

ICECUBE

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

The IceCube Collaboration<sup>1</sup>

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The analysis described here was developed using Monte Carlo simulation and searched for an  $E^{-2}$  astrophysical neutrino-induced cascade flux within IceCube with 79 strings instrumented. In these proceedings, 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 in this analysis is between 44 TeV and 7.7 PeV.

## 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 presented here searches for  $\nu_e$  and  $\nu_\tau$  from charged current and all neutrino flavors from neutral current interactions. These reactions produce electromagnetic and hadronic cascade which yields a spherical hit-pattern.

## 2 Data Sample

The data used in this analysis 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** for a search for cascade-like events comes from cosmic ray muons with a faint track and a single catastrophic energy loss from a bremsstrahlung and from atmospheric neutrinos.

**The signals** in this analysis are  $\nu_e$  and  $\nu_\tau$  from CC and all neutrino flavors cascades from NC interactions. IceCube does not distinguish  $\nu$  from  $\bar{\nu}$  and in this paper  $\nu$  denotes the sum of  $\nu$  and  $\bar{\nu}$ . The flux normalization of signal events used in this analysis:

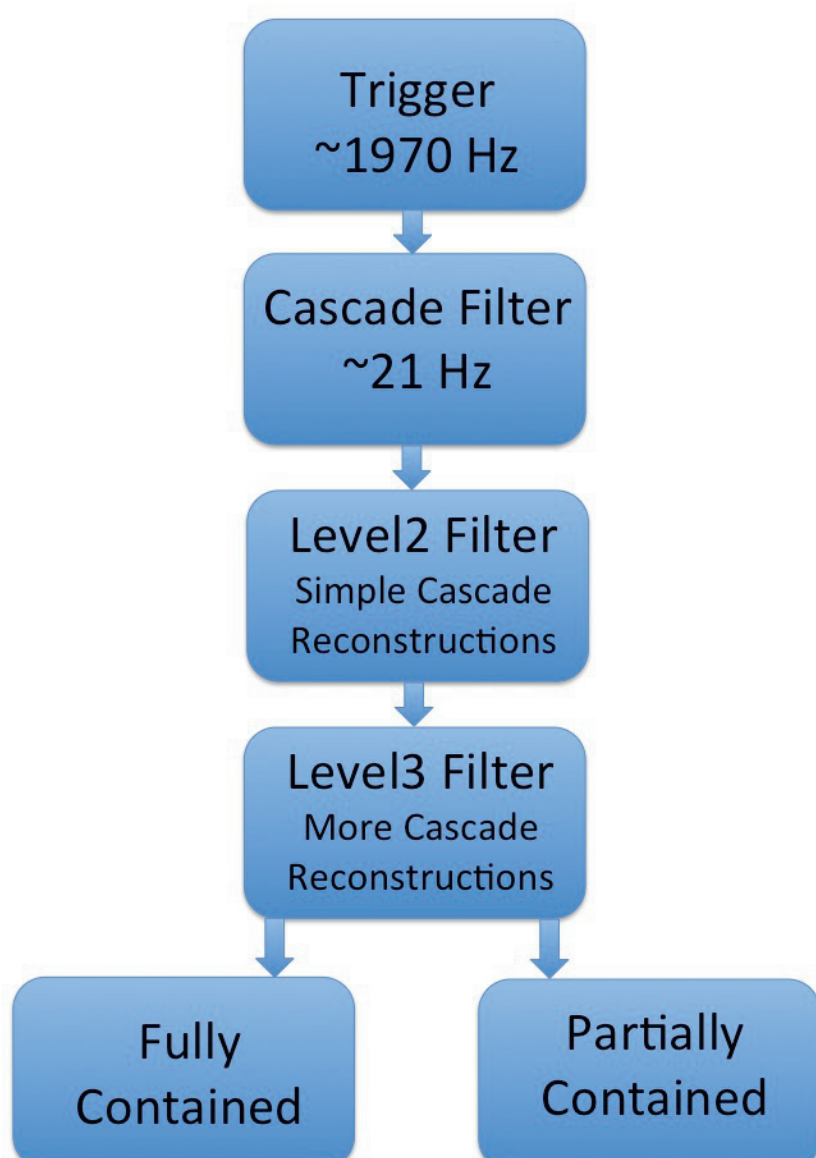
$$\Phi_{model} = 1.0 \times 10^{-8} (E/\text{GeV})^{-2} \text{GeV}^{-1} \text{s}^{-1} \text{sr}^{-1} \text{cm}^{-2}. \quad (1)$$

