DFUB 88/15

THE TRACK-ETCH DETECTOR OF THE MACRO ESPERIMENT

Invited paper at the 1988 Lahore meeting on Nuclear Track Detectors

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Abstract - The MACRO (Monopoles, Astrophysics and Cosmic Ray Observatory) detector is presently being installed in Hall B of the Gran Sasso National Laboratory. It is a large area detector with an acceptance for isotropic particles of about 10.000 m^2 sr. It is designed to search for rare particles and rare phenomena in the natural penetrating radiation. It will search for GUT Magnetic Monopoles and any supermassive penetrating charged particles; it will perform a survey of cosmic point sources of high energy gammas and neutrinos and a systematic study of cosmic ray muons and multimuons. Three complementary techniques are used: liquid scintillation counters, limited streamer tubes and track-etch. Here we describe the track-etch detector, its implementation for the first supermodule and the tests in progress on CR39 exposed to high energy ions.

1. INTRODUCTION

The MACRO detector, shown schematically in Figs 1 and 2, is a large area, multipurpose, deep underground, high energy particle detector optimized for the detection of penetrating high energy cosmic radiation with velocity larger than 10^{-4}c. Its acceptance for isotropic particles will be larger than 10000 m^2sr. The detector will measure particle trajectory, velocity and ionization using three complementary techniques: liquid scintillators, limited streamer tubes and track-etch detectors (1).

Its main physics objectives can be summarized as follows.

a) A systematic study of penetrating cosmic ray single muons and multimuons. In one year the full detector will collect 10 million muons and 300000 multimuons. For single muons one will be able to study time and space variations. For multimuons the large acceptance of the apparatus (more than twice the multimuon average size) will make possible the study of the multiplicity distribution and of the transverse structure.

b) A search for GUT supermassive magnetic monopoles (2) at a level well below the astrophysical bound based on the existence of the galactic magnetic field (3). This sensitivity extends to any other supermassive penetrating particle. The presence of three separate methods of detection yields considerable redundancy.

c) The muon tracking capability with good angular resolution and large acceptance allows a sensitive search for cosmic ray point sources of very high energy gamma rays and neutrinos, by detecting the resulting fast muons coming from above and from below ground.

d) The presence of a large mass of liquid scintillator (about 1000 t) yields a high sensitivity to neutrino bursts from supernovae in our galaxy. The average energy of the secondary positron is expected to be larger than 10 MeV. Background studies have indicated that the liquid scintillator detector will have a threshold between 7 and 10 MeV.

MACRO is presently being installed in hall B of the Gran Sasso National Laboratory. The first supermodule with a global volume of $12x12x5\ m^3$ is essentially ready (see Fig. 4). It consists of two horizontal layers of scintillation counters, 10 layers of limited streamer tubes and the track-etch detector. The sides are closed with vertical detectors (Fig.4).

In the following we shall concentrate on the track-etch detector, its implementation in the first MACRO supermodule, the response of the used CR39 to fast ions and the implications of the track-etch detector for the detection of magnetic monopoles.

2. SUPERMASSIVE MAGNETIC MONOPOLES

Grand Unified Theories (GUT's) of strong and electroweak interactions predict the existence of magnetic monopoles with masses $\sim 10^{16}$ GeV/c^2 and magnetic charges $g=g_{Dirac}=\hbar c/2e$ (2). However these theories leave completely open the question of their abundance, which could range from a large and measurable number to a negligible number in the whole Universe. Standard Cosmology would predict too many monopoles; models with inflation at the GUT phase transition would predict very few.

The existence of large scale magnetic fields, in particular on the galactic scale, leads to an astrophysics constraint (the Parker bound), an upper limit on the pole flux at the level of 10^{-15} monopoles $cm^{-2}s^{-1}sr^{-1}$ (3).

Several superstring models predict the existence of multiply charged ($g=3g_{Dirac}$) magnetic monopoles with large masses ($\sim 10^{16}$ GeV) (4-5). In some models the primordial monopoles, although heavy, first appear when the temperature of the Universe reached relatively low values, of the order of 1 TeV. Consequently these monopoles should not have been diluted by inflation in the early Universe; superstring models lead to other mechanisms for diluting the initially large number of monopoles. From these mechanisms the monopoles may be present now at the level of the Parker bound, which for poles with $g=3\ g_{Dirac}$ could be at the level of $3x10^{-16}$ monopoles $cm^{-2}s^{-1}sr^{-1}$.

