IceCube Science

Elisa Resconi, T.U. Munich

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

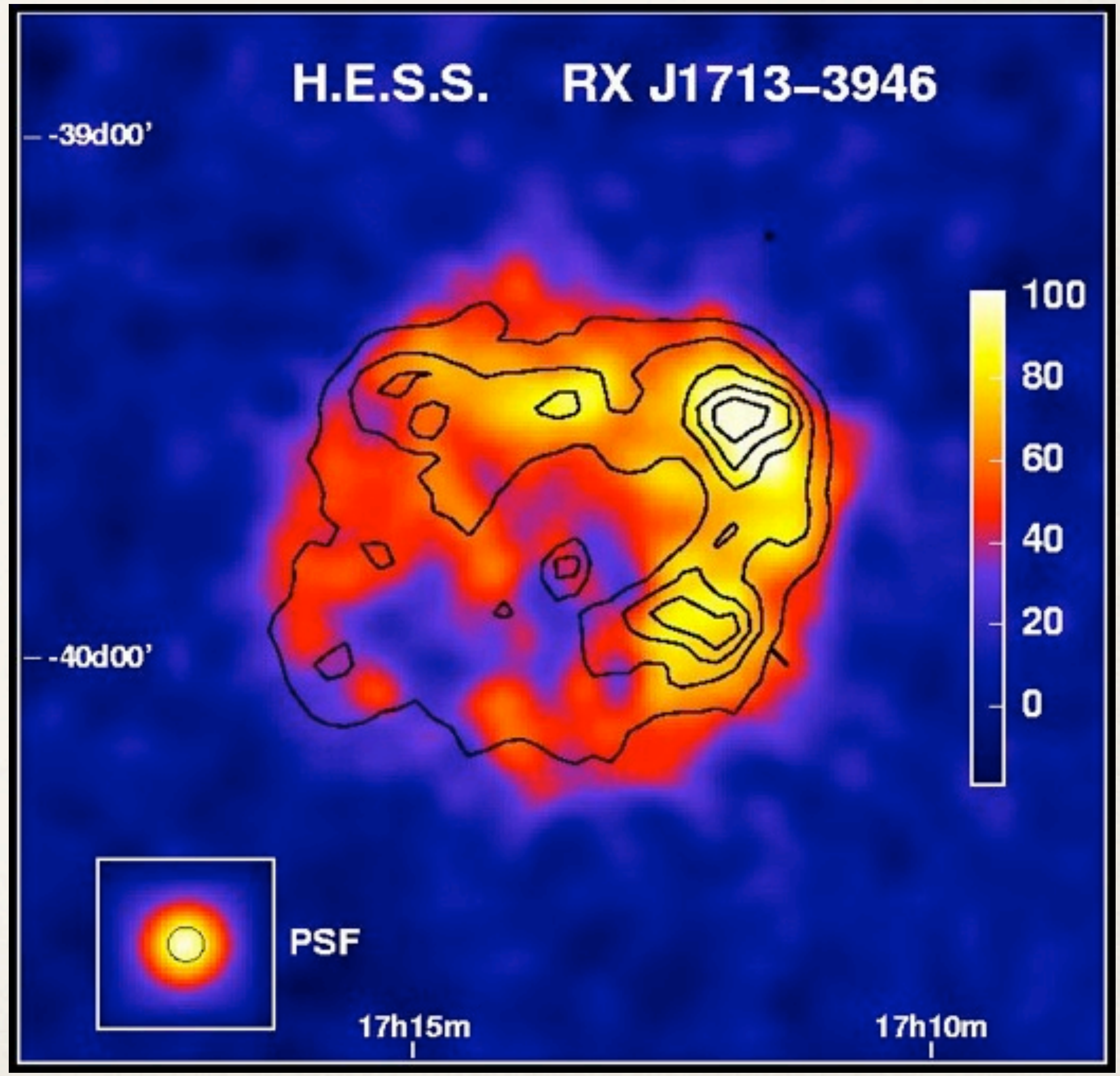
High Energy (> 100 GeV) Neutrino Astronomy

- 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

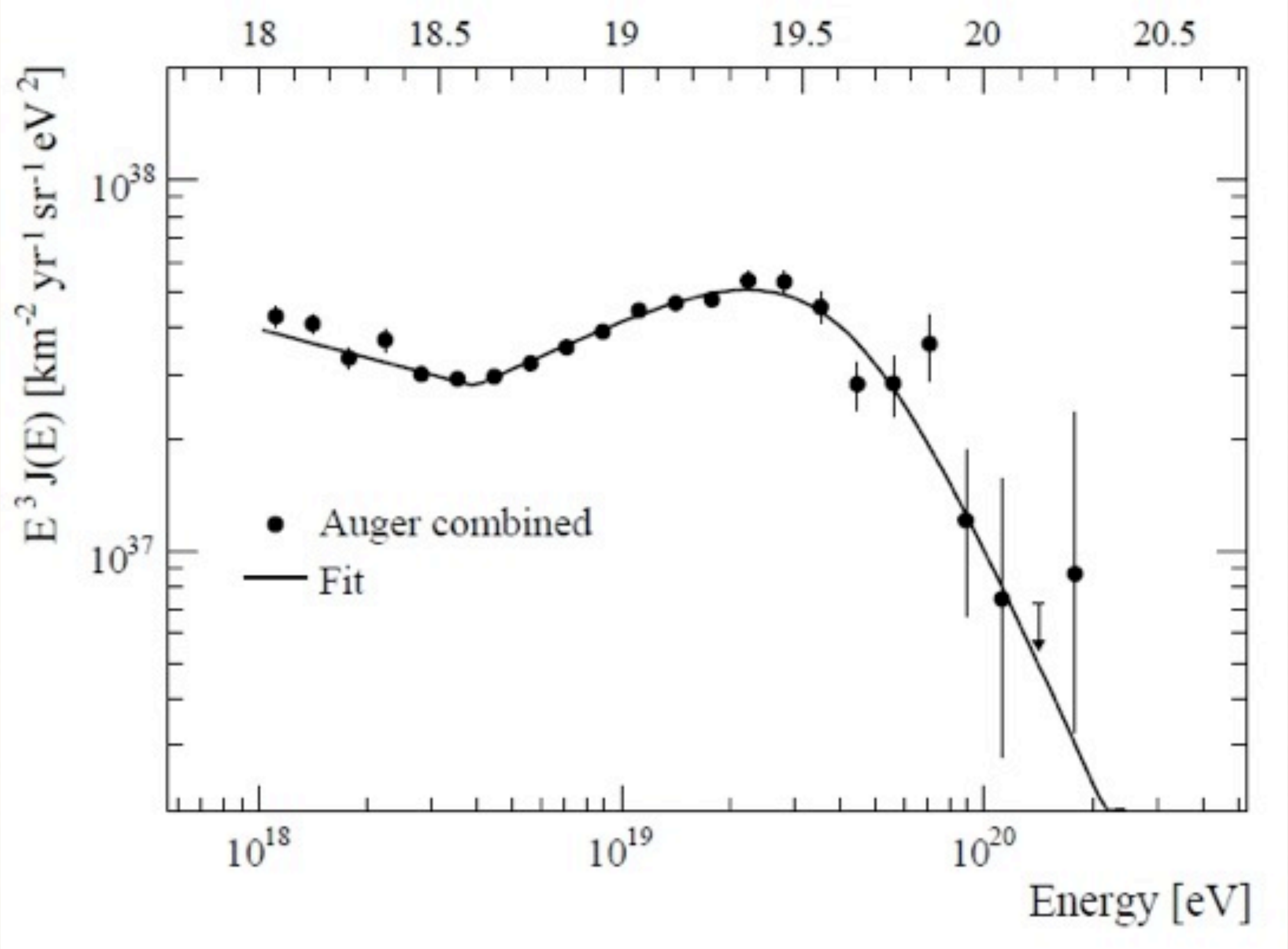
leptonic or hadronic origin?



Cosmic Rays: Extra-galactic

- Cosmic particles up to 10^{20} eV
- Unresolved astrophysical sources
  intrinsic spectrum $\propto E^{-2}$
  Diffuse neutrino flux
  Waxman-Bahcall upper bound
- AGN, GRBs
- Cosmogenic neutrinos (EHE):
  cosmic-rays interacting with the cosmic microwave background
  GZK cutoff?

The Auger Collaboration



How do we search for Cosmic Ray Sources?

IceCube is a discovery instrument ☞ no guaranteed recipe

- All-sky searches: diffuse flux, 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

The IceCube Collaboration, corresponding author: S. Grullon

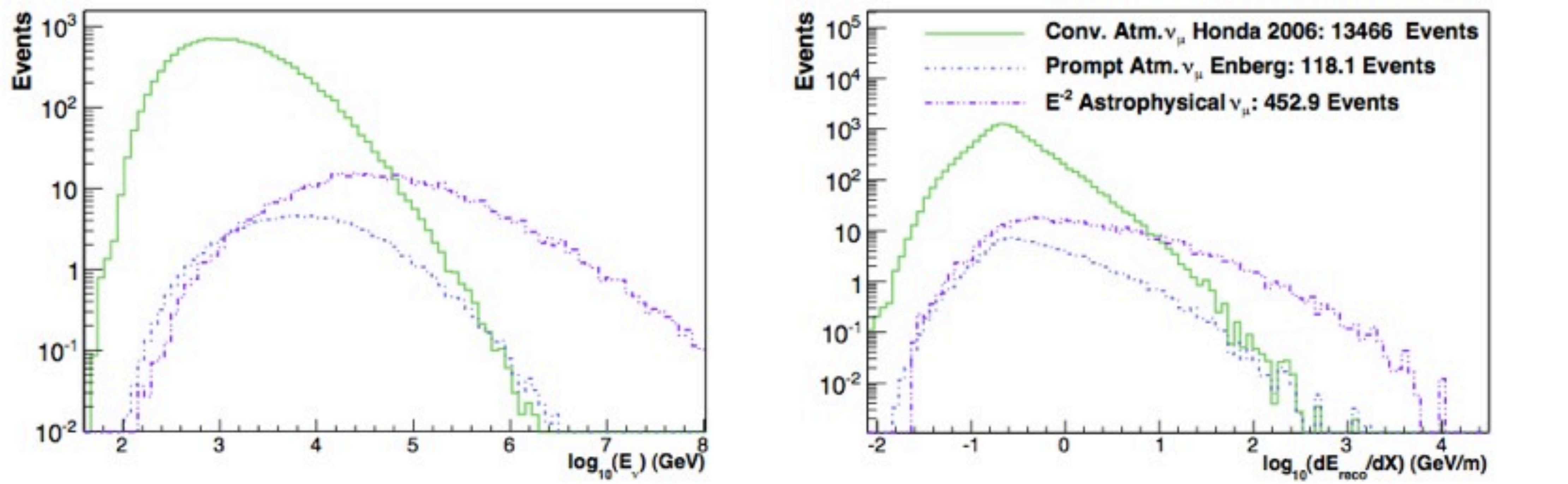


FIG. 7. Simulated neutrino energy distribution (left plot) and the simulated reconstructed muon energy loss distribution (right plot) of the final event sample for the Honda *et. al* conventional atmospheric ν_μ (green) flux model, the Enberg *et al.* prompt atmospheric ν_μ (light blue) flux model, and 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

