Point source analysis for cosmic neutrinos beyond PeV energies with AMANDA and IceCube

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IceCube

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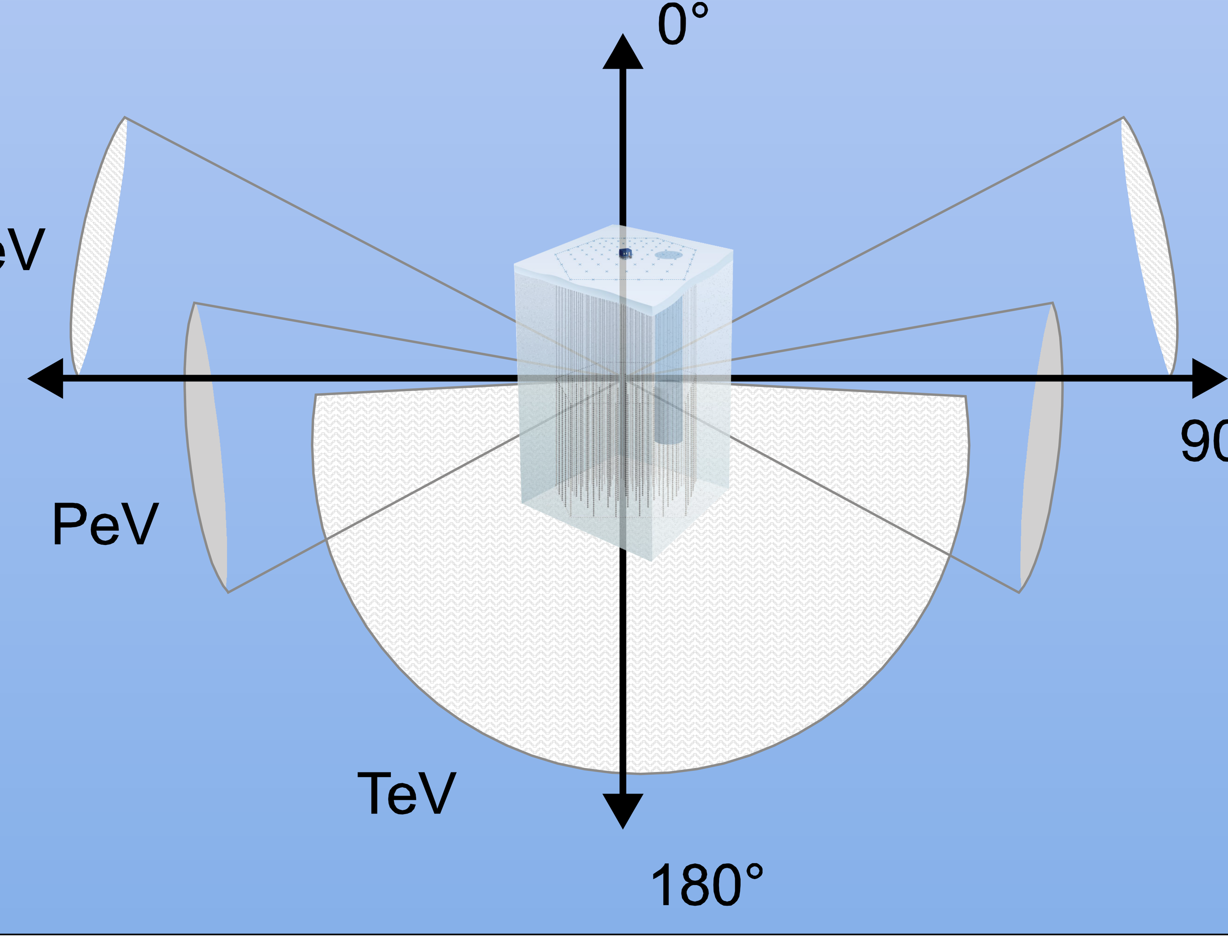
Overview
This search for cosmic point sources of neutrinos is designed for events with 10^5 to 10^{10} GeV, the highest energies accessible with the AMANDA-II detector, part of the IceCube observatory.

