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Revised Calibration Beam Design

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I. Introduction

The needs and justification of test-beams for the SSC have been described elsewhere [1].

The test-beam switchyard and calibration hall is located in the west campus site and the muon vectors remain confined in the west campus, see Fig. 1. The SCDR [2] describes a possible scenario for a test-beam layout at the SSC. It foresees 3 beams at 200 GeV each with allowance for a future 3 beams at 2 TeV, all ending up in the same calibration hall. The footprint (Fig. 2) calls for a rather wide calibration hall since all three beams may be 200 GeV or 2 TeV. The layout is limited to 3 beams and a future upgrade to more beams would require a split of the beams far upstream and new beamlines as well as new calibration halls. A main feature of the SCDR design is its construction as cut and cover with the exception of a tunnel of approx. 800' to climb out of the MEB and come close to the surface. A profile is presented in Fig. 3.

Fig. 3 also shows new, very likely elevations of the HEB and MEB as solid lines. These new elevations would affect the SCDR design by increasing the cost by approximately 1.1 million dollar for increased tunnel length. The whole footprint would be shifted by the same length (by stretching the primary beam) with no additional influence, e.g. muon shielding after the calibration hall.

For the time being the actual requirements of the experiments are not known. We tried however to work through several designs in order to understand the problems involved. In this report we summarize our experience in two possible scenarios, dubbed "short" and "long" version, which could serve as a basis for a design of the actual test-beam facility at the SSC. Both versions have an upgrade potential from three to six 200 GeV beams with minimal additional civil construction and merely an enlargement of a modest calibration hall. The price tag is a limitation to only 2, instead of 3, 2 TeV beams. In contrast to the SCDR, we tried to provide level secondary beams, as some experimenters expressed a strong feeling for level beams. In a first phase three 200 GeV beams would be built with an easy upgrade of an additional 2 TeV beam.

The short version is a maximum cost saving option. It forfeits the possibility of accommodating the 2 TeV beams in the same switchyard. The 2 TeV beams would be completely independent, and therefore, very expensive upgrade. This short version was just studied in order to see at what minimal cost some beams could be provided at the SSC.

The long version represents our favorite solution for the time being. Without the 2 TeV tunnel connecting the HEB to the MEB, it can be built at about the same costs as the SCDR version.

The total extracted beam from the MEB is 2.3E18 protons per year (5 x 10E11 protons/pulse, 15 pulses per min, 5000 hrs operation/year). The slow spill cycle time is 4 sec, flat-top is 1 sec.

These latter SCDR parameters as well as the energy of the MEB will be different in the actual design. The energy of the MEB was lowered to 180 GeV in order to save on power for accelerator operation. For test-beam operation however occasional ramping to 200 GeV will be provided in order not to lose on electron yield (see section 7). The total extracted beam however will be the same order of magnitude.

2. Beam Requirements and Specifications

The test-beam requirements and specifications represent a consensus of the physics community and have been worked out at workshops like Snowmass [3]. Here we just summarize the main issues to have the information at hand.

Two important issues to be addressed in calibration beams are lepton identification (both electron and muon), and jet energy measurement and resolution. Leptons are among the most important signatures of many physics topics to be studied at the SSC and therefore one wishes to study the full energy range available. Jets on the other hand consist mainly of a collection of low energy (1 to 50 Gev) hadrons. Thus, calibration of calorimeters at the low energy end is important. Some jets may however have leading particles. In order to study mis-identification of pions as muons, a pion beam over the full energy range should be available.

Should no 2 TeV beams be available, the energy deposition may be studied by using bunches of e.g. ten 200 GeV protons. This simulation may be useful but does not permit a study of the complete response, e.g. the shower development, of a calorimeter.

To study lepton identification, fluxes of 100 to 1000 Hertz for each particle type (electrons, muons and pions), over the full energy range, should be available. The minimum flux at which useful data could be taken is about 1 Hertz.

Some experiments may want to use the primary protons directly so that the magnets must be able to transport the beam at maximum MEB energy. The primary beam with its low momentum bite may also be used to survey/calibrate the tagging system.

The required fluxes for hadrons are similar to those for leptons. However to study pileup issues high fluxes of about 10E7 per pulse are required.

Todays calorimeters have resolutions of about ($15\%/\sqrt{E}$ + < 1%) [4,5] and the barium fluoride electromagnetic calorimeters reach ($1.3\%/\sqrt{E}$ + 2%) [6]. Thus to calibrate the scale of the calorimeter absolute momenta of the test beam (given by $\int Bdl$ of the tagging magnet and the survey of the tagging detectors) should be known to better than 0.3%. To facilitate measurements of the calorimeter resolution the relative momenta (given by the resolution of the tagging system) should be known to about 1/3 of that e.g. better than 0.05%.

The rejection power for pions over electrons for typical calorimeters for the SSC will exceed 100 [5], so that particle identification should be better than 1000:1. In particular the misidentification of pions as electrons should be below this level. Therefore the particle rejection has to be 1000 divided by the ratio of electrons to non-electrons in the beam.

Fake muons may be produced by pions not interacting or via hadronic punch through. For these studies again a particle identification of 1000:1 is required. True muons may be identified by their survival in or beyond the beam dump or with a TRD at energies between 100 and 150 GeV.

Hadronic studies require mass identification of pions, kaons and protons in the energy range 1 to 100 GeV with a misidentification of no more than a few percent.

During calorimeter calibrations there should be no muons in the calorimeter in the measurement time window. This may be achieved by a veto counter rejecting any muons entering the calorimeter for two integration times of the calorimeter before, and one integration time after the particle passes through the calorimeter. The dead time, even for a liquid ionization calorimeter, is not substantial as long as the muon flux is kept below 150 kHz/m^2.

Testing and calibration of standard tracking devices calls for a precision location of the beam particles. Drift chambers and scintillating fibres have a typical resolution of 150 and 300 μm respectively, while strawtubes reach about 100 μm. So typical instrumentation should have a position resolution of about 50 μm.

Inner trackers with silicon strips and/or pixel detectors call for a position accuracy of some 10 μm which can only be reached by using such devices themselves in the calibration beam.

These requirements are summarized in Table 1. They are certainly rather demanding on the instrumentation but reasonable and do not represent a cost driver. The technical aspects of the instrumentation are further discussed in section 9.

3. Short Version

3.1 Basic Layout

For this version we only studied the 200 GeV beams, since the 2 TeV beams would be completely independent in a separate tunnel underneath the 200 GeV beams and would be built later, if ever.

It is an unlikely scenario which was only studied to see what the absolute cheapest version of test-beams would look like and how much it would cost. This allows to then compare the cost of a more realistic layout. The 2 TeV expansion in the future would be extremely expensive for this version, since it would be like building a completely new beamline.

We realized that real estate is the main cost driver. For this reason we tried to make the whole switchyard as short as possible. It turns out that the additional needed components (septa and benders including power supplies) are much cheaper than the needed additional footage of tunnel or even cut and cover part of the test beam real estate. Fig. 4 shows a planned profile and Fig. 5a the footprint. A detailed analysis of the civil construction for this particular version dictated a location of the secondary beam further downstream by approx. 1000', see section 3.2.

The switchyard allows the beam to be split into 2 and further downstream each of these 2 into 3 independent beams with a full range of splitting ratios. In a first phase only 3 of these beamlines and the associated civil construction would be constructed as indicated in Fig. 5a.

The three beams have to be separated by at least 30 feet at the calibration hall in order to have enough radiation shielding (see section 8) between the three test stations. The calibration hall must also be shielded from the target pile by at least 720 feet of "Austin chalk", the geological formation of the West complex, to reduce the muon flux to less than 150 kHz/m^2 (see section 8). This latter distance drives the total length of the footprint. This length for a future 2 TeV beam is 1670 feet from the 2 TeV target.

At several strategic points along the beam some trim magnets allow for adjustment and leveling of the beam position.

These constraints and parameters fix the size of the footprint as shown in Fig. 5a. The total length (MEB to calibration hall) of the beamline is 4200 feet, 900' longer than in Fig. 5a. All magnets for this design are of conventional type (Table 2).

3.2 Primary Beam

The beam is extracted in the straight section M7 of the MEB and bent upwards by 21.3 mrad in order to just clear the quads of the MEB, see Fig. 4. After 1300' the primary beam is being levelled by a bending string of 3 dipoles. The beam is always at least 30' below the grade to allow for radiation shielding. For the last third of the beam, the falling terrain is compensated by a berm.

The primary beam footprint was actually developed for a total length of 1600' as shown in Fig. 5a, but the final selection of the civil construction layout dictated an additional 900' of real estate for the primary beam in order to save on excavation for both the target hall as well as the calibration hall. Technically this has the advantage of saving some bending magnets, and hence also operating power. The magnet count table (Table 2) however is for the shortest possible footprint, the difference being only minimal compared with the total costs.

In a first phase, we implement only three 200 GeV beams. In order to get the same beam direction as with the 6 beam option we replace the future septa string by a single trim magnet. For the same reason we replace the string of three lambertsons by 2 dipoles.

Two dipoles direct the center of the 3 upper (eastern) beams to the calibration hall so that the lowest of the 3 beams has the same 30' separation from the topmost of the 3 lower (future) beams. This footprint is shown in Fig. 5a.

Further downstream 2 sets of 5 septa each provide the 3 way split. This split is accomplished by first splitting the beam in two and then split one of the two in two again.

The split ratio is adjusted by physically moving the septa bank through the beam. The ratio is given by the relative amount of beam that lies to either side of the wires. The septa run at 45 kV/cm, some 90% of their maximum field, to allow trouble free operation. Care has to be taken in the design of the beam optics so that the beam is wide at the position of the septa. This prevents damaging of the wires, reduces scattering and facilitates the adjustment of the splitting ratio.

The horizontal separation takes place in the next enclosure with three 3-way-Lambertsons.

Further downstream 2 dipoles are needed to get the separation of 30' between the 3 beams.

The beam transport is done with quadrupole doublets having an aperture of 3 inches. Eight quads are needed to transport the 3 beams and take care of constraints like magnet apertures and beam size at the septa. No quads are placed between the splitting station and the lambertsons. This would refocus the beam and therefore cancel the (small) separation.

Type and field of the magnets are listed in Table 2. Fig. 6 shows the beam envelope.

There will be enough space upstream of the target to implement an angle varying system as an upgrade in the future to allow production at angles different from 0 degrees.

The target pile is discussed in section 5.

3.3 Secondary Beam

A wide band beam approach has been chosen. Such a beam at Fermilab [7] has an excellent electron yield as well as a high hadron flux.

A triplet system acts as a flux gathering system 150' downstream of the target. It provides point to parallel imaging. The same enclosure contains the first dipole of the double dogleg system which provides muon shielding from the production target. A bend angle of 6 mrad allows for reasonable real estate and and for good momentum measurement, as shown in section 9.

Exactly halfway between the target and the calibration hall are the next two magnets of the dogleg structure. The momentum bite and beam size may be varied with a variable aperture collimator sitting in the same enclosure. Fig. 7 shows the relative momentum bite versus the transverse dimension at this location.

