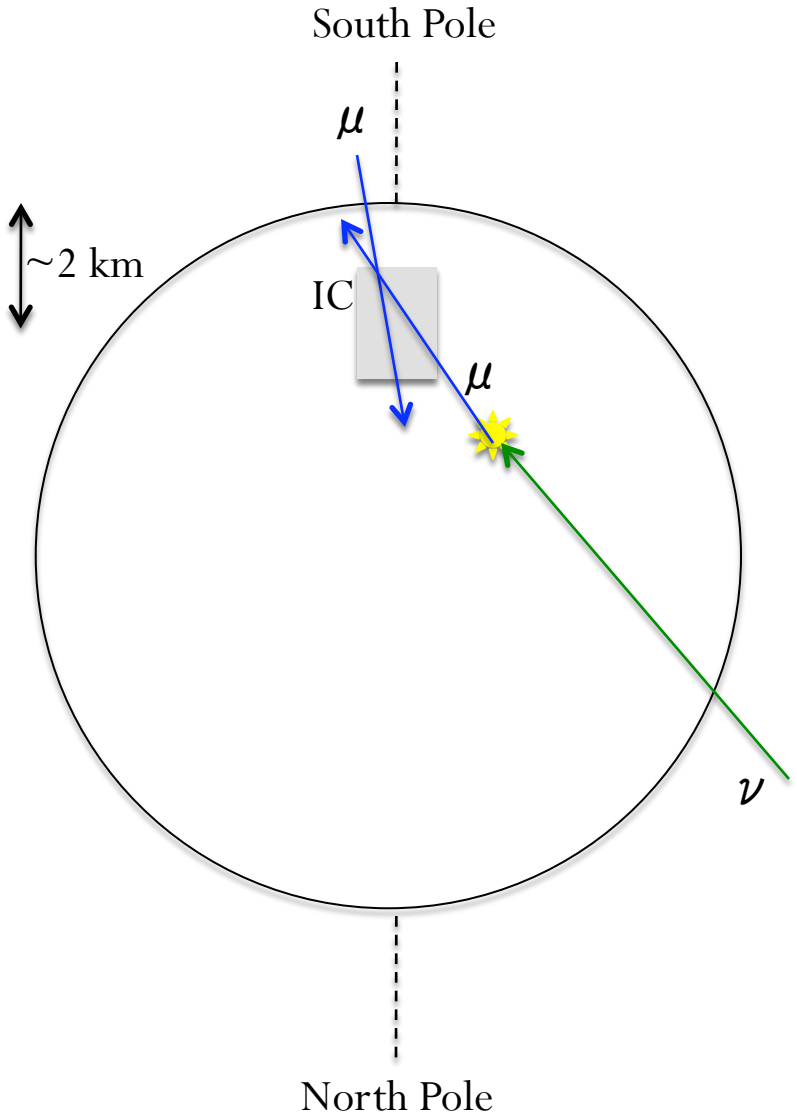
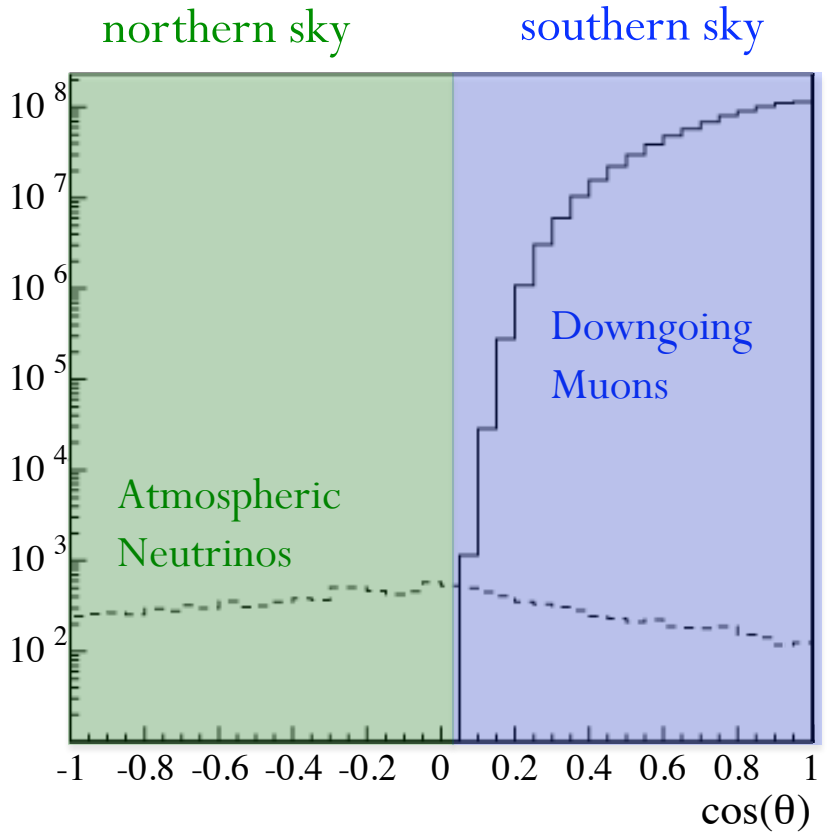
IceCube 40-string Point Source Search: The First 6 Months

