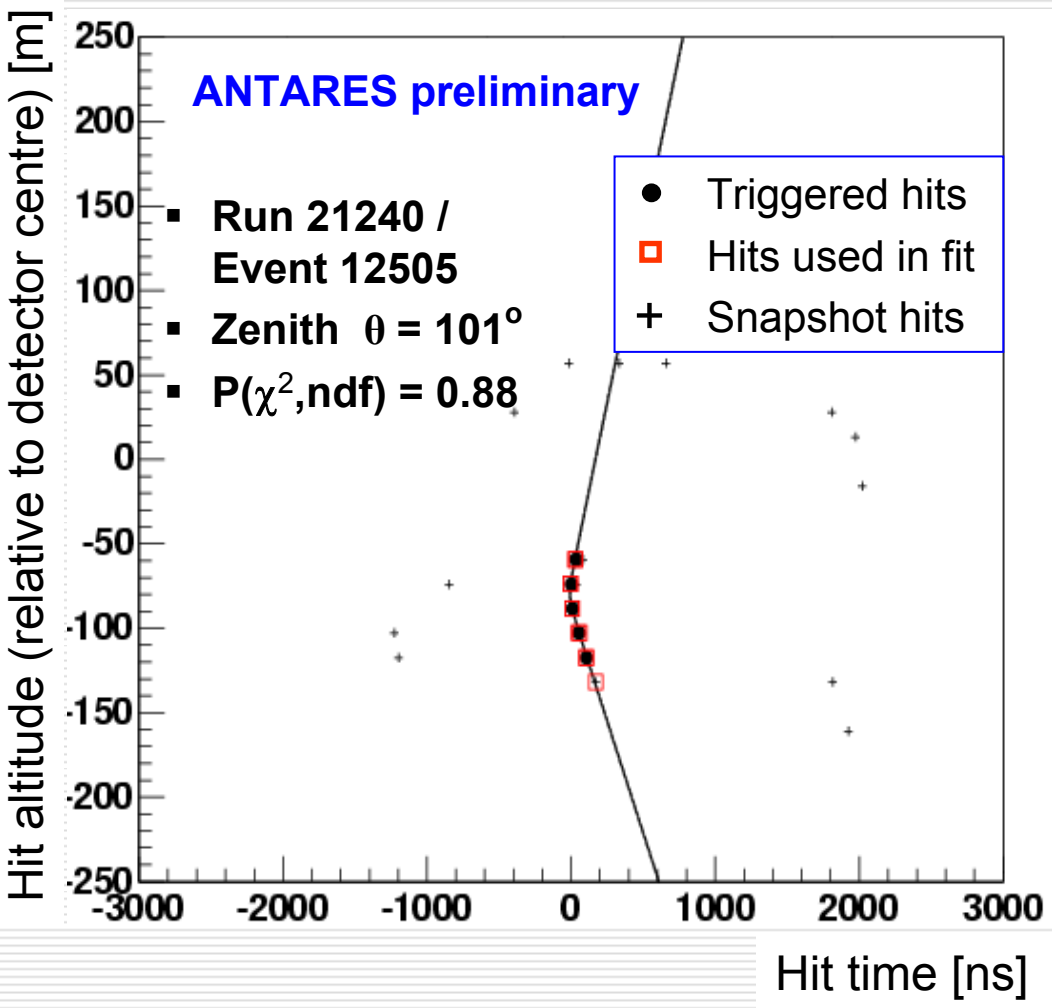
- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking photomultipliers (PMs), axis at 45° to vertical;
- 2500 m deep.



Recent ANTARES results: see Vincent Bertin's talk

ANTARES: Status and Outlook

- Deployment and operation of several prototype lines in 2003-2005 confirm expected functionality and help to fix last design issues.
- First full line deployed and connected, taking data since March 2, 2006.
- All subsystems operational. Time and position calibration verified.
- First muons reconstructed.
- Detector completion expected by end of 2007.



NESTOR: Rigid Structures Forming Towers

- Tower based detector (titanium structures).
- Dry connections (recover − connect − redeploy).
- Up- and downward looking PMs (15’’).
- 4000 m deep.
- Test floor (reduced size) deployed & operated in 2003.
- Deployment of 4 floors planned in 2007

