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Nuclear Instruments and Methods in Physics Research A 588 (2008) 130–134
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

IceTop — Cosmic ray physics with IceCube

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Available online 12 January 2008

Abstract

The IceCube experiment at South Pole consists of two detector components — the IceTop air shower array on the surface and the neutrino telescope at depths from 1450 to 2450 m below. Currently, 26 IceTop stations and 22 InIce strings are deployed. With the present size of the IceTop array, it is possible to measure cosmic rays with energies ranging from 0.5 to 100 PeV. Coincident events between the IceTop and the InIce detector provide useful cross-checks of the detector performance and furthermore make it possible to study the cosmic-ray composition. This paper gives an overview on the current status of IceTop.

PACS: 95.55.Vj; 95.85.Ry; 96.50.S−; 96.50.sd

Keywords: IceTop; Cosmic rays; Extensive air shower; Composition

1. Introduction

The IceCube neutrino telescope [1] being built at South Pole, consists of two major detector components. The actual neutrino telescope (InIce) is buried at depths between 1450 and 2450 m in the antarctic ice and will consist of 4800 individual photon detectors (**D**igital **O**ptical **M**odules), lined up on 80 strings in an hexagonal pattern. The IceTop air shower array is located on the ice surface above the InIce detector. It consists of 80 stations, close to the position of the InIce strings, with a spacing of 125 m. Presently 26 stations are operational and are arranged as shown in Fig. 1.

The IceTop air shower array is a multi-purpose detector with several scientific aspects and technical goals. It helps to understand the background of single muons in the InIce detector and acts as a veto against muon bundles from cosmic ray induced extensive air showers (EAS). Furthermore, it is used independently to detect high energy cosmic rays with energies ranging from approximately 500 TeV up to about 1 EeV (in its final stage). Coincident air shower events, measured by the IceTop and the InIce detector, make it possible to study the cosmic-ray composition since the number of muons, which are able to reach the InIce detector, is also sensitive to the mass of the primary cosmic-ray particle. In addition, coincident events provide very useful cross-checks for the precision of the direction- and energy-reconstruction in IceTop and InIce. The following sections summarize the current status of IceTop and give some examples for the performance of the detector.

2. The IceTop array

Each of the 80 IceTop stations consists of two Ice-Cherenkov tanks with an inner diameter of 1.86 m and an ice thickness of 0.9 m as shown in Fig. 2. The tanks are buried under a thin layer of snow at a distance of about 10 m apart. The inner surface of the tanks is covered with a diffusive coating to homogeneously reflect the induced Cherenkov light. Two DOMs, identical to those used in the InIce detector, are frozen half submerged in the ice surface and measure the Cherenkov emissions in the tank. One DOM is operated at high gain (HG) and the other at low gain (LG) in order to extend the dynamic range of the tank.

After deployment of a tank the freezing process of the ice is controlled by a freeze control unit (FCU) which circulates and degases the water in the tank while the

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doi:10.1016/j.nima.2008.01.015

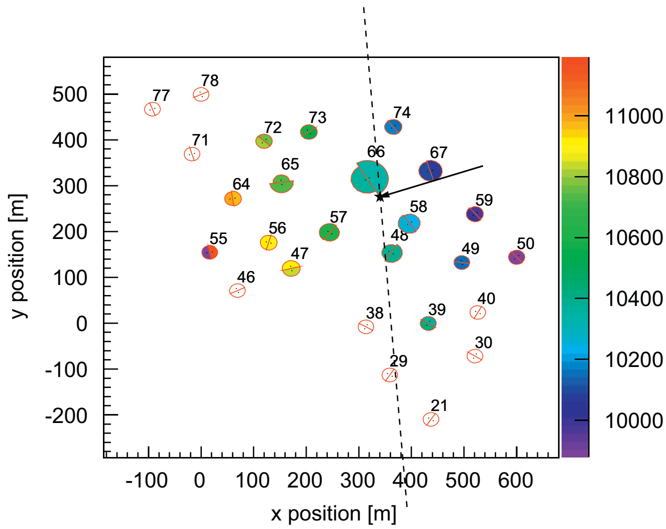

Fig. 1. Event display with the present layout of the 26 station IceTop array. Each station consists of two tanks, represented by a half circle. The radius of the half circles scales with the signal in the tanks and the different colors correspond to the signal times. The reconstructed core and direction are illustrated by the star and the arrow. The dashed line traces the shower plane through the core on the surface of the array.

