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subject: **Booster Ring**

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The booster synchrotron accelerates 200 to 250 MeV electrons from the SAL linac/energy compressor system up to the 1.5 to 2.9 GeV operating energy of the main storage ring. This report describes the booster lattice and the booster injection and extraction requirements.

1. Lattice

The booster lattice is shown in Figure 1. Because the ring is compact, it fits into the area circumscribed by the main ring. The ring has a FODO structure with “missing dipoles” to provide straight sections for injection, extraction and RF cavities. The resulting lattice has two families of 14 quadrupoles and 20 identical dipole magnets. The lattice also contains two families of orbit correctors: 14 horizontal correctors, following each QF quadrupole, and 7 vertical correctors, following every second QD quadrupole.

There are four different cell structures in the booster lattice. These include two straight cells and two bend cells as shown in Figure 2. (Physical lengths of quadrupoles are shown.)

The machine functions for one-half of the booster lattice are shown in Figure 3. The functions are plotted beginning with the first cell after the injection point. The machine functions for the other half of the lattice are the same. Parameters for the booster synchrotron are given in Table 1.

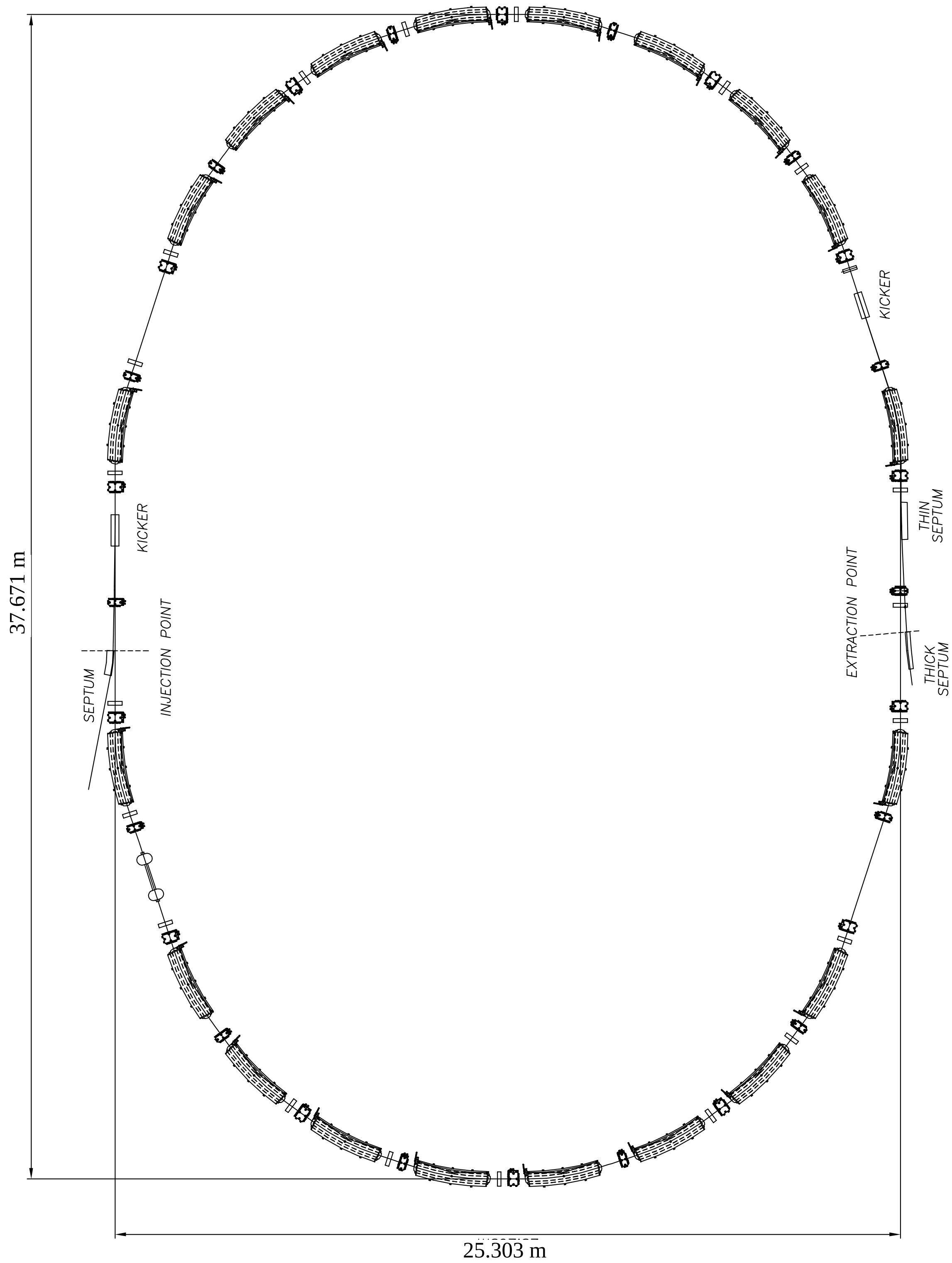

Figure 1 The booster lattice.

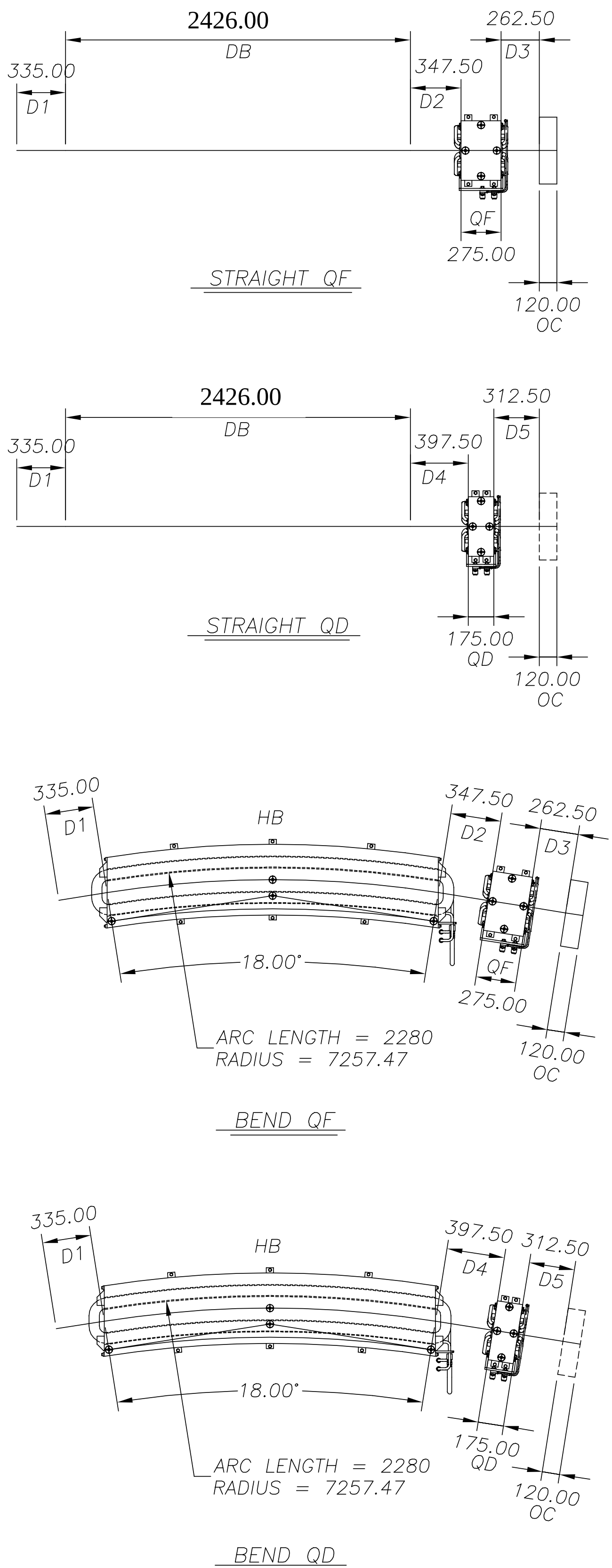

Figure 2 The lattice cells for the booster ring.

