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SEARCH FOR MAGNETIC MONOPOLES WITH THE ANTARES DETECTOR

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Abstract. The ANTARES neutrino telescope is fully operational since May 2008. Located at a depth of 2500 m in the Mediterranean Sea, 40 km off the Provencal coast, it comprises a large three-dimensional array of 885 Optical Modules deployed on 12 vertical lines. The telescope is aimed to observe high energy cosmic neutrinos through the detection of the Cherenkov light produced by up-going induced muons. Besides the detection of high energy neutrinos, the ANTARES telescope offers an opportunity to improve sensitivity to exotic cosmological relics, like magnetic monopoles. Monopoles are hypothetical particles initially predicted by Dirac in 1931, and reintroduced some decades later in a large class of Grand Unified Theories. Relativistic magnetic monopoles can emit a large amount of Cherenkov light when passing through matter, with intensity 8500 times higher than that radiated from a muon. Dedicated trigger algorithms and search strategies have been developed to search for such bright objects with the ANTARES detector. The data filtering, background rejection and final selection criteria will be described, as well as the expected sensitivity of ANTARES to exotic physics.

1 Introduction

The ANTARES neutrino telescope is aimed to observe high energy cosmic neutrinos through the detection of the Cherenkov light produced by up-going induced muons. However, the ANTARES detector is also sensitive to a variety of exotic particles, and can provide an unique facility for the search of magnetic monopoles.

2 The ANTARES detector

The ANTARES detector has reached its nominal size in May 2008. The 885 Optical Modules (OM) are deployed on twelve vertical lines in the Western Mediterranean, at depths between 2050 and 2400 meters. The OMs, consisting of a glass sphere housing a 10" Hamamatsu photomultiplier (PMT) (Aguilar J.A. et al. 2005), are arranged by triplet per storey. Each detector line, made of 25 storeys, is connected via interlinks to a Junction Box, itself connected to the shore station at La Seyne-sur-Mer through a 40 km long electro-optical cable. The strategy of the ANTARES data acquisition is based on the "all-data-to-shore" concept (Aguilar J.A. et al. 2007). This implementation leads to the transmission of all raw data above a given threshold to shore, where different triggers are applied for storage.

For the analysis presented here, only the two most generic triggers are described. Both are based on local coincidences. A local coincidence (L1 hit) is defined either as a combination of two hits on two OMs of the same storey within 20 ns, or as a single hit with a large amplitude, typically 3 pe. The first trigger, a so-called directional trigger, requires five local coincidences anywhere in the detector but causally connected, within a time window of 2.2 μs. The second trigger, a so-called cluster trigger, requires two T3-clusters within 2.2 μs, where a T3-cluster is a combination of two L1 hits in adjacent or next-to-adjacent storeys. When an event is triggered, all PMT pulses are recorded over 2.2 μs.

The ANTARES observatory was built gradually, giving rise to various detector layouts used for physics analysis. The 5-line, 10-line and 12-line detector configurations match with data taken from January 2007, from December 2007 and from May 2008, respectively.

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3 Introduction to magnetic monopoles

Most of the Grand Unified Theories (GUTs) predict the creation of magnetic monopoles in the early Universe. Indeed, in 1974, 't Hooft (t'Hooft G. 1974) and Polyakov (Polyakov A.M. 1974) showed independently that elements caracterising well a magnetic charge, as introduced by Dirac in 1931 (Dirac P.A.M. 1931), occur as solutions in unified gauge theories, in which $U(1)_{E.M.}$ is embedded in a spontaneously semi-simple gauge group. These particules are topologically stable and carry a magnetic charge defined as a multiple integer of the Dirac charge $g_D = \frac{\hbar c}{2e}$, where e is the elementary electric charge, c the speed of light in vacuum and $\hbar$ the Planck constant. Depending on the group, the masses inferred for magnetic monopoles can take range over many order of magnitudes, from 10^8 to 10^{17} GeV.

As magnetic monopoles are stable, and so would survive until now, they should have been very diluted in the Universe, as predicted by numerous theoritical studies which set stringent limit on their fluxes, like the Parker limit flux. More stringent limits were set recently by different experiments as MACRO (Giacomelli G. & Margiotta A. 2007), and AMANDA (The Icecube Coll. 2007).

