Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 917–920

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

A radio air shower surface detector as an extension for IceCube and IceTop

J. AUFFENBERG[1], T. GAISSER[2], K. HELBING[1], T. HUEGE[3], T. KARG[1], A. KARLE[4]
[1]*Bergische Universität Wuppertal, Fachbereich C – Astroteilchenphysik, 42097 Wuppertal, Germany*
[2]*Bartol Research Institute, University of Delaware, Newark, DE 19716, USA*
[3]*Institut für Kernphysik, Forschungszentrum Karlsruhe, Postfach 3640, 76021 Karlsruhe, Germany*
[4]*Department of Physics, University of Wisconsin, Madison, WI 53706, USA*
jauffenb@uni-wuppertal.de

Abstract: The IceCube neutrino detector is built into the Antarctic ice sheet at the South Pole to measure high energy neutrinos. For this, 4800 photomultiplier tubes (PMTs) are being deployed at depths between 1450 and 2450 meters into the ice to measure neutrino induced charged particles like muons. IceTop is a surface air shower detector consisting of 160 Cherenkov ice tanks located on top of IceCube. To extend IceTop, a radio air shower detector could be built to significantly increase the sensitivity at higher shower energies and for inclined showers. As air showers induced by cosmic rays are a major part of the muonic background in IceCube, IceTop is not only an air shower detector, but also a veto to reduce the background in IceCube. Air showers are detectable by radio signals with a radio surface detector. The major emission process is the coherent synchrotron radiation emitted by e^+ e^- shower particles in the Earths magnetic field (geosynchrotron effect). Simulations of the expected radio signals of air showers are shown. The sensitivity and the energy threshold of different antenna field configurations are estimated.

Introduction

When the IceCube[1] neutrino telescope will be finished in 2011 it will consist of up to 80 strings deployed in the Antarctic ice, each one containing 60 PMTs (Fig. 1). One of the main goals of IceCube is to measure high energy neutrinos from cosmic sources. It is designed to measure up-going neutrino induced muons, since only neutrinos are not absorbed in the Earth.

IceTop is built on the surface above IceCube (Fig. 1) to detect air showers in the energy range from 10^{15} eV to 10^{18} eV and to study the composition of cosmic rays.

The emission of coherent synchrotron radiation from e^+ e^- shower particles in the Earth magnetic field can be measured [1] and could be the basis for an extension of the IceTop and IceCube detection systems.

Possible Radio Air Shower Arrays

The LOPES collaboration has shown air shower detection by its radio emission and demonstrated the possibility to reconstruct the inclination angle and the shower core from the radio signal [2]. There are mainly two ways that a radio air shower surface detector for IceCube could improve IceTop and IceCube.

Expansion of the Surface Array

An expansion of the area of IceTop with surface radio antennas would be an enhancement of the air shower detector to higher primary energies and to more inclined showers. The idea is to build an antenna array in rings of increasing radius around the IceTop array. Muon bundles from air showers can be mis-reconstructed as an up-going signal in the IceCube detector. With an expansion in area of the IceTop detector it would be possible to de-

1. http://icecube.wisc.edu/

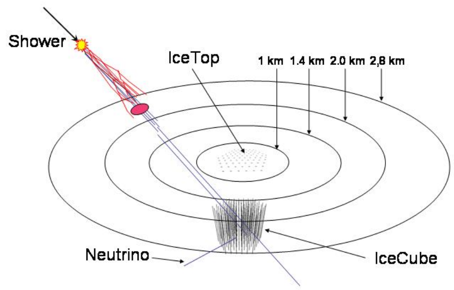

Figure 1: Schematic view of an antenna array together with IceTop (hexagon) and IceCube. The surface antennas would be installed on the rings. At higher distances only more inclined showers can hit IceCube for which simulations predict stronger radio signals. This allows larger antenna spacing for the outer rings.

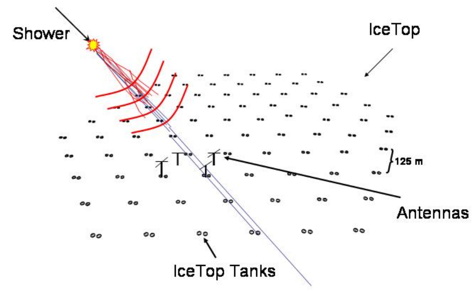

Figure 2: Possible antenna field configuration that could serve for first test measurements. An infill array would look similar. The black dots are the Ice Top tank positions. The antenna positions of an infill array are in-between the tanks. A test array should be on top and in-between the Ice Top tanks to determine the RFI from Ice Top.

tect and veto signals from very inclined air showers (cf. Fig. 1).

