Search for Muons from WIMP Annihilation in the Center of the Earth with the AMANDA-B10 Detector

Philip Olbrechts[1] for the AMANDA Collaboration[2]
(1) Vrije Universiteit Brussel, Dienst ELEM, B-1050-Brussel, Belgium
(2) Complete author list in G.C. Hill et al., these proceedings

Abstract

In this paper we present results of an indirect search for non-baryonic dark matter in the form of weakly interacting massive particles (WIMP) using the AMANDA-B10 high energy neutrino detector. We present an updated analysis using new data and new algorithms for the search for near-vertical upgoing muons from neutralino annihilation in the center of the earth. We present upper limits on both the annihilation rate of neutralinos in the center of the earth and the corresponding muon flux for neutralino masses between 50 and 5000 GeV. All results quoted are preliminary.

1. Introduction

If cold dark matter in the Universe is constituted of supersymmetric particles in the form of neutralinos then these can accumulate gravitationally, in e.g. the center of the earth, and annihilate [1]. In this annihilation process neutrinos are produced which generate upgoing near-vertical muons in a detector like AMANDA. These muons will appear as an excess over the expected background of muons from the atmospheric neutrinos coming through the earth from the Northern Hemisphere.

We describe briefly experimental and simulated data. We discuss the improved analysis techniques used. The results of the present analysis based on data from 1999 are compared with the results obtained in the analysis of 97 data [1]. The last section summarizes the results.

2. Simulated and experimental events

The current analysis uses the data taken with the AMANDA-B10 detector [1] during the austral winter of 1999. The effective live time after rejection of bad data taking runs was found to be equal to 187.03 days, which corresponds to $1.1 \cdot 10^9$ events at trigger level. We have simulated downgoing atmospheric muon events and upgoing atmospheric neutrino events of which $20 \cdot 10^6$ and $1.9 \cdot 10^6$, respectively, have passed the trigger requirement. In the data the atmospheric muon events are about 10^6 times more abundant than the atmospheric neutrino events.

pp. 1677–1680

The simulated WIMP signal sample consists of 14 sub-samples of 500000 events each. We have generated two different annihilation channels: $\chi\chi \to W^+W^-$ as a reference hard neutrino spectrum and $\chi\chi \to b\bar{b}$ as a reference soft neutrino spectrum. These two channels have been simulated for 7 different neutralino masses from 50 GeV to 5000 GeV each.

3. Method

The first part of the analysis focuses on the rejection of the downgoing muon events. The idea is to find a selection procedure that points out the most sensitive variable to cut on (among a chosen set of 32 variables which parametrize the quality of an event, e.g. number of hit optical modules) and on top of that also determines the most optimal cut value. We evaluate

$$\epsilon_{\text{signal}}(x; x_{\text{cut}}) \cdot (1 - \epsilon_{\text{background}}(x; x_{\text{cut}}))$$

with $\epsilon_{\text{signal}}(\epsilon_{\text{background}})$ the fraction of signal(background) events which pass the cut, x_{cut}, in the variable x.

Calculation of $\epsilon_{\text{signal}} \cdot (1 - \epsilon_{\text{background}})$ as function of x_{cut} for the variables used results in a function that peaks at a certain cut value. We take this cut value as our optimal cut on the studied variable. The corresponding value of $\epsilon_{\text{signal}} \cdot (1 - \epsilon_{\text{background}})$ is used as "weight of the variable" which tells us how efficient this variable is with respect to the other variables. The variable with the highest weight is taken for the first selection and a cut is performed at the optimal cut value. After this, the same procedure is executed for all the remaining variables. We continue developing cuts using this method until we have rejected all the downgoing atmospheric muon events. Figure 1A shows that after 6 cuts the data follow the same course as expected for upgoing atmospheric neutrinos. At this stage the data consist only of upgoing atmospheric neutrinos and a possible WIMP signal.

In order to reject the remaining atmospheric neutrinos, we continue developing cuts using the previously described method until the last cut. This cut is optimized using the model rejection factor technique [2]. A detailed study of the zenith angle distribution shows no statistically significant excess of vertical muons on top of the expected atmospheric neutrino background. No WIMP signal has been detected.

4. Results

The effective volume reflects the detector performance and the cut efficiency. It is defined as:

$$V_{\text{eff}}(\text{cut}) = \frac{n_{\text{cut}}}{n_{\text{gen}}} V_{\text{gen}}$$

