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Search for Monopoles Above the 15-Foot Bubble Chamber

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ABSTRACT

Magnetic monopoles having energies less than about 40 TeV will be slowed to their terminal velocity by the earth's atmosphere. They may then be gathered by the fringing magnetic field of the 15-foot bubble chamber. We propose placing detectors of Lexan and nuclear emulsion at convenient locations above and below the bubble chamber. Such a system would be sensitive to monopole masses between 10 GeV and 100 TeV and to monopole charges between $\sim$0.7 and 10 $\hbar c/2e$. The experiment would require the construction of a special light roof and would run for 5 weeks during a time when the bubble chamber is filled with air and not in use for other experiments. This study would lower the existing limit on in-flight detection of monopoles (at the earth's surface) by a factor of 20.

Physics Justification

Let us, for the moment, assume that the event found recently in the upper atmosphere is really a magnetic monopole having twice the Dirac charge $\hbar c/2e$ and at least 600 times the proton mass.[1] Is there any way that such a monopole could have escaped detection in the other searches that have been completed in the last decade? In the following table we summarize the most sensitive of these searches:

authors	area x time product for one event (cm^2-sec)	limits (on energy of monopole when it enters earth's atmosphere).	technique
Kolm, Villa, and Odian (1971)[2]	$\gtrsim 5 \times 10^{17}$	$E \lesssim 10^{16}$ eV	monopoles trapped in iron spherules contained in sea sediment
Eberhard, Ross, Alvarez, and Watt (1971)[3]	$\gtrsim 5 \times 10^{17}$	$E \lesssim 10^{13}$ eV	monopoles trapped in magnetic crystals in lunar samples
Fleischer, Hart, Jacobs, Price, and Aumento (1969)[4]	$> 5 \times 10^{17}$	$E \lesssim 10^{16}$	monopoles trapped in sediment
Fleischer, Price and Woods (1969)[5]	$> 2 \times 10^{18}$	$E > 10^{14}$ eV	stored tracks in mica/and obsidian
Fleischer, Hart, Nichols, and Price (1971)[6]	$> 9 \times 10^{12}$	$E > 10^{14}$ eV	tracks in Lexan at sea level
Carithers, Stefanski, and Adair (1966)[7]	$> \cancel{7}\ 2^{*} \times 10^{13}$	$E < 10^{14}$ eV	north-seeking monopoles slowed in atmosphere and collected by the fringing field of the magnet for the 14-inch bubble chamber

*factor of two inserted since this experiment is sensitive only to poles of one sign.

Price, Shirk, Osborne, and Pinsky (1975)[1]	$\gtrsim 1 \times 10^{12}$	$E > 2 \times 10^{11}$ eV	balloon and Skylab flights

Four of these searches set upper limits approximately a million times more stringent than that suggested by the recent event. Further, these searches are complementary. The experiments of Kolm et al and Eberhard et al require that the monopole have sufficiently low energy that it can be stopped close to the surface of the earth (or moon). Conversely, the experiment of Fleischer et al[5] required that the monopole have sufficiently high energy to pass through naturally occurring mica or obsidian.

The latter experiment, however, was only marginally sensitive to monopoles bearing twice the Dirac charge. The former experiments assume that a monopole may be trapped in ferromagnetic material for geologically-long periods.

These trapping experiments contain a series of assumptions, each plausible but none proved. Because the possibility exists that one or more of the assumptions are wrong, alternative types of experiments should be performed.

If the four most sensitive experiments are - for any reason - incapable of detecting monopoles, the next limiting experiment is that of Carithers et al. The upper limit set by this experiment is still a factor of about 35 more stringent than the rate suggested by the recent event. But 35 is a much smaller number than a million. We are thus led to the following working hypothesis:

i) Monopoles are produced in (or impact on) the upper atmosphere at a rate consistent with the upper limit set by Carithers *et al*.

ii) The monopoles have sufficiently low energy to be slowed to their terminal velocity by the earth's atmosphere (Energy < 40 TeV for very heavy poles and $<10^{20}$ eV for poles of 10 GeV mass).[8]

iii) Once slowed, the monopoles drift along magnetic field lines towards the earth's surface (as in the original hypothesis of Malkus).[9]

iv) Monopoles which are drifting along field lines above the bubble chamber will be gathered in by the fringing field of the bubble chamber,[10] the polarity of the magnet being adjusted so as to attract north-seeking monopoles.

v) This magnetic field will accelerate monopoles to sufficiently high energies that they leave visible tracks in Lexan detectors and nuclear emulsions.

