AMANDA:
A Neutrino Telescope at the South Pole

Carlos P. de los Heros
Department of High Energy Physics.
Uppsala University.
Uppsala, Sweden
(for the AMANDA collaboration)

The Physics
The Detector
Status: prototype results
Future: ICECUBE
AMANDA
Antarctic Muon And Neutrino Detector Array

University of California, Berkeley, USA
Ryan C. Bay, Yudong He, John Jacobsen, Doug Lowder, Predrag Miocinovic.
P. Buford Price, Mike Solarz, Kurt Woschnagg

University of California, Irvine, USA
Steven W. Barwick, Jeff Booth, Patrick C. Mock, Rodin Porrata, Eric Schneider,
Gaurang Yodh

University of Pennsylvania, USA
Doug Cowen

University of Wisconsin, Madison, USA
Matthew Carlson, Cesar G. S. Costa, Tyce DeYoung Gary Hill, Lori Gray, Francis Halzen,
Rellen Hardtke, Vijaya Kankhadai, Albrecht Karle, Igor Liubarsky, Robert Morse,
Serap Tilav

Bartol Research Institute, USA
Tim C. Miller

Stockholm University, Sweden
Per Askebjer, Lars Bergström, Adam Bouchta, Eva Dalberg, Patrik Ekström,
Ariel Goobar, Per Olof Hulth, Julio Martino, Verónica Sorin, Christian Walck

University of Uppsala, Sweden
Olga Botner, Allan Hallgren, Pia Loaiza, Pawel Marciniewski, Carlos Pérez de los Heros,
Hector Rubinstein

Kalmar University, Sweden
Staffan Carius, Pär Lindahl

DESY — Institute for High Energy Physics, Germany
Alexander Biron, Stephan Hundertmark, Matthias Leuthold, Peter Niessen,
Christian Spiering, Ole Streicher, Thorsten Thon, Christopher H. Wiebusch,
Ralf Wischnewski

Lawrence Berkeley National Laboratory, USA
David Nygren

Amundsen-Scott South Pole Station winter overs, Antarctica
Eduardo C. Andrés, Steffen Richter, Robert Schwarz
PHYSICS

Particle Physics, Astrophysics, Cosmology

- $\nu$s from cosmic point sources: AGN, GRBs (origin of HE cosmic rays)
- Indirect detection of dark matter candidates
- $\nu$s from Supernovae
- Global map of the sky in $\nu$s
- Glaciology (ice properties...)

$\nu$s travel directly from the emission point
$p$'s do not point if $E<10^{19}$eV

- No significant attenuation.
  - $\gamma$'s absorbed on background light (IR to CMB)
  - $p$'s absorbed for $E>10^{19}$eV
    - photprod. of $\Delta$ on CMB $\gamma$'s
HE $\nu$ production @ cosmic accelerators

($\geq$ TeV)

$p$ accelerator
Target
AGN
jet, accretion disk
GRB
fireball
SN, pulsar
SN shell

Also:
HE cosmic rays
interstellar medium
CMBR photons

hadro/photo production of $\pi$'s $\rightarrow \nu$'s
Dark Matter candidates

- MSSM $\rightarrow$ LSP: Neutralino ($\chi$)

- $\chi$ 'natural' non-barionic dark matter candidate: can provide 'correct' cosmological density $\Omega_{\chi} h^2$ to give $\Omega \sim 1$

- Gravitational accumulation in heavy objects (Earth) annihilation: $\chi\chi \rightarrow c\bar{c}, b\bar{b}, t\bar{t}, \tau^+\tau^-, W^+W^-, ZZ, ..$

- $\nu$'s: decay products of secondaries.

