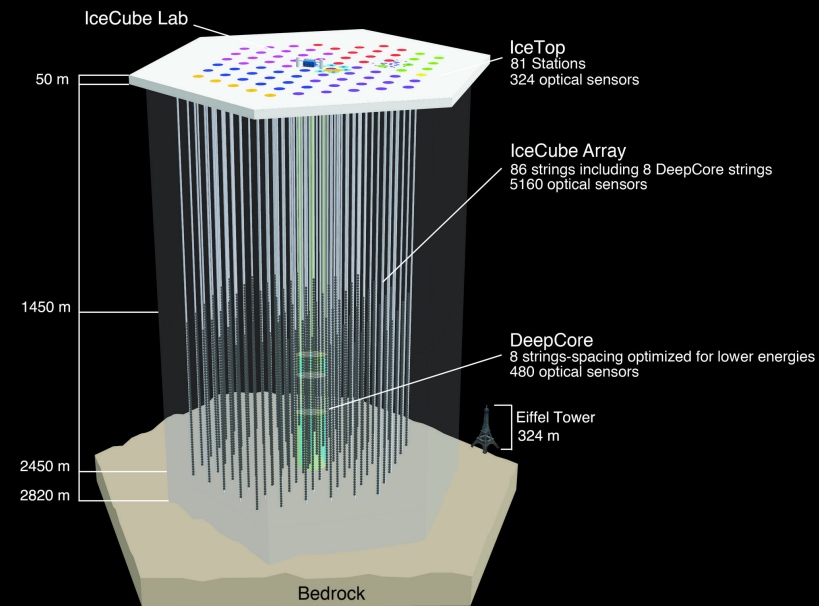
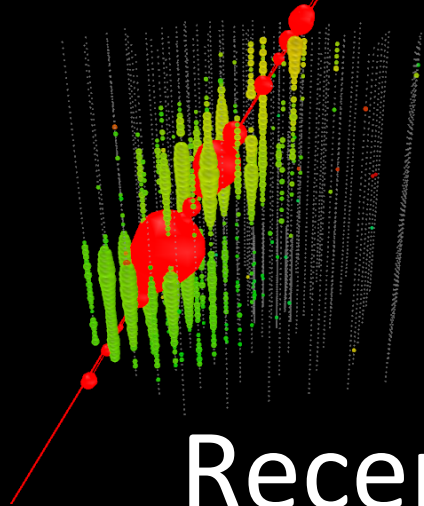
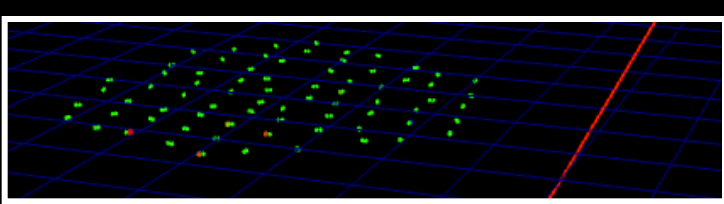




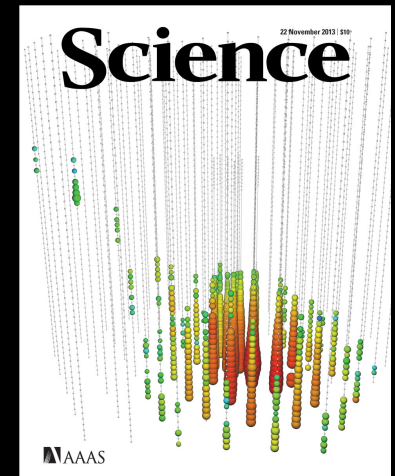
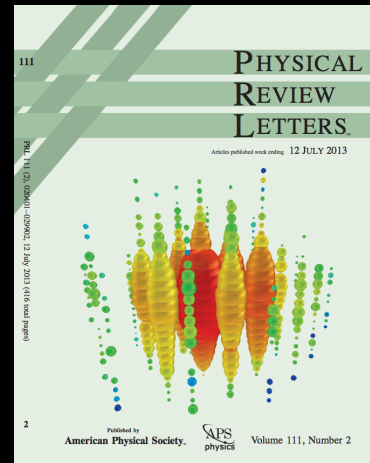
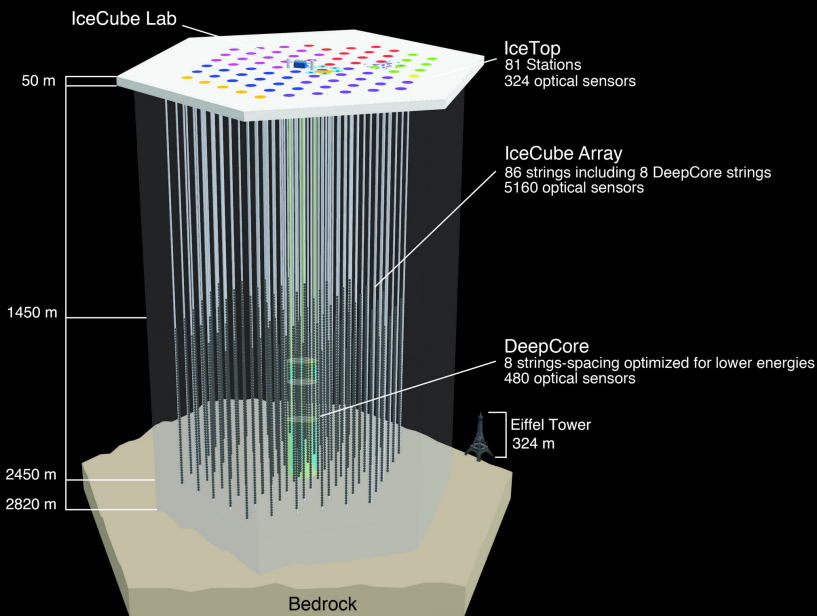
Recent IceCube results

IceCube found neutrinos.



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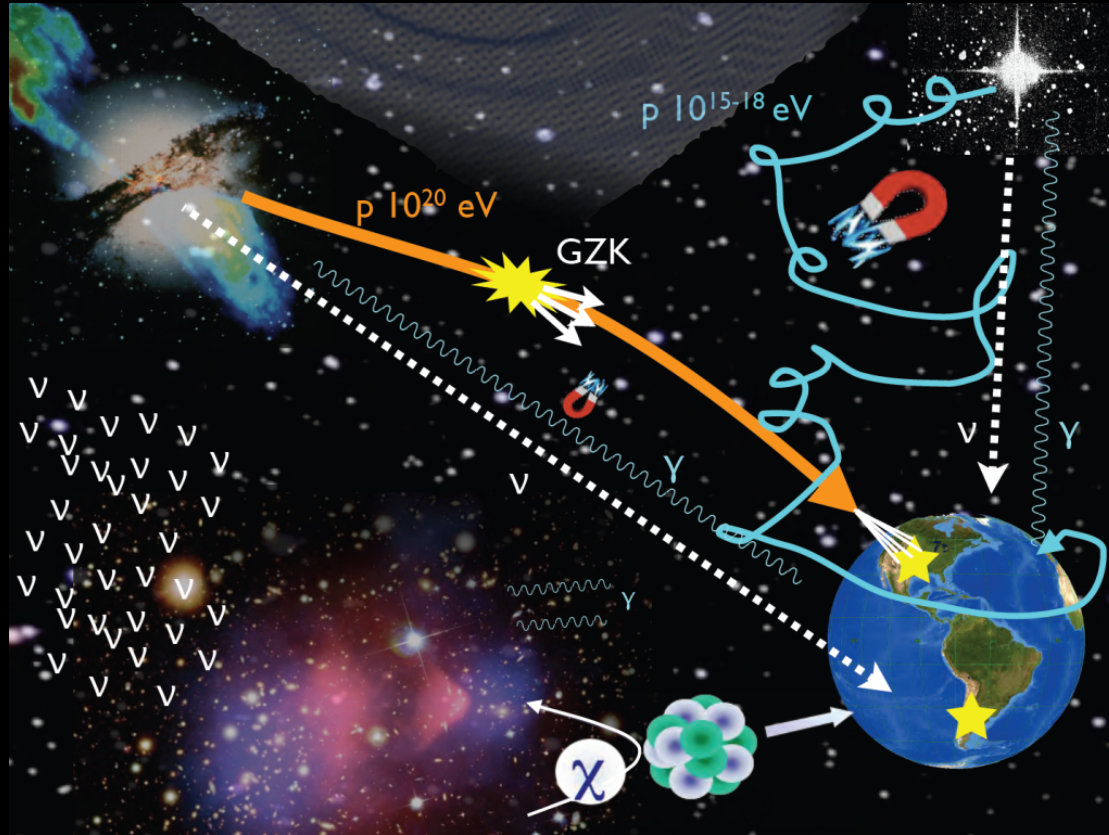




Content...

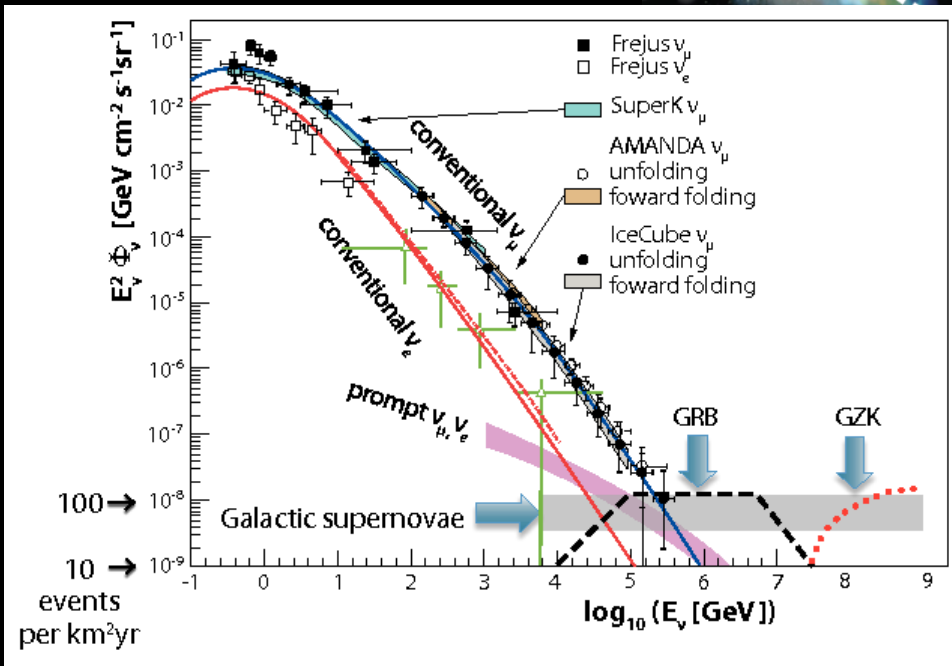
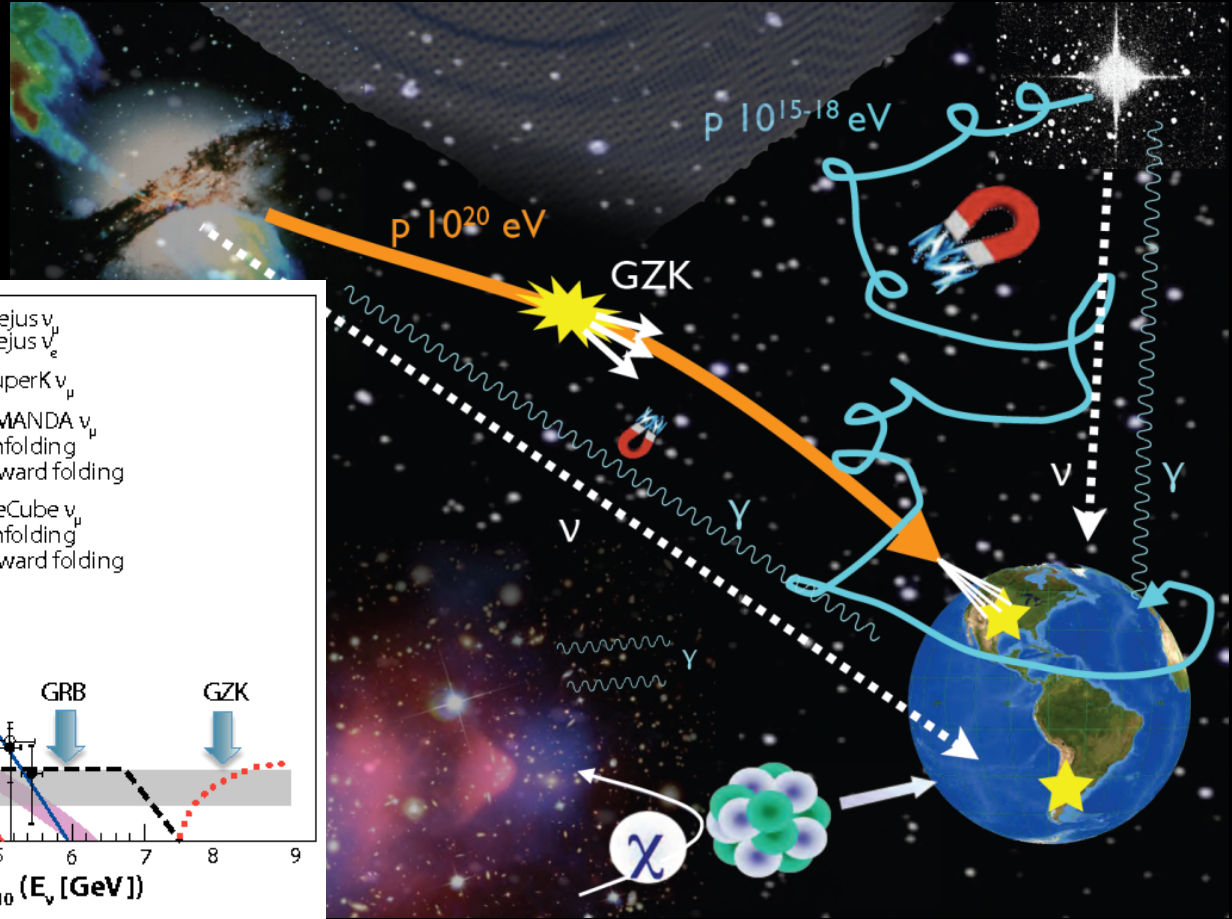
- IceCube
- New diffuse results on high energy neutrinos
- Recent point source results
- The mysteries of astrophysical neutrinos
- Future Ideas
- What I did not talk about...

Why astrophysical neutrino search?



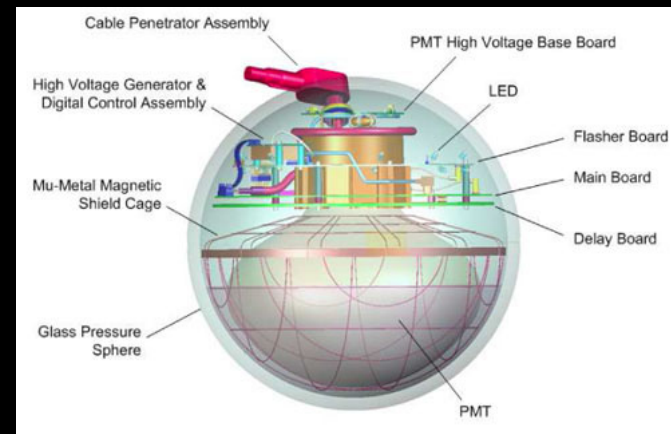
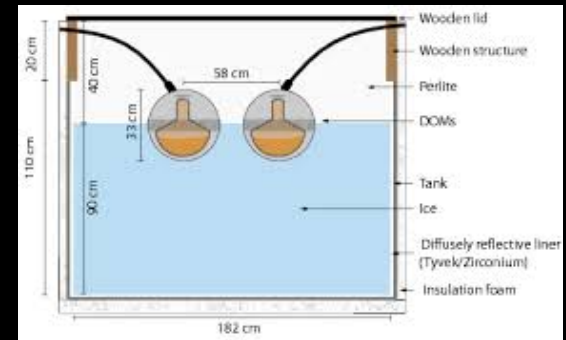
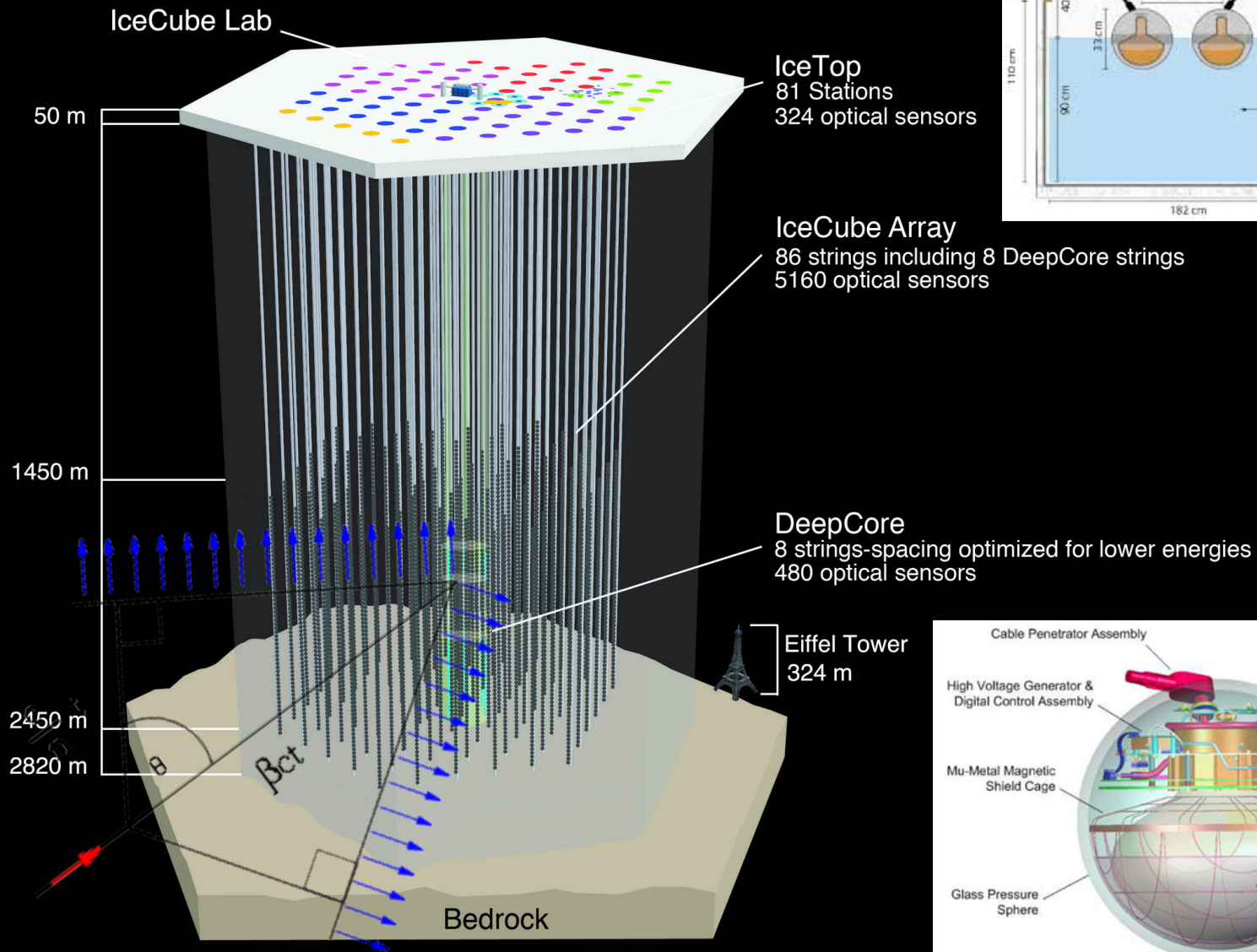
Neutrinos point back to their sources !

