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# NPAS USERS GUIDE

Stanford Linear Accelerator Center
Stanford University
Stanford, California 94305

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# I. GENERAL INFORMATION

## 1. INTRODUCTION

This *NPAS* Users Guide is primarily intended as a source of information about policies, procedures, and facilities appropriate for users in the program of Nuclear Physics at *SLAC* (*NPAS*). It is a supplement to the *SLAC* Users Handbook, first issued in the 1960's and maintained through 1973. As with all rapidly changing fields of research, the information in this book is correct as of the date of publication (January 1984), but can become out of date. For further information about the actual status of the *NPAS* program, the *SLAC* facilities, or the schedule, contact the *NPAS* Coordinator or the *SLAC* staff.

## 2. NUCLEAR PHYSICS AT SLAC

*NPAS* is a program of nuclear structure experiments at the Stanford Linear Accelerator Center funded by the Department of Energy within the U.S. nuclear physics program. It is based on the availability of an intense electron beam in the energy range 0.5 to approximately 6 GeV. This beam is produced using an off-axis electron gun and in-line injector, the Nuclear Physics Injector (*NPI*), installed at a point 6 sectors from the downstream end of the *SLAC* linac. The maximum intensity of this beam is larger than that available from the full 30 sector linac when operated in the energy range below 6 GeV due to the decreased effects of beam breakup in the shorter accelerator. The nuclear structure measurements are carried out using the facilities of *SLAC* End Station A.

The *NPAS* program is administered by the Associate Director, *SLAC* Research Division, with the assistance of the *NPAS* Coordinator. A Nuclear Program Advisory Committee (*NPAC*) is primarily responsible for program decisions. The Chairman of the *NPAC* advises the Associate Director of program decisions, and the Associate Director has final power of approval. The *NPAS* program is open to competitive proposals from all qualified experimenters. The nuclear structure experiments are carried out within the financial constraints of the *NPAS* budget, and within the constraints of *SLAC*'s resources and operating schedule.

## 3. GENERAL POLICIES AND PRACTICES

### 3.1 National Facility

The Stanford Linear Accelerator Center is a National Facility maintained and operated by Stanford University under contract to the U.S. Department of Energy. The contract with the *DOE* provides, among other things, that Stanford will operate *SLAC* as a National Facility for the purpose of pursuing a vigorous, forward looking research program in high energy physics; that it will support and accommodate scholars from other institutions as well as those from the University to utilize the National Facility to the fullest extent; that scientific priority should generally govern the allocation of machine time for carrying out experiments; and that scientists from other laboratories and institutions participate in the deliberations regarding allocation of machine time and laboratory resources. There is a Scientific Policy Committee (*SPC*), including scientists from *SLAC* and other institutions, to advise the President of Stanford University who in turn reports to the *DOE* on the performance of *SLAC* in its role as a National Facility. The *SPC* meets regularly to review the plans, activities, and policies of *SLAC*, to hear reports from *SLAC* staff, users, and others interested in the operation of *SLAC*. A major concern of the *SPC* is to ascertain that the facilities of the Accelerator Center are made available to qualified scientists from other institutions as well as Stanford University, subject only to the quality and productiveness of the research program.

### 3.2 Scheduling Policies

This is a description of policies and procedures of the *NPAS* program for scheduling the assignment of beam time of the accelerator, of the major facilities, and of the major pieces of apparatus available for general use. The *NPAS* program operates within the *SLAC* high energy physics program with respect to scheduling policies and procedures. The *NPAS* program decisions are made by the Nuclear Program Advisory Committee (*NPAC*), while the Associate Director, Research Division, maintains final power of approval. The scheduling of beam time for *NPAS* experiments is done by the *SLAC* Director with the assistance of the Program Coordinator and the Program Scheduling Officer. In general *NPAS* experiments will be conducted within the constraints of the overall *SLAC* schedule. Running time for approved nuclear physics experiments will be scheduled some months in advance.

The major facilities available to the *NPAS* program are :

1. End Station A
2. End Station A Counting House
3. The 1.6 GeV spectrometer
4. The 8 GeV spectrometer
5. The 20 GeV spectrometer

Major pieces of apparatus include magnets, power supplies, targets, and beam dumps.

A. Nuclear Program Advisory Committee

The *SLAC* Director appoints a Nuclear Program Advisory Committee (*NPAC*) which meets with the Associate Director, Research Division, to assist him in establishing the *NPAS* program commitments for the use of the Accelerator. The

Director also appoints the Chairman of the *NPAC*. The meetings of the *NPAC* are scheduled by the Associate Director and the *NPAC* Chairman. The Director of *SLAC* also appoints an *NPAS* Coordinator, who manages the daily operations of the *NPAS* program. The *NPAC* consists of at least seven members. Appointments to the *NPAC* are for terms of two years and may be extended. The *SPC* and the *DOE* are informed of all changes in the membership of the Nuclear Program Advisory Committee. At each meeting of the *SPC* the Associate Director and the *NPAS* Coordinator may report on all scheduling decisions that may have occurred in the interval between meetings.

B. Categories of Experiments Requiring *NPAC* approval

The various categories of experiments carried out in the Nuclear Physics Program at *SLAC* are described below. The categories which require *NPAC* approval are:

1. Nuclear physics experiments
2. Checkout runs preliminary to approved nuclear physics experiments

C. Proposals for Experiments

Proposals are to be submitted in writing. They may be described at first in a preliminary form, but will normally become more specific after a discussion with the *SLAC* staff and the *NPAS* Coordinator regarding the availability of equipment and the special characteristics of the accelerator. Such informal discussions prior to formal submission of a proposal are strongly encouraged. A detailed proposal will be required before commitments are given for beam time.

Proposals for experiments requiring *NPAC* approval are received by the Associate Director who presents them to the *NPAC* on the next suitable occasion. The *NPAS* Coordinator presents to the *NPAC* information regarding the availability and suitability of the Laboratory's resources for carrying out any particular proposal, as well as relevant information regarding the interaction of the various proposed programs. Proposals will need to be spelled out in sufficient detail to provide a reasonable basis for a decision. The proposals should, in particular, give a quantitative justification for the requested amount of setup, testing, and running time as well as estimates of the *SLAC* services and equipment that will be required. The experimenters will normally be asked to give an oral presentation to the Committee. Only proposals for specific experiments or tests will be considered. There will not be allocations of blocks of time for unspecified use.

D. Criteria for Selection

In making a judgment of the suitability of any particular proposal at a particular time, the Associate Director and the *NPAC* consider, among other factors: (a) the scientific merit of the proposed experiment; (b) the technical feasibility of the proposed experimental method and equipment; (c) the compatibility of the proposed experiment with other experiments which might be accommodated in the same time period; (d) the availability of service manpower (such as engineers, alignment technicians, and rigging crews); (e) the availability of magnets, electrical power, and special equipment; (f) the requirement for accelerator downtime or any other interactions with the total experimental program; (g) the possible complementary features of experiments that could make it desirable to accommodate them together on the schedule (so as, for example, to provide flexibility and backup for the day-to-day scheduling); (h) limitations imposed by the *NPAS* budget and by the *SLAC* operating budget. The competence of a particular group to accomplish a proposed experiment is also taken into account in the deliberations.

Every experiment which is accepted in the program is required to meet *SLAC* safety requirements before it can be installed in the experimental area.

E. Acceptance for the program

All firm decisions to accept or reject a particular proposed experiment are made by the Associate Director with the advice of the *NPAC* at a scheduling meeting of the *NPAC*, and are announced at the meeting. A particular experiment may be discused at several meetings of the *NPAC* before a firm decision is reached. Under normal circumstances the *NPAC* will approve experiments at such a rate that they can be expected to run within one to one and one half calendar years.

An experiment accepted for the long-range operation will normally be assigned a specific amount of running time to be provided in a particular running period. A "running period" will normally be a block of time — which will probably be from two to six months long — during which an experimental area will remain in a fixed configuration. The beginning and end of a running period will be somewhat flexible and will normally be adjusted to accommodate slippage of schedules or current developments in physics. Experiments will, in general, not be scheduled in the order of their submission or of their acceptance.

An experiment may be removed from the schedule for sufficient reason by the Associate Director after consultation with the *NPAC*. An experiment may be rescheduled for a later running period whenever it appears that equipment will not be ready in time for its assigned running period.

F. Records

Records are kept of all experiments proposed to *SLAC* and of the disposition of the proposals. The records include the dates of submission and the dates of acceptance or rejection. For proposals accepted, the records show the amount of beam time assigned and the beam time actually received. These records are reviewed annually with the *SPC*, are transmitted to the *DOE*, and are publicly available at *SLAC*. Submitted proposals are public information and copies are kept in the *SLAC* library.

G. Scheduling Procedures

On the basis of the recommendation of the *NPAC* and the Program Coordinator, the Director of *SLAC* will assign an approved experiment to a particular schedule period. Normally, the experimental program is arranged in large blocks of time called cycles (three to four months), and approved experiments are assigned to particular cycles. *NPAS* beam time may in some cases be made available in a semi-dedicated mode during periods when the high-energy program is not in operation. In other cases the *NPAS* beam may be operated during a regular experiment cycle while other beams are being delivered.

The tentative long-range schedule is prepared by the *SLAC* Scheduling Officer. The tentative intermediate range schedule is prepared by the Experiment Scheduling Office. The short term schedule is prepared and distributed by the Short Term Schedule Coordinator, who also may make adjustments in the light of day-to-day problems. Special test runs are scheduled by the Experiment Scheduling Office subject to approval of the Program Coordinator

H. Categories of Experiments

The various categories of experiments carried out in the *NPAS* program at *SLAC* are described below. These are in addition to the categories of experiments carried out in the high energy physics program, as described in the *SLAC* Users Handbook, Section A.

1. Approved Nuclear Physics Experiments (NE). These are programs which have been submitted to *SLAC* in the form of proposals, studied and recommended by the Nuclear Program Advisory Committee, and approved by the Associate Director. The proposals usually state the beam parameters required to carry out the experiment, the general-purpose and special-purpose equipment needed, and the number of hours of experimental beam time requested.

Generally, an approved experiment is granted a designated number of hours of experimental time (not necessarily the same as the time requested) at a specified pulse repetition rate. Sometimes the approval allocates a fraction of the time requested in order to prove feasibility, with provisions for extending the time after further review of the preliminary results. For the purposes of scheduling and record keeping, approved nuclear physics experiments are designated by the letter "NE" followed by a number (the same number used to identify the original proposal).

2. Checkout runs preliminary to approved experiments (NC). Checkout time for approved experiments can be allocated upon request of the experimenter. The pulse repetition rate will generally be restricted to 20 pps or less. After approval by the *SLAC* Program Coordinator, an attempt will be made to schedule these runs at least 1 to 3 months before they occur. Checkout time is charged against the time allocated to an approved experiment. For recording purposes, these runs will be designated by the letters "NC" followed by the experiment

number.

3. Test of general-use research equipment (NT). Tests of general-use research equipment (e.g., spectrometer optics tests, beamline tests, injector tests) are scheduled upon approval of the *SLAC* Program Coordinator. These runs will usually be scheduled two weeks to three months in advance. Time will be recorded but will not be charged against an approved experiment. For recording purposes, these runs will be designated by the letters "NT" followed by an identifying number.

4. Special short nuclear physics runs (ND). Certain nuclear physics runs of short duration may be scheduled by the NPAS Coordinator, in consultation with the Associate Director, without prior review and recommendation of the Nuclear Program Advisory Committee. In these cases the *NPAS* Coordinator will advise the *NPAC* of these runs at its next scheduled meeting. These runs will generally be scheduled 1 to 3 months in advance. For recordkeeping purposes these runs will be designated by the letters "ND" followed by an identifying number.

5. Parasite runs (NP). A parasite run is defined as one which does not require a primary beam other than that already run for some other approved experiment. The parasite experiment may make use of the primary beam directly or of the secondary beams created by the primary beam; in either case the parasite run should not interfere with the host experiment or with any other experiment in progress. "No interference" includes the requirement that a parasite run should not divert the attention of the control room operators from concentrating on the higher priority experiments underway. Parasite runs can be scheduled 2 to 4 weeks in advance upon approval of the short term schedule coordinator and provided that the necessary auxiliary equipment is available and can be set up without interfering with other approved programs. For record keeping purposes, these runs will be designated by the letters "NP" followed by an identifying number.

