CPPM PhD Seminars

STUDY OF OM EFFICIENCY AND NEUTRINO OSCILLATIONS WITH THE ANTARES DETECTOR

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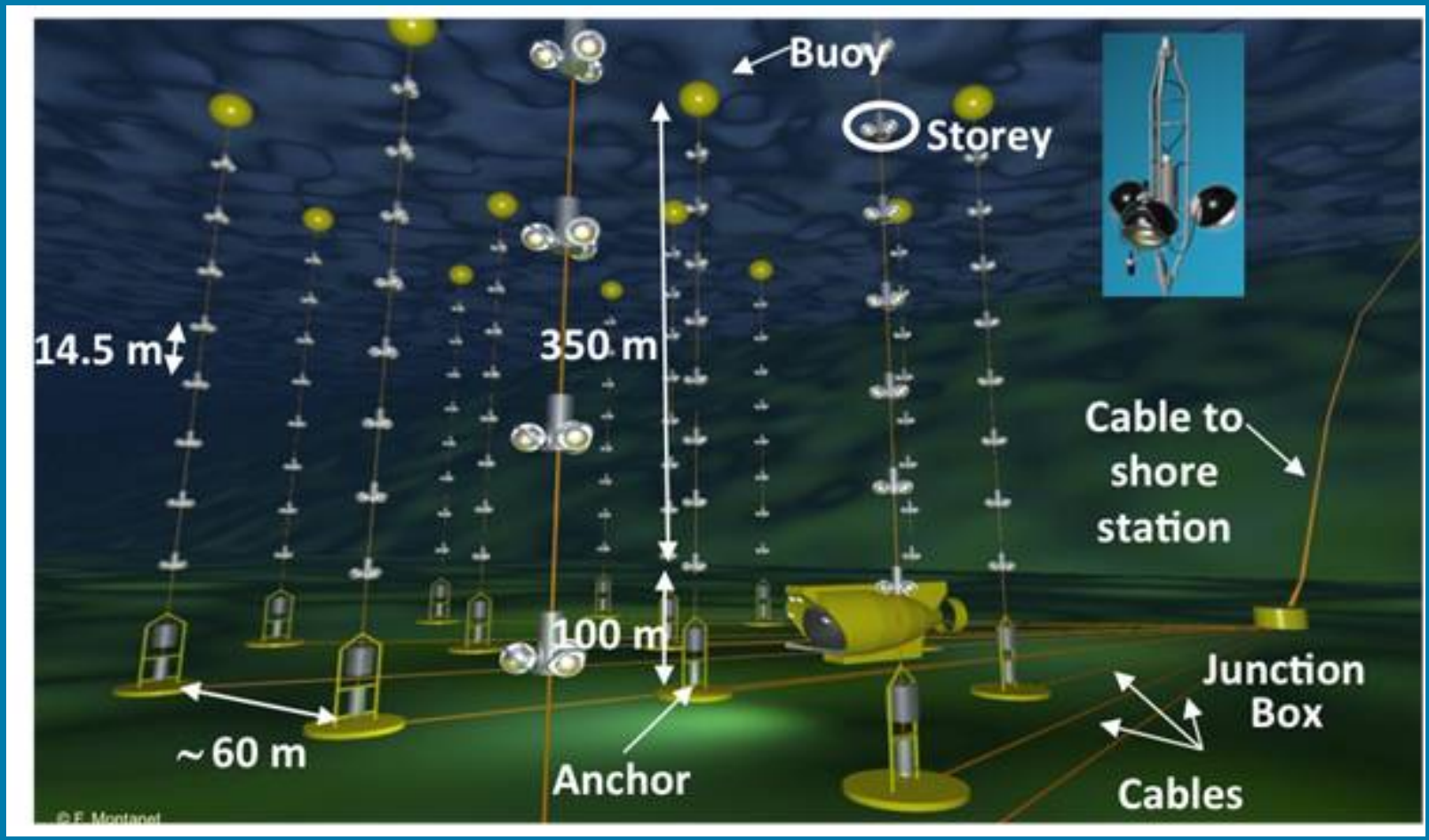
CPPM, 14th October 2016

