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ANTIPROTON STORAGE RING DESIGN

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Introduction

There has recently been a considerable amount of interest in various colliding beam experiments, with perhaps one of the more interesting, and certainly the most modest in terms of magnitude or expense being that of antiprotons on protons. One major problem which must be faced is that of the low production of $\bar{p}$'s at anything but very high energies. Several schemes have been put forth for the production of $\bar{p}$'s at relatively high energies, followed by subsequent coolings (stochastic, electron, adiabatic deceleration).[1] A realistic approach to the collection of a fairly intense $\bar{p}$ beam is to produce antiprotons at an energy of approximately 5 GeV, inject them into the booster and decelerate them to around 200 MeV. The antiproton beam can then be injected into a separate ring inside the present booster tunnel and "cooled" using the method of Budker at Novosibirsk, USSR.[2] This cooling reduces the emittance of the $\bar{p}$ beam so that one can inject and stack many pulses, thus reaching some fairly high intensity. A design of a storage ring to fit in the booster tunnel, compatible with the above mentioned scheme, is presented below.

There are many design criteria which a ring used for $\bar{p}$ storage must satisfy. For electron cooling, it is desirable to have several long straight sections with large, parallel beams in the horizontal and vertical planes. Typically, one wants free straight sections of the order of 15 meters and beta values of some 40 meters. Further, the geometry is severely constrained to fit into the booster tunnel. Also, of course, one would like to use as few magnets and power supplies as possible, and to keep the beam size within the magnets small so as to minimize the required aperture.

In addition, it is desirable to be able to incorporate two of these straight sections into a smaller, racetrack structure which could be constructed above ground for preliminary investigations and studies of the process of electron cooling, initially on a beam of protons. One would like the racetrack design to use less magnets than the structure to be put into the booster tunnel, although using the same magnets, of course. The lattice of the racetrack should offer great flexibility to change the beam properties in the cooling straight section so that the effects of different beam sizes, etc., upon the cooling rates could be studied. Finally, one wants the usual other requirements of an accelerator or storage ring design - the tunes to be in large free regions of the stability diagram, adequate space for injection and extraction, and so on. The designs presented below, both for a structure to be put into the booster tunnel and also for an above ground racetrack, satisfy all of these criteria.

The Booster Tunnel Ring

The booster tunnel is a 24-sided figure made of 12 short and 12 long straight pieces. The only two simple geometries which would fit into the tunnel have either 24- or 12-fold symmetry The requirements of using few magnets and having long free spaces leads one to consider a regular, twelve-sided structure. A plot of the lattice functions beta and momentum dispersion eta for one twelfth of this design is shown in Figure 1, and the main parameters of interest are listed in Table 1. The values chosen for β_x, β_y, and η represent a good guess as to what one will eventually want for electron cooling, although they will have to be checked in the smaller, experimental racetrack. Should it be found desirable for the beam to have different properties, the lattice can be redesigned with relative ease. Also, should one wish to slightly change the overall length, or perhaps the spacing between dipoles to juggle the ring around within the tunnel, the lattice can be easily modified without significantly changing any of the properties of the ring.

The Racetrack

Figure 2 shows a plot of the beta and eta values for one quadrant of the present racetrack design, and Table 2 lists its main properties. The example shown here has identical properties in the cooling region to those of the 12-sided ring. Studies have shown that this design has a very large degree of flexibility - for example, one can hold the betas at the cooling region constant and vary η from ~3 meters to almost zero while keeping the tunes steady by simply varying the quadrupole supplies. Such a change also has very little effect on beam sizes through any of the magnets. Table 2 lists the lattice functions for two particular eta values in the cooling region. One can, of course, have values of η^* between 0 and 3 also.

References

1. See, for example, D. Cline, et al., "Proposal to Construct an Antiproton Source for the Fermilab Accelerators", Fermilab Proposal #492

2. G.I. Budker, et al., "Experimental Study of Electron Cooling", Institute for Nuclear Physics, Preprint IYaF 76-33, Novosibirsk, 1976

Table I

12-Sided Ring

Regular, 12-sided polygon	12 x 40.4 meters
straight sections (free)	12 x 17.2 m
Energy	200 MeV
Magnets:	24 4' dipoles @ 4.6 kG
	60 2' quadrupoles @ ~15 kG/m
superperiod	12
ν_x	7.85
ν_y	5.85
β_x^* (cooling region)	40 m
β_y^*	25.6 m
η^*	2.97 m
η'^*	0
β_x max	41.9 m
β_y max	49.6 m
η max	2.97 m
No. of quadrupole supplies	3

