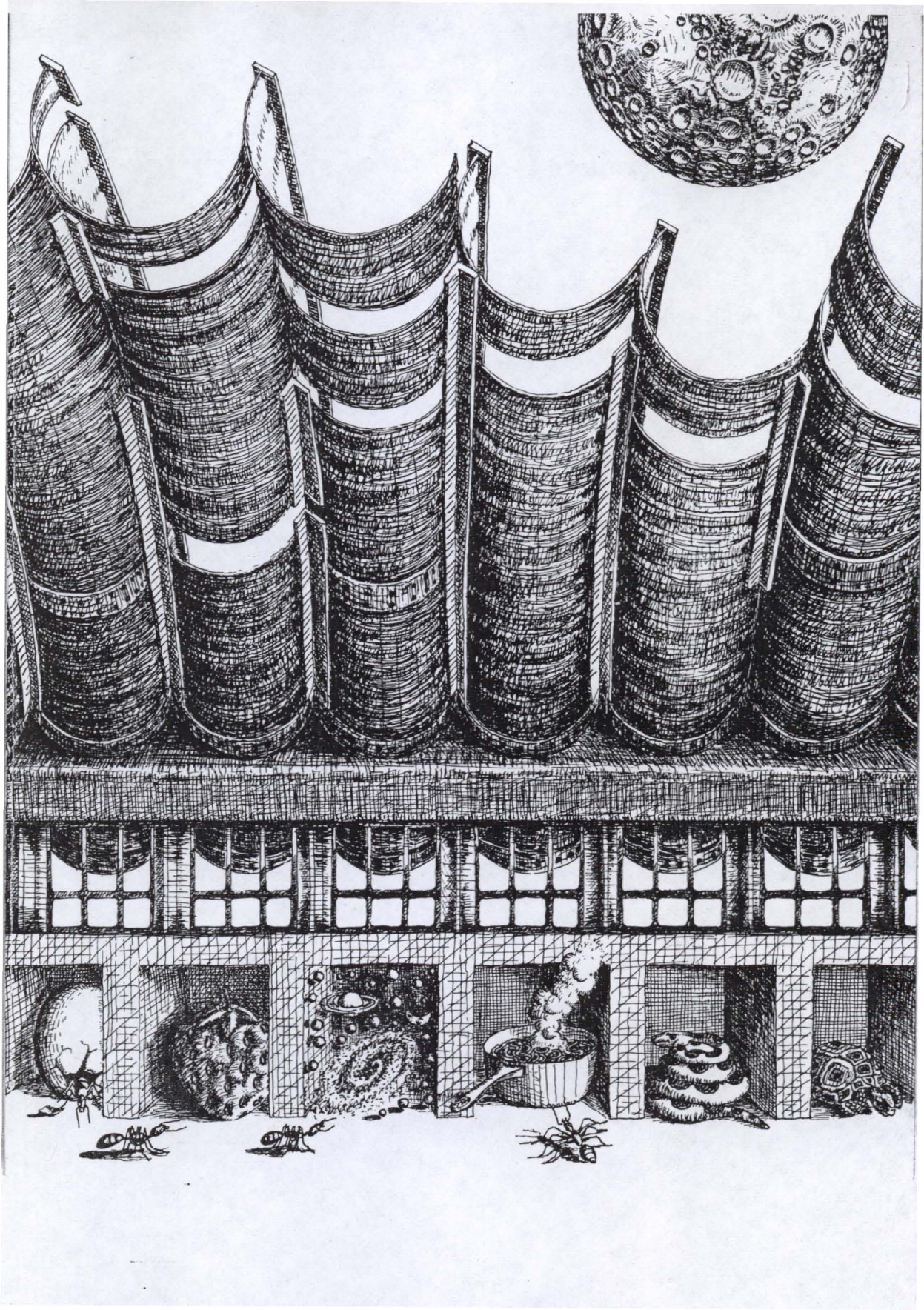

# Meson Laboratory

## Preliminary Design Report
## March 1971

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TABLE OF CONTENTS

Preface . . . . . v

Abstract . . . . . vii

I. Introduction . . . . . 1

A. Purpose and Scope . . . . . 1

B. Summary of the Design. . . . . 2

II. Detailed Beams and Other Systems Descriptions . . . . . 3

A. Extracted Proton Beam . . . . . 3

B. Targeting and Target Box . . . . . 5

C. Secondary Beam M1, 3.5-mrad Beam . . . . . 6

D. Secondary Beam M2-Diffracted Proton Beam . . . . . 11

E. Secondary Beams M3 (Neutron Beam) . . . . . 14
and M4 ($K_L^o$ Beam)

F. Secondary Beam M5-15 mrad Beam . . . . . 19

G. Secondary Beam M6, 2.5-mrad Beam . . . . . 22

H. Monitor Channel . . . . . 26

I. Beam-Line Equipment . . . . . 28

J. Physical Plant . . . . . 32

K. Costs and Schedules. . . . . 36

L. Some Future Options . . . . . 36

# PREFACE

This report is directed at a wide variety of readers; in some instances it will be a physicist who is planning an experiment in the Meson Laboratory, in others it will be an employee of NAL who is working in the Meson Laboratory. In any case, the object of this report is to explain precisely what it is that we are planning to build. The report is divided into two parts. In the first part the purpose and scope of the Meson Laboratory are discussed and a summary of its design is presented. In the second part of the report the particle beams and associated facilities in the Meson Laboratory are described in detail.

The design of the Meson Laboratory has been inspired and guided by NAL Director Robert Wilson. In addition, many NAL staff members have contributed in widely varying degrees to the design, so it is not possible to give proper credit to them. A list of principal contributors to the work described in each chapter of the report is given under the chapter heading. The people whose names have been listed have not participated in the writing of the report and therefore cannot be held responsible for the material contained herein. The work of E. J. Bleser, D. P. Eartly, A. W. Maschke, and J. R. Sanford has been so extensive that for simplicity their names have not been added to more than two lists.

Architectural-engineering design work has been performed by DUSAF, a joint venture of four firms: Daniel, Mann, Johnson and Mendenhall; the Office of Max O. Urbahn; Seelye Stevenson Value and Knecht, Inc.; George A. Fuller Company.

Shirley Burton, Angela Gonzales, and James Sanford have all assisted greatly in the preparation of this report.

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# NATIONAL ACCELERATOR LABORATORY MESON LABORATORY PRELIMINARY DESIGN REPORT

J. R. Orr and A. L. Read

March 1971

## ABSTRACT

This report describes the design of the Meson Laboratory at the National Accelerator Laboratory. Included in the report are descriptions of the overall plan of the Meson Laboratory, the designs of the six secondary particle beams, the beam-line equipment, and the conventional facilities. Plans for the early phases of the high-energy physics research program are briefly discussed.

# I. INTRODUCTION

## A. Purpose and Scope

One of the major research facilities being built for use with the 200-500 BeV proton synchrotron of the National Accelerator Laboratory is the Meson Laboratory. It will be used to provide a variety of general-purpose secondary particle beams produced by bombardment of metal targets by the 200-BeV proton beam from the accelerator. The Meson Laboratory is so named because most of the secondary beams are meson beams ($\pi^{\pm}$, $K^{\pm}$, and also $K_L^o$), although there are in addition two other secondary beams--a neutron beam and a diffracted proton beam.

Many of the high-energy physics experiments which are planned for the next two to three years at NAL can be carried out by the repeated use of relatively fixed secondary particle beam lines. A set of six such semi-fixed beam lines is the dominant feature of the design of the Meson Laboratory. The secondary beam lines consist of a rather economical configuration of small concrete enclosures to house the beam components. The enclosures will be covered by an earthen mound 10-20 ft thick for hadron shielding and approximately 1000 ft long for muon shielding.

At the end of the secondary beam lines, the particles emerge from the earthen shield into a building which houses the experimenters and their experiments. There will be a transverse beam-to-beam separation of about 40 ft to provide space for the experimental apparatus.

The six secondary particle beams to be built in the Meson Laboratory are as follows:

Beam M1 ("3.5-mrad beam")--a high-energy beam of charged $\pi$ and K mesons, protons, and antiprotons, of energies up to about 200 BeV, produced at an angle of 3.5 mrad.

Beam M2 ("diffracted proton beam")--a secondary ("diffracted") beam of 200-BeV protons, also capable of providing useful fluxes of negative pions with reversed magnet polarities.

Beam M3 ("neutron beam")--a neutral beam produced at a target at a very small angle (1.75 mrad) to the 200-BeV primary proton beam--this beam consists mostly of neutrons.

Beam M4 ("$K^o$ beam")--a second neutral beam produced at a larger angle (6.5 mrad)--this beam contains more $K^o$ particles relative to neutrons than does the neutron beam (M3).

Beam M5 ("15-mrad beam")--a medium-energy beam (energies up to about 80 GeV) of charged $\pi$ and K mesons, protons, and antiprotons produced at 15 mrad.

Beam M6 ("2.5-mrad beam")--a high-energy beam of $\pi$ and K mesons, protons, and antiprotons (energies up to about 180 BeV) with extremely well-defined particle energies--the energy spread of the beam is to be less than 1/10 of 1%. This is the so-called "high resolution" beam; its production angle is 2.5 mrad.

## B. Summary of the Design

The NAL accelerator is in the form of a large ring located in the southwest quadrant of the site (see Fig. 1). During acceleration, the protons travel around this ring in a clockwise direction, gaining energy on each revolution as they pass through the "rf" or acceleration system. At full energy, (200 BeV for the Meson Laboratory), the proton beam is extracted from the accelerator at straight section A0. When the protons are used for experiments in the Meson Laboratory (see Fig. 2), the 200-BeV extracted proton beam is deflected to the left, under the master substation, and is bent up to the Meson Laboratory target area.

At the target, the six secondary particle beams will be produced. These beams will be semi-fixed installations, for repeated use by experimenters. The beams are defined in size by a system of slits (collimators) and are transported with use of beam-transport magnets to a 246 ft × 158 ft building (Meson Laboratory Building) which houses the experiments. This building is situated at the far end of a 1,000-ft long earthen radiation shield which is needed in order to reduce the amount of background radiation (mostly muons) to a low enough level for safe personnel protection.

The secondary particle beams are produced by a common proton-beam targeting system (see Fig. 3). At the downstream end of a pre-target enclosure which houses the final elements of the proton-beam transport system, the proton beam enters a steel box ("Meson Target Box") of length 80 ft. The production target for secondary beams is located in the middle of this target box. The target box is needed in order to make possible the positioning, repair, and placement of the highly radioactive metal targets and associated apparatus.

Bending magnets placed just upstream of the production targets are used to vary the angle of incidence of the proton beam upon the target, thereby making it possible to vary the angles of incidence of the proton beam upon the target. Thus, one can vary the angles at which the secondary beams of particles are produced. Following the production target, the unused protons and the unwanted particles that are produced (mostly "hadrons") are stopped by a beam dump and a hadron radiation shield. The secondary beams pass through variable-aperture slits which serve as secondary-beam intensity controls. The first several components in the secondary beams--dipole and quadrupole magnets, mostly--are housed in an underground vault ("Front End Hall") which is covered by earth for hadron radiation shielding purposes (see Fig. 3).

Upon leaving the Front End Hall, the individual secondary beams pass through small concrete enclosures--connected where there are no active beam-line elements by sections of vacuum pipe (see Figs. 4, 5, 6, 7, and 8). In this region, the beam-line enclosures are covered by an earthen radiation shield 1,000 ft long. The primary function of this shield is to stop the muons which arise from the decay of $\pi$ mesons and K mesons which are produced at the target in the target box.

At the end of the muon shield, the four beams of charged particles (M1-3.5-mrad beam, M2-diffracted proton beam, M5-15-mrad beam, and M6-2.5-mrad beam) and the small-angle neutral beam (M3 neutron beam) emerge into an experimental hall of 245 ft width and 158 ft depth (see Fig. 9). Experiments will be set up in this building, side by side, with appropriate radiation shielding between them. For experiments which extend beyond the north wall of the building, special auxiliary structures will be built to house the apparatus.

In the case of the large-angle neutral beam (M4-$K^o$ beam) which reaches the experimental area at a lower elevation than the other five secondary beams, a special 350 ft long trench will be built, to the north of the experimental hall, to house the apparatus for experiments using this beam.

Outdoor areas in the 3.5-mrad beam (M1) and in the 2.5-mrad beam (M6) immediately upstream of the experimental hall, are provided for large-volume liquid hydrogen targets.

## II. DETAILED BEAMS AND OTHER SYSTEMS DESCRIPTIONS

### A. Extracted Proton Beam (A. Maschke and R. Mobley)

The secondary beams in the Meson Laboratory are produced by a beam of 200-BeV protons which is extracted from the NAL accelerator and then transported to strike a metal target inside the target box.

The design intensity of the accelerator is $5 \times 10^{13}$ protons/pulse. The planned accelerator cycle for long spill at 200-BeV proton energy is four seconds in length, including a 1 second flat-top for electronic experiments. This corresponds to a duty factor of 25%, with an instantaneous proton-beam intensity during flat-top of $5 \times 10^{13}$ protons/sec and an average beam intensity of $1.3 \times 10^{13}$ protons/second.

The calculated emittances and duty cycles of the external proton beam, at synchrotron energies of 50 GeV and 200 GeV, are shown in Table I. The energy spread of the accelerated proton beam is about 0.01%.

At a given energy, the emittances $E_H$ and $E_V$ are fixed. However, with the use of an appropriate set of quadrupole focusing elements, it is of course possible to increase (and decrease), in inverse proportion to one another, the size and divergence of the proton beam incident upon a given secondary beam-production target.

Table I. Proton-Beam Emittances (Calculated).

| Energy (GeV) | Spill | $E_H$ horiz. (mm × mrad) | $E_V$ vert. (mm × mrad) | Duty Cycle |
|---|---|---|---|---|
| 50 | Slow | 1.0 | 1.5 | ~25% |
| 200 | Fast | 0.7 | 0.3 | |
| 200 | Slow | 0.2 | 0.3 | ~25% |

The proton beam is extracted from the main accelerator in the Transfer Hall and is transported to the experimental areas through a series of earth-covered concrete enclosures which are connected, where there are no beam-line components, by evacuated beam pipes.

Figure 10 shows the tunnel and magnet layout for the proton-beam transport system to the Meson Laboratory. Figure 11 shows a typical beam-transport enclosure cross section. The magnets will be hung from brackets embedded in the concrete, allowing more free space for passage of large components. The accessways have been designed to allow installation of 12-ft long magnets. The beam lines from tunnel to tunnel pass through evacuated 12 in. or 8 in. steel pipe in most cases. The sectional tunnel design has two advantages, namely that possible radiation areas are decoupled and also that the pipe lines are possible locations for clean-up collimators.

The focusing system consists of a number of quadrupole lens doublets. The placements and settings of the quadrupoles have been calculated to meet the following requirements:

1. The acceptances of the beam systems are sufficient for a fast-extracted beam with emittances specified in the NAL Design Report:

$$\pi E_H = 0.23 \times 10^{-6} \text{ m-rad}$$

and at 200 GeV/c

$$\pi E_V = 0.09 \times 10^{-6} \text{ m-rad.}$$

The lowest momentum at which we can transport the entire proton beam from the main ring is 50 GeV/c.

2. The acceptable band width is $\Delta p/p = \pm 10^{-3}$. This is greater than expected from the main ring but allows reasonable tolerances on the currents in the dipole magnets.

3. The beam sizes at locations reserved for beam splitting stations are compatible with gap widths of approximately one centimeter for the electrostatic septa.

4. The spacing between F and D quadrupoles in the system of doublets is the preferred free parameter, so that as many as possible of the quadrupoles can be powered in series. Small shunt supplies can be used for those few quadrupoles which require slightly different currents.

5. Both the horizontal and the vertical bending of the beam are achromatic.

B. Targeting and Meson Target Box (D. Eartly and A. Maschke)

The design of appropriate proton-beam targets and beam stops is especially difficult with the proton-beam energies and intensities which will be available at NAL. The power in a beam of $1.3 \times 10^{13}$, 200-BeV protons per second is about 400 kilowatts. This gives rise to tremendous heating problems for targets and beam dumps; the levels of induced radioactivity in these elements and their associated cooling systems will be correspondingly high. This beam power is approximately two orders of magnitude greater than the beam power at the Brookhaven AGS.

The central feature of the targeting system which has been developed to handle the targeting and dumping of the 400 kilojoule proton beam is a so-called "Target Box" (see Fig. 12). This box is a steel structure of cross section 44 in. × 44 in. by 80-ft long and is covered by earth and iron to provide the requisite hadron shielding. The proton beam will hit the secondary-beam production target about halfway along the Meson Target Box.

Components are moved into the Meson Target Box on railroad cars. Because the radioactivity of the target and beam stop will be $\sim 10^3$-$10^4$ R/hour when removed from the box, it will be necessary to be able to make adjustments to the target and other elements by remote control. This will be accomplished by removal of the target train from the box by remote control and bringing the train into an area serviced by mechanical manipulators and cranes.

Sequentially, the components in the Meson Target Box (see Fig. 12) will be a collimator to protect the upstream (service) end of the target box from backstreaming radiation from the target, three proton-beam steering magnets (horizontal bends), beam instrumentation, a target manipulator, a proton-beam spoiler and stop, fixed secondary-beam collimators (which define the production angles and solid angles of the beams), variable horizontally-defining collimators and a group of fixed vertically-defining collimators. The apertures of the collimators will be set to provide the desired fluxes of secondary particles into the experimental area. When a particular secondary beam is not being used, the appropriate collimators will be closed.

The three proton-beam steering magnets are small-gap, air-cooled dipole magnets, and are powered in series. These magnets will be used to manipulate the proton beam before it hits the target. In this way, the angle of production of secondary particles in fixed beam lines can be changed. The proton beam-line instrumentation will include a torroid for absolute calibration of the proton-beam intensity, a secondary emission monitor, a profile monitor, and a differential displacement detector to locate the position of the beam and to provide appropriate servo signals for the proton-beam control system.

The target manipulator allows one to move any of 8 possible targets into the proton beam. At present, the plan is to have small diameter (1 mm, 1-1/2 mm) beryllium and tungsten targets, larger diameter (2-3 mm) beryllium and tungsten targets, a carbon or aluminum target, a spare, and one target mount of mirrors for auto-collimation of the reference trajectories of secondary beams.

The proton beam dump will consist of a water-cooled aluminum block with fixed collimator apertures for the secondary beam lines, and a projecting blade of aluminum or beryllium to spread the nuclear cascade (energy deposition) before the proton beam impinges on the aluminum block. Subsequently, there is another iron block of fixed-aperture collimators, with shutters.

C. Secondary Beam M1, 3.5-mrad Beam (T. L. Collins and K. P. Pretzl)

This beam is produced at 3.5 mrad with respect to the incident proton beam and has a maximum momentum capability of 200 GeV/c. An important criterion in the design of this beam has been the emphasis on high intensity rather than on good energy definition of the secondary particles transported along the beam line. A list of the components used in the 3.5-mrad beam (M1) and of its principal design parameters, is given in Table II.

The 3.5-mrad beam (M1) has a solid angle of acceptance of 2 $\mu$sr at the production target and has energy acceptance $\Delta E/E$ of $\pm 2\%$. If desired, energy-definition with a precision of $\Delta E/E = 0.2\%$ can be obtained in this beam line.

A typical estimate of intensity of particles in the 3.5-mrad beam (M1) is $10^7$ 150-GeV $\pi$ mesons/pulse (see Figs. 13 and 14). In the first experiments using this beam, the total cross sections of protons, antiprotons, $\pi$ mesons, and K mesons, on targets of hydrogen and deuterium, will be measured at various particle energies. In later experiments, the elastic scattering of these particles, at various angles, for different particle energies, will be measured.

The principal features of the beam, its solid-angle acceptance, its momentum acceptance and its momentum resolution, are all defined by the first stage of the beam, which reaches to the first focus. A half-quadrupole doublet $Q_1Q_2$ focuses the particles horizontally point-to-point and vertically point-to-line 440 feet downstream of the production target. A string of four bending magnets (with a total bend angle of 37.2 mrad) separates the beam horizontally from its neighbor beams and provides a 3 cm/% $\Delta p/p$ dispersion at the first focus. The horizontal object magnification at that focus is about 2.0.

Momentum recombination is achieved in the second stage of the beam, which consists of the part between the first and second foci. The off-momentum rays will be recombined by a quadrupole doublet $Q_3Q_4$, which acts as a field lens in front of the

first focus, and by a string of three bending magnets with a total bend angle of 36.0 mrad. The doublet $Q_5Q_6$ then provides a horizontal and a vertical image at a point 886 ft downstream of the production target with horizontal and vertical magnifications of 1.0 and 2.0 respectively.

