The AMANDA Neutrino Detector - Status Report

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The first stage of the AMANDA High Energy Neutrino Detector at the South Pole, the 302 PMT array AMANDA-B10, is taking data since 1997. We describe results on atmospheric neutrinos, limits on indirect WIMP detection, seasonal muon flux variation, relativistic monopole flux limits, a search for gravitational collapse neutrinos, and a depth scan of the optical ice properties. The next stage 19-string detector AMANDA-II with ~650 PMTs will be completed in spring 2000.

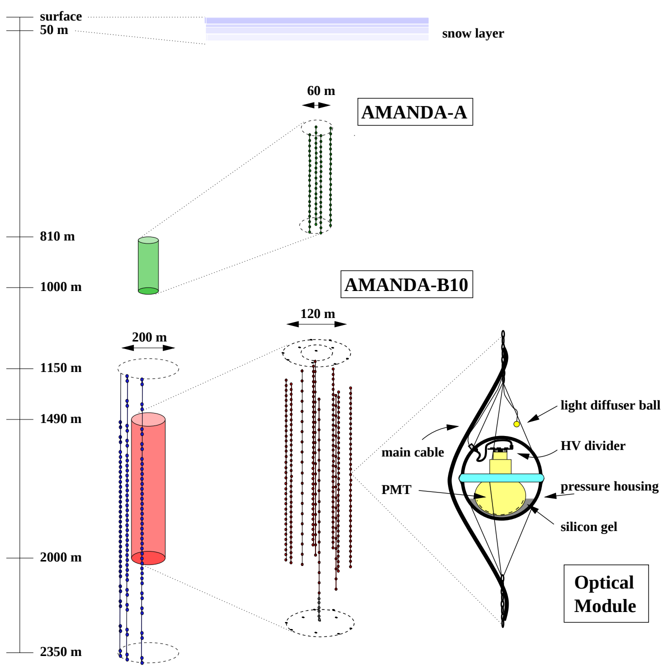


Figure 1. The AMANDA detector layout: Amanda-B10 at 1.5-2.0 km depth, three new strings (1.3-2.4 km) and Amanda-A (0.8-1.0 km).

1. Introduction

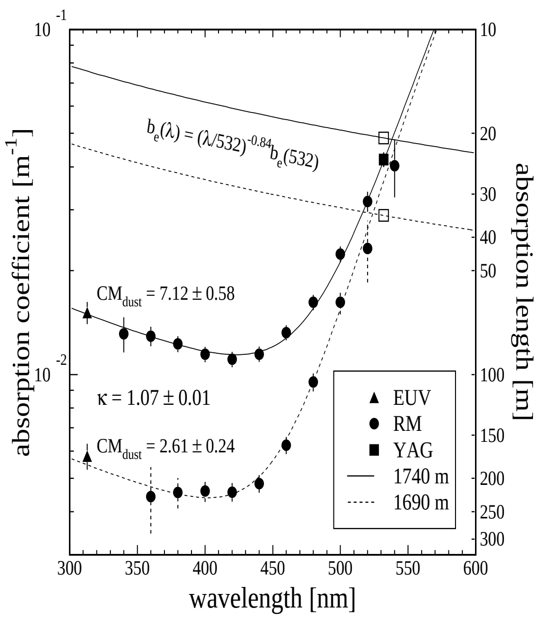
The first stage Neutrino Detector AMANDA-B was deployed in 1996-1997, at a depth of 1500-2000 m into the antarctic ice shield at the South Pole [1]. It consists of 302 Optical Modules (OMs) on 10 strings, see Fig. 1. Each OM houses a 8”-Hamamatsu PMT, operated at 10^9 gain over an individual 2 km electrical cable to the surface.

During the 1997/98 campaign, 3 new strings with 123 OMs in total were deployed. They are testing fiber-optic analog signal transmission and allow for ice studies from 1300-2400 m. The first full detector calibration (timing and geometry) has been completed, and a new Data Acquisition System was installed.

