Fermi National Accelerator Laboratory

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Wide Band to "Double Band" Upgrade

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Abstract

The Wide Band beam currently uses electrons obtained from secondary photon conversions to produce the photon beam incident on the experimental targets. By transporting the positrons produced in these conversions as well as the electrons it is possible to almost double the number of photons delivered to the experiments per primary beam proton.

I INTRODUCTION :

Motivation :

In order to obtain the high statistics required to study various rare physics processes, most fixed target experiments are keen to find ways of improving their experimental sensitivities. The Wide Band experiments are no exception. One way of obtaining the desired flux increases is to improve the production EFFICIENCY of tertiary beams. This proposal describes a way of increasing the the production efficiency of the Wide Band Photon Beam per incident primary proton by roughly a factor of 2.

Existing Beam:

A schematic diagram showing the steps involved in producing the wide band photon beam is shown in fig. 1.

The primary proton beam strikes the PB4 primary target to produce a neutral beam consisting of photons from pi-zero decays accompanied by K-zeros and neutrons. The secondary charged particles and uninteracted protons are dumped using vertically bending magnets.

The neutral beam hits a lead converter where the photons produce electron-positron pairs which are gathered by the PB4 quadrupoles and passed through a set of momentum-dipersing dipoles. The uninteracted neutral beam continues on in a straight line to be absorbed in the neutral dump in PB5. Dipoles in PB5 collect a +/- 15% momentum bite from the dispersed electrons and combine with the dipoles in PB6 to reconstruct an electron beam with zero net deviation. This beam is then focussed onto the experimental target by another set of quadrupole magnets in PB6. For the lowest momentum particles within the accepted momentum bite, the two sets of quadrupoles give point to point focusing between the production target and the PB5 momentum slit and point to point focusing between the momentum slit and the experimental target. The highest momentum particles however, undergo point to parallel focusing followed by parallel to point focusing.

Finally, the electrons strike a lead radiator in PB6 where they produce the final photon beam by bremstrahlung. A series of sweeper magnets deflect the secondary electrons into the RESH (Recoil Electron SHower counter) tagging system and the electron dump.

With this beam we transport >3.5 E-5 electrons (of 350 GeV nominal energy) per incident primary proton and write 1.0 E-9 events to tape per incident primary proton. The background trigger rates due to hadronic contamination of the beam is negligible.

II PROPOSED UPGRADE :

Strategy :

The symmetry of the existing beam with respect to the primary beam direction makes it possible to consider transporting the positrons produced at the converter as well as the electrons. The first quadrupole triplet collects the positrons as well as the electrons and the first dipole bend forms a momentum dispersed positron beam bent in the opposite direction to the electron beam. If this positron beam is intercepted by a set of dipoles and collimators in PB5 analogous to the ones for the electron beam, then the remaining beam elements will be able to collect and focus both the positron and electron beams onto the radiator. Since positrons radiate just as well as electrons, we can in principle double the number of photons incident on the experimental target per incident proton. A schematic of the modified beam line is shown in fig. 2. From this schematic we see that in principle the upgrade simply involves moving two magnets in PB5 and symmetrising the electron dump and RESH tagging system in PB6.

Beam Trajectories and Profiles :

Though the quadrupoles will focus both electron and positron beams equally, the size of the focus in the horizontal and vertical directions will be reversed for the two beams. To investigate the effect this might have on the relative acceptance and the shape of the beam spot at the experimental target, we have used the program TURTLE to trace equal numbers of rays through the existing beam line and studying the effects of reversing the quadrupole polarities. The electron momentum spectra was obtained by generating pi-zeros from 800 GeV proton interactions according to the Bourquin-Gaillard formula, and allowing them to decay to photons which then convert to electrons and positrons with an appropriate momentum loss due to Bremstrahlung in the converter. The beam profiles at the experiment target corresponding to electrons and positrons are shown in figures 3 and 4. No significant difference in acceptance is observed.

Special Considerations :

Background

Unlike the electron beam, the positron beam can potentially produce a neutron background due to protons transported along the beam. The protons are produced at the converter by neutrons undergoing charge exchange processes. The protons then charge exchange at the radiator to produce forward neutrons which can strike the experimental target. The expected background due to this process has been calculated to give approximately 3.7 E-6 protons incident on the radiator and 7.8 E-12 neutrons interacting in the experimental target per incident primary proton.

These numbers contain the following ingredients :-

- The combined interaction and escape probability of primary protons in the existing Beryllium target. (0.4)
- The production cross-section for forward neutrons by 800 GeV primary protons. (Here we used the experimental results on inclusive neutron production by protons on different target materials of Whalley et al.) We estimate 0.07 neutrons within +/- 1.4 mr with momentum >250 GeV per interacting proton.
- The interaction probability of the neutrons on the exisiting lead converter. (0.016)
- The production cross-section for forward protons by the neutrons. We assumed that this would be very similar to the proton-to-neutron cross-sections as used above.
- The acceptance of the beamline for these protons was calculated using TURTLE.
- The interaction probability of the protons on the lead radiator. (0.006)
- The neutron production cross-sections were used again to find the number of neutrons incident on the experimental target.
- The interaction probability of the neutrons in the experimental target. (0.1)

Small as it is this background will be further reduced by the trigger requirement of detecting an associated electron or positron in the RESH counters. In conclusion, we anticipate no problems due to this background.

Other backgrounds are common to both beams and were found during the last fixed target run to be entirely negligible.

Electron Sweeping and Photon Tagging System

The proposed extension of the electron sweeping, electron dumping, and photon tagging systems are depicted in Figures 5, 6, and 7. The sweeping magnet configuration (Fig. 5) has been symmetrized such that the photon beam is centered horizontally in the magnets. The sweeping magnets M3 and M4 have been removed and magnets M5 and M6 have been moved upstream. This will provide apertures large enough to allow tagging of both low energy electrons and positrons (high energy photons) simultaneously. The magnets M6 and M5 have been interchanged to minimize the vacuum chamber modifications. Notice that the radiated electron aperture will extend between the coils of M6 and M5 out to the steel return legs. With this reduced magnet configuration, the electron and positron beams can be dumped at the nominal 4.2 inch deflection from the photon beam given a corresponding increase in magnet current.

	Energy	Sweeper Current
Existing Beam	350 GeV	1180 Amps
Double-Band	350 GeV	1433 Amps
	415 GeV	1700 Amps
	500 GeV	2048 Amps.

Information from Fred Mills, the designer of these TeV1 dipoles, indicates that the copper conductor was sized to be "plenty big" for operation at 1200 Amps continuous. These dipoles have never been tested above this level. The TeV1 dipole specifications rate this conductor at 1700 Amps. The water flows must be specified accordingly. 1700 Amps corresponds to 415 GeV maximum electron or positron momentum in this configuration. These dipoles have been routinely ramped at Wide Band.

The electrons and positrons will be dumped in a configuration which is a simple extension of the existing electron dump (Fig. 6). The electron beam channel for E-774 will remain in the electron (west side) dump. An open question remains as to the effects on E-774 generated by dumping the background protons in this nearby position. However, they will probably be negligible.

An additional lead-lucite shower tagging hodoscope will be placed on the east (positron) side of the beam. It is proposed to use some of the similar components that are no longer required for the TPL tagging system. In this configuration, the limiting aperture is the return leg of M5. The minimum electron or positron energy corresponds to x = e'/e0 = 0.09 nominal, and the maximum nominal tagged photon energy corresponding to y = k/e0 = 0.91. Previously, E-687 tagged out to y = 0.90.

