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

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Gamma 2012 Conference





Neutrinos astronomy & C.R./γ connection





Detection Methods





DOM Low Noise rate (500 Hz) (300 Hz with deadtime) -> Galactic MeV v SN search 99% DOMs are operational Uptime: 99.1% (May 2012) >2 kHz of muons >220 atm. v_{μ} per day

light collection by DOMs

LED Flashe Board

> RTV ael

Mu-metal grid

Cosmogenic (GZK) neutrino search



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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 v, GZK v, conv. Atm v, dowing-going μ



Energy 1-10 PeV



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Time Integrated Point Source Search



IceCube Selected Sources

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

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

Cyg OB2 308.08 41.51 UNID - - 1GRO J2019+37 305.22 36.83 PWN -	Source	RA (deg)	Dec (deg)	Туре	Distance	P-value	PKS 0235+16	4	39.66	4 39.66 16.62	4 39.66 16.62 LBL	4 39.66 16.62 LBL z = 0.94
GRO J2019+37 305.22 36.83 PWN - - GRO J1908+06 286.98 6.27 SNR - 0.38 as A 350.85 58.81 SNR 3.4 kpc - C443 94.18 22.53 SNR 1.5 kpc - eminga 98.48 17.77 Pulsar 100 pc - rab Nebula 83.63 22.01 SNR 2 kpc - ES 1959+650 300.00 65.15 HBL z = 0.048 - ES 2344+514 356.77 51.70 HBL z = 0.044 - C566A 35.67 43.04 Biazar z = 0.129 - LLac 330.68 42.28 HBL z = 0.031 - rk S01 25.347 39.76 HBL z = 0.031 - rk S01 25.347 39.76 HBL z = 0.1020 - rk S01 25.347 39.76 HBL z = 0.139 0.39 gS0 2029+200 38.20 20.29 HBL z = 0.139 0.39 </td <td>yg OB2</td> <td>308.08</td> <td>41.51</td> <td>UNID</td> <td>-</td> <td>-</td> <td>PKS 0528+134</td> <td></td> <td>82.73</td> <td>82.73 13.53</td> <td>82.73 13.53 FSRQ</td> <td>82.73 I 3.53 FSRQ z = 2.060</td>	yg OB2	308.08	41.51	UNID	-	-	PKS 0528+134		82.73	82.73 13.53	82.73 13.53 FSRQ	82.73 I 3.53 FSRQ z = 2.060
IGRO J1908+06 286-98 6.27 SNR - 0.38 as A 350.85 58.81 SNR 3.4 kpc - C443 94.18 22.53 SNR 1.5 kpc - eminga 98.48 17.77 Pulsar 100 pc - rab Nebula 83.63 22.01 SNR 2 kpc - ES 1959+650 300.00 65.15 HBL z = 0.048 - ES 2344+514 356.77 51.70 HBL z = 0.044 - C66A 35.67 43.04 Blazar z = 0.049 0.4 H26+428 217.14 42.67 HBL z = 0.029 - LLac 330.68 42.28 HBL z = 0.034 0.19 rk 501 253.47 39.76 HBL z = 0.031 - rk 201 166.11 38.21 HBL z = 0.139 0.39 g87 187.71 12.39 BL Lac z = 0.042 0.38 50716+71 10.47 71.34 LBL z > 0.39 0.39	IGRO J2019+37	305.22	36.83	PWN	-		PKS 1502+106		226.10	226.10 10.49	226.10 10.49 FSRQ	226.10 10.49 FSRQ z = 0.56/1.839
Cas A 350.85 58.81 SNR 3.4 kpc C443 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 Crab Nebula 83.63 22.01 SNR 2 kpc IES 1959+650 300.00 65.15 HBL z = 0.048 IES 2344+514 356.77 51.70 HBL z = 0.044 IC66A 35.67 43.04 Blazar z = 0.129 RLac 330.68 42.28 HBL z = 0.049 0.4 YKS 2155-304 PKS 2155-304 PKS 2155-304 PKS 2155-304 PKS 1622-297 QSO 1730-130 Trk 501 253.47 39.76 HBL z = 0.031 V Comae 185.38 28.23 HBL z = 0.139 0.39 167.11 10.47 71.34 LBL z > 0.3 0.49 YSC10229+200 38.20 2	1GRO J 1908+06	286.98	6.27	SNR	-	0.38	3C 273		187.28	187.28 2.05	187.28 2.05 FSRQ	187.28 2.05 FSRQ z = 0.158
