The AMANDA-II Telescope
- Status and First Results -

Ralf Wischnewski / DESY Zeuthen
for the
AMANDA Collaboration

TAUP2001 September 2001 LNGS/Italy

ralf.wischnewski@desy.de
HE $\nu'$ Telescopes ...

HE $\nu$-Telescopes are still "novel" instruments proving sensitivity to their primary channels

$$\nu_\mu \ N \rightarrow \mu \ X$$

$$\nu_e \ N \rightarrow e \ X$$

→ from Astrophysical Sources (Point / Diffuse)

→ calibration possible only with atmospheric $\nu$'s
1. AMANDA-II Detector

2. Calibration of the AMANDA-B10 detector with Atmospheric $\nu$'s

→ Physics results from B10/1997, see A. Hallgren

3. Performance & Sensitivity of AMANDA-II
**AMANDA-II Construction**

- **1996**
  - 4 strings, coax transmission OMs
  - total 86 OMs
  - \(\Rightarrow\) AMANDA-B4

- **1997**
  - +6 strings, twisted pair transmission OMs
  - total 302 OMs at 10 strings
  - \(\Rightarrow\) AMANDA-B10

- **1998**
  - +3 strings, fiber transmission OMs
  - total 424 OMs
  - \(\Rightarrow\) AMANDA-B13

- **2000**
  - +6 strings, fiber and digital transmission OMs
  - total 677 OMs at 19 strings
  - \(\Rightarrow\) AMANDA-II

- **2003-2008**
  - ~80 strings with 60 OMs each, total 5000 OMs
  - \(\Rightarrow\) ICECUBE
AMANDA-II
(February 2000)

- 677 PMTs
- 19 Strings
- \( d = 200 \text{ m} \)
- \( h \sim 500 \text{ m} \)
\[ \rightarrow V_{\text{geo}} \sim 1.6 \times 10^7 \text{ m}^3 \]

Trigger:
- Majority
  >23 OM in <2.5 \( \mu \text{s} \)
- String multiplicity
**V-Signature:** Upgoing muon

**Background:** Misreconstructed atmospheric muons

**Noise/Signal =**

\[
\frac{\mu_{\downarrow}}{\mu_{\uparrow}(v_{atm})} = 10^5 \ldots 6
\]

Zenith of \( \mu \)'s triggering AMANDA
Variation of track parameters until the spectrum of arrival times has highest Likelihood. Scattering results in a distance dependent time-delay relative to the Cherenkov cone.
$85 < \lambda_{\text{absorption}} < 225 \text{ m}$

$15 < \lambda_{\text{scattering}} < 40 \text{ m}$
Atmospheric $\nu$-Analysis

- Two (largely) independent analyses were done for the 1997 data set of Amanda-B10 with respect to
  - methodical aspects (Cut definitions, minim.functional)
  - data cleaning (electronic noise ...)

- Used same signal & atmospheric muon Background MC (BG-MC) and track model (ice optics and single muon)
Analysis A: Overview

- Conventional Likelihood description (no zenith weight)
- Multi-photon Likelihood and hit-probabilities
- Background rejected by specific cuts: e.g. cascade fit for muon bremsstrahlung.
- Reject instrumental BG by the hit-topology
- Cuts developed with emphasis on BG-MonteCarlo

- Deterministic method to define a small set of final Cut parameters and their values (↓ CutEval)
Neutrino Analysis Chain (A)

Pre-processing:
Hit cleaning, Calibration ...

Level 1:
Fast track approximation (line fit)
Simple up/down cut

Level 2:
Time-likelihood reconstruction.
Simple cuts (zenith, L, Ndir)

Level 3:
First cut optimization.
Full likelihood reconstruction.

Level 4:
Final Neutrino Cuts (CutEval)

\[
\begin{array}{|c|c|c|c|}
\hline
\text{N}_{\text{events}} & \phi_{\text{bg}} & \phi_{\text{sig}} & \text{S/N} \\
\hline
1 \cdot 10^9 & 0.95 & 0.95 & 1 : 2 \cdot 10^5 \\
5 \cdot 10^7 & 5 \cdot 10^{-2} & 0.37 & 1 : 3 \cdot 10^4 \\
4 \cdot 10^5 & 4 \cdot 10^{-4} & 0.15 & 1 : 5 \cdot 10^2 \\
1 \cdot 10^4 & 1 \cdot 10^{-5} & 0.07 & 1 : 30 \\
223 & 2 \cdot 10^{-8} & 0.04 & 10 : 1 \\
\hline
\end{array}
\]
Analysis A: Neutrino Cuts & Sample Size

Find **(minimum)** set of Cut-Variables, which **optimize** the signal to background efficiency.

Define "Sample Quality":

\[ Q = -\log \left( \frac{N_{BG}}{N_{TL}} \right) \]

---

**Data**

**Sig-MC**

**BG-MC**

Sample Quality, **Q**
## Neutrino Events – Statistics

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Analysis A</th>
<th>Analysis B</th>
<th>Overlap</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\nu}_e$-MC (stand)</td>
<td>223</td>
<td>378</td>
<td>-</td>
<td>325</td>
</tr>
<tr>
<td>$\bar{\nu}_e$-MC (new)</td>
<td>204</td>
<td>265</td>
<td>-</td>
<td>102</td>
</tr>
<tr>
<td>Background</td>
<td>237</td>
<td>-</td>
<td>10%</td>
<td>119</td>
</tr>
</tbody>
</table>

130. days live time
Systematic Uncertainties

Calibration
- Time: -5%
- Geometry: -5%
- Amplitude: <5%
- OM sensitivity: -20%

Optical properties
- Bulk Ice: ±10%
- Vertical structures: ±10%
- Hole Ice: -50%

Physics
- μ-propagation: ±20%
- ν-flux: ±30%
- ν-oscillations: -20%
Zenith angle distribution

