IL NUOVO CIMENTO Vol. 24 C, N. 4-5 Luglio-Ottobre 2001

Search for magnetic monopoles at the Chacaltaya cosmic ray laboratory(*)

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(ricevuto il 13 Ottobre 2000; approvato il 12 Febbraio 2001)

Summary. — The new large area (400 m^2) experiment—SLIM—to search for magnetic monopoles and other exotic massive particles is presented. It uses of nuclear track detectors and is being deployed at the Chacaltaya cosmic ray laboratory for at least 4 years. The detection capability of the experiment is discussed.

PACS 14.80.Hv – Magnetic monopoles.
PACS 29.90 – Other topics in elementary-particle and nuclear physics experimental methods and instrumentation.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Grand Unified Theories (GUT) of electroweak and strong interactions predict the existence of superheavy magnetic monopoles (MM) with masses larger than 10^{16} GeV [1]. They would have been produced at the end of the GUT epoch, at the mass scale

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(*) Paper presented at the Chacaltaya Meeting on Cosmic Ray Physics, La Paz, Bolivia, July 23-27, 2000.

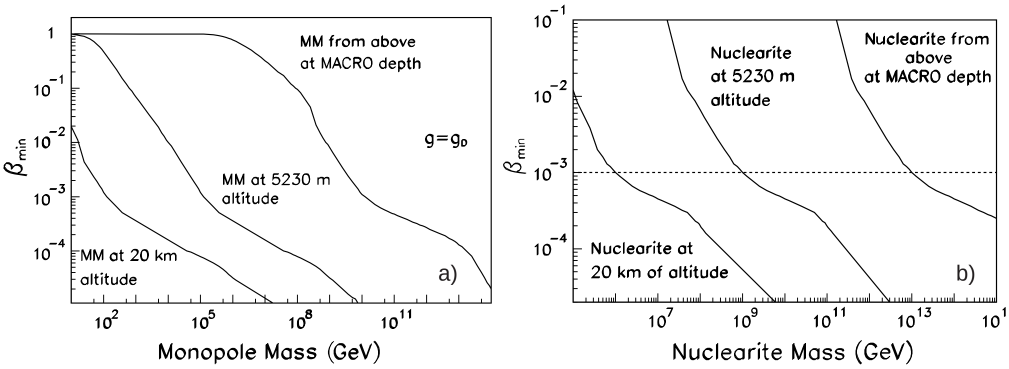

Fig. 1. – Left: Accessible regions in the plane (mass, β) for monopoles with magnetic charge $g = g_{\rm D}$ coming from above for an experiment at altitudes of 20 km, 5230 m, and for an underground detector at the Gran Sasso Lab. (like the MACRO detector). It is assumed that monopoles interact only via the electromagnetic interaction, and no radiative effects are considered [9]. If a light monopole attaches a nucleon or if it has some strong interaction, it could interact in the higher atmosphere, like primary protons and nuclei of the cosmic radiation. Right: Accessible region in the plane (mass, β) for nuclearites. Only the energy losses via electromagnetic interaction are considered (bremsstrahlung is not considered). If nuclearites are part of the dark matter they would have typical velocities of $\beta \sim 10^{-3}$. It is highly probable that low mass nuclearites interact strongly; thus they may not reach the lower atmosphere.

$\sim 10^{14}$ GeV and cosmic time of $\sim 10^{-34}$ s. Such monopoles cannot be produced with existing accelerators, nor with any foreseen for the future, but can be searched for in the cosmic radiation.

Several experiments, using different techniques, have tried to detect superheavy monopoles with velocities greater than $10^{-5}c$. The MACRO experiment at LNGS is the one providing the best experimental flux upper limit for GUT MMs over the widest velocity range [2].

The existence of MMs with masses around 10^6–10^{10} GeV that require a phase transition in the early universe in which a semisimple gauge group yields a $U(1)$ factor at a lower energy scale, has also been proposed (see, *e.g.*, [3]). One of the recent interests in relatively low mass MMs is connected also with the possibility that relativistic MMs could be the sources of the highest energy cosmic rays, with energies larger than 10^{20} eV [4, 5]. For monopoles possible acceleration mechanisms are known: since the basic magnetic charge should be very large, relatively light monopoles can be accelerated to relativistic velocities and to energies of the order of 10^{20} GeV in one coherent domain of the galactic magnetic field, or in the intergalactic field, or in many astrophysical sites, like in the magnetic field of Active Galactic Nuclei (AGN) and even of neutron stars. Experimental signatures for these monopoles can be established considering how they interact in the upper atmosphere and yield electromagnetic showers [6]. Other detection techniques can be devised in the case a monopole forms a bound state with a proton (a dyonic system) which may interact with a cross-section typical of a relativistic hadron ($\sigma \geq 10^{-26}$ cm^2) [7]. Monopole masses of 10^6–10^{10} GeV could be consistent with a flux at the Parker limit [8], *i.e.* $\sim 10^{-15}$ cm^{-2} s^{-1} sr^{-1}.

