

# Results from ANTARES

**M Bouwhuis, on behalf of the ANTARES collaboration**

NIKHEF, Kruislaan 409, 1098 SJ Amsterdam, The Netherlands

E-mail: `mieke.bouwhuis@nikhef.nl`

**Abstract.** Results are presented from the first ANTARES detector line, which has been operational since March 2006. The remaining 11 lines will be deployed in the course of the next 18 months. The first examples of reconstructed traversing muons are presented, as are the first results on the general detector performance.

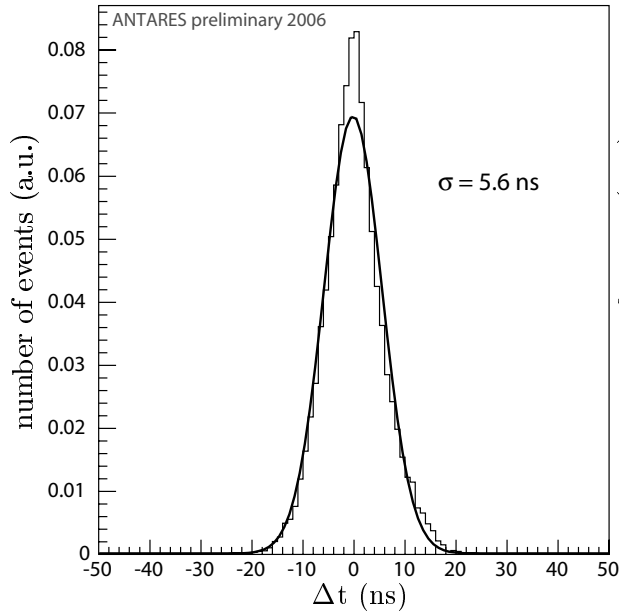
## 1. Introduction

The ANTARES neutrino telescope [1] is being deployed in the Mediterranean Sea, and will be used to detect high-energy neutrinos from astrophysical sources. The detector will consist of 12 vertical lines, each consisting of 25 storeys. Each storey is equipped with a triplet of photo-multiplier tubes (PMTs). After a muon-neutrino interaction in the vicinity of the detector, a muon is produced that emits Cherenkov light that can be detected by the PMTs. From the arrival times of the detected Cherenkov photons, and the positions of the PMTs, the path of the muon can be reconstructed. As the muon direction corresponds to the original neutrino direction, the neutrino source can be found.

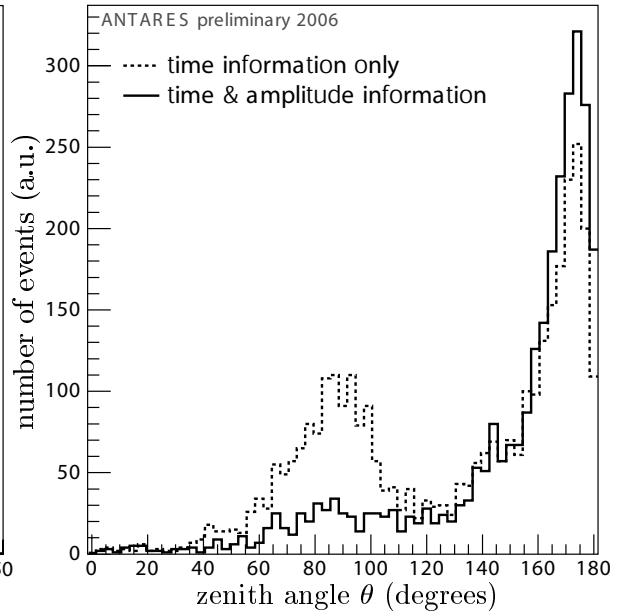
The first line of the ANTARES detector, also referred to as Line 1, has been operational since March 2006 [2]. Line 1 has been read out successfully according to the general readout system that will also be used for the complete detector [3]. In this system, all raw data are sent in a continuous data stream to shore, and on shore divided over a farm of PCs. Each of these PCs run a data filter program that looks online in the data for signals that resemble the signal produced by a muon traversing the detector, using the positions of the PMTs, and the arrival times of the Cherenkov photons. Once such a signal is found, it is stored on disk as a physics event. These events are used by the reconstruction for further data analysis.

## 2. Reconstruction

The physics events found by the data filter programs are reconstructed to determine the direction of the detected muon, and its position relative to Line 1. In this reconstruction only the first of all Cherenkov photon hits in each detector storey (i.e. a triplet of PMTs) is taken into account, to suppress the effect of late arrival times due to light scattering. With this selection of hits, a direction is assumed, and a three-parameter fit is performed to find the position of the muon track. This is done for all zenith angles between  $0^\circ$  and  $180^\circ$ , and for each assumed direction the fit finds the local minimum. For each local minimum, the zenith angle of the muon track is then fitted by a four-parameter  $\chi^2$  fit. The fit with the lowest  $\chi^2/\text{NDOF}$  is taken as the reconstructed track. With only Line 1 operational, the azimuthal angle of the muon track can not be fitted.



