SLAC-PUB-234
October 1966

THE INITIAL EXPERIMENTAL PROGRAM OF SLAC*

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The experimental program to be carried out with the two-mile-long 20-GeV electron beam produced at the Stanford Linear Accelerator Center (SLAC) and the associated experimental apparatus have been designed to take full advantage of the unique features of this accelerator. These have been described in detail in the previous article and so only the main qualitative features are listed here:

1. Highest energy and intensity of electrons and photons.
2. Highest energy and intensity of positrons.
3. Very small phase volume of electron beams.
4. Highest intensity and purity of muon beams of quite high energy.

A slight qualification should be made to the above since in principle one could obtain higher energies at the large proton accelerators of Brookhaven or CERN from π^0 decay into gamma rays and occasionally into electron-positron pairs, but the intensities are so low that only a very limited class of experiments has so far been attempted.

There has also been a considerable amount of thought given to the production by electrons of beams of strongly interacting particles, namely, π's, K's and anti-protons, which was not contemplated at the time of the original Stanford Proposal.[1, 2, 3] Such production, however, is not considered a unique feature of this accelerator because it turns out that, while these beams will be competitive (for some experiments) with similar beams at the large proton accelerators,

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(Submitted to Physics Today)

* Work supported by the U. S. Atomic Energy Commission.

they will not be superior. For some counter experiments they will be inferior because of the poor duty cycle of the linear accelerator. This is not to say that there can't be classes of experiments with strongly interacting particles that are better done at SLAC than elsewhere.

It is interesting to explore this a bit further in view of some misunderstanding as to the nature of the linear accelerator which has a high repetition rate (360 cycles/sec) of short bursts (no longer than 1.7 microseconds). For some measurements, especially coincidence counting, this is a poor duty cycle as compared with circular machines. For example, the AGS at Brookhaven pulses once every three seconds for 300 milliseconds each, and is therefore "on" about 10 percent of the total time. At SLAC the corresponding number is 0.06%, a factor of 160 less. This must be partially compensated by using precision measurements of displacement and angle alone in order to determine the kinematics of the interactions and thus leads to complicated and large apparatus which will be described later.

On the other hand, some decided advantage can be derived from these machine characteristics. For example, very short machine bursts (10-100 nanoseconds), which are easily obtainable, allow a background-free measurement of particles which decay during the time between machine pulses (π's, K's, μ's). Or a background of medium energy (<500 MeV) neutrons can be avoided by pulsing the detector "off" a short time after the machine pulse is over. Furthermore, devices like hydrogen bubble chambers, while unable to follow the fast repetition rate of the accelerator, function well with short pulses and can operate indefinitely at say, one expansion per second while only using a fraction of a percent of the total available pulses of the beam. Another interesting feature predicted from the nature of the production process is the possibility of obtaining beams of high energy π^+ mesons with a low background of protons without the necessity of using a complicated mass separator.

Experimental Apparatus and Special Beams

Three spectrometers, two magnet spark chambers, and two hydrogen bubble chambers are all expected to be in operation at SLAC within the next year. These are all intended as part of the general facilities of the laboratory and will be made available to qualified experimenters. The bulk of the initial experimentation with electrons and protons will be done with three huge spectrometers now nearing completion in End Station A, one of the experimental halls (see Fig. 1). In terms of historical usage, the word "spectrometer" is not adequate to describe the scale to which the SLAC instruments are being built. For example, the largest is 165 feet long and weighs 1700 tons; yet these are designed to measure angles to a precision of $\pm 1.5 \times 10^{-4}$ radians and momenta to $\pm$ 0.05%. Put in other terms, these are precise beam transport systems, mounted with their detectors on rigid frames which are then rotatable around the beam target.

Figure 2 shows a drawing of the 8 GeV/c (the maximum resolvable energy) spectrometer which will be the first to operate.

This device can swing from 15 to 100 degrees around the target, corresponding to 2.3 to 165 degrees in the center-of-mass system of the beam electron and the target proton. Figures 3 and 4 show the 20 GeV/c and the 1.6 GeV/c spectrometer respectively. The corresponding numbers are 0 to 25 and 90 to 180 degrees in the laboratory system, while in the center of mass they are 0 to 80 degrees and 155 to 180 degrees. So, as can be seen, the full range of 180 degrees in the CM system is covered by the combination of these three instruments. Any of the spectrometers operating at full excitation is designed with enough precision so as to be able to distinguish an elastic electron-proton scattering event from one in which one or more pions are produced. This, of course, is also predicated on the assumption that the beam from the accelerator has a phase volume of less than 10^{-5} cm-steradians.

A very large volume magnet is being built into which a streamer spark chamber will be placed. The magnet, a drawing of which is shown in Fig. 5, weighs approximately 500 tons and will develop a field of 15 kG in the open configuration shown. Figure 6 is a photograph of the magnet iron being installed. The streamer chamber[4] which will be 2.4 × 1.6 × 0.6 meters in volume is a device which allows for stereo photography of an event much like in the Wilson cloud chamber. However, this device has a rapid response and can be triggered by counters which surround it. The interactions will originate in a small diameter tube of gaseous hydrogen placed inside the chamber and the outgoing tracks can be measured with precision both in angle and momentum. This chamber also allows for the observation of decays-in-flight of neutral or charged unstable particles of appropriate lifetimes. A smaller version has been tested at the 300-foot, 1 GeV Mark III linear accelerator at the High Energy Physics Laboratory of Stanford, and a picture of electron tracks in the chamber is shown in Fig. 7.

A smaller magnet to be used with more conventional plate spark chambers is also being constructed and a drawing is presented in Fig. 8. This is meant to be a flexible device around which a large variety of experimental setups can be centered. Its initial use will be in muon-proton scattering experiments.

A 40-inch-diameter 20-inch-deep hydrogen bubble chamber is under construction at SLAC. This is a conventional chamber with a bellows-connected piston designed to pulse at two cycles per second in a magnetic field of 20 kG.

A drawing of this chamber is shown in Fig. 9, and a photograph of the magnet and vacuum tank is shown in Fig. 10.

A second chamber is a modified version of the famous Alvarez 72-inch which has done yeoman work in strong interaction physics at the Lawrence Radiation Laboratory. A new chamber of the piston expansion type and of effective length of 82 inches will be placed in the present magnet, tested at LRL, and then brought to SLAC. The new version is also designed to operate at two cycles per second.

Three beams of special interest are being constructed at SLAC. The first is a high energy secondary particle beam which can produce $\pi^{\pm}$, $K^{\pm}$ or $p^{\pm}$ by means of a beam transport system coupled with a radiofrequency particle separator. Such beams have already been established both at CERN and Brookhaven, but they require two such separators – one for bunching in time and the other for mass separation. At SLAC the linear accelerator provides inherent internal bunching so that only one separator is required. This makes for simpler and, more important, shorter beams so that the attrition due to decay is less damaging. This beam will separate K particles from π's and protons at any energy between 10 and 15 GeV.

A muon beam transport system capable of momentum analyzing and transporting muons of momenta up to 14 GeV/c is being assembled. The SLAC accelerator has some advantages in creating muon beams. The main one is that the muons are created in pairs just as in electron-positron pair production, whereas at proton accelerators the muon beams are derived from the decay-in-flight of π-mesons produced in the primary proton interaction. The SLAC muon beams will originate from a highly localized source which, just as in optical beams, allows for improved resolution at the detector. Furthermore, the contamination of π-mesons in the beam can easily be held to 1 in 10^7 muons – a very important feature because the π's are strongly interacting. The muon beam at SLAC is derived from the electrons hitting a copper target followed by a filter which contains 16 attenuation lengths of beryllium. The muons will degrade in energy by 15% and multiple scatter (this somewhat increases the effective source size but not seriously) whereas the pions are reduced in intensity by a factor of 3×10^{-7}. Furthermore, this number can be made almost arbitrarily small by adding more filter material.

A quasi monochromatic beam of gamma rays is being developed at SLAC. This is made possible by the positron intensity which is expected to be approximately 10^{10}/pulse at energies up to two-thirds of the machine energy, or 14 GeV. When these positrons hit a hydrogen target three major reactions will take place, namely, annihilation-in-flight, bremsstrahlung from protons, and bremsstrahlung from electrons. The predominant final state from annihilation is two photons and the kinematics of this reaction leads to the following relation between angle and energy

$$\theta_1^2 = \frac{2m_e(E_o - k_1)}{k_1 E_o}$$

where θ_1 is the angle at which gamma ray 1 is emitted in the laboratory and k_1 is its energy. E_o is the energy of the incoming positron.

A detailed calculation of the shape of the gamma spectrum has been done by Ballam et al.[5] and Dufner et al.[6] A typical spectrum is shown in Fig. 11. The width of the annihilation peak can be adjusted by collimation and in practice could be as small as ±0.3% of the value at the peak. At this width the calculated intensity is 100-300 photons per pulse inside the band depending on the positron intensity available.

A calculation made by Drell and Berman[7] predicts a useful flux of high energy neutral particles, both anti-neutrons and K^0 mesons. These, of course, are also produced at proton accelerators, but are usually accompanied by a very large number of neutrons in the forward direction which make up an extremely difficult background. The nature of the production of these particles by electrons reduces this neutron background by a factor of about 100 and makes a whole new class of experiments possible.

The Experimental Program

Elastic electron-proton scattering, in order to examine further the electromagnetic structure of the proton, will be one of the first experiments done at SLAC. This is an obvious and necessary extension of the fundamental work done by R. Hofstadter at Stanford and extended later to higher energies by groups at Cornell, the Cambridge Electron Accelerator, and most recently at DESY, the 6 GeV electron synchrotron in Hamburg, Germany. A review of the work done in this area has been given by R. Wilson[8] and supplemented more recently by W. Albrecht.[9] In general the scattering process has been described by the Rosenbluth formula for the differential cross section given as:

$$\frac{d\sigma}{d\Omega} = \sigma_{ns} \left\{ \frac{G_E^2 + \frac{q^2}{4m^2} G_m^2}{1 + \frac{q^2}{4m^2}} + \frac{2q^2}{4m^2} \left(\tan^2 \frac{\theta}{2} \right) G_m^2 \right\}$$

where σ_{ns} is the ordinary nucleon scattering cross section (point charge)

q is the four-momentum transfer to the proton

θ is the scattering angle

and G_E and G_m are the electric and magnetic form factors respectively of the proton.

