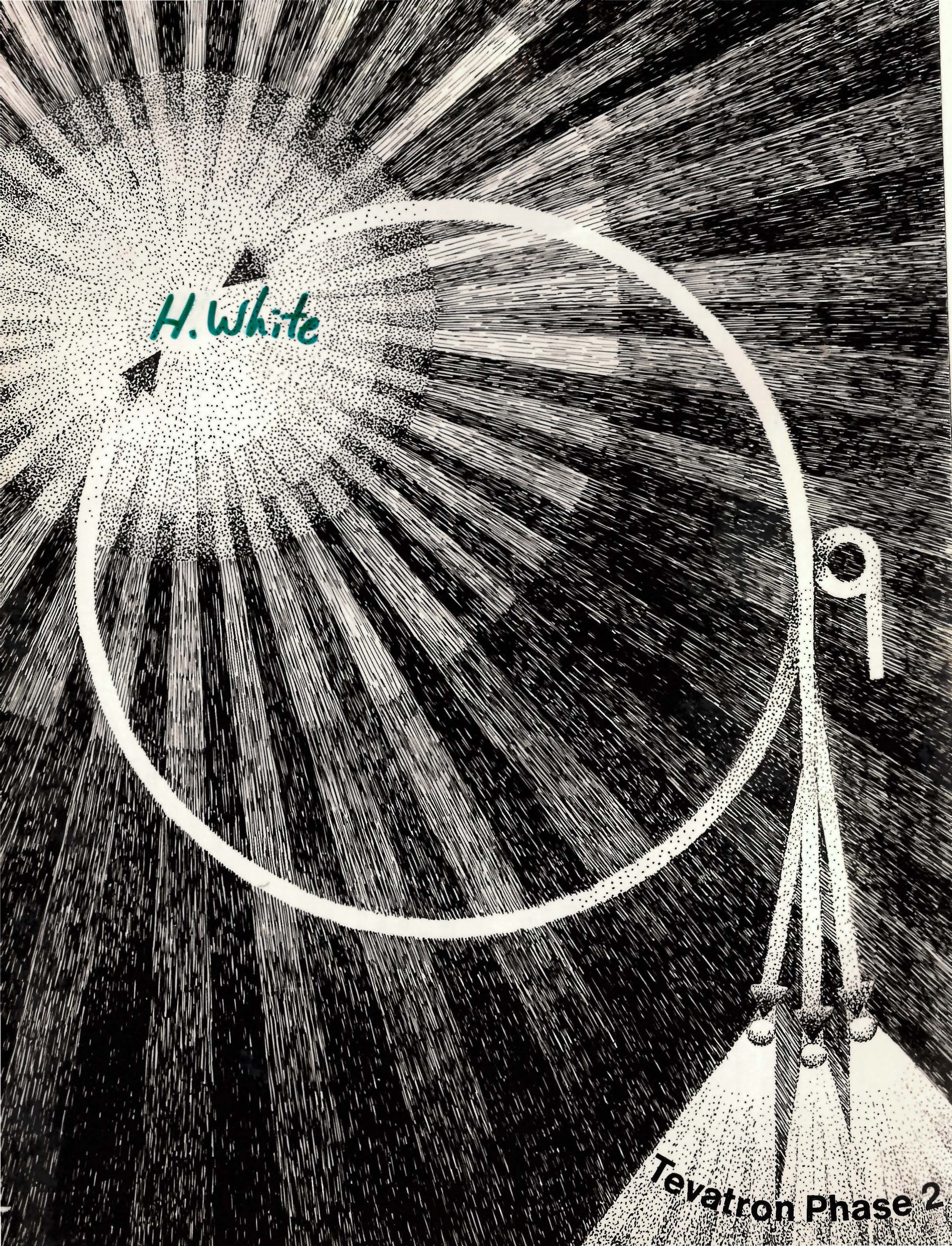
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Tevatron Phase 2

DESIGN REPORT

TEVATRON PHASE 2 PROJECT

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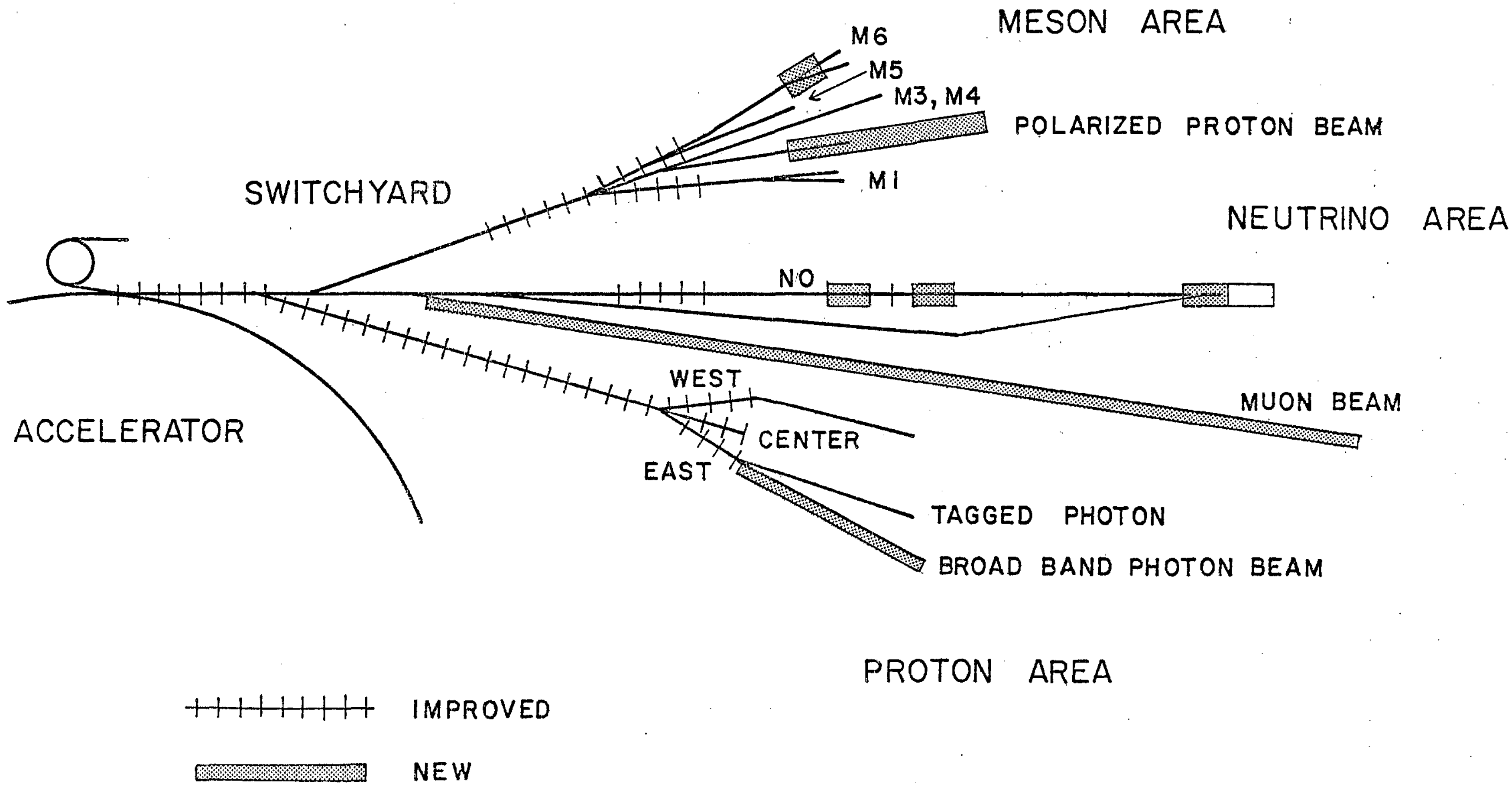
FIGURE I-I SCHEMATIC OF TEVATRON-2 CONSTRUCTION



1. DESCRIPTION OF THE PROJECT

1.1 Scope and Purpose

The TEVATRON, a superconducting accelerator to reach proton energies near 1000 GeV (1 TeV), is being built at the Fermi National Accelerator Laboratory. The aim of the project discussed in this report, TEVATRON PHASE 2, is to provide extracted 1-TeV proton beams and experimental-area facilities for a fixed-target research program.

The facility will provide the highest-energy secondary-particle beams in the world and will give the United States international leadership for many years. The opportunities afforded for experimental investigation of important fundamental issues in the study of the basic constituents of matter are rich and unique.

The research and development work leading to this design has been extensive. A summer study was held in 1976, followed in the last year by workshops treating the individual experimental areas. There are many technical papers available on particular studies. Many of these papers are given as references in the following chapters. At every stage of the work leading to this design report, experimenters and users from the entire national and international particle-physics community have participated and contributed. It is for the research work of this community of users that Tevatron Phase 2 is proposed.

1.2 Relation to Other Tevatron Projects

The Energy Saver, a project authorized in FY79, will provide the superconducting magnet ring of the Tevatron and enough refrigeration and acceleration to operate the accelerator at an energy of 500 GeV, with substantial saving in electric-energy costs. Several Accelerator Improvement

Projects will have made operation of the experimental areas at 500 GeV possible.

The Tevatron Phase 1 project, included in the President's FY81 budget, will provide the refrigeration and acceleration to operate the accelerator at a proton energy of 1 TeV, together with an intense source of antiprotons to produce stored beams of protons and antiprotons at 1 TeV and two colliding-beams experimental areas. This will make it possible to operate the Tevatron as a storage ring to provide colliding-beams interactions at 2 TeV in the center of mass, the highest available energy of any accelerator system in the world. Tevatron Phase 2 will provide the potential for fixed-target physics at 1 TeV.

Simultaneous fixed-target and colliding-beams physics will not be possible , so the Tevatron will operate alternately for one program or the other. The period of operation in one mode is expected to be months. The division of Tevatron research between the fixed-target and colliding-beams modes will depend on the state of physics and technical considerations that arise during commissioning. The two construction programs are largely independent of one another and are not phased in time. Fixed-target research at Tevatron energies should begin during 1982 and have a full year (1983) of operation in the developing external areas before the colliding-beam option is available. By the mid-1980's the Tevatron will have the options of a highly developed fixed-target program and two colliding-beams experiments.

1.3 Elements of the Project

The Tevatron Phase 2 project includes:

(i) The construction of a slow-extraction system for the 1-TeV TEVATRON.

(ii) Improvement of the external-beams Switchyard to 1 TeV and the provision for 1-TeV targeting in the present external experimental areas.

(iii) The construction of facilities for new secondary-beam enclosures and support facilities in each external experimental area in order to take full advantage of the fixed-target physics opportunities of the Tevatron. The total number of secondary beams will not be increased, because the new beams will replace existing beams, but the energies and intensities of the secondary beams will be significantly increased.

The project includes the installation of the various electrostatic septa, septum magnets, kicker magnets and other specialized components needed to extract the 1-TeV protons into the existing Switchyard. Slow resonant extracted beams (1 to 10 sec), required for electronic-detector systems, and fast resonant extracted beams (1 to 3 msec) preferred for neutrino experiments, will be provided. Additional septa, bending magnets, focusing magnets and ancillary components necessary to transport the 1-TeV protons to the three external experimental areas are also included.

The target stations and experimental facilities of all three areas will be modified to optimize the handling of 1-TeV proton beams and to permit full utilization of the increase in secondary-particle energies produced in the existing secondary-beam lines. Beam lines with necessary enclosures will be added to each laboratory to exploit the unique opportunities presented by 1-TeV protons on external targets. Ancillary storage and materials handling capability will be provided for the improvement of efficiency and flexibility in carrying out experiments.

The present 400-GeV experimental areas consist of three laboratories, the Neutrino Area, the Proton Area, and the Meson Area. These experimental areas and their relation to the accelerator are shown in Fig. 1-1, which shows the improvements coming from the Tevatron Phase 2 Project.

The Neutrino Area includes a flexible and powerful neutrino beam, N0, that feeds several major electronics experiments and the 15-ft bubble chamber. A modest muon-hadron beam, N1, serves several detectors. The flux from that beam is now considerably smaller than that at the CERN SPS facilities in Europe. A hadron beam system, N3/N5, can provide secondary particles to either the 30-in. bubble chamber or the neutrino detectors for calibration purposes. At the completion of Tevatron Phase 2, the Neutrino targets and shielding will have been improved to permit experiments with 1-TeV protons on target. This requires the addition of massive steel shielding in the N0 line. A completely new muon beam and experimental area will be constructed to make a first-class muon facility.

Three independent primary proton beams are provided in the Proton Area, using a three-way split. In P-West, the beam feeds a powerful high-intensity charged-particle beam. P-Center is currently used to produce a flexible high-energy hyperon beam. P-East is used to operate two heavily used photon beams, a tagged-photon beam and a broad-band photon beam. It is not possible to operate both beams simultaneously. At the completion of Tevatron Phase 2, the high-intensity beam of P-West and the hyperon beam of P-center will have been improved to a 1-TeV production level. Completely independent target stations will be provided for the two photon beams to permit simultaneous operation at higher energies.

The Meson Area has been used principally for experiments that utilize secondary-particle beams. At present, six beams are derived from two independent production targets at the South end of the area. The beams include three flexible charged-particle beams, M1, M2, M6, with peak energies of 400 GeV, a neutral beam for K^0_L and neutrons, M3, a test beam, M5, and a fourth less-flexible charged-particle beam, M4. At the completion of Tevatron Phase 2, the Meson Area will be improved to target 1-TeV protons on three independent targets. A new Target Service Gallery will be constructed to allow remote handling of radioactive targets. In addition, the improvements in muon shielding needed for higher energies and new experimental enclosures will be provided. A polarized proton beam will also be built.

Tevatron energies and intensities imply a new level of size and scale of experimental equipment. The facilities of the laboratory for handling and storage of Tevatron experimental equipment will become inadequate, due in part to the increased weight of new components. This project will eliminate these inadequacies by providing storage, increased hard-stand area and improved component-handling capability throughout the laboratory experimental areas.

For most secondary beams, the existing components will be able to operate initially with substantially increased beam intensity, albeit lower energies than are ultimately feasible with the Tevatron. Secondary-beam changes will be evolutionary, rather than lumped together in Tevatron Phase 2. The exact configurations of the new technical components of the secondary beams will be tailored to the requirements of the specific 1-TeV fixed-target research proposals recommended by the Fermilab Physics Advisory Committee and approved. These requirements will evolve as the program comes into operation and will continue to change throughout its life. Most of the equipment installations for secondary beams that have applications to the Tevatron program are also useful at present energies. Most frequently, the evolutionary changes in the beams in the Tevatron era will be in the direction of continuing to raise the energies of the secondary beams. For all these reasons, the secondary-beam development will be carried out principally with separate "equipment not related to construction" funds.

1.4 Estimated Cost

Cost estimates for the work of Tevatron Phase 2 have been prepared in considerable detail and are presented in Chapter 8. A summary of the estimates is given in Table 1-1. These estimates are given in 1983 dollars and escalation is included.

Table 1-1. Summary of Estimated Tevatron Phase 2 Costs

(in millions of dollars)

A. Construction Costs			
1. Extraction System		1.7	
2. 1-TeV Construction and Modification			
a. Neutrino Area	2.3		
b. Proton Area	3.7		
c. Meson Area	5.0		
		11.0	
3. Beam-Line Construction			
a. Neutrino	7.6		
b. Proton	5.0		
c. Meson	1.4		
		14.0	
4. Storage and Handling Facilities		4.8	
Total Construction Costs			31.5
B. Engineering Design Inspection and Administration			6.6
C. Contingency			7.6
D. Project Engineering and Design			0.8
Total Estimated Project Cost			$46.5M

1.5 Physics Opportunities

The collision of 1-TeV protons with nuclear targets will provide an intense source of muons, electrons, neutrinos, photons, mesons, and baryons with which to study the emerging picture of the weak, electromagnetic, and strong interactions of the fundamental constituents of matter. In each of the three existing external laboratories at Fermilab, many new research opportunities will be possible. The gain in the event rate of energetic interactions and the doubled energy of the proposed muon beam will allow detailed measurements of quark structure functions of protons and neutrons and sensitive tests of quantum-chromodynamics (QCD) predictions of their energy variations. The careful measurement of high-energy neutrino charged and neutral-current interactions will test the unified description of the weak and electromagnetic interactions of leptons, including the predicted damping of the total cross sections from the postulated effect of the intermediate vector boson.

The production and study of heavy quarks is greatly enhanced at higher energies. The combination of high energy and advanced detector technology will make it possible to study particles with lifetimes as short at 10^{-13} sec. It will be possible to study charmed mesons in detail. One-TeV energies and these techniques may be a very practical way to study b-quarks.

Studies of the strong-interaction dynamics of quarks will be enhanced by the increased energies available in hadronic interactions, as well as the improved duty cycle of the TEVATRON, which will permit greater average secondary-beam intensities. Observations of particle-jet phenomena, and measurements of fundamental properties and polarization phenomena of hadrons become easier and more decisive at higher energies. The increased fluxes open new domains in the study of high transverse-momentum interactions. Studies of high transverse momenta, which imply small impact parameter scattering, will be crucial in the elucidation of the correct dynamics of quarks and gluons.

The succeeding chapters of this Tevatron Phase 2 report discuss the physics opportunities and the design. The physics that can be done with 1-TeV protons on a fixed target is discussed in Chapter 2, the accelerator and switchyard modifications in Chapter 3, and the separate experimental areas in Chapters 4 (Neutrino), 5 (Proton), and 6 (Meson). The handling and storage facilities are discussed in Chapter 7 and the cost estimates and schedule are discussed in Chapter 8. Chapter 9 gives an overview of operation and future development of the Tevatron fixed-target program.

2. A 1-TEV FIXED-TARGET PHYSICS PROGRAM

2.1 Introduction

Many physics opportunities exist that justify fully exploring the various fixed-target physics options made possible with the completion of the 1-TeV proton accelerator, the Tevatron. The decade of the 70's has been filled with many discoveries at Fermilab that belie the mere factor of 5 increase in energy from the previous 80-GeV energy limit at Serpukhov. The increase in the total cross sections and increase in the differential cross-sections for meson and baryon scattering at large angles, the existence of significant hyperon polarization and the subsequent precision measurements of magnetic moments proved that even the large strong-interaction cross sections can reveal interesting aspects of underlying constituent interactions. The confirmation of the predicted weak neutral-current interactions in neutrino physics and the detailed study of the production and lifetime of the charmed-quark family have certainly depended on the more energetic secondary beams produced at 400 GeV. The existence of an energy threshold was most dramatically apparent in the exciting discovery of the upsilon (or b-quark) heavy-quark family. Discovery of the upsilon would have been delayed 3 to 5 years had the Fermilab accelerator had been built with a 200-GeV upper limit as originally planned. The upsilon production rate increases by a factor of 10 between 200 GeV and 400 GeV and is expected to increase by an additional factor of 4 between 400 GeV and 1 TeV.

The ensemble of results from incident particle energies up to 400 GeV has revealed a picture of hadrons as composite structures of pointlike quarks and vector bosons called gluons that bind the quarks together. It is also found that the structure observed in hadrons depends on the wavelength (or energy) of the scattered particle. The closer one looks, the richer is the constitution of hadrons. Our current theoretical description of this emerging picture of hadrons, quantum chromodynamics (QCD), needs testing with probes of shorter wavelengths (higher energy) and different internal structure (different secondary-beam particles available only at fixed-target accelerators). The interaction of muons and neutrinos with hadrons is also believed to be accurately described by the weak and electromagnetic interaction theory of Weinberg and Salam in combination with QCD. The exact structure of the weak currents also deserves precise testing with higher energy probes.

Many of the physics issues to be addressed by the Tevatron fixed target program in the mid-1980's will also be addressed by various colliding beam machines at much higher energies. Already the e^+e^- colliders, PEP and PETRA, attain center-of-mass energies comparable to what will be available for the Tevatron fixed-target program. SPEAR will have been running for years as a D factory, and CESR as a bottom-factory. Hard collisions of quarks will be measured at the CERN and Fermilab colliders, with final-state transverse momenta greater than 100 GeV instead of the approximately 10 GeV available with fixed-target experiments. Electroweak theory will get its most crucial test in the search at the $p\bar{p}$ colliders (and ultimately LEP or other higher-energy e^+e^- machines) for the intermediate bosons W and Z^0. And if the top-quark exists, it may well be too massive to be studied in fixed-target experiments.

It therefore appears that in this context the Tevatron fixed-target program, despite its possessing the highest-energy particle beams in the world (which can be anticipated to be true even in 1990), will be "medium-energy" physics, not at the cutting edge of highest energy. Such a point of view may be entertained, given a very conservative outlook of the physics opportunities in this energy regime. But it is not supported by past history, which abounds in examples of fundamental advances carried out in experiments of less than the highest energy (e.g. CP violation, neutral currents, the J, electroweak asymmetry in ep scattering). In the context of the Tevatron-2 program, one may cite the search for the ν_τ or for Higgs-like bosons that couple to $q\bar{q}$ or $\mu^+ \mu^-$, but not strongly to e^+e^-, as immediate examples of unique opportunities for totally exploratory studies. No doubt the truly interesting examples are ones that are not possible to now predict.

Even if one sets aside the exploratory opportunities available to the Tevatron fixed-target program, there remains a broad spectrum of studies that either compete very well with collider experiments or provide very complementary information. For example charm and even bottom-quark production occur at rates much greater than possible in e^+e^-machines. At present, exploitation of these large rates has been largely blocked by the very large backgrounds. But in the long run, this problem can be expected to be greatly reduced in magnitude by advances in precision vertex detectors, sophisticated trigger processors, and higher-resolution detectors. Bottom-quark production, of course, benefits by orders of magnitude given the increased Tevatron beam energies and lengthened duty cycle.

Given the assumption that the Weinberg-Salam model is correct, many weak-interaction experiments boil down to measurements of $\sin^2\theta_W$. Once the Z^0 is isolated and studied (e.g. in an e^+e^- Z^0 factory), one will have available extremely accurate measurements of $\sin^2\theta_W$. It is then a valid question as to whether fixed-target measurements become irrelevant. This is <u>not</u> the case. Comparison of relatively low Q^2 measurements of $\sin^2\theta_W$ with high Q^2 ($\simeq m_Z^2$) measurements may provide a determination of the radiative corrections to lowest-order electroweak theory; these in turn depend on what goes on at still higher energies. On the other hand, the standard model may be incorrect or incomplete, in which case one may expect manifestations at all energies, high and low. Then the diversity of possible experimental approaches provided by the Tevatron is a distinct advantage.

Other cases where fixed-target measurements complement collider information are dilepton production and high-$p_\perp$ jet production. In these cases, the high luminosity of fixed-target experiments allows one to put a large fraction of incident energy into the high-$p_\perp$ system. Furthermore the opportunities to study dependence on the initial beam or target (including nuclei) are other unique features that compensate for the reduced energy scale available.

These are only a few examples: in no way is the Tevatron fixed-target program made obsolescent or uninteresting by the existence of a variety of collider processes of much higher energy and cleanliness. Much of the program remains unique, and a good deal of the remainder is highly complementary to the collider programs. In the following sections on Hard Collisions, Heavy Quarks and Soft Collisions, we outline measurements made possible with a 1-TeV fixed-target program.

2.2 Hard Collisions

A scale typical of the excitation energy of the constituents or partons in hadrons is 0.3 GeV; this is manifested both in the excitation spectra of hadrons and in the average four-momenta exchanged in the elastic scattering of various hadrons. Collisions involving transfer of energy or momenta considerably in excess of this 0.3 GeV reveal the dynamics of parton interactions and test the theoretical understanding of the elementary processes involved. The large momentum-transfer scattering of muons and neutrinos from hadrons, the direct production of lepton pairs in hadron collisions, the production of heavy quark states in hadron collisions, and the direct scattering of quarks and gluons forming high-momentum jets of hadrons are examples of processes that probe the direct interactions of the partons. The cross sections for these large momentum-transfer parton interactions are typically quite small, of the order of 10^{-31} cm^2 or less, even well above threshold. Hence the factor of 10^6 greater luminosity enjoyed by fixed-target experiments over colliding-beam experiments often enhances the observation of these constituent scatters at fixed-target accelerators despite the lower center-of-mass energy.

In deep inelastic scattering of muons and electrons from nucleons the squared momentum transfer, Q^2, from the lepton to the parton can range from zero to the kinematical limit of $2m_pxE$, where E is the lab energy of the incident lepton and x is the fraction of the incident hadron's momentum carried by the scattered quark in the lepton-quark center of mass frame. QCD makes definite predictions on the variation of the lepton scattering rate as a function of Q^2. The range of Q^2 variation extends upward from the 10-GeV^2 lower threshold, given by "higher-twist" or bound-state effects beyond present 200-GeV^2 limits to about 1000 GeV^2. The log Q^2 variation is extended by 50%.

The Weinberg-Salam description of neutrino scattering prescribes a similar variation of inelastic neutrino scattering as that seen in muon scattering. Neutrino experiments at Tevatron energies will also extend up to Q^2 of about 1000 GeV^2. This will allow simultaneous checking of the weak couplings of neutrinos (for instance any log Q^2 variation of $\sin^2\theta_W$) and the constituent picture of hadrons.

Dilepton production in hadron collisions has emerged in the last decade as an important probe of quark momentum distributions within hadrons. The fractional quark momentum probed is related to the mass of the lepton pair through the Drell-Yan mechanism of quark-antiquark annihilation. The comparison of structure functions measured by this reaction to those measured in deep inelastic scattering is a sensitive test of higher-order QCD effects. The transverse momentum that the lepton pair acquires in the reaction is sensitive to quark-gluon couplings and to second-order QCD effects. Asymmetries in the momenta of the muons arise from electroweak interference.

The existence of families of massive vector mesons that decay directly to dilepton pairs eliminates certain mass regions as tests of the Drell-Yan annihilation model. Masses below 4 GeV are dominated by the J/ψ family and lighter vector mesons and the region from 9 GeV to 10.6 GeV contains the upsilon family. Tevatron energies allow a large increase from 20 GeV to 30 GeV in the mass region explored and hence a complete coverage of Q^2 up to 1000 GeV^2 with little interference from the low-lying vector-meson states.

The structure of mesons and hyperons can be probed via the Drell-Yan mechanism at high energies. This is the only means possible to study the details of how varying quark masses affect the momentum distribution of quarks and gluons within a nucleon. The intense high-energy secondary beams produced by 1-TeV incident protons are a necessity for there studies.

The production of heavy-quark vector-meson states is expected to proceed via 2-gluon and 3-gluon couplings and quark fusion. Studying the excitation dynamics of these resonances at high energies will be a direct probe of gluon distributions within hadrons. The comparisons of gluon distributions in different hadrons, as well as the comparison with gluon distributions inferred from measurements of other hadron collisions, will be an important test of QCD concepts, as well as an important probe of hadron constituent structure.

Once the quark and gluon composition of hadrons is well understood from the measurements mentioned above, we may regard hadron-hadron collisions as sources of quark-quark, quark-gluon and gluon-gluon collisions. The integrated "parton-parton luminosity" achieved in hadron collisions is larger than the hadron-hadron luminosity. The center-of-mass energy available in the parton-parton collision extends from zero up to the hadron-hadron total energy. In pp colliding-beam devices, only admixtures of gg, gq, and qq can be studied and only at low luminosity or low center-of-mass energy. With the Tevatron fixed-target program the parton-parton collision types can be varied by varying the incident hadron type. Meson-nucleon collisions are rich in qq and $\bar{q}q$ at high collision energies and nucleon-nucleon collisions are rich in qq collisions. Proton-antiproton collisions in colliding beams will be dominated by gg collisions.

2.3 Heavy Quarks: Charm and Bottom Physics

While the discovery and elucidation of the properties of charmed hadrons has been dominated by the research at e^+e^- colliding-beam facilities, there is nevertheless reason to anticipate that in the long run, charmed-particle physics--including spectroscopy--may be most fruitfully pursued in high-energy fixed-target experiments. The reason for this is that charm is abundantly produced in neutrino (10% of total cross section), photon (1% of total cross section) and hadron (0.1% of total cross section) interactions with nucleons. Typical attainable rates are illustrated in Table 2-1. For e^+e^-, we take SPEAR at the ψ'' and CESR at the Υ'''. For fixed target, we take conservatively an incident Tevatron hadron beam with 10^7 interactions/min into an open-geometry spectrometer.

Table 2-1. Quark Spectroscopy Rates in Different Accelerators

	e^+e^-	Fixed Target
Charm events/hour	200	10^6
Bottom events/hour	10	1000
$\sigma(\text{charm})/\sigma_{tot}$	0.3	10^{-3}
$\sigma(\text{Bottom})/\sigma_{tot}$	0.4	10^{-6}

The difficulty with exploitation of these large rates lies in the relatively poor signal/background ratio.

Recently there has been a great deal of progress, both in the observation of charm in fixed-target experiments and in the development of a variety of techniques for isolating the signal. The number of D's and charmed baryons observed in fixed-target experiments begins to rival the number observed in e^+e^- collisions. In addition, information inaccessible to e^+e^-colliders, such as lifetimes, is being gleaned from fixed target experiments. The techniques used for fixed-target charm studies can be expected to continue to be greatly improved in the coming years. Direct-lepton triggers that exploit the appreciable semileptonic branching ratio known for charm and expected for beauty are already in common use. More sophisticated electronic triggers that select events on the basis of particle types, topologies, and special kinematics have already been successfully used for charm production. The continued evolution of trigger processors and the attendant detector hardware is a prerequisite to efficient utilization of the substantial production rates that may be realized in hadronic interactions. Detector live time is another important determinant of efficiency for experiments bearing on heavy-quark physics. The long spill envisaged for the Tevatron, with its implied reduction of instantaneous trigger rates (for a given interaction rate per cycle), makes the use of detailed trigger algorithms all the more attractive. In addition, high-resolution vertex detectors (streamer chambers, rapid cycling bubble chambers, or novel track chambers) can be expected to be another vital element in the efficient extraction of the charm signal. It is difficult to estimate whether these improvements will be sufficient to fully exploit the rate advantages evidenced in Table 2-1, but it is important to note that there is no competition. Even if it takes a decade to succeed in such an endeavor, there is no known alternative--unless a significant increase in the luminosity of low energy e^+e^- machines can be achieved.

Studies of hadrons containing b quarks via fixed-target experimentation will evidently be more difficult, but upon taking the long view, there are again some reasons to expect a great deal of progress. An immediate reason is the e^+e^- program itself, especially at CESR, which should within the next year provide excellent information on the basic properties of mesons containing a bottom quark, in particular the nature of their decay modes. If, as widely anticipated, b-quarks have a large branching fraction into charmed quarks, a successful program of isolation of charm from background in fixed target experiments will ipso facto lead to isolation of bottom from the background. In any case, a successful fixed-target program for study of bottom quark properties will build on the basic knowledge obtained from e^+e^- experimentation, just as the ongoing program of charm studies greatly benefits from the knowledge obtained in e^+e^- collisions.

What are the physics issues? These include production characteristics, lifetime studies, observation of "exotic" hadrons such as (csu) or (bsu) baryons (which may be produced in the Σ^- beam), bottom baryons in general, and studies of rare decay modes.

A study of the strong-interaction production dynamics of states containing c-and b-quarks can of course only be accomplished at a proton accelerator. The issues here are the relation to light-quark dynamics and the comparison between the production of hidden-flavor states (J/ψ, etc.) and of explicit flavored particles. Moreover, a comparison of the production characteristics and a variety of beams ($\gamma, \pi, K_L^0, n, p, \bar{p}, \Sigma^-$) will illuminate the roles of quarks and gluons in the production process. Diffractive photoproduction and leptoproduction of the hidden-flavor states provides information on the total cross section for quarkonium-nucleon scattering and other strong-interaction parameters.

The lifetimes of charmed particles contain crucial information about the weak interactions of hadrons. Emulsion techniques, which are well matched to the expected lifetimes of order 5×10^{-13} sec, have already begun to produce significant samples of short-track candidates for charm decay in neutrino interactions. It is important to refine this information and to make systematic measurements of the lifetimes of individual species. Further evolution of high-data-rate, high-resolution devices will make it possible to exploit the much-larger event rate possible in hadron collisions. This is a convenience for charm, but it is essential for b-particles, because samples in neutrino-emulsion experiments are not likely ever to exceed the level of a few examples. In photon and neutrino interactions, b-production is expected at perhaps 10^{-3} -10^{-4} of the total cross section, whereas the level in hadron collisions should be approximately 10^{-5} -10^{-6} of the total cross section. It is evident that the increased energy provided by the Tevatron should increase the b signal by an order of magnitude.

The variety of secondary beams available at the Tevatron may provide better access to some of the more exotic states containing heavy quarks. For example, the charged-hyperon (Σ^-) beam may have important advantages for the production of charmed-strange baryons. A systematic study of the weak-decay properties of many different charmed particles is clearly of considerable interest.

Finally, we should not overlook the possibility of unexpected rare decay modes of charm and bottom quarks involving, e.g. Higgs-exchanges or other generation-changing couplings. Such couplings can be expected to be stronger for heavy-quark systems than for light-quark systems. In a more general sense, one need only look at history: how much physics would one have lost were the properties of strange hadrons not explored in great depth? Charm physics is now in the state that strange-particle physics was shortly after the discovery of associated production. At that time, the theory was described by the Cabibbo hypothesis for the effective Lagrangian, but it was well before the discovery of CP violation or of rare decays such as K_L . The potential for major surprises and advances in charm physics is also present. We cannot afford to deem charm physics uninteresting even before the F is established in the particle-data tables. The Tevatron fixed-target program has the potential of being in the long run the most incisive source of information on properties of charmed matter. And while it is premature to fully evaluate the ultimate potentialities of the Tevatron for bottom physics, one fact is clear: the increased energy is a decisive advantage and in the long run will make it a unique facility.

2.4 Soft Collisions

Soft collisions of hadrons, the predominant field of strong-interaction physics in the 1960's and early 1970's, nowadays play a much less dominant role. One reason is that many of the interesting and most accessible experimental questions regarding the gross structure of high-energy collisions were already answered from the research carried out in the early 1970's, both at the CERN ISR and at Fermilab. But a major reason lies in the remarkable and rapid progres in understanding hard collisions within the framework of quantum chromodynamics (QCD), the leading candidate for an underlying basic theory of the strong interactions. In hard collisions, the language used is that of the basic degrees of freedom of the theory: quarks and gluons and their couplings to each other. For soft processes, the language is usually different: dispersion relations and finite-energy sum rules, Regge-poles and Reggeon calculus, current algebra and PCAC, duality , string-models, etc. The relationship between soft-collision physics and hard-collision physics is perhaps similar to the relationship of molecular and atomic physics to the physics of the hydrogen atom, or general nuclear physics to the physics of the nucleon-nucleon force. While the most elementary systems provide the cleanest information about underlying basic structure, this by no means implies that the remaining, more-complex systems and processes are uninteresting.

What is interesting in the case of soft hadron-collision phenomena? Let us for simplicity assume that QCD does turn out to be the correct underlying description of hadron physics. (It should be clear that the alternative has implications just as interesting). Then, as hard collisions become increasingly well-described by QCD perturbation theory (i.e. a relatively small number of quark-gluon Feynman diagrams), theoretical interests in the phenomenology of the (admittedly) relatively poorly understood confinement side of QCD can be expected to increase. Furthermore, there is growing evidence that the theoretical difficulties involved in escaping the confinement of perturbation-theory calculations are not insurmountable, and that one may, optimistically, eventually see theoretical models of hadrons based on first principles of QCD. Such models can be expected to relate, but not necessarily replace, the aforementioned conceptual structure of the strong interactions of the 1960's to the quark-gluon structure of QCD at short distances.

How can the Fermilab Tevatron program contribute to this evolution? The most-direct theoretical problem to be addressed is that of hadron structure, i.e. spectroscopy. The spectroscopy of hadrons is quite a mature subject, usually associated with much lower energies. But Tevatron energies are very advantageous under certain circumstances. For example, relatively intense beams of hyperons (Σ, Ξ, even Ω) can be formed, and thus many excited states of these systems can be expected to be found. The classification schemes of the baryons, so vital to the constituent quark-model interpretation, can therefore be considerably enlarged. Another area of interest lies in the study of meson-meson (e.g. $\pi\pi$, πK, $K\bar{K}$) scattering at higher energies, especially location of high-spin Regge recurrences of the low spin resonances. The spectroscopy of mesons built of light quarks is still not in the best of condition, and more information would certainly be welcome.

As understanding of the quark-gluon structure of hadrons progresses, QCD theorists will be in better position to attack the problems of collision dynamics. At low energy, much of this can be phrased in terms of Reggeon exchanges and duality. The relevance of flavor-carrying Regge poles to collision dynamics has already been well established in a series of beautiful experiments (many of them at Fermilab, a fact often forgotten) on π and K charge-exchange processes, on K° regeneration, and on total cross-section differences. While there may be good reasons to extend such measurements to high energies, experimental attention will more likely focus on the properties of the less well-understood Pomeranchuk trajectory. Processes mediated by

Pomeranchuk-trajectory exchanges benefit in a vital way from the higher Tevatron energies. The figure of merit for such processes is the rapidity interval available in the so-called "central plateau," which at present energies is of the order of 1 unit and at the Tevatron is of the order of 2 units, a very significant increase. The development of the central plateau is accompanied by the rise in the total hadron-hadron cross-section. The properties of σ_{tot} and σ_{el} for pp scattering are already rather well measured at the ISR. In the Tevatron era, one may expect pp cross-sections at even higher energies also to be available from the ISR and CERN and Fermilab collider. Thus the phenomenology of σ_{tot} and σ_{el} for pp and $\bar{p}p$ collisions will have been extended well above the energy range available to the fixed-target Tevatron program. Therefore the interest in these questions can be expected to center on beam-dependences (meson vs. baryon, strange vs. non-strange or doubly strange, etc.) and concomitant questions of "factorization." The high precision and flexibility in choice of beam is compensation for the diminished scale of energy available; thus such studies are complementary to those carried out at colliding-beam facilities.

Many questions associated with the rise in the total cross section are still unanswered. The rise is associated both with the increase in the radius of the outer gray cloud (increased importance of diffraction excitations) as well as increased opacity of the central core (onset of gluon-induced, relatively "hard" constituent collisions). The appropriate description of all this, beginning from QCD, is--to say the least--obscure. Reggeon-calculus is in principle a systematic way of trying to untangle the quite subtle issues involved in these phenomena. Low-multiplicity inelastic processes containing "rapidity gaps" are especially useful; for example double-Pomeron exchange processes like $pp \to p(\pi^+\pi^-)p$. Tevatron energies approach what is needed for a clean study of such processes, and again, beam dependence may be useful for ultimate interpretation.

At this point we may mention that beam dependence for all the above processes should include photon beams, both real and virtual. Real, or slightly virtual ($Q^2 \lesssim 2$ GeV^2) photons (not to mention the virtual W's present in neutrino-induced reactions) serve as a useful transitional probe between what are considered ordinary "soft" and deep-inelastic collisions. That is, the understanding of the Q^2 dependence of soft processes as one proceeds from $Q^2 = m_\rho{}^2$ (corresponding to a real ρ incident; presumably an incident π provides a good substitute) to $Q^2 = 0$ to $Q^2 \gg 2$ GeV^2 in the deep-inelastic regime may well be an especially useful tool in building a bridge between the 1960's language of soft collisions and the 1970's language of quarks and gluons in hard collisions. This field has been thus far almost completely neglected at Fermilab and SPS energies.

Another tool for exploration of soft (as well as hard) collisions lies in the A-dependence of various particle production processes. It is a basic kinematic fact that the scale of longitudinal distances important in a high-energy collision increases approximately linearly with energy and already at Fermilab energies exceeds the diameter of large nuclei. Thus, collisions initiated via nuclei sense the pre-asymptotic evolution of the collision process. For example, in the parton model, the properties of the production of leading hadrons should, at sufficiently high energy, be independent of atomic number of the target, essentially because the fast particles are produced far downstream of the nucleus and forget their origin in the nuclear collision (short-range correlation in rapidity). In QCD, more correlation can be expected. The present experiments on A-dependent effects in photoproduction and electroproduction at Fermilab energies just begin to enter this fascinating energy domain and the increaseed energy of the Tevatron is vital for clean interpretation of such measurements.

A-dependent effects in photoproduction and electroproduction are especially interesting. It is already known that photon absorption on nuclei does not scale in proportion to the atomic number A, as expected naively, but more like $A^{0.9}$, which is in the direction observed for the absorption of hadrons such as K_L. What happens as the photon becomes virtual? The experimental situation is unclear. As for theory, the naive parton model suggests that as the scaling variable $x \sim Q^2/W^2$ increases from zero to $x \approx$ 0.1-0.2, the linear A dependence will be restored. On the other hand, QCD would suggest restoration beyond a fixed value of Q^2. Likewise once Q^2 gets large, the naive parton model suggests essentially a limiting-fragmentation behavior (A independence) for production of energetic hadrons. On the other hand, QCD suggests deviations originating from the multiple scattering and gluon bremsstrahlung of the struck (but "undressed") quark as it propagates through the nucleus. Tests of all these ideas greatly benefit by the large energies of the Tevatron beams.

Yet another feature of the Tevatron soft-collision program is the eventual availability of a polarized-proton beam. Measurement of the polarization dependences of the exclusive or low-multiplicity processes we have outlined will provide a strong constraint to the theoretical models designed to interpret these processes. The ZGS polarization measurements of elastic pp scattering provide a good case history of how such measurements can provide a graveyard for otherwise respectable theoretical interpretations of such phenomena. And there seem to be no shortage of high-energy polarization phenomena to study, as evidenced by the surprisingly large (but very welcome) polarization of leading strange baryons at high energy. Indeed the dependence of this phenomenon on incident-beam polarization may provide clues to the interpretation of this as yet rather puzzling phenomenon.

All these remarks only scratch the surface of the subject of soft collisions at high energy. While it is less likely that spectacular breakthroughs will occur in this field comparable to the discovery of a new particle or the verification of fundamental laws of nature at the level of electroweak theory or of short-distance QCD, it should be clear that the subject is a rich one, deserving of continuing study. The Fermilab Tevatron program provides a unique and important environment for this work. The level of effort invested will depend on the degree of development of the theoretical conceptual structure, on the interest and ingenuity of the experimental community, and on the resources available for mounting such experiments.

3. THE 1-TEV ACCELERATOR

3.1 Fermilab Accelerator Construction Projects

Tevatron Phase 2 is one phase of a series of projects whose purpose is to give a unique extension of the energy range over which physics experiments are possible. These Fermilab projects are all involved with the construction of the world's first superconducting particle accelerator and storage ring, the Tevatron.[1]

The other phases of the Tevatron are:

(i) The Energy Saver, which includes construction of a ring of superconducting magnets in the existing Main-Ring Accelerator tunnel. Beam will be injected from the Main-Ring at 150 GeV and accelerated to 400 or 500 GeV to service the existing Fermilab research program with a large saving in power cost. The Energy Saver project was authorized in FY79 and construction is now under way.

The superconducting magnet ring will be able to operate in a dc mode at any energy up to its peak. One advantage that will accrue to the Energy Saver is therefore the possibility of very long beam spills. Secondary-particle yields will also be higher at 500 GeV than at 400 GeV, the energy to which the present program is limited by power costs.

(ii) The Tevatron Phase 1, which includes upgrading of the accelerator refrigeration and acceleration systems to allow sustained operation at 1000 GeV (1 TeV), a high-intensity source of high-energy antiprotons, and special devices and experimental areas to make possible colliding-beams experiments with protons and antiprotons beams at 1-TeV energies.[2] This project will give a useful energy of 2 TeV for physics experiments.

The added refrigeration and acceleration systems will make it possible to accelerate to 1 TeV at a rate close to 100 GeV/sec and to provide long beam spills for experiments. A repetition rate of several cycles per minute with a duty factor of 50% or more will be possible.

These two projects will encompass the entire accelerator except for 1-TeV beam extraction and transport to experimental areas. This beam extraction and transport and improvement of the experimental areas for 1-Tev fixed-target physics comprise the work of Tevatron Phase 2.

3.2 Accelerator Specifications

The primary goal of the Tevatron Phase 2 project is to provide the accelerator-related and experimental-area facilities to support a fixed-target physics-research program at more than twice the present Fermilab energy.

Much of the character of the Tevatron Experimental Facilities is determined by the accelerator specifications. These specifications are largely fixed by the properties of the magnet, power-supply, and refrigeration systems of the Energy Saver ring now being constructed and by the additional refrigeration and acceleration systems that are part of the Tevatron Phase 1 project. The specifications resulting from these constraints are given in Table 3-1 below.

Table 3-1 Fixed-Target Accelerator Specifications

Peak energy	1000 Gev
Intensity	2×10^{13} ppp
Injection energy	150 GeV, single turn
Repetition rate	1-2 cycles/min
Acceleration rate	50-75 GeV/s
Flattop time	Variable to dc
Extraction	Slow: 1 to 10 sec
	Fast: 1 msec
Beam-abort system	Single - turn extraction

The acceleration rate, given as 50 to 75 GeV/sec, is limited by the acceptable level of heating from ac losses in the magnets. This rate is to be regarded as a minimum goal; it is expected to be better in most operations. The magnets are individually tested at a ramp corresponding to 90 GeV/sec as part of the acceptance testing. The rate ultimately depends on the state of the refrigeration system. When it is operating in a reasonable mode, it will be possible to ramp the accelerator at a rate close to 100 GeV/sec. One could then achieve a duty factor better than 1/3 with 2 cycles/min. The flat-top length is not limited by magnet losses, but by the difficulty of maintaining good extraction efficiency over very long beam spills. Extraction is discussed in Sec. 3.5 below.

3.3 Description Of The Accelerator

The Fermilab superconducting accelerator is described in detail in a design report[1]. This section will give a short review of these designs for reference.

3.3.1 Superconducting Accelerator.

In 1967, at the time the Fermilab accelerator was first designed, superconducting magnets had not reached a state of development at which it was sensible to base the design of an important new accelerator on them. But space was left in the tunnel for later addition of a superconducting magnet ring to double the peak energy. Development work on accelerator superconducting magnets began in 1972 at Fermilab, as soon as the accelerator was put into operation.

The superconducting magnets have been developed to production status. An assembly line and testing facility are set up in the industrial buildings at Fermilab. The completed magnets are installed in the Main-Ring tunnel under the magnets of the conventional 400-500 GeV Main Ring, as shown in Fig. 3-1. These magnets will also be used extensively throughout the experimental areas.

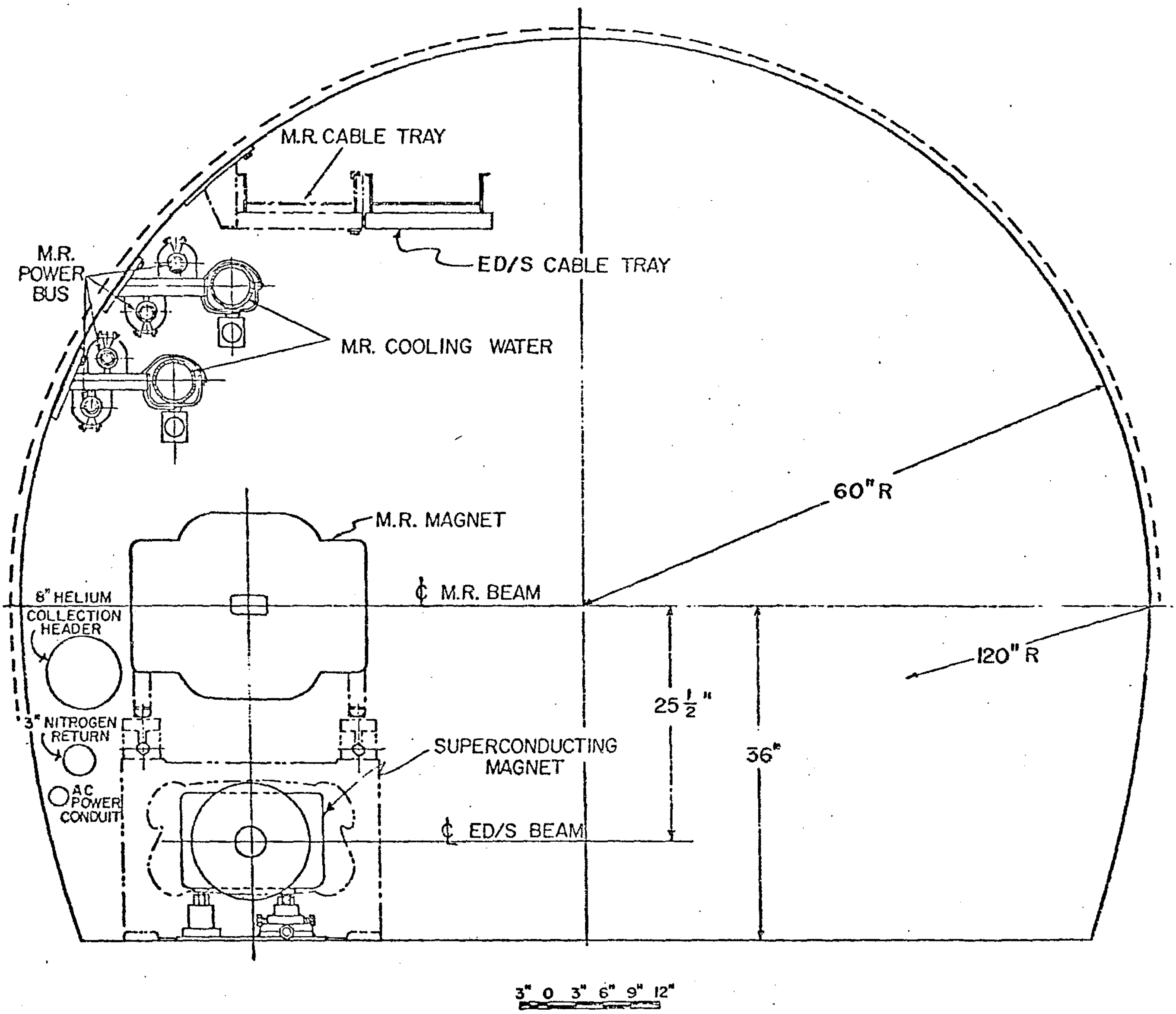

M.R. CABLE TRAY
ED/S CABLE TRAY
M.R. POWER BUS
M.R. COOLING WATER
60" R
M.R. MAGNET
℄ M.R. BEAM
6" HELIUM COLLECTION HEADER
120" R
25 1/2"
36"
3" NITROGEN RETURN
SUPERCONDUCTING MAGNET
AC POWER CONDUIT
℄ ED/S BEAM
3" 0 3" 6" 9" 12"

FIGURE 3-1

The lattice design of the superconducting ring is constrained by the existing tunnel and equipment, so that the superconducting ring has six long straight sections like the Main Ring, a dipole beneath each Main-Ring dipole, and a quadrupole arrangement differing from the Main Ring at the long straight sections.