Fig.4 shows the restricted energy losses in CR39 of monopoles with different magnetic and electric charges as a function of monopole velocity (5). The horizontal line is a conservative threshold for CR39. One may thus conclude that CR39 should be capable of detecting $g=3\ g_{Dirac}$ monopoles with any velocity down to $3x10^{-5}$c. Monopoles with a magnetic charge $g = g_{Dirac}$ should be detected in the range $4 \times 10^{-5} < v/c < 2 \times 10^{-4}$ and $v/c > 4 \times 10^{-3}$. If monopoles carry an electric charge, or have attached a nucleus, the sensitivity would be adequate for any $v/c > 3x10^{-5}$. The sensitivity to monopoles with $v/c > 10^{-3}$ is based on the electronic contribution to the energy loss (6), while the sensitivity to $v/c \sim 10^{-4}$ is based on diamagnetic repulsion of atoms (5-7).

3. THE MACRO TRACK-ETCH DETECTOR

The main purpose of the MACRO track-etch detector is the search of magnetic monopoles; the track etch detector will have a size of about 1000 m^2. The track-etch detector is placed horizontally in the middle of the bottom half of the MACRO structure. The basic units will be 25x25 cm^2 in size, each unit consisting of three sheets of CR39, 1.4 mm thick, interleaved with one aluminium absorber and four lexan sheets of 0.2 mm thickness (see Fig.5). The packets will fit into plastic holders, which will slide on rails.

The passage of a monopole should result, after chemical etching, in collinear etch-pits of equal size on both faces of the CR39 sheets.

The track-etch detector will be mainly used "triggered" by a signal in the scintillation counters and/or the limited streamer tubes; in this case one must search for the monopole track in the CR39 around the expected position (which is defined to a few square centimeters). For this operation the scanning effort is expected to be small. The relative position of the monopole track in the different sheets of CR39 can be determined with a precision of better than 100 μm. The precise knowledge of the position and angles of the track will reduce drastically the background and provide further information to the electronic apparatus.

We plan also to use the track-etch detector as a purely passive detector, without any electronic trigger, as proposed by Doke et. al (8). For this purpose one needs to heavily etch one layer of CR39 (exposed for an extended period of time) to produce a hole; then one needs to perform an automatic scanning. A scan for holes could be performed with an electrical conductivity technique already used at CERN (9) or with a low magnification optical method (8). The other two sheets of CR39 would be used for precision measurements.

After a number of tests (10), 1000 sheets, 98x98 cm^2 in size and 1.4 mm thick, were casted by the Intercast Company of Parma (Italy). Their composition is 95% CR39 (PPG monomer), 4.8% CHPC and 0.2% DOP. The sheets were then cut with a mechanical saw into pieces of 24.5x24.5 cm^2. Packages containing three CR39, 4 lexan and 1 aluminium sheets, sealed in aluminized mylar envelopes will be assembled directly in the Gran Sasso Hall B. The sealed packages will be deposited in carts, arranged in "trains", which slide into position on rails already mounted in a plane inside the first supermodule.

We have performed a number of preliminary tests with CR39 samples exposed to Neon (10+) ions of 0.2, 0.8 and 1.1 GeV/nucleon at the Saclay synchrotron and to Oxygen (8+) and Sulphur (16+) ions of 200 GeV/nucleon at the CERN-SPS. After etching at 70 degrees centigrades in a 6N NaOH solution, track diameters were measured with standard optical microscopes and with an image analyzer using samples of different thicknesses corresponding to different times after the beginning of the etching. We were thus able to estimate the reduced etch ratio $p=vT/vB$, (were vT is the track etch rate and vB is the bulk etch rate) as a function of the Restricted Energy Loss (REL). Fig.6 shows p-1 versus REL, obtained from the various exposures. The lowest point was obtained with the Oxygen exposure, while the other points were obtained from the Neon and Sulphur exposures. The fact that one observes relativistic oxygen ions proves that we already have the sensitivity indicated in Fig.2.

For the exposure to sulphur ions with 200 GeV/nucleon we measured the same incident track 5 times in three different sheets (entrance and exit of each sheet). The results of the measurements give a clean peak with half-width-at-half-maximum of 10 microns squared, which is a factor of two better than that of a single measurement. Fig.7 shows the spectrum of tracks after 1 cm of lead. Also in this case five measurements were performed on each track. The sulphur peak is still dominant, but to the left of it one observes nuclear fragments with various Z values down to Z = 8.

We plan to pursue further the tests of Fig.7, increasing both the statistics and the number of measurements per track.

4. CONCLUSIONS AND OUTLOOK

The installation of the first MACRO supermodule is almost completed.

