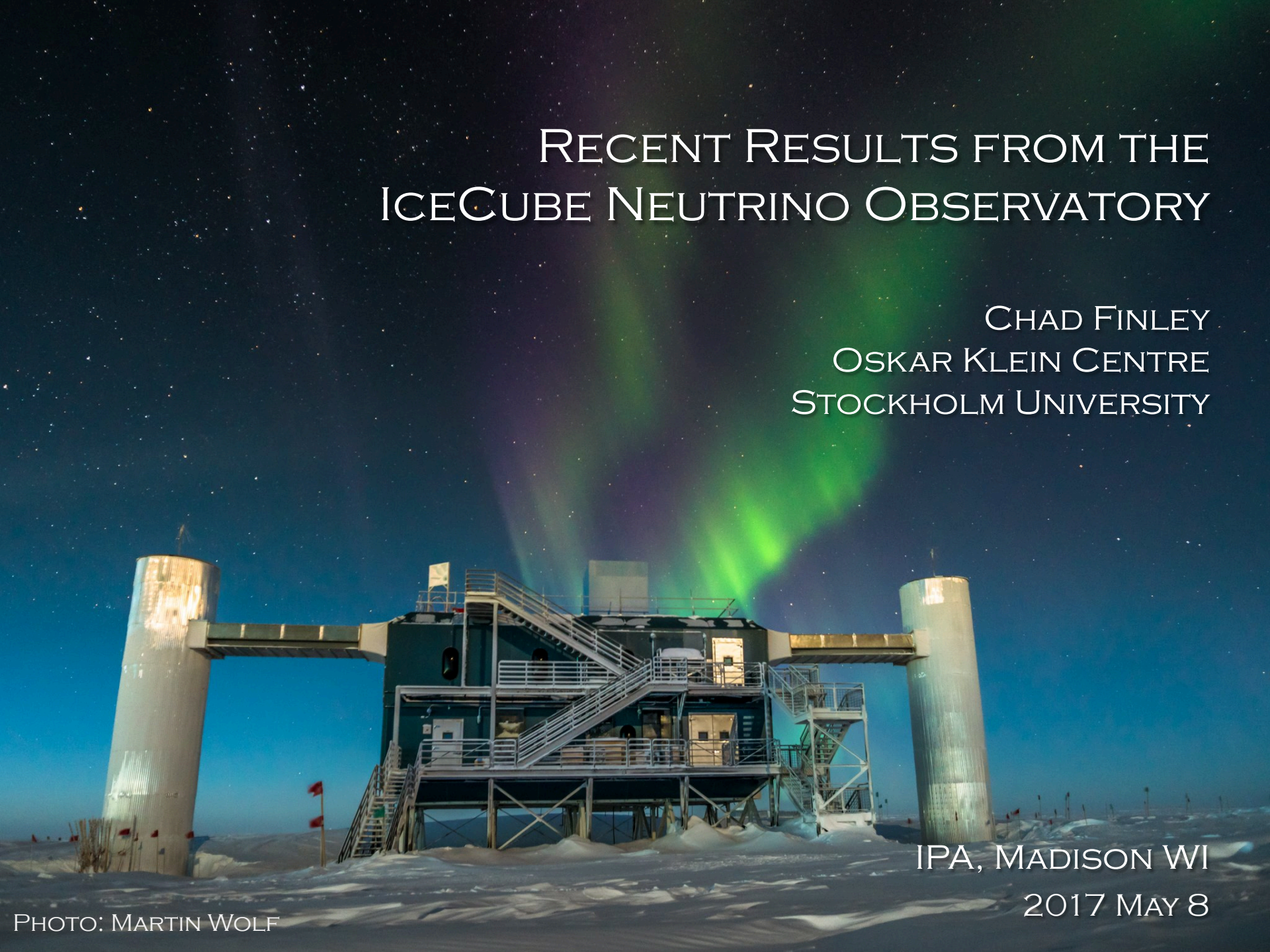
Recent Results from the IceCube Neutrino Observatory

Chad Finley
Oskar Klein Centre
Stockholm University

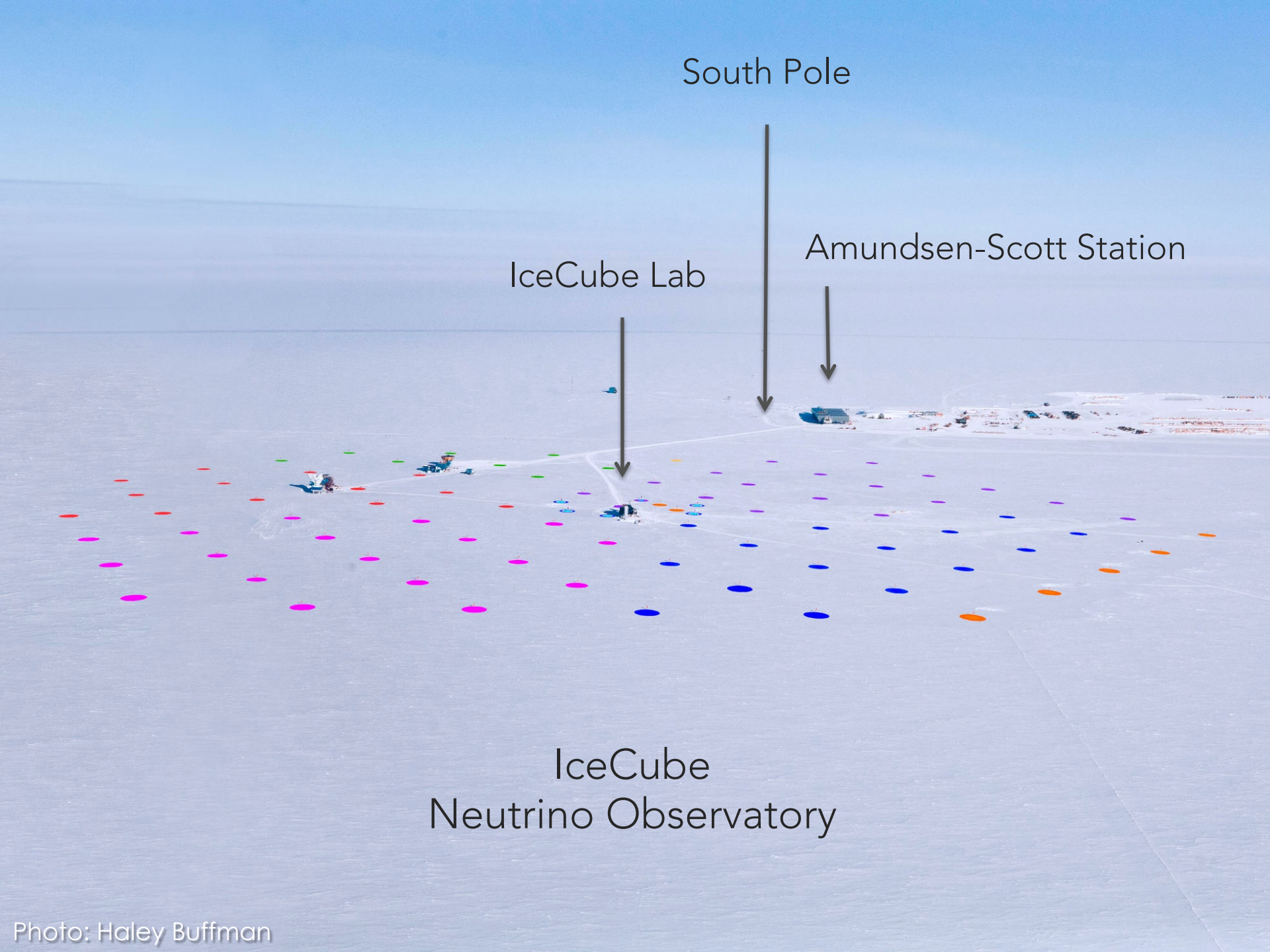


IPA, Madison WI
2017 May 8

Photo: Martin Wolf

IceCube Collaboration

12 countries — 47 institutes — 300 scientists


South Pole
Amundsen-Scott Station
IceCube Lab
IceCube
Neutrino Observatory
Photo: Haley Buffman

IceCube Neutrino Observatory

86 strings

60 Optical Modules per string

5 160 total modules in Ice

1 km^3 = Gigaton instrumented volume

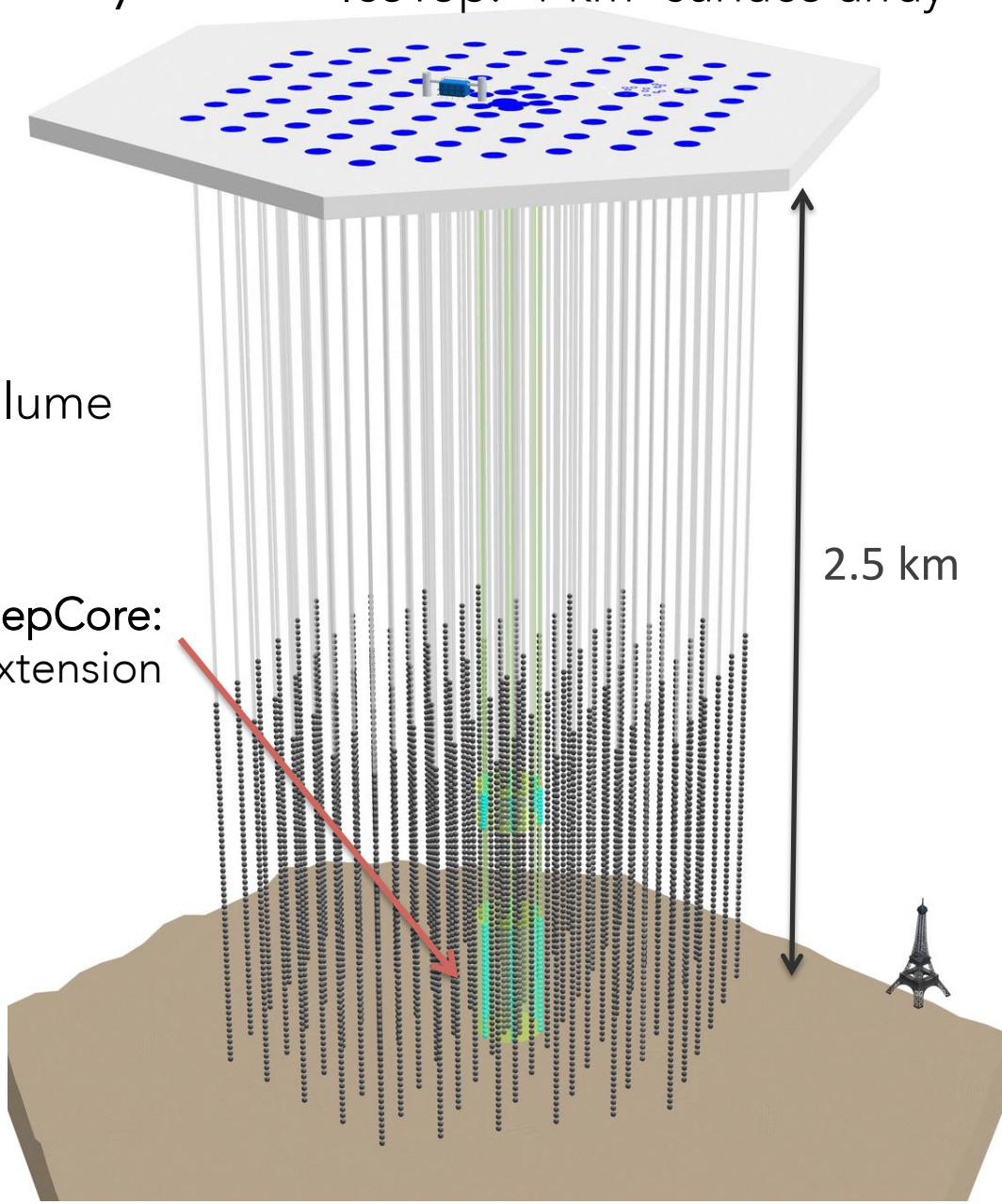
Began full operations May 2011

Highly stable operation.