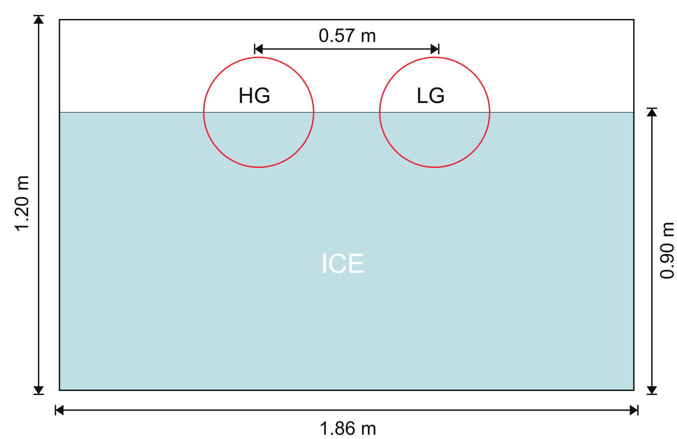

Fig. 2. Sketch of an IceTop tank containing a high gain (HG) and a low gain (LG) DOM. The inner surface of the tanks is covered by a reflective coating.

temperature is slowly decreased. This way the water freezes from the top to the bottom of the tank and the number of bubbles is significantly reduced [2]. The freezing process of a tank usually takes six to eight weeks. After the freezing is completed the FCUs are recovered and refurbished to use them in the next deployment season.

The two tanks that make up a station are linked together by local coincidence conditions between their DOMs in order to reduce the number of accidental coincidences. A local coincidence basically occurs if two DOMs in different tanks of a station measure a signal within 250 ns. If at least six IceTop DOMs report a local coincidence within 2 μs a Simple Multiplicity Trigger (SMT) is generated, causing the data acquisition to read out the air shower event. The SMT trigger rate depends on the size of the array and is currently of the order of 14 Hz. In addition the IceTop array is always read out when the InIce detector has been triggered or vice versa.

The IceTop tanks are calibrated conventionally using atmospheric muons to determine the mean signal of a Vertical Equivalent Muon (VEM) in the tanks. This unit can be easily compared to air shower simulations. Muon telescope measurements and simulations show that the actual muon peak is at about 95% of the peak position of the full recorded spectrum of all hits [3].

3. Reconstruction accuracy and stability

Due to the special layout of the IceTop array with two tanks (*A* and *B*) per station, it is possible to subdivide the array into two identical sub-arrays (*A* and *B*) with just one tank per station. This way an air shower event can be independently reconstructed by the two sub-arrays. The comparison of the results gives an estimate for the stability of the reconstruction and the uncertainties of the various shower observables. An example for the Δx-distribution of the core reconstruction for the 16 station array in 2006 is given in Fig. 3 where only contained events which fulfill the SMT trigger condition were taken into account. The distribution in Fig. 3 is fitted by a Gaussian function. Since the spread $\sigma_{\Delta x}$ of this distribution emerges from the fluctuations of $\Delta x = x_A - x_B$ the uncertainties $\sigma_{A,B}$ of the individually reconstructed x-coordinates x_A or x_B can be obtained from

$$\sigma_{\Delta x} = \sqrt{\sigma_A^2 + \sigma_B^2} = \sqrt{2} \cdot \sigma_{A,B}. \quad (1)$$

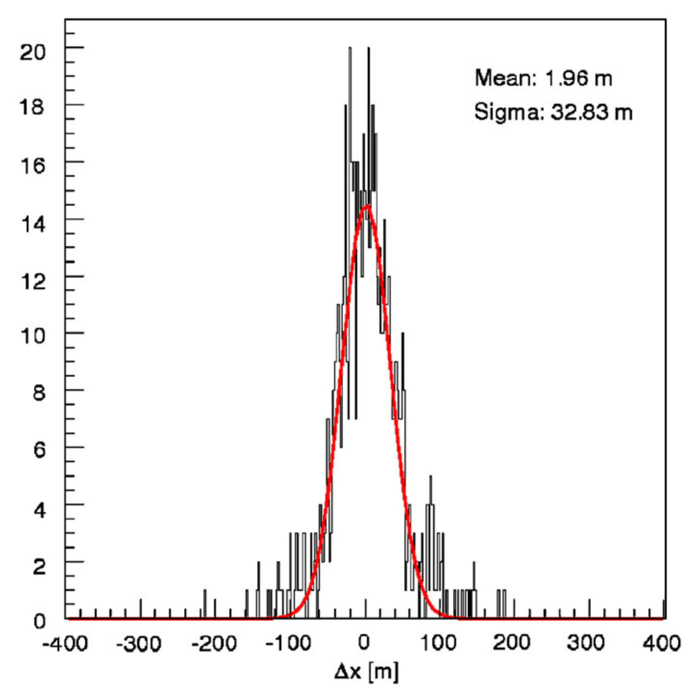

Fig. 3. Δx-distribution of the individually reconstructed x-coordinates of the shower cores in the two sub-arrays. See text for details.