BOOSTER EXTRACTION, BOOSTER-TO-STORAGE RING TRANSPORT AND STORAGE RING INJECTION FOR THE ALS

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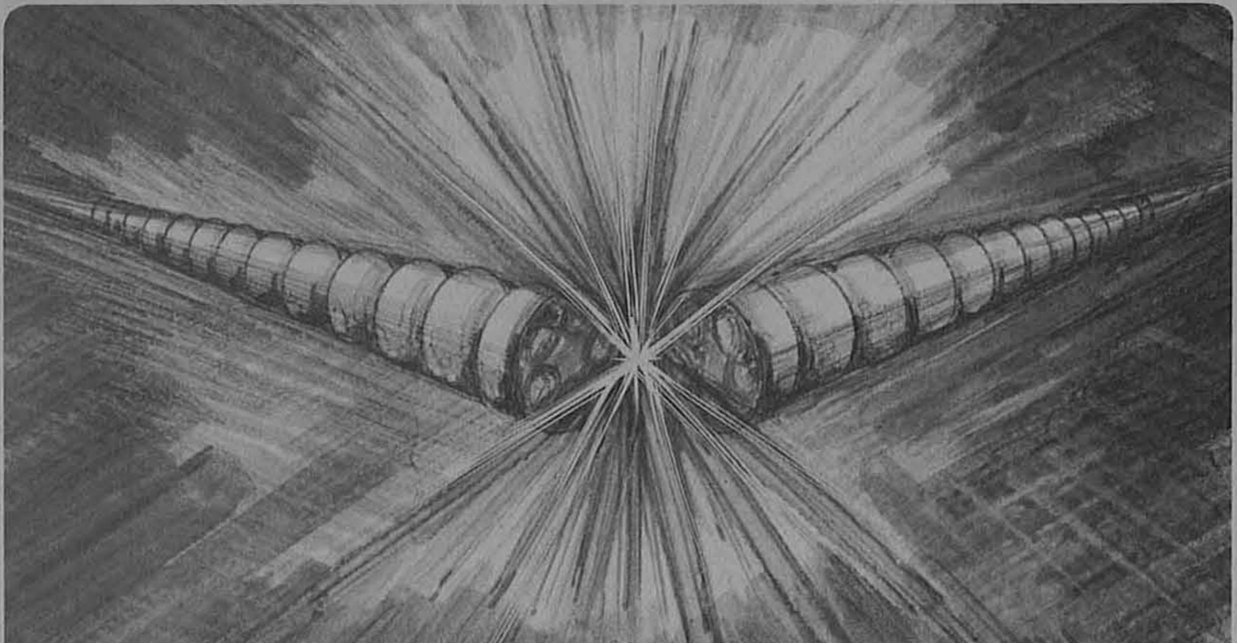

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Abstract

A status report on the design of the ALS injection system is presented. The various modifications that have occurred since the time of the ALS Conceptual Design Report in July, 1986 are described, along with the reasons for the changes.

I. INTRODUCTION

In this paper, we describe the present status of the injection system for the LBL 1-2 GeV Synchrotron Radiation Source, commonly referred to as the "Advanced Light Source" or ALS. The injection system for the ALS consists of the following major components:

- a high-current electron gun
- a gun-to-linac (GTL) transport line
- a 50-MeV, traveling wave linac
- a linac-to-booster (LTB) transport line
- a 1.5-GeV, 1-Hz booster synchrotron
- a booster-to-storage ring (BTS) transport line

The 50 MeV linac operates at 2.998 GHz. It has been designed—and is being fabricated—in collaboration with Matthew Allen's group at SLAC. The electron gun, which is similar in design to that utilized for the Stanford Linear Collider at SLAC, has been ordered from a commercial supplier.

Design of the booster, a 75-m missing magnet FODO structure, was carried out by Alan Jackson of LBL. This device will be assembled by LBL staff, although many of the components will be partially or wholly provided by outside vendors.

The remaining segments of the injection system are the three beam transport lines that connect the gun and linac (GTL), the linac and booster (LTB), and the booster and storage ring (BTS).

Although considerable design effort has been expended on all portions of the system in the past 18 months, we will focus in this paper primarily on the high energy part of the design, from booster extraction to storage ring injection.

In the time since the Conceptual Design Report[1] (CDR) for the ALS was completed, a number of significant changes have been made to the injection system parameters, especially the booster-to-storage ring (BTS) transfer line. Although the design of the transfer line—and those of the booster extraction and storage ring injection magnets that it connects—have not been entirely frozen, things have settled down now to the point where it is useful to document the status as of today.

System Requirements and Design Philosophy

Before discussing the details of the system, it is useful to review the operational requirements and philosophy that provide the framework for our design efforts. The goals envisioned for the ALS injection system include:

- providing a 1.5 GeV electron beam for the storage ring
- giving a filling time (to 400 mA) of less than 5 minutes
- allowing unrestricted access to user beam lines during injection
- being compatible with the future possibility of positron injection

In the context of positron injection, a 10-Hz cycle rate would be required to obtain reasonable filling times. Thus, we define "compatibility" here to mean that the booster synchrotron must be capable of operating at a 10-Hz rate. It will not, however, be initially configured with this capability, but will operate at only a 1-Hz rate.

Our design philosophy is predicated on the injection system being the heart of the entire ALS facility. Thus, we stress a reliable and conservative design. In addition, we are cognizant of the fact that the injection system is generally the largest source of radiation at the facility. (We are especially sensitive to this problem at LBL because the location of the ALS building puts it quite close to the site boundary of the Laboratory.) For this reason, we try to ensure that the beam losses take place preferentially at low energies and, where possible, in locally well shielded areas. We note that this approach tends to minimize any negative impact on users during the injection process; ideally, it will be possible to have user access to all beam lines during the filling procedure.

Insofar as possible, we are attempting to take advantage of the design features of our storage ring magnets for the booster ring. This permits us to make the best use of—always scarce—engineering resources and avoid "reinventing the wheel." Of course, the requirements for booster magnets are generally less stringent than those for storage ring magnets, so this concept cannot be carried to extremes. (In reality, cost considerations tend to preclude going overboard with this philosophy.)

These principles have guided our activities since the CDR phase of the project.

Section II of this paper briefly describes the status of the injection system as it existed at the time of the CDR. The present status of the system is covered in Section III. In Section IV, we discuss the booster extraction process, and indicate the parameter changes made to the magnets in the booster extraction channel. Section V covers the design philosophy and optics of the BTS transport line itself. Injection into the storage ring is described in Section VI. Finally, a brief summary of the present status and an indication of possible future modifications is given in Section VII.

II. STATUS AT THE TIME OF THE CDR

Before discussing the recent modifications to the injection system design, it is worthwhile to review where things stood at the time of the CDR, i.e., in July 1986.

GTL Line

The design of this portion of the injection system was somewhat rudimentary at this stage. It was envisioned that a 500-MHz chopper would be placed between the gun and the S-band buncher to minimize the capture losses in the booster.

LTB Line

A reasonable solution for the transverse phase space matching into the booster had been obtained, but the matching of the dispersion had not been done.

Booster

The booster lattice (Fig. 1), whose main parameters are summarized in Table I, was essentially completely defined at the time of the CDR. Outstanding issues included the specification of the extraction bump parameters and optimization of the injection and extraction pulsed magnet designs.

BTS Line

The layout of the original BTS line, taken from the CDR, is shown in Figs. 2 and 3. At that time, the booster and storage ring were oriented in such a way that three 20° dipoles and 9 quadrupoles were required to transport the beam from one ring to the other.

III. PRESENT STATUS

GTL Line

Compared with the design presented in the CDR, the main change here has been the decision to use a pair of subharmonic bunchers rather than the chopper specified earlier. In the present scenario (being studied by F. Selph and C. Kim), there is a 125-MHz cavity downstream from the electron gun to collect and compress the 2.5-ns gun pulses. These pulses are then further bunched in a 500-MHz cavity located upstream of the S-band buncher at the linac entrance.

The reason for this design change is to make more efficient use of the electron pulses from the gun. The subharmonic buncher system, which is patterned after the CID injector for the SLC project, gives a high overall transmission through the linac, thus minimizing beam losses and making the system easier to optimize.

LTB Line

In the CDR layout, the dispersion matching into the booster had not been worked out in detail. A more careful investigation led to the inclusion of an additional dipole (bending in the same direction as the injection septum) to simplify this aspect of the matching.

Booster

This part of the injection system has not been significantly changed since the time of the CDR, with the exception that one SD sextupole (the leftmost SD shown in Fig. 1) has been removed from each superperiod to make room for correction magnets.

There has, however, been some rethinking of the schedule for booster magnet fabrication. This resulted from the recognition that there would, at some future time, be a conflict for resources between the booster and storage ring in the area of magnetic measurements. To avoid this problem, it was decided to push rapidly ahead on the fabrication schedule for the booster magnets. By doing so, we expect to have the booster magnet measurements completed prior to facing the heavy load of storage ring magnets, which are required about 1 year later.

Because of this change in schedule, we have made significant progress in the design of booster components. The design of the laminated dipoles (by E. Hoyer) is nearly complete. Material for the prototype device is already on hand or has been ordered, and we expect to have fabricated and measured the prototype magnet by summer of 1988.

