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H^- INJECTION INTO THE LOW ENERGY BOOSTER OF THE SSC

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Abstract

Protons are accumulated into the low-energy booster of the SSC by utilizing $H^- \rightarrow H^+$ conversion in a 225 μg/cm^2 carbon stripping foil. Synchronous injection is performed for 26 turns into stationary rf buckets, thereby allowing operation with variable bunch spacing. By injecting the beam offset in x and y we obtain the required rms normalized transverse emittance of 0.75 mm-mr. Similarly the required rms longitudinal emittance area of $1.75\pi \times 10^{-3}$ eVs is obtained by injecting a single linac micropulse, centered at ϕ=0, and dp/p = +0.12%, into each 49.9 MHz rf bucket formed with an rf voltage of 350 kV. The resulting bunching factor is near 33%. The transverse space-charge tune shift is -0.17 for 10^{10} protons/bunch accumulated at 600 MeV.

1 Introduction

The function of the low-energy booster (LEB) is to accumulate 10^{10} protons per bunch into as many as 72 bunches, and accelerate them up to a final momentum of 8.45 GeV/c for transfer into the medium energy booster (MEB). This process takes place at a repetition rate of 10 Hz. For each bunch the required beam quality is for a rms normalized transverse emittance ε_t of 0.75 mm-mr and rms longitudinal phase space area A_z of $1.75\pi \times 10^{-3}$ eVs. The input linac beam is of the order of 3.8×10^8 H^- per microbunch with ε_t=0.45 mm-mr and A_z=$1.7\pi \times 10^{-5}$ eVs. Therefore some scheme must be developed to increase the linac emittances to the required final values during the injection. In this paper we describe how the required beam quality is obtained

Table 1: PARAMETERS OF THE LOW-ENERGY BOOSTER

Circumference (m)	342.711
Momentum Range (GeV/c)	1.22 - 8.45
Repetition Rate (Hz)	10.0
Number of Protons/Pulse	7.2×10^{11}
Betatron Tunes Q_x, Q_y	11.84, 11.78
Chromaticity ξ_x, ξ_y	-15.3, -15.6
Transition Gamma	10.32
RF Harmonic	72

during the injection process. Multiparticle simulations are carried out to demonstrate the efficiency of the process.

2 The Machine

Figure 1 shows a plan view of the latest version of the ring.[1] It is in the shape of a racetrack with two 180° arcs with dispersion suppressors, and two long straight sections, each of length 30.83 m. The straight sections are used for beam transfers and rf cavities. Table 1 lists the basic ring parameters.

3 The Injection Straight Section

The injection will take place in the 6 m drift in the center of the long straight section. Figure 2 shows an elevation view of the H^- injection and circulating proton beam envelopes section. During the injection period the circulating proton beam is displaced vertically by the orbit bumps 0_1 and 0_2 and traverses the stripping foil at a vertical position 3 1/3 cm above beam centerline. The incoming H^- are sent downward through a current septum S and into 0_1. The initial point is at y=347 mm and y′=-166.67 mr. The magnetic fields in S, 0_1 , and 0_2 are held at 0.45 T. The magnetic lengths 1.5 m, 1.0 m, and 1.0 m, respectively. The H^- strip to H^+ in the foil at about 3.5 cm above beam centerline. Greater than 95% stripping efficiency is obtained with a carbon foil with thickness $\rho\ell$=225 μg/cm^2. After the required number of turns are injected the bumps are rapidly reduced to zero so the protons cease to traverse the foil during the remainder of the cycle. The lower edge of the foil can be at, e.g., y=2.5 cm.

4 Injection into Stationary Buckets

The rf harmonic number has been chosen to be 72. Therefore there will be 72 buckets formed when the rf is energized. At the start of acceleration it is necessary to have bunches with the required A_z of $1.75\pi\times 10^{-3}$ eVs. Figure 3 shows a hypothetical 95% bunch contour within a separatrix formed by a sinusoidal rf voltage of 350 kV/turn.

The SSC users reserve the option for variable bunch spacing. These spacings would be the nominal 4.75 m, as well as 9.5 m and 19.0 m. In the LEB these three cases correspond to all buckets filled, every other bucket filled, or every fourth bucket filled. Furthermore the "empty buckets" should really be free of beam. These requirements preclude use of the standard fill and adiabatic capture technique. Clearly the most efficient filling mechanism is injection of a single microbunch into an existing 49.9 MHz bucket. This takes place turn by turn until the required number of protons is accumulated. Normally a single microbunch is placed into each of the 72 buckets in a turn. For larger bunch spacings, a chopper near the source is used to remove every other, or three out of four microbunches, as the case requires.