Table 2

Two-Sided Racetrack

Oval with 2 straight sections	29 m x 51 meters	
straight sections	2 x 22 m	
distance between inside quads	7 m	
Energy	200 MeV	
Magnets:	24 4' dipoles @ 4.6 kG	
	34 2' quadrupoles @ ~20 kG/m	
superperiod	2	
$\nu_x = \nu_y$	3.70	(3.70)
γ_T	4.15	
β_x^* (cooling)	40 m	(40 m)
β_y^*	25.6 m	(25.6 m)
η^*	2.97 m	(0 m)
η'^*	0	(0)
β_x max	40.4 m	(40.4 m)
β_y max	43.5 m	(43.4 m)
η max	2.97 m	(3.55 m)
No. of quadrupole supplies	6	

Figure 1

One-twelfth of a lattice to go into the booster tunnel. Note that the scales for beta and eta are different. Here, B indicates a dipole magnet, and Q1, Q2, and Q3 refer to the three quadurpole supplies. $Q\frac{1}{2}$ is one-half of a magnet, to mate with the other half upon reflection.

Figure 2

One quarter of the racetrack lattice to be built above ground. The middle of the straight section used for cooling is at the left-hand side of the plots. Note the different scales for beta and eta. Again, B indicates dipole magnets, and Q1, Q2, Q3, Q4, QD, and QF refer to the differently powered quadrupoles. QF/2 is to the middle of the quadrupole, the other half coming from symmetric reflection.

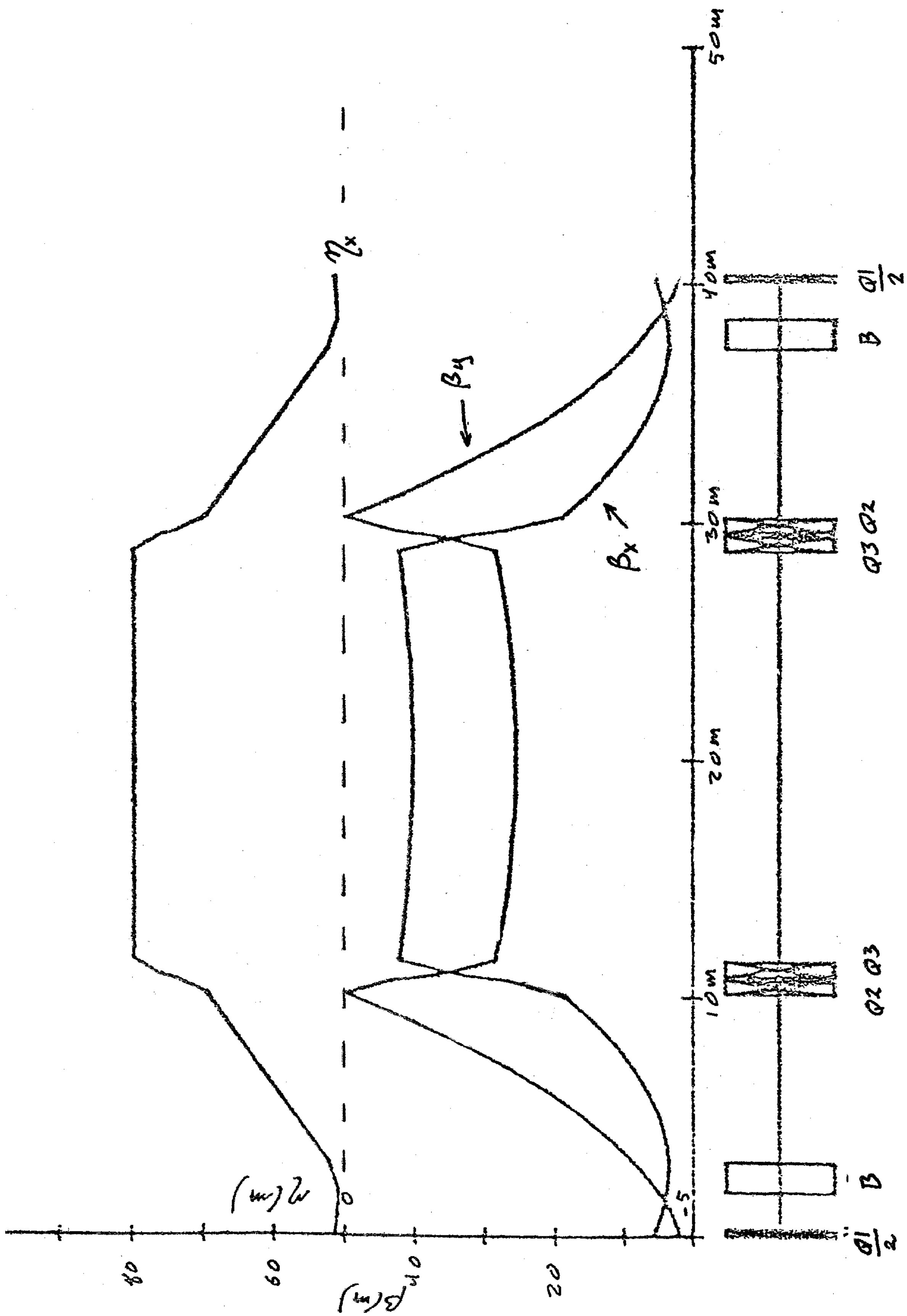
50m
40m
30m
20m
10m
Q1/2
B
Q3 Q2
Q2 Q3
B̄
η_x
β_y
β_x
η(m)
β(m)
80
60
40
20
0
-5