Compared with the parameters in the CDR, we have adjusted the length of the dipole slightly (from 1.094 m to 1.050 m) to make the bending radius identical to that of the storage ring dipoles. (By hindsight, this was a futile endeavor, since the design of the storage ring dipole was subsequently changed anyway.)

Quadrupole design is also being optimized at present (by J. Milburn), using the same approach as for the storage ring quadrupoles. (There are, of course, some fundamental differences between the booster and storage ring designs—the storage ring magnets have a C-magnet design, whereas the booster magnets are symmetric.) Compared with the CDR, the significant parameter change here was to reduce the magnetic length of the QD quadrupole from 30 cm to 20 cm. This was acceptable because the required QD strength is much lower than for the QF quadrupoles. Similar optimization work is being carried out for the booster sextupoles (by S. Hernandez), again guided by the storage ring design.

Work on the correction magnets for the booster is also under way, but at a more preliminary conceptual design stage. These magnets are now envisioned differently than was the case at the time of the CDR. Originally, we contemplated combined horizontal-vertical correctors located in the full FODO cells. Simulations by H. Nishimura have shown, however, that utilizing 16 horizontal correctors—one at each QF—and 16 vertical correctors—one at each QD—permits the orbit to be corrected down to the level of the monitor placement errors. There is another advantage to the use of separate horizontal and vertical correction magnets. Because they can all be built as (identical) C-magnets, there is room at each location to install a vacuum pump, thus potentially providing "extra" space in the lattice.

Design of the vacuum chamber (by K. Kennedy) is also under way. We plan to utilize a 0.75-mm thick stainless steel vacuum chamber. In the dipoles, an elliptical cross section (±30 mm horizontally, ±18 mm vertically) will be employed. A circular cross section (62.5 mm diameter) will be used for the remainder of the circumference, with special chambers for injection and extraction. We recognize that the dipole chamber wall thickness is inappropriate for 10-Hz operation and would require replacement with a suitable thin-walled chamber as part of any upgrade to the higher repetition rate.

BTS Line

Subsequent to the completion of the CDR, it became clear that the booster location shown in Fig. 2 had some "logistical" disadvantages in the context of the construction project timing. Basically, the booster ring was sitting partially in the existing Building 6 floor space and partially in the annular region to be created by new construction. Thus, delays or interferences could easily have perturbed the anticipated schedule of booster installation and commissioning.

For this reason, it was decided—in early 1987—to displace the booster inward sufficiently that the ring and its associated shielding would all sit within the confines of the existing Building 6 floor area.

As part of a redesign of the BTS transfer line, the parameters for booster extraction (bump locations and strengths, kicker angle, septum magnet parameters) were all reexamined and improvements made aimed at maximizing the overall reliability of the system. Many of these changes have subsequently been incorporated into the storage ring injection magnet designs as well, since the requirements here are—more or less—the same as those for booster extraction.

IV. BOOSTER EXTRACTION

The layout of the extraction elements is given in Fig. 4. Extraction from the booster takes place in a single turn. The technique employed is illustrated in Fig. 5. Initially, a series of three bump magnets are excited to produce a local closed-orbit distortion in the extraction area. This moves the circulating beam close to a thin septum magnet. At the appropriate time, the fast kicker in the booster is fired, directing the stored booster beam into a thin septum magnet that will begin to deflect it out of the booster ring. A second, thicker septum magnet then completes the process by further deflecting the beam sufficiently to clear the downstream booster ring dipole and enter the BTS transfer line.

The booster extraction system thus requires a set of three bump magnets, a fast kicker, a thin septum and a thick septum. A summary of the parameters for these magnets, both as they existed at the time of the CDR and the presently adopted values, is given in Table II. (For the bump magnets, no design parameters had been finalized at the time of the CDR, so no entries are given in Table II for this case.)

Although no changes to the basic operation of the extraction system have been made in the intervening time, significant changes have been made in the magnet parameters themselves. There are several reasons for the changes that were made:

- the kicker strength was unnecessarily high
- the field in the thin septum was somewhat high
- the overall extraction angle was too low for adequate clearance of the downstream booster dipole

In the new design, the parameters were modified (see Table II) to address the issues above. In particular, the kicker angle has been reduced from 10 mrad (0.57°) to less than 4 mrad (0.23°), the thin septum angle has been reduced from 2.5° to 2.0°, and the thick septum angle has been increased from 4° to 10.1°. Thus, the overall extraction angle has been increased from about 6.5° to 12°. (As can be seen in Table II, the length of the thick septum has been increased compared with the value taken in the CDR in order to maintain a reasonable field at 1.5 GeV.) With these changes, the beam clears the downstream booster dipole (see Fig. 4) sufficiently to use at least a 5-cm i.d. beam pipe.

Because the mechanical designs for the septum magnets have not been finalized, there is still a small uncertainty on the placement of the thick septum relative to the thin septum. Two possibilities are being considered:

- 20-cm drift between septa (#8A)
- 25-cm drift between septa (#8B)

The #8A solution gives more mechanical clearance between the thick septum exit and the adjacent quadrupole, and a larger downstream beam clearance, but gives less clearance for the extracted beam at the entrance to the thick septum. The #8B solution, where the two septa are separated more, gives more beam clearance at the thick septum entrance, at the expense of a tighter fit at the downstream quadrupole and somewhat lower overall clearance for the extracted beam. The final choice cannot be made until the designs of the septum magnets are further developed, but either alternative is expected to be workable.

To accommodate this present uncertainty, the position of the first dipole in the BTS line (see Section V) is not yet fixed. By making slight changes (a few centimeters) in the location of this dipole, the uncertainty in septum magnet position can be handled with the remainder of the BTS line essentially unchanged. Thus, *the location of the booster with respect to the storage ring position is fixed and only the first segment of the BTS line is floating.*

One difficulty associated with the extraction that was not visible in Fig. 4 is illustrated in Fig. 6. With the actual magnet design for the booster quadrupole included in the extraction CAD drawing, the extraction line clearly interferes with the downstream quadrupole. The required extraction line location in the quadrupole is illustrated in Fig. 7. Fortunately, the iron in this region of the magnet is not carrying significant flux, so the problem is basically "mechanical" rather than magnetic. We expect to accommodate the beam line here by modifying the mechanical structure of the quadrupole, and rerouting its current leads. To avoid building a special one-of-a-kind magnet, the intention is to make all quadrupoles identical and then modify the yoke structure of one of them afterwards.

V. BOOSTER-TO-STORAGE RING TRANSFER LINE

The layout of the present BTS transfer line (based upon the #8A extraction geometry) is shown in Fig. 8. Compared with the original layout shown in Fig. 3, the new transfer line is longer and has more magnets (4 dipoles *vs* 3 originally, and 11 quadrupoles *vs* 9 originally). The design philosophy, however, is unchanged from its original conception.

The function of the BTS line is to deliver a beam to the storage ring that has zero dispersion and is matched to the (displaced) storage ring transverse acceptance. To decouple the transverse matching from the longitudinal matching, a dispersion-free section of the BTS line (between dipoles 3 and 4) is employed. The calculated horizontal and vertical beam sizes (2σ values) are presented in Fig. 9. Taking the uncoupled emittance in the horizontal plane and the fully coupled emittance in the vertical plane, we see that the beam size is expected to be less than 1 cm everywhere in the transfer line.

In Table III, we list the elements of the line, including magnet strengths for the quadrupoles and dipoles. Parameters for the BTS dipoles are rather similar to those for the booster dipoles, except for the increased length. Thus, we might envision some economic benefits from utilizing the same laminations as used for the booster dipoles and simply increasing the magnet length to account for the required 20° bend in the BTS (versus 15° for the actual booster dipoles).

It is not clear, however, that utilizing a common dipole design is the best approach. For example, we note that the first dipole in the BTS line will sometimes be turned off to provide a 0° diagnostics line, terminating in a shielded beam stop. Because of the 24-cm orbit displacement associated with the 20° bend, the nominal booster dipole laminations would not be wide enough to accommodate a 0° line without significant modification. Moreover, (in contrast to the booster dipoles) the BTS magnets are not ramped. This means that there is no need for the very thin laminations used for the booster dipoles. Finally, the magnetic field quality requirements for a transfer line are considerably less stringent than those for the booster ring, so the booster magnets would be "over-designed" for use in a transfer line. We tentatively conclude that cost considerations will favor a different—less costly—design for the BTS dipoles; this will be confirmed later.

From Table III, we also see that the required focusing strengths of the BTS quadrupoles are comparable to those of the booster ring quadrupoles. In this case, however, the BTS quadrupoles will operate from independent power supplies—rather than strings of 16 in series—so it is doubtful that the booster quadrupole design is well optimized for use in the BTS line. As for the dipoles, this decision will be made later in the project, after weighing the cost and performance trade-offs.

To correct for misalignments in the BTS line, a number of combined horizontal-vertical correction magnets will be utilized. At present, we envision 8 such magnets, located as shown in Fig. 10. In the first and last segment of the BTS line, we need multiple correctors to straighten out the beam. Single correctors will be used elsewhere to keep the beam centered in the quadrupole magnets. The correctors are specified to have a 12.5 mrad correction capability at 1.5 GeV. A 0.15-m magnet would then require a field of 0.42 T. These correctors will be powered with individual bipolar supplies.