It was decided to use 350 kV/turn during the injection – for the considered machine this corresponds to a single bucket area of 0.073 eVs and synchrotron tune of 0.039. This bucket area represents over thirteen rms bunch areas (specified as $A_z = 1.75\pi \times 10^{-3}$ eVs). A multiparticle simulation was used to study the injection process. Figure 4(a) shows the position and extent of the injected micropulses into the existing buckets. The center of the beam is placed at $[\phi_c, (dp/p)_c] = (0, +0.12\%)$, i.e., the beam is injected higher in momentum by 1.2 MeV/c. The rms area of the microbunch was taken to be the linac value $A_z = 1.7\pi\times 10^{-5}$ eVs. The width and height of the microbunch were optimized to σ_ϕ=0.0107 (relative to the 49.9 MHz rf) and σ_p/p=0.05%.

To fill longitudinal phase space we inject for 26 turns or roughly one synchrotron oscillation. Figure 4(b) shows the longitudinal phase space as predicted by the simulation program. The rms bunch area is $1.82\pi\times10^{-3}$ eVs, just slightly larger than the

Table 2: MACHINE FUNCTIONS AT THE FOIL LOCATION

Function	Value
β_x	4.433 m
α_x	-0.238
β_y	8.190 m
α_y	-0.124
η_x, η'_x	0, 0
η_y, η'_y	0, 0

desired value $A_z = 1.75\pi \times 10^{-3}$ eVs. The energy of the machine does not change significantly during the 26 turns if we inject during the magnetic field fall just prior to the minimum (26 turns corresponds to 37 microseconds). The ϕ and dp/p projections of Fig. 4(b) are shown in Figs. 5(a) and 5(b), respectively. The bunching factor is of order 33% and the rms relative momentum spread σ_p/p is 0.09%.

If we track the injected beam for a further 100 turns the longitudinal phase space appears as in Fig. 6 – the spirals are nicely wound up but there are some particles near the separatrix. These particles might be lost during the ensuing acceleration. The ϕ and dp/p projections are essentially identical to those shown in Fig. 5.

5 The Transverse Match

The output linac rms normalized emittance (ε_t=0.45 mm-mr) is only slightly less than the desired ring emittance (ε_t=0.75 mm-mr). In practice injection errors and mismatches will bring them nearly into agreement; nevertheless, we outline an idealized scenario and predict the parameters using the multiparticle simulation program. All quantities are evaluated at the foil location. This point is 1 m downstream of center of the long straight section. Table 2 lists the machine parameters at the foil location.

For the simulation it was assumed the linac beam was matched to that of the machine at the foil location. The microbunches were taken to be bi-gaussian in x- x′ and y-y′ phase spaces with rms normalized emittances ε_t=0.45 mm-mr. In x-y space the microbunches were injected as in Fig. 7 at average x, y values of 1.3 mm and

35.0 mm, respectively; the bottom foil edge appears at y=+2.5 cm. The vertical bump was fixed at 33.3 mm so relative to beam center the injected H^- was injected 1.7 mm high. The injected central divergences x′, y′ were both assumed to be zero. The injection was carried out over 26 turns with the simulation program; multiple Coulomb scattering was taken into account for protons traversing the stripping foil. Then the vertical bump was reduced to zero in a few turns. The output phase space distributions are presented in Figs. 8(a) and 8(b). The normalized rms emittances were calculated to be in the range of 0.76-0.78 mm-mr which meets the required specification of 0.75 mm-mr. Furthermore, ∼ 96% of the beam occurs within the normalized emittance area $6\pi\varepsilon_t$. The x and y projections of Figs. 8(a) and 8(b) are both approximately Gaussian with rms value 1.6 mm and 2.2 mm, respectively.

6 Space-Charge Tune Shift

The worst case tune shift for Gaussian distributions is given by

$$\Delta Q_y = -\frac{r_p N_b N_p}{4\pi\beta\gamma^2 B\varepsilon_t}$$

where r_p = classical proton radius (1.54×10^{-18}m), N_b = number of bunches (72), N_p = number of protons/bunch (10^{10}), B=bunching factor (0.33) and ε_t=rms normalized transverse emittance (0.75 mm-mr). We obtain ΔQ_y=-0.17 which is certainly within specifications. It is less, in fact, than the quoted CDG value.

7 Comments

The injection scheme put forth here should easily meet the requirements for 600 MeV H^- injection. We have a few concerns about the machine, however. First, the maximum energy gain per turn will be 260 keV. The rf voltage and phase program which was given to us are not consistent with this energy gain per turn. If the rf voltage is held fixed at 350 kV then the maximum synchronous phase angle will be 47.8°. The single bucket area will shrink to .047 eVs at one point during the acceleration, increasing the probability for beam loss. We recommend an increase in maximum RF voltage to of order 500 kV. Second, the extraction kicker will require a rise time of order 50-100 nsec; this will leave gaps in the beam in all downstream machines. The effects of these gaps on beam stability should be considered.

