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Search for magnetic monopoles with the ANTARES neutrino telescope

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Magnetic monopoles are hypothetical particles predicted to be created in the early Universe in the framework of Grand Unified Theories (GUTs). The signature of the passage of relativistic magnetic monopole in a Cherenkov telescope like ANTARES (Astronomy with a Neutrinos Telescope and Abyss environmental RESearch) [1] is expected to be evident and unambiguous because of the large amount of light emitted compared to that from muons.

A first study has been carried out in ANTARES using a limited data set of 116 days; first upper limits on the magnetic monopoles flux were established for relativistic monopoles with $\beta \geq 0.625$. We present here an update of the analysis, using an enlarged data set (data collected from January 2008 to December 2013) and considering a wider range of values for β. No monopoles have been observed, and new sensitivity has been set, for monopoles with $\beta \geq 0.572$.

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1. Introduction

Grand Unified Theories (GUTs) predict the creation of magnetic monopoles in the early Universe [2]. Their detection in a neutrino telescope is similar to the detection of high energy muons. As for electric charges, magnetically charged particles produce Cherenkov emission when their velocity is higher than the Cherenkov threshold $\beta = {}^{1}/_{n}$, where n is the phase refractive index of the medium.

In this analysis, we restrict the selected sample to up-going monopoles to ensure an easy separation from atmospheric muons. However, fast monopoles can lose an energy of 10^{11} GeV when traversing the full diameter of the Earth, but they are expected to be accelerated in the Galactic coherent magnetic field domain to energies up to 10^{15} GeV. Thus, only monopoles in the energy range $10^{12} - 10^{15}$ GeV are expected to be detectable in this analysis as up-going signals.

2. Monte Carlo simulation and reconstruction

Up-going magnetic monopoles have been simulated using ten equidistant ranges of velocities in the region $\beta = [0.55\ , 0.995]$, and a package named *Simon* has been used [3]. It is based on Monte Carlo generators used in ANTARES to simulate neutrino interactions. This package contains two main programs, *genmon* which is used to generate monopoles, and *geamon* simulating the emission of light and the response of the detector. Monopoles are simulated as tracks. They are generated uniformly over the hemisphere above and below the detector. Atmospheric muons and neutrinos have been also simulated as background.

The events are then reconstructed using an algorithm named *BBFit*, that is usually applied in the analysis of neutrino candidates [4]. Indeed, the standard track reconstruction assumes that particles travel at the speed of light. In order to improve the sensitivity for magnetic monopoles traveling with lower velocities, the *BBFit* reconstruction algorithm has been modified so as to leave the velocity β as a free parameter to be determined by the track fit.

3. Analysis strategy and quality cuts

Some primary cuts are applied for the whole velocity range. The first selection cut, which is expected to remove a large part of down-going muons and neutrinos, concerns the zenith angle which must be smaller than $90°$ since we search for up-going monopoles. In order to further reduce the background, a second cut was applied, which consists to consider only events reconstructed on at least 2 lines of the detector ($nlines \geq 2$). The other discriminative variables are based on physical properties of monopoles and the quality of reconstruction.

Two different strategies are followed in the analysis, depending on monopoles velocity. In the first range of β the optimization is done for 6 values of β ranging from 0.55 to 0.817. The discrimination of magnetic monopoles from background relies on β reconstruction. While muons and neutrinos have approximately the speed of light, monopoles can be distinguished by their specific speed. Thus, to isolate monopoles from atmospheric muons and neutrinos a cut on the reconstructed β is used as a pre-selection cut. Relativistic monopoles ($\beta \geq 0.74$) will emit a large amount of direct Cherenkov light when travelling through the ANTARES detector. For β ranging from 0.817 to 0.995 the track reconstruction algorithm is not able to discriminate the velocity and thus $\beta = 1$ is assumed. The discrimination against the background relies on the number *Nhit* of storeys used by the algorithm to reconstruct the track. Another variable named α containing the track fit quality parameter $t\chi^2$ and *Nhit* is also used in this analysis.

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In order to avoid biases when elaborating the analysis strategy, the ANTARES Collaboration follows a "blind approach": data are "blinded" (information on the direction is "masked") when the process of optimization of the cuts is carried out. However, in order to make comparison between real and Monte Carlo data, the collaboration allows using a sample of real data. The sample used here (Figure 1 and 2) is composed by the so-called "0 runs" (runs ending with a 0).

