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COSMIC RAY

AND

HIGH ENERGY PHYSICS STUDIES IN SPACE

April 1, 1969

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Prepared by:

L. Kaufman

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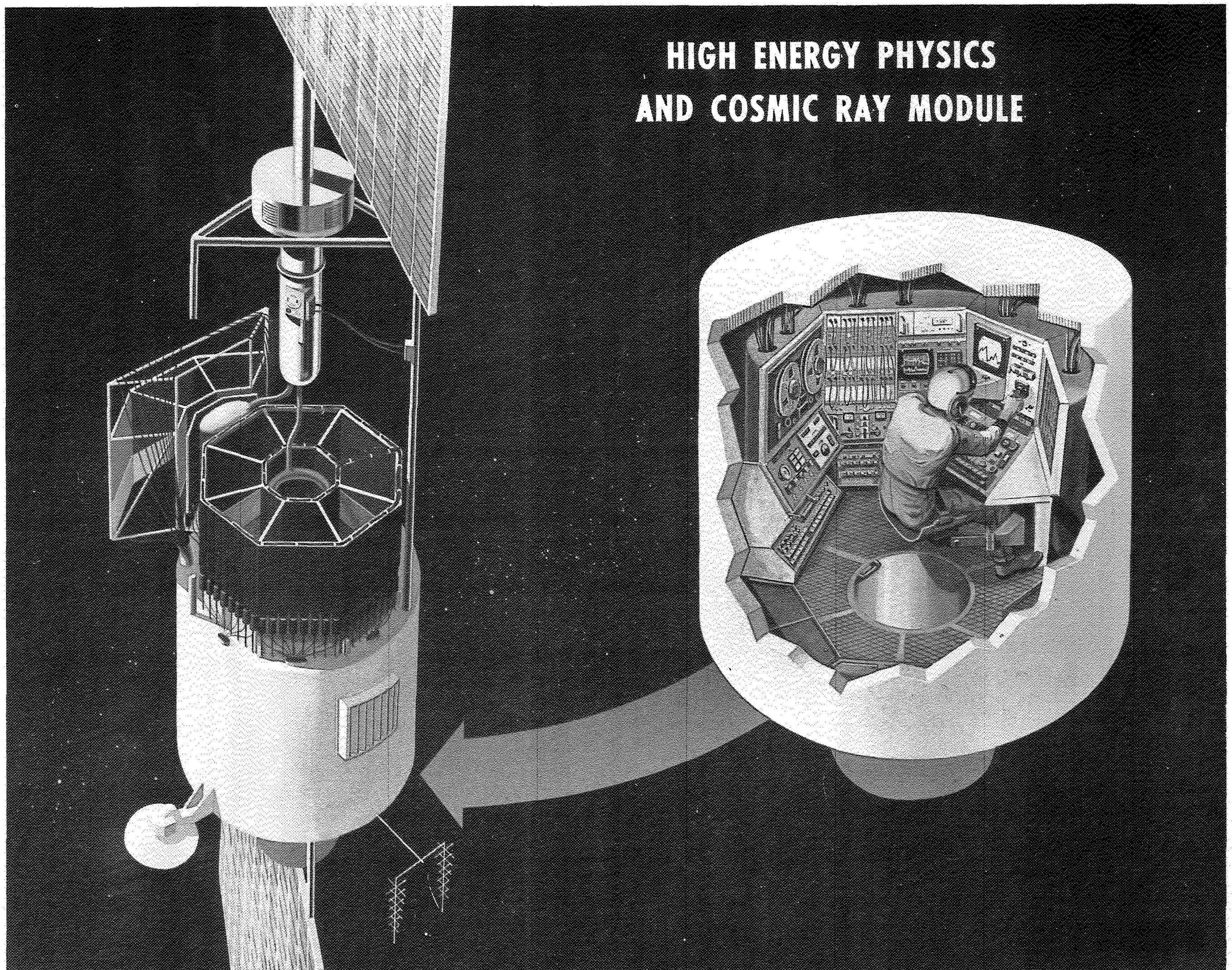
HIGH ENERGY PHYSICS
AND COSMIC RAY MODULE

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ABSTRACT

Cosmic rays are a valuable source of information on both fundamental particle dynamics and astrophysical processes. Since the particles of interest are strongly interacting, small amounts of atmosphere create backgrounds within which the primary information can be lost. This factor, together with the long exposure time necessary to accumulate significant amounts of information regarding the high energy end of the spectrum, makes satellites a natural conveyance for the study of Cosmic Rays.

Under the assumption that a Cosmic Ray Space facility is a valuable enterprise, it becomes tempting to put our space technology to work on the study of not just the primary flux but its interactions with matter as well. Accordingly, the design of a space facility that can perform relevant measurements on the primary cosmic ray flux in the energy range from a few GeV to 10^6GeV is presented. It is shown here that a small increment in the instrumentation of a cosmic ray space station, together with the versatility provided by the presence of men rearranging and servicing the hardware, could give us an experimental facility that would also provide vital information in the field of high energy physics.

Hardware appropriate for space use is described, and various configurations with a large superconducting magnet as the central element are shown. The magnet's capabilities are compared to those of ionization calorimeters.

The implementation of this program is intimately tied to the techniques and needs of accelerator-directed high energy physics, and the involvement of the high energy physics community in this project is presented as a necessary ingredient for its worthiness.

I. INTRODUCTION

For thousands of years man has based his understanding of the Universe on information provided by the light that reaches the solar system. Very recently, his quest for an answer to the question of the creation, behavior, and future, of the Universe has been aided by the study of portions of the electromagnetic spectrum other than the visible.

Together with this radiation there is also a steady flux of particles, some of them with energies higher than are likely to be attained on Earth. The study of the energy spectrum (extending into the 10^{20}eV region), nuclear composition, charge spectrum, and directionality of this radiation yields invaluable insights into the age and origin of the Universe and of the elements. The cosmic ray flux carries with it information on the stellar process that are partly responsible for its creation. The mechanisms that drive supernovae, pulsars, quasars, and matter and magnetic field distributions in the galaxy shape the particle flux in a unique way.(1) The study of the primary flux will help us understand these mechanisms. If antinuclei are detected in cosmic rays, and their energy spectrum measured, we will have advanced a long way towards settling some of our ideas about the creation of the Universe. A complete lack of antinuclei in cosmic rays will necessitate an explanation for the mechanism responsible for this, or, maybe, a revision of our ideas about conservation laws and known symmetries.

Man's search for knowledge of and control over his environment has led him into the realm of the very small, and his advances have been intimately tied to his ability to create and use sources of ever higher energy particles: A 76 GeV proton accelerator has been commissioned in the USSR, and by 1971 the CERN Intersecting Storage Ring is expected to yield a proton-proton center of mass energy of 56GeV. This is equivalent to a 1600 GeV proton colliding with a stationary proton.

In this country a 200GeV accelerator is under construction at the National Accelerator Laboratory (NAL) in Batavia, Illinois(2,3). It should be operational by 1973, and can be uprated to 400GeV later. A storage ring could be operational by the late part of the decade if it were approved now. A new machine, still in the experimental state, is the Electron Ring Accelerator (ERA)[4], under development in the USSR and in the USA at the Lawrence Radiation Laboratory (Berkeley).[5] An accelerator based on this principle can probably be built at a fraction of the cost of comparable energy accelerators based on presend day technology. ERA's can achieve accelerations of the order of 500 to 1000MeV/m, and can produce heavy ion beams as well as protons.

It seems probable then that within NASA's timetable for the implementation of an earth-orbiting space station program, the use of storage rings could make available center of mass energies equivalent to those of an 80,000GeV proton interacting with a stationary proton.*

Many arguments have been advanced making a case for the study of High Energy Physics (HEP) using cosmic rays. Since for a presently proposed space station available flux rates will supply a usable source of cosmic ray protons up to an energy of 10^6GeV, this facility would provide unique data in the energy decade bounded by storage rings on the low side (10^5GeV), and cosmic ray rates on the high side (10^6GeV).

Although it is hard to foresee at this time what experiments will be of interest in this region, it has been pointed out that even in the few hundred GeV region potential users will far outstrip planned facilities, and that the difficulties in interpreting the data could be somewhat alleviated by having independent sets of information.

In view of the strong competitive pressure for NASA funds it is not quite apparent that the arguments presented above are compelling enough by themselves. On the other hand, the study of cosmic rays in the region below 10^6GeV is a very important enterprise that can provide important insights into universal, galactic and stellar processes. <u>If, 1) a Cosmic Ray Facility for a space station is built; and, 2) if productive</u>

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* An NAL Storage Ring under consideration can be uprated to 200GeV, so that one could have 400GeV available in the center of mass at a cost of approximately $\$10^8$.

experiments in the field of HEP can be performed by a relatively small increment in the instrumentation of this cosmic ray facility matched with the versatility made available by the periodic presence of man to rearrange and service the hardware, then the HEP experimental program is a worthwhile project.

II. OBJECTIVES OF COSMIC RAY STUDIES IN SPACE

A cosmic ray facility, supported by a space station situated above the atmosphere so as to be free from its effects on the primary flux, can provide a unique contribution to astrophysics. The major objective of the proposed program will be to study the primary cosmic ray flux in the energy region below 10^6 GeV. We present here the main goals of this effort:

1. To measure the energy spectrum of the proton, electron, light and heavy nuclei components of the cosmic ray flux. This will lead towards an understanding of acceleration and storage mechanisms, and should allow identification of the extragalactic component of the proton flux.

2. To determine the charge composition of nuclei as a function of energy, a parameter relevant in the understanding of nucleosynthesis mechanisms.

3. To determine low mass isotope abundances, thus obtaining a value for the age of cosmic rays, and the average amount of matter they traverse.