An enclosure in front of the calibration hall contains the last dog leg magnet and a triplet focusing the beam on the experimental target.

Table 3 shows a magnet count by types. In order to study particle rates and muon contents of the beam we performed some DECAY TURTLE [8] simulations.

The beam is never momentum dispersed when it passes through a triplet and has therefore a large acceptance of about 6 μsr%.

All of the secondary vacuum pipe between the enclosures is direct buried stainless steel pipe of 16" diameter.

4. Long Version

4.1 Basic Layout

The calibration hall is located somewhat further downstream than in the short version allowing the use of natural terrain for shielding. The 2 TeV beam will be brought up to the level of the 200 GeV beam and be accommodated in the same tunnel. The location of the calibration hall is also chosen so that the amount of excavation is minimized. This however is not independent of the excavation for the beam lines so that a careful compromise has to be made. Some berm downstream of the calibration hall is still needed. To save some expenses here we limited ourselves to 1 TeV secondary beam with a potential upgrade to 2 TeV by just adding some berm material. This will be studied further. E.g. the beams may be extracted downwards instead of upwards of the MEB. But the tradeoff of tunneling versus cut and cover and the excavation for the calibration hall has again to be studied in detail. Fig. 8 shows an elevation view of this scenario. The generic footprint is shown in Fig. 5b.

Since the target hall is a rather large excavation and is a special enclosure one could save some money by combining the 2 TeV target with the 200 GeV target as shown in the same Figure. The compromise would be a tradeoff between loss of particle rate at the low energy end due to decays in the long secondary beam and increased muon background for the 2 TeV operation.

It should be stressed that the 2 TeV tunnel and technical components are not part of the SCDR baseline. This long version should just provide the upgrade potential for the 2 TeV beams at minimal additional costs for the currently planned 200 GeV beams.

4.2 Primary Beam

The 2 TeV beam will be extracted from the HEB and transported in a tunnel to the MEB elevation. This is done with a FODO lattice of 14 quads total separated by 500' each. The beam leaves the straight section of the HEB at an angle of 15 mrad. The total length of the tunnel is 7529'. Near the MEB the beam is levelled with 18 conventional dipoles. The actual construction of the tunnel is not part of the SCDR baseline. We just did the necessary studies for the beam transport to make sure the future upgrade will fit in the chosen footprint. Figure 9 shows the beam envelopes. The necessary magnets, all of the conventional type, are listed in Table 2.

The 200 GeV beam is being transported in a very similar fashion as for the short version. However, advantage of the available real estate is taken and the number of septa, lambertsons and benders is minimized. The magnets are of the same type as listed in Table 2, the count being slightly less. The elevation view is shown in Fig. 8.

4.3 Secondary Beam

The secondary beams are the same as those described in section 3.3 for the short version, though the length is longer. From the optics point of view this is no problem, since one just stretches the parallel beam between the two triplets. Particle production however is affected, as mentioned earlier. Particle yields are given in section 7.

The two future 2 TeV beams would lie on top, or underneath, the 200 GeV beams entering the calibration hall at locations B and E, respectively (see Fig. 5b). They would be separated by 90', enough to prevent mutual muon background.

The magnet types and count are shown in Table 3.

5. Target Pile

So far we have not put any extra work in designing a target pile. We will most probably built a device very similar to the one at FNAL in the wide band beam [7].

The target box is equipped with a one or two dipole magnets.

Depending on the cycle time of the MEB we may choose DC or a ramping mode for the dump magnet.

If we go for DC operation we may choose Eartly type H-frame magnets which may be built to fit exactly our needs and we may live with just one magnet of e.g.15' length. They are easily built out of some steel blocks requiring no punching tools. A possible choice for ramping operation is the B2 magnet as at FNAL. Using this standard length magnet we will have to use 2 magnets which results in an unnecessarily long target pile.

Clearly more work on this subject is needed.

The dump itself may be a watercooled part (aluminum or copper) followed by a second part consisting of steel blocks.

The three 200 GeV targets may be surrounded by a common pile of steel blocks for radiation shielding.

The total length of the pile is approx. 40'.

The 2 TeV target is similar in construction and has an over all length of about 90 feet.

6. Civil Construction Aspects

6.1. General

As already mentioned the civil construction is chosen to make the best compromise between tunnel length, excavation volume for the calibration hall and cut and cover percentage of the entire switchyard. These factors determine the elevation for both the short and long version, respectively.

Cut and cover for the short version begins at the enclosure with the second lambertsons and just downstream of the target hall for the long version, respectively.

The primary beam is put in a 10' concrete tunnel which allows great flexibility of putting additional components for future upgrades/changes.

Care was taken during the design of the footprint to group as many beam elements as possible in order to minimize the number of magnet enclosures and to shorten cable runs.

Potential fire hazard and serviceability of the power supplies requires them to be located above ground, rather than in the tunnel. To distribute the power, as well as cooling water, to the magnets a number of utility shafts of 5' diameter is foreseen along the tunnel.

Personnel access is limited to a few strategic spots. Tunnel access is only via the MEB, at an intermediate point and at the target hall. In addition to the personnel access shafts there are two hatches of 3' x 15' to allow the lowering of beam components.

The tune up dump is located in the target hall. This calls for some extra vacuum pipe but minimizes the radioactive cooling water supply and shielding for the ground water.

The secondary beams are transported in 16" SS pipes between the enclosures. There are 3 magnet enclosures per beam line, each with its own personnel access and hatch for beamline components.

6.2 Calibration Hall

The calibration hall as proposed in the SCDR costs approximately 5 million dollars. Being quite a cost driver this subject called for some further studies.

The main reason for being expensive was the upgrade potential for three 2-TeV beams which calls for a separation of 75' between the individual beams to guarantee a low muon background. This in turn dictates the rather large (200' x 100') dimensions of the calibration hall in the SCDR, see Fig. 10.

Going to only two 2-TeV beams opens a new design possibility as shown in Fig. 11. The individual 200 GeV beams are separated by 30' each. This distance is more driven by available space for the detector subassemblies to be checked than by the muon background at 200 GeV.

In a initial phase only three 200 GeV beams are foreseen, e.g. only half the hall is built. This "half hall" would allow to accommodate one 2 TeV beam in a future first phase of an upgrade without any modifications. The hall is also reduced to 50' in length. The shielding between the beam stations is provided by reusable concrete blocks.

The counting rooms are located outside the calibration hall in reusable trailers.

All of this allows to build a first phase of calibration hall with a cost saving of approximately 3.5 million dollars at the cost of losing one 2 TeV beam in the final version, e.g. 2 instead of 3 beams.

7. Particle Yields and Background

Particle yields were determined using parametrizations of Atherton et al. [9] and taking into account the beamline efficiency. Fig. 12a shows expected pion rates for 1E11 200 GeV incident protons assuming a 1 interaction length Be-target. The required rates are easily reached for most of the momenta except for the lowest ones where decay in the secondary beam line introduces a cutoff. At momenta below approximately 3 GeV/c the rate will be less than 100 Hz.

The muon contamination of the pion beam is in the order of 2-3 % over most of the momentum range.

The pion rates for 1E11 primary protons of 1.8 TeV are shown in Fig. 12b. The required 10E7 Hz to study pile up are easily reached.

The electron yield falls sharply for higher momenta. For a primary momentum of 200 GeV/c the rate drops below 100 Hz above 150 Gev/c, see Fig. 13a. Should the primary momentum be reduced to e.g.180 GeV/c the rate at 150 GeV would drop to a couple of Hz. This shows the importance of preserving the possibility of ramping the primary beam to 200 GeV/c.

Fig. 13b shows the electron rate for a primary beam of 1.8 TeV, as delivered by the HEB.

The muon background was simulated using CASIM . For the 200 GeV beam the shielding is sufficient to have approximately 1E4 muons /m^2, see Fig. 14a. For the 2 TeV beam with a common target hall the shortened secondary beamline results in a flux of over 1E5 muons/m^2. The results shown in Fig. 14b are for the sweeping plane which explains the dip in the curves.

8. Radiation Shielding

As already mentioned in the introduction, the total extracted beam per year will not exceed 2.3E18 protons.

Unwanted hadrons are readily shielded by the surrounding "Austin chalk". The beam line being at least 30 feet below grade provides plenty of shielding. The same holds true in the forward direction towards the calibration hall.

Therefore we concentrate here on the muons. Most of the muons are produced in the production target and in the following proton dump. A smaller fraction of muons comes from the decay of the produced pions. This background is most serious when producing charged pions. An additional source for muons, not affecting the experiments but a safety hazard is the dump of the beam in the calibration hall. Upgrading from 1 TeV secondary beams to 2 TeV operation requires additional shielding (longer berm) behind the calibration hall as mentioned in section 4.1.

The muon radiation is concentrated in a cone along the secondary beams. After a length called muon-vector, the radiation is negligible. The muon-vector for 200 GeV and 2 TeV are 1650' and 6500', respectively. The lateral dimension at maximum, e.g. shortly before the end of the vector, is a radius of 30' for 2 TeV and 25' for 200 GeV.

Some CASIM simulations were done to get the muon flux at the calibration hall and to study the necessary shielding of the target pile as well as the beamlines. In order to get more reliable results the actual design of the target box has to be known.

The expected muon flux distributions at the calibration hall for the horizontal (bending) plane are shown in Fig. 14. The distribution in the vertical plane has about the same peak value, but is narrower and has no dip.

The length of the secondary beam is a trade off between muon flux at the calibration hall and particle yield at lowest momentum. The sweeper magnet broadens the distribution. The widest distribution results when running at full field for high energy electrons.

The chosen footprint foresees 30' separation between the 200 GeV beams at the calibration hall and 90' between the two 2 TeV beams. A look at Fig. 14 shows that the muon background is well below the design value for the short 200 Gev design. For the 2 TeV footprint with a common target hall the muon flux slightly exceeds the design value of 10E5 Hz/m^2 as expected.

9. Instrumentation

Momentum tagging will be done by placing sets of tracking chambers in the beamline that measure the bend in the particle trajectories as they pass trough a magnet. Four detectors are required: Two before and two after the magnet. Using the last magnet of the dogleg structure one has a bend of 6 mrad and a separation of the detectors of ≤ 550' and ≤ 65', respectively. Thus with conventional 1 mm pitch proportional wire chambers at all four stations one would provide absolute momentum resolution of about 0.3%. Adding 100 μm silicon strip detectors at the two downstream detectors would improve this to approximately 0.05%.

Position tagging requires a stack of chambers with transverse dimensions of about a foot and a per plane resolution of ~ 200μm. Position resolution for inner trackers call for silicon devices in the testbeams with a pitch of less than 25μm.

The species tagging is required at a level of 1000:1. Thus, for example, if the beam contains 10% unwanted particles the tagging system must work at the 100:1 level. Fig. 15 shows the ranges of momenta over which two species of particles can be separated at this level or better by various techniques using the beamline tagging devices described below.

To identify the electrons in the presence of heavier particles at energies above about 20 GeV one can employ a Synchrotron Radiation Detector (SRD). Installation of this type of device requires observation of the photons produced when the electrons pass through a bend in the beamline. As long as the size of the bend and the clear drift distance downstream of it allow placement of the photon detector outside of the beam halo this technique will work.