VI. STORAGE RING INJECTION

As was true at the time of the CDR, we envision the process of injection into the storage ring to be more or less the reverse of booster extraction. (This is not strictly true, of course, because we extract the beam in a single turn from the booster, whereas we inject the beam into the storage ring off-axis.) Thus, it was prudent to modify the storage ring injection septum magnet parameters in light of the changes made (see Section IV) to the similar magnets in the booster.

A diagram of the injection process is shown in Fig. 11. In this case, we utilize a four-magnet bump that displaces the beam (and its phase space acceptance) by about 13 mm at the exit of the thin septum. The bump collapses sufficiently rapidly (see Fig. 12) that the newly injected beam will not hit the septum when it returns to the same azimuth four turns later.

Parameters for the storage ring injection magnets from the CDR, along with their new values, are summarized in Table IV. Here too, we have reduced the bend of the thin septum from

2.5° to 2.0°. To keep the transfer line layout the same as before, a corresponding increase was made to the bending angle of the thick septum. By suitably adjusting its length and position, we maintain the same field strength in the storage ring thick septum as was utilized for the booster thick extraction septum, and match properly into the same transfer line segment.

There remains one major area where modifications to the storage ring injection system may be required. In the CDR, we envisioned a movable thin septum magnet. We are presently contemplating a fixed device. This change might require that the septum be located farther from the nominal beam orbit, in order not to become the limiting horizontal aperture in the ring. Although the other magnets would remain the same, the requirements for the bump magnets would increase somewhat (about 40% is estimated) in order to keep the coherent betatron oscillations of the injected beam to a reasonable amplitude ($\leq$ 8 mm). Such a change would be accompanied by a change in position of the injection thick septum magnet, and possibly that of the last of the four BTS transfer line dipoles as well. These changes, while minor, have yet to be investigated.

Another unresolved issue concerns the vacuum properties of the storage ring injection septum magnets. We are presently envisioning these to reside in a common vacuum chamber that is part of the overall storage ring vacuum system. However, neither the ferrite in the thin septum nor the thin laminations of the thick septum are expected to be easily compatible with the 1 nTorr pressure requirements of the storage ring.

A possible solution to this problem that is now being considered is to cool both magnets below room temperature. Based on estimates from K. Kennedy, cooling both devices to about -50°C should reduce outgassing to a level suitable for maintaining a 1 nTorr pressure. Of course, this approach is not without penalty, since both the cooldown and warmup procedures must be carefully controlled. Moreover, we become more vulnerable to an accident involving a major loss of vacuum in the storage ring, since recovery time would be likely to increase substantially.

Another possibility that might be used is to separate the injection magnet vacuum from that of the storage ring by using an isolation foil. The practicality of such a choice when using a 1 mm septum is presently unclear.

Before making this decision, we must investigate the effects of the reduced temperature on the mechanical and magnetic properties of the ferrite material, and we must ascertain that the emittance blowup in an isolation foil would not lead to problems with the injection process. This work is under way.

VII. SUMMARY

In this note, the present status of the booster extraction and storage ring injection processes have been described, along with the changes made to the booster-to-storage ring transfer line. The relative locations of the two rings are now fixed, which means that any required changes must be accommodated by variations in the BTS line. This should not present any difficulty for the types of modification presently being contemplated.

At the booster end of the line, the remaining question is related to the spacing of the thin and thick septum magnets. This issue, which will be resolved as soon as detailed mechanical designs of the septa are available, translates into a few-centimeter uncertainty in the location of the first BTS bending magnet.

On the storage ring end, the location of the thin septum must be finalized. This might lead to the need for some enhancement to the bump magnet capabilities, along with relocating the thick septum magnet and the last of the four BTS bending magnets.

Our present schedule calls for taking beneficial occupancy of Building 6 in November 1989, with injection system (linac and booster) installation to be completed in November 1990. We are looking forward to the commissioning period, where we will get our hands on our own machine hardware at long last!

ACKNOWLEDGMENTS

I would like to thank Alan Jackson for numerous discussions on the fine points of the booster injection and extraction systems originally designed by him. Similarly, discussions on magnet parameters with R. Avery, D. Gough, G. Lambertson and F. Voelker have been most helpful. Finally, I would like to acknowledge the cooperation and patience of Curtis Cummings and Worley Low for persevering through the seemingly endless series of CAD diagrams used to design the system. This work was supported by the Office of Energy Research, Office of Basic Energy Sciences, U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

Reference

1) 1-2 GeV Synchrotron Radiation Source Conceptual Design Report, LBL Report No. PUB-5172 Rev., July, 1986.

Table I.
Booster Synchrotron Parameters[a)]

Circumference [m]	75.0
Energy	
Maximum [GeV]	1.5
Injection [MeV]	50
Natural emittance [π m-rad]	1.44×10^{-7}
Natural energy spread	6.3×10^{-4}
Momentum compaction factor	0.041
RF parameters	
Frequency [MHz]	499.65
Voltage [kV]	250
Harmonic no.	125
Revolution period [ns]	250.2
Lattice	
Type	FODO
No. of superperiods	4
No. of cells (4 empty)	16
Magnets	
Dipoles	
No.	24
Length [m]	1.05
Max. field [T]	1.2
Quadrupoles	
No. (2 families)	32
Length (QF/QD) [m]	0.3/0.2
Max. gradient [T/m]	15.0
Sextupoles	
No.	20
Length [m]	0.1
Max. gradient [T/m^2]	85.0

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a) Energy dependent parameters quoted for 1.5 GeV.

Table II.
Booster Extraction Magnet Parameters at 1.5 GeV

—Original—

	L (m)	B (T)	$\Delta\theta$ (deg)
Kicker	1.0	0.05	0.57
Thin septum	0.6	0.36	2.5
Thick septum	0.6	0.58	4.0

—New—

	L (m)	B (T)	$\Delta\theta$ (deg)
Kicker	1.0	0.02	0.21
Thin septum	0.6	0.29	2.00
Thick septum	0.9	0.98	10.07
Bump-1	0.12	0.15[a)]	0.21
Bump-2	0.12	0.32[a)]	0.43
Bump-3	0.12	0.11[a)]	0.16

[a)] Nominal values. To account for closed-orbit errors, etc., the maximum design values are 1.8 times higher.

Table III.
BTS Transfer Line Parameters[a)]

	Name	Type	L or θ[b)]	B or B'[c)]
1	qbd1	quad	0.100000	-12.758904
2	db1	drift	0.546875	0.000000
3	ebb	edge	7.500000	1.247540
4	bb	bend	1.050000	1.247540
5	ebb	edge	7.500000	1.247540
6	db2	drift	0.249375	0.000000
7	bmp1	bend	0.120000	-0.152885
8	db3	drift	0.127500	0.000000
9	qbf1	quad	0.300000	13.859700
10	dk1	drift	0.300000	0.000000
11	ekb	bend	1.000000	-0.018513
12	dk2	drift	0.573750	0.000000
13	bmp2	bend	0.120000	0.315035
14	db4	drift	0.100000	0.000000
15	qbd2	quad	0.200000	-12.758904
16	db5	drift	0.200000	0.000000
17	tsb	bend	0.600000	-0.291092
18	dttb	drift	0.200000	0.000000
19	thsb	bend	0.900000	-0.977000
20	d1	drift	2.390164	0.000000
21	mq1	quad	0.300000	7.400000
22	d2	drift	4.000000	0.000000
23	q1	quad	0.300000	-5.000000
24	dq	drift	0.300000	0.000000
25	q2	quad	0.300000	1.200000
26	d3	drift	0.787000	0.000000
27	et	edge	10.000000	1.247540
28	bt	bend	1.400000	1.247540
29	et	edge	10.000000	1.247540
30	d4a	drift	1.300000	0.000000
31	qe1	quad	0.300000	-3.400000
32	dq	drift	0.300000	0.000000
33	mq2	quad	0.300000	9.000000
34	d4b	drift	2.421448	0.000000
35	et	edge	10.000000	1.247540
36	bt	bend	1.400000	1.247540
37	et	edge	10.000000	1.247540
38	d5a	drift	0.319683	0.000000
39	dq	drift	0.300000	0.000000
40	mq3	quad	0.300000	10.158712
41	d5d	drift	2.526902	0.000000
42	q3	quad	0.300000	-12.210840
43	dq	drift	0.300000	0.000000
44	q4	quad	0.300000	12.249665
45	d5b	drift	0.400000	0.000000

Table III (cont'd).

	Name	Type	L or θ[b]	B or B'[c]
46	et	edge	10.000000	1.247540
47	bt	bend	1.400000	1.247540
48	et	edge	10.000000	1.247540
49	d6a	drift	2.776640	0.000000
50	dq	drift	0.300000	0.000000
51	d6b	drift	0.952025	0.000000
52	dq	drift	0.300000	0.000000
53	q5	quad	0.300000	10.814260
54	d6e	drift	0.300000	0.000000
55	q6	quad	0.300000	-10.373678
56	d6c	drift	0.853344	0.000000
57	et	edge	10.000000	1.247540
58	bt	bend	1.400000	1.247540
59	et	edge	10.000000	1.247540
60	d7	drift	1.831337	0.000000
61	mq4	quad	0.300000	9.749989
62	d8	drift	4.473932	0.000000
63	thssr	bend	0.742284	1.000000
64	dttsr	drift	0.277097	0.000000
65	tssr	bend	0.600000	0.291085

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a) Taken from optics code LATTICE, written by John Staples.

b) Magnet and drift lengths in meters; edge angles in degrees.

c) Dipole fields in tesla; quadrupole gradients in T/m.

