

Rare Particle Searches with the high altitude SLIM experiment

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The search for rare particles in the cosmic radiation remains one of the main aims of non-accelerator particle astrophysics. Experiments at high altitude allow lower mass thresholds with respect to detectors at sea level or underground. The SLIM experiment is a large array of nuclear track detectors located at the Chacaltaya High Altitude Laboratory (5290 m a.s.l.). The preliminary results from the analysis of the first 227 m² exposed for more than 3.6 y are here reported. The detector is sensitive to Intermediate Mass Magnetic Monopoles, $10^5 < m_M < 10^{12}$ GeV, and to SQM nuggets and Q-balls, which are possible Dark Matter candidates.

International Europhysics Conference on High Energy Physics

July 21st - 27th 2005

Lisboa, Portugal

*Speaker.

1. Introduction

Grand Unified Theories (GUT) of the strong and electroweak interactions at the scale $M_G \sim 10^{14}$ GeV predict the existence of magnetic monopoles (MMs), produced in the early Universe at the end of the GUT epoch, with very large masses, $M_M > 10^{16}$ GeV. GUT poles in the cosmic radiation should be characterized by low velocity and relatively large energy losses [1]. At present the MACRO experiment has set the best limit on GUT MMs for $4 \cdot 10^{-5} < \beta = v/c < 0.5$ [2].

Intermediate Mass Monopoles (IMMs) [$10^5 \div 10^{12}$ GeV] with magnetic charge $g = 2 g_D$ could also be present in the cosmic radiation; they may have been produced in later phase transitions in the early Universe [3]. The recent interest in IMMs is also connected with the possibility that they could yield the highest energy cosmic rays [4]. IMMs may have relativistic velocities since they could be accelerated to high velocities in one coherent domain of the galactic magnetic field. In this case one would have to look for downgoing fast ($\beta > 0.1$) heavily ionizing MMs. Relatively low mass classical Dirac monopoles are being searched for mainly at high energy accelerators [5].

Besides MMs, other massive particles have been hypothesized to exist in the cosmic radiation and possibly to be components of the galactic cold dark matter: nuggets of Strange Quark Matter (SQM), called nuclearites when neutralized by captured electrons, and Q-balls. SQM consists of aggregates of u, d and s quarks (in approximately equal proportions) will slightly positive electric charge [6]. It was suggested that SQM may be the ground state of QCD. They should be stable for all baryon numbers in the range between ordinary heavy nuclei and neutron stars ($A \sim 10^{57}$). They could have been produced in the early Universe or in violent astrophysical processes. Nuclearite interaction with matter depend on their mass and size. In [7] different mechanisms of energy loss and propagation in relation to their detectability with the SLIM apparatus are considered. In the absence of any candidate, SLIM will be able to rule out some of the hypothesized propagation mechanisms. Q-balls are super-symmetric coherent states of squarks, sleptons and Higgs fields, predicted by minimal super-symmetric generalizations of the Standard Model [8] they could have been produced in the early Universe. Charged Q-balls should interact with matter in ways not too dissimilar from those of nuclearites.

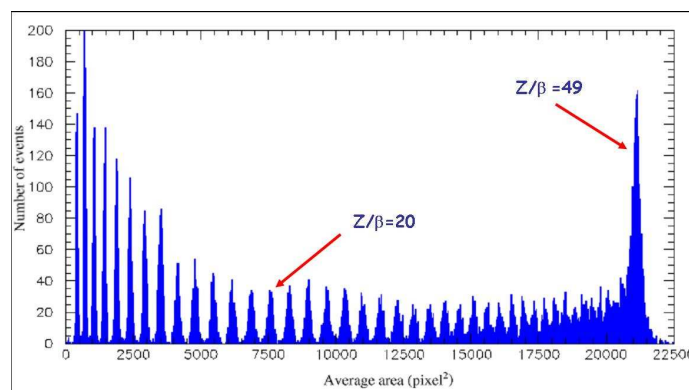


Figure 1: Calibrations of CR39 nuclear track detectors with 158 A GeV In^{49+} ions and their fragments (2 face measurements).

In the followings, after a short description of the apparatus, we present the calibrations, the analysis procedures and preliminary results from the SLIM experiment.

2. Experimental

The SLIM (Search for Light magnetic Monopoles) experiment, based on 440 m² of Nuclear Track Detectors (NTDs), was deployed at the Chacaltaya High Altitude Laboratory (Bolivia, 5260 m a.s.l.) since 2001 [9]. Another 100 m² of NTDs were installed at Koksil (Pakistan, 4600 m a.s.l.) since 2003. The detector modules have been exposed under the roof of the Chacaltaya Lab. at a height of 4 m from ground. The air temperatures are recorded 3 times a day together with the minimum and maximum values. From the observed ranges of temperatures we conclude that no significant time variations have occurred in the detector response. The radon activity and the flux of cosmic ray neutrons were measured by us and by other authors [10].

