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TITLE: **SSC LINAC INJECTOR**

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SSC LINAC INJECTOR*

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ABSTRACT

The para.. .ters for the proposed SSC linac injector system are obtained from the established requirements of the low-energy booster (LEB). The first element of this injector system is a radio-frequency quadrupole (RFQ) that bunches the H^- ions and accelerates these ion bunches to 2.5 MeV. With a suitable matching section, this beam is injected into a drift-tube linac (DTL), which takes the ions to 120 MeV. The final element is a coupled-cavity linac (CCL) designed to accelerate the H^- ions to 600 MeV for injection into the LEB. The conceptual beam dynamics design for the various elements of this linac injector system are described.

INTRODUCTION

The SSC Conceptual Design Report (CDR) was published in March 1986.[1] It included linac information provided by Los Alamos that was based on the design of linac components prepared for other tasks and was not a design optimized for the SSC role. Since then, in order to improve the overall SSC design and also to consider the possibilities for higher beam luminosity, new designs for the Low Energy Booster (LEB) have been discussed. The SSC linac injector parameters are determined by the requirements of LEB. Any changes in the LEB lattice require corresponding changes in the linac injector. Furthermore, in the last few years, there have been some advances in linac design procedures in as far as the control of emittance growth is concerned. It is quite appropriate at this time to launch a new iteration for the SSC linac injector design that provides an H^- ion beam suitable for the LEB painting scheme being considered.

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SSC LINAC INJECTOR PARAMETERS

The SSC linac injector parameters must be established from the requirements of the LEB lattice and the painting scheme. One such painting scheme based on the new LEB lattice design,[2] has been described by Colton and Thiessen.[3] In this scheme, 600-MeV H^- ions with 50-MHz microbunch structure undergo $H^- \rightarrow H^+$ conversion in a 225-μg/cm^2 carbon stripping foil before injection into the LEB with a circumference of 342.71 m. It takes 72 microbunches to fill the LEB ring. Each microbunch contains 3.8×10^8 H^- ions. The painting scheme consists of a 26-turn synchronous injection into the LEB. This dictates a linac pulse length of 37.44 μs, and with the required rep rate of 10 Hz, the linac beam duty factor is therefore ~0.04%. The transverse and longitudinal normalized rms emittances, ε^t(n, rms) and ε^ℓ(n, rms), at 600 MeV are required to be less than 0.45 π mm·mrad and 1.7×10^{-5} π eV·s, respectively. This painting scheme enables the LEB to accumulate 10^{10} protons per bunch into 72 bunches leading to 7.2×10^{11} protons/pulse. Table 1 summarizes the required SSC linac injector parameters based on the painting scheme described in Ref. 3.

TABLE 1

Required SSC Linac Injector Parameters

Energy	600 MeV
Beam microbunch structure	50 MHz
Protons per microbunch	3.8×10^8
Linac pulse length	37.44 μs
Linac rep rate	10 Hz
ε^t(n, rms)	≤0.45 π mm·mrad
ε^ℓ(n, rms)	≤1.7×10^{-5} π eV·s (5.4 π mm·mrad)

SSC LINAC INJECTOR

Simulations with the RFQ design code PARMTEQ have shown that for a 50-MHz, 2.5-MeV, 3-mA H^- RFQ, the expected transverse and longitudinal emittances at 2.5 MeV are ε^t(n, rms) ~ 0.18 π mm·mrad and ε^ℓ(n, rms) ~ 8.2 π mm·mrad. Thus, an SSC linac injector system that starts off with a 50-MHz RFQ could easily satisfy the transverse emittance requirements, but fails to meet the longitudinal emittance goals by about a factor of 2.

Higher frequency RFQs, such as 100-200 MHz, lead to beams with lower transverse and longitudinal emittances. Such an RFQ must be followed by a chopper designed to produce a 50-MHz microbunch beam structure. Thus, one must have a 9-mA average beam (during a macropulse) from a 150-MHz RFQ, since the chopping system will allow only one out of three microbunches to be injected into the drift-tube linac.

We have looked at four nominal RFQ design examples with RFQ frequencies ranging from 50-200 MHz. The output emittances for the four cases are listed in Table 2.

TABLE 2

2.5-MeV H^- RFQ Design Examples

Frequency (MHz)	Average Beam (mA)	ϵ^t (n, rms) (π mm·mrad)	ϵ^ℓ (n, rms) (10^{-5} π eV s)	ϵ^ℓ (n, rms) (π mm·mrad)
50	3	0.18	2.60	8.26
100	6	0.15	1.00	3.18
150	9	0.14	0.45	1.43
200	12	0.12	0.30	0.95

A 150-MHz RFQ leads to a beam with longitudinal emittance decreased by a factor of ~6 over that for a 50-MHz RFQ.

