Status Report
Neutrino-Astrophysics at DESY
AMANDA, Baikal, IceCube

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Neutrino Astrophysics at DESY

- Started working on the Baikal experiment in 1988
- Currently active in the upgrade

- Working in AMANDA since 1994
- One of the leading institutes doing analysis, data processing, responsible for reconstruction software and time calibration of the Optical Modules

- Since 2001 IceCube
- Responsibility for Optical Module production, surface electronics, reconstruction software and integration with AMANDA, and actively involved in “Future Group”
The Antarctic Site

- IceCube
- AMANDA
- 19 strings
- 70...80 strings
- geographic Pole
- Amundsen-Scott South Pole station
The Antarctic Telescopes

Amanda II

Optical Module 8"

IceTop

South Pole

IceCube

Depth

- 1500 m
- 2000 m
- 2500 m

200 m

2400 m

1400 m
The Baikal Site and Detector

Lake Baikal

**Depth Profile**

- Depth profile
- Detector location
- 1 km scale
- Shore station
- Irkutsk
- Selenga
- Ulan-Ude

**NT200 Array**

- 8 strings
- 192 OMs

**Quasar Tubes**

- Ø 37 cm
- 1070 m depth
- 70 m height
- Ø 40 m
Physics topics of AMANDA and Baikal

- Atmospheric muons
- Atmospheric muon neutrinos
- Search for extra-terrestrial muon neutrinos from point sources
- \( \nu' \)'s from Gamma Ray Bursts
- Search for flux of diffuse extra-terrestrial neutrinos
  - muon neutrinos
  - electron or tau neutrinos
  - of ultra-high energies
- High energy muons of prompt or exotic origin
- Search for WIMPs caught in Earth or Sun
- Magnetic monopole
- Neutrinos from Super Novae
- Chemical composition of Cosmic Rays
Measurement of Atmospheric Muons

AMANDA

\( \mu \) vertical intensity

Data vs Corsika MC

Baikal

Shape of the data well described
Normalization exceeds theoretical calculation by ~30%
Atmospheric $\mu$–Neutrinos

Interaction of Cosmic Rays in the atmosphere deliver the test beam (and background) of neutrinos

Unfolding of atmospheric muon-neutrino spectrum

AMANDA spectrum above 1 TeV matches lower-energy data

Compatible with expectation for atmospheric neutrino flux (see below)
Atmospheric $\mu$–Neutrinos

- Published result 1998-99 (502 days) $\rightarrow$ 84 events
- New analysis with different search strategy 1998-2000 data (780 days) $\rightarrow$ 372 events

Complementarity to AMANDA
- different view: to the South
- independent analyses
Search for Neutrino Point Sources

Select upgoing events: maximize $\uparrow \nu$ and minimize $\downarrow \mu$
Optimize cuts in each declination band optimizing for $E^{-2...-3}$ signal spectrum
Sensitivity ~independent of direction

Published analyses:
- 1997 data
- 2000 data
  PRL 92(2004) 071102

New preliminary results with different strategies:
- 2000-01 and 2002 data
- 2000–03 data: 3370 evts in 807 days
  (sensitivity ~3 higher as 2000)

No clustering in skyplot observed $\rightarrow$
No evidence for steady point sources
(measurement compatible with atmospheric $\nu$'s)
• calculate significance of local fluctuations from expectation of atmospheric $\nu_\mu$
• un-binned statistical analysis
• maximum of 3.4 $\sigma$ - compatible with background fluctuation (many search points penalty)
Neutrinos from known Sources?

90% C.L. upper limits (in units of $10^{-8} \text{cm}^{-2} \text{s}^{-1}$) for selected sources for an $E^{-2}$ spectral shape integrated above $E_{\nu} = 10 \text{ GeV}$

- AMANDA-II achieved the sensitivity to search for neutrinos from $\text{TeV} \gamma$-ray sources ($\nu/\gamma \sim 1$)
- TeV Blazars
- GeV Blazars
- MicroQuasars
- SNRs...

