Study of the Ultra High Energy Neutrinos from Diffuse Flux and Point Sources

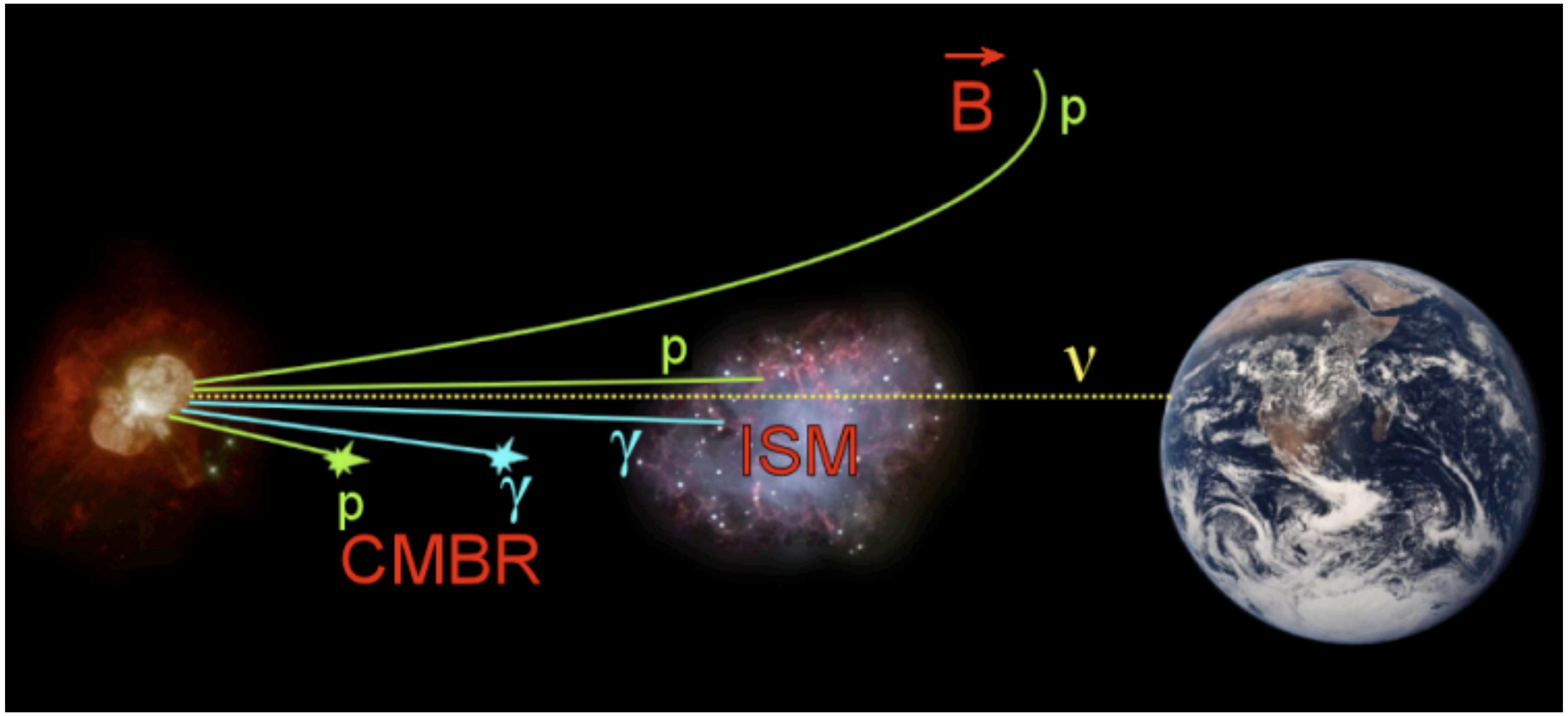
Laura Core
Directeur: Prof. Jean-Pierre Ernenwein

Introduction

- ★ Why neutrino astronomy
- ★ UHE neutrino flux
- ★ The ANTARES detector
- ★ DQ studies
- ★ Simulations and analysis on UHE diffuse flux
- ★ Perspectives and conclusions

Why Neutrino Astronomy

- ★ Neutrinos are the best cosmic probes in the universe;
- ★ Produced in the largest part of cosmic phoenomena (GRB, AGN, supernovae...);
- ★ Possibility to observe the inner source activity;
- ★ Not interacting nor deflected by magnetic fields.



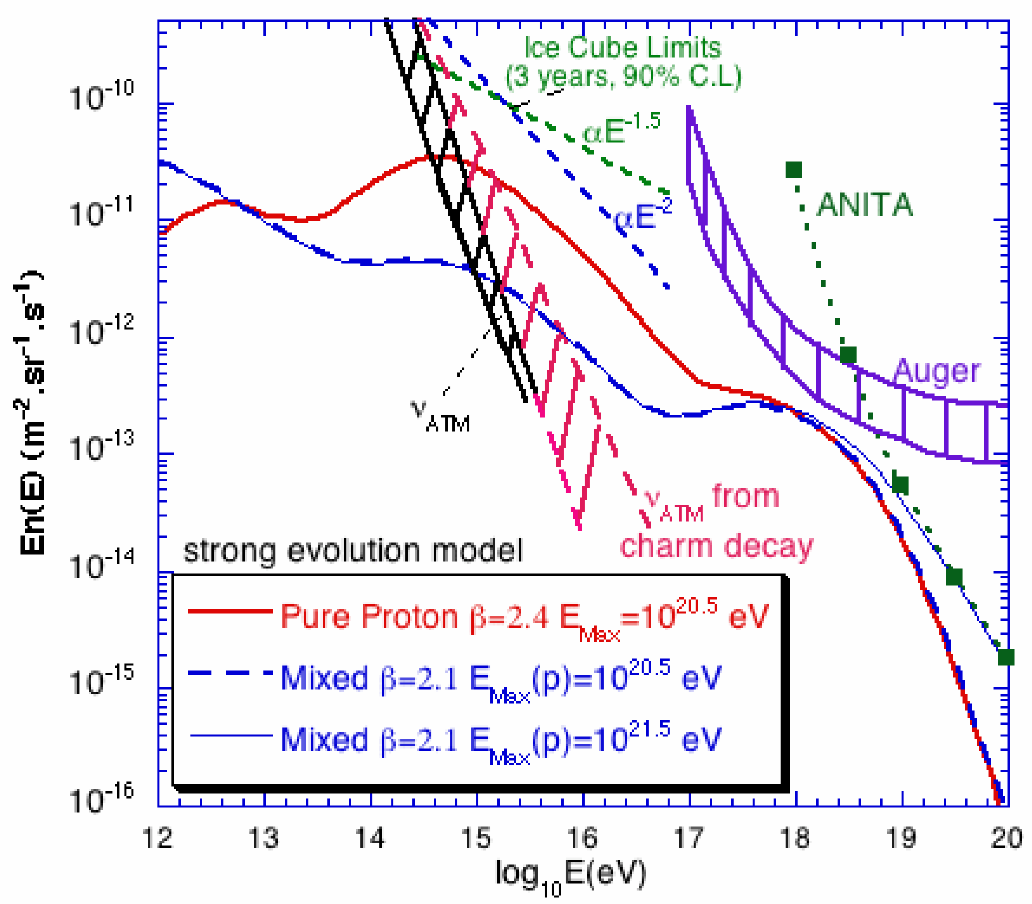
➡ Huge detectors needed!

The UHE neutrino flux

$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow \quad p + \pi^{0} \rightarrow p + \gamma + \gamma$$
$$\rightarrow n + \pi^{\pm} \rightarrow n + \mu + \nu_{\mu}$$

