LEP-70/90
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PARAMETERS OF THE STORAGE RING INJECTOR

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A conceptual design of the Storage Ring Injector (SRI) for LEP-70 was presented in LEP-70/33 to serve as the basis for a study of the hardware requirements. This note summarizes the results of this work and presents a new set of parameters for the storage ring injector incorporating the modifications imposed by technical constraints.

1. Top energy of the SRI remains $\underline{E_{top} = 15 \text{ GeV}}$

2. The LEP dipole will be used $\underline{(L_b = 6.055 \text{ m})}$ but will require normal, multiturn coils since the maximum field is higher than for LEP and the current density would be excessive in the LEP type coils. More free space is therefore required between elements to accommodate the magnet ends. The quadrupole strength, assumed previously, exceeds the value adopted for the LEP quadrupoles. The quadrupoles length is therefore increased to $\underline{L_q = 1.2 \text{ m}}$ enabling the same yoke shape as LEP to be used but with different coils. The same length as in LEP is left for correction elements (sextupoles, multipoles, orbit correction, etc.) and this all implies a cell length of about 17.5 m, i.e. 2 m longer than the previous value (J-P. Gourber, C. Wyss).

3. The vacuum chamber will be the same as in LEP but the cooling will only be sufficient for the standard, pulsed cycle. Continuous operation at 15 GeV (e.g. for polarization) is excluded in the present design (O. Gröbner). The distortions of the pulsed magnetic fields due to the vacuum chamber can be well compensated by using an exponential field rise in one minute and pre-programming the power supplies (S. Oliver).

4. Injection energy is raised to $\underline{E_{inj} = 2.0 \text{ GeV}}$ to reduce the effect of instabilities caused by the high bunch charge (A. Hofmann, K. Hübner, B. Zotter).

5. Since all of the components seen by the beam are identical to those in LEP, the parasitic mode impedance can be obtained from the LEP values by simple scaling (P. Wilson)

$$(Z_{hm})_{SRI} = (Z_{vac})_{SRI} + Z_{rf}\ (SRI)$$

where

$$(Z_{vac})_{SRI} = \left(\frac{C_{SRI}}{C_{LEP}}\ \frac{k_{b\ LEP}}{k_{b\ SRI}}\right)\frac{C_{SRI}}{C_{LEP}} \times 4.73\ G\Omega$$

and

$$(Z_{rf})_{SRI} = \left(\frac{C_{SRI}}{C_{LEP}}\ \frac{k_{b\ LEP}}{k_{b\ SRI}}\right)\frac{L_{c\ SRI}}{L_{c\ LEP}} \times 11.77\ G\Omega$$

6. The klystrons for 357 MHz will deliver 1 MW each and should feed 2^n cavities each. Cooling requirements exclude the use of one cavity per klystron. Increasing the number of cavities increases the parasitic mode loss (a relatively small effect) and decreases the dissipation losses in the cavities. The number of klystrons and cavities must therefore be adjusted to give a coherent set (P. Bramham).

7. The maximum emittance in the SRI is not determined by the aperture since the vacuum chamber is fairly generous, but rather by the injection efficiency in LEP. The value obtained with the previous parameters was well below the maximum permissible and the SRI would be more stable at injection energies if the emittance were larger, i.e. a smaller Q should be chosen (K. Hübner).

With these constraints in mind a new set of parameters can be obtained by following the procedure presented in LEP-70/33.

a) The change in the straight section length in each cell means that a longer circumference is required. The actual length is determined by the harmonic number h_{SRI} which should be divisible by the number of bunches $\underline{k_{bSRI} = 48}$. The value chosen previously was 34 × 48, the next possible number is $\underline{h_{SRI} = 1680}$ (35 × 48). Thus, bunches in the SRI are separated by 35 wavelengths. In order to ensure the correct bunch-to-bunch transfer, the LEP bunches should be separated by p wavelengths where

$$p \times r = 35 \times s$$

with r and s integers. In addition, if all bunches are to be accessed, then r must have no common factor with $k_{b\ \mathrm{LEP}}$ (i.e. r must be odd) and s must have no common factor with $k_{b\ \mathrm{SRI}}$ (48). The harmonic number of LEP $h_{\mathrm{LEP}} = 26444$, so at present p = 6611. The bunch spacing relationship can be satisfied with the present value of h_{LEP} by choosing r = 35 ($8\frac{3}{4}$ turns in LEP) and s = 6611 (i.e. 137 turns plus 35 bunches) successive bunch coincidences occurring every 640 μs. This is still small compared with the interval between bunch transfers ($2\tau_x/4$ = 200 ms) and imposes no restrictions on injection which will be controlled by a clock running at the RF frequency. The LEP circumference (22208 m) and harmonic number (26444) are exactly suitable for the SRI which should have a circumference of $\frac{h_{\mathrm{SRI}}}{h_{\mathrm{LEP}}} C_{\mathrm{LEP}}$; i.e. $C_{\mathrm{SRI}} = 1410.885$ m.

