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Neutrino Astronomy and Cosmic Rays at the South Pole
Latest results from AMANDA and perspectives for IceCube

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The AMANDA neutrino telescope has been in operaton at the South Pole since 1996. The present final array configuration, operational since 2000, consists of 677 photomultiplier tubes arranged in 19 strings, buried at depths between 1500 and 2000 m in the ice. The most recent results on a multi-year search for point sources of neutrinos will be shown. The study of events triggered in coincidence with the surface array SPASE and AMANDA provided a result on cosmic ray composition. Expected improvements from IceCube/IceTop will also be discussed.

Keywords: Keyword1; keyword2; keyword3.

1. Introduction

The observation of high-energy cosmic rays (up to 10^{20} eV) suggests that they are subject to acceleration mechanisms within their sources; the observation of gamma rays with energy spectra compatible with π^0 decays, would stress the suggestion that hadronic processes are important in these sources. The existence of hadronic processes would imply that high-energy neutrinos are produced by the decays of charged pions. The identification of these neutrinos would require large scale detectors. "Guaranteed" neutrino fluxes, i.e. those associated to known cosmic accelerators with an identified pion production target typically require a $\sim$ km^2 scale detector. The AMANDA experiment[a] [1] consists of 677 optical sensors arranged

[a]The full 19-string array, named AMANDA-II, started data taking in 2000. An earlier 10-string stage (comprising the inner 10 strings), called AMANDA-B10, started data taking in 1997 (see Ref. 2).

along 19 vertical strings buried deep in the glacial ice at the South Pole, mainly at depths between 1,500 and 2,000 m. The instrumented volume of ~ 0.016 km^3 could not be enough to detect "guaranteed" extraterrestrial neutrino fluxes, but it is the first sizable tool to explore the detection of high energy extraterrestrial neutrinos. Moreover AMANDA-II has proven to be a valid tool in measuring the main background of atmospheric muon intensity and the energy spectrum of the persistent background of atmospheric neutrinos [2]. AMANDA-II will be embedded within the bigger IceCube [3] array to provide a lower energy threshold sub-array.

IceCube will consist of 80 vertical strings deployed between 1,400 and 2,400 meters deep below the South Pole, containing a total of 4,800 digital sensors[4]. The instrumented volume will be 1 km^3 and the sensors array layout was optimized for high energy neutrino detection. IceCube will be complemented by a surface array called IceTop [5], which consists of 160 frozen water tanks (two at the top of each IceCube string). Each tank has internal reflective walls and contains 2 digital sensors looking inside the clear frozen ice[b].

IceCube will cover neutrino energies from TeV to EeV and will overlap with AMANDA-II which has an energy threshold of $\sim$ 50 GeV. IceTop will provide selective thresholds ranging from a few TeV to a few hundreds of TeV and will be able to identify extensive air showers with energy up to EeV. The coincident events between IceCube and IceTop, with an exposure of $\sim 1/3$ km^{2}sr, can be used to tag down-going energetic muon events and increase the high energy neutrino detection sensitivity. IceCube/IceTop coincident events will also extend the primary cosmic ray detection window (presently performed by AMANDA-B10/SPASE [6]) to EeV range, with unprecedented energy resolution, by probing the correlation between the electromagnetic and muonic component of the showers.

2. Neutrino Detection

The detection of neutrinos requires CC or NC interactions to occur in the ice or bed rock. Among the leptons produced in CC processes the muon is the most penetrating, and the angular offset with respect to parent neutrino is less than 0.8° (0.1°) for energies above 1 (100) TeV. Thus it is possible to point back to the neutrino direction, limited only by the instrument angular resolution, which is bigger and depends on the reconstruction techniques [7] and the understanding of polar ice optical properties [2].

AMANDA-II has engaged in a series of analyses aimed to study the sensitivity for neutrino detection of diffuse and point sources [2 8] over a wide range of energies. The measurement of atmospheric neutrino energy spectrum presents a fundamental calibration of the array capability. The muon pointing resolution is between 1.5° and 2.5°, depending on the muon energy, direction and selection criteria. IceCube

[b]The first 4 strings and 8 tanks will be deployed on January 2005, for a total of 256 deployed sensors.

