29th International Cosmic Ray Conference Pune (2005) **5**, 119–122

Neutrino-Induced Cascades From GRBs With AMANDA-II

B. Hughey[a] and I. Taboada[b] for the IceCube Collaboration
(a) Physics Dept. University of Wisconsin. Madison, WI 53706, USA
(b) Physics Dept. University of California. Berkeley, CA 94720, USA
Presenter: Rodin Porrata (brennan.hughey@icecube.wisc.edu), usa-hughey-B-abs1-og25-oral

Using AMANDA-II we have performed a search for ν-induced cascades in coincidence with 73 bursts reported by BATSE in 2000. Background is greatly suppressed by the BATSE temporal constraint. No evidence of neutrinos was found. We set a limit on a WB-like spectrum, $A_{90}^{\mathrm{all\ flavors}} = 9.5\times10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}. The determination of systematic uncertainties is in progress, and the limit will be somewhat weakened once these uncertainties are taken into account. We are also conducting a rolling time-window search for ν-induced cascades consistent with a GRB signal in 2001. The data set is searched for a statistically significant cluster of signal-like events within a 1 s or 100 s time window. The non-triggered search has the potential to discover phenomena, including gamma-ray dark choked bursts, which did not trigger gamma-ray detectors.

1. Introduction

Gamma Ray Bursts are among the most energetic processes in the universe. High energy neutrinos ($\approx 10^{14}$ eV) are thought to be produced via the process $p + \gamma \to \Delta^+ \to \pi^+[+n] \to \mu^+ + \nu_\mu \to e^+ + \bar{\nu}_e + \nu_\mu$. Neutrino oscillations result in a flavor flux ratio, $\phi_{\nu_e+\bar{\nu}_e}$:$\phi_{\nu_\mu+\bar{\nu}_\mu}$:$\phi_{\nu_\tau+\bar{\nu}_\tau}$, equal to 1:1:1 at Earth[1]. AMANDA-II, a sub-detector of IceCube, was commissioned in 2000 with a total of 677 optical modules arranged on 19 strings, at depths between 1500 m and 2000 m below the surface of the ice at the South Pole. Each OM contains a 20 cm photo-multiplier tube in a pressure vessel. AMANDA-II uses polar ice as a Cherenkov medium. Searches for ν-induced muons with AMANDA-II [1, 2] in coincidence with bursts reported by satellites have been done for 1997-2003 [3]. These searches take advantage of the spatial and temporal localization of the bursts to reduce background, but are restricted to bursts with positive declination because AMANDA-II, located at the South Pole, relies on the use of the Earth to filter out all non-neutrino particles from the northern hemisphere. The cascade channel is complementary to the muon channel. AMANDA-II is uniformly sensitive to cascades from all directions, so objects at any declination can be studied. Further, GRBs without directional information can be used as no correlation to the cascade direction is required. Even though the detector's effective volume is smaller for cascades than for muons, more bursts can be studied with the cascade channel. Isolated cascades are produced by several interactions: $\nu_e N$ charged current, $\nu_x N$ neutral current, $\bar{\nu}_e e^-$ at 6.3 PeV (Glashow resonance) and $\nu_\tau N$ charged current in the case when the τ travels a short distance before decaying and the decay cascade overlaps the $\nu_\tau N$ hadronic cascade. A 100 TeV τ will travel $O(5\ m)$ before decaying. As a comparison, a 100 TeV electromagnetic cascade is $\approx$8.5 m long in ice.

We present two analyses that search for ν-induced cascades in coincidence with GRBs. For the first analysis, hereafter referred to as the *Rolling* analysis, we do not use any correlation with bursts reported by satellites. Instead two time windows, 1 s and 100 s, are rolled along the data taken by AMANDA-II in the year 2001, to search for statistical excess. This technique has the advantage of being sensitive to bursts that were not reported by satellites. The second analysis, hereafter referred to as the *Temporal* analysis, uses the temporal, but not the spatial, correlation with bursts reported by BATSE [4] in the year 2000. Using this correlation reduces the background significantly.

[1] But the ratio ϕ_ν:$\phi_{\bar{\nu}}$ is not 1:1.

2. Simulation and Reconstruction

For both analyses neutrino-induced cascades for all three neutrino flavors were simulated with ANIS [5] from 100 GeV to 100 PeV following an E^{-1} spectrum. This simulation was then re-weighted to follow the flux predicted by the Waxman-Bahcall model [6]. This spectrum is derived from average burst characteristics, and thus it is adequate to describe a large number of bursts simultaneously. Individual burst spectra may deviate significantly from the WB spectrum. We use a break energy, E_B=100 TeV and a synchrotron energy, E_s=10 PeV. For the Rolling analysis signal simulation was verified with TEA [7] which produces a Waxman-Bahcall type broken power law spectrum directly. The outputs of ANIS and TEA were found to be consistent. In both the Rolling and Temporal analyses, background muon events were simulated with CORSIKA [8]. Muons were propagated through ice using MMC [9] and detector response was simulated with AMASIM [10] for both signal and background simulation.