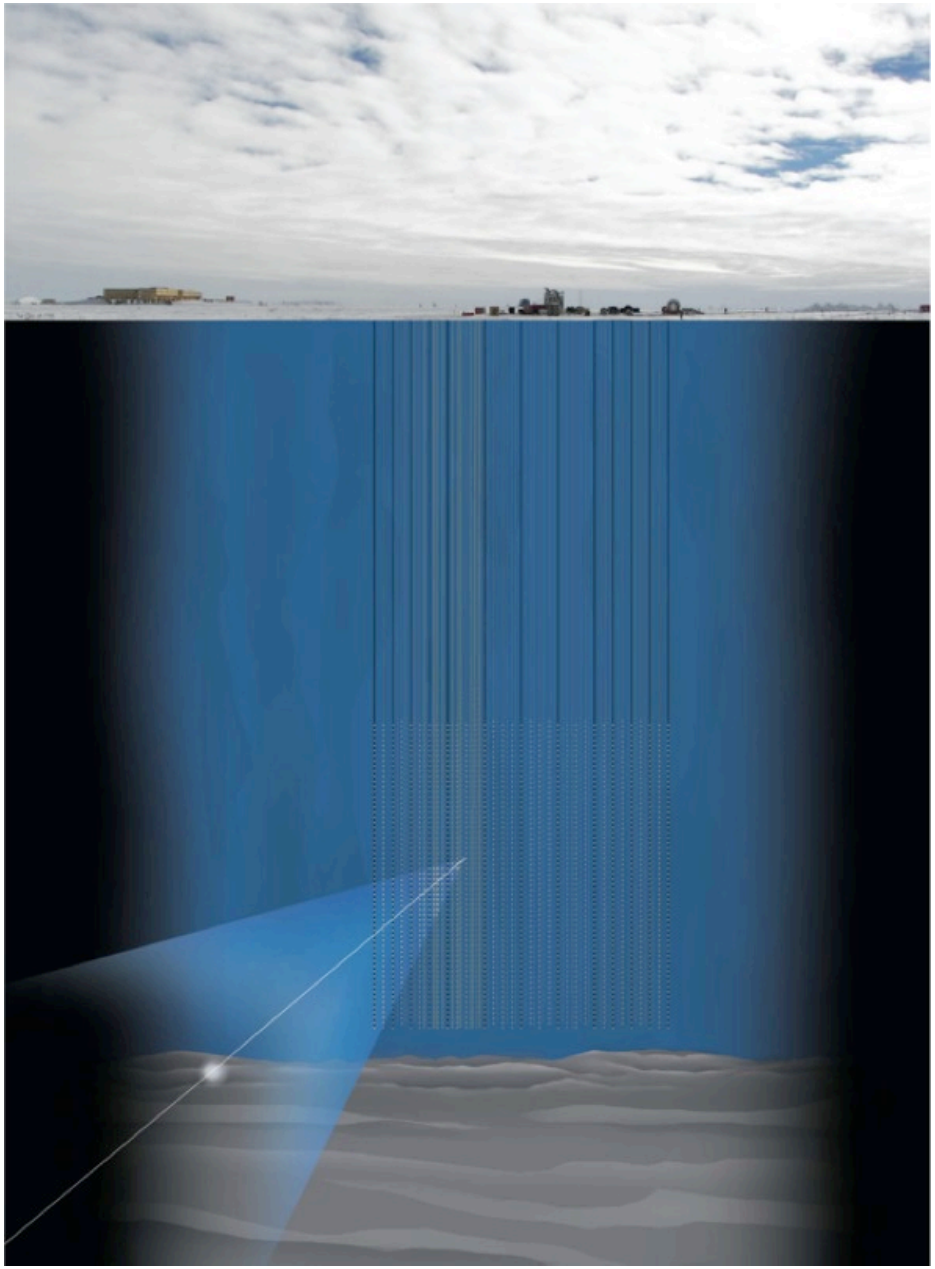
Since 2014: livetime > 99%

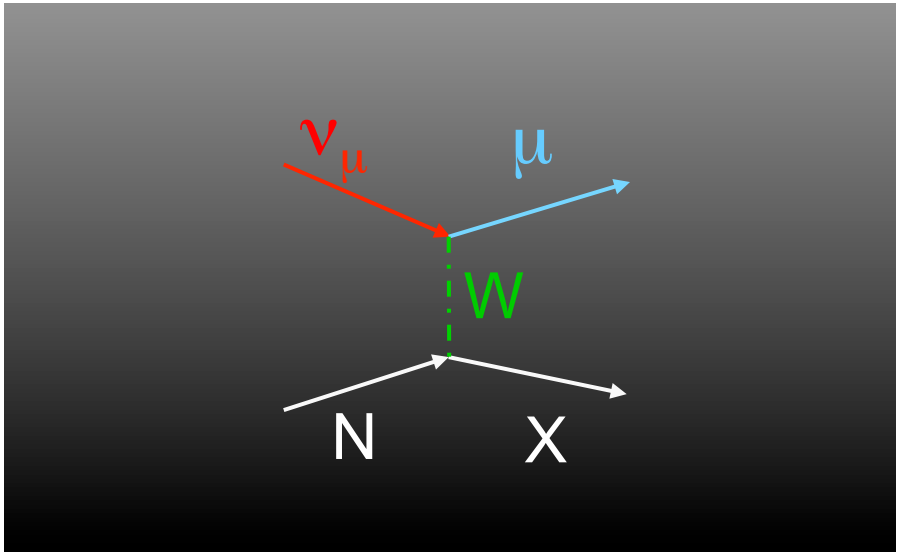
clean-uptime 97-98%

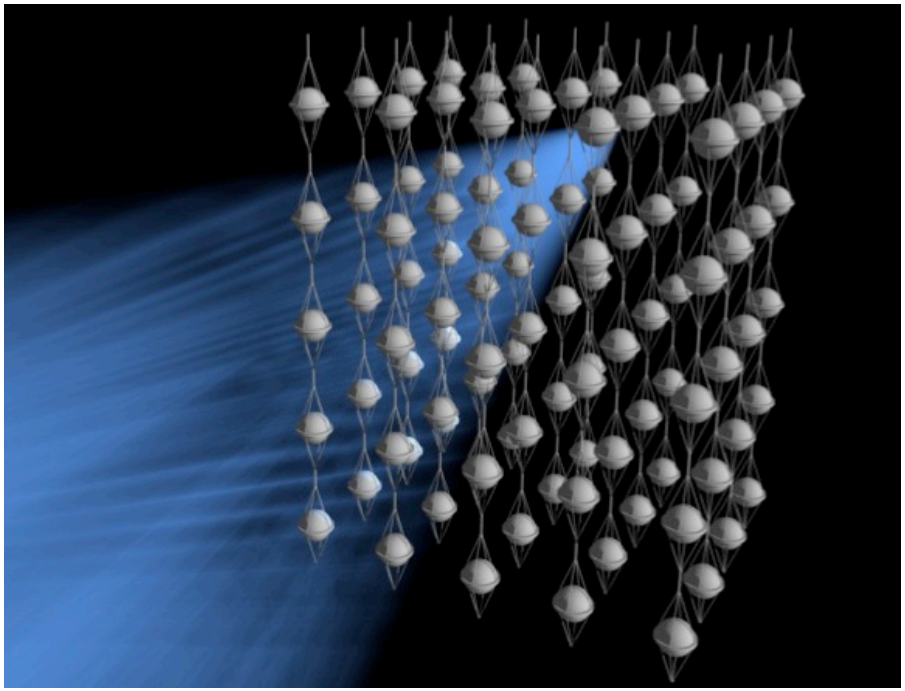
(analysis-ready, full-detector data)