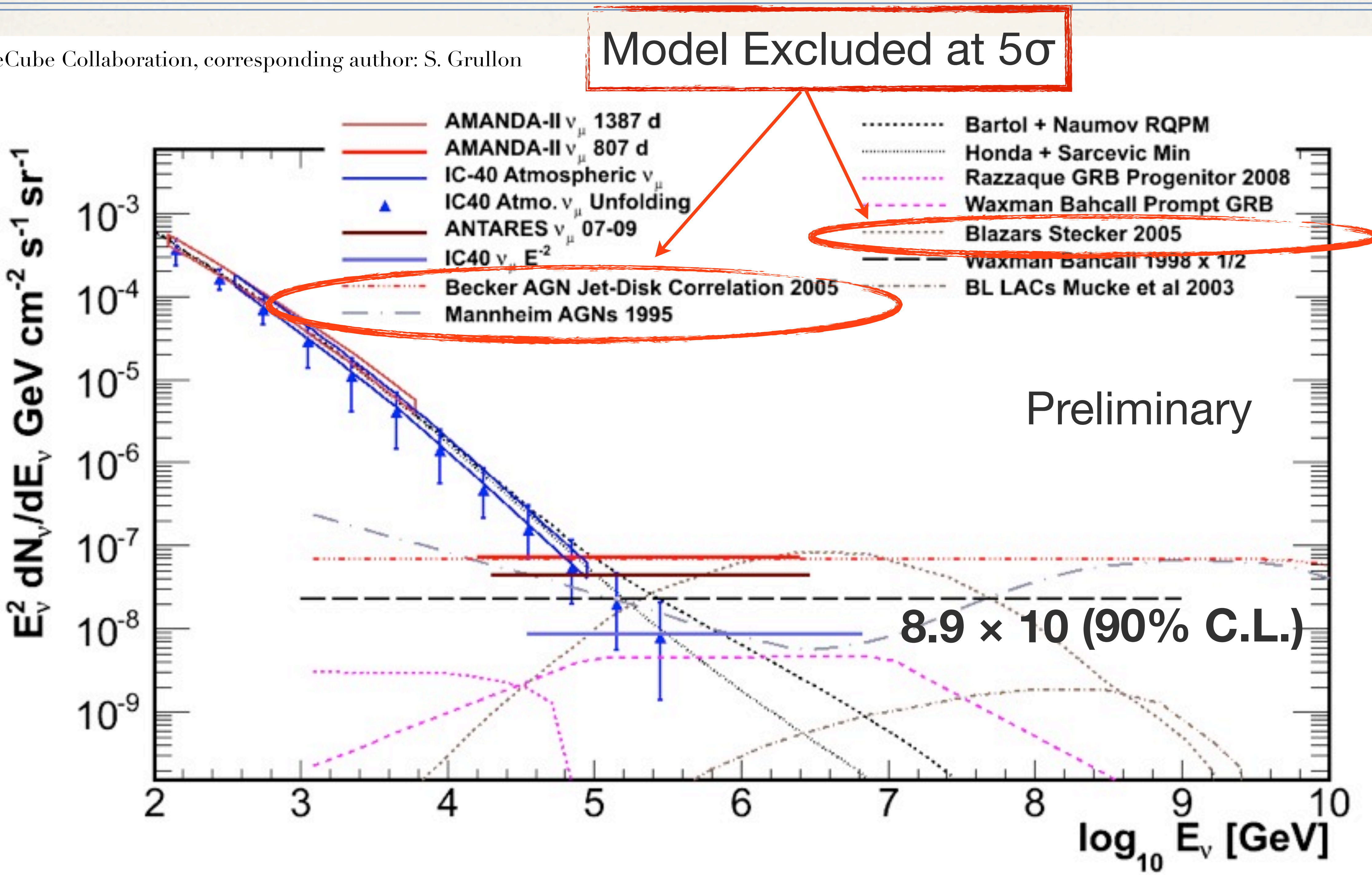
- prompt component atmospheric neutrinos (−44% to +25%)
  ☞ search of the prompt component in the muons

- uncertainty absolute sensitivity digital optical module (± 10%)
  ☞ map of the detector with flashers, muons; multi-wavelength LED;
  hole ice investigations .....