Figure 7 shows the separation of the electron, photon, and positron beams at the dump point and projected back to the downstream end of M5. Note that the beams overlap at the downstream end of M5. The existing vacuum system configuration in this area will be unable to reduce to acceptable levels backgrounds from having these high intensity beams pass through windows, or, even worse, beam pipes at a slanted angle. Instead, we intend to fill the area between the sweepers and the electron dump with a helium bag and, in order to eliminate excessive numbers of vacuum windows, will put helium in the beam pipes running through the sweepers and from the dump to the experiment target.

Trimming and Targeting

In order to minimise the modifications necessary for the neutral dump in enclosure PB5, The nominal beam line will need to be moved 1" closer to the line of zero deviation. (At present this separation is 12".) This will have the effect of changing the momentum acceptance of the beam. The effect of this alteration has been calculated using TURTLE. Thus for a nominal beam energy of 350 GeV we expect the mean electron/positron energy to reduce from 329 GeV to 328 Gev, the RMS momentum spread should increase from 8.7% to 9.1% and the total beam flux should increase by 5%.

One drawback of the proposed scheme is that it will no longer be straightforward to use the trim magnets in enclosure PB6. In the 1987 fixed target run the horizontal trim was not used at all, but the vertical trim was energised in order to compensate for a settling of the platform on which the experimental target sat. This situation will be remedied by raising the target and hence we will not require large scale trimming during normal data taking. Small horizontal adjustments can be made using the dipole magnets in enclosure PB5 and a vertical trim magnet will be required on both the electron and positron beams in that enclosure. A horizontal trim magnet will also be required on one of the beams in order to compensate for any difference in the two dipole pairs. There is however, a question as to how effective the vertical trims will be. As mentioned earlier the low momentum part of the beam undergoes point to point focussing from PB5 to the experimental target. This means that adjusting the direction of the low momentum electrons/positrons in PB5 will produce little or no net displacement at the target. This situation does not apply to the high momentum particles which undergo parallel to point focussing. Fig. 8 shows the effect of 0.1 mr and 0.2 mr trims on the vertical beam profile at the experimental target. Thus we see that small (5mm) adjustments are possible, but attempts at larger adjustments cause unacceptable spreading of the spot size.

Radiation Safety

The shielding around the Wideband Beam was designed to permit the beam to run as a pion or primary proton beam. It therefore greatly exceeds the requirements of the existing electron beam and of the proposed "Double-band" electron-positron beam. The beam is located underground and there is the equivalent of at least 15 feet of earth over it all the way down to (but not including) the experimental hall. The positron dump is located approximately thirty feet upstream of the experimental hall, well inside the heavily-shielded zone.

Access to the experimental hall is not permitted when the beam is being transported into the Hall. Access is permitted with the primary beam striking the production target in PB4 providing that a beam stop located downstream of the target box in PB4 is inserted. At present, all the electrons and positrons strike this beam stop so the intensity and composition of the beam is unchanged by the proposed upgrade and the "Beam-on_target" style access to the experimental hall will continue to be safe.

The muon rate in the Wideband Hall is dominated from pions which emerge from the PB4 production target and decay inside the target box. The decay muons escape from the target box and eventually make their way to the hall. The rate depends only on the number of interacting protons and will not be changed by the installation of the positron beam or by the widening of the pipe between PB5 and PB6. Some additional muons may be produced by decays from protons interacting in the radiator or by showers generated by hadrons inside the positron dump. These will contribute negligibly to the existing muon rate.

The rate of protons hitting the positron dump will exceed the rate of negative pions hitting the electron dump by a factor of about 5. There may well be 10E7 protons striking the dump. Spray from the dump could cause problems for the detector and it seems wise to plan a somewhat heftier dump on the positron side. It's purpose is to limit spray from protons into the detector and is not for radiation safety purposes.

Instrumentation :

Additional instrumentation is required to commission, debug, and trouble shoot the positron branch of the beam. Each device and its purpose is described briefly:

1) A pair of collimators in PB5. One has jaws that close horizontally on the beam. The other has jaws which close vertically on the beam. They must have at least 6" of horizontal aperture and 3" of vertical aperture when fully open so that they do not reduce the aperture of the beam. One needs to be at least 5' long. The other may be shorter -- say two feet long. These are similar in purpose to collimators already located on the negative branch of the beam. Their purpose is to allow us to turn off the positive branch of the beam. This is necessary to enable us to compare the fluxes and beam profiles in the positive and negative arms during beam commissioning. It also allows us to turn off the positive beam for special calibration runs where intensity is not a problem but beam purity is so that it is desirable to use the negative branch alone. Yet another purpose is to allow us to control the intensity and momentum bite of the positive branch in a manner similar to the way we control the negative branch. The collimator openings must be settable and readable through the beamline control system.
2) A lead absorber of 1-2" in thickness, large enough transversely to cover the whole beam (3"x6"). This absorber will cause the positrons to lose nearly all their energy so that they can't be transported through the downstream part of the beam in PB6. The hadron background will, however, mostly survive and will be transmitted through the rest of the beam. This allows us to measure the hadronic background from the positive branch. It also allows the creation of a low intensity proton beam which might be useful for certain studies. The absorber needs to be inserted or extracted from the beam under the control of the beamline control system anad its status (IN/OUT) must also be readable.
3) A vacuum SWIC of the F3G type, fully instrumented with remote control and readout. This will be used mainly during commissionin to check the beam profile at the exit to PB5.

Possible additional equipment from the experiments might include scintillation paddles or ion chambers to measure the relative rates in the two branches in PB5 and a synchrotron radiation detector in PB6 (as described by E774) to reject hadronic background in the beam.

Civil Construction :

The beam pipes from PB4 to PB5 and PB5 to PB6 were originally intended only to carry either a neutral or negative beam and are not necessarily large enough to carry both positive and negative beams simultaneously.

The pipe from PB4 to PB5 has been surveyed over its full length. The results of this survey are shown graphically in fig. 9. We see that the positron beam will be partially occluded in the regions around the 16" to 24" transition point and at the entrance to PB5. The first occlusion is serious and cannot be much reduced by reducing the separation between the positron and electron beams. Thus we propose to replace the last 50' of 16" pipe with 24" pipe. The occlusion near the PB5 entrance is much less severe and can be reduced further still by bringing the electron and positron beams closer together. This will also produce a slight increase in both the momemtum band width and intensity of the beams. Thus we see no need to replace any of the beam pipe at the entrance to the PB5 enclosure.

The two beams will not fit inside the existing beam pipe located between enclosures PB5 and PB6; therefore we propose to replace that pipe with a 30" diameter pipe. The original pipe consisted of 30", 24" and 16" segments. However, in order to improve the performance of synchrotron radiation detectors situated near the entrance to enclosure PB6, we have chosen to replace them with a 30" pipe all the way from PB5 to PB6. There are buried electrical ducts and LCW piping which must be removed and replaced to accomplish this.

In order to shift the two PB5 dipoles onto the positron beam we need to widen the PB5 enclosure. The simplest way to do this is to replace the existing 8' wide precast concrete sections with 10' wide sections. This means that the bend centre of the PB5 dipoles would need to move downstream some 24'. The effect of this shift on the beam optics is negligible, but it would require that the enclosure be extended by a corresponding amount. A secondary beneficial efect of extending the enclosure concerns the beam pipe occlusion problem mentioned above. By extending the enclosure we gain room in the upstream end of the enclosure to enable us to move the neutral dump away from the beam pipe entry point. Thus we can bring the two beams closer together and still dump the entire neutral beam as shown in fig. 9. The proposed enclosure modifications and layout are shown in fig. 10.

Technical Components :

Neutral Dump Modification

The neutral dump will have to be modified to accept the double beam. This modification will take place by moving the dump under the hatch in enclosure PB5 and replacing vacuum pipe and shielding as shown in fig. 11. The dump then has to be repositioned 15' from its original position and all elements reset.