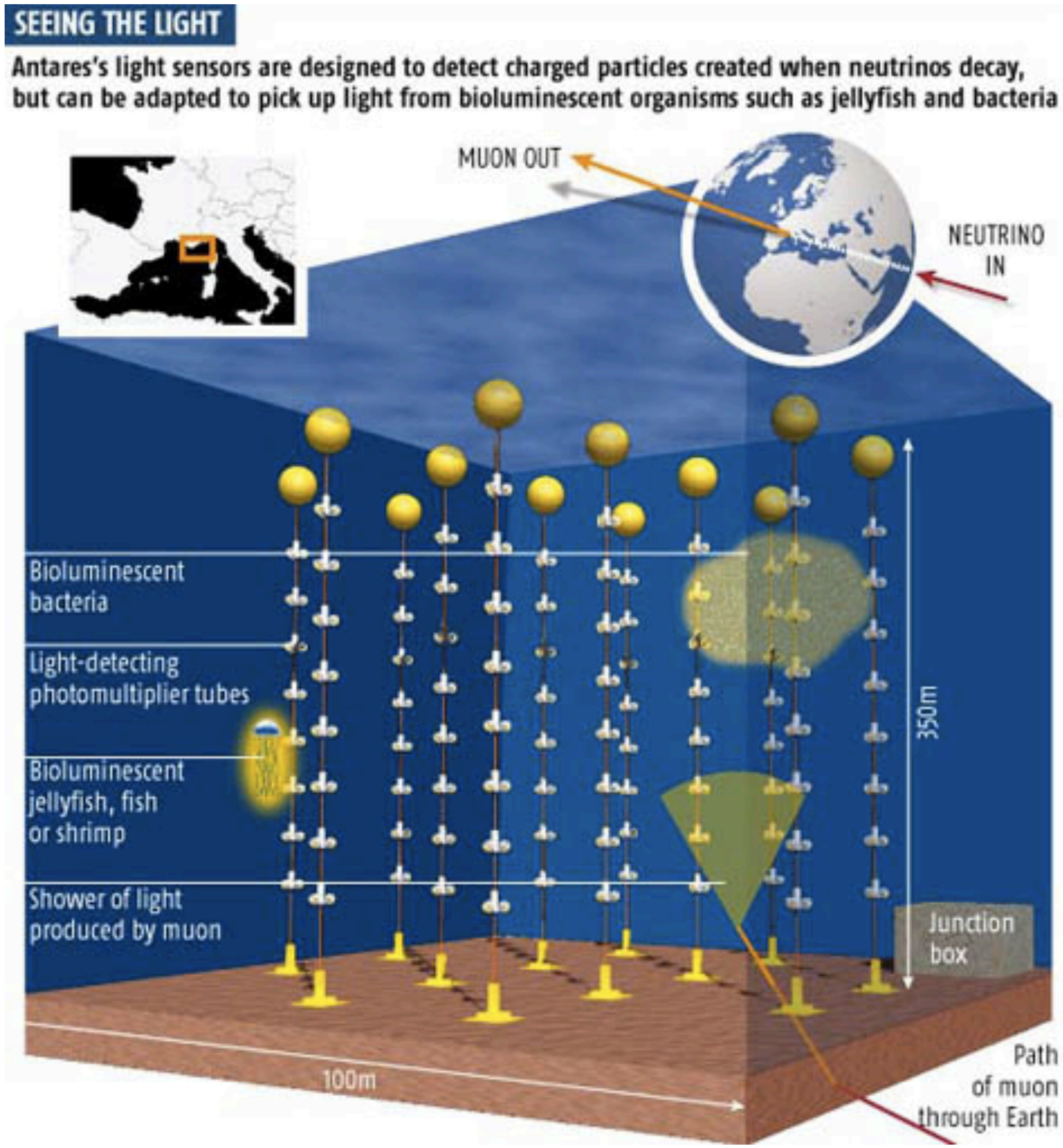
★ CMB photons are a target for high energy CR ($E_{CR}>10^{20}$ eV);
★ Neutrinos from pions decay carry away the 0.05 of initial proton energy;
★ Different parameters play a role on the flux estimation:
- ✳ redshift of the sources;
- ✳ universe evolution;
- ✳ distribution of the sources;
- ✳ source emitting protons or heavy nuclei;

★ Until now no detection from AMANDA/IceCube, only upper limits.



Very low rate: one neutrino/century

ANTARES detector



Resolution: 0.3° for E>10 TeV

- ★ First Cherenkov telescope in the Mediterranean sea;
- ★ Site: 40 km away the coast of Toulon, 2500 m depth;
- ★ Equipped with 885 PMT mounted on 12 lines on the seabed;
- ★ Instrumented volume: 0.01 km^3
- ★ Environmental background sources:
  - ✳ bioluminescent fishes and bacteria;
  - ✳ ^{40}K radioactivity.

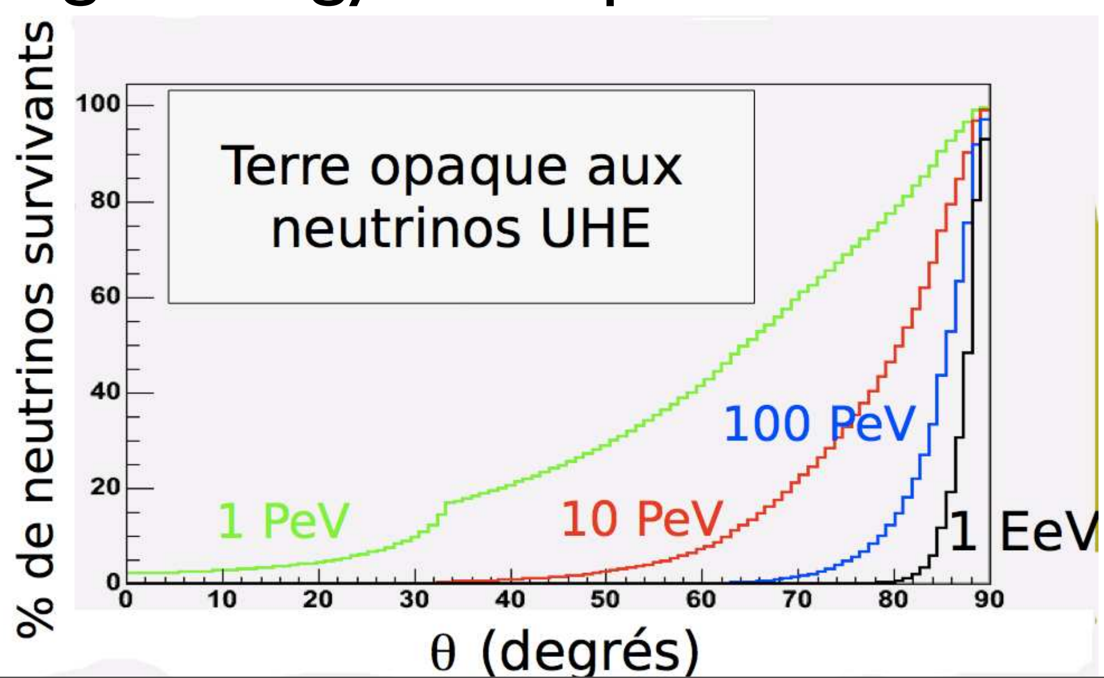
Data Quality

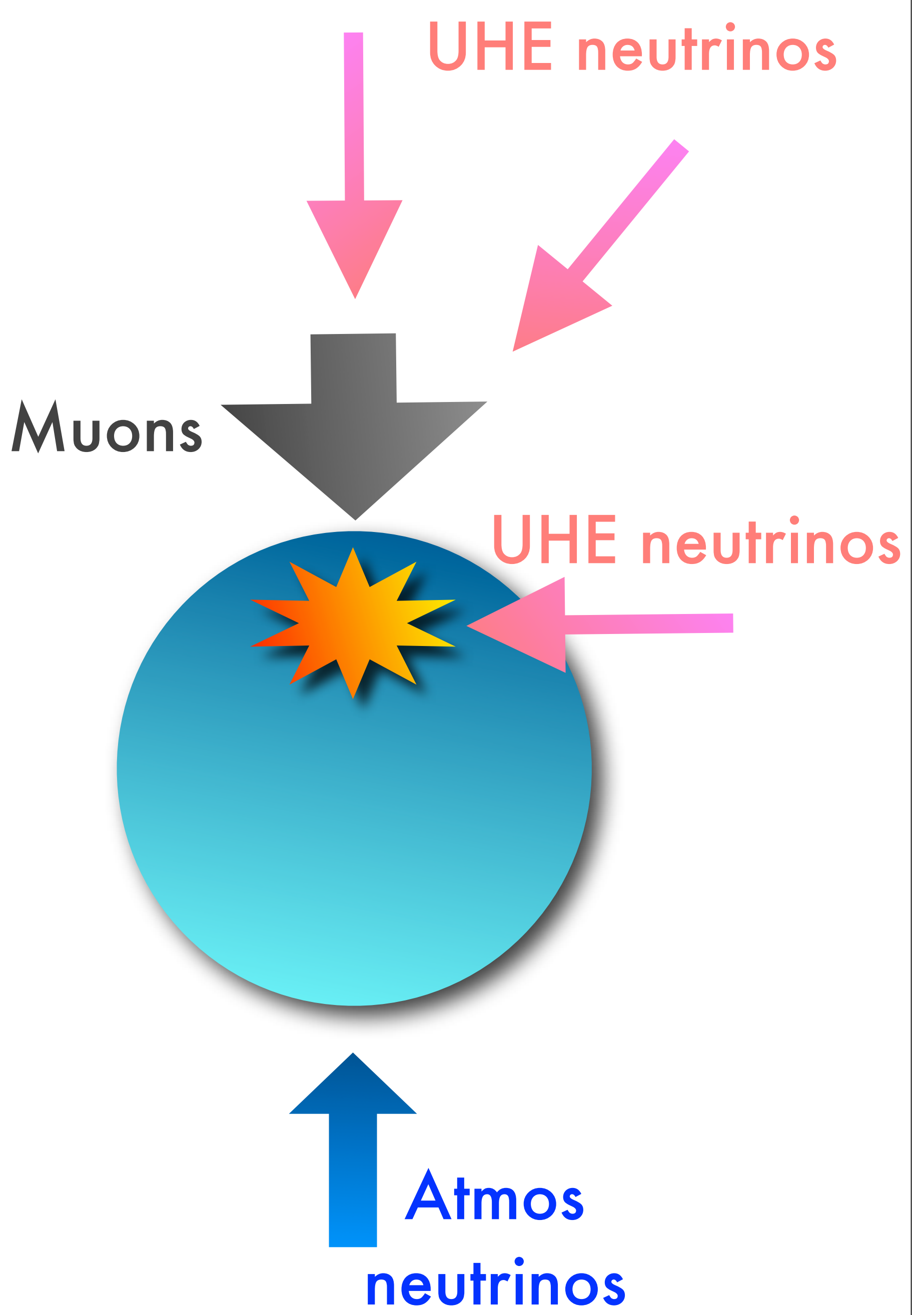
ANTARES service task

- ★ High Threshold: parameter used in the first level ANTARES trigger to identify hits with large amplitude, which are most likely from a physical signal;
- ★ The higher is the threshold, the lower is the background accepted
  - ➡ Compromise between threshold and rate;
  - ➡ Three different values used during data taking: 3, 5 and 10 p.e.
- ★ Cross-check between the measured values and the ones reported in the ANTARES database;
- ★ All the ANTARES data production until 2011 had been alayzed to perform this check.

