Searches for astrophysical sources of neutrinos using cascade events in IceCube

Mike Richman

IceCube Particle Astrophysics Symposium

May 8, 2017
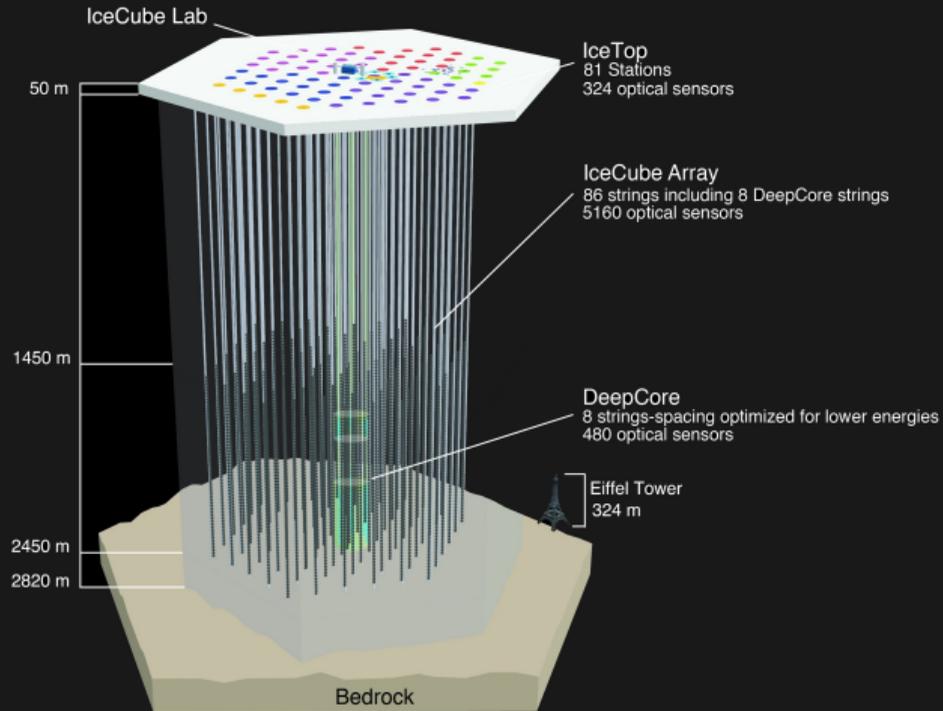
The IceCube Neutrino Observatory

The IceCube Neutrino Observatory

1.5–2.5 km deep in the South Pole glacier

5160 PMTs arranged on **86 strings**

**1 km³** instrumented volume

Constructed **2005–2010**

IceCube Lab

50 m

IceTop
81 Stations
324 optical sensors

IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors

1450 m

DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors

Eiffel Tower
324 m

2450 m
2820 m

Bedrock

Neutrino Detection

interactions and detector signatures

CC ν_μ	CC ν_e / NC ν_*	CC ν_τ

$$\nu_\mu + N \to \mu + X$$

$$\nu_e + N \to e + X$$
$$\nu_* + N \to \nu_* + X$$

$$\nu_\tau \to \tau + X$$
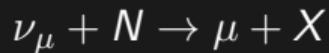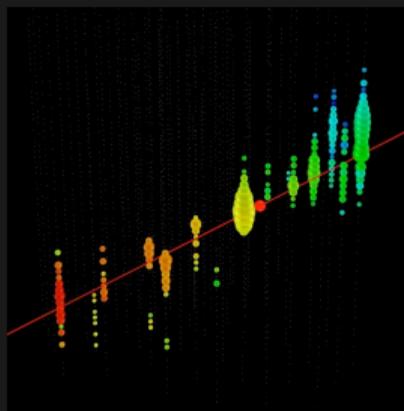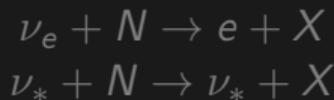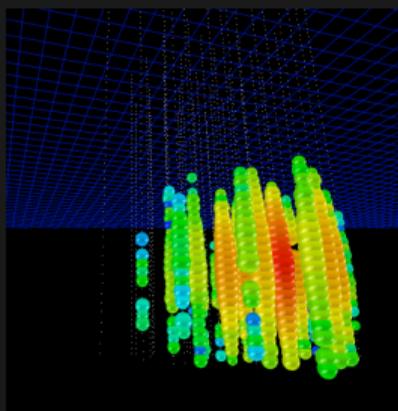
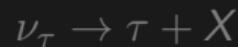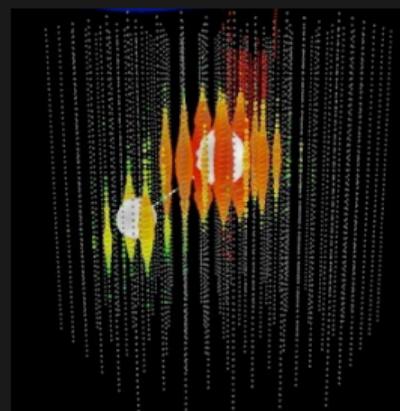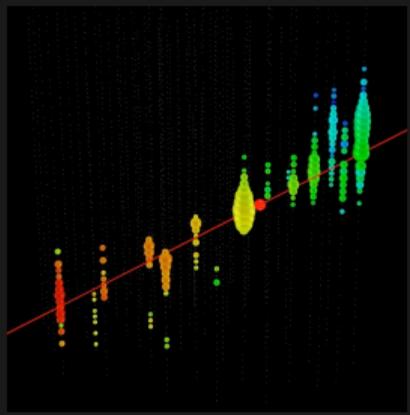*track*

cascade

cascade (or *double-bang*)

Neutrino Detection
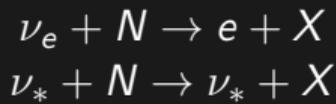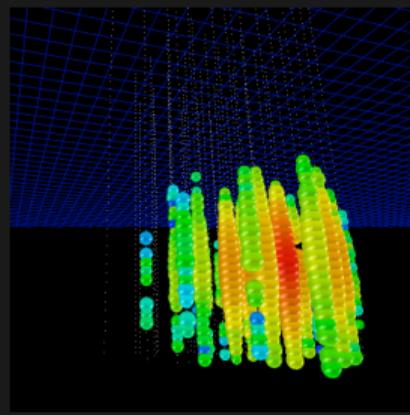
interactions and detector signatures