No indication of a hot source

Preliminary 2000-03

- Crab
- Mk421
- Mk501
- Cyg
- Cas A
- M87
- SS433
Association of \( \nu \) with Gamma Ray Bursts

Low background analysis due to space and time coincidence

Background determined on-source/off-time

Time of GRB

Use sources from GRB catalogs: BATSE (triggered and non-triggered) and IPN3 & GUSBAD ("new")

AMANDA
- 312 BATSE GRBs: observe 0
- 68 BATSE and 46 new: observe 0
- Baikal 722 BATSE evts: observe 0

Data consistent with expected \( \mu \)-bg 90% C.L. differential flux limits

AMANDA uses the muon neutrinos:
\[ E^2\Phi_{\nu} \leq 4 \cdot 10^{-8} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]

Baikal uses the cascade sample:
\[ E^2\Phi_{\nu} \leq 2 \cdot 10^{-6} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]
Search for Diffuse $\mu$-Neutrinos

Use the unfolded atmospheric muon-neutrino spectrum

How much $E^{-2}$ extra-terrestrial $\nu$-signal allowed within uncertainty?

Set limit on diffuse $E^{-2} \nu_\mu$ flux from the bin 100-300 TeV

$E^2 \Phi_{\nu_\mu}(E) < 2.9 \cdot 10^{-7}$ GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$

1997 results
PRL 90, 251101 (2003)
Search for Diffuse Neutrinos

Electromagnetic and hadronic cascades $\Rightarrow$ Sensitivity to all three flavours

$E^2 \Phi_{all \nu(E)} [\text{GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$

AMANDA: $< 0.87 \cdot 10^{-6}$
Baikal: $< 1.0 \cdot 10^{-6}$

(equal mix of all flavors)

$N_{\text{obs}} = 1 \text{ evt}$

$N_{\text{bg}} = 0.96 \pm 0.7-0.3 \text{ evts}$
Neutrinos with Ultra-High Energies

Search in upper (Southern) hemisphere and close to the horizon for very bright events and muon tracks of km lengths

- \( N_{\text{obs}} = 5 \) events
- \( N_{\text{bg}} = 4.6 \pm 1.2 \pm 36\% \) (syst) events

Derive upper limit in the 1 PeV–3 EeV region on a possible diffuse flux of neutrinos from an \( E^{-2} \) source (90% CL)

\[
E^2 \Phi_{\text{all}}(E) < 0.99 \cdot 10^{-6} \ \text{GeV cm}^{-2} \ \text{s}^{-1} \ \text{sr}^{-1}
\]

(flavor mixing \( \nu_\mu:\nu_e:\nu_\tau=1:1:1 \))
Summary Diffuse Fluxes

90% CL upper limits to a diffuse $E^{-2}$ all-$\nu$ flux determined from search for cascade events high energy tail of the atmospheric $\nu_\mu$ spectrum (x3) search for UHEnergy events

Several models of AGN neutrino emission are ruled out by AMANDA measurements.
Exotic Models for the Knee

Use high energy cascade sample to search for an

“Exotic Muon Component” – proposed (Petrukhin) to explain the CR-knee by onset of “new physics” at $E_{\text{thr}} \sim 1$ PeV that pumps “Extended Air Shower” energy to exotic muons/neutrinos

⇒ model excluded
IceCube under Construction

- Full NSF funding since February 2004
- Belgium, Sweden, DESY funded, German universities in 2005
- Deployment of 4200+ Digital Optical Modules on 70+ strings and 140+ DOMs in 70+ IceTop stations between 2005–2010
- This season: install the full chain from DOM to surface electronics, event builder, trigger, data handling and reconstruction, simulation, data verification/analysis
- and AMANDA integration

DESY responsibilities (and contributions)
IceCube DOM and DOR production

- Electronics built at LBNL
- DOM production in Madison, Uppsala, Zeuthen
- two strings in transit to Pole
- DOMs for two strings and IceTop under test

DESY contribution essential
- for DOM production
- Digital surface receiver
DOM production

Extensive tests of bare PMs and DOMs (temperature cycle from -45 to +25 °C) of noise, linearity, sensitivity, pedestal, gain, time

