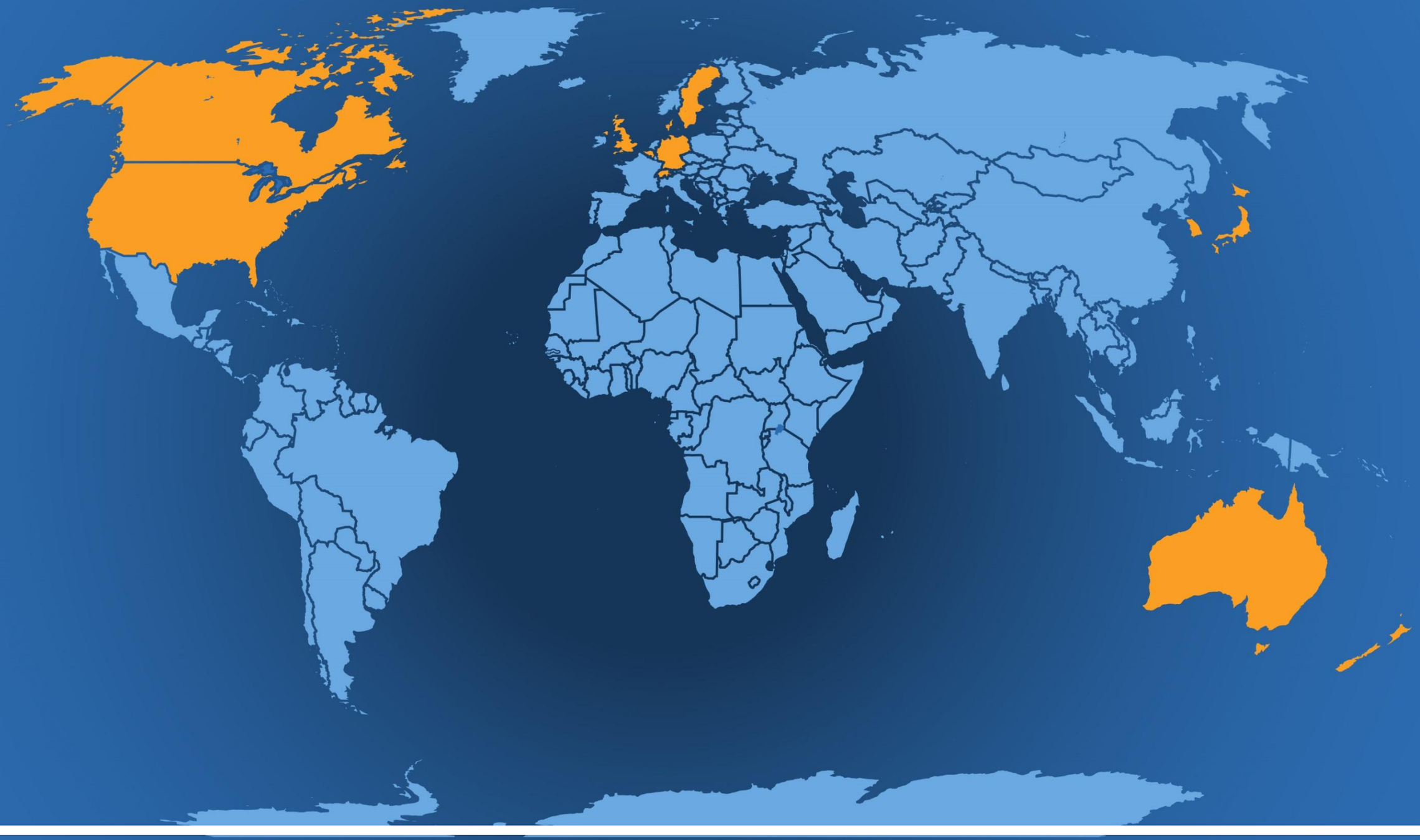
IceCube: Recent Results on astrophyical neutrinos

Christian Spiering

September 2018

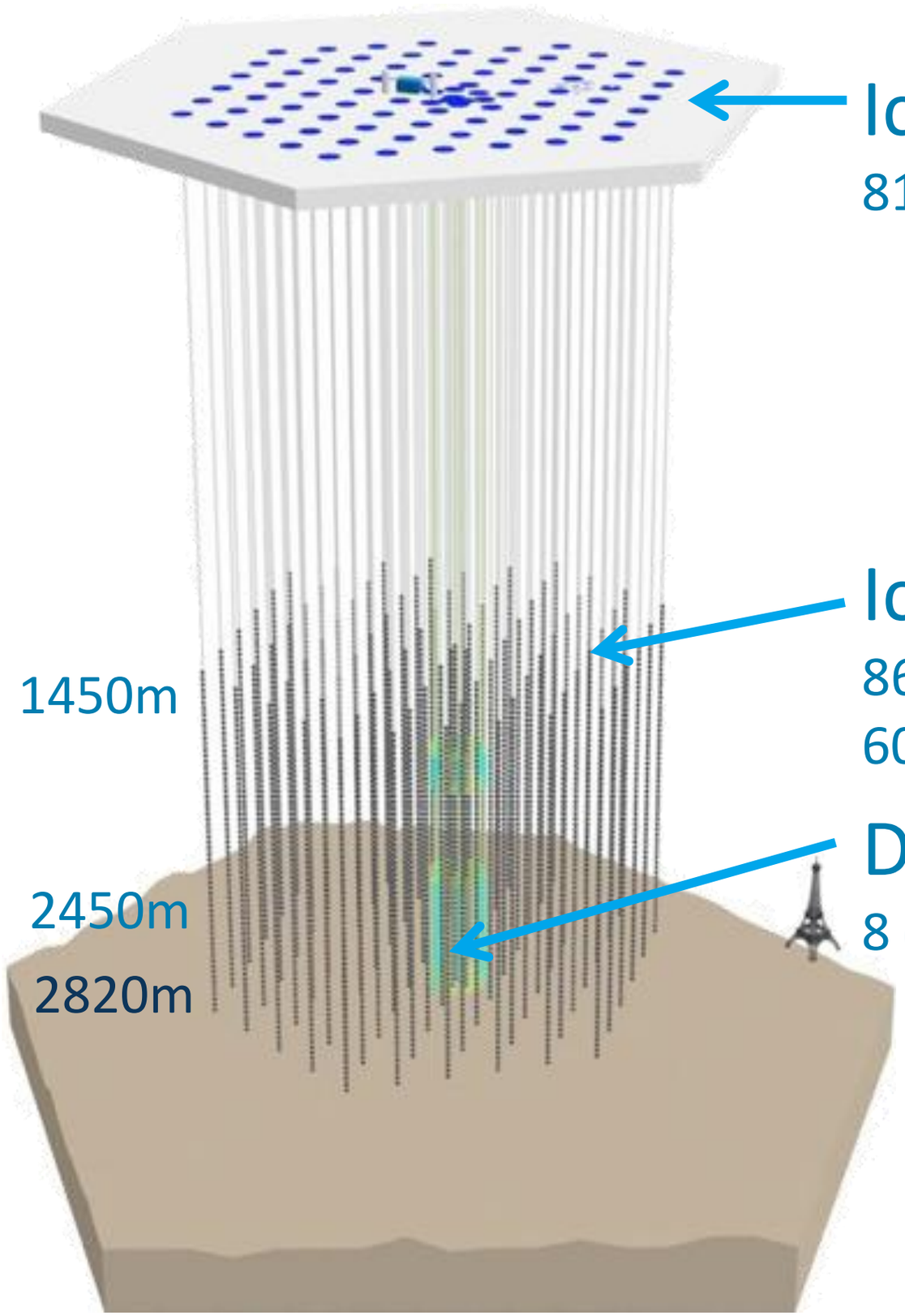
presented by Zhan-Arys Dzhilkibaev

The IceCube Collaboration



46 institutions from 12 countries

IceCube Neutrino Observatory



IceTop air shower detector

81 pairs of water Cherenkov tanks

IceCube

86 strings including 8 Deep Core strings

60 PMT per string

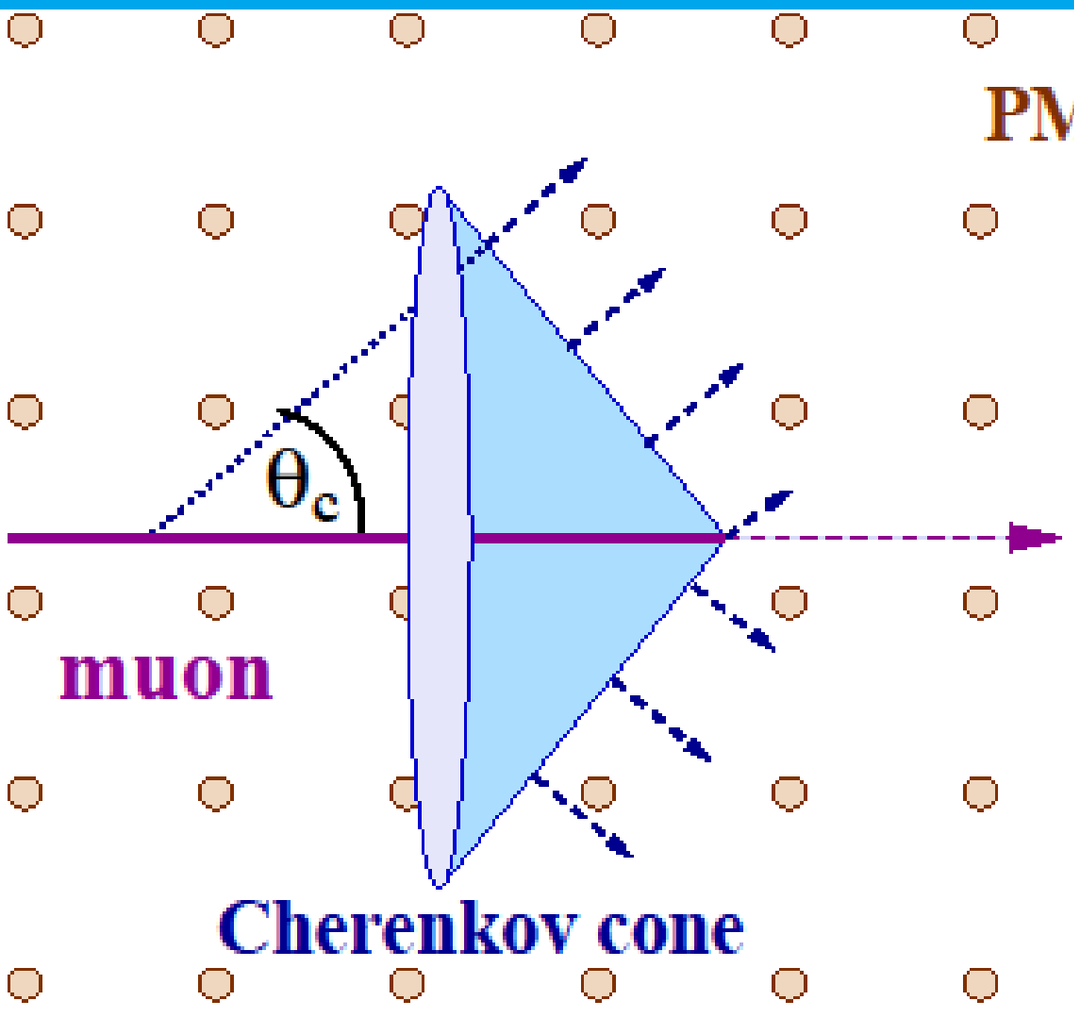
DeepCore

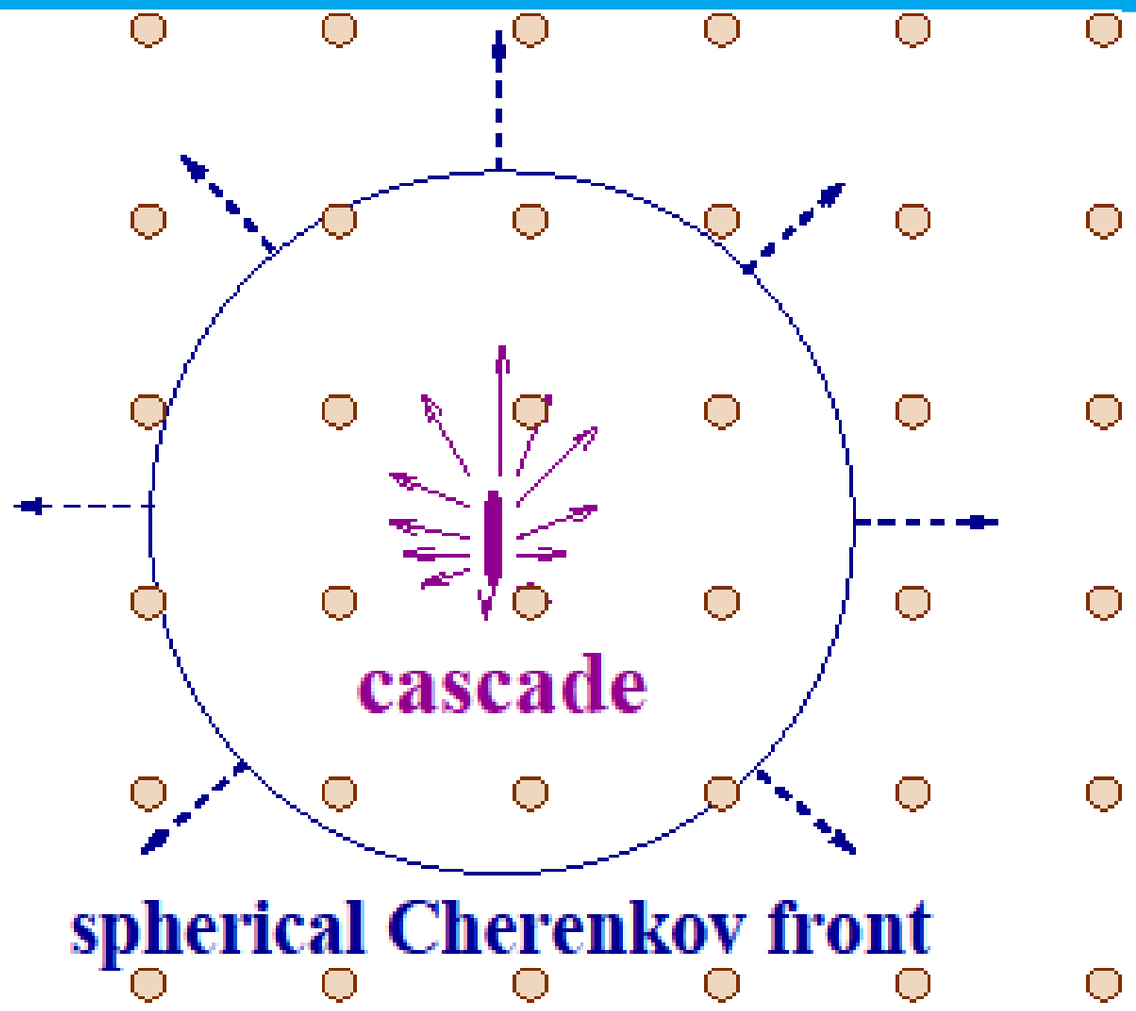
8 closely spaced strings

- ~220 ν/day
- Threshold
  - IceCube ~ 100 GeV
  - DeepCore ~10 GeV

Main Detection Modes

(resolution values are for ice)