Why astrophysical neutrino search?



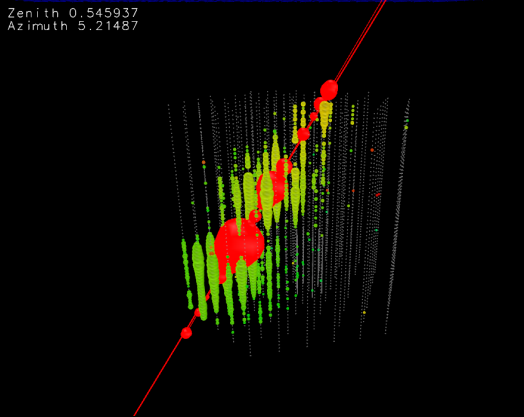
Astrophysical neutrinos may be dominant at ~ 100 TeV

Astrophysical neutrino search



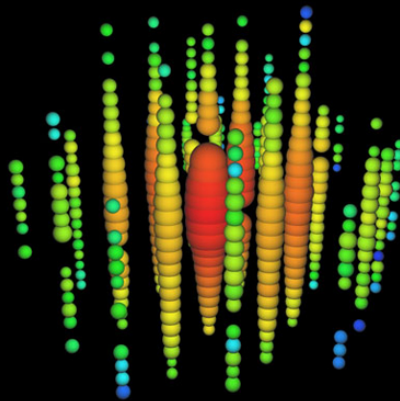
What neutrino produces what signature?

CC Muon Neutrino
so called “track”



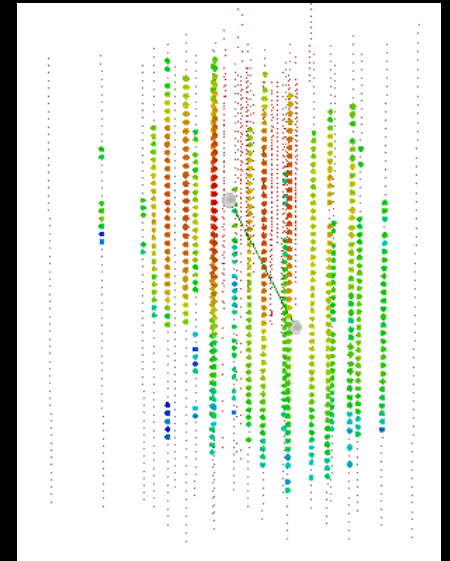
- factor of ≈ 2 energy resolution
- $< 1^{\circ}$ angular resolution

Neutral Current /Electron
Neutrino
so called “cascade”



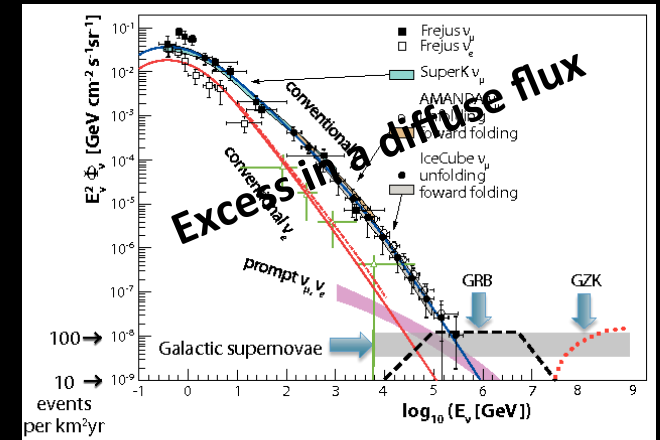
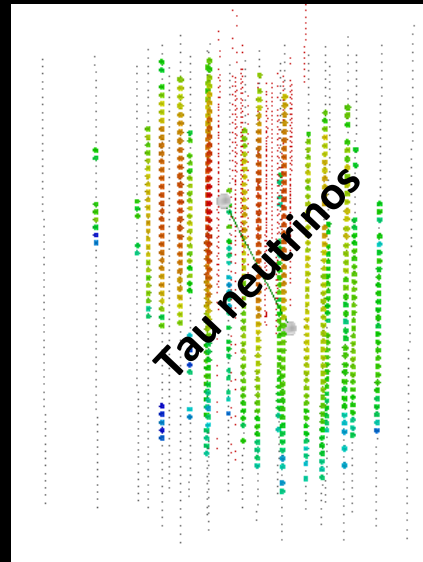
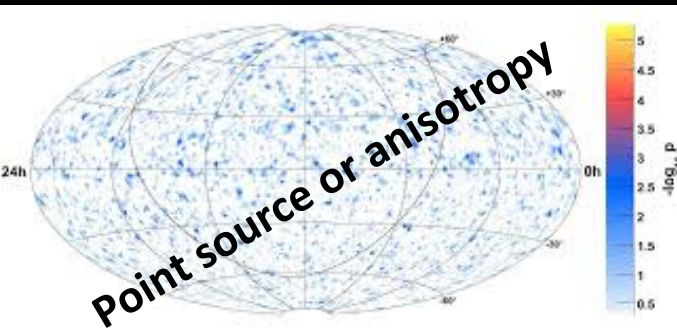
- $\approx \pm 15\%$ deposited energy resolution
- $\approx 10^{\circ}$ angular resolution (at energies $\gtrsim 100$ TeV)

CC Tau Neutrino
so called “double bang”

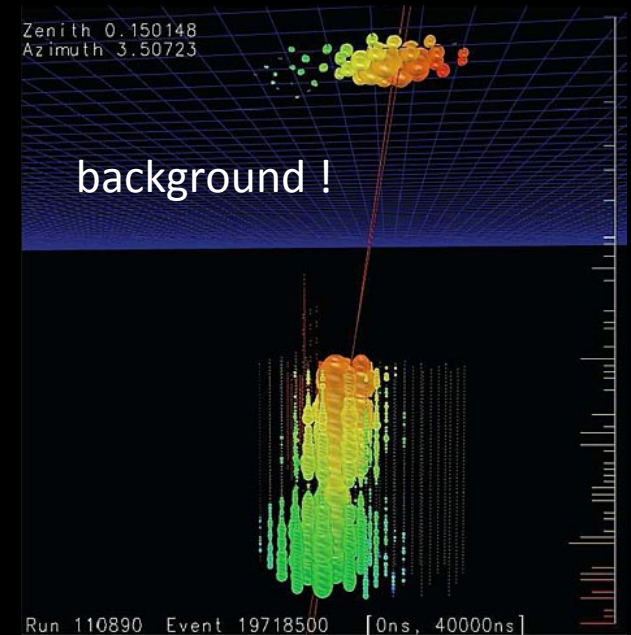


(not observed yet)

What is an astrophysical neutrino signature?



- point sources (tracks point better than cascades)
- Tau neutrinos (suppressed in CR showers)
- excess in neutrino spectrum
- Cosmic Ray induced particles are background!



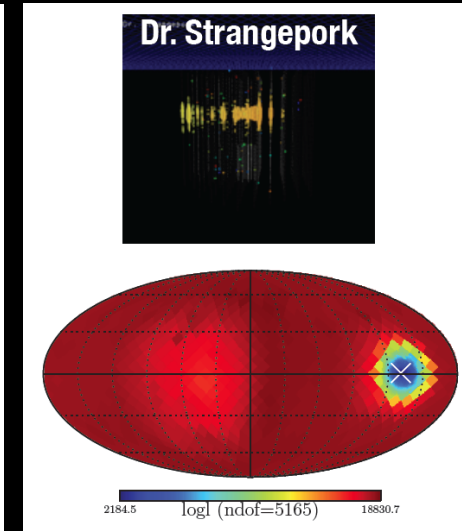
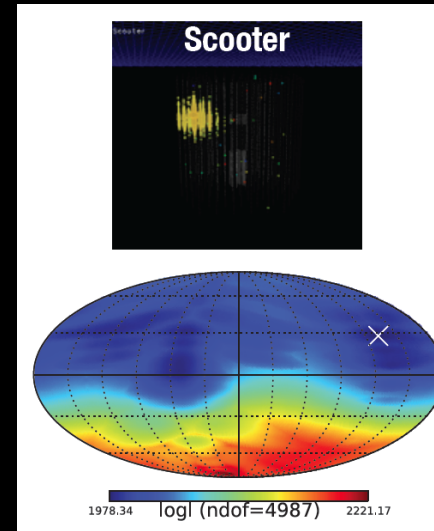
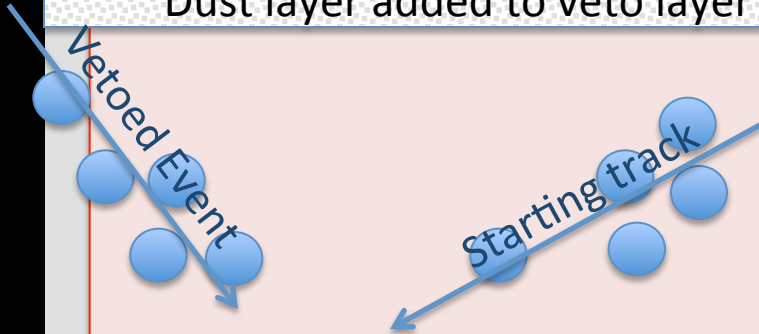
Jan Auffenberg

Starting event analyses

Veto layer where no first hits in time are allowed

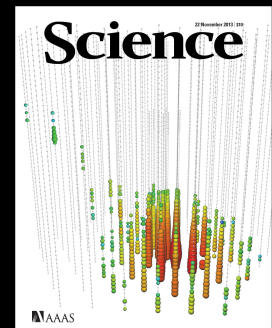
Veto protected volume

Dust layer added to veto layer

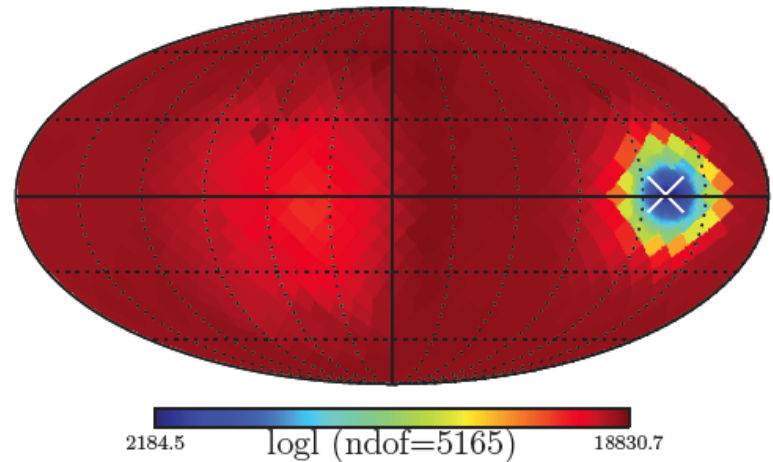
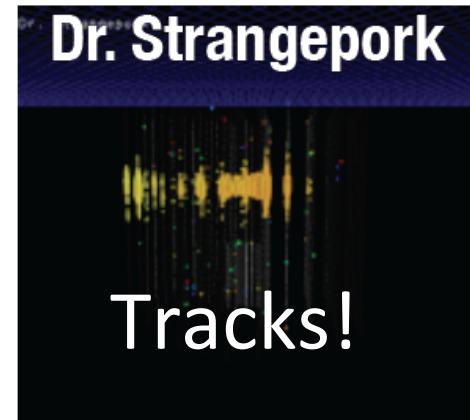
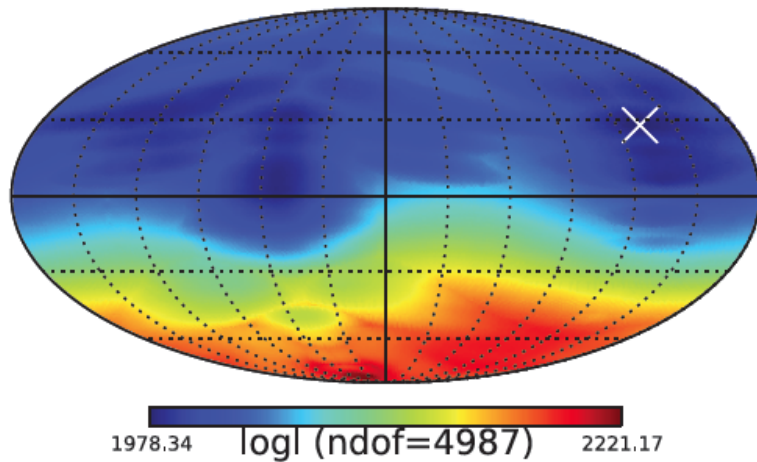
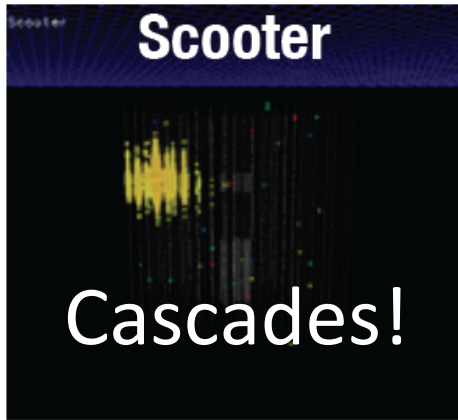


- 28 events in 2 years of data
- less tracks (8) than cascades (20)
- no v_t signature

But what do we see?

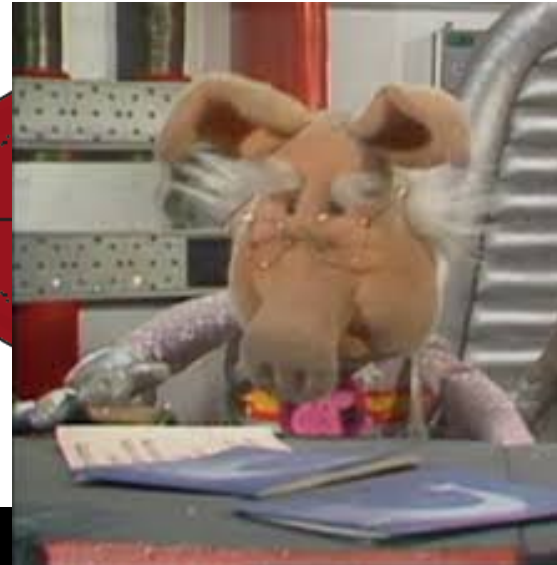
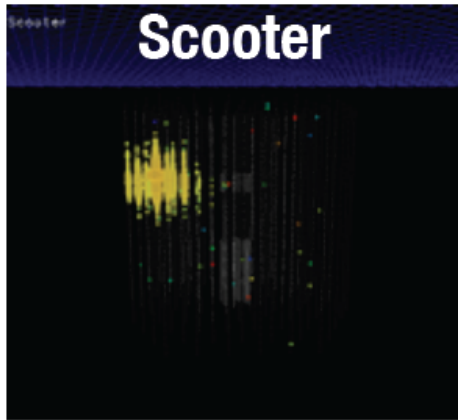


Starting event analyses

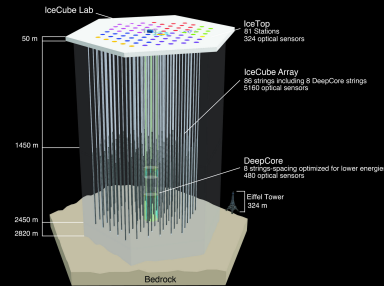


Patterns...