UHE Simulations

- At very high energy Earth is no longer transparent to neutrinos;
- UHE signal composed by muon neutrinos with energy 100 PeV - 10 EeV, mostly downgoing or horizontal (main contribution);
- Two main sources of backgroud:
  - downgoing muons;
  - high-energy atmospheric neutrinos.





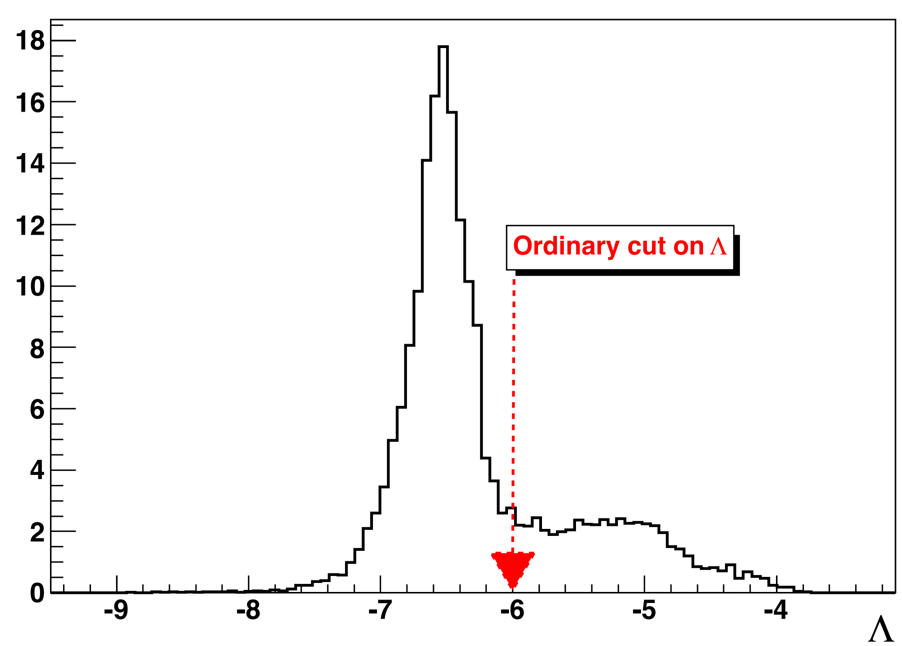
Cuts and variables

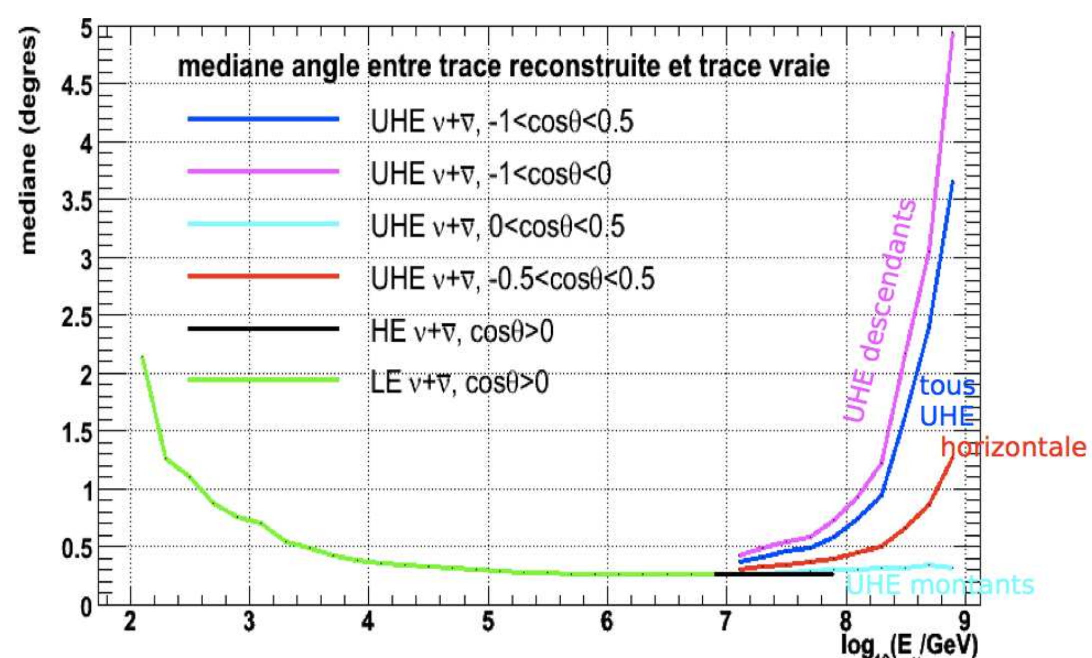
For this kind of analysis, it is mandatory to chose variables strictly bounded with neutrino energy...

Six variables have been chosen and studied to perform the analys and the event selection for UHE neutrinos.

Main problem: due to the large number of hits in the detector, UHE track reconstruction is really difficult.

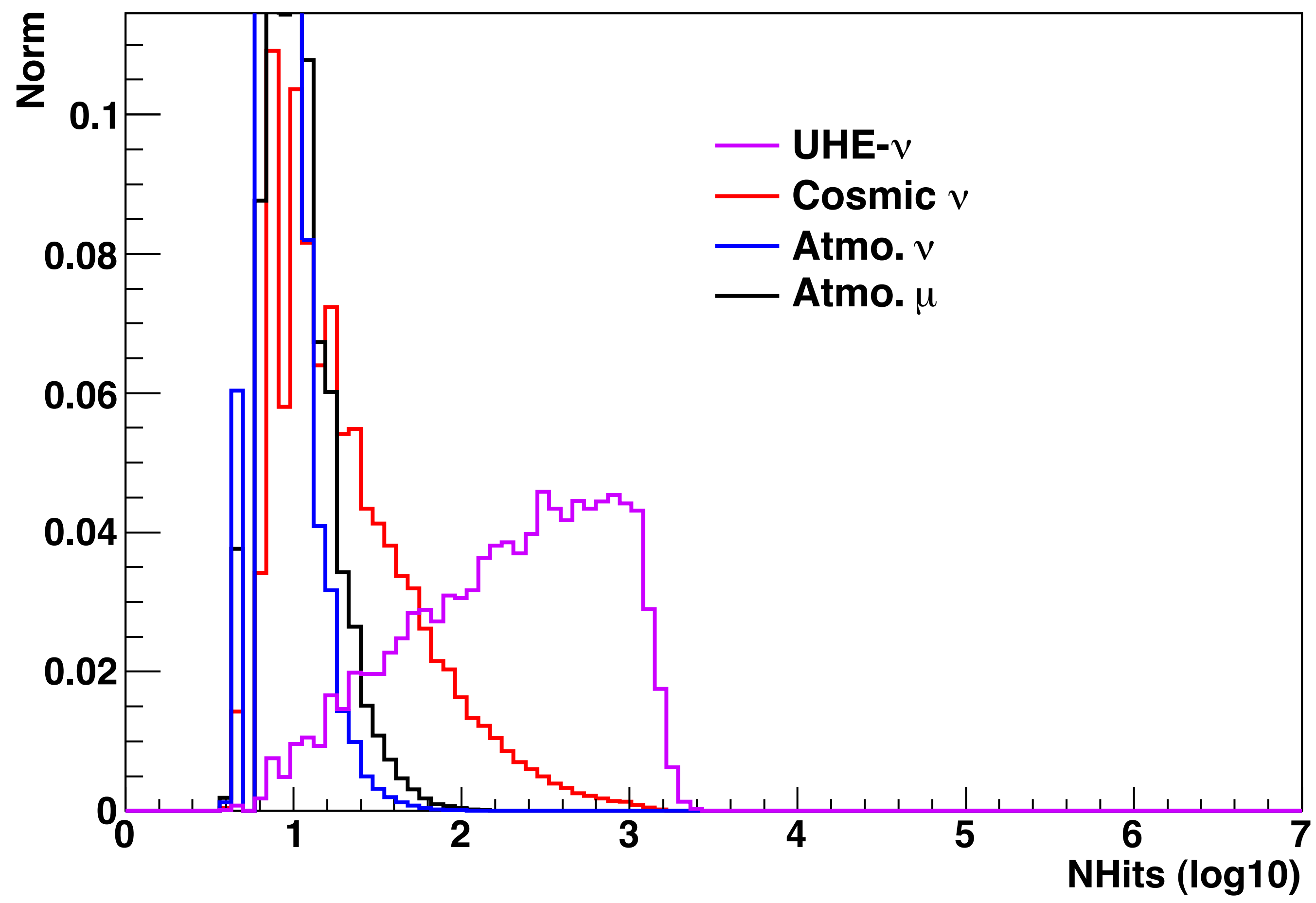
➡ Loose quality track cut, maybe new tracking algorithm.





