The IceTop experiment in 2010

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Abstract

We present the current status of the IceTop air shower array on top of the IceCube neutrino detector that IceTop can use as a huge detector of TeV muons. We laos give a brief discussion of different types of air shower events that contain information on the spectrum and composition of the cosmic rays in a wide energy range.

1 Introduction

IceTop is the air shower array on top of the IceCube neutrino telescope at South Pole. It was proposed to support IceCube in terms of relative and absolute pointing, to guard against high energy air showers being misreconstructed as high energy neutrinos and to perform cosmic ray physics research. This includes:

• measurement of the cosmic ray spectrum using the surface detectors of IceTop

• measurements of the cosmic ray spectrum and composition by studies of the angular distribution of the muon bundles InIce

• measurements of the spectrum and composition of cosmic rays in coincident IceTop/IceCube events

The IceCube tedector is deployed at a depth of 1,500 meters in ice. The surface energy of a verticle muon that reaches the top of IceCube should be 460 GeV. The surface threshold energy for a muon to reach the top of InIce with energy 100 GeV, and to generate a signal in it, is 626 GeV. IceCube can not measure the number of muons that reach it. However, it measures the energy released by these muons in their propagaqtion in 1 km of deep clear ice, which carries valuable information about the shower energy stored in high energy muons.

The surface detectors of IceTop are plastic Cherenkov tanks of radius 1 m with diffusive reflective inside liner. The depth of ice in the tanks is 90 cm. They are covered with a black layer and tank cover.

Eack tank is equipped with two digital optical modules (DOMs) that look down in the tank and are identical to those deployed in the deep ice. One of the photomultipliers of the tank is run in high gain and the other in low gain to increase the dynamic range of the tank. Note that the shower gamma rays often convert in the tanks which measure the energy flow of air shower electromagnetic component plus the contribution of GeV muons.

An IceTop station consists of two tanks at a distance about 10 meters from each other and the corresponding IceCube string. Coincidental hits in both tanks (hard local coincidences) are considered air shower events and participate in the triggering of IceTop which requires 6 triggered DOMs. Single tank hits are considered single particles: muons electrons or gamma-rays. Such events are called soft local coincidences and are also collected by the data acquisition system.

The DOMs contain 10" Hamamatsu R7081 PMT with onboard HV module and onboard digitization performed by 2 300 MHz ATWD, each with three channels with different gains. The calibration of the DOMs is done by the measurement of muon signals which goes continuously throuout the year and affects the difference of the signals in the high gain and low gain DOMs as well as the sensitivity of different tanks and stations.

2 The IceTop air shower array

The proposed IceTop array was supposed to consist of 80 stations in a triangular arrangement at an average distance of 125 m from each other [1]. The total area within the perimeter of the array will be 1 km^2. The currently deployed 73 stations are shown in Fig. 1. The rest of the stations will be deployed in the 2010/11 South Pole season. The five stations at negative x and y will be deployed as shown on the graph. The two missing stations at positive x and y, which are shown on top of previous South Pole experiments, will most likely be deployed in the center of the array, close to the Deep Core strings.

There are four types of triggers that the DAQ collects [2] and a fraction of which are transmitted North for analysis: These are:

- SMT triggers: 3 and more station events
- LMT Triggers: 8 and more station events
- SMT triggers with InIce activity
- InIce triggers with IceTop activity

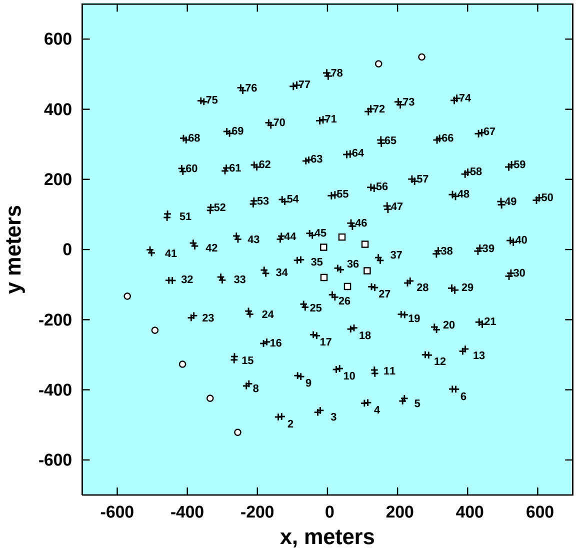

Figure 1: Map of the IceTop stations deployed by the end of the 2009/10 season. Each tank is separately shown together with the station number. Seven stations are not yet deployed and are shown with circles. The Deep Core strongs are marked with empty squares.

When fully deployed IceTop will be able to measure the cosmic ray spectrum and composition between 10^{14} and 10^{18} eV. At the higher energy end its results will coincide with the lower energy extensions of the Southern Auger Observatory and the Telescope Array. One of the advantages of IceTop is that the South Pole is at high altitude and the average atmoepheric depth is less than 700 g/cm^2.

3 Physics, problems, and results

IceTop has completed [3, 4] a determination of the cosmic ray energy spectrum from the data of IceTop26, a stage of the experimenty with only 26 stations deployed and the area of the air shower array was 0.094 km^2. Using this data set the position of the cosmic knee was determined at 3.1$\pm$0.3 Pev

(1 PeV = 10^{15} eV). At this energy the cosmic ray energy spectrum slope changes from $E^{-2.71}$ to $E^{-3.11}$.