G_E and G_m are the quantities which are to be studied by the experiment assuming the Rosenbluth formula is a good approximation. These quantities depend on q^2 and the object is then to measure their behavior at larger and larger values of q^2 where

$$q^2 = 4P_oP \sin^2 \frac{\theta}{2}$$

Here P_o and P are the incident and scattered electron momentum respectively. The cross sections and the corresponding values of the form factors drop rapidly with q^2 so that, based on what is presently known, these become typically, at $q^2 = 16\ (\mathrm{BeV}/c)^2$, of the order of $7 \times 10^{-36}\ \mathrm{cm}^2/\mathrm{sr}$ and it is a remarkable property of the SLAC accelerator that even at this value counting rates of 2-3 per hour can be expected.

Another facet of the scattering problem is to compare e^+p scattering with e^-p. Most of the theoretical predictions of ep scattering are based on the assumption that only one photon gets exchanged in the process, (first Born approximation). This is partially so because most experimental results corroborate this assumption and partially because some of the two photon exchange diagrams have not yet been calculated. One way to resolve this experimentally is to measure the ratio

$$R = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{e^-} - \left(\frac{d\sigma}{d\Omega}\right)_{e^+}}{\left(\frac{d\sigma}{d\Omega}\right)_{e^-} + \left(\frac{d\sigma}{d\Omega}\right)_{e^+}}$$

If R is exactly equal to zero then the two photon processes are non-existent whereas a deviation from zero is a measure of their contribution. At the present time a certain discrepancy exists in the literature as to the value of R – in part because of the difficulty in getting intense positron beams. At SLAC one can redo previous experiments with only a few hours running time and get high accuracy ($\approx 1\%$). Furthermore, a two photon contribution, if it exists, can be traced out to higher values of q^2.

Both kinds of scattering experiments have been scheduled on the 8-GeV/c spectrometer which will be the first of three to be ready.

Photoproduction experiments are scheduled for both the 20 GeV spectrometer and the streamer spark chamber. In both cases a bremsstrahlung beam will be formed by letting the main electron beam hit a thin radiator in the beam switchyard and then deflecting the electron beam downward into an energy absorbing device called a "beam dump." The gamma rays go straight ahead and into a target in the end station.

The spectrometer will be used to examine single photoproduction as a function of q^2 and incoming photon energy (the peak of the bremsstrahlung spectrum). Since this is a difficult energy difference experiment, it again depends on precision measurements to isolate by kinematics alone processes such as

$$\begin{aligned} \gamma p &\to \pi^o p \\ &\to \pi^+ n \end{aligned}$$

which are related to πp scattering.

There is also scheduled an experiment to measure the photoproduction of anti-protons ($\bar{p}$), which would be a first look at baryon exchange in this kind of reaction. Counting rates as high as several per minute for 15 GeV $\bar{p}$ in a momentum range of 1% are expected.

The more complicated events in photoproduction will be studied with the streamer spark chamber. Reactions such as

$$\gamma p \rightarrow \rho + p$$

$$\rightarrow \omega + p$$

as well as an initial survey of multibody final states will be attempted.

A more specific experiment to look at ρ^0 production in great detail has been proposed to be done in the monochromatic photon beam described above. Using the knowledge of the properties of the incoming photon, it is now possible to do an experiment with photons similar to that which has been done with pions. The process being studied is $\gamma p \rightarrow \rho^0 + p \rightarrow \pi^+ + \pi^- + p$ as well as γ + nucleus $\rightarrow \rho^0$ + nucleus. A schematic view of the experiment is shown in Fig. 12. First it demands that no charged particle initiate the reaction, and then that two charged particles appear in the forward direction. The momentum of each is measured as well as the included angle. This is enough to see by reconstruction whether they are a single particle of given mass. The reason for doing the experiment with nuclei as well as protons is to see if at high energies they continue to be produced in a diffraction-like process. Such a production mechanism has been inferred from observations at lower energies.

An interesting experiment has been proposed in which photoproduction of strange particles will be studied by looking at particles emitted backwards. This, of course, is one reason why a relatively low energy device like the 1.6 GeV/c spectrometer is being built. In two-body reactions such as

$$\gamma + p \rightarrow K^- + \Lambda^0$$

$$\rightarrow K^+ + Y^{*-}$$

the K is emitted backward. If one looks near 180 degrees in the center-of-mass, the momentum of the K particle is typically $M_p c$ ($\approx$1 GeV/c) or less – a very good match to the spectrometer. Such momenta can be measured with great relative precision and together with an angle measurement enable one to predict the "missing mass" of the reaction. Thus, if a resonance is being produced, it can be detected in this fashion.

In connection with the design of an rf-separated beam described earlier, there is a proposal to do an initial survey of particles emitted at small angles when the electron beam hits a beryllium target. This would provide a rough measure of the yields of K mesons and protons in the momentum range 10-15 GeV/c and also measure the distribution in time and momentum of all secondary particles produced at the target. This latter measurement will be done using a dynamic crossed field electron-multiplier (DCFEM), a device initially invented at the University of Illinois and developed further at the Lawrence Radiation Laboratory. This device consists of two plane parallel electrodes with a dc magnetic field parallel to the electrodes and a microwave electric field perpendicular to them. The frequency of this microwave is tuned to the accelerator frequency. One of these surfaces is a secondary emitter. Thus when light from a Cerenkov particle detector hits the photocathode of the DCFEM and if the electric field is in the direction to pull the electrons from the surface, they will progress in cycloid fashion down the electrode multiplying as they go. They are then collected through a hole at the end. If, on the other hand, the Cerenkov light is emitted out of phase with the electric field, nothing happens. Thus, since particles will be emitted from the target in phase with the microwave structure of the accelerator and with each other, the phase with which they arrive at the detector then depends on their velocity (momentum), so the detector is a velocity selector. On the other hand if, by means of magnetic analysis and Cerenkov counters, particles having only given velocity are selected from the target, the DCFEM will measure the time structure of the accelerator itself. These kinds of information are necessary in the design of an rf separator which depends critically on the sharpness of bunching in the accelerator beam itself.

One of the first efforts at SLAC will be an experiment to search for new particles. According to the Bethe-Heitler theory of electro-magnetism, any particle having either or both electric charge and magnetic moment can be created in pairs from the field quantum (photon). The cross section for this process falls inversely as the fourth power of the mass so that electron-positron pair production is by far the predominant process. However, at SLAC intensities it is possible to see a "long" lived ($>10^{-9}$ sec) beam particle in a background of 10^6 muons per particle. These may never have been observed at proton accelerators because all experiments reported have concerned themselves with particles either made in strong interactions or decayed from such particles. If a new particle had only weak or electro-magnetic interaction it would not have been seen. The cosmic radiation on the other hand could contain such particles, but previous experiments would not have detected them in as small a ratio to say muons as is claimed above.

The muon beam described before will be used for an extensive survey of muon-proton elastic and inelastic scattering. The existence of the muon is an outstanding puzzle in high energy physics since a whole series of experiments has failed to show any difference between it and an electron except that the former is about 200 times heavier and that each has its own peculiar associated neutrino. At SLAC the exploration of the muon will continue by comparing electron and muon scattering at high energies. Furthermore, at energies where no detectable difference exists, the muon is inherently a better nucleon probe than the electron since it does not radiate much energy when accelerated. The calculation of the so-called "radiative" corrections of electron scattering are both difficult and tedious.

The muons will be scattered in an 80-inch liquid hydrogen target and the momentum will be measured by the magnet previously described. A sketch of the experimental arrangement is shown in Fig. 13. The beam momentum can be measured to within 2% at 10 GeV/c and the muon is identified by its range or lack of interaction in a thick plate spark chamber and iron slab. The elastic events can be isolated by looking at the recoil proton in the opposing spark chamber.

The main limitation is, of course, beam intensity, but at SLAC this is high enough so that cross sections of several microbarns can be measured in a reasonable time. For example, some 100,000 inelastic events are expected in several hundred hours of running time.

The bubble chambers are scheduled for operation during the last half of 1967 and specific experiments have not yet been approved. However, the general program for the first year's operation will be a study of interactions of high energy π's, K's and $\bar{p}$'s via the separated beam into the 82-inch HBC and a study of interaction of photons via the monochromatic gamma beam into the 40-inch HBC.

Figure 14 shows a plan view of the experimental layout of the currently approved program which is just getting underway. It is hoped that it will be in full swing by the spring of 1967.

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LIST OF FIGURES

1. Photograph of the massive supports for the three spectrometers in position in End Station A. The first magnet can be seen placed in the 8 GeV frame. The tube seen in the center of the photo is an evacuated beam pipe proceeding toward a "dump" outside the far end of the building. The tracks on which the spectrometers will rotate can also be seen.
2. An isometric drawing of the 8 GeV spectrometer with magnets in place. The Q's are quadrupole magnets and the B's are bending magnets. Dimensions are in meters.
3. A similar drawing for the 20 GeV spectrometer.
4. An artist's drawing of the 1.6 GeV spectrometer. The detectors are buried in the cube of shielding at the top.
5. An isometric drawing of the magnet in which the streamer chamber will be placed. Note the hollow pole on the top which can be filled with an iron piece in case stronger fields are desired.
6. A photograph of the streamer chamber magnet iron in place in a building placed behind End Station A. The copper coils have not yet been installed. This whole assembly can slide in and out of the electron beam.
7. A photograph taken of the streamers in a magnetic field by an electron-positron pair in one of these chambers. Note the structure of the tracks and the dense apparent ionization left by the delta ray at the beginning. The bottom of the photo shows a side view of the event.
8. An isometric drawing of a magnet to be used with conventional spark chambers. It has the same general flexibility as the streamer chamber magnet.

