EUROPHYSICS LETTERS 1 August 1990

Europhys. Lett., 12 (7), pp. 613-616 (1990)

Search for Magnetic Monopoles at the Tevatron Collider.

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(received 23 April 1990; accepted in final form 7 June 1990)

PACS. 14.80H – Magnetic monopoles.

Abstract. – A search for heavily ionizing particles produced in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV was performed at the Fermilab Tevatron collider using plastic track detectors. No highly ionizing particles were observed. The experiment places a limit on the production of magnetic monopoles with mass $m < 850$ GeV at $\sigma < 2 \cdot 10^{-34}\ \text{cm}^2$ (95% confidence level). The level of radiation present in the collider tunnel is discussed.

Since the proposal by Dirac in 1931 [1], experimental searches for classical, point magnetic monopoles have been performed at nearly every new high-energy accelerator, employing a variety of direct and indirect methods [2-15]. At present the main interest has shifted to poles of extremely high masses as predicted by the unified theories of strong and electroweak interactions [2, 16]. However, one should have an open mind to other possibilities. The searches for classical point monopoles at the highest-energy accelerators are based on the hypothesis that they should have large magnetic charges, $g = ng_D = n\hbar c/2e = 68.5en$, where e is the elementary electric charge and n is an integer. For $n = 1$ and velocities $\beta c > 0.2c$ the poles should ionize as $-(\mathrm{d}E/\mathrm{d}x)_g \simeq (g\beta/e)^2(\mathrm{d}E/\mathrm{d}x)_e$, that is more than $(68.5 \times 0.2)^2 = 188$ times the ionization of minimum ionizing particles. This corresponds to $Z/\beta \geq 14$. Thus they should be easily detectable in plastic track detectors, such as CR39.

The mass of the Dirac monopole is unspecified; one usually assumes that it should be large (because of the large magnetic charge), but that it should be accessible at accelerators. This in contrast to the mass of the non-Abelian gauge monopole whose mass is predicted and lies well outside the range of possibilities of any conceivable accelerator [2, 16].

In this letter a search is described for Dirac magnetic monopoles at the Fermilab Tevatron collider, in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV. The search was based on the plastic track detector technique, using CR39, nitrocellulose and lexan. We used sheets of different types of CR39, since we wanted to test them in a high-level background environment. Though the experiment is sensitive also to «balls of electric charge» [17, 18], we shall quote limits only for magnetic monopoles.

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Twenty-two stacks of dimensions $(7 \times 13)\ cm^2$ were placed around the 10 cm diameter, 0.16 mm thick, stainless-steel beam pipe at the E0 interaction point. Most of the exposures were made in the period from November 1988 to June 1989. Fourteen stacks were exposed for 4 months; 6 stacks were exposed for 6.5 months and the remaining ones were exposed for about 2 months. Additional stacks were exposed earlier, for shorter periods of time, when the Tevatron luminosity was lower.

Each stack consisted of 4 layers of CR39, each 1.4 mm thick, and 4 layers of lexan, 0.35 mm thick; in 4 stacks we also included 2 layers of nitrocellulose, 0.3 mm thick. The CR39 was manufactured by the Intercast Company of Parma (Italy). For most of the stacks the CR39 had the same composition (EN3 type) as that used for the first supermodule of a large-area underground experiment [19, 20], with PPG monomer, CHPC catalyser and DOP plastifier. Other sheets with different compositions, using the IPP catalyser, were also included (L8 type).

The fraction of solid angle covered by the stacks ranged from 0.7 to 0.3 in the different running periods. The mean instantaneous luminosity in the E0 interaction region was several $10^{27}\ cm^{-2}\ s^{-1}$; the effective fraction of beam on time was about 0.5.

The first layer of CR39 was etched in a NaOH solution 8 N at 80 °C for 80 to 100 hours. This strong-etching procedure reduced the thickness of the sheets from 1.4 mm to about $(0.5 \div 0.2)$ mm. A monopole which crossed a sheet would leave a hole after etching and thus would be easily detectable. The etched CR39 plates were scanned with a stereoscopic microscope type Wild-M4 using low magnification, $\times 6$ and $\times 40$. Only 3 holes were found in the strongly etched sheets. For these cases, in order to look for a coincidence, we etched the second CR39 sheets of the stacks using a more conventional etching technique, in NaOH, 6N, at 60 °C for 30 hours. No track was found at the place anticipated from the hole in the first plate.