The third and final stage of the beam, roughly 550 ft long, is designed to be flexible enough to match different beam-optics requirements for the different experiments. The basic transport elements in this section are two symmetric quadrupole lens triplets $Q_7Q_8Q_9$ and $Q_{10}Q_{11}Q_{12}$ which provide point to parallel and then parallel to point focusing in both planes. The length of the parallel section is 120 ft and can be enlarged or shortened by moving the two triplets along their optic axis. This drift distance of 120 ft is sufficient to place one threshold Cerenkov counter (100 ft long) and one DISC Cerenkov counter (15 ft long) in between the triplets. Additional threshold Cerenkov counters can be placed before and/or after the parallel section of the beam. Figure 15 shows the calculated beam profiles.

An optional bending magnet downstream of the second triplet $Q_{10}Q_{11}Q_{12}$ can be used to provide a momentum dispersed beam at the final focus. In this way the third stage of the beam could serve as an incident beam spectrometer.

The beam-transport system design is based on the use of main-ring elements and external proton-beam elements. It includes five B-2 magnets, two 3Q52 (4.33 ft long) quadrupoles, one 3Q84 (7 ft long) quadrupole and 11 external proton-beam quadrupoles (10 ft long).

Specific designs for the elements at the very front end of the beam are necessary in order to match the special geometric and other constraints in that region. For focusing magnets at the beginning of the beam, two 10-ft quadrupoles with 3-in. bore (proton-beam quadrupoles) will be sliced in half. A 1-in. thick mirror plate covers the missing half of a quad and projects 6 in. beyond the rest of the magnet at each end, in order to give reasonable end fields. These quads will be used for the first doublet $Q_1Q_2$ in the 3.5-mrad beam (M1). $Q_1$ is made out of two 10 ft half quads and $Q_2$ out of one 10 ft half quad.

Downstream of the half quads there will be two 10 ft long septum dipole magnets. Their design specifications are 4 in. gap width, 2 in. gap height, 15 kG maximum field, and 2 in. maximum septum width. Special emphasis will be placed in the design of these magnets on the use of power supplies similar to main-ring power supplies.

Considerable improvements on the final spot sizes of the beam can be made by introducing three sextupole magnets (see Table II). In order to correct for small vertical misalignments of the beam-transport elements, 7 vertical vernier magnets will be used. Their positions are specified in Table II. Small adjustments to the

Table II(a). High Energy-High Intensity Beam M1, 3.5 mrad.

| | | | |
|---|---|---|---|
| **Production Target** | | | |
| Material | | Tungsten | |
| Width | | ±0.02 | in. |
| Height | | ±0.02 | in. |
| Length | | 6.00 | in. |
| **Production Angle** | $\theta_p$ | 3.91 | mrad |
| **Lab Angle** | $\theta_v$ | 0.0 | mrad |
| | $\theta_h$ | -3.0 | mrad |
| **Momentum Range** | | | |
| Minimum | $p_{0_{min}}$ | 20 | BeV/c |
| Maximum | $p_{0_{max}}$ | 200 | BeV/c |
| **Solid Angle** | $\Delta\Omega$ | 2.0 | μsr |
| **Angular Acceptance** | | | |
| Horizontal | $\Delta\theta_h$ | ±0.35 | mrad |
| Vertical | $\Delta\theta_v$ | ±2.0 | mrad |
| **Momentum Bite** | | | |
| Minimum | $\Delta p/p$ | ±0.1 | % |
| Maximum | $\Delta p/p$ | ±2.0 | % |
| **Dispersion at Momentum Slit** | $\frac{\Delta x}{\Delta p/p}$ | 3.0 | cm/% |
| **Beam Properties at Experiment (for $\Delta p/p \pm 1.0\%$) Without Sextupole** | | | |
| Beam Width | $\Delta x_f$ | ±0.50 | cm (sec order) |
| Horizontal Divergence | $\Delta x'_f$ | ±0.44 | mrad |
| Beam Height | $\Delta y_f$ | ±0.54 | cm (sec order) |
| Vertical Divergence | $\Delta y'_f$ | ±0.65 | mrad |
| **Nominal Beam Length** | | 1407 | ft |

Table II(b). High Energy-High Intensity Beam M1, 3.5 mrad - Coordinates.

| Z Cent. (ft) | X Cent. (ft) | Position Code | Element Code | B/G(kG) or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 0 | 0 | M1T1 | EPB Target | | | |
| 26.7 | -0.08 | M1C0 | Fixed Collim. | | | |
| 40.5 | -0.12 | M1C1 | Horiz. Collim. 6 ft | | | |
| 45.5 | -0.14 | M1C2 | Vert. Collim. 3 ft | | | |
| 55.0 | -0.17 | M1Q1 | 1/2 Quad. 3Q120 | -2.97 | | |
| 67.0 | -0.20 | M1Q2 | 1/2 Quad. 3Q120 | -2.97 | | |
| 97.0 | -0.29 | M1Q3 | 1/2 Quad. 3Q120 | +4.04 | | |
| 121.5 | -0.36 | M1B1 | Sept. 3-2-120 | -14.4 | | |
| 132.5 | -0.47 | M1B2 | Sept. 3-2-120 | -14.4 | | |
| 163.1 | -0.97 | M1C3 | Vert. Collim. 6 ft | | | |
| 170.1 | -1.08 | M1C4 | Horiz. Collim. 6 ft | | | |
| 176.1 | -1.17 | M1X1 | Sext. 4×30 | | | |
| 189.1 | -1.39 | M1B3 | Bend 4-2-240 | -13.13 | -3399. | 82.5 |
| 210.5 | -1.99 | M1B4 | Bend 4-2-240 | -13.13 | -3399. | 82.5 |
| 224.9 | -3.37 | M1V1 | Vert. Vern. 6-4-30 | ±4.0 | ±224. | 9.3 |
| 316.0 | -6.23 | M1P1 | Beam Pipe (12 in. nom) 95.4 ft | | | |
| 373.8 | -8.56 | M1V2 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 398.5 | -9.55 | M1V3 | Sext. 4×30 | | | |
| 404.5 | -9.80 | M1Q4 | Quad. 3Q84 | -4.64 | -3383 | 51.5 |
| 414.6 | -10.20 | M1Q5 | Quad. 3Q52 | 4.54 | +3310 | 28.6 |
| 419.4 | -10.39 | M1Q6 | Quad. 3Q52 | 4.54 | +3310 | 28.6 |
| 429.0 | -10.78 | M1X2 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 445.5 | -11.44 | M1C5 | Horiz. Collim. 3 ft | | | |
| 449.5 | -11.60 | M1C6 | Vert. Collim. 3 ft | | | |
| 452.2 | -11.71 | M1M1 | Profile Monitor | | | |
| 453.3 | -11.76 | M1M2 | Intensity Monitor | | | |
| 542.5 | -15.34 | M1P2 | Beam Pipe (12 in. nom) 196.5 ft | | | |
| 654.4 | -19.85 | M1V4 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 670.5 | -20.49 | M1C7 | Vert. Collim. 6 ft | | | |
| 678.5 | -20.81 | M1C8 | Horiz. Collim 6 ft | | | |
| 684.6 | -21.06 | M1M3 | Profile Monitor | | | |
| 688.0 | -21.20 | M1X3 | Sext. 4×30 | | | |
| 701.0 | -21.72 | M1B5 | Bend 4-2-240 | -13.13 | -3399 | 82.5 |
| 722.3 | -22.83 | M1B6 | Bend 4-2-240 | -13.13 | -3399 | 82.5 |

| Z Cent. (ft) | X Cent. (ft) | Position Code | Element Code | B/G(kG) or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 743.7 | -24.21 | M1B7 | Bend 4-2-240 | -13.13 | -3399 | 82.5 |
| 761.2 | -25.55 | M1Q7 | Quad. 3Q120 | +3.88 | 82.2 | 9.0 |
| 788.0 | -27.59 | M1Q8 | Quad. 3Q120 | -2.36 | -50.0 | 3.3 |
| 799.0 | -28.43 | M1Q9 | Quad. 3Q120 | -2.36 | -50.0 | 3.3 |
| 807.5 | -29.08 | M1V5 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 846.0 | -32.02 | M1P3 | Beam Pipe (12 in. nom) 73.5 ft | | | |
| 885.8 | -35.05 | M1C9 | Horiz. Collim. 3 ft | | | |
| 889.7 | -35.36 | M1C10 | Vert. Collim. 3 ft | | | |
| 892.7 | -35.58 | M1M4 | Profile Monitor | | | |
| 894.7 | -35.74 | M1V6 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 896.7 | -35.89 | M1M5 | Intensity Monitor | | | |
| 1010.4 | -44.57 | M1Q10 | Quad. 3Q120 | -3.31 | -70.1 | 6.5 |
| 1025.4 | -45.71 | M1Q11 | Quad. 3Q120 | 3.15 | 66.9 | 5.9 |
| 1036.3 | -46.55 | M1Q12 | Quad. 3Q120 | 3.15 | 66.9 | 5.9 |
| 1051.3 | -47.69 | M1Q13 | Quad. 3Q120 | -3.31 | -70.1 | 6.5 |
| 1107.2 | -51.96 | M1K1 | Threshold Counter 100 ft | | | |
| 1166.4 | -56.48 | M1K2 | DISC Counter 17 ft | | | |
| 1180.9 | -57.59 | M1Q14 | Quad. 3Q120 | -2.99 | -63.3 | 5.3 |
| 1195.9 | -58.73 | M1Q15 | Quad. 3Q120 | 2.87 | 60.9 | 4.9 |
| 1206.8 | -59.57 | M1Q16 | Quad. 3Q120 | 2.87 | 60.9 | 4.9 |
| 1221.8 | -60.71 | M1Q17 | Quad. 3Q120 | -2.99 | -63.3 | 5.3 |
| 1227.9 | -61.18 | M1M6 | Profile Monitor | | | |
| 1230.3 | -61.35 | M1V7 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1234.2 | -61.66 | M1V8 | Horiz. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1304.3 | -67.01 | M1K3 | Threshold Counter 100 ft | | | |
| 1374.3 | -72.35 | M1M7 | Profile Monitor | | | |
| 1376.3 | -72.51 | M1M8 | Intensity Monitor | | | |

central trajectory in the horizontal plane will be made by the bending magnets in the transport system itself. Only one horizontal vernier magnet, placed after the last quadrupole triplet, is needed--to correct the beam trajectory into the Meson Laboratory Building.

All main-ring elements in this beam will be powered by modified main-ring power supplies. In the beam design, an effort has been made to allow for powering

as many as possible transport elements in series. All main-ring dipole magnets, the special septum dipoles and also the quadrupoles $Q_3$ and $Q_4$ can be powered by one single power supply. Fixed shunts and adjustable shunts will be provided to match the required small differences (on the order of a few percent) in the currents in various elements and to allow individual current regulation for the elements, where that is needed.

The special magnets, such as verniers, sextupoles and half quads will need their own individual power supplies. For the vernier magnets and the half quads, designs for the power supplies are already available. The quadrupoles in the third stage of the 3.5-mrad beam (M1) will have individual power supplies so that one can vary the focal properties of the beam for different experiments.

The required power-supply regulation for the 3.5-mrad beam (M1) components should be at least as good as 0.1% of the current reading for the quadrupoles and 0.05% for the bending magnets.

In addition to the beam-defining collimators in the Meson Target Box, the 3.5-mrad beam (M1) requires two types of steel collimators with 1/2-in. thick tungsten liners and variable remote-controlled apertures. Both horizontal and vertical collimators, of 3 ft length, will be used at the first and at the second focus of the beam. Other, "clean-up" collimators of 6 ft length will be used at two other points along the beam (see Table II). At these latter locations, the horizontal and vertical beam dimensions are large and a collimator is particularly effective in removing beam halo without affecting the desired beam particles.

D. Secondary Beam M2-Diffracted Proton Beam (J. Sculli and T. White)

The diffracted proton beam (M2) will have an intensity of about $10^{10}$ diffracted protons/pulse. This beam feeds what has been termed a "medium intensity end-station" for studies of proton-proton interactions and of short-lived particles such as hyperons.

The beam uses the same production channel in the Meson Target Box as the small-angle neutral beam (M3-neutron beam) which is described in Section E below. The first sweeping elements in the neutron beam (M3)--for removal of charged particles from that beam--deflect the diffracted protons into a separate transport channel. The diffracted proton beam (M2) is dispersed and focused onto cleanup slits about 600 ft from the production target. In the second half of the beam, momentum recombination in both position and angle is effected. The maximum allowed intensity of this beam will be dictated by radiation shielding needs and problems in the experimental area. A maximum allowed intensity of about $10^{10}$ diffracted protons/pulse is anticipated.

The original design was based on the use of main-accelerator dipole and quadrupole magnets. However, it is expected that the beam will be built with external proton-beam magnets. A list of beam-line components based on the use of proton-beam dipole and quadrupole magnets, is given in Table III. Vernier magnets are

Table III(a). Diffracted Proton Beam M2, 1.75 mrad.

| | | 200 BeV/c Nominal Operation | |
|---|---|---|---|
| **Production Target** | | | |
| Material | | Tungsten | |
| Width | | ±0.02 | in. |
| Height | | ±0.02 | in. |
| Length | | 4.0 | in. |
| **Production Angle** | $\theta_p$ | 1.75 | mrad |
| **Lab Angle** | $\theta_v$ | 0.0 | mrad |
| | $\theta_h$ | 0.0 | mrad |
| **Momentum Range** | | | |
| Minimum | $p_{0_{min}}$ | 20 | BeV/c |
| Maximum | $p_{0_{max}}$ | 200 | BeV/c |
| **Solid Angle** | $\Delta\Omega$ | 0.22 | μsr |
| **Angular Acceptance** | | | |
| Horizontal | $\Delta\theta_h$ | ±0.42 | mrad |
| Vertical | $\Delta\theta_v$ | ±0.17 | mrad |
| **Momentum Bite** | | | |
| Minimum | $\Delta p/p$ | ±0.1 | (Intrinsic) % |
| Maximum | $\Delta p/p$ | ±1.3 | (Acceptance) % |
| **Dispersion at Momentum Slit** | $\frac{\Delta x}{\Delta p/p}$ | 1.04 | in./% |
| **Beam Properties at Experiment** | | | |
| Beam Width | $\Delta x_f$ | ±0.025 | in. |
| Horizontal Divergence | $\Delta x'_f$ | ±0.34 | mrad |
| Beam Height | $\Delta y_f$ | ±0.025 | in. |
| Vertical Divergence | $\Delta y'_f$ | ±0.14 | mrad |
| **Nominal Beam Length** | L | 1350 | ft |

Table III(b). Diffracted Proton Beam M2, 1.75 mrad - Coordinates.

| Z Cent. (ft) | X Cent. (ft) | Position Code | Element Code | B/G(kG)or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 0 | 0 | M2T1 | EPB Target | | | |
| 26.7 | 0 | M2C0 | Fixed Collim. | | | |
| 40.5 | 0 | M2C1 | Horiz. Collim. 6.0ft | | | |
| 45.5 | 0 | M2C2 | Vert. Collim. 3.0ft | | | |
| 202.0 | 0 | M2Q1 | Quad. 3Q120 | +3.12 | +66.1 | 5.8 |
| 234.0 | 0 | M2Q2 | Quad. 3Q120 | -2.89 | -61.2 | 5.0 |
| 246.2 | -0.02 | M2B1 | Bend. 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 257.7 | -0.09 | M2B2 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 265.0 | -0.17 | M2V1 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 306.5 | -0.70 | M2P1 | Beam Box 65.0 ft | | | |
| 348.5 | -1.24 | M2P2 | Beam Pipe (12 in. nom) 29.7 ft | | | |
| 366.0 | -1.46 | M2V2 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 374.2 | -1.58 | M2B3 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 385.7 | -1.80 | M2B4 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 393.0 | -1.97 | M2M1 | Profile Monitor | | | |
| 397.0 | -2.07 | M2C3 | Horiz. Collim. 4 ft (Air atm) | | | |
| 403.0 | -2.23 | M2C4 | Vert. Collim. 4ft (Air atm) | | | |
| 527.7 | -5.93 | M2P3 | Beam Pipe (12 in. nom) 228.8 ft | | | |
| 644.0 | -8.40 | M2M2 | Profile Monitor | | | |
| 648.0 | -8.40 | M2C5 | Horiz. Collim. 4 ft (Air atm) | | | |
| 657.0 | -8.73 | M2Q3 | Quad. 3Q120 | +1.00 | +21.2 | 0.6 |
| 666.0 | -8.96 | M2C6 | Vert. Collim. 4 ft (Air atm) | | | |
| 699.2 | -13.65 | M2P4 | Beam Pipe (12 in. nom) 309.1 ft | | | |
| 1012.0 | -17.82 | M2V3 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | +9.3 |
| 1016.0 | -17.92 | M2M3 | Profile Monitor | | | |
| 1030.8 | -18.32 | M2B5 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 1042.2 | -18.69 | M2B6 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 1053.7 | -19.13 | M2B7 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 1065.2 | -19.64 | M2B8 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 1077.0 | -20.23 | M2Q4 | Quad 3Q120 | -2.82 | -58.7 | 4.7 |
| 1108.0 | -21.82 | M2Q5 | Quad 3Q120 | +2.95 | +62.5 | 5.2 |
| 1116.0 | -22.23 | M2V4 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1121.0 | -22.48 | M2V5 | Horiz. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1216.5 | -27.38 | M2P5 | Beam Pipe (12 in. nom) 188.6 ft | | | |
| 1348.0 | -34.12 | M2M4 | Intensity Monitor | | | |
| 1350.0 | -34.22 | M2M5 | Profile Monitor | | | |

provided at five points along the beam to correct for differential settlements of the floor which supports the beam-line components. The intensity and profile of the beam are monitored by segmented wire ion chambers at three points along the beam. In general, the beam line is to be under a vacuum of 100 microns pressure, or better.

The collimators for intensity control or for momentum spread control are typically 4 ft long, and made of iron. The apertures of the collimators are not evacuated, unlike most of the rest of the beam line.

## E. Secondary Beams M3 (Neutron Beam) and M4 ($K_L^o$ Beam) (E. Bleser and J. Sculli)

The small-angle (1.75 mrad) neutral beam, (M3-neutron beam), consists mostly of neutrons, with a total intensity of about $10^7$ neutrons/pulse. The beam will be used initially in a number of experiments to study neutron interactions at very high energies. Compared with the small-angle neutral beam, the large-angle (6.5 mrad) neutral beam, (M4-$K_L^o$ beam), is relatively rich in the ratio of $K^o$ mesons to neutrons; however, this beam still consists mostly of neutrons (see intensity predictions in Figs. 16 and 17). In the first experiments in the $K^o$ beam, studies will be made of the behavior of $K^o$ mesons at high energies--both their decay properties and their interactions with matter will be investigated.

The neutron beam (M3) is produced at a nominal angle of 1.75 mrad. This angle may be varied over the range 1.75 to 5.0 mrad by changing the angle of incidence of the primary proton beam on the production target. At 200 ft from the production target, there is a charged-particle sweeping and collimation section in the beam. At a distance of about 600 ft from the target, there is provision for a second sweeping and collimation section. There are enclosures to house a third and a fourth set of beam-defining apparatus at 1000 ft and 1300 ft, respectively, from the target.

A list of the components used in the neutron beam (M3) and of its principal design parameters is given in Table IV.

Three magnetized iron slits ("muon-spoilers") of 10-ft length are used at about 400 ft from the production target, to deflect away the halo of muons which surround the "wanted" beam particles. At two other points along the beam, space is provided for the placement of absorbers, which can reduce the relative flux of neutrons to $K^o$'s in the beam, if this is needed for particular experiments using $K^o$'s. Lead radiators are used, in front of the sweeping magnets, to eliminate $\gamma$'s from the beam. In general, the beam line is to be under a vacuum of 1000 microns pressure, or better. The collimators are not evacuated, unlike much of the rest of the beam line.

The large-angle neutral beam (M4-$K_L^o$ beam) is produced at a nominal angle of 6.5 mrad. There are beam-sweeping and beam-defining stations, similar to those in the neutron beam (M3) at distances of 200 ft, 600 ft, 1000 ft, and 1300 ft from the production target.