High Energy Neutrino Detection Principles





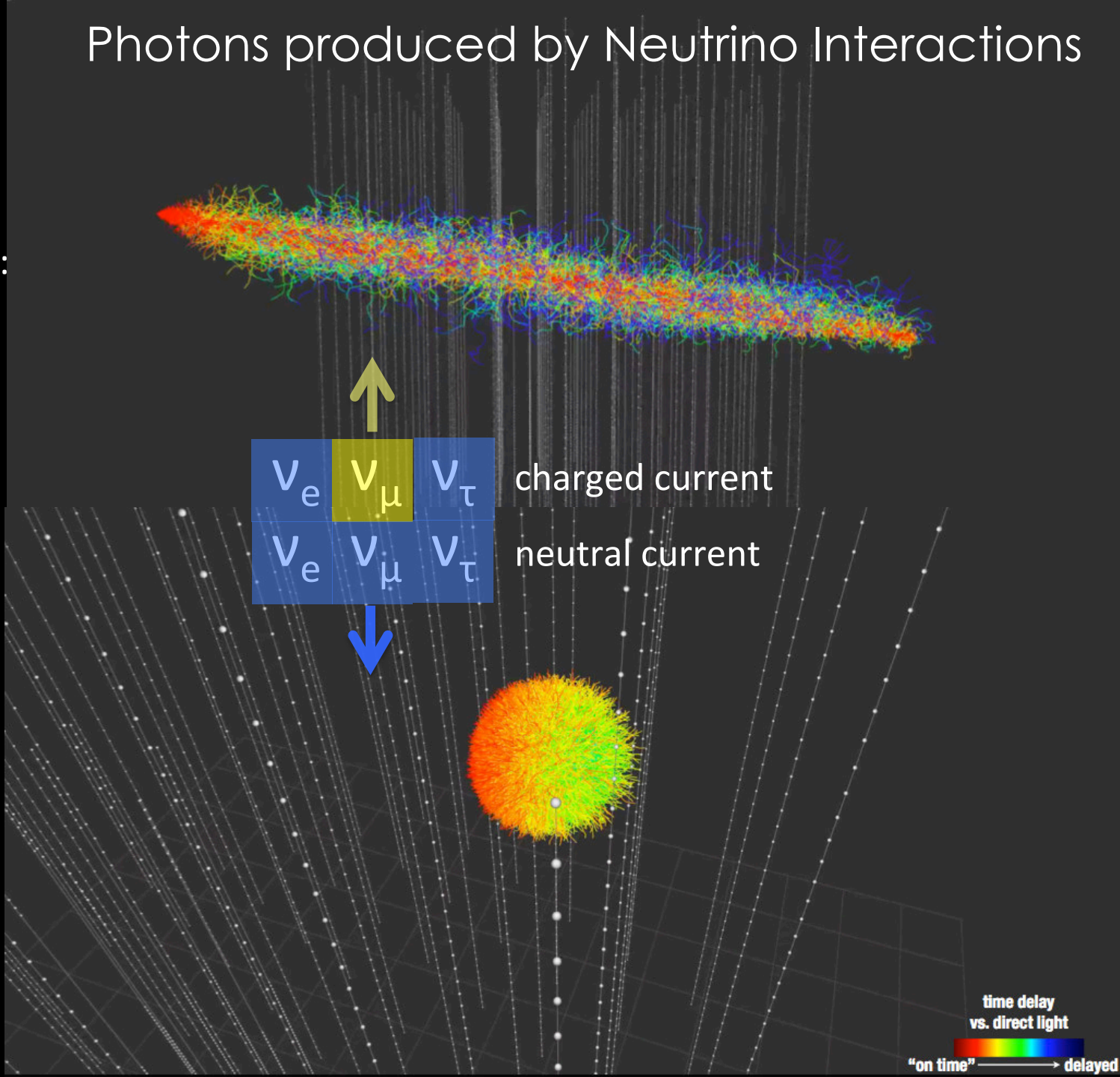


Photons produced by Neutrino Interactions

Track topology

Energy measured: lower bound

Good pointing: 0.2° - 1°

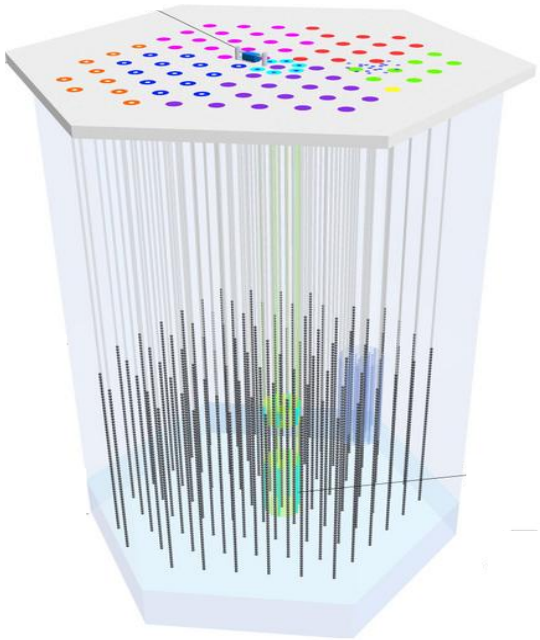


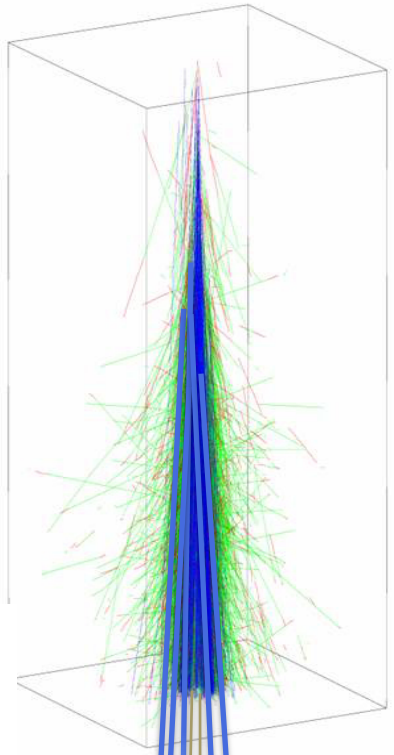
Cascade topology

Good energy resolution, 15%

Some pointing, 10° - 15°

Cosmic Ray-induced events in IceCube





cosmic ray

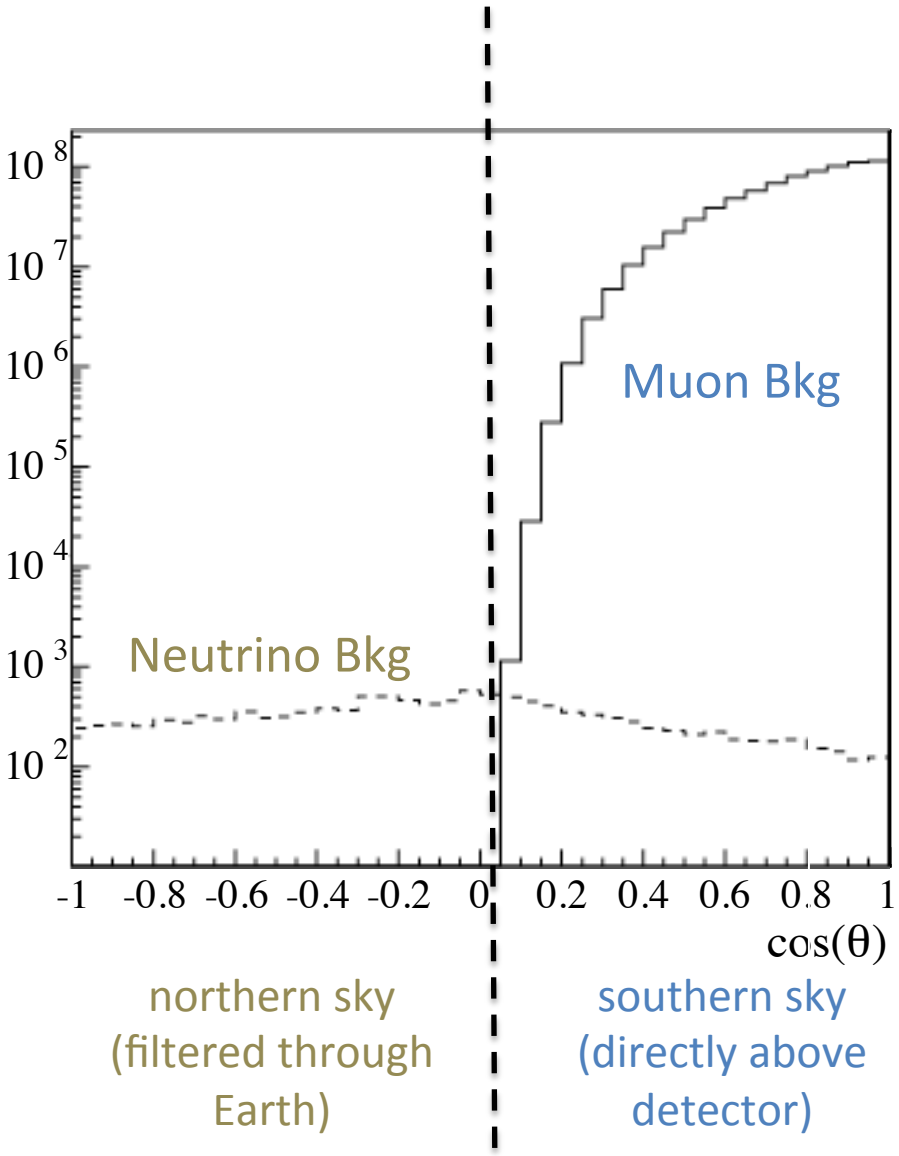
air shower

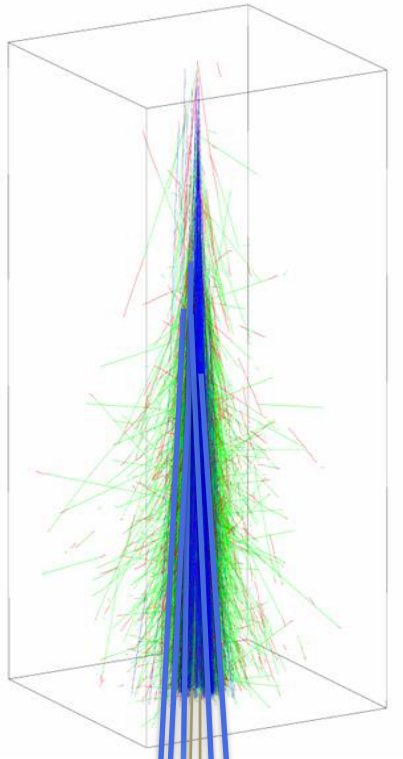
atmospheric muons

atmospheric neutrinos

astrophysical neutrino

Cosmic Ray-induced events in IceCube





cosmic ray

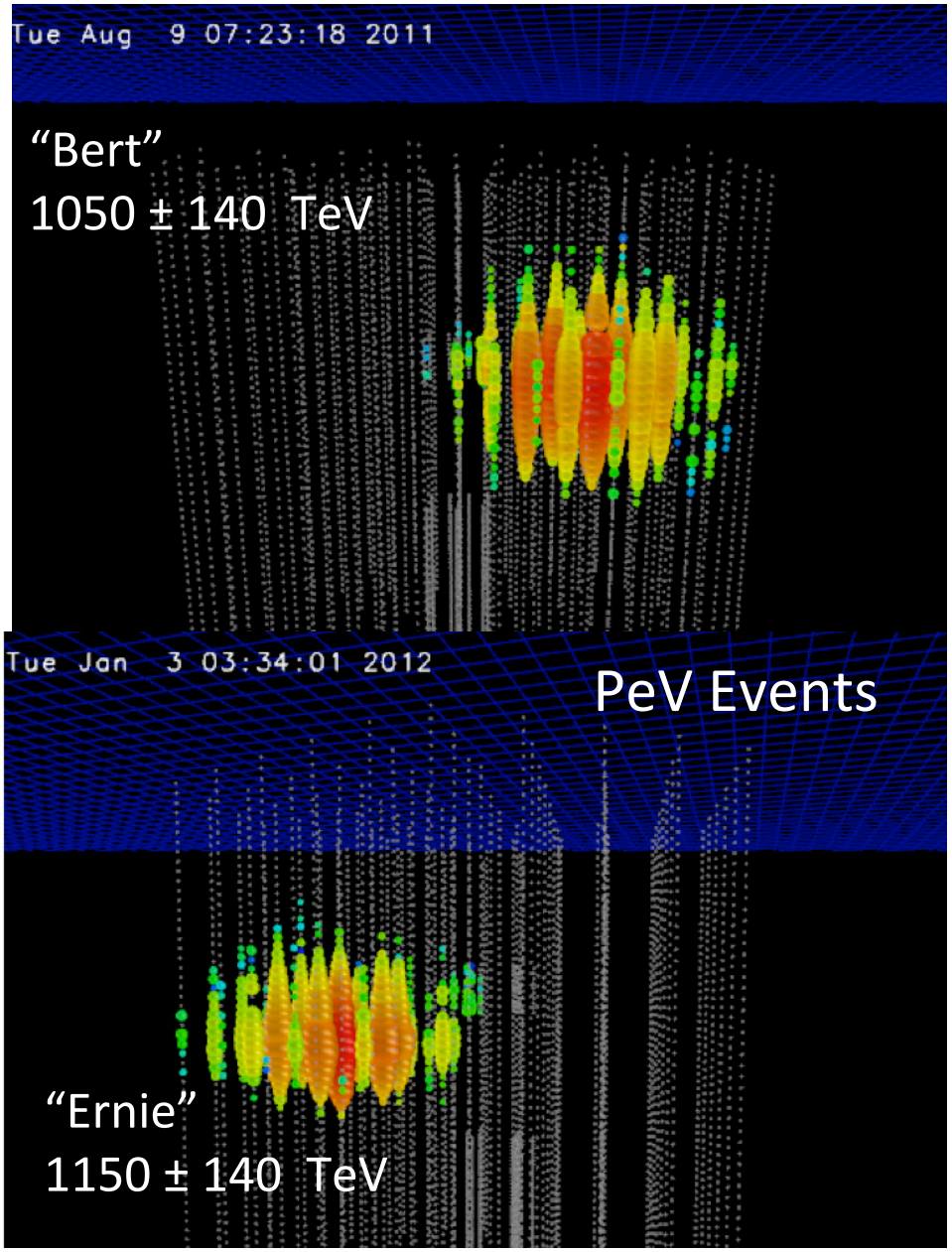
air shower

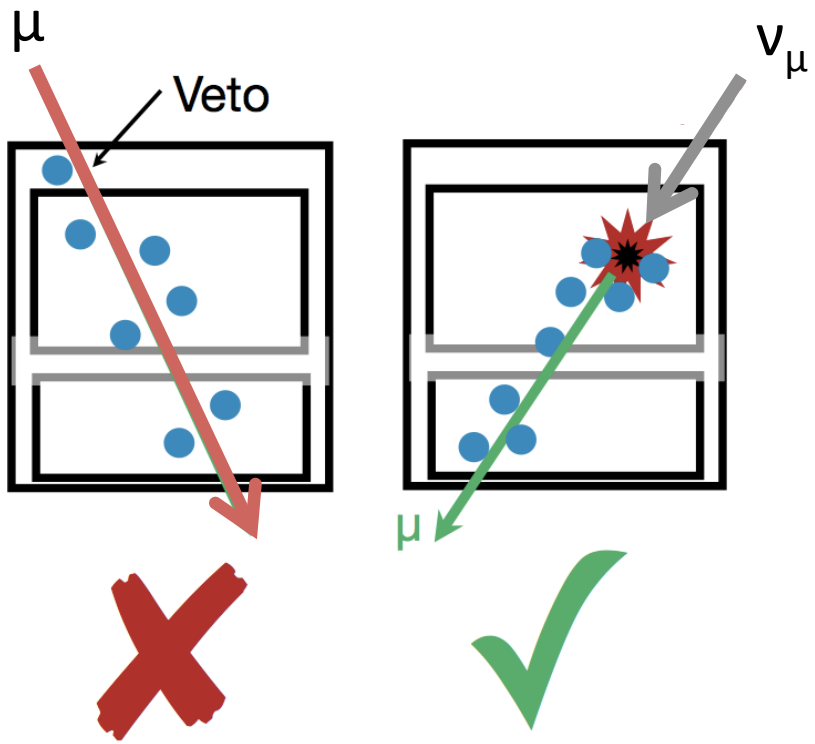
atmospheric muons 10^{11} / yr

atmospheric neutrinos 10^5 / yr

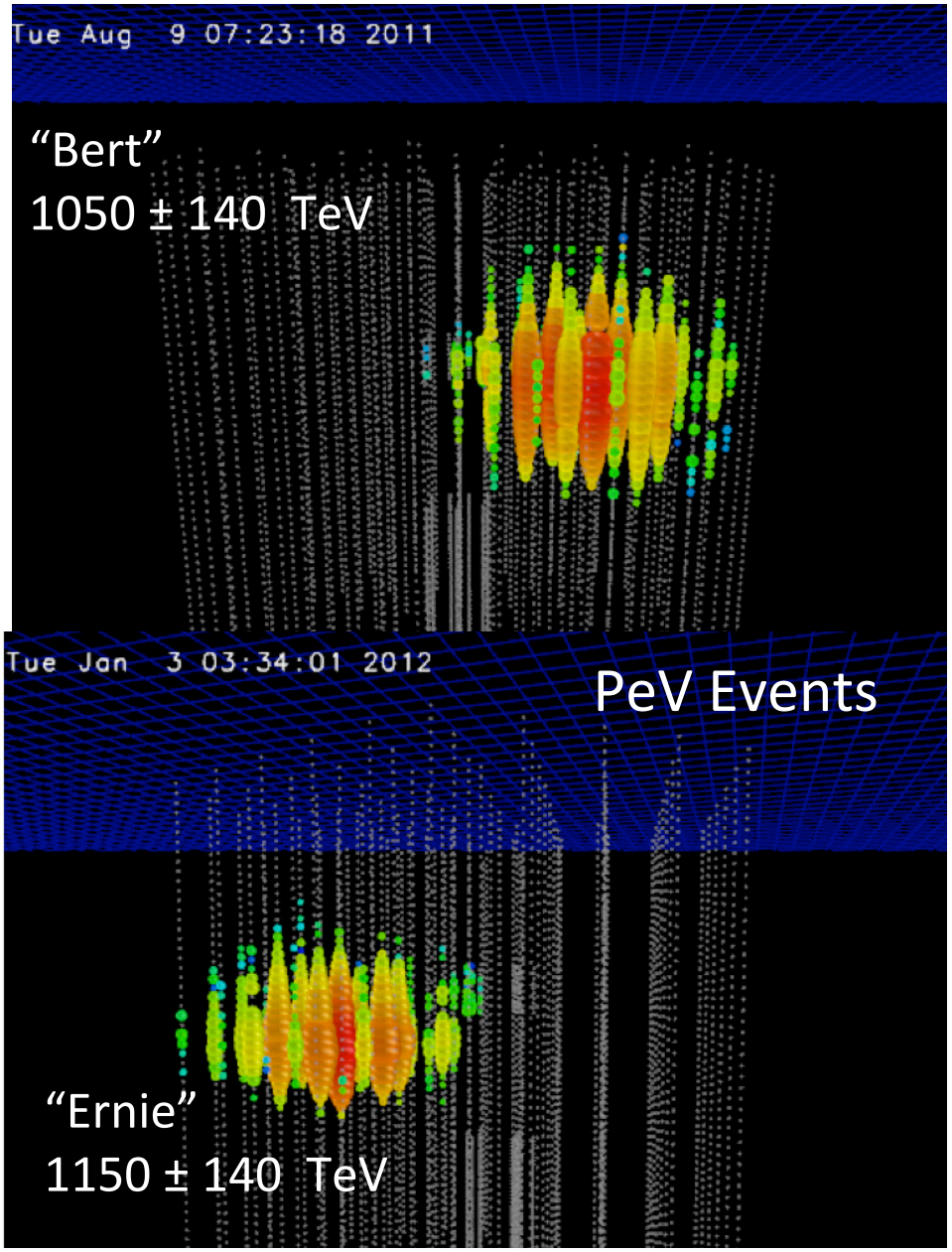
astrophysical neutrino

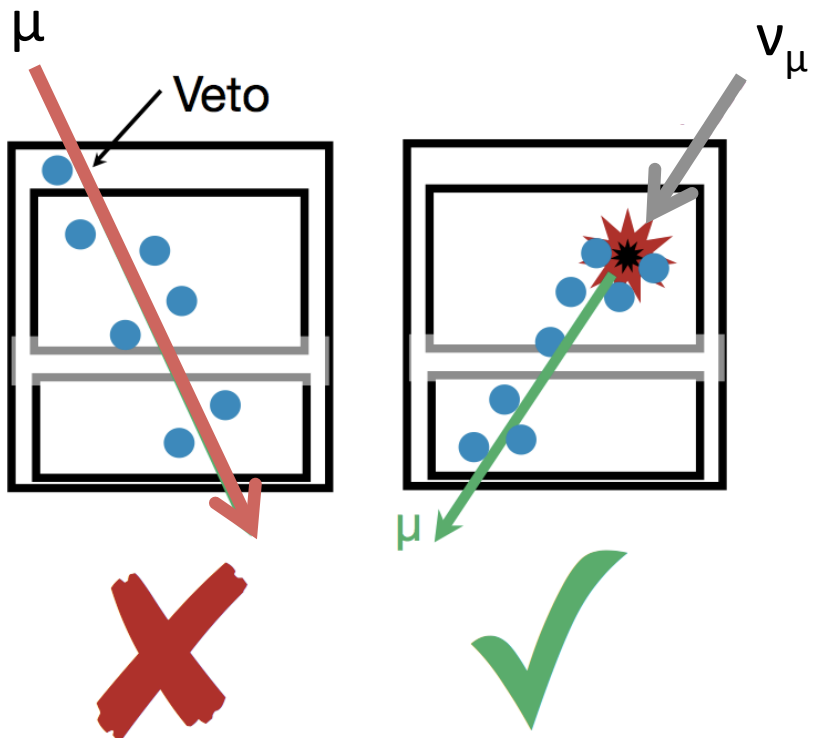
Starting Event Analyses





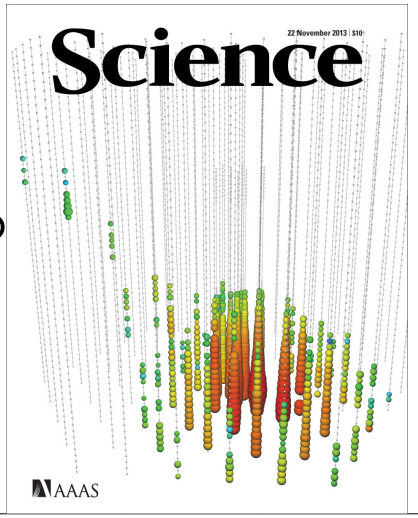
Starting Event Analyses





HESE (High Energy Starting Events):

- Do not start in veto region
- Have at least 6000 photoelectrons



Medium Energy Starting Events

More sophisticated analysis:

Nested layering of vetoes

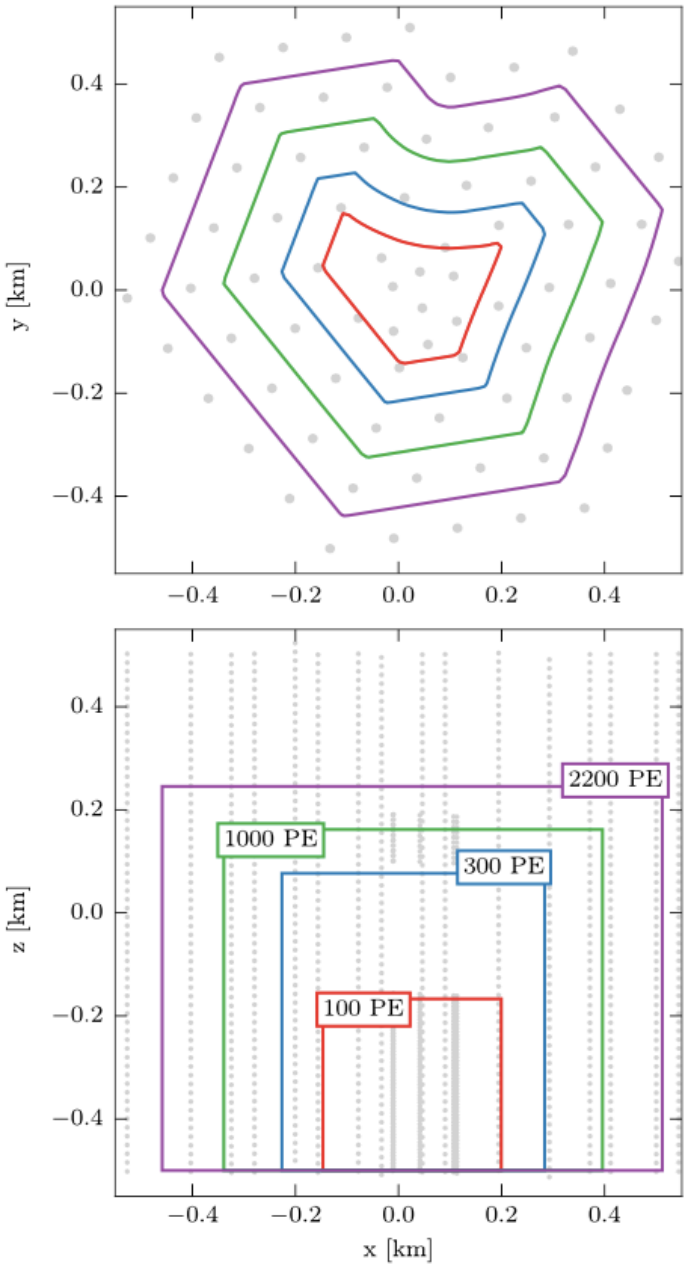
Lower-energy neutrinos retained if starting deep within detector