8 References

1. L. K. Chen and M. A. Furman, "A Possible New Design of the SSC Boosters," SSC-164.

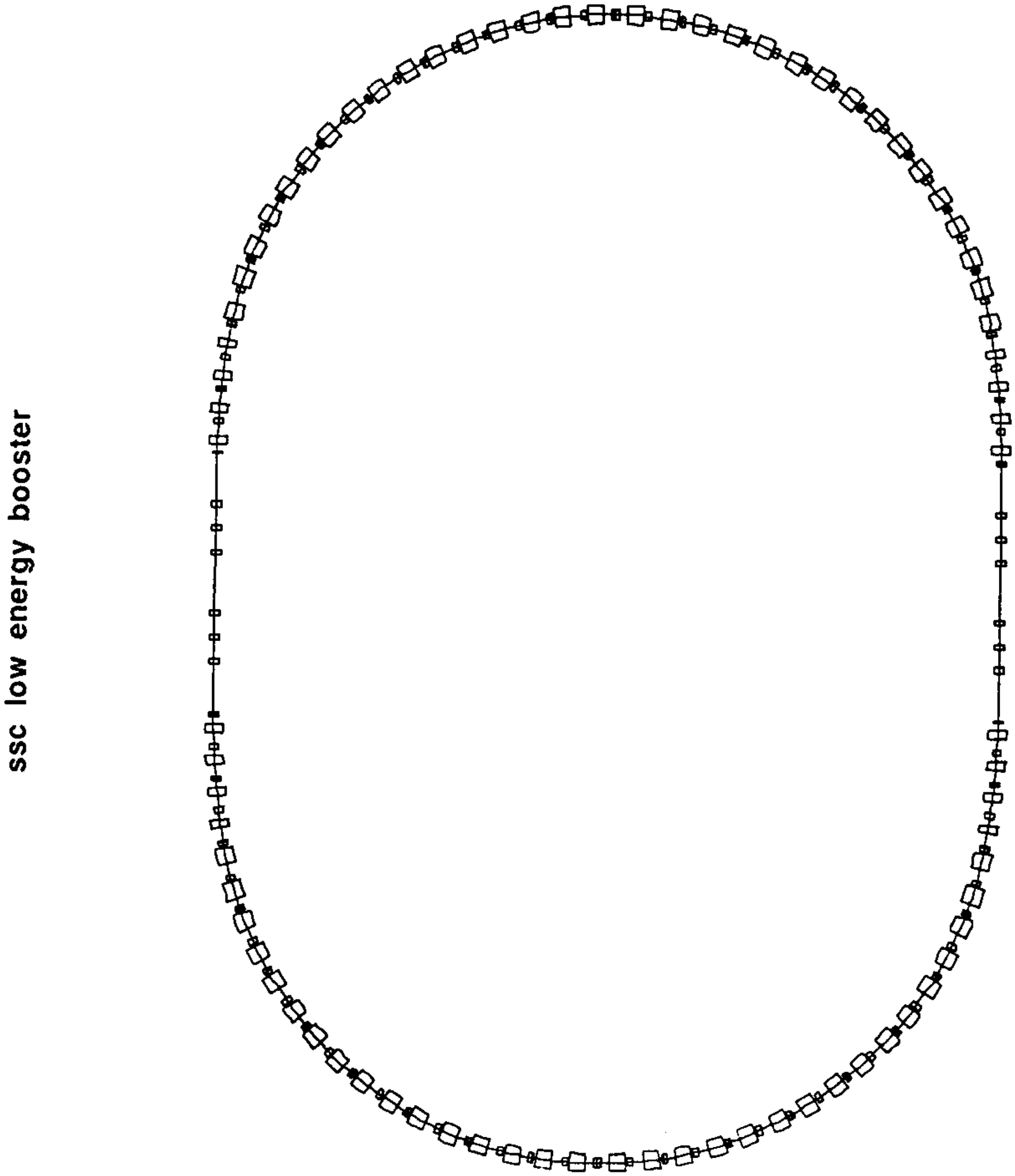

Figure 1: Plan view of the Low Energy Booster. Circumference is 342.71 m.