Jon Dumm

31st ICRC, Łódź 2009

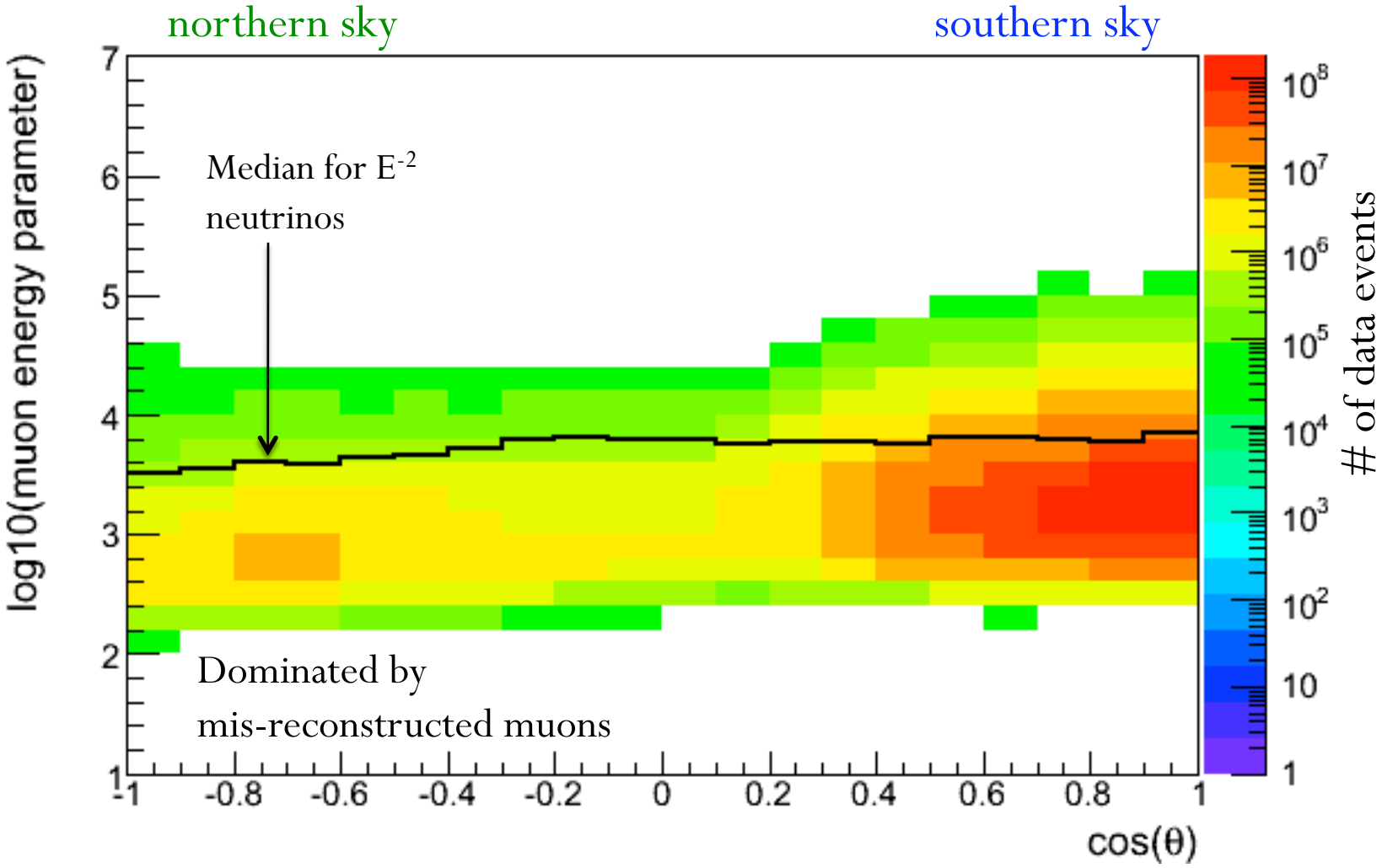
Backgrounds



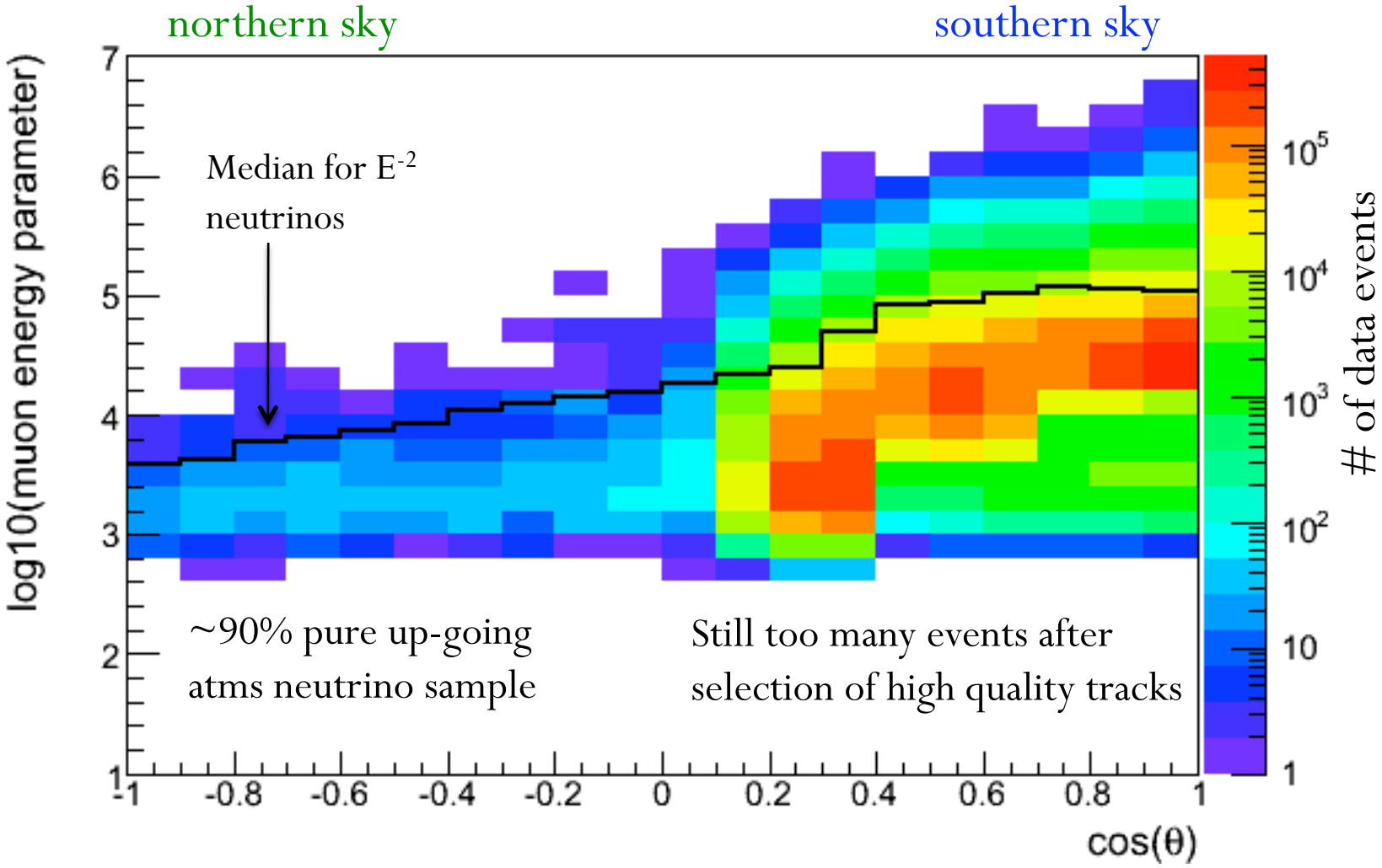


Atmospheric backgrounds to extra-terrestrial neutrino searches at the depth of IceCube

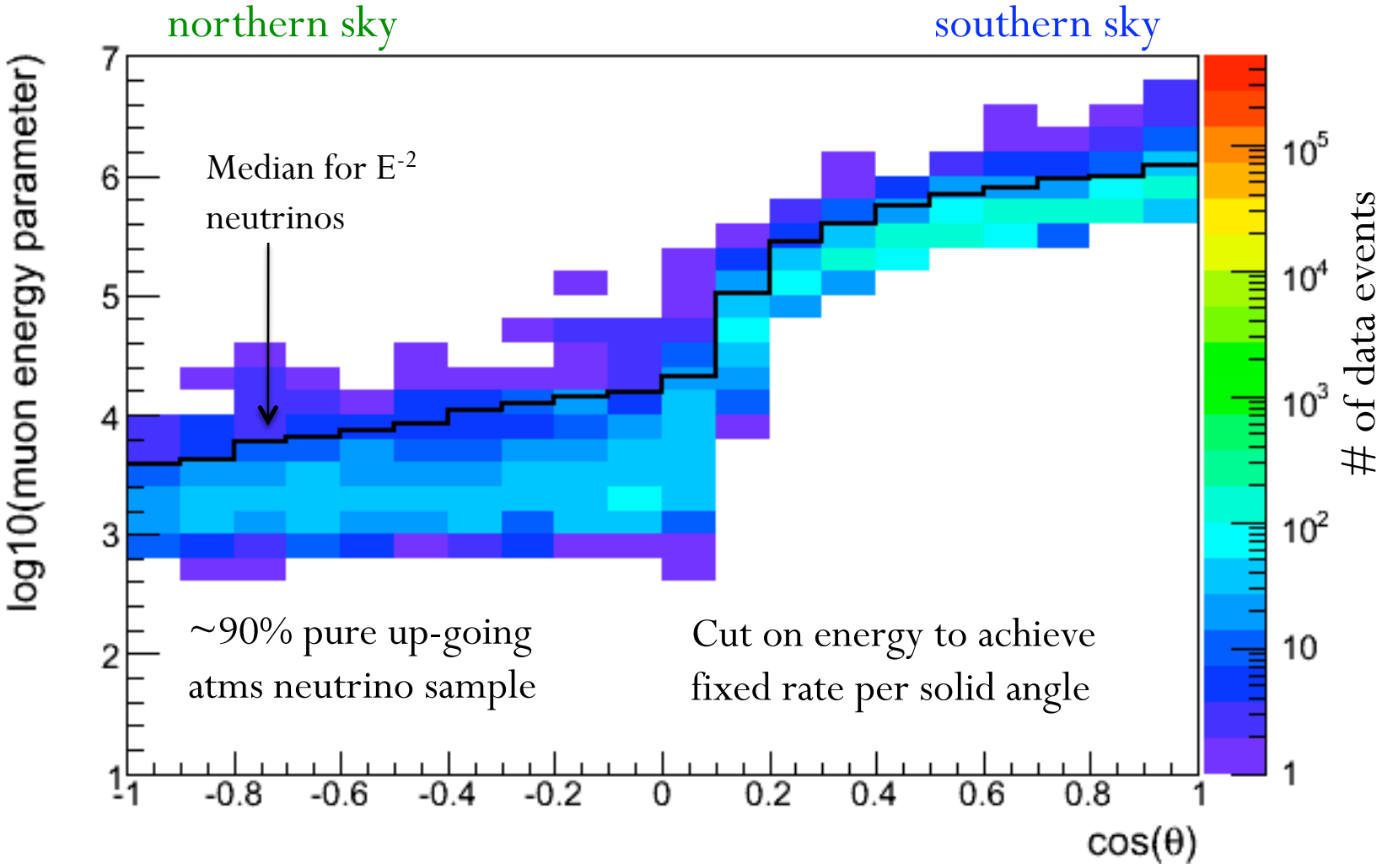
Energy vs Zenith – Trigger Level



Energy vs Zenith – Quality Cuts



Energy vs Zenith – Quality + Energy Cuts



Maximum Likelihood Analysis with Energy

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

Maximum Likelihood Analysis with Energy

Signal PDF:

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

Background PDF:

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

Data used for background

Maximum Likelihood Analysis with Energy

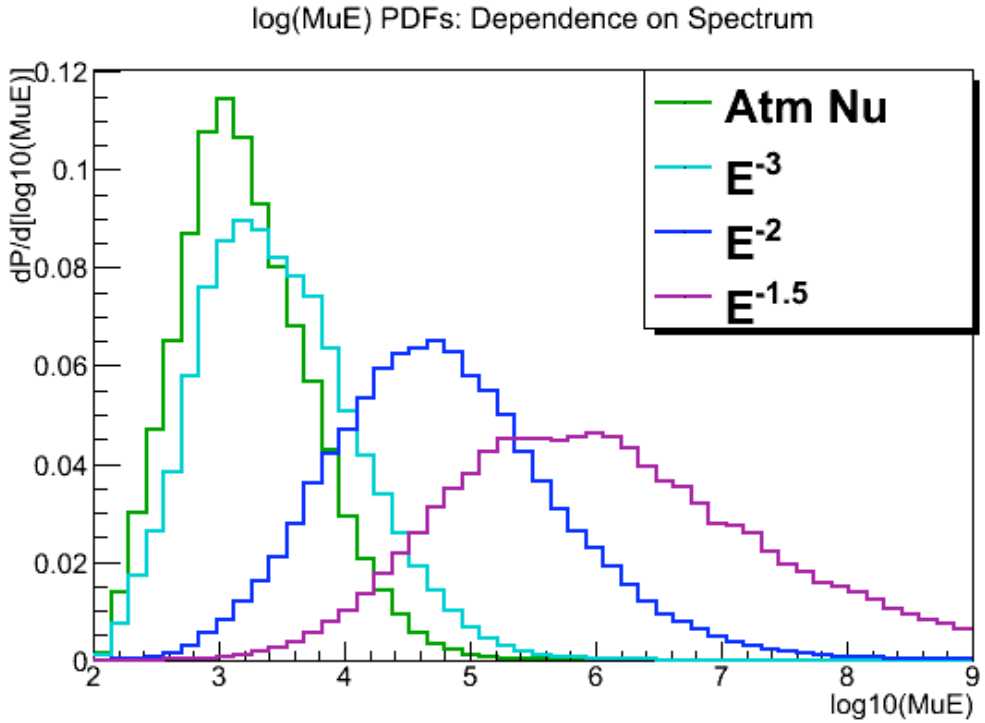
Signal PDF:

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

Background PDF:

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Data used for background

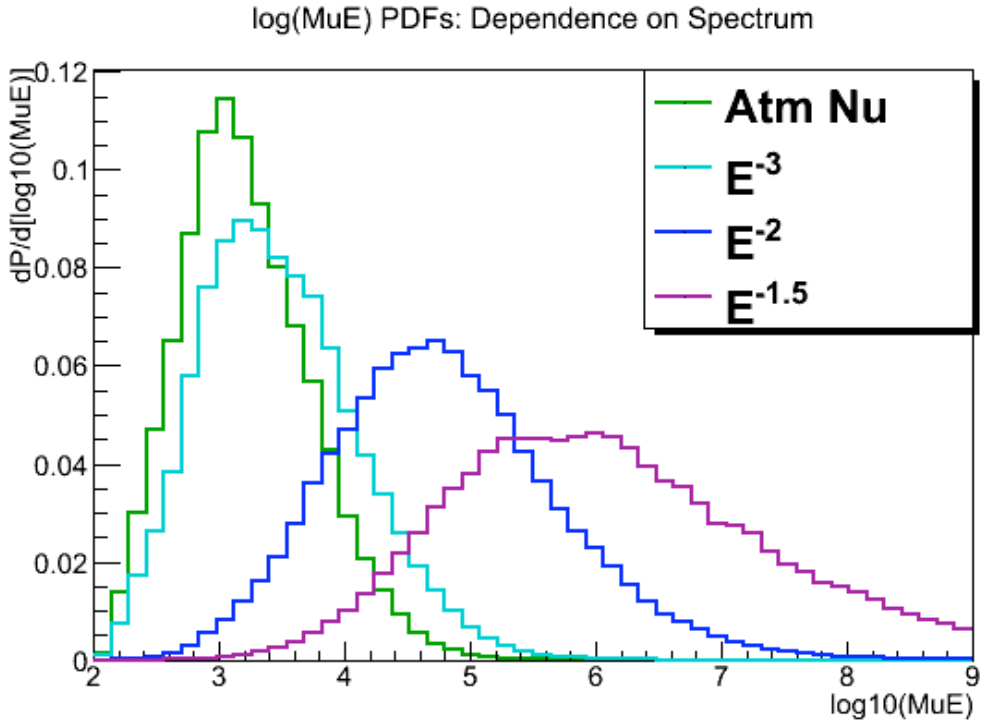


Maximum Likelihood Analysis with Energy

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

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

Data used for background



Final significance comes from scrambling the data in r.a.

Additional terms can be added to likelihood (e.g. time)

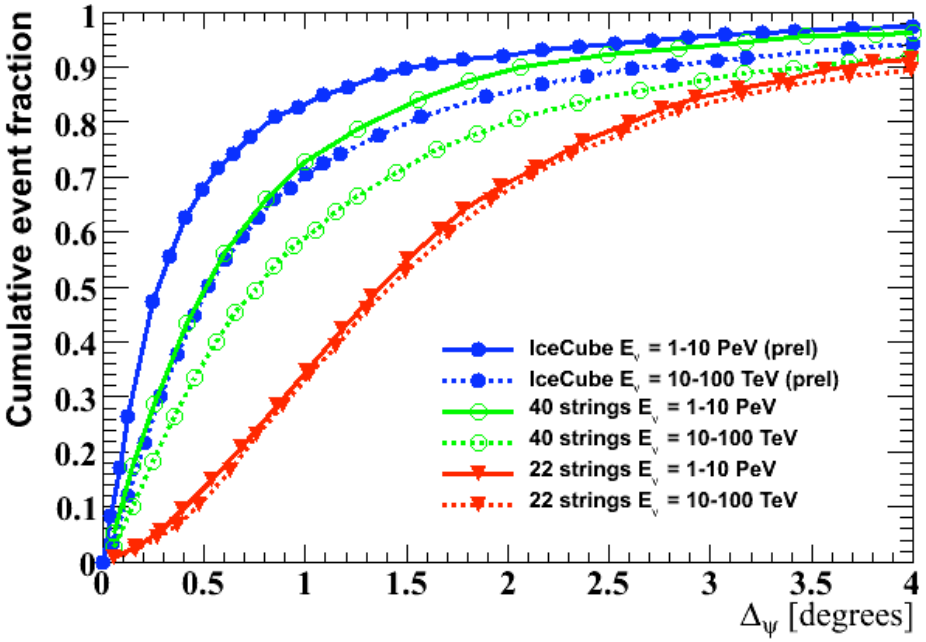
Median of the PSF for
E^{-2} neutrino spectrum:

0.7° in northern sky

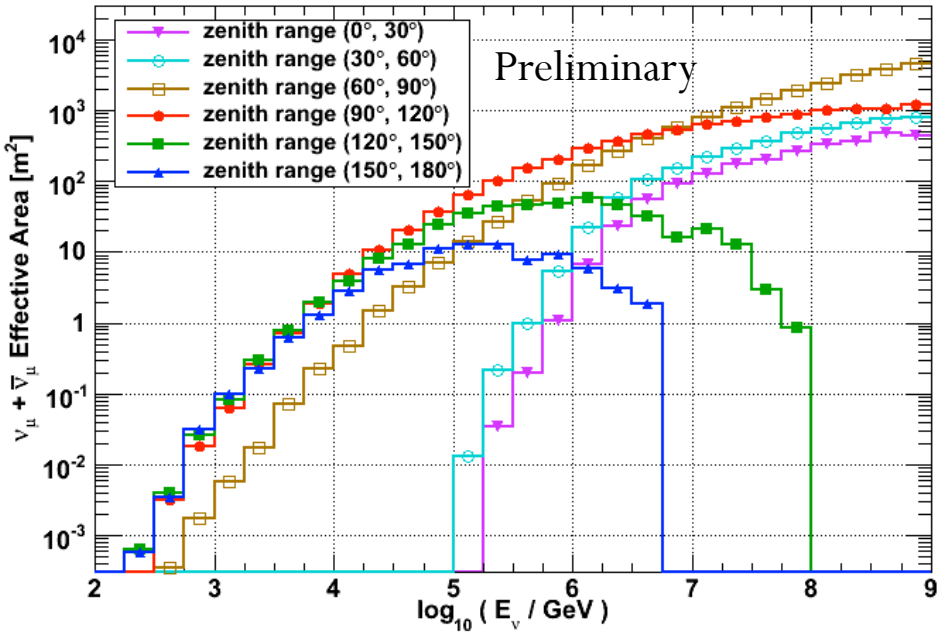
0.5° in southern sky

(difference due to energy of events in final sample)

