Fermilab

$\bar{p}$ Note #388

Updated Set of Parameters and Scenario for the $p\bar{p}$ - SSC Collider

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5/22/84

RF Frequency	53.105 MHz
Circumference, $2\pi R$	104,618.1402 m
Revolution Frequency	2.8656 KHz
Revolution Period	348.97 μsec
Bunch Separation	18.83 nsec
RF wavelength	5.64527 m
Harmonic Number	18,532

Periodicity — Two (with mirror symm.)

Structure of Half-Superperiod:

219 (.C) .IR

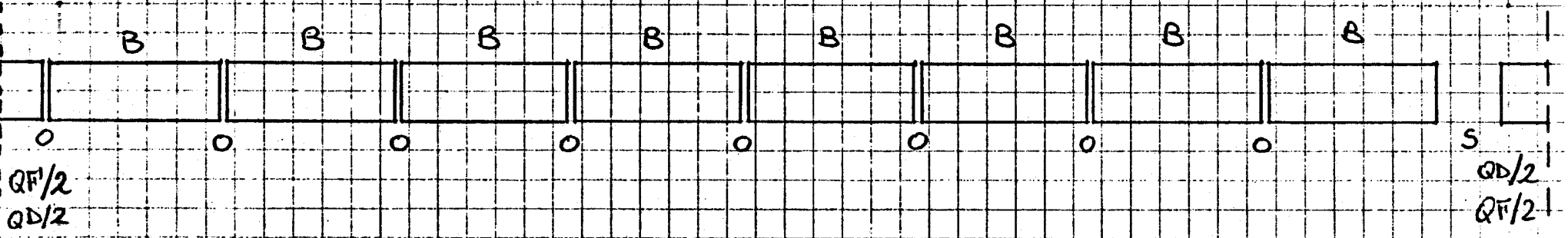
.C ≡ regular cell ≡ .FD .DF

.FD ≡ QF/2 ρ(0 B) S QD/2

.DF ≡ QD/2 ρ(0 B) S QF/2

(see Figure)

Regular ½-Cell for $p\bar{p}$ SSC



Dipoles (B): Length 11.5 m
Strength 5.0 T

Quads (QF/2): ½ Length 3.0 m
(QD/2) Gradient 10.5 KG/cm

Drifts: Lengths (O) 0.5m
(S) 4.3192482 m

Length of ½ Cell: 106.3192482 m

β_{max} = 368.3 m
β_{min} = 122.8 m

η_{max} = 3.66 m
η_{min} = 2.20 m

Phase Advance = 60°/cell

For 20 TeV (Kinetic Energy) $B\rho$ = 66715.97 Tm

.IR ≡ interaction region (half)

