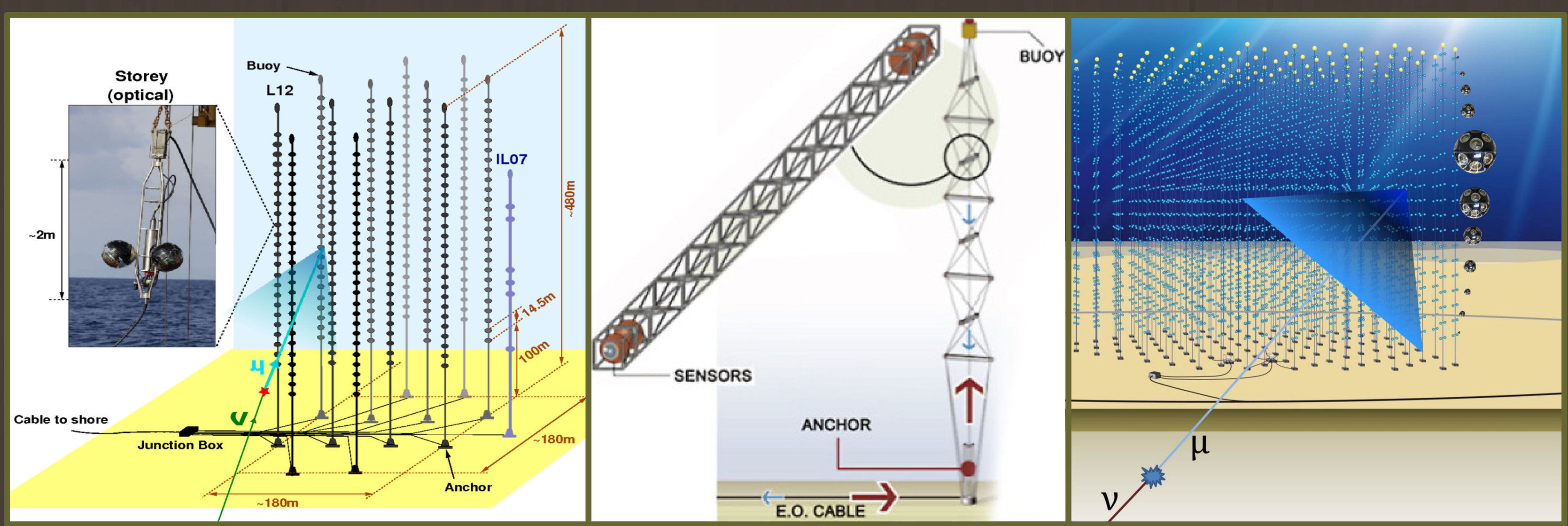
GEANT4 simulation of optical modules in neutrino telescopes

Experimental context

Neutrinos play important role in the multi-messenger astronomy, therefore larges underwater and under-ice neutrinos telescopes have been designed to allow the detection of high energy neutrinos.
The Earth serves as a filter for muon atmospheric background and the sea as target for the detection.
By electroweak interaction the neutrino produces a charged particle (muon). At the TeV scale this charged particle produces Cherenkov effect. The light is detected thanks to an array of Optical Modules (OM) based on photomultipliers tubes (PMT).

ANTARES | NEMO | KM3NeT

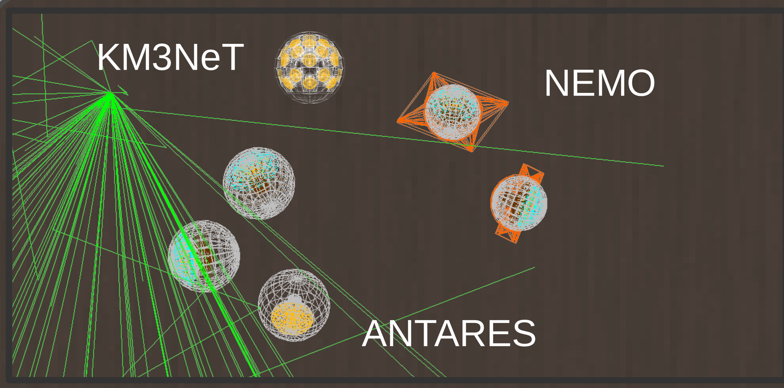


ANTARES
- Situated in deep sea 2,475 m depth (near Toulon)
- 12 lines of 450 m long
- 885 OMs looking 45° down
- Has the Galactic Center in its range
- Currently the biggest in North Hemisphere

