Search for Extraterrestrial Neutrino-Induced Cascades Using IceCube 79-strings

The IceCube Collaboration

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1 Motivation

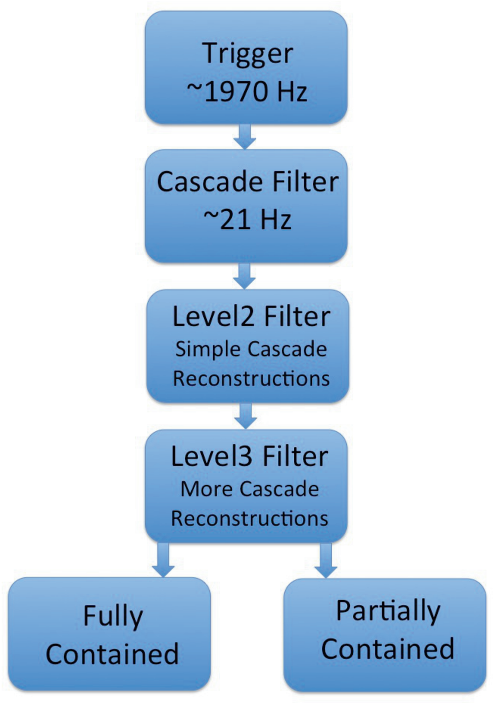
Extraterrestrial neutrinos, anticipated to be produced together with cosmic rays, might provide information about the mechanism of cosmic ray production and help to unveil cosmic ray sources. Although neutrino fluxes from such sources could be too low to be measured individually, an integrated flux over all sources might be possible to detect with IceCube [1], a cubic kilometer scale neutrino telescope located at the South Pole. Incoming neutrinos interact mostly via deep-inelastic nucleon scattering and produce showers of secondary charged particles that produce Cherenkov light that is detected by Digital Optical Modules (DOMs).

2 Analysis Overview

- **Data** used were collected from May 2010 to May 2011 with 79 operational strings of IceCube. This analysis was performed as a blind analysis, the selection criteria to reject the background were developed using 10% of the data ("burnsample"). This burnsample consists of data uniformly distributed over the year to avoid biases in muon background rate due to seasonal variations. The burnsample livetime was 33 days.
- **Background** comes from cosmic ray muons with a faint track and a single catastrophic energy loss from a bremsstrahlung and from atmospheric neutrinos.
- **Signals** are ν_e and ν_τ from charged current and all neutrino flavors from neutral current interactions. These reactions produce an electromagnetic and hadronic showers (cascades) which yield a spherical light pattern in the detector.
- **Cascade Reconstruction**
  - arrival time of the light and amplitude seen by the DOMs are used to reconstruct the interaction vertex, the deposited energy and the direction of the incident neutrino
  - cascades have better energy resolution compared to track-like events.

4 Event Selection

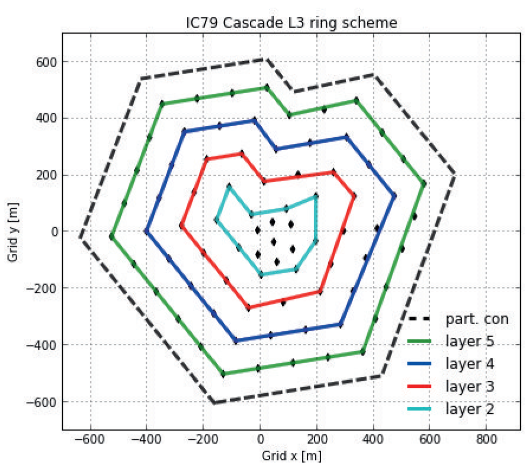
To reduce the background several filters were applied to the data. At Level3 filter, the data was split into two branches: fully contained and partially contained events and each branch was analyzed separately.