Infill Surface Array

An infill surface radio detector could be built on the same area as IceTop with similar distances, but shifted positions with respect to the Cherenkov tank array. This would provide an additional powerful observation technique for cosmic ray research of the same showers. In addition the radio detector field could be an upgrade to higher inclination angles. The infill array would allow one to detect high energy air showers with three independent detector systems: IceTop, IceCube, and the radio surface array (Fig. 2).

First Background Studies

First studies of the radio background at the South Pole have been carried out in November 2006 with a 3 m monopole antenna located close to the AMANDA counting house (MAPO). The signal was amplified using a 39 dB commercial preamplifier (MITEQ[2] AU-1464), transmitted over 100 m RG-58 cable, and recorded with a digital oscilloscope stationed in the MAPO building. The Discrete Fourier Transform of the time sweeps gives the spectral energy density of the radio background. It is corrected for the frequency independent gain of the pre-amplifier and for a mean antenna gain based on calculations with the antenna simulation program EZNEC[3]. The antenna amplification was averaged over the half solid angle, and the polarization of the background signal was assumed to be isotropic. Figure 3 shows the radio background for different regions measured with the same antenna-amplifier set-up. Figures 4 to 6 show the measured background together with simulated air shower signals. The high background below 20 MHz has to be investigated in more detail in larger distances to the South Pole Station. At higher frequencies the background drops to -110 dBm/MHz. The spectrum measured in Argentina seems to be lower than the South Pole spectrum at frequencies below 20 MHz but higher at larger frequencies. The reason might be RFI form the AMANDA counting house at the South Pole. Above 80 MHz the Argentina spectrum shows sharp monofrequent radio transmitters. The spectrum at Wuppertal is higher at all frequencies, as Wuppertal is a region with intense

2. http://www.miteq.com/
3. http://eznec.com/

noise from civilization. There are only few monofrequent transmitters in the region from 5 MHz to 120 MHz at the South Pole. So the background at the South Pole will allow for broad-band measurements of radio air shower signals.

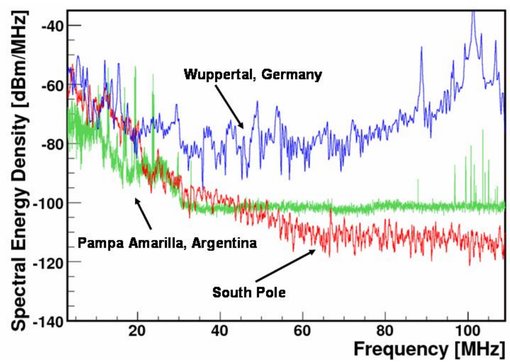

Figure 3: Background studies with the 3 m monopole antenna in Wuppertal (Germany), in the Pampa Amarilla (Argentina), and at the South Pole. The Wuppertal and South Pole spectra are Fourier transforms of time sweeps recorded with a digital oscilloscope. The Argentina spectrum is measured with a spectrum analyzer.

Radio Air Shower Simulation

The REAS2 Code [3], based on air showers simulated with CORSIKA [4], is used to evaluate the electric field vector of the geosynchrotron emission of air showers at the South Pole. We use proton induced air showers with primary energies ranging from 10^{16} eV to 10^{18} eV and South Pole atmosphere and magnetic field.

For the simulation of the radio emission, the local magnetic field $\vec{B}$ and the observation height (2800 m) are important. At the South Pole the field strength is $|\vec{B}| = 55.3\,\mu$T and the field inclination angle is $\Phi = -72.6°$ [5]. Since the power density is given by the norm of the Pointing vector $|\vec{S}| = \frac{1}{Z_0}\vec{E}^2$ with $Z_0 = \sqrt{\mu_0/\epsilon_0}$ the spectral electric field density calculated in the simulation can be easily converted to spectral power density.

Results of the REAS2 simulation are shown in Figures 4 to 6. Figure 4 shows, that a 10^{17} eV proton induced air shower with an inclination angle $\theta = 20°$ from 290°W should be detectable by antennas with distances up to about 300 m from the shower core position on the ground if we require a signal to background ratio of unity. Figure 5 shows that for more inclined showers the detection range increases. The radio signal is nearly independent of the azimuthal direction of the air shower. For higher shower energies the detection sensitivity increases strongly (Fig. 6).

One result of comparisons of air shower simulation and background measurements is, that the distances between the antennas can be larger for more inclined showers. Thus in the option of expanding IceTop, the distance between antennas can increase with distance from IceCube. The range increases with the inclination angle $\theta = \arctan(r/d)$ of the showers which could reach the edge of IceCube (d is the depth of IceCube (2500 m), and r the distance to the edge of IceCube projected on the South Pole surface). If we require again a signal to background ratio of unity for air shower detection one can make the following predictions. In 1000 m distance from the edge of IceCube the inclination angle of a shower which could reach IceCube is $\arctan(1/2.5) = 21.8°$. To detect the radio signal of a 10^{17} eV shower with this inclination angle, the antennas have to be about 300 m distant. Right above the core of IceCube, the distance of the antennas has to be 200 m to detect vertical showers.