I. Execution of Approved Experiments

When a proposal has been approved, it is the responsibility of the staff of *SLAC* and the *NPAS* Coordinator to work with the experimenter for the execution of the experiment. The Experimental Facilities Department (*EFD*) has the responsibility for the design and installation of equipment in the experimental areas. It will also be responsible for operating magnets, targets, and other equipment which is not operated by the experimental group. When an experiment has been approved, *EFD* will assign a beam engineer to work with the experimental group in the execution of the experiment. This engineer will also provide any necessary liaison with other *SLAC* technical support departments.

Since the electron beam can produce lethal levels of radiation, great care is taken to prevent human exposure to dangerous levels. The Radiation Safety

Committee makes rules and establishes criteria for safe operation. An experiment must comply with these rules before it can run. The Health Physics group is responsible for compliance with these rules; it also monitors radiation levels and personnel exposures.

Hydrogen targets are treated as hazardous equipment. Each hydrogen target system must be approved by the Hazardous Experimental Equipment Committee (*HEEC*) before it can be used in an experiment.

Other *SLAC* committees are responsible for electrical safety, earthquake safety, etc.

J. The priority System During Beam Operations

In multiple beam runs, each approved experiment is assigned a rating (i.e, 1,2,3,4, etc.) designating its relative priority in case machine difficulties or other circumstances require that preferential actions be taken. In some instances, priorities are designated on the long or intermediate schedules by the *SLAC* Program Coordinator. Where this is not done, the Short Term Schedule Coordinator will assign relative priorities to ensure orderly and fair operation procedures. It is the responsibility of the Chief Operator to administer the priority system during each operating shift and to make priority judgements affecting the experiments in progress in the light of all available facts.

It should be emphasized that priorities are relative rather than absolute. For example, an experimenter having a given priority should not expect zero interference from all experiments of lower priority. The lower priority experiments are entitled to expect a reasonable amount of operational time to be devoted to establishing, adjusting, and modifying their designated beam parameters. On occasion some of these actions are almost certain to affect the beam quality of the higher priority experiments. It is expected that the affected experimenters will react to these disturbances in a tolerant manner, since they themselves may hope for a like measure of indulgence when the situation is reversed. The Chief Operator is, of course, expected to exert all reasonable efforts to minimize the magnitude and duration of these deleterious effects. If the interactions are extraordinarily long, severe, or disruptive, the Chief Operator may defer or even disallow the beam requirements of the lower priority experiments in order to satisfy the essential requirements of the higher priority experiments.

K. Charging Systems for Experiment Operations

Each approved experiment is allocated a certain number of beam hours for checkout and data taking. At the end of every 8-hour shift, an *Experimenter's Shift Report* is prepared for each experiment during the shift. This report is approved by the responsible experimenter and the *MCC* operator, and is endorsed by the Chief Operator. Care should be taken in the preparation of this report since it is the basis for recording and charging time to approved experiments.

The entries of the experimenter's shift report which are used to determine the time charged to the experiment are those entitled *Experimental Hours* and *Average Repetition Rate.*

The time charged $T_c$ to an experiment is given by:

$$T_c = T_0\left(\frac{R+20}{200}\right)$$

where $T_0$ is the time the beam is available to the experimenter and R is the average repetition rate during each shift. Thus the multiplicative factor is unity at a pulse rate of 180 pps. However, the factor becomes 0.2 at the usual checkout rate of 20 pps. It is 0.1 at zero pps (assuming the beam is scheduled and available but is not being utilized by the experimenter). The factor will be held to a maximum of 1.5 for charging purposes, even when the calculated value exceeds this amount.

When a fault in the accelerator prevents the delivery of a satisfactory beam to the experimenter, he is not charged for the time during which this unsatisfactory condition exists. On the other hand, if the accelerator is capable of delivering a satisfactory beam but the experimenter is not able to use it because of problems in his own equipment or difficulties inherent in the experimental program or procedures, he is charged for beam time during this period in accordance with the above formula. An exception to this rule may be made provided the chief operator ascertains that one of the other experimenters is willing to make use of the extra pulses, and to be charged for them, during the period of difficulty of the first experimenter.

### 3.3 CHARGES FOR NPAS EXPERIMENT SETUP AND OPERATION

The *NPAS* program functions within the high energy physics program at *SLAC*, but the cost for operation of the program are borne by the *NPAS* budgets. This includes cost for setup and operation of approved nuclear physics experiments and nuclear physics test runs, purchase or construction of experimental equipment to be used exclusively by the nuclear physics program, and program administrative costs. The *NPAS* Coordinator is responsible for managing the *NPAS* budgets, in consultation with the Associate Director.

## 4. PREPARATION OF PROPOSALS

This section describes the preparation of proposals for the *NPAS* program. Proposals should include as much information as is necessary to enable the reviewers to understand in some detail the proposed method of execution of the experiment as well as its scientific objectives and significance. In particular, the reviewers must be able to evaluate the demands that the experiment will make on beam time, beam characteristics, *SLAC* facilities and services and so on. The list below enumerates the kinds of information that could in general be usefully included in the proposal. It is not required that the proposal have either the form or the content indicated in this list.

Please submit at least 3 copies on $8\frac{1}{2}$ by 11 inch paper.

Proposals should be submitted to:

R. E. Taylor, Associate Director
Bin 80
Stanford Linear Accelerator Center
P.O. Box 4349
Stanford, California 94305

Suggested Contents of Proposals

1. Short descriptive title.
2. Experimenters.
   (a) Experienced scientists at the Ph.D. level or equivalent. Please indicate the name of a single person who will act as spokesperson for the experiment. This will be someone who is available to whom inquiries concerning the proposal should be made. This need not be the senior scientist of the group.
   (b) Scientists at the graduate student level.
   (c) Technicians and any other group members.
3. Description of the Experiment

   The description of the experiment should include a statement of its purpose, the theoretical background, procedures to be followed, previous experimental results, and a comparison with competing or closely related experiments planned or in progress at other laboratories. Use diagrams where appropriate.
4. Accelerator Operation
   (a) Electron beam energy, current, pulse length, and pulse repetition rate.
   (b) Any special beam characteristics, such as polarization or time structure.
5. Electron Beam or Secondary Particle Beams
   (a) Layout of beam showing position and characteristics of magnets, separators, collimators, etc.
   (b) Solid angle acceptance, momentum, momentum resolution, and expected intensity.
   (c) Other pertinent beam parameters, such as image size and divergence.

6. Experimental equipment

   List all major facilities and equipment to be used, such as spectrometers, magnets, targets, beam dumps, large counters, etc. Indicate whether these are to be supplied by *SLAC*, by the *NPAS* program, or by some other source. It is particularly important to indicate any equipment items which may present hazards to personnel or equipment so that appropriate safety measures can be considered.

7. Date When Equipment Will Be Ready

   The proposal should include an estimate of the date when the equipment to be supplied by the experimenters will be ready. For experiments requiring major pieces of apparatus which have not been completed, give a construction and testing schedule.

8. Machine time required

   The proposal should show clearly the basis for estimating machine time. You may include a reasonable contingency factor for failures and adjustments of the detection equipment, but you should not allow a contingency for failure of the accelerator or the beam system leading up to your apparatus. Time for experiments will be allotted on the basis of a certain number of hours or shifts or pulses during which satisfactory beams are delivered to the experimenter. It is the responsibility of the Director, with the assistance of the Program Coordinator and the Experiment Scheduling Officer, to estimate how many calendar days will be required to give the experimenter his allotted time.

9. Data Analysis

   Indicate what data analysis equipment (including *SLAC*) equipment you expect to use and estimate the time which will elapse between the completion of the run and the completion of data analysis. In the case of short runs to test the feasibility of an experiment, estimate how long it will take from the end of the test run until you can judge the desirability of continuing the experiment.

## 5. SERVICES FOR USERS

In addition to the large general-purpose experimental facilities and accelerator operation, *SLAC* is prepared to offer other services to users according to the following guidelines:

A. Design, Installation, and Setup of Experiments

*SLAC*'s Experimental Facilities Department (*EFD*) will analyze the costs and the feasibility of proposed experiments. When the experiment is approved, an *EFD* engineer will be responsible for design, fabrication, and installation of all beam handling equipment. Rigging, surveying, electrical and mechanical installation of the experimental equipment will be done or arranged for by *EFD*. The costs for these services will be borne by the *NPAS* program.

B. General Support Functions

*SLAC* makes available to users the customary supporting services in the following areas: office and laboratory space (including furniture, telephones, mail service, etc.) library services, purchasing assistance, and so on. *SLAC* will assign engineering and technician assistance to users groups as requested and required, for purposes of liaison and general aid. More elaborate technical assistance can be arranged, in which case the user will be expected to bear the cost. Machine shop and electronics fabrication services and stores items are also available to users at their expense. Operation and maintenance personnel are on duty around the clock during operating periods. Emergency services are available on request. Telephone numbers of *SLAC* employees to be contacted for assistance in various emergencies are listed in the *SLAC* telephone directory. The Chief Operator should be contacted if the problem is serious or if there are questions about procedure.

C. Computation

*SLAC* does not provide extensive computation facilities to users except for the limited computation that may be required for analysis during the course of an experiment. There is a VAX 11-780 computer in the End Station A Counting House for use by the *NPAS* users for online data analysis and experiment monitoring.

E. Salary, Housing, and Travel

These costs are to be borne by the users. *SLAC* will provide assistance in arranging housing and travel. No housing is available on the *SLAC* site.

The *SLAC* site is too large to be conveniently covered on foot. No vehicles are available for users. It is recommended that users groups have rented automobiles, mopeds or bicycles for their use during residence at *SLAC*.

F. Business Arrangements

*SLAC* users should have their University Business Manager contact Eugene B. Rickansrud, Director for Business Services at *SLAC*, to set up a contract or purchase order to cover costs incurred at *SLAC*.

J. High Energy Electronics Pool (*HEEP*) The *SLAC* high energy electronics pool provides experimenters service and support in the area of high speed electronics and other peripheral experimental electronic equipment. *HEEP* maintains lists of equipment available on an experiment-priority basis. *HEEP* also will service, or arrange to obtain service for, standard types of modules brought to *SLAC* by visiting experimenters.

H. Laboratory Electronic Equipment Pool (*LEEP*)

*LEEP* is a pool of commercially manufactured electronic test equipment for use by *SLAC* personnel and visiting experimenters. Included in *LEEP* are oscilloscopes and accessories, pulse generators, signal generators, digital voltmeters, general purpose counters (nonnuclear types), and closed circuit TV cameras and monitors. Arrangements can be made to borrow equipment from *LEEP*, when it is available. *LEEP* will also arrange for necessary repairs and calibration.

## 6. WHO TO CONTACT AT SLAC


| THE LABORATORY ADDRESS | TELEPHONE NUMBER |
|---|---|
| Stanford Linear Accelerator Center<br>Stanford University<br>P.O. Box 4349<br>Stanford California 94305 | 415 845-3300 |

PHYSICAL LOCATION OF THE LABORATORY

(For deliveries, not to be used for mailing address)
2575 Sand Hill Road, Menlo Park, California
Approximately one mile East of the Sand Hill exit from Interstate 280


GENERAL

User support at *SLAC* is the responsibility of the Experimental Facilities Department (*EFD*). A prospective user in need of information and unfamiliar with *SLAC* should contact Lewis Keller, head of *EFD*. The *NPAS* Coordinator is Ray Arnold. Prospective users should feel free to contact the *SLAC* Director, the Associate Director for the Research Division, or the *NPAS* Coordinator if they need information on policy.

