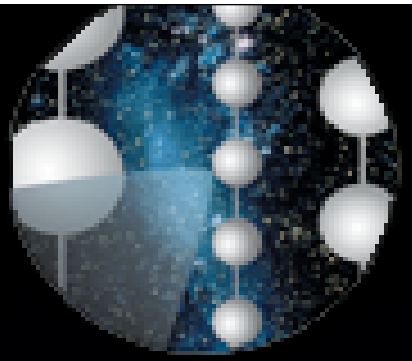


IceCube

First results of the IceCube Observatory on High Energy Neutrino Astronomy

Teresa Montaruli* for the IceCube Collaboration

* at University of Wisconsin - Madison
tmontaruli@icecube.wisc.edu

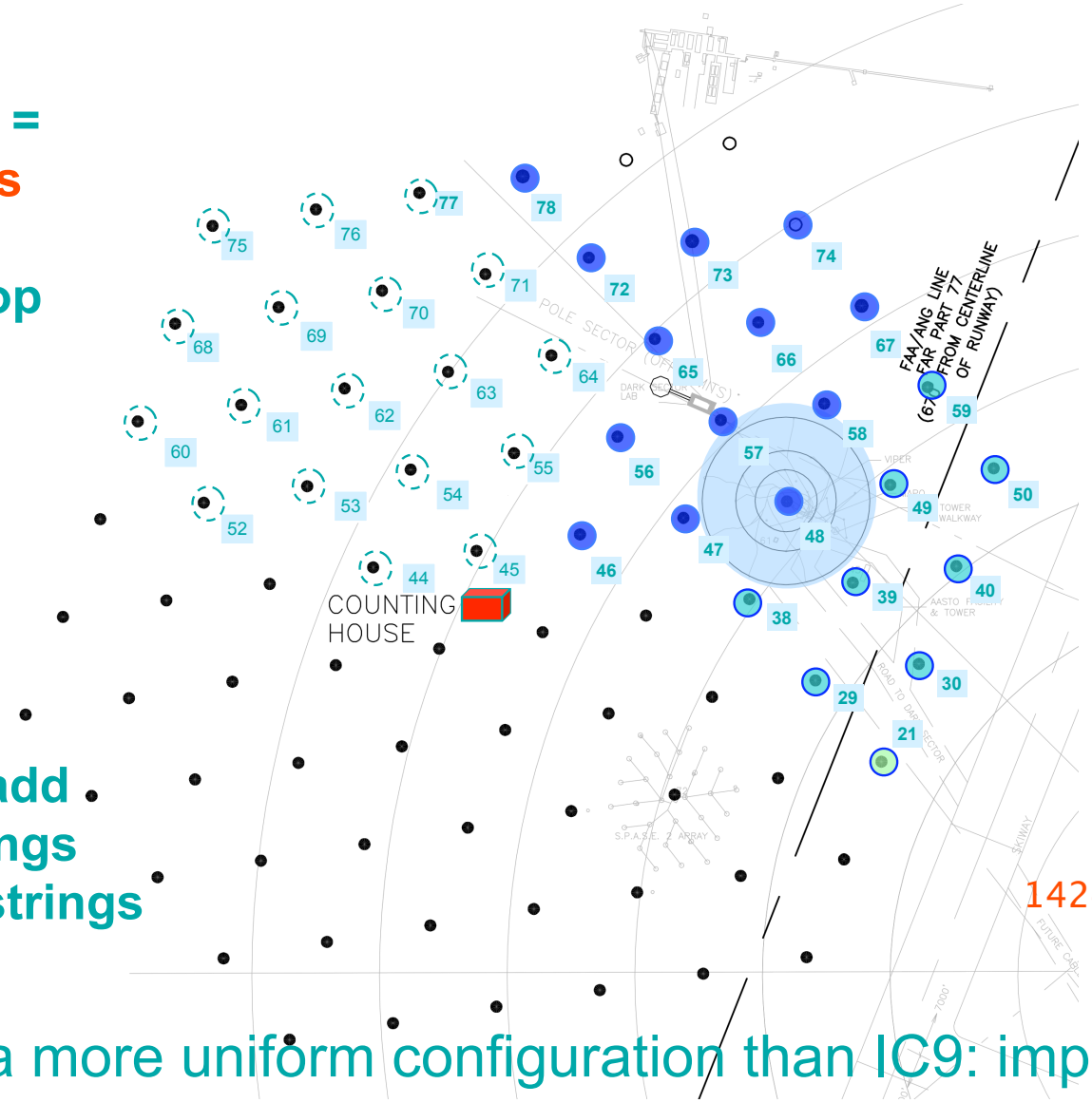
TAUP 2007, Sep. 12, Sendai, Japan

Contents

- Steady point source searches:
  - AMANDA-II published results
  - New method: unbinned likelihood
  - AMANDA-II Results on point-source searches (2005 unblinded, 2006 these days)!
  - IC9 results
  - foreseen performance of IC22, IC40, IC80
- Time dependent searches:
  - GRBs
  - MWL campaigns