Cosmic Ray Muon Background

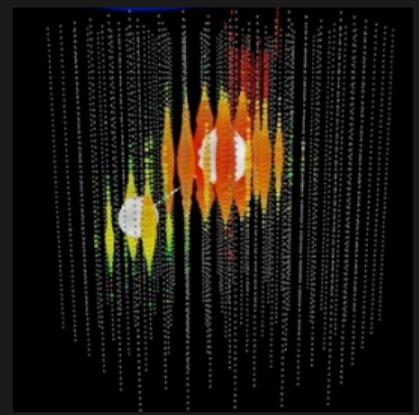*two approaches to neutrino selection*

Classic ν_μ strategy:

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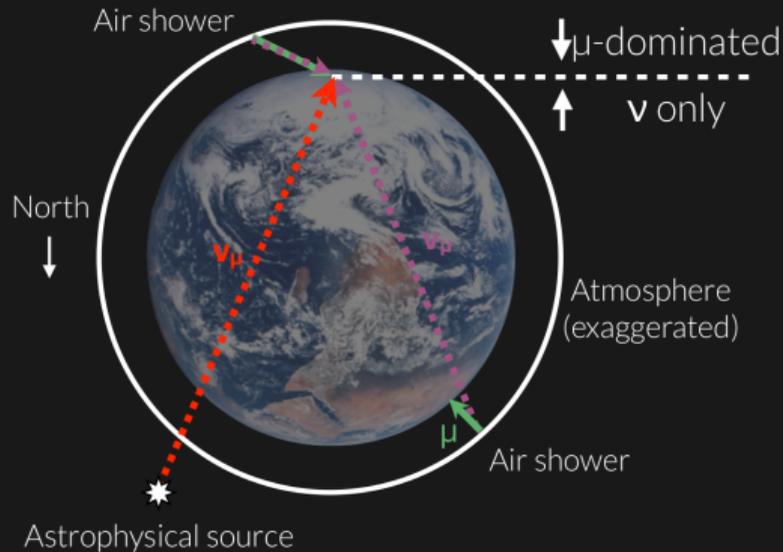

$\rightarrow$ North sky and ν_μ only

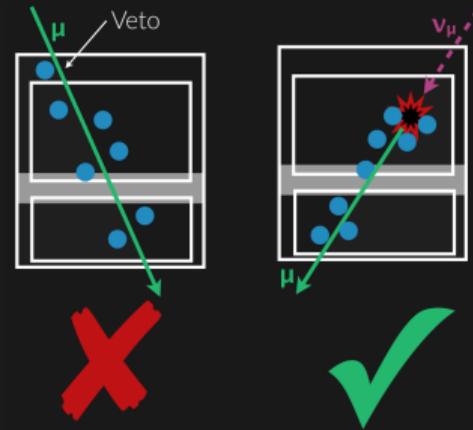# Cosmic Ray Muon Background

two approaches to neutrino selection

Classic ν_μ strategy:

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

Active veto to select starting events:

$\rightarrow$ North sky and ν_μ only

$\rightarrow$ 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 ∼ **60 TeV**

53 events in four years

[PoS(ICRC2015)1081]
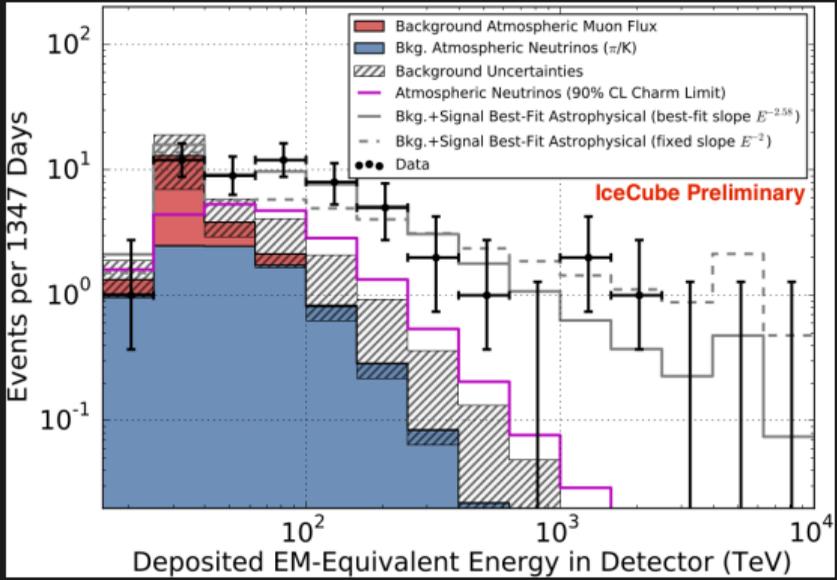
High Energy Starting Events

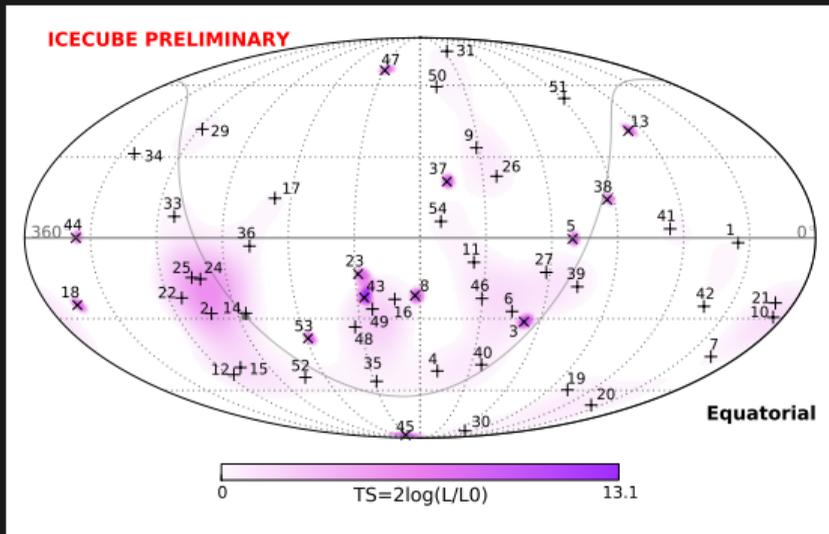*results from four years of data*

Search for **very bright, contained** events

Sensitive to all flavors above $\sim$ **60 TeV**

53 events in four years

Simplified source search includes cascades and tracks

No use of signal MC to connect to source fluxes

[PoS(ICRC2015)1081]

