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SOME CONSIDERATIONS IN PLANNING FOR SUPERHILAC TIMESHARE OPERATION WITH BOTH HEAVY AND LIGHT ION BEAMS*

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Abstract

One of the important problems to be solved for any accelerator, with the exception of those intended for a single purpose such as injection, is providing adequately for multiple use of the machine. Of particular importance is the possibility of timeshare operation, in which two or more experimental setups can be supplied with beam at the same time. The SuperHilac will accelerate ions of all mass numbers, with final energy continuously variable from 2.6 to 8.5 MeV/nucleon. Normally, to change particle and energy in the Hilac requires a careful retuning of many machine parameters and (optimistically) an hour of machine time. For the SuperHilac it is proposed to provide particles of different charge-to-mass ratio on alternate pulses, so that, for example, half of the pulses would be light ions, delivered to one experimental area, and the other half heavy ions, delivered to another experimental area. Consequently a number of new problems need to be solved. These occur at injection, with accelerating and focusing the beams in the linac, in the stripper area, and at the exit from the machine.

Introduction

The SuperHilac, a major renovation of the Berkeley Hilac, has been described in a recent report.[1] It has two injectors, prestripper and poststripper tanks with strong focusing, with a stripper and charge-analysis area between tanks. A switchyard distributes the beam to several experimental caves. In Fig. 1 are shown the major elements that are required for beam transport, with the exception of the drift tube quadrupoles. Of these, the prestripper has 137 and the poststripper 70. The possible operating configurations of this machine are many and cannot be fully discussed here. Attention will be directed to the acceleration of two hypothetical beams.

1) Uranium 11+, provided by injector 1, is accelerated by the prestripper, stripped, then diverted through an analyzing magnet where a slit allows charge state +40 to pass through and be accepted by the poststripper. The ions are then accelerated to 8.5 MeV/n.

2) Carbon 2+, provided by injector 2, is accelerated by the prestripper, is not stripped, and in the poststripper is accelerated to some intermediate energy between 2.6 and 8.5 MeV/n.

Outside the linac tanks, the two beams are kept apart, using the 4 pulsed bending magnets PM1 through PM4. This permits the majority of transport elements to be operated dc. The pulsing rate of the SuperHilac will be about 40 Hz. Pulsed elements will be capable of switching from one beam to the other between pulses.

Prestripper Injection

Injection energy is 0.113 MeV/n. Injector 1 is capable of 3 MV, and for U^{11+}, with charge-to-mass ratio $\epsilon = .046$, requires 2.5 MV. Injector 2 is capable of 0.75 MV, and for C^{2+} with $\epsilon = .17$ is run at 0.66 MV. Heavy ion sources must be replaced frequently, and for this and other reasons the beam emerging from an injector is liable to change its position, direction and focal properties from time to time. The transport lines consequently contain steering magnets to permit small adjustments in beam alignment. Targets for determining the beam position will be installed in several places in the transport lines, and at two positions (PSM) in the prestripper. Viewing screens and beam-reading collimators positioned near the prestripper entrance will be used to monitor focal properties. More complete but slower measurements will be made with emittance-measuring slits at the exit of each injector.

Prestripper

Ions with different charge-to-mass ratio ϵ will be accelerated with the same synchronous phase φ_s if the product of $E\epsilon$ is kept constant. E is the average rf gradient. The transverse focusing forces will be different, however. Because of the large duty factor (up to 50%) and the large quadrupole gradients required, pulsing the drift-tube quadrupoles is not feasible and they are to be run dc. A +-+- focusing pattern (N = 1) has been chosen, because a wide region of stability is needed. Figure 2 shows the transverse stability limits that are applicable for this case.[2] Both the ordinate, θ_o^2, and abscissa, Δ, are dimensionless and given by

$$\theta_o^2 = 2B'\ell\epsilon\beta\lambda/(B\rho)_p \qquad (1)$$

which is proportional to quadrupole strength (i.e., gradient times effective length) $B'\ell$ and

$$\Delta = \pi e\lambda\epsilon ET \sin\varphi_s/(m_p c^2\beta\gamma^3) \qquad (2)$$

which is proportional to the gap-defocusing field. λ is the rf wavelength, T the transit time factor, $(B\rho)_p$ the rigidity of a proton moving with the ion velocity, β, m_pc^2 the proton rest mass. The operating point for each case is shown at a cell about one betatron wavelength from the entrance. The quadrupole strength used is 61 kG, the maximum value which can be achieved inside the prestripper drift tubes. This determines $\theta_o^2 = .78$ for the heavy ions; for the light ions θ_o^2 is higher by the ratio .17/.046 = 3.7. The quadrupole pattern +--+ (N = 2) was also considered as it lowers both stability limits and results in a lower quadrupole strength. However the width of the stability region is only slightly wider than the separation of operating points, which causes the N = 2 case to result in considerably less acceptance for the light ion beam.

