IceCube GRB ν Searches- Toward a Realtime Search

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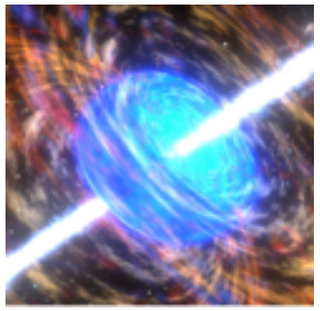
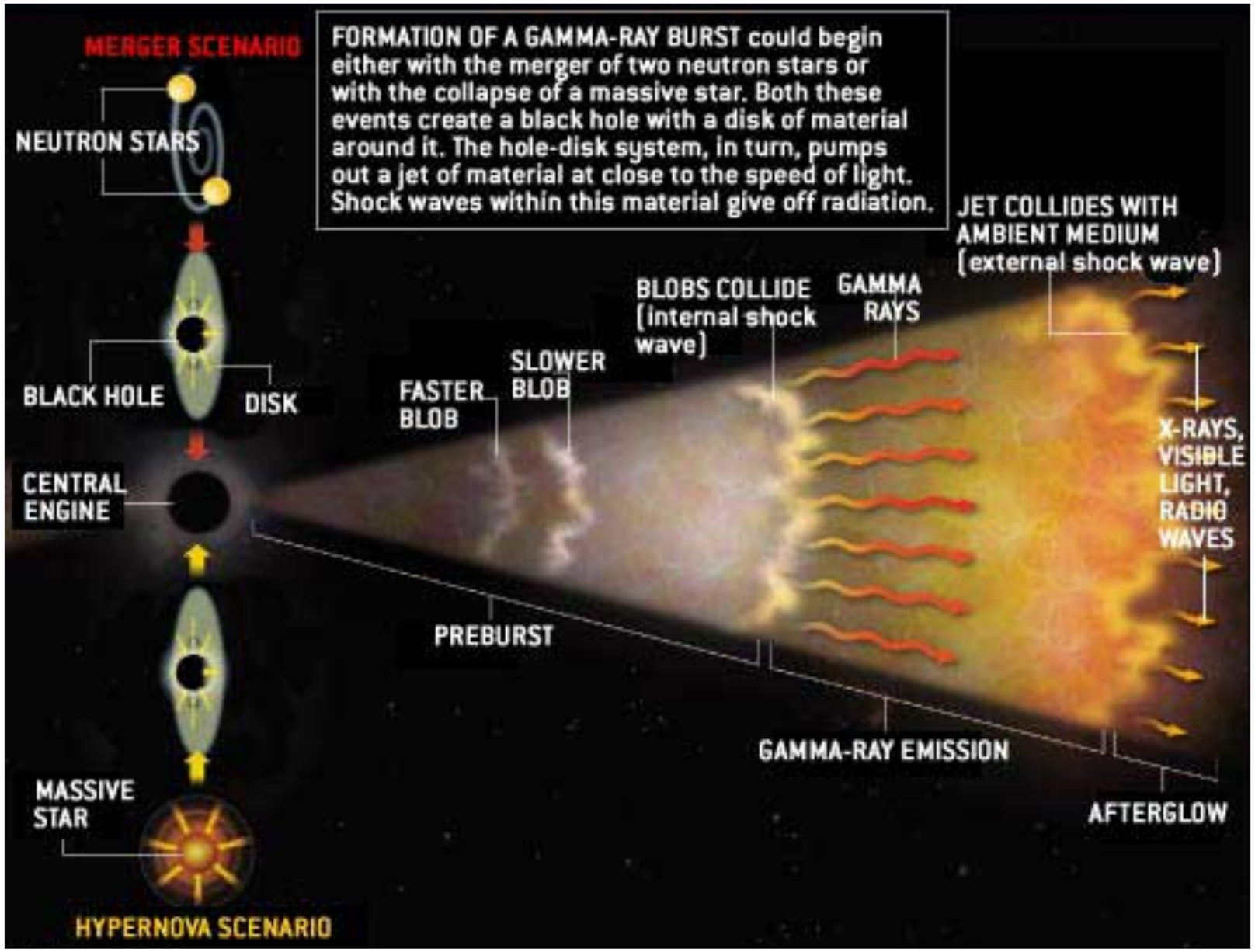
Realtime Astroparticle Physics

Feb 4-6, 2013 - Bonn, Germany

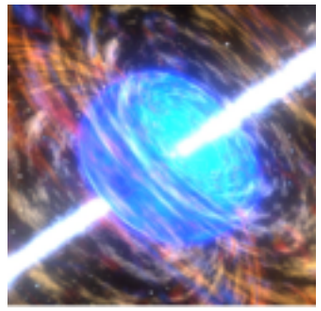
Gamma-ray Burst modeling



- Fireball model is successful at explaining the observed photons
  - Prompt gamma rays
  - Afterglows
- Realistic to believe that baryons are also accelerated
  - Produce high-energy neutrinos

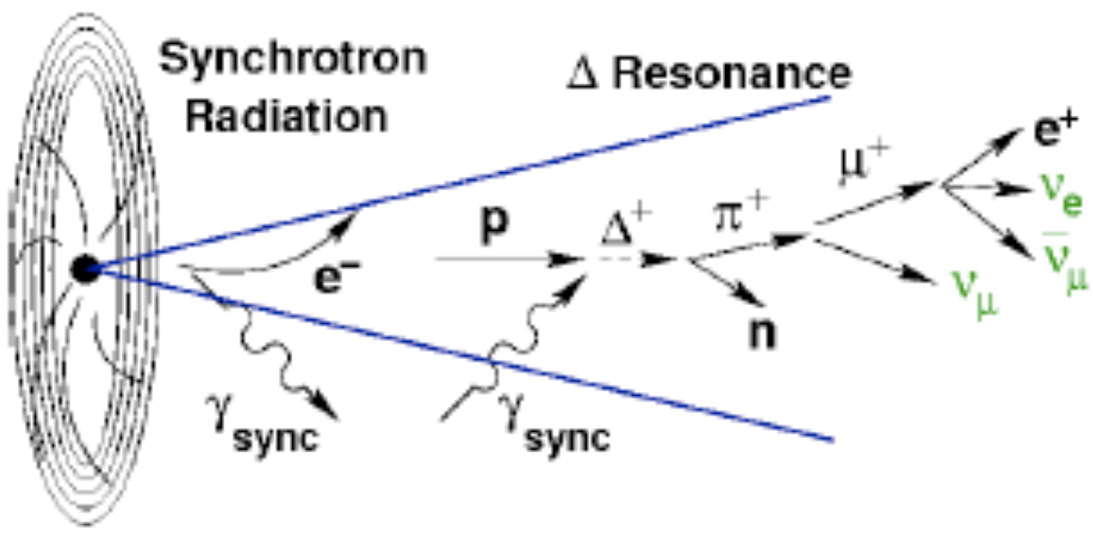


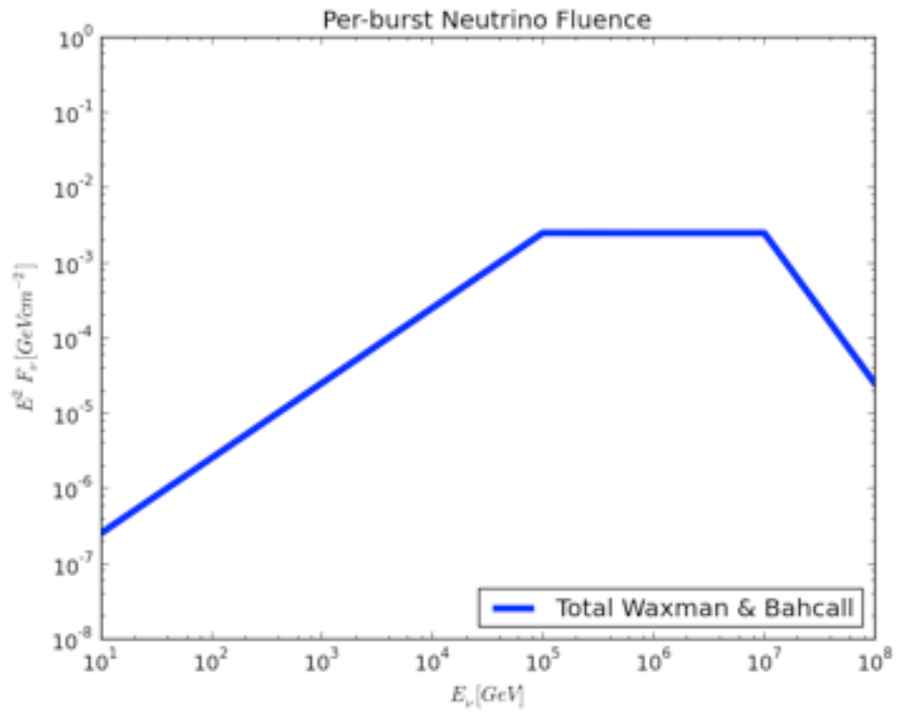
Scientific American, Dec '02



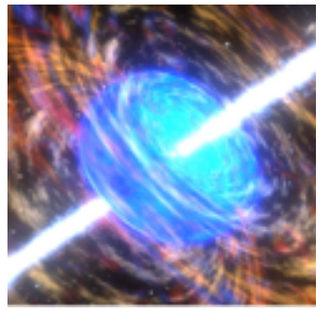
Gamma-ray Burst Neutrinos

- Internal shocks in GRBs are a compelling candidate for the source of acceleration for UHECRs.
  - Acceleration conditions required to produce the observed gamma rays would also be sufficient for UHECR production
  - Observed gamma-ray burst energy injection rate into Universe well matched to observed UHECR energy
  - Waxman-Bahcall modeled neutrino production from photon-hadron interactions in fireball

