Searches for astrophysical sources of neutrinos using cascade events in IceCube

Mike Richman

TeVPA 2017

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The IceCube Neutrino Observatory
The IceCube Neutrino Observatory
1.5–2.5 km deep in the South Pole glacier

- 5160 PMTs arranged on 86 strings
- 1 km$^3$ instrumented volume
- Constructed 2005–2010
<table>
<thead>
<tr>
<th>Neutrino Detection</th>
<th>interactions and detector signatures</th>
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<td>cascade</td>
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Source Searches with IceCube Cascades  TeVPA’17  Mike Richman (Drexel University)
Neutrino Detection

interactions and detector signatures

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track

cascade

Source Searches with IceCube Cascades  
TeVPA’17  
Mike Richman (Drexel University)
Two Year Cascade Selection
Low Threshold Contained Events
probing lower energies than “HESE” with an adaptive veto

[PRD 91, 022001 (2015)]

Active volume decreases with deposited energy
→ threshold reduced to ∼ 1 TeV
Observed Cascades

*events collected in two years of data*

263 cascade events observed between 1 TeV and 1.1 PeV

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More atmospheric $\mu$ but fewer atmospheric $\nu$ from the southern sky

263 cascade events observed between 1 TeV and 1.1 PeV

More atmospheric $\mu$ but fewer atmospheric $\nu$ from the southern sky

Poor angular resolution compared to tracks

Sensitivity driven by low background including “self-veto” of atmospheric $\nu$

Sensitivity vs. Declination
for two years of cascades

Shown here:
\[ E^2 \cdot \frac{dN}{dE} \text{ at } 100 \text{ TeV} \]

Sensitivity has only weak direction dependence

Best IceCube south sky sensitivity yet for soft spectra

Sensitivity vs. Energy

comparing selections scaled to equal livetime

Shown here:
scaling cascades, throughgoing tracks, and starting tracks to three years of livetime

Low background gives good low-energy sensitivity for a southern source

Enhancement at 6.3 PeV expected due to Glashow resonance

Extended Sources

sensitivity for finite-sized sources

Shown here:
sensitivity for sources with Gaussian angular extent

Poor angular resolution → weak dependence on source size

No dedicated extended source search with cascades

- Note: 7 year extended source search with tracks subject to refinement and later publication

Two Year Results
All-sky Scan and Galactic Plane

results from two years of cascades

All-sky scan:
- Hottest spot
  \((\alpha, \delta) = (277.3^\circ, -43.4^\circ)\)
- Pre-trials \(p = 0.6\%\)
- Post-trials \(p = 66\%\)

Galactic Plane:
- Simple line-source test, all-sky and South-only
- Post-trials \(p = 65\%\)

74 source candidates tested

Most significant:
BL Lac at
$(\alpha, \delta) = (330.68^\circ, 42.28^\circ)$

Pre-trials $p = 0.95\%$
Post-trials $p = 34\%$

Flux constraints evaluated for $E^{-2}$ and $E^{-3}$ spectra

Source Catalog

flux constraints from two years of cascades

74 source candidates tested

Most significant:
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Six Year Projections
Point Source Sensitivity

adding four years of data with high signal acceptance

Adding data from the previous talk

Competitive with tracks in the south

Largest gains in the south and at low energies
Diffuse galactic emission model from $\pi^0$ decay fits

Diffuse galactic emission model from $\pi^0$ decay fits

Sensitivity:
$$E^2 \cdot (E/100 \text{ TeV})^{0.5} \cdot dN/dE =$$

Tracks:
$$2.97 \times 10^{-11} \text{ TeV}/\text{cm}^2/\text{s}$$


as viewed with throughgoing tracks
Galactic Plane Sensitivity

Fermi-LAT \( \pi^0 \) decay model for diffuse emission

Diffuse galactic emission model from \( \pi^0 \) decay fits

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Tracks:
\[
2.97 \times 10^{-11} \text{ TeV/cm}^2/\text{s}
\]


