Searching for Astrophysical Neutrinos in Coincidence with Gamma Ray Bursts

TeV Particle Astrophysics 2008

Erik Strahler
University of Wisconsin-Madison
For the IceCube Collaboration

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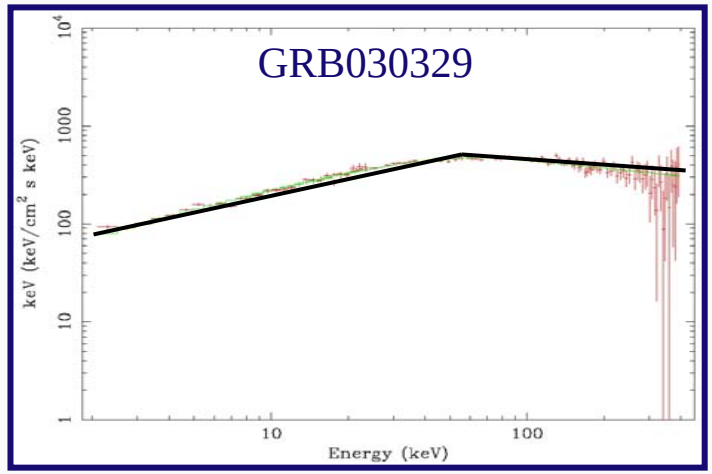
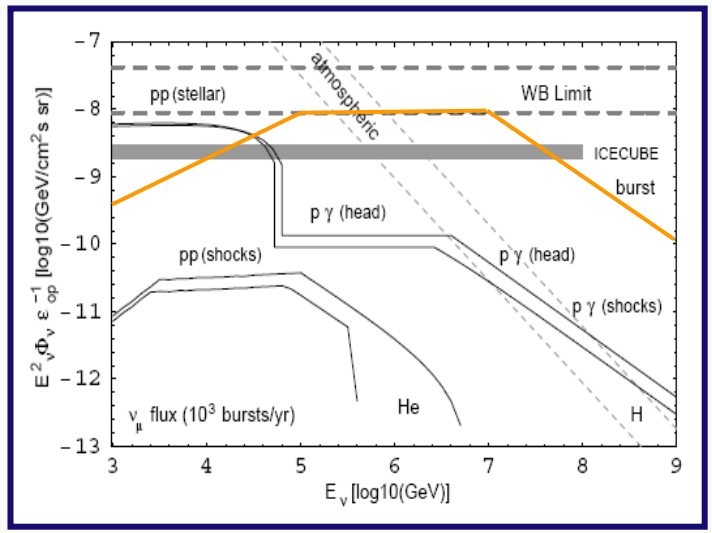
Outline

- Neutrinos from Gamma Ray Bursts
- Detection
- AMANDA-II Analysis
- IceCube Analysis
- Outlook

Neutrinos from GRBs

- Gamma emission from GRBs follows broken power law
- Protons interact with this spectra to produce neutrinos
- Further break at high energy due to pion energy losses



