Neutrino Astronomy with IceCube

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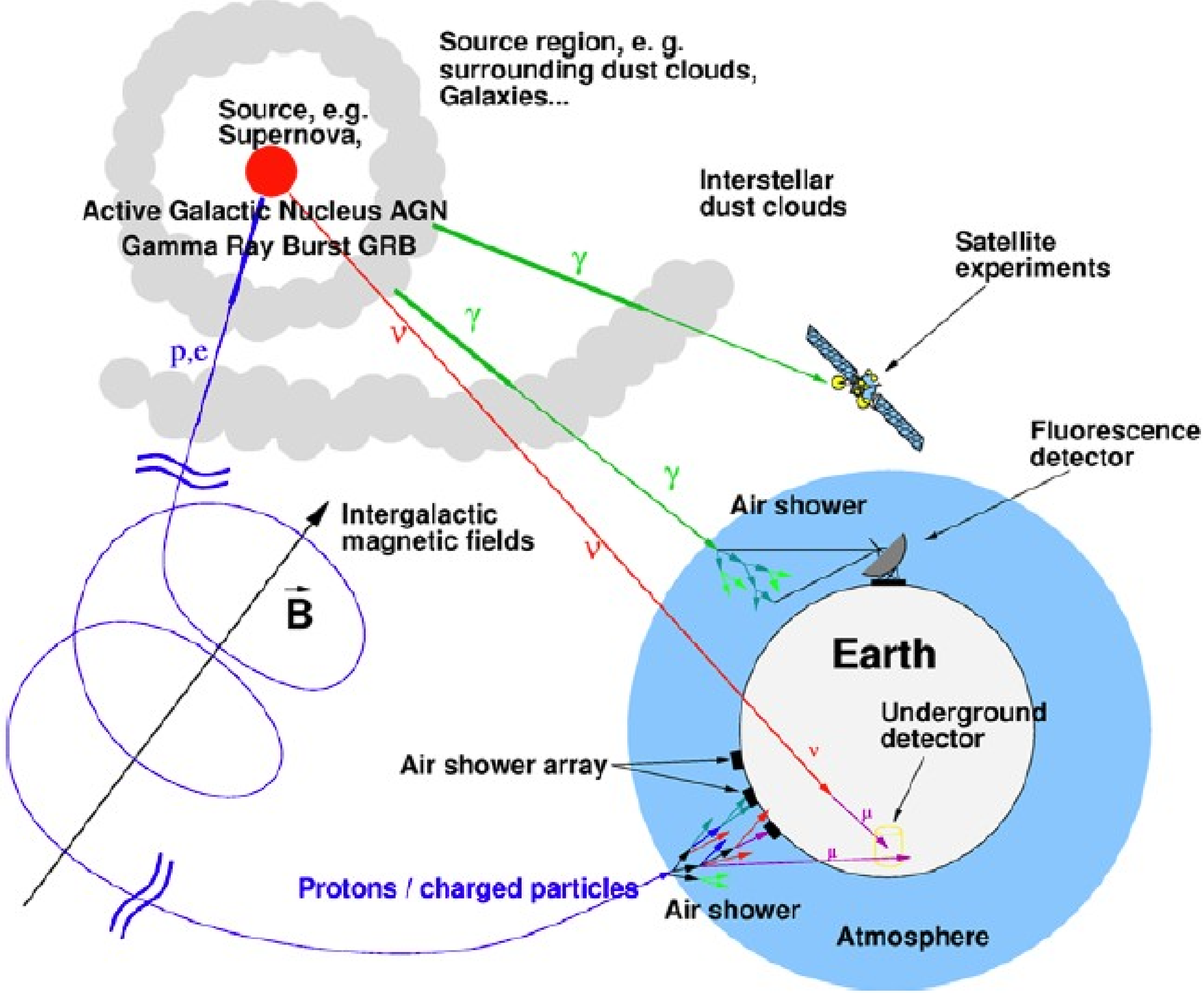
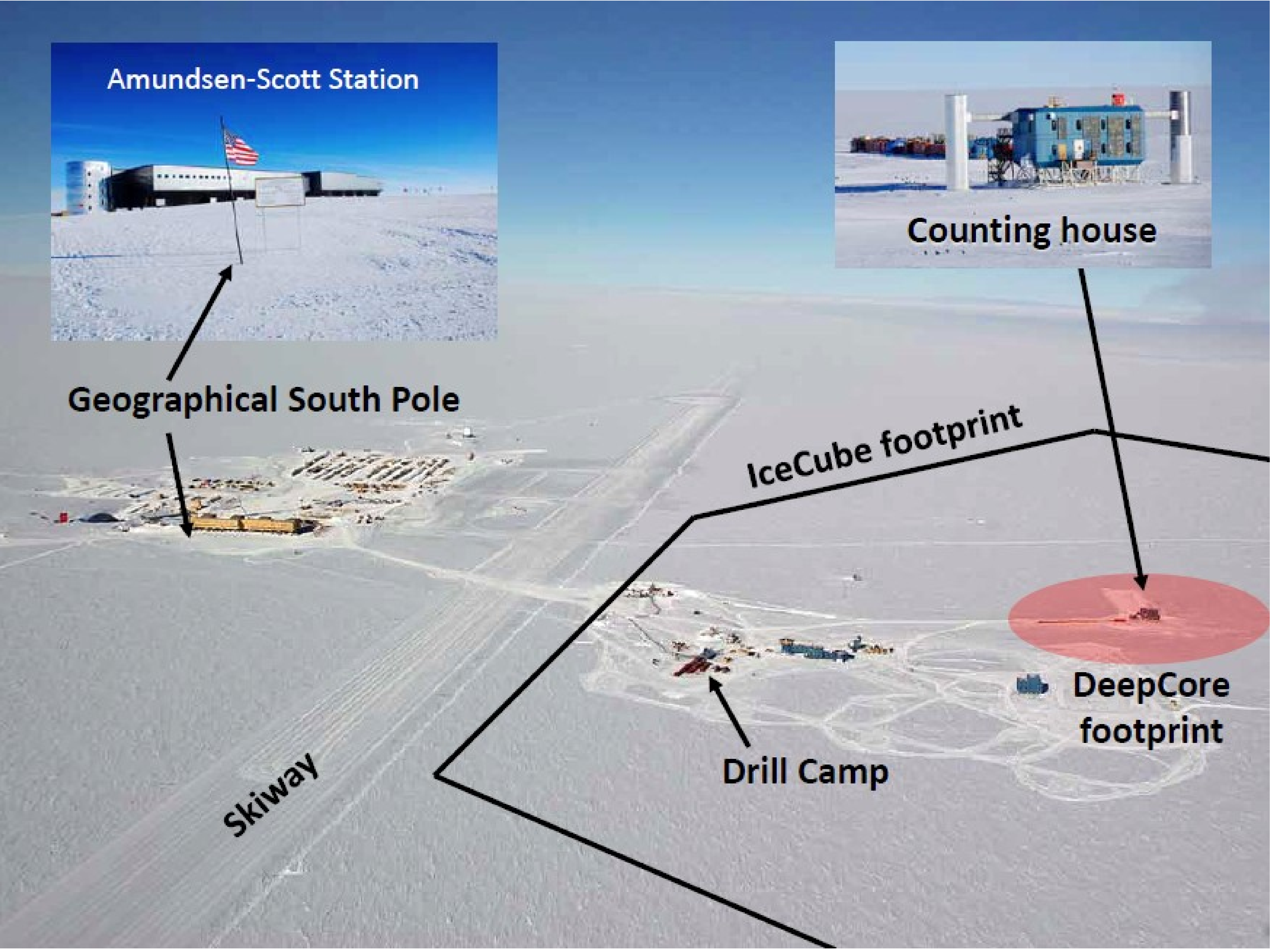
For the IceCube Collaboration

Point Sources

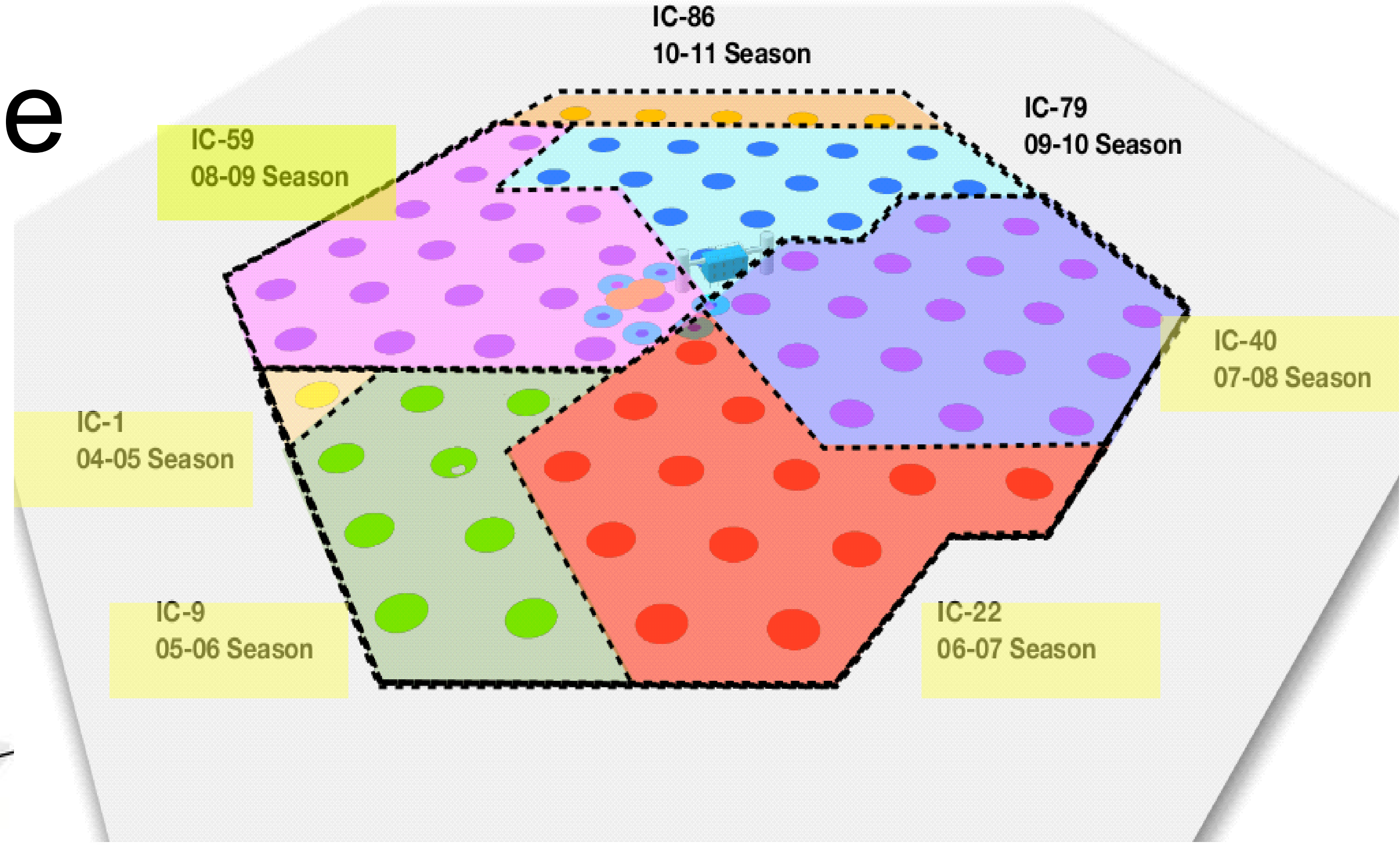
Can we see it with neutrinos???

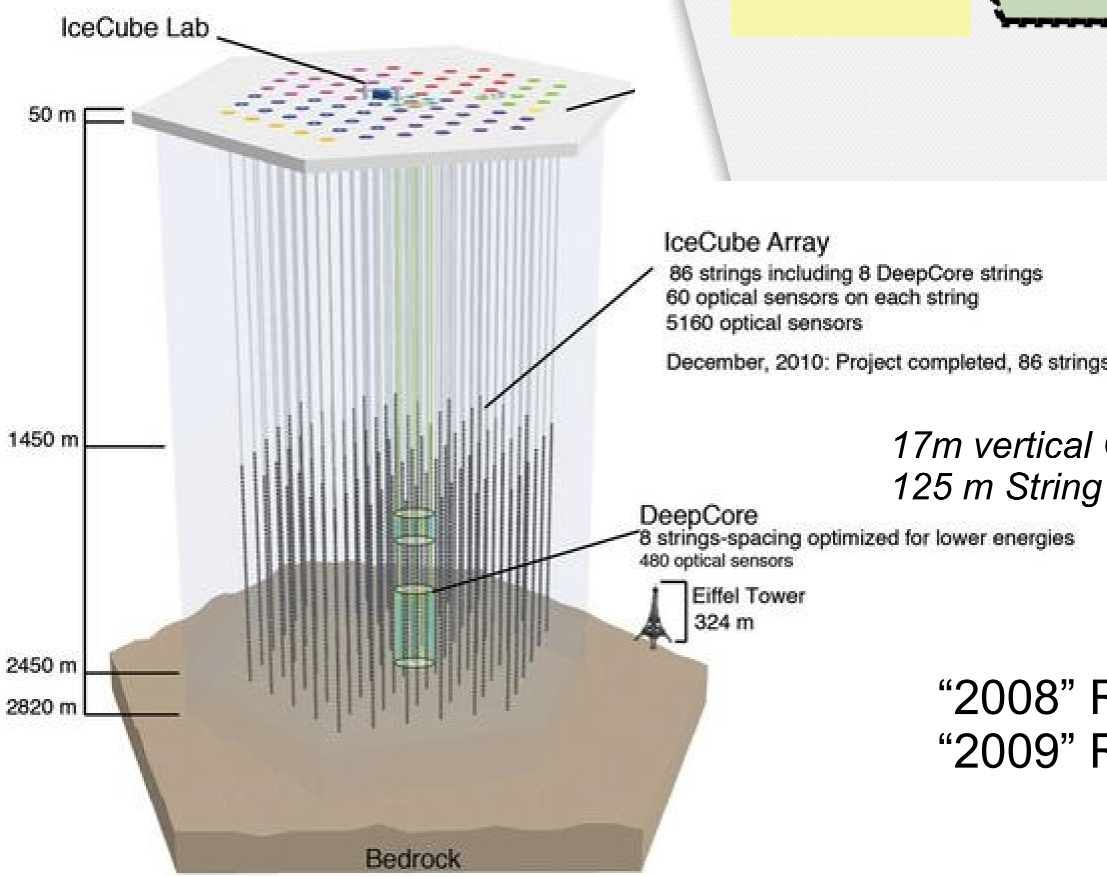
Neutrino Astronomy




Amundsen-Scott Station
Counting house
Geographical South Pole
IceCube footprint
DeepCore footprint
Drill Camp
Skiway

