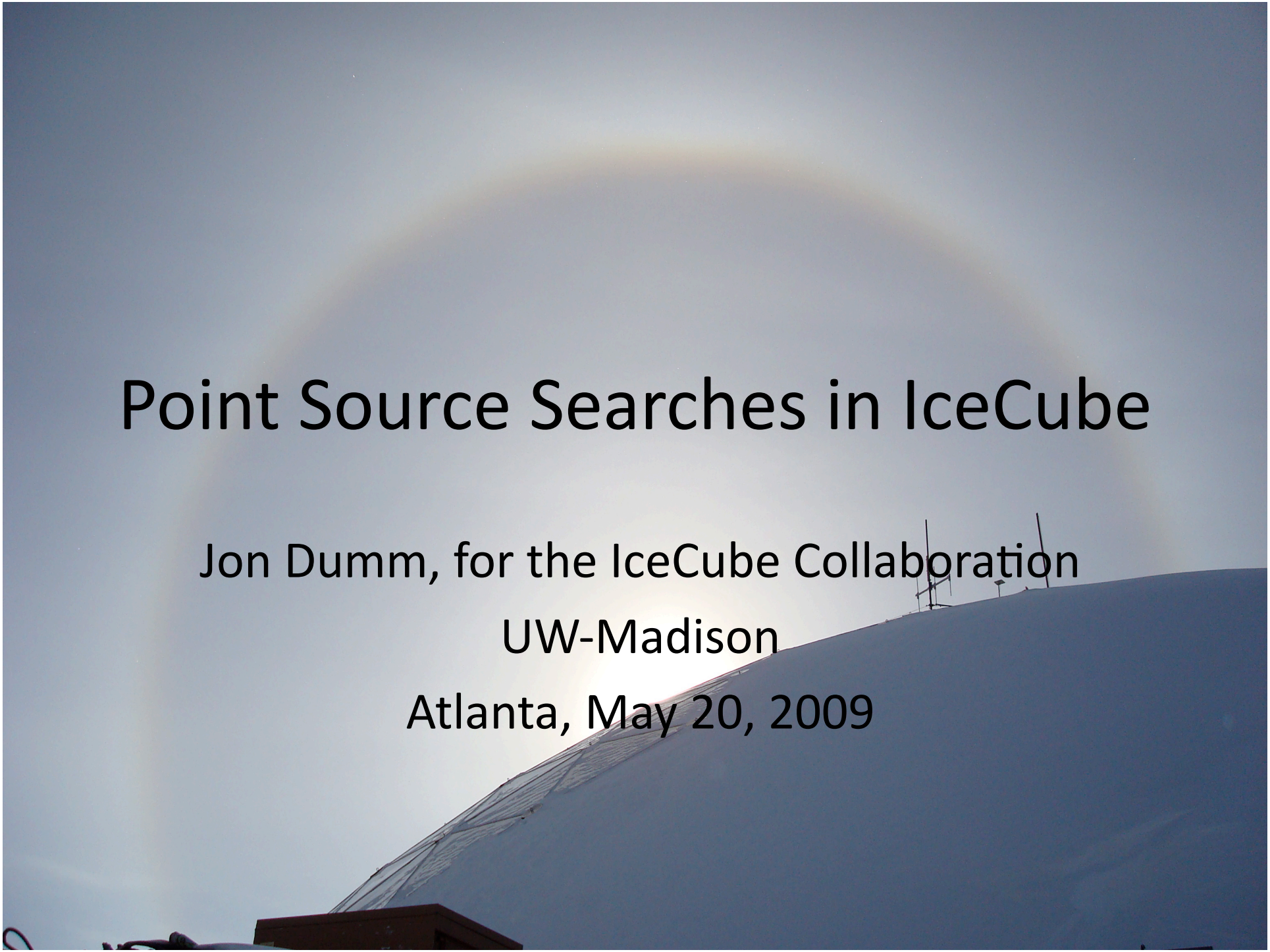


Point Source Searches in IceCube

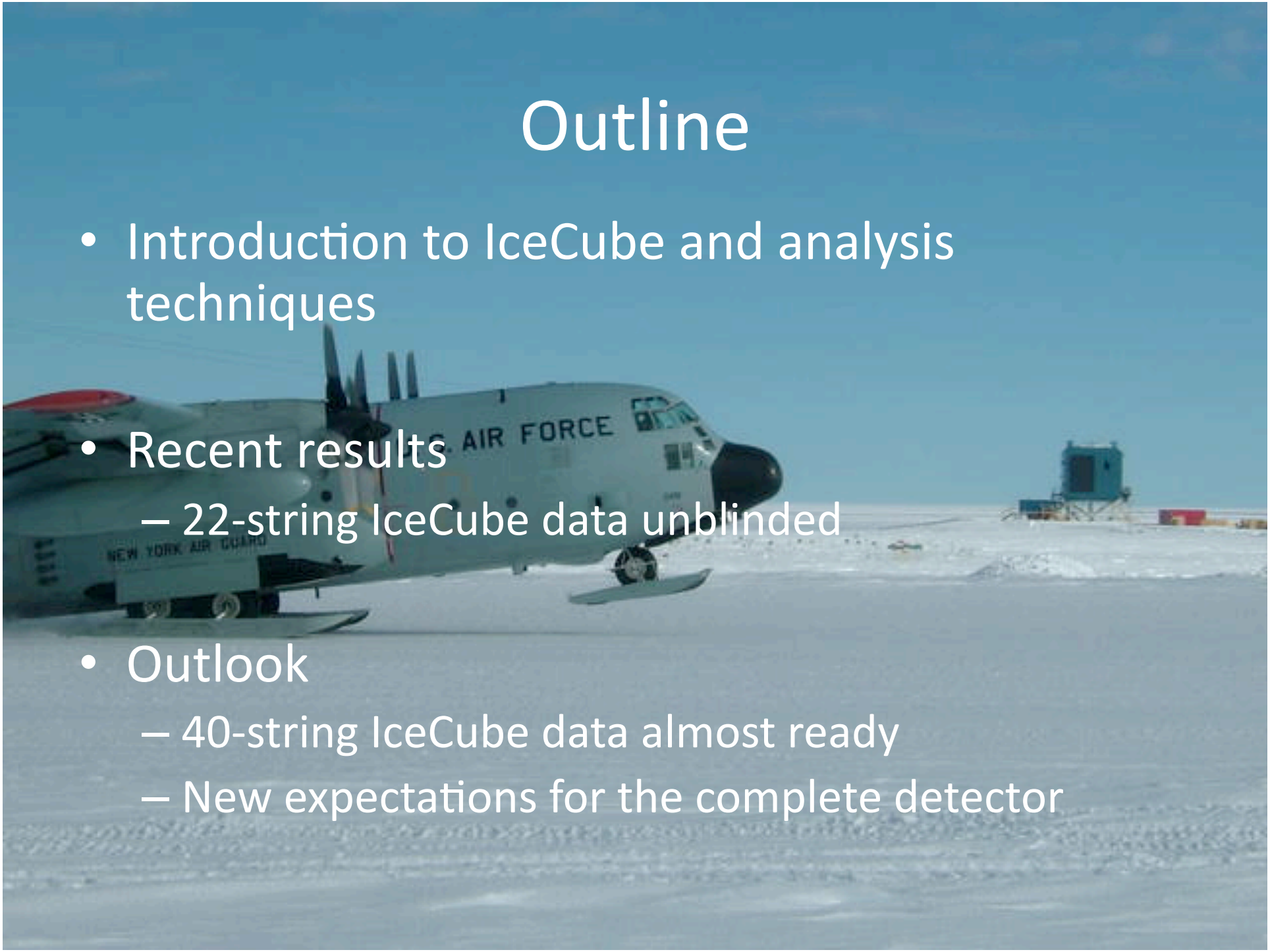
Jon Dumm, for the IceCube Collaboration

UW-Madison

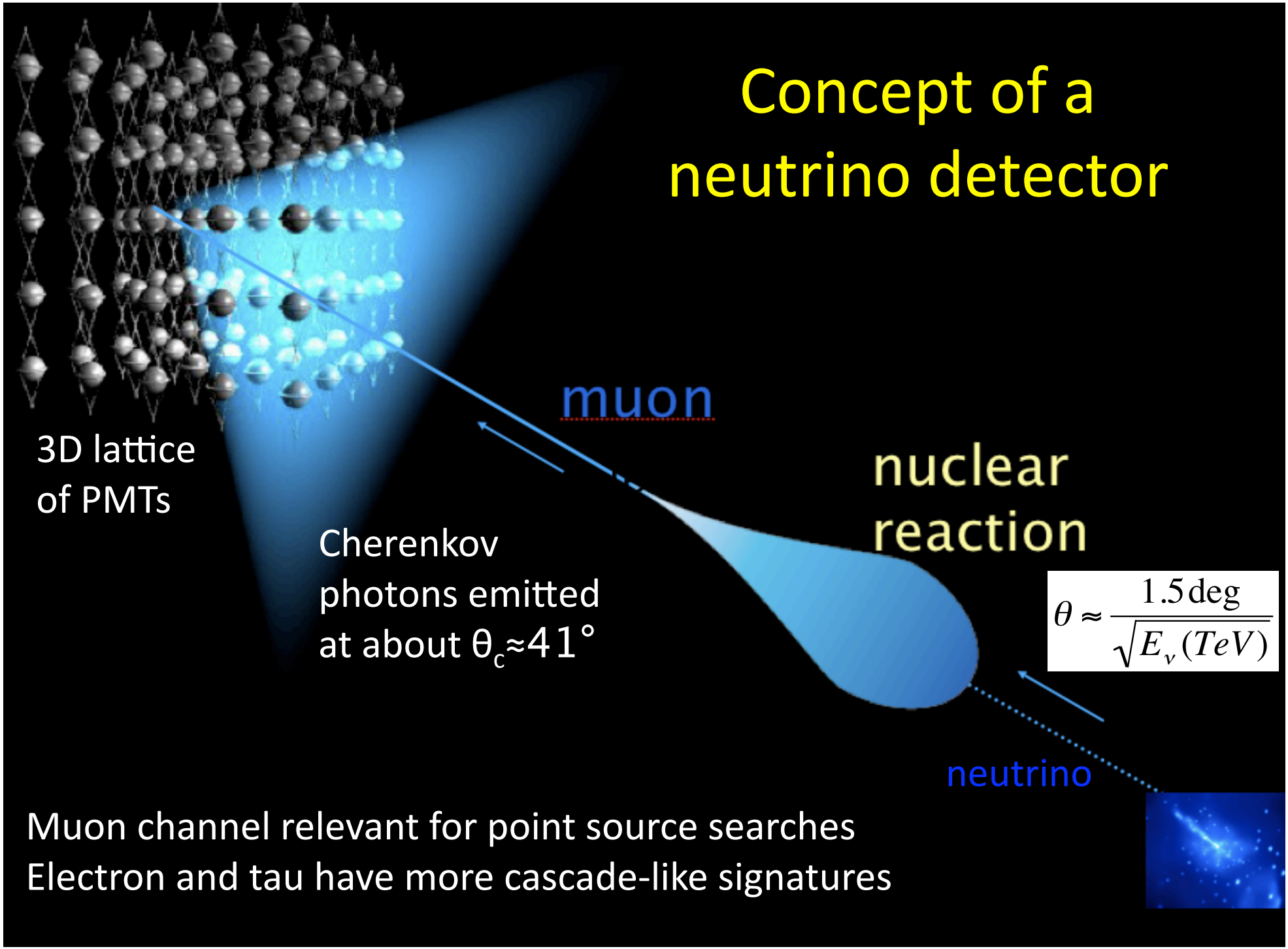