Motivation
Highest energy events from the southern sky are usually not included in a point source analysis. But there are theoretical models for AGNs predicting neutrino spectra to be peaked in the PeV to EeV region.[5, 6]

Down-going neutrinos

The usual approach to reduce the background of atmospheric muons in a point source analysis is by selecting up-going neutrinos only.[1] This effectively limits the accessible neutrino spectrum due to the increase of neutrino cross section with energy. For multi-PeV neutrinos, the interaction length is much smaller than the diameter of the Earth and thus prevents most of the up-going neutrinos in this energy range from reaching the detector. On the other hand, down-going neutrinos from the southern sky high above the horizon have only the ice above the detector as target material and hence a significantly reduced interaction probability. Thus, a dedicated neutrino analysis for highest energies must utilize a zenith angle band around the horizon.

Up-going neutrinos

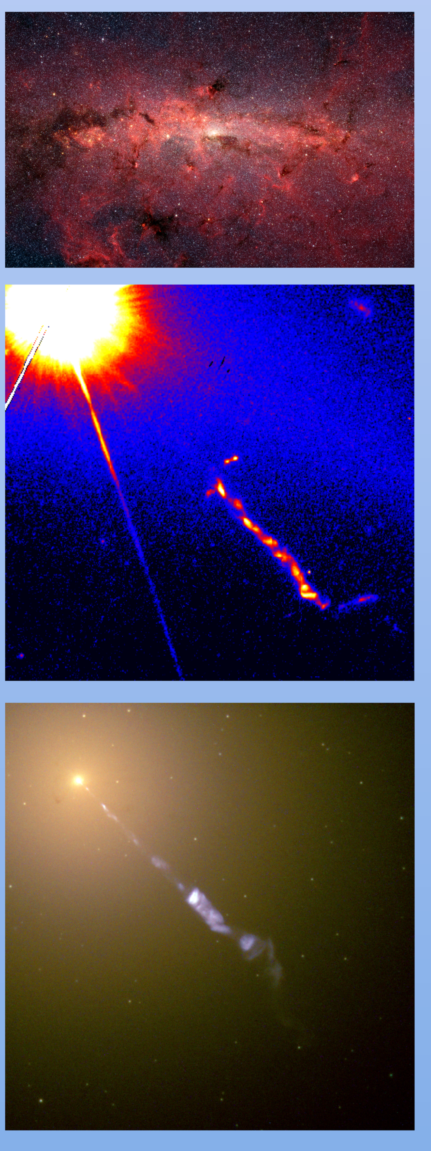


Example source candidates

Galactic Center

QSO 3C273

Radio galaxy M87



Source Selection
The analysis is limited to a zenith angle band around the horizon, approximately between 60° and 110°. Candidate sources in this region include 39 AGNs observed by EGRET[4] and a number of objects detected at TeV energies. In order to choose a sub-sample, basic neutrino flux estimates are being calculated.