The IceCube Detector



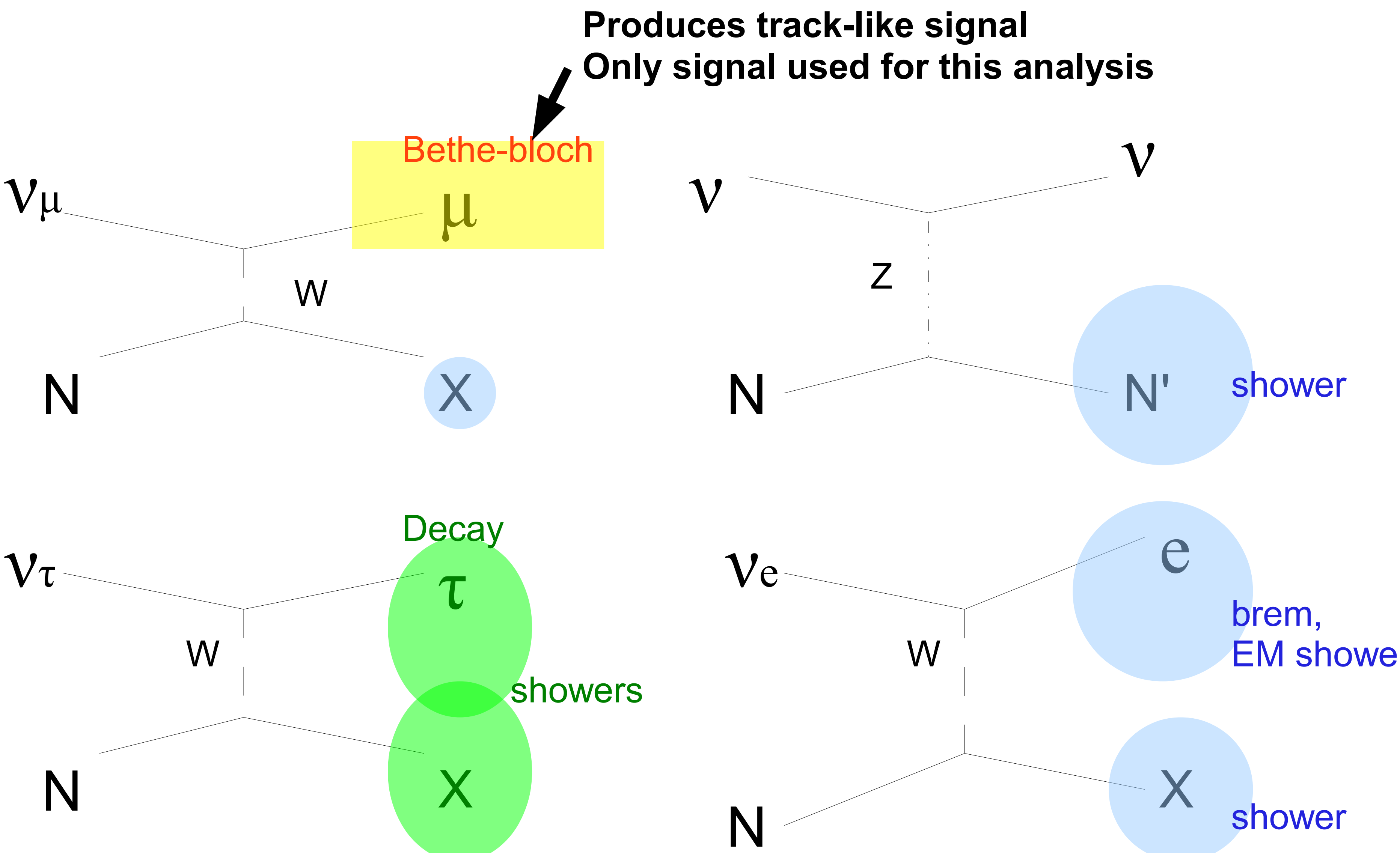


17m vertical Optical Module spacing
125 m String spacing

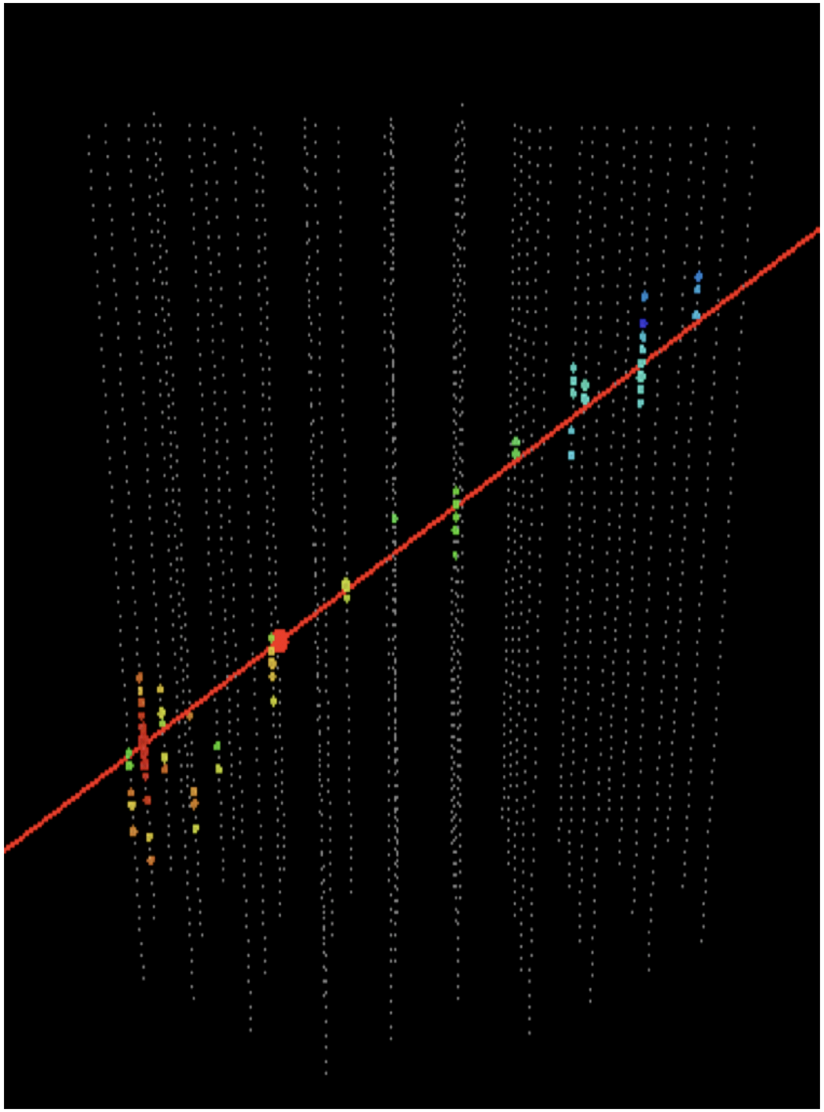
“2008” Runs 40-strings 376 days livetime
“2009” Runs 59-strings 348 days livetime

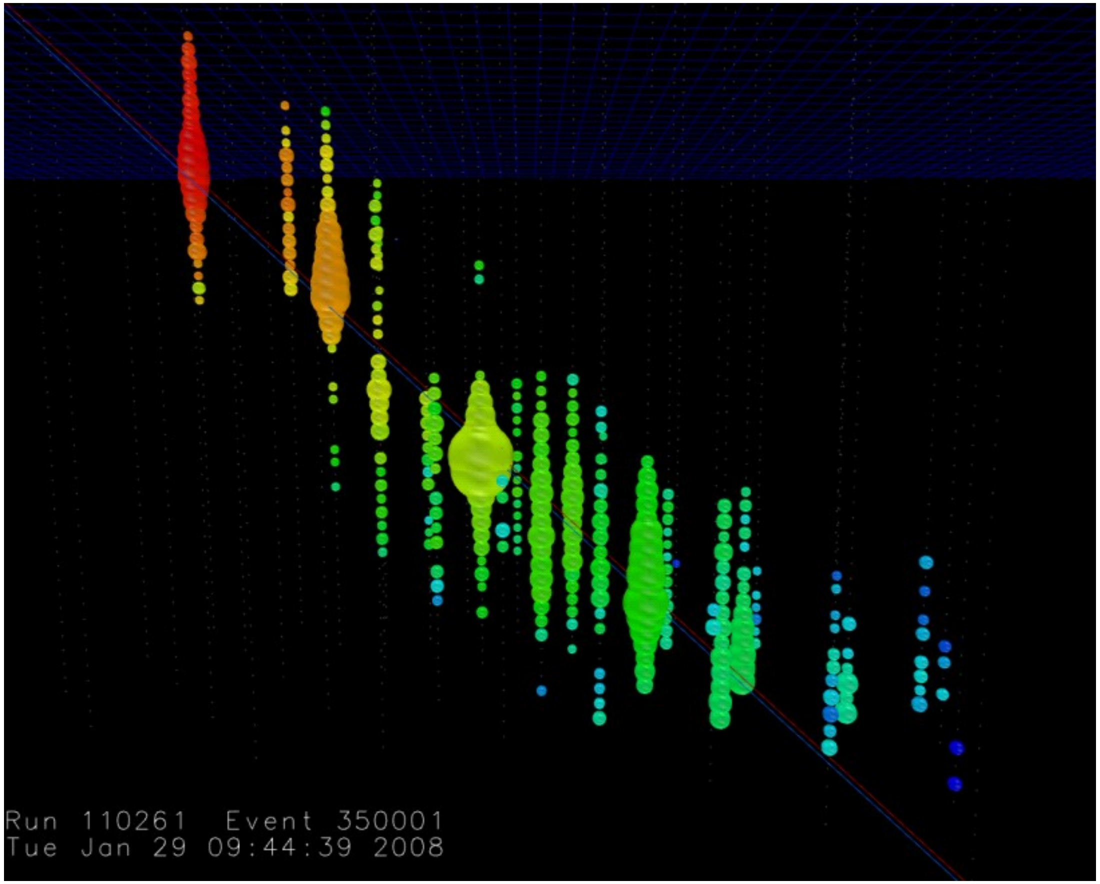
Different Signals

> ~0.1Tev Deep Inelastic Scattering

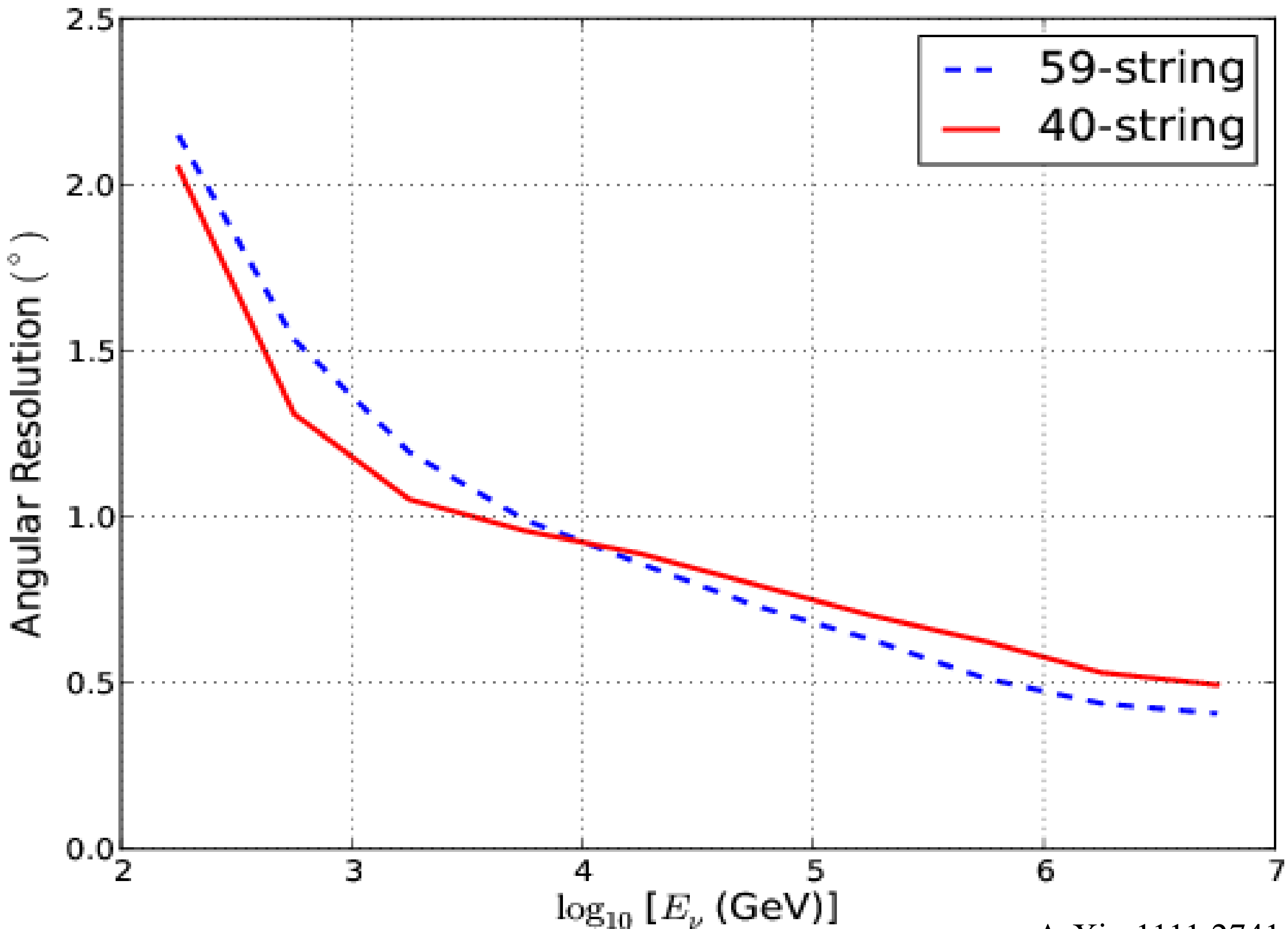


Muon-Induced Tracks





How well can we point?