The SSC linac injector system designed to satisfy the requirements noted in the previous section is shown in Fig. 1. A 10-mA H^- beam from the ion source is properly

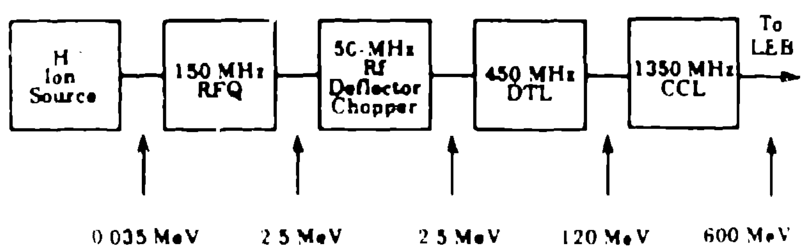

Figure 1 The Suggested SSC Linac Injector System

matched and delivered to a 150 MHz RFQ where the beam is bunched and accelerated to an energy of 2.5 MeV. Simulations show that the beam transmission through the RFQ is ~0.96. Before injection into the 450 MHz DTL, the beam goes through a 50-MHz rf deflector chopper that is designed to retain one out of three microbeam bunches. The 450-MHz DTL, designed for 27-mA peak beam, accelerates the 2.5-MeV beam to 120 MeV. The final accelerating element is a 1350-MHz CCL designed for 81-mA peak operation that takes the energy to 600 MeV.

We shall now describe the individual components of this suggested SSC linac injector system.

1. RFQ

Table 3 shows the PARMTEQ simulation results for the 150-MHz, 2.5-MeV H^- RFQ. This is a conservative design with maximum peak surface electric field of ~ 1.8 Kilpatrick. The RFQ length is 3.45 m.

TABLE 3

PARMTEQ Simulation Results for the 150-MHz H^- RFQ

Energy (MeV)	0.030	2.5
Current (mA)	10	9.6
ε^t(n, rms) (π mm·mrad)	0.10	0.14
ε^ℓ(n, rms) (π mm·mrad)	—	1.43

RFQ length	3.45 m
MPSEF	1.8 E_K

2. RF Deflector Chopper

The 150-MHz RFQ is followed by a 50-MHz rf deflector. One of three beam microbunches needed to be injected into the DTL suffers a deflection to the left, whereas the subsequent two bunches are deflected only slightly to the right where they are collected in a beam stop (see Fig. 2). With this chopping scheme, the empty buckets (2 out of 3) will be truly empty. The portion of the RFQ beam that is not used is neatly collected in a beam stop. The rf deflector would be combined with a matching section consisting of two or three permanent magnet quadrupoles and an rf buncher. It should be possible to keep transverse and longitudinal emittance growth through this combination of elements to ~ 10% or less. Simulation work that will address the emittance growth question has not yet been done.

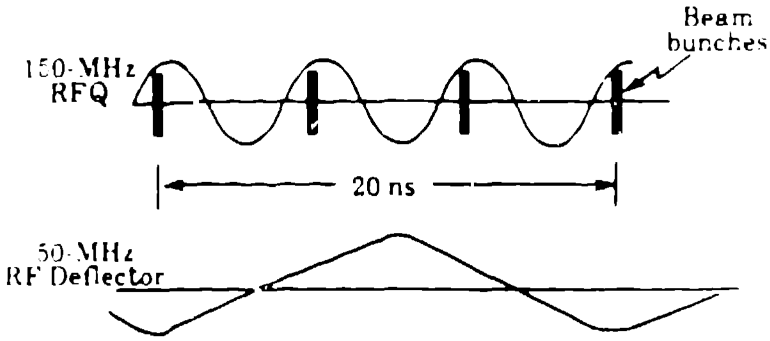

Figure 2 RF Deflector Scheme

3. 450-MHz DTL

Following the rf deflector system, 3-mA, 50-MHz beam microbunches are injected into the 450-MHz DTL. Thus, 1 out of 9 buckets are filled. This 450-MHz DTL is therefore designed for 27-mA peak operation.

The DTL parameters obtained from PARMILA simulations are given in Table 4. The transverse and longitudinal emittance growth in this 2.5-120 MeV linac appears to be less than ~ 10% (see Figs. 3 and 4).