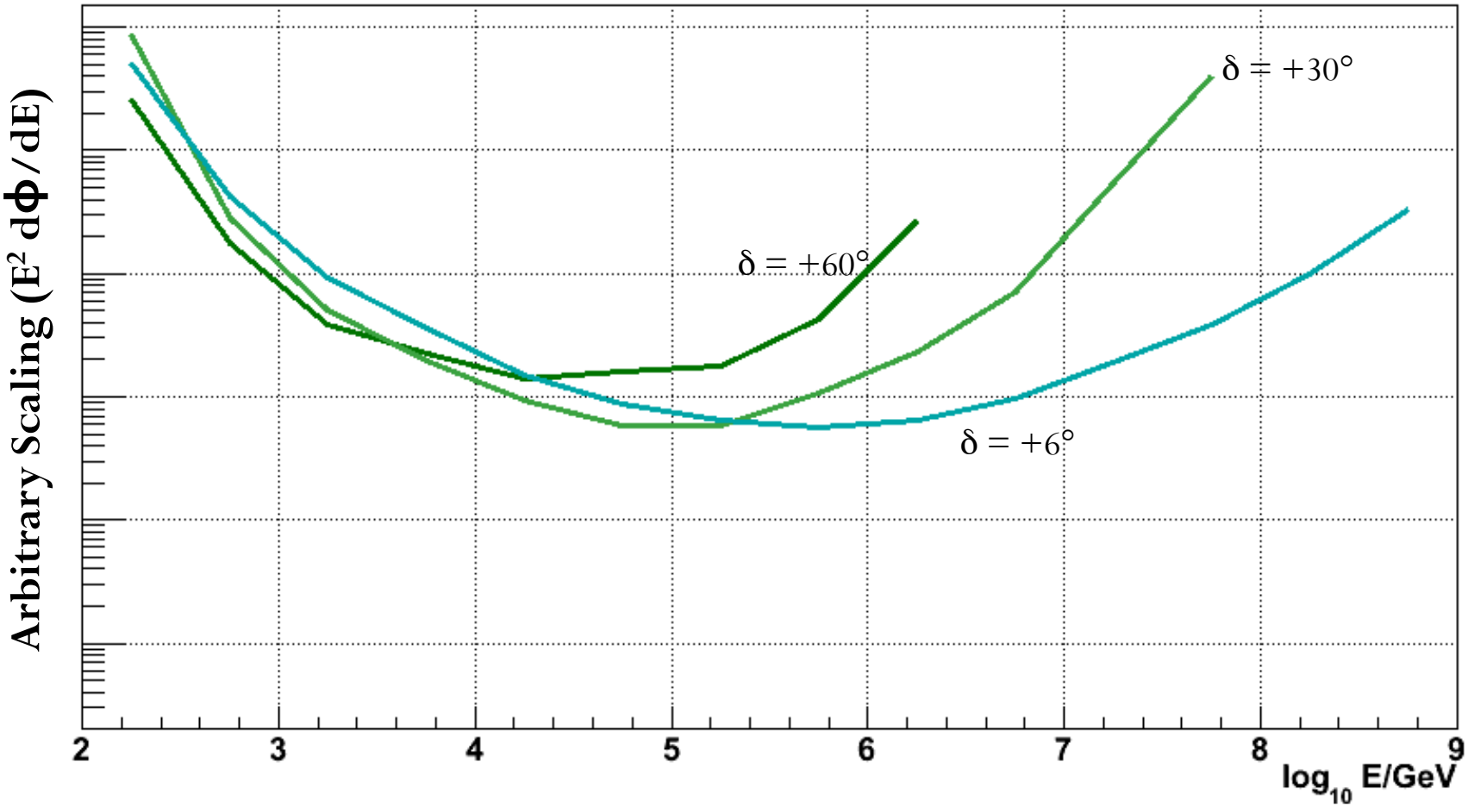
Preliminary



Solid-angle averaged effective area to an equal flux of $\nu_\mu + \bar{\nu}_\mu$, reconstructed within 2° of truth for 6 declination bands

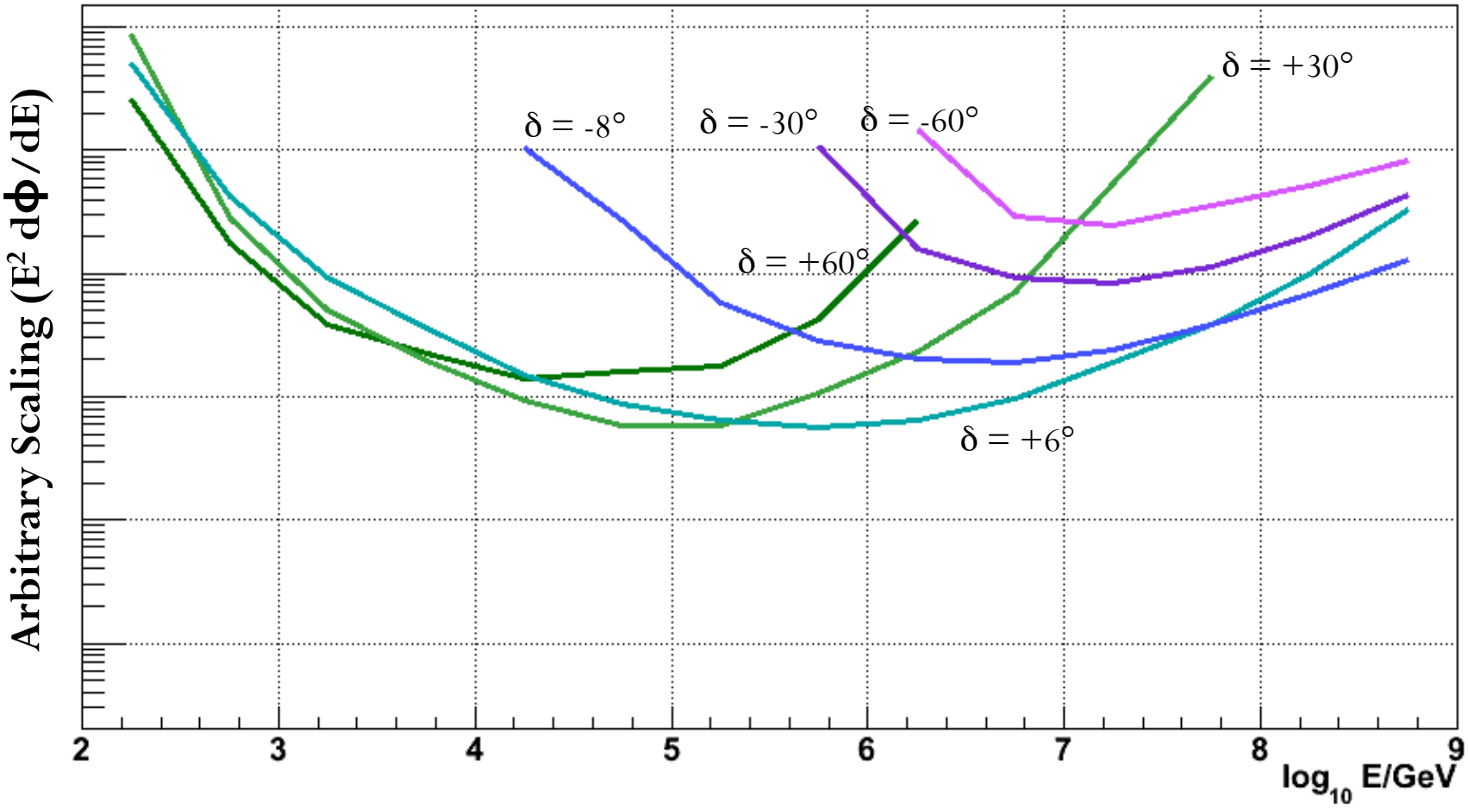


Differential Sensitivity



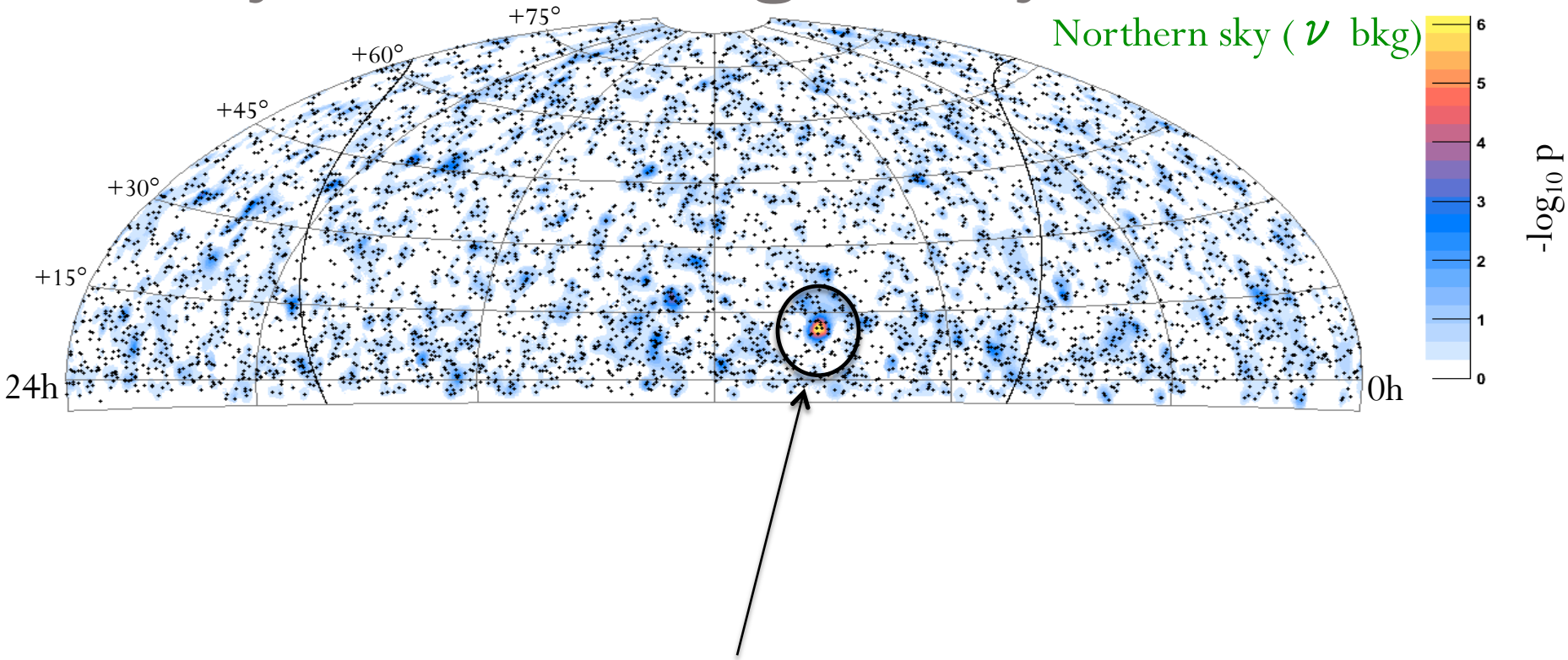
40-string Differential 5σ Discovery Potentials
Northern Sky