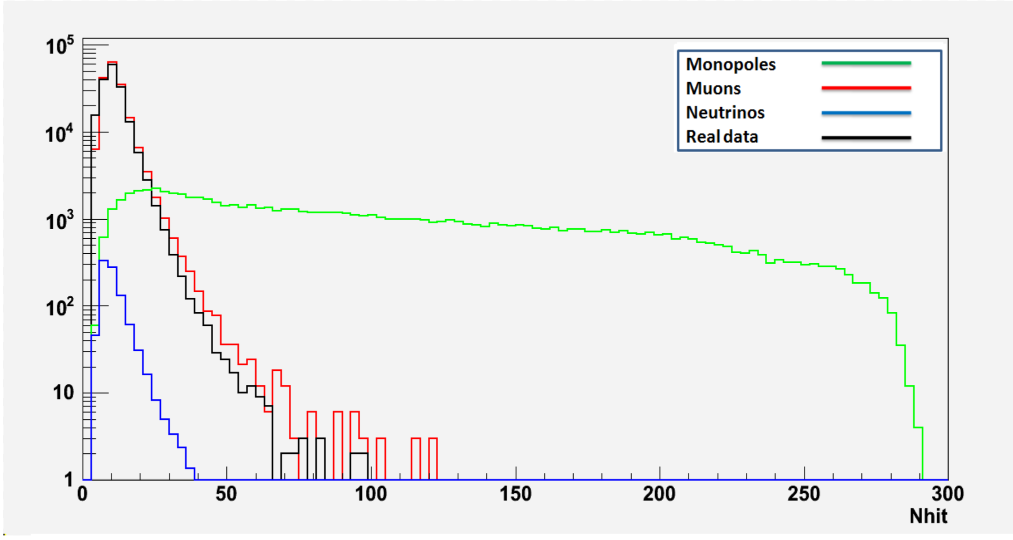

Figure 1: Nhit distribution for monopoles with $\beta = 0.97275$ and background, compared to the selected data set.

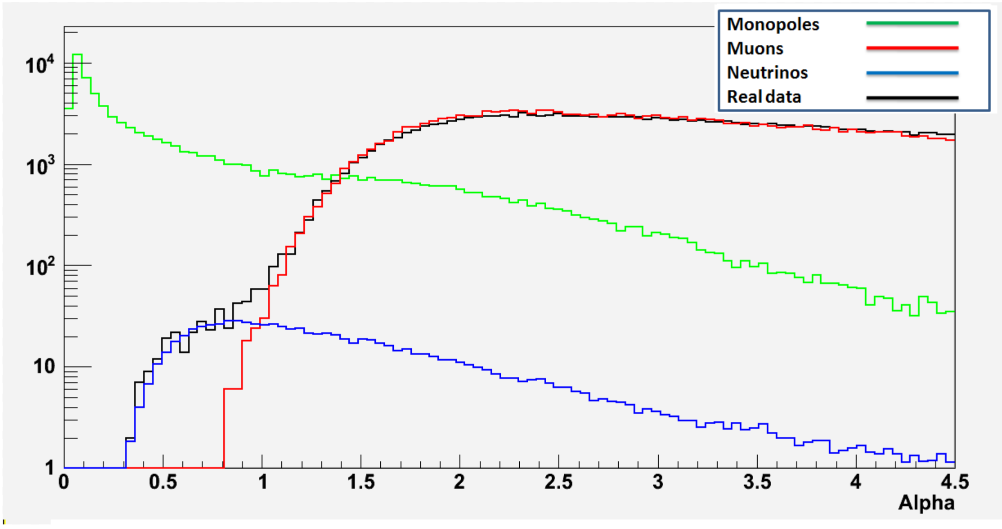

Figure 2: Alpha distribution for monopoles with $\beta = 0.97275$ and background, compared to the selected data set.

4. The Model Rejection Factor

The 90% C.L. sensitivity $S_{90\%}$ is calculated with the Feldman-Cousins formula [5], considering events which follow a Poissonian distribution:

$$S_{90\%} = \frac{\bar{\mu}_{90}(n_b)}{S_{eff} \times T} \quad , \tag{1}$$

where $\boldsymbol{T}$ is the duration of the data taking, and where $\bar{\mu}_{90}$ and S_{eff} are defined as:

$$\bar{\mu}_{90}(n_b) = \sum_{n_{obs}=1}^{\infty} \mu_{90}(n_{obs}, n_b) \frac{n_b^{\,n_{obs}}}{n_{obs}!} e^{-n_b} \quad , \tag{2}$$

$$S_{eff} = \frac{n_{MM}}{\Phi_{MM}} \quad , \tag{3}$$

with n_{MM} the number of monopoles remaining after cuts, and ϕ_{MM} the flux of monopoles generated.