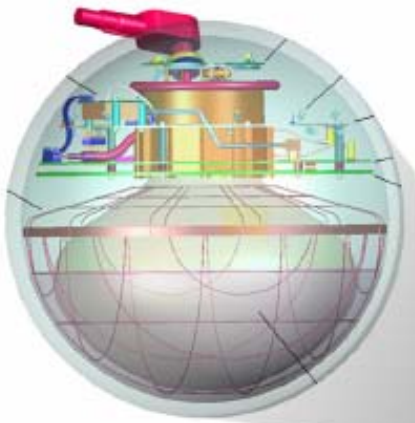


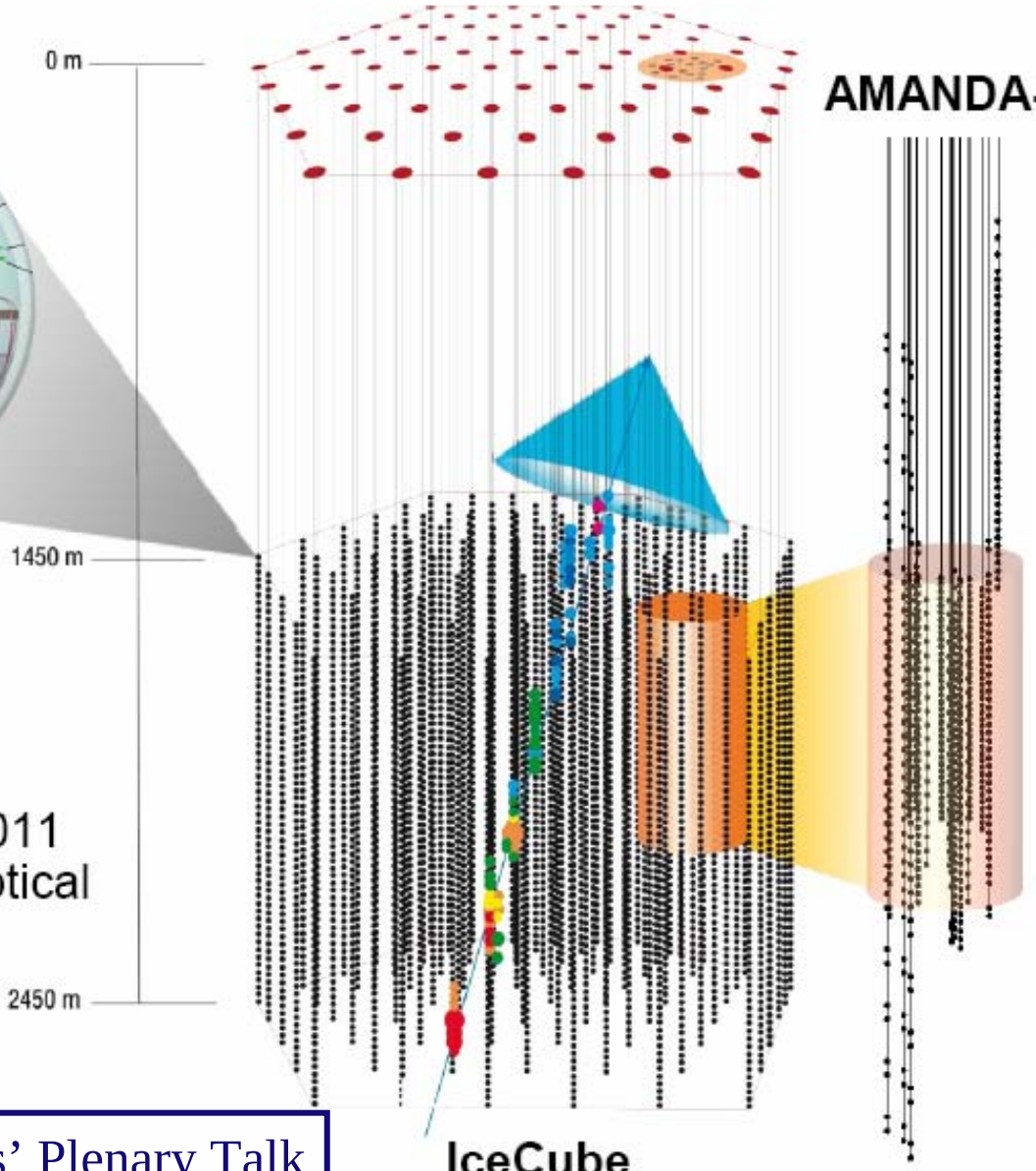
Razzaque, Mészáros, and Waxman, **PRD 68, 083001**

Swift Satellite

- Launched in November 2004
- BAT (Burst Alert Telescope)
  - 1.4 sr field-of-view
    - ⟶ ~100 bursts / yr.
- Slew within 20-75s
- 0.3-5.0 arcsec positioning
- XRT, UVOT
  - Afterglow measurements

IceCube





- 40 of 86 strings complete
- Completion in 2011 (>5000 digital optical modules)

- 19 strings
- 677 optical modules
- Operated 2000-2007
- Now integrated with IceCube