The $K^o$ beam (M4) is produced downward at an angle of 8.25 mrad to the horizontal. The proton beam is traveling downward at an angle of 1.75 mrad when it strikes the target. Thus, the production angle of the beam is 6.5 mrad. At the

Table IV(a). Neutron Beam M3, 1.75 mrad.

| | | | |
|---|---|---|---|
| **Production Target** | | | |
| Material | | Tungsten | |
| Width | | ±0.02 | in. |
| Height | | ±0.02 | in. |
| Length | | 4.0 | in. |
| **Production Angle** | $\theta_p$ | 1.75 | mrad |
| **Lab. Angle** | $\theta_v$ | 0.0 | mrad |
| | $\theta_h$ | 0.0 | mrad |
| **Solid Angle** | $\Delta\Omega$ | 0.04 | μsr |
| **Angular Acceptance** | | | |
| 1st Collimator | | | |
| Horizontal | $\Delta\theta_h$ | ±0.42 | mrad |
| Vertical | $\Delta\theta_v$ | ±0.17 | mrad |
| Last Magnet | | | |
| Horizontal | $\Delta\theta_h$ | ±0.2 | mrad |
| Vertical | $\Delta\theta_v$ | ±0.06 | mrad |
| **Beam Properties at Experiment** | | | |
| Beam Width | $\Delta x_f$ | ±3.4 | in. |
| Horizontal Divergence | $\Delta x'_f$ | ±0.2 | mrad |
| Beam Height | $\Delta y_f$ | ±1.0 | in. |
| Vertical Divergence | $\Delta y'_f$ | ±0.06 | mrad |
| **Nominal Beam Length** | L | 1400 | ft |

Table IV(b). Neutron Beam M3, 1.75 mrad - Coordinates.

| Z Cent. (ft) | Position Code | Element Code | B/G(kG) or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|
| 0 | M2T1 | EPB Target | | | |
| 26.7 | M2C0 | Fixed Collim. | | | |
| 40.5 | M2C1 | Horiz. Collim. 6 ft | | | |
| 45.5 | M2C2 | Vert. Collim. | | | |
| 202.0 | M2Q1 | Quad. 3Q120 | +2.95 | 56.4 | 6.0 |
| 234.0 | M2Q2 | Quad. 3Q120 | -2.71 | -51.8 | 5.0 |
| 246.2 | M2B1 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 257.7 | M2B2 | Bend 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 265.0 | M2V1 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 306.5 | M2P1 | Beam Box 65.0 ft | | | |
| | | Elements Above Common to Beam M2 | | | |
| 348.5 | M3P2 | Beam Pipe (12 in. nom) 29.0 ft | | | |
| 366.0 | M3C3 | Beam Stop 4 ft Lead | | | |
| 370.0 | M3A1 | Lead Radiator 1 in. | | | |
| 374.0 | M3C4 | Collim. 6 ft | | | |
| 383.0 | M3B3 | Muon Spoiler 10 ft | | 200 | 50 |
| 394.0 | M3B4 | Muon Spoiler 10 ft | | 200 | 50 |
| 405.0 | M3B5 | Muon Spoiler 10 ft | | 200 | 50 |
| 527.7 | M3P3 | Beam Pipe (12 in. nom) 228.7 ft | | | |
| 651.0 | M3C5 | Horiz. Collim. 3 in. (0-4 in. range) | | | |
| 656.0 | M3C6 | Vert. Collim. 3 ft (0-4 in. range) | | | |
| 664.3 | M3B6 | Bend 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 675.8 | M3B7 | Bend 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 849.2 | M3P4 | Beam Pipe (12 in. nom) 310.0 ft | | | |
| 1014.0 | M3C7 | Horiz. Collim. 3 ft (0-4 in. range) | | | |
| 1019.0 | M3C8 | Vert. Collim. 3 ft (0-4 in. range) | | | |
| 1027.3 | M3B8 | Bend 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 1038.8 | M3B9 | Bend 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 1048.0 | M3C9 | Vert. Collim. 8 ft | | | |
| 1182.5 | M3P5 | Beam Pipe (14 in. nom) 256.3 ft | | | |

Meson Laboratory Building, the $K^o$ beam (M4) passes under the building through a 14 in. diameter vacuum pipe, and then enters a 10-ft wide, 350-ft long trench to the north of the building, where the experiments using the beam will be housed.

A list of the components used in the $K^o$ beam (M4), and of its principal design parameters, is given in Table V. Muon spoilers are used in the $K^o$ beam (M4) as in

Table V(a). $K^o$ Beam M4, 6.5 mrad.

| | | | |
|---|---|---|---|
| Production Target | | | |
| Material | | Tungsten | |
| Width | | ±0.02 | in. |
| Height | | ±0.02 | in. |
| Length | | 4.0 | in. |
| Production Angle | $\theta_p$ | 6.5 | mrad |
| Lab Angle | $\theta_v$ | 8.25 | mrad |
| | $\theta_h$ | 0.0 | |
| Solid Angle | $\Delta\Omega$ | 0.04 | μsr |
| Angular Acceptance | | | |
| 1st Collimator | | | |
| Horizontal | $\Delta\theta_h$ | ±0.42 | mrad |
| Vertical | $\Delta\theta_v$ | ±0.42 | mrad |
| Last Magnet | | | |
| Horizontal | $\Delta\theta_h$ | ±0.2 | mrad |
| Vertical | $\Delta\theta_v$ | ±0.06 | mrad |
| Beam Properties at Experiment | | | |
| Beam Width | $\Delta x_f$ | ±3.8 | in. |
| Horizontal Divergence | $\Delta x'_f$ | ±0.2 | mrad |
| Beam Height | $\Delta y_f$ | ±1.1 | in. |
| Vertical Divergence | $\Delta y'_f$ | ±0.06 | mrad |
| Nominal Beam Length | L | 1590 | ft |

Table V(b). $K^o$ Beam M4, 6.5 mrad - Coordinates.

| Z Cent. (ft) | Y Cent. (ft) | Position Code | Element Code | B/G(kG) or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 0 | 0 | M2T1 | EPB Target | | | |
| 26.7 | -0.22 | M4C0 | Fixed Collim. | | | |
| 40.5 | -0.33 | M4C1 | Horiz. Collim. 6 ft | | | |
| 45.5 | -0.38 | M4C2 | Vert. Collim. 3 ft | | | |
| 246.2 | -2.04 | M4C3 | Fixed Collim. 3 ft | | | |

| Z Cent. (ft) | Y Cent. (ft) | Position Code | Element Code | B/G(kG) or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 257.7 | -2.13 | M4B1 | Sweep 5-1.5-120 | -14.00 | -1458 | 34.0 |
| 306.5 | -2.53 | M4P1 | Beam Box 65.0 ft | | | |
| 348.5 | -2.88 | M4P2 | Beam Pipe (12 in. nom) 29.0 ft | | | |
| 366.0 | -3.02 | M4C4 | Beam Stop 4 ft lead | | | |
| 370.0 | -3.05 | M4A1 | Lead Radiator 1 in. | | | |
| 374.0 | -3.08 | M4C5 | Fixed Collim. 6 ft | | | |
| 383.0 | -3.16 | M4B2 | Muon Spoiler 10 ft | | 200 | 50 |
| 394.0 | -3.25 | M4B3 | Muon Spoiler 10 ft | | 200 | 50 |
| 405.0 | -3.34 | M4B4 | Muon Spoiler 10 ft | | 200 | 50 |
| 527.7 | -4.35 | M4P3 | Beam Pipe (12 in. nom) 228.7 ft | | | |
| 651.0 | -5.37 | M4C6 | Horiz. Collim. 3 ft (0-4 in. range) | | | |
| 656.0 | -5.42 | M4C7 | Vert. Collim. 3 ft (0-4 in. range) | | | |
| 664.3 | -5.48 | M4B5 | Sweep 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 675.8 | -5.57 | M4B6 | Sweep 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 849.2 | -7.01 | M4P4 | Beam Pipe (12 in. nom) 310.0 ft | | | |
| 1014.0 | -8.37 | M4C8 | Horiz. Collim. 3 ft (0-4 in. range) | | | |
| 1019.0 | -8.41 | M4C9 | Vert. Collim. 3 ft (0-4 in. range) | | | |
| 1027.3 | -8.48 | M4B7 | Sweep 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 1038.8 | -8.57 | M4B8 | Sweep 5-1.5-120 | -10.0 | -1041 | 17.3 |
| 1048.0 | -8.65 | M4C10 | Horiz. Collim. 3 ft | | | |
| 1182.5 | -9.76 | M4P5 | Beam Pipe (14 in. nom) 256.3 ft | | | |
| 1469.0 | -12.12 | M4P6 | Beam Pipe (14 in. nom) 228.5 ft | | | |

the neutron beam (M3) to reduce the muon halo around the beam. Also, as in the neutron beam (M3), space is provided in the $K^0$ beam (M4) for neutron absorbers and for lead radiators. In general, the beam line is to be under a vacuum of 1000 microns pressure, or better. The collimators for intensity control and beam-halo elimination (M4) are of the same design as the collimators in the neutron beam (M3).

Figure 18 shows a cross-section view of one of the enclosures for the two neutral beams (M3 and M4).

## F. Secondary Beam M5-15 mrad Beam (D. D. Reeder and A. A. Wehmann)

This beam is produced at an angle of 15 mrad, has a maximum energy capability of about 80 GeV, and a design energy resolution $\Delta E/E = \pm 0.1\%$. There is space for Cerenkov counters for particle mass identification. A typical intensity will be about $10^7$ $\pi$ mesons/pulse at 50 GeV.

It is expected that a number of inelastic $\pi$ meson scattering experiments, where a pion-proton collision results in the production of a large number (3 or more) reaction product particles, will be performed using the 15-mrad beam (M5).

A list of the components used in the 15-mrad beam (M5) and of its principal design parameters, is given in Table VI. The design is based on the use of main-

Table VI(a). Medium Energy-High Resolution Beam M5, 15 mrad.

| | | | |
|---|---|---|---|
| Production Target | | | |
| Material | | Tungsten | |
| Width | | ±0.02 | in. |
| Height | | ±0.02 | in. |
| Length | | 4.0 | in. |
| Production Angle | $\theta_p$ | 15.1 | mrad |
| Lab Angle | $\theta_v$ | 0.0 | mrad |
| | $\theta_h$ | 15.0 | mrad |
| Momentum Range | | | |
| Minimum | $p_{0_{min}}$ | 8 | BeV/c |
| Maximum | $p_{0_{max}}$ | 80 | BeV/c |
| Solid Angle | $\Delta\Omega$ | 2.8 | μsr |
| Angular Acceptance | | | |
| Horizontal | $\Delta\theta_h$ | ±0.75 | mrad |
| Vertical | $\Delta\theta_v$ | ±1.2 | mrad |
| Momentum Bite | | | |
| Minimum | $\Delta p/p$ | ±0.1 | % |
| Maximum | $\Delta p/p$ | ±0.4 | % |
| Dispersion at Momentum Slit | $\frac{\Delta x}{\Delta p/p}$ | 1.24 | in./% |
| Beam Properties at Experiment-Perfect Magnet Values | | | |
| Beam Width | $\Delta x_f$ | ±0.054 | in. |
| Horizontal Divergence | $\Delta x'_f$ | ±0.74 | mrad |
| Beam Height | $\Delta y_f$ | ±0.056 | in. |
| Vertical Divergence | $\Delta y'_f$ | ±0.45 | mrad |
| Nominal Beam Length | | 1454 | ft |

accelerator dipole and quadrupole magnets. However, the possible use of proton-beam magnets in this beam, in place of many of the main-accelerator magnets, is being seriously considered at the time of writing this report.

Table VI(b). Medium Energy-High Resolution Beam M5, 15 mrad - Coordinates.

| Z Cent. (ft) | X Cent. (ft) | Position Code | Element Code | B/G(kg) or (kG/in) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 0 | 0 | M5T1 | EPB Target | | | |
| 26.7 | 0.40 | M5C0 | Fixed Collim. | | | |
| 40.5 | 0.61 | M5C1 | Horiz. Collim. 6.0 ft | | | |
| 45.5 | 0.68 | M5C2 | Vert. Collim. 3.0 ft | | | |
| 54.0 | 0.83 | M5B1 | Sept. 3-3-132 | +6.37 | +1644 | 87.1 |
| 65.5 | 1.07 | M5Q1 | Quad. 3Q84 | -5.91 | -4309 | 83.6 |
| 74.5 | 1.28 | M5Q2 | Quad. 3Q84 | +5.62 | +4097 | 75.6 |
| 113.5 | 2.25 | M5B2 | Bend 4-2-240 | +8.85 | +2291 | 37.5 |
| 135.0 | 3.18 | M5B3 | Bend 4-2-240 | +8.85 | +2291 | 37.5 |
| 156.4 | 4.60 | M5B4 | Bend 4-2-240 | +8.85 | +2291 | 37.5 |
| 241.7 | 11.61 | M5Q3 | Quad. 3Q84 | -3.47 | -2530 | 28.8 |
| 253.3 | 12.59 | M5Q4 | Quad. 3Q84 | +4.08 | +2974 | 39.8 |
| 261.4 | 13.27 | M5M1 | Profile Monitor | | | |
| 264.3 | 13.51 | M5C3 | Horiz. Collim. 4 ft | | | |
| 266.0 | 13.65 | M5V1 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 322.5 | 18.39 | M5P1 | Beam Pipe(12 in. nom) 108.7 ft | | | |
| 382.1 | 23.38 | M5Q5 | Quad. 3-Q-52 | +2.57 | +1873 | 9.2 |
| 390.6 | 24.09 | M5V2 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 520.1 | 34.94 | M5X1 | Sext. 4 × 30 | | | |
| 527.6 | 35.57 | M5Q6 | Quad. 3-Q-84 | -4.01 | -2923 | 38.5 |
| 538.7 | 36.50 | M5Q7 | Quad. 3-Q-84 | +4.12 | +3003 | 40.6 |
| 545.9 | 37.10 | M5V3 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 609.4 | 42.43 | M5P2 | Beam Pipe(12 in. nom) 88.9 ft | | | |
| 655.6 | 46.30 | M5V4 | Vert. Vern. 6-4-30 | | | |
| 659.4 | 46.62 | M5X2 | Sext. 4 × 30 | | | |
| 676.1 | 47.94 | M5B5 | Bend 4-2-240 | -8.85 | -2291 | 37.5 |
| 697.6 | 49.30 | M5B6 | Bend 4-2-240 | -8.85 | -2291 | 37.5 |
| 719.0 | 50.23 | M5B7 | Bend 4-2-240 | -8.85 | -2291 | 37.5 |
| 740.5 | 50.72 | M5B8 | Bend 4-2-240 | -8.85 | -2291 | 37.5 |
| 762.0 | 50.73 | M5B9 | Bend 4-2-240 | -8.85 | -2291 | 37.5 |
| 772.5 | 50.68 | M5X3 | Sext. 4 × 30 | | | |
| 790.0 | 50.37 | M5Q8 | Quad. 3Q84 | +3.40 | +2478 | 27.7 |
| 801.0 | 50.18 | M5Q9 | Quad. 3Q84 | -3.31 | -2413 | 26.2 |
| 808.5 | 50.05 | M5X4 | Sext. 4 × 30 | | | |
| 890.6 | 48.62 | M5M2 | Profile Monitor | | | |
| 998.3 | 46.75 | M5C4 | Horiz. Collim. 4 ft (Air atm.) | | | |
| 1002.8 | 46.67 | M5C5 | Vert. Collim. 4 ft (Air atm.) | | | |
| 1006.5 | 46.61 | M5V5 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1082.5 | 45.28 | M5P3 | Beam Pipe(12 in. nom) 148.3 ft | | | |
| 1166.5 | 43.82 | M5V6 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1308.8 | 41.35 | M5Q10 | Quad. 3Q52 | +3.47 | +2530 | 16.7 |
| 1319.8 | 41.15 | M5Q11 | Quad. 3Q52 | -3.34 | -2435 | 15.5 |
| 1328.8 | 41.00 | M5K1 | DISC Counter 6 ft | | | |
| 1335.8 | 40.88 | M5K2 | DISC Counter 6 ft | | | |
| 1344.8 | 40.72 | M5Q12 | Quad. 3Q84 | -3.63 | -2646 | 31.5 |
| 1355.8 | 40.53 | M5Q13 | Quad. 3Q84 | +4.04 | +2945 | 39.1 |
| 1361.1 | 40.44 | M5V7 | Horiz. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |

| Z Cent. (ft) | X Cent. (ft) | Position Code | Element Code | B/G(kg) or (kG/in) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 1364.1 | 40.38 | M5V8 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1375.8 | 40.18 | M5K3 | Threshold Counter 20 ft | | | |
| 1396.2 | 39.90 | M5B10 | Bend 4-2-240 | 0/+8.85 | 0/+2291 | 0/37.5 |
| 1417.6 | 39.75 | M5B11 | Bend 4-2-240 | 0/+8.85 | 0/+2291 | 0/37.5 |
| | Off On | | | | | |
| 1438.3 | 39.09/40.36 | M5K4 | Threshold Counter 20 ft | | | |
| 1447.3 | 38.90/40.57 | M5M4 | Profile Monitor | | | |
| 1451.3 | 38.87/40.66 | M5M5 | Intensity Monitor | | | |

An unusual feature of the 15-mrad beam (M5) is the beam-line trajectory under the earthen muon shield. The large angle of deflection of the beam to the right, halfway along the beam line, was incorporated into the design so that the beam would enter the experimental area midway between the 2.5-mrad beam (M6) experiments and the neutron beam (M3) experiments--thus providing an arrangement of 5 secondary beams entering the lab building with roughly equal distances of about 40 ft between adjacent beams.

The specification of the trajectory and of the bending magnets to produce it, preceded the determination of quadrupole positions and gradients. The requirement of achromaticity in position and angle after the set of 5 bend magnets about halfway along the beam line dictated the quadrupole arrangement ahead of that point. The behavior of the principal rays and the envelope function are shown in Figs. 19 and 20.

Vernier magnets are provided at seven points along the beam to correct for differential settlements of the floor which supports the beam-line components. Some of the more significant second-order aberration terms in the beam-transport optics are eliminated with the use of four sextupole correction magnets. The intensity and profile of the beam are monitored by segmented wire ion chambers (SWIC) at three points along the beam. In general, the beam line is to be under a vacuum of 100 microns pressure, or better. The collimators for intensity control or for momentum spread control are typically 4 ft long, and made of iron. The openings of the collimators are not evacuated, unlike most of the rest of the beam line. The first magnets in this beam cannot be main-accelerator dipole and quadrupole magnets because of the close proximity of the 2.5-mrad beam (M6) line. Thus, the design includes an 11-ft long septum dipole magnet as the first magnetic element in the beam line.

Two main-ring magnets used as an incident beam spectrometer can be placed near the end of the beam. Tagging of the momentum of individual particles would depend on measuring position at the clean-up x focus and at the final focus and using one's knowledge of the optical properties of the last section of the beam. The

momenta can be tagged to ±0.07% with position accuracies of ±0.6 mm at the last two x foci and with precise knowledge of optics of the last section, assuming a 40-mrad bend angle in the two spectrometer magnets.

Predicted beam intensities are shown in Figs. 21 and 22 for maximum momentum bite and in Figs. 23 and 24 for 200 MeV/c momentum bite. Figures 25 and 26 include the predicted K fluxes corresponding to Figs. 21 and 22, as well as the K fluxes that one would have if the total number of particles in the beam were restricted to $10^6$ per pulse of $10^{13}$ interacting protons. This kind of operational restriction would apply to many K-scattering experiments using the beam.

G. Secondary Beam M6, 2.5-mrad Beam (D. Carey and R. Carrigan)

A primary use of the 2.5-mrad beam (M6), which is a beam with good momentum resolution ($\Delta p/p \sim \pm 0.05\%$), will be in conjunction with a 180-GeV high-precision focusing-type spectrometer which is to be used for analysis of the high-energy reaction products from the scattering of the secondary-beam particles on hydrogen. A wide variety of experiments will be done with the spectrometer; the first experiment will be a study of elastic scattering of K mesons, protons and antiprotons, on hydrogen and deuterium targets. An experiment to study the elastic scattering of $\pi$ mesons and of protons on protons, at very small angles of scattering, will also be carried out with the use of the 2.5-mrad beam (M6) but not using the high-energy spectrometer facility. A list of the components used in the 2.5-mrad beam (M6) and of its principal design parameters is given in Table VII.

