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

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

2010 Activity Report

Group members

Staff:	Elisa Bernardini
Post-doctoral fellows:	Konstancja Satalecka, Rebecca Gozzini
Graduate Students (supervisor E. Bernardini):	Robert Lauer Jose Luis Bazo Alba Robert Franke Gessica de Caneva Angel Luis Cruz Silva
Summer Students / Guest	Matteo Pelermo Supachai Awiphan

Group Status Overview

Elisa Bernardini and Konstancja Satalecka were both on maternity leave for a fraction of the year (returned in April 2010 and February 2010 respectively).
Konstancja Satalecka and Rebecca Gozzini were hired as post-doc in May and October 2010 respectively.
Robert Lauer and Jose Luis Bazo Alba left the group in Fall 2010.
Angel Luis Cruz Silva and Gessica de Caneva joined the group in September and October 2010 respectively.
Matteo Palermo and Supachai Awiphan joined the group as summer students. Supachai Awiphan was later on invited as a guest for about 3 weeks.

1. Project Overview: IceCube

At 18 December 2010, the last string of the IceCube Neutrino Observatory was deployed. Each of the 86 strings carries 60 photomultipliers, buried in the south polar glacier at depths between 1.45 and 2.45 km. Thirty-three years after first concepts for underwater neutrino detectors with a cubic-kilometer volume was developed, we now have the cubic kilometer and look forward to open a new window to the universe. Meanwhile the focus is on analysis of the experimental data which have been taken since 2006, with the stepwise increasing detector. About 50 Terabyte per year are recorded, plus a much bigger amount of data from Monte-Carlo mass simulation.

The Young Investigator Group contributes to the search for extraterrestrial signals from point sources, exploiting correlations with other messengers (the multi-messenger approach).

The group also develops online filters for the South Pole Data Acquisition System (see Section 4).

High-energy neutrinos must be emitted as a by-product of collisions of charged cosmic rays with matter. Since they can escape much denser celestial bodies than light, they can be tracers of processes which stay hidden to traditional astronomy. Until now no statistically convincing excess of high-energy neutrinos was found (see Section 5).

2. Project Overview: MAGIC

The two 17 m diameter MAGIC dishes on the Canary Island of La Palma, the first of which was commissioned in 2003, the second in 2009, are being operated in stereo mode (MAGIC-II). The superior performance of MAGIC-II exceeds expectations and holds the promise of future milestone discoveries.
Within the first months of observation, MAGIC-II already discovered six new extragalactic emitters of energetic gamma rays, tracers of the highest-energy phenomena in the universe. The new sources are two galaxies located in the Perseus cluster of galaxies, a quasar, a super-massive black hole located at a distance of about 4.5 billion light years (one third of the radius of the universe) and thus belonging to the three most distant energetic sources ever found, the mysterious source J2001+435, the distance and nature of which are still uncertain, and two objects located both at a distance of 1.4 billion light years.
With the second telescope, MAGIC is bridging the observational gap between satellite- and ground-based gamma-ray telescopes.

The DESY Helmholtz Young Investigator Group has worked in 2010 on simulations to compare and optimize different algorithms for energy reconstruction in order to make full use of the stereo mode capabilities (see Section 6).

The group also continues its monitoring program for bright blazars which is of utmost importance for any correlation studies between gamma-ray data and neutrino events. A large fraction of the results are being published as part of multi-wavelength campaigns which try to disclose the phenomenology of the VHE emission[3,4,8,10,15].

Finally, an alert system where MAGIC observations are triggered by neutrino event series taken with IceCube was successfully finalized (see Section 4).