4. To search for neutron rich transuranic elements that may be stable.[6]

5. To study the spallation of cosmic ray nucleons on hydrogen and complex nuclei. Those processes occur in interstellar space and within stars, and consequently they are of great interest since they influence the isotopic composition of the primary flux.

6. To study the possible directionality of the very high energy components of the cosmic ray flux and obtain an approximate idea of the location of sources. By determining whether cosmic rays

originate within or without the galaxy this measurement will have a decisive impact on the two basic models for their origin (galactic vs extragalactic sources).

7. To search for antiprotons and antinuclei in the primary flux, a search of great consequence to cosmological theories.[7] (See Introduction)

8. To measure the electron energy spectrum above 3GeV and the electron to positron ratios as a function of energy, and

9. to measure any possible electron flux anisotropies at high energies. These measurements will help to determine the processes responsible for the origin and injection spectrum of electrons, confinement mechanisms, galactic fields, and interactions with ambient photons (specifically, the 3°K black body radiation).

10. To measure the γ-ray flux and possible directionality in the region of .1 to 10^5GeV/c. These parameters will provide a knowledge of nuclear interactions in the galaxy, and the regions of space where these interactions take place.

11. To search for stable fractionally charged particles (quarks).

12. To study albedo particles with energies higher than .1GeV.

While we have pointed out the particular areas of relevance of some of these goals, their interrelation is complex, and the overall purpose of the space station will be to obtain a synoptic view of these phenomena.

III. OBJECTIVES OF HIGH ENERGY PHYSICS IN SPACE (HEPS)

In addition to fulfilling the goals in Cosmic Ray Physics, a space station can also provide a major facility for studies in HEP.

Some very fundamental questions in this field can be posed at this time and are presented here since we feel that the proposed HEPS facility can contribute substantially to their understanding. The list is representative, and by no means exhaustive. Developments in the field between now and launch time will answer some questions and probably present others. This is why versatility in the HEPS facility is a concept that should be emphasized.

1. Multiperipheral theories predict certain correlations among transverse momentum, longitudinal momentum, multiplicity and total energy. Any correlations measured would be of extreme usefulness.[8] "Fireballs" are phenomena associated with multiperipheral reactions.

2. Proton-proton total cross section at high energy seems to reach an asymptotic form of $\sigma_{tot} \sim E^{-\varepsilon}$ where different theories predict values of ε that may range from $\varepsilon=0$ on up. Measuring this parameter (by doing proton-proton total cross section at large energies), to ± 0.02 is of importance to theoretical models, and feasible as we shall see later. Together with this, the answer to whether elastic cross sections remains constant, ($\varepsilon_{el}=0$), or decrease with increasing energy is of great importance to theoretical developments.[8]

3. An attempt should be made to study proton-proton differential cross sections and to observe the behavior of the forward peak as a function of energy. This experiment could settle the argument between optical vs. Regge Pole theories. (The former predicts that the diffraction peak stays constant, and the latter leads one to expect the peak to shrink as log E.)

4. It is of interest to study the behavior of reaction amplitudes when momentum transfer is increased. If broad transverse momenta distributions were to be found, such an experiment would have a great impact on present theoretical models.[8]

5. Heavy particle production. The existence of heavy hadrons and leptons, the W meson, and hadron sub-structures (quarks) has been proposed. A clue to their

presence will be the observation of the possibly large transverse momenta of decay products. For proton-proton collisions, the total energy E_T of a group of particles in the backward cone is of the order of $(M_T{}^2/M_P)$, where M_T is the total mass of the particles, and M_P is the mass of the proton. The decay of this particle will produce secondaries with transverse momenta $P \sim M_T/2$, so that the angle of this secondary will be of the order of $\theta \sim (M_P/2M_T)$. For $M_T \sim 30$GeV, $P \sim 15$GeV, and $\theta \sim 1$ deg.

6. The ERA, if built, may someday provide us with a source of complex nuclei with energies of many hundreds of GeV per nucleon. Meanwhile, only cosmic rays afford such a source. The study of nuclei-nuclei and nuclei-proton collisions are of interest to high energy physics and astrophysics alike. For the former this will yield data on the behavior of nuclear matter, and for the latter it will give quantitative information on processes that actually occur in space.

It can be seen that the backbone of a productive HEPS experimental program can be formulated at this time. Such a program is compatible with the study of cosmic rays, and can be carried out at only a fractional increase in the cost of a cosmic ray facility.

IV. INSTRUMENTATION

A. General

On very broad terms, the hardware used for a HEPS facility such as discussed above must incorporate the following characteristics:

1) Functional Versatility: Since a rigid program cannot be prepared, each unit must be as functionally independent of configuration as possible, e.g., the target should not be part of the momentum analyzing system, etc.

2) Triggerability: The high background and low rates associated with the experiments of interest make it necessary that the equipment record events of predetermined signature. For example, a wide gap streamer chamber should be used when "bubble chamber-like" data is necessary.

3) Range: The equipment should be able to provide data for many particles at different energies. A magnetic spectrometer can be designed to momentum analyze each individual particle within a group, while a total ionization calorimeter can only give the summed energy of a system of particles.

Other desirable hardware characteristics are: data collected in such a form it is suitable for telemetering, low weight, and low power consumption.

B. Hardware

The hardware described below is suited to the needs of cosmic ray research, and most of it is used in physics work today, or could be built with present day technology.

1) Momentum or Energy Analyzer: An approach that has often been mentioned involves the use of total ionization calorimeters,[9,10,11] or functionally similar devices, Total Absorption Nuclear Cascade Crystals,[12] (TANC), (These are not yet available in the size required for the detection, with reasonable geometry factors, of up to 10^6GeV particles.). Concerning the calorimeters, typical parameters are weight $\sim$10,000 lbs., energy resolution $\sim\pm 20\%$ (logarithmically dependent on energy), and a geometry factor $G \sim 10^{-1} m^2 sr$. These devices cannot make individual energy measurements within a group of particles, (the same holds true for the TANC crystals) and they consist essentially of a large volume filled with heavy metal blocks and scintillators.

Furthermore, it is possible that the cross section for the production of weakly interacting particles increases at high energies. Since these particles decay into neutrinos, the use of energy absorbers -- such as those described above -- to study high energy reactions could introduce large errors in the energy measurements.

To satisfy the need for a versatile facility we propose a superconducting magnet as the momentum analyzer. The state of the art is such that a 2-m diameter "loop" magnet with an average central field of 70 Kgauss will be available within the project's timetable. The power requirements for magnet excitation are small, but a refrigerator must be provided to maintain the liquid helium environment. At present we expect this refrigeration to require 10KW of power for a lightly supported magnet. This can be provided by a nuclear power supply or a solar cell array.

New and expensive superconducting alloys that will allow operation at liquid hydrogen temperatures are now available. We expect that the cost of these materials will decrease in the years to come or that cheaper alloys will be found. The use of these alloys will reduce cooling power requirements to about 1KW.

The momentum resolution provided by the magnet will depend on the spatial resolution of the hardware used in conjunction with it, as we shall see later.

2) Particle Track Location Hardware

a) We expect wire chambers to be used to count particles and to determine their paths through the system. These devices are light, cheap, can cover areas of many square meters, and produce digitized data. Many particle tracks can be resolved by the use of wire planes at various angles and of computer matching of tracks through the magnet.[13,14]

Magnetostrictive readout spark chambers[15,16] can yield track location accuracies of the order of ±0.1mm and can be operated inside magnetic fields;[17] sparkostrictive[18,19] and other[20] wire chambers with digitized readout operate unaffected by magnetic fields; and proportional wire chambers are now under development by G. Charpak[21] in CERN, and J. Fisher of Brookhaven and others in this country. As can be seen, a wide choice of track chambers will be available to the designers of the space station.

b) A wide gap streamer chamber[22] will be a desirable addition to the HEPS facility. This is a triggerable, extremely light device, with low power consumption. Like bubble chambers, streamer chambers are isotropic detectors, and film is used for data collection. Their intrinsic resolution is ∿.16mm, for a single position measurement, without magnetic field containment of the electrons, and presently this is optics limited to ±0.4mm. They are built of very low mass foam, with the viewing wall made of wire-mesh-covered glass, and 1m wide gaps are well within the range of present technology. The chamber can be many meters long. At a loss of spatial resolution the relativistic rise can be measured, so that we expect particle identification to be possible at high energies.

c) New track location hardware providing digitized data over many square meters with accuracies of the order of 0.01mm are intrinsically possible.[23] No such device exists today, but the rapid developments in the field over the last few years are certain to continue as work at the Illinois accelerator will put a high premium on such systems.

3) Charge Detection

A combination of Cerenkov radiation detectors (with response linear in Z) -- solid and/or liquid filled -- together with arrays of $\frac{dE}{dx}$ counters (with response linear in Z^2) can provide unique charge determination up to $Z\sim 20$, $\Delta Z=\pm 1$ up to $Z\sim 50$, and $\Delta Z=\pm 3$ or better for the heaviest elements. Xenon filled, many-layered proportional wire chambers may measure dE/dx and the relativistic rise, while yielding 10nsec resolution times, and accurately determining particle paths at the same time.

4) γ-Detectors

Unique identification of the mass of a charged particle can be achieved if together with the momentum (or energy), the parameter $\gamma=(1-\beta^2)^{-1/2}$ can be determined. Various effects due to the passage of a particle through a heterogenous medium depend on γ. Among these we can cite transition radiation, secondary electron emission, and surface plasma oscillations.[24]

The most promising work so far has been carried out with transition radiation detectors. Various physicists[25-27] in the USSR, and more recently L. C. Yuan of Brookhaven[28], have been engaged in research on transition radiation detectors for some years. It is questionable, however, whether a detector can be built that will have an efficiency high enough to be effective in a space facility.

