Helmholtz-Hochschul Nachwuchsgruppe **VH-NG-205**

"Multi-messenger studies of point sources of cosmic rays using data from IceCube"

2006 Activity Report, March 2007

Group members (2006)

Group Leader:	Dr. Elisa Bernardini, DESY
Post-doctoral fellows:	Dr. Markus Ackermann, DESY Dr. Martin Tluczykont, DESY
Guest Scientists:	Dr. Oleg Kalekin Dr. Maxim Shayduk
Graduate Students (supervisor E. Bernardini):	Robert Lauer, DESY Konstancja Satalecka, DESY
Undergraduate Student (supervisor E. Bernardini):	Robert Franke, Humboldt Univ.

Timeline (2006)

The young investigator group VH-NG-205 started on March 1st 2006 (E. Bernardini and M. Tluzcykont). In August M. Ackermann joined (previously graduate student). R. Lauer and K. Satalecka started in September. For a short time C. Schwenke (PhD student, who left for employment in industry) and two guest scientists (O. Kalekin, Ma. Shayduk) also contributed to the activities.

Main Activities (2006)

The group mostly works on the search for point sources of neutrinos with IceCube (former AMANDA) and on the development of the multi-messenger approach and contribute to the MAGIC project. The activities are summarized below.

1. <u>Neutrino data analysis</u>

1.1. Analysis of AMANDA data (northern sky searches)

In 2006 the group completed the processing of data collected with AMANDA in 2000-2004 and extracted a sample of 4282 neutrino events (Figure 1). This data serves as a standard sample for a series of analyses in IceCube. We searched this sample for point sources of neutrinos. The results are compatible with the background hypothesis and the most stringent upper limits to the flux of cosmic neutrinos were derived [1]. They substantially constrain theoretical predictions on neutrino production in selected objects [2].
For the first time we measured the sensitivity to point sources of neutrino using the tau-neutrino channel, which was never considered before. We found that, due to neutrino oscillations, it gives a relevant contribution to the overall sensitivities, especially at high energies (up to 16% of the results for muon-neutrino, in case of tau neutrino CC interactions, followed by tau decay into muon, with 17.7 branching ratio).

We then accomplished a detailed study of the systematic uncertainties associated to the detection of neutrinos in the energy range between about 100 GeV and a few PeV. In particular, we quantified the effects of the uncertainties on the Optical Module efficiency (or sensitivity, which includes the local re-frozen ice) and on the optical properties of the different ice layers. This work serves as input to several IceCube publications.

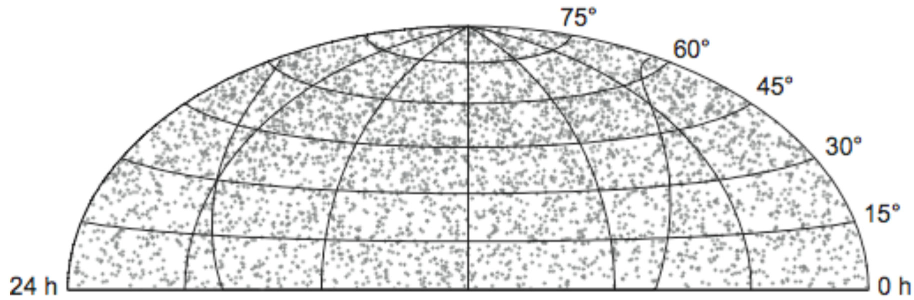

Figure1: Sky map of the 4282 high-energy AMANDA neutrino events detected in 2000-2004.

Another analysis developed by this group in 2006 aims at finding hidden neutrino flares from the direction of pre-selected sources. After the observation of a potentially interesting accumulation of events from the direction of the Blazar 1ES 1959+650 a generalization of that analysis is being developed to find events clustered in time without a-priori limitations on the size (K. Satalecka). The analysis will be applied to the most recent AMANDA data and then further developed and applied to IceCube.