The Model Rejection Factor consists in playing with cuts in order to get the minimum of Rejection Factor (RF) (equation 4) where the best sensitivity is obtained.

$$RF = \frac{\bar{\mu}_{90}(n_b)}{n_{MM}} \ . \tag{4}$$

To optimize the 90% C.L. sensitivity the two quantities to play with are α and *Nhit*. The Rejection Factor is calculated for each couple of cuts (α, *Nhit*), where α is varying from 0 to 4.5, and *Nhit* varying from 0 to 300 (see figure 3).

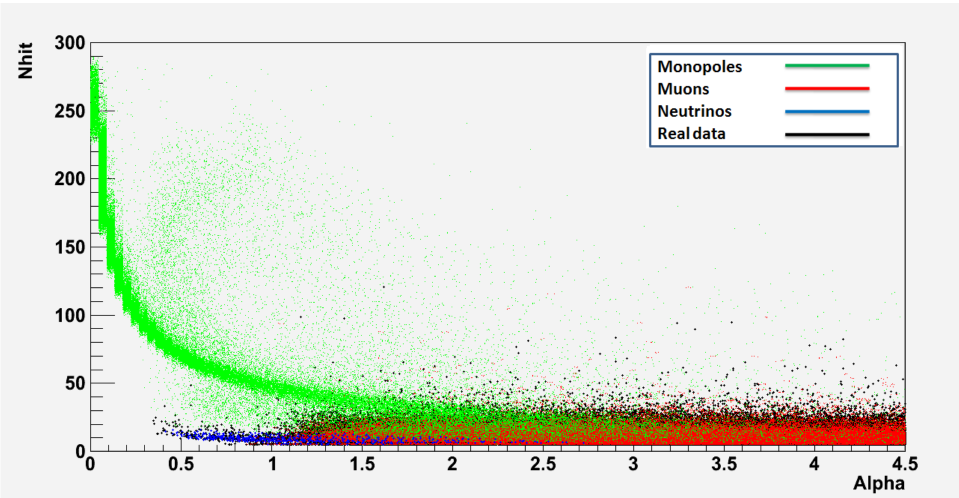

Figure 3: 2D histogram representing the distribution of alpha and Nhit for magnetic monopoles with a speed $\beta = 0.97275$ (green points) and MC atmospheric background (red and blue points), compared to the selected data set.

Figure 4 illustrates the variation of Rejection Factor as a function of (α, Nhit) cuts.

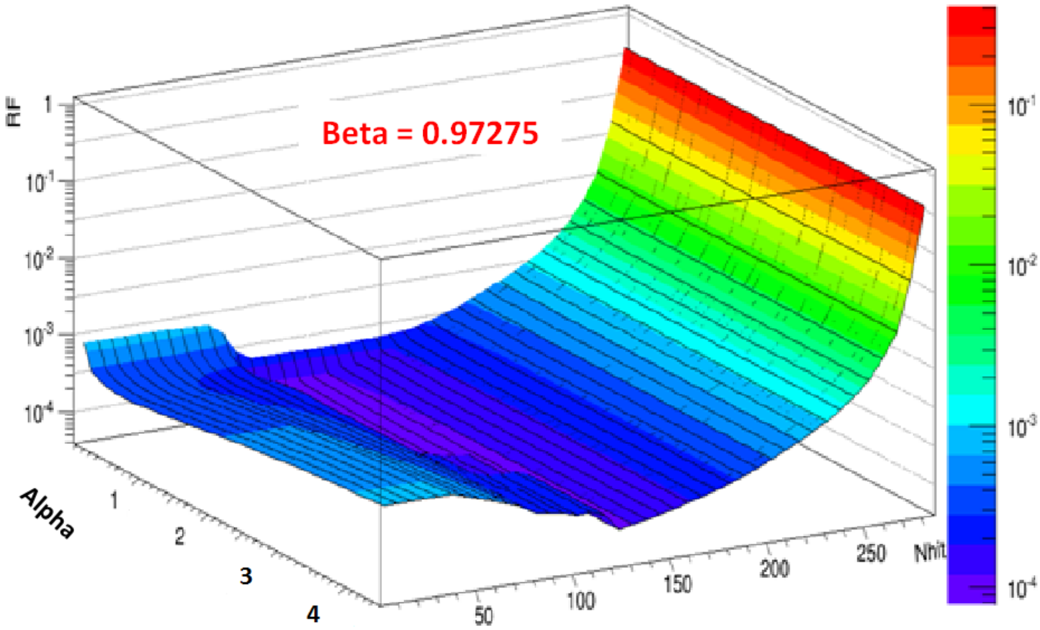

Figure 4: The rejection factor RF as a function of α and nhit cuts.