In order to measure the effective threshold of the used CR39 when heavily etched, as well as for normal etching, we exposed stacks of CR39 to heavy relativistic sulphur ions of 200 GeV/nucleon at the CERN-SPS (see fig. 1) and to neon ions of 0.6 GeV/nucleon at the Bevalac in Berkeley. We found a threshold of $Z/\beta \simeq 8$ for both normal and heavy etching for the EN3 type, and lower ($Z/\beta \simeq 6$) for the other types. We should thus have nearly 100% efficiency for monopoles with $\beta > 0.2$ and $n > 0.5$; n is taken as a fractional number in order to establish a limit. One should also keep in mind that a monopole-antimonopole pair should have been produced.

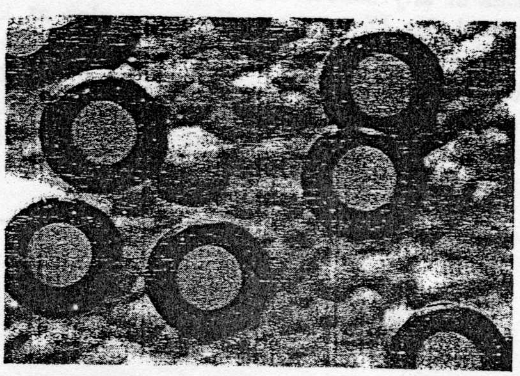

Fig. 1. – Microphotograph of a heavily etched CR39 sheet of type EN3 exposed to sulphur ions of 200 GeV/nucleon. The sheet was etched in a solution of NaOH, 8 N, at 80 °C for 100 hours. The CR39 thickness was reduced from 1.4 mm to 0.2 mm. Note the holes due to sulphur nuclei.

Taking into account the integrated luminosity, the solid-angle coverage and the detection efficiency we obtain an upper limit of $\sigma < 2 \cdot 10^{-34}\,\mathrm{cm}^2$ (95% confidence level) for the production of magnetic monopoles with $n \geqslant 0.5$ and mass less than 850 GeV; for masses smaller than 50 GeV the detection efficiency decreases and the limit increases slightly. The details of the limits as a function of the monopole mass as well as a comparison with previous experiments [2-15] are shown in fig. 2. Note that solid lines refer to direct measurements,

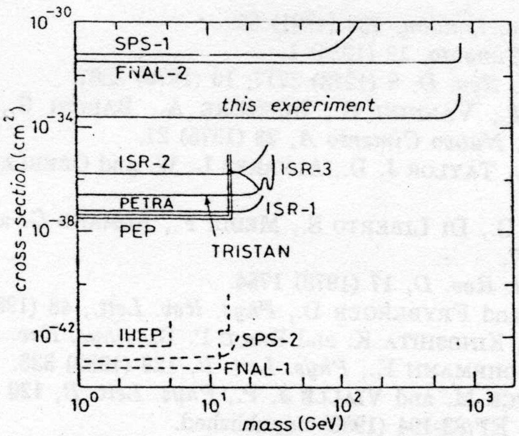

Fig. 2. – Compilation of upper limits for Dirac magnetic monopole production in pN, p̄p and e^+e^- collisions. Solid and dashed lines refer to direct and indirect experiments, respectively.

while dashed lines refer to indirect measurements (in which monopoles were sought long after production, assuming their trapping in ferromagnetic materials and after presumed extraction from matter and acceleration). The figure takes into account the doubts raised in ref. [14] about the sensitivity of kapton foils, in particular when they were located in vacuum.

The E0 region at the Tevatron is a high-radiation environment, because of losses of beam from the Main Ring accelerator, from the Tevatron (minor losses) and because of losses at injection from the Main Ring into the Tevatron. We placed a number of CR39 sheets around this intersection region to study the background. We found that the bulk etching rate of CR39 increased with the radiation dose, rather abruptly (from 4.3 μm/hour to 7 μm/hour) for the first month of exposure and more linearly in the following months (up to 9 μm/hour). The L8 type is the most sensitive. The average dose at E0 during collider operation was roughly estimated at about 5 rads/day. The bulk etching rate increase, after the first month, corresponds to about 0.03 μm per hour per rad.

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We would like to thank the Tevatron staff for the smooth running of the accelerator, F. NEZRICK and the members of the E710 collaboration for their cooperation. We are indebted to a number of colleagues for discussions and comments: we acknowledge the invaluable collaboration of the Bologna INFN technical staff: E. BOTTAZZI, P. CALLIGOLA, L. DEGLI ESPOSTI, M. FOLESANI, I, FRASSINETTI, R. GALEATI, F. MASSERA, F. NICOLI, G. PANCALDI and R. TIRELLI. We thank the Intercast Company of Parma for their cooperation in the manufacturing of the CR39; FP thanks the Intercast Company for a Fellowship. This work was in part supported by an MPI (60%) grant.

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