Number of Hits: the more a neutrino is energetic, the higher is the number of hits recorded by the PMTs during the event.

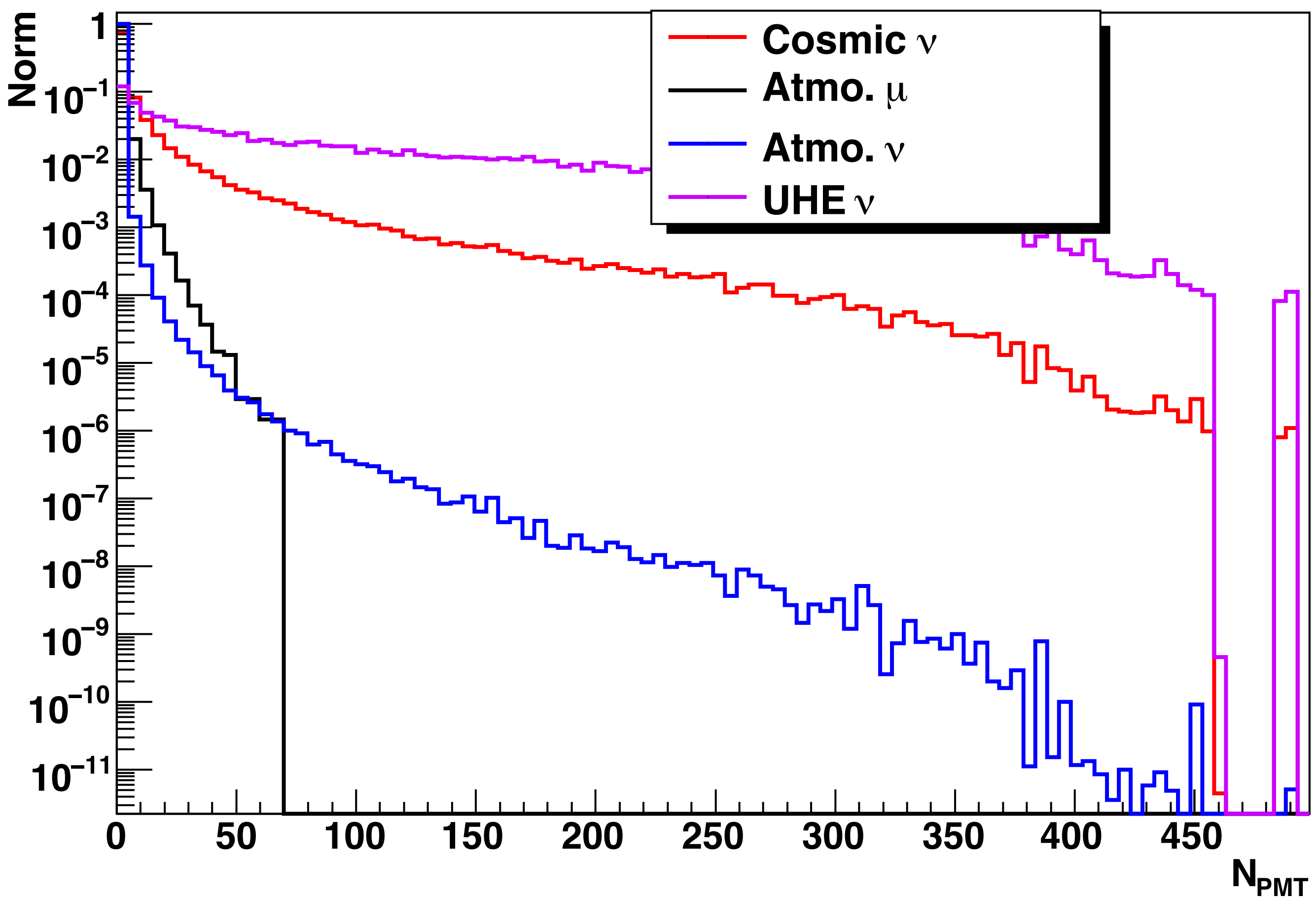
→ Events with great number of hits, correlated to the number of Cherenkov photons detected.



Number of PMT with more than one hit: a good measure of the spatial extension for the event.

UHE neutrinos produce more light along their track, so they touch a larger number of PMTs.

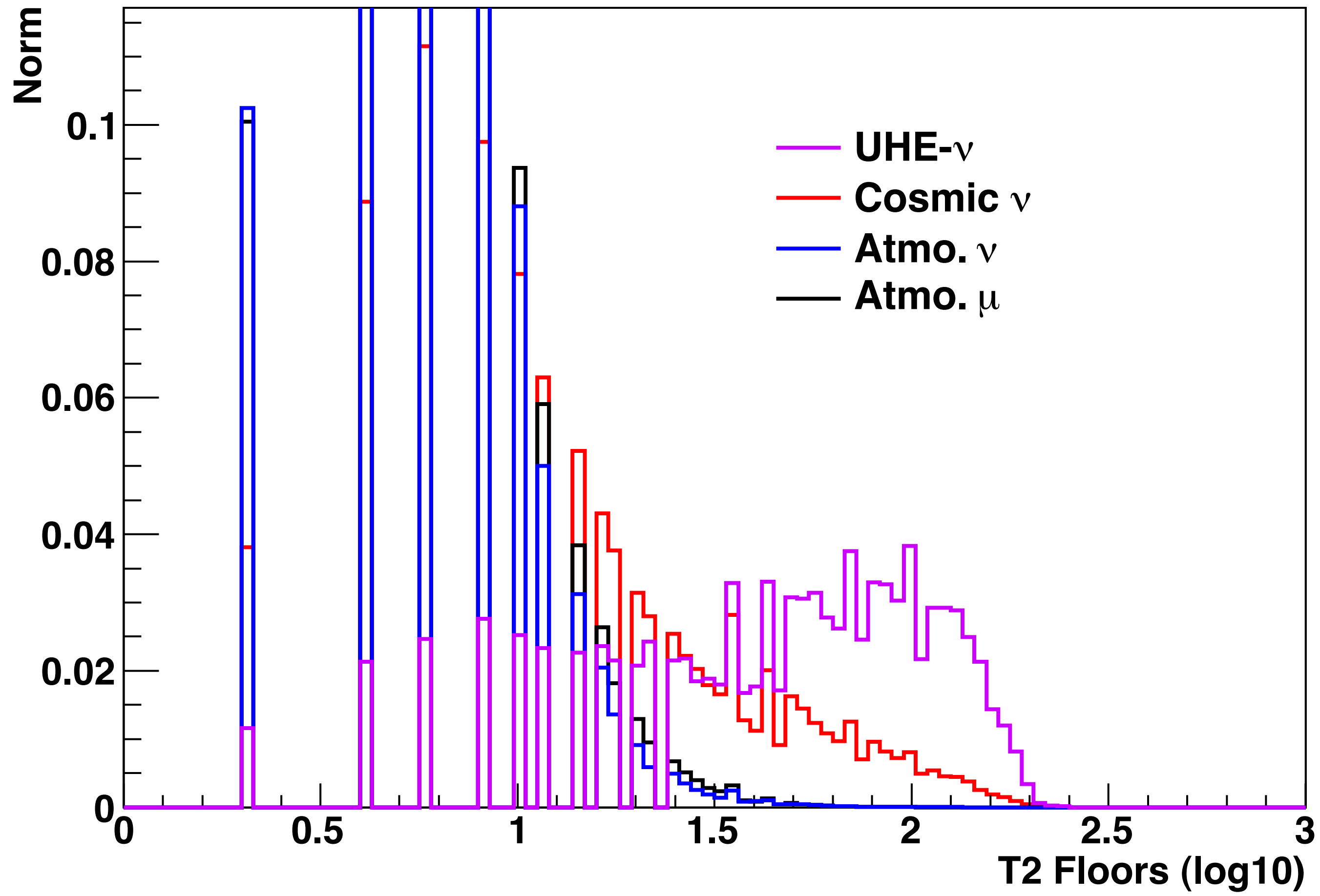
Taking into account only PMTs with $N_{hits}>1$ allow a rejection of muons with long tracks

