Search for relativistic monopoles with the Baikal neutrino telescope

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Abstract

We present a method and first results of a search for relativistic monopoles with the Baikal neutrino telescope. The method is based on the enormous amount of Cherenkov radiation emitted by these particles. The upper limit obtained for the flux of magnetic monopoles is below the Chudakov-Parker limit. This result demonstrates the potential of underwater neutrino telescopes with respect to the search for exotic particles.

1 Introduction

Fast magnetic monopoles with Dirac charge $g \approx 68.5e$ are attractive objects to search for with deep underwater neutrino telescopes. Going through the galaxy a monopole could be accelerated by galactic magnetic fields up to energies of $10^{11} \div 10^{12}$GeV and in case of a sufficiently small mass M< $10^{11} GeV/c^2$ became relativistic. The initial energy significantly exceeds the energy loss of a monopole coming through the Earth. This makes it possible to select monopoles from the lower hemisphere with a significant suppression of the background caused by atmospheric muons. Linear intensity of monopole Cherenkov radiation is about 8300 times higher than muons one. The standard optical module (OM) used in the BAIKAL experiment could detect such objects from distances up to $60 \div 80$m.

The results of a search for fast bare monopoles with one magnetic Dirac charge are presented in this paper. Upper limits on the flux of monopoles with velocities $\beta = v/c \geq 0.8$ have been obtained.

2 The detector

In April 1996, the *NT-96* array consisting of 96 optical modules (OMs) was put into operation Belolaptikov et al.,(1997).The OMs are fixed at four strings, each 72 m long. The OMs are grouped in pairs along the strings. They contain 37-cm *QUASAR* phototubes Bagduev et al.,(1994) . The two tubes of a pair are switched in coincidence in order to suppress background from bioluminescence and dark noise. A pair defines a *channel*.

Each string consists of 12 channels. All OMs face downward, with the exception of the OMs of the second and eleventh layers, which look upward. The distance between downward oriented layers is 6.25 m, the distance between layers facing to each other (layers 1/2 and 10/11) is 7.5 m, the distance between back-to-back layers (2/3 and 11/12) is 5.0 m. The strings are arranged at the edges of a trapezoid with side lengths of 3×18.5 m, and 1×10.2

A *muon trigger* is formed by the requirement of $\geq N$ hit channels within about 500 nsec. N is typically set to the value of 3 or 4. For such events, amplitude and time of all fired channels are digitized and sent to shore. The event record includes all hits within a time window of -1.0 μsec to +0.8 μsec with respect to the muon trigger signal.

3 Search for fast monopoles ($\beta > 0.75$)

The theory of Cherenkov radiation of magnetic monopoles was investigated by various authors Frank I.M.,(1988) and Kirzhnits D.A., Lossjakov V.V.,(1985)

Assuming a permeability $\mu = 1$, the number of Cherenkov photons emitted by a monopole is:

$$\frac{dn_c}{dx d\lambda} = \frac{2\pi\alpha}{\lambda^2}\left(\frac{ng}{e}\right)^2\left(1 - \frac{1}{n^2\beta^2}\right) \quad (1)$$

where n is the refraction index ($n = 1.33$ for water). For given velocity β the monopole Cherenkov radiation exceeds that of a relativistic muon by a factor $(gn/e)^2$ (e.g. for $g = 137e/2$ one has $(gn/e)^2 = 8.3 \cdot 10^3$).
Fast monopoles with $\beta \geq 0.8$ can be detected up to distances of 55 m $\div$ 85 m which correspond to effective areas about 10^4 m^2. The space-dependent number of photo electrons produced in the OM from a monopole is shown in fig.1. The natural way to detect fast monopoles starts with the selection of events with high multiplicity of hits. In order to reduce the background from downward atmospheric muons we restrict ourself to monopoles coming from the lower hemisphere. Two independent approaches have been used to select upward going monopole candidates from data taken during 70 days of live-time with the *NT-96*.

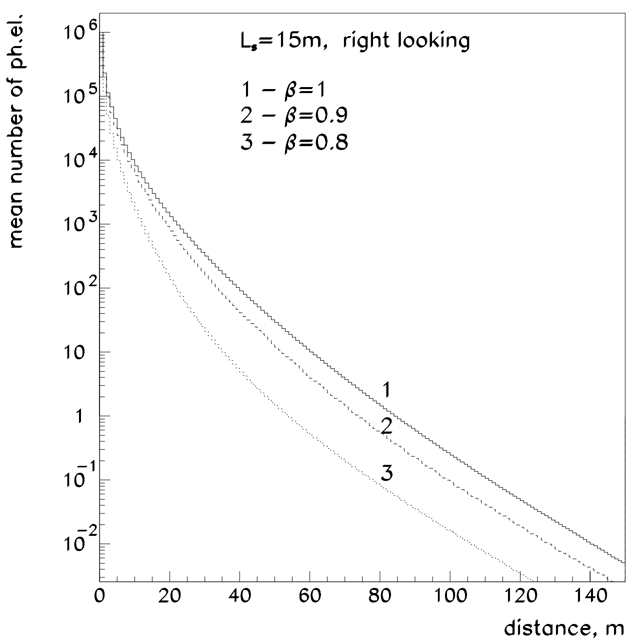

Figure 1: Expected numbers of p.e. versus distance from monopole track to OM

3.1 Timing The first approach is similar to the method which was applied to upward moving muons.

Starting from an isotropic flux of fast monopoles the time cut was applied to a MC sample:

$$|(t_i - t_j) - z_{ij}/c| < (z_{ij}/z_{1,12}) \cdot dt + \delta, \quad (i < j) \quad (2)$$

with $\delta = 10$ nsec and $dt = 70$ nsec. Here, $t_i(t_j)$ is the measured time in the hit channel $i(j)$, z_{ij} – the distance between the channels. The average number of channels hit in *NT-96* by a monopole going at a distance of 60 m from the detector center will be about 40 channels.

