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ABSTRACT

Two experiments of astrophysical importance are suggested: the determination of the cosmic ray electron energy spectrum between 10 and 100 GeV and the measurement of the charge composition of cosmic rays in a similar energy region. Both experiments would utilize magnetic momentum analysis, using a small superconducting magnet suitable for balloon flights to high altitudes.

I. INTRODUCTION

One of the more difficult items to measure in cosmic ray physics is the momentum of the incident particles. This difficulty, thus far, has limited much of cosmic ray astrophysics to low-energy measurements by calorimetric techniques, or exceedingly high-energy measurements by the extensive air shower arrays. Low-energy measurements suffer from the complexity of the solar modulation, and although some correction for modulation can be made, considerable uncertainty is introduced. Exploration of higher energies is, of course, desirable for its own sake, but the avoidance of this modulation-induced uncertainty makes the higher energy region even more attractive. It would be particularly interesting to examine a number of components of the primary radiation in the energy range 10 to 100 GeV, where modulation is no longer important, and where particle fluxes are still sufficiently high to allow good statistical precision in reasonable observation intervals.

Accurate momentum measurements have been made for many years in ground-based experiments by bending the trajectories of particles in a high magnetic field and measuring their curvature. With the recent advent of superconducting-magnet technology, this has become a very feasible method of determining the momentum and the charge of particles observed at balloon or satellite altitudes. A superconducting magnet can be constructed which is relatively light, which will operate in the persistent mode, thus requiring no external power, and which will produce sufficiently high fields for momentum measurements in the 10- to 100-GeV range.

In the following sections are a description of the proposed superconducting-magnet momentum-analysis system and a resumé of the important experiments in which it would be utilized. Two of these experiments, of considerable interest in contemporary cosmic-ray astrophysics, are discussed in detail: the primary cosmic electron spectrum, and the charge composition of the heavier nuclei.

II. OBJECTIVES

The objectives of this proposal are twofold, scientific and technical. The scientific objectives arise from the capability of doing high-energy cosmic-ray measurements at balloon altitudes in the near future. The technical objectives are concerned with development of superconducting magnets and related electronic equipment into reliable systems for eventual inclusion in satellite programs, such as the manned orbiting cosmic-ray laboratory which has been proposed by the Science and Applications Directorate of the NASA Manned Spacecraft Center.

A. Scientific Objectives

1. The High-Energy Primary Electron Spectrum

Probably one of the most interesting discoveries in recent years is the observation that the universe appears to be filled with radiation of the same spectral distribution as that emitted by a black body at a temperature of 3°K. This was first observed by Penzias and Wilson [Astrophys. J. 142, 419 (1965)]. Even more exciting is the correlation of this radiation with that of the primordial fireball hypothecated by Dicke, Peebles, Roll, and Wilkinson [Astrophys. J. 142, 414 (1965)], the "big bang" theory of the creation of the universe. The effect of these 3°K photons on various cosmic phenomena was immediately considered by a number of people. The depletion of high energy electrons due to their energy loss by inverse Compton scattering seems to have been considered first by Hoyle [Phys. Rev. Letters 15, 131 (1965)], and calculated in more detail by Felten [Phys. Rev. Letters 15, 1003 (1965)]. The high energy cosmic-ray electron spectrum can serve as a sensitive probe for the existence and properties of the 3°K radiation. What one observes is a steepening of the spectrum with increasing energy; the effects should become quite noticeable in the 10- to 100-GeV range, and very marked at higher energies. From the theoretical point of view, one understands Compton scattering very well, but is somewhat bothered by questions of storage time in the galaxy, electron injection spectra, etc. Even so, the calculations should not be far wrong at energies above 10 GeV. There are corrections for atmospheric electrons, both direct and albedo, but at high energies one is presumably free from any solar modulation corrections.

The only experiment so far done at high energies was an emulsion stack experiment reported by Daniel and Stephens [Phys. Rev. Letters 15, 769 (1965) and Phys. Rev. Letters 17, 935 (1966)]. These data show the spectrum becoming flatter rather than steeper at high energies, and also indicate slight evidence for a positron excess at high energies, $e^+/(e^+ + e^-) = 0.7 \pm 0.2$, in contrast to an electron excess at lower energies. Daniel and Stephens have interpreted their results as evidence either for doubting the existence of a universal 3°K radiation, or for believing in the existence of some additional component of the electron spectrum that has a different slope and becomes important at energies > 20 GeV. As neither of these solutions is particularly attractive, Daniel and Stephens have received some critical comment suggesting possible inaccuracies in their experimental method as well as other explanations of their data. However, as yet, theirs are the only data for more than 20 GeV, and until other (more accurate) experiments are done, the controversy is not likely to be resolved. To emphasize the current interest and importance of this measurement, one can note that since the discovery of the 3°K radiation in 1965, more than 15 articles have appeared in Physical Review Letters on the subject of the high energy electron spectrum. The only experimental data available are still the five points of Daniel and Stephens, a total of twenty-eight events. Thus it is important that a good experiment, or a set of good experiments, be done to make accurate measurements up to at least 500 GeV. In order to measure both the momentum and the charge of the incoming electrons, one requires a moderately high-field magnet, which should be light enough to be flown at high altitudes.

2. Nucleon Energy Spectra and Charge Composition

The energy spectra of the multiple-charged cosmic-ray nuclei carry important information relating to the origin and propagation of these particles. By making corrections for ionization losses and fragmentation of these nuclei in the interstellar medium, one can presumably derive the composition and energy spectra at the time of injection into the trapping region. Several simplifying assumptions must be made if one is to believe this model, however. Some of these are:

(i) there is no charge-dependent acceleration in the source,

(ii) there is no in-transit acceleration or deceleration,

(iii) the spallation all occurs during propagation and none during acceleration or escape from the source, and

(iv) assumptions must be made about the containment efficiency of the trapping region.

In order to make any meaningful quantitative studies concerning the origin of cosmic rays, it is essential to make accurate measurements of the energy spectra and of the charge and isotopic composition over a broad range of energies. This information, coupled with detailed nuclear-spallation cross sections, should allow for careful interpretive, theoretical studies yielding model constraints eliminating the need for certain of these assumptions, and leading to new insight in theories of cosmic-ray origin.

