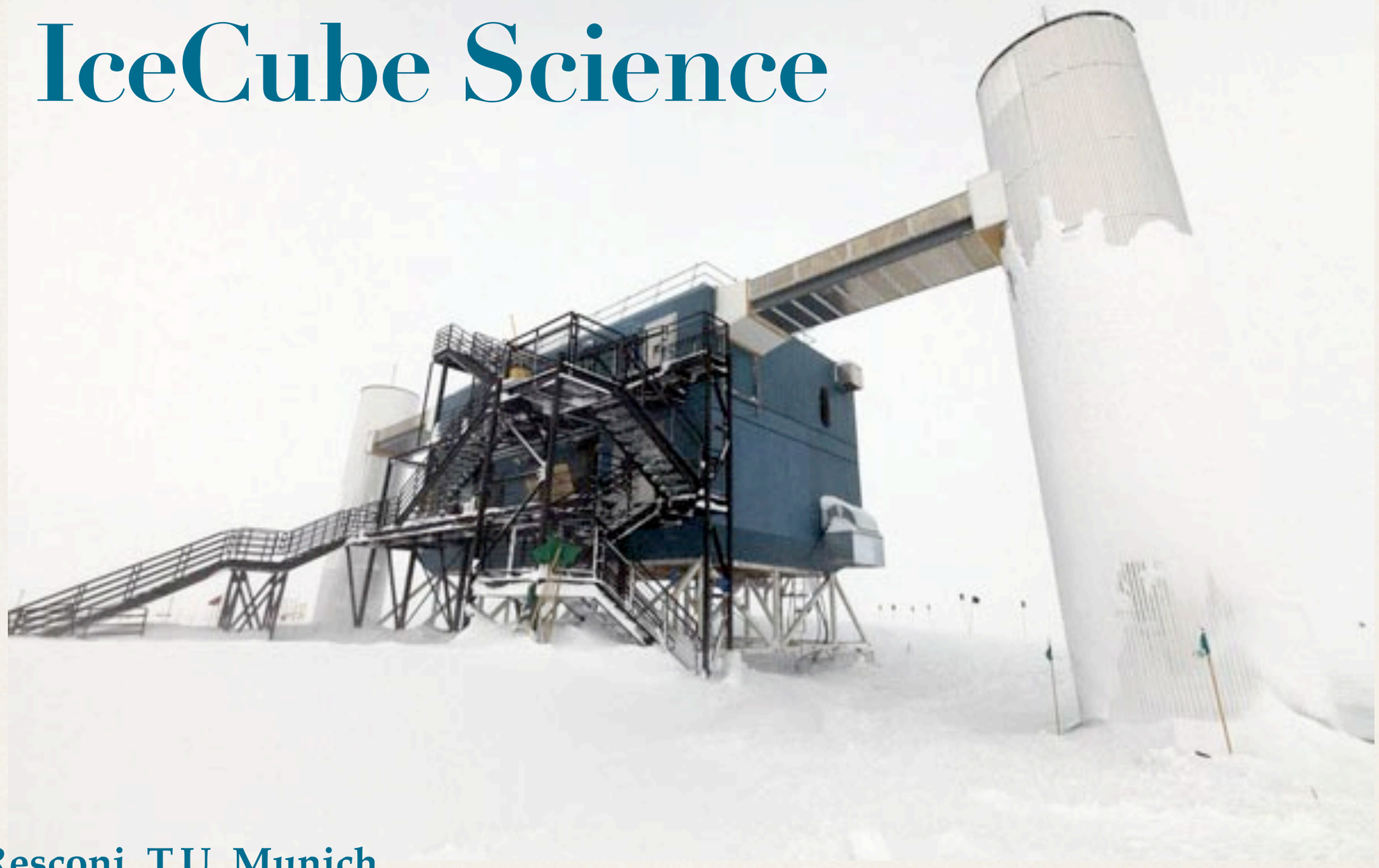
IceCube Science



Elisa Resconi, T.U. Munich

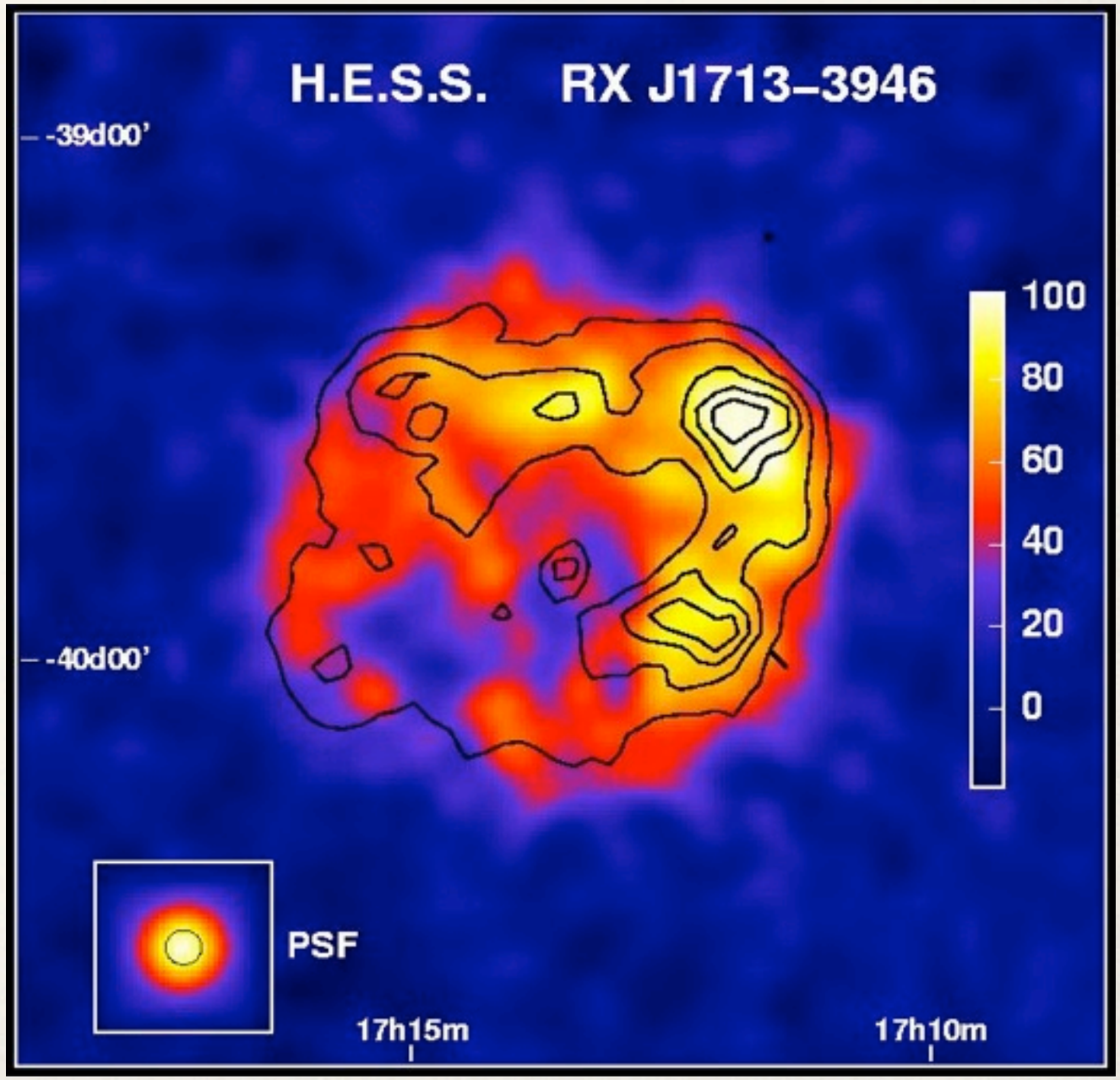
Astrophysics From The South Pole: Status And Future Prospects, 4th Of April 2011

High Energy (> 100 GeV) Neutrino Astronomy

- Discovery Areas:
  - Origin of Galactic / Extra-galactic Cosmic Rays
  - Indirect Search for Dark Matter
  - Beyond the Standard Model of Particle Physics
- Specifically to IceCube:
  - Core-collapse SuperNovae Explosion (time profile)

Cosmic Rays: Galactic

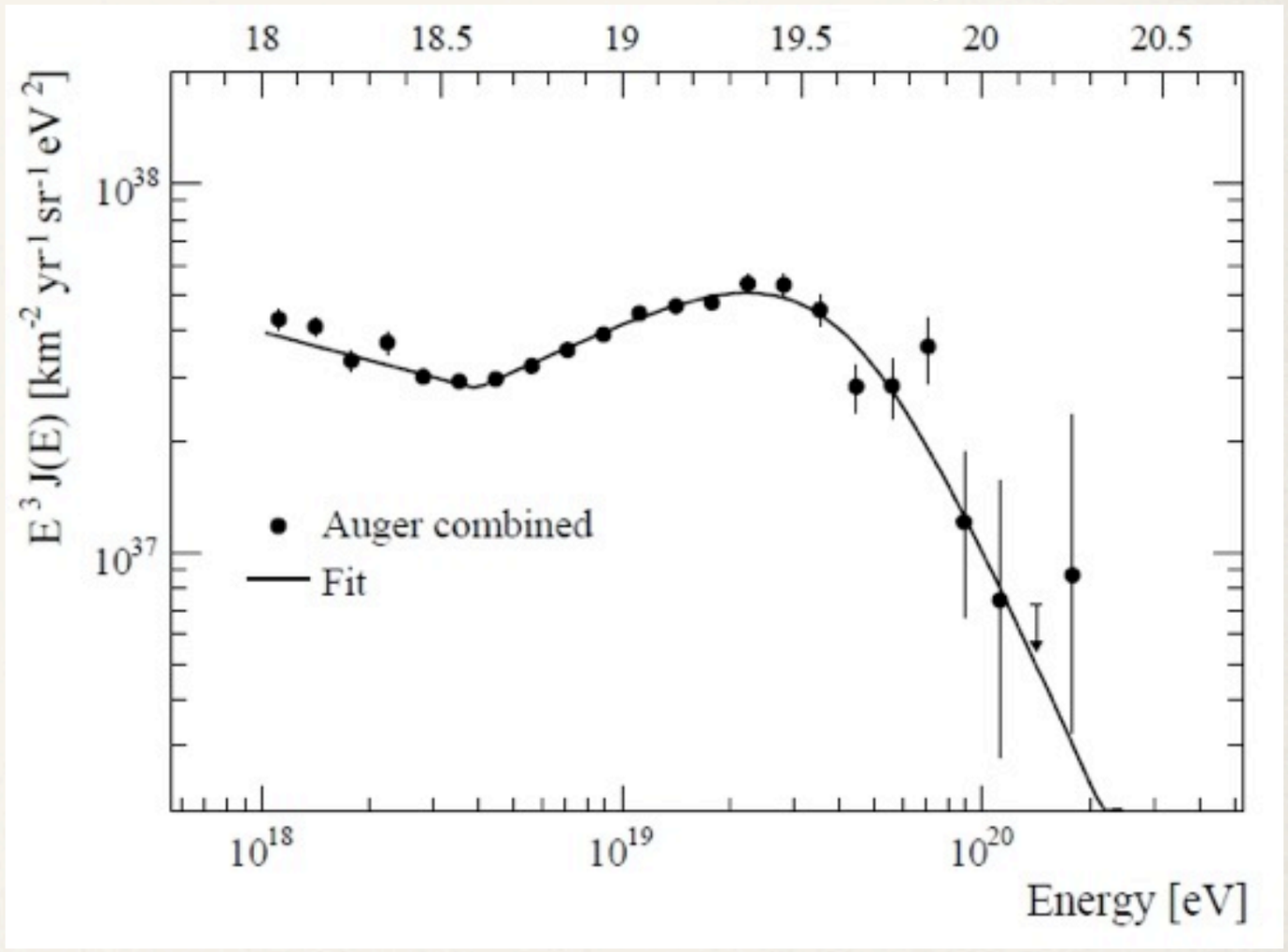
- diffusive shock acceleration in SNRs(collision-less)
- good up to few TeV (Gamma-ray Telescopes)
- nearby molecular clouds, multi-TeV emission possible
- high energy neutrinos: unambiguous prove of hadronic acceleration / interaction



