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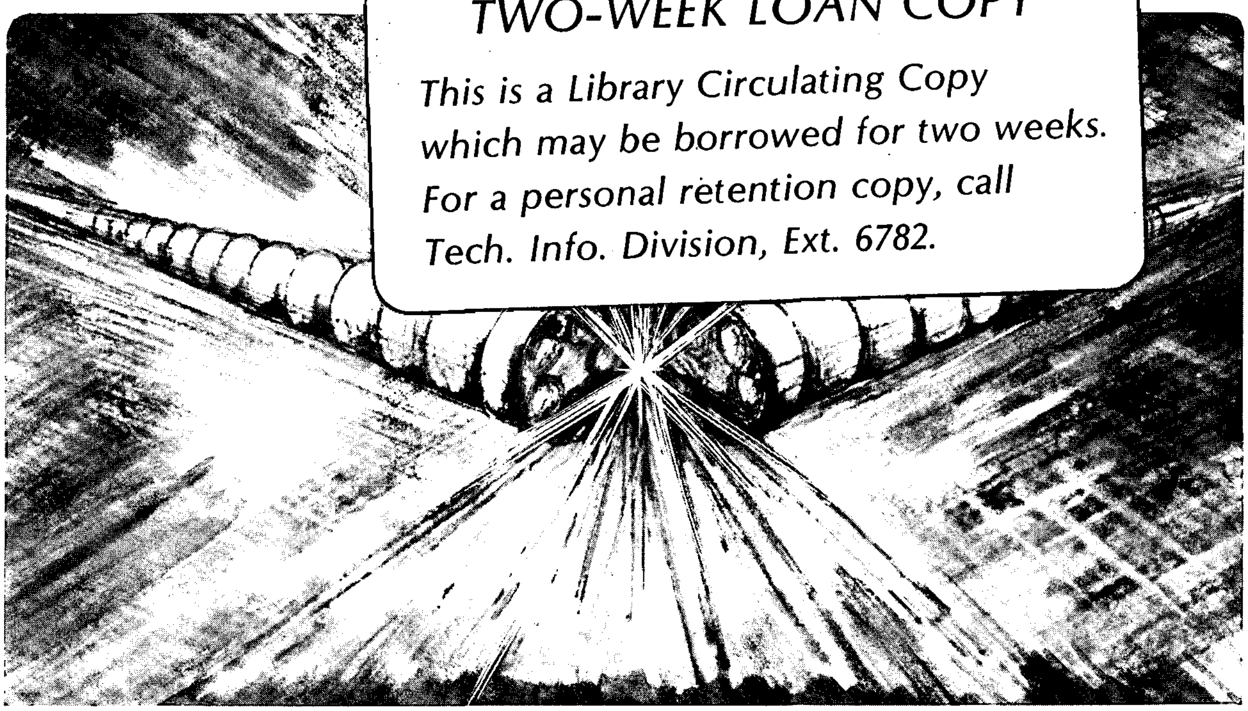

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A lattice containing insertions designed for collisions of 20 TeV proton beams at crossing points having beta values of two meters or less is presented. The machine would use high-field double bore superconducting magnets, with opposite focusing action on the two beams passing through each quadrupole. Hence the focusing pattern in the insertions is antisymmetric about the crossings. The beams, separated by 16 cms in the arcs are made colinear by dipoles common to both beams and then focused to the low-β collision points by quadrupole triplets. A similar machine design for pp collisions is also included.

Introduction

In order to facilitate design studies of a very high energy (20 TeV per beam) hadron collider, it has been thought useful to construct complete lattice examples. This paper describes a pp lattice prepared for the recent workshop at Cornell University[1] and a $\bar{p}p$ lattice derived from it. These lattices are described here, with the disclaimer that many of their parameters have not been optimized. For a systematic discussion concerning the normal cell parameters and the effects of various errors on a 20 TeV machine, the reader is referred to an article by N. M. King.[2] Two related papers are presented at this conference. One[3] presents results of tracking studies, the other pertains to survey and alignment[4] of the $\bar{p}p$ machine.