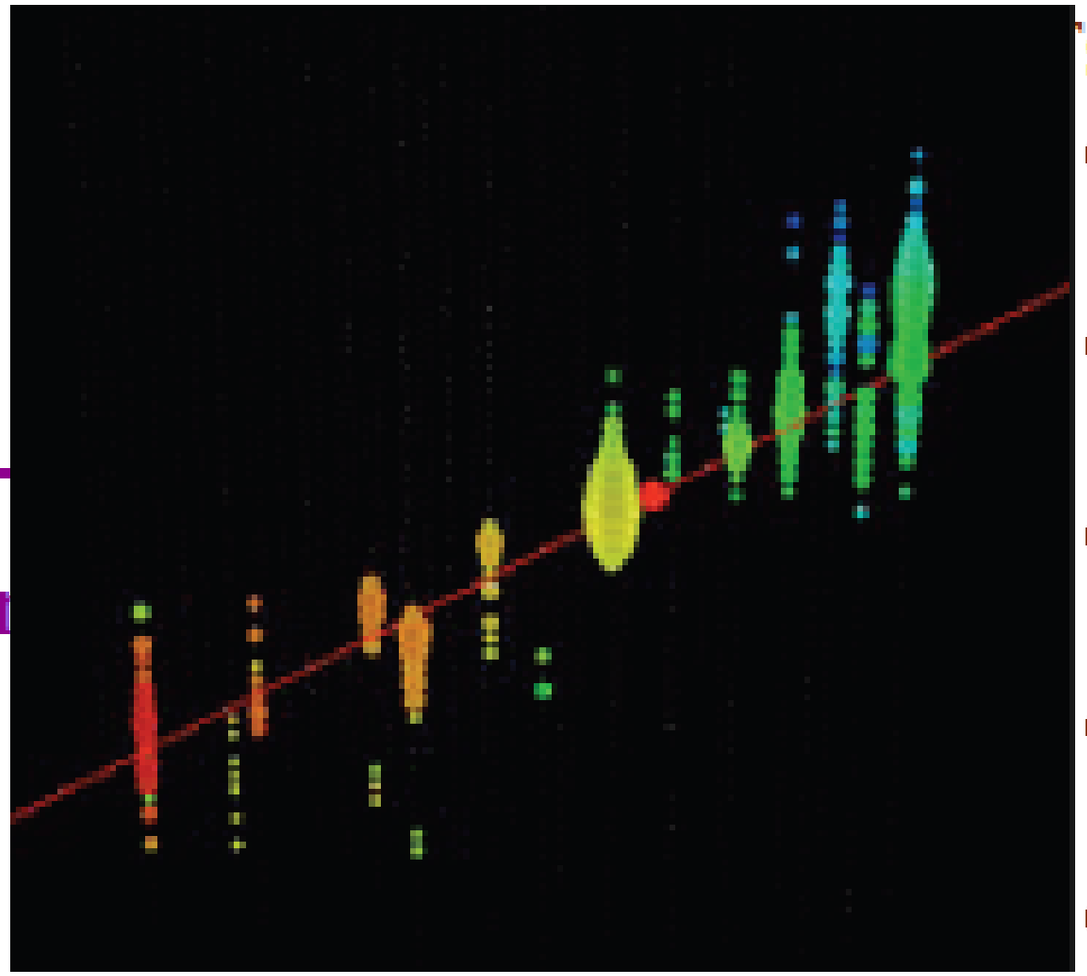


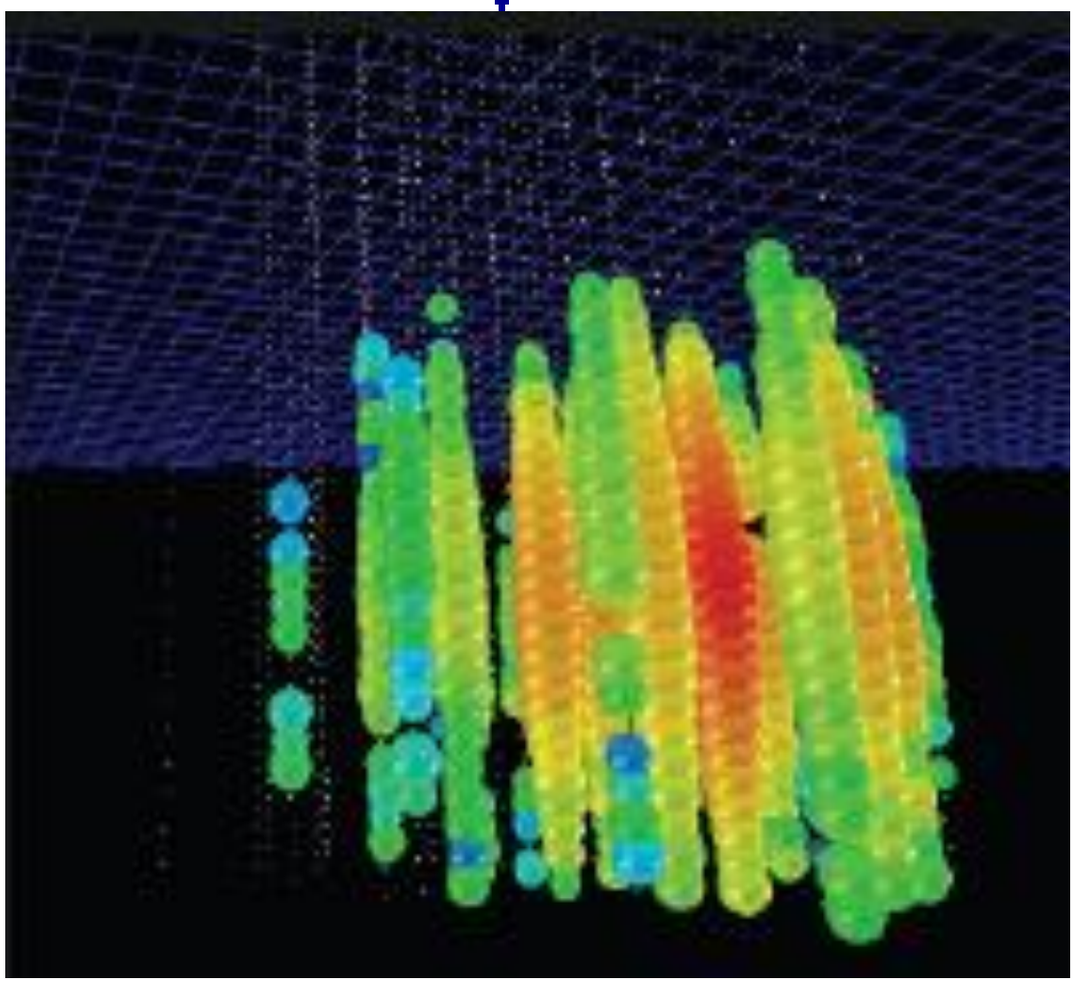
- Muon track from CC muon neutrino interactions
  - Angular resolution < 1°
  - E_μ resolution: factor 2-3

- Cascade from CC electron/tau and NC all flavor interactions
  - Angular resolution 15° at 100 TeV
  - Energy resolution ~ 15%

Main Detection Modes

(resolution values are for ice)





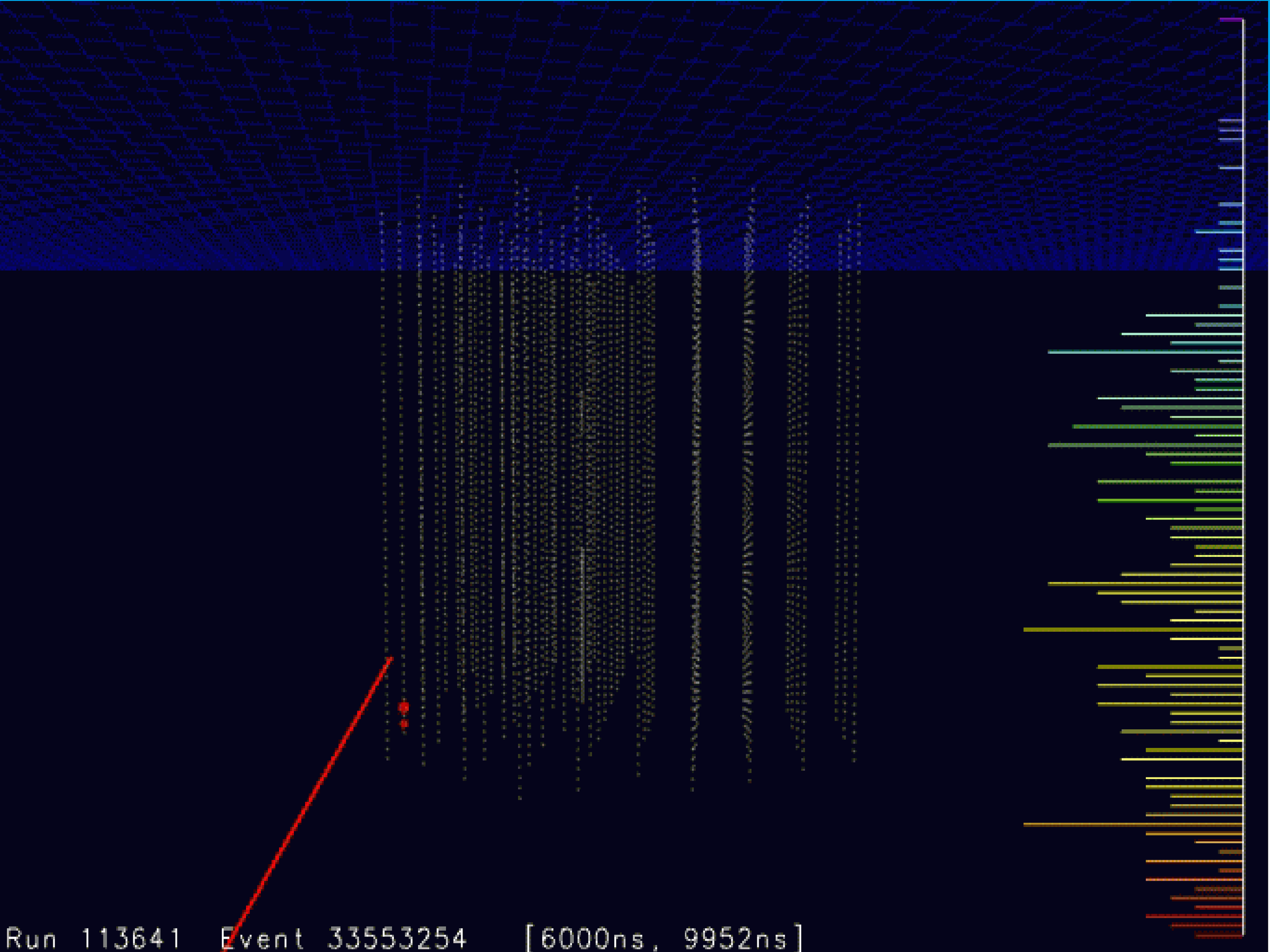
- **Muon track from CC muon neutrino interactions**
  - **Angular resolution < 1°**
  - **E_μ resolution: factor 2-3**

- **Cascade from CC electron and NC all flavor interactions**
  - **Angular resolution 15° at 100 TeV**
  - **Energy resolution ~ 15%**

DIFFUSE COSMIC FLUXES

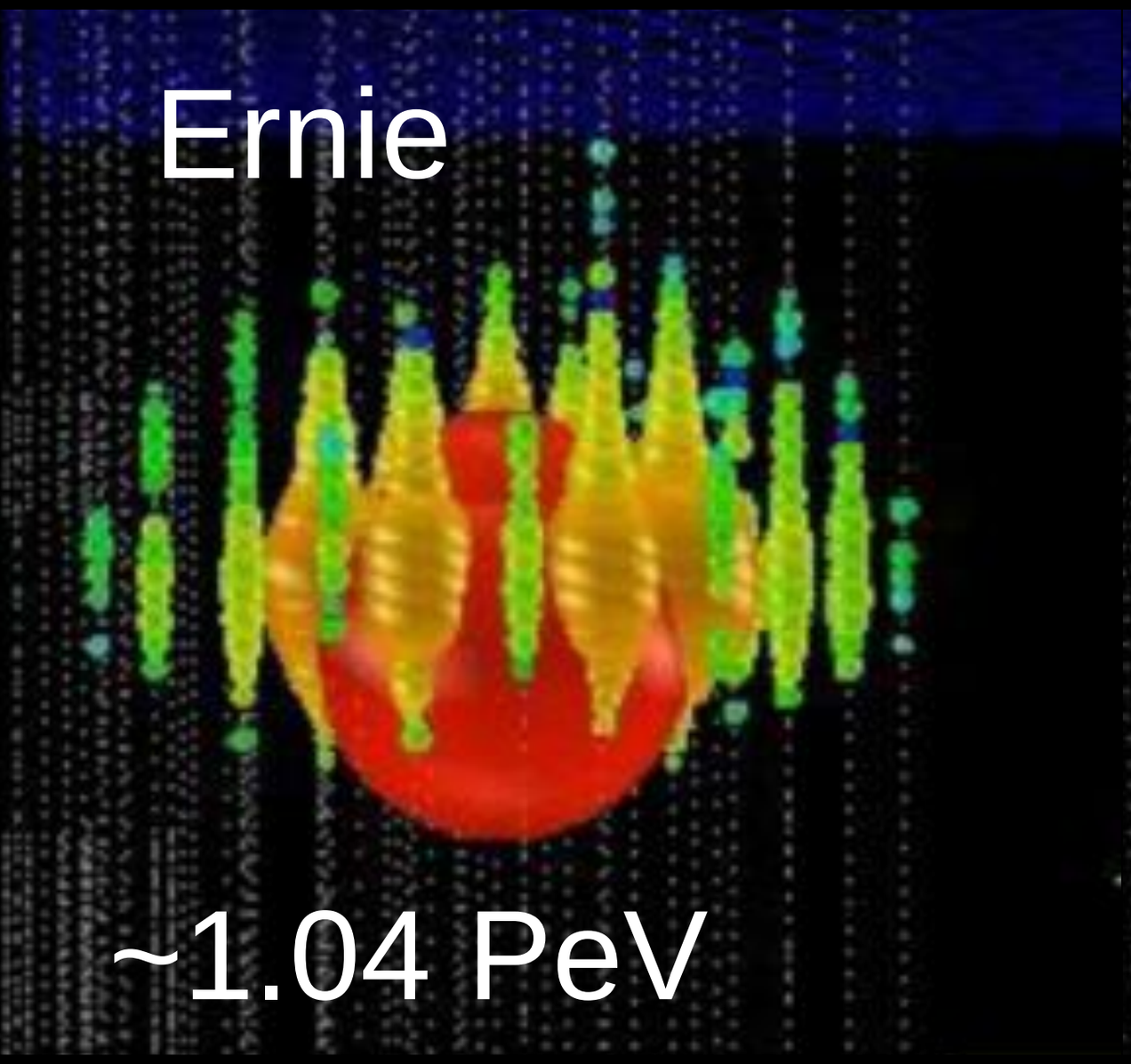
IceCube:~ 10^5 Neutrinos per year.
> 99% of them have atmospheric origin