For simple discrimination between particles heavier or lighter than a chosen mass a long gas filled pipe with a single mirror and phototube at the downstream end is an economical choice. This design requires about 60' of parallel beam for each of the two independent counters to achieve an efficiency of 90% or better for tagging the lighter particles.

The transition radiation detector being considered is based upon a device developed at Fermilab [11] for a hadron beam fixed target experiment. This is a modular device consisting of sets of radiator/detector assemblies. The discriminating power can be adjusted, and the expense of the installation varied, by adding fewer or more modules. The advantage of the TRD over Cerenkov counters or SRD's at those momenta where more than one technique applies is that it makes very few demands on the beam optics (beam does not need to be parallel, for example), and it requires relatively little real estate in the beamline.

Figure 16 shows a schematic diagram of the instrumentation planned. In front of the bender there are wire chambers, a Cherenkov counter, and a TRD. Following the bend are a second Cerenkov, silicon strip detectors, and the SRD. In practice, of course, it may not be necessary to install all of these tagging elements in every beamline.

10. Cost Estimate

The short and long version have been costed in a similar way as in the SCDR. In order to compare apples with apples we did the SCDR costing again with the newest available figures. No professional estimator was available at this time so that some items were done by ourselves and some shortcuts and "guesstimates" were done. The civil construction part was costed by a specialist. A comparison of our estimate with the old one for the SCDR shows a difference of less than 4%, an excellent agreement.

To get a fair estimate with the SCDR we have to recall that the elevations of the HEB and MEB have changed. This causes an cost increase of the SCDR of 1.1 million dollars due to additional tunnel length. Table 4 shows the 3 costings.

Of course the short version comes out somewhat cheaper than the SCDR. But a word of caution should be placed. As mentioned in section 3.1, this is only saved money to provide three 200 GeV beams with a completely independent, very expensive 2 TeV beam in an extra tunnel.

The long version costs an extra 2.3 M$ which is probably masked by the uncertainty of such costing.

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List of Tables

Figure Captions

Table 1

Specifications for the SSC Test Beams

Lepton ID	
Beams to highest possible energy	100-1000 Hz
Minimum	1 Hz
Particle ID	1000:1
Energy resolution	
Absolute	0.3%
Relative	0.05%
Hadron response	
Beam energy	1-100 GeV
Flux	up to 10^7 /s
Particle ID	100:1
Particle Tagging	
Standard tracking	$\leq 50\ \mu m$
Inner tracker	$\sim 10\ \mu m$
Muon flux at calibration hall	$< 150\ kHz/m^2$

Table 2

MEB 200 GeV Extraction, Transfer , and Switchyard					
Magnet Type	Max Field (KG, KG/in, KV/cm)	Aperature (in)	Length (Ft)	Magnet Count 3 Test Beams	Magnet Count 6 Test Beams
Symmetric Lambertson	11.0	1.1	18	1	1
Asymmetric Lambertson	14.9	0.9	18	1	1
3-Way Lambertson	5.1	1.3	10	6	9
Electrostatic Septum	45.9	0.8	10	10	28
4-4-30 Trims	4.0	3.0	2.5	12	20
EPB Quadrupole	4.5	3.0	10	12	20
EPB Dipole	16.1	1.5	10	8	11
Target Sweeper Magnet	19.0	1.3	12	6	12

HEB 1.8 TeV Extraction, Transfer , and Switchyard					
Magnet Type	Max Field (KG, KG/in, KV/cm)	Aperature (in)	Length (Ft)	Magnet Count 1 Test Beam	Magnet Count 2 Test Beams
Symmetric Lambertson	10.9	1.5	16	6	6
Asymmetric Lambertson	12.2	1.3	16	2	2
C Magnet	12.5	1.5	16	6	6
3-Way Lambertson	5.1	1.3	10	3	6
Electrostatic Septum	43.3	0.8	10	0	11
4-4-30 Trims	4.0	3.0	2.5	10	14
EPB Quadrupole	5.0	3.0	10	24	29
EPB Dipole	16.1	1.5	10	36	54
Target Sweeper Magnet	19.0	1.3	12	5	10

Table 3

Secondary Beam 200 GeV					
Type	Max. used field (kG, kG/in)	Aperture (in)	Length (ft)	Count 3 Test beams	Count 6 Test beams
EPB Quadrupole	4.9	3	10	18	36
EPB Dipole	15	1.5	10	12	24
4-4-30 Trim	4	4	2.5	6	12

Secondary Beam 1 TeV					
Type	Max. used field (kG, kG/in)	Aperture (in)	Length (ft)	Count 1 Test beam	Count 2 Test beams
EPB Quadrupole	4.9	3	10	14	28
EPB Dipole	15	1.5	10	8	16
4-4-30 Trim	4	4	2.5	4	8

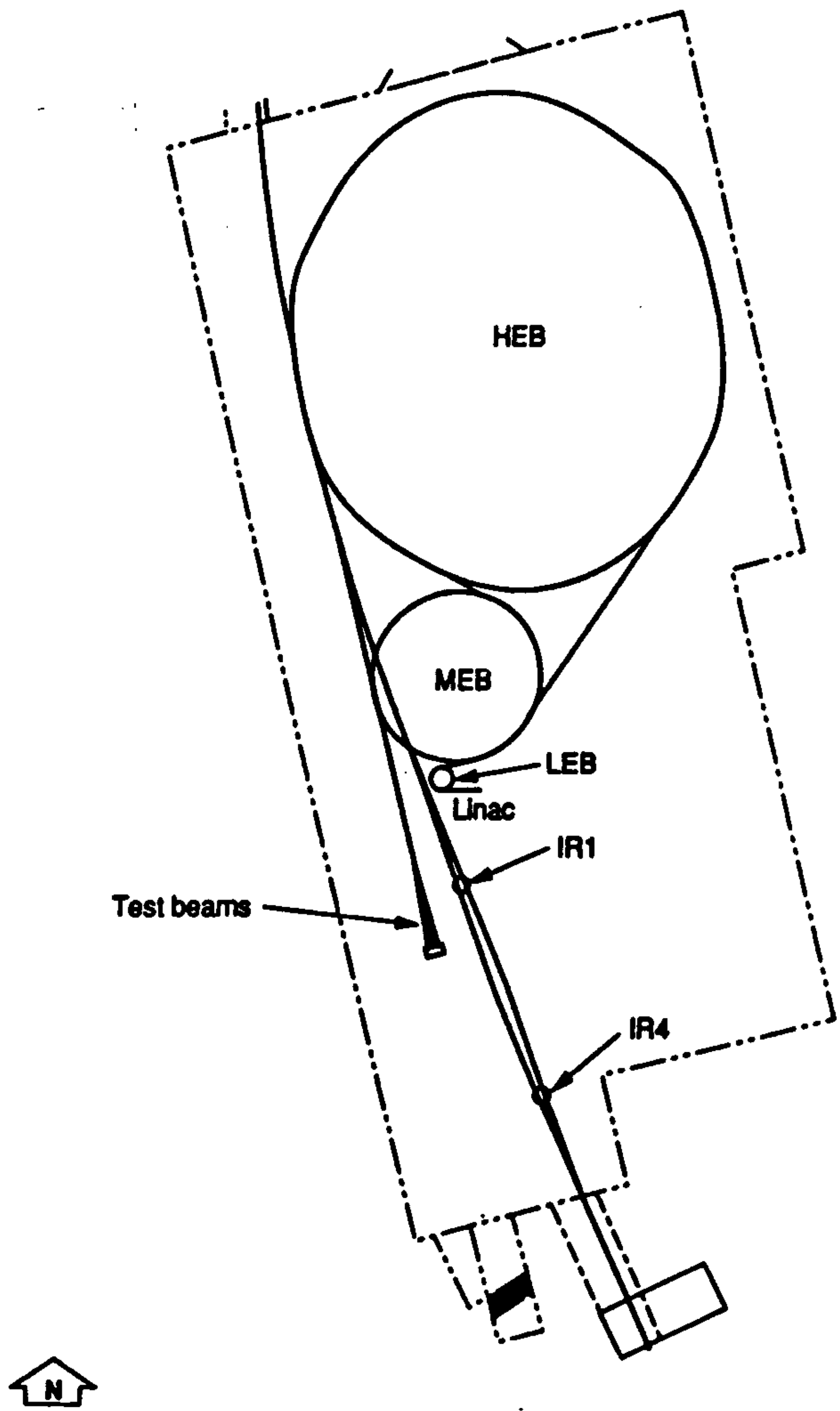


Fig. 1 The West campus area with test beam location.

Table 4

Test Beam Cost Study

	SCDR	Short 3x200 GeV	Long 3x200 GeV w/o HEB tunnel
Technical Components	10169	10608	9700
EDIA	1525	1591	1455
Civil Construction	17552	11125	20035
AE/CM @14% CC	2457	1558	2805
Contingency	3264	2606	3479
Test Beam Total B.Y. 90$	34967	27487	37474
Escalation @ 27.5%	9616	7559	10305
Test Beam Total T.Y. $	44583	35046	47779