The development of the neutrino astronomy in the last decade led to the construction of huge detectors, which allow new hopes in the search for magnetic monopoles. Actually, the ANTARES detector seems to be well designed to detect magnetic monopoles, or at least to improve limits on their fluxes, as described below.

4 Signal and background simulations

Since fast monopoles have a large interaction with matter, they can loose large amounts of energy in the terrestrial environment. The total energy loss of a relativistic monopole with one Dirac charge is of the order of 10^{11} GeV (Derkaoui J. et al. 1998) after having crossed the full diameter of the Earth. Because magnetic monopoles are expected to be accelerated in galactic coherent magnetic field domain to energies of about 10^{15} GeV (Wick S.D. et al. 2003), some could be able to cross the Earth and reach the ANTARES detector as upgoing signals.

The monopole's magnetic charge $g = ng_D$ can be expressed as an equivalent electric charge $g = 68.5ne$, where n is an integer. Thus relativistic monopoles with $\beta \geq 0.74$ carrying one dirac charge will emit a large amount of direct Cherenkov light when traveling through the ANTARES detector, giving rise to $\sim$ 8500 more intense light than a muon. The number of photons per unit length (cm^{-1}) emitted on the path of a monopole is shown in figure 1, as a function of the velocity of the monopole up to $\gamma = 10$ ($\beta = 0.995$).

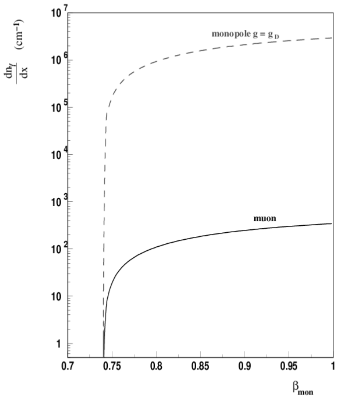

Fig. 1. Number of emitted photons per unit length (cm^{-1}) by a magnetic monopole with a charge $g = g_D$ through direct Cherenkov emission (dashed line) compared to the number of photons emitted by a muon (black line), as a function of their velocities.

For the analysis, monopoles have been simulated inside an optimised volume containing the 12-line detector, for six ranges of velocities between $\beta = 0.74$ and $\beta = 0.995$. In addition, downgoing atmospheric muons have been simulated using the CORSIKA package (Heck D. et al 1998), as well as upgoing and downgoing atmospheric neutrinos according to the Bartol flux (Agrawal V. et al. 1996; Barr G. et al. 1989). Optical background from ^{40}K decay has been added to both magnetic monopole signal and atmospheric background events.

5 Search strategy

The 12-line detector data are triggered by both trigger logics, the directional and the cluster triggers (see section II). A comparison of efficiency was therefore performed on magnetic monopoles and restricted only to upward-going events. As the efficiency of the directional trigger was found to be lower than the cluster trigger, it was decided to perform searches for upgoing magnetic monopoles with the cluster trigger only.
The standard reconstruction algorithm, developped in ANTARES for upward-going neutrino selection, and mainly based on a likelihood maximisation, was applied. In order to select upgoing particules, only reconstructed events with a zenith angle lower than 90° were kept. However, muon bundles are difficult to reconstruct properly and some of them can be reconstructed as upward-going events.
As it is shown in figure 2, a magnetic monopole traversing the detector will emit an impressive quantity of light, compared to atmospheric muons or muons induced by atmospheric neutrinos. The large amount of induced hits in the detector, more precisely the number of T3 clusters, is therefore used as a criteria to remove a part of the atmospheric background.