The advent of the space era has, through the use of high-altitude balloons, sounding rockets, and satellites, provided opportunities for detailed studies of low- and medium-energy (10^{10} eV/nucleon) cosmic rays. Considerable information on the primary energy spectrum above 10^{15} eV has been gathered from extensive air shower work, and it is known that cosmic rays extend up to at least 10^{20} eV. Below a few times 10^9 eV/nucleon, solar modulation effects modify the interstellar spectrum, thus this spectrum can be deduced only from the observed spectra corrected by assumed theoretical models of modulation. The intermediate region between 10^9 and 10^{15} eV is the least well known. Since solar modulation is not effective here, and also since leakage from the galaxy is probably low, this is a most interesting and important energy range for galactic studies.

The energy spectra and charge composition below a few hundred MeV/nucleon and up to Z = 26 have been well determined by small satellite and balloon experiments. From several hundred MeV/nucleon to several BeV/nucleon the measurements are of a much poorer quality because the experiments have quite small geometry factors and poor statistics, and depend upon geomagnetic cutoff for energy determination.

One scientific objective of this program will be to measure the charge composition and energy spectra from around 10^9 eV/nucleon to near 10^{11} eV/nucleon with high charge and energy resolution. The large geometry factor will allow good statistics to be collected on even the lower-flux components. The measurements will be made at 3 to 4 g/cm^2 residual atmosphere and also at lower altitudes, to allow an accurate extrapolation to the top of the atmosphere to correct for spallation effects.

B. Technical Objectives

The first superconducting magnet built for flight in a balloon was the large magnet (9 kilogauss over a 1-meter bore) designed and developed by the HAPPE group headed by Professor Luis W. Alvarez of the University of California. The HAPPE magnet was designed to make momentum measurements on the incoming proton beam at an altitude of about 90 000 feet. It is when one considers doing experiments at altitudes of 120 000 to 130 000 feet that a smaller lighter magnet becomes attractive. In this way a small superconducting magnet (SSCM) program is complementary to the HAPPE program, and indeed, if the SSCM were flown in tandem with the HAPPE magnet, one could magnetically analyze both the incoming beam and the secondaries from the interactions. This would produce a two-magnet package of tolerable weight. Another complementary function would be the flight of the SSCM from the Chico launch site during the winter months, when the HAPPE gondola is prevented from flying by the high-altitude westerly winds.

There are a number of additional reasons why an SSCM would be of significant benefit:

(i) The magnet could be flown at low and high altitudes and instrumented for a variety of particle interactions as well as cosmic-ray experiments. Smaller and less expensive balloons and operational techniques would be required than for HAPPE, including perhaps the use of polyethylene (Stratofilm) balloons. It will be easier to "ruggedize" the package for a land recovery. The package could also be launched from other geomagnetic latitudes in the event they should be desirable for certain experiments.

(ii) The SSCM would provide a versatile instrument for testing and gaining experience with high-field magnets in the laboratory. Presently there is just no way to do this, and the size and weight of the HAPPE magnet do not make it very suitable for this purpose.

(iii) The proposed SSCM could serve as a precursor to a space-hardened version for a Satellite. Questions of the cryogenic operation and heat leak at zero G need to be investigated, as do helium boil-off rates and susceptibility to vibration.

(iv) Considerable experience in the field operations of flying a superconducting magnet can be gained at minimal cost. The development of the necessary skills and techniques for high-altitude operation is a critical part of the technical support of an orbiting laboratory.

C. Magnet Design

The design of the proposed superconducting magnet is a pair of Helmholtz coils of 20-inch diameter. Each coil contains 9000 turns of copper-clad niobium-titanium superconducting wire. It should carry 140 amperes and generate a magnetic field of 40 kilogauss in the center of the bore. The wire has been inorganically insulated by oxidizing the copper surface, and each layer of 60 turns is insulated from neighboring layers by fiberglass insulation. The magnet will be enclosed in a liquid helium Dewar with sufficient He capacity for a 20-hour flight. The effective bore of the magnet is approximately 6×12×20 in., which provides 2000 kG-cm with a magnet-limited geometry factor of 400 cm^2-sr. The weight of the magnet and Dewar should not exceed 700 pounds.

One such 20-in.-diameter prototype coil has been constructed and tested to slightly greater than 80% of the design current. On the basis of these preliminary tests we are very optimistic of attaining the design field.

III. EXPERIMENTAL APPROACH

One can perform several experiments with the experimental apparatus outlined in this proposal. In the following we wish to discuss the feasibility of doing two experiments that we consider to have the highest priority: the charge composition of cosmic rays as a function of their energy, and the electron and positron energy spectrum between 10 and 100 GeV. With the ensuing discussion it will become obvious that with minor additions and modifications other related cosmic-ray experiments could be performed with the apparatus proposed.

To perform the two experiments cited above, the detector system must fulfill the following requirements:

(i) Measure the charge of the incident particle passing through the instrument.

(ii) Measure the momentum of the incident particle.

(iii) Have a large geometry factor so that rare events corresponding to either (or both) very high energy or very heavy nuclei are observed with reasonable frequency.

(iv) Be able to distinguish whether or not the incident particle is accompanied by a number of particles due to interactions in the material above the charge-identification system and the residual atmosphere.

(v) Determine the trajectory of the incident particle. This is necessary both for determining particle momentum by magnetic deflection, and for improving the charge resolution by unfolding the spatial response of the charge-measuring counters.

(vi) Determine whether the particle in the electron experiment is a proton or a positron.

We propose to measure the momentum of cosmic rays by a superconducting-magnet—spark-chamber system that can be flown by balloons at very high altitudes. The use of a high-field magnet allows the determination of the sign of the electric charge as well as the measurement of the energy of a particle without destroying the particle in the measuring process. These two properties enable one to search for a possible antinucleon component in cosmic rays.

The magnet is of the Helmholtz type, a split pair of NbTi coils, 20 in. in diameter, separated by an 8-in. gap. The coils are immersed in a liquid helium Dewar in order to operate in the superconducting mode. Preliminary tests have achieved a magnetic field of 32 kG, in a 6×12 in. aperture and an effective length approximately equal to the coil diameter. This gives a bending power of $\int B(\ell)\, d\ell$ = 32 kG × 50 cm = 1600 kG-cm for the magnet, and allows implementation of a detector system with a geometry factor of about 400 cm^2-sr (see Figs. 1 and 2).

