Point Source Searches in IceCube

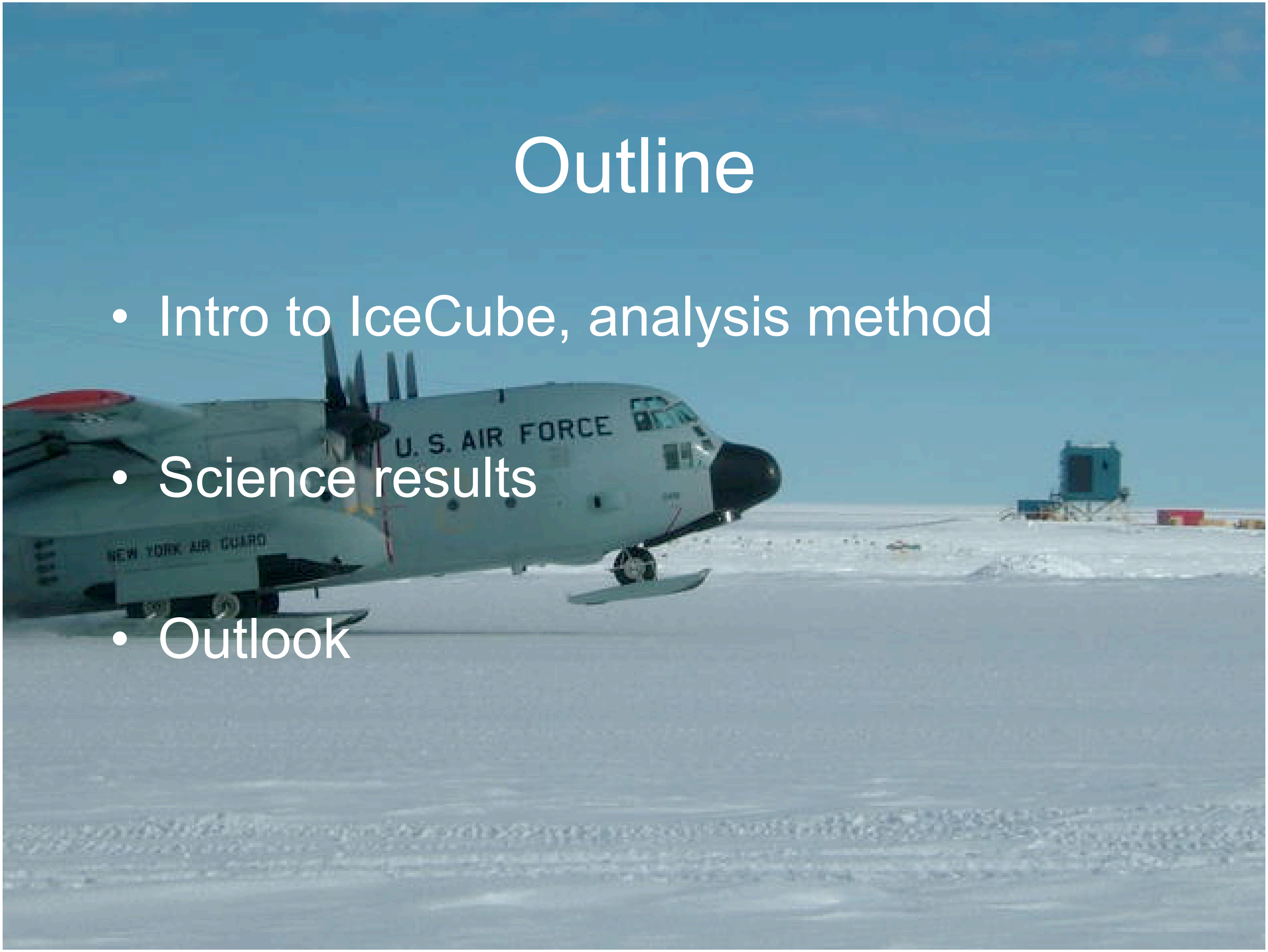
Jon Dumm

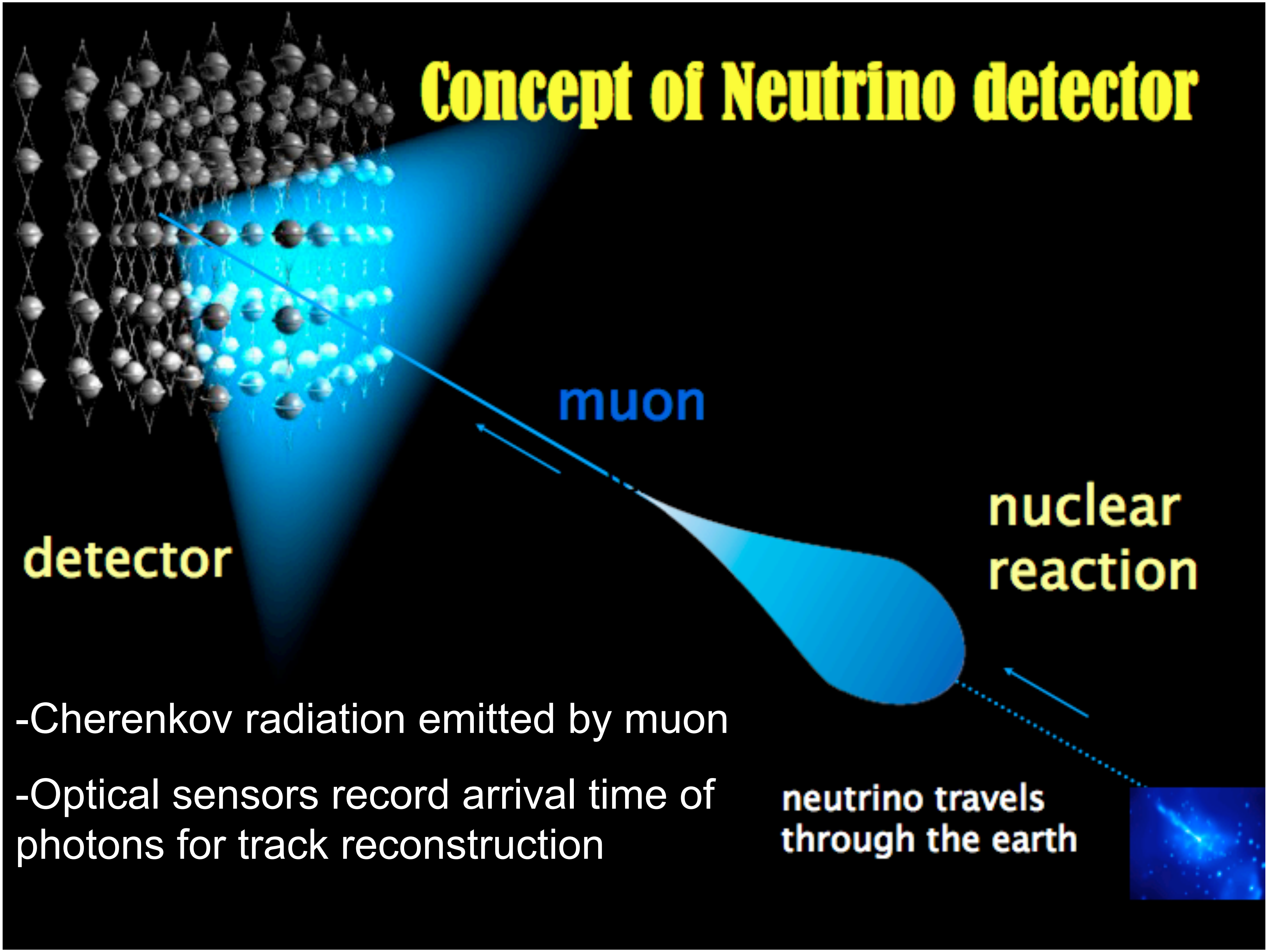
for the IceCube Collaboration

May 21, 2008, Blois

Outline

- Intro to IceCube, analysis method
- Science results
- Outlook