Cascades:
\[
\sim 2.5 \times 10^{-11} \text{ TeV/cm}^2/\text{s}
\]

Combined:
\[
\sim 1.9 \times 10^{-11} \text{ TeV/cm}^2/\text{s}
\]

as viewed with cascades

← IceCube Preliminary
Modified model with hardening near galactic center

Galactic Plane Sensitivity

*KRA-\(\gamma\) model for diffuse emission*

Modified model with hardening near galactic center

KRA-\(\gamma\) (50 PeV cutoff) model sensitivity:

Tracks: \(0.80 \times \) model


as viewed with throughgoing tracks
Galactic Plane Sensitivity

*KRA-\(\gamma\) model for diffuse emission*

Modified model with hardening near galactic center

*KRA-\(\gamma\) (50 PeV cutoff)*

Model sensitivity:

**Tracks:** \(0.80 \times \text{model}\)


**Cascades:** \(\sim 0.41 \times \text{model}\)

**Combined:** \(\sim 0.35 \times \text{model}\)

as viewed with cascades

← IceCube Preliminary
Galactic Plane Sensitivity

*KRA-\(\gamma\) model for diffuse emission*

Modified model with hardening near galactic center

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Combined: \(\sim 0.35 \times \text{model}\)
Outlook

IceCube cascades allow enhanced southern sky sensitivity due to low background rates and the atmospheric neutrino veto.

Results from two years of data were recently submitted to ApJ.

Second-iteration analysis with more livetime, larger effective area, and tests of detailed galactic plane models is currently under development.
Backup Slides
Cosmic Ray Muon Background

two approaches to neutrino selection

Classic $\nu_\mu$ strategy:

- Earth acts as neutrino filter
- Well-reconstructed Northern tracks must be neutrinos

→ North sky and $\nu_\mu$ only
Cosmic Ray Muon Background

two approaches to neutrino selection

Classic $\nu_\mu$ strategy:
- Earth acts as neutrino filter
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Active veto to select starting events:

→ North sky and $\nu_\mu$ only

→ Reduced effective volume, but full sky and all flavor
High Energy Starting Events
results from four years of data

Search for very bright, contained events

Sensitive to all flavors above $\sim 60$ TeV

80(+2) events in six years

PoS(ICRC2017)981
High Energy Starting Events

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Simplified source search includes cascades and tracks

No use of signal MC to connect to source fluxes

Source Searches with IceCube Cascades

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Low Threshold Contained Events

results from two years of data

Astrophysical excess down to \( \sim 10 \text{ TeV} \)

Fit consistent with high energy search but errors are smaller

Model disagreement at 30 TeV not significant \((p = 5\%)\)

[PRD 91, 022001 (2015)]
Astrophysical Muon Neutrinos

results from six years of data

Accept incoming tracks $\rightarrow$ larger effective area

- Restricts search to North sky $\nu_\mu$
- Probes higher energies

Harder best fit spectrum:

$\Phi_\nu(E) = \Phi_0 \cdot (E/100 \text{ TeV})^{-2.13 \pm 0.13}$

$\Phi_0 = 0.90^{+0.30}_{-0.27} \times 10^{-18} \text{ /GeV/cm}^2\text{/s/sr}$

Standard skymap dominated by \textbf{atm. }\nu\textbf{ in the North and atm. }\mu\textbf{ in the South}
- North: $p = 29\%$
- South: $p = 17\%$

Standard skymap dominated by **atm. \( \nu \)** in the North and **atm. \( \mu \)** in the South

- North: \( p = 29\% \)
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Excess of hot spots?

- North: \( p = 25\% \)

Standard Point Source Analysis

search for clustering with 7 years of muon tracks

Standard skymap dominated by atm. $\nu$ in the North and atm. $\mu$ in the South

- North: $p = 29\%$
- South: $p = 17\%$

Excess of hot spots?

- North: $p = 25\%$
- South: $p = 8.2\%$
- Galactic Plane $\pm 15^\circ$: $p = 26\%$

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\[ \text{[ApJ 835 (2017) no. 2, 151]} \]