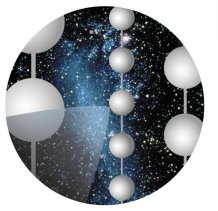
The latest nus from IceCube
(GZK, point sources & GRBs)

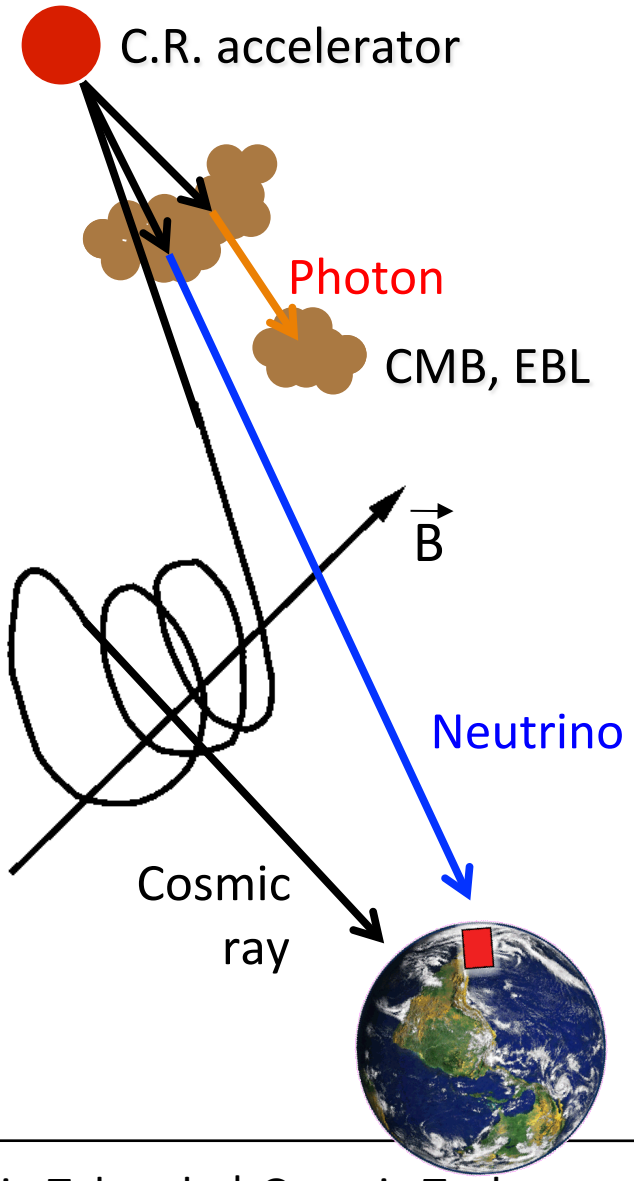
Ignacio Taboada
Georgia Institute of Technology

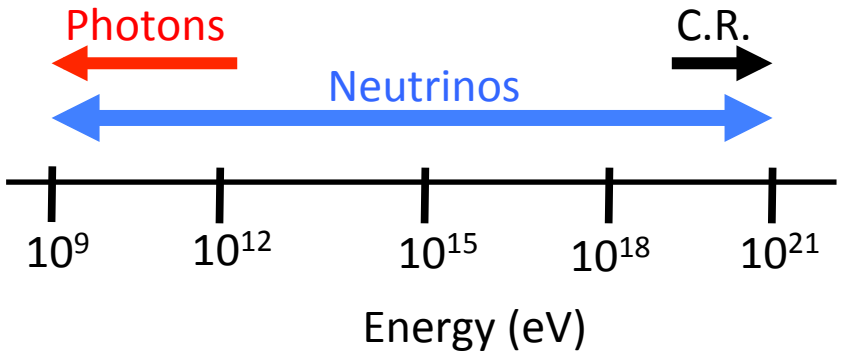
Gamma 2012 Conference

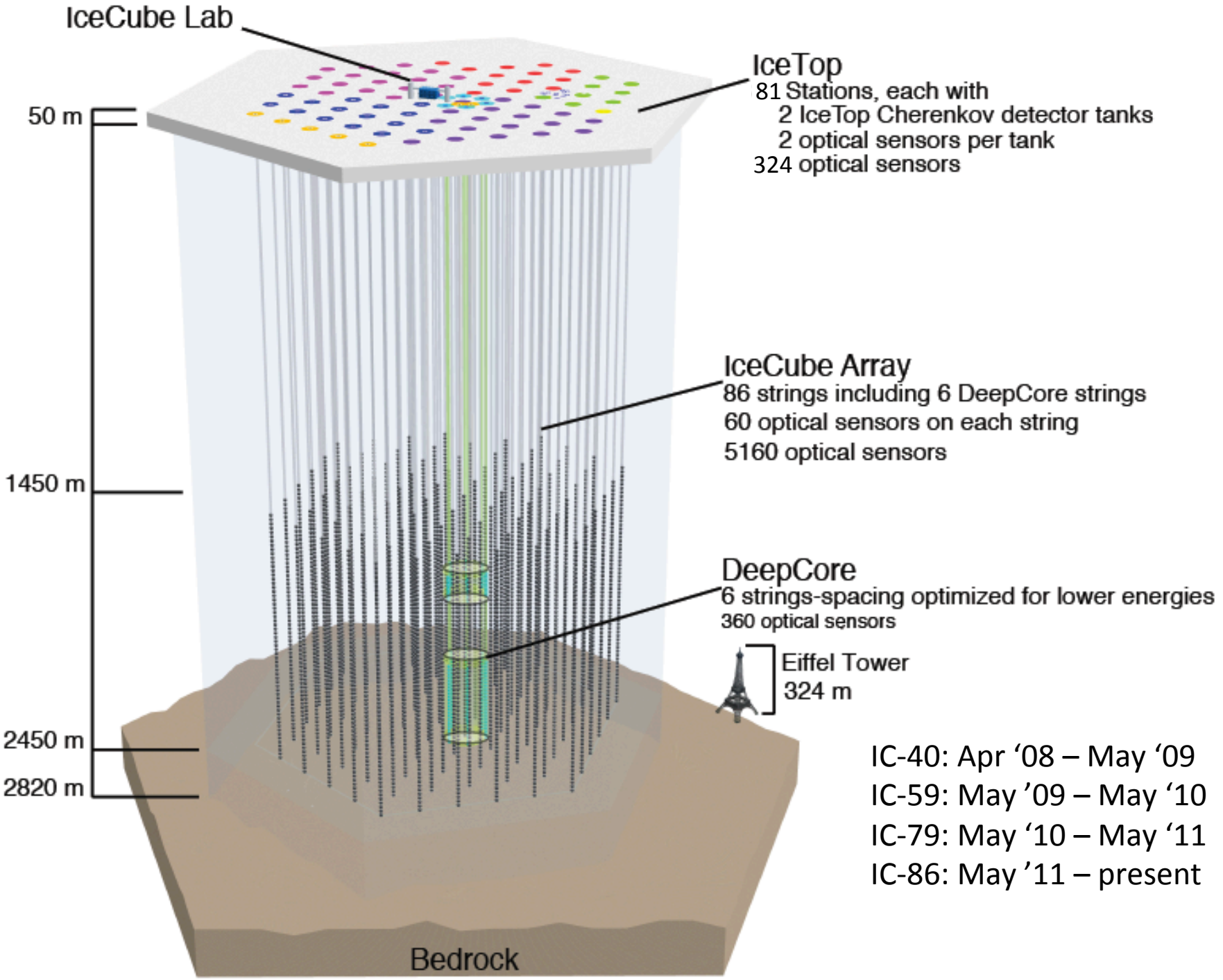


Georgia Tech

Neutrinos astronomy & C.R./γ connection

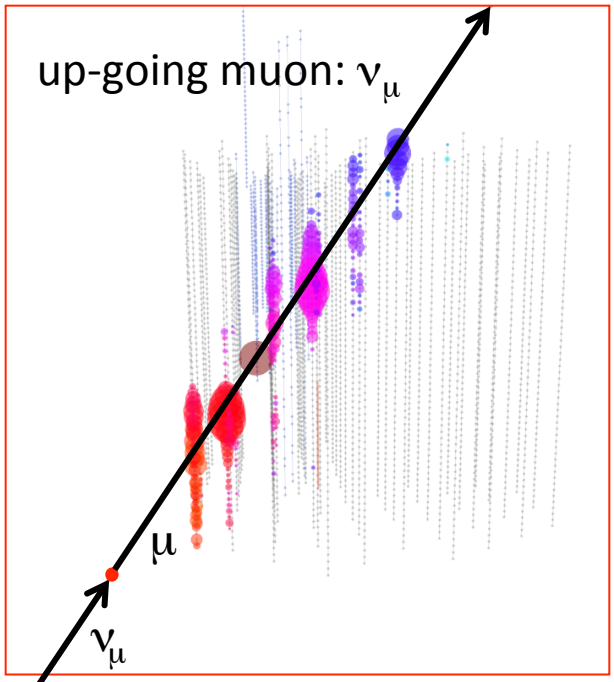


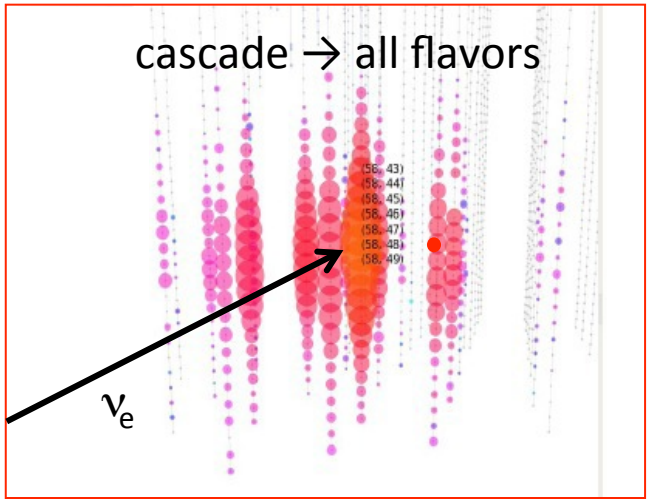


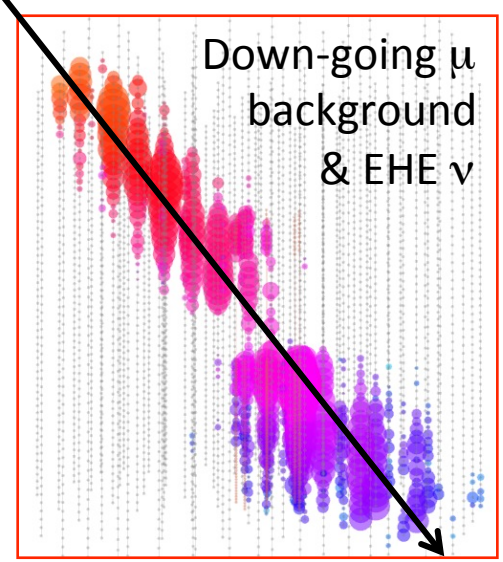


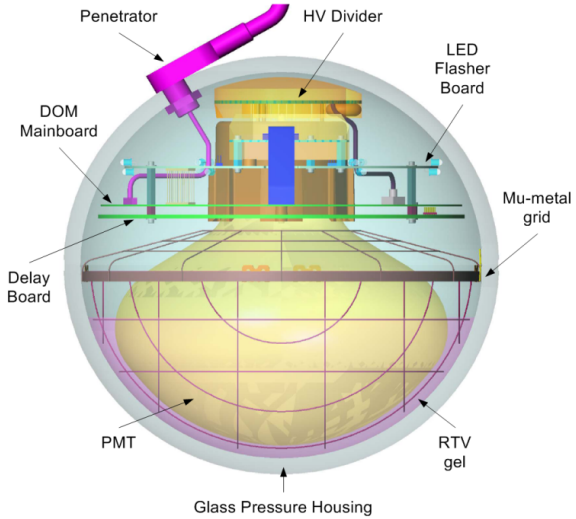
IC-40: Apr ‘08 – May ‘09
IC-59: May ’09 – May ‘10
IC-79: May ‘10 – May ‘11
IC-86: May ’11 – present