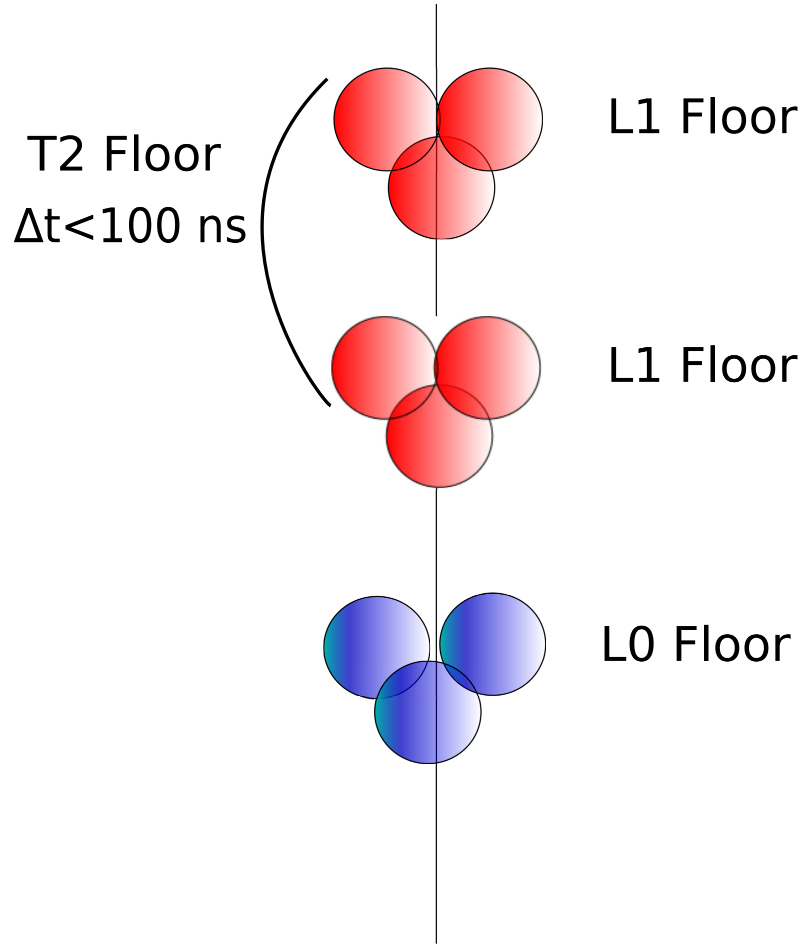


Number of T2 floors: a pair of floor in contact in L1 state, in coincidence less than 100 ns.

UHE neutrinos has a peculiar topology and lot of light, so a larger number of T2 floors.

L1 state: floor with a hit coincidence smaller than 20 ns or a charge larger than 3 pe

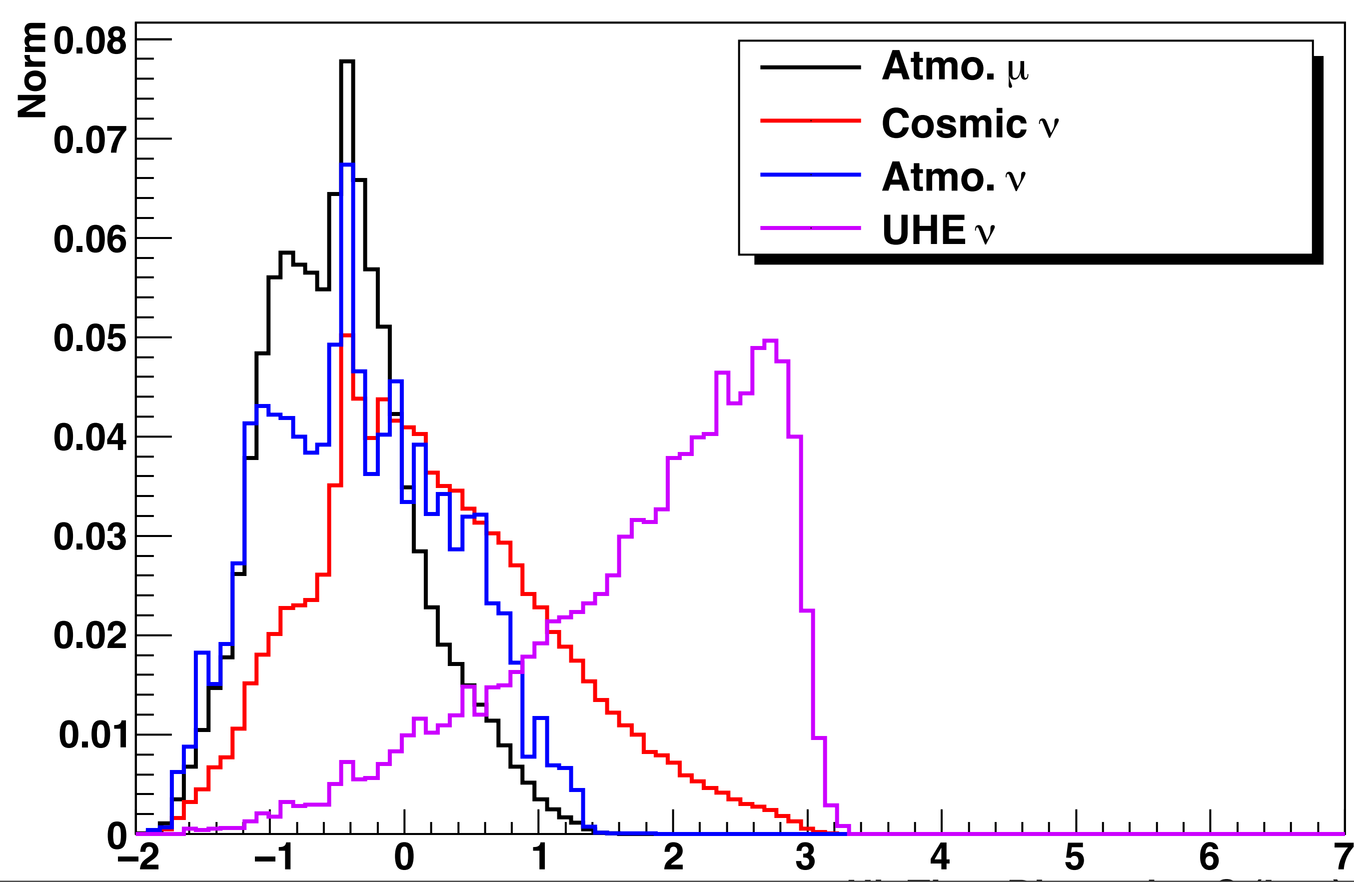




Time dispersion: mean time distributed over the PMTs touched by the event, weighted with event amplitude.

UHE neutrinos produce more hits in the detector, so the time residual distribution is increased, along with the time dispersion

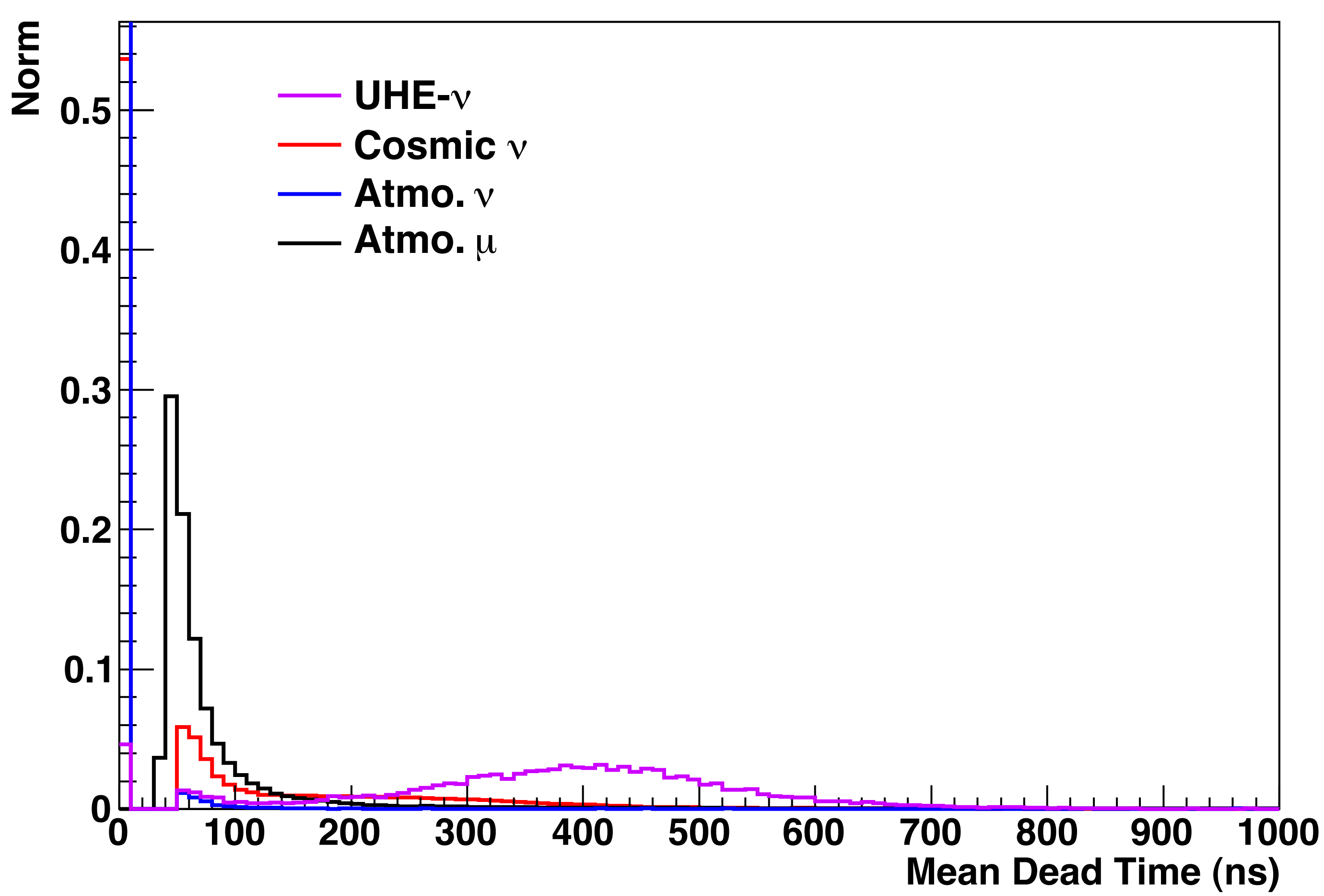
$$S = \frac{1}{N_{\mathrm{PMTs}}} \sum_{p=1}^{N_{\mathrm{PMTs}}} \mathrm{RMS}(A\Delta t) = \frac{1}{N_{\mathrm{PMTs}}} \sum_{p=1}^{N_{\mathrm{PMTs}}} \sqrt{\frac{1}{N_p} \sum_{k=1}^{N_p} \left[A_k(t_k - \overline{t_p})\right]^2}$$