We present here the capabilities of the SLIM (Search for LIght Magnetic monopoles) experiment, an array of 400 m^2 of passive nuclear track detectors, that is currently under

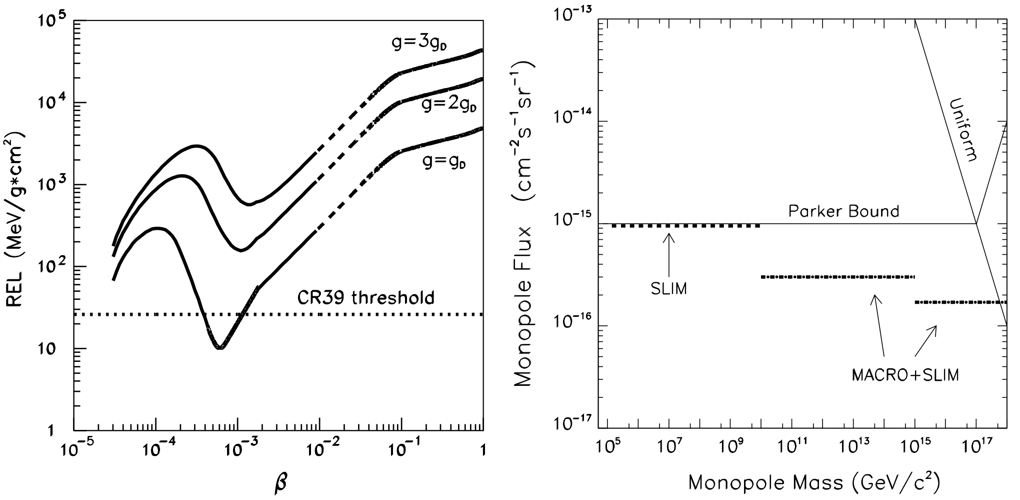

Fig. 2. – Left: Restricted Energy Losses of MMs *vs.* β in the CR39 nuclear track detector [17]. The detector threshold of the SLIM CR39 is also shown. Right: Flux upper limits for MMs *vs.* monopole mass. The expected results (90 % CL) in the absence of candidates, from the SLIM experiment (dashed line) and the combined MACRO [18] and SLIM experiments (dash-dotted line) are shown. The Parker bound, due to the survival of galactic magnetic field and mass density limits for a uniform density of monopoles in the Universe are also plotted.

contruction at the high-altitude Chacaltaya lab (5230 m a.s.l.) for the search for relatively light MMs. In > 4 years of operation it should be able to reach a sensitivity at the level of the Parker bound.

Figure 1 (left) shows the accessible region in the plane (mass, β) for MMs, with charge $g = g_{\mathrm{D}}$ for an experiment, like MACRO, located in the Gran Sasso underground laboratory (at an average depth of 3700 hg/cm^2), at the Chacaltaya altitude (540 g cm^{-2} of atmosphere) and at 20 km height. An exposure at a high-altitude laboratory will allow to search for MMs of lower masses, higher magnetic charges and lower velocities [9].

It must also be remembered the possibility that MMs could be multiply charged, $g = 2g_{\mathrm{D}}$, as in some SUSY theories, and $g = 3g_{\mathrm{D}}$, as in some superstring models ($g_{\mathrm{D}} = \hbar c/2e = 68.5\ e$ is the basic Dirac monopole charge) and that the basic electric charge could be $1/3\ e$ [10].

Byproducts of this MM search are the searches for relatively light nuclearites [11] and Q-balls [12]. We recall that nuclearites (strangelets, strange quark matter) are nuggets of strange quark matter (aggregates of u, d, and s quarks in approximately equally proportions); they could be the ground state of QCD and could be part of the cold dark matter with typical galactic velocities $\beta \sim 10^{-3}$. Q-balls are supersymmetric coherent states of squarks, sleptons and Higgs fields, predicted by minimal supersymmetric generalizations of the Standard Model; they could be produced in the early universe. Relic Q-balls are also candidates for the cold dark matter.