Starting event analyses



Results 2 years starting events



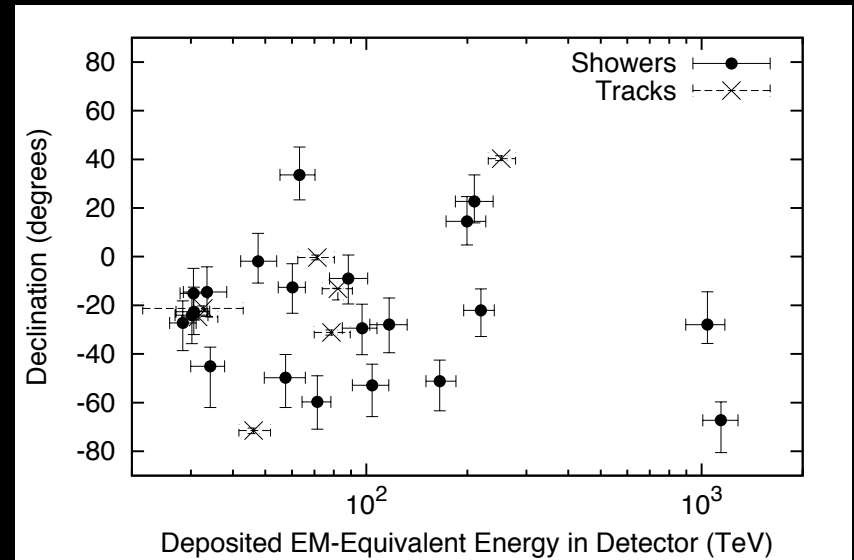
Veto layer where no first hits in time are allowed

Veto region where events are allowed to start

Dust layer added to veto layer

Vetoed Event

Starting track



- 20 Cascades with good energy reconstruction
- 8 tracks with good directional reconstruction

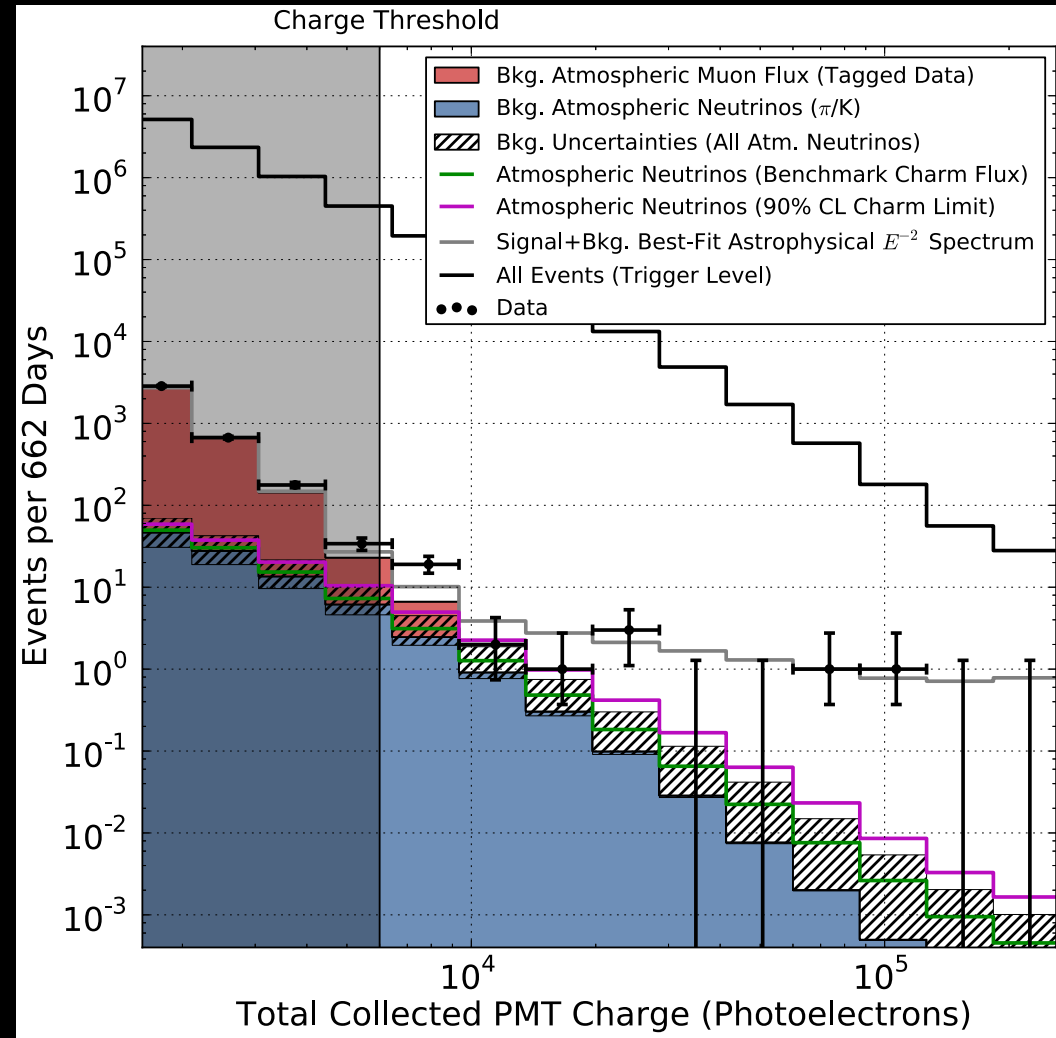
Expectation from not astrophysical sources:

$$10.6^{+5}_{-3.6}$$

Inconsistent at 4.1σ with background (3.6σ for the lower 26 events)

Diffuse flux 2 years

- Harder than any expected atmospheric background
- Merges well into background at low energies

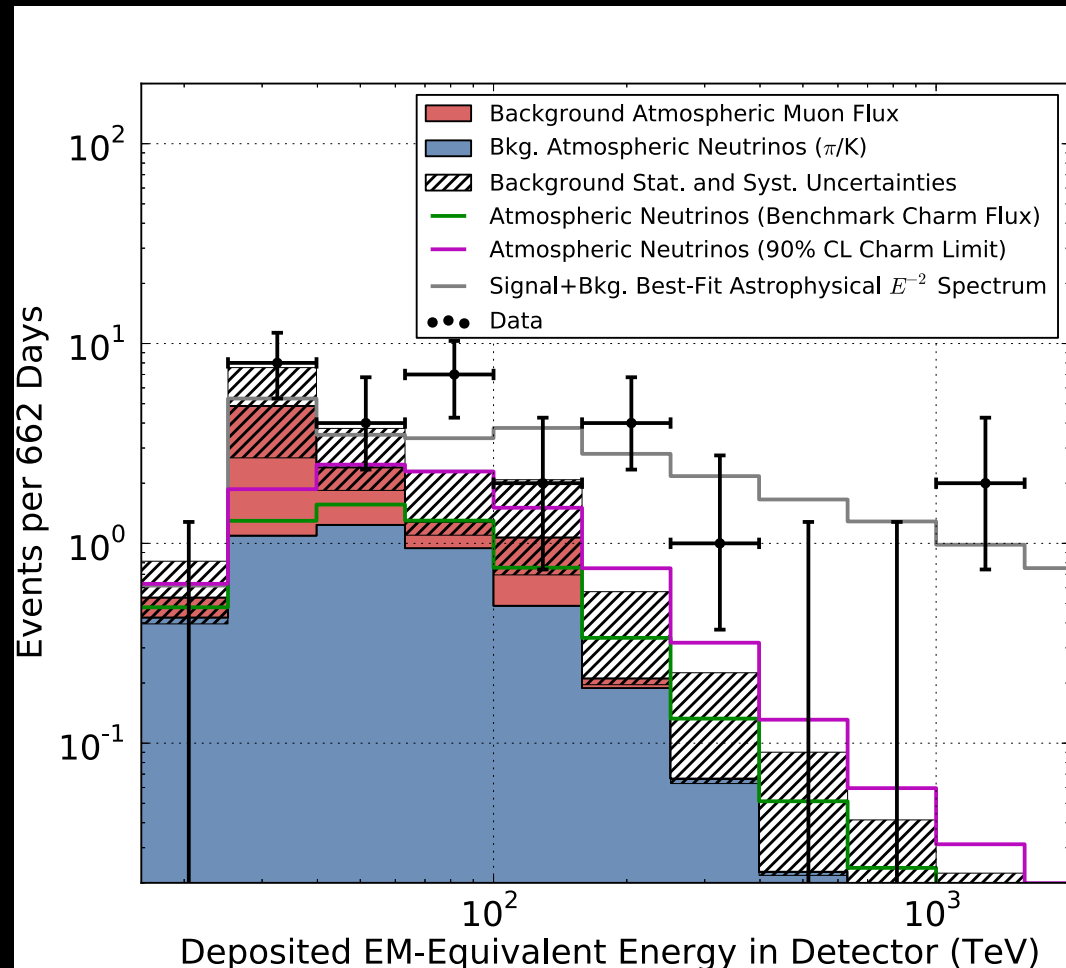


Diffuse flux 2 years

- Harder than any expected atmospheric background
- Merges well into background at low energies
- Potential cutoff at about 2-5 PeV
- at $1.6^{+1.5}_{-0.4}$ PeV when fitting a hard cutoff

Best fit:

- $1.2 \pm 0.4 \cdot 10^{-8} E^{-2} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$

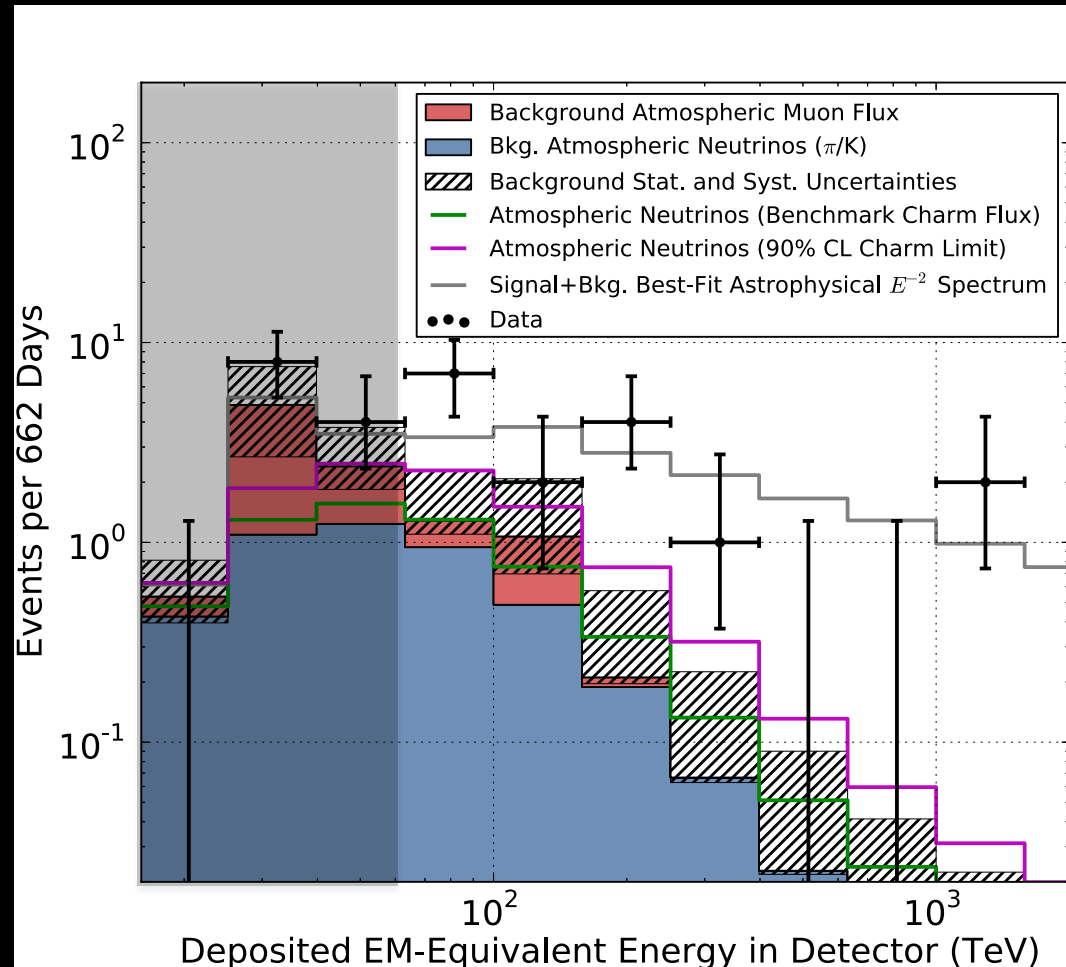


Diffuse flux 2 years

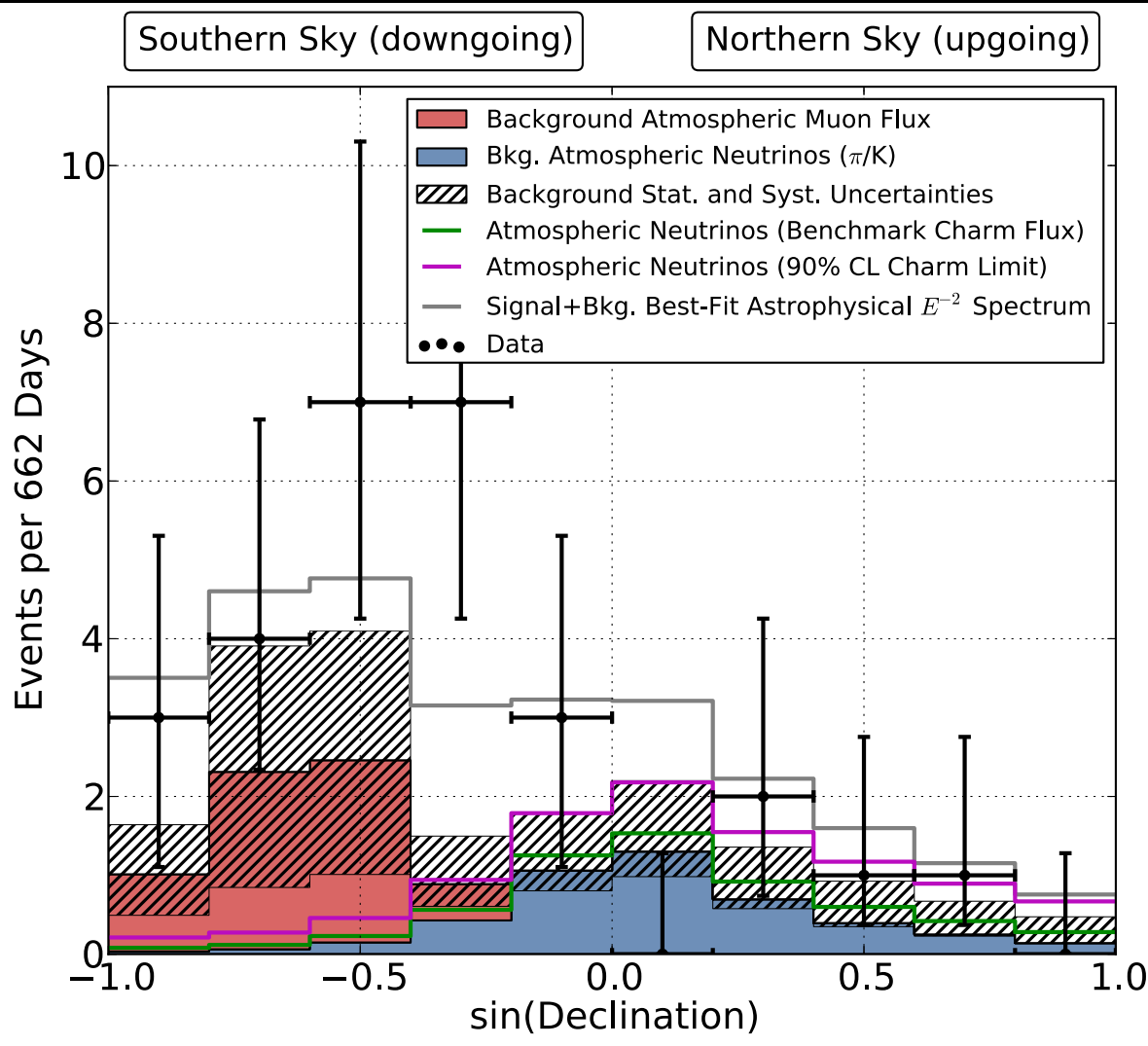
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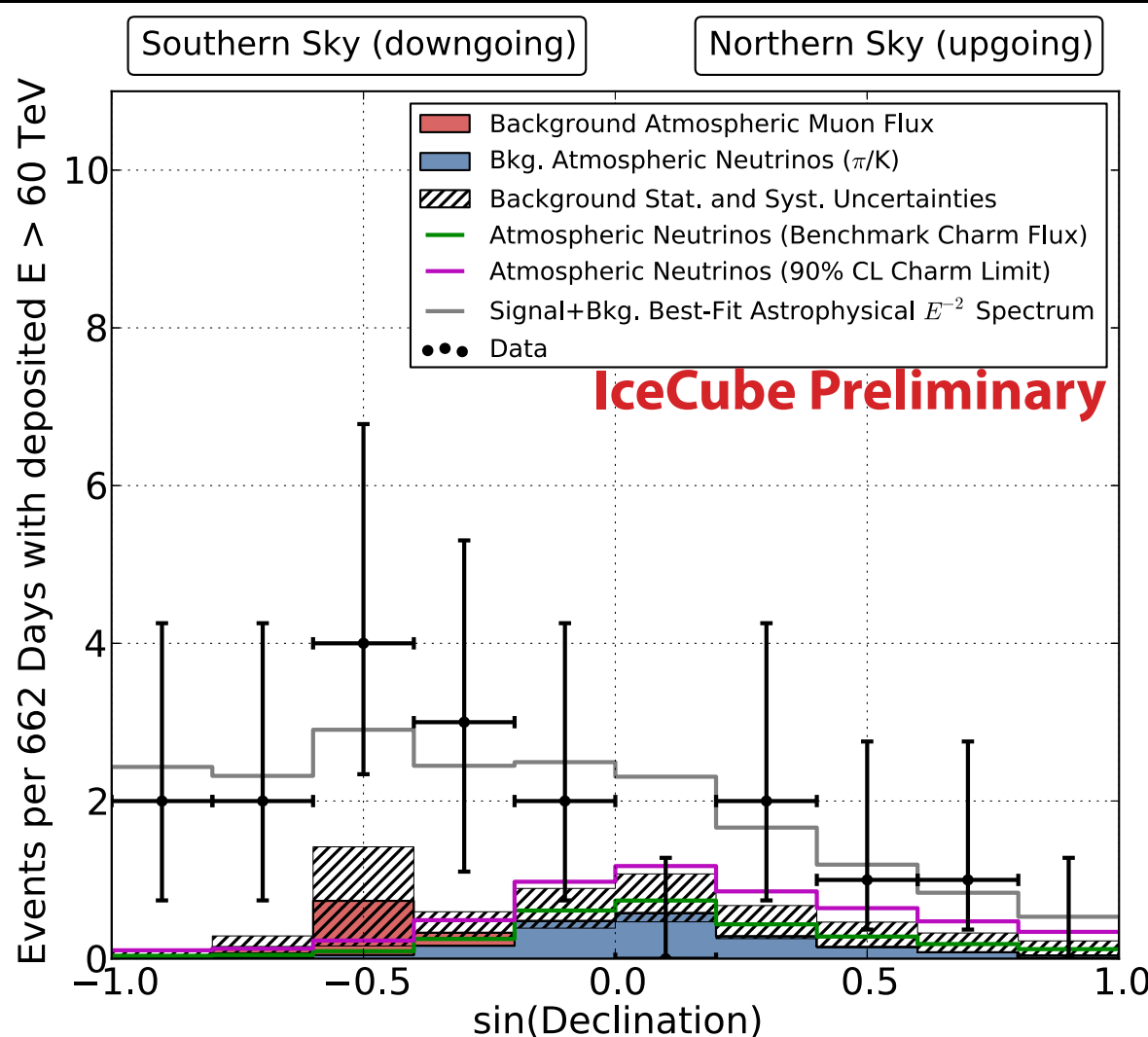
No significant north-south anisotropy



Compatible with isotropic flux

- Events absorbed in Earth from Northern Hemisphere
- Minor excess in south compared to isotropic, but not significant

