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SEARCH FOR MAGNETIC MONOPOLES IN ELECTRON–POSITRON COLLISIONS AT 34 GeV CM ENERGY

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A search for heavily ionizing particles was carried out at the electron–positron storage ring PETRA with the help of Kapton detectors placed inside the vacuum pipe. The total integrated luminosity was 90 pb^{-1} at CM energies above 34 GeV. The search was sensitive to particles with magnetic charge from $1 \cdot \frac{137}{2} e$ to $5 \cdot \frac{137}{2} e$ and with masses up to 10–16 GeV/c^2. No such particle was found, leading to an upper limit of the production cross section of monopole–antimonopole pairs of $4 \times 10^{-38}\ \mathrm{cm}^2$ (95% CL).

Since Dirac's work on magnetic monopoles [1] the question of the actual existence of such particles has remained an important experimental issue [2,3]. The magnetic charge g of a monopole is given by

$$e \cdot g = n \cdot \tfrac{1}{2}\hbar c \,, \qquad (1)$$

e = elementary electric charge = charge of positron, $n = 1, 2, 3, \ldots$

New arguments for the existence of monopoles come from modern gauge theories [4]. These theories place the mass of monopoles well beyond the reach of present accelerators or storage rings. Nevertheless, considering the general difficulty of predicting masses of elementary particles, it is important to continue the search for monopoles at accelerators or storage rings with the largest available energies. The present search was also undertaken with the aim to be sensitive to rather large magnetic charges. If for example the "true" elementary electric charge was $\frac{1}{3}e$ instead of e, the smallest monopole charge according to eq. (1) could be as large as $g = 3 \cdot \frac{137}{2} e$, and it was our aim to include this possibility in our search.

The experiment was carried out at the PETRA e^+e^--storage ring of the DESY Laboratory. The detector consisted of 7 cylindrical layers of Kapton foils, 40 cm long, 18.4 cm diameter, 75μ thick, placed at the SW interaction region inside the vacuum chamber of the storage ring. The solid angle covered was 85% of 4π, using a length of 30 cm of the detector.

The importance of having no material between the interaction point and the detector can be seen by considering the ionization rate of monopoles in matter, which for not too small values of the velocity β is approximately constant, given by

$$\mathrm{d}E/\mathrm{d}x \approx g^2 \,\mathrm{d}E/\mathrm{d}x|_{\mathrm{m}} = n^2 (\tfrac{137}{2})^2 \,\mathrm{d}E/\mathrm{d}x|_{\mathrm{m}} \qquad (2)$$

where $\mathrm{d}E/\mathrm{d}x|_{\mathrm{m}}$ = ionisation rate of a minimum ionizing particle.

For $n = 1$ one has $\mathrm{d}E/dx \approx 9\ \mathrm{GeV}/g\ \mathrm{cm}^{-2}$, but if the "true" elementary electric charge were $\frac{1}{3}e$, and this corresponds to $n = 3$, then $\mathrm{d}E/\mathrm{d}x \approx 80\ \mathrm{GeV}/g\ \mathrm{cm}^{-2}$. A monopole of this kind would be stopped by the PETRA vacuum chambers and therefore escape detection if the detector was placed outside.

Kapton was used as detector, because the ionization threshold above which tracks can be detected in this material is rather high, $\mathrm{d}E/\mathrm{d}x \geqslant 4\ \mathrm{GeV}/g\ \mathrm{cm}^{-2}$, and therefore it is insensitive to background. Also,

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because of its small degassing rate it can be exposed inside the vacuum chamber of the storage ring.

Monopoles would be detected in these foils by their high ionization rate. After exposure the foils are developed in 15% NaCl solution for 4 h and any tracks would appear as holes in the plastic since the etchant preferentially attacks the region of the tracks. The foils are placed between pads soaked with electrolyte and, if a hole were present, electrical contact would be established between the two sides. A survey of this technique can be found in ref. [5 Ad. 7].