The magnets themselves are of a cold-bore, warm-iron design with niobium-titanium coils of braided cabling and liquid-helium cooling supplied by a combination of a central-helium liquefier plant and satellite refrigerators in small service buildings spaced around the ring at ground level. Some completed sections of superconducting ring have already been successfully operated in systems tests.

In the superconducting magnet, there are no steel poles to shape the field, as is the case in almost all conventional magnets, and field quality depends strongly on accurate conductor position. These coil positions must be maintained even under the influence of the strong magnetic forces that are produced when the magnets are energized. The field quality that is required for efficient extraction and beam storage has been achieved in the magnets produced in the Fermilab factory. The ring will also contain a large number of superconducting correction elements to trim fields for extraction and storage.

3.4 Operating Scenario

3.4.1 Startup. The superconducting accelerator is a new kind of device, with new problems arising from the refrigeration system and the possibility of quenching the superconducting state. It is expected that some months of operation and minor modification will take place before the superconducting ring is a reliable device for either fixed-target or colliding-beam experiments.

In a "quench", a microscopic volume of superconductor loses its superconducting property, that goes "normal", because of local heating, perhaps by beam striking it. Thus localized beam loss must be held to very small values if the superconducting magnet is to remain in operation. If only a small volume goes normal, the energy stored in the magnetic field will all be dissipated in that volume by resistive loss and the magnet will almost certainly be damaged. Quench protection is provided by flashing heaters on to make an entire half-cell (4 dipoles and 1 quadrupole) go normal together. Thus only a small part of the ring goes normal. The energy stored in the remainder of the ring is shunted to dissipating resistors outside the tunnel. Some helium is lost to the recovery system in this process and approximately 15 minutes is needed for the system to recover and cool down again.

It is also expected that a considerable fraction of the operating time available will need to be devoted to accelerator studies in order to understand and manage the processes of extraction for the fixed-target program and antiproton accumulation for colliding beams.

3.4.2 Steady State. It is expected that after the first year operation will settle down to a routine with a small maintenance period and a few shifts of accelerator studies per week. In this steady state, operation will be either for colliding beams or fixed targets, but not both simultaneously, because extraction devices and shielding need to be moved in the colliding-beams areas. Thus the schedule will consist of alternating periods of colliding-beam and fixed-target experimentation. It is therefore expected that one of the programs will operate for a period of several months, then change to the other.

Operation of the fixed-target program will be similar to operation of the 400-GeV Fermilab program. The cycle time will be 30 seconds to 60 seconds rather than 10 to 15 seconds, depending on the energy and spill length needed by the program, with correspondingly reduced average proton flux. On the other hand, secondary-particle fluxes will be increased substantially by the higher energy and the duty factor will increase from approximately 10% to 33%. The same extraction paths will be utilized, with improvements discussed in this report. The beam information seen by experimenters will be similar to that in the 400-GeV program.

3.5 Extraction System

3.5.1 Orbit Design. Slow-extracted beam is provided by driving the transverse motion of particles by a perturbing force. When the driving force and the motion are in resonance, the amplitude of motion grows until the particle passes beyond a septum and is deflected into the extraction channel. Particles of lesser amplitude continue to circulate around the accelerator until their amplitudes have grown enough to clear the septum. The first septum system is electrostatic to give a minimum septum thickness w, because the fraction of particles striking the septum is proportional to w. The succeeding septa are progressively thicker and can be magnetic.

The distinctions among particles of different amplitudes is achieved by using a nonlinear perturbing force. Beyond a limiting amplitude, particle motion is unstable and grows exponentially or faster. The nonlinear resonances used have the form $m\nu = n$, where m and n are integers and ν is the number of betatron wavelengths per revolution. Half-integer ($m = 2$) and third-integer ($m = 3$) resonant extraction have both been utilized in the Main Ring. A useful method of visualizing extraction is the phase-space plot. In an approximation appropriate for extraction, there is a "separatrix" curve in phase space separating stable and unstable regions.

The basic design goals of the extraction system are (i) provision of slow resonant extracted beam with uniform spill over times of 1 to 10 sec; (ii) provision of fast resonant extracted beam in the range of 1.0 to 3.0 msec (multipulsed fast resonant extraction is also desirable but presents intrinsic problems in maintaining good extraction efficiencies; the designed extraction system should not be incompatible with this goal); and (iii) high extraction efficiency (losses $< 2\%$) to minimize beam-loss effects on the superconducting magnets.

An accurate estimate of the available effective magnet aperture is essential when considering the extraction process in detail, because extraction will explore the magnet aperture fully and be limited by it. The effective aperture is usually determined by field variation rather than physical obstruction. During the extraction cycle, the maximum-amplitude orbit excursions increase monotonically from turn to turn and each particle will therefore achieve its maximum amplitude on the final turn before being extracted. In order to calculate the effective aperture of a perfectly aligned accelerator with perfect design fields, we must consider a slightly off-momentum orbit, on which the higher-order odd field multipoles do not cancel. A momentum offset of 0.05% will give an average orbit offset of approximately 1.5 mm, representative of the operational tolerances that can reasonably be expected. Figure 3-2 shows data resulting from an analysis of this kind. Using design fields, we have plotted the phase-space trajectory for a half-integer extraction separatrix at the upstream ends of the long straight sections sequentially around the ring, starting at B0.

The growth of the radius vector around the cycle is evident and, starting with the D0 long straight section, we can see the effect of the higher-order terms in the dipole-magnet field multipoles starting to manifest themselves as

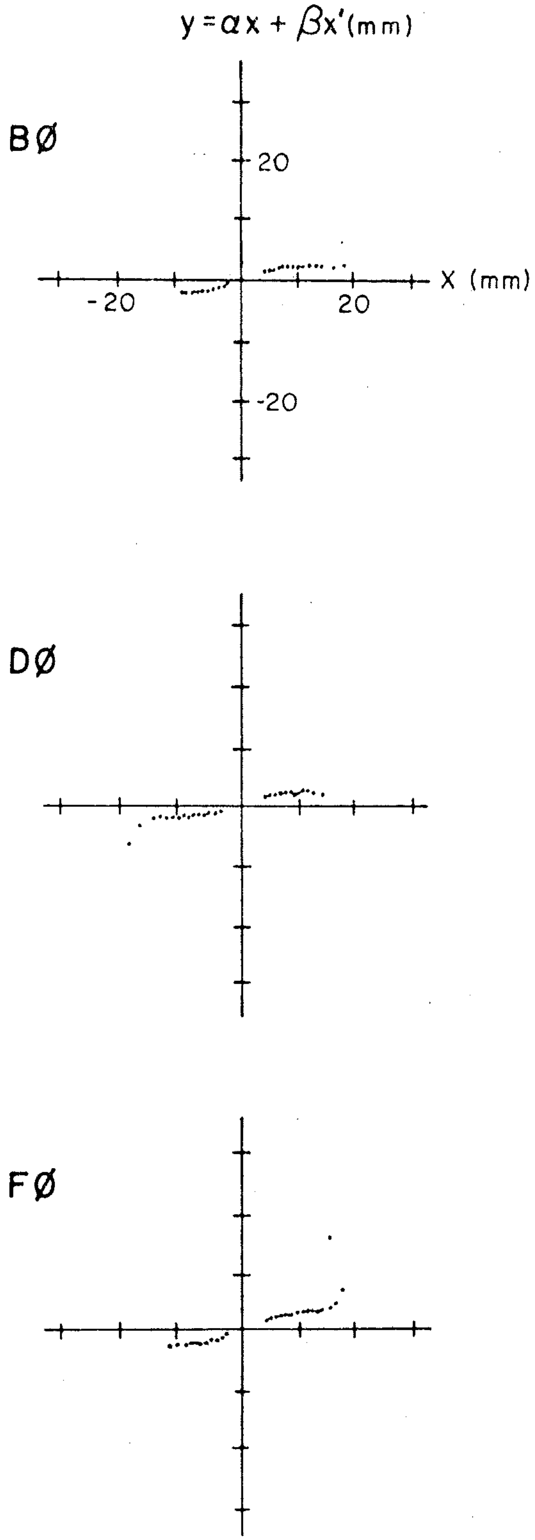


Fig. 3-2 Half-integer slow-extraction separatrix around the ring without high beta.

rotations in the phase-space trajectory; these rotations get progressively larger during the cycle. From a more complete analysis [3,4] we conclude that with the given field multipoles the effective horizontal aperture is slightly larger than the vertical aperture and henceforth we shall only consider horizontal extraction. We also find that we need to control the vertical closed orbit to within ± 3 mm of the dipole center. With this limitation, the maximum-amplitude orbit oscillations must be within $\pm$ 2 cm, with the exception of the final few oscillations in the ring, which can grow to approximately ± 2.5 cm without any major phase-space distortions. The effect of this 2-cm aperture limitation on the extraction system is too severe and would result in unacceptably high extraction losses if the lattice were the same as that of the Main Ring.

The solution of these problems is to redesign the long straight sections containing the magnetic and electrostatic septa to provide a five-fold increase of the amplitude-function (which describes the variation in amplitude and wavelength of oscillations around the ring) of the lattice at the upstream end of the long straight sections.[5] Three different-length quadrupoles are introduced in the 48, 49, 11, and 12 locations, with the polarity of the quadrupole doublets at 49 and 11 reversed from the normal long straight section.

3.5.2 Slow Extraction. We can now discuss the layout of the individual elements and their operational characteristics. The choice of long straight section A is dictated by the extraction channel to the existing external experimental areas. The magnetic septa (Lambertson magnets) will be located at the upstream end of the straight section. The presence of the Main-Ring rf cavities at FO does not leave room for the electrostatic septum and as a result, it will be located at the upstream end of long straight section D. The appropriate harmonics for the quadrupoles (39th) and the octopoles (39th and 0th) needed for slow extraction will be provided by the correction-coil package which will also allow control over the relative phase of the 39th harmonic. In order to inhibit the growth of the oscillation amplitude between the electrostatic and magnetic septa on the final half turn for the extracted beam, only the correction coils in sectors A, B, C, and F will be used in the extraction system. An analysis of 1/3-integer extraction[6,7] shows that for fixed phase-space trajectory and available aperture, the optimum extraction efficiency is achieved when the electrostatic-septum offset and the step size across the septum are equal. This kind of criterion can be used to calculate the relative strengths of quadrupole and octopole needed for extraction. Figure 3-3 demonstrates the behavior of the slow-extraction separatrix around the ring, incorporating all of the factors discussed above. The effect of the high-β sections at A0 and D0 is apparent in increasing the beam amplitude at these points. The septum offset at D0 is 12 mm; the step size is adjusted to be 12 mm. This represents the limiting case of the magnet aperture; the average orbit amplitude over the last half turn is approximately 25 mm. The integrated field strength of the quadrupoles and octopoles in this case is 255 kG-in. and 412 kG-in. at 1 in. respectively. The extraction losses of a system with these operational parameters are approximately 1.5% for a 3-mil effective septum thickness.

<u>3.5.3. Fast Resonant Extraction.</u> Fast resonant extraction is accomplished by using the slow-extraction elements to bring the beam close to resonance and then firing a series of fast-pulsed quadrupoles to drive the beam into resonance. The strength of the pulsed quadrupoles is determined by the requirements on spill duration. We have studied[8] a fast-extraction system

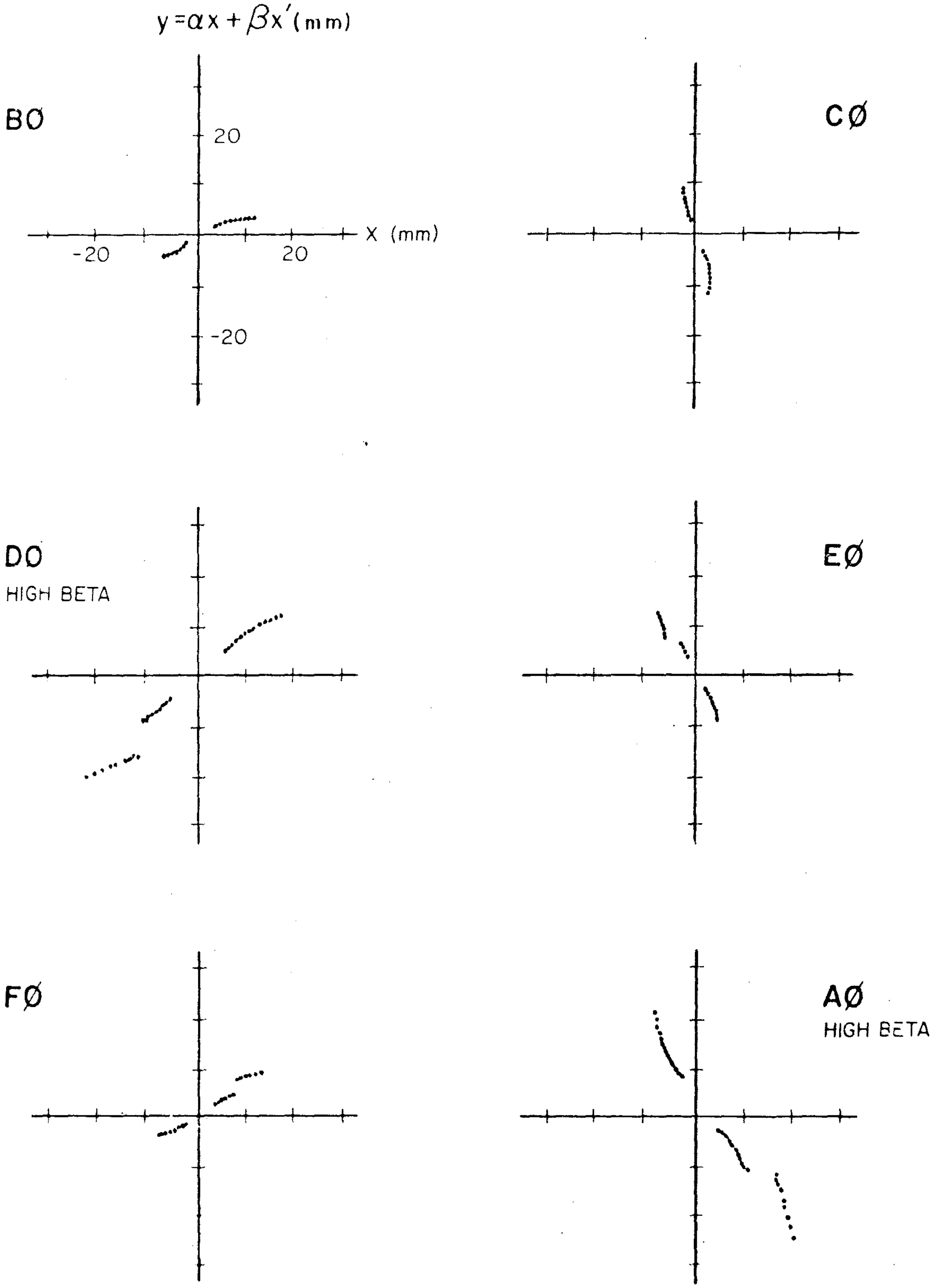


Fig. 3-3 Half-integer slow-extraction separatrix around the ring with high beta.

that satisfies the design criteria. The active elements consist of four pulsed quadrupoles located in the warm 48 lattice positions in sectors A, C, D, and F. Work is currently in progress on a Monte Carlo simulation of this fast-extraction system. Figure 3-4 shows a sample phase-space output at the magnetic septum. The initial results indicate that the required maximum field strength necessary for each element is approximately 25 kG-in. at 1 in. for a 3-msec half-sine-wave pulse.

A list of the active extraction elements with their typical operational parameters is given in Table 3-1.

3.5.4. Straight-Section Layout. A detailed layout of the D0 long straight section from C49 to D11 is shown in Fig. 3-5. The superconducting magnets downstream of D11 are shielded from the extraction losses by a vertical dogleg produced by the bending magnets B1, B2, and B3 and an aperture-limiting scraper downstream of the electrostatic septum. The amplitude of the vertical dogleg is approximately 6 cm. Detailed results of a Monte Carlo study of the loss distributions associated with this design are presented in Chapter 13 of the superconducting accelerator design report. Local orbit control is provided by the conventional bump magnets located as shown, together with one in the C48 mini-straight section. With this system of bump magnets, we have a maximum spatial offset at the septum of 7 mm and an angular range of 150 rad.

3.5.5 Extraction Channel. One of our basic design goals with the extraction channel has been to produce a layout that maintains compatibility with the continued use of the present 400 GeV Switchyard enclosures. The design we are presenting here fulfills this criterion. The layout of the A0 long straight section is shown in Fig. 3-6. The initial beam separation is accomplished by 5 Lambertson magnets, each 220 in. in length with a 12.5-kG field at 1 TeV, producing a total vertical bend of 10.48 mrad, which results in a vertical

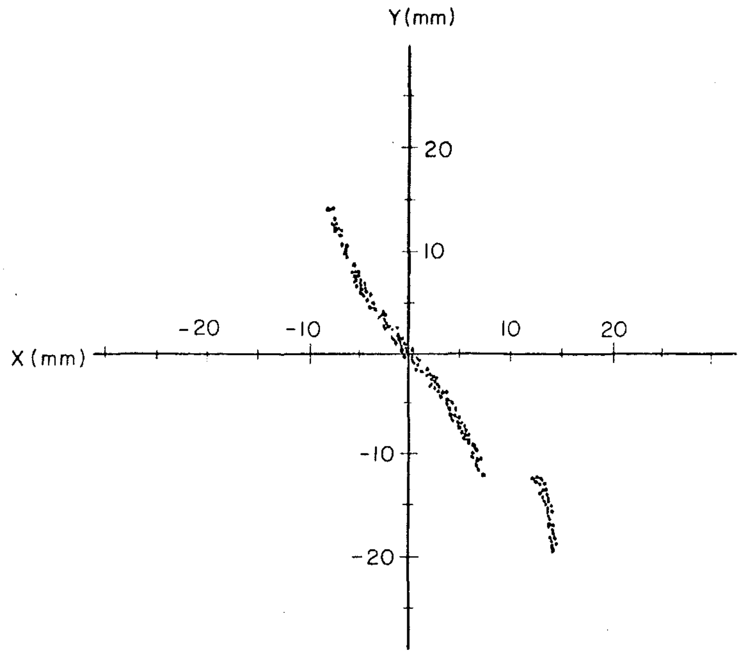
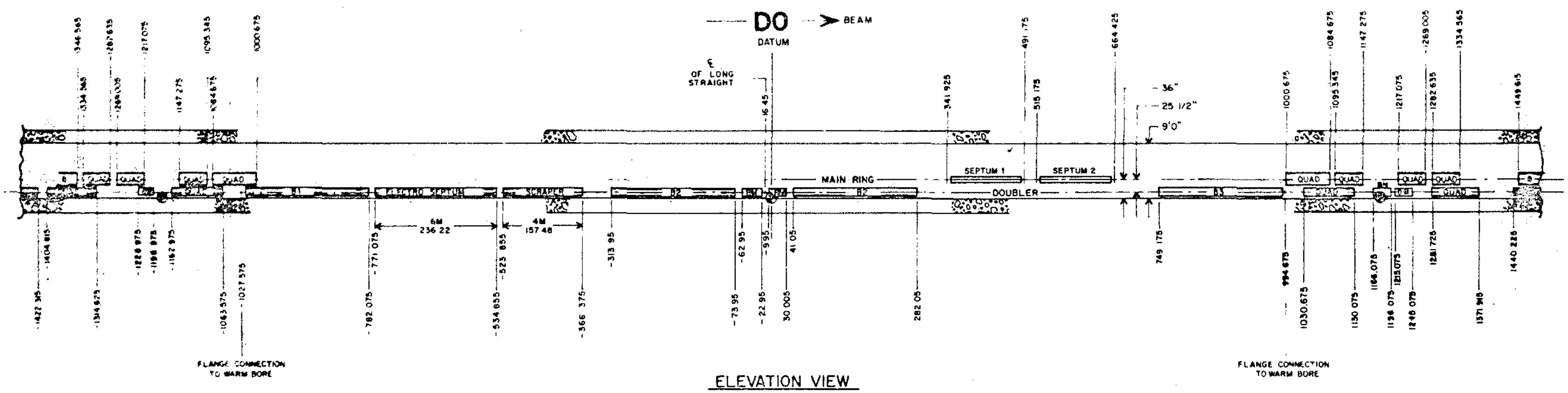


Fig. 3-4 Separatrix for half-integer fast resonant extraction.

Table 3-1. Extraction Elements.

Element	Postition	Parameters
Electrostatic Septum	Upstream D0 long straight section	length 6 m gap 16 mm voltage 75 kV
Magnetic Septum	Upstream A0 long straight section	length 95.5 ft field 12 kG
Slow extraction	Correction coils A, B, C, F(28,42) sectors (stations)	255 kG - in. total quadrupole at 1 in.
Slow extraction	Correction coils A, B, C, F(28,42) sectors (stations)	412 kG - in. total octopole at 1 in.
Fast extraction Quads	A48, C48, D48 F48 mini-straight	25 kG - in. at 1 in. (max) per element for 3.0 msec half sine wave pulse



ELEVATION VIEW

0 1' 5' 10'
SCALE

DO LONG STRAIGHT
(EXTRACTION)

FIGURE 3-5

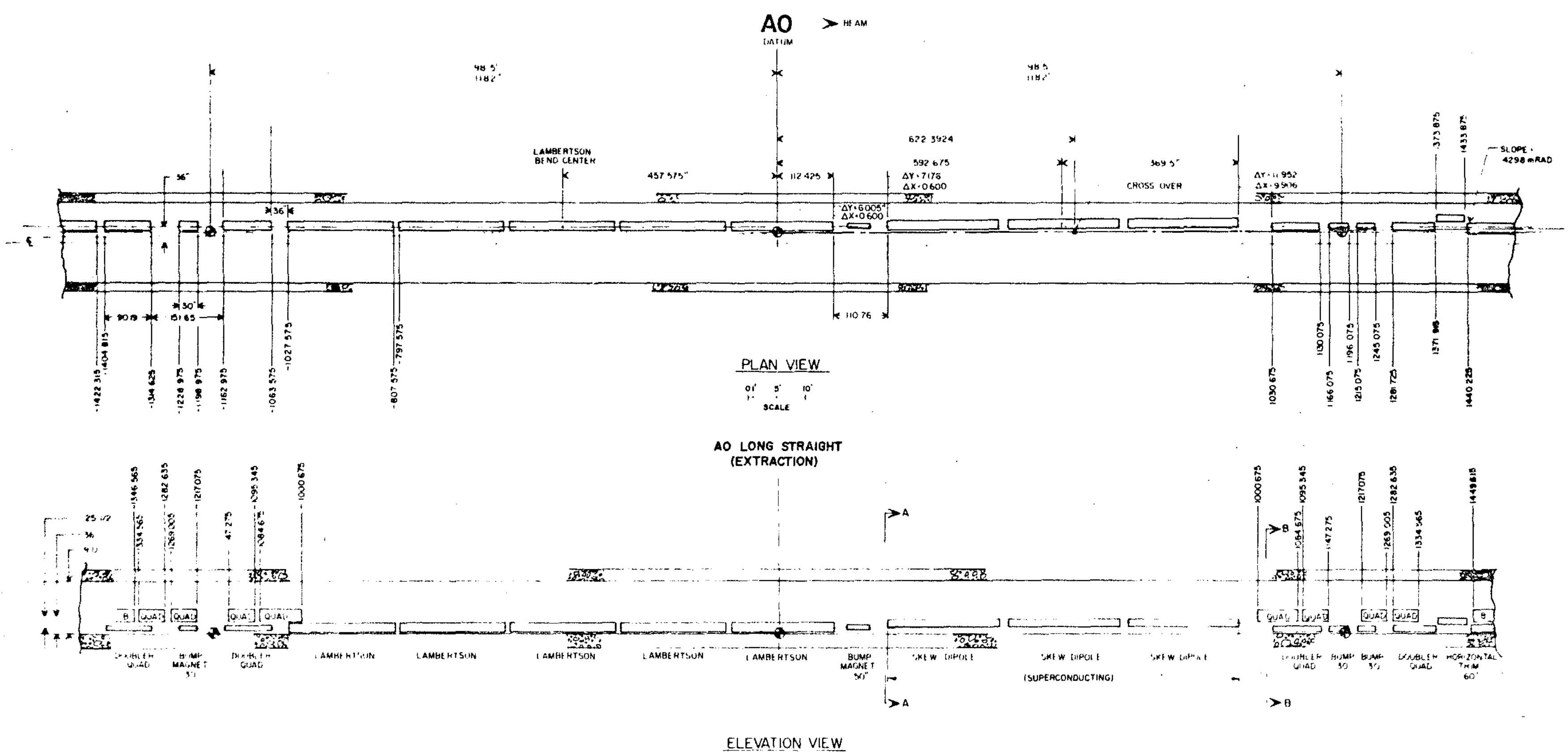
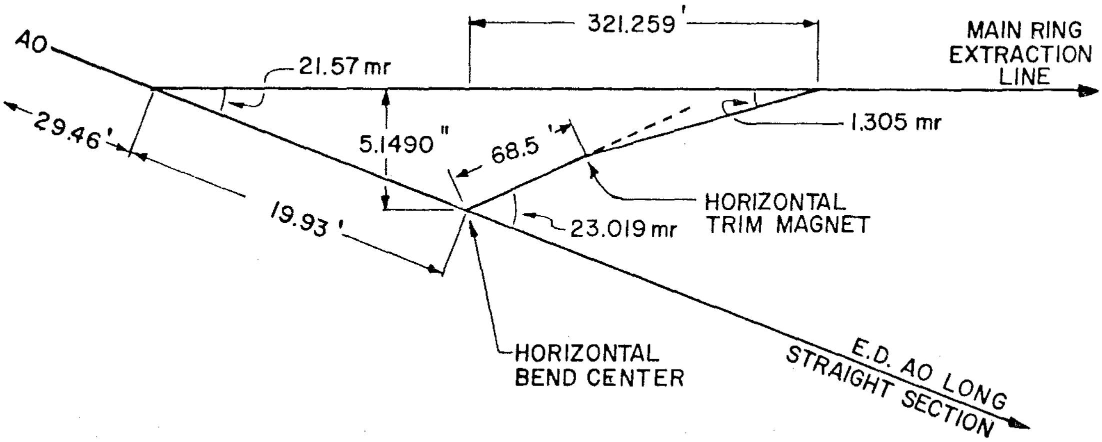

AO
DATUM
BEAM
LAMBERTSON BEND CENTER
CROSS OVER
PLAN VIEW
SCALE
AO LONG STRAIGHT (EXTRACTION)
DOUBLER QUAD
BUMP MAGNET
LAMBERTSON
SKEW DIPOLE
(SUPERCONDUCTING)
HORIZONTAL TRIM
ELEVATION VIEW

FIGURE 3-6

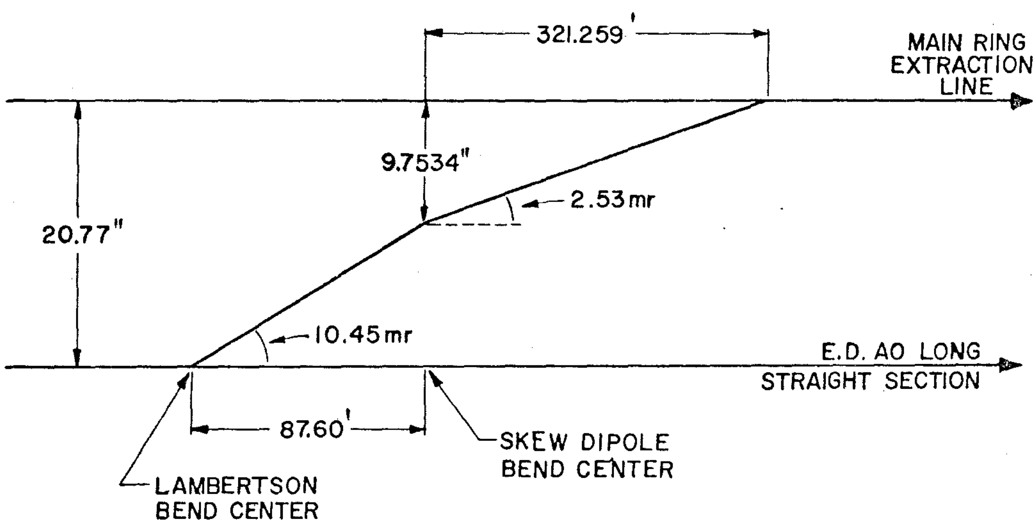
displacement of 6.005 in. from the circulating beam at the downstream end of the magnets. The extracted beam is then deflected both horizontally and vertically by a series of three standard superconducting dipoles powered in series with the super-conducting ring magnets. This string of magnets, rotated by 19.05° from the horizontal, produces a 23.019-mrad radially outward bend and a downward deflection of 7.948 mrad. A horizontal trim magnet 40 ft further downstream is then used to adjust the beam trajectory to produce a simultaneous horizontal and vertical intercept of the beam with the existing extraction channel upstream of Switchyard Enclosure B. At this point, the beam is deflected into the current extraction channel by a Main-Ring dipole, rotated by 32.06° from the vertical position, on a trajectory similar to the Main-Ring extracted beam. The detailed horizontal and vertical geometries of the extracted beam are shown in Fig. 3-7.

The phase-space trajectory of the separatrix across straight-section A in Fig. 3-3 shows the extracted and circulating beam converging with a maximum angle of 110 microradians, which corresponds to a reduction in beam separation of 1.2 mm at the downstream end of the Lambertson magnets. In order to correct this somewhat undesirable situation, the upstream Lambertson magnet will be rotated by 85 mrad from the vertical position, causing the two beams to diverge by 100 microradians.

Figures 3-8 and 3-9 give cross-sectional views of the extraction channel at the postions indicated in Fig. 3-6. The minimum clearance between the circulating beam and the extraction elements is 2 in. at the upstream end of the superconducting dipoles. In order to maintain this minimum clearance, a special custom-made turnaround box will be required for these magnets.

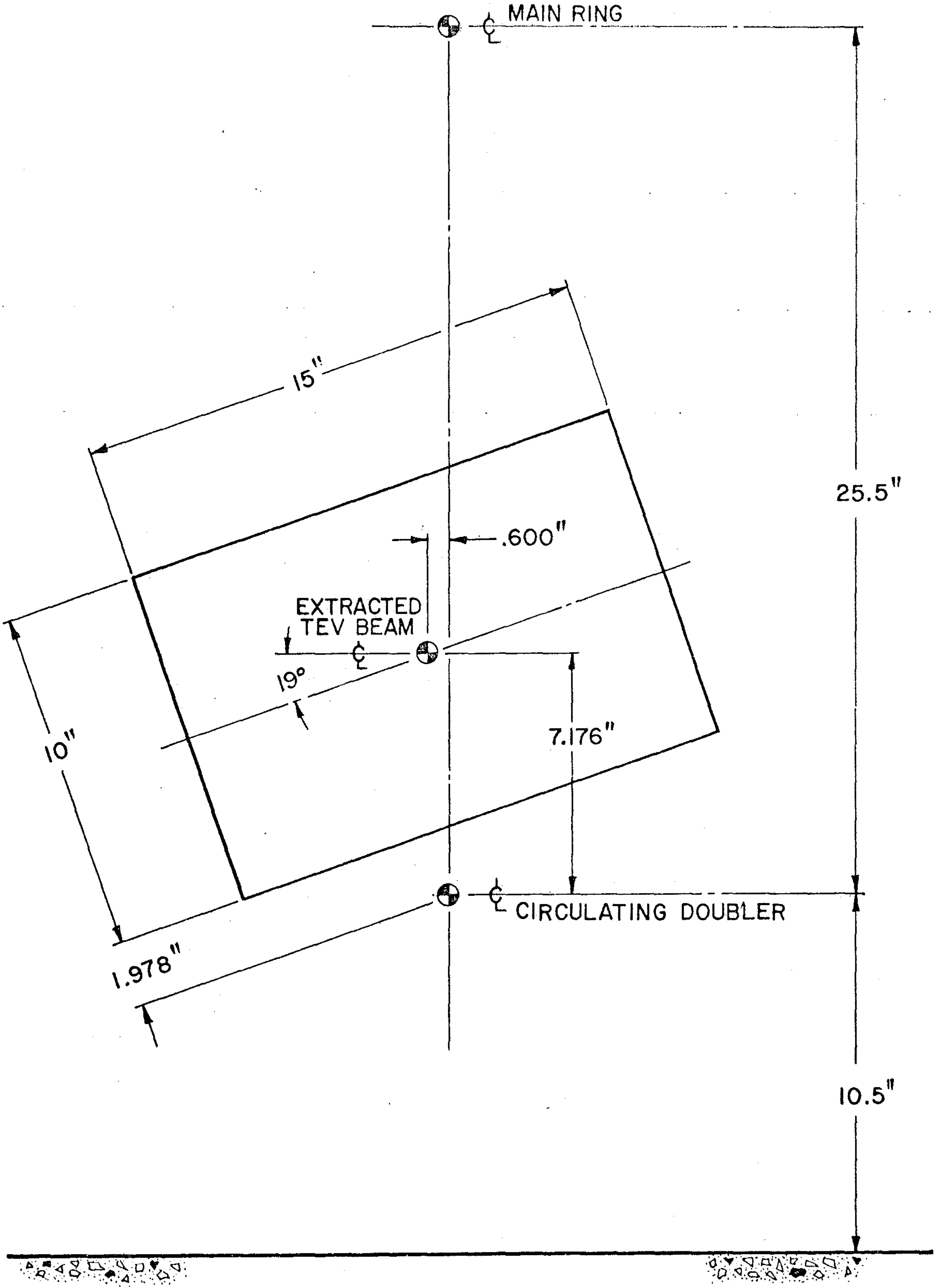


EXTRACTION CHANNEL— HORIZONTAL GEOMETRY



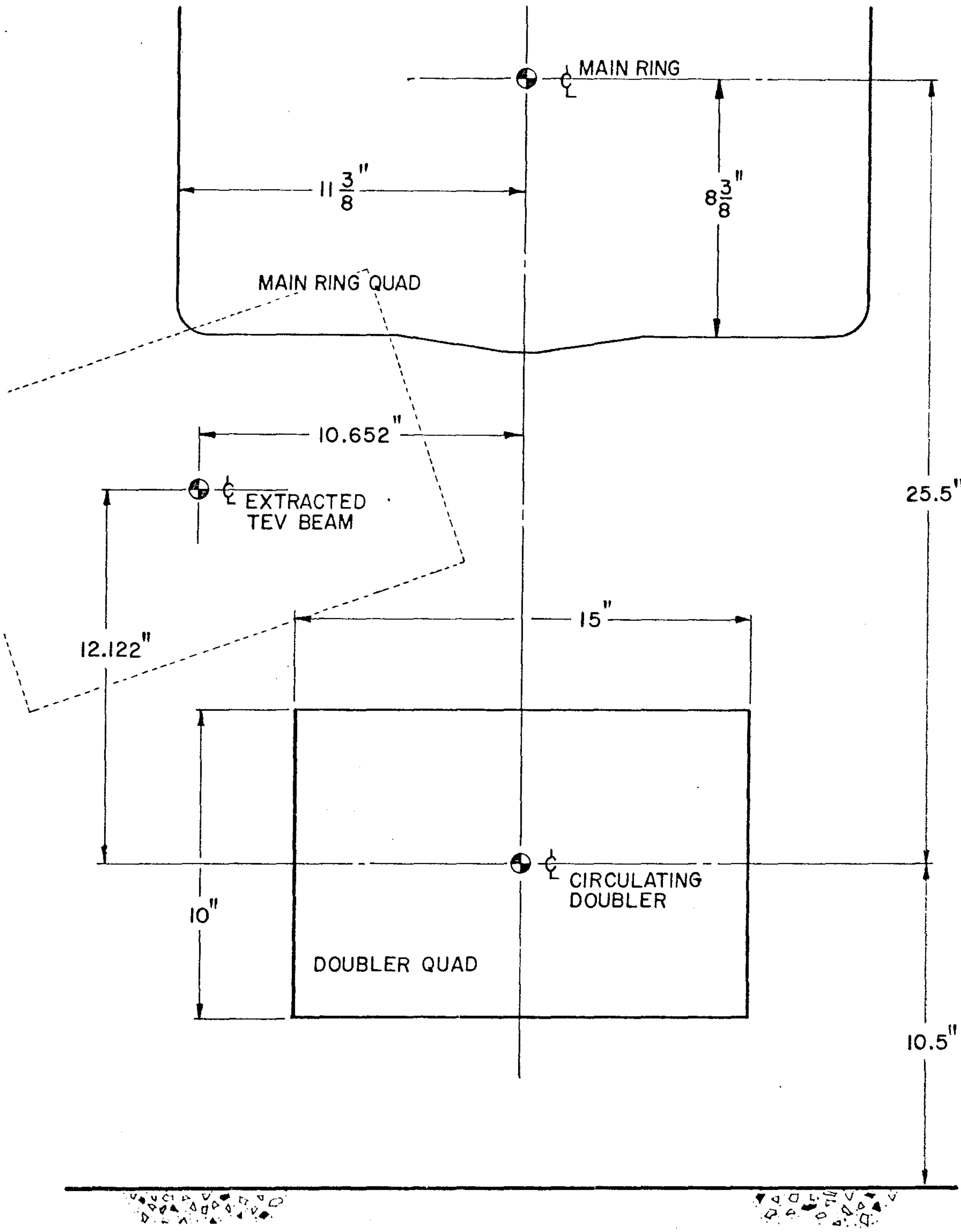
EXTRACTION CHANNEL— VERTICAL GEOMETRY

FIGURE 3-7



MAIN RING
25.5"
15"
.600"
EXTRACTED
TEV BEAM
19°
10"
7.176"
CIRCULATING DOUBLER
1.978"
10.5"

FIGURE 3-8



MAIN RING
11 3/8"
8 3/8"
MAIN RING QUAD
10.652"
EXTRACTED
TEV BEAM
25.5"
15"
12.122"
CIRCULATING
DOUBLER
10"
DOUBLER QUAD
10.5"

FIGURE 3-9

Horizontal and vertical steering into the transport line will be accomplished with the horizontal trim magnet and the Lambertson string. The long downstream lever arm ensures ample positional control at the intercept point with the Main-Ring extraction line.

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4. NEUTRINO AREA

4.1 Introduction

The Neutrino Area is the major Fermilab area for lepton experiments. The N0 neutrino beam line stretches 4500 ft from the target in Neuhall to the 15-ft bubble chamber in Lab B and Labs C and E for electronic detectors. This beam line includes a 1300-ft evacuated decay pipe and more than 3000 ft of earth shielding to filter out particles other than neutrinos. The N1 beam line transports muons of momentum up to 275 GeV/c to the muon area. The N3 beam line transports hadrons to the 30-in. bubble chamber, and the N7 beam line serves as a proton source for the hadron calibration beams to the neutrino experimental area.

Lepton experiments at Fermilab have played an important part in the spectacular increase in our knowledge of fundamental particles and will continue to do so in the Tevatron era.

The Neutrino Area as it will exist upon completion of Tevatron Phase 2 is shown in Fig. 4-1. The Switchyard beam-transport capabilities will be improved[1] to 1000 GeV/c. The most striking addition will be the new 800-GeV/c muon beam which stretches 8000 ft from Switchyard Enclosure G2 to a new experimental area beyond Wilson Road. This beam will replace the old N1 muon beam and is the major new Tevatron beam in the Neutrino Area. The N0 neutrino beam muon shield will be hardened by the addition of 10,000 tons of iron shielding to bring the capability of the main neutrino experimental area up to 1000 GeV. The third project included in Tevatron Phase 2 is the addition of a new experimental hall in the main neutrino experimental area. It is shown in Fig.4-1 as Lab F, just upstream of Lab E.

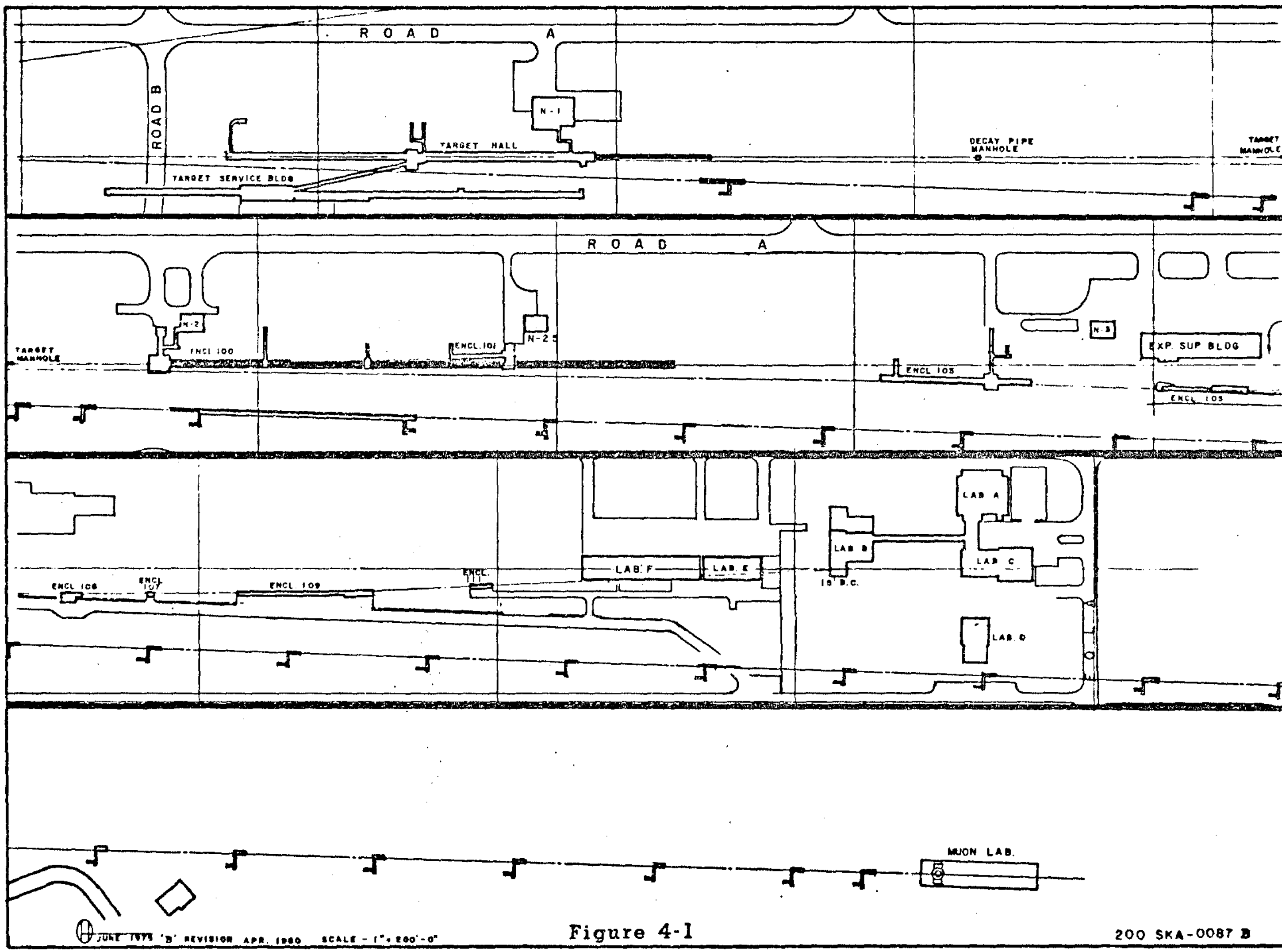


Figure 4-1

Neutrino Area at Completion of Tevatron II

4.2 The Neutrino Area in January 1982

The facilities that will exist by January of 1982 are shown in Fig. 4-2 and 4-3. In the summer shutdown of 1980, three major projects will be carried out that will prepare the Neutrino Area for utilization of primary proton beams of 500 GeV and above. The Neuhall target area will be extended upstream to allow the use of longer target trains. The muon shielding in the main NO beam line will be improved by the installation of 16,000 tons of steel shielding, which will be sufficient[2] to shield the Wonder Building experimental area to 550 GeV/c and the main neutrino experimental area of Labs B, C and E to 700 GeV/c. The third project will be the relocation of the N7 primary proton beam to a location outside the NO muon steel shield.

In FY82, an AIP project will be carried out to construct a beamline originating in switchyard enclosure G2 and ending at a beam dump just east of Neutrino Enclosure 100. The purpose of this project is to provide an alternative beam dump for the primary proton beam when the Neutrino Area is not operating. This project will serve in the Tevatron Phase 2 era as the primary-proton transport to the muon beam target.