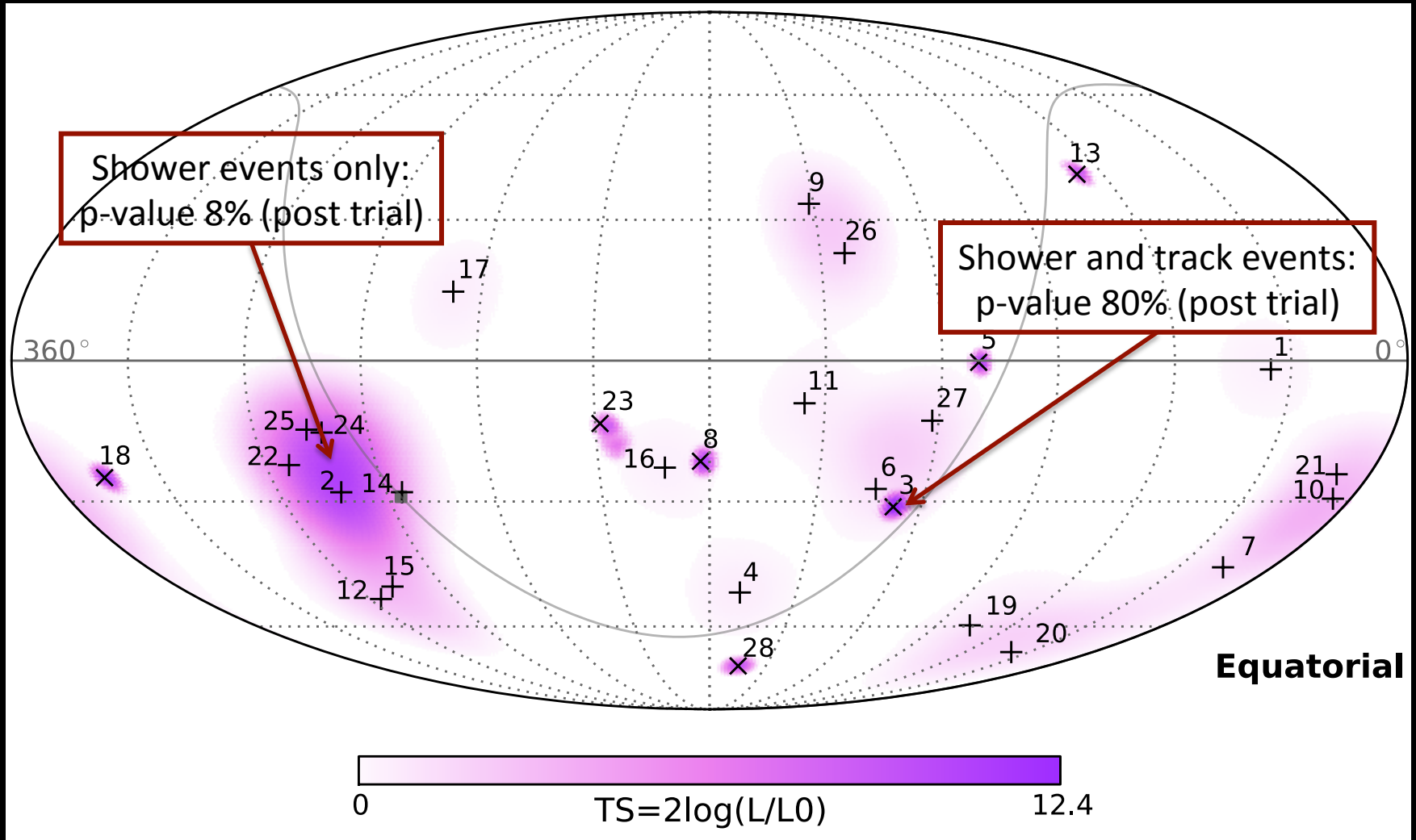
No significant north-south anisotropy



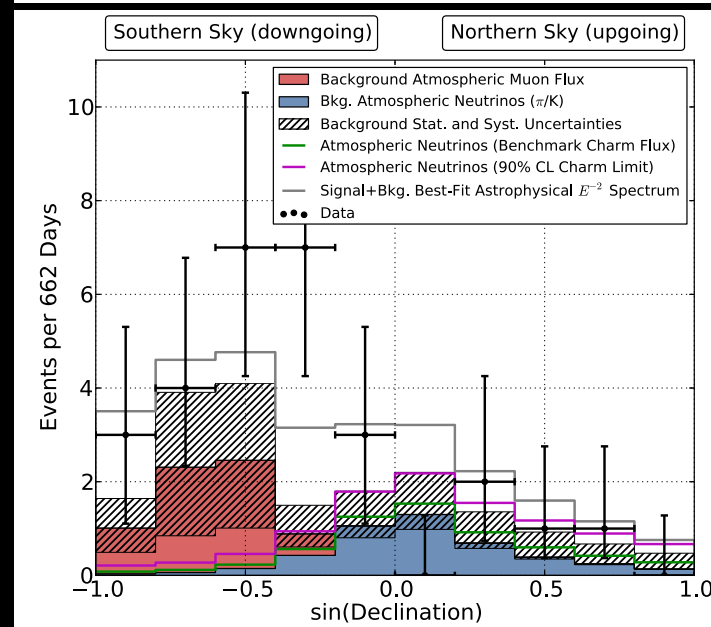
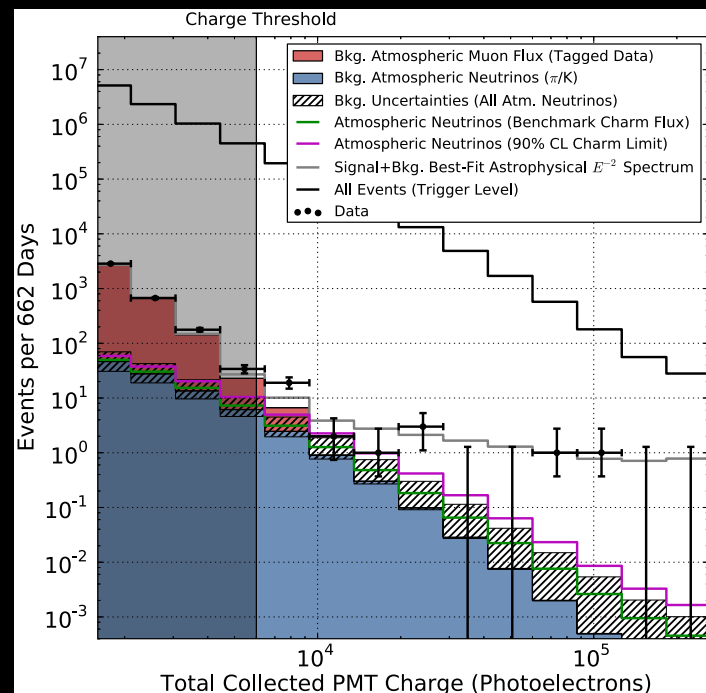
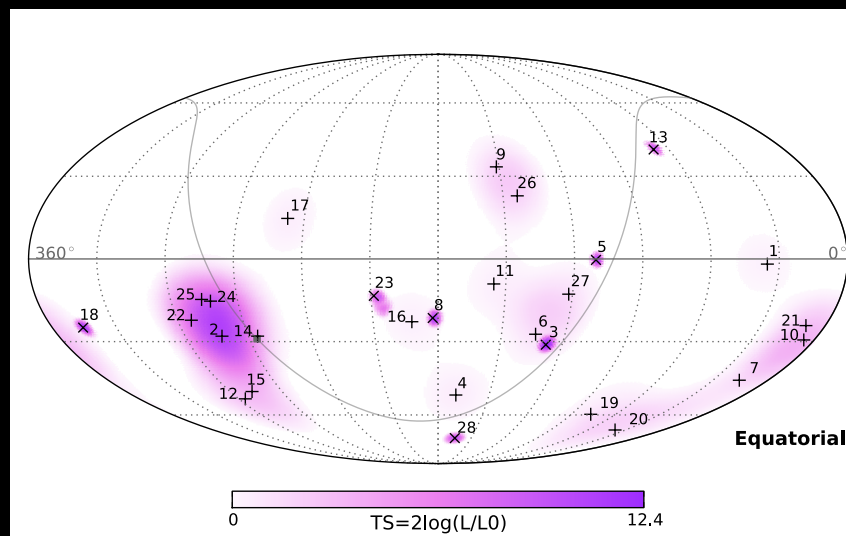
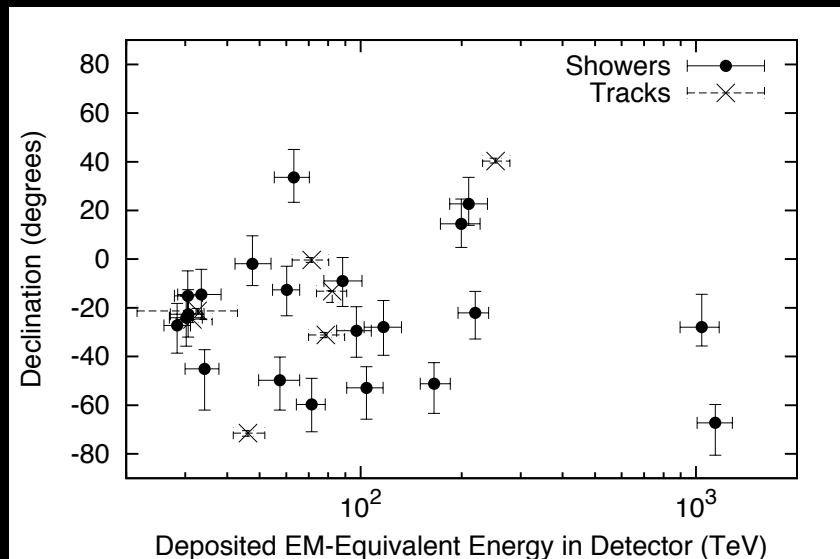
Compatible with isotropic flux

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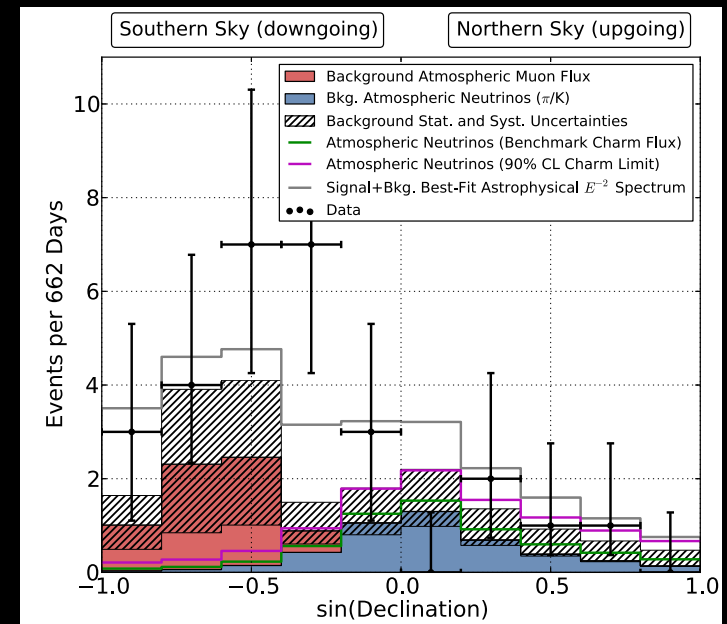
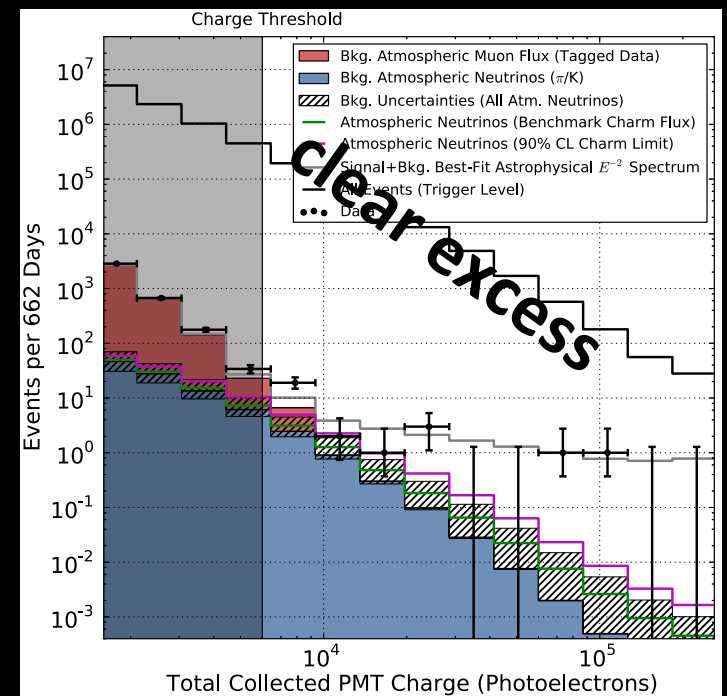
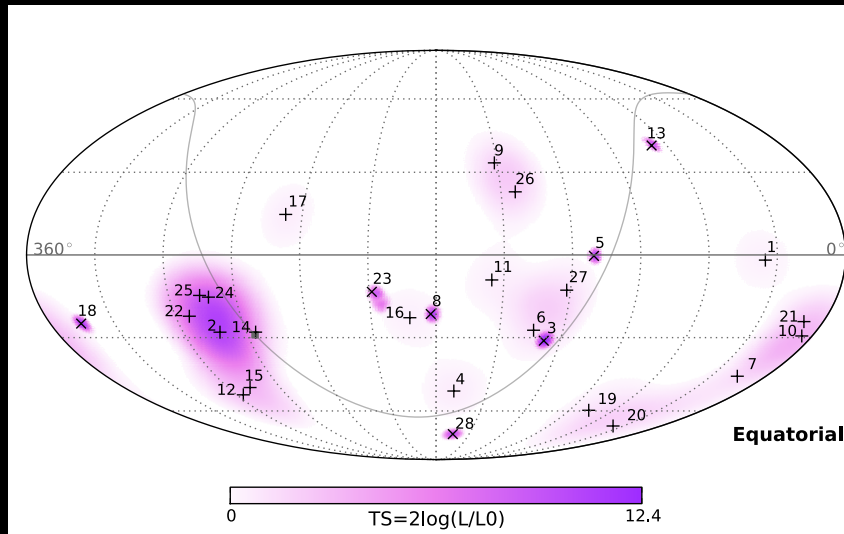
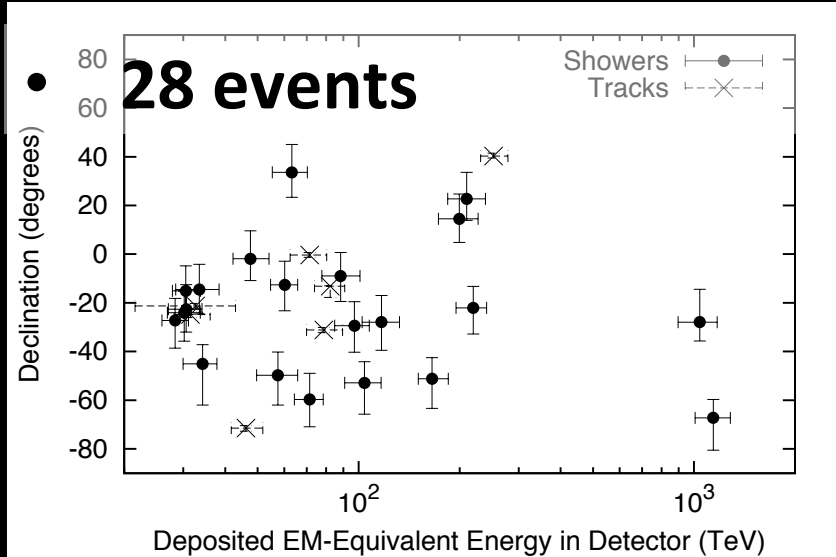
Point source map with no hot spot



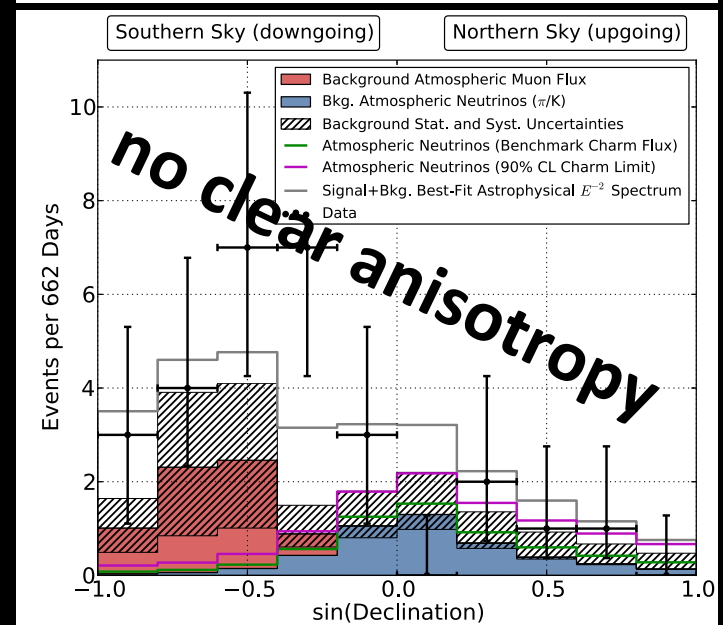
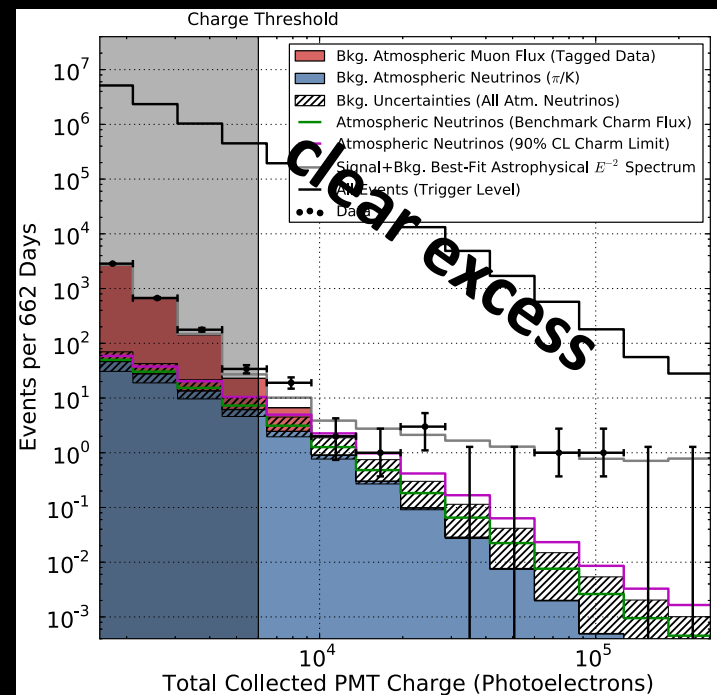
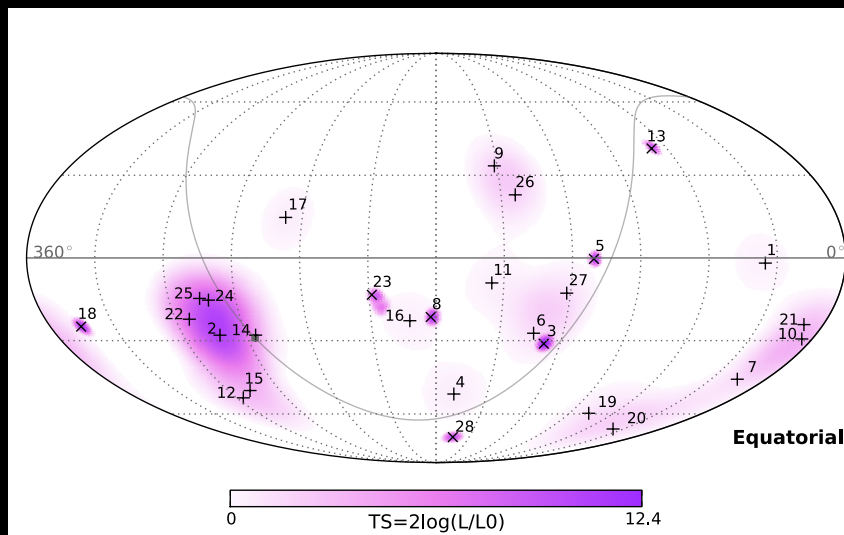
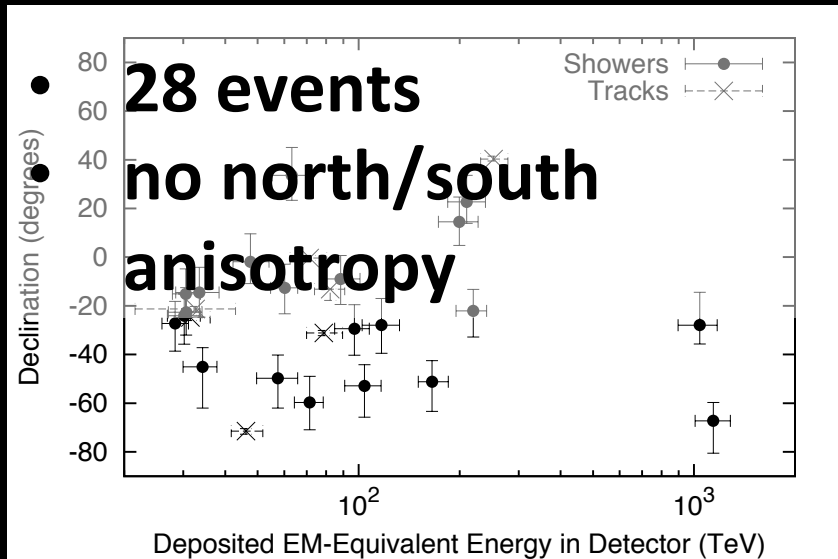
Summary 2 year data:



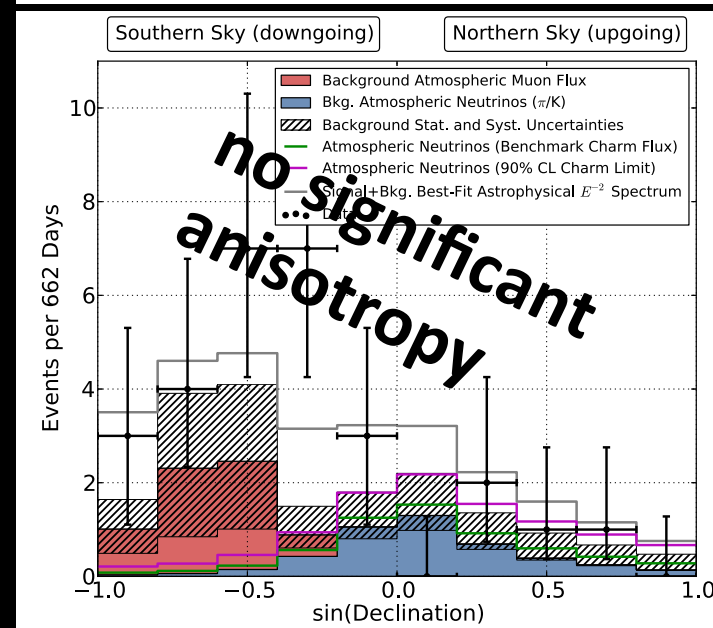
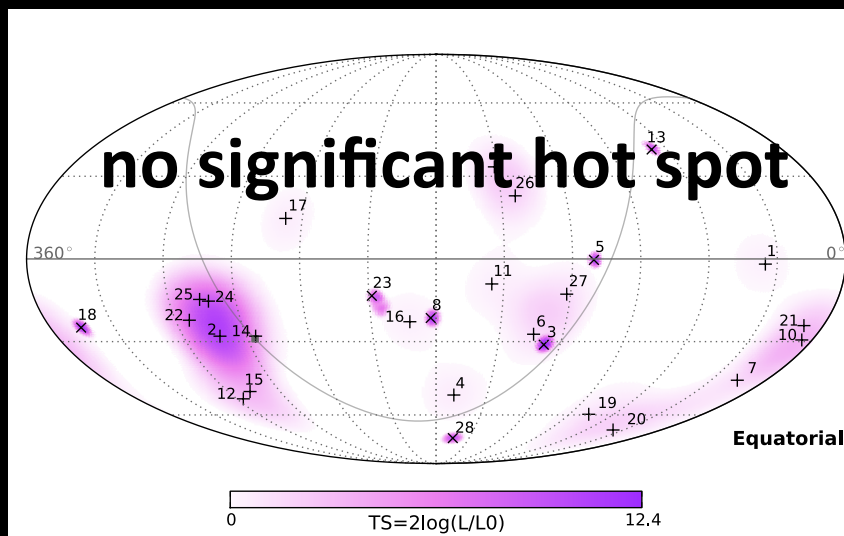
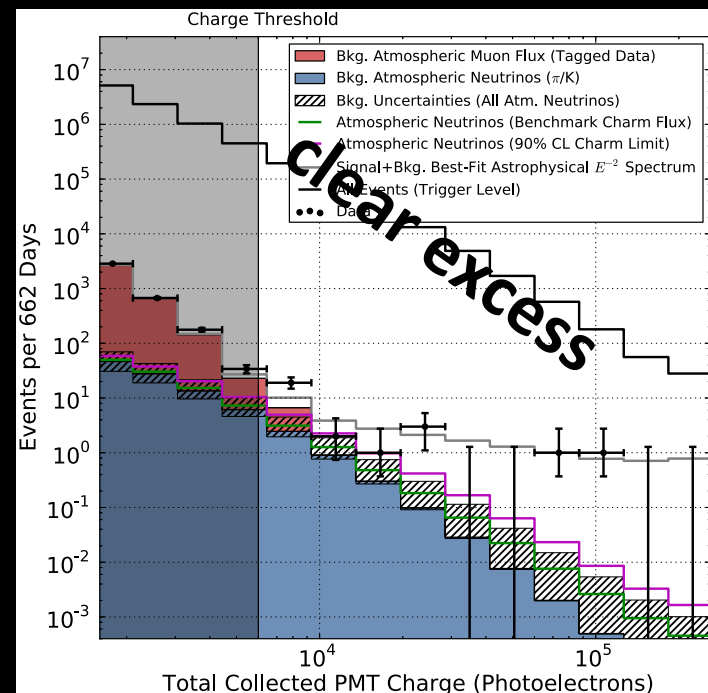
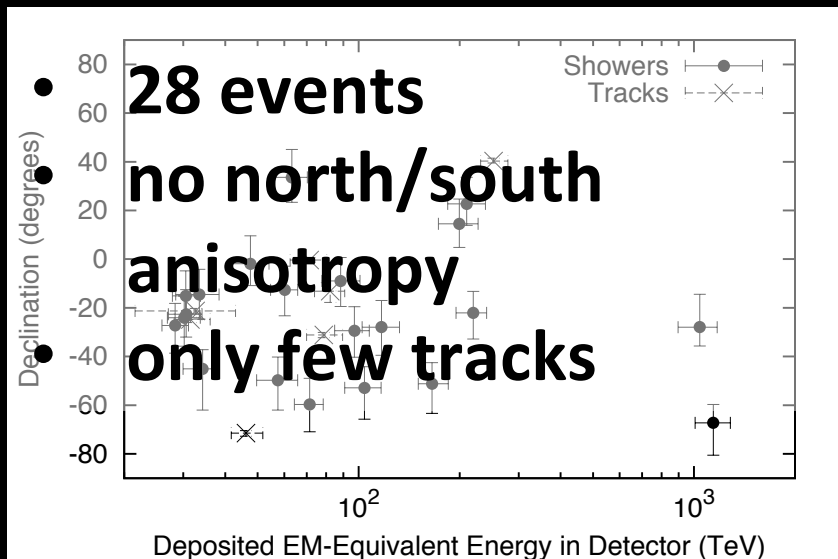
Summary 2 year data:



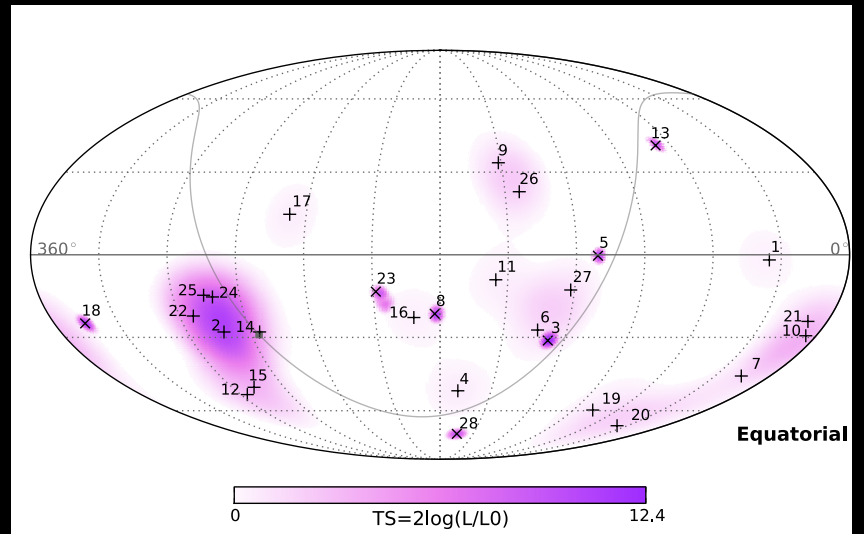
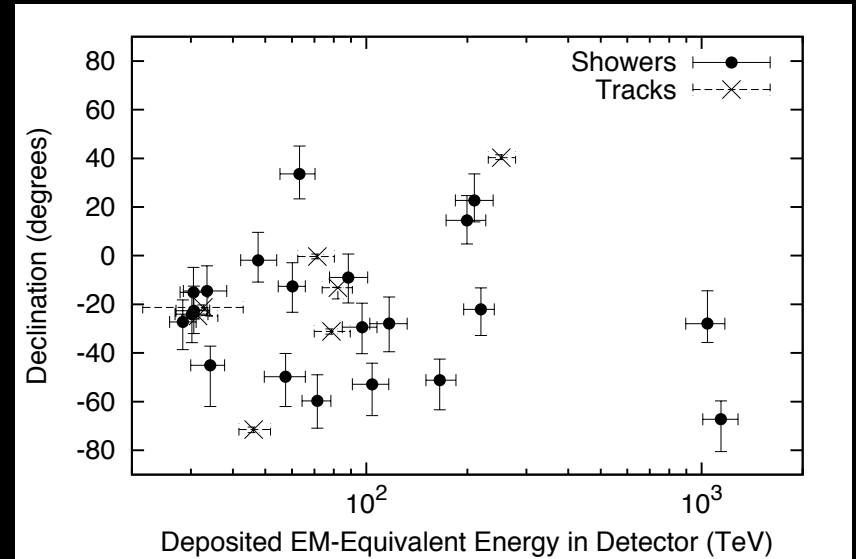
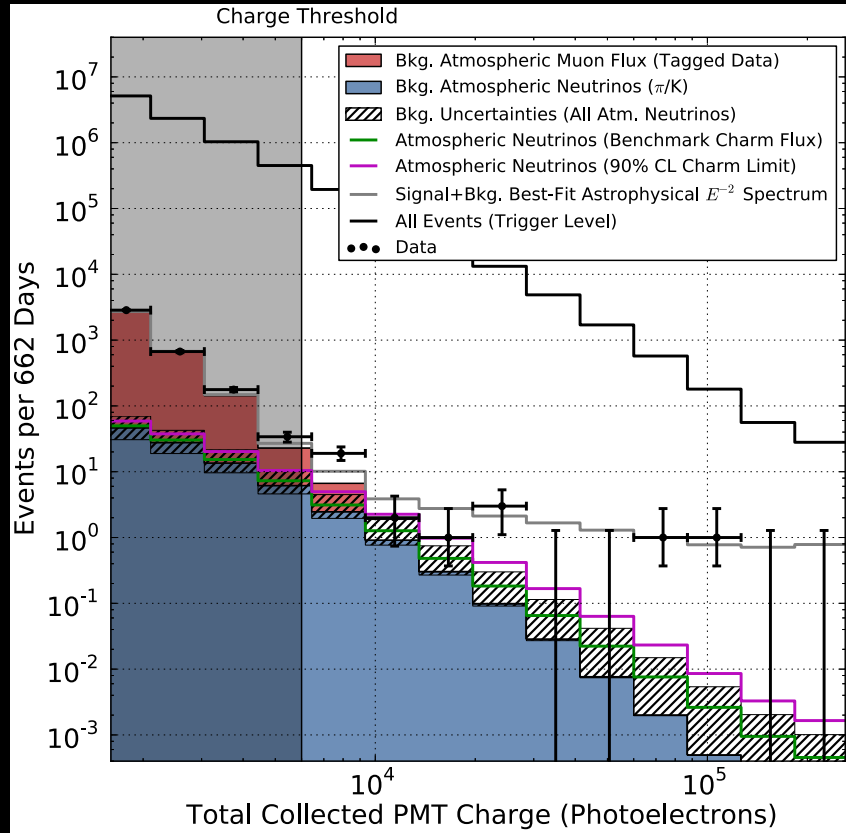
Summary 2 year data:



Summary 2 year data:

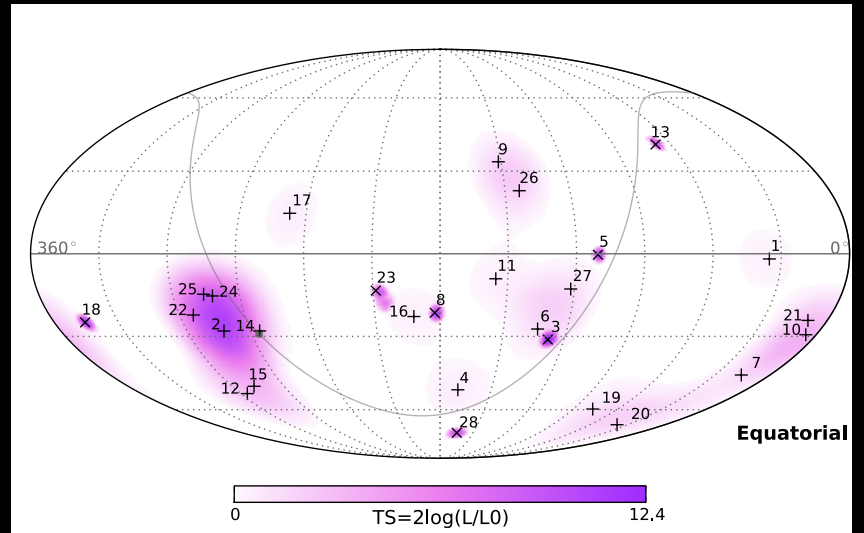
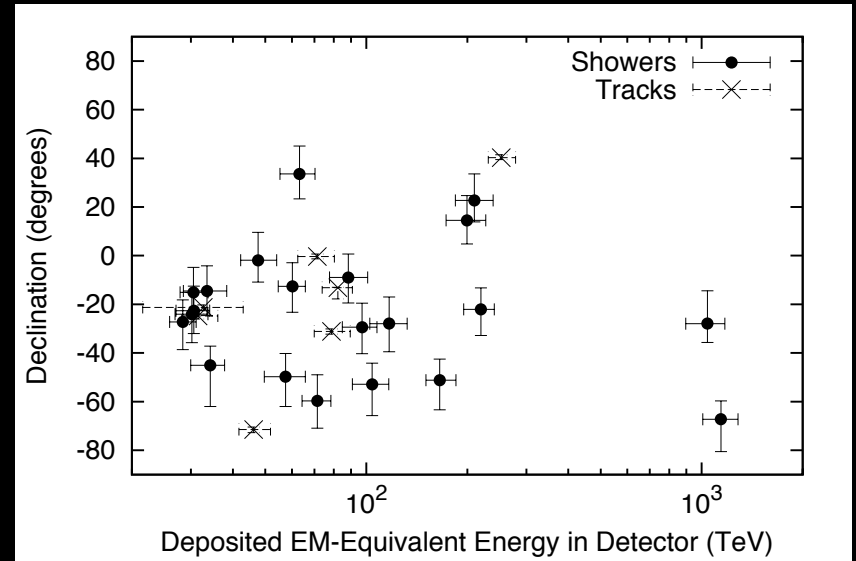
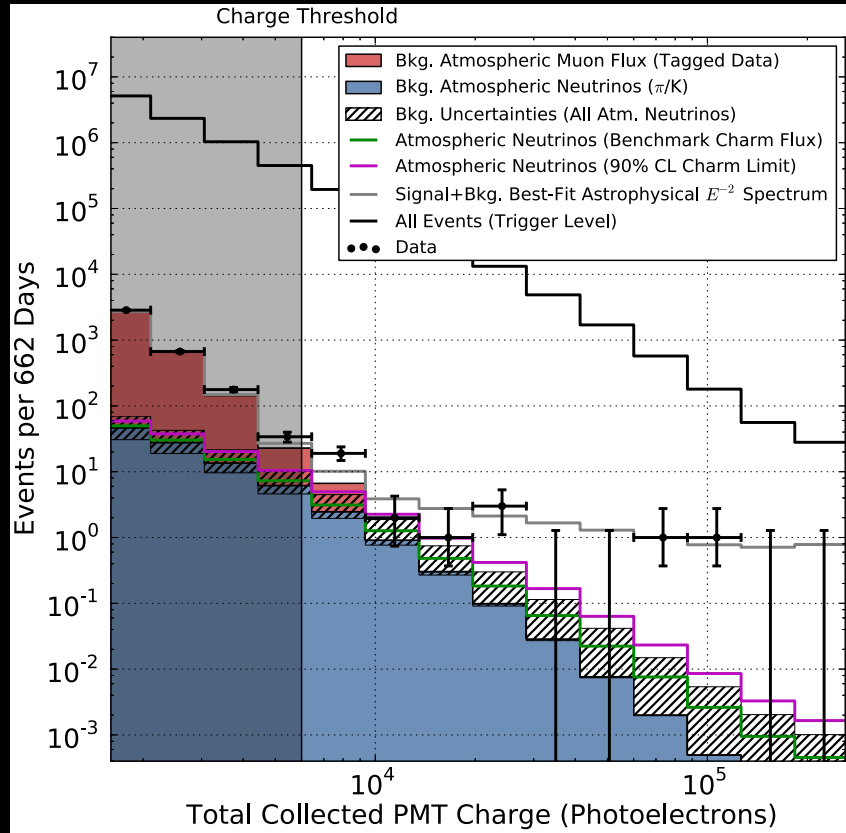


Summary 2 year data:



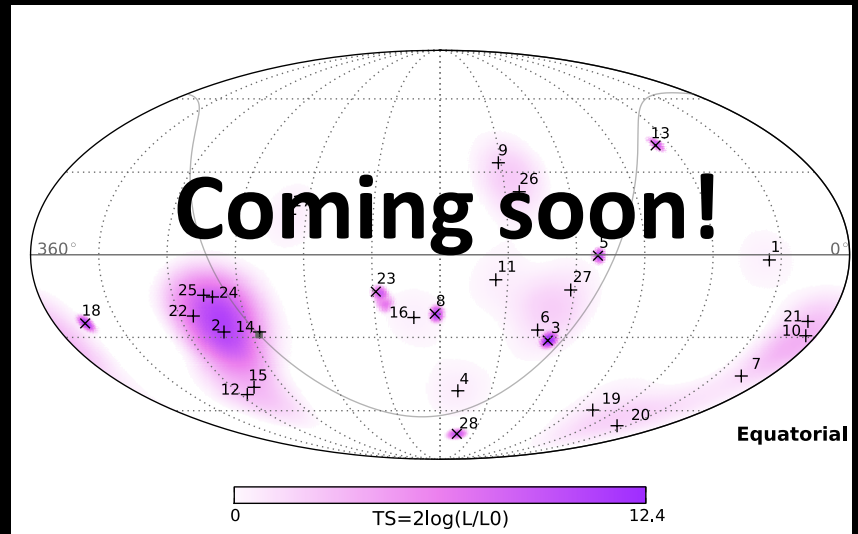
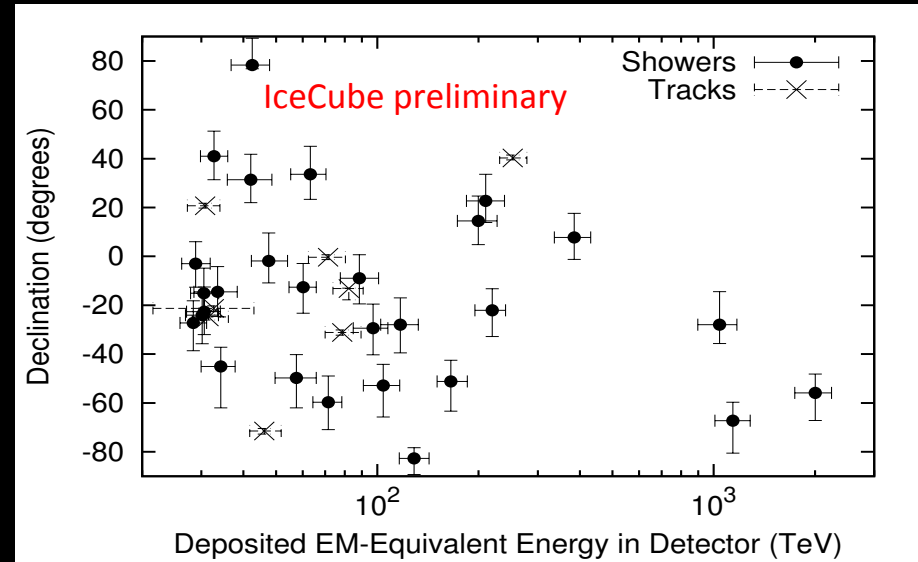
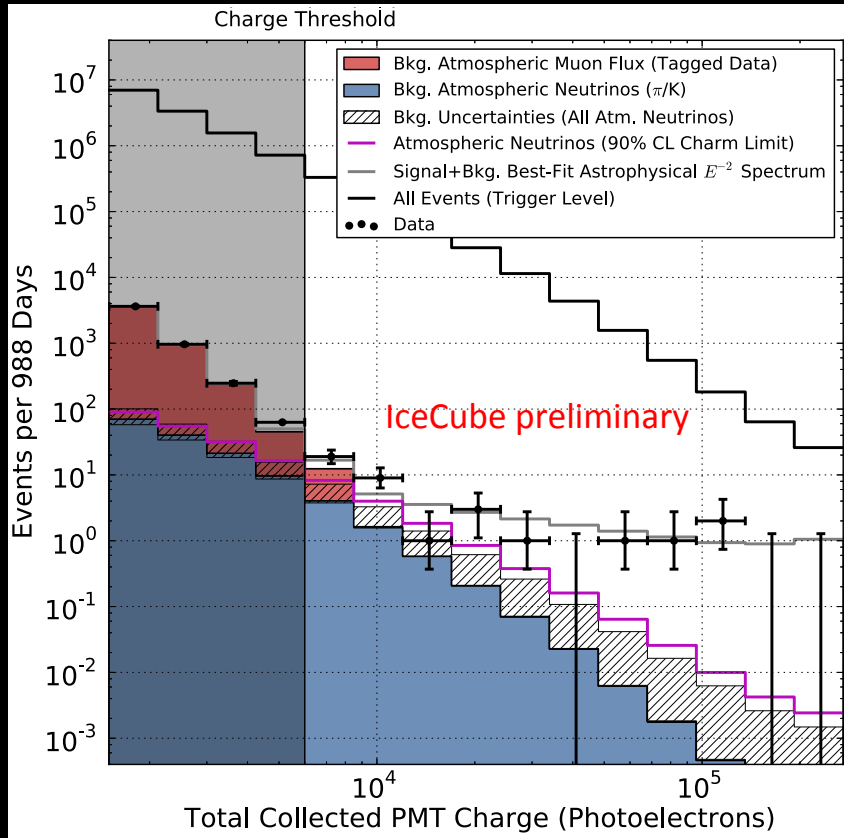
Science article

Summary 2 year data:



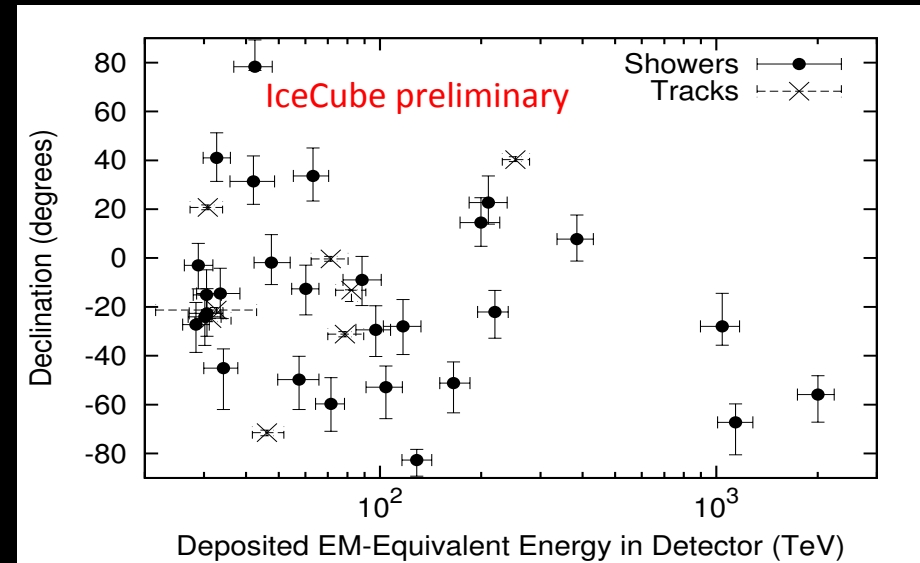
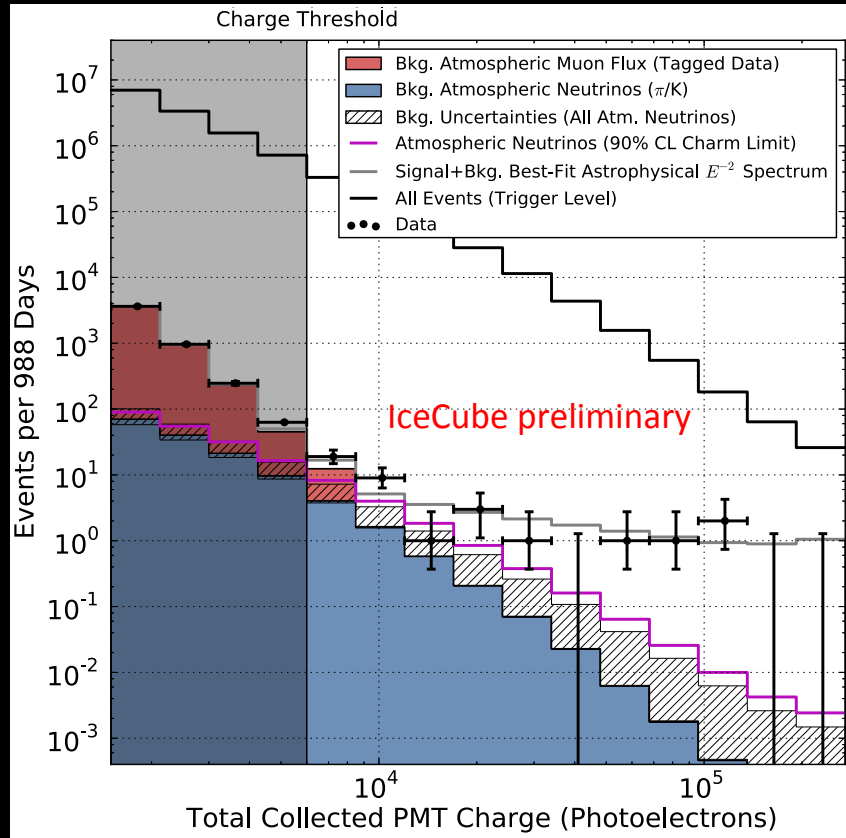
Science article

Summary 3 year data:



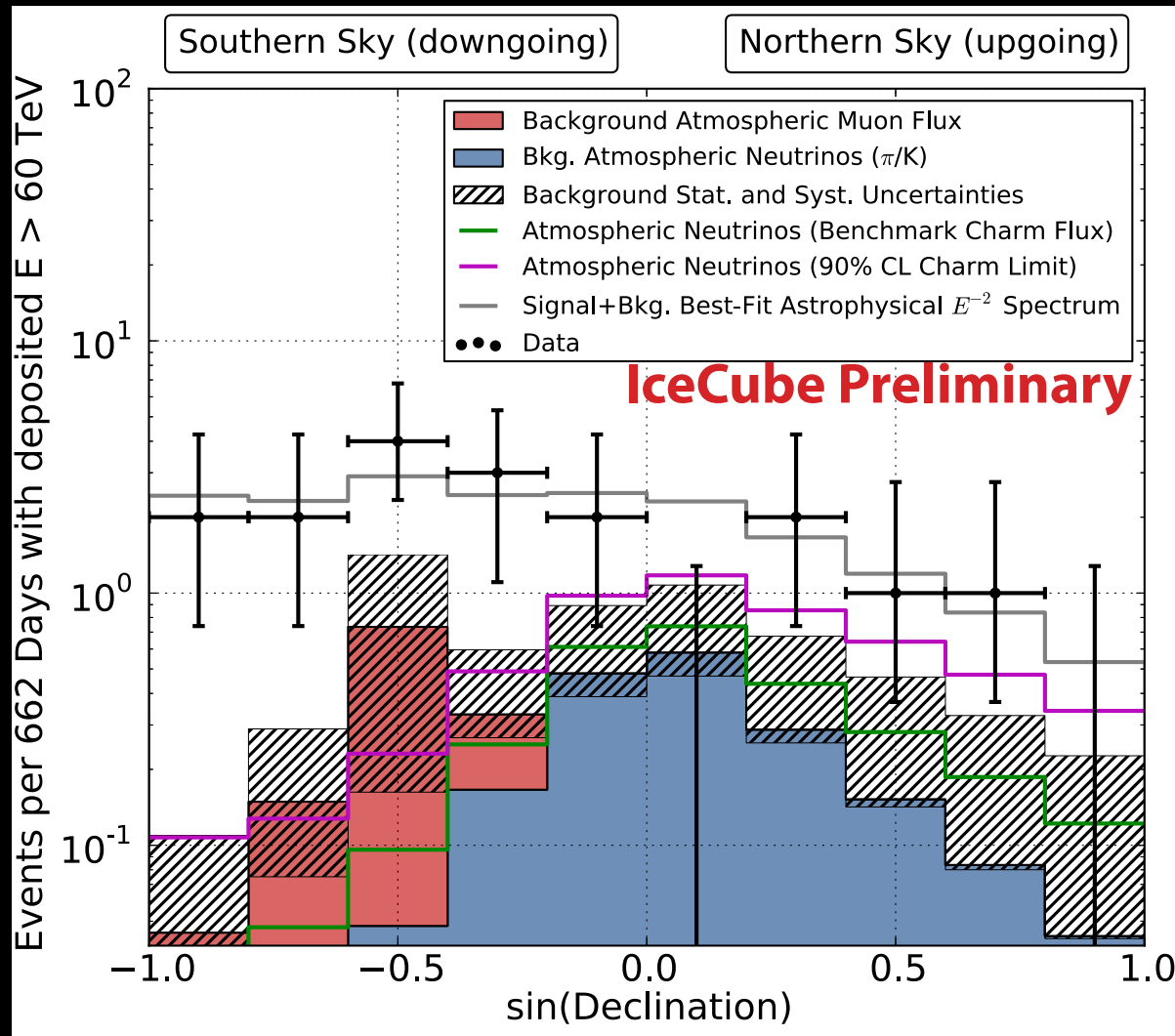
Science article

Summary 3 year data:



- 8 new events (one track)
- sub PeV gap filled
- Background incompatibility:
5.7 σ (preliminary)
(4.8 σ after post incorporating
the first 2 PeV events)

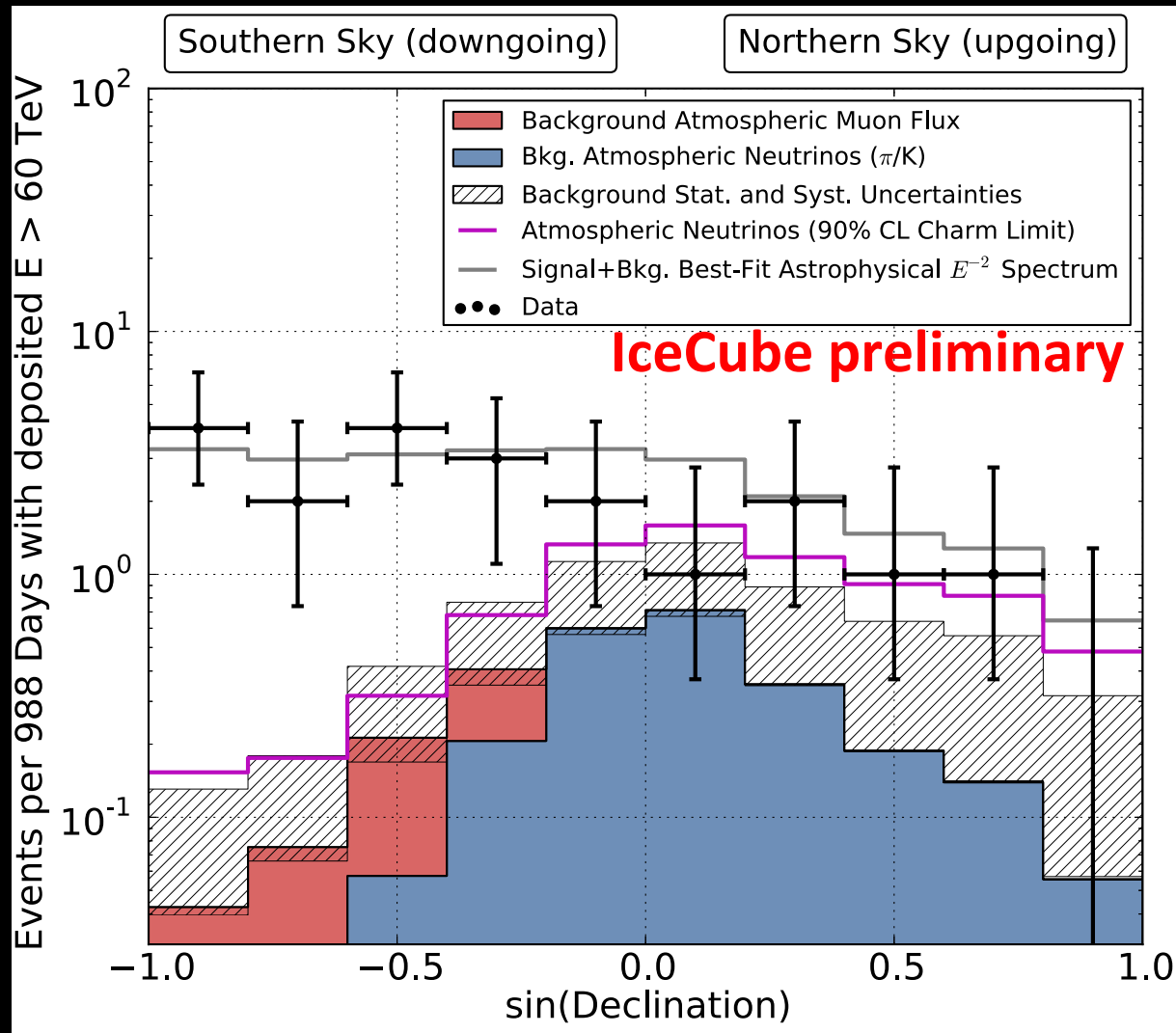
No significant north-south anisotropy with 2 years data



Compatible with isotropic flux

- Events absorbed in Earth from Northern Hemisphere
- Minor excess in south compared to isotropic, but not significant

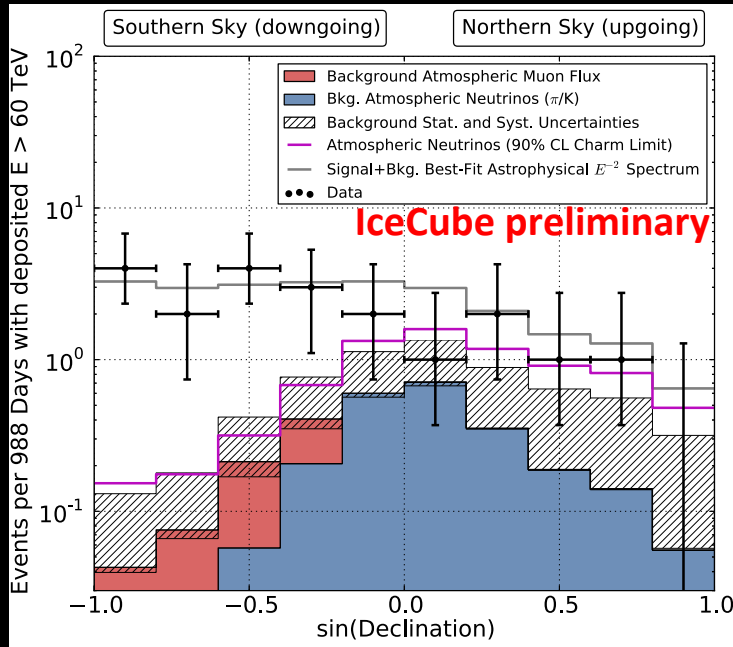
No significant north-south anisotropy with 3 years data



Compatible with isotropic flux

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Future perspectives

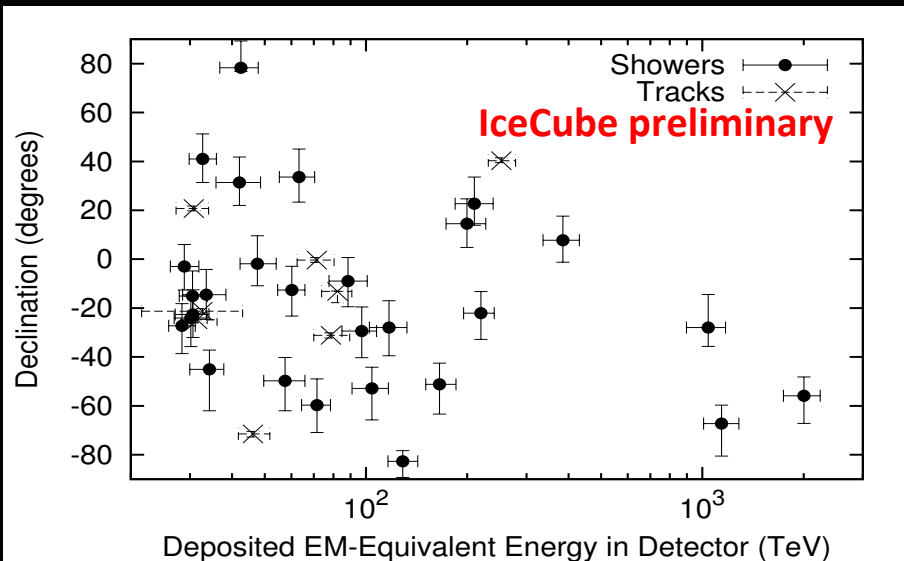


Questions:

- There is a minor excess in the southern sky. Where does it come from?
- what are the extraterrestrial neutrino sources?

