WIMP SEARCHES WITH AMANDA-B10

Presented by Joakim Edsjo for the AMANDA Collaboration:

X. BAI, G. BAROUCH, S.W. BARWICK, R.C. BAY, K.-H. BECKER,
L. BERGSTROM, D. BERTRAN, A. BIRON, O. BOTNER,
A. BOUCHTA, M.M. BOYCE, S. CARUS, A. CHEN,
D. CHIRKIN, J. CONRAD, J. COOLEY, C.G.S. COSTA,
D.F. COWEN, J. DAILING, E. DALBERG, T. DEYOUNG,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
K.-H. BECKER, L. BERGSTROM, D. BERTRAN,
A. BIRON, O. BOTNER, A. BOUCHTA, M.M. BOYCE,
S. CARUS, A. CHEN, D. CHIRKIN, J. CONRAD,
J. COOLEY, C.G.S. COSTA, D.F. COWEN, J. DAILING,
E. DALBERG, T. DEYOUNG, P. DESIATI,
We report on the search for nearly vertical up-going muon neutrinos from WIMP annihilations in the center of the Earth with the AMANDA-B10 detector. The whole data sample collected in 1997, $10^9$ events, has been analyzed and a final sample of 15 up-going events is found in a restricted zenith angular region where a signal from WIMP annihilations is expected. A preliminary upper limit at 90% confidence level on the annihilation rate of WIMPs in the center of the Earth is presented.

1 Introduction

There are strong indications for the existence of dark matter in the Universe. The favourite candidate for the dark matter is a Weakly Interacting Massive Particle, a WIMP, of which the neutralino that arises in supersymmetric extensions of the standard model is a natural candidate. If these WIMPs exist they accumulate in the center of the Earth and the Sun, where they can annihilate pair-wise producing muon neutrinos that can be searched for with neutrino telescopes like AMANDA. Searches of this kind have been performed by existing experiments like MACRO, Baikal, Baksan, Kamiokande and Super-Kamiokande. We here report on searches for muon neutrinos from WIMP annihilations in the center of the Earth with the AMANDA-B10 detector using data from 1997.

2 The AMANDA-B10 detector

AMANDA-B10 consists of an array of 302 Optical Modules (OM) arranged in 10 strings deployed between 1500 and 2000 meters in the South Pole ice cap. Muons from charged-current neutrino interactions near the array are detected by the Cherenkov light they emit when traversing the ice. The timing of the Cherenkov photons reaching the OMs enables us to reconstruct the muon track. A more detailed description of the detector is given in.

3 Signal and background simulations

Our main backgrounds when searching for a WIMP signal are the atmospheric neutrinos and muons. We first discuss the signal and then the background simulations.

3.1 Simulation of WIMP annihilations

WIMPs annihilate pair-wise to, e.g., leptons, quarks and gauge and Higgs bosons. High-energy neutrinos are produced in the decays and/or hadroniza-
tion of these annihilation products. Neutrinos produced in quark jets (from e.g. $b\bar{b}$ or Higgs bosons) typically have lower energy than those produced from decays of $\tau$ leptons and gauge bosons. We will refer to the first type of annihilation channels as ‘soft’ and to the second as ‘hard’. As a typical soft channel we choose $b\bar{b}$ and as a typical hard channel we choose $W^+W^-$ above the $W^+W^-$ threshold and $\tau^+\tau^-$ below. The hadronization and/or decay of the annihilation products were simulated with PYTHIA. For details, see \cite{9}.

3.2 Simulation of the atmospheric neutrino flux

We have simulated the expected atmospheric neutrino flux using the calculations of Lipari \cite{10} and the neutrino and anti-neutrino–nucleon cross sections from Gandhi et al. \cite{11}. The actual neutrino–nucleon interactions have been simulated with PYTHIA using the CTEQ3 parameterization of the nucleon structure functions. A 3-year equivalent atmospheric neutrino sample with energies between 10 GeV and 10 TeV and zenith angles between 90° and 180° has been simulated \cite{13}.

3.3 Simulation of the atmospheric muon flux

The majority of the triggers in AMANDA are induced by muons produced in cosmic ray interactions in the atmosphere and reaching the detector depth. The simulation of this atmospheric muon flux was performed with an algorithm described in \cite{14}. Incoming protons were generated between $0^\circ < \theta < 85^\circ$ and with energies between 1.3 TeV and 1000 TeV assuming a differential energy distribution of $E^{-2.67}$. Simulating a statistically significant sample of atmospheric muon background is an extremely CPU-intensive task due to the high rejection factors needed. We have simulated $6.3 \times 10^{10}$ primary interactions, giving $3.9 \times 10^7$ atmospheric muon triggers, which corresponds to 8 days of detector lifetime.

In all these simulations, muon interaction probabilities from \cite{15} were used.

4 Data analysis

The analysis presented in this paper was performed on data taken with the 10-string AMANDA detector between March and November 1997. The original data set consists of $10^9$ events in a total of 135 days of detector lifetime. We apply five different levels of cuts which primarily cut on the zenith angle, the number of hits, the track length and some variables that describe the space and time topology of the event \cite{16}. At level 5, we have cut away all
the atmospheric muon background and are left with 15 neutrino events in data which is consistent with the expected 16.6 events from the atmospheric neutrinos. The passing rate for a WIMP with mass 250 GeV and a hard annihilation spectrum is 29% at the same level.

