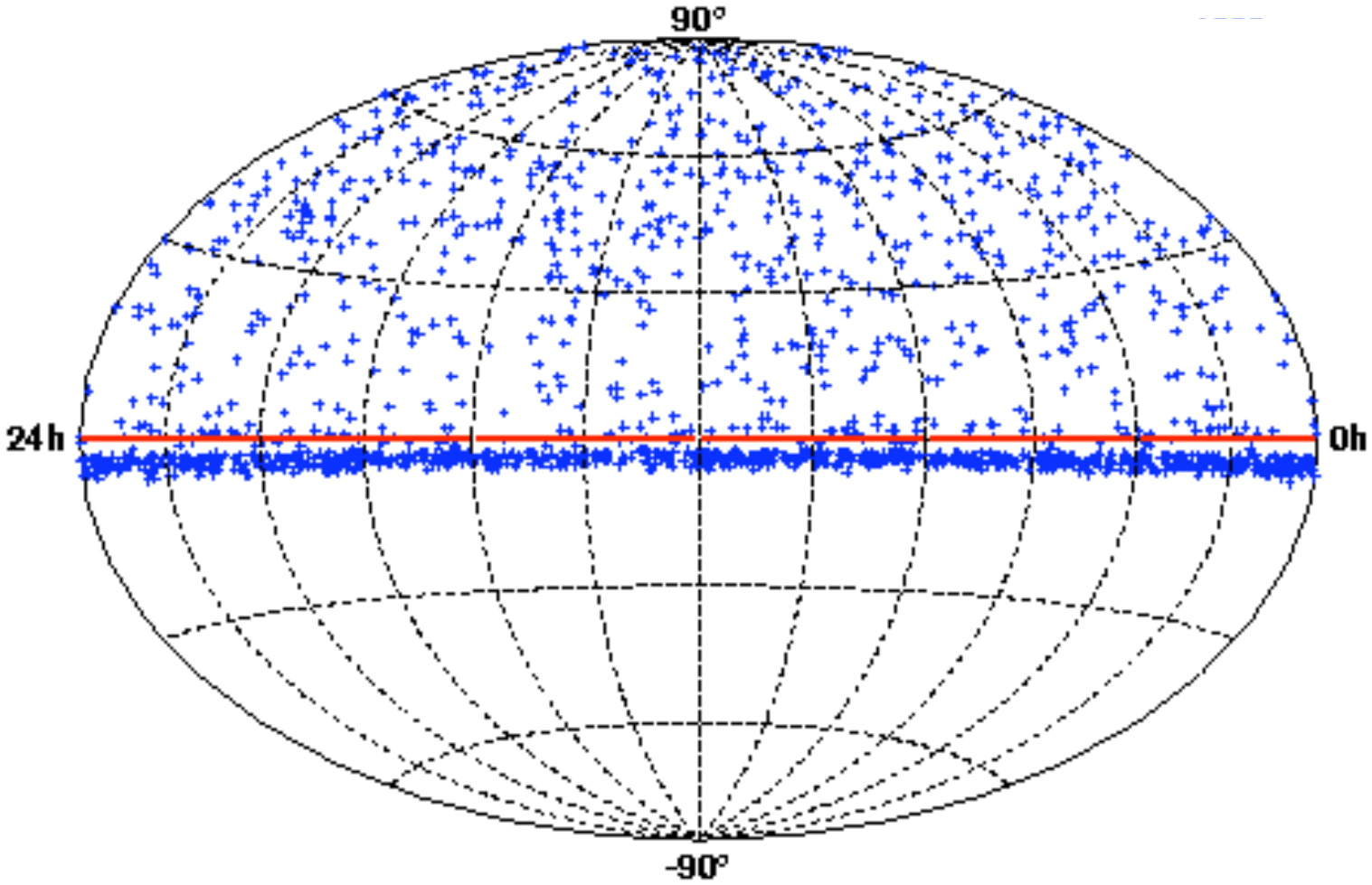
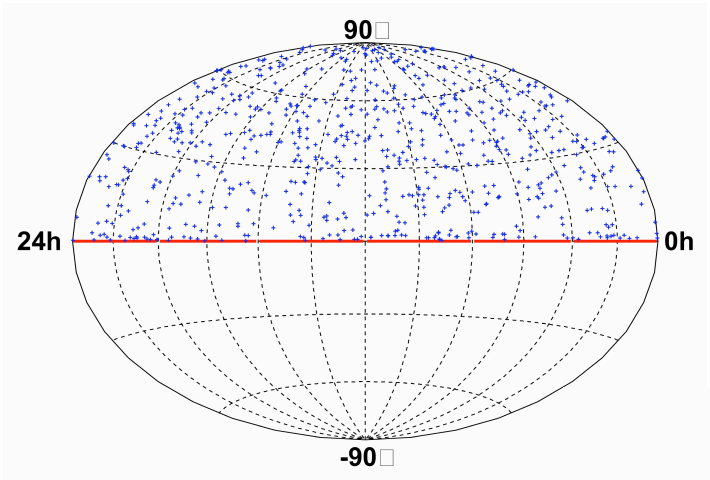
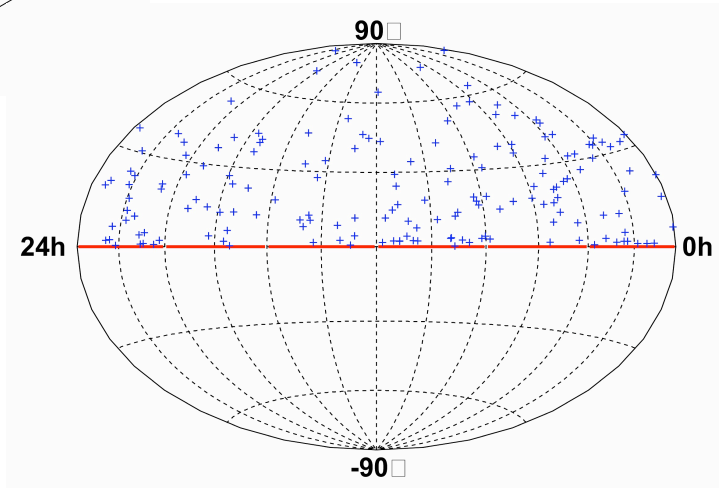
astronomy ?

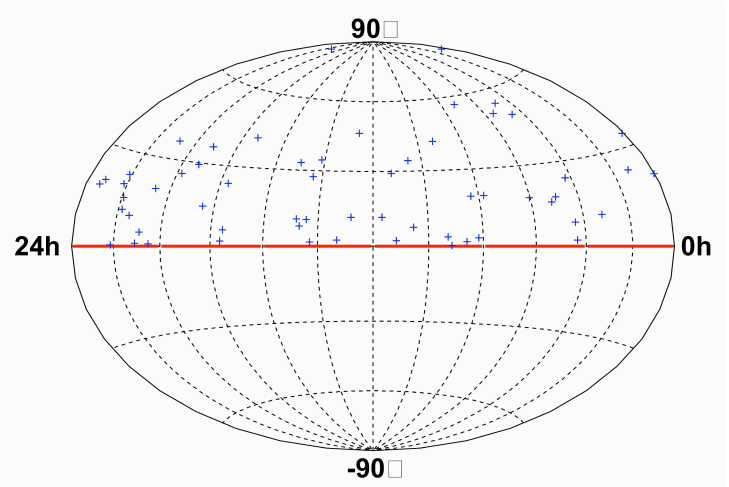
AMANDA II 2000

1555 Events







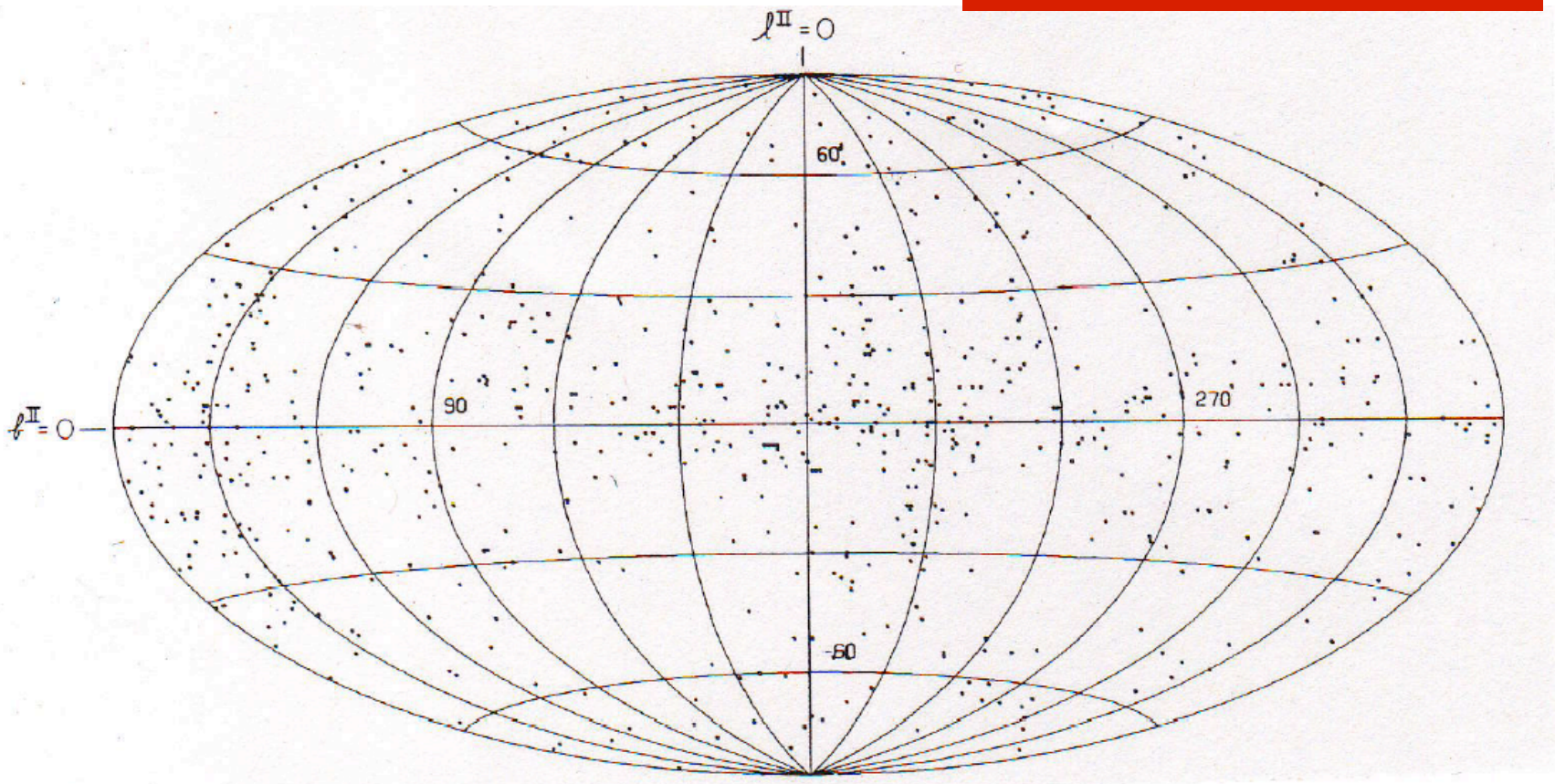


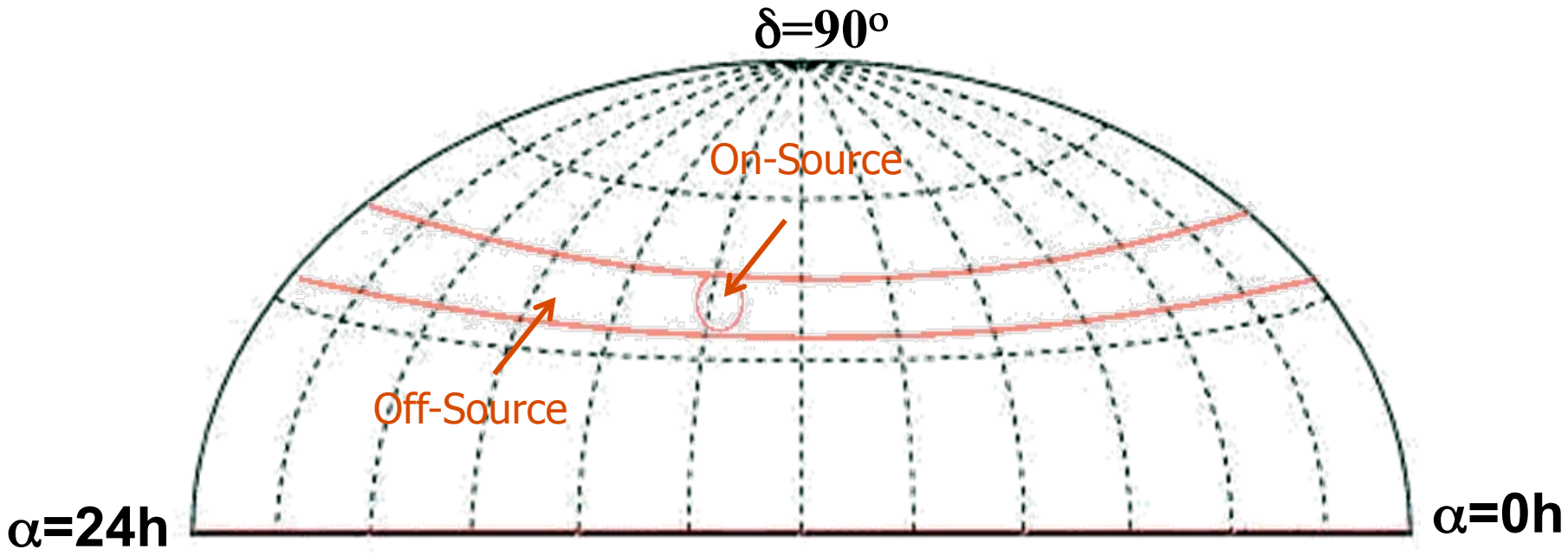
increasing energy

1968 OSO-3 (Kraushaar et al. 1972)

- effective area 4 cm^2
- 600 photons

sources seen in next mission! SAS-2 100 cm^2





search for point sources in the Northern Sky:

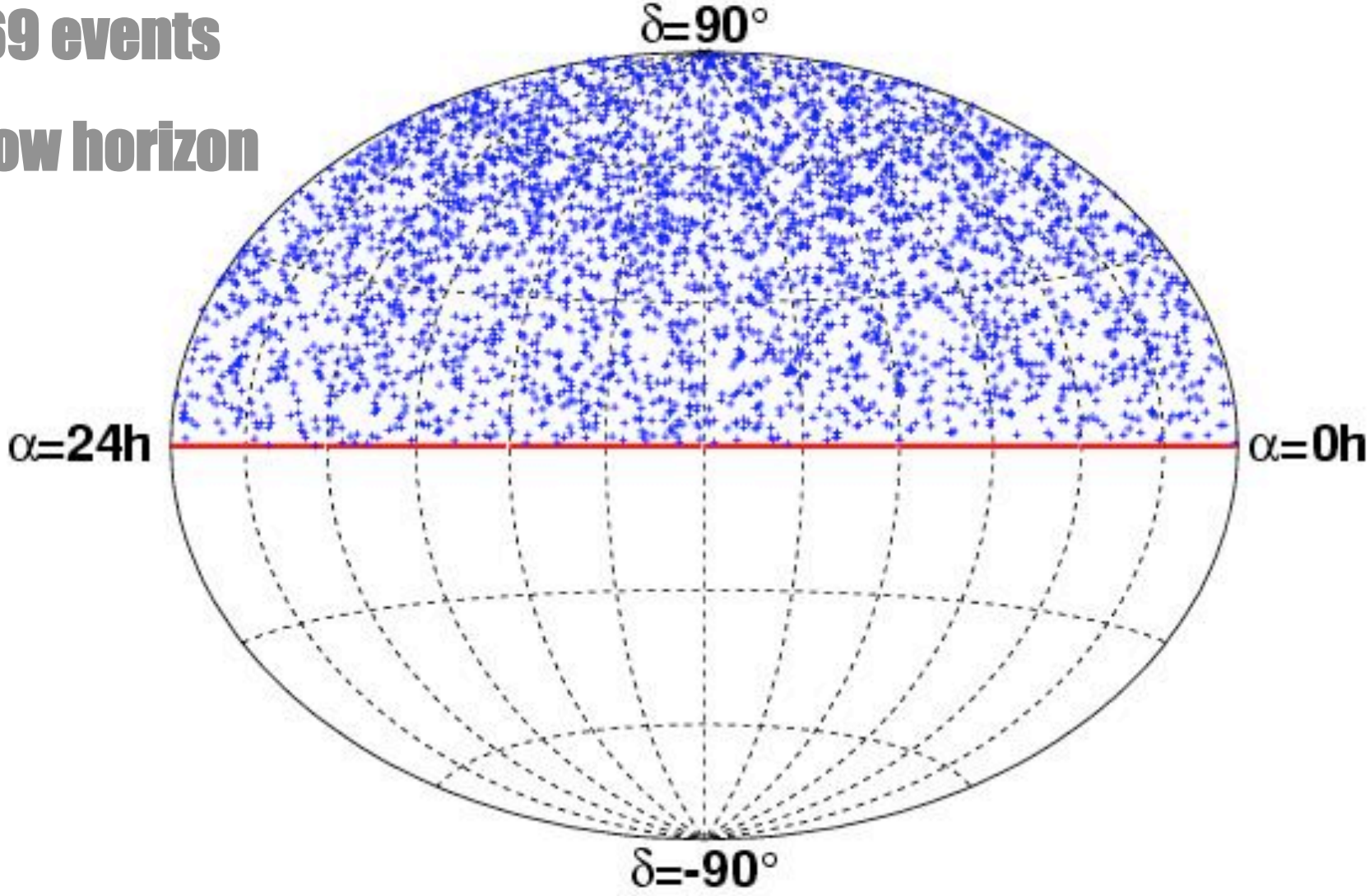
- angular cuts are applied to the reconstructed events to reject misreconstructed atmospheric (i.e. down-wardgoing) muons
- **the background is determined from the event densities in the off-source declination band**
- **at the South Pole a declination band has uniform coverage**

ApJ 583, 1040 (2003); Phys. Rev. Lett. 92, 071102 (2004); Astropart. Phys. 22, 339 (2005)

AMANDA skyplot 2000-2003

3369 events

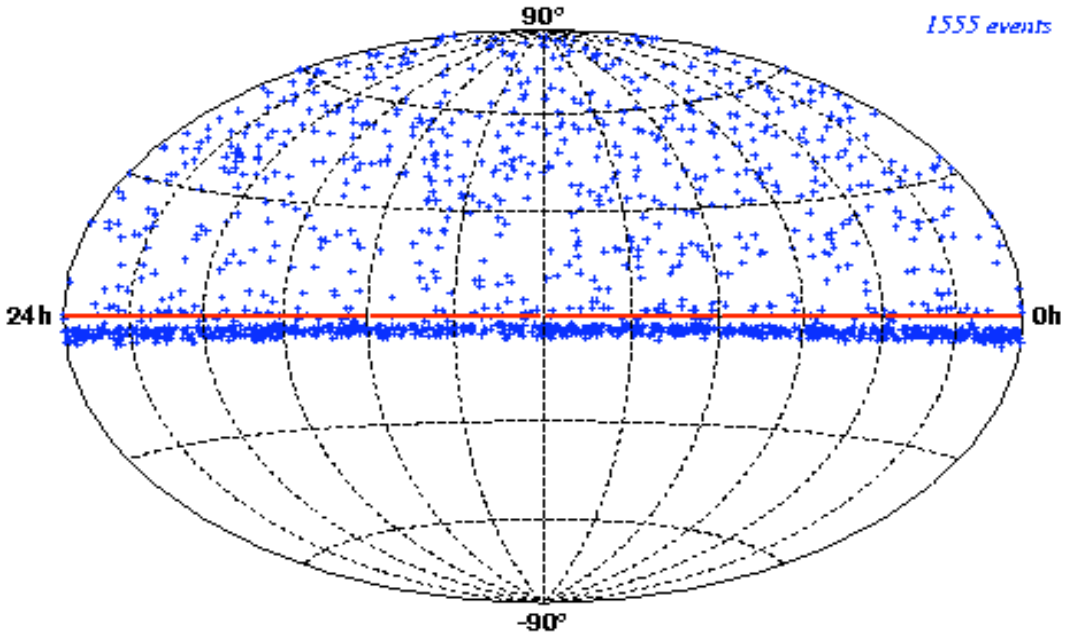
below horizon



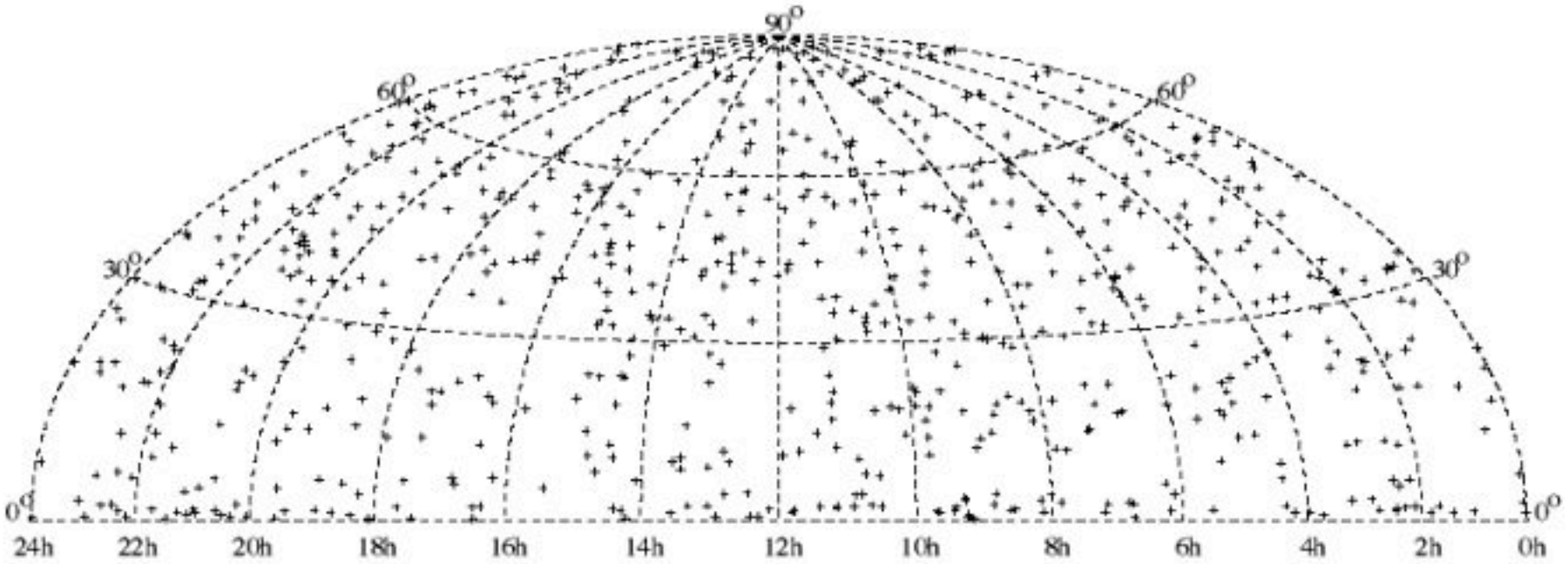
- 90% upper limits calculated using background levels predicted from data

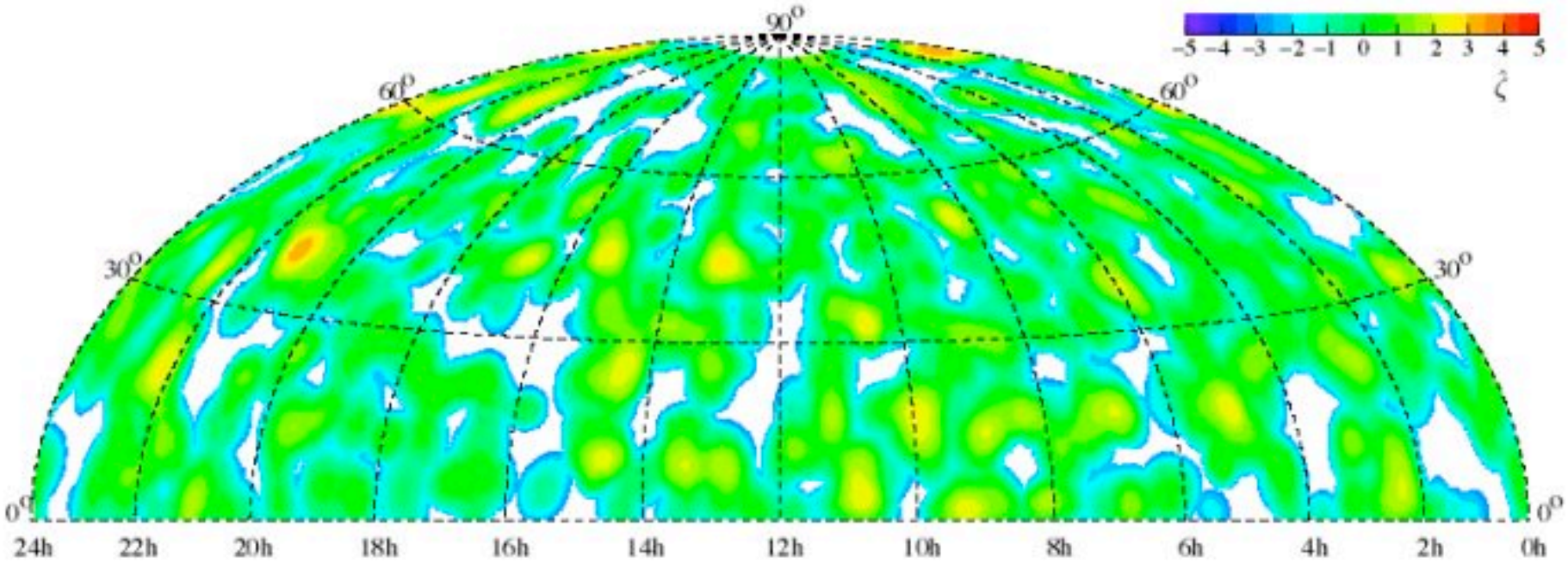
- "neutrino = gamma" sensitivity

- 0.04 km^2 area above 10 TeV



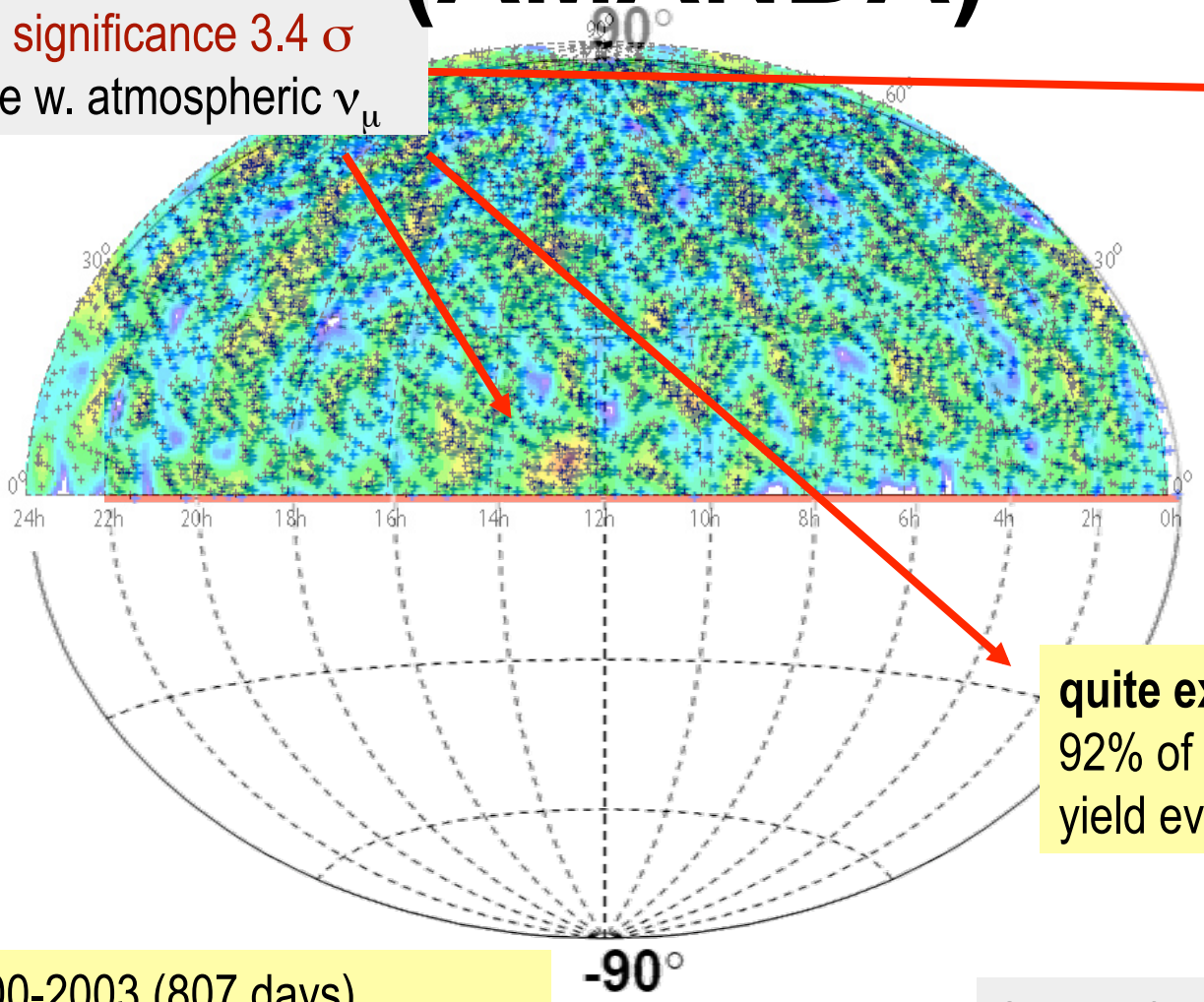
Source\90% limit	muon ($\times 10^{-15}$ cm^{-2} s^{-1})	ν (10^{-8} GeVcm^{-2} s^{-1})
Markarian 421	2.6	3.0
Markarian 501	1.3	1.5
Crab	2.1	2.1
Cas-A	0.7	1.0
SS 433	0.8	0.6
Cygnus X-3	2.5	3.1


90°
60°
60°
30°
30°
0°
0°
24h
22h
20h
18h
16h
14h
12h
10h
8h
6h
4h
2h
0h


90°
60°
60°
30°
30°
0°
0°
24h
22h
20h
18h
16h
14h
12h
10h
8h
6h
4h
2h
0h
−5 −4 −3 −2 −1 0 1 2 3 4 5
ζ̂

Search for localized sources (AMANDA)