Consequence:

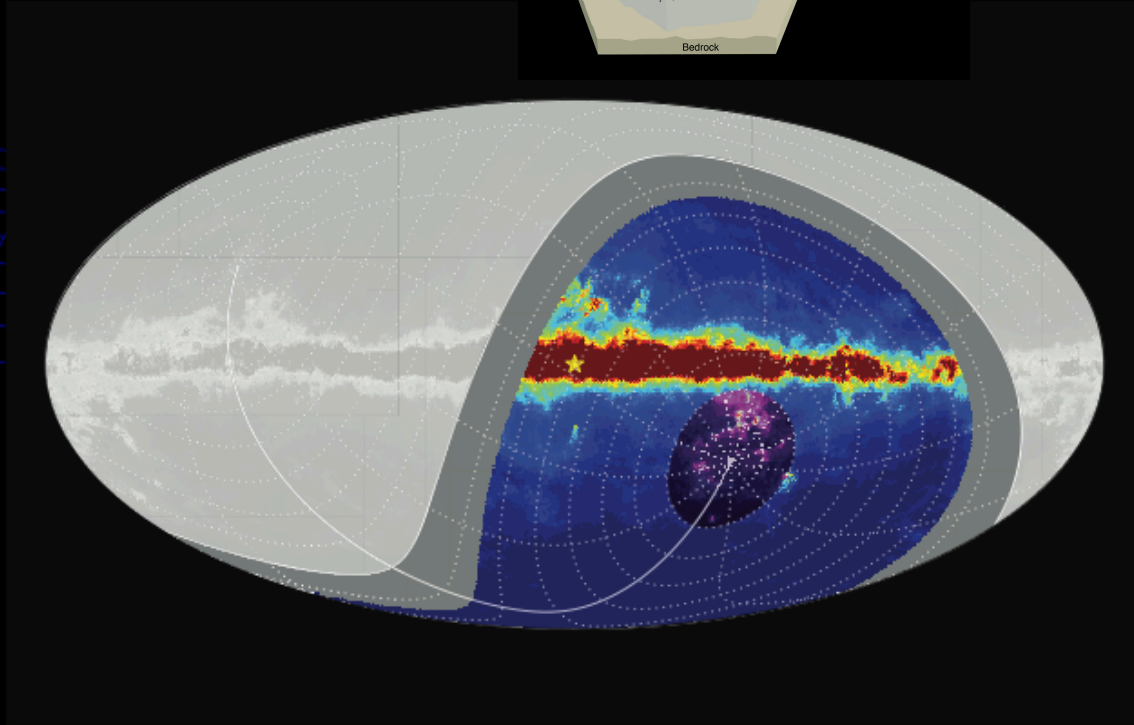
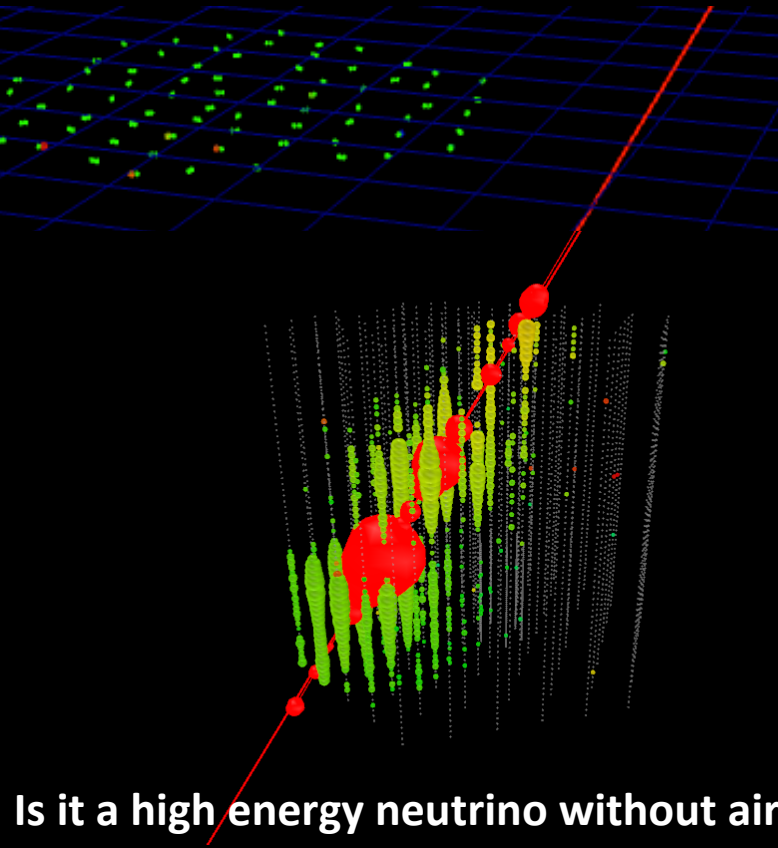
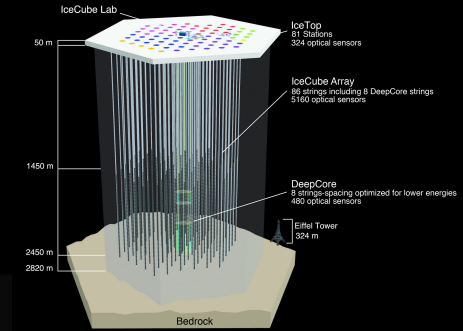
- We need more detections from the southern sky!
- We need more tracks (directional reconstruction)!



possible future extension IceVeto

Requirements:

- We need more detections from the southern sky!
- We need more tracks (directional reconstruction)!



**$E < 100$ TeV Neutrino induced muon tracks
without coincident air shower
in an extended detector Volume**

Is it a high energy neutrino without air shower?

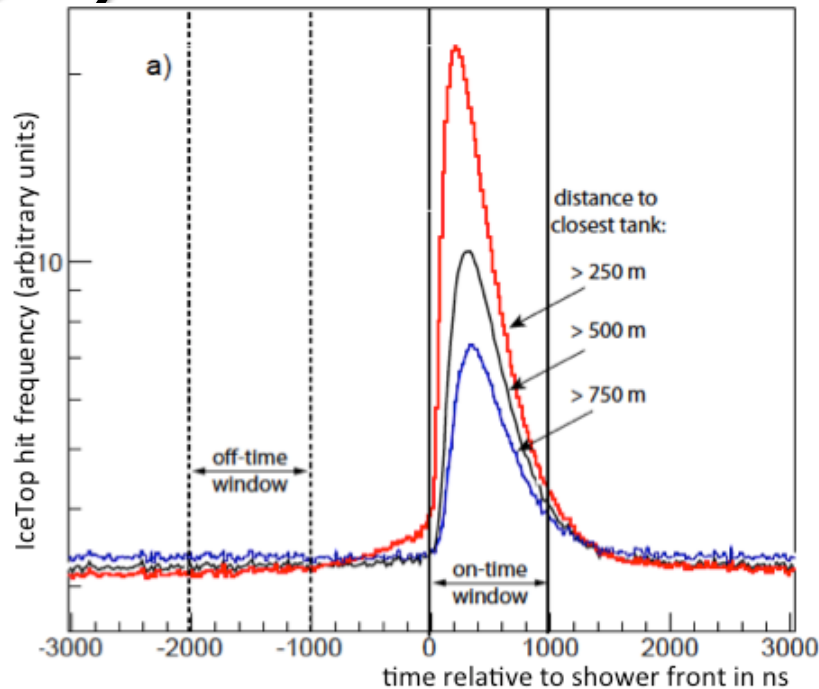
IceTop Veto



IceTop



Air-Shower Front



Coincidences

IceCube
(InIce)

ICRC13 ID 0374

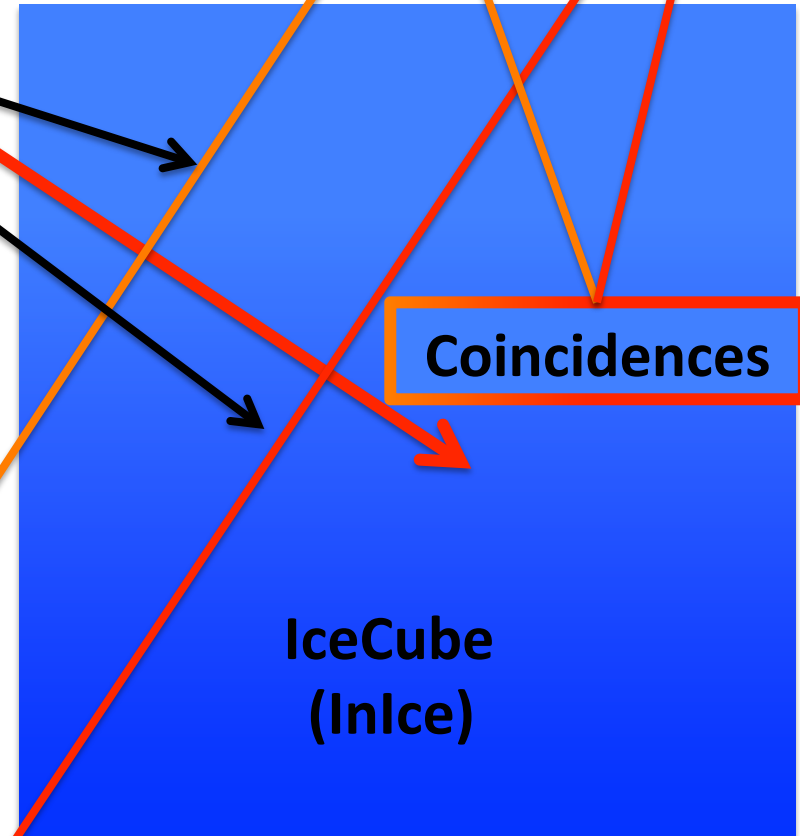
IceTop Veto



IceTop

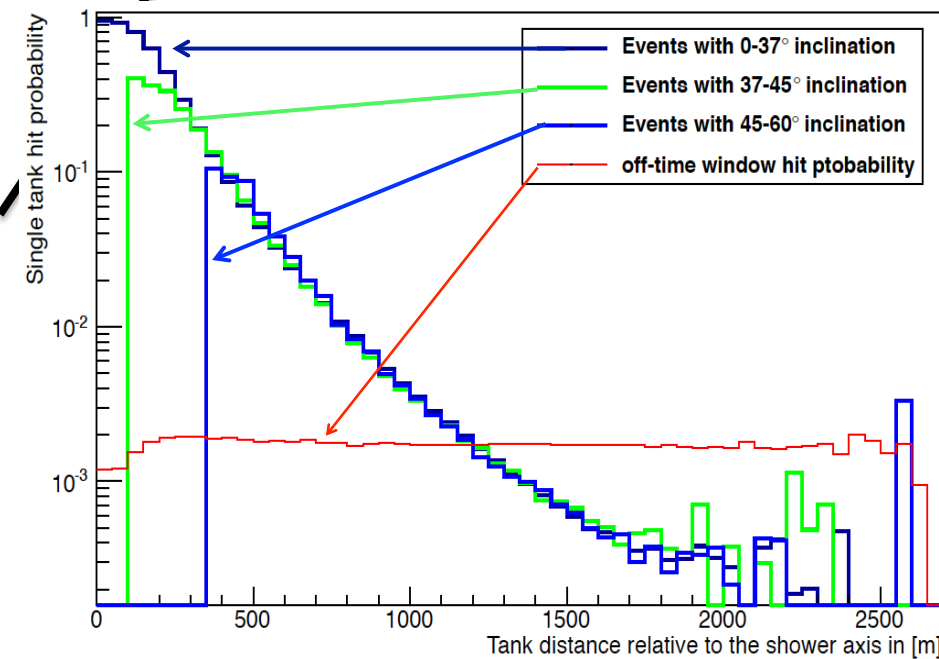


Air-Shower Front

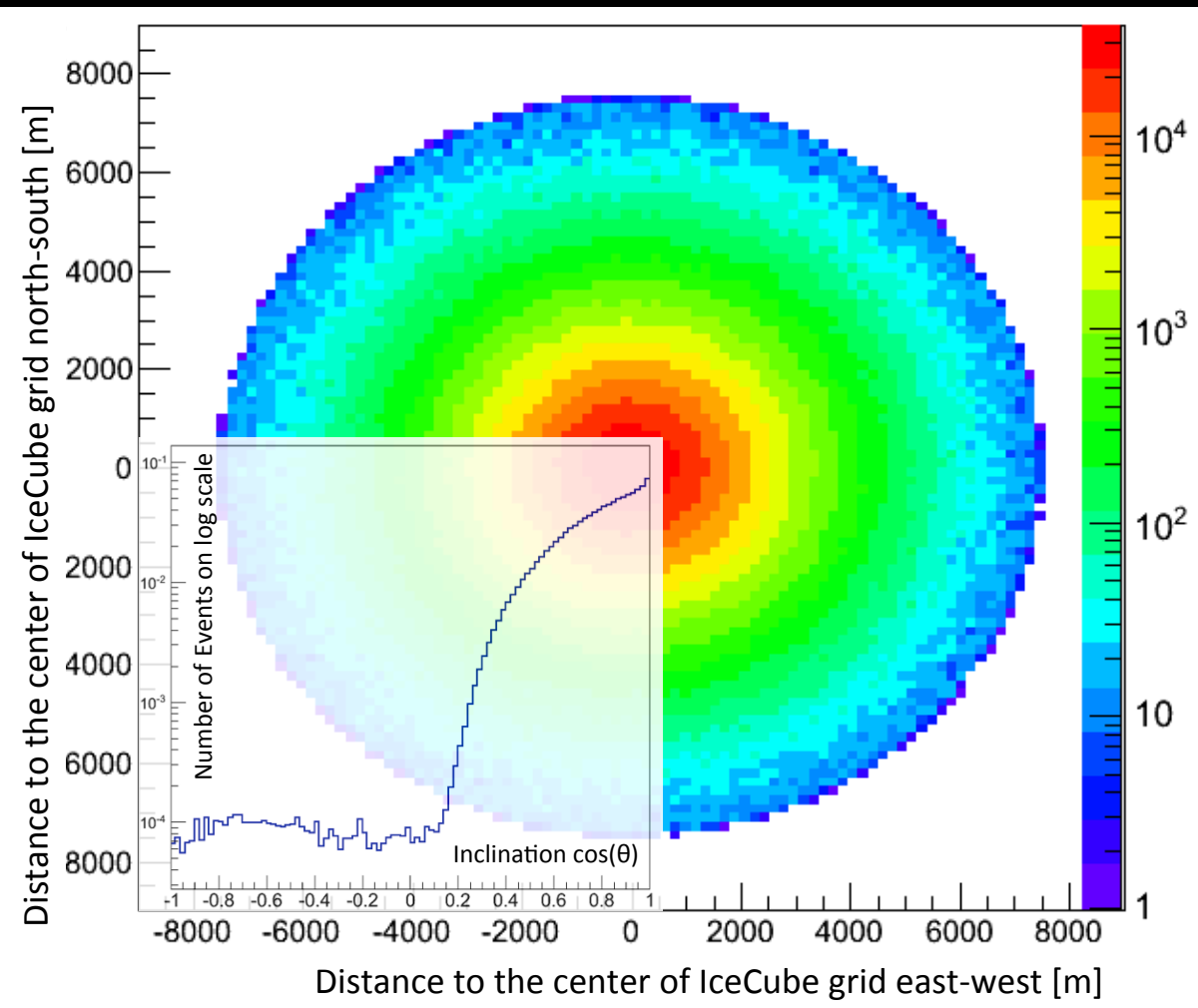


Coincidences

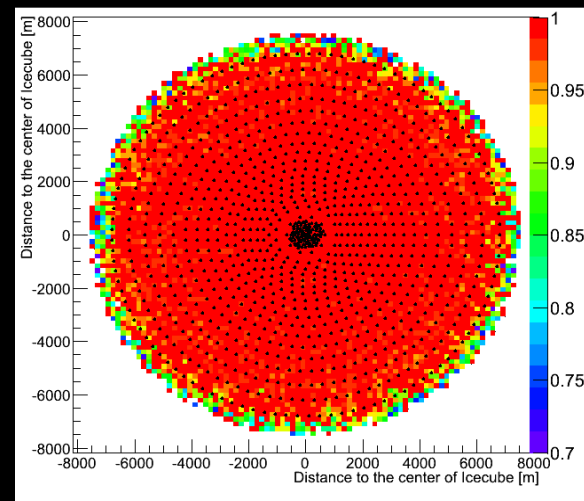
IceCube
(InIce)