Atlanta, May 20, 2009

Outline

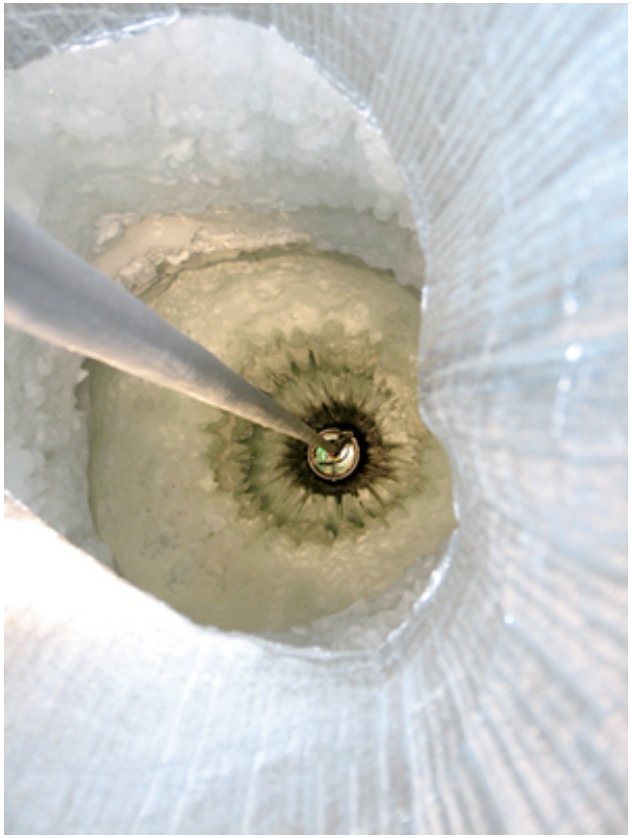
- Introduction to IceCube and analysis techniques
- Recent results
  - 22-string IceCube data unblinded
- Outlook
  - 40-string IceCube data almost ready