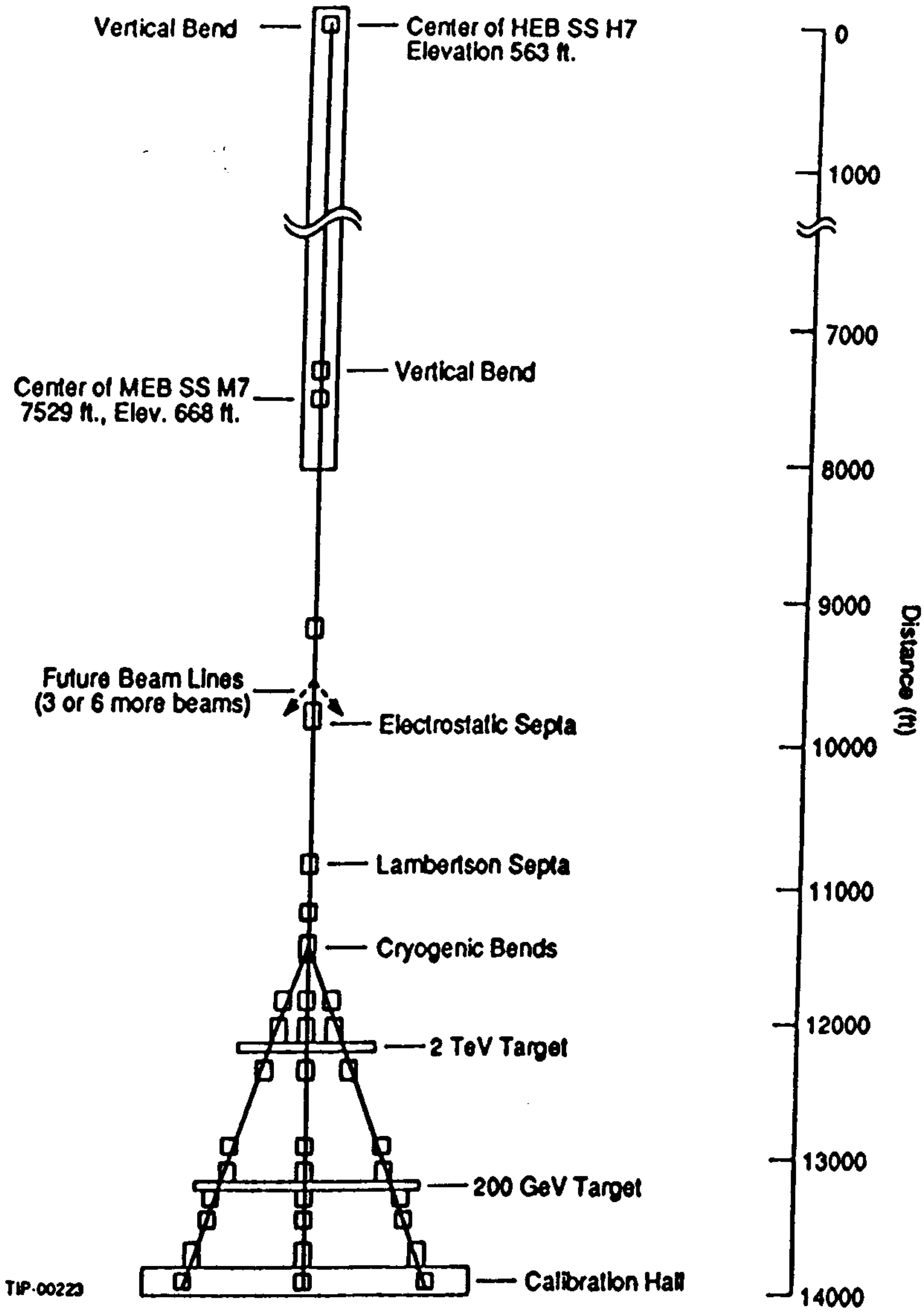


Fig. 2 Footprint of test beams as in the SCDR. Note the use of cryogenic bends to save on real estate.

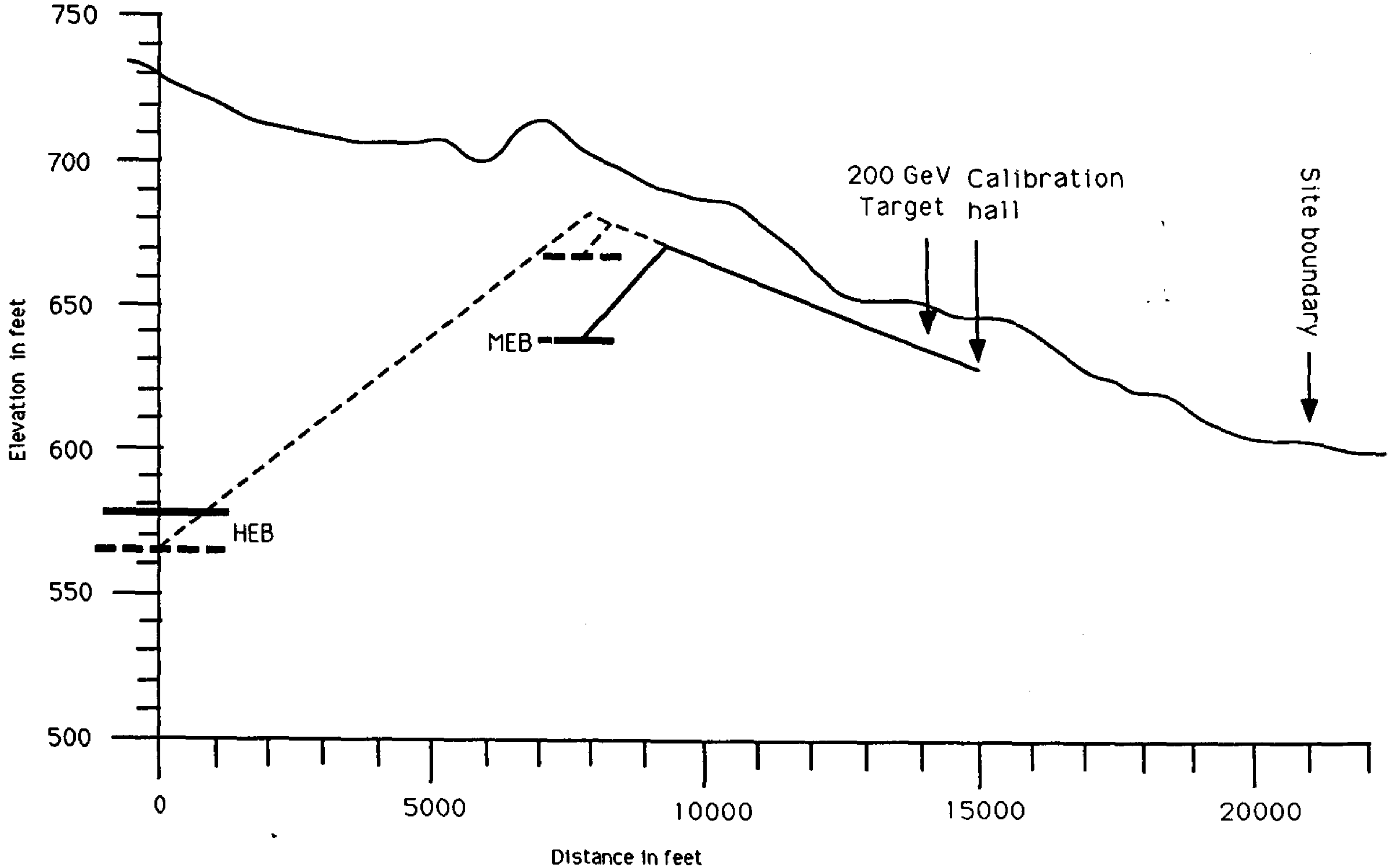


Fig. 3 Elevation view of test beams as in the SCDR. The solid lines indicate elevations as in the SCDR, the dashed ones indicate new, more likely elevations.

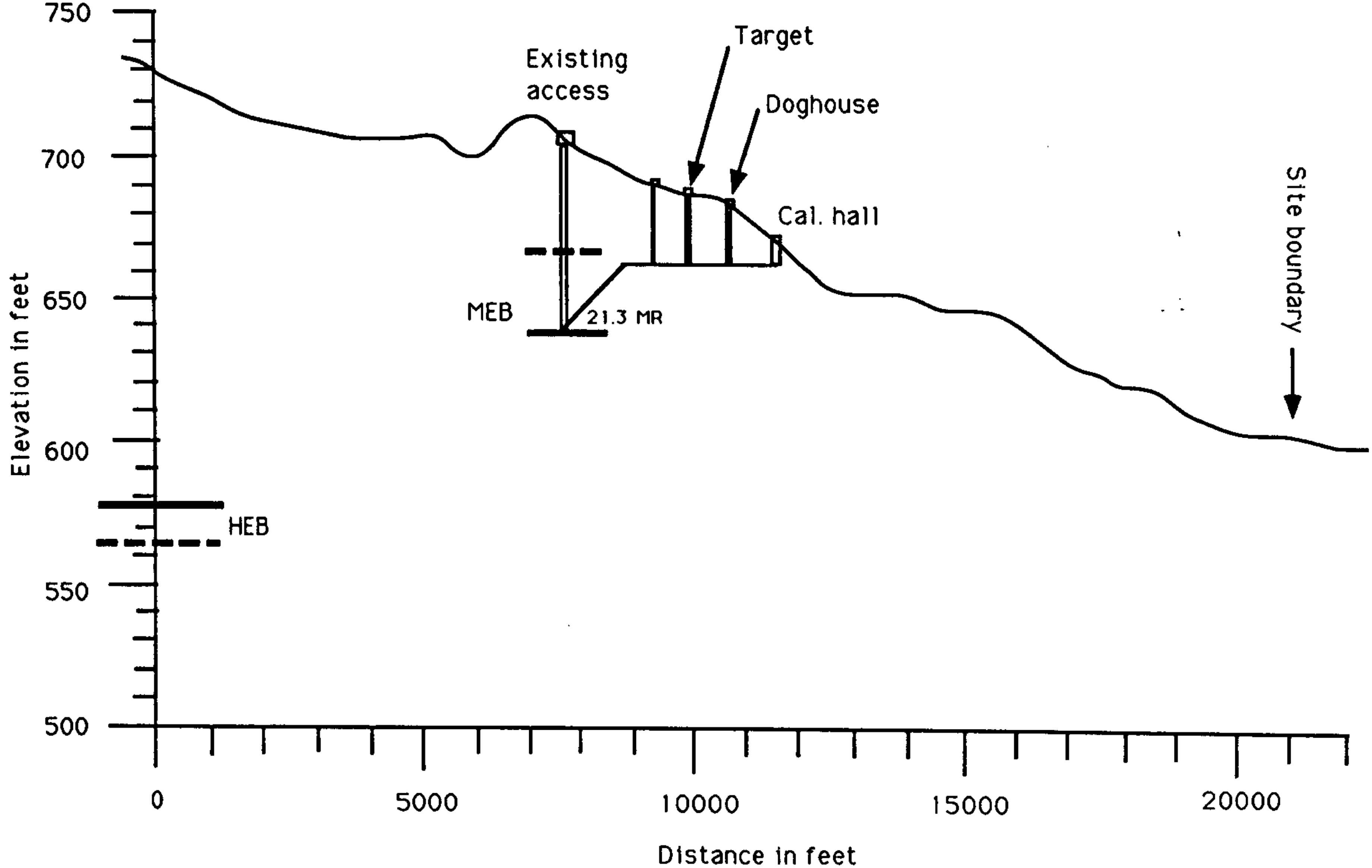


Fig. 4 Elevation view of short version, accommodating only three 200 GeV beams. The 2 TeV beams would be constructed completely independently.