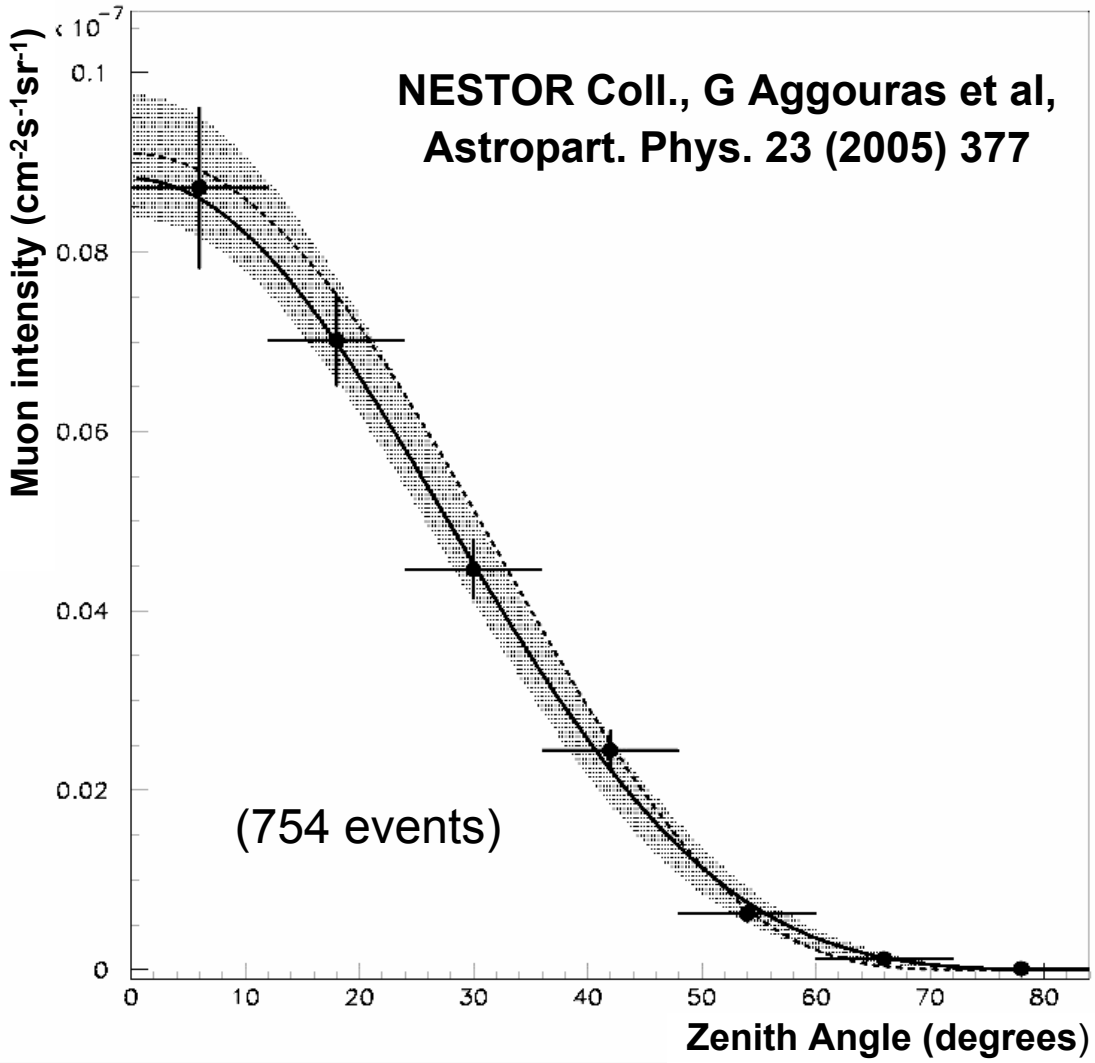
Plan: Tower(s) with12 floors

→ 32 m diameter

→ 30 m between floors

→ 144 PMs per tower

NESTOR: Measurement of the Muon Flux



Atmospheric muon flux determination and parameterisation by

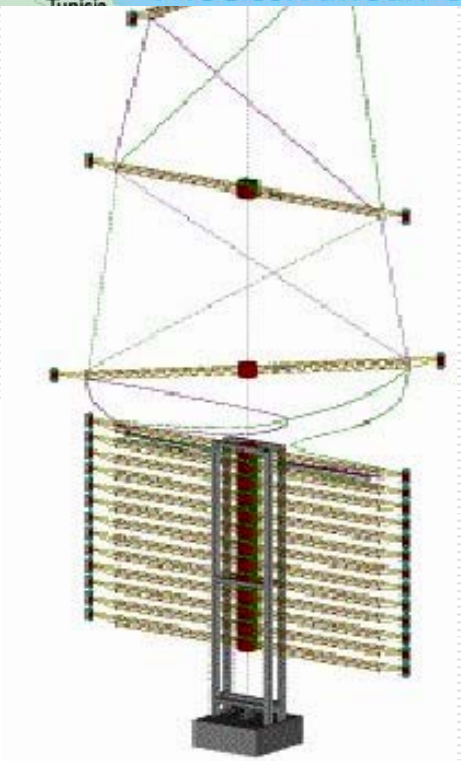
$$\frac{dN}{d\Omega \cdot dt \cdot ds} = I_0 \cdot \cos^{\alpha}\theta$$

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

Results agree nicely with previous measurements and with simulations.