3. Project Overview: Others

In the search for point sources of neutrinos, a working hypothesis being followed by the YIG is that neutrinos signals are variable in time and correlated with the enhanced electromagnetic emission as observed at several wavelengths. Therefore, to limit the trial factor penalty arising from the large amount of data to be scanned in blind searches, external triggers from multi-wavelength data can be used (the so called “multi-messenger approach”). An important ingredient which is necessary to interpret a possible coincidence of neutrinos with electromagnetic “flares” is the random probability to observe “flares” in the first place. This is a rather thorny problem, since electromagnetic observations are in many cases sporadic, scarce or biased (e.g. being triggered on specific states of emission).
Besides being involved in the IceCube and MAGIC experiments, the Young Investigator Group conducts independent research, based on publicly available scientific data. One of the main goals is to constraint the above mentioned probability, at least for a few selected astrophysical sources.

An archive of VHE gamma-ray light-curves was created in 2006 and it is being maintained with newly published information [1]. This provides a way to measure the probability to observe different states of VHE emission.

Since the last few years, the Fermi satellite is in operation, providing a monitoring of the full-sky with constant and frequent sampling. In the context of a summer students project, we compiled light-curves for selected Blazars and obtained a first estimate of the probability of flares at high energy (i.e. > 1 GeV) gamma-rays.

Finally, we explored methods developed in Astronomy to investigate the noise power spectrum [Uttley et al (2002)]. One of the goals is to measure the power law spectral index, to be used as input for the generation of simulated light curves with the method of [Edelson & Krolik (1998)]. If successful in generating artificial VHE light-curves we will be able to develop statistically robust methods to study the correlation between different wavelengths.

4. Neutrino triggered Target of Opportunity (NToO) program

With the aim of triggering follow-up observations of potential neutrino flares, we developed a dedicated on-line filter and alert system to run at the South Pole. The IceCube detector is continuously operated with only very minimal down time and has a field of view of 4. The data that is collected is processed and filtered directly after data taking at the South Pole. A subset of the data (defined by several physics filter streams) is then transferred via satellite to the North for further analysis. This happens however with a substantial delay of several days. To be able to run a fast analysis at the South Pole a second data stream of high quality muon tracks exists whose rate (4.5 Hz) is such that more time consuming reconstructions can be run on it with the available computing power at the South Pole. Based on these reconstructions (that are very similar to the ones also used in offline analysis) we select a neutrino sample for the Northern sky with a rate of about 1.5 mHz. These events are then used to generate the IceCube alerts for significant deviations from the background-only hypothesis of the number of detected neutrinos from certain source directions.
Events that fall in a spacial bin around a source in the source list are written to disk and analyzed by a separate program using a time-clustering algorithm [Satelecka et al.(2007)]. Should a significant deviation in the time distribution of events around a source be found an alert will be issued. We assign a significance to each alert based on the number of observed neutrinos compared to the background expectation. Alerts that surpass a certain definable threshold will be sent to the North for further relay to the MAGIC telescope if the source is visible during dark time.

The alert rates have to be compared to the signal discovery probability. Figure 1 shows the required neutrino fluxes to trigger an alert with a significance threshold of 3 standard deviations for a 10 day flare with in 50 % of the cases. At the location of Mrk421 this equals an integral flux for E > 1 TeV of about 8 Crab units, assuming a photon-neutrino flux ratio of 1 : 1 as predicted by the Blastwave model [Schuster et al.(2001)]. This corresponds to the strongest flares observed to date from Mrk421 (see [Tluczykont et al.(2010)]).

To ensure the IceCube detector is in stable conditions we monitor several trigger and filter rates. This information is immediately accessible in a database and is used to decide if an event from one of the monitored sources is considered a viable neutrino. Also the alert system itself is monitored. In addition to the source locations we run the same time-clustering algorithm on 2000 random points in the sky. This ensures a sufficient statistics of test alerts which we use to monitor several quantities of the system, like e.g. the alert multiplicity distribution, the significance distribution and the average delay between the alert generation at the South Pole and its arrival in the North. All this information is recorded on a webpage to be easily inspected. The online monitoring has been extensively checked against a more elaborate offline monitoring with very good results.