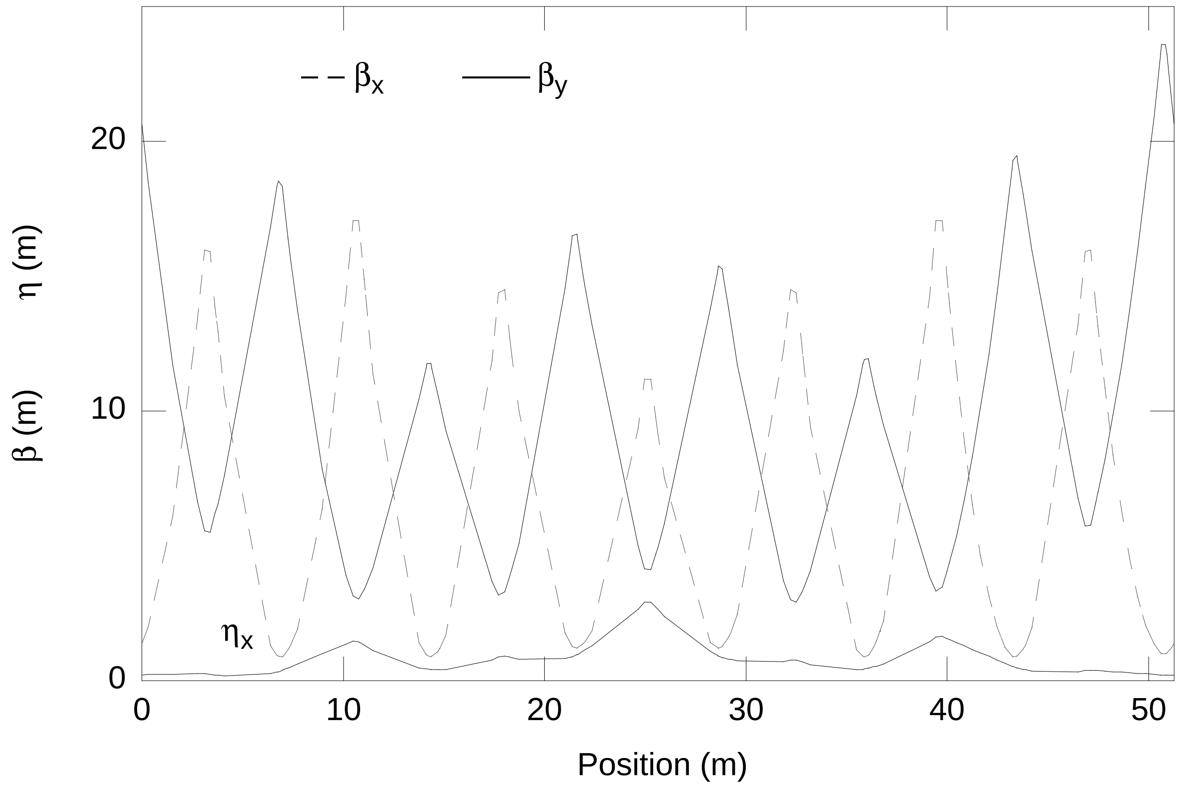

Figure 3 The lattice functions for one half of the booster ring.

Table 1 Booster Ring Parameters

Circumference	102.528 m	
Periodicity	2	
Optics ν_x (tune) ν_y χ_x (natural chromaticity) χ_y momentum compaction	 5.26 2.22 -7.6 -4.2 0.050	
Straights length	8 3.3 m	
RF Cavity frequency voltage harmonic number	 500 MHz 1.5 MV 171	
E (energy)	0.250 GeV	2.9 GeV
B_{dipole}	0.115 T	1.333 T
Damping times τ_x τ_y τ_E	 3.6 s 3.6 s 1.8 s	 2.3 ms 2.3 ms 1.2 ms
ε_x (damped emittance)	4.1 nm-rad	550 nm-rad
ε_x (injected emittance)	300 nm-rad	
δ (damped energy spread)	0.008%	0.092%
δ (injected energy spread)	0.10%	

In the normal operation of the booster, the acceleration process begins before the beam has time to damp. At the high energy end of the acceleration process, the beam quickly damps and the emittance of the extracted beam is that of the damped beam.