For both analyses, data were reconstructed with 2 different hypotheses: a cascade hypothesis and a muon hypothesis. Muon and cascade reconstruction methods are described in refs. [11, 12, 13]. We obtain a cascade vertex resolution of about 6 m in the x,y coordinates and slightly better in the z coordinate. We obtain a cascade energy resolution of $\log_{10} E_{\rm true}/E_{\rm reco} \approx 0.15$. The Rolling analysis reconstructs the position of cascades while for the Temporal analysis both the position and the energy of the cascade is reconstructed. The angular resolution of the muon reconstruction is about 5° [2].

3. Rolling Time Window Analysis

The Rolling analysis currently uses data from the year 2001. We scan the entire data sample for a clustering of events which survive cuts and are not consistent with the expected background. Therefore, it has the potential to detect signals which are not coincident with prior gamma-ray detections. These sources include gamma-ray dark neutrino sources, such as choked GRBs [14] as well as conventional GRBs not detected by the Third Interplanetary Network (IPN3) [15]. The live-time of this analysis is ≈233 days. Two separate rolling searches are performed, with time window lengths of 1 and 100 seconds. These lengths were chosen, based on the bimodal plot of GRB durations produced by BATSE [16], to contain the majority of signal from short and long bursts, respectively, while still being short enough to keep out extra background events. Since there is no temporal or spatial coincidence to aid in background rejection, the use of cuts to reduce the background of atmospheric muons becomes very important. Cuts based on both topology and number of hits in optical modules (which is indirectly tied to event energy) are utilized. After an initial filter is applied to take only high energy events, a final cut is made using a support vector machine (SVM) [17]. Background muon Monte Carlo was found to be in good agreement with experimental data in all 6 variables used in the SVM. A sample of experimental data taken from 5 runs distributed throughout the year was used as background in the SVM. The SVM cut was optimized independently for the 1 second and 100 second searches. Since the background is of stochastic nature, Poisson statistics can be used to estimate the the statistical significance of a cluster of events. Preliminary calculations result in a sensitivity of 2.7×10^{-6} GeV cm^{-2} s^{-1} sr^{-1} for a time-averaged diffuse neutrino flux of all flavors, with energy spectrum according to the Waxman-Bahcall model. This sensitivity assumes 425 bursts during the live-time of this analysis based on the average rate of GRB detection by the BATSE experiment and does not account for the unknown number of bursts with weaker or non-existent gamma-ray signals. Final results are not yet available at the time of writing.

[2] Better angular resolution is achieved by analyses that focus on the muon channel.

4. Temporal Analysis: Bursts reported by BATSE in 2000

AMANDA-II began normal operation Feb. 13, 2000. The last BATSE burst was reported May 26, 2000. In this period 76 bursts were reported. Since the GRB start time and duration[3], are well known, the separation of ν-induced cascade signal from the down-going muon background is simplified. We use three selection criteria based on the two reconstruction hypotheses to discard the down-going muon background and keep the neutrino-induced cascade signal. A total of ≈7800 s per burst were studied. A period of 600 s (*on-time* window) centered at the start time of the GRB was initially set aside in accordance with our blind analysis procedures. Two periods of data of 1 hour duration (*off-time* window) just before and after the on-time window are also studied. We optimize the selection criteria using the off-time window and signal simulation. Thus the background is experimentally measured. We only examined the fraction of the on-time window corresponding to the duration of each burst. Keeping the rest of the on-time window blind allows for other future searches, e.g. precursor neutrinos. We determined the detector stability using the off-time window experimental data. Only GRBs for which the detector is found to be stable in the off-time windows were used. Of the 76 bursts reported by BATSE in coincidence with AMANDA-II, for two bursts there are gaps in the AMANDA-II data and for one burst, AMANDA-II data was found to be unstable. Figure 1 shows a sample of the plots used to determine the stability. We applied the selection criteria in two steps, a filter and final selection. The filter rejects down-going muons, $\theta_\mu > 70°$, and keeps events that are cascade-like, $L_{mpe} < 7.8$. The parameter L_{mpe} is the reduced likelihood of the cascade vertex reconstruction and has smaller values for cascade-like events. The final selection criteria are $L_{mpe} < 6.9$ and $E > 40$ TeV, where E is the reconstructed cascade energy. One event in the off-time window remains after all cuts. This is equivalent to a background of $n_b = 0.0054^{+0.013}_{-0.005}$ (stat) in the on-time window. After un-blinding the on-time window, no events were found. To set a limit, we assume a WB-like spectrum with $E_b = 100$ TeV and $E_s = 10$ PeV. We assume neutrino flavor flux ratio of 1:1:1 and p-γ neutrino generation. The 90% c.l. limit on the all-flavor flux factor is 9.5×10^{-7} GeV cm^{-2} s^{-1} sr^{-1}. The event upper limit is 2.44. These limits have not yet been corrected for systematic uncertainties. Once the systematic uncertainties have been taken into account this limit will worsen slightly.