ADMINISTRATION (January 1984)

| | |
|---|---|
| Submit proposals to Associate Director . . . . . . | Richard Taylor, |
| Technical Division . . . . . . . . . . . . . . . . . | Burton Richter |
| Accelerator Physics . . . . . . . . . . . . . . . . | Matthew Allen |
| Accelerator Operations . . . . . . . . . . . . . . | J. M. Paterson |
| Research Division . . . . . . . . . . . . . . . . . | Richard Taylor |
| Experimental Facilities Department . . . . . . . . | Lewis Keller |
| Program Coordinator . . . . . . . . . . . . . . . . | Clive Field |
| Experimental Scheduling Officer . . . . . . . . . | David Fryberger |
| Short Term Scheduling Coordinator . . . . . . . . | Dave Tsang |
| *HEEC* (Hazardous Experimental Equipment Committee) | Hobey DeStaebler |
| NPAS Coordinator . . . . . . . . . . . . . . . . . | Ray Arnold |

SERVICES

| | |
|---|---|
| Design, Installation, Setup of Experiments: Experimental Facilities Department . . . | Lewis Keller |
| Physics Instrumentation Design . . . . . . | Ray S. Larsen |
| *HEEP* (High Energy Electronics Pool) . . . . | Donald E. Farwell |
| *LEEP* (Laboratory Electronics Equipment Pool) | Edward Schulte |
| Hydrogen Target Group . . . . . . . . . . . | John Mark |
| Computation . . . . . . . . . . . . . . . . | Charles Dickens |
| Off-Site Housing . . . . . . . . . . . . . . | Gwen Bowen |
| Office Space, Furniture, Telephones, Radiation Film Badges . . . . . . . . . . | Dorothy Edminster |
| Technical Typing, Illustrations, Publications . | Tiana Hunter |
| Health Physics . . . . . . . . . . . . . . . | Gary Warren |
| Radiation Physics . . . . . . . . . . . . . | Richard McCall |
| Business Arrangements . . . . . . . . . . . | Eugene B. Rickansrud |

## II. EXPERIMENTAL FACILITIES

### 1. BEAM

#### 1.1 General Electron Beam Parameters

In its original configuration the accelerator has a maximum energy of 21 GeV with a maximum intensity of 40 to 50 $\times 10^{10}$ electrons per pulse through momentum slits of $\pm 0.5\%$ . The beam pulses are 1.6 $\mu$s long with a maximum pulse repetition rate of 180 pulses per second yielding an average current of up to 12 $\mu$A. For beam energies below 6 GeV the beam current drops with decreasing energy. The lowest practical beam energy from the full 30 sector linac is approximately 1 GeV where the peak pulse current is approximately 1 mA.

The accelerator can be reconfigured in about 1 shift to operate in the *SLED* mode (*SLAC* Energy Doubler). This can give beam energies up to 34 GeV with a pulse length of approximately 100 ns. The intensity can be as high as $6 \times 10^{10}$ electrons per pulse.

By 1987 the accelerator will be modified to provide energies up to 30 GeV in the non-*SLED* mode and 50 GeV in the *SLED* mode for the *SLAC* Linear Collider (*SLC*). New klystrons will be provided, and the pulse forming network (modulators) may be modified to produce longer pulses (4 $\mu$s in the non-*SLED* mode).

Beginning in 1985 the Nuclear Physics Injector (*NPI*) will provide low energy high intensity electron beams using the last six sectors of the *SLAC* linac. In 1985 the maximum beam energy will be 4 GeV and the maximum intensity will be approximately $10^{12}$ electrons per pulse. After 1985 the maximum beam energy and current will be determined by developments in the *SLC* project. When the *SLC* project achieves 30 GeV in the non-*SLED* mode using new klystrons, the *NPI* will produce approximately 6 GeV maximum. The maximum beam current decreases with decreasing beam energy. Figure 1 shows the maximum current versus energy expected for the 6-sector beam.

#### 1.2 End Station A Beams

The electron beam into *ESA* is energy-analyzed by slits in the A bend. Over 90% of the beam can be passed through slits set at $\pm 0.5\%$ . Depending on conditions in the accelerator, approximately half of the beam intensity is available inside $\pm 0.2\%$ slits. Settings as small as $\pm 0.05\%$ have been used with a corresponding reduction in beam intensity. Plans have been considered to modify the A bend magnet system to increase the maximum energy from 21 GeV to 50 GeV for possible use of the high energy beam produced by the *SLC* project.

The beam profile at the target in End Station A depends on many factors in the accelerator and also on the settings of the quadrupole focusing in the A line. The smallest beam spot is typically 2 mm in diameter. The beam shape and alignment can be observed on video monitors looking at two movable zinc sulphide screens. The beam profile can also be measured and monitored using a set of vertical and horizontal secondary emission wires in the A line that are read out and displayed by an online LSI-11 computer. The beam position is adjusted using steering magnets in the A line controlled by the LSI-11.

The beam intensity is measured to better than 1% using two independent toroids in the A line and two sets of toroid electronics in End Station A Counting House.

Polarized beams

Polarized electron beams have been used for several experiments at *SLAC*. There does not presently exist a polarized electron source in operation. There is under development a new polarized source for the *SLC*, using a GaAs cathode with laser driven photo emission similar to one developed previously at *SLAC*. Physical space has been provided in the *NPI* for the possible future addition of a polarized electron gun.

Photon beams

Bremsstrahlung beams produced by high energy electrons have been used in End Station A. There exists a beam dump just upstream of the entrance to the end station for dumping the electron beam after a photon production target.

## 2. END STATION A FACILITIES

### 2.1 End Station A Counting House

The End Station A Counting House is equipped to monitor and control the experimental equipment in the end station and to collect and analyze the data from the spectrometers. Most of the computation work is done by a VAX 11-780 computer equipped with two disk drives, two 6250 bpi tape drives, a Versatec printer/plotter and numerous terminals. The experimental equipment is connected to the computer through three CAMAC branches. This includes display scopes, control panels, digital volt meters, and the fast electronics modules for data readout. The VAX can be accessed using DECNET and/or the *SLAC* MICOM digital switch connected to the central computer. The MICOM switch is accessible by telephone from outside *SLAC*.

Programs exist for general housekeeping tasks, such as controlling magnet currents, visual displays, CAMAC control, and data acquisition. Extensive software development is usually required to accommodate the needs of individual experiments. The VAX has the capacity to analyze a fraction of the data online and has been used for off-line analysis, sometimes concurrently with on-line experiment operation.

The Counting House has controls, readout, and diagnostic equipment for the electron beam, spectrometer power supplies, detectors, targets, and other *ESA* equipment. Fast trigger logic is assembled by the experimenters according to the requirements of individual experiments, using modules from *HEEP*, or provided by the users.

## 2.2 The Spectrometer Facilities

### A. General

There are three large magnetic spectrometers in End Station A. This section summarizes the design parameters and the operational experience with these instruments.

The three spectrometers were designed to reach maximum momenta of 1.6 GeV/c, 8 GeV/c and 20 GeV/c. All rotate on concentric rails about a common pivot. The 20 GeV/c spectrometer can cover an angular range between 0° and 20°; the 8 GeV/c spectrometer, 12° to 100°; and the 1.6 GeV/c Spectrometer, 25° to 165°. The End Station A floor plan is shown in Fig. 2.

In addition to the three spectrometers, there are available other magnets, beam line components, and shielding materials that can be used in "building block" type setups.

### B. Optics Considerations

The kinematics of most high-energy physics reactions in which a single particle is detected in the final state imply that if good momentum resolution of the detected particle is required, then it is also necessary to determine the scattering angle at which the particle is produced or scattered to an accuracy well within the angular acceptance of the spectrometer. On the other hand, normally one is not interested in knowing the precise position in the target where the reaction took place. Therefore, all three spectrometers have been designed to focus point-to-point from target to image plane in the vertical (bend) plane and line-to-point in the horizontal plane. The momentum of the transmitted particle is dispersed in the vertical plane while the production angle relative to the central orbit of the spectrometer is dispersed in the horizontal plane. An illustration of the first-order focal properties is shown below for each spectrometer.

The basic first- and second-order optics design was achieved using the *SLAC* program TRANSPORT[1] and the final optics of each spectrometer were calibrated in 1967-1968 with the *SLAC* electron beam. In addition the 1.6 GeV/c spectrometer was calibrated using the floating wire technique. For the optics measurements each spectrometer was set at zero degrees and the electron beam of a prescribed energy was transmitted through a system of three small bending magnets and into the spectrometer. The three-magnet system was designed to steer the beam to different horizontal entrance displacements and to prescribed horizontal and vertical entrance angles. Zinc sulphide screens, appropriately placed along the beam line near the focal positions of the spectrometer, were used to measure the position of the beam as it was transmitted through the spectrometer. The spectrometer was set to several slightly different momenta and the measurements repeated. From these measurements the optics of the system were checked and the various first- and second-order optics matrix elements and the solid-angle acceptances were calculated. These measurements were repeated again for different electron beam energies.

### 2.3 The 1.6 GeV/c Spectrometer

The 1.6 GeV/c spectrometer[2] is a weak-focusing ($n = 0$), 90°-vertical-bend, 100-inch-bending-radius device with a maximum acceptance exceeding 3 millisteradians of solid angle, 20 centimeters of projected target length and ±5 percent in momentum. Rotated entrance and exit pole faces introduce first-order focusing conditions which make the production angle and momentum focal planes coincident in space. Second-order corrections, introduced by shaping the pole faces at three distinct locations, introduce "beta lens" or sextupole regions to correct both geometric as well as chromatic aberrations. The principle chromatic aberration is set to zero so that the momentum focal plane is normal to the central ray. The use of a homogeneous $n = 0$ magnetic field makes it possible to utilize window frame design and thus to operate the magnet without any appreciable saturation or change in focusing properties up to fields of 21 kilogauss.

The first-order focal properties are shown in Fig. 3. The magnet and coils, including a cross-sectional view of the beta lens sections, are shown in Fig. 4. The complete spectrometer assembly including magnet, carriage, and shielding is shown in Fig. 5. Table I shows the measured and theoretical values of some of the first- and second-order coefficients of the magnet.

The first-order dispersion of 4.19 centimeters per percent in momentum and 0.808 centimeter per milliradian in production angle, and the measured second-order matrix elements yield resolutions in momentum and horizontal production angle of ± 0.08 percent and ±0.4 milliradian respectively. These resolutions were calculated for the following source conditions:

$$x_0 = y_0 = 0$$
$$\theta_0 = \pm 17 \text{ mrad}$$
$$\phi_0 = \pm 30 \text{ mrad}$$
$$\delta = \pm 5 \text{ percent}$$

where the notation is that given by Brown [1].

| | |
|---|---|
| $x_0(y_0)$ | in is the horizontal(vertical) displacement projected at the source perpendicular to the central ray of the spectrometer |
| $\theta_0(\phi_0)$ | is the horizontal (vertical) production angle at the source |
| $\delta = \frac{\Delta P_0}{P_0}$ | is the momentum acceptance of the spectrometer when set at momentum $P_0$ |

It is possible to increase the $\phi_0$ acceptance to about ±50 milliradians with a resulting increase in the resolution to approximately ±0.2 % in momentum and ±0.5 milliradian in $\theta$.

The rationale for making the momentum and production angle focal planes coincide is that, over the kinematic region for the two-body processes accessible to the 1.6 GeV/c spectrometer, the focus of particles from a particular two-body process is approximately a straight line in the focal plane and thus these particles can be selectively detected by appropriate scintillation counters which can be rotated into alignment along the appropriate kinematic curve. This technique thus eliminates the complex decoding necessary for systems which use separate hodoscopes for both production and momentum measurements and makes it possible to count particles at 100 MHz rates with relatively simple electronic systems.

The 1.6 GeV/c spectrometer was accidentally damaged by overheating in January 1968. Since this time, two short circuits have developed in one of the four coils. Consequently, turns have been shorted in a symmetrical arrangement, reducing the total number of ampere turns, but preserving the optical characteristics. A total of 24 of 144 turns have been shorted. Wire orbit measurements of the magnetic field were performed by experimenters[3] after these shorts were made. They indicate no significant change in the optics. At the present time, this spectrometer has been operated at 1.4 GeV/c, and it is expected that it could be run at somewhat higher excitation with increased risk of further damage to the coils.

## 2.4 THE 8 GEV/C SPECTROMETER

The 8 GeV/c spectrometer[4] is composed of three quadrupoles (Q81, Q82, and Q83) which provide the required focusing, and two rectangular, $n = 0$, 15° bending magnets (B81 and B82) which produce the momentum dispersion. The arrangement of the magnets and the first-order focal properties are shown in Figs. 6 and 7. The spectrometer has a maximum solid-angle acceptance of greater than 0.75 millisteradian, an acceptance of 20 centimeters in target length projected perpendicular to the central ray, and a momentum acceptance of ±2 percent. The measured first-order dispersions at 8 GeV/c are 4.57 centimeters per milliradian in production angle, and -2.91 centimeters per percent in momentum. Because of the large chromatic aberrations, the momentum focal plane is tipped at an angle of 13.7° to the central ray. The production angle focal plane is kept perpendicular to the central ray because it is not affected strongly by the second-order aberrations. It is separated from the center of the momentum focal plane by 0.5 meter to allow separate momentum measurements by two hodoscopes, one lying in each focal plane. The original hodoscope detector system is no longer used. The 8 GeV/c spectrometer is now equipped with a set of 10 planes of multiwire proportional chambers for measuring the particle tracks in the region of the focal planes.