b) Having fixed the circumference, the number of cells can now be determined which must be a multiple of the superperiodicity 4. From the approximate cell length a value $n_c = 80$ is found and the cell length becomes exactly $L_p = 17.63606$ m split up as follows:

Quadrupole length	$L_q = 1.20$	m
Quadrupole bend space	$= 0.50303$	m
Bending magnet	$L_b = 6.055$	m
Space for correcting elements	$= 1.06$	m

The layout of the cell is shown in Fig. 1. The bending radius $\rho = 119.84$ m which is much less than the previous value of 135.9 m. The magnetic field in the bending magnets is increased to $B_{\mathrm{max}} = 0.42$ T and there is a corresponding increase in the synchrotron energy loss per turn. This is partially offset by the increase in circumference giving a reduction of the circulating current for the same number of stored particles I = 169 mA.

c) The same overall layout is maintained as shown schematically in Fig. 2. Four straight sections are provided, one for injection (both electrons and counter-rotating positrons), one for ejection (both particles) and two for RF and all four should be zero-dispersion regions. A consistent set of RF parameters requires $L_c = 42.0$ m (20 five-cell cavities) and 10 klystrons. The space provided in the straight sections in the previous design was sufficient for only 2 × 8 cavities. The straight sections therefore required redesigning to obtain extra space in the dispersion free region of one half-cell. The layout of the RF cavities in this region is then as shown in Fig. 3 with the klystrons above ground as in Fig. 4 (P. Bramham).

d) The new values of the horizontal and vertical tunes are $Q_h = 17.90$ and $Q_v = 17.92$ giving a phase advance per cell of $\mu \approx 81^0$. The missing magnet dispersion suppressor can be suitably modified with this tune value to give the extra half-cell per dispersion suppressor required for the RF cavities. The dispersion suppressor involves four half-cells containing bending magnets of length 1.7 m, 6.055 m, 0.8 m and 0.8 m, all with the same magnetic field as the lattice bends, as shown in Figs. 1 and 5. The extra RF cavities fits in the dispersion free region next to the 1.7 m bend and the wiggler magnets (two blocks per dispersion suppressor) are placed either side of the D quadrupole between the 0.8 m magnets. The additional dispersion-free half-cells either side of the long straight section are separated by exactly π phase advance and are suitable sites for the kickers required in the injection and ejection regions.

e) In the course of this operation, the space for the wiggler magnets has been reduced but this is more than offset by the increase in injection energy. This reduces the natural damping time $\tau_{x\ nat}$ where

$$\tau_{x\ nat} = \frac{12.7575}{E^3}\ \mathrm{s}$$

and enables longer individual wiggler magnets to be used without the sagitta displacing the beam into the vacuum chamber walls. The damping time at injection energy should be about 0.48 s to allow two damping times between successive transfers into the same bunch. The ring contains 16 wiggler blocks consisting of three magnets 0.8 m, 1.6 m and 0.8 m long, (see Fig. 1 for the layout) and the parameters at different energies are shown in Table I. For injection at 2 GeV the magnetic field required is less than that of the lattice bends at 15 GeV so the same yoke will be used and the sagitta is sufficiently small that by placing the wiggler magnets near the horizontally defocusing D quadrupole where the beam is narrowest, the standard vacuum chamber can be used. Synchrotron radiation power and critical energy are all much less than at top energy and pose no problems.

Table I - Wiggler parameters

Lattice bending length $L_0 = 753.0$ m
Wiggler bending length $L_w = 51.2$ m
Bending radius in lattice $\rho_0 = 119.84$ m

Energy	3.0	2.5	2.0	1.5	1.0	
τ_x nat	0.47	0.82	1.59	3.78	12.76	s
ρ_w	-	189.5	20.5	11.9	6.2	m
B_w	-	0.223	0.325	0.420	0.540	T
sagitta	-	4.6	42.5	73.3	140.6	mm

Injection system of the storage ring injector (SRI)

In order to fill the SRI with electrons and positrons an injection system is required which will consist of an electron linac (EL), a positron linac (PL) and a booster synchrotron (BSY). There are definite advantages in limiting the repetition rate of the BSY to 12.5 Hz as this avoids the necessity for ceramic vacuum chamber, stranded cables, etc. A configuration with four bunches in the BSY is suitable and for single turn ejection into the SRI, the bunch-bunch spacing should be the same in the two machines, i.e. $C_{BSY} = 117.57$ m. The RF frequency should be a sub-harmonic of the LEP and SRI frequency of 357 MHz since this increases the capture efficiency of positrons from the linac. Choosing the seventh sub-harmonic of 51 MHz gives a harmonic number of $h_{SRI} \frac{C_{BSY}}{C_{SRI}} \frac{51}{357} = 20$ which is divisible by the number of bunches in the BSY (4) as required. With a repetition rate $f_{BSY} = 12.5$ Hz each bucket is accessed every 0.96 s, i.e. two damping times in the SRI and the efficiency of the process will be high. Injection into the BSY will use the system of four bunches from a single linac pulse as proposed by K. Hübner, each bunch going into a separate bucket (i.e. this is not multi-turn injection). The spacing of the linac pulses should then be 294 ns, 490 ns or 686 ns and will require a fast repetitive kicker of the type proposed by J-C. Schnuriger (see Fig. 6). The synchrotron itself will have a combined function lattice as is usual for relatively fast cycling machines.