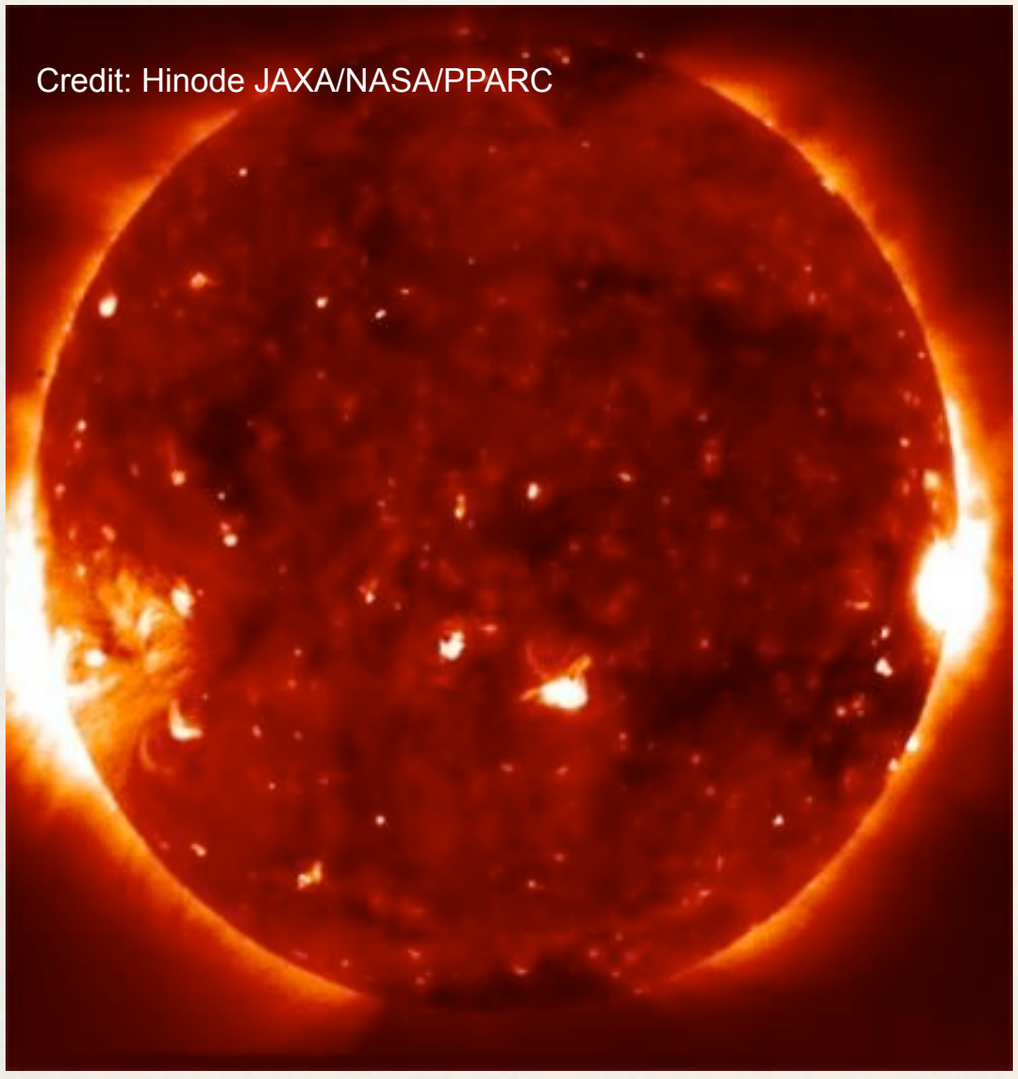
Cosmic Rays: Extra-galactic

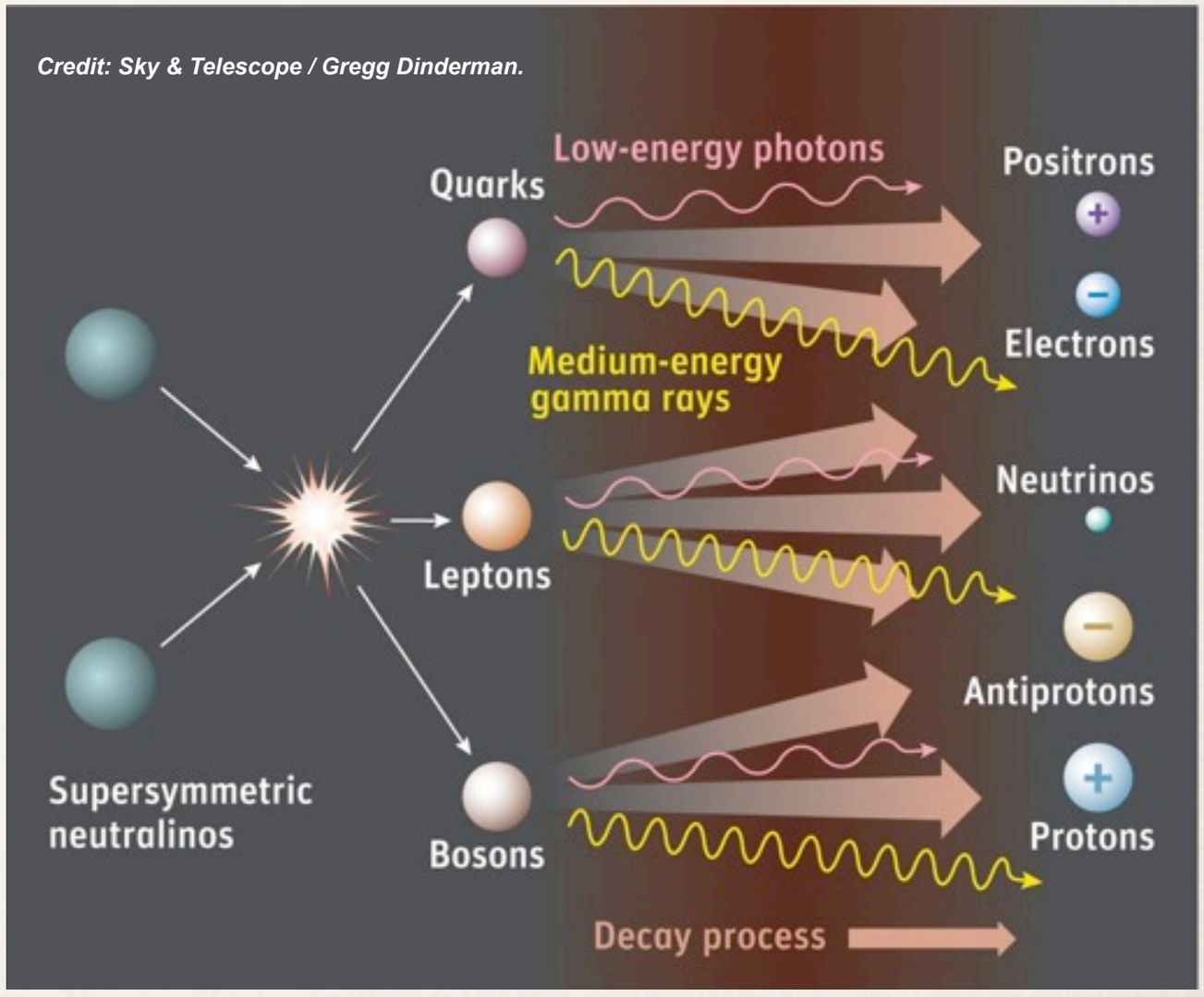
- Cosmic particles up to 10^{20} eV
- GZK cutoff?
- ... add

The Auger Collaboration



Indirect Dark Matter Search



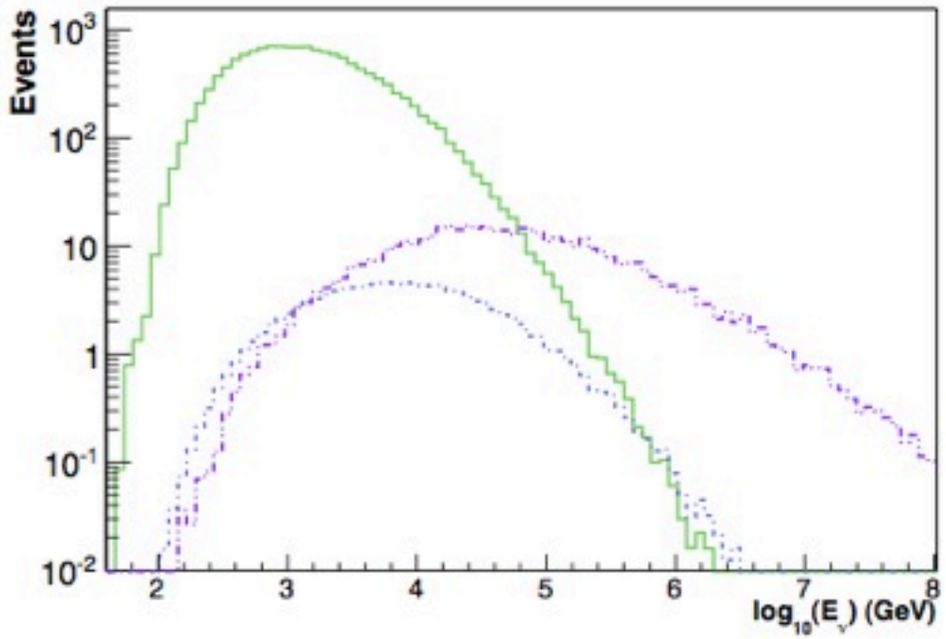


How do we search for Cosmic Ray Sources?