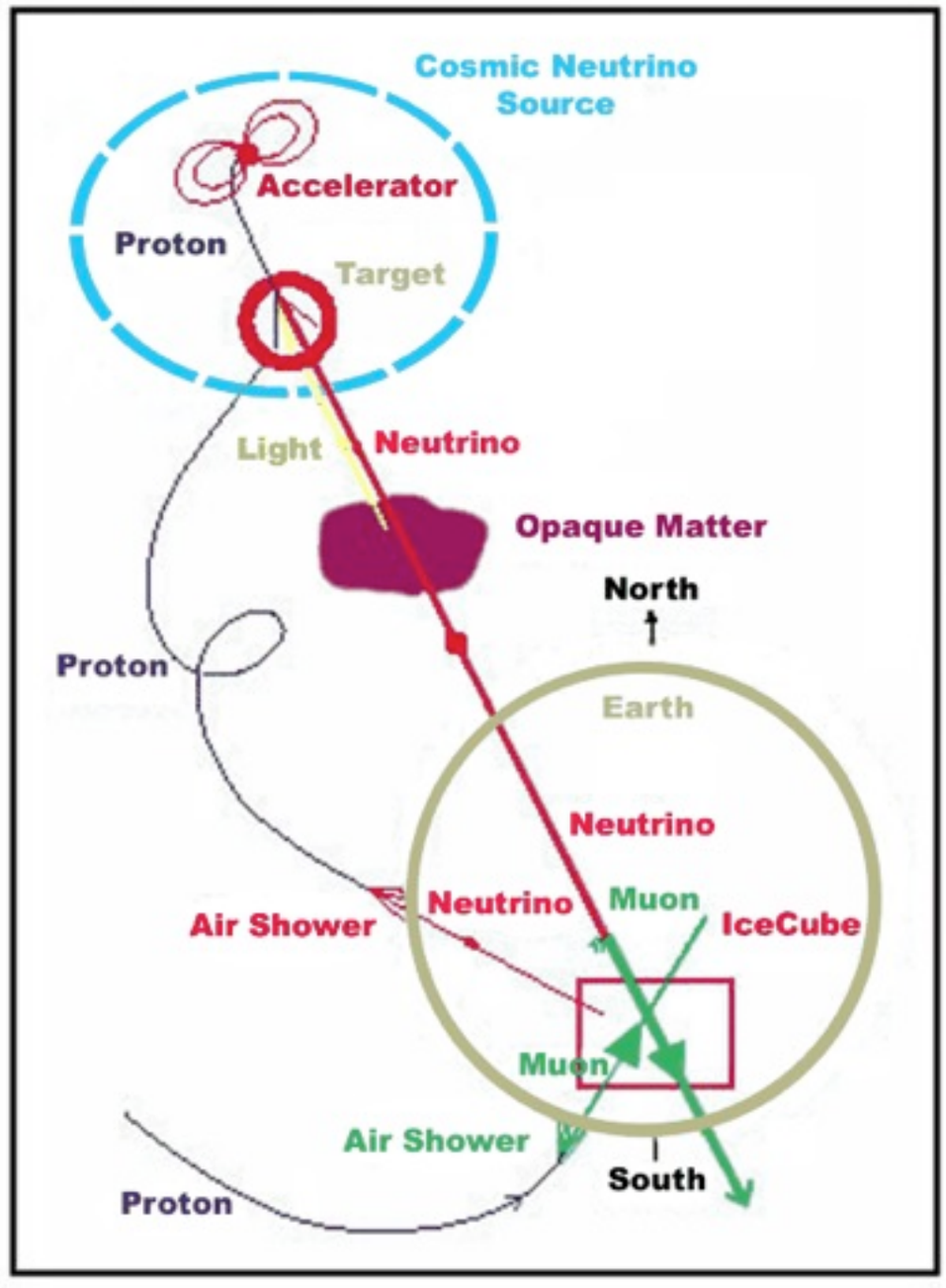


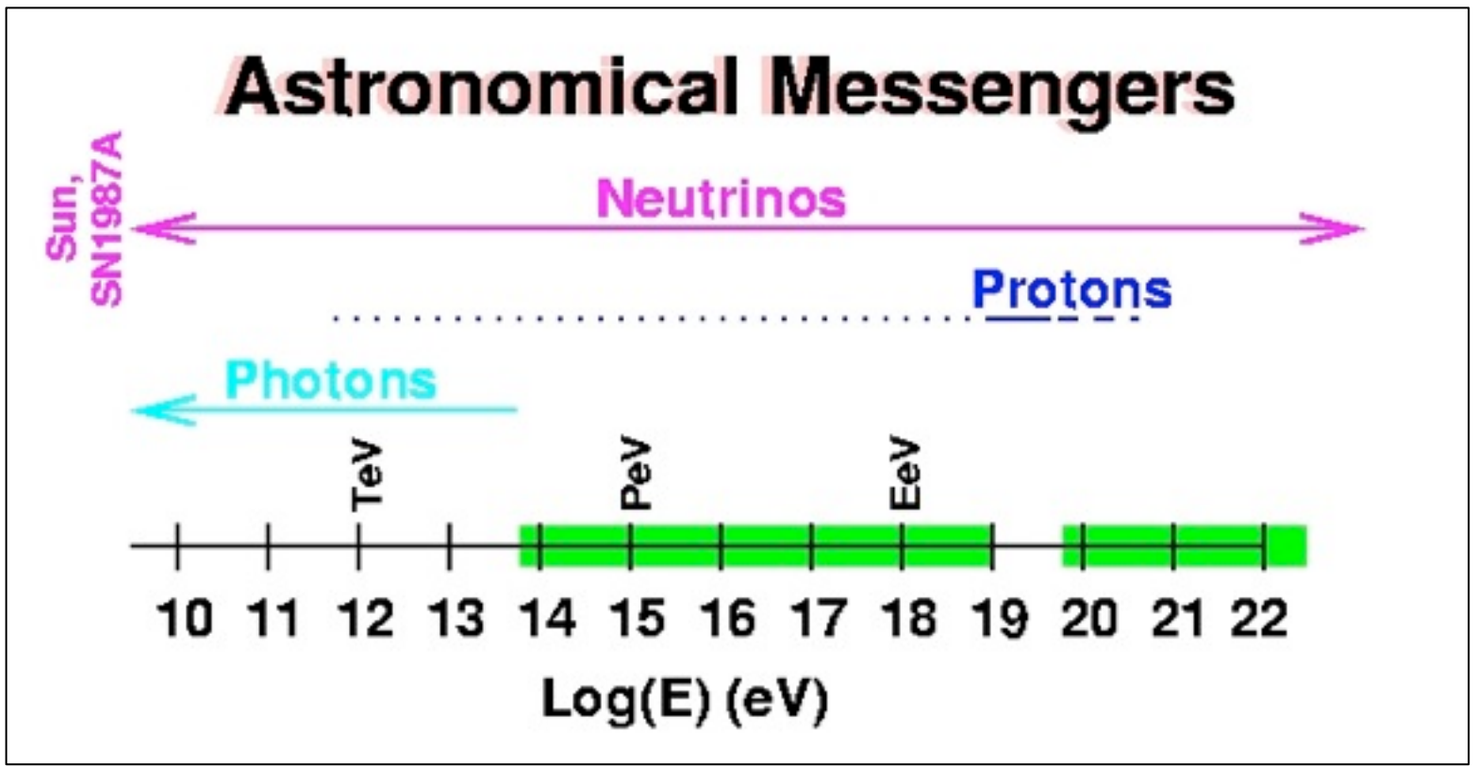


Neutrinos: Astronomical messengers

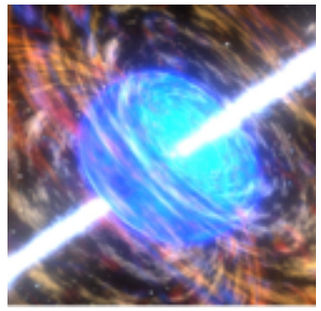


- At the highest energies, neutrinos are an astronomical messenger with several advantages:
  - Neutral
  - Freely propagate from source regions
- But you do need a large detector....

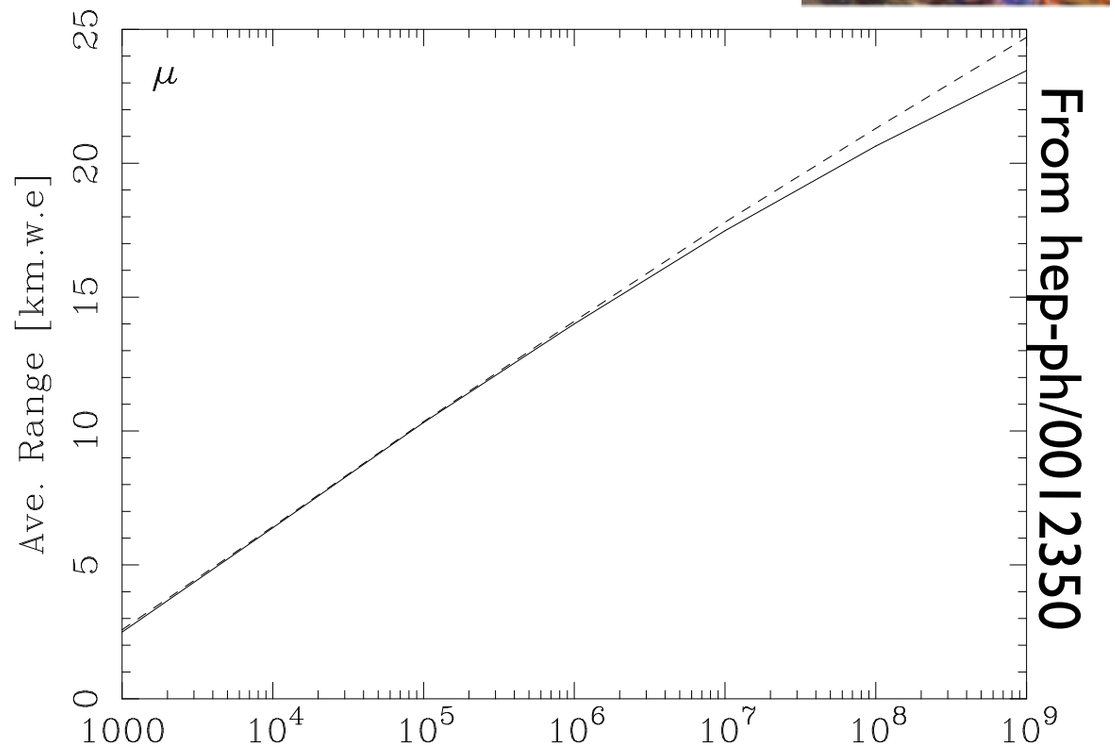




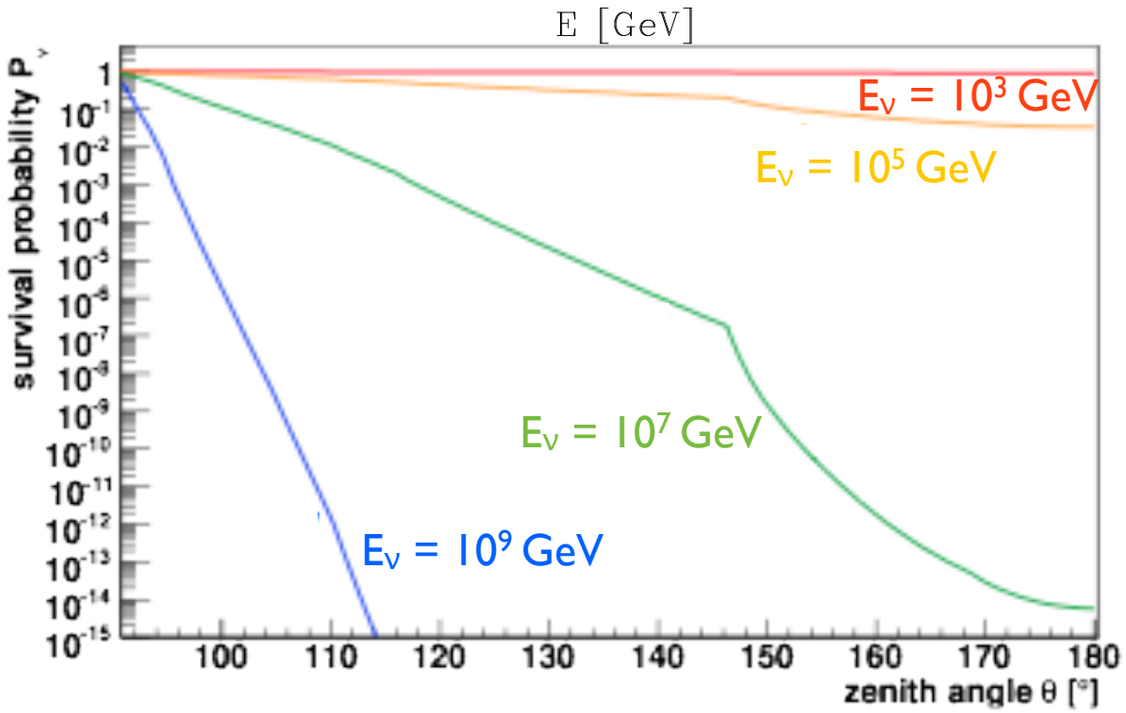
Neutrino Astronomy



- Cosmic neutrinos will interact in or near detectors:
  - $\nu_l + N \rightarrow X + l$
- If lepton is a μ, interaction region can be much larger than detection volume, as long as μ reaches detector.
  - Good angular correlation between neutrino and μ
    - Better than 1° for E_ν > 1 TeV (~ 3.5° at 100 GeV)
- Generally search for "upgoing" tracks
  - Not possible at higher energies
  - Downgoing tracks at higher energies also distinguished from atmospheric muon background



From hep-ph/0012350



Cable for power, communication and support

Digital optical modules (phototubes and data acquisition)

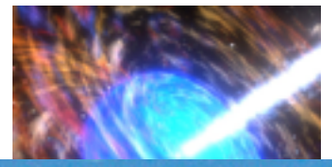
Water or clear ice serves as both a target medium and a Cerenkov radiator

μ

ν_μ

Due to the scale required for a high energy neutrino detector, man-made tanks are impractical. Large natural reservoirs are needed.