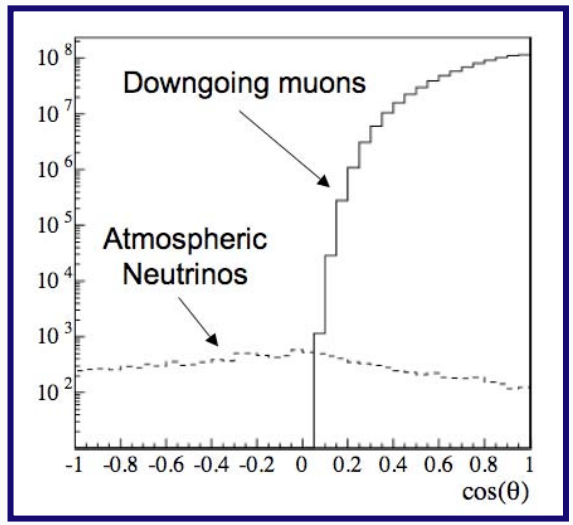
See Erik Blaufuss' Plenary Talk

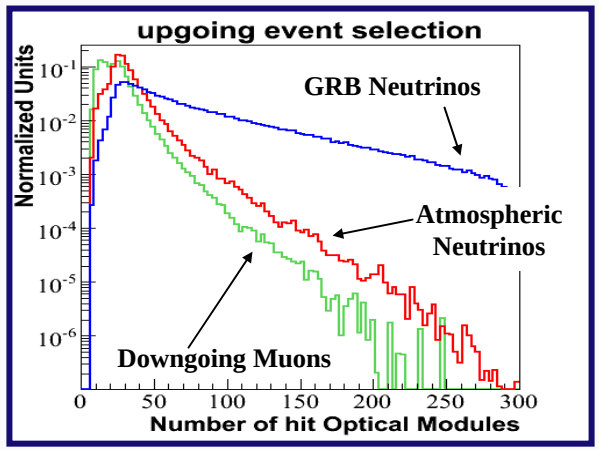
AMANDA-II Analysis

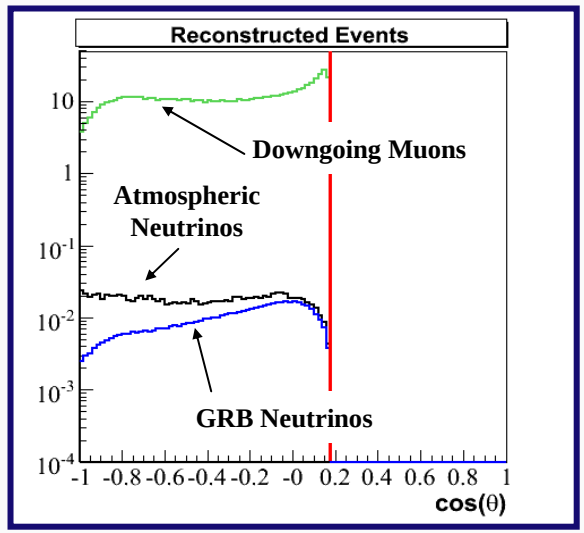
- Previous searches for neutrino-induced muons (Achterberg A. et al. 2008, ApJ, **674**, 357) and cascades (Achterberg A. et al. 2007, ApJ, **664**, 397) saw no events and set upper limits on GRB neutrino fluxes
- 2005-2006 data sample contains 85 northern hemisphere bursts that pass all detector stability criteria.
- Largest sample in the post-BATSE era.

Detection Challenges

- Down-going muons from CR showers misreconstructed as up-going
  - Particularly coincident muons from independent showers
  - Must reject with tight quality cuts
- Up-going atmospheric neutrinos from CR showers on other side of Earth
  - Softer energy spectrum than GRB signal
  - Isotropically distributed

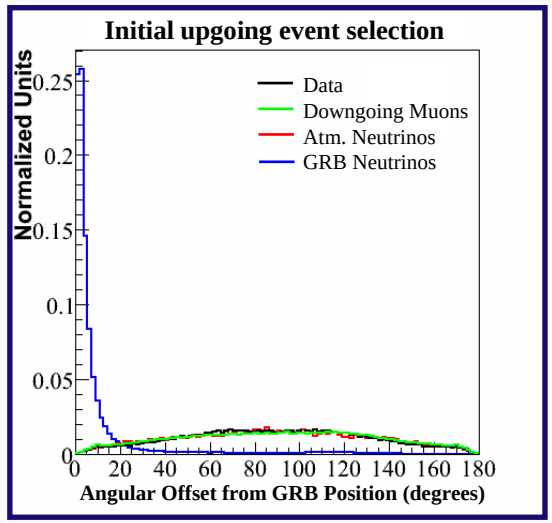


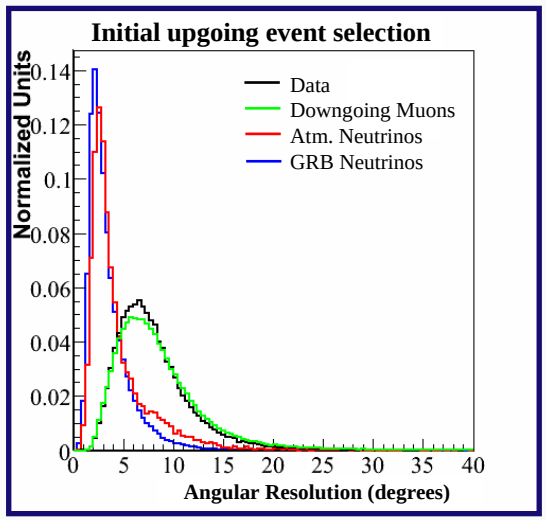


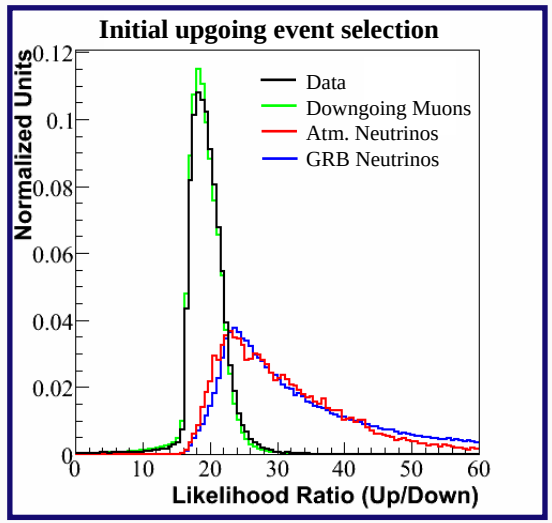


Event Selection

- Angular offset from GRB position
- Angular resolution of tracks
- Timing coincidence with gamma emission
- Likelihood ratio of upgoing reconstruction vs. downgoing reconstruction