2. Injection

As shown in Figure 1, two straight sections are used for injection, one for a 9.8^{o} injection septum and the following straight section for a fast kicker to put the beam on the booster axis.

The 9.8^o septum brings the injected beam to the injection point, 60 mm from the booster axis and 1.55 m upstream from the centre of the following QD quadrupole. At this point, the beam is inclined toward the booster axis at an angle of 1.20^o. The QD quadrupole deflects the beam to an angle of about 0.72^o. Finally the beam crosses the booster axis at the position of the fast injection kicker, 1.57 m upstream from the centre of the following QF quadrupole. The machine functions at the injection point are: $\beta_x = 4.53, \alpha_x = 1.96, \eta_x = 0.29, \eta_x' = -0.05, \beta_y = 13.74$ and $\alpha_y = -2.63$.

To have time to ramp the injection kicker down to zero, the injected beam is only 136 ns (68 booster buckets) long. This leaves 206 ns to ramp down the kicker. The pulse train in the booster is one-third the length of the desired pulse train in the main ring.

3. Acceleration

The acceleration of the beam from a nominal injection energy of 0.25 GeV to a final energy of 2.9 GeV has been investigated for a sinusoidal ramping of the magnets over 0.2 s. The beam energy as a function of time is shown in Figure 4.

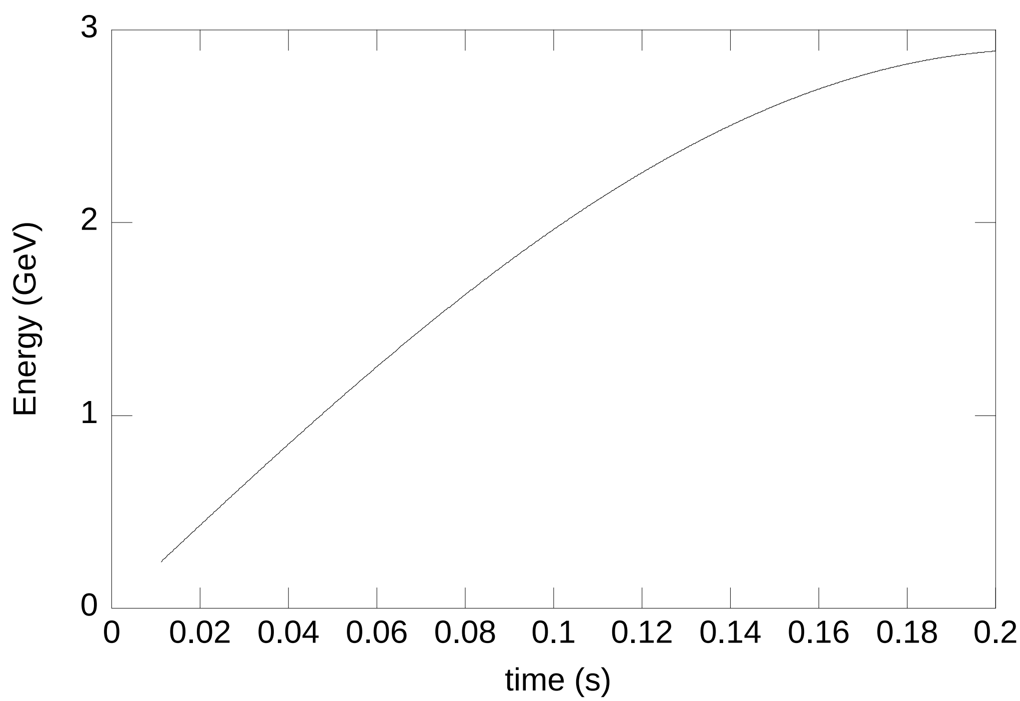

Figure 4 Beam Energy vs. Time.