Since both nuclearites and charged Q-balls lose a large amount of energy for $\beta > 4 \times 10^{-5}$ [13, 14] they would be easily detectable with the SLIM apparatus. For low mass nuclearites one would reach a level of sensitivity more than one order of magnitude lower than any of the existing limits [13, 15]. Figure 1 (right) shows the accessible region in the plane (mass, β) for nuclearites, at MACRO depth, at the Chacaltaya altitude

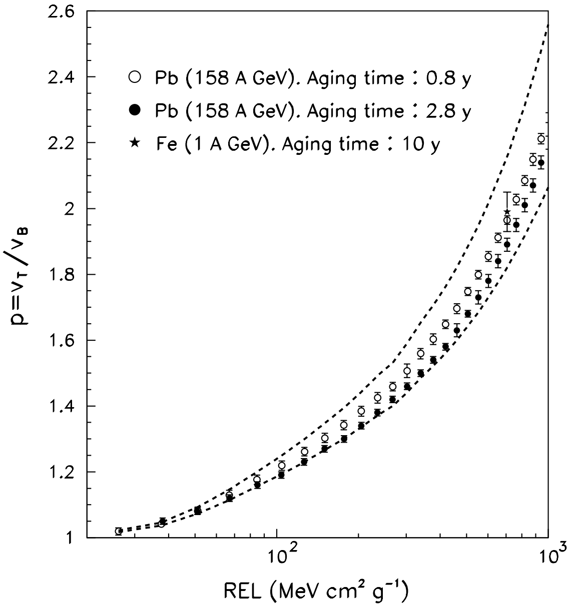

Fig. 3. – $p = v_T/v_B$ *vs.* REL for CR39 exposed to Pb^{82+} ions of 158 A GeV and Fe $^{26+}$ ions of 1 A GeV at different times after production. This was done to estimate possible aging effects. The dashed line indicate the systematic uncertainty arising mainly from fluctuations of the bulk etching rate v_B.

(540 g cm^{-2} of atmosphere) and at 20 km height assuming that the nuclearites have standard energy losses [11]. Lower-mass nuclearites should be much more abundant than higher mass ones [16].

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. From this point of view, it is important that the site be at the highest possible altitude.

2. – Experimental method

The SLIM apparatus will consist 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 $\beta = v/c$ 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, for nuclearites and for Q-balls.

Figure 2 (left) shows the Restricted Energy Loss (REL) *vs.* β for MMs of magnetic charges $g =\ g_D$, 2 g_D and 3 g_D, in the CR39; the detector threshold is also shown [17].

The polycarbonate has a higher threshold, and it is useful for monopoles, nuclearites and Q-balls with $\beta > 10^{-4}$.

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

TABLE I. – *Background activity measured in different locations of the experimental room.*

Location no.	Activity (Bq/m^3)
3	42 ±12%
5	35 ±10%
6	40 ±12%
7	45 ±11%
8	69 ±9%

three weeks; no significant leakage was detected in any of them. From our experience with MACRO, where the same CR39 have been used we know that such material does not suffer from "aging effects", at least for exposure times shorter than 8 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. Tests were made for searching for such effects. Two sets of samples, 0.8 y and 2.5 y old, respectively, were exposed in November 1994 to 158 A GeV Pb^{82+} ions. For each detected nuclear fragment the reduced etch rate $p = v_\mathrm{T}/v_\mathrm{B}$ (v_T and v_B are the track and bulk etching rates, respectively) was computed and plotted *vs.* REL (fig. 3). The lines represent the limits of the systematic uncertainties coming mainly from 1 standard deviation uncertainty on v_B. A more recent test was made by exposing CR39 samples 10 y old to 1A GeV Fe^{26+} ions. The results indicate that within experimental uncertainties aging effects in the MACRO CR39 are negligible and confidently the same will happen for the SLIM CR39.

3. – Environmental background

We have installed 100 m^2 in March 2000, and an additional 90 m^2 at the end of July 2000. We expect to complete the apparatus by July 2001. We are presently making 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.

Preliminary results of radon concentration in the experimental room have been obtained by using E-PERM radon dosimeters. In table I we present the measured activity in six different positions. From our experience at LNGS with the MACRO experiment, we can conclude that the measured levels of radon activity are not a problem for the experiment.

4. – Conclusions

The new CR39 array currently being built at the Chacaltaya high-altitude laboratory has good capability to detect a magnetic monopole flux at the Parker bound level in a reasonable time interval over a wide range of masses, charges and velocity (see fig. 2, right). This experiment will also be able to search for low mass nuclearites and for supersymmetric dark-matter Q-balls at a high-altitude laboratory; in this respect it is at this moment unique.

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We would like to acknowledge fruitful discussions with A. DE RÚJULA, S. GLASHOW, J. STEINBERGER. We would like to thank E. BOTTAZZI, L. DEGLI ESPOSTI, D. DI

Ferdinando and C. Valieri of INFN, Sezione di Bologna for their help in preparing the experiment and G. Landini of ITeSRE/CNR, Bologna for the vacuum test.

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