Two Year Cascade Selection

Medium Energy Starting Events

probing lower energies with an adaptive veto
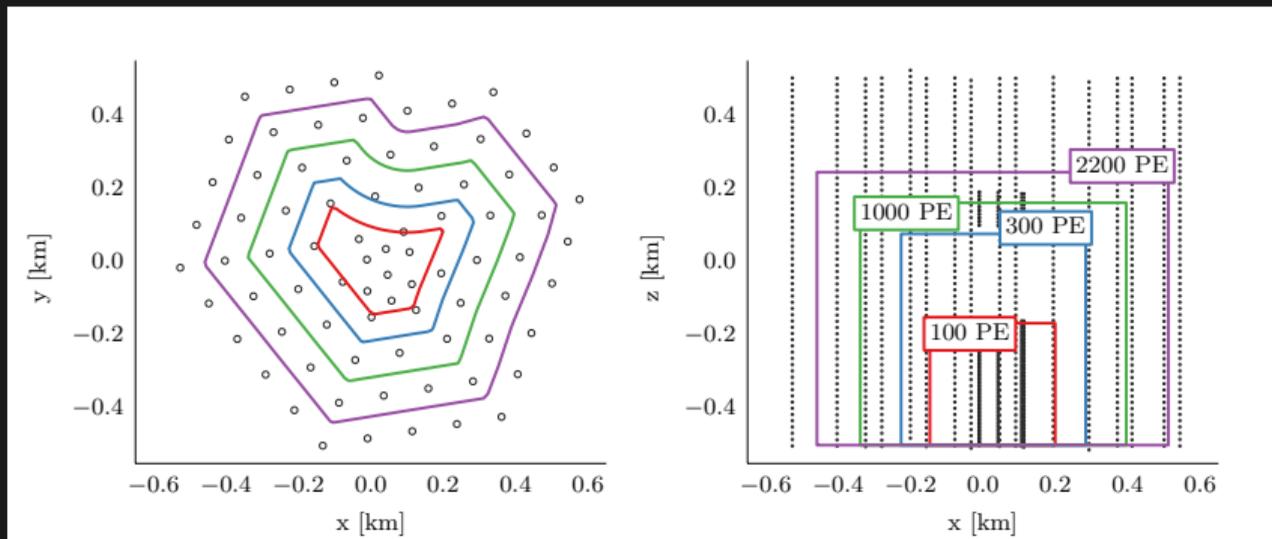
[PRD 91, 022001 (2015)]

Active volume decreases with deposited energy — 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
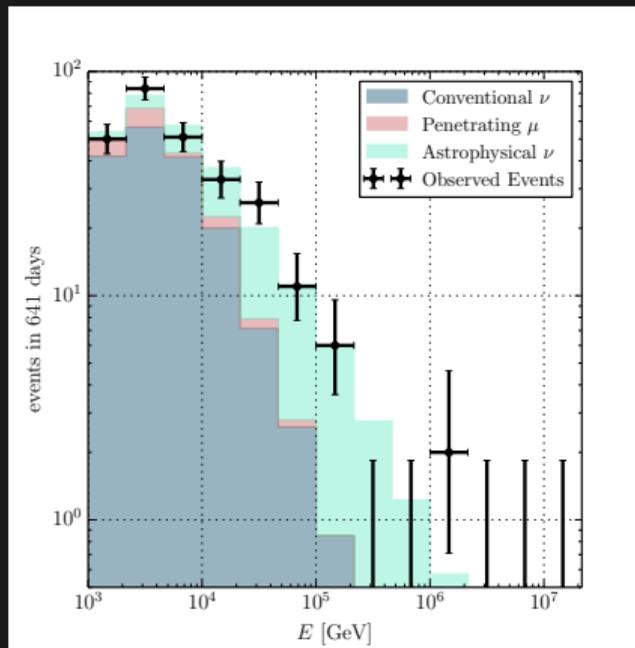
[Submitted to ApJ]

Observed Cascades

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263 cascade events observed between $1\,\text{TeV}$ and $1.1\,\text{PeV}$

More atmospheric μ but fewer atmospheric ν from the southern sky
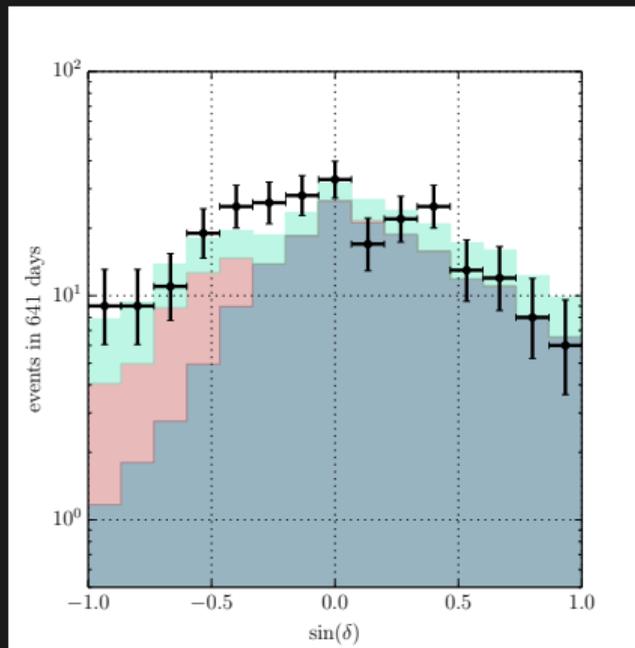

[Submitted to ApJ]