Table IV.
Storage Ring Injection Magnet Parameters at 1.5 GeV

—Original—

	L (m)	B (T)	$\Delta\theta$ (deg)
Bumps	0.7	0.10	0.86
Thin septum	0.6	0.36	2.5
Thick septum	1.0	0.70	8.0

—New—

	L (m)	B (T)	$\Delta\theta$ (deg)
Bumps[a)]	0.7	0.10	0.86
Thin septum	0.6	0.29	2.00
Thick septum	0.76	0.98	8.50

[a)] Under review. Not yet modified.

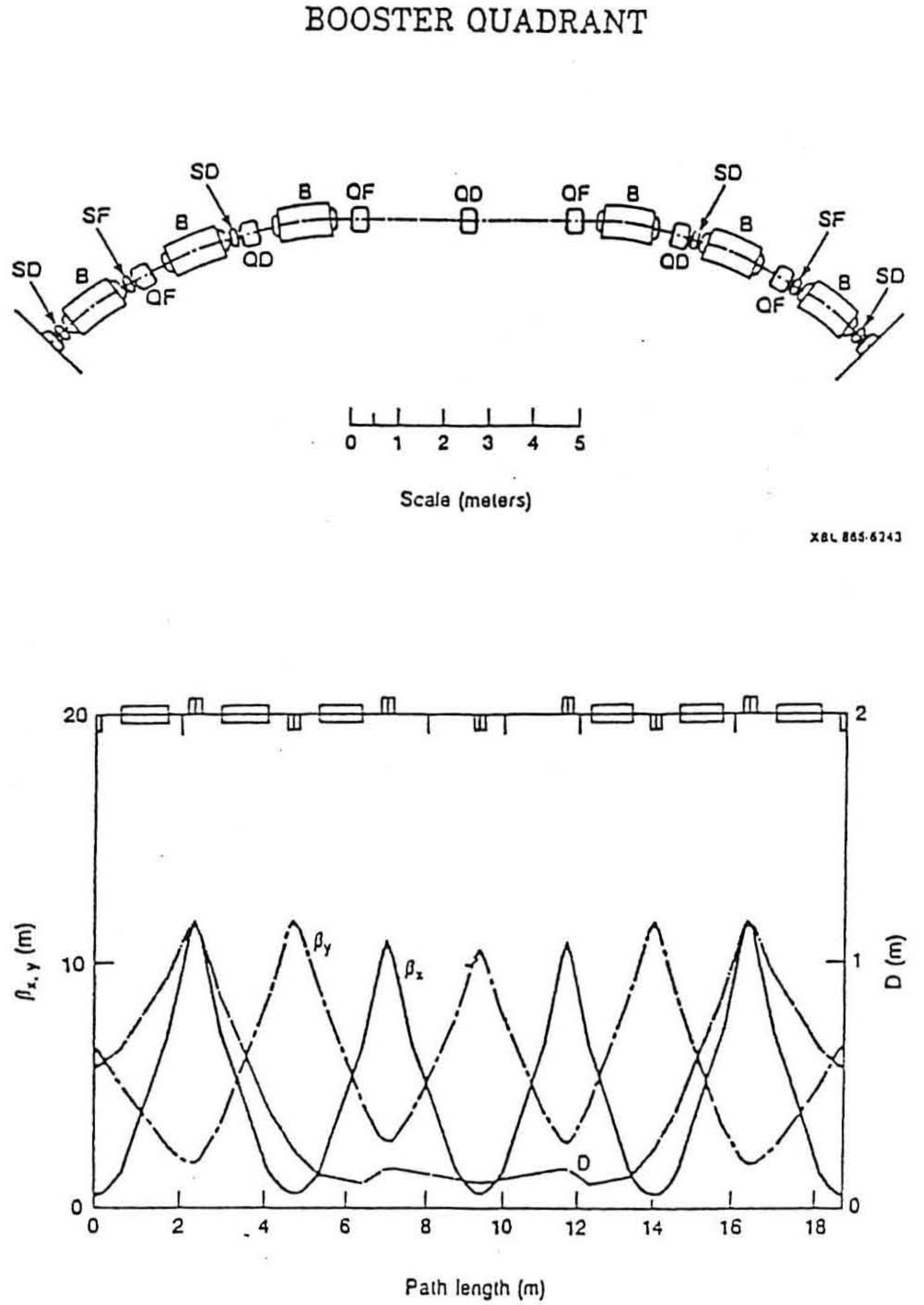
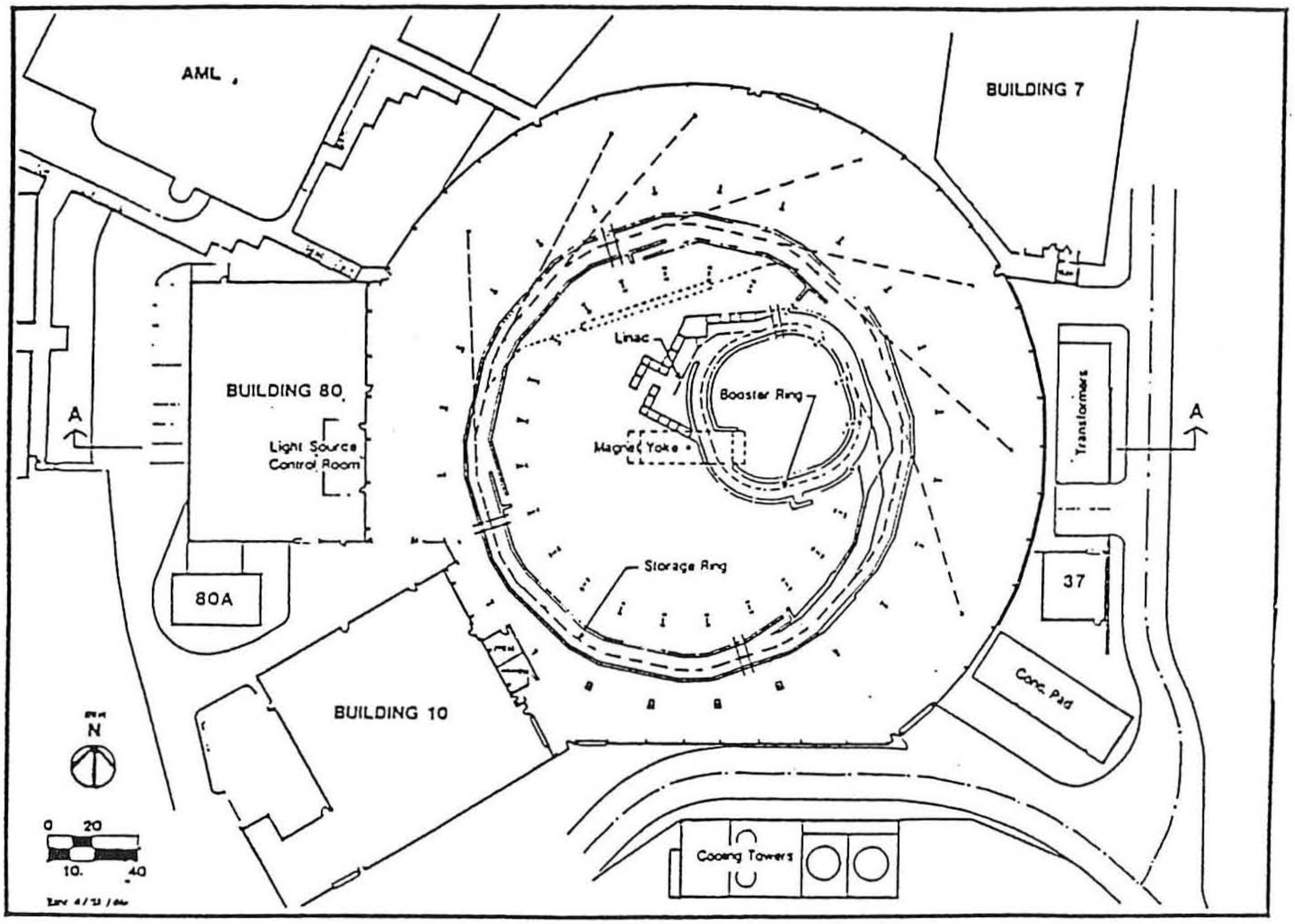


Fig. 1 Top: Layout of booster FODO lattice. The leftmost SD sextupole was subsequently removed to provide space for correction magnets.

Bottom: Lattice optical functions.



XBL 868-2865

Fig. 2 Layout of the original booster and BTS line. Note that the booster and its shielding protrude beyond the inner circle of building columns that marks the outer boundary of the existing building.