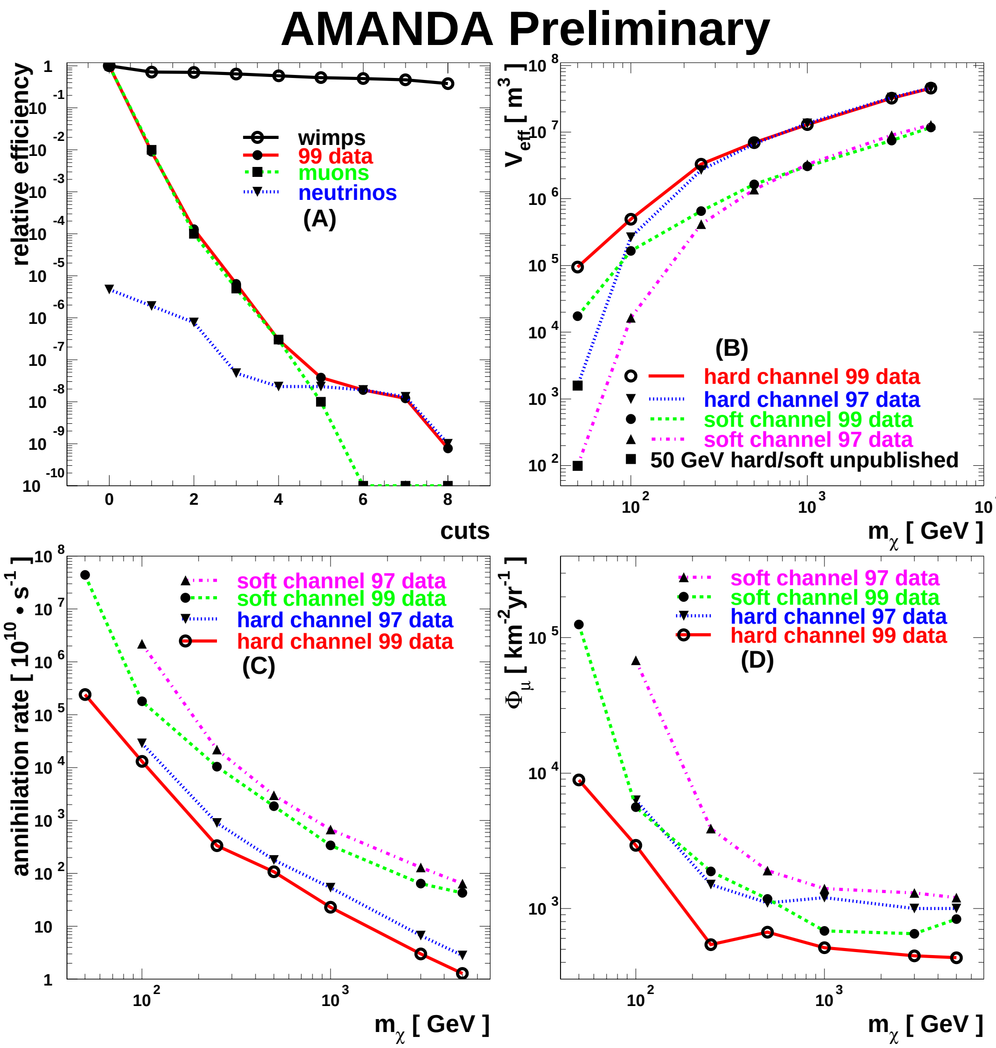

Fig. 1. (A) Relative efficiency of the selection procedure for the data, simulated signal events (WIMP 5000 GeV hard) and simulated background events (atmospheric muons and atmospheric neutrinos) as a function of the cuts. All samples have been normalized to 1 at trigger level (cut 0), except for the atmospheric neutrinos that have been normalised to the effective live time of the experimental data; (B) Effective volume as function of the neutralino mass at the final cut level; (C) The 90% confidence level upper limit on the annihilation rate of neutralinos in the center of the earth as function of the neutralino mass; (D) The 90% confidence level upper limit on the muon flux coming from neutralino annihilations in the center of the earth as function of the neutralino mass. We have normalized the upper limits to a muon energy threshold of 1 GeV; The results are given for both the hard and soft annihilation channel and for the 99 and 97 data analyses in 1B, 1C and 1D; no systematic errors are included in the limits in 1C and 1D.

where n_{cut} is the number of events that pass the cuts and n_{gen} the number of events that have been generated in a volume V_{gen} around the detector. In figure 1B we plot the effective volume as function of the neutralino mass at the final cut level. We show the results from the present analysis and from the 97 data analysis for both the hard and soft annihilation channel. Effective volumes at the final cut level obtained with the 99 data analysis agree with those of the 97 data analysis for the high neutralino masses. For low masses the present analysis is more efficient. Especially for the 50 GeV and 100 GeV channels, the gain in effective volume is 1 - 2 orders of magnitude. This is mainly due to the fact that we opted for a strategy where cuts are optimized independently for each mass.

Figure 1C shows the upper limit on the annihilation rate of neutralinos in the center of the earth as function of the neutralino mass. Comparing the upper limits on the annihilation rate of neutralinos from the 99 data analysis with those from the 97 data analysis, an improvement over the full mass range for both the hard and soft channels is seen. Figure 1D shows the resulting upper limit on the muon flux at the surface of the earth. These limits have been normalized to a muon energy threshold of 1 GeV (we use 10 GeV in the simulation). The upper limits on the muon flux obtained from the 99 data analysis are stronger over the full mass range compared to the results from the 97 data analysis. The improvement of the upper limits on the annihilation rate and the muon flux is due to the larger effective live time in 1999 and the development of cuts adapted to each WIMP mass individually. A comparison with the results of MACRO, Super-Kamiokande and Baksan shows that AMANDA has reached an equivalent sensitivity especially for the high neutralino masses [1].

5. Summary

A search has been performed for a statistically significant excess of vertically upgoing muons with the AMANDA neutrino detector, as a signature for WIMP annihilation in the center of the earth. Limits on the neutralino annihilation rate and the corresponding muon flux have been derived from the non-observation of a signal excess over the predicted atmospheric neutrino background. The present limits are significantly better than those obtained in the analysis of 1997 AMANDA data.

The effect of the detector systematic uncertainties on these upper limits is still under investigation.

References

[1] Ahrens, J. et al., Phys. Rev. D 66, 032006 (2002) and W.Wagner et al, this volume

[2] Hill, G.C. and Rawlins K., Astropart. Phys. 19, 393 (2003)