The evolution of the transverse emittances and the energy spread of the beam is shown in Figure 5. The starting beam parameters are typical for the beam coming from the SAL linac and energy compression system. They are: $\varepsilon_x = \varepsilon_y = 0.3$ mm-mrad and $\delta = 0.1\%$. The figure shows that the emittances and energy spread initially undergo adiabatic damping until the effects of quantum fluctuations bring the beam parameters to final equilibrium values at 2.9 GeV.

The evolution of the phase space area of the beam bunch and the RF bucket are shown in Figure 6. The RF voltage is constant over the acceleration process at 1.5 MV. (This may not represent the actual mode of operation. An RF ramping scheme is being investigated.) While the bucket size remains fairly constant, the bunch area starts relatively small and increases to about 10% of the bucket size at 2.9 GeV. It is obvious from the figure that the beam bunch is well contained by the RF bucket throughout the entire acceleration process.

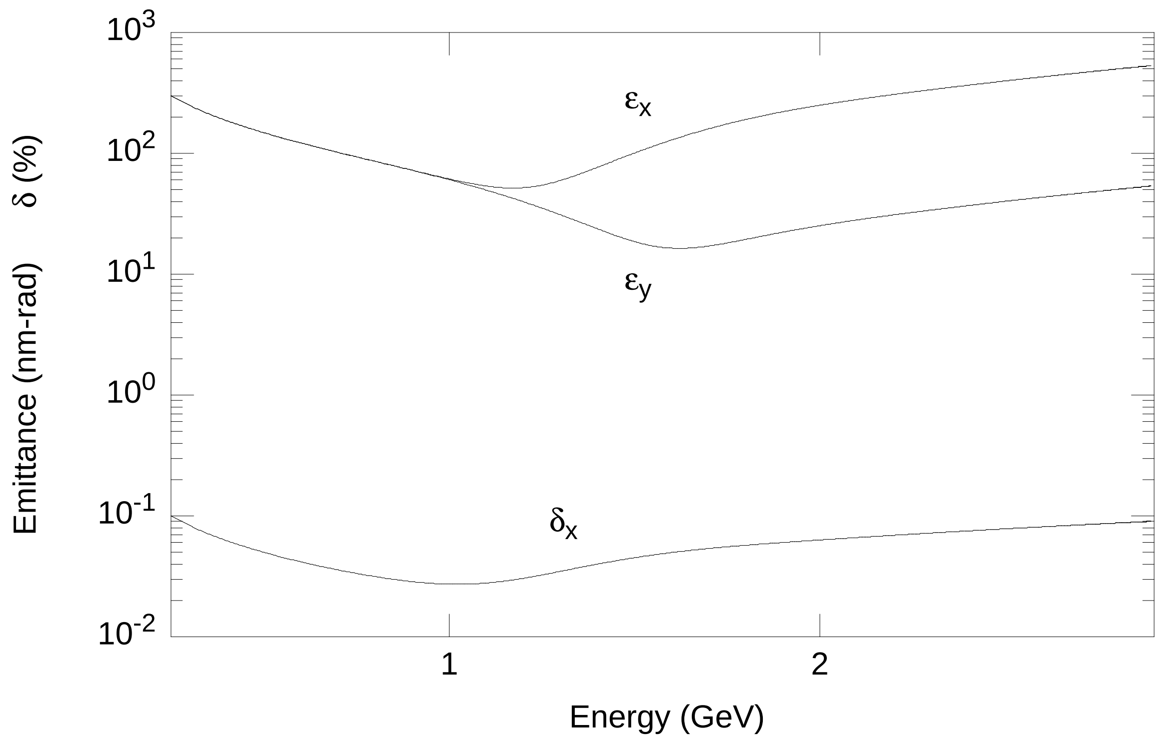

Figure 5 Evolution of beam emittances and energy spread.