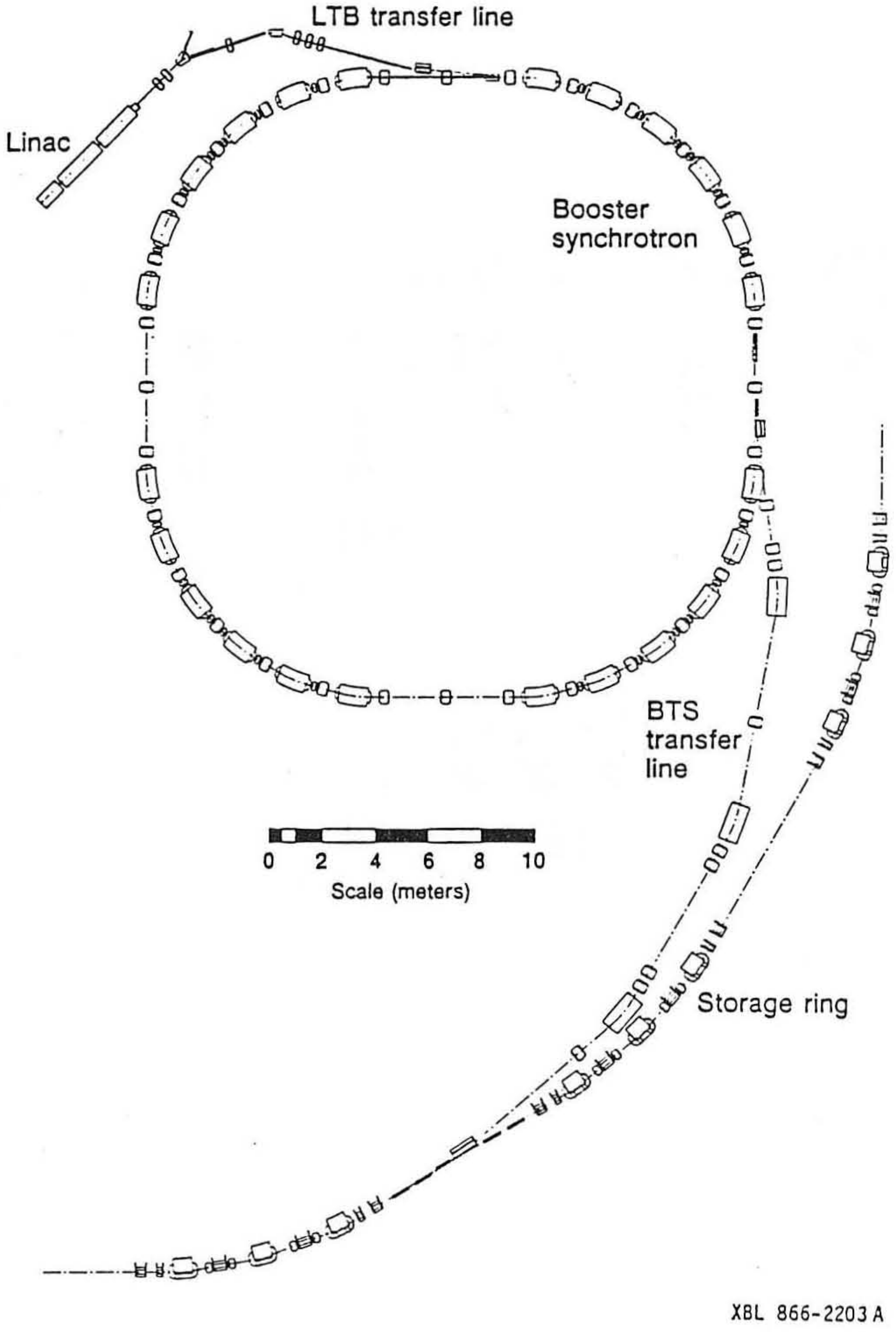


Fig. 3 Original BTS line with only 3 dipoles.

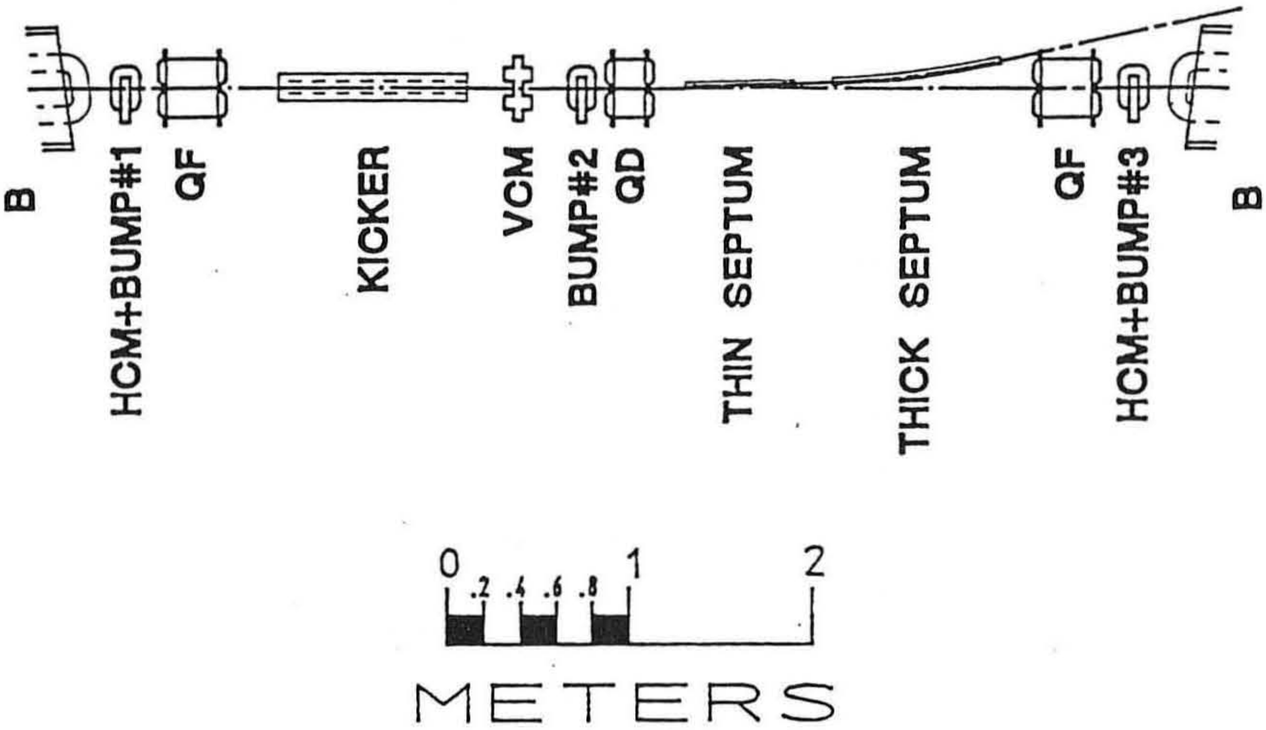


Fig. 4 Layout of the booster extraction elements.

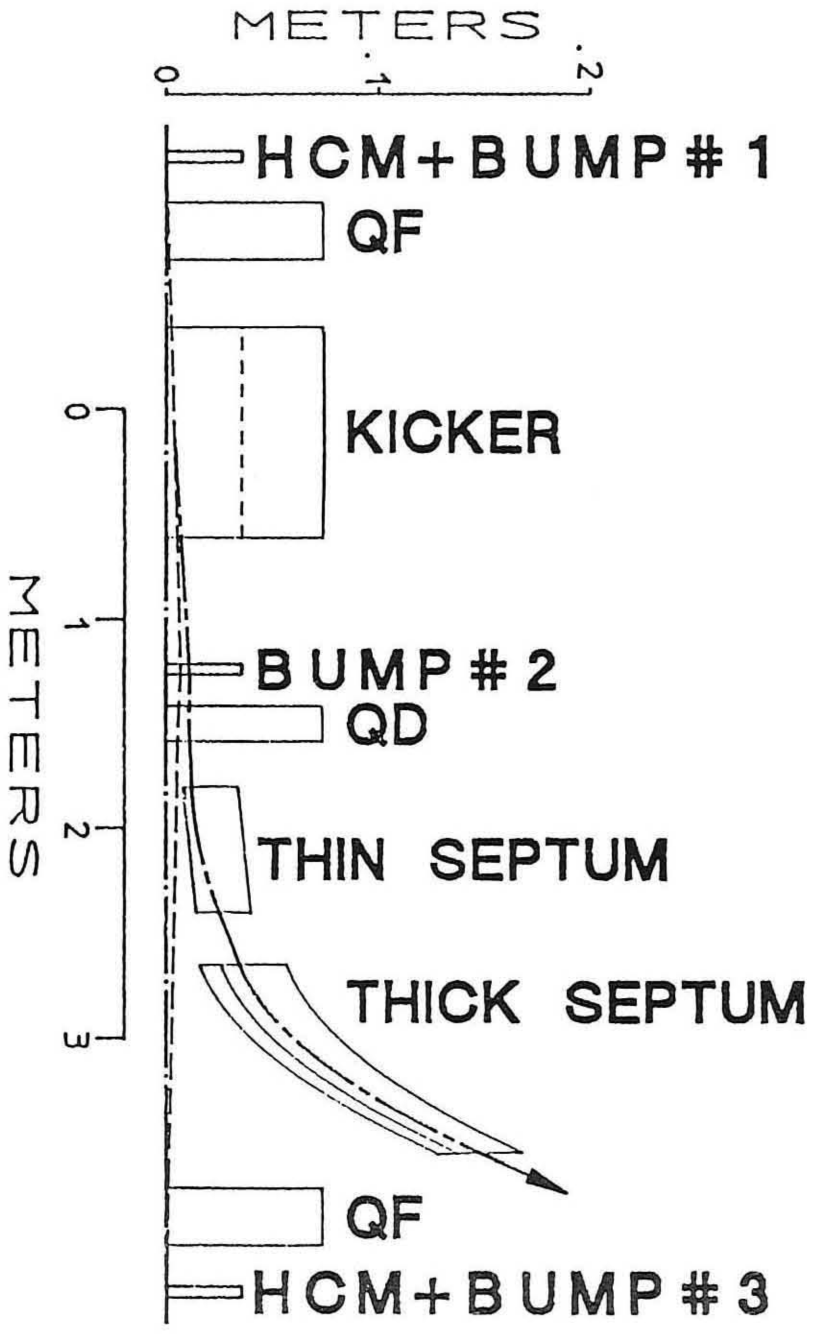


Fig. 5 Anamorphic diagram of the booster extraction process.