TABLE 4

PARMILA Simulations for the 450-MHz
2.5-120 MeV DTL for the SSC Linac Injector

	Input	Output
Energy (MeV)	2.5	120
Current (mA)	27	27
ϵ^x(n, rms) (π mm-mrad)	0.140	0.145
ϵ^y(n, rms) (π mm-mrad)	0.140	0.150
ϵ^ℓ(n, rms) (π mm-mrad)	1.43	1.44
DTL length	41.66 m	
No. of cells	218	
E_0	4.8 MV/m	
DTL lattice	FODO	

4. 1350-MHz CCL

The matching section between the 450-MHz DTL and the 1350-MHz CCL is 1.7 m long and consists of one buncher tank and four quadrupoles. The coupled-cavity linac takes the energy from 120-600 MeV in a total length of 94.1 m. This linac design is for 81-mA peak operation. The CCL lattice chosen for this design example is also FODO. Simulations show no beam loss and no emittance growth. The 600-MeV beam phase-space plots are shown in Fig. 5.

SUMMARY

Beam dynamics designs for the components of the proposed SSC linac injector system show that the LEB requirements can be satisfied. The suggested system is only intended as an example. The designs for the individual components have not been optimized.

The complete SSC linac injector system is ~ 145 m long. The transverse and longitudinal emittances at 600 MeV are $\epsilon^t(n, rms) \sim 0.15\,\pi$ mm-mrad and $\epsilon^\ell(n, rms) \sim 1.45\,\pi$ mm-mrad, respectively.

R. Diebold has suggested[4] that a future SSC upgrade should aim at a luminosity increase of 10. This would call for an increase of $\sqrt{10}$ in the beam current delivered by the linac injector system to the LEB. PARMTEQ and PARMILA simulations show that the three accelerating elements of this linac injector system, i.e., 150-MHz RFQ, 450-MHz DTl, and the 1350-MHz CCL, can carry beam currents ~ 3 times larger than required to meet the requirements of the LEB. Transverse emittance at 600 MeV for the 3 times higher beam would increase by about a factor of 2.

ACKNOWLEDGMENTS

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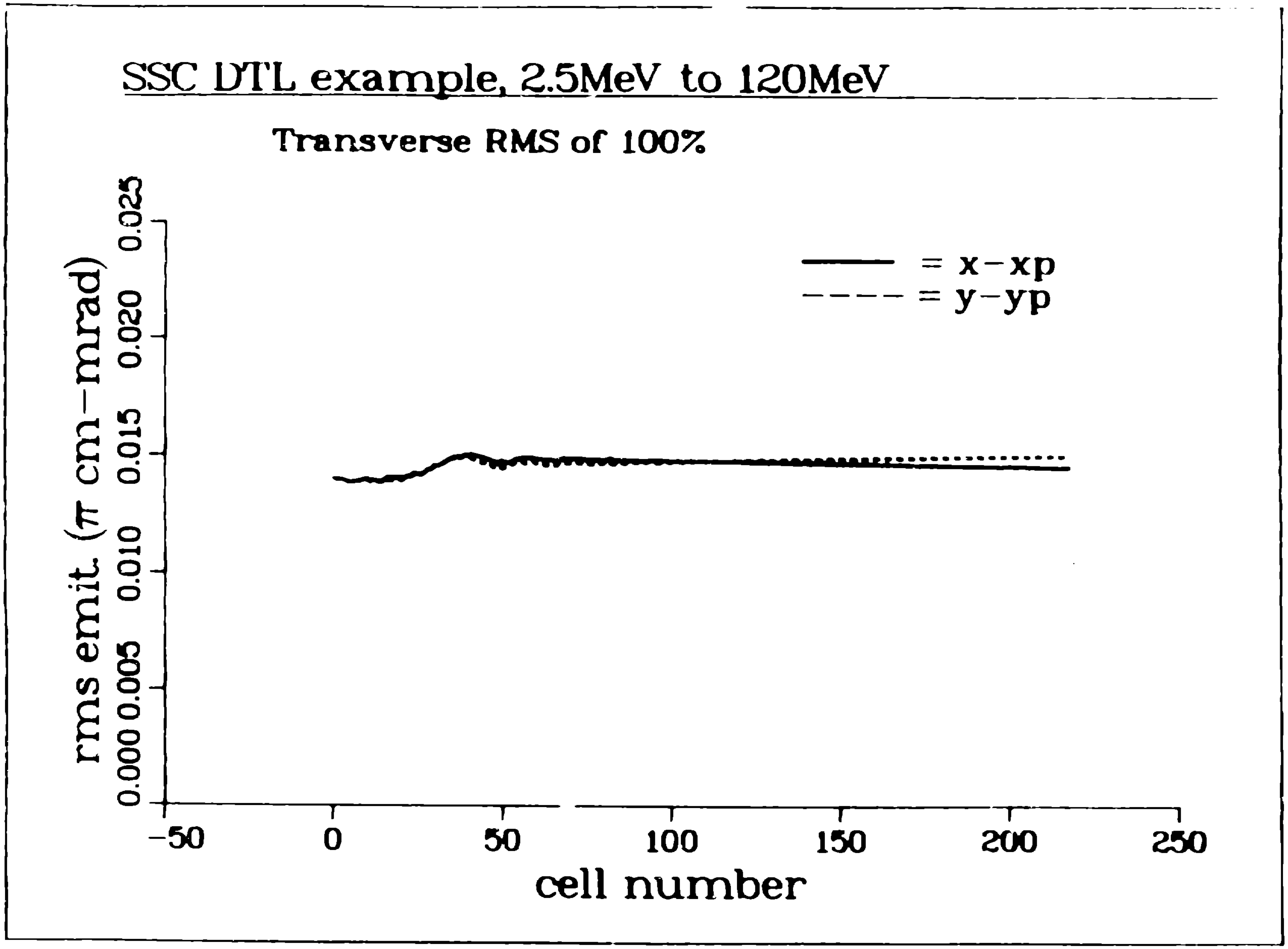