In the focal planes, the resolutions calculated from the design values of the first- and second-order coefficients are ±0.05 percent in momentum and ±0.2 milliradian in horizontal production angle[4]. These resolutions were calculated for the following source conditions:

$$\begin{aligned} x_0 &= \pm 10 \text{ cm} \\ \theta_0 &= \pm 8 \text{ mrad} \\ y_0 &= \pm 0.15 \text{ cm} \\ \phi_0 &= \pm 30 \text{ mrad} \\ \delta &= \pm 2 \text{ percent} \end{aligned}$$

Actual resolutions and other optical properties for the 8 GeV/c spectrometer must be calculated for each experiment. Optics test data for this purpose may be obtained from the *NPAS* Coordinator.

The complete spectrometer assembly, including the magnets, carriage, detector boom, and shielding is shown in Fig. 8. The detectors are carried on a boom which extends beyond Q83. The detector shielding is carried on a set of two separate shielding carriages which open and close around the detectors like a clam shell.

The magnets are mounted on the carriage in such a way that they can be aligned relative to one another with sufficient accuracy to insure the resolutions mentioned above. The entire spectrometer rides on a set of rails and it can be rotated about the pivot either manually or under computer control.

In Table II are listed the first- and second-order matrix elements for the 8 GeV/c spectrometer as measured with the *SLAC* electron beam. It was not possible to get detailed agreement between the measured parameters, and the theoretical parameters calculated using TRANSPORT[1] with the magnetic properties of each individual magnet as measured prior to installation in the spectrometer. It is suspected that these differences are due to fringe-field effects between the closely spaced magnets and to the presence of the nearby steel of the spectrometer carriage. A TRANSPORT model in which the magnet properties of the quadrupoles were adjusted from the magnetically measured values by a few percent will, in fact, reproduce satisfactorily the observed matrix elements. This same model, when used with a Monte Carlo ray-tracing program, will reproduce the measured solid-angle acceptance.

The 8 GeV/c spectrometer has been operated satisfactorily at 9 GeV/c, and optics test data exist at this excitation.

## 2.5 THE 20 GEV/C SPECTROMETER

The 20 GeV/c spectrometer[5] is the most complicated of the three spectrometers, both mechanically and optically. It consists of four rectangular, $n = 0$, 5.2° bending magnets (B201, B202, B203, and B204), four quadrupole magnets (Q201, Q202, Q203, and Q204), and three sextupole magnets (S201, S202, and S203). The arrangement of the magnets and the first-order focal properties are shown in Figs. 9 and 10.

The momentum dispersion and resolving power obtained in the 8 GeV/c spectrometer is a direct consequence of the large angle of vertical bend present in the system. As the momentum becomes larger, this type of optics solution results in an abnormally high and structurally complicated spectrometer. For this reason the dispersion and resolving power of the 20 GeV/c spectrometer is achieved with two sets of bends of opposite sense, with an intermediate vertical image located one third of the way between S202 and Q203 so that the momentum dispersion of the two pairs of bending magnets are additive. The dispersed beam thus emerges from the spectrometer horizontally and the total height of the system is kept within reason.

This "reverse-bend" solution was not achieved without some added complexity. Primarily because of the intermediate vertical cross-over, the chromatic aberrations are much more severe than in the 8 GeV/c spectrometer. Three sextupole magnets are used to control these aberrations and to increase the momentum focal plane angle from about 2° to 45° as measured from the central ray. Thus separate angle and momentum measurements may be made by two hodoscopes at focal planes separated, as in the 8 GeV/c spectrometer, by 0.5 meter.

The spectrometer has a maximum solid-angle acceptance of greater than 100 microsteradians, an acceptance of 6 centimeters of target length projected perpendicular to the central ray, and a momentum acceptance of ±2.3 percent. The measured first-order dispersions are 1.63 centimeters per milliradian in production angle and 3.24 centimeters per percent in momentum. The resolutions calculated from the design values of the first- and second-order coefficients are ±0.06 percent in momentum and ±0.25 milliradian in horizontal production angle.[6]

These resolutions were calculated for the following source conditions:

$$x_0 = \pm 3 \text{ cm}$$
$$\theta_0 = \pm 4.5 \text{ mrad}$$
$$y_0 = \pm 0.15 \text{ cm}$$
$$\phi_0 = \pm 8 \text{ mrad}$$
$$\delta = \pm 2 \text{ percent}$$

Actual resolutions and other optical properties for the 20 GeV/c spectrometer must be calculated for each experiment. Optics test data for this purpose may be obtained from the *NPAS* Coordinator.

The complete spectrometer assembly, including magnets, magnet carriage, and shielding carriage is shown in Fig. 11. Because of the length of the spectrometer it was necessary for practical reasons to mount the detectors and shielding on a separate carriage and to drive that carriage independently from the magnet carriage. It was not practical to mount the magnets on a tricycle type of support utilizing the common pivot, as was done with the 1.6 GeV/c and 8 GeV/c spectrometers. It was desired to allow the spectrometer to approach zero degrees as closely as possible and still allow the primary electron or photon beam to continue past the spectrometer to a beam dump located behind the end station. For this reason, the front of the spectrometer is supported from one side only, and the first bending magnet is built asymmetrically with the ends of the window-frame coil bend completely to one side of the magnet, and the outside of the magnet steel on the opposite side notched along the center of the magnet to allow a minimum of interference with beam pipes.

For certain classes of experiments the existing support structure can keep the magnets aligned within the required tolerances only if precision surveying of the magnets and repositioning of the spectrometer frame are done each time the spectrometer angle is changed.

In Table III are listed the major first- and second-order optics coefficients as measured with the electron beam. The measured aberrations are quite large, in part because of the asymmetry of B201. Since many of the large second order coefficients involve the vertical entrance angle $\phi_0$, experimenters sometimes use slits to reduce the spectrometer aperture in $\phi$, thus reducing the contribution from these $\phi$ aberrations. This increases the data-taking time per experimental point but considerably simplifies the data analysis.

From a study of the properties of the 20 GeV/c spectrometer, it appears possible to operate it at a momentum of 21.5 GeV/c. It is not expected that the aberrations will be much worse at this excitation.

## 2.6 DETECTOR INSTRUMENTATION

General Each spectrometer in End Station A is constructed with a "hut" space of some cubic meters for the location of particle detection equipment. Previous generations of high-energy physics experiments have used various packages of detectors suited to the needs of each experiment. In some cases parts of those packages are still available and working. In other cases the detector and associated cabling, utilities, and electronics systems are either not available or no longer in working order. Experimenters may regard the detector package as a variable in their experimental plans and may propose to make alterations, improvements, or additions. The detector package is the responsibility of the experimenters.

1.6 GeV/c spectrometer The 1.6 GeV/c spectrometer was used in the 1960's and early 1970's to detect and identify both electrons and hadrons using different packages of detectors. An existing hadron detecting system is shown in Fig. 12. Since this spectrometer has not been used recently for a major experiment, no new detector packages have been developed. To make optimum use of this spectrometer for the nuclear physics program, the detectors will have to be upgraded. There is need for a new wire chamber system for track measurement and new Čerenkov and shower counters for particle identification.

8 GeV/c spectrometer The 8 GeV/c detector system has recently been modernized. The original hodoscope system located at the momentum and angle focal planes for measuring the particle tracks are no longer used. There is now a set of 10 multiwire proportional chambers with associated CAMAC high voltage and event readout systems. In addition there is a segmented lead glass shower counter for electron identification. One of the gas filled Čerenkov counters used in previous generations of experiments is also available.

20 GeV/c spectrometer The 20 GeV/c spectrometer system has not been upgraded since 1968. It is equipped with a set of multiwire proportional chambers for track measurements, a gas filled Čerenkov counter, and a combination lead-glass and lead-lucite shower counter for electron identificaion. Most of these systems are in working order.

## 2.7 TARGETS

A wide variety of solid, cryogenic liquid, and gas targets have been constructed at *SLAC*. Experiments have used liquid hydrogen and deuterium targets up to 60 cm long, and helium gas targets at 50 atm pressure, 20 degrees K, and 30 cm long. There exists a collection of target components and scattering chambers that can be used or adapted to particular experimental requirements. A typical target configuration includes several lengths of liquid or gas target cells, empty target cells, and a number of solid targets which can all be positioned in the beam by remote control.

## REFERENCES


1. K. L. Brown, Report No. SLAC-75, Stanford Linear Accelerator Center (1969); K. L. Brown, S. K. Howry, Report No. SLAC-91, Stanford Linear Accelerator Center (1970).
2. R. L. Anderson, D. Gustavson, R. Prepost, D. Ritson, Nucl. Instruments and Methods 66 , 328 (1968).
3. W. B. Atwood, Thesis, Report No. SLAC-185 , Stanford Linear Accelerator Center (1975).
4. L. Mo, C. Peck, Report No. SLAC-TN-65-29, Stanford Linear Accelerator Center (1965). The concepts described in this note are still correct although the detailed numbers have been superseded by the data presented in this Users Guide.
5. L. Mo, Report No. SLAC-TN-65-40, Stanford Linear Acclerator Center (1965). The concepts described in this note are still correct although the detailed numbers have been superseded by the data presented in this Users Guide.

Table I. Measured and theoretical values of some of the first and second order coefficients of the 1.6 GeV/c spectrometer.

| Coefficient | Theoretical Value | Experimental Value | Source of Measurement |
|---|---|---|---|
| $\langle y/\delta \rangle$ momentum dispersion | 4.19 cm per % | 4.19 ± 0.05 cm/% | Wire float |
| $\langle x/\theta_0 \rangle$ angular dispersion | 0.823 cm per mrad | 0.808 ± 0.038 cm per mrad | Electron beam spot survey |
| $\langle \phi/\phi_0 \rangle$ relation of input to output angles | 1.514 | 1.52 ± 0.02 | Wire float |
| $\langle y/\delta^2 \rangle$ | $6.07 \times 10^{-2}$ cm/(%)$^2$ | $4.95 \pm 1.0 \times 10^{-2}$ cm/(%)$^2$ | Wire float |
| $\langle x/\theta_0\delta \rangle$ | $1.25 \times 10^{-2}$ cm/mrad · % | $1.24 \times 10^{-2}$ cm/mrad · % | Electron beam spot survey |
| $\langle y/\phi_0\delta \rangle$ | $1.03 \times 10^{-3}$ cm/mrad · % | $\approx 0$ | Electron beam spot survey |
| $\langle y/\phi_0^2 \rangle$ | $2.47 \times 10^{-4}$ cm/(mrad)$^2$ | $\approx 2.5 \times 10^{-4}$ cm/(mrad)$^2$ | Electron beam spot survey |

The notation used is that given by Brown.[1]

$\delta$ is the momentum difference from the central orbit.

y is the displacement at the focal plane along the "momentum" axis.

$\phi_0$ is the input angle in the momentum plane.

$\phi$ is the output angle in the momentum plane.

x is the displacement in the focal plane along the "angular axis."

$\theta_0$ is the input "production" angle.

Table II. Measured values (at 8 GeV/c) and transport predictions for first and second order matrix elements for 8 GeV/c spectrometer.

First Order: Measured values above the Transport prediction

| | $x_0$ | $\theta_0$ | $\phi_0$ | $\delta_0$ |
|---|---|---|---|---|
| x | 0.028 cm/cm<br>0.028* | 4.575 ± 0.046 cm/mrad<br>4.575* | -0.019 cm/mrad<br>0. | 0.027 cm/%<br>0. |
| $\theta$ | -0.194 mrad/cm<br>-0.189 | 4.858 mrad/mrad<br>4.893 | -0.020 mrad/mrad<br>0. | 0.071 mrad/%<br>0. |
| y | -0.002 cm/cm<br>0. | 0.007 cm/mrad<br>0. | -0.004 cm/mrad<br>-0.014 | -2.907 ± 0.029 cm/%<br>-2.907* |
| $\phi$ | -0.008 mrad/cm<br>0. | 0.027 mrad/mrad<br>0. | -1.077 mrad/mrad<br>-1.090 | 0.094 mrad/%<br>0.203 |

*Measured values equal Transport predictions by definition.