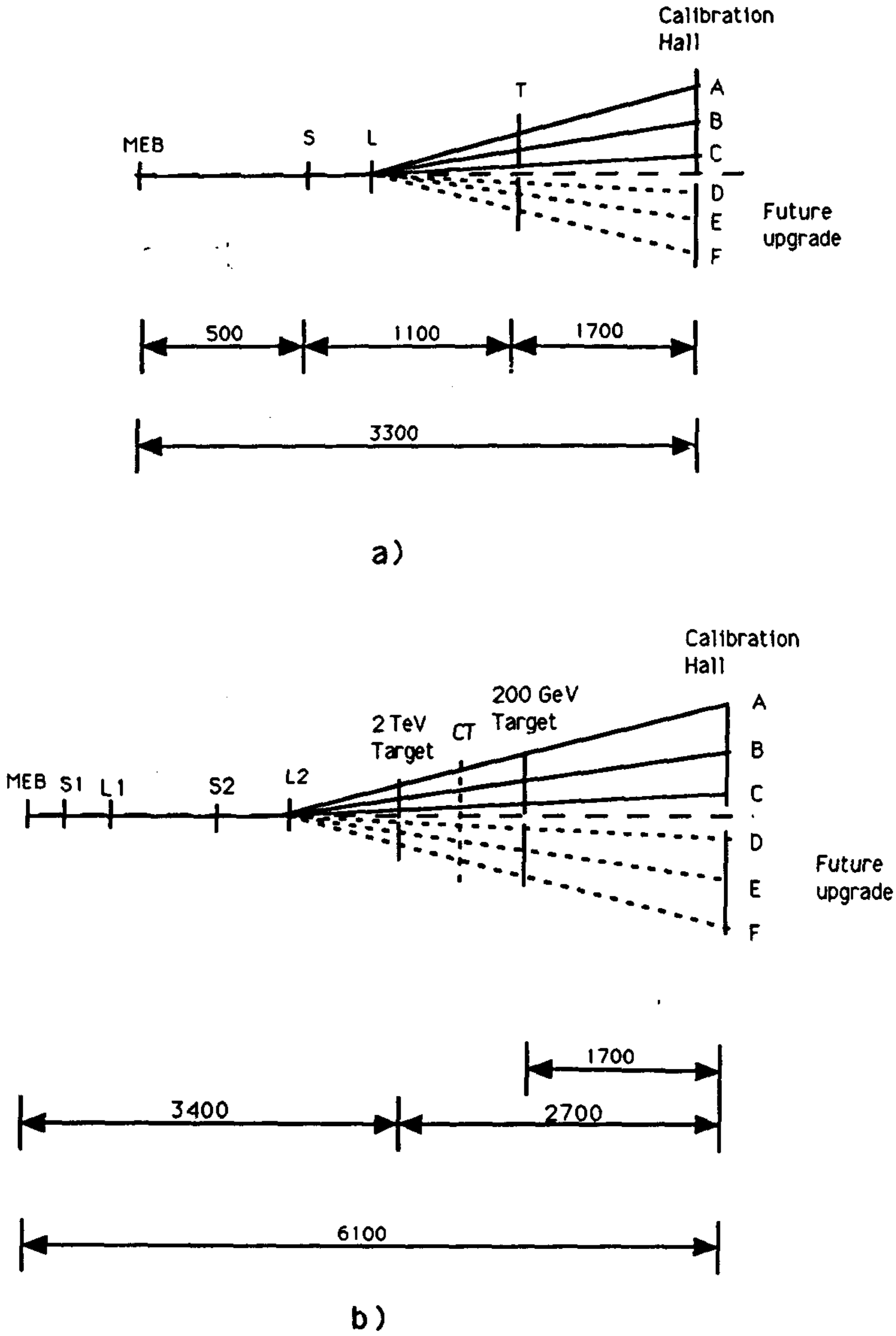


Fig. 5 Schematic test beam footprints. a) shows the short version for three 200 GeV beams, upgradeable to 6 beams. This layout does not allow an upgrade for 2 TeV. b) shows the long version. The 2 TeV targets may be located in a common target hall dubbed "CT".

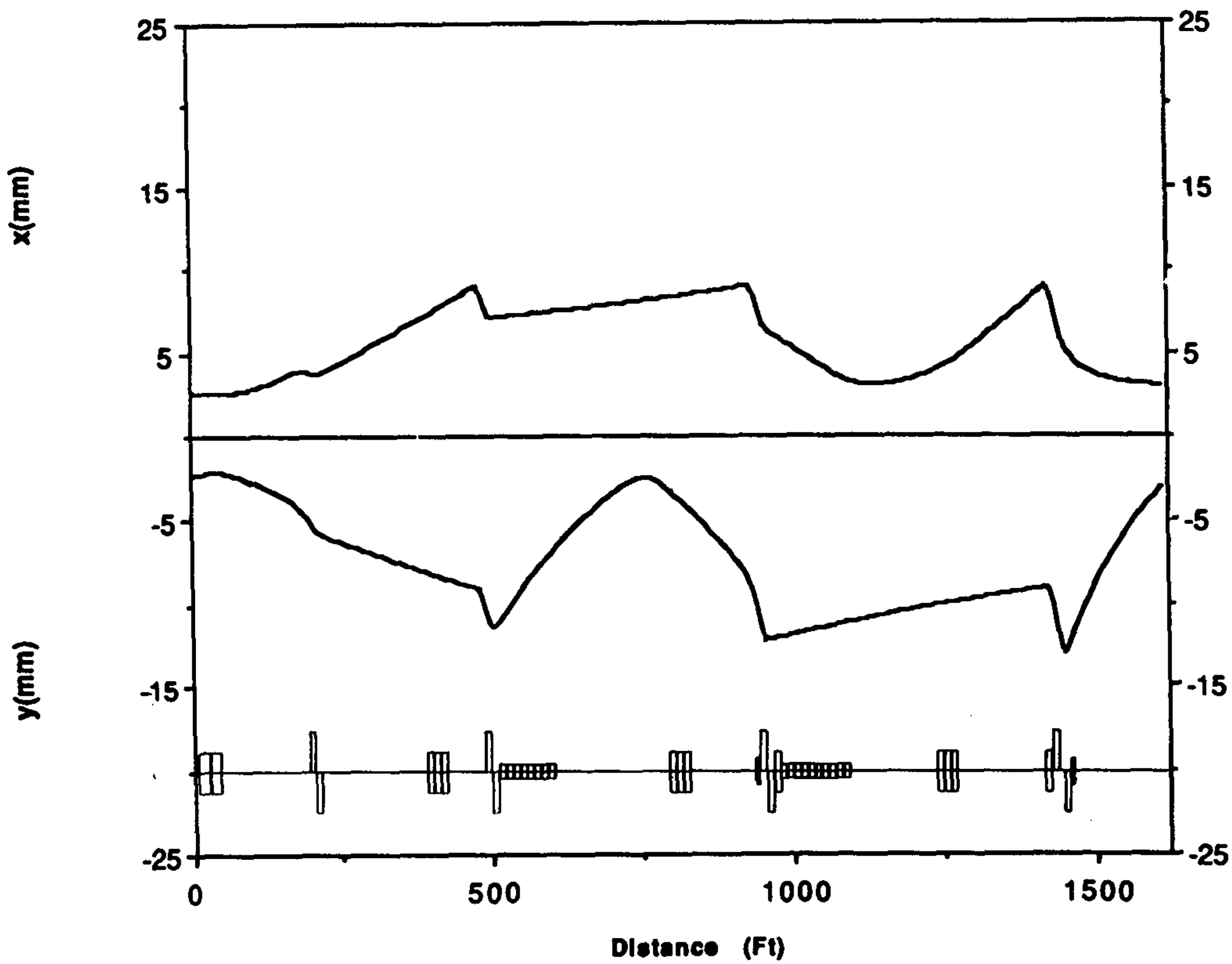


Fig. 6 Switchyard beam envelopes (3 sigma) for 200 GeV beam.

```
HISTOGRAM NO  4
HORIZONTAL AXIS     X IN CM       137.850 M      FROM THE START
VERTICAL AXIS    DP/P IN PC       137.850 M      FROM THE START
                  -20.000    -10.000      0.000     10.000     20.000 TOTALS
                    I**---**---**---**---**---**---**---**---**I--------
 -40.000 TO -38.000 I                                          I       0
 -38.000 TO -36.000 I                                          I       0
 -36.000 TO -34.000 I                                          I       0
 -34.000 TO -32.000 I                                          I       0
 -32.000 TO -30.000 I                                          I       0
 -30.000 TO -28.000 I                                          I       0
 -28.000 TO -26.000 I                                          I       0
 -26.000 TO -24.000 I                                          I       0
 -24.000 TO -22.000 I                                          I       0
 -22.000 TO -20.000 I        YN1                               I      58
 -20.000 TO -18.000 I        $$$9                              I     151
 -18.000 TO -16.000 I        3J$$$9                            I     174
 -16.000 TO -14.000 I          D$$$H1                          I     174
 -14.000 TO -12.000 I           5V$$RA                         I     155
 -12.000 TO -10.000 I            4UYTXS3                       I     161
 -10.000 TO  -8.000 I             4H$$S$A2                     I     175
  -8.000 TO  -6.000 I              3HZXVUI3                    I     170
  -6.000 TO  -4.000 I               2KSWZ$N8                   I     189
  -4.000 TO  -2.000 I                3LRQSSOD                  I     170
  -2.000 TO   0.000 I                 2DEQPQIC                 I     136
   0.000 TO   2.000 I                  4GKIQSOI3               I     157
   2.000 TO   4.000 I                   6GKRHRQF3              I     157
   4.000 TO   6.000 I                   17HMJKONF6             I     154
   6.000 TO   8.000 I                     EMIEDHAFE            I     137
   8.000 TO  10.000 I                      CBFGBCDH4           I     111
  10.000 TO  12.000 I                      3FBEHGIIH3          I     132
  12.000 TO  14.000 I                       4DH7DCF7H81        I     114
  14.000 TO  16.000 I                       13CFD75DB96        I      95
  16.000 TO  18.000 I                        36BECHNG6H4       I     129
  18.000 TO  20.000 I                         5CCE5F7D573      I      98
  20.000 TO  22.000 I                         25AA6A78685      I      77
  22.000 TO  24.000 I                          1BB989GBA6      I      92
  24.000 TO  26.000 I                           6A778B786      I      70
  26.000 TO  28.000 I                           59H8AD9D4      I      88
  28.000 TO  30.000 I                            577G5676      I      59
  30.000 TO  32.000 I                                          I       0
  32.000 TO  34.000 I                                          I       0
  34.000 TO  36.000 I                                          I       0
  36.000 TO  38.000 I                                          I       0
  38.000 TO  40.000 I                                          I       0
                    I**---**---**---**---**---**---**---**---**I--------
                    I                                          I
                    I                                          I
                    I        11111111111111111111111           I
                    I       8010311144435474453443108653       I
              TOTALS I 0000000404666500688804237027949870000000 I    3383

         TOTAL NUMBER OF ENTRIES =       3383 INCLUDING UNDERFLOW AND OVERFLOW AS FOLLOWS

                             LEFT                           RIGHT
         ABOVE                 0              0               0
                               0           3383               0
         BELOW                 0              0               0

  SUM OF SQUARES =      81655.
         CENTER =      -0.553   RMS HALF WIDTH =      7.145
         CENTER =       1.056   RMS HALF WIDTH =     13.662
         CORRELATION =      0.9479

NO    4 TWO DIMENSIONAL PLOT OF
HORIZONTAL AXIS     X IN CM      137.850 M     FROM THE START
```

Fig. 7 Relative momentum bite vs. transverse dimension at doghouse (geometric center of secondary beams).