9. Assembly drawing of the SLAC 40'' hydrogen bubble chamber which will use "scotchlite" retrodirective optics and a sealed-off hydroformed bellows expansion.

10. A photograph of the 40'' chamber magnet taken from the beam exit side. The magnet is shown in its open position. The vacuum tank and the chamber can also be seen in place.

11. A typical gamma spectrum from a positron-hydrogen atom collision at a fixed angle. k is photon energy, k_a is the 2γ annihilation energy and the point E_0 indicates the incident positron energy.

12. Schematic layout for the ρ^0 production experiment. The tungsten stopper is to absorb forward going μ's and electrons made in the target by the photon beam. The wire spark chambers in this experiment will be provided by LRL and will have magneto-striction readout.

13. Schematic layout of μ-p experiment (elevation).

14. A plan view of the experiments in position in the experimental area.

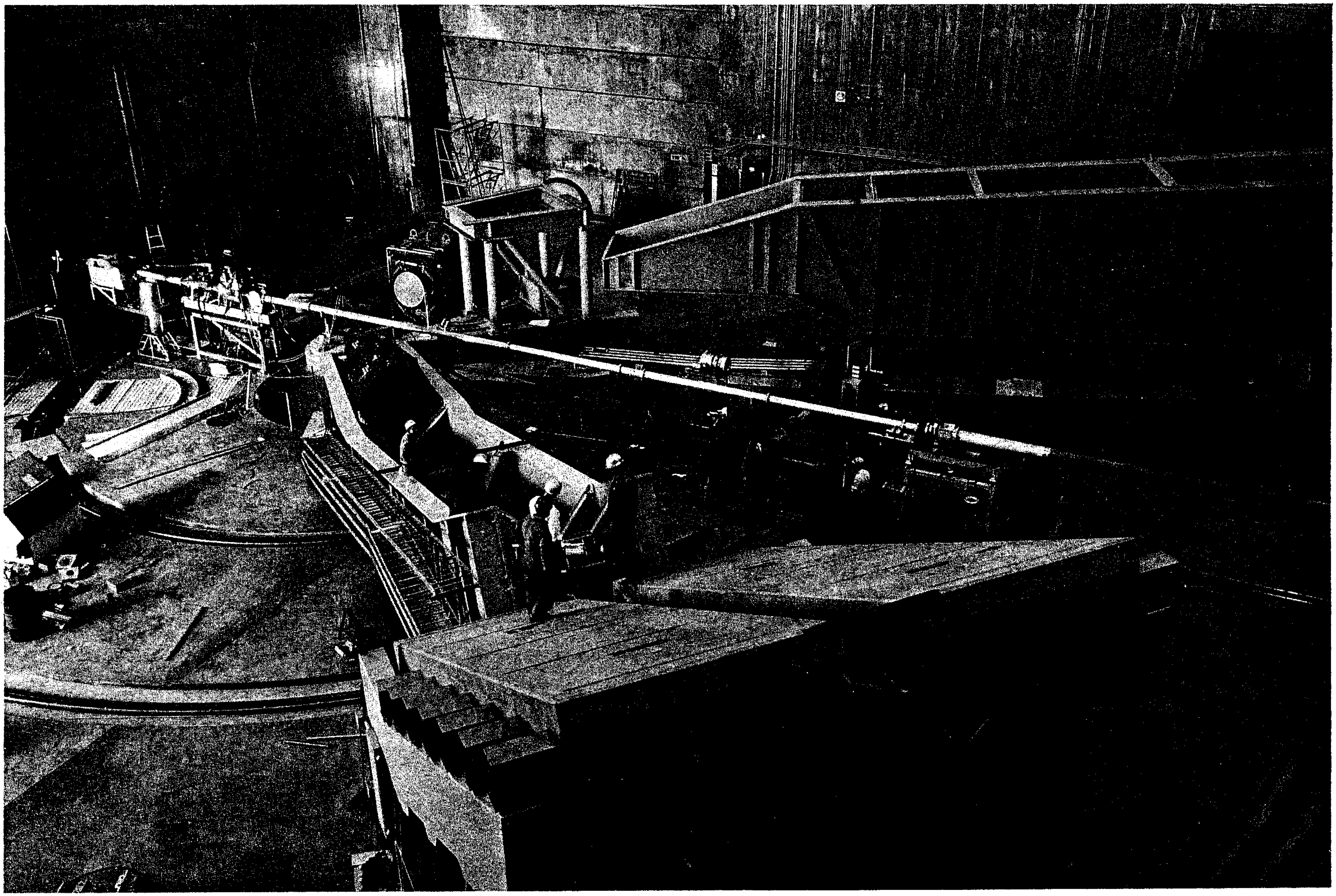
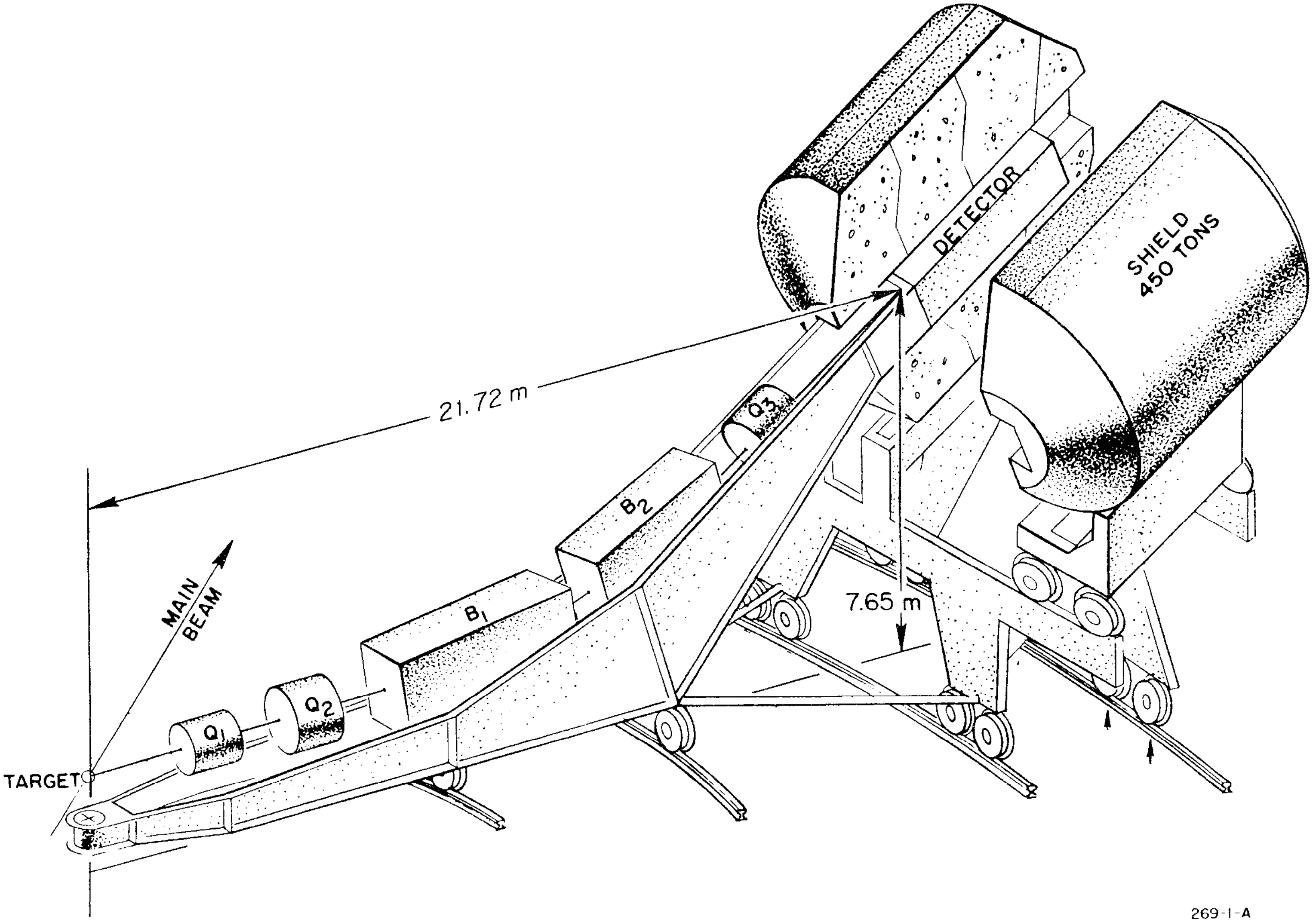