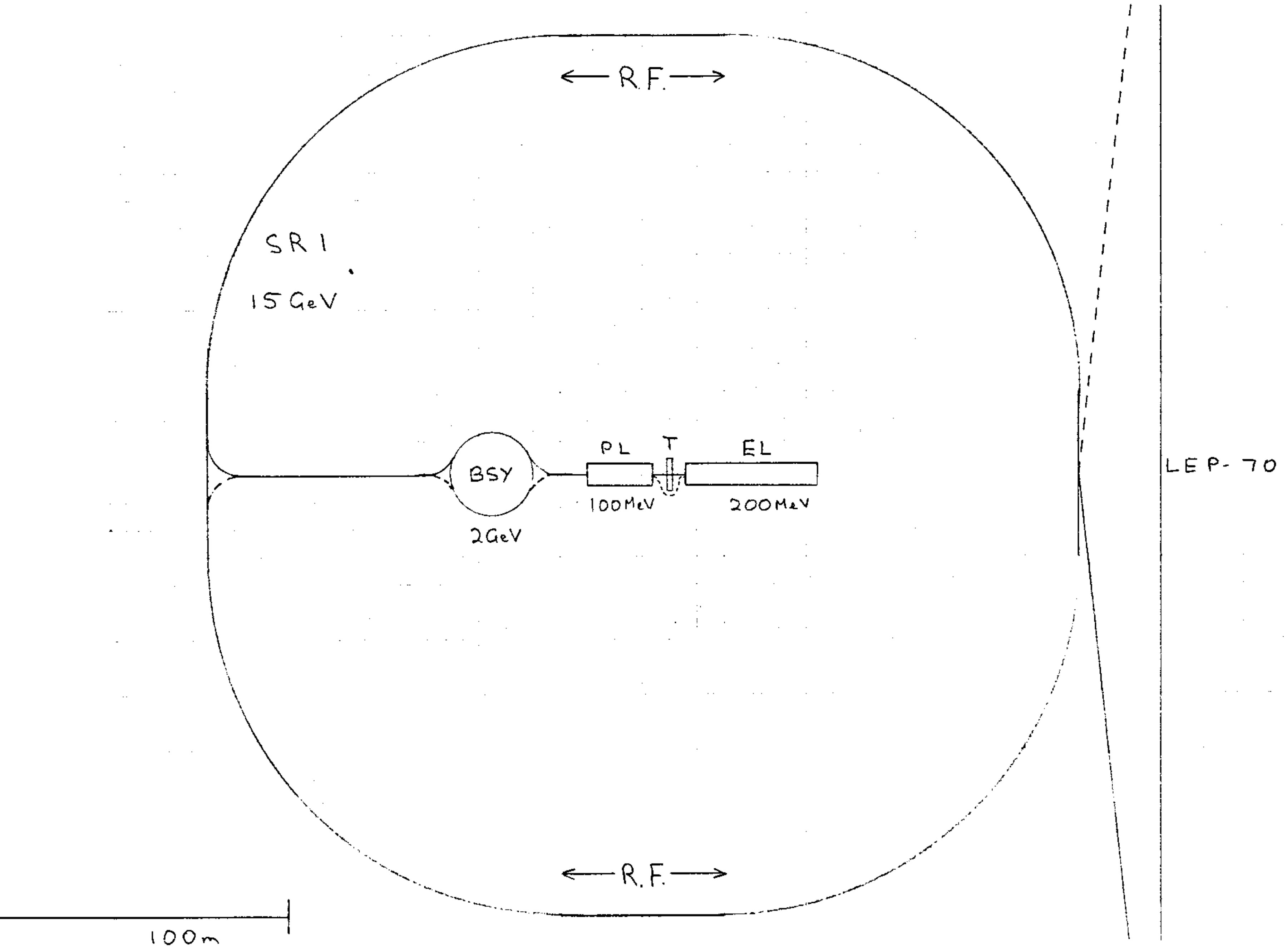
A detailed optimization of the linac energies has not yet been performed, it is assumed that the electron linac is 200 MeV and the positron linac is 100 MeV. This enables an estimate to be made of the filling times of the SRI as shown in Table II (based on work by P. Brunet).

