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Search for a diffuse flux from sources of high energy neutrinos with AMANDA-B10

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Abstract. We report the status of the search for a diffuse flux of high energy muon-neutrinos from extra-terrestrial sources, using data collected with the AMANDA-B10 detector during the austral winter 1997. Here we describe the search method, and discuss the expected sensitivity of the detector to such a source. Systematic uncertainties in the sensitivity of the detector are still being assessed, and results of the application of this search to the data set will be reported at the conference.

1 Introduction

Various models of neutrino production in astrophysical objects have been postulated. Neutrinos are believed to be produced in energetic environments through proton-proton or proton-photon interactions via pion production and decay. Such an accelerator might be the core of an active galaxy, powered by a supermassive black hole. In their pioneering work, Stecker, Done, Salamon and Sommers (1991,1992) calculated the expected diffuse flux of neutrinos from the sum of all active galaxies and found that such a flux could be observable in a large deep neutrino detector. Many subsequent models predict a similar result. More recent predictions have come from Stecker and Salamon (1996), Waxman and Bahcall (1999) and Mannheim, Protheroe and Rachen (2000). With the construction and operation of the first high energy neutrino detectors, the sensitivity has been reached to enable such models to be tested. Limits have been reported by the Frejus (Rhode et al. 1996) and Baikal (Balkanov et al. 2000) (Dzhilkibaev et al. 2001) experiments. This paper describes such a search, for upgoing neutrino-induced muons, conducted with the AMANDA-B10 detector, operated at the South Pole during the austral winter of 1997.

2 High energy neutrino search

In searching for high energy neutrino-induced muons from extra-terrestrial sources, there are two sources of background that must be eliminated. Firstly, there are the misreconstructed downgoing atmospheric muons, which are also the background to an atmospheric neutrino search. The successful identification of atmospheric neutrinos with AMANDA-B10 has been demonstrated (Gaug 2000, Andrés et al. 2001, DeYoung 2001, Wiebusch et al. 2001). Finally, these atmospheric neutrinos are the background to the extra-terrestrial neutrino search. Typically, a model of an extra-terrestrial source of neutrinos has a harder spectrum (E^{-2}) (Stecker and Salamon 1996) than that of the atmospheric neutrinos ($E^{-3.7}$) (Agrawal et al 1996). We detect these neutrinos by looking for the secondary muons that might have travelled many kilometres to the detector from the interaction point. We are then left to separate signal from background by using muon energy as a discriminant. A very simple measure of the muon energy is the event hit multiplicity, (N_{ch}) – the number of optical modules that fire in response to the through-going muon. Figure 1 shows the correlation between hit multiplicity and incident neutrino energy for an E^{-2} spectrum. As an example, events with approximately 100 hit channels come from neutrinos with energies of order 300 TeV. There is still sufficient correlation between the multiplicity and the incident neutrino energy to allow discrimination of source spectra from atmospheric background.

3 Unbiased cut optimisation for upper limits

We use the "model rejection potential" method (Hill and Rawlins 2000) in choosing the cuts in order to get the best on-average limit from the detector. This method, based only on Monte Carlo predictions, avoids the biases introduced by the commonly used method of cutting on the last data event - a method that leads to confidence intervals which fail tests of frequentist coverage.

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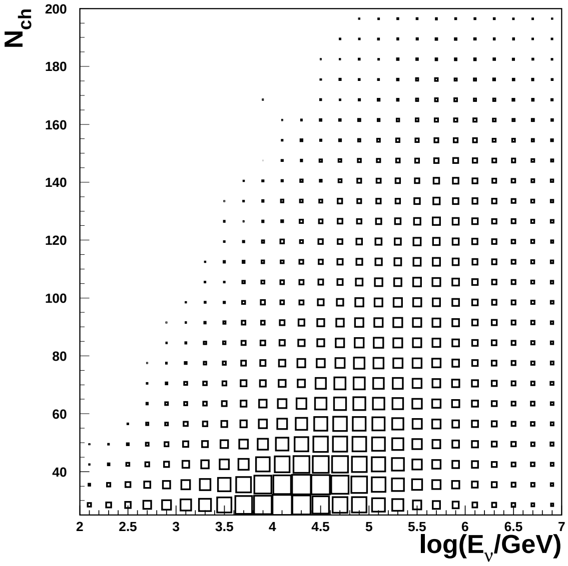

Fig. 1. Correlation between hit multiplicity and incident neutrino energy.