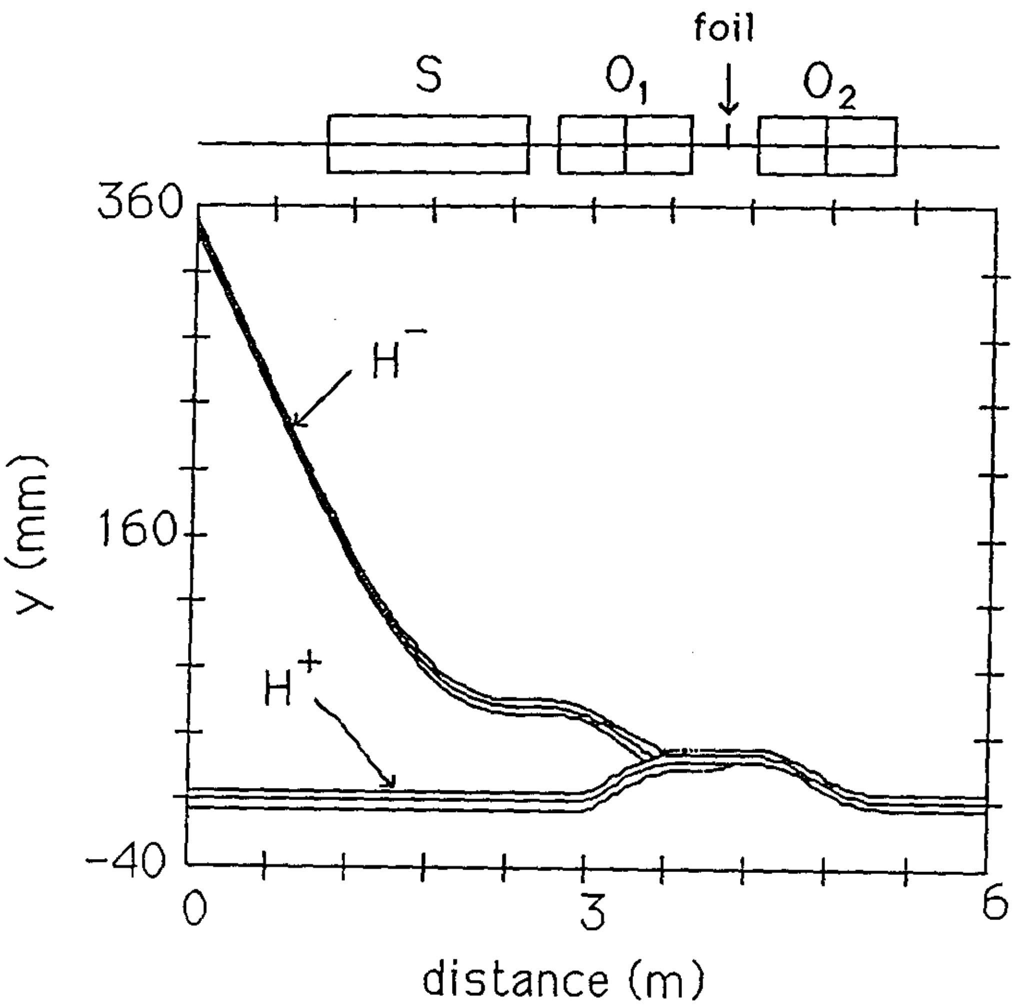

Figure 2: Elevation view of beam envelopes in the 6.0 m injection straight section.

