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: $\theta_c \approx 43^\circ$
- Spectral range used: $\sim 350-500$nm.

Angular resolution in water:
- Better than $\sim 0.3^\circ$ for neutrino energy above $\sim 10$ TeV, $0.1^\circ$ at 100 TeV
- Dominated by angle($\nu, \mu$) below $\sim 10$ TeV ($\sim 0.6^\circ$ at 1 TeV)
Astro- and Particle Physics with $\nu$ Telescopes

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

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

**Dark matter search (WIMPs):**
- Direction, Energy

**Astrophysical point sources:**
- Direction, (Energy), Time

**Diffuse cosmic neutrino flux:**
- (Direction), Energy

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

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High-energy $\gamma$ sources in the Galactic Disk

Update June 2006:

- 6 $\gamma$ 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.

W. Hofmann, ICRC 2005
Sky Coverage of Neutrino Telescopes

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

We need $\nu$ telescopes in both hemispheres to see the whole sky.

Mediterranean site:

>75% visibility

>25% visibility
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
• 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) with 12 floors
- 32 m diameter
- 30 m between floors
- 144 PMs per tower
NESTOR: Measurement of the Muon Flux

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

\[ \alpha = 4.7 \pm 0.5 \text{(stat.)} \pm 0.2 \text{(syst.)} \]
\[ I_0 = 9.0 \pm 0.7 \text{(stat.)} \pm 0.4 \text{(syst.)} \times 10^{-9} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]

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 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 downward-looking PMs.
NEMO Phase I: Current Status

February 2006: Completion of the first phase of NEMO.

- Test site at 2000 m depth operational.
- Funding ok.
- Completion expected by 2006.

Shore station: 2.5 km e.o. Cable with double steel shield.
21 km e.o. Cable with single steel shield.
5 km e.o. cable.

Geoseismic station: SN-1 (INGV)
5 km e.o. cable.

NEMO Phase I: Current Status

- Deployment of 2 cable termination frames (validation of deep-sea wet-mateable connections).
- Acoustic detection system (taking data).

- 10 optical fibres standard ITU-T G-652.
- 6 electrical conductors Φ 4 mm².
NEMO Phase-1: Next Steps

Deployed January 2005

Summer 2006: Deployment of JB and mini-tower

Junction Box (JB)

TSS Frame

NEMO mini-tower (4 floors, 16 OM)

Mini-tower, compacted

15 m

Mini-tower, unfurled

300 m

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KM3NeT: Towards a km$^3$ Deep-Sea $\nu$ Telescope

Existing telescopes “times 30”? 
- Too expensive 
- Too complicated (production, maintenance) 
- Not scalable (readout bandwidth, power, ...)

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

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

- Too expensive 
- Too complicated 
- Not scalable
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

- 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.

All these questions are highly interconnected!
Detector Architecture

(D. Zaborov at VLVνT)

- Top view
- 16 floors, 4 PMs each
- 64 NEMO-like towers
- Homogeneous lattice of 20 x 20 x 20 downward-looking 10-inch photomultiplier tubes

- 50 floors, 20 m step
- 25 towers, each consists of 7 strings

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20 m step
20 x 60 m = 1200 m
20 x 20 m = 400 m
50 x 20 m = 1000 m
50 floors
20 m step
Sea Operations

- Rigid towers or flexible strings?
- Connection in air (no ROVs) or wet mateable connectors?
- Deployment from platform or boat?
## KM3NeT: Path to Completion

**Time schedule (partly speculative & optimistic):**

<table>
<thead>
<tr>
<th>Date/Phase</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01.02.2006</td>
<td>Start of Design Study</td>
</tr>
<tr>
<td>Mid-2007</td>
<td>Conceptual Design Report</td>
</tr>
<tr>
<td>February 2009</td>
<td>Technical Design Report</td>
</tr>
<tr>
<td>2009-2010</td>
<td>Preparation Phase (possibly in FP7)</td>
</tr>
<tr>
<td>2010-2012</td>
<td>Construction</td>
</tr>
<tr>
<td>2011-20xx</td>
<td>Data taking</td>
</tr>
</tbody>
</table>
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)

Sebastian Kuch, Univ. Erlangen

preliminary!
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:
Dark Matter Event Rates in KM3NeT

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

\[ 0.094 < \Omega_{\text{WIMP}} h^2 < 0.126 \text{ (WMAP 2}\sigma) \]

Holger Motz, Univ. Erlangen
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, km³-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.