The fully contained events were defined as those with:

- both the reconstructed vertex and the light seen first inside the most outer string layer of the detector, the green polygon (layer 5)
- the first light in the event was seen between ±430 meters in depth and the reconstructed vertex position Z was between ±450 meters in the detector.
- the earliest hit in the event occurred in any but the seven topmost DOMs
- FillRatio higher than 0.6

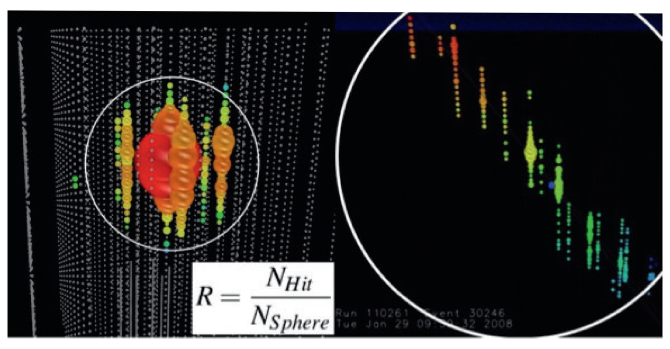
The partially contained branch consisted of the events with the reconstructed vertex position Z below the IceCube detector between -600 and -500 meters, or near the outside boundry of the IceCube detector - between green and dashed black polygons. Next, further quality criteria e.g. on the development of the hit pattern in time (TimeSplitPosition), were applied.



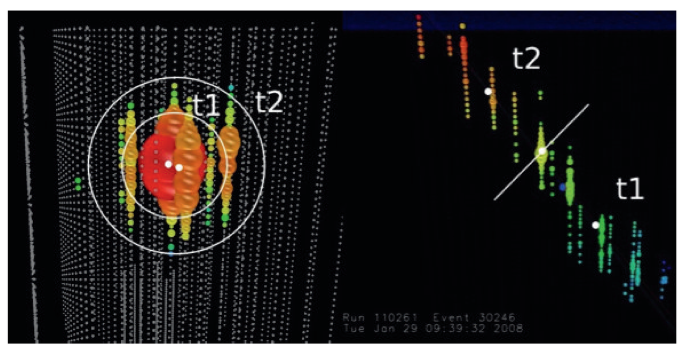
3 Selected Cascade Variables

To isolate the cascade signal from muon background, different selection criteria like the specific topology of cascade-like events and the development of the light pattern in time were used:

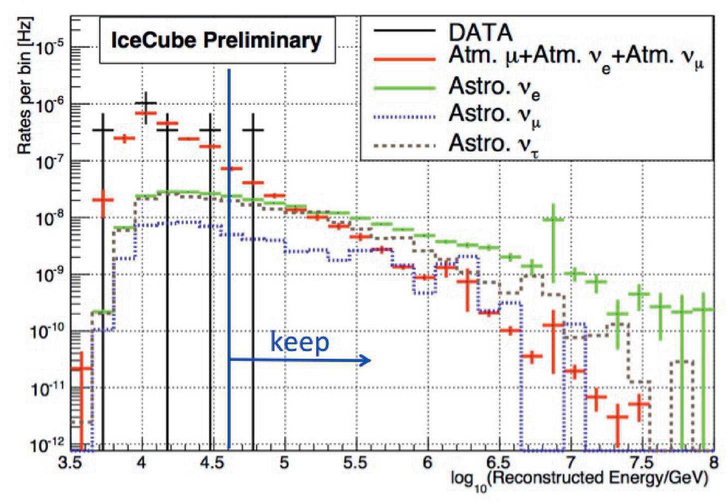
- **FillRatio** (R) - the ratio of number of DOMs that saw a photon (hit DOMs) to the total of all DOMs in the sphere with the mean radius being the mean distance between the vertex position and all hit DOMs. For a neutrino signal cascade-like events this number is close to one while for the track-like events this number would be uniformly distributed.



- **TimeSplitPosition** - each event was split into two halves (t_1,t_2) based on the charge-weighted mean time, and the cascade reconstruction was run on each half separately. TimeSplitPosition is the difference between reconstructed vertex positions for both halves. For the events consistent with a signal cascade hit pattern this number has a smaller value than for track-like events.