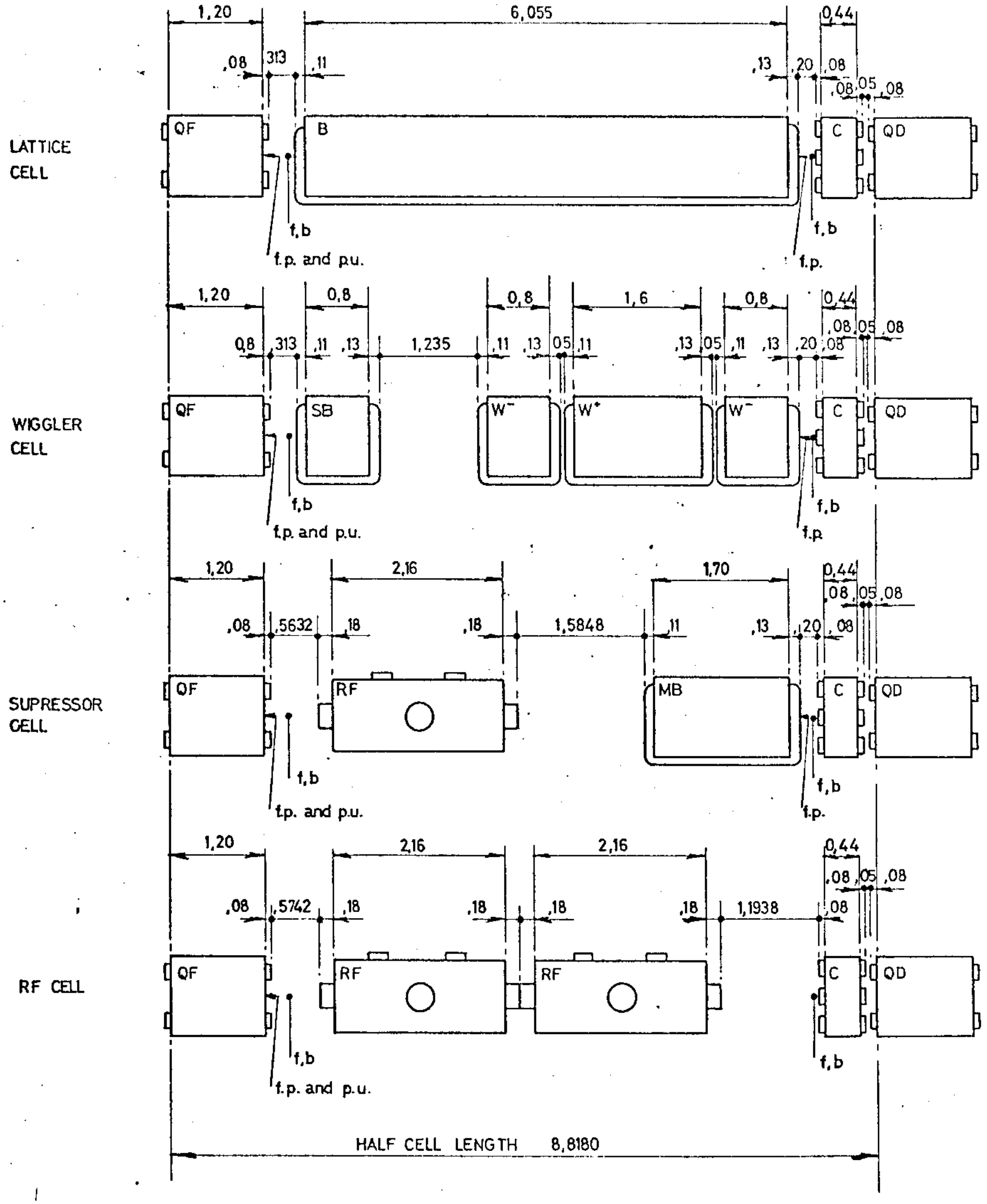
Table II - Positron filling time

Electron gun	Peak current 7.5 A	
	Pulse length 7 ns	
	Number of electrons from gun	3.28×10^{11}
Electron linac (200 MeV)	Gun-prebuncher $\eta = 0.4$	
	Acceleration to converter η 0.9	
	Number of electrons at converter	1.18×10^{11}
Converter	Conversion $\eta_c = 2.94 \times 10^{-5}$ E^- (MeV)	
	Conversion at 200 MeV = 5.9×10^{-3}	
	Number of positrons at converter	6.9×10^{8}
Positron linac (100 MeV)	Transfer efficiency $\eta = 0.5$	
	Positrons available per gun pulse	3.5×10^{8}
	Repetition rate $4 \times 12.5 = 50$ Hz	
	Average positron flux to BSY	1.75×10^{10}/s
Transfer	Accepted in BSY from linac 0.7	
	Accepted in SRI from BSY 0.5	
	Accepted in LEP from SRI 0.7	
	Average positron flux accepted in LEP	4.4×10^{9}/s
	Number of positrons required in LEP	5.0×10^{12}