Additional Equipment

An extra horizontal trim magnet with an independent power supply is required in PB5. The two vertical trim magnets already exist there but need to be put onto separate power supplies. Another 5 ft. long vertical collimator and non-standard horizontal collimator are required.

For the electron dump in enclosure PB6, more shielding and a new support are required as shown in fig. 6. Also the vacuum pipes in the two downstream sweepers will need to be modified in order to maintain the acceptance for low momentum, recoil electrons and positrons. The M5 magnet (see fig. 5) will need be removed to PB7 in order to install the new vacuum pipe.

Acknowledgements :

We wish to thank L. Ketcham's alignment group for the work done in surveying the PB4 to PB5 beam pipe.

We would also like to thank L. Kula's group for useful discussions in planning the civil contruction work.

Fig. 1

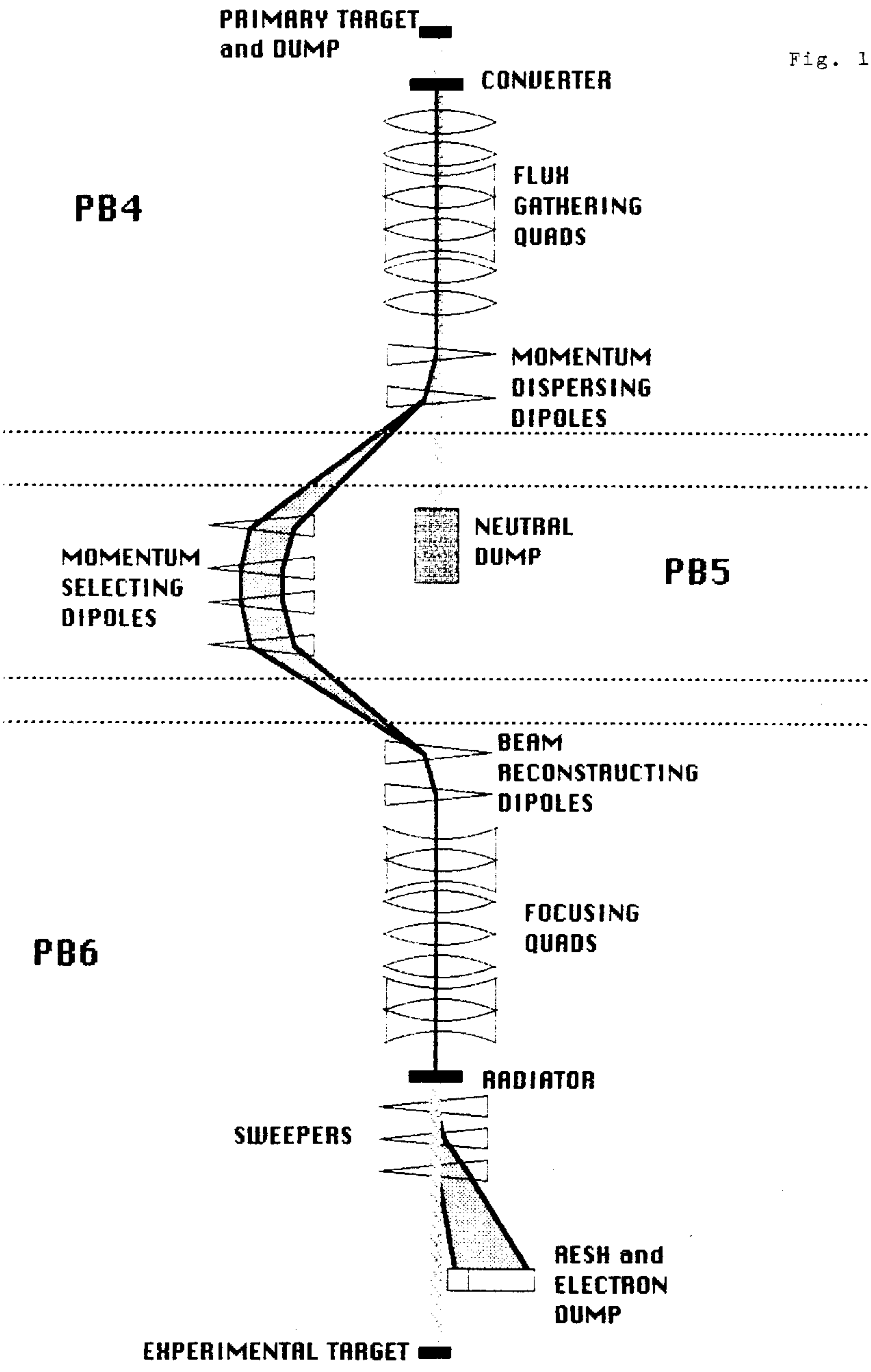

PRIMARY TARGET and DUMP
CONVERTER
PB4
FLUX GATHERING QUADS
MOMENTUM DISPERSING DIPOLES
NEUTRAL DUMP
MOMENTUM SELECTING DIPOLES
PB5
BEAM RECONSTRUCTING DIPOLES
FOCUSING QUADS
PB6
RADIATOR
SWEEPERS
AESH and ELECTRON DUMP
EXPERIMENTAL TARGET