Differential Sensitivity



40-string Differential 5σ Discovery Potentials
Northern and Southern Sky

Last year: 22-string all-sky results

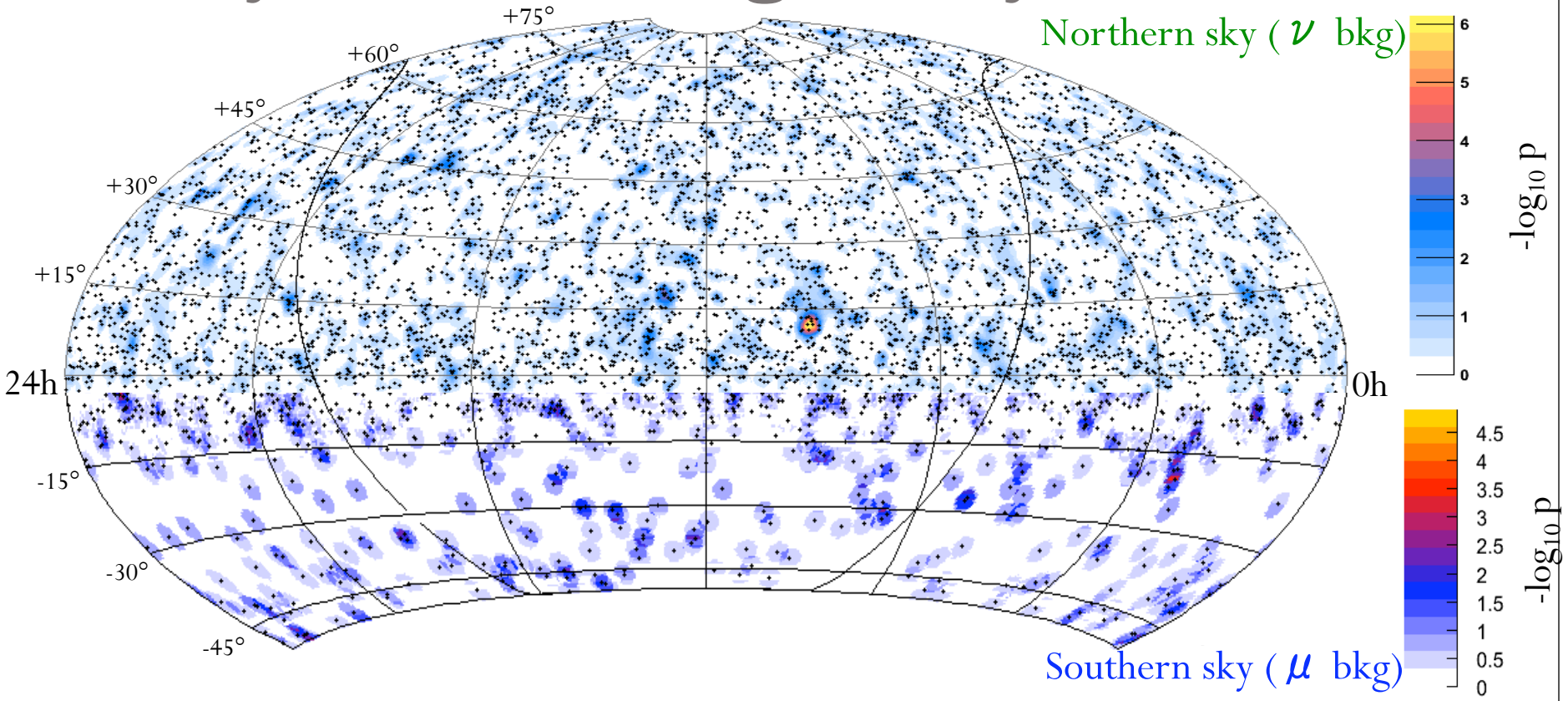


Hottest spot found at r.a. 153.4° , dec. 11.4°

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

Paper submitted to ApJL
http://arxiv.org/abs/0905.2253

Last year: 22-string all-sky results

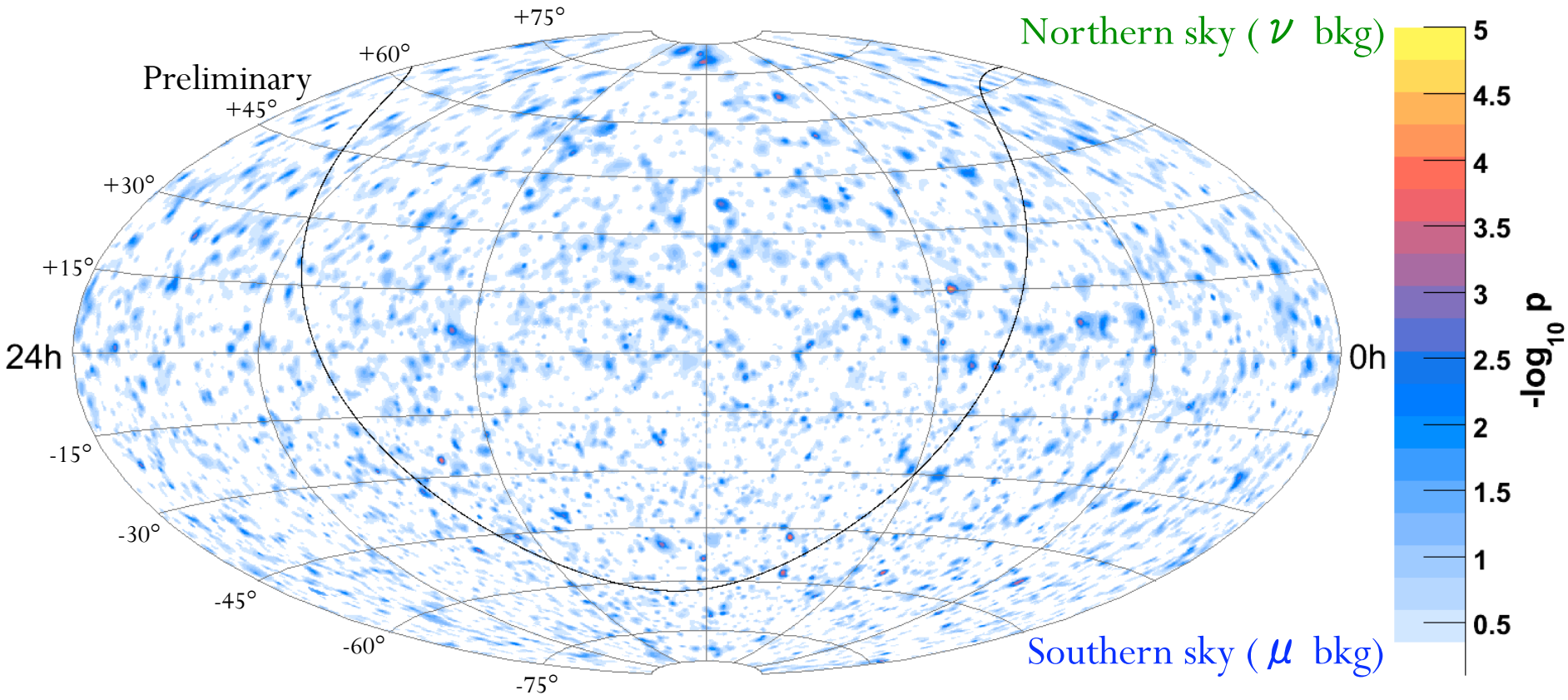


First IceCube analysis extended to -50° dec

R. Lauer,
Heidelberg Workshop, Jan09
arXiv:0903.5434

For follow-up on flares, see poster by M. Baker and talk by J.L. Bazo Alba
For low-energy extension, see poster by C. Portello-Roucelle

