Searches for astrophysical sources of neutrinos using cascade events in IceCube

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The IceCube Neutrino Observatory

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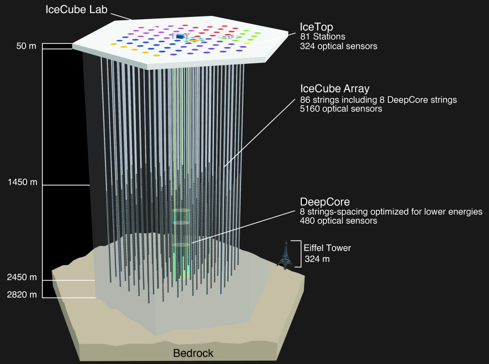
1.5–2.5 km deep in the South Pole glacier

5160 PMTs arranged on
86 strings

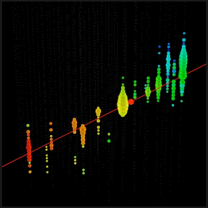
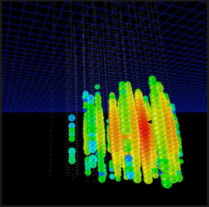
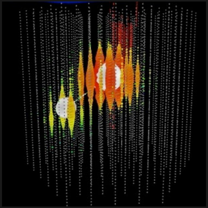
1 km^3 instrumented volume

Constructed **2005–2010**



Neutrino Detection

interactions and detector signatures

CC ν_μ	CC ν_e / NC ν_*	CC ν_τ
		
$\nu_\mu + N \rightarrow \mu + X$	$\nu_e + N \rightarrow e + X$ $\nu_* + N \rightarrow \nu_* + X$	$\nu_\tau \rightarrow \tau + X$
track	*cascade*	*cascade* (or *double-bang*)

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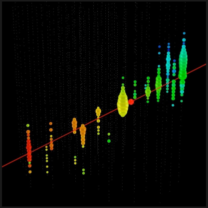	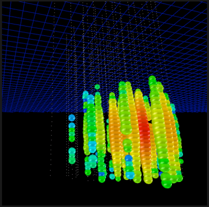	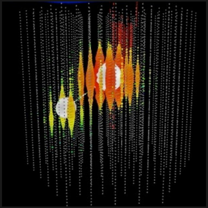
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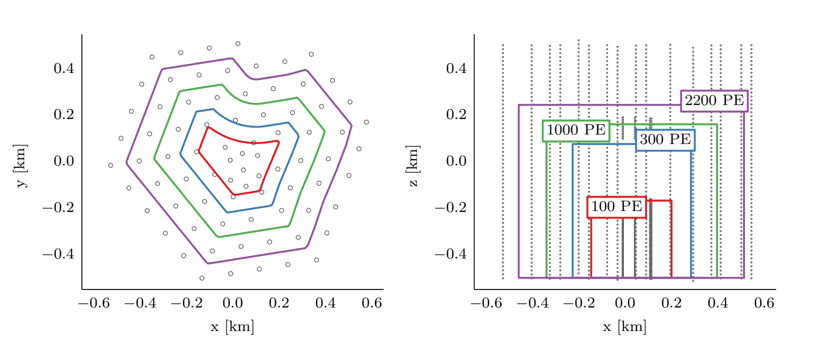
Two Year Cascade Selection

Low Threshold Contained Events

probing lower energies than "HESE" with an adaptive veto



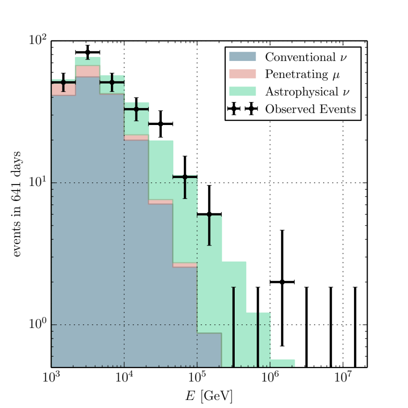
[PRD 91, 022001 (2015)]

Active volume decreases with deposited energy
$\rightarrow$ threshold reduced to $\sim 1\,\text{TeV}$