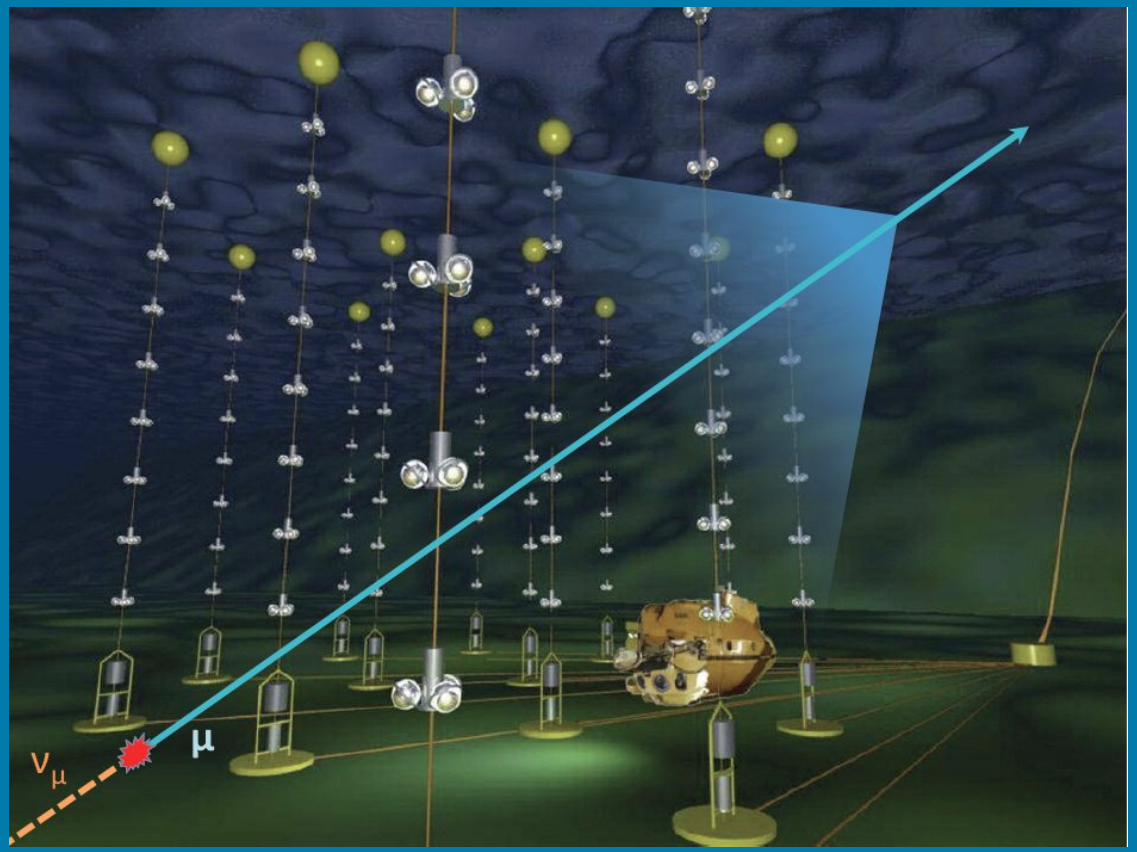
The ANTARES Detector

Completed in 2008!



The ANTARES Detection Method

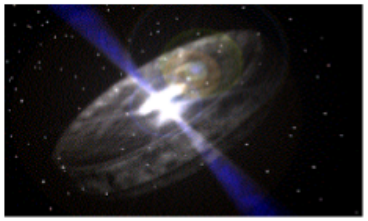
Using Cherenkov light emitted by ultra relativistic particles produced by neutrino interactions under water!



ANTARES Physics Goals

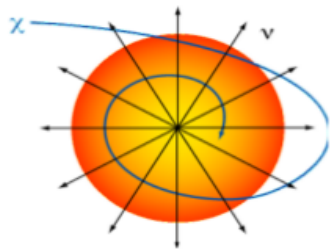
The main goals of ANTARES are:

- the study of particle acceleration mechanisms in energetic astrophysical objects;



High Energy
$E_\nu > 1$ TeV

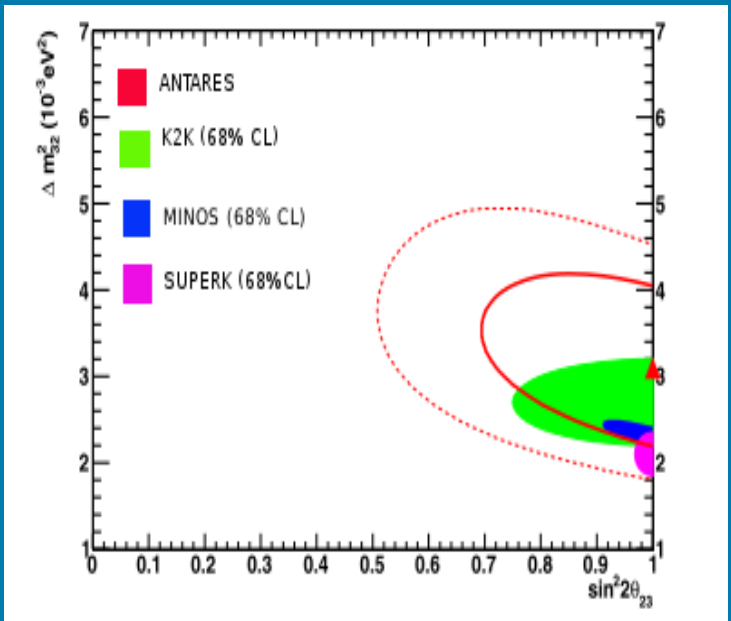
- the detection of non-baryonic dark matter (WIMPs) through the neutrinos produced by annihilation of WIMPs in the cores of the Earth and the Sun;