Maximum significance 3.4 σ
compatible w. atmospheric ν_μ



Preliminary

quite expected ...
92% of experiments would yield even higher maximum

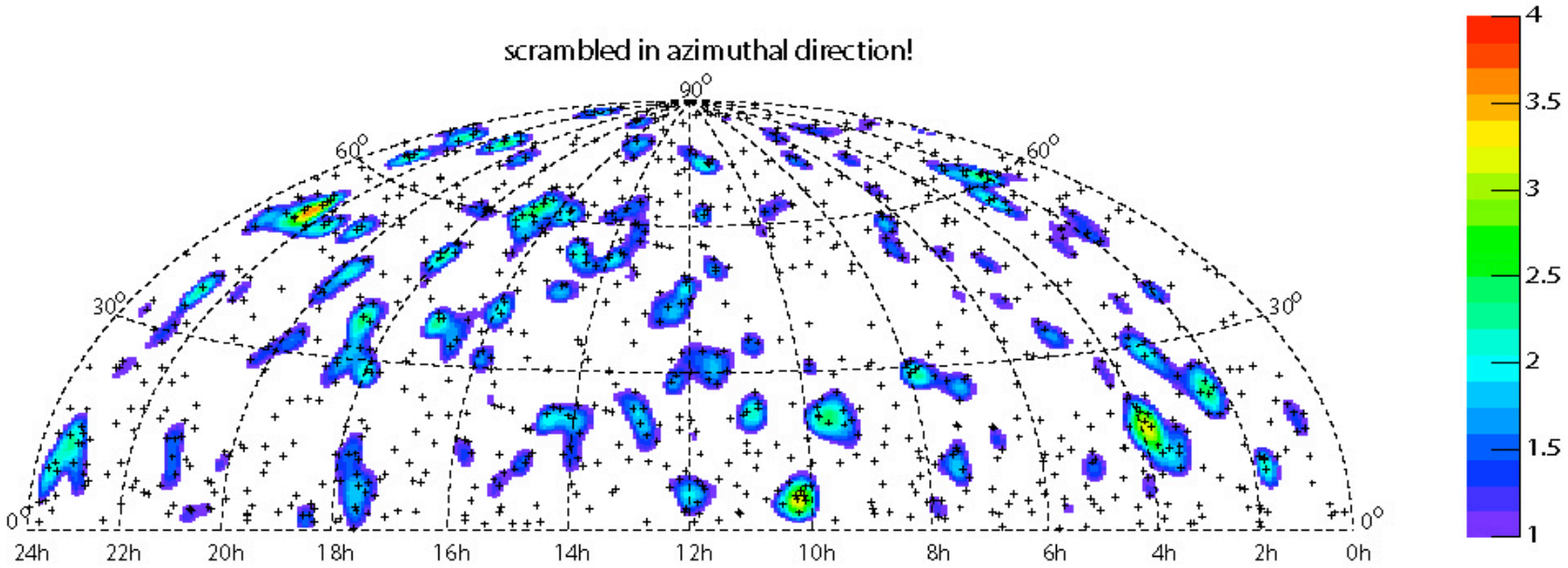
2000-2003 (807 days)
3329 μ from northern hemisphere
3438 μ expected from atmospheric ν_μ

Search for clustering
un-binned statistical analysis
no significant excess

Combined PS Search 2000-2002

SCRAMBLED

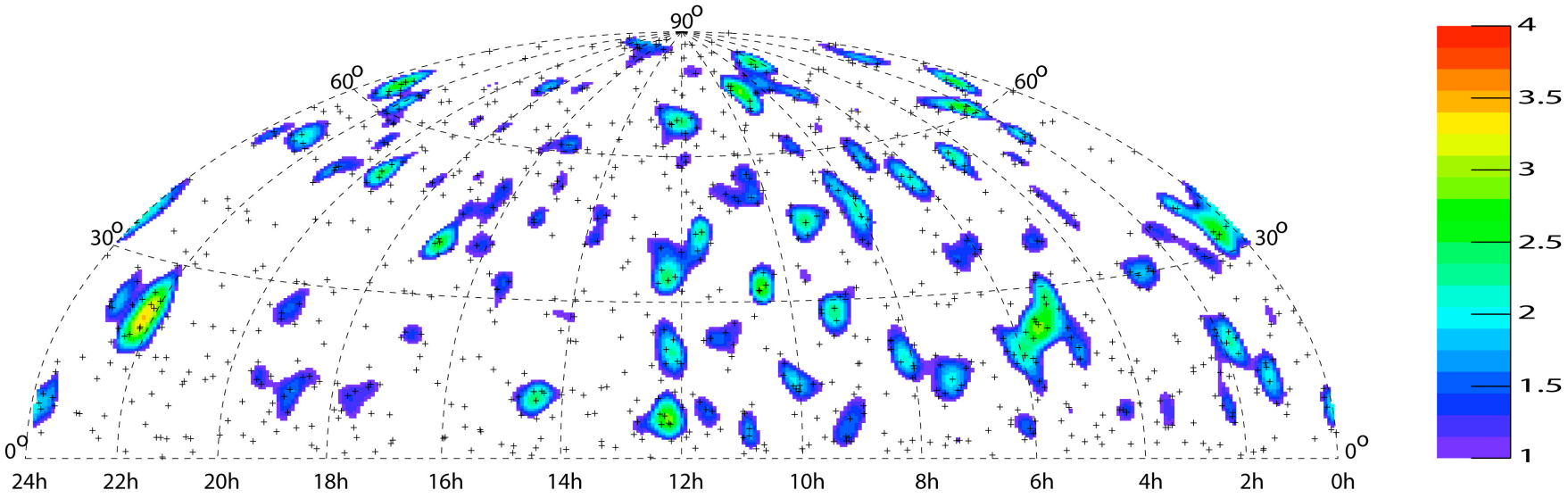
- combined 2000/2001 analysis: 959 events (453 above 90°)
- standalone 2002 analysis: 927 (469 above 90°)
  - putting together both data sets w/o re-optimizing for best sensitivity yields 1883 events (922 above 90°)



- on average expect 2.3 hotspots with > 3σ
- two spots seen with > 3σ, maximum 3.6σ

Combined PS Search 2000-2002

UNSCRAMBLED



- one spot seen with > 3σ
- observed maximum significance is 3.41σ
- very **close to what is expected**

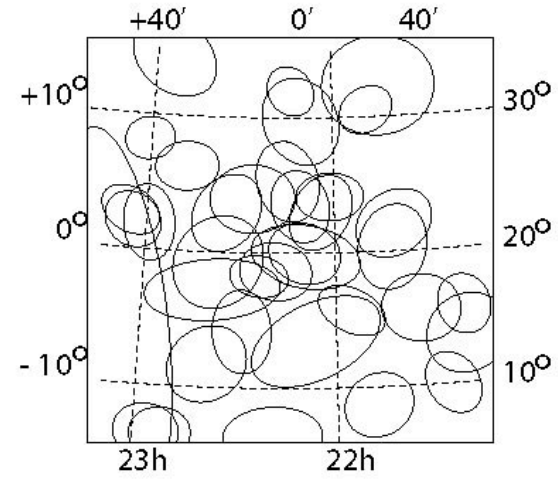
▶ no evidence for signal

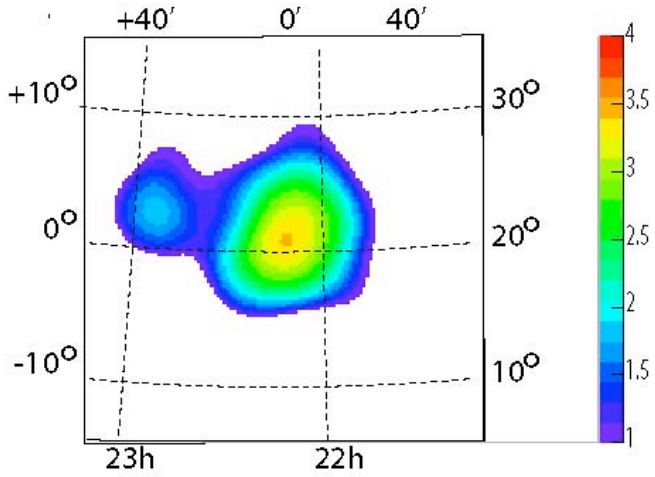
Thomas Becka, Wuppertal AMANDA meeting, June 20-24, 2004

