Simulations for the KM3NeT Project

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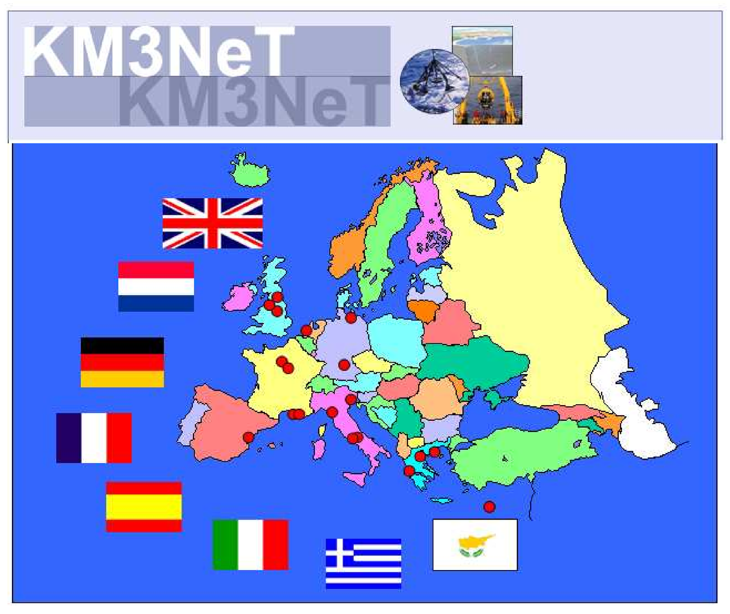
The KM3NeT Design Study is a common European effort for the design of a km^3-scale deep-sea neutrino telescope. Calculations and simulations show that an instrumented volume of this magnitude is necessary to explore the full potential of neutrino astrophysics. For the upcoming Design Study, simulations have been performed using modified ANTARES software. Several concepts and ideas have been tested for their merits and feasibility.

1. The KM3NeT Design Study

www.km3net.org

KM3NeT, an European deep-sea research infrastructure, will host a neutrino telescope with a volume of at least 1 km^3 at the bottom of the Mediterranean Sea. **KM3NeT is an accepted EU FP6 Design Study project** .

The KM3NeT consortium currently includes:
35 Institutions from 8 EU countries
Coordinated by Erlangen University.



Time schedule:

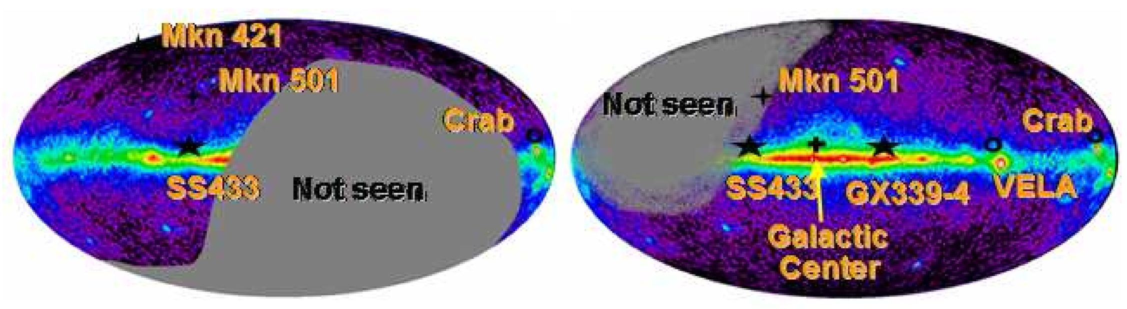
02/2006	Start of design study
Mid-2007	Conceptual Design Report
end-2008	Technical Design Report
2009-2013	Construction
from 2010	Data Taking

The current KM3NeT activity in Erlangen University includes:

- Monte Carlo simulations to test different concepts and options for KM3NeT optical modules (for example multi-PM cylindrical optical modules) and design geometry (for example inhomogeneous and ring geometries)

2. Motivation

The main scientific motivation for building a km^3-scale neutrino telescope is the observation of astrophysical point sources and the diffuse flux of high energy cosmic neutrinos. These observations will help to reveal the origin of cosmic acceleration and the nature of Dark Matter. Neutrino telescopes are complementary to the astroparticle physics experiments with high energy photons (HESS, MAGIC, etc.) and ultra high energy cosmic rays (Pierre Auger).
Large neutrino telescopes in both hemispheres are necessary to observe the whole sky:



Sky views from the South Pole (IceCube) and the Mediterranean Sea (ANTARES/NESTOR/NEMO).

Why the Mediterranean ?