Fig. 1

16 r M3



SHIELD
450 TONS
DETECTOR
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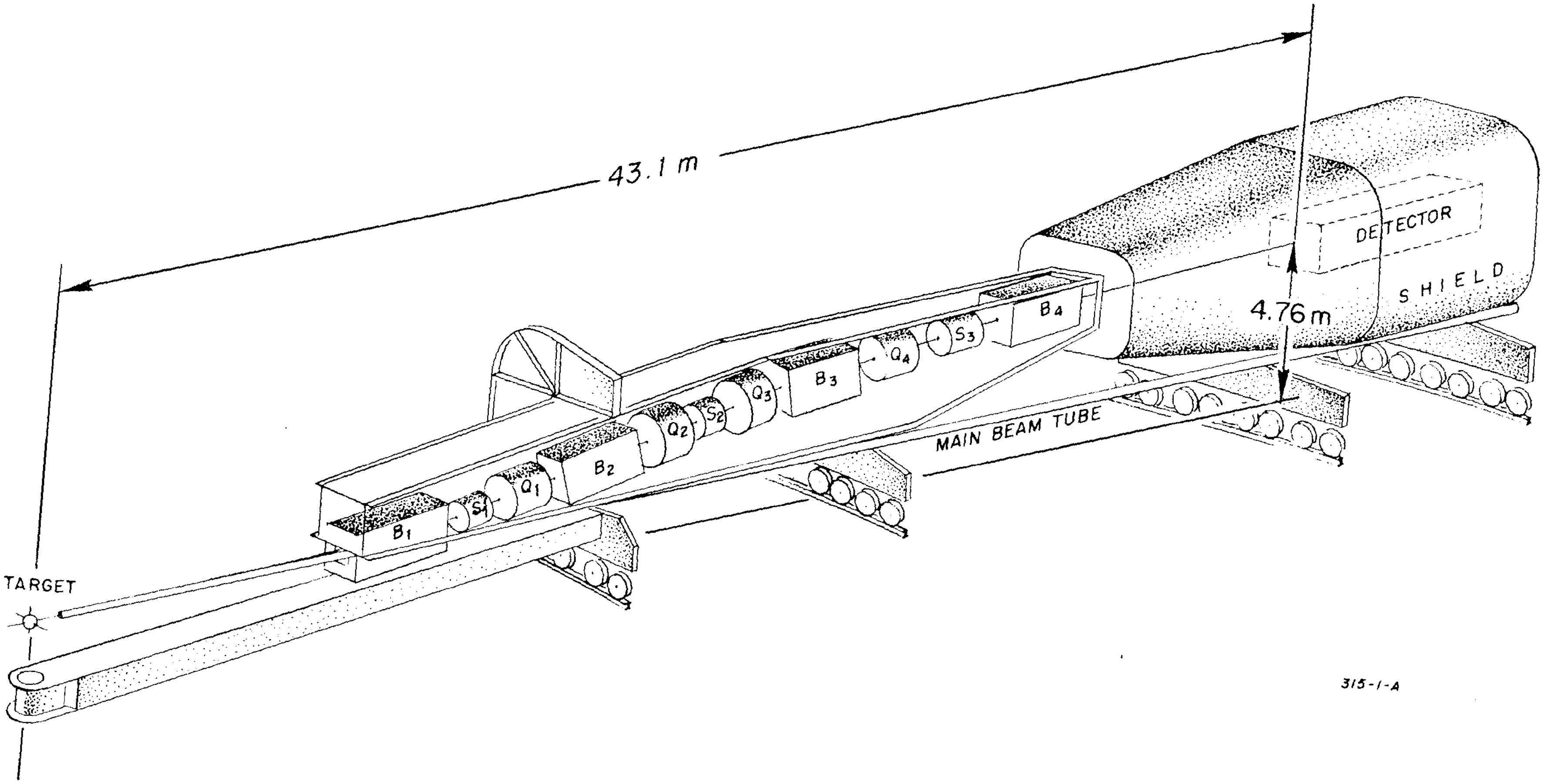
Q3
B2
7.65 m
MAIN
BEAM
B1
Q2
Q1
TARGET
269-1-A

Fig. 2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4.76 m
DETECTOR
SHIELD
B4
S3
Q4
B3
Q3
S2
Q2
B2
Q1
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B1
MAIN BEAM TUBE
TARGET
315-1-A

Fig. 3

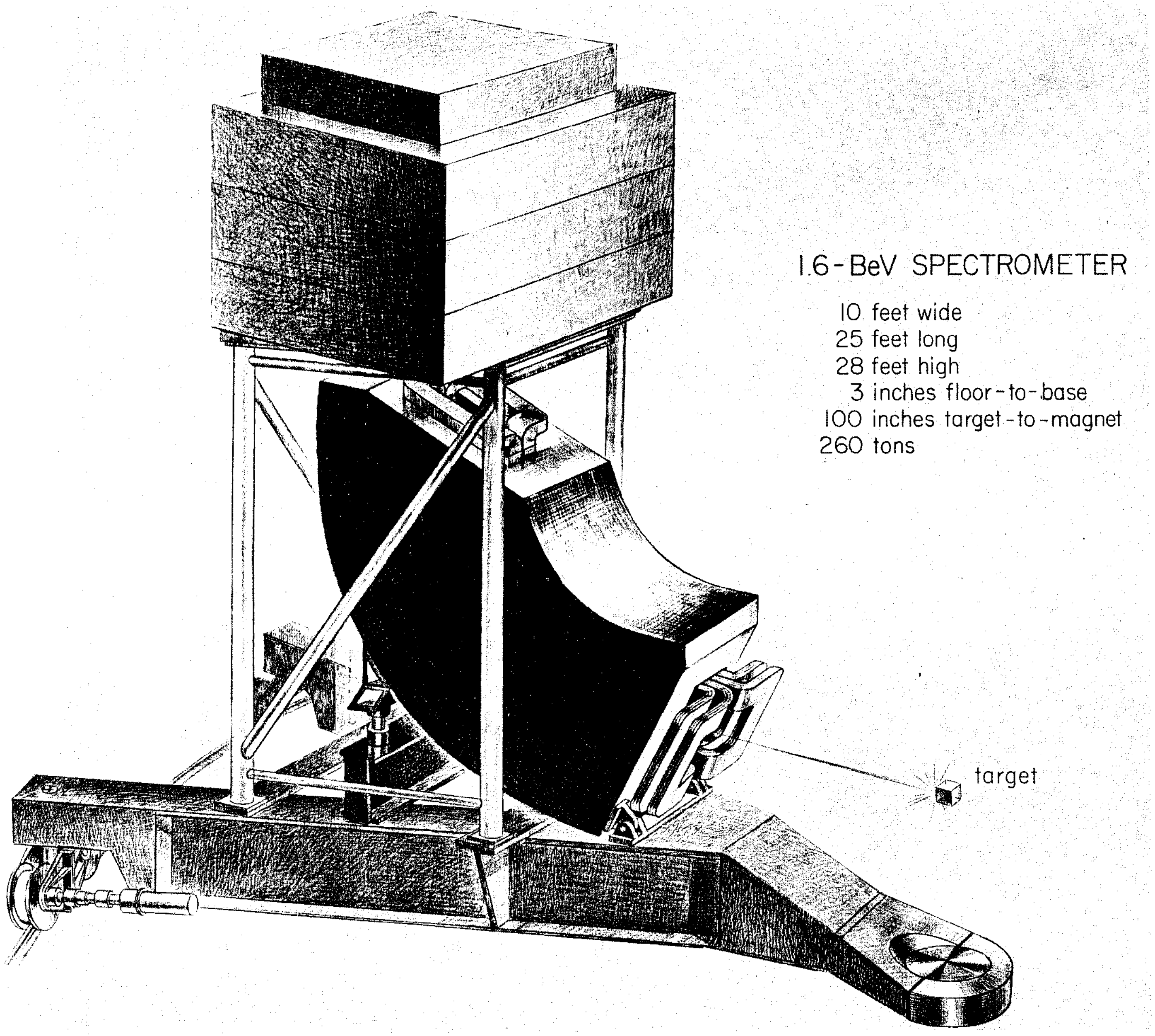
1.6-BeV SPECTROMETER
10 feet wide
25 feet long
28 feet high
3 inches floor-to-base
100 inches target-to-magnet
260 tons
target

Fig. 4

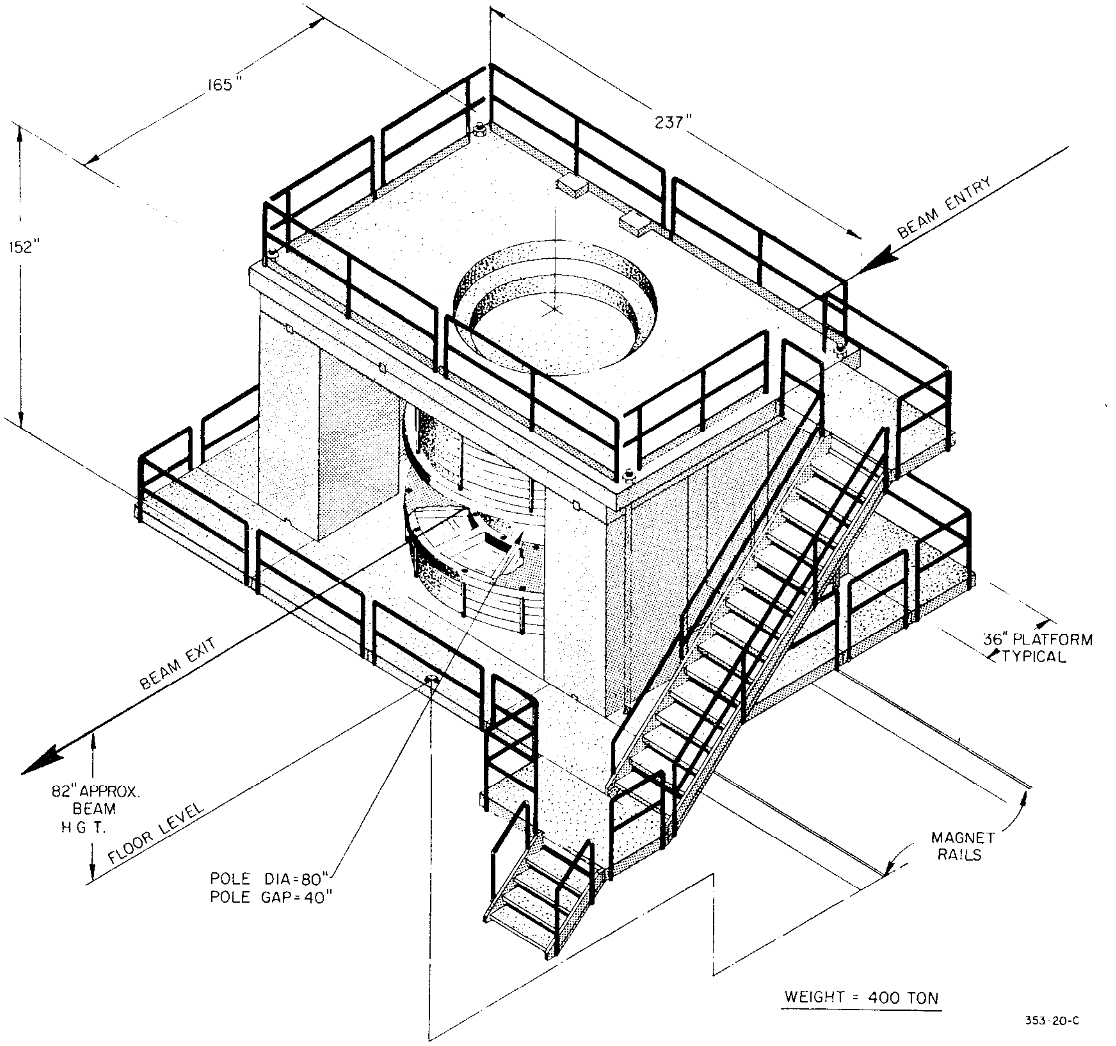
165"
237"
152"
BEAM ENTRY
BEAM EXIT
36" PLATFORM TYPICAL
82" APPROX. BEAM H G T.
FLOOR LEVEL
POLE DIA = 80"
POLE GAP = 40"
MAGNET RAILS
WEIGHT = 400 TON
353-20-C