Setting a limit on a flux $\Phi(E)$ involves determining an experimental event upper limit $\mu(n_{obs}, n_b)$, which is a function of the number of observed events, n_{obs}, and expected background, n_b, after the cuts are applied. The complete Monte Carlo chain tells us the number of signal events, n_s, expected from the source flux $\Phi(E)$. The limit on the source flux will then be

$$\Phi_{limit}(E) = \Phi(E) \times \frac{\mu(n_{obs}, n_b)}{n_s} \tag{1}$$

The source flux is strongly constrained whenever the ratio $\mu(n_{obs}, n_b)/n_s$ is small – i.e. a large source expectation after cuts, in the presence of a small observed event upper limit, leads to a strong constraint on the source flux. Of course, the event upper limit $\mu(n_{obs}, n_b)$ is known only after the experiment is performed. However, before conducting the experiment, we can compute an "average upper limit" – the ensemble average of the expected limits, in the absence of a true signal, for hypothetical repetition of the experiment. This average upper limit is identical to the "sensitivity" defined by Feldman and Cousins (1998) in their work on "unified" classical confidence interval construction, but is generally applicable to any formulation of confidence intervals. In the presence of only the background n_b we will expect various observations of n_{obs}, each of which will result in a limit $\mu(n_{obs}, n_b)$. Weighting each of the limits obtained from this hypothetical ensemble of experiments by their Poisson probability of occurrence leads to an average upper limit –

$$\bar{\mu}(n_b) = \sum_{n_{obs}=0}^{\infty} \mu(n_{obs}, n_b) \; \frac{(n_b)^{n_{obs}}}{(n_{obs})!} \exp(-n_b) \tag{2}$$

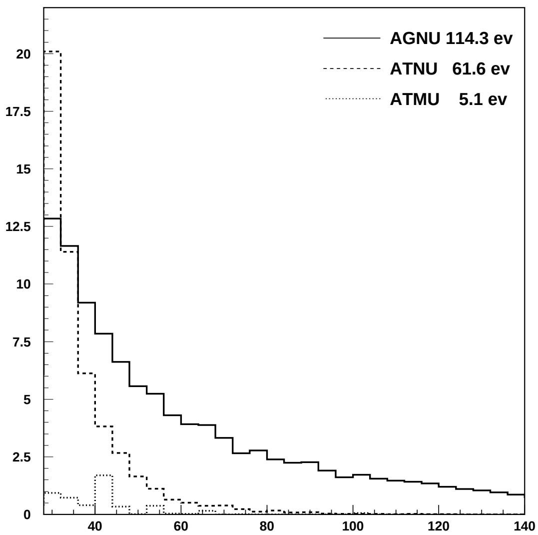

Fig. 2. Hit multiplicity distribution after final cuts, showing the expected excess of events from an E^{-2} spectrum at the higher multiplicities.

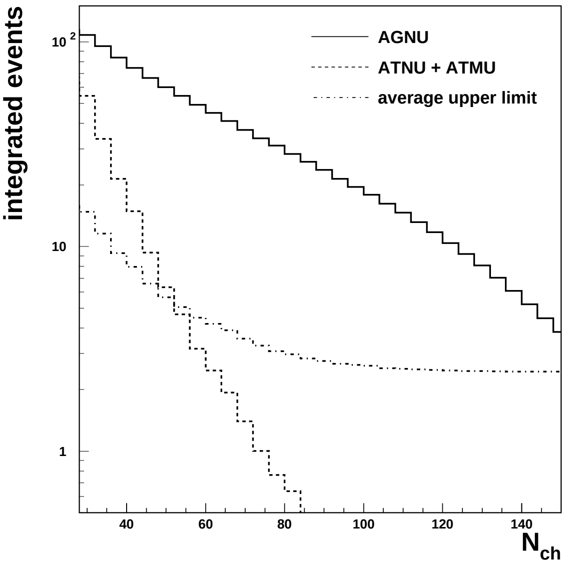

Fig. 3. Integrated distributions of event numbers as a function of the multiplicity cut. The solid line shows the "average upper limit" derived from the expected background.

The model rejection factor, (MRF), is equal to the average upper limit divided by the signal expectation. Choosing cuts to minimise the model rejection factor will on average lead to the most restrictive limit.

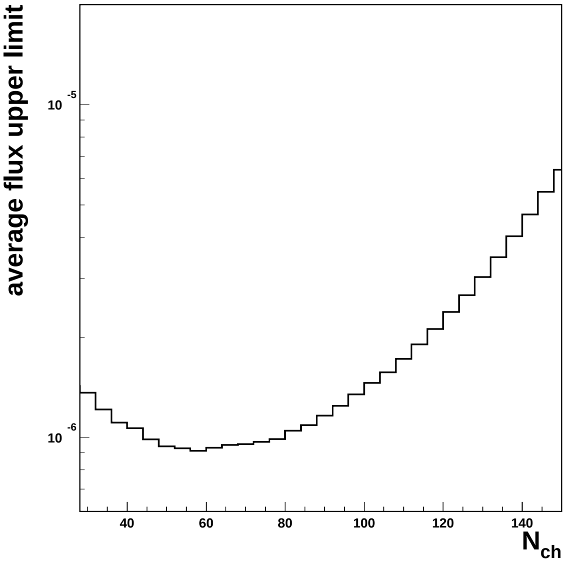

Fig. 4. The ensemble average flux upper limit as a function of the hit multiplicity cut.