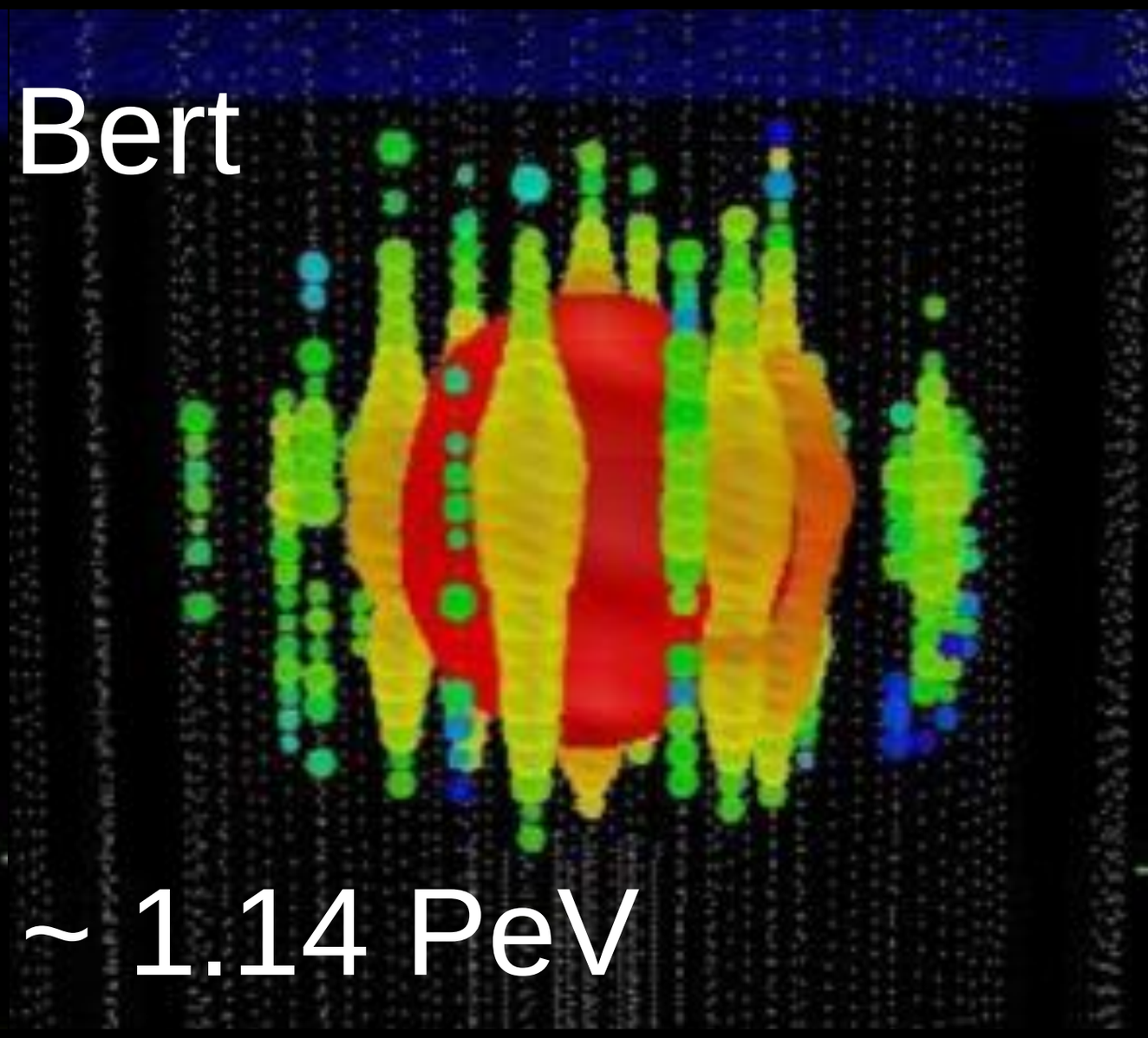
like the following:


Run 113641 Event 33553254 [6000ns, 9952ns]

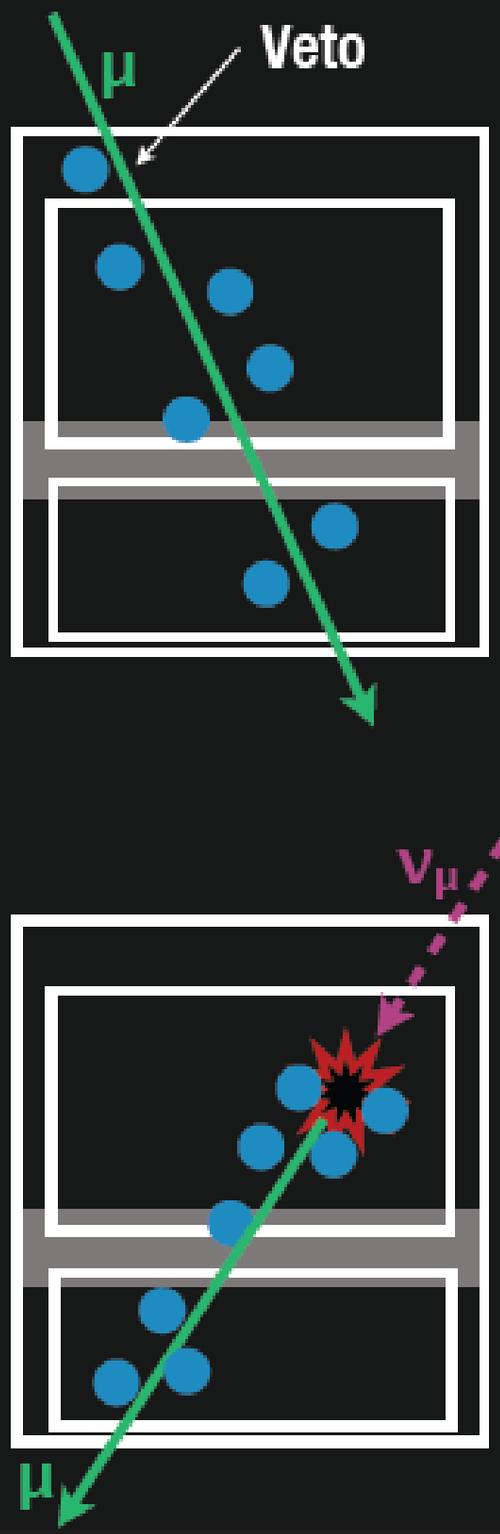
Special search for neutrinos with E_ν > 500 TeV

IC79/IC86 2.8 σ





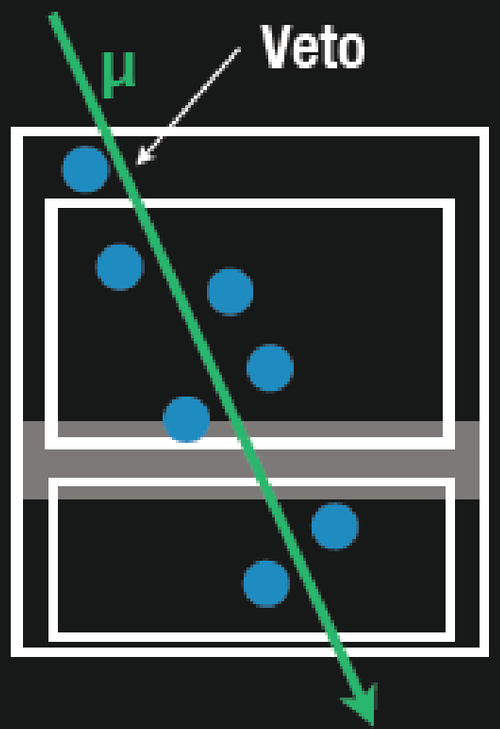
HESE analysis (High Energy Starting Event)



- Muon Veto
- Q_{tot} > 6000 photoelectrons

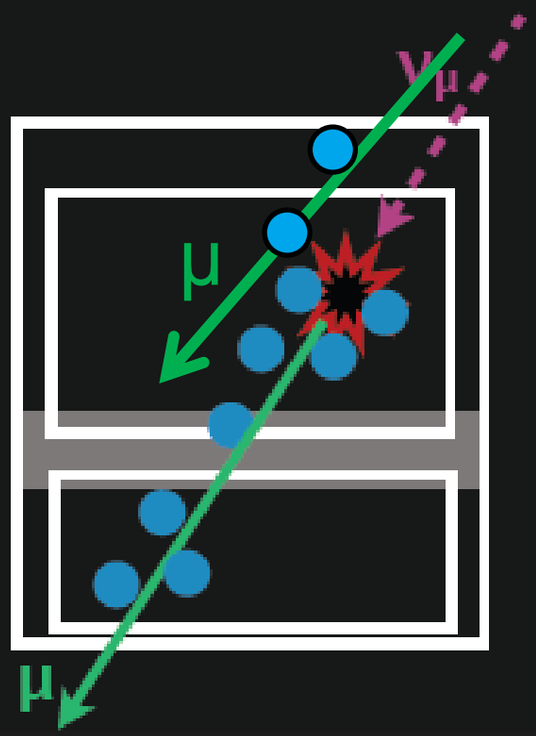
→ 400 Mton eff. Volume

HESE analysis



- Muon Veto
- Q_{tot} > 6000 photoelectrons

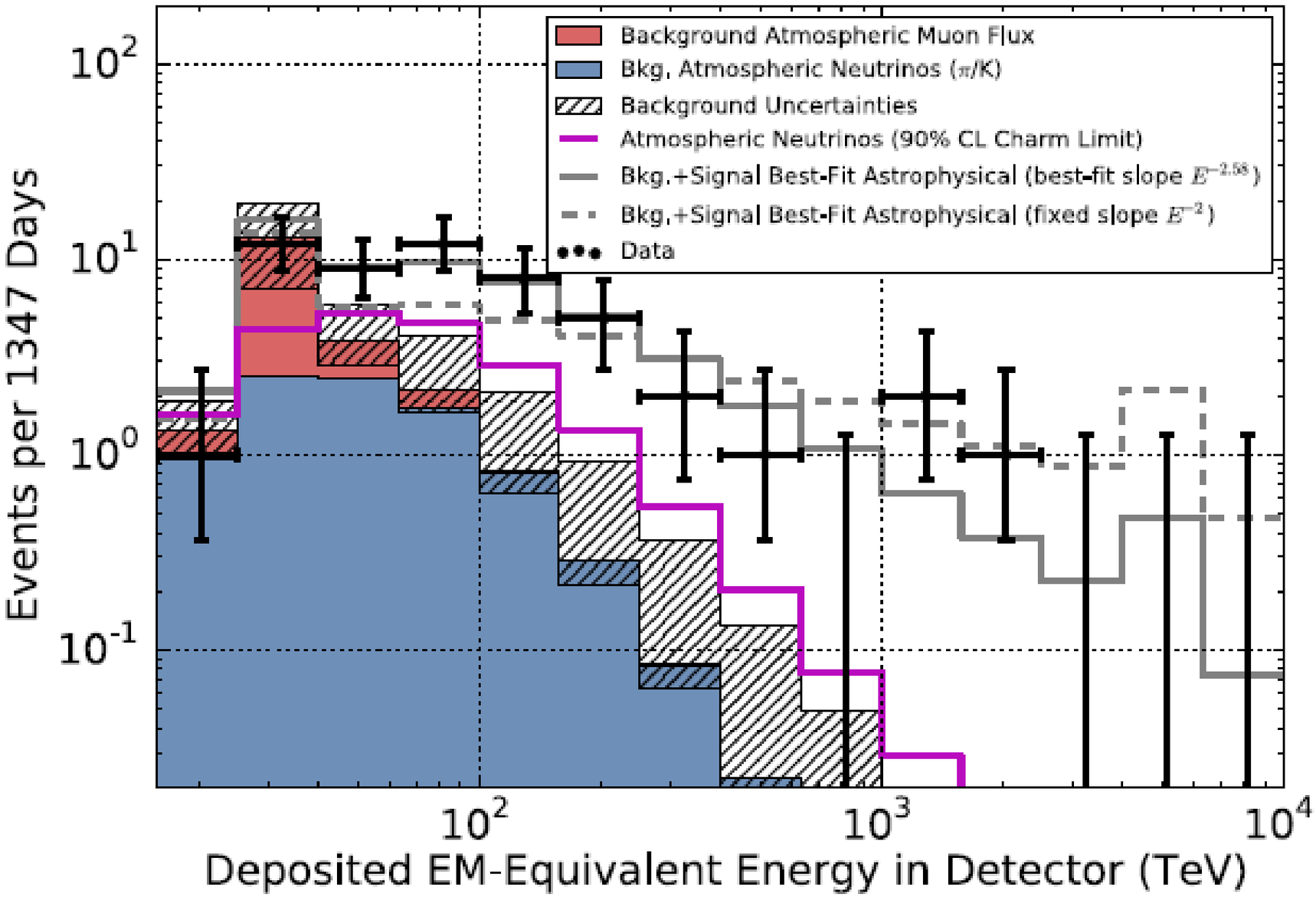
→ 400 Mton eff. Volume



Veto is also good for rejecting large part of atmospheric ν !!

Follow-up Analysis: HESE (High Energy Starting Event)

First evidence for an extra-terrestrial h.e. neutrino flux



2 yrs data, 28 evts 4.1σ
Science 342 (2013)

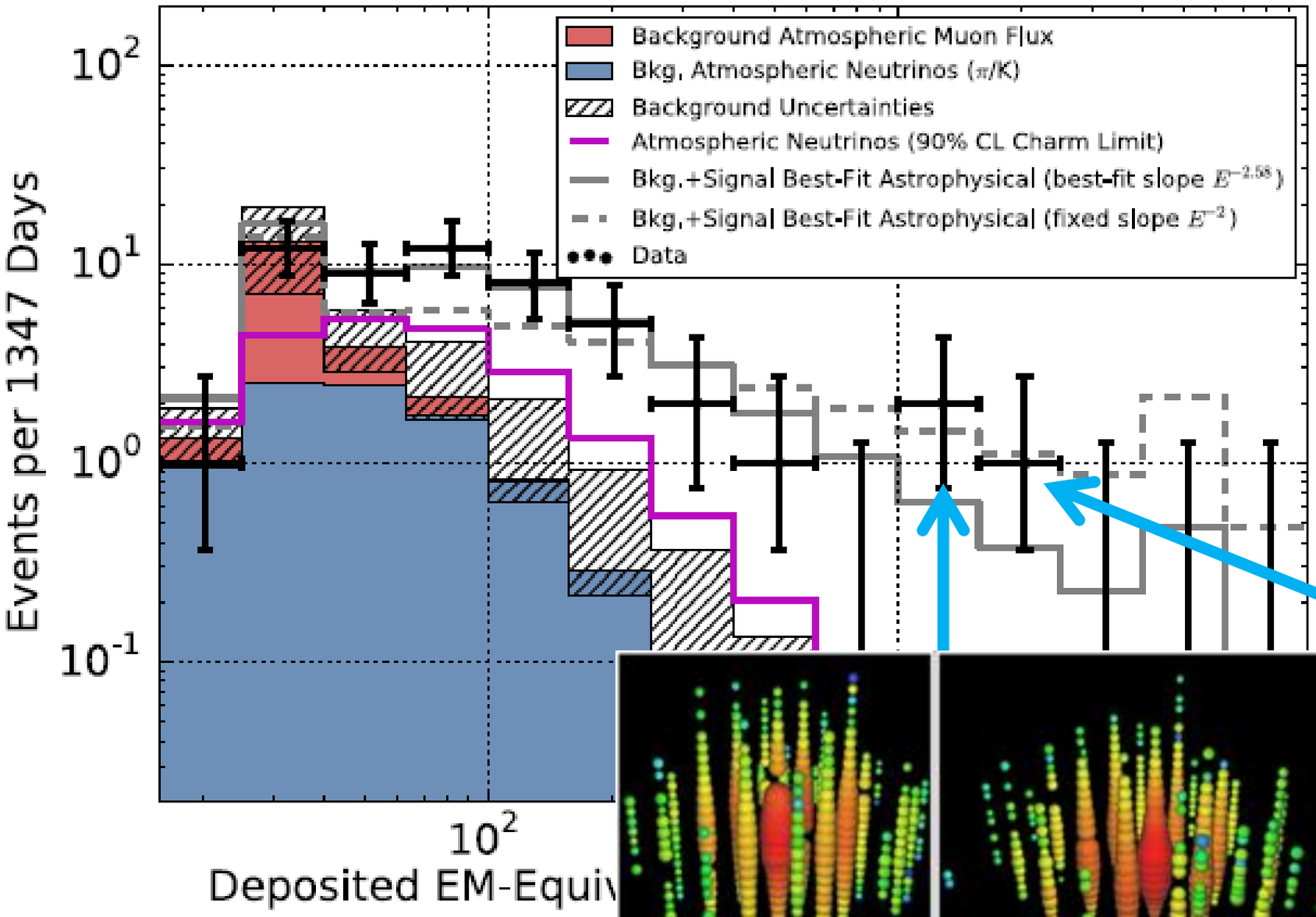
3 yrs data, 37 evts 5.9σ
Phys.Rev.Lett. 113:101101 (2014)

