Search for Magnetic Monopoles at a High Altitude Laboratory

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Abstract

A large area (400 m^2) experiment -SLIM- to search for intermediate mass magnetic monopoles and nuclearites has been installed at the Chacaltaya high - altitude laboratory since 2001. It is based on stacks of CR39 and Makrofol nuclear track detectors. In more that 4 years of operation it will be able to reach a sensitivity at the level of the Parker bound for monopole masses $M_M > 10^5$ GeV/c^2 over a wide velocity range. Preliminary results regarding the study of the local background (radon concentration, cosmic ray neutrons) are reported. An analysis of a first sample of about 50 m^2 of the exposed detector is also presented.

1. Introduction

Grand Unified Theories (GUT) of electroweak and strong interactions predict the existence of superheavy magnetic monopoles (MMs) with masses larger than 10^{16} GeV. They would have been produced at the end of the GUT epoch, at the mass scale $\sim 10^{15}$ GeV and cosmic time of $\sim 10^{-35}$ s, and could be present in the cosmic radiation [1].

The MACRO experiment provided the best direct experimental flux upper limit for GUT MMs over the widest velocity range [2].

Intermediate Mass Monopoles (IMMs) may have been produced in later phase transitions in the Early Universe, in which a semisimple gauge group yield a U(1) group, as for instance in the following sequence

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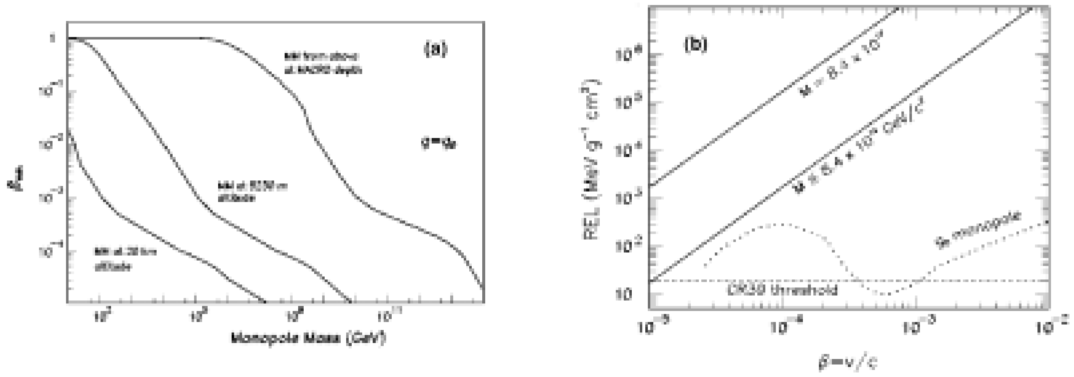

Fig. 1. (a): Accesibility regions for the search for IMM's (minimum velocity at the top of the atmosphere versus the monopole mass) for diferent altitudes. (b): Restricted energy losses of $1g_D$ magnetic monopoles and of nuclearites in CR39.

$$SO(10) \quad \xrightarrow[10^{-35}s]{10^{15}\ GeV} \quad SU(4) \times SU(2) \times SU(2) \quad \xrightarrow[10^{-23}s]{10^{9}\ GeV} \quad SU(3) \times SU(2) \times U(1) \tag{1}$$

which would lead to MMs with masses of the order of 10^{10} GeV; these monopoles would survive inflation, are stable, "doubly charged" and do not catalyze nucleon decay [3]. IMM's with masses between 10^5 and 10^{12} GeV may be accelerated to relativistic velocities in the galactic magnetic field and in several astrophysical sites. Thus, one would have to look for $\beta > 0.01$ fast, heavily ionizing MM's. It has been speculated that very energetic IMM's could yield the highest energy cosmic rays [4].

Detectors underground, underwater and under ice would mainly have a sensitivity for poles coming from above. Detectors at the Earth surface could detect MMs coming from above if they have masses larger than $10^5 - 10^6$ GeV [5]; lower mass MMs may be searched for with detectors located at high mountain altitudes, or in balloons and in satellites. Fig. 1 shows the experimentally accessible region in the search for IMM's: the minimal velocity at the entry point in the atmosphere versus the monopole mass, for different altitudes.

The SLIM experiment is searching for fast IMMs with nuclear track detectors at the Chacaltaya high altitude lab (5230 m above sea level) [6].