IceCube is a discovery instrument ☞ no guaranteed recipe

- All-sky searches: muon neutrinos sky map
- Pre-defined list of candidate neutrino sources
- Search for transients (GRBs, flares, periodic)
- On-line
  - Neutrinos from SuperNovae Core Collapse
  - Neutrino Alerts to Rotse, PTF, Swift, Magic

All-sky Searches: Diffuse Flux



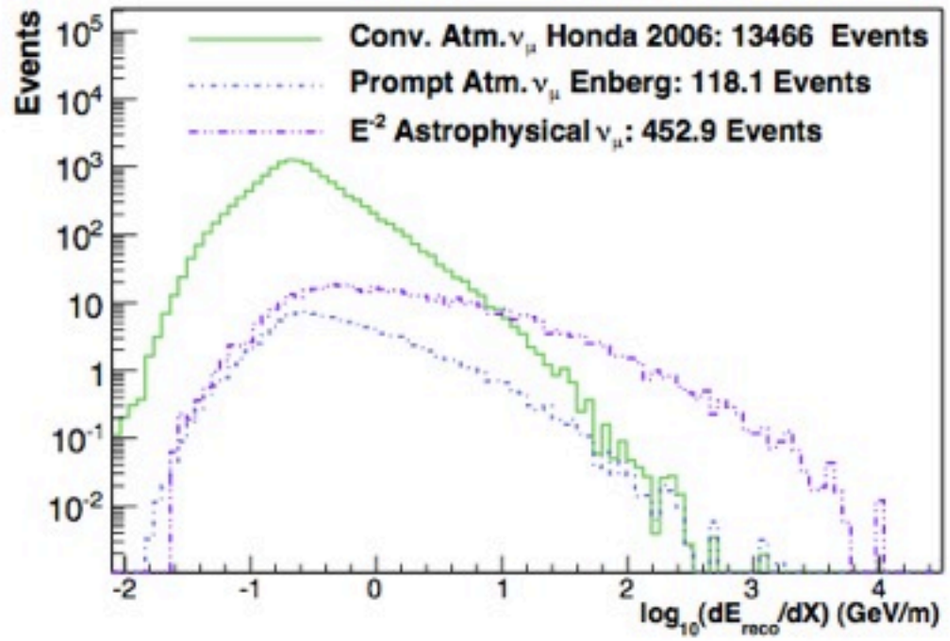


FIG. 7. Simulated neutrino energy distribution (left plot) and the simulated reconstructed muon energy loss distribution (right plot) of the final event sample for the Honda *et. al* conventional atmospheric ν_μ (green) flux model, the Enberg *et al.* prompt atmospheric ν_μ (light blue) flux model, and an astrophysical E^{-2} (purple) flux with a normalization of $N = 10^{-7}\text{GeV cm}^{-2}\text{ s}^{-1}\text{ sr}^{-1}$.

Profile likelihood construction method

Systematic errors as nuisance parameters

All-sky Searches: Diffuse Flux

Largest systematics ☞ on-going actions / ideas

- overall normalization of atmospheric neutrino flux (± 25%)
  ☞ identification of fully contained events

- prompt component atmospheric neutrinos (−44% to +25%)
  ☞ search of the prompt component in the muons

- uncertainty absolute sensitivity digital optical module (± 10%)
  ☞ map of the detector with flashers, muons

- measured properties of the glacial ice at the South Pole (± 10%)
  ☞ new ice model under implementation

IC-40 Results

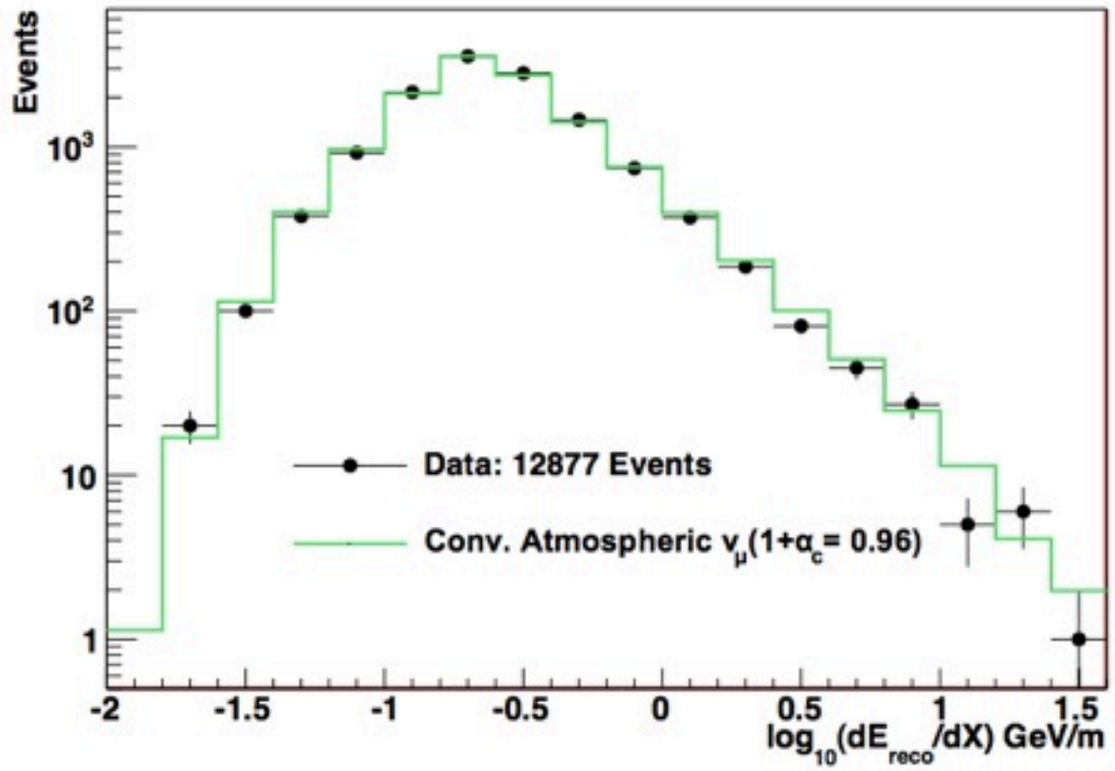


FIG. 8. The fitted muon energy loss distribution of the final event sample is shown. The best fit to the data (black, shown with 1σ error bars) consists only of conventional atmospheric ν_μ, and no evidence is found for a prompt atmospheric ν_μ flux or an astrophysical E^{-2} ν_μ flux.

