

Status of simulations in NEMO



- Introduction and framework
- Simulation of atmospheric μ (HEMAS and MUSIC)
- Response of a km^3 underwater Cherenkov telescope based on “NEMO towers”
 - detector lay-out, triggers, background rejection, ... (OPNEMO code)
 - effective areas and angular resolutions after reconstruction, ... (ANTARES software)
- Conclusions and perspectives

The NEMO activity is devoted to two main issues:

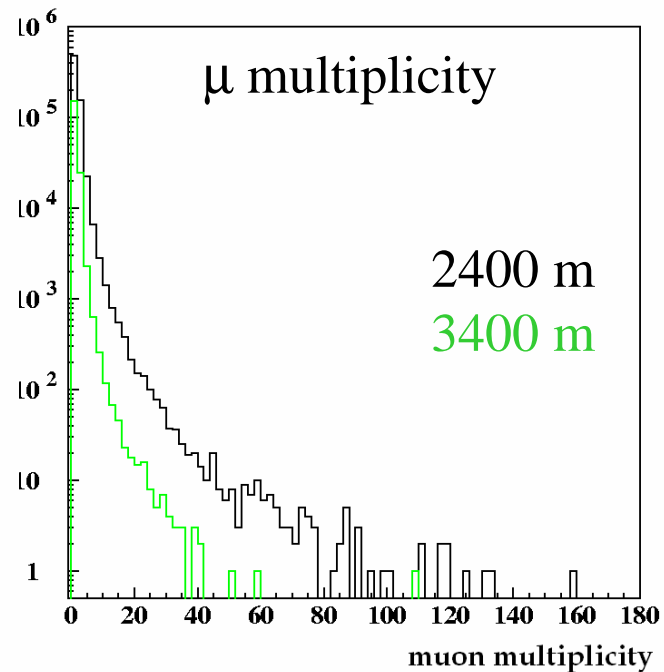
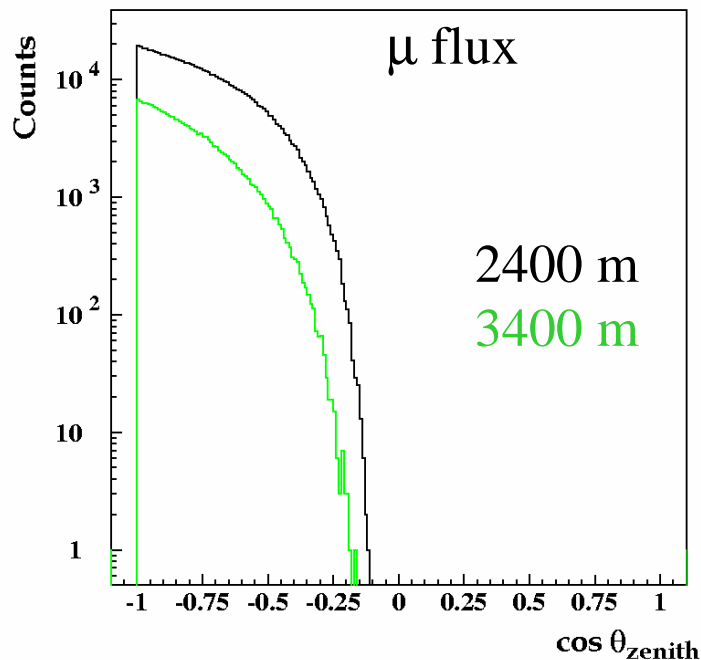
- R&D for a km³ underwater Cherenkov detector for high energy neutrino astronomy (design, mechanics, electronic, transmission, ...)
- Search and characterization of a deep underwater site, for the installation of a km³ Cherenkov detector

Software simulations in NEMO support these activities

The depth of the site is related to the shielding from atmospheric muons

HEMAS code (vrs7-02) has been used to simulate the atmospheric down-going muon flux at sea level for zenith angles up to about 85°

MUSIC code has been used to propagate muons from sea level to the detector can at 2400 m and 3400 m underwater



Strong muon flux and multiplicity reduction at 3400 m, especially at large angle
Effect on detector performance is under investigation