4.3 Improvement to 1 TeV

4.3.1 General Plans. The projects of the previous section can be easily converted to Tevatron operations. The extension of the Neuhall target area is of sufficient length to accommodate dichromatic neutrino target trains of energies up to 750 GeV/c and wideband neutrino beams up to 1000 GeV/c. Neutrino fluxes are shown in Fig. 4-4. The NO steel muon shielding will have to be further increased[2] in length to shield the main neutrino experimental complex up to 1000 GeV/c. The Wonder Building experimental area will be decommissioned and replaced by shielding, because the cost of improving the shielding to retain the use of this area is prohibitive. The N7 beam will be

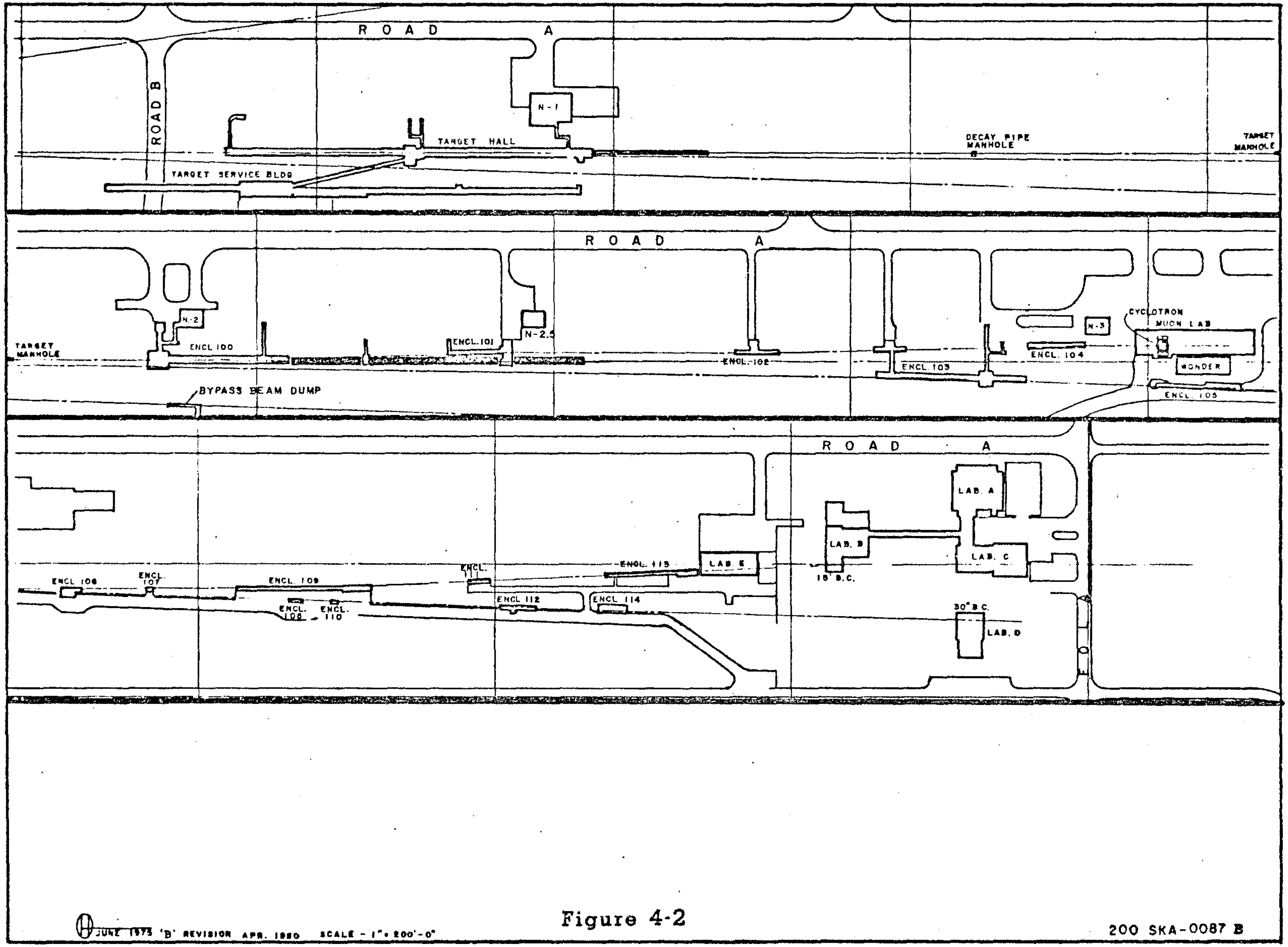


Figure 4-2

Neutrino Area at Beginning of Tevatron II

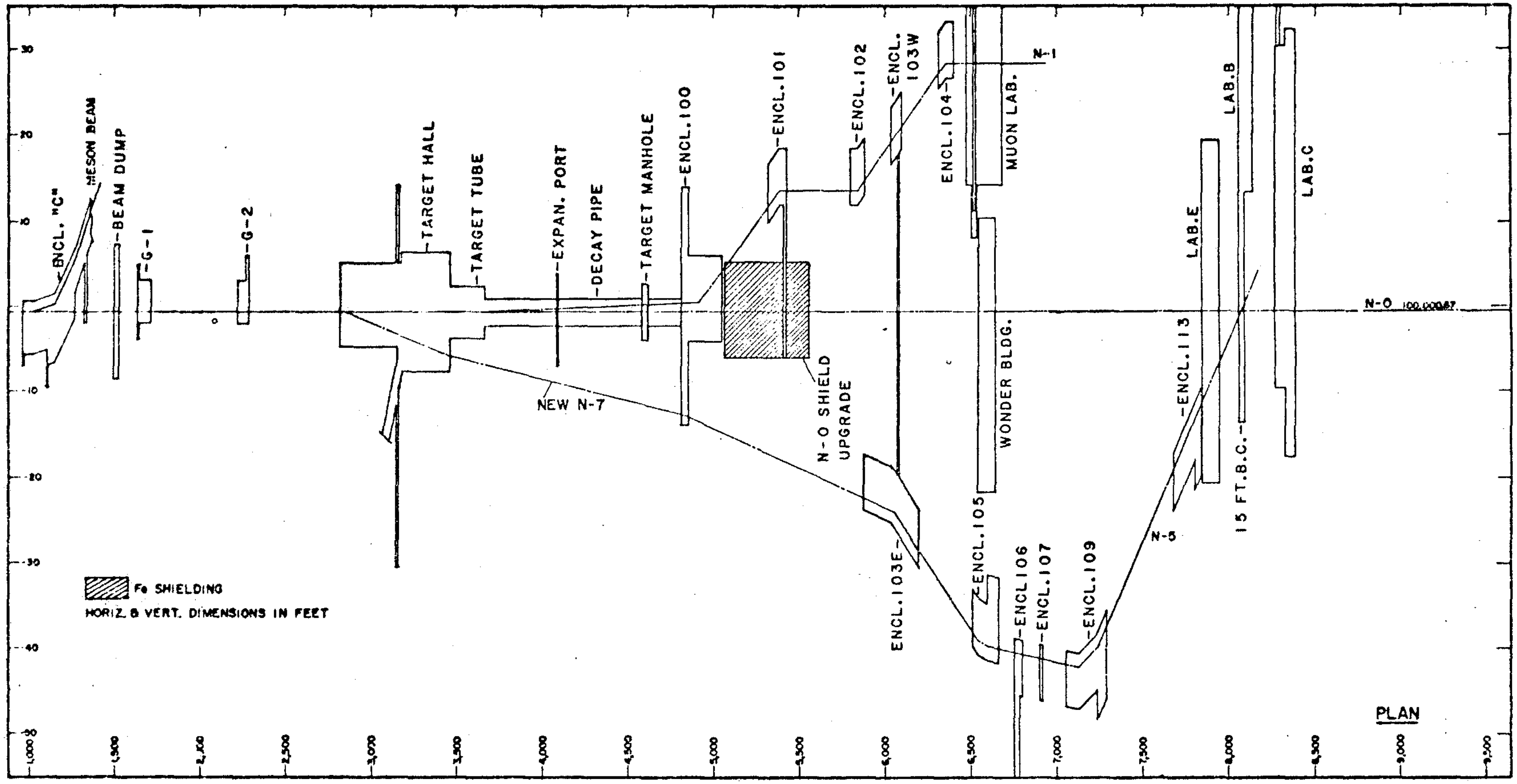


Figure 4-3 Schematic of Neutrino Area-Fall 1980 after completion of Target Hall Addition, N-0 muon shield upgrade, andN-7 relocation.

NOTE: 50:1 distortion of horizontal and vertical scales.

Cate: 5 March 1980

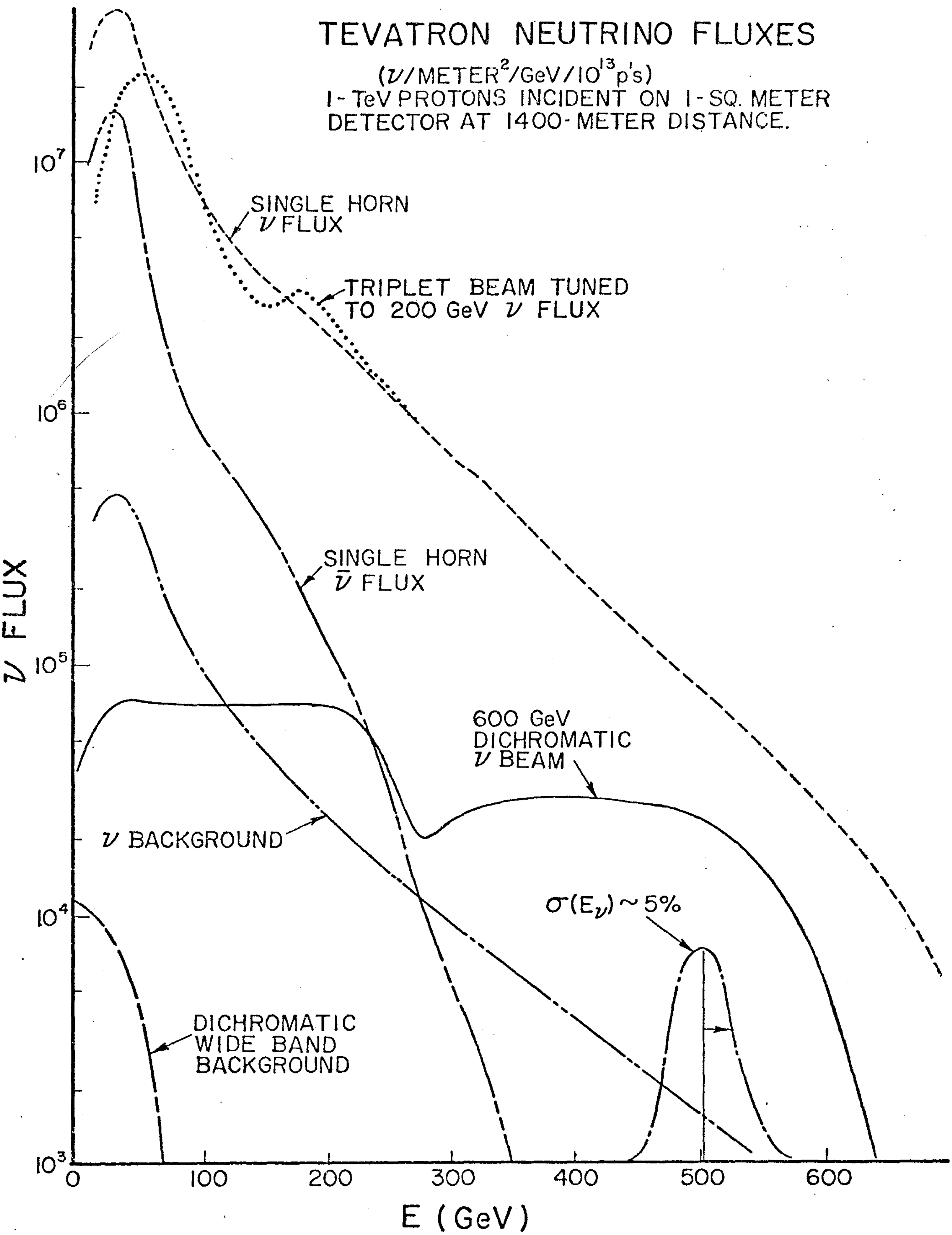


Figure 4-4 Neutrino Beam Fluxes From 1 TeV Protons

raised to higher energies by the addition of more bending magnets. The N1 muon beam (designed originally as a muon beam) will be decommissioned because of the prohibitive cost of shielding the beam. The N3 beam to the 30-in. bubble chamber will also be decommissioned, because the 30-in. chamber will cease to operate in this location and because of the prohibitive cost of shielding this beam for higher-energy operation.

4.3.2 Switchyard Improvement. The Switchyard improvement for the neutrino beams[1] consists mainly of installing more electrostatic septa in Enclosure B and more magnets in Enclosure C and Enclosure G2, which are being enlarged during 1980 and 1981.

The septum in Enclosure B will be increased to six electrostatic modules, each 10 ft in length with an electric field of 65 kV/cm. This septum station begins the Meson-Neutrino split. The vertically split beams will exit the septa at 0.12 mrad with respect to each other.

Enclosure C (Fig. 4-5) will contain six Lambertson magnets at 8 kG, followed by six C-magnets at 12 kG to bend the main proton beam to the Meson west bend. The NO proton beam, after passing through the field-free region of the Lambertson magnets and just east of the C-magnet field region, will enter the MV100 string, which provides an up bend of 9.992 mrad. Seventy feet of Main-Ring B2 magnets at 15.62 kG will be used to replace the present four EPB magnets at 12 kG.

The next elements in the proton beam for the NO neutrino beam are in Enclosure G2. (Fig. 4-6) Four EPB quadrupoles (3Q120) will form a doublet to focus the beam, followed by four EPB dipoles (5-1.5-120) which form the main switching system to direct the proton beam to the new upstream target point dichromatic neutrino beams, to the old downstream tareget for wideband neutrino beams or into the relocated N7 beam for hadron beams. Operationally,

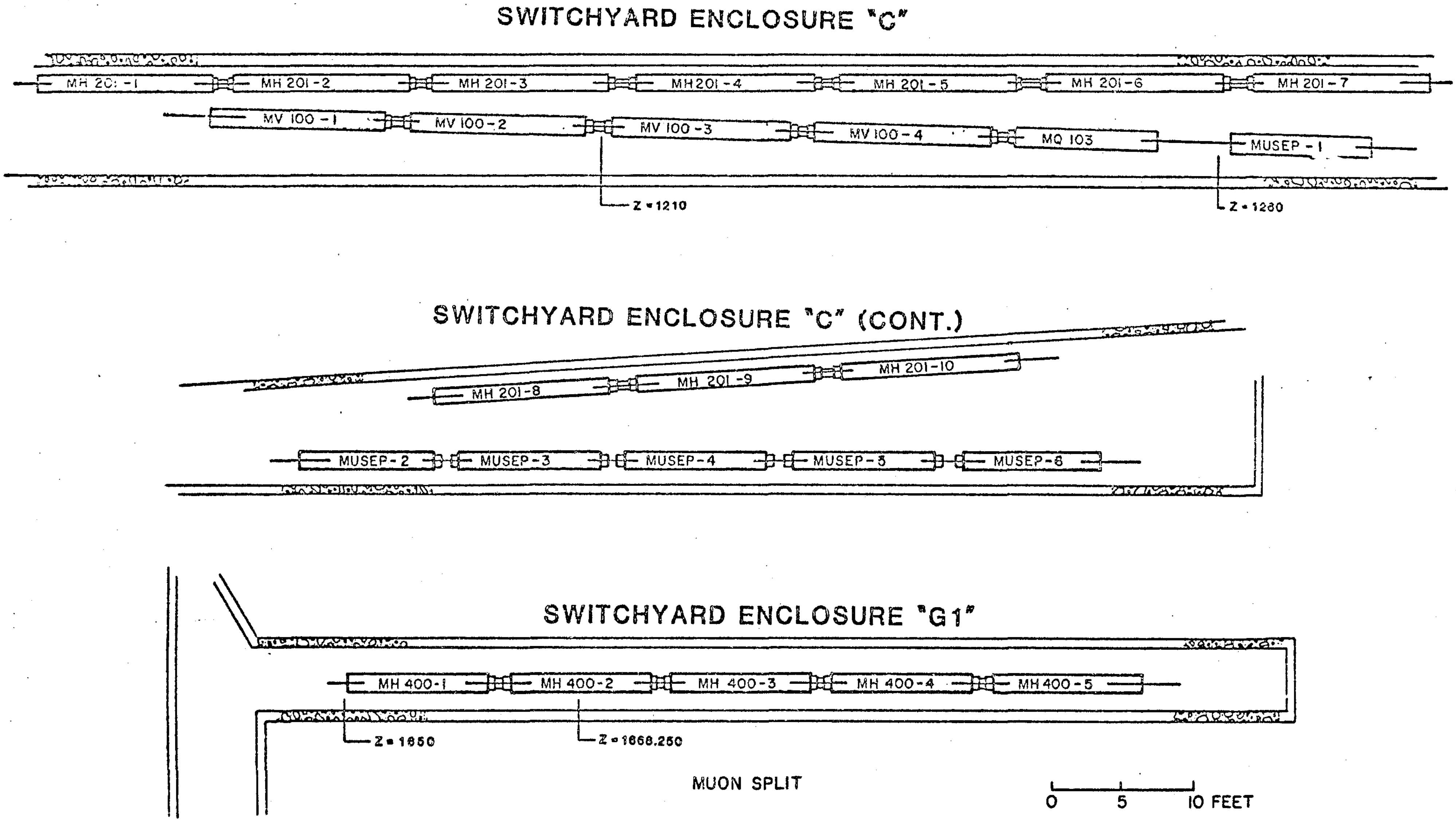
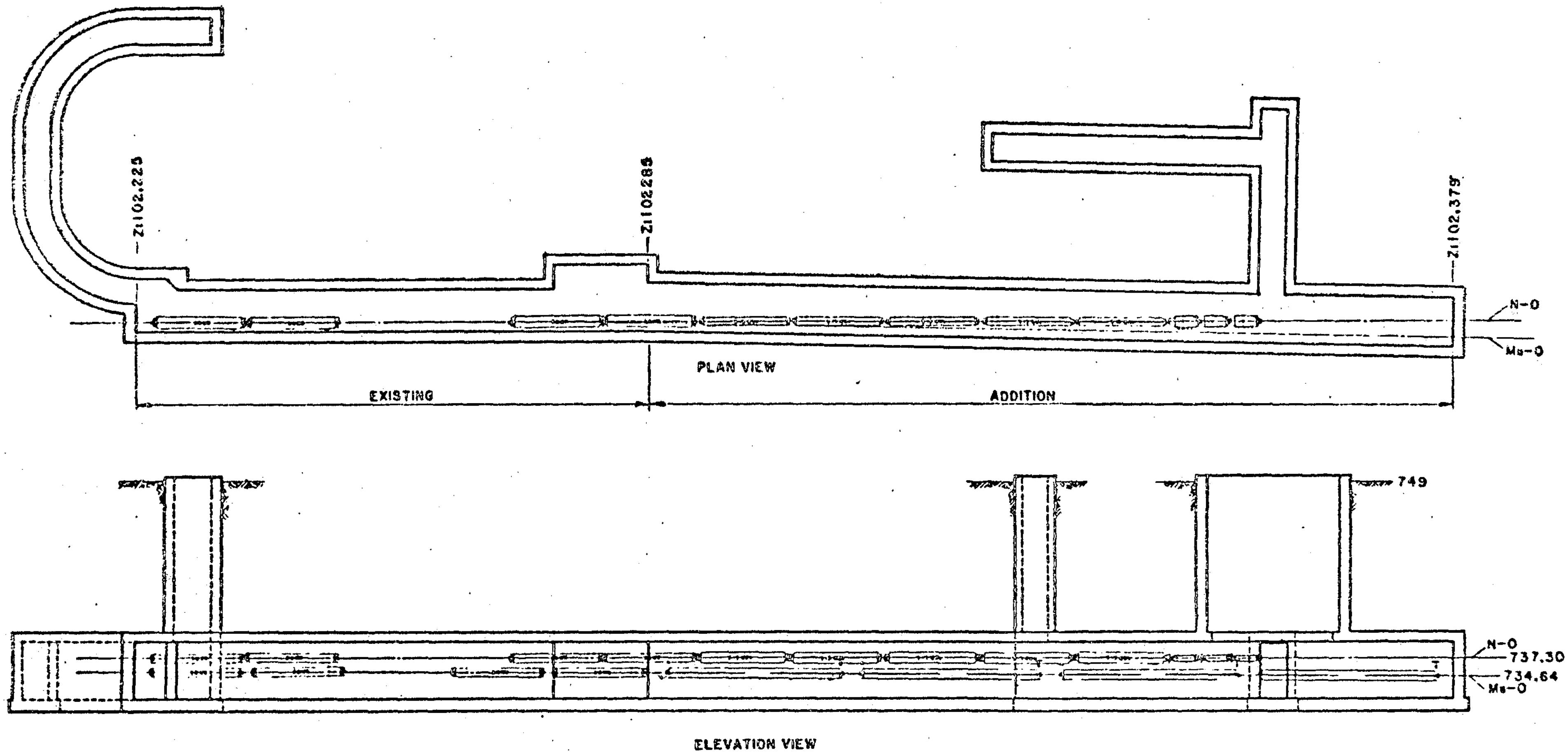


Figure 4-5

Beam Transport Elements for Tevatron
Proton Handling, Muon and Neutrino Lines



SWITCHYARD ENCLOSURE "G-2"

Figure 4-6

Tevatron Proton Transport to Neutrino and Muon Targets only one of the neutrino beams will run at any one time, with the change between dichromatic and wideband beams being made between running periods. The hadron beam will, however, share the proton beam with the neutrino lines. The time to switch the slow or fast spill between the neutrino and hadron lines will be 0.5 sec at 1 TeV. These switching dipoles will be followed by four 4-4-30 vernier magnets used in making steering corrections. To house the power supplies for these beam elements and refrigeration for the muon beam bends, it will be necessary to add a service building at Enclosure G2.

The next enclosure containing beam elements will be Neuhall. The transport of the NO beams through Neuhall is dependent upon the particular target system being used, but will usually be by conventional magnets. The elements in the N7 beam in Neuhall are likewise conventional magnets that remove the 9.992-mrad vertical bend introducted by MV100 and add a 5.5-mrad bend to the east to direct the beam to the hadron beam target area in Neutrino Enclosure 103. All the changes in these transport systems in Neuhall will be carried out by increasing the number of conventional magnets within an existing enclosure.

4.3.3 New Construction for 1 TeV. The main construction requirements within the Neutrino Area itself are to upgrade the NO muon shield for 1-TeV operation and to construct a new detector building to replace the Wonder Building experimental area, which must be decommissioned because of inadequate shielding.

The improvement of the NO muon shield[2] that was initiated in 1979 is sufficient to harden the shield to 700 GeV for Labs B, C, and E. It consists of installing a 3.5m x 3.5m x 150m steel plug in the beam beginning immediately downstream of Enclosure 100. In order to upgrade the main neutrino experimental area of Labs B, C, and E to 1000 GeV, an additional

3.5m x 3.5m x 100m steel plug of 10,000 tons must be added[2], as shown in Fig. 4-1.

There are two possibilities for extensions of the detector buildings in the main experimental area. The first possibility is to expand one or more of the present detector facilities of Lab E or Lab C, which are used to house electronic detectors, or Lab B which houses the 15-ft bubble chamber. The second possibility is to build a completely new experimental hall either upstream or downstream of the present area. Figure 4-1 shows a new Lab F just upstream of Lab E. The appropriate time to made the choice between these alternatives will be at the Program Advisory Committee meeting considering the first Tevatron neutrino experiments.

4.3.4 Properties of Existing Beams at 1 TeV. The properties of the neutrino beams at 1 TeV incident proton energy are shown in Fig. 4-4.[3] The most intense neutrino beams are the wide-band neutrino beams generated by the single-horn and the triplet beams; the horn beam is the more intense of the two. The lowest-intensity neutrino beam is the dichromatic beam, but this beam has the smallest backgrounds and has additional information of the neutrino energy, because a correlation can be made between neutrino energy and location in the detectors. This correlation is not possible with the wide-band beams. As a rule, the dichromatic beam is used for total cross-section and nucleon structure-function measurements and wide-band beams are used for new-particle searches and rarer processes.

The N7 beam will transport 1-TeV protons to a target in Enclosure 103. There the protons are targeted and the secondary particles are transported by the N5 beamline back to the main neutrino experimental area to serve as a calibration beam for neutrino detectors.

4.4 High-Energy Muon Beam

4.4.1 Beam Properties. A completely new muon beam and a new experimental area are planned for the Tevatron.[4] The new beam is located to the east of the present neutrino experimental facilities. The location of this beam is shown in Figs. 4-1 and 4-7.

The new beam, which is planned to be of FODO type, will have useful intensities at muon energies up to 800 GeV. A summary of its properties is given in Table 4-1.

Table 4-1. Tevatron Muon-Beam Parameters

Beam Energies:	275-750 GeV/c, μ^+ and μ^-
μ/p interacting:	1.2×10^{-5} @ 750 GeV/c μ^+
	9.0×10^{-5} @ 550 GeV/c μ^+
	30×10^{-5} @ 275 GeV/c μ^+
Halo/Beam: (3m x 3m area)	8% @ 750 GeV/c
	4% @ 550 GeV/c
	7% @ 275 GeV/c
Beam Spot Size:	4.0 cm horiz and 2.0 cm vert FWHM
Momentum Spread:	$\Delta p/p$ = 20% FWHM (tagged to 2%)
Beam Length:	920m Decay (FODO)
	430m Muon (FODO)

4.4.2 Muon-Beam Switchyard. As discussed in Section 4.3.2, the first element of the new muon beam is 60 ft of electrostatic septa at 60 kV/cm, which begins the neutrino-muon split in Enclosure C (Fig. 4-5). The two beams exit the septa at a relative horizontal angle of 0.22 mrad.

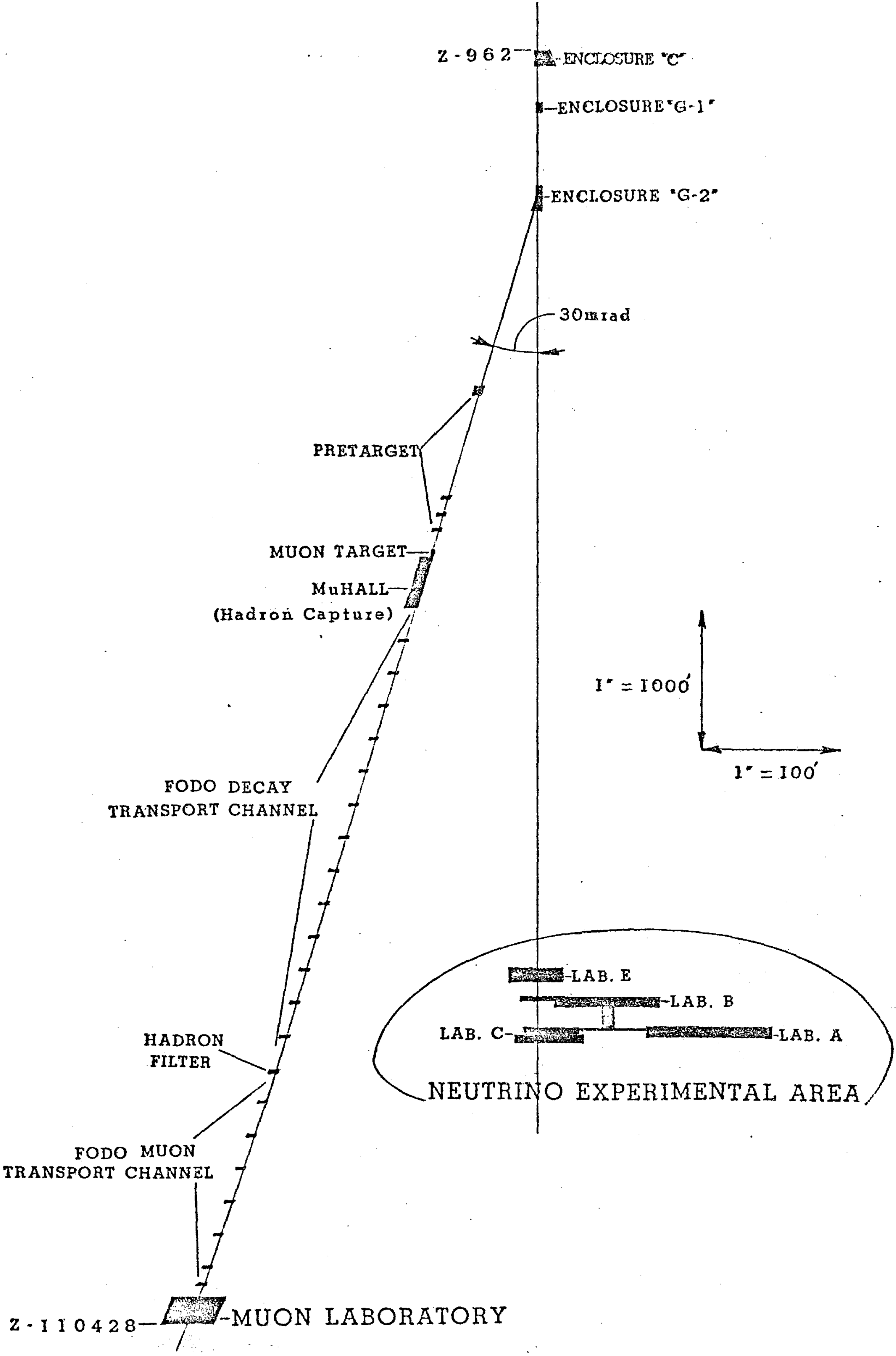


Figure 4-7

Tevatron Muon Beam Layout

A set of five 10-ft long Lambertson septum magnets is located in manhole G1. (Fig. 4-5) The proton beam for NO passes through the field-free hole and the proton beam for the muon target (MuO) is bent 2.70 mrad downward. At the end of the Lambertson string, the two beams are separated 1.07 in. horizontally and 0.87 in. vertically.

In the G2 manhole, (Fig. 4-6) the MuO beam enters a chain of superconducting dipole magnets that bend the beam 8.55 mrad downward and 30 mrad horizontally. These magnets operate at a field of 38.51 kG and are mounted at an angle of 16.035° with respect to the horizontal to accomplish the horizontal and vertical bends simultaneously. The MuO beam leaves this enclosure at a downward angle of 1.26 mrad and an eastward angle of 30 mrad. The space to house these magnets (the extended G2 Enclosure) will be constructed with 1981 AIP funds. G2 will also be used to house the switching magnet between the NO and N7 lines. An above-ground service building will house the helium refrigerator for the superconducting m_u0 magnets.

The MuO beam drifts approximately 2400 ft to a position 75 ft east of Enclosure 100 and 12 ft below the surface, where it is focused onto the target.

Most of the Switchyard changes necessary for the muon beam will be carried out in 1982 as an AIP project, NO Bypass Beam Dump, which is to construct a beam dump for use when the Neutrino Area is not operating. During the Tevatron Phase 2 era, this transport will be upgraded to 1000 GeV/c and converted to a split instead of a switch and will serve as the proton source for the muon beam.

4.4.3 Proton Targeting and Muhall. Approximately 300 ft before the target, a quadrupole triplet is used to focus the proton beam onto either of two targets used as the source of the muon beam. The two targets will be separated by 24 ft. These targets will be housed in an area where the groundwater has been protected against contamination by the produced radionuclides. The upstream target will be used whenever the parent pion beam is tuned for a momentum greater than 600 GeV/c. Immediately following the target is a 15-ft water-cooled collimator which will serve as a dump for all secondary particles not accepted in the downstream transport system.

The downstream transport consists of three parts, as shown in Fig. 4-5: i) the hadron capture section, ii) the FODO decay channel, and iii) the muon-transport section.

The purpose of the hadron capture section is to collect as many pions and kaons from the target in as large a momentum band as possible. Immediately downstream of the collimator is a quadrupole triplet followed by a magnetic dogleg, with bending magnets to screen out the low-energy or wrong-sign pions and kaons. The dogleg also contains a collimator dump to absorb these particles. When this dogleg is tuned for momenta below 600 GeV/c, the non-interacting primary proton beam is also dumped on this collimator. Above 600 GeV/c, the residual primary proton beam is transported through this collimator and into the decay channel, together with the parent pions and kaons. The entire hadron capture section will be housed in an underground enclosure approximately 450 ft long, which will have shielding both above and below to protect the environment. This enclosure is called Muhall.

4.4.4 Decay Channel and Muon Transport. The decay channel is located after the magnetic dogleg. The decay channel consists of a FODO array of fifteen quadrupoles with spacings of 200 ft between each magnet for a total length of 3000 ft. A typical quadrupole enclosure is shown in Fig. 4-8.

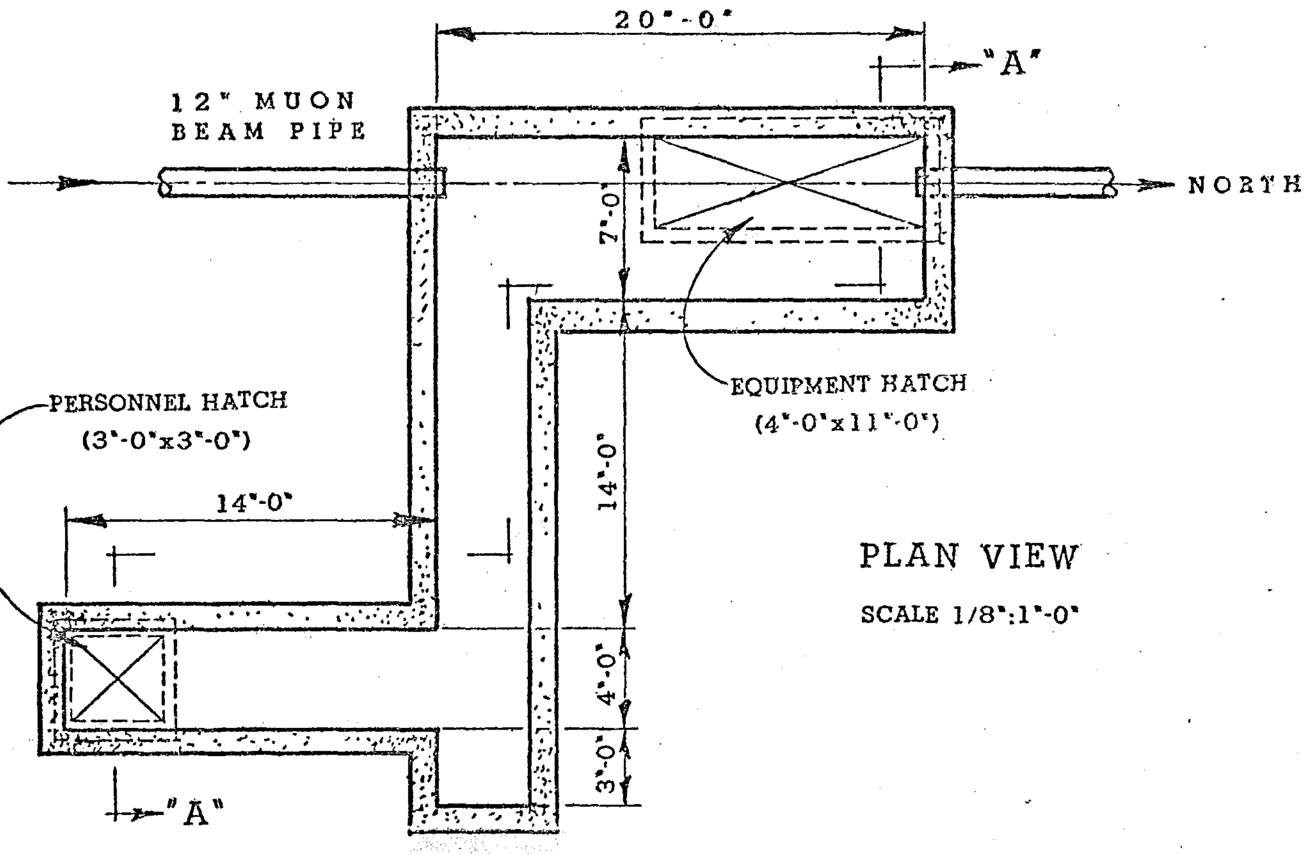
A hadron absorber is located at the end of the decay channel and at the beginning of the final muon FODO section to screen out parent pions and kaons and also to serve as the primary proton beam dump when the beam is tuned to high-energy positive muons. The hadron absorber consists of 35 ft of beryllium located in the bending magnets that form part of the muon momentum-selection and tagging system.

This section is followed by six more quadrupoles with the same spacing as the decay FODO channel and final bending magnet, in the same direction as the first, placed to cancel d /dp, the change of angle with momentum. Momentum tagging of individual muons can be accomplished by following the trajectories through this last dipole using multiwire proportional counters and scintillation counters.

A system of toroidal magnets is used in the muon transport section to improve the beam to halo ratio.

The decay channel and muon transport section occupy a beamline 4400 ft long. The magnetic components will be housed in 22 small underground enclosures spaced at 200-ft intervals along this beamline. The beamline is located approximately 12 ft beneath the surface. The choice was made to locate the beam below grade level in order to minimize offsite radiation exposure from operation of this line.

4.4.5 Muon Laboratory Building. The last item in the new muon beam is the muon laboratory building shown in Fig. 4-9. The building will contain two stories, one story a pit below grade approximately 40 ft by 200 ft, which will house the experimental apparatus. A second story at grade level, approximately 50 ft by 250 ft, covering the pit, will consist of a high bay above grade



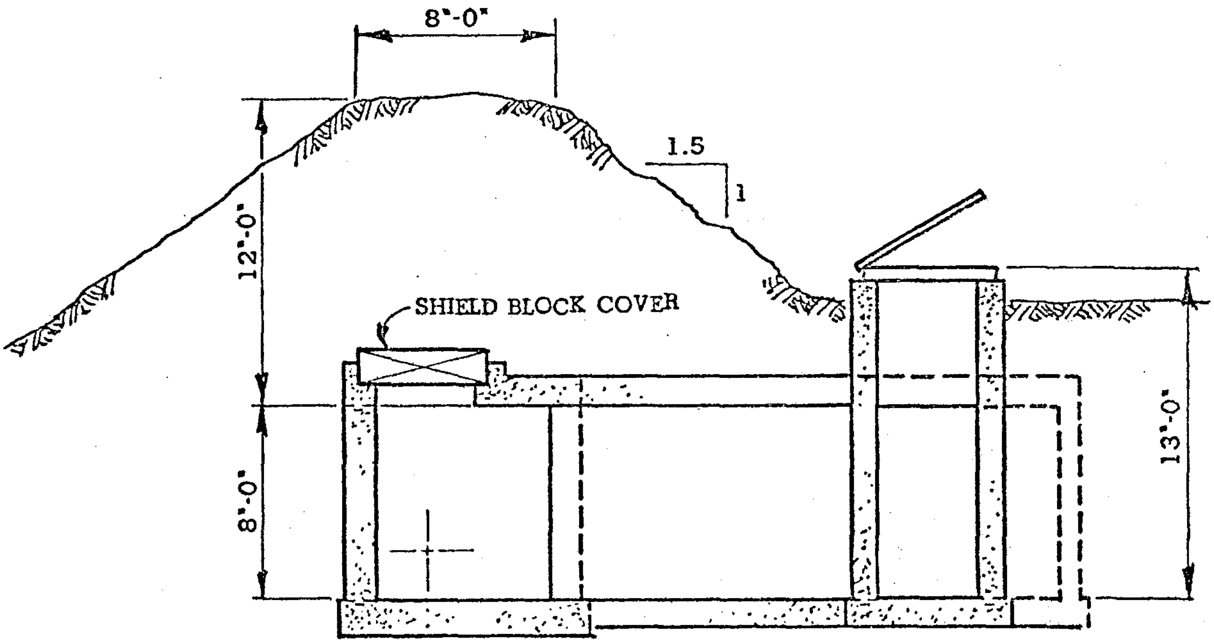
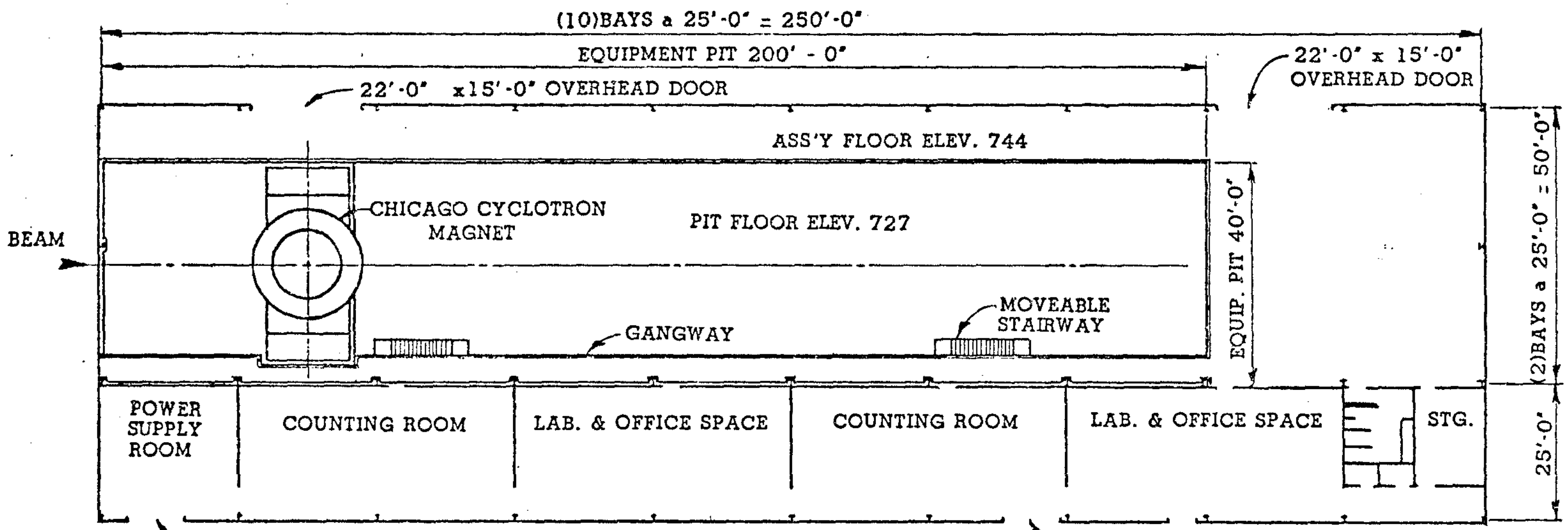


Figure 4-8

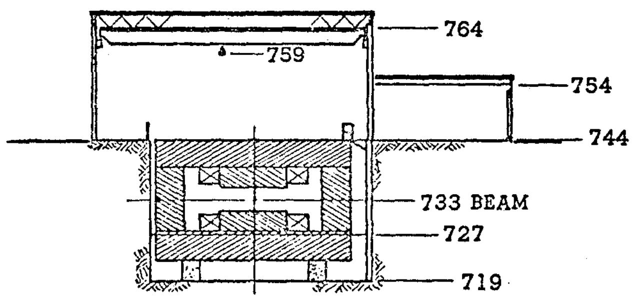
Design For The Muon Quadrupole Enclosures



PLAN VIEW

SCALE
1" : 30'-0"

NORTH



CROSS SECTION
Z = 110,256.502

Figure 4-9

Design for a New Muon Experimental Hall

utilizing structural steel frame and insulated metal siding. A second portion of the above-grade structure approximately 25 ft by 250 ft will house light laboratories, counting rooms, and office space. This second area will be adjacent and connected to the first area.

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5. PROTON AREA

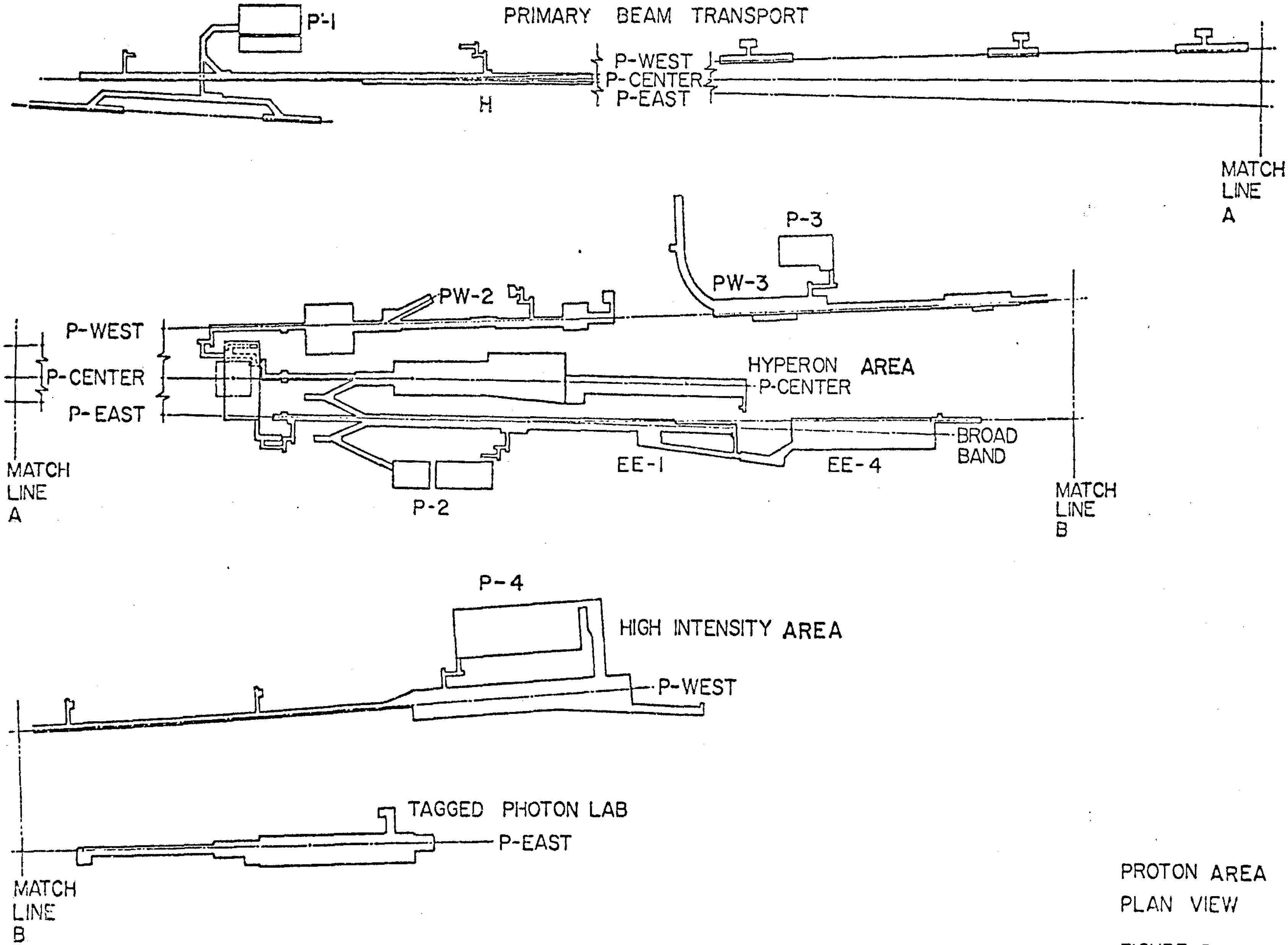
5.1 Introduction

The Proton Area has three independent primary proton beams that can be targeted to produce simultaneously up to three zero degree secondary beams. Proton West is used to produce a high-intensity pion beam.[1] A flexible hyperon beam that can supply either charged or neutral hyperons is fed by the Proton-Center beam.[2,3] Proton East produces two photon beams, the broad-band beam[4] and tagged-photon beam.[5] These two beams share the same target and physical space in such a way that only one can be used at any given time. A feature of the Proton Area is that it is constructed below grade to take advantage of earth shielding for high-energy experiments. The Tevatron Phase 2 project will make it possible to extend each of these beams to higher energy and intensity and will make the two photon beams capable of simultaneous operation. Some of the plans described here were developed earlier and described in previous reports or design studies.[6,7]

5.2 The Proton Area in January 1982

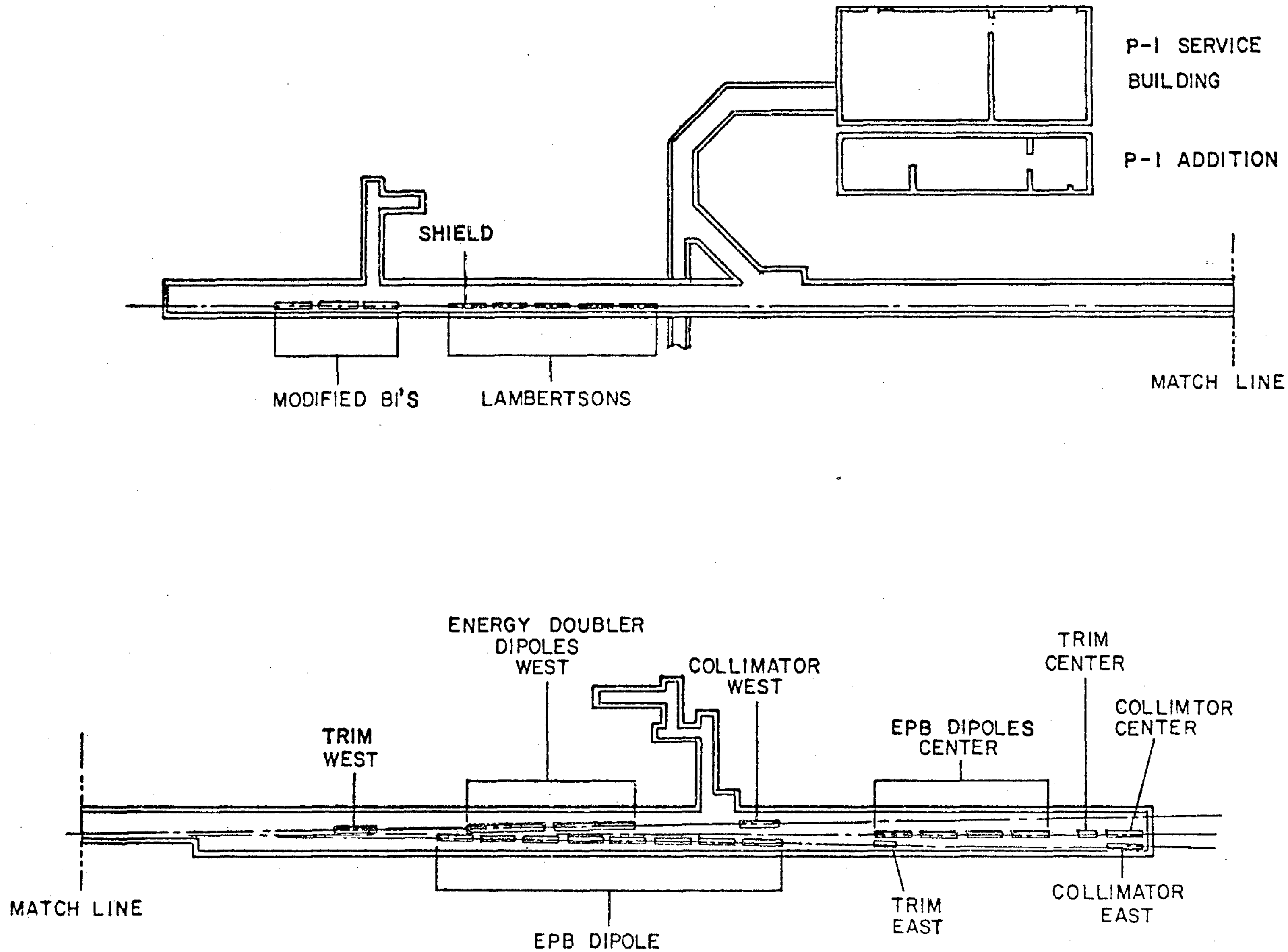
Several AIP projects that will be completed in FY 81 will improve the Proton Laboratory and its capabilitites beyond what exists today. Figure 5-1 shows a plan view of the Proton Area beam enclosures, service buildings, and experimental areas as they will exist in January 1982.