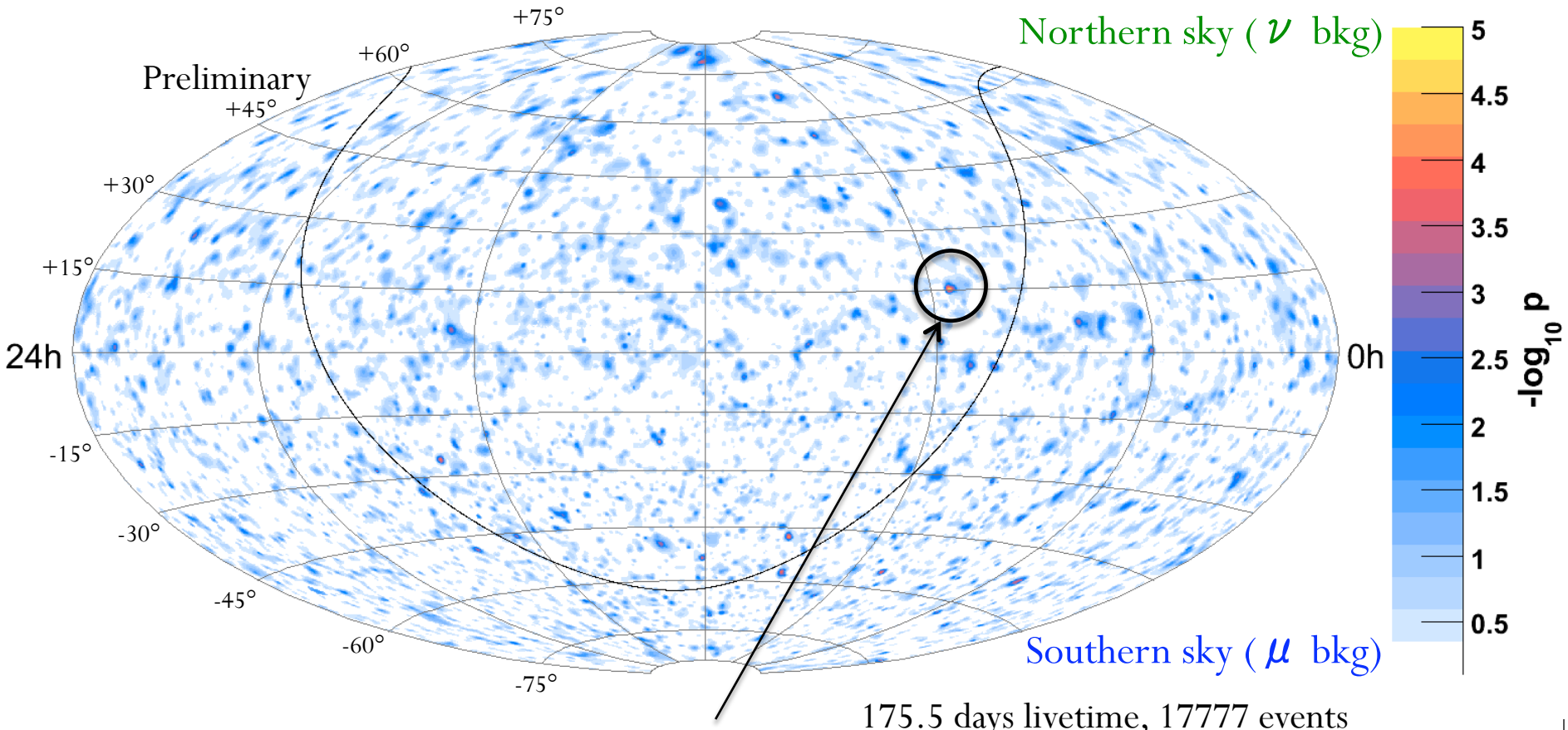
40-string 6-month all-sky results



Hottest location in the all-sky search is:
r.a.=114.95°, dec.=15.35°

175.5 days livetime, 17777 events
6796 up-going, 10981 down-going

40-string 6-month all-sky results



Hottest location in the all-sky search is:
r.a.=114.95°, dec.=15.35°

175.5 days livetime, 17777 events
6796 up-going, 10981 down-going

In background simulated trials (scrambling data in r.a.), an equal or greater excess occurs by chance 611/1000 times. => all-sky p-value is **61%**, not significant

40-string 6-month source list results

Northern Sky Sources:

Highest significance comes from southern sky
(see next slide)

P-values >=0.5 (downward fluctuations) are given as "---"

(aside: chance of obtaining 27 or more downward fluctuations out of 39 sources is 10%)

Source Name	Ra , Dec (deg)	p-value
Cyg_OB2	(308.083, 41.510) :	0.47834
MGRO_J2019+37	(305.220, 36.830) :	---
MGRO_J1908+06	(286.976, 6.269) :	---
Cas_A	(350.850, 58.815) :	---
IC443	(94.179, 22.529) :	---
Geminga	(98.476, 17.770) :	---
Crab_Nebula	(83.633, 22.014) :	---
1ES_1959+650	(299.999, 65.149) :	---
1ES_2344+514	(356.770, 51.705) :	---
3C66A	(35.673, 43.043) :	0.36423
H_1426+428	(217.136, 42.672) :	---
BL_Lac	(330.680, 42.278) :	---
Mrk_501	(253.468, 39.760) :	0.42203
Mrk_421	(166.114, 38.209) :	0.32724
W_Comae	(185.382, 28.233) :	---
1ES_0229+200	(38.202, 20.287) :	0.34695
M87	(187.706, 12.391) :	---
S5_0716+71	(110.473, 71.343) :	---
M82	(148.967, 69.680) :	---
3C_123.0	(69.268, 29.671) :	---
3C_454.3	(343.491, 16.148) :	---
4C_38.41	(248.815, 38.135) :	0.47002
PKS_0235+164	(39.660, 16.620) :	---
PKS_0528+134	(82.735, 13.532) :	---
PKS_1502+106	(226.104, 10.494) :	0.27947
3C_273	(187.278, 2.052) :	---
NGC_1275	(49.951, 41.512) :	---
Cyg_A	(299.868, 40.734) :	---
IC-22_maximum	(153.375, 11.375) :	---

22-string hottest spot is now a downward fluctuation →

←

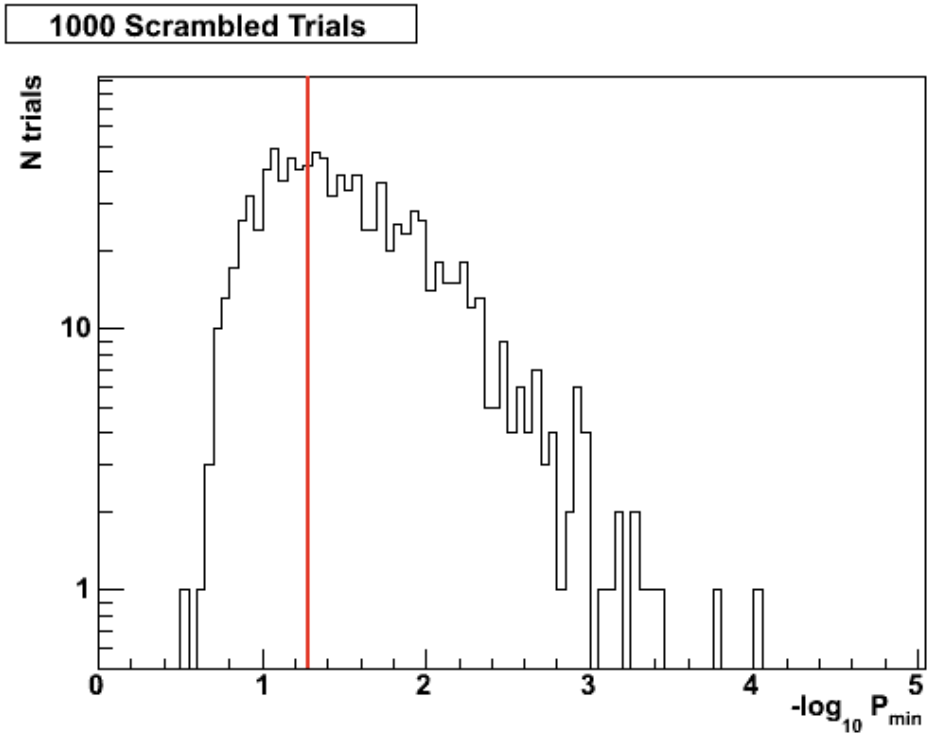
…Southern Sky sources continue on next slide…

40-string 6-month source list results (cont.)

Southern Sky Sources:

Highest significance from list of 39 sources comes from PKS 1622-297

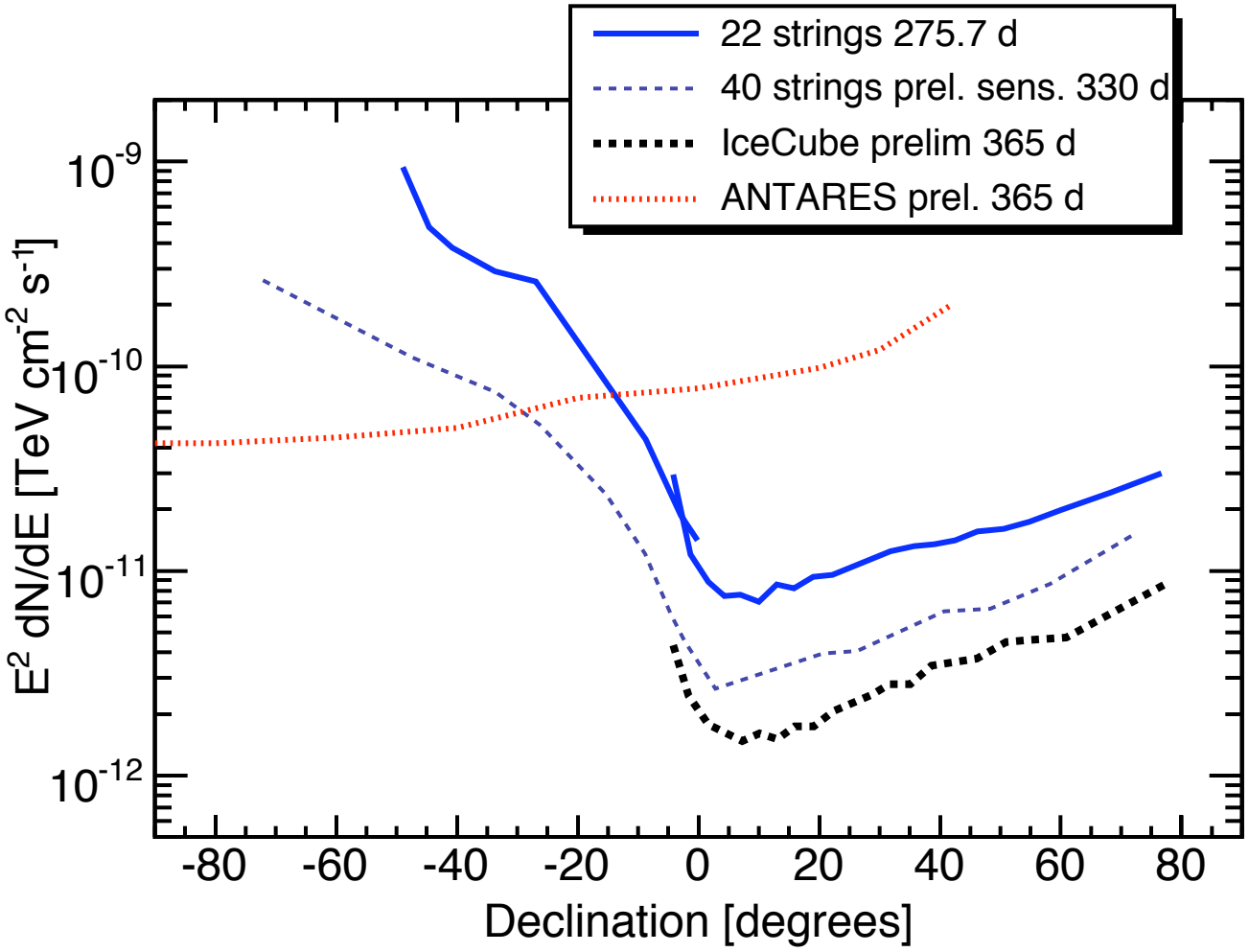
Source Name	Ra , Dec (deg)	p-value
Sgr_A*	(266.417, -29.008) :	0.50000
PKS_0537-441	(84.710, -44.086) :	---
Cen_A	(201.365, -43.019) :	0.34066
PKS_1454-354	(224.361, -35.653) :	---
PKS_2155-304	(329.717, -30.225) :	0.20422
PKS_1622-297	(246.525, -29.857) :	0.05233
QSO_1730-130	(263.261, -13.08) :	0.25087
PKS_1406-076	(212.235, -7.874) :	---
QSO_2022-077	(306.420, -7.640) :	---
3C279	(194.050, -5.790) :	---



Pretrial p-value of 5.2% or less for any of the 39 sources happens in 618/1000 scrambled skymaps

=> source list final p-value is **62%**, not significant

Sensitivity

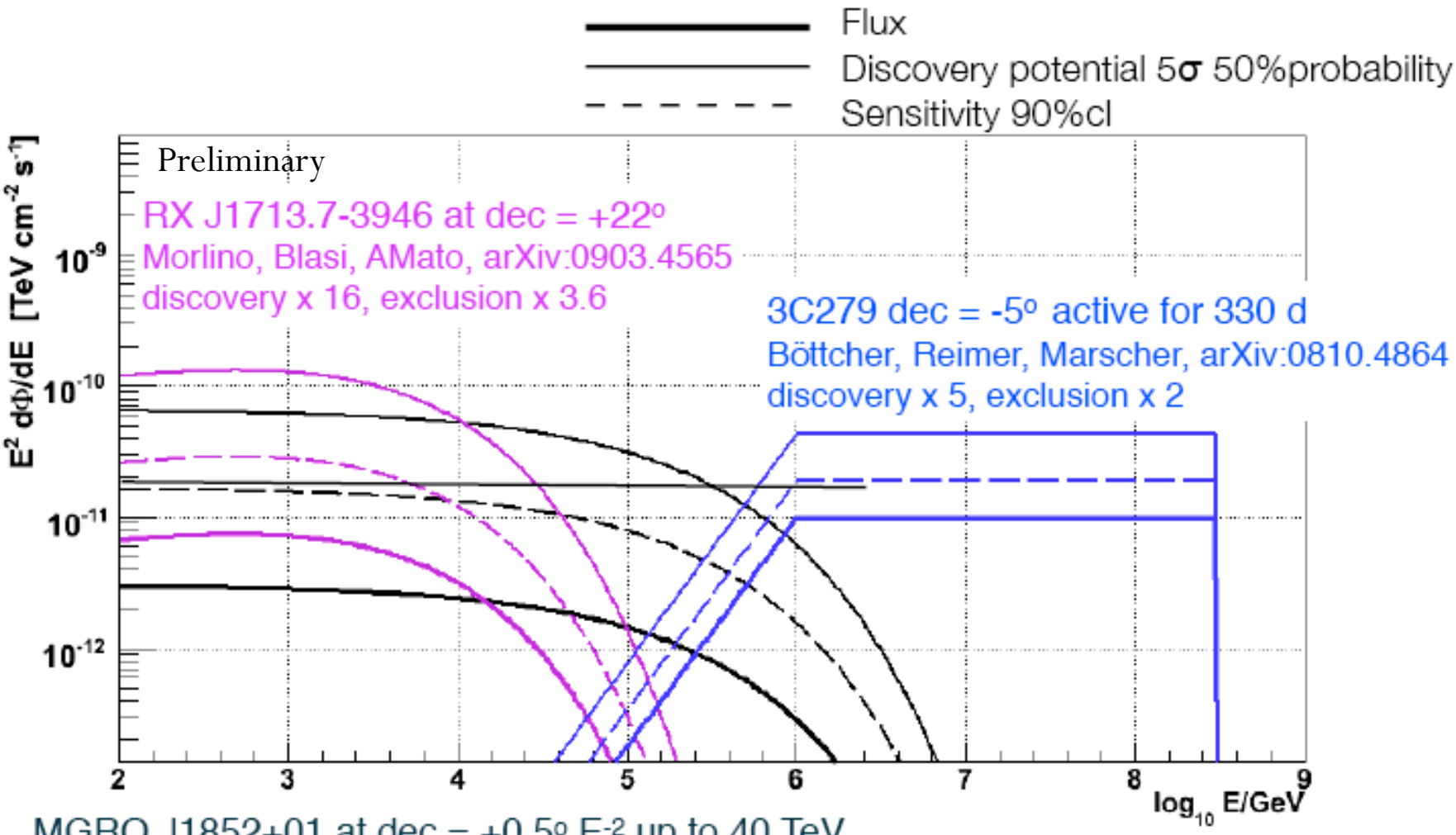


Conclusions

- The 40-string configuration of IceCube recently finished taking ~1 yr of data
  - A search for point sources of neutrinos over the entire sky was developed and unblinded using 6 months of the data
  - No evidence is found for a signal in these 6 months
- First ½ of the 40-string dataset already provides slightly better neutrino limits than the 22-string dataset
  - Full year of 40-string data will be unblinded in the coming months and will provide over a factor of two improvement on 22-string sensitivity
- IceCube now has 59 of the planned 86 strings deployed and taking data – an exciting time for IceCube