The AMANDA-A detector [1,2], deployed in 1994 at 800-1000 m in bubbly ice (see Fig. 1), and the airshower detectors SPASE and GASP at the ice surface, provide unique external calibration sources by tagging high energy muons.

The main physics goal of Deep Underwater/-Underice Detectors is High Energy Neutrino Astrophysics - the search for sources of highest energy cosmic rays; they also cover a wide range of topics from particle physics to glaciology.

These novel technique detectors, sparsely instrumented as compared to Underground Water Cerenkov Detectors like SuperK or IMB ($\sim 10^3$ less density of PMTs per effective detector area), put their initial experimental focus on (1) verification of high quality muon track reconstruction and (2) physics detector calibration by detection of atmospheric neutrinos (ν_μ and $\overline{\nu}_\mu$) to establish an atmospheric muon background rejection capability of $\geq 10^5$ [1].



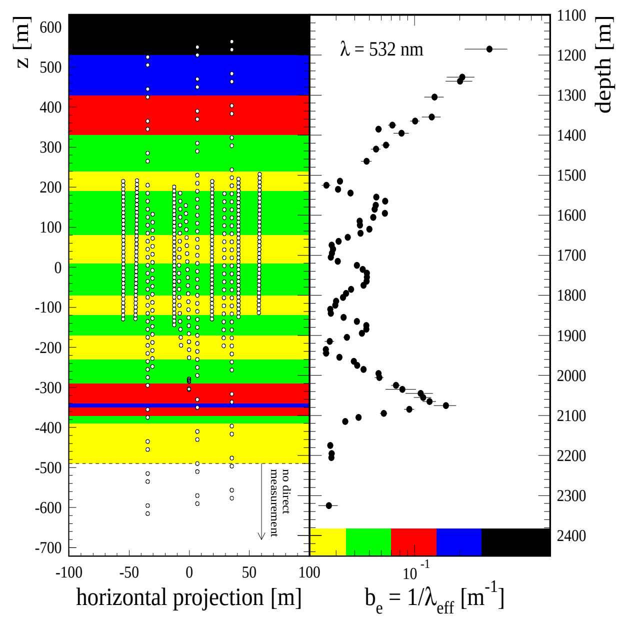


Figure 2. (left) Absorption coefficient $a = 1/\lambda_{abs}$ and scattering coefficient b_e as function of wave length at 1690 m and 1740 m depth.
Figure 3. (right) Scattering coefficient $b_e = 1/\lambda_{eff}$ at 532 nm as function of vertical depth. The location of the strings is indicated.

2. Optical Ice Properties and Calibration

Optical ice properties in AMANDA are measured with a variety of in-situ pulsed and constant light sources, and cross checked with atmospheric muons. The global ice properties, averaged over wavelength and depth between 1500 m and 2000 m, are given by effective scattering and absorption lengths of λ_{eff} ~24 m and λ_{abs} ~100 m [1]. Depth scans reveal a depth dependence of both λ_{eff} and λ_{abs}, as shown in figs. 2 and 3. Between one of the dust bands (at 1740 m) and one region of clear ice (at 1690 m) λ_{abs} varies between ~90 m and ~200 m, while λ_{eff} changes between ~15 m and ~35 m over the instrumented AMANDA-B10 ice region for 532 nm [3].

Timing calibration of the array is done with laser pulses sent down over 2 km fibers to each PMT, yielding a precision of ~5 nsec.

The geometry of the array is determined using drill logging and interstring laser pulsing, resulting in a typical distance precision of ~1 m for the Optical Modules.

3. First Results

With the detector calibrations under control, physics calibration is focused on the detection of atmospheric muons and neutrinos.

Spatial reconstruction of muon tracks is done by fitting the recorded hit times to a single muon track model, including light scattering [1]. Tight track quality criteria, which are applied after reconstruction, include a minimum number of unscattered photon hits (typically $\geq$5) and geometry related cuts, to achieve a $\geq 10^5$ background rejection rate against downgoing atmospheric muons misreconstructed as upgoing tracks.

Detailed tests were made with the 1996 AMANDA-B 4-string data. The reconstructed flux of downgoing atmospheric muons compares well with the standard depth-intensity curve [1].