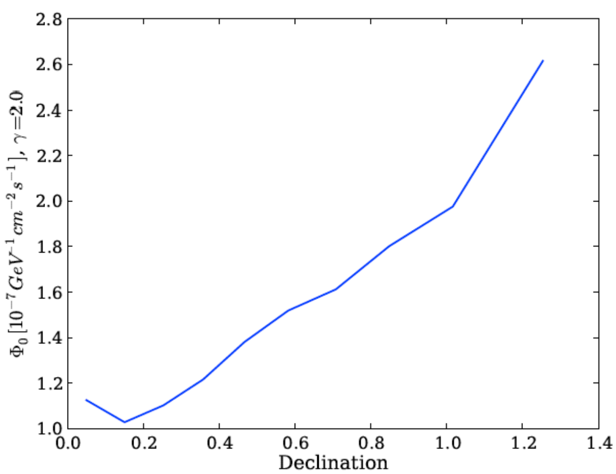

Figure 1: Necessary neutrino flux 0 for a flare with a duration of 10 days with $dN/dE = \phi 0 \cdot 10^{-7}$ $GeV^{-1} cm^{-2} s^{-1} (E/GeV)^{-2}$ to trigger an alert with an alert threshold of 3 with a probability of 50 % as a function of declination.

5. Search for point sources of high energy neutrinos

Results of searches for flares of neutrinos from variable astrophysical sources were described din the 2009 Annual Report. This year's work was focused on the corresponding publication and on the developed of advanced approach looking for multiple flares (as opposed to the most significant one) from individual objects. Results will be presented at the Summer conferences.
A slight directional correlation of IceCube neutrino events with cosmic ray events observed with the Auger Observatory in Argentina was also reported in the 2009 Annual Report. This correlation has weakened in 2010 with more statistics from both Auger and IceCube [26].
The various non-observations have led to record limits on the corresponding fluxes which are displayed in Figure 2.

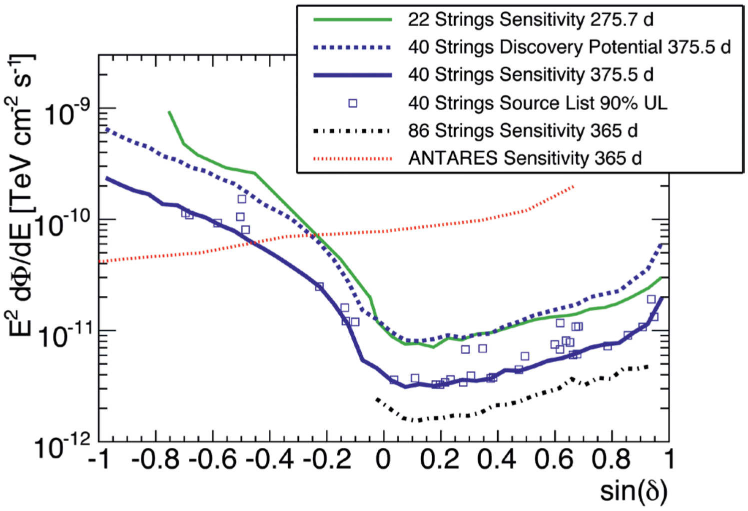

Figure 2: Upper limits on the flux from point sources.

6. Energy reconstruction in MAGIC

The group has benchmarked different methods developed within the MAGIC Collaboration to reconstruct the energy of the stereo recored events. It was demonstrated that a method based on look-up tables is optimal for energies below 300 GeV, whereas a second (Random Forest method) shows better performance for energies above 1 TeV – with comparable performance (15-20% resolution) in the mid energy range.