Fig. 2

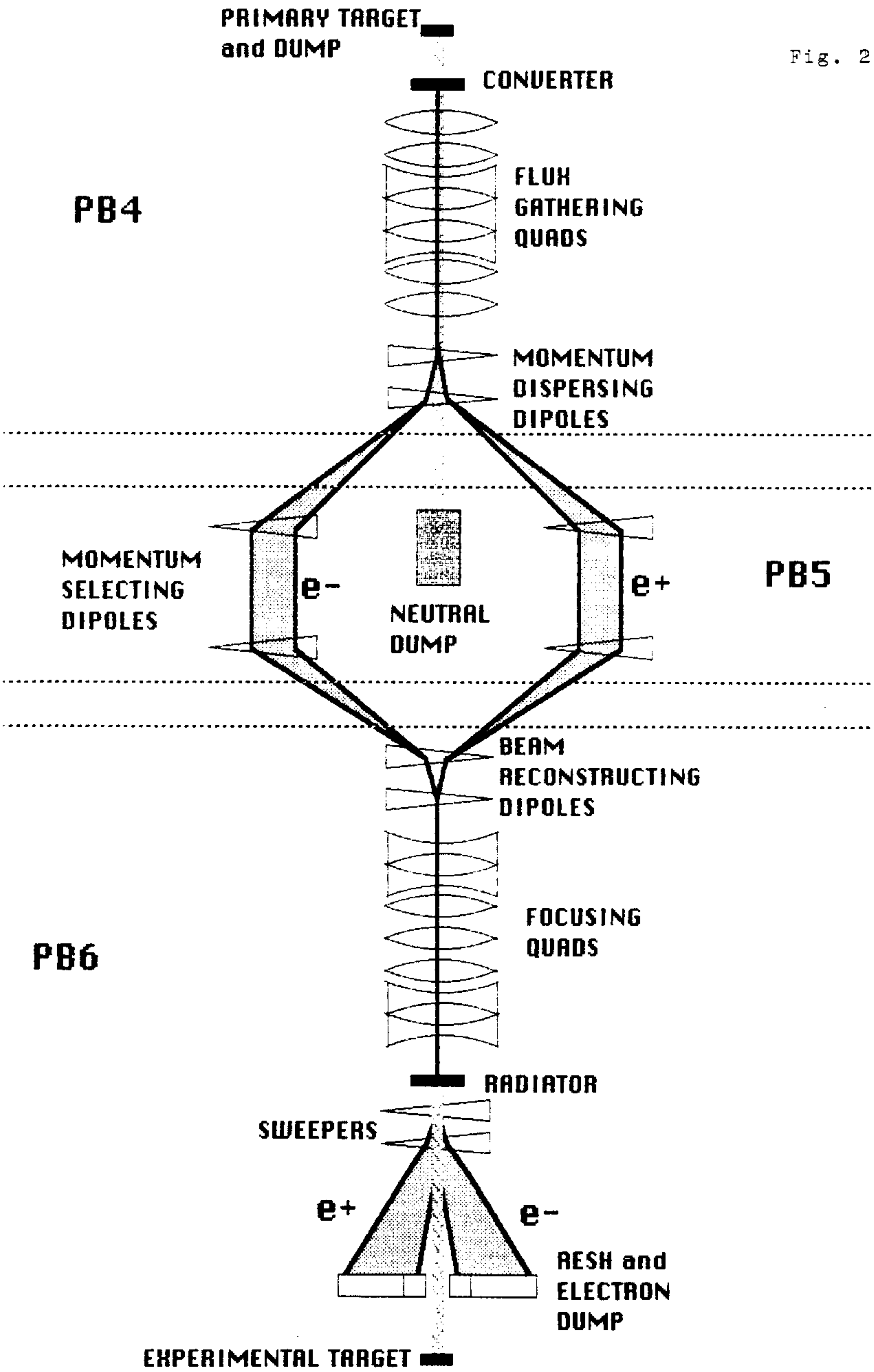
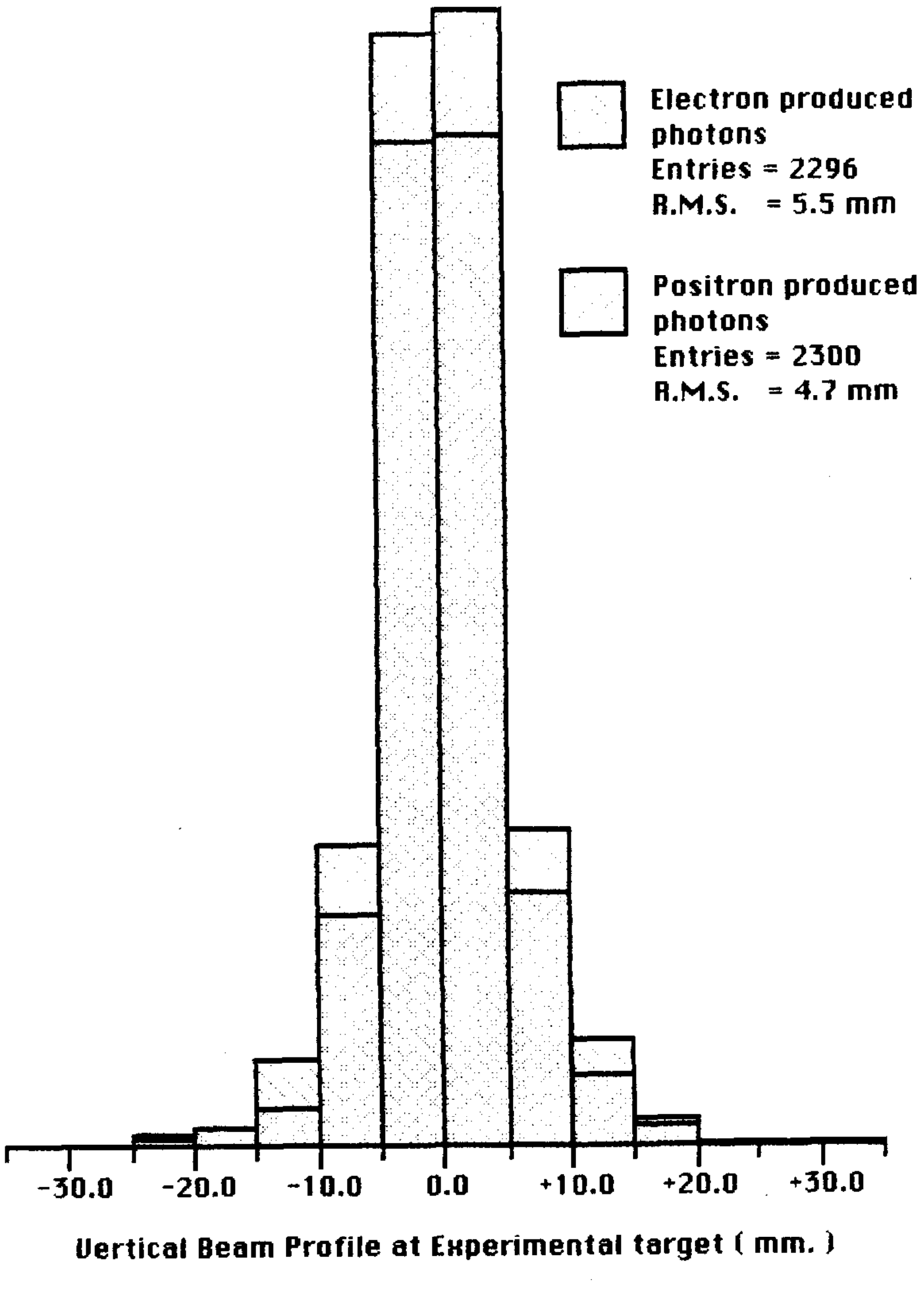

PRIMARY TARGET
and DUMP
CONVERTER
FLUX
GATHERING
QUADS
PB4
MOMENTUM
DISPERSING
DIPOLES
MOMENTUM
SELECTING
DIPOLES
e-
NEUTRAL
DUMP
e+
PB5
BEAM
RECONSTRUCTING
DIPOLES
FOCUSING
QUADS
PB6
RADIATOR
SWEEPERS
e+
e-
RESH and
ELECTRON
DUMP
EXPERIMENTAL TARGET