Observed Cascades
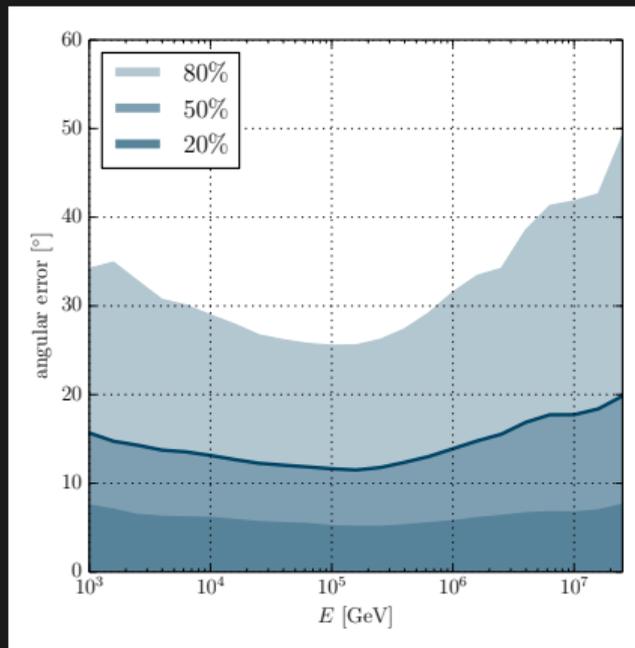*events collected in two years of data*

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]
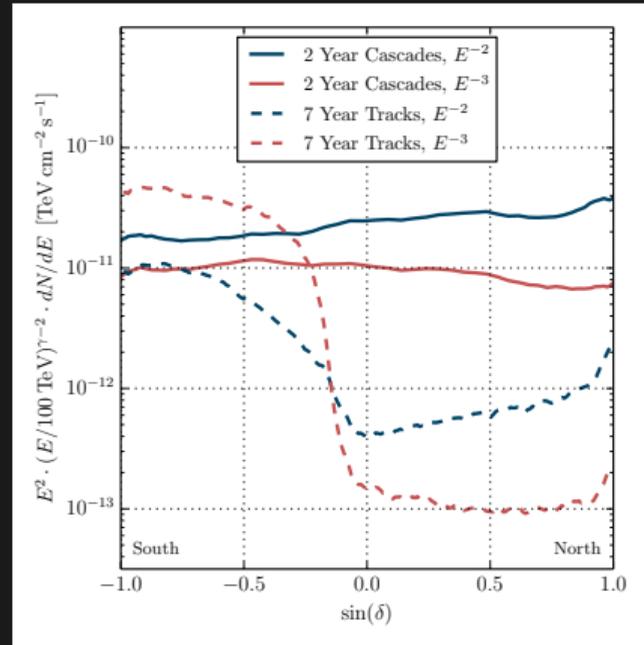
Sensitivity vs. Declination

for two years of cascades

Shown here: $E^2 \cdot dN/dE$ at $100\,\mathrm{TeV}$

Sensitivity has only weak direction
dependence

Best IceCube south sky sensitivity yet
for soft spectra

[Submitted to ApJ]
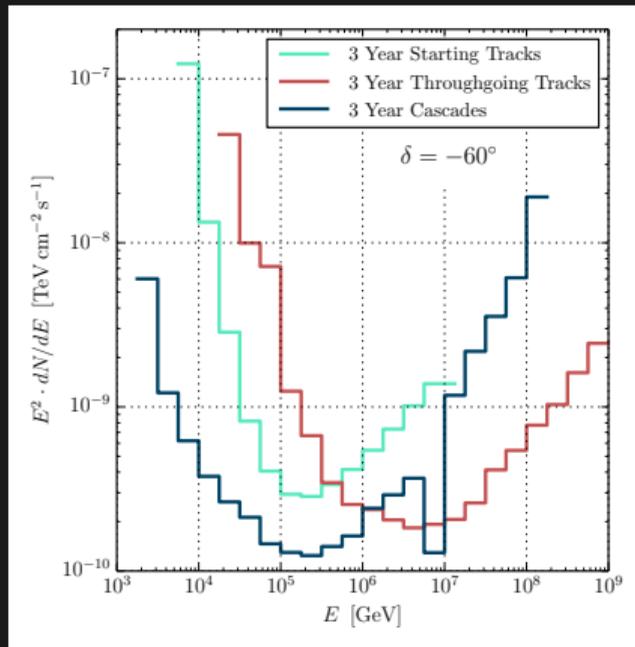
Sensitivity vs. Energy

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 $6.3\,\mathrm{PeV}$ expected due to Glashow resonance

[Submitted to ApJ]

Extended Sources
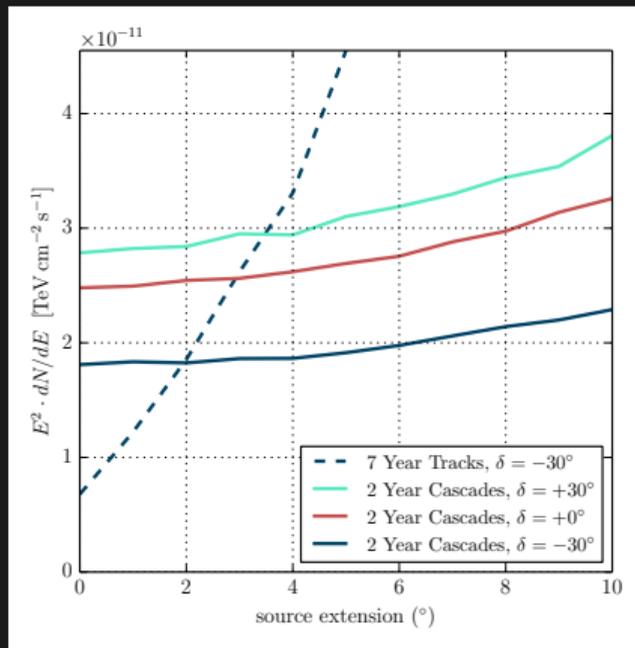*sensitivity for finite-sized sources*

Shown here: sensitivity for sources with Gaussian angular extent

Poor angular resolution $\rightarrow$ 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

[Submitted to ApJ]