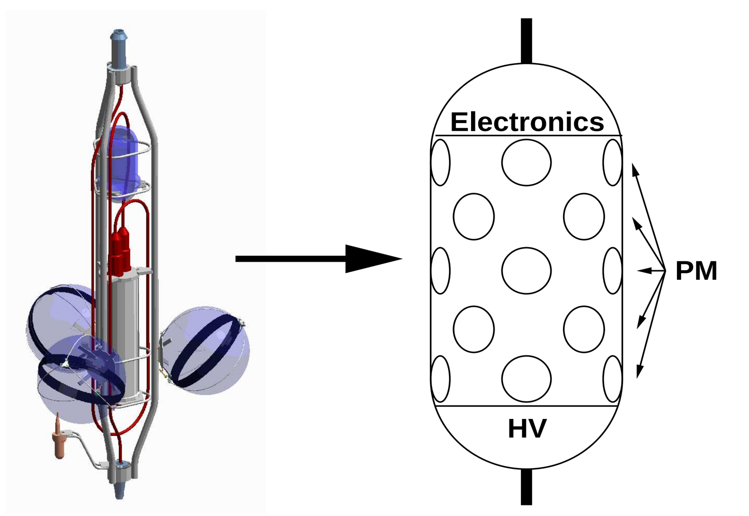
- Excellent pointing accuracy due to the long scattering length, availability of deep sites and developed logistical infrastructure
- ANTARES, NESTOR and NEMO are Mediterranean projects in high energy neutrino astronomy and comprise the leading expertise in this field
- The future km^3 project (KM3NeT) will be prepared as a unified effort of these groups

3. The cylindrical optical module

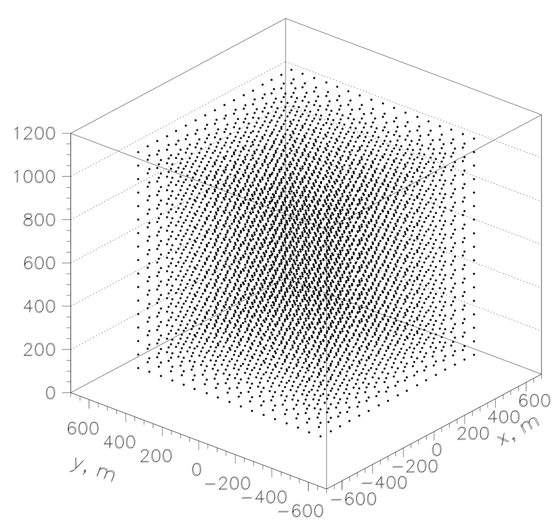
Option: Instead of few large hemispherical photomultipliers in pressure spheres use many small ones in a single pressure cylinder!
In this example: 35 3" PMs instead of 3 10" PMs (appr. same photocathode area!)

Advantages:

- higher quantum efficiency
- better time resolution
- 4π-sensitivity
- less deep-sea connectors
- cost reduction



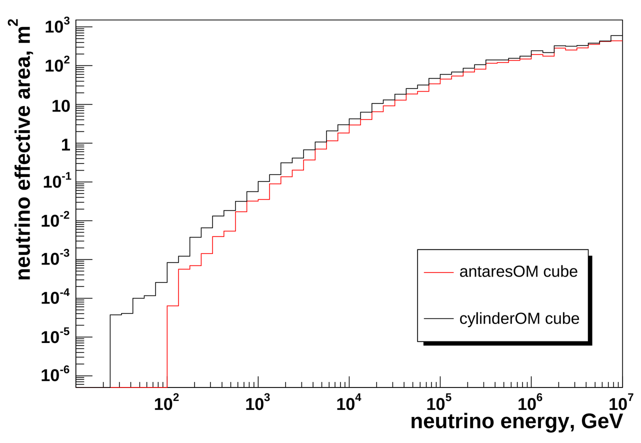
ANTARES storey **cylinder Optical module**

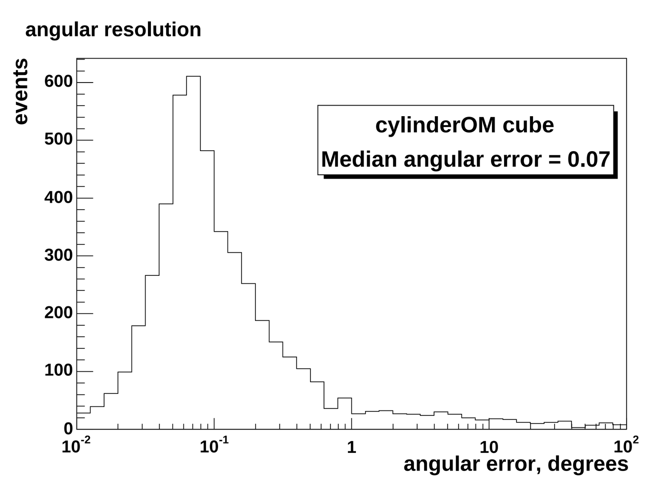


For comparison in the detector simulation, the respective OMs were placed in a km^3-size homogeneous cube grid (distance 62.5m, 4913 modules, 289 strings).
Two parameters have been studied for different detector models: Effective area and angular resolution of the reconstructed neutrinos.
The effective area is defined as:

$$A^{\nu}_{eff}(E_\nu) = V^{\nu}_{eff}(E_\nu)\sigma(E_\nu)\rho N_A P_{earth}(E_\nu)$$

(with V_{eff} effective volume, $\sigma(E_\nu)$ neutrino cross-section, ρN_A target nucleus density and $P_{earth}(E_\nu)$ transmission probability through the earth)
The angular resolution is taken as the **median angular error** between simulated and reconstructed tracks.





$\Rightarrow$ **cylindrical OM presents promising alternative**

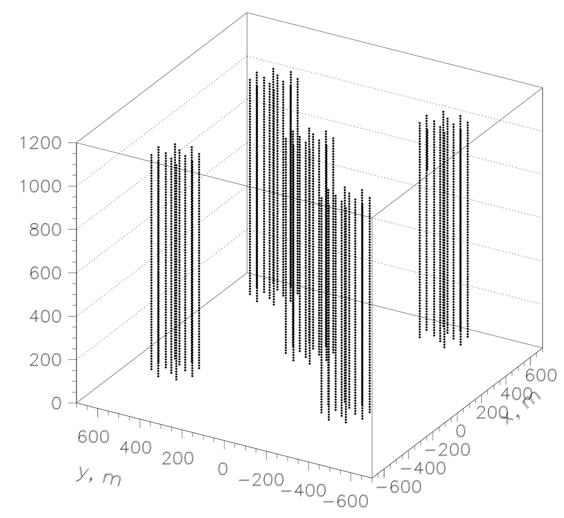
4. Inhomogeneous geometries

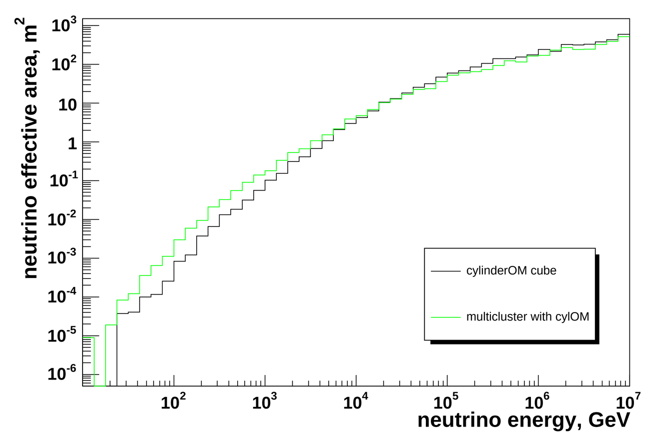
Option: Build detector with clusters of densely instrumented strings.

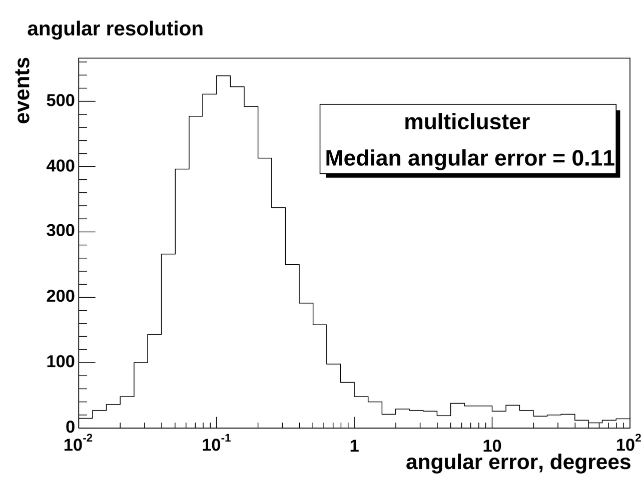
- reduces number of strings (cost!)
- low energy neutrino events ($\rightarrow$ short muon track) are reconstructed inside clusters
- high energy neutrino events ($\rightarrow$ long muon track) hit several clusters

$\Rightarrow$ reduce number of strings without loss of performance

In this example 5 identical clusters, 12 strings each, 83 cylindrical OMs per string
(570 m cluster distance, 60 m string distance inside cluster, 12 m distance between OMs on string, 4980 OMs, 60 strings)