Figure 3. Transverse emittance vs cell number for the 450-MHz DTL.

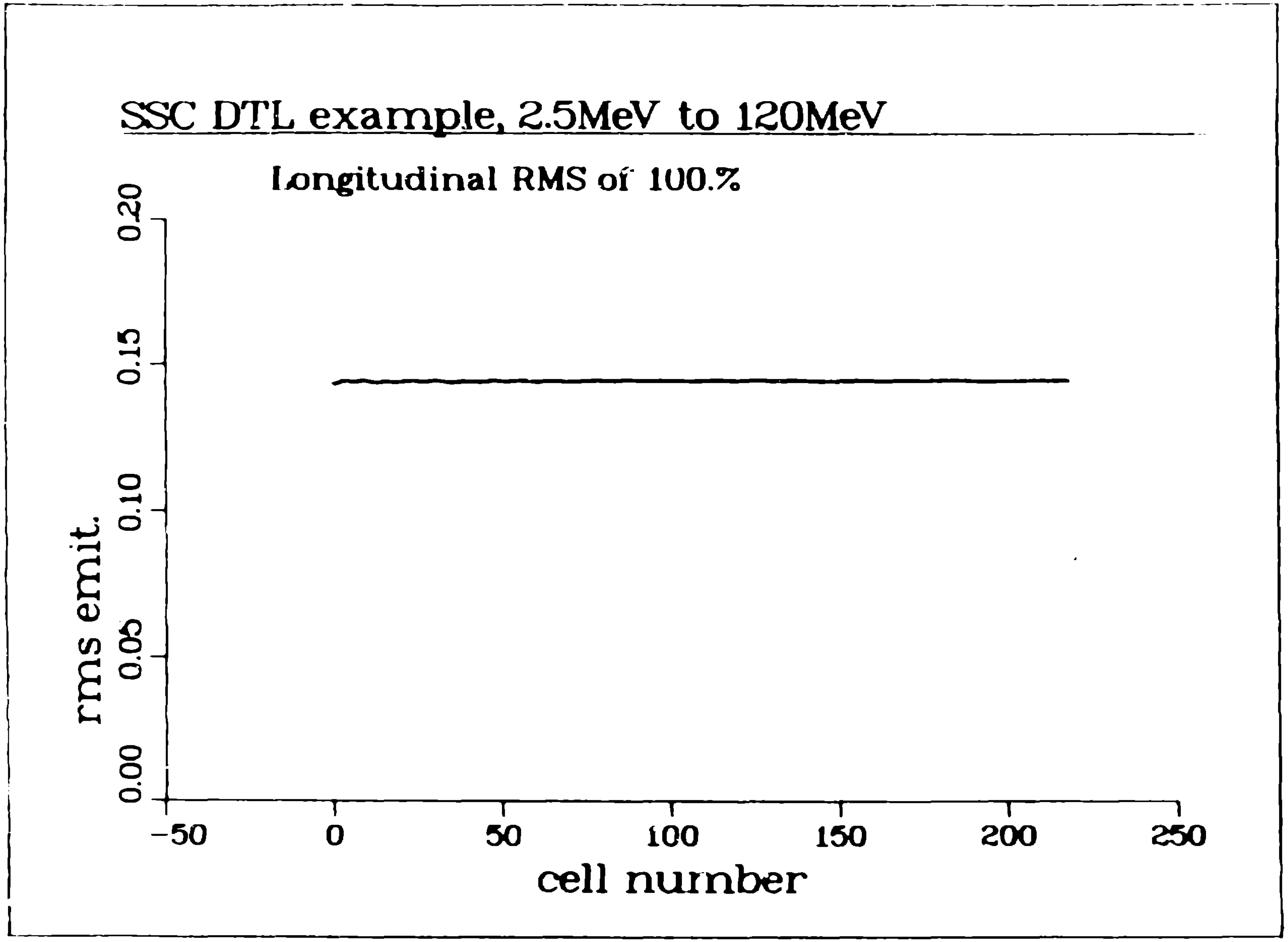

Figure 4. Longitudinal emittance vs cell number for the 450-MHz DTL.