Nuclearites (strangelets, strange quark matter) are nuggets of strange quark matter (aggregates of u, d, and s quarks in approximately equal proportions); they could be the ground state of QCD and could be part of the cold dark matter with typical galactic velocities $\beta \sim 10^{-3}$ [7].

Cosmic nuclearites lose a large amount of energy for $\beta > 4 \times 10^{-5}$; thus they would be easily detectable with the SLIM apparatus. Fig. 1b shows the Restricted Energy Loss in CR39 for nuclearites and for $g = g_D$ magnetic monopoles. The high altitude exposure will allow detection of the above mentioned particles even if they had strong interaction cross sections which could prevent them from reaching the earth surface [8].

2. Experimental method

The SLIM apparatus consists of 400 m^2 of CR39 and Makrofol nuclear track detectors. The CR39 allows to search for magnetic monopoles with one unit Dirac charge (g=g_D), for β around 10^{-4} and for $\beta > 10^{-3}$, the whole β-range of $4 \times 10^{-5} < \beta < 1$ for MMs with $g \geq 2g_D$, for dyons, and for nuclearites. The polycarbonate has a higher threshold, and it is useful for fast ($\beta > 0.1$) monopole and for nuclearites.

The track-etch detector is organised in modules of 24 cm × 24 cm, each made of 3 layers of CR39, 3 layers of polycarbonate and of an aluminium absorber 1 mm thick; this module is sealed in an aluminized plastic bag filled with dry air. Since the atmospheric pressure at Chacaltaya is 0.5 atm, we made a test in which some envelopes filled with 1 atm of air were sealed and placed in a chamber at a pressure of about 0.3 atm for three weeks; no significant leakage was detected in any of them. From our experience with MACRO, where the same CR39 material was used we know that such material does not suffer from “aging effects”, for exposure times as long as 10 years, that is, there is no appreciable dependence of the detector response on the time elapsed between the date of production and the passage of the particle [9].

The SLIM apparatus was completed in July 2001. We performed tests by exposing nuclear track detectors in Bologna and at the Chacaltaya mountain station, in order to study the effects of possible backgrounds and of possible climatic conditions.

3. Results and conclusions

Preliminary results of radon concentration in the experimental rooms at Chacaltaya were obtained by using E-PERM radon dosimeters. The radon activity (in different locations around SLIM) was found to be about 40 - 50 Bq/m^3. From our experience with the MACRO experiment at LNGS, we conclude that such levels of radon activity are not a problem for the experiment.

We made also preliminary measurements of the flux of cosmic ray neutrons with energy $1 < E_n < 20$ MeV, in the vicinity of the SLIM detector, using bubble counters and BF_3 gaseous detectors. We obtained $\Phi_n = (1.7 \pm 0.8) \times 10^{-2}$ $cm^{-2}s^{-1}$, in agreement with other reported neutron flux data at such altitudes [10].

A small quantity of modules exposed in SLIM was removed and processed (manly for testing the procedures). The analysed area totalises 51.8 m^2, with an average exposure time of 2.4 years. No candidate survived the tests, so the 90% C.L. flux upper limit for fast IMM's and nuclearites coming from above is at the level of 2×10^{-14} $cm^{-2}sr^{-1}s^{-1}$.

The analysis of the full detector will be started at the begining of 2004. As it can be seen in Fig. 2, in four years of operation SLIM should be able to reach a sensitivity of 10^{-15} $cm^{-2}sr^{-1}s^{-1}$ for $\beta \simeq 10^{-2}$ IMMs with masses larger than 10^4 GeV.

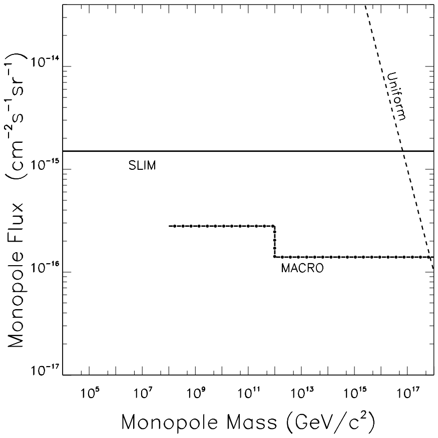

Fig. 2. Flux upper limits for IMMs versus monopole mass: the expected results (90% C.L. in the absence of candidates) for the SLIM and MACRO experiments are shown. The mass density limit for a uniform density of monopoles in the Universe is also plotted.

4. Aknowledgements

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5. References

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