These examples use magnetic fields of 8T and gradients of 200 T/m, near the high end of the spectrum currently discussed, but most of the features of these designs could be incorporated in larger circumference rings of lower field and gradient. An important exception is the strength of the interaction region (I.R.) quadrupoles, which should have high gradients to limit the maximum beta values.

The principal parameters of the pp lattice are given in Table I, and those of the $\bar{p}p$ lattice that differ from those of the pp lattice are shown in Table II. The following discussion pertains mainly to the pp lattice; the $\bar{p}p$ lattice is discussed in the last section.

Focusing Topology

The topology of the pp lattice is similar to one designed for a 2-in-1 version of the CBA[5] in which the vacuum tubes and superconducting coils for the two beams are embedded in a single iron yoke. The dipole fields are necessarily opposite on the two beams and the gradients are by choice the same, since in this case one quadrupole has opposite focusing effect on the two beams, which partly decouples the closed orbit responses to positioning errors. The opposite focussing in the cell lattice also fits well with that of the single bore quadrupoles near the interaction point (I.P.) that both beams share. Fig. 1 shows the topology of the rings schematically.

A consequence of the opposite focussing is that the insertions, as viewed by each beam, are antisymmetric with respect to the I.P. This causes the number of superperiods to be half that of the number of crossings. In the CBA case and in the lattices of this paper there are six crossings, so there will be three superperiods, and half-integer structure resonances of off-momentum particles occur at tune intervals of 1 1/2. It was shown in ref. 5 that the contribution of the I.R. quadrupoles to these resonances can be mitigated by symmetrizing the lattice about the arc center points and by requiring an odd number of quarter betatron wavelengths between the I.R. quadrupoles at opposite ends of a sextant.

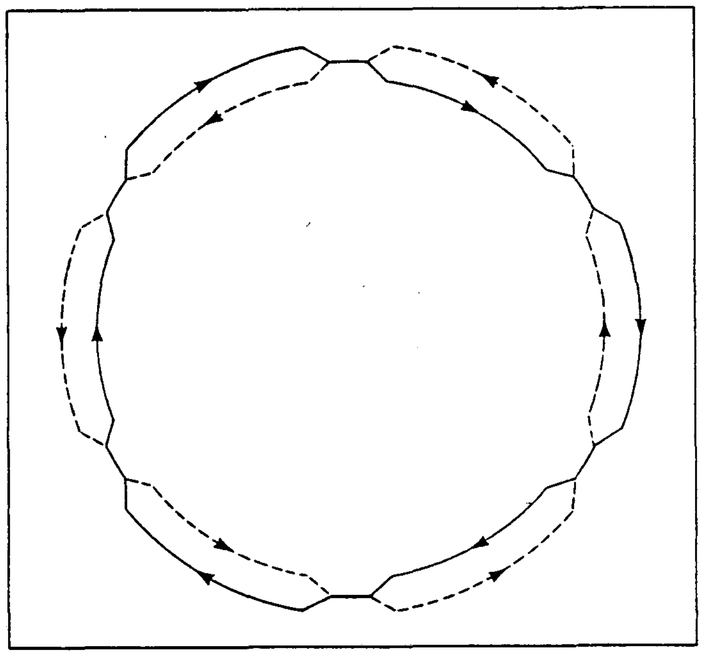

Fig. 1 Topology of 2 in 1 pp lattice

Layout

The 78.5 km circumference ring consists of six circular arcs and six straight sections. The two beams are parallel and separated horizontally by 0.16 m, except in the I.R. region where the beams collide head on or at very small angles. Fig. 2 shows the longitudinal dimensions of one-twelfth of the machine, from an arc center on the left to an I.P. on the right.

The arc center point is in a QF for the outer beam and a QD for the inner one. Extending to the right are 35 160 m separated function cells whose lattice and orbit functions are shown in Fig. 3. Their betatron phase advance is 60°, a value chosen to reduce the chromaticity and simplify dispersion suppression, which is produced by one cell without dipoles and a normal cell at the end of the arc.