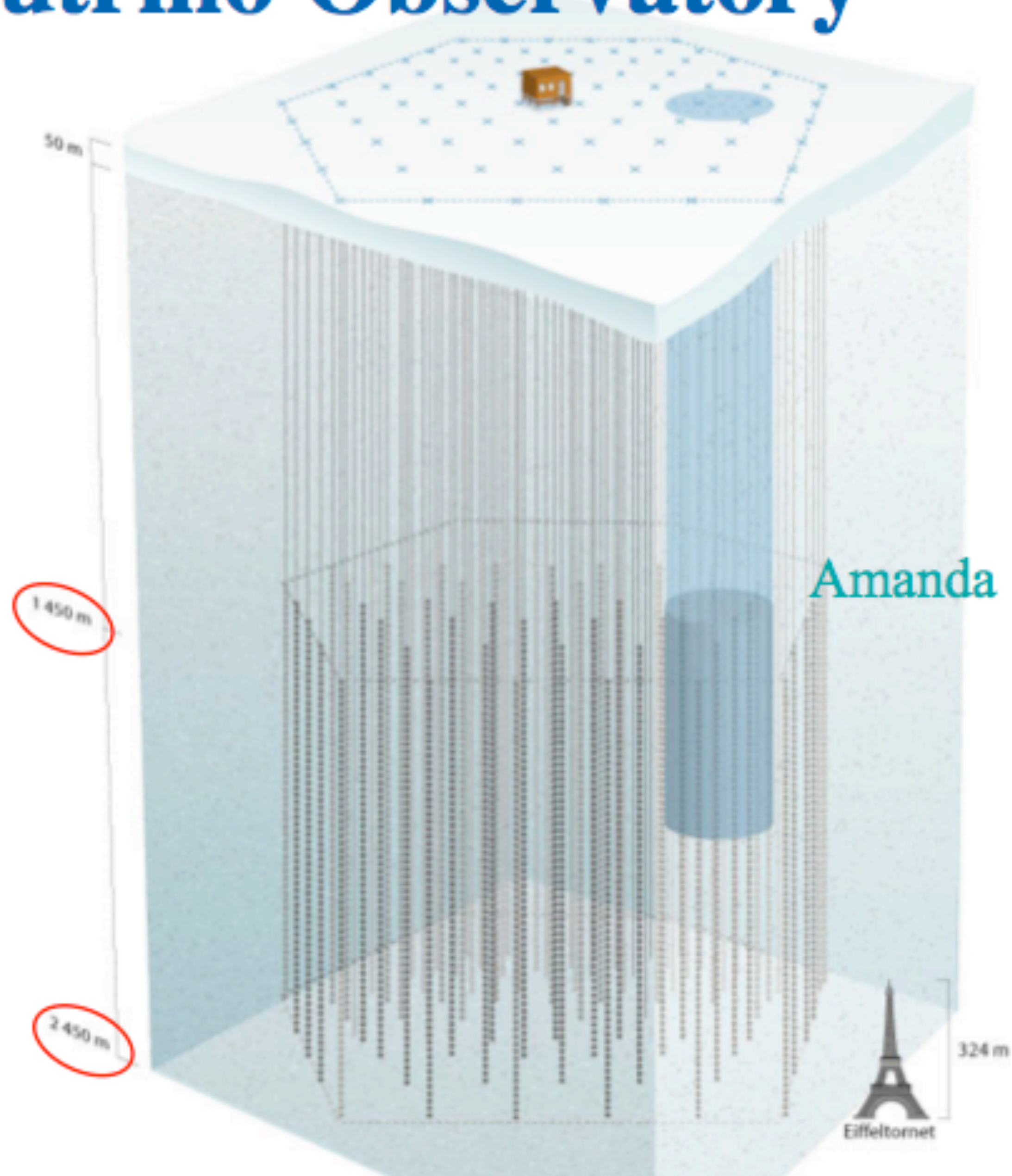

Concept of Neutrino detector
muon
detector
nuclear
reaction
-Cherenkov radiation emitted by muon
-Optical sensors record arrival time of photons for track reconstruction
neutrino travels
through the earth

