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Extension of Fermi National Accelerator Laboratory magnetic-monopole search to 400 GeV

R. A. Carrigan, Jr., F. A. Nezrick, and B. P. Strauss
*Fermi National Accelerator Laboratory, Batavia, Illinois 60510**
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In a search for magnetic monopoles an aluminum target has been exposed to 5.7×10^{16} protons of 400 GeV energy at the Fermi National Accelerator Laboratory. The search apparatus employs equipment used previously in a search for monopoles produced by 300-GeV protons where a cross section of 6×10^{-42} cm^2 was established using an iron dump. For the 400-GeV experiment the equipment was modified to detect magnetic charges down to 1/30 of the Dirac magnetic charge. No magnetic monopoles were found with magnetic charges in the interval from 1/30 to 24 times the Dirac magnetic charge. The upper limit at a 95% confidence level for the cross section per nucleon in aluminum is 5.1×10^{-42} cm^2.

In this phase of the Fermi National Accelerator Laboratory monopole experiment, two changes were made from the earlier 300-GeV search.[1] The energy was increased to 400 GeV, and the minimum detectable magnetic charge was reduced to $\frac{1}{30}$ of the Dirac charge. By going to higher energies, it is possible to produce particle pairs with larger masses. The mass limit for production of monopole pairs in 400-GeV collisions neglecting the magnetic binding effect is 13.7 GeV per monopole. The second modification involved an addition to the detector system so that magnetic monopoles with smaller magnetic charges might be detected. The charge range searched in the original experiment spanned the region from $\frac{1}{6}$ to 24 times the Dirac charge, which more than covers the range of theoretical suggestions. However, because of magnetic binding it should become easier to produce free monopoles as the magnetic charge becomes smaller. From this standpoint, it appears reasonable to enlarge the sensitivity to small magnetic charges when looking for free magnetic monopoles. The extension was accomplished by adding several thicker counters (6.35 mm thick) to the original array of 0.25-mm counters. The new counters could produce pulses 25 times larger than the 0.25-mm scintillators. The thicker counters were placed at the downstream end of the detection system and included in a separate trigger system. Either the original charge-range trigger or the new lower charge-range trigger could trigger the system.

The monopole collector was a 30.5 cm long $\times$15.2 cm wide $\times$5.1 cm high aluminum target enclosed in a diamagnetic sheath of brass. The collector was segmented into pieces 5.1 cm long $\times$ 2.5 cm $\times$ 3.8 cm so that it could easily be processed in the monopole extraction system. The target used was for a 400-GeV neutrino run. During the run the target was moved several times resulting in the proton beam exposure being distributed somewhat over the target face. Whenever the target was handled, care was taken not to bring the target into regions of high magnetic field. The target was exposed to 5.7×10^{16} protons. The proton flux was determined by comparing the Na^{22} activity in the aluminum sample to that of a second aluminum sample that had been exposed to a known number of protons. Use of the 2.6-year half-life of Na^{22} minimized considerations of both the length of the production run and the delay of the extraction run.

Aluminum is a paramagnetic substance. Some models of binding suggest that in aluminum magnetic poles will migrate to the surface and eventually leave the surface under the effect of stray magnetic fields.[2] Other models, particularly that of Sivers at Berkeley,[3] suggest that binding might attach the pole directly to a nucleus where it would remain fixed since the atom is anchored in the solid matrix of the material. The cross-section calculations in this experiment are based on the assumption that the poles were contained within the collector and could be extracted with the applied magnetic field of 80 kG.

Since the aluminum collector is paramagnetic rather than ferromagnetic, it is necessary to consider the process of placing the aluminum into the magnetic field of the solenoid. The extraction and detection system was designed so that the "fringe field" of the 80-kG solenoid would extract monopoles from a ferromagnetic collector at a position on the axis of the solenoid where there was good focusing of the monopoles into the detection system. The counters are sized for the good-focusing geometry. On the other hand, for aluminum collectors, monopoles would be extracted by the lower magnetic field farther from the solenoid, and most of the focusing effect would be lost. To circumvent this problem an iron panel was attached to the front end of the aluminum target segments. The target segments were then introduced into the region of the solenoid along its axis with the magnetic field off. When the aluminum target elements were in approximately the right position the field was turned on and the aluminum plus the iron guard were inserted into the bore of the solenoid. This technique had the effect of extracting any poles first from the aluminum, then catching them in the iron, and finally reextracting them from the iron at the good-focusing extraction position.

No magnetic monopoles were found in the magnetic charge interval that was searched.

Using the hypotheses above, and bearing in mind the possible difficulties with the binding hypothesis, the following cross-section limit is determined. The cross-section limit for free monopole production by 400-GeV protons on aluminum at a 95% confidence level is 4.6×10^{-41} cm^2/nucleus. Assuming that only the surface nucleons contribute to the production the cross section per nucleon at a 95% confidence level is 5.1×10^{-42} cm^2/nucleon. Figure 1 illustrates this cross-section limit on a graph of cross section versus monopole mass along with the data from the 300-GeV experiment as well as several other experiments that have been carried out at lower energy.[4–7]

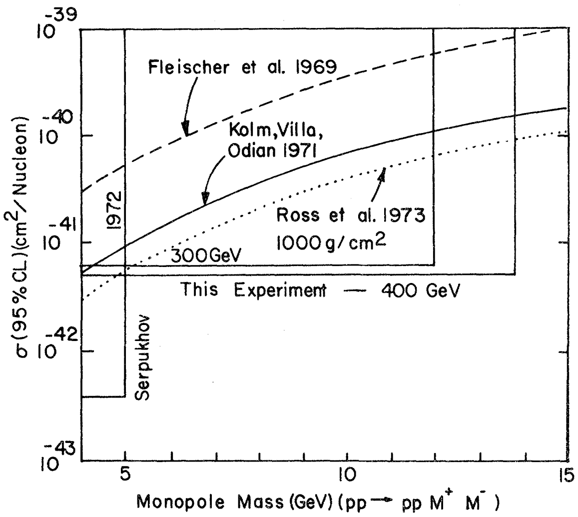

FIG. 1. Upper limit for the cross section of monopole production in p-nucleon collisions. Relevant cross sections based on $A^{2/3}$ are shown. The 13.7-GeV limit is the result of this experiment, while the 12-GeV limit is the result of the 300-GeV run (see Ref. 1). The 5-GeV limit is Serpukhov (Ref. 4). The dashed line is Fleischer *et al.* (Ref. 5), the dotted line is Ross *et al.* (Ref. 6), and the solid line is Kolm *et al.* (Ref. 7).

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