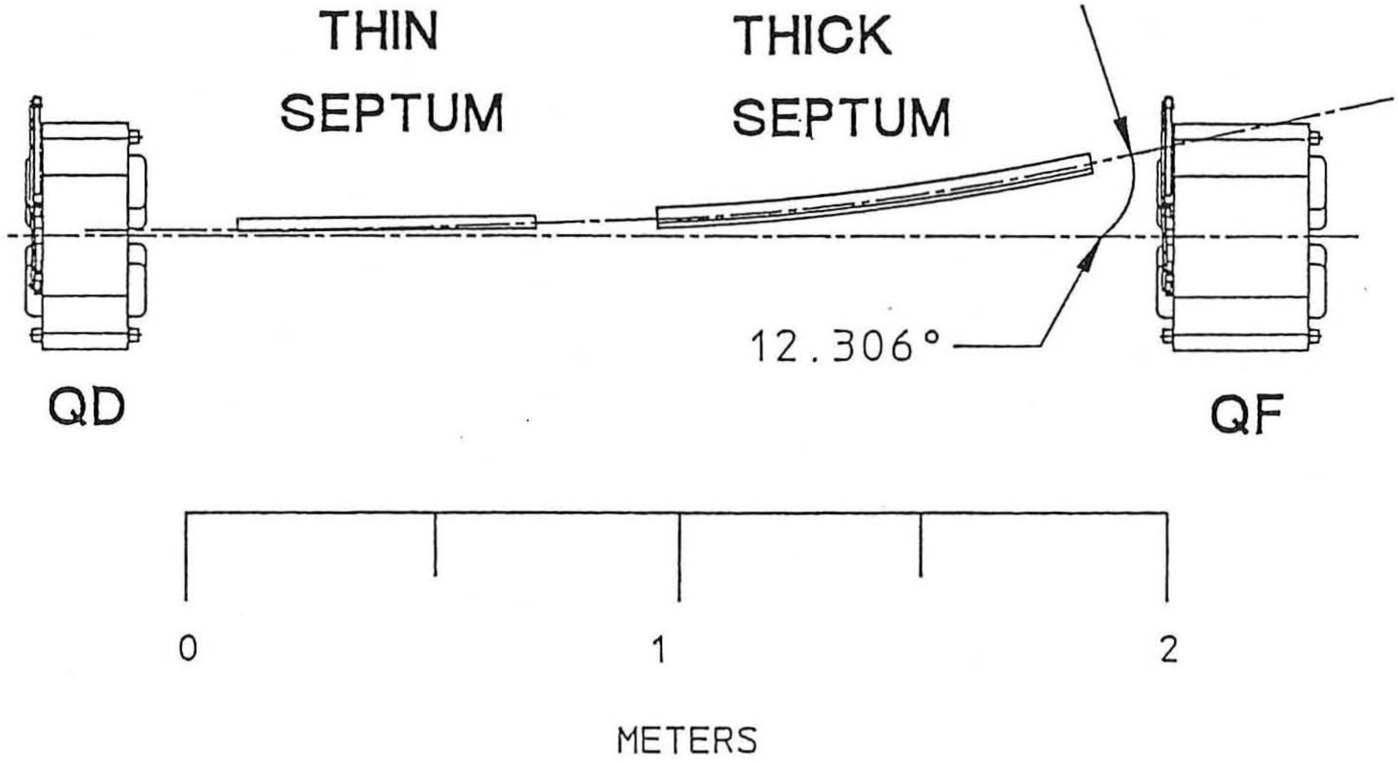


Fig. 6 Updated booster extraction layout showing interference with downstream QF.

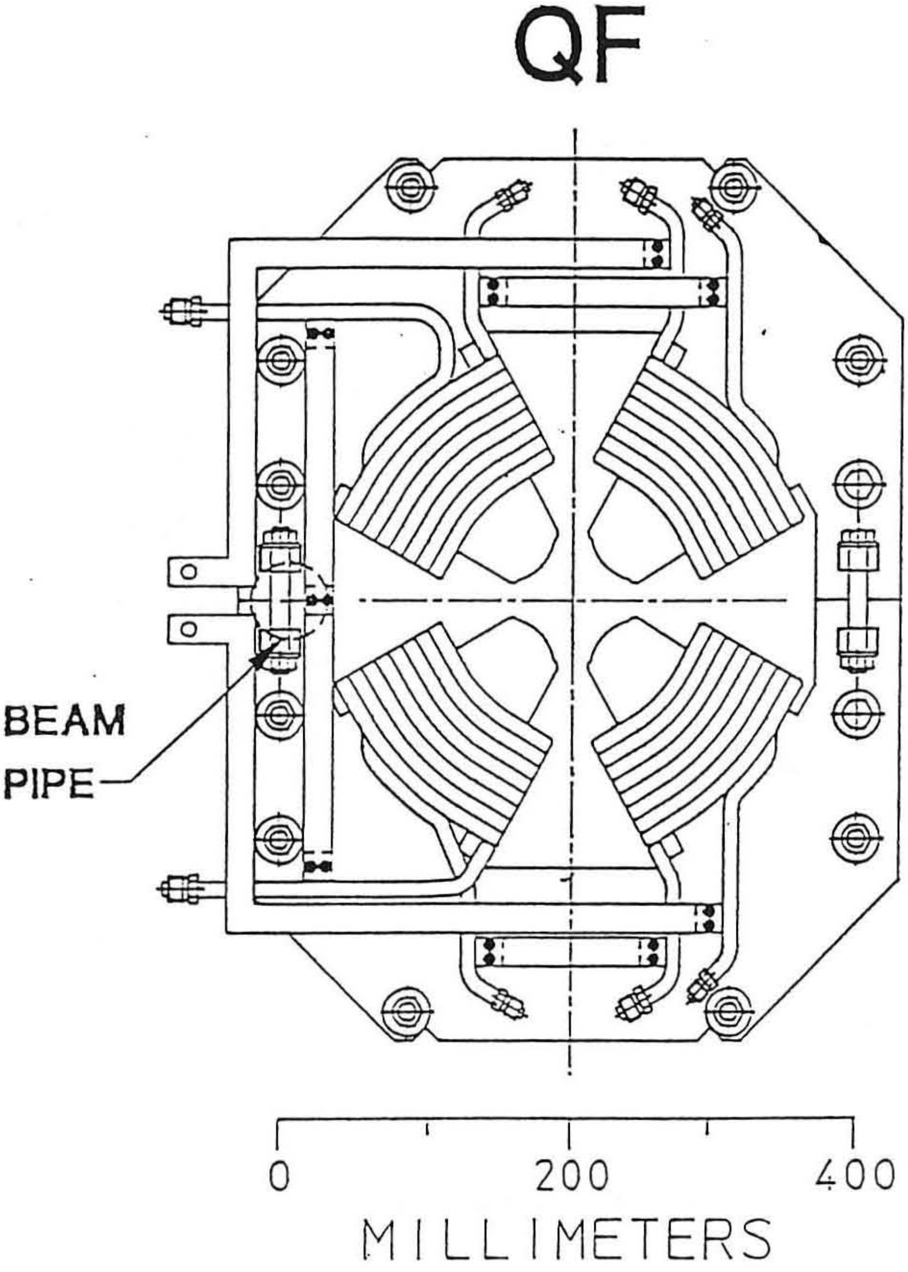


Fig. 7 Cross section of QF showing location of extraction beam line. The mechanical detail of one quadrupole will be modified suitably to accommodate the extracted beam.