  - New expectations for the complete detector



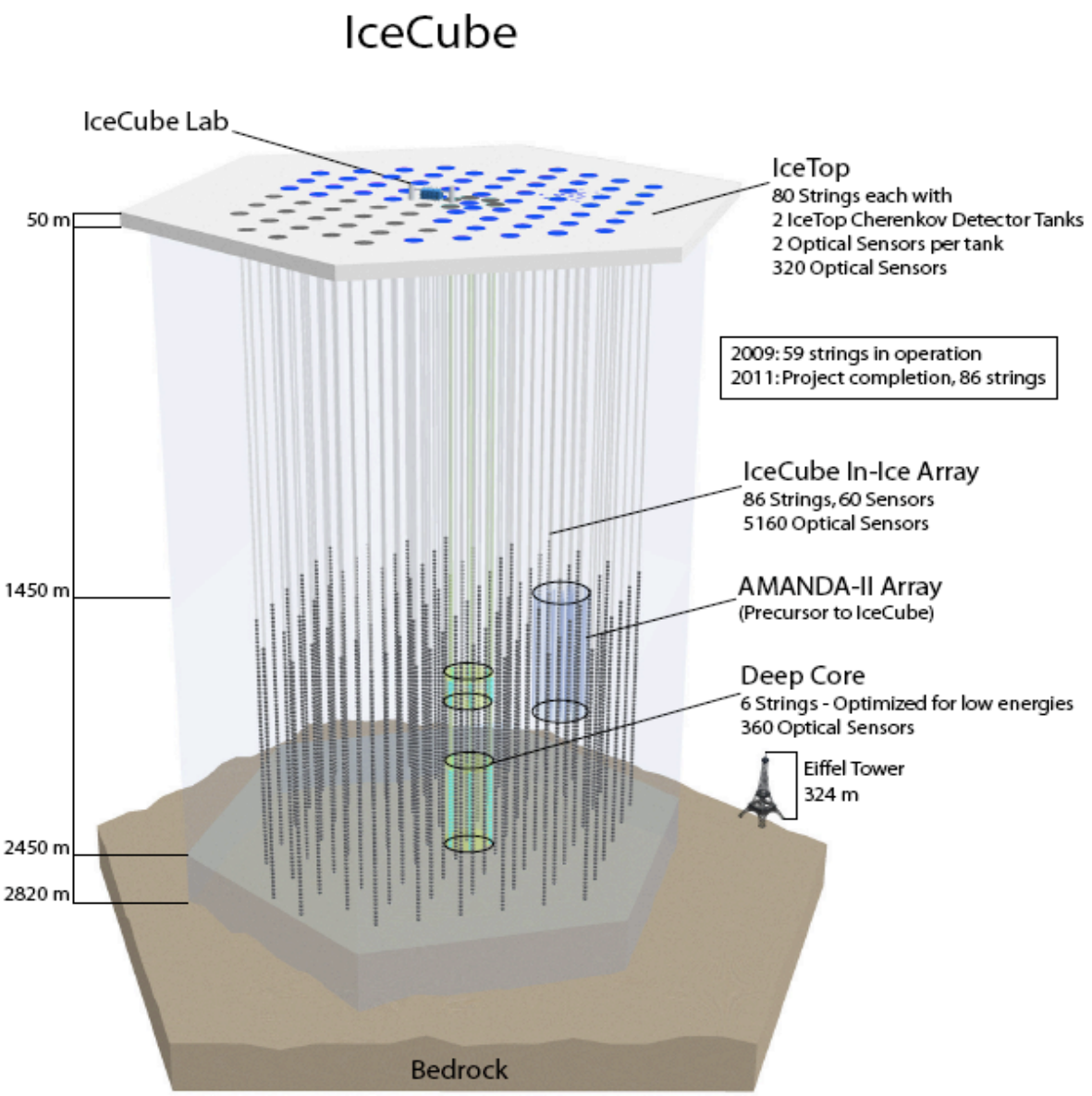
Concept of a neutrino detector



Muon channel relevant for point source searches
Electron and tau have more cascade-like signatures