Detection Methods









light collection by DOMs

DOM Low Noise rate (500 Hz)
(300 Hz with deadtime)
-> Galactic MeV ν SN search

99% DOMs are operational

Uptime: 99.1% (May 2012)

>2 kHz of muons
>220 atm. ν_μ per day

Cosmogenic (GZK) neutrino search

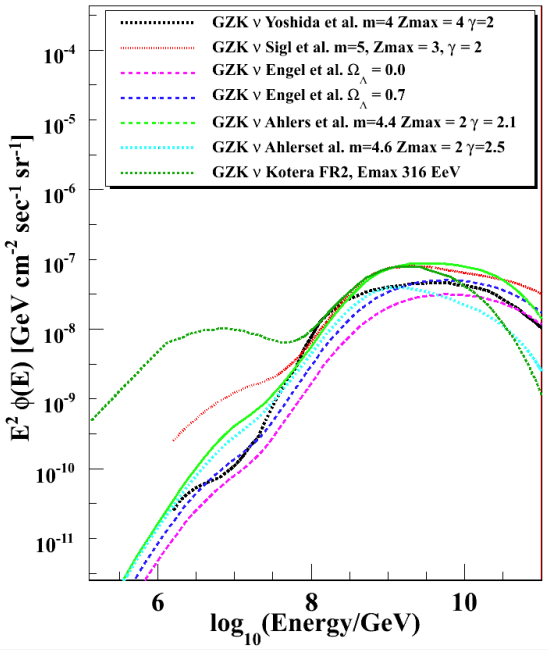
> 100 EeV

$$p + \gamma_{\mathrm{CMB}} \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$

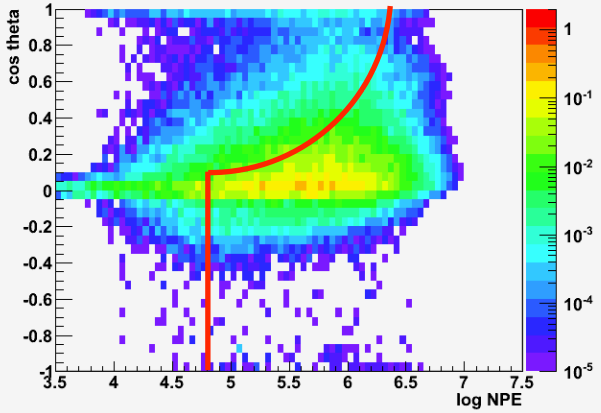
$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$

$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu}$$

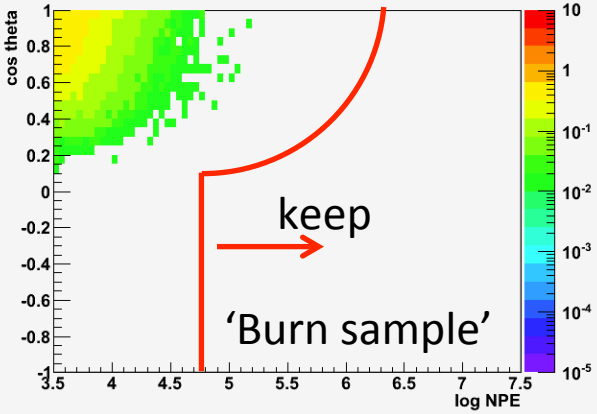
Include oscillations



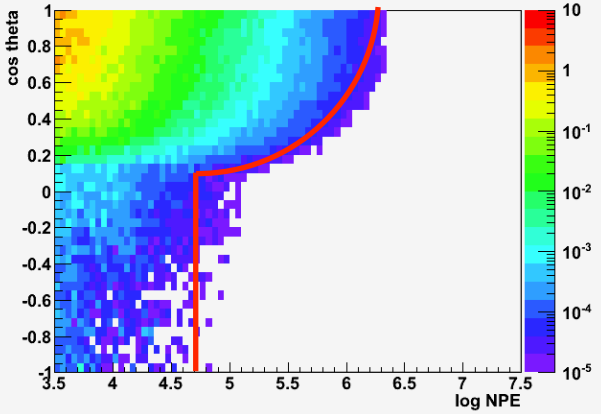
79- and 86-string IceCube (2 years)



Signal MC



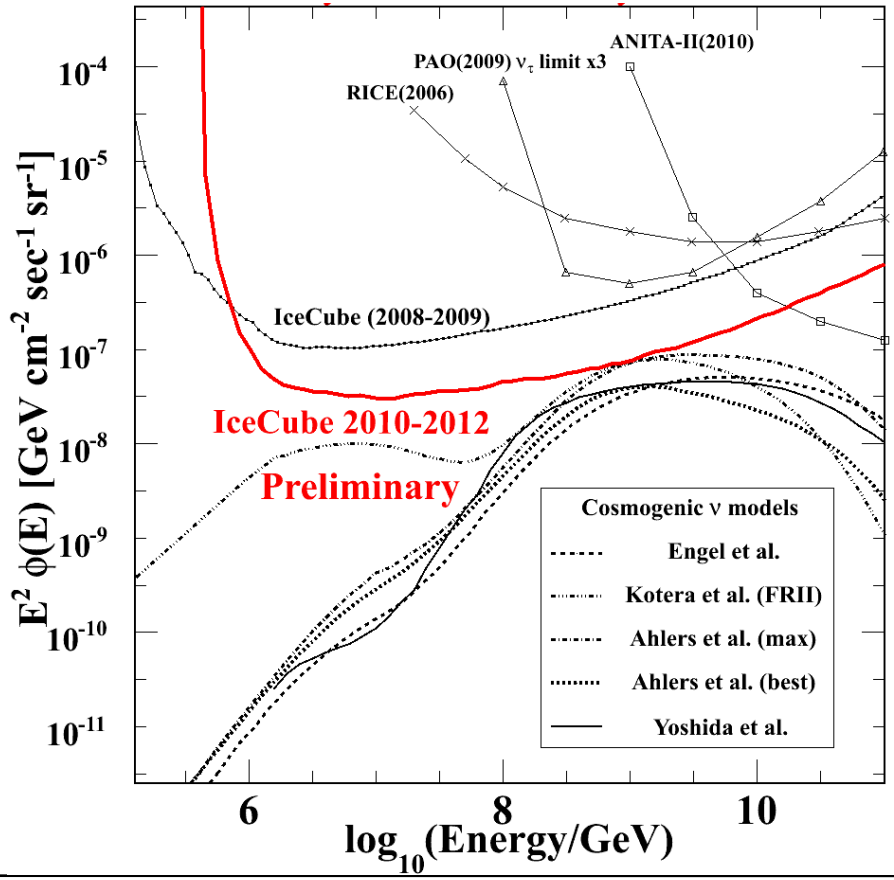
Data (10% '11-12')



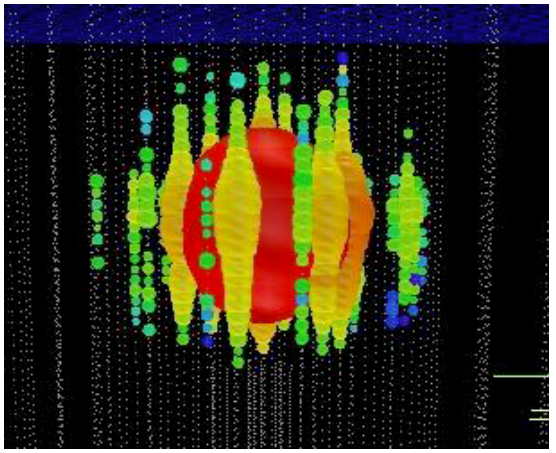
Background MC

Cosmogenic (GZK) neutrino search

Two cascade-like events pass selection criteria (672.7 days)
Bckg expectation: 0.14 evt (down-going muons + atm nus)
Preliminary p-value 0.0092 (2.36 sigma)
Origin: diffise (E^{-2}), prompt atm ν, GZK ν, conv. Atm ν, dowing-going μ

