RESULTS FROM ICECUBE

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IceCube is a cosmic ray and neutrino detector located at the geographic South Pole with an instrumented volume of approximately 1 km^3. As of 2010, 79 out of 86 cables ("IC79") supporting photomultiplier tubes have been deployed in the ice, and 73 out of 81 surface array stations have been installed. While the main scientific goal of astrophysical neutrino detectors is the search for the origin of cosmic rays, the potential for additional physics investigations remains very strong. Being by far the largest of its type, IceCube is well positioned to deliver a wide range of significant and original measurements.

1 Neutrino Astronomy

One of the most important unresolved questions in astrophysics is the origin of high-energy cosmic rays [1]. Direct detection of neutrino emission from extrasolar sources would provide an unambiguous answer to this problem. The arrival direction of charged particles is scrambled by magnetic fields and photons can be produced by purely electromagnetic processes. Neutrinos on the other hand will not be deflected and are expected to be predominantly generated by decay of hadrons produced by interactions of nuclei in the vicinity of cosmic accelerators.

The main experimental challenge in the observation of astrophysical neutrinos lies in the small cross section of neutrino-nucleon interactions. Current detectors aiming at the TeV energy range therefore make use of naturally occurring reservoirs of transparent media, such as deep bodies of water or, in the case of IceCube, the Antarctic ice sheet.

Cosmic-ray induced air showers cause a high rate of background events that are in principle indistinguishable from neutrino-induced muons. For this reason, most IceCube analyses focus on upgoing muon tracks from earth-crossing neutrinos. Another important detection channel is formed by cascade-like events, which will appear to be originating from a single point due to the granularity of the instrument. Cascade events may be caused by ν_e, ν_τ or neutral-current interactions, all of which can be detected by IceCube. Their signature is full containment within the detector volume and lack of visible incoming particles.

2 The IceCube Detector

An overview of the current configuration of the IceCube detector is shown in Figure 1. Throughout the entire instrument, Digital Optical Modules (DOMs), each containg one photomultiplier tube (PMT)[2] are used to register photons caused by Cherenkov emission along the tracks of high-energy particles. For the part deployed inside the ice, the DOMs are suspended on cables

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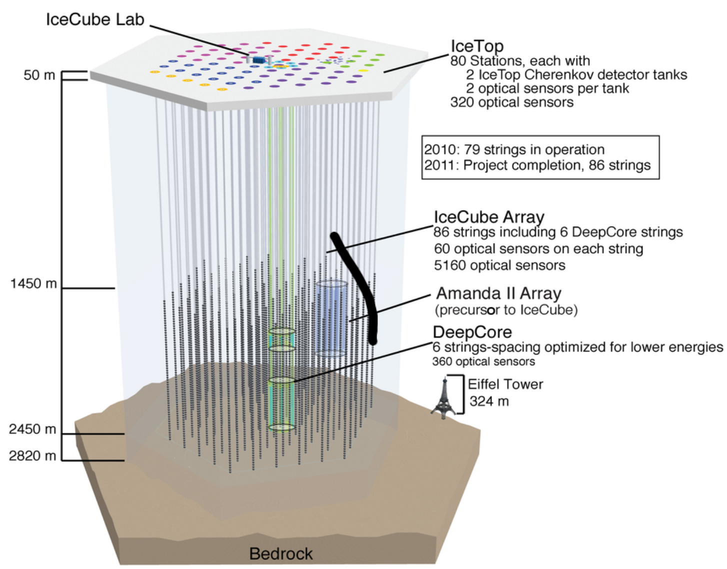

Figure 1: Schematic view of the IceCube detector, showing the three distinct components: IceTop surface air shower array, DeepCore low-energy detector and InIce strings. Also shown is the AMANDA-II precursor array, which stopped operating in 2008.

which supply power and allow data readout. All observed signals are digitized within the modules themselves and transmitted as digital information to the main laboratory located on the surface of the ice.

Besides the main volume detector, there are two additional components. The surface detector array IceTop consists of frozen water tanks located on top of each string. By measuring the low-energy particle content in air showers, it extends the physics reach of IceCube to direct investigations of the primary particle composition in the PeV-EeV range. In addition, it provides the ability to reduce background from large air showers in analyses searching for neutrino events from the upper hemisphere.