This beam (M6) is produced at an angle of 2.5 mrad, can be tuned over the energy range 20-180 GeV, and is designed to have an energy definition capability $\Delta E/E = \pm 0.05\%$. It is a three-focus beam. In the first section, the beam is imaged onto an energy-definition slit, with a dispersion factor of about 6 centimeters/percent $\Delta E/E$. By opening up the energy definition slit, a maximum transmission of $\Delta E/E \simeq \pm 1\%$ can be obtained. In the second stage, the beam is focused onto vertical and horizontal cleanup slits. In the final stage of the beam, there is momentum recombination in both position and angle at the third focus. By changing the tune of some of the focusing lens elements in the third stage of the beam-line, an energy-dispersed final image can be obtained as an alternative option; dispersion in this case is 2 cm/% $\Delta E/E$. There is space available in the beam-line for the placement of two threshold Cerenkov counters for particle mass identification. Also, there are two spaces each of about 30 ft length in parallel-beam sections in the third stage of the beam, suitable for the operation of DISC differential Cerenkov counters. A typical intensity of the 2.5-mrad beam (M6) would be $10^6$ $\pi$/pulse, at an energy of 150 GeV. The intensities as a function of energy for positive and negative particles are given in Fig. 27 and Fig. 28 respectively.

Table VII(a). High Energy-High Resolution Beam M6, 2.5 mrad.

| | | | |
|---|---|---|---|
| Production Target | | | |
| Material | | Tungsten | |
| Width | | ±0.02 | in. |
| Height | | ±0.02 | in. |
| Length | | 6.15 | in. |
| Production Angle | $\theta_p$ | 3.05 | mrad |
| Lab Angle | $\theta_v$ | 0.0 | mrad |
| | $\theta_h$ | 2.5 | mrad |
| Momentum Range | | | |
| Minimum | $p_{0_{min}}$ | 20 | BeV/c |
| Maximum | $p_{0_{max}}$ | 180 | BeV/c |
| Solid Angle | $\Delta\Omega$ | 1.93 | μsr |
| Angular Acceptance | | | |
| Horizontal | $\Delta\theta_h$ | 0.80 | mrad |
| Vertical | $\Delta\theta_v$ | 0.77 | mrad |
| Momentum Bite | | | |
| Minimum | $\Delta p/p$ | ±0.05 | % |
| Maximum | $\Delta p/p$ | ±1.0 | % |
| Dispersion at Momentum Slit | $\frac{\Delta x}{\Delta p/p}$ | 2.51 | in./% |
| Beam Properties at Experiment (for $\Delta p/p = \pm 0.032\%$) | | | |
| Beam Width | $\Delta x_f$ | ±0.017 | in. |
| Horizontal Divergence | $\Delta x_f$ | ±0.87 | mrad |
| Beam Height | $\Delta y_f$ | ±0.017 | in. |
| Vertical Divergence | $\Delta y_f$ | ±0.50 | mrad |
| Nominal Beam Length | L | 1440 | ft |

At the beginning of the 2.5-mrad beam (M6), two septum dipoles are used to deflect the beam far enough so that the neutron beam (M3) clears the first quadrupole magnets. These septa also provide some dispersion early to eliminate radiation problems in the downstream beam-line elements. The first quadrupoles are narrow so that the demands on the septa are less stringent. The position of these quadrupoles represents a compromise involving a conflict between the requirements of large solid angle and clustering of elements in the Front End Enclosure, as opposed to deterioration of the energy resolution of the beam by increasing the object distance of the quadrupole lens doublet. These two quadrupoles focus the beam point-to-parallel.

Table VII(b). High Energy-High Resolution Beam M6, 2.5 mrad - Coordinates.

| Z Cent. (ft) | X Cent. (ft) | Position Code | Element Code | B/G(kG) or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 0 | 0 | M6T1 | EPB Target | | | |
| 26.7 | 0.07 | M6C0 | Fixed Collim. | | | |
| 40.5 | 0.10 | M6C1 | Horiz. Collim. 6.0 ft | | | |
| 45.5 | 0.11 | M6C2 | Vert. Collim. 3.0 ft | | | |
| 85.8 | 0.23 | M6B1 | Sept. 2-2-132 | +8.49 | +2991 | 242 |
| 98.8 | 0.31 | M6B2 | Sept. 2.5-2.5-132 | +6.89 | +2993 | 138 |
| 137.2 | 0.74 | M6V1 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 145.0 | 0.82 | M6Q1 | Quad 4Q120 | -4.85 | -472.1 | 89.6 |
| 157.0 | 0.96 | M6Q2 | Quad 4Q120 | +4.47 | +435.2 | 76.1 |
| 164.7 | 1.04 | M6X1 | Sext. 4×30 | | | |
| 167.2 | 1.07 | M6M1 | Profile Monitor | | | |
| 178.5 | 1.28 | M6B3 | Bend 4-2-240 | +16.83 | +4357 | 135 |
| 200.0 | 1.89 | M6B4 | Bend 4-2-240 | +16.83 | +4357 | 135 |
| 221.5 | 2.86 | M6B5 | Bend 4-2-240 | +16.83 | +4357 | 135 |
| 234.2 | 3.57 | M6X2 | Sext. 4×30 | | | |
| 241.9 | 4.05 | M6Q3 | Quad. 3Q52 | +7.13 | +5198 | 70.6 |
| 254.4 | 4.83 | M6Q4 | Quad. 3Q52 | -7.38 | -5380 | 75.6 |
| 262.6 | 5.34 | M6X3 | Sext. 4×30 | | | |
| 266.4 | 5.58 | M6V2 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 339.2 | 10.13 | M6P1 | Beam Pipe (12 in. nom) 140.8 ft | | | |
| 411.0 | 14.61 | M6S1 | Spacer 4.7 ft | | | |
| 477.7 | 18.77 | M6P2 | Beam Pipe (12 in. nom) 127.7 ft | | | |
| 541.6 | 22.76 | M6M2 | Profile Monitor | | | |
| 544.1 | 22.92 | M6V3 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 548.3 | 23.18 | M6C3 | Horiz. Collim. 4 ft | | | |
| 556.8 | 23.71 | M6Q5 | Quad. 3Q52 | +2.70 | +1968 | 10.1 |
| 563.1 | 24.11 | M6C4 | Vert. Collim. 4 ft | | | |
| 628.2 | 28.17 | M6P3 | Beam Pipe (12 in. nom) 125.3 ft | | | |
| 692.3 | 32.17 | M6S2 | Spacer 4.7 ft | | | |
| 719.8 | 33.89 | M6P4 | Beam Pipe (12 in. nom) 49.2 ft | | | |
| 749.2 | 35.73 | M6V4 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 753.2 | 35.98 | M6X4 | Sext. 4×30 | | | |

| Z Cent. (ft) | X Cent. (ft) | Position Code | Element Code | B/G(kG) or (kG/in.) | I(Amp) | p(kW) |
|---|---|---|---|---|---|---|
| 761.4 | 36.49 | M6Q6 | Quad. 3Q84 | -4.61 | -3361 | 50.9 |
| 778.9 | 37.58 | M6Q7 | Quad. 3Q84 | +4.19 | +3054 | 42.0 |
| 786.6 | 38.06 | M6X5 | Sext. 4×30 | | | |
| 799.3 | 38.94 | M6B6 | Bend 4-2-240 | +16.83 | +4357 | 135 |
| 812.0 | 39.87 | M6X6 | Sext. 4×30 | | | |
| 819.7 | 40.48 | M6Q8 | Quad. 3Q84 | +5.45<br>(+6.25) | +3973<br>(+4556) | 71.1<br>(93.5) |
| 832.3 | 41.48 | M6Q9 | Quad. 3Q84 | -5.84<br>(-6.88) | -4257<br>(-5016) | 81.6<br>(113) |
| 840.5 | 42.13 | M6X7 | Sext. 4×30 | | | |
| 844.5 | 42.45 | M6V5 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 955.3<br>(907.0) | 51.27<br>(47.43) | M6K1 | Threshold Counter 120 ft | | | |
| 1016.1<br>(967.8) | 56.11<br>(52.27) | M6M3 | Profile Monitor | | | |
| 1018.6<br>(970.3) | 56.31<br>(52.47) | M6C5 | Horiz. Collim. 3 ft | | | |
| 1026.5<br>(978.3) | 56.95<br>(53.10) | M6Q10 | Quad. 3Q52 | +4.28<br>(+4.41) | +3120<br>(+3215) | 25<br>(27.0) |
| 1034.5<br>(986.3) | 57.58<br>(53.74) | M6C6 | Vert. Collim. 3 ft | | | |
| 1078.9<br>(1055.6) | 61.12<br>(59.25) | M6K2 | Threshold Counter 80 ft (130 ft) | | | |
| 1123.1 | 64.63 | M6V6 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |
| 1131.3 | 65.28 | M6Q11 | Quad. 3Q84 | -6.55<br>(-5.32) | -4775<br>(-3878) | 102<br>(67.7) |
| 1148.6 | 66.66 | M6Q12 | Quad. 3Q84 | +5.73<br>(+5.32) | +4177<br>(+3878) | 78.6<br>(67.7) |
| 1165.1 | 67.89 | M6B7 | Bend 4-2-240 | -16.83 | -4357 | 135 |
| 1186.5 | 69.23 | M6B8 | Bend 4-2-240 | -16.83 | -4357 | 135 |
| 1208.0 | 70.20 | M6B9 | Bend 4-2-240 | -16.83 | -4357 | 135 |
| 1228.0 | 70.85 | M6K3 | DISC Counter 17 ft | | | |
| 1248.0 | 71.33 | M6B10 | Bend 4-2-240 | -16.83 | -4357 | 135 |
| 1269.5 | 71.56 | M6B11 | Bend 4-2-240 | -16.83 | -4357 | 135 |
| 1289.5 | 71.53 | M6K4 | DISC Counter 17 ft | | | |
| 1303.0 | 71.45 | M6Q13 | Quad. 3Q84 | +4.60<br>(+5.30) | +3353<br>(+3864) | 50.6<br>(67.2) |
| 1320.0 | 71.35 | M6Q14 | Quad. 3Q84 | -4.60<br>(-6.07) | -3353<br>(-4425) | 50.6<br>(88.2) |
| 1326.2 | 71.31 | M6V7 | Vert. Vern. 6-4-30 | ±4.0 | ±224 | 9.3 |

After three main-ring bending magnets, another set of quadrupoles focuses the beam horizontally and vertically at a horizontally focusing field lens. The focal length of this section of the beam provides a linear magnification of about a factor of two at the momentum slit. Similar point-to-parallel, parallel-to-point optics is repeated through two more sections but with shorter focal lengths. Figure 29 illustrates the principal rays for the beam.

The beam is arranged to provide a second achromatic branch. The final two bending magnets in the beam are switched off so that the beam moves to a line 34 mrad further out (i.e. to the west). In the middle of the experimental hall this separates the two branches by about five feet. The final sets of quadrupoles will have to be moved to change branches.

This preliminary design of the 2.5-mrad beam (M6) given in this report is based on the use of main-accelerator dipole and quadrupole magnets. However, an alternate beam design, which includes the use of some external proton-beam magnets in place of many of the main-accelerator magnets, is being seriously considered at the time of writing this report.

Vernier magnets are provided at seven points along the beam to correct for differential settlements of the floor which supports the beam-line components. Some of the more significant second-order aberration terms in the beam-transport optics are eliminated with the use of seven sextupole correction magnets. The intensity and profile of the beam are monitored by segmented wire ion chambers at four points along the beam. In general, the beam line is to be under a vacuum of 100 microns pressure, or better. The collimators for intensity control or for momentum-spread control are typically 4 ft long, and made with iron, with 1/2-in. wide tungsten liners at the beam aperture. The openings of the collimators are not evacuated, unlike most of the rest of the beam line.

## H. Monitor Channel (D. Eartly)

At an angle of 25 mrad to the incident proton beam, there will be a monitor channel. This system, which consists of a dipole, a collimator, and a set of detectors, will provide a measure of the number of protons interacting in the secondary-beam target. Table VIII gives a list of the monitor-channel components.

The only magnetic element in the monitor channel consists of a single dipole momentum analyzing in the vertical plane. The monitor secondary flux consists of 30 GeV/c ($\Delta p/p = \pm 2.5\%$) $\pi^+$ and protons, accepted through a fixed collimator above and behind the analyzing magnet. Behind the collimator, there are two ion chambers (one in, one out of the beam) whose differential output is digitized for parallel and

Table VIII(a). Test Beam M7, 25 mrad.

| | | |
|---|---|---|
| Production Target | | |
| Material | | Tungsten |
| Width | | ±0.02 in. |
| Height | | ±0.02 in. |
| Length | | 6.15 in. |
| Production Angle | $\theta_p$ | 25 mrad |
| Lab Angle | $\theta_v$ | 00 mrad |
| | $\theta_h$ | -25 mrad |
| Momentum Range | $p_{0_{max}}$ | 20 BeV/c |
| Nominal Beam Length | L | 269 ft |

Table VIII(b). Test Beam M7, 25 mrad - Coordinates.

| Z Cent. (ft) | X Cent. (ft) | Y Cent. (ft) | Position Code | Element Code |
|---|---|---|---|---|
| 0 | 0 | 0 | M7T1 | Target |
| 26.7 | -0.67 | 0 | M7C0 | Fixed Collim. |
| 57.0 | -1.43 | 0 | M7B1 | Bend 5. -0.5-120 +15.0 kG |
| 116.0 | -2.90 | +2.71 | M7C1 | Collim. 6 ft |
| 120.5 | -3.01 | +2.92 | M7M1 | Profile Monitor 3 ft |

serial readout. These chambers will operate over two orders of magnitude dynamic range.

In addition, there is a triplet telescope of small scintillation counters whose coincidences are counted in an all-integrated-circuit 100 MHz parallel readout scaler. This telescope provides a monitor over the whole dynamic range of incident proton-beam current.

While all this instrumentation is housed in the Front End Hall, it is located about 3 ft above the beam lines and is upstream of the bending magnets in the six secondary beams.

## I. Beam-Line Equipment (A. Brenner, D. Eartly, F. Hornstra, and W. Nestander)

In this chapter we will briefly describe the components used in the secondary-beam lines. These include the following: dipole and quadrupole magnets, power supplies, collimators, muon spoilers, septum magnets, sextupoles, half-quads, beam detectors, and monitoring and control equipment.

### Secondary Beam Magnets and Power Supplies

The Meson Laboratory secondary beams were originally designed using main-ring quadrupoles and dipoles as the major beam-transport elements. Because of the low coil resistance of these magnets, all beams were designed with equal dipole currents and almost equal quadrupole currents. This feature allows these magnets to be connected in series to minimize the number of power supplies as well as the power loss in the necessarily long dc busses.

Differences in current (typically less than 10%) among individual quadrupoles are compensated for by the use of shunts. Most of the shunted power is carried in a fixed water-cooled shunt adjacent to the quadrupole. A small amount of flexibility is provided by a variable shunt (0-80 A) connected in parallel with the fixed shunts.

In one case, the diffracted proton beam (M2), the quadrupole currents are close enough in value to the dipole current so that all of the main-accelerator magnets in the beam could be connected in series. This arrangement would further reduce the required amount of water-cooled dc bus. The quadrupole-to-dipole current difference is overcome by the use of a low current power supply servoed to the main supply. A diagram showing this circuit and the shunt connections is given in Fig. 30.

The series strings of main-ring type magnets in the secondary beams will be powered by modified main-ring power-supply modules. A typical module will switch 2200 A at 500 V in a 12-phase arrangement. Whenever possible these supplies will be pulsed in order to conserve power.

Some of the Meson-Laboratory beams (e.g., M2, M3, and M4) will be constructed of dipoles and quadrupoles of the type used to transmit the proton beam from the main accelerator to the experimental areas. These magnets do not require as high a current as the main-ring magnets at the same magnetic field; therefore, we plan to power them individually, rather than in series strings.

Table IX gives the major power-supply requirements for the secondary beams.

Special magnets (e.g. septum dipoles, half-quads, sextupoles, vernier magnets) will be required, in addition to the main beam-transport elements. The magnet requirements for the secondary beams are given in Tables II through VIII.

Table IX. Major Power-Supply Requirements - Meson Lab.

| Beam | Power Supply Supplying Indicated Magnets | Supply Power at Maximum Momentum (includes 25% dc bus loss for main-ring type magnets) Current (A) | Voltage (V) | DC Power (kW) |
|---|---|---|---|---|
| M1 | B1-7; Q4-6 | 3400 | 376 | 1278 |
| | Q1-2 | 63 | 120 | 8 |
| | Q3 | 85 | 81 | 7 |
| | Q7 | 82 | 157 | 13 |
| | Q8-9 | 50 | 191 | 10 |
| | Q10 | 70 | 134 | 9 |
| | Q11 | 67 | 128 | 9 |
| | Q12 | 67 | 128 | 9 |
| | Q13 | 70 | 134 | 9 |
| | Q14 | 63 | 120 | 8 |
| | Q15 | 61 | 116 | 7 |
| | Q16 | 61 | 116 | 7 |
| | Q17 | 63 | 121 | 8 |
| M2 | B1-8 | 1970* | 319* | 628* |
| | Q1 | 84* | 160* | 13* |
| | Q2 | 78* | 149* | 12* |
| | Q3 | 32* | 61* | 2* |
| | Q4 | 78* | 149* | 12* |
| | Q5 | 84* | 160* | 13* |
| M3 | B3-6 | 1125 | 79 | 89 |
| M4 | B1 | 1125 | 20 | 23 |
| | B2-6 | 1125 | 79 | 89 |
| M5 | B1 | 1645 | 66 | 109 |
| | B2-9 | 2291 | 164 | 375 |
| | B10-11 | 2291 | 41 | 94 |
| | Q1-2 | 4309 | 46 | 200 |
| | Q3 | 1874 | 6 | 12 |
| | Q4-11 | 3004 | 98 | 295 |
| | Q12-13 | 2950 | 30 | 89 |
| M6 | B1-2 | 3000 | 158 | 475 |
| | B3-9 | 4357 | 272 | 1186 |
| | Q1-2 | 472 | 441 | 208 |
| | Q3-4 | 5381 | 28 | 151 |
| | Q5 | 1969 | 6 | 12 |
| | Q6-7 | 3361 | 38 | 127 |
| | Q8-12 | 4800 | 94 | 450 |
| | Q13-14 | 3354 | 38 | 128 |

*At "270" GeV/c tune for quark search experiment.

Muon Spoilers

These consist of 16 in. × 16 in. × 10 ft blocks of magnetized Fe with a 2 in. × 2 in. beam window. The iron is magnetized with two small air-cooled coils (130 turns at 10 A typically, for a field of 15 kG in 1010 steel). Details of these devices are shown in Fig. 31.

Collimators

In most of the collimators, externally driven slit blocks of Fe (6 in. × 6 in. × 36 in.) move within a vacuum box (see Fig. 32). The apertures are controlled by threaded drives powered with low rpm slo-syn motors. The accuracy in the aperture is ±0.25 mm. A readout system has been designed. Limit switches on the slit blocks prevent the drive from binding on closure or from exceeding a 4.0-in. opening. The jaw faces will be lined with tungsten.

For the outside enclosure on the momentum slits we have provided manual jacks and support drive beds for alignment. In the case of vertical cleanup slits, the corresponding vertical rotation alignment is not as critical and alignment is done through jacks.

Beam-Line Control

There are many demands which could be made of a secondary beam-line control system. Some of these are time-critical, i.e., the measurement or other exchange must occur at times determined either by the accelerator cycle, or the experimenter or his equipment. Other demands placed upon the computer tend to be non-time-critical. If a large fraction of computer power required of the central computer is in the non-time critical area, then a single mini-computer can handle several different beam lines simultaneously and with no interaction between users. The functions to be involved in the central system include the following:

1. Addressing and setting of power supplies for a beam line to a selected set of values.

2. Changing such set values as required quickly and conveniently.

3. Monitoring of magnet currents and/or Hall probe currents and/or NMR frequencies.

4. Readout of beam monitors.

5. Monitoring of other selected analog values, e.g., liquid $H_2$ target levels, Cerenkov counter pressures, collimator, slit positions and beam-line vacuum status.

6. Monitoring of other selected digital values, e.g., certain beam scalers.

7. Displaying or printing of any or all of these monitored values on demand, or for record keeping, or if certain preset limits of any monitored function are exceeded. These displays include histograms and graphs as required.

It is planned that each experimenter will have a remote terminal linked to the beam-lines control computer. This terminal will present a visual or hard-copy display pertaining to any of the above parameters and will permit such data to be entered into the experimenter's computer. A keyboard at the remote terminal will allow communication with the control computer. The extent to which the experimenter

will control a beam and associated equipment will be determined by the NAL staff member who is responsible for the operation of the secondary-beam lines.