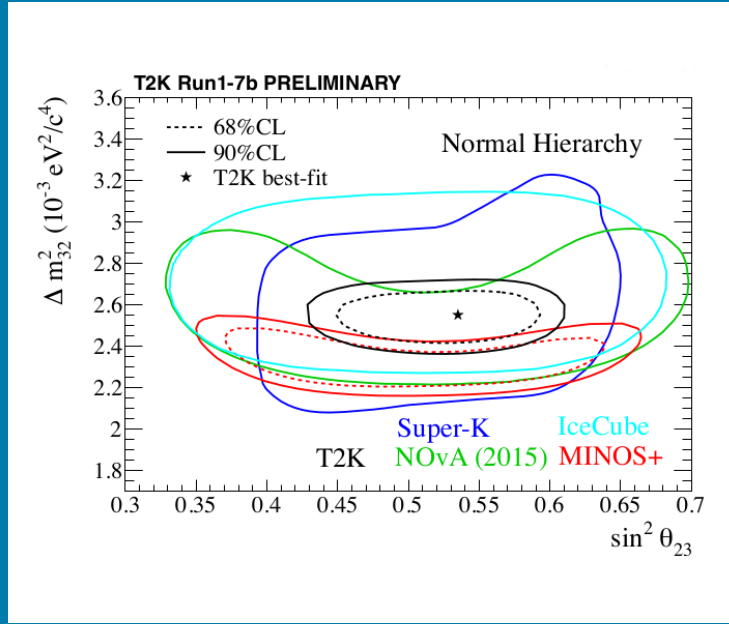


Medium Energy
10 GeV < E_ν < 1 TeV

ANTARES Physics Goals

- the study, at energies below $100\,GeV$, of neutrino oscillations by analyzing distortions in the energy/angular spectrum of upward-going atmospheric neutrinos.



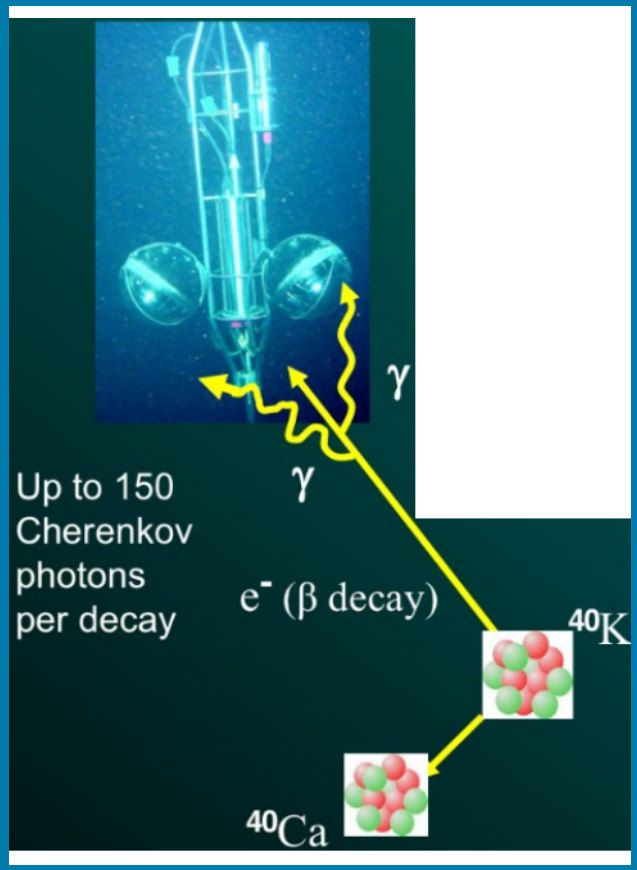


Physics Letters B 714 (2012) H. A. Tanaka (Neutrino 2016)

STUDY OF THE OPTICAL MODULES EFFICIENCY WITH THE ^{40}K TRIGGER METHOD

OM Efficiency Study

- ^{40}K is the most abundant radioactive isotope in sea water;