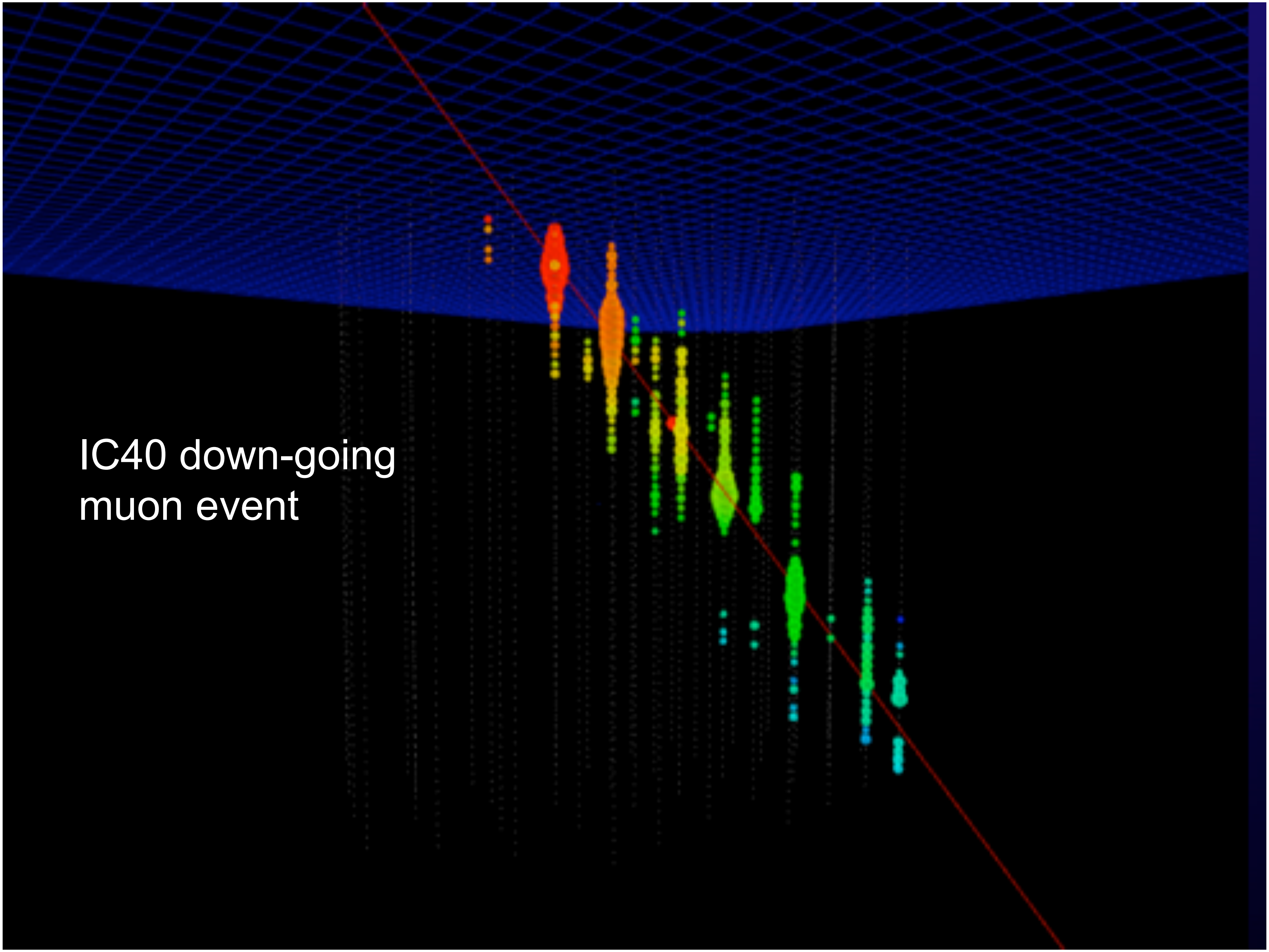
IceCube Neutrino Observatory

IceCube

up to 80 strings with 60 Digital Optical Modules
4800 DOMs
17 meters between them
125 meters between strings
1 Giga Ton Detector
No single point failure in a string!
DOM failure rate about 1%

Now: 2400 DOMs on 40 strings!

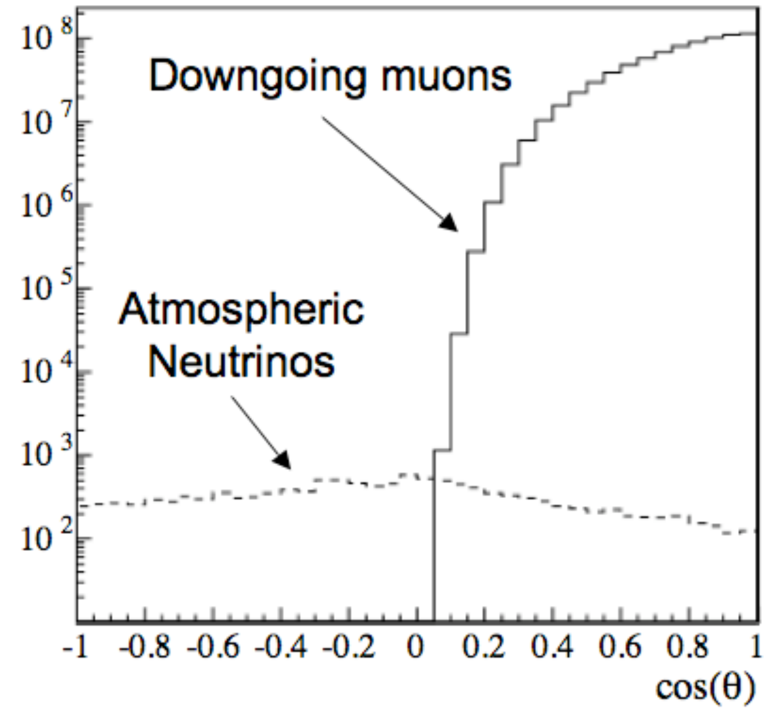



IC40 down-going
muon event

Challenges in IceCube for point sources

- Down-going muons from CR showers misreconstructed as up-going
  - Particularly coincident muons from independent showers
  - Must reject with tight quality cuts

- Up-going atmospheric neutrinos from CR showers on other side of Earth
  - Irreducible background when looking for extra-terrestrial neutrinos



At the depth of IceCube, ~2000m

Unbinned Maximum Likelihood Analysis

- Partial Prob for each event $$P_i(x, n_s) = \frac{n_s}{N} S_i(x) + \frac{N - n_s}{N} B_i(x)$$
- Likelihood function $$L(n_s) = \prod P_i(x_i, n_s)$$
- Log Likelihood Ratio $$\log \lambda = \log \frac{L(\hat{n}_s)}{L(n_s = 0)}$$

$\hat{n}_s$ is the number of signal events which maximize the likelihood

$S_i(x)$ is the signal pdf, based on individual reconstructed uncertainty estimates

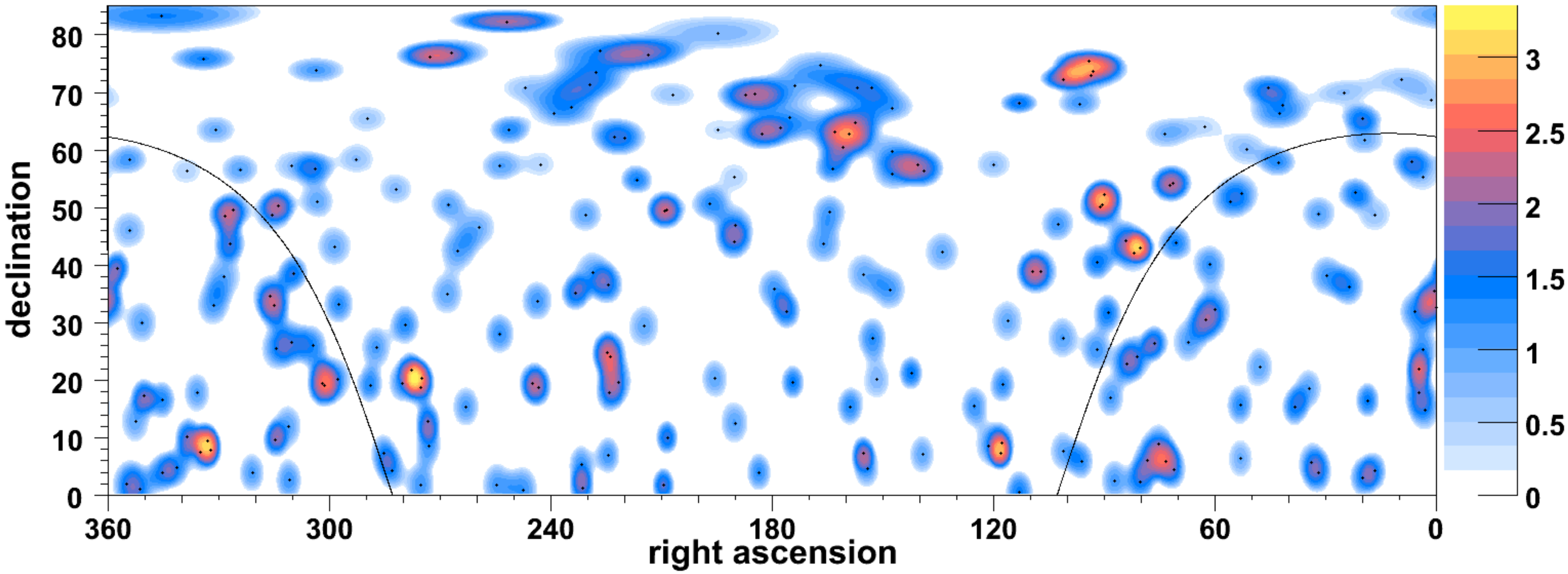
$B_i(x)$ is the background pdf, based on dec. distribution of data