## 4 Analysis

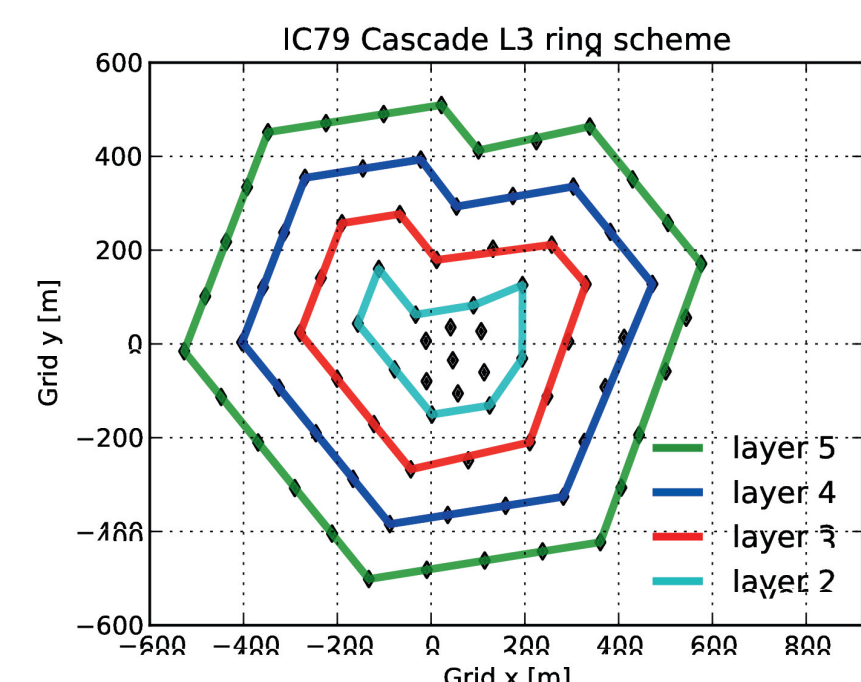
To reduce the background coming from atmospheric muons and muon bundles several filters were applied to the data (see charts below). At Level3 filter, the data was split into two branches: fully contained and partially contained events and each branch was analyzed separately. Only the fully contained 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 in Fig. below
- 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 seen by 4 or more strings and with the reconstructed energy was higher than 10 TeV were selected. In the next step, simple quality criteria on the event topology, the development of the hit pattern in time e.g. TimeSplitPosition were applied.