2005-2008 configurations

1+ 9 + 13 =
22 strings
to date
+26 IceTop stations



AMANDA

IceCube string deployed 01/05

IceCube string deployed 12/05 – 01/06

IceCube string deployed 12/06 – 01/07

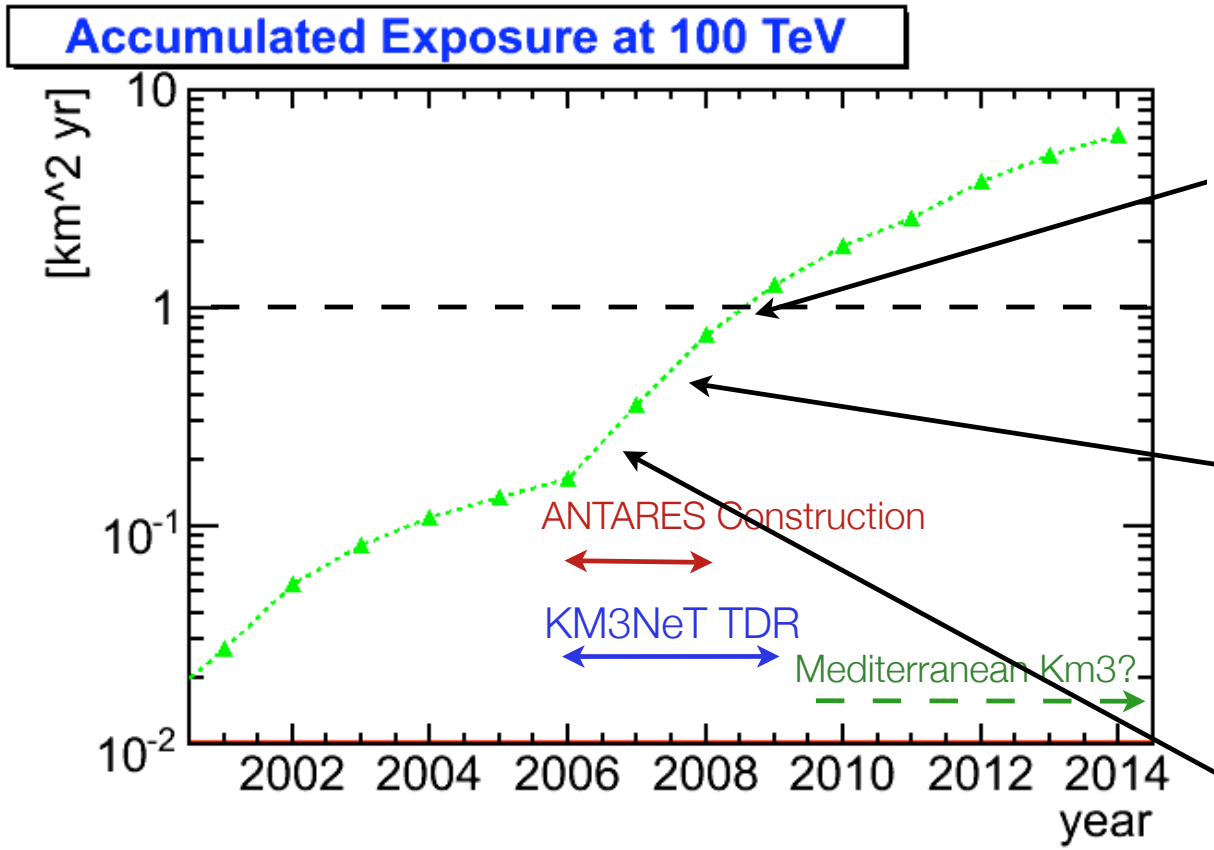
IceCube Lab commissioned

2007/08: add 14-18 strings
2011: 80 strings

1424 DOMs deployed to date

IC22 is a more uniform configuration than IC9: important for angular resolution improvement and isotropy!

IceCube Accumulated Exposure with time



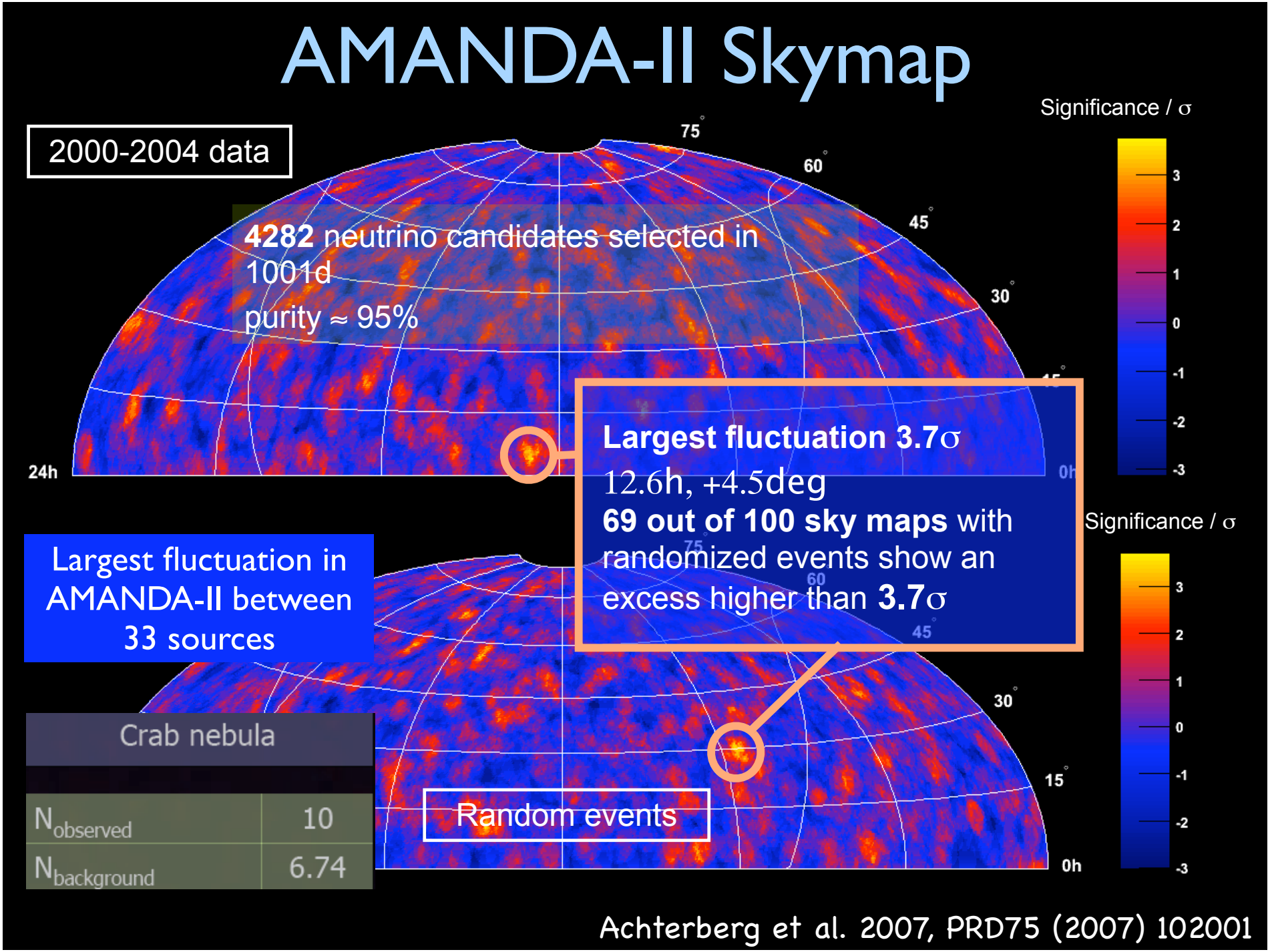
IC36-40: Science Run starts in Apr 2008 (GLAST launch Jan 2008)

IC22: Science Run started in May 2007 until Mar 2008 more uniform than IC9 Milagro, VERITAS, Magic, Argo,...

Jun-Nov 2006 data
IC9≈AMANDA-II sensitivity
Point-source results presented at ICRC2007