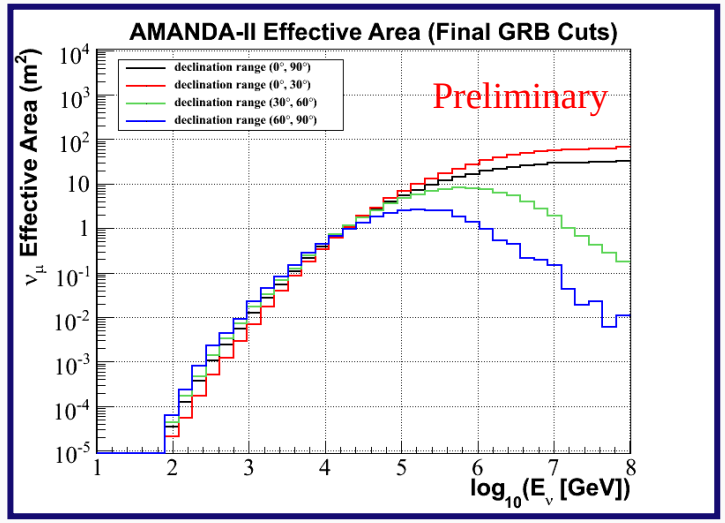


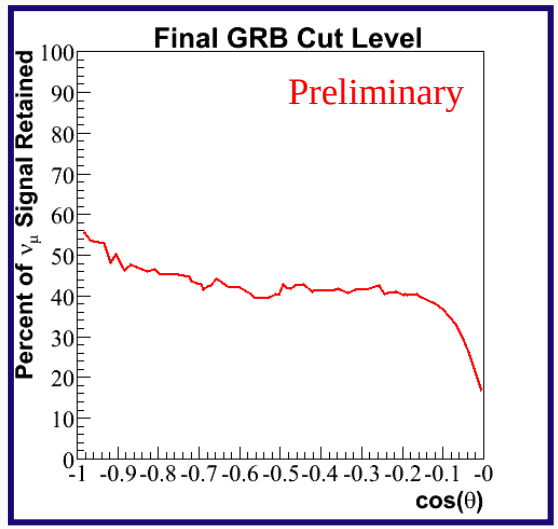




Cut Optimization

- Optimize for Discovery
  - 5σ observation in 90% of experiments
- Search for best cuts for summed contribution of all GRBs
  - Tight cuts to remove the aggregate background





Results

Expected

	Upgoing filter	Final Cut Level
2005-2006 data	1703.9	**0.00087**
2005-2006 GRB signal	0.501	**0.166**

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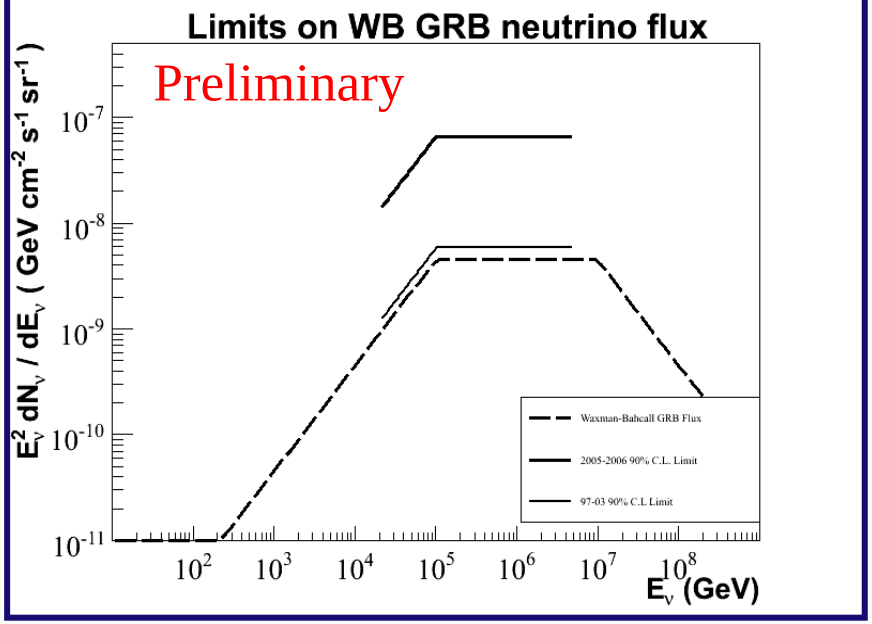
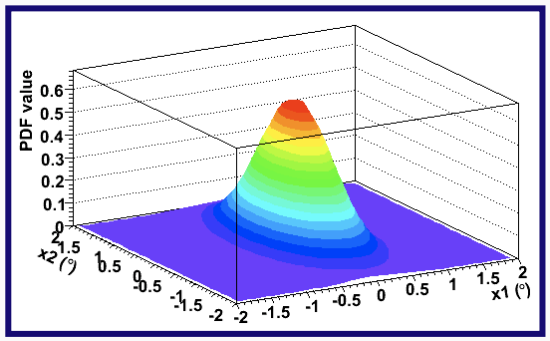
Limit