Acceptance

In Fig. 3 the acceptance of the prestripper, averaged over accelerating bucket width, is shown as a function of θ_o^2, calculated with the computer program PARMILA. The solid curve shows the acceptance expected from the machine when misalignments are neglected. The expected injector emittance is 2π for heavy ions and 4π for light ions. If beam is to be accelerated without loss, it is necessary to match the emittance to the acceptance figure, taking into account the changes in shape and orientation of the acceptance figure with phase. In Figs. 4 and 5 acceptance figures are shown for heavy and light ions, respectively, for several values of φ_o. With $\varphi_s = -20^\circ$, acceptance area is nearly constant from $\varphi_o = -40^\circ$ to $\varphi_o = 20^\circ$ and negligible outside this range. The area common to all figures is considerably less than $\bar{A}$ for the heavy ion beam, not so much less for the light ion beam.

Misalignments

Misalignment of quadrupoles causes the beam to wander from the axis. This not only can reduce the acceptance but causes the emergent beam to be displaced from, and at an angle to, the axis. To minimize this wandering, careful alignment of the quadrupoles is necessary. However, it is anticipated that a quadrupole placement error no smaller than 5 mils rms can be achieved. The behavior of beams in the prestripper with quadrupoles randomly misaligned has been studied with PARMILA; Figure 6 shows typical results with 5 mils rms misalignment. In these calculations a symmetrical distribution of particles is traced through the machine; at each drift tube centerline the average particle displacement X_{av}, and the absolute maximum displacement $|X|_{max}$ are found. These quantities can be regarded as the beam center and the envelope size, respectively. If quadrupoles are not misaligned, X_{av} remains coincident with the axis. With misalignments of 5 mils rms, the displacement of X_{av} builds up to a maximum of about 0.8 cm (for the light ions). A striking feature of the X_{av} curves is their fairly regular oscillatory behavior. The oscillation wavelength corresponds roughly to the betatron wavelength. A different choice of random errors produces curves that are different in detail, but with approximately the same wavelength and amplitude. The amplitude increases along the machine; it is shown in Ref. 2 that growth is at least proportional to the square root of the cell number. To accommodate this growth, the aperture has been progressively increased along the machine, but misalignments still reduce the acceptance to some extent. The average acceptance with 5 mils rms misalignment is indicated as a dotted curve in Fig. 3.

If a steering magnet is placed at the point where the X_{av} curve crosses the axis (Fig. 6), the beam can be aligned with the axis and the effect of subsequent misalignments reduced. Two sets of steering magnets (PSM, Fig. 1 and 6) have been included for this purpose. They must be pulsed because the steering correction required for each beam will be different. Targets placed at these locations will indicate the position of the beam. If it is not centered on the axis, focusing parameters can be changed to make it so.

Stripper Area

The heavy ion beam is stripped immediately upon leaving the prestripper in order to make bending and focusing easier. The light ion beam is not stripped. The beams must be independently focused in order to achieve matching to the poststripper acceptance. This is made easier by the fact that the heavy ion beam is switched through a siding for charge analysis, while the light ion beam goes straight through (see Fig. 1). Elements located in the lines that the two beams share at either end of the stripper area must, of course, be pulsed.

Poststripper

In the poststripper both beams will have approximately the same ϵ; so in the first section at least all beams will be near the same region of the stability diagram. However, energy for either beam can be varied from 2.6 to 8.5 MeV.[1] Since the quadrupole focusing is dc, and $B'\ell$ is set for θ_{01}^2 = const for the full energy beam, θ_{02}^2 will be higher for a lower energy beam. Making use of Eq. 1, near the exit, we can have

$$\theta_{02}^2/\theta_{01}^2 = (8.5/2.6)^{1/2} = 1.8 \quad .$$

This range of stability required for focusing is much less than was required for the prestripper, which was 3.7. Consequently N = 2 focusing can be employed without any danger of exceeding the stability limits (Fig. 7).

Adequate aperture has been provided in the drift tubes to allow for beam wandering due to quadrupole misalignment. In the poststripper, the difficult tuning problems are likely to be associated with partial energy beams. The method for obtaining partial energy was discussed in Ref. 3. For these beams, the most important parameters to measure and control are energy, energy spread and phase. The final energy and energy spread will be measured with a calibrated bending magnet in the beam switchyard. If phase probes are used, they must be placed inside the poststripper tank. Room has been provided by omitting quadrupoles from the drift tubes at the rf diaphragm locations (labeled "U" in Fig. 1). There is enough space inside these empty drift tubes to also install steering magnets if beam wandering is more troublesome than anticipated.

Experimental Area Switchyard

At the exit of the poststripper several tasks must be carried out before a beam of known properties is delivered to an experiment.

1) A fast switching magnet separates the two beams.

2) Beam energy is determined with a bending magnet having a calibrated field.

3) Beams must be properly focused. This requires a pulsed quadrupole doublet as the first transport line element.

To save space, the pulsed-switching magnet and pulsed doublet are placed within the last two drift tubes of the poststripper (Fig. 1).

Acknowledgement

The concepts described here have benefited greatly from discussions and consultations within the Super-Hilac design group led by R. M. Main.

References

*This work was done under the auspices of the Atomic Energy Commission.