Fig. 3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R.M.S. = 5.5 mm
Positron produced photons
Entries = 2300
R.M.S. = 4.7 mm
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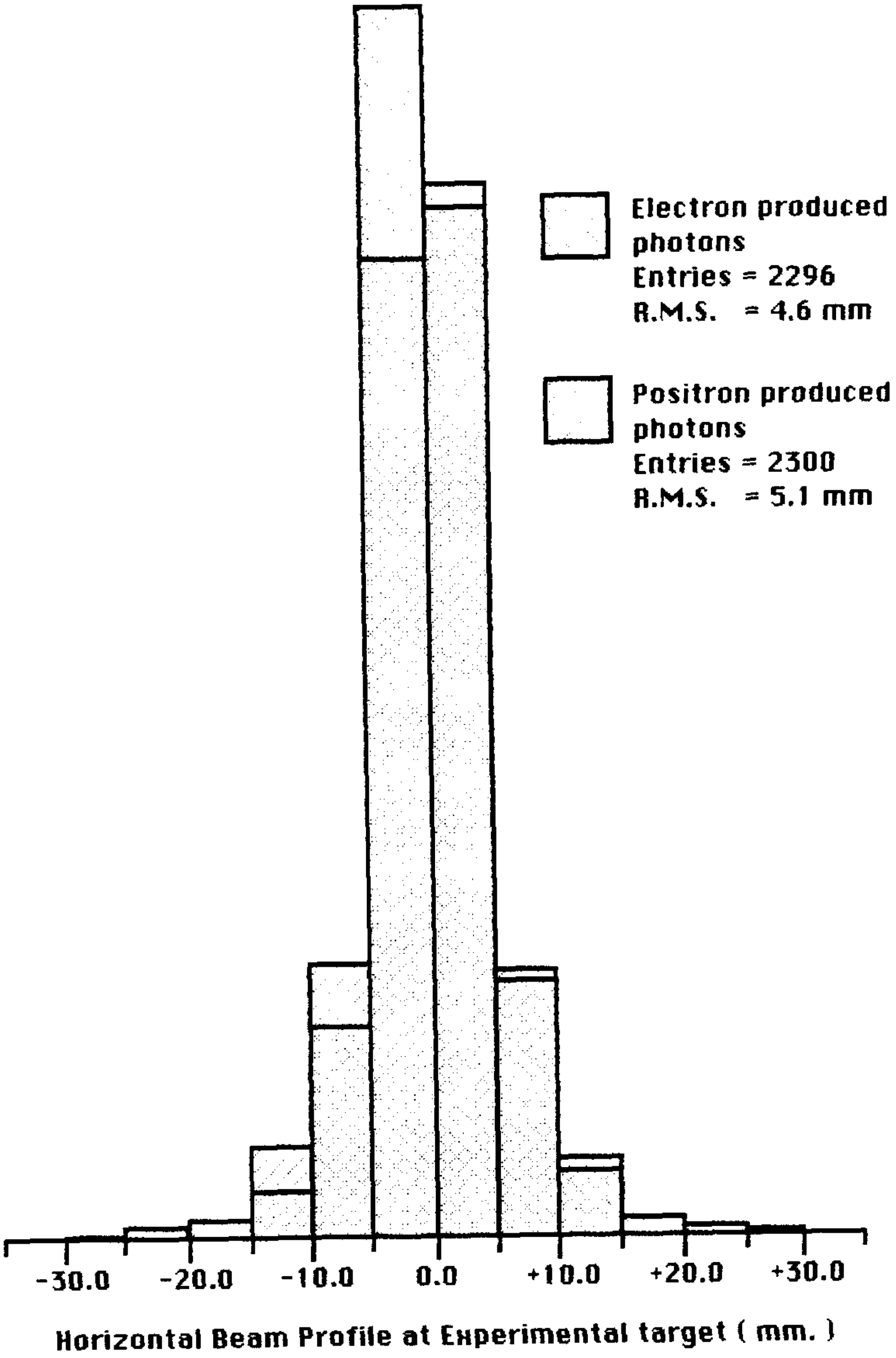
-20.0
-10.0
0.0
+10.0
+20.0
+30.0
Vertical Beam Profile at Experimental target (mm.)

Fig. 4


Electron produced photons
Entries = 2296
R.M.S. = 4.6 mm
Positron produced photons
Entries = 2300
R.M.S. = 5.1 mm
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+10.0
+20.0
+30.0
Horizontal Beam Profile at Experimental target (mm.)

Fig. 5

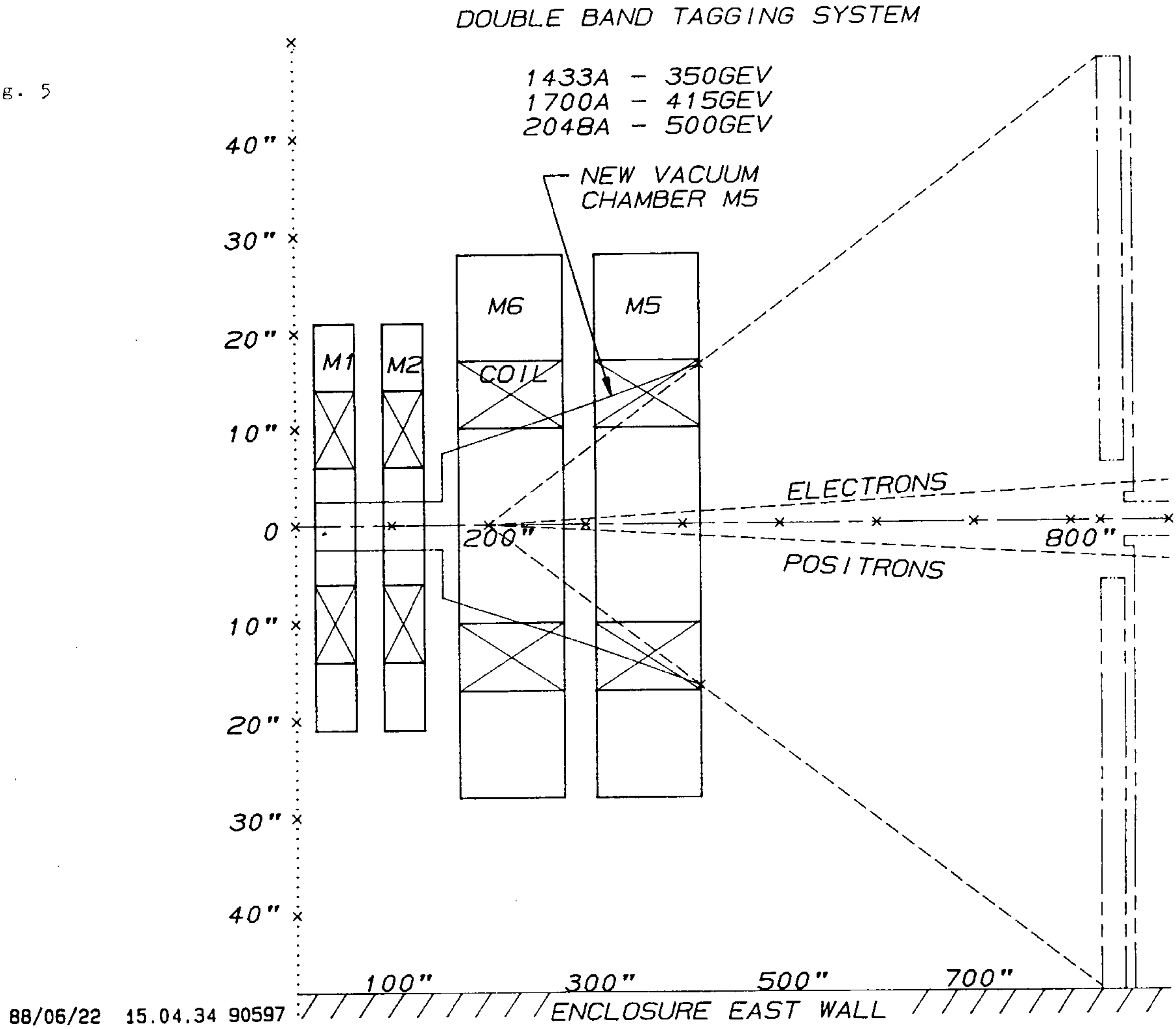
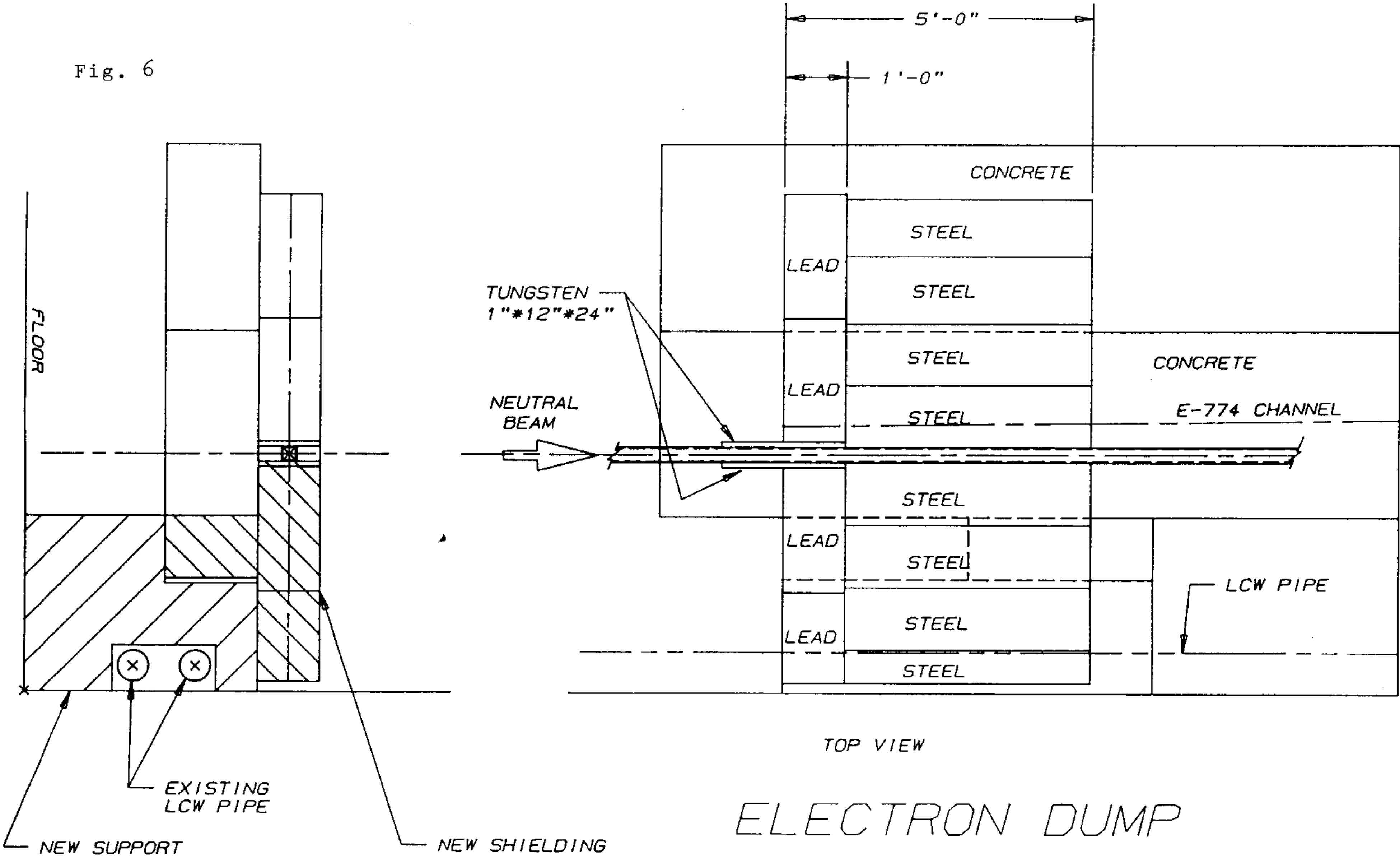