The NEMO Project

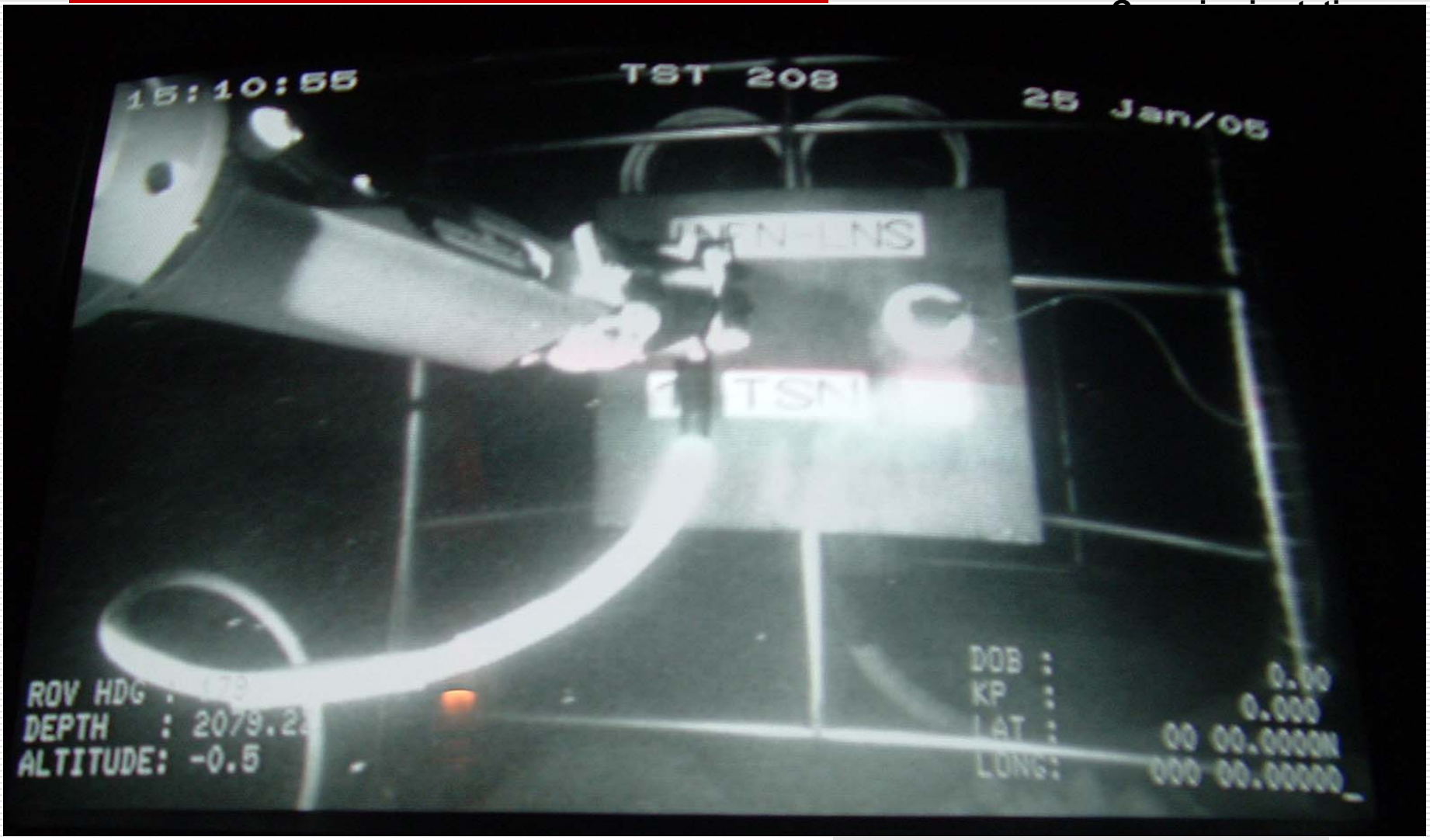
- Extensive site exploration (Capo Passero near Catania, depth 3500 m);
- R&D towards km³: architecture, mechanical structures, readout, electronics, cables ...;
- Simulation.