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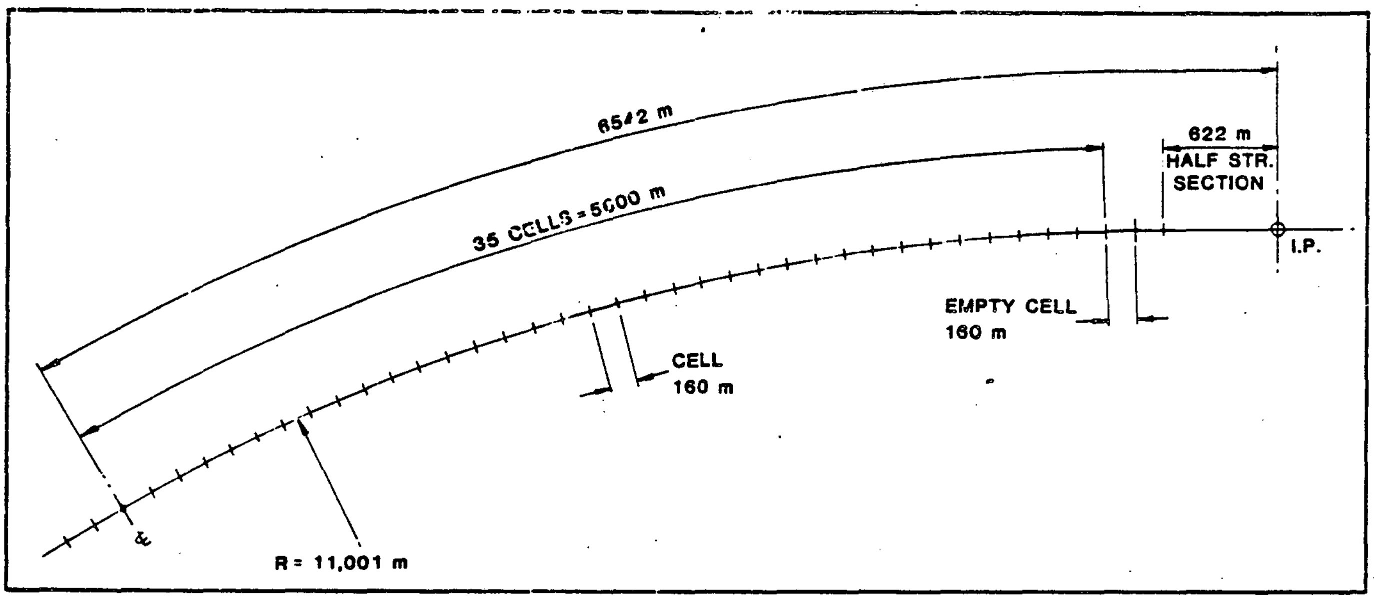

Fig. 2 Geometry of a half-sextant of the pp Collider.

Following the dispersion suppressor cells is a straight section (except for the dipoles that produce the crossings). The lattice and orbit functions of the insertion are shown in Fig. 4, which shows the focusing pattern and orbit functions for the beam that goes from left to right, from the outside of the left-hand arc to the inside of the right-hand one. The antisymmetry is apparent from the reversal of F and D quadrupoles (above and below the line respectively) and interchange of β_x and β_y. The four long drift spaces per half-insertion in the empty cell and straight section will be used for injection, extraction to a beam dump, and RF cavities. Some of the magnets are composite in order to limit their length to 10 m or less. Fig. 4 shows the focusing pattern and orbit functions for the beam that goes from the outside of the left-hard arc to the inside of the right-hand one. The antisymmetry is apparent from the reversal of F and D quadrupoles (above and below the line respectively) and interchange of β_x and β_y.

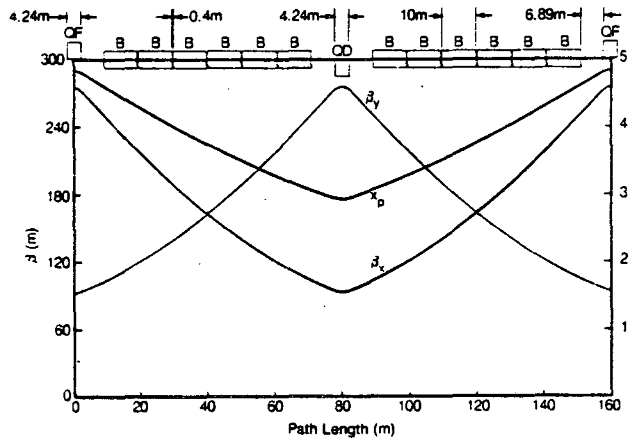

Fig. 3 Normal cell lattice and orbit functions.