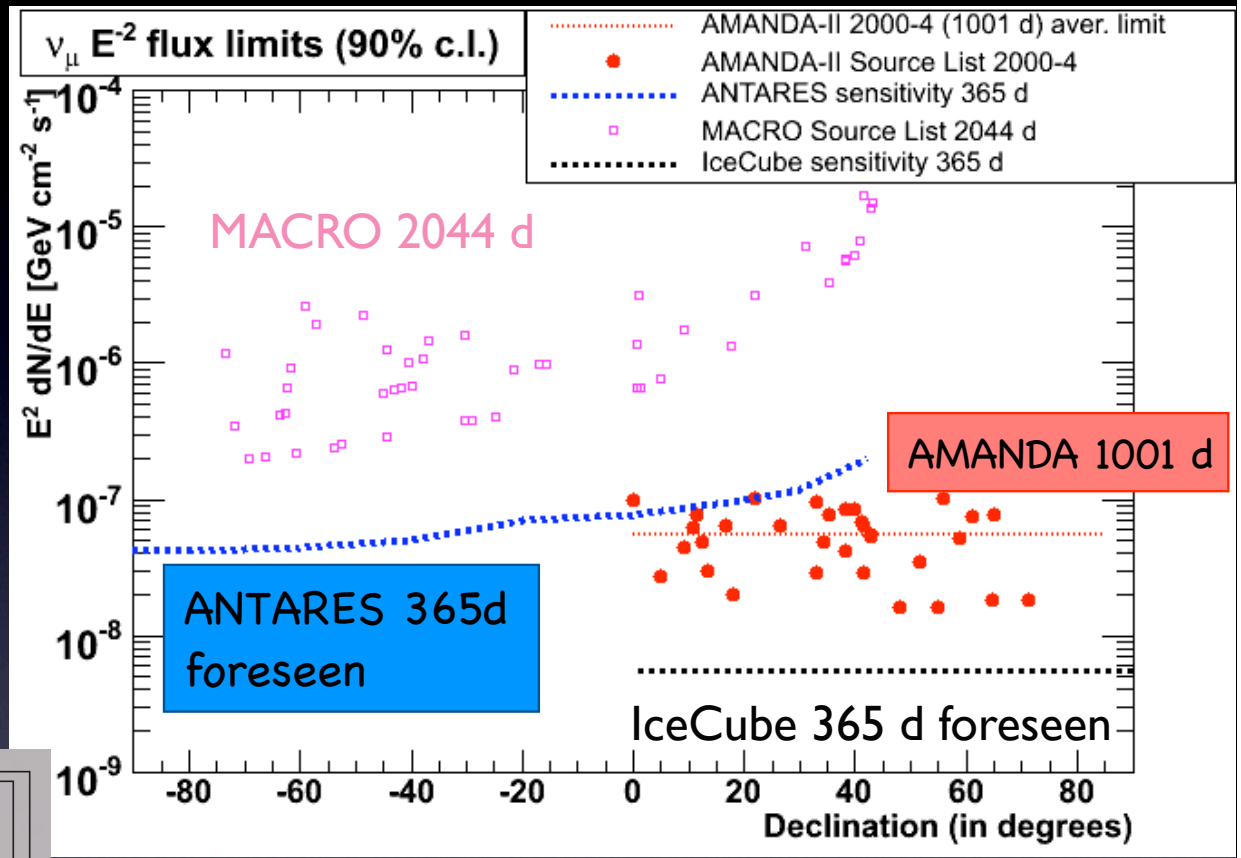
Effective area for muons at 100 TeV

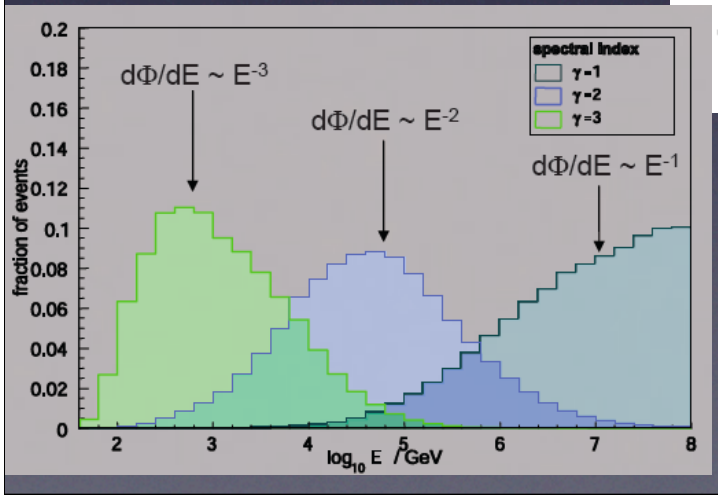
AMANDA-II Skymap



Achterberg et al. 2007, PRD75 (2007) 102001

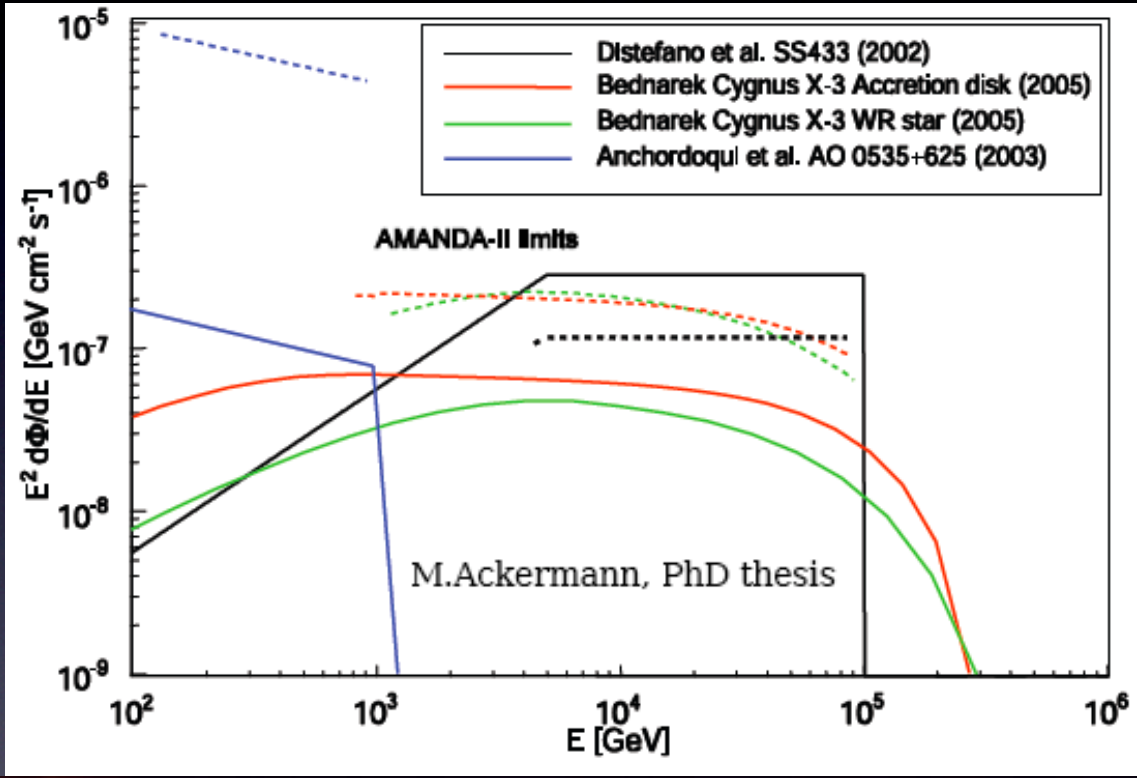
Flux limits and sensitivities





MACRO: astro-ph/0002492
AMANDA: astro-ph/0611063
ANTARES: A. Heijboer, Ph.D. thesis
IceCube:stro-ph/030519