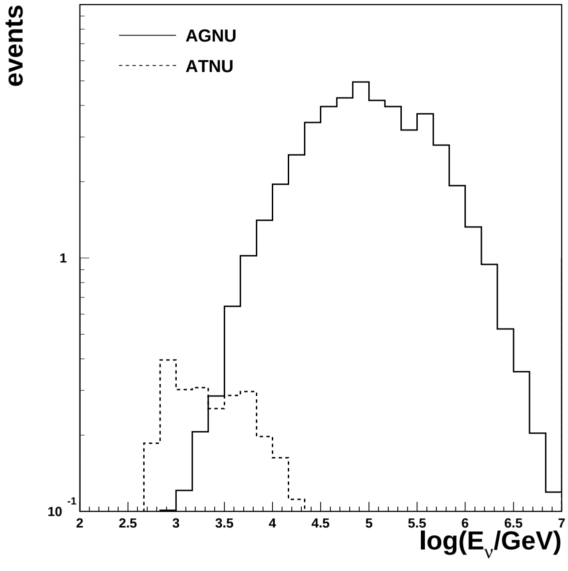

Fig. 5. Energy spectrum of the incident neutrinos for events that pass the final cuts, and have hit multiplicity greater than the optimum cut of 56 channels.

4 Sensitivity to a diffuse E^{-2} flux

A preliminary upper limit from the AMANDA-B10 diffuse flux search, using data corresponding to 130 days live time, has been reported (Andrés et al. 2000). Since that time, more detail on the sensitivity of the detector to high energy neutrinos has become known. We are still in the process of assessing the systematic effects of phenomena like photon propagation in the ice, and the sensitivity of the optical modules. While progress is being made, it should be emphasised that the Monte Carlo results used here to assess the sensitivity of the array are preliminary. We use a new set of cuts, optimised toward the rejection of atmospheric neutrinos, and the retention of high energy neutrinos. From detailed comparisons of data to Monte Carlo in the atmospheric neutrino search, we believe that the standard Monte Carlo overpredicts the array sensitivity. Here we use a Monte Carlo that corresponds to a low value of the array sensitivity, viewing this as a conservative approach to determining the limit setting capabilities of the detector. The hit multiplicity distribution after application of quality cuts to this Monte Carlo is shown in figure 2. The remaining background (sum of atmospheric neutrinos (ATNU) and muons (ATMU)) is 66.7 events. An E^{-2} flux of level $E^2\Phi = 10^{-5}\,\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}GeV}$ (AGNU), simulated in the energy range $10-10^8$GeV, would produce 114.3 events, and, most importantly, a significant excess at high multiplicity. Once the initial cuts are applied, we then use the model rejection potential method to optimise the final choice of multiplicity cut. The integrated hit multiplicity distribution is shown in figure 3. Also shown is the 90% confidence level Feldman and Cousins average upper limit which is a function of the expected background. The optimal cut is the one where the model rejection factor $\mu(n_{obs}, n_b)/n_s$ is minimised. Figure 4 shows the average flux upper limit ($E^2\Phi \times \mathrm{MRF}$) as a function of the choice of multiplicity cut. The minimum flux limit occurs at a cut of $nch > 56$, where we expect $n_b = 3.0$ and an average event upper limit of 4.4. The E^{-2} signal would produce 48.1 events. This leads to an expected average limit on the source flux of

$$E^2\bar{\Phi}_{90\%}(E) \quad = 0.9 \times 10^{-6}\,\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}GeV} \tag{3}$$

We note that the expected overall flux limit is relatively insensitive to the choice of cut, with a broad minimum in the range of multiplicities 50-65. This sensitivity is consistent with previously quoted preliminary limits (Andrés et al. 2000). We emphasise again that further understanding of the sensitivity of the array is needed before this method can be applied to the data set to give the experimental limit. We expect that, after accounting for systematic uncertainties, this final limit will lie in the range $0.5 - 2.0 \times 10^{-6}\,\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}GeV}$.

Figure 5 shows the neutrino energy spectrum of the events that pass the multiplicity cut of 56 channels, for both atmospheric neutrinos and neutrinos from an E^{-2} spectrum. The multiplicity cut corresponds to an energy threshold of close to 500 GeV, and we see that the detector response to E^{-2} neutrinos is peaked close to an energy of 10^5 GeV, with a sensitive energy range spanning the region $10^4 - 10^6$ GeV, outside of which few events are expected.

5 Conclusion and Outlook

The AMANDA-B10 detector, operated during the austral winter 1997, is capable of placing limits on diffuse extra-terrestrial neutrino fluxes. The Monte Carlo study discussed here suggests a level of sensitivity $E^2\Phi(E) \sim 1 \times 10^{-6}$ $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\mathrm{GeV}$ can be reached with 130 days of data taking. A limit at this level begins to test predictions (Stecker and Salamon 1996) of neutrino emission in extra-terrestrial objects such as active galaxies. Further systematic checks are underway, that will allow a better understanding of the array sensitivity, before determination of the final experimental limit.

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