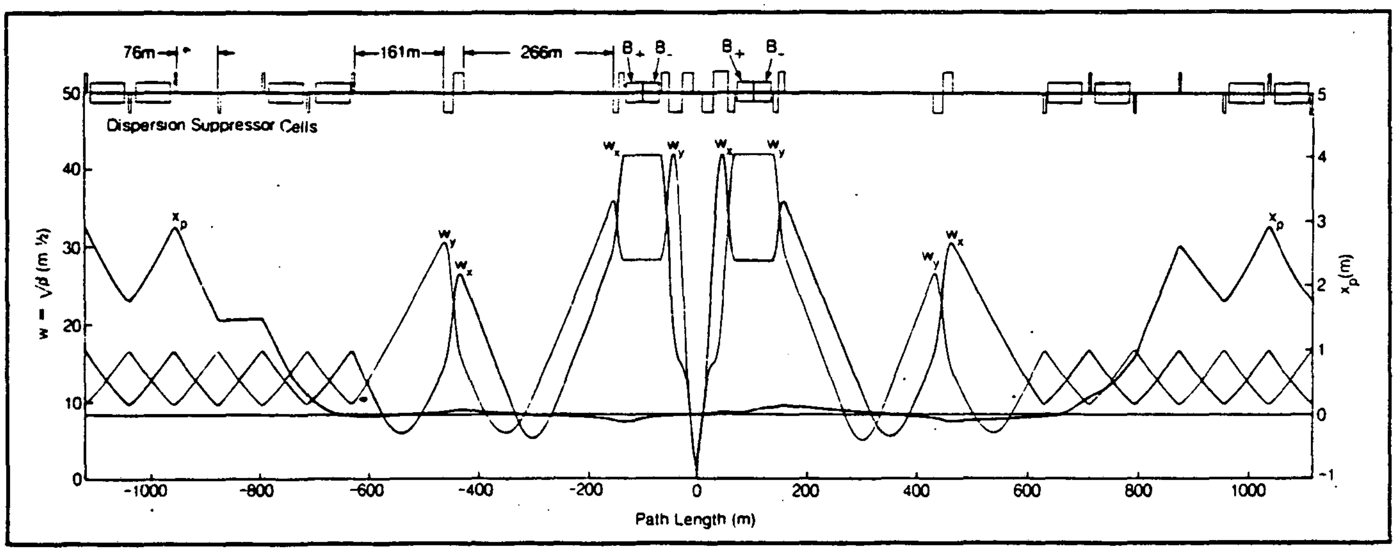

Fig. 4 Antisymmetric insertion of pp collider.