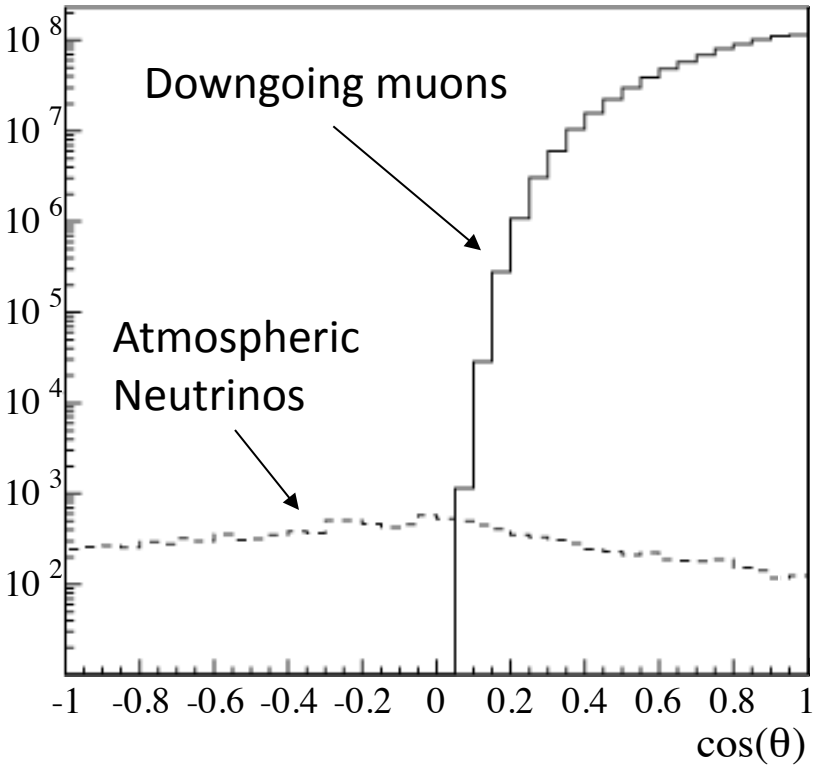






86 strings each with 60 DOMs
Includes 6 DeepCore strings,
optimized for low energies

Backgrounds



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

Northern and southern sky have very different backgrounds

Northern: Earth is used as a filter for atmospheric muons, leaving only atmospheric neutrino-induced muons traveling upward through IceCube
(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
(PS search is primarily sensitive to a neutrino signals >~PeV)

Maximum Likelihood Analysis with Energy

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

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

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

Data used for background

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

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

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

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

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

22-string Results I: A Priori Source List

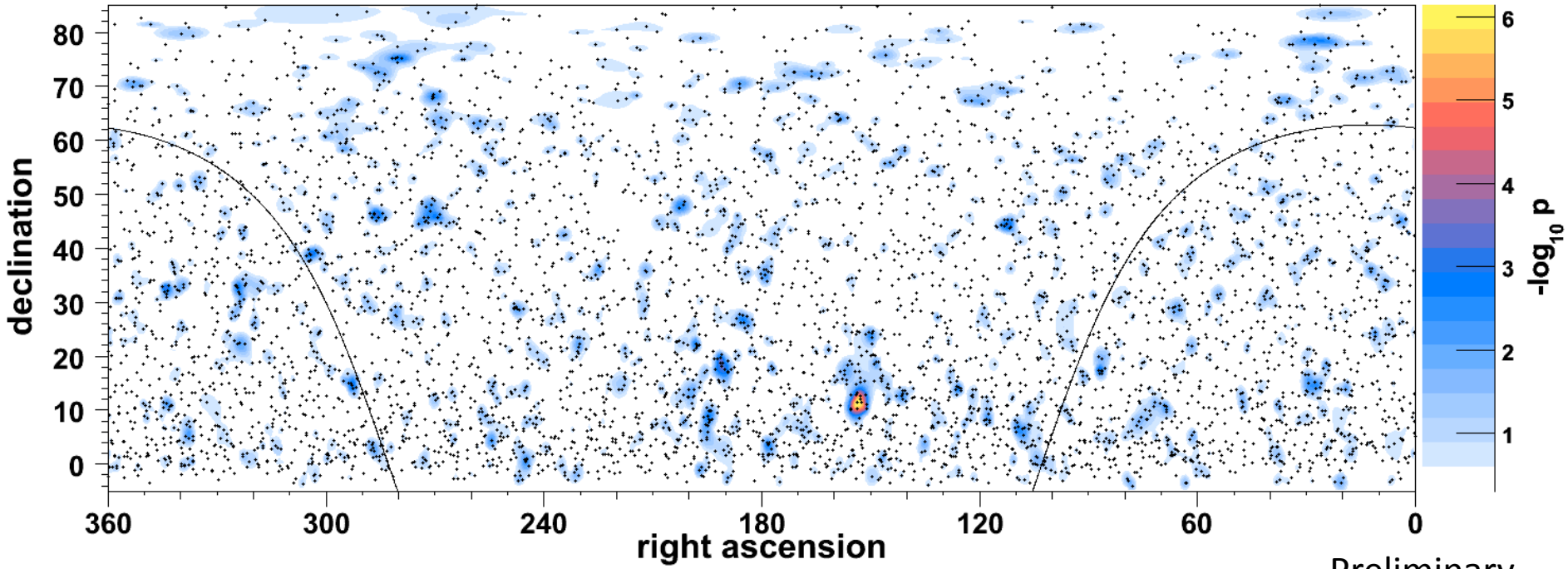
Lowest p-value (0.07) is for 1ES 1959+650.