The terms dependent on $y_0$ were not measured. However, the calculated $(y/y_0)$ matrix element equals -0.928.

Second Order: (only the largest matrix elements listed)

| | Measured | Predicted |
|---|---|---|
| $<x/x_0\delta>$ | 0.0433 cm/cm · % | 0.0428 cm/cm · % |
| $<x/\theta_0\delta>$ | -0.0104 cm/mrad · % | -0.0135 cm/mrad · % |
| $<\theta/x_0\delta>$ | 0.0484 mrad/cm · % | 0.0450 mrad/cm · % |
| $<\theta/\theta_0\delta>$ | -0.0236 mrad/mrad · % | -0.0282 mrad/mrad · % |
| $<y/\phi_0\delta>$ | 0.0120 cm/mrad · % | 0.0126 cm/mrad · % |
| $<\phi/\delta\delta>$ | -0.0486 mrad/(%)$^2$ | -0.0505 mrad/(%)$^2$ |

The notation used is that given by Brown.[1]
$\delta$ is the momentum difference from the central orbit.
y is the displacement at the focal plane along the "momentum," or vertical, axis.

$\phi_0$ is the input angle in the momentum plane.
$\phi$ is the output angle in the momentum plane.
x is the displacement in the focal plane along the "angular," or horizontal, axis.
$\theta_0$ is the input "production" angle.

Table III. Measured first and second order matrix elements for the 20 GeV/c spectrometer.

| | | | | |
|---|---|---|---|---|
| First Order: | $\langle x/\theta_0\rangle$ | $= 1.623 \pm 0.016$ cm/mrad | $\langle y/\delta\rangle$ | $= 3.259 \pm 0.033$ cm/% |
| | $\langle x/x_0\rangle$ | $= -0.023$ cm/cm | $\langle y/\phi_0\rangle$ | $= -0.015$ cm/mrad |
| | $\langle \theta/\theta_0\rangle$ | $= 0.054$ mrad/mrad | $\langle \phi/\phi_0\rangle$ | $= 0.804$ mrad/mrad |
| Second Order: | $\langle x/\theta_0^2\rangle$ | $= +9.2 \times 10^{-3}$ cm/(mrad)$^2$ | $\langle y/\theta_0^2\rangle$ | $= -2.09 \times 10^{-2}$ cm/(mrad)$^2$ |
| | $\langle x/\theta_0\delta\rangle$ | $= +2.70 \times 10^{-2}$ cm/mrad $\cdot$ % | $\langle y/\theta_0\phi_0\rangle$ | $= -6.2 \times 10^{-3}$ cm/(mrad)$^2$ |
| | $\langle x/\theta_0\phi_0\rangle$ | $= +1.47 \times 10^{-2}$ cm/(mrad)$^2$ | $\langle y/\phi_0^2\rangle$ | $= -4.1 \times 10^{-3}$ cm/(mrad)$^2$ |
| | $\langle x/\phi_0^2\rangle$ | $= +3.6 \times 10^{-3}$ cm/(mrad)$^2$ | $\langle y/\phi_0\delta\rangle$ | $= -6.3 \times 10^{-3}$ cm/mrad $\cdot$ % |
| | $\langle x/x_0\theta_0\rangle$ | $= +1.4 \times 10^{-2}$ cm/cm$\cdot$mrad | | |

The notation used is that given by Brown.[1]

- $\delta$ is the momentum difference from the central orbit.
- $y$ is the displacement at the focal plane along the "momentum," or vertical, axis.
- $\phi_0$ is the input angle in the momentum plane.
- $\phi$ is the output angle in the momentum plane.
- $x$ is the displacement in the focal plane along the "angular" or horizontal axis.
- $\theta_0$ is the input "production" angle.

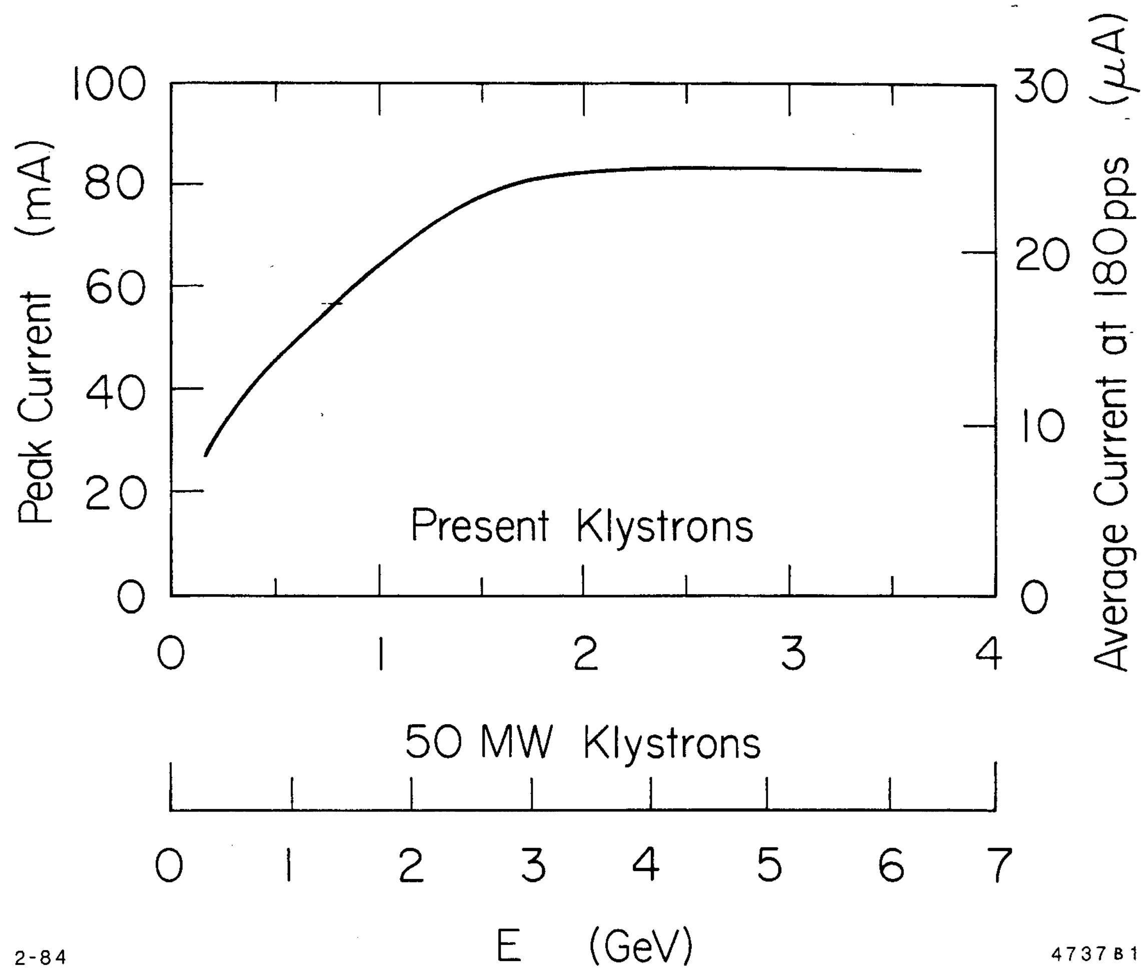


Fig. 1. Maximum beam current as a function of beam energy expected from the Nuclear Physics Injector and the last 6 sectors of the SLAC linac. The curve shown was extrapolated from measurements made of the maximum current obtainable in the first 5 sectors. The maximum beam energy will increase approximately as indicated by the lower energy scale when the SLC klystrons are operational. A useful rule of thumb is that the current for the standard SLAC pulse length of 1.6 $\mu$s corresponds to $10^{10}$ electrons/pulse per mA peak current.

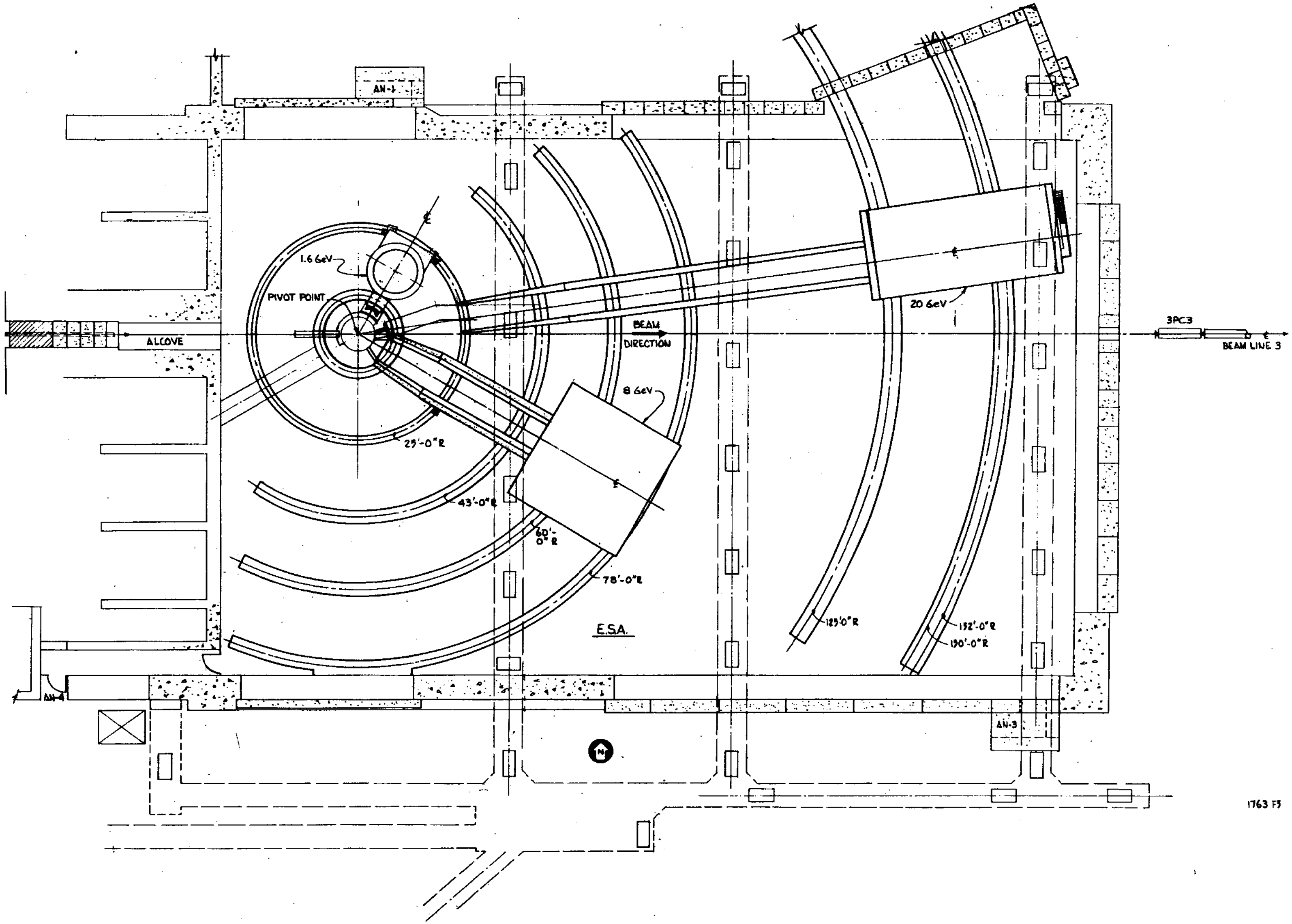


Fig. 2. End station A floor plan.