≡ .DK 2(.CE) $.DK^{-1}$ .C .DK .LINS

.LINS $.DK^{-1}$ .C .DK .LINS

.DK ≡ dispersion Killer cell

≡ QF/2 L QD/2 .DF

L, drift = 100.3192482 m

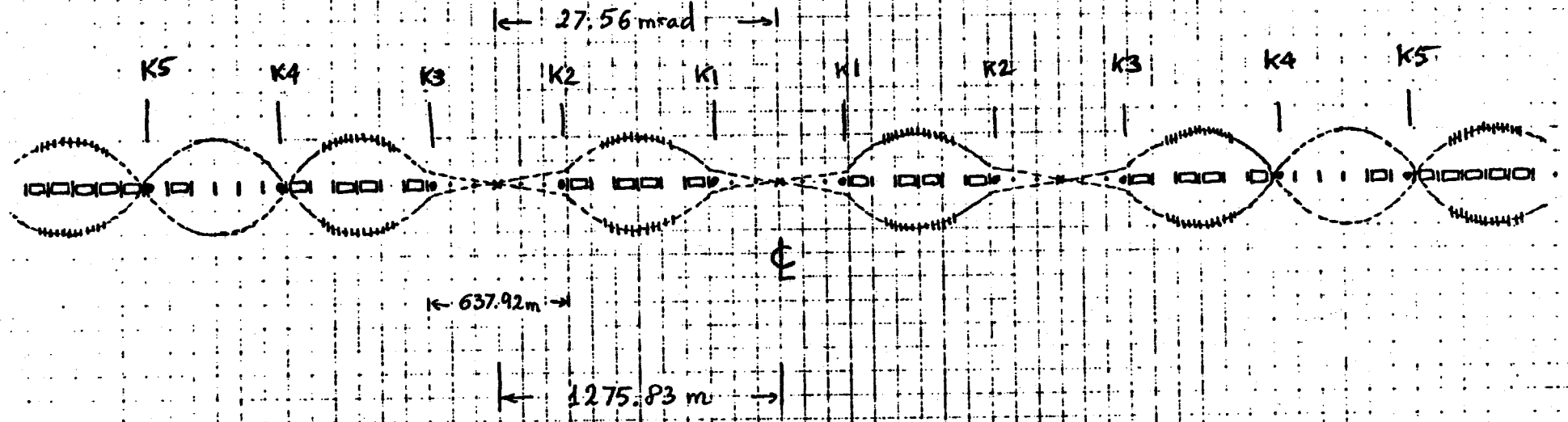
$.DK^{-1}$ ≡ .DF QD/2 L QF/2

.CE ≡ empty cell, with no bending magnets

≡ QF/2 L QD/2 QD/2 L QF/2

.LINS ≡ half low-beta insertion which has the length of 3 regular cell

(see Figure)



Interaction Region for $p\bar{p}$ - SSC

The length of a regular cell is adjusted so that 3 of them together include 113 RF wavelengths exactly -

The total circumference is ideally devided in 492 regular cells -

Betatron Tune	~ 82	
Transition Energy (γ_T)	~ 75	
Bending Angle / Dipole	0.86118 2	mrad
Bending Angle / Cell	13.77892	mrad
No. of Bending ½ Cells	912	
No. of Experimental Area	3 / period	

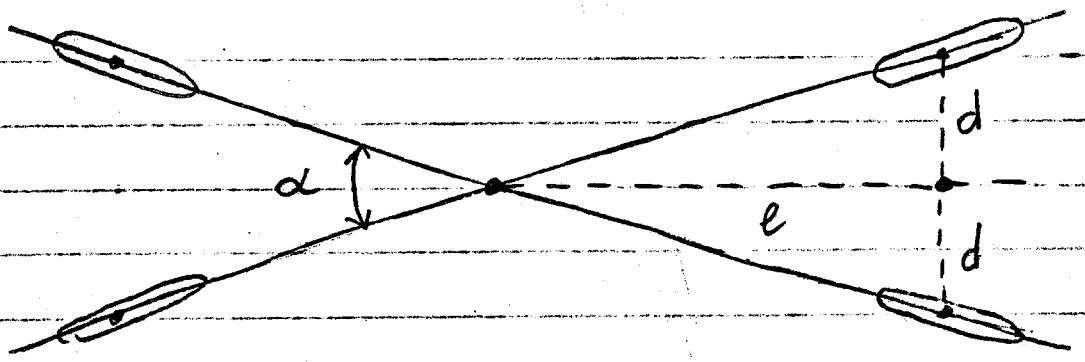
Luminosity, $L = \dfrac{N_p N_{\bar{p}} B f_{rev}}{4\pi\sigma^2 f}$

$f = \sqrt{1+\rho^2}$, $\rho = \dfrac{\alpha\sigma_\ell}{2\sigma}$

Kinetic Energy	20 TeV
γ	21,317
Normalized Emittance, ε_N	24 π mm·mrad
Actual Emittance, H and V $6\pi\sigma_{H,V}^2/\beta_{H,V}$	0.001126 π mm·mrad
$\beta_H^* = \beta_V^*$ $(\alpha_V^* = \alpha_H^* = 0)$	1.0 m
η^*	0.0 m
Rms Beam Size @ Crossing, σ	0.0137 mm
Crossing Angle, α (total)	0.1 mrad
Rms Bunch Length, σ_ℓ	20 cm
ρ	0.73
f	1.2381

(See bunch separation geometry, next figure)