Determine significance by evaluating Log Likelihood Ratio over background-only (scrambled) datasets

Braun et al, arXiv:0801.1604

First IC9 Skymap

233 up-going events in 137d; median ang res = 2°



Max deviation of 3.35 sigma at ra=276.6°, dec=20.4°

Chance probability of hottest spot from background = 60%

Presented at ICRC2007, C. Finley, J.Dumm

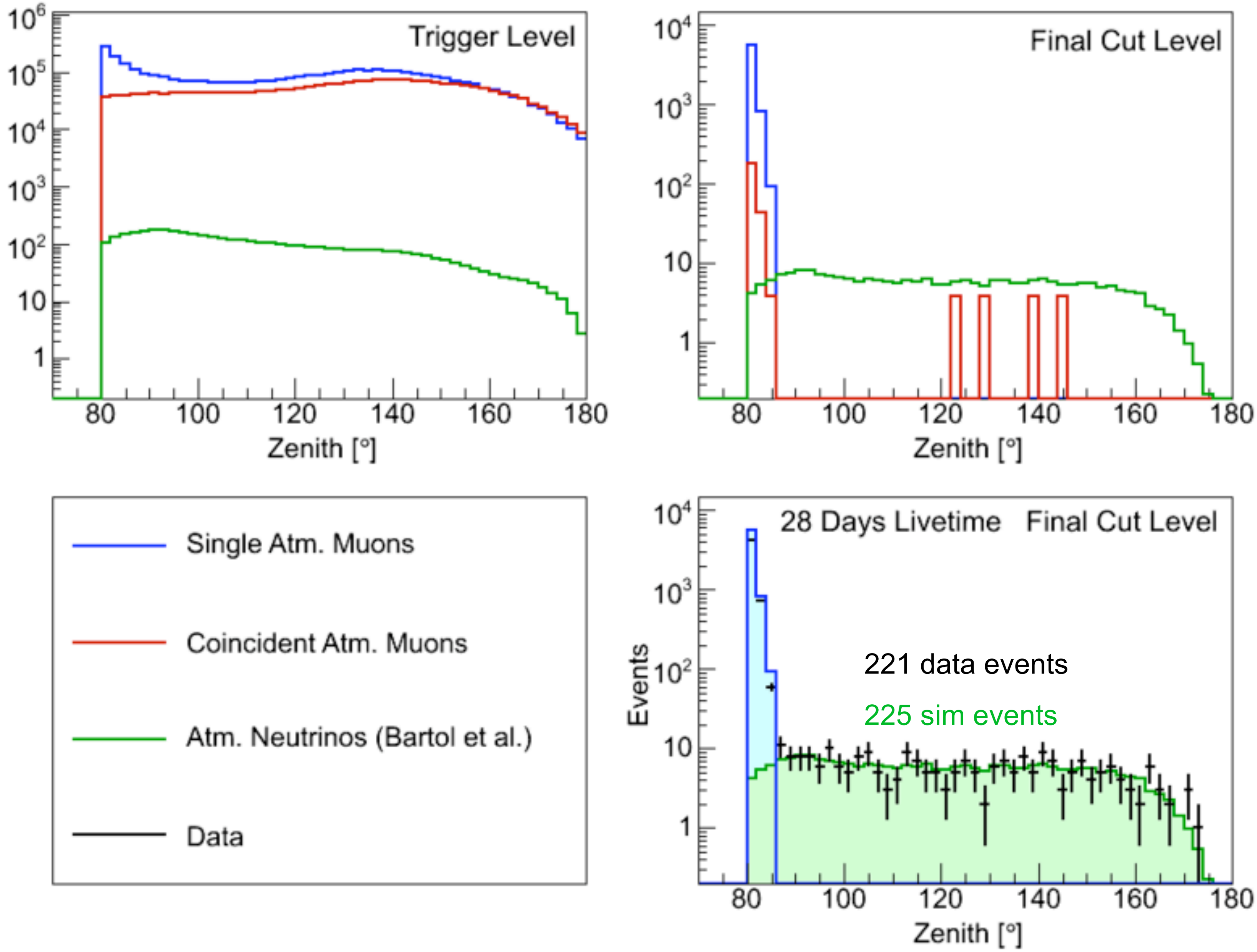
IC9, A priori sources

Object	(r.a. , dec) :	sigma	n_s est.	90% C.L. upper limits n_s	Φ
MGRO J2019+37	(304.83,36.83) :	0.00	0.0	2.6	11.2
Cyg OB2/TeV J2033+4130	(308.29,41.32) :	0.24	0.2	2.9	13.7
Mrk 421	(166.11,38.21) :	0.00	0.0	2.6	11.8
Mrk 501	(253.47,39.76) :	0.00	0.0	2.6	12.0
1ES 1959+650	(300.00,65.15) :	0.00	0.0	3.1	13.6
1ES 2344+514	(356.77,51.71) :	0.00	0.0	2.7	10.9
H 1426+428	(217.14,42.68) :	0.00	0.0	2.9	13.3
BL Lac (QSO B2200+420)	(330.68,42.28) :	0.29	0.4	3.0	13.9
3C66A	(35.67,43.04) :	0.00	0.0	2.8	12.9
3C 454.3	(343.49,16.15) :	1.09	0.7	3.7	14.9
4C 38.41	(248.82,38.14) :	0.00	0.0	2.6	11.8
PKS 0528+134	(82.74,13.53) :	0.00	0.0	2.7	9.9
3C 273	(187.28, 2.05) :	0.00	0.0	2.5	11.1
M87	(187.71,12.39) :	0.68	0.5	3.3	11.8
NGC 1275 (Perseus A)	(49.95,41.51) :	0.00	0.0	2.7	12.7
Cyg A	(299.87,40.73) :	0.41	0.4	3.0	13.6
SS 433	(287.96, 4.98) :	0.13	0.1	2.3	8.0
Cyg X-3	(308.11,40.96) :	0.52	0.4	3.1	14.4
Cyg X-1	(299.59,35.20) :	0.53	0.4	3.0	12.7
LS I +61 303	(40.13,61.23) :	0.00	0.0	3.0	13.5
GRS 1915+105	(288.80,10.95) :	0.00	0.0	2.7	9.4
XTE J1118+480	(169.55,48.04) :	0.00	0.0	2.6	11.5
GRO J0422+32	(65.43,32.91) :	0.64	0.8	3.1	12.9
Geminga	(98.48,17.77) :	0.00	0.0	2.5	10.2
Crab Nebula	(83.63,22.01) :	1.77	1.6	5.0	20.3
Cas A	(350.85,58.82) :	0.67	0.5	3.9	16.5