The track-etch, the electronics and the computer will be installed within 1-2 months. Tests are being performed and will continue. It is expected that the first supermodule will be operational by September 1988. It will serve as a prototype test of the whole detector.

The mass produced CR39 is already of a satisfactory quality. We nevertheless plan further tests to improve the quality of the surfaces, the reproducibility and the long range sensitivity.

It may be mentioned that a precision measurement of the index of refraction and of the hardness of the CR39 samples provides a good non-destructive test of the quality and reproducibility of the material (10).

Two more supermodules may be installed this year and the full MACRO detector may be operational by the end of 1989.

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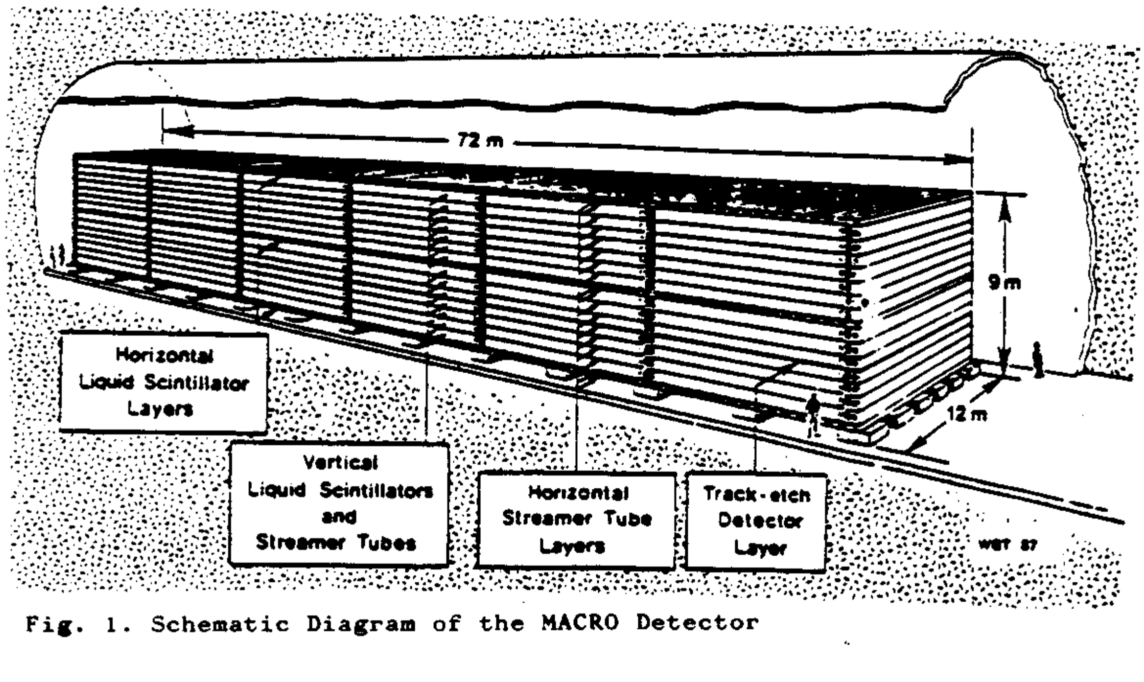