Bunch Separation 18.83 nsec = 5.6451 m



$$\beta = \beta^* \left(1 + \frac{\ell^2}{\beta^{*2}}\right)$$

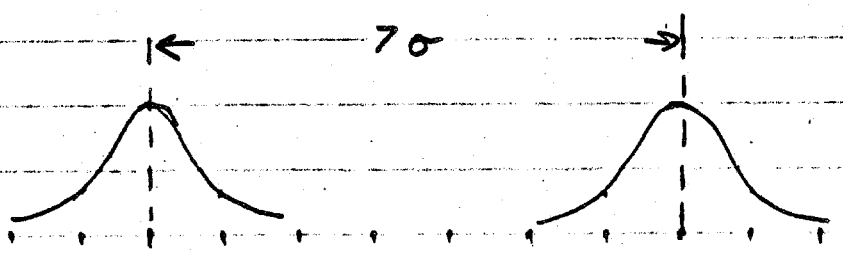
$\varepsilon = 0.001126\ \pi$ mm.mrad

$$\sigma = \sqrt{\frac{\varepsilon\beta}{6\pi}} = (0.0137\ \text{mm})\sqrt{1 + (\ell/\beta^*)^2}$$

$d = \ell\alpha/2$

$\begin{cases} d = 0.14113\ \text{mm} \\ \sigma = 0.041\ \text{mm} \end{cases}$

$\begin{cases} \ell = 2.82255\ \text{m} \\ \alpha = 0.1\ \text{mrad} \\ \beta^* = 1\ \text{m} \end{cases}$



Luminosity, L	$1.0 \times 10^{32}\ cm^{-2}\ s^{-1}$
$N_p N_{\bar{p}} B$	1.02×10^{24}
No. of "Batches"	82
No. of Bunches / Batch	54
Batch length	0.998 μsec
Gap between Batches	3.2577 μsec
Total no. of Bunches, B	4428
$N_p N_{\bar{p}}$	2.30×10^{20}
Total Cross Section, σ_{tot}	100 mb
No. of Events / Crossing, $\langle n \rangle$	1.1
No. of Protons / Bunch	3.0×10^{10}
No. of Antiprotons / Bunch	0.77×10^{10}
Total No. of Antiprotons	3.4×10^{13}

Beam-Beam Tune-Shift, $\Delta\nu = \dfrac{3 N_p r_0}{\pi \varepsilon_N (1+f)}$

r_0, proton classical radius	1.535×10^{-18} m
B.B. Tune Shift / Crossing, $\Delta\nu$	0.00082
Rms Interaction length	7.3 cm

Total No. of Protons	1.33×10^{14}	
Total No. of Antiprotons	3.4×10^{13}	
Beam Energy, Proton	414	MJ
Antiproton	109	MJ
Total	523	MJ

Bending Field	5	Tesla
Bending Radius	13.35	km
Energy Loss/Turn/Particle	93.5	KeV/turn
Average Current, Proton Beam	57.5	mA
Antiproton Beam	15.2	mA
Peak Current, Proton Bunch	2.9	A
Antiproton Bunch	0.7	A
Synchrotron Radiation, Protons	5.3	KW
Antiprotons	1.5	KW
Total	6.8	KW

$$\left|Z/n\right| \leq 3\,\frac{E|\eta|}{e\,I_p}\left(\frac{\sigma_E}{E}\right)^2$$

Transition Energy, γ_T	~ 75
Coupling Impedance, $\left\|Z/n\right\|$	1.2 ohm
Rms Energy Spread, σ_E/E	0.18×10^{-4}
Bunch Area $(= 6\pi\,\sigma_E\,\sigma_e/c)$	4.5 eV-sec

RF Parameters for $p\bar{p}$ - SSC

Colliding Mode:	
Peak RF Voltage	2.8 MV
Bucket Height	± 3.2 GeV
Bucket Area	78. eV-sec
Phase Oscillation Frequency	0.764 Hz
Acceleration:	
Kinetic Energy: Injection	1 TeV
Top	20 TeV
Total Energy Gain	19 TeV
Acceleration Rate	1 TeV/minute
Energy Gain/turn	6.0 MeV/turn
Peak RF Voltage	10. MV
RF Phase Angle, ϕ_s	36.87°
Bucket Parameters: α	0.246
γ	0.698
Injection:	
Peak RF voltage	1.8 MV (**)
Bucket Height (*)	± 577 MeV
Bucket Area (*)	13.8 eV-sec
Phase Oscillation Frequency (*)	1.53 Hz

