MONOPOLE SEARCH BELOW THE PARKER LIMIT WITH THE MACRO DETECTOR AT GRAN SASSO

The MACRO Collaboration
Presented by G. Tarlé, Department of Physics
The University of Michigan, Ann Arbor, MI 48109

ABSTRACT

The MACRO detector approved for the Gran Sasso Underground Laboratory in Italy will be the first capable of performing a definitive search for super-massive GUT monopoles at a level significantly below the "Parker" flux limit of 10^{-15} $cm^{-2}sr^{-1}s^{-1}$. GUT monopoles will move at very low velocities ($V \sim 10^{-3}c$) relative to the Earth and a multifaceted detection technique is required to assure their unambiguous identification. Calculations of scintillator response to slow monopoles and measurements of scintillation efficiency for low energy protons have shown that bare monopoles and electrically charged monopoles moving at velocities as low as $5\times10^{-4}c$ will produce detectable scintillation signals. The time-of-flight between two thick (25cm) liquid scintillation layers separated by 4.3m will be used in conjunction with waveform digitization of signals of extended duration in each thick scintillator to provide a redundant signature for slow penetrating particles. Limited streamer tubes filled with He and n-pentane will detect bare monopoles with velocities as low as $1\times10^{-4}c$ by exploiting monopole induced level mixing and the Penning effect. A layer of solid state nuclear track detectors located in the center of the detector will be processed in the event that the active detectors record a monopole candidate. With an acceptance of $\sim12000 m^2 sr$, MACRO will reach a sensitivity to monopole fluxes $F < 10^{-16} cm^{-2}sr^{-1}s^{-1}$ in a few years. For a monopole mass of 10^{16} GeV/c^2 this flux corresponds to 10% of the "Parker" limit. If no events are detected, monopoles would be ruled out as contributing no more than 4% to the "missing" mass of the universe.

1. Introduction

The existence of supermassive ($M>10^{16}$GeV/c^2) magnetic monopoles is a natural consequence of Grand Unified Theories (GUTs) that are characterized by a single coupling constant. Such monopoles should have been copiously produced in a standard early universe and the failure to detect them has created a problem for GUTs. New inflationary universes have been proposed that alleviate this problem by delaying the symmetry breaking phase transition to a later epoch. At the present time cosmology offers little guidance in prediction of monopole fluxes. Astrophysical constraints on monopole flux can be obtained from the continued existence of the Galactic Magnetic Field (GMF) and the closure density of the universe. The so-called "Parker" limit[1] ($10^{-15}cm^{-2}sr^{-1}s^{-1}$) is derived by demanding that monopoles do not extract energy from the GMF at a rate faster than it can be replenished by a Galactic dynamo. Mechanisms have been proposed that circumvent the Parker limit by permitting monopoles to interact with the GMF in a resonant fashion. For a nominal velocity of $10^{-3}c$ and a mass of 10^{16} GeV/c^2 an isotropic flux of monopoles of $10^{-15}cm^{-2}sr^{-1}s^{-1}$ would constitute 40% of the critical density $\rho_c = 2\times10^{-29}g/cm^3$ needed to close the universe. It is both a peculiar and intriguing coincidence that these two completely independent astrophysical limits are so close to one another. It would indeed be interesting to find monopoles at the Parker limit resonantly interacting with the GMF in some way that regulates its magnitude. Today an "interesting" search for monopoles is one that goes well beyond the Parker and closure limits with detection techniques that are convincing regardless of whether the search is positive or negative.

2. Slow Monopole Detection

A variety of techniques have been applied to the detection of slow monopoles. Superconducting detection and certain detection methods based on ionization or excitation can be considered as direct in that they rely solely on the electromagnetic interaction of monopoles. Although superconducting detectors respond to monopoles of arbitrary velocity it is difficult to build them large enough to perform an "interesting" search. Any detector based on ionization and/or excitation will likely have a minimum threshold velocity determined by kinematic limitations on energy transfers to atomic electrons and the need to provide a minimum excitation energy to the system. Ahlen and Tarlé[2] have shown that scintillators make ideal monopole detectors both because their velocity threshold $V \sim 5 \times 10^{-4} c$ is well below the astrophysically important region and because they can be fabricated in large areas at relatively low cost. By scaling monopole-electron and proton-electron cross sections and by using available data on scintillation by low energy recoil protons they were able to calculate the response of scintillators to slow monopoles. Empirical verification that electromagnetically interacting particles moving as slowly as $9 \times 10^{-4} c$ can produce scintillation light has recently been obtained by Ahlen et al[3]. By exposing scintillators to a neutron beam at the Brookhaven High Flux Beam Reactor, low energy recoil protons were produced within the volume of the scintillator and a response curve (see figure 1) was obtained. Two different models of proton stopping power were used to convert the measured light output per unit energy, dL/dE, to light output per unit length, dL/dx. The measured points lie somewhat below the predicted curve of Ahlen and Tarlé but are within the quoted uncertainties of the calculation. An interesting technique to extend the response of ionization detectors to bare monopoles as slow as $1 \times 10^{-4} c$ has been suggested by Drell et al[4]. This method takes advantage of monopole induced level mixing in He atoms and employs the Penning effect to transfer this excitation to a gas of low ionization potential.