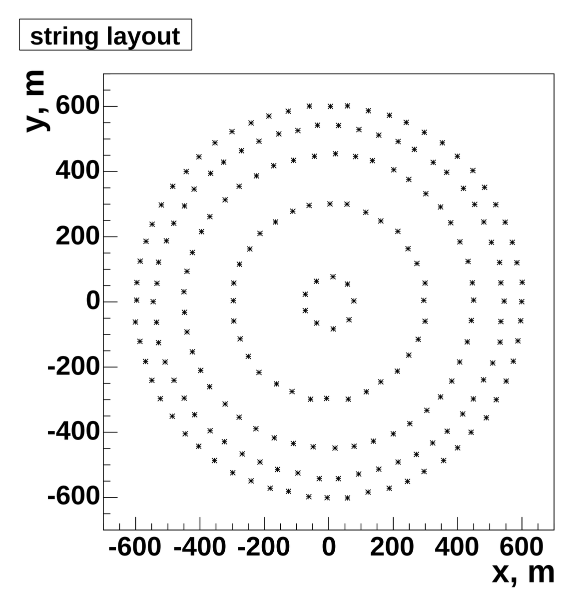


$\Rightarrow$ **cluster structure sensitivity superior at low and medium energies**

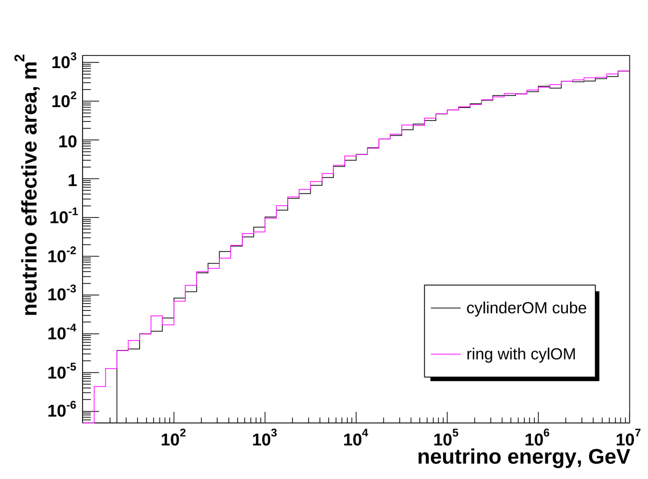
5. Ring geometry

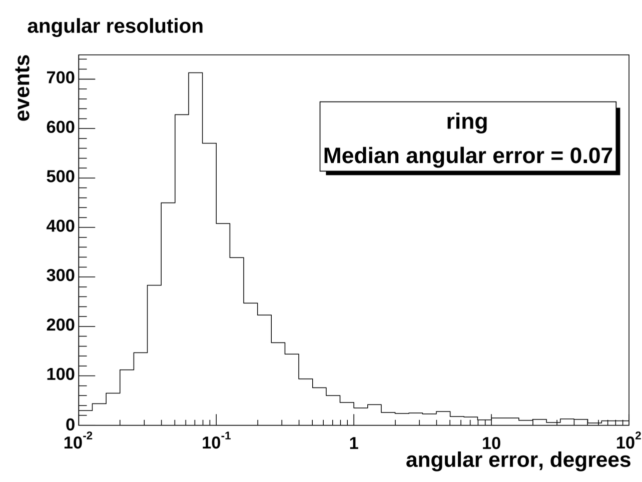
Option: Build a detector with ring-shaped geometry with a densely instrumented shell and scarcely instrumented core.
(In this example: Radius of the outer ring 600 m, distance of string in ring 60 m, 25 cylindrical OMs per string, 42 m distance between OMs on string, 5000 OMs, 200 strings)

At energies above 1 TeV the average muon range is about the same size as the dimensions of the instrumented volume.



$\rightarrow$ Most muons enter the detector from the outside
$\rightarrow$ cross-sectional area of instrumented volume decisive for detection efficiency





$\Rightarrow$ **performance of ring detector with less strings comparable to homogeneous cube**

6. Summary

- KM3NeT is an accepted EU FP6 Design Study, coordinated by Erlangen University
- The design study for the km^3 detector in the Mediterranean sea will start from 2006
- Different options for the optical modules and design geometries were tested in Monte Carlo simulations in the Erlangen University. The preliminary results of this studies indicate that:
  - **cylindrical optical modules** with small PMs are a promising alternative to large hemispherical PMs
  - by building densely instrumented **clusters** the performance at low energies can be improved without significant losses at higher energies, while reducing the number of strings
  - By using a **ring geometry** the number of strings can be reduced without losses of performance