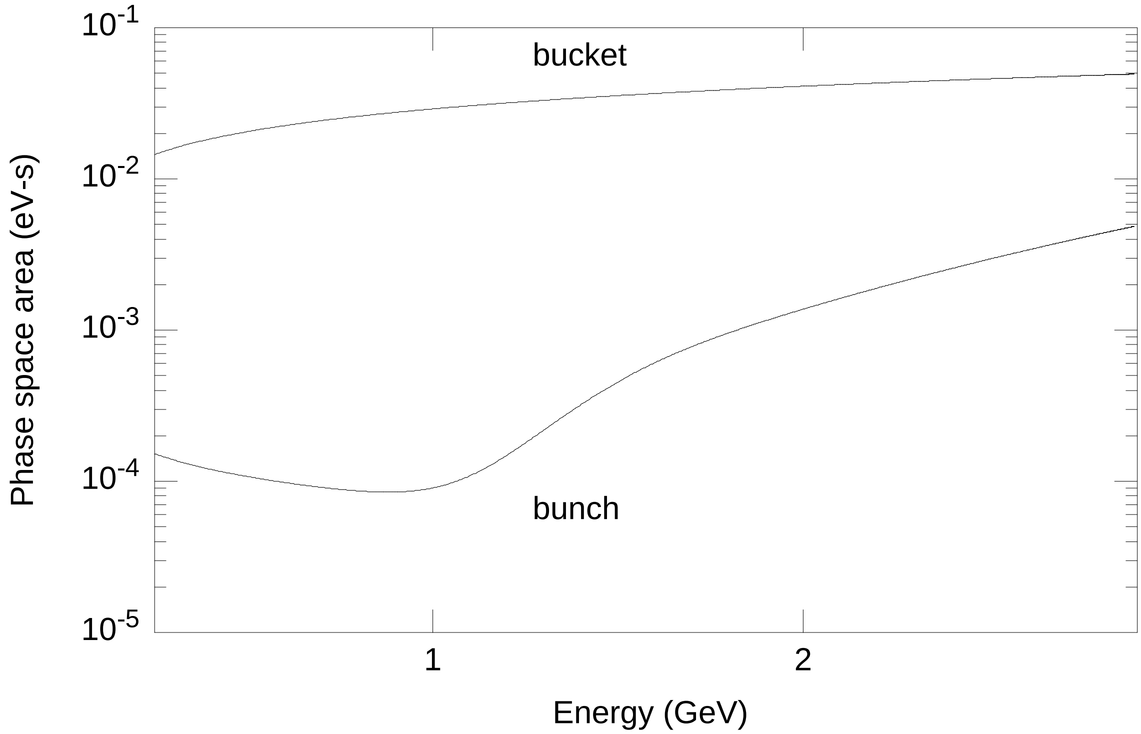

Figure 6 Evolution of bunch and bucket areas.

4. Extraction

The extraction elements are shown in Figure 1. They include a thin 3.3^{o} septum magnet and a thick 4.0^{o} septum magnet in the following straight section. An upstream straight section contains the fast kicker used to bring the beam into the first extraction septum (thin septum). These elements must operate at a beam energy of 1.5 to 2.9 GeV.

The extraction process is initiated by the fast kicker. The gap in the circulating beam pulse allows adequate time to ramp up the kicker field. Prior to extraction, the beam can be brought closer to the thin septum by a local beam bump, but this is not necessarily required. Without a local bump, a 3.3 mrad kick will put the beam into the thin septum aperture. The initial kick is enhanced when the beam passes through the downstream QD quadrupole, but before reaching the septum the beam is bent towards the booster axis by the QF quadrupole.

At the entrance of the thin septum magnet, the beam is 21.3 mm off axis and converging toward the booster axis at an angle of 8.5 mrad. The thin septum must intercept the extracted beam while allowing passage of the stored beam. Using a local bump could ease the spatial requirements on the thin septum.

The thin septum magnet bends the beam 3.3°. The beam is extracted through one more QD quadrupole and on to the thick septum. The beginning of the thick septum is defined as the extraction point of the lattice. This point is used as the starting point of the booster-to-main ring transfer line. At this position, the beam is 19.87 cm from the booster axis diverging at an angle of 3.0°. This transport analysis uses QD as modelled with POISSON, at large beam displacements where QD no longer behaves as a quadrupole. The actual field maps of these elements will have to be used to determine the exact alignment and field strengths of the extraction septa. The machine (beam) functions at the extraction point are: $\beta_x = 2.32$, $\alpha_x = -1.23$, $\eta_x = 0.13$, $\eta_x' = -0.06$, $\beta_y = 39.58$ and $\alpha_y = -6.51$.