5) Cryogenic Targets

Present understanding of the theory of particle interactions is limited enough that hydrogen has to be used as the target element, since data produced by cosmic rays interacting with complex nuclei would be very hard to interpret. This requirement is compatible with astrophysical needs, since most cosmic ray collisions in space are with hydrogen. A target of 4-m^2 area and 1-m depth ($7 g/cm^2$) can be cooled by about 1KW of power, or built so it needs resupplying times of the order of three months or more, concomitant with presently planned shuttle flights to the space station.

V. THE SPACE STATION

A. Cosmic Ray Measurements

The design of a HEP and Cosmic Ray facility is not by any means unique. The "optimum" configuration will not only vary as we go from one physicist to another, but changes in particle detection technology influence the design as well. Our purpose is to show that present techniques permit us to satisfy present goals.

We will assume that the total cosmic ray flux is given by Figure 1[29] (the flux shown may be off by as much as a factor of four), and that protons are the main component.

We use a 2-m diameter, 66 Kgauss average field, superconducting magnet as the core of the facility (Figure 2). This magnet could be a simple "loop", as presently proposed by Alvarez, et al. Surrounding the magnet there are 16 wire track chambers arranged in two concentric octagons, 2-m apart in the radial direction. We prefer this configuration to the one where cylindrical chambers are used, since the latter fix the geometry, while the former allows for various deployment schemes.

The inner chambers are approximately 1x1-m and the outside ones $\sim$2x2-m. Each chamber consists of a module of 4 gaps, each gap with two wire planes, the wires being at various angles to each other. This configuration helps in identifying many-track events, and provides eight independent measurements of each (local) x, y coordinate for a track.

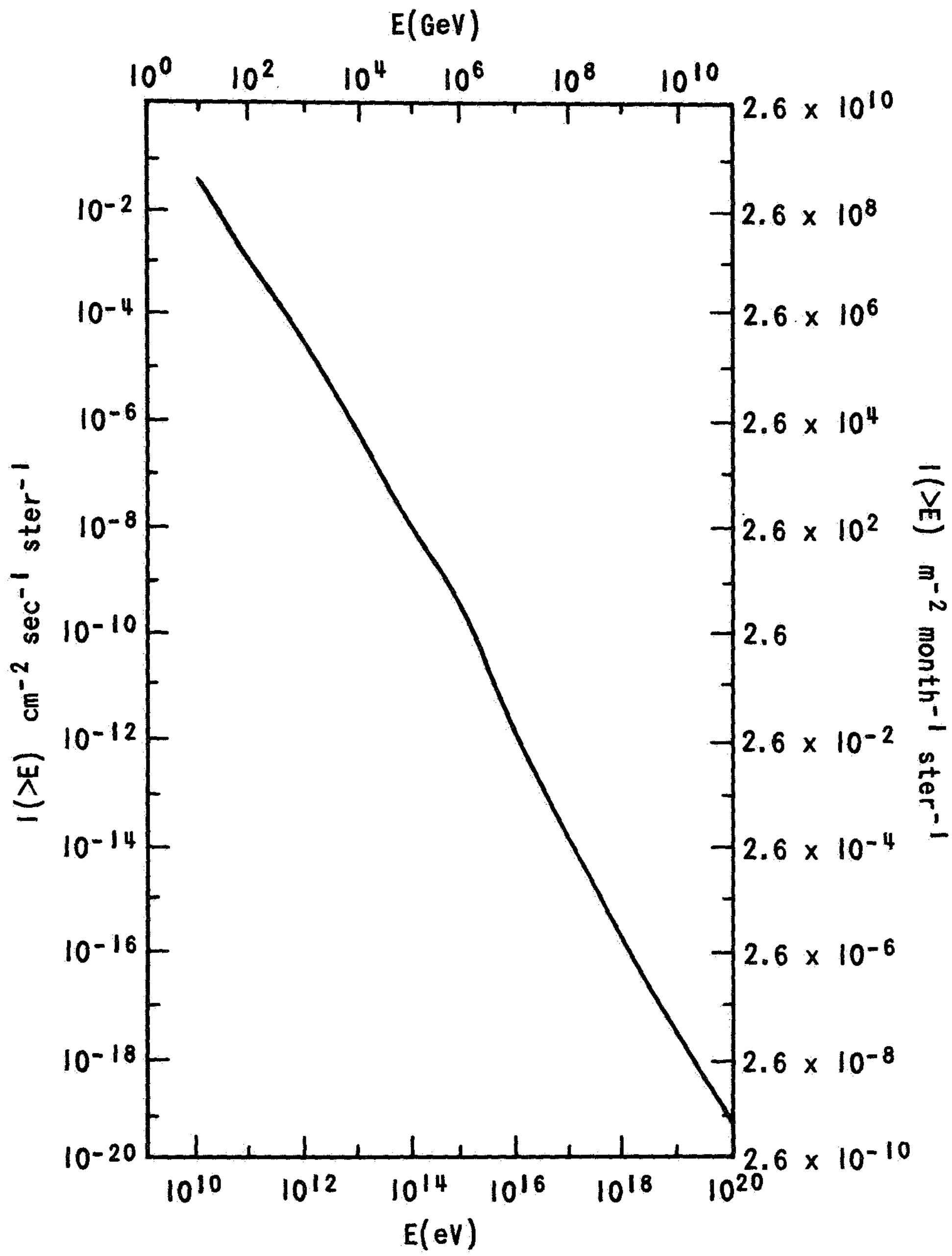

FIGURE 1 - COSMIC RAY FLUX. THE VALUES GIVEN MAY BE OFF BY AS MUCH AS A FACTOR OF FOUR. PROTONS ARE THE MAIN COMPONENT.

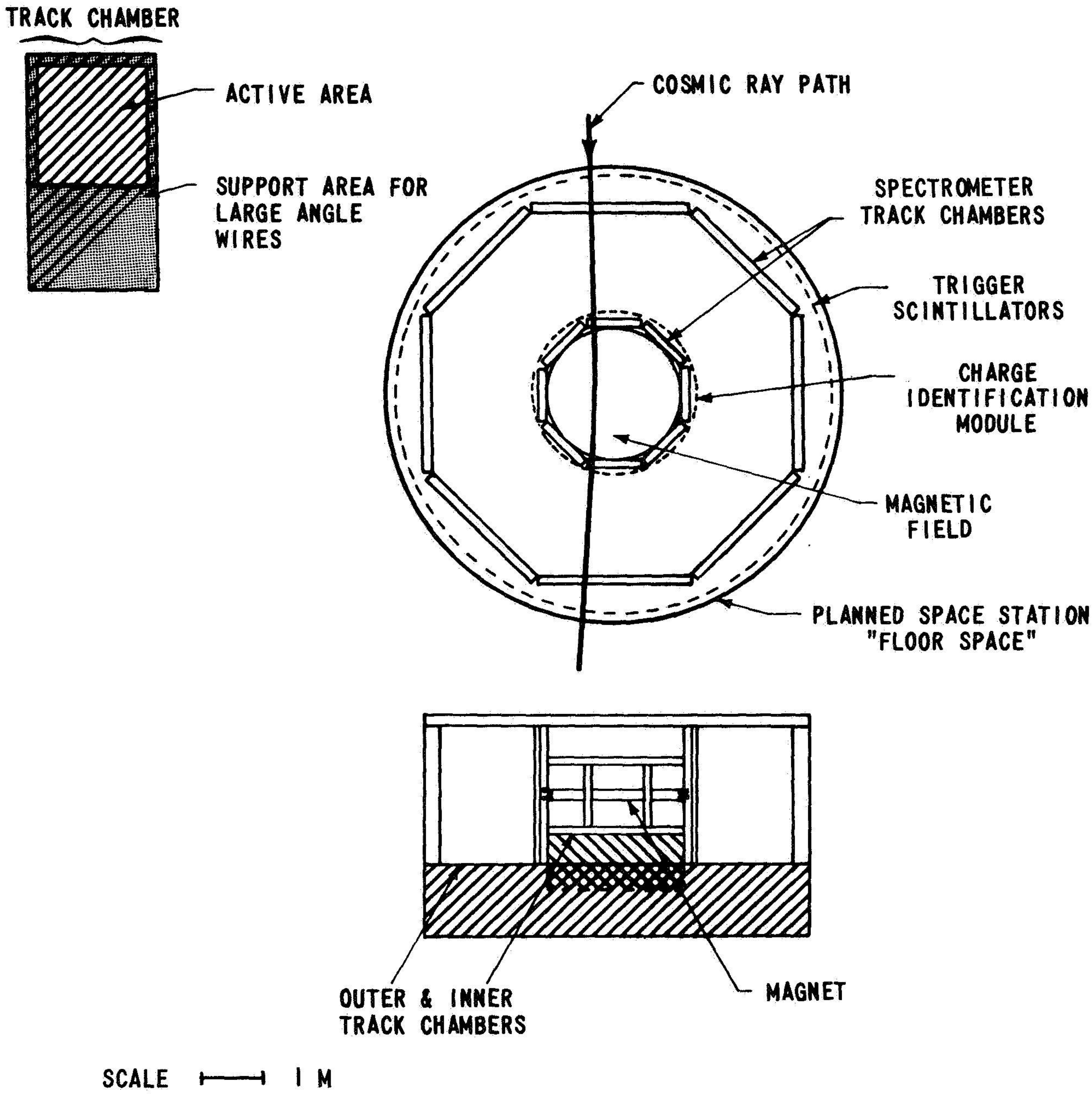

FIGURE 2 - SCHEMATIC LAYOUT OF A COSMIC RAY SPACE STATION. THIS "2π" CONFIGURATION HAS A GEOMETRY FACTOR $G \sim 8 m^2 sr$, AND A MOMENTUM CUT-OFF OF 10^5 GeV/c.