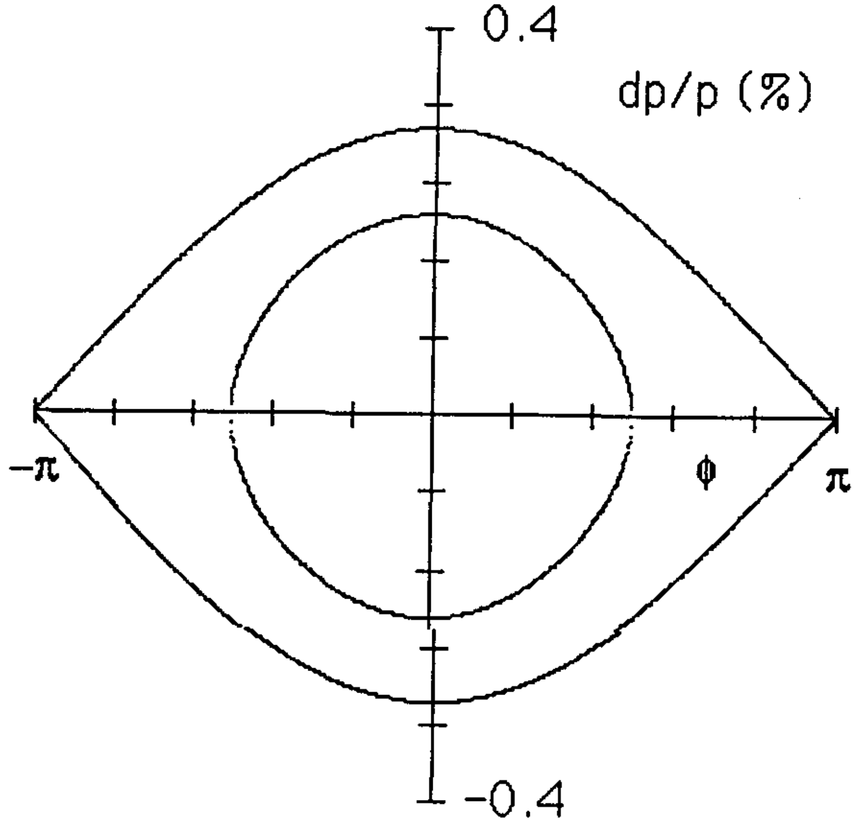

Figure 3: Hypothetical bunch contour within separatrix formed by 350 kV rf voltage. Bucket area 0.073 eVs; bunch area 0.031 eVs.

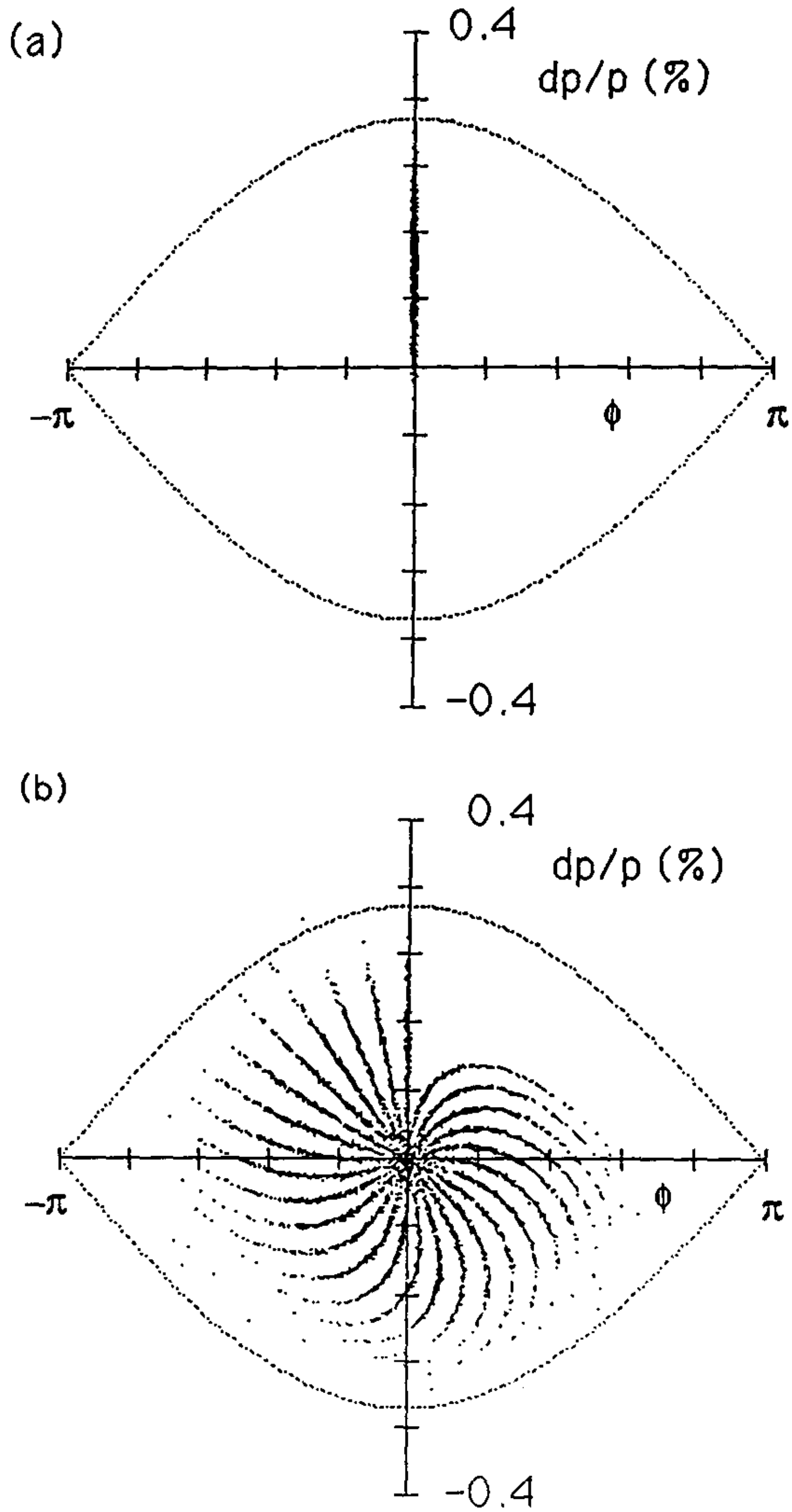

Figure 4: (a) Injected microbunch within an existing 49.9 MHz rf bucket. (b) Longitudinal phase space after 26 turns of injection. Rms single bunch area $A_z=1.82\pi\times 10^{-3}$ eVs.