(*) No Acceleration

(**) To match 1.4 MV in the 1 TeV Super Conducting Ring

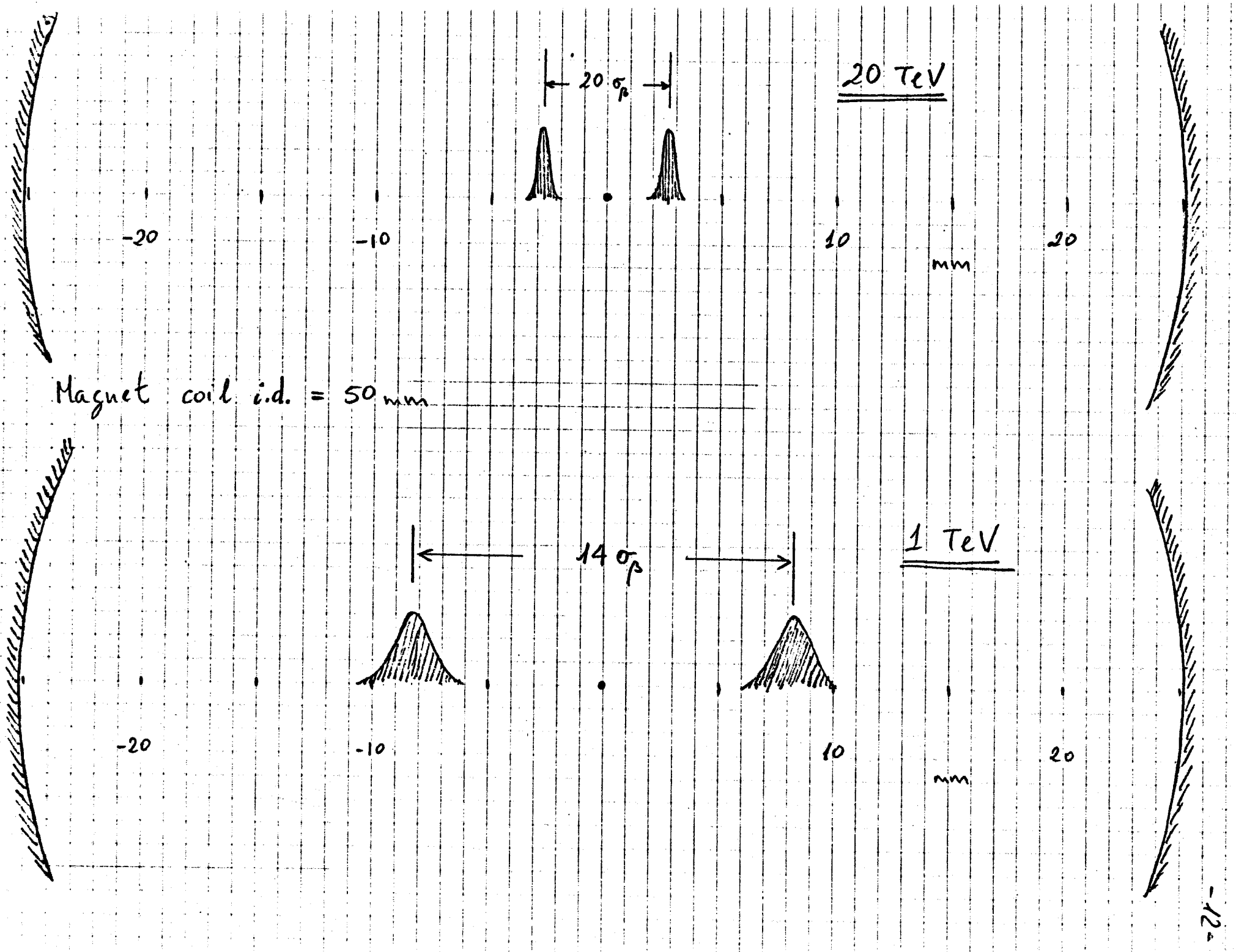
Beam Separation (Vertical)