Fig. 1. Schematic Diagram of the MACRO Detector

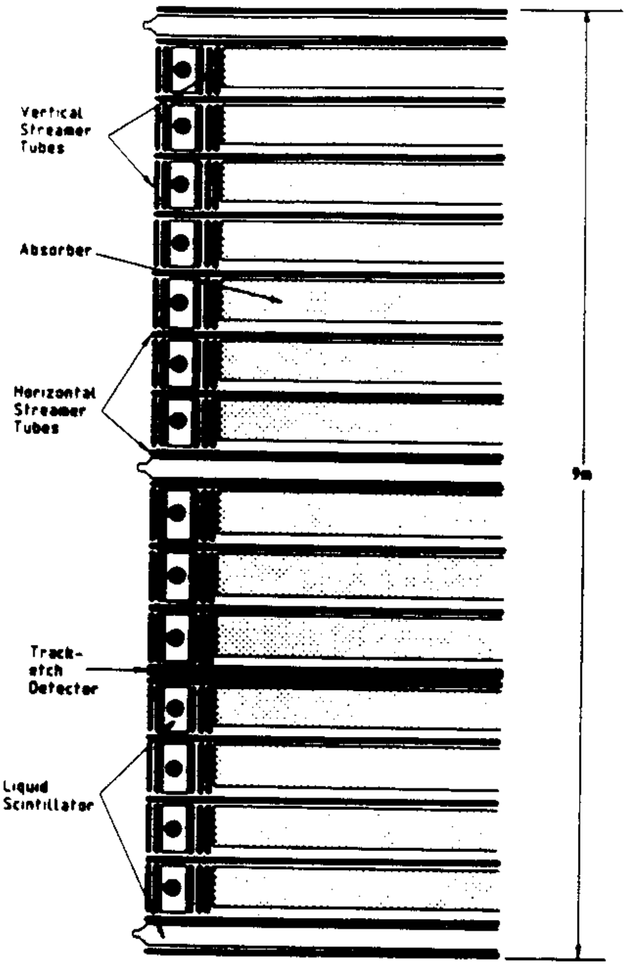

Fig. 2. Cross sectional view of the MACRO detector

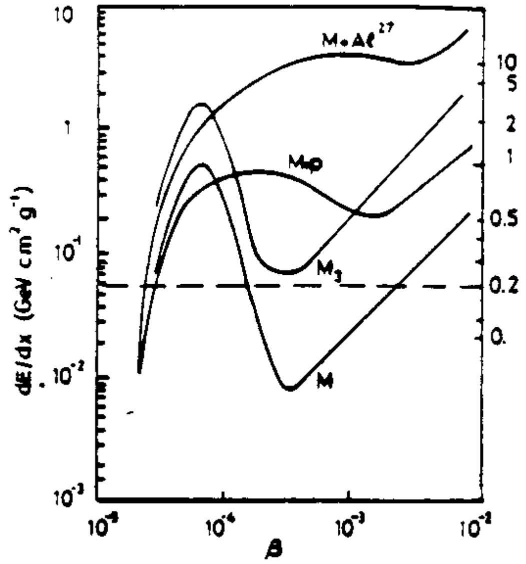

Fig. 4.
Restricted energy losses in CR39 for free monopoles with $g = g_{Dirac}$ (M), $g = 3g_{Dirac}$ (M_3) and for bound monopoles with $g = g_{Dirac}$ (M+p, M+Al). The right vertical scale gives the reduced etch rate; the horizontal line at $vT/vB - 1 = 0.2$ represents an average conservative energy loss threshold in CR39.

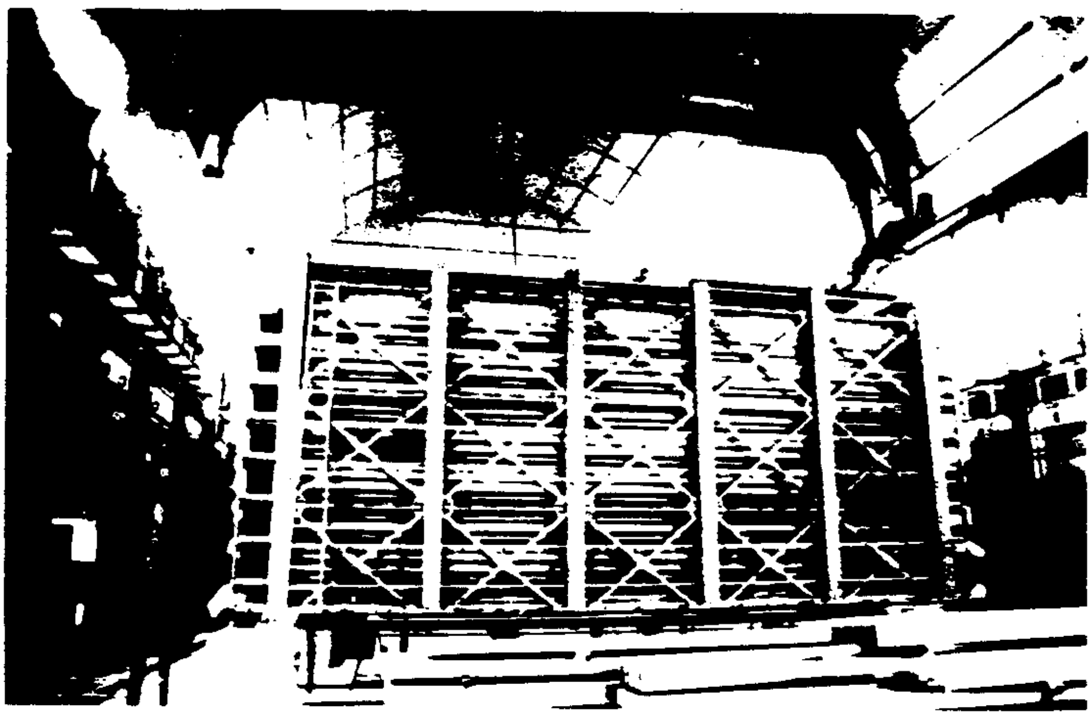

Fig. 3. Photograph of the first MACRO supermodule assembled in Hall B.