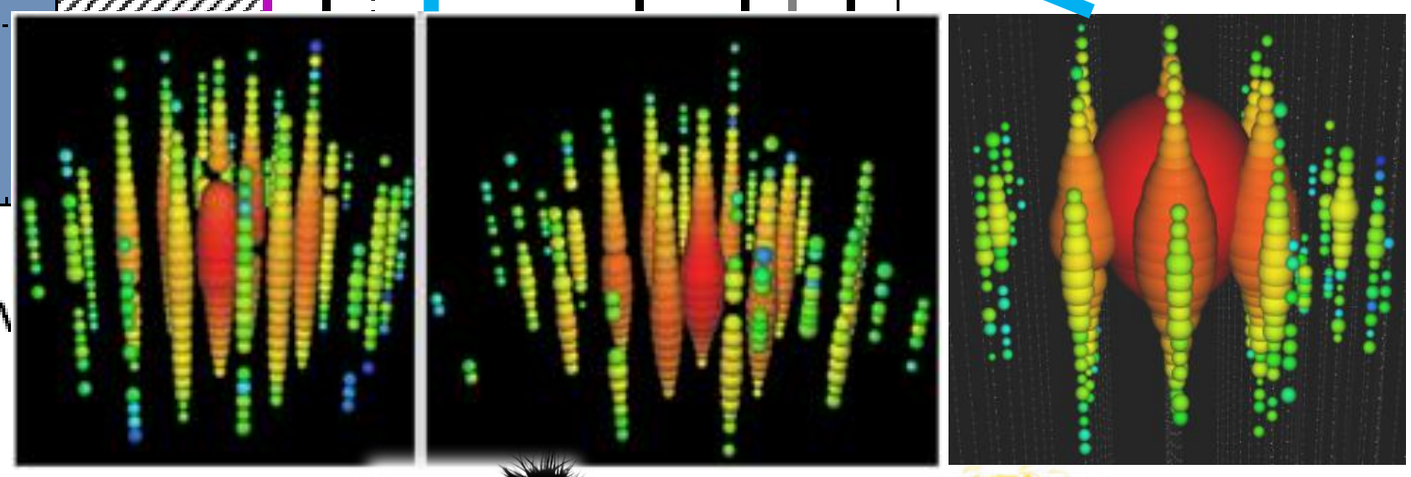
4 yrs data, 54 evts 6.7σ

Threshold ~ 30 TeV

Follow-up Analysis: HESE (High Energy Starting Event)

First evidence for an extra-terrestrial h.e. neutrino flux





"Bert"
1.04 PeV
Aug. 2011

"Ernie"
1.14 PeV
Jan. 2012

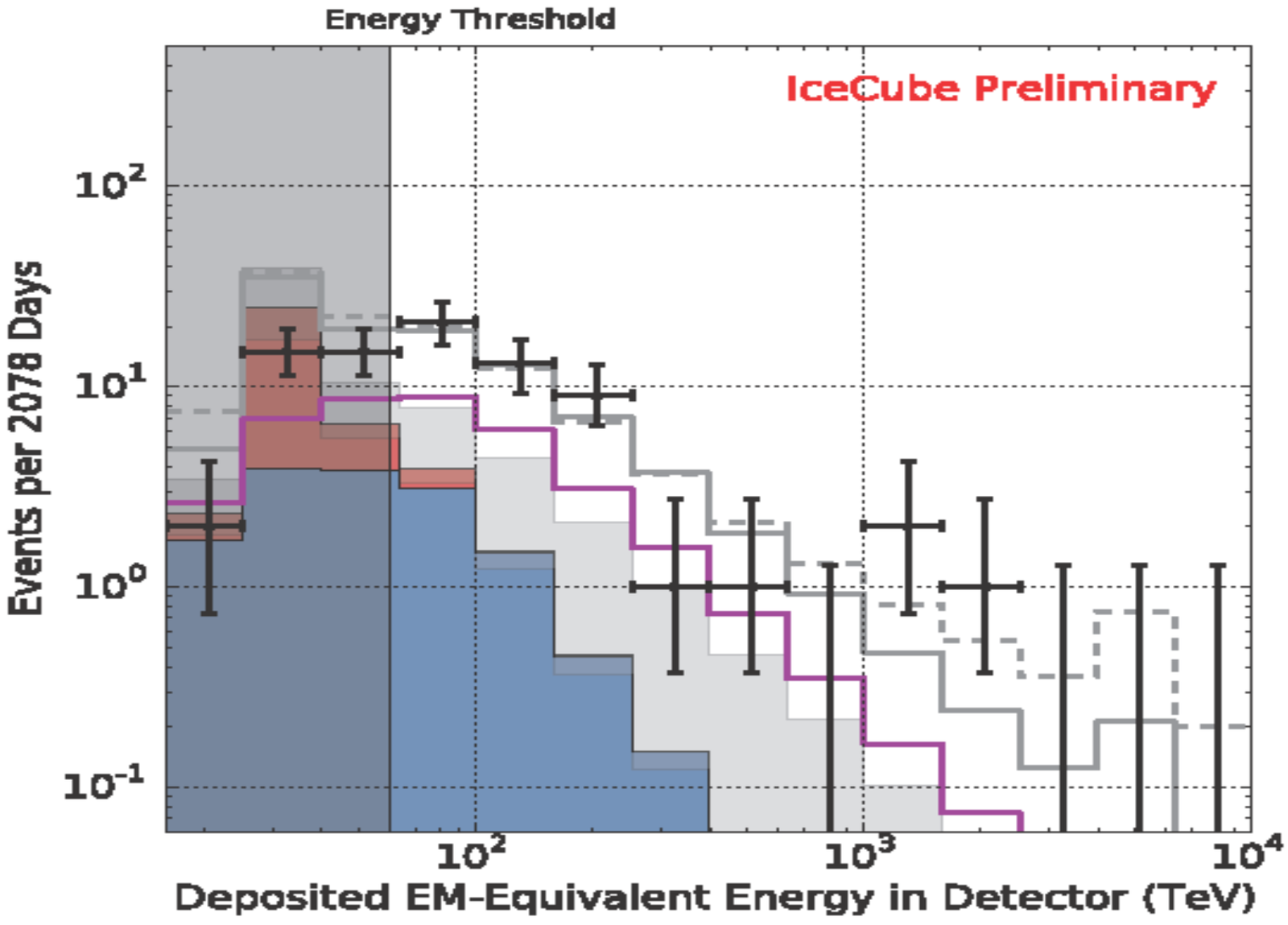
"Big Bird"
2 PeV
Dec. 2012

2 yrs data, 28 evts 4.1σ
Science 342 (2013)

3 yrs data, 37 evts 5.9σ
Phys.Rev.Lett. 113:101101 (2014)

4 yrs data, 54 evts 6.7σ

Follow-up Analysis: HESE (High Energy Starting Event)



2 yrs data, 28 evts 4.1σ
Science 342 (2013)

3 yrs data, 37 evts 5.9σ
Phys.Rev.Lett. 113:101101 (2014)

4 yrs data, 54 evts 6.7σ

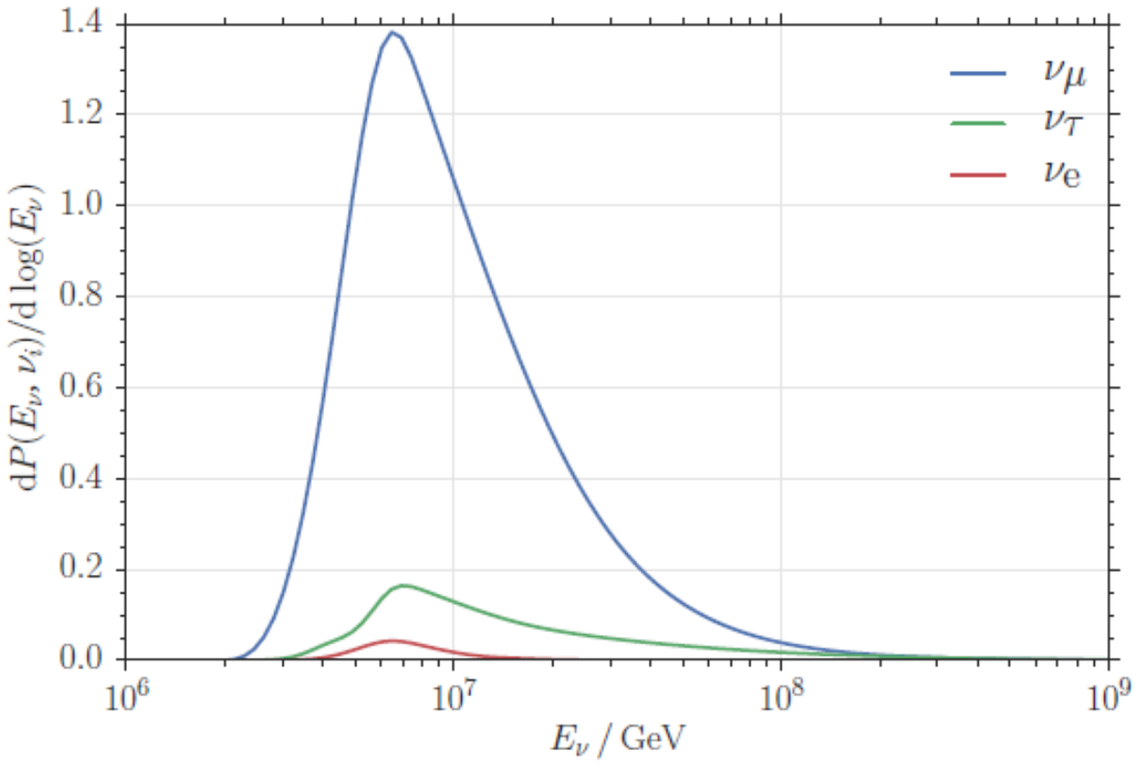
6 yrs data, 85 evts. > 7σ, no further events above 400 TeV
(distribution above)

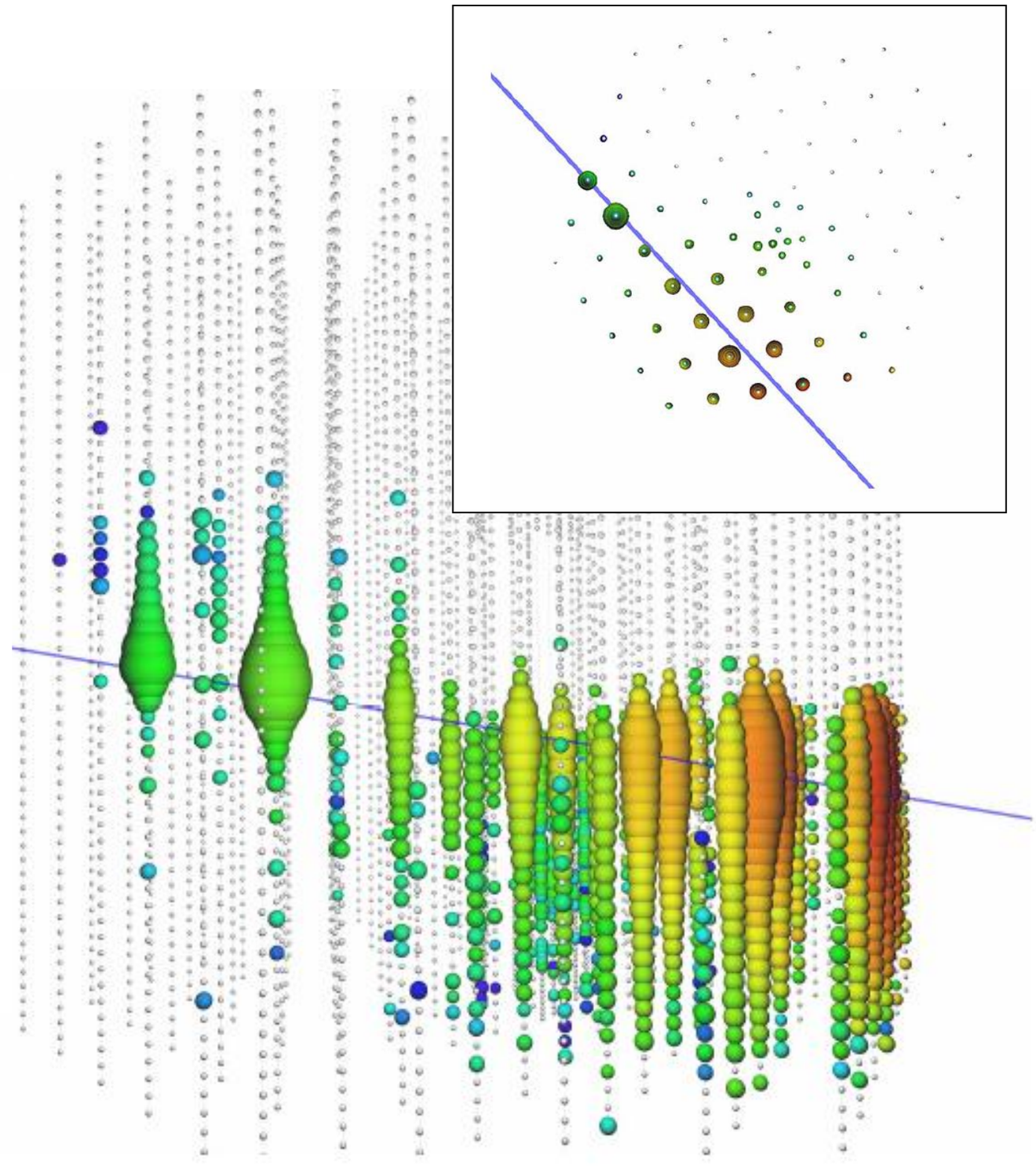
7.5 yrs data, 103 evts. , gap fills up (2 evts with 400 <E <1000 TeV)