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)	:	0.251
MGRO_J1908+06	(287.270 , 6.280)	:	-----
Cyg_OB2	(308.083 , 41.510)	:	-----
SS_433	(287.957 , 4.983)	:	0.317
Cyg_X-1	(299.591 , 35.202)	:	-----
LS_I_+61_303	(40.132 , 61.229)	:	-----
GRS_1915+105	(288.798 , 10.946)	:	-----
XTE_J1118+480	(169.545 , 48.037)	:	0.082
GRO_J0422+32	(65.428 , 32.907)	:	-----
Geminga	(98.476 , 17.770)	:	-----
Crab_Nebula	(83.633 , 22.014)	:	-----
Cas_A	(350.850 , 58.815)	:	-----
Mrk_421	(166.114 , 38.209)	:	-----
Mrk_501	(253.468 , 39.760)	:	-----
1ES_1959+650	(299.999 , 65.149)	:	0.071
1ES_2344+514	(356.770 , 51.705)	:	-----
H_1426+428	(217.136 , 42.672)	:	-----
1ES_0229+200	(38.202 , 20.287)	:	-----
BL_Lac	(330.680 , 42.278)	:	0.368
S5_0716+71	(110.473 , 71.343)	:	0.309
3C66A	(35.665 , 43.035)	:	0.313
3C_454.3	(343.491 , 16.148)	:	-----
4C_38.41	(248.815 , 38.135)	:	-----
PKS_0528+134	(82.735 , 13.532)	:	-----
3C_273	(187.278 , 2.052)	:	0.369
M87	(187.706 , 12.391)	:	-----
NGC_1275	(49.951 , 41.512)	:	0.213
Cyg_A	(299.868 , 40.734)	:	-----

(only excesses reported, otherwise given as "---")

22-string Results II: All Sky Search



Preliminary

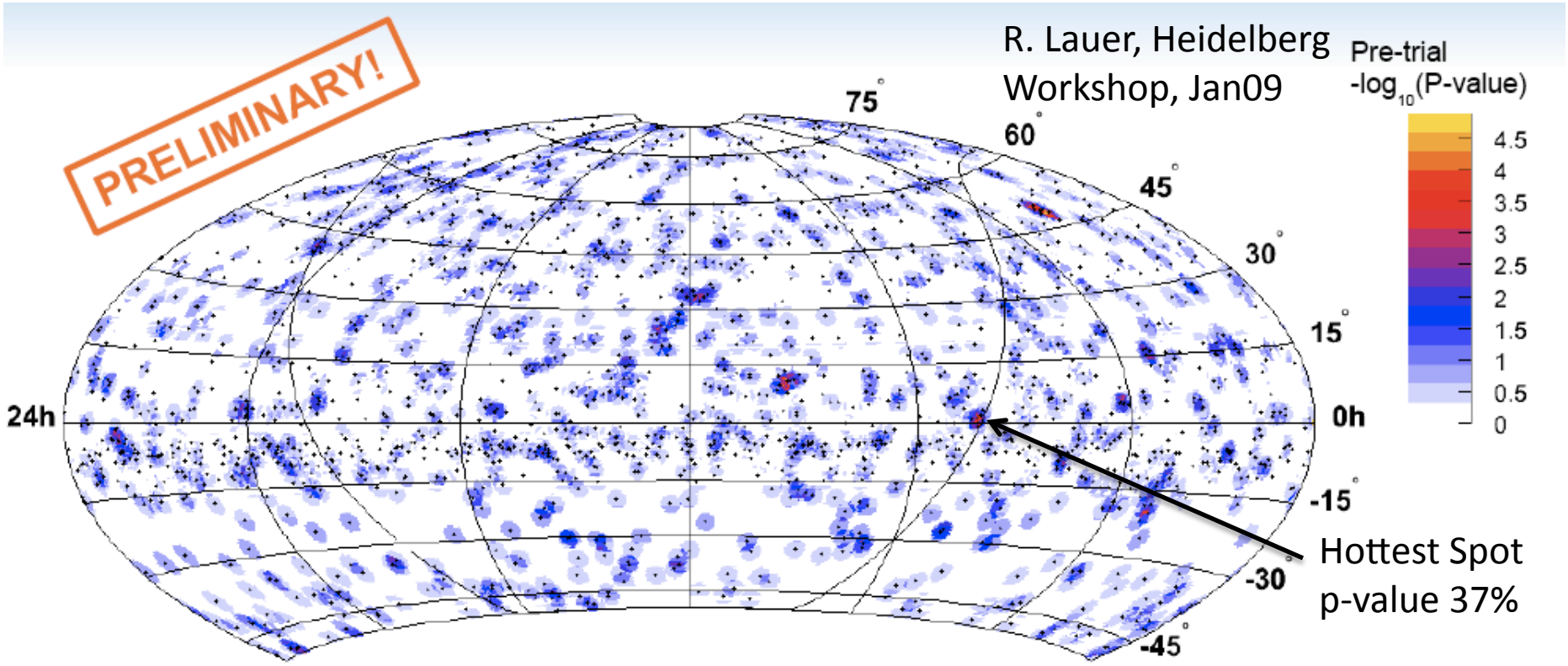
Paper submitted

Hottest spot found at r.a. 153.4° , dec. 11.4°
est. nSrcEvents = 7.7 est. gamma = 1.65
est. pre-trial p-value: $-\log_{10}(p)$: 6.14 (4.8 sigma)