Two Year Results

All-sky Scan and Galactic Plane
results from two years of cascades
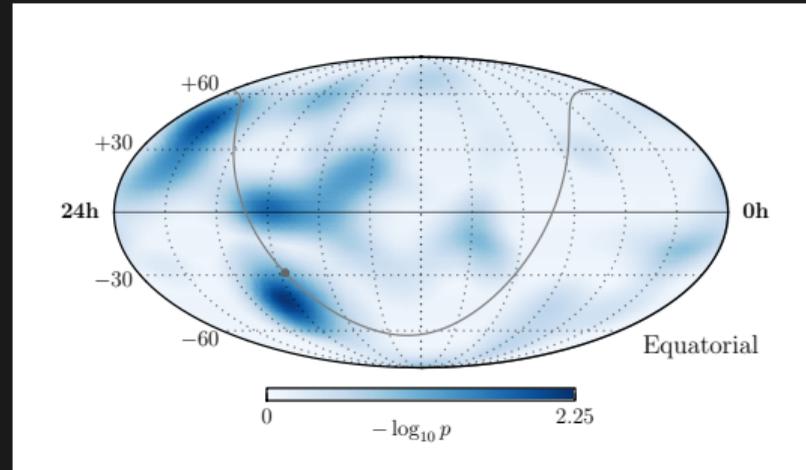
All-sky scan:

- 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 $p = 65\%$

[Submitted to ApJ]

Source Catalog
flux constraints from two years of cascades
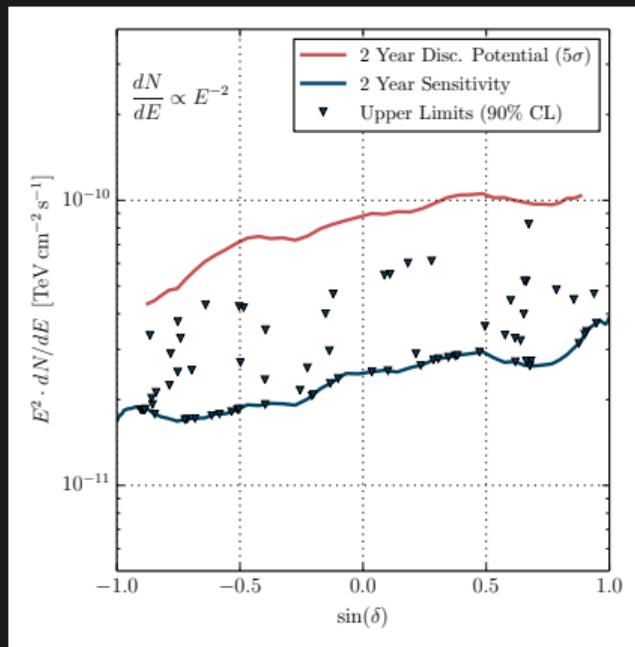
74 source candidates tested

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

[Submitted to ApJ]

Source Catalog

flux constraints from two years of cascades
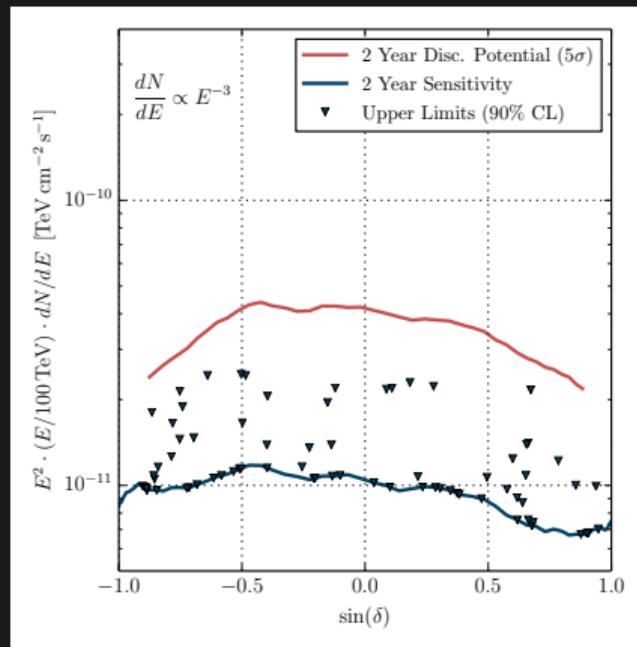
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Six Year Projections

High Acceptance Cascade Sample

Search for **partially contained** cascade events

Increased effective area available already in two year analysis

Events and spectral fit from six years currently under review

Six year sample includes additional less clean but numerous low energy events
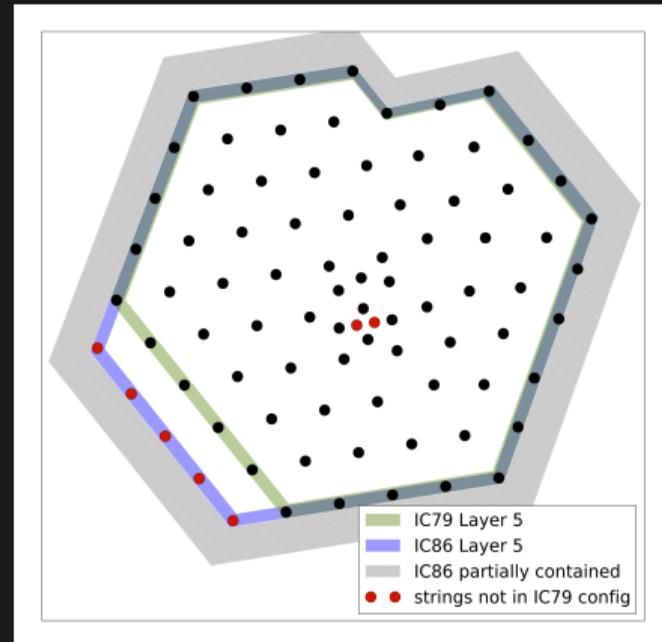

[PoS(ICRC2015)1109]