Positron filling time = 19 minutes

FIGURE 2 SCHEMATIC LAYOUT OF STORAGE RING INJECTOR





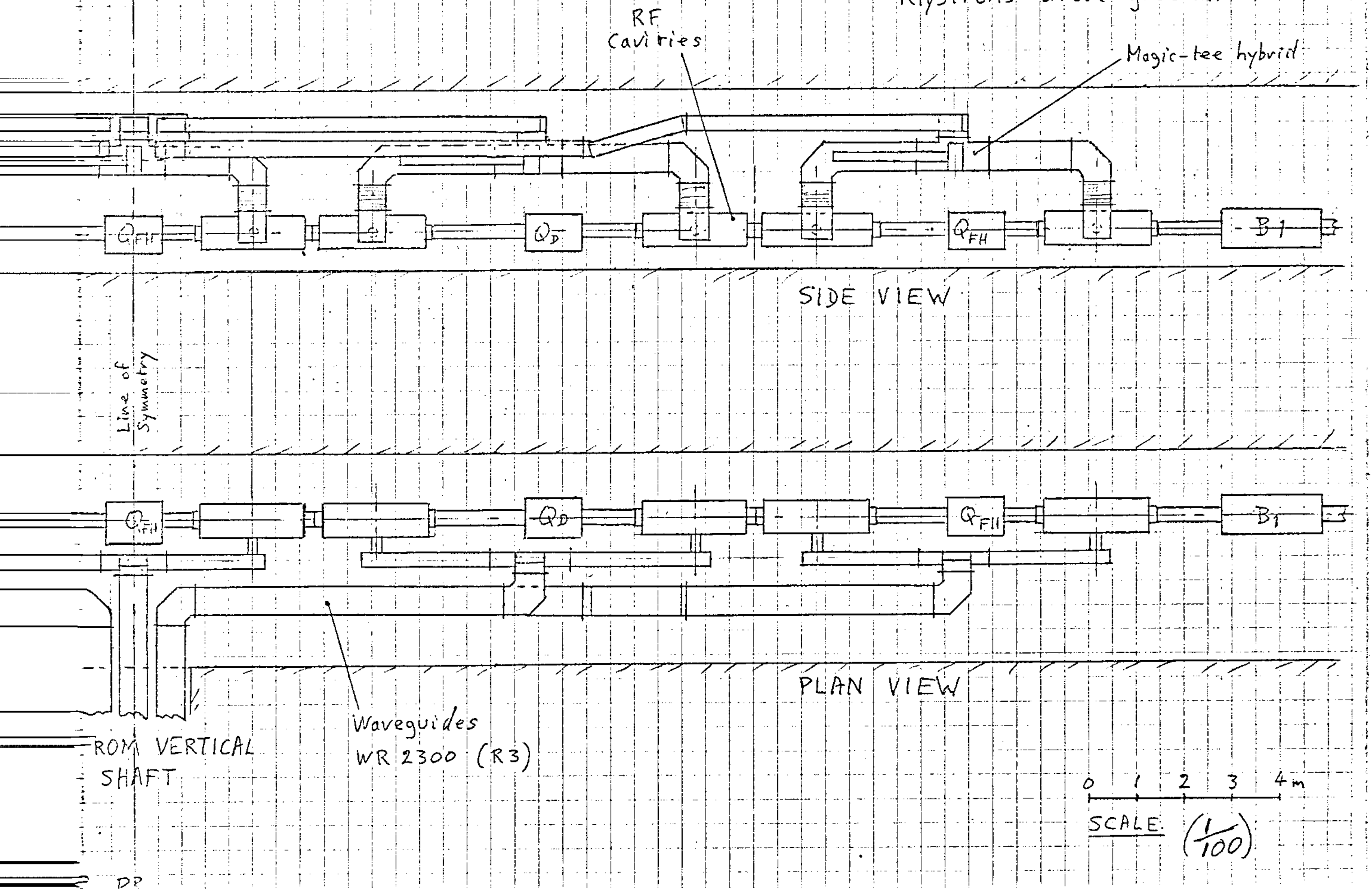
QF, QD	quadrupoles	MB	medium bending magnet	f	flange
C	correction element	SB	short bending magnet	b	bellows
B	bending magnet	W⁻	negative wiggler magnet	f.p.	fixed point
RF	5 cell RF cavity	W⁺	positive wiggler magnet	p u	pick up

Figure 1

Figure 3 SRI : RF SYSTEM LAYOUT.

12 cavities / klystron

Klystrons above ground.