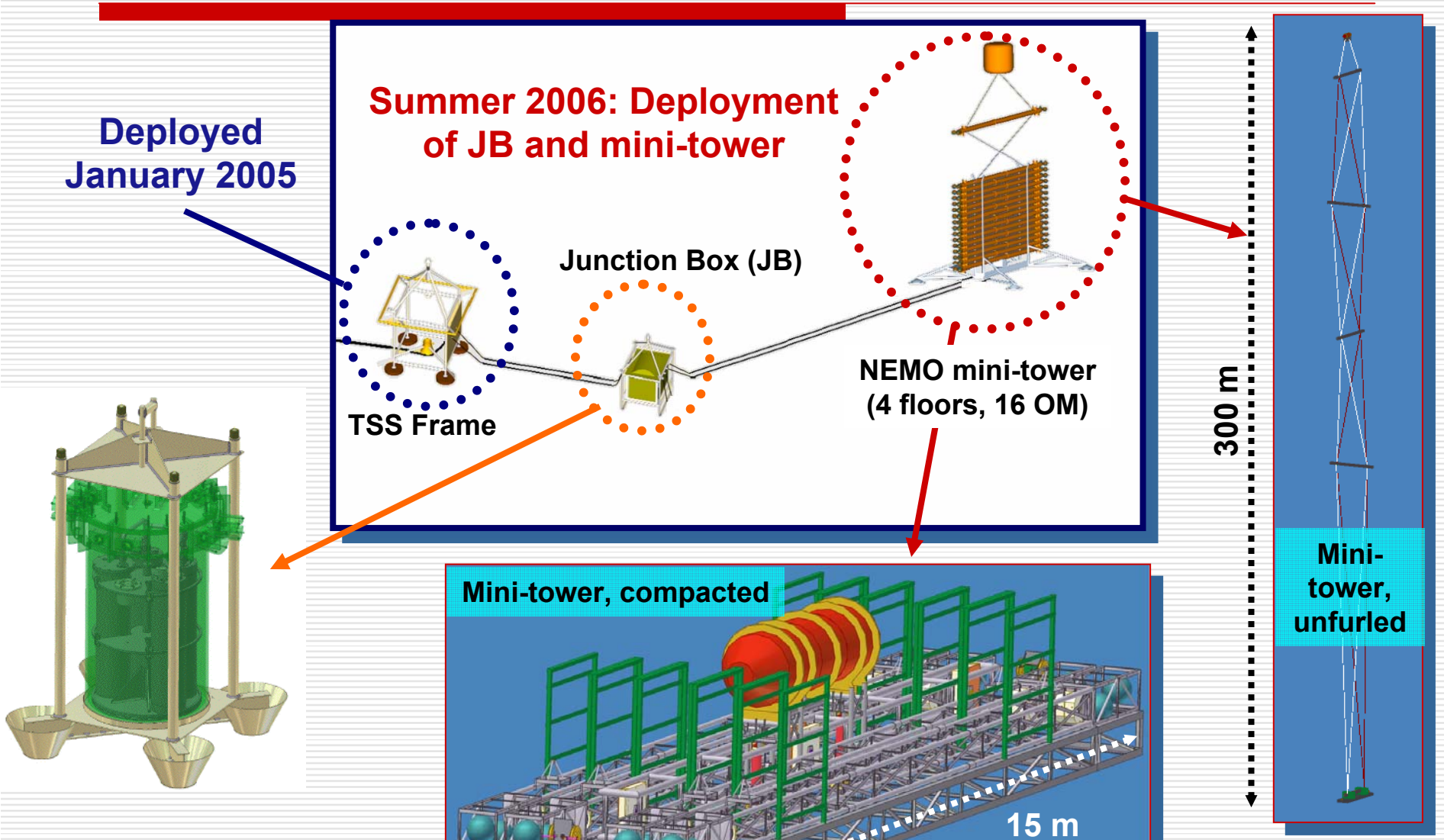
Example: Flexible tower

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

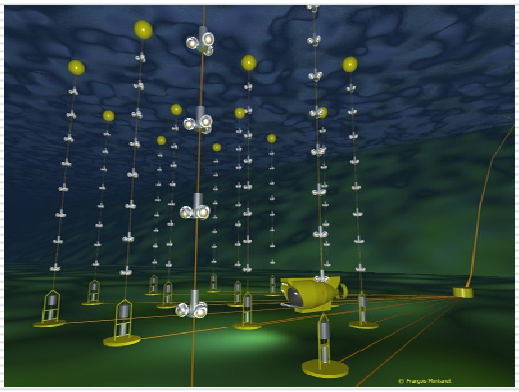
NEMO Phase I: Current Status



NEMO Phase-1: Next Steps



KM3NeT: Towards a km³ Deep-Sea ν Telescope



scale up

dilute

new design

Existing telescopes "times 30" ?

- Too expensive
- Too complicated
  (production, maintenance)
- Not scalable
  (readout bandwidth, power, ...)

Large volume with same number of PMs?

- PM distance:
  given by absorption length in water (~60 m) and PM properties
- Efficiency loss for larger spacing

R&D needed:

- Cost-effective solutions
  to reduce price/volume by factor ~2
- Stability
  goal: maintenance-free detector
- Fast installation
  time for construction & deployment less than detector life time
- Improved components

The KM3NeT Design Study

Scope and consortium:

- Design Study supported by the European Union with 9 M€, overall volume ~20 M€.
- Participants: 29 particle/astroparticle physics and 7 sea science & technology institutes from 8 European countries (coordinator: Univ. Erlangen).
- Started on Feb. 1, 2006; will run for 3 years.

Major objectives:

- Conceptual Design Report by summer 2007;
- Technical Design Report by February 2009;
- Limit overall cost to 200 M€ per km³ (excl. personnel).

The KM3NeT Vision

- KM3NeT will be a multidisciplinary research infrastructure:
  - Data will be publicly available;
  - Implementation of specific online filter algorithms will yield particular sensitivity in predefined directions → non-KM3NeT members can apply for observation time;
  - Data will be buffered to respond to GRB alerts etc.
  - Deep-sea access for marine sciences.
- KM3NeT will be a pan-European project
  - 8 European countries involved in Design Study;
  - Substantial funding already now from national agencies.
- KM3NeT will be constructed in time to take data concurrently with IceCube.
- KM3NeT will be extendable.