Combined PS Search 2000-2002

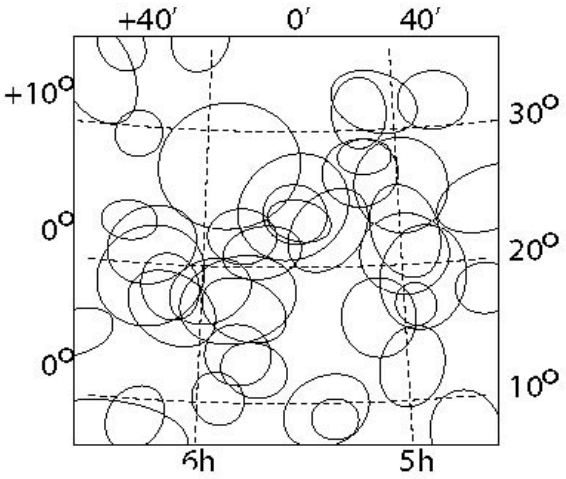
hotspots

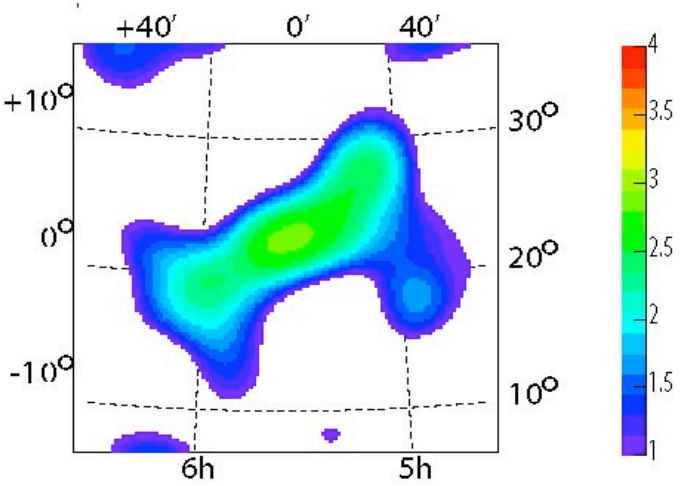
Spot with highest significance





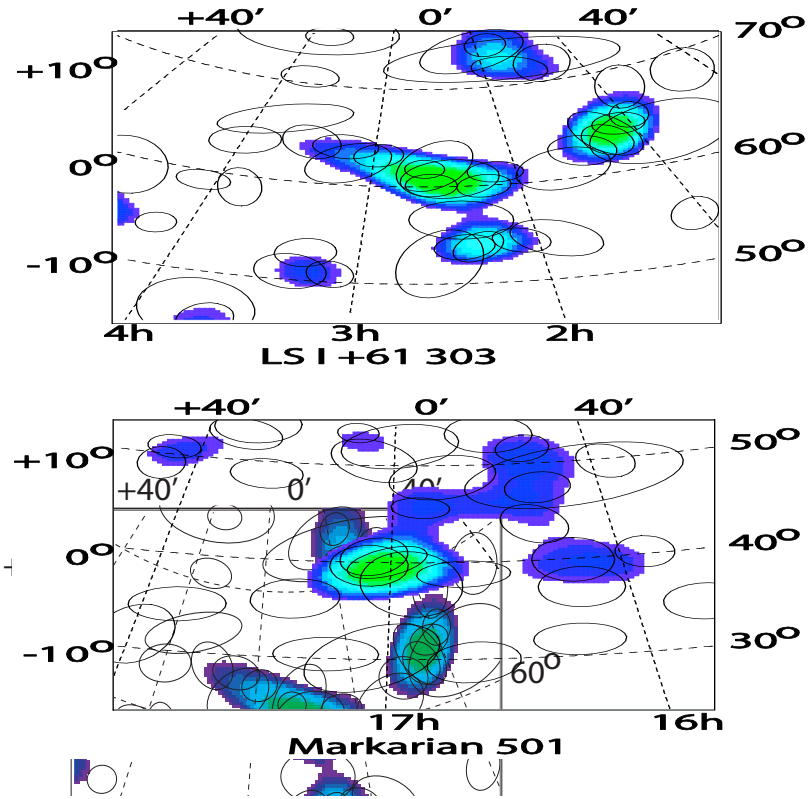
Crab nebula

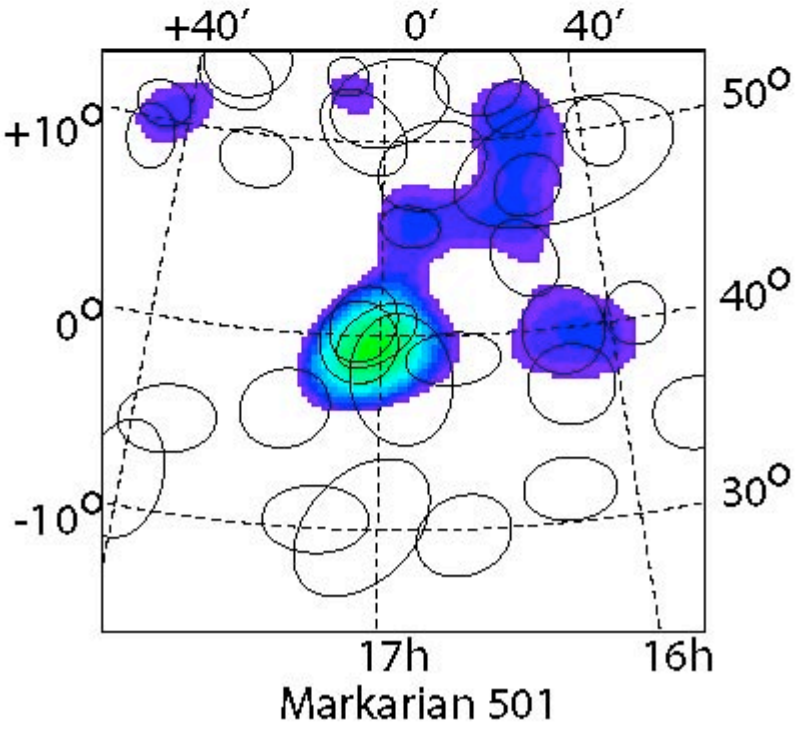




Combined PS Search 2000-2002

more hotspots



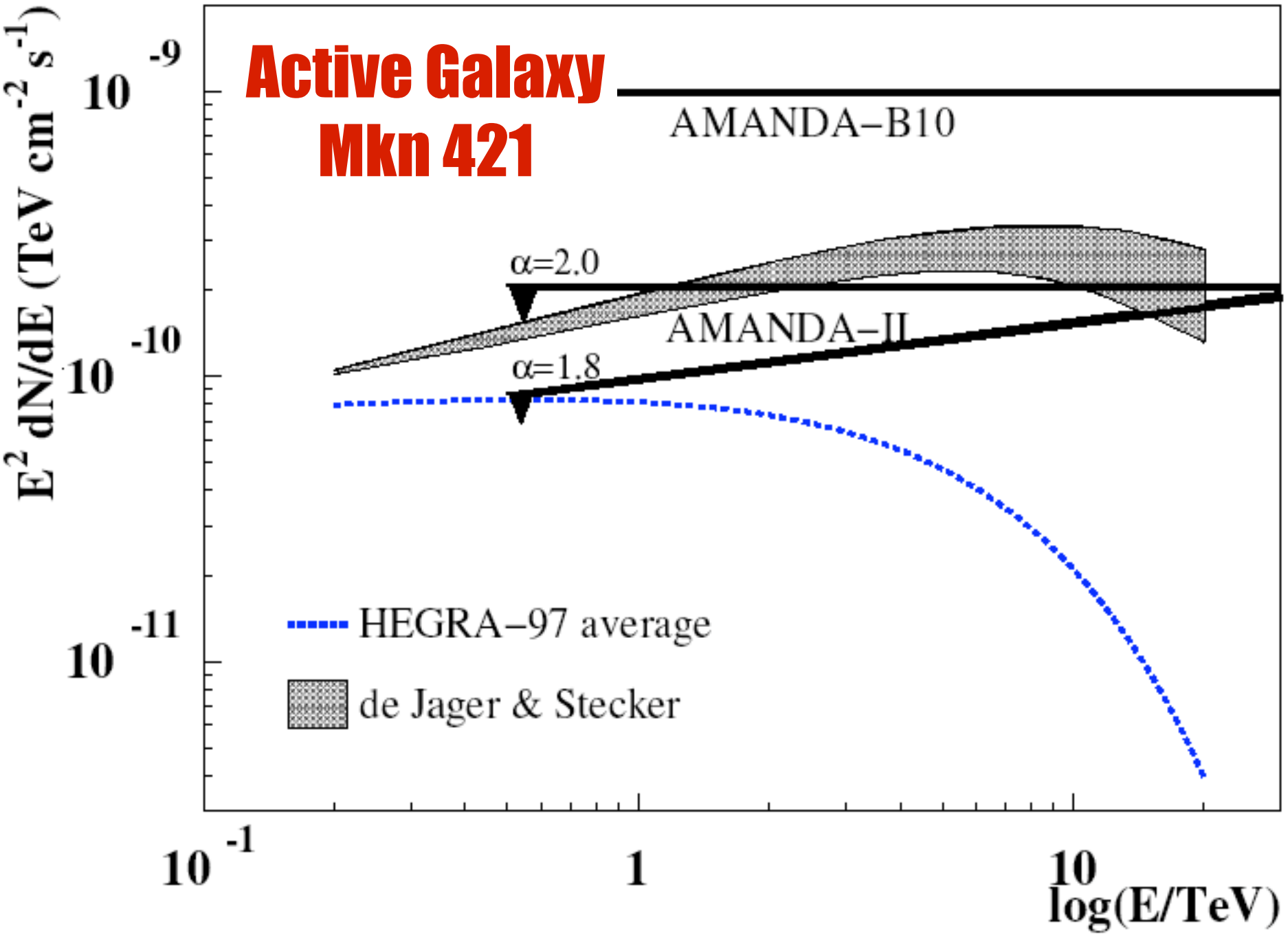


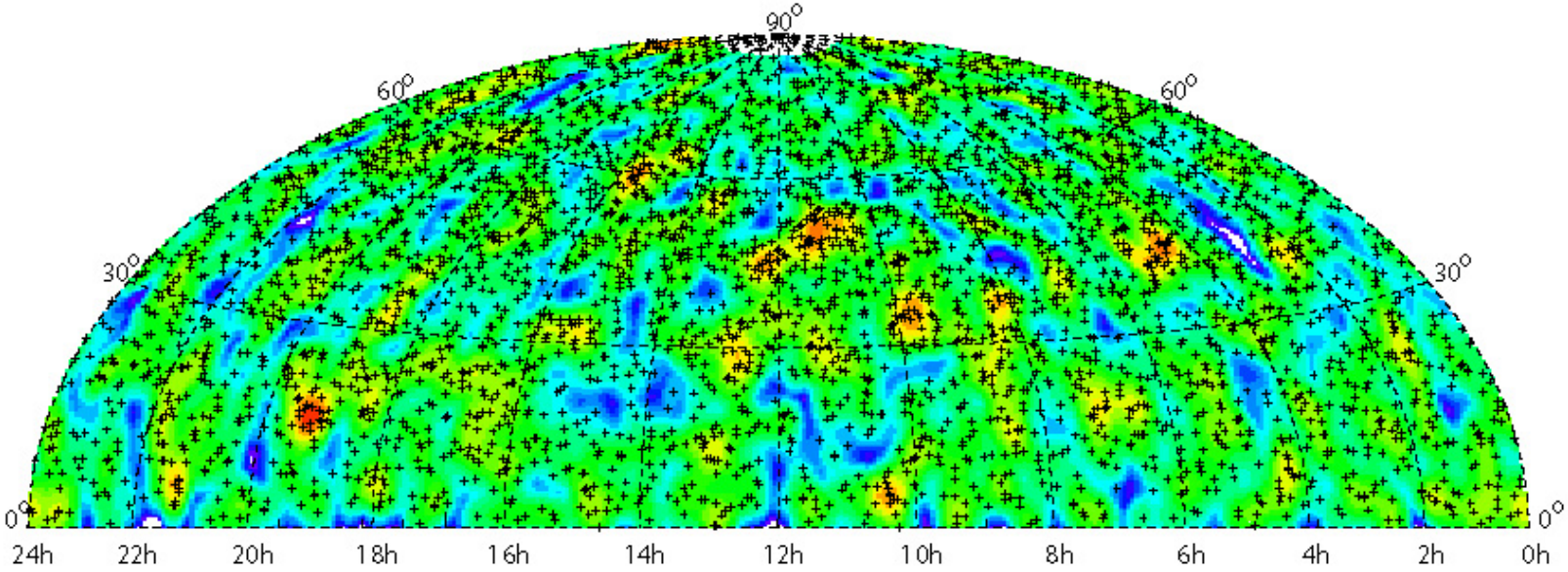
note:

with 30 „random“ sources to discuss,

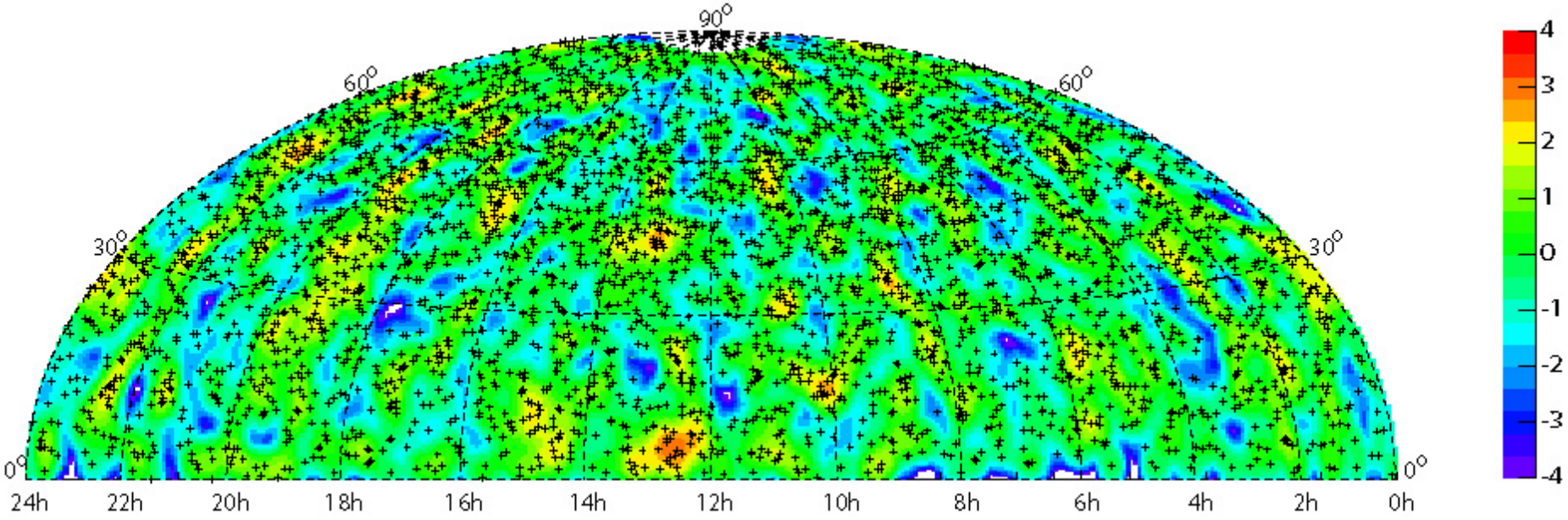
probability that >0 source falls into 2 sigma hotspot: ≈ 40%

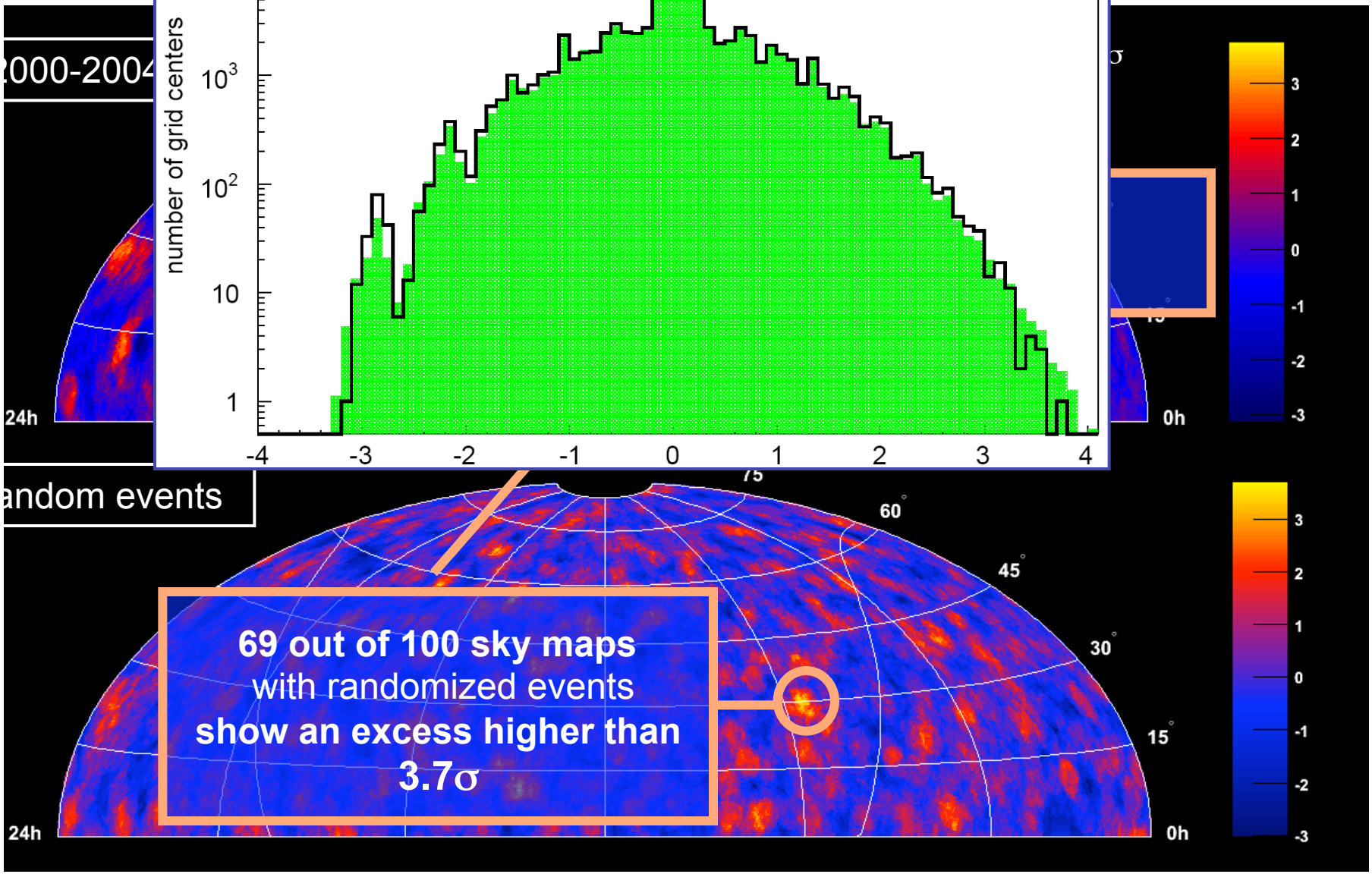
3 sigma hotspot: ≈ 4%

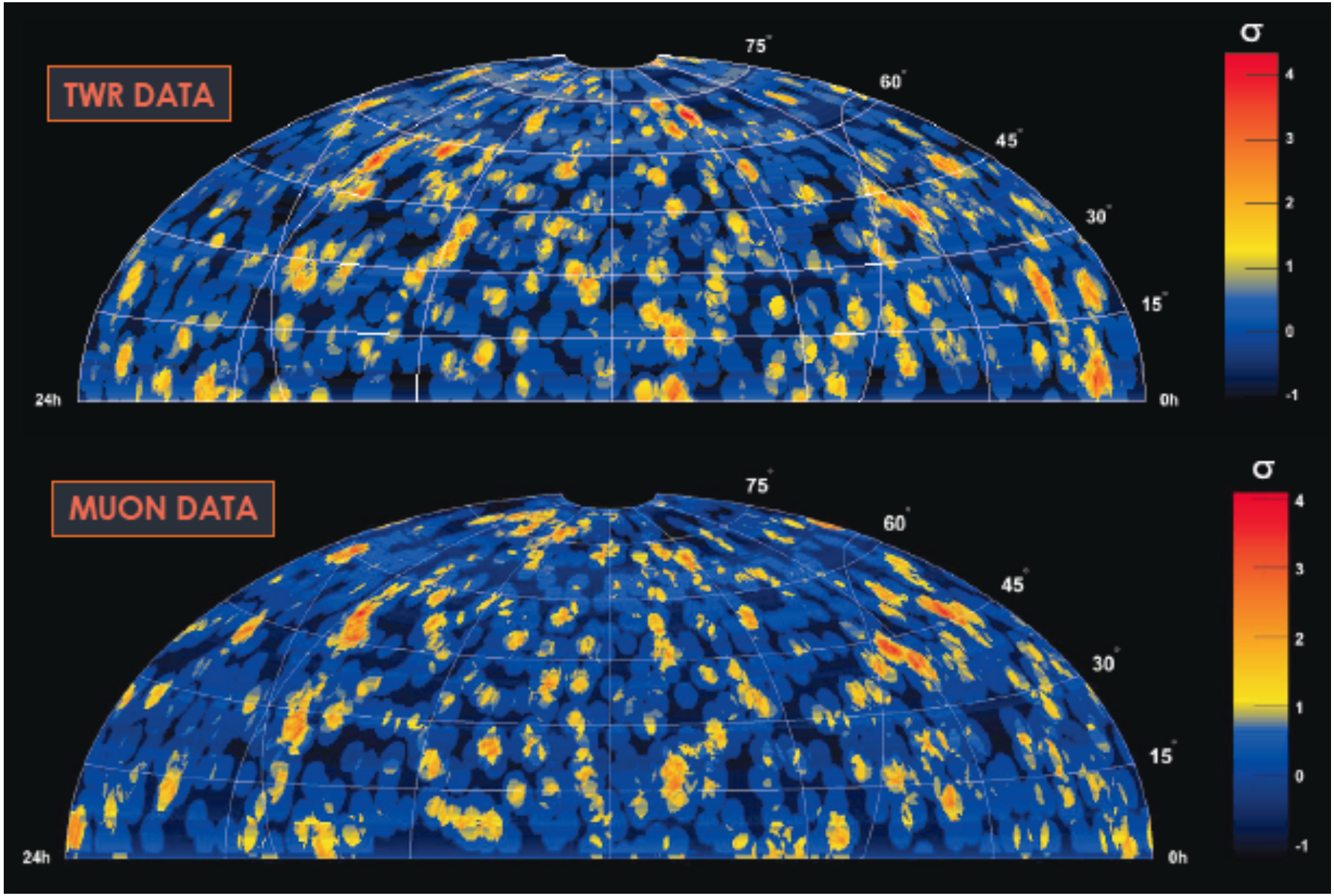

Active Galaxy
Mkn 421
AMANDA–B10
α=2.0
AMANDA–II
α=1.8
HEGRA–97 average
de Jager & Stecker
E² dN/dE (TeV cm⁻² s⁻¹)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹
1
10
log(E/TeV)