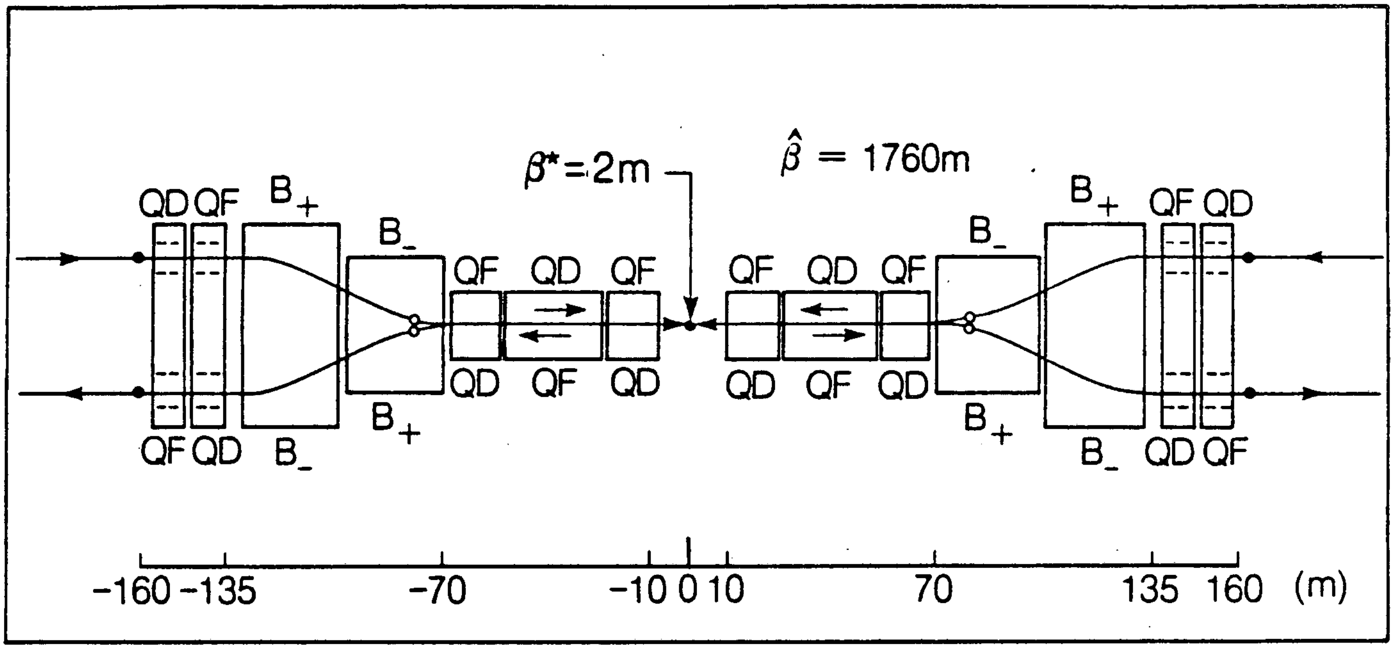

Fig. 5 Basic interaction region design for head-on collisions.

Interaction Regions

The basic design is for head-on collisions of proton bunches brought into colinearity by the dipoles B_+ and B_-, which are common to both beams - see Fig. 5. The labeling above and below the magnets reflects the focussing as seen by the upper or lower beams. The β-values at the I.P. are $\beta^* = 2$ m in both planes, and the dispersion is zero. Ten meters of free space are provided on each side of the I.P. for the detectors. The maximum beta value in the I.R. magnets is 1760 m. One meter β^* values can also be obtained by relatively minor gradient changes, but with corresponding increases in β_{max} and chromaticity. With $\beta^* = 2$ m, the chromaticity from the insertions is about equal to that from the regular cells.

The black dots in Fig. 5 represent proton bunches at the moment when a collision takes place; the open circles show them passing at a later time. The minimum bunch separation ℓ_{sep} is determined by the requirement that these passing bunches have adequate transverse separation. For head-on collisions $\ell_{sep} = 160$ m.

Two alternate methods will be mentioned that reduce ℓ_{sep} and the emittance and events per bunch collision. In the first, see Fig. 6, the beams cross at small angles which reduces ℓ_{sep} to about 50 m. Parameters for this case were given by Courant at the Cornell workshop.[1]

The second scheme was proposed at the Snowmass 1982 summer study[6] and is shown schematically in Fig. 7. The beams colliding head on are separated by small dipole magnets before entering septum quadrupoles.

Tuning

As with lattices designed for the CBA, the phase advances across the insertion 4π (between the last QF's of the arcs). The insertion then has unit transfer matrix, and tune changes can be made by altering the two gradients in the cells alone, without retuning the insertion.