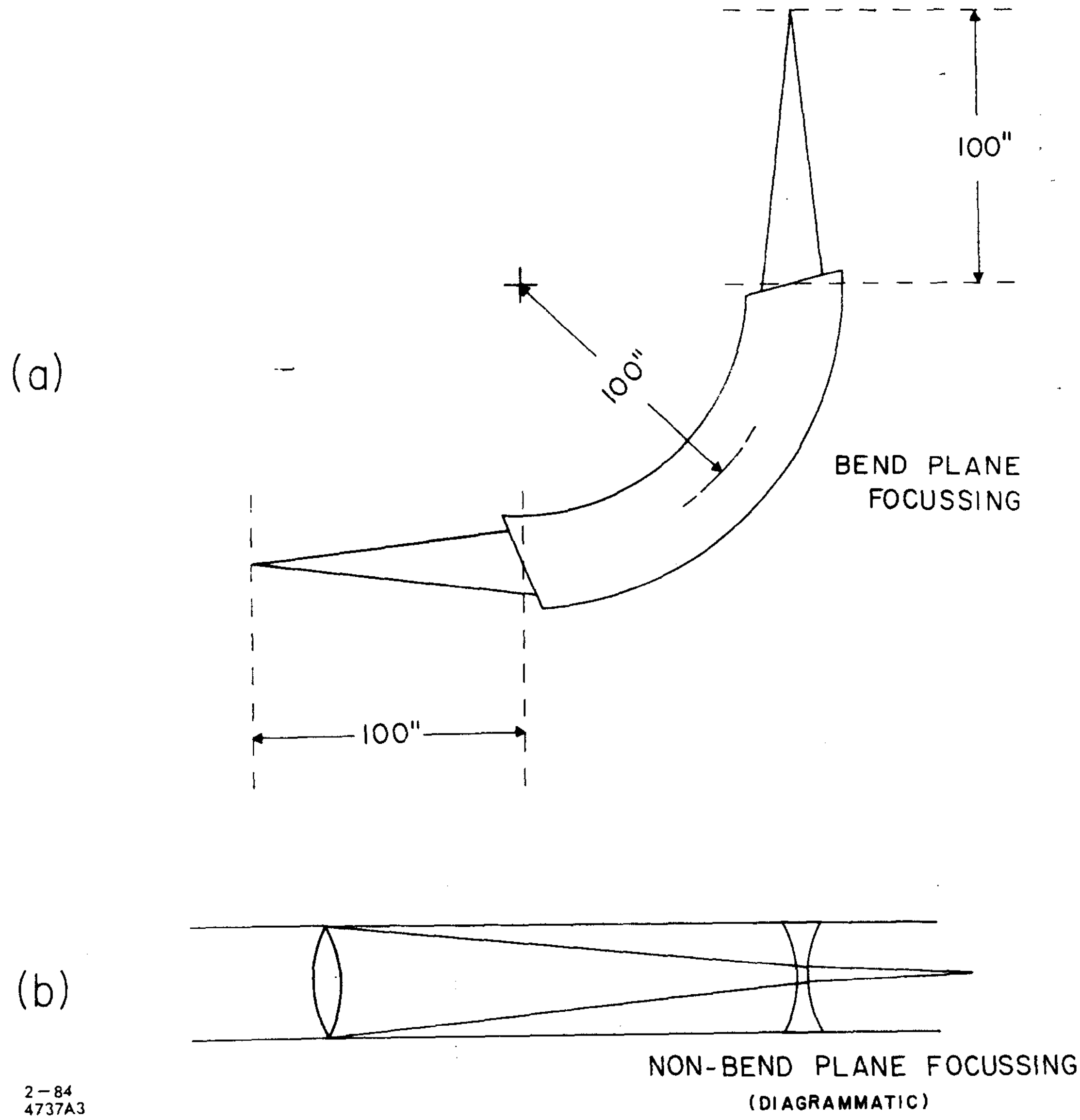


Fig. 3. First-order focal properties of the 1.6 GeV spectrometer.

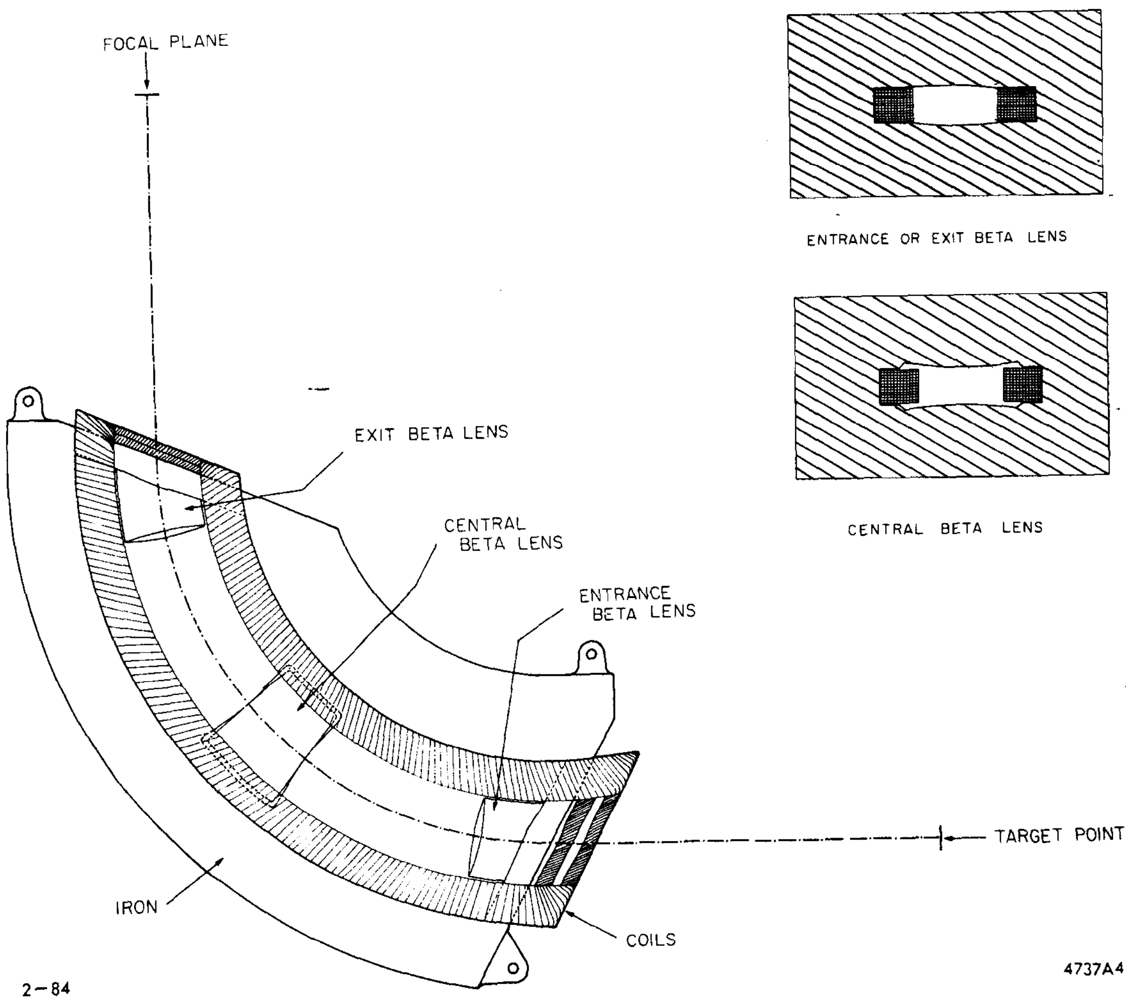


Fig. 4. **1.6 GeV spectrometer magnet and coils, and a cross-sectional view of the beta lenses.**

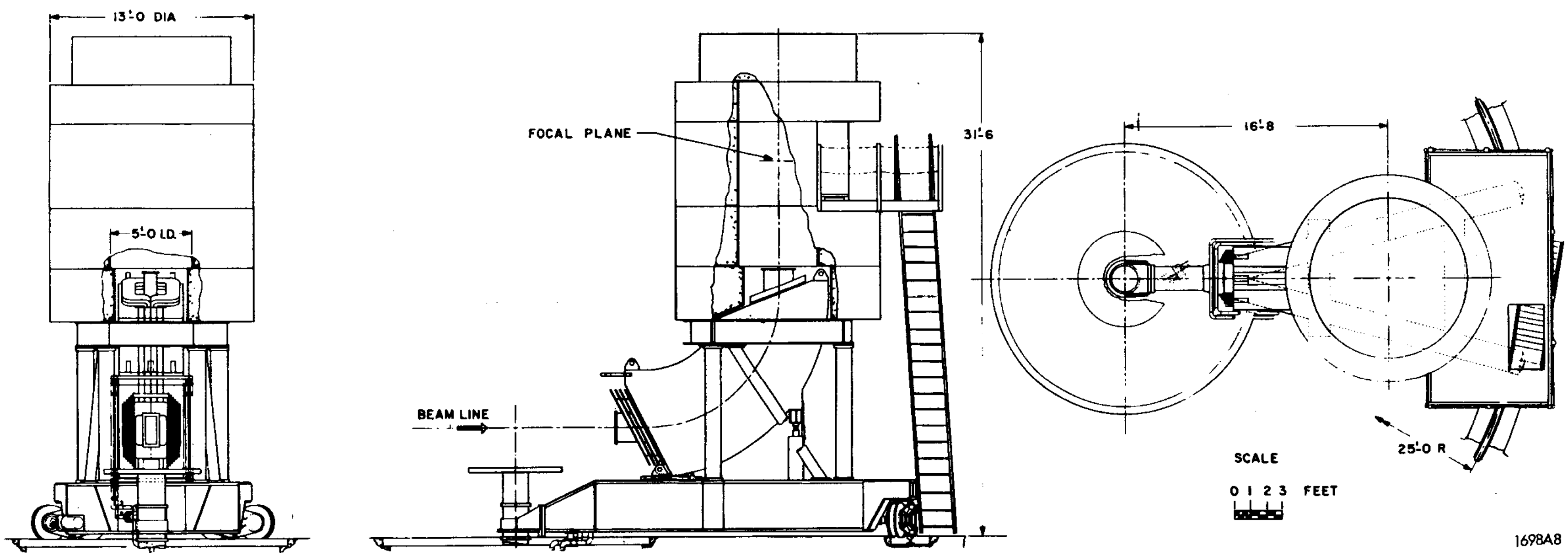


Fig. 5. 1.6 GeV spectrometer assembly.

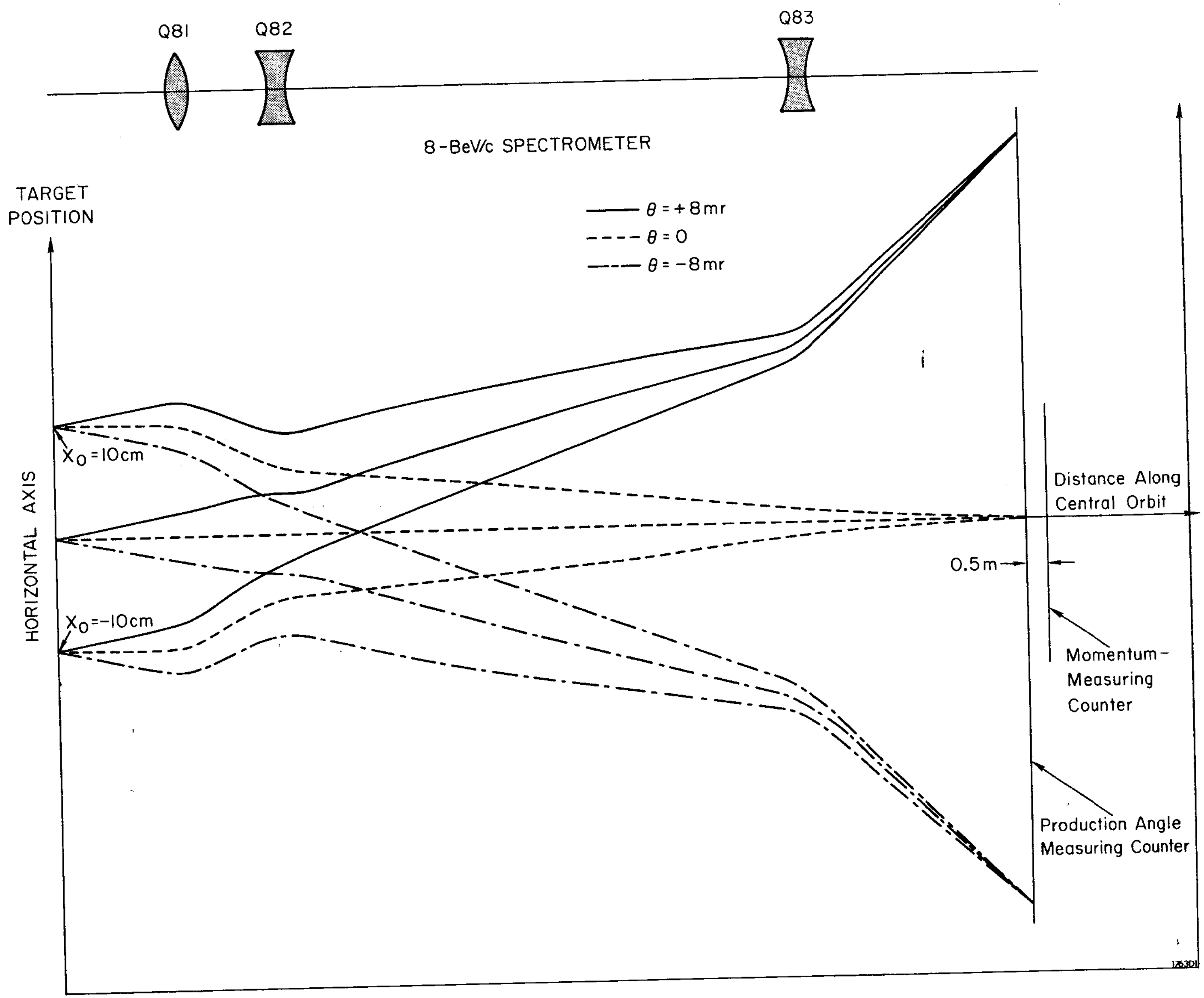


Fig. 6. Horizontal plane first-order focal properties of the 8 GeV spectrometer.