The current analysis concentrates on the following phases of the air shower array with 40, 59 and the current 73 stations deployed. As with any new and to large degree unusual experiment, there are some problems that take time to solve. One of them is the ever increasing size of the detector which requires separate Monte Carlo detector calculations depending on the array size and shape. Another one the increasing with time snow coverage of the tanks that changes the waveform shapes and magnetide of the signals.

IceTop is analyzing at least three main types of events. The first one are nearly vertical showers (zenith angle less than 35^o) that could be analyzed separately in IceTop and InIce. The small zenit angle is required so that the events are well contained on the surface and in deep ice. The energy on the surface is determined from the data of IceTop, while the energy loss of the muon bundle is measured InIce. Using both data sets improves the zenith angle and air shower core determination [5]. It also helps to eliminate events in which an air shower coincides in time with a high energy single muon. For air showers with 5 or more hard local coincidences the energy threshold for protons is 300 TeV and for iron showers is about 500 TeV.

It is important to note that on average 53 muons of energy above 100 GeV would reach the top of IceCube from an vertical iron shower of energy 10 PeV. From a proton shower of the same energy 22 detectable muons reach the top of IceCube. Another important parameter is the energy loss in propagation inside IceCube. One TeV muon loses 643 GeV in propagation on 1 km of ice. Since the average energy of muons in Fe initiated showers is lower that those in proton showers the Fe shower muon bundle will have a stronger decrease of the energy loss with depth. All this physics of the muon bundles energy loss is being implemented in the analysis of such events.

The second type of showers is illustrated with an experimental event in Fig. 2. It shows a muon bundle of zenith angle 72.5^o detected by IceCube. This muon bundle has triggered 536 InIce DOMs and deposited in them almost 50,000 photoelectrons. The shower axis must be more than 5 km away from IceTop but it still triggers a responce at the edge of the detector. The energy estimate for this shower is $3{\times}10^{18}$ eV.

Most of the high energy events that trigger IceTop are not well contained within the array. When the muon bundles of these showers are well contained InIce, as it is in the event shown in Fig. 2, they can still be analyzed. The extension of the muon bundle track to the surface track to the surface determines the position of the shower axis on the surface within 50 meters.

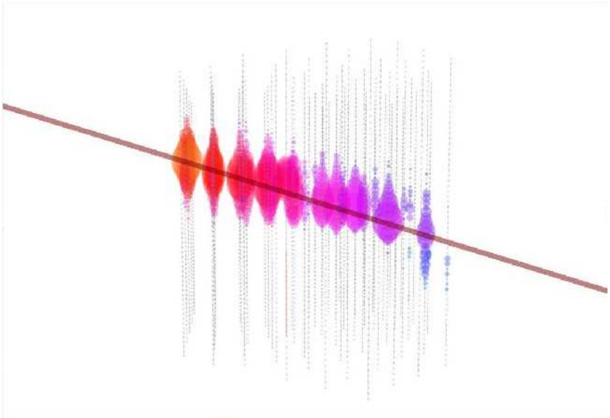

Figure 2: The muon bundle from an inclined shower with zenith angle of 72.5^o detected by IceCube. This event was found by P. Berghaus.

Together with the information from the surface stations triggered in such an event the analysis is certainly possible. The electromagnetic and GeV muons signal on the surface should give a good estimate of the shower primary energy and the energy released by the TeV muons InIce contains the information about the type of the primary cosmic ray nucleus. The average surface energy of a muon to be detected by IceCube at a zenith angle of 72.5^o is 5.1 TeV and the muon bunch shown in Fig. 2 contains many such muonss.

The third type of extensive air showers that are currently being analyzed are the smallest air showers that trigger only three or four stations in IceTop [6]. Such events could be very interesting because they are in the energy range where the cosmic rays spectrum and composition are studied directly with balloon and satellite detectors. The comparison of the IceTop data to the more detailed experiments results will help us understand better the composition related air shower parameters.

Three station events must contain only internal stations that are next to each other. In such case the three triggering stations are in the shape of amost uquilateral triangle. Four station events have a diamond shape. The reconstruction of these low energy showers is simpler and not as good as that of the showers that trigger more stations. One cannot, for example, account for the curvature of the shower front and has to treat is as a plain wave.

The advantage is that they correspond to a relatively small and narrow energy range. Monte Carlo calculations of proton showers with $\cos\theta$ higher than 0.9 show that the width of the energy distribution that creates such showers in IceTop is only 0.2 in $\log_{10} E$, from $10^{5.3}$ to $10^{5.5}$ GeV. Iron showers show higher average energy and somewhat wider energy distribution - from $10^{5.5}$ to $10^{5.8}$ GeV [6]. With increasing zenith angle the energy of the cosmic rays that create such showers also increases and one can study the cosmic rays between 200 and 1,000 TeV by looking at the three and four station triggers.

As a summery, IceTop is almost fully deployed and in less than a year it will have an area of 1 km^2. The experiment is working very well and the events collected during the deployment of the array are being analyzed. The existence of a huge muon detector as IceCube is makes it an air shower array that can be very successful in studies of the cosmic ray composition between 10^{14} and 10^{18} eV.

DISCUSSION

WOLFGANG KUNDT You surprize me with the long cooling time of your tanks at -25^{o}C, of order months. The rain water collectors of my house near Bonn take days to freeze if the temperatures fall below 0^{o}C. What is the osmotic contents of your water?
TODOR STANEV The water quality in IceTop is very good. It is filtered and well tested. There are two main reasons for the slow freezing of the tanks:// 1) When ice forms on the bottom and the walls of the tanks the freezing slows down because ice is very good insulator.
2) There is a pump at the bottom of the tank that circulates the water in a system that deletes the air bubbles from the water. This pump creates heat that also slows down the freezing.

References

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