Mean Dead Time: time interval of ARS (ANTARES electronic) blinding, defined as the mean interval between two hits on the same PMT over all the PMTs

In a UHE event there is a huge number of photons arriving on the PMTs. It is possible that the ARS are not able to process all of them at the same time, creating a dead time.

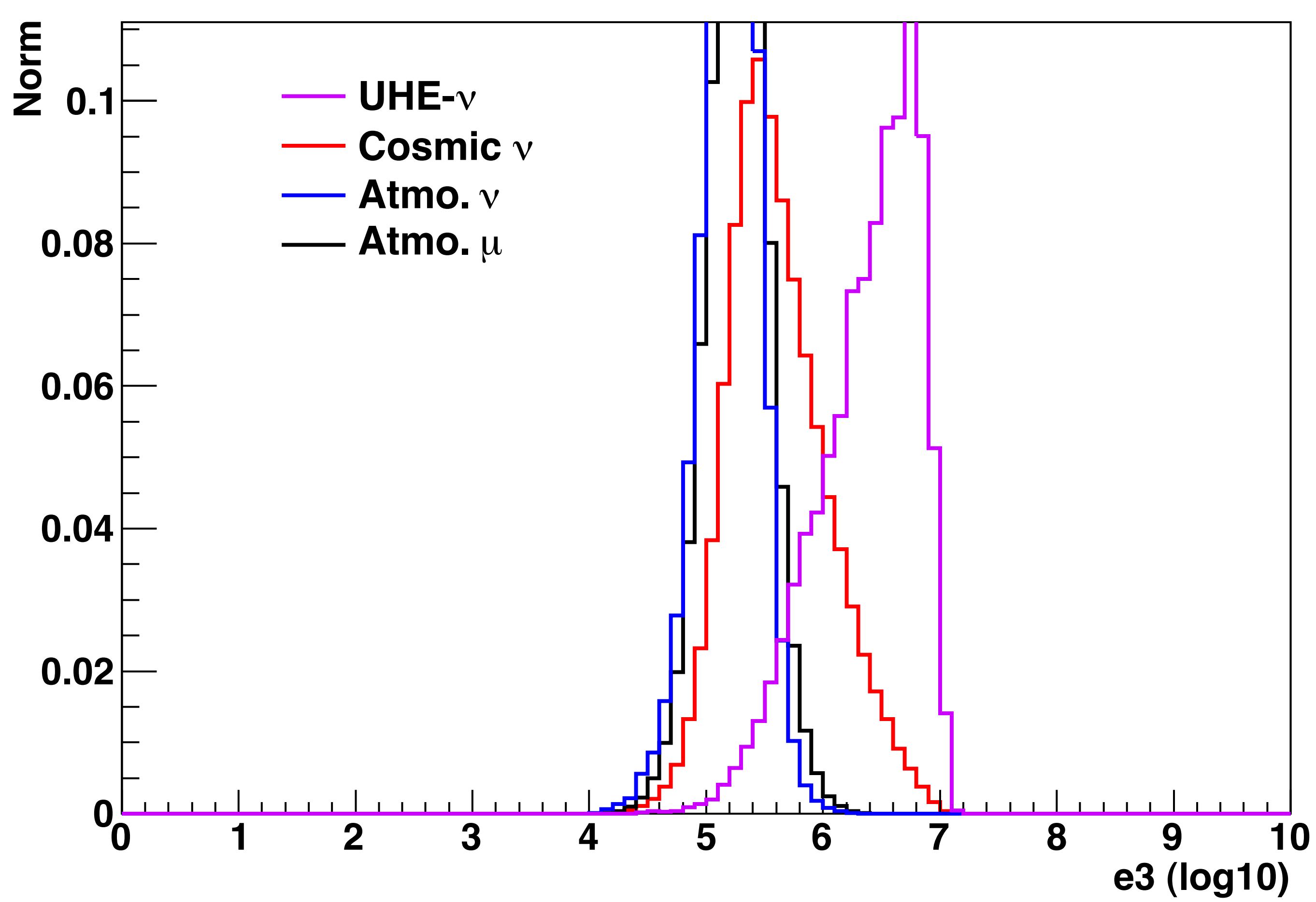
$$\bar{d} = \frac{1}{N_{\rm double}} \sum_{i=1}^{N_{\rm hits}} \sum_{j>i}^{N_{\rm hits}} \delta^{PM_i PM_j} |t_i - t_j|$$

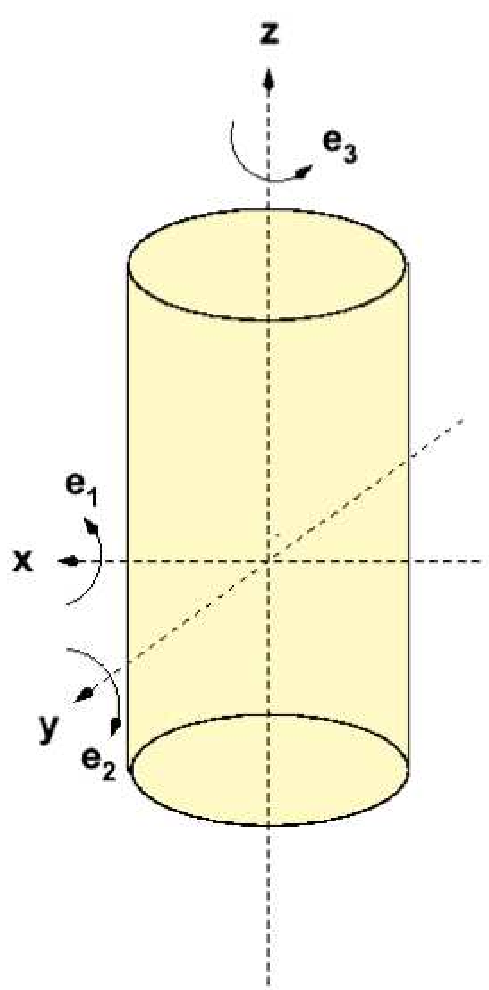


Inertia tensor: analogous to the mechanic one, using the amplitude as mass. Its eigenvalues, as event axis, are useful to evaluate the event shape