First 2-year analysis: 388 events

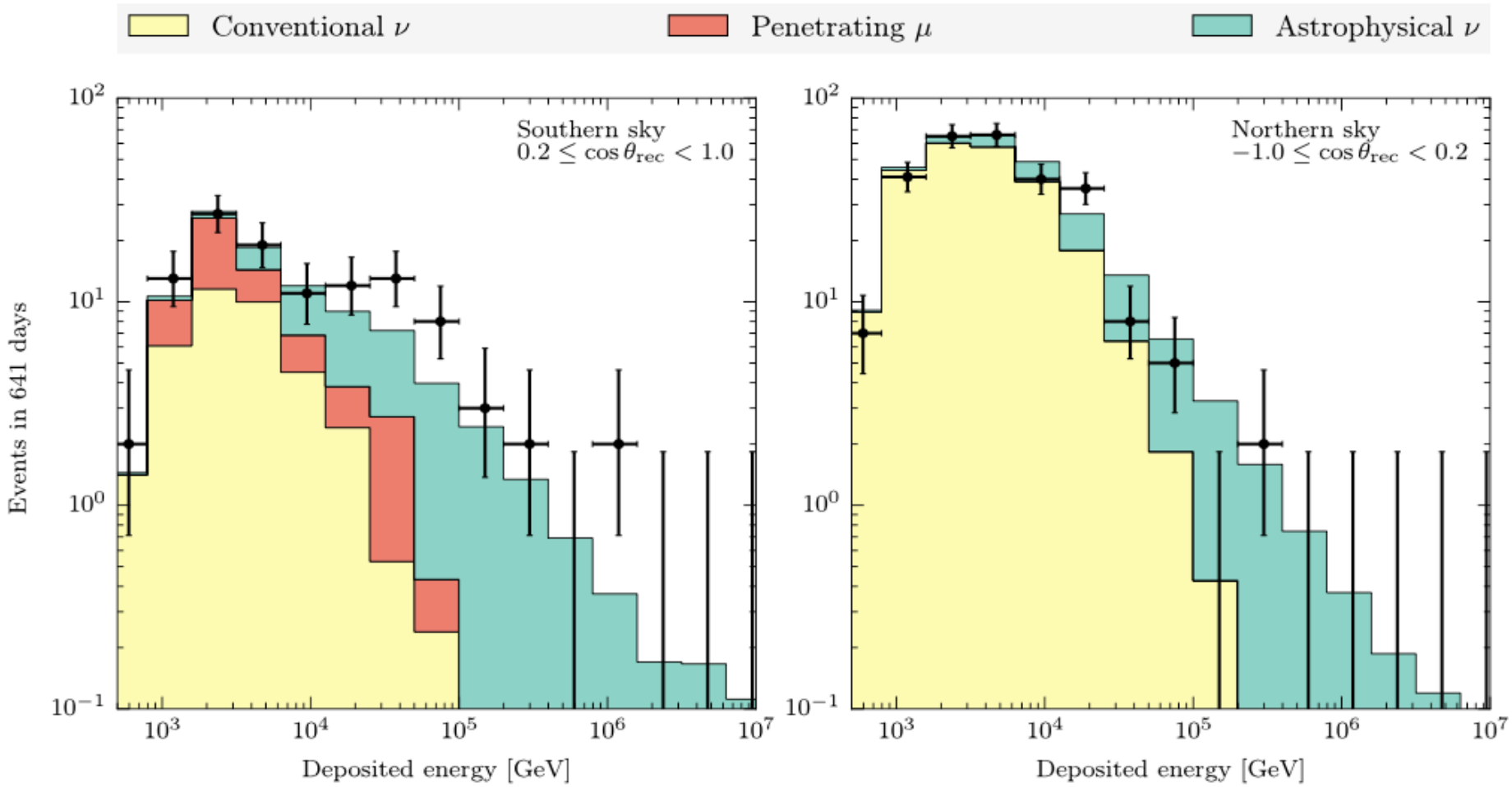
Both starting tracks and cascades

Best-fit: 87 ± 14 astrophys. neutrinos

PRD 91:022001 (2014)



Medium Energy Starting Events



Best-fit astrophysical spectral index $E^{-\gamma}$: $\gamma = 2.46 \pm 0.12$

For the neutrino energy range 20 TeV – 2 PeV

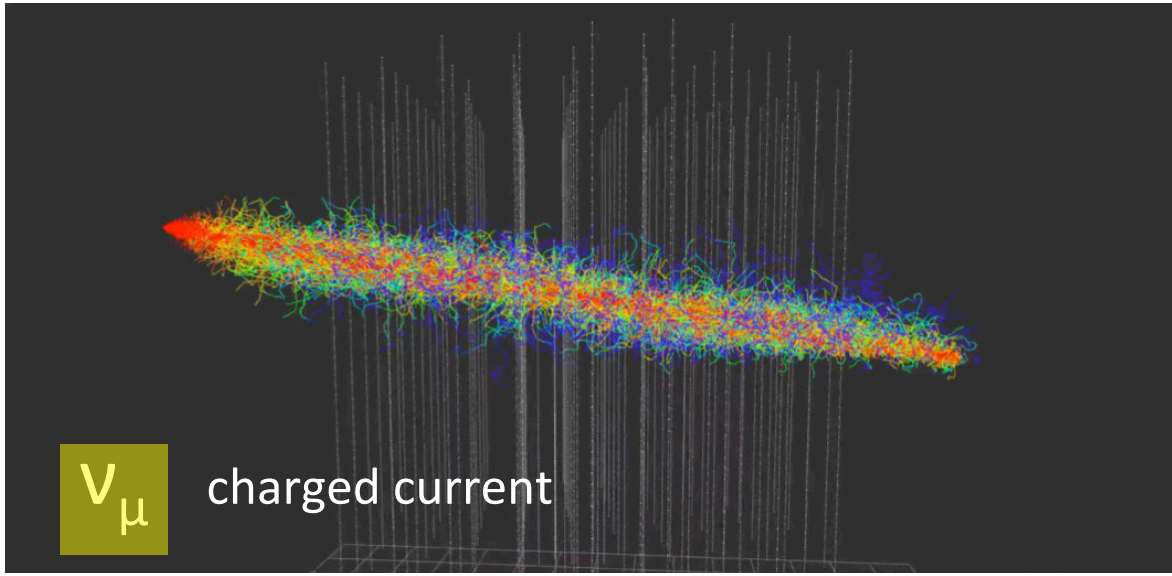
Muon Neutrino Diffuse Analysis

Complementary analysis to Starting Event analysis

Allow tracks to enter from outside detector

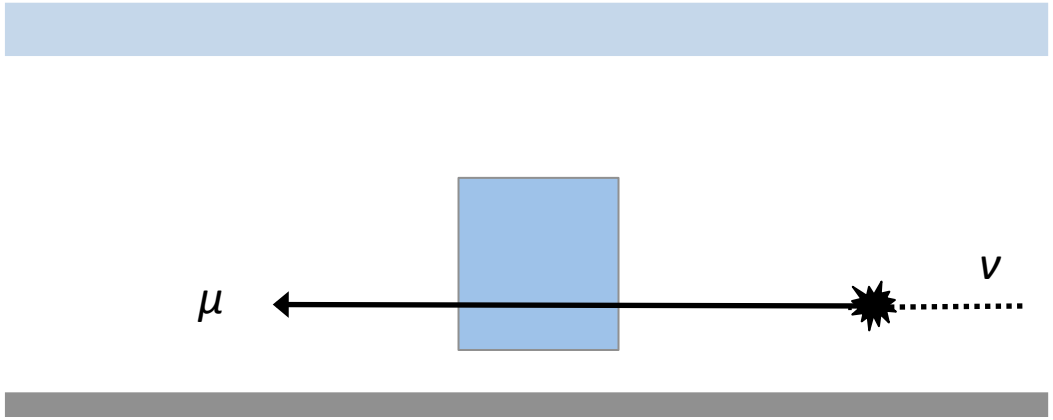
Use Earth as filter against muons from cosmic rays

→ muon neutrino analysis

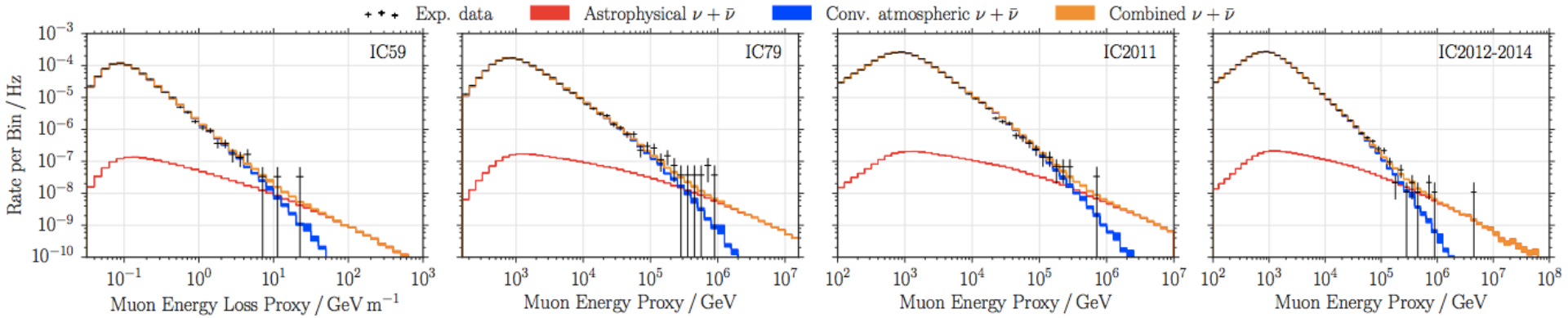


$\log_{10}$ muon energy resolution ~ 0.3 (at energies ~ 100 TeV)

Good pointing: ~ 0.4°



Diffuse Flux with Muon Neutrinos

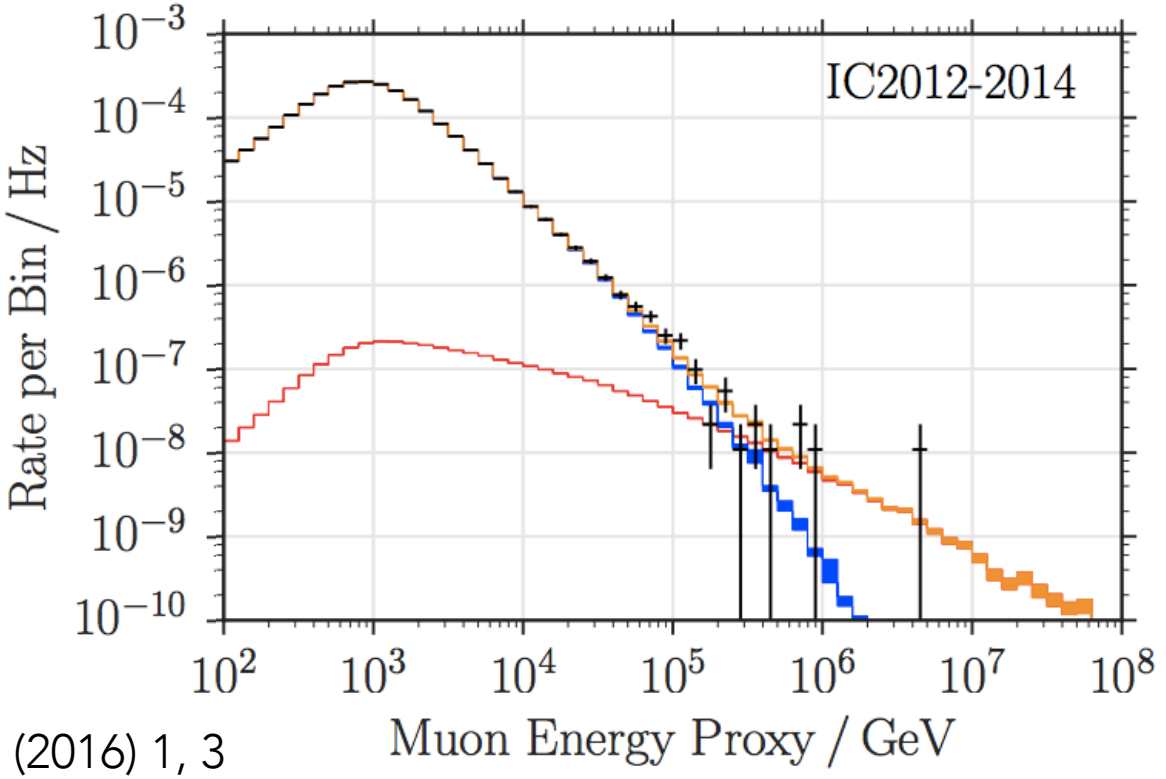


Upgoing or Horizontal track = Earth-filtered

350 000 events in 6-year analysis

Estimated 99.7% pure muon-neutrino sample

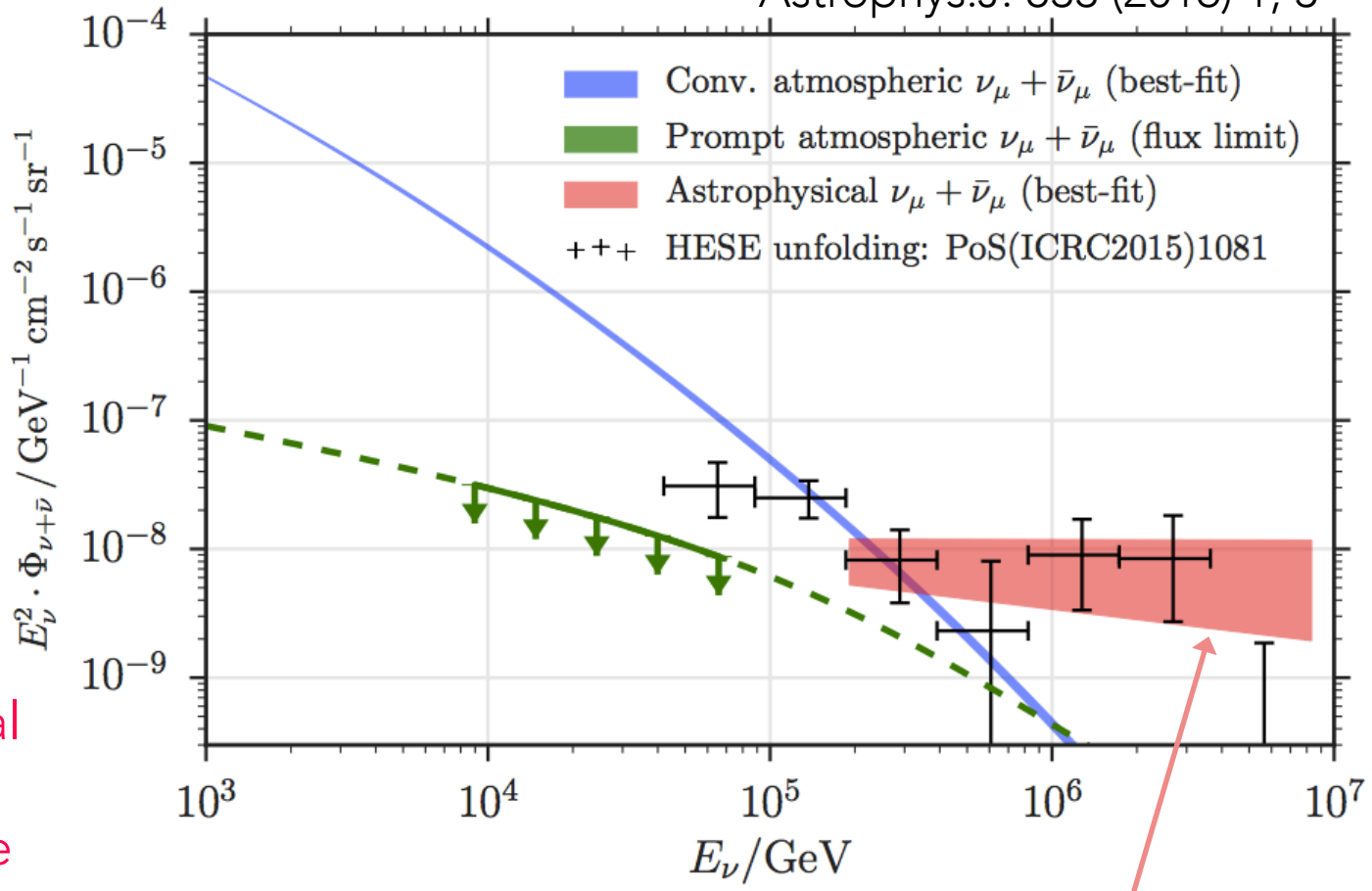
5.6σ for astrophysical flux



Astrophys.J. 833 (2016) 1, 3

Diffuse Flux with Muon Neutrinos

Astrophys.J. 833 (2016) 1, 3



Fit the astrophysical neutrino flux in the energy range 190 TeV – 8 PeV

Best fit:

$$\Phi_{\nu+\bar{\nu}} = \left(0.90^{+0.30}_{-0.27}\right) \cdot \left(E_\nu/100\,\mathrm{TeV}\right)^{-(2.13\pm0.13)}$$

in units of $10^{-18}\,\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{s}^{-1}$