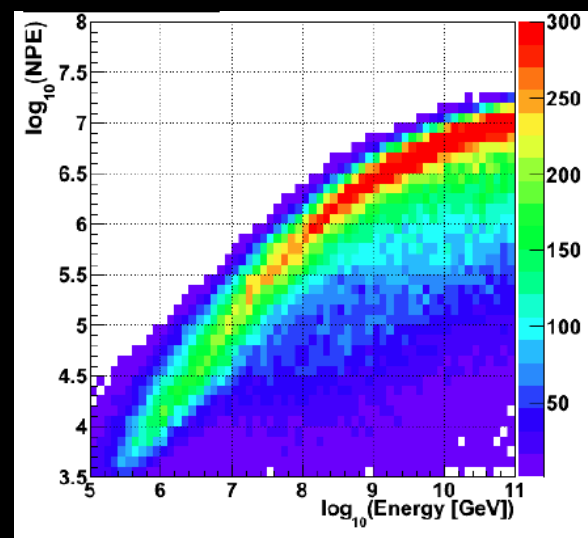
IceVeto simulation



943 additional modules

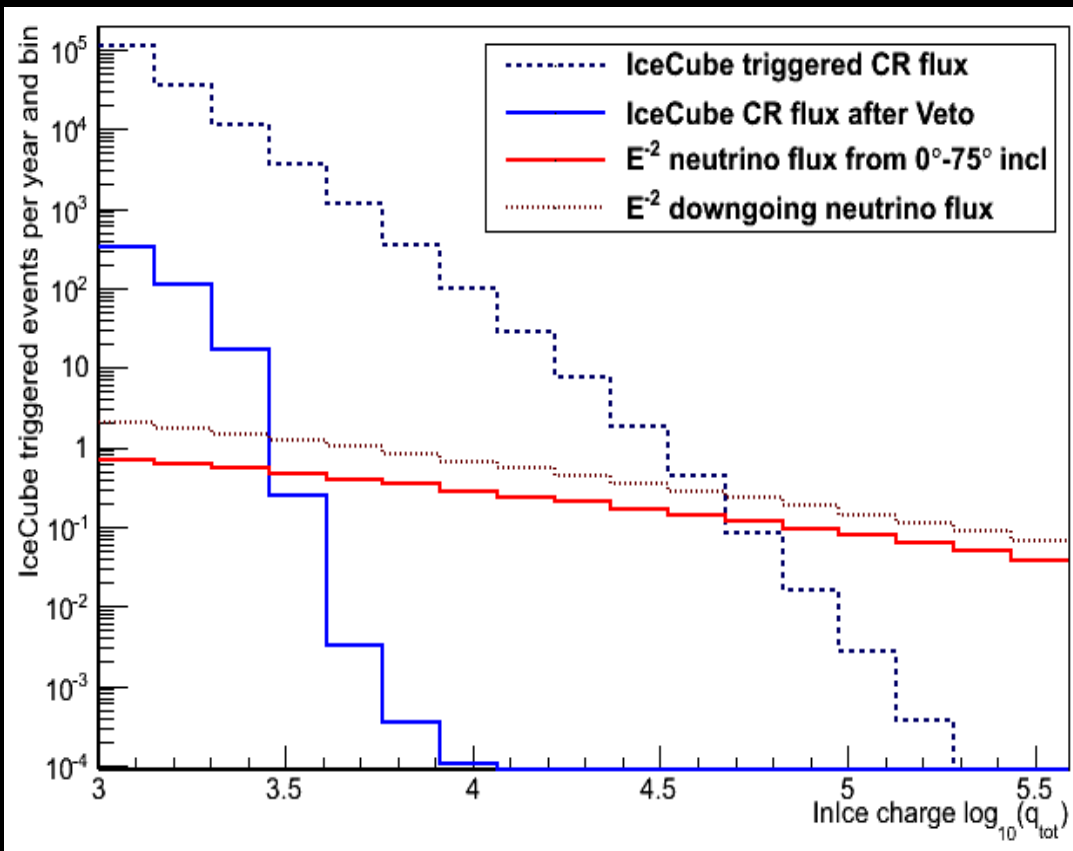


99.999% Veto efficiency
For PE > 4000



IceVeto is a sub-PeV CR energy veto with 10^4 efficiency!

Diffuse muon neutrino flux



Based on current IceCube Simulations for 79 string configuration and current IceCube diffuse neutrino flux limits integrated up to 10 PeV.

IceVeto would lead to ~ 2.6 events

detected on 0.06 background per year!

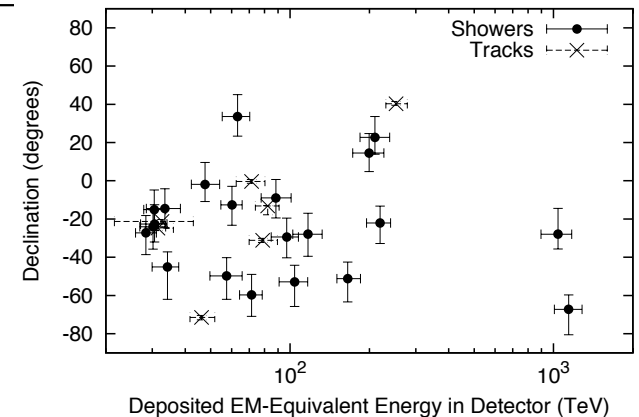
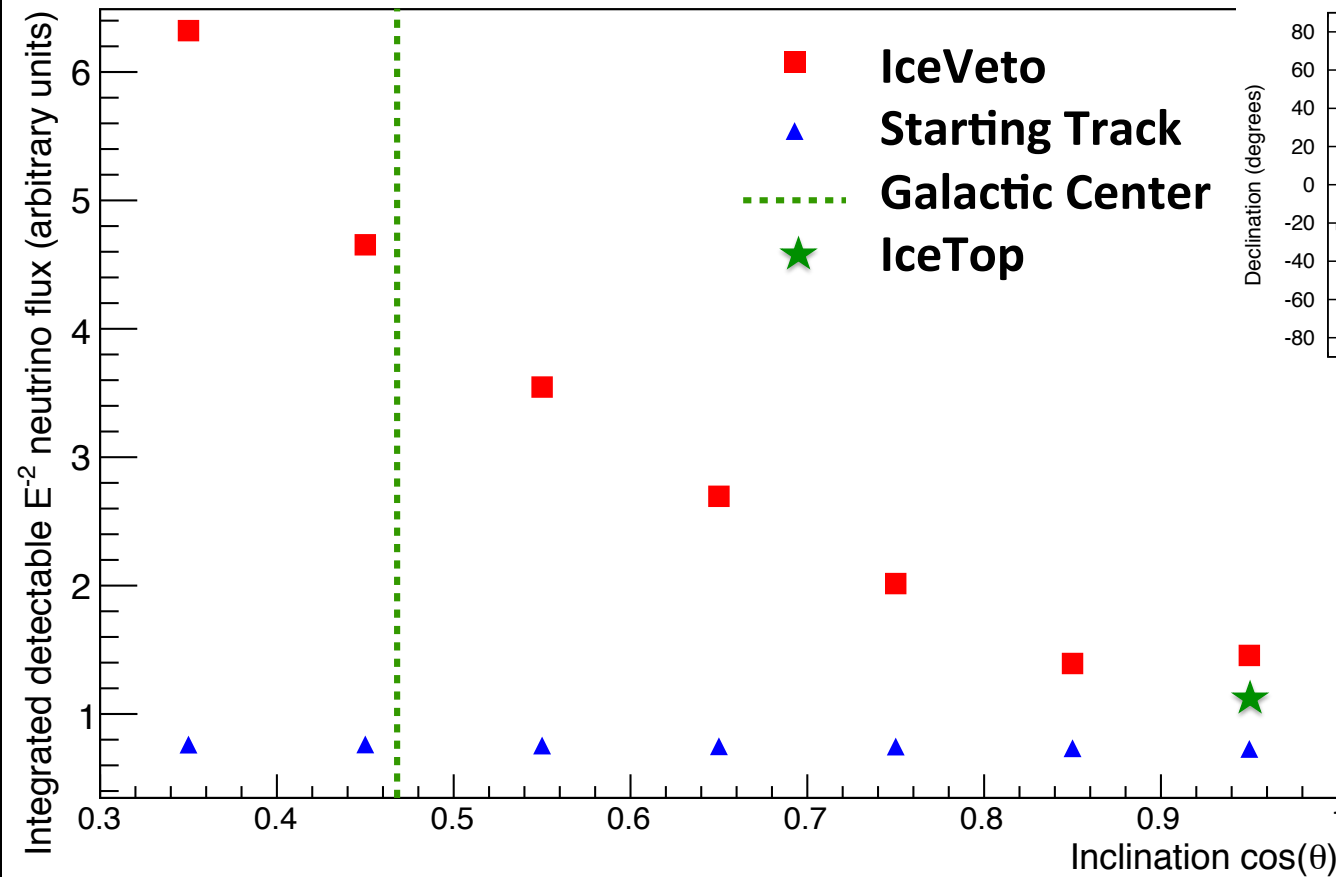
$>5\sigma$ significance
(without systematic errors)
after one year.

The strongest argument remains
background free pointing

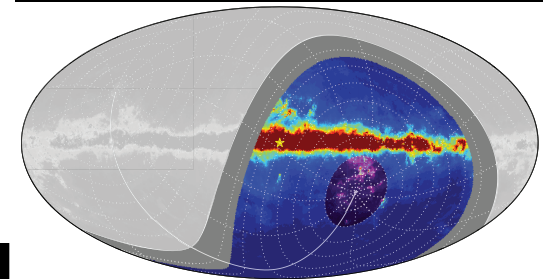
Remember:

The applied Veto efficiency is calculated with simulations that are **based on real data**.

Many more tracks compared to starting track analyses

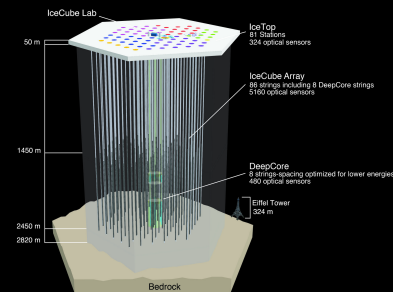
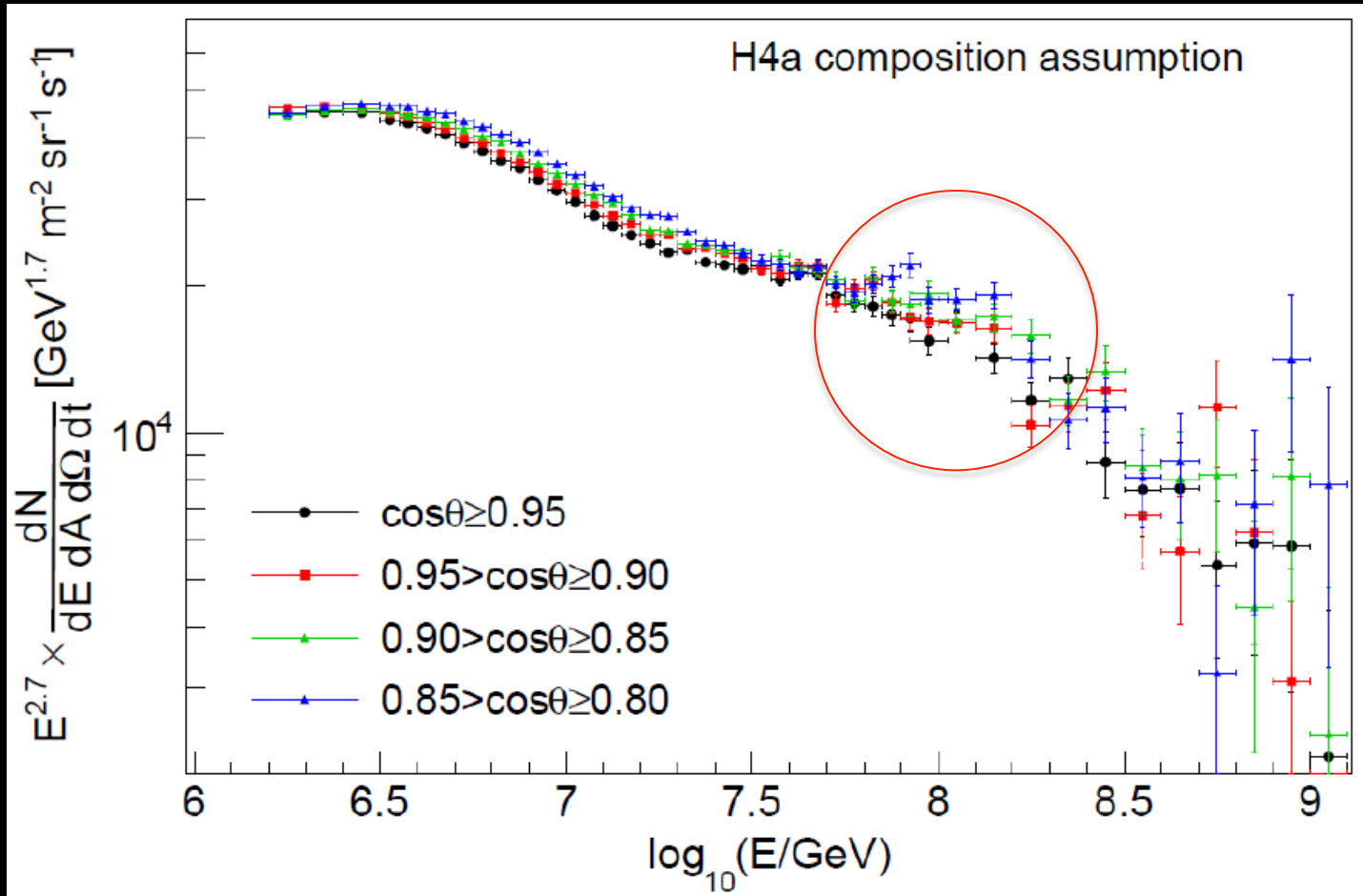


Only the crosses are tracks!



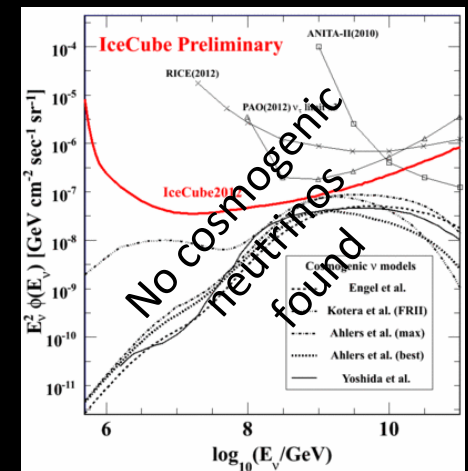
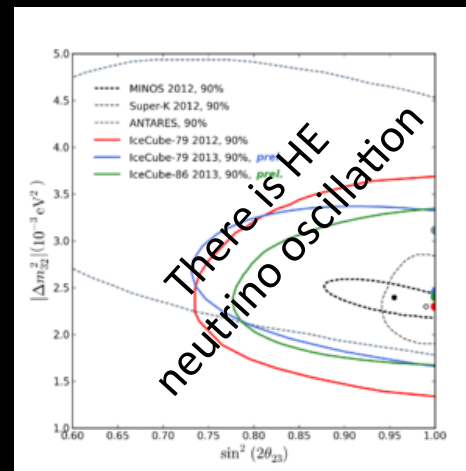
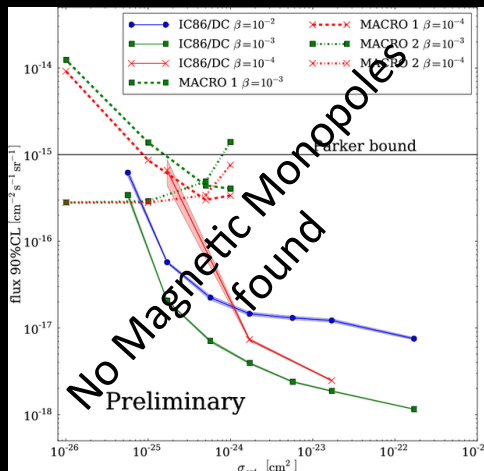
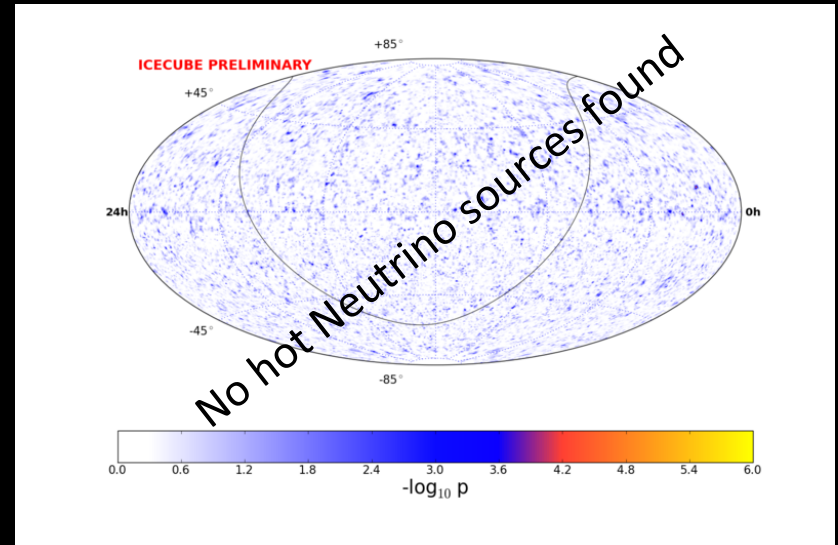
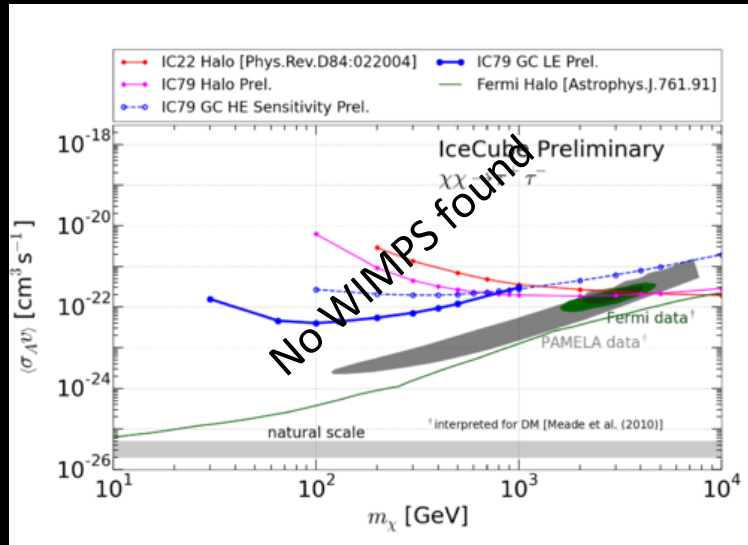
5.5 times more neutrino induced muon tracks from the Galactic Center (62° inclination) between 30 TeV -5 PeV based on an E^{-2} neutrino flux.

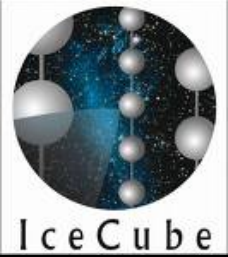
Interesting for CR Physics?



- Ice Veto has 8.5 times more statistics for coincident detection after the knee compared to IceTop/IceCube
- Also: high p_T muon detection to constrain charm production experimentally

What I could not talk about in detail





Summary

- with 3 years of data IceCube found a neutrino flux that is at 5.7σ incompatible with standard background (number preliminary)
- neutrino sources and anisotropy remain unclear (new point source analysis coming soon)
- future surface extensions could help to solve the mystery especially at the southern sky
- Future remains interesting!