β_{max} = 368.3 m

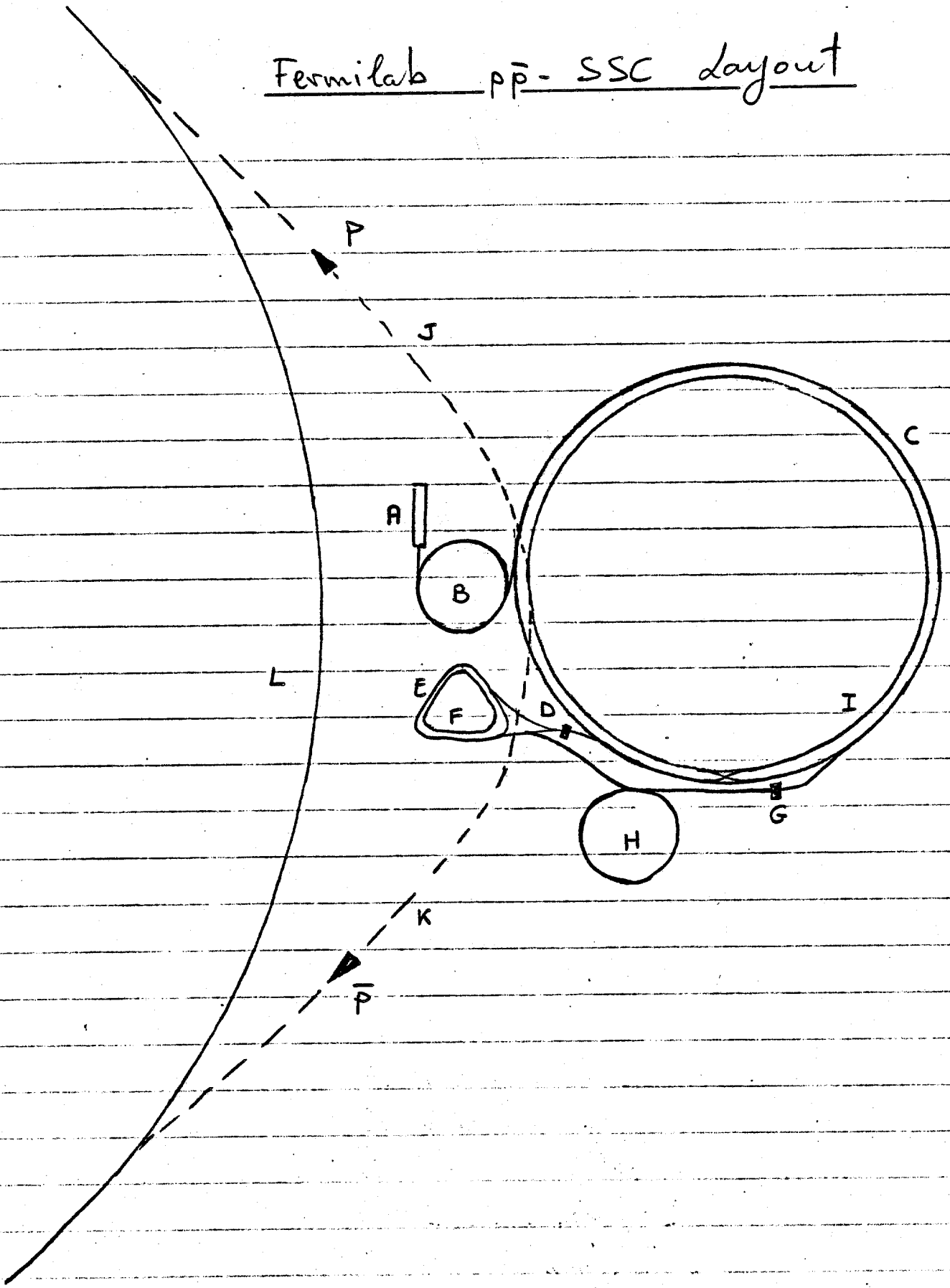
η_{max} = 3.66 m

Emittance, $\varepsilon_{H,V} = 6\pi \frac{\sigma_{H,V}^2}{\beta_{H,V}} = \frac{24\pi \text{ mm·mrad}}{\gamma}$

Energy	1 TeV	20 TeV
rms β-width, σ_β	1.176 mm	0.263 mm
rms p-spread	0.15×10^{-3}	0.018×10^{-3}
rms p-width, σ_p	0.549 mm	0.066 mm
$\sigma = \sqrt{\sigma_\beta^2 + \sigma_p^2}$	1.298 mm	0.271 mm
d = max. beam separation		
d/σ_β	14	20
$d/2$	8.23 mm	2.71 mm
Deflection Angle, θ	40. μrad	13. μrad
Integrated Electric Field $(\int E dl)$	(50 KV/cm) × 8m	(50 KV/cm) × 52 m


20 σp
20 TeV
-20
-10
10
20
mm
Magnet coil i.d. = 50 mm
14 σp
1 TeV
-20
-10
10
20
mm