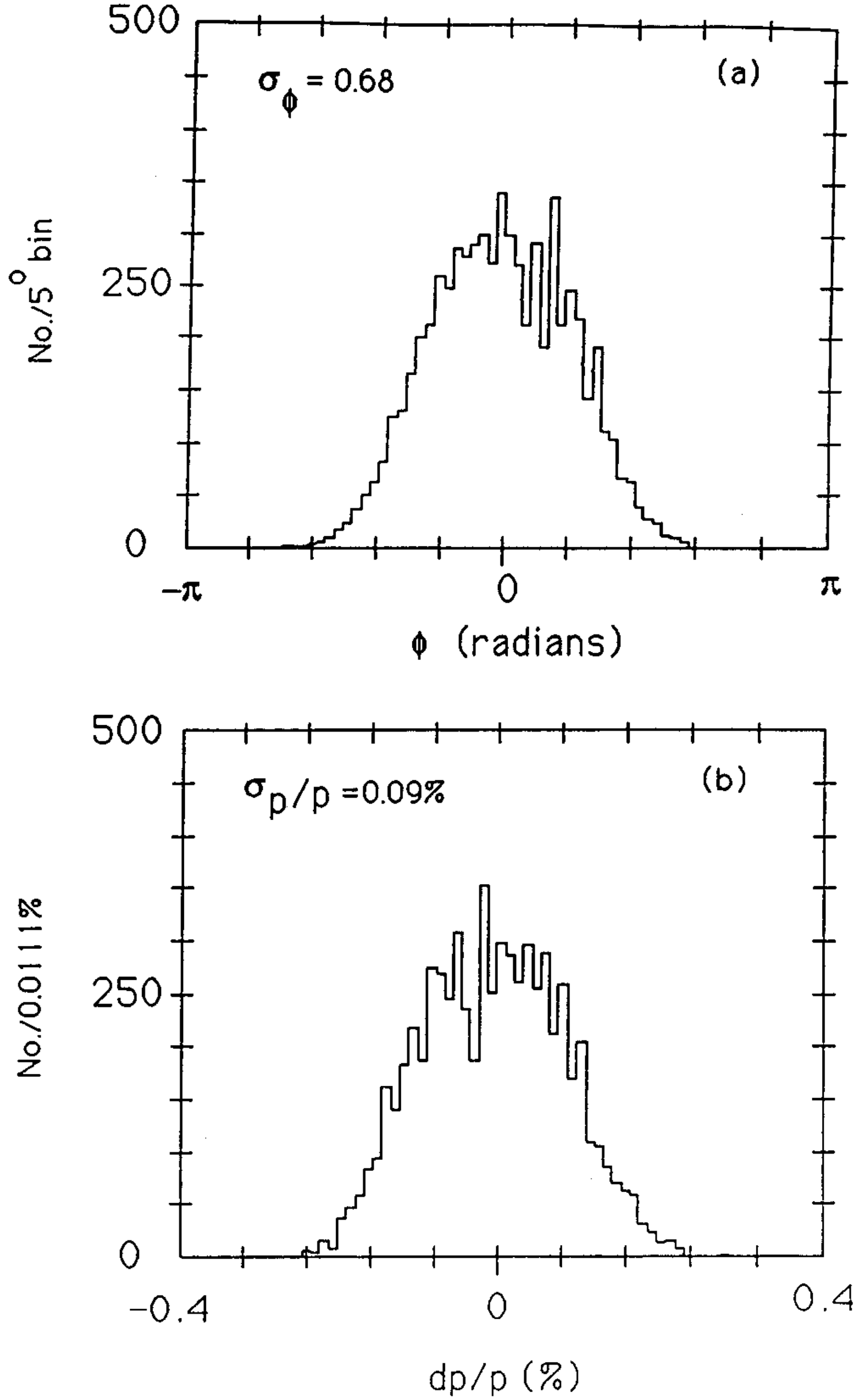

Figure 5: Projections of Fig. 4(b): (a) $dN/d\phi$; (b) $dN/dp/p$.