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2. L. Smith and R. L. Gluckstern, Rev. Sci. Instr. 26 (1955) 220-228.

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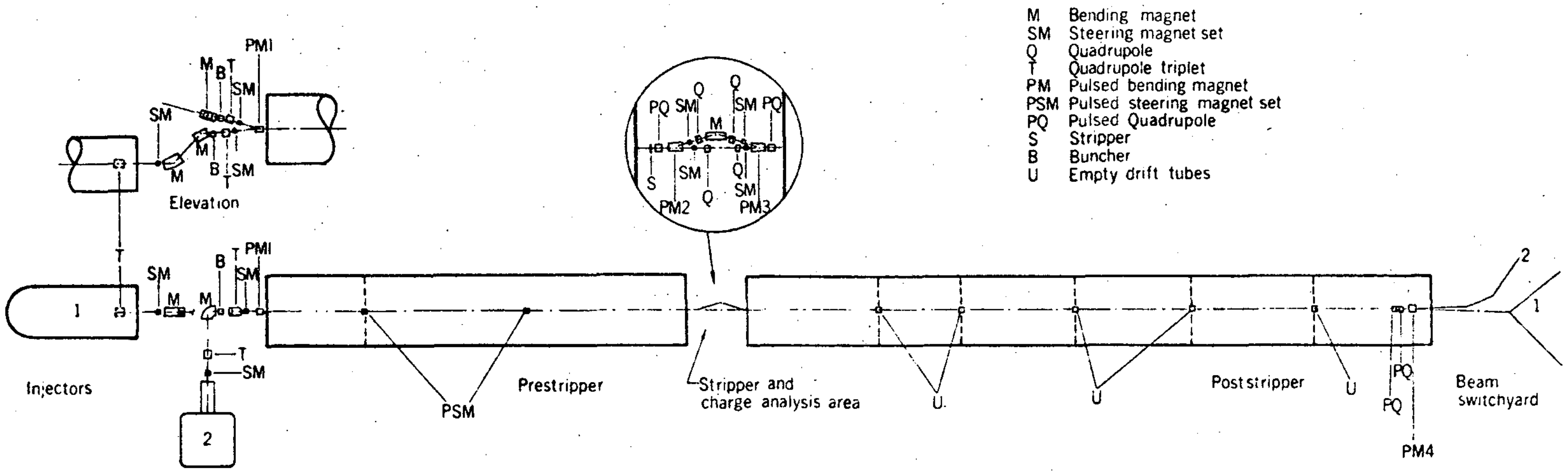

Plan of SuperHILAC

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Fig. 1. Schematic plan of SuperHilac showing major beam handling components.