Extensive test studies were made in order to improve the etching procedures of CR39 and Makrofol NTDs, improve the scanning and analysis procedures and speed, and keep a good scan efficiency. "Strong" and "soft" etching conditions have been defined [9]. CR39 "strong" etching conditions (8N KOH + 1.25% Ethyl alcohol at 77° C for 30 hours) are used for the first CR39 sheet in each module, in order to produce large tracks, easier to detect during scanning. CR39 "soft" etching conditions (6N NaOH + 1% Ethyl alcohol at 70° C for 40 hours) are applied to the other CR39 layers in a module, if a candidate track is found in the first layer. It allows more reliable measurements of the restricted energy loss (REL) and of the direction of the incident particle. Makrofol layers are etched in 6N KOH + Ethyl alcohol (20% by volume), at 50° C.

The detectors have been calibrated using 158 A GeV ⁴⁹⁺In (see Fig. 1) and 30 A GeV ⁸²⁺Pb beams at the CERN SPS. For "soft" etching conditions the threshold in CR39 is at REL ~ 50 MeV cm² g⁻¹; for strong etching the threshold is at REL ~ 200 MeV cm² g⁻¹. Makrofol has a higher threshold (REL ~ 2.5 GeV cm² g⁻¹). The CR39 allows the detection of IMMs with two units Dirac charge in the whole β -range of $4 \cdot 10^{-5} < \beta < 1$. The Makrofol is useful for the detection of fast MMs. Nuclearites with $\beta \sim 10^{-3}$ can be detected by both CR39 and Makrofol.

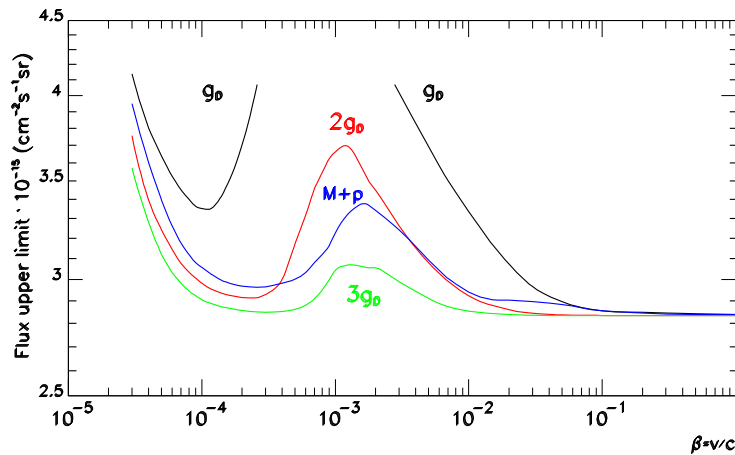


Figure 2: Present 90% CL upper limits for a downgoing flux of IMMs with $g = g_D, 2g_D, 3g_D$ and for dyons (M+p, $g = g_D$) plotted vs β .

The analysis of a SLIM module starts by etching the top CR39 sheet using "strong" conditions, reducing its thickness from 1.4 mm to ~ 0.6 mm. Since MMs, nuclearites and Q-balls should have

a constant REL through the stack, the signal looked for is a hole or a biconical track with the two base-cone areas equal within the experimental uncertainties. The sheets are scanned with a low magnification stereo microscope. Possible candidates are further analysed with a high magnification microscope. The size of surface tracks is measured on both sides of the sheet. We require the two values to be equal within 3 times the standard deviation of their difference. A track is defined as a "candidate" if the REL and the incidence angles on the front and back sides are equal to within 15%. To confirm the candidate track, the bottom CR39 layer is then etched in "soft" conditions; an accurate scan under an optical microscope with high magnification is performed in a region of about 0.5 mm around the expected candidate position. If a two-fold coincidence is found the middle layer of the CR39 (and in case of high Z candidate, the Makrofol layer) is analyzed with soft conditions. No two-fold coincidence was found, that is no MM, nuclearite or Q-ball candidate was detected.

3. Results and Conclusions

We etched and analysed 227 m² of CR39, with an average exposure time of 3.6 years. No candidate passed the search criteria: the 90% C.L. upper limits for a downgoing flux of fast ($\beta > 0.1$) IMM's, nuclearites and Q-balls of any speed, all coming from above, are at the level of $2.83 \cdot 10^{-15}$ cm⁻² sr⁻¹ s⁻¹ (see Fig. 2). By the end of 2006 the 440 m² analysis will be completed and the experiment will reach a sensitivity of $\sim 10^{-15}$ cm⁻² sr⁻¹ s⁻¹ for IMM's with $\beta \geq 10^{-2}$; the same sensitivity should be reached also for nuclearites and Q-balls with galactic velocities. Moreover this search will benefit from the analysis of further 100 m² of NTDs installed at Koksil.

We acknowledge the collaboration of E. Bottazzi, L. Degli Esposti, G. Grandi and C. Valieri of INFN Bologna and the technical staff of the Chacaltaya Laboratory. We thank INFN and ICTP for providing grants for non-italian citizens.

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