Muon track reconstruction and absolute pointing accuracy was confirmed by muons tagged by the SPASE and GASP detectors [1,4]. An angular resolution of $\sim 3°$ has been concluded, which depends on the imposed quality criteria.

With the AMANDA-B10 detector, an initial neutrino search yielded 17 ν_μ-candidates for 50% of the 1997 data sample [5]. A MC-simulation of atmospheric ν_μ's predicted 21 upgoing events. The distribution of zenith angle for data and MC is given in fig. 4. It was concluded at this stage, that the detected ν_μ-candidate events are compatible with the expected atmospheric ν_μ-flux.

Improved reconstruction and filtering algorithms now yield more than 3 times as many neutrinos. It is now verified with sufficient MC statistics of background events that the applied quality cuts do not systematically fake signals from downgoing atmospheric muons. Discrepancies between MC and data are under study and possibly due to the assumption of homogeneous optical ice properties in the MC.

Estimations of the effect of ν_μ-vacuum oscillations suggest that the atmospheric event rate would be reduced by $\nu_\mu \rightarrow \nu_X$ disappearance by less than 25% for allowed mixing parameters. However, given our current understanding of the detector systematics, we are not sensitive to this effect.

A search for signals from WIMP annihilation in the center of the earth makes use of the atmospheric ν_μ-events. Upper limits on the muon flux from WIMPs are obtained for $M_{WIMP} = 10^2 - 5 \cdot 10^3\,\mathrm{GeV}$ [6].

With less stringent reconstruction cuts a search for ν_μ from astrophysical point sources yields preliminary results with sensitivities comparable to large underground detectors [7].

To verify the stability of the AMANDA-B10 detector at the %-level we investigated the seasonal variation of the atmospheric muon flux, which is known to be modulated by temperature variations in the upper atmosphere. Fig. 5 shows for 8 months in 1997 the good agreement between the relative variation of the atmospheric muon flux $\Delta R_\mu / R_\mu$ and the variation of the effective atmosphere temperature $\Delta T_{eff}/T_{eff}$ [8].

A search for relativistic Monopoles with β_{mon}=0.8-1.0 has been performed. The Monopole signature is high multiplicity events, since the Cerenkov light yield is 8300 times as high as for muons. The upper flux limit obtained for part of the 1997 lifetime is well below the Parker limit and of the order of other experiments results [9].

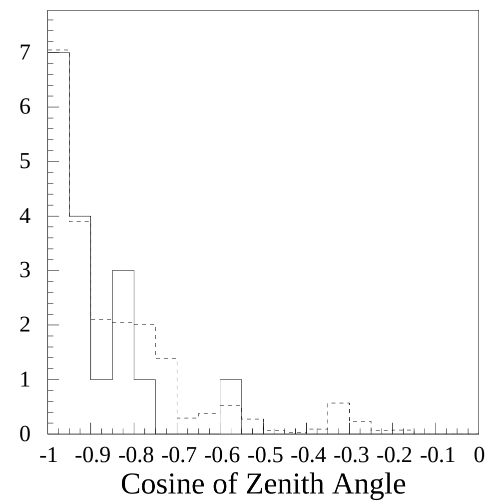


Figure 4. Zenith angle distribution for ν_μ-candidates (full line) and atmospheric ν_μ-MC events (dashed). (Vertical upward $cos(\theta) = -1.$)

Detection of MeV neutrino bursts from stellar collapses, recorded by a special trigger system, is possible up to ~8 kpc source distances. Fig. 6 shows the variation of the 10 sec averaged counting rate of AMANDA-B10 PMTs, together with the cut for 90% detection efficiency for galactic Supernova of SN1987-luminosity at distances of 6 kpc and 8 kpc for 110 days of 1997 lifetime [10].