Figure 1

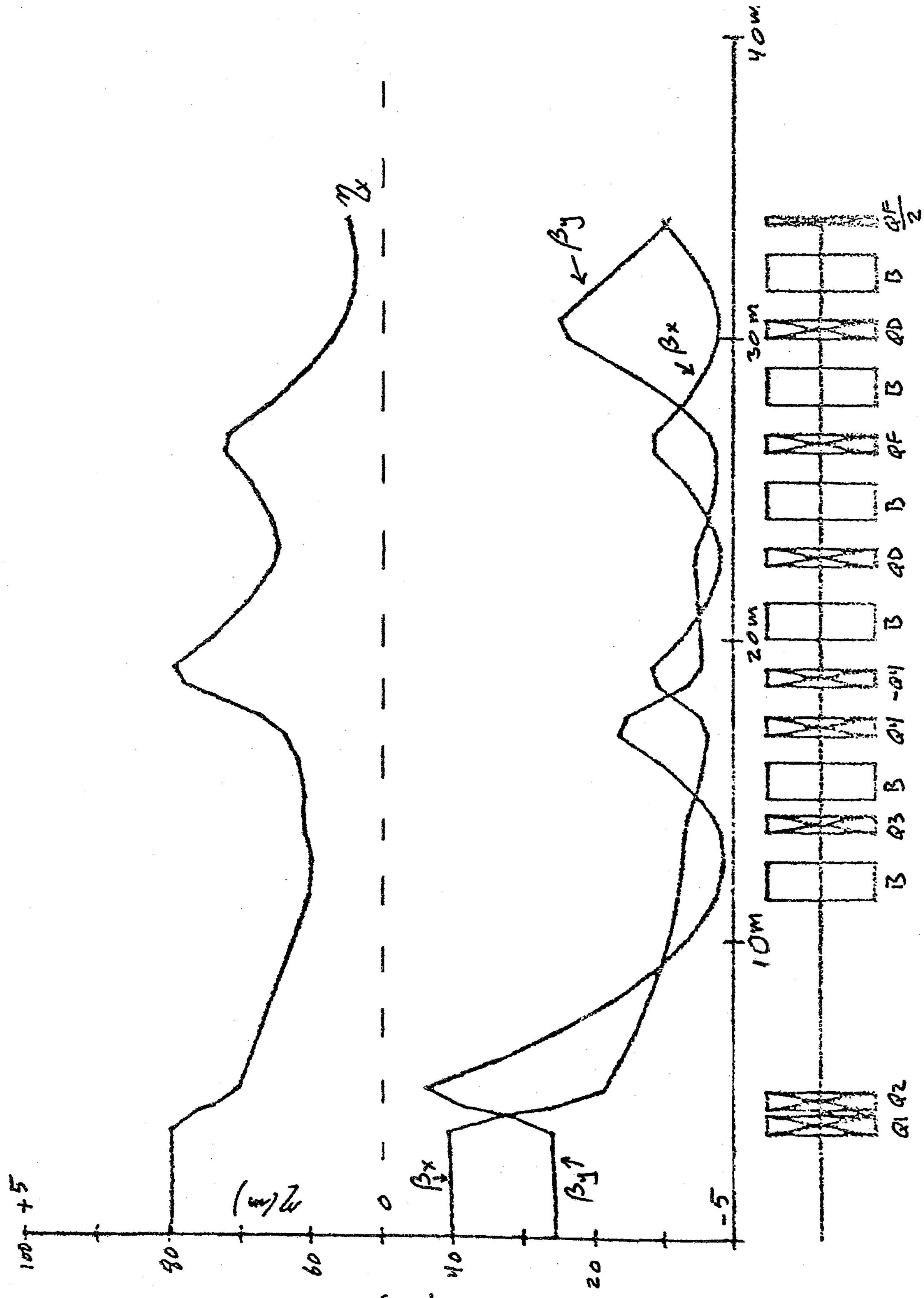
β(m)
η(m)
100
80
60
40
20
+5
0
-5
η_x
β_x
β_y
10m
20m
30m
40m
Q1 Q2
B
Q3
B
Q4
-Q4
B
QD
B
QF
B
QD
B
QF/2

Figure 2