IceCube at the South Pole



South Pole Station

IceCube

Skiway

Geographic South Pole

Dark sector

IceCube

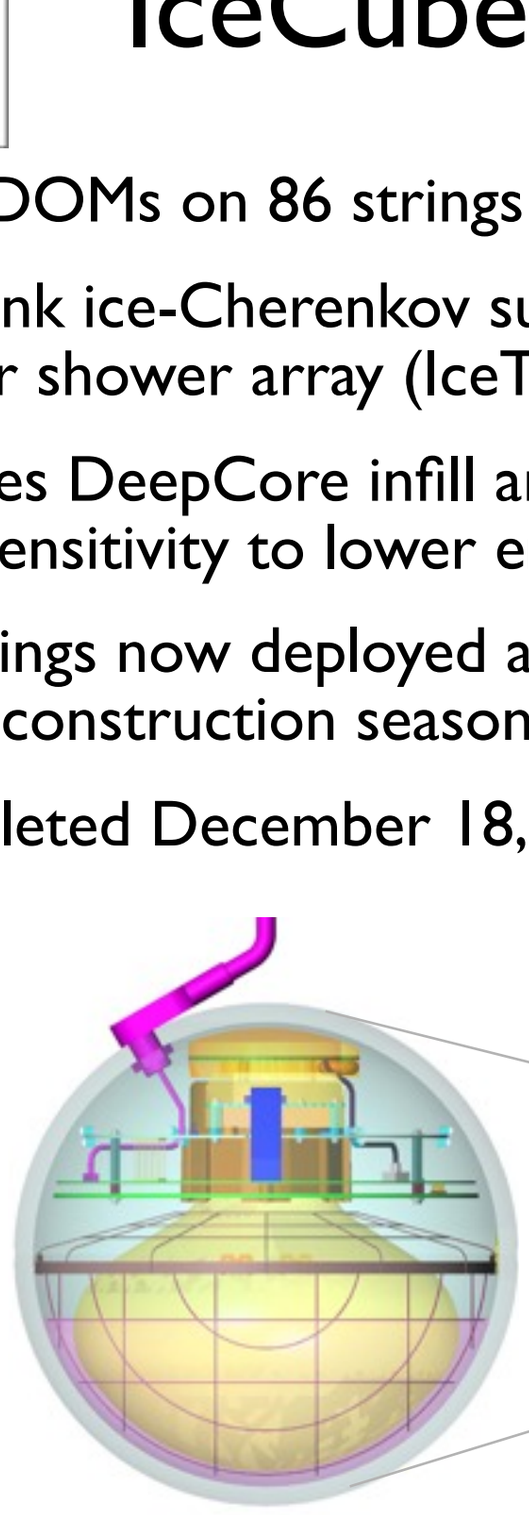
5160 DOMs on 86 strings

162 tank ice-Cherenkov surface air shower array (IceTop)

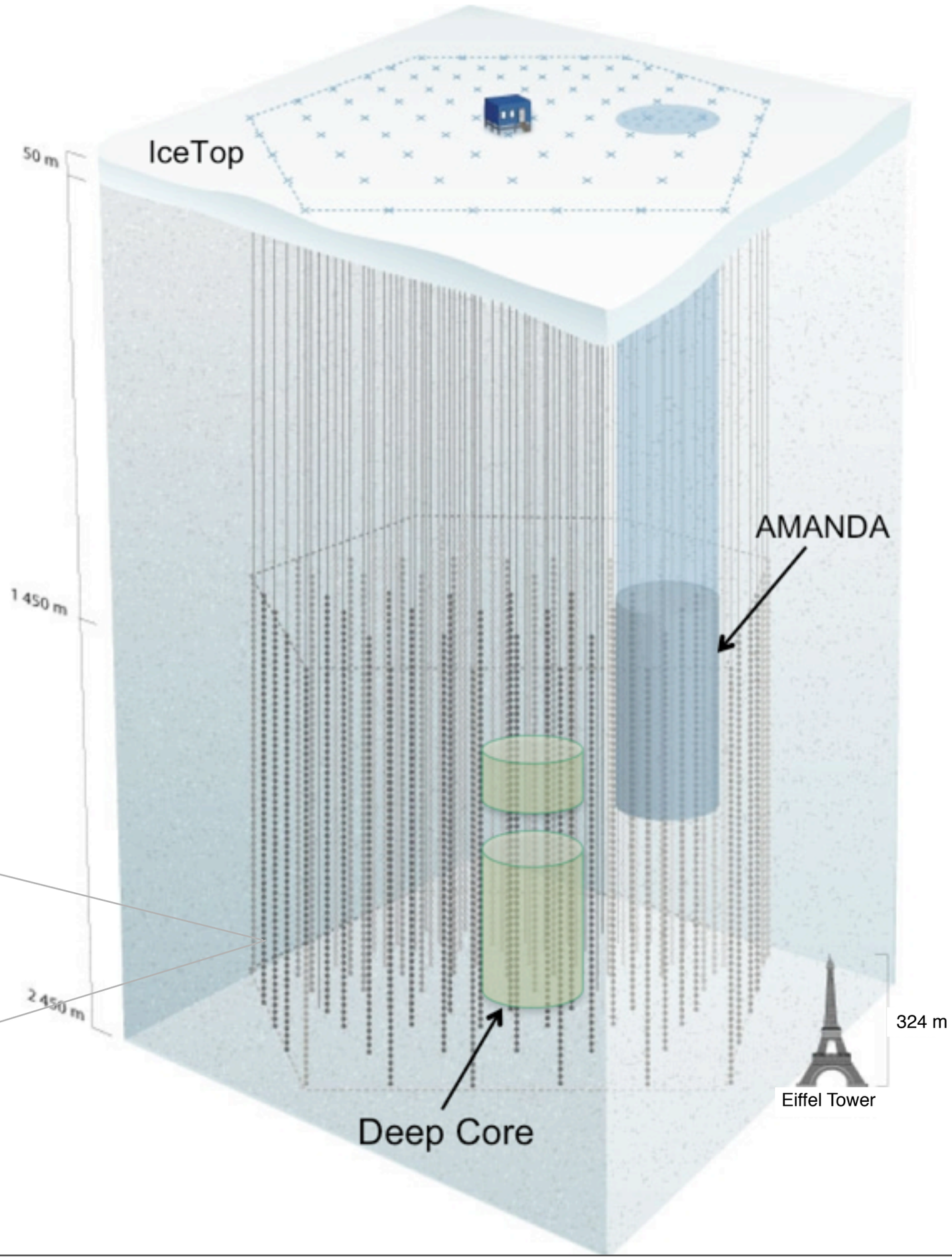
Includes DeepCore infill array (sensitivity to lower energies)

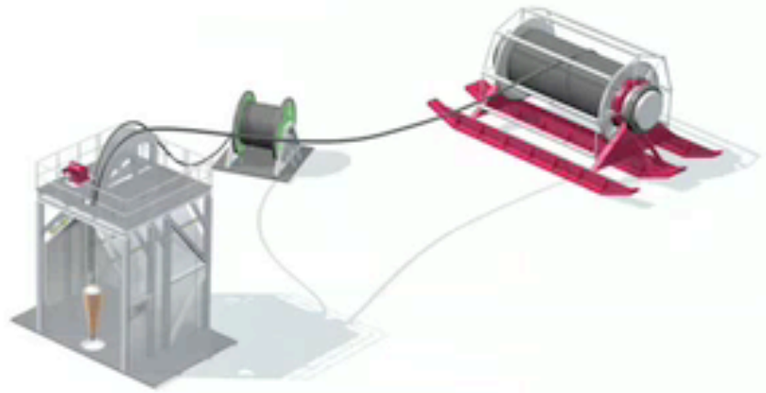
All strings now deployed after 7 construction seasons

Completed December 18, 2010

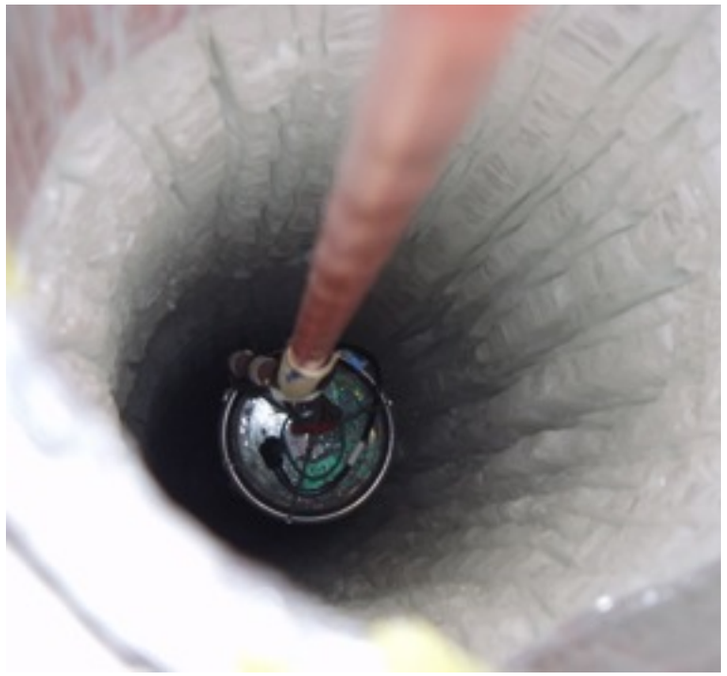


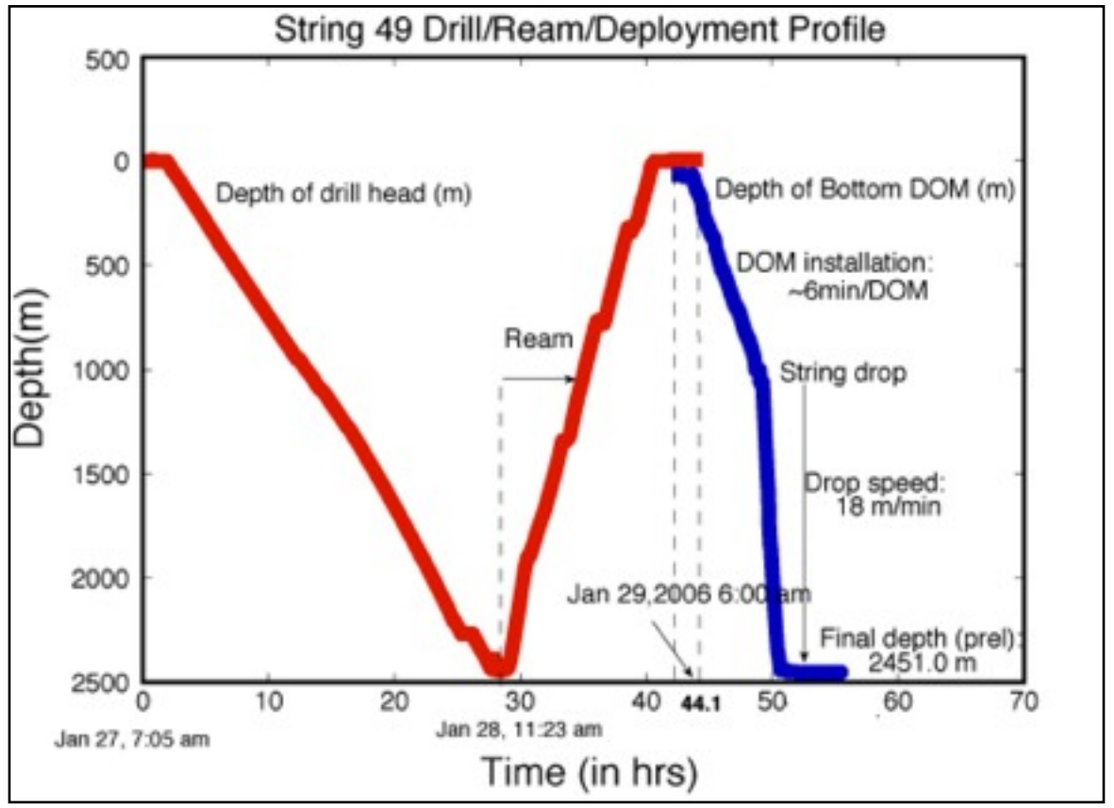
Digital Optical Module (DOM)