A single MAC 16 computer configured similarly to some of those in use in accelerator control will be able to handle several secondary-beam lines without any further connection to another computer. This computer will be located in the designated control building for the Meson Laboratory. The MAC computer will communicate with several local stations along the beam lines in the area with a communication link, probably a serial line. Clusters of elements geographically close to one another will be connected to the local station to which they are closest. Thus it is likely that elements from more than one beam line will feed data through a single local station, thereby reducing the required number of local stations. Figures 33 and 34 are diagrams of the general scheme.

In general the MAC would serve for control of the beam elements in the Meson Laboratory. In analogy to other accelerator components, the memory of old conditions and the display of current conditions would probably be generated at the central control computer, i.e., the Σ7.

Beam-Line Instrumentation

The beam-line equipment summary tables (Tables II-VIII) show the locations of the instrumentation allocated to each beam line. Devices for operation of the lines include the profile and intensity monitors which will be installed initially. Space is allocated for Cerenkov counters to be installed later as required by the experimental program.

In general, provisions are made to monitor the intensity, beam size, beam position, and beam divergence at the end of a beam line and to measure the beam profile and position at intermediate locations, such as slits and foci. The relative vertical position of the beam at these intermediate points will also serve as a check on settlement of the floors of the enclosures.

The specific device required to measure a quantity of interest depends upon the beam intensity.

The neutral beam profiles can be obtained by parallel wire proportional chambers with a suitable material placed immediately upstream to convert a fraction of the neutrals. The resulting charged-particle intensity will be within the capability of the proportional chambers.

The number of monitoring points along the beam lines will be kept to a minimum consistent with the tuning and monitoring requirements of the beam. Additional instrumentation may be added later as requirements dictate. Table X shows the number and type of monitors for each beam line.

Table X. Meson Lab Beam Instrumentation.

| Type of Instrument | No. Required in Beam | | | | | | |
|---|---|---|---|---|---|---|---|
| | M1 | M2 | M3 | M4 | M5 | M6 | M7 |
| Profile Monitor | 6 | 4 | 1 | 1 | 4 | 3 | |
| Intensity Monitor | 1 | 1 | | | 1 | 1 | 1 |
| Threshold Cerenkov Counter | 2 | | | | 2 | 2 | |
| DISC Counter | 1 | | | | 2 | 2 | |
| Radiation Monitor | 1 | 1 | 1 | 1 | 1 | 1 | |

J. Physical Plant (DUSAF, E. Bleser, F. Mallie, W. Nestander, J. Sanford)

The conventional facilities in the Meson Laboratory consist of housings for the proton beam, for the target area, for the secondary beams and for the experiments; also service buildings, electrical substations, LCW cooling systems, and other facilities. These are shown in Fig. 2.

A series of underground concrete structures, covered by heavy concrete or earth shielding, will house the steering and focusing magnets which transport the 200-BeV proton beam to the target area, and similar structures will house the magnets which transport the secondary beams from the target area to the experimental area. The beams travel between the enclosures through evacuated steel tubes. The principal means of entrance to the proton-beam enclosures is through an access leading to the Transfer Hall and Transfer Gallery which were built as part of the Main-Accelerator project. A secondary means of access is located approximately 800 ft downstream of this primary access route. Emergency exits are provided where required for the safe egress of operating personnel.

The central feature of the target area is the Meson Target Box. This consists of an evacuated steel structure constructed at grade level and covered by iron and earth shielding to house a four-car target train which includes the targets, target-moving mechanisms, proton beam dump, variable- and fixed-aperture secondary beam-defining collimators, proton beam steering magnets, proton beam intensity and position monitors, and iron radiation shielding.

The Target Box is immediately preceded by the Meson Target Hall, which consists of an earth-shielded ground-level concrete structure to house bending magnets, focusing magnets, and vacuum equipment which comprise the final stages of the proton-beam transport system to the target; a remote-controlled manipulator facility to service the train-mounted target mechanisms and proton-beam stop equipment; proton beam-stop water-cooling system and vacuum system for the target assembly.

This enclosure also incorporates personnel, utility, train and equipment access through the shielding berm.

The railroad, which is used to transport target mechanisms and proton-beam stop equipment into and out of the Meson Target Box, consists of narrow-gauge track throughout the Meson Target Box and Meson Target Hall, with a spur track exiting through the shielding berm via an access enclosure.

Downstream of the Meson Target Box is the Front End Hall. This consists of an earth-shielded ground-level concrete structure to house equipment for six secondary particle beam lines, including horizontal bending magnets, focusing magnets, vacuum equipment, monitoring devices, collimators and portable iron and concrete shielding. This enclosure incorporates personnel, equipment, and utility access through the shielding berm.

The target area is served by two utility buildings, Service Buildings M1 and M2. Service Building M1 consists of a single-story concrete masonry structure at grade located opposite the Meson Target Hall at the base of the shielding berm. This service building houses control equipment for the remote manipulator facility, magnet power-supply equipment and controls for the proton beam and Target-Box components, toilet facilities, and environmental-control equipment.

Service Building M2 consists of a single-story concrete masonry structure at grade located opposite the Front End Hall at the base of the shielding berm. This service building houses magnet power-supply equipment, controls, instrumentation of vacuum and radiation monitoring, communications equipment, toilet facilities, LCW cooling equipment, and environmental-control equipment.

Between the Front End Hall and the Meson Laboratory Building, which houses the experiments, the secondary particle beams are transported through the Beam-Transport Enclosures. These consist of earth-shielded, ground-level reinforced-concrete structures, with typical internal dimensions of 6 ft 6 in. × 8 ft high, with nominal beam height 18 in. above the floor. Figure 35 shows a cross-section view of a typical enclosure. These enclosures house the bending magnets, focusing magnets, vacuum equipment, monitors, Cerenkov counters, and other components of the secondary-beam lines. Connecting the Beam-Transport Enclosures are beam pipes for each beam line.

Utilities for the Beam-Transport Region of the Meson Laboratory are fed from Service Building M2, described previously, and also Service Building M3 (see Fig. 2), which consists of a single-story concrete masonry structure at grade located midway along the 1000-ft long Beam-Transport Region, at the base of the shielding berm. The facilities provided at Service Building M3 are similar to those provided at M2.

The Beam-Transport Region also includes a number of personnel and equipment accesses, of concrete construction and incorporating both geometric and earth-radiation shielding, to interconnect the Beam-Transport Enclosures, the Service Buildings, and the Meson Laboratory Building, to provide access for utilities, equipment, and personnel. The north ends of the diffracted proton (M2), neutron (M3), and 15 mrad (M4) beam lines extend through their final concrete enclosures directly into the Meson Laboratory Building. The east and west beam lines (3.5 mrad, M1, and 2.5-mrad, M6, beams, respectively) pass at their north ends through 40-foot long outdoor spaces before entering the Meson Laboratory Building.

The Meson Laboratory Building is situated at the north end of the Beam Transport Region about 1400 ft from the secondary-beam production target. This building (see Figs. 8 and 9) consists of an arch-shaped, steel structure resting on sloping concrete walls. The building is approximately 246 ft wide by 158 ft long (outside dimensions). The arch, spanning east-west, consists of 12 "C"-shaped corrugated metal elements, attached to steel sheets, spaced 12 ft on center. The sloping reinforced concrete walls and columns form cubicles which house offices, toilets, electrical and mechanical equipment rooms, and space for NAL equipment. The north and south enclosing walls are composed of translucent glass-fiber reinforced corrugated plastic. A 20-ton underhung crane spans nearly the full length and width of the building. The crane is suspended from the arched structure. At the south end of the building is a mezzanine which is 128 ft wide by 28 ft deep. The shielding berm over the Beam Transport Region stops against a retaining wall which acts as the other support for the mezzanine. The Meson Laboratory Building will house magnet power-supply equipment, controls, instrumentation for vacuum and radiation monitoring, LCW equipment, environmental control equipment and equipment for experiments under the 20-ton crane.

Many of the experiments done in the Meson Laboratory will extend well to the north of the Meson Laboratory Building. Appropriate housings for the experimental equipment, and utilities and other services, will be designed and built, as the planning of the experimental-physics program progresses. To date, one experimental layout has already been designed. This experiment, in beam M4 ($K^0$ beam), requires underground "beam-transport" structures of concrete construction, joined in the center by a 25 ft × 25 ft open area for equipment access from above, and also with an open area for housing a hydrogen target or a methane target. A large spectrometer magnet will be located in the 25 ft × 25 ft central "open" area. Utilities for this area, the south end of which is 80 ft to the north of the Meson Laboratory Building, will be provided from the latter building via underground conduits.

The conventional facilities in the Meson Laboratory, in addition to what has already been described, include a number of general facilities which are provided throughout the Proton Beam Area, Target Area, Beam-Transport Area, and Experimental Area. These include the following:

Electrical power supply and distribution systems, including yard substations, transformers, switchgear, motor-control centers, conduit, wiring and protective devices to serve the environmental central equipment, and the conventional building services; also, lighting systems; interior, exterior and battery-operated emergency lights, including lighting panels, fixtures, conduit, wiring and switches;

Provision for communications systems and equipment, including ducts, sleeves, conduit; space for telephones, closed-circuit TV monitors and safety interlock systems equipment in the Service and Laboratory Buildings;

Environmental control systems and equipment, including air-handling systems, ductwork, filters, controls, and provisions for heating and ventilation; limited air conditioning in the Meson Laboratory Building;

Plumbing systems and equipment, including floor drains, underdrains, sump pumps, industrial supply piping and compressed air within enclosures, Service Buildings and Meson Laboratory Building;

LCW cooling and distribution equipment, including air coolers, heat exchangers, pumps, valves, piping and heaters;

Installation of empty conduit banks interconnecting the Service Buildings and Beam Enclosures, sized for communication, control and monitoring systems, and for dc magnet power-supply cables;

Fire-alarm system and smoke-detection system, including sensing devices, alarms, wiring and provisions for future connection to a master system;

Fire-protection system including hydrants, piping, valves, and provision for fire extinguishers;

Survey monuments in the enclosures and the Meson Laboratory Building.

All underground utilities which serve the various Meson Laboratory systems including extensions to interface at the utility corridor along the west side of Road A-1. These utilities include electrical ducts and feeders, communication and control ducts, industrial cold-water supply, domestic water supply, sanitary sewer and natural gas;

Drainage of underground enclosures, storm drainage of above-ground structures and roads, to interface with the site drainage system;

Parking areas and aprons adjacent to the Service Buildings and the Meson Laboratory Building, access roads from the Meson Laboratory to Road A-1;

Further details of the design specifications for the physical plant--buildings, utilities, roads, etc., can be found in the following four Title I Reports prepared by DUSAF:

Proton Beam Enclosures: dated April 1, 1970.

Target Area 2: dated July 27, 1970.

Experimental Area 2 (Revision #1): dated December 23, 1970.

Experimental Area 2 (Revision #2): dated June 10, 1971.*

## K. Costs and Schedules (J. Sanford)

Information on cost estimates and construction schedules for the conventional facilities is given in Table XI. The conventional facilities in the Meson Laboratory are being built under four major contracts--Proton Beam Enclosures (housing the proton beam splitting and transport--this contract also includes proton transport to the Neutrino Laboratory and part way to the Proton Laboratory), Meson Laboratory Phase I (the target area), Meson Laboratory Phase II (the secondary-beam transport area), and Meson Laboratory Phase III (the experimental area).

Information on cost estimates and fabrication and installation schedules for equipment in the secondary beam lines is given in Tables XII and XIII. In FY 71 it is planned to build the proton-beam transport to the Meson Laboratory target area, also the diffracted proton beam (M2) and the two neutral beams (M3 and M4). Some of the long-lead-time items of equipment for the other three secondary beams will also be purchased in FY 71--mostly these will consist of main-accelerator dipole magnets. In FY 72, the rest of the equipment for secondary particle beams in the Meson Laboratory will be built.

The schedule for early experiments is under intensive study and discussion at this time. We will not attempt in this Design Report to describe the developing plans for the operation of the Meson Lab for high-energy physics experiments.

## L. Some Future Options (K. P. Pretzl and A. A. Wehmann)

There are a number of future options which are inherent in the design of the secondary beams in the Meson Lab. These possibilities are each described briefly below.

### "Target-Magnet" in Meson Target Box

The future installation of a "target-magnet" immediately downstream from the secondary-beam production target in the Target Box, would make it possible to attain 0° production of the charged secondary particle beam, thereby increasing the intensity of the beam by a factor ~ 2 to 5 times.

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*Added in proof.

Table XI. Costs and Schedules - Meson Lab Construction.

| | Proton Beam[a] 7-1 | TA 2 Meson I 7-2-1 | EA 2 Meson II 8-1-1 | EA 2 Meson III 8-1-2 |
|---|---|---|---|---|
| Title I Est. (DUSAF) | $3,182,500 | | | |
| Title II Est. (DUSAF) | $2,614,000 | $1,736,291 | $2,140,533 | |
| Low Bid | $1,889,500 | $1,497,410 | $1,467,000 | |
| Notice To Proceed | 28 Aug 70 | 29 Oct 70 | 2 Dec 70 | |
| Scheduled Completion | 14 July 71 | 6 July 71 | 19 Aug 71 | |
| Expected Completion | 14 July 71 | 6 July 71 | 19 Aug 71 | |
| Beneficial Occupancy | | Enclosure and beam pipes 27 Apr 71<br>S. B. M2 1 July 71 | S. B. M3 20 June 71<br>Enclosures and beam pipes 5 July 71 | Mezzanine 1 Sept. 71 |

[a]Includes beam to Neutrino and Meson Labs and part of a future beam.

Table XII. Meson Lab Secondary Beams - Equipment Cost Summary.

| Beam | | Base K$ | 25% Contingency K$ | Total K$ |
|---|---|---|---|---|
| M1 | 3.5 mrad | 700 | 175 | 875 |
| M2 | Diffracted proton | 210 | 55 | 265 |
| M3 & M4 | Neutron & $K^o$ | 135 | 35 | 170 |
| M5 | 15 mrad | 615 | 155 | 770 |
| M6 | 2.5 mrad | 815 | 205 | 1020 |
| M7 | Monitor | 15 | 4 | 19 |

GRAND TOTAL = $3.1M

Table XIII. Preliminary Schedule for Fabrication and Installation of Meson Lab Secondary Beam Equipment - Beams M2, M3, and M4.

| Period of February 15 - August 1, 1971 | |
|---|---|
| February 15 | - prototype EPB dipole |
| March 1 | - prototype EPB quadrupole<br>- order support stands |
| March 15 | - order power supplies<br>- prototype vernier magnet<br>- order vernier magnets |
| April 1 | - order vacuum pumps<br>- order vernier power supplies<br>- complete utilities distribution design |
| April 15 | - order vacuum pipe and fittings<br>- order beam detectors |
| May 1 | - order control interfaces<br>- complete cabling layouts |
| May 15 | - begin cable and water installation |
| June 1 | - begin alignment |
| August 1 | - complete installation of beams M2, M3, M4 |

Branches in Secondary Beams

Near the downstream (north) end of the four charged secondary particle beams, the installation of one or more dipole magnets will make possible the addition of branches to these beams. The efficiency of use of these beams may be appreciably improved, according to current experience at other accelerator laboratories, if two experiments can be simultaneously set up, side by side, to use a beam which can readily be switched between them.

Possible RF-Separated Beam

Preliminary studies of the 15-mrad beam indicates that the beam design is consistent with the future addition of either room temperature (or superconducting) rf separators operating at S-band, to produce a separated K-meson beam of energy up to about 40 GeV, and a separated antiproton beam of energy up to about 60 GeV.

"Switch" Between 2.5-mrad (M6) and 15-mrad (M5) Beams

Future addition of a string of bending magnets at the crossover (see Fig. 7) of the 2.5-mrad (M6) and 15-mrad (M5) beams, with a deflection angle of about 100 mrad, would make it possible to bring a high-energy beam (>> 80 GeV) into the "15-mrad (M5) experiment line." This could be useful, if a relatively complicated experimental arrangement had been installed at the end of the 15-mrad (M5) beam line, and if it was subsequently desired to raise above 80 GeV/c the momentum of the incident particles into the experiment without having to re-rig the experimental apparatus.

Muon Beam in 3.5-mrad Beam (M1)

Because of its large solid angle and momentum acceptance the 3.5-mrad beam (M1) could be used as a $\mu$ beam. An intermediate focus of the beam in both vertical and horizontal planes is obtained at 1200 ft downstream of the production target by appropriate retuning of Q7, Q8, and Q9 (see Table II). At this point, the muons are filtered by a hadron absorber, and a following sweeping magnet. The doublet Q10-13 together with a bending magnet serve as a muon-beam spectrometer. Monte Carlo calculations based upon the particle production model of Hagedorn and Ranft show that at 100 GeV/c a flux of about $10^6$ muons/$10^{13}$ interacting protons in the production target can be expected in the muon version of the 3.5-mrad beam (M1).

Proton Energy Above 200 BeV

It may turn out that the muon-shield design is overly conservative. In that event, the power supplies for the 200-BeV primary proton transport could be boosted, in the future, to (say) 250 BeV proton energy. The secondary beams above 100 GeV would be considerably enhanced in intensity, if the proton-beam target could be struck by 250-BeV protons instead of 200-BeV protons. Also, secondary beams of energy greater than 200 BeV could in the future become a practical possibility, especially in the cases of the 3.5-mrad beam (M1), the diffracted proton beam (M2), and the neutron beam (M3).

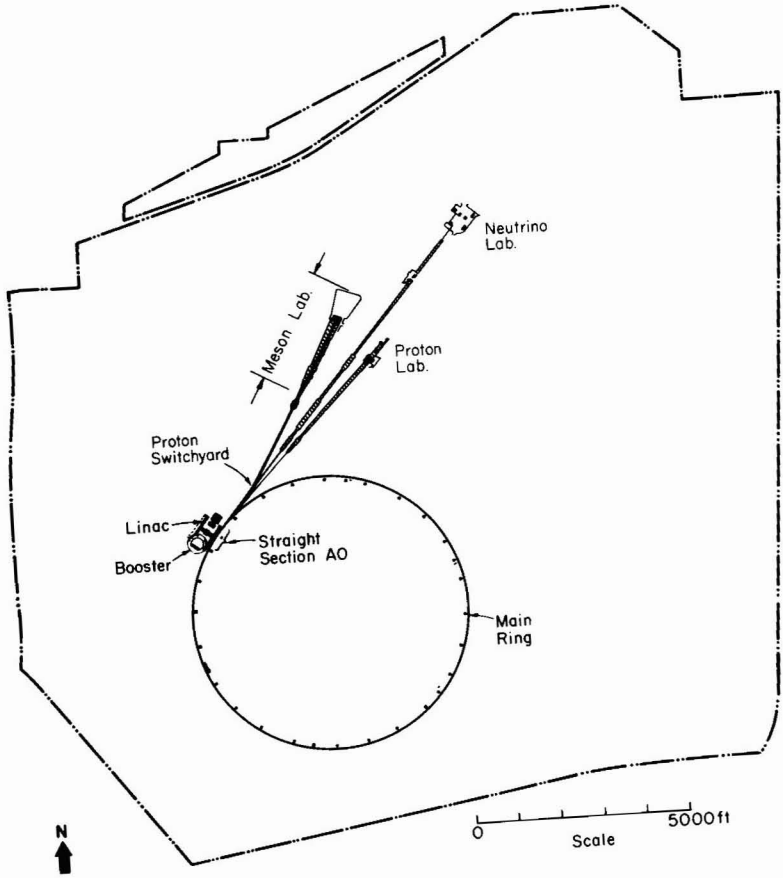


Fig. 1. Location of the Meson Laboratory relative to the accelerator.

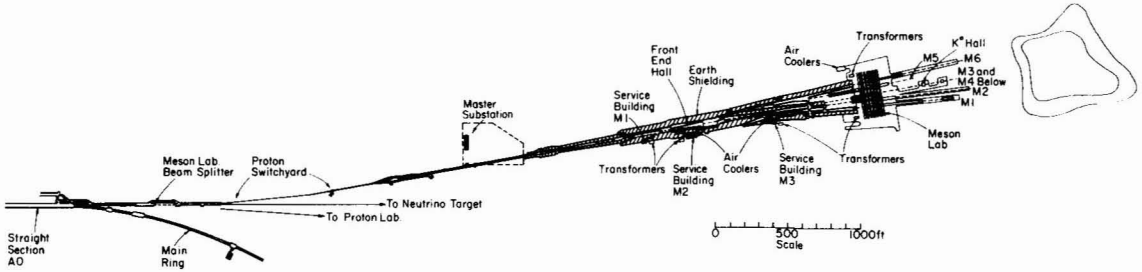


Fig. 2. Overall layout of the Meson Laboratory.

