Searches for Neutrinos from GRBs with IceCube

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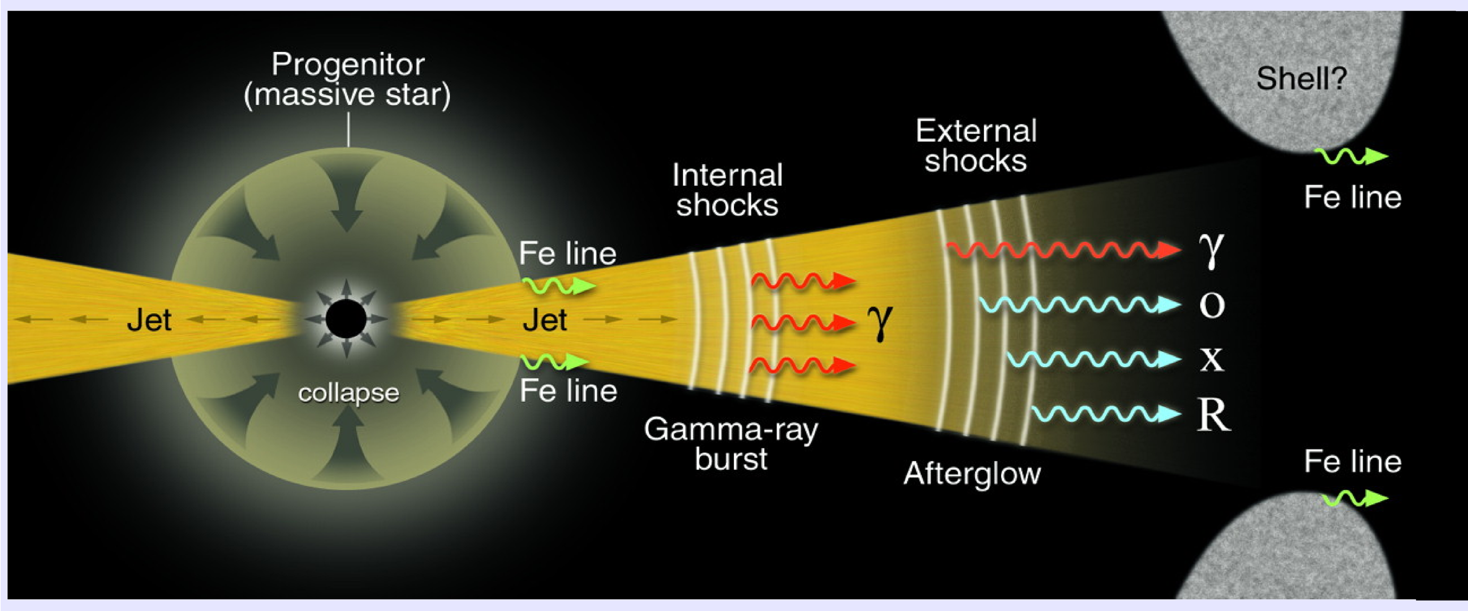
High energy neutrinos from Gamma-Ray Bursts (GRBs)