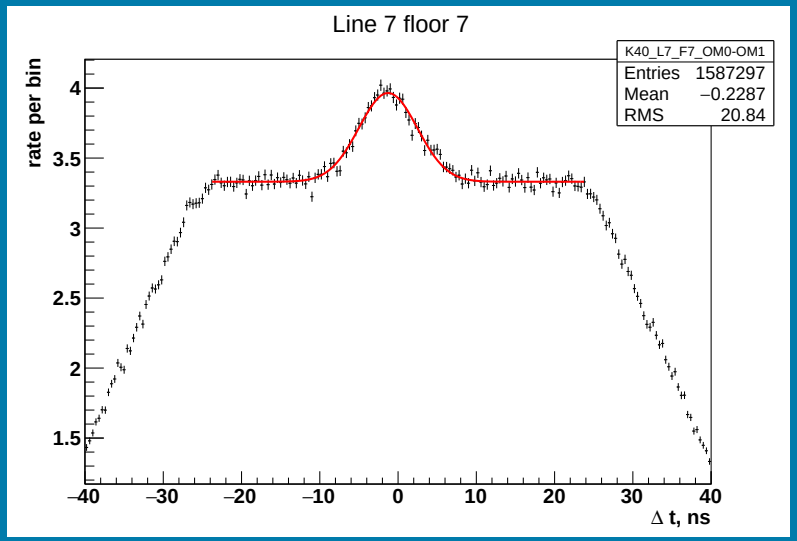


- GENUINE COINCIDENCES (a ^{40}K decay is recorded by two OMs)
- RANDOM COINCIDENCES (two distinct ^{40}K decays are recorded by two OMs)

OM Efficiency Study

The histograms of the hit time differences between hits from adjacent PMTs can then be fitted with a Gaussian plus a flat distribution, and the fit parameters can be stored for further analysis:

$$f(t) = p + a \exp(-\frac{(t - t_0)^2}{2\sigma^2})$$



OM Efficiency Study

- From the fit parameters we can obtained three correlated coincidence rates for each storey;
- From those rates we can analytically deduce the three OM efficiency.

Why is the OM efficiency so important?

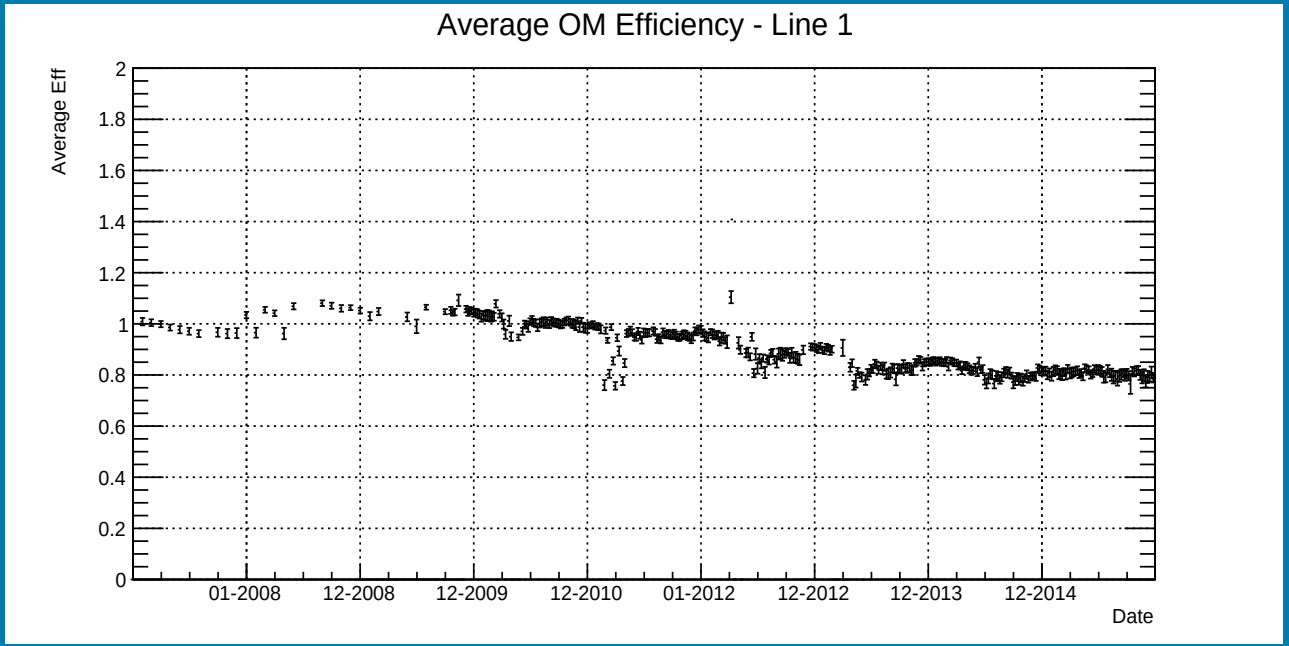
- The sensitivity of OMs can vary from module to module and can also vary in time;
- All these variations may affect track and energy reconstructions, as well as the overall detector efficiency.

OM Efficiency Study

My work consisted in:

- Rewriting the script which produces the coincidence histograms;
- Fitting them and finding a proper set of sanity cuts to get rid of the bad fitted histograms;
- Computing the OM efficiency as a function of time, both for each OM and for each detector line.

OM Efficiency Study



Ten years in the water!!

- The efficiency decreases with time due to biofouling and PMT ageing;
- Steps are due to HV tuning.

NEUTRINO OSCILLATIONS

WITH ANTARES

Neutrino Oscillation Analysis

- The expected atmospheric ν_μ flux which traverse the Earth is expected to be significantly suppressed by neutrino oscillations in the range of a few tenth of GeV;
- It is possible to put constraints on the atmospheric neutrino oscillation parameters by studying the observed muon rate as a function of the reconstructed energy and zenith angle.