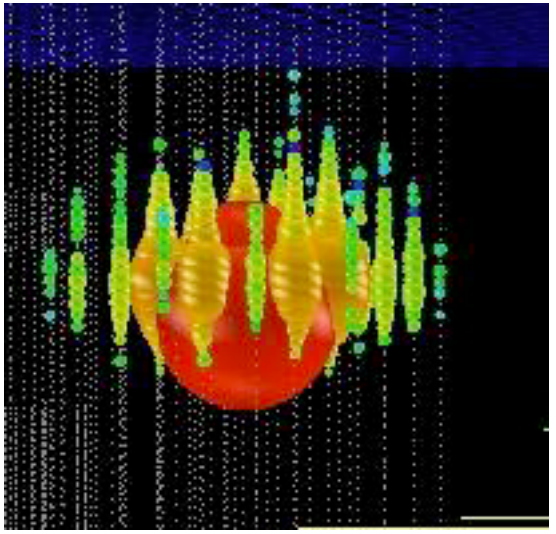


Energy 1-10 PeV



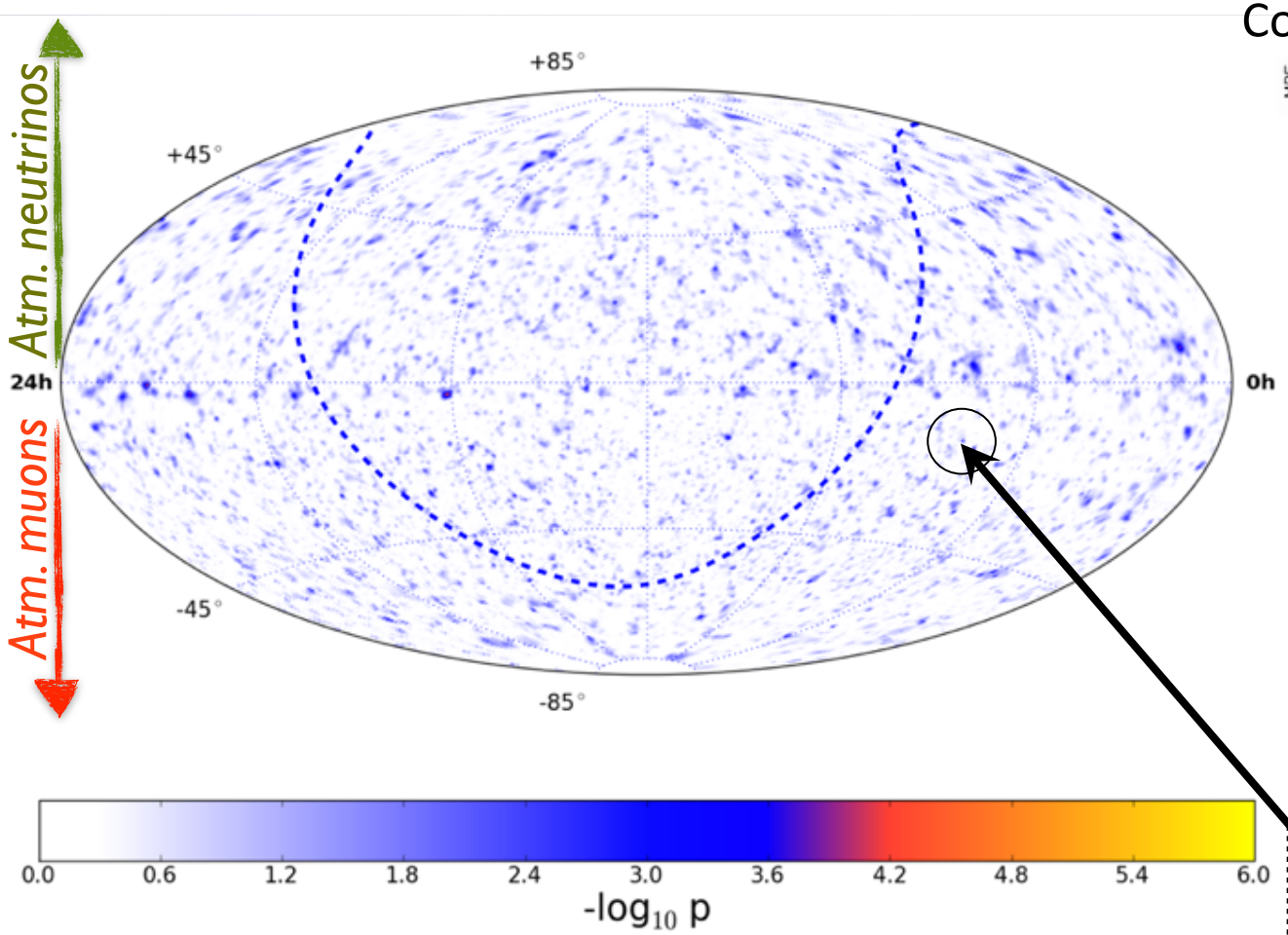
Aug 9th, 2011

Energy 1-10 PeV

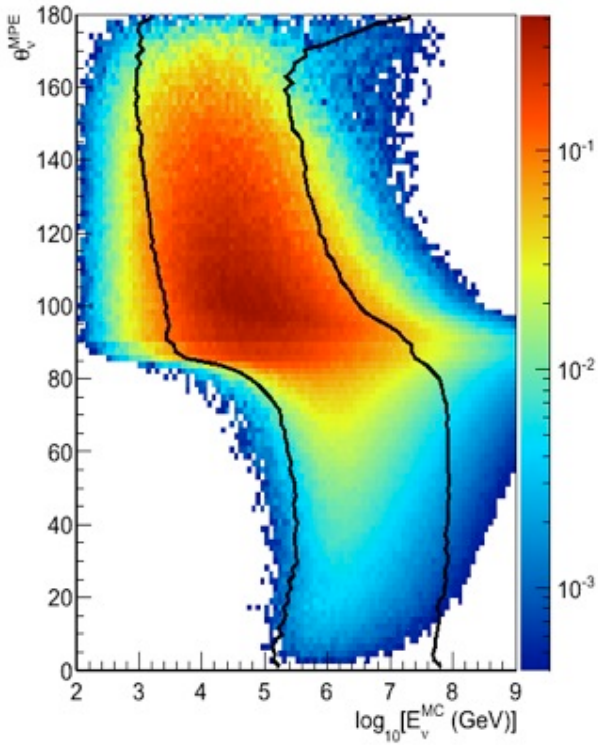


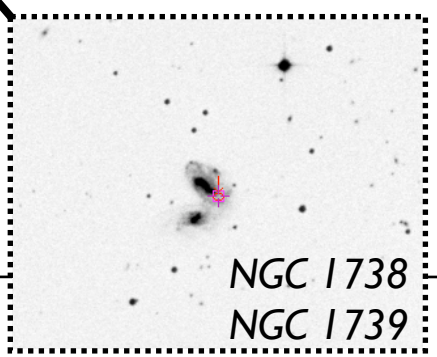
Jan 3rd, 2012

Time Integrated Point Source Search



Combined IC40/IC59





Hottest Spot. RA 75.45, DEC: -18.15
post trial 74.2 %

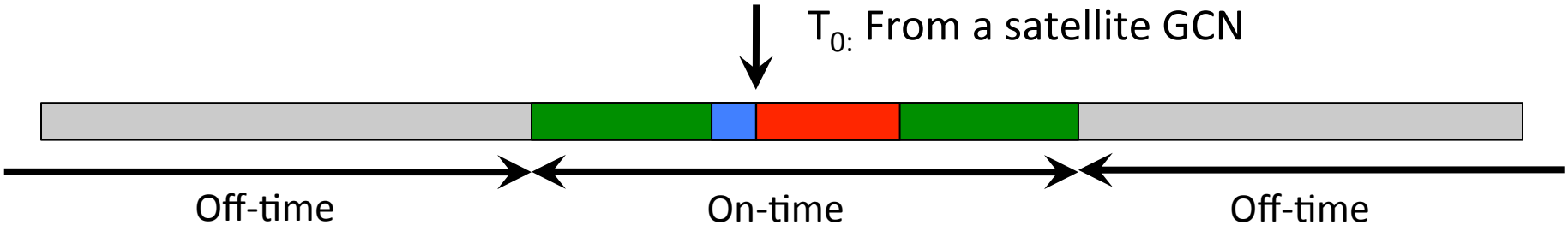
IceCube Selected Sources

13 Galactic (SNR, etc)
30 Extragalactic (AGN, etc)

No significant detections at this point: 95.7 % post-trials p-value

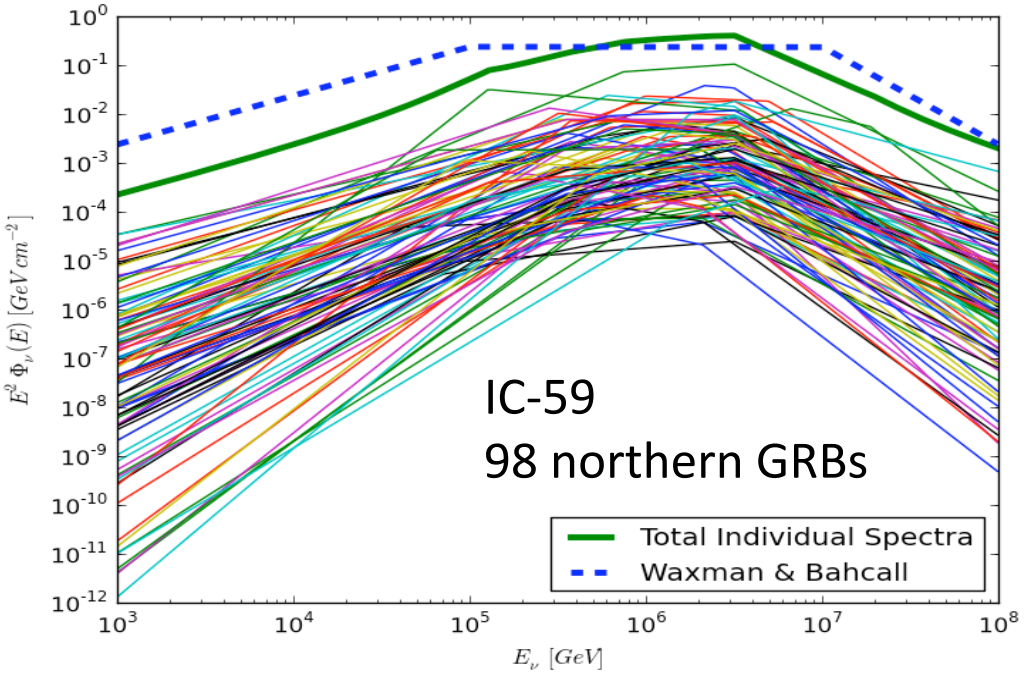
Source	RA (deg)	Dec (deg)	Type	Distance	P-value
Cyg OB2	308.08	41.51	UNID	-	--
MGRO J2019+37	305.22	36.83	PWN	-	--
MGRO J1908+06	286.98	6.27	SNR	-	0.38
Cas A	350.85	58.81	SNR	3.4 kpc	--
IC443	94.18	22.53	SNR	1.5 kpc	--
Geminga	98.48	17.77	Pulsar	100 pc	--
Crab Nebula	83.63	22.01	SNR	2 kpc	--
1ES 1959+650	300.00	65.15	HBL	z = 0.048	--
1ES 2344+514	356.77	51.70	HBL	z = 0.044	--
3C66A	35.67	43.04	Blazar	z = 0.44	0.42
H 1426+428	217.14	42.67	HBL	z = 0.129	--
BL Lac	330.68	42.28	HBL	z = 0.069	0.4
Mrk 501	253.47	39.76	HBL	z = 0.034	0.19
Mrk 421	166.11	38.21	HBL	z = 0.031	--
W Comae	185.38	28.23	HBL	z = 0.1020	--
1ES 0229+200	38.20	20.29	HBL	z = 0.139	0.39
M87	187.71	12.39	BL Lac	z = 0.0042	0.38
S5 0716+71	110.47	71.34	LBL	z > 0.3	0.49
M82	148.97	69.68	Starbust	3.86 Mpc	--
3C 123.0	69.27	29.67	FRII	1038 Mpc	--
3C 454.3	343.49	16.15	FSRQ	z = 0.859	0.48
4C 38.41	248.81	38.13	FSRQ	z = 1.814	0.3
PKS 0235+164	39.66	16.62	LBL	z = 0.94	0.18
PKS 0528+134	82.73	13.53	FSRQ	z = 2.060	0.49
PKS 1502+106	226.10	10.49	FSRQ	z = 0.56/1.839	--
3C 273	187.28	2.05	FSRQ	z = 0.158	--
NGC 1275	49.95	41.51	Seyfert Galaxy	z = 0.017559	--
Cyg A	299.87	40.73	Radio-loud Galaxy	z = 0.056146	0.44
Sgr A*	266.42	-29.01	Galactic Center	8.5 kpc	0.49
PKS 0537-441	84.71	-44.09	LBL	z = 0.896	0.44
Cen A	***201.37***	***-43.02***	***FRI***	***3.8 Mpc***	***0.14***
PKS 1454-354	***224.36***	***-35.65***	***FSRQ***	***z = 1.42***	***0.14***
PKS 2155-304	329.72	-30.23	HBL	z = 0.116	--
PKS 1622-297	246.53	-29.86	FSRQ	z = 0.815	0.27
QSO 1730-130	263.26	-13.08	FSRQ	z = 0.902	--
PKS 1406-076	212.24	-7.87	FSRQ	z = 1.494	0.36
QSO 2022-077	306.42	-7.64	FSRQ	z = 1.39	--
3C279	194.05	-5.79	FSRQ	z = 0.536	0.45
TYCHO	6.36	64.18	SNR	2.4 kpc	--
Cyg X-1	299.59	35.20	MQSO	2.5 kpc	--
Cyg X-3	308.11	40.96	MQSO	9 kpc	--
LSI 303	40.13	61.23	MQSO	2 kpc	--
SS433	287.96	4.98	MQSO	1.5 kpc	0.48