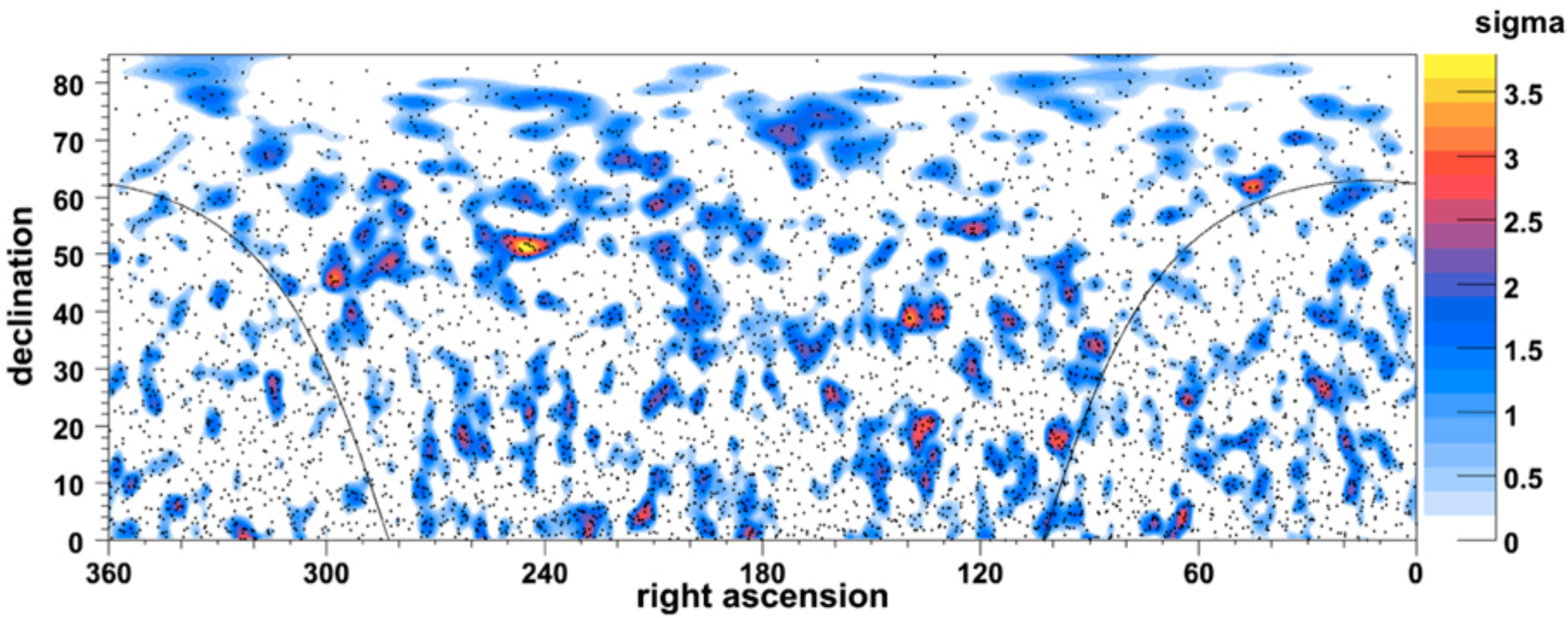
On a list of pre-determined sources, largest deviation of 1.77 Sigma at Crab