Since the 15-foot bubble chamber has a monopole-gathering power 30 times as great as that of the 14-inch chamber used by Carithers *et al*, a search at this installation should either find several monopoles or should be able to set stringent limits on their properties. The proposed experiment will be sensitive to a wider range of charge and mass than the experiment of Carithers *et al*.

To be generally useful, such a search should cover a range of monopole masses and charges which includes, but is not limited to, the particular parameters of the event of Price et al. We propose to accomplish this search by exposing Lexan sheets and nuclear emulsions at convenient locations above and in the 15-foot bubble chamber.

Experimental Technique

Distinguishing a monopole from a fragmenting, heavy nucleus in the presence of the primary cosmic radiation is - as is now known - a difficult experimental problem. Fortunately, this problem is obviated at sea level by the observed absence of penetrating heavy nuclei.[6] We do not expect that the proximity of the accelerator will produce any such nuclei[11] and the beam will not be in use in the bubble chamber area during the proposed experiment.

Even if penetrating heavy nuclei (or other new particles) are found, however, the fringing field of the bubble chamber provides a mechanism for distinguishing slow, magnetically charged particles from electrically charged ones. The former will be accelerated along field lines, whereas the latter will not (see fig. 1).

A convincing demonstration of a moving monopole would require the presence of tracks along a consistent trajectory in at least two detectors. One layer of Lexan will be used for rapid scanning since, when completely etched through, an area may be scanned at the rate of 1 sq ft per minute. The emulsion will be used to determine the velocity of the particle. If the mass of the monopole is a TeV or greater, it would be accelerated only to small velocities ($0.01 \lesssim \beta \lesssim 0.5$) by the fringing field of the bubble chamber. At such speeds, emulsions provide unambiguous velocity measurmments.

Consider a slowed monopole attracted by the fringing field. The descent of the monopole is controlled by the ionization loss in air (fig. 2) and by the energy gained from the fringing field (fig. 3). Using these two curves, one can readily determine the energy, velocity, and range in Lexan at any given altitude of a monopole of given charge and mass.

<u>Need for a Temporary Roof</u>

At the altitude of the existing roof the range of a previously slowed monopole would be only a millimeter of plastic. Since this roof has 3 to 7 inches of fiberboard insulation, it would undoubtedly stop the monopole. Is the local magnetic field (600 G) sufficient to pull the monopole through the insulation and the aluminum sheeting which forms the underside of the roof?

The chemistry of monopole migration in solids may be treated quantum mechanically. Amaldi <u>et</u> <u>al</u> have hypothesized that a monopole will jump to an adjacent lattice site at a rate given by

$$r = \nu \exp [- (W - dgH)/kT] .$$

Here,

ν is the atomic vibration frequency (10^{13} Hz)

d is the lattice dimension (2 Ångstroms)

g is the monopole charge ($7 \cdot 10^{-8}$ emu, twice the Dirac charge)

H is the local magnetic field (600 G)

and W is the amplitude of the potential fluctuation in the binding of the monopole to the lattice.[12]

W is a critical parameter in the rate calculation. If W is 0.5 eV, we find a respectable downward diffusion rate of 10^5 cm/sec. However, if W is 2.0 eV, the rate is reduced to 10^{-22} cm/sec!