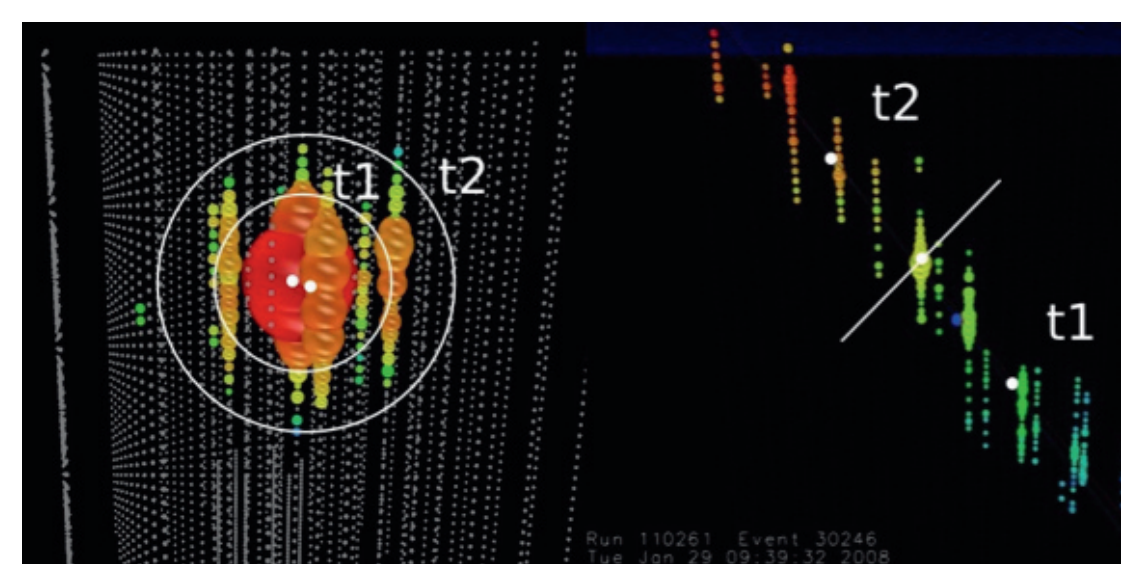
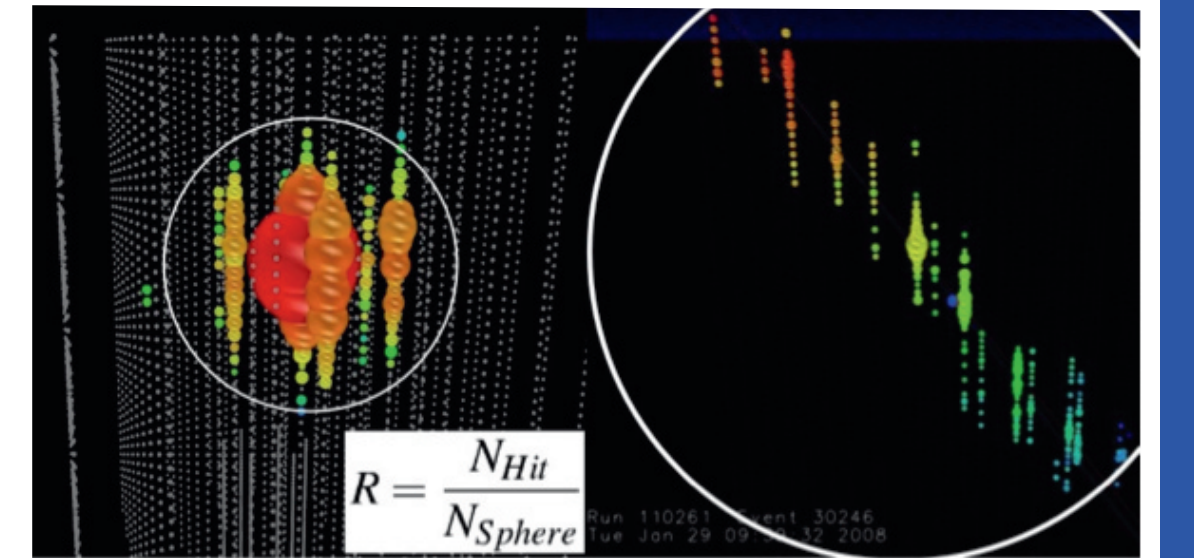
## References

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- [2] G.J. Feldman, R.D. Cousins, *Phys. Rev.* **D57** (1998) 3878 doi: 10.1103/PhysRevD.57.3873.
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- [4] R. Abbasi *et al.*, *Phys. Rev.* **D84** (2011) 072001 doi:10.1103/PhysRevD.84.072001.
- [5] E. Middell *et al.*, Proceedings of the 32nd ICRC, 2011 Included in arXiv:astro-ph/1111.2736.
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- [7] IceCube Collaboration, paper 0662 these proceedings.