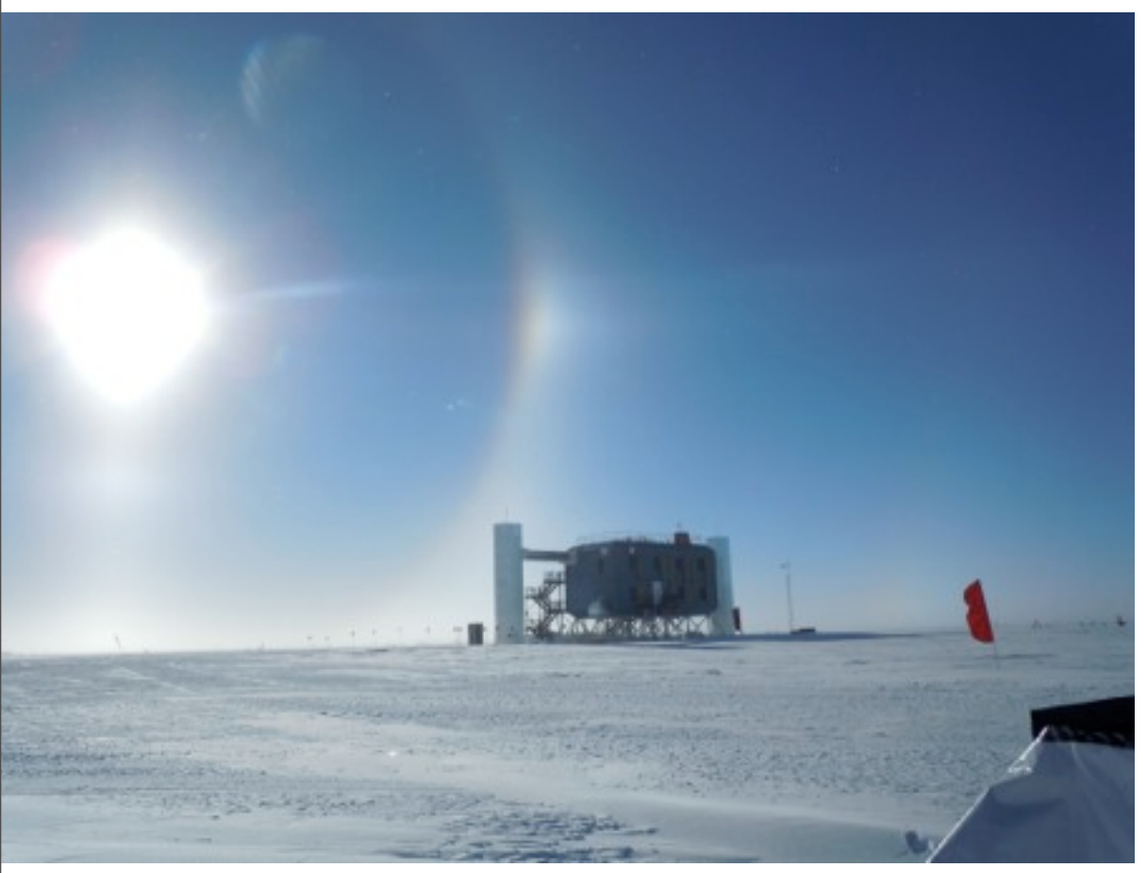




Drilling and deployment

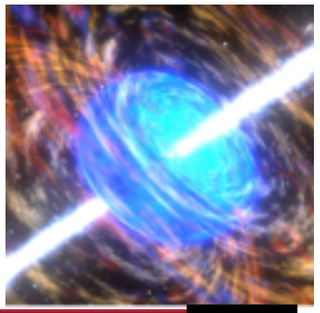


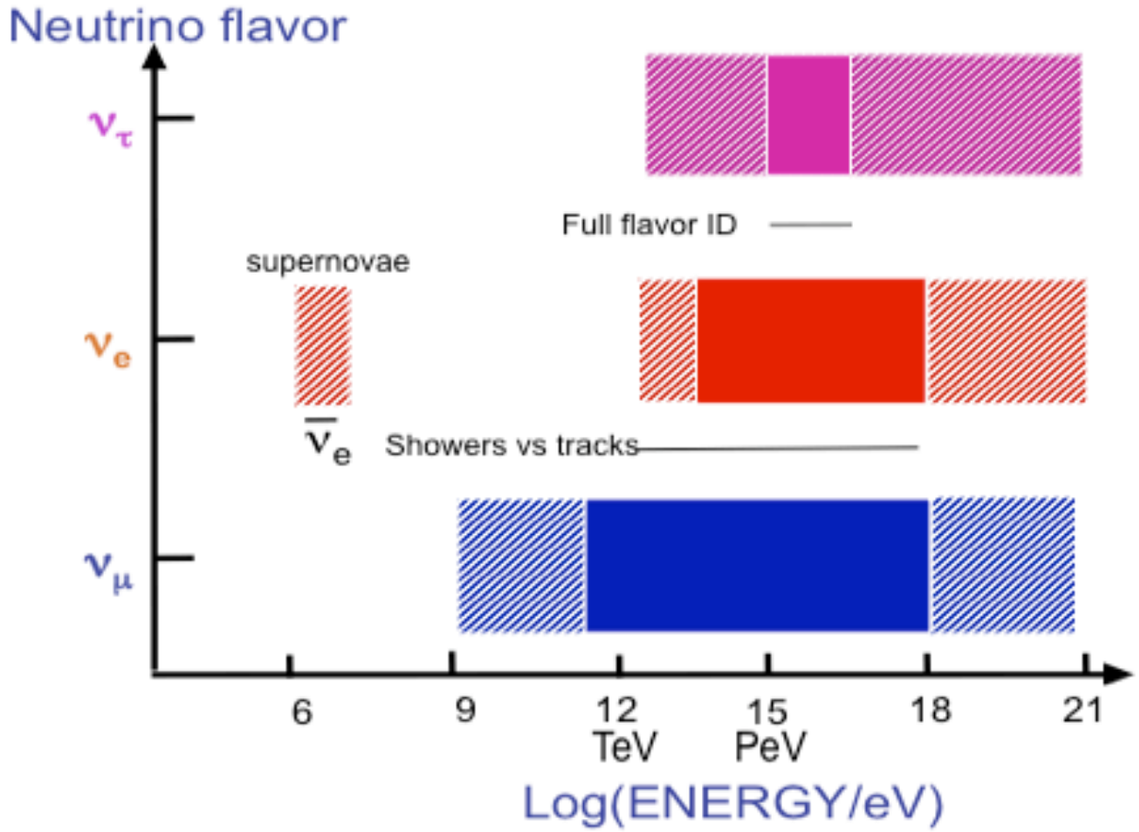




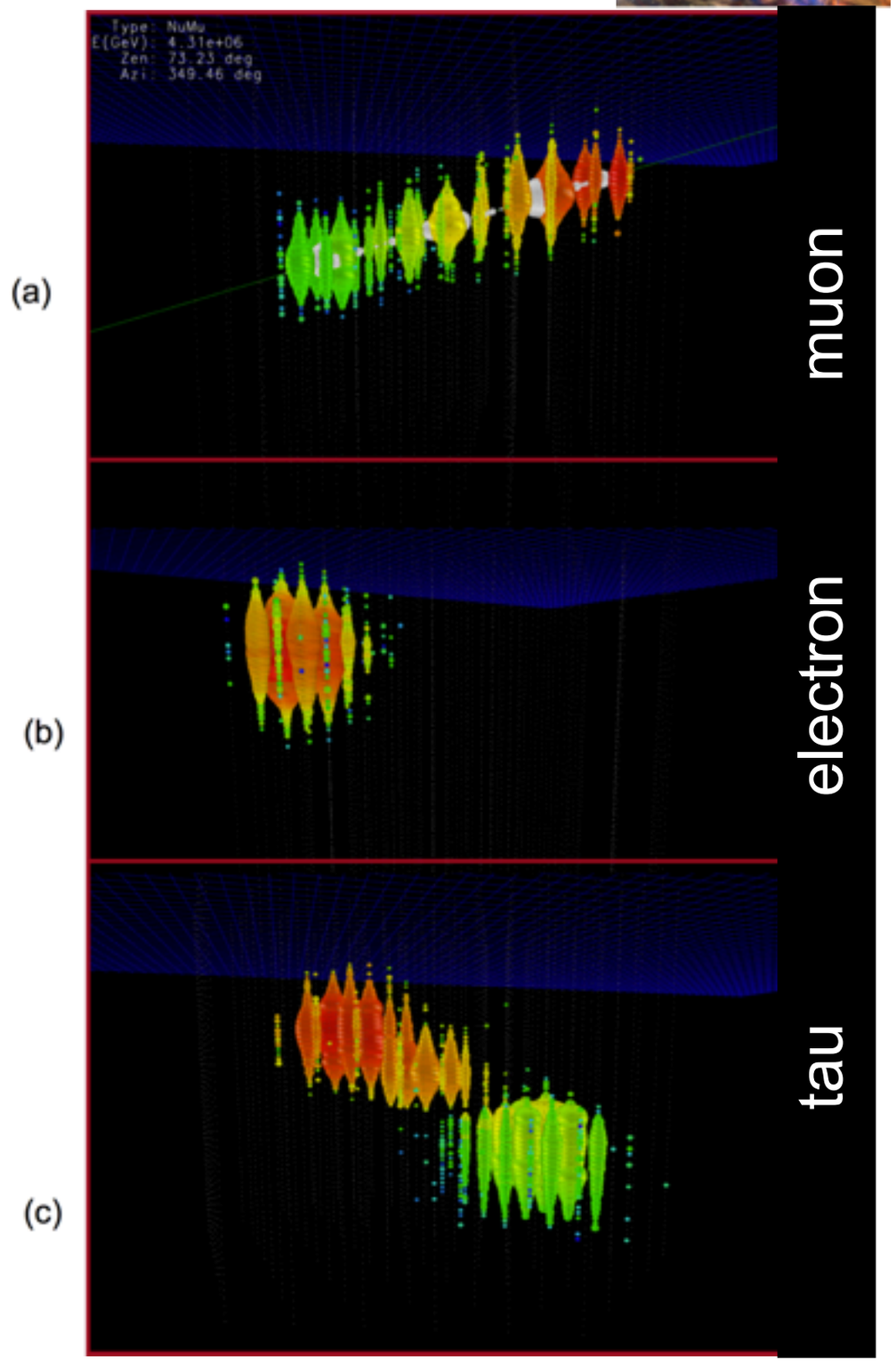

Corona

IceCube sensitive to ALL ν flavors

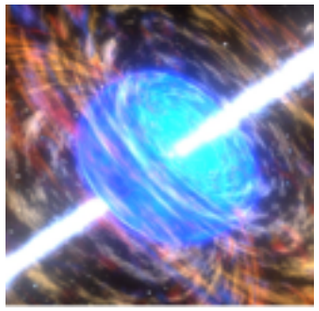




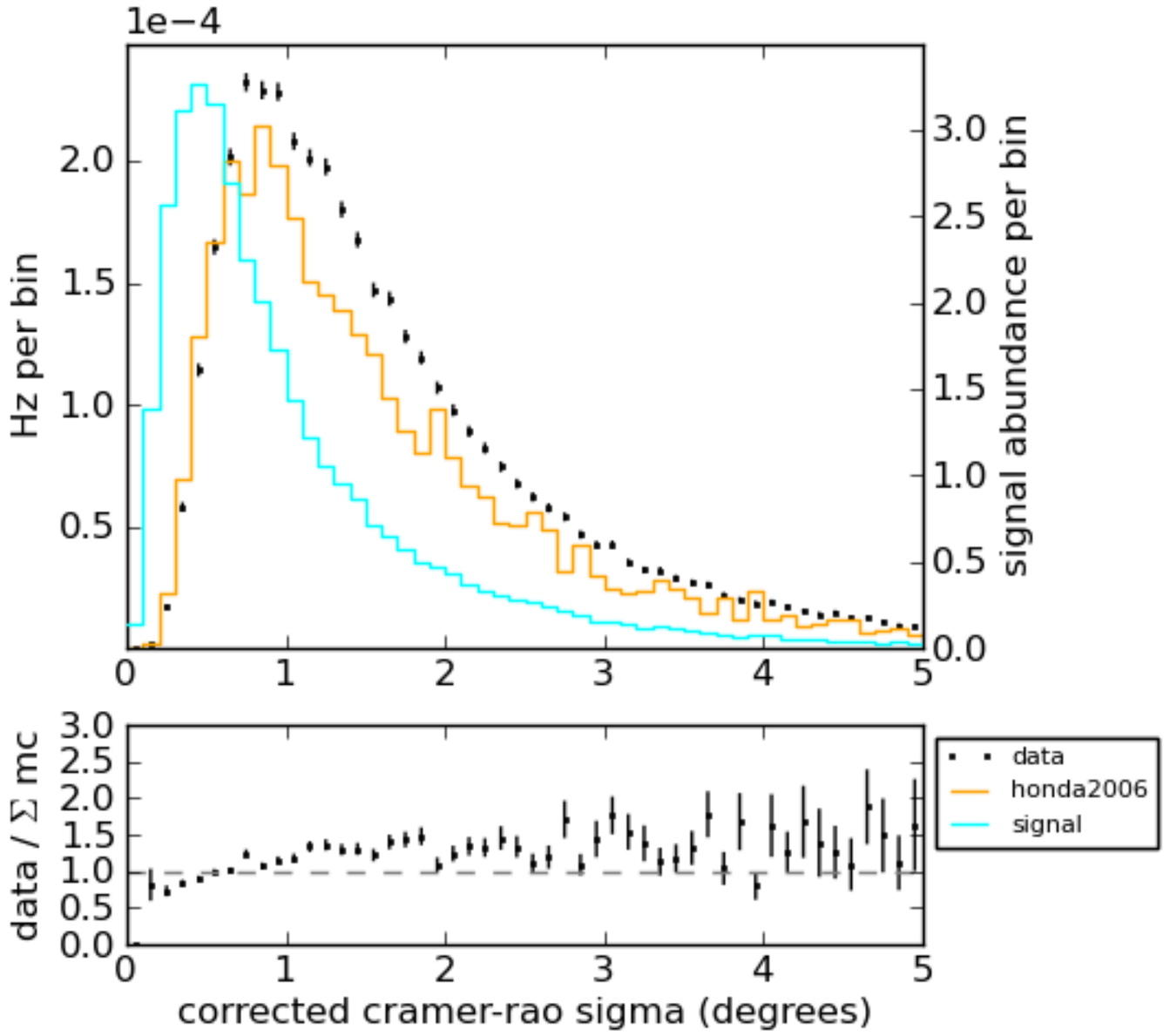
- Cosmogenic neutrinos are fully oscillated at Earth
  - 1:2:0 → 1:1:1
- ν_μ is preferred channel for GRBs