These numbers make it clear that the aluminum roof constitutes an intolerable barrier to monopole motion. Consider the effect of the trace amounts of iron dissolved in aluminum. A monopole is bound with an energy μH, where μ is the magnetic moment of iron (taken as two Bohr magnetons) and H is the field of the pole. For the pole at one atomic radius from the iron the binding is 4.88 eV for twice the Dirac pole strength, so that a 600 G field would be ineffective in removing it. And for as little as a part per million of iron (a small fraction of the 5,000 - 10,000 ppm that is usually present) the mean free path between iron atoms is $\sim 3 \times 10^{-2}$ cm, so that trapping is to be expected.

Even though it may be conceivable that a slow monopole penetrate the existing roof,[13] it is the intention of this proposal to make the most complete search for slowed monopoles that is possible with present magnets. The present roof is not compatible with this goal.

Fortunately, the roof was designed to be removable. We propose replacing it with a temporary wood truss and canvas one (see fig. 4). The temporary roof, shaped like an inverted frustrum, would place no solid material in the way of the monopole until an altitude 8 feet below the present roof line. At such an altitude the monopole should have acquired enough energy to penetrate the canvas with ease.

Detectors

We plan to place detecting sheets on top of the bubble chamber and in the bubble chamber (see fig. 4).

The following table summarizes the characteristics of the detectors:

Locations for Monopole Detectors

	Top of Bubble Chamber	Bottom of Bubble Chamber
Detector Area (sq m)	6.6	3.7
Altitude (above center of bubble chamber)	12'	-5'
Average magnetic field	6,000 G	30,000 G
Magnetic flux collected from earth's field (kG-cm^2)	$2.8 \cdot 10^5$	$1.7 \cdot 10^{4\dagger}$
Fraction of possible flux collected	85%	5%†
Area x Time sampled* ($10^{13} cm^2$-s)	125	8
Limits on monopole pole strength n, where $g = n\hbar c/2e$	0.7-10	0.7-15
Limits on monopole mass (TeV) (assuming n = 2)	0.005-80	0.005-4000
Range in Lexan of 1 TeV, n = 2 monopole	2.0 cm	14cm
Energy of monopole when it strikes detector (GeV)	37	390
Maximum Energy put into monopole by magnetic field ($g\int_{\infty}^{z} H.dl$, in GeV)	80	440

*Assuming an exposure of 35 days
†Assuming that monopoles which do not make it through the open top optics port (0.28 m^2) are stopped by the top shell and bubble chamber

Timetable for Experiment

The timetable for the experiment is constrained by the need for a temporary roof. The proposed new roof is not compatible with the hydrogen safety requirements of normal bubble chamber operation. In addition, this temporary roof will shed rain but not snow. Fortunately the magnetic field may be energized even when the chamber itself is filled with air. Thus, we propose running this experiment for a minimum of 5 weeks during one of the long scheduled shutdowns of the 15-foot bubble chamber. The summer of 1976 is a particularly attractive possibility. Extension of the exposure to greater times is highly desirable.

Equipment Needs and Fermilab Manpower Needs

	cost	provider
825 m^2, 0.0250 cm thick Lexan sheet (450 lb)	$900	GE
220 sq ft, 300 micron thick G-5 emulsion (700 cu in)	$3,100	Princeton
Stand above bubble chamber	$2,000	CU
Temporary roof	$3,000	CU
Riggers for installation and removal of temporary roof	$5,000	Fermilab†
Two men to maintain magnetic field (10 man-months)	$10,000	Fermilab
Processing of nuclear emulsion	$2,000	CU
Scanning equipment	$8,000	GE*
Lexan etching equipment	$3,000 $2,000	GE CU

Other Committments of Experimenters

D. Bartlett and M. G. White are committed to the completion of the search for tachyon monopoles (E-202). This search, however, should be completed at the end of the current cooldown. M. G. White is the principal investigator for the Princeton cyclotron. Robert Fleischer, Howard Hart, and Antonio Mogro-Campero are presently using plastic detectors similar to Lexan in several medical and seismological applications.

†Approximately 1/2 of this cost could be charged against the expense of removing the present E-202 box. This removal is simplified if the box can come off along with the standard roof rather than being laboriously rigged out through the inside of the bubble chamber room.