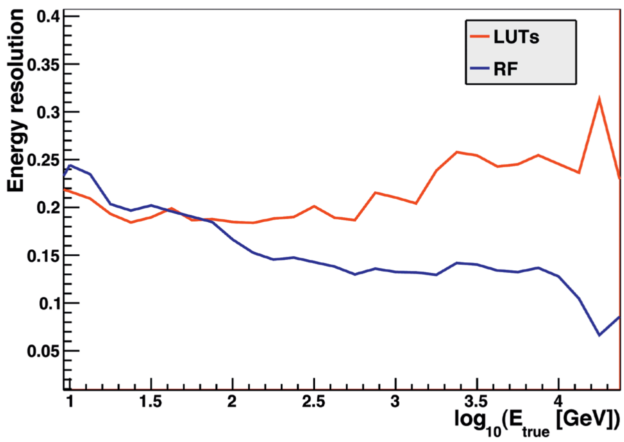

Figure 3: Energy resolution of the Look-up table method (LUT) and the Random Forest method (RF) as a function of the energy of gamma-ray events.

Teaching

Detectors for High Energy Physics at the Humboldt University of Berlin/Germany (E. Bernardini, Summer Semester 2010).

Refereed journal publications (Few authors)

1.LONG-TERM LIGHTCURVES FROM COMBINED UNIFIED VERY HIGH ENERGY GAMMA-RAY DATA, M. Tluczykont, E. Bernardini, K. Satalecka, R. Clavero, M. Shayduk, and O. Kalekin, A&A 524, A48 (2010).

Refereed journal publications (MAGIC)

2.MAGIC DISCOVERY OF VHE EMISSION FROM THE FSRQ PKS 1222+21, MAGIC Collaboration (J. Aleksić et al.), Astrophys. J. Letters 730 , L8 (2011).

3.PG 1553+113: FIVE YEARS OF OBSERVATIONS WITH MAGIC, MAGIC Collaboration (J. Aleksić et al.), submitted for publication to Astrophys. J.

4.MAGIC OBSERVATIONS AND MULTIWAVELENGTH PROPERTIES OF THE QUASAR 3C279 IN 2007 AND 2009, MAGIC Collaboration (J. Aleksić et al.), Astron. Astrophys. 530, A4 (2011).

5.OBSERVATIONS OF THE BLAZAR 3C 66A WITH THE MAGIC TELESCOPES IN STEREOSCOPIC MODE, MAGIC Collaboration (J. Aleksić et al.), Astrophys. J. Lett. 726, 58 (2010).

6.DETECTION OF VERY HIGH ENERGY Γ-RAY EMISSION FROM THE PERSEUS CLUSTER HEAD-TAIL GALAXY IC 310 BY THE MAGIC TELESCOPES, MAGIC Collaboration (J. Aleksić et al.), Astrophys. J. Lett. 723, L207-212 (2010).

7.MAGIC UPPER LIMITS FOR TWO MILAGRO-DETECTED, BRIGHT FERMI SOURCES IN THE REGION OF SNR G65.1+0.6, MAGIC Collaboration (J. Aleksić et al.), Astrophys. J. 725, 1629 (2010).

8.SPECTRAL ENERGY DISTRIBUTION OF MARKARIAN 501: QUIESCENT STATE VS. EXTREME OUTBURST, VERITAS and MAGIC Collaborations (V.A.Acciari et al.), Astrophys. J. 729, 2 (2010).

9.MAGIC CONSTRAINTS ON GAMMA-RAY EMISSION FROM CYGNUS X-3, MAGIC Collaboration (J. Aleksić et al.), Astrophys. J. 721, 843 (2010).

10.INSIGHTS INTO THE HIGH-ENERGY GAMMA-RAY EMISSION OF MARKARIAN 501 FROM EXTENSIVE MULTIFREQUENCY OBSERVATIONS IN THE FERMI ERA FERMI, MAGIC and VERITAS Collaborations, accepted for publication Astrophys. J. 2010 October.

11.SEARCH FOR AN EXTENDED VHE GAMMA-RAY EMISSION FROM MRK 421 AND MRK 501 WITH THE MAGIC TELESCOPE, MAGIC Collaboration (J. Aleksić et al.), accepted for publication to Astrophys. J.