An example of interpretation: X-Ray Binaries



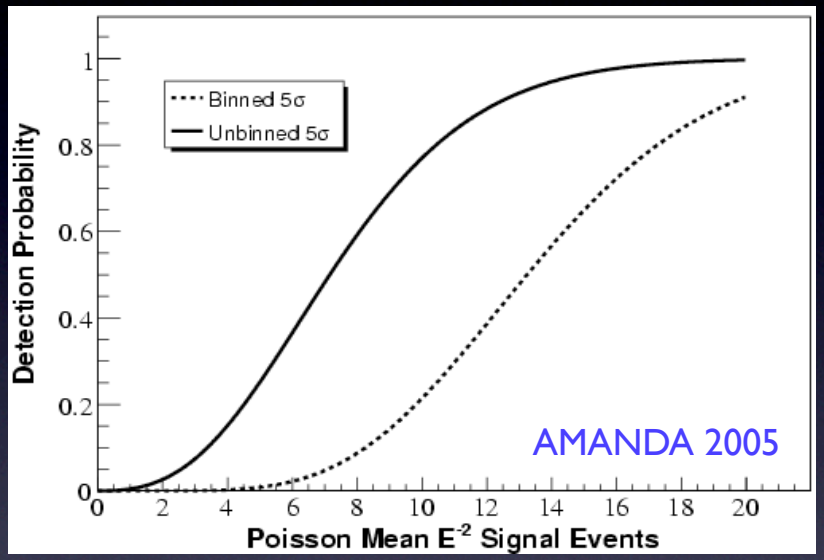
SS433	
N_{obs} / N_{bg}	4 / 6.14
Cygnus X-3	
N_{obs} / N_{bg}	7 / 6.48
AO 0535+625	
N_{obs} / N_{bg}	7 / 6.48

- Distefano et al.: pγ-interaction in the jet with int. and ext. photons ($N_{\nu,exp}$=7.8 for SS 433)
- Bednarek: pp-interaction in WR star and accretion disk after photo-dissoziation of heavy nuclei in the jet ($N_{\nu,exp}$=2.1 / 1.4 for Cygnus X-3)
- Anchordoqui et al.: Protons accelerated in electrostatic gap interact in accretion disk ($N_{\nu,exp}$=0.12 for AO 0535+625)

Microquasar SS433 (VLBA)

2005-6 AMANDA-II and IceCube analysis

- likelihood method utilizes event direction, detector PSF and energy estimator (eg Nch)
- improves up to 40%
- time dependent LH can be introduced (eg lightcurve from X-ray, TeV, optical telescopes)



- In preparation: 1997-99 (AMANDA B10)+2000-6 (AMANDA-II)
- IC9 presented at ICRC07
- now working on IC22

LH method

Source hypothesis in IC9 analysis uses **individual point spread functions** for each event, based on **angular uncertainty estimate** of track reconstruction. 2D gaussian approximation works also well.

Background hypothesis based on **declination distribution of data events** (i.e. scrambled in right ascension) **to correctly account for all backgrounds**

- Spectra reconstruction using Pi(Nch|spectral index)

- Partial Probability for each event

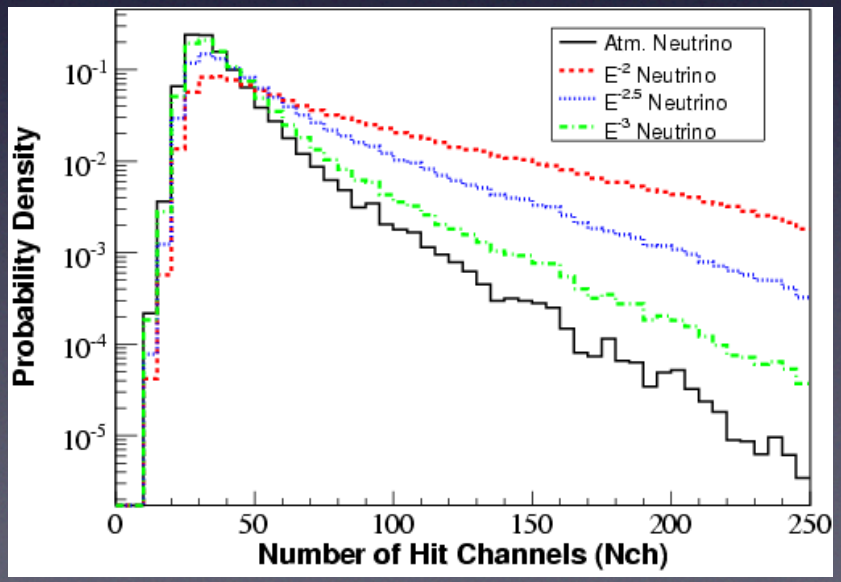
$$P_i(x, n_s) = \frac{n_s}{N} S_i(x) + \frac{N - n_s}{N} B_i(x)$$