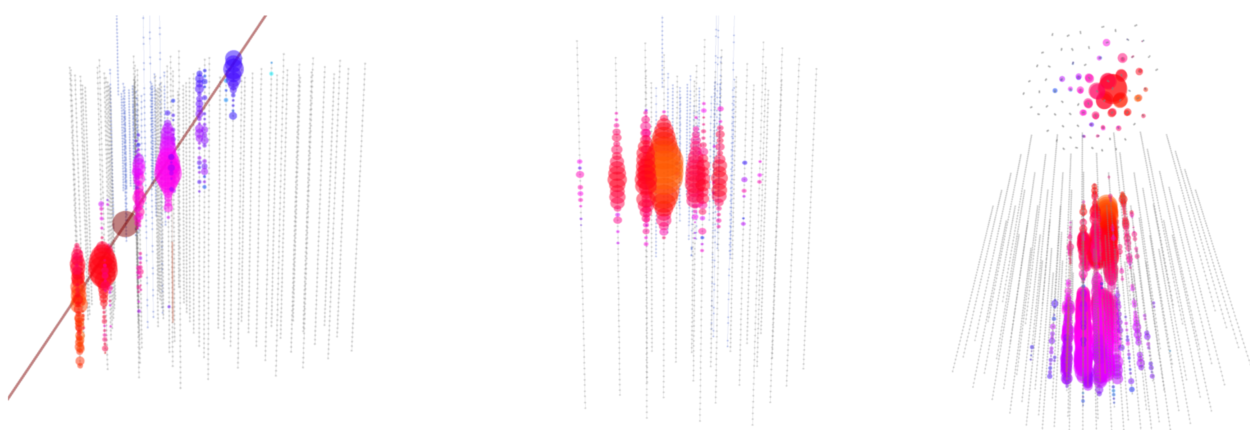

Figure 2: Three types of physics events in IceCube. Left: Upgoing neutrino-induced muon track with an energy of approximately 100 TeV (IC40). Center: Cascade candidate with reconstructed energy of 133 TeV (IC22) [3]. Right: Large air shower registered in all three IceCube components (IC79). The primary energy lies in the range of 20-40 PeV. The bundle of high-energy muons penetrating to the depth of the volume detector has a total energy of the order of 100 TeV. The size of the spheres indicates the total number of photo-electrons registered in the DOMs, and the color corresponds to the time (orange: earliest, blue: latest).

In order to improve sensitivity to neutrino interactions at energies in the GeV range, six additional strings have been deployed to form the DeepCore array. These have smaller spacing between the individual modules and contain PMTs with improved quantum efficiency. The nested location allows limited vetoing of downgoing muon tracks by the main detector.

The trigger rate with 79 strings is about 2000 s^{-1}, to which cosmic-ray induced muons penetrating the ice make by far the most important contribution. For comparison, the trigger rate of the air shower array lies around 30 s^{-1}, and the rate of neutrino events from atmospheric sources at trigger level is of the order of 100/hour. Three examples of physics events seen in data taken during recent years are shown in Figure 2.

3 Physics Results

One of the main focuses in IceCube so far has been the search for TeV neutrino point sources in the northern celestial hemisphere using up-going muon tracks [4]. The same methodology has also been applied to down-going muon tracks [5]. In that case, the strong background from cosmic-ray induced muon bundles requires an increase of the energy threshold to values in the PeV range, and flux sensitivity is both substantially lower and strongly zenith-angle dependent. The final sample of the latest point-source search is shown in Figure 3. In order to further improve the detection potential, possibilities to incorporate results from gamma-ray and other electromagnetic telescopes have been studied extensively [6].

Other publications include a search for cosmogenic neutrinos [7], neutrinos in coincidence with gamma-ray bursts [8] and an indirect search for Dark Matter through neutralino pair annihilation processes in the Sun [9]. While no analysis so far has yielded an unambiguous signal detection, even at this early stage IceCube has been able to set very competitive flux limits. An overview of IceCube results for various neutrino searches is shown in Figure 4.

A first indication of the detector's significant potential for original cosmic-ray physics can be seen from the measurement of the incoming primary anisotropy [10]. Although similar results have earlier been achieved by large air-shower arrays, this represents the first time that such a search has been conducted in the Southern Hemisphere and with a volume detector.

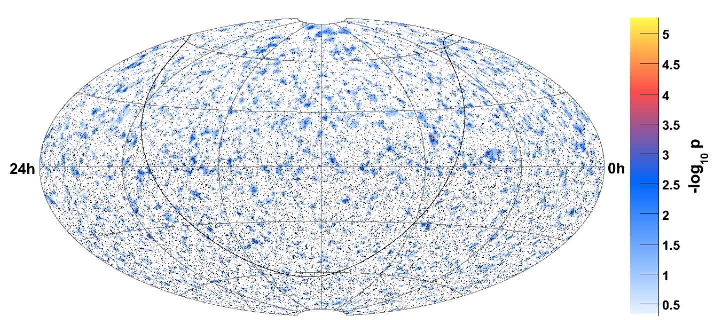

Figure 3: Final event sample in the all-sky neutrino point source search from IceCube in its 40-string configuration (IC40). The data sample is dominated by TeV atmospheric neutrinos below, and cosmic-ray induced muon bundles from PeV primaries above the horizon. No significant excess has been observed.

4 Conclusion and Outlook

Construction and operation of the IceCube detector has proceeded smoothly and according to schedule. The full configuration is expected to be completed during the Austral summer 2010/11. In the meantime, analysis of existing data has already yielded significant physics results.

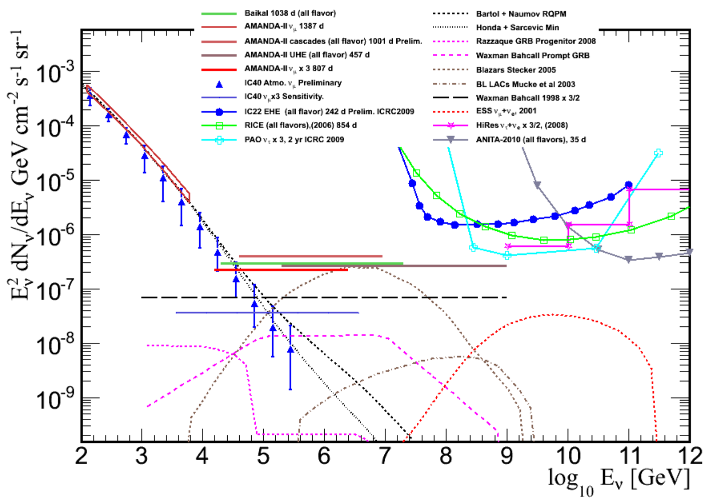

Figure 4: Overview of diffuse neutrino flux limits from various experiments compared to model predictions. The energy range of IceCube extends down to 100 GeV and lower, where astrophysical signals are obscured by the atmospheric neutrino flux. Note that all IceCube results as shown in this graph are at the time of writing still prelimary. References for the curves can be found in [11].

With increasing sophistication of methodologies and understanding of the detector, the IceCube collaboration should in the coming years be able to make significant contributions to a wide range of particle and astrophysics.

References

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