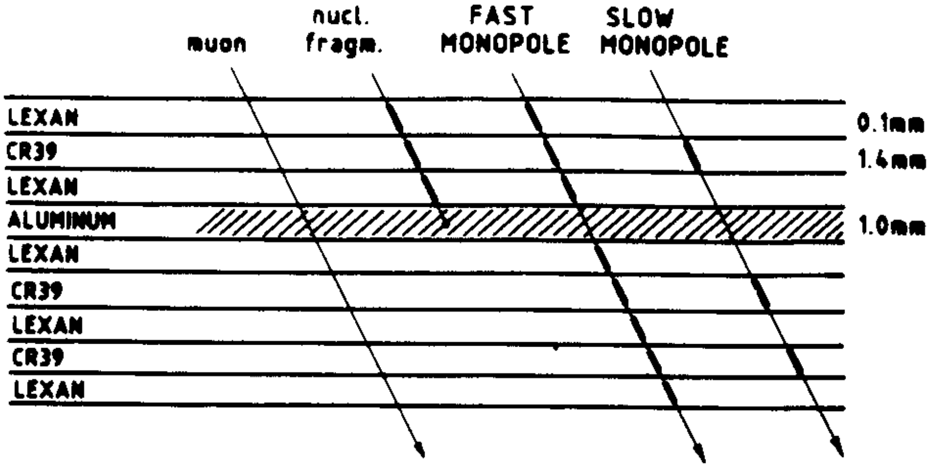

Fig. 5. Schetch of the MACRO track-etch detector.

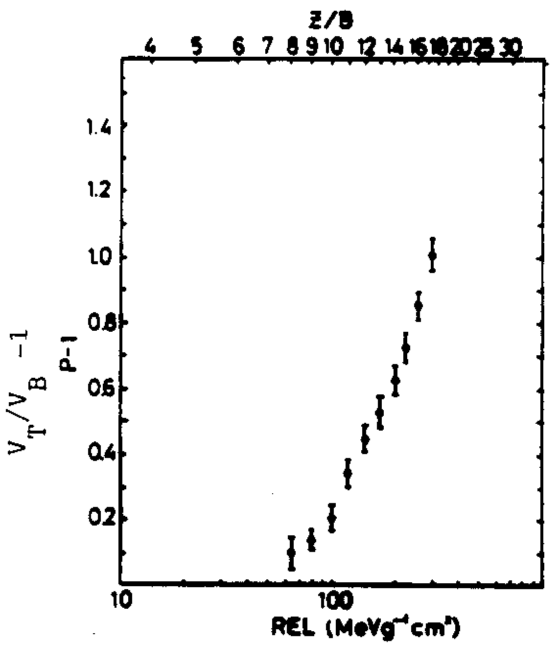

Fig. 6.
Experimental values of p-1 versus REL in one CR39 sample.

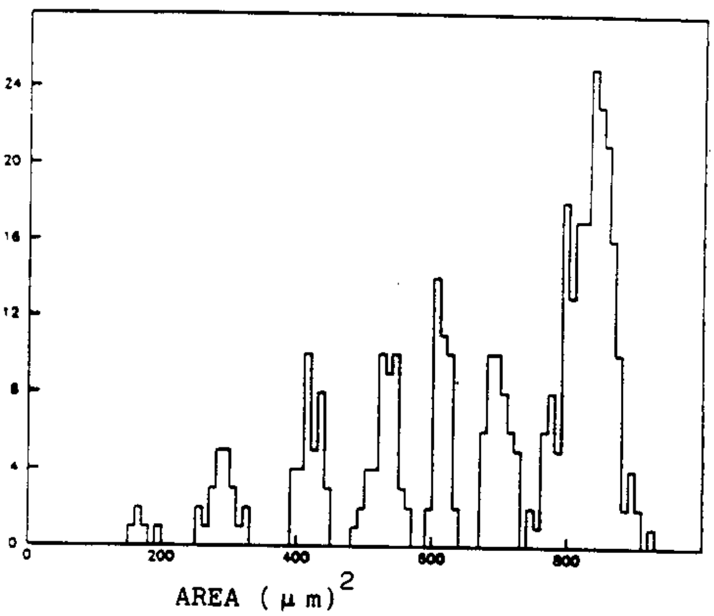

Fig. 7.
Exposure of CR39 to S (16^+) ions of 200 GeV/Nucleon. Results of preliminary measurements of tracks (5 measurements for each track).