A $\geq$1.5 TeV Superconducting Synchrotron Design for the Fermilab Tunnel

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Abstract

A design for a new high field superconducting synchrotron to occupy the Fermilab main enclosure is presented. A peak energy in the range of 1.5-1.8 TeV is envisaged. Following a brief discussion of the motivation and expected performance of the ring, the layout and lattice design effort is described. By combining the beam transfers and acceleration system in a single straight section a potential third interaction region is acquired. The beam transfers from the Main Injector motivate us to choose a focusing optics reversed in sign from that of the present Tevatron. In order to facilitate beam separation schemes the dispersion function is reduced by increasing the tune and matching the long straight sections to the standard cells in the arcs.

1 Introduction

The overall Fermilab upgrade plan is described elsewhere in these proceedings [3]. The final phase of this plan involves the construction of a new superconducting synchrotron in the existing main accelerator enclosure. Despite the constraints imposed by the pre-existing tunnel, a variety of approaches to the layout anad lattice of the new ring are possible. Some of these options are also described elsewhere in these proceedings [1]. Here, we carry the development of one such option to the point of exhibiting a complete layout.

The R&D program for the magnets is described in yet another paper at this conference [2]. The peak field is expected to lie in the range of 6.6-8.0 Tesla, corresponding to a peak energy in the range of 1.5-1.8 TeV. The necessity of accomodating separated proton and antiproton orbits as well as retaining the capability of slow extraction, makes this a magnet of aperture comparable to the Tevatron. The content of the remainder of this paper is independent of the final energy attained.

2 Overall Layout

The Main Injector is to be located south of the antiproton source and tangent to the Tevatron ring at the F0 straight section as shown in Figure 1. The acceleration system for the Tevatron is already located at the F0 straight section, and it is desirable to keep that function in the same place. So we were led to combine the injection anad acceleration systems into one straight section. This leaves the E0 straight section, presently used for beam transfer between the Main Ring and Tevatron, free for consideration as a potential interaction region. The functions of the remaining straight sections are unchanged.

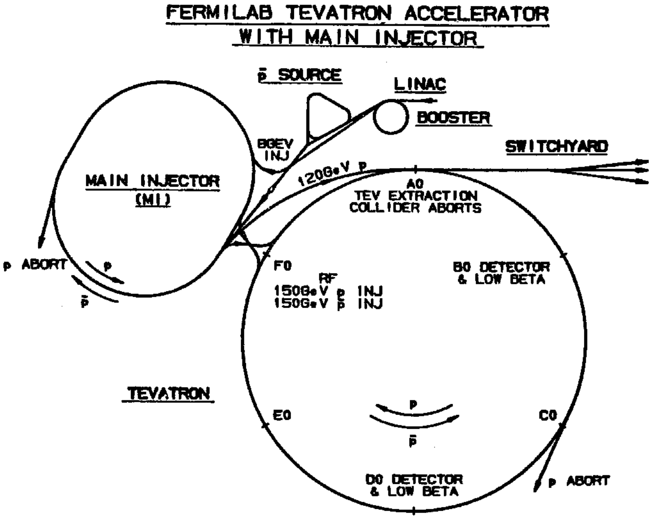

Figure 1: Layout of Fermilab Accelerators

In order to achieve the highest possible energy for colliding beams physics we must use only one bending magnet field, which excludes the possibility of lengthening the long straight sections to any significant degree. The fixed target program, therefore, will find its primary beam energy limited to that which can be extracted from a 50 m straight section. We estimate that limit to be 1.5 TeV.

The new synchrotron will occupy the space vacated by the Main Ring. Though the cryostat for the high field magnets will be significantly larger than that of either the Tevatron or the Main Ring magnets, the beam separation has been set at 60 cm, slightly less than the present separation between the Main Ring and Tevatron beams. We want to make this figure as small as possible in order to facilitate collisions between beams in the two superconducting rings if such an option is to be exploited in the future. A tunnel cross section for a typical location in the ring is shown in Figure 2.

3 Lattice Design

The lattice used in this design is the second option described in [1]. The lattices used in both the Main Ring and Tevatron do not employ dispersion matching across the long straight sections. Thus, the dispersion in the arcs is larger than that appropriate

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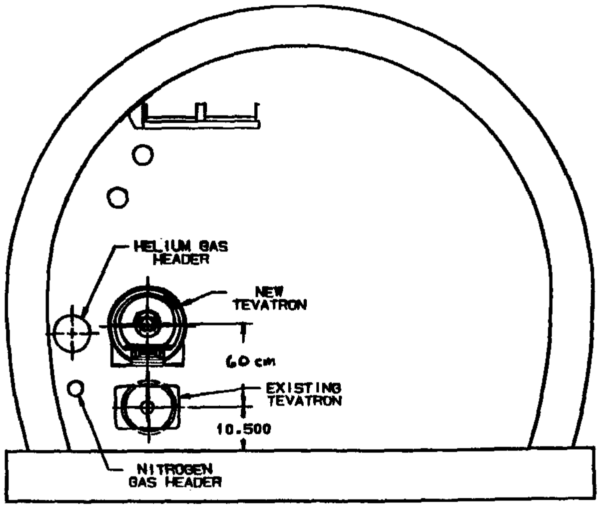

Figure 2: Tunnel cross section.

