Results of Searches for Muon Neutrinos from Gamma-Ray Bursts with IC-22

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Overview

- Data Sample
- Signal Fluxes
- Event Selection
- Unbinned Search
- Systematics
- Upper Limits
- Paper Status
IC22 Data Sample

- **41** high quality northern hemisphere bursts
- Filtered to L3
- Use complete year for background rejection
  - Blind runs containing GRB triggers
  - Yields good statistics (~77M events)
  - 269 days livetime in off-time data
- Bursts windows taken from the Swift “T100”s
  - Conservative
  - Easier than trying to figure out T90 information + padding
  - Total ontime: 4961.3s
Signal

- **Prompt Emission**
  - From Waxman-Bahcall model, using measured parameters for individual bursts

- **Precursor Emission**
  - Using Razzaque et al. model
  - 100s emission immediately preceding prompt phase

- **Generic Wide Window Search**
  - -1 to +3 hrs surrounding trigger
  - $E^{-2}$ energy spectrum

Note: flux shown is at source
Invididual Spectra

![Graph showing individual spectra and their characteristics. The x-axis represents energy (GeV) and the y-axis represents the product of energy squared and differential number of events per energy (GeV cm^-2). The graph includes lines for 41 individual bursts, the sum of 41 individual bursts, the average WB burst, and the sum of 41 WB bursts.](image)
Unbinned Event Selection

• Same as IC-22 Unbinned Point Source Search
  – ~5000 neutrino candidates all-sky
  – >90% purity
Binned Event Selection

- Support Vector Machine containing event variables of interest
  - Single cut for all GRBS
  - Tightened to avoid boundary

- Space Angle cut on a per burst basis
  - Retaining 75% of signal neutrinos
  - Angular resolution is $\theta/\phi$ dependent
Important Parameters

Binned search slightly better
PSF due to optimized event selection for individual GRBs
Effective Area (unbinned)
Likelihood Method

Signal PDF: \( S(\vec{x}_i, t, \vec{E}) = \text{PDF}^S_i(\vec{x}) \times \text{PDF}^T_i(t) \times \text{PDF}^E_i(\vec{E}) \)

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

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 \( n_s \)
Test Statistic Distribution

- $10^8$ Background only trials to determine NULL distribution
Prompt Sensitivity

- Unbinned is about factor 1.7 better than binned at 5σ
IC-22 Results

- In all windows the test statistic is consistent with the null hypothesis.
- Checks with looser cuts reveal no signal-like events.
- For binned search, no events survive final cuts in the on-time window.
Systematics

- **Ice Properties**
  - Same method as GRB080319B analysis

- **DOM efficiency**
  - Generate MC over range of efficiencies to determine effect

- **Neutrino and Muon Propagation**

- ** Variation in Background Rate**
Upper Limits

- **Prompt Emission**
  - $3.7 \times 10^{-3}$ erg cm$^{-2}$ (72 TeV – 6.5 PeV)

- **Precursor Emission**
  - $1.16 \times 10^{-3}$ erg cm$^{-2}$ (2.2 TeV – 55 TeV)

- **Wide Window**
  - $2.7 \times 10^{-3}$ erg cm$^{-2}$ (3 TeV – 2.8 PeV)
Paper Status

- Written and in version 0.3
- In GRB Working Group under review
- Hope to send to collaboration soon after meeting