Event Reconstruction & Reduction

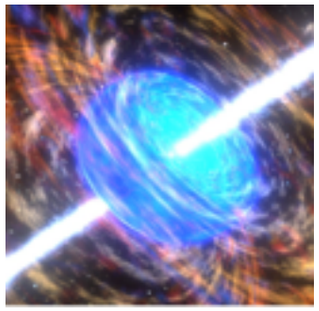


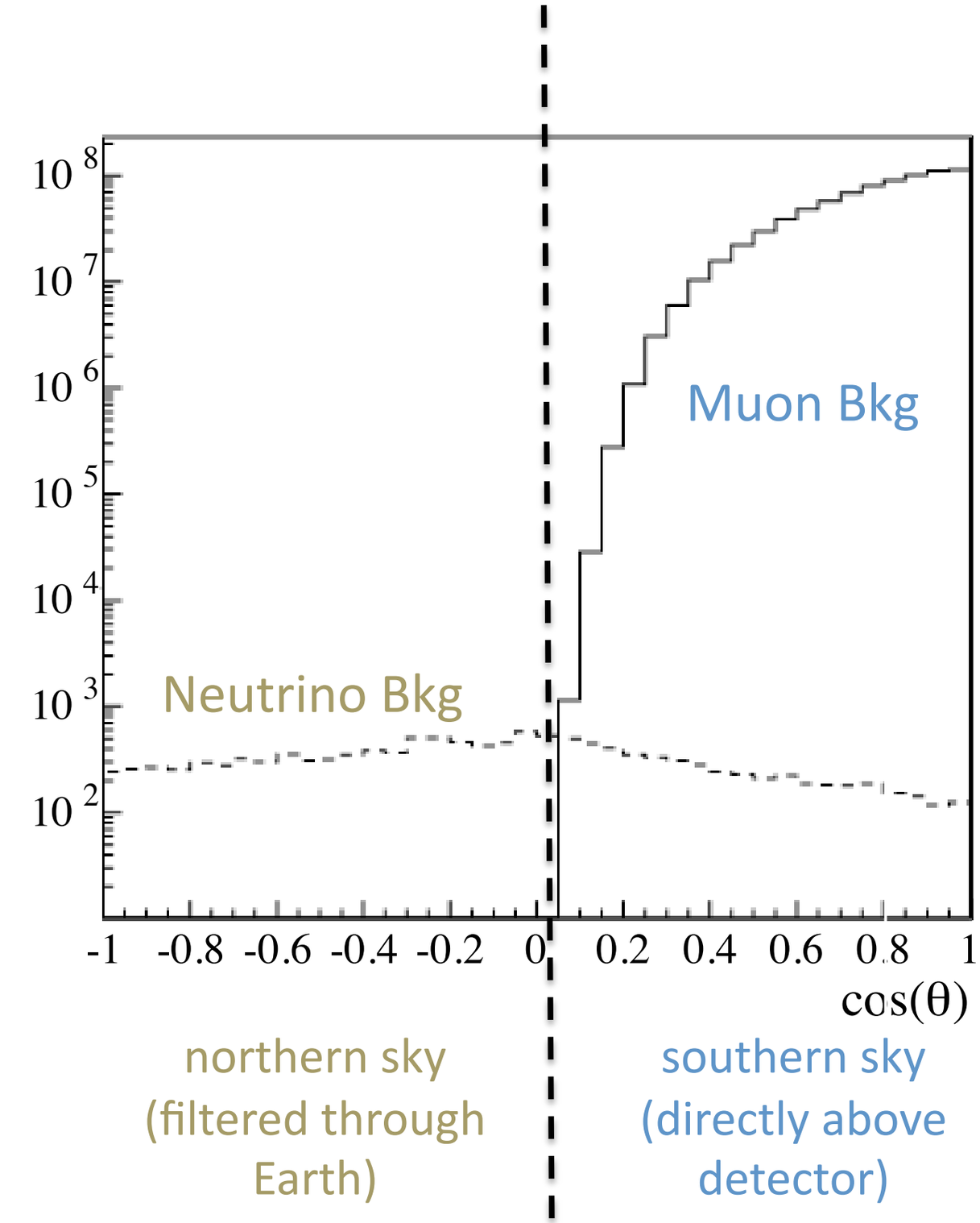
- Events direction is reconstructed using hit DOMs in an iterative likelihood reconstruction.
  - Scattering is dominant in ice.
- Even after this, misreconstructed events dominate the data sample.
  - Multiple tracks in detector at once
- Further track quality cuts required:
  - Reduced LLH and likelihood space
  - Number/length of "direct hits"
- Final sample of events dominated by atmospheric neutrinos

