Nearly vertical upgoing muons in the AMANDA-B10 detector

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Abstract

Data taken during 1997 by the AMANDA-B10 neutrino detector has been analyzed for upgoing neutrino-induced muons from the center of the Earth. The expected background of atmospheric neutrinos and limits on the neutrino-induced muon flux from WIMP annihilations in the Earth are discussed.

1 Introduction

We have analyzed a total of 85 days of detector live-time from the 1997 data set with the aim of detecting nearly vertical upgoing muon tracks. The flux and angular distribution of upgoing events is found to agree reasonably well with expectations from Monte Carlo simulations of atmospheric neutrinos, see also A. Karle (1999) where a separate analysis of this data set is compared with expectations from atmospheric neutrinos. The measured flux has been tested against the hypothesis that the dark matter in the universe could be constituted by WIMPs, e.g. neutralinos. These particles naturally arise in supersymmetric extensions of the Standard Model and would be captured gravitationally by the Earth after being elastically scattered while traversing it. An accumulation would take place in the Earth's centre, where pair-wise annihilation would produce a neutrino flux that could be measured as an excess of nearly vertical muons in AMANDA (see for example the review by Jungman, Kamionkowski and Griest 1996).

2 Simulations

The overwhelming number of triggers in the detector is caused by down-going muons from cosmic ray interactions with the atmosphere. These muons have been simulated by the generator basiev (Boziev et al., 1989). The simulations include the propagation and energy-loss of the muons, and the emission, absorption

Mass	Type	V_{eff} [m^3]			A_{eff} [m^2]		
[GeV]		level 4	level 4	level 4	level 4	level 4	level 4
		$\theta \geq 165°$	$\theta \geq 170°$	$\theta \geq 175°$	$\theta \geq 165°$	$\theta \geq 170°$	$\theta \geq 175°$
100	hard	2.40×10^5	2.13×10^5	8.77×10^4	1060	930	370
250	hard	1.95×10^6	1.91×10^6	1.36×10^6	3600	3500	2380
500	hard	4.81×10^6	4.77×10^6	3.97×10^6	4890	4830	3890
1000	hard	9.77×10^6	5.48×10^6	7.78×10^6	5700	5659	4970
3000	hard	2.43×10^7	2.42×10^7	2.21×10^7	6760	6720	6100
5000	hard	3.47×10^7	3.45×10^7	3.15×10^7	7300	7260	6580
100	soft	2.50×10^4	1.95×10^4	7.04×10^3	140	110	40
250	soft	3.27×10^5	3.09×10^5	1.73×10^5	1110	1030	540
500	soft	9.94×10^5	9.79×10^5	7.06×10^5	2140	2100	1430
1000	soft	2.41×10^6	2.38×10^6	1.91×10^6	3200	3130	2350
3000	soft	6.55×10^6	6.51×10^6	5.77×10^6	4200	4170	3580
5000	soft	9.28×10^6	9.25×10^6	8.30×10^6	4370	4350	3850

Table 1: The effective volumes and effective areas for different WIMP masses and annihilation channels. The effective areas are defined as $V_{\text{eff}}/\bar{L}_\mu$ with $\bar{L}_\mu$ being the average muon range in the sample of muons from WIMP annihilations that survive the corresponding cuts.