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

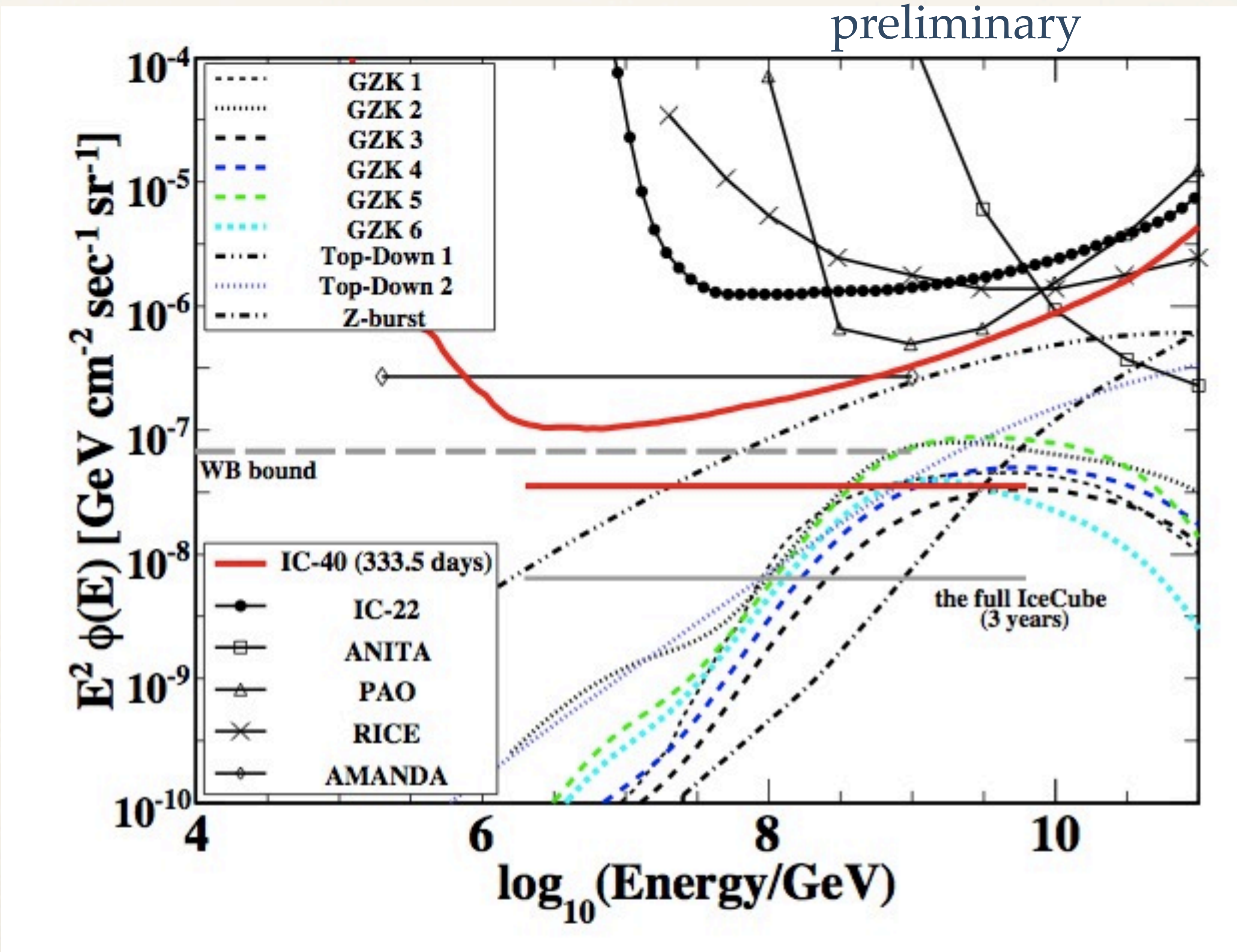
IC-40 Diffuse Neutrino Flux Upper Limit

The IceCube Collaboration, corresponding author: S. Grullon



Cosmogenic Neutrinos

All flavor neutrino flux differential limit and E^{-2} spectrum integrated limit

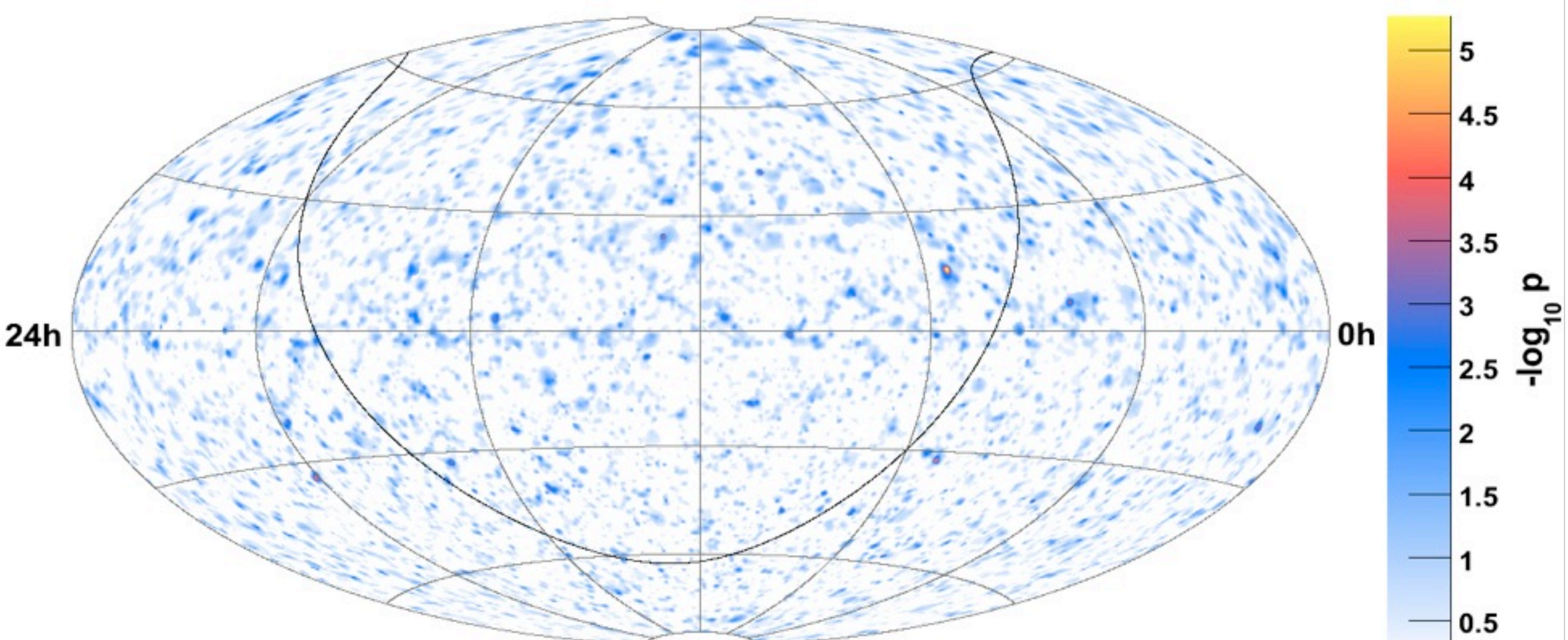


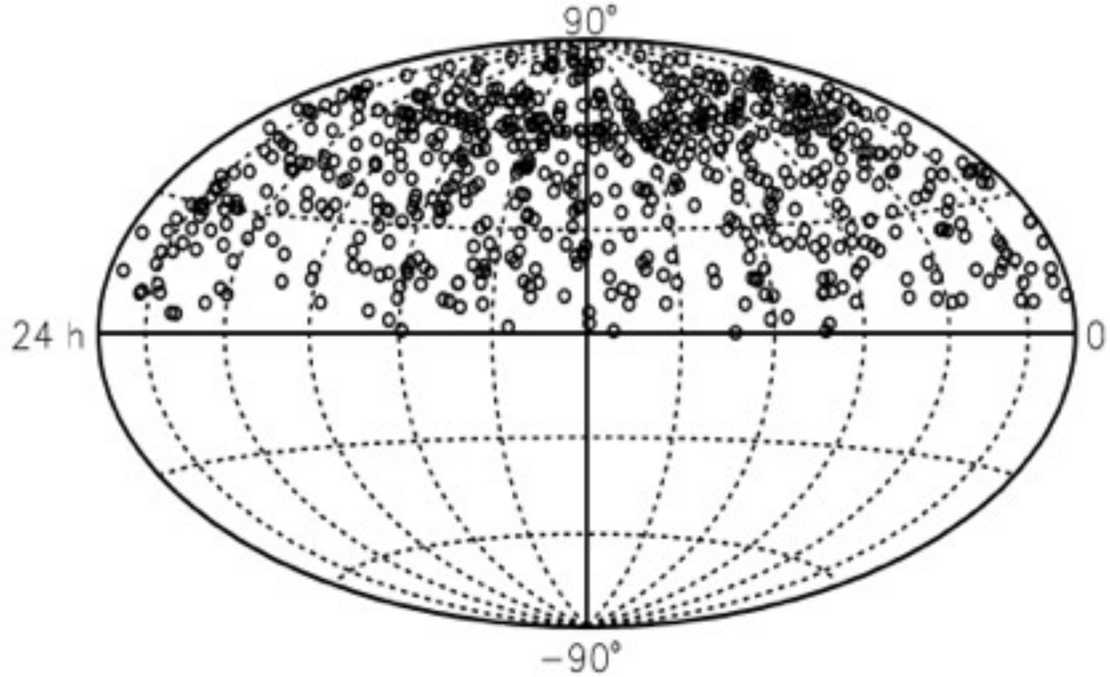
All-sky Searches: Point Sources

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

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

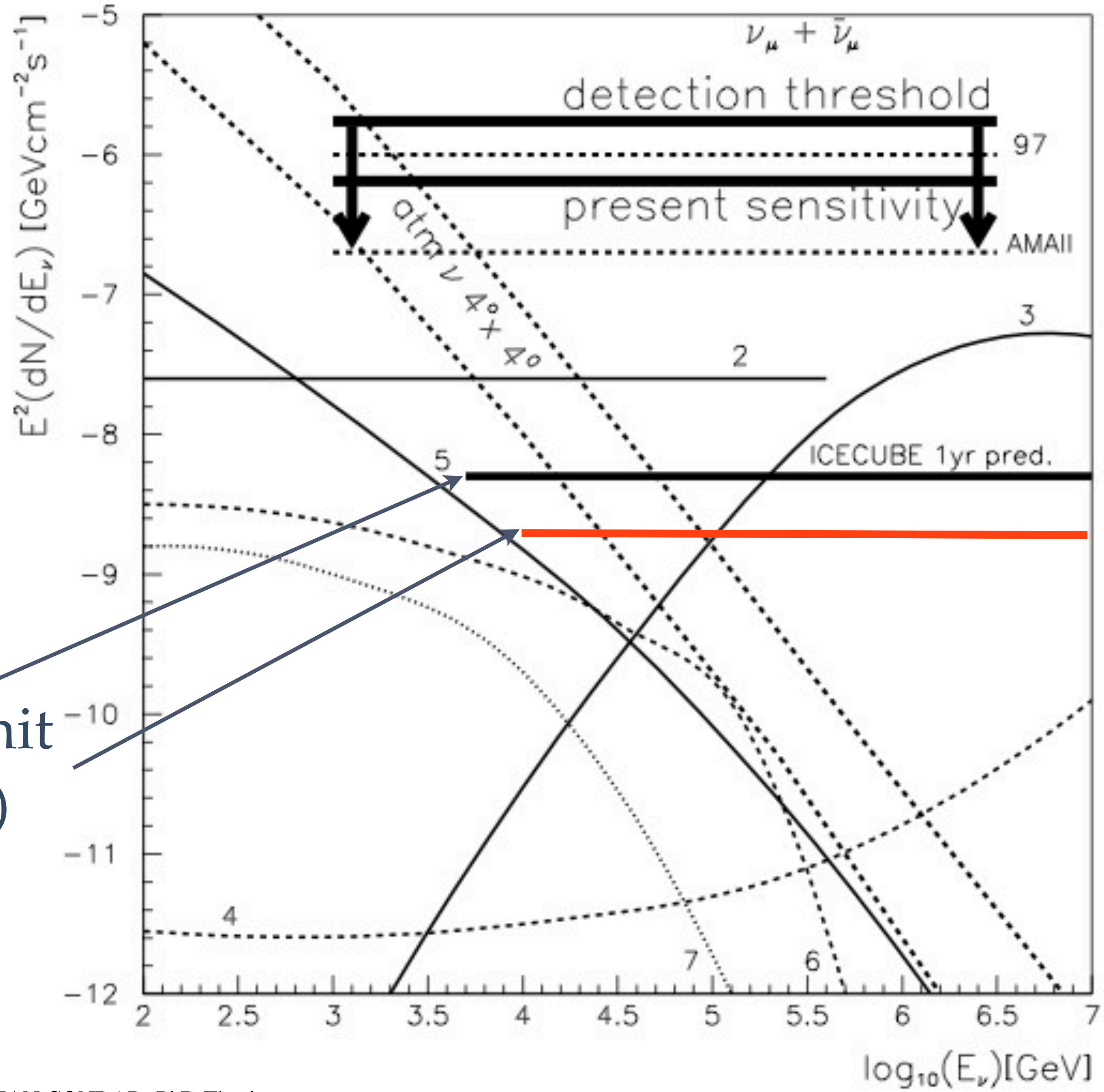
The IceCube Collaboration, corresponding author: J. Dumm





JAN CONRAD, PhD Thesis

1997, AMANDA-B10, 642 events



1 year IceCube predicted

1 year IceCube-40 best upper limit

(2 order of mag improvement!)

JAN CONRAD, PhD Thesis

all-sky p-value = 18%

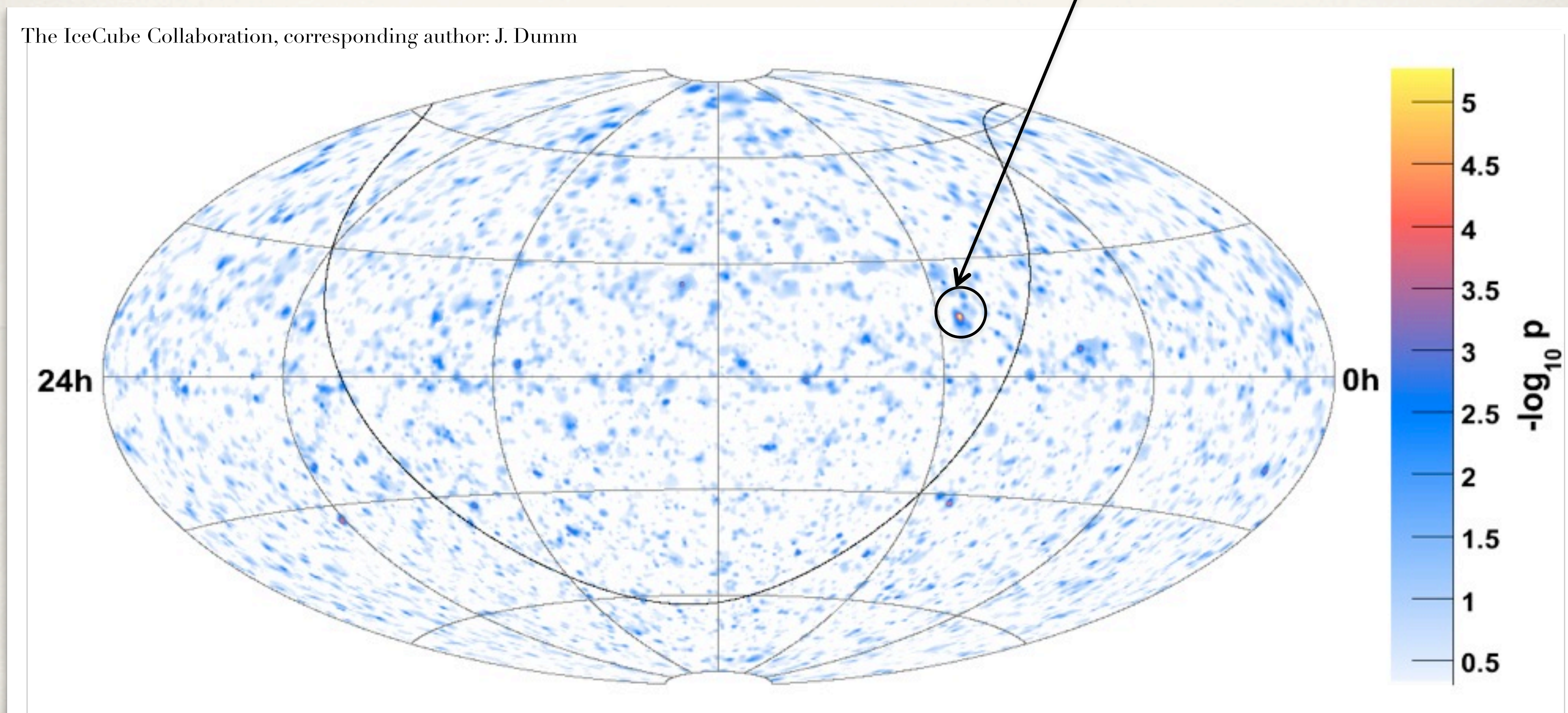
not significant, no evidence of neutrino source