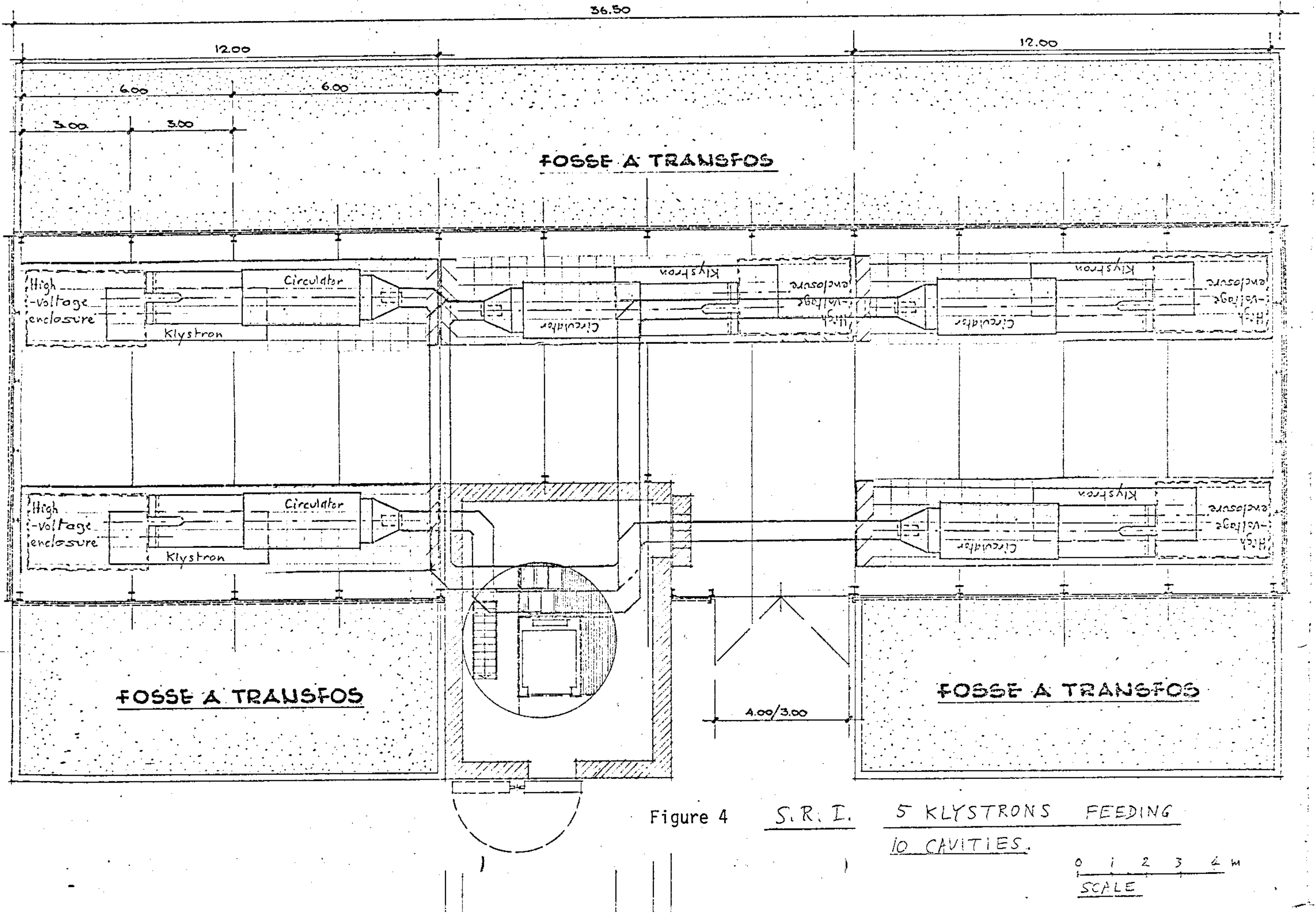


Figure 4 S.R.I. 5 KLYSTRONS FEEDING 10 CAVITIES.