5 Results

In Fig. 1 we plot the events at level 5 together with the prediction for the atmospheric neutrinos. We also plot the expected angular distribution from a WIMP. As can be clearly seen, we do not see any statistically significant excess of nearly vertical neutrino-induced muons. Hence, we will use these remaining events to derive an upper limit on the WIMP signal.

5.1 Limits on the WIMP signal

As seen in Fig. 1, the WIMP signal is very peaked towards vertical muons, suggesting that we should cut further in the zenith angle. If we cut at $\theta = 165^\circ, 170^\circ, 172.5^\circ$ or $175^\circ$ we can derive 90% C.L. limits on the number of signal events, 7.0, 5.6, 4.5 and 5.2 events respectively. Although the systematic
Table 1. The 90% confidence level on the neutrino to muon conversion rate ($\Gamma_{\nu\mu}$) (for muons above 10 GeV), the WIMP annihilation rate ($\Gamma_A$) and the muon flux (above 1 GeV).\[10^8\] uncertainties for different angular cuts currently are under investigation, we choose here to use the angular window which gives the best limits. From these limits on the number of signal events we can calculate limits on the neutrino-to-muon conversion rate, $\Gamma_{\mu\nu}$, which is the number of neutrinos that interact and produce a muon per volume element per second. In Table 1 we show the limits on the neutrino-to-muon conversion rate where the muon energy (at the neutrino-nucleon vertex) is above 10 GeV. We also show the corresponding limits on the WIMP annihilation rate in the center of the Earth, $\Gamma_A$ and to compare with previous experiments, we also show the calculated limits on the neutrino-induced muon flux above 1 GeV.

In Fig. 2, the limits on the annihilation rate are shown and in Fig. 3 we show the limits on the neutrino-induced muon flux. In that figure we also show predictions from the MSSM when the WIMP is a neutralino and we also compare with other experiments. We see that, especially at higher masses, AMANDA is already with this limited data set competitive with previous experiments.

5.2 Systematic uncertainties

The limits are subject to experimental and theoretical systematic uncertainties which affect the estimated background and the effective volume and propagate to our derived limits. The precise effect is currently under detailed in-
vestigation but preliminary estimates indicate that the limits may have to be increased by about a factor of 2–3.

6 Conclusions

We have performed a search for an excess of vertically upgoing muons with the AMANDA-B10 neutrino detector as a signature for WIMP annihilations in the center of the Earth. Limits on the signal from WIMPs have been derived from the non-observation of an effect. The limits presented here are obtained with 135 days of effective detector lifetime and are already comparable with limits obtained by Baikal, Baksan, Super-Kamiokande and MACRO, with much longer accumulated lifetimes. The systematic uncertainties are under investigation and preliminary results suggest that the limits may increase by about a factor of 2–3 when they are included.
Acknowledgments

This research was supported by the U.S. NSF office of Polar Programs and Physics Division, the U. of Wisconsin Alumni Research Foundation, the U.S. DoE, the Swedish Natural Science Research Council, the Swedish Polar Research Secretariat, the Knut and Alice Wallenberg Foundation, Sweden, the German Ministry for Education and Research, the US National Energy Research Scientific Computing Center (supported by the U.S. DoE), U.C.-Irvine AENAS Supercomputer Facility, and Deutsche Forschungsgemeinschaft (DFG). D.F.C. acknowledges the support of the NSF CAREER program. P. Desiati was supported by the Koerber Foundation (Germany). C.P.H. received support from the EU 4th framework of Training and Mobility of Researchers. St. H. is supported by the DFG (Germany). P. Loaiza was supported by a grant from the Swedish STINT program.

References

1. See e.g. L. Bergström Rept. Prog. Phys. 63 (2000) 793.
2. See e.g. G. Jungman, M. Kamionkowski and K. Griest, Phys. Rep. 267 (1996), 195.
3. M. Ambrosio et al., Phys. Rev. D60 (1999) 082002; T. Montaruli et al. (MACRO Collaboration), 26th ICRC, Salt Lake City, 1999.
4. V. A. Balkanov et al., Proc. of 2nd Intl. Conf. on Nonaccelerator New Physics (NANP 99), Dubna, Moscow Region, Russia, 28 Jun - 3 Jul 1999.
5. O. Suvorova et al. (BAKSAN Collaboration), in Non-Accelerator New Physics, Dubna, Russia (1997); M. M. Boliev et al., Nucl. Phys. Proc. Suppl.70 (1999), 371-373.
6. M. Mori et al., Phys. Rev. D48 (1993), 5505-5518.
7. E. Andrés et al., Astropar. Phys. 13 (2000) 1.
8. T. Sjöstrand, Comm. Phys. Comm. 82 (1994), 74.
9. H. L. Lai et al., Phys. Rev. D58 (1998), 103519.
10. P. Lipari, Astropart. Phys. 1 (1993), 195.
11. R. Ghandi et al., Astropart. Phys. 5 (1996), 81.
12. H. L. Lai et al., Phys. Rev. D51 (1995), 1280.
13. E. Dalberg, PhD Thesis. Stockholm University (1999).
14. S. N. Boziev et al. INR preprint P-0630, Mowcow (1989).
15. W. Lohmann et al., CERN Yellow Report CERN-EP/85-03, (1985).
16. P. Loaiza, Licentiat thesis, Uppsala University (2000).
17. The AMANDA Collaboration, in preparation.