Neutrino Oscillation Analysis

Old Analysis	New Analysis
2007-2010 data	2007-2015 data
muon track length	vertex + containment + muon length + shower energy
$1D$ fit in L/E	$2D$ fit in L and E

Energy Reconstruction Algorithm

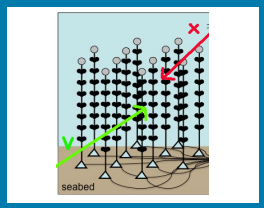
The basic idea is:

- Reconstruct the muon energy by the estimation of the muon track length and the interaction vertex;
- Reconstruct the neutrino energy from the reconstructed muon track length and the hits used by the track reconstruction algorithm.

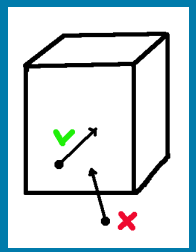
Energy Reconstruction Algorithm

The first step is try to select the hits from the muon track:

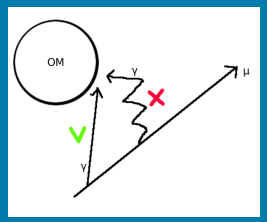
Low Energies



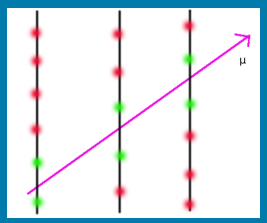
Up-going tracks



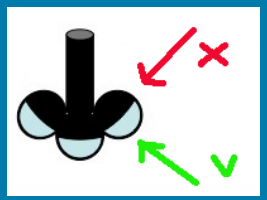
Containment



Direct Photons



OMs around track

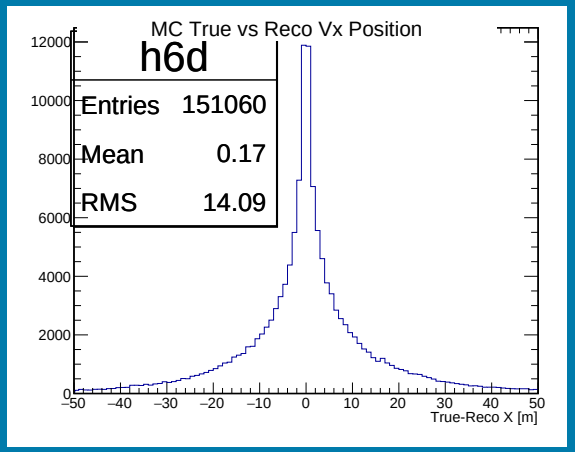


Facing Photons

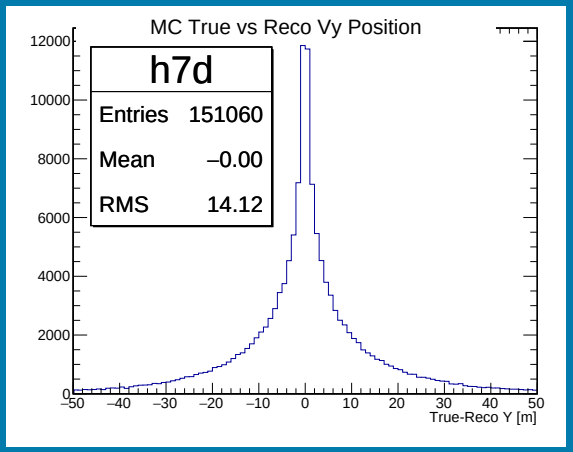
Energy Reconstruction Algorithm

- We projected back to the track the Cherenkov photons selected;
- Using the first hit (based on the photon emission time) we can estimate the interaction vertex;
- We also tried to apply a containment condition in order to see whether this can improve the energy estimation.