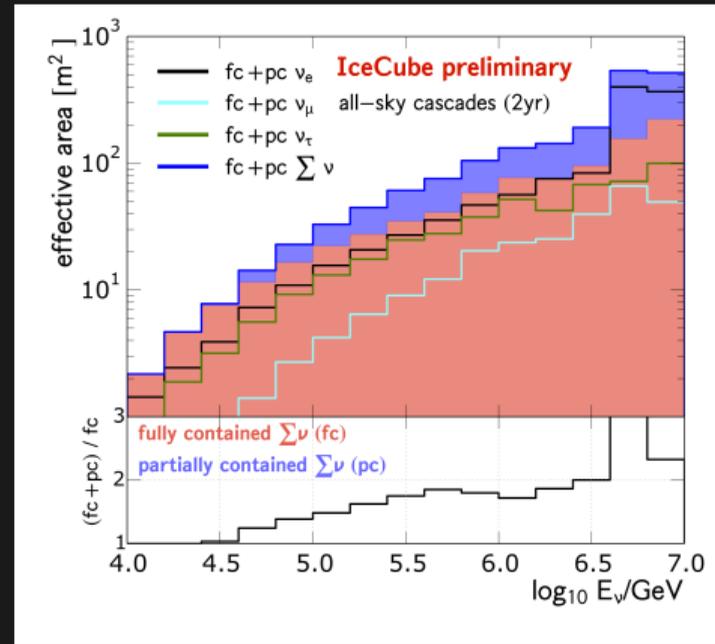# High Acceptance Cascade Sample

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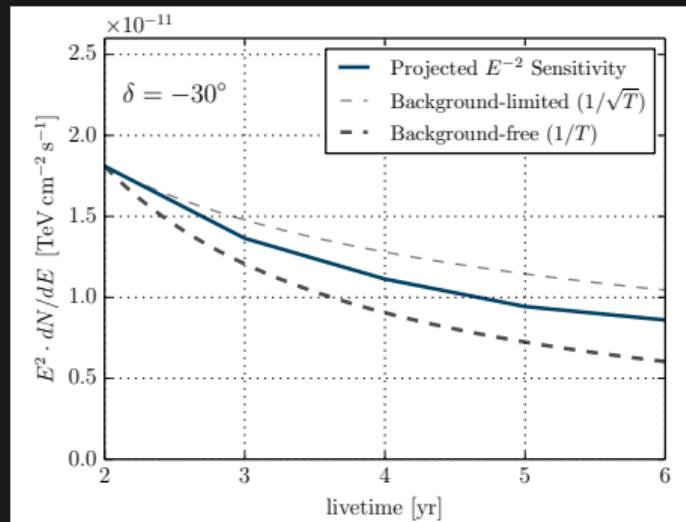

[PoS(ICRC2015)1109]

Projected Six Year Sensitivity

estimate using only signal and background Monte Carlo

Compared to two years, expected gain
between $\sqrt{3}\times$ and $3\times$

[Submitted to ApJ]

Projected Six Year Sensitivity

estimate using only signal and background Monte Carlo

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Competitive with tracks in the south

Especially promising for cascade and
all-channel galactic plane searches
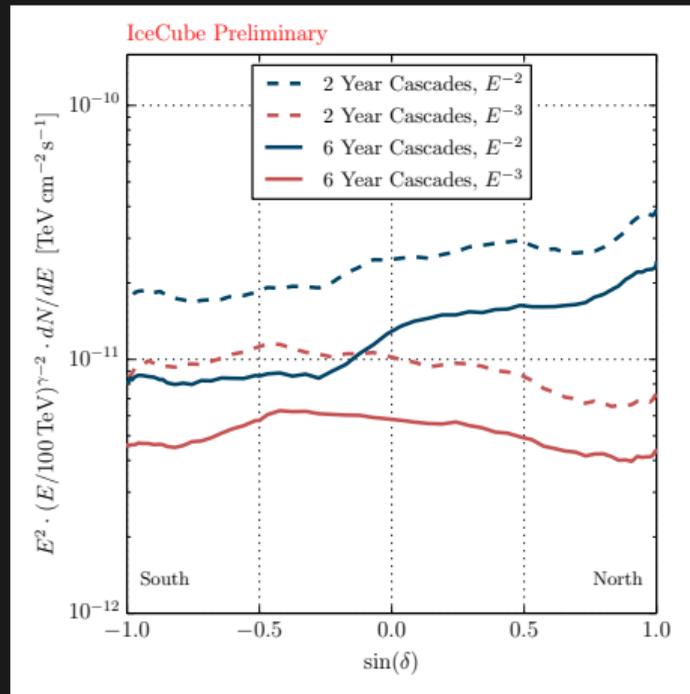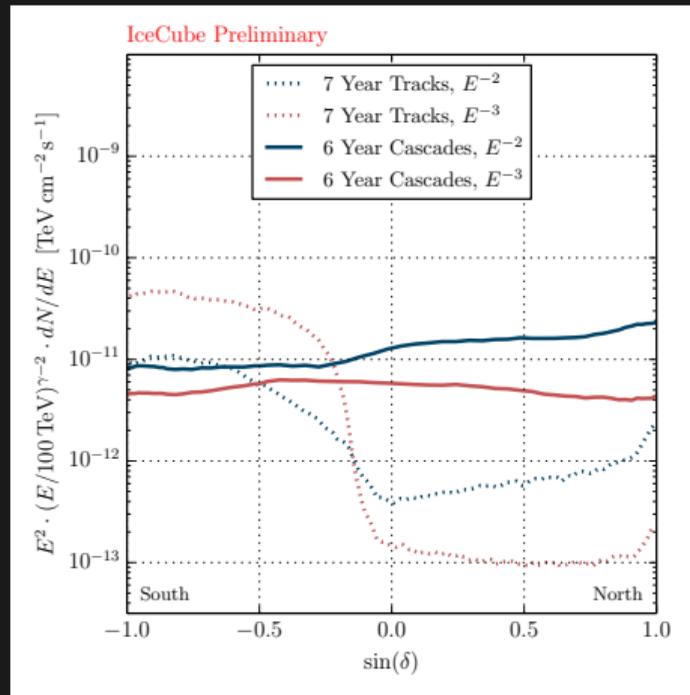(under development)

Projected Six Year Sensitivity

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Competitive with tracks in the south

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Outlook

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

Results from two years were recently submitted to ApJ.

The second-iteration analysis with more livetime and
larger effective area is currently under development.