Track Reconstruction

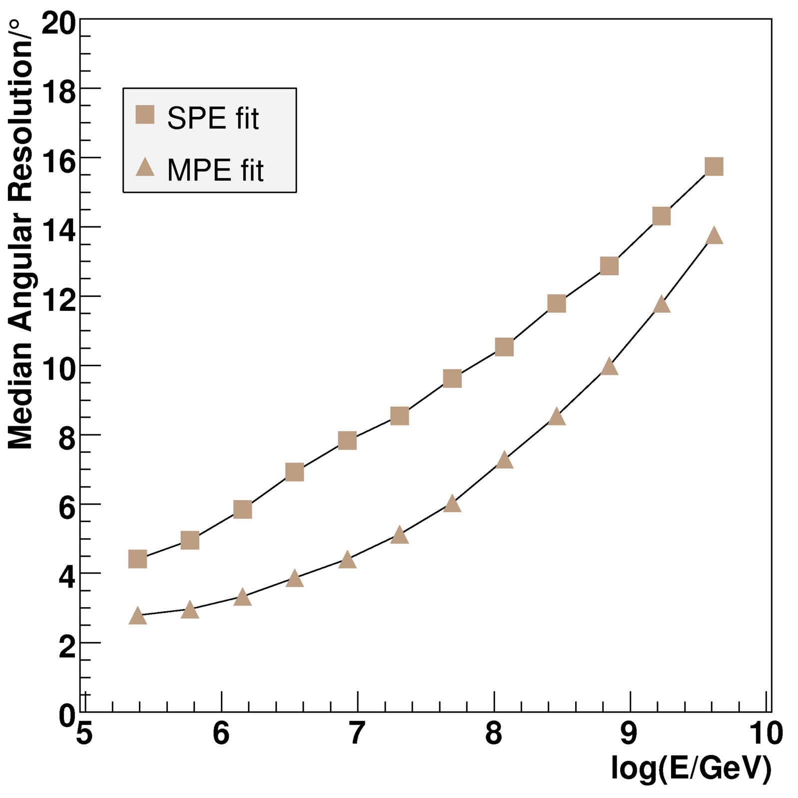
General approach:
A maximum likelihood track fit of photon arrival times accounts for scattering based on an empirical ice model.

Standard implementation:
- using only first hit in each optical module (photomultiplier)[2]
- iterative likelihood maximization with different seed tracks

Multi-PeV analysis:
- higher energy muons emit more photons per track length
- increased impact of randomization of photon arrivals by individual scattering

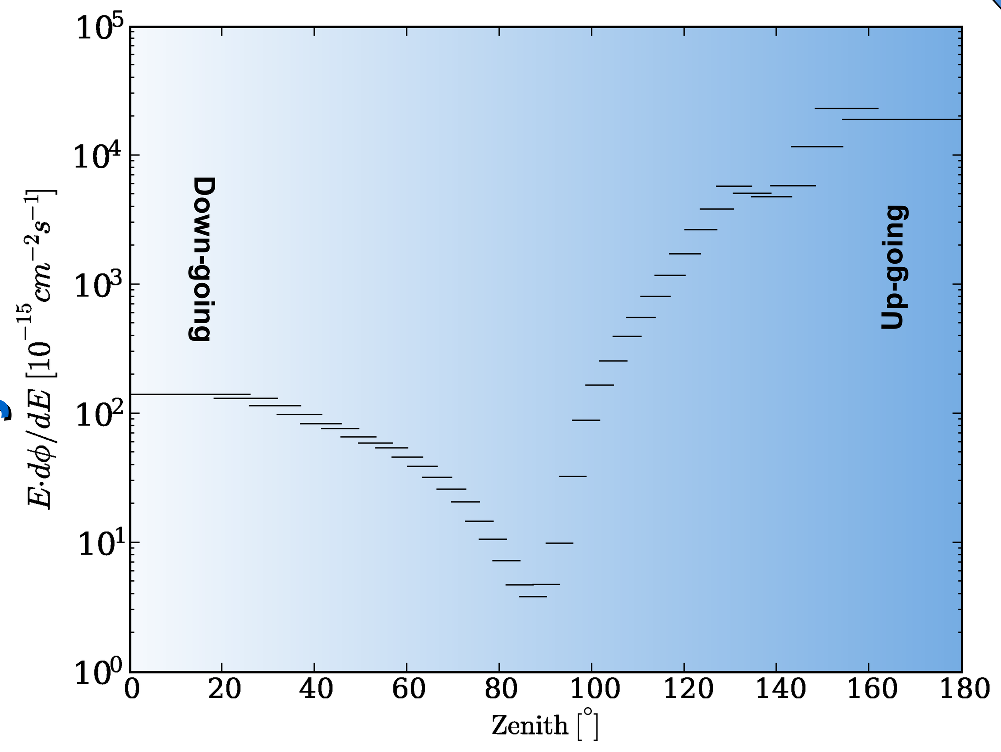
Improved method:
- accounts for multiple hits and probabilities for any of the emitted photons to arrive as first hit[2]
- computationally expensive numerical integration over probability density function
- no iterative fitting, but usage of standard likelihood track fit result as seed

Median angular resolution:
For a neutrino signal E^{-2} spectrum with high energy event selection (see below): 3.87°
(compared to 6.9° for the standard implementation) [3]



Median angular resolution in degrees as a function of primary neutrino energy from Monte Carlo simulation, reconstructed with the simple (SPE) and improved fit (MPE) accounting for multiple scattered photons.