Using the above value for the bending power, the expression for the momentum resolution is

$$\frac{\Delta p}{p} = \sqrt{2}\,\frac{\Delta\theta}{\theta} = \frac{\sqrt{2}}{0.3}\,\frac{R\Delta\theta}{\int B(\ell)\cdot d\ell} = 2.94\, R\Delta\theta,$$

where R is the rigidity in GV, p is the momentum in GeV/c, and $d\theta$ is the error in the measurement of the particle's entrance or exit angle in mr.

Accompanying the magnet are two spark chambers, one above the magnet and one below, as shown in Figs 1 and 2. Each spark chamber consists of ten 1-in. gaps separated by 1-mil Al foil plates (13×35 in.). Each chamber will be powered by a Marx generator power supply, triggered by a coincidence pulse produced by three counters (S_1, S_2, and C) of the charge detection system, and photographed via a system of mirrors by a rapid-advance camera.

If we assume a spatial resolution for the spark chamber and associated optics of ±1 mm, then the error in the measurement of either the entrance or exit angle can at most be $d\theta$ = 1 mm/254 mm = 4 mr. In actual practice one uses all the gaps that fired and fits the sparks to a space curve, with a resulting increase in precision.

A. Charge Composition Experiment

We now discuss our experimental approach, using the momentum-analysis system described above, for measuring the charge composition of heavy nuclei with kinetic energies ranging between 1 and 50 GeV/nucleon.

The momentum resolution corresponding to an angular measuring error of 4 mr is

$$dp/p\ (\%) = 1.16\ R(GV).$$

Assuming Z/A = 1/2 for nuclei, the momentum resolution will be 25% at 10 GeV/nucleon, 60% at 25 GeV/nucleon, and 95% at 40 GeV/nucleon. With some development work on track-measuring procedures and spark distortions due to high fields, one should be able to reduce these errors by

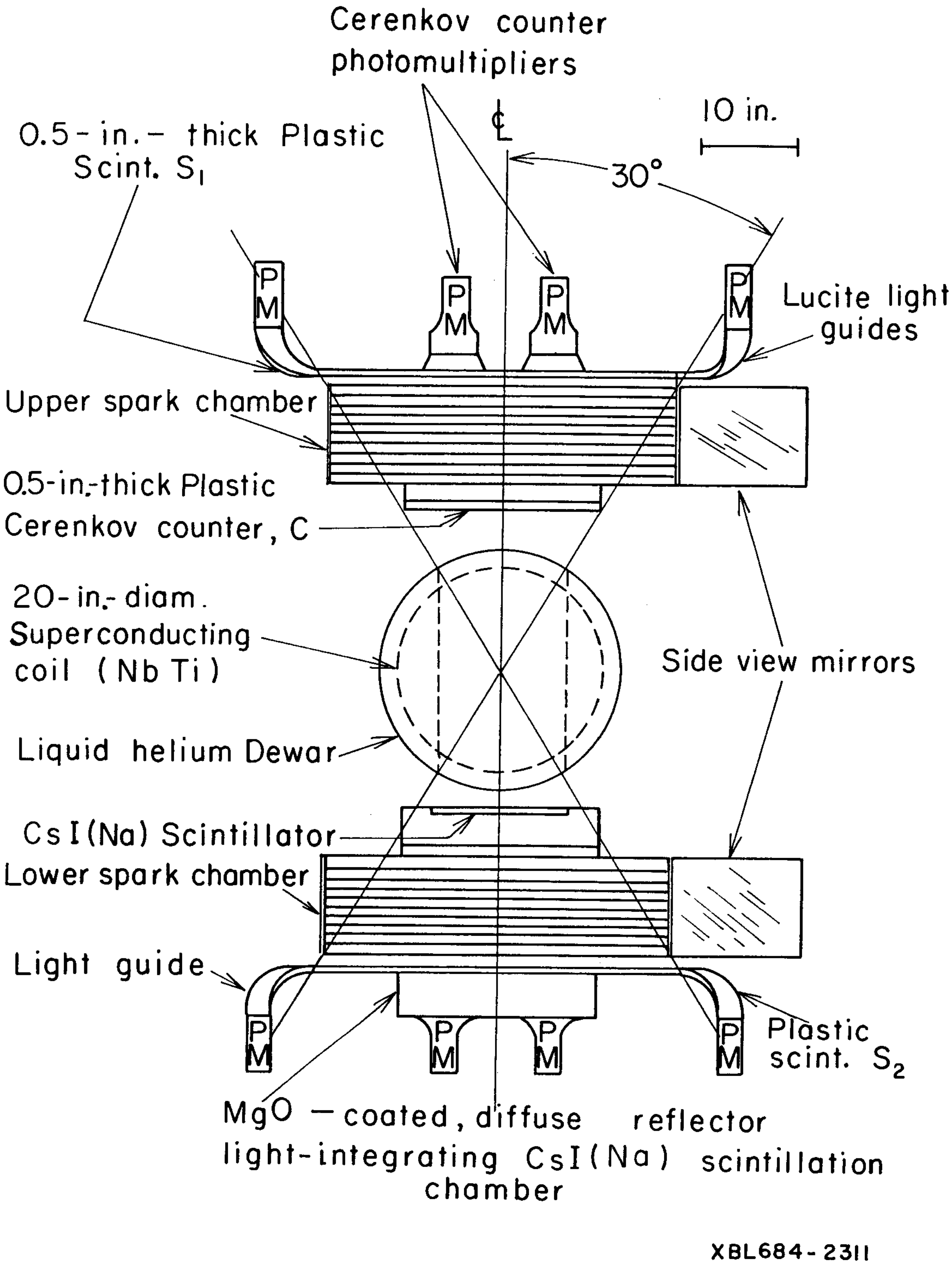

Fig. 1. Front view of charge-composition experiment.

