APPENDIX XV. ENERGY DOUBLER PARAMETERS

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A. Principal Parameters

1.	Final energy	1000 GeV
2.	Intensity	5×10^{13} protons/pulse
3.	Circumference	6283.185 m (20614.13 ft)
4.	Magnetic radius	788.49 m (2586.9 ft)
5.	Lattice type	Separated function with matched long straight sections
6.	Injection energy	100 GeV
7.	Betatron-oscillation wave number	19.4
8.	Synchrotron-oscillation wave number	$(2.4 \text{ to } 1.1)\times10^{-13}$
9.	Transition kinetic energy	16.7 GeV
10.	Rise time (Fall time)	24 sec
11.	Flat-top time	10 sec
12.	Repetition rate	1 pulse/min
13.	Duty factor	1/6
14.	Beam emittance at 1000 GeV	0.02π mm-mrad
15.	Momentum resolution	10^{-4}

B. Lattice Structure and Orbit Parameters

1.	Normal cell (C)	
	a. Length of dipole (B)	252 in.
	b. Length of cell quadrupole (QF and QD)	53 in.
	c. Length of separation between magnets (S)	12 in.
	d. Length of mini straight section (SS)	62 in.
	e. Cell structure	(QF)SS(B)S(B)S(B)S(B)S (QD)SS(B)S(B)S(B)S(B)S
	f. Length of cell	2342 in.
	g. Number of normal cells	84
2.	Cell with medium straight section (M)	
	a. Length of medium straight section (MS)	590 in.
	b. Cell structure	(QF)MS(B)S(B)S (QD)SS(B)S(B)S(B)S(B)S
	c. Length of cell	2342 in.
	d. Number of cells with MS	6
3.	Cell with matched long straight section (L)	
	a. Length of cell	6098.25 in.
	b. Number of cells with LS	6
4.	Sector	
	a. Structure	LCCMCCCCCCCCCCCC
	b. Length of sector	41228.25 in.(1047.198m)
	c. Number of sectors	6
5.	Pulse form	
	a. Rise and fall time between 100 GeV and 1000 GeV	24 sec
	b. Flat-top time	10 sec
	c. Bottom turn-around time	2 sec
	d. Total cycle time	60 sec

C. Magnet System

1.	Rise time (fall time)	24 sec
2.	Flat-top time	10 sec
3.	Dipole	
	a. Number of unit	774
	b. Effective field length	252 in.
	c. Coil length	258 in.
	d. Gross length	264 in.
	e. Coil ID	3.0 in.
	f. Aperture diameter	2.80/2.00 in.
	g. Field at 1000 GeV	42.344 kG
	h. Number of coil turns per pole	34 + 21
	i. Current at 1000 GeV	4337 A
4.	Normal-cell quadrupoles (Q7) (Q4 dimensions in parentheses)	
	a. Number of units	180
	b. Effective gradient length	53 in. (30 in.)
	c. Coil length	59 in. (36 in.)
	d. Gross length	65 in. (42 in.)
	e. Coil ID	3.25 in.
	f. Aperture diameter	2.625 in.
	g. Field gradient at 1000 GeV	24.2 kG/in.
	h. Number of coil turns per pole	16 + 13 + 10
	j. Current at 1000 GeV	4337 A

D. Refrigeration System

1.	Heat load per dipole	13 W (2W/m)
2.	Heat load per quadrupole	3 W (2W/m)
3.	Total heat load	10.8 kW
4.	No. of satellite refrigerators	24
5.	He circuits	48

6. Magnets in each circuit

Circuit	B	Q7	Q4
I-U	16	4	4
I-D	18	5	-
II-U	16	4	-
II-D	16	4	-
III-U	16	4	-
III-D	16	4	-
IV-U	16	4	-
IV-D	15	3	4

7. Capacity per satellite refrigerator 450 W (150 ℓ/hr.)

E. Vacuum System

1.	Vacuum-enclosure temperature	4.2 K
2.	Vacuum pressure (at 4.2 K)	10^{-8} Torr (10^{-11} Torr for Storage Ring mode)

F. Radio-Frequency System

1.	Injection energy	100 GeV
2.	Final energy	1000 GeV
3.	Acceleration Cycle Time	
	a. Rise or fall time	24 sec
	b. Flat-top time	10 sec
	c. Bottom turn-around time	2 sec
	d. Total cycle time	60 sec
4.	Field rise-rate	1.59 kG/sec
5.	Energy Gain per turn	0.786 MeV/turn
6.	Synchronous phase	42°
7.	Peak rf voltage per turn	1.175 MV/turn
8.	Harmonic number	2226
9.	Injection frequency	106.2056 MHz
10.	Final frequency	106.2102 MHz
11.	Relative frequency range	4.28×10^{-5}
12.	Number of cavities	1

13.	Cavity type	Cylindrical 140° double gap drift-tube cavity
14.	Cavity length	45 in.
15.	Cavity diameter	30 in.
16.	Beam current (5×10^{13} protons)	0.382 A
17.	Power to beam	300 kW
18.	Cavity shunt impedance	1 MΩ
19.	Power to cavity	100 kW
20.	Total rf power	400 kW
21.	Future addition	3 cavities will accelerate at 100 GeV/sec