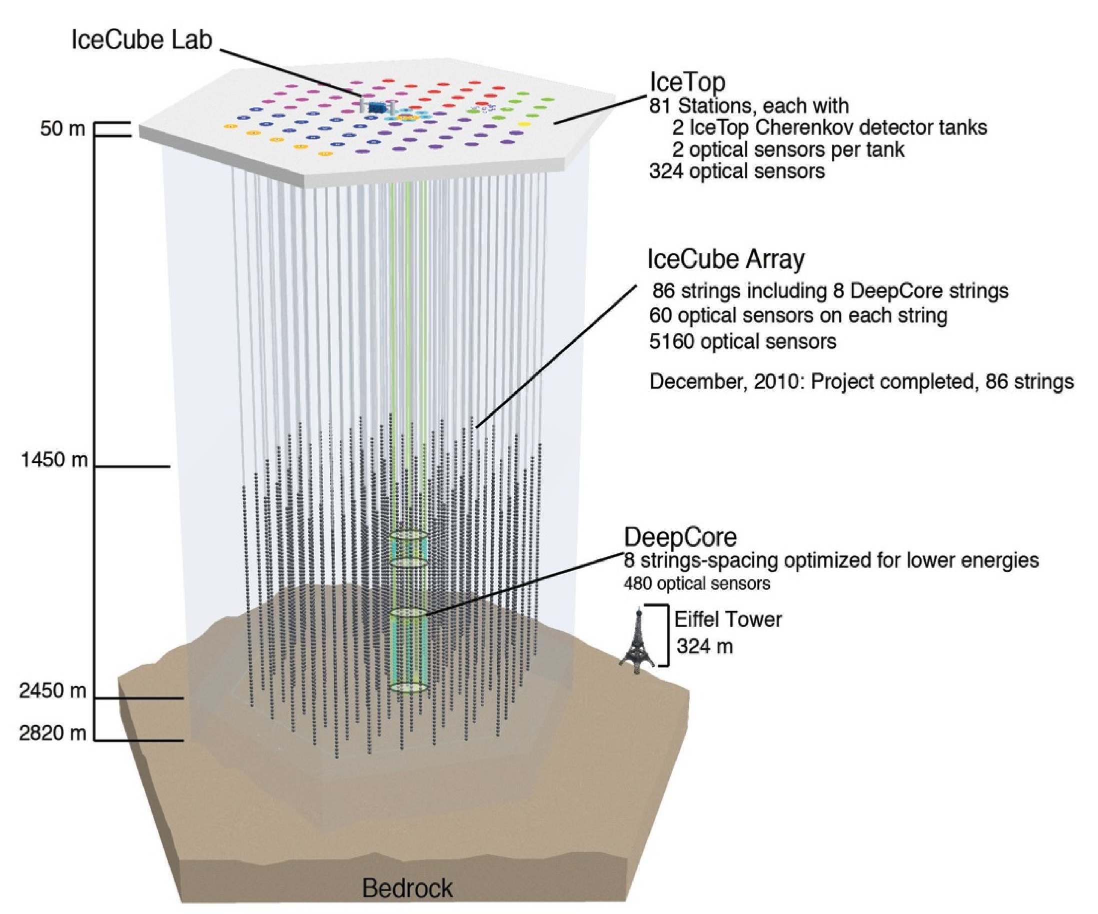
Fireball shock model [1]

Matter is ejected in a relativistic jet. Internal and external shocks accelerate charged particles producing electromagnetic emission at various wavelengths in synchrotron and inverse Compton processes.

GRBs are one of the leading candidates for the source of the highest energy cosmic rays. Protons accelerated along with the electrons in GRB would interact with the ambient photon field producing Δ resonances. Neutrinos are produced in the decay chain of the Δ particle, and their detection would be definitive evidence for proton acceleration in the GRB fireball. With no neutrino candidates found in 2 years of data, neutrino flux upper limits from GRBs are found, and these results interpreted in terms of GRBs as the source of the highest energy cosmic rays.

$$p+\gamma\rightarrow\Delta^{+}\rightarrow n+\pi^{+} \qquad \pi^{+}\rightarrow\mu^{+}+\nu_{\mu} \qquad \mu^{+}\rightarrow e^{+}+\nu_{e}+\overline{\nu}_{\mu}$$

IceCube



- $1 km^3$-scale neutrino detector in the Antarctic ice
- Construction finished in December, 2010
- Cherenkov light from secondary charged particles is detected 5160 Digital optical modules
- Energy threshold: ~ 100 GeV
- Results presented here were obtained with the 40-string and 59-string configuration from 2 years of operation (2008-2010)

GRB Neutrino Searches in IceCube

IceCube performs two independent searches for neutrinos with strong spatial and temporal correlation with reported GRB positions [2]. Candidate event energies are considered for additional rejection of the irreducible atmospheric neutrino background.