For the energies of interest, the system is not limited by multiple scattering but by the accuracy of track location, which in this case we assume to be $\Delta x \stackrel{\sim}{\sim} \pm 0.1$mm, <u>for each measurement</u>. For the configuration described the angular resolution is $\pm 3.5 \times 10^{-5}$ rad. The momentum resolution is then given by Figure 3. The momentum cutoff in this configuration is at 10^5GeV/c. This "2π" geometry has a vertical acceptance of $\sim$1 rad, and $G \sim 8m^2$sr. To increase the cutoff to 10^6GeV/c, one can change the configuration so that the distance between spark chambers (lever arm) is increased, increasing the resolution proportionally (resolution proportional to (lever arm)$^{-1}$), and accepting a loss in the geometry factor. The same hardware, reconfigured, could yield a cutoff of 10^6GeV/c for $G \sim 1.2m^2$sr. This would yield over 300 events per month in the interval 10^5-10^6GeV, and about 10 events per month at $E > 10^6$GeV.

Charge identification modules (dE/dx and Cerenkov counters) will be placed around the inner track chambers to minimize the detector area needed ($8m^2$). The multiple scattering in this additional mass will degrade the momentum resolution in the lower energy range, but since this is $\sim 10^{-3}$% at 10^2GeV, the effect of doubling it is inconsequential. At momenta above 10^3GeV/c the effects due to multiple scattering in the charge detection module are negligible.

Triggering will be done by logic requirements on scintillators. Some seventy scintillators $\sim$0.3m wide x 2m high deployed around the external track chambers as shown in Figure 2 will permit discrimination against particles below 10^2GeV/c by geometrical considerations, when used in coincidence with the inner ring of Cerenkov counters.

The track chambers will be able to determine the incoming direction of the particle to better than 10^{-4}rad, within an ambiquity of $\sim\pi$. This ambiquity can be resolved by fast coincidence measurements, since the traversal time across the apparatus is over 20nsec., well within the range of present timing techniques.

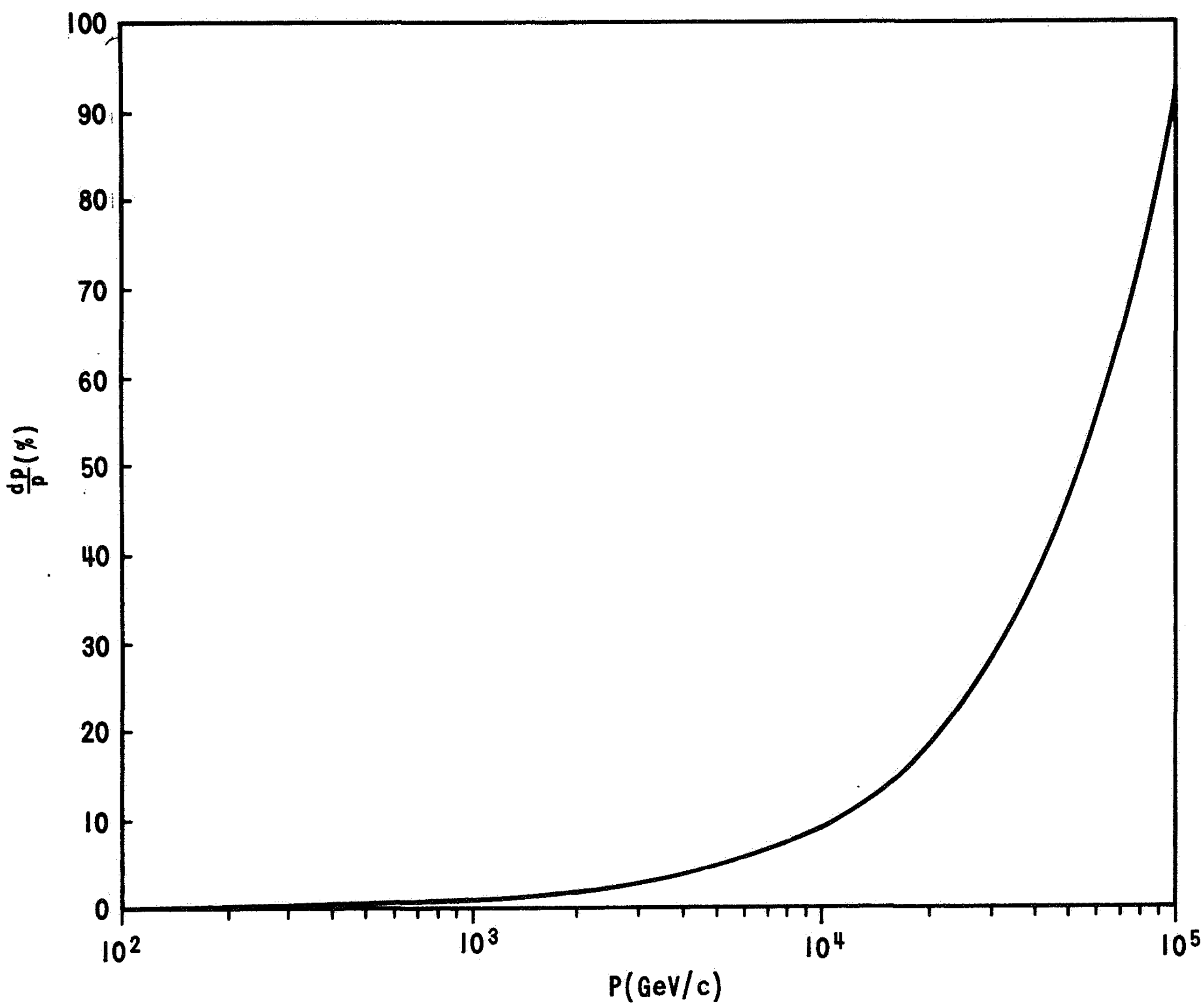

FIGURE 3 - MOMENTUM RESOLUTION FOR THE SPATIAL-RESOLUTION-LIMITED MAGNETIC SPECTROMETER SHOWN IN FIGURE 2.

Protons and antiprotons will be differentiated from positrons and electrons by observing the direction of bend in the magnet and by relativistic rise dE/dx detectors[30,31] in the charge identification module. We expect too, that these detectors will enable us to perform isotopic analysis of low mass nuclei.

Antinuclei, if present in the primary flux, will be easily identified since they will have signatures of negative charges greater than Z=1.

B. Alternate Geometries

The addition of a liquid-hydrogen target of 1m depth ($7g/cm^2$) and $\sim 4m^2$ area will allow a number of particle physics experiments in the $E<10^6$GeV region to be carried out.

The objectives of Section II can be attained with just one magnet, which can be used in two modes: Either as a "beam" analyzer, where the momentum and charge of the incoming particle are measured; or as an analyzer for the reaction products, where the total energy is estimated from summing over the individual momenta of charged particles and adding 1/3 of that sum to account for the energy going into neutrals. Simple as the latter method is, it will perform about as well as a calorimeter in the region $E<10^5$GeV, being increasingly better than the calorimeter as the total energy diminishes.

The most straightforward configuration is shown in Figure 4, where the target is added to one of the faces of the Cosmic Ray facility.

Two simultaneous modes of operation are possible, each with a geometry factor $G \sim 0.8m^2.sr$:

1) The incoming particle goes through the magnet where it is momentum, mass, and charge analyzed and strikes the target. The reaction products are counted and their paths determined in the track chambers. This mode can be used for total cross section and multiplicity measurements.