65% chance of 1 in 26 sources having this sigma from background alone

IC22 analysis almost ready
Transition to Atms Nu in IC22



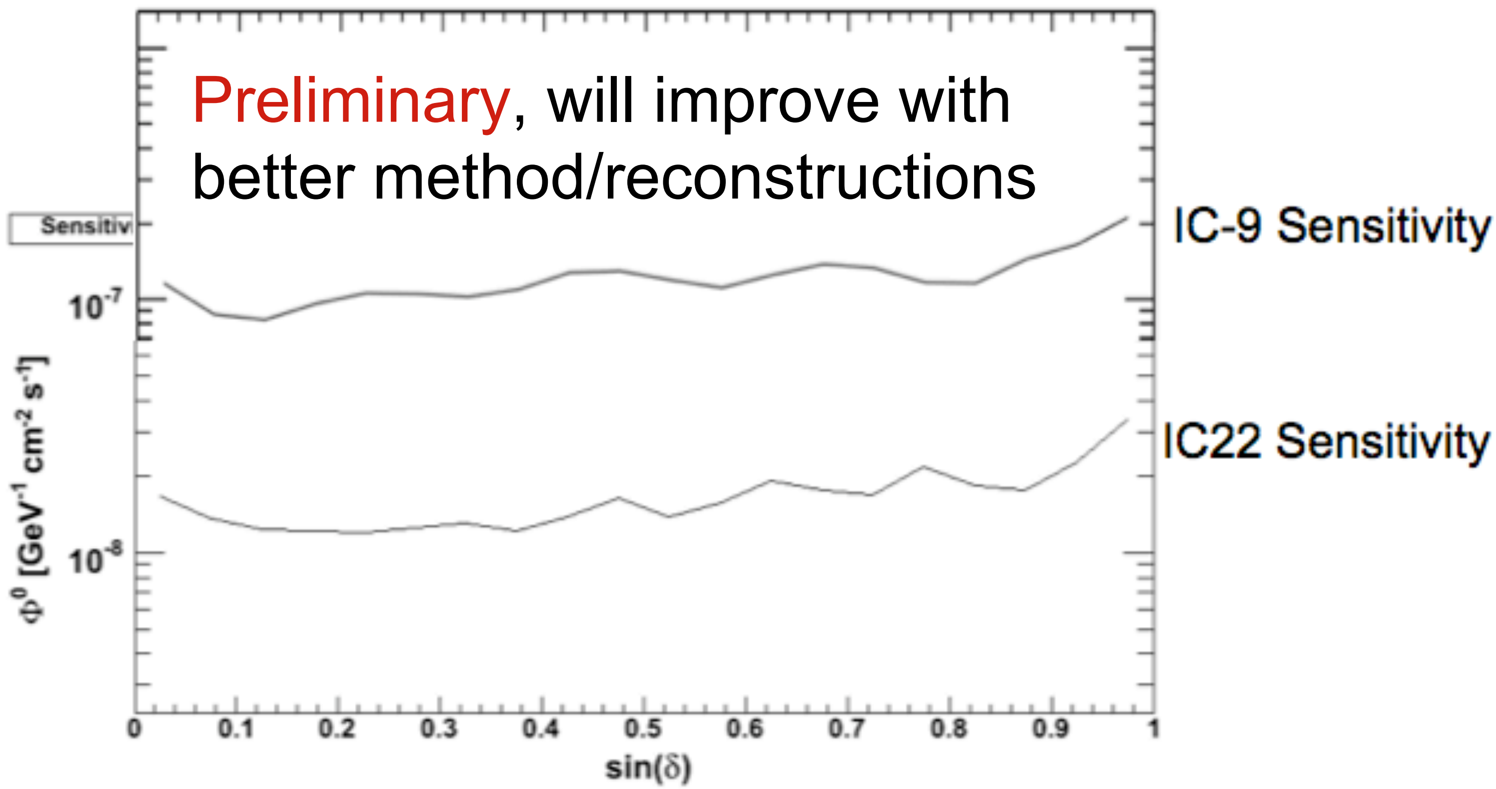
IC22 scrambled skymap



~6000 neutrino candidates in 300d of IC22

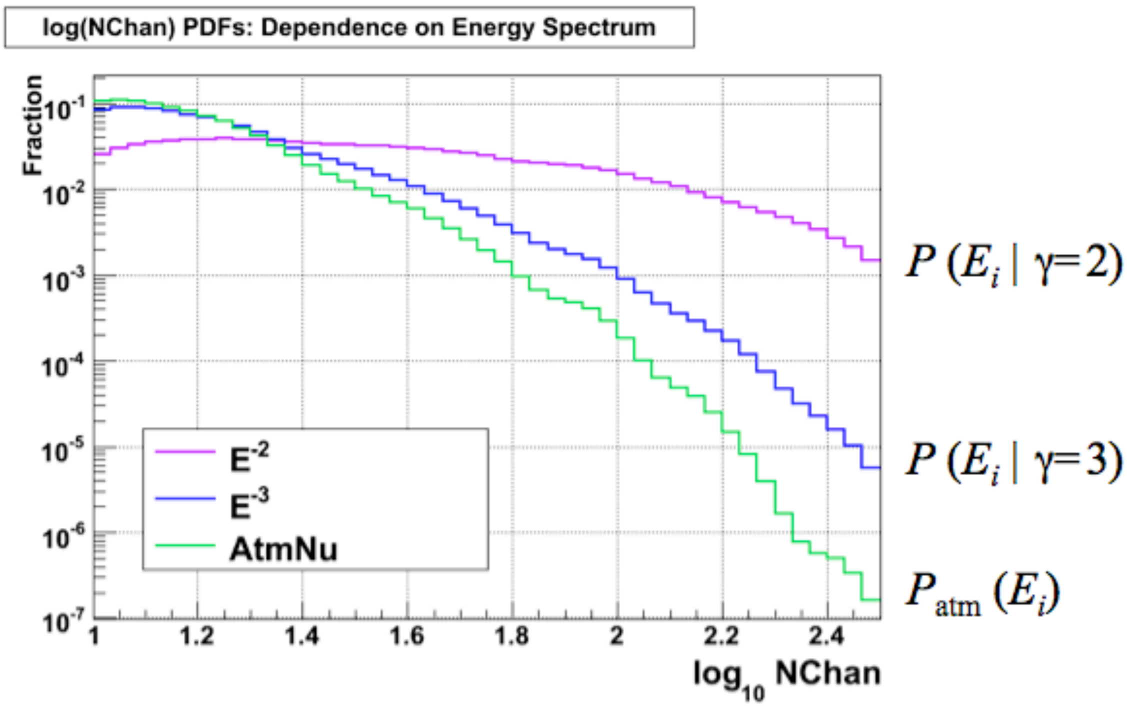
~1.5° median resolution

IC22 sensitivity studied



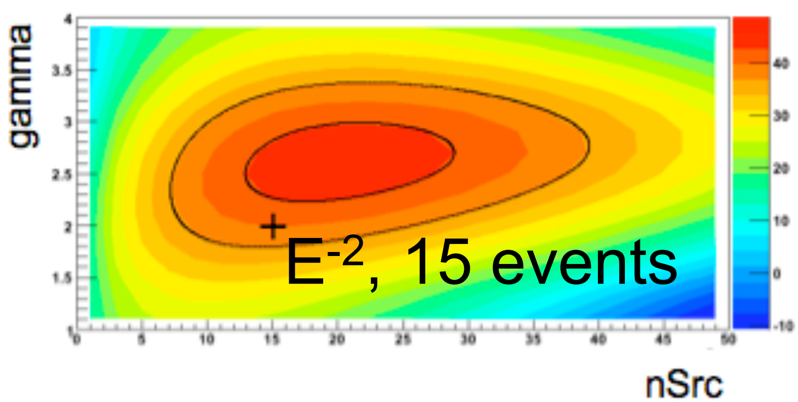
E^{-2} average sensitivity $\Phi^0 = 1.7\times10^{-11}$ TeV^{-1} cm^{-2} s^{-1}