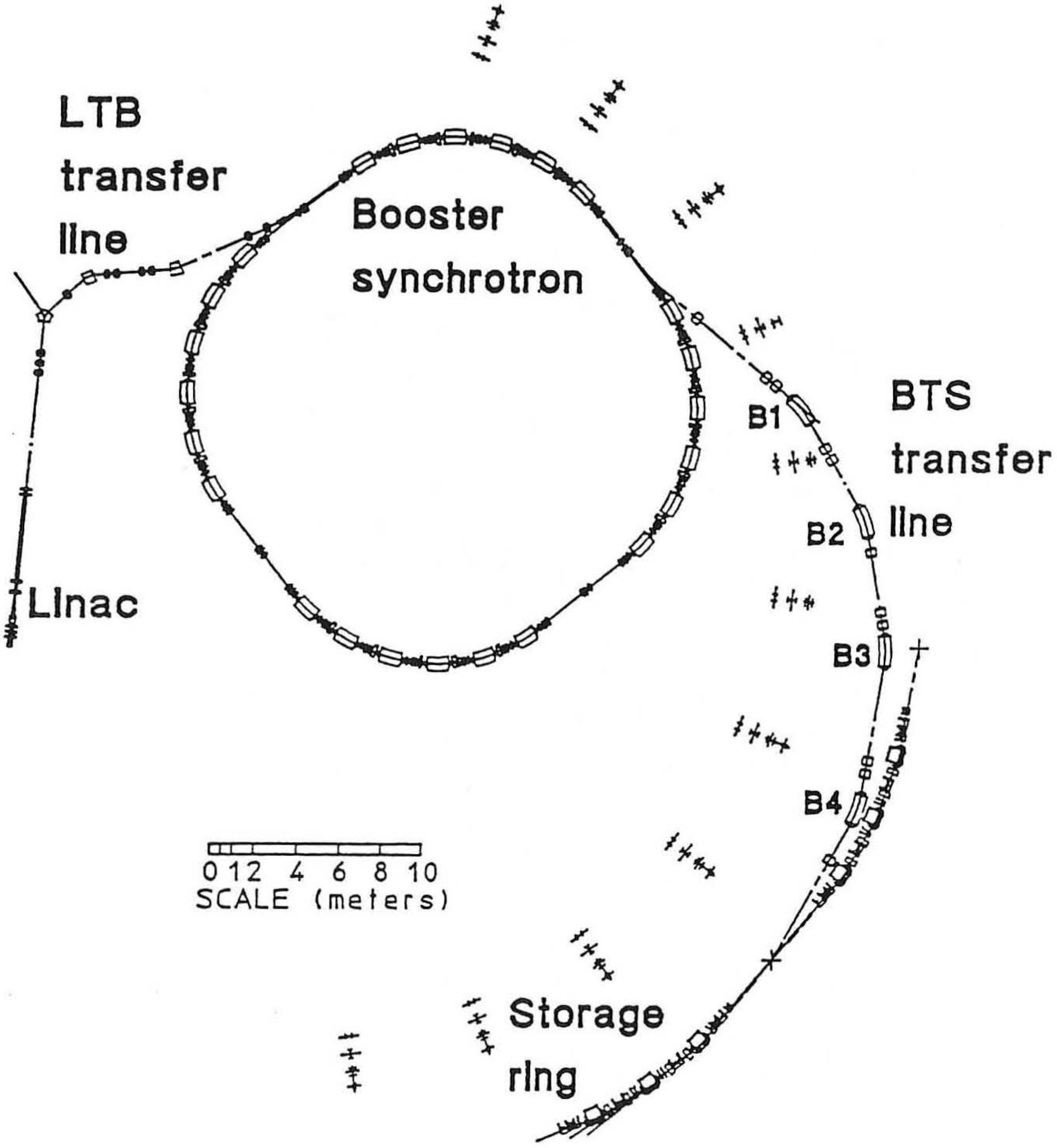


Fig. 8 Layout of present BTS line. The booster is now contained entirely within the floor space of the existing building (cf. Fig. 1).

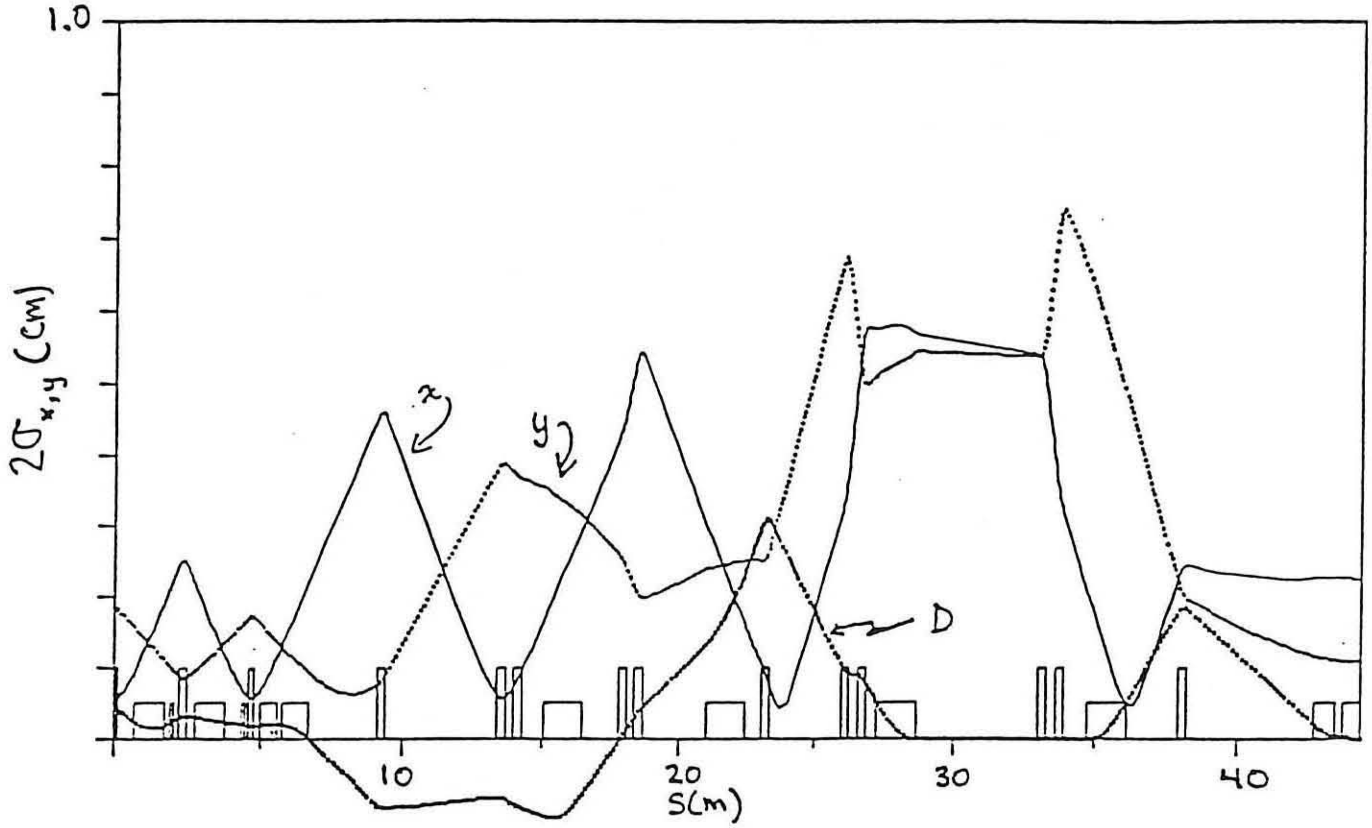


Fig. 9 Optics of present BTS line. Beam profiles shown correspond to 2σ sizes.

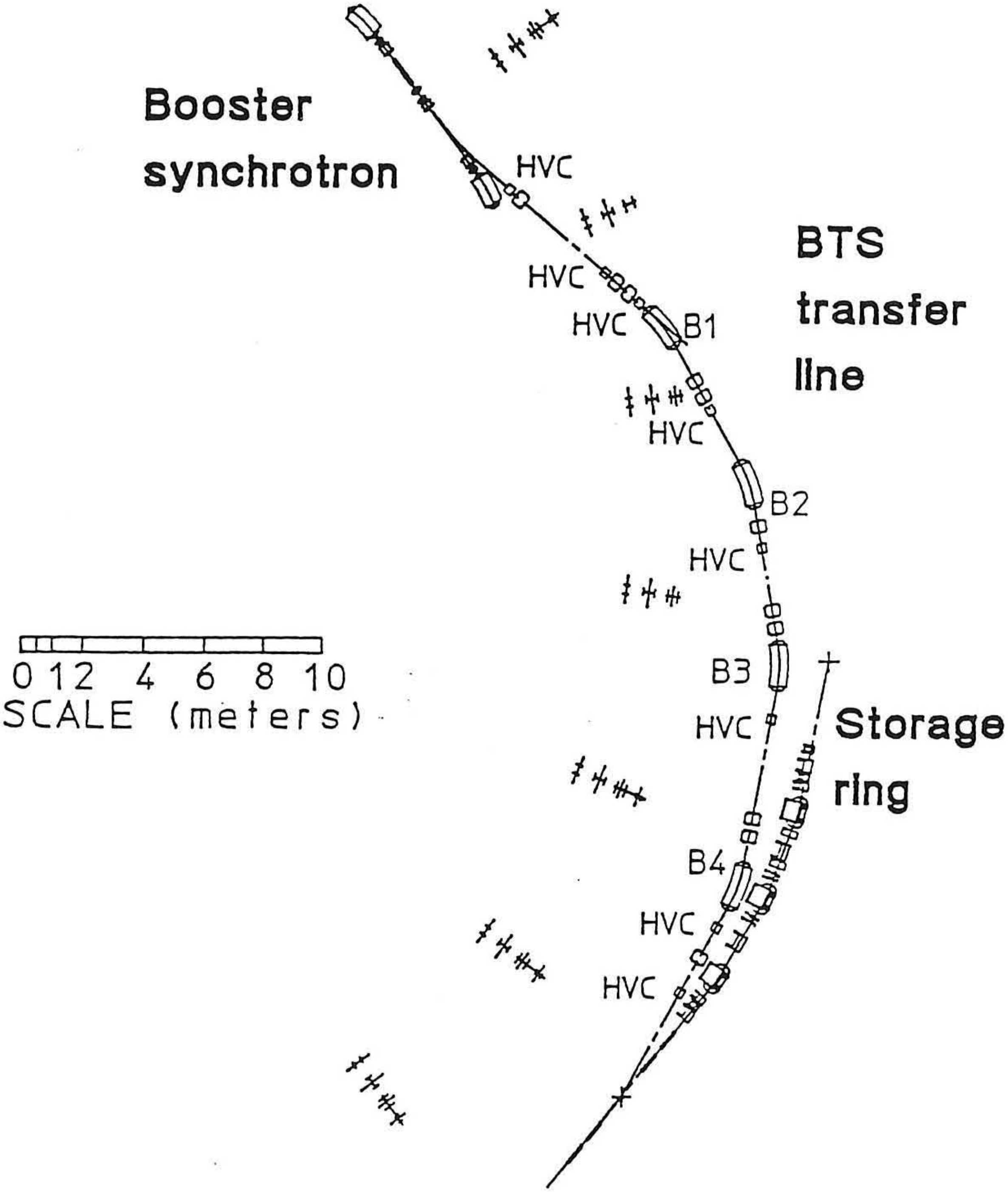


Fig. 10 Tentative locations of horizontal-vertical correction (HVC) magnets in the BTS line.