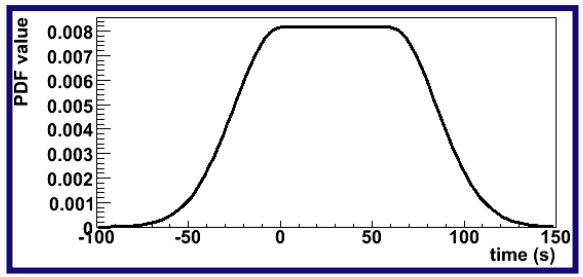


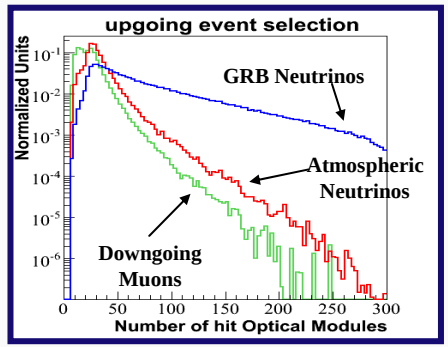
05-06 Limit: **14.7 * WB flux**

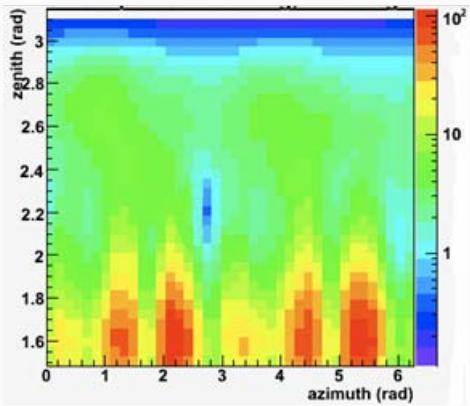
Preliminary Combined Limit: 1.1 * WB flux

Likelihood Method









Background PDF from data

Signal PDF: $S(\vec{x}_i, t, \tilde{E}) = \mathrm{PDF}_i^S(\vec{x}) \times \mathrm{PDF}_i^T(t) \times \mathrm{PDF}_i^E(\tilde{E})$

Likelihood function: $\ln(\mathcal{L}) = -n_s - n_b + \sum_{i=1}^{N} \ln(n_s S(\vec{x}_i) + n_b B(\vec{x}_i))$

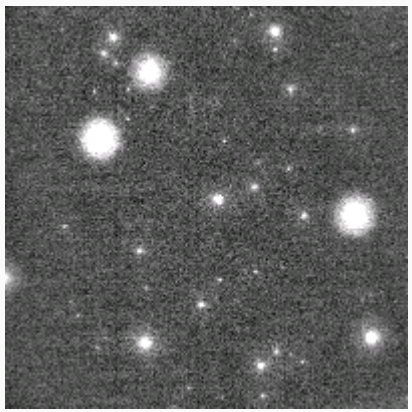
Null hypothesis: $\ln(\mathcal{L}_0) = -n_b + \sum_{i=1}^{N} \ln(n_b B(\vec{x}_i))$

Likelihood Ratio: $\ln(\mathcal{R}) = \ln\left(\frac{\mathcal{L}}{\mathcal{L}_0}\right) = -n_s + \sum_{i=1}^{N} \ln\left(\frac{n_s S_i}{n_b B_i} + 1\right)$