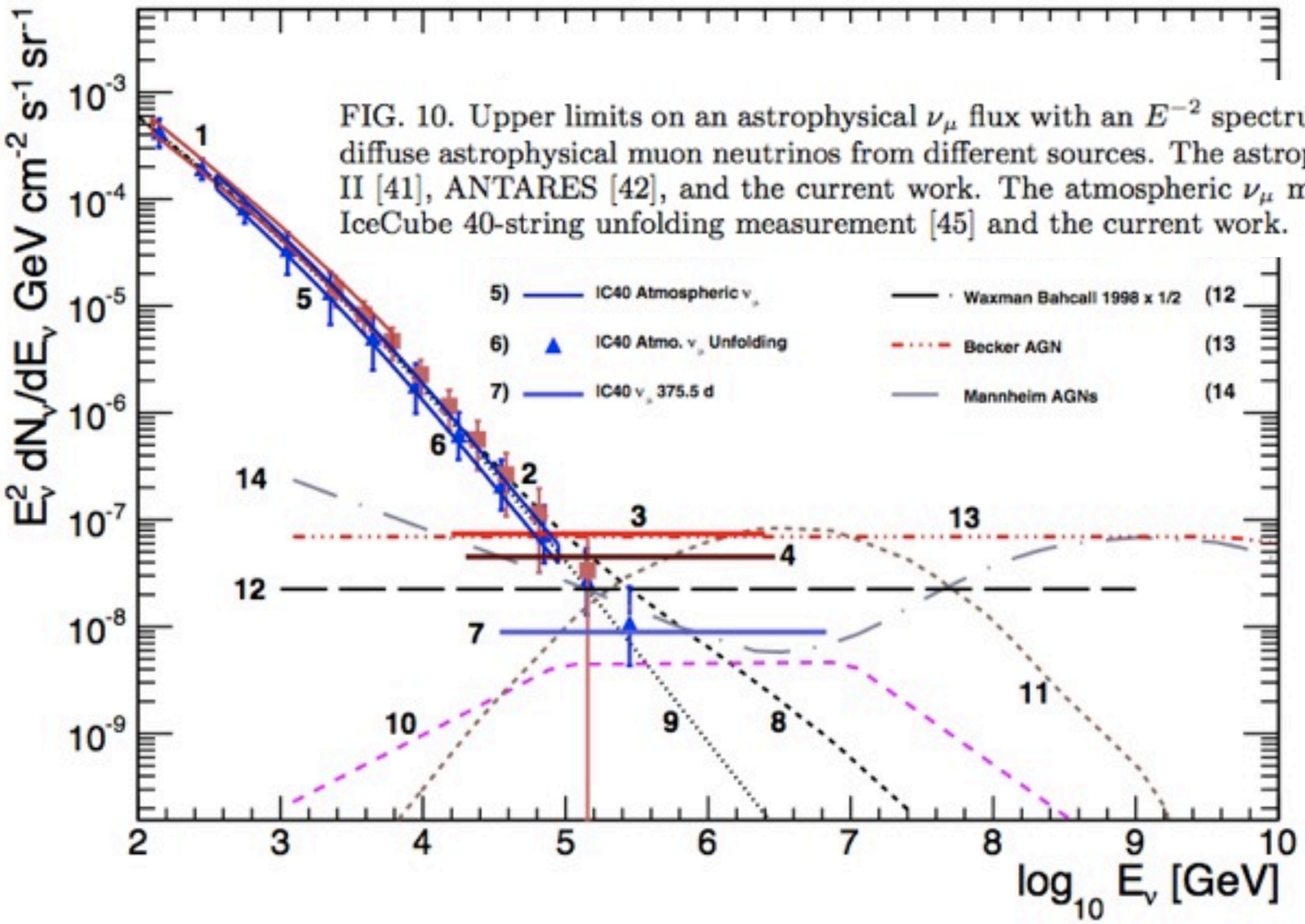
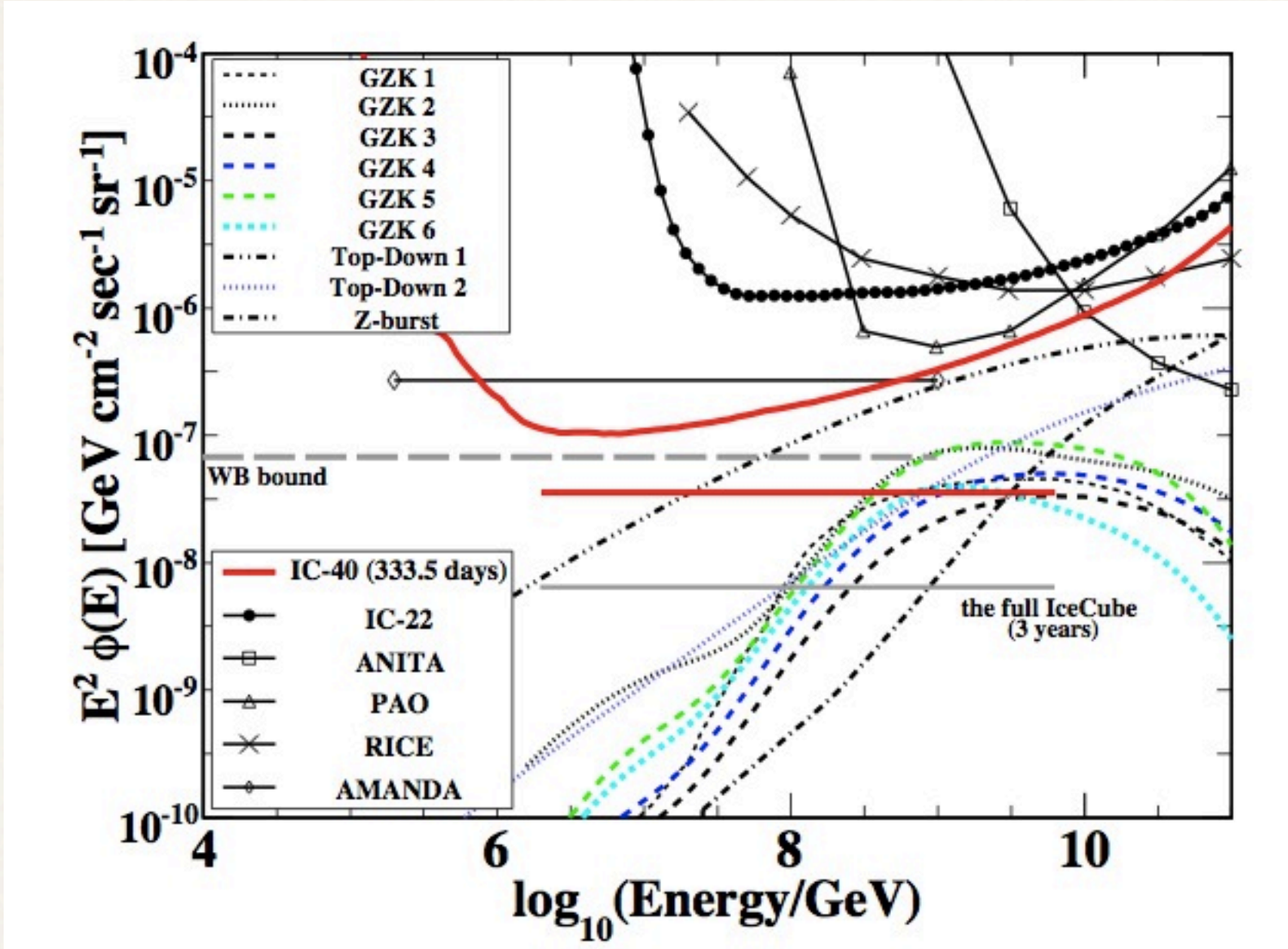


FIG. 10. Upper limits on an astrophysical ν_μ flux with an E^{-2} spectrum are shown along with theoretical model predictions of diffuse astrophysical muon neutrinos from different sources. The astrophysical E^{-2} ν_μ upper limits shown are from AMANDA-II [41], ANTARES [42], and the current work. The atmospheric ν_μ measurements shown are from AMANDA-II [43] [44], the IceCube 40-string unfolding measurement [45] and the current work.

EHE?

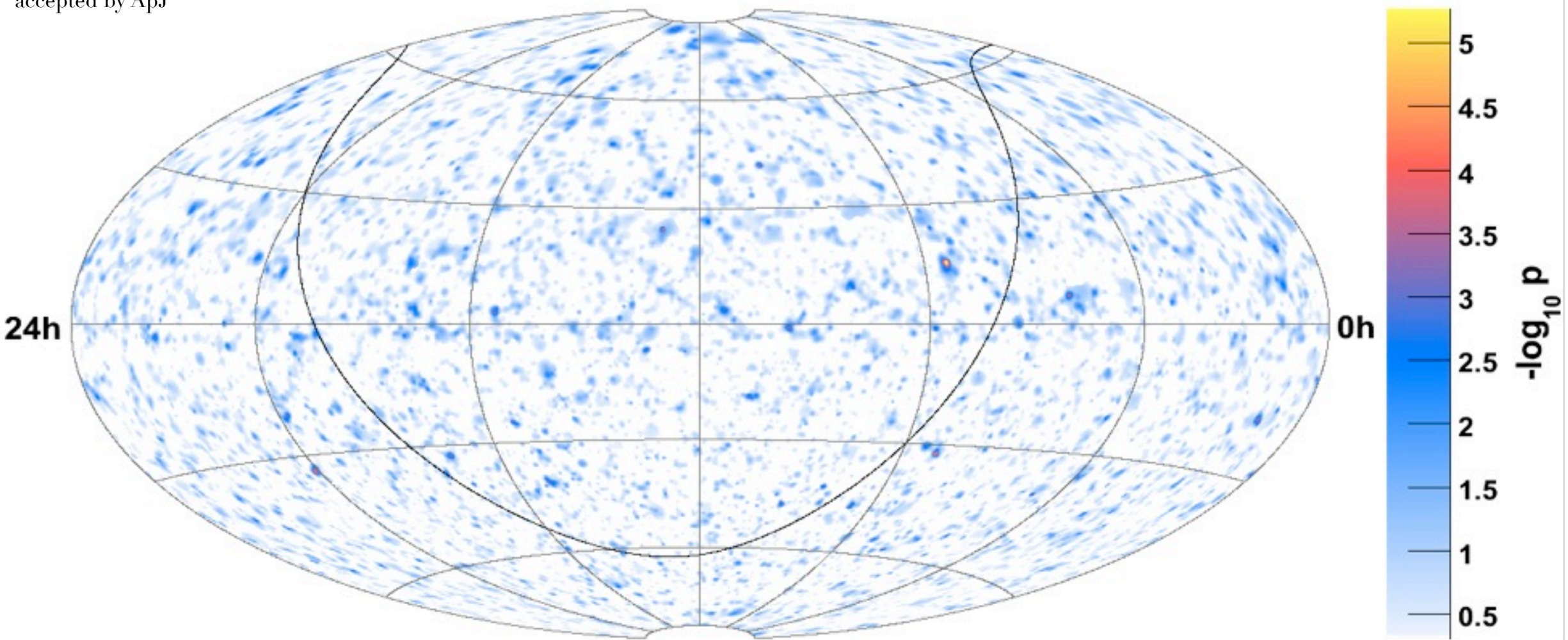

GZK 1
GZK 2
GZK 3
GZK 4
GZK 5
GZK 6
Top-Down 1
Top-Down 2
Z-burst
WB bound
IC-40 (333.5 days)
IC-22
ANITA
PAO
RICE
AMANDA
the full IceCube
(3 years)
$E^2\phi(E)$ [GeV cm^{-2} sec^{-1} sr^{-1}]
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
4
6
8
10
$\log_{10}$(Energy/GeV)

All-sky Searches: Point Sources

$$S_i(|x_i - x_s|, E_i, \gamma) = \frac{1}{2\pi\sigma_i^2} \exp\left(-\frac{|x_i - x_s|^2}{2\sigma_i^2}\right) P_{SigNch}(E_i|\gamma).$$

$$B(x_i, E_i) = P_{BkgDec}(x_i)\, P_{BkgNch}(E_i).$$

accepted by ApJ



all-sky p-value = 18%

not significant, no evidence of neutrino source

Lifetime = 375.5 days

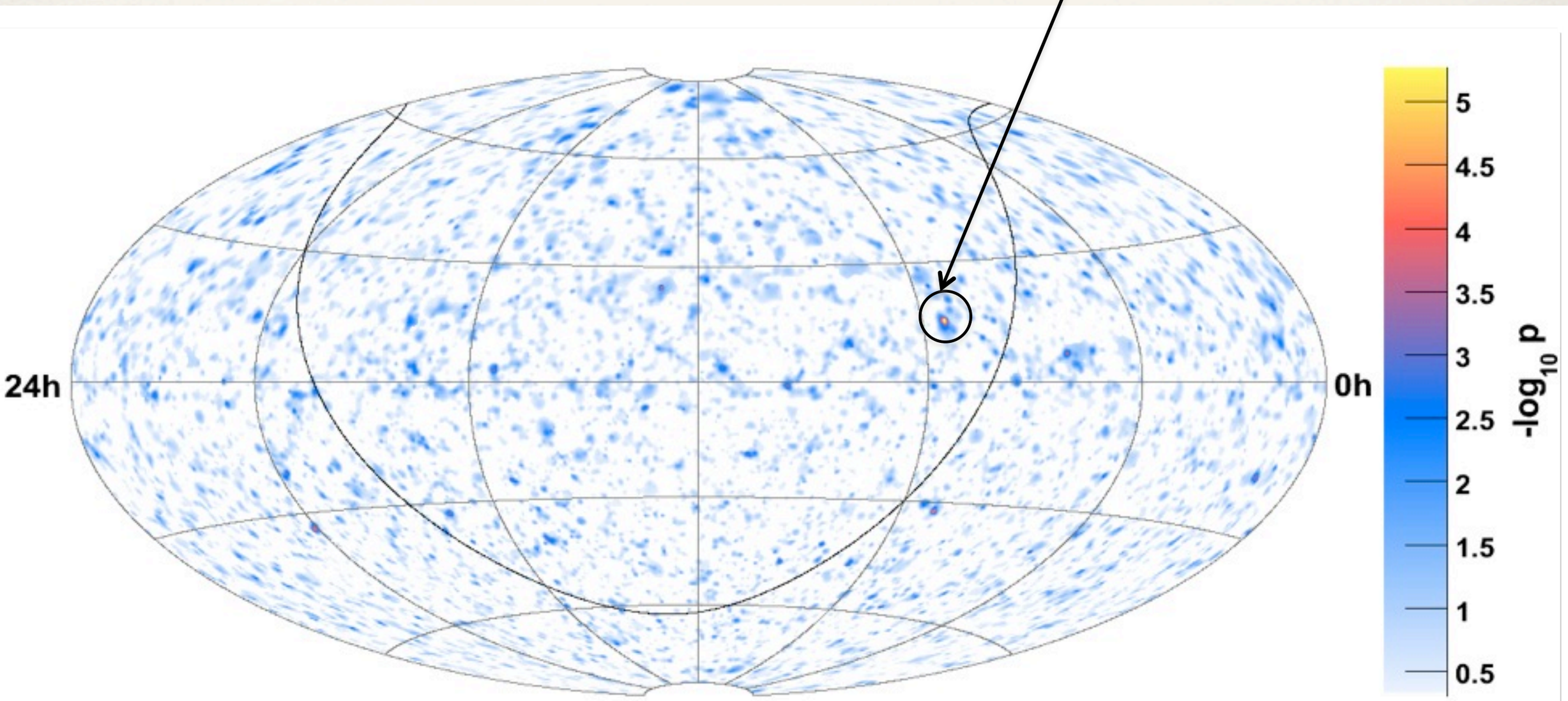
Events = 36900
(14121 up-going,
22779 down-going)