Through-going muons: The highest energy event

Deposited energy 2.6±0.3 PeV

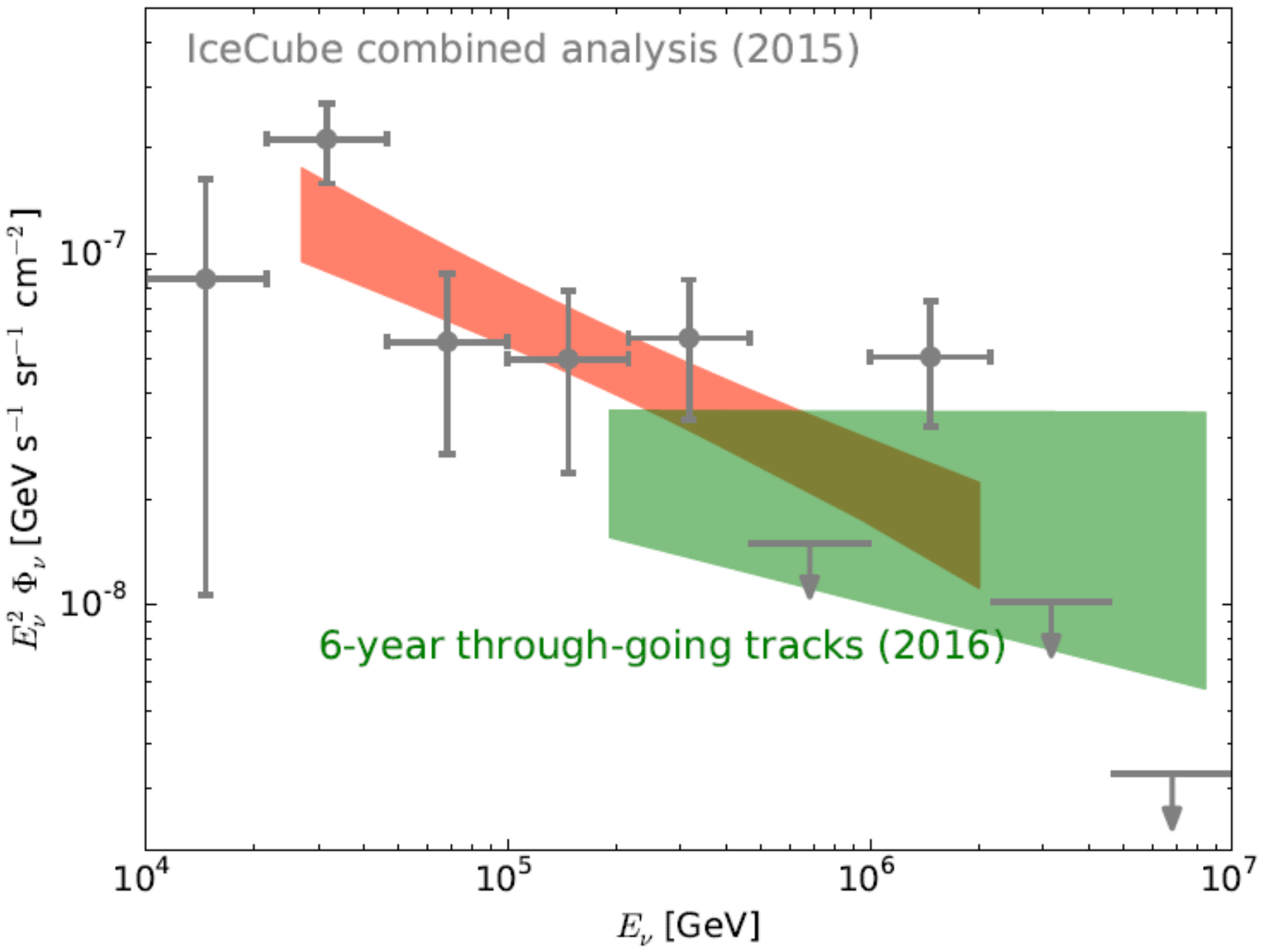
Most probable ν energy ~7 PeV
(for E^{-2} assumption)





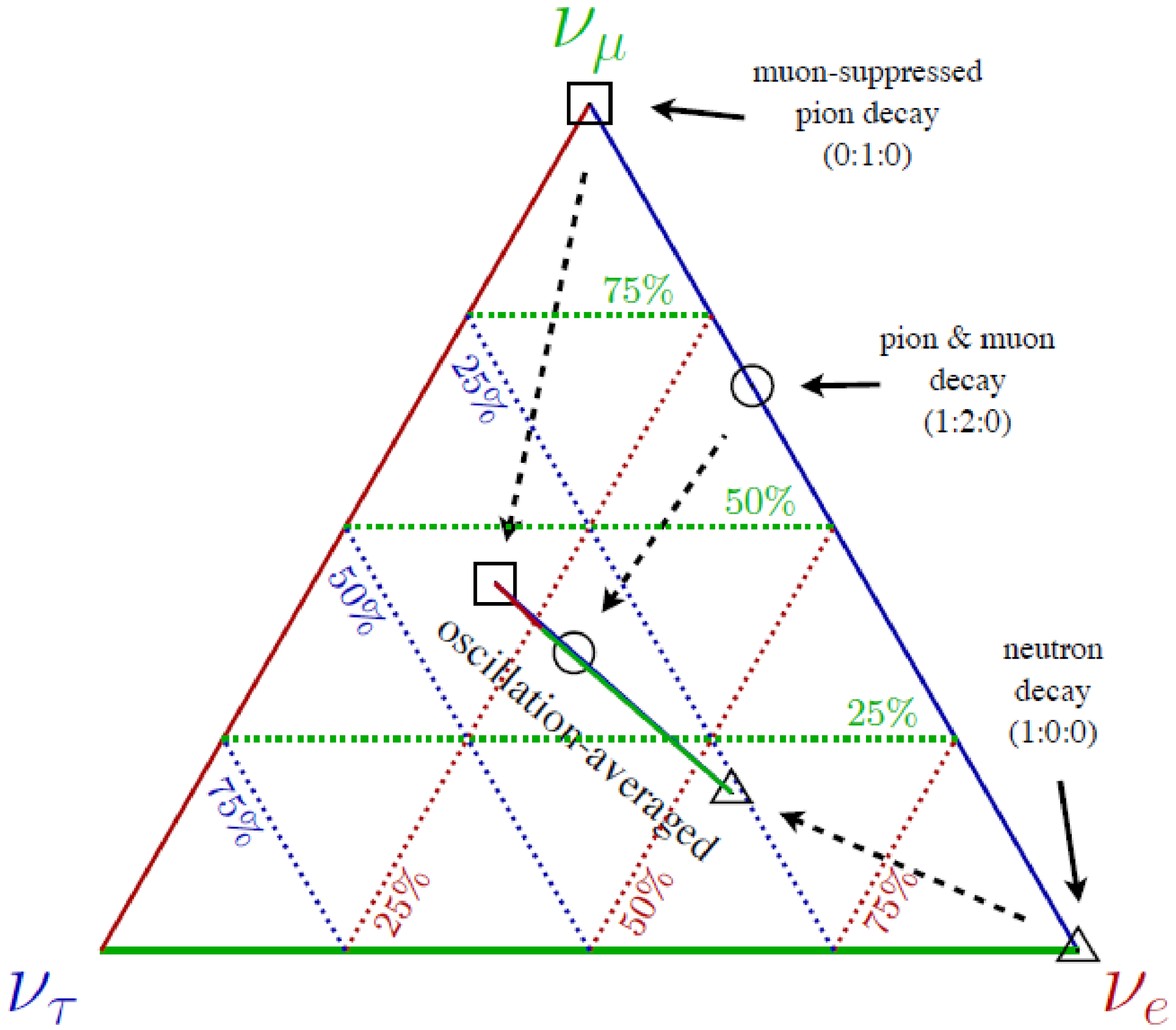
Broken Spectrum?

$$\Phi = \Phi_0 \times E_\nu^{\gamma}$$



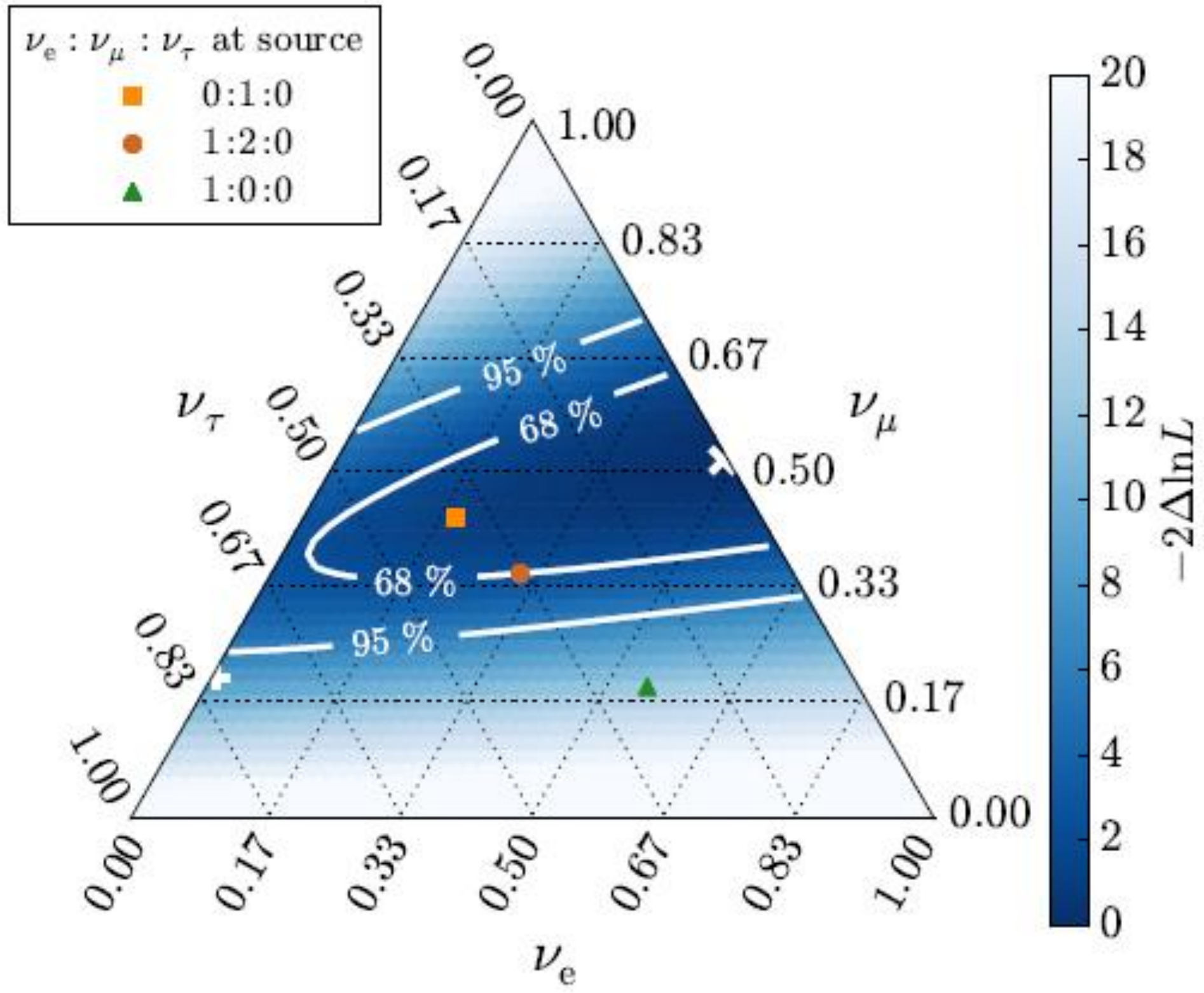
- Red band: combined analysis, power-law spectrum hypothesis
- Dots: fit of flux in different energy bands
- Green band: through-going muons, power-law spectrum hypothesis

Flavor composition: what do we expect?



Flavor composition: what do we measure?