In this case of $\beta = 0.97275$ the minimum of RF corresponds to 5.9×10^{-5}, which is then taken to calculate the sensitivity. This is done for each value of the velocity.

5. Sensitivity

Figure 5 presents the ANTARES sensitivity obtained assuming data collected during 6 years when applying equation (1), compared to the upper limits on the flux found by other experiments and including the upper limit (116 days) of the previous analysis of ANTARES. As we see, despite the fluctuation of the sensitivity at lower β, it is better than all the upper limits obtained so far.

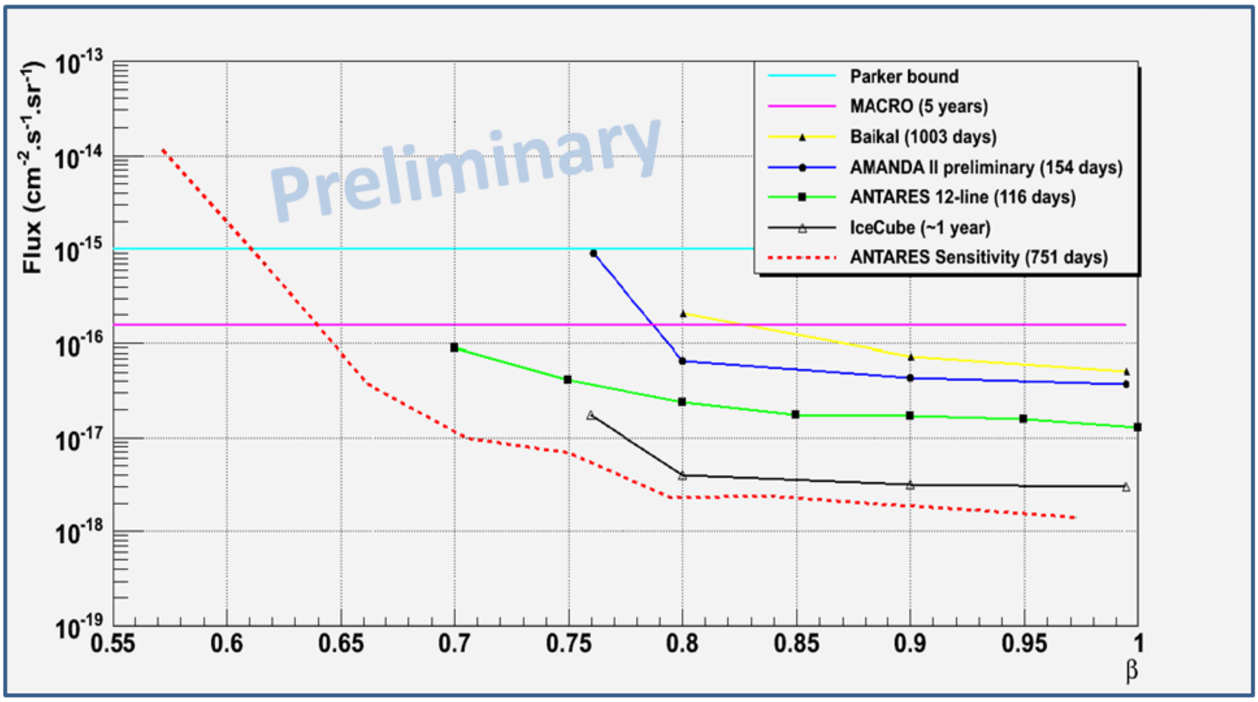

Figure 5: ANTARES sensitivity on the flux of monopoles as a function of beta, found assuming data collected during 6 years (red), compared to the upper limits on the flux obtained by other experiments.

6. Conclusion

This paper presents a preliminary result of the analysis performed to search for up-going magnetic monopoles with velocity β ranging from 0.55 to 0.995. The optimization of the Model Rejection Factor has led to find a new sensitivity on monopoles flux. The analysis strategy here discussed is very promising to investigate a wide range of values of β and will be soon applied to the entire set of ANTARES data collected from January 2008 to December 2013.

References

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