*Presently available at GE.

Appendix

Some useful formulas follow:

MONOPOLE FORMULAS

Energy Gain	$\frac{dE}{dx} = 20\ nH$ [MeV/cm], H in Kilogauss
Energy Loss (ionization)	$-\frac{dE}{dx} = 10\ n^2 \left[\frac{\text{GeV}}{\text{g/cm}^2}\right]$ (high energy limit)
Area x Time factor for consistency with Galactic Mag. field (of Age 200 M. yr.)	$= 10^{15}\ n\ [\text{cm}^2\text{s}]$
Energy loss through atmosphere (vertical incidence)	$= 10^4\ n^2$ [GeV]
Energy loss ratio: monopole/charged particle	$\frac{-(dE/dx)_{mon}}{-(dE/dx)_{ze}} = \left[\frac{g\beta}{ze}\right] = 4.7\ 10^3 \left[\frac{\beta n}{z}\right]^2$

Footnotes

1. P. B. Price, E. K. Shirk, W. Z. Osborne, and L. S. Pinsky, Phys. Rev. Letts. 35, 487 (1975). P. B. Price, Bull. Am. Phys. Soc. 21, 61 (1976).

2. H. H. Kolm, F. Villa, and A. Odian, Phys. Rev. D 4, 1285 (1971).

3. P. H. Eberhard, R. R. Ross, L. W. Alvarez, R. D. Watt, Phys. Rev. D 4, 3260 (1971).

4. R. L. Fleischer, H. R. Hart, Jr., I. S. Jacobs, P. B. Price, W. M. Schwartz, and F. Aumento, Phys. Rev. 184, 1393 (1969).

5. R. L. Fleischer, P. B. Price, and R. T. Woods, Phys. Rev. 184, 1398 (1969).

6. R. L. Fleischer, H. R. Hart, Jr., G. E. Nichols, and P. B. Price, Phys. Rev. D 4, 24 (1971).

7. W. C. Carithers, R. Stefanski, and R. K. Adair, Phys. Rev. 149, 1070 (1966).

8. The detectors will, of course, be sensitive to penetrating monopoles of higher energies. The detectors, however, are only large enough to permit setting a limit on penetrating monopoles comparable to that of Ref. 6.

9. W. V. R. Malkus, Phys. Rev. 83, 899 (1951).

10. If the drift velocity is too low, a strong wind could blow the monopole away. We calculate that even with attached (paramagnetic) oxygen molecules a monopole in the earth's magnetic field should have a velocity of at least 50 m/s and so be impervious to anything less than a hurricane. (See N. A. Fuchs, "Mechanics of Aerosols", Pergammon, Lond., p. 29, 1964.)

11. It is kinematically possible for a 300 GeV nucleus to emerge in the forward direction when a 400 GeV proton strikes a heavy target. However, such production is very strongly suppressed. A search for penetrating heavy ions near a primary target has been done already with negative results. (L. Lederman, private communication).

12. E. Amaldi, G. Baroni, H. Bradner, H. G. deCarvalho, L. Hoffmann, A. Manfredini and G. Vanderhaeghe, CERN 63-13 (1963).

13. Lexan sheets have been placed in the bottom of the E-202 box to see whether any monopoles can penetrate the roof.

Figure Captions

Fig. 1. Trajectories of an $n = 2$ Monopole of Various Masses in Fringing Field of Bubble Chamber.

Fig. 2. Ionization Loss of an $n = 2$ Monopole in Air and Lexan.

Fig. 3. Magnetic Field vs. Altitude Above the Bubble Chamber.

Fig. 4. Elevation of Bubble Chamber Room Showing Two Detector Planes and Proposed Lightweight Roof.