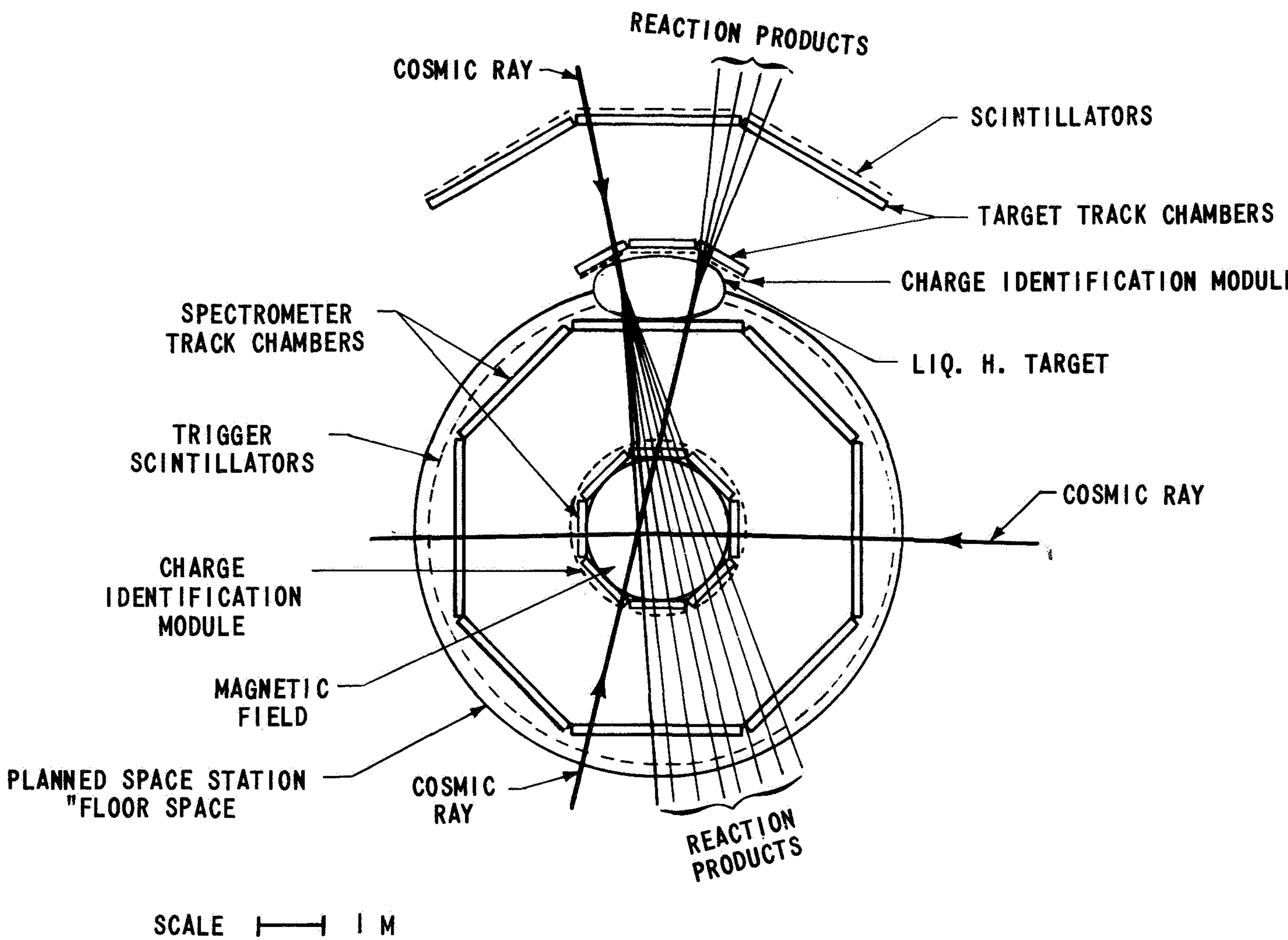

FIGURE 4 - SCHEMATIC LAYOUT OF A HIGH ENERGY PHYSICS AND COSMIC RAY SPACE STATION. THIS CONFIGURATION HAS A GEOMETRY FACTOR $G \sim 0.8 m^2$ sr, AND A MOMENTUM CUT-OFF OF 10^5 GeV/c.

2) The second operating mode allows a particle that goes through the target chambers to be charge analyzed and then interact in the target. The reaction products are then momentum analyzed in the magnet. This allows for the measurement of, and correlations between, longitudinal and transverse momenta, multiplicity, and total energy. Heavy particle searches, essentially independent of the incoming particle's energy, can be carried out in this mode, while cosmic ray measurements are continued in the section of the spectrometer not shadowed by the cryogenic target.

A configuration that can perform these measurements more efficiently is shown in Figure 5. This lay-out has a geometry factor $G \sim 1.4 m^2 . sr$, and allows a look at the large angle reaction products (it is of interest to be able to observe particles coming out at angles as large as 45° in the laboratory system).

As a typical example of the performance of this system we show what the results could be for a six month experiment measuring proton-proton total inelastic cross sections. It can be seen (Figure 6) that for the cross sectional dependence $\sigma_t \sim E^{-\varepsilon}$, ε can be easily measured to ± 0.02, which is the goal of the experiment.

Figure 7 shows a configuration suited for the observation of reaction products being produced at large angles. All these configurations allow for the continuation of cosmic ray flux and energy measurements.

A streamer chamber can later be placed by the magnet, opposite to the target. The magnetic field acts as a separator, so that operating this chamber in a mode that permits relativistic rise effects to become observable will allow mass identification of the reaction products. Configuration, trigger mode, and new equipment, will certainly change as new areas of interest develop.

C. Secondary Interactions

One of the most attractive possibilities of accelerators is the production of secondary beams. For ultrarelativistic energies time dilation effects make hyperon beams, as well as the (now) standard pion and kaon beams, possible.

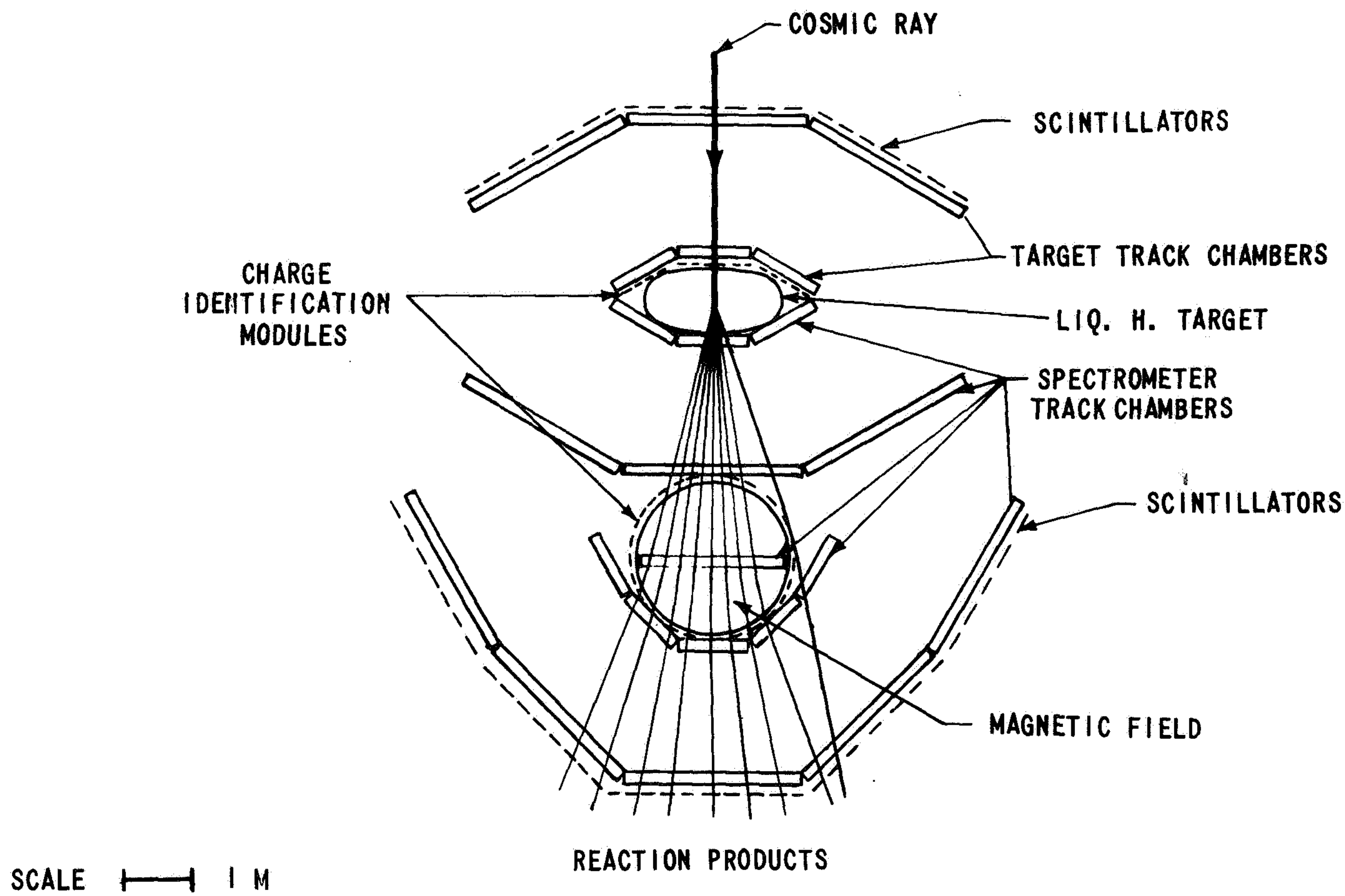

FIGURE 5 - SCHEMATIC LAYOUT OF AN "OPTIMIZED" HIGH ENERGY PHYSICS SPACE STATION. THIS CONFIGURATION HAS A GEOMETRY FACTOR $G \sim 1.4 m^2 sr$, A MOMENTUM CUT-OFF 10^5 GeV/c, AND IT ALLOWS A LOOK AT LARGE ANGLE REACTION PRODUCTS.