Backup Slides

Medium Energy Starting Events
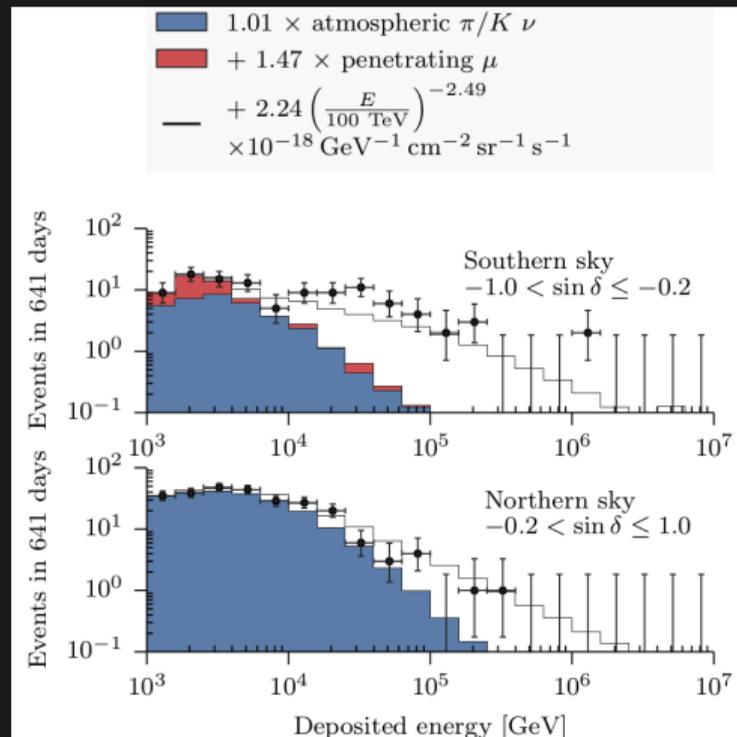
results from two years of data

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)]

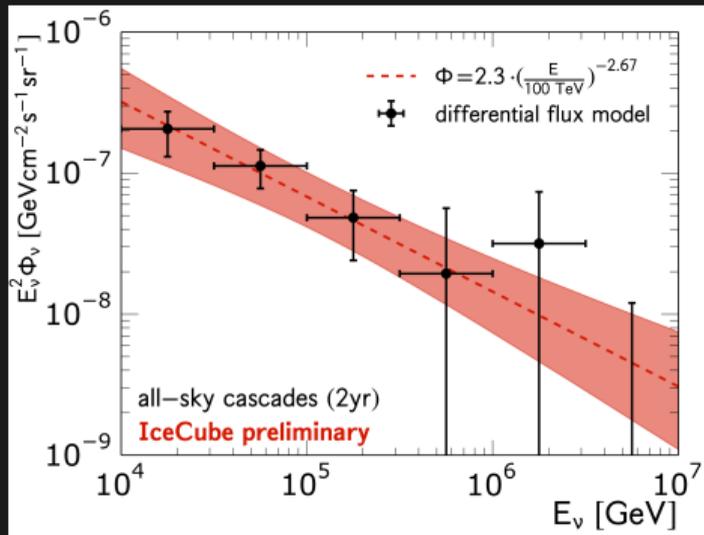# Partially Contained Cascades

results from two years of data

Search for **partially contained** cascade events

Increased effective area

Softer best-fit spectrum:

$$\Phi_\nu(E) = \Phi_0 \cdot (E/100\,\text{TeV})^{-2.67}$$
$$\Phi_0 \simeq 2.3 \times 10^{-18}/\text{GeV}/\text{cm}^2/\text{s}/\text{sr}$$

[PoS(ICRC2015)1109]

Astrophysical Muon Neutrinos
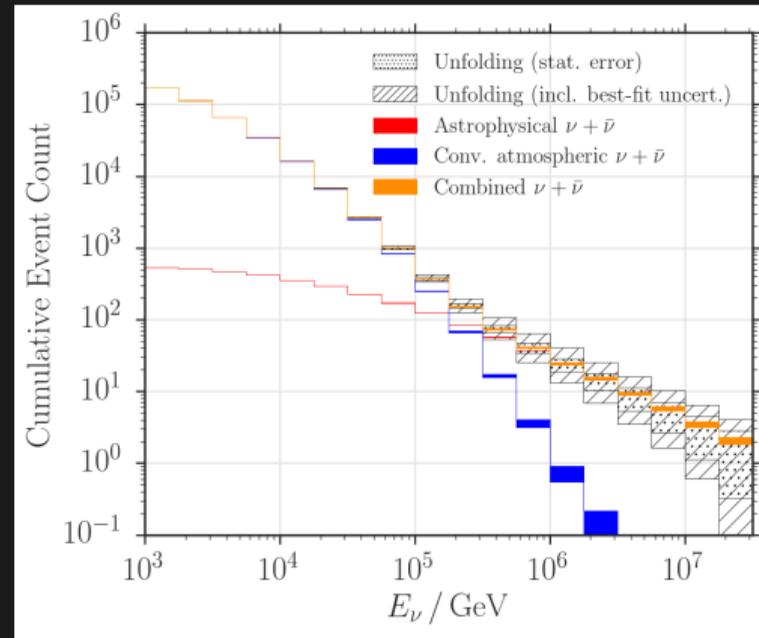*results from six years of data*

Accept incoming tracks $\rightarrow$ larger effective area

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

Harder best fit spectrum:

$$\Phi_\nu(E) = \Phi_0 \cdot (E/100\,\mathrm{TeV})^{-2.13 \pm 0.13}$$
$$\Phi_0 = 0.90^{+0.30}_{-0.27} \times 10^{-18}/\mathrm{GeV/cm^2/s/sr}$$

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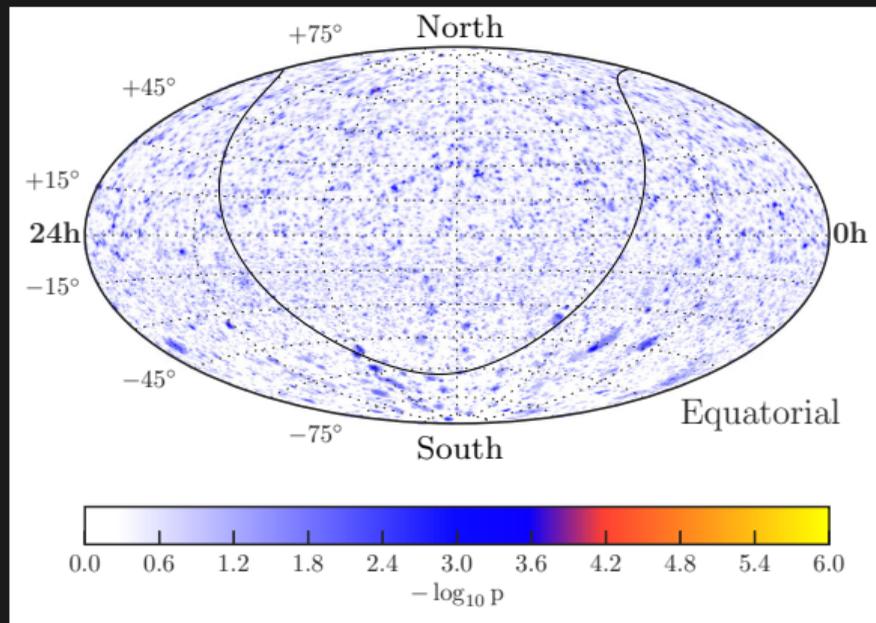- South: $p = 17\%$