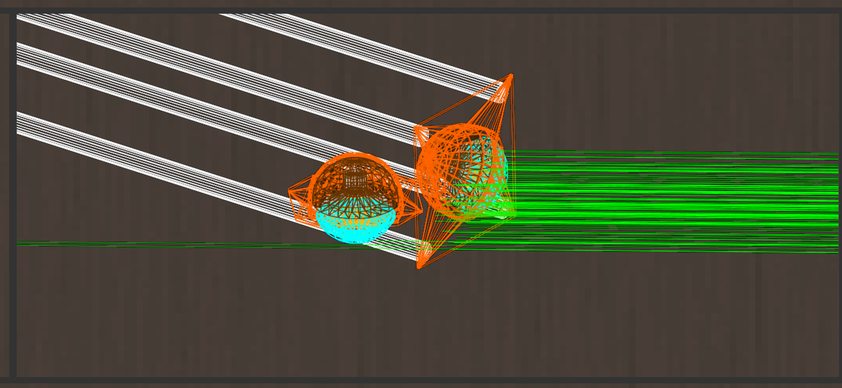
NEMO
- Situated in deep sea 3,500 m (near Capo-Passero)
- 1 prototype, a rigid structures of 8 floors was deployed
- 4 OMs per floor
- Has run 1 full year (2013-2014)

KM3NeT
- Planned to be multi-sites (Toulon, Capo-Passero and pylos) and km³ scale
- 118 lines per building blocks
- 18 Digital OMs per vertical lines
- 2 densities between DOMs: ORCA and ARCA