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

A time-dependent follow-up revealed no signature of a burst in time

22-string Results III: HE Extension

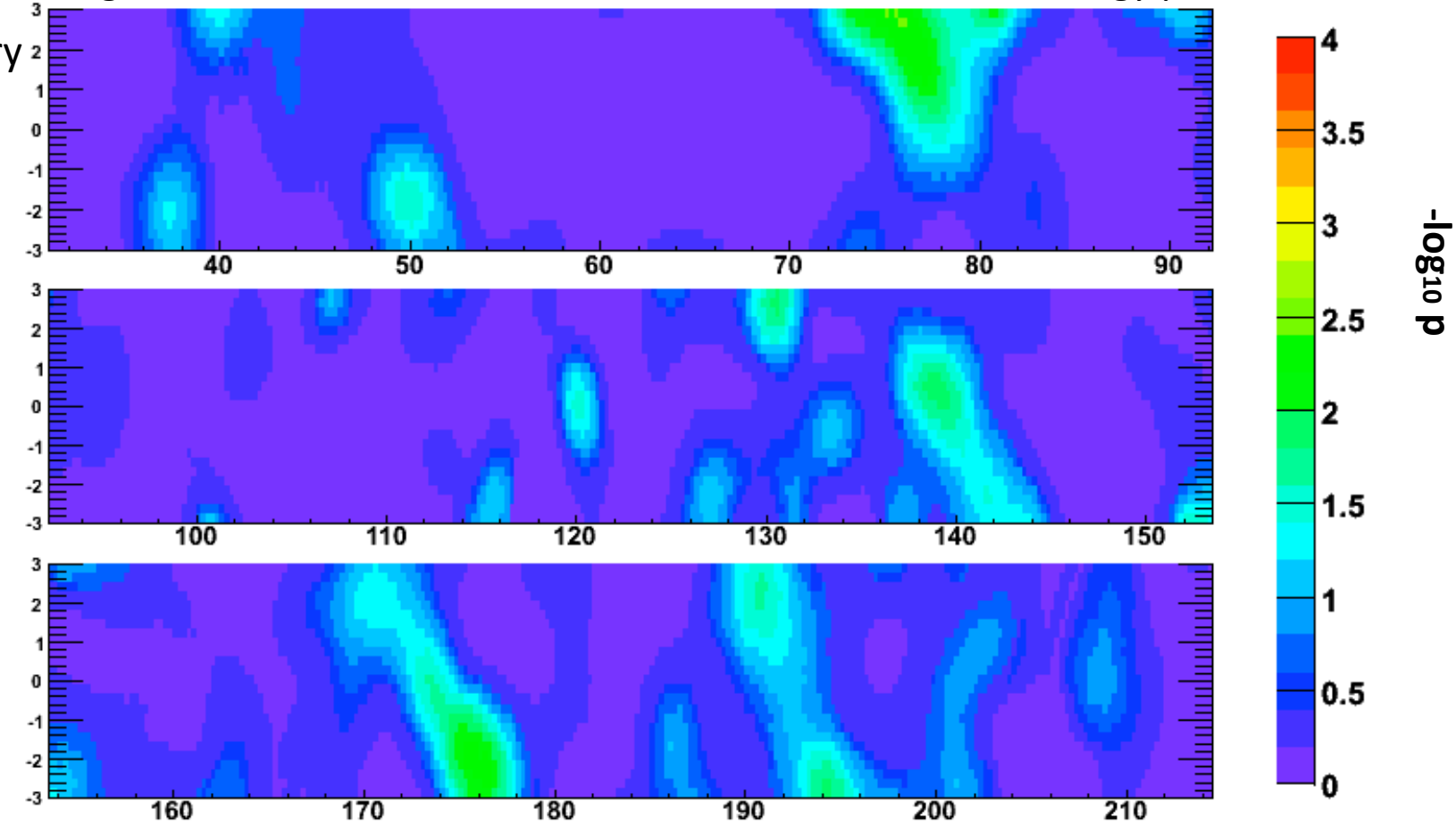


-Search extend above the horizon for the first time in IceCube
-Event selection optimized for E^{-2} and harder spectra, binned analysis
-New reconstruction used, better performance at high energies

22-string Results IV: LE Extension

IceCube merged with smaller, denser AMANDA, for enhanced low energy performance

Preliminary



Galactic Plane Scan:

hottest spot: l=75.875, b=2.675 (gal. coord.)

smallest pre-trial p-value: 0.0037 (2.7 sigma)