Observed Cascades

events collected in two years of data

263 cascade events observed between 1 TeV and 1.1 PeV



[Submitted to ApJ (arXiv:1705.02383)]

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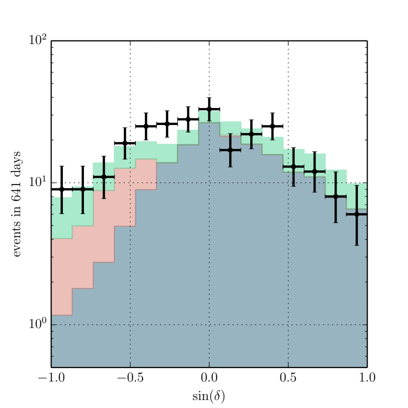
More atmospheric μ but fewer atmospheric ν from the southern sky



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Observed Cascades

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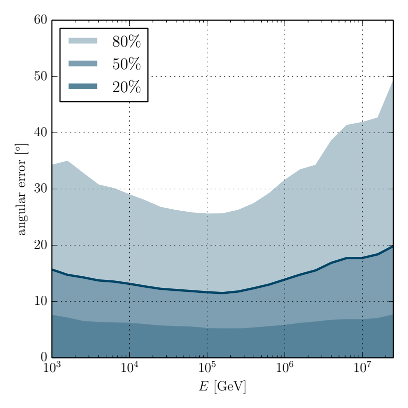
263 cascade events observed between 1 TeV and 1.1 PeV

More atmospheric μ but fewer atmospheric ν from the southern sky

Poor angular resolution compared to tracks

Sensitivity driven by low background including "self-veto" of atmospheric ν



[Submitted to ApJ (arXiv:1705.02383)]

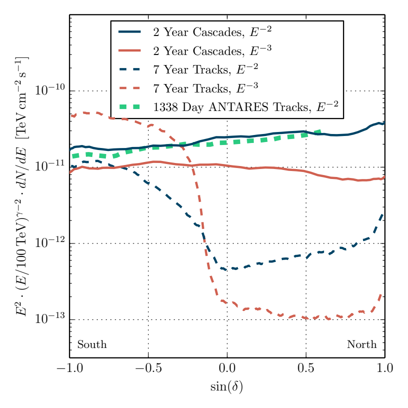
Sensitivity vs. Declination

for two years of cascades

Shown here:
$E^2 \cdot dN/dE$ at 100 TeV

Sensitivity has only weak direction dependence

Best IceCube south sky sensitivity yet for soft spectra



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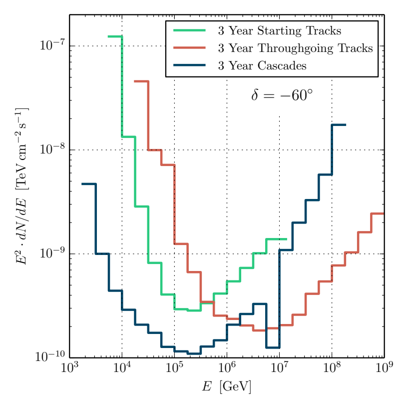
Sensitivity vs. Energy

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



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Extended Sources

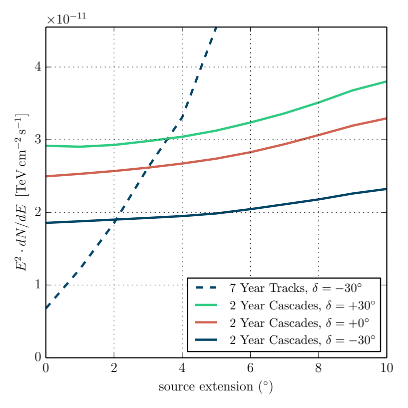
sensitivity for finite-sized sources

Shown here:
sensitivity for sources with Gaussian angular extent

Poor angular resolution → weak dependence on source size

No dedicated extended source search with cacades

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



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Two Year Results

All-sky Scan and Galactic Plane

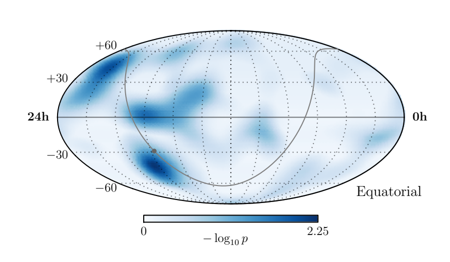
results from two years of cascades

All-sky scan:

- Hottest spot $(\alpha, \delta) = (277.3°, -43.4°)$
- Pre-trials $p = 0.6\%$
- Post-trials $p = 66\%$

Galactic Plane:

- Simple line-source test, all-sky and South-only
- Post-trials $p = 65\%$



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Source Catalog

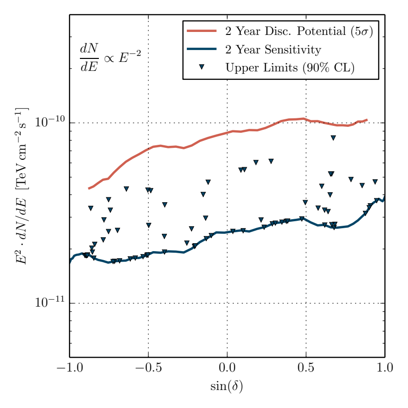
flux constraints from two years of cascades

74 source candidates tested

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

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

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



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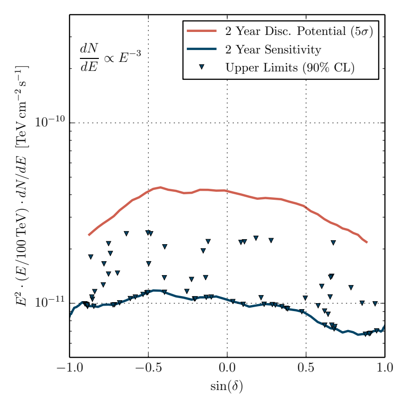


[Submitted to ApJ (arXiv:1705.02383)]

Six Year Projections

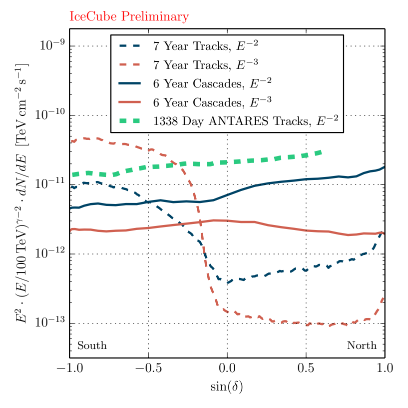
Point Source Sensitivity

adding four years of data with high signal acceptance

Adding data from the previous talk

Competitive with tracks in the south

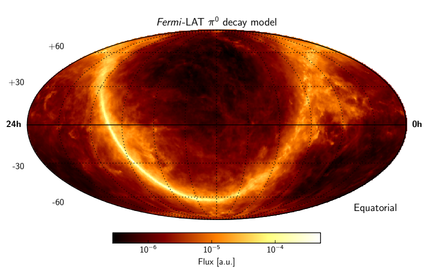
Largest gains in the south and at low energies



Galactic Plane Sensitivity

Fermi-LAT π^0 decay model for diffuse emission

Diffuse galactic emission model from π^0 decay fits



[ApJ 750 (2012) 3]

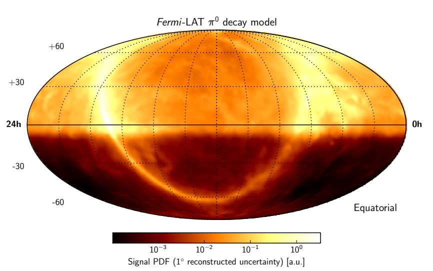
Galactic Plane Sensitivity

Fermi-LAT π^0 decay model for diffuse emission

Diffuse galactic emission model from π^0 decay fits

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

Tracks:
$2.97 \times 10^{-11}\,\text{TeV}/\text{cm}^2/\text{s}$
[Submitted to ApJ (arXiv:1707.03416)]



as viewed with throughgoing tracks

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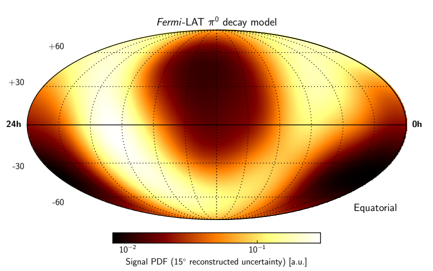
$2.97 \times 10^{-11}\,\text{TeV}/\text{cm}^2/\text{s}$
[Submitted to ApJ (arXiv:1707.03416)]