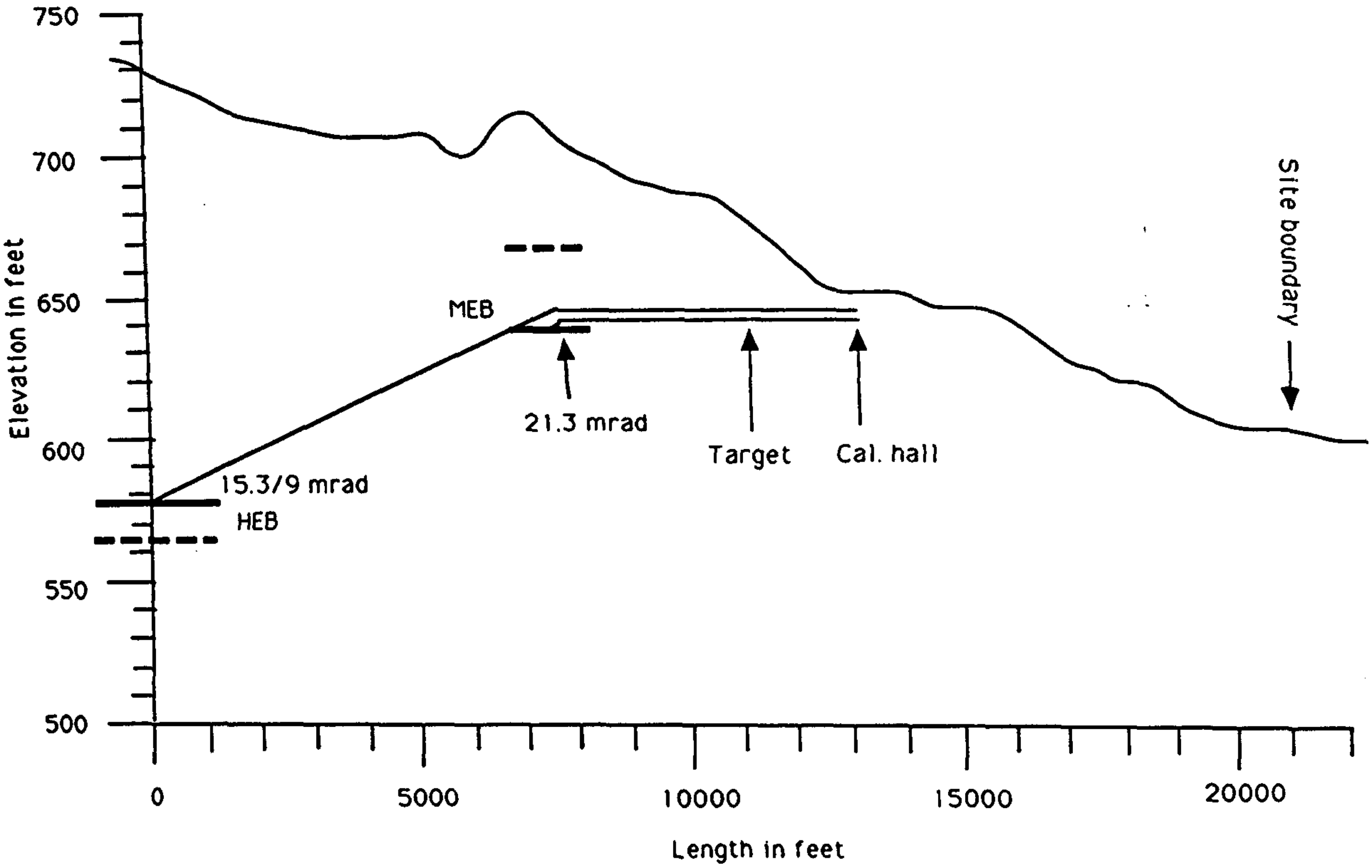


Fig. 8 Elevation view of long version. An angle of 15.3 mr is needed to clear the HEB, 9 mr is needed to meet the MEB.

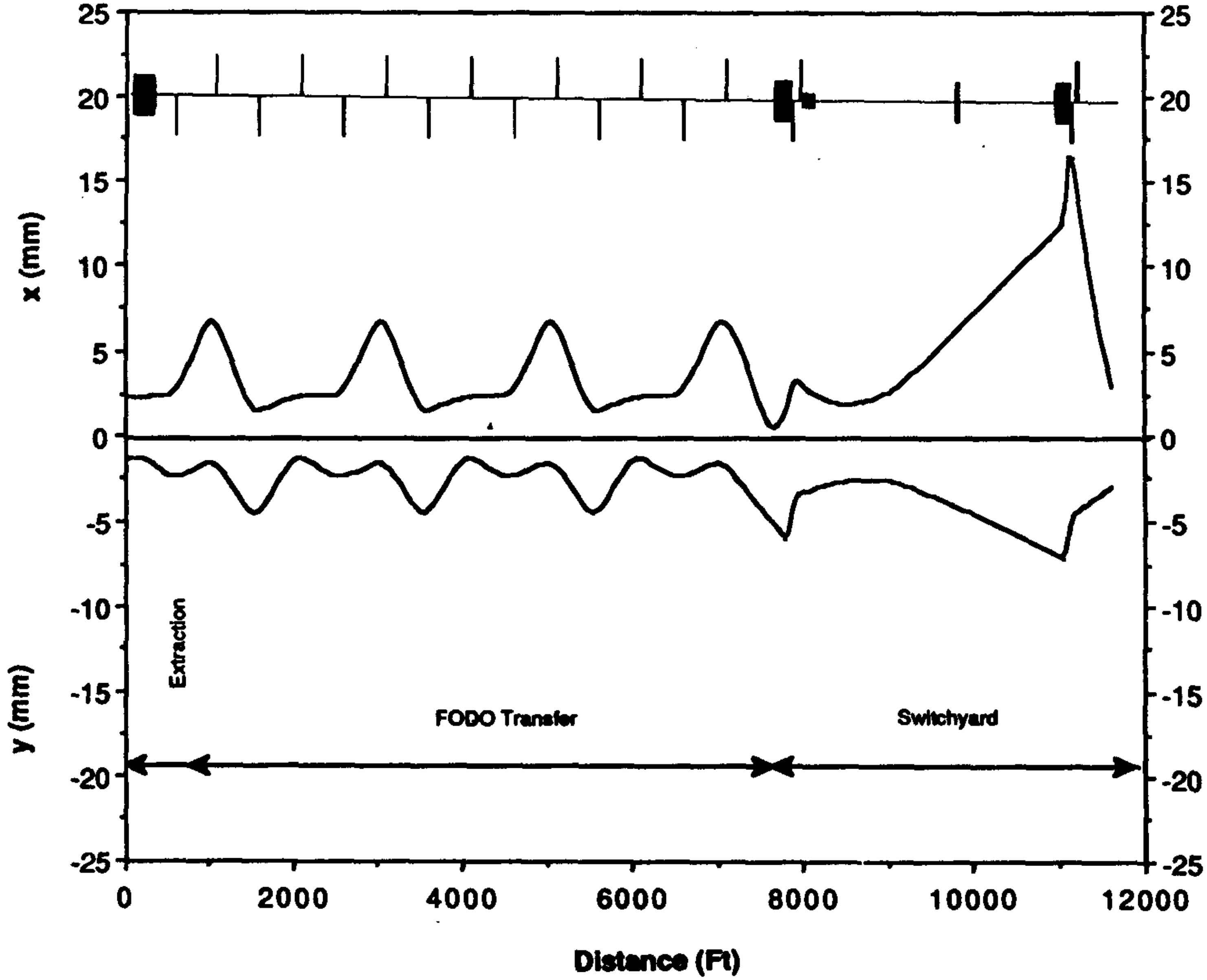


Fig. 9 Beam envelopes of 2 TeV primary beam. A FODO transfer line transports the beam in the 8000 foot tunnel to the actual switchyard.

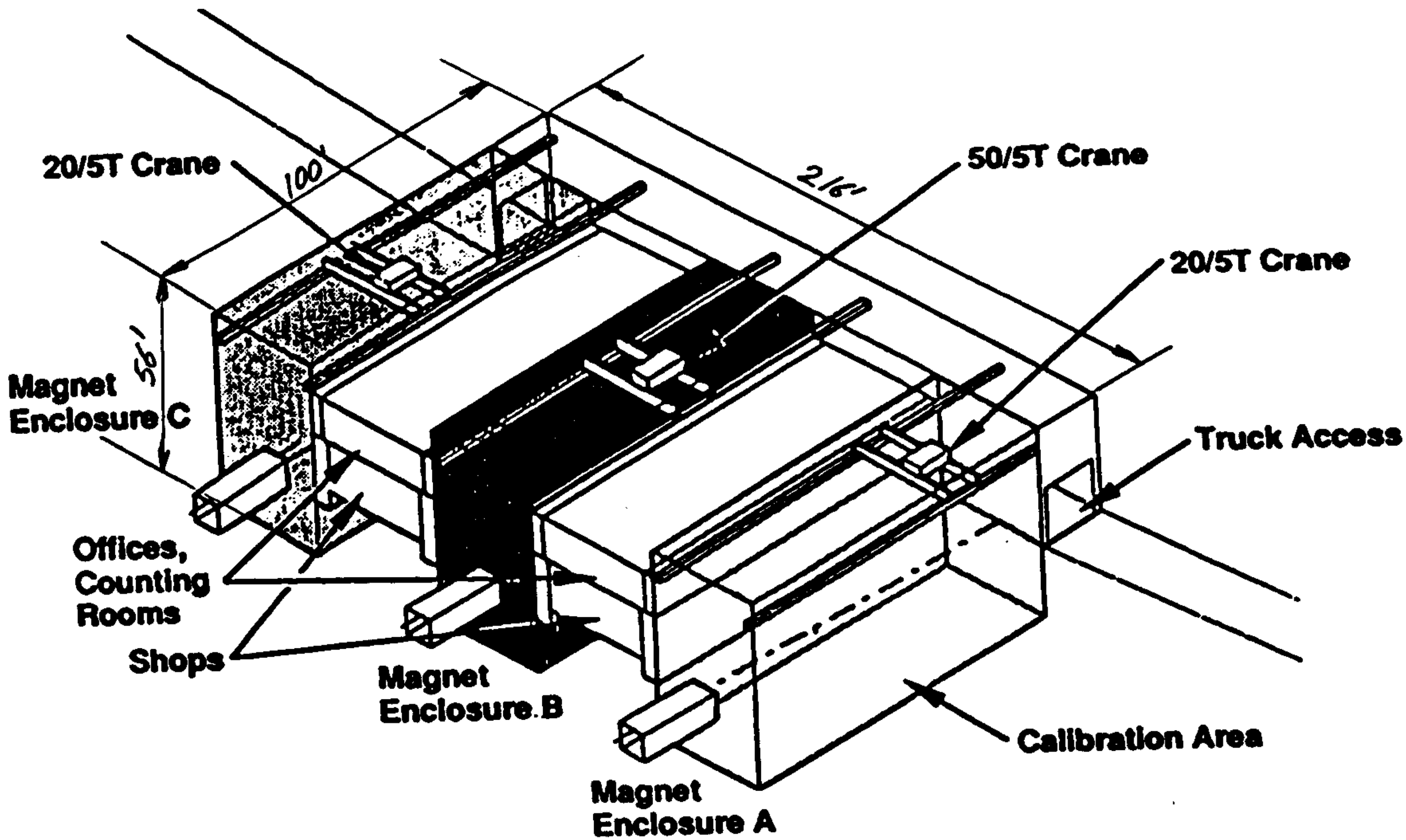


Fig. 10 Calibration Hall as described in the SCDR. The width of 216' is driven by each calibration area allowing 2 TeV operation.