5. Outlook and Conclusions

Two methods for searching for neutrino-induced cascades from GRBs using AMANDA-II have been presented. A Rolling Time Window search is being conducted to search for a neutrino GRB signal at any time and from any direction. This method serves as a useful complement to satellite-coincident GRB searches conducted with AMANDA-II. Its sensitivity to individual bursts suffers from the lack of temporal constraints, but it has the potential to observe neutrino signals from transients which would otherwise be missed. Although this search is currently being conducted on the 2001 data set, it is relatively straightforward to expand the search to data sets from later years. This method can also be adapted to use the muon channel in addition to cascades.

Temporal correlation with satellites was used to perform a search with very low background. No evidence for neutrinos was found and we have set a limit based on the WB flux. The 90% c.l. limit on the all-flavor flux factor, supposing 1:1:1 flavor flux ratio, is 9.5×10^{-7} GeV cm^{-2} s^{-1} sr^{-1}. This value has not yet been corrected for systematic uncertainties. Previous searches by AMANDA-II, performed on a much larger set of bursts [3], have a significantly better sensitivity than what has been presented here. Given a large random set of bursts with both positive and negative declination, we expect the cascade channel sensitivity to be roughly half as sensitive as the muon channel. It is expected that only a small fraction of all bursts will contribute significantly an eventual observed neutrino flux. By monitoring both hemispheres we increase the probability

[3] We use $T90$, the time over which a burst emits from 5% to 95% measured fluence, as the duration

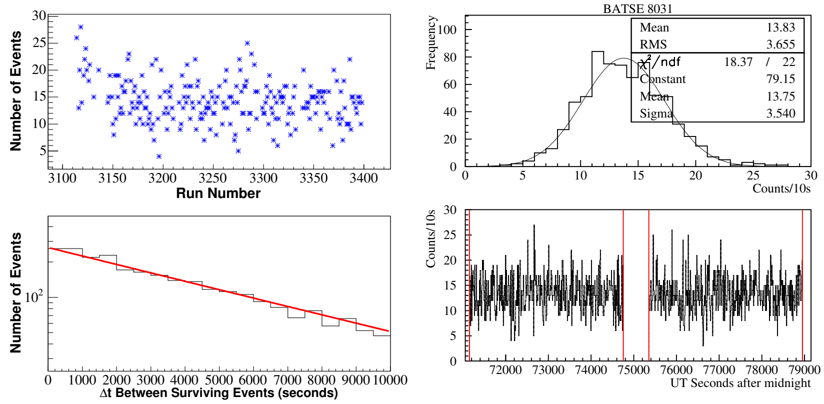

Figure 1. Left - Rolling Analysis: Plots showing background stability. The upper plot shows background counts per day after the SVN cut and the lower plot shows time between events surviving cuts. The line is the prediction assuming Poissonian statistics. Right - Temporal Analysis: Stability plots for BATSE-8031. The upper panel shows the frequency of events/10s that pass the filter in the off-time window. The lower panel shows the number of events/10s that pass the filter versus time in seconds after midnight (UTC). The vertical lines indicate the off-time period. The on-time period is analyzed according to our blindness procedures.

of discovery. The Temporal Analysis can be expanded to include bursts reported by IPN3, Swift and by using newly or soon to be deployed IceCube strings.

References

[1] E. Andrés et al., Nature 410, 441–443 (2001).
[2] K. Woschnagg et al., Nuclear Physics B Proc. Suppl. 143, 343–350 (2005).
[3] R. Hardtke, K. Kuehn, M. Stamatikos et al., Proc. 28^{th} ICRC, Tsukuba, Japan (2003) 1117–1120.
[4] W.S. Paciesas et al., Astrophys. J. Suppl., 122, 465 (1999). arXiv:astro-ph/9903205.
[5] A. Gazizov and M. Kowalski, DESY report DESY 04-101 (2004), arXiv:astro-ph/0406439.
[6] E. Waxmann and J. Bahcall, Phys. Rev. Lett. 80, 3690 (1997).
[7] URL: http://amanda.wisc.edu/software/cascade-tea/
[8] D. Heck, Tech. Rep. FZKA 6019 Forshungszebtrum Karlsruhe (1998).
[9] D. Chirkin and W. Rhode, Proc. 27^{th} ICRC, Hamburg, Germany (2001) 1017–1020.
[10] S. Hundertmark Proc.1^{st} Workshop Methodical Aspects of Underwater/Ice Neutrino Telescopes, Zeuthen, Germany (1998)
[11] J. Ahrens et al., Nucl. Instr. Meth A 524, 169 (2004).
[12] M. Kowalski and I. Taboada Proc. 2^{nd} Workshop Methodical Aspects of Underwater/Ice Neutrino Telescopes, Hamburg, Germany (2001).
[13] J. Ahrens et al., Phys. Rev. D 67, 012003 (2003).
[14] P. Meszaros and E. Waxman, Phys. Rev. Lett. 87, 1711 (2002).
[15] K. Hurley, Astron. Telegram #19. (1998).
[16] URL: http://www.batse.msfc.nasa.gov/bastse/grb/duration/
[17] T. Joachims, Making Large-Scale SVM Learning Practical. Advances in Kernel Methods - Support Vector Learning. MIT Press, (1999), 1^{st} ed.