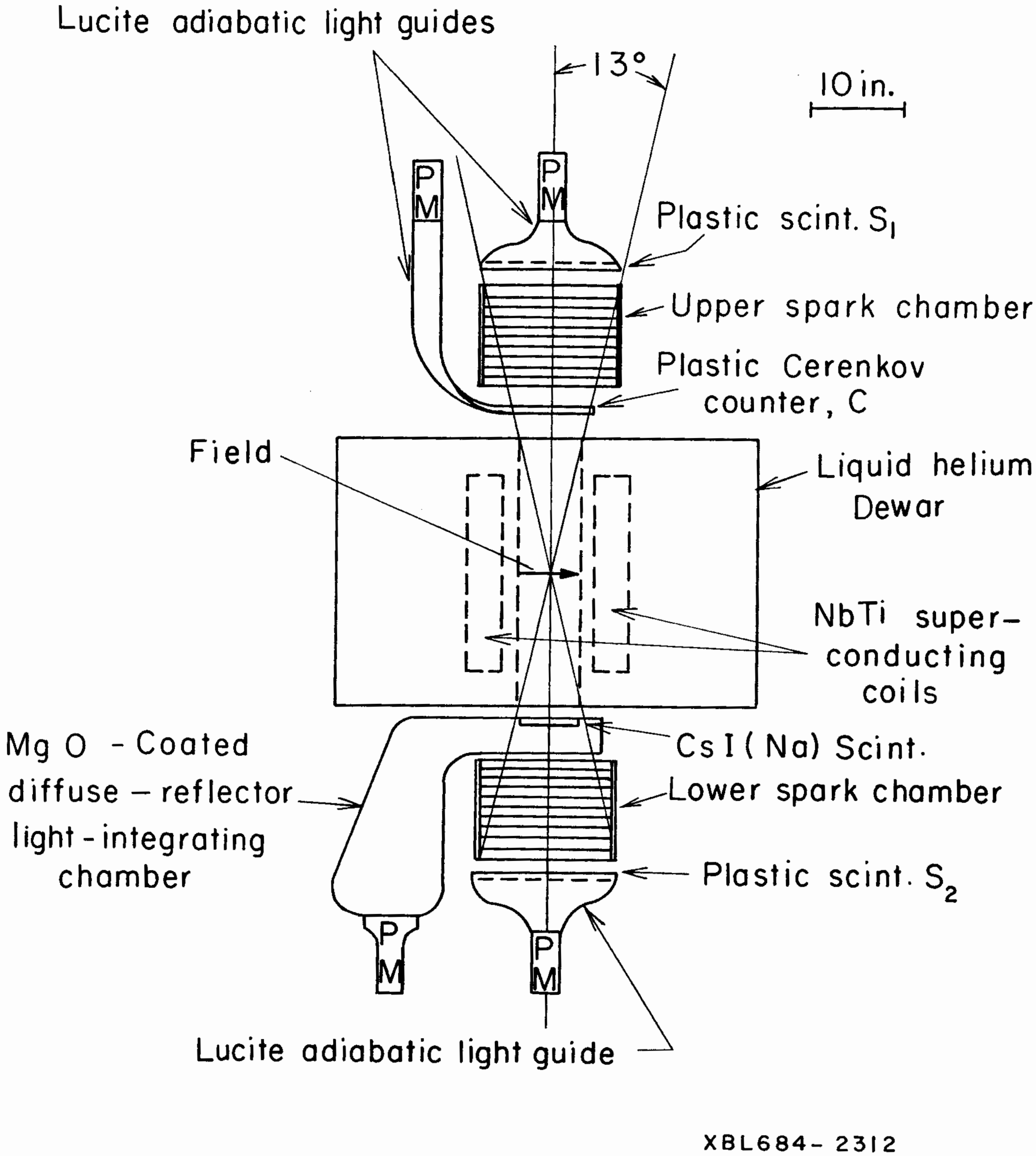

Fig. 2. Side view of charge-composition experiment.

a significant factor. If satisfactory emulsion—spark chamber systems became available, they could conceivably reduce the error an order of magnitude. However, with spark chambers alone the energy resolution is sufficient to do significant heavy-nuclei cosmic-ray physics in the range 1 to 50 GV/nucleon.

The lower limit of energy observed will most likely be set by the local geomagnetic cutoff and not by the superconducting magnet. The geometry of the magnet—spark chamber system limits the rigidity to be greater than 0.6 GV, whereas at Chico, for example, the cutoff rigidity is 3 GV. This corresponds to a kinetic energy of 2 GeV/nucleon for protons and 1 GeV/nucleon for heavier nuclei. For practical purposes the upper energy limit for the various charge groups is limited by their fluxes and by balloon flight times.

For example, if we assume that we launch our experiment from Chico, the total integral flux at the top of the atmosphere for this cutoff is 1200/m^2-sr-sec. If we take into account the change in charge-to-mass ratio between $Z = 1$ and $Z \geq 2$ and a geometry factor of 400 cm^2-sr for our detector, the expected counting rates of the various charge groups are:

Group	Z	Counts/hr.
p	1	144×10^3
α	2	$26\text{-}31\times10^3$
L	3-5	576
M	6-9	1870
H_3	10-15	519
H_2	16-19	≈ 0
H_1	20-28	346

The total rate for $Z \geq 3$ is then 3311/hour, which is compatible with a reasonable film capacity. However, the p and α rates will have to be decreased to a level comparable to the $Z \geq 3$ rate, or simply eliminated by not triggering on pulse heights corresponding to $Z = 1$ or 2.

Finally we can indicate how the $Z \geq 3$ nuclei flux puts an upper limit on the highest energy one can observe during a balloon flight by quoting the energy for each charge group corresponding to 1 count/hour.

Group	Energy (GeV/nucleon)
L	80
M	164
H_1	75
H_3	58

A schematic of the charge-detection system is shown in Figs. 1 and 2. It consists of two plastic scintillators, S_1 and S_2, a CsI(Na) scintillator, and a plastic Cerenkov counter C. The two plastic scintillators define the geometry of the system, while the CsI and Cerenkov counters are the principal charge-determining elements. Consistency checks will also be obtained from the pulse-height data of the plastic scintillators.