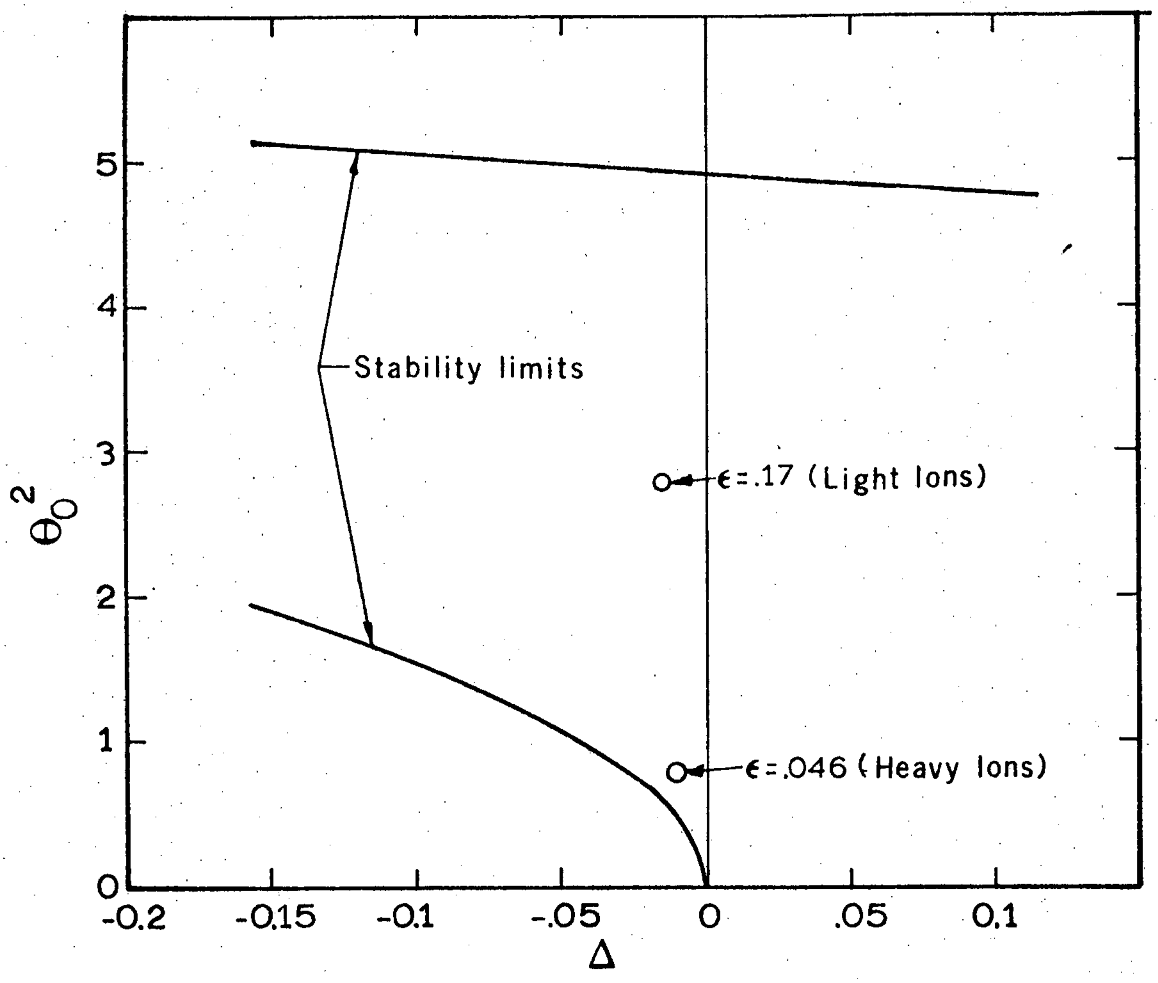

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Fig. 2. Transverse stability limits for N = 1, showing prestripper operating points after one betatron wavelength for heavy and light ion beams.

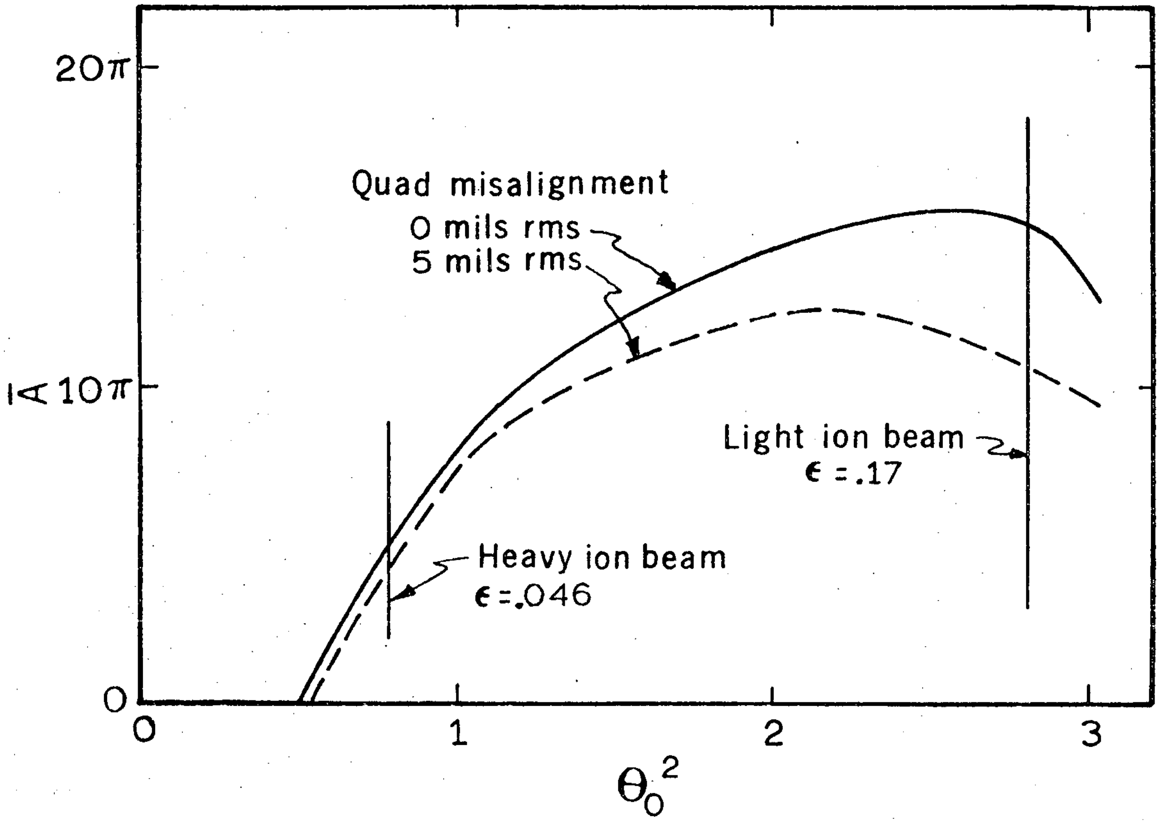

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Fig. 3. Prestripper averaged acceptance as a function of θ_o^2.