Fermilab $p\bar{p}$ - SSC Layout



Fermilab $p\bar{p}$ - SSC Components

A.	200 MeV	p-Linac	
B.	8 GeV	Booster	
C.	150 GeV	Main Ring	
D.	120 GeV	Target Station #1	
E.	8 GeV	Debuncher Ring	
F.	8 GeV	Accumulator Ring	
G.	150 GeV	Target Station #2	+
H.	10 GeV	Super Debuncher Ring	+
I.	1 TeV	Super Coudning Ring	
J.	1 TeV	p - Transfer Line	•
K.	1 TeV	$\bar{p}$ - Transfer Line	•
L.	20 TeV	SSC	•

• Do not exist yet, but required
+ Essential for phase II

Phase I : present $\bar{p}$-Source (TeV I)
luminosity = 1.0×10^{31} $cm^{-2} s^{-1}$
Filling Time = 19 hours

Phase II : improved $\bar{p}$-Source (TeV III)
luminosity = 1.0×10^{32} $cm^{-2} s^{-1}$
Filling Time = 11.5 hours
or $L = 1.0 \times 10^{31}$ $cm^{-2} s^{-1}$ w/ Filling Time = 1.15 hours

RF Parameters (Source)

	150 GeV Main Ring	1 TeV Super Conduct. Ring
Average Radius	1000. m	1000. m
RF Frequency ($\beta=1$)	53.105 MHz	53.105 MHz
Harmonic Number	1113	1113
Peak RF Voltage	4.0 MV	1.4 MV
Injection Energy	8.0 GeV	150 GeV
Top Energy	150 GeV	1 TeV
Transition Energy, γ_T	18.75	18.75
RF Bucket Area:		
@ Injection	1.0 eV-sec	5.0 eV-sec
@ Top	8.5 eV-sec	12.9 eV-sec

A save figure for the bunch area to get through the transition energy in the Main Ring is

0.2 eV-sec

Antiproton Production

	TeV I	TeV III
Proton Beam Energy	120 GeV	150 GeV
Antiproton Energy	8 GeV	10 GeV
Cycle Period	2.0 sec	1.5 sec
No. of Proton Bunches / Cycle	80	100
No. of Protons / Bunch	2.5×10^{10}	3.0×10^{10}
Momentum Spread Accepted	$\pm 1.5\%$	$\pm 3.0\%$
Betatron Acceptance	20π mm.mrad	50π mm.mrad
Production Rate (*)	$5 \times 10^{7}\ s^{-1}$	$8.25 \times 10^{8}\ s^{-1}$
Required no of $\bar{p}$'s	3.4×10^{12}	3.4×10^{13}
Luminosity	$1.0 \times 10^{31}\ cm^{-2} s^{-1}$	$1.0 \times 10^{32}\ cm^{-2} s^{-1}$
Filling Time	19 hours	11.5 hours

(*) Improved target efficiency by a factor 1.5 -

Momentum Stochastic Stacking

	Phase I	Phase II
Cycle Time	2.0 sec	1.5 sec
No. of $\bar{p}$'s / cycle	1×10^8	1.2×10^9
Flux	$5 \times 10^7 \, s^{-1}$	$8.25 \times 10^8 \, s^{-1}$
$\Delta p/p$ after rotat + debun.	0.23 %	0.45 %
Beam Width	± 10 MeV	± 10 MeV (*)
Initial Density	$5 \, eV^{-1}$	$60 \, eV^{-1}$
Core Density	$3 \times 10^3 \, eV^{-1}$	$3.6 \times 10^4 \, eV^{-1}$
Core Width, full	7.5 MeV	- 7.5 MeV
No. of Particles in Core	2.25×10^{10}	2.7×10^{11}
No. of Cycles / Extraction	225	225
Period / Extraction	450 sec	337.5 sec
Core Beam Area	12 eV-sec	12 eV-sec
Pulse Length	1.6 μsec	1.6 μsec
Harmonic Number	84	84
Area of Bunch @ extract.	0.143 eV-sec	0.143 eV-sec
No. of $\bar{p}$'s / bunch extracted	2.7×10^8	3.2×10^9

(*) With Momentum Precooling of a factor 2.5 in the Super Debuncher Ring after deceleration from 10 down to 8 GeV