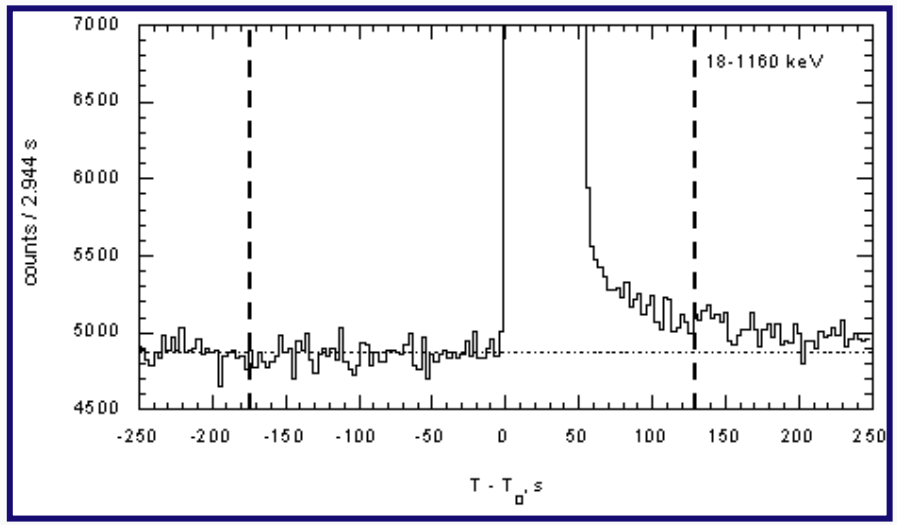
Maximize LLH ratio by varying n_s

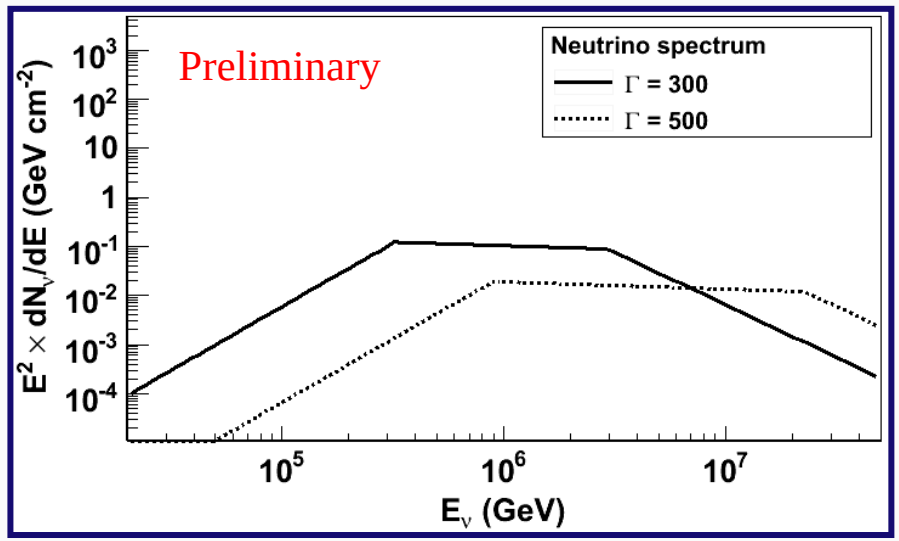
GRB080319B

- Extremely bright burst
  - Visible to naked eye



Expect 0.1 events in IceCube





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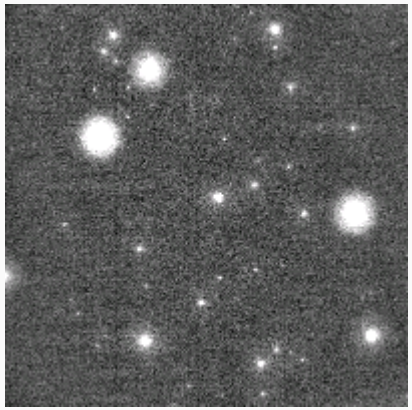
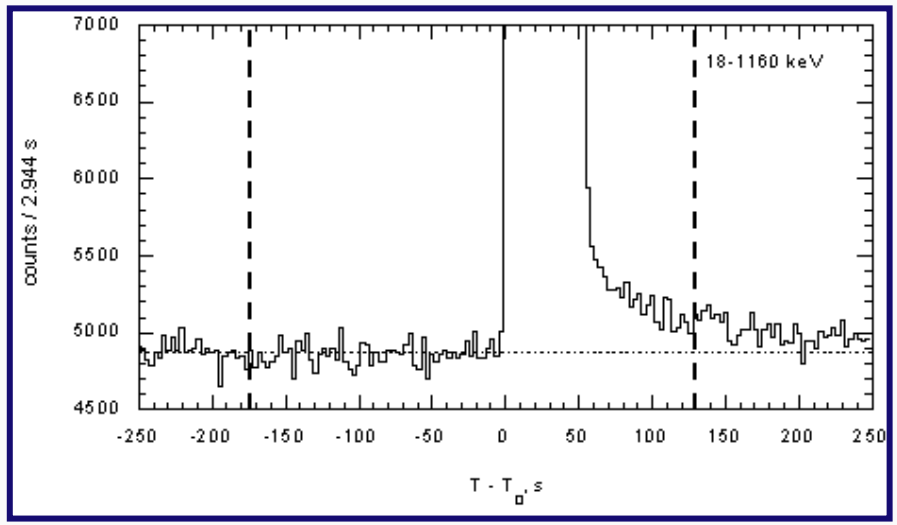