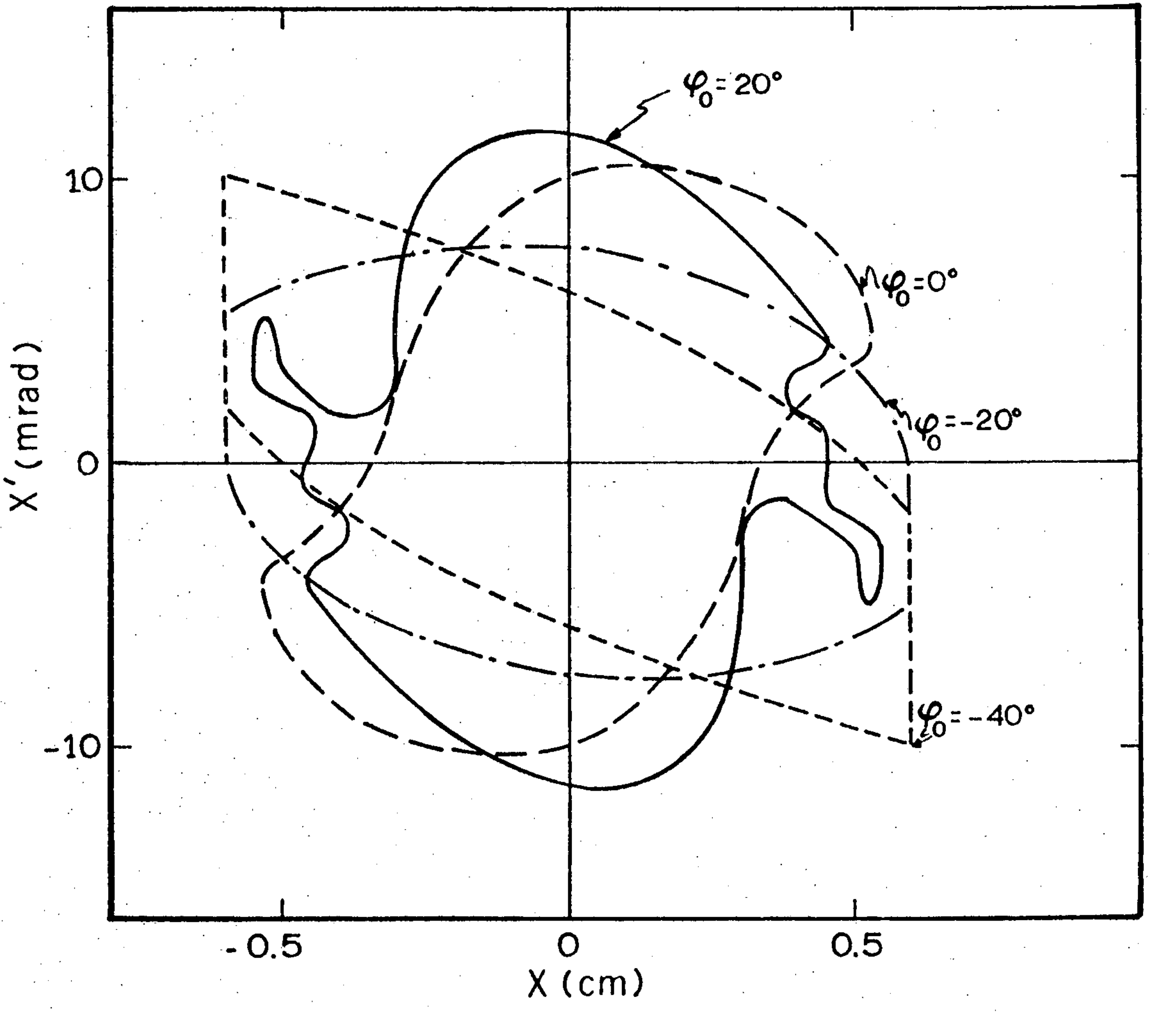

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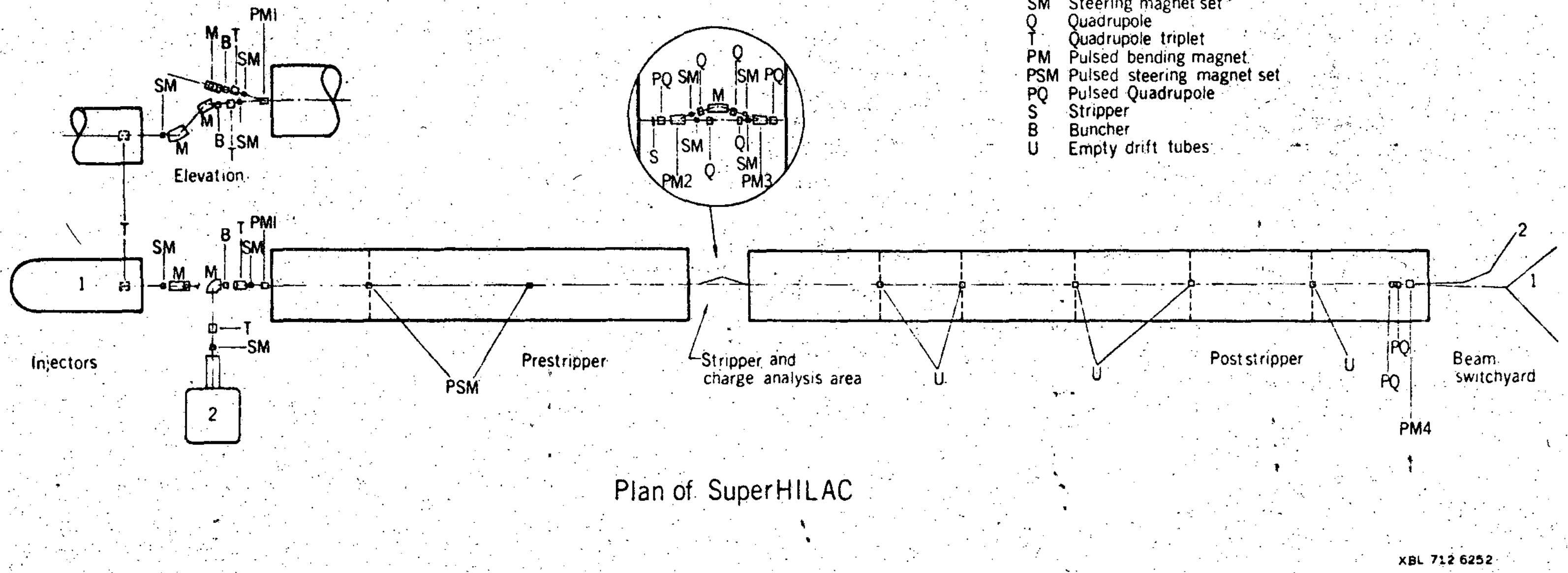
Fig. 4. Prestripper acceptance figures for heavy ion beam (θ_o^2 = .78).