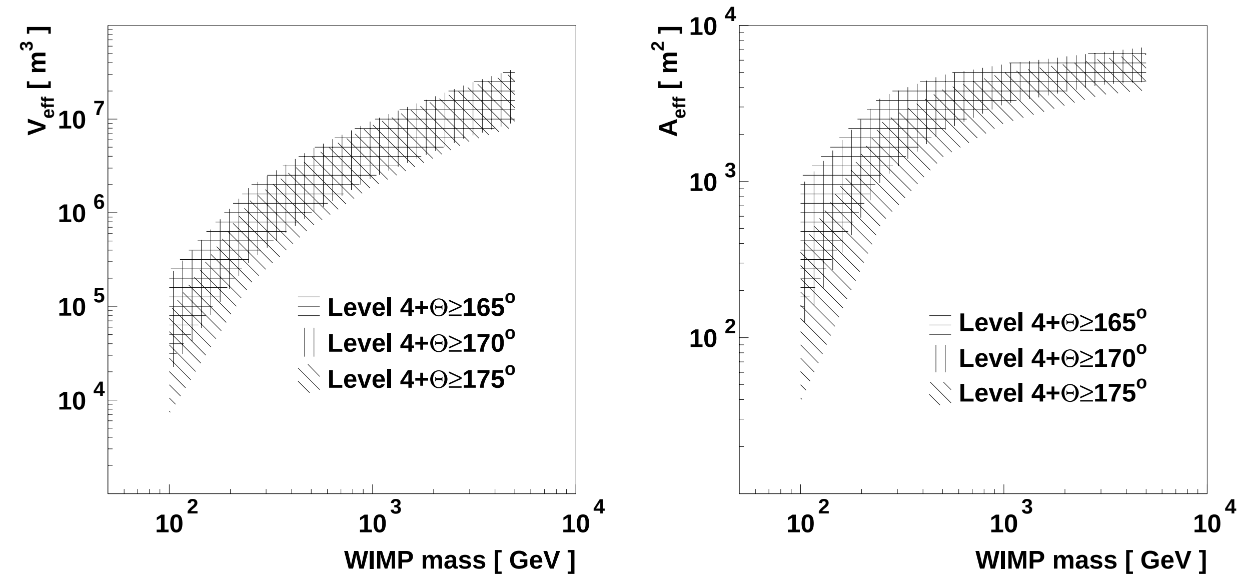

Figure 1: The effective volumes and the effective areas for the level 4 cut and different angular cuts. The widths come from two different annihilation channels, which give typical hard or soft neutrino spectra respectively.

and scattering of photons. The response of the optical modules and the trigger is also simulated (Hundertmark, 1999). Agreement between data and Monte Carlo is reasonably good, see G. Hill (1999).

Another background in the WIMP analysis is the muons from atmospheric neutrinos. The energy and angular spectra of these neutrinos have been taken from Lipari (1993) for this study. For the signal of neutrinos from WIMP annihilation we have used the distributions by Bergström, Edsjö and Gondolo (1998). We note that the angular distribution of the neutrinos from any given WIMP candidate can be parameterized in terms of the WIMP mass and the hardness of the annihilation spectrum (e.g. annihilation into W^+W^- gives a hard spectrum and annihilation into $b\bar{b}$ gives a soft spectrum). We will investigate WIMP masses up to 5000 GeV with both soft and hard annihilation spectra.

3 Analysis method

The data was reduced by ~90% in a first general data reduction in order to suppress the number of down-going muons. After this first level filtering, a full reconstruction of the events took place, as described in Wiebusch et al. (1997). We have then applied the level 4 cuts as described in A. Karle (1999). Those cuts were optimized for atmospheric neutrinos, but work well for a first WIMP analysis as well. Work is in progress to improve these cuts for the WIMP signal. Compared to the level 4 cuts in A. Karle (1999), our analysis have some differences; most importantly we use a newer, improved track reconstruction model and a different Monte Carlo for the atmospheric neutrino simulations.

Since the WIMP signal is collimated towards the center of the Earth, we can apply strong cuts on the zenith angle to improve the signal to noise ratio. We have chosen to look in three different angular windows, $\theta \geq 165°$, $\theta \geq 170°$ and $\theta \geq 175°$ (with θ being the zenith angle). In Table 1 and Fig. 1, the effective volumes and the corresponding effective areas for neutrino-induced muons from WIMP annihilation in the Earth are given.

4 Measured fluxes

The cuts described in the previous sections were applied on the 85 days of data. In Table 2 we show the remaining number of events from data and from simulated atmospheric neutrinos. The simulations of down-going atmospheric muons correspons only to about one day of live-time. No events in this sample remains

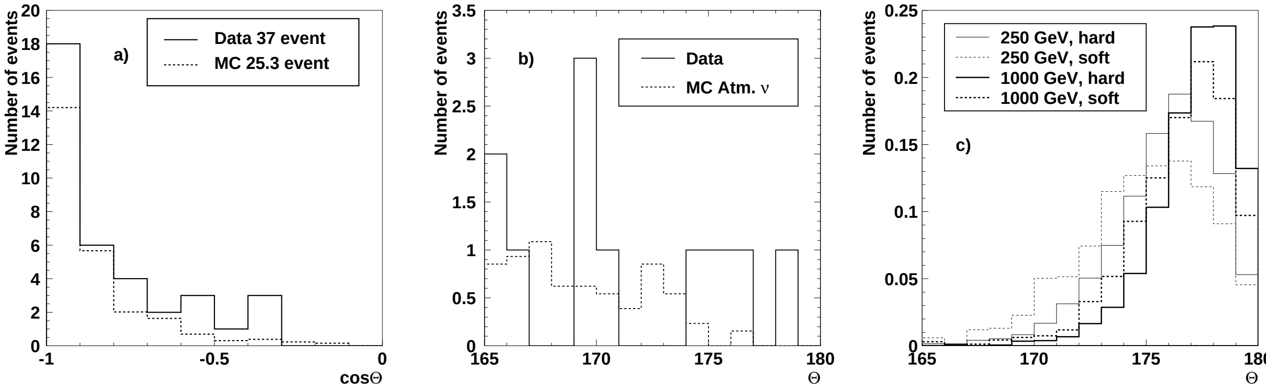

Figure 2: The angular distribution of neutrino-induced muons from a) data compared with expectations from atmospheric neutrinos, b) same as a) but zoomed in one the most vertical tracks and c) WIMPs with a hard and soft annihilation spectrum and a mass of 250 and 1000 GeV after the level 4 cut. In c) the distributions have been normalized to 1.