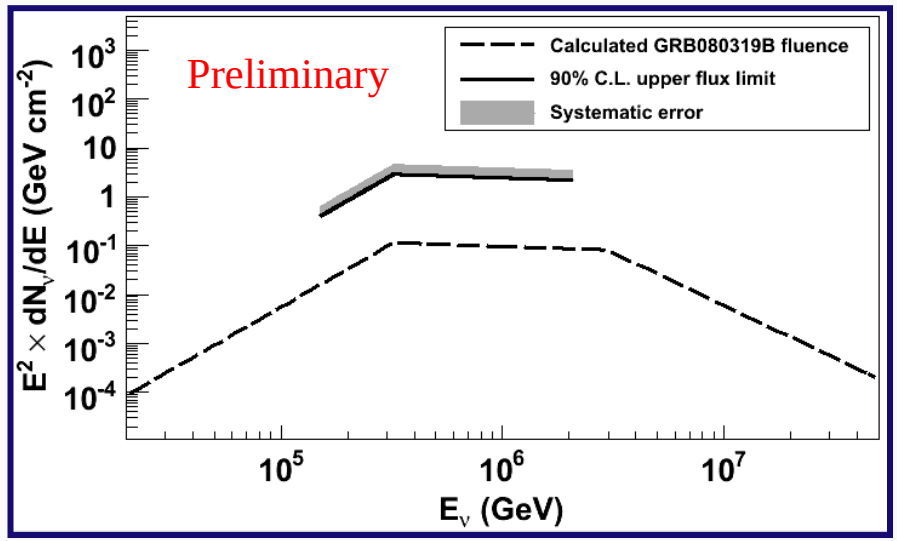




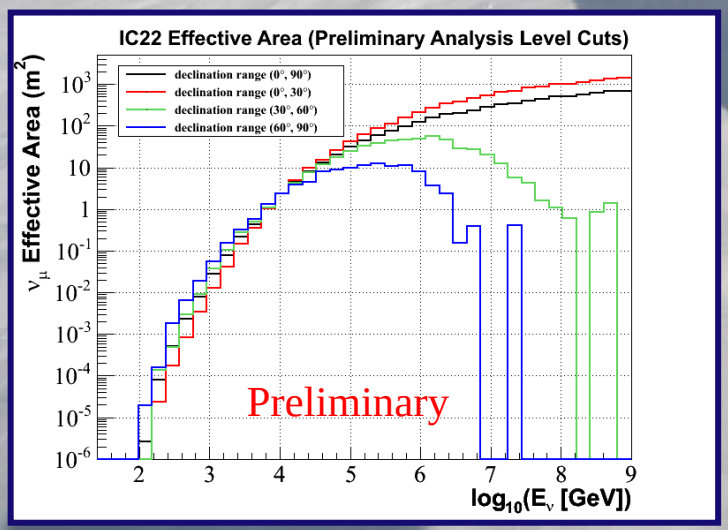


data consistant with background only hypothesis

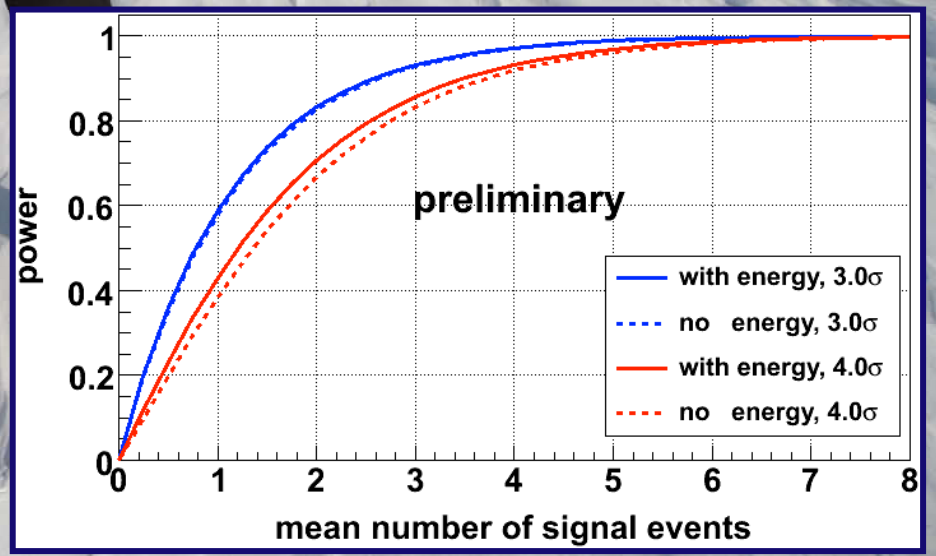
Limit: 25.2 * Fireball Model Prediction

GRBs with IceCube

- Currently analysing 22 string configuration
- 43 bursts from Swift, AGILE, others.
- Unbinned Method, incorporating energy information