Hottest location in the all-sky search is:
Ra=113.75, Dec=15.15

Pre-trial $-\log_{10}$(p-value) = 5.28

Best-fit # of source events = 11.0

Best-fit spectral index = 2.05



Pre-defined list of candidates
(to reduce the "trial" factor)

- Extra-galactic sources

  ☞ TeV, GeV-blazars, stacking of AGN families, stacking of cluster of galaxies

- Galactic sources (soft spectra), Dark matter from the Sun

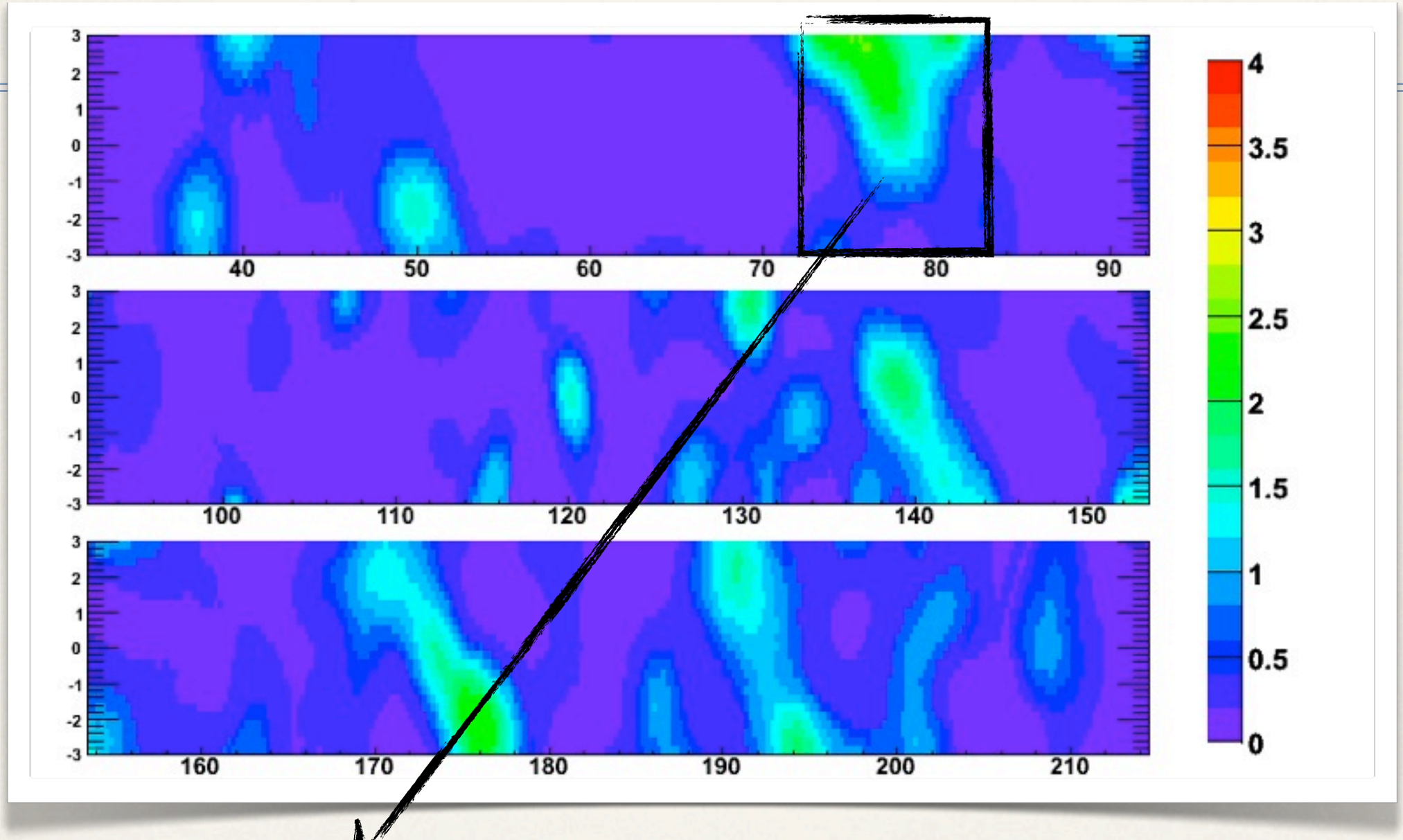
  ☞ Lower energies via inclusion of AMANDA, DeepCore

- Extended sources: Cygnus region

  ☞ Multi-Point-Source method (2pt correlation function)

The Cygnus Region

Cygnus Region (region defined a priori)

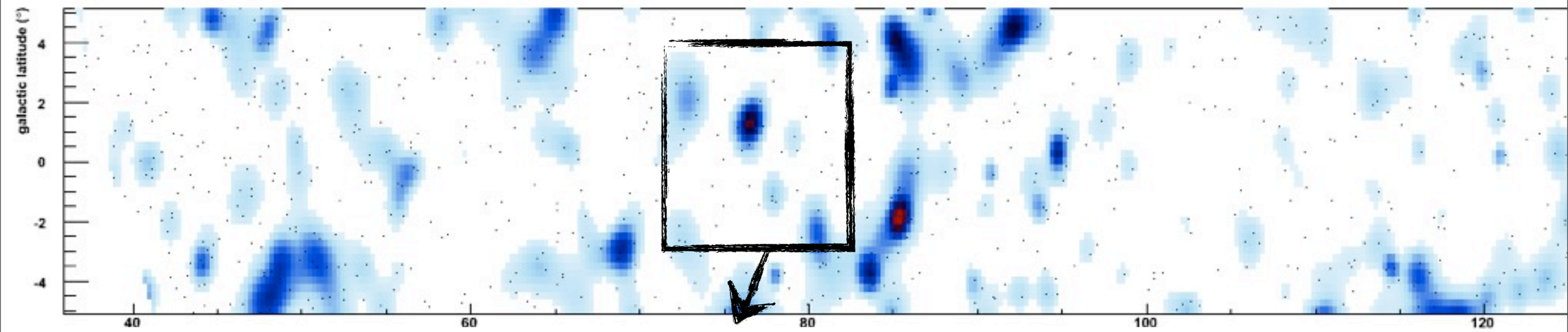


2-point correlation analysis for the entire extended region

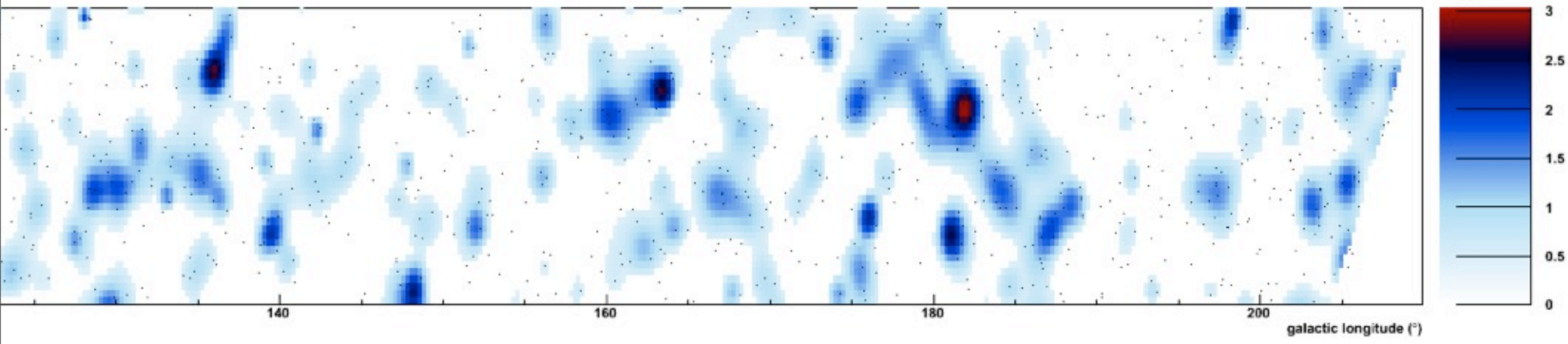
[method and region defined a-priori]

The Cygnus Region

Cygnus Region (region defined a priori)