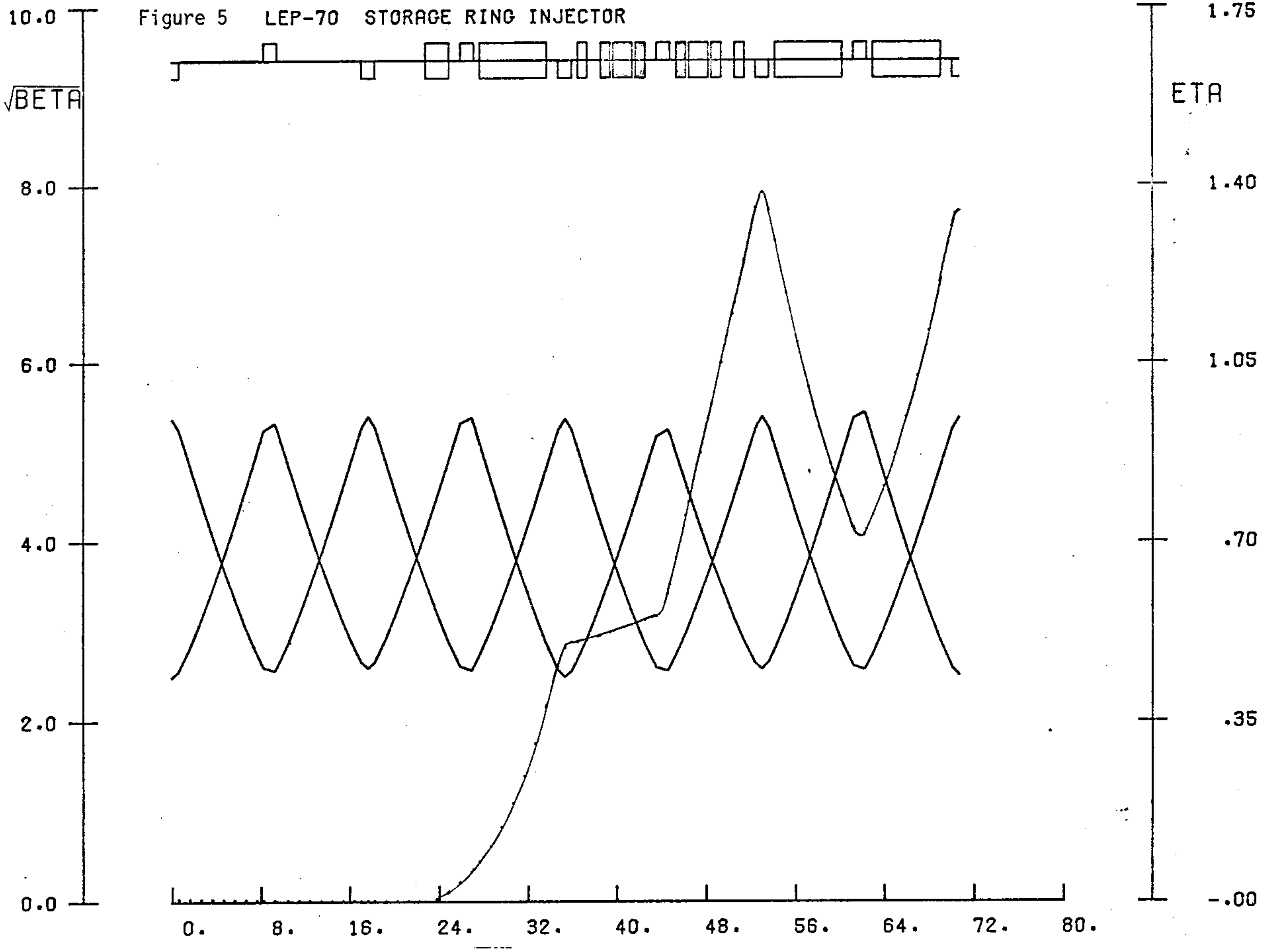
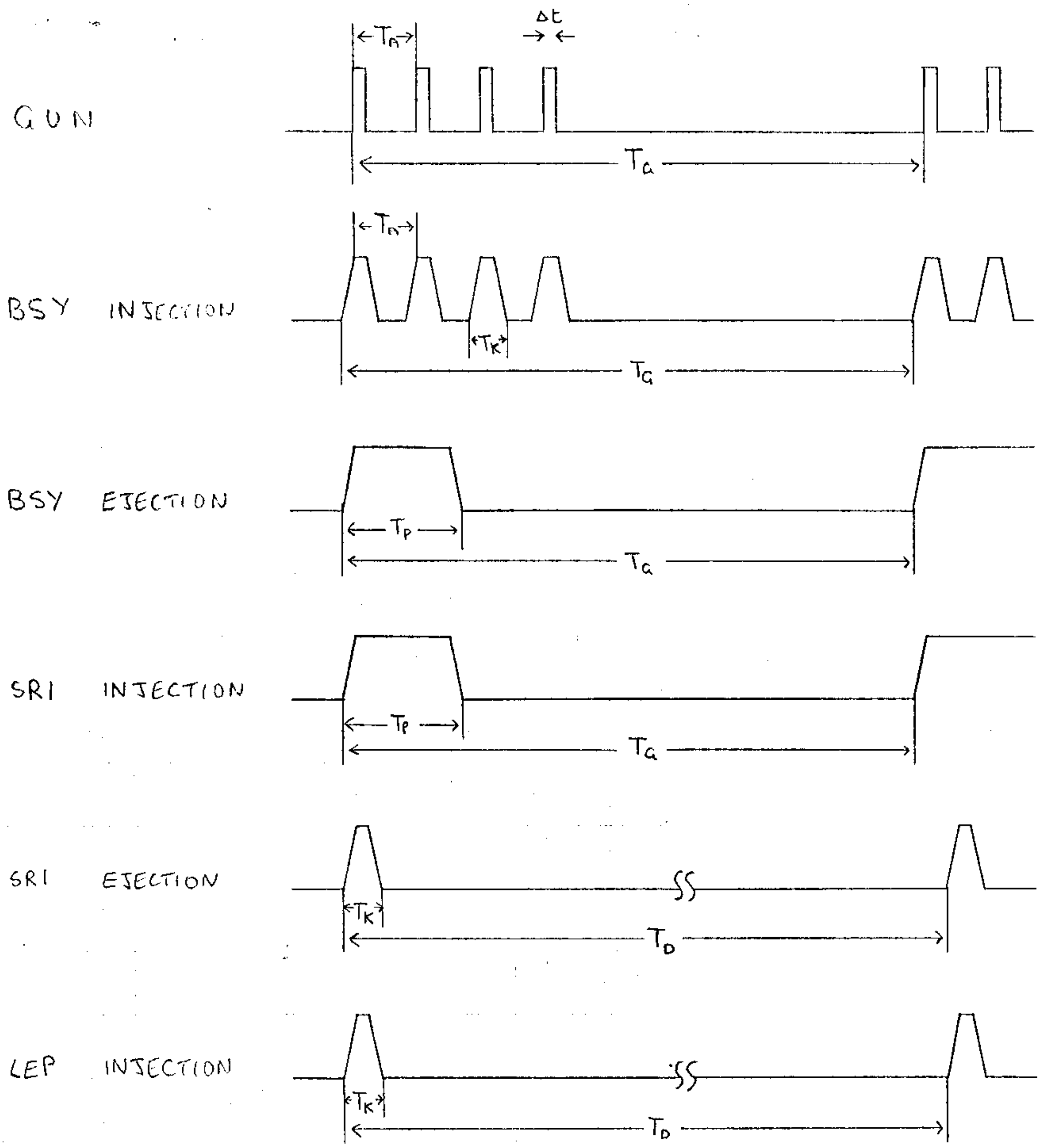