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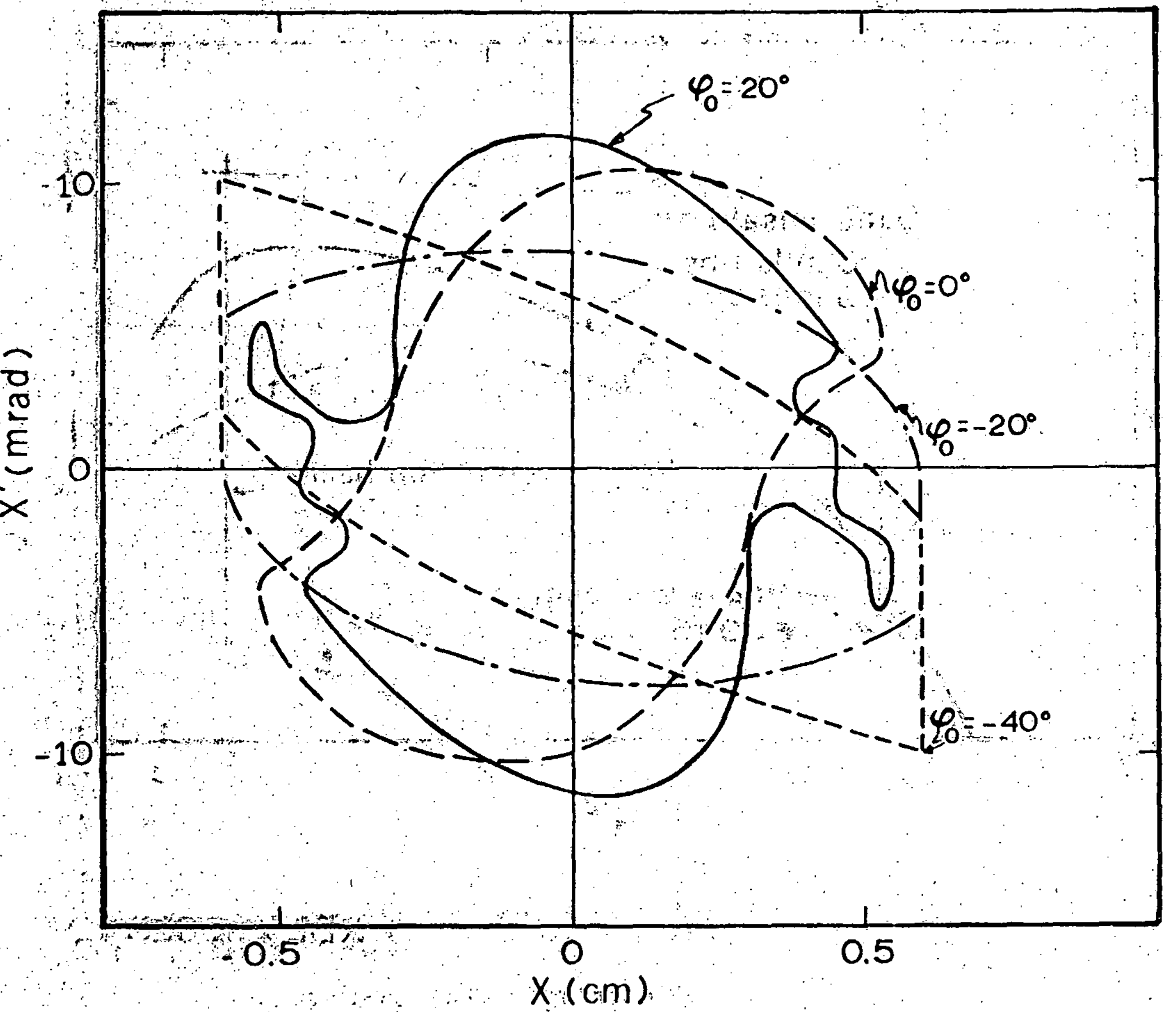

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Fig. 4. Prestripper acceptance figures for heavy ion beam (θ_0^2 = .78).