1.2. Improvement of the IceCube performance (multi-channel formalism)

We aim at improving the IceCube performance in the search for point sources of neutrinos, both at high and low energies. We work on the identification of different classes of events to be combined for common searches (multi-channel approach).
Besides measuring the efficiency to tau neutrinos for point source searches (Section 1.1), the group works out a new analysis concept to extend the searches of Section 1.1 to higher energies (above a few hundred TeV). At these energies the absorption of neutrinos in the earth becomes relevant and searches for cosmic neutrinos should focus to the southern sky. Two parallel analyses are being developed: one for AMANDA (R. Franke, diploma work) and the other for IceCube (R. Lauer, PhD work).
To extend the sensitivity at low energies (below 100 GeV), M. Tluczykont is instead studying the improvement of the reconstruction efficiency of the combined AMANDA+IceCube detector (cfr. Figure 2).
In 2007 the group will extend this effort and focus on the development of a multi-dimensional likelihood formalism to combine of data sets with large differences in detection efficiency and properties (e.g. energy range of the events, Jose Luis Baso Alba, PhD work starting in May 2007).

1.3. Enhancement of signal-to-noise ratio (Multi-messenger approach)

To increase the chance to discover point sources of neutrinos, the group focuses on the development of a multi-messenger approach, by searching for correlations between high-energy neutrinos and established signals, particularly very high-energy gamma-rays (GeV/TeV). In 2006 we worked on the archiving of historical observations and on the analysis of the obtained data records (Figure 3, [3]). In particular, we developed criteria for the relative calibration of different gamma-ray detectors. The results are unsurpassed in their completeness and coverage and allow new investigations of the phenomenology of the sources. Based on this data set, we are currently selecting periods-of-interest to look for coincident neutrinos. Interesting for the group is also the extraction of information on the frequency of

states of high gamma-ray emission, which is mandatory for the interpretation of possible correlation with high energy neutrinos (see also Section 3.1).
To independently improve the signal-to-noise ratio R. Lauer started to work on the classification of candidate sources, according to the expected energy spectrum of the potentially emitted neutrinos and, in case of variable sources, the wavelength range of the electromagnetic emission that can be correlated to the neutrino signal. The goal is the compilation of source catalogues for the different analyses in progress.

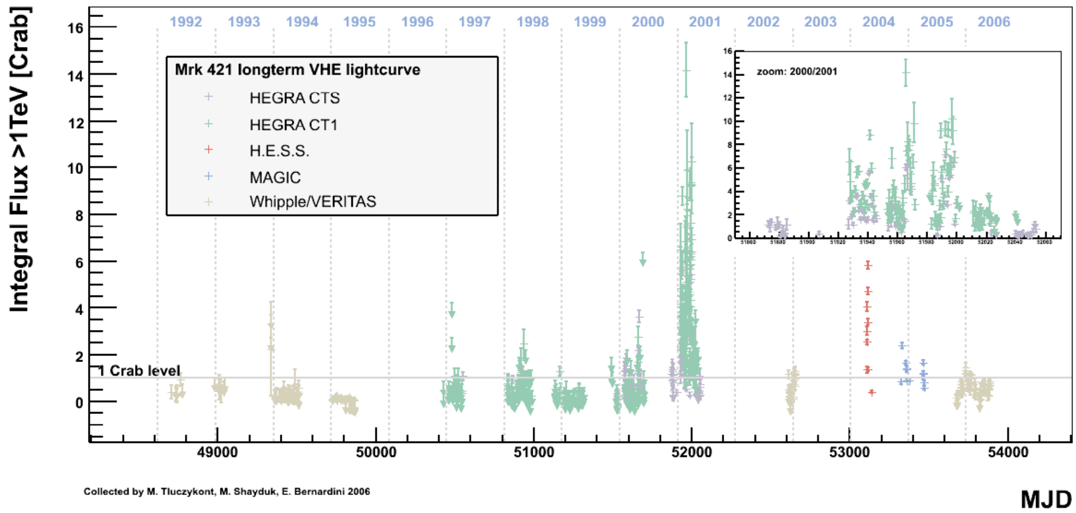

Figure 3: Combined light curve of the prominent BL-Lac-object Markarian-421.