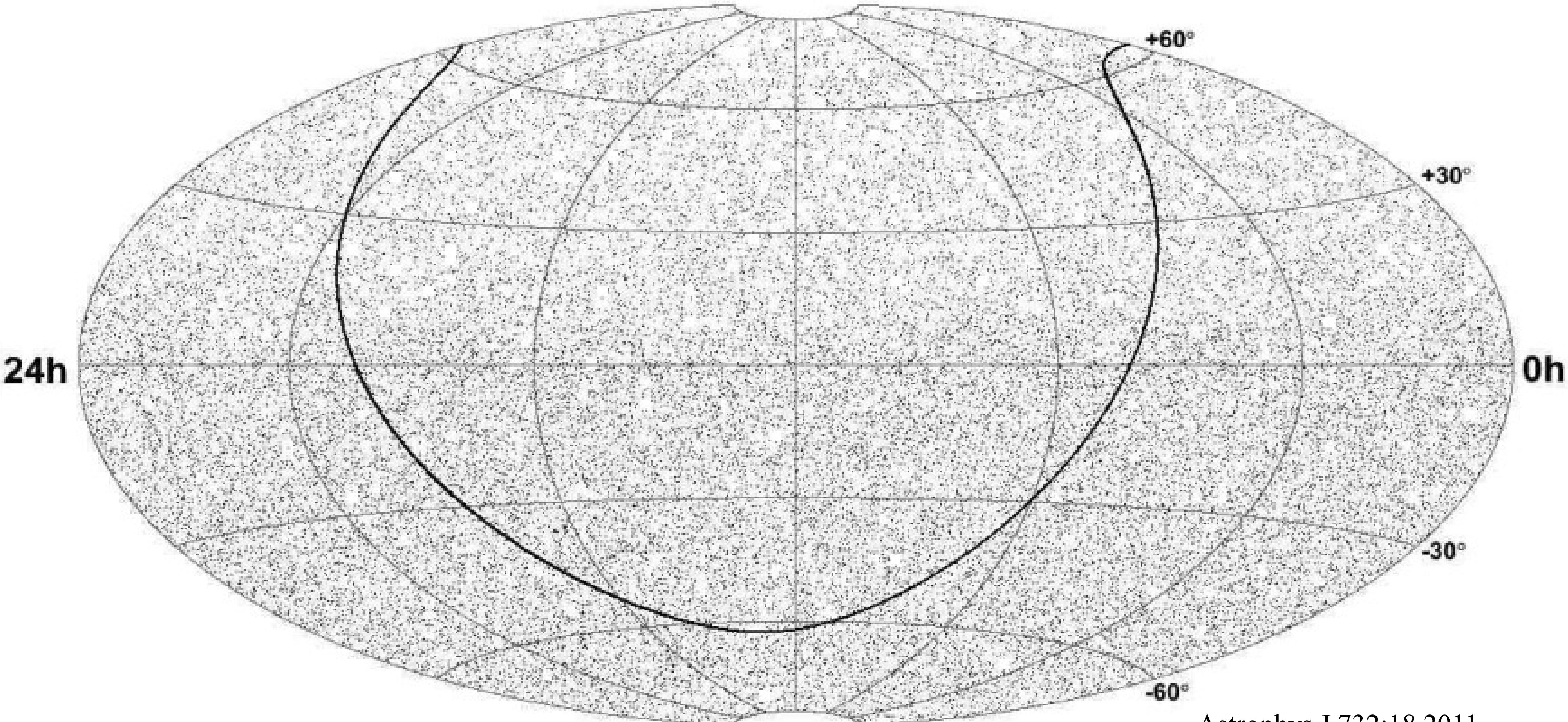


ArXiv:1111.2741

This is for final level “Good Events” only....

*59-string data had looser cuts at low energy; worse resolution but > 3 times in number of event

Do you see a point source?

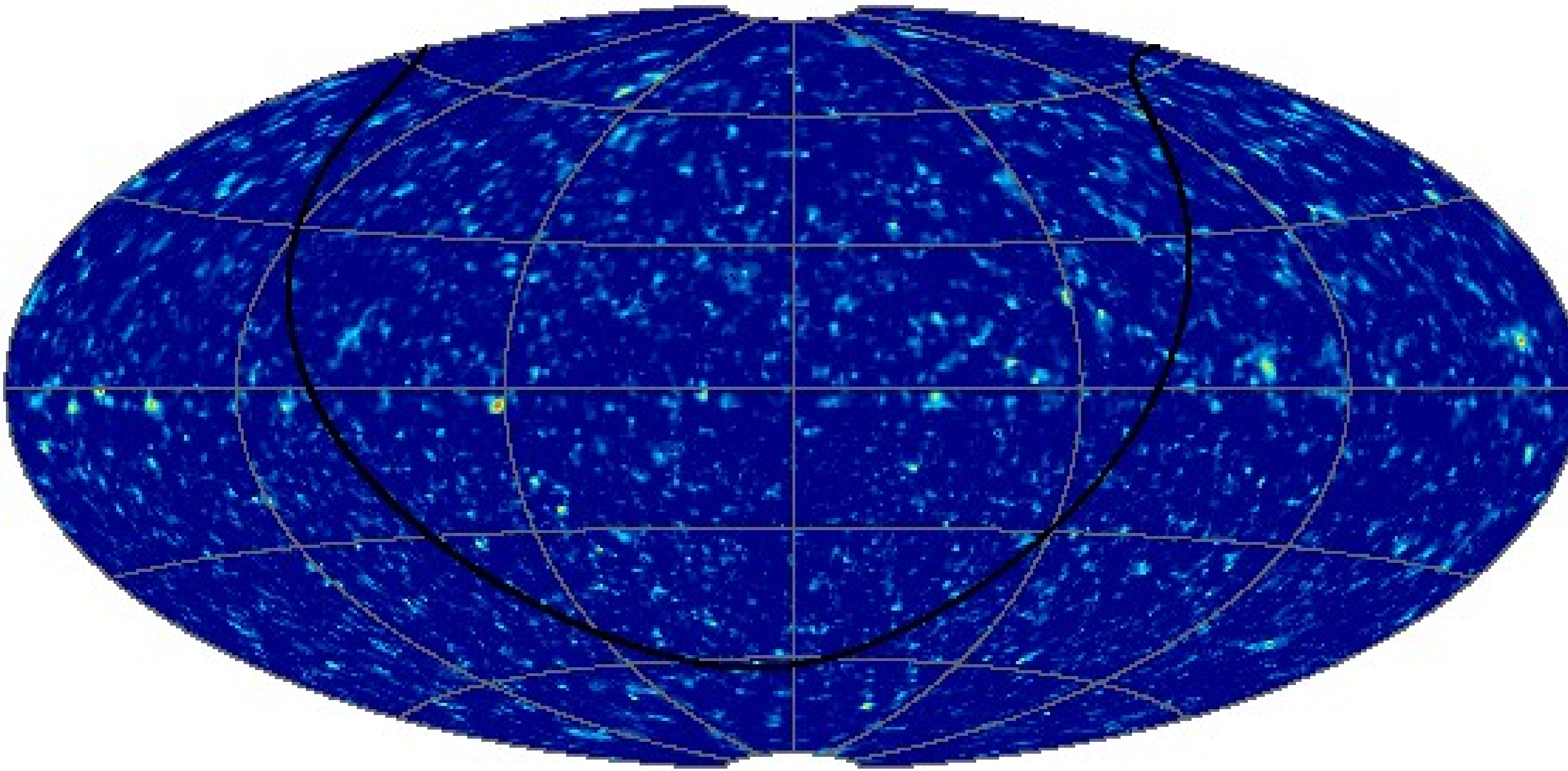


Astrophys.J.732:18,2011

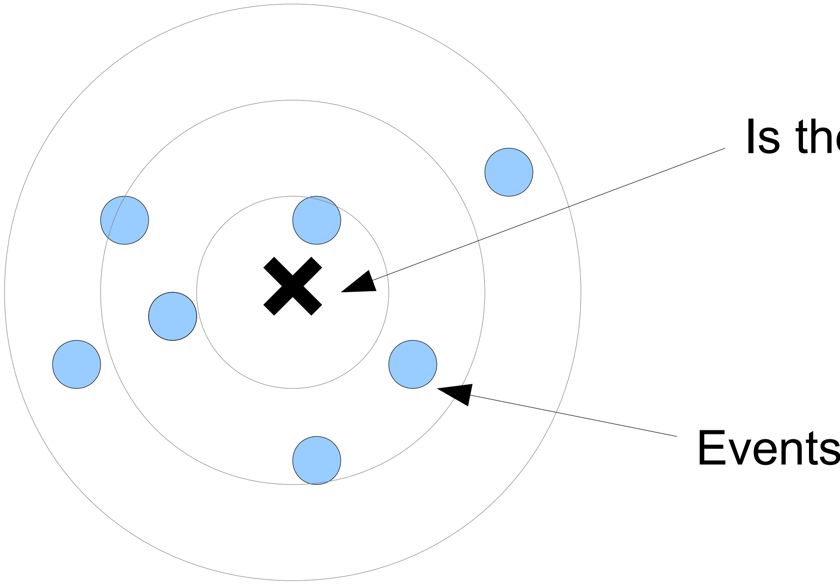
“2008” year 40-strings data
~37,000 events

(59-string “2009” data has ~108,000 events... too many to plot!)

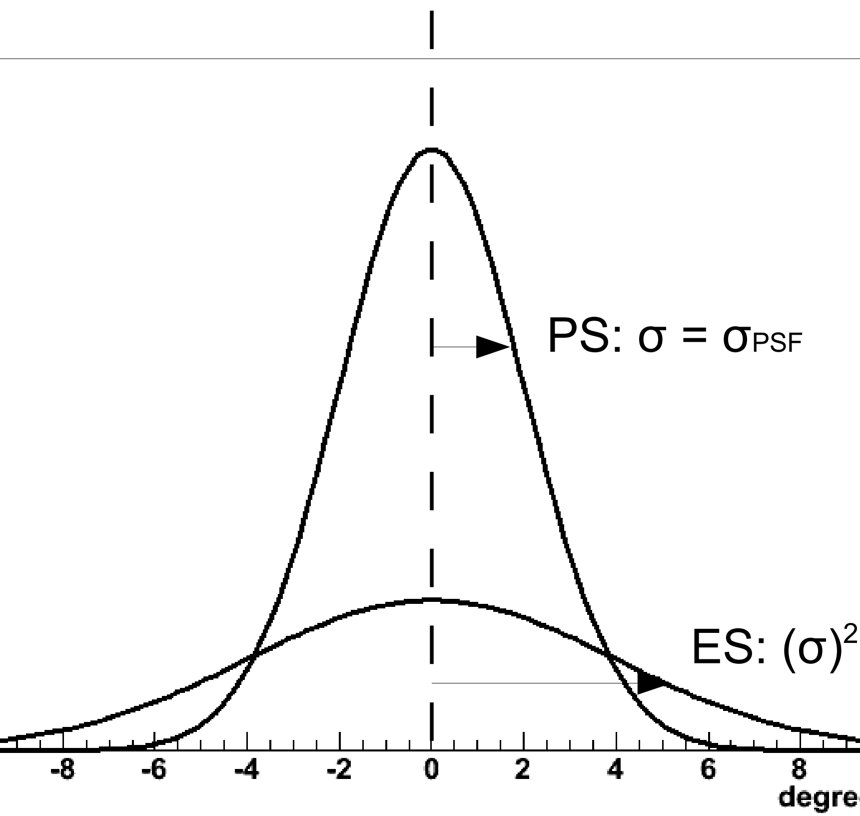
Likelihood Map



The Likelihood (1)



The closer you are, the more likely it came from a source there



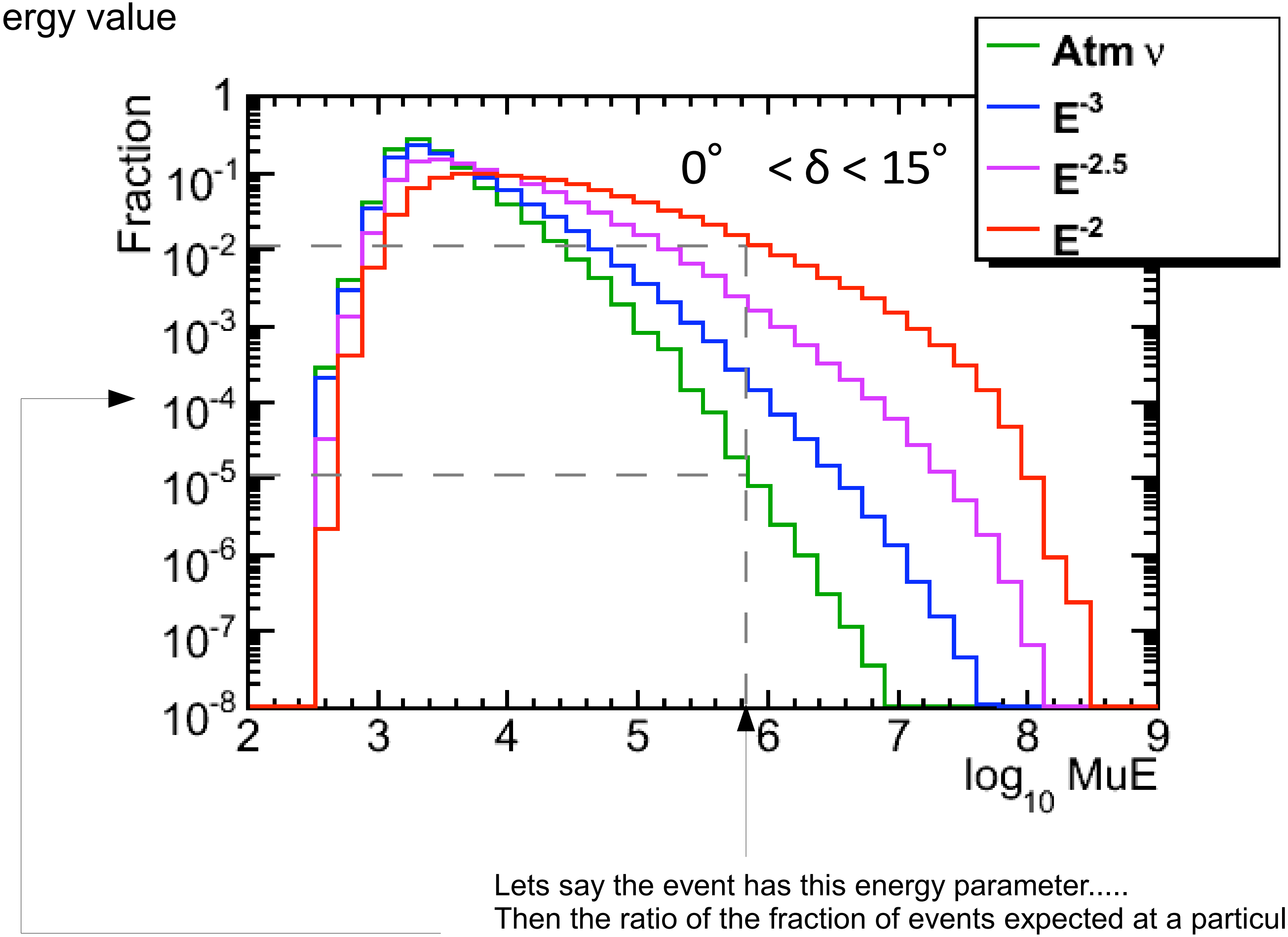
Point Source (PS) = source extension is point like, PSF is the only "smearing"

Extended Source (ES) = source extension of 3° added to PSF

Spacial PDF $$\mathcal{N}(\vec{x}_i) = \frac{1}{2\pi\sigma_i^2} e^{-\frac{|\vec{x}_i - \vec{x}_s|^2}{2\sigma_i^2}}$$

The Likelihood (2)

- Each spectrum hypothesis predicts a different distribution (PDF) of the energy of events
- The likelihood uses the ratio of a signal PDF and a background PDF evaluated at this energy value



Lets say the event has this energy parameter.....
Then the ratio of the fraction of events expected at a particular spectrum over the measured background spectrum becomes the energy PDF

Put it all together...