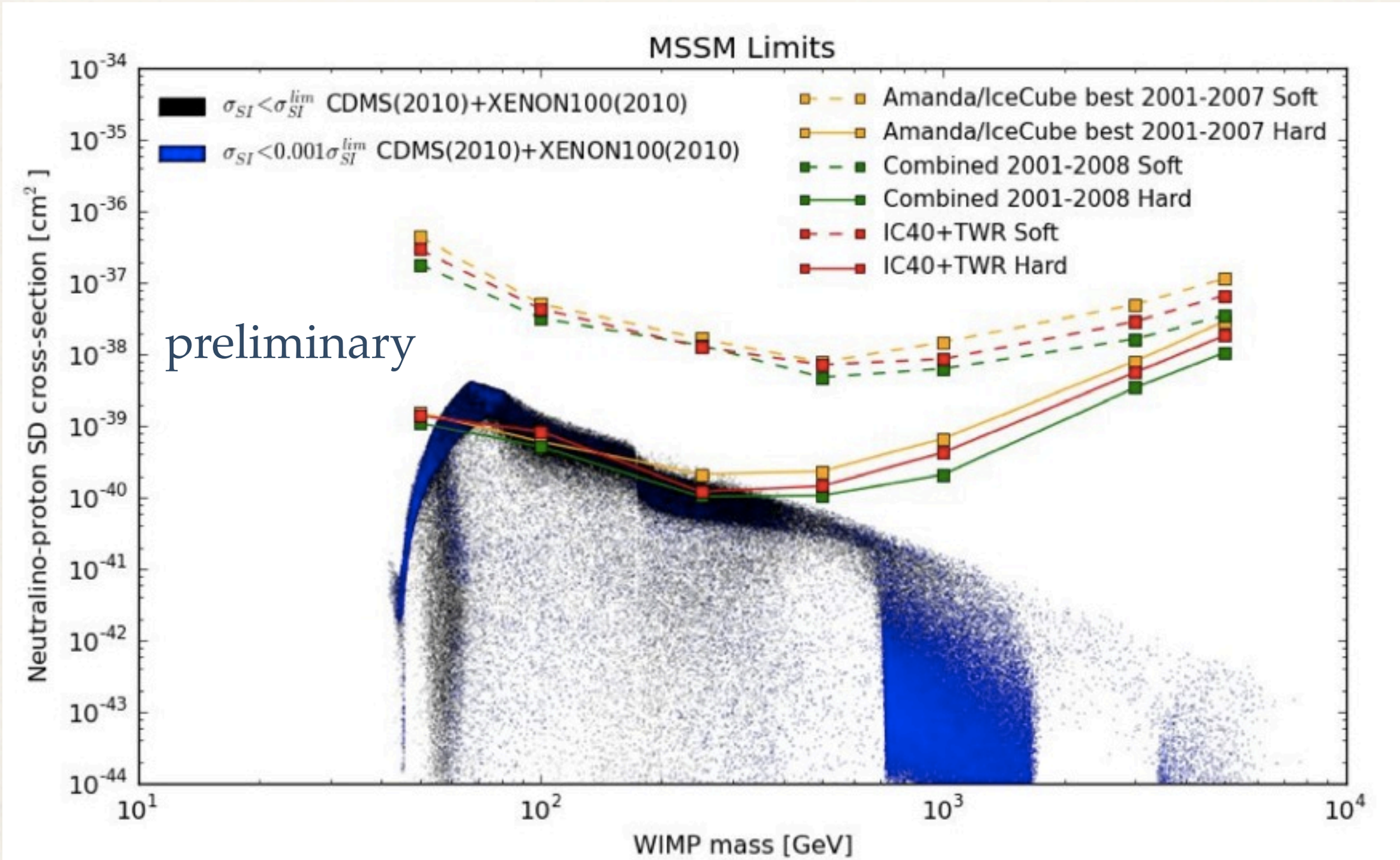


2-point correlation analysis for the entire extended region: the region under-fluctuates!



Lesson learned: 1% fluctuations tend to disappear!

Indirect Dark Matter Search
AMANDA 01-07, IC22, IC40 combined



Transients

- GRBs
- Flaring sources
- Periodic sources

Riccardo Giacconi, **Phys. Rev. Lett. 9, 439–443 (1962)**

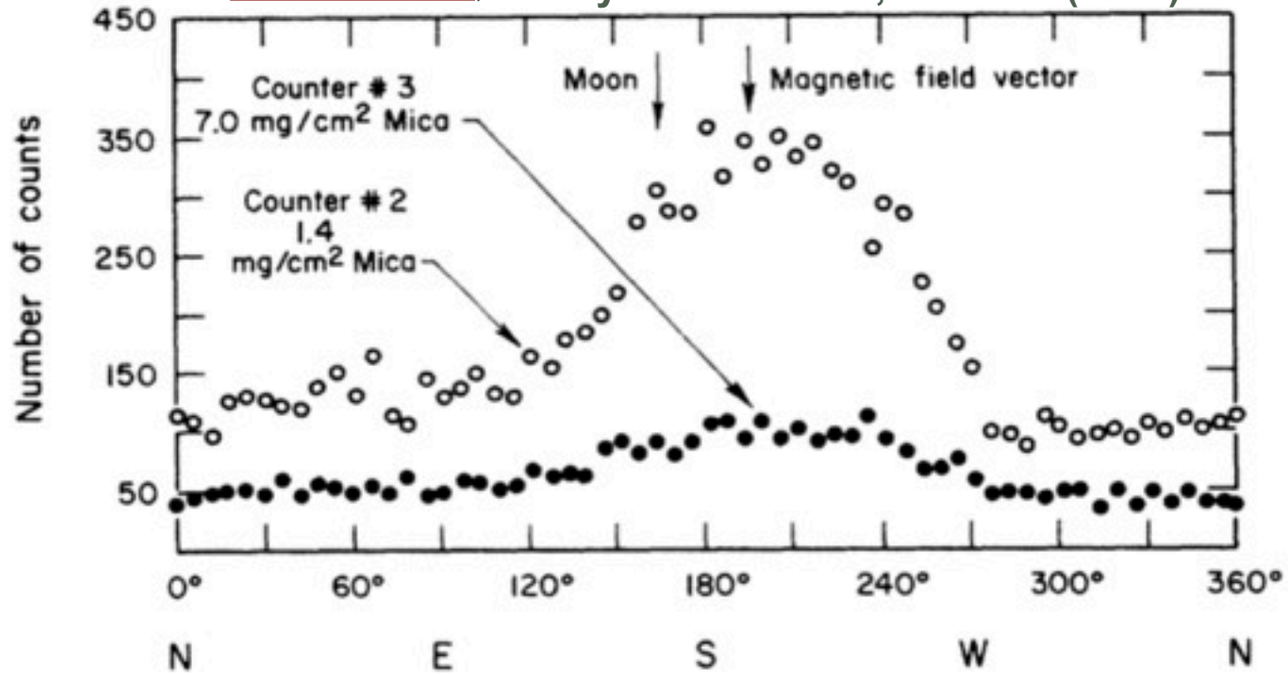
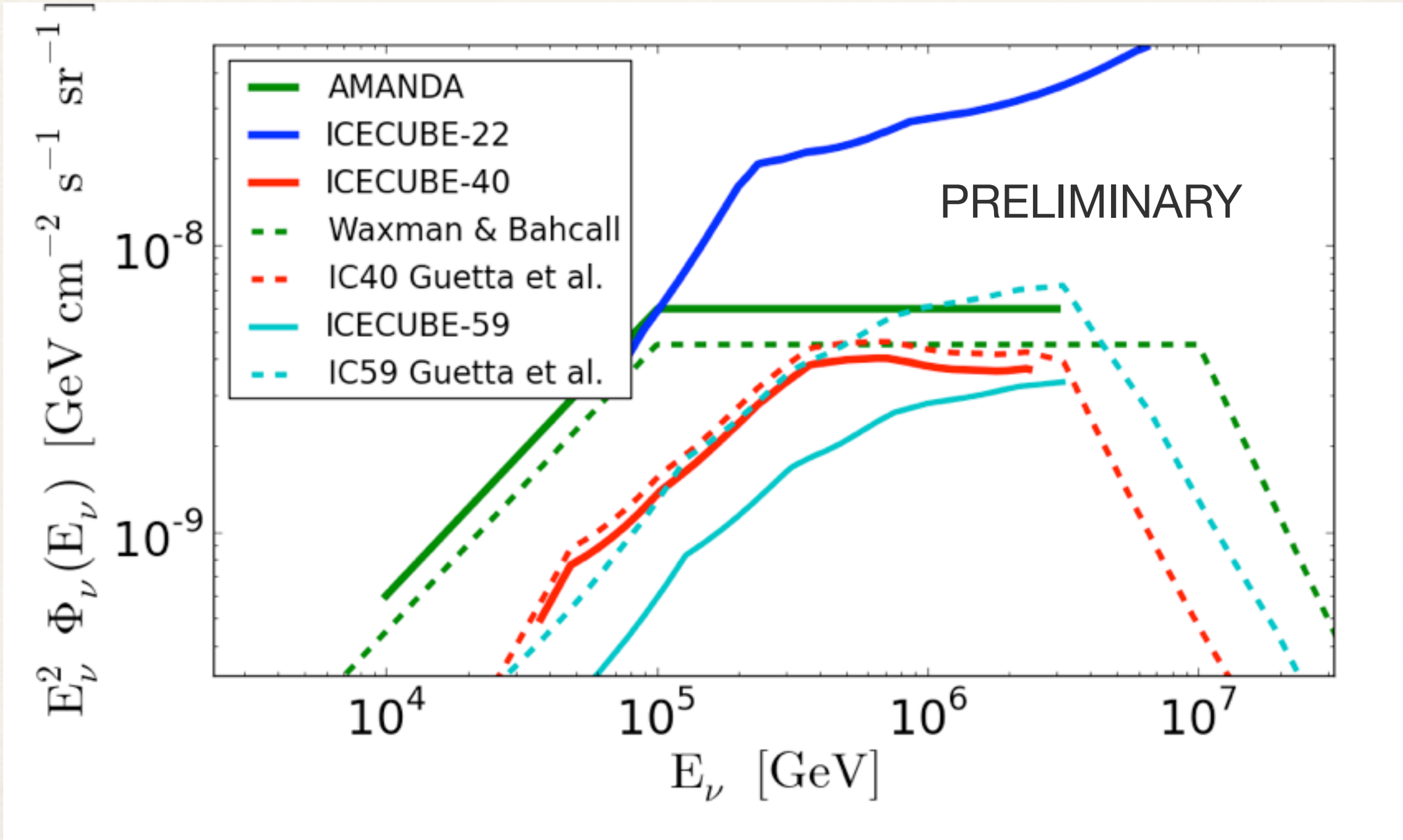
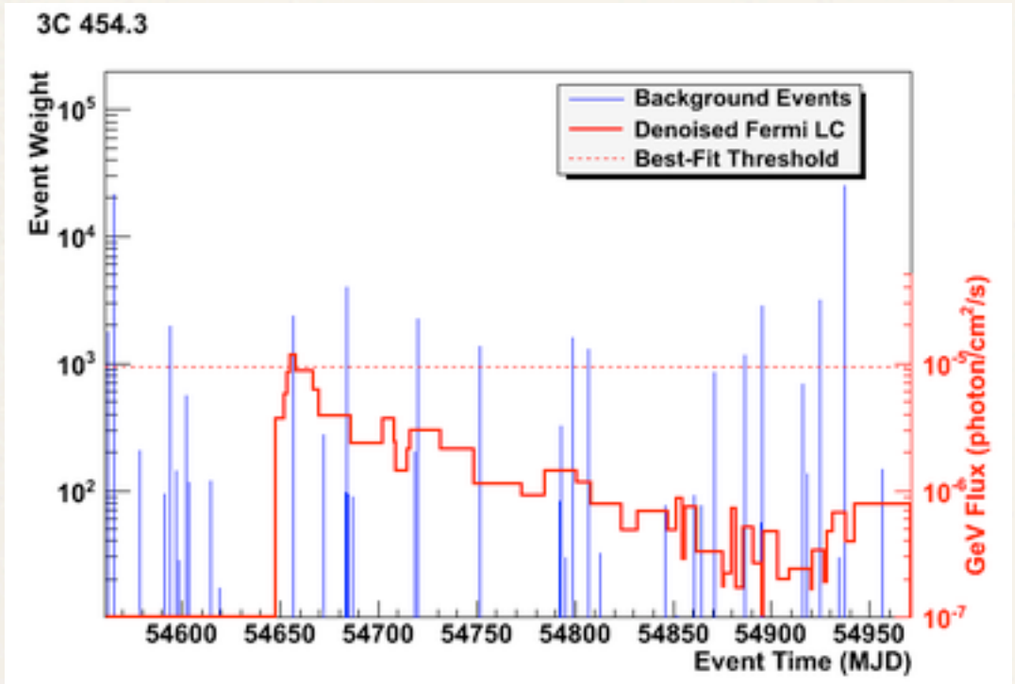