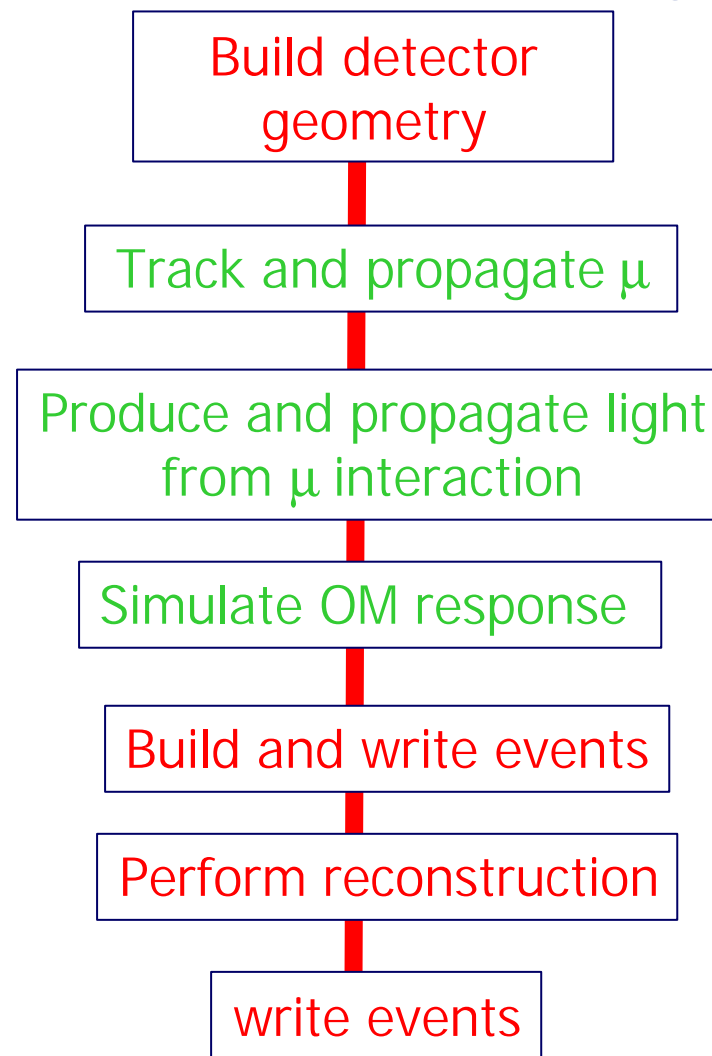
OPNEMO code (S. Bottai and T. Montaruli) is a fast first generation Monte-Carlo tool

OPNEMO has been used to define km³ detector lay-out and triggers in the NEMO Collaboration

Main limitations:

- scattering of light not taken into account
- **track reconstruction in presence of optical background not implemented**
- ...

It has provided indications for the detector lay-out



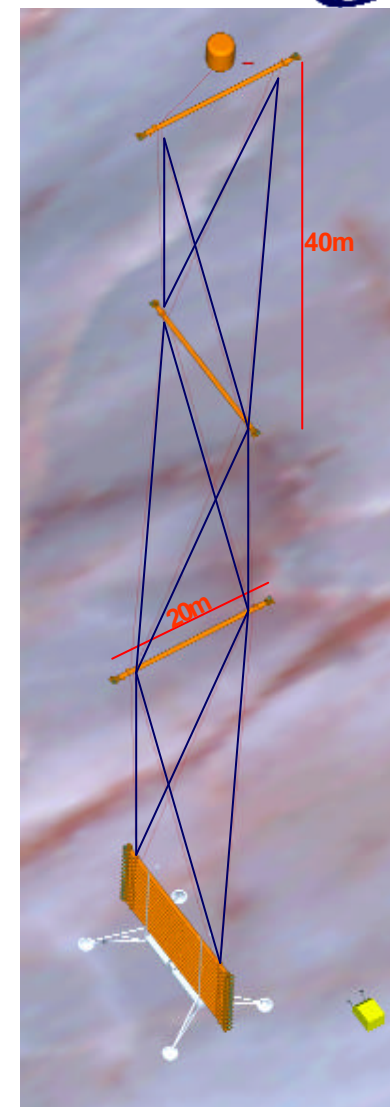
Main constraints imposed to the detector design:

- number of PMTs < 6000
- number of strings/towers < 100
- distance between strings/towers > 100 m
- string/tower height < 1 km

Mechanics by G. Raia, M. Musumeci et al
Simulations with OPNEMO

Characteristics of the NEMO tower for km³:

- | | |
|--------------------------|-------------|
| - total height | 750 - 830 m |
| - instrumented | 600 - 680 m |
| - number of bars | 16 - 18 |
| - number of PMTs per bar | 4 |
| - number of towers | 64-81 |
| - number of PMTs | 4096-5832 |
| - bar length | 20 m |
| - bar vertical distance | 40 m |



Detector configuration - dependence on the tower distance -

OPNEMO without optical background (C. Distefano et al)



Simulation inputs:

surf. μ generation

$N_{\text{tower}} = 64$

$H_{\text{tower}} = 600$ m

$N_{\text{PMT}} = 4096$

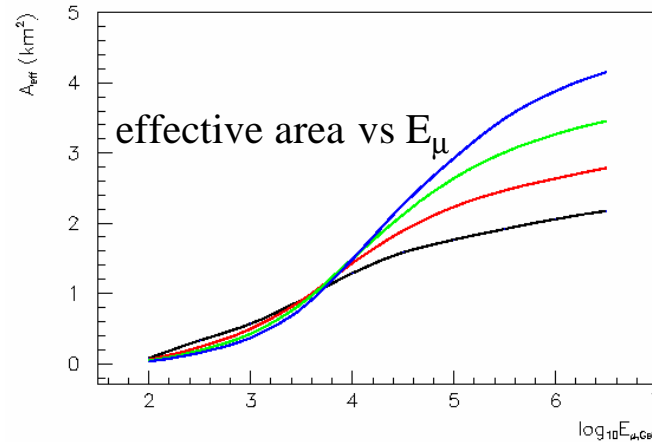
$D_{\text{PMT}} = 10''$

$S_{\text{PMT}} = 2.5$ nsec

$\lambda_a(450 \text{ nm}) = 40$ m

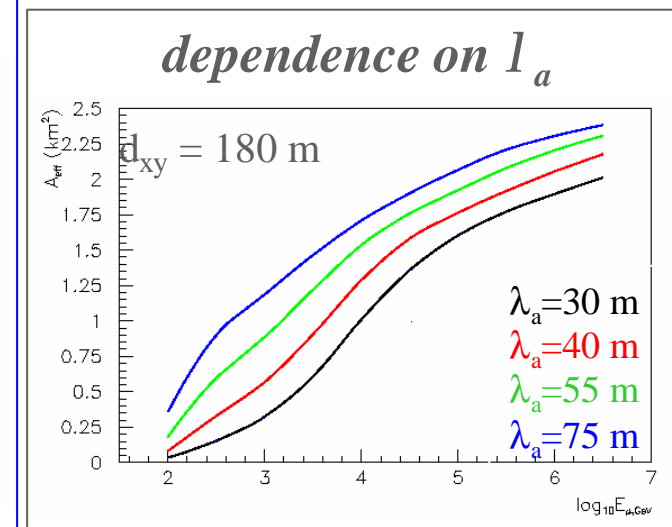
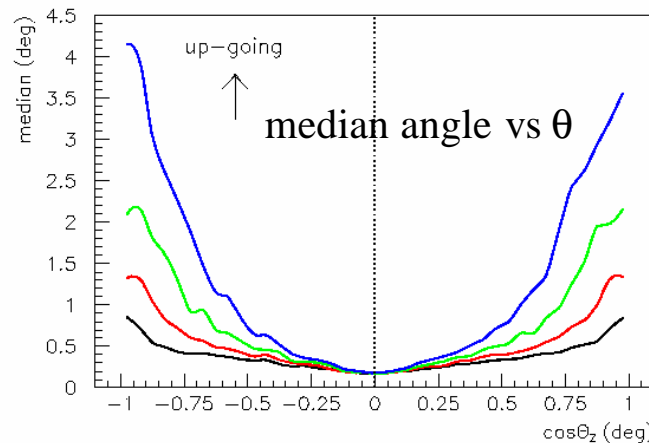
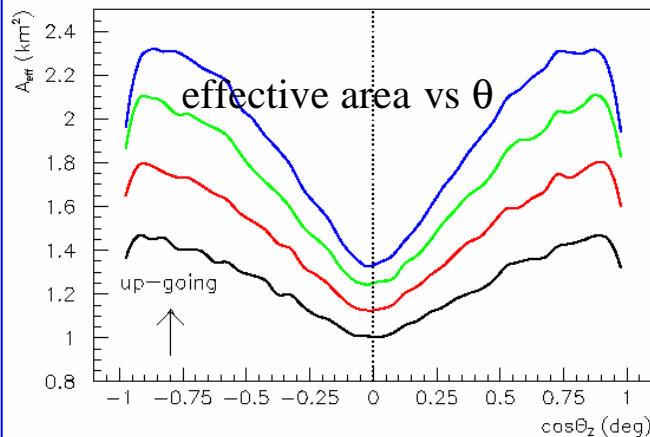
OM up-down

180 m 220 m 260 m 300 m



Rather good performances are obtained for distances of about 180 m.