**Figure 1.** Measured distribution of hit time residuals.



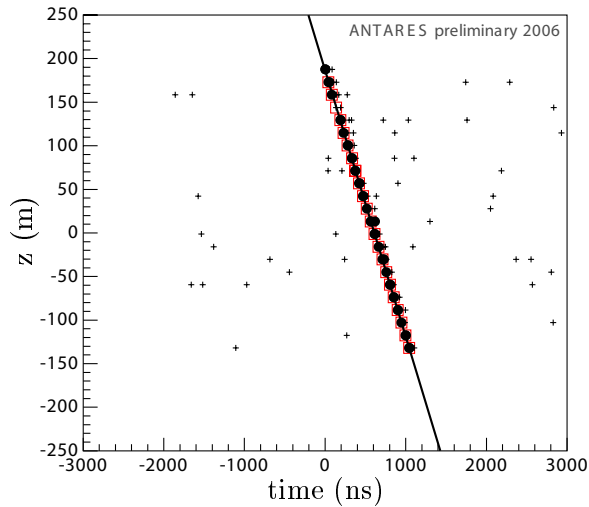
**Figure 2.** Zenith angle distribution of reconstructed muon tracks.

The measured distribution of hit time residuals is shown in figure 1. The majority of the reconstructed muons are downgoing atmospheric muons. As the PMTs are looking downward, most of the Cherenkov light that is detected from downgoing muons is scattered light. This scattered light, as opposed to direct Cherenkov light, causes a spread in the hit time residuals. Also atmospheric muon bundles (that are considered as a single muon) cause a spread in the hit time residuals due to a different position of each muon in the bundle. These two effects determine to a large extent the observed width in the distribution (5.6 ns).

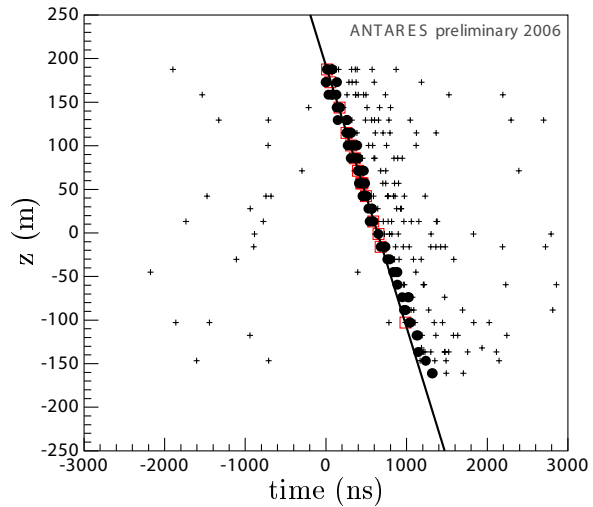
Figure 2 shows the distribution of the zenith angle of reconstructed muon tracks, where  $180^\circ$  corresponds to a vertically downward going muon. As expected, most of the muons are reconstructed as downgoing, and can be identified as the atmospheric muon background. When only the time information of the detected light is taken into account (dashed line in figure 2), a peak appears at about  $90^\circ$  (the difference between the main peak and twice the Cherenkov angle). These solutions arise particularly with only Line 1 operational, and are caused by muon tracks for which only photons from one side of the Cherenkov cone are detected. This causes an ambiguity in the solutions found by the reconstruction, as the track can in this case be reconstructed as upward and downward. This ambiguity can be suppressed by also taking into account the amplitude of the hits (solid line in figure 2), as the amplitude of the hits increases as the muon is closer to the PMTs. In this way a distinction can be made between upward and downward going muons. The events that remain as horizontally reconstructed muons in this distribution are mainly due to electromagnetic showers, as will be explained in section 3.

### 3. Reconstructed muon tracks

A reconstructed muon event can be visualised by the displays shown in figures 3–7. In these displays, the height of the PMTs on Line 1 is shown as a function of the hit times of the detected Cherenkov photons. The middle of Line 1 is chosen to be at 0 m. The black dots indicate the hits that are found by the data filter as space-time correlated hits, and that together form the physics event. A subset of these triggered hits are in general the hits that are used by the reconstruction. The line represents the projection of the cross section of the Cherenkov cone of