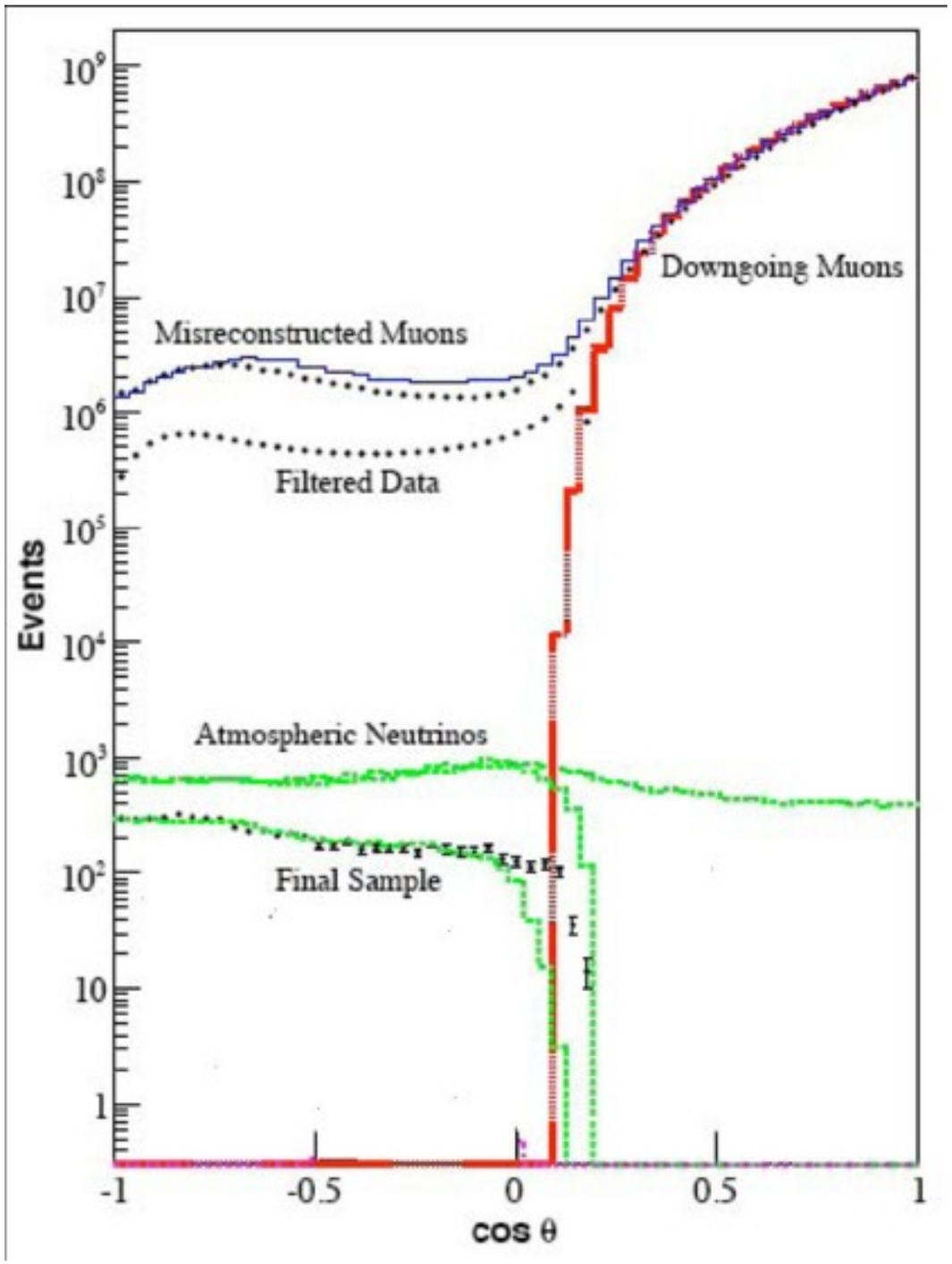


IC86 Angular error estimate
Median signal resolution: 0.7°

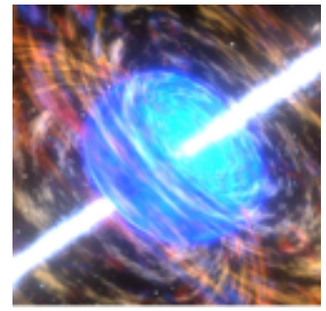
Event Reconstruction & Reduction

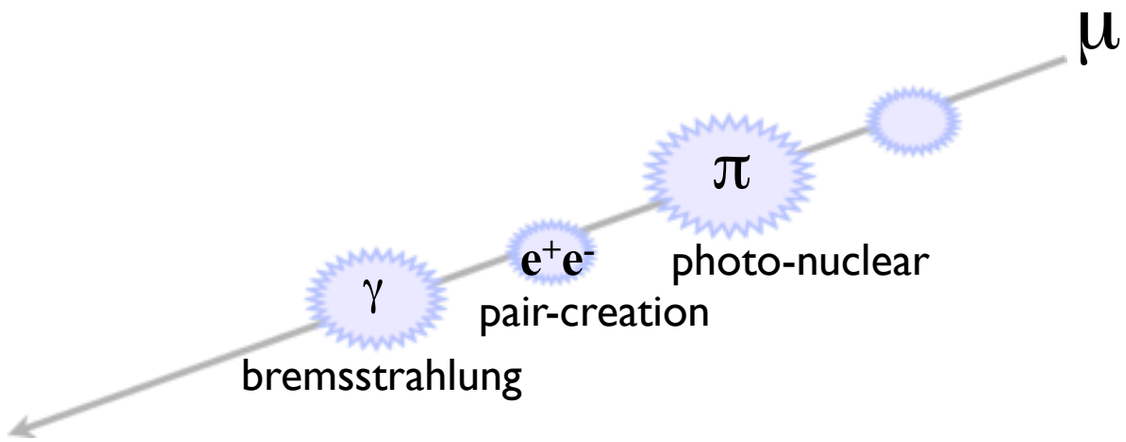




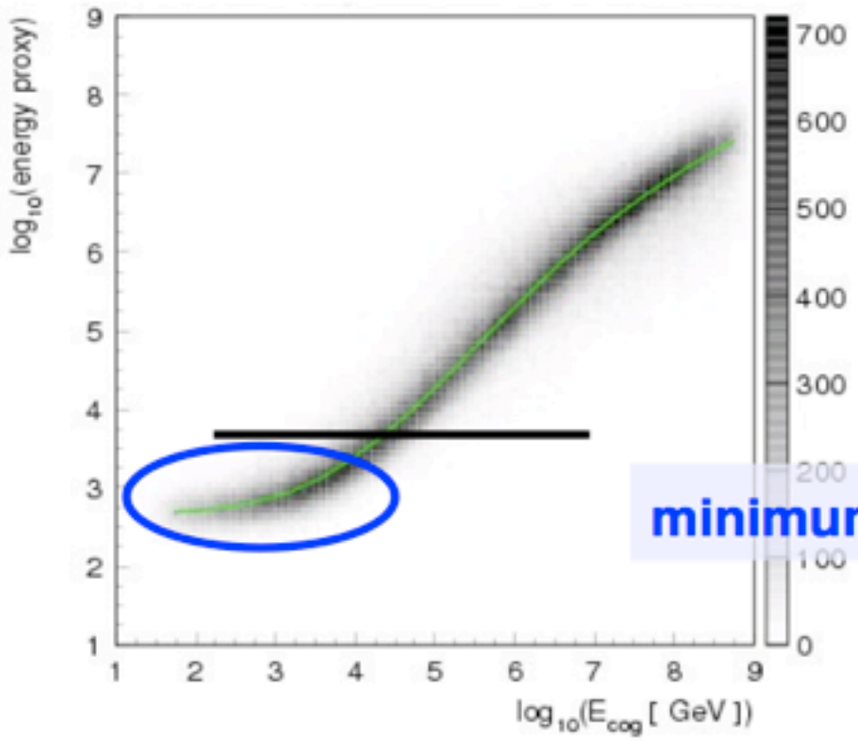


Energy reconstruction

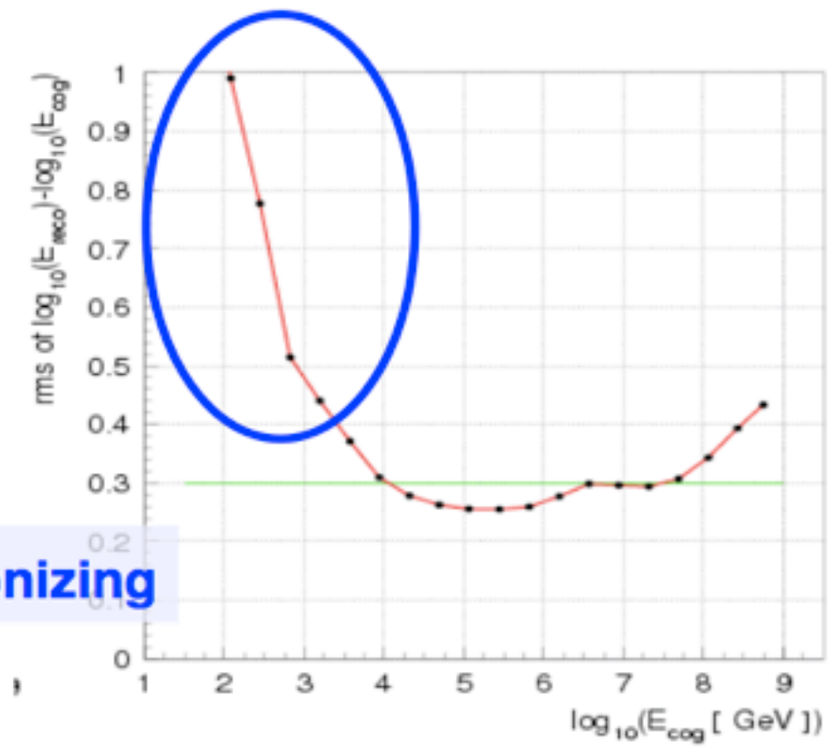




Energy estimators are possible over most of IceCube's sensitive range

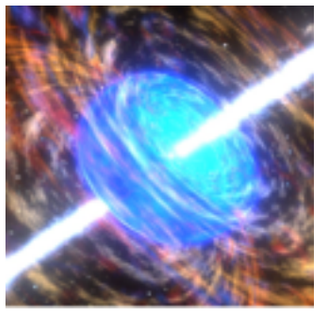


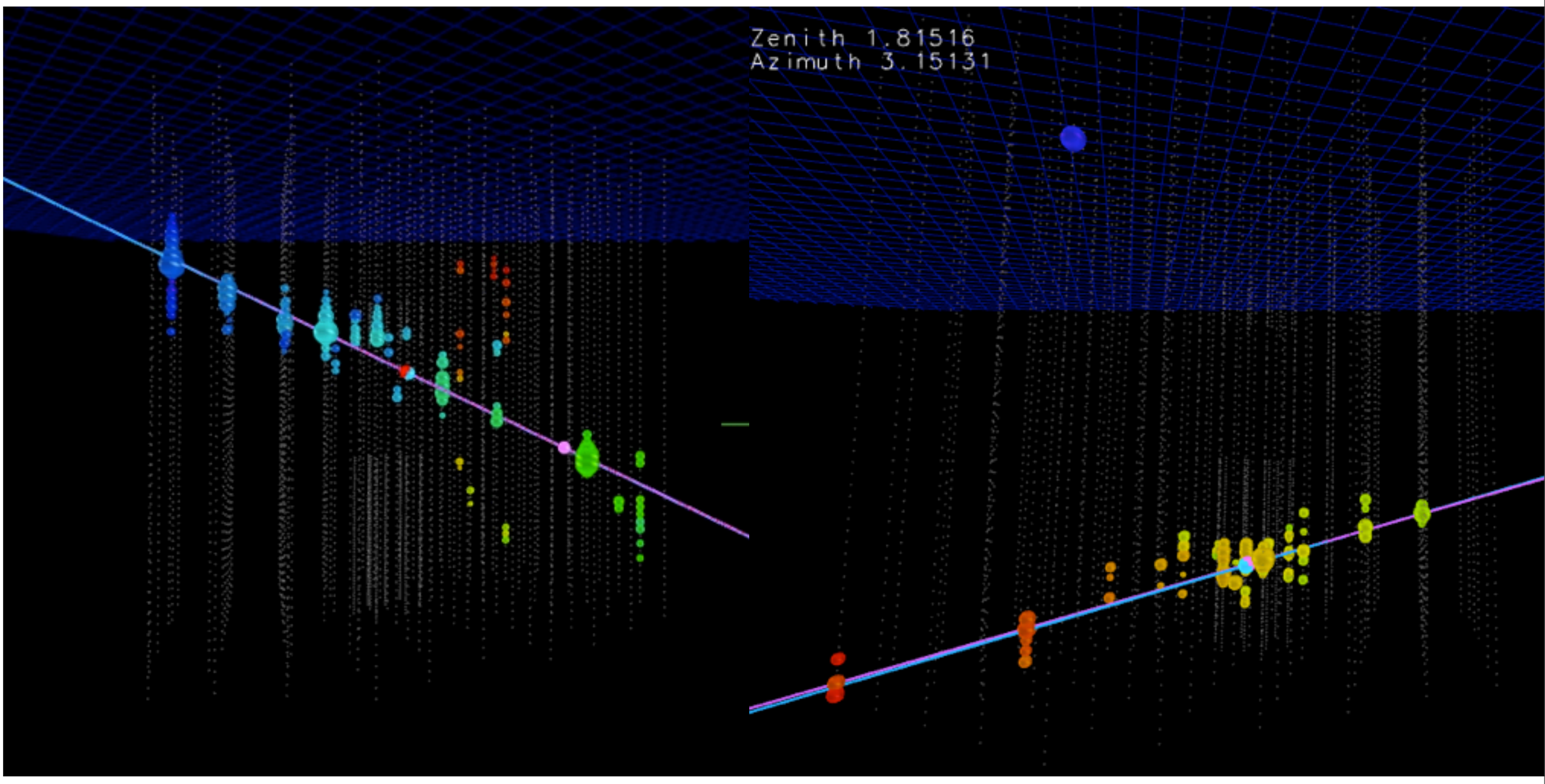
Source: D. Chirkin, UW



Energy Resolution
$\sigma(\log_{10}E) \sim 0.3$

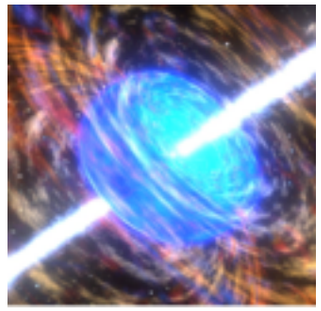
86 String neutrinos



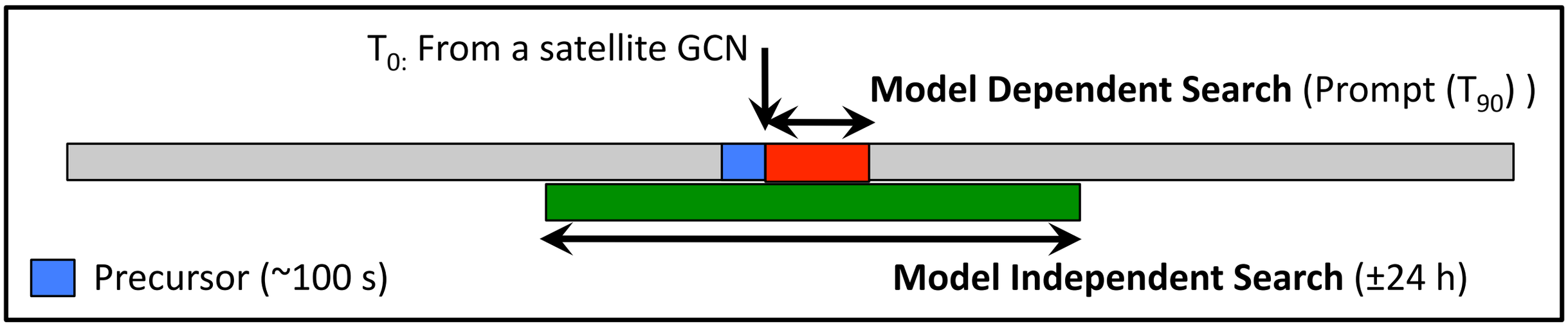


Neutrino events found in online search.
Likely atmospheric neutrinos, our irreducible background

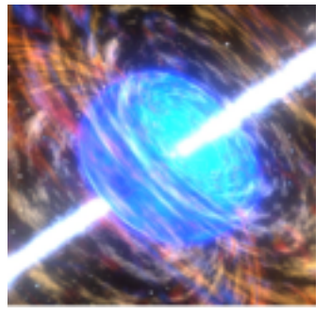
GRB Neutrino Searches



- IceCube performs several searches for neutrinos associated with GRBs.
  - Gamma-ray triggered - stacked searches for all bursts with good IceCube data
    - Model dependent search - optimized for a time window matching observed gamma emission
    - Model independent search - expanding time window around each GRB (+/- 10 seconds → +/- 1 day)
  - Neutrino triggered - alerts to optical observatories
    - See Markus Voge's and Andreas Homeier's presentations
- Combination of spatial and time correlation of neutrino events with GRB yield low background searches