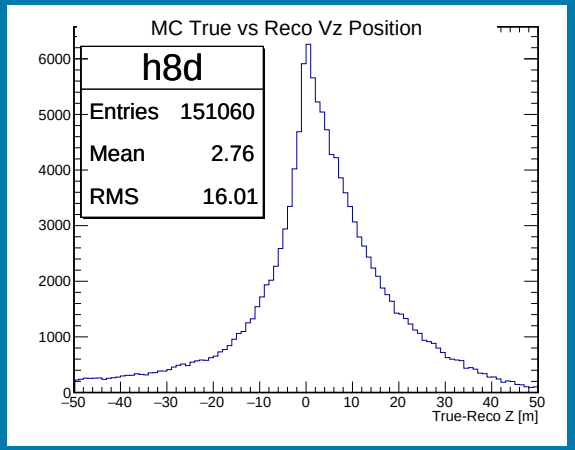
Energy Reconstruction Algorithm



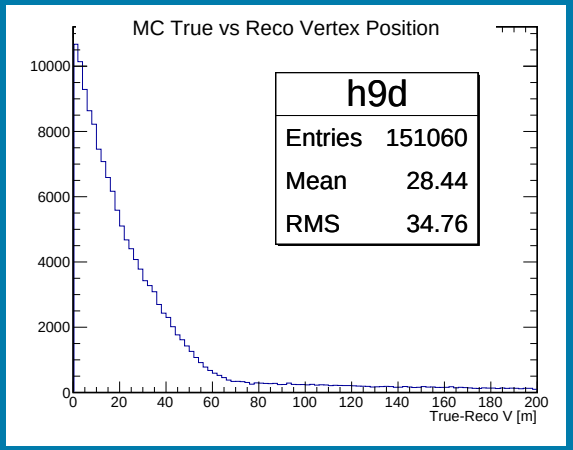
True vs Reco Vx



True vs Reco Vy



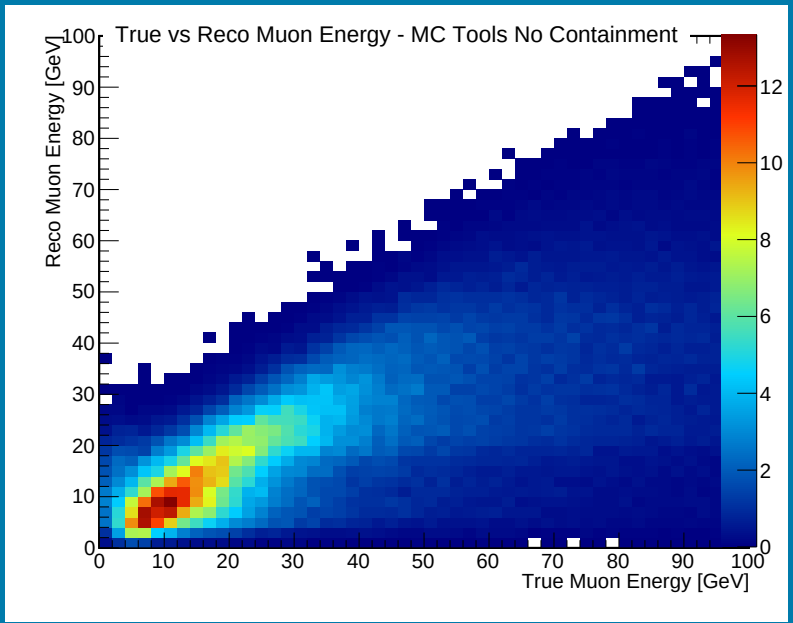
True vs Reco Vz



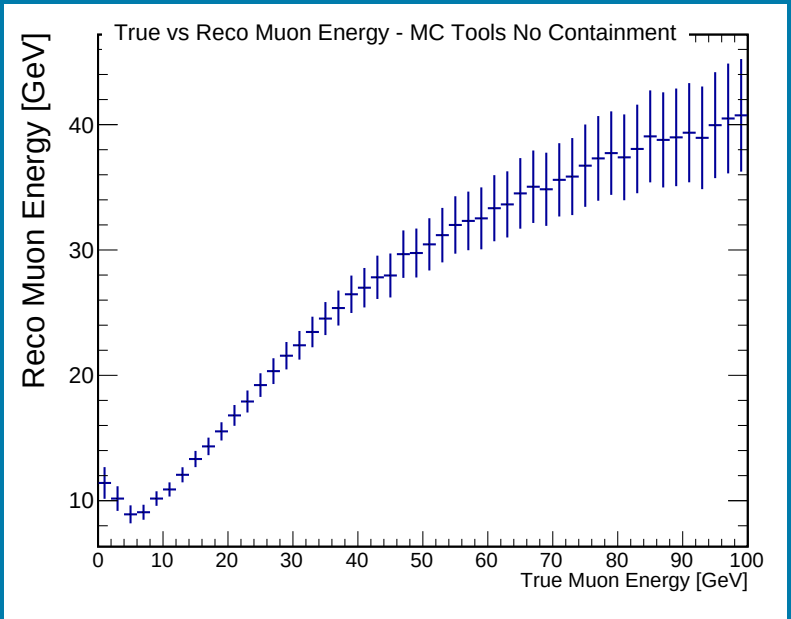
True vs Reco V

Energy Reconstruction Algorithm

- From the first and last photon we can estimate the muon track length;
- From the muon track length the muon energy is estimated by $E_\mu[GeV] = 0.24 L_\mu$



True vs Reco Muon Energy



Profile Plot

Energy Reconstruction - Shower

- One can then simply correlate the muon energy with the neutrino one;
- Before doing this we tried different things in order to add information on the hadronic shower and improve the energy estimator:
  - we chose a set of criteria to select hits from the shower, based on time residual and spatial distributions with respect to the reconstructed vertex, to try to reconstruct the shower energy;
  - we tried to look for possible empirical corrections to the muon energy, in order to estimate the neutrino energy;
  - Still WORK IN PROGRESS!