In order to check that kapton does not lose its detection properties at the conditions inside the storage ring a small piece of kapton, which had previously been exposed to heavy ions, was kept inside the PETRA vacuum chamber for 9 months. No change in its sensitivity was observed.

The foils were exposed in the period from February 1981 to January 1983. The total integrated luminosity was 1.9 pb^{-1}, 3.4 pb^{-1}, 89 pb^{-1}, 1.5 pb^{-1} at CM energies of 14 GeV, 22 GeV, 34.5 GeV and 38 GeV respectively.

After development no hole was found which could be interpreted as being produced by a single ionizing particle.

In order to compute a limit for the production cross section, we assume the following mechanism for the production of a monopole antimonopole pair:

$$e^+e^- \to M^{(+)}M^{(-)} .$$

The energy of the monopole is then equal to the beam energy of the storage ring, and therefore the velocity β of the monopole as function of its mass m is known.

The kapton foils are only sensitive for monopoles above a threshold velocity β_{th}, because the ionisation rate is a decreasing function of β. Using the work of ref. [6] [‡1] on the ionisation rate of monopoles, and a safe value of 6 GeV/g cm^{-2} for the sensitivity limit of kapton, one obtains $\beta_{\text{th}} = 0.6$ for $n = 1$ or $g = \frac{137}{2}e$. For larger values of the magnetic charge, the limit on β is given by the requirement that the monopole should penetrate at least one foil at the largest angle inside the acceptance of the detector. These values of β_{th} were again calculated using ref. [6] [‡1]. The values of β_{th}, which depend on the magnetic charge $g = n\frac{137}{2}e$, imply upper limits for the mass of a monopole which can be detected. These mass limits are shown in fig. 1 as a function of the magnetic charge. Also included in fig. 1 are the limits obtained in a similar experiment with PEP at SLAC [8].

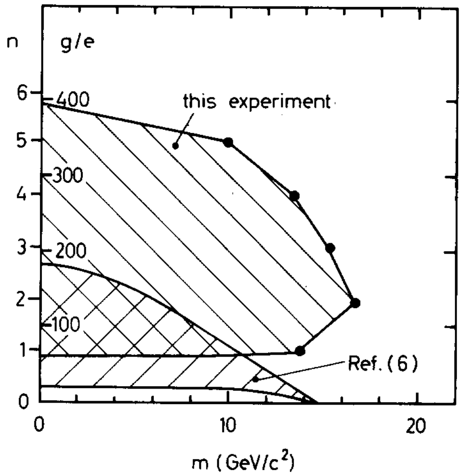

Fig. 1. The monopole mass m, for which this experiment was sensitive, is shown (shaded), g = magnetic charge g of the monopole, n = magnetic charge of monopole in multiples of the Dirac charge $(137/2)e$; also shown for comparison are the limits obtained by ref. [8].

In order to compute an upper limit for the pair production cross section σ, we assumed isotropic production of the monopoles. Using only the luminosity above 34 GeV CM energy, one obtains

$$\sigma < 4 \times 10^{-38}\ \text{cm}^{-2} \quad (95\%\ \text{CL}) .$$

This value can be compared with the limit of 0.9 $\times 10^{-36}$ cm^{-2} obtained in a similar experiment at SLAC [8]. It can also be compared with the QED point cross section σ_0 of producing a fermion antifermion pair with charge e

$$\sigma_0 = \tfrac{2}{3}\pi(\alpha^2/E^2_{\text{cm}})\beta(3 - \beta^2) ,$$

which is 0.7 $\times 10^{-34}$ for 34.6 GeV CM energy and $\beta = 1$.

Comparison with a recent experiment at the p$\bar{\text{p}}$ collider at CERN [3] is more difficult, because the production mechanism is different. A cross section limit about 10^{-32} cm^{-2} was given there, with mass limits of course larger than those obtained here.

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[‡1] For small values of β, see ref. [7].

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