SEARCH FOR MAGNETIC MONOPOLES IN PROTON–ANTIPROTON INTERACTIONS AT 540 GeV CM ENERGY

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Received 4 November 1982

A search for magnetic monopoles has been pursued at the proton–antiproton collider at CERN, with plastic detectors. No candidates were found. Limits for the production cross section of such objects are given.

The concept of magnetic monopole arose very long ago from experimental observation of the forces exerted by magnets on each other. In addition, the existence of magnetic sources and currents would symmetrize the Maxwell equations. However, the strongest argument in favour of the magnetic monopole is provided by quantum mechanics, from which Dirac [1] was able to predict the strength g_D of the magnetic pole $g_D = hc/2e$. All magnetic charges g would be multiples of g_D: $g = Ng_D$. If the electron is elementary, the least magnetic charge is g_D. If fractional charged quarks are elementary the least magnetic charge is $3\,g_D$.

So far, experimental searches for monopoles have failed [‡1]. Nevertheless, a recent publication [3] has reported a possible candidate from cosmic radiation observed in an experiment using a superconducting coil.

The masses of the monopoles are not predicted by theory, except in some of the Grand Unified Theories. For this reason, the new energy domain of the proton–antiproton collider, with 540 GeV energy in the centre of mass, was explored in the present experiment [4].

The experiment aims at identifying the monopoles by their high ionization rate:

$$(\mathrm{d}E/\mathrm{d}x)/(\mathrm{d}E/\mathrm{d}x_m) = N^2\beta^2(g_D^2/e^2)\,,$$

where $\mathrm{d}E/\mathrm{d}x_m$ is the ionization rate for a minimum ionizing particle, β is the monopole velocity. Plastic detectors [‡2], in which tracks left by heavily ionizing particles are developed by chemical etching after exposure, are well adapted to this search. They have the advantage of being insensitive to minimum ionizing particles, which are copiously produced at accelerators. They are thin and have a moderate stopping power. Finally, by choosing various materials, it is possible to cover a large range of ionization.

As the ionization loss of monopoles is expected to be very large, of the order of $N^2 \times 10$ GeV/g/cm^{-2} for relativistic monopoles, their range may be short. Moreover, possible binding of slow monopoles with nuclei or electrons would diminish the detection efficiency. Consequently, the presence of any material between the region of production and the detector has to be avoided as much as possible. This is particularly the case if monopoles have large magnetic charges. In the present experiment, part of the detector is placed inside the vacuum pipe of the collider around the collision region. After a series of tests the plastic Kapton was chosen for this purpose. This plastic resists the high temperatures encountered during baking of the intersection region and has a very low degassing rate. The portion of the detector which is located inside the vacuum pipe consists of 3 cylindrical sections. These sections are each 1 m long with a diameter of 12 cm and are separated from each other by 2 m.

‡1 For a recent compilation, see ref. [2].

‡2 For a review, see ref. [5].

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Background due to short range spallation nuclear fragments is reduced by employing a double layer of Kapton in this region. In order to eliminate this background, it is sufficient to choose the thickness of the detector, $2 \times 75\ \mu$ in the present case, to be much larger than the range of the spallation products (of the order of one micron). Monopoles, on the other hand, would be much more penetrating.

Around the beam pipe, which is a stainless steel corrugated cylinder of 0.2 mm thickness, a third layer is wrapped over a length of 6 m. Large plastic sheets are also placed around the central detector of the UA1 colliding experiment in order to possibly track the monopoles through the magnetic field. The results presented here were obtained using one of the three interior sections and the complete detector placed outside the pipe during the first period of operation of the proton–antiproton collider from August to December 1981 [4]. The total integrated luminosity during this period is $(2.5 \pm 1) \times 10^{32}/\mathrm{cm}^2$, the uncertainty on the luminosity coming from the lack of knowledge of the beam shapes and from uncertainties in the intensity measurement.