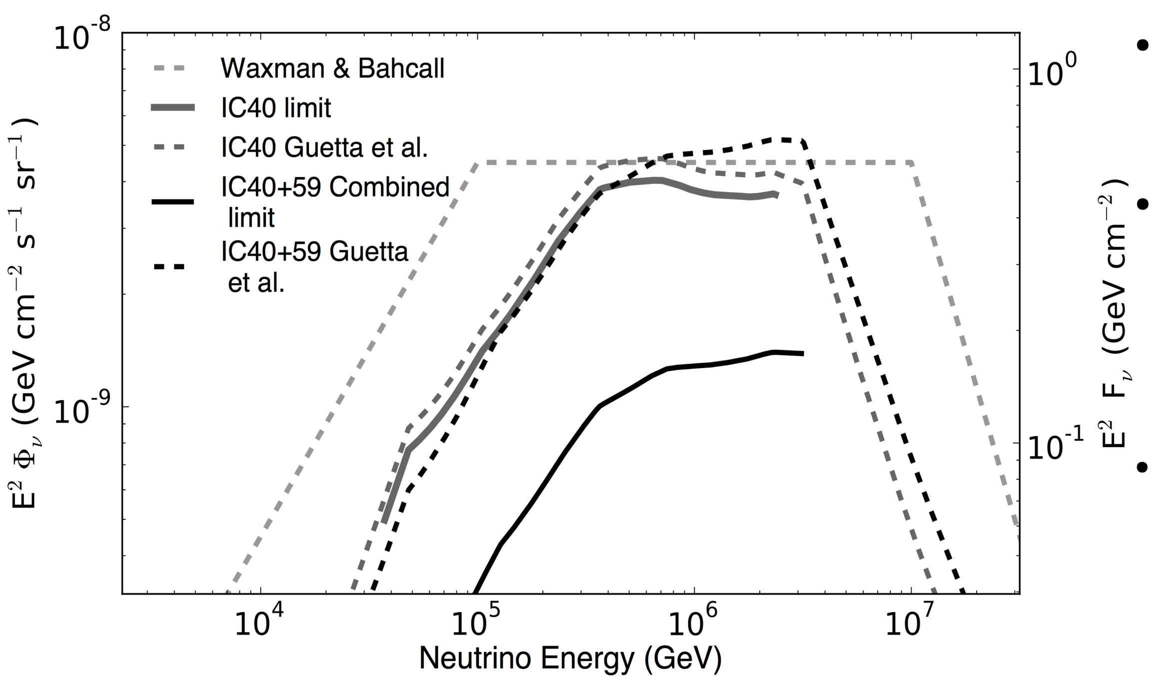
Model Dependent Search

- Designed to search for neutrinos promptly produced in coincidence with the gamma rays
- Utilizes an unbinned maximum likelihood search to differentiate signal from irreducible background
- Optimized to high energy neutrino spectrum modeled by pγ interactions[5,6]