Analysis of data still going on:
A full report at the next PRC
Upgrades of the Baikal experiment

from NT200 to NT200+

36 additional PMTs on three far strings
⇒ four times larger effective volume
and improved cascade coordinates
and energy measurement

Status:
– virtual control room in Moscow
  and Zeuthen
– DAQ upgrade
– new shore cable installed
– faster data transmission installed
– two strings installed

Completion in 2005
Summary

AMANDA and Baikal are unique and complementary
(Northern/Southern sky, ice/water, different analyses techniques)
Both experiments have a rich physics program

- Understanding of atmospheric $\mu$’s as calibration “beam”
- Measurement of the atmospheric neutrino spectrum
- Point source search in data between 1997 and 2003
- Search for neutrinos coincident with Gamma Ray Bursts
- Limits on diffuse extraterrestrial neutrino flux for TeV-EeV $\nu$’s
- Search for “exotic” muon component around the knee

No extraterrestrial $\nu$ signal observed…yet

Many other results not shown
See http://amanda.uci.edu
http://baikal1.jinr.ru

- SuperNova-DAQ $\rightarrow$ contribution to SNEWS
- Indirect search for WIMPs in Sun and Earth
- Search for fast and slow monopoles
- Prompt muons
AMANDA
– new FADC readout (TWR) will be used in trigger and analyses
– data taking and analyses continue

Baikal
– NT200+ upgrade with DESY support
– Ensure stable operation

IceCube
– Installation: four strings early 2005
... finally 70+ strings early 2010 and IceTop stations
– will do physics with the first strings and include AMANDA
Outlook II: IceCube Future Group

- Discuss possibilities to increase physics potential of the experiment at highest energies \( > 10^8 \text{ GeV} \) already during construction
- Measure GZK neutrinos as a standard candle with “reasonable” statistics
- Compare different technologies: optical (HyperCube), radio (SuperRICE) and acoustic (still R&D)
- Study issues like calibration, signal production and ice propagation, deployment, cost and advantages of corresponding combinations
- ARENA Detector – volume needed: \( O(50 \text{ km}^3) \)

Studies at UCBerkeley and Wuppertal predict 20...80 GKZ neutrinos/ year

MonteCarlo studies started (also at DESY)
Neutrino Astro-Physics

Cosmic ray flux

\[ \frac{dN}{dE} \sim E^{-2.7} \]

\[ \sim \epsilon^{-\Gamma} e^{-\left(\epsilon/\epsilon_0\right)}, \quad \Gamma \sim 2 \]

Energy (eV)

- Cosmic rays with energy \( \gtrsim \)TeV observed - are there neutrinos?
- What are the neutrino sources: correlation with supernovae, blazars, quasars, gamma ray bursts... and/or WIMPs?

see also the latest \( \gamma \) results by CANGAROO and HESS on RXJ 1713.7-3946 (\( \pi^0 \)) and by MILAGRO on Crab and 3EG J0520+2556

HEGRA astro-ph/0003159
The AMANDA Collaboration

Europe
- VUB-IIHE Brussel
- ULB-IIHE Bruxelles
- Université de Mons-Hainaut
- Imperial College London
- DESY Zeuthen
- Gutenberg Universität Mainz
- Bergische Universität Wuppertal
- Stockholms Universitet
- Uppsala Universitet
- Kalmar Universitet

The Americas
- Bartol Research Institute
- UC Berkeley
- LBNL Berkeley
- Univ. Simón Bolivar Caracas
- UC Irvine
- UW Madison
- PennState
- UW River Falls

~150 members
The Baikal Collaboration

Russia – Germany

- Institute of Nuclear Research, Moscow
- Moscow State University
- Irkutsk State University
- Nishni Novgorod State Technical University
- State Marine Technical University, St.Petersburg
- Kurchatov Institute, Moscow
- JINR, Dubna
- DESY, Zeuthen

~45 authors
DOM production

PY3 DOM Production Summary

- Cumulative main boards shipped from LBNL
- Cumulative DOMs ready for DFL - all sites
- Cumulative DOMs shipped - all sites

~10 days
Main boards shipped
~35 days
Built DOMs
Tested DOMs

Average slope (rate) after startup: ~150/month