Energy Spectrum of Astrophysical Neutrinos

Analysis based primarily on cascades:

$\gamma = 2.5 \pm 0.1$

Based on northern sky ν_μ tracks:

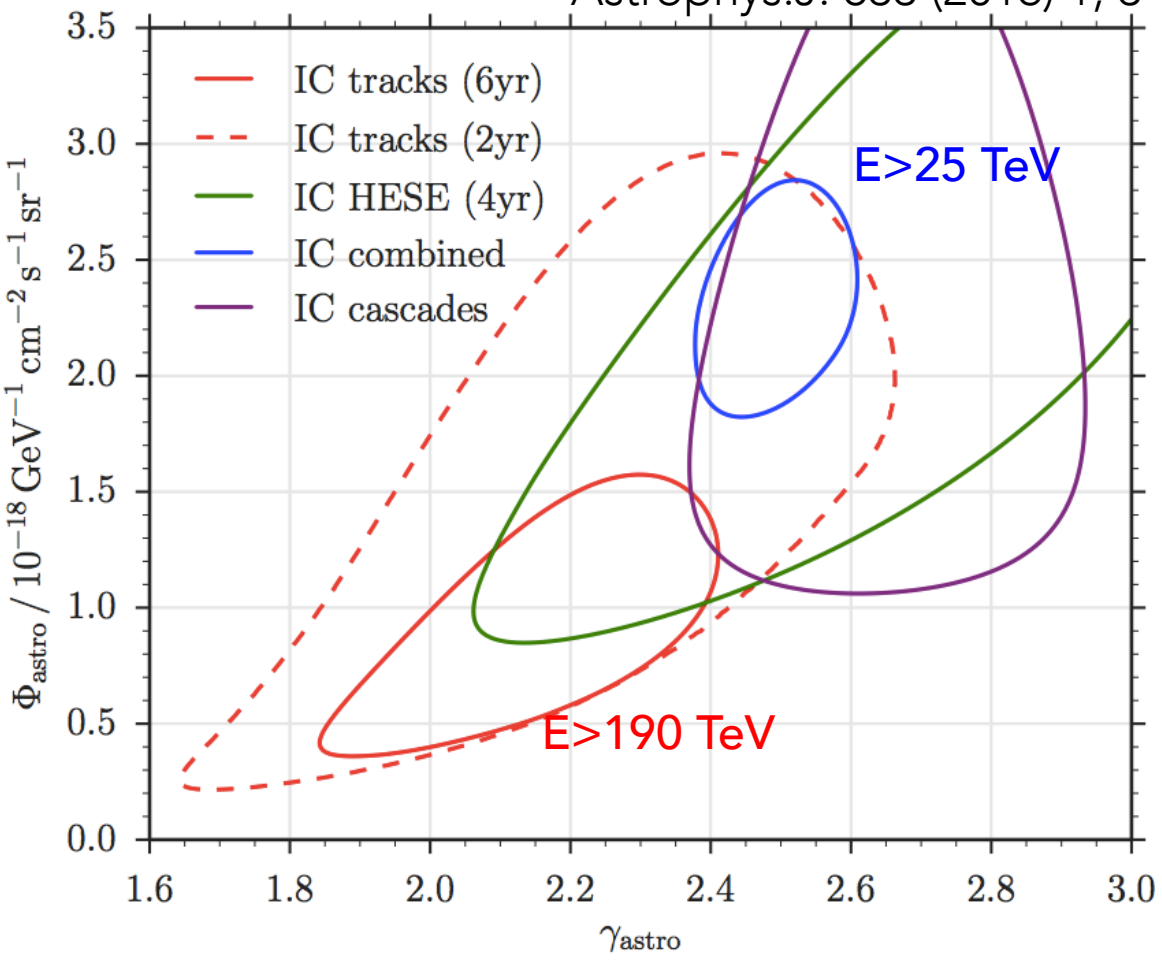
$\gamma = 2.1 \pm 0.1$

3.3σ tension...

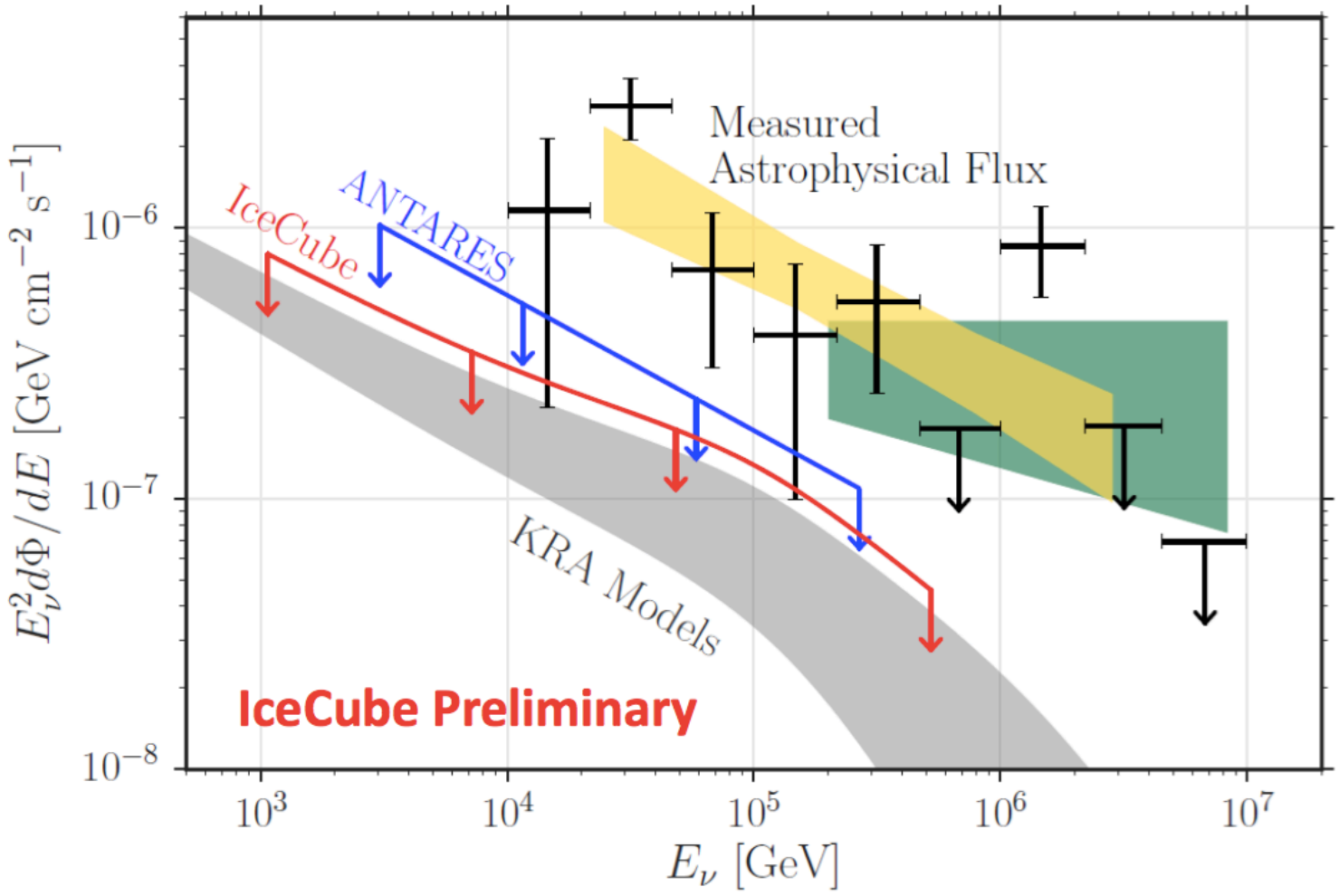
Could be: change in the power-law spectrum above 100 TeV...

Could be: softer component in southern sky due to galactic contribution...

