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 geographic 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).

The cascade analysis searches for ν_e and ν_τ from charged current and all neutrino flavors from neutral current interactions that produce electromagnetic and hadronic cascade which yields a spherical hit-pattern. The analysis was developed using Monte Carlo simulation and searched for an E^{-2} astrophysical neutrino-induced cascade flux within IceCube with 79 strings instrumented. We present all flavor sensitivity using high-energy contained cascade events in the IceCube detector. We also discuss adding partially contained events, to increase the effective volume. The neutrino energy range is between 44 TeV and 7.7 PeV.

2 Data Sample

The data used were collected from May 2010 to May 2011 with 79 operational strings of IceCube. The burnsample livetime was 33 days. The numbers presented here are based on the remaining 90% of the data, 317 days.

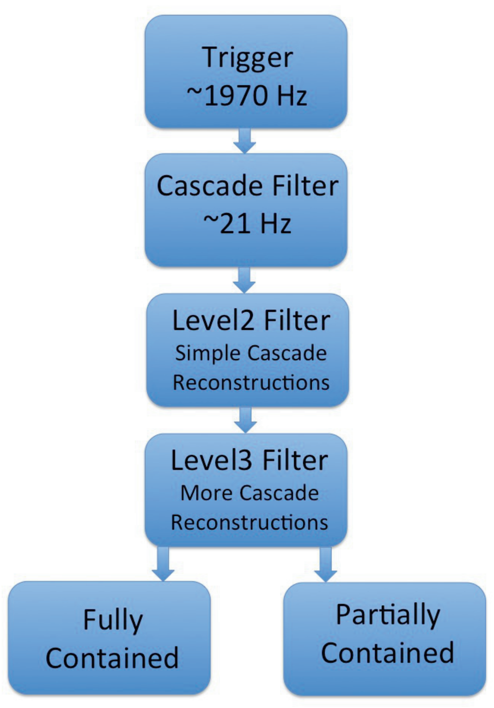
Background comes from cosmic ray muons with a faint track and a single catastrophic energy loss from a bremsstrahlung and from atmospheric neutrinos.

The signals are ν_e and ν_τ from CC and all neutrino flavors cascades from NC interactions. IceCube does not distinguish ν from $\bar{\nu}$ and in ν denotes here the sum of ν and $\bar{\nu}$. The flux normalization of signal events:

$$\Phi_{model} = 1.0 \times 10^{-8} (\mathrm{E/GeV})^{-2} \mathrm{GeV}^{-1}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{cm}^{-2}. \qquad (1)$$

4 Analysis

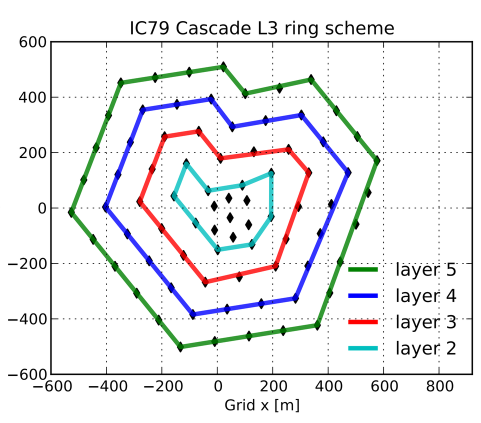
To reduce the background coming from atmospheric muons and muon bundles several filters were applied to the data. At Level3 filter, the data was split into two branches: fully contained and partially contained events and each branch was analyzed separately. Only the fully contained events selection criteria are described here but the partially contained events were used to enhance the sensitivity of this analysis for neutrino events with energies $E >$100 TeV.



The fully contained events were defined as those with:

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

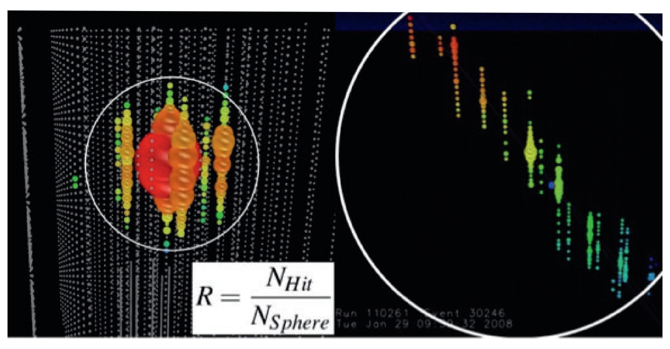
Next, the events having hits on 4 or more strings and with the reconstructed energy was higher that 10 TeV were selected. Then, further quality criteria e.g. on the development of the hit pattern in time (TimeSplitPosition), were applied to reduce muon and atmospheric neutrino backgrounds.



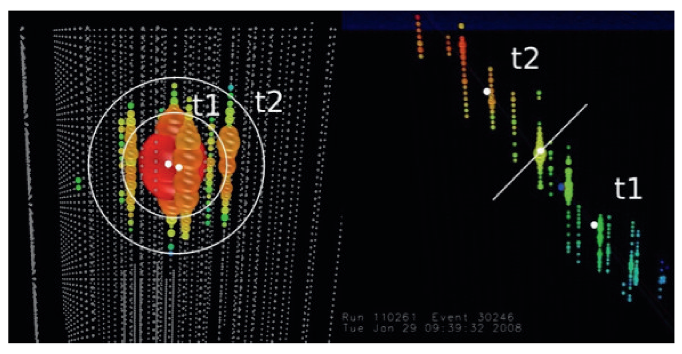
3 Selected Cascade Variables

To isolate the cascade signal from muon background, different selection criteria like the specific topology of cascade-like events, the development of the hit pattern in time, as well as causal and likelihood methods were used.

