The First Year IceCube-DeepCore Results

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The First Year IceCube-DeepCore Results

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Abstract. The IceCube Neutrino Observatory includes a tightly spaced inner array in the deepest ice, called DeepCore, which gives access to low-energy neutrinos with a sizable surrounding cosmic ray muon veto. Designed to be sensitive to neutrinos at energies as low as 10 GeV, DeepCore will be used to study diverse physics topics with neutrino signatures, such as dark matter annihilations and atmospheric neutrino oscillations. The first year of DeepCore physics data-taking has been completed, and the first observation of atmospheric neutrino-induced cascades with IceCube and DeepCore are presented.

1. Introduction
The DeepCore extension to IceCube, shown in Fig. 1, triggers on atmospheric neutrinos at energies between about 10 GeV and 1 TeV \cite{1,3}. The understanding of the production and oscillations of the neutrinos at these energies is intrinsically interesting \cite{2}, not least because these neutrinos constitute an important background to astrophysical signal searches, such as neutrinos from WIMP annihilations \cite{4} and neutrinos from soft-spectrum point sources \cite{5}.

To observe neutrinos in this energy range, DeepCore relies on compact sensor spacing, high quantum efficiency photomultiplier tubes (PMTs), deployment in the clearest ice, and a lower trigger threshold than the surrounding IceCube detector \cite{1}. We report the DeepCore performance with 79 strings of IceCube operating (IC-79), and highlight results from the first observation of atmospheric neutrino-induced cascades in IceCube.

2. IC-79 Data
The IC-79 data collected between May 31, 2010 and May 13, 2011 have been processed and analyzed. The raw data include a series of waveforms read out from digital optical modules (DOMs) in two modes \cite{6}. In hard local coincidence (HLC) mode, in which both the primary DOM and the nearest or next nearest neighbor DOM report a hit within a $\pm 1000$ ns time window, full waveform digitization is acquired. If a DOM is in soft local coincidence (SLC) mode without neighboring hits, a reduced waveform data is acquired consisting of the three digitization bins from the first 16 samples: the highest bin and its two neighboring bins. Therefore, hits in this paper mean DOM readouts in HLC plus SLC modes unless specified. Software is used to remove spatially and temporally isolated SLC hits due to noise. The additional SLC hit information improves event reconstruction, background rejection, and particle identification especially for low multiplicity events.

A low threshold trigger (SMT3), demanding 3 or more HLC hits within a time window of 2500 ns, is applied to DOMs in the fiducial region (the shaded area below the dust band in Fig.
1). Additionally, upgraded PMTs in the DeepCore strings with a $\sim 35\%$ increase in quantum efficiency compared to standard IceCube PMTs, help trigger on neutrinos with energies as low as 10 GeV \[7\].

3. Observation of Atmospheric Neutrino-induced Cascades

Atmospheric neutrinos are the decay products of charged mesons ($\pi^\pm$, $K^\pm$) produced in cosmic ray collisions with nucleons in the atmosphere. Cascades are produced by charged-current (CC) electron and tau neutrino interactions, and neutral-current (NC) neutrino interactions of any flavor, and create spherically-symmetric light distributions in ice. Although many atmospheric neutrino-induced muons, long tracks created by CC interactions, have been collected by IceCube \[8\], cascades have not been conclusively observed in other IceCube analyses \[3, 10, 11\] due to lack of a sufficient veto against the cosmic ray muons, and their low rate \[9\].

3.1. Background

The dominant backgrounds for the atmospheric cascades consist of cosmic ray muons that mimic signal events and $\nu_{\mu}^{CC}$ events with dim tracks. In conventional atmospheric $\nu_{\mu}^{CC}$ detection, muon direction information is used to reject background while a cascade analysis identifies the light pattern of the showers and enforces containment of the signal. Therefore, veto techniques with strict signal containment in DeepCore were developed to remove more than six orders of magnitude of background events while retaining reasonable signal efficiency for atmospheric neutrino-induced cascades in the fiducial volume.

3.2. Event Selection

IC-79 collected data for 348 days. Over 90% of the data are high quality and are used for physics analyses. A DeepCore on-line filter is run on the SMT3 triggered event sample at the South Pole. The pass rate is 17.5 Hz. The filtered data are sent north for subsequent processing. The filter algorithm \[1\] starts by calculating the center of gravity (COG) of all HLC hits in the fiducial volume to get an interaction vertex and time estimate. Then, the filter disregards any events consistent with a cosmic ray muon entering the detector volume by examining the speed between an individual HLC hit in the veto volume and the COG. A factor of 10 reduction in data compared to the triggered events are reached by this algorithm while keeping 99% atmospheric neutrinos that interact in the fiducial volume. After applying noise cleaning algorithms that remove hits which are not correlated in space and
3.3. Results
A set of tight cuts is made on the previously selected BDT7 sample which contains a large fraction of atmospheric neutrinos. The cuts aim for high purity cascade detection by rejecting as many
Table 1. The number of events are shown with final selections. $N^{\text{obs}}$ means observed events in 281 days of real data. $C^{\text{sig}}$ and $C^{\text{bg}}$ refer predictions of the cascade signal and its background respectively. The MC numbers use 281 days normalization and their statistical errors are $\sim 3\%$.

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4. Conclusion

We report on the first observation of atmospheric neutrino-induced cascade events with IceCube and DeepCore. The preliminary summary of the results is shown in Table 1. Systematic errors originating from ice modeling, detection efficiency of DOMs, neutrino-nucleon cross-sections, and atmospheric neutrino flux model are under evaluation. In the near future, data analyses using a similar technique as that presented here, focusing on neutrino oscillations, WIMP searches, and neutrino surveys for the southern sky, are expected.

References