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



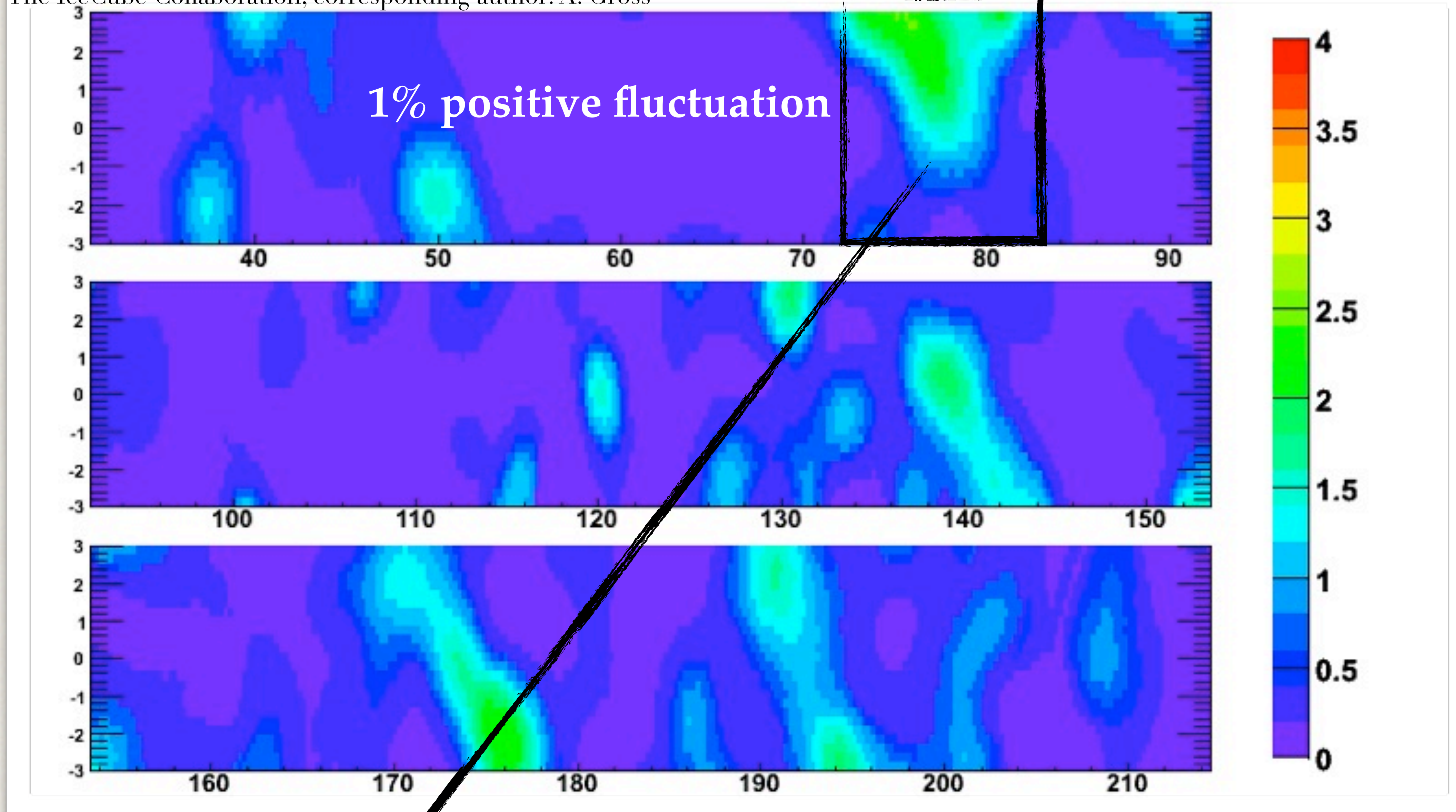
Pre-defined list of candidates
(to reduce the "trial" factor)

- Extra-galactic sources
  - ☞ TeV, GeV-blazars, stacking of AGN families, stacking of cluster of galaxies
- Galactic sources (soft spectra)
  - ☞ Lower energies via inclusion of AMANDA, DeepCore
- Extended sources: Cygnus region
  - ☞ Multi-Point-Source method (2pt correlation function)

The Cygnus Region

Data sample: IC22+AMANDA

The IceCube Collaboration, corresponding author: A. Gross

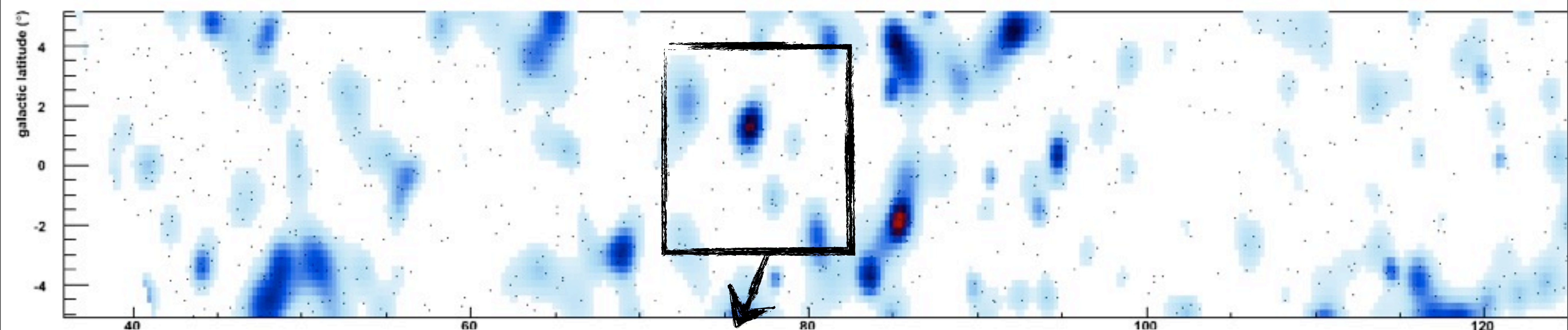


2-point correlation analysis for the entire extended region [method and region defined a-priori]

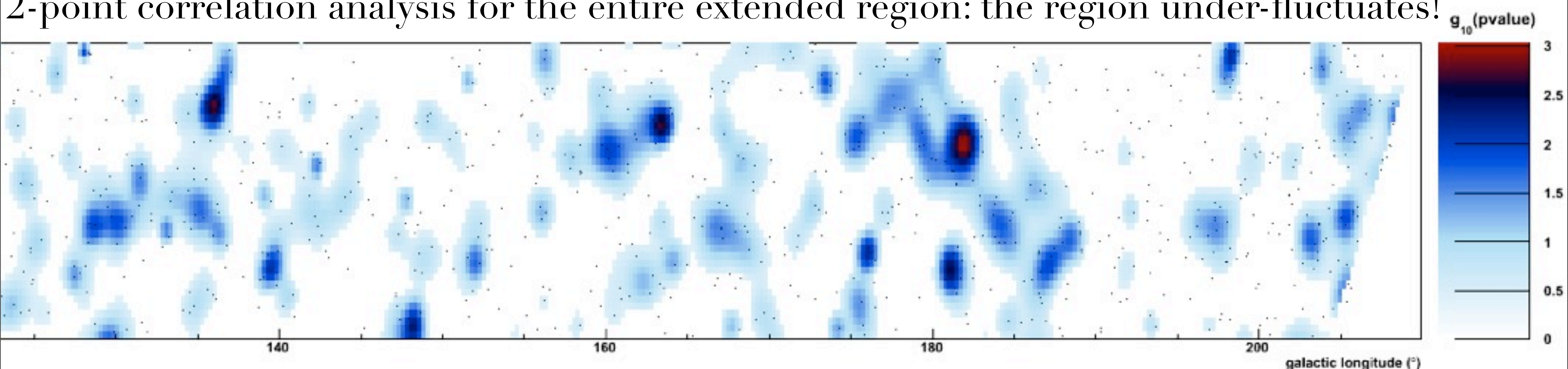
The Cygnus Region

Data sample: IC40+AMANDA

The IceCube Collaboration, corresponding author: S. Odrowski

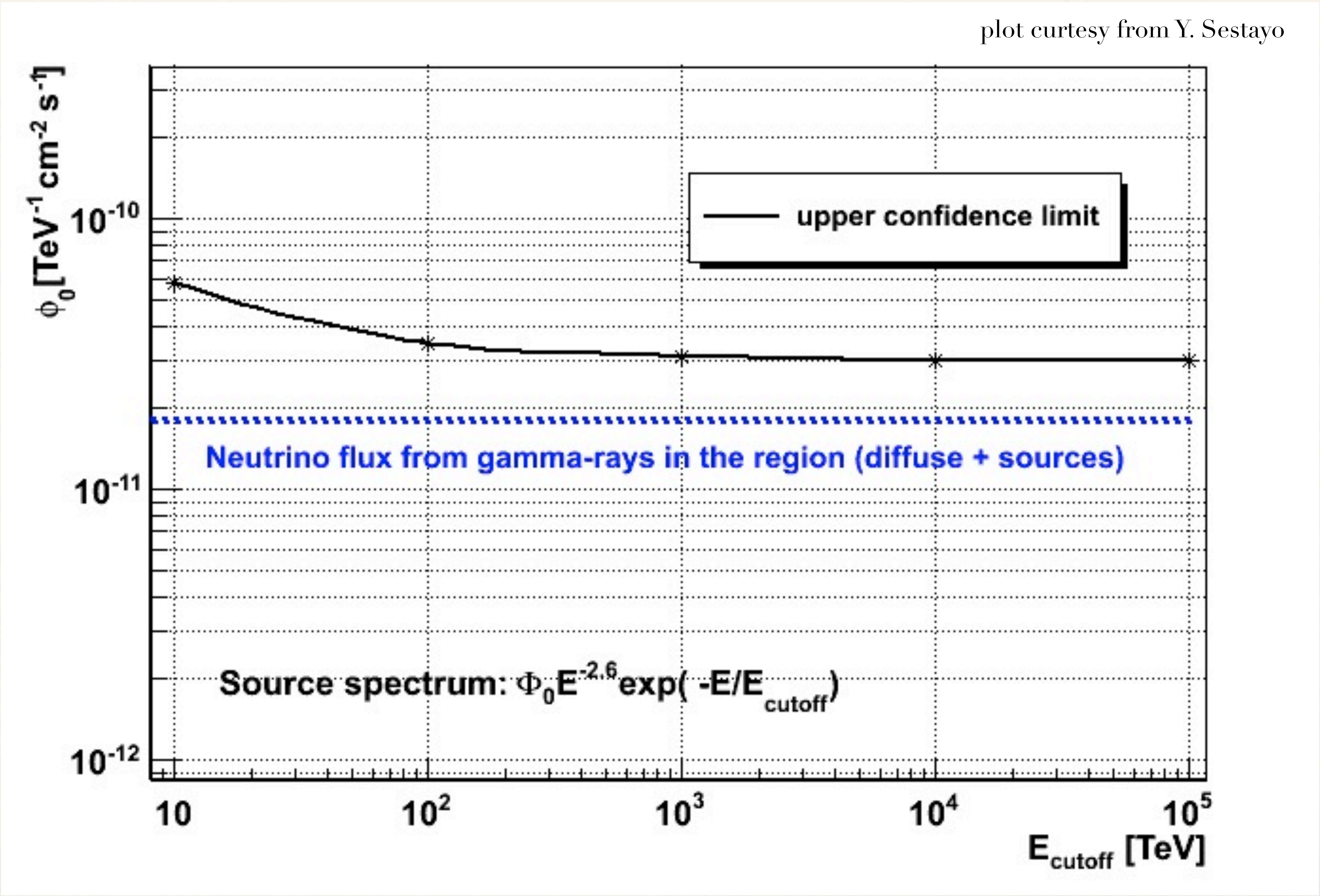


2-point correlation analysis for the entire extended region: the region under-fluctuates!