Trajectories of Monopoles in Fringing Field

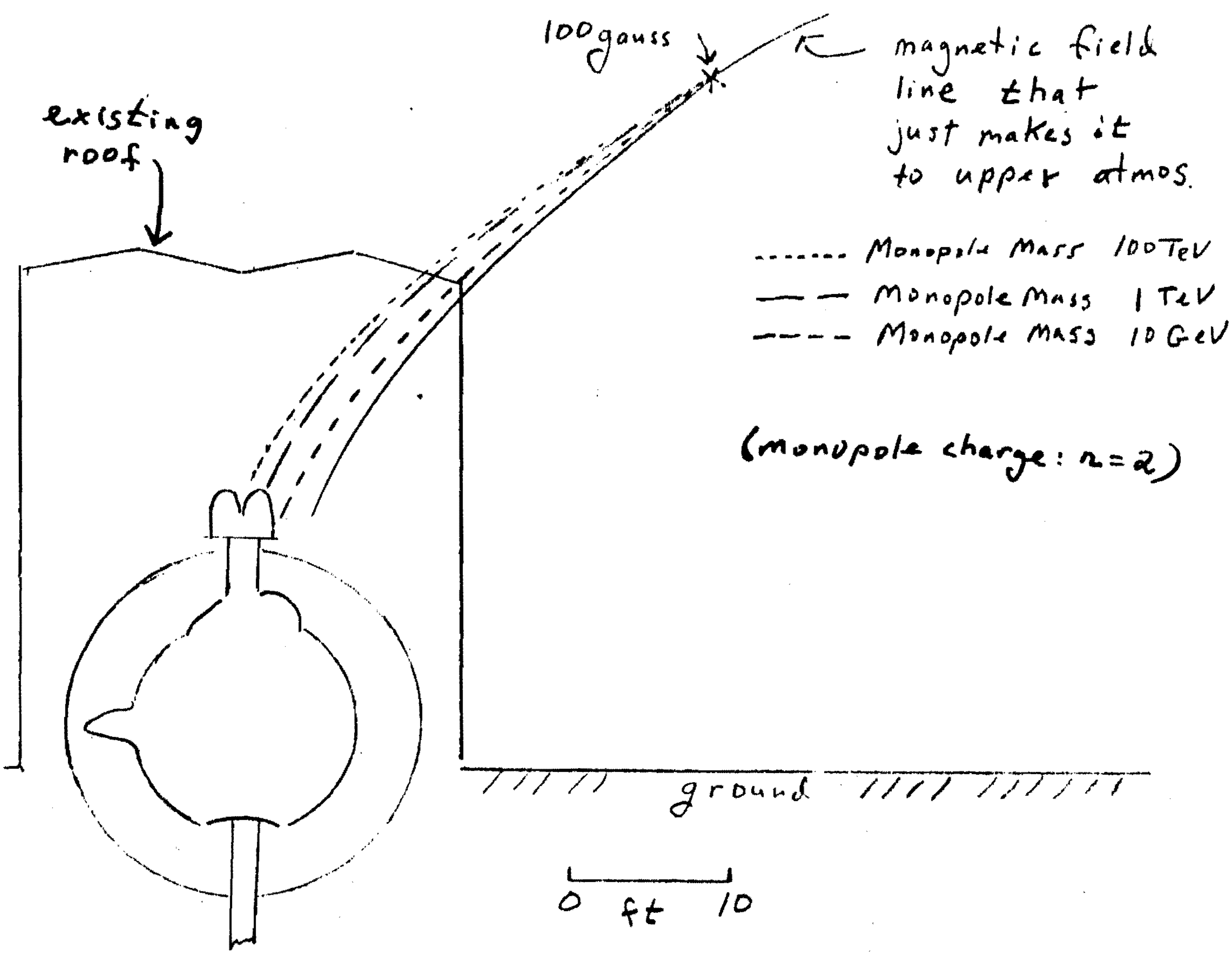
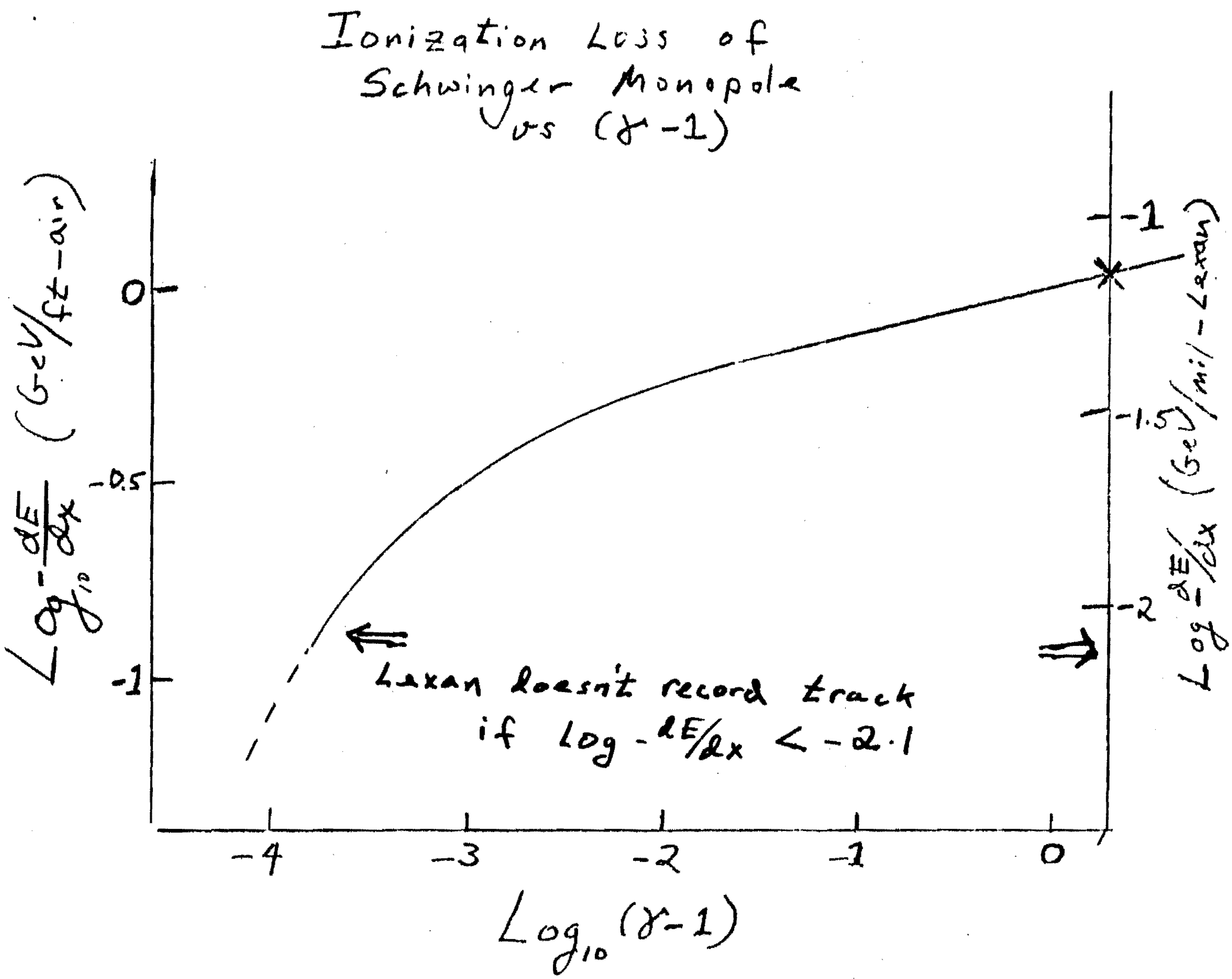