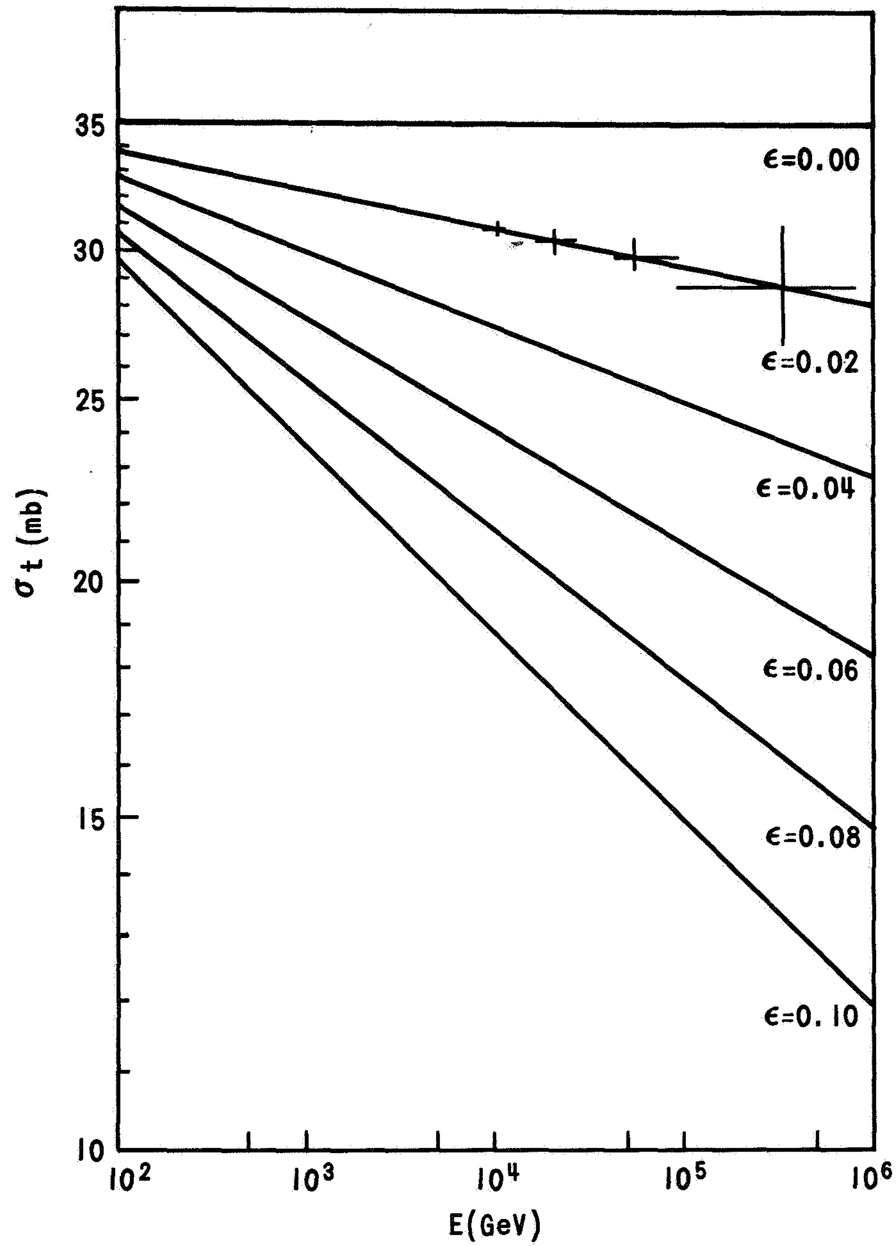

FIGURE 6 - PROTON-PROTON TOTAL INELASTIC CROSS SECTION MEASUREMENTS FOR A SIX MONTH EXPERIMENT IN THE CONFIGURATION SHOWN IN FIGURE 5. THE ERROR BARS SHOW THE FEASIBILITY OF MEASURING THE ASYMPTOTIC PARAMETER ϵ, IN $\sigma_t \sim E^{-\epsilon}$, TO 0.02 AT HIGH ENERGIES.

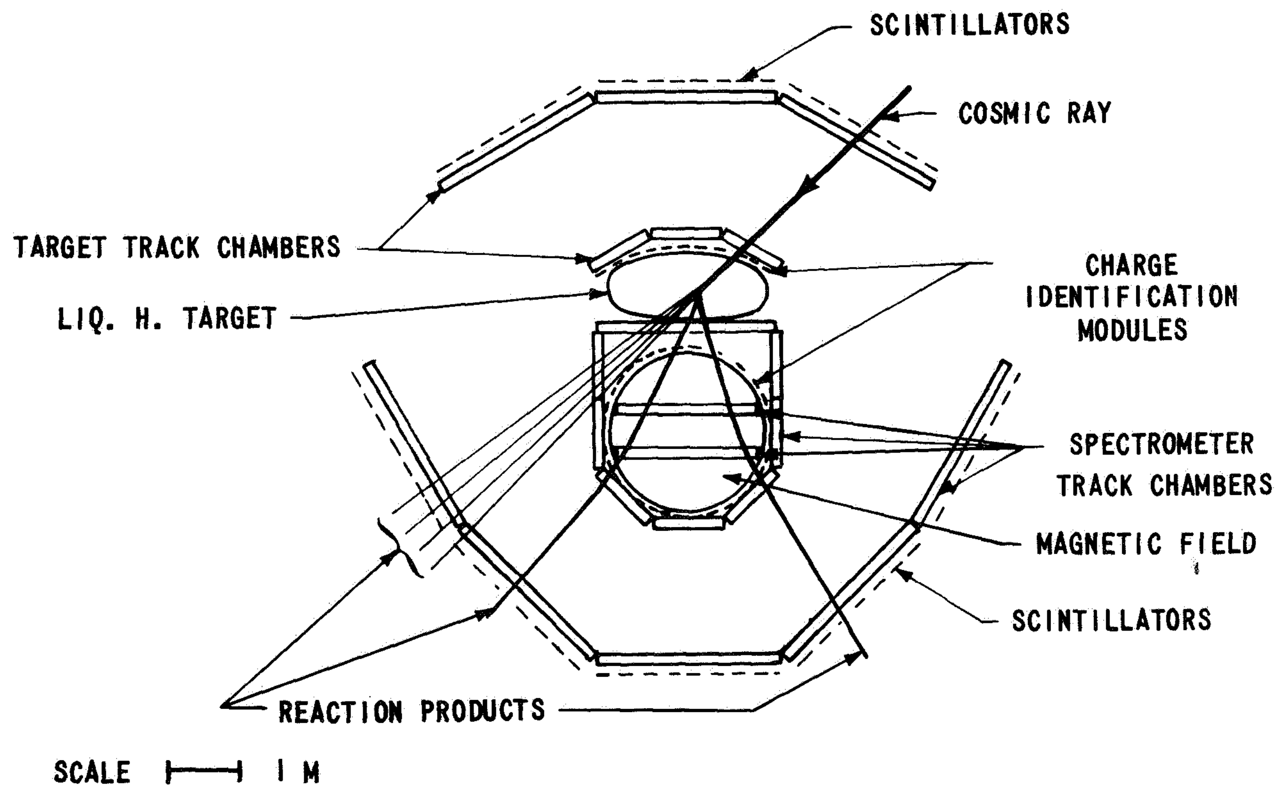

FIGURE 7 - SCHEMATIC LAYOUT OF A HIGH ENERGY PHYSICS AND COSMIC RAY SPACE STATION SUITED FOR THE STUDY OF PARTICLES PRODUCED AT LARGE ANGLES. THE GEOMETRY FACTOR OF THIS CONFIGURATION IS ENERGY AND REACTION DEPENDENT, AND HAS A MOMENTUM CUT-OFF OF 10^5 GeV/c.

The configurations shown in Figures 4, 5 and 7 are not suited for experimentation with secondary interactions. If previous results and accelerator work show the desirability of this type of experiments, a second generation space facility could include a thin target and a small solid angle acceptance spectrometer. A streamer chamber will identify the reaction products, and secondary interactions in the thin target will be observed in the added spectrometer. (Fig. 8)

Another way to accomplish equivalent results is by having a streamer chamber -- with an internal target (cryogenic or otherwise) -- inside a strong magnetic field. Reaction products from incoming cosmic ray and the secondary interactions can then be observed in this chamber.

D. γ-ray Astronomy and Interactions

A search for very high energy γ-ray will be possible by adding some thin targets (i.e., lead or tungsten plates) and rearranging the equipment in the configuration of Figure 9. Present plans for the study of γ-ray are limited to energies below which the opening angle of the conversion electrons is measurable. In the proposed configuration the high energy limit is determined by the momentum resolution of the spectrometer only ($\sim 10^5$GeV), since Coulomb scattering is negligible at this energies.

VI. ORBITAL CONSIDERATIONS

A. Operating Mode

Operation of the HEPS and Cosmic Ray Facility will be automatic. The key to its versatility will be the periodic presence of men to rearrange experiments, and update and service the hardware as needed. This station should be away from other facilities where sensitive measurements are being performed, since the electromagnetic noise output of high voltage pulsed equipment will probably create an intolerable background. A free flying module seems to be an attractive possibility at this time.

We have calculated that for a typical low inclination orbit the maximum force produced by the earth's magnetic dipole field is of the order of 10^{-4}lb. (at 6700Km), directed approximately in a radial direction. This is negligible when compared with