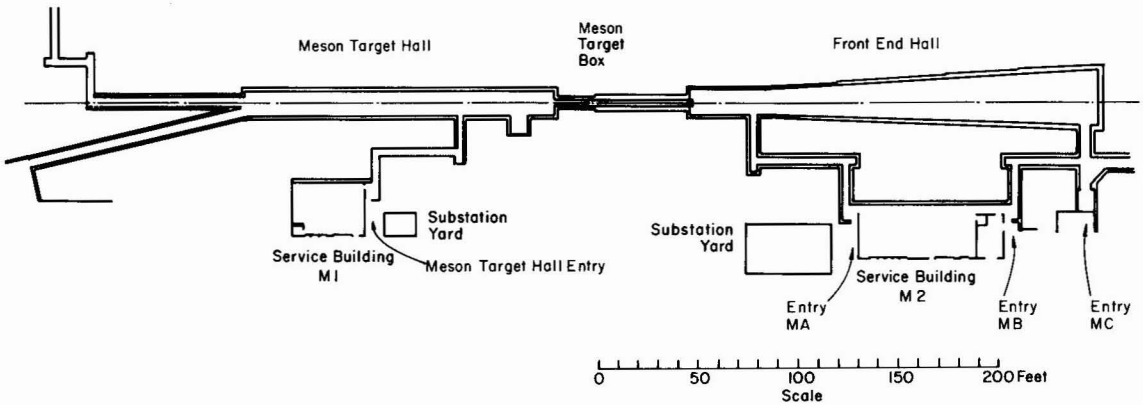


Fig. 3. Housing for proton-beam targeting system and first components in secondary-beam lines.

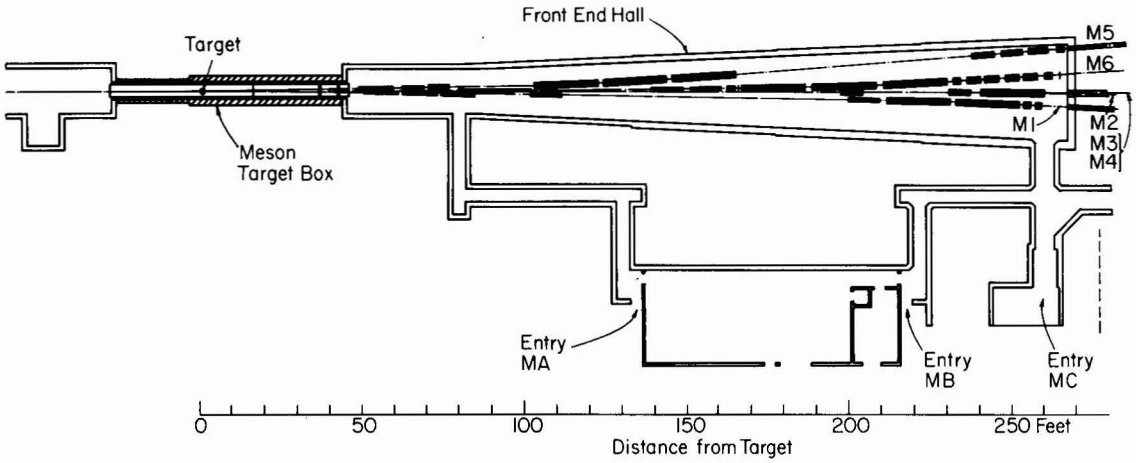


Fig. 4. Layout of secondary-beam lines. I. (From production target, z = 0 to z = 270 ft).

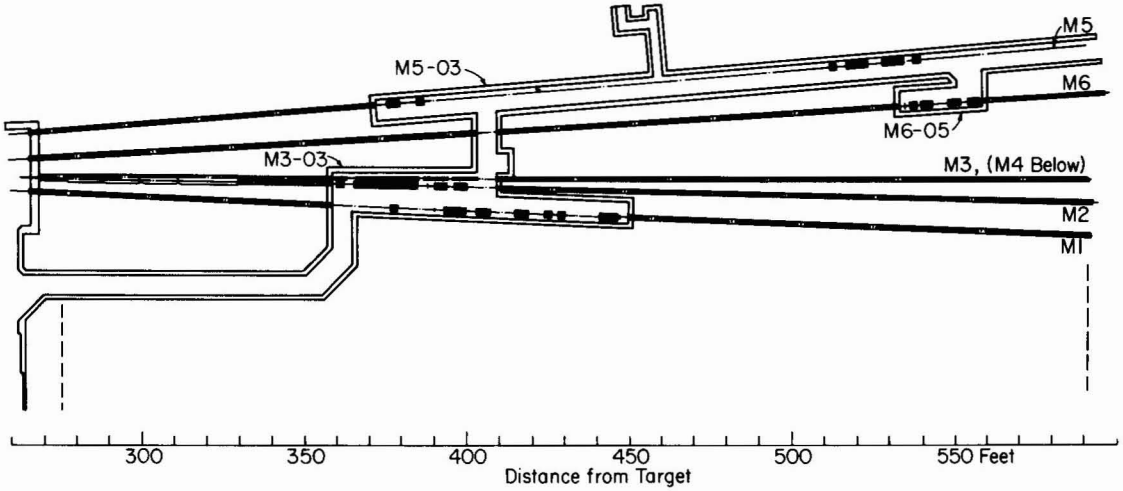


Fig. 5. Layout of secondary-beam lines. II. (From z = 270 ft to z = 600 ft).

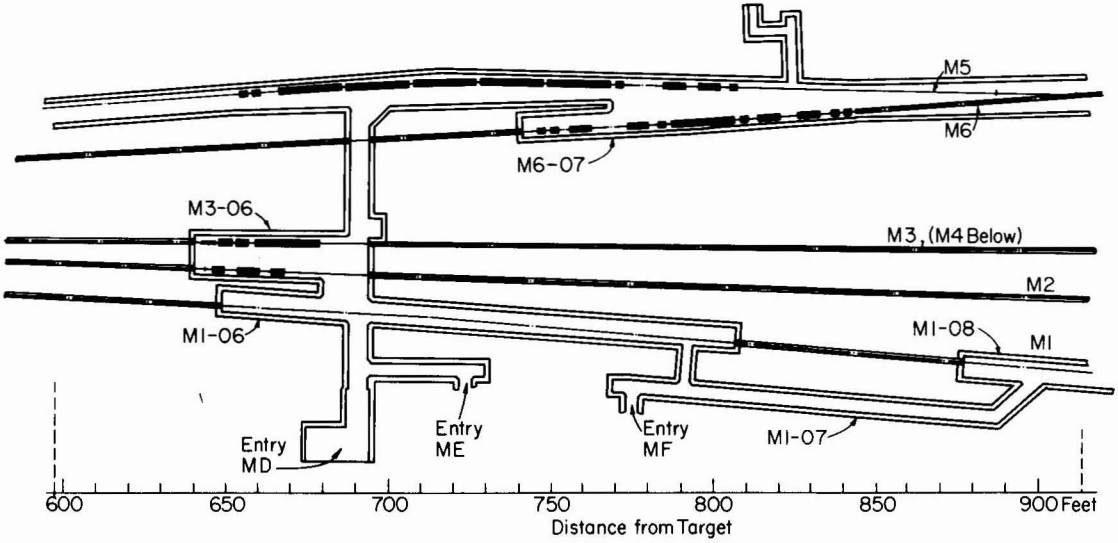


Fig. 6. Layout of secondary-beam lines. III. (From z = 600 ft to z = 900 ft).

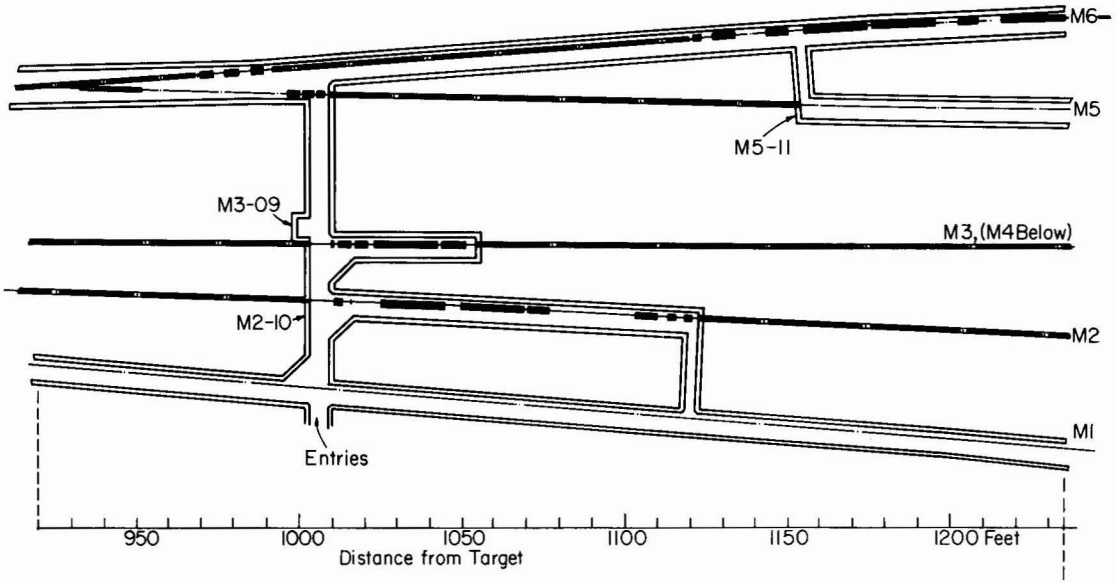


Fig. 7. Layout of secondary-beam lines. IV. (From z = 920 ft to z = 1230 ft).

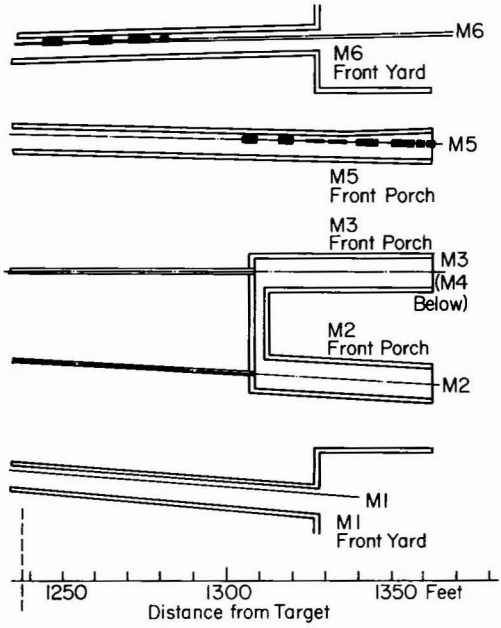


Fig. 8. Layout of secondary-beam lines. V. (From z = 1240 ft to z = 1380 ft).

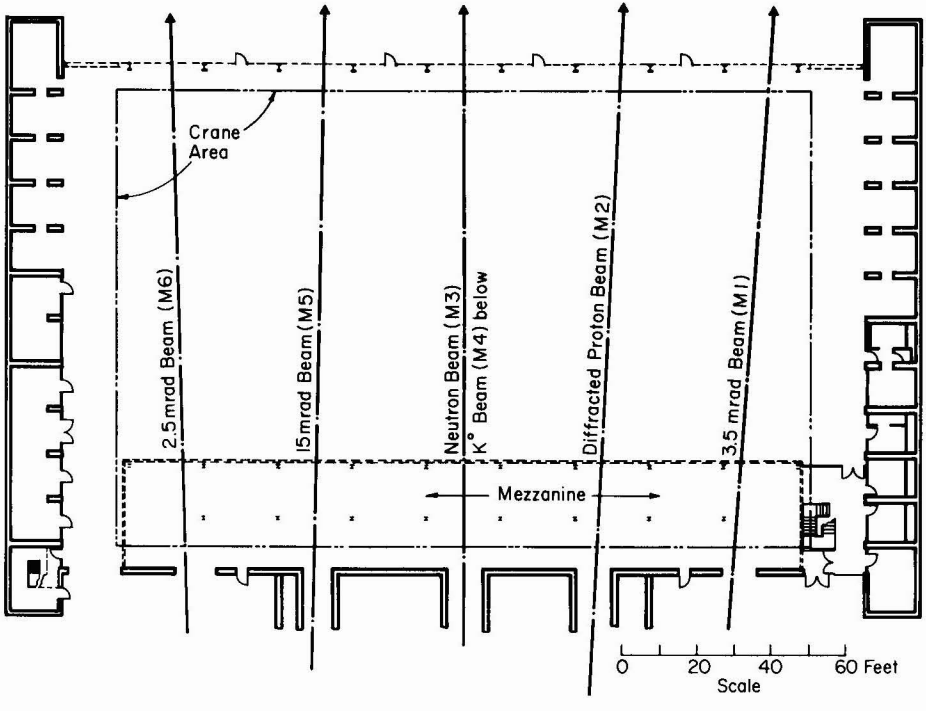


Fig. 9(a). Plan view of the Meson Laboratory Building.

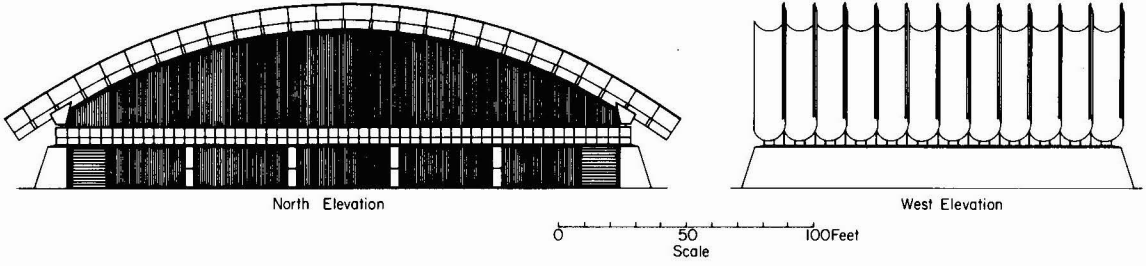


Fig. 9(b). Elevation views of the Meson Laboratory Building.

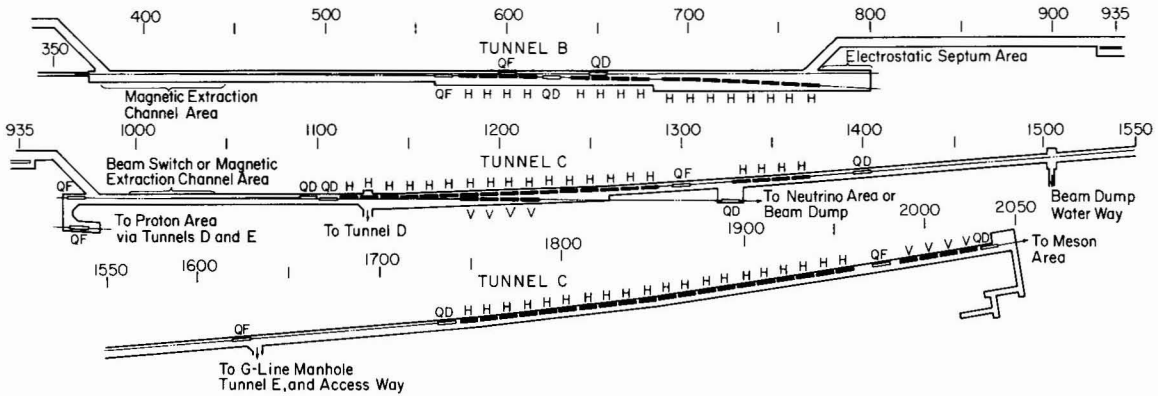


Fig. 10. Tunnel and magnet layout for the proton-beam transport system to the Meson Laboratory.

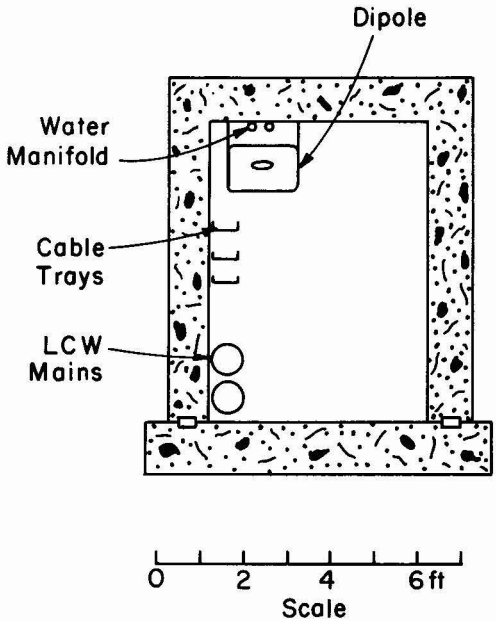


Fig. 11. Cross-section view of a typical proton-beam transport enclosure.

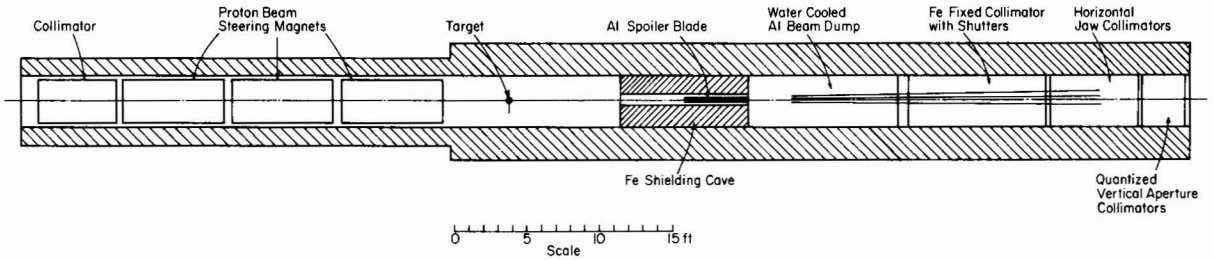


Fig. 12. Target Box: layout of steering magnets, target, beam stop, and collimators.

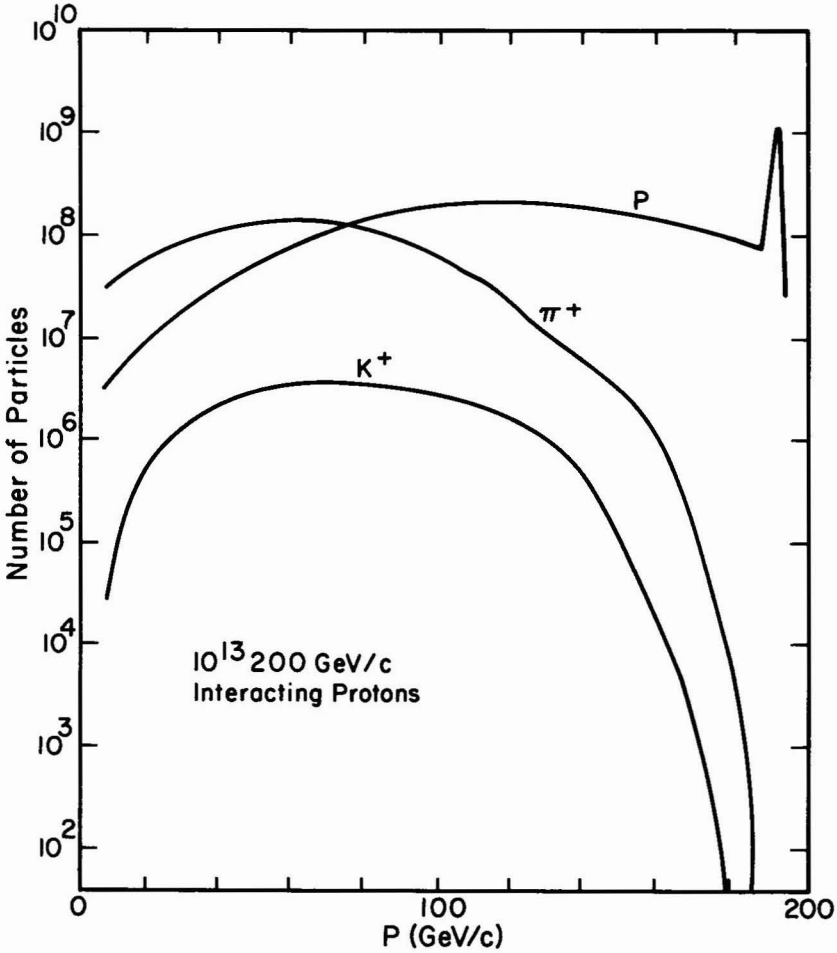


Fig. 13. Predicted positive particle intensities (Hagedorn-Ranft model) in the 3.5-mrad beam (M1).