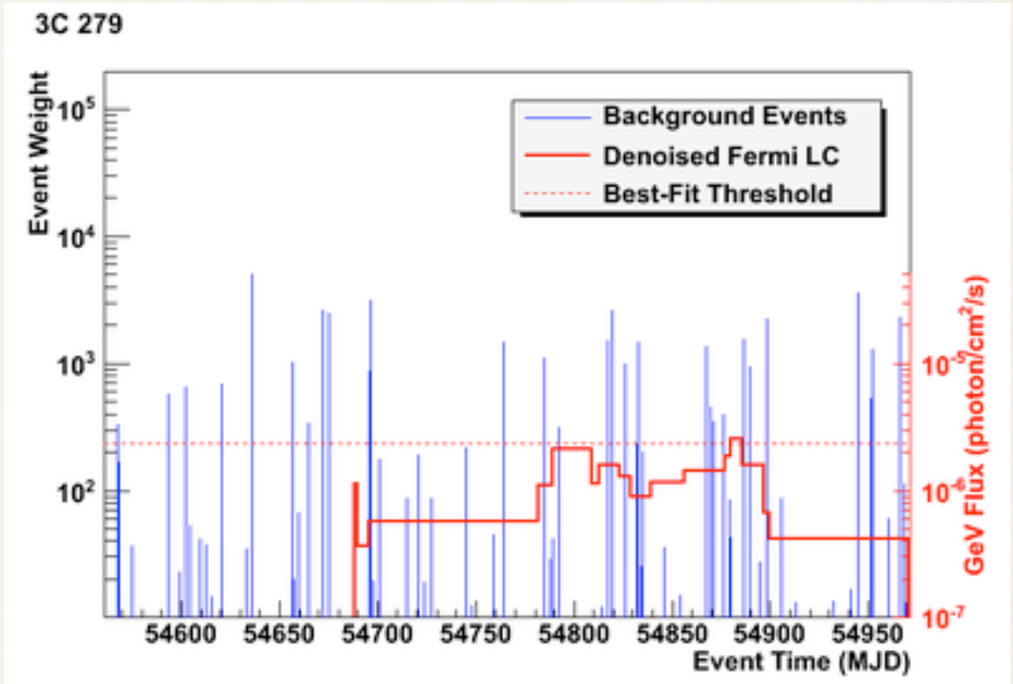
FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.

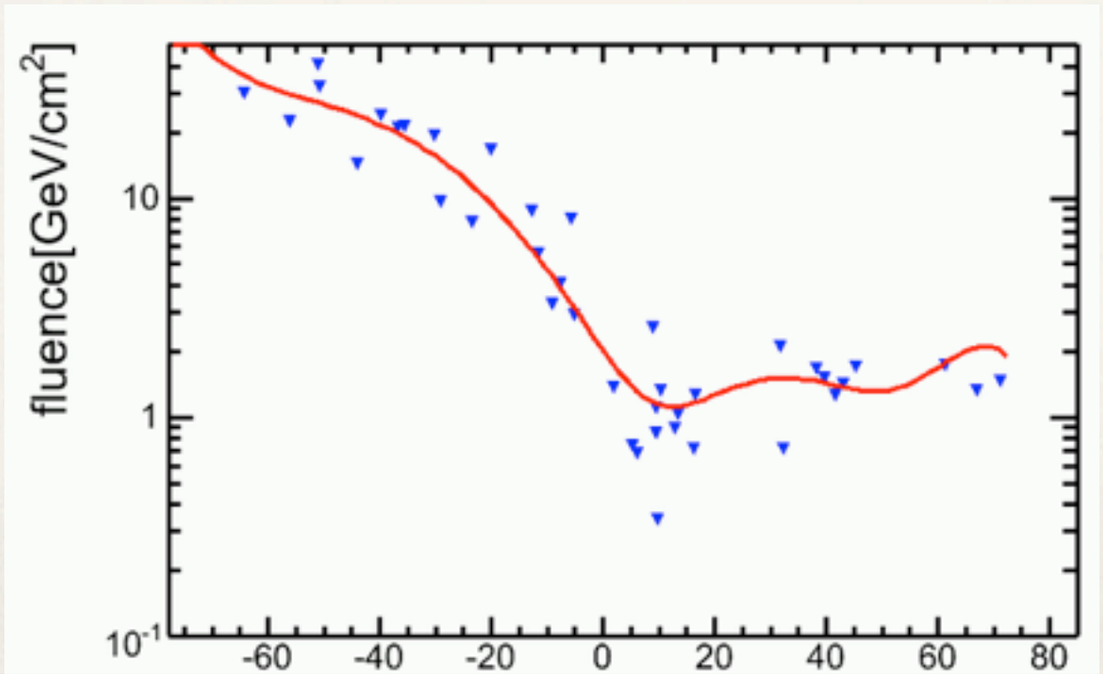
Gamma-Ray-Bursts



Flares







No Evidence of Neutrino Flares up to IC40.

On-line Programs

- Core Collapse SuperNovae
- Alerts to Rotse, PTF, Swift
- Alerts to Magic

Core Collapse SuperNovae

☞ count single rates on top of low noise background

- $\bar{\nu}_e + p \rightarrow e^+ + n$
- 2 ms timing resolution
- IceCube sends real-time datagrams to Supernova Early Warning System (SNEWS)
- Sensitivity:
  - supernova @ galactic center like megaton-scale supernova search experiment
  - 20 standard deviations: ~30 kpc
  - 6 standard deviations: ~50 kpc (Large Magellanic Cloud)

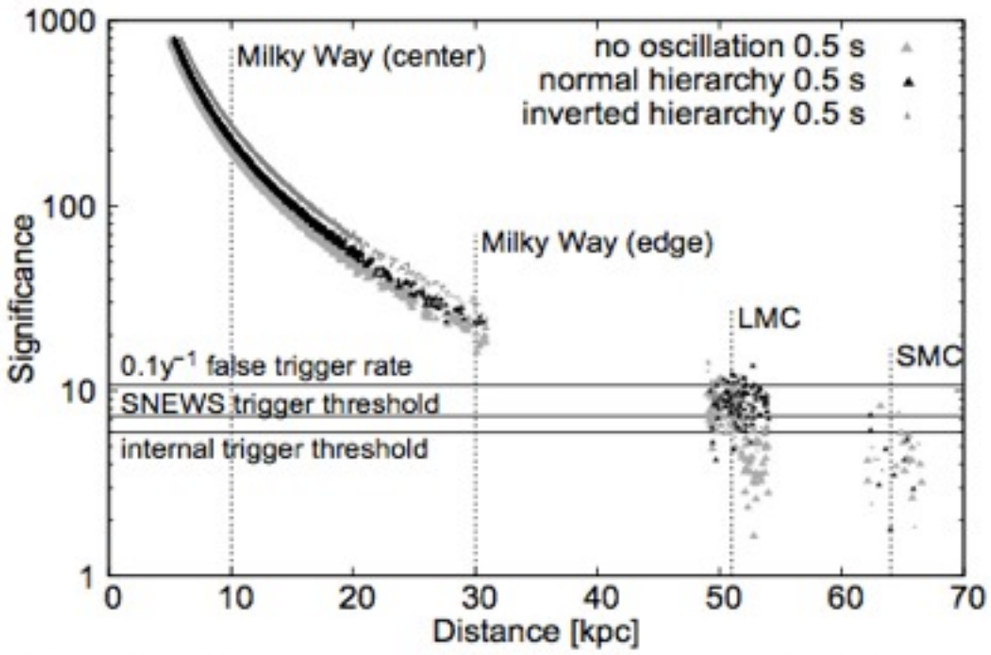


Fig. 12. Significance versus distance assuming the Lawrence-Livermore model. The significances are increased by neutrino oscillations in the star by typically 15 % in case of a normal hierarchy (Scenario A) and 40 % in case of an inverted hierarchy (Scenario B). The Magellanic Clouds as well as center and edge of the Milky Way are marked. The density of the data points reflect the star distribution.