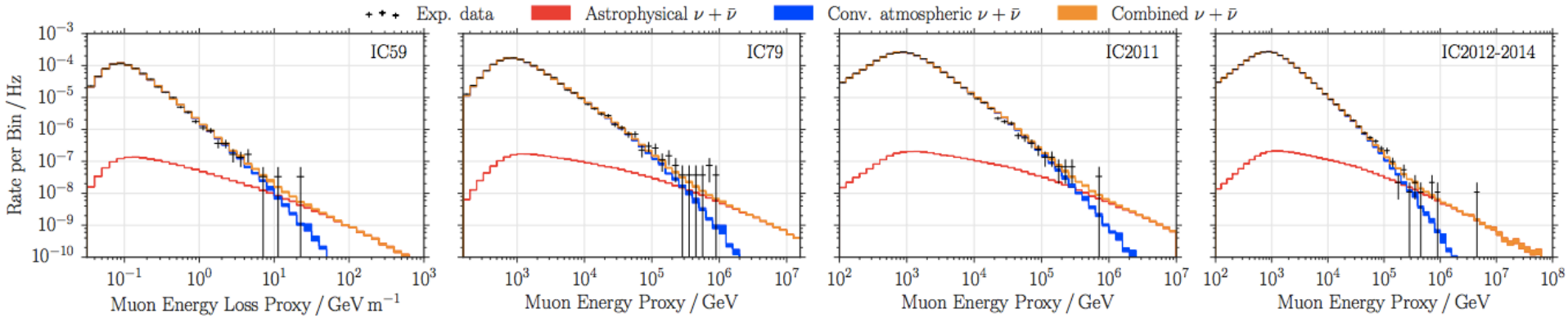
Astrophys.J. 833 (2016) 1, 3



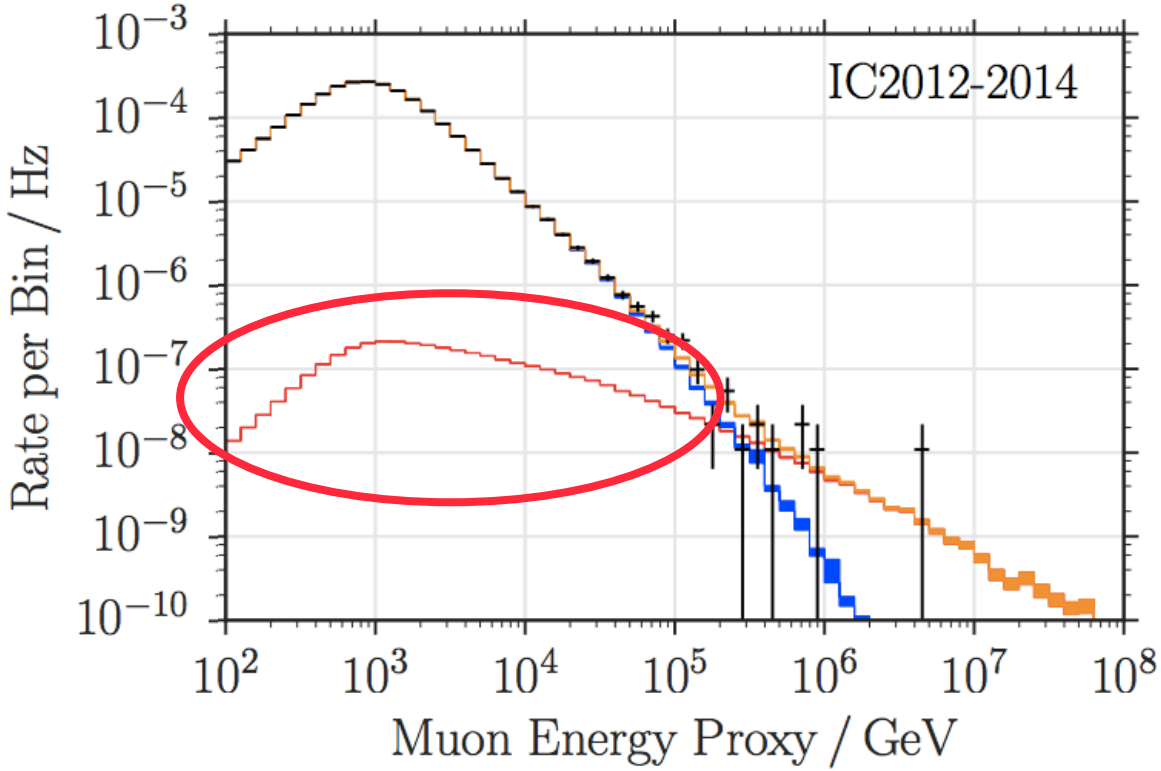
Galactic Plane Searches



Christian Haack, Jon Dumm, parallel session

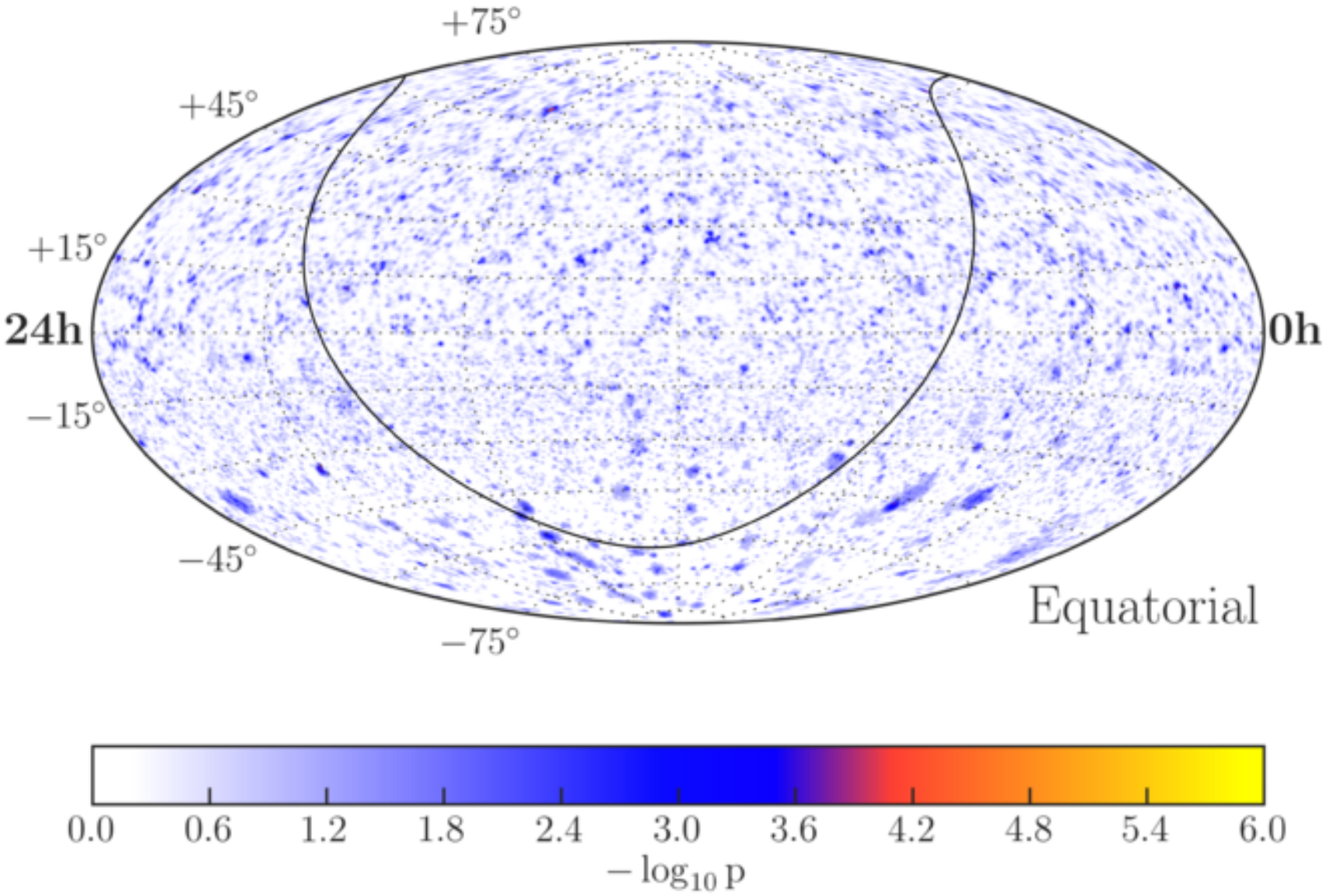


Hundreds of astrophysical neutrinos, hidden in background of atm. neutrinos

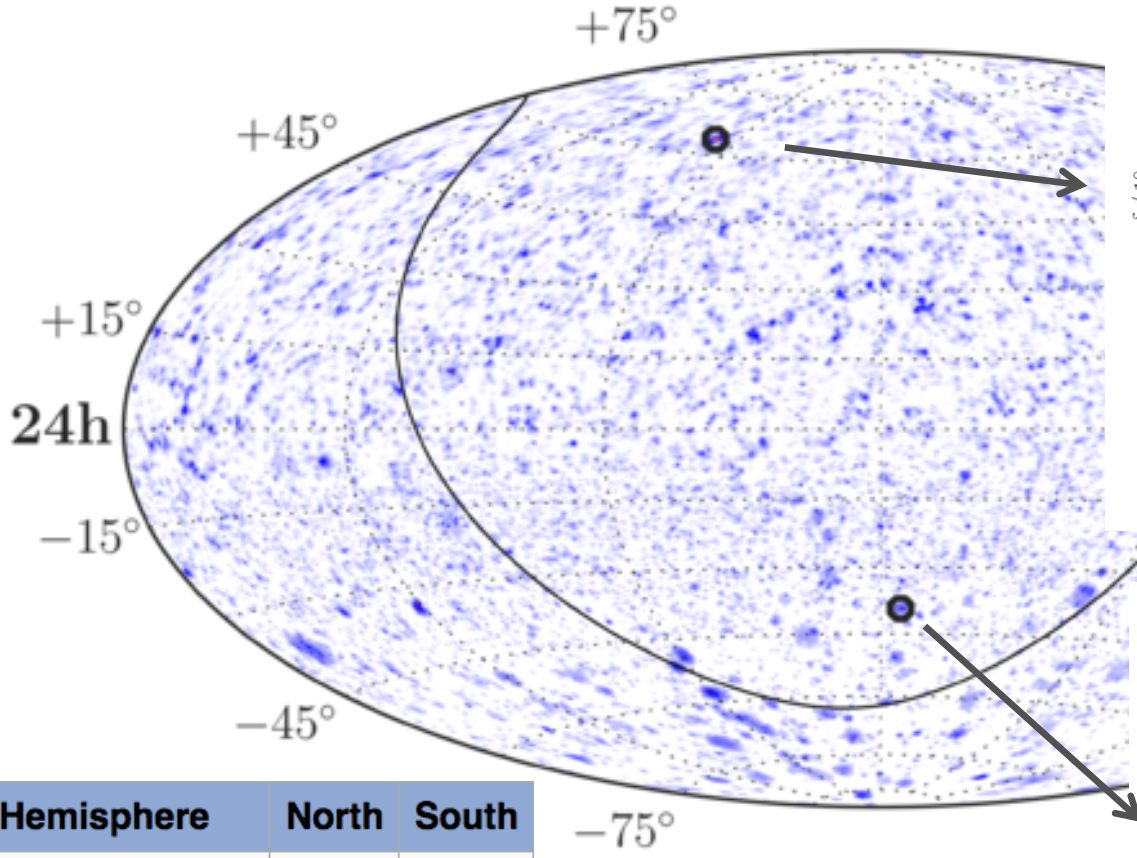


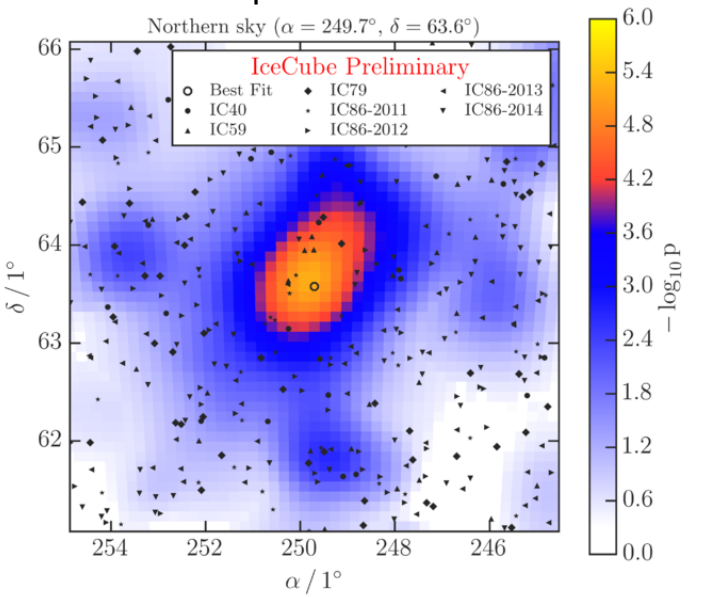
7-year Point Source Search

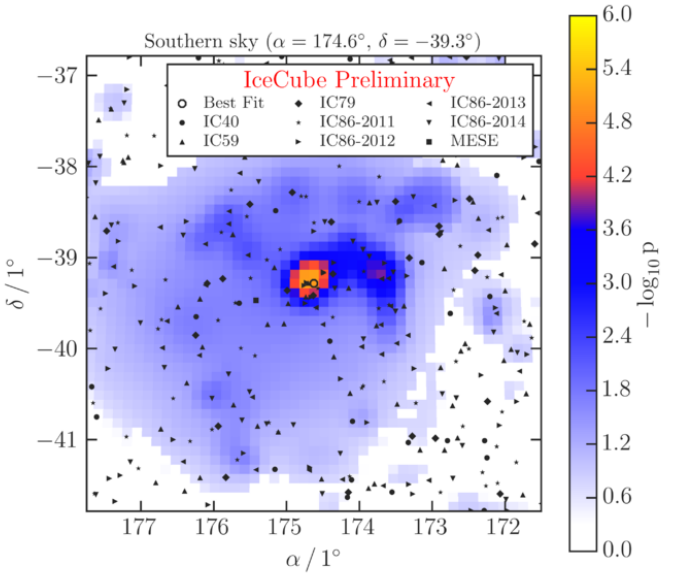
ApJ 835 (2017) 2, 151



7-year Point Source Search ApJ 835 (2017) 2, 151

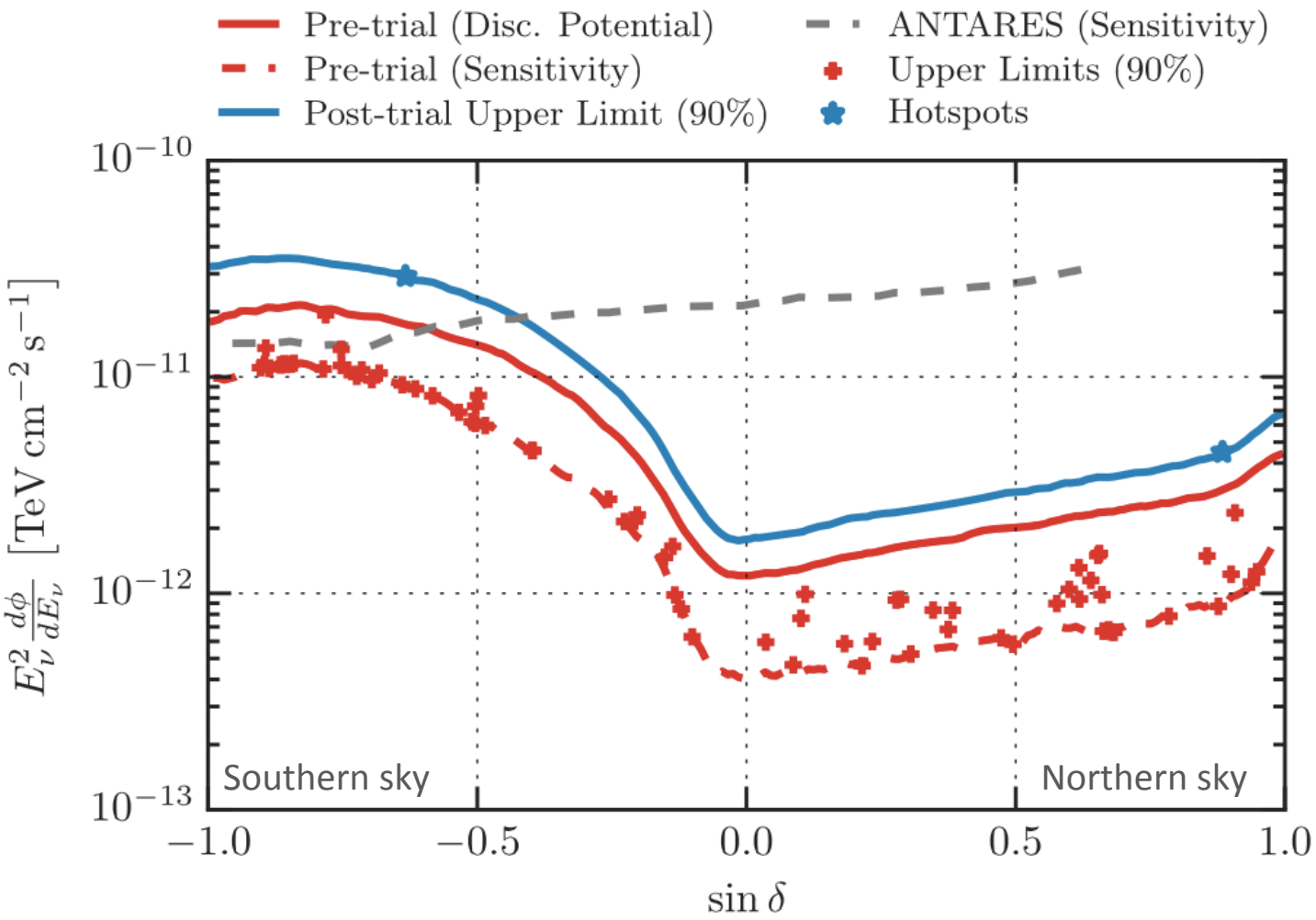






Hemisphere	North	South
N_Sources	27.22	15.54
Gamma	1.95	2.84
Test statistic	18.99	20.26
-log10(Pre-Trial P)	5.24	5.33
Post Trial P	44%	39%

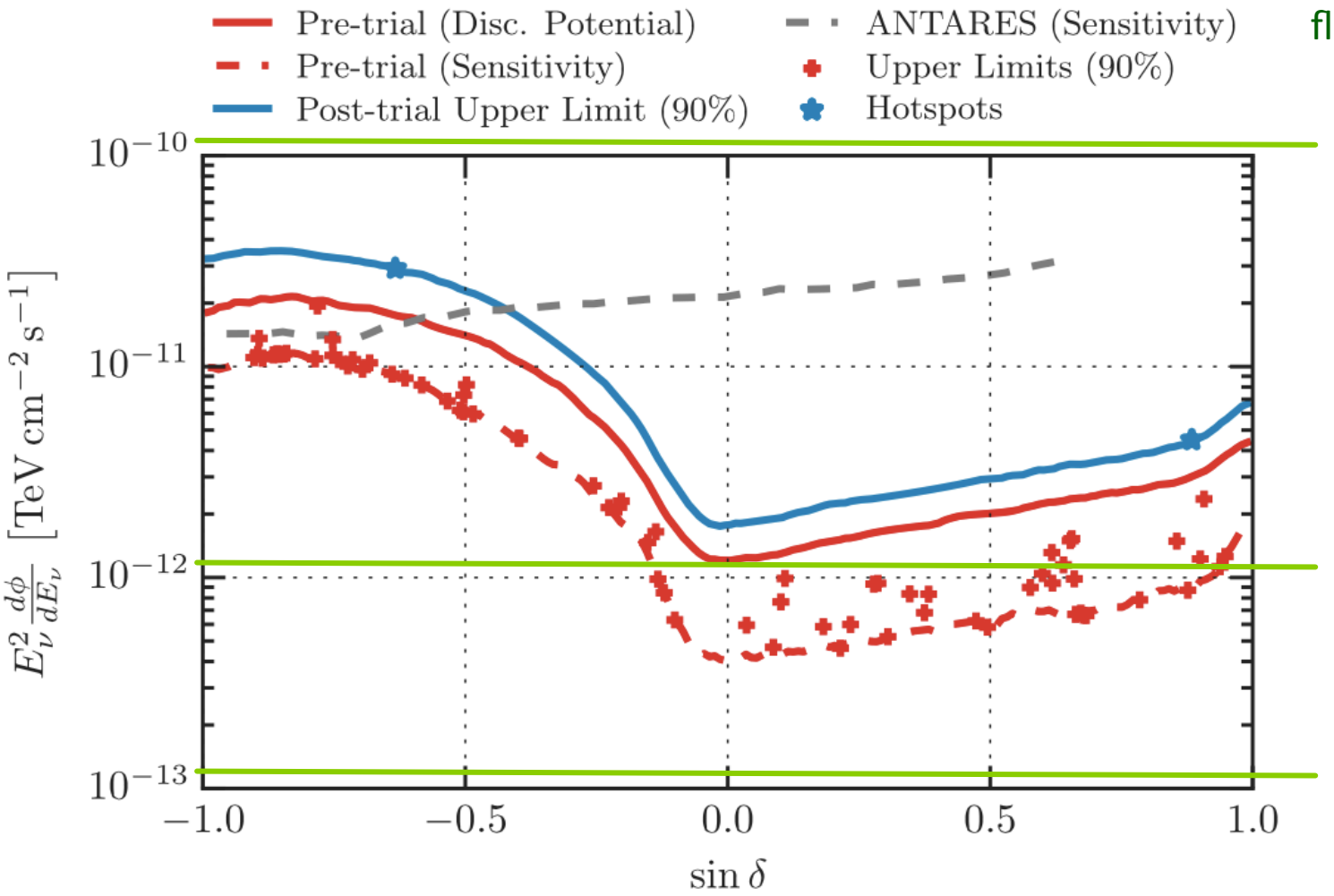
7-year Point Source Search



ApJ 835 (2017) 2, 151

Relating Diffuse and Point Source fluxes

Point-source equivalent flux if the diffuse astrophysical flux came from:



one point in the sky

100 points in the sky

1000 points in the sky

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Population studies with Stacking Searches

Point-Source Population Study: Blazars

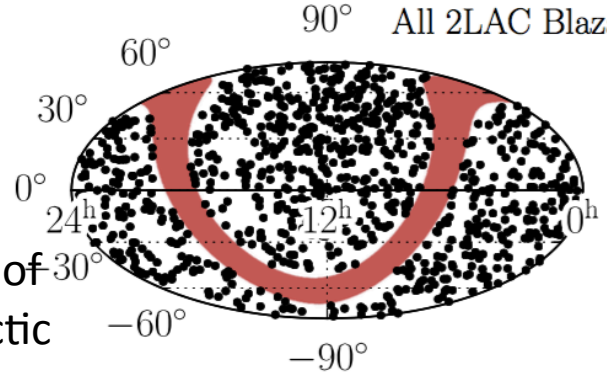
Stacked Neutrino Point Source Search

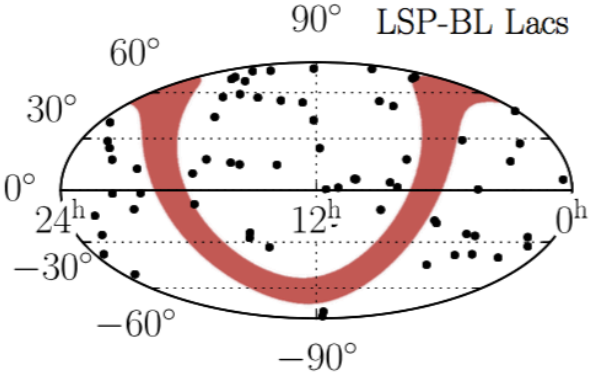
using Fermi LAT catalog of 862 Blazars (active galactic nuclei whose jets point directly at us)