12.GAMMA-RAY EXCESS FROM A STACKED SAMPLE OF HIGH-FREQUENCY PEAKED BLAZARS OBSERVED WITH THE MAGIC TELESCOPE, MAGIC Collaboration (J. Aleksić et al.), Astrophys. J. 729 (2010) 115.

13.SIMULTANEOUS MULTI-FREQUENCY OBSERVATION OF THE UNKNOWN REDSHIFT BLAZAR PG 1553+113 IN MARCH-APRIL 2008, MAGIC Collaboration (J. Aleksić et al.), Astron. Astrophys. 515, A76 (2010).

14.SEARCH FOR VERY HIGH-ENERGY GAMMA-RAY EMISSION FROM PULSAR-PWN SYSTEMS WITH THE MAGIC TELESCOPE, MAGIC Collaboration (H. Anderhub et al.), Astrophys. J., 710 (2010).

15.MAGIC TEV GAMMA-RAY OBSERVATIONS OF MARKARIAN 421 DURING MULTIWAVELENGTH CAMPAIGNS IN 2006, MAGIC Collaboration (J. Aleksić et al.), Astron. Astrophys. 519, A32 (2010).

16.MAGIC OBSERVATION OF THE GRB 080430 AFTERGLOW, MAGIC Collaboration (J. Aleksić et al.), Astron. Astrophys. 517, A5 (2010).

Refereed journal publications (IceCube)

17.SEARCH FOR A LORENTZ-VIOLATING SIDEREAL SIGNAL WITH ATMOSPHERIC NEUTRINOS IN ICECUBE, IceCube Collaboration (R. Abbasi et al.), Phys. Rev. D82, 112003 (2010).

18.SEARCH FOR RELATIVISTIC MAGNETIC MONOPOLES WITH THE AMANDA-II NEUTRINO TELESCOPE, IceCube Collaboration (R. Abbasi et al.), Eur. Phys. J. C69 (2010).

19.THE FIRST SEARCH FOR EXTREMELY-HIGH ENERGY COSMOGENIC NEUTRINOS WITH THE ICECUBE NEUTRINO OBSERVATORY, IceCube Collaboration (R. Abbasi et al.), Phys. Rev. D82, 072003(2010).

20.SEARCH FOR MUON NEUTRINOS FROM GAMMA-RAY BURSTS WITH THE ICECUBE NEUTRINO TELESCOPE, IceCube Collaboration (R. Abbasi et al.), Astrophys. J. 710 (2010) 346.

21.MEASUREMENT OF SOUND SPEED VS DEPTH IN SOUTH POLE ICE FOR NEUTRINO ASTRONOMY, IceCube Collaboration (R. Abbasi et al.), Astrop. Phys, in press, March 2010.

22.CALIBRATION AND CHARACTERIZATION OF THE ICECUBE PHOTOMULTIPLIER TUBE, IceCube Collaboration (R. Abbasi et al.), NIM, in press, accepted manuscript, March 2010.

23.MEASUREMENT OF THE ANISOTROPY OF COSMIC RAY ARRIVAL DIRECTIONS WITH ICECUBE, IceCube Collaboration (R. Abbasi et al.), Astrophys. J. Lett. 718, L194 (2010).

24.THE ENERGY SPECTRUM OF ATMOSPHERIC NEUTRINOS BETWEEN 2 AND 200 TEV WITH THE AMANDA-II DETECTOR, IceCube Collaboration (R. Abbasi et al.), Astrop. Phys. 34, 48 (2010).

25.LIMITS ON A MUON FLUX FROM KALUZA-KLEIN DARK MATTER ANNIHILATIONS IN THE SUN FROM THE ICECUBE 22-STRING DETECTOR, IceCube Collaboration (R. Abbasi et al.), Phys. Rev. D81 (2010) 057101.

Non-refereed journal publications (IceCube)

26.DIRECTIONAL CORRELATIONS BETWEEN UHECRS AND NEUTRINOS OBSERVED WITH ICECUBE, IceCube Collaboration (R. Lauer et al.), arXiv:1011.1093 (2010).