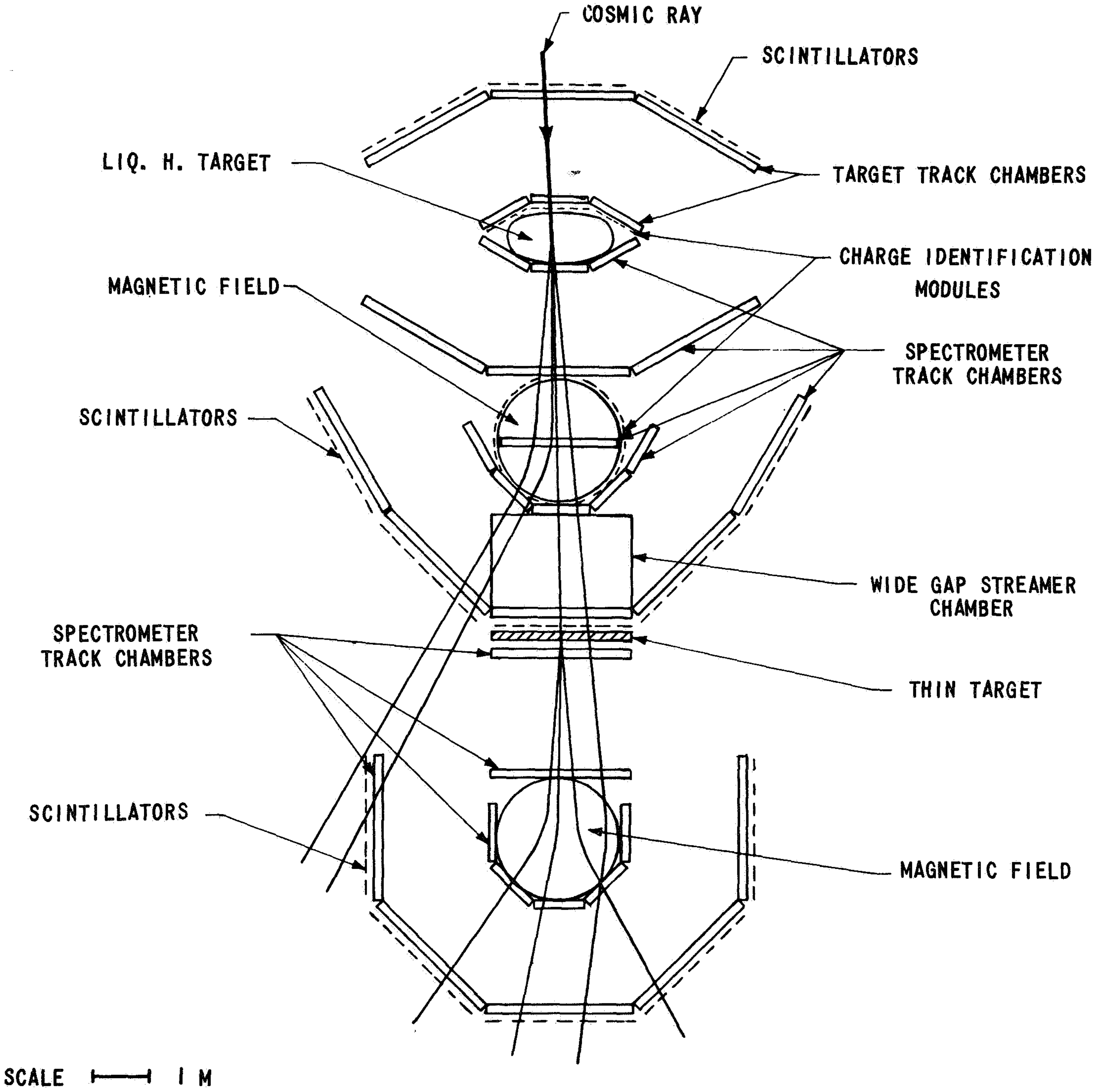

FIGURE 8 - SCHEMATIC LAYOUT OF A SECOND GENERATION HIGH ENERGY PHYSICS SPACE STATION SUITED FOR THE STUDY OF SECONDARY INTERACTIONS. THIS CONFIGURATION HAS A GEOMETRY FACTOR $G \sim 0.5 m^2 sr$, AND A MOMENTUM CUT-OFF OF 10^5 Gev/c.

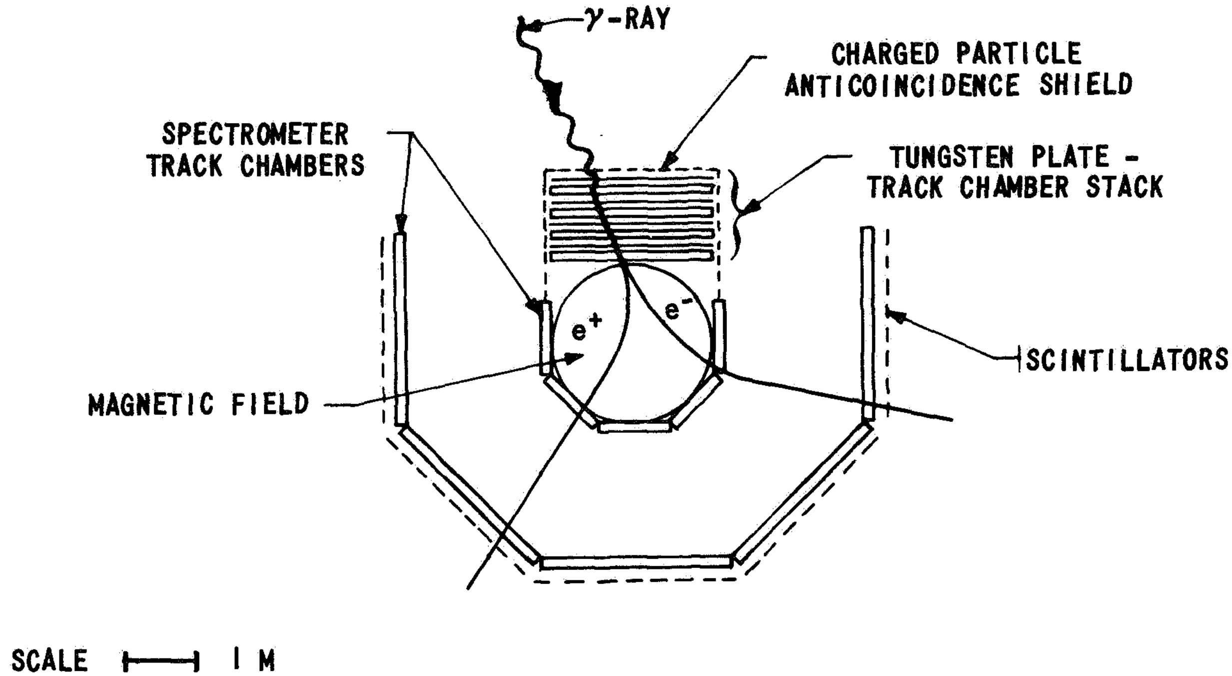

FIGURE 9 - SCHEMATIC LAYOUT OF A γ- RAY ASTRONOMY AND INTERACTIONS SPACE STATION WITH A GEOMETRY FACTOR $G \sim 4m^2sr$, and A MOMENTUM CUT-OFF OF 10^5 Gev/c.

drag forces at comparable altitudes. The maximum torque in this case is calculated to be approximately 660 ft-lb.

In a low inclination orbit this torque will rotate the spacecraft so as to make the axis of the magnet approximately parallel to the surface of the earth. This means that in the "2π" configuration described above, part of the useful area of the detector will be shadowed by the earth. This is not totally undesirable since study of albedo particles is of interest. Otherwise, the following options are open: a) loss of part of the 2π detection capability; or b) continuous attitude control; or c) a higher orbits with lesser requirements on attitude control and less earth shadowing.

HEP experiments will not be affected by orientation since their angular acceptance is of the order of $\frac{2}{3}\pi$, and the station can be rotated about the magnet's axis so that the target is not shadowed by the earth.

VII. FINAL CONSIDERATIONS

A. Other Hardware

Facilities designed with a total ionization calorimeter as their central element would be limited to perform only the simplest of experiments, such as cross section measurements. Even for calorimeters of large weight (>10,000 lbs.), the geometry factor would be of the order of $10^{-1} m^2 sr$, and the resolution about 20%.

We do not see any advantage to a magnet-calorimeter combination, since the second element can only add little information, at the cost of large loss in geometry factor and large weight penalty. It must be emphasized that the calorimeter provides better resolution above 20,000GeV only, a region where we feel that good statistics are of more importance than energy resolution anyway.

A second magnet may eventually prove useful but the decision to add it should wait for the results of the first experimental program. We feel that improvements in the performance of the facility should not depend on the addition of a calorimeter or second magnet, but on the upgrading of the system previously described.

B. Momentum Resolution

The dependence of the momentum uncertainty measured by a magnetic spectrometer on parameters other than multiple scattering is

$$\frac{dp}{p} \simeq \frac{66pr}{HZ\ xl\sqrt{N}}, \text{ where}$$

p is the momentum, in GeV/c;

r is the accuracy of coordinate location, or spatial resolution, obtained by a single measurement; in meters;

H is the average magnetic field, in Kilogauss;

Z is the charge of the particle being observed;

x is the average field length, in meters;

N is the number of times a position measurement on a coordinate is performed; and

l is the distance between entrance (exit) track chambers, or lever arm, in meters.

For the spectrometer described above,

$r = \pm 10^{-4}m = \pm 0.1mm$

H = 66 Kilogauss

x = 2m

N = 8 (Eight gaps on each side yield eight independent measurements of the local x coordinate and eight of the local y coordinate)

l = 2m

For $p = 10^4$ GeV/c and Z = 1, $\frac{dp}{p} \simeq 9\%$.

If we aim to reduce this value by a factor of 3, the following are some of the alternatives open:

1) An increase in the number of gaps in the track chambers from eight on each side of the magnet to seventy two. This is clearly a brute force method, where the cost of track chambers goes up as the square of the improvement in resolution.

2) An increase of the magnetic field: this is an attractive alternative, but strongly dependent on superconducting magnet technology.

3) An increase in the diameter of the magnet. This is not attractive because the cost of superconducting materials goes up linearly with the extent of the field. Both this alternative and

4) an increase in lever arm, call for larger systems, and increases in the area of the spark chambers if solid angle acceptance is to be kept constant. Otherwise a loss in geometry factor has to be accepted.

5) Momentum measuring accuracy can be increased by the use of emulsion plates to improve spatial resolution. These emulsions would be used together with track chambers in a mode such that the latter would indicate where to search for tracks in the former.[32] The increase in momentum measurement accuracy achieved is directly proportional to the increase in track location accuracy.

The engineering problems posed by having to put these emulsions[33] through the accelerations of launch and recovery while keeping their dimensions constant to within microns over large areas are not trivial. One possible solution would consist of including an emulsion measuring facility in the space station. This may require a continuously manned module, an alternative certainly not as attractive (at this time) as the concept of periodically manned attendance. We feel that problems other than the ones of engineering nature, or tediousness of analysis, will limit the generalized use of emulsions.

The total flux of charged particles is approximately $1 cm^{-2}.sr^{-1}.sec^{-1}$, or $2.6x10^{10} m^{-2}.sr^{-1}.month^{-1}$. Since present plans call for supply missions spaced by 3 to 4 months, we expect that an emulsion plate will have $\sim 10^{12}$ tracks/m^2 after that time has elapsed. The use of track chambers will determine a circle of confusion of area $3\times10^{-8}m^2$ within which the desired event is located. This means that about 30,000 tracks will have to be analyzed to find which one satisfies the angular requirements imposed by the track chambers! This process has to be repeated four times to get the information necessary to process one event. Even with angular restrictions on the track, 15% of the events will be ambiguous. In these cases the ambiquity will have to be resolved by computer matching of tracks through the magnet. If used, this method will have to be limited then to the analysis of a small fraction of the total events.

Rewarding results could be obtained if advantage were to be taken of the fact that a spatial resolution of 10^{-4}m is at least an order of magnitude larger than the intrinsic limits to which particle coordinates can be located in automatic readout devices.[23] Research and development of new devices is not an expensive enterprise when compared to R&D in superconductivity or space technology. We strongly recommend that NASA sponsor the development of digitized readout track chambers with location accuracies $\Delta x<10^{-4}$m, since we feel that this is the best way to attain significant increases in the momentum resolution of the system without adding large amounts of equipment or scaling the hardware to gigantic dimensions.