DOUBLE BAND TAGGING SYSTEM
1433A - 350GEV
1700A - 415GEV
2048A - 500GEV
NEW VACUUM CHAMBER M5
M1
M2
M6
M5
COIL
ELECTRONS
POSITRONS
40"
30"
20"
10"
0
10"
20"
30"
40"
200"
800"
100"
300"
500"
700"
ENCLOSURE EAST WALL
88/06/22 15.04.34 90597

Fig. 6



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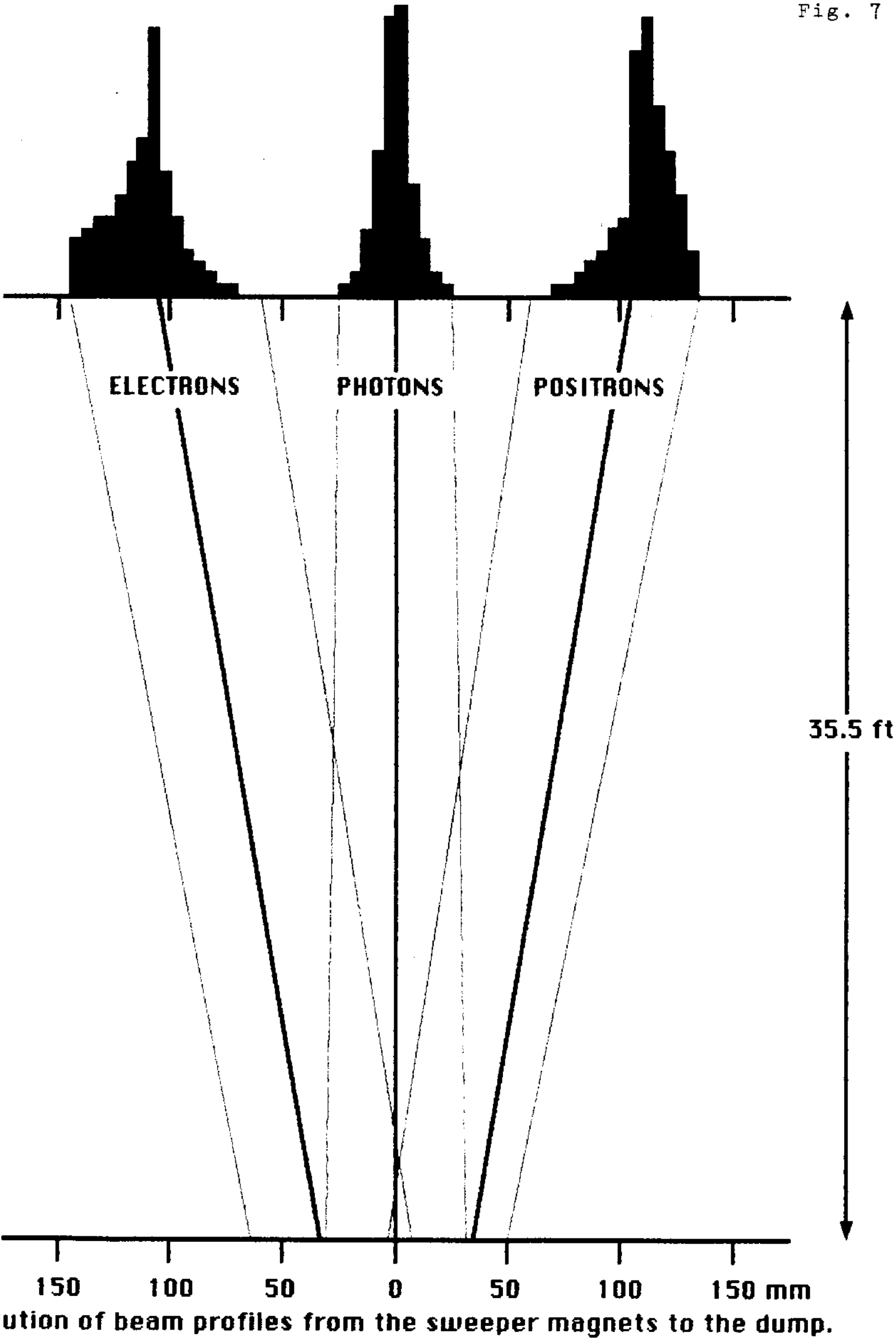
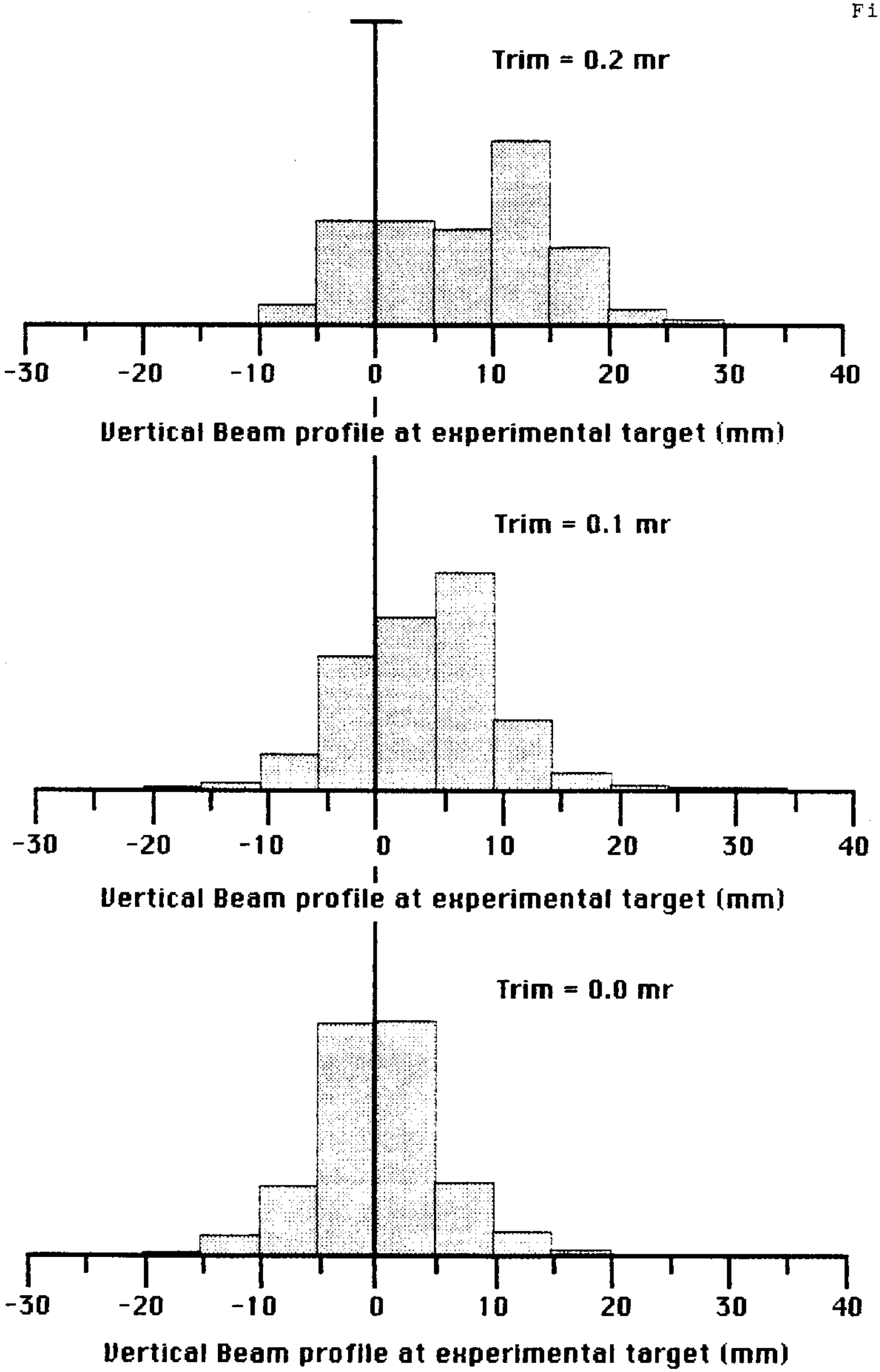