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

Combined:
$\sim \mathbf{1.9 \times 10^{-11}\,TeV/cm^2/s}$



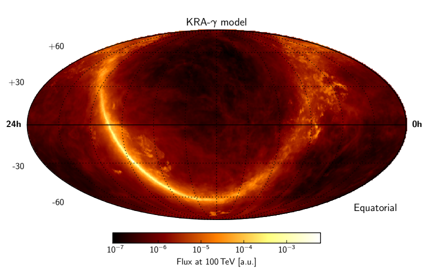
as viewed with cascades

← IceCube Preliminary

Galactic Plane Sensitivity

KRA-γ model for diffuse emission

Modified model with hardening near galactic center



[ApJL 815 (2015) L25]

Galactic Plane Sensitivity

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Modified model with hardening near galactic center

KRA-γ (50 PeV cutoff) model sensitivity:

Tracks: $0.80 \times$ model
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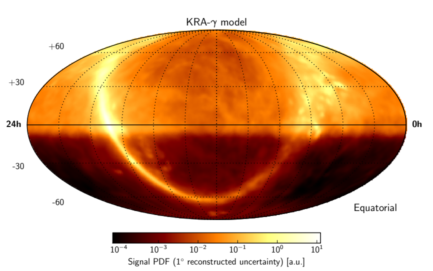

as viewed with throughgoing tracks

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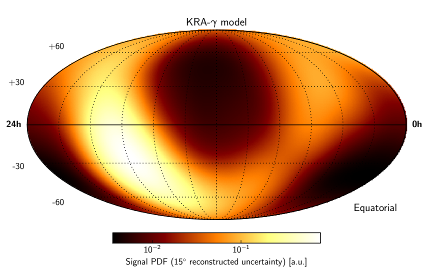
Cascades: $\sim 0.41 \times$ model

Combined: $\sim 0.35 \times$ model



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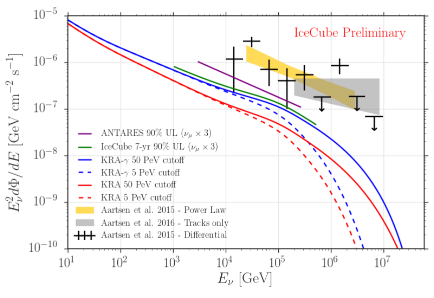


← IceCube Preliminary

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.

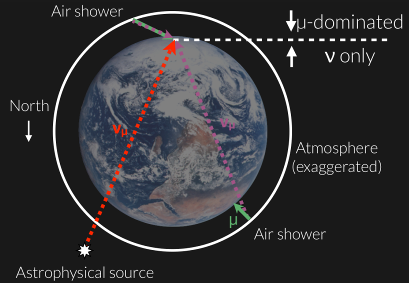
Backup Slides

Cosmic Ray Muon Background

two approaches to neutrino selection

Classic ν_μ strategy:

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



→ North sky and ν_μ only

Cosmic Ray Muon Background

two approaches to neutrino selection

Classic ν_μ strategy:

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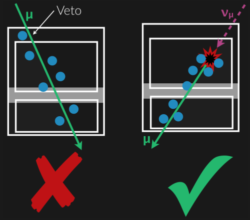
→ North sky and ν_μ only

Active veto to select starting events:



→ Reduced effective volume, but full sky and all flavor

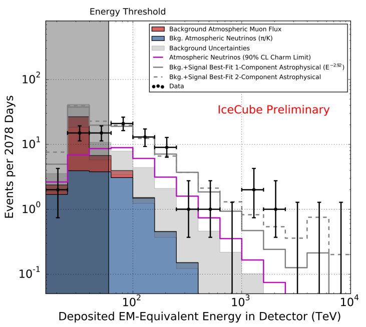
High Energy Starting Events

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

results from four years of data

Search for **very bright, contained** events

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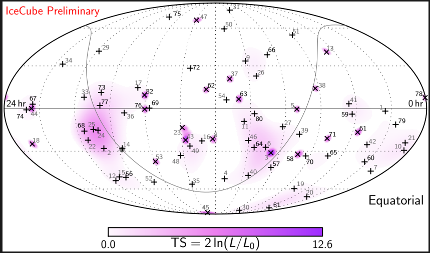
Simplified source search includes cascades and tracks