the best fit flavor composition disfavors 1:0:0 at source at 3.6 σ

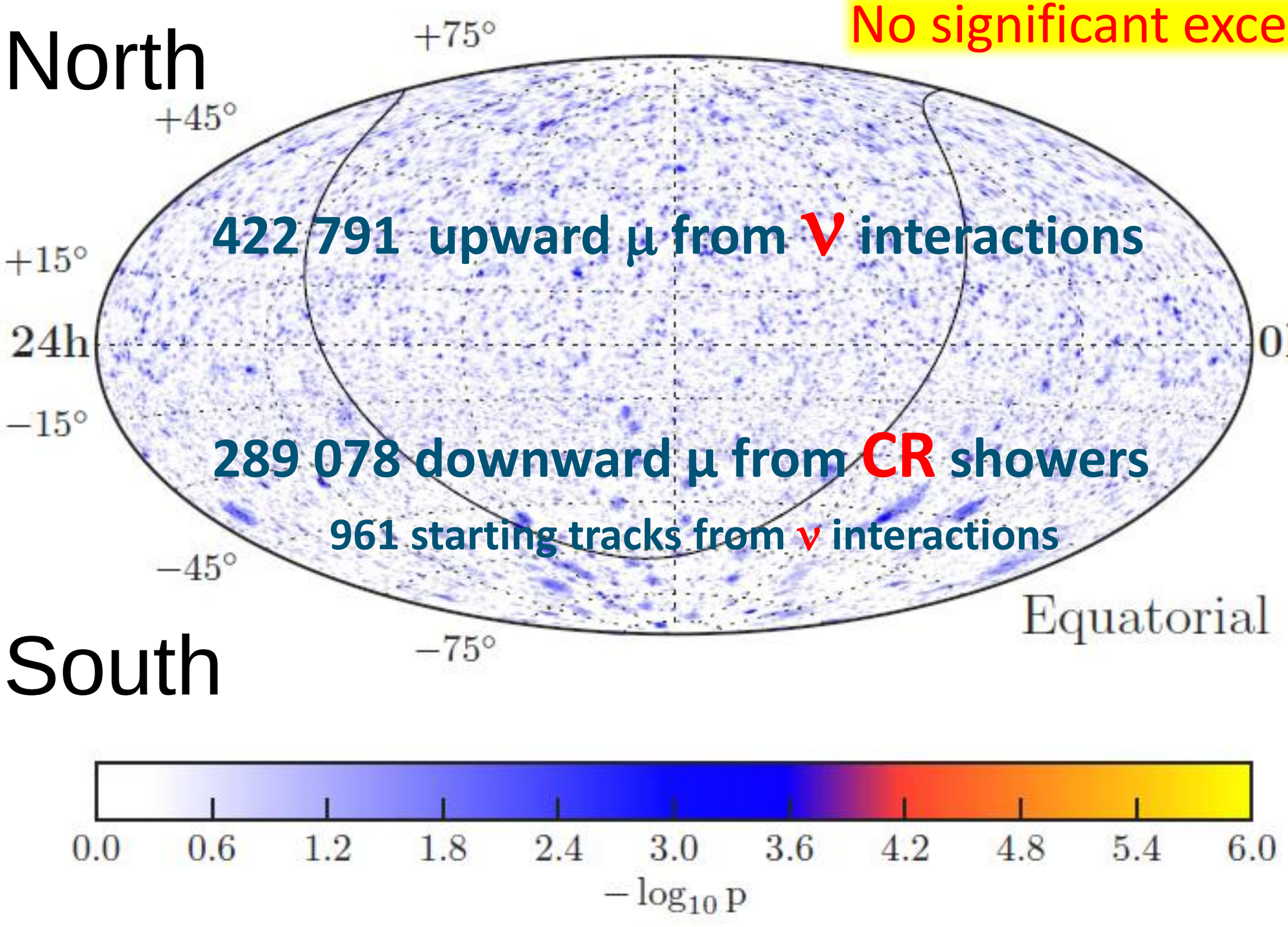


SEARCH FOR STEADY POINT SOURCES

IceCube 7 years

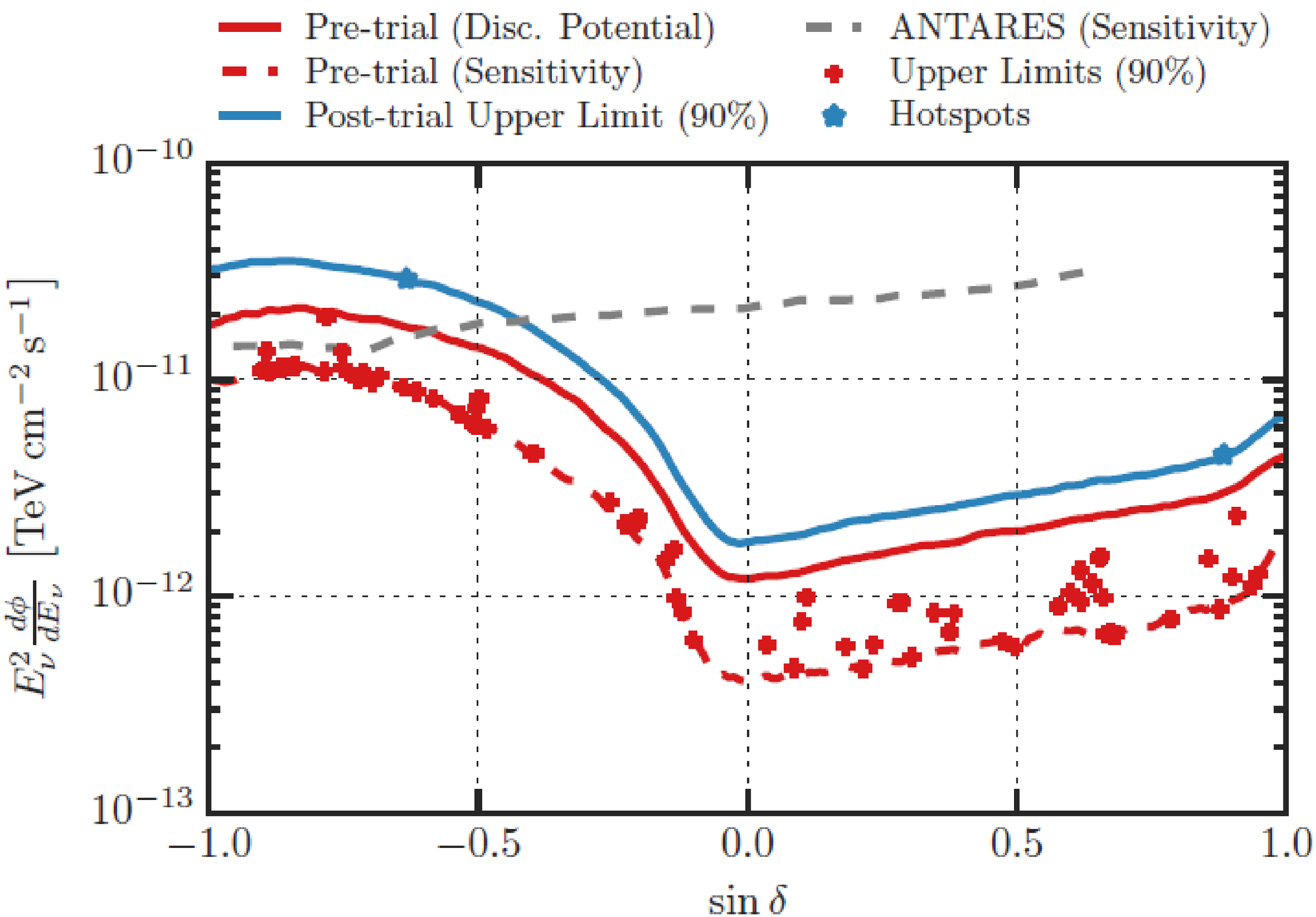
pre-trial significance skymap

No significant excesses



IceCube 7 years

Sensitivities and upper limits



Fermi-2Lac Blazars, Galactic Plane and diffuse TeV-PeV flux

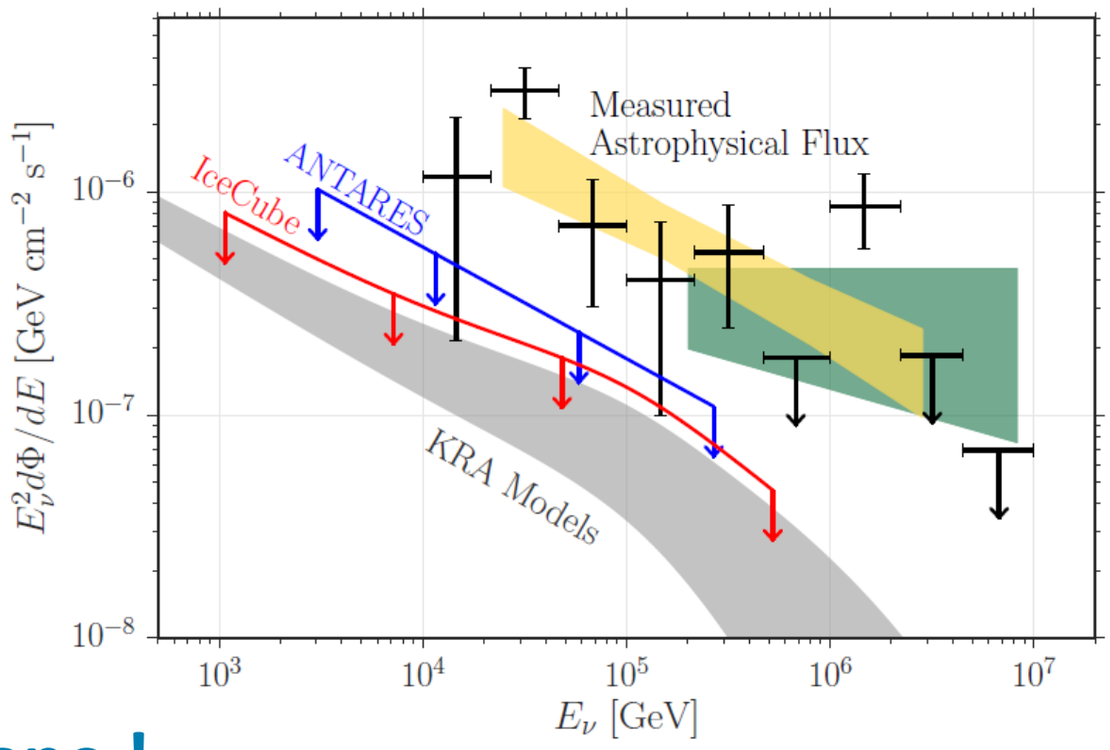
By a stacking analysis of the blazar regions on the shown sky-map ("On"-regions: ~ 1 degree bins around all 826 blazars in the 2nd Fermi-LAT AGN catalogue, data from 2009-2012) we conclude that the 2LAC blazars contribute

$\leq$ 27% for spectral index 2.5

< 50% for spectral index 2.2

to the HESE flux.

The contribution of sources from the Galactic plane is for energies larger than 1 TeV is < 14%
(assuming an $E^{-2.5}$ spectrum)

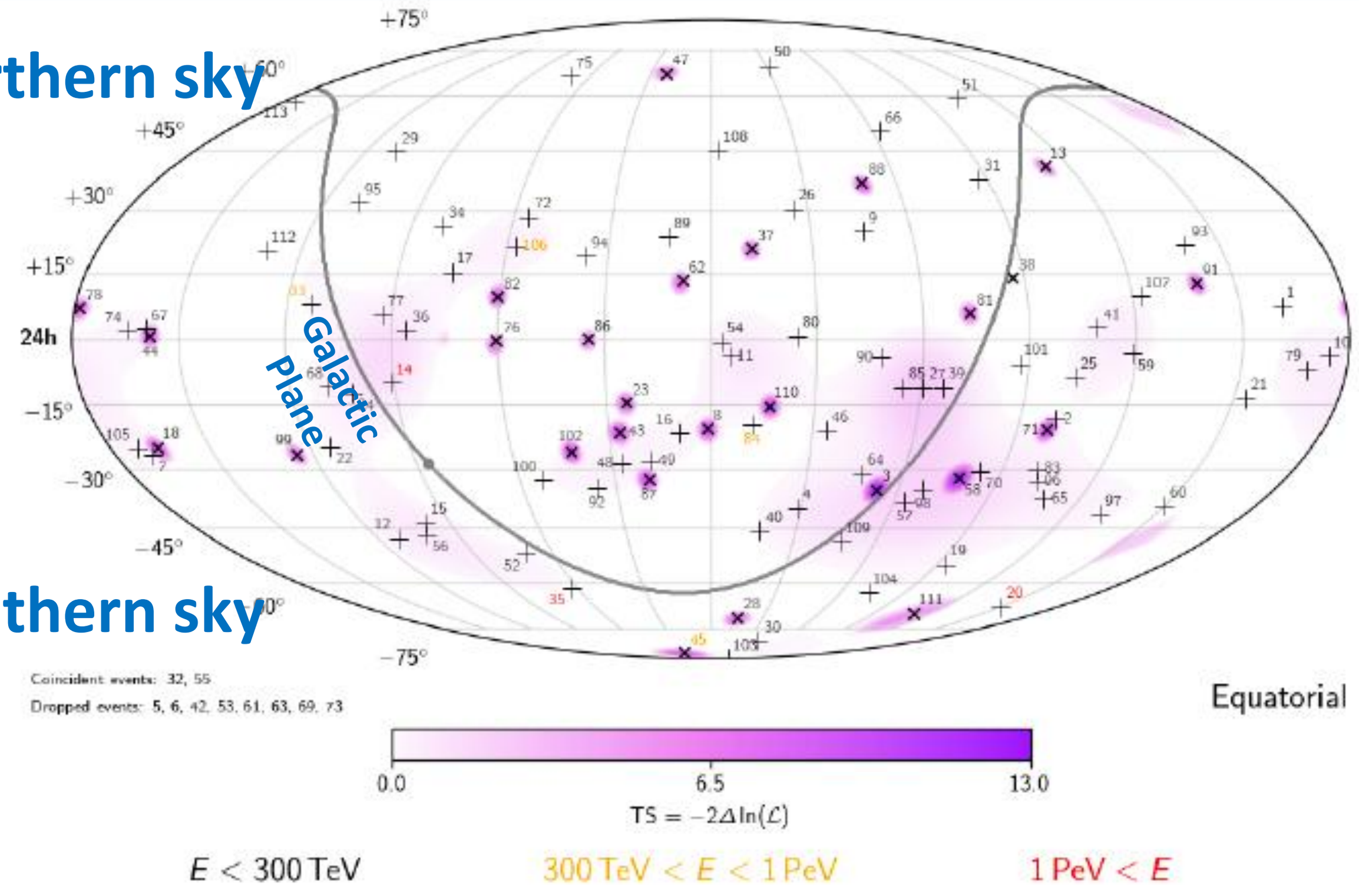


This is close to models for diffuse emission from the Galactic Plane !

EVIDENCE FOR A FIRST EXTRAGALACTIC POINT SOURCE

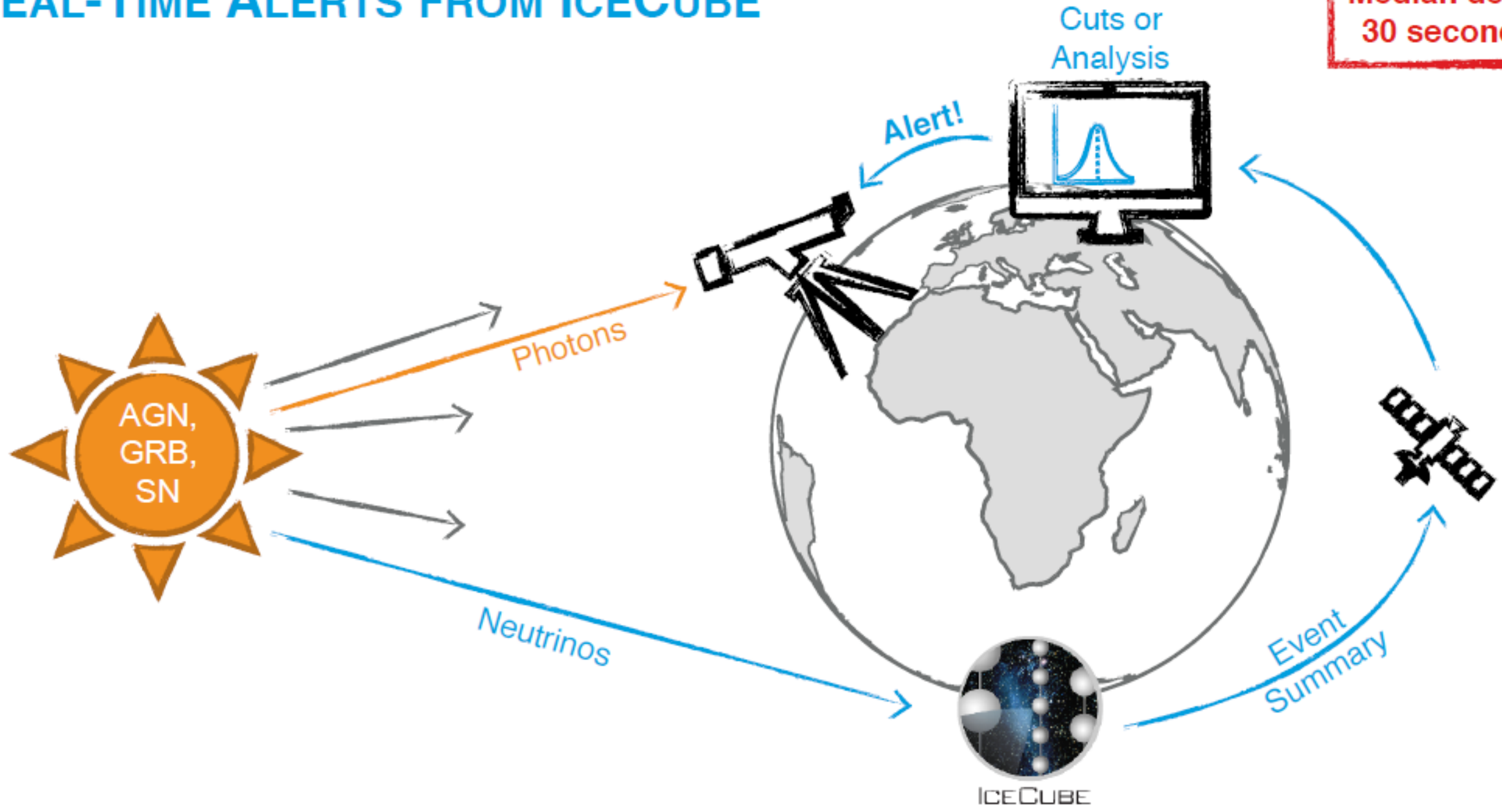
~100 high-energy events but no indication of a local excess, in particular not of an excess correlated to a known astrophysical source.