C443 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 ES 1959+650 300.00 65.15 HBL z = 0.048 IES 1959+650 300.00 65.15 HBL z = 0.044 IC66A 35.67 43.04 Blazar z = 0.129 I 1426+428 217.14 42.67 HBL z = 0.034 0.19 Thk 501 253.47 39.76 HBL z = 0.034 0.19 Thk 421 166.11 38.21 HBL z = 0.034 0.19 YKS 1452-297 2 QSO 1730-130 2 N Comae 185.38 28.23 HBL z = 0.034 0.19 187 187.71 12.39 BL Lac z = 0.042 0.38 S0716+71 110.47 71.34 LBL z > 0.3 0.49 TYCHO 6 Cyg X-3 3 3 182	Cas A	350.85	58.81	SNR	3.4 крс		NGC 1275	4	19.95	19.95 41.51	19.95 41.51 Seyfert Galaxy	19.95 41.51 Seyfert Galaxy z = 0.017559
Germinga 98.48 17.77 Pulkar 100 pc Crab Nebula 83.63 22.01 SNR 2 kpc IES 1959+650 300.00 65.15 HBL z = 0.048 IES 2344+514 356.77 51.70 HBL z = 0.044 IC66A 35.67 43.04 Blazar z = 0.129 I 1426+428 217.14 42.67 HBL z = 0.034 0.19 I 1426+428 217.14 42.67 HBL z = 0.031 NC comae 330.68 42.28 HBL z = 0.031 YK S 1622-297 246 QSO 1730-130 263 PKS 1622-297 246 QSO 1730-130 263 PKS 1622-297 246 QSO 2022-077 306 1rk 421 166.11 38.21 HBL z = 0.1020 V Cormae 185.38 28.23 HBL z = 0.139 0.39 187 187.71 12.39 BL Lac z = 0.0042 0.38 50716+71 110.47 <td>C443</td> <td>94.18</td> <td>22.53</td> <td>SNR</td> <td>1.5 kpc</td> <td>-</td> <td>СудА</td> <td>299</td> <td>9.87</td> <td>9.87 40.73</td> <td>9.87 40.73 Radio-loud Galaxy</td> <td>9.87 40.73 Radio-loud Galaxy z = 0.056146</td>	C443	94.18	22.53	SNR	1.5 kpc	-	СудА	299	9.87	9.87 40.73	9.87 40.73 Radio-loud Galaxy	9.87 40.73 Radio-loud Galaxy z = 0.056146
Crab Nebula 83.63 22.01 SNR 2 kpc IES 1959+650 300.00 65.15 HBL z = 0.048 IES 2344+514 356.77 51.70 HBL z = 0.048 ICC66A 35.67 43.04 Blazar z = 0.129 IL426+428 217.14 42.67 HBL z = 0.069 0.4 Trk 501 253.47 39.76 HBL z = 0.031 NC Comae 185.38 28.23 HBL z = 0.120 VC Comae 185.71 12.39 BL Lac z = 0.031 NC Comae 185.78 28.23 HBL z = 0.0120 IES 0229+200 38.20 20.29 HBL z = 0.139 0.39 187 187.71 12.39 BL Lac z = 0.0042 0.38 150 716+71 110.47 71.34 LBL z > 0.3 0.49 182 148.97 69.68 Starbust	Geminga	98.48	17.77	Pulsar	100 pc	-						
IES 1959+650 300.00 65.15 HBL z = 0.048 IES 2344+514 356.77 51.70 HBL z = 0.044 IC66A 35.67 43.04 Blazar z = 0.129 I 1426+428 217.14 42.67 HBL z = 0.129 SL Lac 330.68 42.28 HBL z = 0.034 0.19 Thk 501 253.47 39.76 HBL z = 0.139 0.39 Thk 421 166.11 38.21 HBL z = 0.139 0.39 V Comae 185.38 28.23 HBL z = 0.1020 VComae 185.71 12.39 BL Lac z = 0.0042 0.38 S5 0716+71 110.47 71.34 LBL z > 0.3 0.49 182 148.97 69.68 Starbust 386 Mpc IC 123.0 69.27 29.67 FRI 1038 Mpc IC 138.41 248.81 38.13 FSRQ z = 0.859 0.48 IC 38.41 248.81 38.13 FSRQ <td>Crab Nebula</td> <td>83.63</td> <td>22.01</td> <td>SNR</td> <td>2 kpc</td> <td>-</td> <td>Sg⊢A*</td> <td>266.42</td> <td></td> <td>-29.01</td> <td>-29.01 Galactic Center</td> <td>-29.01 Galactic Center 8.5 kpc</td>	Crab Nebula	83.63	22.01	SNR	2 kpc	-	Sg⊢A*	266.42		-29.01	-29.01 Galactic Center	-29.01 Galactic Center 8.5 kpc