VIII. IMPLEMENTATION AND RECOMMENDATIONS

HEP and cosmic ray facilities can and should be integrated so that both areas can be covered simultaneously. Design of this facility should allow flexibility and the addition of new hardware as it becomes desirable. Although the main thrust of present efforts on large cosmic ray stations is toward total ionization calorimeters, we proposed in Section V a facility designed with a large superconducting magnet as its main component. At a not much larger cost, the latter will provide the versatility necessary for a synoptic study of cosmic rays, uprating potential, and the capability to conduct significant HEP experiments.

We have shown that the major goals of cosmic ray measurements and significant HEP experimenation are attainable in an integrated facility, and that no major technological breakthroughs are necessary for successful implementation of this program.

Theoretical developments and experimental progress in HEP have been rapid, and the interests and instruments of the physicist have changed radically in the last ten years. New accelerators are coming of age and this may point to new directions or stop the quest for higher energies altogether.

The proposed space facility overlaps plans for the NAL Storage Rings in three areas: goals, implementation time, and cost. The HEPS facility provides higher energies (see Introduction) at the expense of intensities that are many orders of magnitude below the ones planned for the storage rings. As pointed out in the Introduction, it is hard to foresee what experiments, if any, will be of interest at the highest energies available in the space facility, while high intensities are a clearly desirable goal. For this reason we do not feel that the proposed HEP program is an important justification for the development of a manned capability in space. However, this capability will eventually exist, and within the next ten to fifteen years it can profitably be put to use in cosmic ray studies.

It is important to recognize that both goals and implementation means are in a continuous state of change. NASA should support and encourage general research and the development of the instrumentation needed for the station (specifically, superconducting magnets with the associated cryogenics, and high spatial resolution digitized readout detectors), but the lead times for the construction of the equipment should be kept as short as possible so that we may maximize the advantages of using state of the art technology. The main pitfall of hardware planning for a time too far into the future is that equipment becomes obsolete, and the data obtained is not as complete as it could be otherwise.

We believe that it would be to NASA's benefit to work in conjunction with the AEC, and to approach a small but interested and representative group of experimental physicists that would be encouraged to carry out mission oriented research and development while continuing their present work. As a group they would have advisory capacity, setting guidelines for the Cosmic Ray and HEPS programs. At a time no longer than three years before estimated launch time these physicists, or others associated with them, should be consulted and involved in the construction of the space facility. Even then the design should remain as flexible as feasible.

Unless NASA can generate attractive programs the men who are performing successful research in the field of HEP will prefer to stay with accelerators.[34] This will be detrimental to a project such as the one described above since the involvement of the HEP community is an ingredient necessary to assure that the collection of instruments called a Cosmic Ray and HEPS facility is a valuable enterprise.

1015-LK-rghe

L. Kaufman

Attachment
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Appendix

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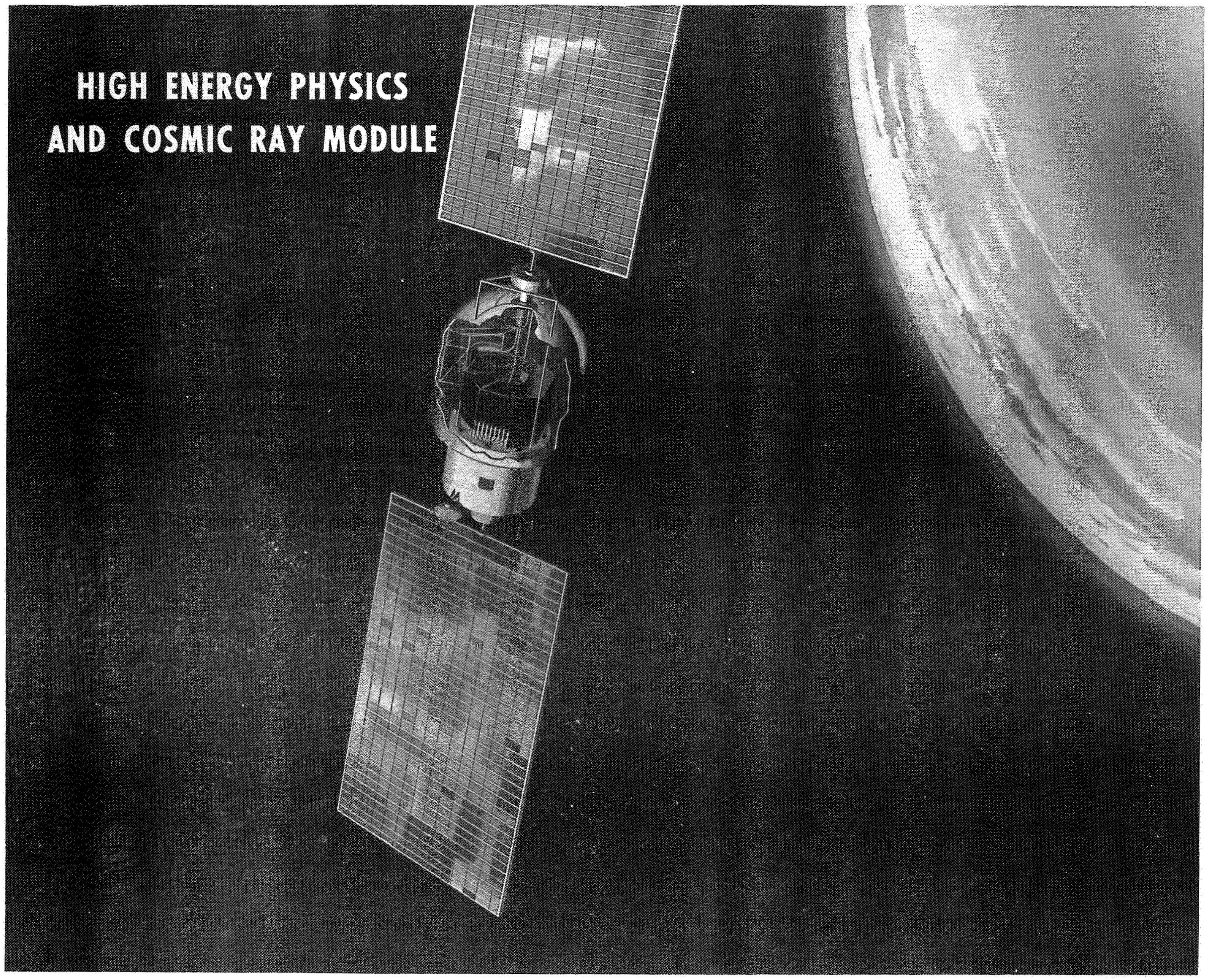
From "Space Research Directions for the Future":

"The participation of universities in space research can best be facilitated by taking into account those conditions that characterize academic work. Thus, the most imaginative scientists in our universities can be attracted to space research if there is reasonable continuity to their work and if successful flights of experiments are reasonably certain.

"The ratio of graduate students to senior university investigators in space-flight experiments is relatively low. The cause lies largely in the scheduling of these experiments, which would somehow have to match the schedule of graduate training if graduate students are to contribute. Even at the professional and postgraduate levels, however, the long lead times of space work are a problem. It is reasonable to expect that as conventional launchings increase and become more routine, their lead times will become shorter and more flexible. Coupled to suitably supported ground, balloon, and rocket research of direct space interest, and assisted by a vigorous and growing Sustaining University Program, a varied activity that will embrace continuity and timely flight opportunities should become available for even graduate participation. To achieve this goal will nevertheless require energetic and imaginative steps within NASA.

"There is, however, a related problem now facing the scientific community and NASA that appears far less amenable to solution: as more powerful spacecraft become available late in this decade, and as planetary investigations begin, lead

times and support will become more difficult problems. Two to five years between the "freezing" of a payload and the actual mission will be common. Such lead times may discourage imaginative scientists from submitting experimental proposals and may make difficult continuity of work, particularly on the part of younger men. Moreover, the funding of experiments itself may be more complicated, in part to ensure sustained work on a problem during a flight-waiting period, in part because ground-based work in the waiting period may outmode a given experiment or reveal modifications not easily added, in part because scientific advances may yield experiments of importance they cannot be accommodated in a reasonable time when few missions to, say, a given planet in a decade, are in the offing. Because this problem requires further analysis, no recommendation is being submitted, but the Working Group requests that the Space Science Board undertake an appropriate study of the problem as soon as possible."


HIGH ENERGY PHYSICS
AND COSMIC RAY MODULE

APPENDIX I

Relevant Parameters for the Cosmic Ray and High Energy Physics Module

Many of the parameters presented here are understandably tentative. Numbers given with a low confidence level are indicated by an asterisk (*).

Performance:	. Momentum cut-off: 10^5GeV/c . Experimental cut-off: 10^6GeV/c
Uprating Potential:	. Momentum cut-off: 10^6GeV/c
Superconducting Magnet parameters:	. Configuration: Thin "loop" . Diameter: 2m . Average field: 66 Kgauss . Cooling power requirement: 10 KW for liquid He environment; 1 KW for liquid H environment . Weight (without cryogenic refrigerator): 10,000 lbs (*)
Cryogenic Target:	. Element: Hydrogen, Deuterium . Weight: 1,000 lbs. . Area: $4m^2$. Depth: 1m ($7g/cm^2$) . Cooling power requirement: 1KW
Associated Hardware:	. Weight: 7,000 lbs.(*) including structural support
Electronics:	. Weight: 3,000 lbs.(*) . Raw data output: 3-30 K bits/sec (dependent on experiment configuration) . Power requirement: 1KW(*)

Module:

- Weight: 30,000 lbs.(*) (includes cryogenic refrigerator, assumes solar cell as power source)
- Life time: 2 year minimum
- Power requirement: 3-13 KW (dependent on superconductor temperature)
- Volume: 23,000 ft^3
- Orbit: High altitude preferred

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