Astropart.Phys.29:299-305,2008

Event-by-event probability density function

$$P_i(\vec{x}_i, E_i, \gamma, n_s) = \frac{n_s}{n_{tot}} S(\vec{x}_i, E_i, \gamma) + (1 - \frac{n_s}{n_{tot}}) B(\vec{x}_i, E_i)$$

$$S(\vec{x}_i, E_i, \gamma) = \frac{1}{2\pi\sigma_i^2} \exp\left(\frac{-\left|\vec{x}_i - \vec{x}_s\right|^2}{2\sigma_i^2} \right) P_{SigMue}\left(E_i \mid \delta_i, \gamma\right)$$

$$B(\vec{x}_i, E_i) = P_{BckDec}(\vec{x}_i) P_{BckMue}(E_i, \delta_i)$$

Our Likelihood $L(\gamma, n_s) = \prod P_i(\vec{x}_i, E_i, \gamma, n_s)$

Our Likelihood Ratio $R = L(\gamma,\, n_s) \,/\, L(n_s = 0)$

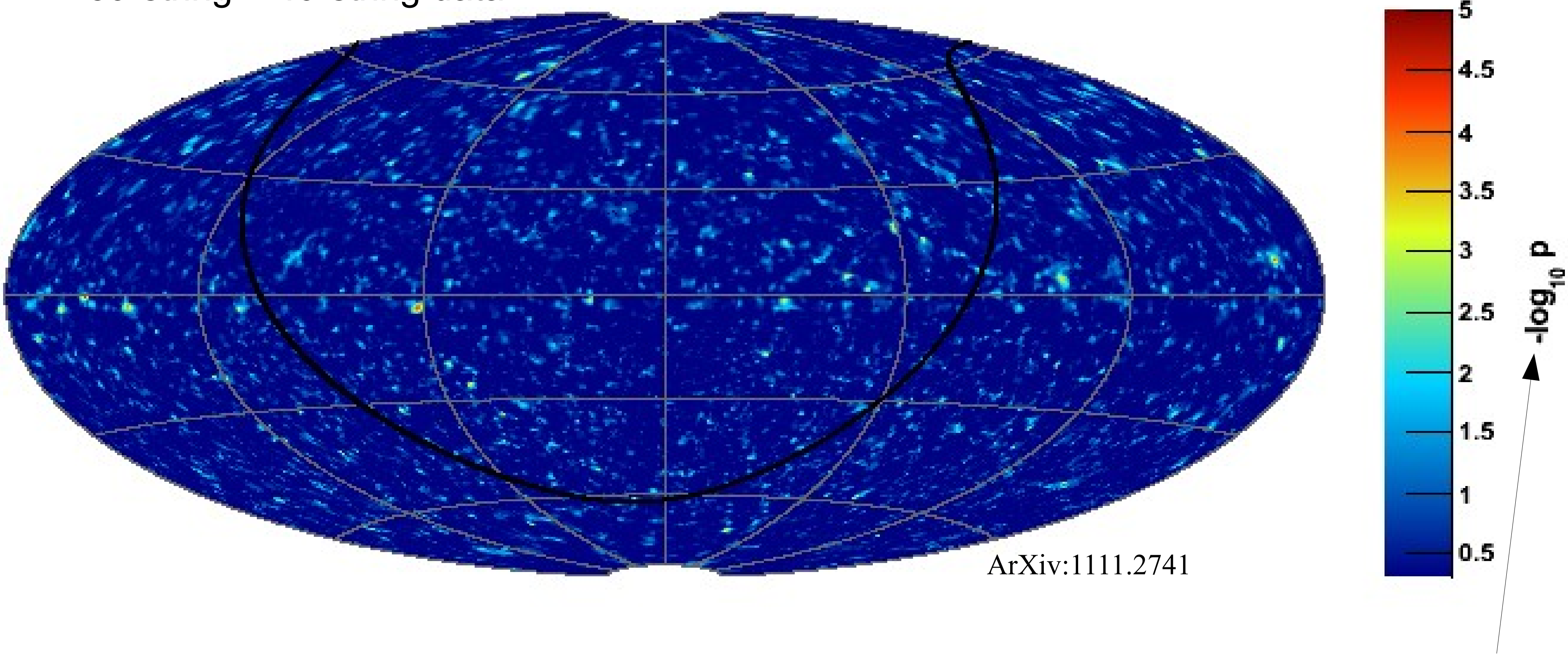
Maximize likelihood ratio at different points in the sky

Maximized Likelihood → P-value

repeat this analysis at different points in the sky, you get a map!

0.1° x 0.1° grid of point source locations tested

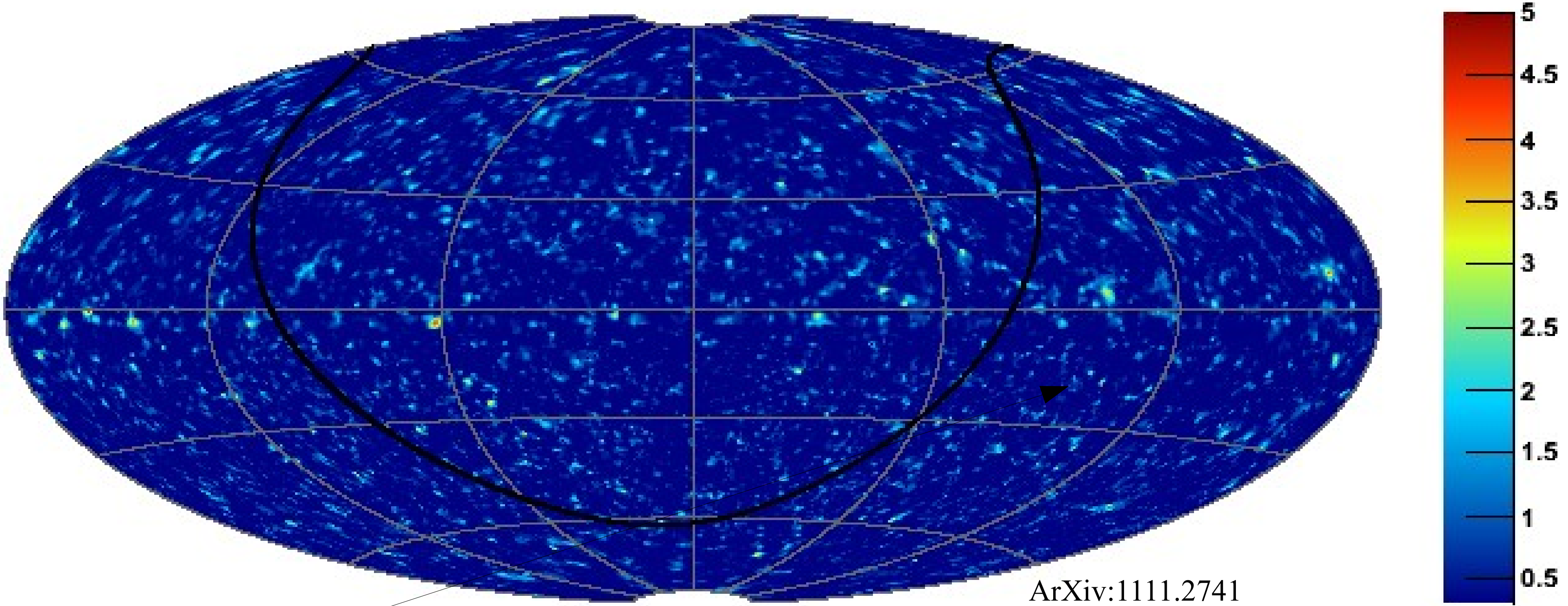
59-string + 40-string data



P-value = how often you get the maximized likelihood by chance

Now lets look for point sources

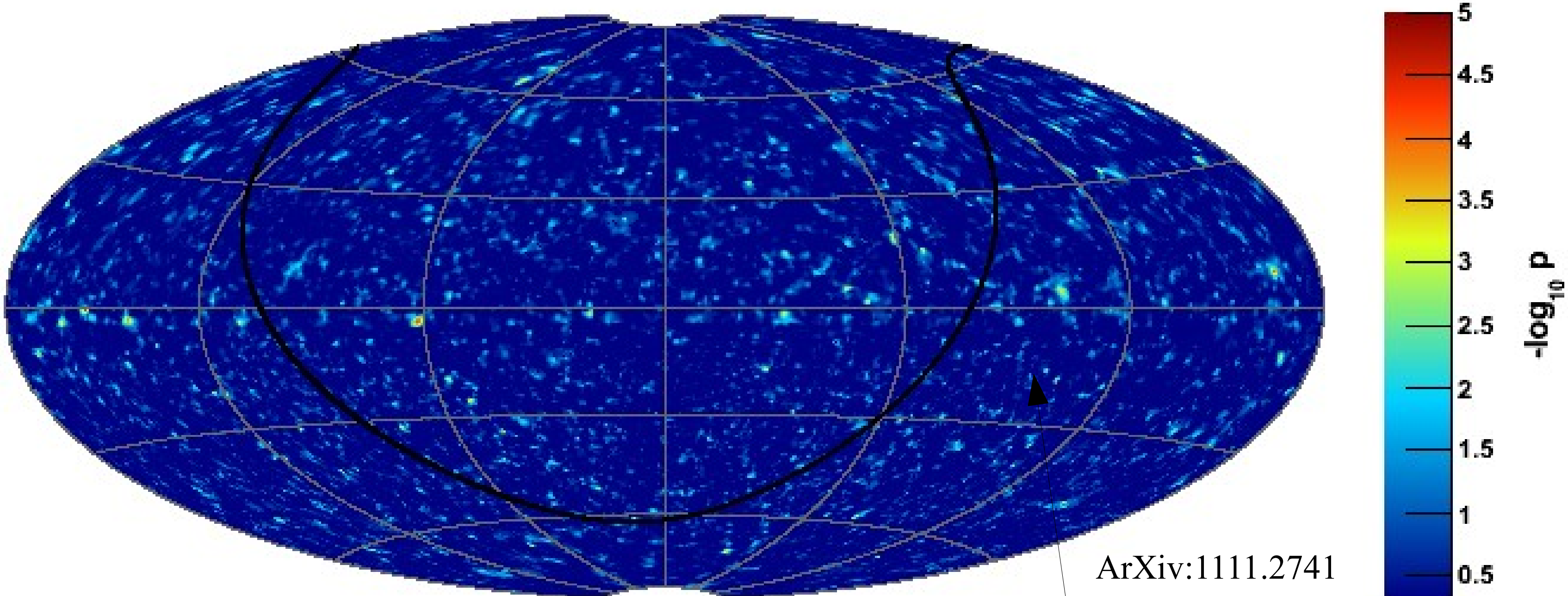
0.1° x 0.1° grid of point source locations tested



Hottest Spot
-log10(p) = 4.65
Ra: 75.45
Dec: -18.15

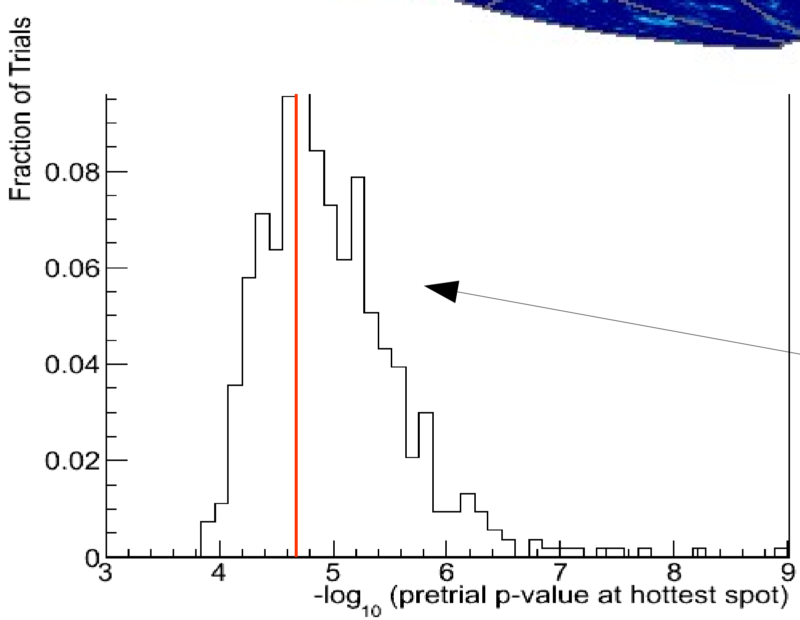
Pre-trial → Post-trial

Take into account the fact that we looked at multiple points in the sky....