IES 2344+514 356.77 51.70 HBL z = 0.044 - 3C66A 35.67 43.04 Blazar z = 0.44 0.42 1 1426+428 217.14 42.67 HBL z = 0.129 - 3L Lac 330.68 42.28 HBL z = 0.069 0.4 1rk 501 253.47 39.76 HBL z = 0.031 - YK 6 1622-297 246.53 QSO 1730-130 263.26 YK 421 166.11 38.21 HBL z = 0.031 - YK 6 1422-297 246.53 QSO 1730-130 263.26 YKS 1454-354 222.49 QSO 1730-130 263.26 YKS 1454-354 224.36 PKS 1456-376 212.24 QSO 1730-130 263.26 PKS 1406-076 212.24 QSO 2022-077 306.42 36.42 36.42 36.42 187 110.47 71.34 LBL z > 0.3 0.49 TYCHO 6.36 182 148.97 69.68 Starbust 3.86 Mpc - - Cyg X-3 308.11 IC 123.0	IE\$ 1959+650	300.00	65.15	HBL	z = 0.048	-	PKS 0537-441	84.7 I	-	-44.09	-44.09 LBL	-44.09 LBL z = 0.896
BC66A 35.67 43.04 Blazar z = 0.44 0.42 1 426+428 2 7.14 42.67 HBL z = 0.129 3L Lac 330.68 42.28 HBL z = 0.069 0.4 1rk 501 253.47 39.76 HBL z = 0.034 0.19 1rk 421 166.11 38.21 HBL z = 0.031 N Comae 185.38 28.23 HBL z = 0.1020 NC Omae 185.38 28.23 HBL z = 0.139 0.39 187 187.71 12.39 BL Lac z = 0.0042 0.38 1802 148.97 69.68 Starbust 3.86 Mpc 162 123.0 69.27 29.67 FRI 1038 Mpc 162 13.0 69.27 29.67 FRI 1038 Mpc 162 143.1 248.81 38.13 FSRQ z = 0.859 0.48 S433 20.30	IES 2344+514	356.77	51.70	HBL	z = 0.044	-	Cen A	201.37	+	-43.02	-43.02 FRI	-43.02 FRI 3.8 Mpc
H 426+4282 7.1442.67HBL $z = 0.129$ BL Lac330.6842.28HBL $z = 0.069$ 0.4Trk 501253.4739.76HBL $z = 0.034$ 0.19Trk 421166.1138.21HBL $z = 0.031$ V Cornac185.3828.23HBL $z = 0.1020$ HES 0229+20038.2020.29HBL $z = 0.1020$ 187187.7112.39BL Lac $z = 0.0042$ 0.38182148.9769.68Starbust3.86 MpcC 454.3343.4916.15FSRQ $z = 0.859$ 0.48C 38.41248.8138.13FSRQ $z = 1.814$ 0.3	3C66A	35.67	43.04	Blazar	z = 0.44	0.42	PKS 1454-354	224.36		35.65	-35.65 FSRQ	-35.65 FSRQ z = 1.42
BL Lac330.68 42.28 HBL $z = 0.069$ 0.4 Yrk 501253.4739.76HBL $z = 0.034$ 0.19 Yrk 421166.1138.21HBL $z = 0.031$ $-$ W Cornae185.3828.23HBL $z = 0.1020$ $-$ IES 0229+20038.2020.29HBL $z = 0.139$ 0.39 187187.7112.39BL Lac $z = 0.0042$ 0.38 55 0716+71110.4771.34LBL $z > 0.3$ 0.49 182148.9769.68Starbust 3.86 Mpc $-$ IC 123.069.2729.67FRII1038 Mpc $-$ IC 38.41248.8138.13FSRQ $z = 1.814$ 0.3	H 426+428	2 7.14	42.67	HBL	z = 0. 29	-	PKS 2155-304	329.72	-3	30.23	30.23 HBL	30.23 HBL z = 0.116
Mrk 501253.4739.76HBL $z = 0.034$ 0.19Mrk 421166.1138.21HBL $z = 0.031$ M Comae185.3828.23HBL $z = 0.1020$ NES 0229+20038.2020.29HBL $z = 0.139$ 0.39187187.7112.39BL Lac $z = 0.0042$ 0.385 0716+71110.4771.34LBL $z > 0.3$ 0.49182148.9769.68Starbust3.86 Mpc1C 123.069.2729.67FRII1038 Mpc1C 454.3343.4916.15FSRQ $z = 0.859$ 0.481C 38.41248.8138.13FSRQ $z = 1.814$ 0.3	BL Lac	330.68	42.28	HBL	z = 0.069	0.4	PKS 1622-297	246.53		0 86		