GridFit vs BBFit - Signal Optimization

- GridFit and BBFit are the ANTARES track reconstruction algorithms more suitable for low energy regimes;
- We tried to understand which one performs better for our oscillation analysis;
- For this purpose we need to consider:
  - the number of ML vs SL reconstructed events;
  - the purity of the sample after applying a reasonable set of quality cuts;
  - the expected event difference due to oscillations.

GridFit vs BBFit: ML and SL Events

Considering all MC runs of 2008, and taking only reconstructed up-going muon neutrino events with $E_\nu^T < 200 GeV$, without applying any quality cuts and assuming no oscillations, we expect:

	SL	ML
BBFit	1134.78	523.69
GridFit	3.83	2809.43

- SL events are more complex for the vertex estimation and the consequent energy reconstruction, since they do not have a full knowledge of the track direction!

GridFit vs BBFit: Quality Cuts

- For BBFit ML events we applied the same quality cuts used in the previous neutrino oscillations analysis:

$$tchi2 < 1.3 \quad \&\& \quad \#_{sto} > 5$$

- For GridFit there are quite a lot of quality parameters one can play with:
  - Ratio (R): ratio of clustered hits in up-going and down-going direction;
  - Reduced Likelihood (rLogL);
  - WOM: angular error estimate.

GridFit vs BBFit: Quality Cuts

We used the same set of cuts suggested in ANTARES-SOFT-2013-002:

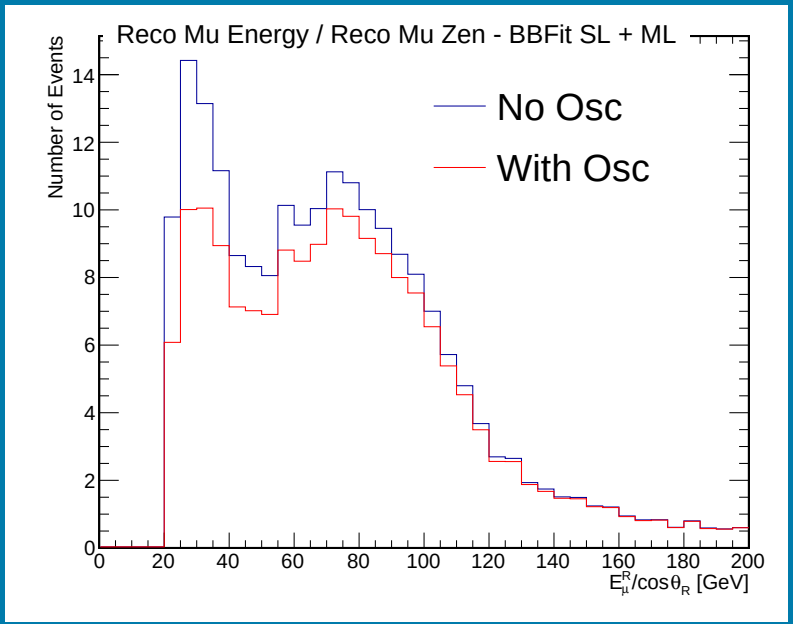
- $R > 3.5$
- $rLogL < 6.3$
- $WOM < 20.0 deg$

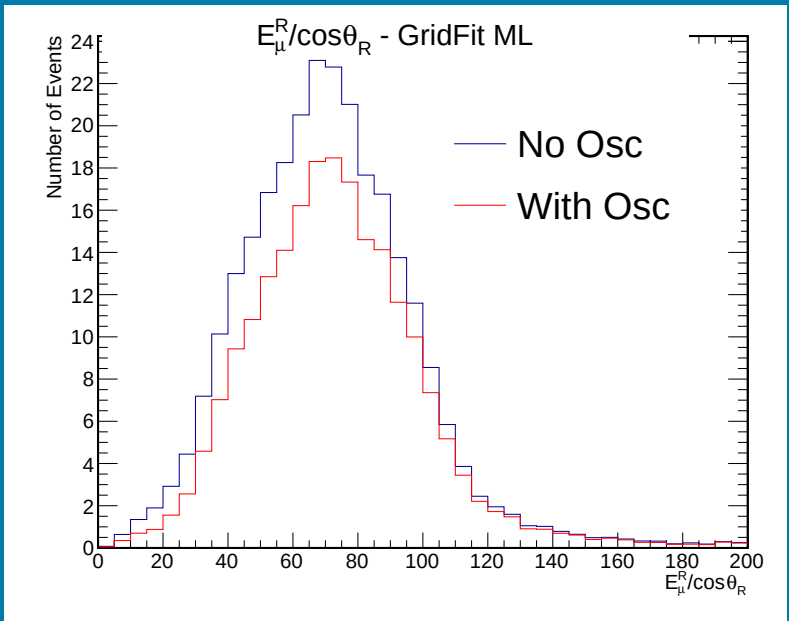
plus, to recover the higher energy events:

- $R > R_0 - [0.02(\#_{hits} - 5)]^2$, with $R_0 = 2$;
- $rLogL < 5.9$
- $WOM < 20.0 deg$

GridFit vs BBFit: Effect of Oscillations

After applying the quality cuts, considering only up-going neutrinos and all the runs of 2008:





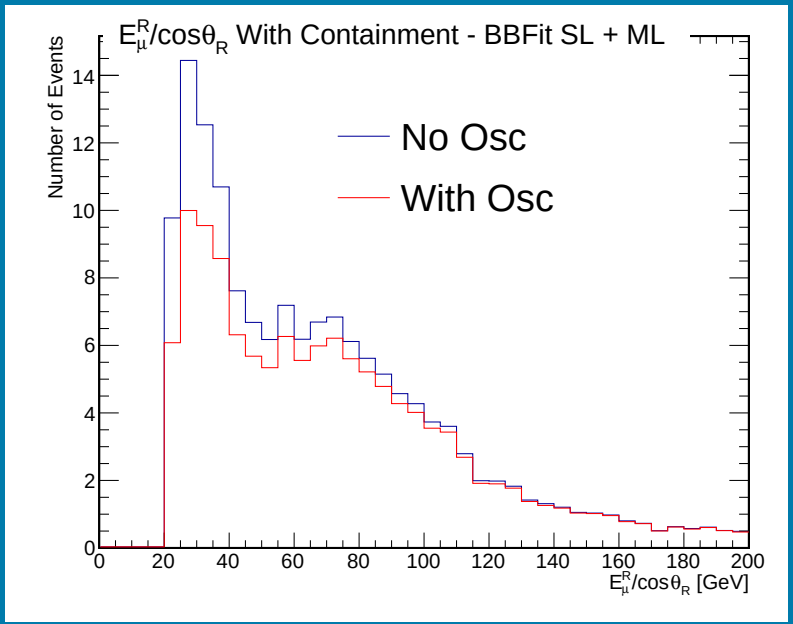
BBFit(Evt Diff $= 15 + 12$)

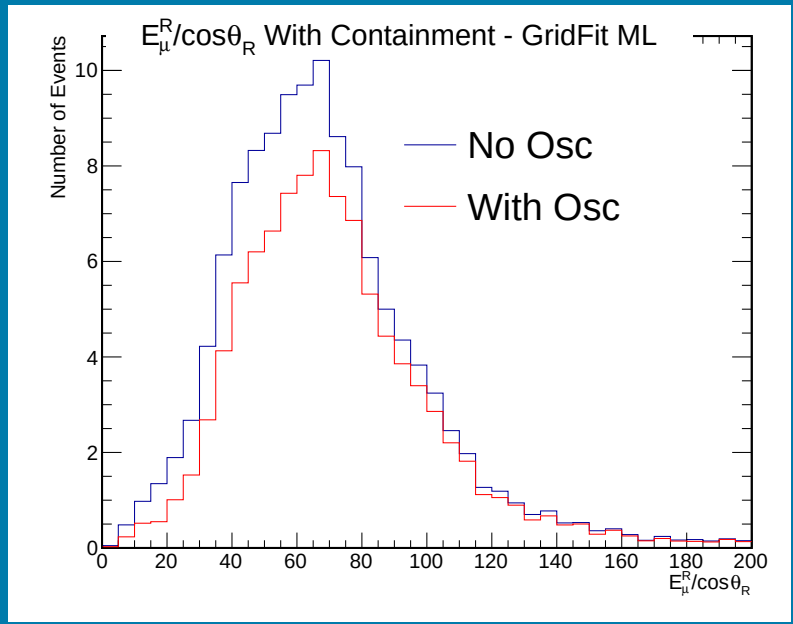
GridFit(Evt Diff $= 58$)

Without Containment Condition

GridFit vs BBFit: Effect of Oscillations

After applying the quality cuts, considering only up-going neutrinos and all the runs of 2008:





BBFit(Evt Diff $= 9 + 12$)

GridFit(Evt Diff $= 26$)

With Containment Condition

GridFit vs BBFit: Event Overlapping

We had a look at the events selected for all the runs of 2008, in order to understand the overlapping between the GridFit and BBFit samples:

- 172 unique GridFit events;
- 117 unique BBFit events;
- 104 equal events.

$\Rightarrow$ It seems we can gain events by combining the two track reconstruction algorithms!

Summary and Conclusions

- The ANTARES OM efficiency with the ^{40}K trigger method has been computed and results have been used in some MC test productions;
- An energy estimator suitable for low energy regions is under implementation;
- A study for signal optimization for neutrino oscillation analysis has been performed, showing a possible gain in number of events by combining the two track reconstruction algorithms.

Next Steps

- Finalize the energy estimator;
- Optimize the quality cuts and test the purity of the final sample against atmospheric muons;
- Start the oscillation analysis.