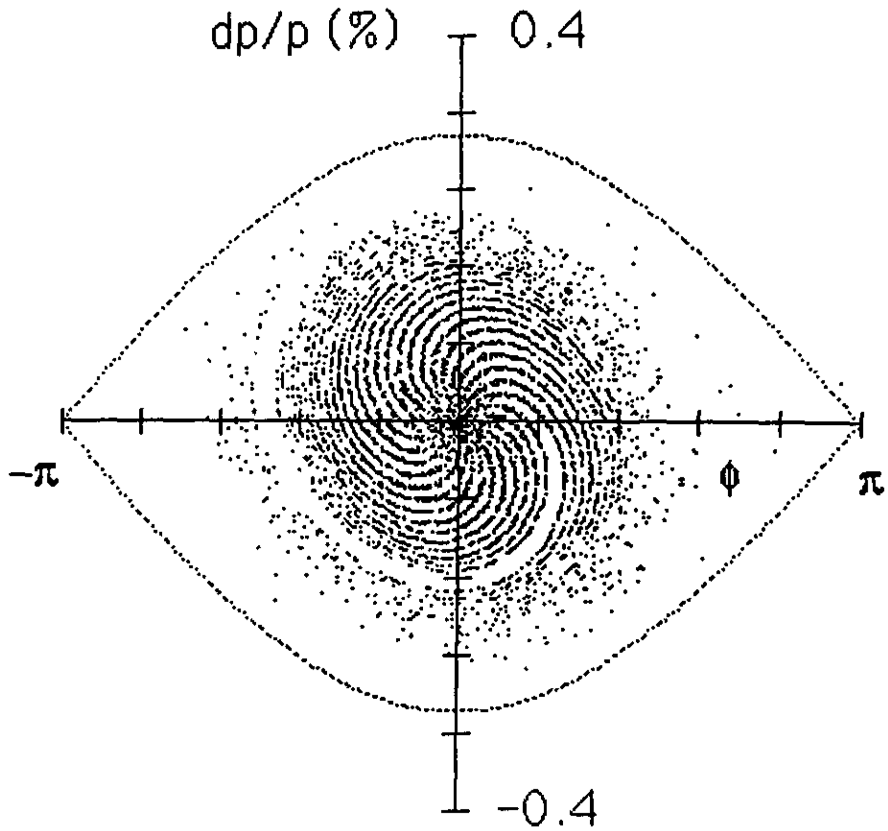

Figure 6: Longitudinal phase space obtained for 26 turns of injection as in Fig. 4(b) followed by 100 turns of beam circulation with the rf voltage held at 350 kV.

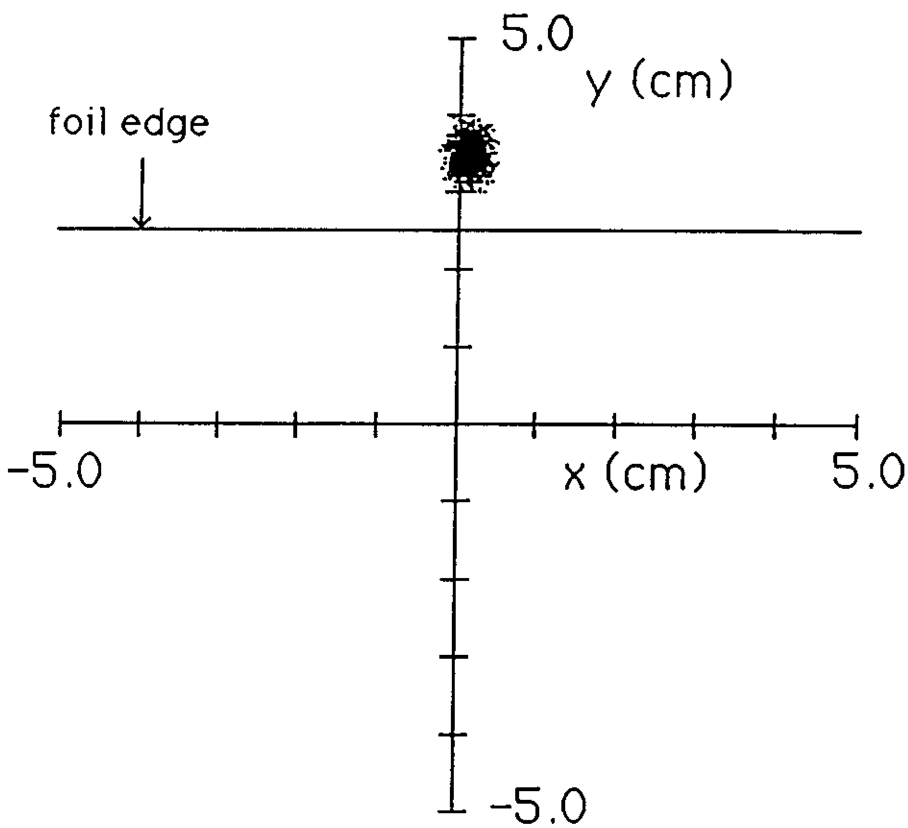

Figure 7: Spatial (x-y) distribution of injected H^- microbunch at the foil location. The lower edge of the stripping foil is at y=2.5 cm.