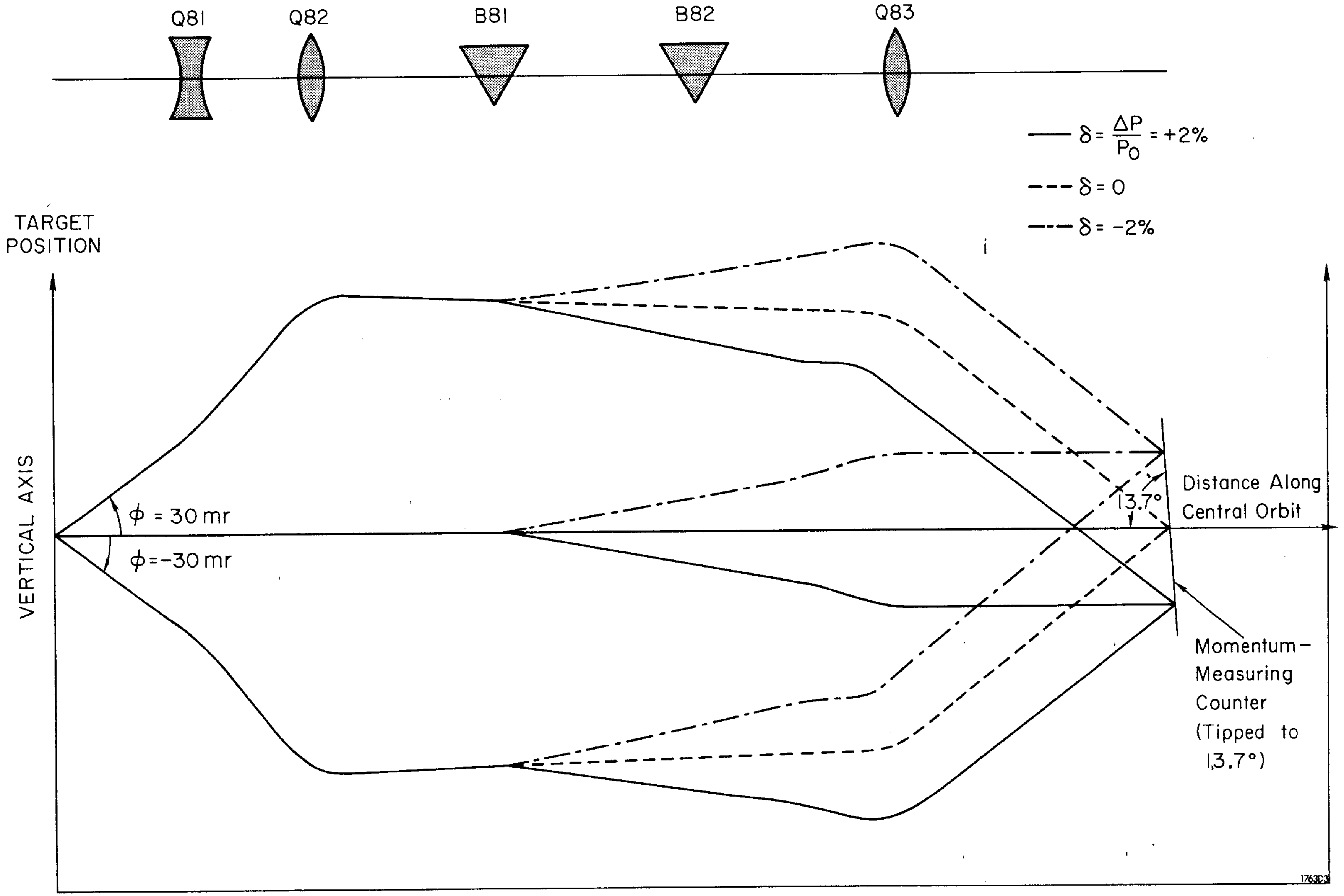


Fig. 7. Vertical plane first-order focal properties of the 8 GeV spectrometer.

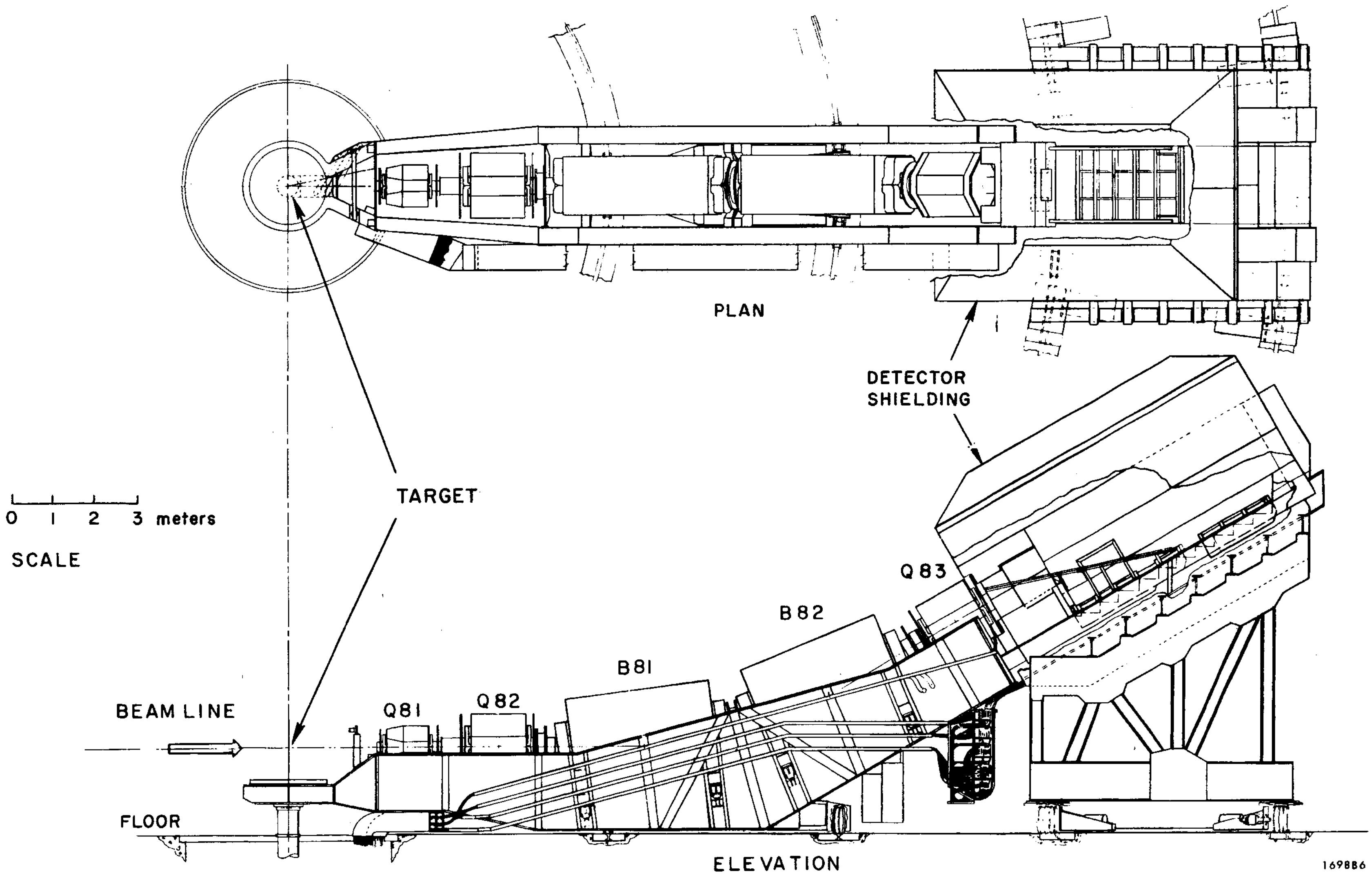


Fig. 8. 8 GeV spectrometer assembly.