Fig. 5

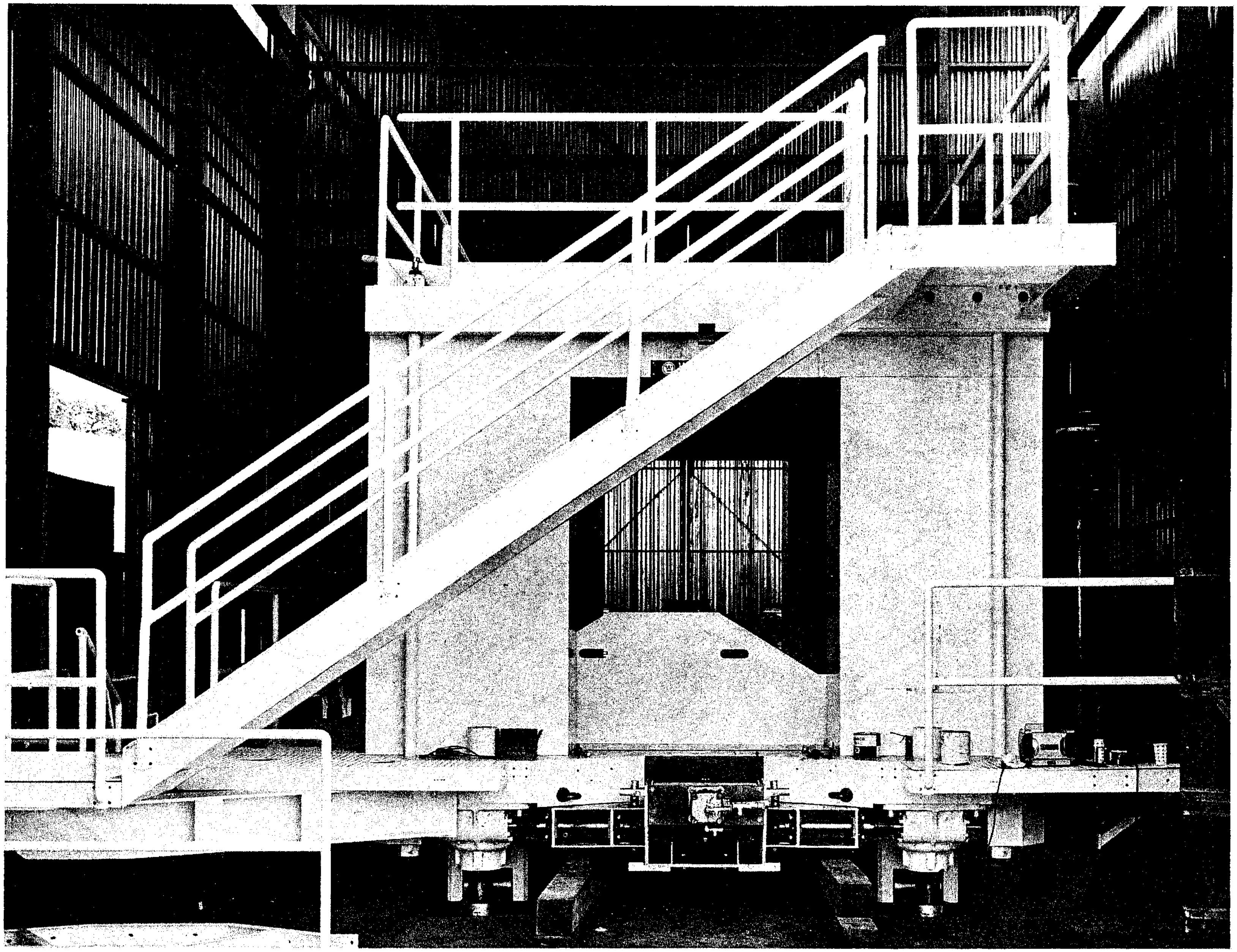

Fig. 6

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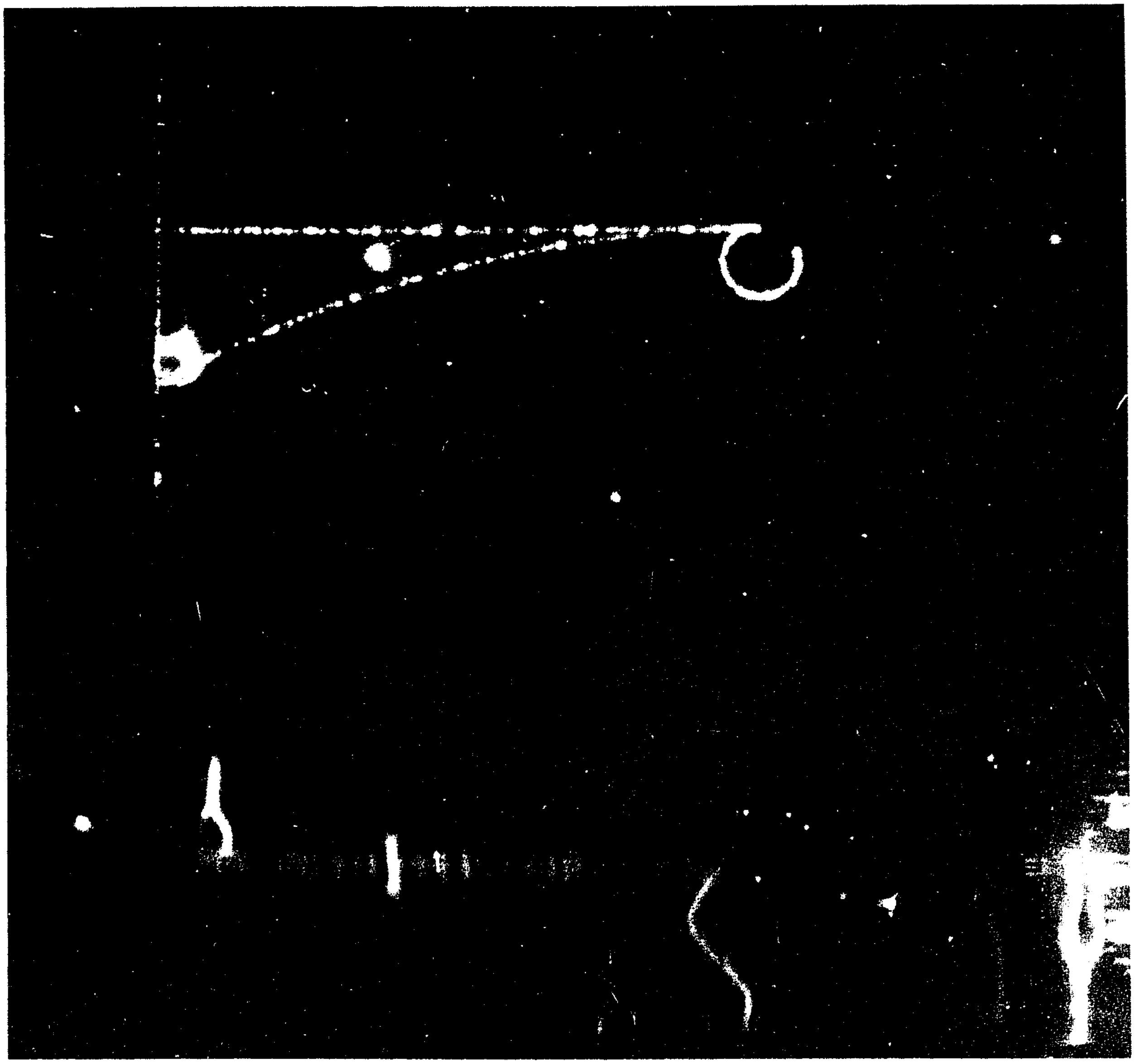