Figure 5 LEP-70 STORAGE RING INJECTOR

Figure 6

STORAGE RING INJECTOR SYSTEM - KICKERS + PULSES



Δt = 5ns

T_A = 294ns, 490ns or 686ns

$T_K \leqslant$ 95ns

T_G = 80 ms

T_P = 450 ns

$T_D \approx$ 250ms

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APPENDIX

Parameter List for 15 GeV Storage Ring Injector (SRI)

Overall machine parameters

Maximum energy	E_{top}	15	GeV
Superperiodicity		4	
Number of bunches	k_b	48	
Circumference	C_{SRI}	1410.885	m
Average radius	R_{SRI}	224.55	m
Horizontal and vertical tune	Q_x, Q_y	17.9	
Momentum compaction factor	α	4.171×10^{-3}	
Circulating current	I	169	mA
Total number of particles	N	5.0×10^{12}	
Number of particles per bunch	N_b	10^{11}	
Uncorrected chromaticities	ξ_x	-21.6	
	ξ_y	-21.5	
Energy variation of damping partition number	$dJ/(dp/p)$	-112.8	

Cell parameters

Number of cells		80	
Cell layout		QF-B-QD-B	
Length of cell	L_p	17.636	m
Length of bending magnets	L_b	6.055	m
Length of quadrupoles	L_q	1.2	m
Maximum bending field	B_{max}	0.42	T
Bending angle per period	θ_p	101.05	mrad
Bending radius	ρ	119.84	m
Phase advance per cell	μ	81	degrees
Maximum quadrupole gradient		7	T/m

	β_x	β_y	η
Orbit parameters in F quadrupoles	28.9	6.3	1.40
Orbit parameters in D quadrupoles	6.7	26.4	0.76

Horizontal rms beam radius in F quadrupoles	σ_x	2.77	mm
Vertical rms beam radius in D quadrupoles	σ_y	1.66	mm
Horizontal aperture requirement	A_x	± 38	mm
Vertical aperture requirement	A_y	± 22	mm

RF system parameters

RF frequency	f_{RF}	357.0	MHz
Harmonic number	h_{SRI}	1680	
Total RF structure length	L_c	42.0	m
Number of cavities		20	
Shunt impedance	Z	24	MΩ/m
Maximum RF voltage	$\hat{V}_{RF}$	55.3	MeV
Maximum generator power	$\hat{P}_g$	9.4	MW
Assumed higher mode impedance	Z_{hm}	3.6	MΩ

Energy dependent parameters

Energy	E	15.0	2.0 *)	GeV
Synchrotron energy loss/turn	U_0	37.4	0.039	MeV/turn
Peak RF voltage **)	V_{RF}	55.3	0.815	MeV
RF generator power	P_g	9.4	0.113	MW
RF bucket height	σ_b	0.0075	0.01	
Stable phase angle	$\emptyset_s$	136.7	127.3	degrees
Synchrotron tune	Q_s	0.055	0.0165	
Relative energy spread	σ_E	0.00117	0.00033	
Quantum lifetime	τ_Q	10	$> 10^{50}$	hr
Touschek lifetime	τ_T	6500	6	hr
Transverse damping time	τ_x	0.004	0.48	sec
Polarization time	τ_{pol}	0.12	185	hr

*) With wigglers calculated to give required transverse damping time.

**) Determined by quantum lifetime at 15 GeV and Touschek lifetime at 2 GeV.