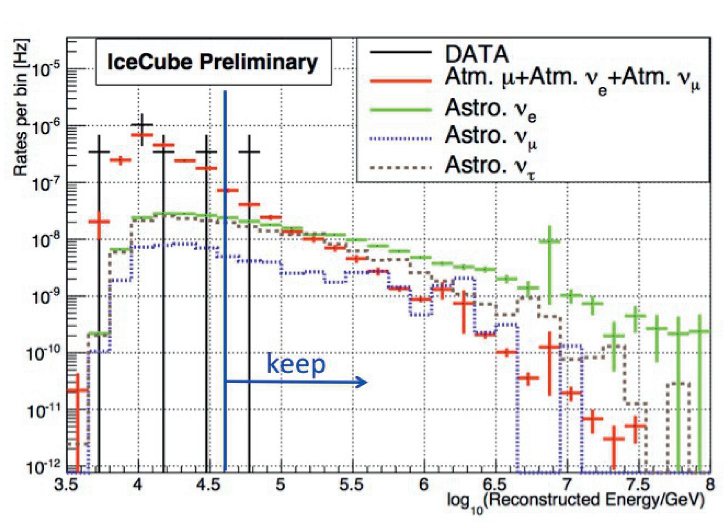
- **FillRatio** (R) - the ratio of number of DOMs that saw a light (hit DOMs) to the total of all DOMs in the sphere of the mean radius being the mean distance between the vertex position and all hit DOMs. For a neutrino signal cascade-like events this number is close to one while for the track-like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



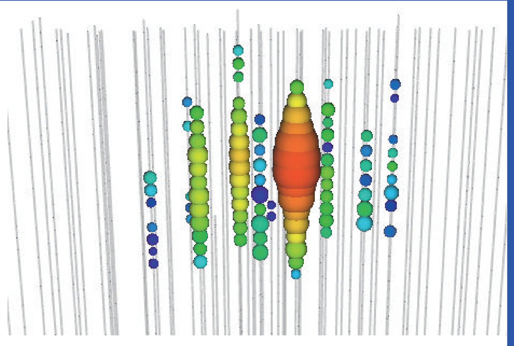
5 Final Energy Cut



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 energyand its minimum was found at an energy of E=40 TeV and the energy cut was placed at this value.

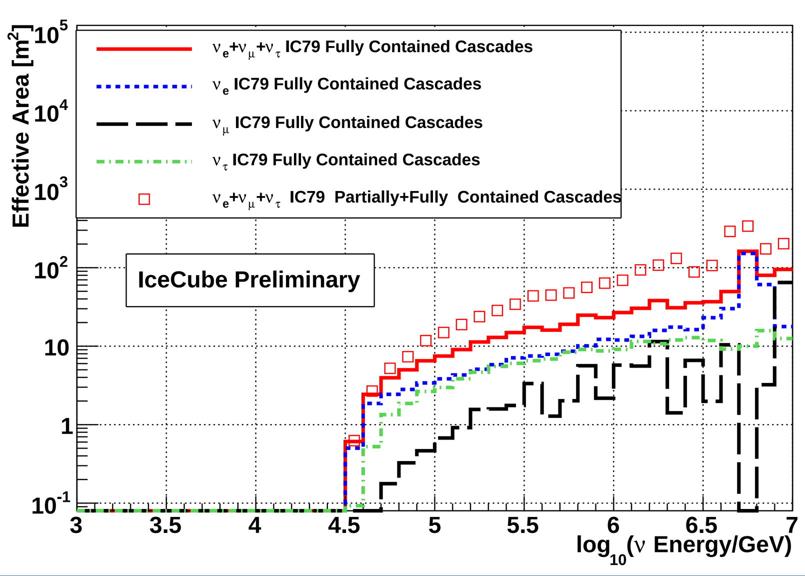
6 Results

One burn sample data event of 70 TeV reconstructed energy was retained. In 317 days (90% of the experimental data) we expect 4.1 $\pm$ 0.2 (stat) ν_e, 0.83 $\pm$ 0.06 (stat) ν_μ and 2.76 $\pm$ 0.06 (stat) ν_τ signal events for an astrophysical flux defined in Eq. (1). The selection criteria rejected all of the CORSIKA events and the conservative estimate on the number of cosmic-ray muons at the final level was taken as an upper boundry at 90% C.L. interval of 1.6 events. 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 $\times$ 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 $\times$ 10^{-8} GeV s^{-1} sr^{-1} cm^{-2} for all-flavor neutrino events with energies between 44 TeV and 7.7 PeV.

The obtained result is more stringent than the expected upper limits from previous IceCube cascade analyses with smaller sized detector configurations with 22-, 40- and 59-strings [4, 5, 6, 7] .



References

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[7] IceCube Collaboration, paper 0662 these proceedings.

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