Gamma Ray Bursts

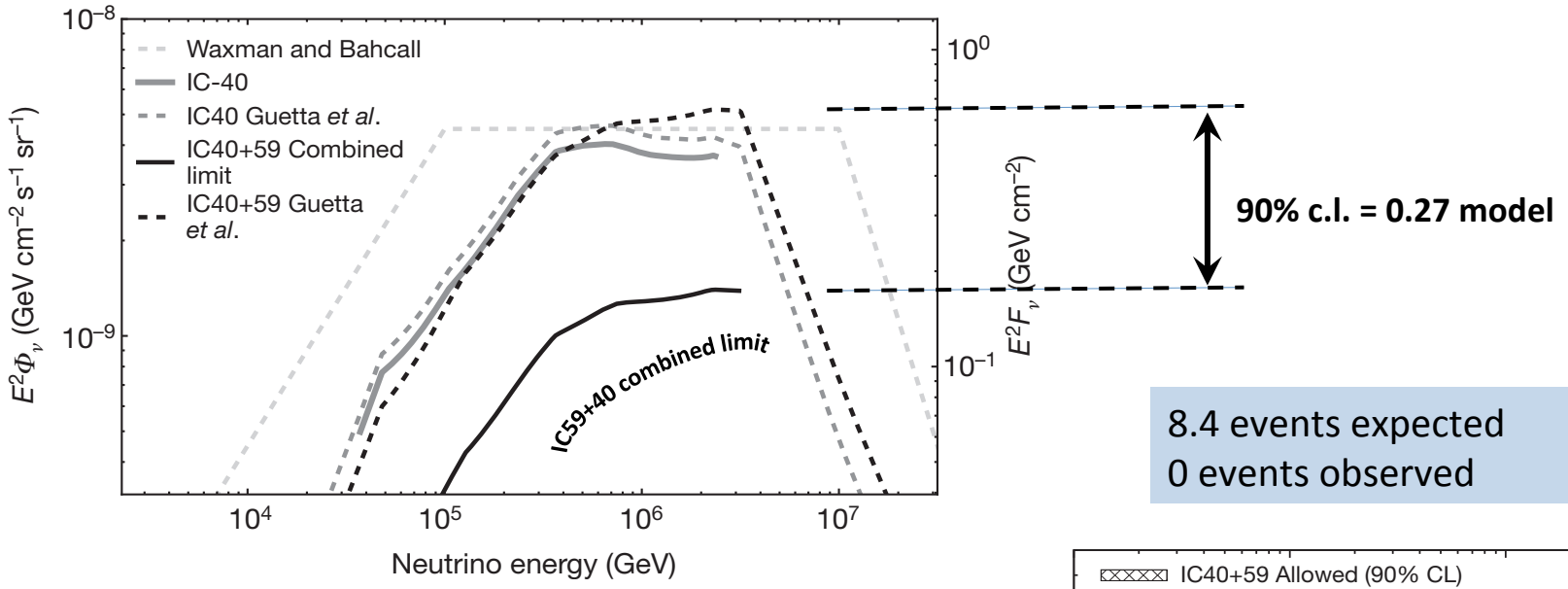


- Precursor (~100 s)
- Prompt (T_{90})
- Model Independent (±24 h)
- Off-time (full year)

Very low background
One event can be significant

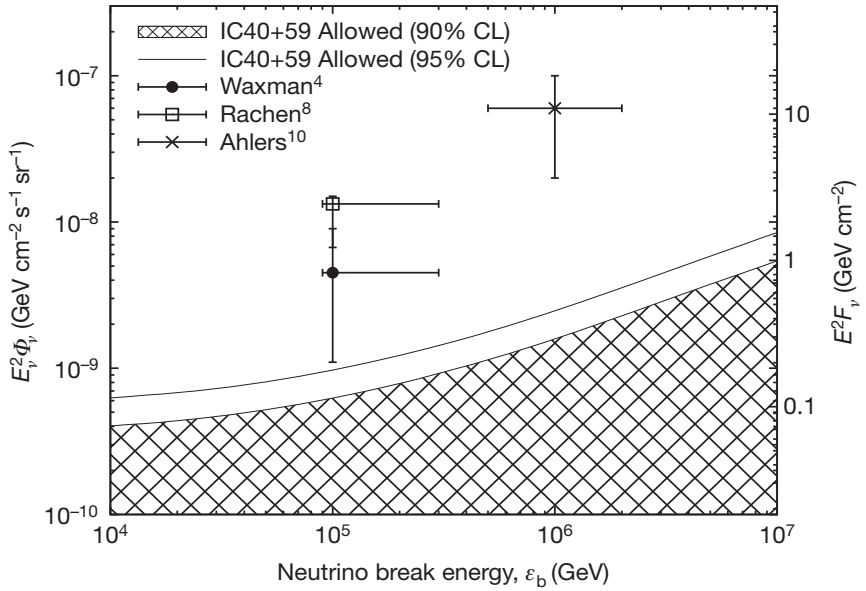


IC40 + IC59 GRB Results – Prompt Neutrinos



8.4 events expected
0 events observed

Nature Vol **484**, 351 (2012)



GRB fireball neutrinos
- Theory is being revisited
- Recalculations change prediction significantly

GRBs are THE source of highest energy CR
- Excluded for neutron escape models

Outlook

- ✓ IceCube is now complete. Pay attention to galactic sources over the next 2-3 years. GRB models being challenged.
- ✓ DeepCore already producing results and ready for astrophysical studies (southern hemisphere at >10 GeV, oscillations, dark matter, choked GRBs, etc)
- ✓ South Pole is being transformed into a neutrino facility: Dark Matter search (a la DAMA), >GeV neutrinos (DeepCore Extensions) and GZK neutrinos (ARA)

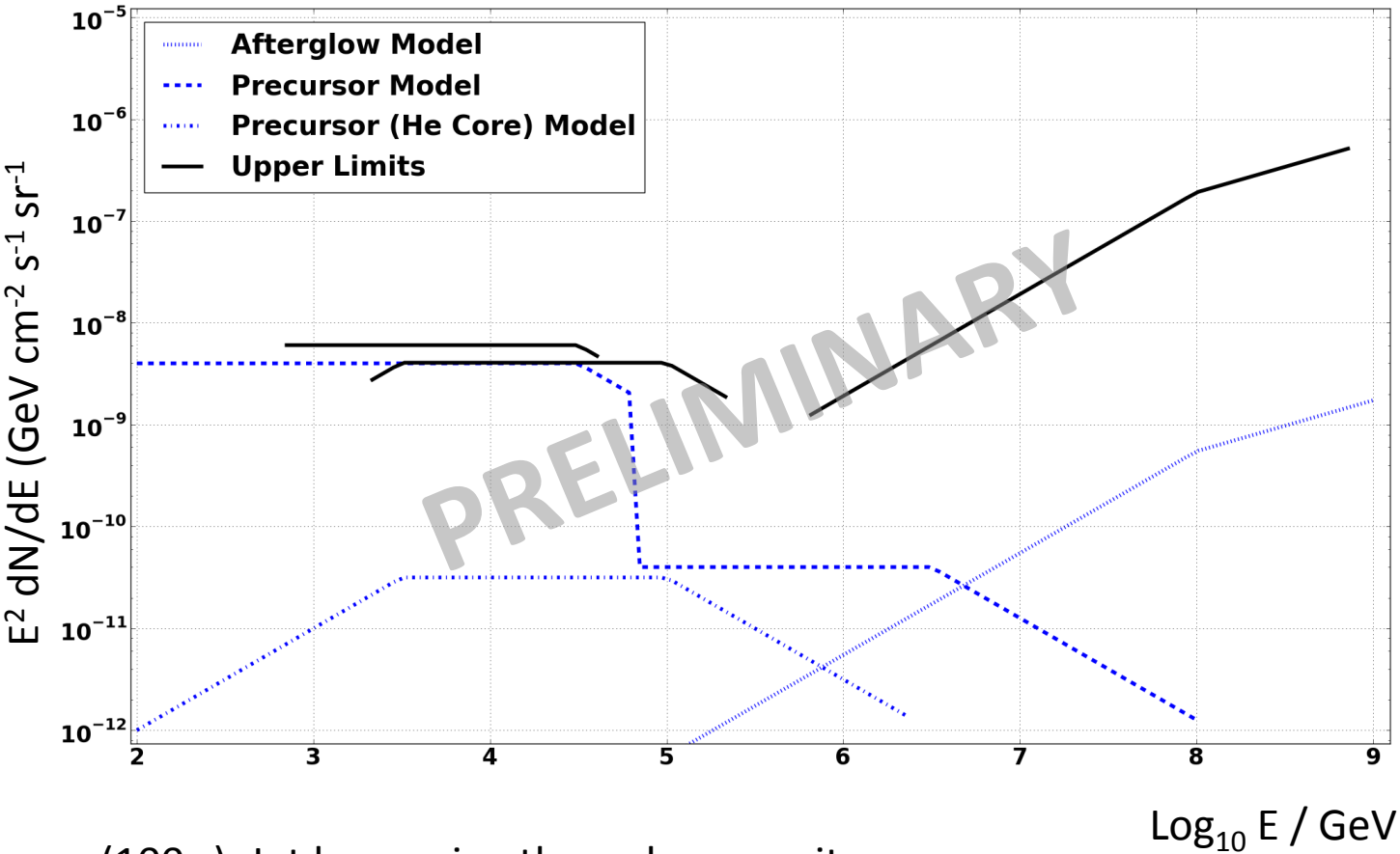
The IceCube Collaboration

International Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

Backup

IC40 + IC59 GRB Results – Precursor & Afterglow



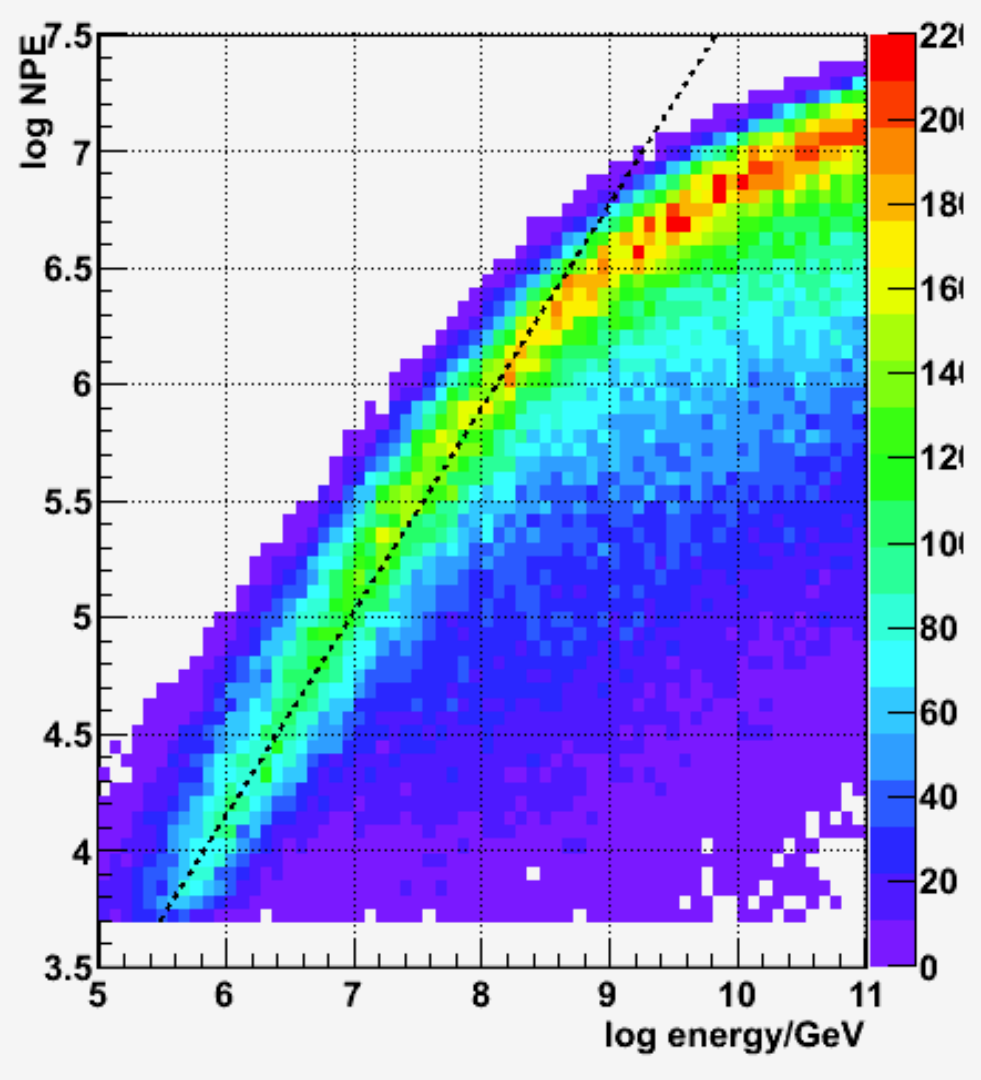
Precursor (100 s). Jet borrowing through progenitor

Hydrogen Envelope Model Rejection factor: 1.51

Unlikely anyway as (long) GRB progenitors are type Ic SNe.