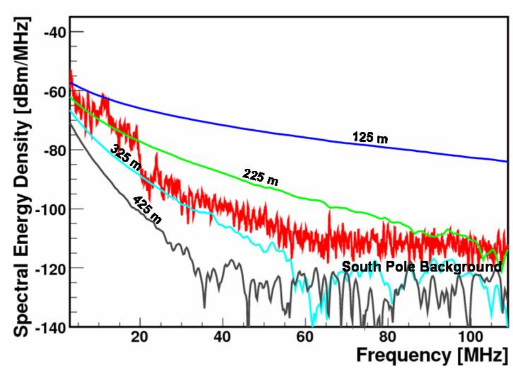

Figure 4: Radio emission from a proton induced 10^{17} eV air shower with inclination angle $\theta = 20°$ for antennas at different distances to the shower core position on the ground. For comparison radio background measurements from the South Pole are shown (red curve).

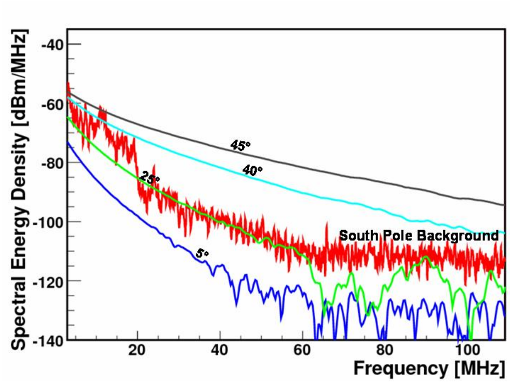

Figure 5: Radio emission from a proton induced 10^{17} eV air shower with 325 m distance to the shower core position on the ground for different inclination angles from $\theta = 5°$ to 45°. For comparison radio background measurements from the South Pole are shown (red curve). The highest line is the same as in Figure 6.

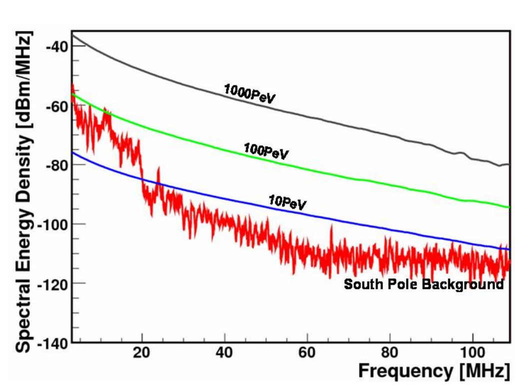

Figure 6: Radio emission from a proton induced shower with an inclination angle $\theta = 45°$ at 325 m distance to the shower core position on the ground for different shower energies from 10^{16} eV to 10^{18} eV shown together with background measurements from the South Pole. Even lower energetic showers will be detectable at higher inclination angles.

Conclusions and Outlook

A comparison of background measurements and simulation results shows, that the lower energy threshold of a radio air shower surface detector at the South Pole will be around 10^{17} eV dependent on the antenna spacing. An infill detector of IceTop with radio antennas would allow one to cross-calibrate both detection systems. The expansion in area is a promising possibility for vetoing muon bundles from inclined air showers in IceCube.

To improve predictions concerning the radio signal emitted by air showers, more detailed simulations will be made up to higher primary energies and inclination angles. Further, the polarization of the radio emission will be studied. These results have to be confirmed by events measured with a test antenna array at the South Pole.

To investigate the properties of the background in more detail a multi antenna array is planned. Figure 2 shows a possible array configuration to measure at four positions with all field orientations.

The simulation underlines the effectivity of an antenna field for increasing inclination angles (Fig. 5). For higher energies the shower will be detectable at larger distances to the antennas (Fig. 6).

The results of radio air shower simulations and background measurements at the South Pole show that both, the expansion in area and the radio infill array are excellent detection systems to improve the existing detection systems IceCube and IceTop.

Acknowledgements

This work is supported by the German Ministry for Education and Research and the U.S. National Science Foundation.

References

[1] T. Huege, H. Falcke, Astron. Astrophys. **412** (2003) 19.

[2] H. Falcke et al., Nature **435** (2005) 313.

[3] T. Huege, R. Ulrich, R. Engel, Astropart. Phys. **27** (2007) 392.

[4] D. Heck et al., Report **FZKA 6019** (1998), http://www-ik.fzk.de/corsika/physics_description/corsika_phys.html.

[5] National Geophysical Data Center (NGDC), http://www.ngdc.noaa.gov/seg/geomag/jsp/IGRF.jsp.