The Proton Area begins in Enclosure H,[6,8] where three vertically separated primary proton beams from the Switchyard are split horizontally by three-way septum dipoles and sent on to the three beam lines. By the beginning of 1982, the West bend in Enclosure H will have been converted to a superconducting bend made of two Energy Saver dipoles. A refrigerator in the P1 service building will provide liquid helium for these dipoles. Figure 5-2 shows this configuration for Enclosure H.



PROTON AREA
PLAN VIEW

FIGURE 5-1



PROTON LAB
ENCLOSURE H
500 GEV CONFIGURATION

FIGURE 5-2

In Proton East, the two photon beams will still be targeted using the same primary proton beam line. It will not be possible to run both beams simultaneously. The P2 service building will have been enlarged in order to accommodate power supplies and controls that are presently located in EE1, a primary-beam enclosure. This will give better utilization of the two beam lines and less radiation exposure to Laboratory personnel. In addition, EE1 will be replaced by a concrete underground enclosure covered with 16 ft of earth in order to improve shielding over the beam line. Table 5-1 summarizes the capabilitites of all of the Proton Area secondary beam lines as they will exist in January 1982.

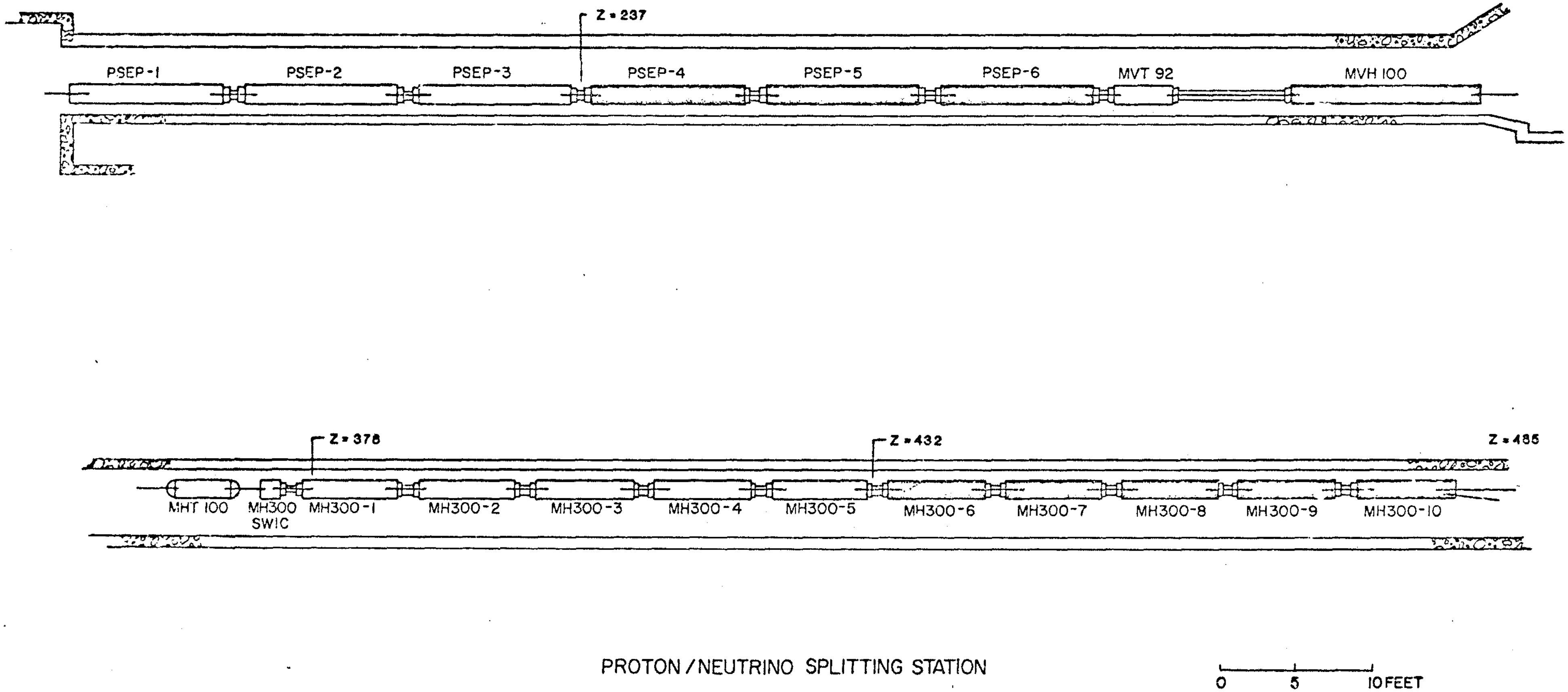
The beam properties given in Table 5-1 are also accurate for the beam lines today, with one exception. The P-West High Intensity Beam line will have a 400-GeV capability in 1981. The successful operation of a satellite refrigerator, 450 ft of helium transfer line, and a 4-ft low-current, superconducting dipole has increased the maximum momentum of the limiting bend string. It is now possible to rearrange some beam elements to obtain a 400 GeV capability. By 1982 the transfer line in the tunnel will have been continued to the up stream service building, P3. This will facilitate the early replacement of conventional magnets with low-current superconducting magnets, which will be necessary in order to run E-615, an experiment with a large dimuon spectrometer, without a major power increase in the P-West experimental hall.

5.3 1-TeV Primary Beam Improvements

5.3.1 Proton Switchyard. The external proton beam split creating the Proton Laboratory beam is made in the Transfer Gallery immediately following the extraction channel. Figure 5-3 indicates the position of the three electrostatic septa that will be added to the beam configuration of the

Table. 5-1. Proton-Area Beam Properties in January 1982.

Beam Line	Particle Beams Available	Maximum Energy	Flux for 400 GeV incident Protons
Proton West	π^-, $\bar{p}$	400 GeV	$\sim 3\times 10^9 \pi^-$ at 200 GeV 10^{13} protons $1\times 10^7 \bar{p}$ at 100 GeV 10^{13} protons
Proton Center	Hyperons	350	$\sim 2\times 10^5 \Sigma^-$ at 300 GeV 10^{11} protons $\sim 10\Omega^-$ at 250 GeV 3.5×10^{10} protons
Tagged Photon	e^-, tagged γ	300	$\sim 5\times 10^6 e^-$ at 200 GeV 5×10^{12} protons
Broad band Photon	n, K^0, γ	neutral spectrum to machine energy	neutrons: $4\times 10^7/10^{12}$ protons with $E_n >$ 100 GeV (40 μster acceptance) γ : $1.5\times 10^7/10^{12}$ $\langle E_\gamma \rangle =$ 50 GeV $1.5\times 10^6/10^{12}$ $E_\gamma >$ 100 GeV (130 nster acceptance)



PROTON / NEUTRINO SPLITTING STATION

FIGURE 5-3

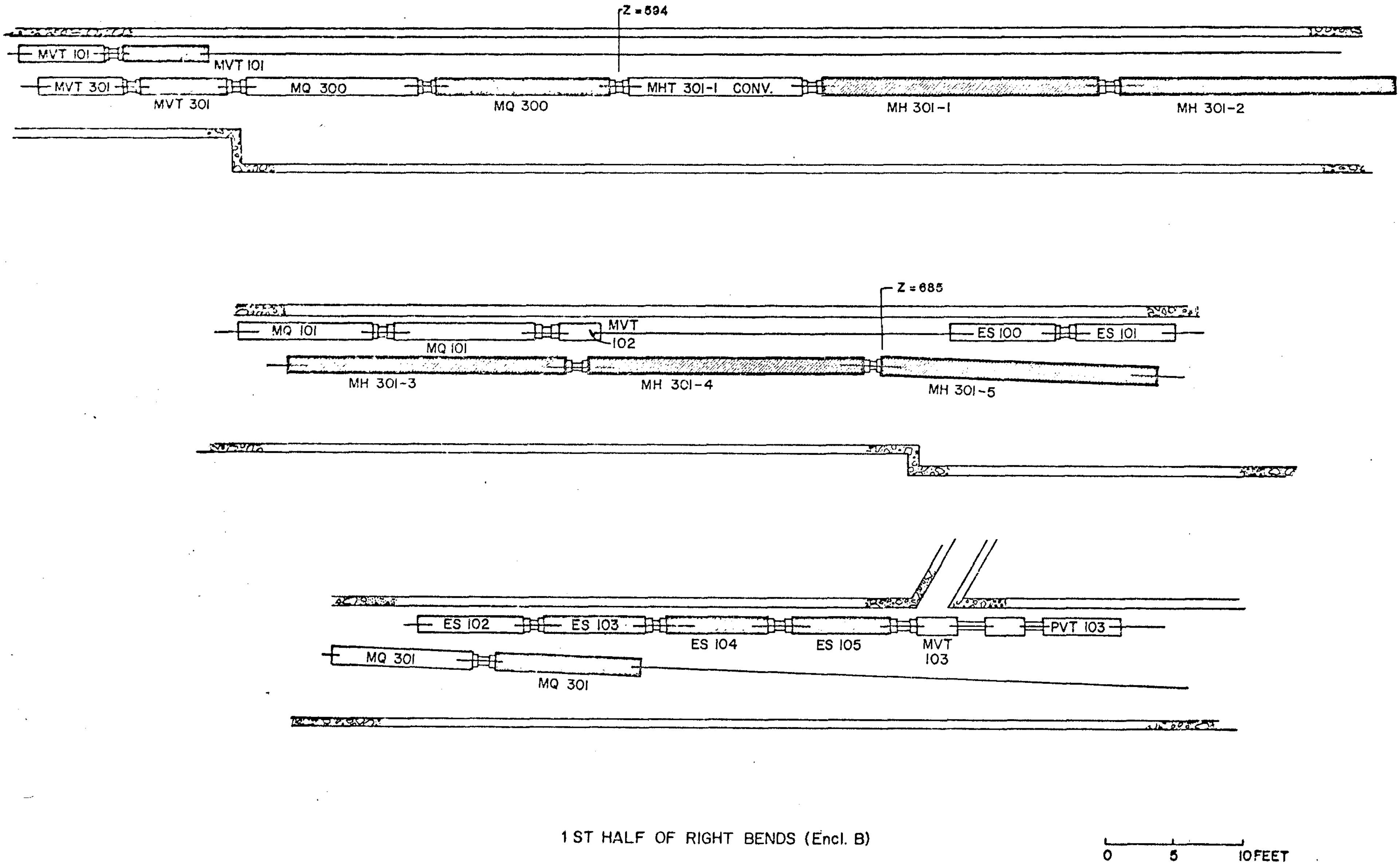
Transfer Gallery proton split. Vertical dipole MVH100 rotates the extracted Tevatron proton beam back into the plane of the switchyard, as discussed in section 3.5.5. The Lambertson magnetic septa string in enclosure B will be upgraded by adding five more septa in series.

The existing conventional 31 dipole magnet string forming the 5° east bend to the Proton Laboratory must be replaced with superconducting Energy Saver dipoles to reach 1 TeV. A string of five superconducting dipoles in enclosure B (Fig. 5-4) and six superconducting dipoles in Enclosure D (Fig. 5-5) comprise the bend. An additional satellite refrigerator must be added to the existing Switchyard Service Building to provide the refrigeration for the dipoles. Quadrupole focusing power is doubled everywhere by adding additional conventional 3-in. quadrupoles.

The present primary proton triple split in the Proton Area starts with a double electrostatic split in enclosure E. The energy capability of this split is increased to 1 TeV by doubling all the conventional components. Five electrostatic septa, three main ring dipoles, two 3-in. quadrupoles and three trim dipoles are added (see Fig. 5-6).

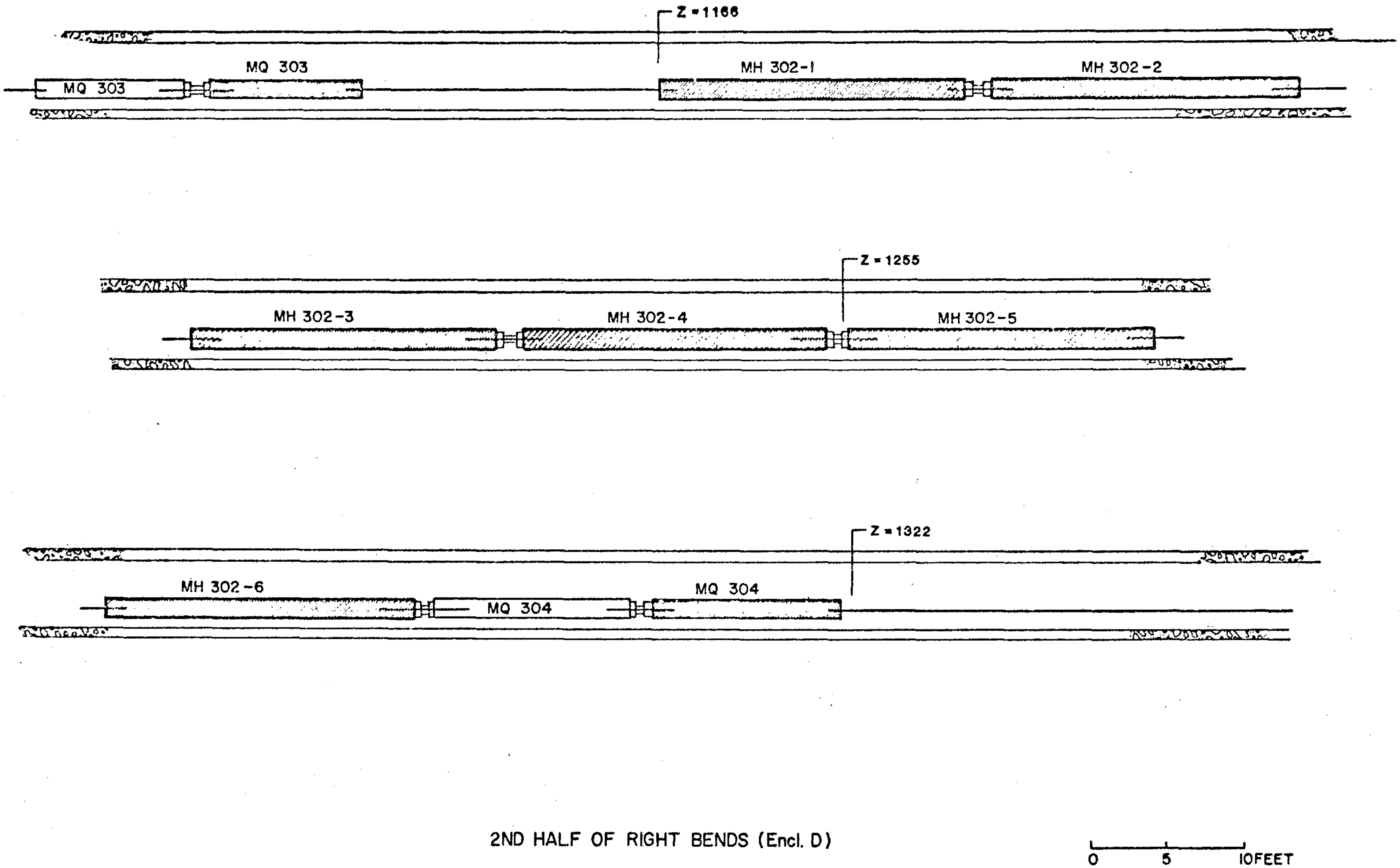
5.3.2 Enclosure H Before the availability of Tevatron 2 funding, the Proton Area will have the capability of simultaneously transporting 500-GeV beams to the three primary targets in P-East, P-Center, and P-West. One of the primary Tevatron goals will be to upgrade the beam-splitting station in Enclosure H and the primary proton-beam transports to 1 TeV in order to target existing beams.

Enclosure H will require the addition of one modified B1 dipole[9] for the vertical bend at the upstream end. One additional three-way split Lambertson magnet[10] will maintain the required horizontal separation of the three beams.



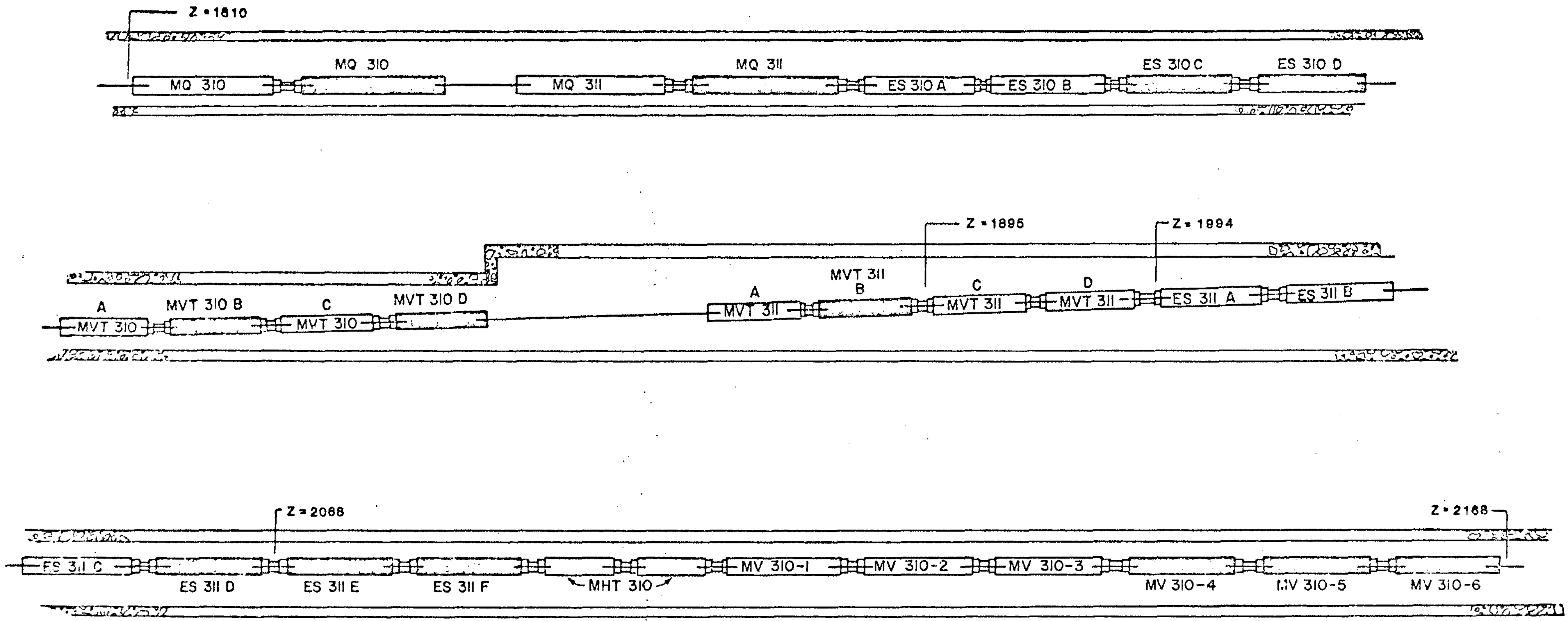
1 ST HALF OF RIGHT BENDS (Encl. B)

FIGURE 5-4



2ND HALF OF RIGHT BENDS (Encl. D)

FIGURE 5-5



PROTON 3-WAY SPLIT

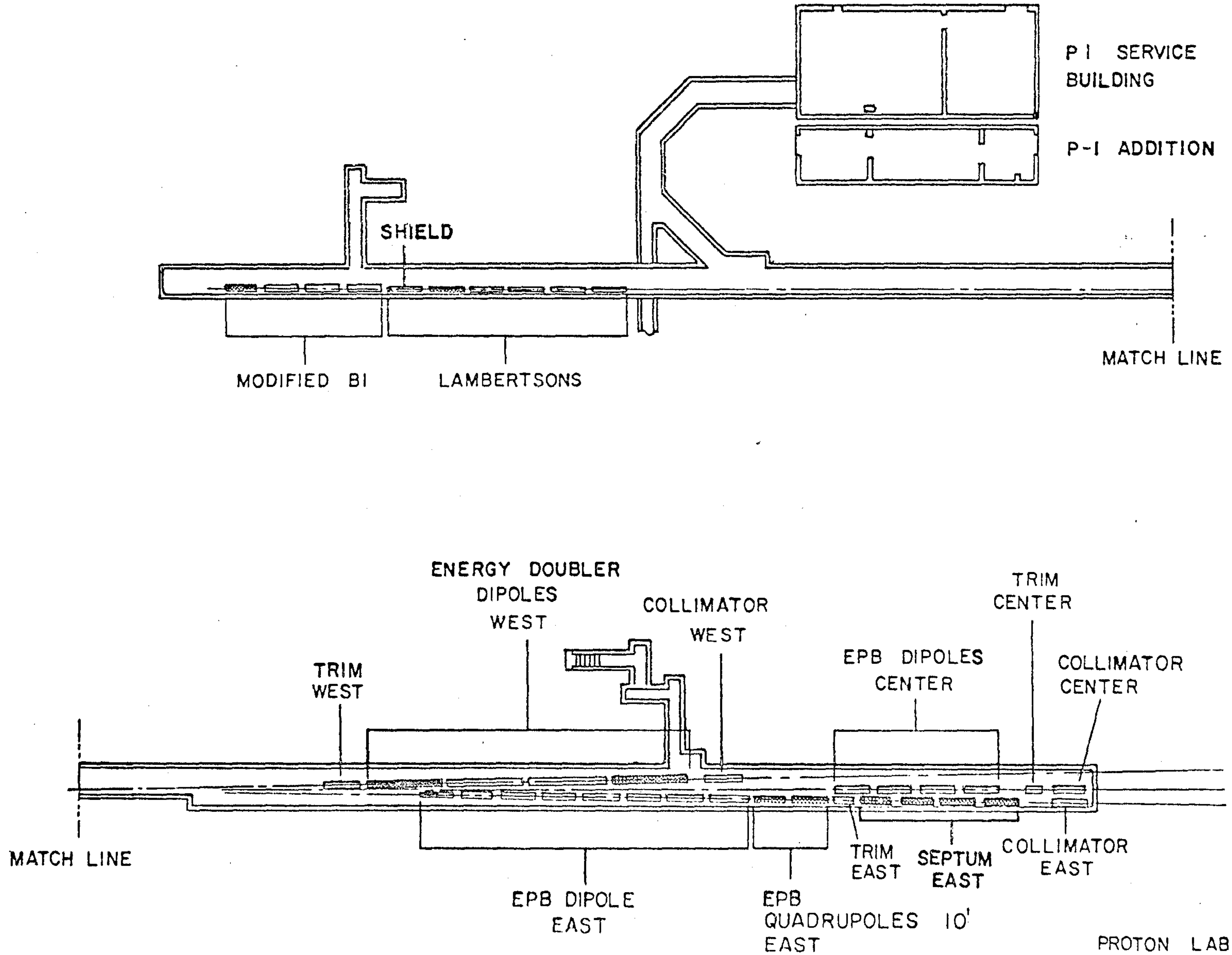
FIGURE 5-6

Finally, two Energy Saver dipoles will complete the bend string to P-West. Figure 5-7 shows Enclosure H in its 1-TeV configuration.

In the East branch, the indicated electrostatic septa are necessary for the new Wide-Band Charged and Neutral beam. This beam is discussed in more detail in Section 5.5 below.

5.3.3 Proton West. The primary proton targeting for P-West will remain conventional. Two B2 dipoles in Enclosure PW-2 will provide the extra horizontal bend at 1 TeV. The existing four 4Q120 quadrupoles will be replaced by six 3Q120's and the remaining three EPB dipoles will move slightly upstream. The ability to dump the primary beam safely in PW-2 will be maintained. This configuration does not require a new substation and only one new TR500 Power supply must be added. The required water-cooled bus for the B2 dipoles is already installed. Total peak power consumption is 700 kVA at 1 TeV. The PW-3 pre-target pitching dipoles will be adequate for 1 TeV targeting of the zero degree charged-pion beam. Targeting at zero degree for the antiproton option will not be possible. A mimimum production angle of 1.5 mr must be maintained in order to dump the 1-TeV primary proton beam safely. This results in only a 45% loss in antiproton flux at 250 GeV over the maximum possible. The present P-West target station and dump have been designed to permit high-intensity operation at 1 TeV. Figure 5-8 shows the P-West pre-target beam element configuration before and after upgrade to 1-TeV capability.

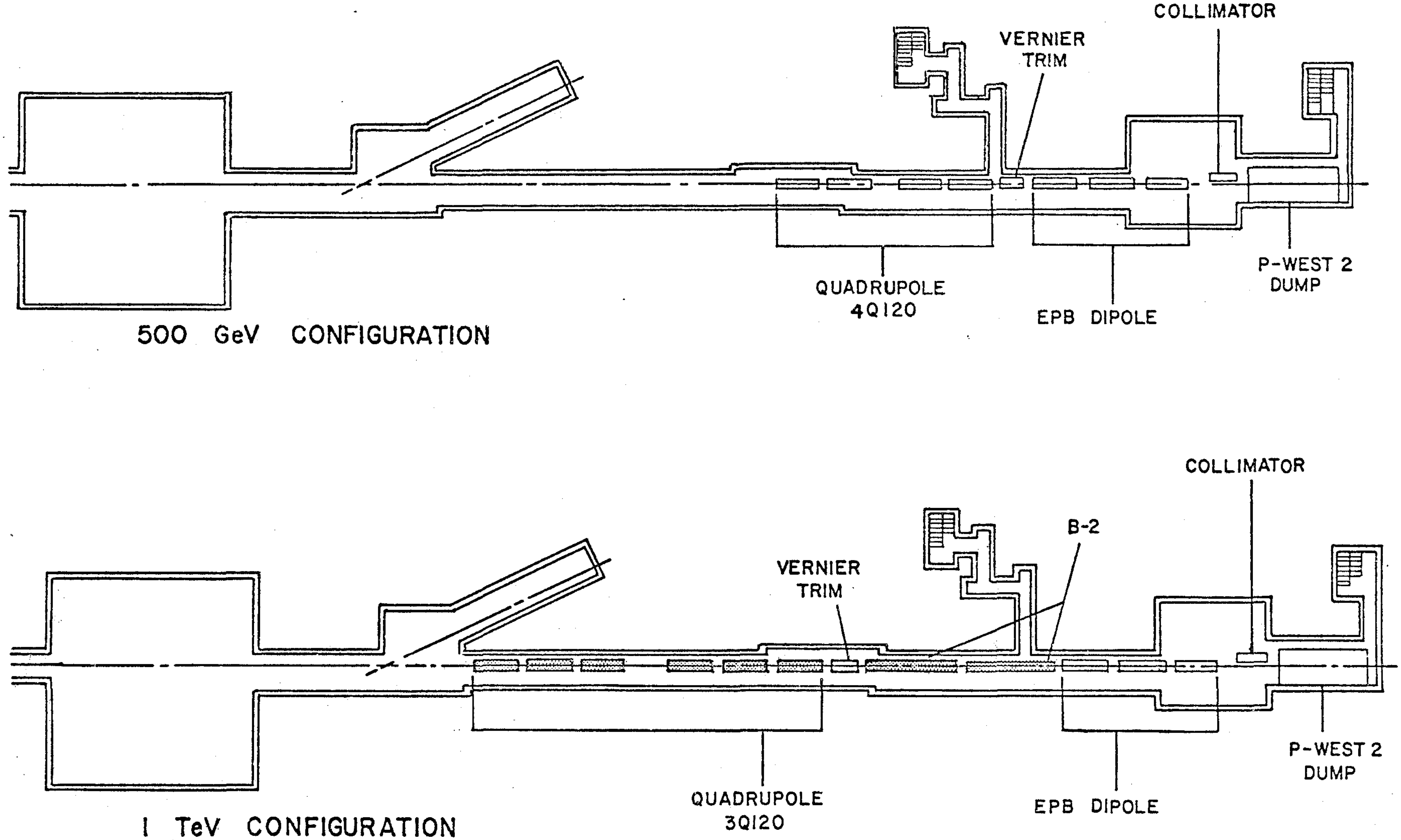
5.3.4 Proton Center. Contingent upon the experimental requirements, no major upgrades of the P-Center pretarget beam are anticipated. The existing quadrupoles will have insufficient strength to produce an ideally small spot; a broadened 20 mm x 10 mm primary-beam spot size at the present hyperon



ELEMENTS NEEDED FOR TEV II PROJECT

PROTON LAB
ENCLOSURE H
1 TEV CONFIGURATION

FIGURE 5-7



NEW ELEMENTS REQUIRED FOR TeV II PROJECTS

P-WEST
PRE-TARGET
COMPONENT CONFIGURATION

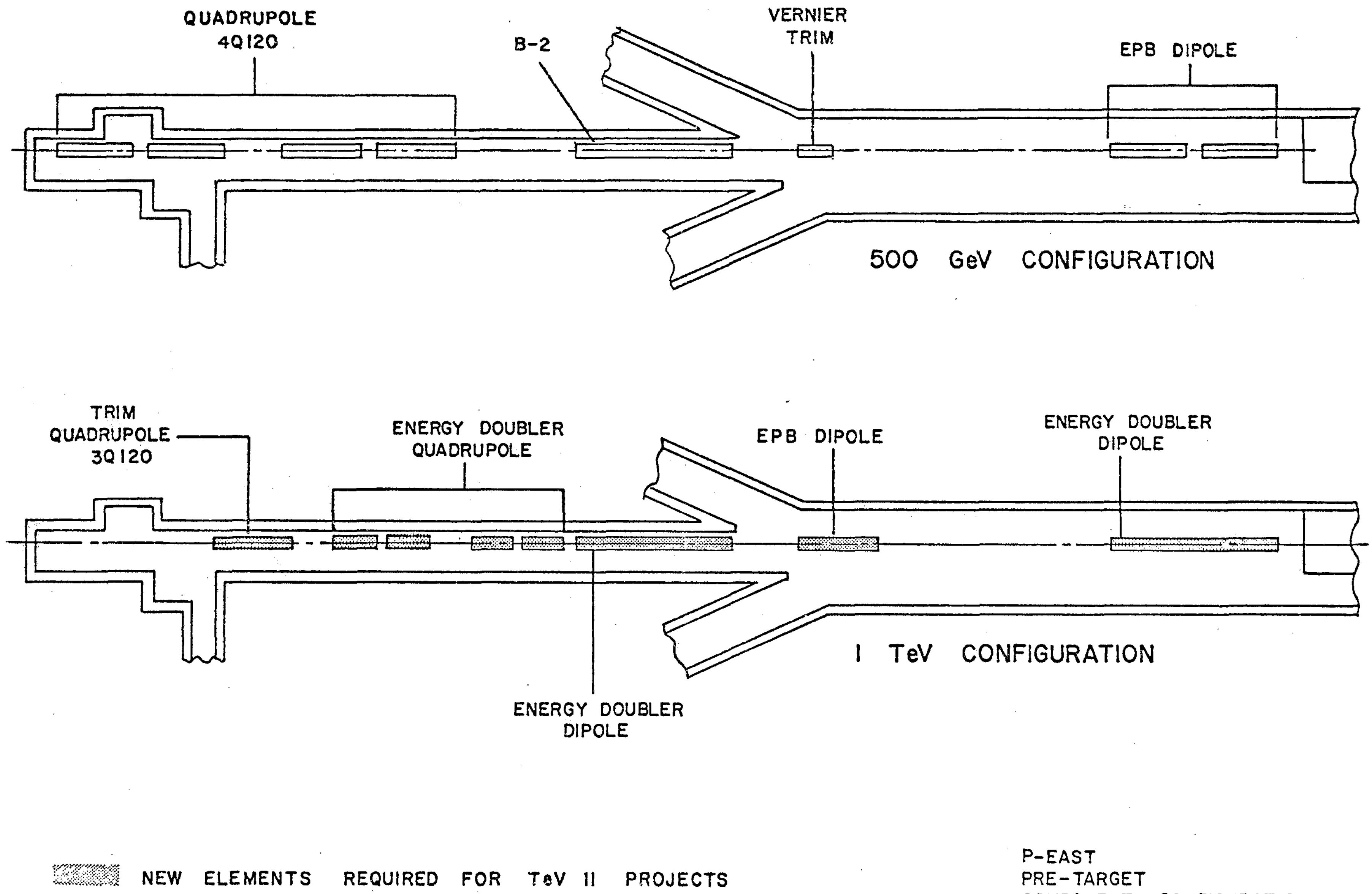
FIGURE 5-8

production target can be achieved with the existing installation. The existing pitching-magnet system will allow variation of the production angle up to ± 3.6 mrad, or P_t to 1.25 GeV/c for 350-GeV hyperon production. When smaller spot sizes are required for future experiments, the hyperon-channel magnet and shielding will be moved 16 m downstream, and three additional 10-ft quadrupole magnets added.

5.3.5 Proton East. The primary beam transport for the P-East tagged-photon beam will be converted to Energy Saver superconducting magnets. A liquid-helium refrigerator will be installed in the P2 service building and be linked to the pre-target magnets by a 150-ft transfer line. The focusing quadrupoles and the major vertical bend will use a common current, thereby minimizing high-current lead heat loads. A 3Q120 quadrupole will act as a trim for the doublet optics. The horizontal bend will function as a beam-abort safety device. The electron-beam target box will be reconfigured to provide for greater reliability, flexibility, shielding, and higher primary-flux capability. Figure 5-9 shows the P-East pre-target beam-element configuration before and after upgrade to 1-TeV capability.

5.4 Performance of Existing Beams at 1 TeV

The energy and intensity capabilitites of existing beam lines in the Proton Area will be substantially enhanced when 1-TeV protons become available. This performance increase, which can be done with little or no modification of the beams themselves, becomes a natural and exciting doorway into the TeV region. The mature beam lines of Proton East and Proton West have well-understood properties at present energies; their characteristics at 1 TeV are predictable in a straightforward manner. The new hyperon beam line in Proton Center has not yet been commissioned, so its performance characteristics at 1 TeV are more speculative.



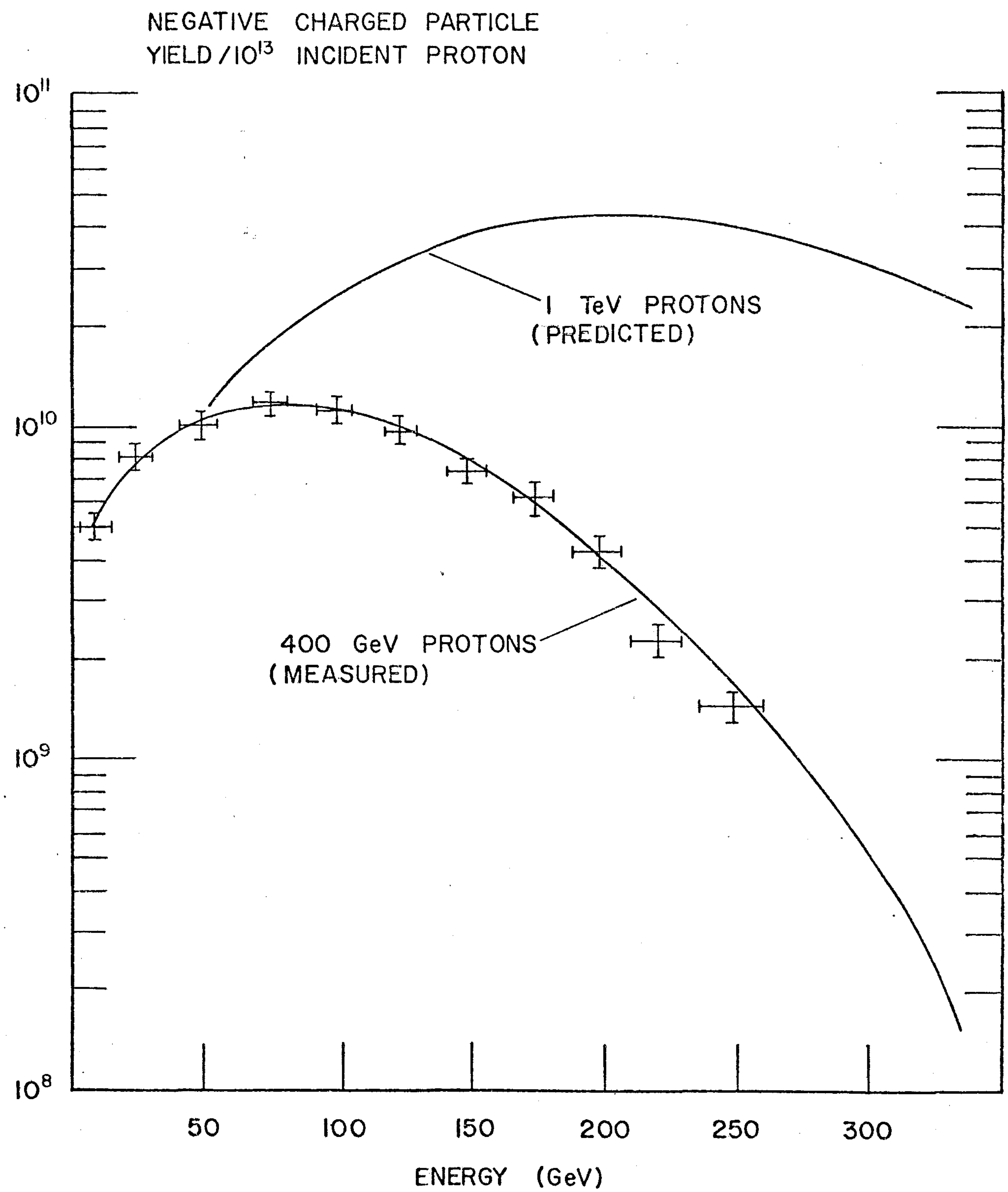
P-EAST
PRE-TARGET
COMPONENT CONFIGURATION

FIGURE 5-9

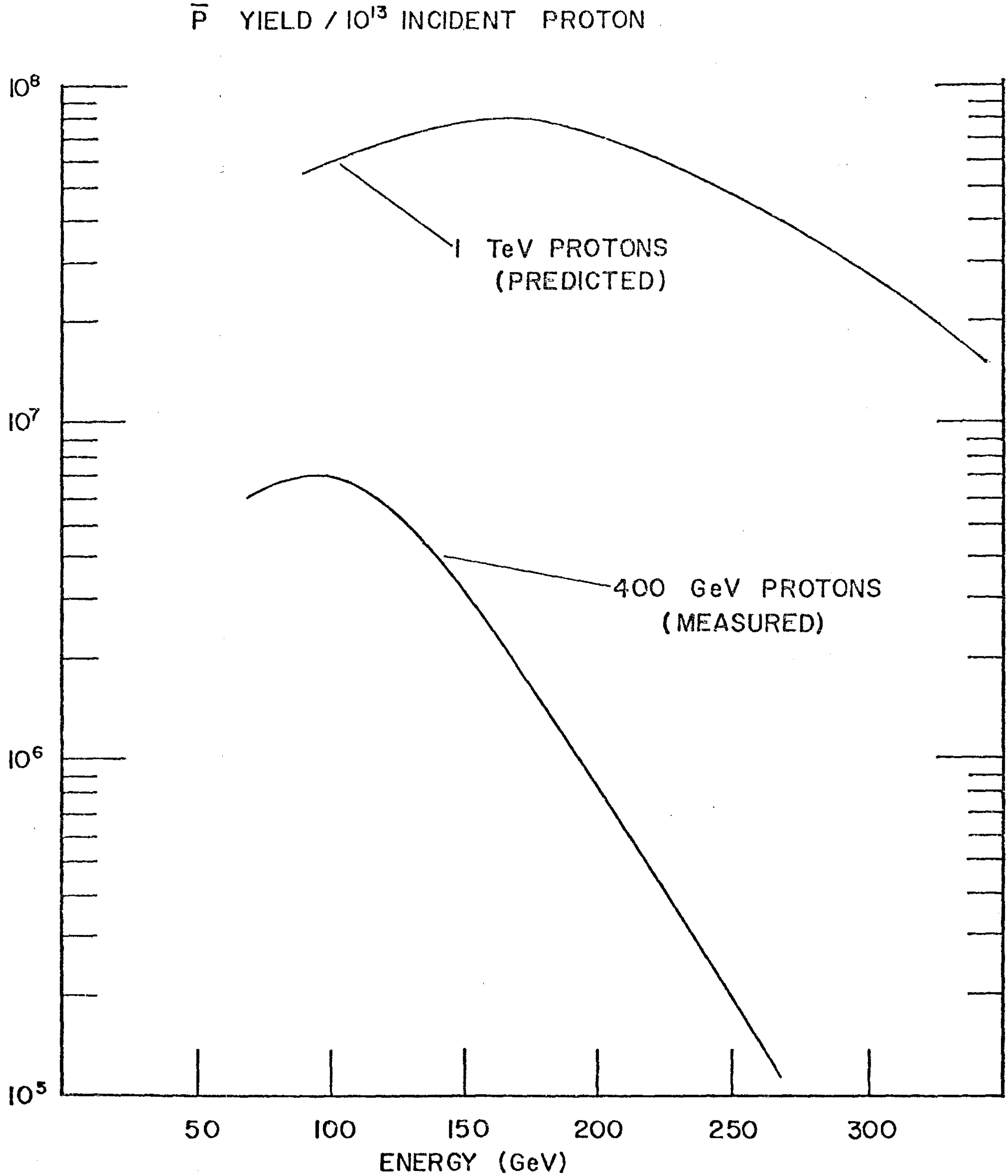
The measured yields of pions and antiprotons for the high-intensity beam of Proton West are shown in Fig. 5-10a and 5-10b, together with the predicted yields from targeting 1000-GeV protons. There is a gain of intensity of one to two orders of magnitude in the momentum region above 150 GeV/c.

The Proton East tagged-photon beam serves a large multi-particle spectrometer that is now being commissioned. The large increase predicted in the electron-beam intensity, particularly at high energies, is seen in Fig. 5-11, where fluxes are compared for 400-GeV and 1-TeV incident particles. The resulting photon flux is directly proportional to this electron flux. Hence, approximately three orders of magnitude greater photon flux will be available in the very important high-energy photon region. Experiments with 300-GeV electrons will be possible without improving the existing secondary-beam optics.

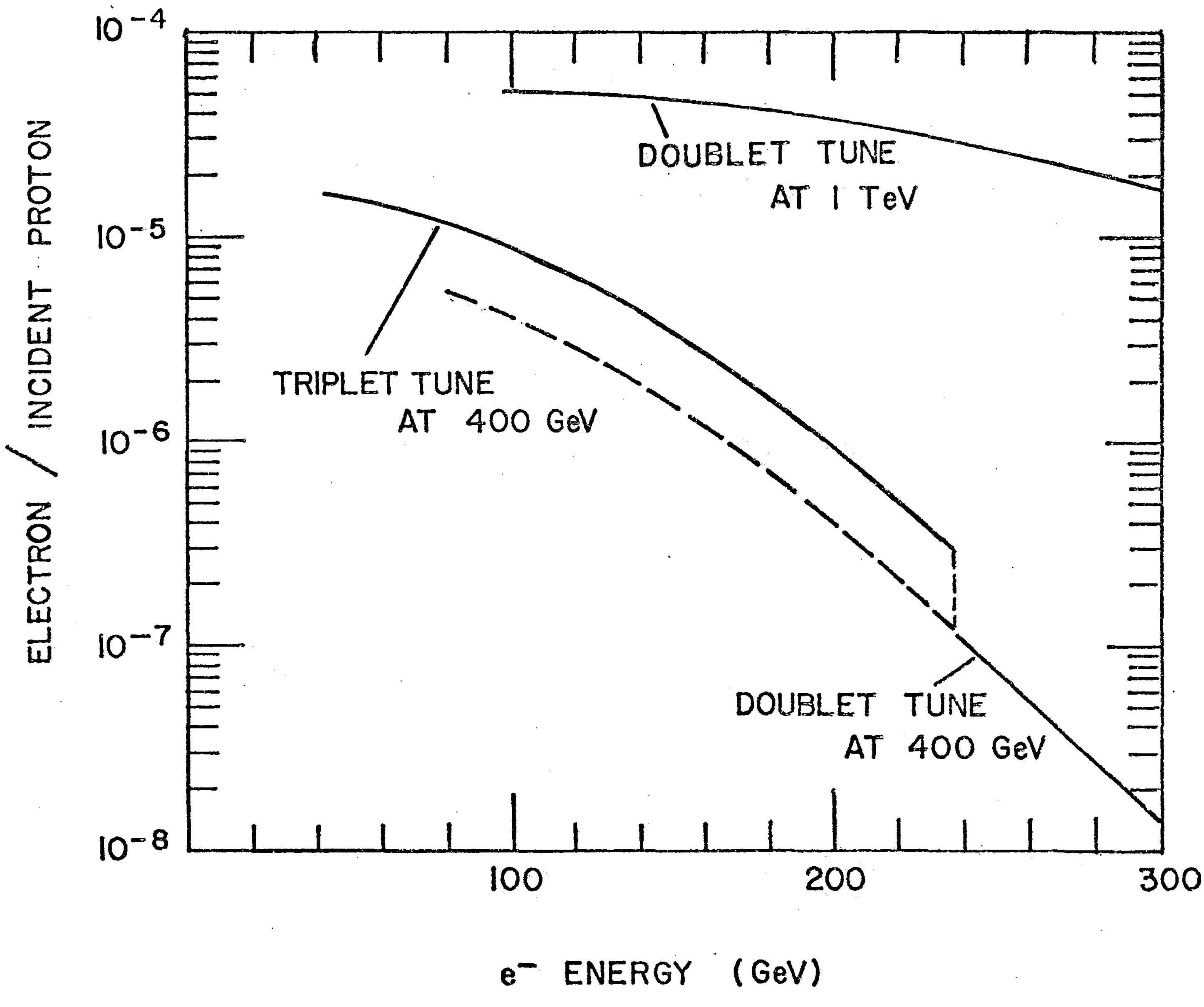
The hyperon beam in Proton Center fills a gap between the long(500-m) charged-particle beams of the Meson Laboratory and those detectors that see both the primary beam interaction point and the subsequent decay. Although primarily designed for studies of charged hyperons in the 100 to 350 GeV/c momentum range, it is a general-purpose beam for studying phenomena that occur approximately 10 m from the production target. It will be commissioned in the spring of 1980. It will have the highest intensity and purity strange-particle flux in the world ($10^7 \Sigma^-$/pulse, 80% purity). Fluxes expected are given in Fig. 5-12 for both positive and negative particles with 400-GeV protons. With 1-TeV protons on the target, we expect a greatly enhanced flux of antihyperons for momenta in the range 100 to 350 GeV/c. This enrichment of the antihyperon fluxes will allow detailed studies to be made of the properties of these little-studied particles. With the present set of



HIGH INTENSITY LAB
PION FLUX
FIGURE 5-10-A

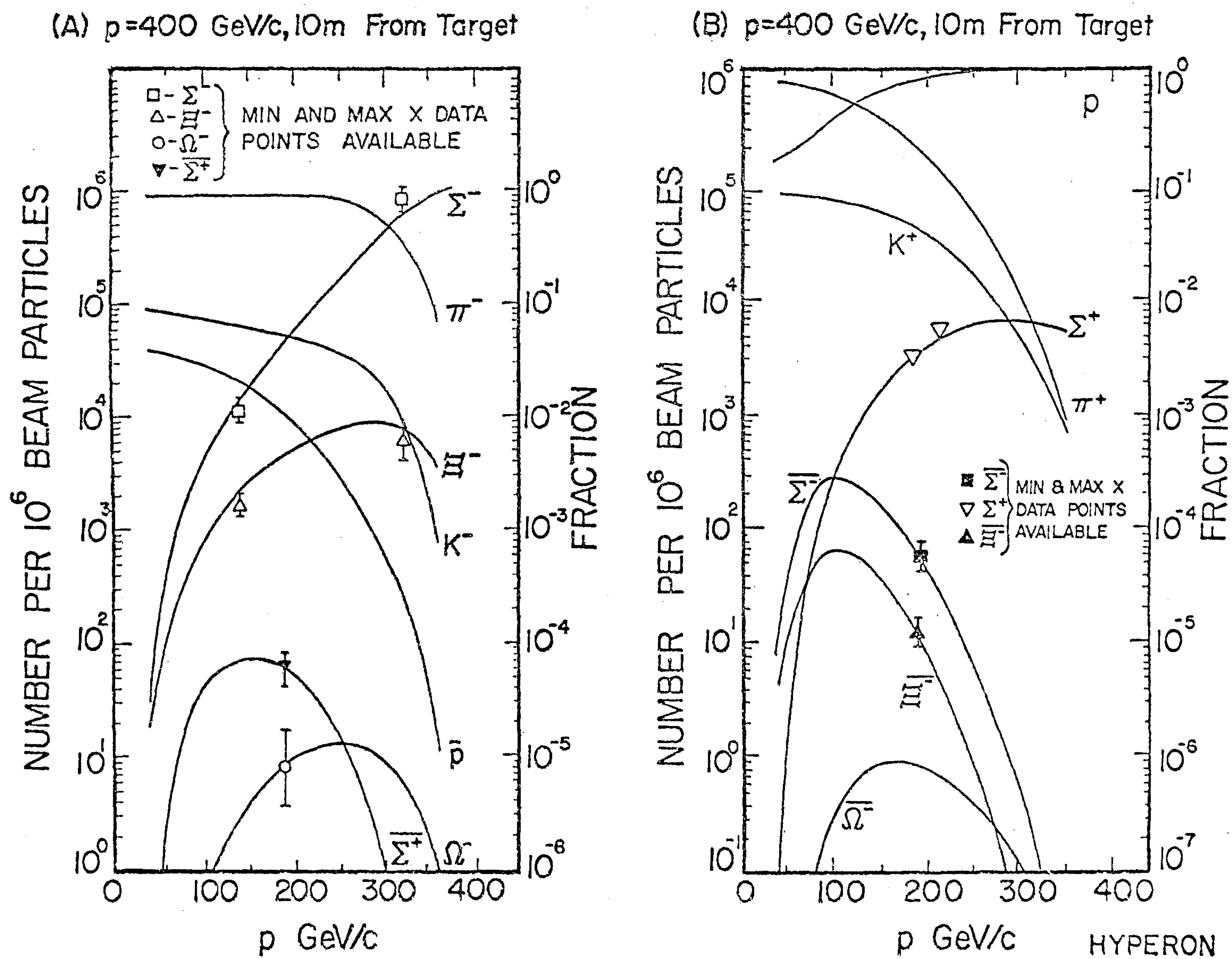


HIGH INTENSITY LAB
$\overline{P}$ FLUX
FIGURE 5-10-B



TAGGED PHOTON LAB
ELECTRON BEAM FLUX

FIGURE 5-11



Flux estimates for the Fermilab charged hyperon beam. The data points represent the range in x of measurements made with other charged hyperon beams. See Doroba, K. 1978. Fermilab TM-818 for details.