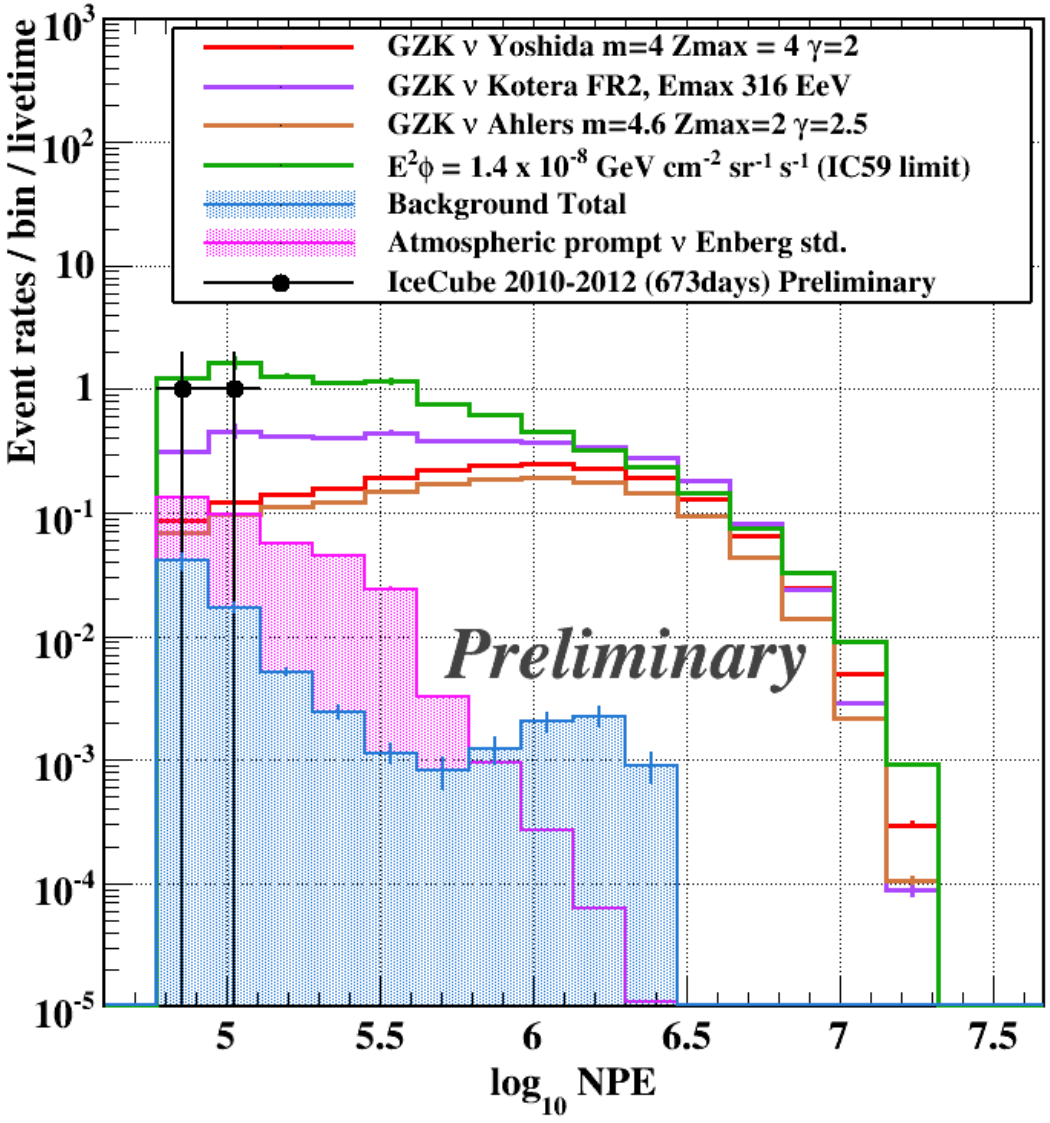
Afterglow (1000 s). p-γ neutrinos, from early X-ray afterglow

Energy – Charge correlation – GZK search

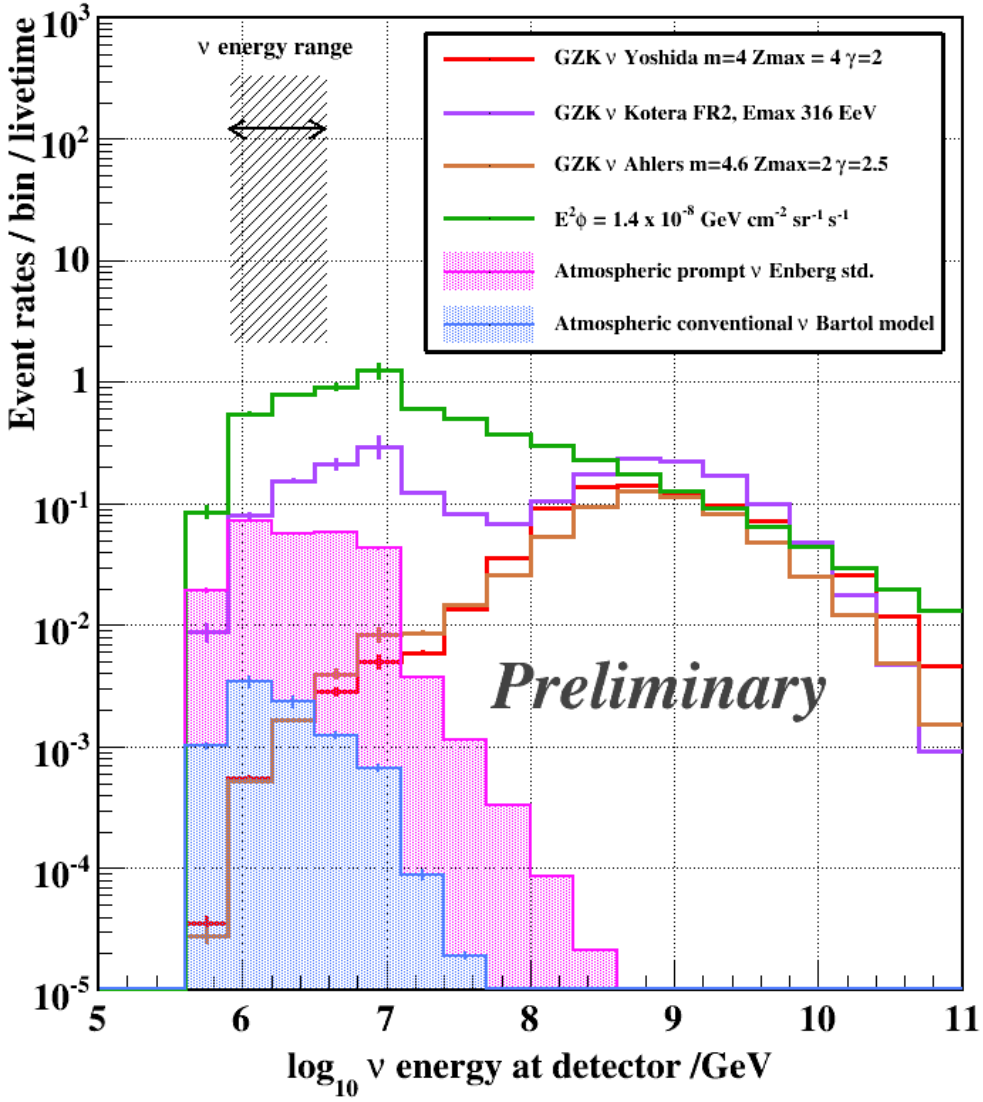


Channel # > 300

Event Charge Distribution



Neutrino Energy Distribution – GZK search



Likelihood and Density Functions – Point Source

Signal pdf:

$$\mathcal{S}_i = \frac{1}{2\pi {\sigma_i}^2} e^{-{r_i}^2/2{\sigma_i}^2} \cdot P(E_i|\gamma)$$

Background pdf:

$$\mathcal{B}_i = B(\theta_i) \cdot P_{atm}(E_i)$$

Likelihood:

$$\mathcal{L}(n_s, \gamma) = \prod_{i=1}^{N} \left(\frac{n_s}{N} \mathcal{S}_i(\gamma) + (1 - \frac{n_s}{N}) \mathcal{B}_i \right)$$

Maximize wrt:

- γ , the neutrino spectral index
- $\mathbf{n_s}$, number of signal events

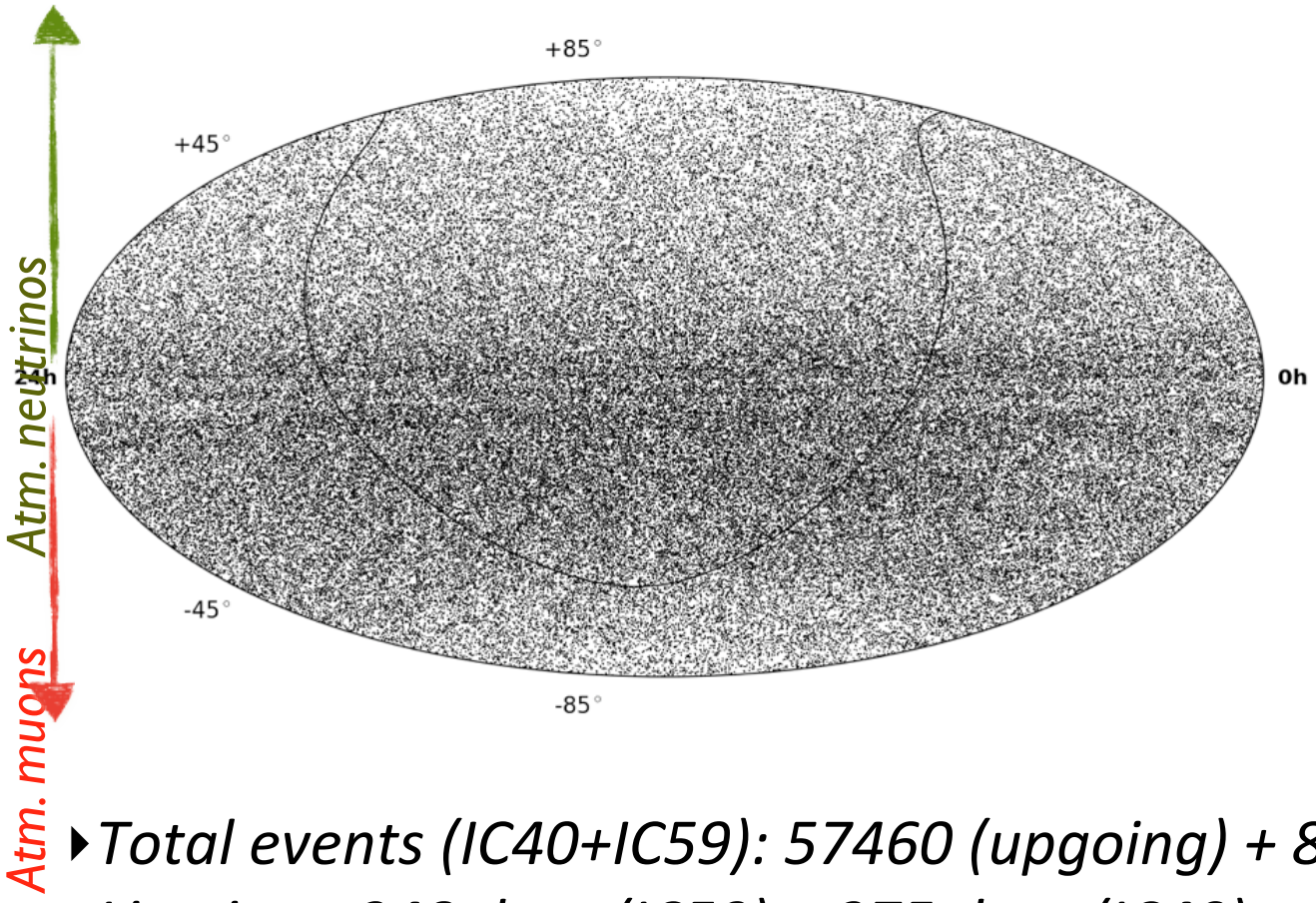
Maximization of the likelihood ratio:

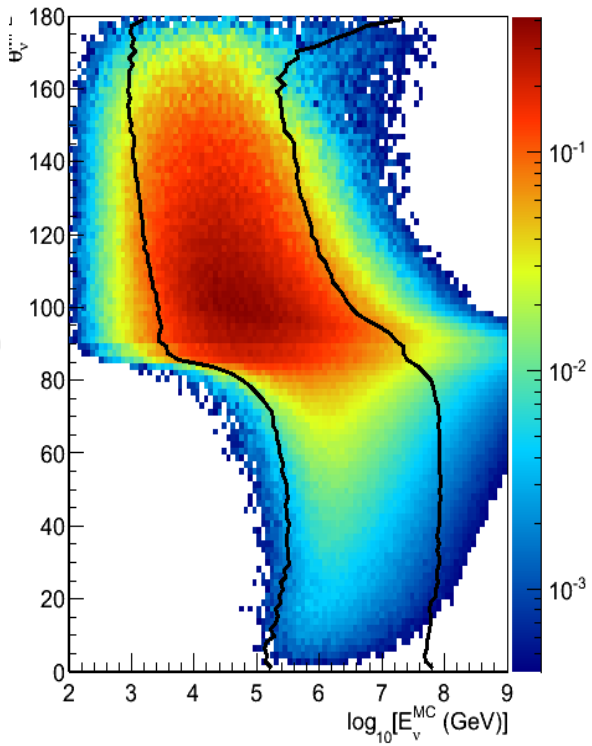
$$\log \lambda = \log \left(\frac{L(\hat{\gamma}, \hat{n}_s)}{L(n_s = 0)} \right)$$

Estimates that maximize the Likelihood

The final significance is determined by scrambling the data in r.a. and repeating the analysis.

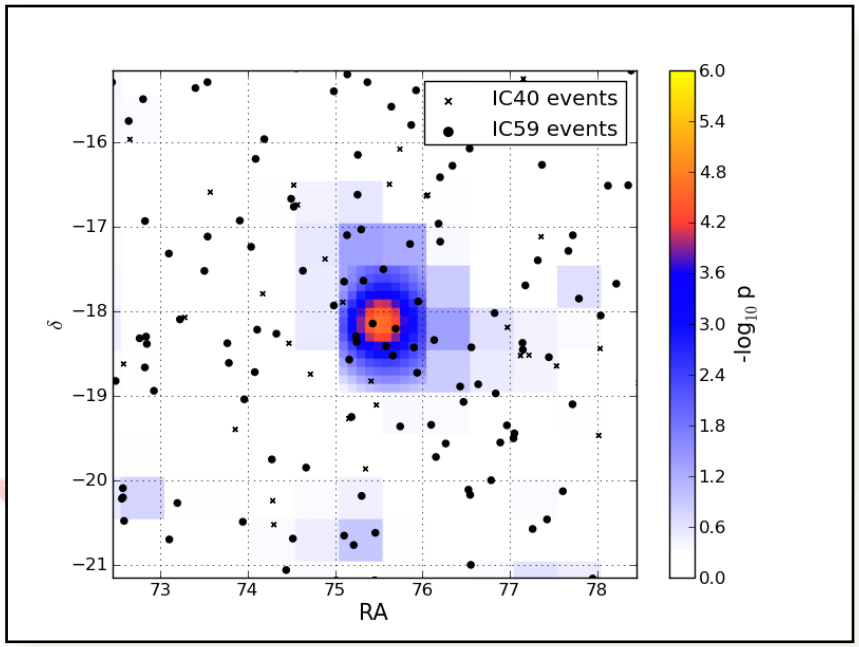
Combining datasets – Point Source Search

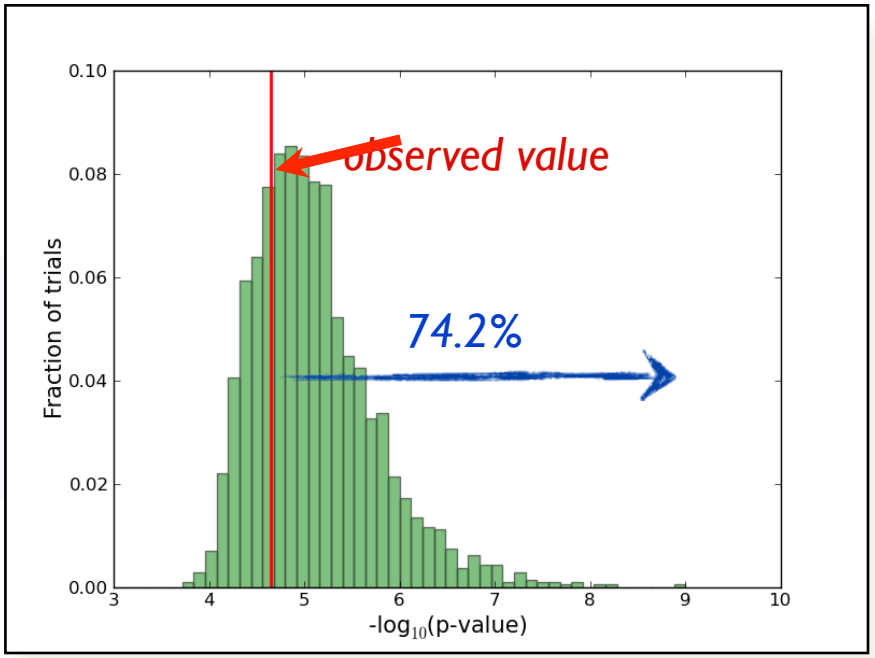




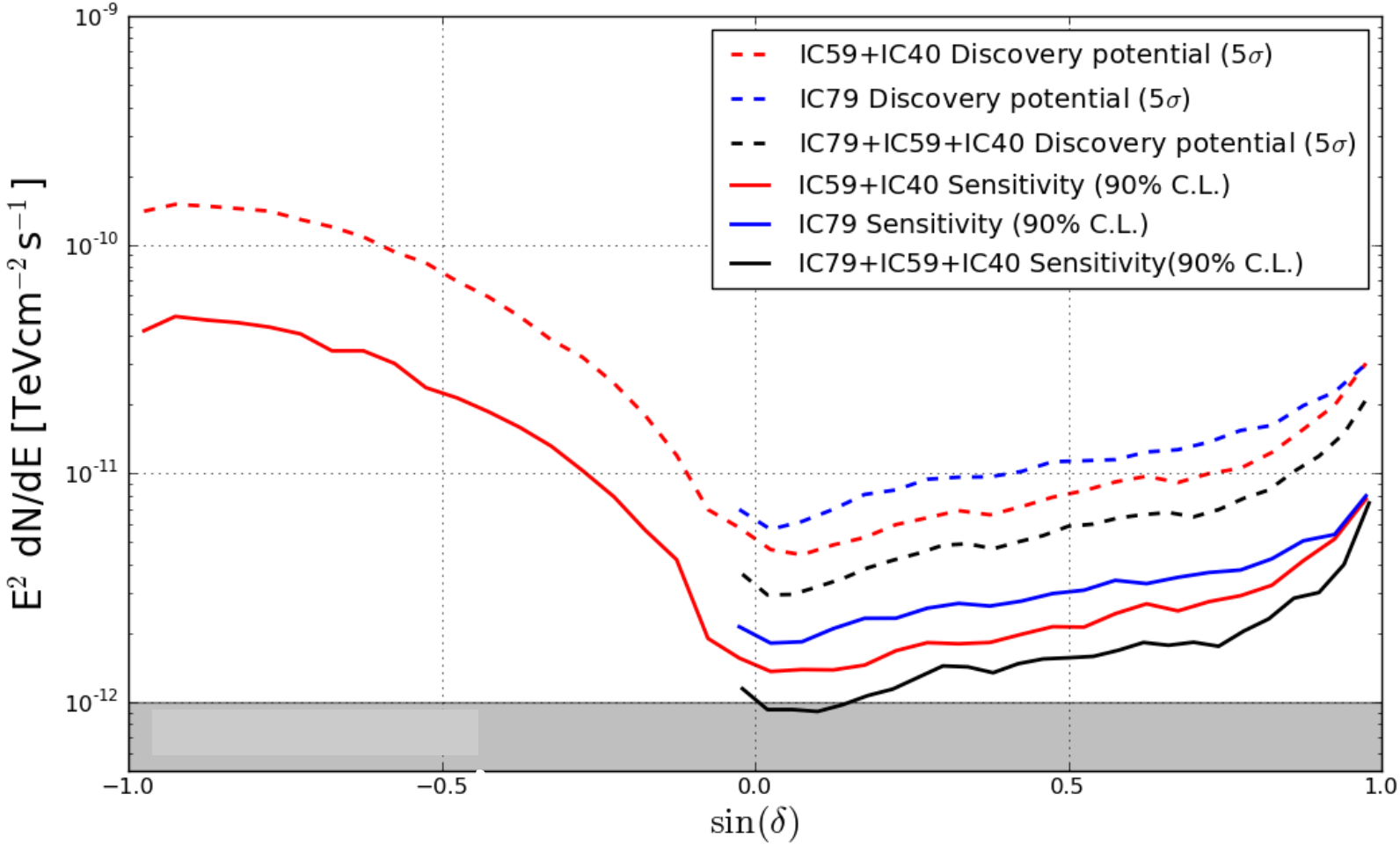
- *Total events (IC40+IC59): 57460 (upgoing) + 87009 (downgoing)*
- *Livetime: 348 days (IC59) + 375 days (IC40)*

Combining datasets – Point Source Search





IC79 Analysis Outlook – Point Source Search



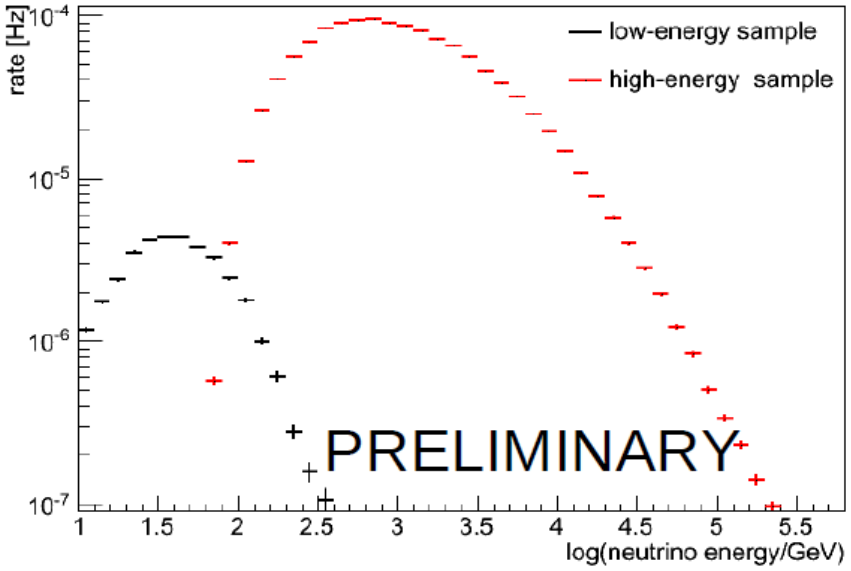
IceCube: First Step in Neutrino Oscillation Physics

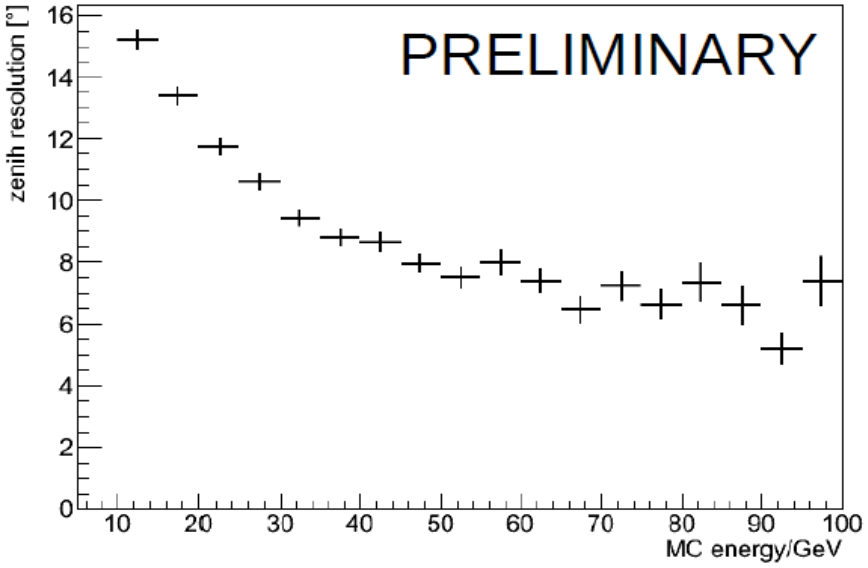
Simple cuts and reconstruction in DeepCore. Extend sample to Low energy.
Search for consistency with standard neutrino oscillations.