FIG. 7

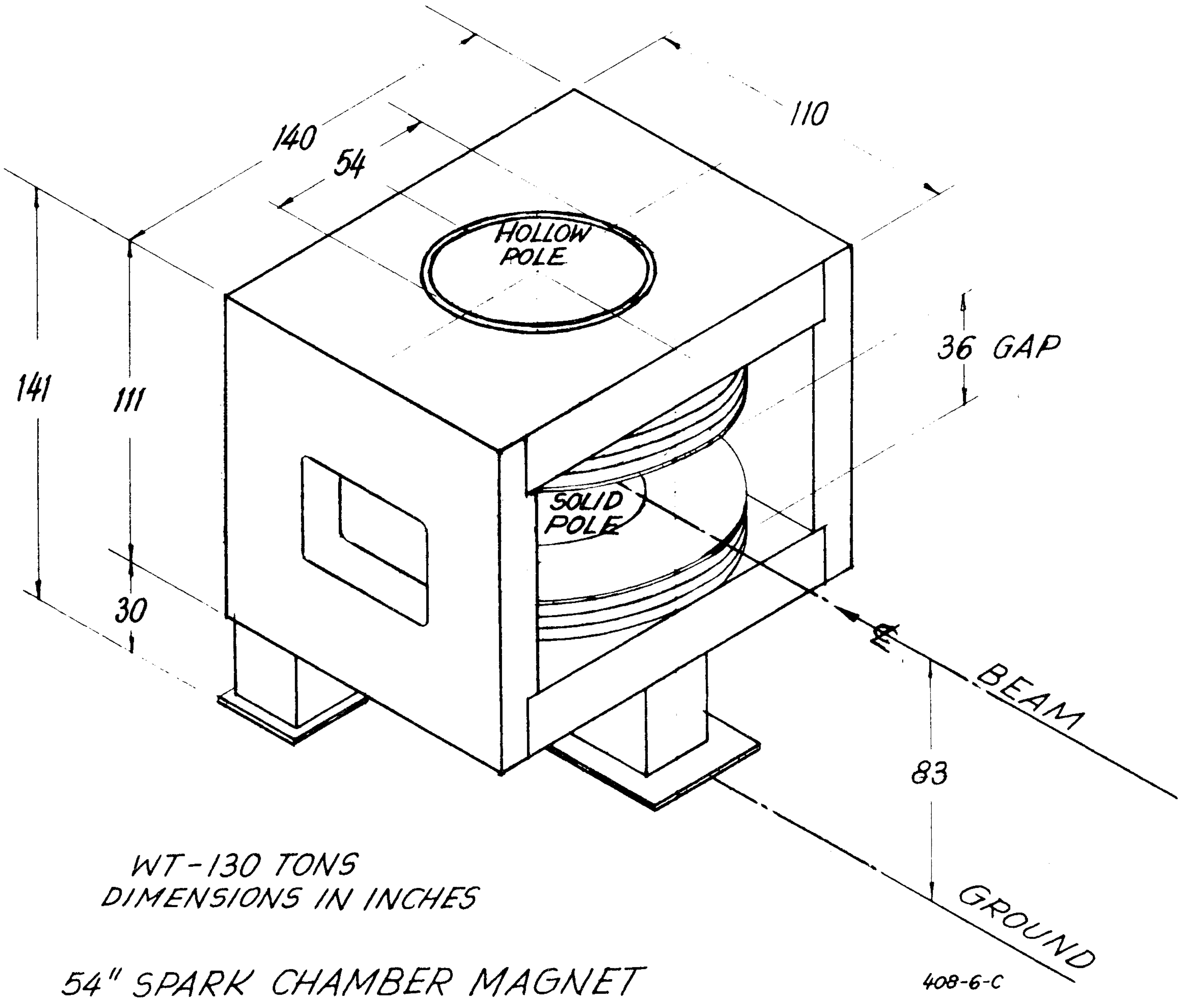
140
54
110
HOLLOW POLE
36 GAP
141
111
30
SOLID POLE
℄
BEAM
83
GROUND
WT-130 TONS
DIMENSIONS IN INCHES
54" SPARK CHAMBER MAGNET
408-6-C

Fig. 8

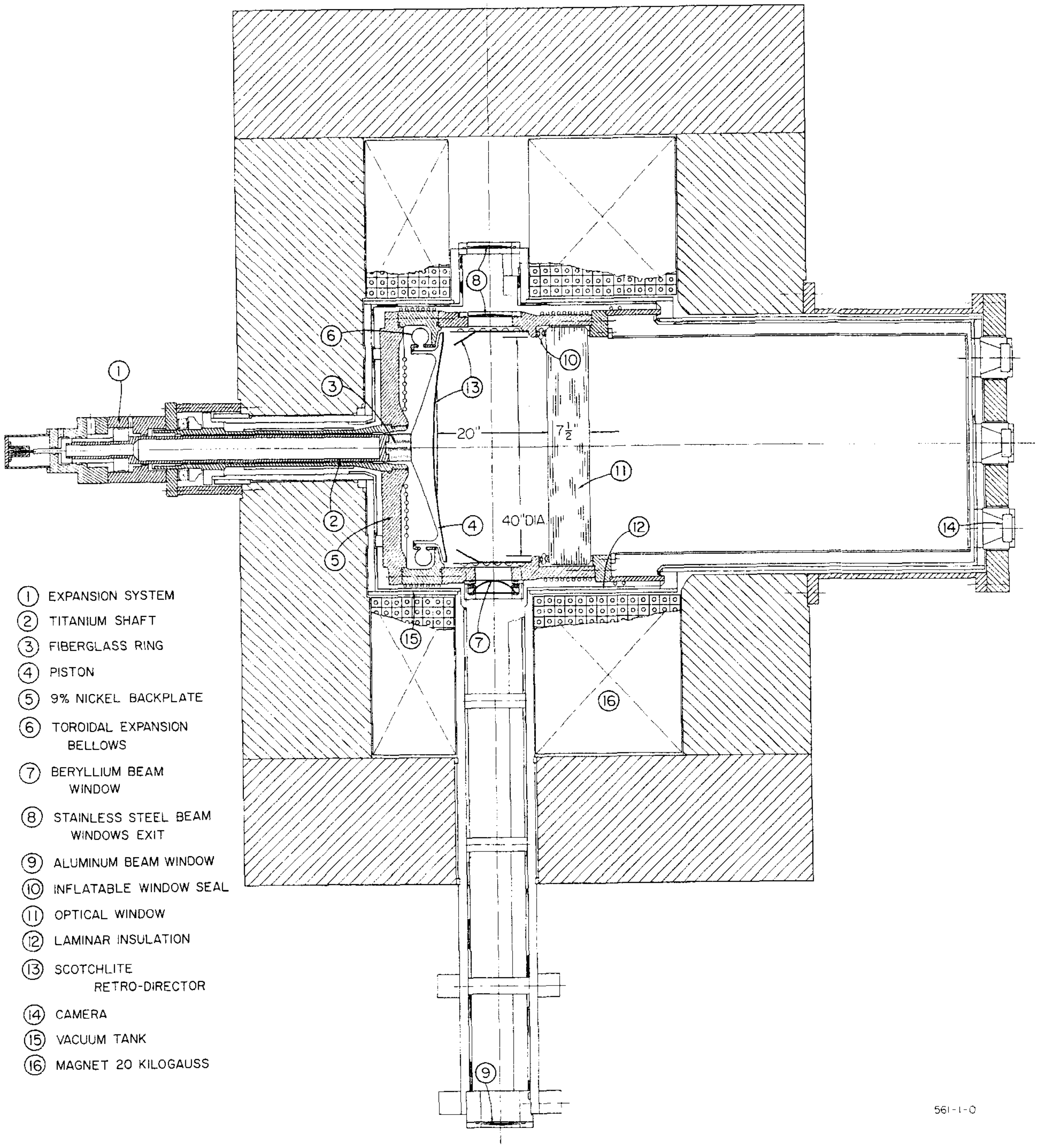
① EXPANSION SYSTEM
② TITANIUM SHAFT
③ FIBERGLASS RING
④ PISTON
⑤ 9% NICKEL BACKPLATE
⑥ TOROIDAL EXPANSION BELLOWS
⑦ BERYLLIUM BEAM WINDOW
⑧ STAINLESS STEEL BEAM WINDOWS EXIT
⑨ ALUMINUM BEAM WINDOW
⑩ INFLATABLE WINDOW SEAL
⑪ OPTICAL WINDOW
⑫ LAMINAR INSULATION
⑬ SCOTCHLITE RETRO-DIRECTOR
⑭ CAMERA
⑮ VACUUM TANK
⑯ MAGNET 20 KILOGAUSS
20"
7½"
40" DIA
561-1-0