after the cuts have been applied. For this analysis we will assume that the background of misreconstructed down-going muons is zero for the full set of 85 days. In this context this is a conservative approach, since the limits we derive would be lower in the presence of such a background. Work is in progress to enlarge the sample of simulated atmospheric muons. The simulated sample of atmospheric neutrinos corresponds to three years of live-time. We assume that the total number of events from this sample that survives the cuts is at least a factor of 2 uncertain. In Fig. 2 (a) we show the events remaining in data after the level 4 cuts together with the Monte Carlo expectations from atmospheric neutrinos. Fig. 2 (b) again shows both data and atmospheric neutrinos now zoomed in on the nearly vertical muons, while in Fig. 2 (c) we have plotted the angular distributions for the expected signal of neutrino-induced muons from WIMPs of 250 and 1000 GeV in the same angular region. Due to the highly restrictive cuts applied and the relatively small data sample, the data curves are characterized by strong statistical fluctuations. The question of how well the expected number of vertically upgoing muons matches the measured flux will have to wait until the whole 1997 data sample is analyzed and specific cuts for this type of signal are developed. However, within the present statistical errors at this stage of the analysis, we believe that data as seen in Fig. 2 gives a reasonable agreement with the atmospheric neutrino expectation.

Zenith angle	Events	Expected from atmospheric ν
$\theta \geq 165°$	11	$6.8^{+6.8}_{-3.4}$
$\theta \geq 170°$	5	$2.7^{+2.7}_{-1.4}$
$\theta \geq 175°$	3	$0.2^{+0.2}_{-0.1}$

Table 2: The number of events remaining after level 4 cuts and the angular cuts indicated.

Mass	ϕ_μ $[10^{-14} cm^{-2} s^{-1}]$					
	Hard spectrum			Soft spectrum		
[GeV]	level 4 $\geq 165°$	level 4 $\geq 170°$	level 4 $\geq 175°$	level 4 $\geq 165°$	level 4 $\geq 170°$	level 4 $\geq 175°$
100	14.1	9.8	23.6	103.8	82.2	231.3
250	4.2	2.6	3.7	13.4	8.9	16.4
500	3.1	1.9	2.3	7.0	4.4	6.2
1000	2.6	1.6	1.8	4.7	2.9	3.8
3000	2.2	1.4	1.5	3.6	2.2	2.5
5000	2.1	1.3	1.3	3.4	2.1	2.3

Table 3: Derived 90% confidence level upper limits for muon fluxes for different WIMP masses and annihilation channels. The limits have been calculated using the central values of the expected number of background events.

5 Limit on excess flux of nearly vertical muons

Using the results in Tables 1 and 2 we can derive a limit on the excess flux of nearly vertical upgoing muons from WIMP annihilation in the Earth, see Table 3 and Fig. 3 (our method is described in Particle Data Group, 1996). Due to the geometry of the AMANDA-B10 detector, our sensitivity drastically improves for WIMP masses above ~ 200 GeV. A preliminary WIMP search with the 4-string AMANDA prototype and 180 days of detector live-time has been reported earlier (Bouchta, 1997). Note that with only 85 days of exposure time we obtain comparable limits to (Bouchta, 1997). Our preliminary results are also comparable with recently reported limits achieved by the Baikal detector (Balkanov et al., 1999), and are only slightly higher than those from other types experiments with much longer exposure times, such as Baksan (Boliev et al., 1996), Kamiokande (Mori et al., 1993) and MACRO (Ambrosio et al., 1999). We expect that the limits quoted here will be improved in the near future by using specially optimized cuts for the WIMP search on the whole 1997 data set. Work in this direction is in progress.

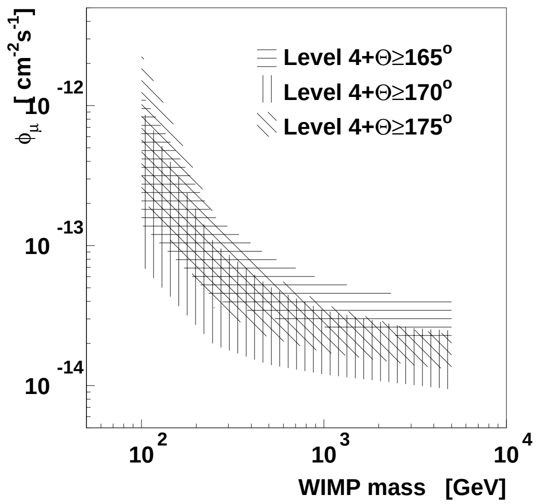

Figure 3: 90% confidence level upper limits of the muon fluxes as a function of WIMP mass. The bands include the estimated factor of 2 uncertainty in the simulated background expectations, but the spread is dominated by the difference due to hard and soft neutrino energy spectra.

6 Conclusions

We have analyzed half of 1997 data with the AMANDA-B10 detector focusing on nearly vertical upgoing muons. We find reasonable agreement between expectations from atmospheric neutrinos and data and use this measured flux to put limits on neutrino-induced muon fluxes coming from WIMPs annihilating in the center of the Earth. This analysis is preliminary in the sense that a) the applied cuts have not been optimized for a WIMP signal and b) not all of the 1997 data has been analyzed yet.

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