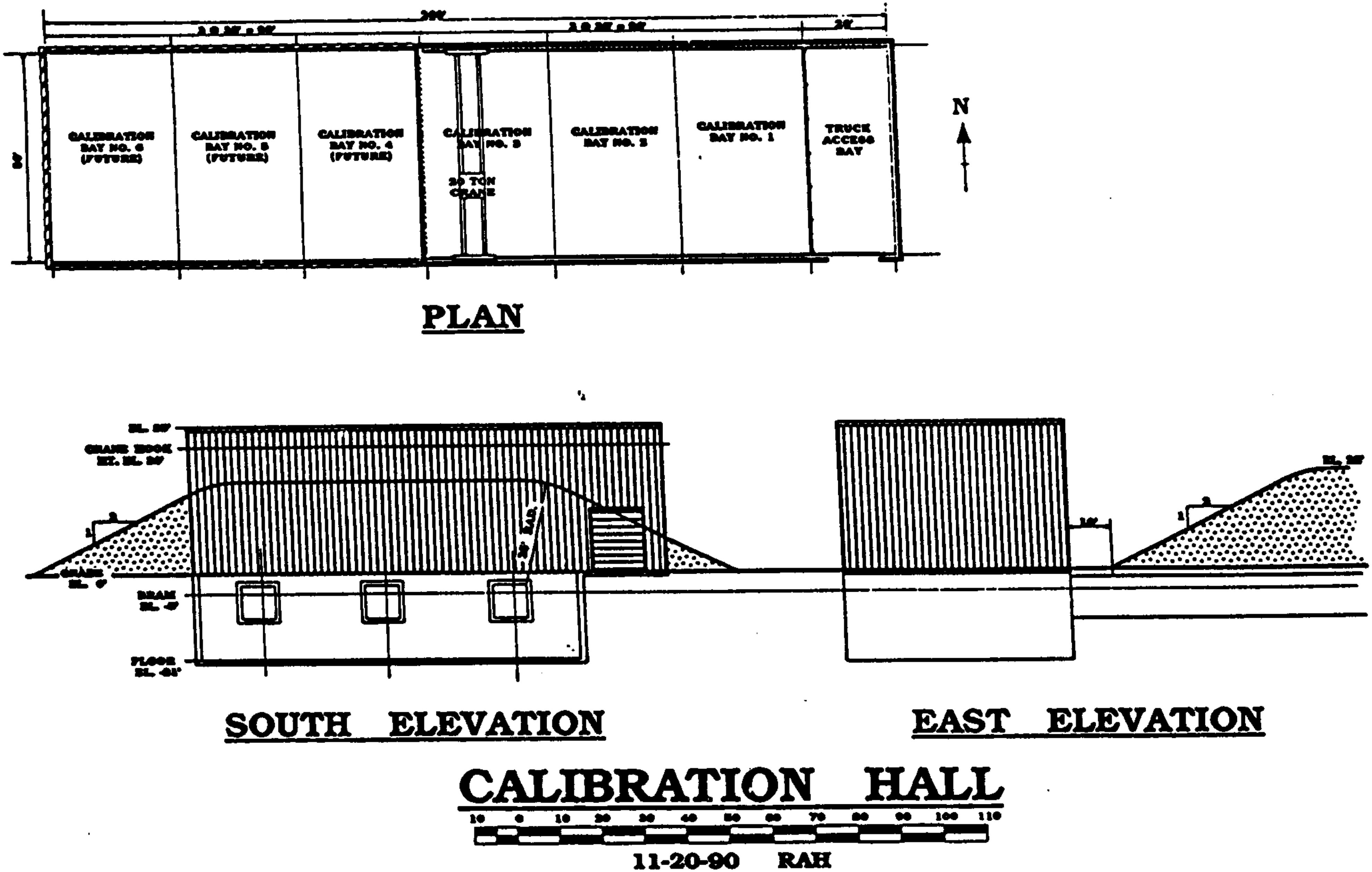
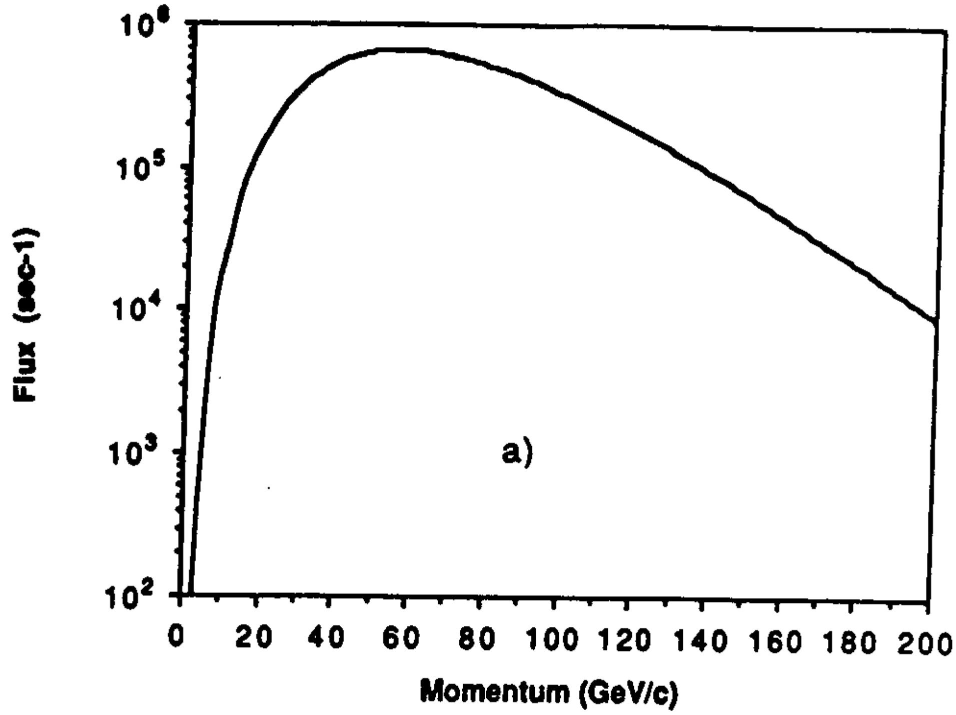


Fig. 11 New cost effective calibration hall. The first phase of the hall accommodates only one potential 2 TeV beam.



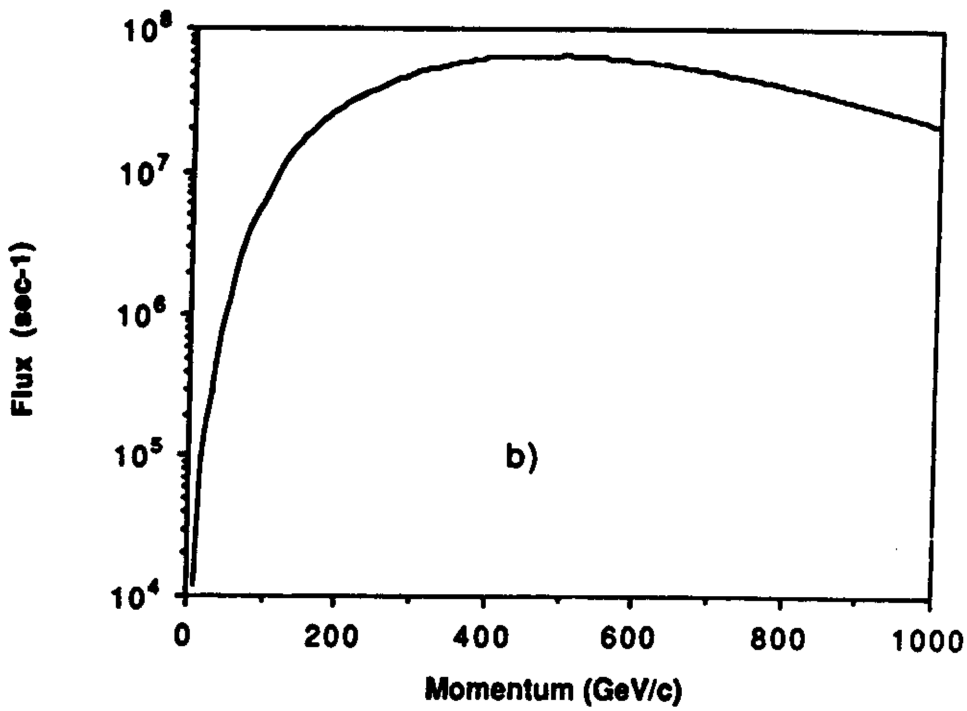


Fig. 12a) Pi minus flux vs. momentum for 200 GeV beam assuming 1E11 primary protons/s. b) Same for 2 TeV beam. The secondary beam momentum is limited to 1 TeV.