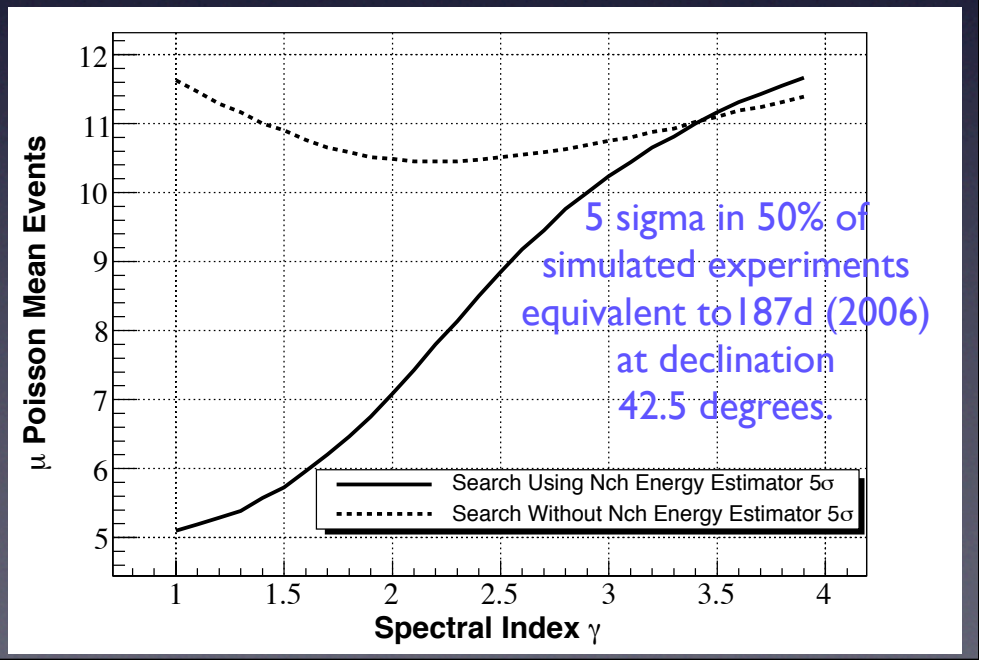
- Likelihood function

$$L(n_s) = \prod P_i(x_i, n_s)$$

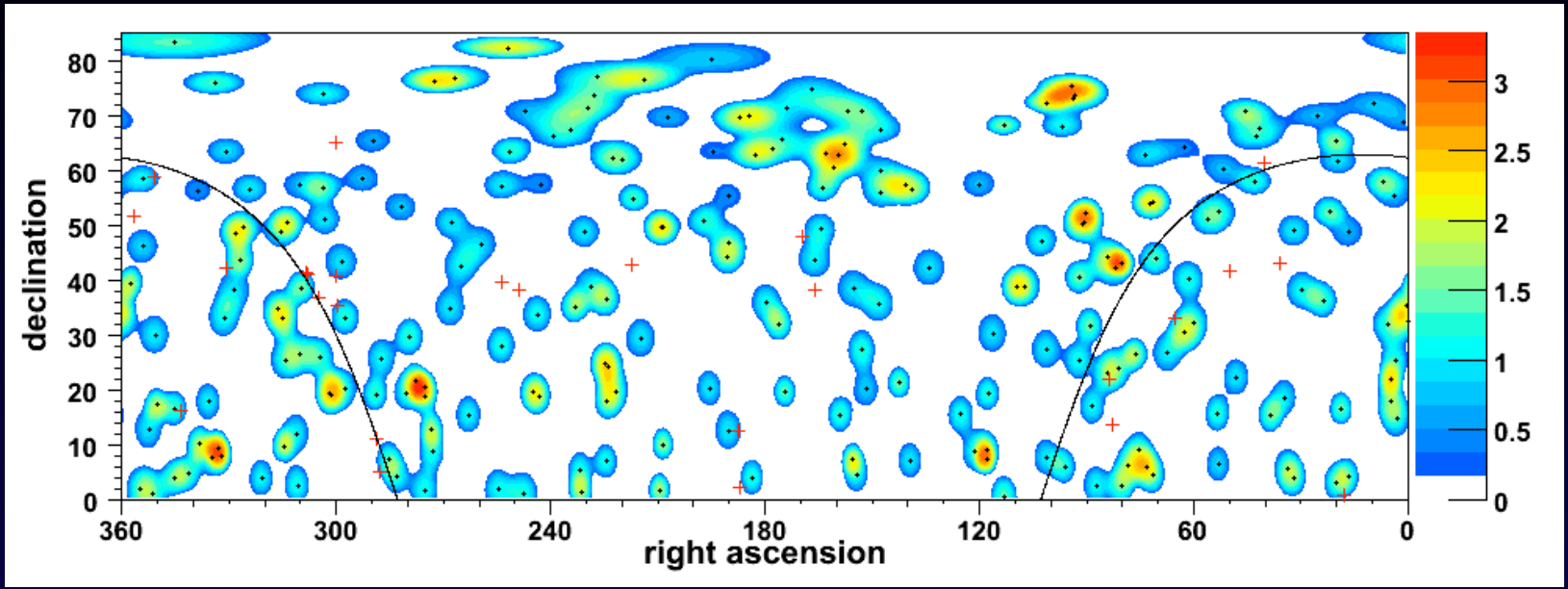
- Log Likelihood Ratio

$$\log \lambda = \frac{\log L(\hat{n}_s)}{\log L(n_s = 0)}$$





1st IceCube data Sky Map



The maximum deviation is 3.35 sigma, at r.a. = 276.6° , dec = 20.4°.
Random clustering of background: **60%** of simulated background trials (data scrambled in right ascension), have a maximum deviation (anywhere) of **3.35 sigma** or greater.

Largest deviation from background: sigma = 1.77 (one-sided p-value = 0.04), in the direction of the Crab Nebula when looking at IC9 26 source list.
Chance to obtain a p-value of 0.04 or lower with 26 independent trials is **65%.**

137 d IC9 Averaged Sensitivity ($E^{-2}\,\nu_\mu$):
$12 \times 10^{-8}\ (E/GeV)^{-2}\ GeV^{-1}\ cm^{-2}\ s^{-1}$

1001 d AMANDA-II Averag. Sensitivity ($E^{-2}\,\nu_\mu$):
$5 \times 10^{-8}\ (E/GeV)^{-2}\ GeV^{-1}\ cm^{-2}\ s^{-1}$
(sys error ~15%)