Mrk 421166.1138.21HBL $z = 0.031$ W Comae185.3828.23HBL $z = 0.1020$ IES 0229+20038.2020.29HBL $z = 0.139$ 0.39187187.7112.39BL Lac $z = 0.0042$ 0.3855 0716+71110.4771.34LBL $z > 0.3$ 0.49182148.9769.68Starbust3.86 Mpc1C 123.069.2729.67FRII1038 Mpc1C 123.069.2729.67FRIQ $z = 0.859$ 0.481C 38.41248.8138.13FSRQ $z = 1.814$ 0.3	Mrk 501	253.47	39.76	HBL	z = 0.034	0.19	PR3 1022-277	210.33	-2	7.00	7.00	7.00 1500 2-0.015
W Comac185.3828.23HBL $z = 0.1020$ PKS 1406-076212.24-7.81E5 0229+20038.2020.29HBL $z = 0.139$ 0.390.390.390.390.390.390.390.38306.42-7.6187187.7112.39BL Lac $z = 0.0042$ 0.380.493C279194.05-5.755 0716+71110.4771.34LBL $z > 0.3$ 0.49TYCHO6.3664.182148.9769.68Starbust3.86 MpcCyg X-1299.5935.31C 123.069.2729.67FRII1038 MpcCyg X-3308.1140.91C 454.3343.4916.15FSRQ $z = 0.859$ 0.48S5433287.964.94	Mrk 421	166.11	38.21	HBL	z = 0.031	-	QSO 1730-130	263.26	-13	.08	.08 FSRQ	.08 F5RQ z = 0.902
IES 0229+200 38.20 20.29 HBL z = 0.139 0.39 187 187.71 12.39 BL Lac z = 0.0042 0.38 iS 0716+71 110.47 71.34 LBL z > 0.3 0.49 182 148.97 69.68 Starbust 3.86 Mpc - iC 123.0 69.27 29.67 FRII 1038 Mpc - iC 454.3 343.49 16.15 FSRQ z = 0.859 0.48 iC 38.41 248.81 38.13 FSRQ z = 1.814 0.3	W Comae	185.38	28.23	HBL	z = 0.1020	-	PKS 1406-076	212.24	-7.87	, ,	' FSRQ	z = 1.494
M87 I87.71 I2.39 BL Lac z = 0.0042 0.38 3C279 194.05 -5.79 i5 0716+71 110.47 71.34 LBL z > 0.3 0.49 TYCHO 6.36 64.18 182 148.97 69.68 Starbust 3.86 Mpc - - Cyg X-1 299.59 35.20 IC 123.0 69.27 29.67 FRII 1038 Mpc - - Cyg X-3 308.11 40.96 IC 454.3 343.49 16.15 FSRQ z = 0.859 0.48 LSI 303 40.13 61.23 IC 38.41 248.81 38.13 FSRQ z = 1.814 0.3 S433 287.96 4.98	IE\$ 0229+200	38.20	20.29	HBL	z = 0. 39	0.39	QSO 2022-077	306.42	-7.64		FSRQ	FSRQ z = 1.39
S5 0716+71 110.47 71.34 LBL z > 0.3 0.49 182 148.97 69.68 Starbust 3.86 Mpc 1C 123.0 69.27 29.67 FRI 1038 Mpc 1C 454.3 343.49 16.15 FSRQ z = 0.859 0.48 1C 38.41 248.81 38.13 FSRQ z = 1.814 0.3	M87	187.71	12.39	BL Lac	z = 0.0042	0.38	3 C 279	194.05	-5.79		FSRQ	FSRQ z = 0.536
M82 I48.97 69.68 Starbust 3.86 Mpc Cyg X-1 299.59 35.20 3C 123.0 69.27 29.67 FRII 1038 Mpc Cyg X-3 308.11 40.96 1C 454.3 343.49 16.15 FSRQ z = 0.859 0.48 LSI 303 40.13 61.23 1C 38.41 248.81 38.13 FSRQ z = 1.814 0.3 SS433 287.96 4.96	\$5 0716+71	110.47	71.34	LBL	z > 0.3	0.49	ТҮСНО	6.36	64.18		SNR	SNR 2.1 kpc
AC 123.0 69.27 29.67 FRII 1038 Mpc Cyg X-3 308.11 40.96 AC 454.3 343.49 16.15 FSRQ z = 0.859 0.48 LSI 303 40.13 61.23 AC 38.41 248.81 38.13 FSRQ z = 1.814 0.3 SS433 287.96 4.98	M82	148.97	69.68	Starbust	3.86 Mpc	-	Cyg X-I	299.59	35.20		MQSO	MQSO 2.5 kpc
AC 454.3 343.49 16.15 FSRQ z = 0.859 0.48 LSI 303 40.13 61.23 IC 38.41 248.81 38.13 FSRQ z = 1.814 0.3 SS433 287.96 4.96	3C 123.0	69.27	29.67	FRII	1038 Mpc	-	Cyg X-3	308.11	40.96		MQSO	MQSO 9 kpc
IC 38.41 248.81 38.13 FSRQ z = 1.814 0.3 SS433 287.96 4.98	3C 454.3	343.49	16.15	FSRQ	z = 0.859	0.48	LSI 303	40. 3	61.23		MQSO	MQSO 2 kpc
	4C 38.4I	248.81	38.13	FSRQ	z = 1.814	0.3	\$ \$43 3	287.96	4.98		MQSO	MQSO I.5 kpc