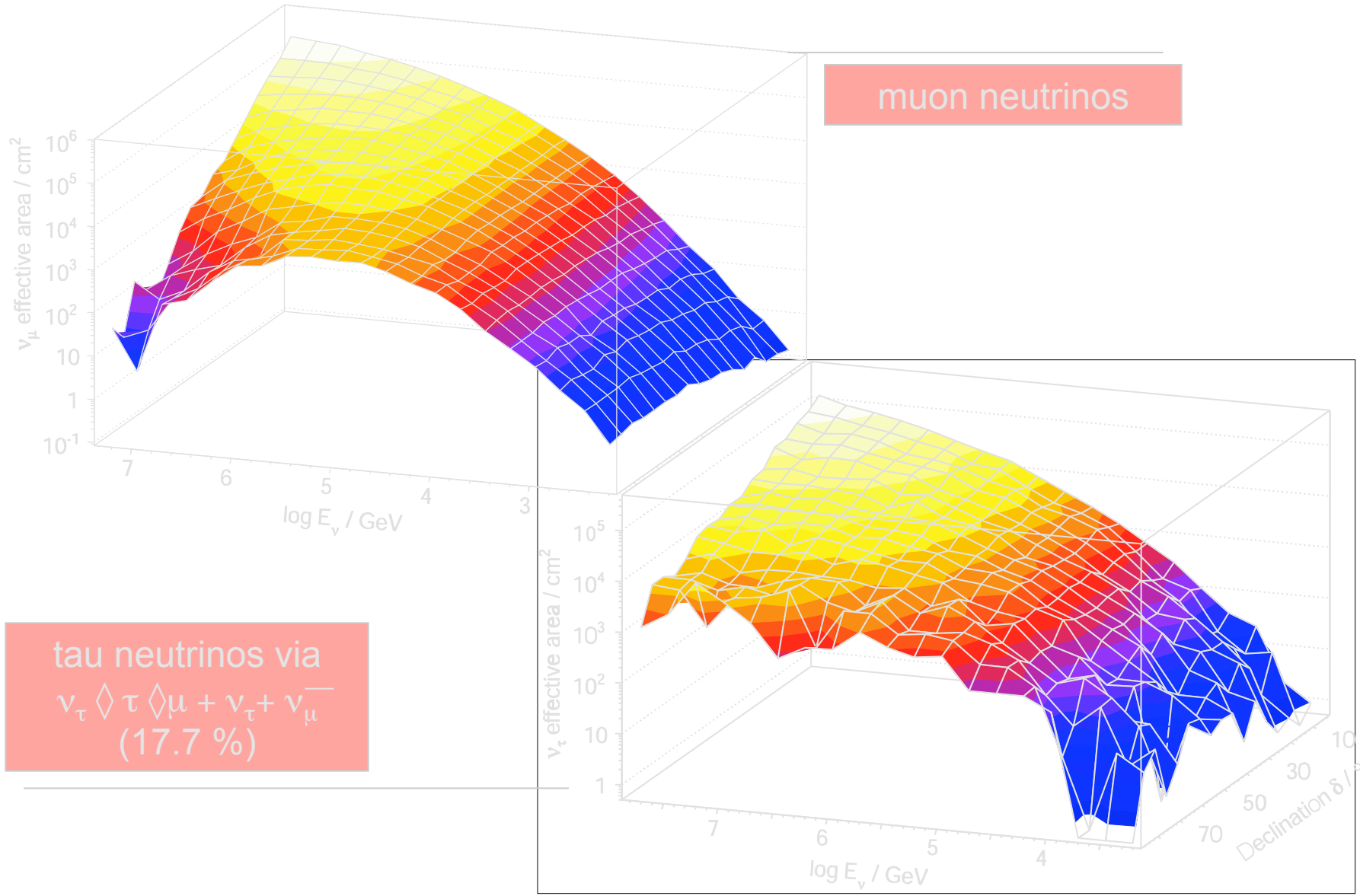


2000-03: scrambled (top) and unblinded (bottom)

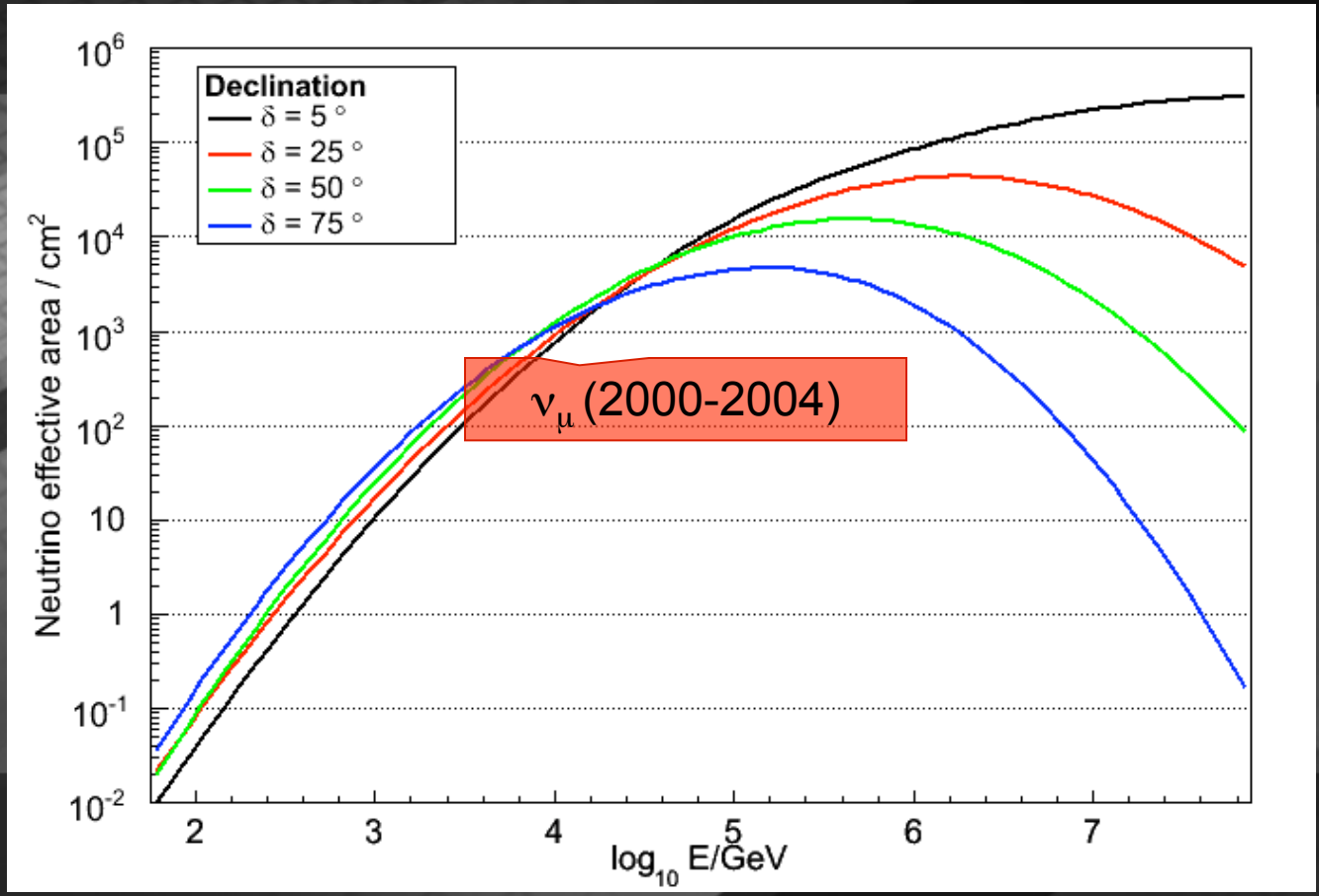



2000-2004
andom events
number of grid centers
Data
Randomized events
24h
0h
75
60
45
30
15
69 out of 100 sky maps
with randomized events
show an excess higher than
3.7σ

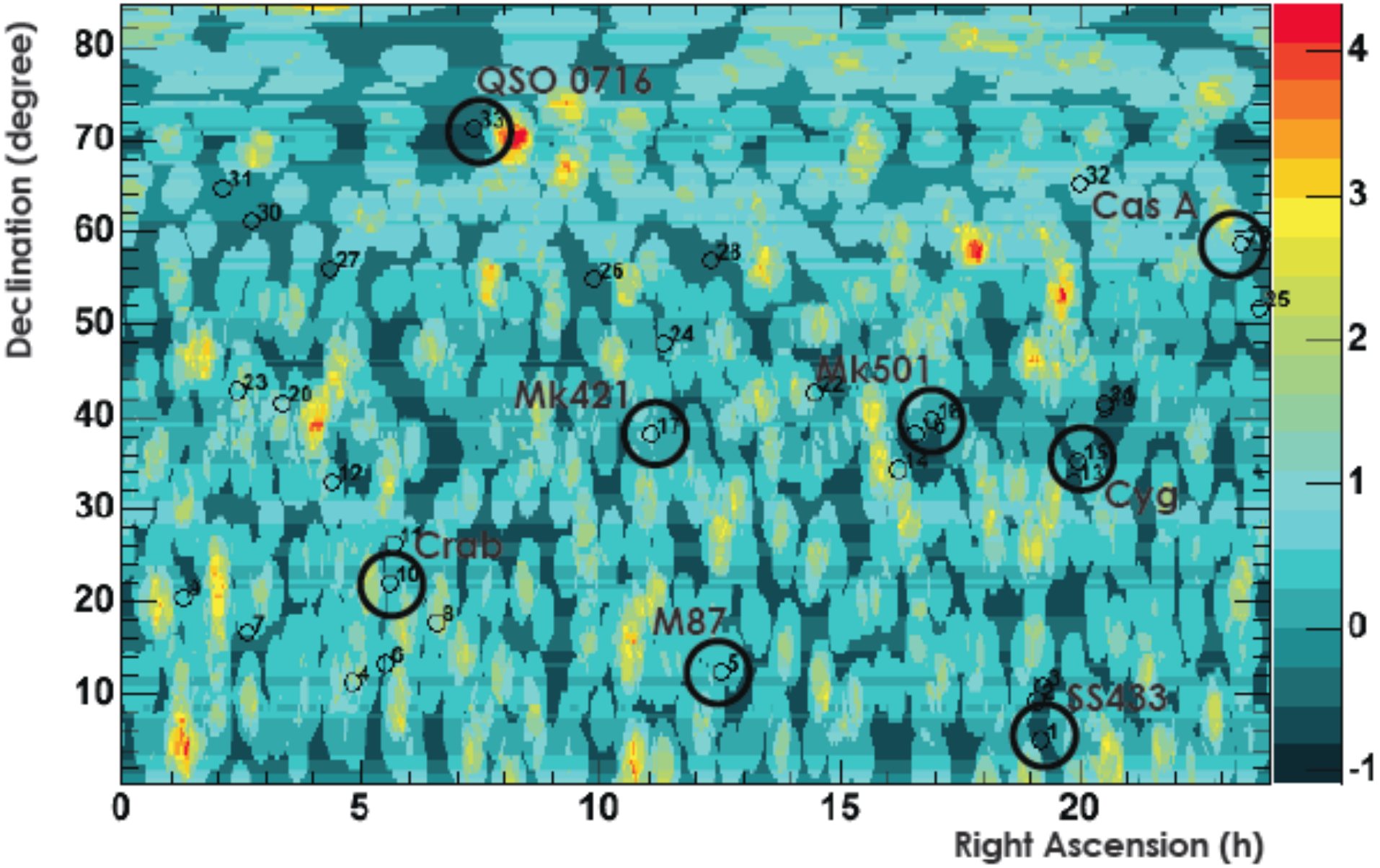

TWR DATA
75°
60°
45°
30°
15°
24h
0h
σ
4
3
2
1
0
-1
MUON DATA
75°
60°
45°
30°
15°
24h
0h
σ
4
3
2
1
0
-1


muon neutrinos
ν_μ effective area / cm^2
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
7
6
5
4
3
log E_ν / GeV
tau neutrinos via
$\nu_\tau \Diamond \tau \Diamond \mu + \nu_\tau + \bar{\nu}_\mu$
(17.7 %)
ν_τ effective area / cm^2
10^5
10^4
10^3
10^2
10
1
7
6
5
4
log E_ν / GeV
10
30
50
70
Declination δ / °

neutrino effective area



33 selected sources



search for clusters of events in the Northern sky

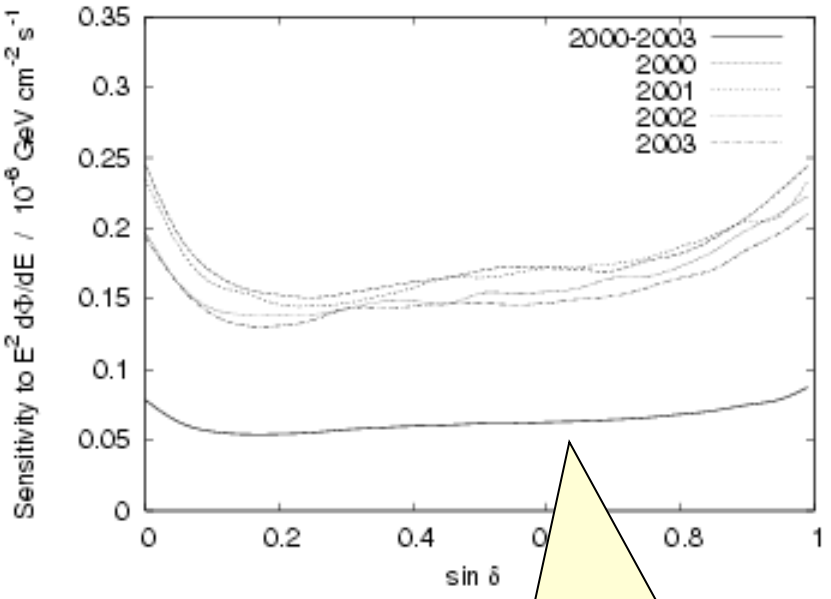
Sensitivity $\Phi_\nu/\Phi_\gamma \sim 2$ for 200 days of "high-state" and spectral results from HEGRA

Crab Nebula: MC probability to obtain an entry with at least this excess significance is **64%**

Source	Nr. of ν events (4 years)	Expected backgr. (4 years)	Flux Upper Limit $\Phi_{90\%}(E_\nu>10$ GeV) $[10^{-8}cm^{-2}s^{-1}]$
Markarian 421	6	5.58	0.68
1ES1959+650	5	3.71	0.38
SS433	2	4.50	0.21
Cygnus X-3	***6***	***5.04***	0.77
Cygnus X-1	4	5.21	0.40
Crab Nebula	10	5.36	1.25

... out of 33 sources

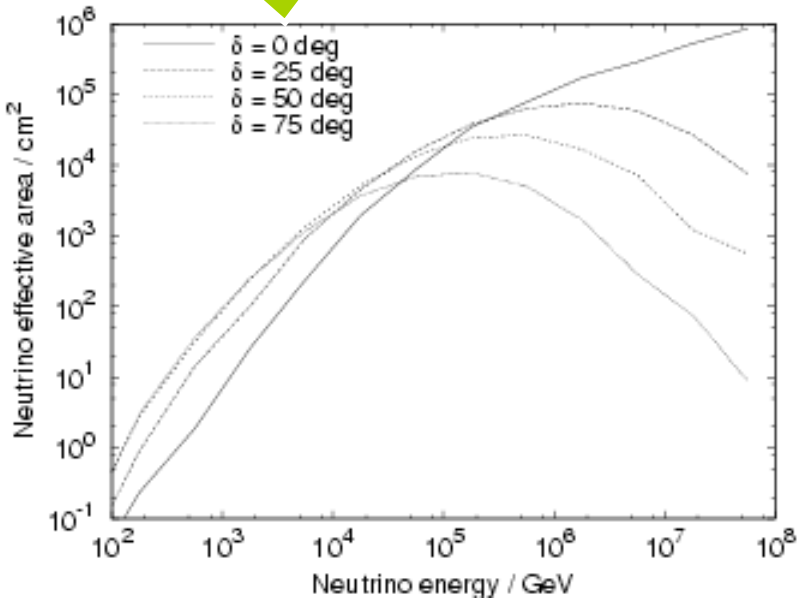
sensitivity to point sources



Declination averaged **sensitivity**, integrated in energy (E>10 GeV), **dN/dE ~ E^{-2}** :
$\Phi_\nu^{lim} \approx$ **0.6·10^{-8}** cm^{-2}s^{-1}

Sensitivities to point source with an energy spectrum proportional to dN/dE ~ E $^{-2}$

Neutrino effective area vs energy and declination



$$n_p(\nu) = T_{\text{live}} \cdot \int_\Omega \int_{E_\nu^{\min}}^{E_\nu^{\max}} A_{\text{eff}}^\nu(E_\nu, \delta) \frac{d\Phi_\nu}{d\Omega dE_\nu} d\Omega dE_\nu$$

Statistical test of 33 pre-selected objects

	Source	Nr. of ν events	Expected background	$\Phi_{90\%}(E_\nu>10\ \mathrm{GeV})$ $[10^{-8}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
TeV Blazars		6	5.6	0.7
	Markarian 501	5	5.0	0.6
	1ES 1426+428	4	4.3	0.5
	1ES 2344+514	3	4.9	0.4
	1ES 1959+650	5	3.7	1.0
GeV Blazars	QSO 0528+134	4	5.0	0.4
	QSO 0235+164	6	5.0	0.7
	QSO 1611+343	5	5.2	0.6
	QSO 1633+382	4	5.6	0.4
	QSO 0219+428	4	4.3	0.5
	QSO 0954+556	2	5.2	0.2
	QSO 0716+714	1	3.3	0.3
MicroQuasars	SS433	2	4.5	0.2
	GRS 1915+105	6	4.8	0.7
	GRO J0422+32	5	5.1	0.6
	Cygnus X-1	4	5.2	0.4
	Cygnus X-3	6	5.0	0.8
	XTE J1118+480	2	5.4	0.2
	CI Cam	5	5.1	0.7
	LSI +61 303	3	3.7	0.6
SNRs	SGR 1900+14	3	4.3	0.4
	Crab Nebula	10	5.4	1.3
	Cassiopeia A	4	4.6	
	Geminga	3	5.2	