No significant excess seen

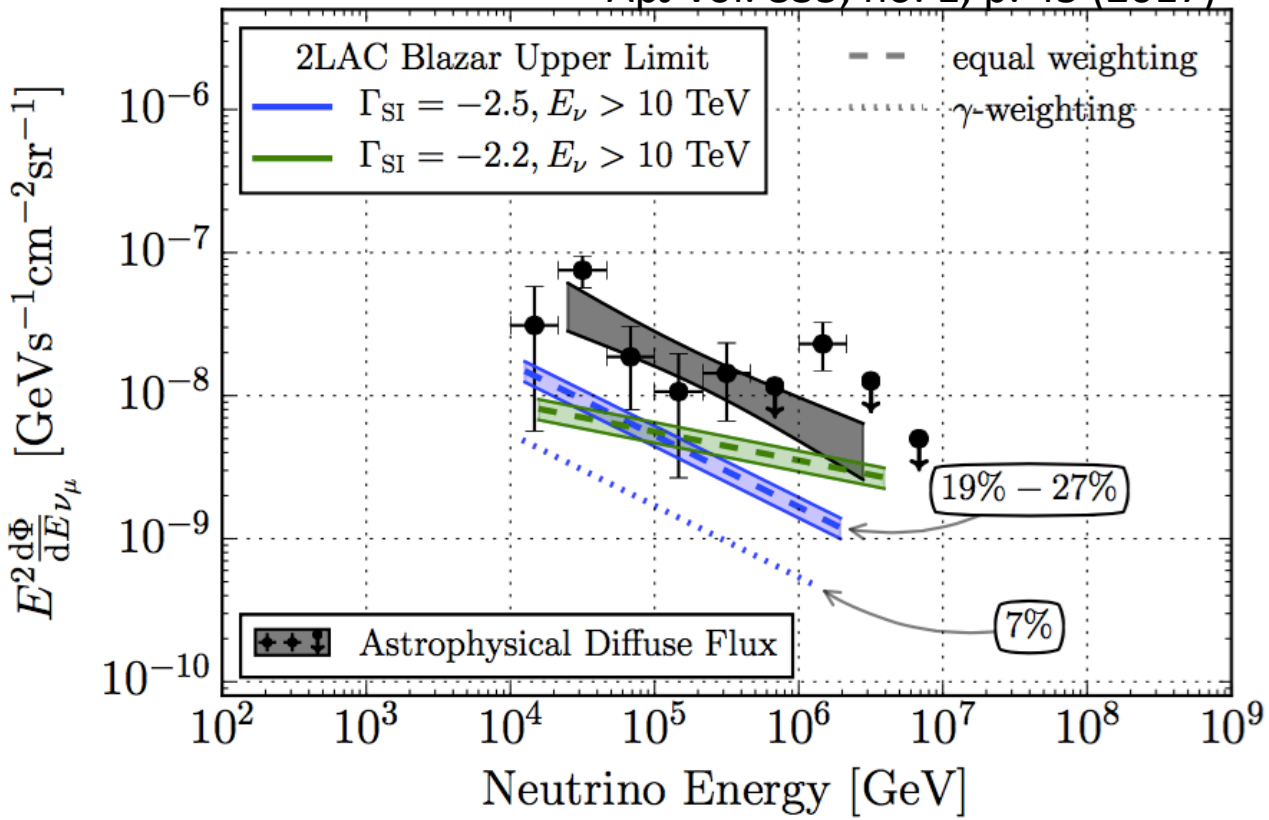
Total flux upper limit is below measured diffuse neutrino flux

Gamma-ray Bursts already excluded, < 1% of diffuse astrophysical neutrino flux





ApJ vol. 835, no. 1, p. 45 (2017)



Realtime Public Alerts via AMON, GCN

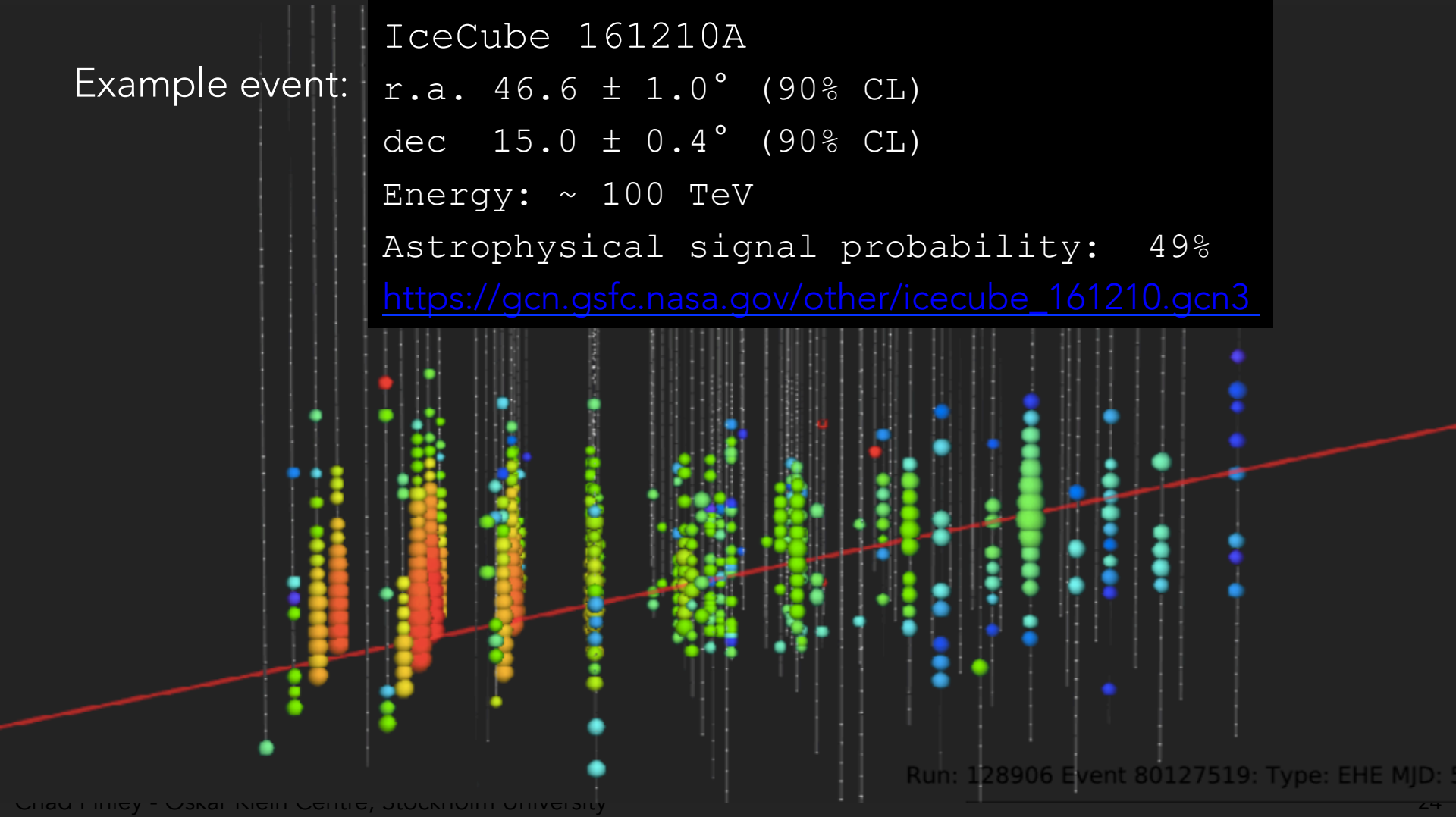
Operating since April 2016 (second filter stream added during summer)

~~9~~ 10 alerts in first year

Example event:

```
IceCube 161210A
r.a. 46.6 ± 1.0° (90% CL)
dec  15.0 ± 0.4° (90% CL)
Energy: ~ 100 TeV
Astrophysical signal probability:  49%
```

https://gcn.gsfc.nasa.gov/other/icecube_161210.gcn3



IceCube Realtime Alert System

arXiv:1612.06028

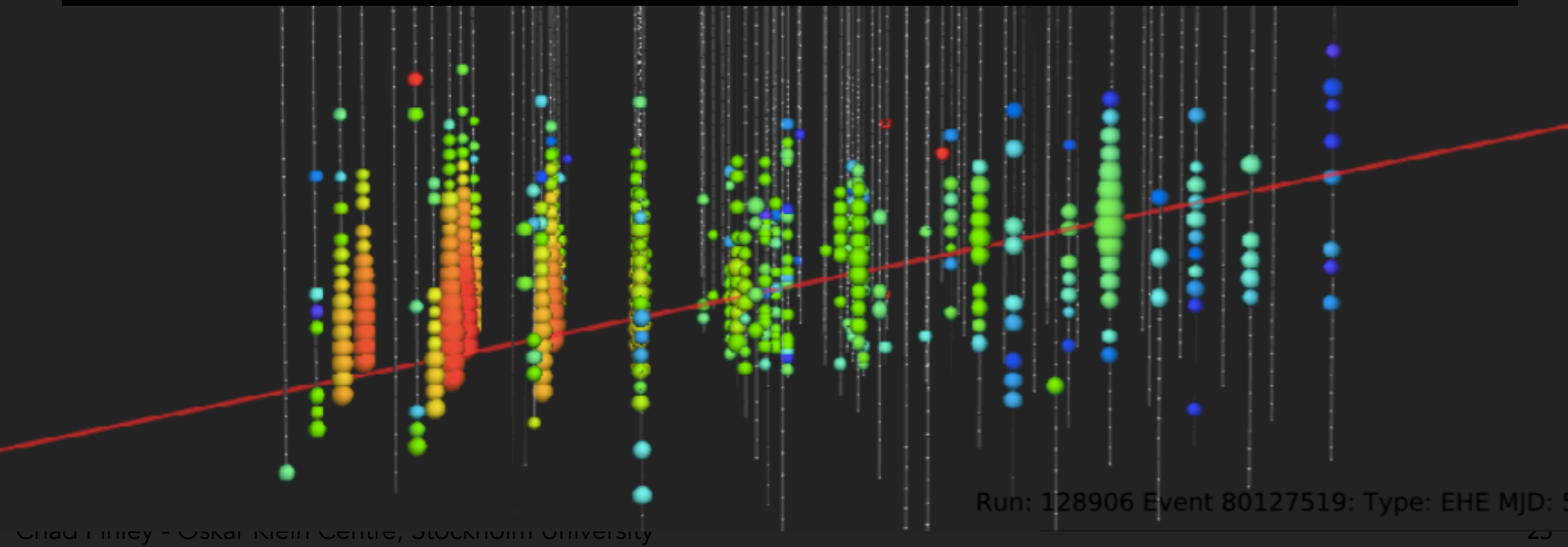
10 alerts in first year

Expect (assuming $E^{-2.6}$ spectrum): 3.5 signal + 5.6 bkg per year

Time from event at South Pole to public alert: < 1 min

For highly signal-like events, many follow-up observations reported:

AGILE, ANTARES, FACT, Fermi-GBM, Fermi-LAT, HAWC, H.E.S.S., INTEGRAL, IPN, Konus-Wind, LCOGT, MAGIC, MASTER, Maxi/GSC, Pan-STARRS, PTF, Swift, VERITAS



Indirect Dark Matter Searches

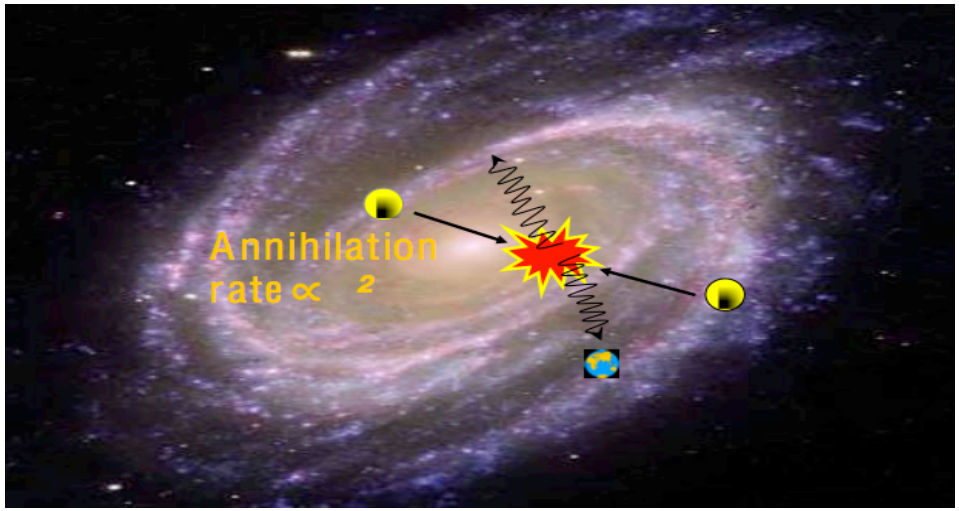
$$\chi + \chi \rightarrow W + W \rightarrow \nu + \nu$$

Neutrinos are typical end products of dark matter annihilation

Galactic Halo Searches:

Annihilation occurs in densest region of dark matter halo in galactic center

Search sensitive to annihilation cross section

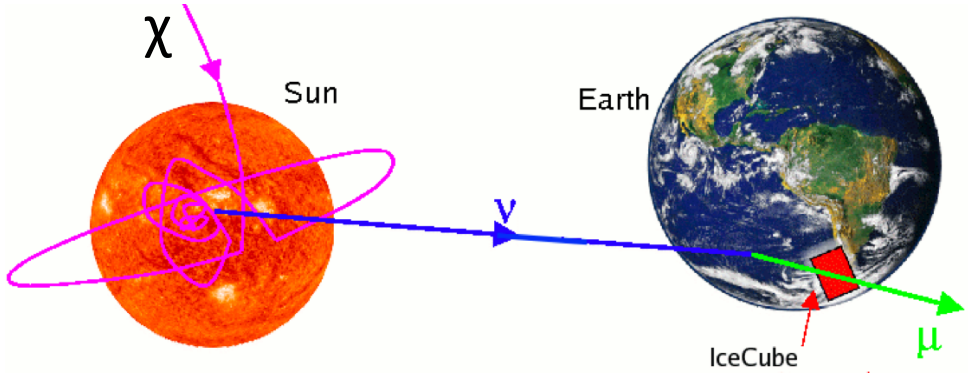


Solar Searches:

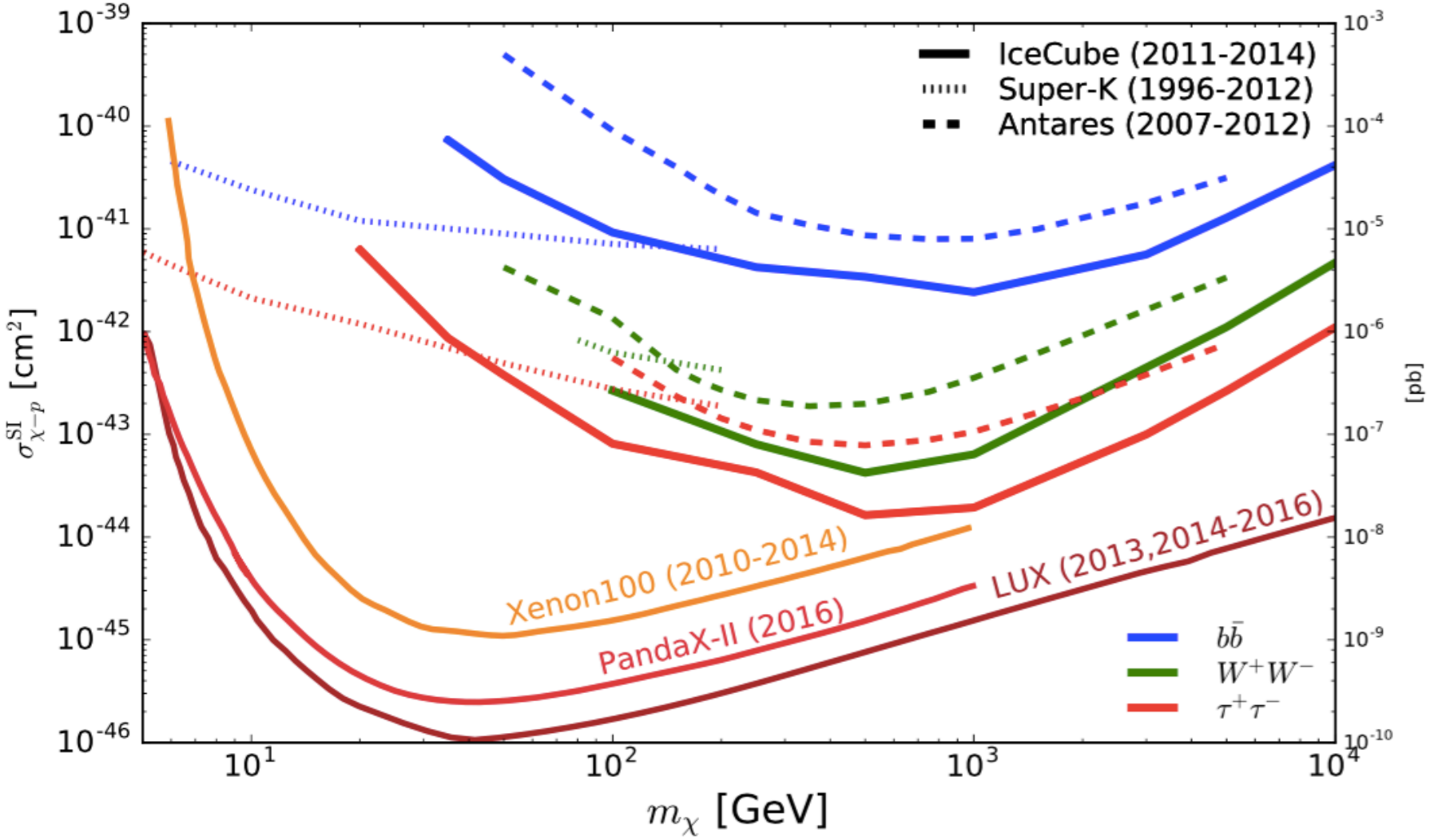
Dark matter particles scatter and get trapped in sun.

As trapped density grows, annihilation rate reaches equilibrium with capture rate.

Search sensitive to scattering cross section



Spin **Independent** Scattering Cross Section Limits



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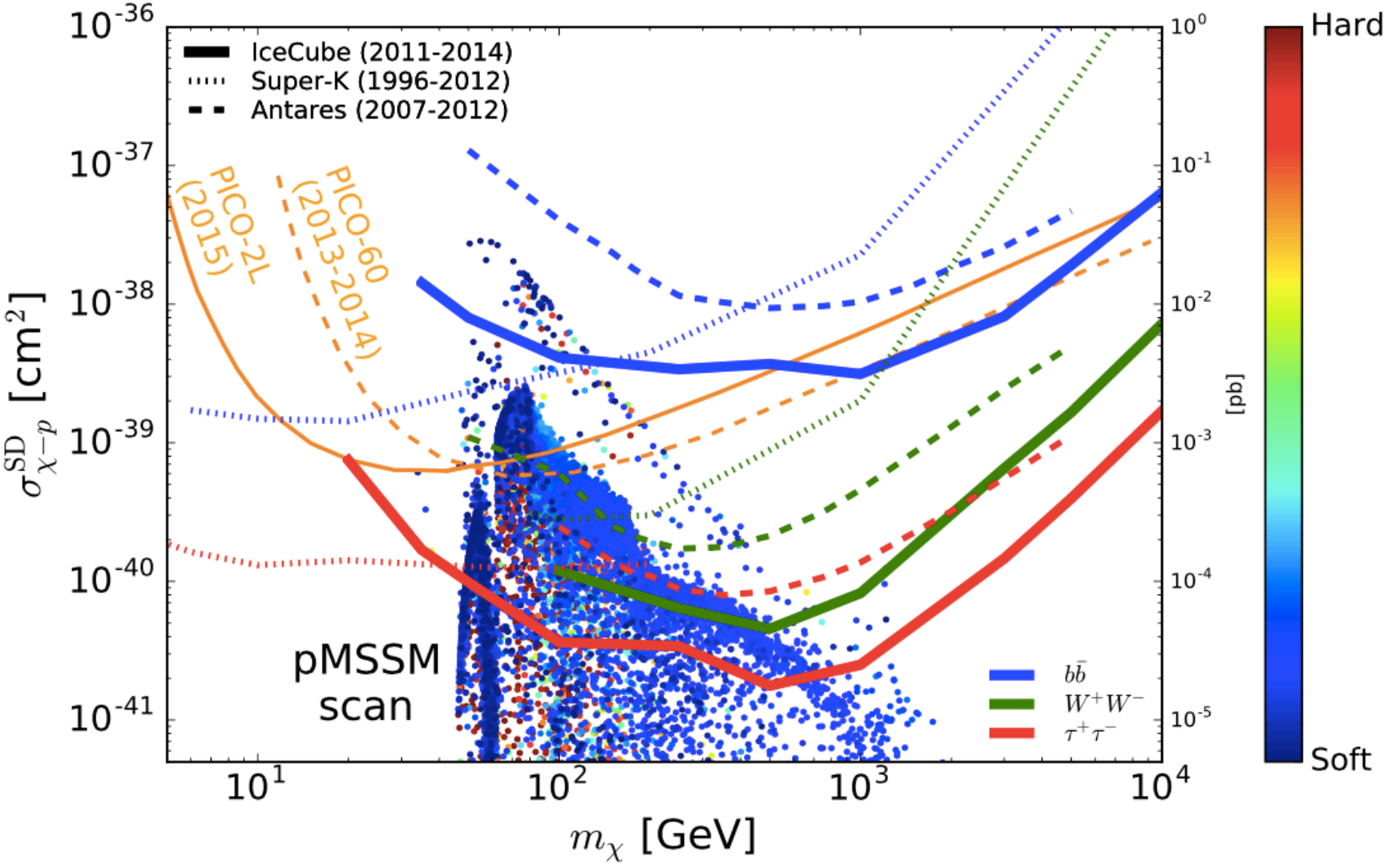
Spin **Dependent** Scattering Cross Section Limits



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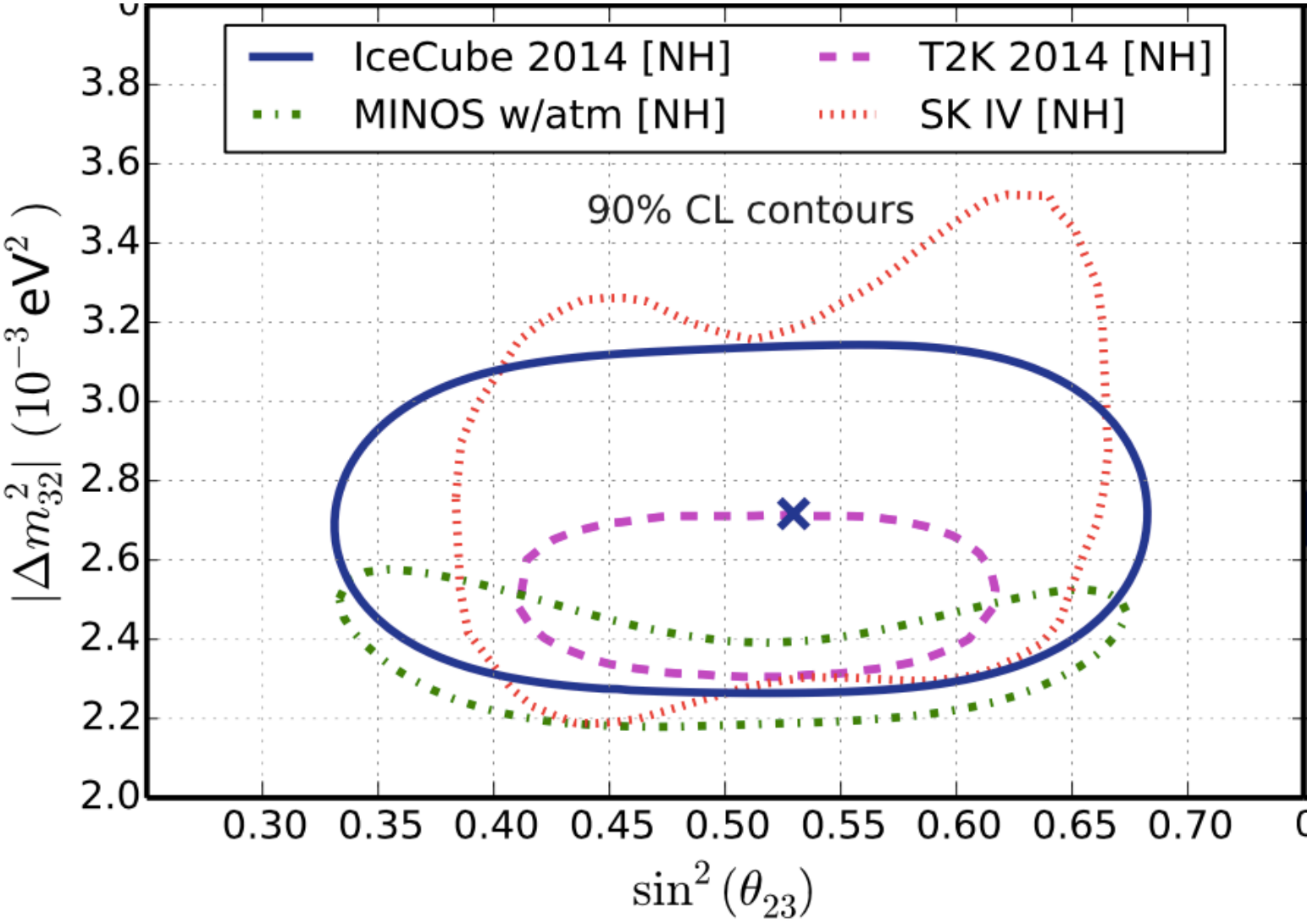
Points correspond to models from a scan of the pMSSM, color coded by the 'hardness' of the resultant neutrino spectrum.

Neutrino Oscillations

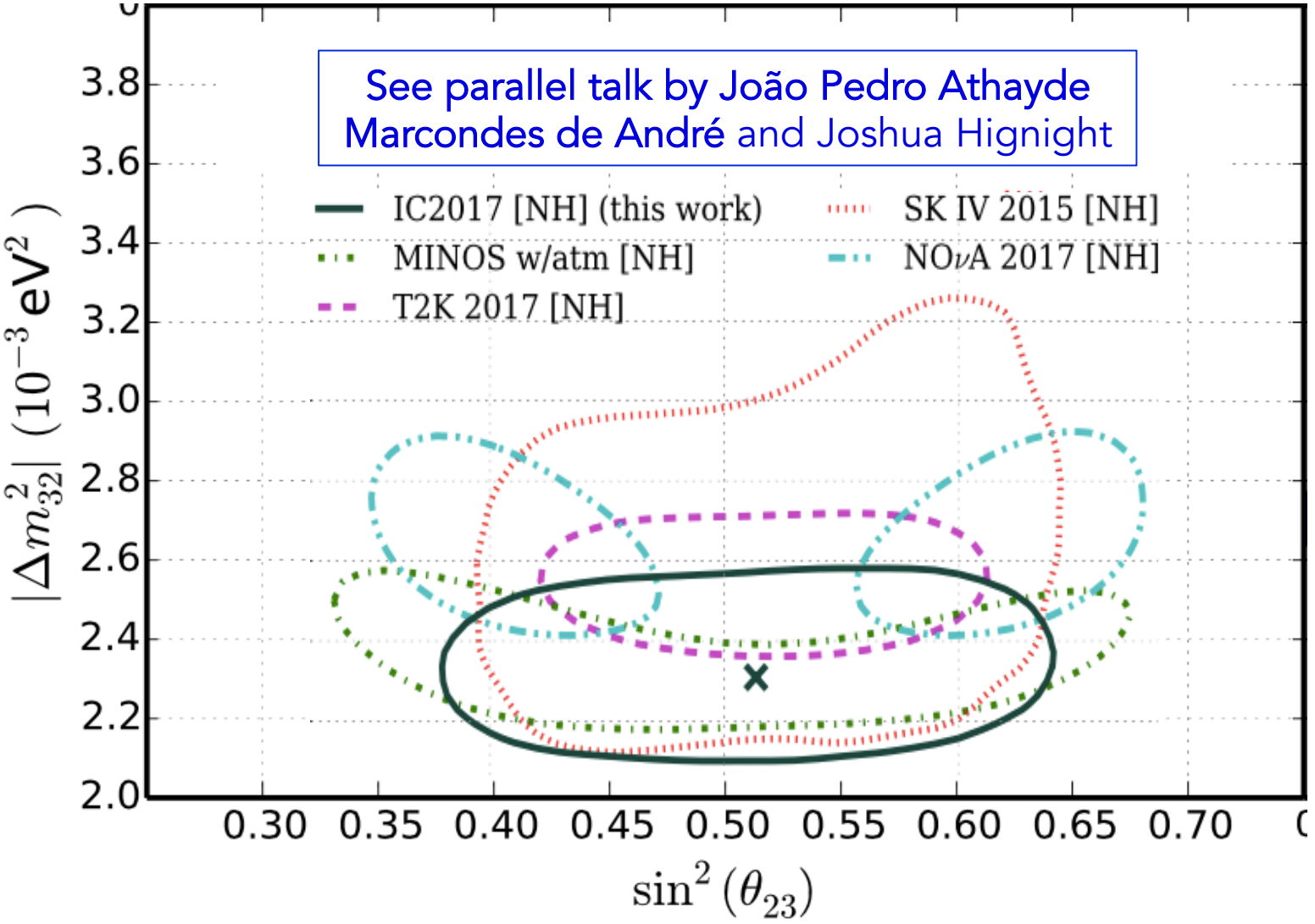


3-year IceCube-Deepcore analysis

Phys. Rev. D 91, 072004 (2015)

Neutrino Oscillations

IceCube Preliminary 90% CL contours



Also 3-year analysis, but new event selection with 10x more events
Result still statistics limited

IceCube is entering 7th year since construction completion.

Extremely stable and high performance.

Continual improvements in event selection, reconstruction, and analysis. Leading and competitive results across diverse topics

Many more analyses being presented here at IPA:

Diffuse galactic emission, Fast radio bursts, Decaying dark matter, Tau neutrinos, Point-source searches with new track and cascade selections, ...

Photo: Martin Wolf

For the astrophysical neutrino flux:

New analyses of cascade events coming later this year:

- 2yr -> 6yr of data
- improved: event selection, reconstruction, analysis

Un-broken power-law, or features in energy spectrum?

Signal from galactic plane will (eventually) be detected

- Some models predict soon

Realtime alerts: telescope follow-up may identify first transient source

What IceCube cannot answer today...

IceCube Gen2 may answer tomorrow....

see M. Kowalski talk