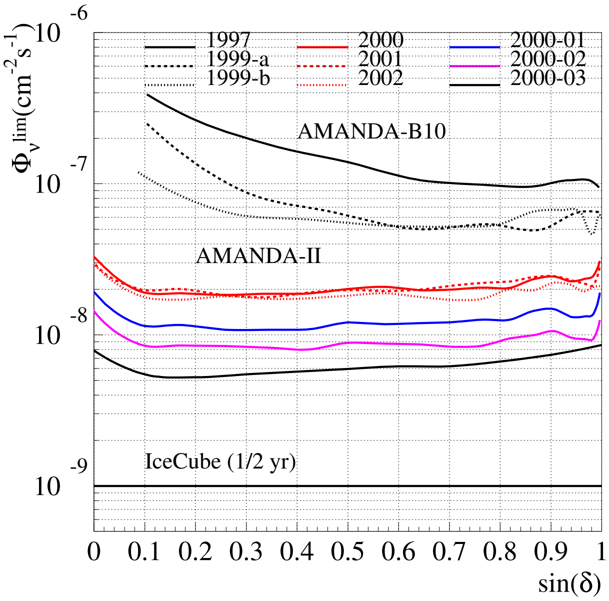

Fig. 1. Average upper limits (sensitivity), integrated above 10 GeV and relative to different analyses, for the detection of high energy neutrinos from point sources. The sensitivities were calculated for a signal spectrum $\propto E^{-2}$, except the one for the years 2000-03, obtained for spectra of E^{-2}-E^{-3}. The IceCube sensitivity for half year is also shown.

pointing resolution is better than 0.8° for energies above 1 TeV [3]. Improved angular resolution results in enhanced background rejection, strengthening the case for IceCube in addition to the ~ 50 fold increase in instrumented volume. The search for high energy neutrinos from extraterrestrial sources is the analysis which most benefits from the pointing capabilities of AMANDA and IceCube.

Fig. 1 shows the sensitivity[c] for the detection of neutrinos, with energy above 10 GeV, from extraterrestrial steady point sources. A signal would be identified as a significant deviation over the average upper limit from a point in the sky. The AMANDA-II sensitivity has increased by improving the track reconstruction capabilities and by optimizing the background rejection, in addition to the increase in detector size. The Figure clearly shows that the larger AMANDA-II detection sensitivity is less dependent of the source direction in the sky than AMANDA-B10. No signal from point sources was found. The predicted sensitivity for half a year operation of IceCube is almost a factor of 5 better than the combined AMANDA-II four-year value.

[c]defined as the average upper limit over an ensemble of identical experiments in the hypothesis of no signal.

3. Cosmic Ray Detection

The AMANDA-II absolute pointing accuracy has been measured by separately reconstructing the atmospheric air shower directions with the surface array SPASE [6] and the corresponding muon component with AMANDA. It is better than half a degree, i.e. smaller than the AMANDA-II angular resolution [9]. The scintillator surface array SPASE measures the extensive air shower particle density at the surface of the ice[d], at 30 m distance from the reconstructed shower core. The deep-ice AMANDA detector measures the total Cherenkov light emitted by the penetrating muons, with energy above 500 GeV, passing in the vicinity of the array [10]. The latter observable is a measurement of the total muon energy loss detected by AMANDA, and it's proportional to the muon bundle multiplicity. The simultaneous measurement of these two observables allows access to primary cosmic ray energy and mass composition. Due to the robustness of the measured observables and to the fact that at the South Pole atmospheric depth their fluctuations are smaller than at sea level, the resulting primary energy resolution is ~ 0.07 in $\log_{10}(\mathrm{E}_{prim})$ and it is independent on the mass of the primary. The primary composition, obtained by probing relative change of muonic to electromagnetic energies in the extensive air showers, provides a rather robust method against systematic uncertainties, and is consistent with an increased cosmic rays average mass composition for primary energies between 0.5-6 PeV [10].

IceCube/IceTop coincident measurement can cover energies up to EeV with an improved mass-independent primary energy resolution. The energy extension up to EeV will provide a probe to possibly clarify the transition from galactic to extra-galactic cosmic rays.

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[d] at an atmospheric depth of about 600 g/cm^2.

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