ArXiv:1111.2741

hotspot

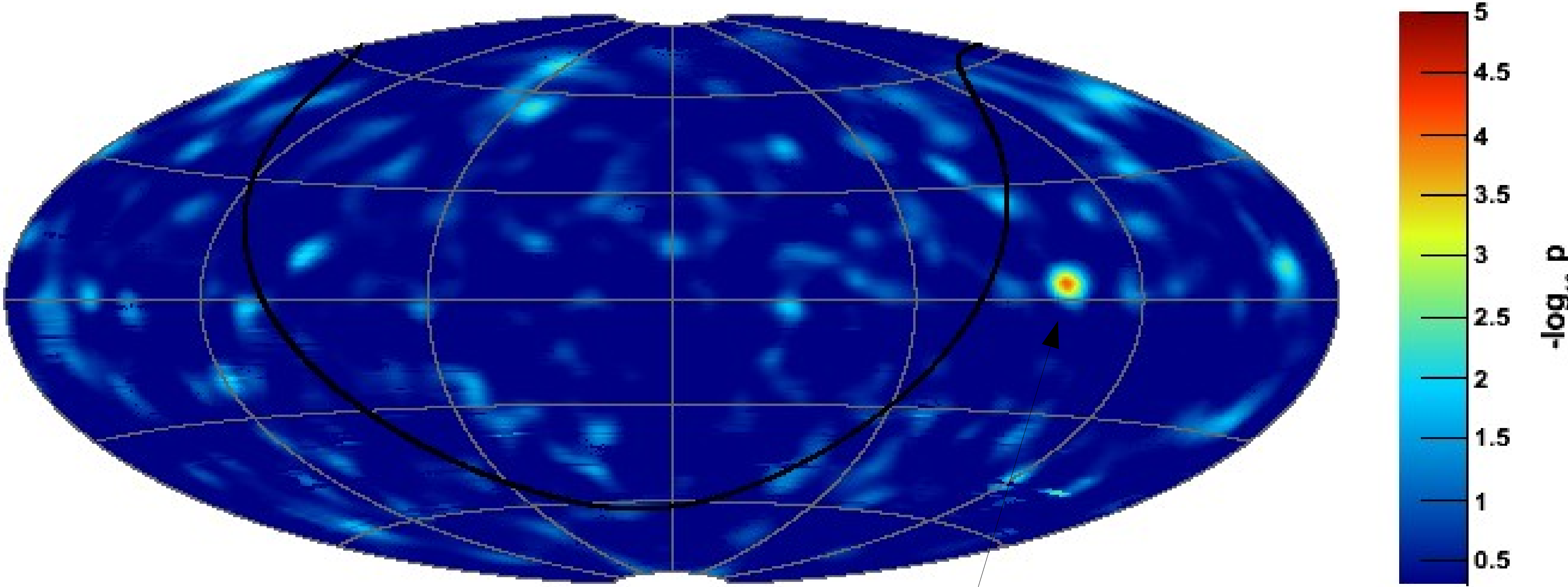


67 out of 100 scrambled maps have higher hottest spot p-value than the unblinded map of real data

Post-trial P-value = 67%

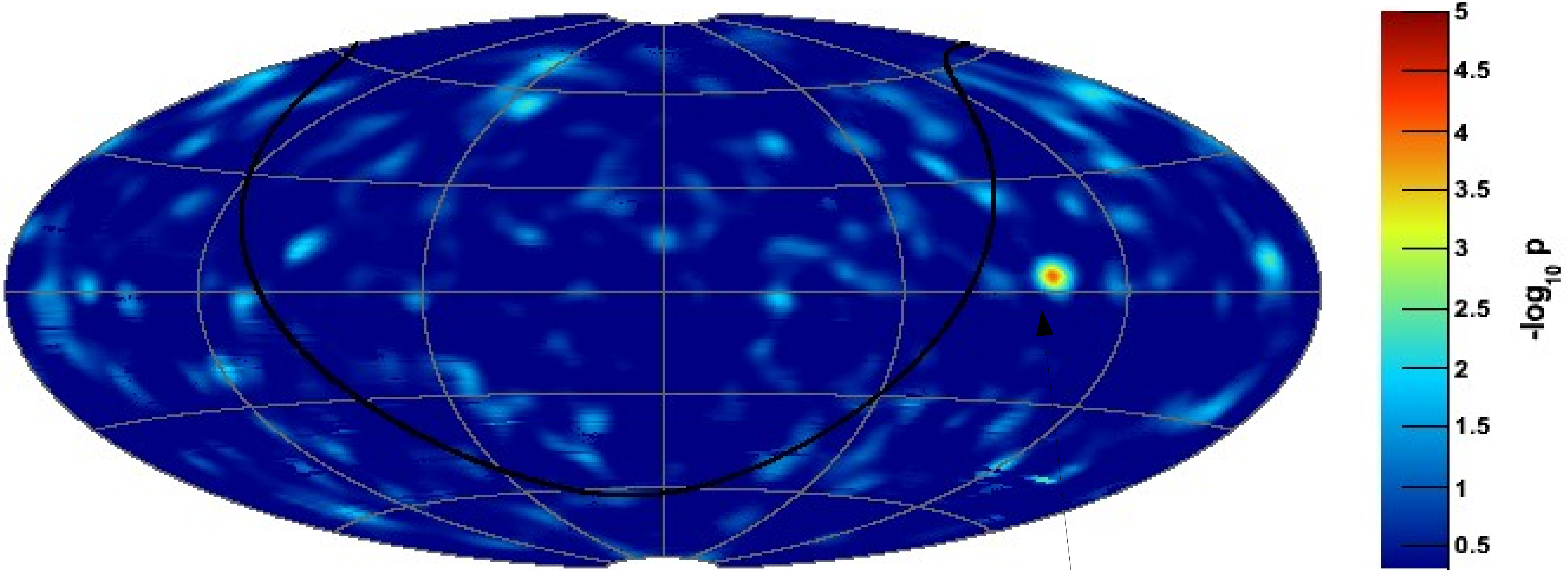
ES (3°)

0.5° x 0.5° grid of point source locations tested

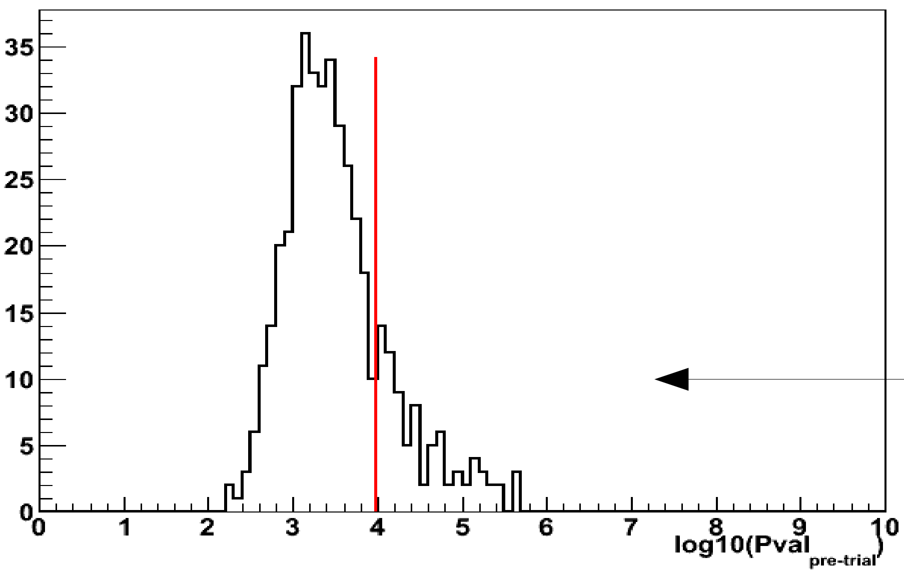


-log10(p) = 3.9790
Ra: 80.75
Dec: 4.25
Ns: 71.73
Γ: 2.45

Pre-trial → Post-trial, 3° map



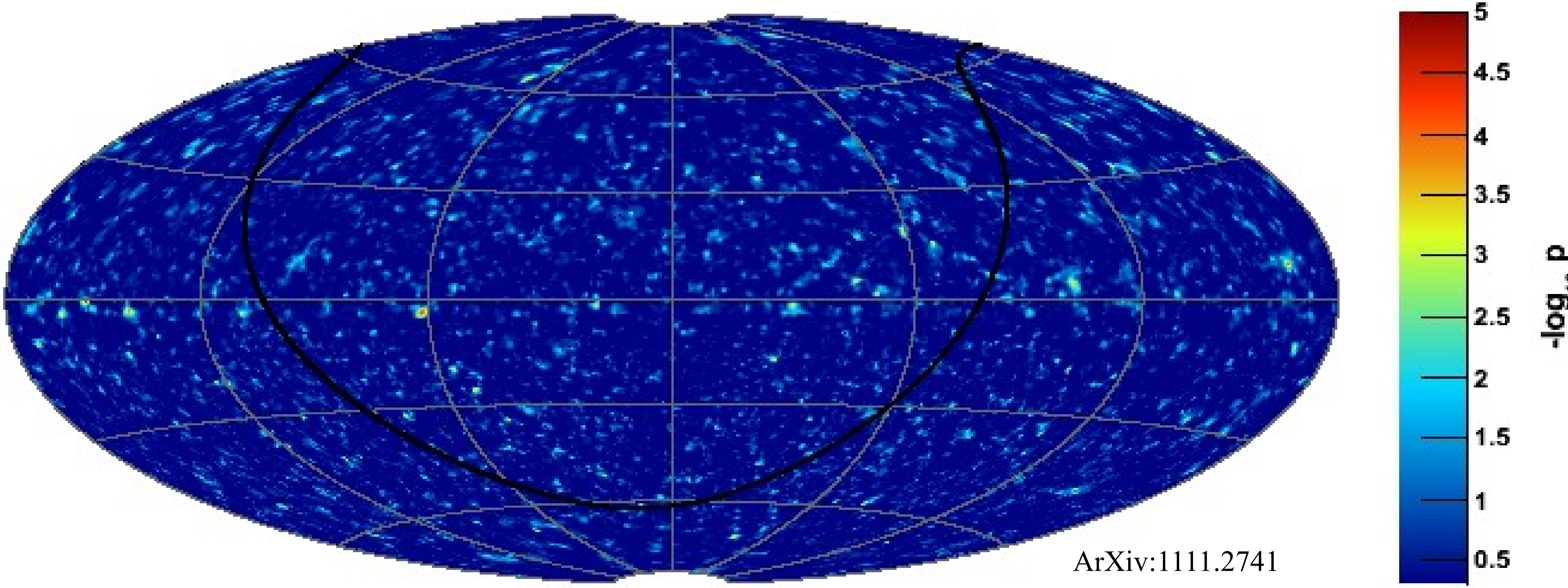
Hot Spot
-log10(p_pretrial) = 3.98
Ra: 80.75
Dec: 4.25



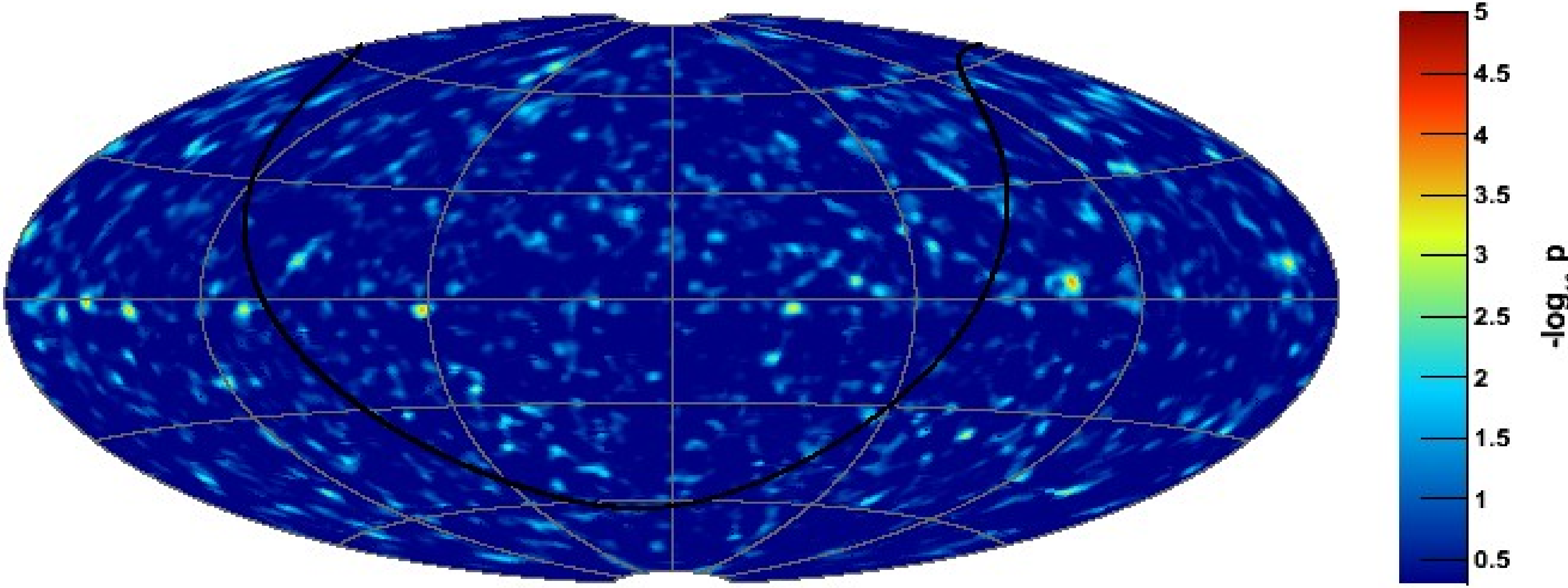
86 out of 432 scrambled maps have higher hottest spot p-value than the unblinded map of real data

Post-trial P-value = 19.9%

PS (0°)

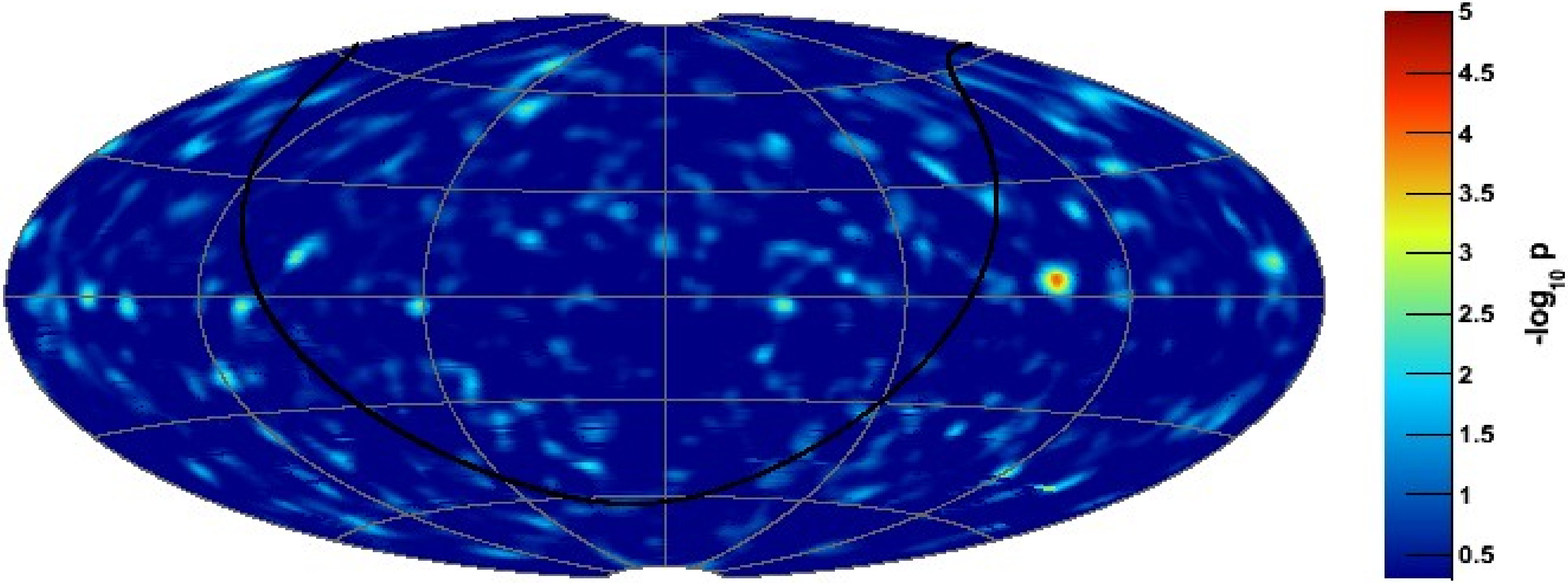


ES (1°)