The Kapton foils were developed by immersion in a 15% NaClO solution for 4 h. The action of the developer is to etch the bulk of the material at the rate of about 5 μm per hour whilst etching zones which have been damaged by the passage of highly ionizing particles at several times this rate. The net result of this differential attack is to leave a hole along the path of the particle. To search for such holes the developed plastic sheet is placed between two sponges wetted with an electrolyte; these sponges are in turn connected to a battery in series with a microammeter. In the case of a traversing hole the electrolyte connects the two sponges and a current of some microamperes flows. During the scanning process the apparatus is continually calibrated using holes of known diameter. No hole was found which could be attributed to the passage of a highly ionizing and penetrating particle.

The main difficulty which arises in extracting limits for the production cross section of monopoles is the complete absence of a good production model, because perturbation methods are inapplicable. In the following, the hypothesis is made that monopole production is not due directly to a proton–antiproton interaction, but is rather similar to a Drell–Yan process, i.e. $q\bar{q} \to g\bar{g}$. The x_1 and x_2 distribution of quarks and antiquarks in the proton and antiproton are taken to be $(1 - x^3)$ as indicated by lepton production experiments. The production can only occur for $x_1 x_2 S \geqslant (2M_g)^2$. The contribution of the quarks from the sea is neglected. No angular dependence of the cross section is explicitly assumed. Note that the effect due to the x-distribution of quarks is generally omitted in the discussion of previous experiments, whereas it is important in hadron reactions.

The external detector only was used to set a limit on the monopole production cross section, because the developed internal detector covers a small solid angle and then adds little information. Furthermore, the corresponding result would have been very model-dependant.

The ionization threshold for Kapton has been taken into account. It has a significant effect for $g = g_D$, but is almost ineffective for $g = 3g_D$. A small energy loss, of the order of $N^2 \times 1.5$ GeV is due to the traversal of the vacuum pipe by monopoles and is also taken into account. The results are given in fig. 1. Typical values of the limiting cross sections lie between 10^{-32} and 10^{-31} cm^2, depending on monopole mass and charge values, assuming that the above production mechanism is a valid hypothesis.

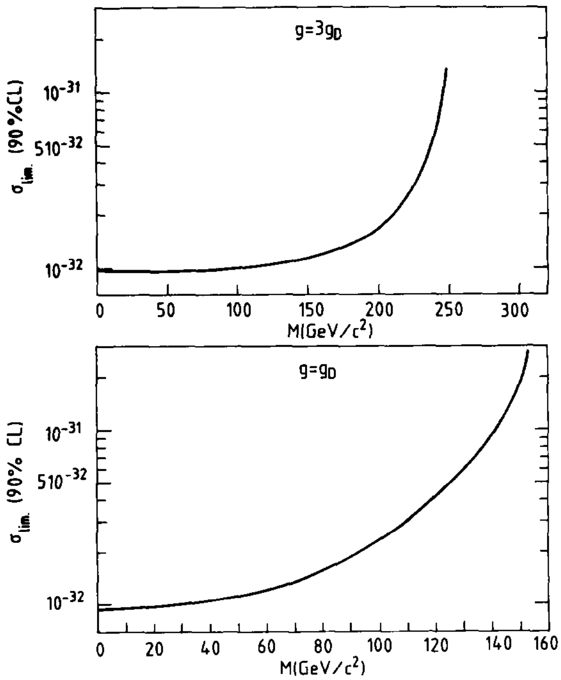

Fig. 1.

An order of magnitude increase in sensitivity is expected to be obtained in the next year of operation of the collider.

We would like to thank all our colleagues who were involved in the collider construction, and in particular B. Angerth, G. Engelmann and M. Genet for their active contributions in the preparation of the detector. We also wish to thank the ISR vacuum group for earlier technical developments, O. Piolatto for his help in the development and scanning of the foils and our colleagues of the UA1 experiment for the opportunity they gave us to place our detector inside their apparatus.

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