Evolution of beam profiles from the sweeper magnets to the dump.

Fig. 8


Trim = 0.2 mr
-30
-20
-10
0
10
20
30
40
Vertical Beam profile at experimental target (mm)
Trim = 0.1 mr
-30
-20
-10
0
10
20
30
40
Vertical Beam profile at experimental target (mm)
Trim = 0.0 mr
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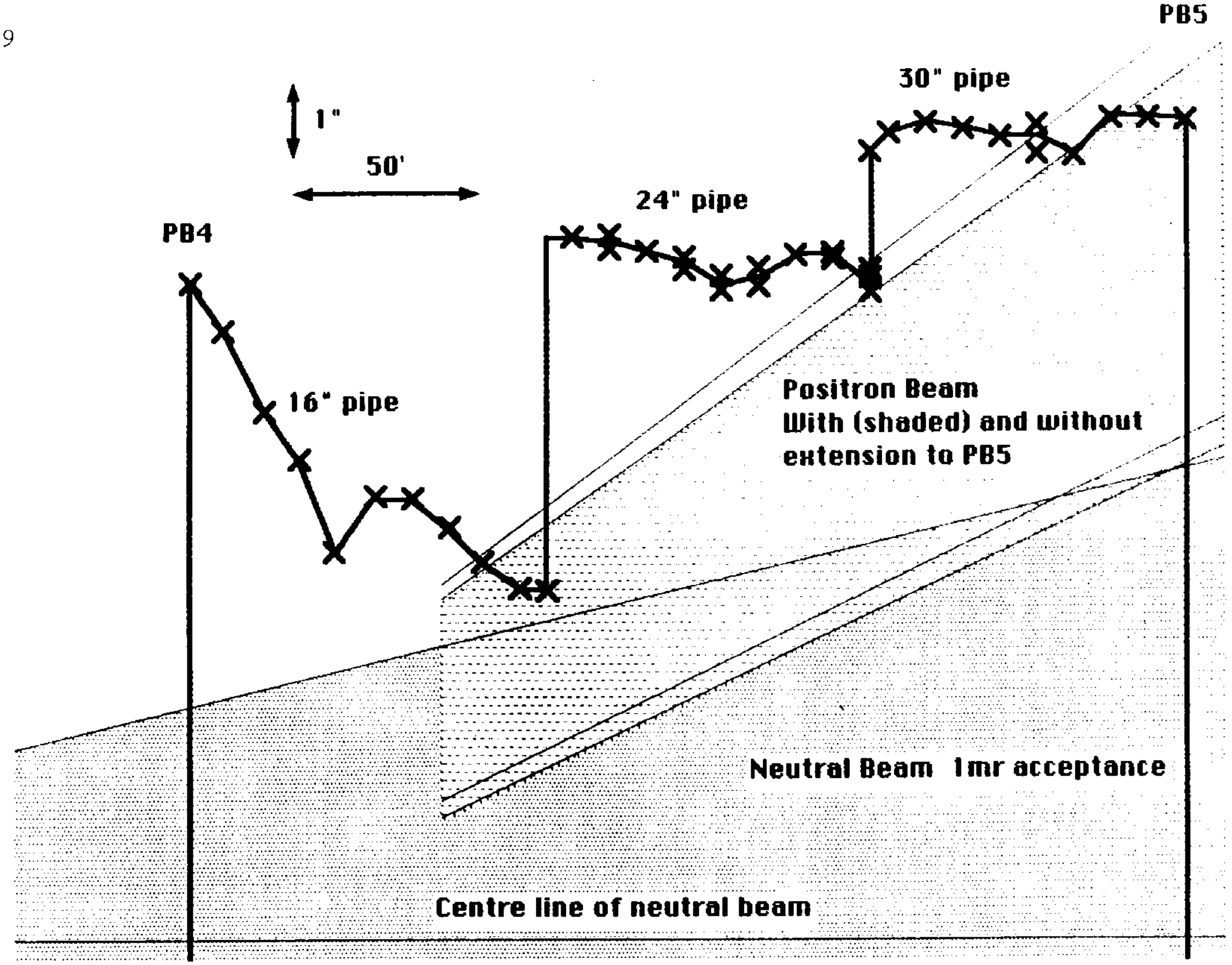
-10
0
10
20
30
40
Vertical Beam profile at experimental target (mm)

Fig. 9


PB5
30" pipe
1"
50'
24" pipe
PB4
16" pipe
Positron Beam
With (shaded) and without
extension to PB5
Neutral Beam 1mr acceptance
Centre line of neutral beam