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

Standard Point Source Analysis

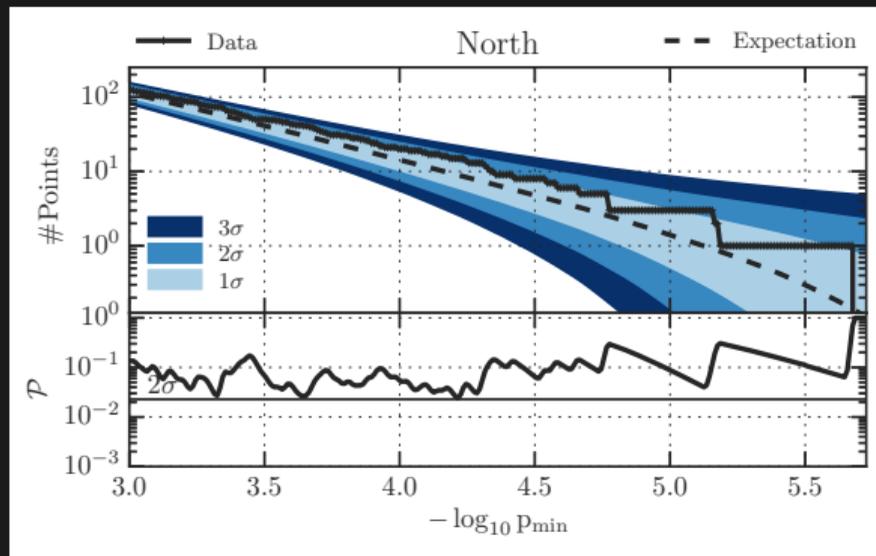*search for clustering with 7 years of muon tracks*

Standard skymap dominated by
atm. ν in the North and **atm. μ**
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- North: $p = 29\%$
- South: $p = 17\%$

Excess of hot spots?

- North: $p = 25\%$

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

Standard Point Source Analysis

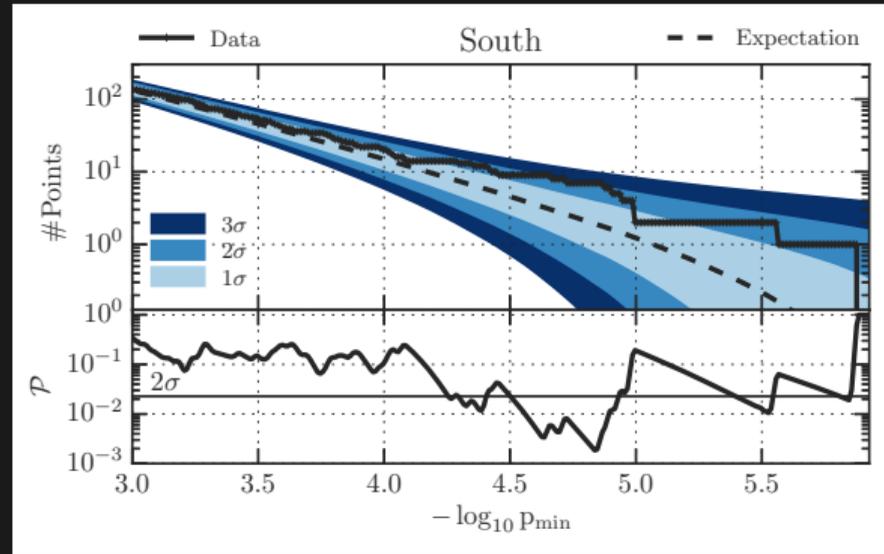*search for clustering with 7 years of muon tracks*

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Excess of hot spots?

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

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

Standard Point Source Analysis

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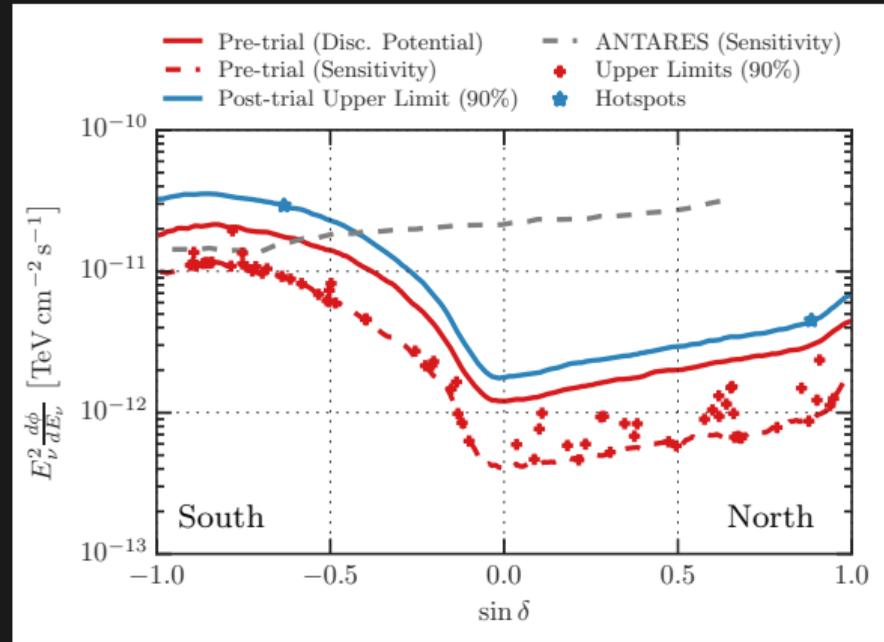
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