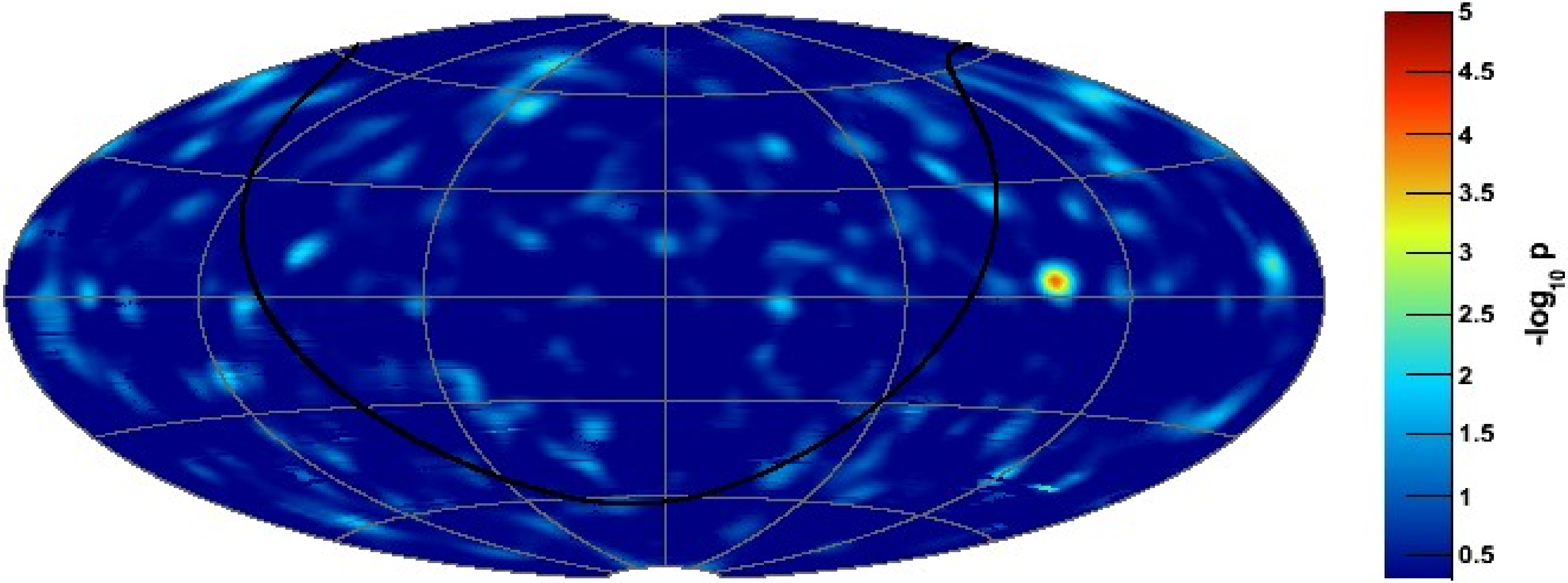
-log10(p) = 3.6705
Ra: 79.25
Dec: 4.25
Ns: 28.76
Γ: 2.31

ES (2°)



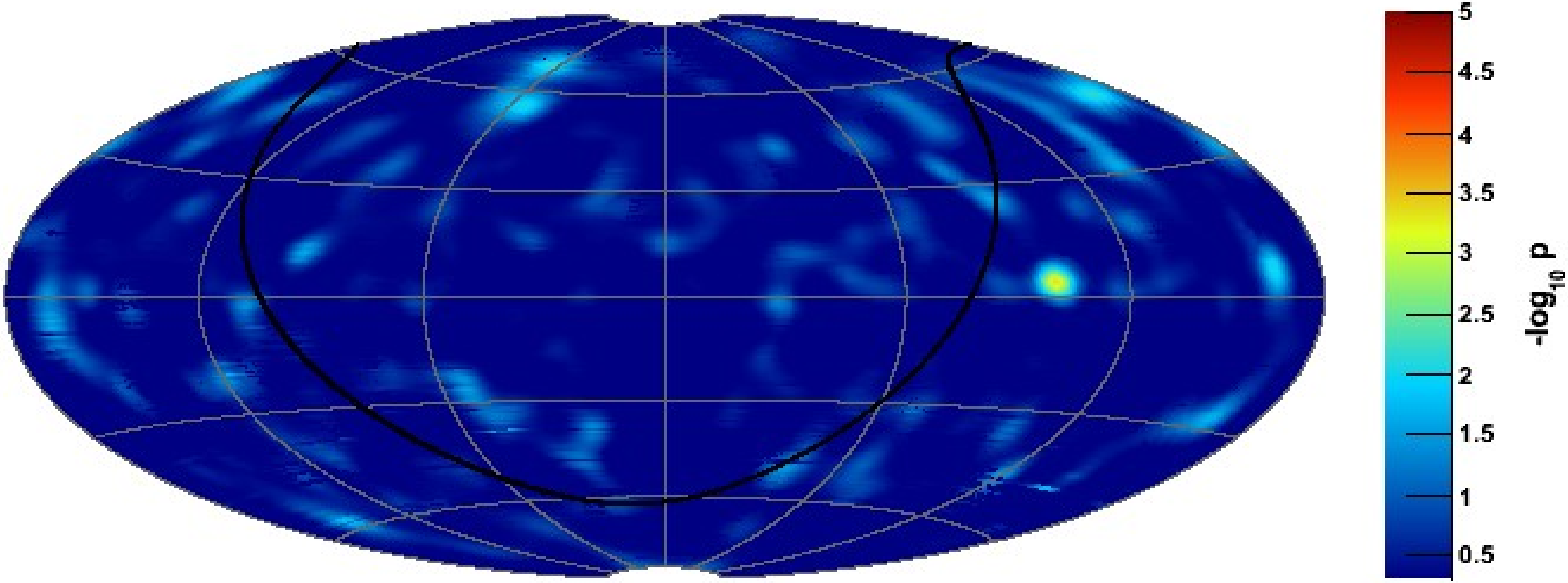
-log10(p) = 4.01669
Ra: 80.25
Dec: 4.25
Ns: 52.60
Γ: 2.41

ES (3°)



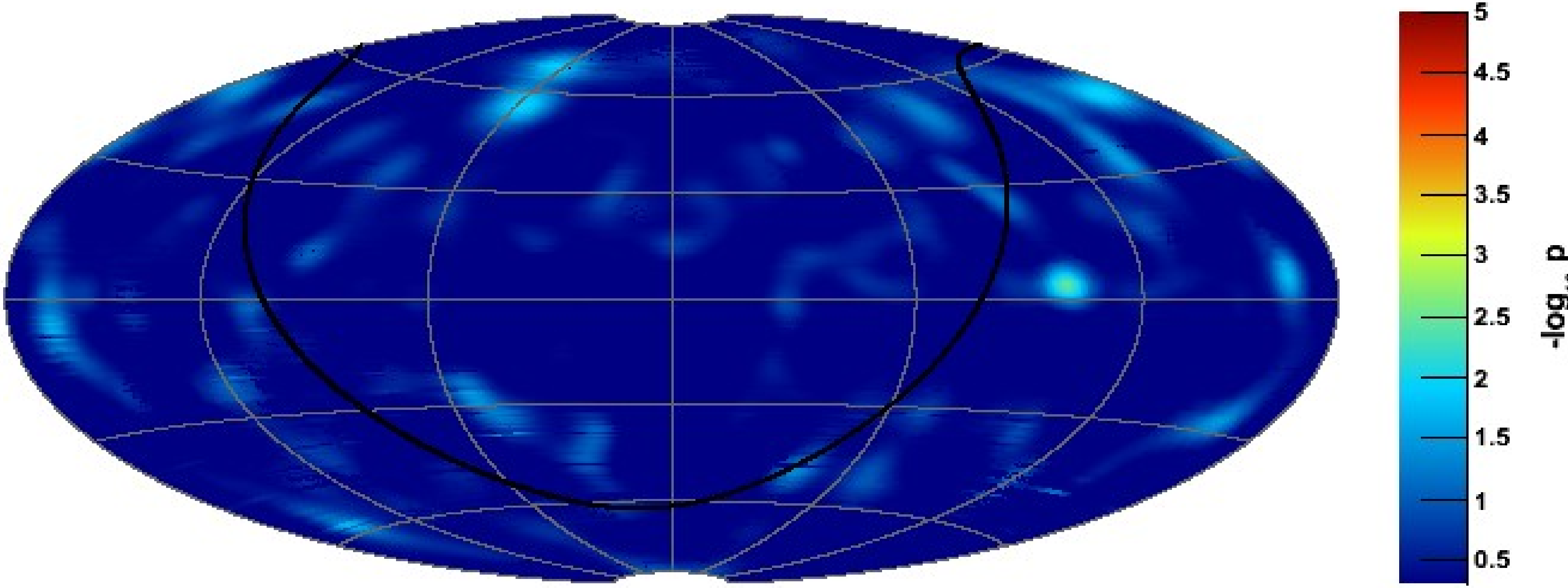
$-\log10(p) = 3.9790$
Ra: 80.75
Dec: 4.25
Ns: 71.73
Γ: 2.45

ES (4°)



-log10(p) = 3.3015
Ra: 80.25
Dec: 3.75
Ns: 78.36
Γ: 2.45

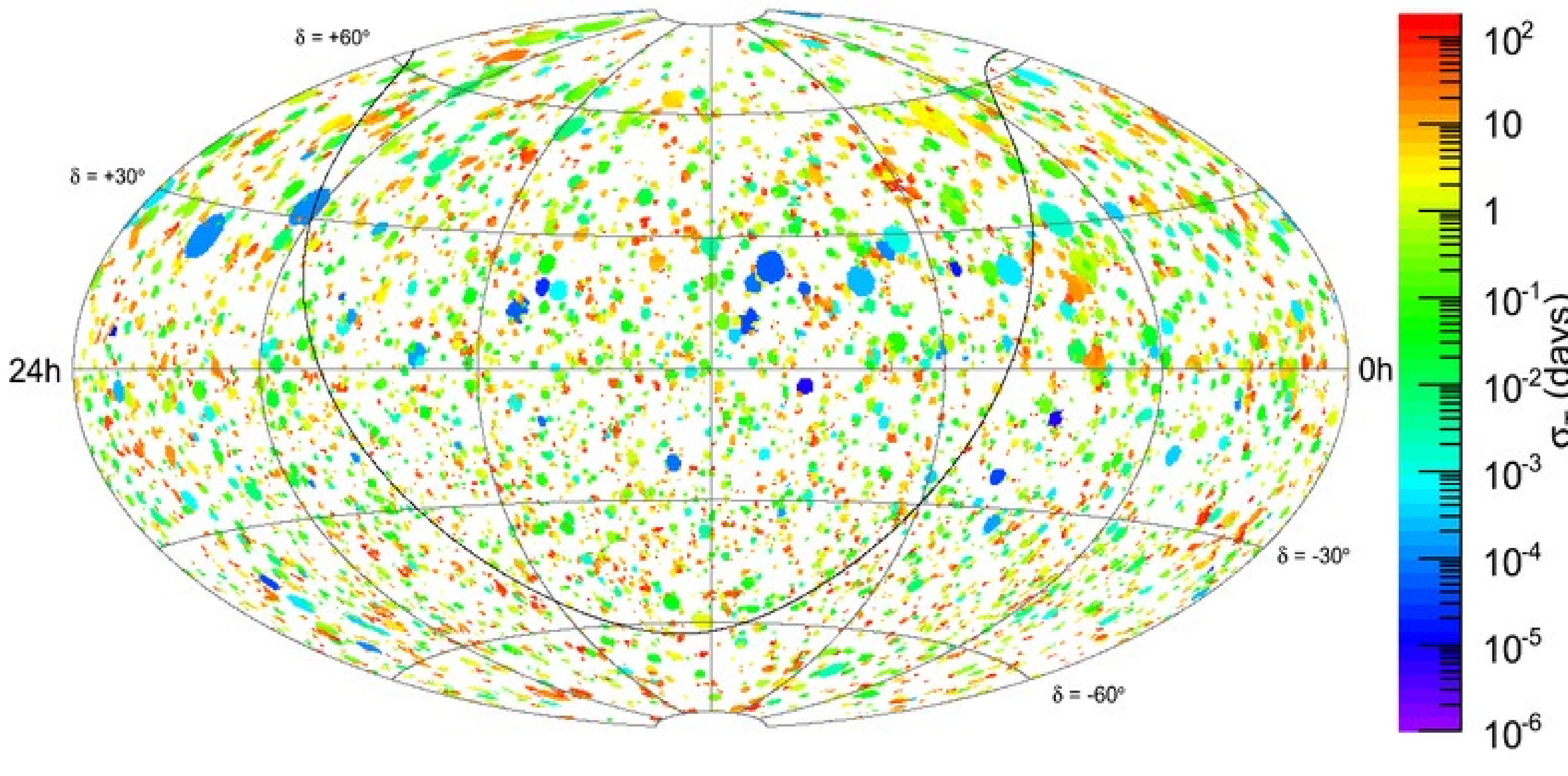
ES (5°)