HYPERON BEAM FLUX

FIGURE 5-12

pre-target area quadrupoles, the spot size at the target is expected to grow in area by a factor of 100 at 1 TeV. Additional focusing may be needed by specific experiments, although a 1-TeV flux measurement will be possible without modifications.

Improvements for existing secondary beams, such as the high-intensity pion beam in P-West and the tagged-photon beam in P-East, will be accomplished using equipment funds. In P-West, it is expected that the pion beam will be improved to a 750-GeV capability using low-current superconducting magnets developed by the Proton Department. One prototype dipole has been installed and is operating.

No specific upgrade is presently planned for the tagged photon beam. The beam presently has 300 GeV capability, but it is operated at energies below 200 GeV because of particle-flux limitations. The Tevatron 2 project will allow this beam to realize its full potential at 300 GeV. It would be relatively straightforward to upgrade this beam to higher momenta at some future time by using superconducting elements if that should become desirable for the experimental program.

5.5 Broad-Band Beam Improvement

5.5.1 Present Beam. The Broad-Band beam, located in Proton East, is the most intense source of high-energy (>100 GeV) photons presently available at any accelerator. Experiments using incident photons and neutrons have been conducted there since 1974. For several reasons, this beam is now reaching the end of its usefulness and should be replaced by a different kind of beam. These reasons are:

(i) It is not possible to use the Broad-Band Beam and the Electron Beam simultaneously. In fact, access to the Broad-Band detector building is prohibited because of radiation from Electron-Beam elements in the detector building while the Electron Beam is running. This has resulted in very inefficient use of beam time in Proton East and discourages the installation of a major new detector in the existing enclosure.

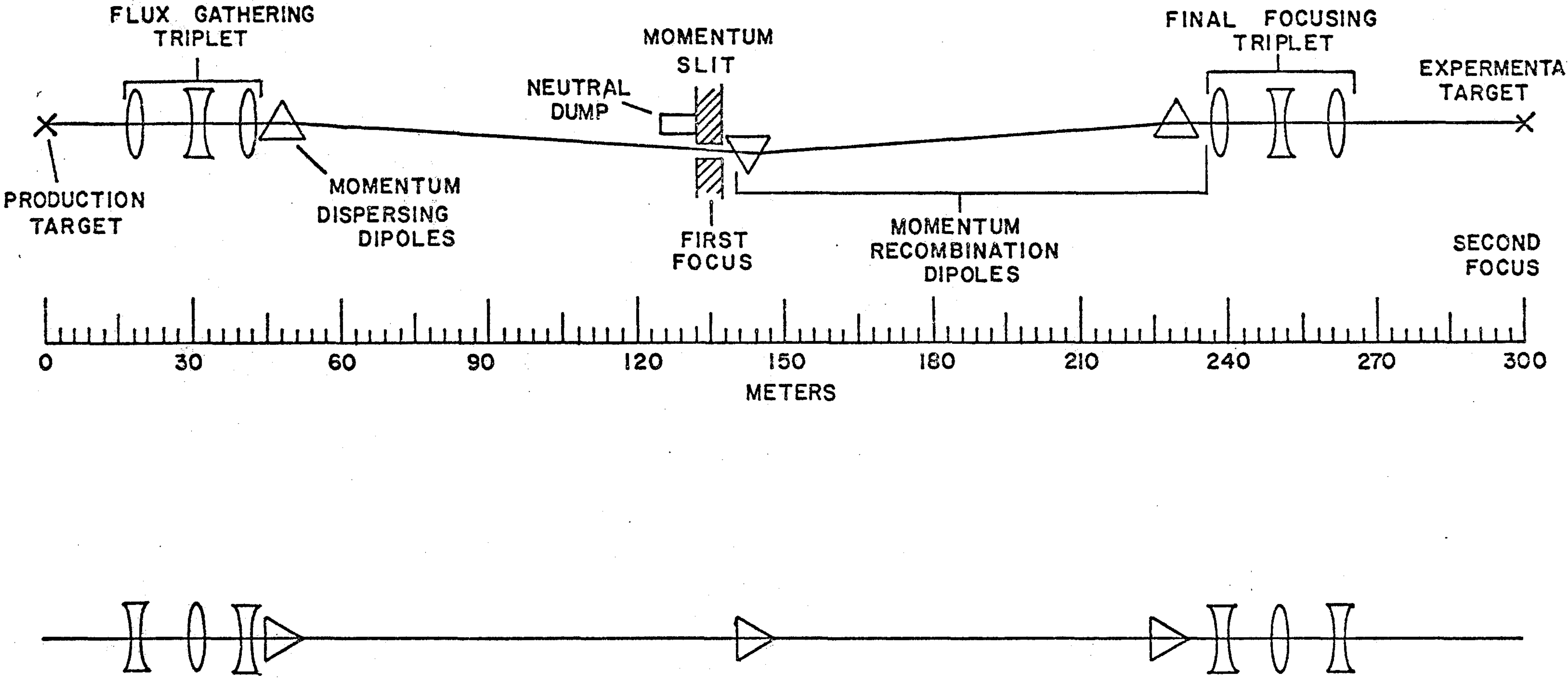
(ii) Muon rates in the detector building are unpleasantly large.

(iii) The Broad-Band Beam and the Electron Beam share the same target box. This necessitates frequent changeovers involving relocation of pre-target beam elements resulting in unnecessary radiation exposures, operating costs, and loss of beam time.

(iv) The beam contains a significant background of neutral hadrons (neutrons and K°_{L}'s).

<u>5.5.2 Design Solution</u>. The solution chosen for these problems has four parts:

(i) The existing Broad-Band Beam will be replaced by a new high-energy, high-intensity electron beam.[12] The new beam will have very large momentum acceptance, $\pm15\%$, and a large solid angle of four microsteradians. It will be able to transport electrons up to 800 GeV. These will be converted to photons in a radiator. The beam will be operated purely as a bremsstrahlung beam with no tagging of the photon energy. In this manner, high fluxes of photons up to 500 GeV can be obtained. We estimate that the hadron background will be reduced by at least a factor of 10 from that of the existing Broad-Band Beam. We also intend to maintain the capability of having a high-energy neutral beam. This is



BROAD BAND BEAM
OPTICS DIAGRAM
1 TeV

FIGURE 5-13

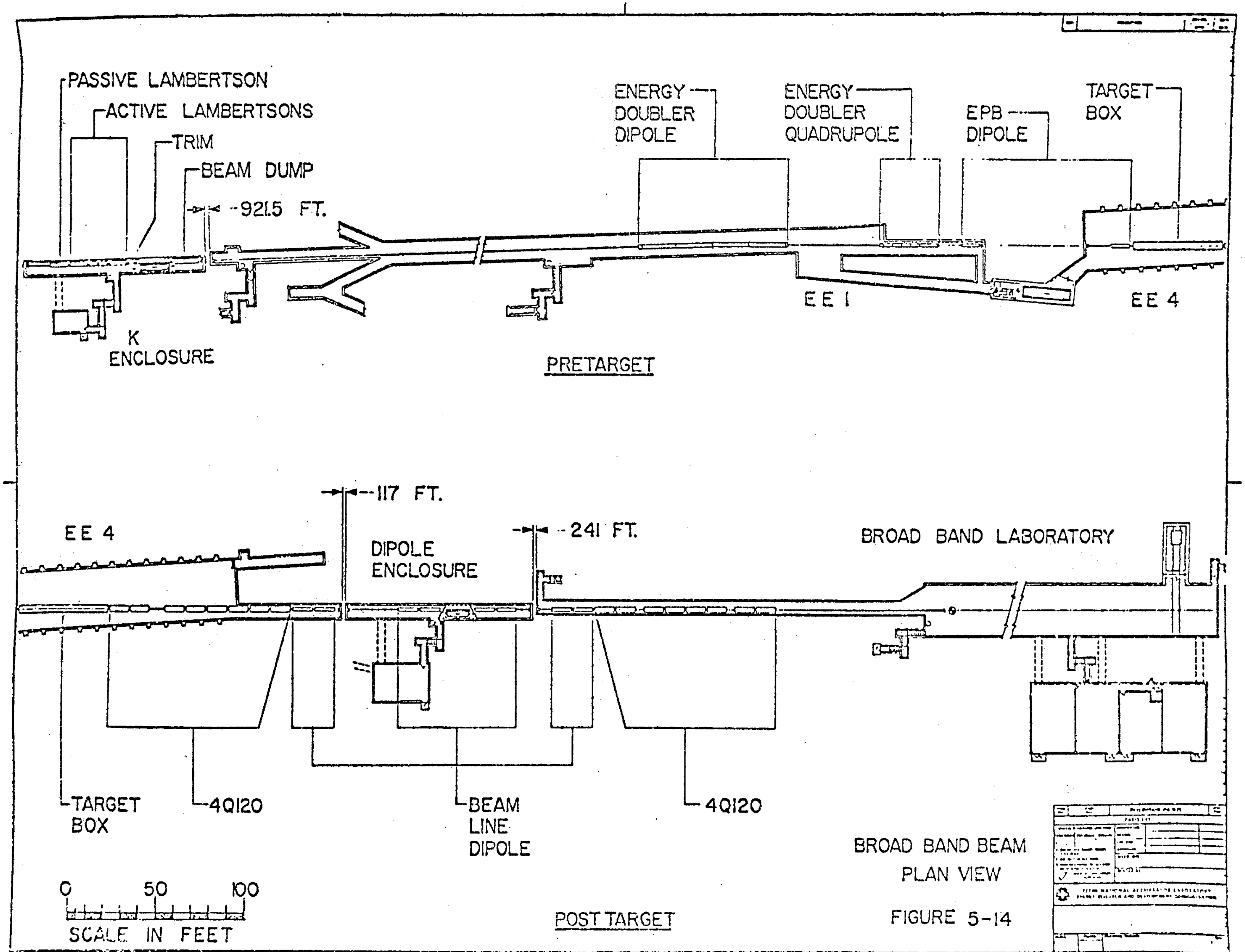
accomplished by having zero net deflection from the direction of the incident proton beam.

(ii) A splitting station will be installed in Proton East so that two beams can be targeted simultaneously.

(iii) A new detector enclosure will be constructed for the new beam a few hundred feet farther from the target point than the present detector building. This will provide space for additional muon shielding.

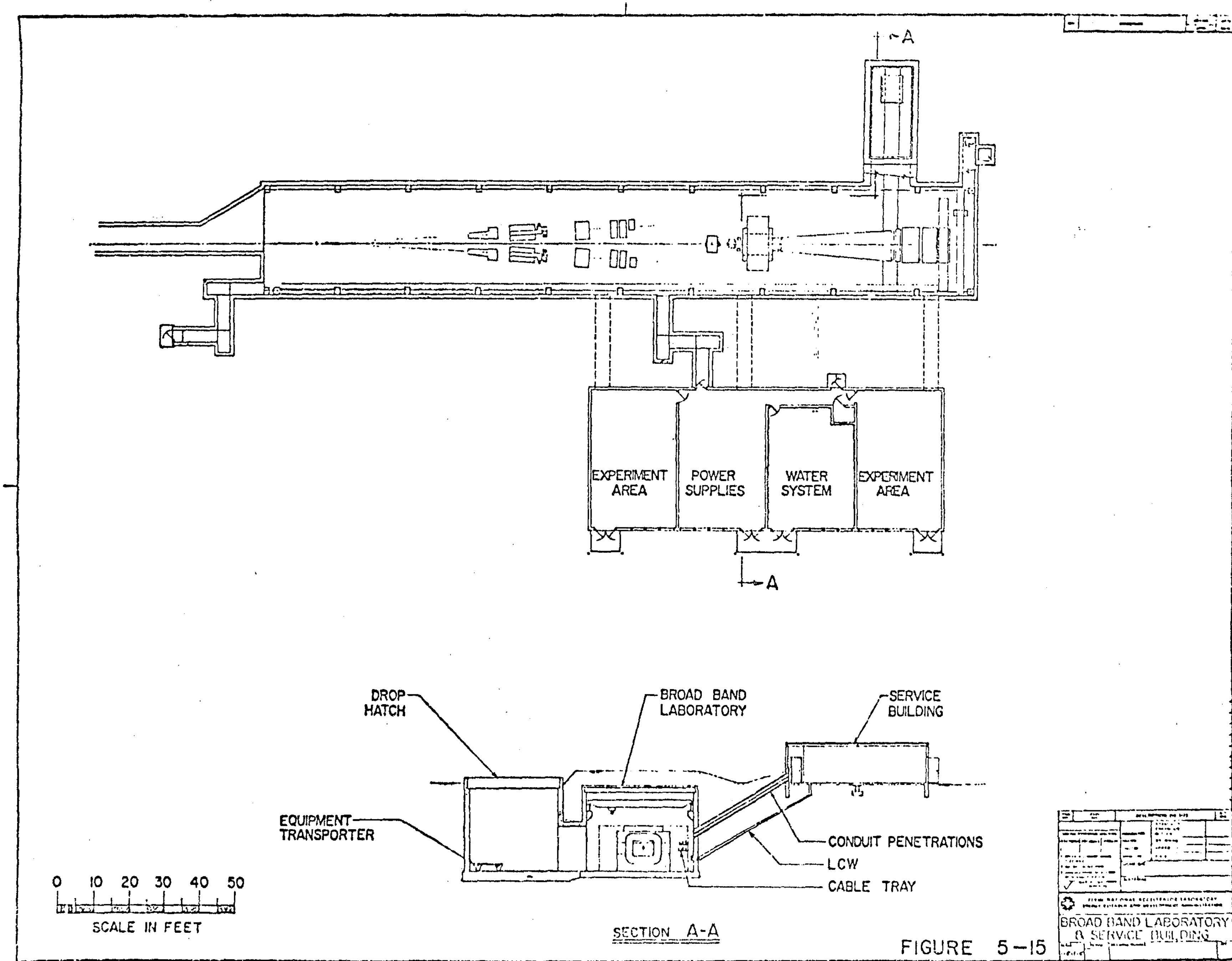
(iv) The new beam will be targeted in a location far downstream of the present target box, which will continue as the origin of the Tagged Photon Laboratory Electron Beam.

5.5.3 Beam Design. A design for the new beam is shown in Fig. 5-13. A layout of the new beam and its target box and detector building is given in Fig. 5-14 and 5-15. Figure 5-16 shows electron yields expected for this beam for 1-TeV protons on target. The primary proton beam is transported through the present target box and is bent 30 mrad. to the east by four Energy Saver dipoles. A system of Energy Saver quadrupoles located in EE1 focuses the proton on a production target at the upstream end of EE4, the present Broad-Band Beam experimental detector enclosure. The target box is followed immediately by a flux-gathering quadrupole lens and dipoles that disperse the beam in momentum. A small enclosure (dipole enclosure) contains a dump for neutral particles, a momentum collimator, and additional dipoles that begin to recombine the beam. The final stage completes the recombination of the beam and produces a final focus at the experimental target. The radiator and appropriate sweeping magnets are located in this area. Finally, there is a new experimental hall capable of supporting two experiments.



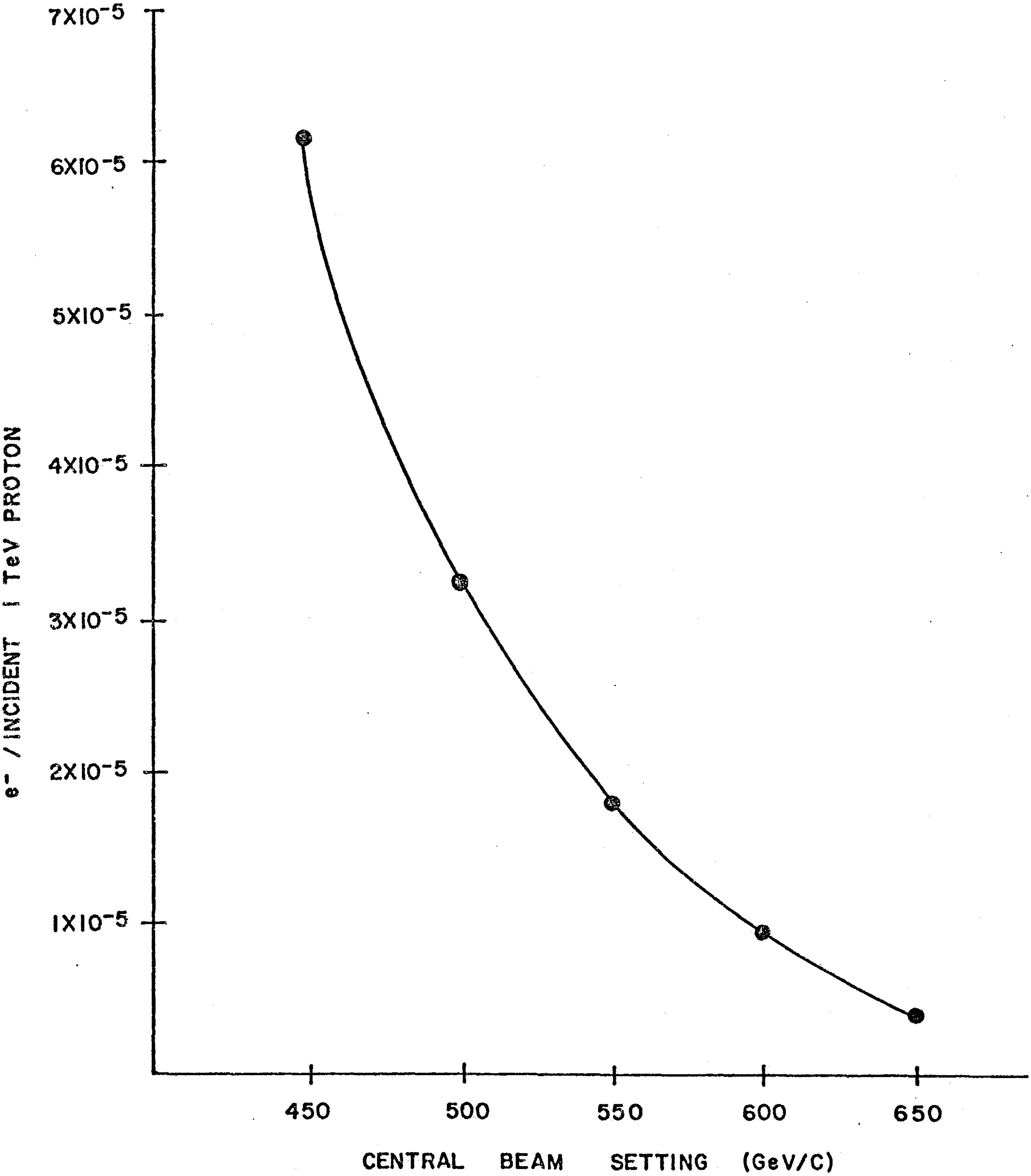
BROAD BAND BEAM
PLAN VIEW

FIGURE 5-14



A
EXPERIMENT AREA
POWER SUPPLIES
WATER SYSTEM
EXPERIMENT AREA
A
DROP HATCH
BROAD BAND LABORATORY
SERVICE BUILDING
EQUIPMENT TRANSPORTER
CONDUIT PENETRATIONS
LCW
CABLE TRAY
0 10 20 30 40 50
SCALE IN FEET
SECTION A-A
BROAD BAND LABORATORY & SERVICE BUILDING

FIGURE 5-15



BROAD BAND BEAM
ELECTRON FLUX

FIGURE 5-16

Because the net deflection of the dipoles in the beam is zero, it is possible to make a neutral beam by removing the neutral beam dump in the dipole enclosure. The target-box magnet will be energized sufficiently to dump all charged particles produced at the primary target inside the shielded target box. The beam-line magnets will then serve as downstream sweeping elements. Another attractive feature of this mode for the beam is that with the target-box magnet off, a primary proton beam (1-TeV protons) could be made available in the experimental hall for experiments.

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6. MESON AREA

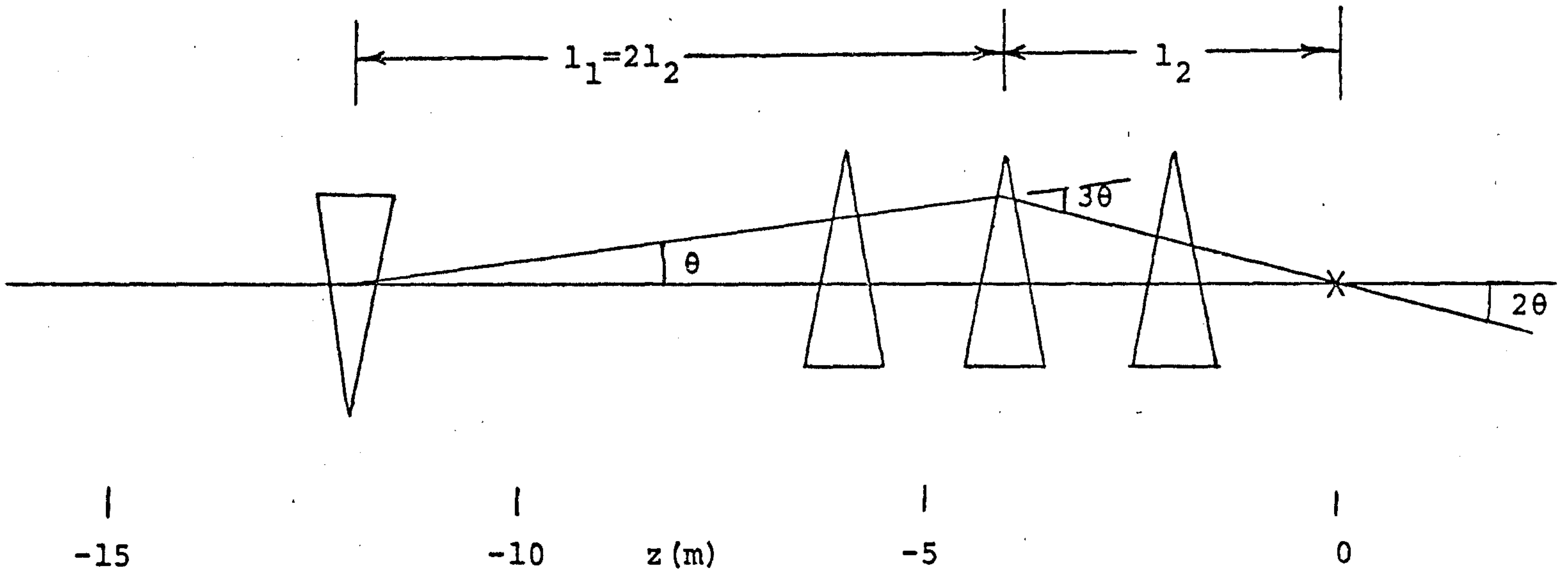
6.1 Introduction

The Meson Area has long been the workhorse of Fermilab for hadron experiments. The great strong point of the Meson area is the flexibility provided by the above-ground location of the detector building and the large number of beams provided. It was originally designed as a 200-GeV area with one primary beam, but has been improved to 400-GeV proton energy and, more recently, to two primary beams, M-West and M-Center. This flexibility will be further exploited in the increase to 1 TeV.[1] These two beams are split by an electrostatic septum in the F1 manhole. The M-West and M-Center primary beams both have flexible steering systems to permit changing the incident angle on the target through a range of 3 mrad. A schematic layout of one of these systems is shown in Fig. 6-1. In addition, the M-Center beam can be switched to M-East to supply primary beam through the M1 tunnel system to the Detector Building.

There are single targets in the M-West and M-Center systems. Downstream of each target is a series of water-cooled collimators that dump the non-interacting primary beam and partially define the secondary-beam apertures (Figs. 6-2 and 6-3). The present beam lines are[2]:

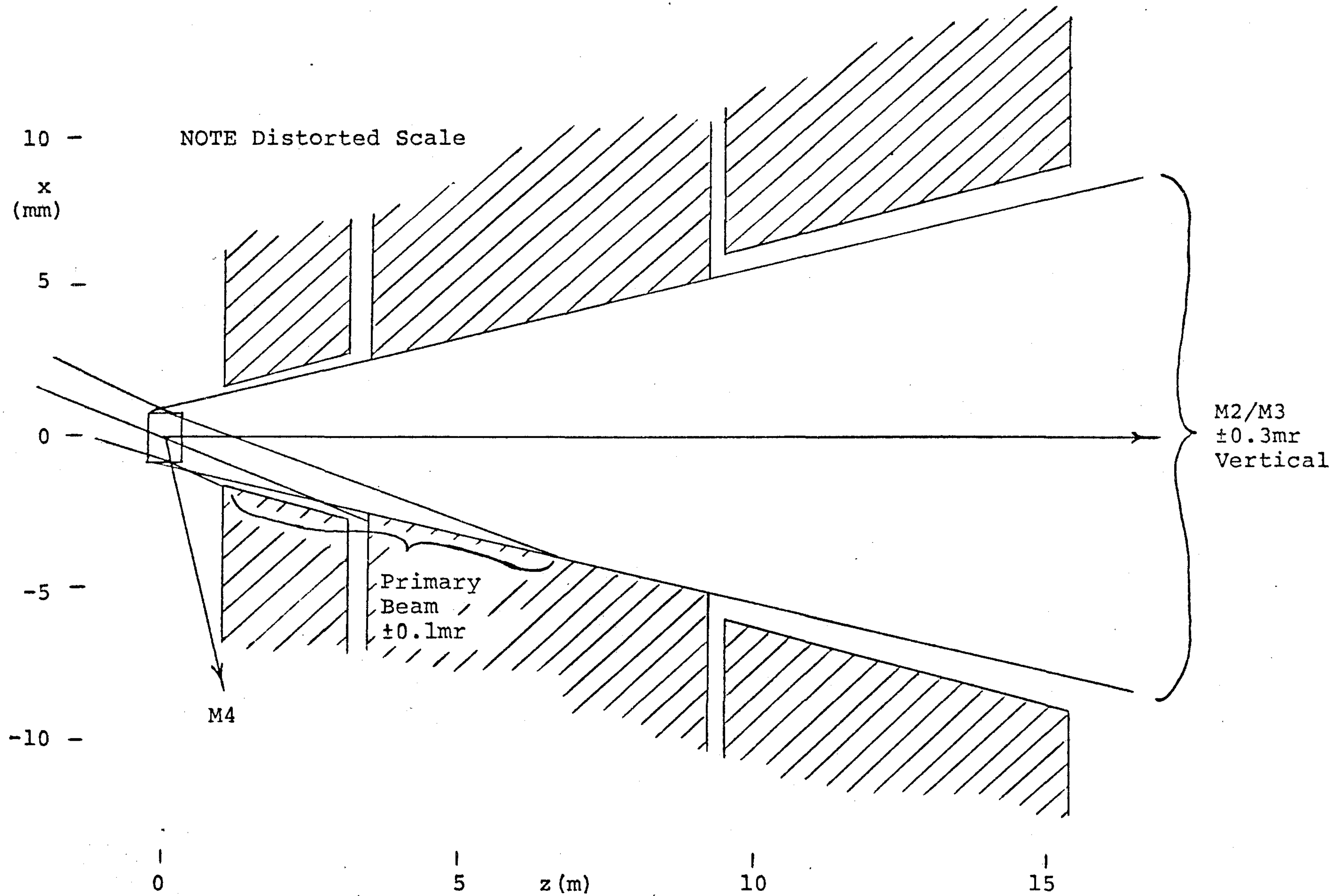
(i) <u>M1</u>. This line is currently a medium intensity hadron beam using the M Center target. Plans for its future are discussed below.

(ii) <u>M2 and M3</u>. M2 and M3 are the other principal beam lines using the M-Center target. M2 is normally run as a diffracted-proton beam in the intensity range from 10^8 to 10^{10} protons per pulse, although recently it was run as a primary proton beam at approximately 10^{12} protons per pulse. M3 is a neutral hadron beam with an acceptance of approximately 0.6



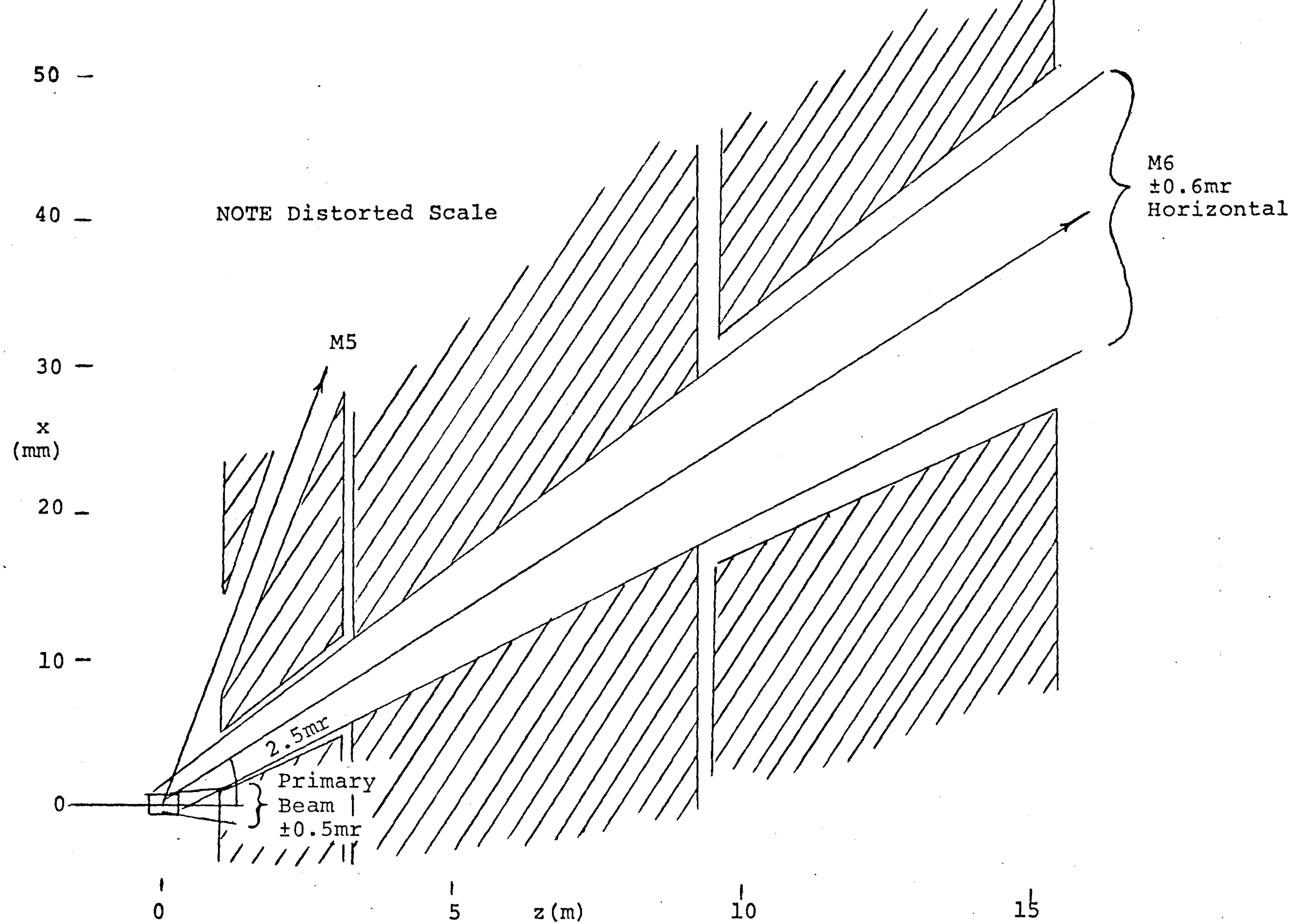
Invariant Angle Varying Bend (AVB) System

FIGURE 6-1



M Center (M2/M3) Primary Beam Dump/Collimators

FIGURE 6-2



M West (M6) Primary Beam Dump/Collimators

FIGURE 6-3

ster. This beam produces large fluxes of gammas, neutrons and K_L mesons.

For the first 64 m, these two beam lines share the same line. At this point, 9 m of dipole magnets bend M2 (and all charged hadrons) away from M3. M3 then proceeds through additional sweepers and variable collimators to the experimental area 425 m from the production target. M2 is a conventional two-stage beam with simple doublet focusing and a total of 50 mrad of bend. The smallest production angle possible in M2 is 0.5 mrad.

(iii) M6. M6 is the principal beam using the M-West target. It is the last fully tagged hadron beam at Fermilab. Hadrons can be tagged as to position, angle, momentum and species. Currently this beam has two branches, M6 East and M6 West, with maximum energy of 200 and 400 GeV respectively. M6 West transports beam to the Multiparticle Spectrometer (MPS) a large, intensively instrumented detector facility. The M6 beam is a three-stage beam providing a parallel section for particle-species tagging with a DISC differential Cerenkov counter. Additional threshold Cerenkov counters are provided for further enhancement of particle identification. At the higher energies, it is also possible to employ transition radiator detectors to the same end. The smallest production angle possible in M6 is 1 mrad.

(iv) Test Beams M4 and M5. M4 and M5 are the wide-angle beams using the M-Center and M-West targets respectively. M4 is a charged beam that was converted from a neutral beam several years ago. It therefore has an extremely broad momentum acceptance. It is also the only Meson Area beam that is underground, sloping 8 mrad downward under the M3 small-angle neutral beam. It has been used extensively in the past as a source of moderate-flux kaon beams.. Because of its underground location, access is limited. Long-range plans call for improving its accessibility as funds become available.

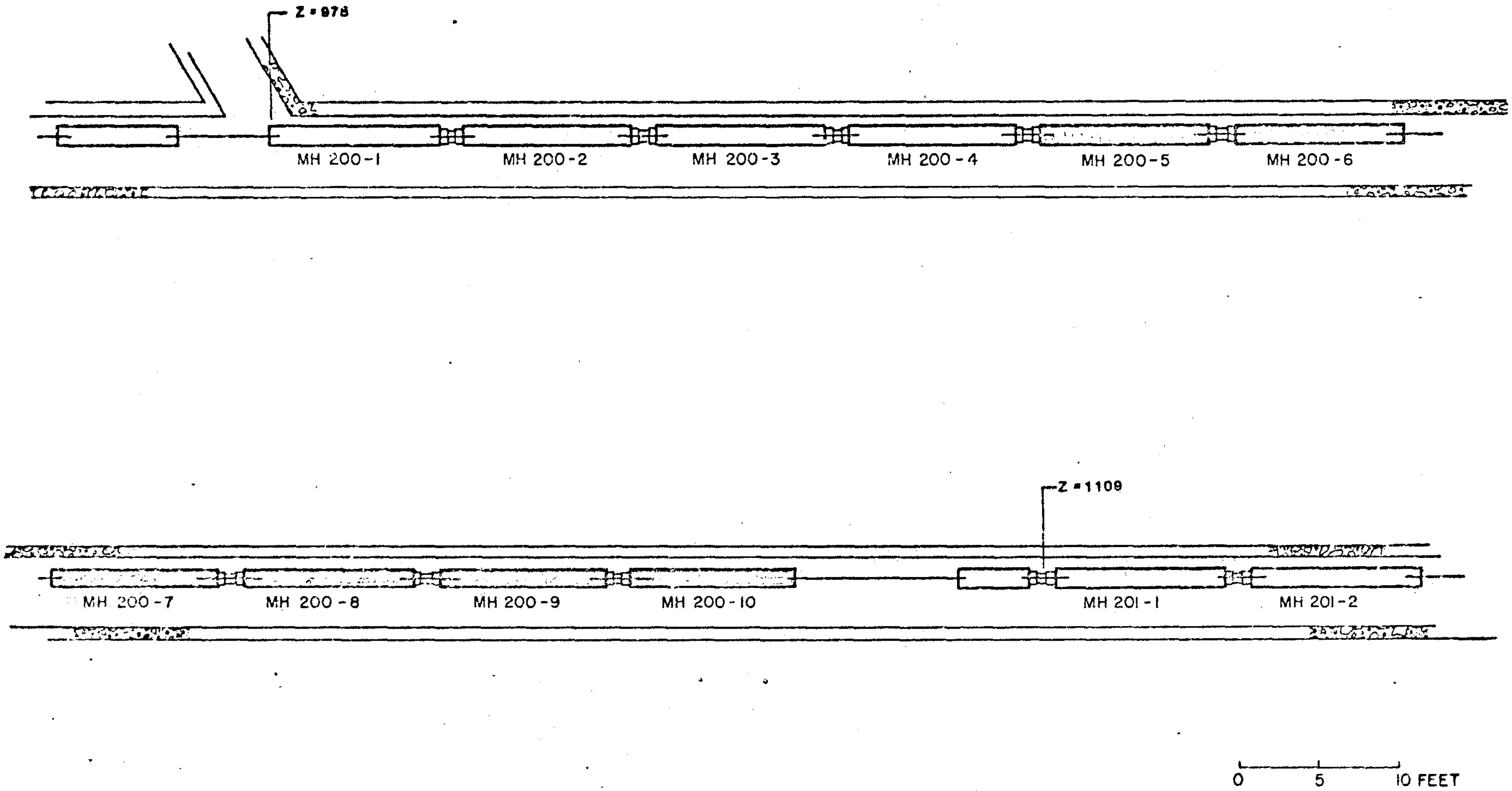
M5 is the heavily used 50-GeV test beam. It supplies moderate-flux hadron and electron beams to a test area under the Detector Building Crane. With the facilities in this area, including computers and beam-line counters, this area is the only area at Fermilab specifically designed to test apparatus in a convenient, quick manner. It is also one of the most heavily used beams at Fermilab.

The flexibility of the Meson area is exemplified by the fact that both M1 and M2 are, or will be shortly, primary proton beams. The necessary hadron shielding is provided by large piles of removable steel and concrete shielding. The muon shielding needed for the above-ground location is supplied by the large magnetized target dump magnets included in the present experiments.

6.2 Switchyard Improvement to 1 TeV

Prior to Tevatron Phase 2, the primary beams to the Meson Area will have had much of the 1-TeV improvement completed. In particular, the 56 external proton beam (EPB) dipoles in the left bend will have been replaced by 21 Energy Saver dipoles. In addition, a second split of the M Center beam (M-East) will be supplying primary beam through the M1 tunnels to E-605 in the Detector Building.

The improvement of the superconducting left bends to 1 TeV is straightforward[3]. The Neutrino-Meson electrostatic septa in Enclosure B are shown on the Proton drawing, Fig. 5-4. Enclosure C elements are shown in Figs. 6-4 a-e. On both figures the additional elements added for 1-TeV operation are shaded. The electrostatic septa that start the split must be



MESON SPLIT
SUPERCONDUCTING LEFT BEND

FIGURE 6-4a

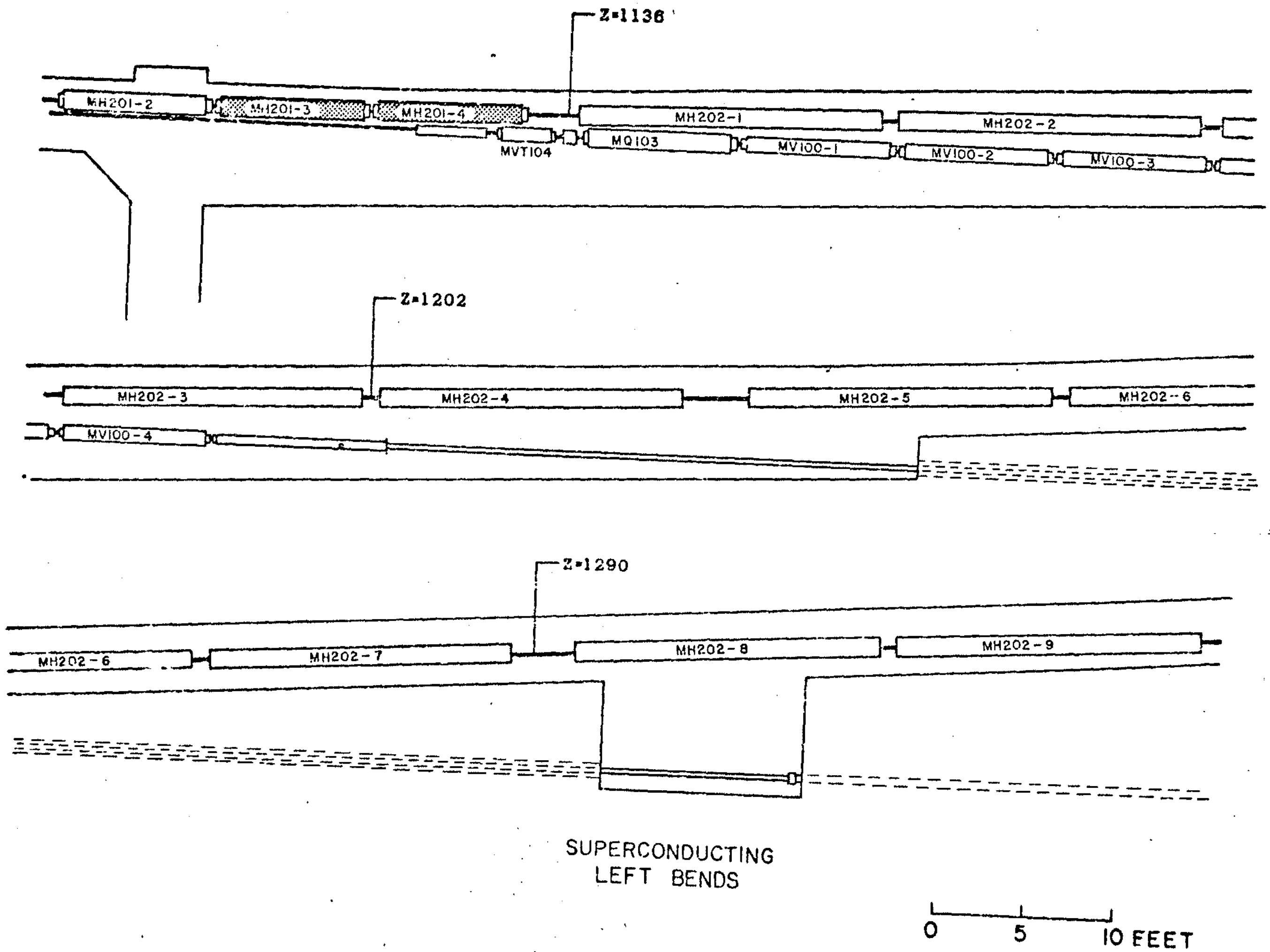
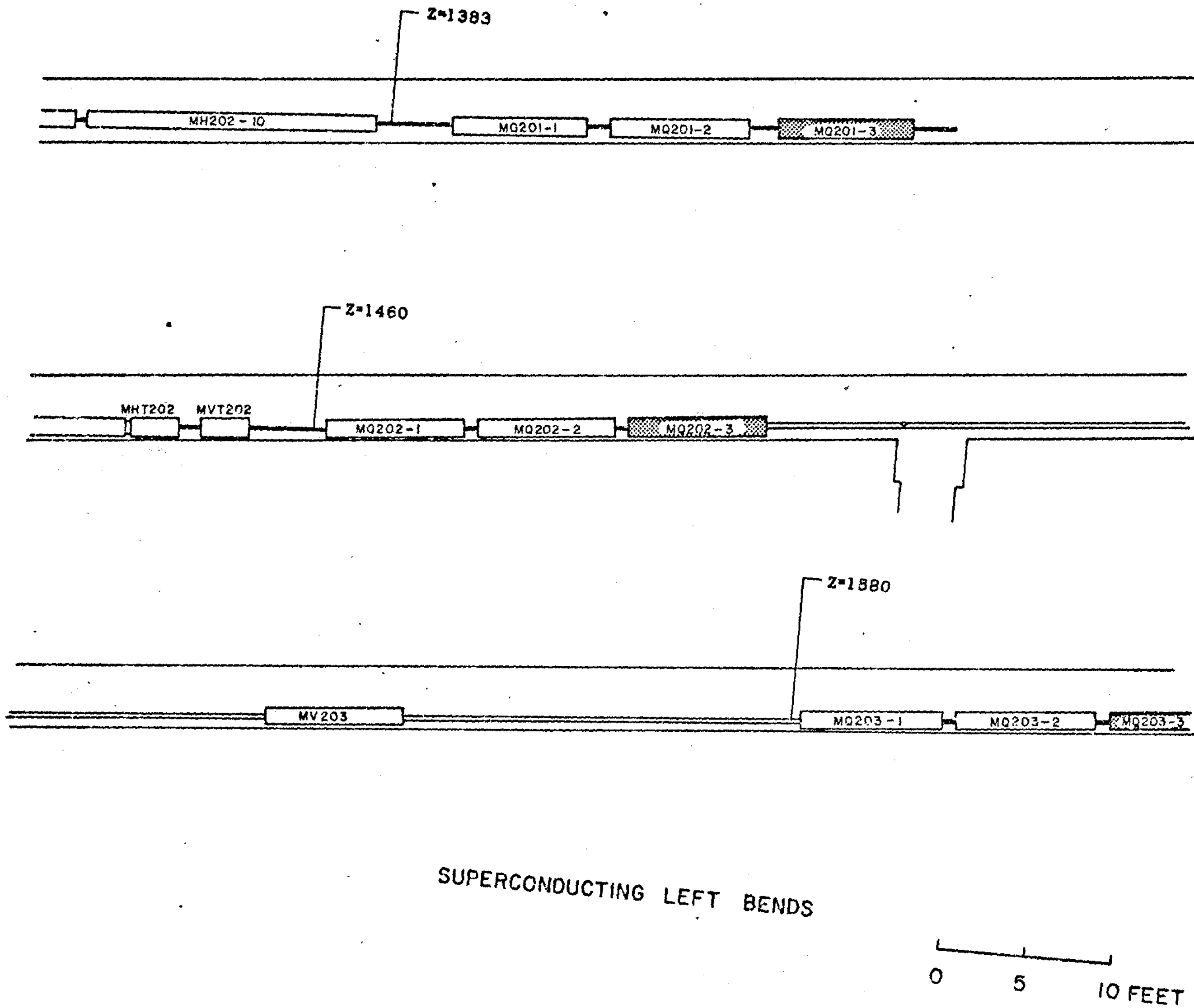
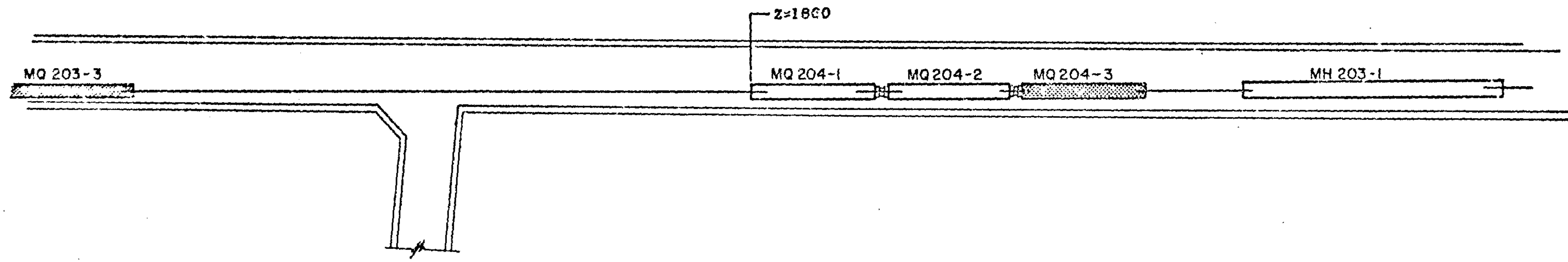

Z=1136
MH201-2
MH201-3
MH201-4
MH202-1
MH202-2
MVT104
MQ103
MV100-1
MV100-2
MV100-3
Z=1202
MH202-3
MH202-4
MH202-5
MH202-6
MV100-4
Z=1290
MH202-6
MH202-7
MH202-8
MH202-9
SUPERCONDUCTING
LEFT BENDS
0
5
10 FEET

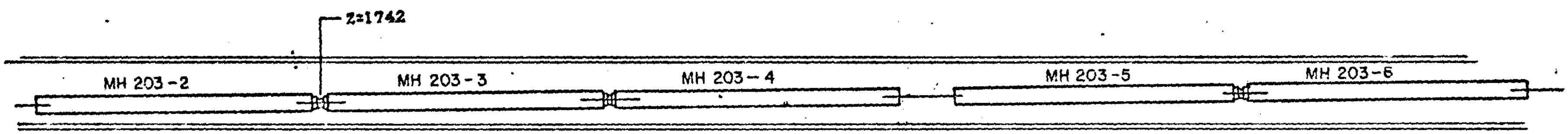
FIGURE 6-4b



SUPERCONDUCTING LEFT BENDS

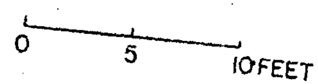
FIGURE 6-4c

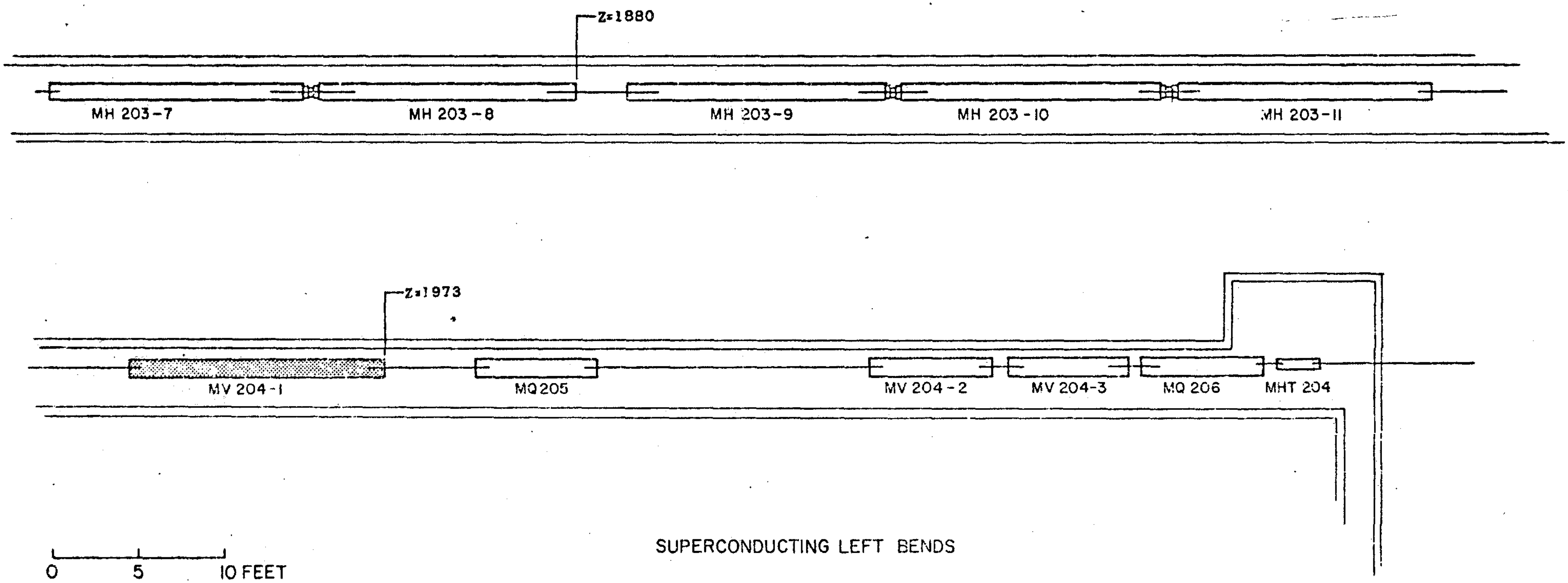




SUPERCONDUCTING
LEFT BENDS

FIGURE 6-4d





SUPERCONDUCTING LEFT BENDS

FIGURE 6-4e

augmented by three additional septa to increase the splitting power. The existing five Lambertson magnets that start the horizontal separation of the beams will become six Lambertsons plus six C magnets. The 21 Energy Saver dipoles that perform the major portion of the 165-mrad left bend will be unchanged, but the focusing quadrupoles must be augmented by four additional magnets. The vertical bends at the downstream end of Enclosure C will be modified to increase the available bend power. Two of the EPB dipoles will be replaced by an Energy Saver dipole that will be run in series with the left-bend dipoles. The other two EPB dipoles will be moved to maintain the same bend center.