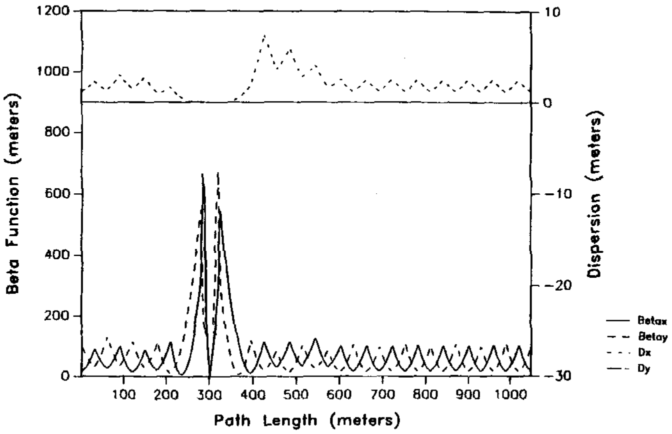

Figure 3: Lattice functions of a superperiod which includes a preliminary low-beta insertion.

to the standard arc cells. In the proton–antiproton collider, high bunch intensities are achieved by coalescing bunches in longitudinal phase space. The momentum spread in the coalesced bunch is therefore several times that of the original bunches. With the large dispersion function the design of separator schemes is made more difficult. In order to reduce the dispersion function the phase advance of the standard cell is increased from 68° to 90° and the straight sections are dispersion matched. The result is that the maximum dispersion in the arcs of a standard superperiod is reduced from 6 m to 2.6 m. This process, of course, does not change the amplitude function significantly. The lattice functions of the standard superperiod are shown in [1].

Because the two superconducting rings are situated one above the other, it is convenient for the incoming beams to approach the two rings horizontally. The use of magnetic injection septa implies that the final kick onto the closed orbit will be vertical. If the optics of the Tevatron were replicated, the only available locations for the kickers would have small vertical amplitude functions. We therefore reverse the optics in sign to achieve favorable β values at these locations with no other effect on the functioning of the ring.

A preliminary low beta lattice is depicted in Figure 3. For this case, $\beta^* = 0.5$ m and the dispersion has been brought to zero through the interaction region. A parameter list is given in Table 1.

4 The F0 Straight Section

A fair bit of our effort went into the accomodation of both injection anad acceleration in a single 50 m straight section. The injection energy of 150 GeV is to be preserved, as is the independence of the proton and antiproton acceleration systems. Figure 4 shows the result in plan view. The RF cavities are all located at the right hand side (south end) of the F0 straight section, while the injection lines from the Main Injector converge on a point located at the left hand side (north end). The Main Injector is located off the bottom of this figure and only a portion of the proton anad antiproton injection lines is shown. Both beams pass through the same magnetic septa (Lambertsons). The injection

Table 1: Machine Parameters

	Present Ring	New Ring	
Peak energy	1.0	1.8	TeV
Radius	1000	1000	m
Harmonic Number	1113	1113	
ν	19.4	25.6	
γ_t	18.4	23.0	
Number of Bunches (Collider)	6	6-44	
ϵ_N	12 π	12 π	mm-mar
ϵ_L	3	3	eV-sec
β^*	.7	.25	m
β_{max}(arcs)	100	100	m
β_{max}(low-β)	1650	770	m
D_{max}(arcs)	5.8	2.6	m
D_{max}(near IR)	9	7	m
Number of Str. Secs.	6	6	
Number of Possible IRs	2	3	
Standard Cell Length	59.4	59.4	m
Cell Phase Advance	68	90	deg.
RF Frequency	53	53	MHz
RF Voltage	1	1	MV
No. of Dipoles in Cell	8	6	
Dipole Field (max)	4.4	8	Tesla
Dipole Length (standard)	6.1	8.1	m
Cell Quad Gradient (max)	76	140	T/m
Cell Quad Length	1.7	1.7	m
IR Quad Gradient (max)	140	200	T/m

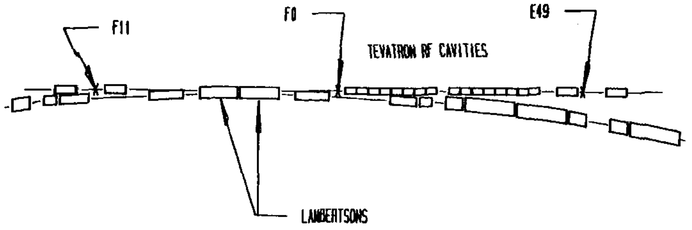

Figure 4: Plan view of F0 straight section.