However, more accurate simulations including the effect of the optical background are needed.



Detector configurations – OM arrangement - OPNEMO without optical background (C. Distefano et al)

surf. μ generation

$$N_{\text{string/tower}} = 64$$

$$H_{\text{string/tower}} = 600 \text{ m}$$

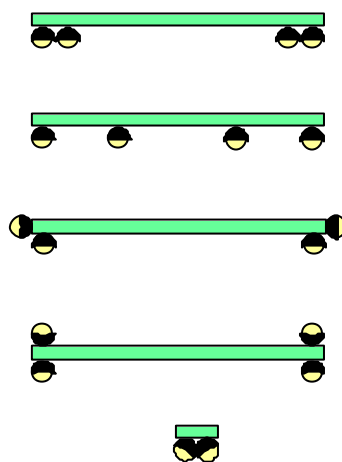
$$N_{\text{PMT}} = 4096$$

$$D_{\text{PMT}} = 10''$$

$$S_{\text{PMT}} = 2.5 \text{ nsec}$$

$$d_{xy} = 180 \text{ m}$$

$$\lambda_a(450 \text{ nm}) = 40 \text{ m}$$



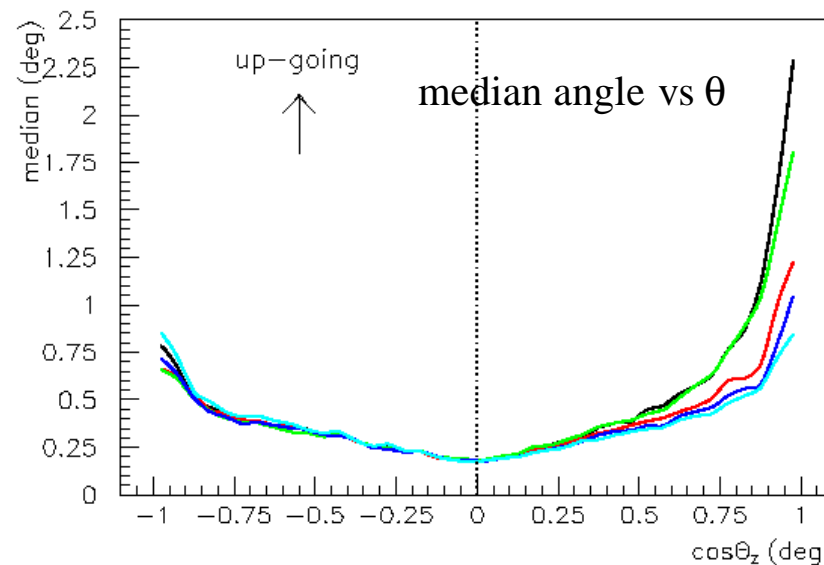
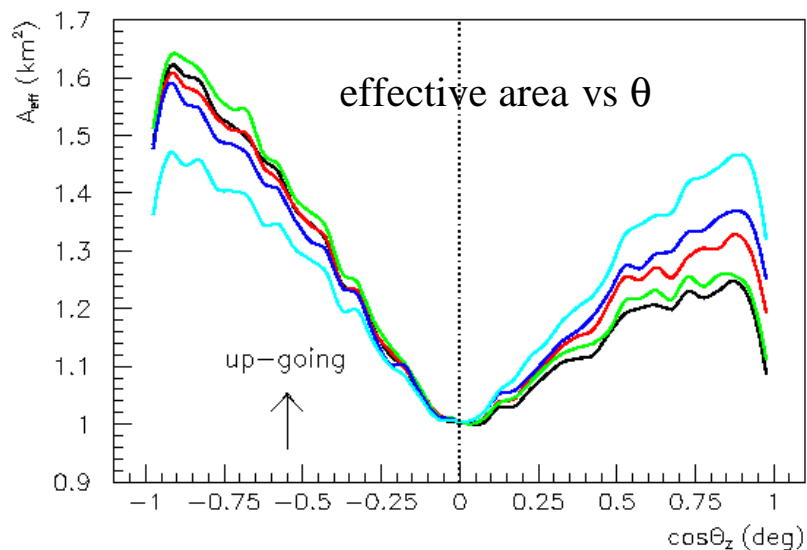
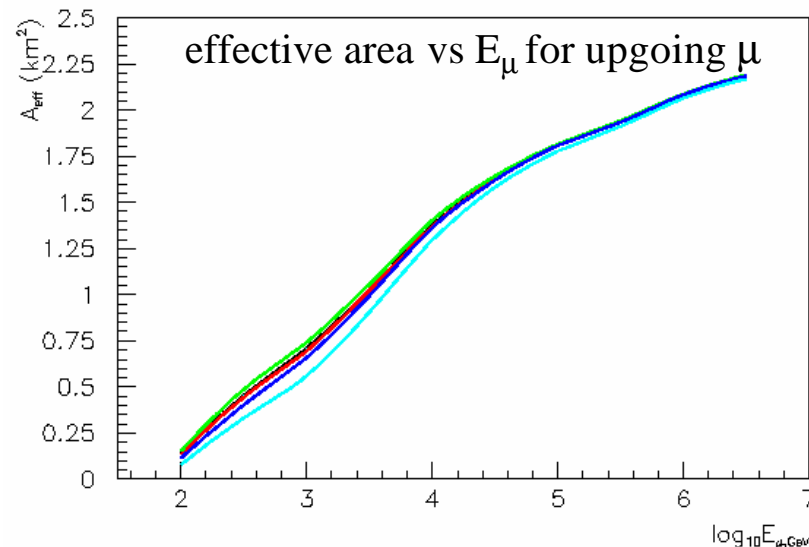
dd