DOUBLE BEAM 9

Fig. 10

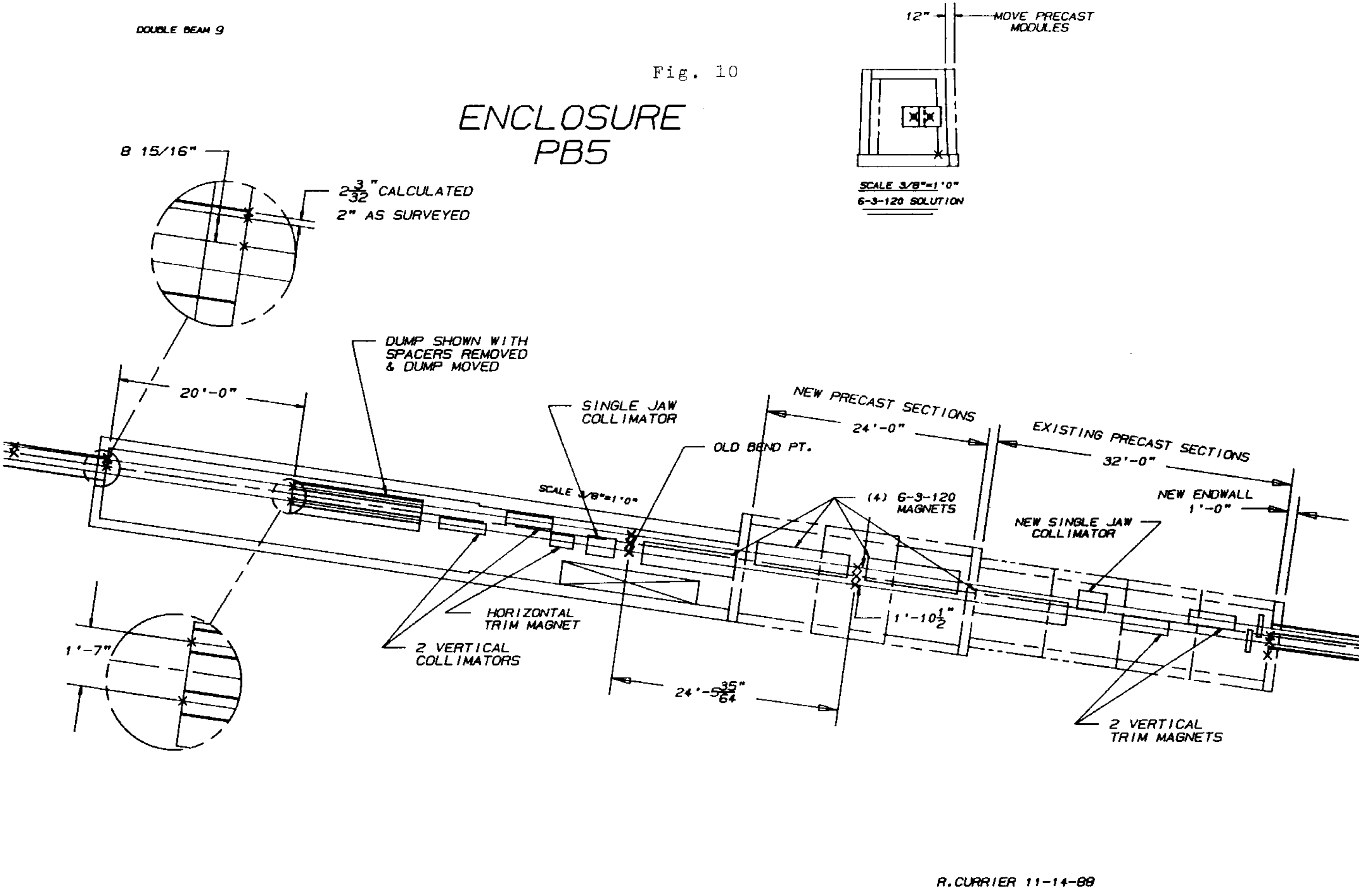


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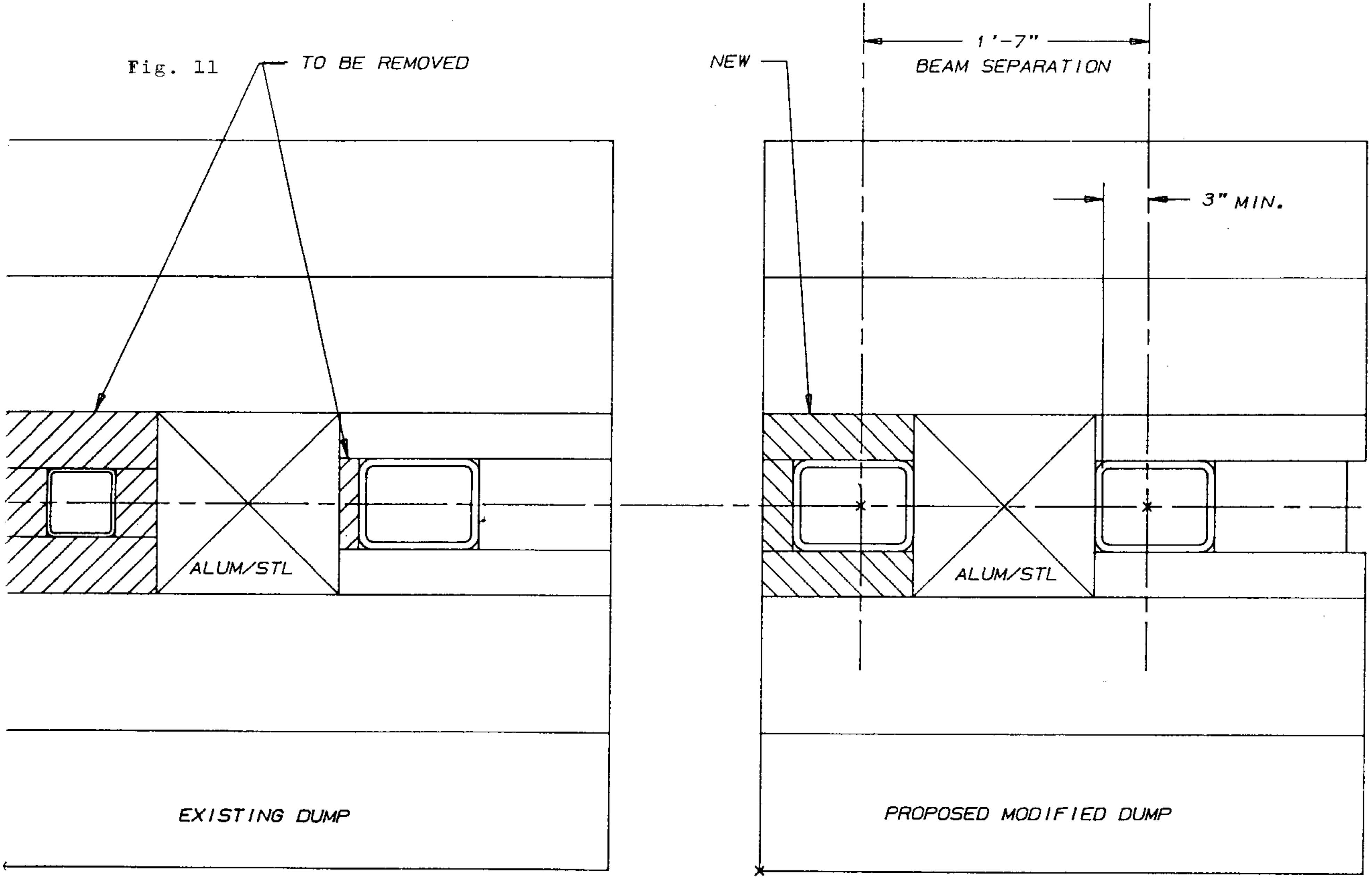
Fig. 11


TO BE REMOVED
ALUM/STL
EXISTING DUMP
NEW
1'-7"
BEAM SEPARATION
3" MIN.
ALUM/STL
PROPOSED MODIFIED DUMP