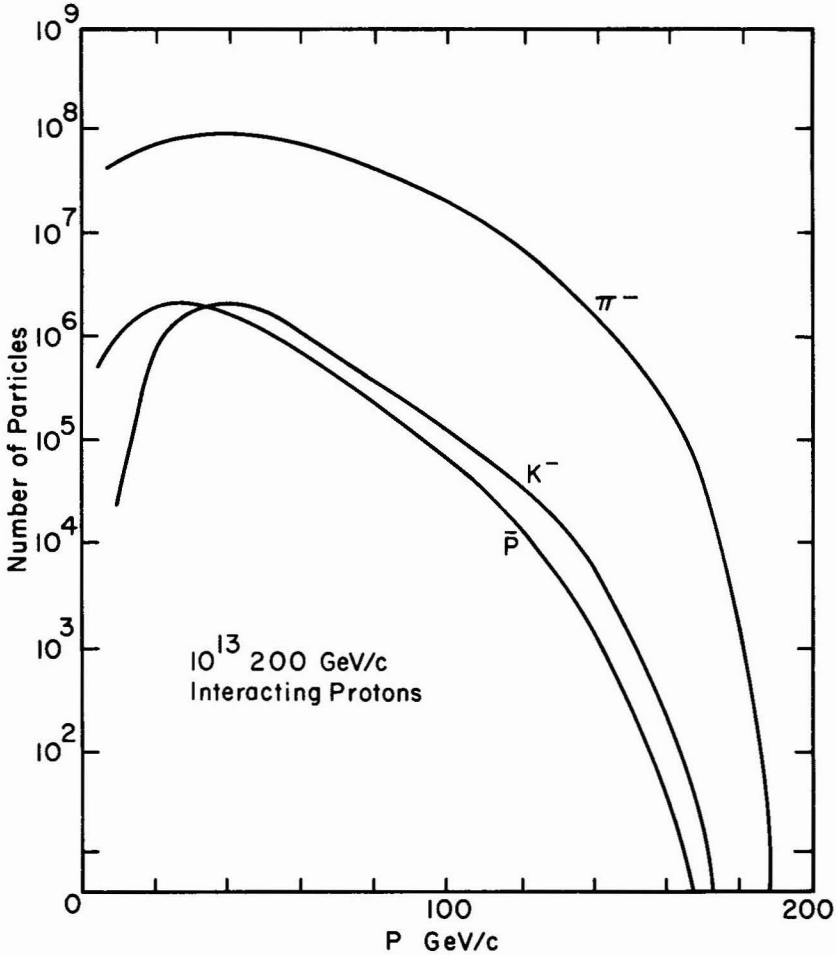


Fig. 14. Predicted negative particle intensities (Hagedorn-Ranft model) in the 3.5-mrad beam (M1).

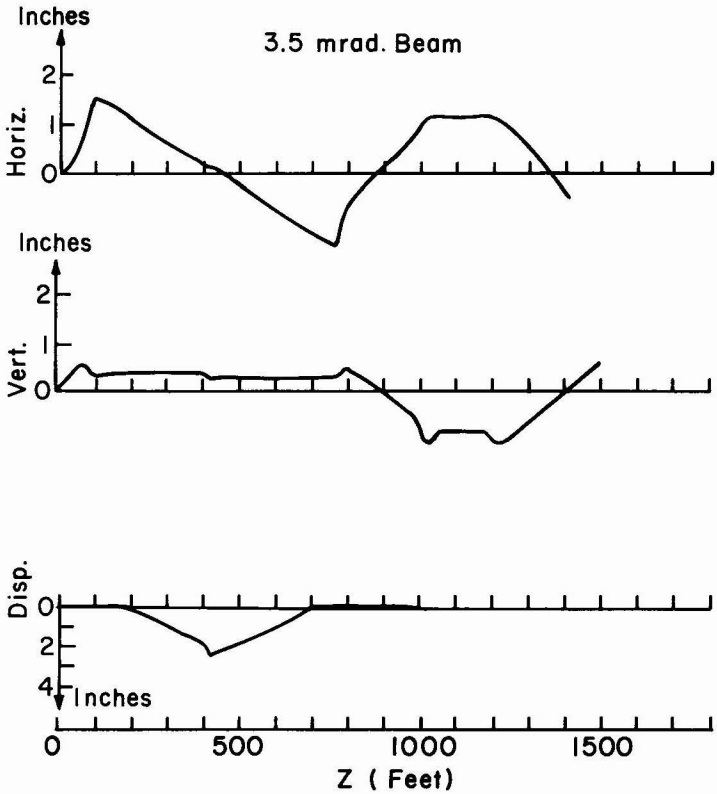


Fig. 15. Calculated particle trajectories in the 3.5-mrad beam (M1).

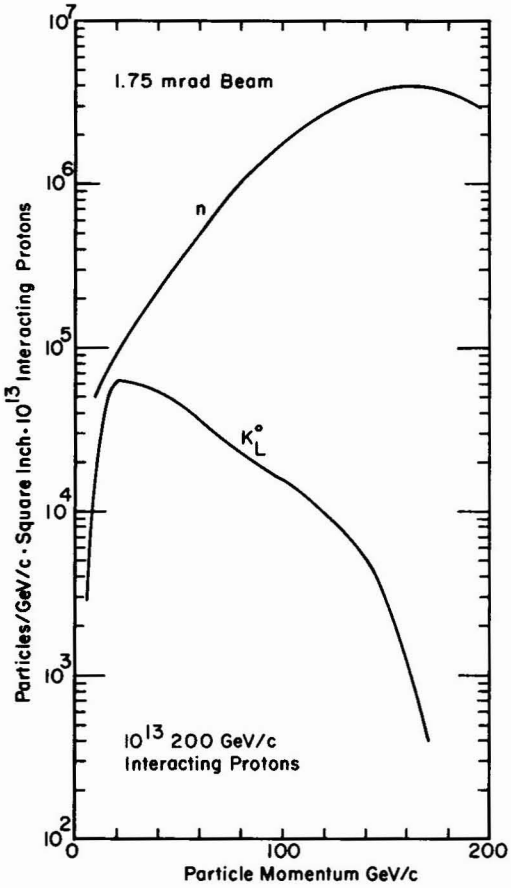


Fig. 16. Predicted neutral particle intensities (Hagedorn-Ranft model) in the neutron beam (M3).

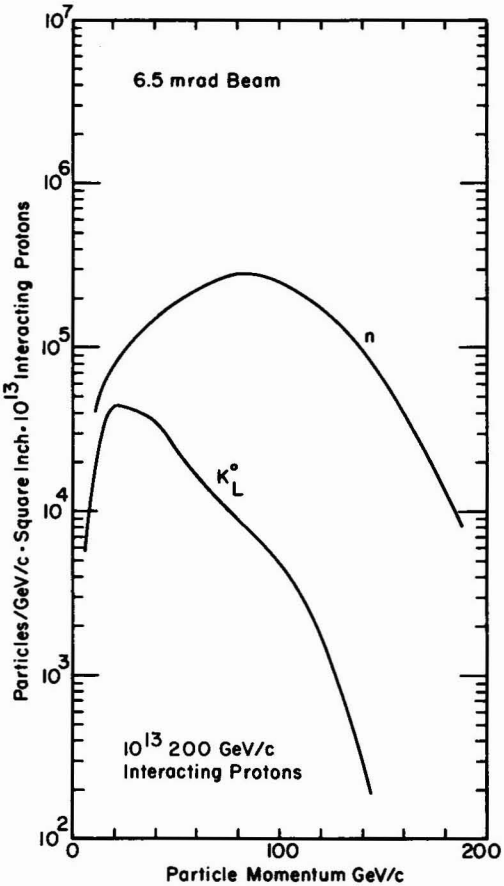


Fig. 17. Predicted neutral particle intensities (Hagedorn-Ranft model) in the $K^o$ beam (M4).

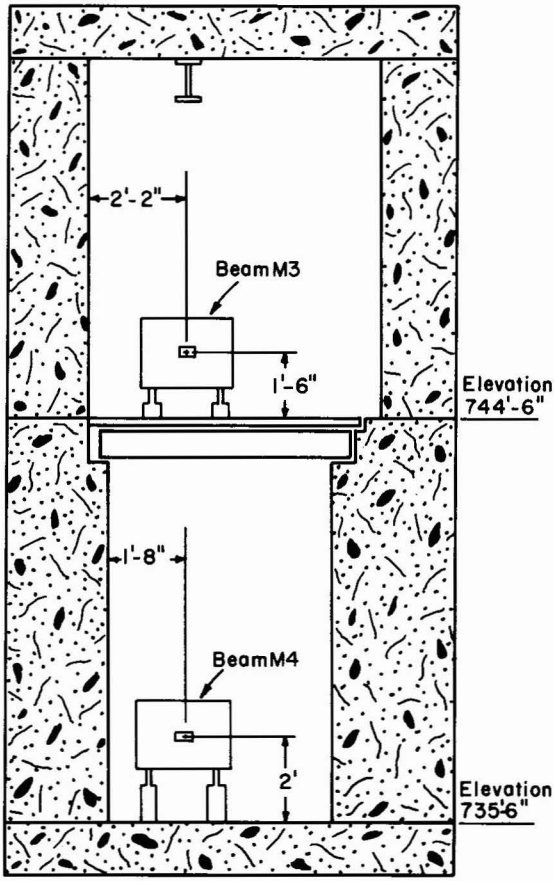


Fig. 18. Cross-section view of one of the enclosures for the two neutral beams (M3 and M4).

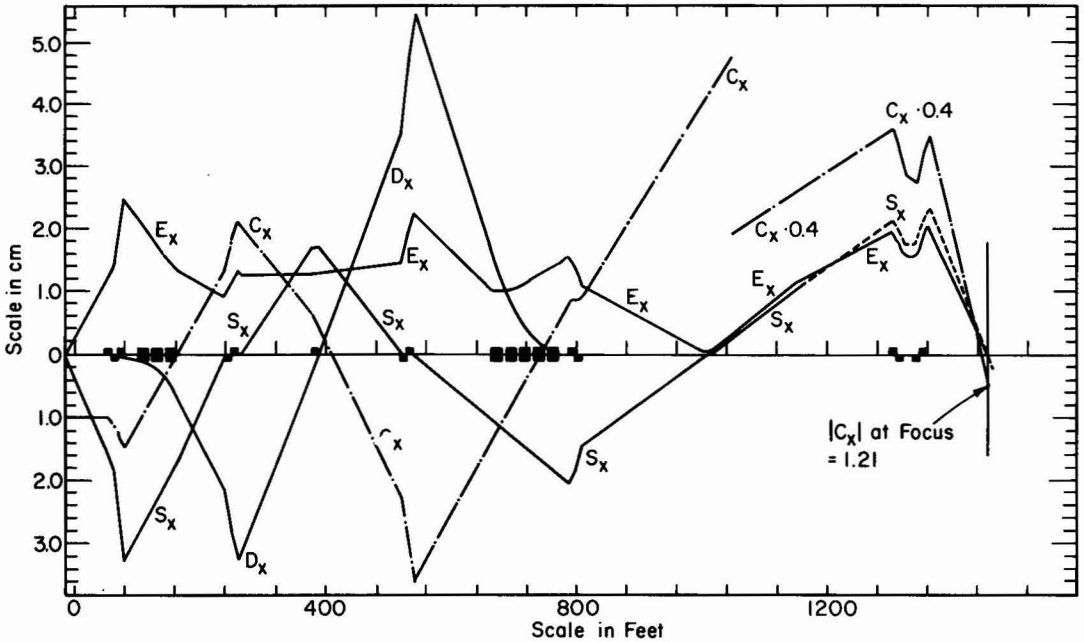


Fig. 19. Principal rays and envelope function for the 15-mrad beam (M5): I. Horizontal plane.

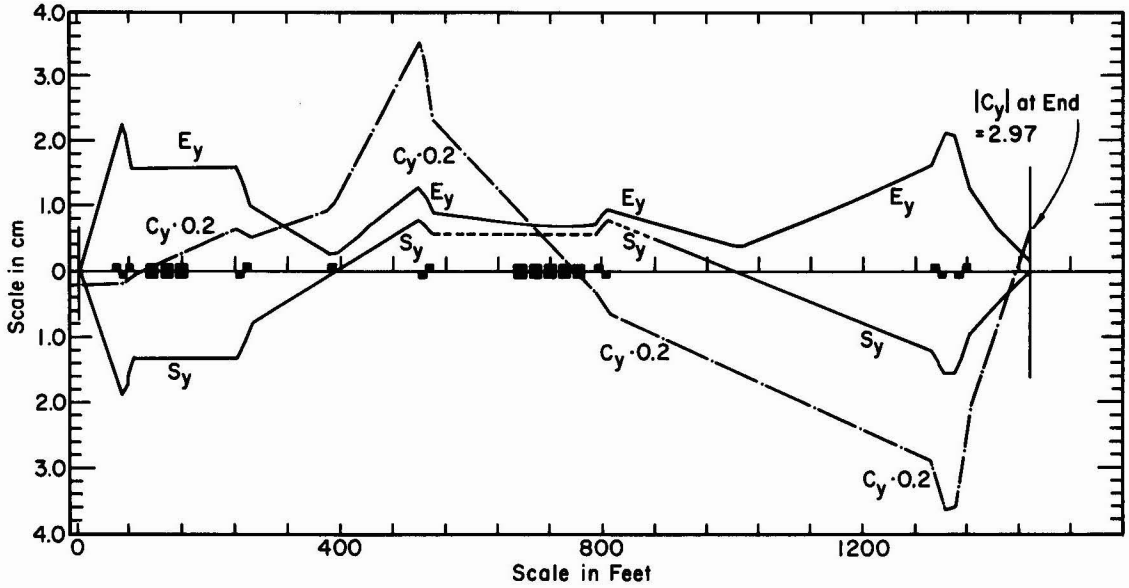


Fig. 20. Principal rays and envelope function for the 15-mrad beam (M5): II. Vertical plane.

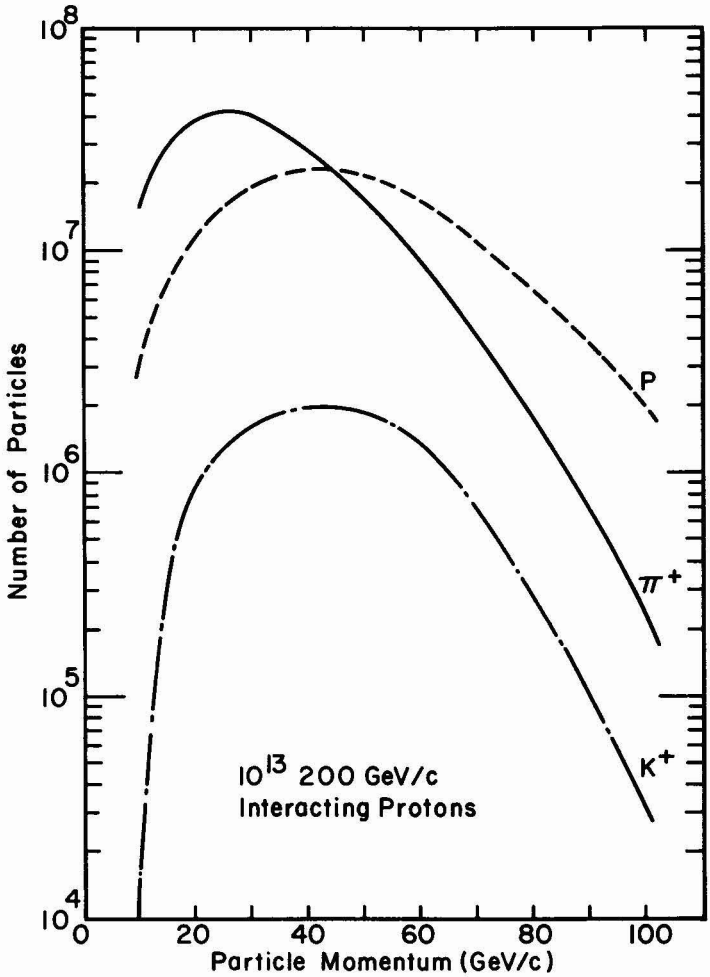


Fig. 21. Predicted positive particle intensities (Hagedorn-Ranft model) in the 15-mrad beam (M6). I. Maximum momentum bite.

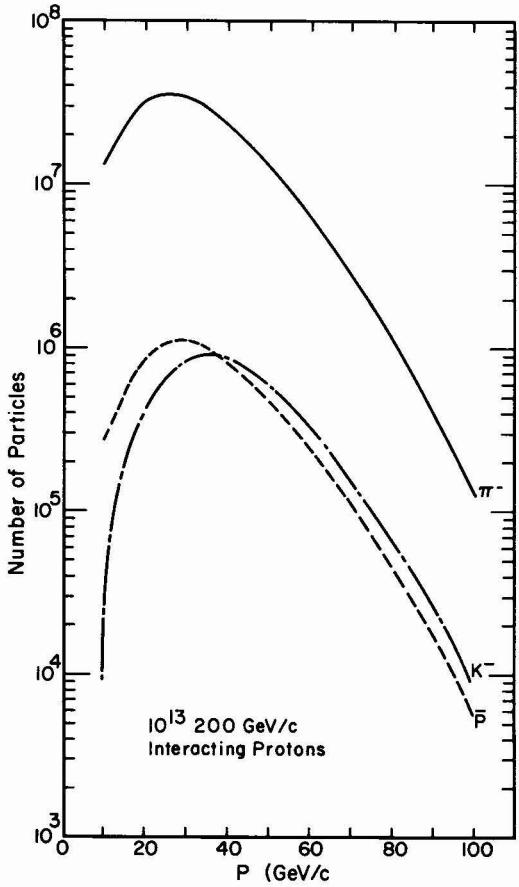


Fig. 22. Predicted negative particle intensities (Hagedorn-Ranft model) in the 15-mrad beam (M6). I. Maximum momentum bite.

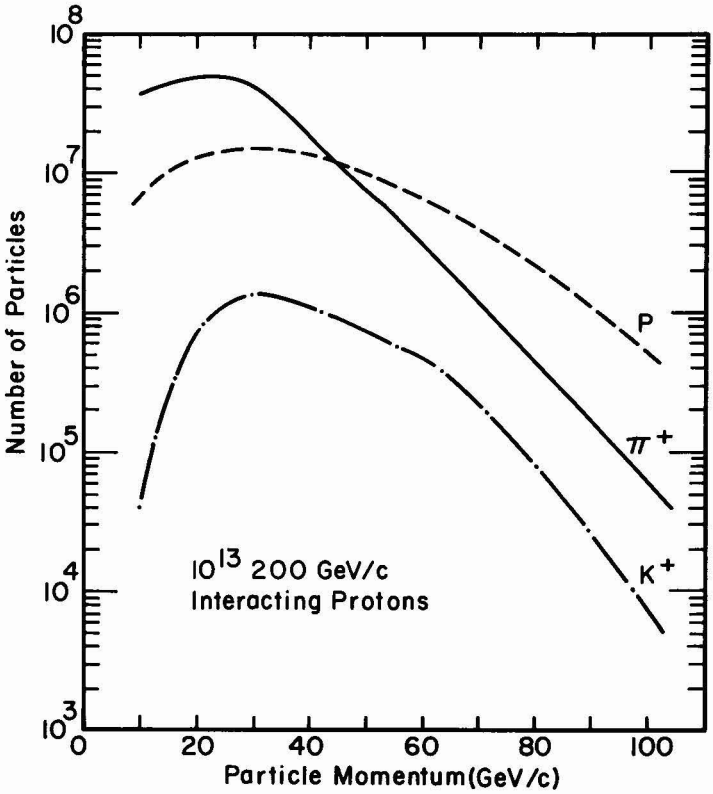


Fig. 23. Predicted positive particle intensities (Hagedorn-Ranft model) in the 15-mrad beam (M6). II. Momentum bite = 200 MeV/c.