4d

dh

ud

d90



software package (R. Coniglione, P.S. et al)

During the ANTARES meeting held in Catania on september 2002, the ANTARES and NEMO collaboration agreed to start a stronger cooperation towards the km³. In particular, activities concerning site characterization and software were mentioned. By the end of 2002, ANTARES software was installed in Catania by D. Zaborov.

Detector configuration

NEMO10dh140

number of PMTs 5832

number of towers 9x9=81

distance between towers 140

tower height 680 (830 total)

bar length 20 m

bar distance 40 m

instrumented volume 1140 x 1140 x 680

PMT diameter 10"

OM down-horizontal

Simulation inputs

Zaborov version for km³ detectorssurface μ generationcan radius $d_{\max}/2 + 100$ mUpgoing muons with E^{-1} spectrum

ANTARES water parameters

0.5 p.e. threshold

2.5 p.e. trigger

opt. back. 500 nsec -> 1000 nsec offset

20, 45, 60, 120 kHz

reconstruction with "Aart strategy"

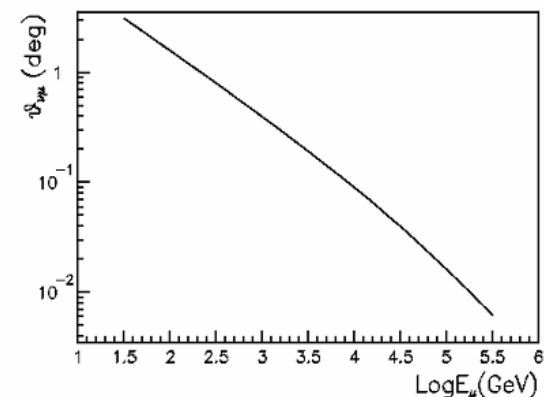
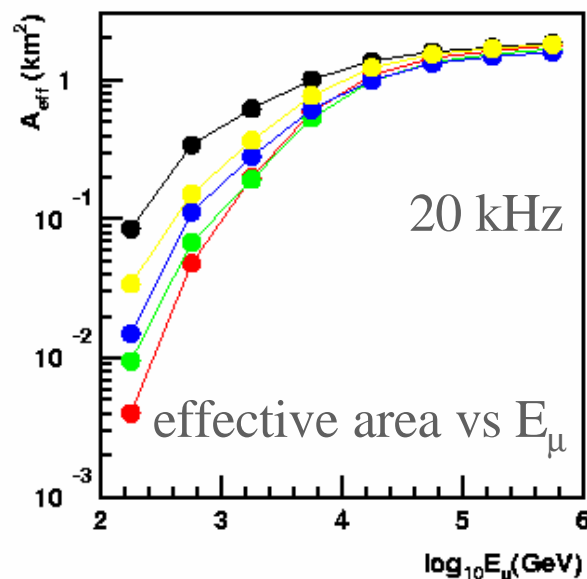
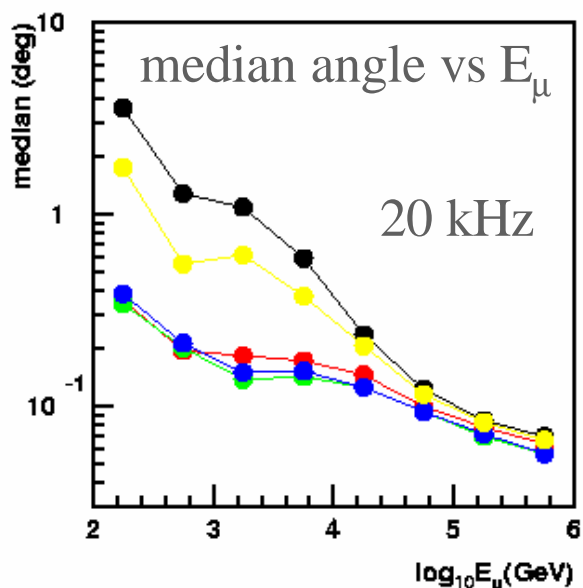
software package (R. Coniglione, P.S. et al)

Requirements for detector performance has to be defined.

To fulfil the requirements both design optimisation and tuning of trigger and reconstruction are needed.

In the following, a s.p.e. uncorrelated optical background of 20 kHz is considered. This value is close to values measured in Capo Passero (G. Riccobene talk).

An amplitude trigger based on the presence of at least three signals above 2.5 p.e. was used (Zaborov).



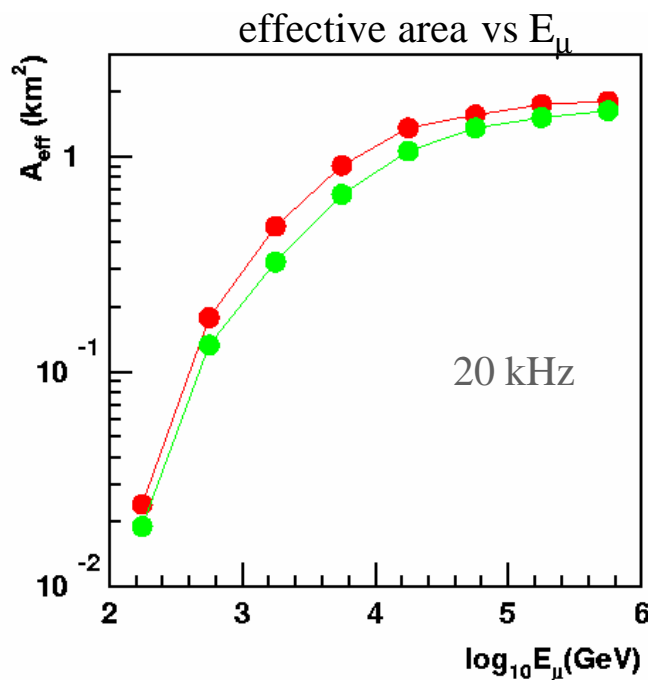
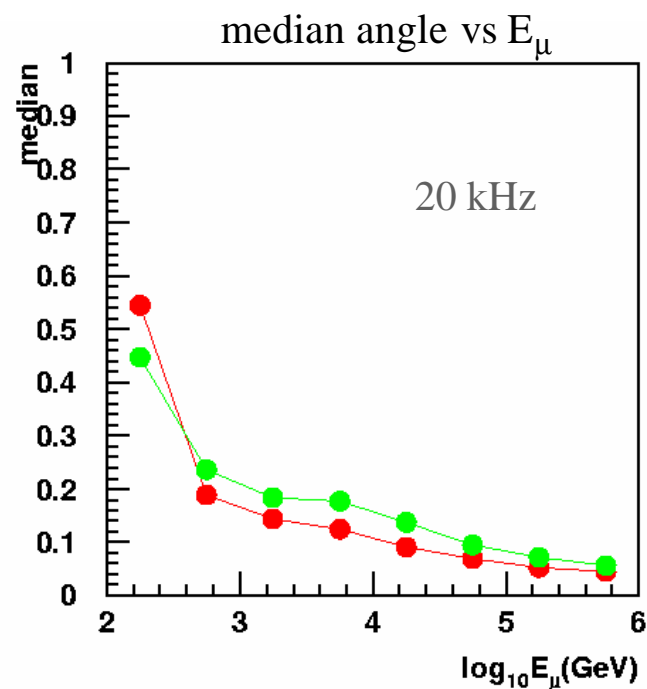
original