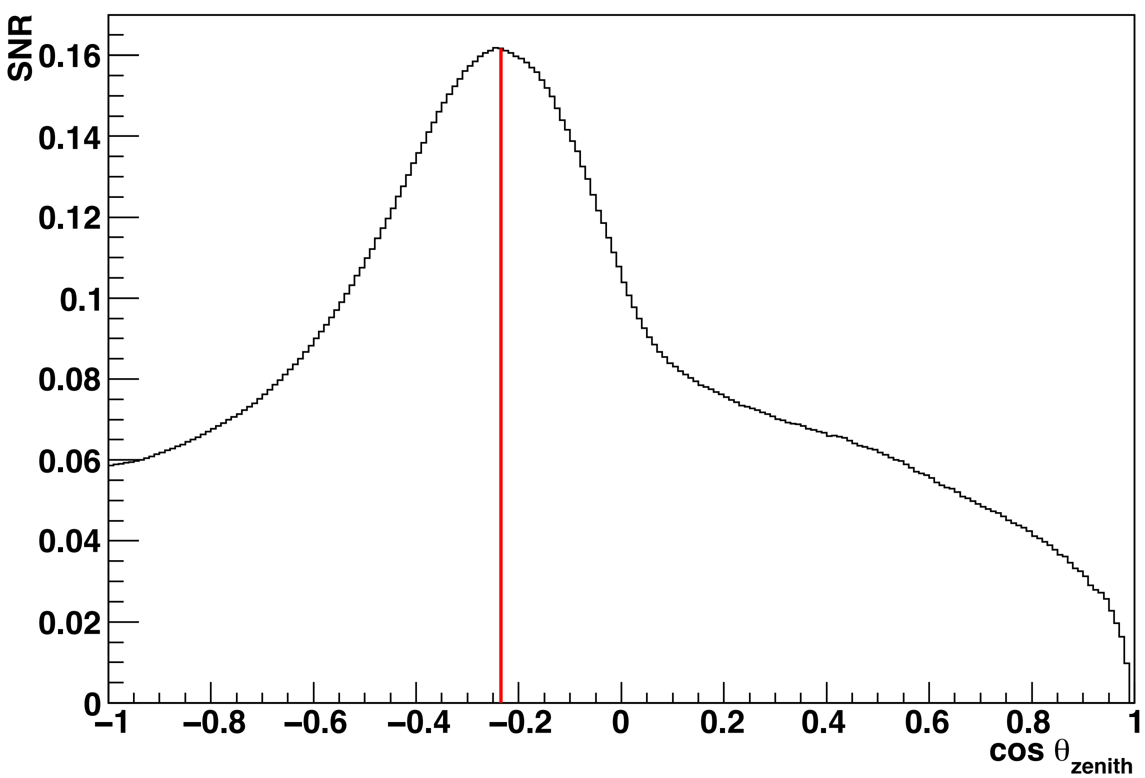
A cigare-like event has e_3<(e_1, e_2) and it considered bad reconstructed. Cascade-like events has equal eigenvalue. e_3 is used to select UHE events

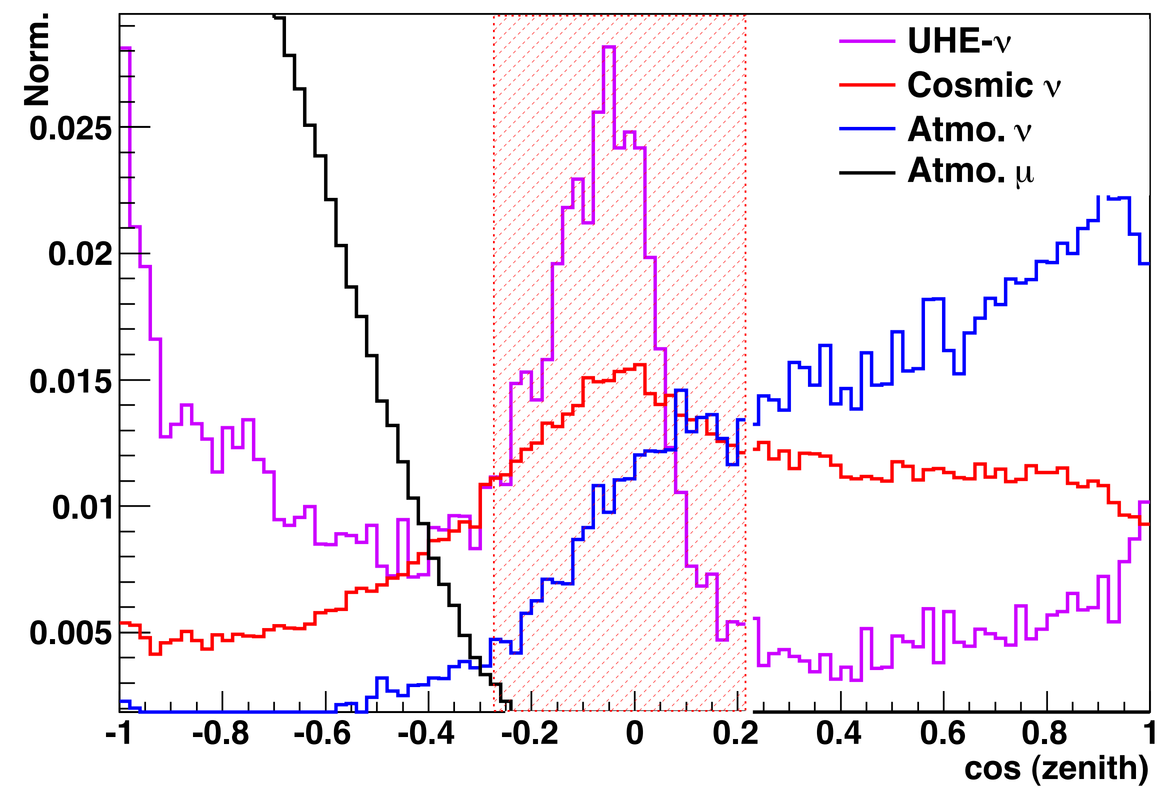
$$I^{k,l} = \sum_{i=1}^{885} (A_i)^w \left[\delta^{k,l} \cdot (\mathbf{r})^2 - r_i^k \cdot r_i^l\right]$$





To have a better discrimination between the two sources of background, I define an angular selection to classify the events as downgoing or quasi-horizontal (selection optimized by SNR).



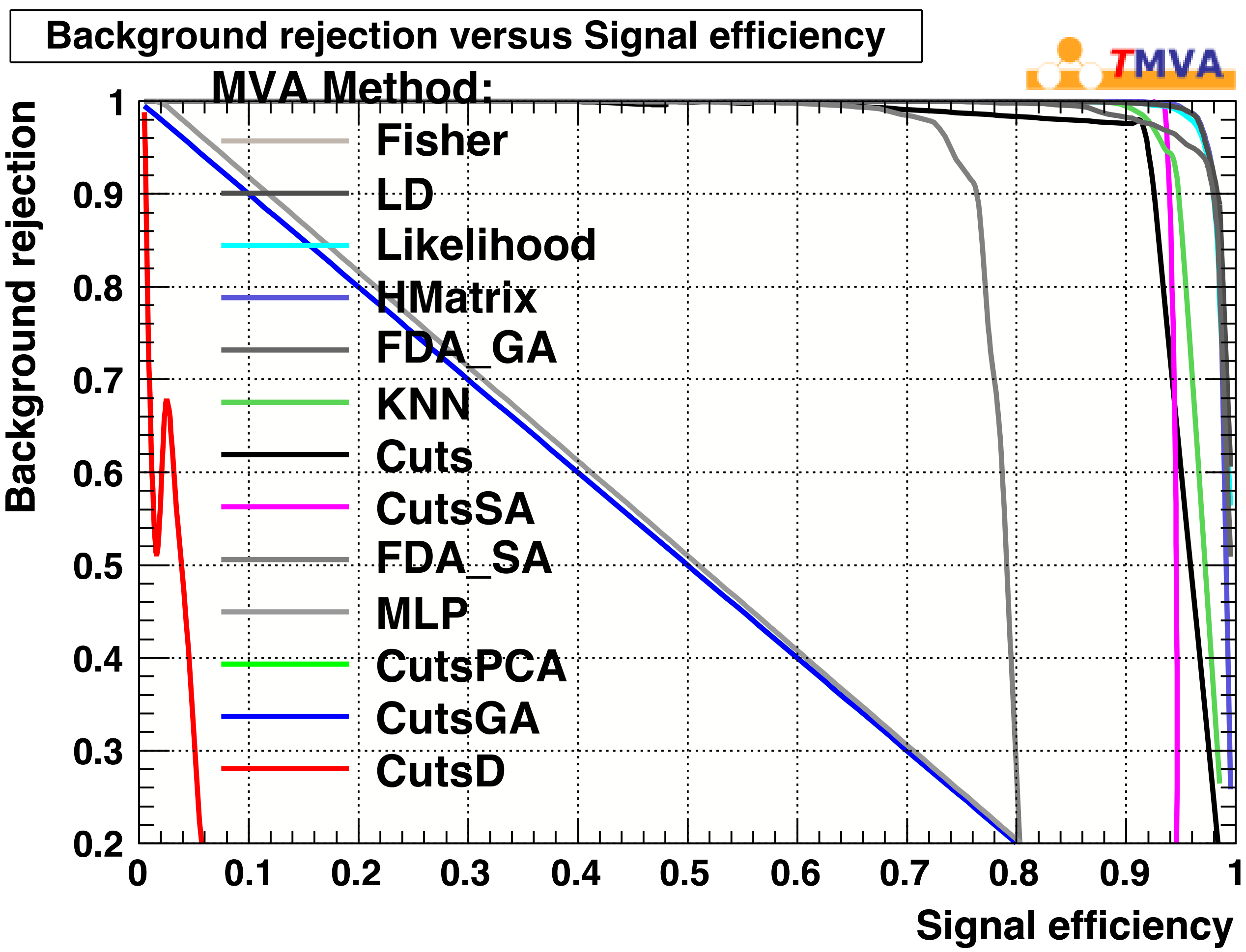


The best cut is for a zenith angle of 103°, selecting the 40% of UHE signal.