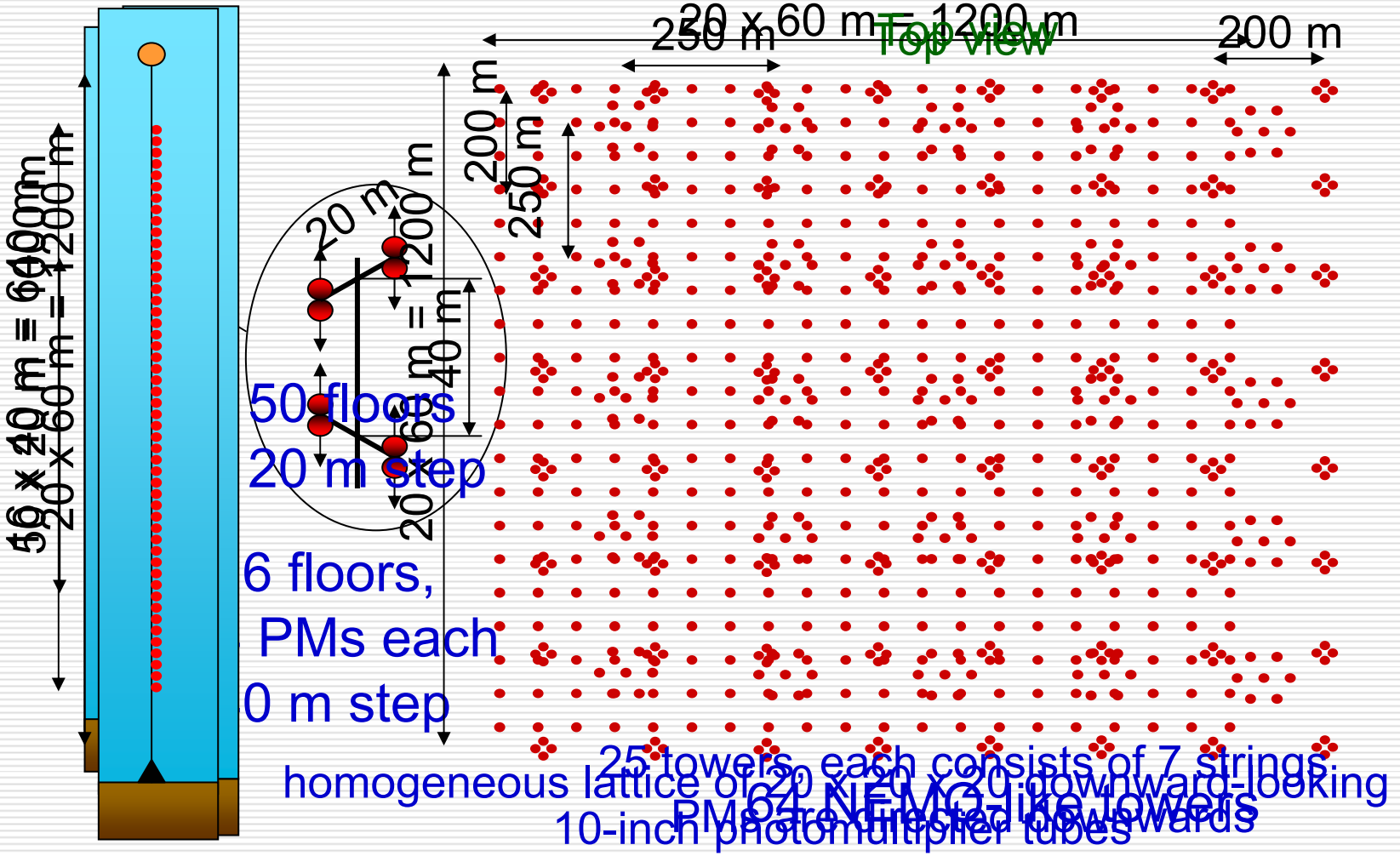
Some Key Questions

All these questions are highly interconnected !

- 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?
  (separate 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: path to site decision.

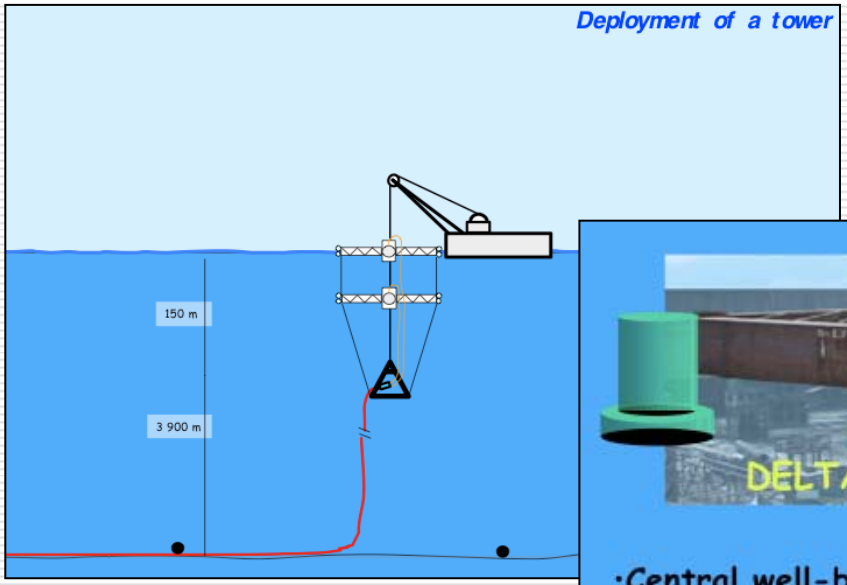
Detector Architecture

(D. Zaborov at VLVνT)