No use of signal MC to connect to source fluxes



[PoS(ICRC2017)981]

Low Threshold Contained Events

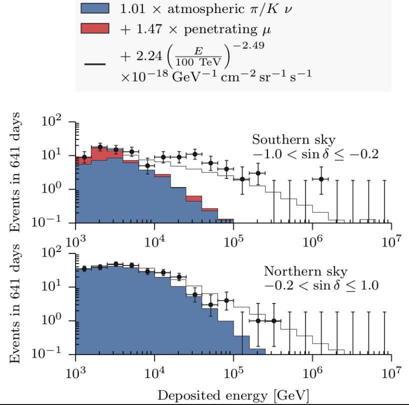
results from two years of data

Astrophysical excess down to $\sim$ **10 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

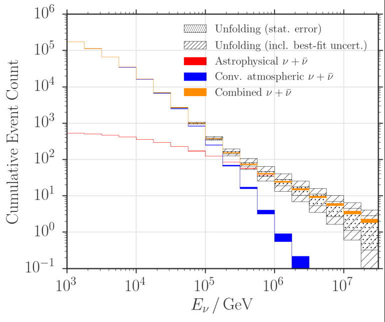
results from six years of data

Accept incoming tracks → larger effective area

- Restricts search to **North sky ν_μ**
- Probes **higher energies**

Harder best fit spectrum:

$$\Phi_\nu(E) = \Phi_0 \cdot (E/100\,\text{TeV})^{-2.13\pm0.13}$$
$$\Phi_0 = 0.90^{+0.30}_{-0.27} \times 10^{-18}/\text{GeV}/\text{cm}^2/\text{s}/\text{sr}$$



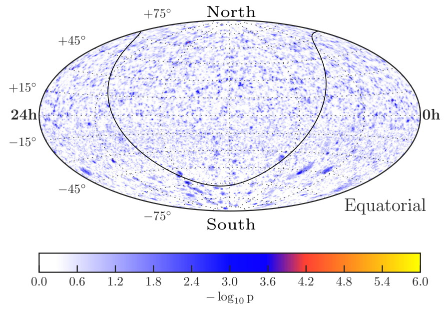
[ApJ 833 (2016) no. 1, 3]

Standard Point Source Analysis

search for clustering with 7 years of muon tracks

Standard skymap dominated by **atm.** ν in the North and **atm.** μ in the South

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



[ApJ 835 (2017) no. 2, 151]

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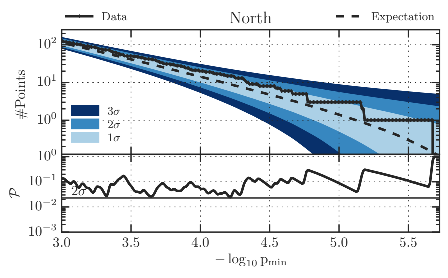
- North: $p = 25\%$



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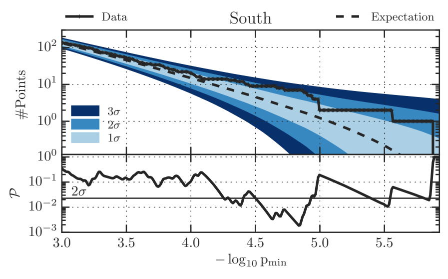
- Galactic Plane $\pm 15°$: $p = 26\%$



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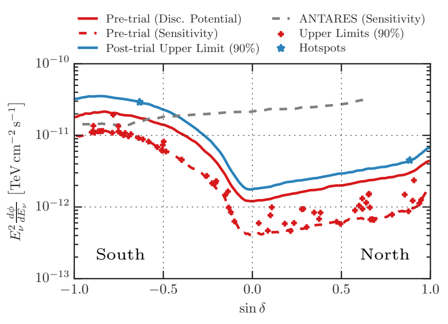

[ApJ 835 (2017) no. 2, 151]