The improvement of the three F Manholes, which contain the initial splitting components, is straightforward. These enclosures are shown in Fig. 6-5, with the new elements shaded. In F1 the number of quadrupoles and electrostatic septa will be doubled to four and two, respectively. In order to make room for these the manhole will be extended downstream by 30 ft. In F2 only a single additional electrostatic septum is needed. In F3 it is only necessary to double the number of Lambertson septa to a total of four.

The improvement of Meshall[4] is more complicated because there are three beam lines to consider, and two of the three must be focused onto targets within 70 m. Figure 6-6 shows Meshall in its 400-GeV/c, 3-way split configuration, while Fig. 6-7 shows the planned configuration at 1 TeV. This upgrade requires the construction of a Target Service Gallery over the present target box and the removal of the top of the target box. This Target Service Gallery is discussed in detail in Sec. 6.5.2 below. As one can see by comparing Fig. 6-6 and 6-7, the improvement of M-West is straightforward. The four EPB dipoles forming the western vertical bend are replaced by two Energy Saver dipoles and the normal quadrupoles are replaced one for one by Energy

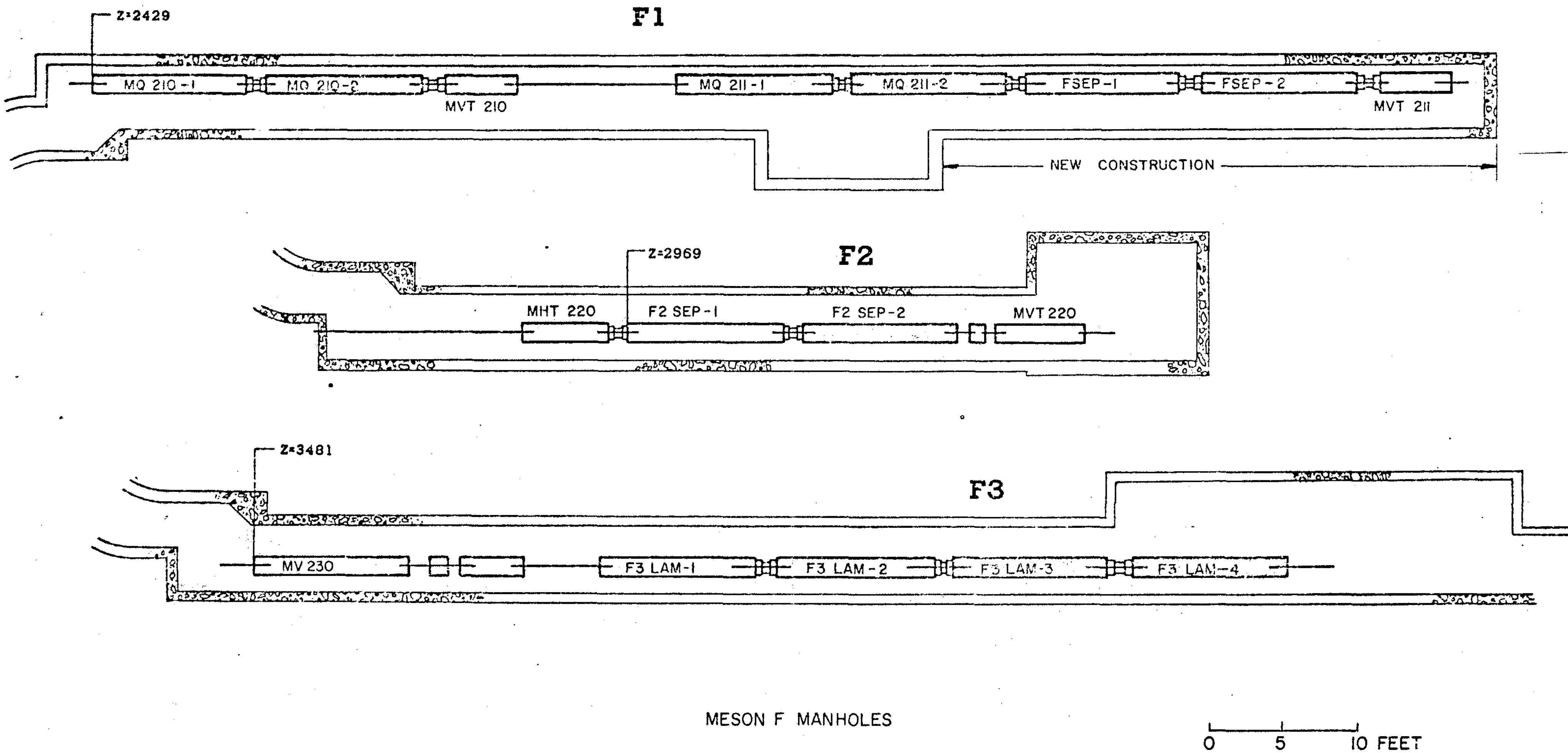
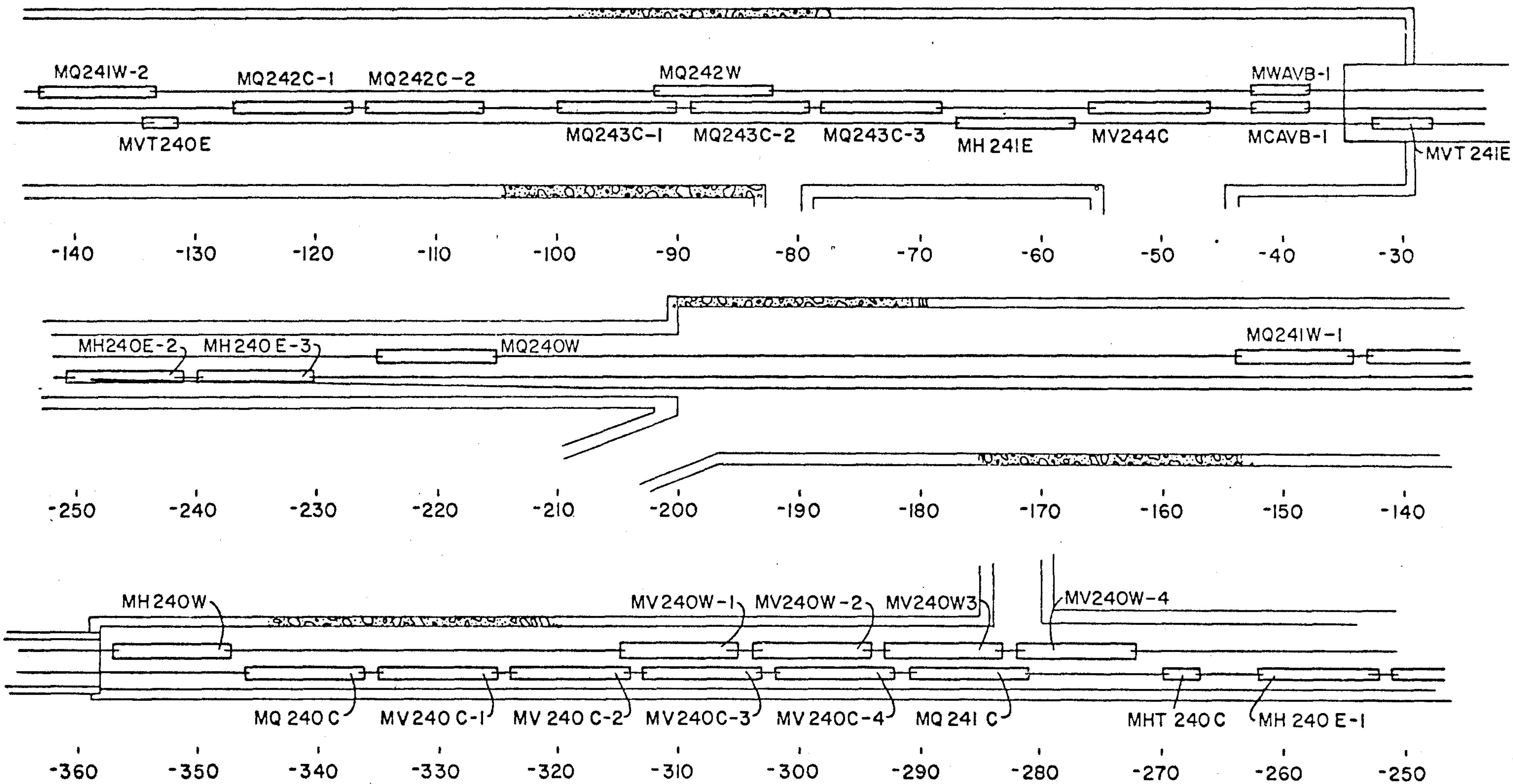
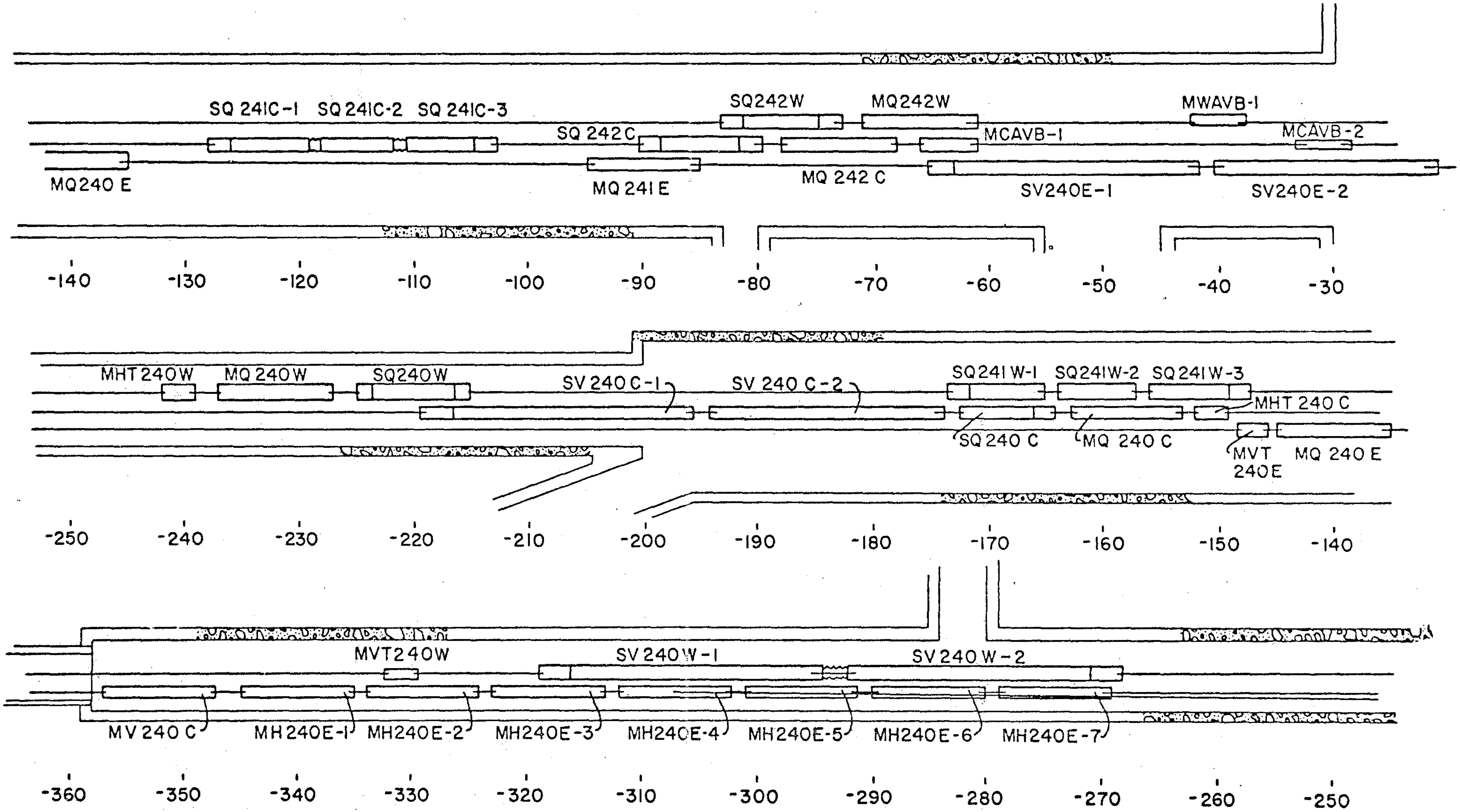

Z=2429
F1
MQ 210-1
MQ 210-2
MVT 210
MQ 211-1
MQ 211-2
FSEP-1
FSEP-2
MVT 211
NEW CONSTRUCTION
Z=2969
F2
MHT 220
F2 SEP-1
F2 SEP-2
MVT 220
Z=3481
F3
MV 230
F3 LAM-1
F3 LAM-2
F3 LAM-3
F3 LAM-4
MESON F MANHOLES
0
5
10 FEET

FIGURE 6-5



400 GeV 3 WAY SPLIT

FIGURE 6-6



1 TeV 3 WAY SPLIT /W TARGET SERVICE GALLERY

FIGURE 6-7

Saver quadrupoles plus two normal trim quads. To save refrigerator capacity, the quadrupoles are run in series with the dipoles. Neither the dipoles nor the quadrupoles are running at full current because the required bend is only 5 mrad per Energy Saver dipole. Running all the magnets in series increases the number of quadrupoles needed, but greatly reduces the refrigeration required by eliminating at least one power-lead box.

In the M Center-M East lines, the Lambertson septa are augmented by four magnets and the order of the Lambertson split and the vertical bends is reversed. This reversal allows the use of two superconducting vertical bends instead of a single high-power normal bend. It also creates more room for quadrupoles in the M-Center branch, which allows the use of Energy Saver quadrupoles plus trim quadrupoles in series with the dipoles. Without the reversal, the center-branch quads must all be Energy Saver in two strings with added cooling requirements. The reversal also means that the 2-ft increase in final elevation of the East Branch can be obtained by placing its vertical bend downstream of the Central Branch bend, rather than having to put in an additional vertical dogleg.

In the Target Service Gallery, the M-West and M-Center beams will strike targets near the present targets. Both these beams will have flexible steering and completely new dump systems. M-East passes through this area at the new target elevation. In the Front End Hall, it is bent an additional 40 mrad into the existing M1 tunnels. There are two versions of the focusing structure in this portion of the beam. Initially only a weak doublet structure will be needed to transmit the primary beam to the downstream portion of the beam line. Ultimately, as the experimental requirements dictate, stronger focusing will be required to focus the beam onto a target in the M1 target hall.

This improvement of the Switchyard and targeting is straightforward. It makes heavy use of superconducting technology to minimize power use where possible. Two additions are needed to accomplish the improvement, a minor 30-ft extension of the F3 manhole and the new Meson Target Service Gallery. The required satellite refrigerator[5] will be housed in an extension to the M1 Service Building being built for the 400-GeV three-way split.

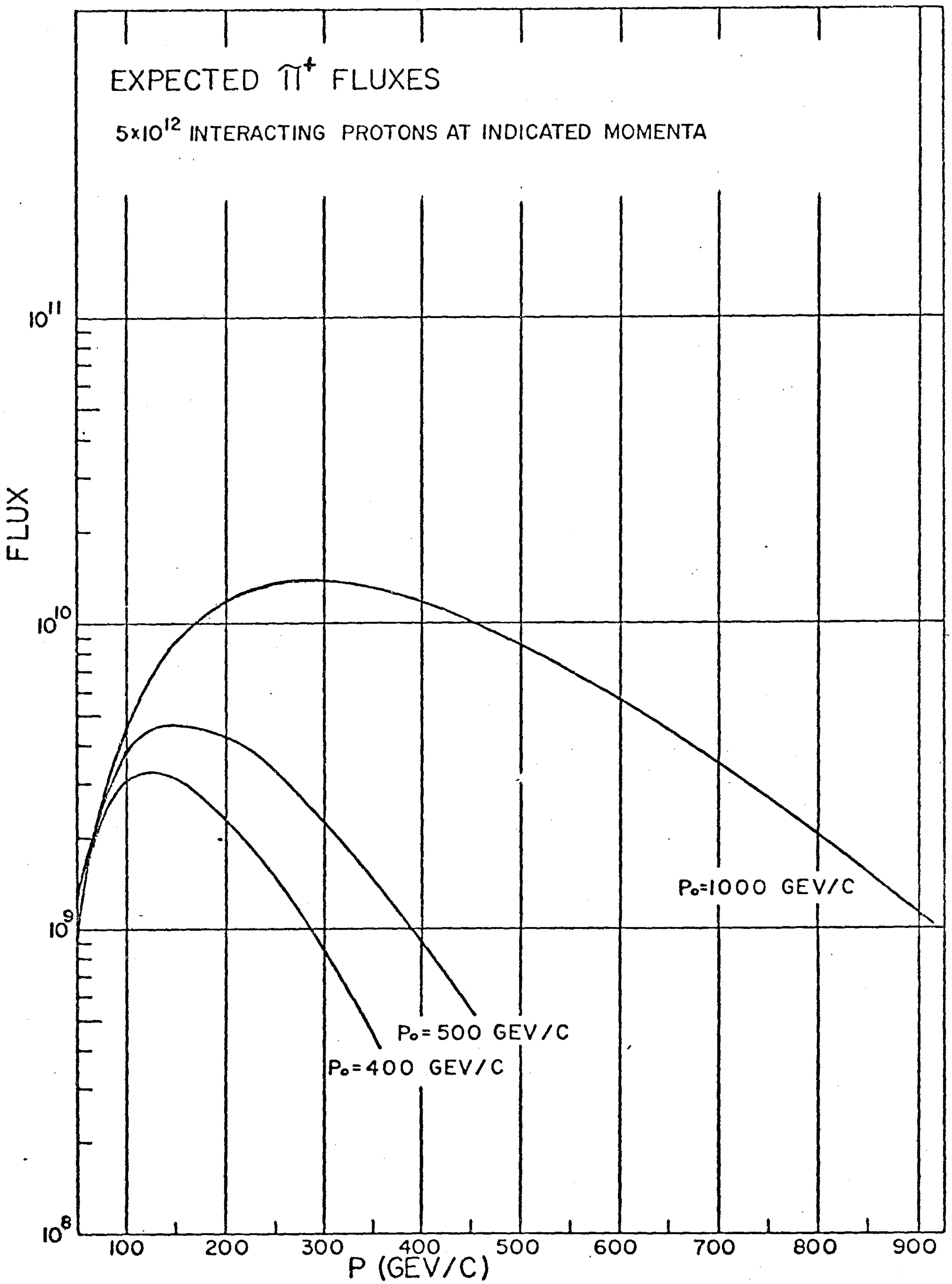
6.3 Meson-Area Beams At 1 TeV

The general plans for Tevatron Phase 2 improvements in the Meson Area include a major renovation of Meshall for 1 TeV, reconstruction of targets and dumps, renovation and expansion of the spectrometer facilities in M6, and construction of a polarized-proton beam.

Table 6-1 gives a summary of the properties of the beams in the Meson Area at the completion of Tevatron 2.

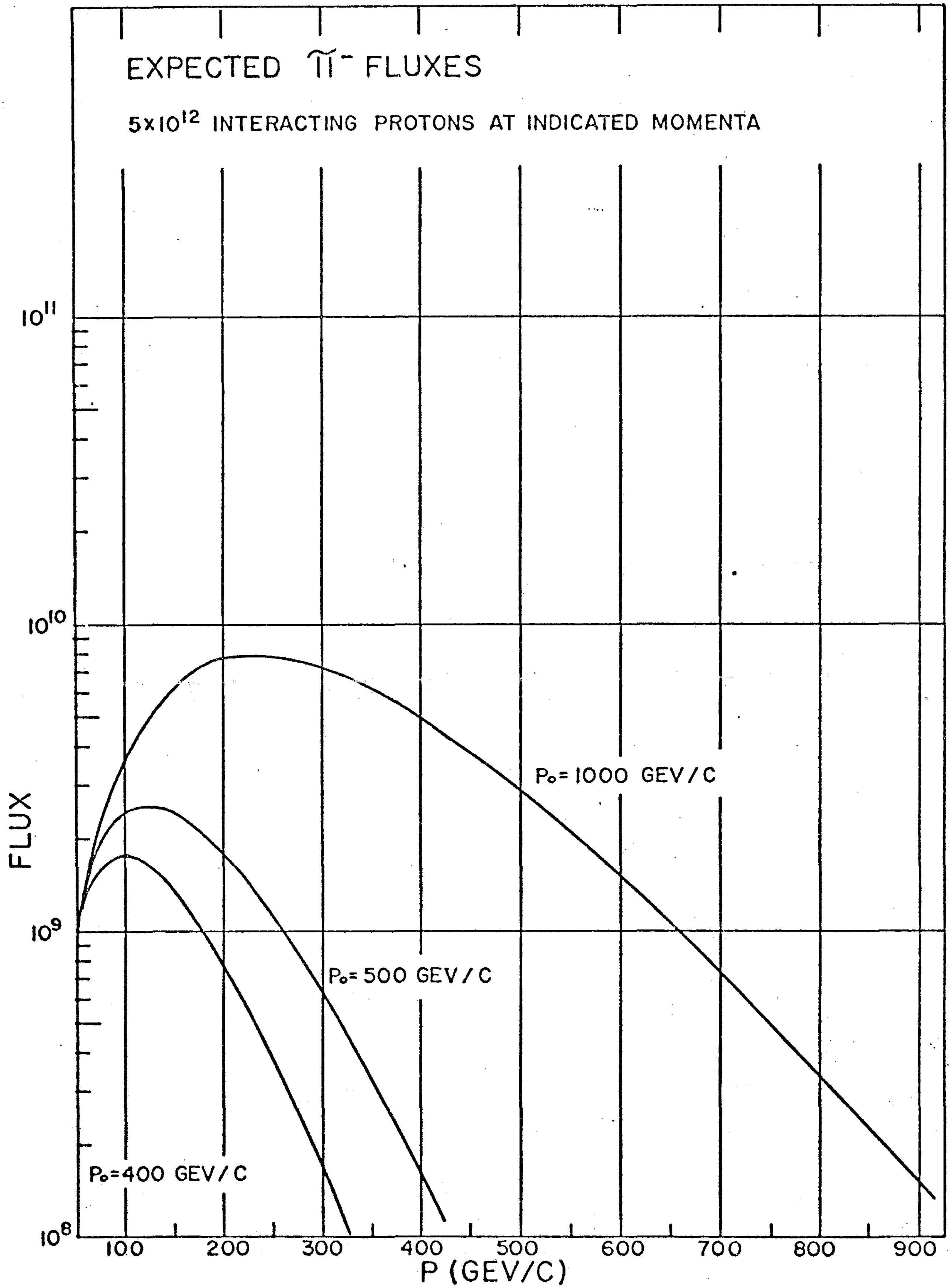
During 1981 and 1982, the M1 beam line will be converted to a primary proton beam by installation of Energy Saver, dipoles in two bend strings and installation of a switch in the M-Center line. The new M1 line has been designed to localize loss points, which have been shielded to handle single-pulse losses of 10^{13} protons safely. It will safely transport more than $3x10^{12}$ protons per pulse to the Detector Building. As equipment funds allow and the physics program demands, the beam will be rebuilt into a high-intensity pion beam.[6] The expected beam fluxes for pions are shown in Figs. 6-8 and 6-9.

M2 will be an improved version of the present beam. It can be used as either a primary beam or a diffracted-proton beam at intensities ranging from 10^8 to 5×10^{12} protons per pulse. One of its functions will be to transport primary protons to the production target for the Polarized-Proton Beam[7]



M1 High Intensity Pion Beam
Energy Saver Aperatures 20.μstr%

FIGURE 6-8



M1 High Intensity Pion Beam

Energy Saver Aperatures 20.μstr%

FIGURE 6-9

discussed in Sec. 6.6 below. By removing the first section of the Polarized Beam, it will still be possible to use the M2 line in its traditional role.

M3 is a K_L^0 and neutron beam and its upgrade, except for planned changes in targeting and the primary beam dump, is straightforward.[8] The folding forward of the secondary angles results in the estimated Tevatron fluxes listed in Table 6-1.

M4 will initially be the present beam. In the long range, this beam will have its pit enlarged and access improved to make it useful as a high-energy test beam as well. The beam will then be a wide-angle beam limited to 200 GeV/c.

M5 is and will be a low-intensity wide-angle test beam with a maximum energy of 50 GeV. It will be essentially unchanged from the present beam.

M6 will be upgraded to Tevatron energies while maintaining its present character.[9] It will still provide particle identification, using the presently installed Cerenkov counters and transition radiation detectors. It will maintain a momentum-dispersed focus where momentum tagging can be done. The expected fluxes are listed in Table 6-1. The construction in the M6 area itself is discussed in Sec. 6.5 below.

6.4 Targeting And Dumps

6.4.1 Problems of the Present System. The present Meson primary beam targets and dumps have several properties that are annoying now, but that will become serious problems at Tevatron energy. The worst of these arise from the fact that secondary particles are produced at angles that become smaller as 1/E, where E is the energy. As the energies of the secondary beams follow the primary energy, we can expect that these typical angles will decrease by a factor of 2.5 from the present. The Meson Area was first designed and built

TABLE 6-1. 1-TeV Meson Area Beams

1 TeV Meson Area Beams

Line	Type	Energy (GeV)	Intensity (per 5×10^{12} protons)
M1	Primary protons	1000	$< 5 \times 10^{12}$
		500 +	8×10^{9}
	(Hi-intensity pion beam to be built later)	300 +	1.5×10^{10}
		500 −	3×10^{9}
		300 −	8×10^{9}
M2	Primary	1000	$< 5 \times 10^{12}$
	(Supplies primary beam to polarized proton beam)		
M3	K_L+ neutron	100	2×10^{8}
M4	Test Beam	200 max	
M5	Test Beam	50 max	
M6	Tagged Hadrons	1000 max	$< 1 \times 10^{9}$
		500 +	4×10^{8}
		300 +	7×10^{8}
		500 −	1.5×10^{8}
		300 −	4×10^{8}

for a 200-GeV accelerator, so these angles will be five times smaller than the Meson Area was originally designed to use.

The obvious result of this fact is that to obtain the same proton economy, each beam line must be run at smaller production angles, roughly one-fifth the original angles. By installing the three-way split, we will have gone a long way toward this goal, allowing four of the six lines to run simultaneously at 1 mrad or less. Unfortunately, we can go no further with the present dump concept, because the non-interacting primary beam and a large fraction of the secondary particles must be dumped in a safe place. In addition, as many as possible of the secondary particles that are not accepted by the secondary-beam line must be absorbed before they decay into muons. This point is especially important for 1-TeV operation. The Meson Area shielding berm was designed for a 200-GeV accelerator. At 1 TeV, a large fraction of all secondary particles will have energies greater than 200 GeV. A significant fraction of the resulting decay muons will have enough energy to pass through the berm, creating unwanted radiation in the Detector Building and further downstream.

The present collimator-dump systems are passive systems using long (15 m) steel and water-cooled aluminum blocks containing small beam-defining holes, as was shown in Fig. 6-2. These collimator-dumps restrict the passage of unwanted beams by restricting the angular range of the transmitted secondaries. As the production angle is decreased[10], a second source of secondaries appears in the area of the collimator jaws where the primary beam is dumped. At small angles it also becomes possible to missteer the primary beam so that it passes completely through the collimator and is dumped somewhere downstream. In addition, at any production angle, the collimator passes all secondary momenta within the angular acceptance. Only a small fraction of these are accepted by the beam line. The others are a potential source of radiation, either by decaying to muons or by activating downstream beam-line elements.

It was decided in the original design that use of massive amounts of fixed radiation shielding was the cost-effective way to provide environmental shielding. The single target-dump assembly was therefore built on four 6-m long bedplates that are rolled into a shielded cave, 1.2 x 1.2 m^2. The target-box cave is covered by 6m of earth and is above an impermeable membrane for ground-water activation control. Because of the insertion-extraction mechanisms and mounting system, only the upper 1 x 0.3 m^2 of this box is usable for the actual dump.

If any parts of the present targets or dumps fail, they are unfixable, and are pulled out and thrown away. This has happened every 1.5 years on the average, although two were repaired and reinserted at a shorter interval. Because the dump system is relatively cheap and disposable, no provisions were made to handle radioactive components in the Meson Area.

The present dump has, however, two complete systems for the two beams targeted there plus a water-cooled emergency dump for M East. Unlike the other areas at Fermilab, if one of the beam dumps requires repair, the others must be out of service for the entire repair period, currently a minimum of three weeks. It is possible to run an ailing beam dump at reduced intensity until it is convenient to pull the system for repair, but this will no longer be true with the new active dumps discussed below.

For these reasons, it is essential that the Meson Area improve its target-dump handling capabilities to include rapid replacement or repair of highly radioactive elements from the targets or dumps.

6.4.2 Target Dump Design: Target Service Gallery. The problems discussed above can be eliminated or minimized by using active beam dumps and targets with provision for removing and replacing failed components.[11,12] If a component fails, it will be replaced by a spare and taken in a shielded transfer case to a cooling area. All connections and all radiation-sensitive components will be outside the shield. Thus repair can be done with minimum radiation exposure to personnel.

We will excavate the berm above the present target box, cut off the top of the present box and build a Target Service Gallery with overhead crane coverage. An elevation-view sketch of this building is shown in Fig. 6-10. The most difficult part of this construction project is cutting through the highly radioactive box. But the highest activity is limited to the central portion of the structure, and by cutting off only the top, the cutting can be done remotely. This part of the box will be buried adjacent to its present location, solving the disposal problem. Once the box is cut apart and the top is buried, the remainder of the box will be covered with a layer of shielding; the rest of the construction can then be carried out with normal construction techniques. The excavated earth will require special handling because it will be mildly radioactive, but this kind of work is not unusual and is in fact now being done for several other 1-TeV construction projects at Fermilab.

The Target Service Gallery will be covered with earth shielding to lessen the amount of internal shielding required. The principal consideration determining the ratio of dense shielding near the targets and dumps to the lighter earth shielding is the desire to keep residual radiation levels in the gallery as low as possible. For this reason, the most radioactive elements, the dumps, are surrounded with 1.2 m of iron and 1 m of concrete. The target

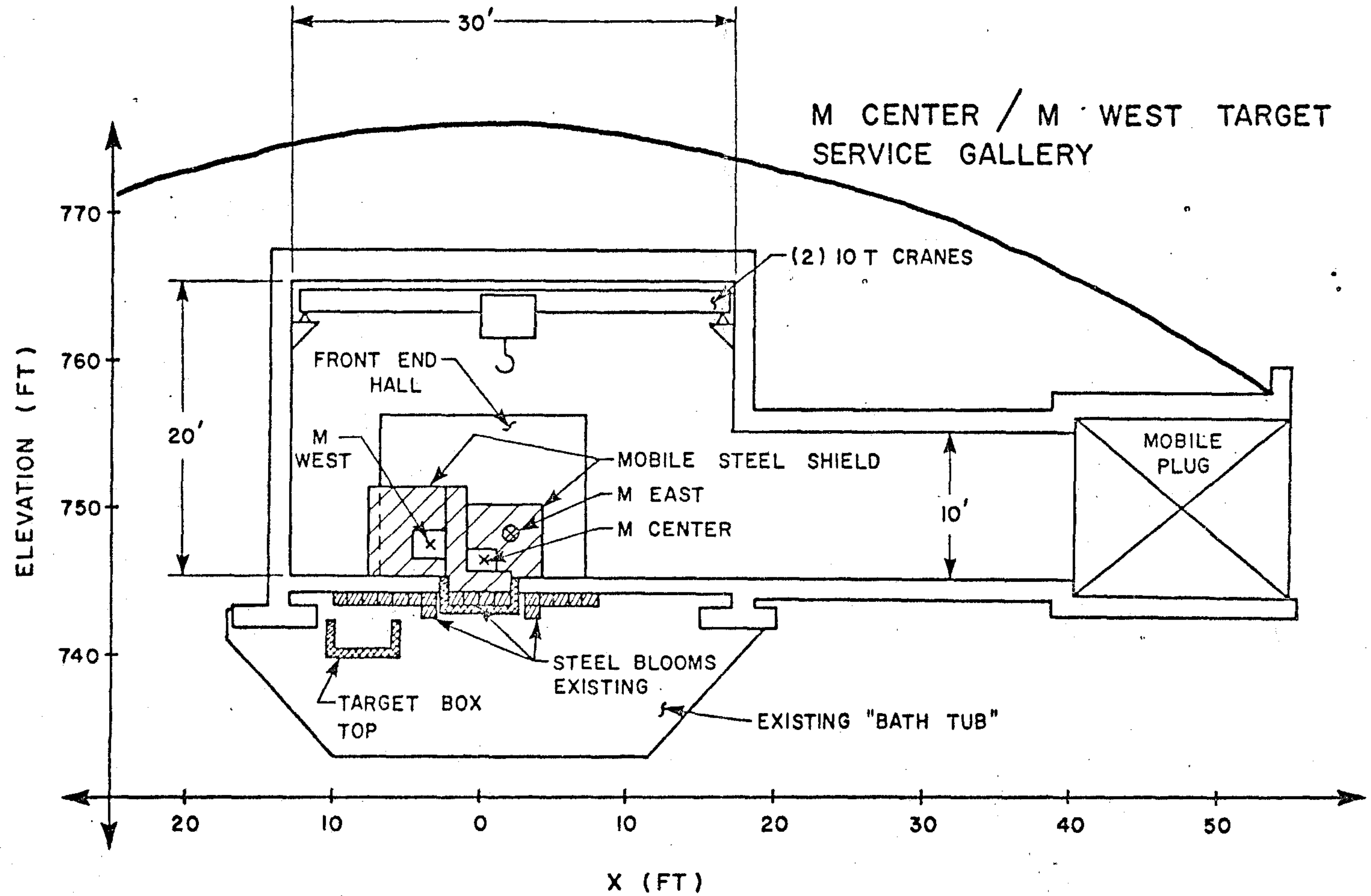

M CENTER / M WEST TARGET SERVICE GALLERY
30′
(2) 10 T CRANES
FRONT END HALL
M WEST
MOBILE STEEL SHIELD
M EAST
M CENTER
20′
10′
MOBILE PLUG
STEEL BLOOMS EXISTING
TARGET BOX TOP
EXISTING "BATH TUB"
ELEVATION (FT)
770
760
750
740
20
10
0
10
20
30
40
50
X (FT)

FIGURE 6-10

will be surrounded by 1 m of iron plus concrete and the dump magnets by 30 cm of iron. Most of this shielding around the targets and magnets is to handle accident conditions. These will normally run much cooler than the dumps. The required interior shielding is sketched on the plan view in Fig. 6-11.

The steel shielding will have mobile sections as shown in Fig. 6-10. The center portion between M Center and M West will be fixed, while the outer portions will roll away to expose the inner, active-component area. In the area of the heavy dump shielding, only 30 cm of movement is required, while the light magnet shielding requires 60 cm. The steel will be built in short sections approximately 2 m long. Each piece will weigh less than 30 tons, an easy weight to handle by rolling.

Components will be replaced using the crane, the shielded transfer case, and the remote connections. At no time during the operation are personnel exposed to highly radioactive surfaces. The only difficult part of the operation will be aligning the new elements. It is envisioned that the base structure of the shielding cave will incorporate a grid of large (2.5 cm) conical rods on precise, fixed centers. Mating holes on the element will provide the required alignment. If this precision is insufficient, it will be possible to provide means to survey and adjust positions in safety. In particular, the target assembly will hang from an exterior manipulator that will do the precise positioning necessary.

The Target Service Gallery will provide services for the M-West and M-Center target area. The M-East target will be 140 m downstream in the M-1 target gallery. This gallery already exists and when the target station is built, it will be almost identical to that discussed above, though smaller.

The Target Service Galleries and the mobile shielding described in this section will, for the first time, provide the Meson Area remote-handling

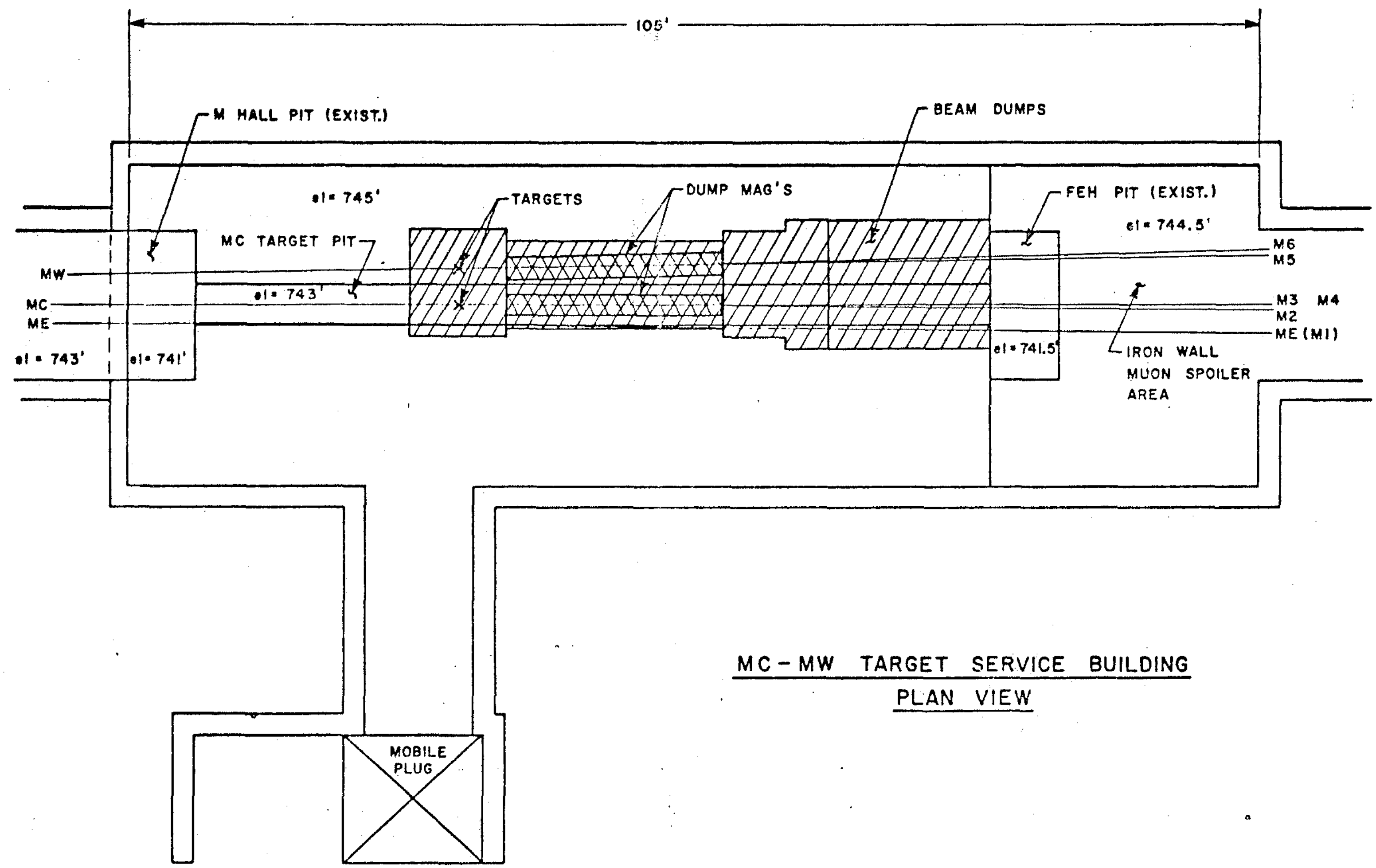
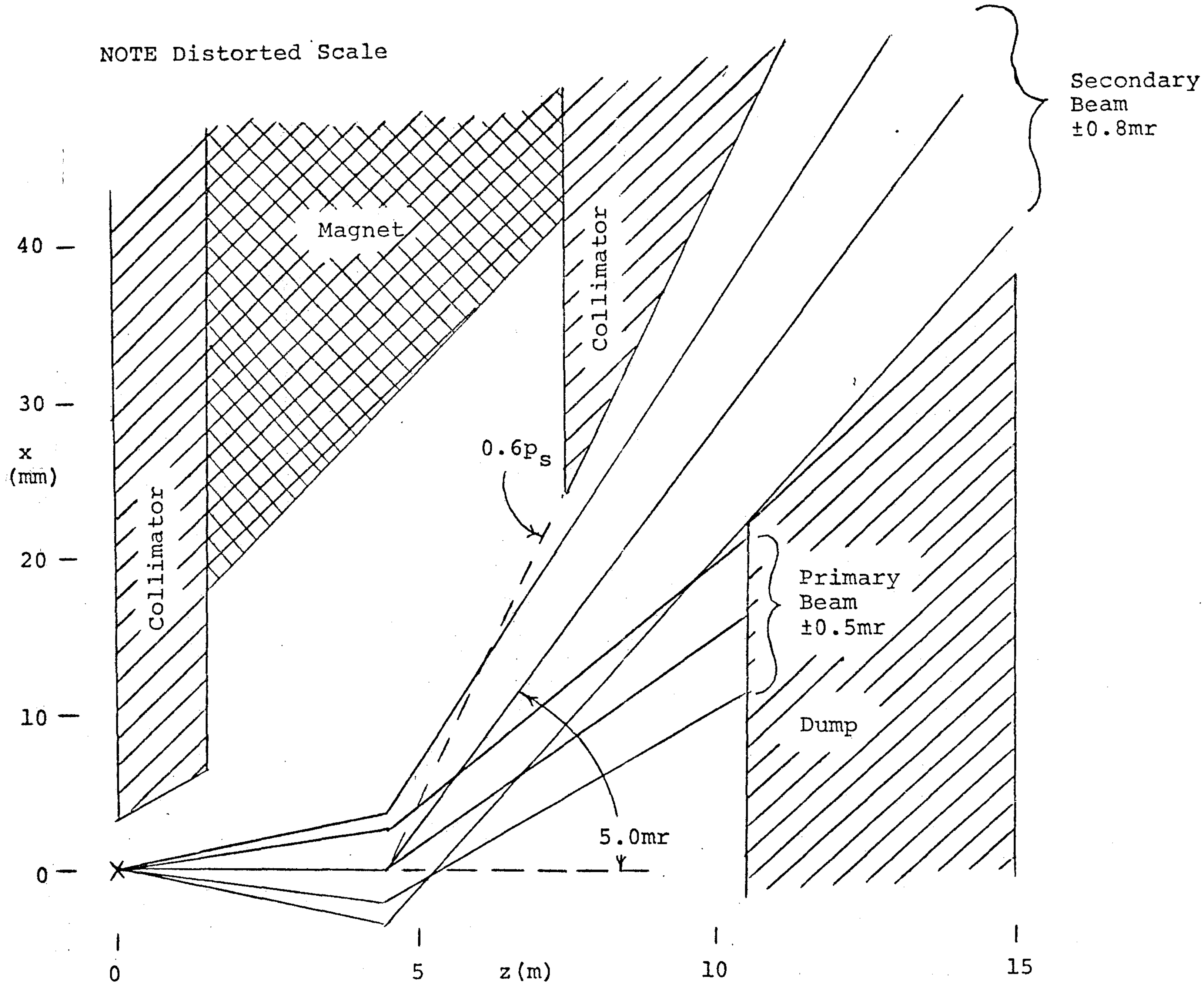

105'
M HALL PIT (EXIST.)
BEAM DUMPS
el= 745'
TARGETS
DUMP MAG'S
FEH PIT (EXIST.)
el= 744.5'
MC TARGET PIT
M6
M5
MW
el= 743'
MC
ME
M3 M4
M2
ME (M1)
el = 743'
el= 741'
el= 741.5'
IRON WALL
MUON SPOILER
AREA
MOBILE
PLUG
MC - MW TARGET SERVICE BUILDING
PLAN VIEW

FIGURE 6-11

capability for failure-prone, radioactive target-area objects. This capability is made essential by the increased complexity of the target and dump systems needed for Tevatron operation. At the same time the systems will greatly speed repair of these crucial elements, decreasing loss of beam time.