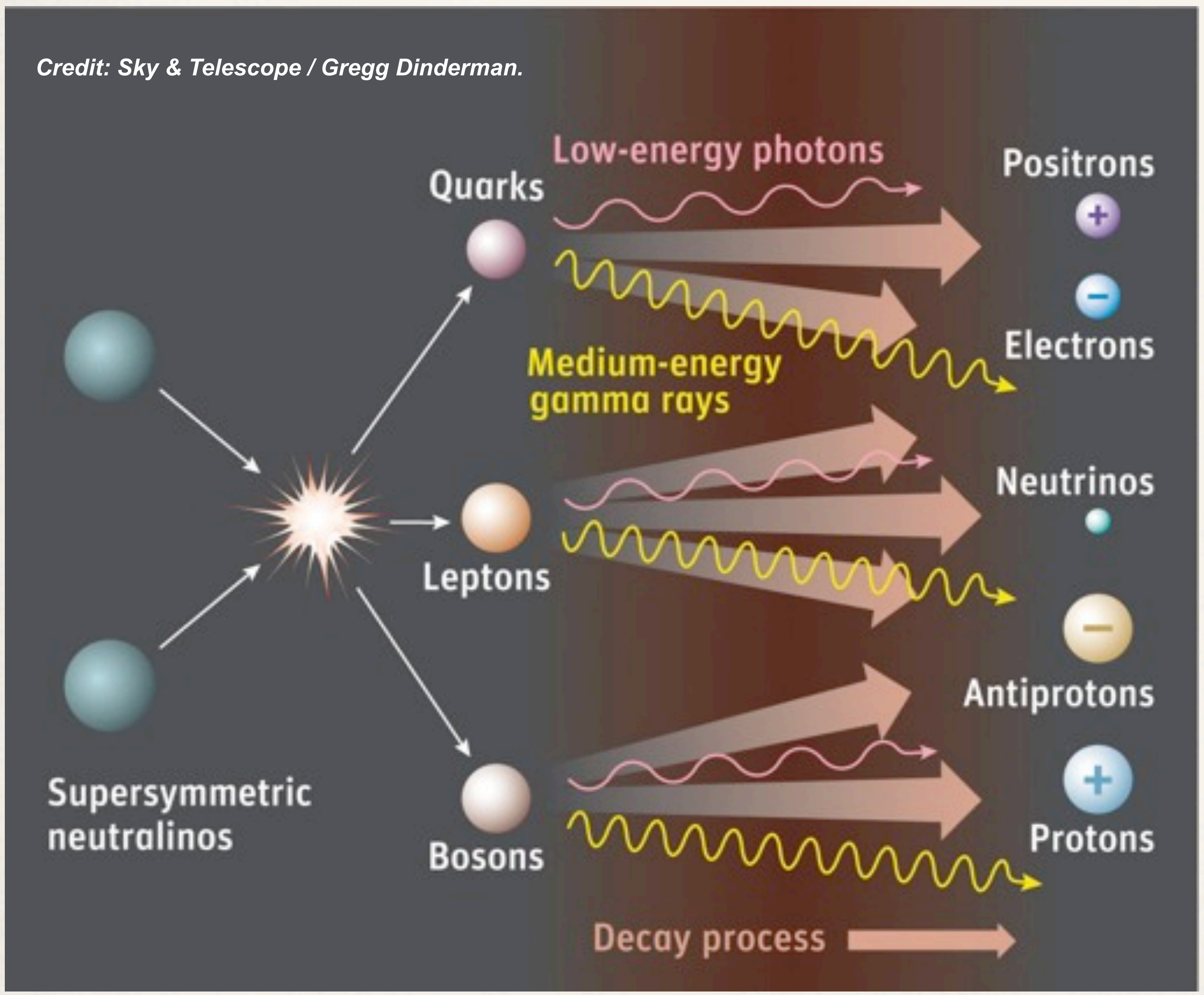


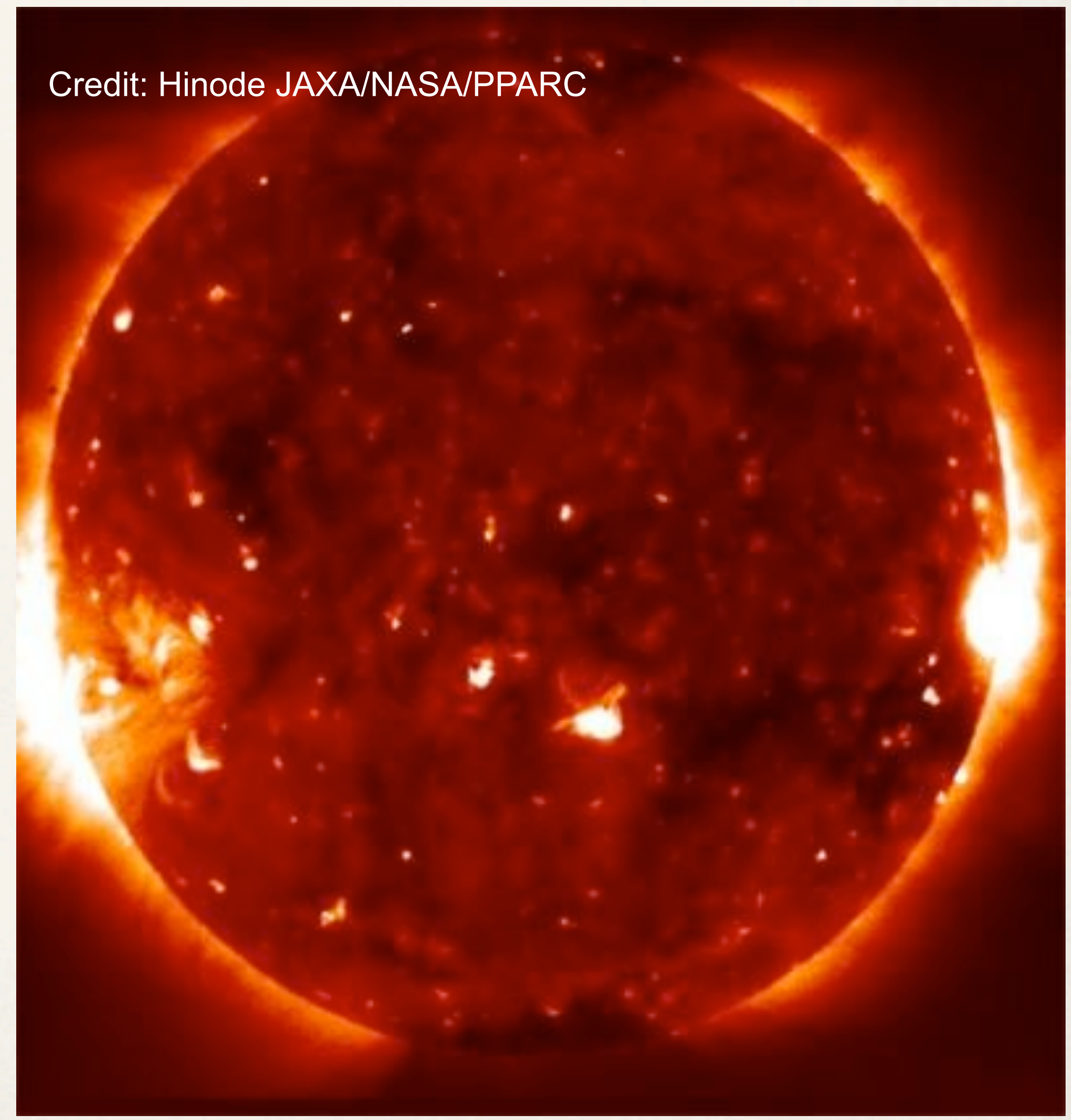
Lesson learned: 1% fluctuations tend to disappear!