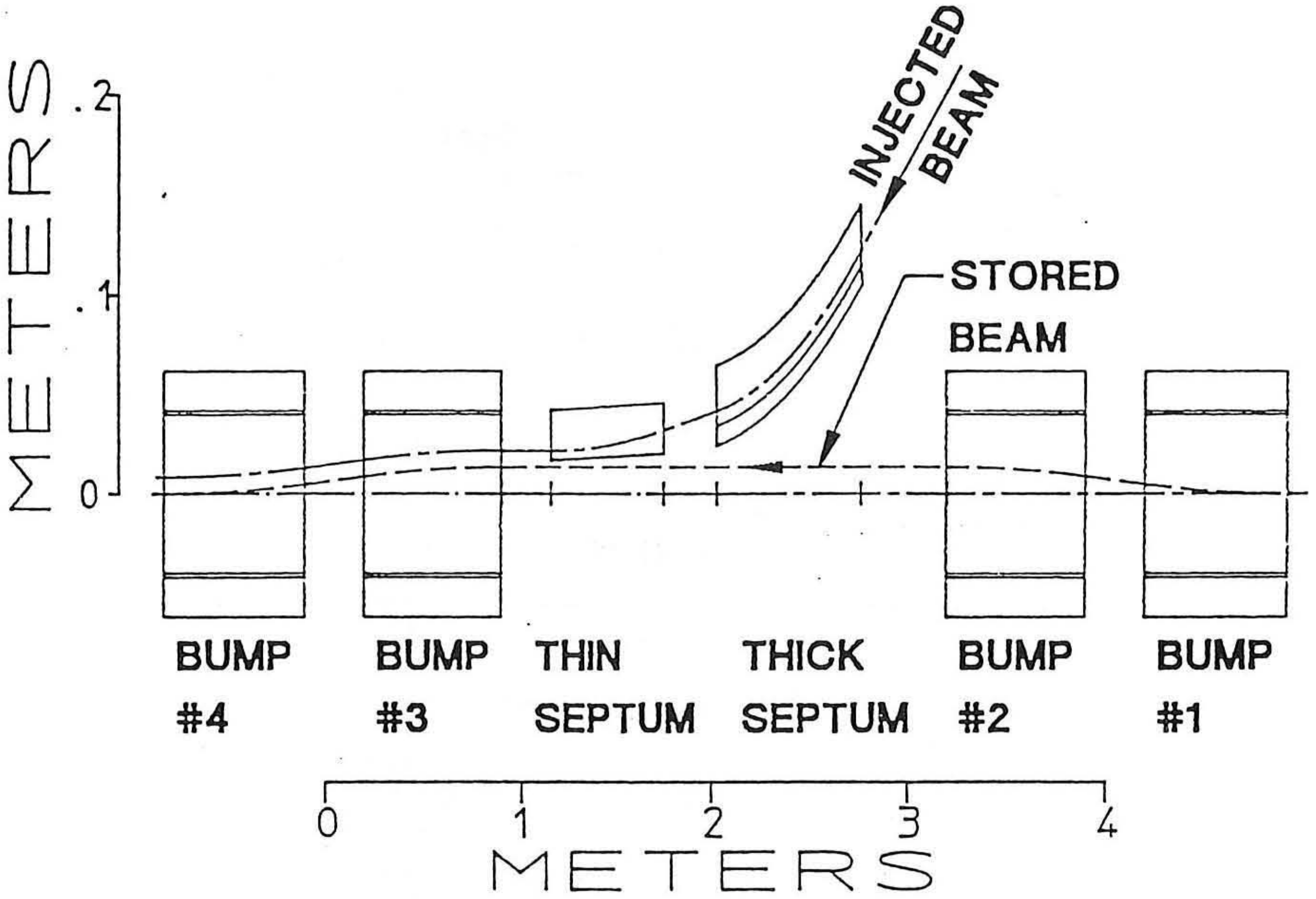


Fig. 11 Anamorphic diagram of the storage ring injection process.

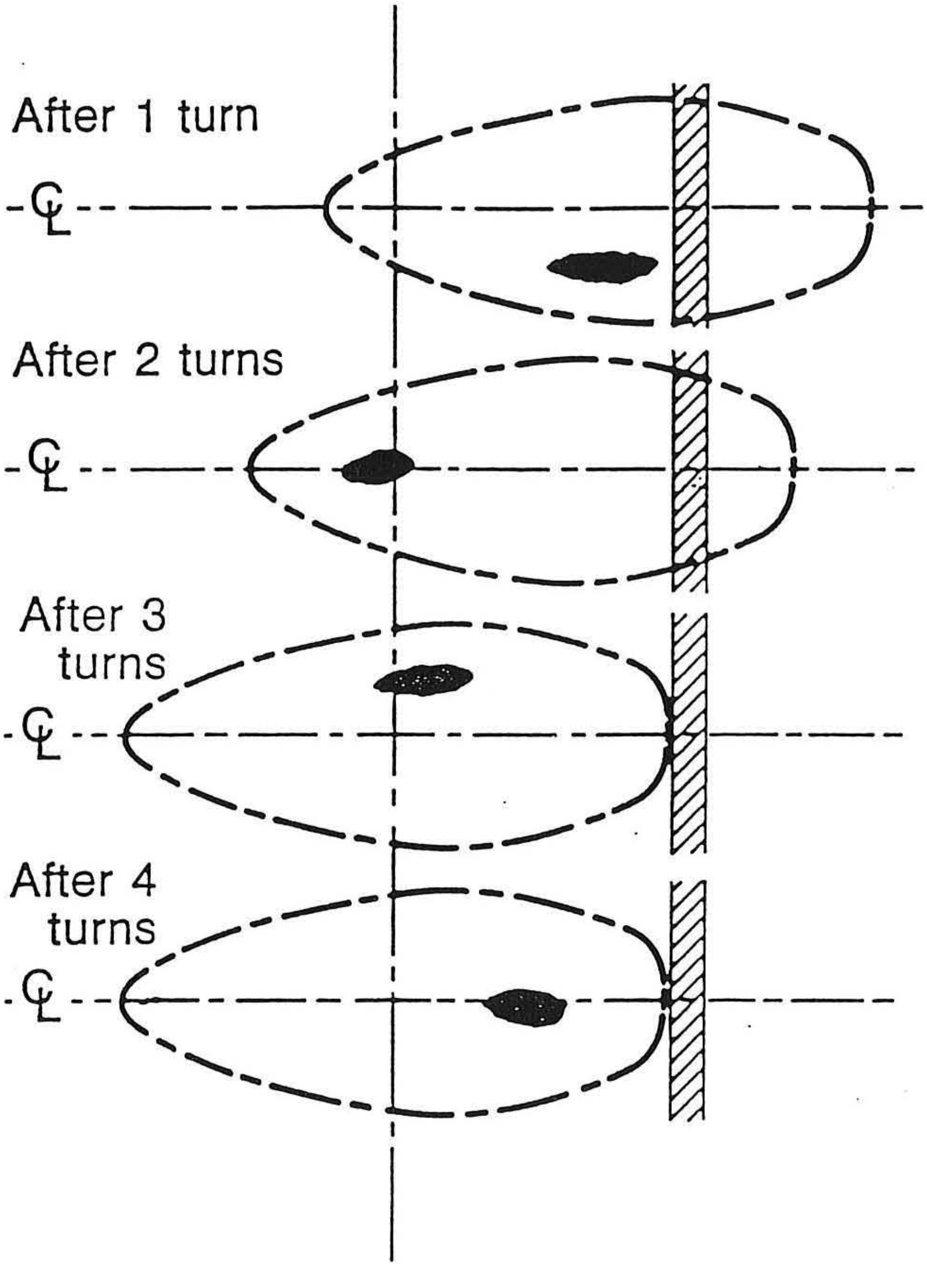


Fig. 12 Evolution of the bumped storage ring acceptance and the injected beam in horizontal phase space; taken from Ref. 1.