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EXPERIMENTAL SEARCHES FOR MAGNETIC MONOPOLES AT PARTICLE COLLIDERS

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The concept of magnetic monopoles is almost as old as the study of magnetism itself. However, only since 1931, the year of publication of Dirac's[1] classic paper, have monopoles had a fundamental role in modern physics. Of late, Grand Unified Theories have been able to provide predictions of the mass of the magnetic monopole, a parameter missing from Dirac's analysis. Although recent investigations have concentrated on the detection of very heavy GUT monopoles there seem to be no serious theoretical constraints forbidding the existence of monopoles with lower mass. The experimental searches for such light monopoles described here were carried out at three particle colliders with large center of mass energies: the CERN ISR, the CERN SPS collider and PETRA at DESY.[2,3,4] The maximum center of mass energies and particle types were respectively 60 GeV (pp and $p\bar{p}$), 540 GeV ($p\bar{p}$) and 40 GeV (e^+e^-).

Light magnetic monopoles produced in colliders would have high velocities and the search technique is based on the fact that such monopoles would have a high ionization loss. The predicted magnetic charge of the monopole is

$$g = n\hbar c/2e = en/2\alpha = 137ne/2 \qquad (1)$$

where the symbols have their usual significance and n is an integer. A magnetic monopole travelling at velocity βc would produce a circulating electric field $(137/2)\beta$ times stronger than the field due to a singly (electrically) charged particle. The expected ionization rate is of the order of $9(n\beta)^2$ GeV g^{-1} cm^2.

In the environment of a particle collider many electrically charged particles can be expected to pass through a monopole detector which should, ideally, be insensitive to them. Some plastic detectors possess sufficient insensitivity; in these detectors a trail of damage on the microscopic level produced by the passage of a highly ionizing particle can be subsequently revealed by suitable chemical treatment. The commercially available plastic foils Kapton and Makrofol have ionization thresholds of 5 GeV g^{-1} cm^2 and 2.5 GeV $g^{-1}cm^2$ respectively and are thus insensitive to minimum ionizing particles. The detectors themselves take the form of several sheets of plastic foils (to avoid accidental coincidences). The thickness of the individual foils is determined by the fact that they should be sufficiently thin to permit easy development but should be thick enough to prevent heavily ionizing end-of-range protons from simulating a signal. Foil thicknesses of the order of 50–100 μm are used which satisfy both these criteria.

As noted above, magnetic monopoles with very large velocities would be highly ionizing and in all three experiments efforts are made to minimize the amount of material between the production region and the detectors themselves. In each experiment Kapton foils are used directly inside the vacuum chamber of the collider; extensive tests had demonstrated the excellent high temperature and degassing properties of this material. In all three experiments magnetic fields are present: 1.5 T at the ISR, 0.7 T at the SPS collider and 1.7 T at PETRA. Such fields serve to separate any $g\bar{g}$ pairs produced and, in the case of the ISR experiment, would actually direct one of the monopoles toward the detector.

In the ISR experiment the foils are located in a tube attached to the main vacuum chamber. The foils, which are arranged in three pairs, are situated some 70 cm from the intersection zone. The SPS experiment is located at the same intersection zone as the UA1 experiment. The internal detectors take the form of three cylinders made of double layers of kapton foil. These cylinders, of length 1 m and diameter 12 cm, are placed 2 m apart straddling the intersection region. There are also two external sets of Kapton foils. In the PETRA experiment the detector consists of a cylinder wound from seven layers of Kapton and again placed around the intersection region.

The Kapton foils were developed in NaOCl solution at 90 °C for 2 hours while the Makrofol foils, used in part of the ISR experiment, were treated in an NaOH solution at 50 °C for 8 hours. The principle of this etching procedure is that attack of the material occurs at a much higher rate along the track of the heavily ionizing particle than in the bulk of the material. This differential attack eventually results in the formation of a hole along the trail of the particle. The bulk thickness of the foils is reduced by about 25% by this process. Holes in the plastic foils are located by placing them between two electrolyte soaked sponges connected in a circuit containing a microammeter. Calibration of this device using foils exposed to fission fragments had established that a current of 1 μA corresponded to a hole of 4 μm diameter. No holes were seen which could be interpreted as being due to magnetic monopoles.