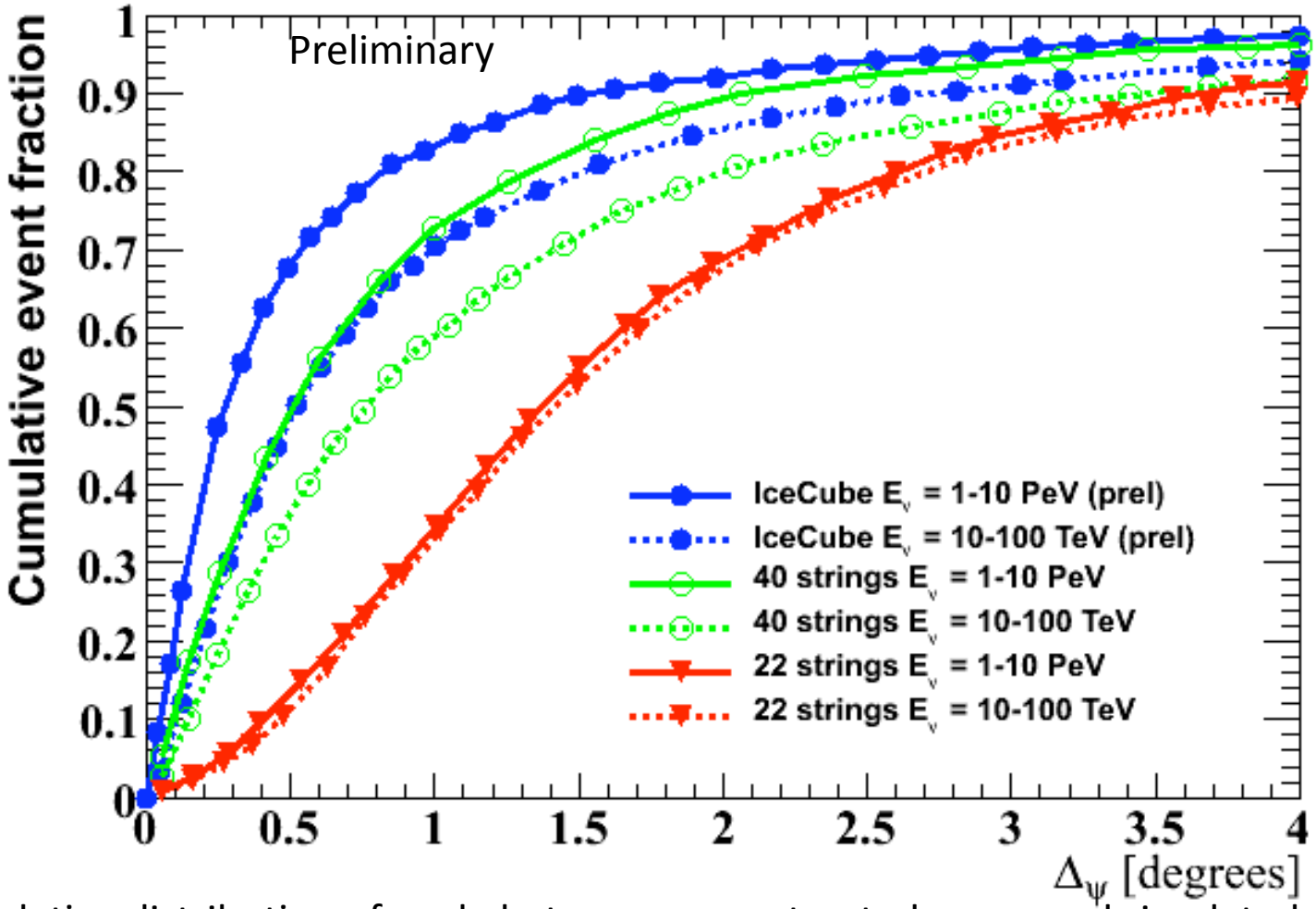
expected in 95% of randomized samples

A priori Source Candidate List:

- **Crab Nebula: p=0.14, Ns = 3.3**
- **Cas A: p=0.65, Ns=-1.9**
- **SS433: p=0.67, Ns=-0.9**
- **LS I +61 303: p=0.47, Ns= -0.4**