This changed on Sept 22, 2017 !!

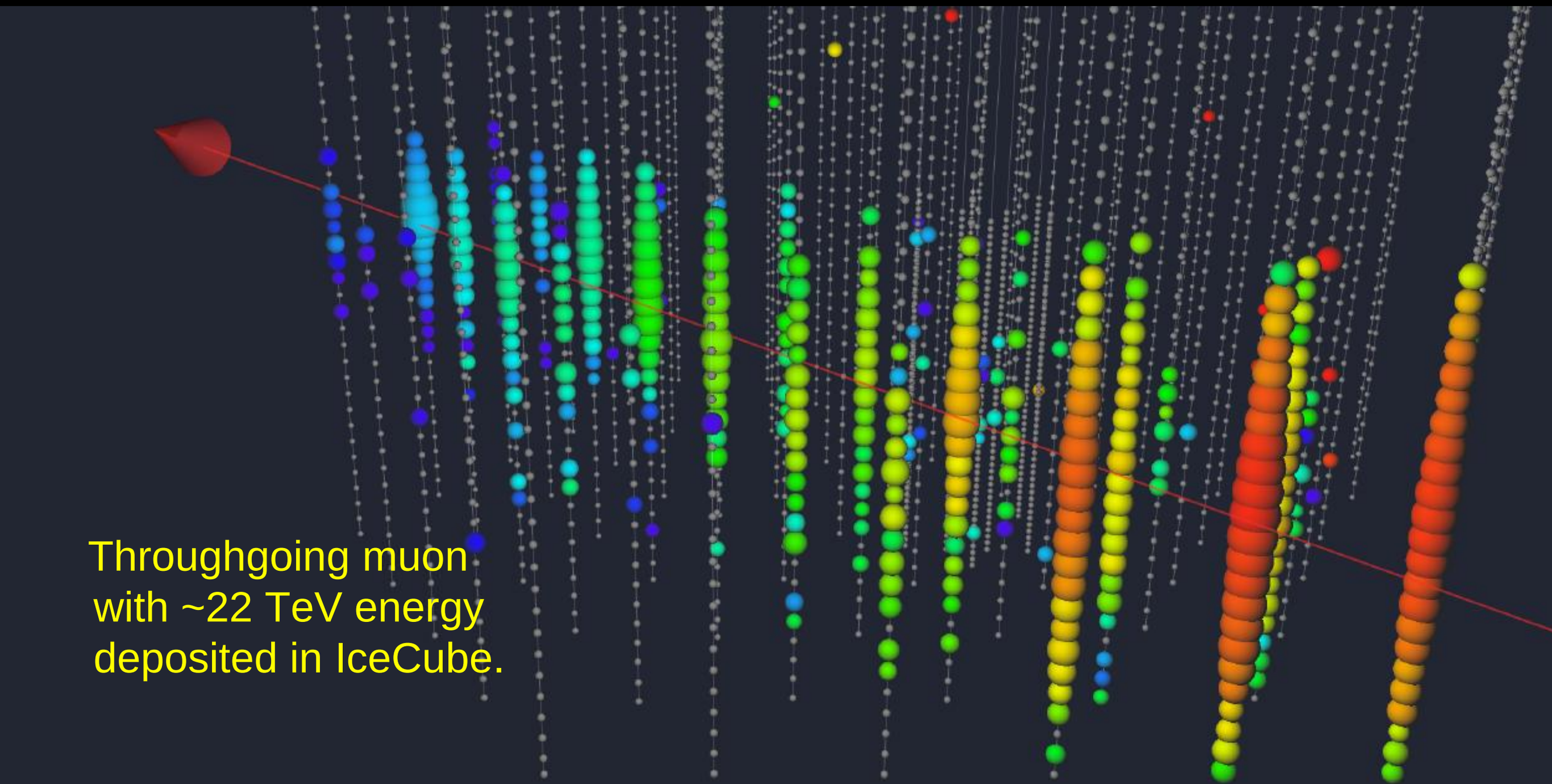


Alerts to optical, radio and gamma-ray telescopes and to x-ray detectors on satellites

REAL-TIME ALERTS FROM ICECUBE



22. September 2017, 20:54 UTC



Throughgoing muon
with ~22 TeV energy
deposited in IceCube.

43 seconds later: alert (“GCN Notice”) with initial estimate
of direction and energy.

Following day(s)

- Sequence of refined reconstruction algorithms
- **~ 4 hours later: GCN Circular issued**
- 22 TeV deposited energy → most probable energy of the parent neutrino ~290 TeV depending only weakly on the assumed spectrum.
- “Signalness” (probability for cosmic origin) 56%.
- **Broad multi-wavelength campaign**

28. 9. Fermi-Satellite:

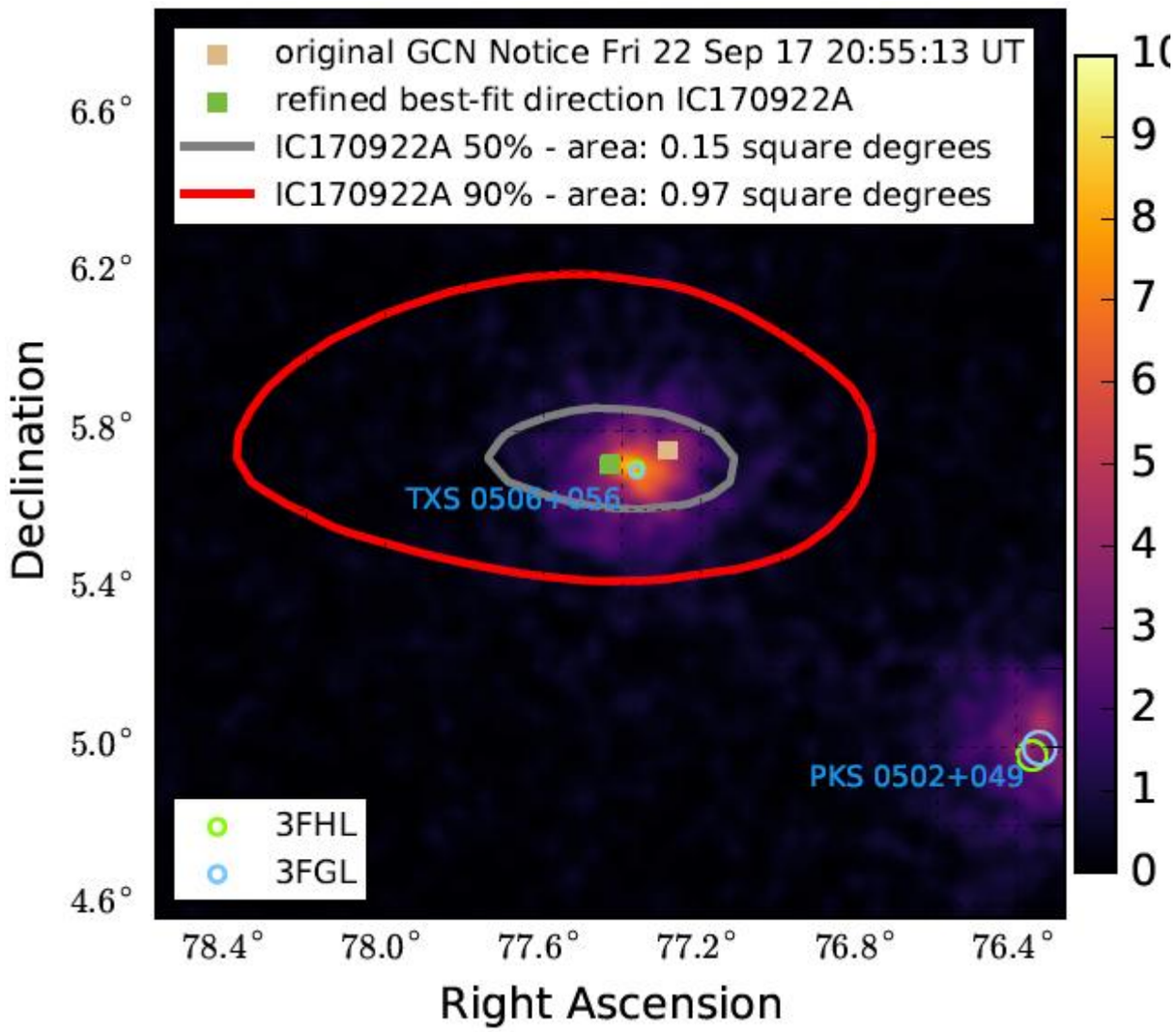
- Source: Active Galaxy TXS 0505+056, which is in a flaring state

From 29.8. on

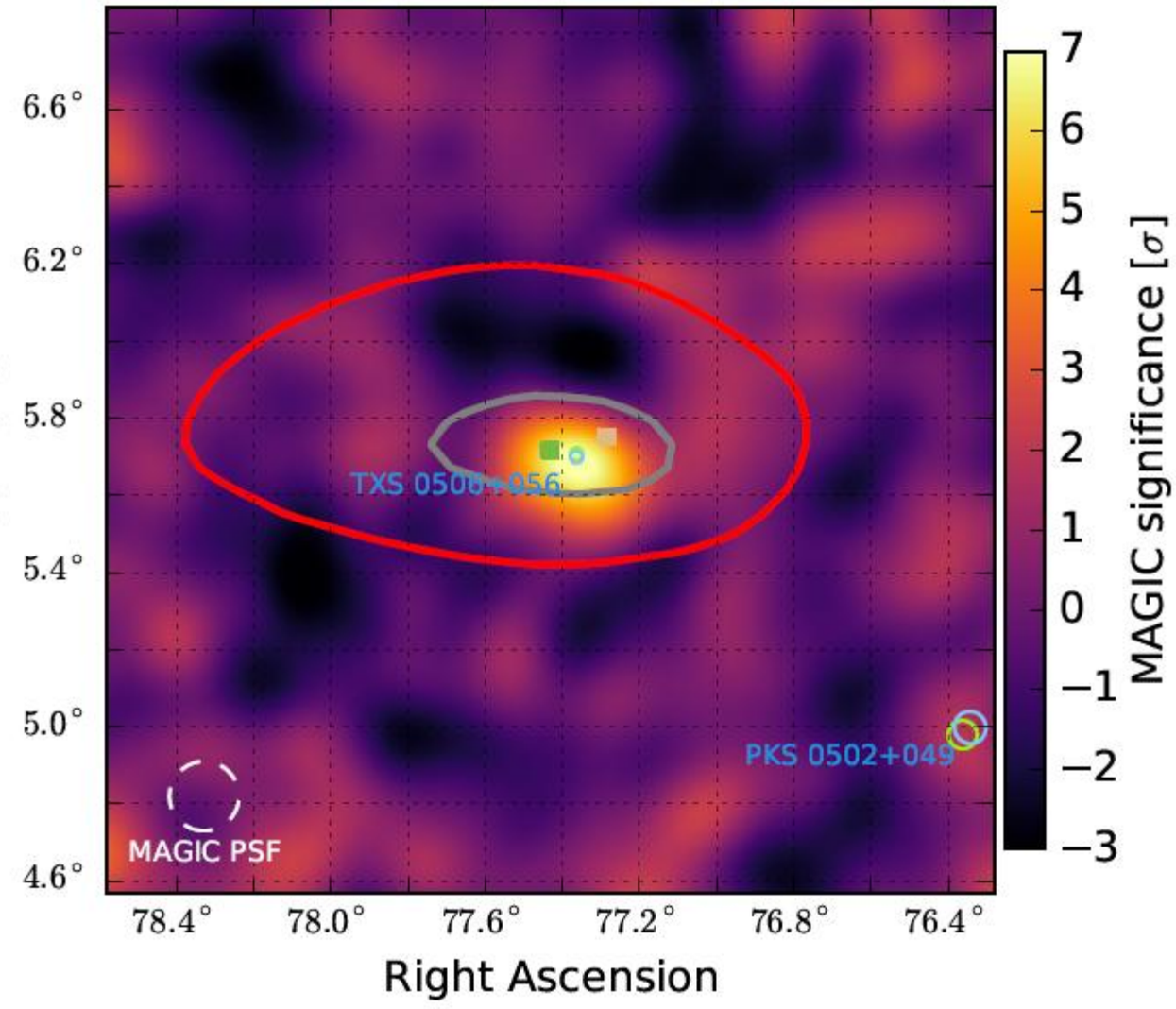
MAGIC looks longer than the initial hour to TXS 05060+056 and observes it flaring with high significance