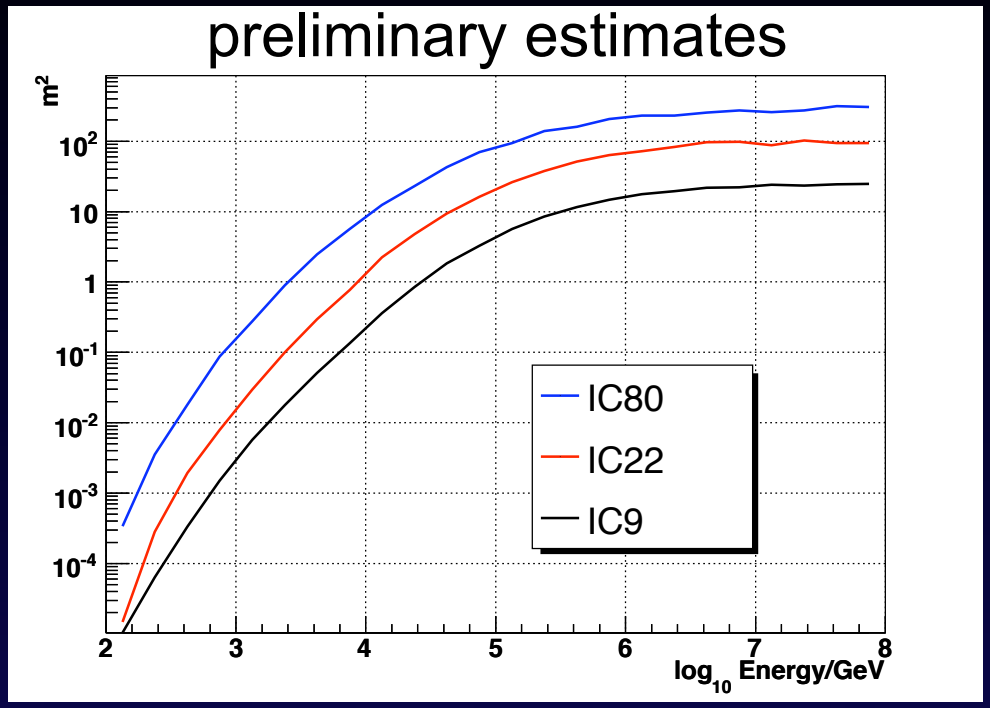
Results: Source List Search

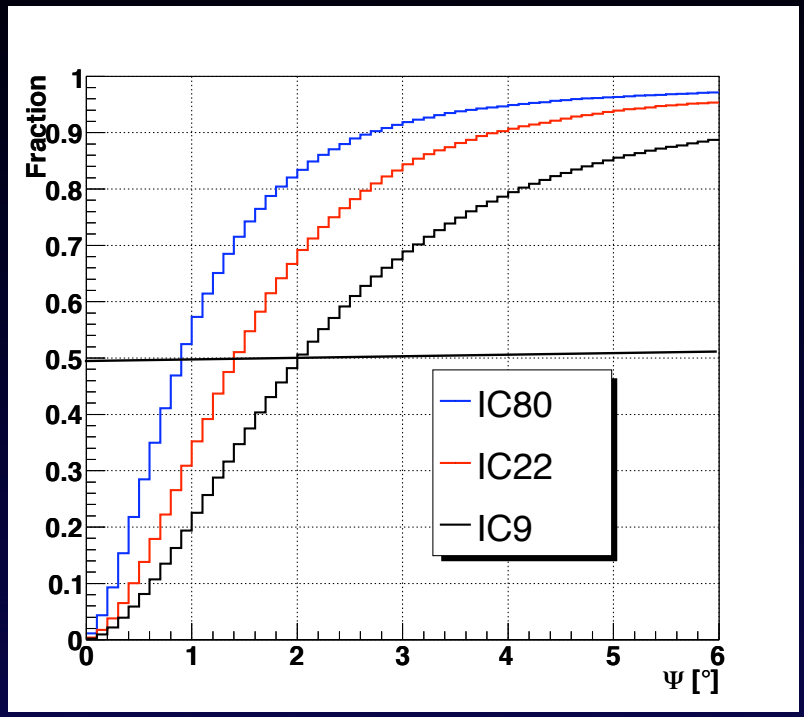
Object	(r.a. , dec)	:	sigma	n_s est.	n_s	90% C.L. upper limits Φ
MGRO J2019+37	(304.8, 36.8)	:	0.00	0.0	2.8	12.7
Cyg OB2/TeV J2033+4130	(308.3, 41.3)	:	0.23	0.2	2.9	14.0
Mrk 421	(166.1, 38.2)	:	0.00	0.0	2.9	13.1
Mrk 501	(253.5, 39.8)	:	0.00	0.0	2.7	11.5
1ES 1959+650	(300.0, 65.2)	:	0.00	0.0	3.3	14.6
1ES 2344+514	(356.8, 51.7)	:	0.00	0.0	2.8	11.4
H 1426+428	(217.1, 42.7)	:	0.00	0.0	3.0	14.5
BL Lac (QSO B2200+420)	(330.7, 42.3)	:	0.28	0.4	3.2	15.7
3C66A	(35.7, 43.0)	:	0.00	0.0	3.0	13.3
3C 454.3	(343.5, 16.1)	:	1.08	0.7	3.6	14.4
4C 38.41	(248.8, 38.1)	:	0.00	0.0	2.8	12.6
PKS 0528+134	(82.7, 13.5)	:	0.00	0.0	2.8	10.3
3C 273	(187.3, 2.0)	:	0.00	0.0	2.5	11.0
M87	(187.7, 12.4)	:	0.67	0.5	3.2	11.4
NGC 1275 (Perseus A)	(50.0, 41.5)	:	0.00	0.0	2.8	13.4
Cyg A	(299.9, 40.7)	:	0.41	0.4	3.0	14.5
SS 433	(288.0, 5.0)	:	0.12	0.1	2.4	8.2
Cyg X-3	(308.1, 41.0)	:	0.51	0.4	3.0	14.5
Cyg X-1	(299.6, 35.2)	:	0.52	0.4	3.0	12.2
LS I +61 303	(40.1, 61.2)	:	0.00	0.0	3.2	14.2
GRS 1915+105	(288.8, 10.9)	:	0.00	0.0	2.8	9.8
XTE J1118+480	(169.6, 48.0)	:	0.00	0.0	2.8	12.4
GRO J0422+32	(65.4, 32.9)	:	0.65	0.8	3.1	13.5
Geminga 98.48	(17.8, 0.6)	:	0.65	0.8	3.0	16.4
Crab Nebula	(83.6, 22.0)	:	1.77	1.6	5.2	21.8
Cas A	(350.9, 58.8)	:	0.67	0.5	4.4	19.9

Φ Flux Units: 10^{-11} $(E / \text{TeV})^{-2}$ TeV^{-1} cm^{-2} s^{-1}

None of the a priori source locations shows significant excess

IC9 (2006-7), IC22 (2007-8), IC40 (2008-9), IC80 (2010-11)





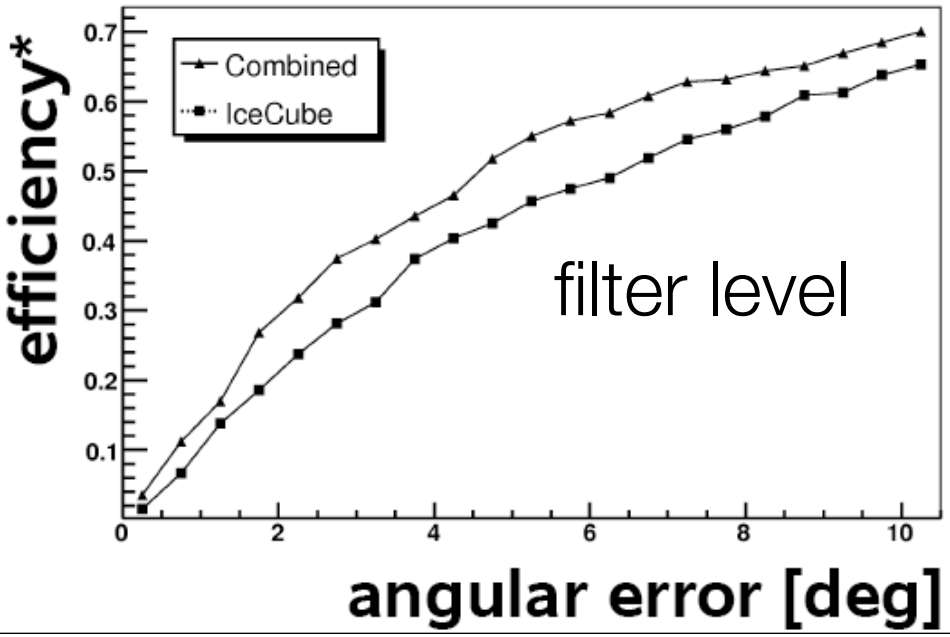
IC22, IC80 analysis not optimized yet (reconstruction and cuts optimized for IC9), nonetheless ang res already for IC22 much better than for IC9 (median 1.5° compared to 2° in IC9)

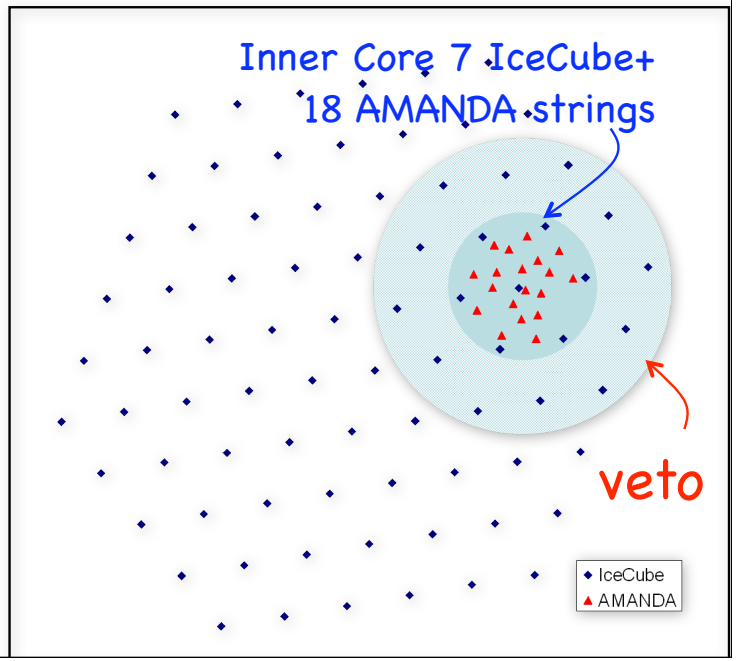
In 2008 IC40 will collect about 12000 atm neutrinos/yr and the background in a bin of radius 1.5° is 4 ev/yr (> 1 TeV => 1.8 ev/yr). The sensitivity will improve by about 8 respect to IC9.