Model-Independent Search

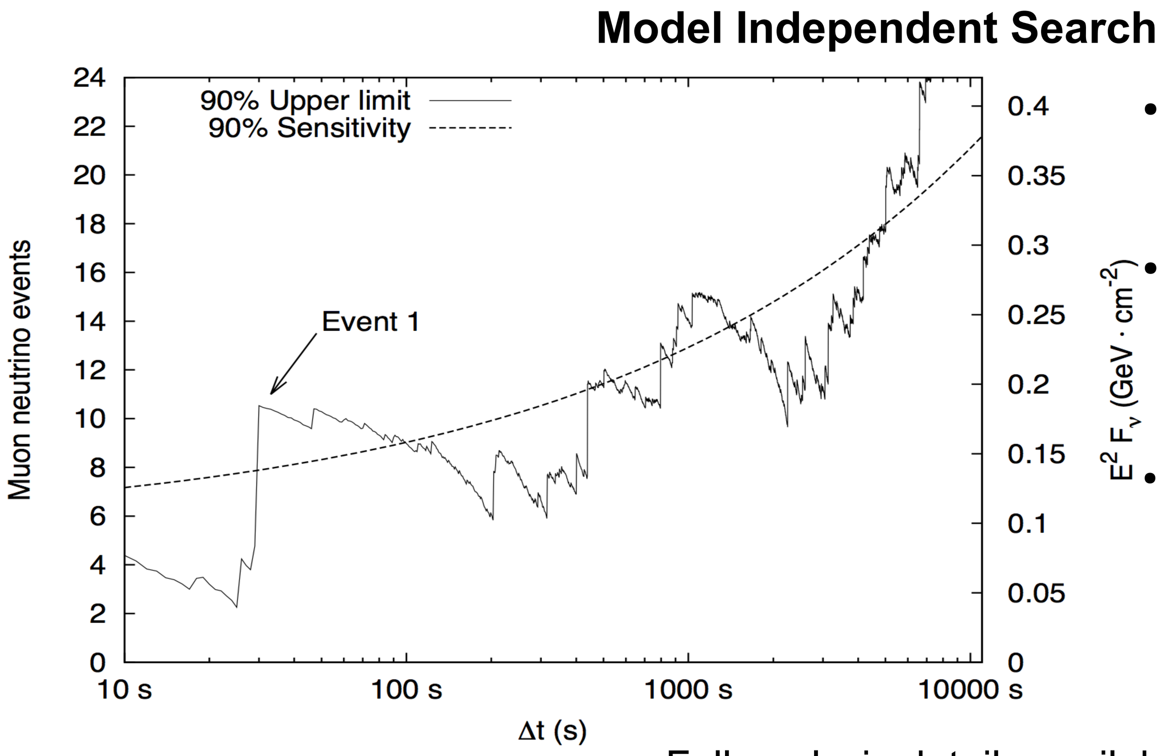
- Search for any neutrino emission from GRB in expanding time window about GRB trigger, ±10 seconds to ±1 day.
- Perform minimal cuts to reconstructed events, use a weighted analysis[3], giving higher weights to strong neutrino candidates
- Optimized for more generic E^{-2} neutrino spectrum

Model Dependent Search Results



- GRB catalog:
  - IC40: 117 northern sky GRBs[4]
  - IC59: 98 northern sky GRBs
- The neutrino flux predictions calculated using observed gamma-ray spectra and normalized to gamma-ray fluence[5,6].
  - 8.4 signal events predicted by model in stacked GRB sample
- No observed events in coincidence with GRBs yields limit of 0.27 modeled flux