Not optimized. Ongoing Work: more sophisticated analysis for measurement of oscillation parameters

	Data (317.9 days)	MC , Std ocillation	MC, no oscillation
Low Energy	719	789 ± 28 (stat)	1015 ± 32 (stat)
High Energy	39639	33710 ± 770 (stat)	338810 ± 770 (stat)

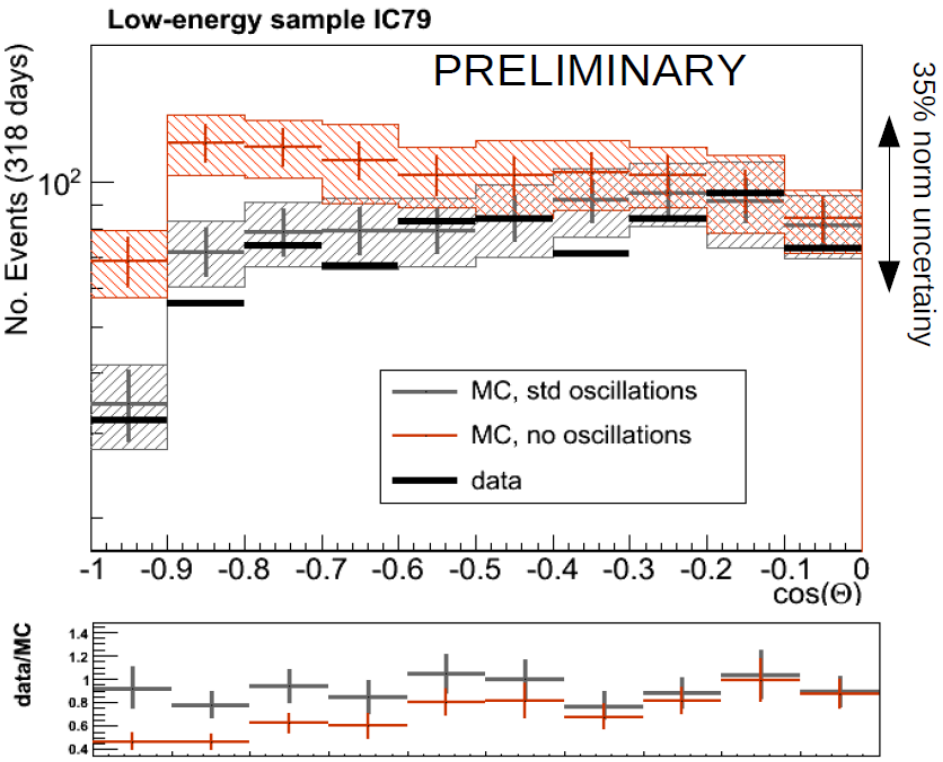
IceCube & DeepCore 79 Strings

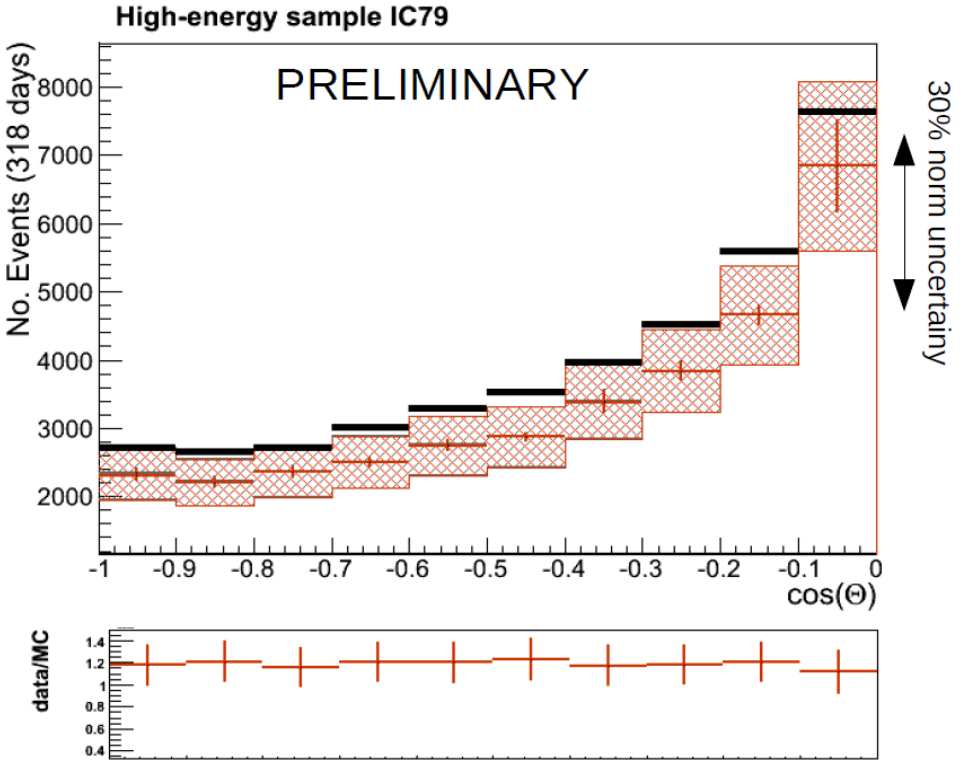




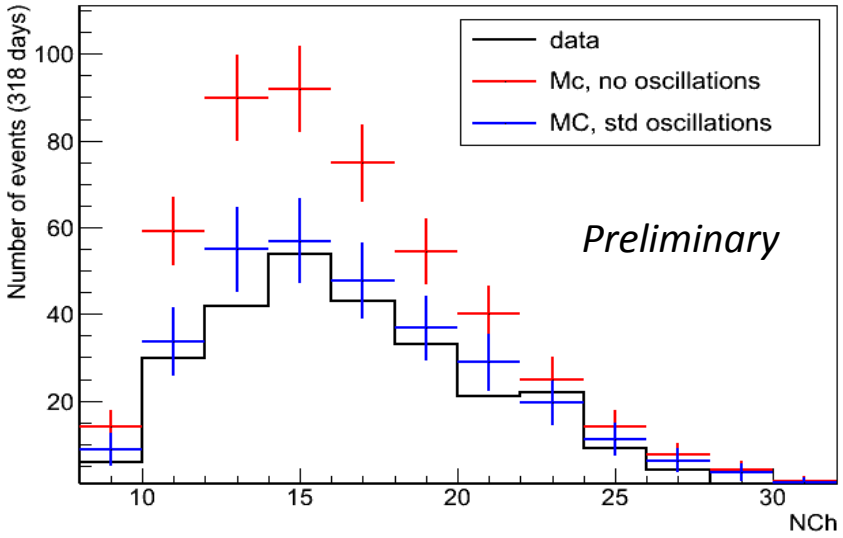
IceCube ν_μ disapperance. Zenith Angle Distribution

$\chi^2 = 52.7$ (no oscillation) $\chi^2 = 19.4$ (std. oscillation) dof = 20





Cross Check: The energy-proxy "Nchannel" distribution of the LE sample

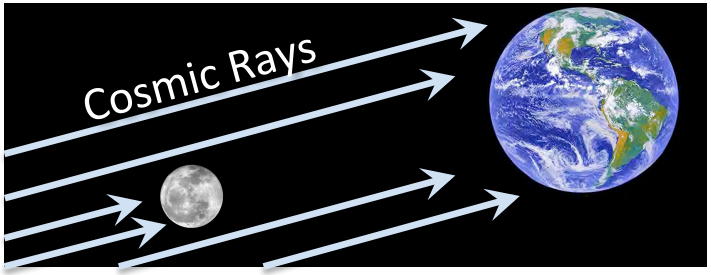


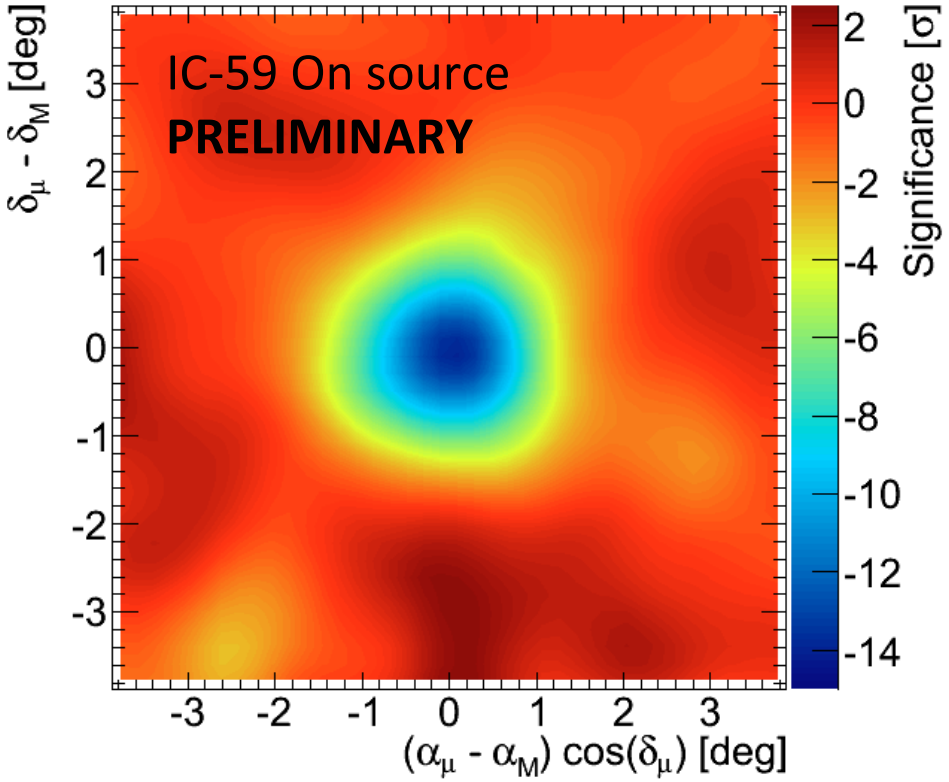
Distribution of the number of hit DOMs for vertical events (cos(theta)<-0.55) of the low-energy event selection. *Errors are statistical only.*

- IceCube DeepCore has now explored the energy region where standard neutrino oscillation are expected with IC79
- the non-oscillation hypothesis is rejected with high statistical significance.
- Data are in good agreement with standard oscillation expected from global best fit mixing parameters available from the literature.
- Systematic effects have been investigated and factorized in normalization, correlated and uncorrelated terms.