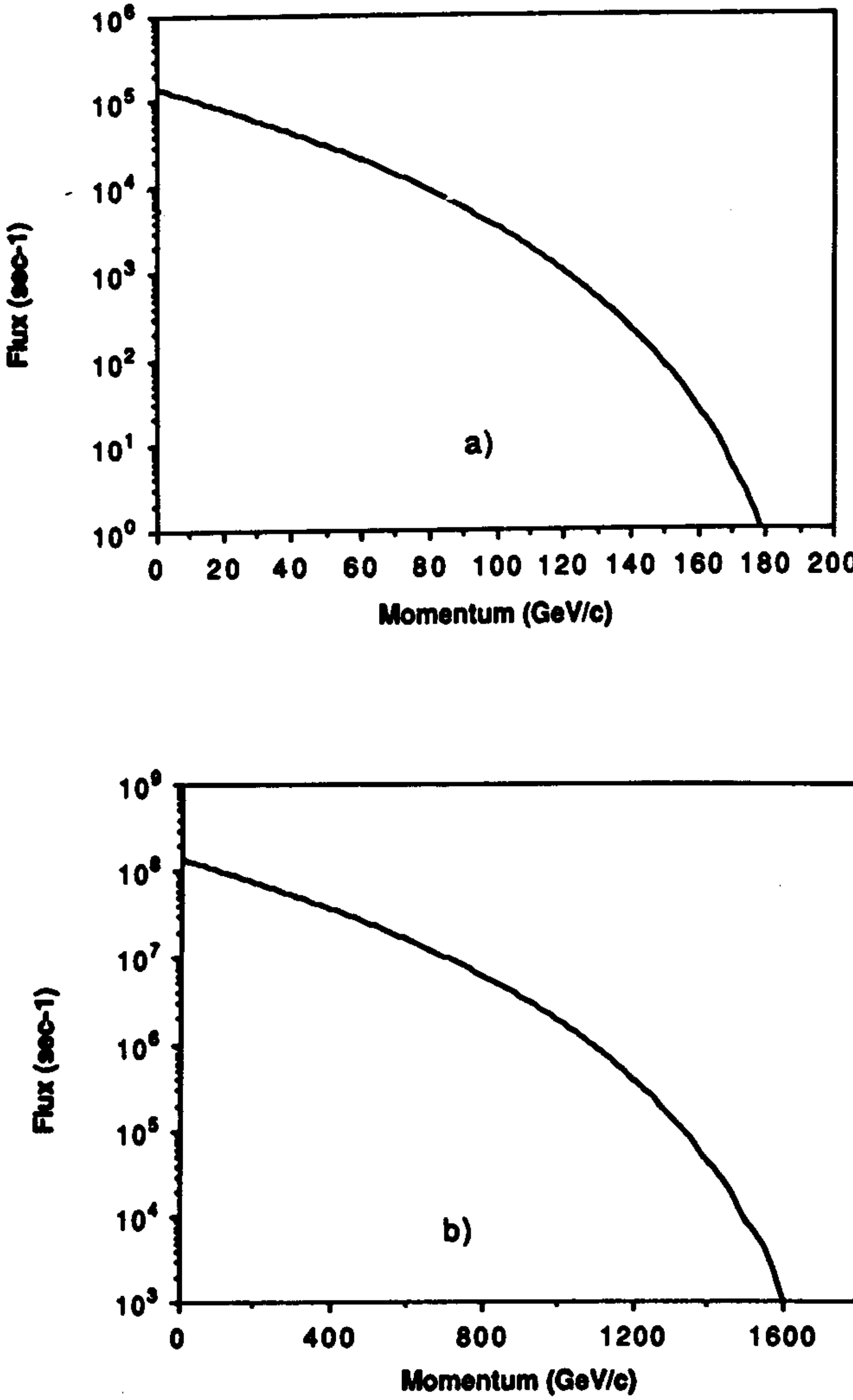


Fig. 13a) Electron flux for 200 GeV beam assuming 1E11 primary protons/s. b) Same for 2 TeV.

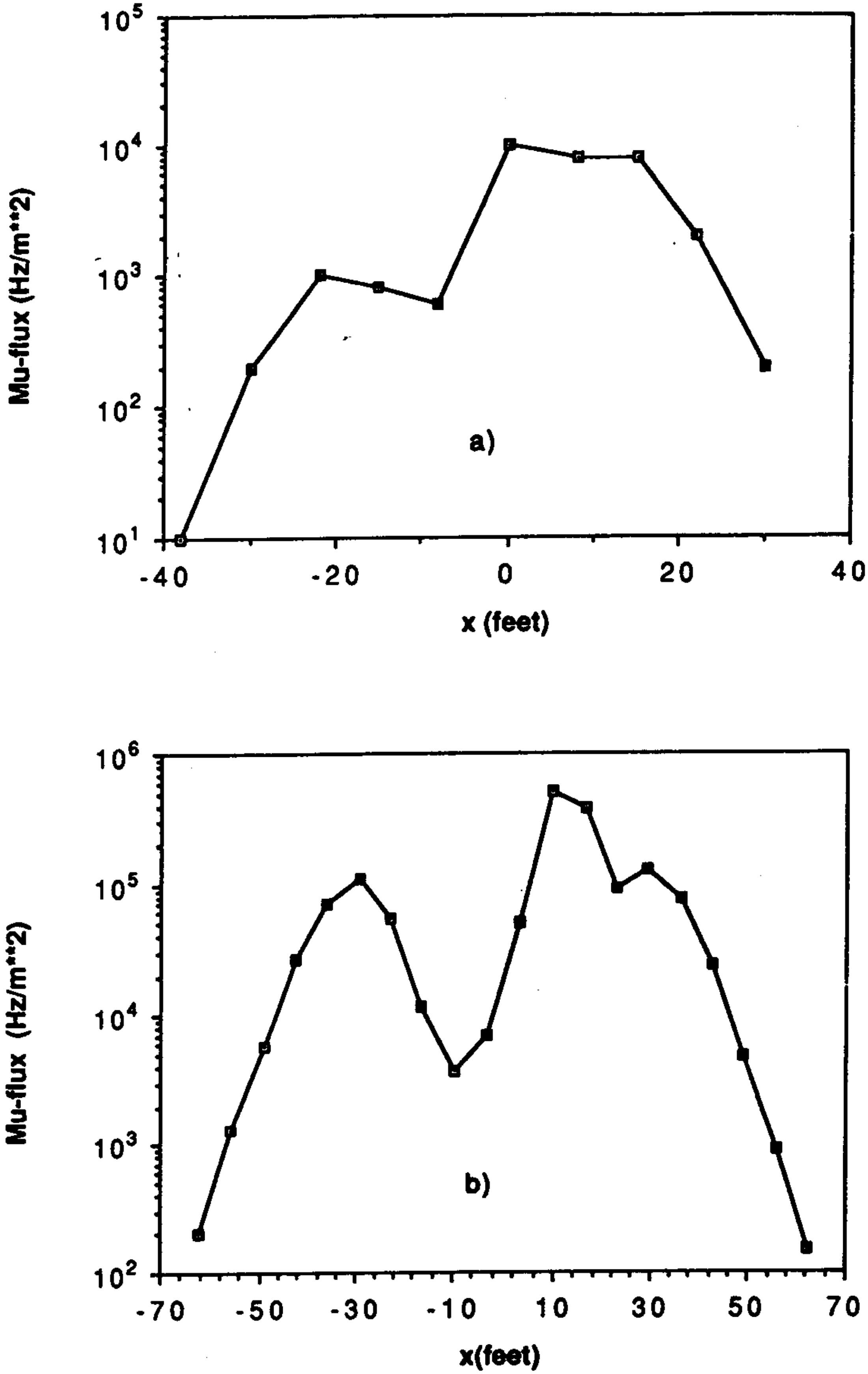


Fig. 14a) Muon flux at 1600 foot for 200 GeV. The dip is due to the sweeping magnet in the target pile. b) Same for 2 TeV using the common target hall.

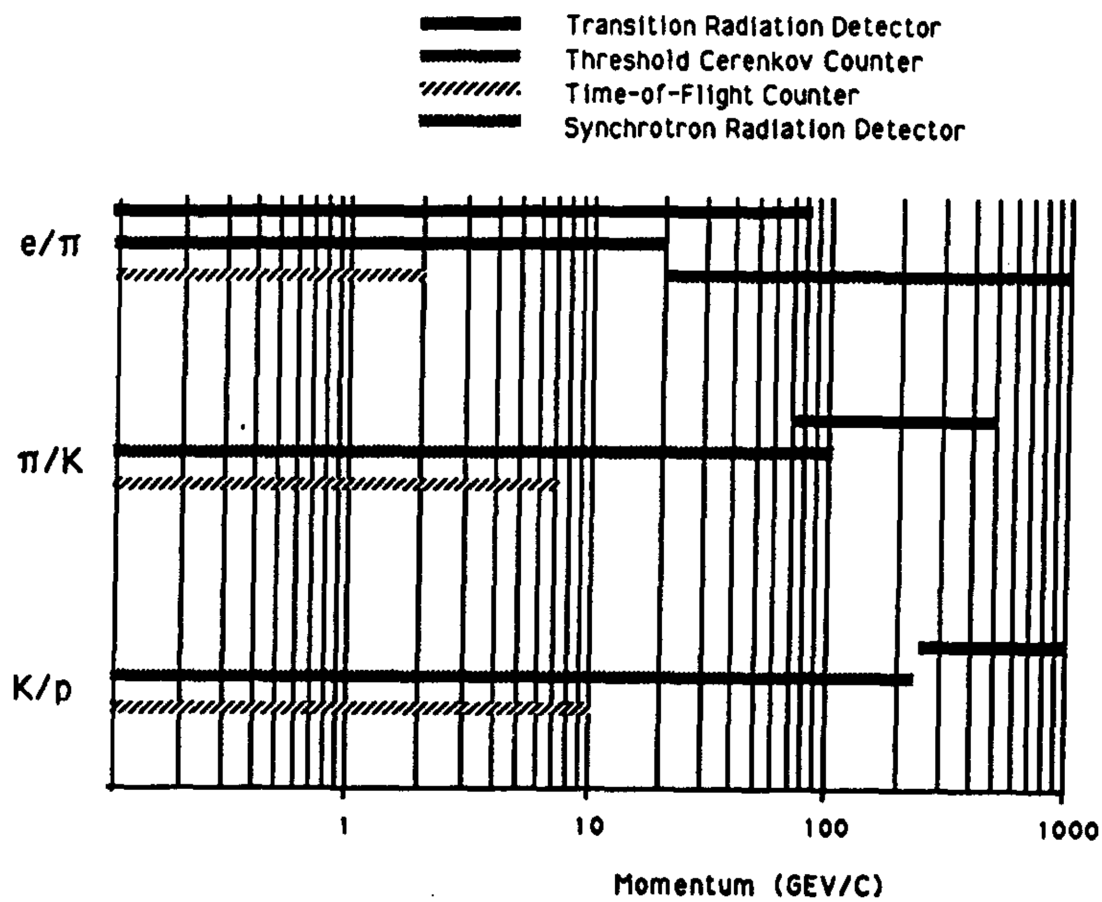


Fig. 15 Usable momentum range of various particle identification techniques given limits on length (60') and diameter (1.5') of detector.

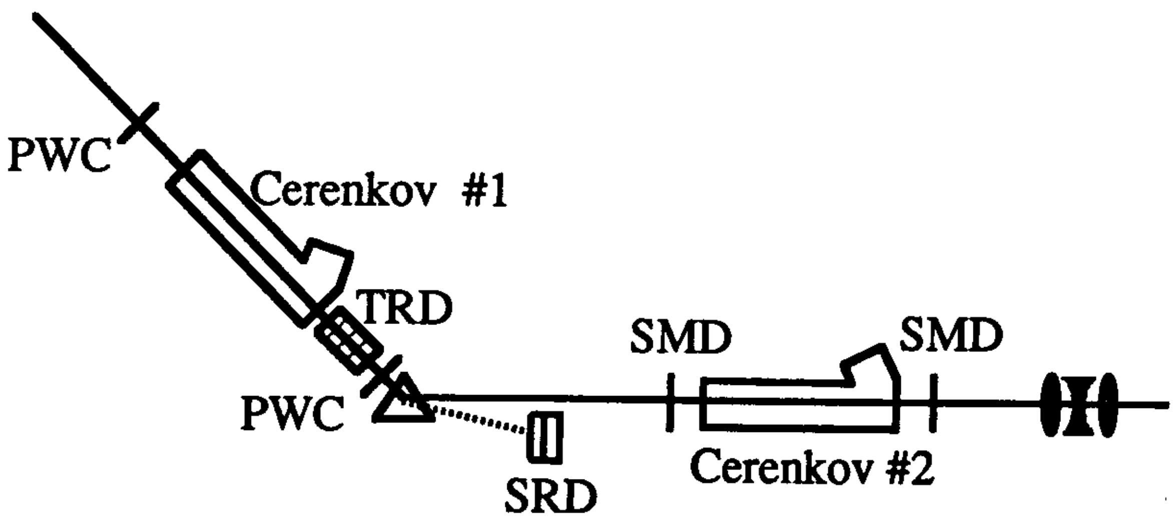


Fig. 16 Beamline instrumentation schematic.