Neutrino Astronomy at the South Pole: latest Results from AMANDA-II

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Abstract. AMANDA-II is the largest neutrino telescope collecting data at the moment, and its main goal is to search for sources of high energy extra-terrestrial neutrinos. The detection of such sources could give non-controversial evidence for the acceleration of charged hadrons in cosmic objects like Supernova Remnants, Micro-quasars, Active Galactic Nuclei or Gamma Ray Bursts. No significant excess has been found in searching for neutrinos from both point-like and non-localized sources. However AMANDA-II has significantly improved analysis techniques for better signal-to-noise optimization. The km^3-scale IceCube telescope will enlarge the observable energy range and improve the sensitivities of high energy neutrino searches due to its 30 times larger effective area.

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INTRODUCTION

The detection of extra-terrestrial multi-TeV neutrinos would significantly contribute to the understanding of the energy balance of the Universe and of the origin, acceleration and propagation of high energy cosmic rays. It would also influence the results of the most recent gamma ray experiment results, like those of H.E.S.S. [1].

Neutrinos can propagate through the Universe without being affected by interactions or magnetic fields. Therefore they are ideal high energy cosmic messengers and, for the same reason, unfortunately very difficult to detect. Even the so called "guaranteed" neutrino fluxes, i.e. those associated to known cosmic accelerators with an identified pion production target, typically require a $\sim$ km^3 scale detector. AMANDA-II [2, 3], with its ~ 0.016 km^3 instrumented volume, is currently the largest operating neutrino telescope. Its sensitivity is improving because of larger data sample collected, of better apparatus understanding and of more efficient background rejection techniques.

The main background for neutrino telescopes is the intense flux of downward penetrating cosmic muons which can mimic the upward neutrino-induced event signature. A total rejection factor of 10^6 is required to isolate atmospheric neutrino-induced muons. AMANDA-II has improved reconstruction algorithms [4] and analysis techniques and currently it is able to select about four atmospheric muon neutrinos per day [5]. These events constitute the main background to the search of extraterrestrial neutrino fluxes.

The following sections describe the searches for localized neutrino sources and for a diffuse neutrino flux from many weak sources, respectively.

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[1] For the Collaboration list see http://www.icecube.wisc.edu/pub_and_doc/conferences/panic05/

NEUTRINOS FROM POINT-LIKE SOURCES

Since the main background consists of downward-going cosmic ray muons, the search for neutrinos is restricted to the northern hemisphere. A point source in the sky would be identified as a localized significant excess of events, above the irreducible measured atmospheric muon neutrino background. The event selection is independently performed on different declination bands[2]. The band width depends on the angular resolution at the given declination. The optimization of event selection is done by requiring the best sensitivity, i.e. the best 90% CL expected average upper limit in the case of no signal [6], at each declination band. The final sample contains 3329 events in the first 807 days of lifetime of AMANDA-II (see Fig 1), which has an estimated background contamination of less than 10% and corresponds to a median angular resolution of $\sim 1.5^\circ - 2.5^\circ$, depending on declination. The sensitivity, for an assumed energy spectrum of E^{-2}, is 6×10^{-8} GeVcm^{-2}s^{-1}, and it is almost independent on declination [2, 5]. No excess with respect to the expected background has been reported so far [7, 8].

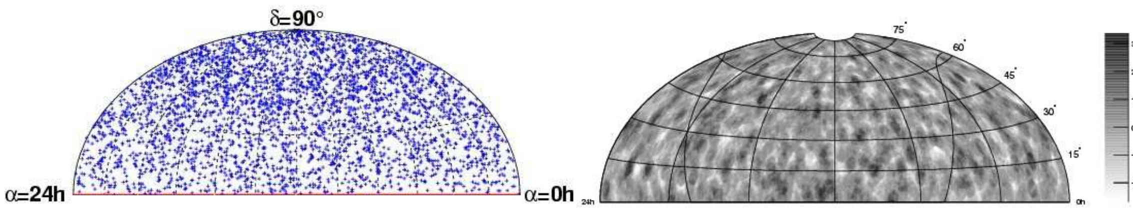

FIGURE 1. Left: sky map of the selected 3329 neutrino events from the year 2000-03. Right: significance map of the search for clusters of events in the northern hemisphere, based on the selected events (gray scale is in sigma).

The absence of a significant excess could simply be caused by the small size of AMANDA-II apparatus and faint neutrino fluxes from the point sources. Besides increasing the collected data, a possibility to improve the signal-to-noise ratio is to search for events from a pre-selected list of source candidates [3, 7, 8], or for events in coincidence with known periods of enhanced electromagnetic emission of selected objects [3]. Another possibility is to perform a stacking source search using well defined classes of Active Galactic Nuclei and under the assumption that neutrino emission is similar to the electromagnetic one [9]. With respect to the single point source candidate search the stacking analysis achieves $\sim$ 2-3 times better sensitivity for some of the selected source classes.

Searches for neutrinos in coincidence with Gamma ray Bursts were also performed [10], where the time constraint significantly reduces the background contamination, but no signal was found.

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[2] for assumed spectra with E^{-2} to E^{-3} energy dependence.

NEUTRINOS FROM NON-LOCALIZED SOURCES

The search for high energy neutrinos from all the possible sources in the Universe emitted throughout its evolution could enhance a very faint signal not detectable from single sources. The search for a diffuse neutrino flux relies on the simulation of the background and the signal-to-noise optimization is performed on the energy estimation of the selected events. It is expected that neutrinos have a hard energy spectrum proportional to E^{-2}, whereas the atmospheric neutrinos have a steeper spectrum ($\sim E^{-3.7}$). Therefore, after having assured the quality of selected events, an energy cut is optimized to have the best sensitivity. The preliminary sensitivity for the search of diffuse muon neutrinos is 9.5×10^{-8} GeVcm^{-2}s^{-1}sr^{-1} for 807 days of livetime, in the energy range between 13 TeV and 3.2 PeV [3]. This preliminary search did not reveal any signifi cant excess with respect to the background.

A search for all neutrino flavor events undergoing neutral current interaction was also performed. Reconstruction of the cascade position and energy allows to extend the search to the full sky (not only the northern hemisphere), since shower events could be discriminated from tracks. Even so, the major background consists of bremsstrahlung showers produced by cosmic muons [11]. At Ultra High Energy ranges (i.e. above 10^3 TeV) the events are very extensive and full reconstruction is not necessary. At these energies the background of atmospheric events starts to become negligible and the search can be done by counting the fraction of optical sensors with more than one detected photon, which increases with energy [12].

The absence of signal detection in AMANDA-II is an indication that the flux of extra-terrestrial neutrinos, if any, is very small. A $\sim$ km^3-scale experiment may open this new observation window by profi ting not only of its larger size and more powerful analysis techniques being developed in AMANDA-II, but also of the full digitized response of IceCube array sensors [13].

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[3] which contains 90% of the selected events