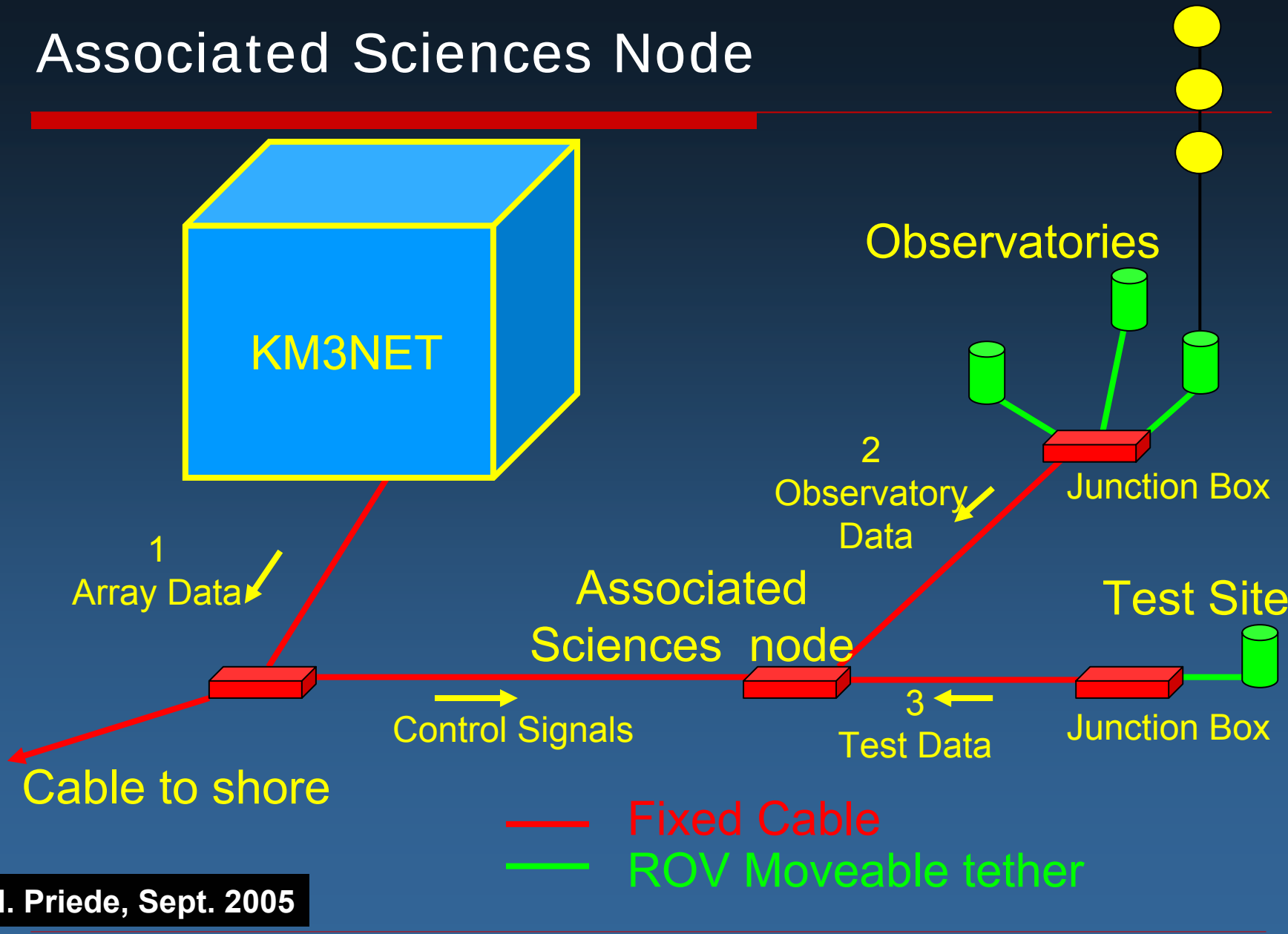


Sea Operations

- Rigid towers or flexible strings?
- Connection in air (no ROVs) or wet mateable connectors?
- Deployment from platform or boat?



Associated Sciences Node



M. Priede, Sept. 2005

KM3NeT: Path to Completion

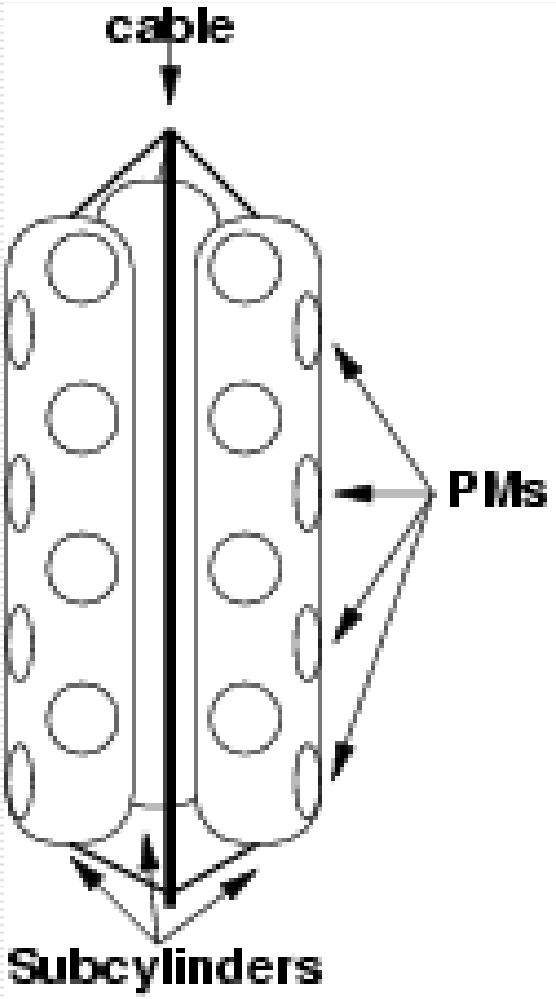
Time schedule (partly speculative & optimistic):