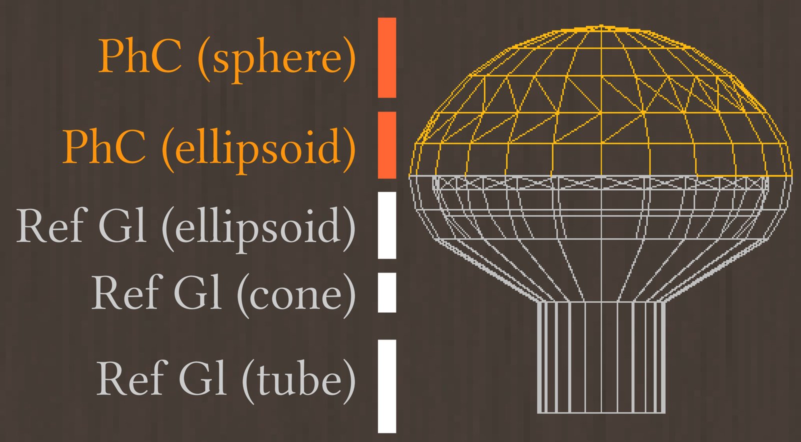
Description



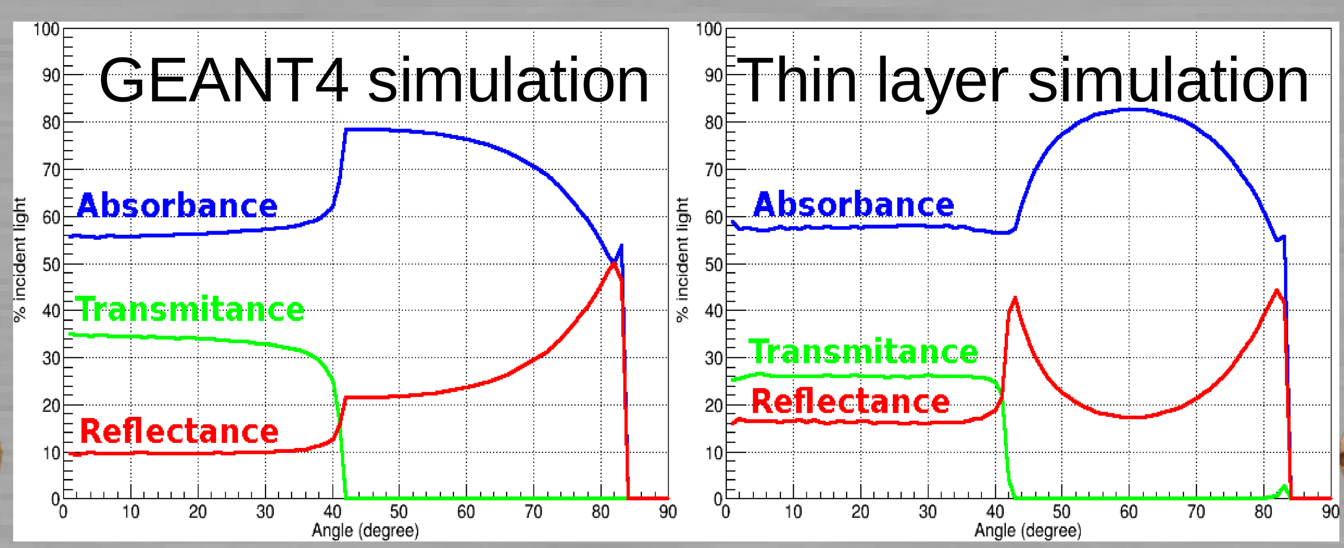
40K estimation with the 3 detectors


Angular efficiency with NEMO full geometry

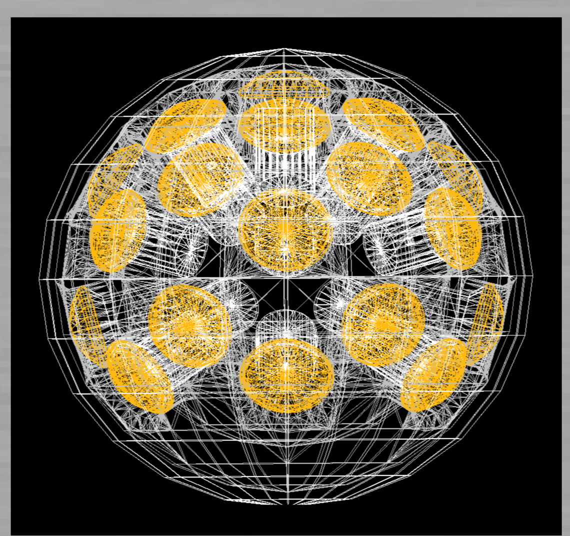
__Mathematics calculations are used for the exact geometry__ for each component's size/position, based on the Hamamatsu specifications. Can easily reproduce a lot of different PMTs.

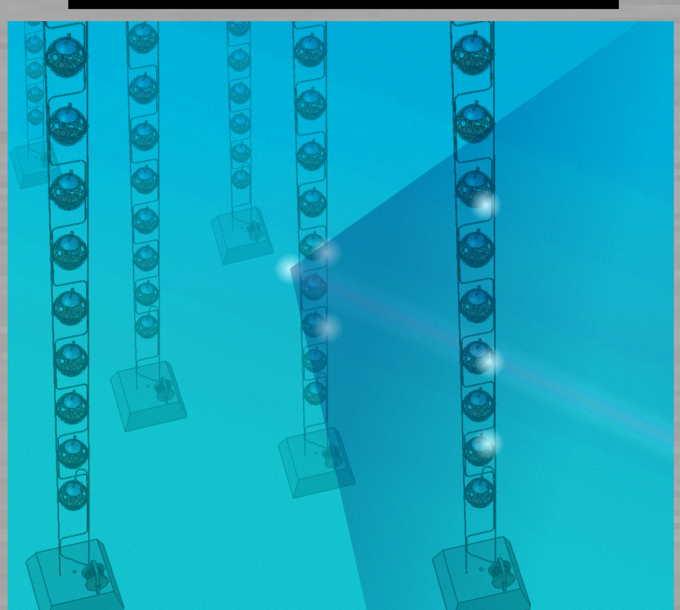


Plus a reliable thin layer optical model to describe the photocathode efficiency as a function of angles and energies, depending on:
- The photocathode thickness
- The particle/wave duality of the photon
- The complex refractive index of the photocathode



The simulation principle





The ray-tracing simulation is based on GEANT4, a C++ toolkit for simulating the passage of particles through matter. It is based on a step by step Monte Carlo: the photon is followed from its production to its detection in a defined geometry (shape and material).
The first point is to have a well defined detector structure (Gel, glass, supporting frame...):
So it requires as input:

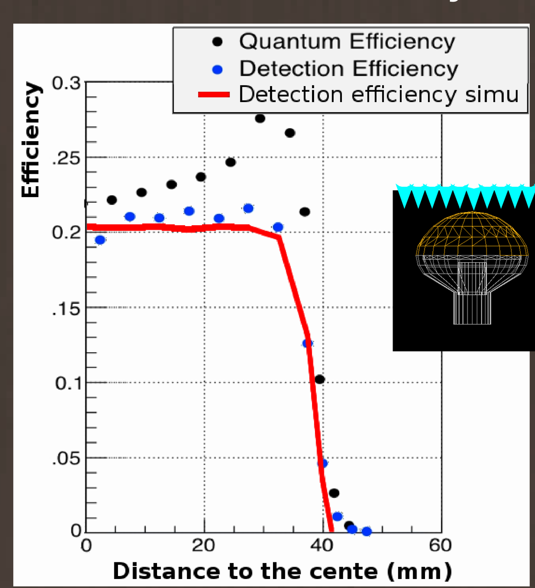
- A detailed knowledge of each Optical Module (OM and DOM):
- The materials properties
- The precise geometry of the detector
- PMTs characterization (Hamamatsu R7081-20 and R12199)
  - From the manufacturer
  - Experimentally deduced
- The environment properties:
  - Absorption length
  - Scattering length