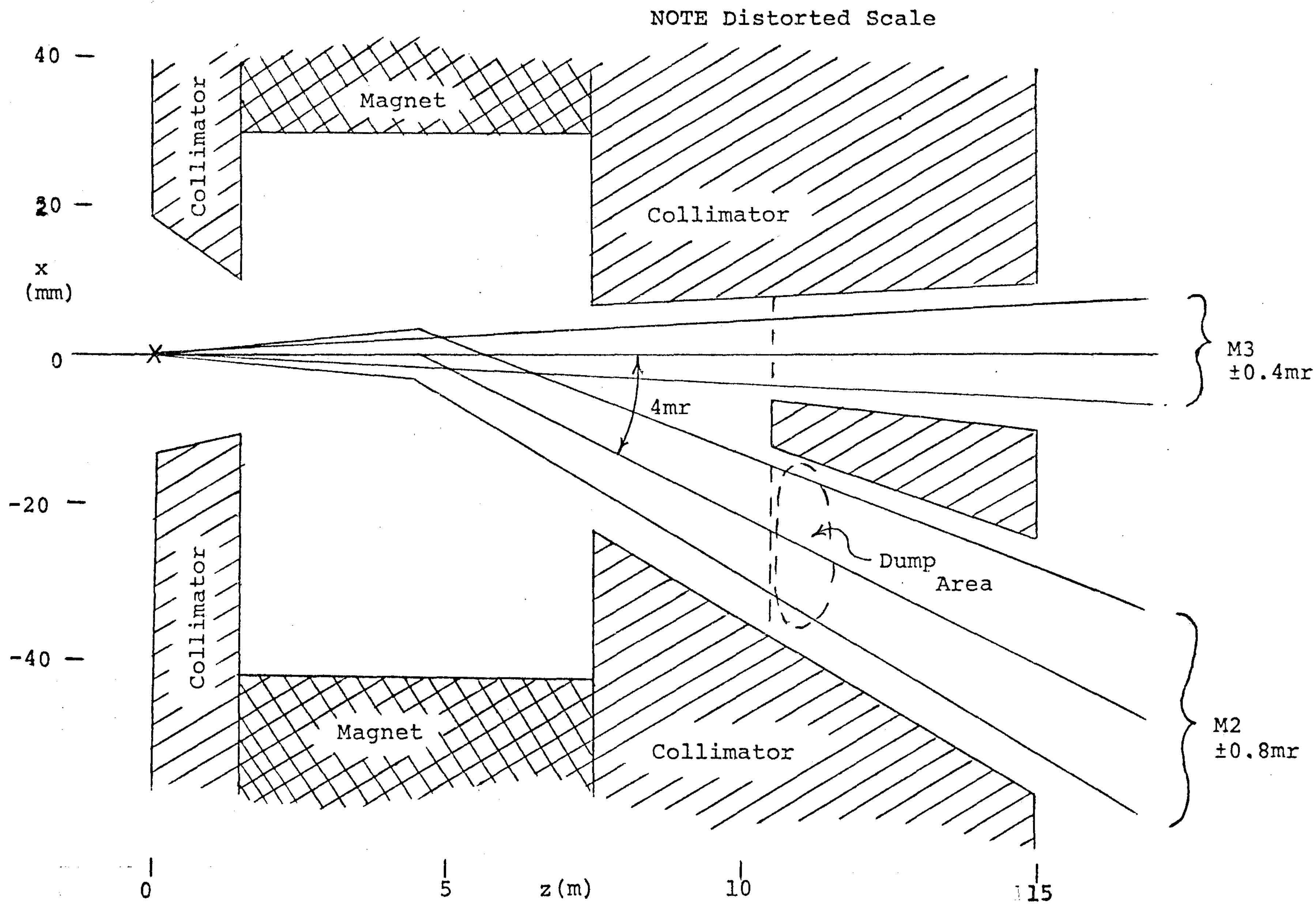
6.4.3 Beam Lines and Dumps. Figure 6-12 shows the dump proposed for both M-West (M6 and M5) and the M-East (M1) beam lines. In this design, the first element in the secondary beam line is a dipole magnet very close to the production target. For all negative-beam tunes and for positive-beam tunes up to approximately 50% of the primary-beam momentum, production angles that are exactly zero are possible. Downstream radiation problems are minimized in this design by limiting the relative momentum band passed through the dump-collimator to roughly ± 40%. In addition, the neutral-beam aperture is very small and at large angles. The angular range passed is also restricted but not so tightly as in the past.

The M-Center (M2, M3) dump is quite different. M2 is normally run as a diffracted-proton beam, and the neutral beam, M3, must be maintained. In this case, if it were not for the muon problem, the present-style collimator with the addition of a re-entrant dump would be the solution of choice. The muon problem is solved by adding a shielding magnetic field, just as was done for the other beams, but here the necessary production angle and dumping will be in the vertical plane, although the field will bend horizontally. Horizontal and vertical views of this dump are shown in Figs. 6-13 and 6-14. Using a horizontal bending magnet as a shield also separates M2 and M3 at the earliest possible point, eliminating restrictions on the M3 flux arising from M2 magnet apertures. With the bend angle shown, the beams are separated by 20 cm at 50 m, enough separation to install the M2 quadrupole magnets. This choice of



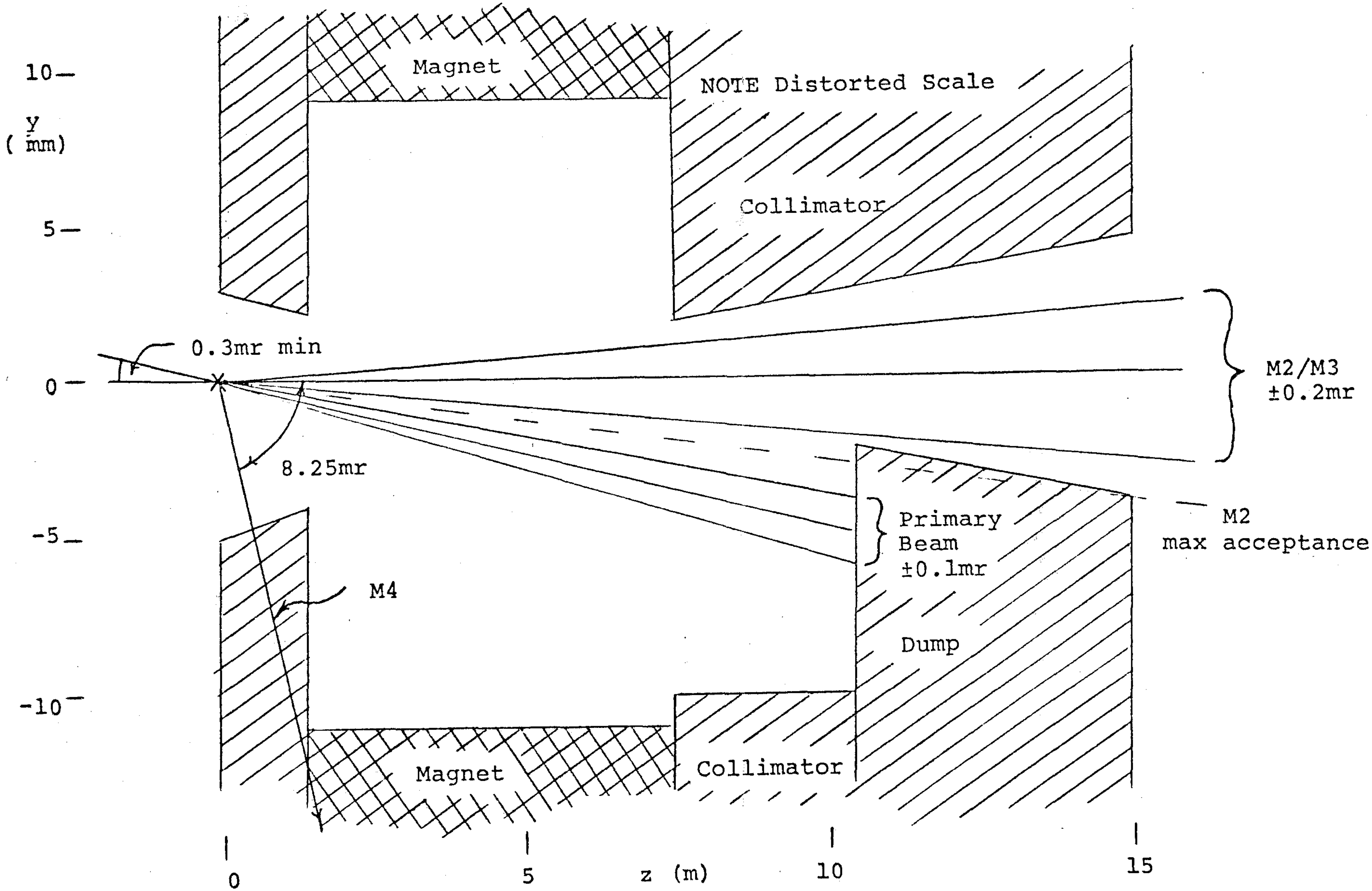
M West and M East Active Dump

FIGURE 6-12



M Center Active "Shield" Horizontal

FIGURE 6-13



M Center "Passive" Dump Vertical

FIGURE 6-14

bend angles also means that the bending in M2 can be combined into a single 21-mrad bend (3 Energy Saver dipoles) at the location of the present downstream bend.

In both M-Center and M-West, the wide-angle beams (M4 and M5) will be maintained by taking them off at approximately 8.25 mrad perpendicular to the bend plane of the dump magnets. The magnets will have holes through their pole tips for this purpose. Targeting efficiency and steering will be monitored using directional detectors through these holes.

Both the dump systems described above require flexible steering systems upstream. The M-West and M-East dumps are limited to transporting 500-GeV/c positive beams with 1 TeV primary protons incident, assuming the bend angle and divergences shown in Fig. 6-12. By going to a small production angle, larger positive momenta can be transported without transmitting the primary beam. At + 750 GeV/c, an angle of 0.73 mrad is needed.

It is also not possible for this dump magnet to transport 1-TeV beam by itself, but by moving the target, or providing a second target displaced from the first by 5 mm and by using the angle-varying magnets appropriately, diffracted protons can be transported. Primary beam can be transported in an analogous manner.

This feature of the dumps will be used as a safety mechanism. With the angle-varying bend magnets off, the primary beam will be incident on the target at an angle of approximately 0.5 mrad. Thus it will be impossible to transport primary beam through the dump magnet (which is limited to 22 kG) with the angle-varying bend magnets off, if the beam is on target or off on the side away from the beam aperture. This last requirement will be guaranteed by an upstream aperture. A similar safety feature will exist in the M-Center line. Here, with the angle-varying bend magnets off, the beam will have a downward pitch of nearly 2 mrad. To bring a high-intensity beam down M2 or M3 will require the angle-varying bends to be on at significant currents.

These angle-varying bends will be conventional magnets of the type now used for this purpose in the Meson Area. The steering system for M-East will be identical to that for M-West. The existing angle-varying bend in M-West will produce $\pm$ 1.8 mrad variations at 1 TeV, which are adequate. The bends in M-Center must be augmented by one more magnet to reach 2 mrad.

These bends are series-connected dipoles with the first magnet bending opposite to the others as shown in Figure 6-1. By choosing the relative positions appropriately, energizing these magnets will vary the angle of the beam at the target without changing its position. The magnets will be interlocked to the security systems of the appropriate beam line to reduce the amount of beam that must be intercepted by a beam stop. Because they do not change the beam position, there will be no problem with coordination with the main control room, and, because they are conventional magnets, they can react quickly.

One additional feature of these target-dump systems should be noted. The dump magnets sign-select the beam close to the target and it is therefore possible to use muon spoilers downstream to bend all muons produced in the vicinity of the targets and dumps down into the earth. This requires approximately 6 m of iron magnetized to 15 kG.

The target-dump systems described in this section will supply the very small production angle secondary beams required for Tevatron operation while solving the background-muon problems that would otherwise arise from this operation. They will also provide the necessary flexible operation, while still being inherently safer than the present dumps.

6.5 M6 Construction

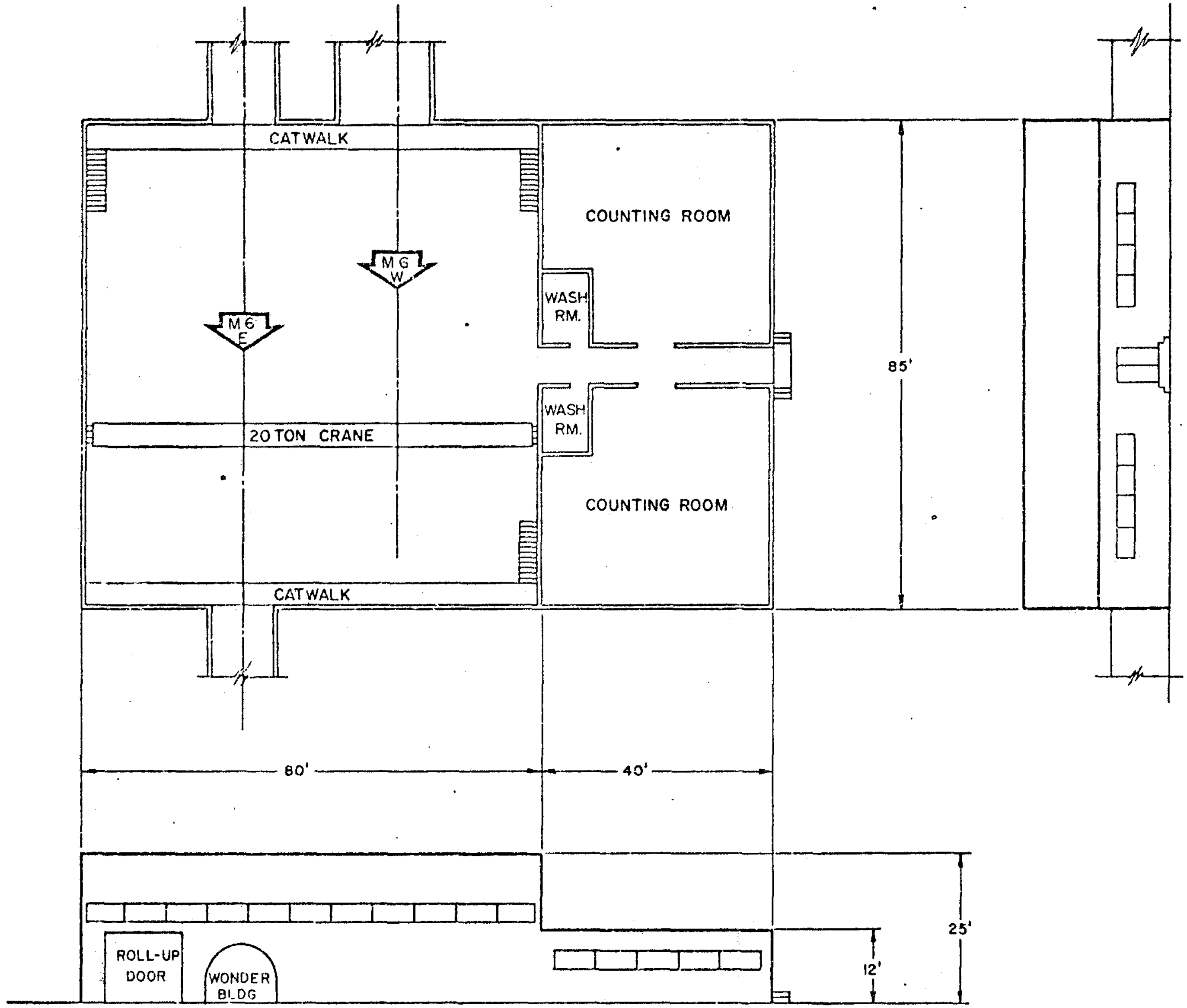
The M6 beam will be the only beam line in which incident particles can be tagged in position, direction, momentum and mass. This feature will be utilized in the Multi-Particle Spectrometer in M6-West and a possible new detector facility to replace the Single Arm Spectrometer in M6-East. An enclosure consisting of a high-bay area with crane and two counting rooms will be built to house both these facilities. This structure will release some Wonder Buildings, which can be relocated in the M6 beam area to make it a viable installation.

The MPS detectors will not be moved for the installation. Instead, the enclosure will be built over this facility so that it will occupy one-half the high-bay area of Figure 6-15.

The east half of the high-bay area will house the new detector facility. Access to it from the counting room will be via the overhead catwalks when the MPS is running. Beam intensities in this area will be low enough to permit such access. A single 20-ton crane will span the area, and a roll-up door at the east end will provide access for large equipment. The counting rooms will have raised flooring to provide space for cable runs and ducting for cooling air. Movable partitions will be used to separate electronic and computer areas from workshop and office space.

Wonder Building structures will house the components leading the two beams to the area. An additional structure downstream from the building in the M6E line will hold the forward-arm spectrometer of the new detector facility.

The housing of the two spectrometer facilities in one building has obvious operational advantages. A single liquid-helium supply will service



CATWALK
COUNTING ROOM
M G W
M 6 E
WASH RM.
WASH RM.
20 TON CRANE
COUNTING ROOM
CATWALK
85'
80'
40'
ROLL-UP DOOR
WONDER BLDG
25'
12'

FIGURE 6-15

both installations, because they run in an alternating mode. Operating personnel can be shared between the two facilities.

The Wonder Buildings shown in Fig. 6-16 all presently exist in M6, but most will require relocation. The 40 ft by 80 ft building presently covering the MPS will be moved to cover both M6W and M6E just downstream of the detector building in order to relieve the congestion in that region. This move will liberate 160 ft of beam-line enclosure. An additional 110 ft will become available from the new high-bay area. This total of 270 ft will be added downstream to house the forward arm of the new detector. It will also provide partial coverage for a hadron total cross-section experiment and for possible small angle scattering experiments. The M6E beam enclosure from the Detector Building to the new area will be straightened out to house a Cerenkov counter. The M6W beam enclosure will not be changed. A bypass from the M5 to the M6 tunnel will enable the M5 tunnel to be used to bring a beam to the detector facilities along the present final beam line.

6.6 Polarized-Proton Beam

The proposed beamline, to be built in collaboration with Argonne National Laboratory, will provide polarized protons in a 10% momentum band from 70 to 350 GeV/c, utilizing 1000-GeV primary protons. Polarized antiprotons can also be provided.

When the primary (unpolarized) proton beam from the accelerator strikes a target, lambdas are produced, together with many other types of particles. When these lambdas decay, the resultant protons are polarized; the direction of polarization is determined by the geometry of the particular decay. This phenomenon is used to produce a high-energy polarized proton beam, which is then guided by a series of magnets, conserving the polarization, to a

M6 WONDER BUILDINGS

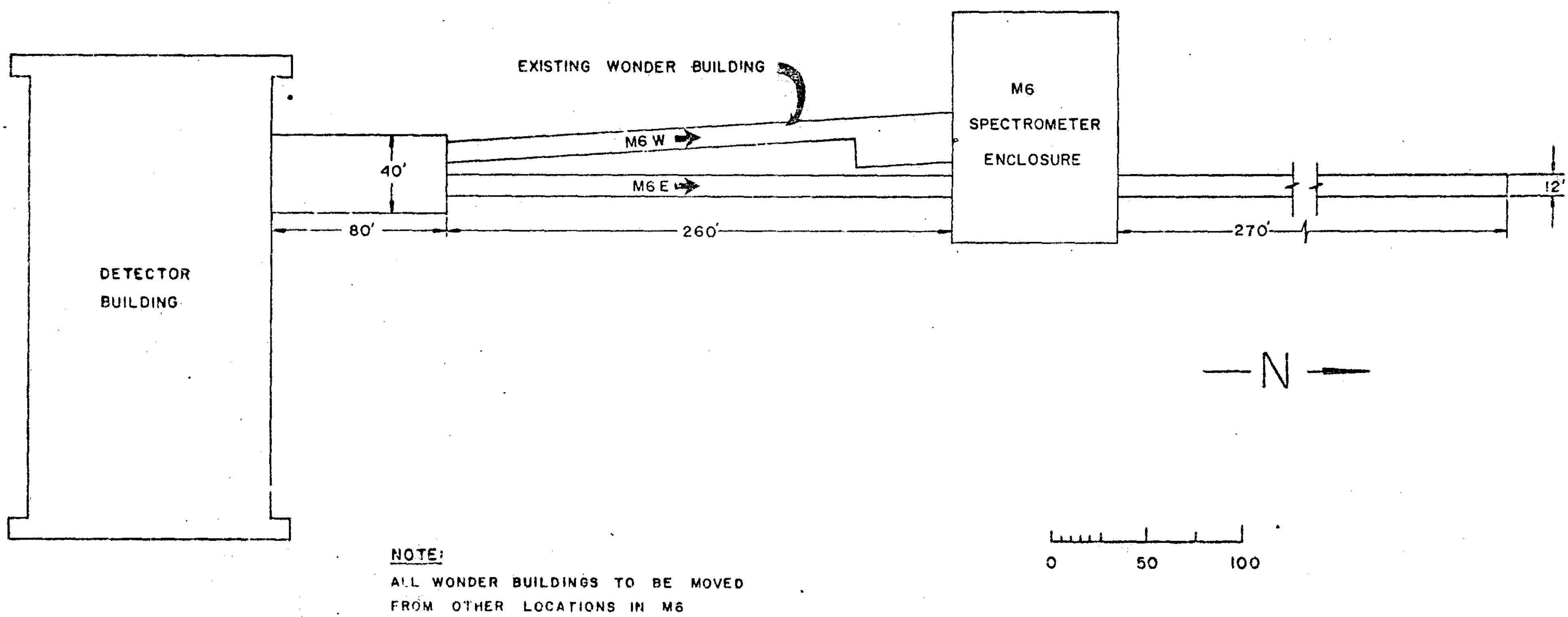


FIGURE 6-16

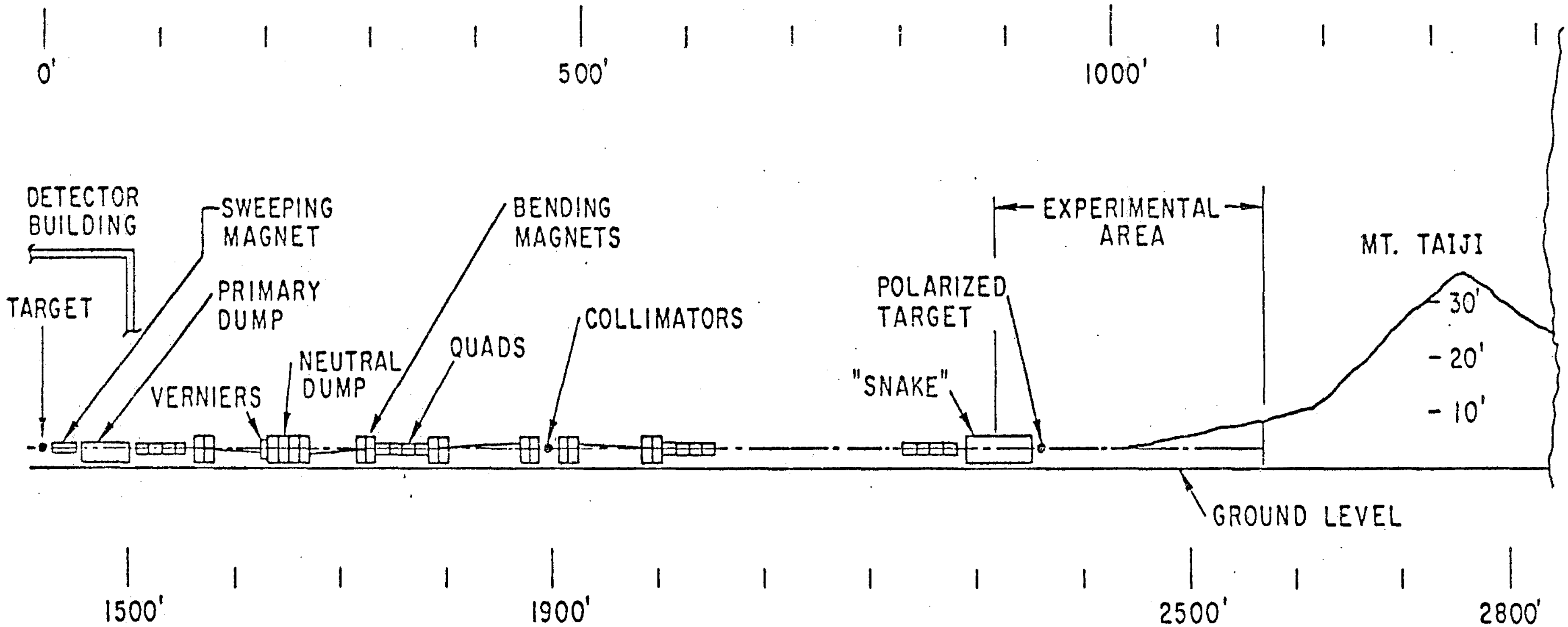
polarized target. The spin dependence of exclusive and inclusive processes can then be measured to study spin effects in quark-quark scattering.

The production target will be located in the M2 beam line at the 1420-ft mark, which is in the Meson Detector Building. Figure 6-17 shows the layout following this target. The charged secondaries and remaining primary protons are dumped after a sweeping magnet. The lambdas then decay to give the polarized protons. The remaining neutral particles are absorbed in the neutral dump. The beam has a focus at the collimators and there the protons with the desired polarization are selected. The beam is again refocused at the polarized target, some 1000 ft from the production target.

Beam-transport elements include 16 large-aperture dipole magnets and 16 large-aperture high-field quadrupole magnets. The former are expected to be BM-105 magnets provided by Argonne National Laboratory and the latter to be superconducting quadrupoles developed and provided by Argonne. The plane of polarization can be rotated from transverse to vertical or longitudinal using a magnetic "snake" preceding the polarized target. This snake consists of eight superconducting dipole magnets. The elements will be powered from a 2.5-MW substation.

The clusters of magnets will be housed in Wonder Buildings, and these will be connected by sections of 6-in. beam pipe enclosed in concrete-block shielding. A 100-ft Wonder Building extending downstream from the polarized target will provide housing for the experiments and will house the final beam stop. It will contain, for example, the polarimeter used to measure the beam polarization in some experiments.

In a typical experiment, 3×10^{12} protons per spill will be targeted on the production target, which will be surrounded by steel and concrete. The

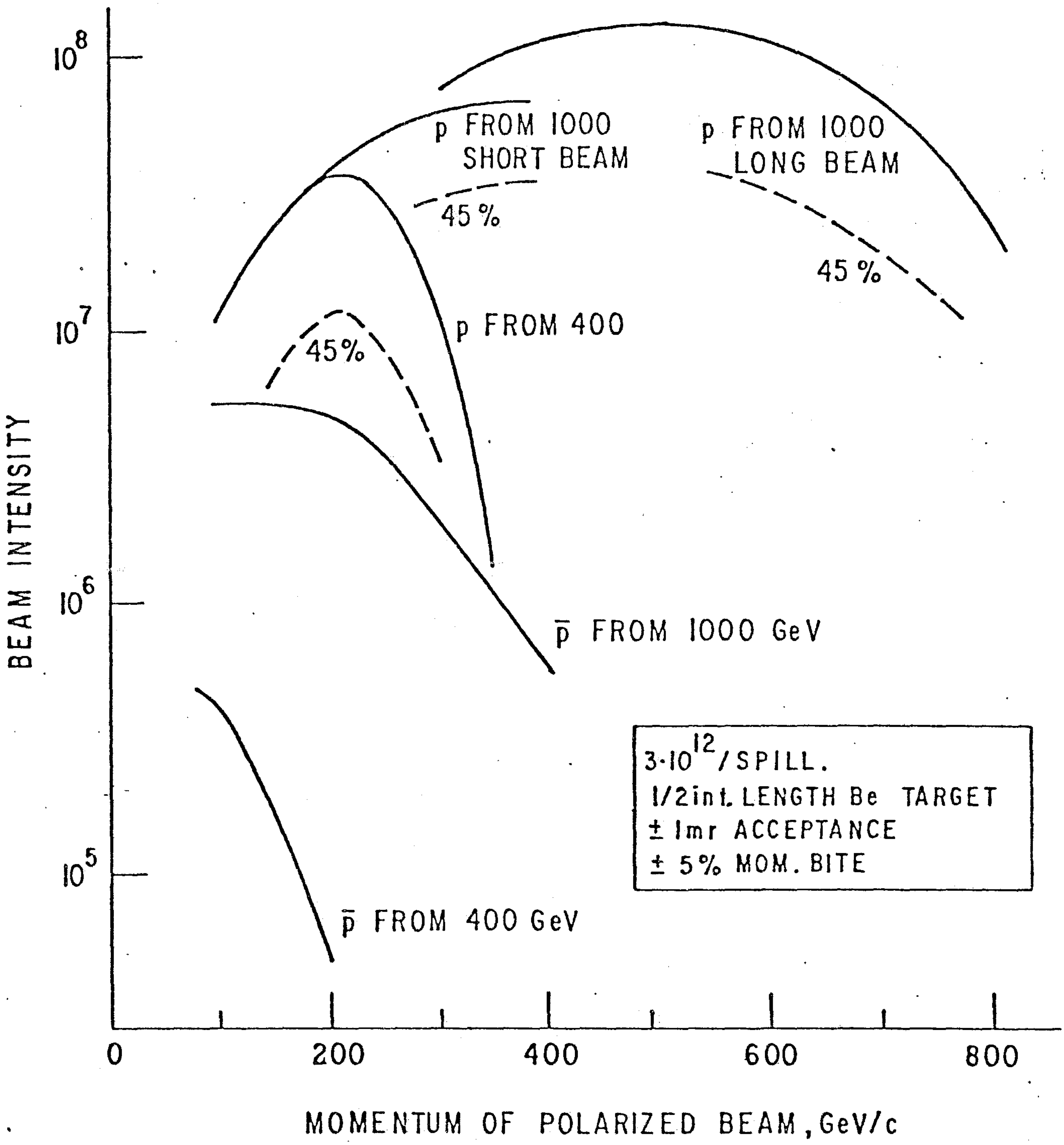


Polarized Proton Beam - Elevation

FIGURE 6-17

intensities of polarized protons and antiprotons expected under these conditions from 1000-GeV primary protons are given in Fig. 6-18.

When not used to provide polarized protons, the beam can feed primary (unpolarized) protons, pions, and other secondary particles to the polarized target or to an experiment at the central focus.



10^8
10^7
10^6
10^5
BEAM INTENSITY
p FROM 1000
SHORT BEAM
p FROM 1000
LONG BEAM
45 %
45 %
45%
p FROM 400
p̄ FROM 1000 GeV
p̄ FROM 400 GeV
3·10^12 / SPILL.
1/2 int. LENGTH Be TARGET
± 1mr ACCEPTANCE
± 5% MOM. BITE
0
200
400
600
800
MOMENTUM OF POLARIZED BEAM, GeV/c

FIGURE 6-18

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7. STORAGE AND MATERIAL-HANDLING NEEDS

The advent of large second-generation experiments for the 400-GeV program has strained the limited storage and assembly facilities of the Laboratory. There is a need to expand our current material-handling capabilities and create more space for storage and research and development of technical and experimental physics components. This project includes two new buildings, to be located in the experimental areas, with increased fixed and self-propelled lifting capacity to handle the larger items expected in the Tevatron era.

7.1 General-Purpose Laboratory Buildings

The laboratory buildings in the Fermilab Village Area serve as a model for the needs of the 1-TeV program. Although they are general-purpose work areas, it is believed that they best serve long-range research and development projects for the laboratory. Similar buildings with larger materials-handling capabilities and, in addition, located more conveniently to the existing experimental areas are needed.

Support-personnel space should also be included as an integral part of these buildings. The prefabricated houses currently serving this function in the village are not well-suited to this requirement. The laboratory continues to convert these village houses to much-needed visiting scientist housing uses.

The conceptual design of a storage and laboratory building includes a 30-ton overhead crane and office space for 10 support personnel. The two buildings would be located near the Industrial Area complex. This area is very close to the center of the Switchyard and is convenient to the three external laboratories.

7.2 Materials-Handling Capabilities

The Laboratory has been hampered by a lack of heavy-duty material-handling equipment. Currently any material in excess of 20 tons must be handled by special contract with commercial contractors. This has caused undue delay in the program of the Laboratory, because large equipment must usually be scheduled many months in advance.

The secondary-road and hardstand complex in the vicinity of the Industrial Building complex will be improved to develop an integrated storage and materials-handling complex convenient to all experimental areas. This area should serve the Laboratory's needs through the 1980's.

8. PROJECT COST ESTIMATES AND SCHEDULES

The Tevatron phase-II fixed target physics program will provide a 1 TeV proton targeting capability in the three existing experimental areas at Fermilab. The project includes funds for the slow-spill extraction from the 1-TeV accelerator, construction of the necessary additions and modifications to the physical plant, and the extra technical components needed to target 1 TeV protons on the existing external target stations. New secondary beam lines and support facilities will be constructed in each external experimental area. The total number of secondary beams will not be increased since the new beams will replace existing beams which become obsolete at 1-TeV energies.

A program of development is underway to adapt Energy Saver dipoles and quadrupole magnets and refrigeration systems to the existing physical plant in the Neutrino, Proton, and Meson areas. The target-handling and muon shielding requirements associated with 1 TeV energies are also being studied. Further studies are planned to increase the intensity capabilities of the Tevatron accelerator, in order to further improve the research potential of the 1 TeV fixed target program.

The funding pattern for the total project is given in Table 8-1. The detailed conceptual-design estimates of the costs of the construction items in table 8-1 are given in Table 8-2. Escalation has been included in all these estimates at an average rate of 15% for FY80, 12% for FY81, 10% for FY82 and 8% for FY83. The 20% contingency reflects both the uncertainty in technical detail and the uncertainty in the escalation during the life of this project.

Figure 8-1 shows the distribution of the construction costs over the three fiscal years of the project. This table complements Fig. 9-1 below which outlines the timetable for completion of the various components of this construction project.

Table 8-1. Tevatron 2 Funding Summary
(In thousands of dollars)

A.	Engineering, Design and Inspection (21% of construction)				$ 6,600
B.	Construction Costs				31,500
	i)	Extraction System		1,700	
	ii)	1-TeV Construction and Modification of Existing Facilities		11,000	
		1. Neutrino	2,300		
		2. Proton	3,700		
		3. Meson	5,000		
	iiii)	Conventional Beam-Line Construction		14,000	
		1. Neutrino	7,600		
		2. Proton	5,000		
		3. Meson	1,400		
	iv)	Ancillary Storage and Materials Handling Capability		4,800	
C.	Contingency (20%)				7,600
TOTAL					$45,700