The potential charge resolution of a Cerenkov detector is better than scintillation detectors because of the absence of two effects that limit the resolution of scintillation detectors at high charge values. These effects are Landau broadening, and saturation of the light output. Also, a Cerenkov counter is much less sensitive to low-energy nuclear fragments from nuclear interactions in the radiating material. On the other hand, Cerenkov detectors suffer from two disadvantages: low useful light output and extremely direction-sensitive response when internal reflection is used for light collection. These deficiencies might be simultaneously alleviated with the use of wavelength-shifting additives. The shifter would absorb Cerenkov light and isotropically re-emit photons at a wavelength that is transmitted by the radiator and light guides. Experimental studies of plastic Cerenkov radiators incorporating wavelength shifters are being carried out at the NASA Manned Spacecraft Center in Houston, Texas.

The two plastic scintillators, S_1 and S_2 (35×13×1/2 in.) define the geometry of the detector. Each scintillator is viewed by two photomultipliers via adiabatic light guides. The Cerenkov counter consists of a (20×7×0.5-in.) ultraviolet-transmitting plastic plate with wavelength-shifting additives, viewed by two Lucite adiabatic light guides and photomultiplier tubes. Its light output is expected to be proportional to Z^2 with no saturation effects. The pulse from the Cerenkov counter is fast and can therefore be used in conjunction with S_1 and S_2 to form a trigger for the spark chambers. The CsI scintillator consists of a 6×14×1/8-in. single crystal or mosaic of crystals placed in a light-integrating chamber (i. e., the scintillation light is viewed by diffuse reflection inside a chamber painted with MgO_2, rendering the CsI response spatially uniform). The pulse from CsI is slow, with a rise time of ≈1 μsec, and hence not suitable for incorporating in the spark chamber trigger. Both the CsI counter and the plastic Cerenkov counter are situated next to a spark chamber enabling one to unfold, if necessary, the spatial response of either counter. This can be accomplished by mapping the counter pulse height as a function of position and renormalizing the observed pulse height according to the particle's incident position.

The amount of matter in the detector system is ≈4.1 g/cm^2, and hence the interaction probability is not excessive. It is possible to correct for the effects of nuclear interactions in the instrument with adequate precision by viewing the track multiplicity in the spark chambers.

1. Electronics

A block diagram of the electronics logic is shown in Fig. 3. One output from each detector will be fed to a two-level discriminator. A lower-level output will indicate a detector output above the lower noise-pulse-suppression threshold and less than approximately six times the output of a

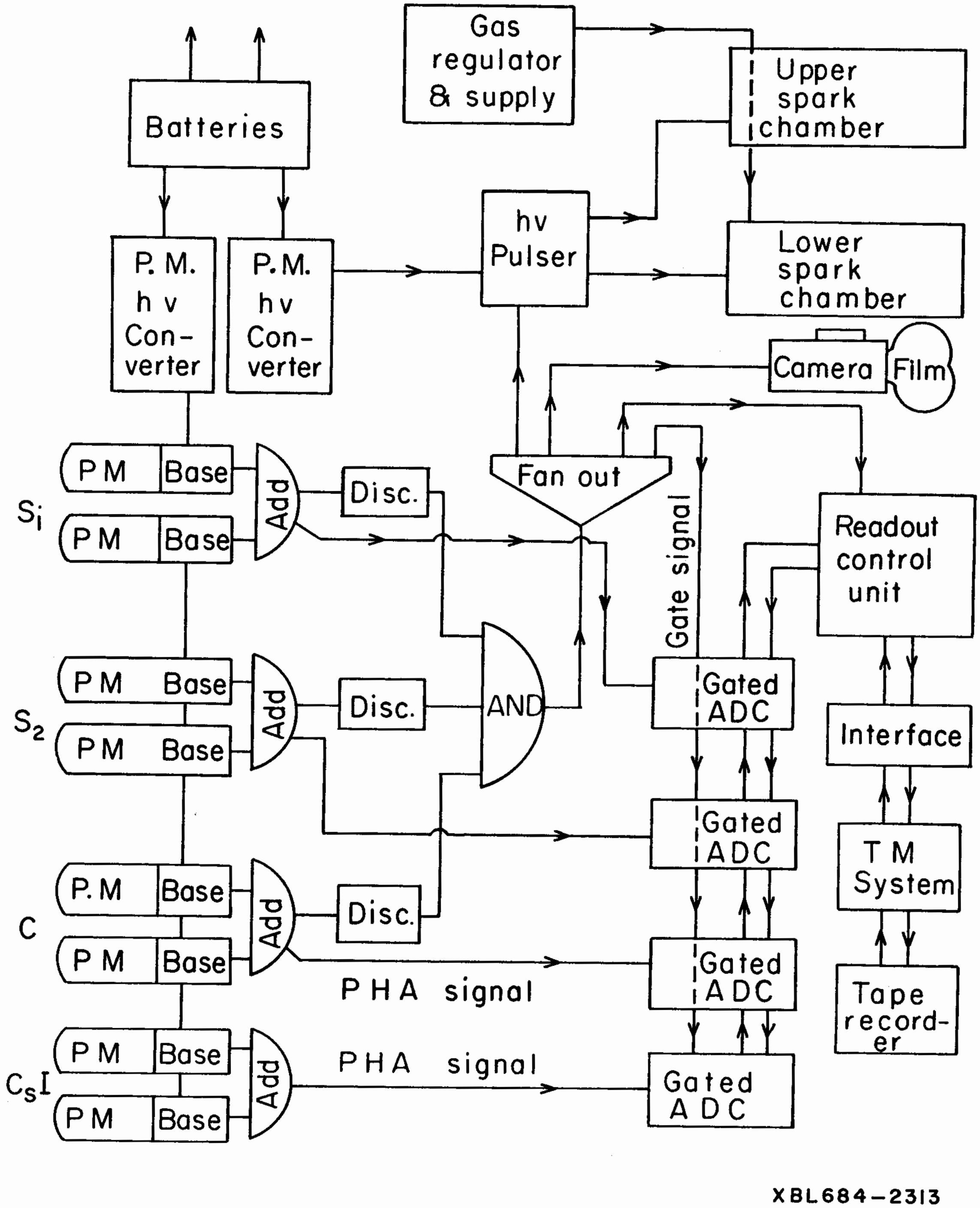

Fig. 3. Proposed electronics logic for charge-composition experiment.

relativistic, singly charged particle. An upper-level output will indicate a detector output greater than six times minimum level. A second output from each detector will be pulse-height analyzed.