**Figure 3.** Single downward going atmospheric muon detected in all storeys of Line 1.

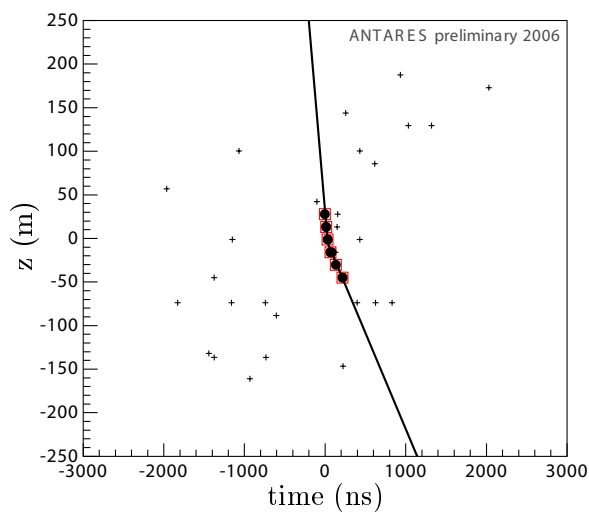


**Figure 4.** Atmospheric muon bundle detected in all storeys of Line 1.

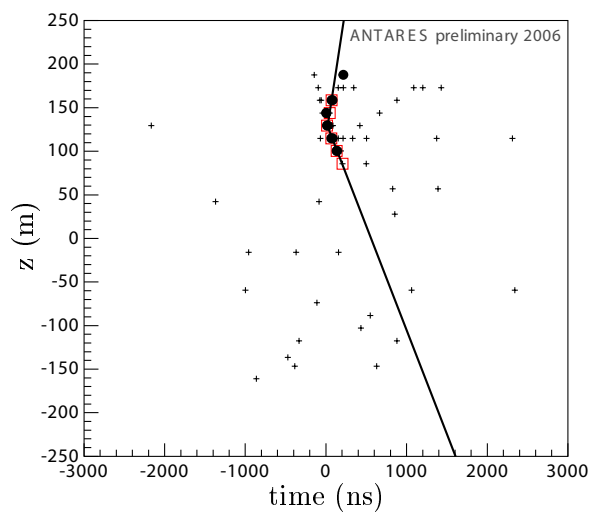
the reconstructed track through Line 1. The remaining hits, indicated by the small + signs, are all other hits that were detected in the time window shown.

Figure 3 shows a single vertically downward going atmospheric muon, where all storeys of Line 1 detected the Cherenkov light. Figure 4 shows an atmospheric muon bundle. For this event, a spread in the arrival time of the photons can be seen on each storey due to a different position of each muon in the bundle.

Figure 5 shows an event that was reconstructed at an angle of about  $55^\circ$  above the horizon. For this event the two sides of the Cherenkov cone are clearly observed. As opposed to figures 3 and 4, where only one side of the Cherenkov cone is observed, this muon crosses the detector line which is displayed by the bend in the projection of the Cherenkov cone of the reconstructed muon track on Line 1.

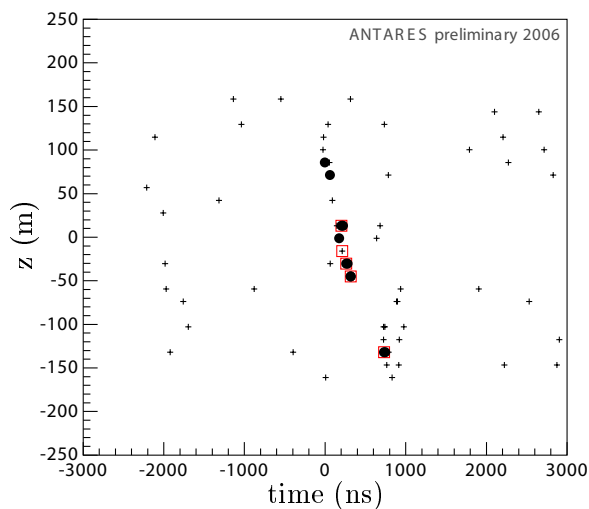


**Figure 5.** Cherenkov cone of an atmospheric muon reconstructed at an angle of about  $55^\circ$  above the horizon.



**Figure 6.** Electromagnetic shower of a downward going atmospheric muon, reconstructed as a horizontal event.

Individual electromagnetic showers from a muon can also be observed. Such a shower is displayed in figure 6. Results obtained from a simulation of the response of Line 1 to muons have shown that the hit pattern in figure 6 can be identified as an electromagnetic shower produced along a muon track. With such a hit pattern, the fit typically yields a horizontal muon, as shown by the line in the figure. Hits directly from the muon track are still visible in the display, at earlier times in the top of the line, that indicate that this event is due to a downgoing muon. However, the hits from the shower dominate in number and amplitude, and were thus triggered by the data filter as the event, and are also preferred by the reconstruction. Figure 7 shows a possible example of a traversing muon that showered several times. As can be seen in the display, the typical hit pattern of an electromagnetic shower is visible at three different heights on Line 1.



**Figure 7.** A possible example of three electromagnetic showers from a downgoing atmospheric muon.

#### 4. Conclusions

Line 1 has been operated and read out successfully since March 2006, and the first results of reconstructed atmospheric muons have been presented. The ambiguity in the obtained zenith angle distribution can be suppressed by taking into account the hit amplitudes. Apart from muon tracks, also individual electromagnetic showers caused by traversing muons can be observed. The second detector line has been operational since September 2006, and the complete 12-line detector is planned to be operational at the end of 2007.

#### References

- [1] Aslanides E et al. 1999 A deep sea telescope for high energy neutrinos *Preprint astro-ph/9907432*
- [2] Giacomelli G and Kooijman P 2006 ANTARES Collaboration detects its first muons *CERN Courier* Vol.46 No.7
- [3] Aguilar J A et al. 2006 The data acquisition system for the ANTARES neutrino telescope, accepted for publication in *Nucl. Instrum. Meth. A* (*Preprint astro-ph/0610029*)