- Clear signal: $\nu$–flux highly directional.

\[
\Theta_\nu \propto \frac{1}{\sqrt{m_\chi/\text{GeV}}}
\]

\[
\text{Flux} \propto \frac{1}{m_\chi/\text{GeV}}
\]
Angular distribution of $\nu$-induced muons from $X$ annihilations

$XX \rightarrow W^+ W^-, \nu \bar{\nu}$
The Muon Fluxes in the Earth/Sun vs $m_\chi$

![Graphs showing muon fluxes from the Earth and Sun vs neutralino mass.](image)

---

gaugino  mixed  higgsino
AMANDA 1997

Depths

| 60m | 30m |

A

810 m
190 m
1000 m
120 m

B

1520 m
380 m
1900 m
2000 m

Neutrinos – nice in ice
Electronic feedthrough

Main cable

Optical fiber

Nylon ball

Voltage divider

Metallic harness

Photomultiplier (300-600 nm)

Silicon gel

Glass sphere (600 atm.)
DETECTION METHOD

Reconstruction of $\mu$ tracks produced in

$$\nu_{\mu} + N \rightarrow \mu + X$$

$\mu$s $\rightarrow$ Detected from its Čerenkov emission in ice

$$\Theta_c = 40^\circ$$

$\sim$ 300 photons/cm

$$\nu-\mu \text{ angle } \sim \frac{1.5^\circ}{\sqrt{E_\nu(\text{TeV})}}$$

$\implies$ Possibility of doing astronomy

DETECTOR CONCEPT:

- Array of PMs covering a large volume
- ns resolution to map the Čerenkov cone
- Shielded from atmospheric $\mu$s ($1/10^6$)
TRACK RECONSTRUCTION

Essential: Optical properties of the ice @ 1500-2000m

- Laser analysis
  \[ L_{\text{scatt}} = 24 \pm 2 \text{ m} \]
  \[ L_{\text{abs}} = 100 \text{ m between 350-480 nm} \]
  \[ \cos(\theta) = 0.8 \]

Reconstruction:

- Minimization of maximum likelihood, \(-\log P\)
  \[ P = P(\vec{r}_{OM}, t_{hit}|L_{\text{scatt}}, L_{\text{abs}}) \]
- first guess:
  \[ \vec{r} = \vec{r}_o + \vec{v}t \]
- At least N 'direct hits' required ([-15,15]ns)
Scattering $\Rightarrow$ LATE photons

Selecting tracks with several direct hits improves angular resolution
$\cos(\theta_{\text{rec}})$ is shown with cuts on the number of residuals in the interval $[-15; 25]$ ns. The histogram represents Monte Carlo simulations with a trigger of 8-2 μsec and the dots represent the real data.
ADVANTAGES OF THE ICE

- Low temperature ($\sim -30^\circ$)
  $\rightarrow$ PMs operated at $10^9$ ($10^7$ in SK):

- No radioactivity (Rd in rock, $^{40}K$ in the sea.)

- No biological activity (bioluminiscence, debris).
  $\rightarrow$ OM noise $\sim 300$ (1000) Hz. (100 kHz in BK)
  Trigger: simple majority threshold on number of hit PMs

- The detector is fixed after re-freezing.

- Short cables: $\sim 2$km ($\geq 40$km in ocean projects).
  $\rightarrow$ Simple OM design. Electronics at the surface.
CURRENT STATUS

• 4-string prototype (86Ms) built in 1995/96 season.
  - $4 \times 10^8$ events analysed from 6 months life-time
  - Threshold: $E_\nu \geq 25$ GeV
  - Track angular resolution $\sim 3^\circ$
  - Observed: 2 up-going candidates
  - $\mu^-$'s from upgoing atmospheric $\nu_s$: 3 ± ?
  - Currently working on detector efficiency.

• $\rightarrow$ Technique proven to work.
  Able to manage background.
  Bulk ice optical properties understood.

• 10-string (302 OMs) detector deployed in 1996/97
  - $10^9$ events from 8 months life-time in 1997
  currently being analyzed.

• 13-string (420 OMs) detector deployed in 1997/98
  - Taking data now.
FUTURE: ICECUBE

Natural extension of AMANDA $\rightarrow \text{KM}^3$.

80 strings, $\sim 60$ OMs: $\sim 5000$ OMs

Proposal to DoE/NSF by fall 1998


Features:
Angular resolution $\sim 1$ degree
Energy measurement through cascade analysis
Flavour id ($e, \mu, \tau$)