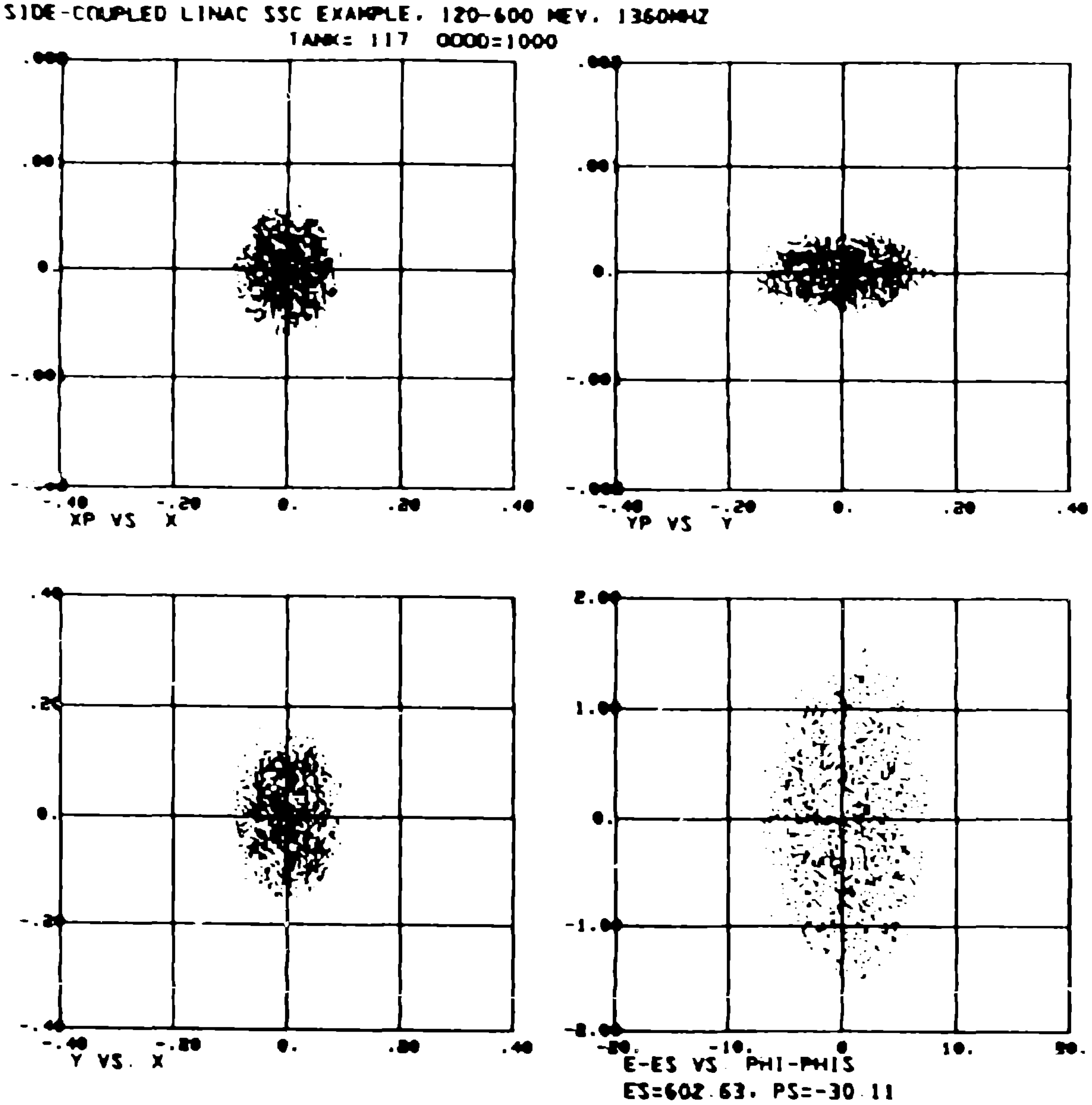

Figure 5. Phase-space plots at 600 MeV.