One of the major difficulties in calculating limits of production cross section in the pp and $p\bar{p}$ experiments is that the detection efficiency depends on the production model. For the ISR results it is assumed (following previous authors[5,6]) that the monopoles are produced isotropically in the reaction $p + p \rightarrow p + p + g + \bar{g}$ and that the available energy is divided among the outgoing particles proportionally to the relativistic phase space. In Fig. 1 the production cross section limit is plotted as a function of monopole mass. A more reasonable hypothesis may be that monopole production is not due directly to a proton-proton interaction but is similar to a Drell-Yan process $q\bar{q} \rightarrow g\bar{g}$ (the anti-quark being supplied from the sea). This hypothesis is considered in the analysis of the $p\bar{p}$ results (here, of course, the anti-quark comes from the anti-proton). The x-distribution of quarks in the proton and anti-quarks in the anti-proton is taken to be $(1-x^3)$ as indicated by lepton production experiments. If x_1 refers to the quark and x_2 to the anti-quark then monopoles can only be produced when $x_1 x_2 \geq (2M_g)^2$.

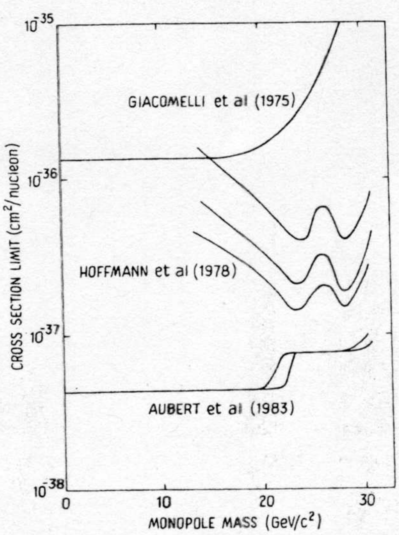

Fig. 1. Limits on monopole production cross section (95% C.L.) as a function of monopole mass in the ISR experiment.

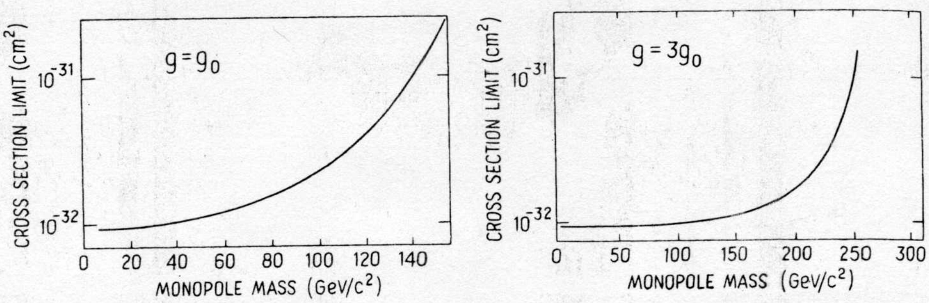

Fig. 2. Limits on monopole production cross section (90% C.L.) as a function of monopole mass in the SPS experiment.

It is assumed that production is isotropic in the center of mass system of the quark-anti-quark pair and that, on account of the x-distribution, the produced monopoles will suffer Lorenz boosts in the laboratory system. The results for the SPS collider experiment are shown in Fig. 2.

In the PETRA experiment isotropic monopole production was assumed which, for a center of mass energy $\geq$ 34 GeV gives an upper limit of monopole production cross section in the reaction $e^+e^- \to g\bar{g}$ of 4×10^{-38} cm^2 (95% C.L.). This value can be compared to the limit of 9×10^{-37} cm^2 obtained in a similar experiment at SLAC.

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