Comparison between Simulation and experiment

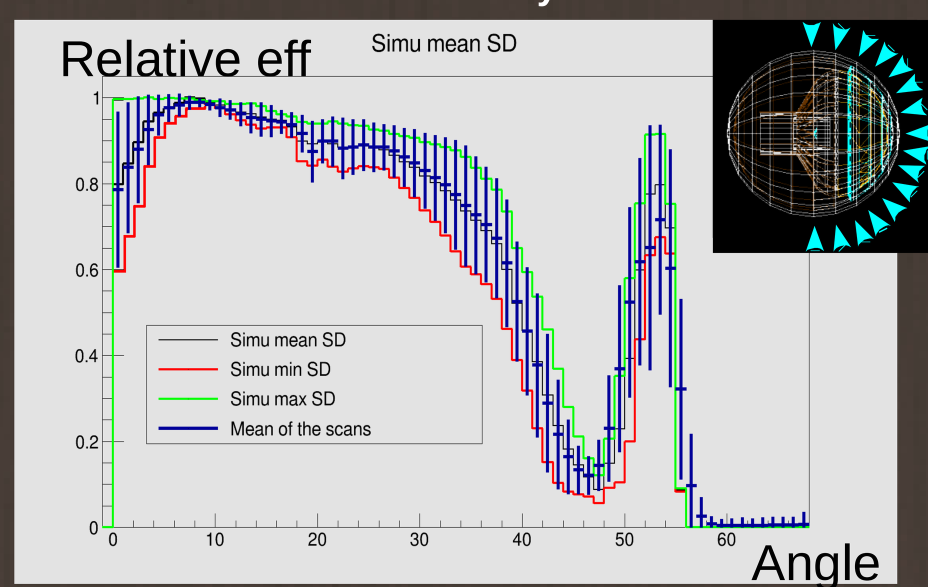
Results

Optical module angular efficiency

KM3NeT PMT efficiency



ANTARES Full OM efficiency



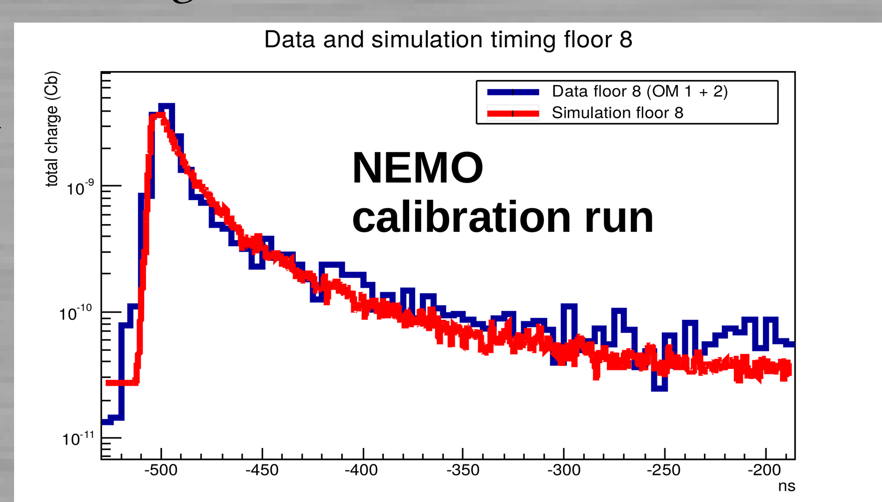
Optical module absolute efficiency: the ^{40}K

Experiment	Antares	NEMO
Experimental ^{40}K coincidences rate	~16 Hz	~21 Hz
Simulated ^{40}K coincidence rate	15.3 Hz	21.6 Hz

KM3NeT coincidences folds	2	3	4
Experimental ^{40}K coincidences rate	1.2 kHz	45 Hz	4.5 Hz
Simulated ^{40}K coincidence rate	1 kHz	50 Hz	6 Hz

Water properties

To study the water properties the LED beacon emits regularly light pulses. The arrival delay of the light to the OMs is due to the scattering in the water.
The comparison between the simulation and the calibration data allows to evaluate it:



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