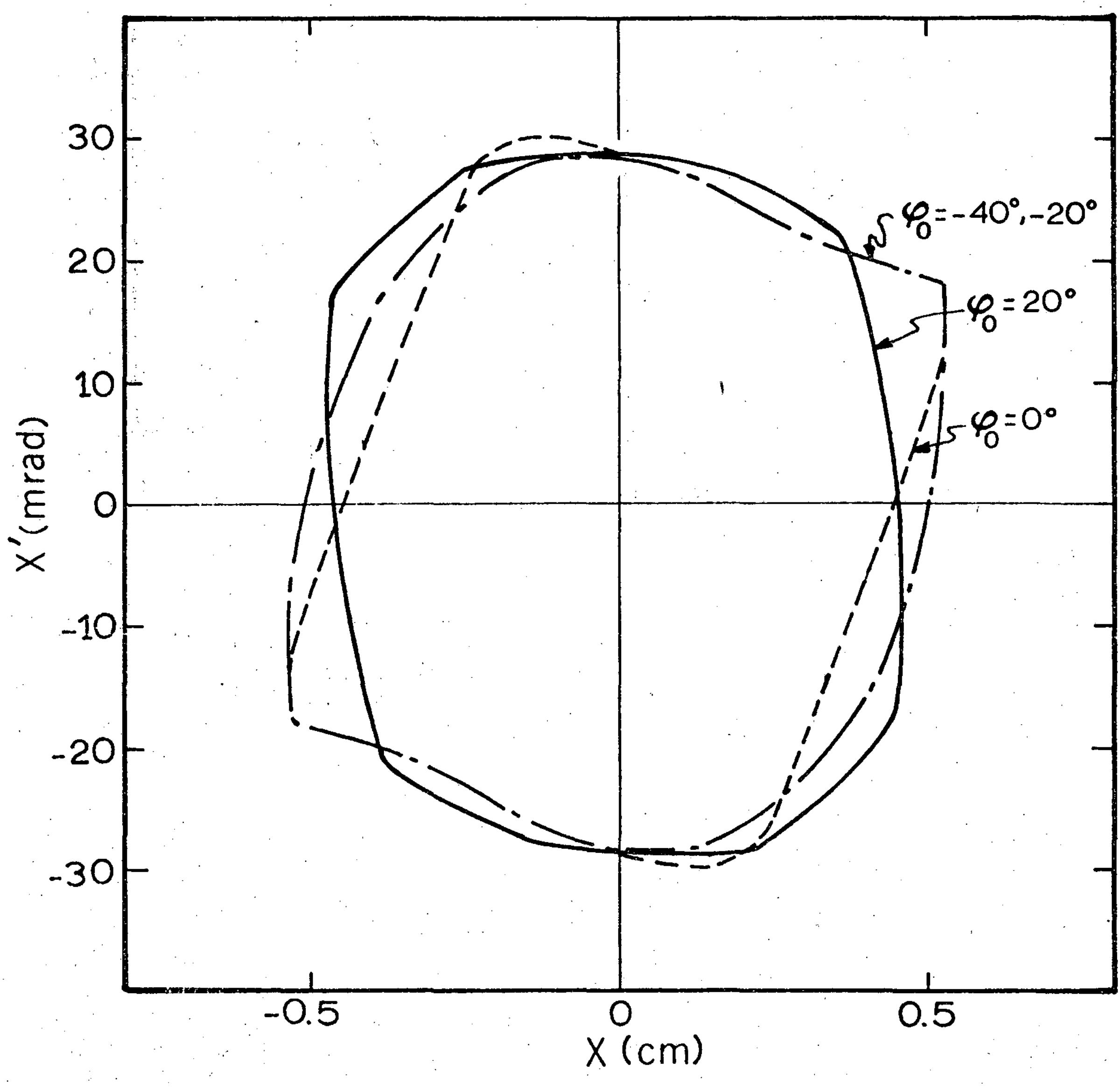

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Fig. 5. Prestripper acceptance figures for light ion beam (θ_o^2 = 2.8).