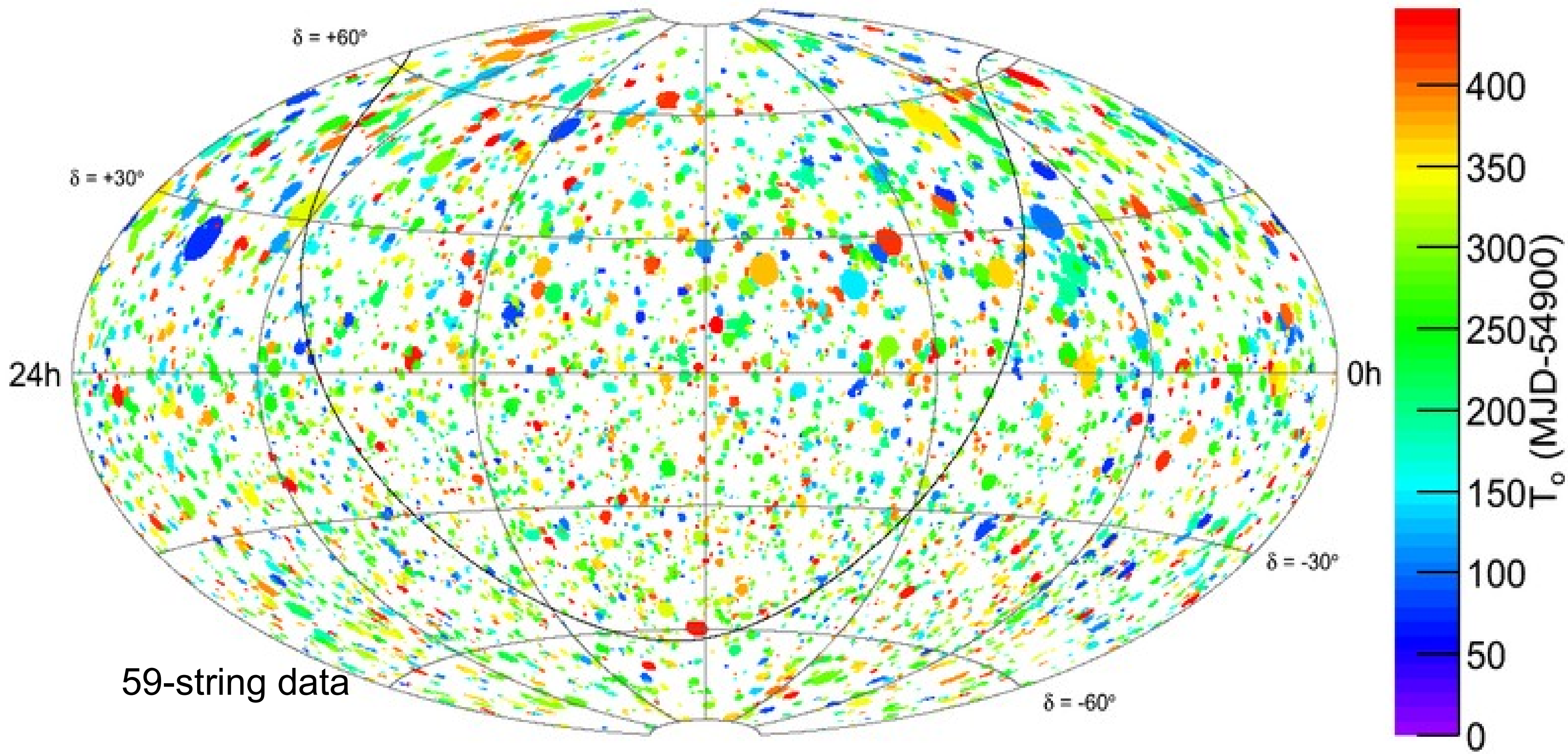
-log10(p) = 2.4498
Ra: 80.75
Dec: 3.75
Ns: 78.23
Γ: 2.45

What if the point source flared and sent a short burst of neutrinos?

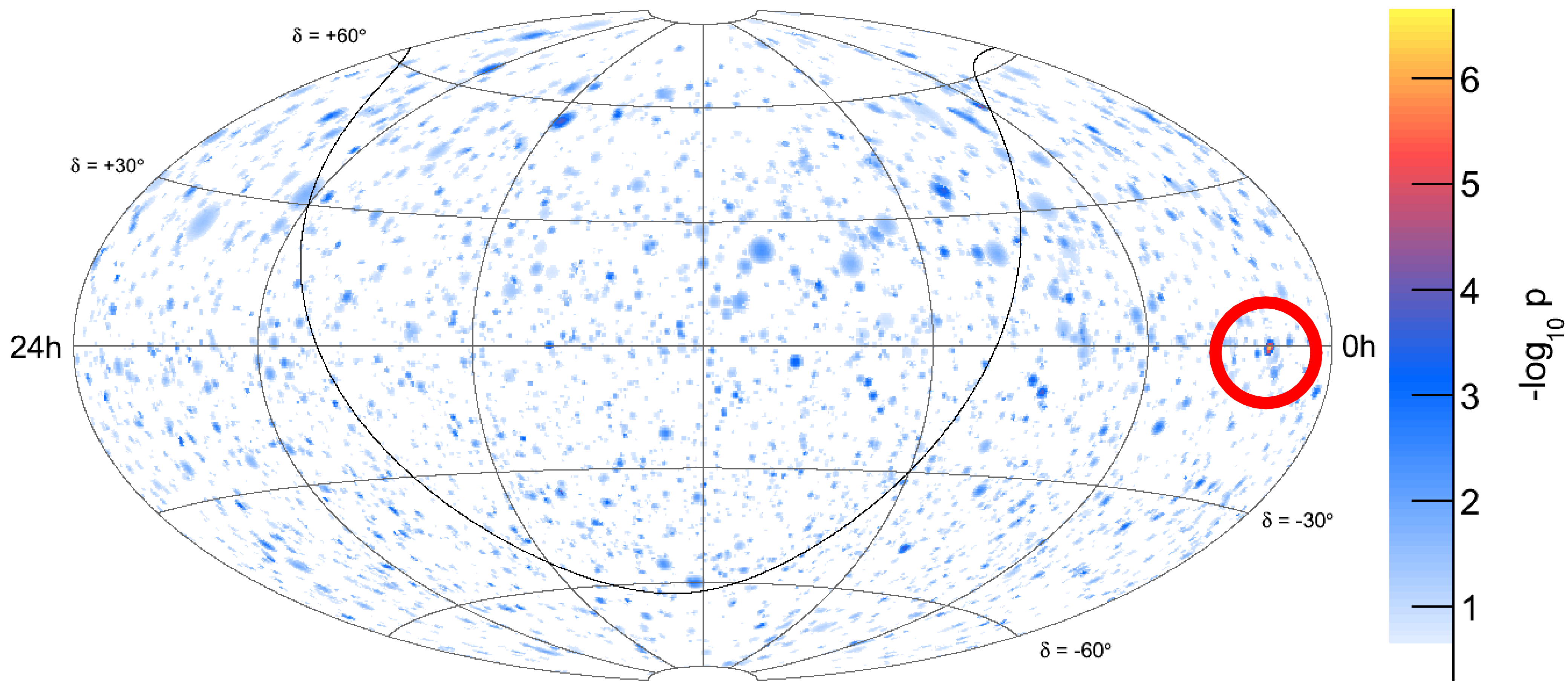
Width of the flare (how long did it last)



Peak of the flare (when did it happen)



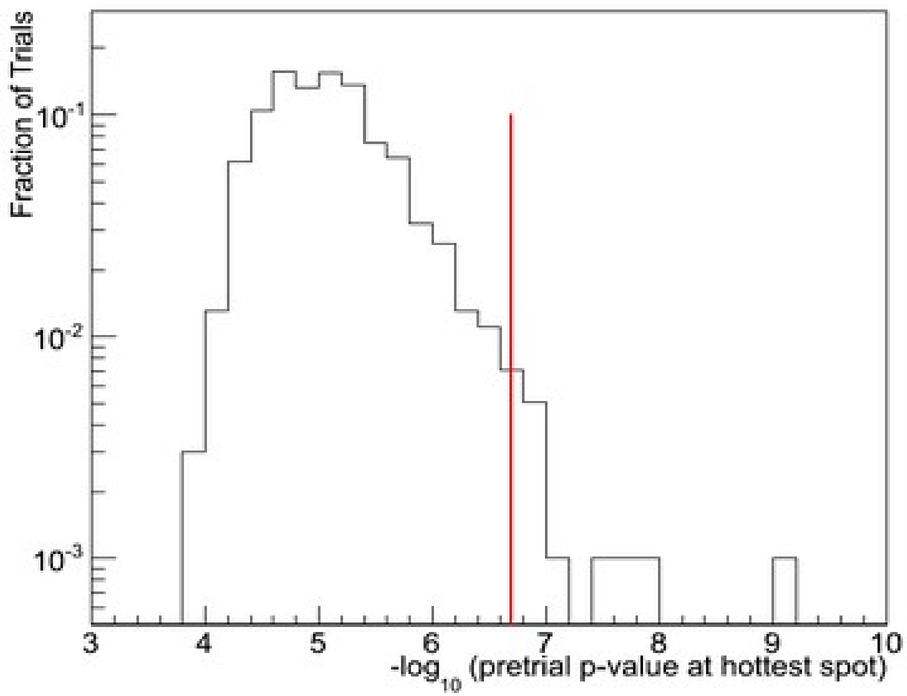
P-values of Flare Search



The strongest fluctuation is from (RA=21.35, dec=-0.25), the method finds an excess of 14.5 events, spectrum of E^-3.9, a mean of MJD 55259 and Gaussian width of 5.5 days (or a FWHM of 13 days). **March 4th 2010**

-log10(p) = 6.69

Post-trial P-value



The distribution of the -log10(pretrial p-value) of the most significant flare of 1000 scrambled skymaps, 14 of which have a hottest spot more significant than that found in data. The value found in data is marked with a red line. P-value = 1.4%

More Ways Of Doing Point Source Analysis

- Testing specific sources
- “Stacking” similar types of sources
- Time dependent flare searches
  - Light-curve analysis
  - Periodic sources
  - 2010 Crab Nebula Flare
- GRBs – Missing Neutrinos?
- Diffuse extended sources
  - Galactic plane
  - “Fermi bubble”

ArXiv:1111.2741

ApJ 745 (2012) 45

Nature 484, (2012) 351–354

Coming soon!

Come talk to me if you're interested in any of these results!

View from McMurdo Station's airfield, Pegasus

Thank you

The IceCube Collaboration
Stockholm University
Uppsala Universitet
Deutsches Elektronen-Synchrotron
Humboldt Universität
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität München
Universität Bonn
Universität Dortmund
Universität Mainz
Universität Wuppertal
University of Alberta
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Clark Atlanta University
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Ohio State University
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Stony Brook University
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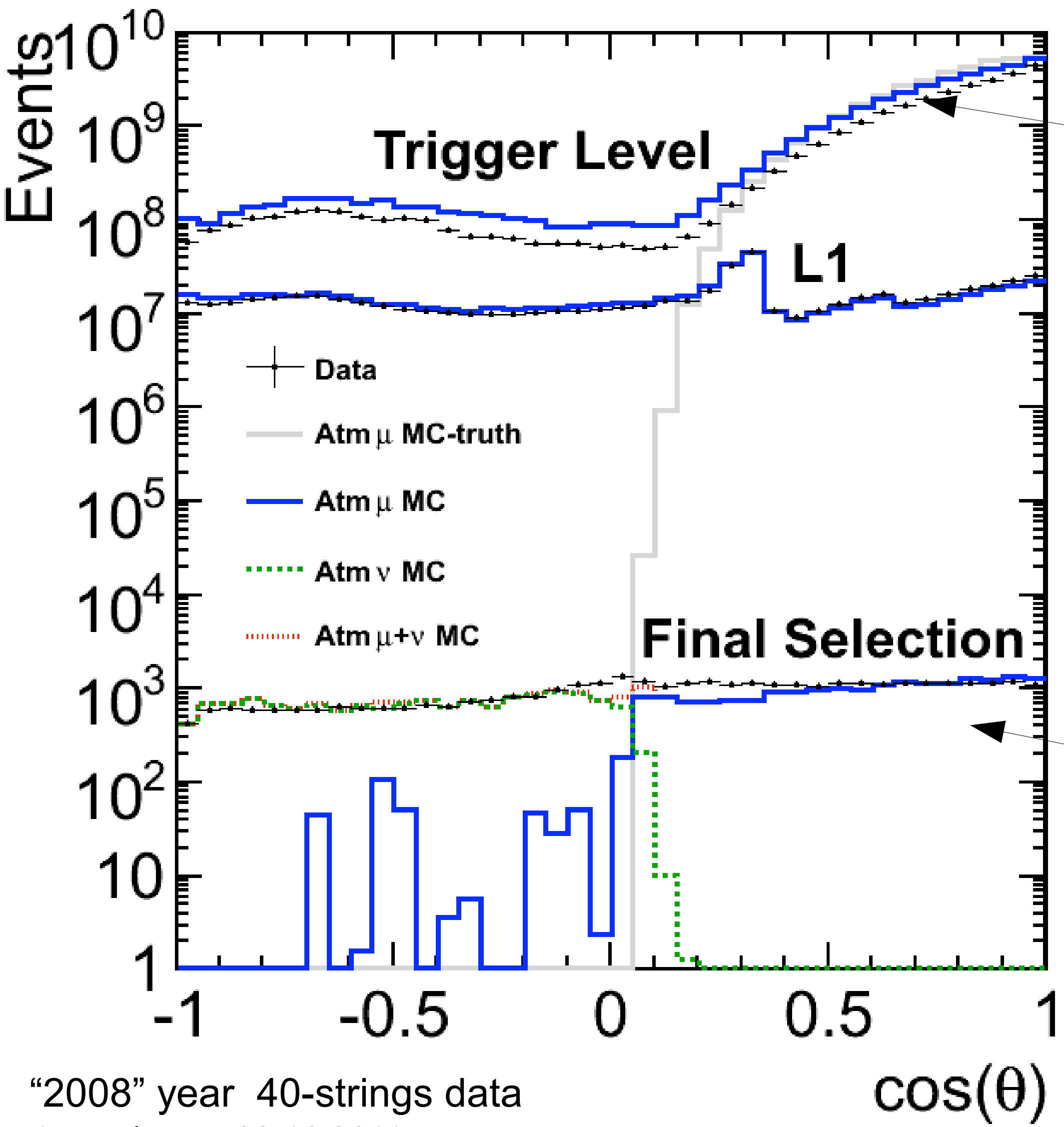
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

BACKUP SLIDES

Sifting through for good events



"2008" year 40-strings data
Astrophys.J.732:18,2011

Completely dominated by cosmic-ray muons..... not neutrino-induced muons

These should all be downgoing, but our reconstruction gets fooled a lot

At this point, most of our data is

Downgoing: cosmic-ray muons
Upgoing: atmospheric neutrinos (induced muons)