Sensitivity: 1.8 * WB flux

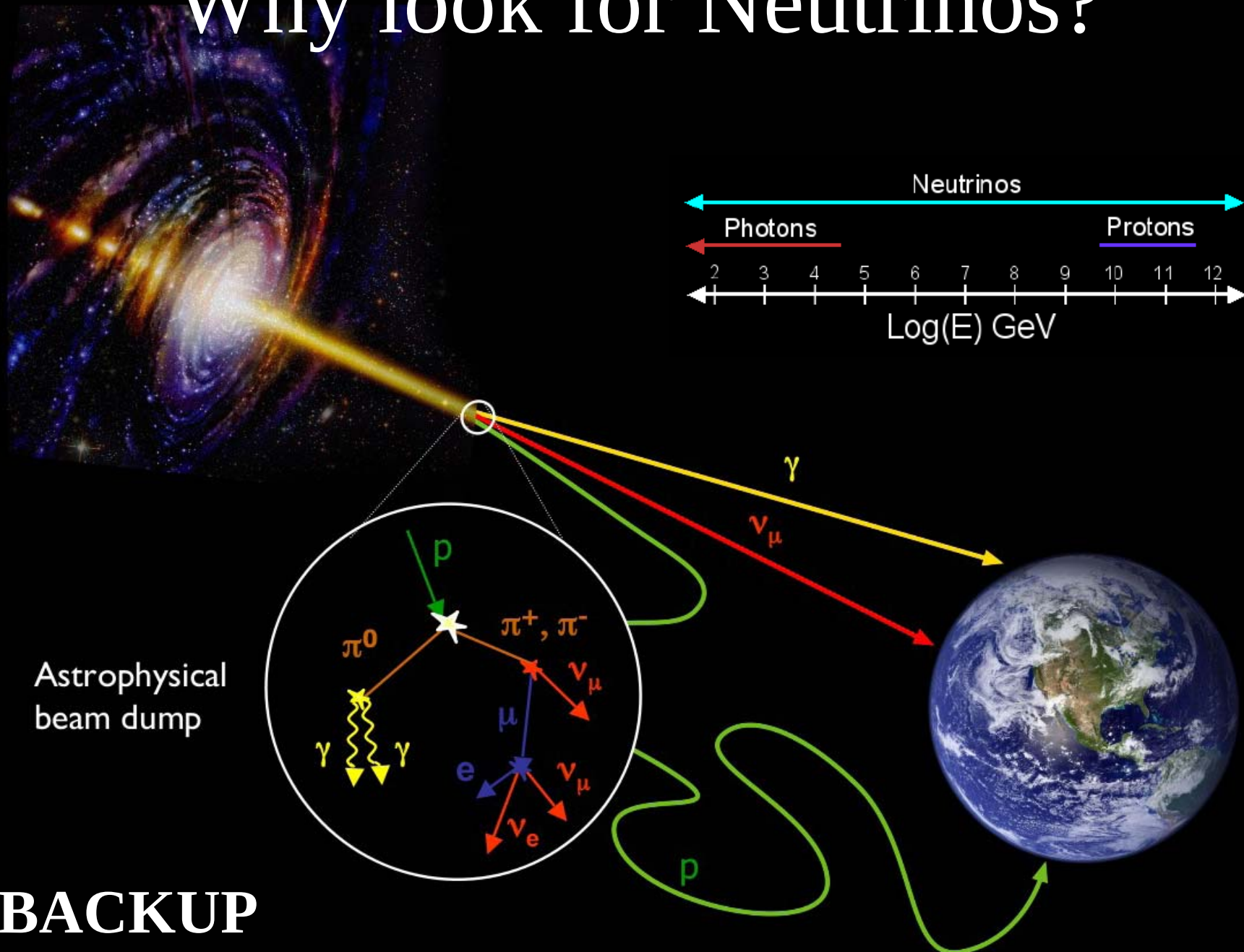


Conclusions and Outlook

- No neutrinos from GRBs yet
- 22 String IceCube analysis nearing completion
- 40 string IceCube configuration online from April 2008
  - Already as large as full detector on long axis
  - GRB analysis framework in develpoment
  - Data run complete in April 2009

- Fermi GST adds significant observation opportunities
- 80 string IceCube only a few years away. Expect 1-10 neutrinos per year with full detector
- See signal or constrain Waxman-Bahcall flux very soon!

Why look for Neutrinos?



BACKUP