5. Appendix - DIMAD input

```
 TITLE
BOOSTER Sept. 99 (500 MHZ)
D1:DRIFT,L=.335;
D2:DRIFT,L=.335;
D3:DRIFT,L=.25;
DK2:DRIFT,L=1.426;
DS2:DRIFT,L=1.226;
DQD:DRIFT,L=.05;
DE1:DRIFT,L=.465
DE2:DRIFT,L=.0202
DI1:DRIFT,L=1.065
DI2:DRIFT,L=1.361
DI3:DRIFT,L=1.343
DI4:DRIFT,L=1.083
HD:DRIFT,L=2.426/2.;
HDT:DRIFT,L=2.426/10.;
HC:SBEND,L=2.28,ANGLE=.314159265, &
HGAP=.025,E1=.15708, &
E2=.15708,FINT=.6,FINTX=.6
 QF:QUADRUPOLE,L=.3,K1=1.7051718,APERTURE=.03;
 QD:QUADRUPOLE,L=.2,K1=-1.510844,APERTURE=.03;
 OC:CORRECTOR,L=.12;
!Injection Kicker:
KINJ:GKICK,L=.0,DXP=.012536
!Thin extraction septum:  .057595865 radians is 3.3 degrees
```

```
ESEPT:GKICK,L=.12,DXP=.0057595865
!Extraction Kicker:
KEXT:GKICK,L=.1,DXP=.00033
! off axis quad values from poisson
 QDE:MULTIPOLE,L=.2/2,K1=.299,K2=-6.8,APERTURE=.03;
 QSH:GKICK,L=0.,DX=-.124
 QSH2:GKICK,L=0.,DX=.124
 QDK:GKICK,L=0.,DXP=.00357
QE:LINE=(QSH,QDE,QDK,QDE,QSH2)
 BD:LINE=(&
D1,2*HD,D2,DQD,QD,DQD,D3,OC &
)
 BDR:LINE=(&
D1,2*HD,D2,QF,D3,OC &
)
 BH:LINE=(&
D1,HC,D2,DQD,QD,DQD,D3,OC &
)
 BHR:LINE=(&
D1,HC,D2,QF,D3,OC &
)
 BL:LINE=(&
BH,BHR &
)
HRING:LINE=( BDR,BH,BDR,4*BL,BD,BHR,BD )
HRING2:LINE=( BH,BDR,4*BL,BD,BHR,BD,BDR )
RING:LINE=( 2*HRING)
IRING:LINE=( DI1,D2,DQD,QD,DQD,D3,OC,D1,DI3,KINJ,DI4,D2,QF, &
D3,OC,HRING2, &
BH,BDR,4*BL,BD,BHR,D1,DI2 )
!BH,BDR,4*BL,BD,BHR,D1,DI2 )
! extraction ring: use QD for QE to get machine functions
ERING:LINE=( 10*KEXT,DK2,D2,DQD,QD,DQD,D3,OC, &
BHR,D1,10*ESEPT,DS2,D2,DQD,QE,DQD,D3,OC, &
D1,DE1,DE2,8*HDT,D2,QF,D3,OC, &
HRING2, &
BH,BDR,4*BL,D1 )
USE,ERING
DIMAT
MATRIX
2 -1,
HARDWARE
2.9  0. 0. 0. 0. 0. 0.0 0. 1. 0,
```

```
MACHIN
0. 0. 0. 0. 0. 0. 0. 0.
0,
!machine functions at beginning of KEXT
!use to get machine functions at extraction point
!using ERING
!MACHIN
!.25 2.9 2.65 1 .025 1 1
!   11.494   3.5411  1.418  -.318  5.349  -1.5705   0. 0.
!0,
TRACKing for extraction
-1 0 1 1
.000 .000 0 0 .0 0.000
0;
STOP;
TRACKing for injection
-1 0 1 1
.060 -.02094395 0 0 .0 0.000
0;
STOP;
```