= 2.25°-3.75°

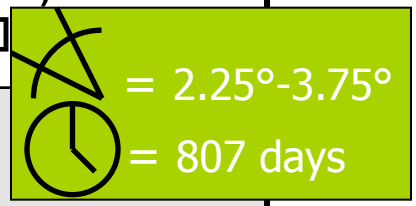
= 807 days

The statistical significance is evaluated with MC experiments on events with randomized right ascension

The chance probability of such an excess (or higher) in any of the 33 objects is **64%**

Statistical test of 33 pre-selected objects

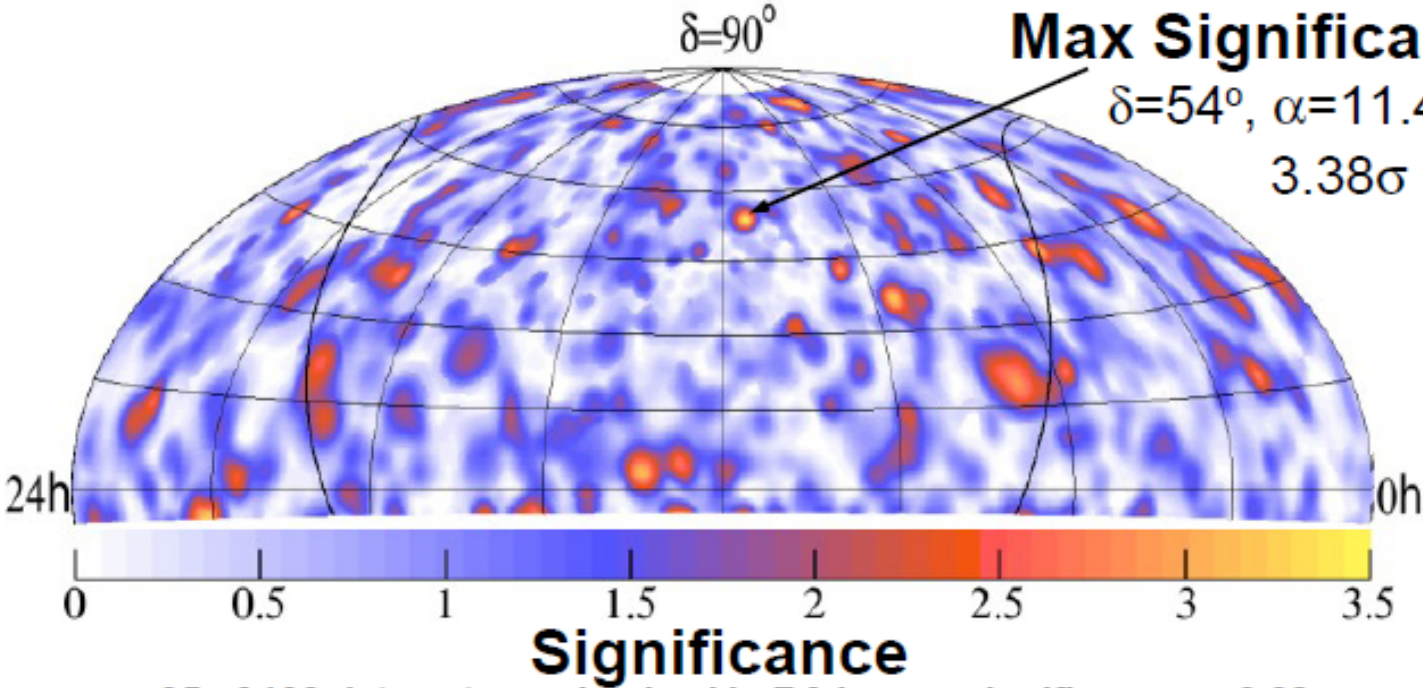
	Source	Nr. of ν events	Expected background	$\Phi_{90\%}(E_\nu>10$ GeV) $[10^{-8}cm^{-2}s^{-1}]$
TeV Blazars	Markarian 421	6	5.6	0.7
	Markarian 501	5	5.0	0.6
	1ES 1426+428	4	4.3	0.5
	1ES 2344+514	3	4.9	0.4
	1ES 1959+650	5	3.7	1.0
GeV Blazars	QSO 0528+134	4	5.0	0.4
	QSO 0235+164	6	5.0	0.7
	QSO 1611+343	5	5.2	0.6
	QSO 1633+382	4	5.6	0.4
	QSO 0219+428	4	4.3	0.5
	QSO 0954+556	2	5.2	0.2
	QSO 0716+714	1	3.3	0.3
MicroQuasars	SS433	2	4.5	0.2
	GRS 1915+105	6	4.8	0.7
	GRO J0422+32	5	5.1	0.6
	Cygnus X-1	4	5.2	0.4
	Cygnus X-3	6	5.0	0.8
	XTE J1118+480	2	5.4	0.2
	CI Cam	5	5.1	0.7
	LSI +61 303	3	3.7	0.6
SNRs	SGR 1900+14	3	4.3	0.4
	Crab Nebula	10	5.4	1.3
	Cassiopeia A	4	4.6	
	Geminga	3	5.2	



The statistical significance is evaluated with MC experiments on events with randomized right ascension

The chance probability of such an excess (or higher) in any of the 33 objects is **64%**

AMANDA All-Sky Search



95 of 100 data sets randomized in RA have a significance ≥ 3.38σ

Source	μ_{90}	P-value
Crab	9.27	0.10
MGRO J2019+37	9.67	0.077
Mrk 421	2.54	0.82
Mrk 501	7.28	0.22
LS I +61 303	14.74	0.03
Geminga	12.77	0.0086

$E^2\Phi < \mu 90 * 10^{-11}$ TeV cm^{-2} s^{-1}

The probability of obtaining p ≤ 0.0086 for at least one of the 26 sources is 20%

intermezzo on point source search

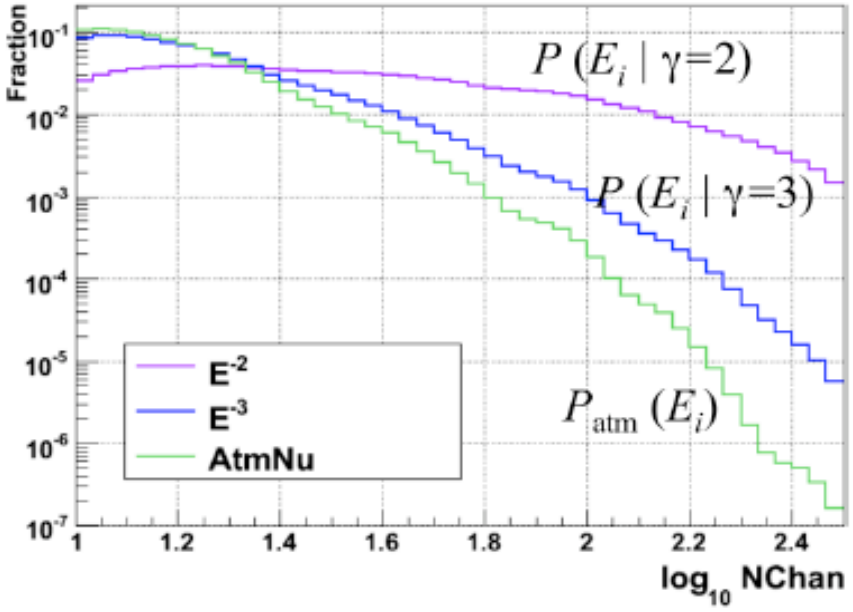
Signal PDF: $$\mathcal{S}_i(\vec{x}_i, \vec{x}_s, \sigma_i, Nch_i, \gamma) = \underbrace{\frac{1}{2\pi\sigma_i^2} e^{-\frac{|\vec{x}_i - \vec{x}_s|^2}{2\sigma_i^2}}}_{\text{Space Angle}} \cdot \underbrace{P(Nch_i|\gamma)}_{\text{Energy}}$$

Space Angle Term:

- Assume $P(|x_i - x_s|)$ is a 2-D Gaussian
- Space angle uncertainty σ_i can be measured for each event during reconstruction

Energy Term:

- Use number of hit channels (Nch) as a measure of energy



Point Source Search

Background: Atmospheric neutrinos are uniform in RA

$$\mathcal{B}_i = \frac{1}{\Omega} \cdot P_{atm}(Nch_i)$$

Assume a fraction of events are signal, remainder are background

Partial probability for each event:

$$P(\vec{x}_s, n_s, \gamma, \vec{x}_i, Nch_i, \sigma_i) = \frac{n_s}{N}\mathcal{S}_i + (1 - \frac{n_s}{N})\mathcal{B}_i$$

Likelihood function:

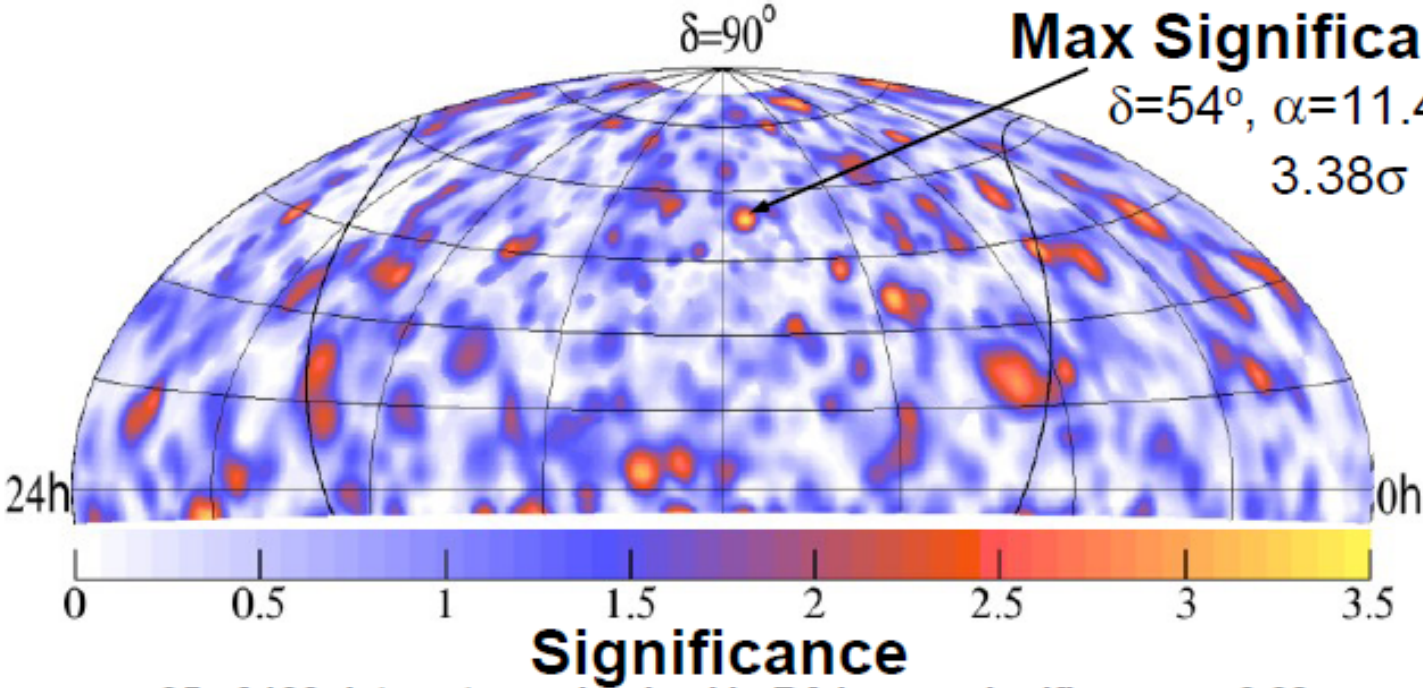
$$\mathcal{L}(\vec{x}_s, n_s, \gamma) = \prod_{i=1}^{N} P(\vec{x}_s, n_s, \gamma, \vec{x}_i, Nch_i, \sigma_i)$$

Numerically minimize -Log L with respect to n_s and γ, obtaining best fit values $\hat{n}_s, \hat{\gamma}$

Log likelihood:

$$\lambda = -2 \cdot log\left[\frac{\mathcal{L}(\vec{x}_s, n_s = 0)}{\mathcal{L}(\vec{x}_s, \hat{n}_s, \hat{\gamma})}\right]$$

AMANDA All-Sky Search



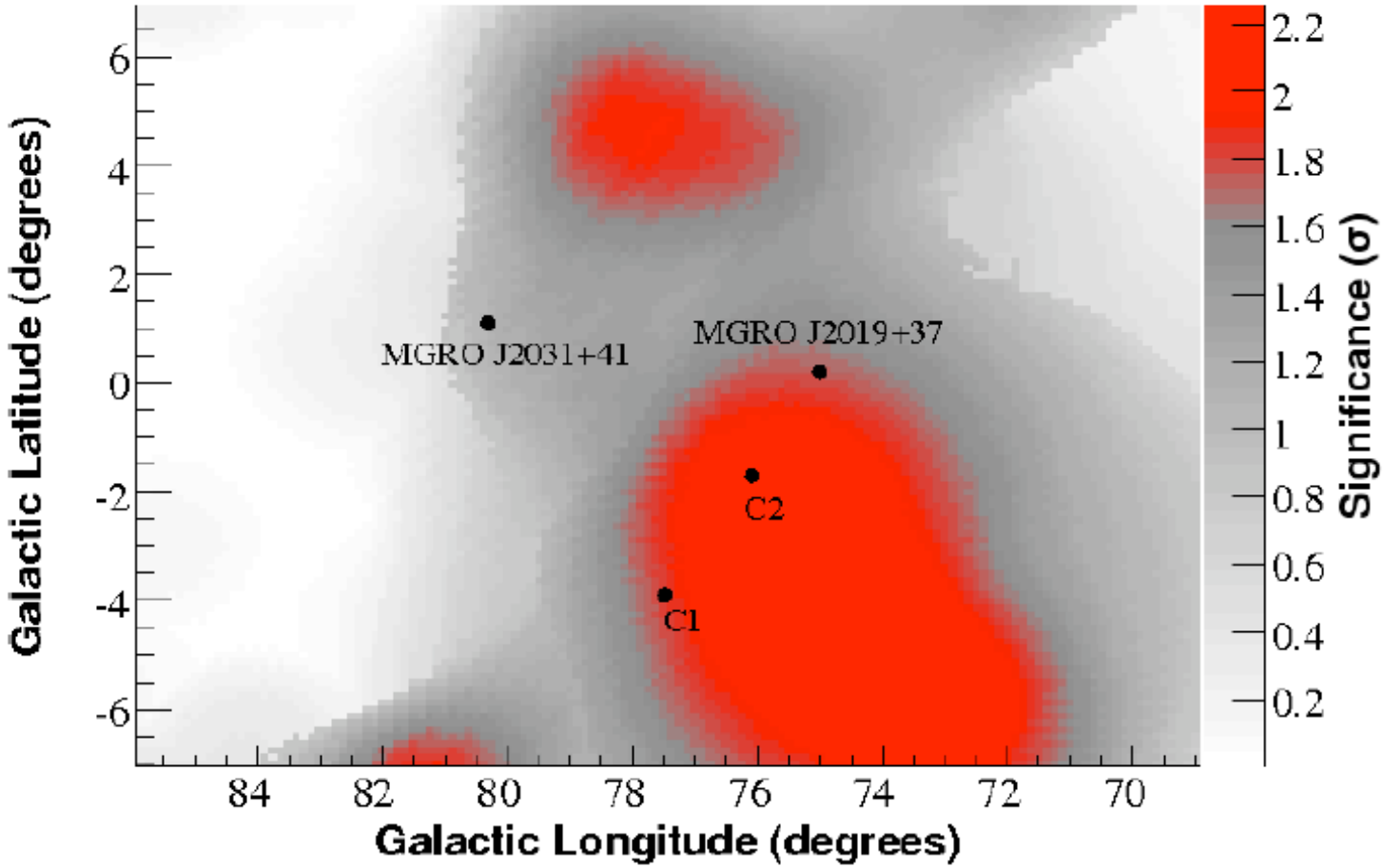
95 of 100 data sets randomized in RA have a significance ≥ 3.38σ