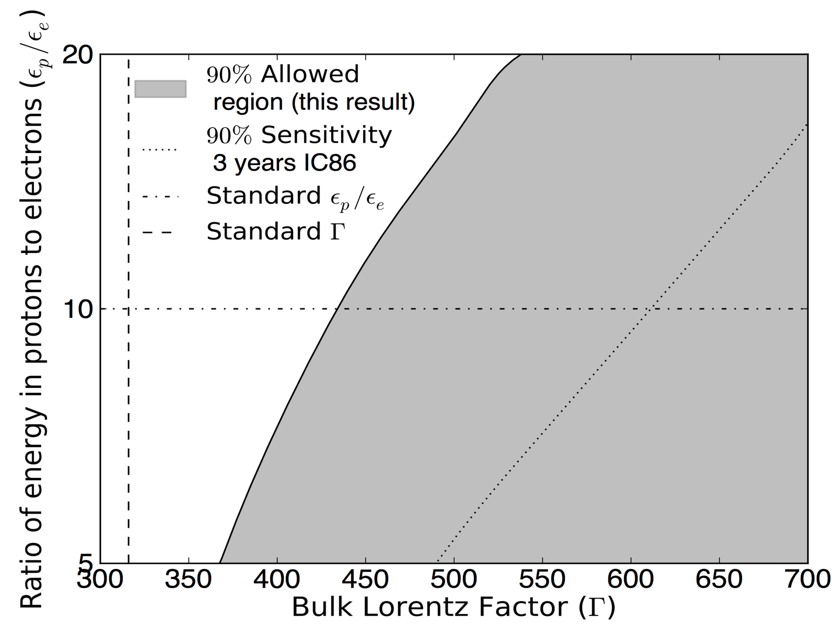
Model Independent Search Results



- GRB catalog:
  - IC40: 117 northern sky GRBs[4]
  - IC59: 190 all sky GRBs
- Expected number of -like events for all considered time windows
  - Event at Δt = 30 s consistent with background cosmic ray event.
- No observed excess of events in coincidence with GRBs yields 90% flux upper limit, shown for all time windows
  - Good agreement for short durations with model dependent search results

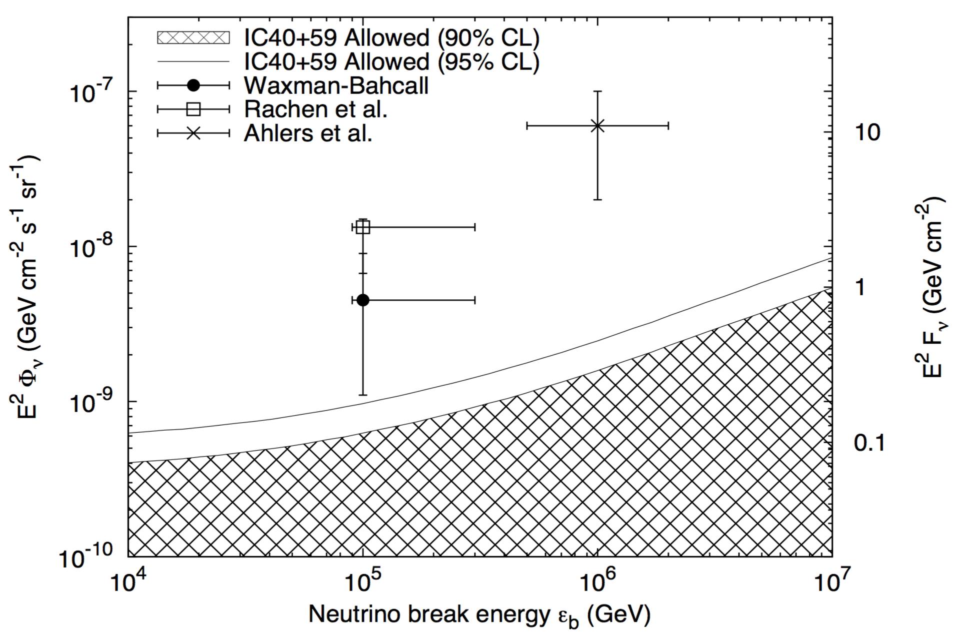
Full analysis details available here [7]

Constraints on GRB fireballs



- Two modeled variables, the average fireball bulk Lorentz factor, Γ, and the ratio of energy in protons to electrons $\varepsilon_p / \varepsilon_e$ were varied yielding allowed regions for this result and sensitivity for 3yr of data from IC86

- Decreasing the energy deposited in protons $\varepsilon_p / \varepsilon_e$ directly decreases the neutrino flux.
- An increase in Γ leads to an increase of the proton energy threshold for pion production in the observer frame reducing the neutrino flux.



- Shown are the allowed regions of neutrino flux vs. the neutrino break energy (ε_b) in comparison to model predictions with estimated uncertainties. [1, 8, 9, 10]

- Neutrino break energy is related to fireball bulk Lorentz factor (ε_b Γ^2), with models assuming $\Gamma \approx 300$.
- Limits exclude all tested models with standard parameters and uncertainties.
- Allowed parameter regions favors low density of high energy protons or low efficiency for neutrino production

With no high energy neutrinos candidates found in coincidence with observed GRBs, neutrino flux limits are found. These limits place constraints on current models that produce the highest energy cosmic rays in GRBs, suggesting that the proton density on GRB fireballs is substantially below the level required to explain the observed flux of the highest energy cosmic rays, or the physics of GRB shocks is significantly different from what is included in current models.

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