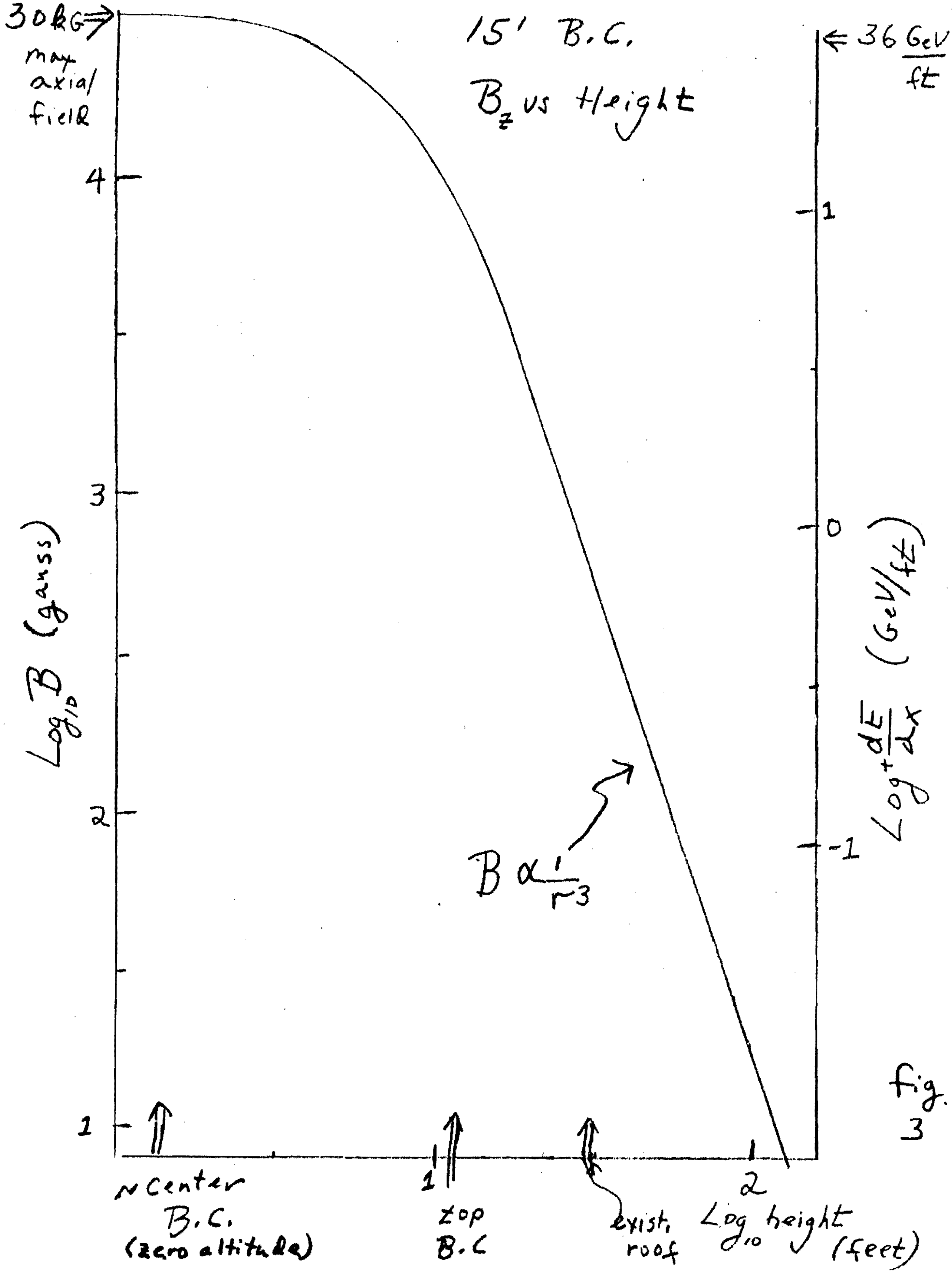