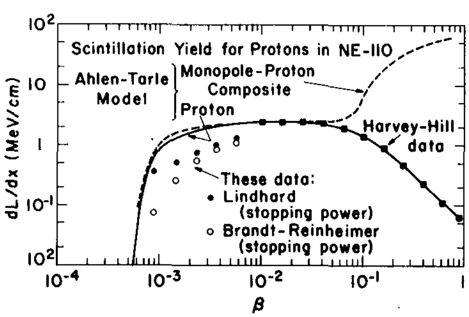

Fig. 1. Light output of organic scintillator for low velocity particles (see text).

Several novel yet indirect techniques have been used to search for monopoles with special properties at levels below the Parker limit. For example Price et al[5] has searched for monopole-Al induced tracks in ancient muscovite mica. This technique requires monopoles to pick up a nucleus at least as heavy as Al in the Earth's crust prior to penetrating the mica buried at an average depth of 5km. If monopoles are produced as positive dyons or pick up protons in the early universe or the interstellar medium as suggested by Bracci and Fiorentini[6] then Coulomb repulsion would prevent the capture of Al nuclei and no tracks would be formed in the mica. It has been argued[7] that cross sections are large for monopole induced baryon nonconserving reactions (the so-called Rubakov effect). If so, then it has been suggested that neutron stars could be used as monopole detectors. From observational limits on ultraviolet and x-ray backgrounds, very stringent flux limits have been placed on GUT monopoles[8] ($<10^{-22}cm^{-2}sr^{-1}s^{-1}$). A less stringent limit ($10^{-14}cm^{-2}sr^{-1}s^{-1}$) has been placed[9] by looking directly for monopole induced baryon decays with the IMB proton decay detector. Caution is required when interpreting limits requiring the Rubakov effect. For example, it has not yet been established that baryon number is not strictly conserved. The problem with indirect techniques is that if no monopoles are found, a long list of experimentally unverifiable assumptions must be satisfied before a negative observation can be interpreted as a limit.

3. The MACRO Detector

The MACRO detector now approved for the Gran Sasso underground laboratory in Italy (for a complete decription see ref. 10) will be the first capable of extending a direct search for monopoles to flux levels significantly below the Parker limit. The principal detection scheme for monopoles (figure 2) will involve the use of two thick (d=25cm) liquid scintillator layers separated by a large distance (D ~ 4m). A slow monopole will produce a characteristic signal of extended duration in each of the thick layers. Waveform digitizers will record these signals and continuity of pulse height and timing information will provide redundancy for slow particle identification. In addition we will require that the ratios of pulse durations in the two scintillators and time-of-flight between layers $\Delta t_1:\Delta t_2:T$ are in the same ratio as the layer thicknesses and separation d:d:D. the scintillation detectors will respond to monopoles of arbitrary electric and magnetic charge and having any velocity in excess of $\sim 5\times10^{-4}c$. In addition to the scintillation system there will be 10 layers of limited streamer tubes filled with a 3:1 mixture of He and n-pentane and having a separate trigger. The Drell mechanism will allow detection of bare monopoles down to a velocity of $1\times10^{-4}c$. For monopoles with positive electric charge the Drell mechanism will not be operative[11] and the threshold velocity will exceed $2\times10^{-3}c$ as a result of kinematics. In the event a monopole candidate is observed by either the scintillator or limited streamer tube system, two types of solid state nuclear track detectors (Lexan and CR-39) located in the center of the MACRO detector will be etched and scanned for tracks. The CR-39 threshold for bare monopoles is $\sim 5\times10^{-3}c$ although diamagnetic effects may reduce this threshold[12] to as low as $5\times10^{-5}c$. The Lexan detectors with a threshold of 0.3c will only be sensitive to events having large signals in the electronic detectors. The MACRO detector is in the form of a box 12m x 5m x 111m with detectors covering all sides. The total acceptance for monopoles will be $\sim 12000 m^2 sr$ corresponding to four events/year at the Parker bound.