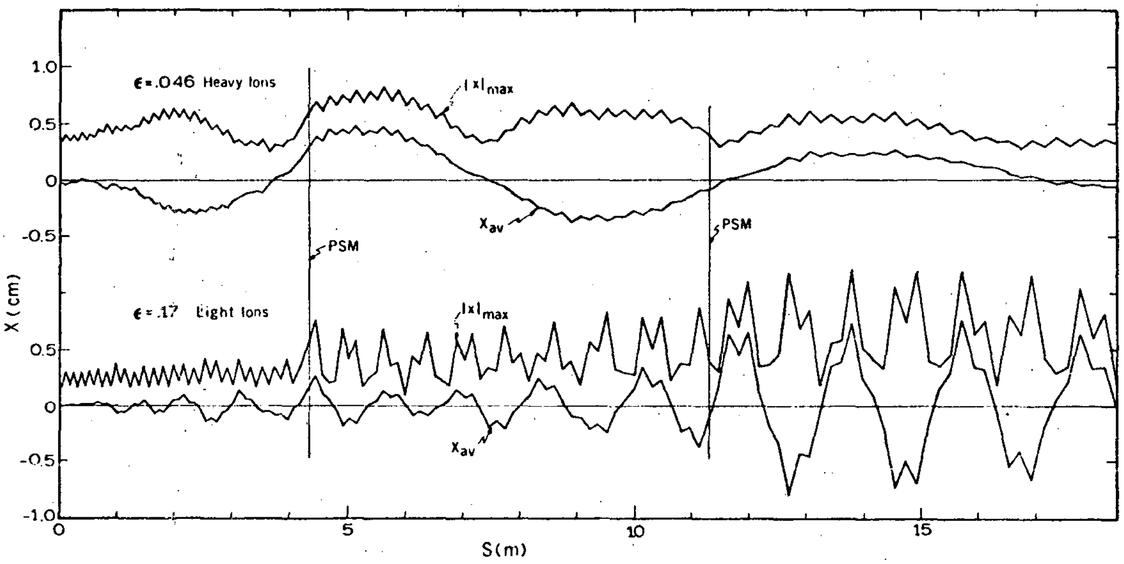

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Fig. 6. Prestripper beam envelopes and beam centers with quadrupoles randomly misaligned by 5 mils rms.

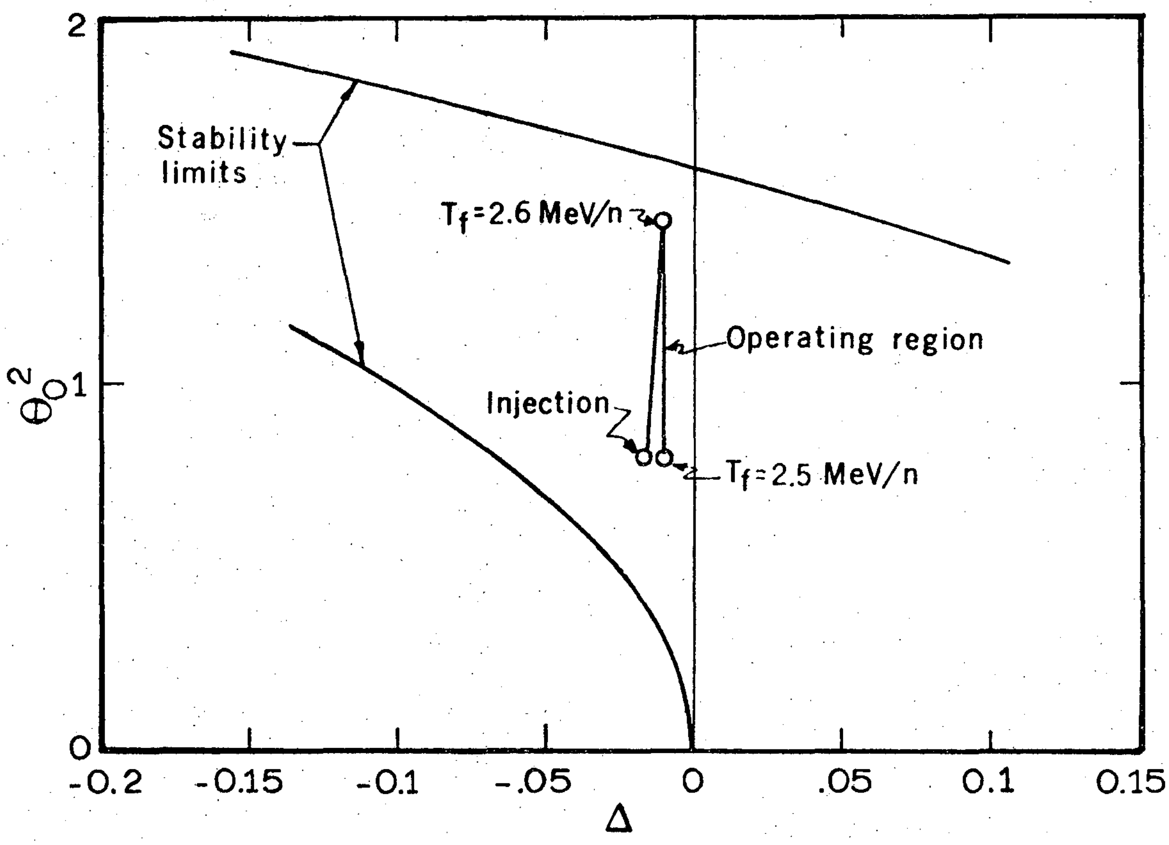

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Fig. 7. Transverse stability limits for N = 2 showing operating region for post-stripper beams.

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