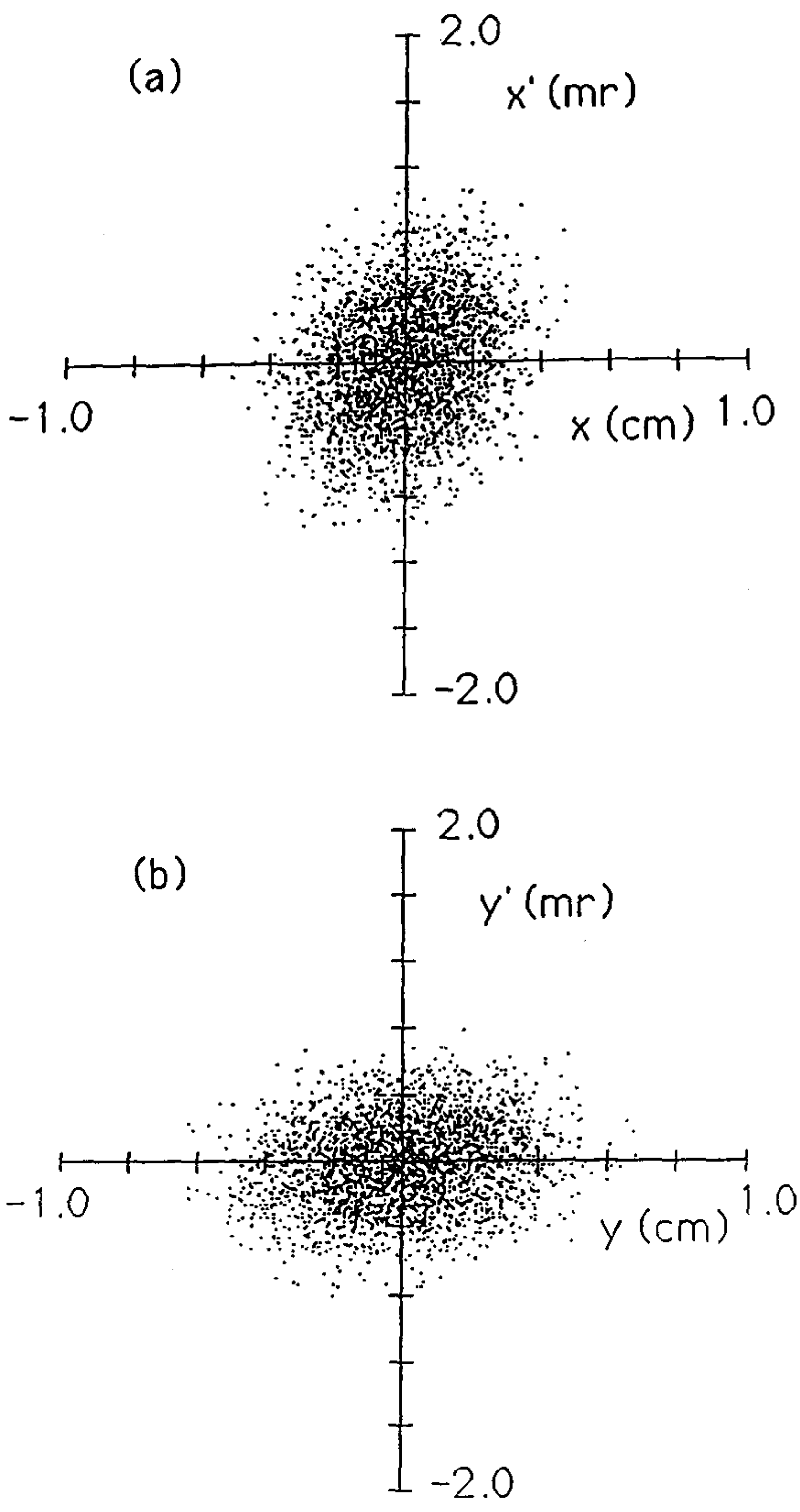

Figure 8: Injection phase-spaces at the foil location after 26 turns of injection: (a) x-x′ distribution; (b) y-y′ distribution - y is measured relative to a 3.33 cm bump.