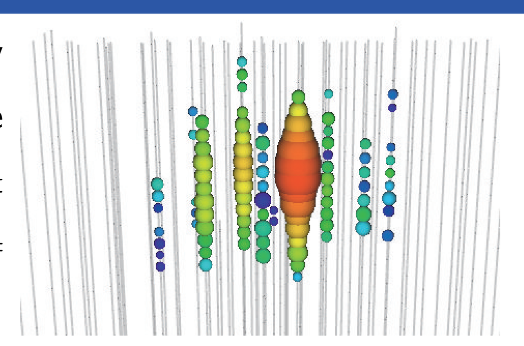


5 Final Energy Cut



Finally, using the Feldman-Cousins method [2], a cut on reconstructed energy was optimized and used to suppress remaining muon and atmospheric neutrinos background. The Model Refection Factor (MRF) [3] was calculated as a function of reconstructed energy and its minimum was found at an energy of E=40 TeV and the energy cut was placed at this value. The energy resolution for an E^{-2} astrophysical spectrum for fully contained events is $\Delta(\log_{10}E_\nu) \sim 0.04$ and the vertex position resolution is $\sim$ 4 meters, while for the partially contained analysis is poorer: energy resolution of $\Delta(\log_{10}E_\nu) \sim 0.3$, and the vertex resolution of $\sim$ 10 meters.

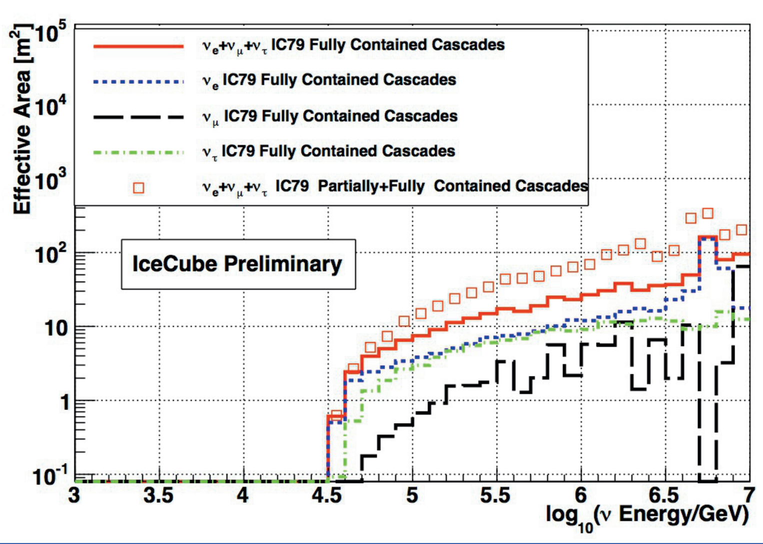
6 Results



Within the burn sample one event of 70 TeV reconstructed energy was retained. In 317 days (90% of the experimental data) we expect 4.1 ± 0.2 (stat) ν_e, 0.83 ± 0.06 (stat) ν_μ and 2.76 ± 0.06 (stat) ν_τ signal events for an astrophysical flux of $\Phi_{model} = 1.0 \times 10^{-8}(\mathrm{E/GeV})^{-2}\mathrm{GeV}^{-1}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{cm}^{-2}$. The selection criteria rejected all of the simulated cosmic-ray muons and the conservative estimate of 1.6 events in 317 days was taken as an upper boundry at 90% C.L. interval. The systematic uncertainties have not been taken into account and are currently being evaluated.

The sensitivity for the diffuse all flavor flux of extraterrestrial neutrino signal, defined as the average flux upper limit at 90% C.L. in the absence of signal resulted in 2.3 × 10^{-8} GeV s^{-1} sr^{-1} cm^{-2} for the all-flavor neutrino energies between 42 TeV and 6 PeV. No systematic uncertainties were taken into account. Including partially contained events increases the sensitivity to 1.8 × 10^{-8} GeV s^{-1} sr^{-1} cm^{-2} for all-flavor neutrino events with energies between 44 TeV and 7.7 PeV.

The sensitivity exceeds that of previous IceCube cascade analyses with smaller sized detector configurations with 22-, 40- and 59-strings [4, 5, 6, 7].



References

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