The Cygnus Region



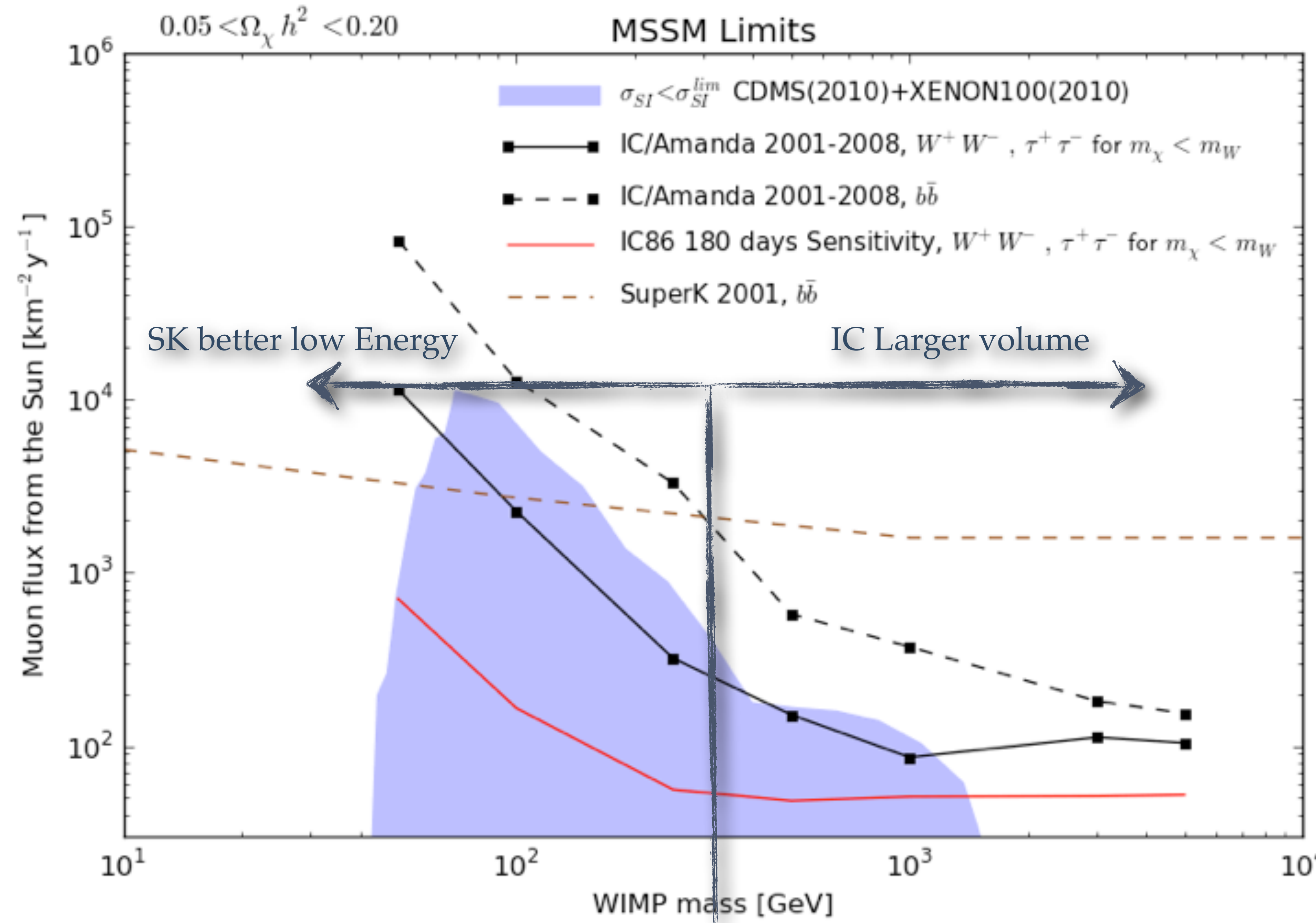
Indirect Dark Matter Search





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

The IceCube Collaboration, corresponding author: O. Engdegård



Transients

Data sample: IC40

- GRBs, SN
- Flaring sources
- Periodic sources

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

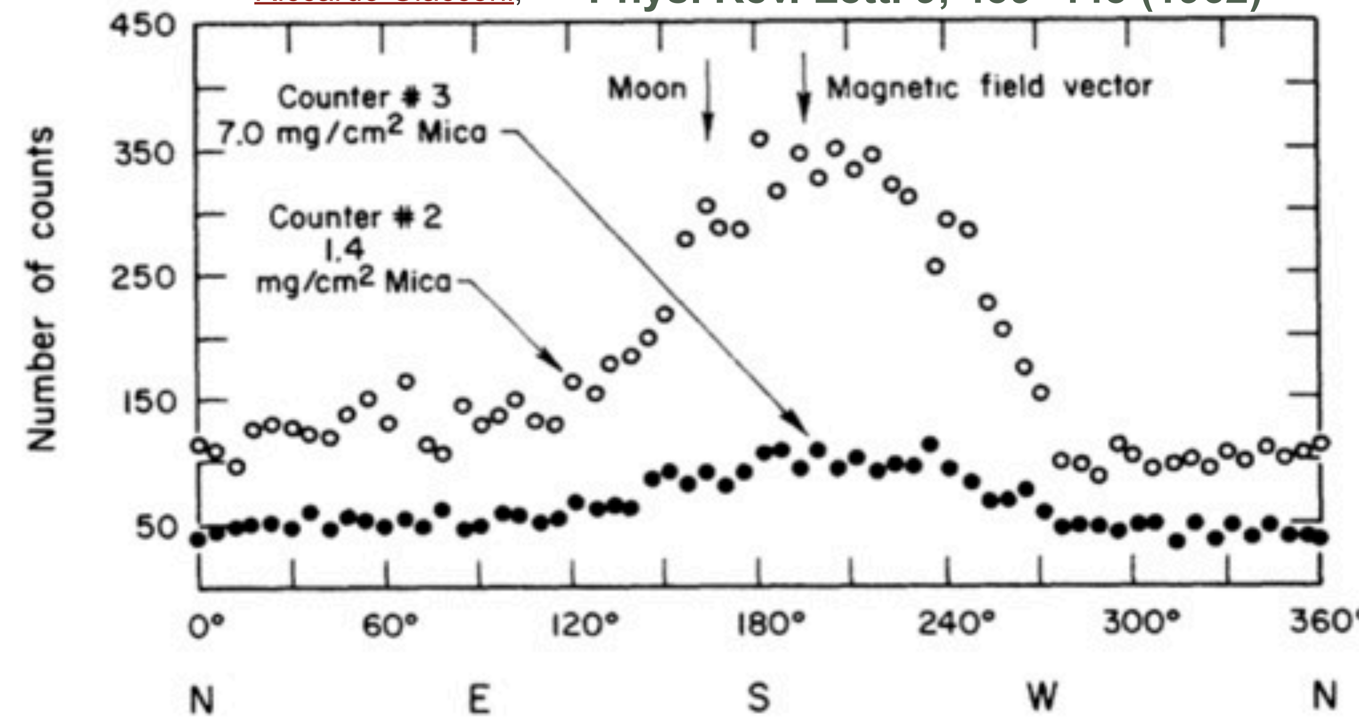
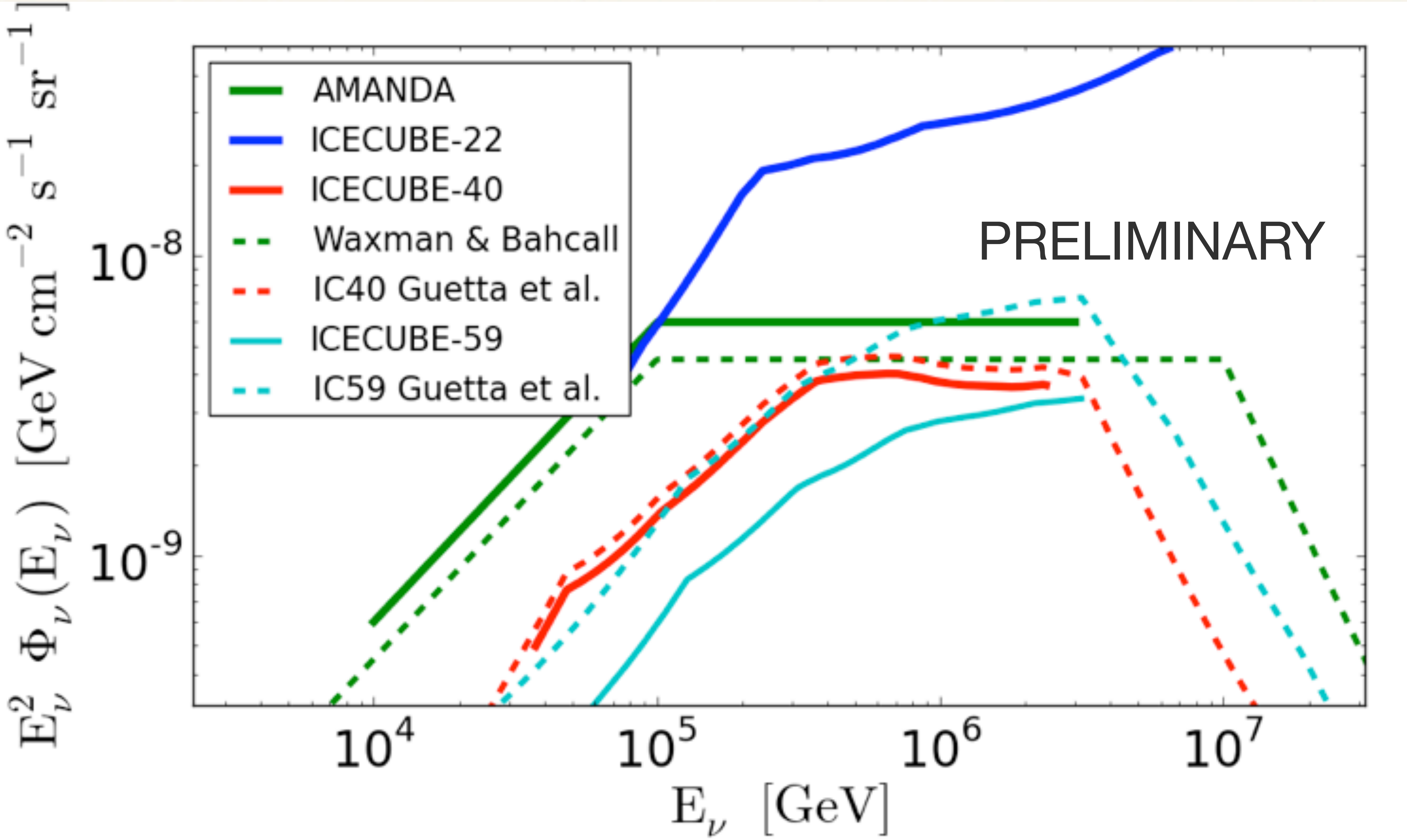


FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.