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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

Stockholm University Uppsala Universitet

University of Oxford

Ecole Polytechnique Fédérale de Lausanne University of Geneva

> Université Libre de Bruxelles Université de Mons University of Gent Vrije Universiteit Brussel

University of the West Indies

39 Institutions ~250 collaborators

Deutsches Elektronen-Synchrotron Humboldt Universität Ruhr-Universität Bochum RWTH Aachen University Technische Universität München Universität Bonn Universität Dortmund Universität Mainz Universität Wuppertal

Chiba University

University of Adelaide

University of Canterbury

International Funding Agencies

Clark Atlanta University

Ohio State University

Stony Brook University

University of Alabama

University of Kansas University of Maryland

Georgia Institute of Technology

Pennsylvania State University

University of Alaska Anchorage University of California-Berkeley University of California-Irvine University of Delaware

University of Wisconsin-Madison University of Wisconsin-River Falls

Lawrence Berkeley National Laboratory

Southern University and A&M College

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University of Alberta

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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



Event Charge Distribution



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Neutrino Energy Distribution – GZK search



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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: $\mathcal{L}(n_s, \gamma) = \prod_{i=1}^{N} \left(\frac{n_s}{N} S_i(\gamma) + (1 - \frac{n_s}{N}) B_i \right)$ Maximize wrt:
γ, the neutrino spectral index
ns, 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



Fotal 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



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IceCube: First Step in Neutrino Oscillation Physics

Simple cuts and reconstruction in DeepCore. Extend sample to Low energy. Search for consistency with <u>standard</u> 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



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Diffuse ν_{μ} flux limits



DeepCore Filter



- ✓ Superb muon veto
- $\checkmark~$ 10 300 GeV over 4 π sr
- ✓ Search for DM
- ✓ Neutrino Oscillations
- ✓ Choked GRBs

Model Independent IC40 / IC59

IC40+IC59 Model Independent Results



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