The electronic trigger requirements for nuclei with $Z > 2$ will be a threefold coincidence between the upper-level discriminator outputs of counters S_1, S_2, and C. This will be used to trigger the spark chambers, advance the cameras, and gate off the analog-to-digital converters (ADC) while firing the spark chambers. The fourfold redundancy in the charge determination by pulse height should ensure good resolution in the presence of fluctuations due to Landau effect.

2. Balloon Requirements

The weight of the superconducting magnet and Dewar is 700 pounds. The weight of the spark chambers, mirrors, cameras, batteries, electronics, gondola, etc. is less than 1000 pounds. If we can keep the weight of the balloon, ballast, control packages, etc. less than 1800 pounds, we then have a gross payload of 3500 pounds. One can put such a payload at 125 000 feet (3.6 g residual atm) with a 13-million-ft^3 He balloon. At this altitude the amount of material presented to incident heavy nuclei by the matter in the detector system approximates the amount presented by the residual atmosphere. To go higher in altitude becomes costly from the ballooning standpoint, and one gains slowly from the physics standpoint because the detector material rapidly becomes the limiting factor. Thus corrections to the observed charge composition of cosmic rays as a function of altitude must be made because the incoming nuclei are contaminated quite severely by the fragmentation of heavier nuclei in the atmosphere above and in the detector material itself, as shown in the table below:

Fragmentation Contamination at 4.2 g/cm^2 residual atmosphere

	H_1	H_3	M	L
Fragmentation contribution	0.086	0.082	0.217	0.375
Primary flux	0.819	1.31	4.45	1.37
Observed flux	0.905	1.39	4.67	1.75
Relative fragmentation contribution	9.5%	5.9%	4.7%	21.5%

It is seen that the corrections necessary for the L group, even at this altitude, are too large to tolerate the uncertainty involved in a calculated correction. Therefore experimental data that can enable one to extrapolate the observed flux to the top of the atmosphere must be obtained. There are at least two conceivable methods that could be used: (i) analysis of the data as a function of zenith angle, and (ii) floating at two depths in the atmosphere during the flight. The accuracy of the extrapolation from the first method is limited by the small range of angles (≤ 30 deg) accepted by the instrument. The second method sacrifices a smaller statistical error on the results at the highest altitude, for a more reliable determination of a systematic background correction to the data.

B. Electron - Positron-Flux Measurements

The unique advantage of a magnetic momentum-analysis system is its ability to distinguish the sign of the electric charge of a particle. This property makes it an ideal instrument for differentiating negative and positive electrons. The momentum-measuring system outlined in the preceding section can be utilized in conjunction with a Cerenkov counter and an electron shower counter to measure the primary electron and positron momentum spectra up to 100 GeV/c. The configuration of the gondola would be as shown in Figs. 4 and 5.

1. Detector Description and Operation

The Cerenkov detector would have a threshold of 50 GeV for protons. With the requirement that the C pulse height be 0.75 times the high-energy limit for a particle of unit charge, the detector would be sensitive to protons of energy greater than 90 GeV. The Cerenkov detector would be sensitive to electrons of energy greater than 45 MeV.

The momentum-detection system would have the momentum resolution given in the previous section. It is sufficiently accurate to allow a determination of the sign of an electron's charge at energies up to 100 GeV.

The shower counter system $E_1E_2E_3E_4$ is currently under development and will be calibrated at the Stanford Linear Accelerator Center. Its final form may be like that illustrated in Fig. 6. The lead above E_1 serves to multiply an electron into at least three particles with a probability of 95% for an incident electron with an energy of 10 GeV. The subsequent two layers of lead in conjunction with counters E_2 and E_3 will provide more information for distinguishing electron showers from nuclear interactions. The beryllium layer and E_4 serve as a detector of nuclear-active particles. The odds for an energetic electron to traverse the three lead sheets without interacting and then interact in the beryllium are $< 1{:}10^6$, whereas the odds for an energetic nuclear particle to traverse the lead without interacting and then interact in the beryllium are $< 1{:}70$. Thus showers that begin in the beryllium are very nearly all nuclear events; these events provide a good measure of the flux of nuclear particles.

The spark chambers would be triggered on C_1, C_2, S_1, S_2, E_4, $\overline{G}$ logic. C_1 and C_2 will be required to have a pulse height of between 0.75 and 1.5 of the pulse height of a minimum ionizing singly charged particle. S_1 and S_2 will be required to have pulse heights between 0.5 and 1.5 times minimum ionizing. An upper limit on the pulse heights is used to prevent low-energy heavy particles' triggering the C detection by knock-on electron emission. E_4 will be required to be 1.5$\times$ minimum ionizing to insure that the particle did multiply in the shower counter. Detectors C_1, C_2, S_1, S_2, $E_1 \cdots E_4$ will be pulse-height analyzed for each trigger.

Using a 400 cm^2-sr geometry factor and assuming the electronic component has a flux of 1% of the nuclear flux, we can calculate the triggering rate. For a flight at cutoff rigidity = 3 GV:

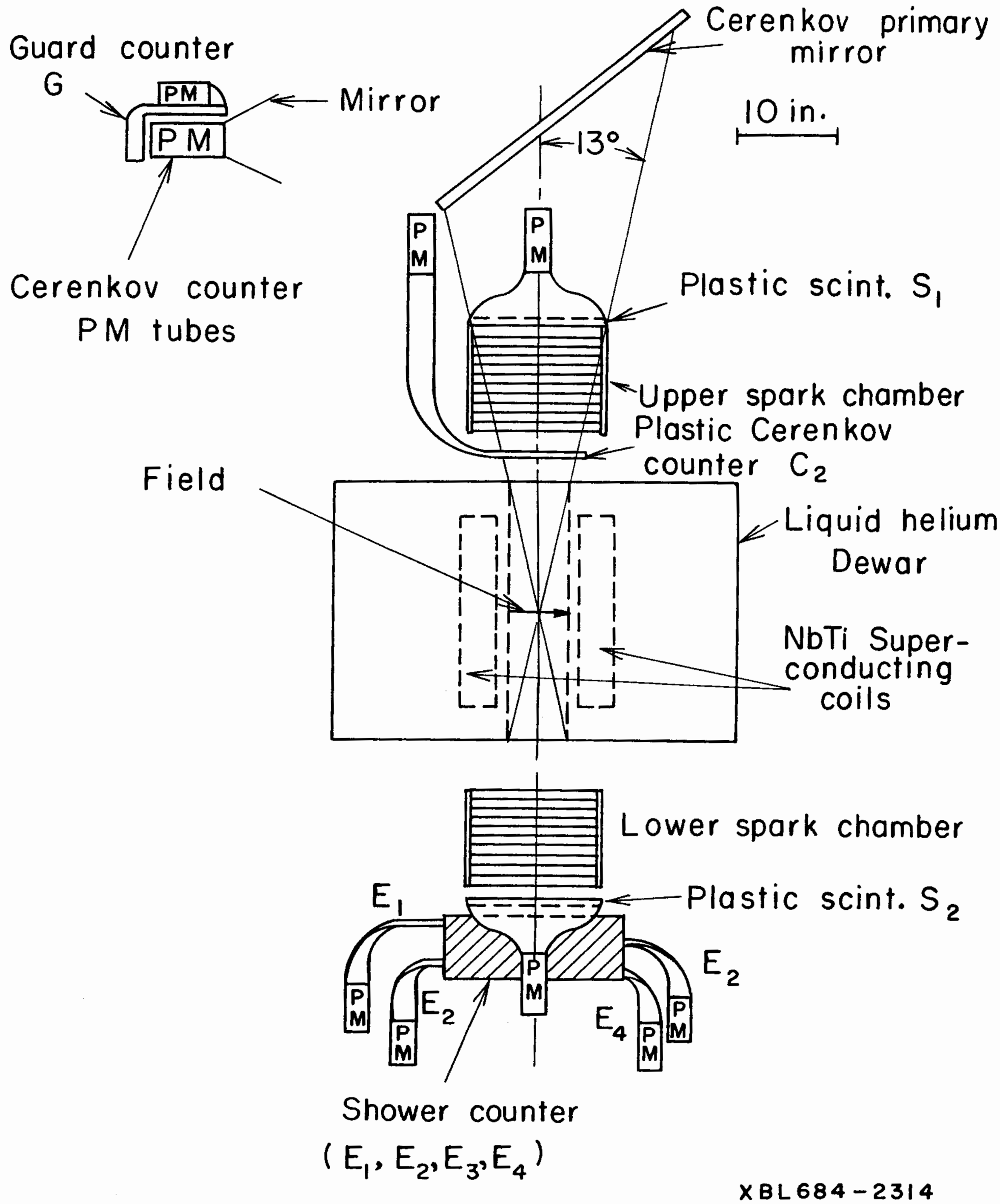

Fig. 4. Front view of electron experiment.

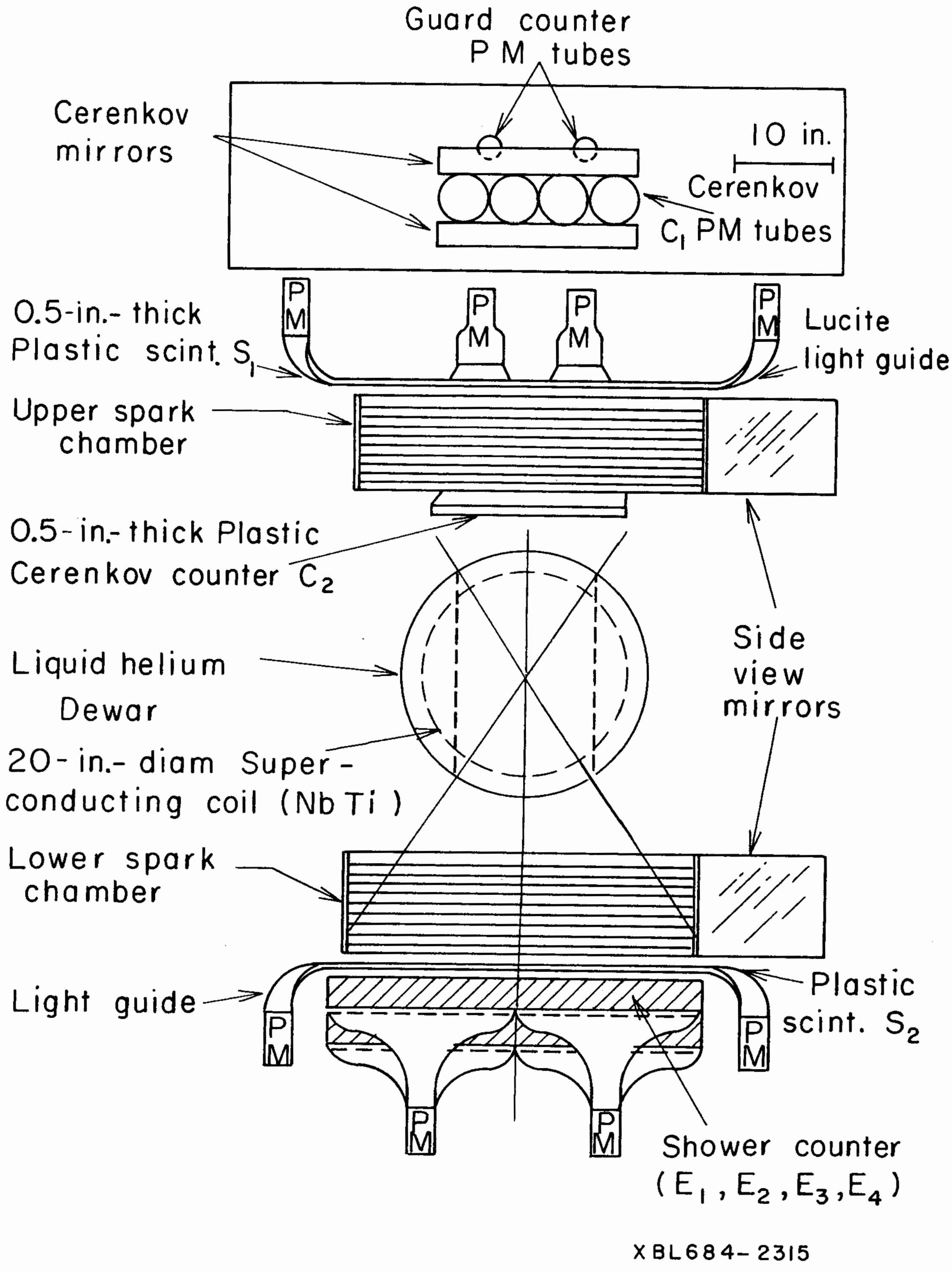

Fig. 5. Side view of electron experiment.