Gamma-Ray-Bursts

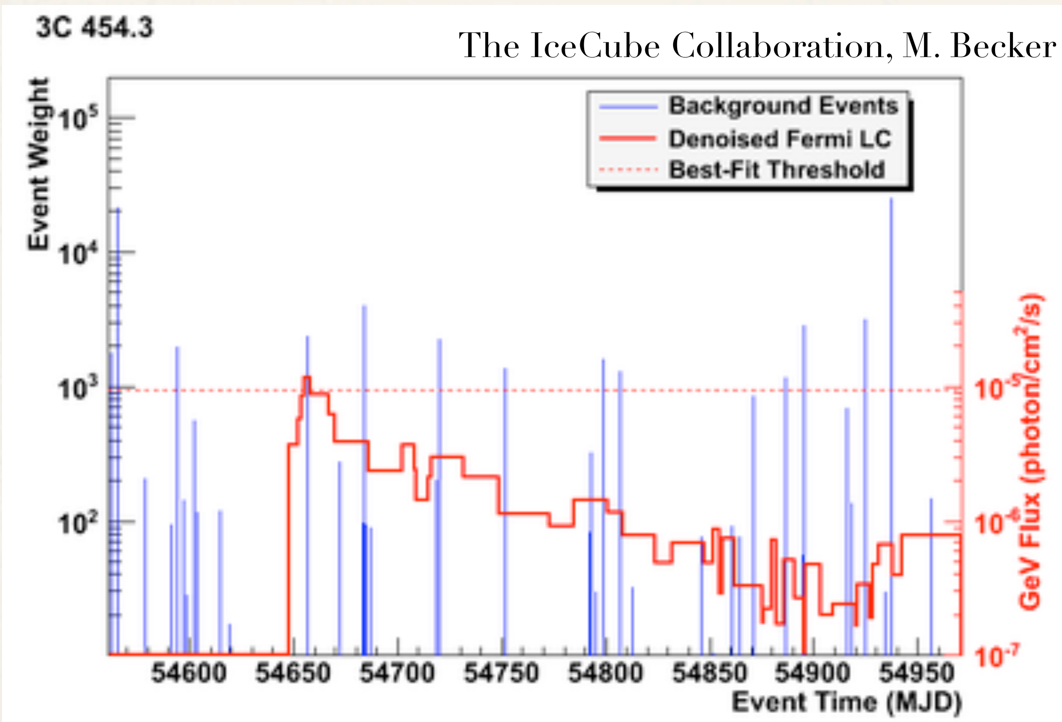
Data sample: IC22, IC40, IC59

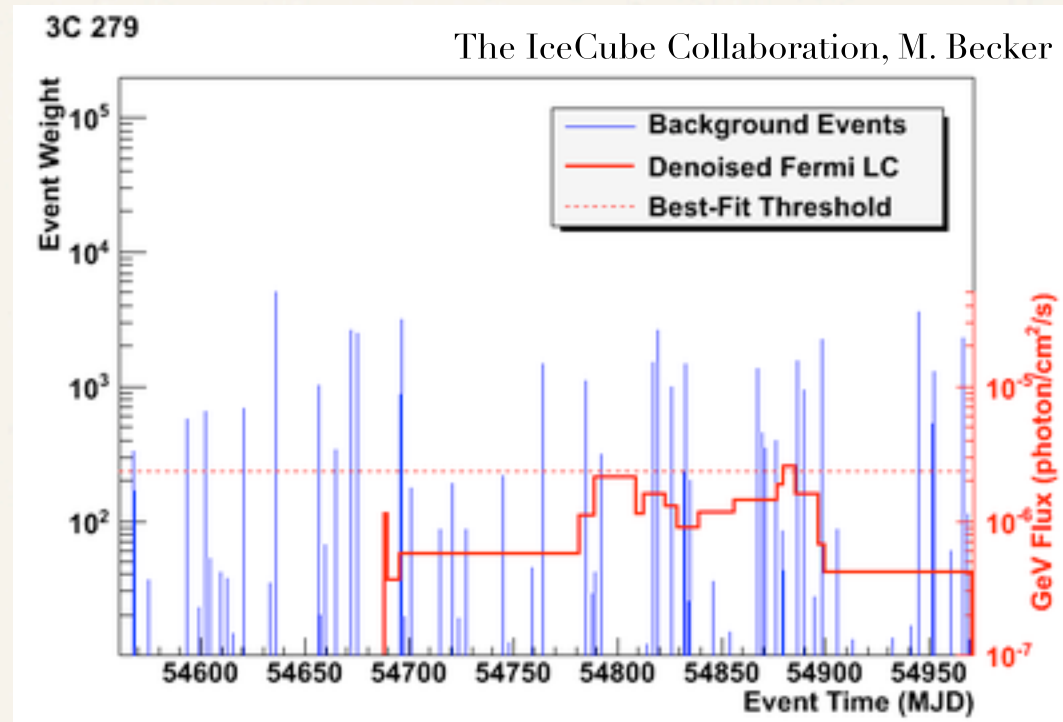


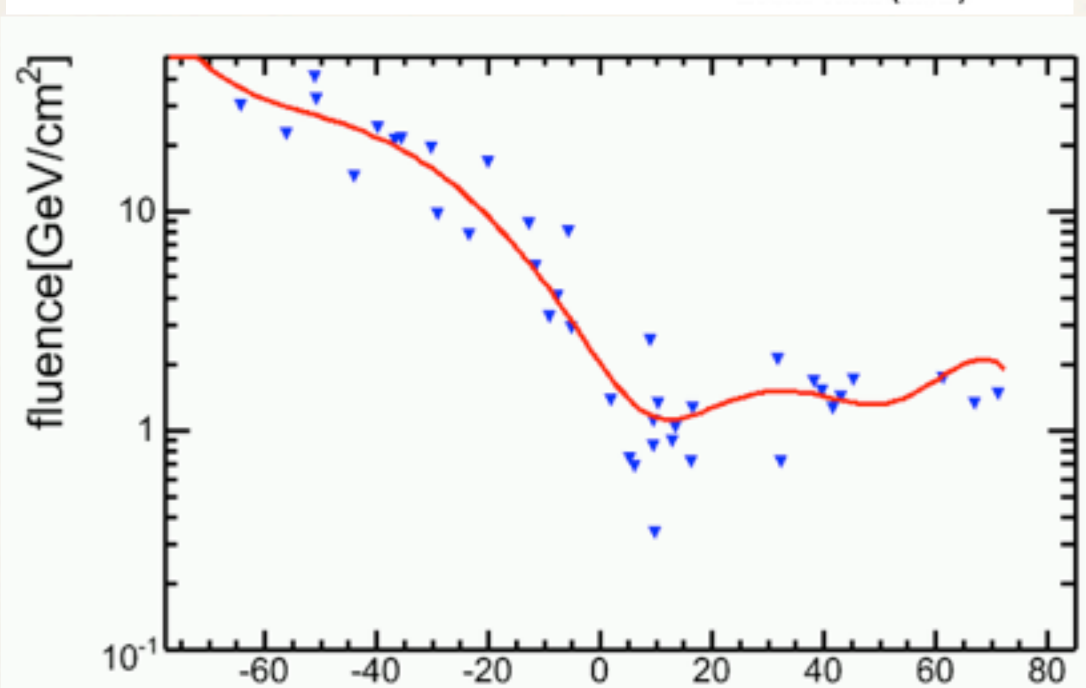
The IceCube Collaboration, corresponding author: P. Redl

Blazars Flares

Data sample: IC40







The IceCube Collaboration, J. Bazo Alba

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

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

The IceCube Collaboration, L. Koepke

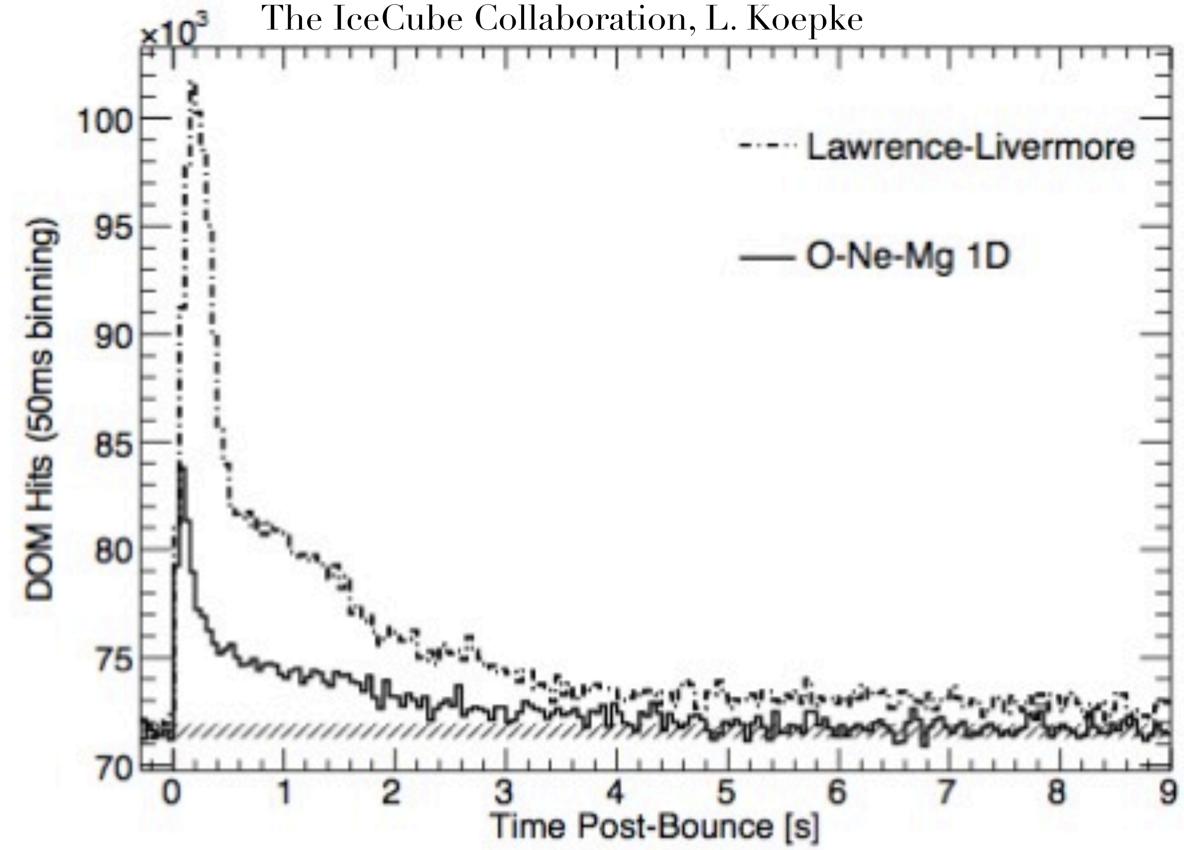
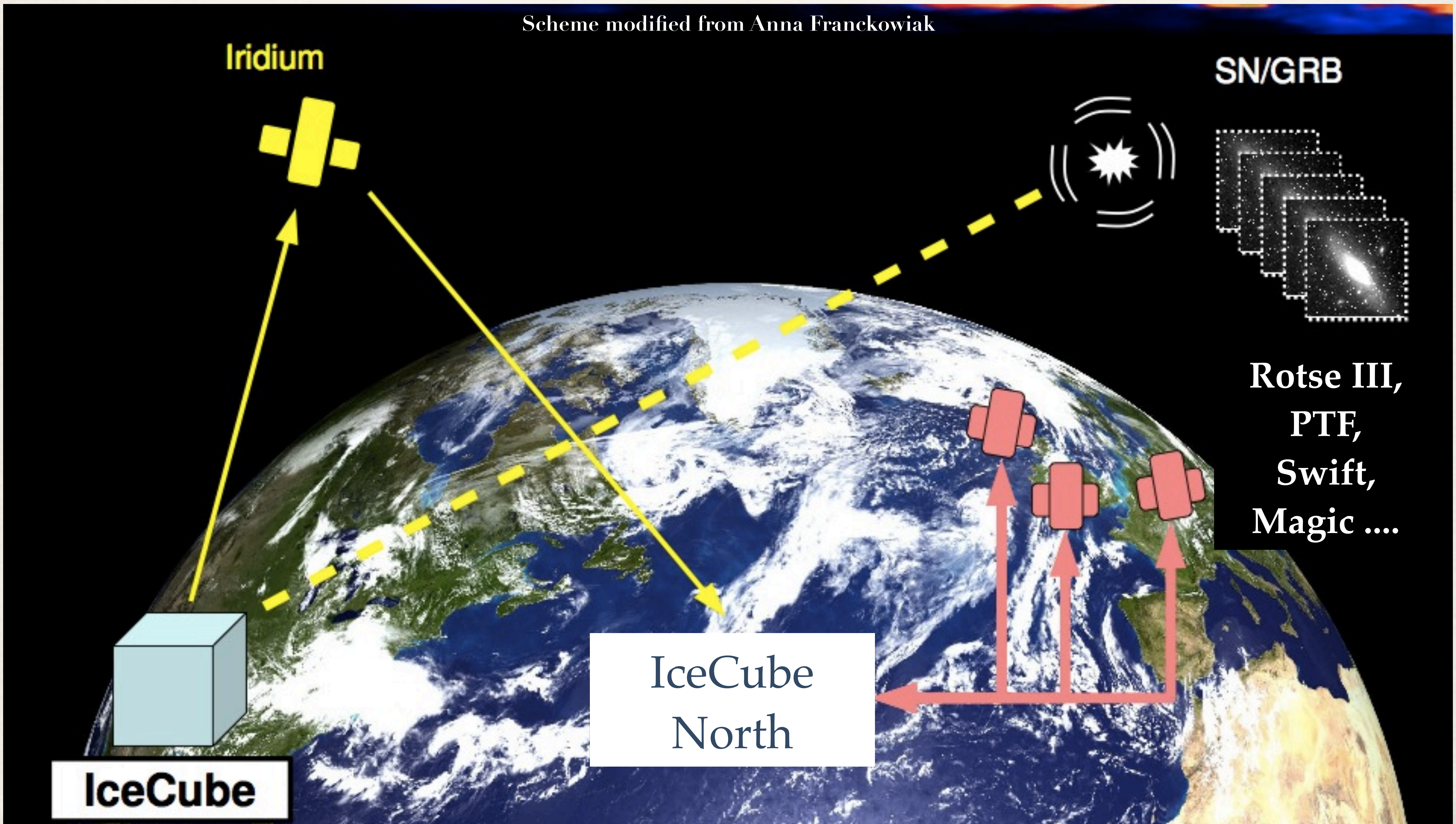


Fig. 10. Expected rate distribution at 10 kpc distance for the Lawrence-Livermore model (dashed line) and O-Ne-Mg model by Hüdepohl et al. (2010) with the full set of neutrino opacities (solid line). The 1σ-band corresponding to measured detector noise (hatched area) has a width of about ± 330 counts.