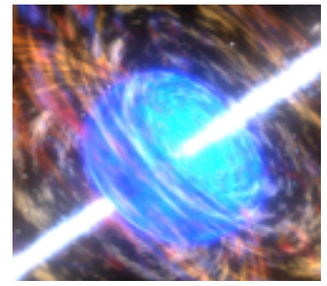


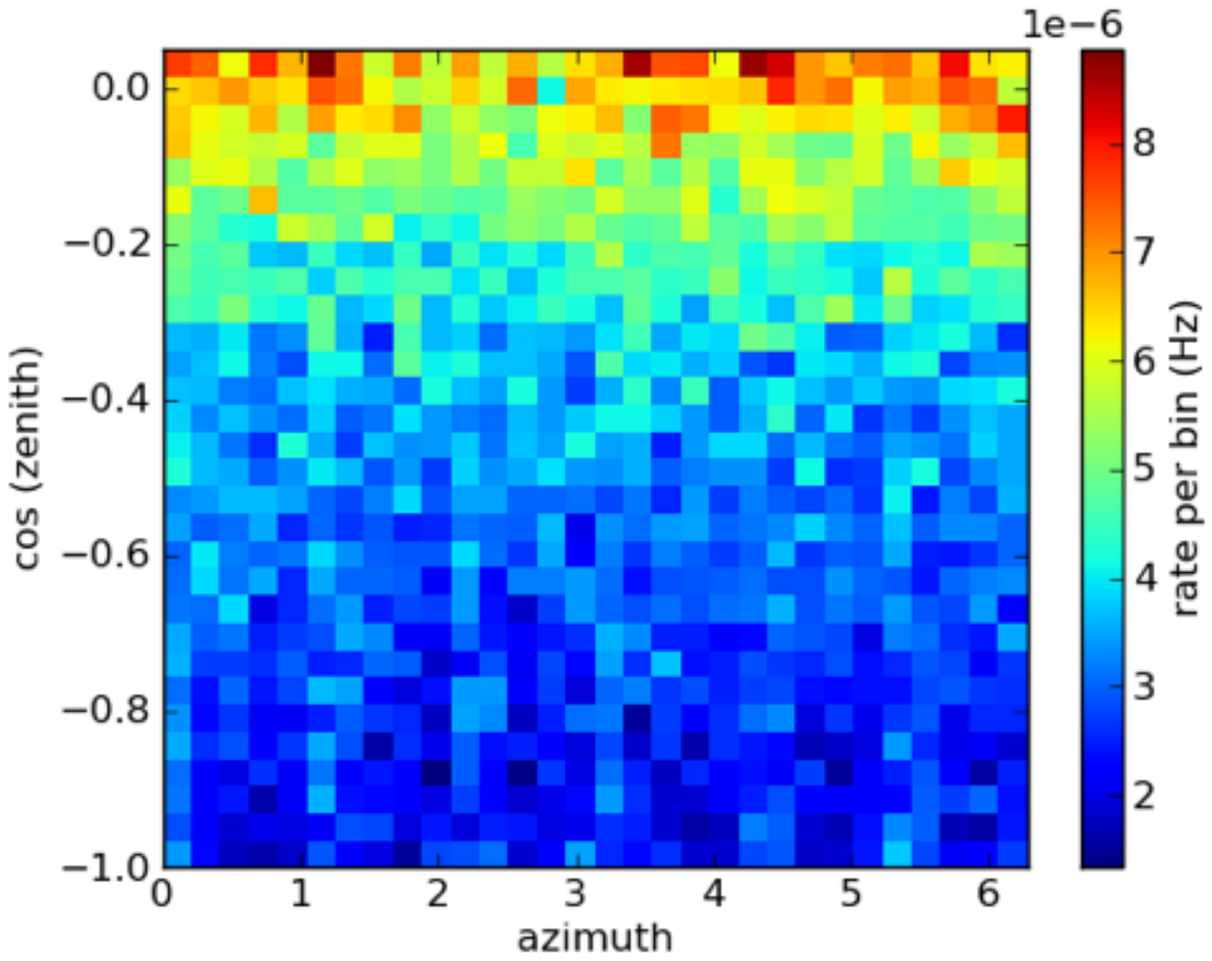
GRB Neutrino Searches



- We perform an unbinned maximum-likelihood search
- Several advantages over a simple binned search:
  - Utilize the expected signal and background spectral differences
  - Poorly measured burst localizations/neutrino directions are handled naturally
- Background PDFs derived from off-time data
- Signal PDF derived from measured gamma-ray data and simulation of neutrino events.
  - Was (IC40+59): Guetta, et al. parameterization of neutrino spectrum based on per-burst measured gamma ray fluence/ spectrum
  - Now(IC86): Generic E-2 input spectrum
  - In general searches generally insensitive to modeled spectrum
- Significance determined by repeatedly time scrambling data

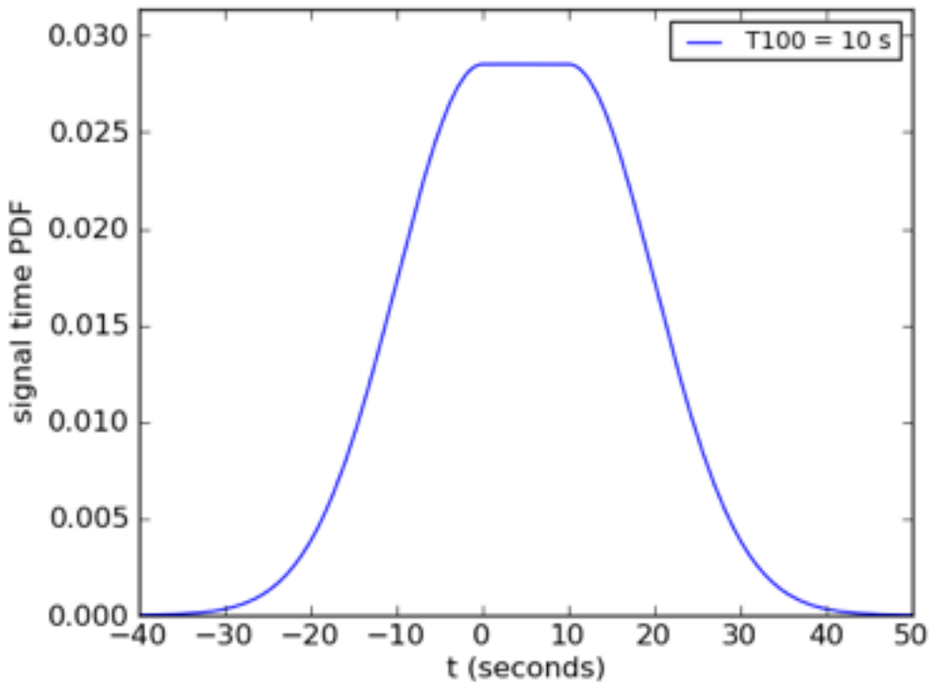
GRB Neutrino search PDFs

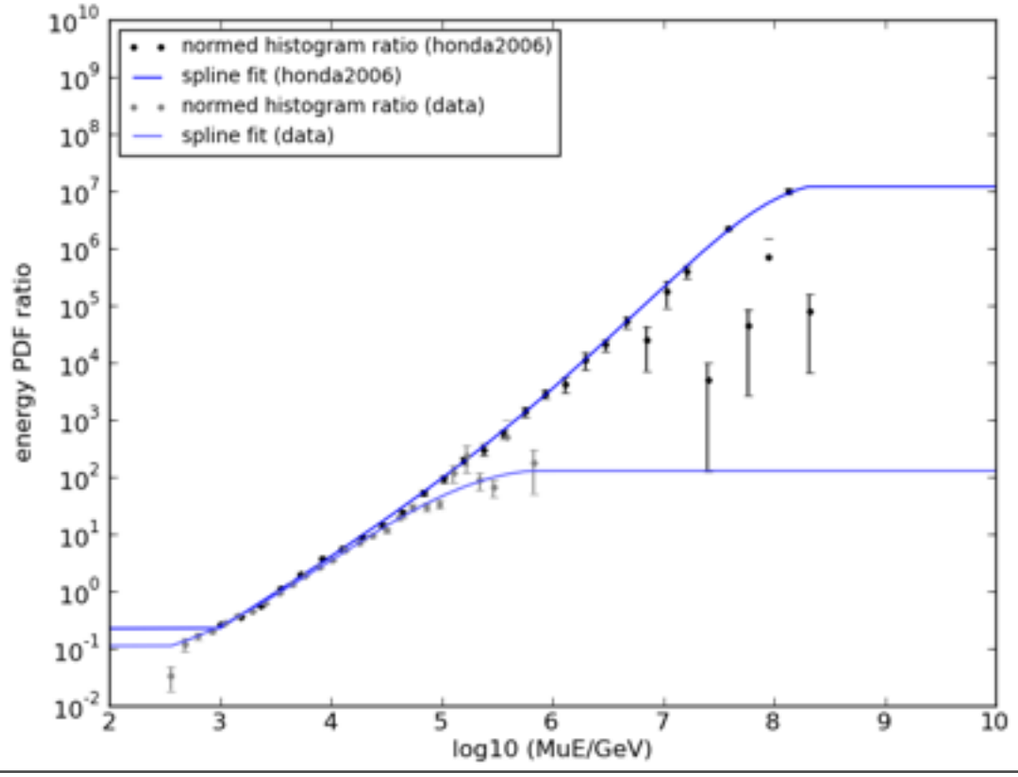




Background space pdf

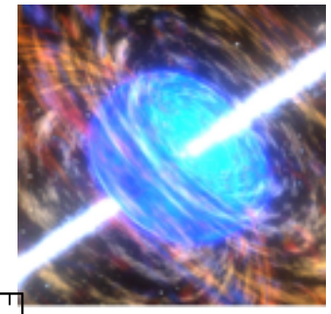
$$PDF_i^{space}(\vec{x}) = \frac{1}{2\pi\sigma_s^2} e^{\frac{(\vec{x}_i - \vec{x}_{GRB})^2}{2\sigma_s^2}}$$



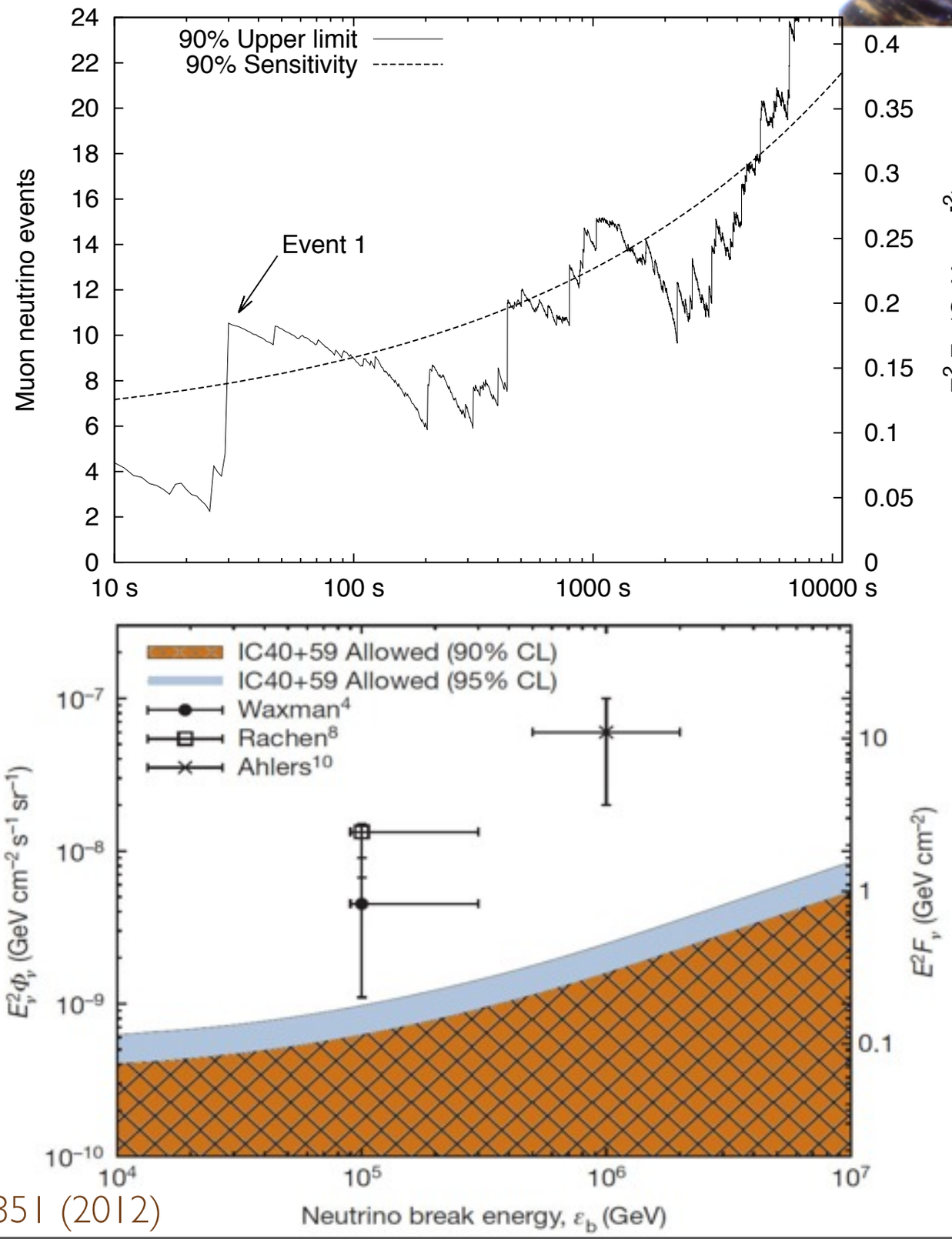


IC86 search pdfs

Search results (IC40+59) - No neutrinos



- Model dependent search
  - Focused on northern hemisphere bursts
  - 0 events found on time and on-source
- Model-independent search
  - Burst from entire sky, timescales +/- 10sec
  - 2 low significance events found. IceTop indicate likely cosmic ray muons
- Models constrained
  - Neutron escape models ruled out