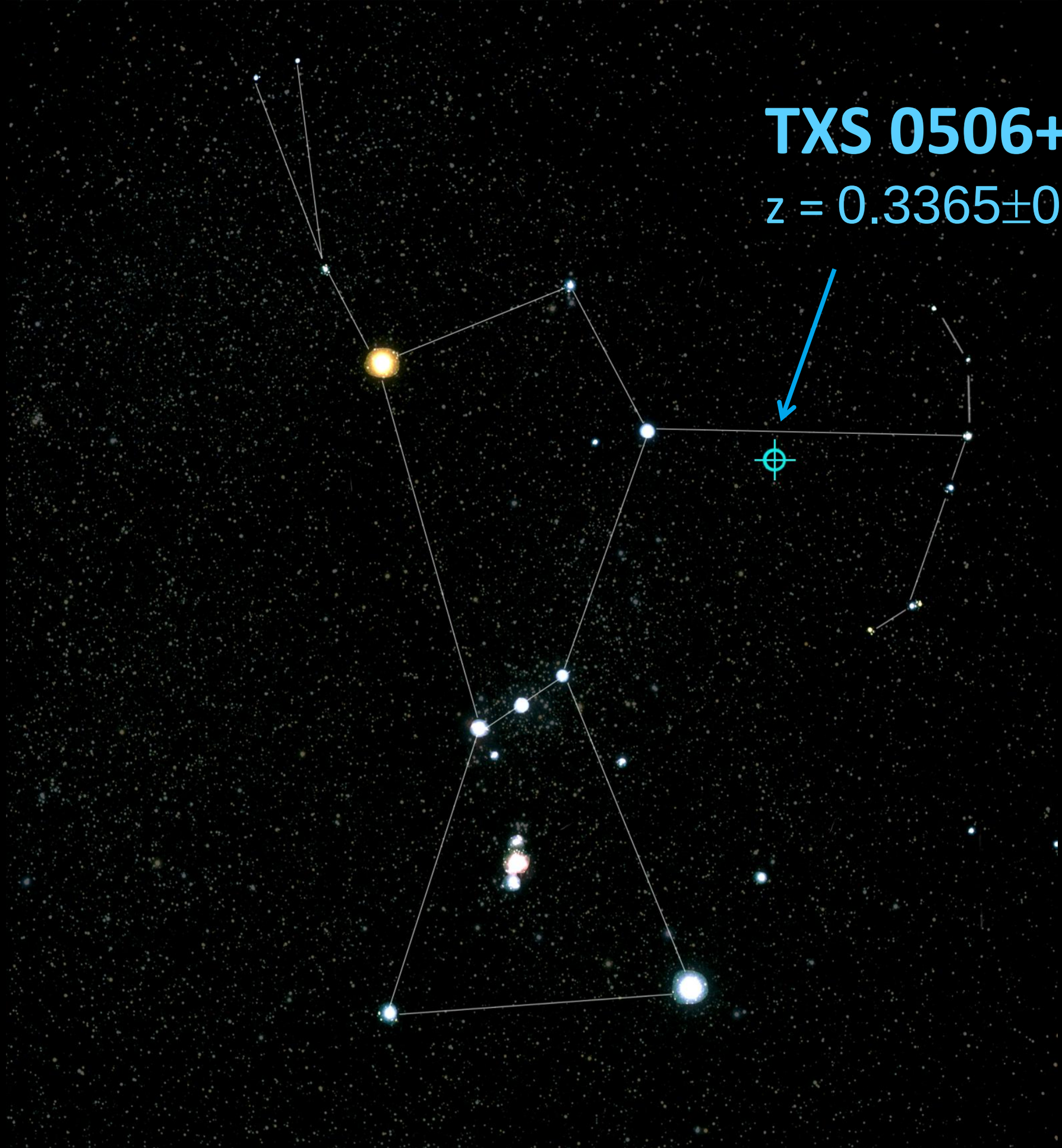
Comparison to Fermi and MAGIC data

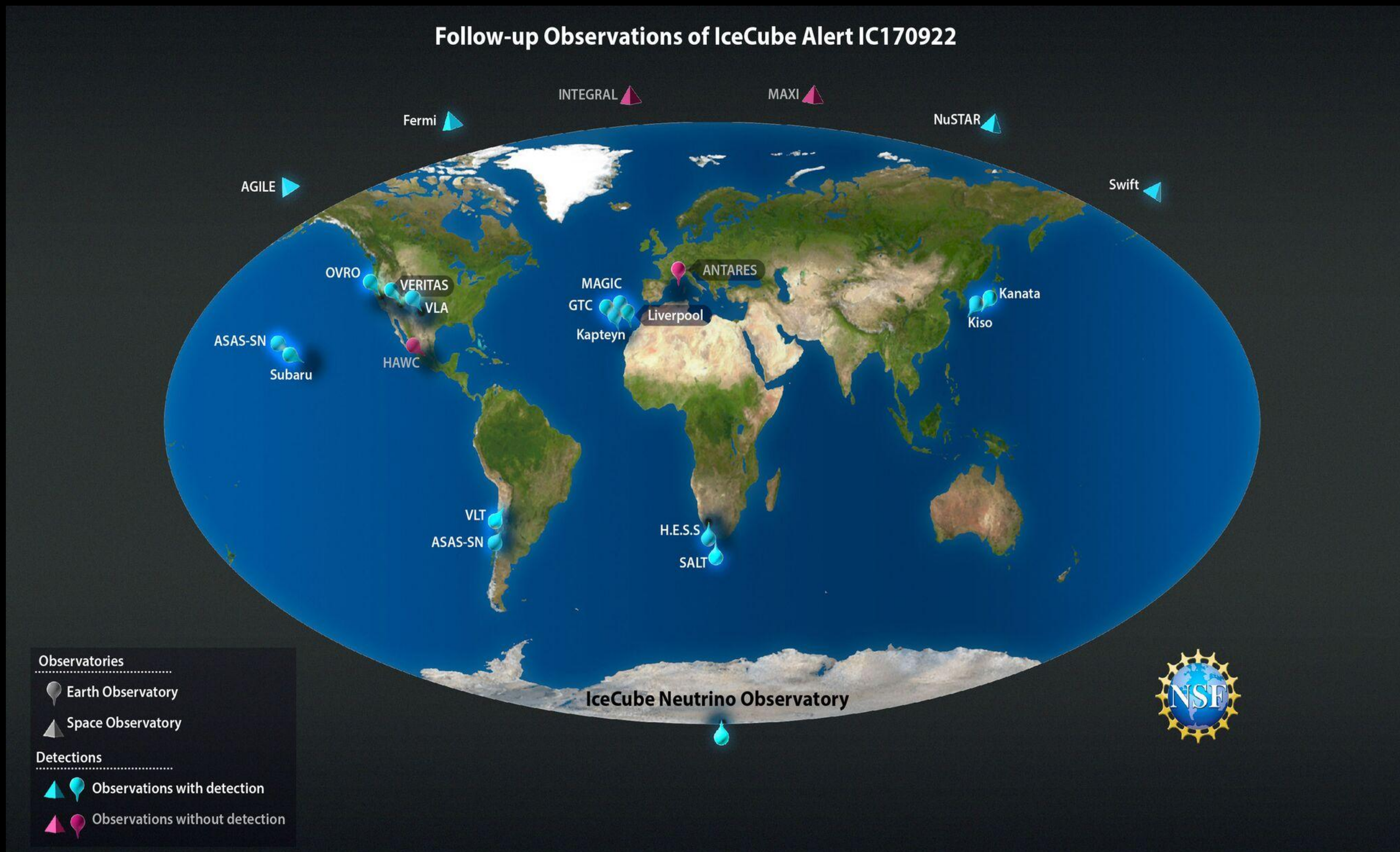
Fermi LAT (> 100 MeV)



MAGIC (> 90 GeV)




TXS 0506+056
z = 0.3365±0.0010



Significance of the coincidence ~ 3σ

Time dependent analysis of 9.5 years IceCube data

- **Two generic profiles:**

  Gaussian-shaped time window

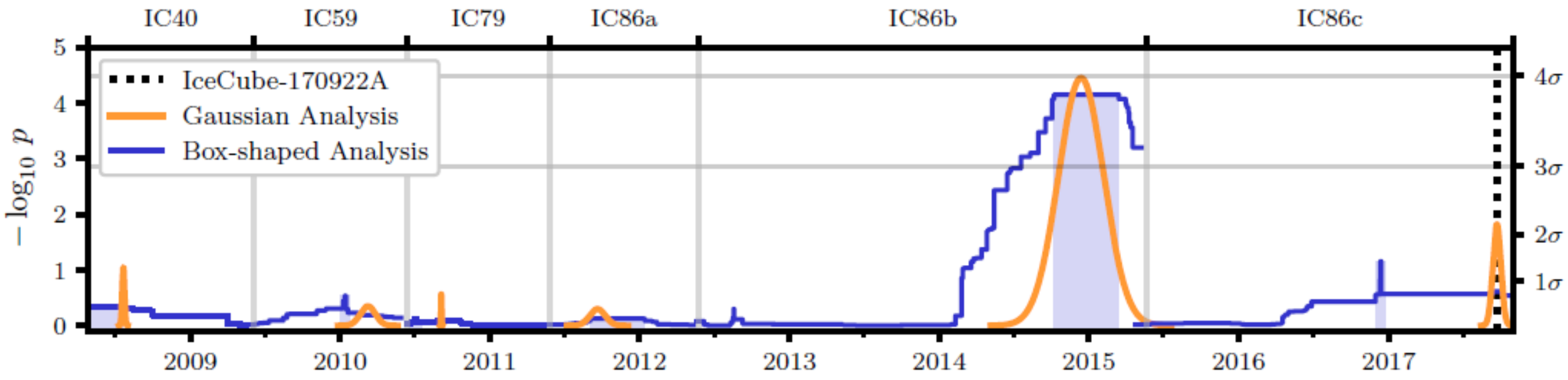
  Box-shaped time window

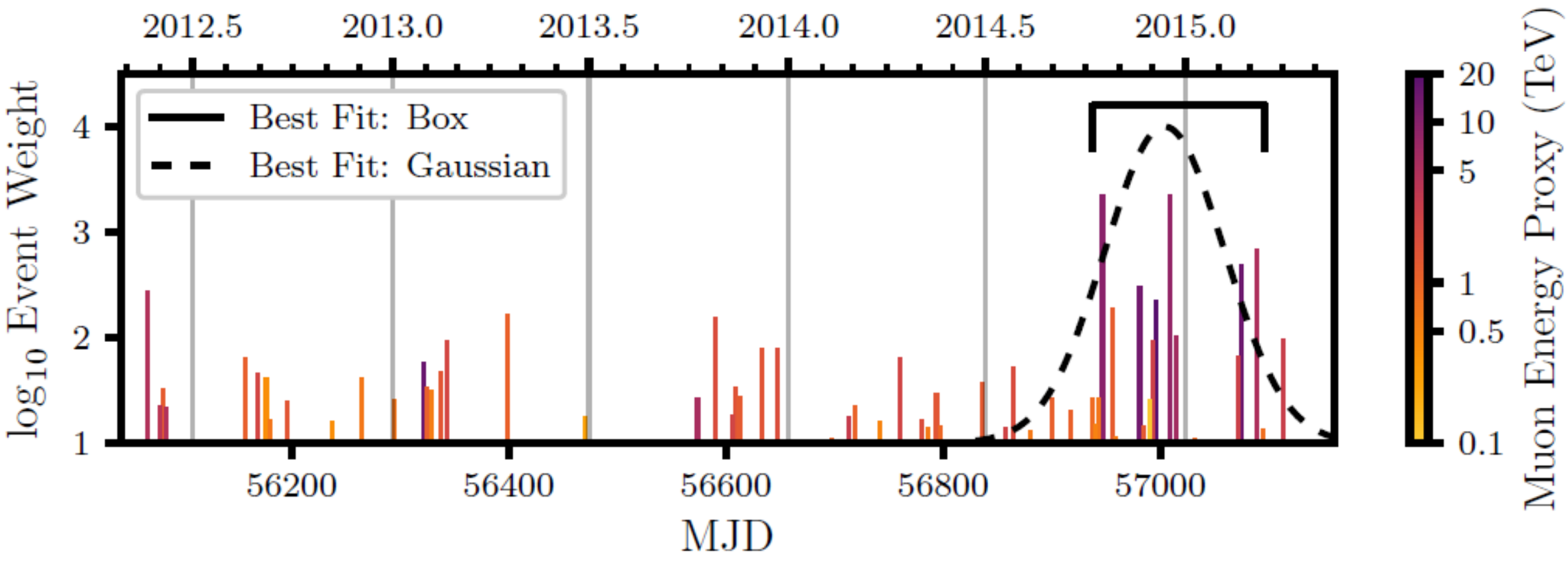
- Vary the central time, T_0, and duration T_W (from seconds to years) of the potential signal to find those four parameters

  Flux at 100 TeV, spectral index γ , T_0 , T_W

  that maximize a well-defined test statistic (TS)

Time profile and significance





Fit parameters

- **Box time window:**

  T_0 ~ December 16, 2014, T_W = 158 days

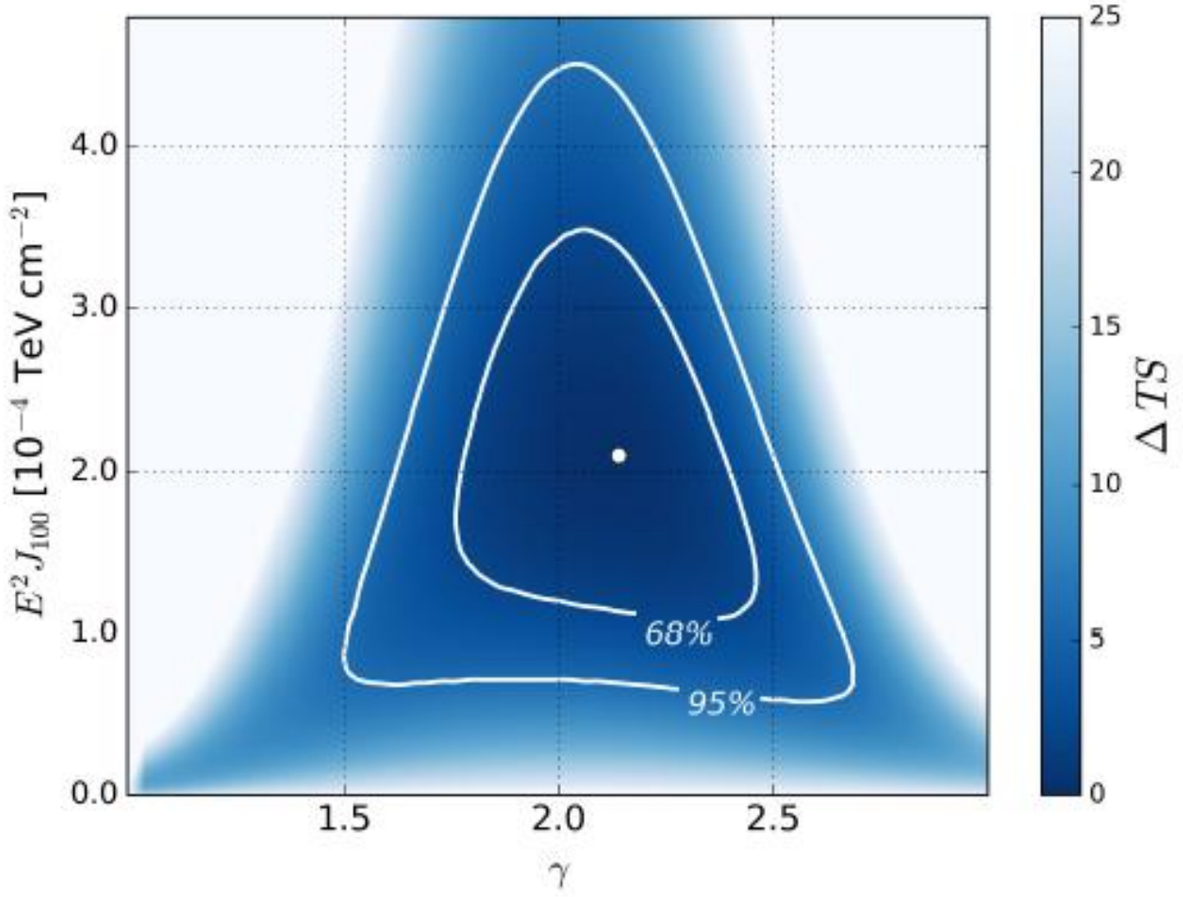
- **Gaussian time window:**

  T_0 ~ December 13, 2014, T_W = 110 days

- **Best-fit for flux normalization @ 100 TeV: 1.6×10^{-15} TeV^{-1} cm^{-2}s^{-1}**

- **Best fit for spectral index γ: 2.2**

- **Significance after trial corrections ~ 3.5σ**



Conclusions on TXS 0506+056

- The implied neutrino luminosity of TXS 0506+056 is at comparable levels to its observed gamma-ray luminosity.
- This provides evidence that blazars, especially TXS 0506+056, are a site of very-high-energy cosmic ray acceleration (and that they contribute to IceCube's diffuse astrophysical neutrino flux).
- Further detections and additional observations are needed to clearly resolve the source of all cosmic neutrinos observed by IceCube.

Fantastic demonstration of the potential of multi-messenger observations !

Most remarkable IceCube results by 2018

- 2012: Ernie and Bert, the first two PeV neutrinos
- 2013: Discovery of a diffuse cosmic neutrino flux
- 2015: Constraints on oscillation parameters comparable to best accelerator experiments
- 2016: Exclude Waxman-Bahcall model for GRB
- 2016: Record constraints of sterile neutrinos
- 2018: First possible point source

Thank you for your attention