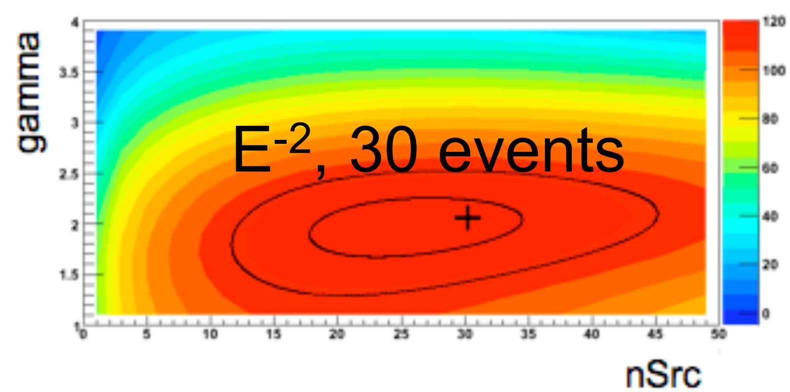
Adding Energy to Likelihood



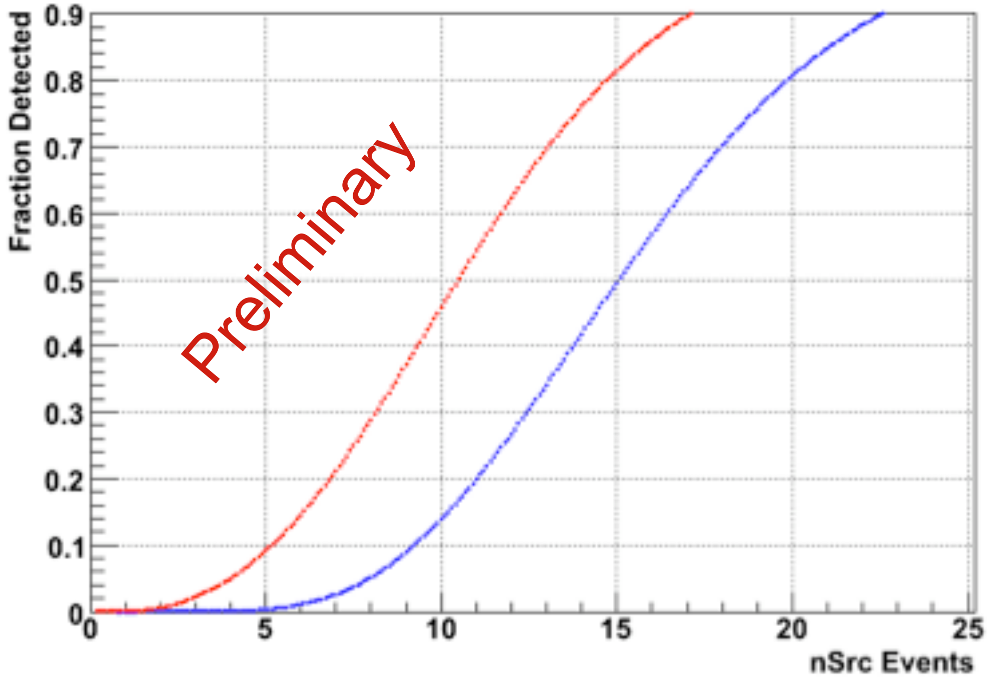
Any observable that distinguishes signal from background can be incorporated into the likelihood analysis

First try something simple - the number of channels hit.





Adding Energy to Likelihood



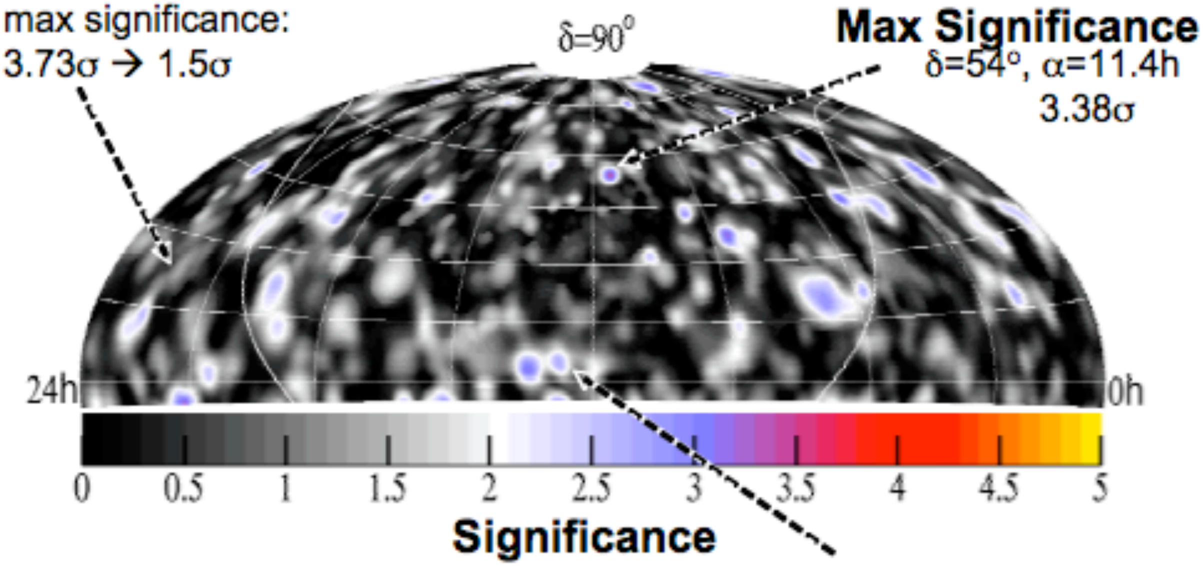
Simulated E^{-2} source at declination +30:

5-sigma Discovery potential (Power 50%):

without energy term in likelihood: 6.1×10^{-8} GeV^{-1} cm^{-2} s^{-1} $(E/GeV)^{-2}$
(mean number of source events: 15)

with energy term in likelihood: 4.2×10^{-8} GeV^{-1} cm^{-2} s^{-1} $(E/GeV)^{-2}$
(mean number of source events: 10.5)

7yrs AMANDA result



6595 ev/3.8 yr

Year	Livetime
2000	197 d
2001	193 d
2002	204 d
2003	213 d
2004	194 d
2005	199.3 d
2006	187 d
Total	**3.8 Yr.**

$E2\Phi < \mu90*10^{-11}$ TeV $cm^{-2}s^{-1}$
@90% CL

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

Selected Sources

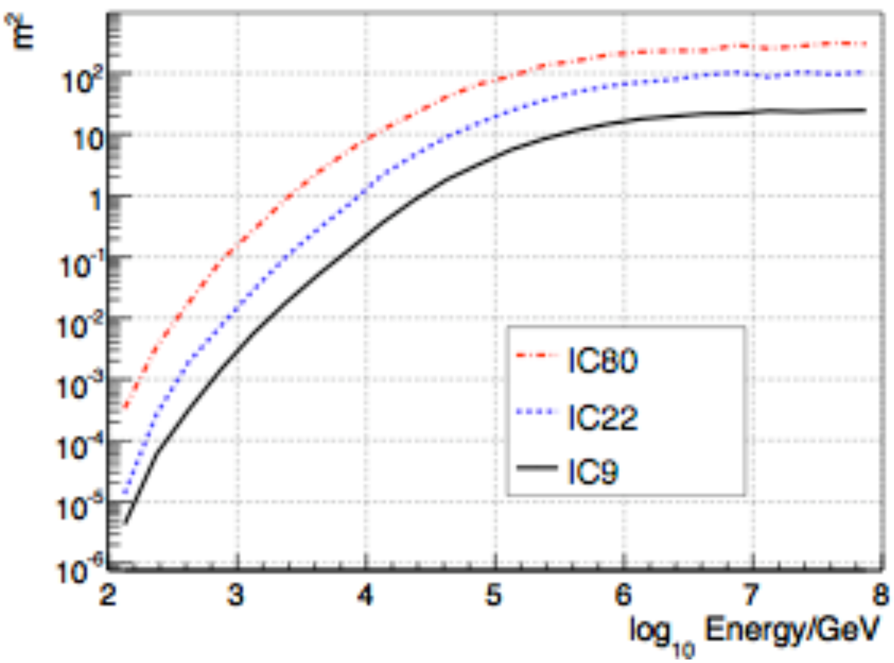
Source	μ_{90}	P-value
Crab	4.62	0.10
MGRO J2019+37	4.14	0.077
Mrk 421	0.67	0.82
Mrk 501	2.97	0.22
LS I +61 303	9.62	0.03
Geminga	10.72	0.0086