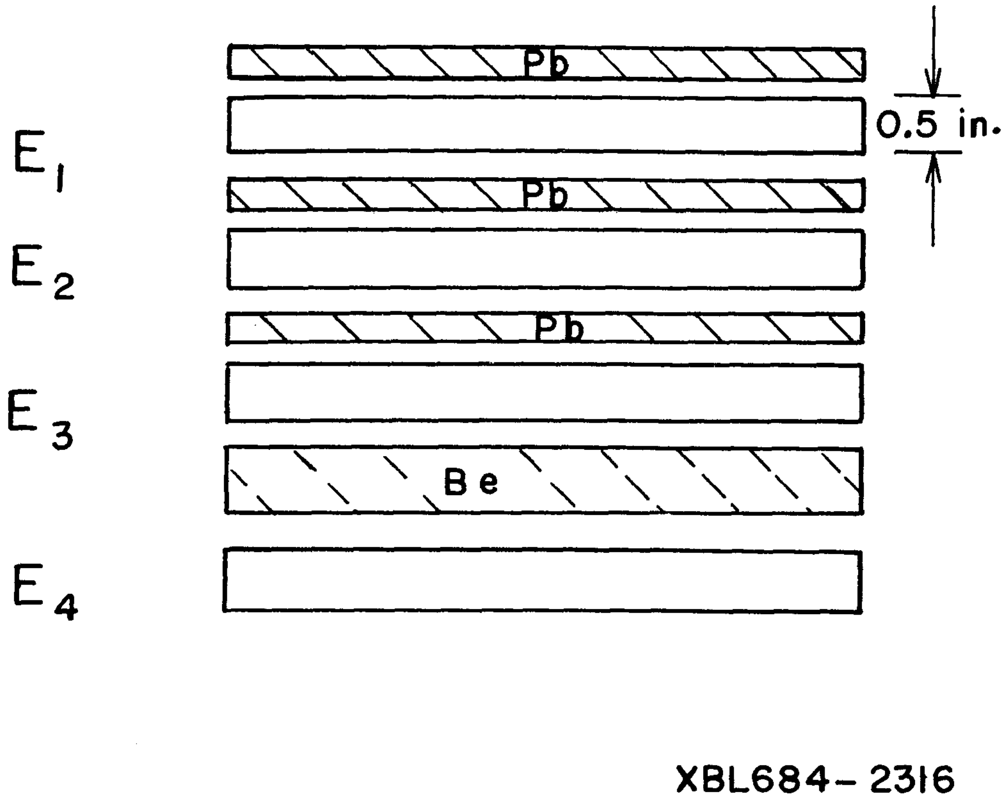

Fig. 6. Shower counter $E_1E_2E_3E_4$.

$$R = \overset{(1900/\text{hr})}{R_{\text{electrons}}} + \overset{(1200/\text{hr})}{R_{\text{protons}}} = 3100/\text{hr}.$$

With an 8×10^4-frame film capacity, 11-hour flights are possible with a safety factor of 2 in film supply.

Data Analysis

In principle, electrons and positrons will constitute almost all triggers due to particles with momenta below the Cerenkov limit (90 GeV) for protons. If a float altitude of ≈ 4 g/cm^2 is attained, triggers due to atmospheric pions should be less than 0.4% of the electron triggers, and can occur only for pions with energy greater than 13 GeV. In addition to the triggering criteria, the data from $E_1\ E_2\ E_3\ E_4$ can be used to further delineate the electronic component.

The most important source of background is atmospheric secondaries produced above the gondola. Little is known about nuclear reactions at energies above 30 GeV, but it is quite plausible that there are more secondary positrons than there are secondary electrons, because of the positive charge of the primary particles and the target. Thus atmospheric secondaries could produce a grossly misleading picture of the electron-positron ratio. The anticipated secondary fluxes at 4 g are of the order of 10^{-5}/cm^2-sec-sr above 3 GeV, as compared with anticipated electron and positron fluxes of 10^{-3}/cm^2-sec-sr above 3 GeV. Another source of background is reentrant albedo electrons. The background is serious (perhaps 10%) for energies near the Stormer cutoff. The reentrant particles can be distinguished by extrapolating their trajectory backwards into the magnetosphere until the trajectory either leaves the magnetosphere or reintersects the earth's atmosphere.

For an 11-hour flight at an altitude of 4 g/cm^2 and at cutoff rigidity of 3 GV, the following data should be obtained (assuming a primary electron integral flux = $0.7\times10^{-2}\ E^{-1.5}$/cm^2-sec-sr):

Energy(GeV)	Number of primary electrons	Number of secondary electrons	Minimum detectable ratio $e^+/(e^++e^-)$
3 - 10	1.8×10^4	250	1.4×10^{-2}
10 - 30	2.8×10^3	16	5.7×10^{-3}
30 - 90	5.5×10^2	1.3	2.4×10^{-3}

The atmospheric background was assumed to have an integral flux of $2.2\times10^{-4}\ E^{-2.3}$/cm^2-sec-sr.

The minimum detectable positron-to-electron ratio is approximately the ratio of the atmospheric background to the primary flux. This is because in the worst case the atmospheric background would consist entirely of positrons, and thus it limits the lowest detectable positron flux.

Footnotes

*Work done under auspices of U. S. Atomic Energy Commission.

†NASA Manned Spacecraft Center, Houston, Texas