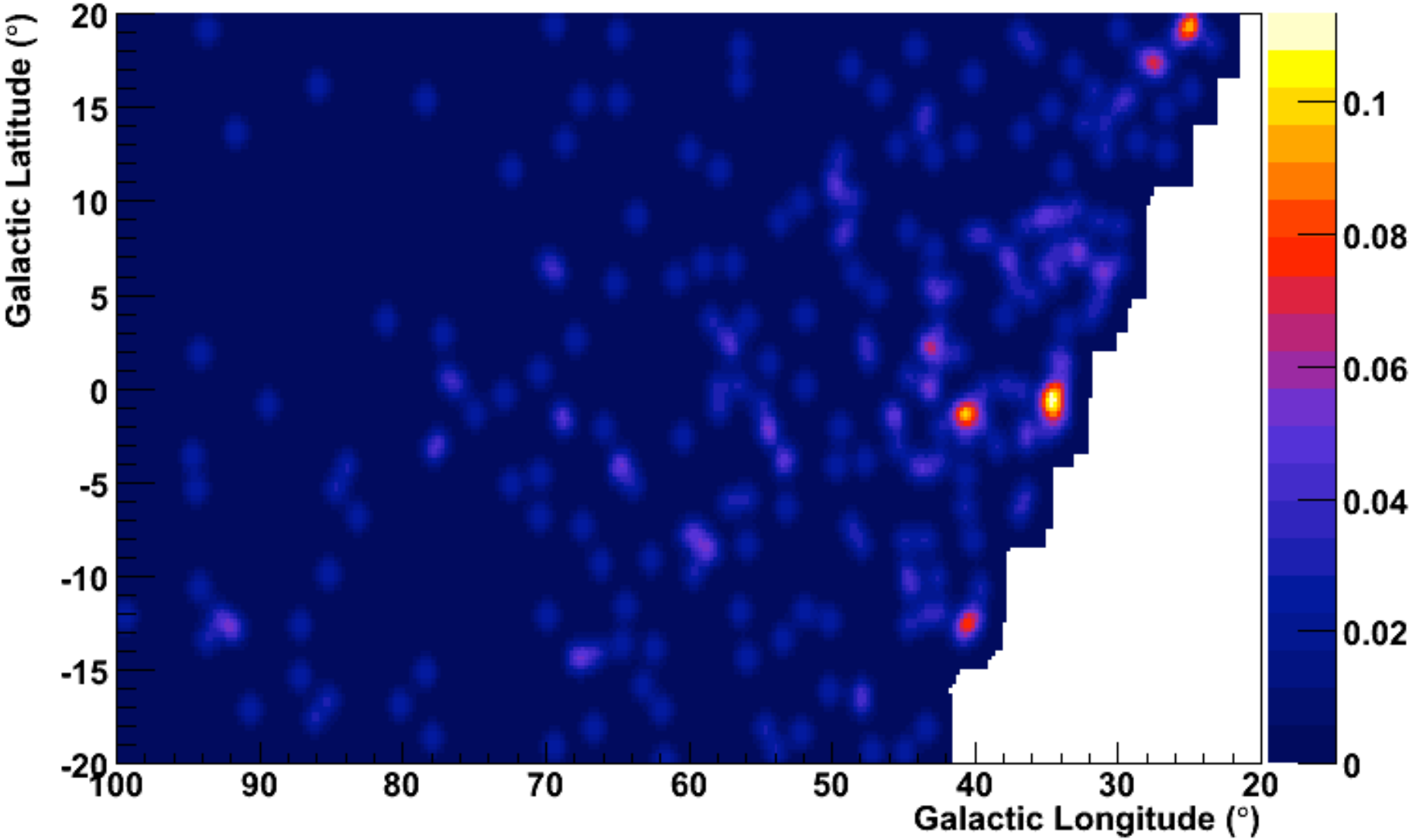
Source	μ_{90}	P-value
Crab	9.27	0.10
MGRO J2019+37	9.67	0.077
Mrk 421	2.54	0.82
Mrk 501	7.28	0.22
LS I +61 303	14.74	0.03
Geminga	12.77	0.0086

$E^2\Phi < \mu 90 * 10^{-11}$ TeV cm^{-2} s^{-1}

The probability of obtaining p ≤ 0.0086 for at least one of the 26 sources is 20%

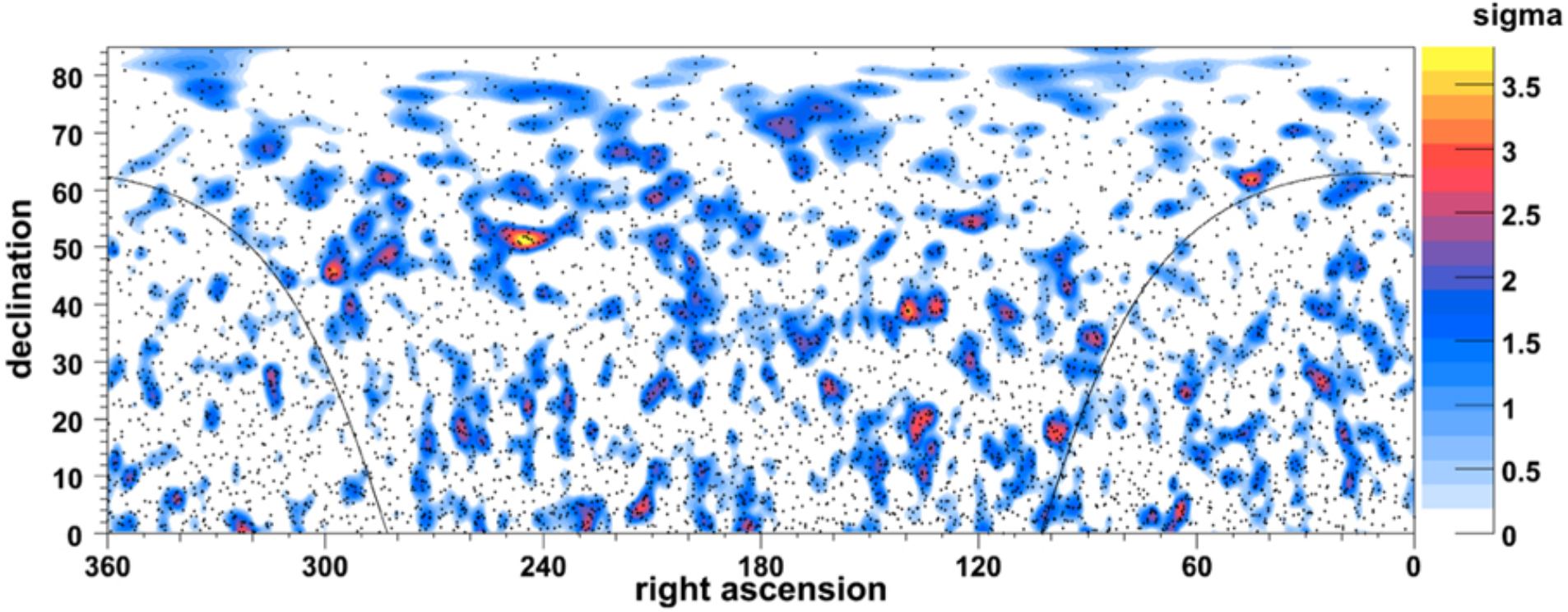
The Cygnus Region





IceCube 5 years (E > 40 TeV)

data taken with IceCube 22 strings (>5000 events)



22strings

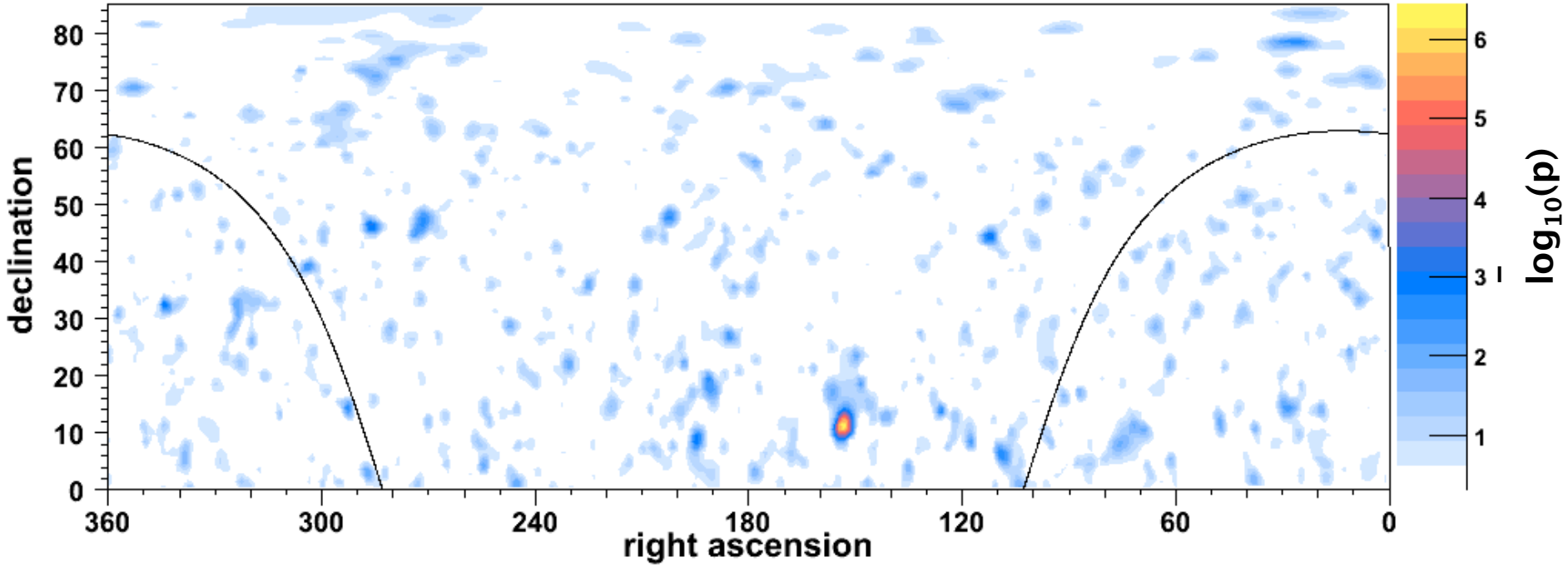
- 250 days
- > 25 per day

80 strings
(conservatively)

- 200 per day

(scrambled map)

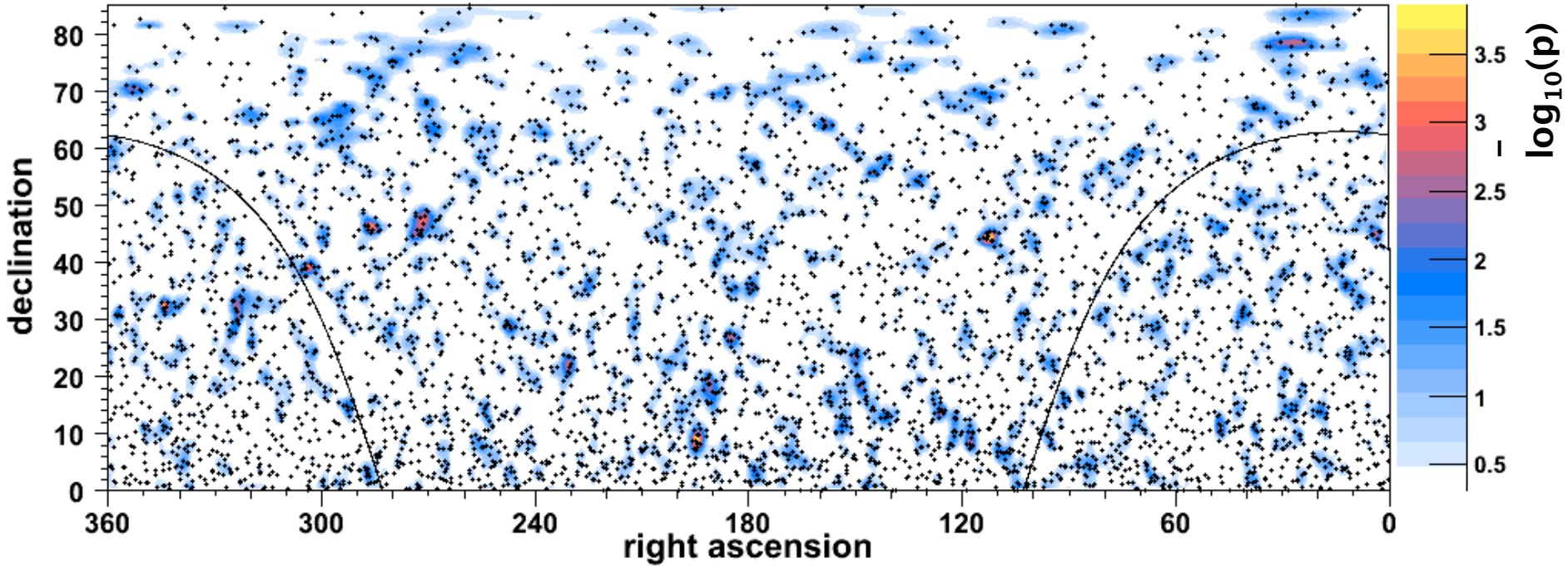
IC22 (255 days) all-sky results (unblinded)



the hottest spot location is: Ra 153.5 , Dec 11.5
estimated number of events = 7.7 estimated gamma = 1.65

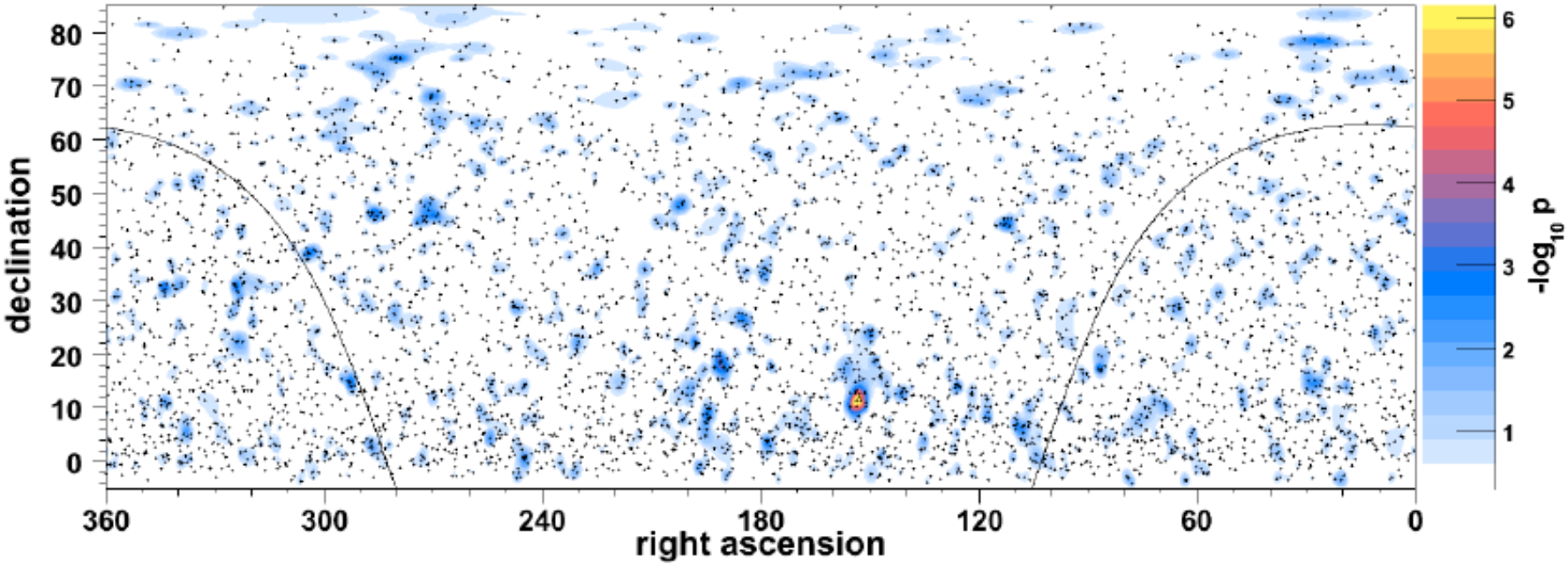
pre-trials: $-\log_{10}$(p-value) : 6.14 (4.8 sigma)

IC22 (255 days) All-Sky Results



all sky search, not using energy term in likelihood
neutrino events overlayed

IceCube 22 String



the hottest spot location is: Ra 153.5 , Dec 11.5
estimated number of events = 7.7 estimated gamma = 1.65

pre-trials: $-\log_{10}$(p-value) : 6.14 (4.8 sigma)

post-trials p-value of analysis is ~ 1.34% (2.2 sigma)

Results I: A Priori Source List

Lowest p-value (0.07) is for 1ES 1959+650.