J. Braun

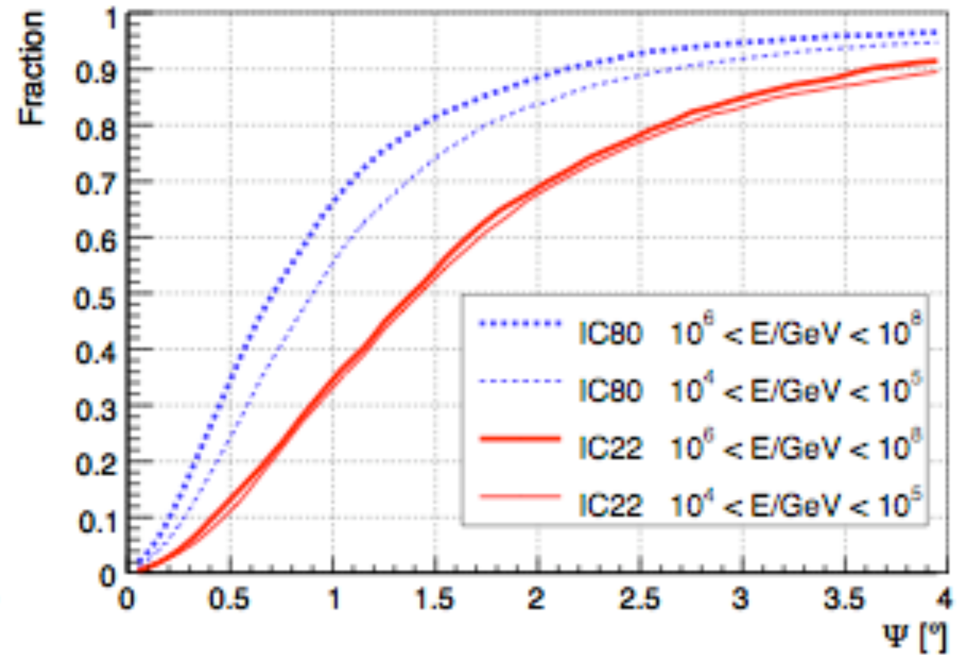
The probability of obtaining p ≤ 0.0086 for at least one of the 26 sources is 20%

Performance, now and then

Effective area for neutrinos



Cumulative PSF for neutrinos

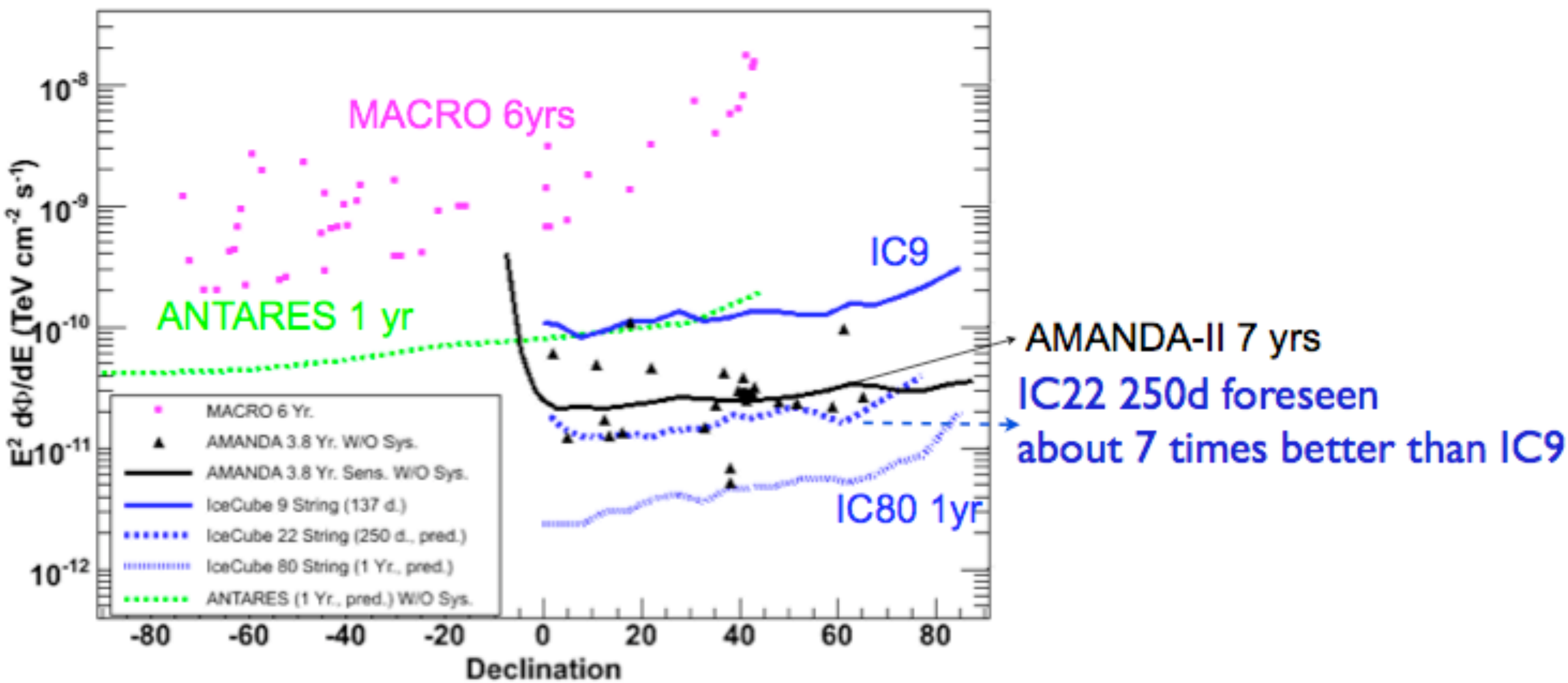


IC22: 20 nu/day; 1.5° after cuts

IC80: 200 nu/day; 0.8° after cuts

Gain is manyfold while detector increasing in size!

Point-source Limits



Multi-messenger studies

- More can be gained if you know more about your sources
  - Flaring (e.g. AGN) or transient (e.g. GRB) coincidence studies
- Starting to define many partnerships
  - MAGIC, ROTSE, Swift, AGILE, RATAN, GLAST, LIGO, VERITAS

Conclusions

- 1 year of 9-string data unblinded
- 1 year of IceCube 22-string data almost ready for unblinding; already expecting an improvement over AMANDA 7-yrs
- IceCube 40-string configuration taking data, ready for discovery!
- IceCube ~80-string configuration ready by 2011