2. IceCube Maintenance and operation

The group contributes to the operation of IceCube through several tasks. E. Bernardini has been appointed as one of the leaders of the point source working group, which coordinates all IceCube analyses on these subjects (50 members subscribed, bi-weekly conference calls). It also coordinates all activities related to multi-wavelength and multi-messenger analyses and accomplishes a series of trans-working group activities, like data processing, detector verification and interdisciplinary analyses. M. Tluzcykont instead contributed in 2006 to the development of the reconstruction and event selection on-line IceCube chain implemented for the year 2007. M. Tluzcykont is also responsible for the DESY share of the Monte Carlo mass production of IceCube.

3. Cooperation with MAGIC (Multi-messenger approach)

3.1. Development of Target of Opportunity strategies

Since Cherenkov telescopes have a small field of view and their duty cycle is small, the observation time is distributed among several objects. Limited information therefore exists on the gamma-ray emission of interesting sources at the time when neutrino events are detected, making cross-correlation analysis difficult. To increase the probability to collect gamma-ray data (quasi-) simultaneous to high-energy neutrinos, the group promoted and developed in 2006 a Neutrino triggered Target Of Opportunity (NToO) program [4]. A tentative neutrino signal is used to alert gamma-ray observations. The detection of a positive coincidence can enhance the discovery chance (see Table 1 for a numerical example). More generally, this scheme of operation can increase the availability of simultaneous observations.
In 2006 we worked on a first technical implementation of this scheme involving AMANDA and MAGIC has been realized for few pre-selected sources in a successful short test run (Sept. to Dec. 2006), with the aim of a feasibility study [5]. Five alerts have been sent to MAGIC collaboration. The data collected is currently being

analyzed independently and the results will be presented as a joined IceCube and MAGIC talk at the next ICRC Conference (July 2007).
This has been the first realized cooperation between a neutrino and a gamma-ray telescope and served as a prototype for an NToO program with IceCube: we developed guidelines for the exchange of information and necessary toolboxes, like a test client to interactively send alerts to a server at the MAGIC site. This allows an automatic observation-pipeline system similar to what adopted by MAGIC to follow GRB alerts by satellites [6].
The program will be further promoted and in 2007 its extension using data from IceCube will be developed (S. Odrowski, diploma thesis, starting April 2006).

Neutrinos (observed/background)	# coincident gamma-ray flares	significance (σ)
3 / 1	?	1.4
3 / 1	2	4.0
3 / 1	3	5.1

Table 1: Numerical example showing how the observation of states of high emission of gamma-rays coincident with neutrinos could dramatically enhance the significance of the results. In this example it is assumed that the probability to observe a high state in the gamma-ray emission is 1%.

3.2. Data analysis

To strengthen the potential of multi-messenger studies, another activity of the group aims at further enlarging the available statistics of gamma-ray time series. Konstancja Satalecka started to analyze data collected with the MAGIC telescope during an active galactic monitoring program that took place in 2006. This work is being carried out with the support of the MAGIC group at the Max-Planck Institute for Physics in Munich.

4. Teaching

In Dec. 2006 E. Bernardini has been recognized by the Humboldt University of Berlin the right of independent research and teaching as well as the right to supervise students and review theses. She took part to the organization of research seminars and the first lecture will be held in the 2007 Winter Semester (Astroparticle Physics).

Publications

[1] M. Ackermann, E. Bernardini et al., “Five years of searches for point sources of astrophysical neutrinos with the AMANDA-II neutrino telescope”, submitted to Phys. Rev. D, astro-ph/0611063.

[2] M. Ackermann et al., “Upper limits on neutrino fluxes from point-like sources with AMANDA-II”, Proceedings to Multi-messenger Conference, Barcelona 2006, Astrophys. and Space Science ASTRPA-63.

[3] M. Tluczykont, M. Shayduk, O. Kalekin, E. Bernardini, “Long-term gamma-ray lightcurves and high state probabilities of Active Galactic Nuclei”, Proceedings to TeV Particle Astrophysics II, Madison 2006.

[4] M. Ackermann, E. Bernardini, “Proposal for a Target of Opportunity program to search for point sources of high energy neutrinos including data from AMANDA/IceCube”, icecube/200611002, April 2006.

[5] M. Ackermann, E. Bernardini, “Test Run for target of opportunity gamma-ray observations triggered by neutrinos”, icecube/200611003, August 2006.

[6] N. Galante, F. Goebel, E. Bernardini, M. Ackermann, “Neutrino Alert System”, icecube/200704002, December 2006.