On-line alerts



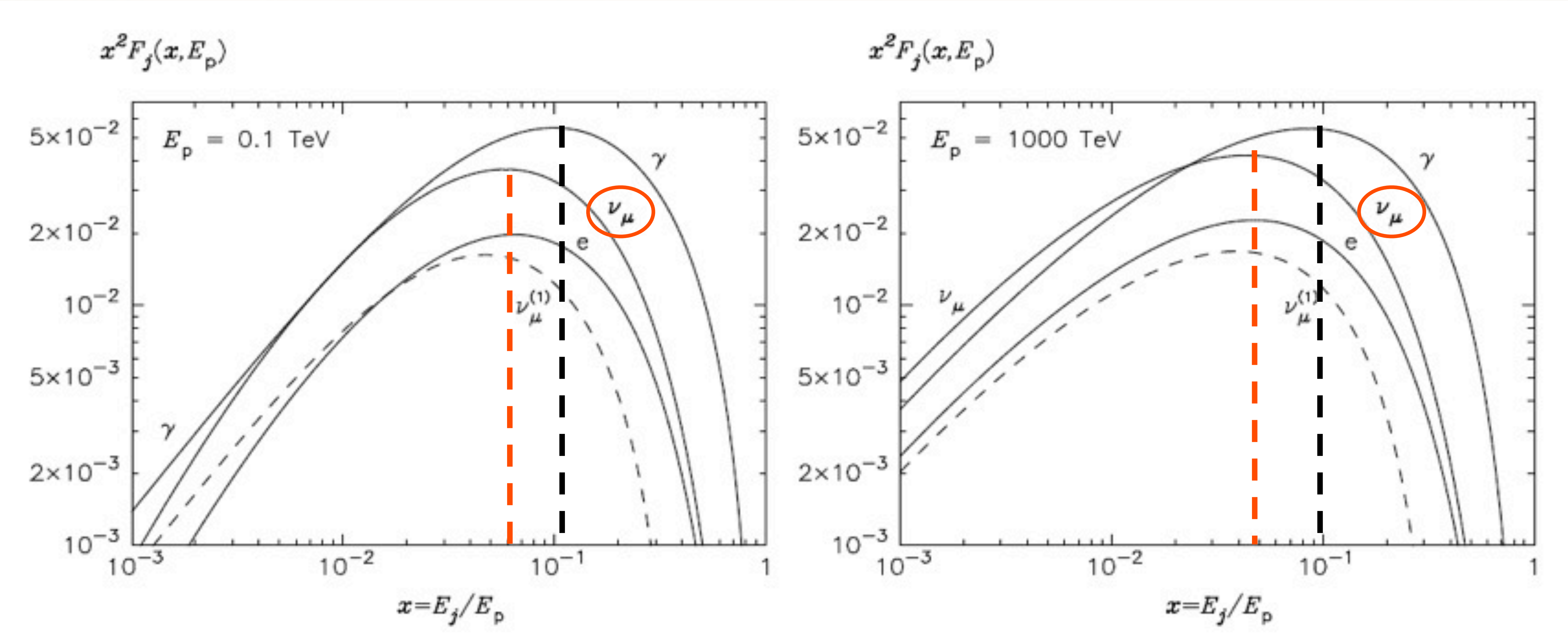
Conclusions

- Cosmic ray physics: a modern puzzle, IceCube role of fundamental importance
  - First models rejected, upper bound crossed with 1/2 of the detector
  - Sensitivity scales faster then volume
- Indirect Dark Matter Searches: scan of the same parameter space region of then most sensitive direct detection experiments
- Supernovae Core Collapse: IceCube is the most precise experiment for neutrino light curves
- On-line programs: collaboration with astrophysical missions of great importance for the IceCube science

backup

Cosmic Rays - Neutrinos - TeV Gamma Rays

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



Ep:Eγ:Eν = 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/]

Atmospheric neutrino spectrum

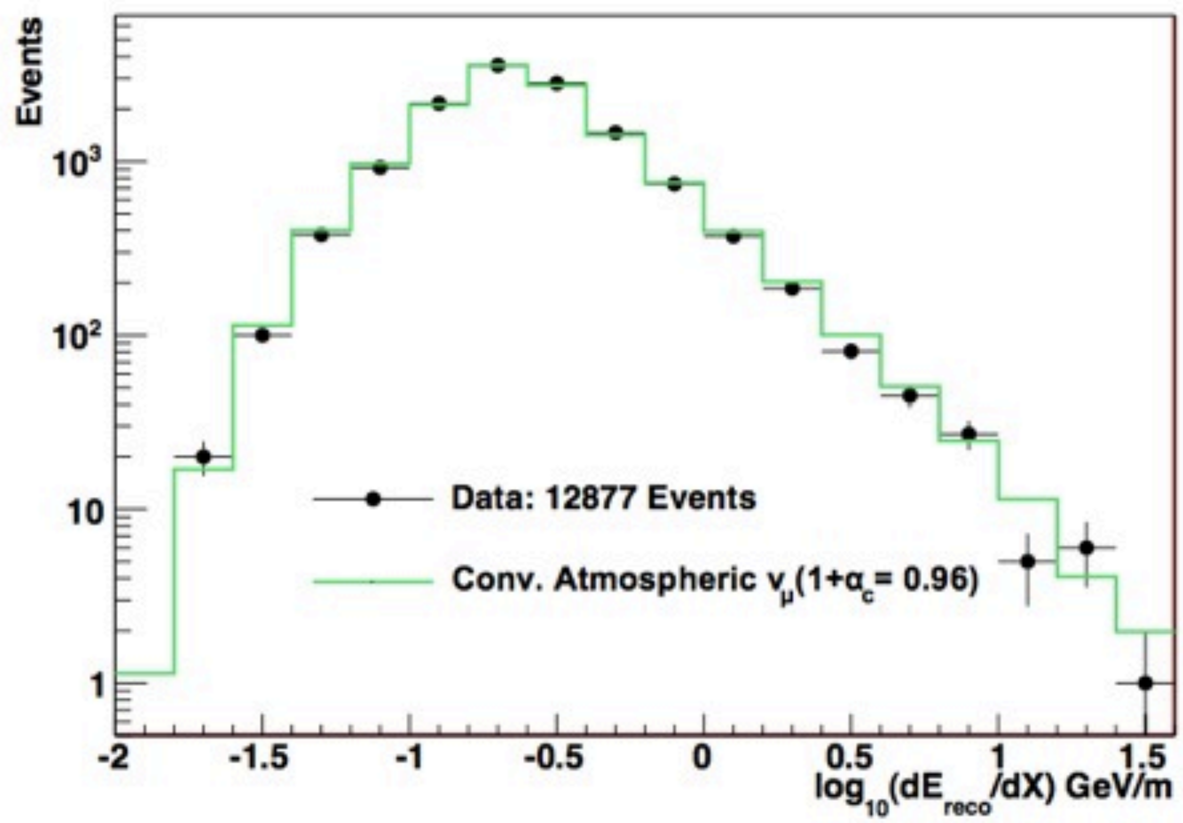


FIG. 8. The fitted muon energy loss distribution of the final event sample is shown. The best fit to the data (black, shown with 1σ error bars) consists only of conventional atmospheric ν_μ, and no evidence is found for a prompt atmospheric ν_μ flux or an astrophysical E^{-2} ν_μ flux.

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)

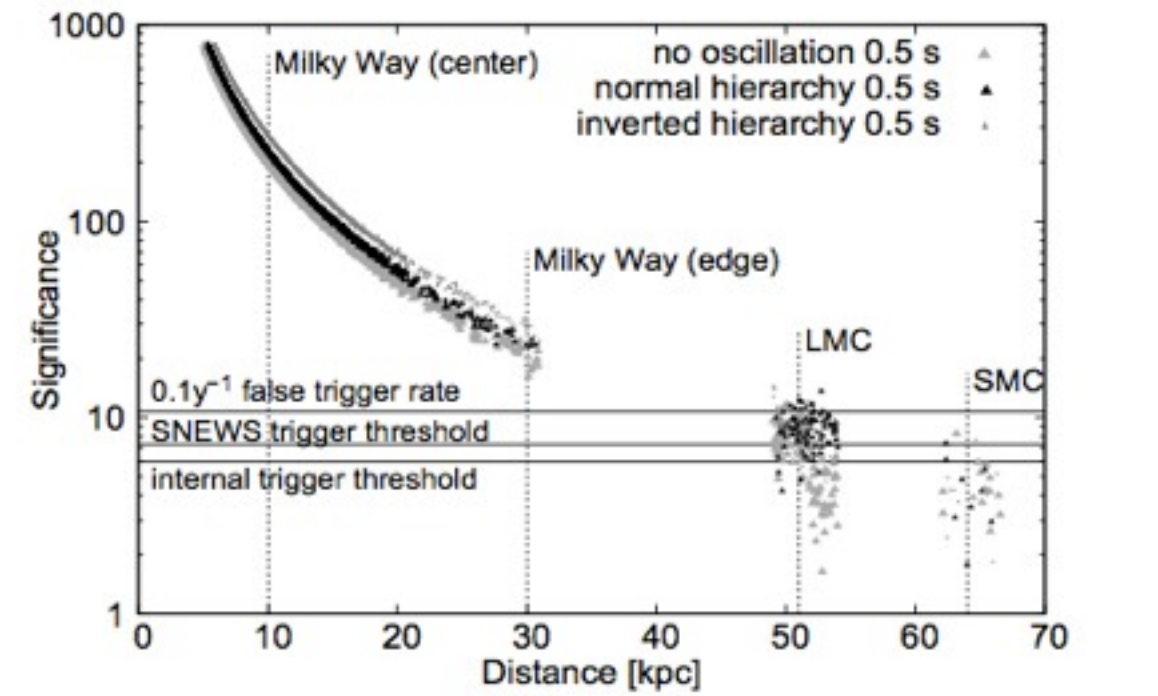


Fig. 12. Significance versus distance assuming the Lawrence-Livermore model. The significances are increased by neutrino oscillations in the star by typically 15 % in case of a normal hierarchy (Scenario A) and 40 % in case of an inverted hierarchy (Scenario B). The Magellanic Clouds as well as center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