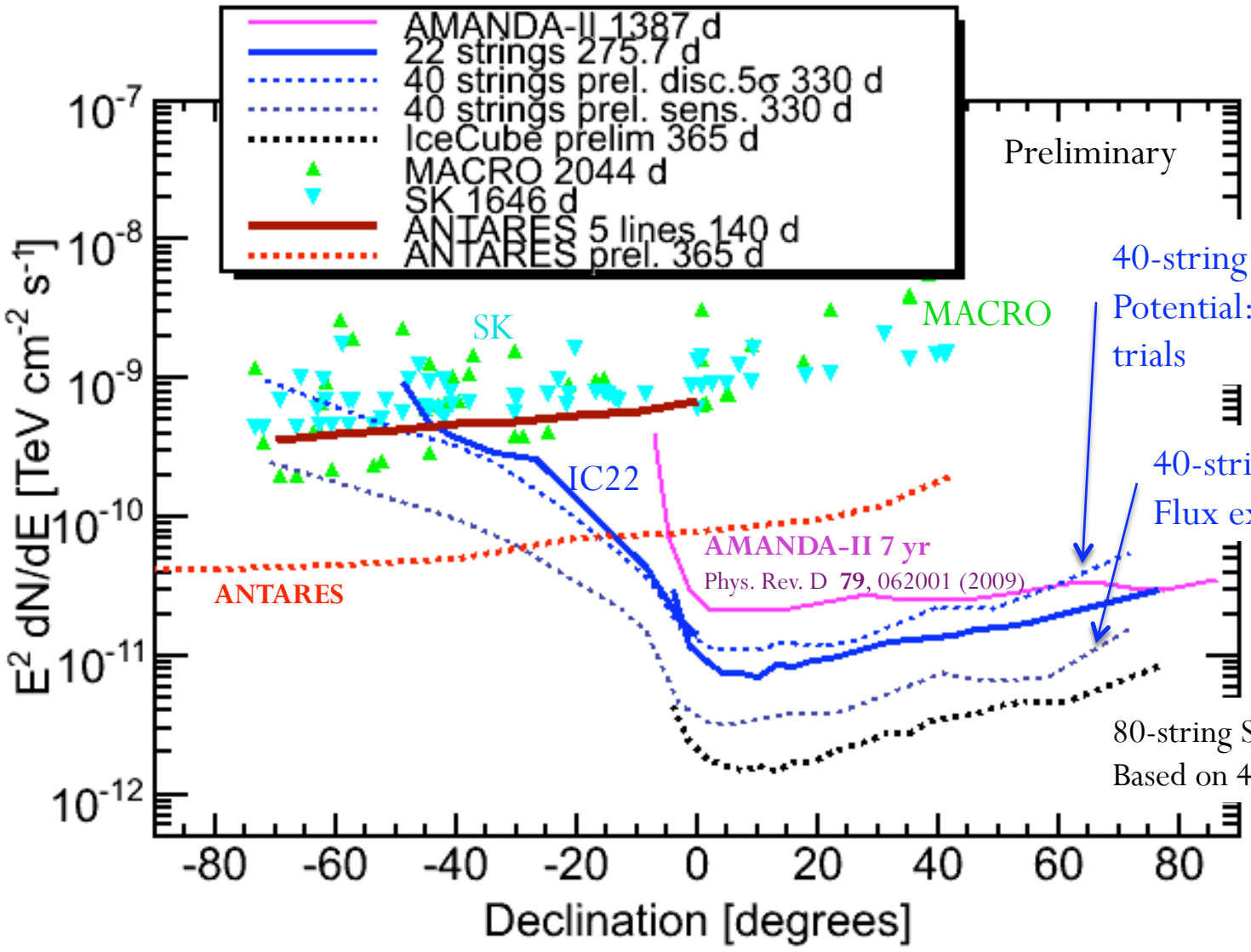
Backup slides

Model Sensitivities



MGRO J1852+01 at dec = +0.5° E^{-2} up to 40 TeV
Gonzalez-Garcia, Halzen, Mohapatra, arXiv:0902.1176
discovery x 21, exclusion x 6

E^{-2} Sensitivity: Past, Present, Future

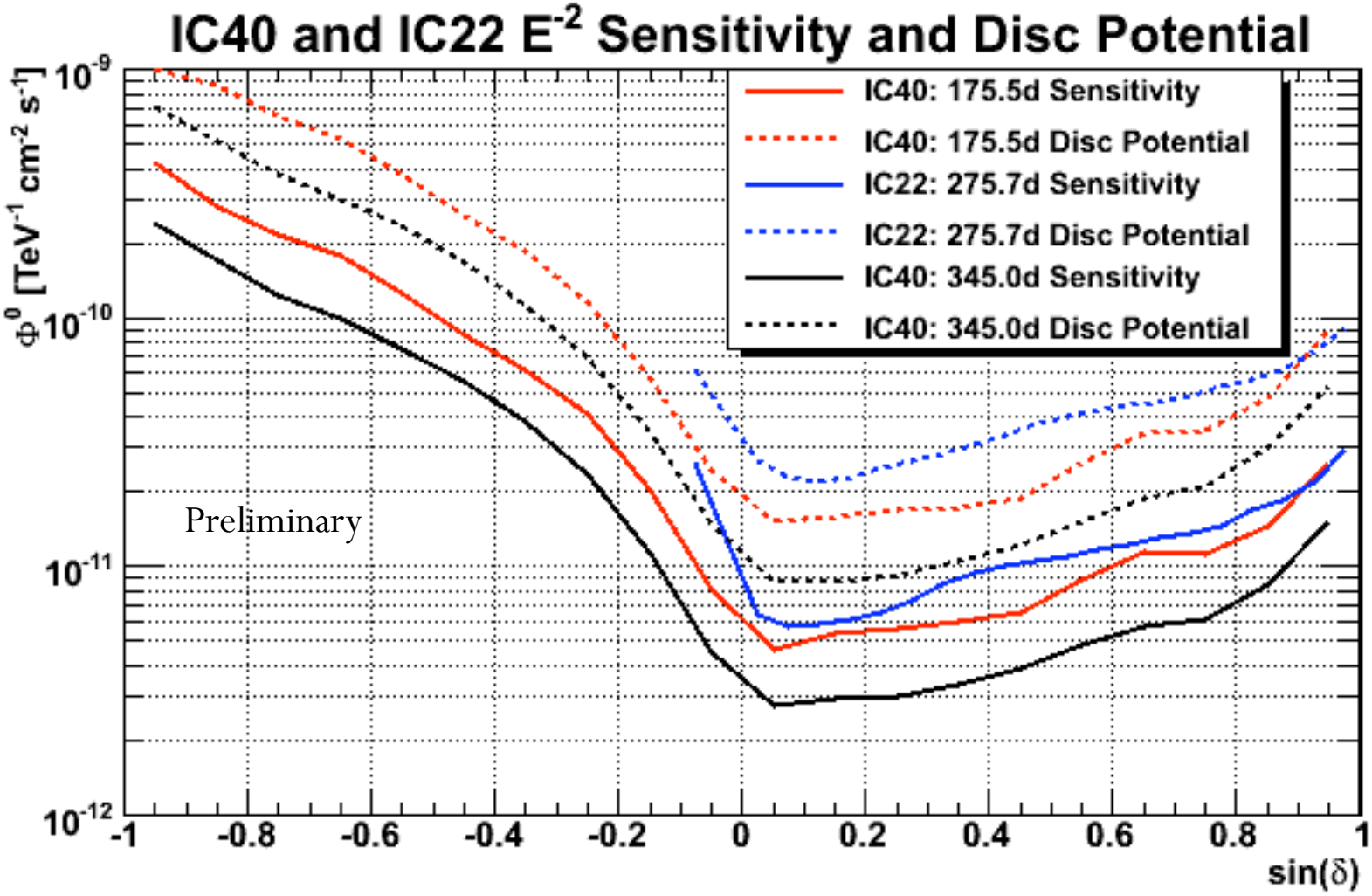


40-string Discovery Potential: 5 σ in 50% of trials

40-string Sensitivity: Flux excluded at 90%cl

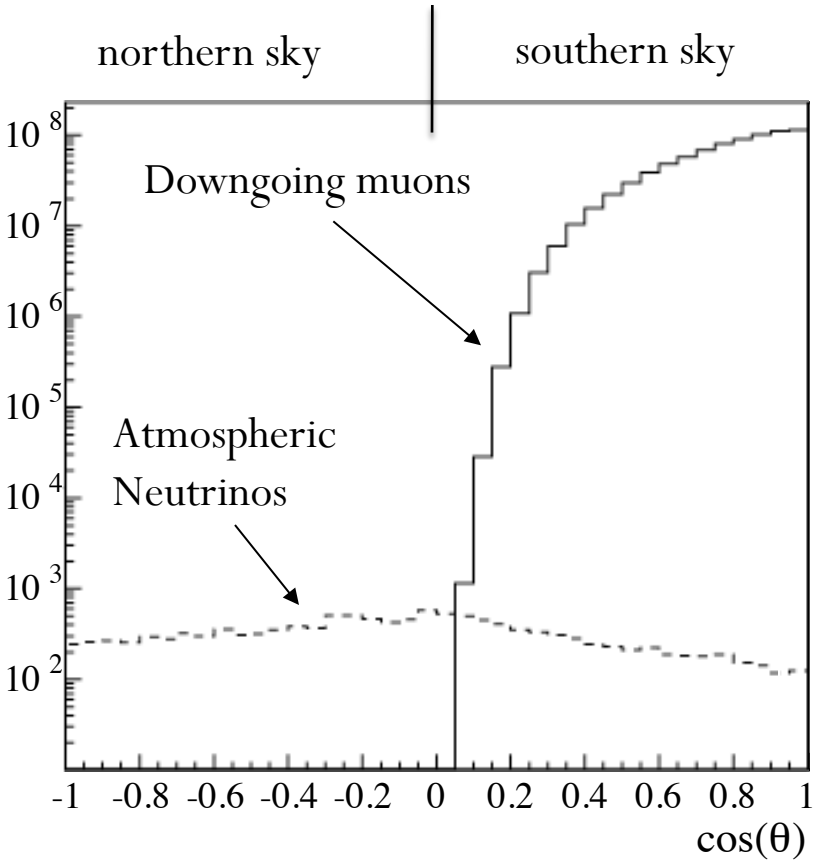
80-string Sensitivity: Based on 40-string analysis

Sensitivity and Disc Potential



- There will still be a substantial improvement when the remainder of the 40-string dataset is added

Backgrounds



Backgrounds to extra-terrestrial neutrino search at the depth of IceCube

Northern:

•Earth is used as a filter for atmospheric muons, leaving only atmospheric neutrino-induced muons traveling upward through IceCube

•Strong quality cuts are required to reject mis-reconstructed muon background

•PS search is sensitive over a large range in energy, >~TeV

Southern:

•Atmospheric muons penetrate to the depth of the detector, largely indistinguishable from neutrino-induced muons

•Strong energy cuts are required to reject low-energy muon background

•PS search is primarily sensitive to a neutrino signals >~PeV

Maximum Likelihood Analysis with Energy

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

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

Data used for background

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

Likelihood:
$$L(\gamma, n_s) = \prod_i P(\vec{x}_i, E_i, \gamma, n_s)$$

Log Likelihood Ratio (test statistic):
$$\log\lambda = \log\left(\frac{L(\hat{\gamma}, \hat{n}_s)}{L(n_s = 0)}\right)$$

Estimates which maximize the Llh

A final significance is evaluated by scrambling the data in r.a. and repeating the analysis

Additional terms besides direction and energy may be added to the likelihood function, such as time (e.g. flares or periodicity searches)