For this selection we have a background of 2000 muons and 3 atmospheric neutrinos per day.

★ To have a better energy estimation and signal efficiency, a multivariate analysis is performed using all the variables previously selected

★ Different methods have been tested using the TMVA Root tools.

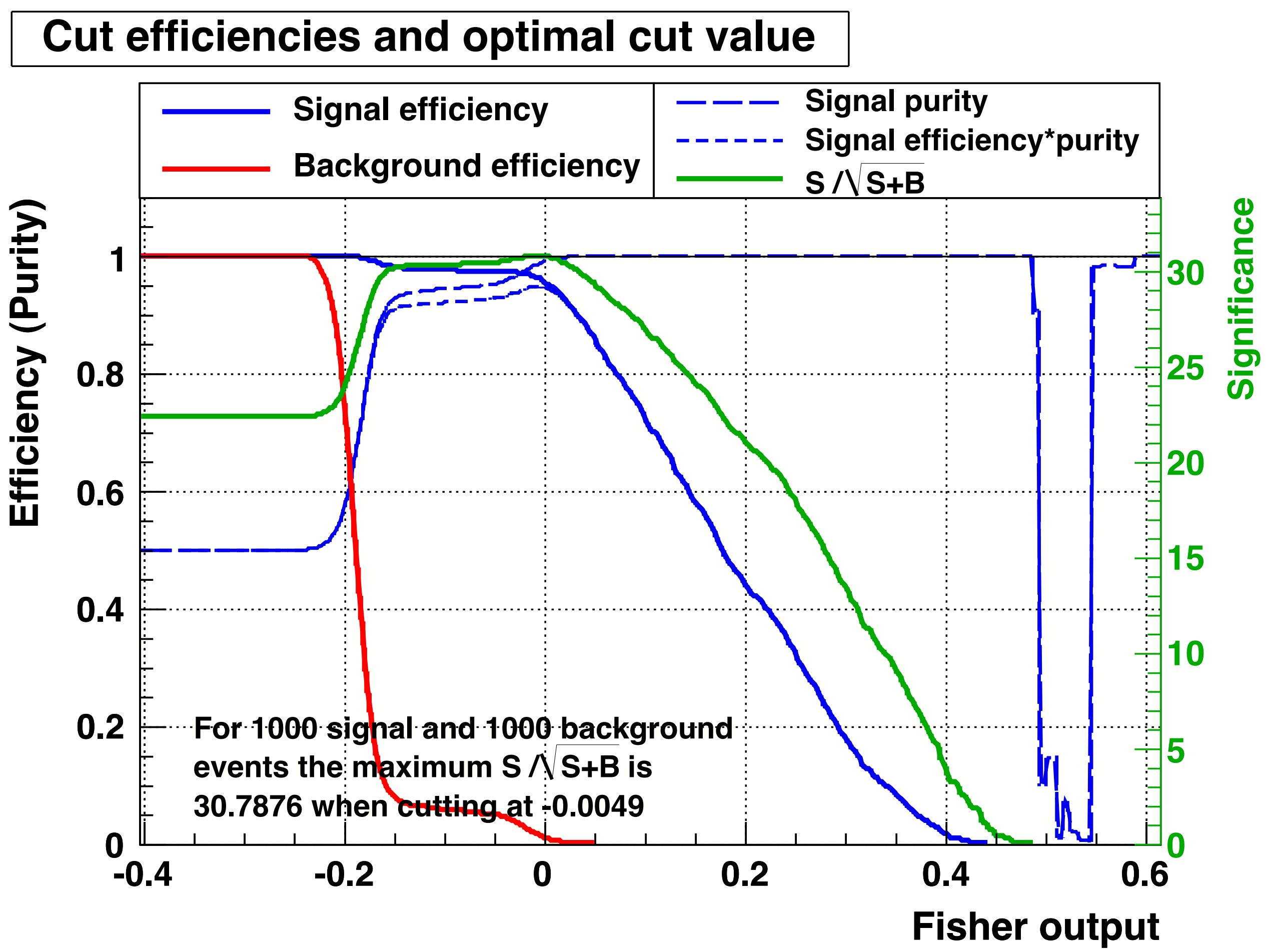


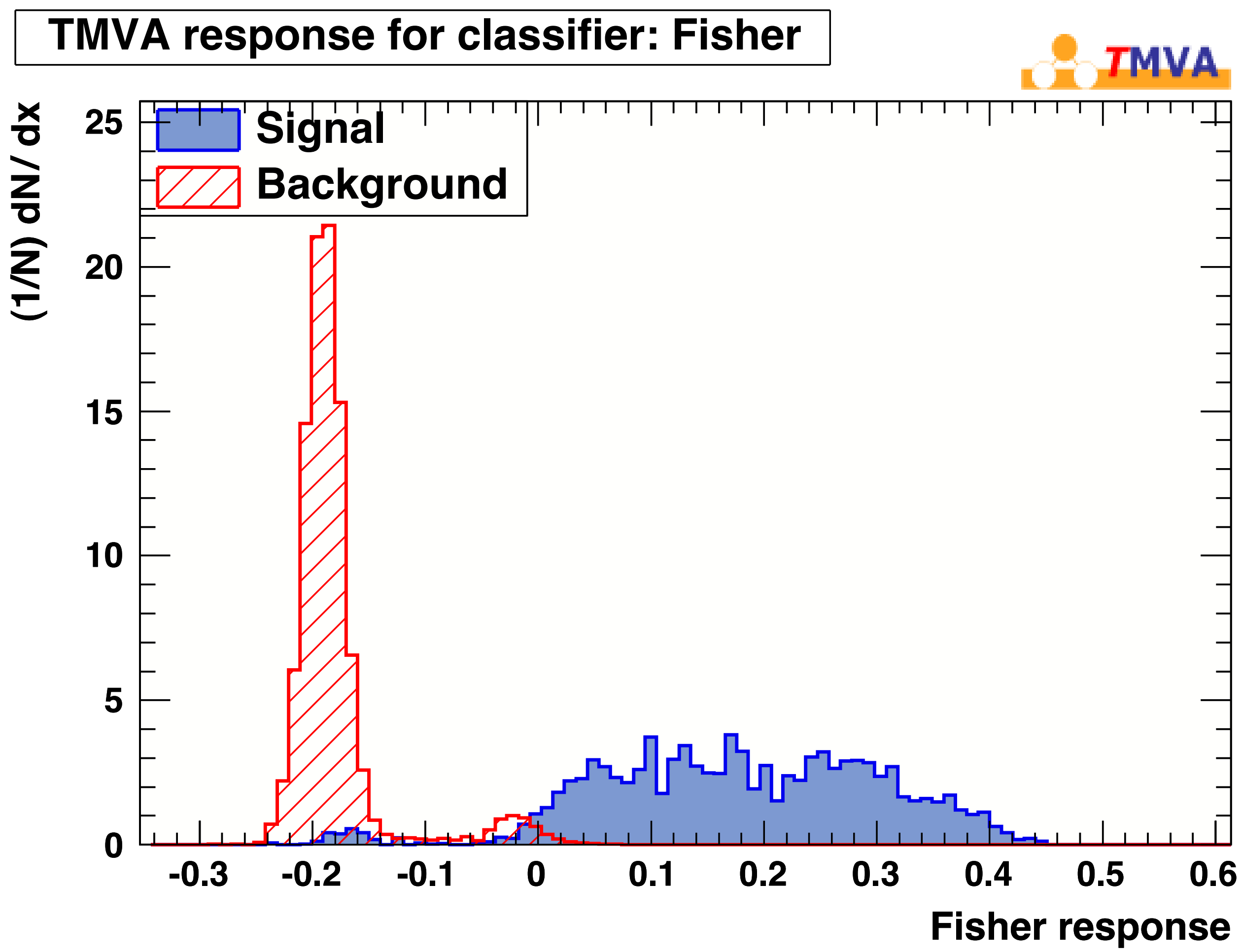
Cuts	0.9193	0.02561
CutsD	0.04644	0.0537
CutsSA	0.9541	0.0181
Likelihood	0.9597	0.01821
KNN	0.9144	0.01387
HMatrix	0.9651	0.01839
Fisher	0.9606	0.01287
LD	0.9606	0.01287
FDA GA	0.9729	0.05848
FDA SA	0.7296	0.02612

Due to the very important background, the choide falls upon the method with the best background rejection.

Warning! In this preliminary phase only the UHE neutrinos (from 10^8 to 10^{10} GeV) is used as signal.

Fisher test resulted to be the method with the best signal efficiency/ background rejection...





A preliminary cut can be made at 0 to cut off the largest part of the backgroud.

➡ A more precious and reliable cut will be made using the Model Rejection Function.

Conclusions

During this first PhD year:

✓ Getting acclimatized with ANTARES software and analysis framework;

✓ Three ANTARES shifts performed;

✓ Data Quality service task accomplished;

✓ Work on UHE diffuse flux MonteCarlo started and in progress.

Perspectives:

➡ Optimization of the MVA on simulations;

➡ Data unblinding for diffuse flux;

➡ Analysis on UHE neutrinos from point sources.