![Graph showing the zenith angle distribution with data points and error bars.](image)
Energy distribution

\[ E_V \sim 0.7 - 3.4 \text{ TeV} \]

Events (r.a.e.)
Pointing: 3° - 4°  No clustering

Combined sample
325 events
130.1 days live-time
Amanda-II

• Larger effective area by 9 more strings (>double OMs)

• New technologies
  - improved timing
  - MultiHit resolution (muon bundles & HE events)
  - reduced electronic noise
  - Upgrade: full waveform sampling (FADCs) in 2002

• Triggering
  - HE events by majority trigger
  - E<100 GeV by string trigger
  - EAS-Array (SPASE) as efficient veto for UHE events

• Improved angular sensitivity range; resolution ~ 2 degrees
Summary: B-10 atmosphere \( \nu \)'s

- The AMANDA-B data from 1997 (130.1 days live time) have been analysed for neutrino induced events

- 2 independent analyses find a total of 325 neutrino events with less than 10% background contamination

- Results are consistent with the MC expectation for background (atmospheric muons) and signal (atmospheric neutrinos) within (still relatively large) systematic uncertainties

- Improvement excepted from
  - better local ice-properties & OM sensitivity calibration
  - improved MC light tracing & HE muon light yield

- AMANDA has reached "design luminosity"!
Amanda-II

• Amanda-II analysis for 2000 started in spring 2001
  (1.2 TB Data back from Spole)

• Neutrino Analysis profits substantially from Amanda-B10 analysis.
  Tuning to new geometry and hardware is under way.

• Minimum bias and low neutrino-cut level data look ok vs. MC.

• MC-results given below for „final AM-II neutrino cuts“ \((A_{\text{eff}}, ...)\)
  are still preliminary.
Amanda-II: Detector response

Number of hit Optical Modules

- All Strings (1-19)
- Inner Strings (1-10)
- Outer Strings (11-19)

Data - dots
MC - line
Amanda-II: Detector response

Minimum bias Zenith & Azimuth acceptance

![Graphs showing minimum bias Zenith and Azimuth acceptance with plots of entries vs. $\cos(\Theta_{\text{reco}})$ and entries vs. $\phi_{\text{reco}}$.]
Atmospheric $\gamma$ MC: Energy response

Trigger Level

After BG Rejection

$A_{eff}(E)$ much improved compared to AMANDA-B10
Atmosph. $\nu_\mu$ MC: Angular Sensitivity

$\sim$200 atm $\nu$ per angular bin & livetime-year

Nearly uniform angular sensitivity to horizon

- AMANDA-B10 (level 0)
- AMANDA-II (level 0)
- AMANDA-B10 (final level)
- AMANDA-II (final level)

Trigger Level

After B6 rejection
A horizontal neutrino event

No external geometry file is opened.
Detector: antares-b-11, 19 strings, 580 modules
Data file: event_e304_nu_def.txt
File contains 6 events.
Displaying data event 2218020 from run 304
Recorded ytd: 2000/145
52216-31081/50 seconds past midnight.
Before cut: 32 hits, 29 OMs
After cut: 32 hits, 29 OMs

(prelim.)
An almost vertical AMANDA-II event ($\theta = 175^\circ$)
Am-II: Effective Area vs zenith

$A_{\text{eff}} \times 10^3 \text{ m}^2$

$E = 10 \text{ TeV}$

$A_{\text{eff}}$ depends sensitively on the physics objective!

Point source sensitivity is uniform to near horizon
Amanda-II - Effective Volume

\begin{align*}
\langle V_{\text{eff}} \rangle \quad (\text{km}^3) \\
\hspace{1cm} &
\begin{cases}
0.1 & \text{for } E_v \text{ (TeV)} = 10^1 \\
0.3 & \text{for } E_v \text{ (TeV)} = 10^2 \\
0.5 & \text{for } E_v \text{ (TeV)} = 10^3
\end{cases}
\end{align*}

\begin{align*}
V_{\text{eff}}(v_\mu) \quad \text{is} \\
0.3-0.5 \text{ km}^3 \\
\bullet R_\mu > 10 \text{ km}
\end{align*}

for Point Source Cuts
Diffuse Flux $\nu_\mu$

$E^2 (dN/dE) \ [\text{GeV} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$

$E_{\nu} \ (\text{GeV})$

- Atm. $\nu$
- AMANDA-B10 (97)
- AGN Core
- 3C273
- AMANDA-II (3 yr)
- IceCube
- Anticipated sensitivity
- New techniques
- Convolved energy resolution

Earth Shadows
Point Sources

![Graph showing energy resolution and atmospheric effects on neutrino fluxes.](image)

- **Atmospheric $\Phi_v +$ energy resolution**
- **AMANDA-B10 ('97)**
- **AMANDA-II (3 yr)**
- **Mk501 ($\nu=\gamma$)**
- **3C273**
- **Crab**
- **IceCube**
- **AGN Core**

**$E^2 \langle dN/dE \rangle$ [GeV cm$^{-2}$ s$^{-1}$]**

**$E_\nu$ (GeV)**
Summary

• AMANDA-B10

  Final Analysis (1997) yields 325 HE neutrino events
  The first high statistics neutrino-event sample for an
  UWater/Uice Telescope
  Proof of principle of operation in Antarctic scattering ice.

• AMANDA-II

  \( >10^5 \text{ m}^2 \) Trigger Area - the Largest Muon and Neutrino
  Telescope ever built.
  Improved performance compared to B10-Telescope
  Horizontal Angular acceptance

  Event rates of 4-5 atm. nu’s per livetime day,
  800-1000 nu’s for year-2000.