Fig. 9

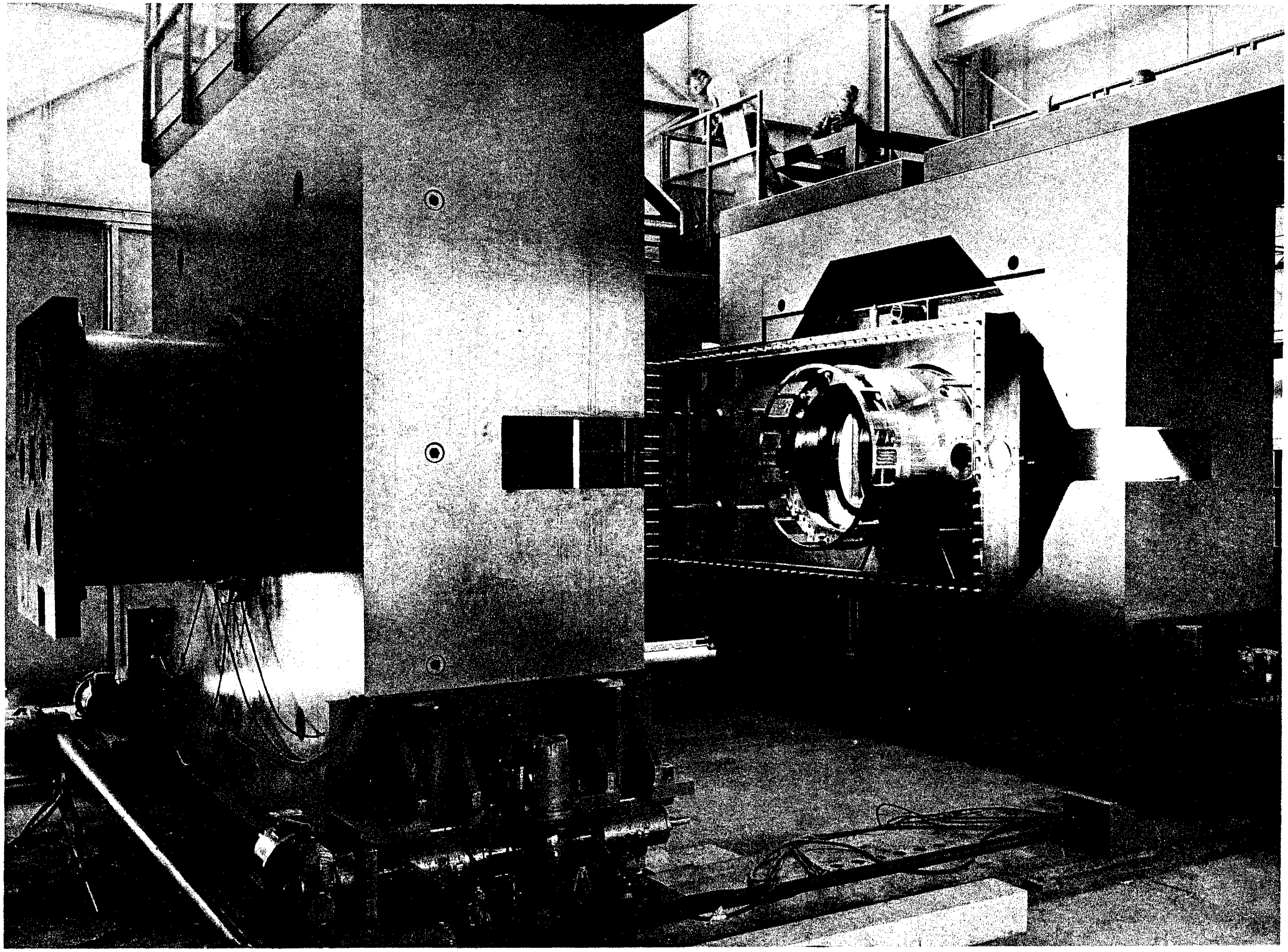

Fig. 10

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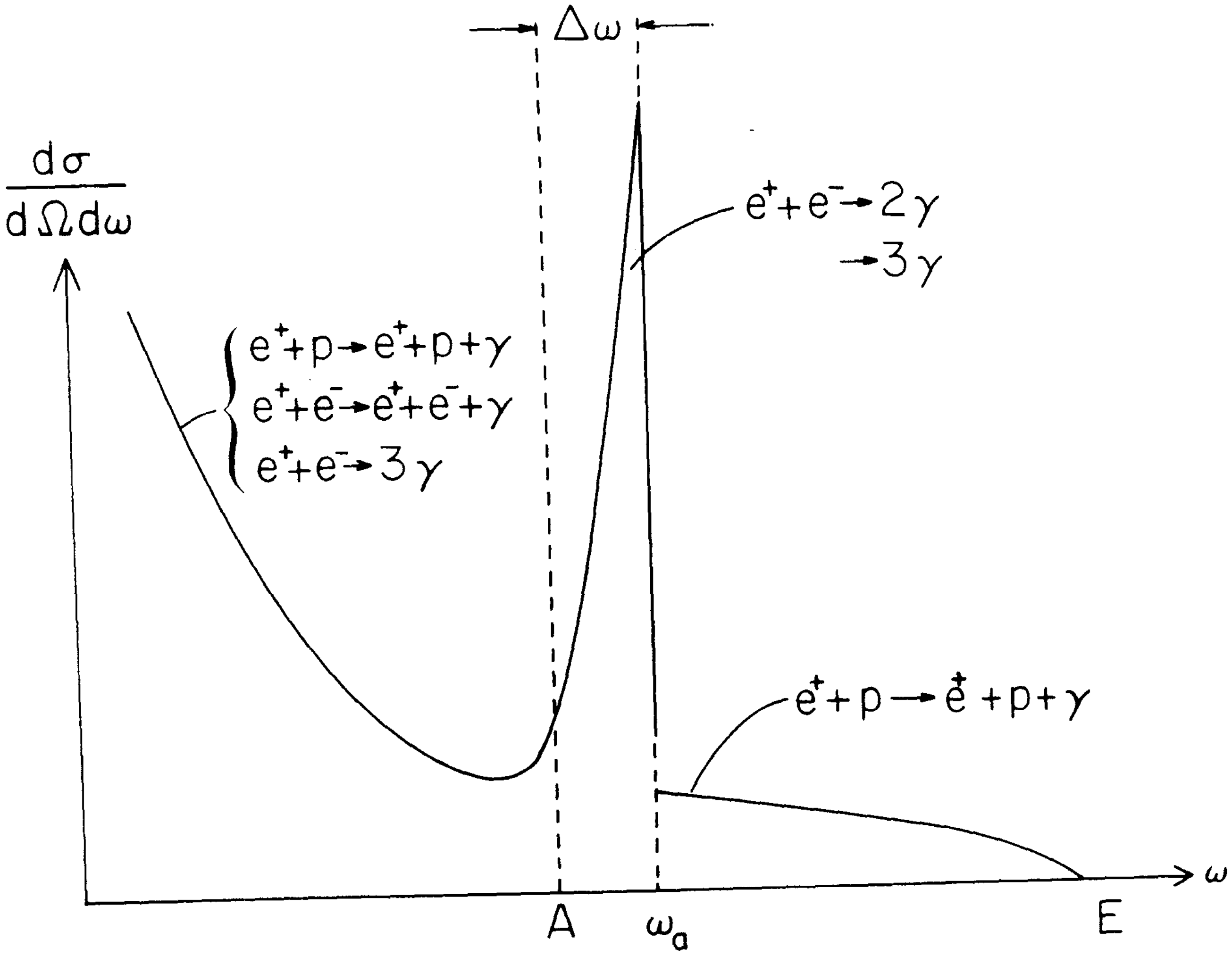
$\Delta\omega$
$\frac{d\sigma}{d\Omega d\omega}$
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$\to 3\gamma$
$e^+ + p \to e^+ + p + \gamma$
$e^+ + e^- \to e^+ + e^- + \gamma$
$e^+ + e^- \to 3\gamma$
$e^+ + p \to e^+ + p + \gamma$
ω
A
ω_a
E
309-1-A

Fig. 11

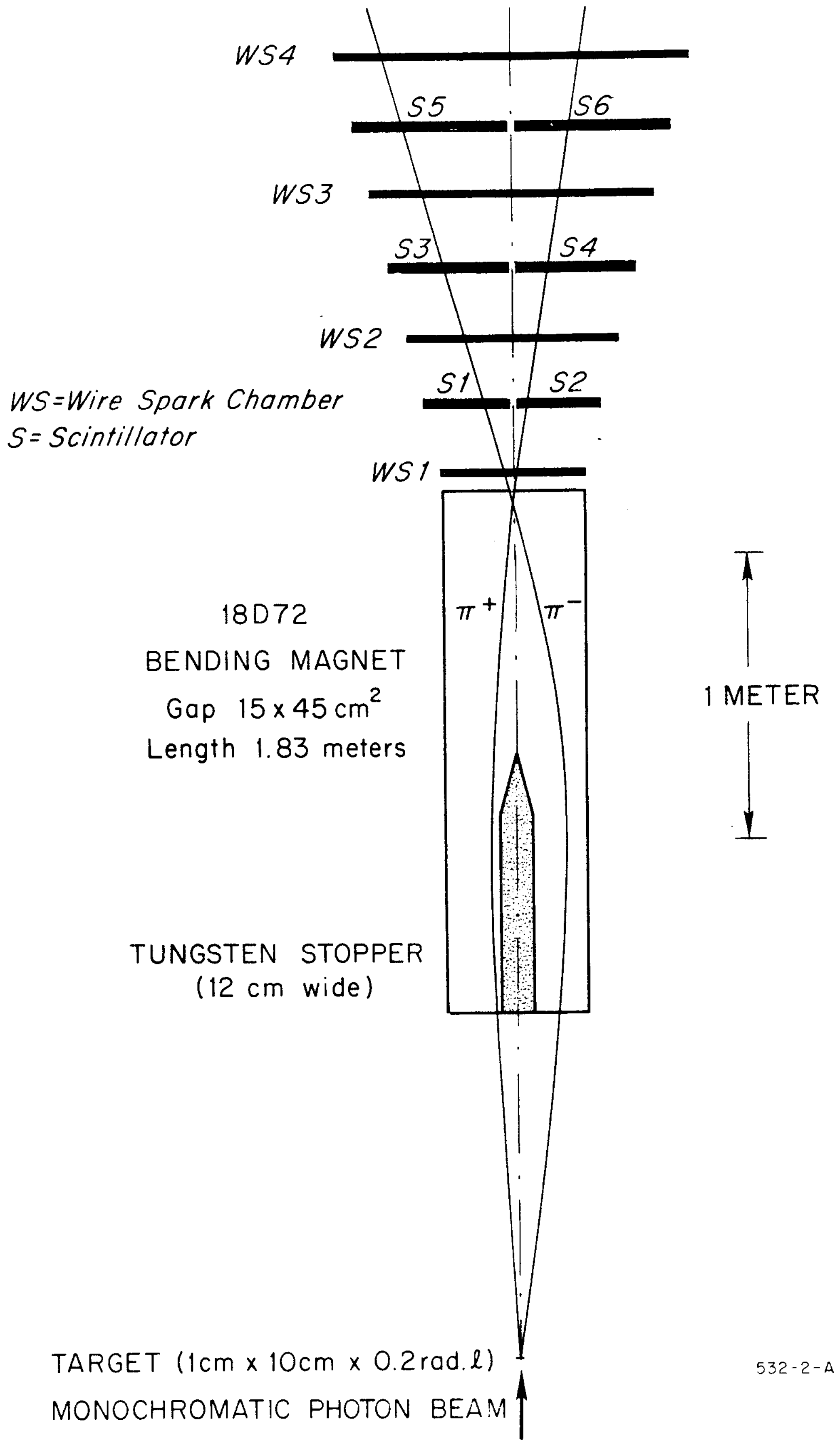

WS4
S5
S6
WS3
S3
S4
WS2
S1
S2
WS=Wire Spark Chamber
S= Scintillator
WS1
18D72
BENDING MAGNET
Gap 15 x 45 cm^2
Length 1.83 meters
π^+
π^-
1 METER
TUNGSTEN STOPPER
(12 cm wide)
TARGET (1cm x 10cm x 0.2rad.ℓ)
MONOCHROMATIC PHOTON BEAM
532-2-A