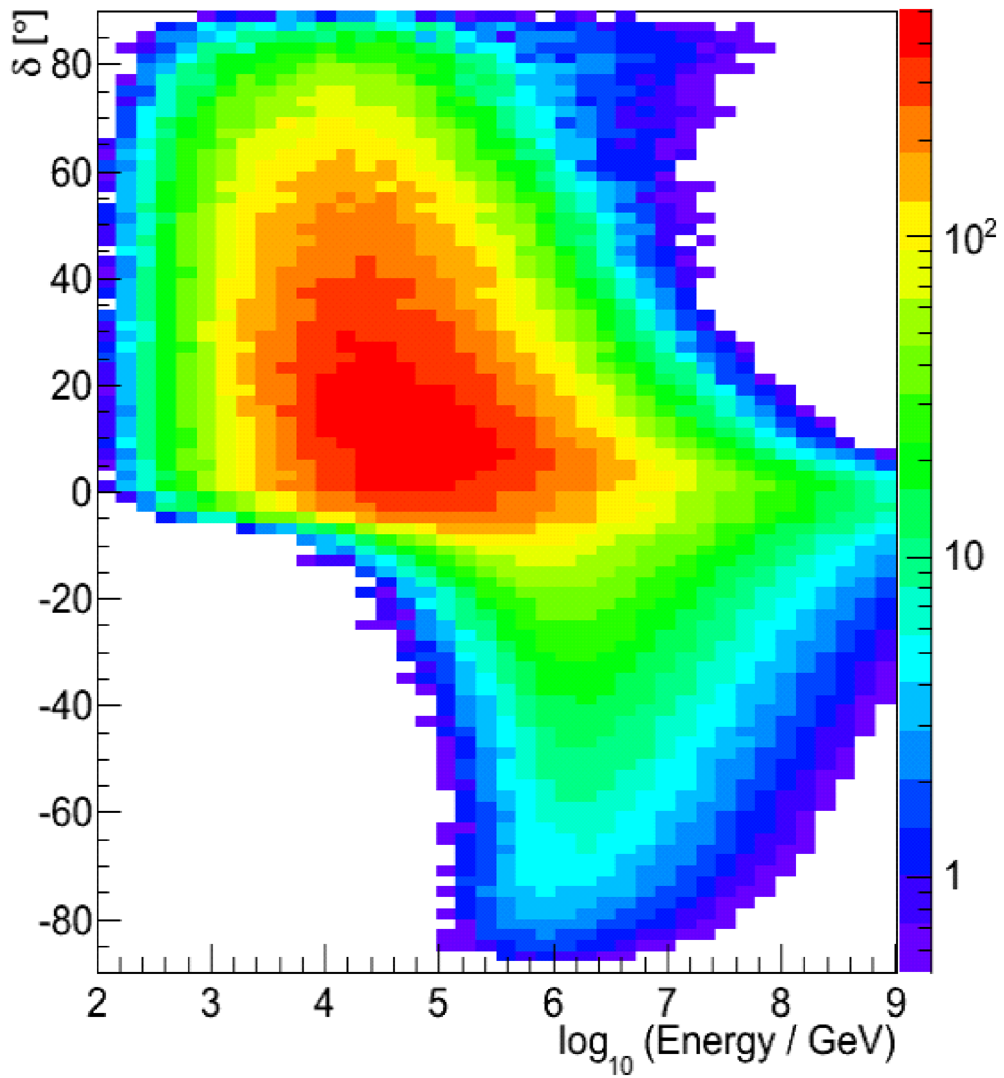
Declination (Zenith) dependent energy range

Population of E^{-2} spectral neutrinos that survive

- Includes earth absorption

- All neutrinos need to reach the detector

- Then pass all our filtering

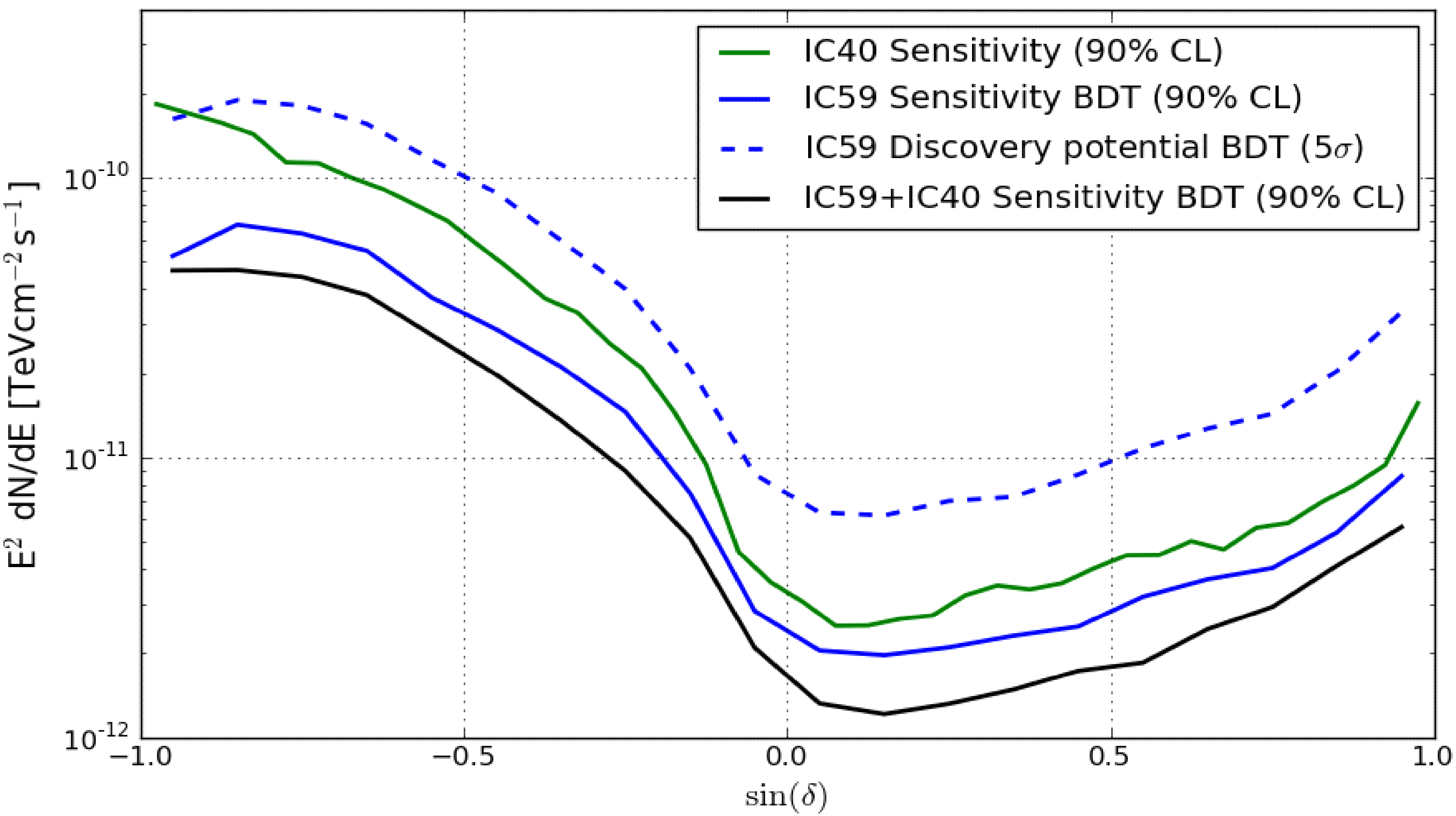


Great perk @ South pole
declination ~ zenith!!!

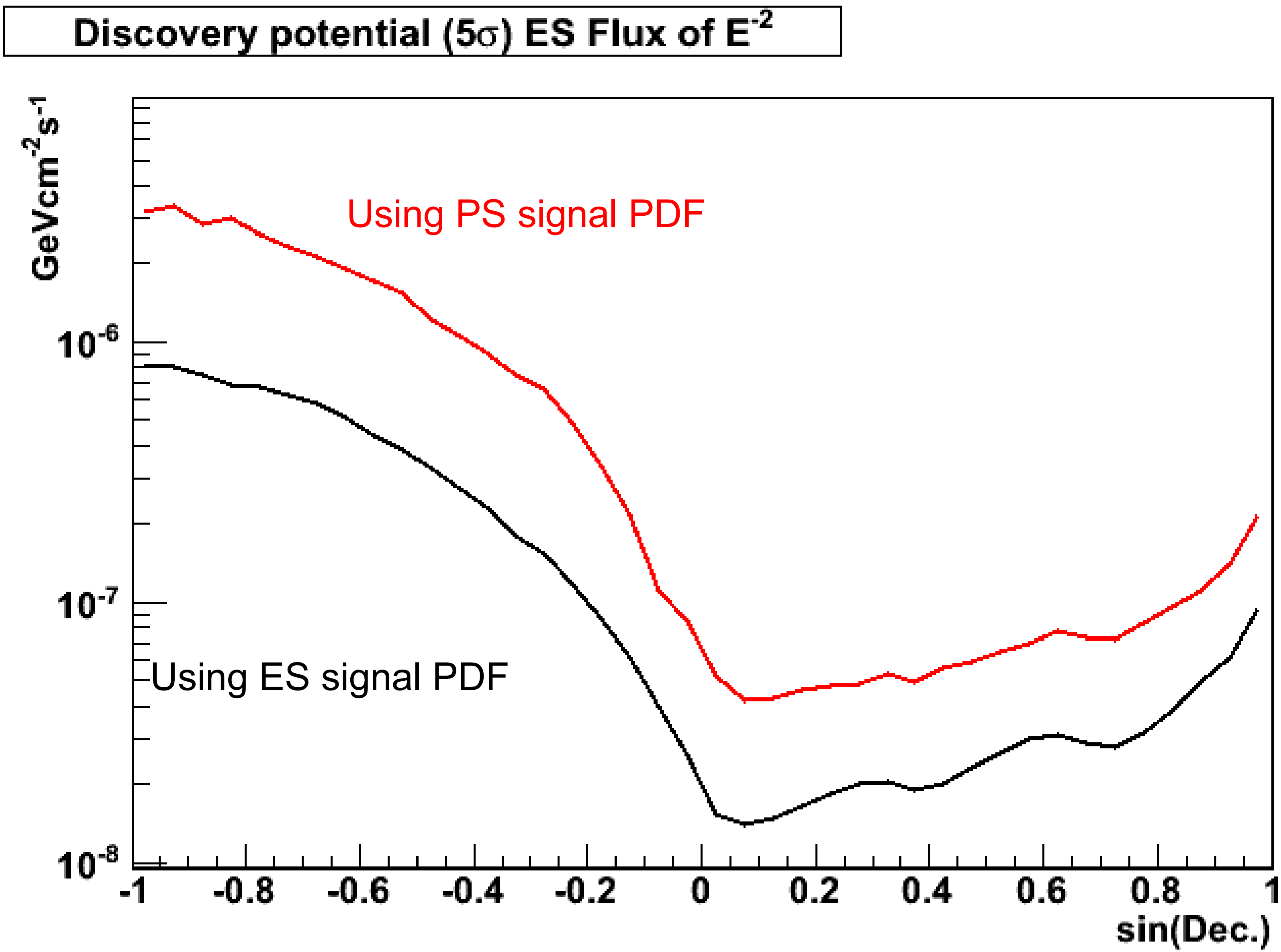
Stacking Results Summary

	Data Set	Fit Parameters	IC59+40 p-value (IC40 p-value)
Milagro 17	IC40 + IC59	Nsrc, γ	– (32%)
Milagro 6 SNR	IC59	Nsrc, γ	– (2 % a posteriori)
Starburst Galaxies	IC40 + IC59	Nsrc, γ	– (–)
Galaxy Clusters	IC40 + IC59	Nsrc, γ	– (–)
UHECR	IC40 + IC59	Nsrc, γ, σ	-- (–)
SNR-MC	IC40 + IC59	Nsrc, γ	– (new analysis)

* – indicates >=50%

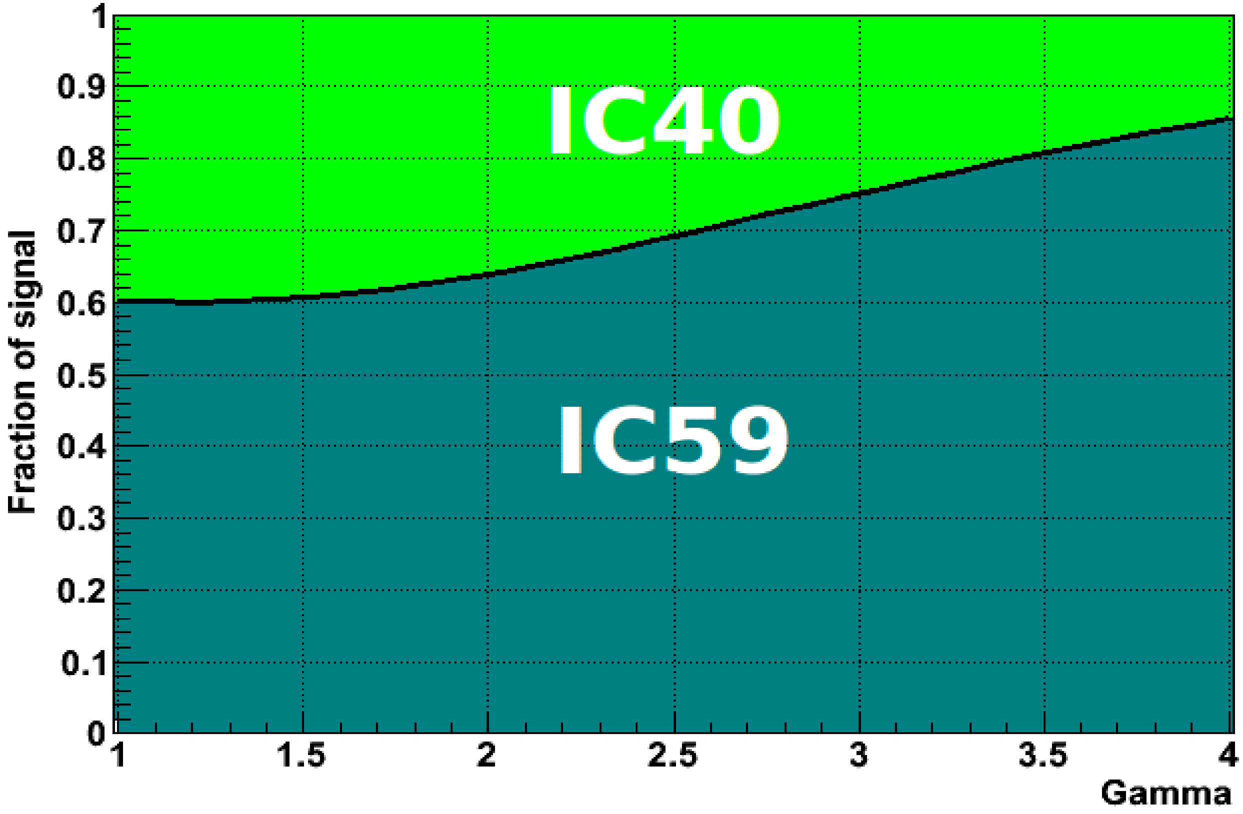


IC40 Sensitivity (90% CL)
IC59 Sensitivity BDT (90% CL)
IC59 Discovery potential BDT (5σ)
IC59+IC40 Sensitivity BDT (90% CL)
10^{-10}
10^{-11}
10^{-12}
E^2 dN/dE [TeVcm^{-2}s^{-1}]
−1.0
−0.5
0.0
0.5
1.0
sin(δ)



Discovery potential (5σ) ES Flux of E-2
GeVcm-2s-1
Using PS signal PDF
Using ES signal PDF
10-6
10-7
10-8
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
sin(Dec.)

Different detector, different event selection



Contribution of the two data sets, given a source with spectral index gamma

Advantage of flare search