01.02.2006	Start of Design Study
Mid-2007	Conceptual Design Report
February 2009	Technical Design Report
2009-2010	Preparation Phase (possibly in FP7)
2010-2012	Construction
2011-20xx	Data taking

Estimating the KM3NeT Sensitivity

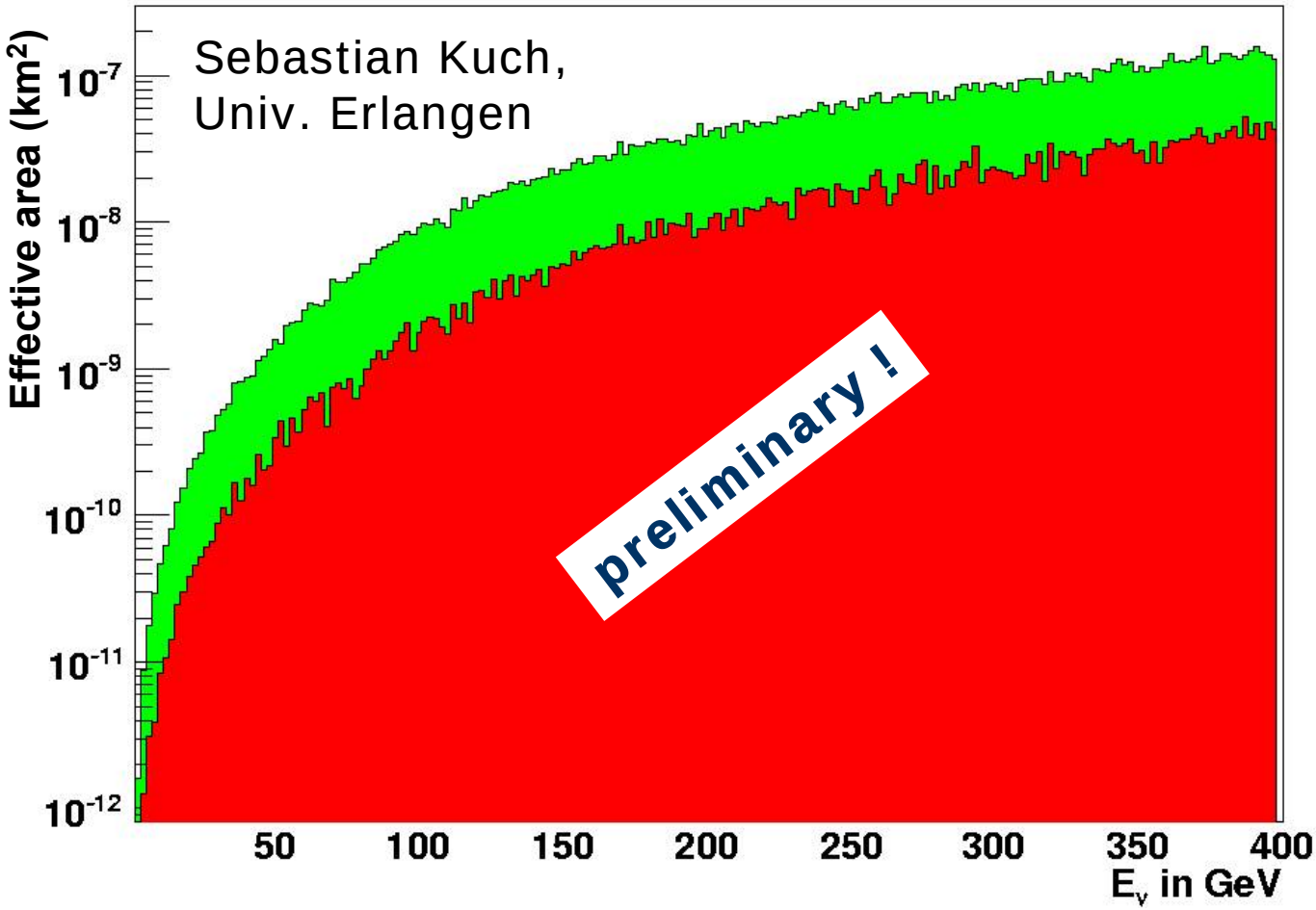
- Assume a km3-scale detector layout:
  - photo-detector characteristics
    (here: several small PMs in triple cylinders)
  - detector geometry
    (here: 22x22 strings with 10 storeys each,
    ~600m long, on square grid with distance
    ~60m).
- Simulate
  - neutrino interactions,
  - light transport,
  - signals + backgrounds.
- Reconstruct events
  - minimum requirement: 10 hits;
  - perform full muon reconstruction.

Currently: ANTARES software used.