Fig. 12

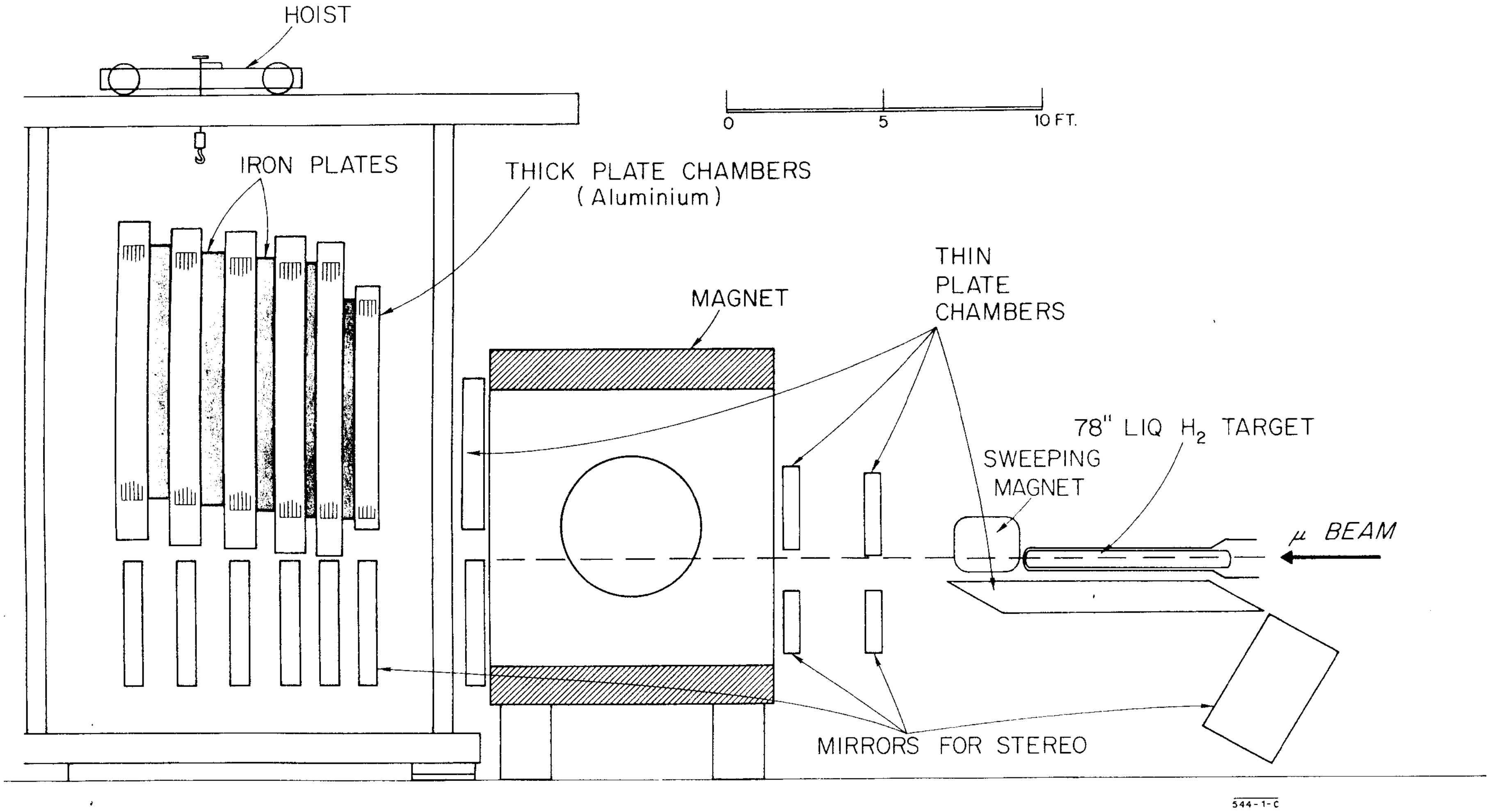
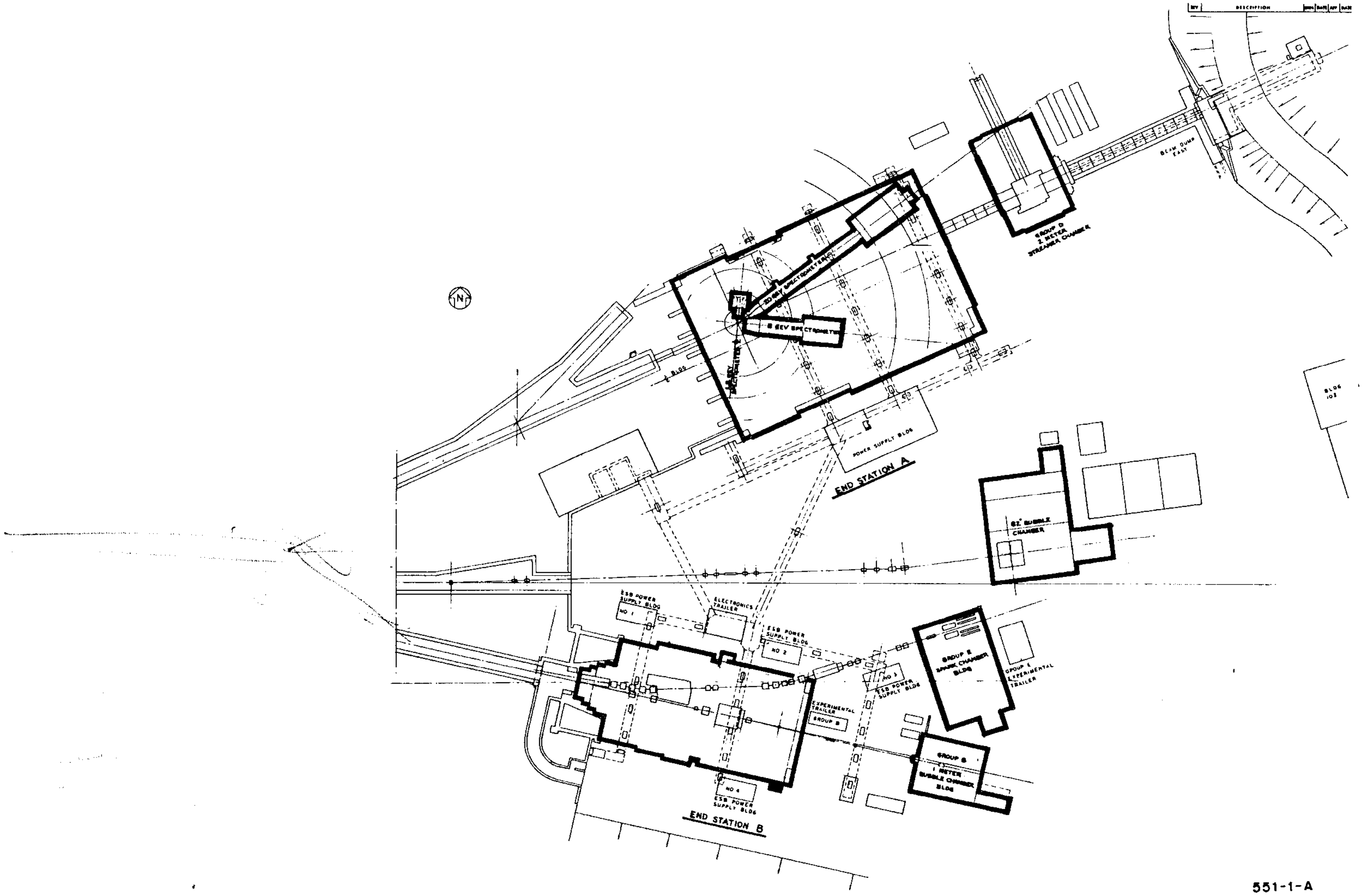

HOIST
0
5
10 FT.
IRON PLATES
THICK PLATE CHAMBERS
(Aluminium)
MAGNET
THIN
PLATE
CHAMBERS
78" LIQ H_2 TARGET
SWEEPING
MAGNET
μ BEAM
MIRRORS FOR STEREO
544-1-C

Fig. 13

M204-2


N
20 GEV SPECTROMETER
8 GEV SPECTROMETER
1.6 GEV SPECTROMETER
BLDG
POWER SUPPLY BLDG
END STATION A
GROUP D
2 METER
STREAMER CHAMBER
BEAM DUMP
EAST
BLDG
103
82" BUBBLE
CHAMBER
ESB POWER
SUPPLY BLDG
NO 1
ELECTRONICS
TRAILER
ESB POWER
SUPPLY BLDG
NO 2
NO 3
ESB POWER
SUPPLY BLDG
GROUP E
SPARK CHAMBER
BLDG
GROUP E
EXPERIMENTAL
TRAILER
EXPERIMENTAL
TRAILER
GROUP B
GROUP B
1 METER
BUBBLE CHAMBER
BLDG
NO 4
ESB POWER
SUPPLY BLDG
END STATION B

551-1-A

Fig. 14