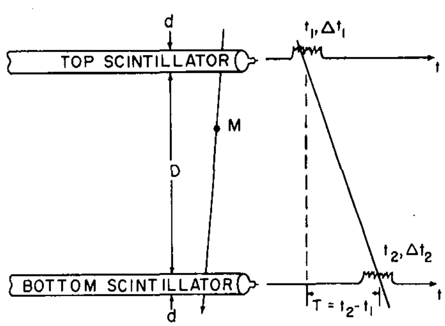

Fig. 2. Simplified monopole detection scheme for MACRO.

4. Conclusions

The current status of searches for GUT monopoles is shown in figure 3. Experiments involving indirect techniques or those for which the response to monopoles is uncertain have been shown with dashed lines. The Baksan scintillation detector[13] is the only detector using direct techniques that has approached the Parker bound. Because the effective integration time of the Baksan trigger electronics is only 50ns, slow particles will have a higher effective velocity threshold than the excitation threshold of scintillators. According to the model of Ahlen and Tarle the effective threshold for monopoles in the Baksan detector is 1×10^{-3}c. The new results of Ahlen et al[2] suggest that this threshold should be even higher. The MACRO detector will have seven times the acceptance of Baksan and will have an integrated trigger that will

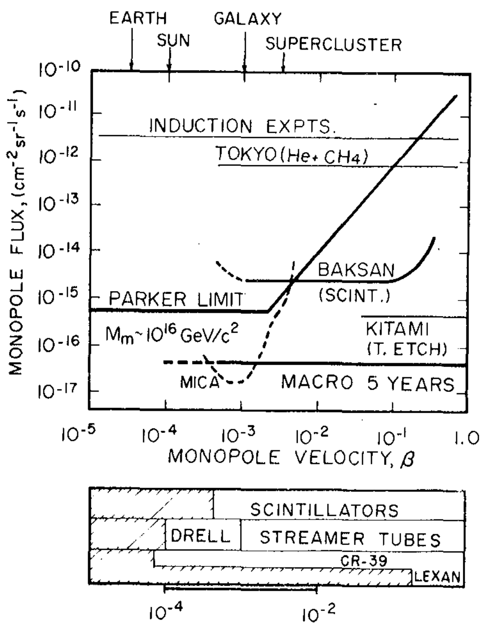

Fig. 3. Current status of GUT monopole searches and expected sensitivity of MACRO. Escape velocities for various astrophysical objects are indicated.

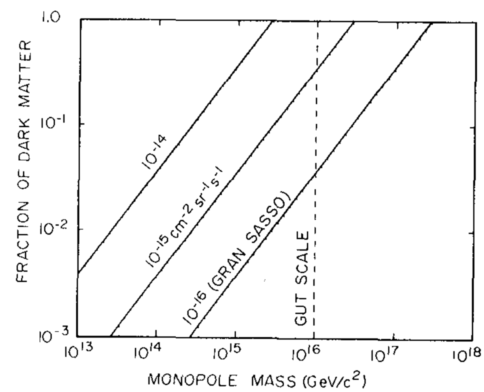

Fig. 4. Sensitivity of monopole search experiments to dark matter.

respond to monopoles having velocities only slightly in excess of the excitation threshold for scintillators. After five years of operation the MACRO detector will reach a sensitivity of better than $10^{-16}cm^{-2}sr^{-1}s^{-1}$. Figure 4 shows that at this level, the sensitivity of MACRO to dark matter composed of monopoles is a few percent of ρ_c for monopole mass and velocity having nominal values of $10^{16}GeV/c^2$ and $V=10^{-3}c$ respectively.

References

1. Turner, M.S., Parker, E.N. and Bogdan, Phys. Rev. 26D, 1296 (1982).
2. Ahlen, S.P. and Tarle , G., Phys. Rev. 27D, 688 (1983).
3. Ahlen, S.P. et al, submitted to Phys. Rev. Lett. (1985).
4. Drell, S.D. et al., Phys. Rev. Lett. 50, 644 (1983).
5. Price, P.B. et al., Phys. Rev. Lett. 52, 1265 (1984).
6. Bracci, L. and Fiorentini,G., Phys. Lett. 143B, 357 (1984).
7. Rubakov, V., JETP Lett. 33, 644 (1981).
8. Kolb, E.W. et al., Phys. Rev. Lett. 49, 1373 (1982).
9. Errede, S. et al., Phys. Rev. Lett. 51, 245 (1983).
10. The MACRO Collaboration, HE6.1-4, these proceedings.
11. Kroll, N. et al., Monopole '83, ed. J.L. Stone (Plenum, NY, 1984), pp. 295-315.
12. Price, P.B., CERN EP/84-28, submitted to Phys. Lett. (1984).
13. Chudakov, A.V., Proceedings of UP'85, St. Vincent. (1985).