Not significant after trial factor of 28 sources in list.

Obj. Name	ra(deg)	dec(deg)	p-value (pre-trial)
MGRO_J2019+37	(304.830 ,	36.830) :	0.250960
MGRO_J1908+06	(287.270 ,	6.280) :	0.500000
Cyg_OB2	(308.083 ,	41.510) :	0.500000
SS_433	(287.957 ,	4.983) :	0.316697
Cyg_X-1	(299.591 ,	35.202) :	0.500000
LS_I_+61_303	(40.132 ,	61.229) :	0.500000
GRS_1915+105	(288.798 ,	10.946) :	0.500000
XTE_J1118+480	(169.545 ,	48.037) :	0.081888
GRO_J0422+32	(65.428 ,	32.907) :	0.500000
Geminga	(98.476 ,	17.770) :	0.500000
Crab_Nebula	(83.633 ,	22.014) :	0.500000
Cas_A	(350.850 ,	58.815) :	0.500000
Mrk_421	(166.114 ,	38.209) :	0.500000
Mrk_501	(253.468 ,	39.760) :	0.500000
1ES_1959+650	(299.999 ,	65.149) :	0.070597
1ES_2344+514	(356.770 ,	51.705) :	0.500000
H_1426+428	(217.136 ,	42.672) :	0.500000
1ES_0229+200	(38.202 ,	20.287) :	0.500000
BL_Lac	(330.680 ,	42.278) :	0.367984
S5_0716+71	(110.473 ,	71.343) :	0.309062
3C66A	(35.665 ,	43.035) :	0.313330
3C_454.3	(343.491 ,	16.148) :	0.500000
4C_38.41	(248.815 ,	38.135) :	0.500000
PKS_0528+134	(82.735 ,	13.532) :	0.500000
3C_273	(187.278 ,	2.052) :	0.369104
M87	(187.706 ,	12.391) :	0.500000
NGC_1275	(49.951 ,	41.512) :	0.212796
Cyg_A	(299.868 ,	40.734) :	0.500000

(p-values > 0.5 are not estimated, and reported as 0.5)

The Near Future: IceCube-40

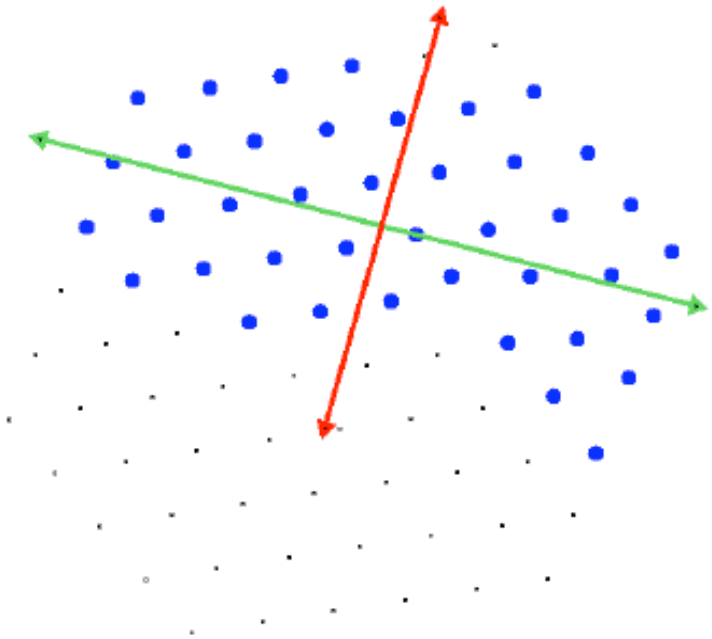
IceCube currently running with 40 strings deployed.

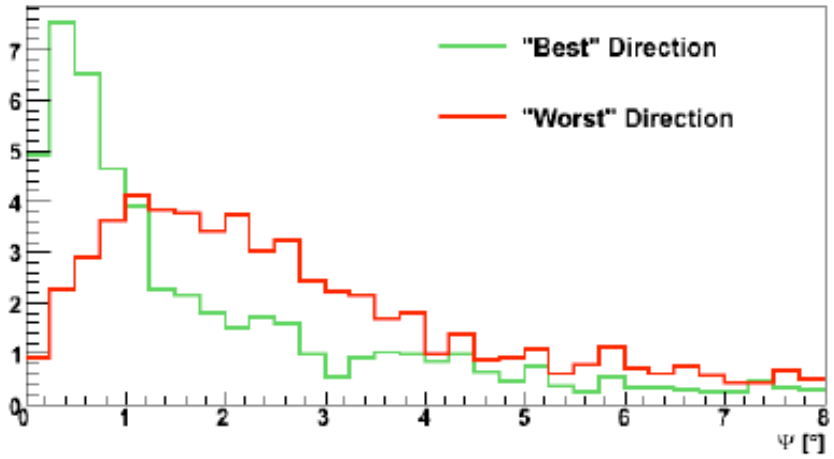
~ 2x effective area of 22 strings.

More fully contained strings.

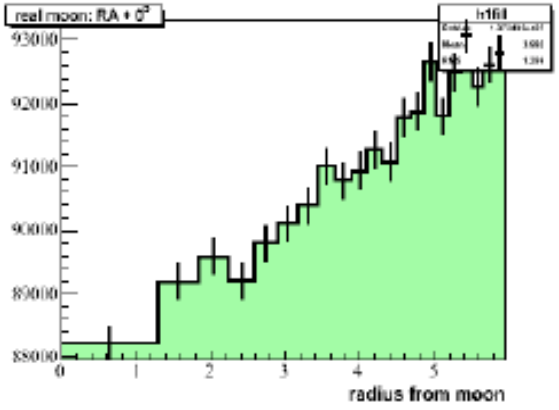
Short direction: angular resolution comparable to IceCube 22.

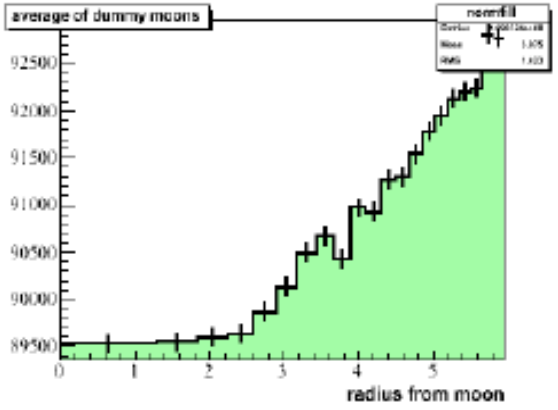
Long direction: angular resolution comparable to full IceCube 80 configuration.

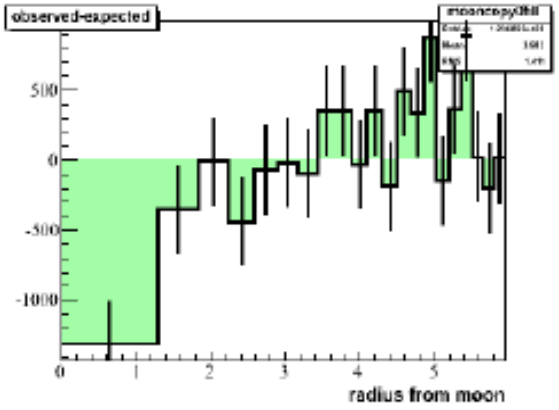


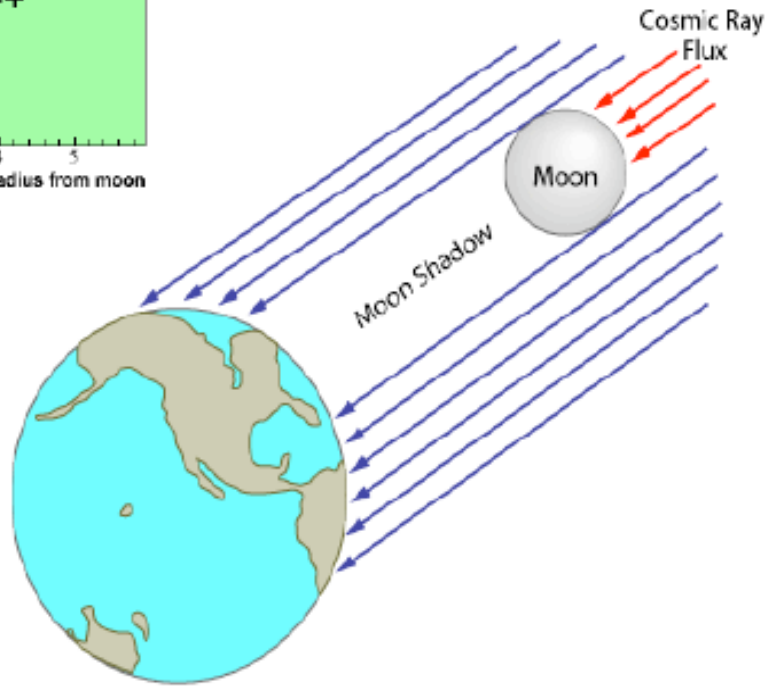


Moon Shadow

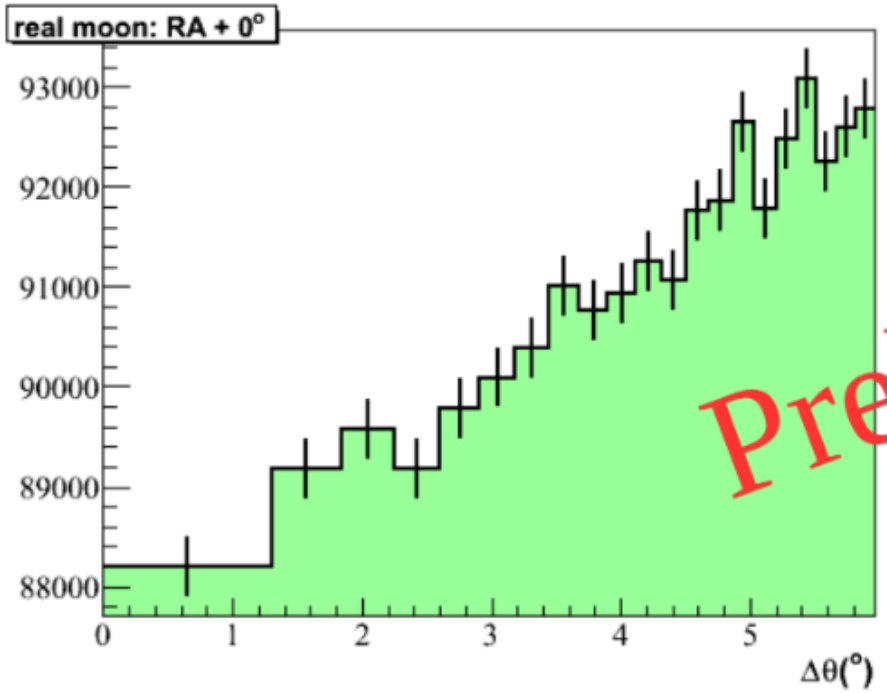


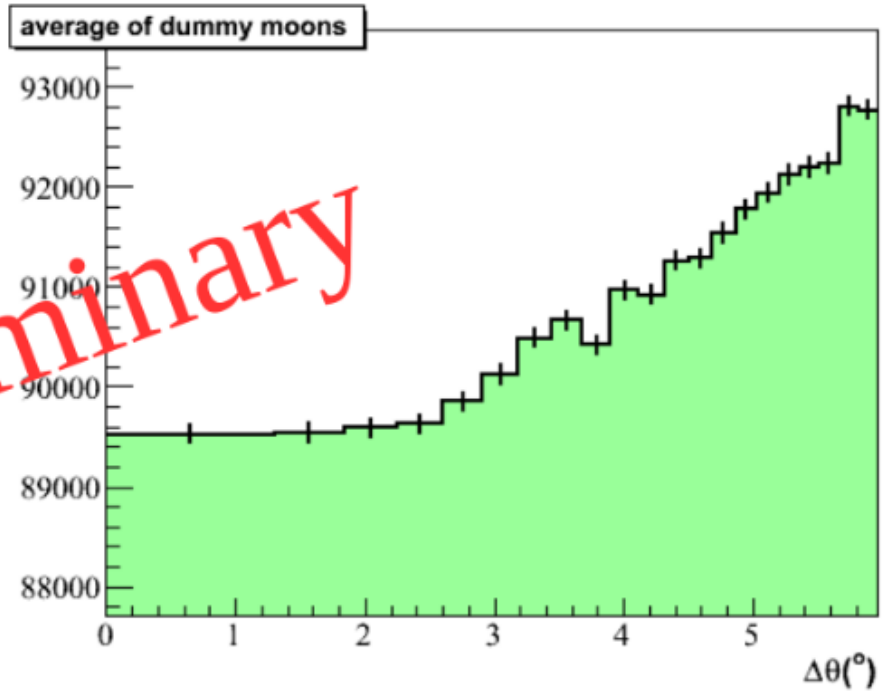


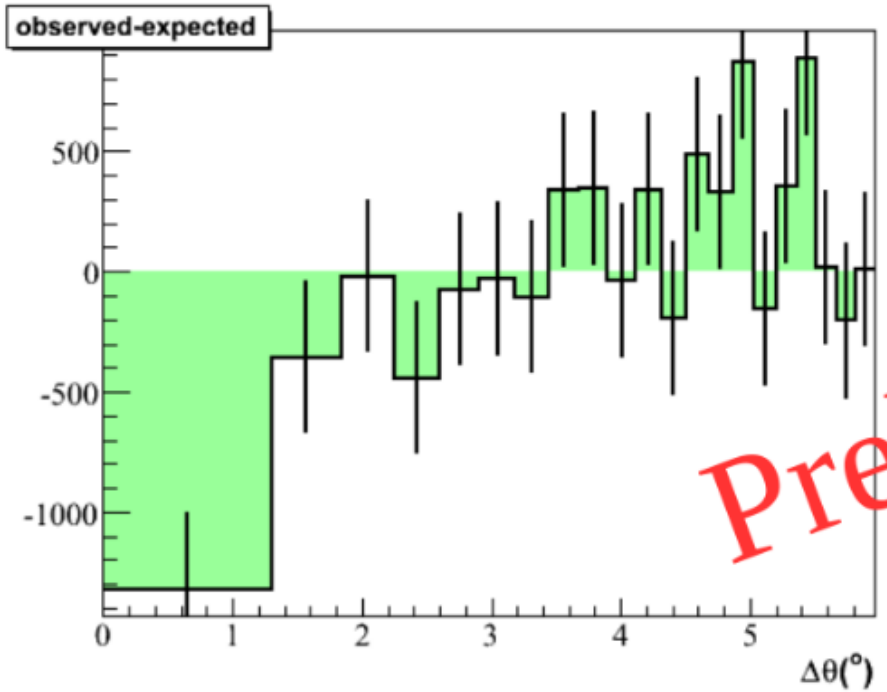




4.2σ deficit of events from direction of moon in the IceCube 40-string detector confirms pointing accuracy







Preliminary

Preliminary

observed: 88202 events

expected: 89522 events

deficit: -1320 events

error: 315 events

significance: -4.2 σ