IC80 eff area will be about 1 order of magnitude larger than IC9

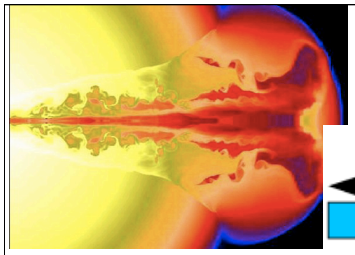
The low energy core of IceCube: AMANDA

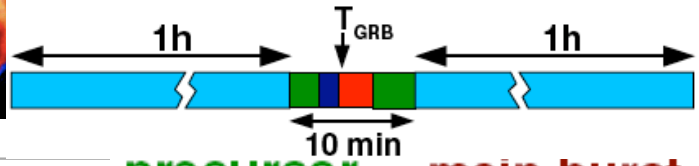
- Larger event rates for galactic sources: 10% more events for source cut-off at 3-10 TeV for IC22+AMANDA than IC22 standalone.
- Threshold at about 30 GeV, good for atmospheric neutrino studies. For point-sources increased background BUT better angular resolution
- Using IceCube as VETO possible identification of neutrinos interacting in the inner core detector.

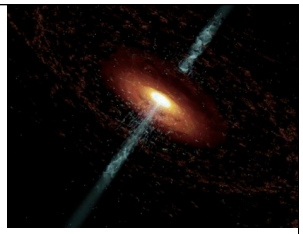


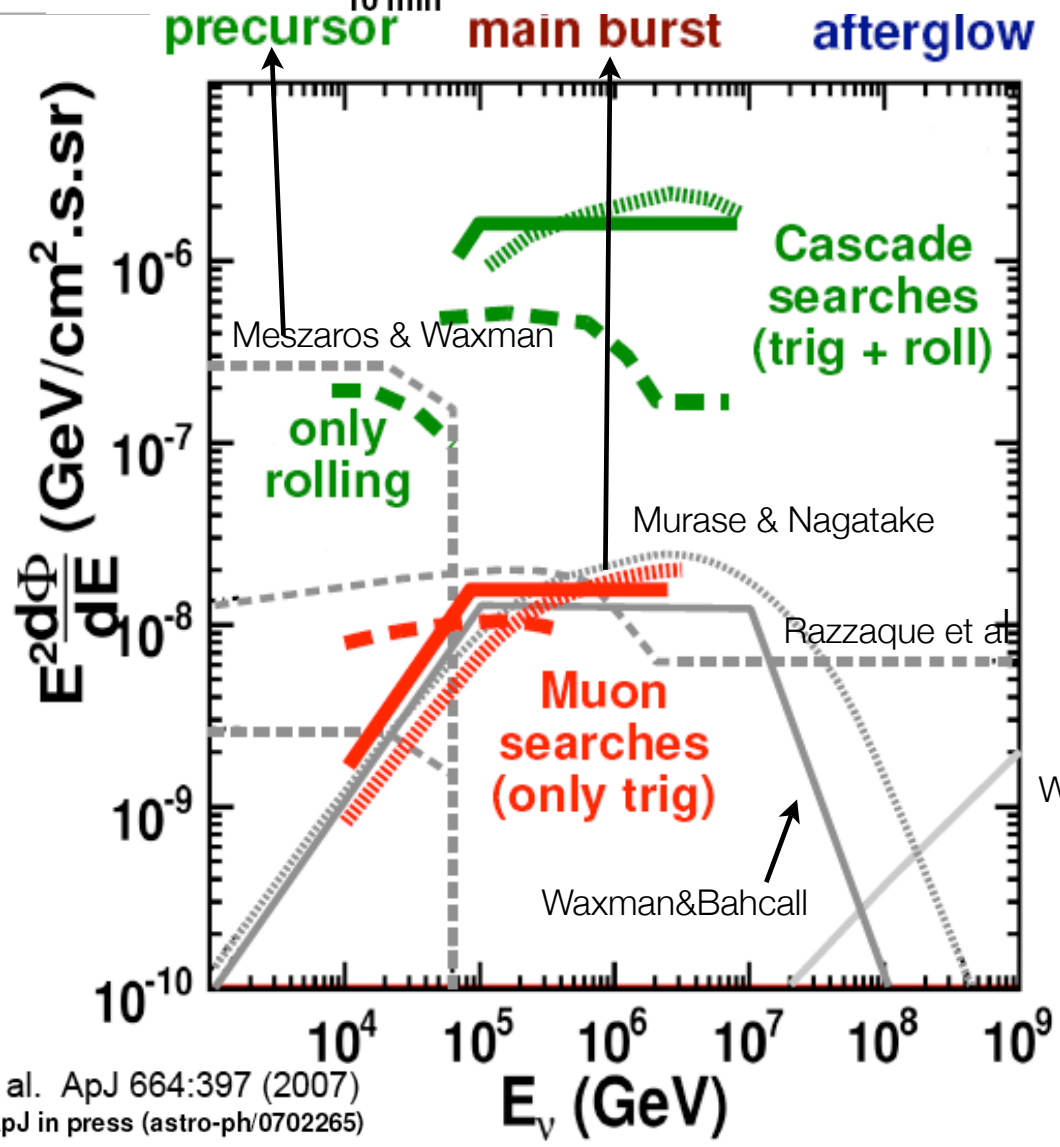


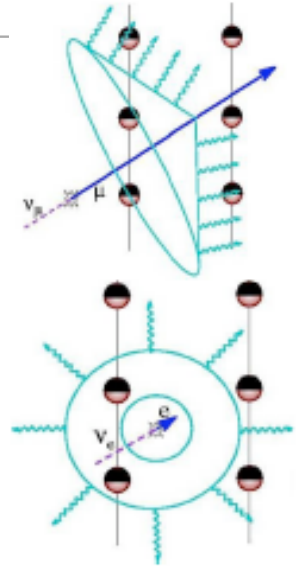
Gamma-ray Bursts











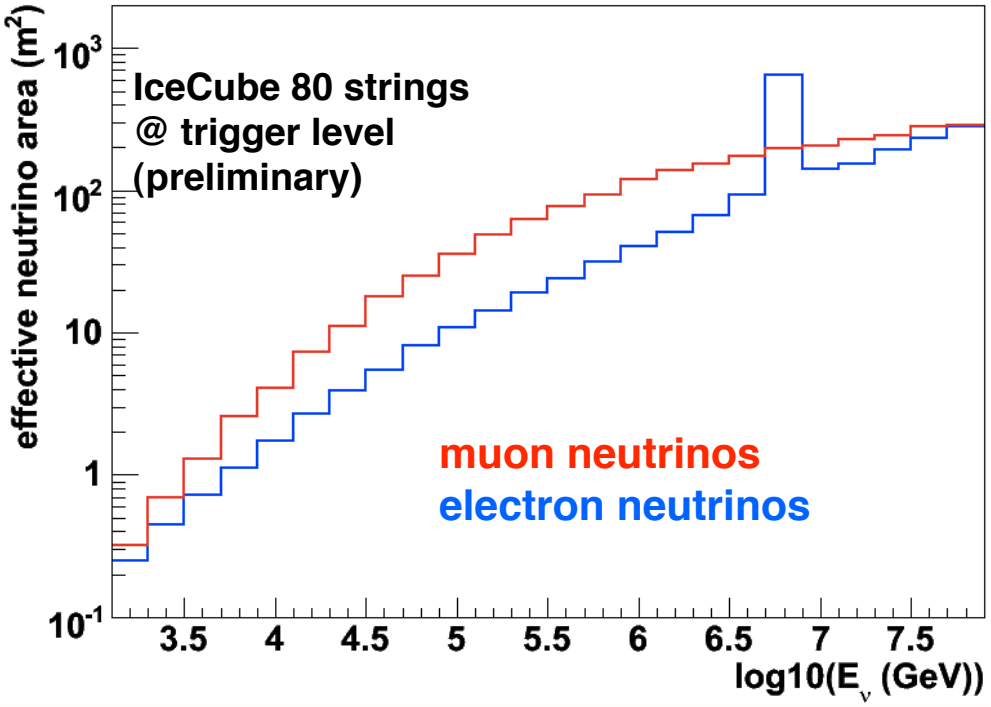
flavor ratio at Earth (1 : 1 : 1)