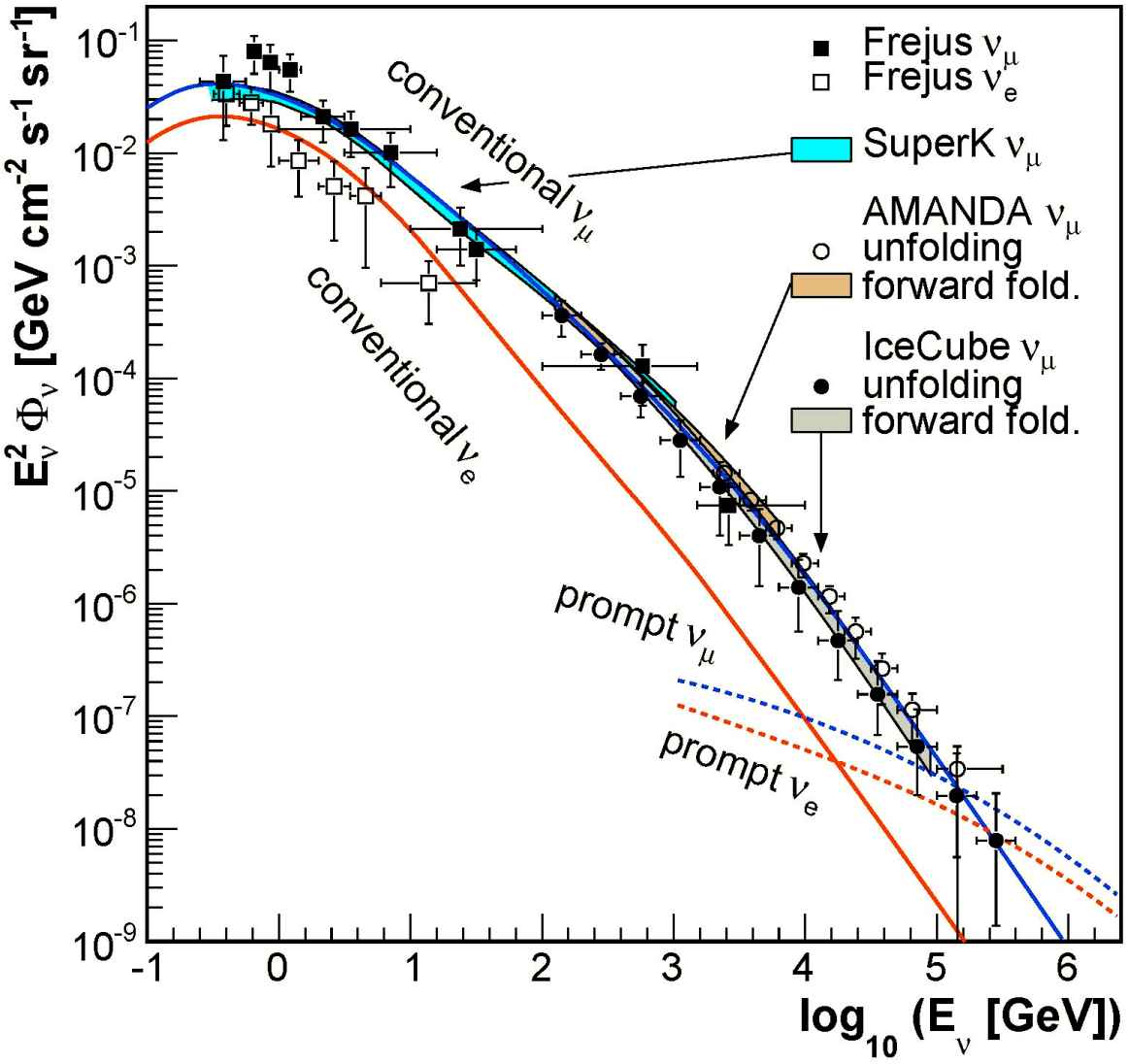
Moon Shadow

- ✓Unbinned method
- ✓IC-40 10.5 σ
  (15 moon cycles)
- ✓IC-59 14.4 σ
  (14 moon cycles)
- ✓Full IceCube:
  >5 σ each moon cycle
- ✓Test PSF

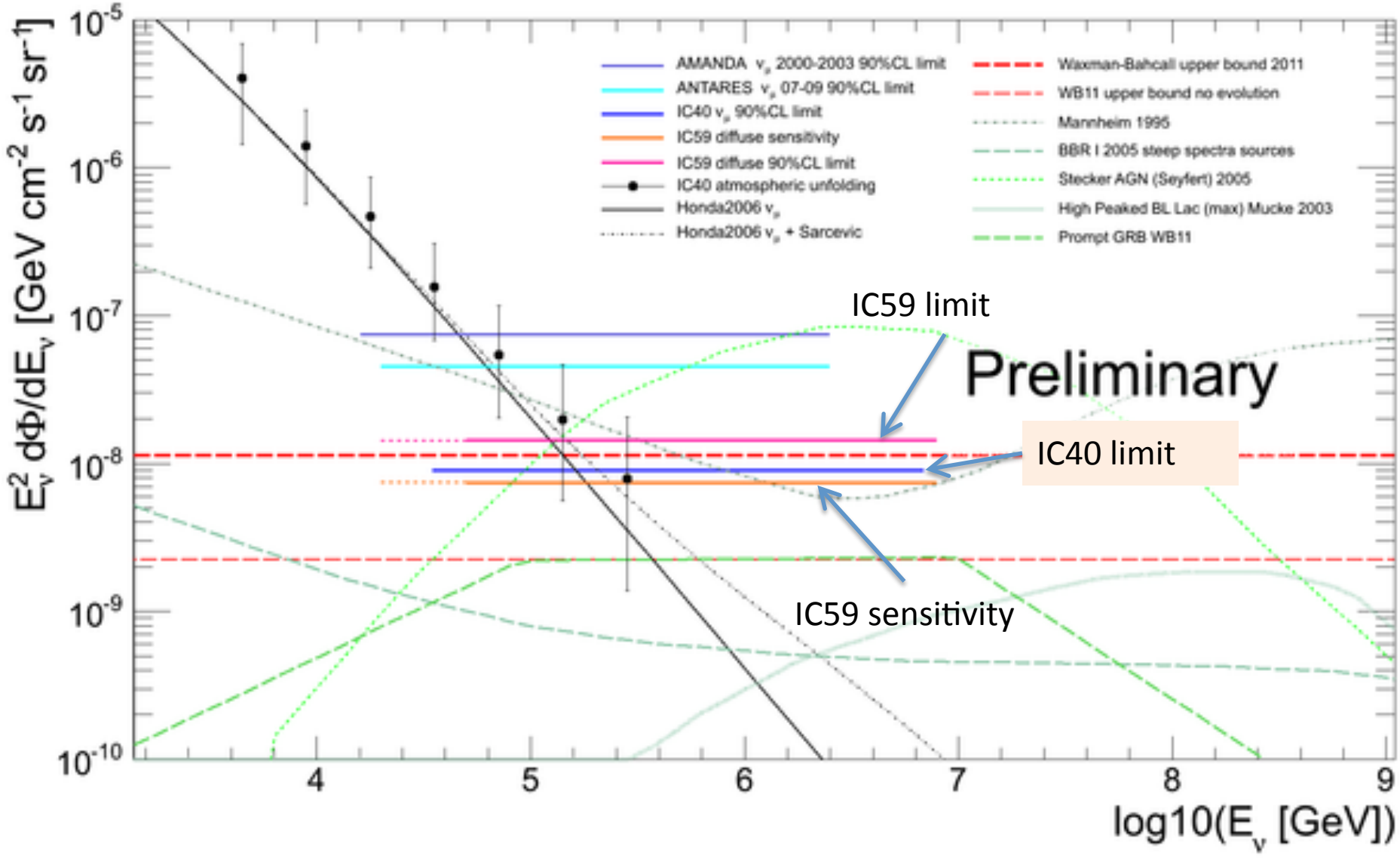




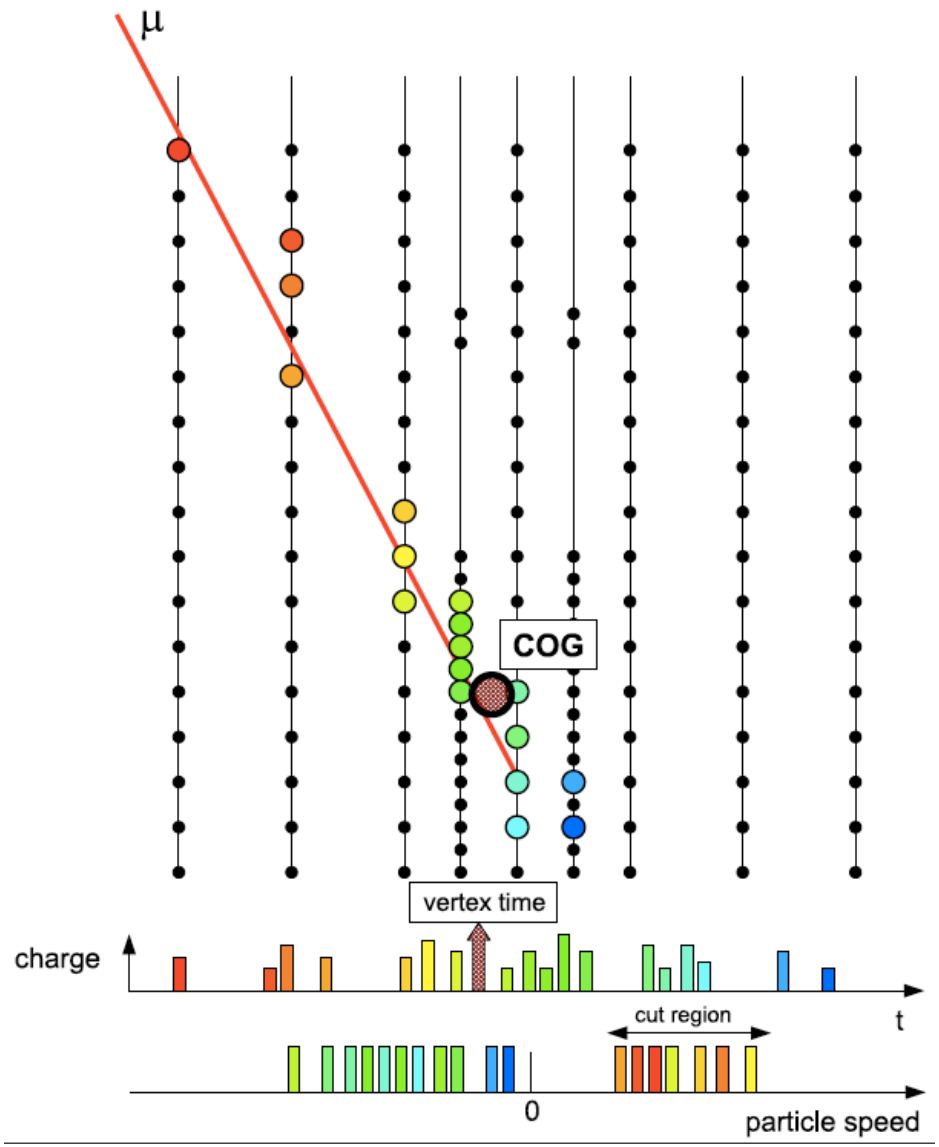
Atmospheric Neutrinos



Diffuse ν_μ flux limits



DeepCore Filter



- ✓ Superb muon veto
- ✓ 10 – 300 GeV over 4 π sr

- ✓ Search for DM
- ✓ Neutrino Oscillations
- ✓ Choked GRBs

Model Independent IC40 / IC59