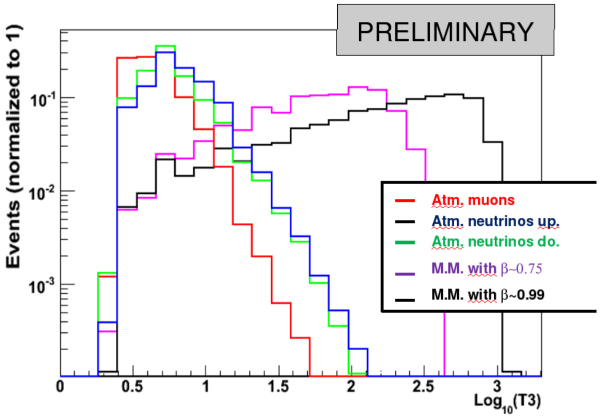

Fig. 2. Normalized events as a function of the number of T3 clusters for downgoing atmospheric muons, upgoing and downgoing atmospheric neutrinos, and upgoing magnetic monopoles with $\beta \sim 0.75$ and $\beta \sim 0.99$.

Before to apply supplementary cut to reduce the remaining background, 10 active days of golden[1] data were taken as reference to check the data MonteCarlo agreement. The comparison of T3 distributions between the data and the background simulation for 10 days is shown in figure 3.

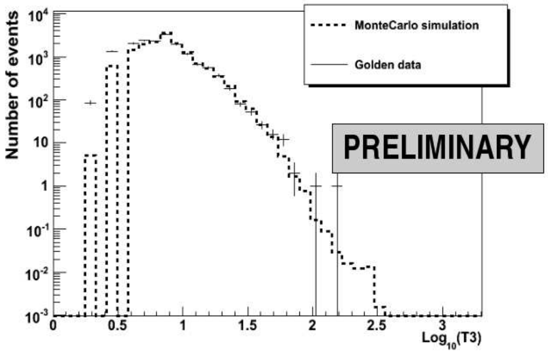

Fig. 3. Comparison of T3 distributions between data and MonteCarlo simulations for 10 days of data taking.

We optimised the cuts on the number of T3 clusters to maximise the 90% C.L. sensitivity, calculated with the

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[1] Golden data assumes experimental data complying with certain selection criteria like low baserate and burstfraction.

usual Feldman-Cousins formula (Felman G.J. & Cousins R.D. 1998), for magnetic monopoles after one year of data taking. In the optimisation process the same selection criteria have been applied to calculate the sensitivity to magnetic monopole events over the whole velocity range $0.74 \leq \beta \leq 0.995$.
Finally the 90% C.L. sensitivity for this range was found, for a cut of at least 140 T3 clusters, for which around 1.9 background events are expected. The 90% C.L. sensitivity for ANTARES after one year of data taking is shown in figure 4.

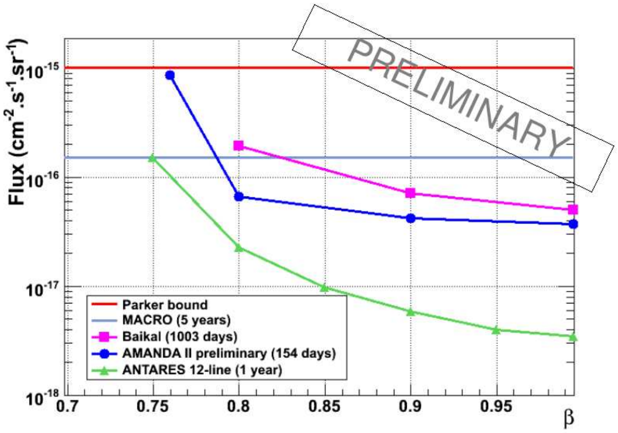

Fig. 4. Preliminary expected sensitivity with 90% C.L. with the 12-line ANTARES detector after one year of data taking, compared to upper limits set by other experiments.

6 Conclusion

The emergence of neutrino astronomy in the last decade gives new opportunities for the search of exotic particles. In this paper was presented the search strategy employed for upgoing relativistic magnetic monopoles with the ANTARES detector in the 12-line configuration. As shown, the signal emitted by a relativistic magnetic monopole in sea water would be easily isolated from the background light coming mainly from atmospheric muons, and neutrinos. This study leads to a sensitivity on magnetic monopoles of the order of $\sim 1.10^{-17} cm^{-2} s^{-1} sr^{-1}$ with 90% C.L. after one year of data taking, competitive with upper limits set by the other experiments over the whole velocity range $0.74 \leq \beta \leq 0.995$.

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