Figure 8-1

TEVATRON PHASE II

```
  CALENDAR YEAR      1980   I     1981     I     1982     I     1983     I     1984
   FISCAL YEAR        I       1981    I       1982    I       1983    I       1984    I
                     OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT

EXTRACTION             $1.7M.  .   .   .  <----------$1.7M--------->  .   .   .   .   .   .   .

NEUTRINO LAB           $9.9M.  .   .   .  <-----(Total $1.15M)----I-----(Total $4.85M)----I-----(Total $3.9M)----->

  NO-Shielding Dev.     1.0M   .   .   .   .   .   .   .   .   .   .   .  <----------$1.0M--------->
  Detector Building    1.15M   .   .   .   .   .   .   .  <----------$1.15M-------->  .   .   .
  Switchyard Dev.      0.15M   .   .   .  <----------$0.15M-------->  .   .   .   .   .   .   .
  Muon Beam             7.6M   .   .   .   .   .   .  <$1.0MI---------$3.7M---------I---------$2.9M--------->

PROTON LAB             $8.7M.  .   .   .  <-----(Total $2.75M)----I-----(Total $4.45M)----I-----(Total $1.5M)----->

  Switchyard Dev.       2.0M   .   .   .  <----------$2.0M--------->  .   .   .   .   .   .   .
  Enclosure-H          0.35M   .   .   .  <----------$0.35M-------->  .   .   .   .   .   .   .
  Targetting-PW,PE     1.35M   .   .   .   .   .  <---$0.4M---I---------$0.95M-------->  .   .   .
  Broad-Band Beam       5.0M   .   .   .   .   .   .   .  <----------$3.5M---------I---------$1.5M--------->

MESON LAB              $6.4M.  .   .   .  <-----(Total $1.8M)-----I-----(Total $3.2M)-----I-----(Total $1.4M)----->

  Target Building       1.5M   .   .   .   .   .   .   .  <----------$1.5M--------->  .   .   .   .
  M6 Beam Enclosure     1.1M   .   .   .   .   .   .   .   .   .  <---$0.6M---I---$0.5M--->  .   .
  Switchyard+Meshall    2.4M   .   .   .  <----------$1.8M---------I---$0.6M--->  .   .   .   .   .
  Polarized Proton B    1.4M   .   .   .   .   .   .   .   .   .   .  <$0.5MI---------$0.9M--------->

STORAGE & HANDLING     $4.8M.  .   .   .  <-----(Total $0.3M)-----I-----(Total $2.0M)-----I-----(Total $2.5M)----->

  Building #1           1.0M   .   .   .   .   .   .   .  <----------$1.0M--------->  .   .   .   .
  Building #2           1.0M   .   .   .   .   .   .   .   .   .   .   .  <----------$1.0M--------->
  Handling Equip.       2.8M   .   .   .  <----------$0.3M---------I---------$1.0M---------I---------$1.5M--------->

EDIA                   $6.6M.  .   .   .  <----------$2.0M---------I---------$3.0M---------I---------$1.6M--------->

CONTINGENCY            $7.6M.  .   .   .   .   .   .  <$0.6MI---------$2.0M---------I---------$5.0M--------->

TOTALS                $45.7M.  .   .   .  <----------$10.3M--------I---------$19.5M--------I---------$15.9M-------->

*                    OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT
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Table 8-2. Details of Tevatron 2 Construction Cost Estimates
(In thousands of dollars)

i.	Extraction System				
	a. 4 electrostatic septa and power supply		95		
	b. 8 Lambertson magnets		240		
	c. Bump magnets and power supplies		100		
	d. Supports, stands, and auxiliary equipment		120		
	e. Extraction channel				
	2 C-magnets	30			
	6 Energy Saver dipoles	300			
	2 Energy Saver quadrupoles	76			
	Vacuum	40			
	Refrigerator & transfer lines	300			
	Collimator and shield	29			
	Sub-total		775		
	f. Remodeling of existing beam line components and installation		300		
	g. Control hardware		70		
	Total Extraction System				1700
ii.	1 TeV Construction and Modification of Existing Facilities				
	1. NEUTRINO AREA				
Neutrino Switchyard					
Enclosure B					
	1 3-in. dia. quadrupoles		30		
Enclosure C					
	4 B1 main ring magnets		80		
Installation			40		
	Subtotal Switchyard			150	
NO Shielding (10,000 tons @ \$100/ton) (assume scrap steel)				1000	
Detector Building					
	40 ft x 250 ft (@ \$100/ft ^{2})		1000		
	With crane		150		
	Subtotal Detector Building			1150	
	Neutrino Total (1 TeV construct. and mod.)				2300

2. PROTON AREA

Proton Switchyard

Transfer Hall

a.	3 electrostatic septa + supports	70	70

Enclosure B

a.	5 Lambertson magnets	150	
b.	2 3-in. dia. quadrupoles	70	
c.	5 Energy Saver dipoles	250	
d.	1 Trim dipoles	10	
Subtotal			480

Enclosure D

a.	6 energy saver dipoles	300	
b.	2 3-in. diameter quadrupoles	70	
c.	2 trim dipoles	20	
Subtotal			390

Enclosure E

a.	5 electrostatic septa	110	
b.	3 B2 main ring dipoles + supports	50	
c.	3 trim dipoles	30	
d.	2 3-in. dia. quadrupoles	70	
Subtotal			260

Miscellaneous Switchyard

a.	Refrigerator (for right bend)	420	
b.	Transfer line	170	
c.	Installation	150	
d.	Access shaft	60	
Subtotal			800

Enclosure H

a.	1 Modified B1 dipole	25	
b.	1 Lambertson magnet	30	
c.	2 Energy Saver dipoles	100	
d.	Power Supplies	150	
e.	Installation	45	
Subtotal			350

Proton West Pre-Target

a.	2 B2 Main Ring dipoles + supports	30	
b.	6 3-in. dia. quadrupoles	210	
c.	1 trim dipole	10	
Subtotal			250

Proton Center Pre-Target

a.	Move target channel magnet downstream		100	

Proton East Pre-Target

a.	1 3-in. dia. quadrupole	35		
b.	4 Energy Saver quadrupoles	152		
c.	2 Energy Saver dipoles	100		
d.	1 Trim dipole	10		
e.	3 lead boxes + turn-around boxes	100		
f.	Refrigerator	413		
g.	Transfer line	40		
h.	Installation + supports	150		
Subtotal			1000	
Proton Total (1 TeV construc. and mod.)				3700

3. MESON AREA

Meson Switchyard

Enclosure C

a.	3 electrostatic septa	66		
b.	1 Lambertson magnet	30		
c.	6 C-magnets	150		
d.	4 3-in. dia. quadrupoles	140		
e.	1 Energy Saver dipole (vertical bend)	50		
Subtotal			436	

F1 Manhole

a.	1 electrostatic septum	22		
b.	2 3-in.dia quadrupoles	70		
c.	Manhole extension	75		
Subtotal			167	

F2 Manhole

a.	1 electrostatic septum	22		
Subtotal			22	

F3 Manhole

a.	2 Lambertson magnets	60		
b.	Install - all Switchyard	50		
Subtotal			110	

Meshall

a.	6 Energy Saver dipoles	300	
b.	6 Energy Saver quadrupoles	225	
c.	2 Lambertson magnets	60	
d.	2 C-magnet	50	
e.	Refrigerator	300	
f.	Transfer line	50	
g.	Turn around box	100	
h.	Power supplies	80	
i.	Installation	100	
Subtotal			1265

M1 Primary Beam

a.	5 Energy Saver dipoles	250	
b.	2 Energy Saver quadrupoles	76	
c.	Transfer line	50	
d.	Installation	24	
Subtotal			1200

Target Building and Shielding

a.	100 ft x 30 ft @ $250/ft^2 (includes removal of existing target box top)	750	
b.	Cranes and remote handling	200	
c.	Passive and active shielding	250	
d.	Target Train Components	300	
Subtotal			1500

M6 Enclosure

Spectrometer Enclosure

a.	6800 ft^2 @ $50/ft^2	360	
b.	340 ft^2 @ 40/ft^2	135	
c.	Power and lighting	50	
d.	Heat and A.C.	70	
e.	Crane	185	
Subtotal			800

Wonder Building Moves

a.	Concrete slabs 6440 ft^2 @ 15/ft^2	95	
b.	Power runs	10	
c.	Enclosure moving	65	
Subtotal			170

Recommend → we buy switchyard components for TeV-II !!

How many EPB's are left at moment!!!

M5-M6 Bypass

a.	250 ft pipe @ $265/ft	65		
b.	50 ft quad enclosure 8 ft x 8 ft x 80 ft @ $800/ft	65		
	Subtotal		130	
	Meson Total (1-TeV construct. and mod.)			5000

iii. Conventional Beam Line Construction

1. MUON BEAM

Switchyard and Proton Targeting Construction

a.	G2 service building	100	
b.	Switchyard components	350	
c.	Pre-target quad enclosures 37 ft x 8 ft x 30 ft @ 555/ft^2)	350	
d.	2200 feet communication duct	225	
Subtotal			1025

need 4.16 mrad of bend in G2

Muhall

a.	450 ft long - 8 ft x 10 ft precast underground enclosure (@ 177/ft^2)	800	
b.	Access	110	
c.	Beam dump	175	
d.	Service building (30 ft x 50 ft @ 77/ft^2)	115	
Subtotal			1200

Quadrupole Enclosures

a.	21 - 7 ft x 8 ft x 25 ft underground enclosures with personnel access (@ 340/ft^2)	1250	
b.	4200 ft beam pipe and berm	850	
c.	4200 ft communication ducts	425	
d.	Hadron filter and momentum tagging underground enclosures (2 - 8 ft x 8 ft x 100 ft)	275	
Subtotal			2800

Muon Lab

a.	High bay 40 ft x 250 ft - (@ $125/ft^2)	1250	
b.	Low bay 25 ft x 250 ft - (@ $60/ft^2)	375	
c.	Crane (10 ton)	60	
Subtotal			1685

Electrical Power Modifications

a.	2 new 1.5 kV substations	200		
b.	Switchboard, panels, and transformers	150		
c.	480 volt distribution	190		
Subtotal			540	

Water System Modifications

a.	Extension of LCW lines	350	350	
Total Muon Beam				7600

2. BROAD-BAND PHOTON BEAM

H Enclosure

a.	4 electrostatic septa	90	
b.	2 3-in. dia. quadrupoles	70	
c.	Installation and Power Supplies	40	
Subtotal			200

K Enclosure

a.	4 Lambertson 2-way split magnets	120	
b.	Tunnel (7 ft x 7 ft x 100 ft long at $1400/ft)	140	
c.	Service building (with access to tunnel)	105	
d.	Beam pipe including downstream extension of 900 ft	235	
e.	Power supplies and installation	100	
Subtotal			700

EE-1

a.	4 Energy Saver dipole	200	
b.	6 Energy Saver quadrupole	230	
c.	2 Lead boxes and turnaround box	60	
d.	Transfer line (304 ft)	55	
e.	Installation + miscellaneous	55	
f.	Power supplies	150	
Subtotal			750

EE-4

a.	1 - Target box (15 m long)	500	
b.	Tunnel (7 ft x 7 ft x 50 ft long @ $1500/ft)	75	
c.	Installation	85	
d.	Power supplies	200	
Subtotal			860

Dipole Enclosure

a.	LCW and electrical installation	85		
b.	Tunnel (7 ft x 7 ft x 80 ft @ $1500/ft)	120		
c.	Entrance from tunnel to service building 3 ft wide, 2 stair labyrinth	60		
d.	Drop hatch (2 1/2 ft x 12 ft)	50		
e.	Installation and beam pipes	75		
Subtotal			390	

Broad Band Beam Enclosures

a.	LCW system and electrical installation	100		
b.	Tunnel (7 ft x 7 ft x 200 ft @ $1200/ft)	240		
c.	Escape hatch	20		
d.	Experimental hall including crane (30 ft x 200 ft with 2 ft covering berm @ $250/ft^2)	1500		
e.	Service building (30 ft x 80 ft @ $100/ft^2)	240		
Subtotal			2100	
Total Broad-Band Photon Beam Total				5000

3. MESON POLARIZED-PROTON BEAM

a.	New wonder buildings (10,000 ft^2 @ 40/ft^2)	400		
b.	Site work (concrete pads, roads)	350		
c.	Utilities and power distribution	650		
Total Meson Polarized Proton Beam				1400

iv. Ancillary Storage and Materials Handling Capability

a.	2 - 80 ft x 250 ft warehouses with supports for 50 ton cranes ($50/ft^2)	2000		
b.	Racking and storage equipment	500		
c.	2 - 200 ft x 500 ft hardstands ($2/ft^2)	400		
d.	Road extensions	400		
e.	Mobile cranes, lift trucks and rigging equipment	1000		
f.	Building cranes @ $250K each	500		
Total Ancillary Storage				4800
Total Estimated Construction Cost				31,500

Estimated costs have also been split up by category. This division is shown in Table 8-3.

Table 8-3. Tevatron 2 Costs By Category

	FY82	FY83	FY84
Energy Saver Magnets	1601	1008	0
Cryogenic Installation, Refrigerators & Vacuum	1555	918	0
Conventional Magnets, Power Supplies & Septa	2180	1225	0
Installation	685	629	0
Miscellaneous	219	1500	1000
Conventional Construction	1460	9595	8300
EDIA	2000	3000	1600

Estimates have also been made of manpower needs of the Tevatron Phase 2 project and Table 8-4 gives a summary of the manpower needs by year.

Table 8-4. Manpower Requirements

(in Man Years)

Fiscal Year	1981	1982	1983	1984
Accelerator				
R + D	5	4	3	
EDIA		5		
Construction		10		
Meson, Proton, Neutrino				
R + D	7	5	4	
Equip.	5	8	12	16
EDIA		40	50	30
Const.		20	40	30
Storage & Handling				
EDIA		5	10	10

In section 9.2 following, a description is given of the equipment funding that will be needed to implement a program of 1 TeV fixed target physics experiments. Although the detailed arrangement of technical components in any secondary beamline will depend on the experiments approved, equipment costs associated with the various secondary beams can be estimated and are detailed in Fig. 8-2. Explanation of many of these items is given in section 9.2.

Further programatic equipment funds are needed to construct new large detectors which will be approved for 1 TeV experiments. Estimates of these costs can only be inferred from present experience. Section 9.3 presents information on some of the recently constructed large detectors. They are representative and will probably be themselves incorporated into 1 TeV experiments.

Figure 8-2

BEAMLINE PROGRAMMATIC EQUIPMENT OBLIGATIONS

CALENDAR YEAR / FISCAL YEAR	1980 (OCT 1979 – OCT 1980)	1981 (OCT 1980 – OCT 1981)	1982 (OCT 1981 – OCT 1982)	1983 (OCT 1982 – OCT 1983)	1984 (OCT 1983 – OCT 1984)	1985 (OCT 1984 – OCT 1985)
M1 to 1 TeV Pion Beam		$120	$700			$1500
M2 to 1 TeV Polarized Beam			$230	$800	$400	
M6 Upgrade						
M6W 600 GeV	$135	$300				
M6W 1 TeV				$800		
M6E 500 GeV					$200	
Cryogenic & Power		$460	$413	$700	$733	$600
Meson Subtotal	$135	$880	$1343	$2300	$1333	$2100
N0 to 1 TeV		$115				
Dichromatic Beam (750 GeV)		$400	$445	$300		
N7/N5 Hadron Beam (relocated)		$665				
Beam Dump			$1000			
Muon Beam			$750	$1555	$300	$400
Neutrino Subtotal		$1180	$2195	$1855	$300	$400
P-West Upgrade	$55	$745	$735	$850	$410	$300
Broad Band Beam		$25		$530	$860	$530
Shielding (broad band beam)					$1500	$500
P-Center New Channel	$265				$525	
Tagged Photon Upgrade	$175					$570
Cryogenics & Power				$660	$660	$660
Enclosure H	$35	$660	$415			
Proton Subtotal	$530	$1430	$1150	$2040	$3955	$2560
	665 / 3490 / 4155	3490	4688	6195	5588	5060

9. OVERVIEW OF THE 1-TEV FIXED-TARGET PROGRAM

9.1 Operating Scenario

9.1.1 Startup. The commissioning of the Tevatron experimental areas is distinctly different than the commissioning of the Energy Saver accelerator. For the accelerator it will be necessary to have all the major systems operating at some level to achieve any beam. For the experimental areas, it will be possible to bring up any one of the areas independently. Indeed, individual beam lines can and will probably be brought into operation independently once the extraction line to an area is operating. It is also true that most of the secondary-particle beams can be operated with no modification at all when the Tevatron first comes into operation. The yield of particles in a secondary beam operating at the present energy will be substantially increased when the energy of the primary protons is more than doubled.

The actual order in which the individual areas and beams will be brought into operation will depend on the scientific program. That program will evolve over the next several years from proposals made by individual experimental groups around the world and by the actions on these proposals by the Fermilab Physics Advisory Committee. The program will be tailored to respond to the needs of commissioning while optimizing as much as possible the physics research. As an example, if the accelerator beam intensity is less than maximum in the initial operating phase, it may be better to concentrate on hadron physics initially at the expense of neutrino physics, which usually requires higher intensity.

With the caveat that the approved program will determine the actual turn-on, it is still possible to consider the optimum turn-on program from the standpoint of ease of commissioning.

Perhaps the easiest area to bring into operation will be the Neutrino Area. Very few switchyard elements are needed to bring the beam straight into this area. The existing neutrino trains are capable of operating with substantially increased yield. The muon shield will have already been hardened and will be effective at Tevatron energies. In addition, all the existing sophisticated neutrino detectors will work effectively. With the schedule shown in Fig. 9-1, it will be possbile to start experimental operation in October 1982, when the Neutrino part of the Switchyard is completed.

Operation of the Proton and Meson Areas will be possible after the completion of their Switchyard installations in October, 1983. The new Muon Area will be the last to come into operation, in October 1984. It requires the construction of both a new beam and a new experimental area. Individual beams in the Meson and Proton areas will also follow by some time the commissioning of the two areas. The polarized-proton beam and facility that will be built jointly with the Argonne National Laboratory will be completed in the fall of 1984. The broad-band photon beam in the Proton Laboratory will also be completed about the same time.

The 1 TeV protons available from the Tevatron will be the most energetic particles available in any laboratory in the world for many years to come. Each pulse from the Tevatron will deliver 2×10^{13} protons with a spill for experiments of one to ten seconds. Fast spills of the order of approximately 1-msec length will also be available for neutrino experiments.

9.1.2. <u>Steady State</u>. Both the Tevatron fixed target program and the colliding-beams experiments will make use of the Tevatron. The programs are complementary, the Tevatron fixed-target program will operate with a wide

Figure 9-1

TEVATRON PHASE II SCHEDULE

	FY1981	FY1982	FY1983	FY1984
Extraction	Studies	Design, Fabricate	Commission	
Neutrino Laboratory				
Switchyard		Procure & Fabricate		
Detector Building		Design	Construction	
N0 Shielding			Studies, Design	Construction
Muon Beam	Studies	Design		
			Construction	
Proton Laboratory				
Switchyard	Studies	Design & Const.		
Enclosure H		Proc. & Fab.		
Targeting PW, PE	Studies	Design, Construction		
Broad Band Beam		Studies, Design	Construction	
Meson Laboratory				
Switchyard & Meshall		Design, Proc. & Fab.	Comm.	
Target Building	Studies	Design	Construction	Comm.
M6 Enclosures			Design, Construction	
Polarized Proton Beam		Studies	Design, Construction	
Storage and Handling				
Building #1		Design	Construction	
Building #2			Design	Construction
Handling Equipment		Procurement		

'Studies' include R&D and Conceptual Engineering and Physics Calculations needed to define the design and construction criteria.

diversity of beams of different particles, while the collider will provide proton-antiproton interactions at the highest possible energies. It will only be possible to operate one of these programs at a time and it will therefore be necessary to alternate between them. It is expected that the fixed-target program will operate approximately half of each calendar year.

When the Tevatron Phase 2 project is completed and the fixed target areas are completely commissioned, the individual areas will operate independently. It will be feasible to turn off individual areas and indeed, even individual beams, to install equipment while the other areas continue to operate. The P-East branch is an illustration of this added flexibility. In the existing configuration, the broad-band photon beam experimental pit cannot be entered when the tagged photon beam is operating. After Tevatron Phase 2 is completed, these beams will operate completely independently.

Most of the Tevatron era beams will be able to make use of higher proton intensities than those now used for the same beams. This proton hunger is due to several factors. Beam-targeting systems will have been hardened. The spill length increase from 1 sec to 10 sec will allow many duty-cycle-limited experiments to increase their requests. Physics interest at the Tevatron will be concentrate on the very highest energies, where the secondary particle yields are perforce smaller. As a result, more protons will be needed to get to reasonable secondary intensities. Finally, increasing interest in high-P_t physics, where cross sections are smaller, mandates more intense beams. For these reasons it is expected that there will be continuing pressure for intensity increases.

9.2 Equipment Related to the Tevatron Phase 2 Project.

For most beams, the presently existing components will be able to operate initially with a substantially increased beam intensity, although at lower energies than are feasible with the Tevatron. To a large extent the beams will be improved for higher energy using equipment that presently exists at the Laboratory such as magnets, power supplies, and utilities distribution and control system. The exact configurations of the technical components of the secondary beams will be tailored to the requirements of the specific 1 TeV fixed target research proposals. The same situation prevails for many of the major detectors that will be used at the Tevatron. Existing detectors will either be used as they are or improved to make use of the higher energies. These beams and detectors will continue to be modified and improved throughout the life of the Tevatron research program. In view of these facts, a large part of the equipment for secondary beams and detectors will be purchased using "equipment not related to construction" funds, rather than be included as a part of Tevatron Phase 2. (See Fig. 8-2 above.) Some possible areas of significant equipment acquisitions are:

(i) Broad-band photon beam. A new broad-band photon beam is being developed under Tevatron Phase 2. The secondary beam components in this beam depend on the details of the physics proposed for this beam and will be procured with equipment funds. To exploit this flexible new beam fully, it will be necessary to develop a large spectrometer somewhat along the lines of the detector already operating in the Tagged Photon Laboratory.

(ii) Improvement of P-West. Plans exist for ultimately raising the energy of P-West to 1000 GeV. These plans make use in part of special low-current, large-aperture magnets that have been developed for general use in the research areas. Full exploitation of P-West will eventually require use of these magnets.

(iii) Muon Laboratory Detector. An entirely new muon beam and muon laboratory are being developed for the Tevatron fixed-target program. This beam will have the highest energy and intensity of any muon beam in the world. The compnents in the secondary muon beam will be equipment expenditures. Sufficient laboratory spare will exist so that several experiments can be mounted in the beam. It is possible that one of the detectors will be built on the framework of a detector from the present muon beam, but it is quite likely that an entirely new detector will need to be developed to explore fully the range of muon physics that will become accessible with the Tevatron.

(iv) Polarized-Proton Area. The polarized-proton area is being developed as a joint project with Argonne National Laboratory. The Tevatron Phase 2 project will cover much of the conventional-facility development for this area. Argonne will bring the magnet elements for the beam and some elements of the detector. As the detector matures, additional equipment will be necessary.

(v) M6-East Multiparticle Spectrometer. It is quite likely that a new large multiparticle spectrometer will be developed in M6-East in the future. A logical candidate for the vertex magnet for such a system may be the converted 30-in. bubble-chamber magnet. That magnet is currently being modified to superconducting operation as an energy conservation project. Additional equipment funds will also be necessary to bring an adequate secondary particle beam into this enclosure.

9.3 Some Typical Detectors

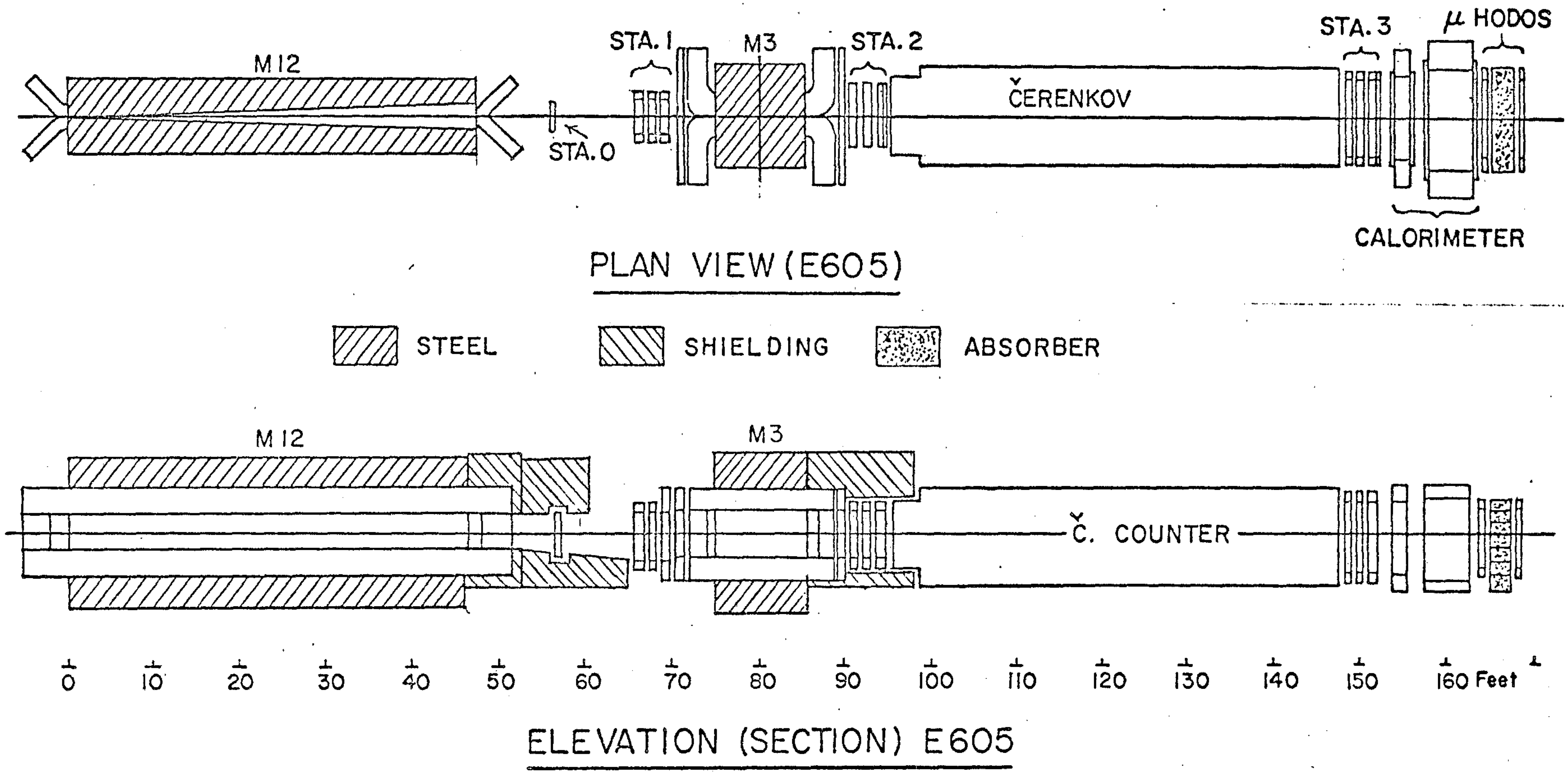
In this section we review some of the large detectors built recently as part of the 400-GeV fixed target program. It is expected that many of these detectors will be used for measurements at the higher energies provided by the Tevatron. They are also typical of the detectors that might be built with programmatic equipment funds in the Tevatron era.

(i) E-605. A Dilepton and Hadron Spectrometer Facility. The current E605 design shown in Fig. 9-2 includes two large-aperture magnets utilizing the steel from the yoke of the decommissioned Nevis Cyclotron. The first magnet weighs 1500 tons and is followed by a smaller 500-ton magnet. With pole inserts, the field strength in the upstream magnets ranges from 30 kG to 15 kG along its length.

Five planes of scintillation counters are used to form a fast trigger at the first three stations, with approximately 50 phototube counters at each station. In addition, a total of 20 planes of chambers will be used, an avalanche chamber, proportional wire chambers, and drift chambers. The total number of wires for the drift chamber system is approximately 2400 and the expected resolution is 0.2 mm.

At the downstream end of the apparatus, beyond a particle defining Cerenkov counter, a calorimeter and muon hodoscope for electron, hadron, and muon identification will be located. The calorimeter is composed of 20 radiation lengths of lead and 10 interaction lengths of steel. The current estimated cost for this apparatus and the M1 beam improvements required by the experiment is $5 million. Only minor modifications are needed to adapt this apparatus to 1 TeV.

(ii) E-537. Multiparticle Lepton Spectrometer. The current layout of E-537 shown in Fig. 9-3 includes a large-aperture conventional analysis magnet, with a gap of 36in. x 72in. x 60in., an operating field strength of 15 kG and a massive copper hadron absorber-beam dump approximately 60 in. long. The muon detector, consisting of an iron and concrete configuration weighing 350 tons interleaved with 342 scintillation counters, is downstream of this point. The drift chamber array consists of 4 sets of three planes totaling 2200 wires. There are additional proportional wire chambers and beam chambers adding



M12
STA. 0
STA. 1
M3
STA. 2
ČERENKOV
STA. 3
μ HODOS
CALORIMETER
PLAN VIEW (E605)
STEEL
SHIELDING
ABSORBER
M12
M3
Č. COUNTER
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160 Feet
ELEVATION (SECTION) E605

FIGURE 9-2

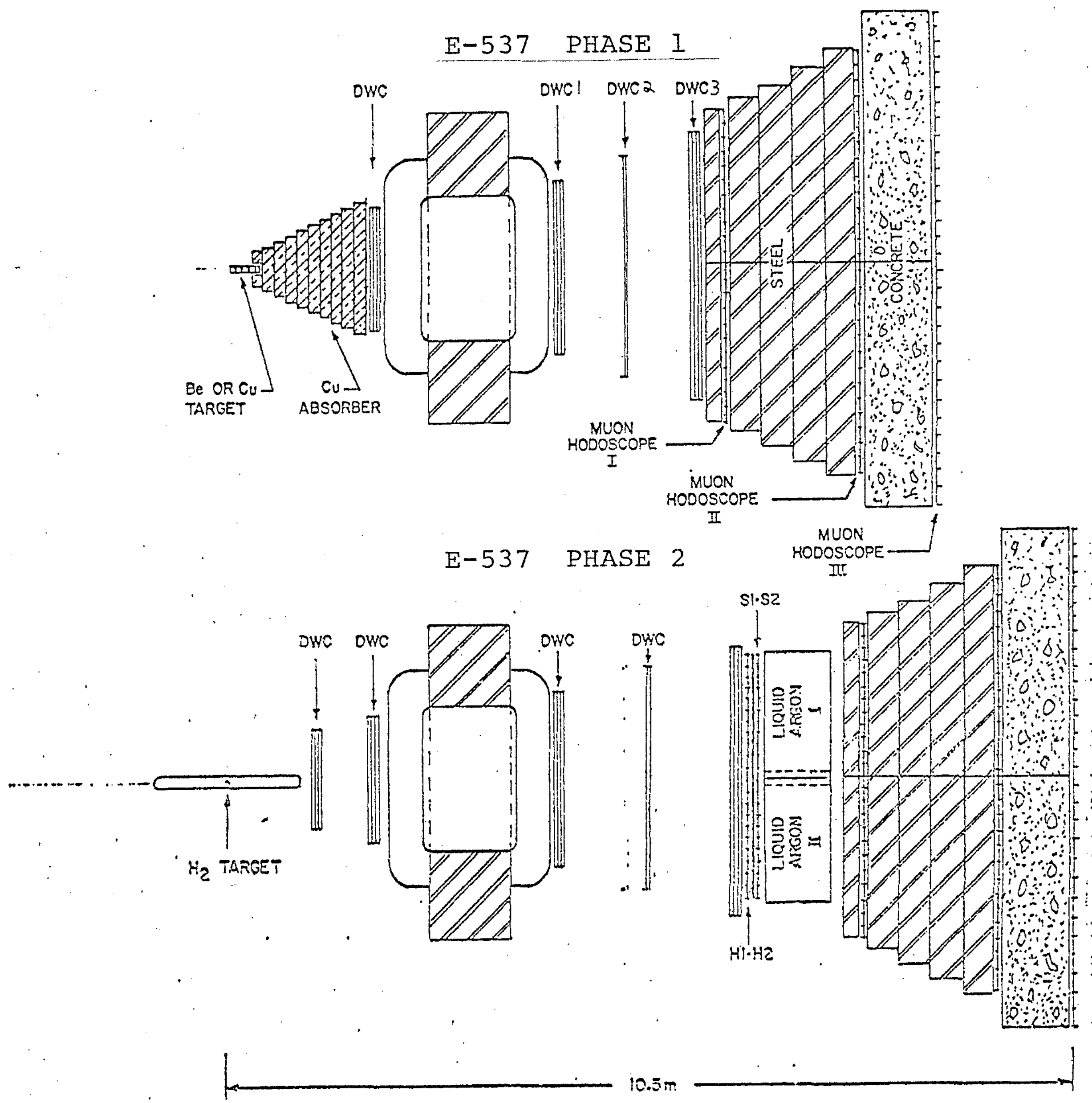

E-537 PHASE 1
DWC
DWC 1
DWC 2
DWC 3
STEEL
CONCRETE
Be OR Cu TARGET
Cu ABSORBER
MUON HODOSCOPE I
MUON HODOSCOPE II
MUON HODOSCOPE III
E-537 PHASE 2
S1·S2
DWC
DWC
DWC
DWC
LIQUID ARGON I
LIQUID ARGON II
H_2 TARGET
H1·H2
10.5m

FIGURE 9-3

4 sets and 2200 wires to the counter arrays. The current cost of this system is nearly $2 million.

(iii) E-610. Multiparticle Hadronic Detectors. This apparatus, shown in Fig. 9-4, contains beam-defining counters in an eight-element hodoscope. The veto counters consist of 20-cm square proportional wire chambers with 2-mm wire spacings. Additional counters upstream of the Magnetic Spectrometer consist of 10 multiwire proportional chambers, each 80 cm x 80 cm and 110 cm x 120 cm. This spectrometer includes the Chicago Cyclotron Magnet, which has a gap of 1.29m and pole tip diameter of 4.32m. It operates at a magnetic-field strength of 10.5 kG. Downstream of this magnet is an 18 cell Cerenkov counter surrounded by 2 planes of 1.2 m x 2.4 m drift chambers. The apparatus also includes scintillation counter planes, a 100-element lead glass array immediately followed by an Iron Hadron Absorber, and muon trigger counters. The current cost of this system is $1.5 million.

(iv) E-497. Hyperon Beam Facility. The 400-GeV hyperon facility in Proton Center, shown in Fig. 9-5, includes the large Hyperon Target Magnet (290 in. x 28 in. x 17 in.) operated at 35.7 kG, high-resolution beam detectors and a variable Hyperon decay region and detector apparatus. The target magnet provides a primary beam target, a dump for the primary beam and unwanted secondaries, and deflection of downstream charged muons. Beyond the Hyperon Decay Region is the Decay Spectrometer, consisting of 3 proportional wire planes (152 wires in a doublet array), a decay region, and a spectrometer to reconstruct the hyperon decay. The spectrometer includes 2 BM109 analyzing magnets with 6 clusters of drift chambers. At the end of the beam line, a neutron detector and proton hodoscope detect the decay baryon. The current cost of this system is $1.5 million.

E-610 SPECTROMETER

1 BEAM CNTRS, MWPC S
2 13 / BE TARGET
3 80CM X80 CM MWPC S
4 110CM X120 CM MWPC S
5 CHICAGO CYCLOTRON MAGNET
6 150 CM X240 CM DRIFT CHMS
7 18 CELL CERENKOV COUNTER
8 SCINTILLATION COUNTER PLANE
9 PB GLASS CONVERTER ARRAY
10 PROPORTIONAL TUBE ARRAY
11 100 ELEMENT PB GLASS ARRAY
12 FE HADRON ABSORBER
13 MUON TRIGGER COUNTER ARRAY
14 FAST ELECTRONICS RACKS

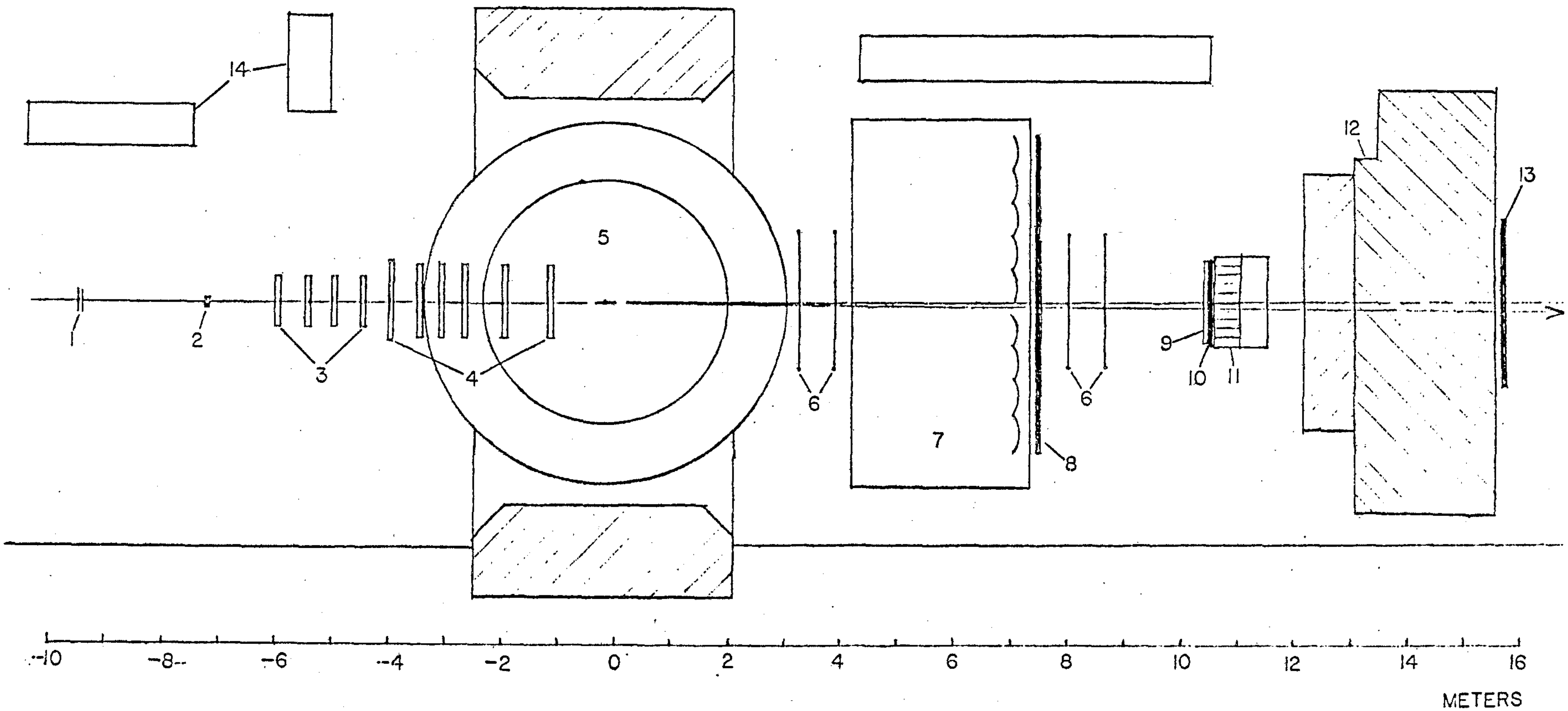
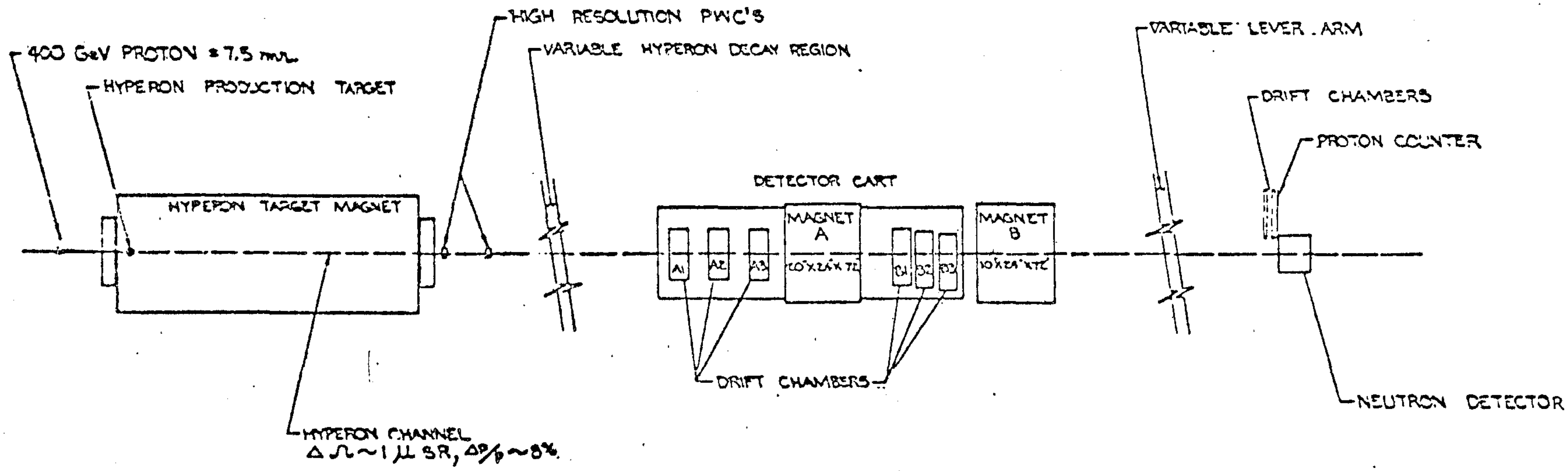


Figure 9-4

HYPERON FLUX MEASUREMENT



NEW PARTICLE SEARCH

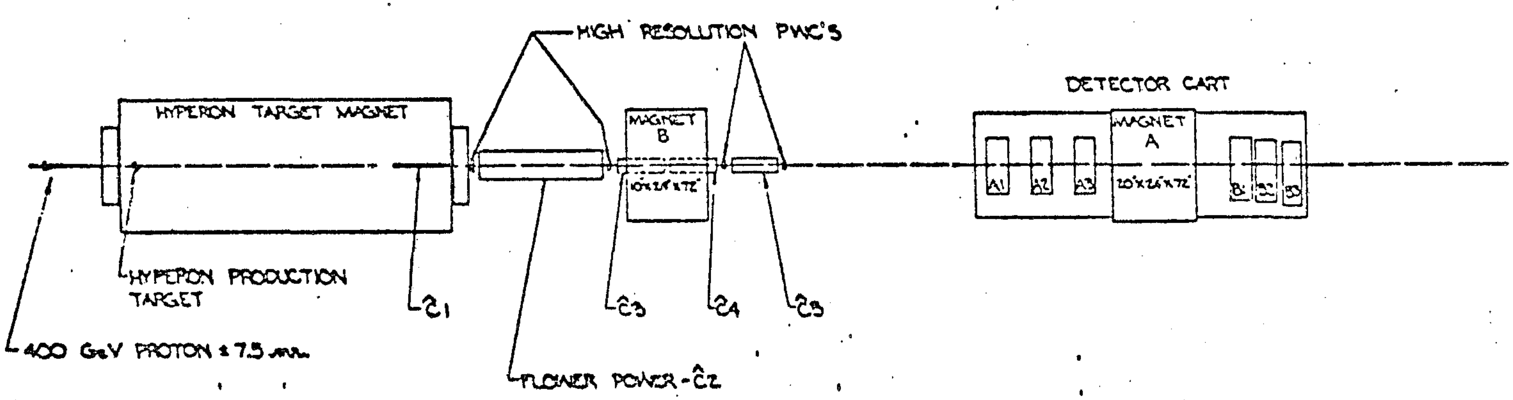


FIGURE 9-5

(v) E-516. Tagged Photon Magnetic Spectrometer The recoil system shown in Fig. 9-6 will measure the momentum of particles recoiling from the hydrogen target. In addition to the recoil detector, two large analysis magnets with field strength of 5 kG are located in the upstream end of the apparatus. As part of the particle-identification system, charged particles are tracked in the forward spectrometer by 32 planes of drift chambers, some of which are sandwiched between two large Cerenkov counters. The drift chamber system contains about 4000 cells total. The two segmented Cerenkov counters record approximately 15 photoelectrons from a single minimum ionizing particle. There is a segmented liquid scintillator shower counter, containing about 16 tons of lead which is 22 radiation lengths long, located just upstream of the hadrometer, a steel absorber, and muon counters. The hadrometer is divided into four sections, each containing 32 steel plates 1 in. thick, and 16 strips of acrylic scintillator, each 0.5 in. thick and 4 in. wide. The total cost of this facility is nearly $2.5 million.

9.4 Future Possibilities

For many years to come the Tevatron fixed target areas will offer the highest energy beams of pions, photons, hyperons, neutrinos, muons, and electrons available. Interactions of these secondary particles permit study of many phenomena that are inaccessible to collider facilites. Much of the present knowledge of particle physics has come from studies with beams of these types. The factor of 2.5 in primary-beam energy from 400 GeV to 1 TeV corresponds to the net jump from Serpukhov energies to initial Fermilab operation. That earlier jump opened many new opportunities in particle physics.

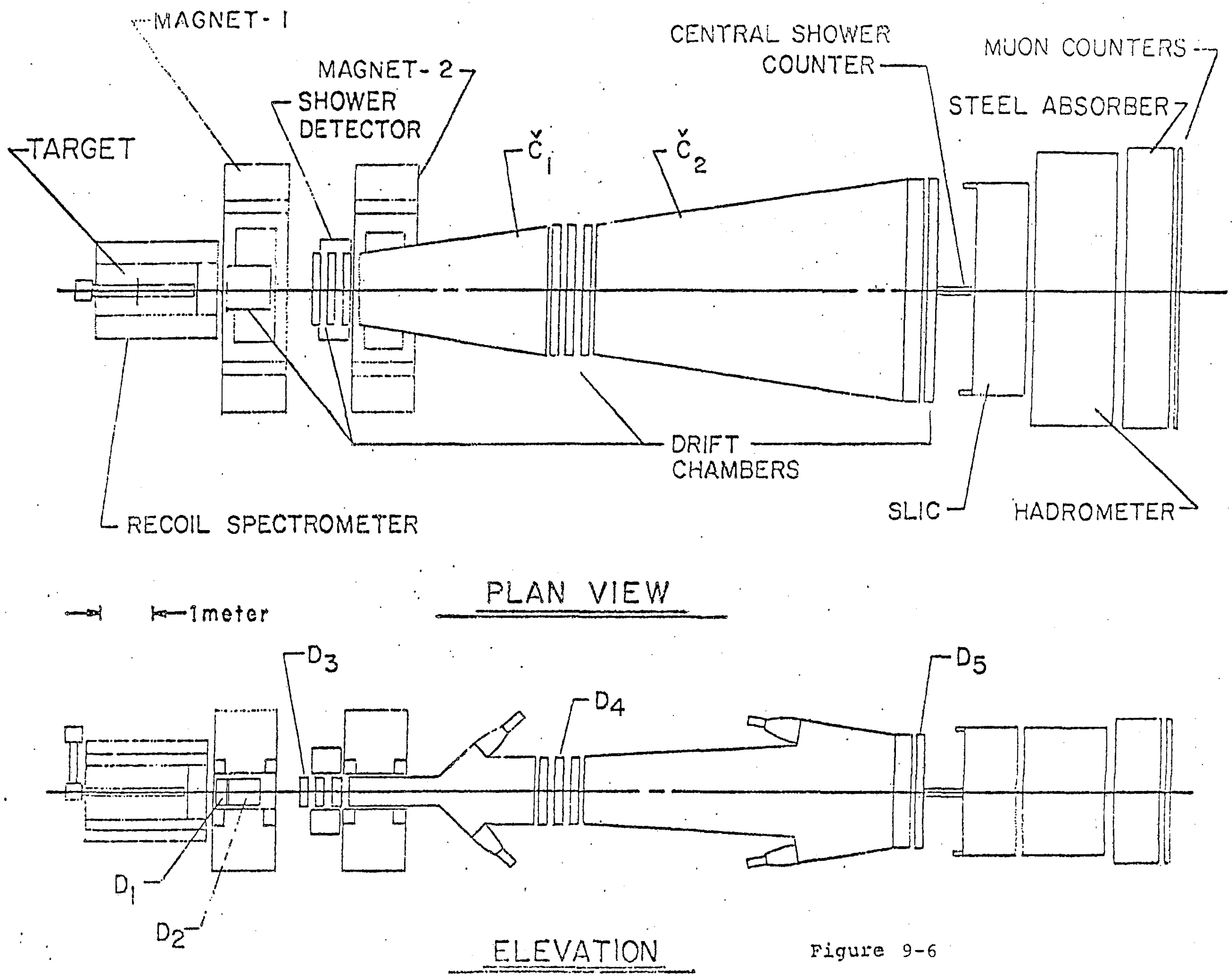

MAGNET-1
MAGNET-2
SHOWER DETECTOR
TARGET
CENTRAL SHOWER COUNTER
MUON COUNTERS
STEEL ABSORBER
Č1
Č2
DRIFT CHAMBERS
RECOIL SPECTROMETER
SLIC
HADROMETER
PLAN VIEW
1meter
D3
D5
D4
D1
D2
ELEVATION

Figure 9-6

With this jump in energy, one cannot be sure of what possibilities will be opened up. For example, charm and other short lived particles will have longer path lengths in the Laboratory. These longer path lengths, coupled with some advances in detectors that are on the horizon, may revolutionize the investigation of short-lived particles.

The beams and facilities that are included in the Tevatron Phase 2 project for the fixed target experimental areas are reasonably general and flexible. Many possibilities for future Tevatron facilities can be developed directly on the frameworrk of the original set of beams. Indeed, there are very few types of fixed target experiments that cannot be done using the proposed facilities or at most simple future modifications of them.

A facility that could be contemplated is a beam-dump area for prompt neutrino beams. Such a facility would offer the possibility of a tau neutrino beam mixed with neutrinos from charm decay. In addition, 400-GeV dump experiments have given tantalizing hints of possibily new phenomena. At present, a new beam-dump experiment is being mounted in the Meson Area and studies are underway on the possibilities of such experiments in the Neutrino Area. When the Meson experiment is further along and the studies are complete, it may proved useful to develop such a facility. With the Tevatron Neutrino Area, it will be feasible to incorporate a beam dump upstream of the existing neutrino detectors. Such a facility will probably require large amounts of magnetized steel. The Laboratory is already investigating possibilities for acquiring such steel.

Full exploitation of the broad band photon beam is another possibility for future development. The beam line has been designed so that it has the possibility of delivering a large number of particles species other than photons. A later program might be directed toward the full development of that flexibility.

APPENDIX

SCHEDULE 44

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CHICAGO OPERATIONS AND REGIONAL OFFICE
Field Office

HIGH ENERGY PHYSICS
FERMI NATIONAL ACCELERATOR

1. Title and location of project:
Tevatron, phase II
Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No.
82-CH-101

3. Date A-E work initiated: 1st Qtr. FY 82

3a. Date physical construction starts: 2nd Qtr. FY 1982

4. Date construction ends: 4th Qtr. FY 84

5. Previous cost estimate: ($49,000)
Date: 3/27/79

6. Current cost estimate: $46,500
Less amount for PE&D: $800
Net cost estimate: $45,700
Date: March 20, 1980

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1982	$45,700	$12,500	$12,500	$10,300
1983	0	20,000	20,000	19,500
1984	0	13,200	13,200	15,900

8. Brief Description of Project

This project, TEVATRON, Phase II, provides necessary facilities for a 1 TeV fixed target experimental program to fully exploit the higher energy of the superconducting accelerator, the TEVATRON. The elements of this project are:

a) The construction of a slow extraction system for the 1 TeV accelerator, the TEVATRON.

b) The upgrade of the external beams switchyard to 1 TeV and the provision for 1 TeV targetting in the present external experimental areas.

1. Title and location of project:	2. Project No.
Tevatron, phase II Fermi National Accelerator Laboratory, Batavia, Illinois	82-CH-101

8. (continued)

c) The construction of new secondary beams in each external experimental area, and support facilities, in order to fully exploit the fixed target physics opportunities of the TEVATRON. The total number of secondary beams will not be increased since the new beams will replace existing beams.

This project provides for the installation in FY82 of the various electrostatic septa, septum magnets, kicker magnets and other specialized components which are needed to extract the 1000 GeV protons into the existing beam branching switchyard. Provision will be made for slow resonant extraction (1 to 10 secs) which is required for electronic detector systems and for the fast resonant extracted beam (1 to 3 ms.) which is preferred for neutrino experiments.

Additional septa, bending magnets, focussing magnets and ancillary components which are necessary to transport the 1 TeV protons to the three external experimental areas are also included. Additionally, the target stations and experimental facilities of all three areas will be modified to optimize the handling of the 1 TeV proton beams and to permit full utilization of the increase in secondary particle energies produced in the existing secondary beam lines. Beam lines with necessary enclosures will be added to each laboratory to fully exploit the unique opportunities presented by 1 TeV protons on external targets. Ancillary storage and materials handling capability will be provided for the improvement of efficiency and flexibility of the conduct of experiments.

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9. Purpose, justification of, need for, and scope of project

The Fermilab 1 TeV accelerator will provide a unique opportunity for producing secondary particle beams at higher energies and intensities than anywhere else in the world. The Tevatron fixed target program will give Fermilab international leadership for many years. It will be possible for scientists to use and extend this facility to study many new phenomena involved in the fundamental interactions of matter. Study of these phenomena are at the heart of our understanding of the most significant natural processes.

The collision of 1 TeV protons with nuclear targets will provide an intense source of muons, electrons, neutrinos, mesons, and baryons with which to study the emerging pictures of the weak, electromagnetic and strong interactions of the fundamental constituents of matter. In each of the three existing external laboratories at Fermilab, many new research opportunities will be possible at 1 TeV. The gain in the event rate of energetic interactions and the factor of 2 increase in the energy of the proposed muon beam will allow detailed measurements of quark structure functions of protons and neutrons and sensitive tests of quantum chromodynamics (QCD) predictions of their energy variations. The careful measurement of high energy neutrino charged and neutral current interactions will test the unified description of the weak and electromagnetic interactions of leptons, including the predicted damping of the total cross sections due to the postulated effect of the intermediate vector boson.

The production and study of heavy quarks is greatly enhanced at higher energies. The combination of high energy and advanced detector technology makes it possible to study particles with lifetimes as short as 10^{-13} seconds. It will be possible to study charmed mesons in detail. One TeV energies and these techniques may be the only practical way to study b-quarks.

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9. (continued)

The studies of the strong interaction dynamics of quarks will be enhanced by the increased energies available in hadronic interactions, as well as the improved duty cycle of the TEVATRON which permits greater average secondary beam intensities. Observations of particle jet phenomena, and measurements of fundamental properties and polarization phenomena of hadrons become easier and more decisive at higher energies. The increased fluxes open new domains in the study of high transverse momentum interactions. Studies of high transverse momenta, which imply small impact parameter scattering, will be crucial in the elucidation of the correct dynamics of quarks and gluons.

The TEVATRON fixed target program, in reaching new energy and sensitivity thresholds, may uncover new phenomena. The Higgs boson, a required particle in present field theories, may be seen in dilepton searches. It is possible that the top quark may be observed in neutrino interactions.

The TEVATRON, Phase II project is necessary to fully exploit the physics potential of the Energy Saver/Doubler. Without the project the Energy Saver will indeed be able to effect significant energy conservation. However, the important possibilities of more than doubling the energy available to study a large species of elementary particle collisions would be lost. Any delay of the Phase II project would seriously compromise U.S. leadership in the study of fundamental interactions at high energies. In Europe, the CERN SPS program, a similar effort to the present Fermilab 400 GeV program, funded at twice the level of Fermilab, is making continued competition at present energies increasingly difficult.

Tevatron energies and intensities imply a new level of size and scale of experimental equipment. The facilities of the laboratory for handling and storage of Tevatron experimental equipment will become inadequate due in part to the increased weight of new components. This project will eliminate these inadequacies by providing storage, increased hard-stand area and improved component handling capability throughout the laboratory experimental areas.

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HIGH ENERGY PHYSICS
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10. Details of Cost Estimate*

	Item Cost	Total Cost
a) Engineering, Design and Inspection at approximately 21% of construction costs		$ 6,600+
b) Construction Costs		31,500+
i) Extraction System	$ 1,700	
ii) 1 TeV construction and modification of existing facilities		
Meson Laboratory	5,000	
Neutrino Laboratory	2,300	
Proton Laboratory	3,700	
iii) Conventional Beam-line Construction		
Meson Lab Beam	1,400	
Neutrino Lab Beam	7,600	
Proton Lab Beam	5,000	
iv) Ancillary Storage and Materials Handling Capability		
Storage Facilities	1,000	
Racking and Storage Equipment	500	
Hardstand and Roads	800	
Heavy Equipment Handling Devices	1,000	
Cranes and supports	1,500	
c) Contingency at approximately 20% of the above costs		7,600
Total		$45,700+

*Based on conceptual design
+Escalation is included (15% in FY81, 12% in FY82, and 10% in FY83).

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11. Method of Performance

Design of facilities will be by the operating contractor and subcontractor as appropriate. To the extent feasible, construction, procurement and installation will be accomplished by fixed-price subcontracts awarded on the basis of competitive bidding.

12. Incorporation of Fallout Shelters in Future Federal Buildings

Efforts will be made to slant the design of any suitable buildings to incorporate shelters at no additional cost to the project.

13. Incorporation of Measures for the Prevention, Control, and Abatement of Air and Water Pollution at Federal Facilities

This project consists of devices to extract the 1-TeV beam from the TEVATRON accelerator in the existing Main-Ring tunnel, magnets and beam-splitting septa to transport the 1-TeV beam through the existing switchyard tunnels to the primary target stations, target devices and shielding appropriate for 1 TeV, additional shielding for secondary beam lines appropriate to higher-energy secondary particles, and modificatins of experimental stations appropriate for higher energies. Radiation shielding will be adequate to reduce levels outside to less than those allowed for the general public. Power and cooling for all parts of the project will be supplied by existing Fermilab facilities.

The operation of the project will not generate environmental pollutants; therefore, the requirements of Executive Order 11752 are considered to have been met in which case an environmental impact statement is not required.

14. Evaluation of Flood Hazards

These projects will be located in an area not subject to flooding as determined in accordance with the requirements of Executive Order 11296.

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15. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY1982	FY1983	FY1984	Total
A) Total Project Funding					
1) Total facility costs					
a) Construction Line Item	0	10,300	19,500	15,900	45,700
b) PE&D	800	0	0	0	800
c) Expense Funded Equipment	0	0	0	0	0
d) Inventories	0	0	0	0	0
Total facility costs	800	10,300	19,500	15,900	46,500
2) Other project funding					
a) Direct R&D operating costs necessary to complete constr.	900	700	500	0	2,100
b) Other project related costs	2,000	800	2,000	1,000	5,800
Total other project funding	2,900	1,500	2,500	1,000	7,900
Total project funding (items 1 & 2)	3,700	11,800	22,000	16,900	54,400

B) Total Related INCREMENTAL Annual Funding Requirements (estimated life of project: ~~10~~ 20 years)

1) Facility operating costs	~~$20,000~~	3,000
2) Programmatic operation expenses directly related to the facility	~~15,000~~	4,000
3) Programmatic equipment costs	~~15,000~~	7,000
4) GPP, AIP programmatic costs	~~4,000~~	2,000
Total	$54,000	12,500

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16. Narrative Explanation of Total Project Funding and Related Funding Requirements

A) Total Project Funding
1) Total facility costs
a) Construction line item: The scope and justification for this project has been described earlier in this schedule.
b) PE&D expense: An earlier allocation of $800K was made to cover conceptual planning and design for this project.
c) Expense funded equipment: There is no expense funded equipment for this project.
d) Inventories: There are no inventory expenses planned for this project.

2) Other project funding
a) R&D operating costs: A program of development is underway to adapt energy saver dipole and quadrupole magnets and refrigeration systems to the existing physical plant in the Meson, Neutrino and Proton areas. The target handling and muon shielding requirements associated with 1 TeV energies are also being studied. Further studies are being undertaken to increase the intensity capabilities of the Tevatron accelerator in order to further improve the research potential of the 1 TeV fixed target program.

b) Other project related costs: This schedule covers principally the construction and modification of the experimental areas, extraction systems, and primary beams for 1 TeV Tevatron operation. For most beams the presently existing components will be able to operate initially with a substantially increased beam intensity, albeit lower energies than are ultimately feasible with the Tevatron. The exact configurations of the technical components of the secondary beams are tailored to the requirements of the specific 1 TeV fixed target research proposals recommended to the Director by the Fermilab Physics Advisory Committee. The requirements evolve as the program comes into operation and continue to change throughout the life of the program. Most of the equipment installations for secondary beams that

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.6. (continued)

have applications to the Tevatron program are also useful at present energies. Most frequently, the changes are in the direction of continuing to raise the energies of the secondary beams. For this reason the secondary beam development is to be handled on "equipment not related to construction" funds.

B) Total Related Incremental Annual Funding

1) Facility operating costs
The fraction of the total Fermilab operating expenditures that relates directly to the 1 TeV fixed target program will increase from one quarter in FY82 to about three quarters in FY84 and beyond. The operating funds needed follow closely the experience of the existing 400 GeV program. ~~This follows from the assumption of approximately 7 months of external beam operation per year and the same number of secondary beam lines and experimental research stations as currently exist~~.

2) Programmatic operations expenses include R&D
Same as 16.B.1 above.

3) Programmatic equipment costs
The Tevatron fixed target program will require an increase in the annual equipment budget beyond the present funding of the research program. This will be particularly true in the early years of the Tevatron when new equipment will be necessary to upgrade some detectors, to build entirely new detectors, and to add additional beam line equipment. The level of incremental funding which is requested is equivalent to the incremental request for the present fixed target program.

4) GPP, AIP programmatic costs
The incremental GPP and AIP funds needed will follow closely the experience of the existing 400 GeV program.

~~W~~ It is expected that the savings in electrical power consumption in the superconducting external beam-line and analysing magnets will be offset by ~~the~~ increased expenditures for cryogenic liquids and cryogenic system maintenance. ~~The~~ However, the increase in scheduled beam hours to the fixed target program ~~raising~~ from ~~the~~ from the present 25 weeks of operation to about 30 weeks will ~~necessitate~~ require ~~an entry~~ incremental funding in facility operating costs.

The increased facility usage will require additional funds for programmatic R+D and experimental facility operating costs.