4. Summary

The Neutrino Detector AMANDA-B10 at the South Pole with an effective muon detection area of $\sim 0.5 - 1 \cdot 10^4\,\mathrm{m}^2$ is stable working and calibrated. With a first reconstruction of 50% of the 1997 data set, a sample of 17 ν_μ-event candidates had been isolated. First physics results are limits on the flux of upward muons from WIMP-annihilation in the earth and on relativistic magnetic Monopoles, and a search for low energy neutrinos from gravitational stellar collapses.

The detector will be upgraded to the ~650 PMT detector AMANDA-II in spring 2000.

A proposal for ICECUBE, a km^3-detector with ~5000 PMTs at the South Pole [11], is currently being submitted.

ACKNOWLEDGEMENTS

We thank the Polar Ice Coring Office and B. Koci and the NSF (USA), the Swedish National Research Council, the K.A.Wallenberg Foundation and the Swedish Polar Research Secretariat.

REFERENCES

1. E. Andres *et al.*, DESY-99-073, astro-ph/-9906203, Astropart.Phys. (in press)
2. P. Askjeber *et al.*, *Science* **267**, 1147 (1995)
3. K. Woschnagg *et al.*, Proceed. 26th Int. Cosmic Ray Conf., Salt Lake City, USA (1999), Vol.2, 200p
4. G. Hill *et al.*, ibid., Vol.2, 432p
5. A. Karle *et al.*, ibid., Vol.2, 221p
6. E. Dalberg *et al.*, ibid., Vol.2, 348p
7. J. Kim *et al.*, ibid., Vol.2, 196p
8. A. Bouchta *et al.*, ibid., Vol.2, 108p
9. P. Niessen *et al.*, ibid., Vol.2, 344p
10. R. Wischnewski *et al.*, ibid., Vol. 2, 229p
11. F. Halzen *et al.*, ibid., Vol. 2, 428p

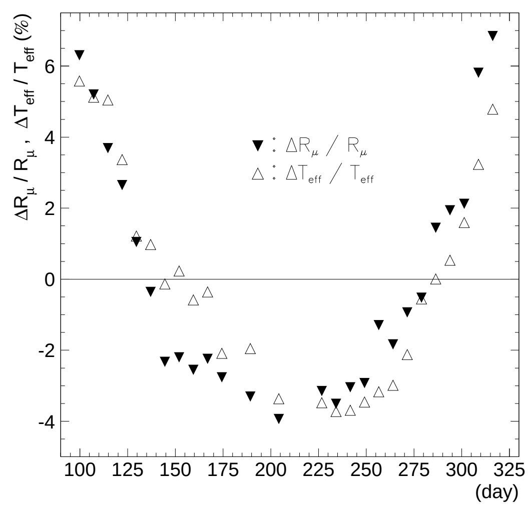


Figure 5. Seasonal variation of the atmospheric muon flux $\Delta R_\mu/R_\mu$ compared to variation of the effective atmosphere temperature $\Delta T_{eff}/T_{eff}$ as function of day in 1997.

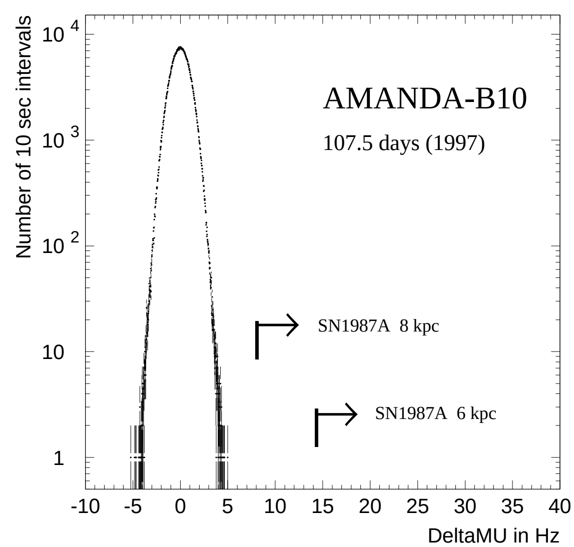


Figure 6. SN-search: Variation of PMT noise rate for 107 lifetime days in 1997. Arrows indicate search intervals for SN1987A-type supernova signals at 6 kpc and 8 kpc distance.