p<0.14 expected in 37% of randomized samples

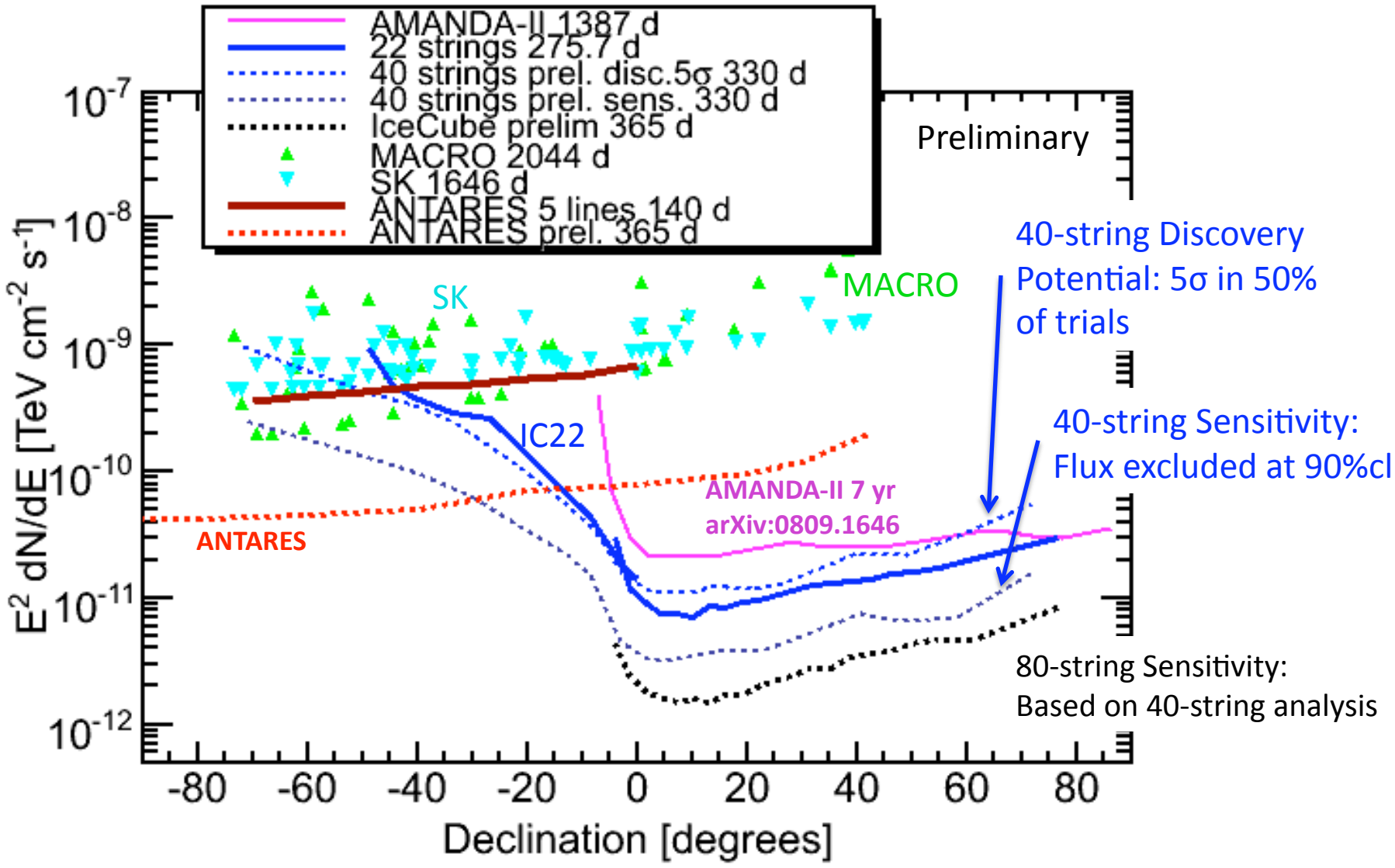
PSF: As the Detector Grows



-cumulative distribution of angle between reconstructed muon and simulated neutrino

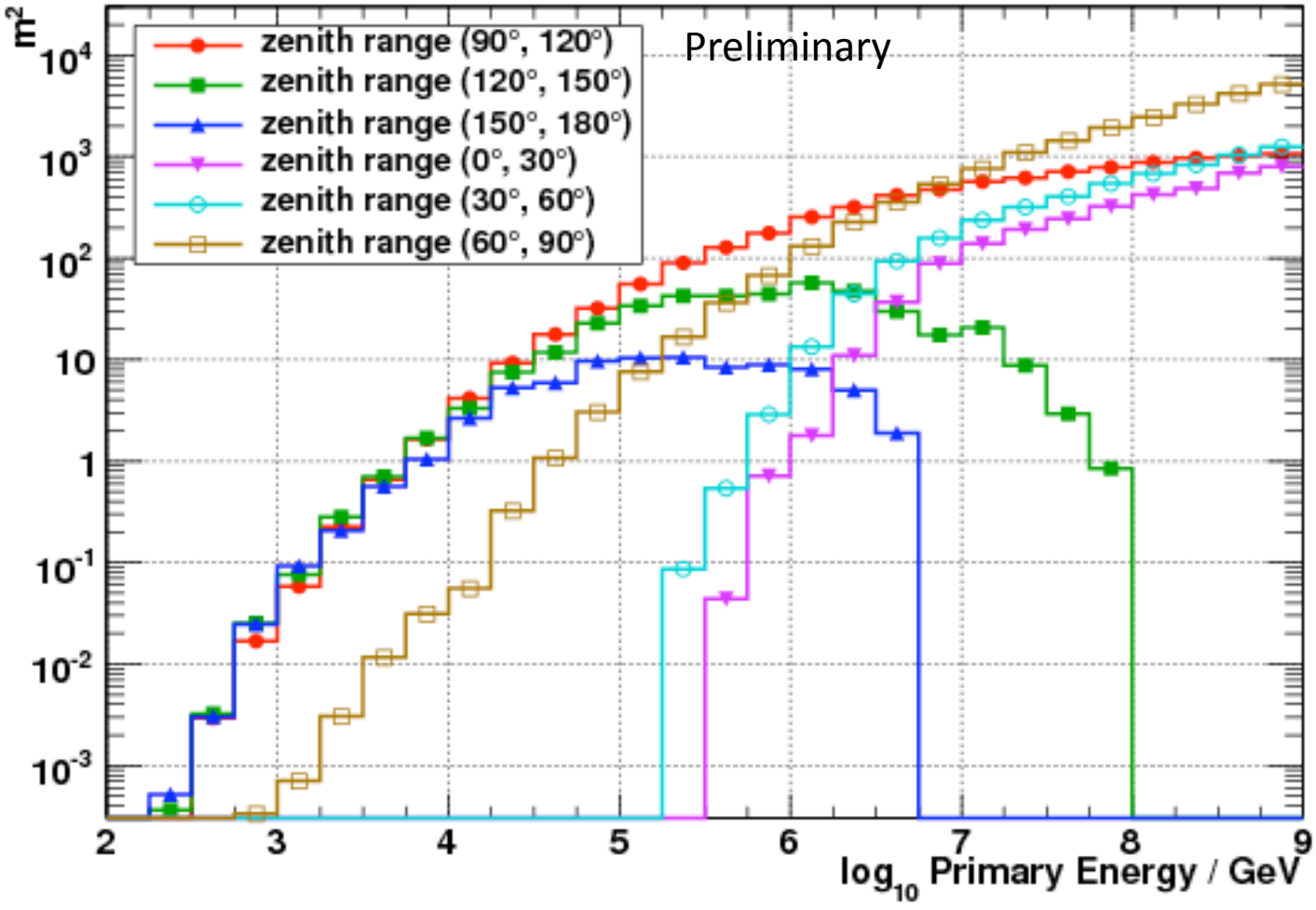
-Improvement at high energies is mostly due to an improved reconstruction technique, which accounts for the total charge in each Optical Module

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



40-string dataset is almost ready for unblinding – unified into an all-sky analysis

40-string Effective Area



Solid-angle averaged effective area to $\nu+\nu_\mu$ flux of neutrinos, reconstructed to within 2° of truth for 6 declination bands

Conclusions

- 22-string configuration of IceCube still provides the best limits for northern sky neutrino sources >~TeV
  - No evidence for a source yet
- 40-string science run is nearly complete
  - Data analysis underway
- IceCube has deployed 59 out of 86 strings
  - 59-string data taking will begin very soon
- Ready for discovery or to provide useful constraints on astrophysical models