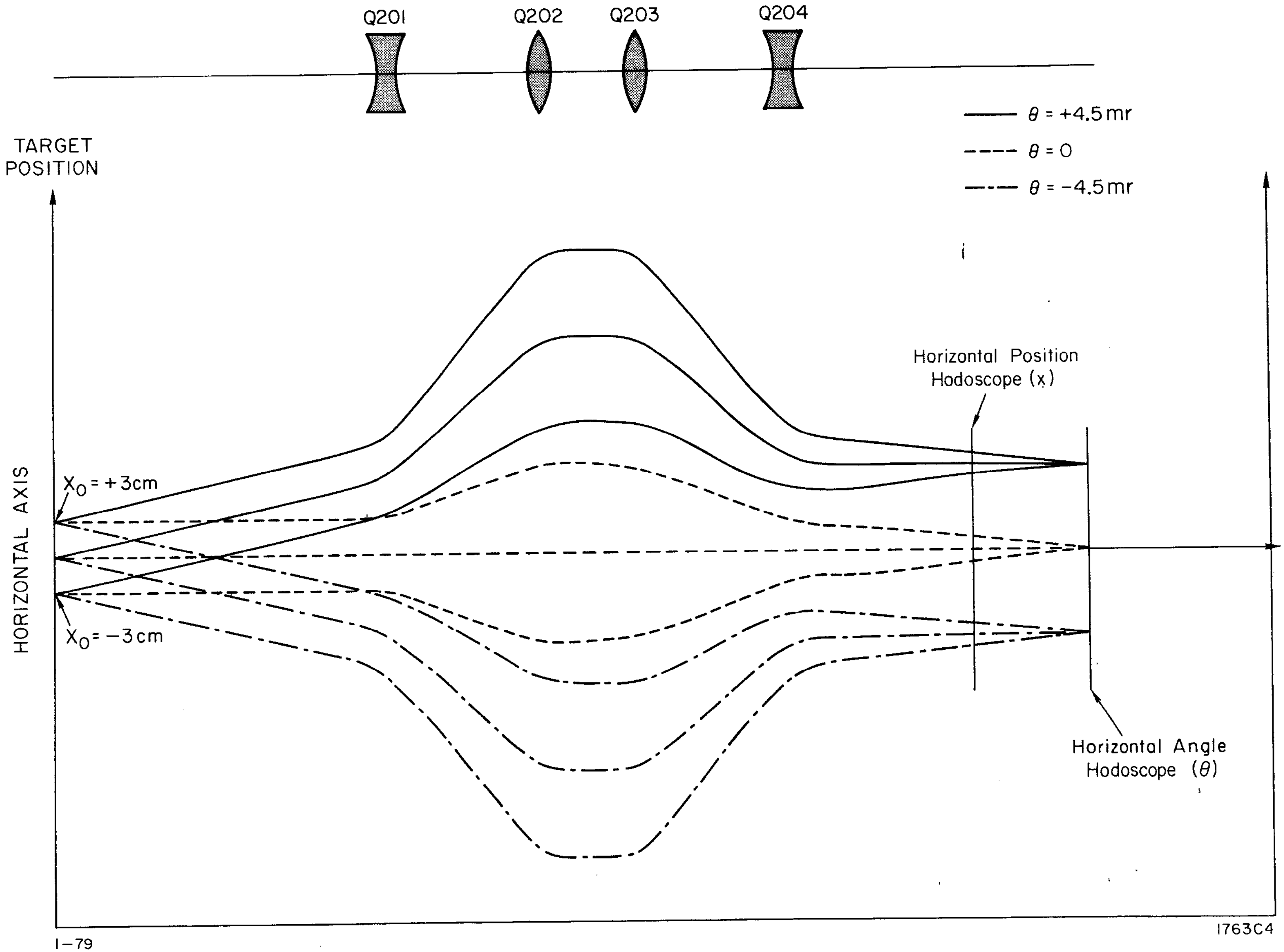


**Fig. 9. Horizontal plane first-order focal properties of the 20 GeV spectrometer.**

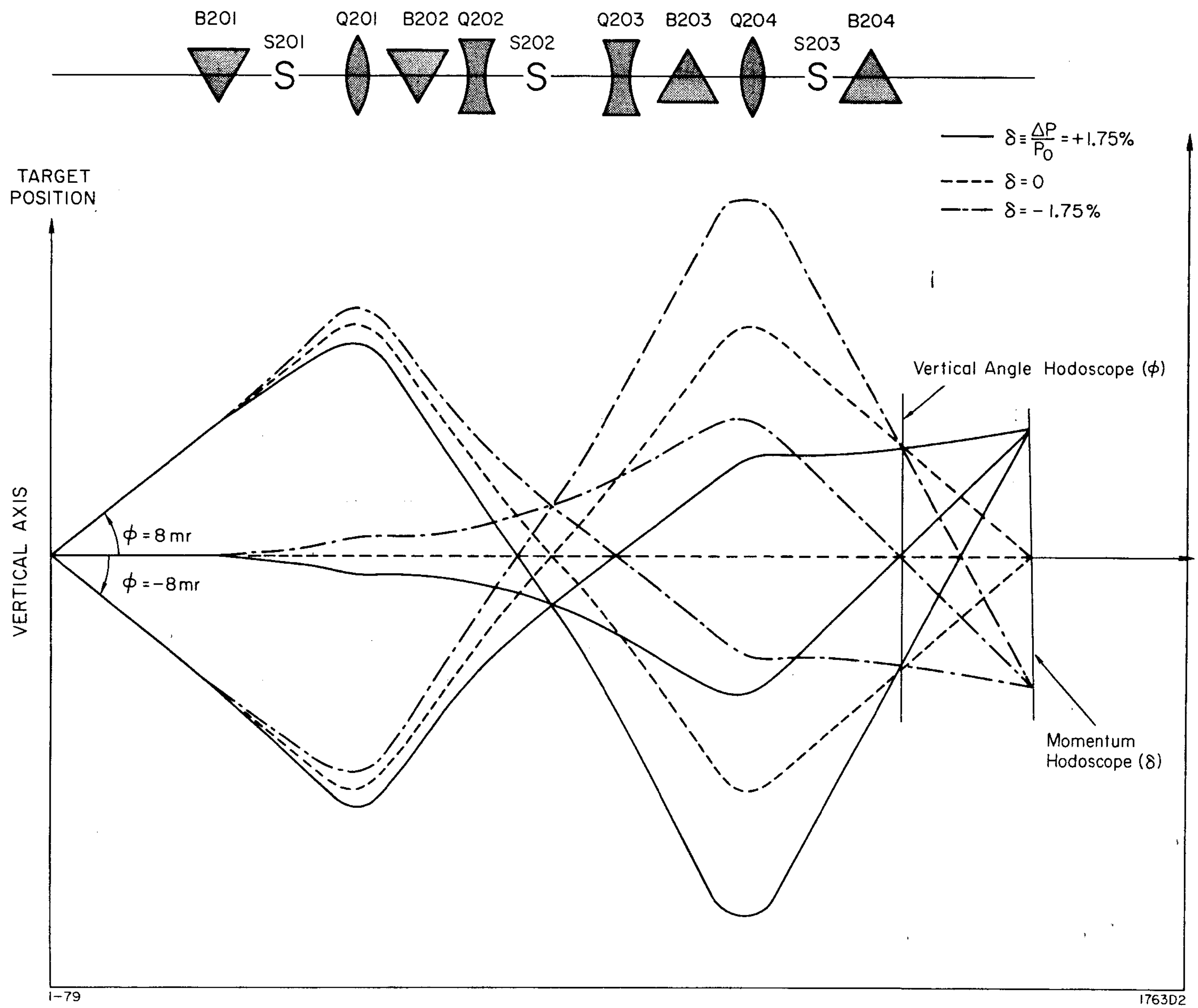


**Fig. 10. Vertical plane first-order focal properties of the 20 GeV spectrometer.**

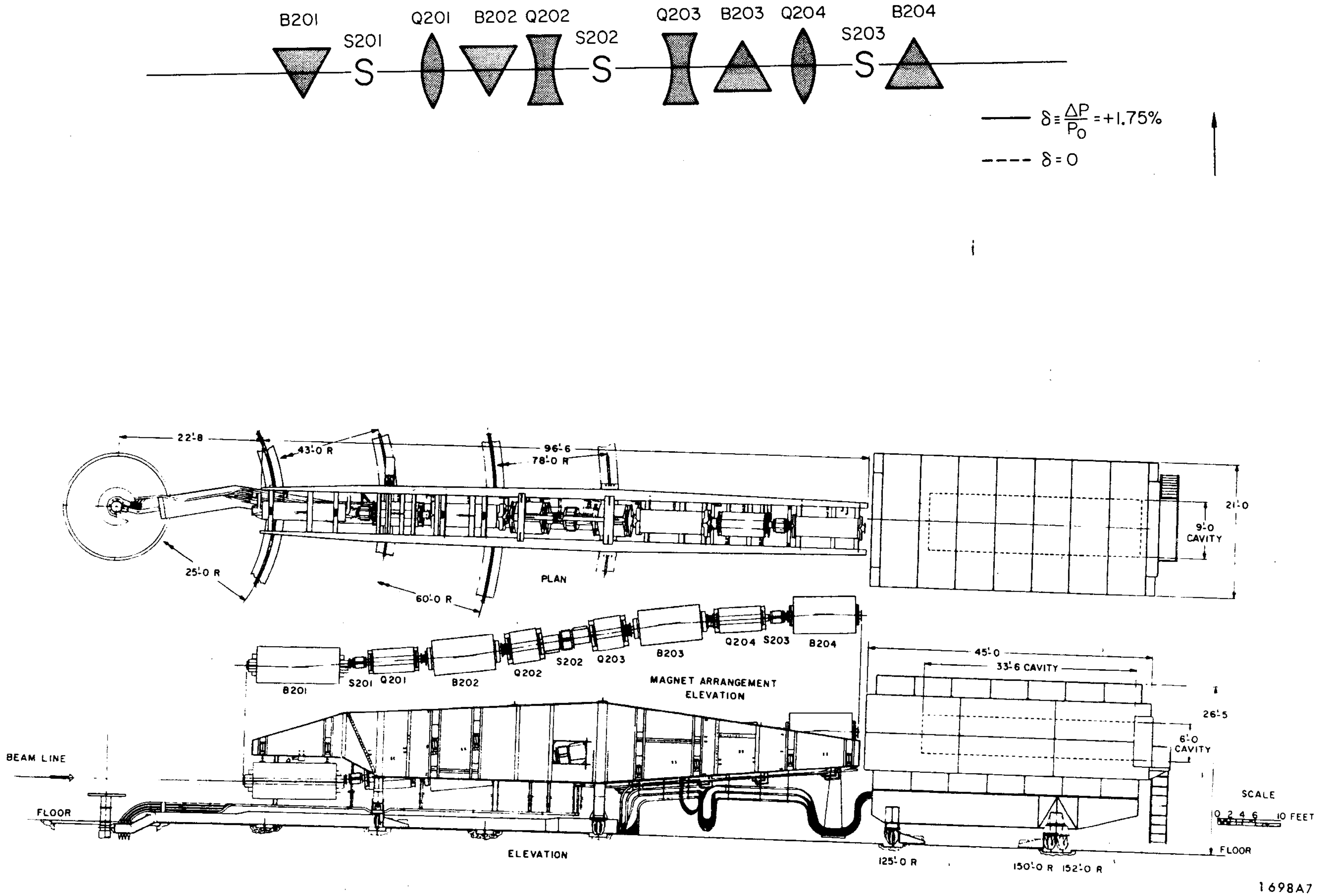


Fig. 11. 20 GeV spectrometer assembly.

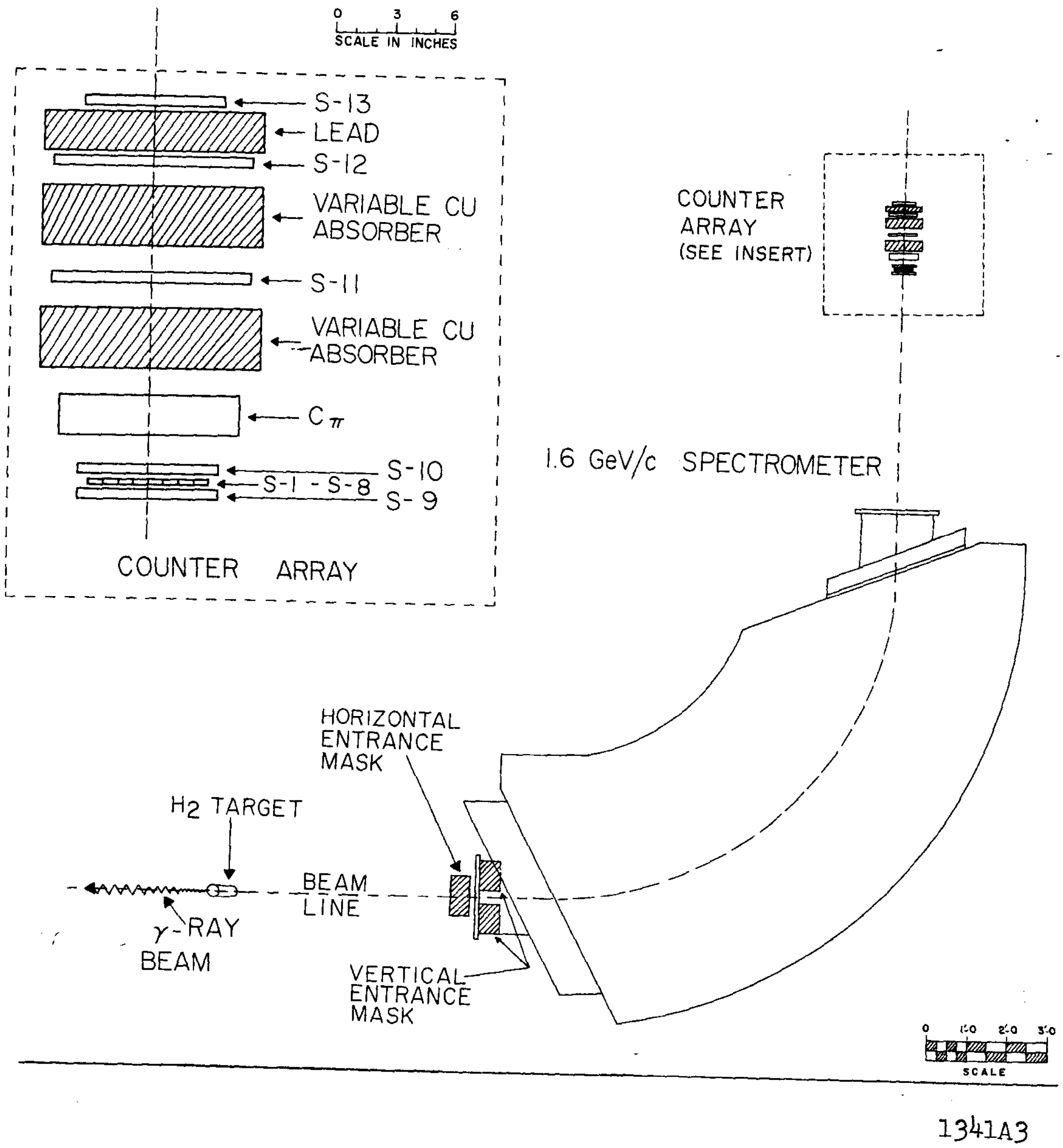


Fig. 12. A typical detector scheme in the 1.6 GeV spectrometer.