## 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.

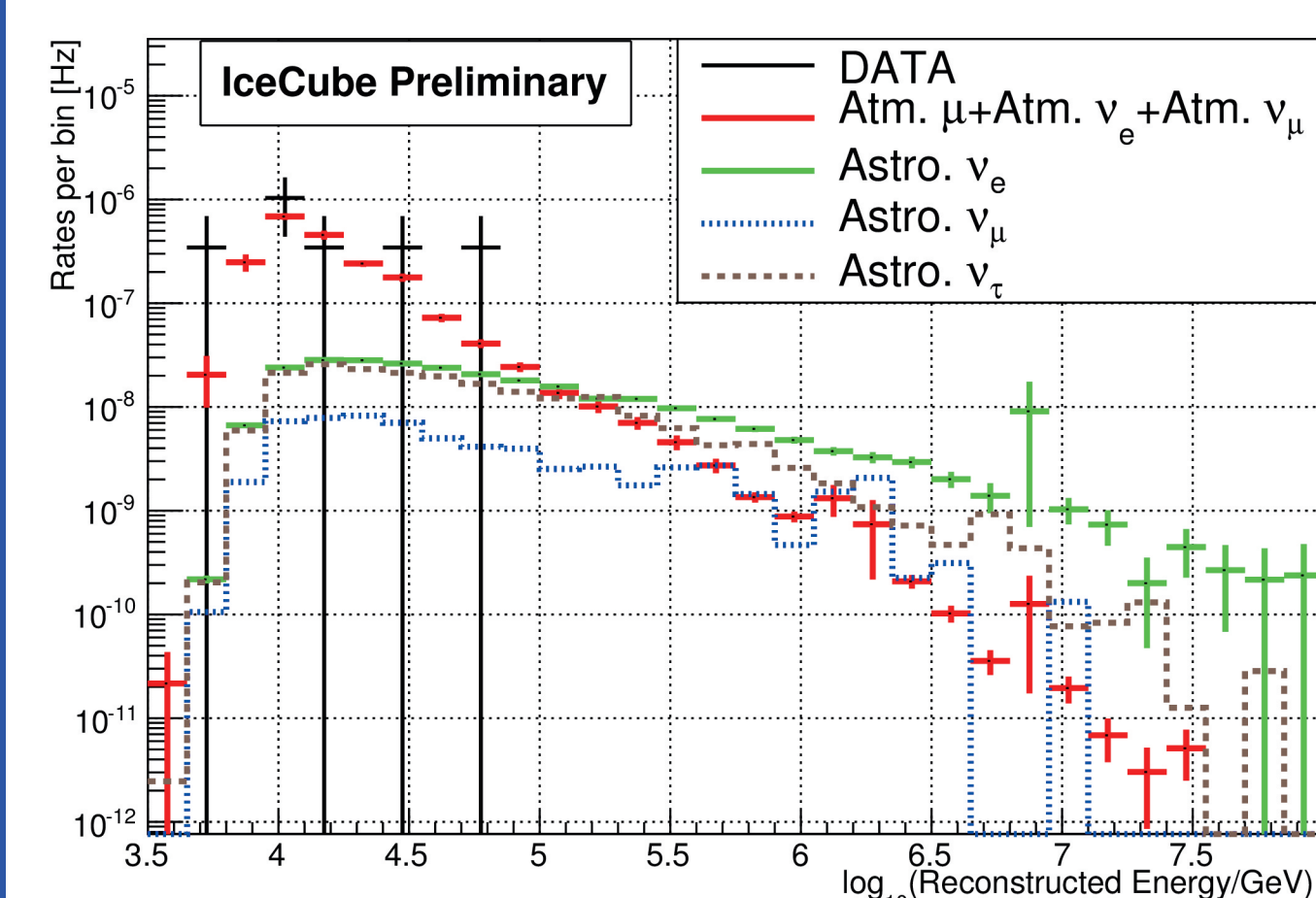
The FillRatio ( $R$ ) defined as the ratio of number of hit DOMs to the total of all DOMs in the sphere of the mean radius being the mean distance between the vertex position and all hit DOMs (see Fig. below). For a neutrino signal cascade-like events this number is close to one while for the track-like events this number would be uniformly distributed.



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. Then, the difference TimeSplitPosition between reconstructed vertex positions for both halves was calculated. 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

Using the Feldman-Cousins method [2], a cut on reconstructed energy (see Fig. below) was optimized and used to suppress remaining muon and atmospheric neutrinos background. The Model Reflection Factor (MRF) [3] was calculated as a function of reconstructed energy.



The minimum of the MRF distribution was found at an energy of  $E=40$  TeV and the energy cut was placed at this value. One burn sample data event of 70 TeV reconstructed energy was retained.  $4.1 \pm 0.2$  (stat)  $\nu_e$ ,  $0.83 \pm 0.06$  (stat)  $\nu_\mu$  and  $2.76 \pm 0.06$  (stat)  $\nu_\tau$  signal events for an astrophysical flux defined in Eq. (1) are expected in 317 days (90% of the experimental data).

## 6 Results

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 was calculated and resulted in  $2.3 \times 10^{-8} \text{GeV s}^{-1} \text{sr}^{-1} \text{cm}^{-2}$  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  $1.8 \times 10^{-8} \text{GeV s}^{-1} \text{sr}^{-1} \text{cm}^{-2}$  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 [4, 5, 6, 7]. The systematic uncertainties are currently being evaluated.