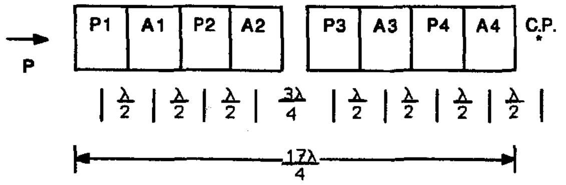

Figure 5: RF cavity placement at F0.

kickers are outside of the straight section proper; their location is not shown in the figure. The phase advance between septa anad kickers is more favorable with the septa located at the north end of F0.

To allow for independent high voltage control for the proton and antiproton beams, pairs of cavities need to be separated by an odd number of quarter RF wavelengths. Each cavity is one half wavelength long, so that the entire system of eight cavities requires 4.25 wavelengths, as depicted in Figure 5. In this figure, the pairs of cavities P1-P3 anad P2-P4 are used for proton acceleration, while A1-A3 and A2-A4 are used for antiproton acceleration. The center of cavity A4 is located one half wavelength from the proton-antiproton collision point.

The cavity phasing is shown in Figure 6. Here, the circled arrows indicate the direction of the cavity field when the synchronous particle is present. The upper portion of the figure illustrates a synchronous proton moving left to right, while the lower portion of the figure illustrates a synchronous antiproton moving right to left. If one of the cavities trips off, an increase or a reduction of the RF bucket area by roughly 10% will be seen by each beam. No RF phase offsets are induced by a tripped station.

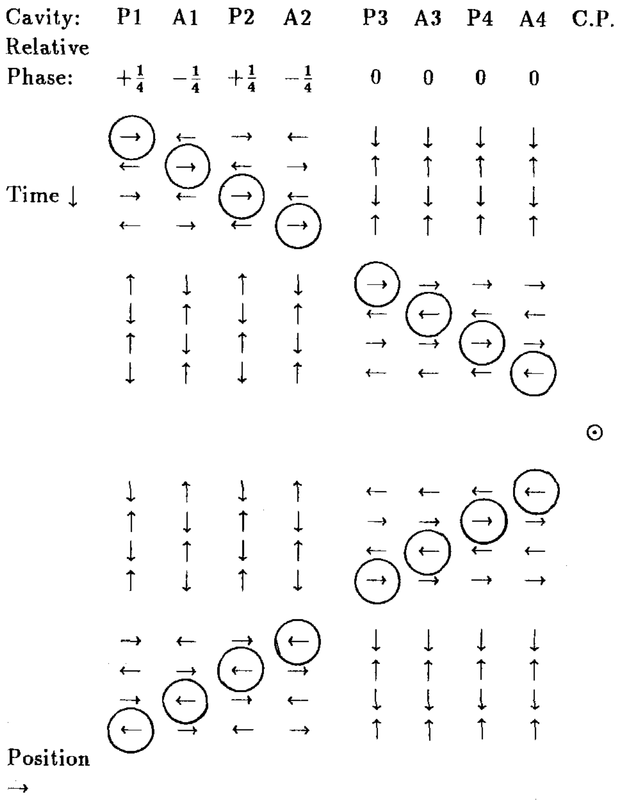

Figure 6: RF cavity phasor diagram.

5 Concluding Remarks

The purpose of this report is to present the current status of the design of a new high energy superconducting synchrotron for the Fermilab upgrade program. Much work is necessary to turn this preliminary version into a full design. The low-beta lattice shown in Figure 3 has an unacceptable high dispersion point just outside the interaction region that must be improved upon. The lattice design must also include a program for tuning the optics from injection to the final value of β^*. Realistic schemes for providing separated orbits for the proton and antiproton beams have not yet been investigated. Nevertheless, we think that we have demonstrated that there is latitude within the constraints imposed by a near-fixed geometry to improve the lattice design for this synchrotron.

References

[1] A. A. Garren, M. J. Syphers, "1.8 TeV Tevatron Upgrade Lattices," these proceedings.

[2] M. Harrison, et al., "A High Field Dipole for the Tevatron Upgrade," these proceedings.

[3] S. Holmes, et al., "Upgrading the Fermilab Tevatron," these proceedings.