G. Beam Transfer System

1.	Extraction kicker in MR	
	Location	A46
	Length	1.5 m
	Field	1 kG
	Rise time	<0.2 μsec
	Kick angle (horizontal out)	0.44 mrad
	Horizontal beam displacement from central orbit at A50	30 mm
	Horizontal beam angle at A50	0.13 mrad
2.	Extraction Lambertson	
	Length	8.0 m
	Location	A50 (-25 m to -17 m from B0)
	Septum position	25 mm outward from central orbit
	Field	9.16 kG
	Bend angle (vertical down) (skewed slightly to take out the horizontal beam angle of 0.13 mrad)	21.8 mrad
	Horizontal beam displacement from central orbit	30 mm
3.	Injection Lambertson	
	Length	8.0 m
	Location	B0 (-4 m to +4 m)
	Septum position	20 mm outward from central orbit
	Field	9.16 kG
	Bend angle (vertical up) (skewed slightly to produce a horizontal beam angle of -1.32 mrad)	21.8 mrad
	Vertical beam displacement from MR orbit	-457 mm = 18 in. (beam vertically on ES/D orbit)
	Horizontal beam displacement from central orbit	30 mm
4.	Injection kicker in ES/D	
	Length	4.5 m
	Location	B10 (20.5 m to 25 m)
	Field	1 kG
	Fall time	<0.2 μsec
	Kick angle (horizontal out) (after kick beam on ES/D orbit)	1.32 mrad

H. Extraction System

1.	Extraction Channel	
	a. Location	Long Straight A
	Entrance	F50 (-25.4 m from A0)
	Exit	72.375 m (from A0)
	(at exit the beam follows the present EPB line)	
	b. Lambertson (vertical up)	
	Length	20 m
	Location	-25.4 m to -5.4 m

Field	8.937 kG
Bend angle	5.35 mrad
Septum position	11 mm outward from central orbit
Septum thickness	2 mm
Beam vectors	Entrance / Exit
Horizontal:	$\begin{pmatrix} 15\ \text{mm} \\ 0\ \text{mrad} \end{pmatrix}$ $\begin{pmatrix} 15\ \text{mm} \\ 0\ \text{mrad} \end{pmatrix}$
Vertical:	$\begin{pmatrix} 0 \\ 0 \end{pmatrix}$ $\begin{pmatrix} 53.5\ \text{mm} \\ 5.35\ \text{mrad} \end{pmatrix}$

c. Superconducting dipole (horizontal out)

Length	20 m
Location	4.6 m to 24.6 m
Field	40.017 kG
Bend angle	23.97 mrad
Beam vectors	Entrance / Exit
Horizontal:	$\begin{pmatrix} 15\ \text{mm} \\ 0\ \text{mrad} \end{pmatrix}$ $\begin{pmatrix} 254.7\ \text{mm} \\ 23.97\ \text{mrad} \end{pmatrix}$
Vertical:	$\begin{pmatrix} 107.1\ \text{mm} \\ 5.35\ \text{mrad} \end{pmatrix}$ $\begin{pmatrix} 214.1\ \text{mm} \\ 5.35\ \text{mrad} \end{pmatrix}$

d. Skew superconducting dipole (in and down)

Length	4.76 m
Location	67.62 m to 72.38 m
Skew angle	Bending direction 20.2° from vertical
Field	-40.016 kG
Bend Angle	-5.70 mrad (horizontal -1.97 mrad) (vertical -5.35 mrad)
Beam vectors	Entrance / Exit
Horizontal:	$\begin{pmatrix} 1285.9\ \text{mm} \\ 23.97\ \text{mrad} \end{pmatrix}$ $\begin{pmatrix} 1395.4\ \text{mm} \\ 22.0\ \text{mrad} \end{pmatrix}$
Vertical:	$\begin{pmatrix} 444.5\ \text{mm} \\ 5.35\ \text{mrad} \end{pmatrix}$ $\begin{pmatrix} 457.2\ \text{mm} \\ 0\ \text{mrad} \end{pmatrix}$

(at exit beam follows present EPB line)

e. Overall geometry

2. Slow extraction (horizontal $\frac{1}{3}$-integer resonance)

a. Sextupole

Location	10 m downstream of D0
Length	2 m
Strength	$B'' = 1.22\ \text{kG/cm}^2$

b. Electrostatic wire-septum

Location	F10 (downstream end of long straight F)
Septum position	20 mm outward from central orbit
Thickness	0.05 mm
Length	6 m
Field	100 kV/cm
Deflection angle	0.06 mrad
Aperture	1 cm^2

c. Extraction channel

Entrance location	F50 (upstream end of long straight A)
Entrance septum thickness	2 mm

(For details see Extraction channel)

d. Beam behavior

Extraction starts	$\nu_h = 19.3364$
Extraction completes	$\nu_h = 19.3333$
(Long-spill mainly by momentum pealing)	
Step-size at ES septum	9 mm

	Horizontal Vectors		
	Just inside ES-septum	Just outside ES-septum	Extreme outside
Entrance to ES-septum	(20.0 mm, 0.21 mrad)	(20.0 mm, 0.21 mrad)	(29.0 mm, 0.30 mrad)
Exit from ES-septum	(21.3 mm, 0.21 mrad)	(21.5 mm, 0.27 mrad)	(31.0 mm, 0.36 mrad)
Entrance to channel	(9.3 mm, -0.16 mrad)	(12.5 mm, -0.08 mrad)	(16.7 mm, -0.16 mrad)

Gap to clear channel septum	3.2 mm
Width of beam entering channel	4.2 mm
Average vector of beam entering channel (with orbit tilt)	(15 mm, 0 mrad)

3. Fast extraction (horizontal one-turn)

a. Fast kicker	
Location	A10 (downstream end of long straight A)
Length	3 m
Field	1 kG
Kick angle	0.09 mrad
Rise time	<0.2 μsec
b. Beam at entrance to channel (F50)	
Displacement kicked	6.6 mm
Width of beam	2.2 mm
Gap to clear channel septum	4.4 mm