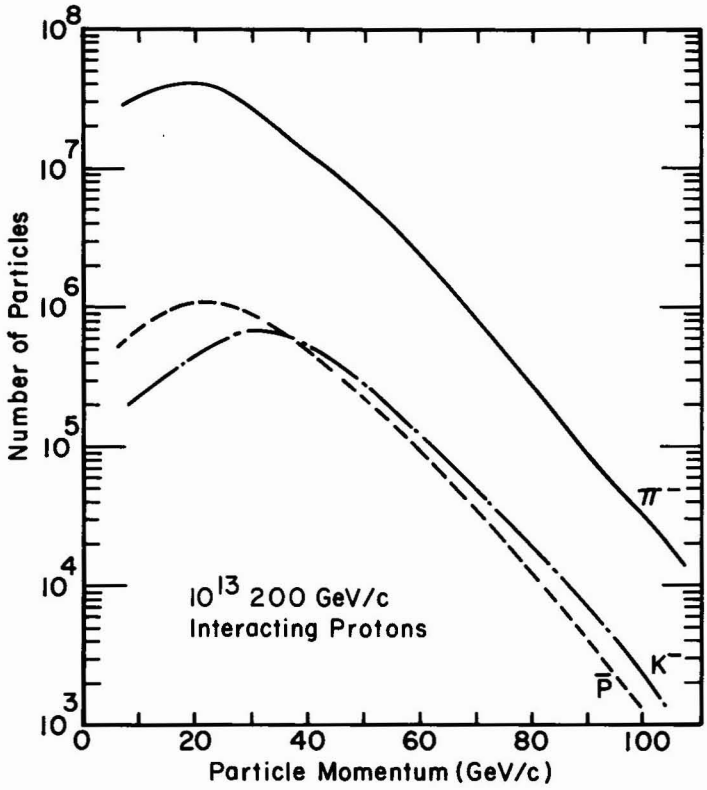


Fig. 24. Predicted positive particle intensities (Hagedorn-Ranft model) in the 15-mrad beam (M6). II. Momentum bite = 200 MeV/c.

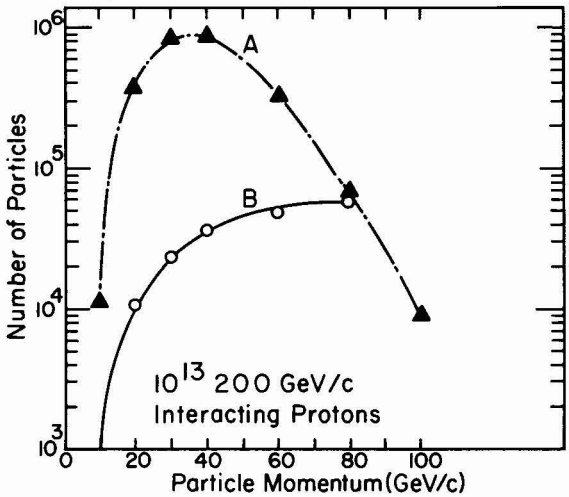


Fig. 25. A: Predicted $K^-$ intensities (Hagedorn-Ranft model) in the 15-mrad beam (M5).
B: Predicted ($K^-$ intensity)/(sum of $\pi^-$, $K^-$, and $\bar{p}$) $\times 10^6$.

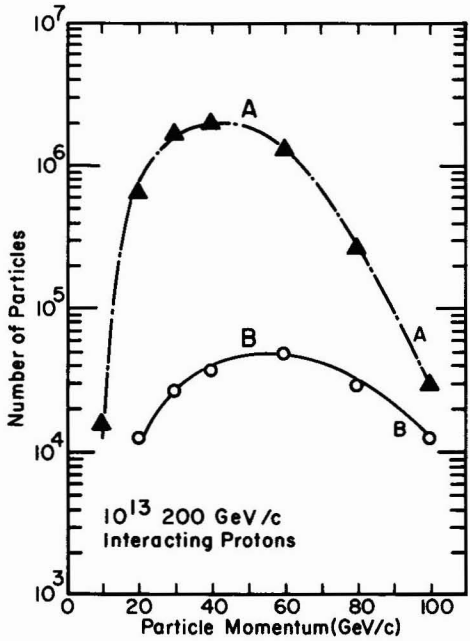


Fig. 26. A: Predicted $K^+$ intensities (Hagedorn-Ranft model) in the 15-mrad beam (M5).
B: Predicted ($K^+$ intensity)/(sum of $\pi^+$, $K^+$, and p) $\times 10^6$.

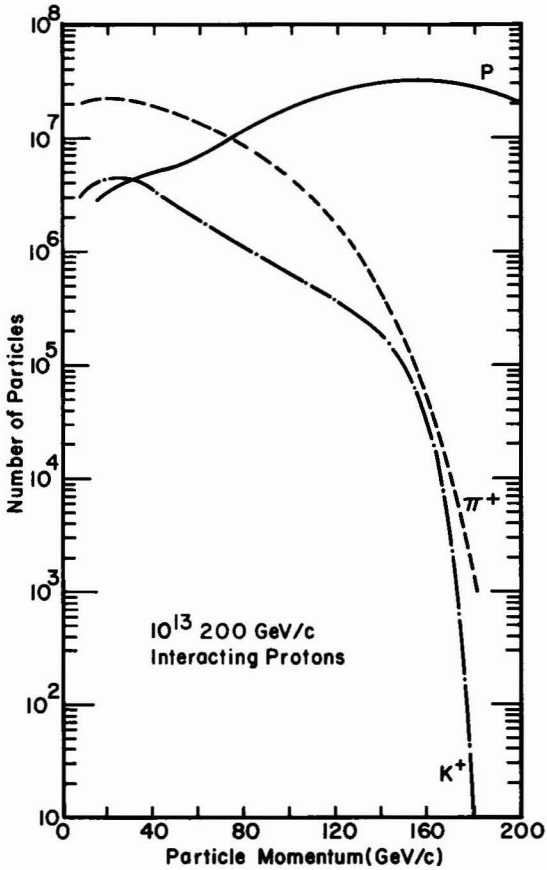


Fig. 27. Predicted positive particle intensities (Hagedorn-Ranft model) in the 2.5-mrad beam (M6).

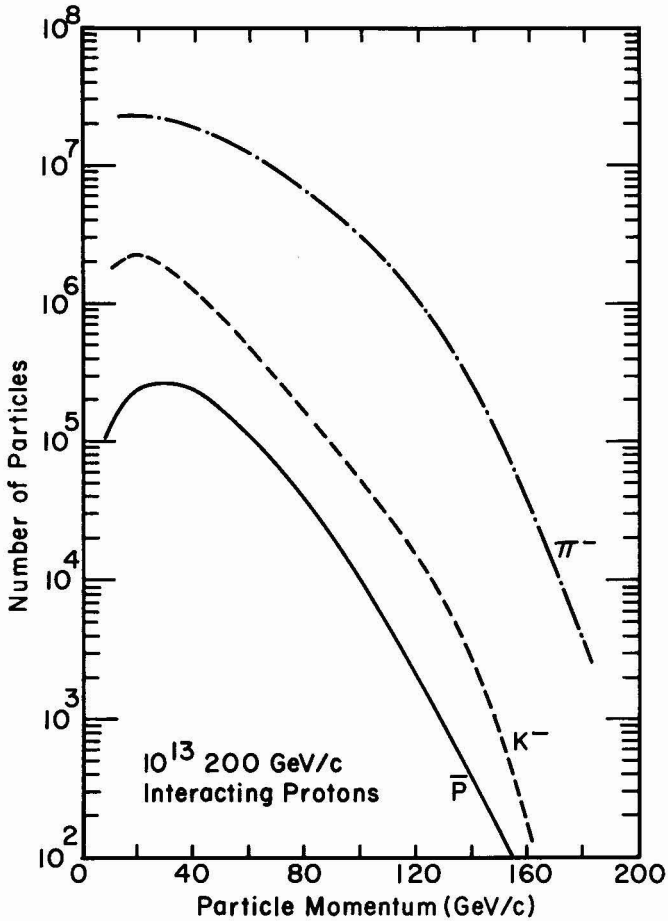


Fig. 28. Predicted negative particle intensities (Hagedorn-Ranft model) in the 2.5-mrad beam (M6).

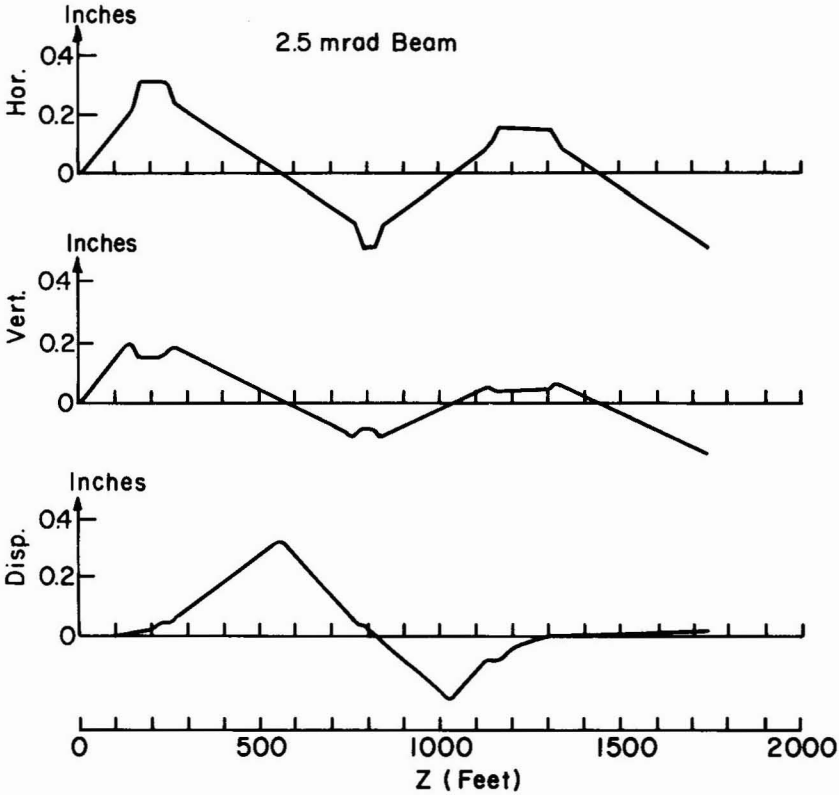


Fig. 29. Calculated particle trajectories in the 2.5-mrad beam (M6).

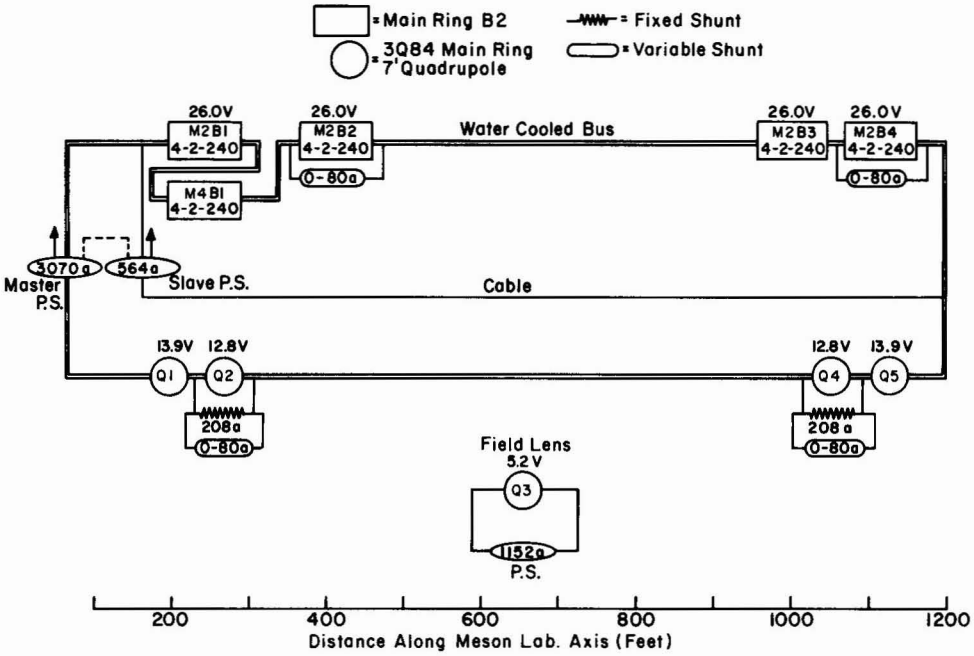


Fig. 30. Circuit diagram for secondary beam M2, including shunt connections.

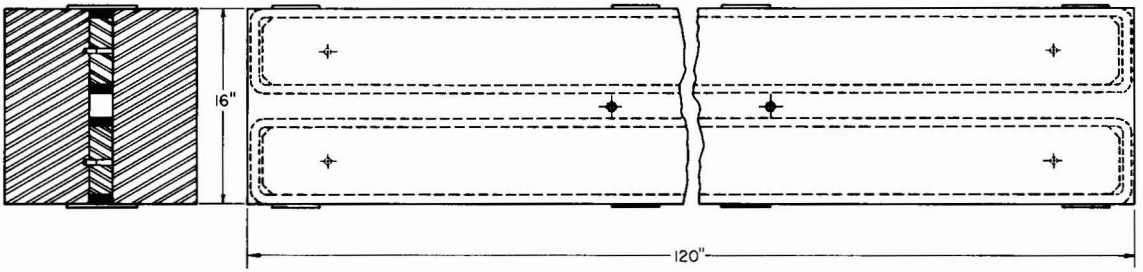


Fig. 31. Typical muon spoiler: cross-section and plan views.

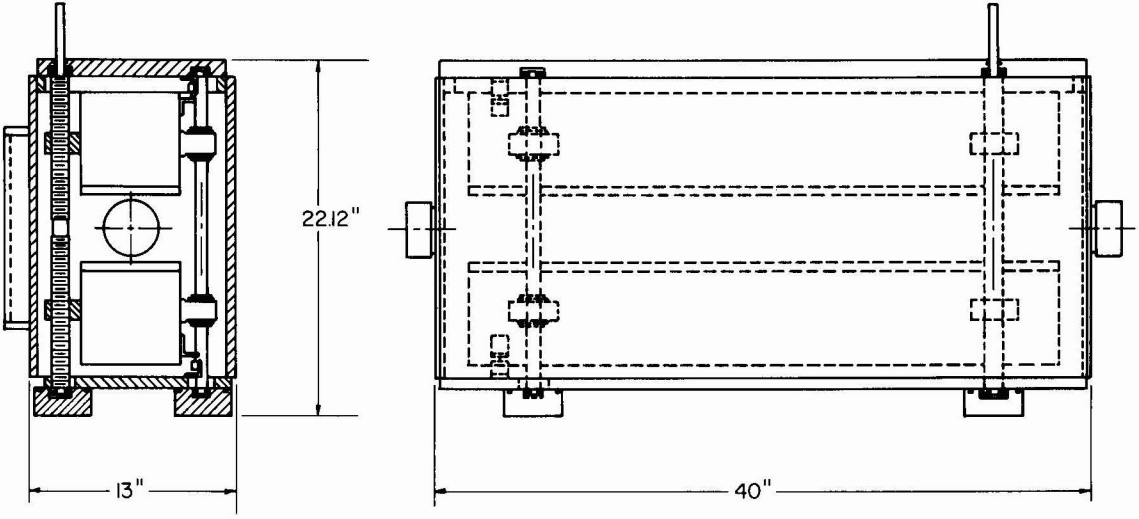


Fig. 32. Typical variable aperture collimator: cross-section and plan views.

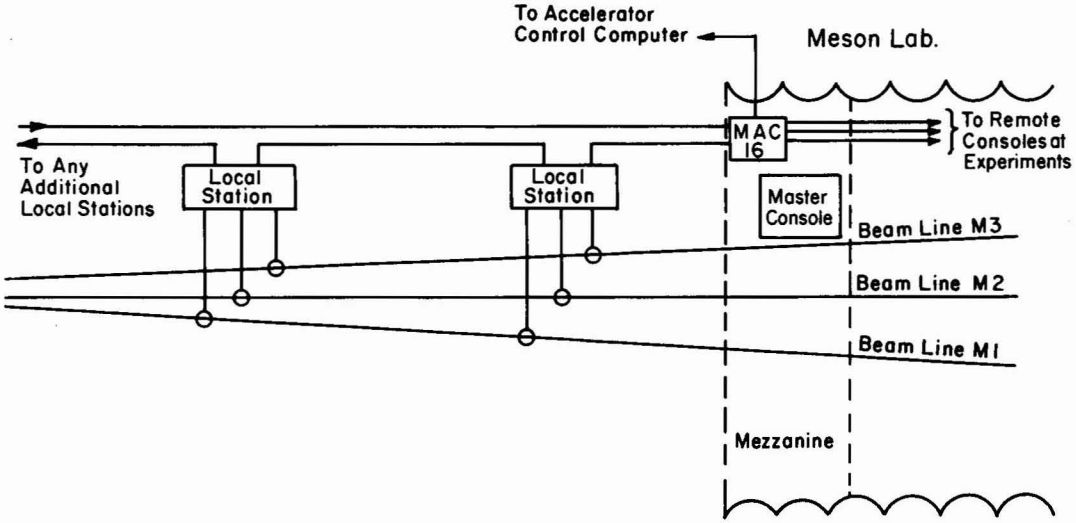


Fig. 33. Secondary-beam control system: block diagram of overall layout.

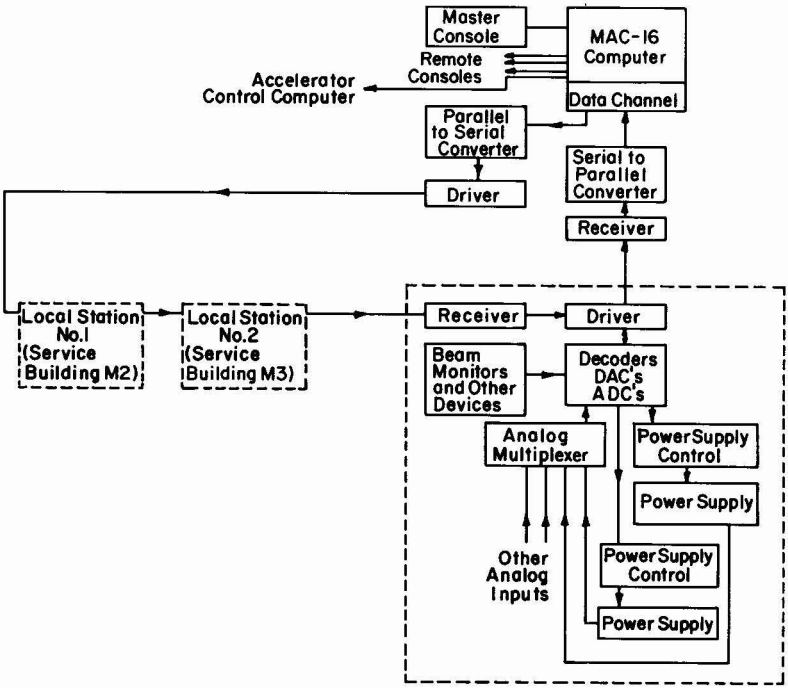


Fig. 34. Secondary-beam control system: block diagram of a typical local control station.

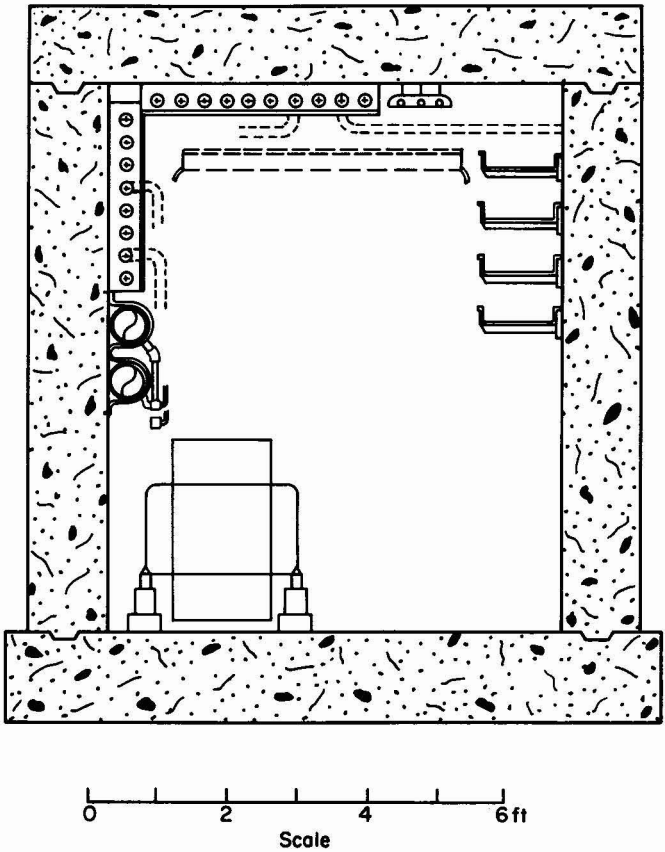


Fig. 35. Cross-section view of a typical secondary-beam transport enclosure.