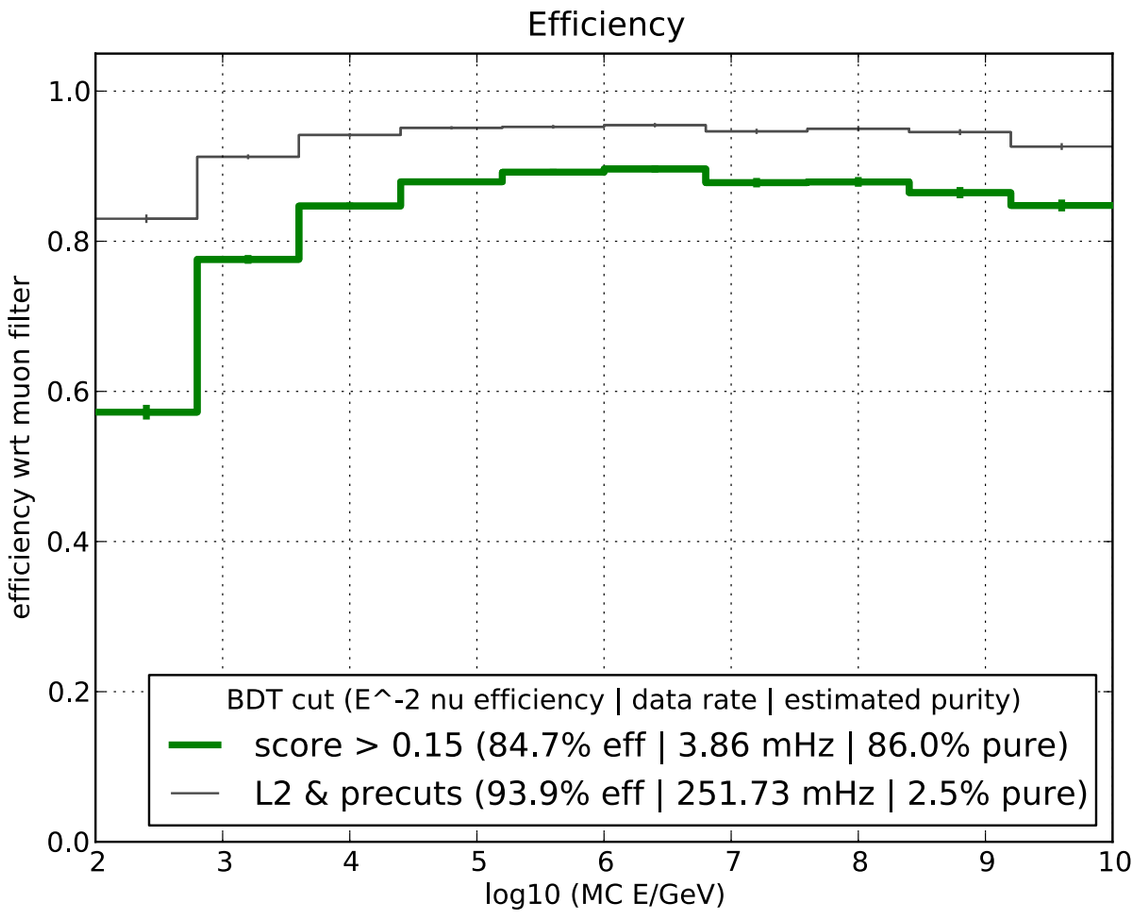
Nature **84**, 351 (2012)

Now what?

- Non-detection of neutrinos has constrained older Fireball internal shock model neutrino predictions
- New set of models, up to ~10 reduction in predicted neutrino fluxes
  - More complete modeling of particle physics that generates neutrinos
- What now for IceCube's searches?
  - Low background search - sensitivity improves linearly with exposure
  - Results from 3 additional years of data available soon
  - Broaden our searches
    - Multiple signal channels
    - All sky
  - (Near) realtime searches for most mature

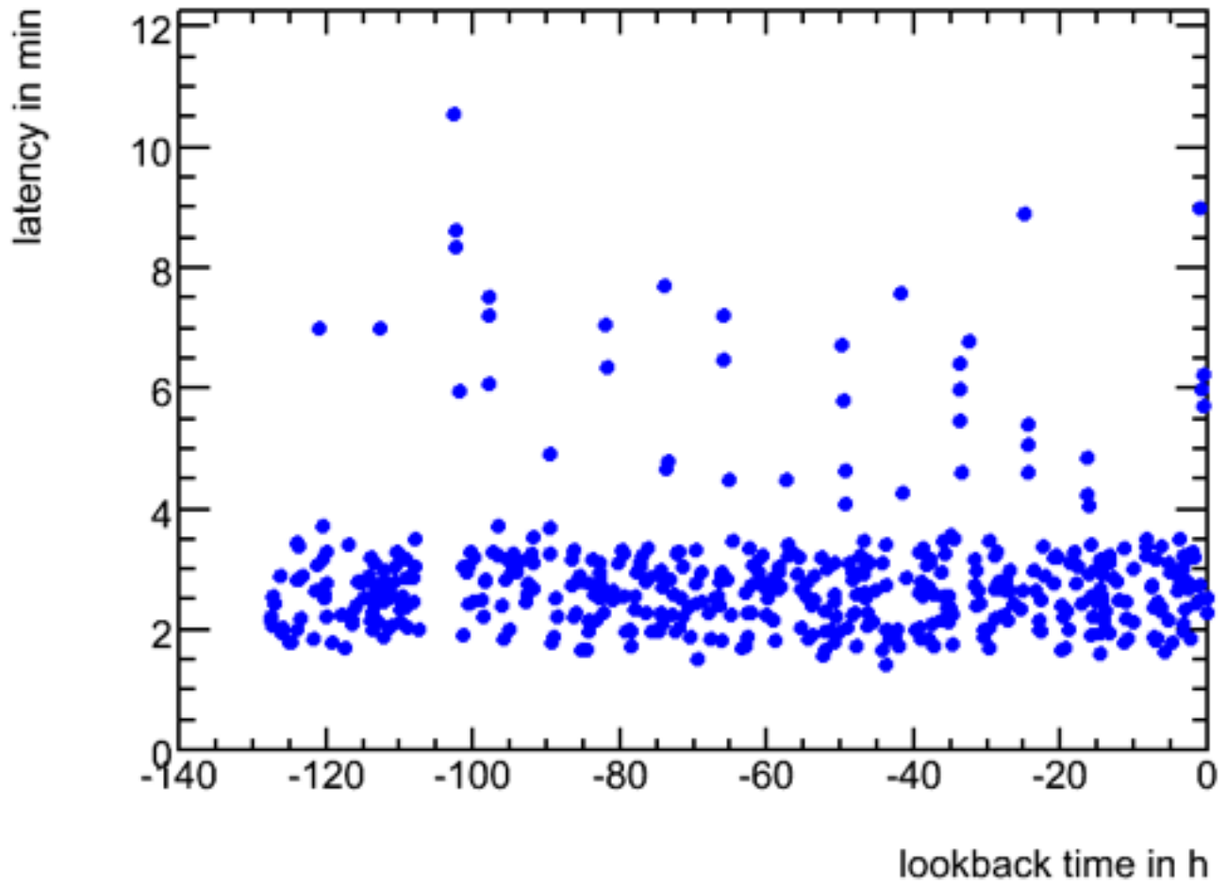
Example

- IC86-2011 GRB analysis
  - Based completely on online neutrino selection
  - OnlineL2 + event quality preselection + BDT cut = neutrinos



Highest efficiency GRB search to date, obtained with values we calculate in realtime ONLINE.

How "Realtime" can we do?



Realtime (online) search latency: time between time-of-alert and event time

- Realtime processing can obtain results within ~few minutes of data being collected
  - Alerts only travel out
- For gamma-ray triggered searches, difficult to get GCN alerts to pole in timely manner for realtime analysis
  - Plan to analyze data once neutrino data arrives in the North (~12-24 hr delay)

Near realtime GRB search

TDRSS

Data arrives in ~12-24 hours

Online Filter

IceCube

Southern Hemisphere

Data Warehouse

Standard Analysis Pipelines

Proceed on ~1 year timescales

Northern Hemisphere

Near-Realtime Analysis Pipeline servers and storage

Triggered by arrival of new data

Neutrino Event Database

GCN Alerts

- Realtime GRB search
- GCN followups for any neutrino detection

Goal: Notify community as quickly as possible when a neutrino/GRB coincidence is found

Tools

- GRBweb - database of GRB data
- IceCube complete - stable detector
- Very low background search
  - Up-going "background" rate is O(0.01) Hz all sky
  - A single event can be a significant discovery.
- Improved search techniques
  - Angular reconstruction improvements - insufficient computing resources at South Pole to apply in some cases
  - Better rejection of multiple muon backgrounds from intelligent event splitting

GRB-web

grbweb.icecube.wisc.edu/?sent=0&date_from=2012%2F04%2F01&date_to=2012%2F12%2F31&searchgrb=Submit

Useful | IceCube | Python | LBNE | JOBS | UMD Administrative | SarahHW | HOME | Google Calendar | Other Bookmarks

grbweb

BETA

Sunday 3rd of February 2013

Home Help

Welcome to grbweb. Use the form below to select a GRB period. Looking for the IceCube version? Click here.

From GCN message date 2012/04/01 (yyyy/mm/dd) to 2012/12/31 (yyyy/mm/dd)

Submit Reset

Select All Unselect All Download selected (txt) Print selected Draw W&B spectrum Draw sky map

GRB		Position			Time			Spectrum							Other				Neutrino Spectrum					
Name	RA	Decl	ERR	T100	UTT	T1	T2	α_γ	β_γ	ε_γ	F_γ	E_{min}	E_{max}	z	T1 GCN	T2 GCN	Light Curve	Num. Circulars	f_ν	$\varepsilon 1$	$\varepsilon 2$	α_ν	β_ν	γ_ν
120401A	58.083	-17.636	**0.0004**	145.69	2012-04-01 05:24:15	-92.97	52.72	1.66	**2.66**	**200**	9.1E-7	0.015	0.15	**2.15**	13186 swiftbat	13186 swiftbat	NO	6	1.18e-15	0.35	3.17	0.34	1.34	3.34
120402A	314.326	19.258	0.05	0	2012-04-02 00:00:00	0	0	**1**	**2**	**1000**	**1.0E-5**	0.015	0.15	**0.5**			NO	4	8.33e-14	0.35	3.17	1	2	4
120402B	223.7	-10.4	10.72	27.652	2012-04-02 16:04:00	-7.46	20.192	1.35	2.44	37.2	3.4E-6	0.01	1	**2.15**	13194 fermigbm	13194 fermigbm	YES	3	2.92e-16	3.07	3.17	0.56	1.65	3.65
120403A	42.458	40.489	**0.0383**	1.4	2012-04-03 01:05:23	0	1.4	1.64	**2.64**	**1000**	1.0E-7	0.015	0.15	**0.5**	13195 swiftbat	13195 swiftbat	NO	4	1.12e-16	0.31	2.10	0.36	1.36	3.36
120403B	55.276	-89.009	0.0006	8.3	2012-04-03 20:33:56	-3	5.3	1.51	**3.51**	182	4.6E-7	0.004	**10**	**2.15**	13207 swiftbat	13207 swiftbat	YES	9	4.28e-16	0.26	3.17	-0.51	1.49	3.49
120404A	235.01	12.885	0.0004	45.76	2012-04-04 12:51:02	-7.31	38.45	1.85	**2.85**	**200**	1.6E-6	0.015	0.15	2.88	13220 swiftbat	13220 swiftbat	NO	23	2.64e-15	0.23	2.57	0.15	1.15	3.15
120410A	159.63	-17	13.5	1.08	2012-04-10 14:02:01	-1.02	0.06	1.05	2.25	205	2.907E-7	0.008	1	**0.5**	GBMDb	GBMDb	NO	1	4.49e-17	2.10	3.26	0.75	2.75	4.75
120411A	38.07	-7.24	13.4	38.91	2012-04-11	0	38.91	1.05	2.25	205	1.464E-6	0.008	1	**2.15**	GBMDb	GBMDb	NO	1	9.16e-16	0.74	3.17	0.75	1.95	3.95

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Outlook

- IceCube neutrino searches from GRB have found no neutrino candidates to date
  - Constrained models
- New generation of GRB models predicts a reduced flux of neutrinos
  - Very low background searches will continue to search
- Next : move to near realtime GRB neutrino searches
  - Provide rapid alert for additional followup in the event of a signal detection.
  - How can we ensure this is the done in the most useful way?

The IceCube Collaboration

International Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
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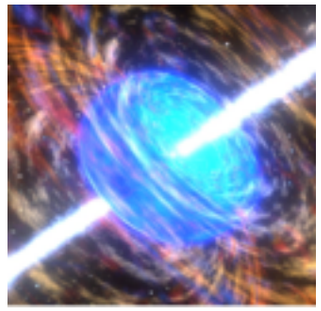

- Backups