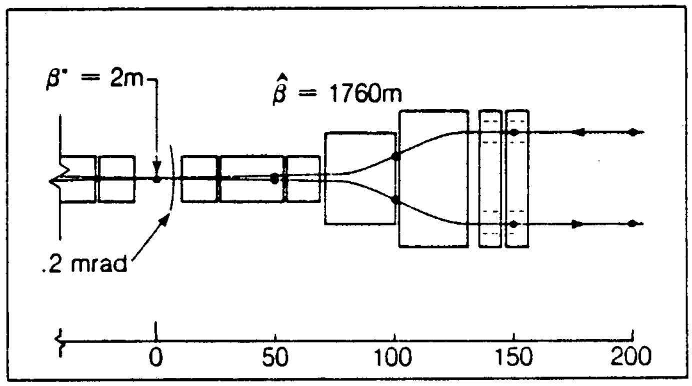

Fig. 6 Small crossing angle configuration of I. R. region.

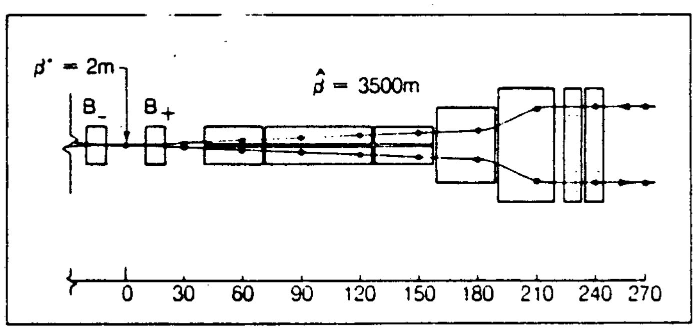

Fig. 7 Modified I.R. design using septum quadrupoles.

$\bar{p}p$ Lattice

The $\bar{p}p$ single ring lattice was derived from the double ring pp lattice by symmetrizing the insertions, removing the crossing dipoles B_+ B_-, rematching, and modifying the tunes. For the present exercise the β^* values were equal as in the $\bar{p}p$ machine, though this is no longer necessary, and the insertion has lost the unit matrix feature. Of course these properties can be modified in the future. The immediate purpose of this lattice was to serve as a model for survey and alignment studies[3]. Since the $\bar{p}p$ machine has six superperiods rather than three, less computer storage is required.

Table I

Lattice Parameters of the pp Collider

Peak Energy	E	20	TeV
Magnetic Field	B_0	8.089	T
Gradient	G	200.1	T/m
Magnetic Radius	ρ	8.251	km
Circumference	$2\pi R$	78.50	km
Average Radius	R	12.49	km
Number of Superperiods	N_{sp}	3	
Number of Crossings	N_x	6	
Number of Cells	N_C	444	
Cell Phase Advance	μ	60	deg
Lengths, cell:	L_C	160	m
–dipole (6 per half-cell)	L_B	10	m
–quadrupole	L_Q	4.241	m
–space for correctors	0_Q	6.889	m
–space between dipoles	0	0.4	m
Interaction region space	L_{int}	±10	m
Horizontal separation between beams	w	0.16	m
Crossing angle	α	0.0	
Tunes	ν_x/ν_y	85.30/85.31	
Chromaticity	ξ	-153	

Orbit functions:	quadrupoles	dipoles	I.P.	Maxima	
β_x	276	249	2.0	1758	m
β_y	276	249	2.0	1762	m
x_p	2.90	2.76	0.0	2.91	m

Table II

Lattice Parameters of the $\bar{p}p$ Collider
(Unless specified, the parameters of Table I apply)

Circumference	$2\pi R$	78.14	km
Average Radius	R	12.44	km
Number of Superperiods	N_{sp}	6	
Lengths in cell:			
quadrupole	L_Q	4.258	
space for correctors	0_Q	5.871	
Cell phase advances	μ_x/μ_y	61.2/59.2	
Tunes	ν_x/ν_y	88.40/82.39	
Chromaticities	ξ_x/ξ_y	-143/-159	

Orbit functions:	quadrupoles	dipoles	I.P.	Maxima	
β_x	272	245	2.0	1746	m
β_y	279	252	2.0	1759	m
x_p	2.80	2.65	0.0	2.82	m

Acknowledgements

The writer wishes to thank Mrs. A.S. Kenney for her contributions to the SYNCH program, and Drs. E.D. Courant, M. Cornacchia and J. Claus for collaboration on other 2-in-1 lattices.

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