our conditions + quality cuts

our cond. + coincidences

our cond. + coinc. + quality cuts

Comparison of NEMO detector with a homogenous lattice detector



NEMO 140 dh 9x9 with quality cuts 5832 PMTs
Regular lattice 400strings 60m x 60m 5600 PMTs

NEMO140dh at 20kHz has performance comparable to a 60x60m lattice detector

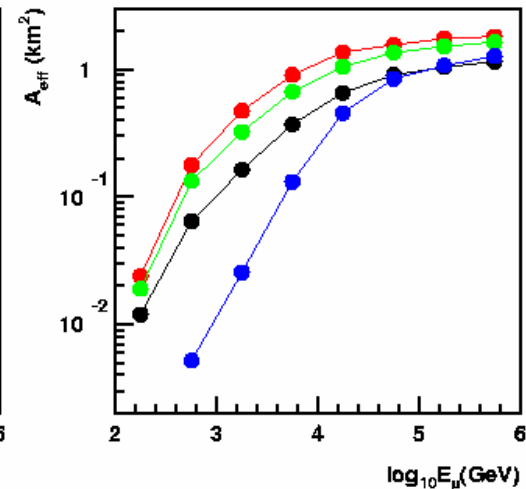
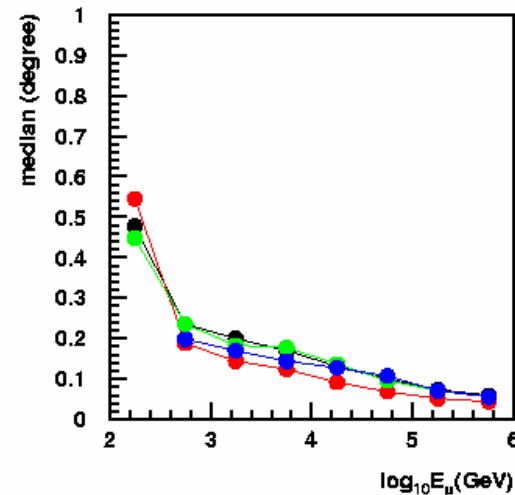
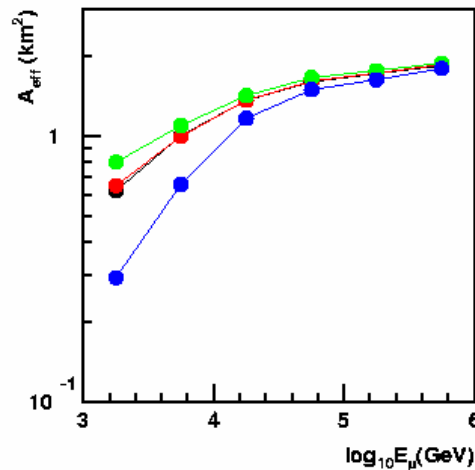
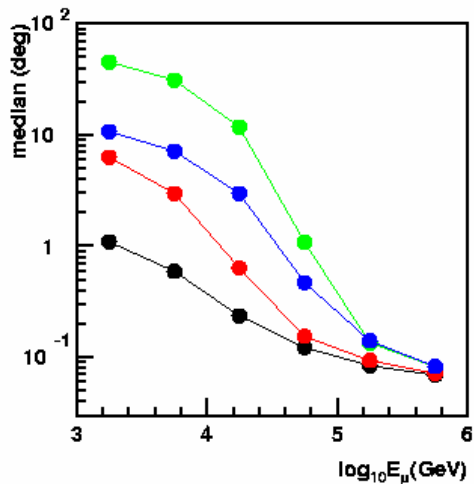
Optical background dependence

Optical background dependence

In order to make comparisons for the same angular resolution quality cuts must be applied

median angle vs E_μ

effective area vs E_μ



NEMO 140 dh 9x9 20 kHz
NEMO 140 dh 9x9 60 kHz
NEMO 140 dh 9x9 120 kHz
NEMO 140 dh 9x9 120 kHz th. 1.5 p.e.