KM3NeT Effective Areas

- green:
  ≥10 hits
  (too optimistic)
- red:
  events fully
  reconstructed
  (too pessimistic)

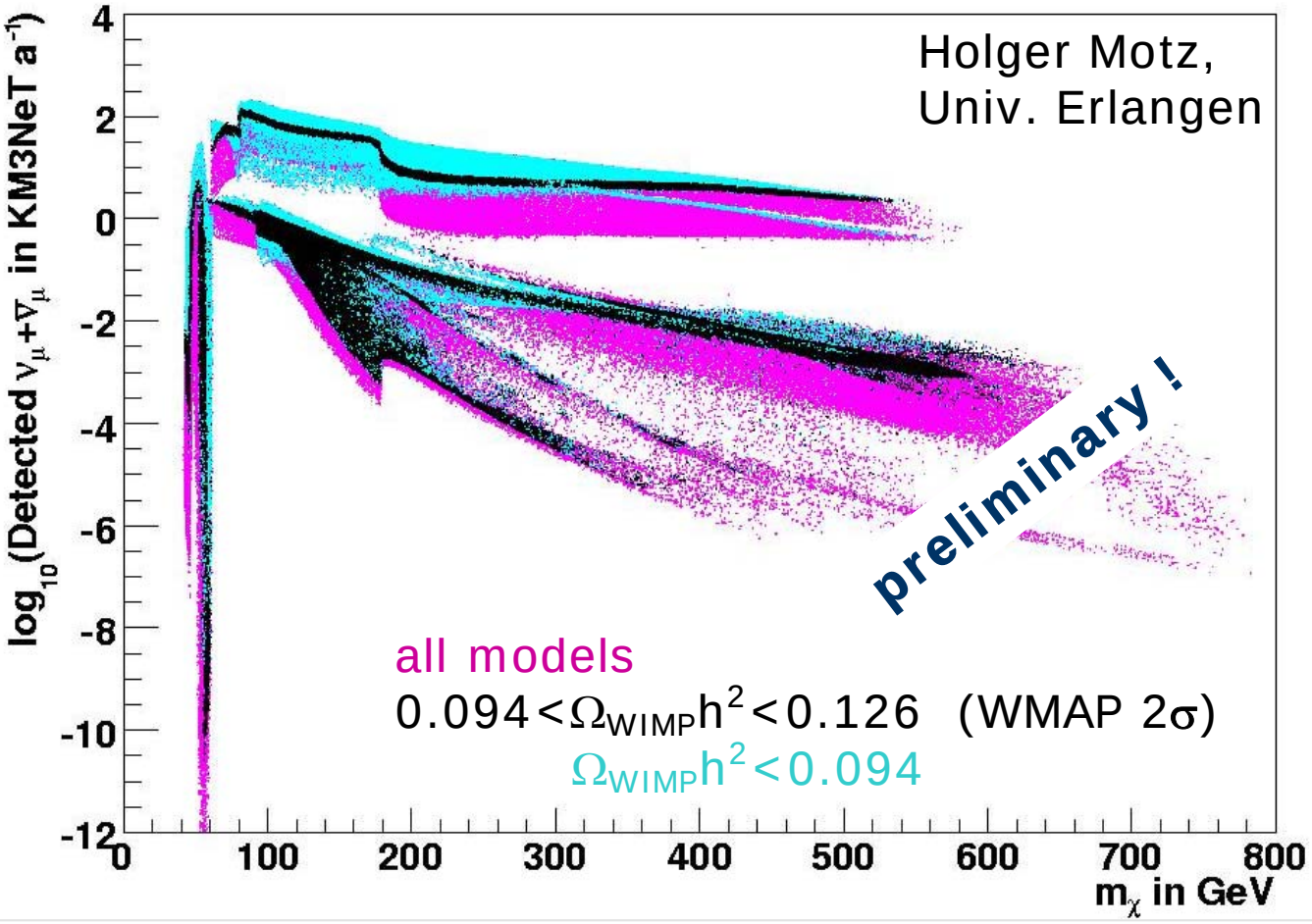


Example: WIMP Annihilation in the Sun

- Analysis chain (Holger Motz, Univ. Erlangen):
  - scan mSUGRA parameter space;
  - use Navarro-Frenk-White model to fix neutralino density Sun;
  - for each parameter set, determine neutrino flux $\Phi(E_\nu)$ from neutralino annihilation in Sun (using DarkSUSY);
  - track neutrinos to Earth (oscillations, absorption);
  - use KM3NeT effective area to determine numbers of detected neutrino events.
- Not yet studied in detail:
  - signal/background separation;
  - significance of possible observation.
- See also recent review on indirect WIMP detection:
  - J. Carr, G. Lamanna, J. Lavalle, Rept.Prog.Phys.69:2475(2006).

Dark Matter Event Rates in KM3NeT

- Numbers of detected ν_μ's per year in KM3NeT.
- Up to several 100 events for some parameter sets.
- Effective area for reconstructed μ's (pessimistic).



Conclusions and Outlook

- The Mediterranean-Sea neutrino telescope projects ANTARES, NEMO and NESTOR have proven the feasibility of large-scale deep-sea neutrino telescopes.
- ANTARES, NEMO and NESTOR have united their efforts to prepare together the future, km^3-scale deep-sea detector.
- The EU-funded KM3NeT Design Study (2006-09) provides substantial resources for an intense 3-year R&D phase; Major objective: Technical Design Report by end of 2008.
- The KM3NeT neutrino telescope will provide potential for indirect Dark Matter observation.