Core Collapse SuperNovae

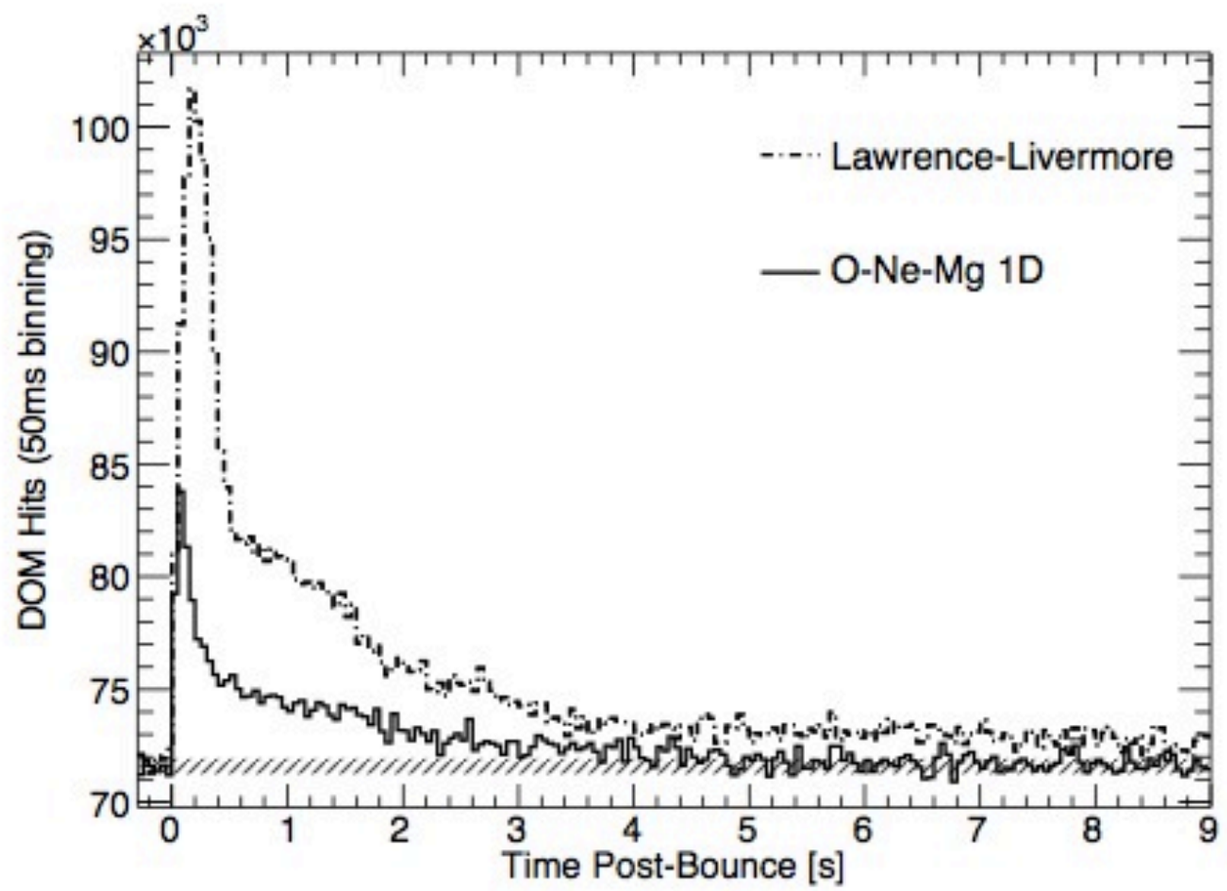
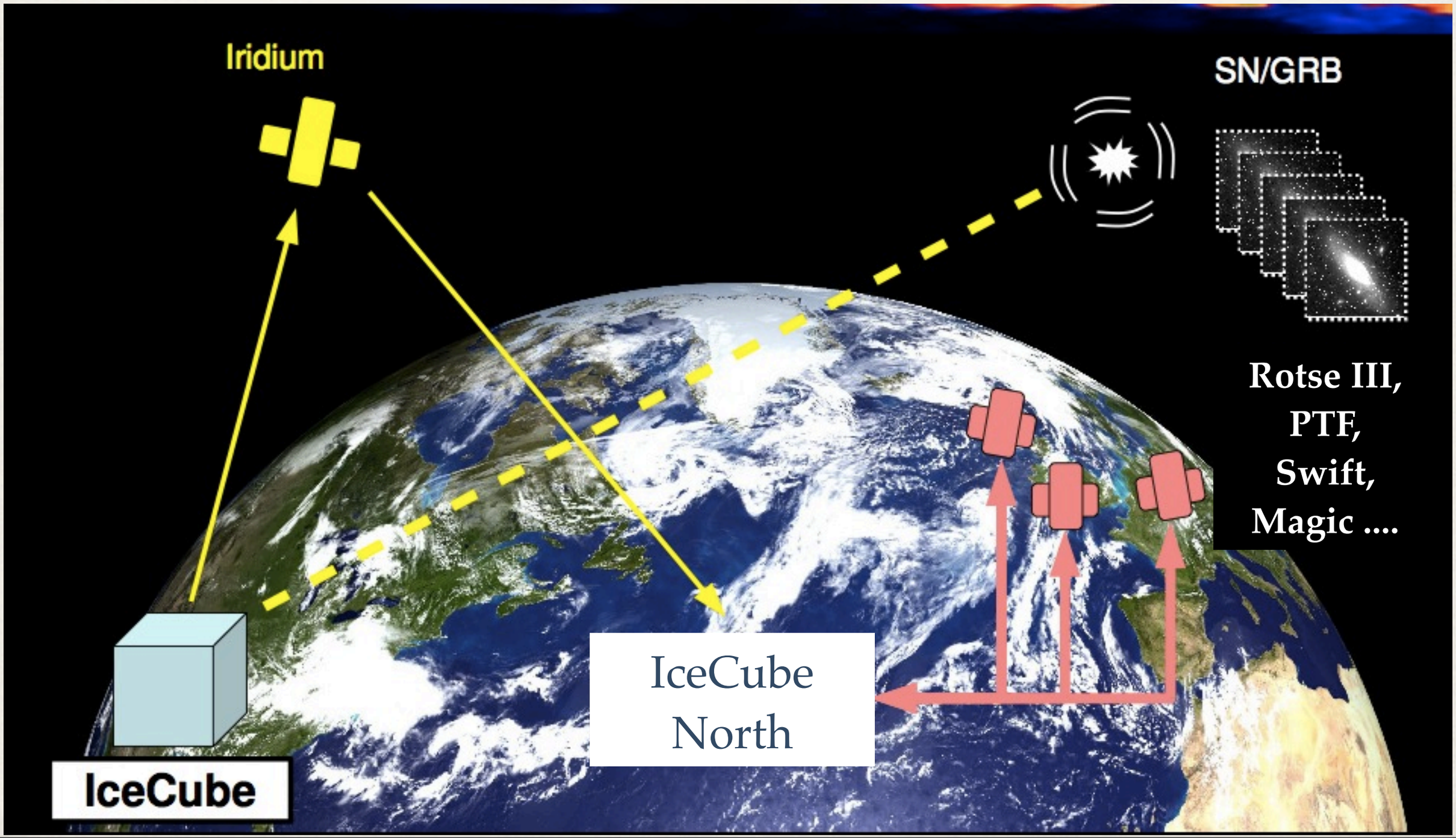


Fig. 10. Expected rate distribution at 10 kpc distance for the Lawrence-Livermore model (dashed line) and O-Ne-Mg model by Hüdepohl et al. (2010) with the full set of neutrino opacities (solid line).The 1 σ-band corresponding to measured detector noise (hatched area) has a width of about ± 330 counts.

- **IceCube is the world‘s most precise detector for determining the neutrino**
- **light curve of close supernovae**

On-line alerts



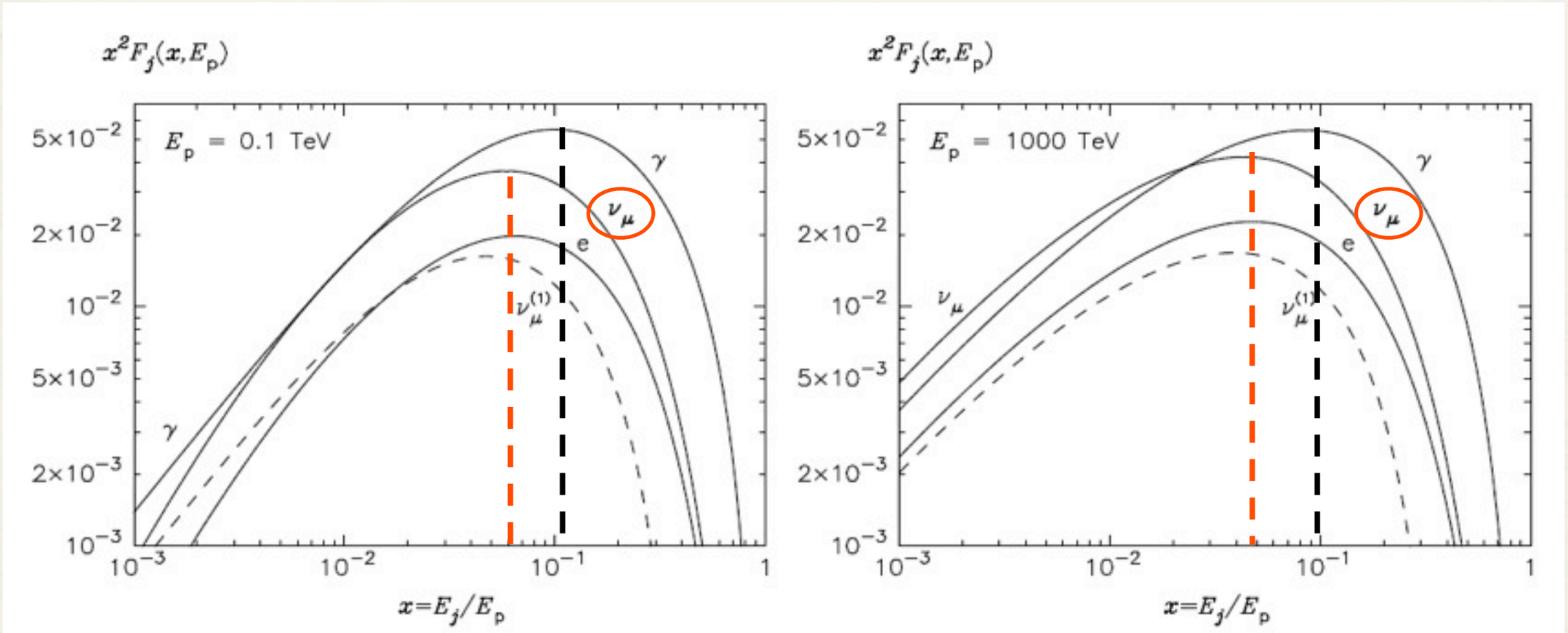
Conclusions ...

working, fighting, stop fighting, working, hoping, dreaming ....
(I will put something serious, don't worry)

backup

Cosmic Rays - Neutrinos - TeV Gamma Rays

Energy spectra of all decay products - pp interaction - two energies of incident protons



$$Ep:E\gamma:E\nu = 1:0.1:0.05$$

- [pp Interaction (S.R. Kelner, F. A. Aharonian,V.V. Bugayov, Phys.Rev.D74:034018,2006), pγ Interaction (S.R. Kelner, F.A. Aharonian, Phys.Rev.D78:034013,2008), A. Reimer et al., SOPHIA MonteCarlo, http://ebl.stanford.edu/]