Regular lattice 400 strings 60m x 60m
NEMO 140 dh 9x9 20 kHz with qual. cuts
NEMO 140 dh 9x9 60 kHz with qual. cuts
NEMO 140 dh 9x9 120 kHz th. 1.5 p.e. & q. c.



The NEMO tower lay-out allows space-time coincidence between PMTs in the bar and between adjacent bars. The possibility of using these coincidences as trigger is under investigation. Preliminary results are promising.

TRIGGER: 3 PMTs hits on a bar or 2 PMTs + 2 PMTs hits in nearby bars with space-time correlation plus a threshold on total charge

Simulation inputs:

surf. μ generation

$N_{tower} = 64$ (8x8)

$H_{tower} = 600$ m

$N_{PMT} = 4096$

$D_{PMT} = 10''$

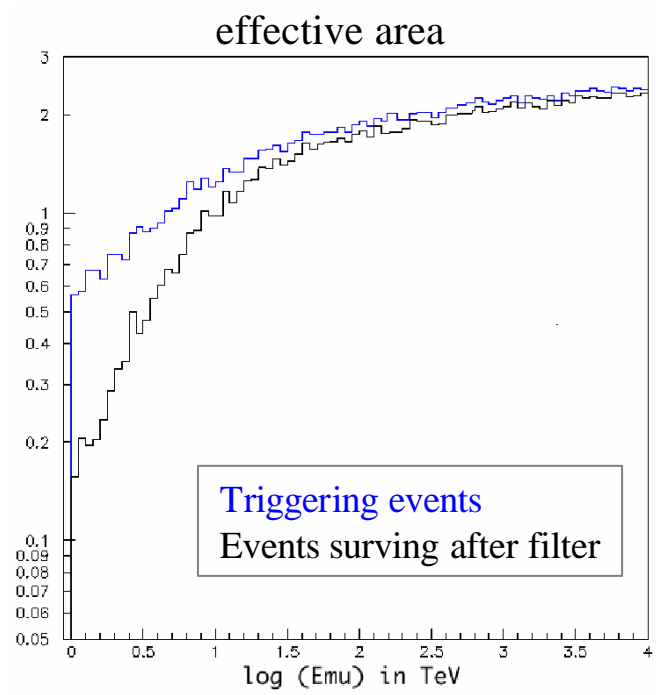
$S_{PMT} = 2.5$ nsec

$d_{xy} = 200$ m

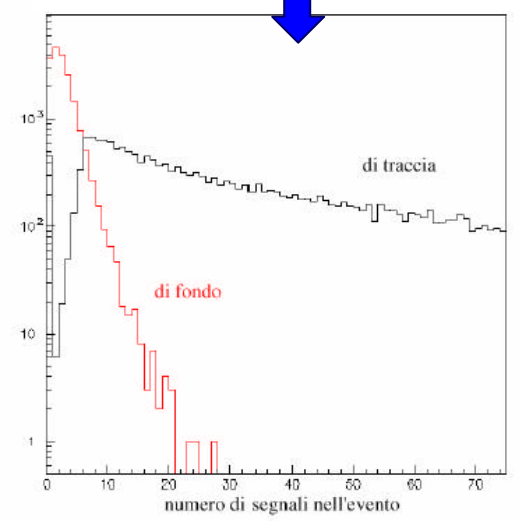
$\lambda_a(450\text{ nm}) = 55$ m

threshold 0.25 p.e.

opt. back. rate = 44 kHz



Number of **background** and muon signals in the events



Conclusions and perspectives



- **Strong muon flux and multiplicity at the can of a km³ NEMO detector at 3400 m respect to 2400 m, especially close to horizon (HEMAS and MUSIC).
Effect on the detector performance understudy.**
- **Effect of the optical background rate on the detector performances has been simulated with the ANTARES package.**
- **A down-horizontal arrangement of the 4 PMTs at the edges of the bar seems a good compromise (OPNEMO).**
- **Tuning of triggers and reconstruction parameters on detector design and enviromental conditions is necessary.**

Angular dependence - *Nemo10dh140* 20 kHz $1 \text{ TeV} < E < 1 \text{ PeV}$

without quality cuts
with quality cuts