Sensitivity



Preliminary sensitivity for AMANDA-II for an E^{-1} flux of muon neutrinos in the energy range from 10^5 to 10^{10} GeV vs. zenith angle. The upper limit is shown as a limit to the normalization constant Φ_0 of the differential flux $d\Phi/dE=\Phi_0 E^{-1}$. The horizontal lines indicate the width of the overlapping zenith bands were the cuts were independently optimized for sensitivity.

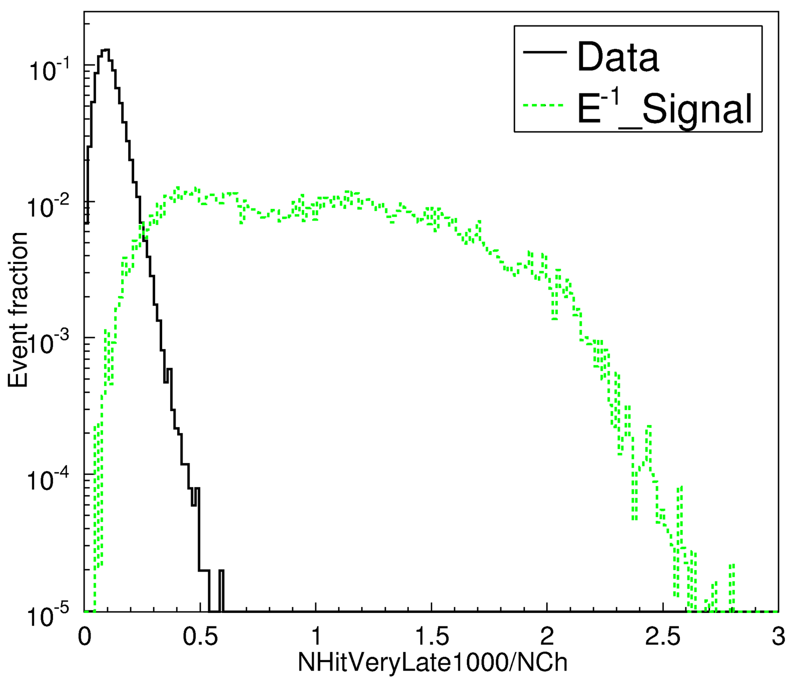
Event Selection

High energy selection based on light output per event:
- number of hits in the detector >140
- fraction of one-photoelectron hits <0.72

Main background: Intense muon bundles

Two-step discrimination based on signal simulation with data as background:

1. More very late hits for signal than for background
   - Variable: fraction of optical modules with very late hits (>1000ns after first hit)
   - Cut: fraction > 0.15 (20% of data kept, 94% passing rate for E^{-1} neutrino signal)
2. Three additional variables, sensitive to light output:
   - Variables:
     - number of photons with distance to the track fit >50m
     - ratio of hit optical modules to the total number of hits
     - ratio of late hits to the total number of hits
   - Cuts: Optimized for sensitivity



Ratio of late hits (hits occurring more than 1000 ns after the first hit in that OM) to the number of hit OMs for an E-1 signal spectrum and experimental data.

Conclusion & Outlook

The analysis enlarges the angular window of AMANDA-II to parts of the southern sky. This concept is being developed further with the aim to be applied to the data taken with IceCube in the 9 string configuration of 2006. A preliminary study of reconstruction methods after a basic selection of high multiplicity events shows an angular resolution of approximately 3°.

References
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