Achterberg A. et al. ApJ 664:397 (2007)

A. Achterberg etal, ApJ in press (astro-ph/0702265)

GRBs in IceCube

- Satellite bandwidth for IC22: 30 GB/d
- Online Filter (>Jun 2007): all data in ± 1 hr around GCN alert transferred to North



IC80

3σ sensitivity for Waxman-Bahcall GRB flux with ~100 (~300) detected bursts in muon (cascade) channel

(GLAST ~200 bursts per year, 4 π)

SWIFT 100/yr

		FoV (sr)	PSF	Band	Operation
Integral	IBIS	0.02	12'	15 keV – 10 MeV	Oct '02 -
Swift	BAT	1.4	15'	15 – 150 keV	Nov '04 -
Agile	SuperAgile	1	6'	15 – 60 keV	Jun '07 -
	mCal	N/A	N/A	300 keV – 100 MeV	
GLAST	GBM	9.5	1.5°	8 keV – 30 MeV	Apr '08 -
	LAT	2.4	15'	20 MeV – 300 GeV	

Multi-wavelength programs

☆Offline Programs: many offline analyses, SGR1806-20 Dec 2005 flare, WIYN-VERITAS-IceCube,HESS sources with muons from gammas, Milagro data, and many more GLAST Guest Investigator proposals Cycle 1:GRBs with GBM data, transient sources with LAT data

☆Online programs:

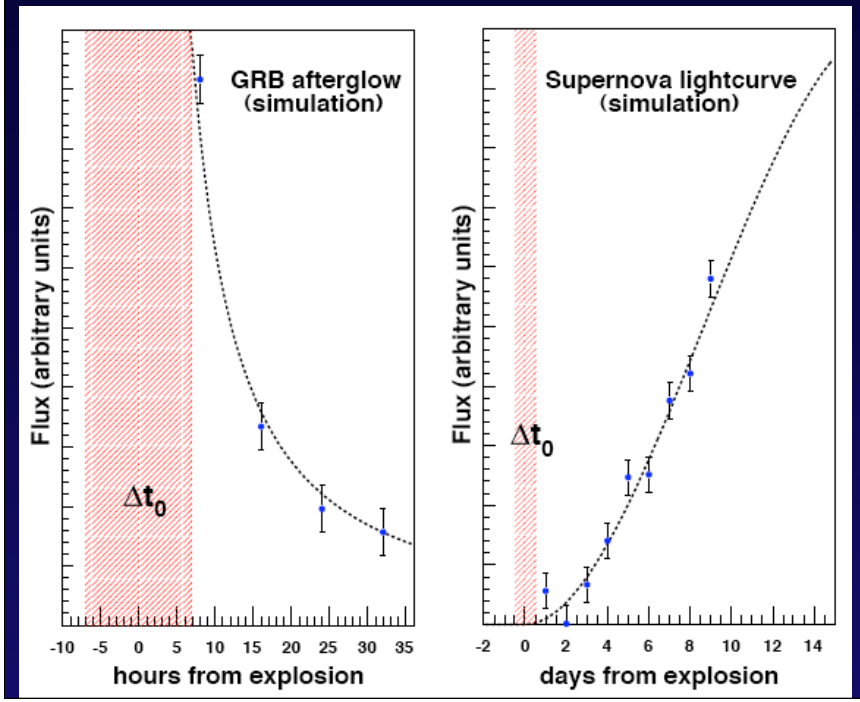
☆Neutrino alerts: NToO test run AMANDA-Magic and proposal of ToO for GRBs and SNe with networks of Optical Telescopes

☆SN collapse - IceCube should enter SNEWS this year

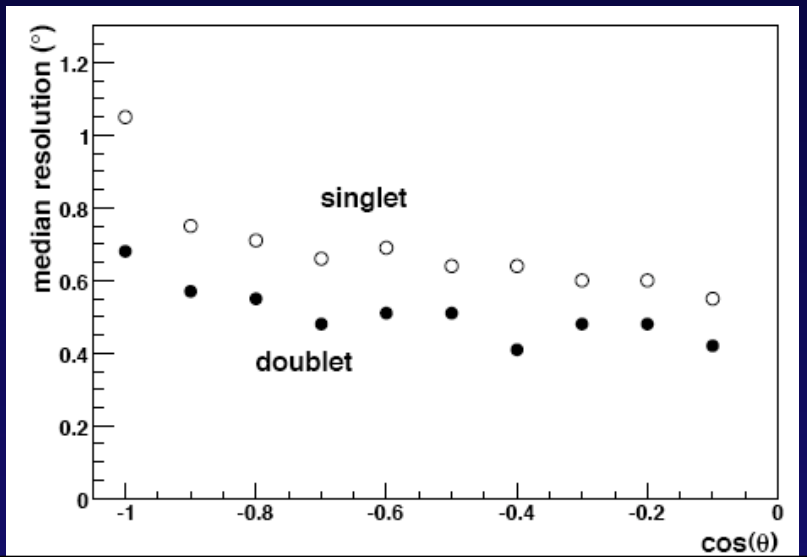
Optical follow-up for neutrino events

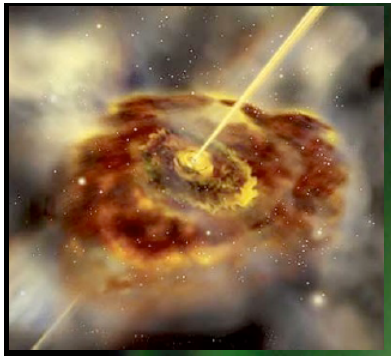
Kowalski & Mohr, astro-ph/0701618

- ν event direction reconstructed online and if energy or multiplicity > a given threshold a notice is sent to a network of optical telescopes
- t_0 can be reconstructed from light curves with precision < 1d from GRB afterglows and SNe light curves
- Rate of doublets of atm. neutrino backg. for max separation of 3^o and Δt = 100 s => 30/yr hence follow-up feasible



ROTSE-III: 4 automated telescopes would cover > 80% of IceCube PSF for doublets





Conclusions

IC22 science run now under way:
- expected to deliver 10 months lifetime
- sensitivity: ~ x4 AMANDA-II (1001d)

IC40 (April 2008) will be 1/2 completed detector and angular resolution close to optimal

Beginning of 2009: km3 yr integrated exposure