In the next step events with a hit multiplicity $N_{hit} > 25$ were selected as monopole candidates. Fig.2 shows the effective areas for three monopole velocities. Applying the same cuts to experimental data, no candidates have been found.

3.2 Space-time correlation The second approach is based on the fact that for an upward going particle the times of hit channels increase with rising z-coordinates from the bottom to the top of the detector. To select upward moving particles, a cut on the value of space-time correlation for events has been applied:

$$corztf = \frac{\sum_{i=1}^{N_{hit}}(t_i - \overline{T})(z_i - \overline{z})}{N_{hit}\ sigma_t \sigma_z} > 0.6, \quad (3)$$

where $\overline{T}$ and $\overline{z}$ are mean values for times and z-coordinates of hit channels, σ_t and σ_z are gaussian errors of the times and z-coordinates for each event.

The cut on hit multiplicity was set to $N_{hit} > 35$.

In this approach the aperture of *NT-96* for $\beta = 1.0$, 0.9 and 0.8 is about $2.9 \cdot 10^4 \mathrm{m}^2\mathrm{sr}$, $2.1 \cdot 10^4 \mathrm{m}^2\mathrm{sr}$, and $0.8 \cdot 10^4 \mathrm{m}^2\mathrm{sr}$ respectively, taking into account the decreasing number of operating channels during 70 days. After applying the same cuts to the data sample, no candidates have been found.

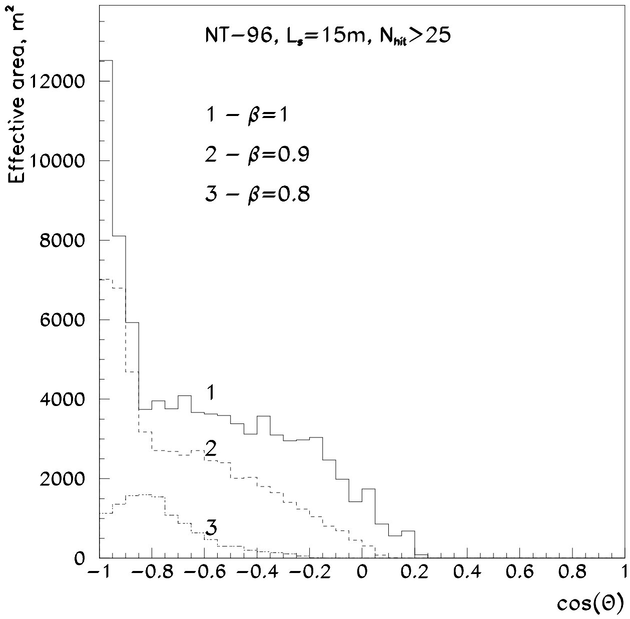

Figure 2: Effective area of *NT-96* for fast monopole detection in the first approach.

3.3 Upper limit on the flux of fast monopoles An approach similar to the one described in 3.1 was applied to the data taken during 0.42 year of live-time of the neutrino telescope *NT-36* Balkanov et al.,(1998).

¿From the non-observation of candidate events in *NT-96* and *NT-36*, an upper limit on the flux of fast magnetic monopoles was obtained. The combined 90% C.L. upper flux limit for an isotropic flux of bare fast magnetic monopoles obtained by us is compared to those obtained by other experiments Orito et al.,(1951), Ambrosio et al.,(1998), Adarkar et al.,(1990), Thorn et al.(1992) in Fig.3.

The results obtained with the pilot array *NT-96* illustrate the capability of the Baikal underwater experiment for searching bright objects, like fast magnetic monopoles. The full-scale neutrino telescope *NT-200* has been launched in April 1998. A limit on fast monopole flux of about 10^{-16} cm^{-2} sec^{-1} ster^{-1} can be obtained during one full year live-time data collecting by *NT-200*.

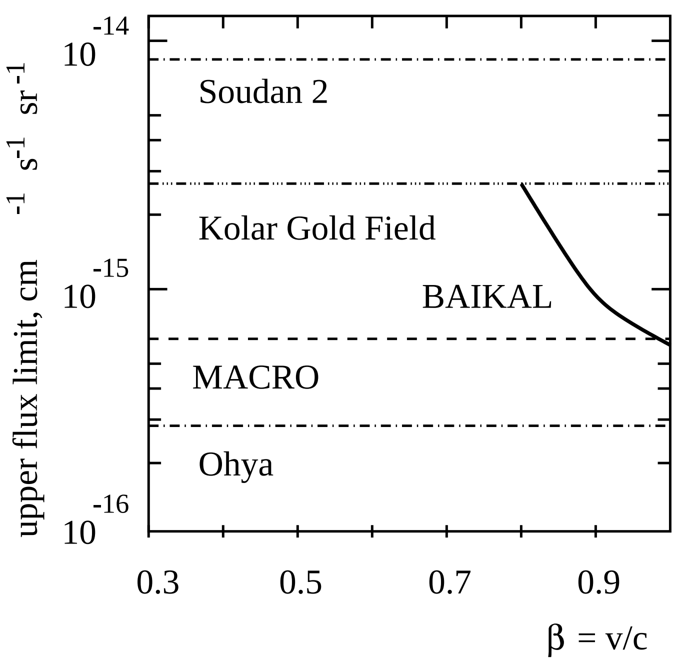

Figure 3: 90% C.L. upper flux limit obtained by Baikal experiment for an isotropic flux of fast bare magnetic monopoles compared with those obtained by other experiments.

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