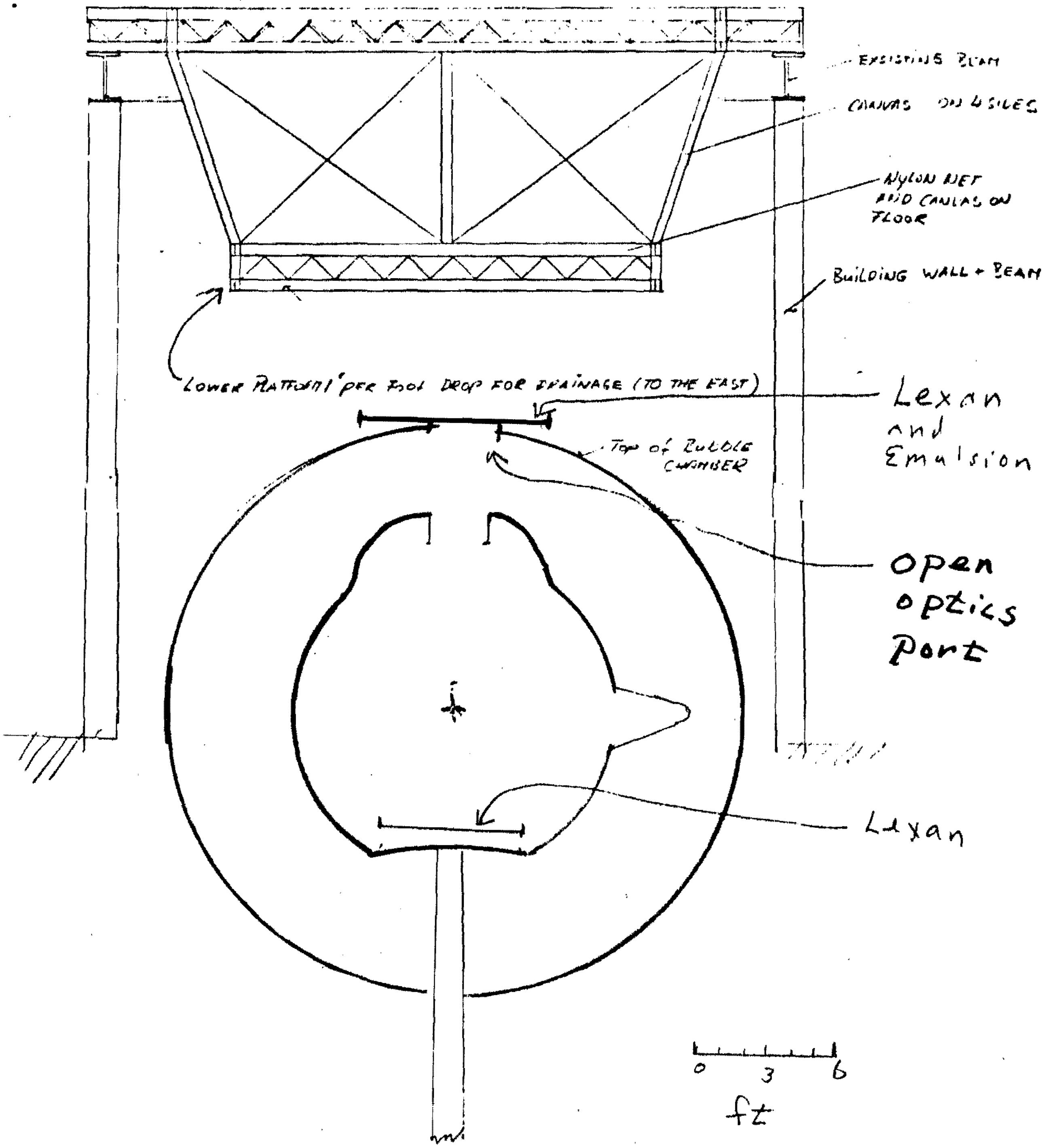
fig 1



Point X gives "conventional" point equivalent to $(137)^2 \times$ ionization for minimum ionizing, singly charged electrical particle.

fig 2


15' B.C.
B_z vs Height
30 kG ⇒ max axial field
⇐ 36 GeV/ft
4
3
2
1
1
0
-1
$\log_{10} B$ (gauss)
$\log^{+} \frac{dE}{dx}$ (GeV/ft)
$B \propto \frac{1}{r^3}$
1
2
center B.C. (zero altitude)
top B.C
exist. roof
$\log_{10}$ height (feet)
fig. 3



ELEVATION SHOWING TEMPORARY ROOF AND PLACEMENT OF LEXAN AND EMULSIONS

fig 4