2.2. Lattice Issues

The Recycler ring lattice mimics closely the Main Injector lattice with two 4.267 m long 1.45 kG gradient magnets in each arc half cell. The ring was designed such that it replicated the Main Injector cell length and hence followed the footprint of the Main Injector. The center of the Recycler ring vacuum chamber is placed over Main Injector at a distance of 7' from the floor. The Recycler has been designed to have exactly the same radius as the Main Injector. Figures 2.2.1 and 2.2.2 show the beam's eye, plan, and elevation views of both the Recycler and Main Injector in a standard arc cell.

The only exception to the rule that the Recycler is placed over the Main Injector is at MI-60, the RF straight section. Because of the power tubes over the Main Injector RF cavities, the Recycler ring swings to the radial outside by 18" at that straight section. Figure 2.2.3 shows a tunnel cross-section of the geometry in the MI-60 region.

The other straight sections are identical to the Main Injector. In figures 2.2.4 and 2.2.5 plan and elevation tunnel views of a straight section and the dispersion cells which surround them are displayed.

The Recycler lattice is virtually indistinguishable from the Main Injector lattice, even with the bypass at MI-60 included. It is a strong focusing FODO lattice made up of either two gradient magnets or two quadrupoles (in the dispersion free straight sections) above each Main Injector quadrupole. The horizontal and vertical tunes of the Recycler are split by an integer to minimize transverse coupling effects. The lattice has been designed to have base tunes of Q_x=25.425 and Q_y=24.415 with a maximum horizontal dispersion of 2 m and a corrected chromaticity of -2 units in each plane. Figure 2.2.5 shows the lattice functions for the entire ring.

The Recycler is made of three basic cell structures. The first are the arc cells which have a horizontal phase advance of 86.8° and a vertical phase advance of 79.3°. There are 54 arc cells, each consisting of four 4.267 m magnetic length (add 88.9 mm to each end for a physical length of 4.445 m) permanent gradient magnets with a half-cell length of 17.288 m. The different horizontal and vertical phase advance require different gradients between the focusing and defocusing arc cell gradient magnets. In addition, pole faces of the arc gradient magnets include a sextupole component to reduce the chromaticity to -2 in each plane.

The second cell type is that of the (dispersion free) straight section cells with the same horizontal and vertical phase advance as the arc cells. There are three lengths of straight sections; four 3 half-cell, two 4 half-cell, and two 8 half-cell to make a total of 18 straight section cells, each made up of four 0.5 m long permanent magnet quadrupoles. The separation of the two quadrupoles at each focusing (defocusing) location was tuned to match the lattice amplitude functions of the arc cells.

The third basic cell type is that of the dispersion suppresser cell. These form a dispersion suppresser insert (2 cells) on either side of each straight section to make a total of 32 dispersion suppresser cells. The half-cell length of this insert is 12.966 m such that the product of the bend angle and cell length is exactly half that the arc cells, thus canceling the horizontal dispersion. There are actually two flavors of this insert because of the two different straight sections lengths (i.e. 3 or 4 half-cells in length). One matches between the arc and straight section focusing cells while the other matches between defocusing locations. The dispersion suppresser insert is made up of eight (2/3)*4.267 m long (2.845 m magnetic, 3.023 physical) permanent gradient magnets and produce 180° of phase advance in both planes.

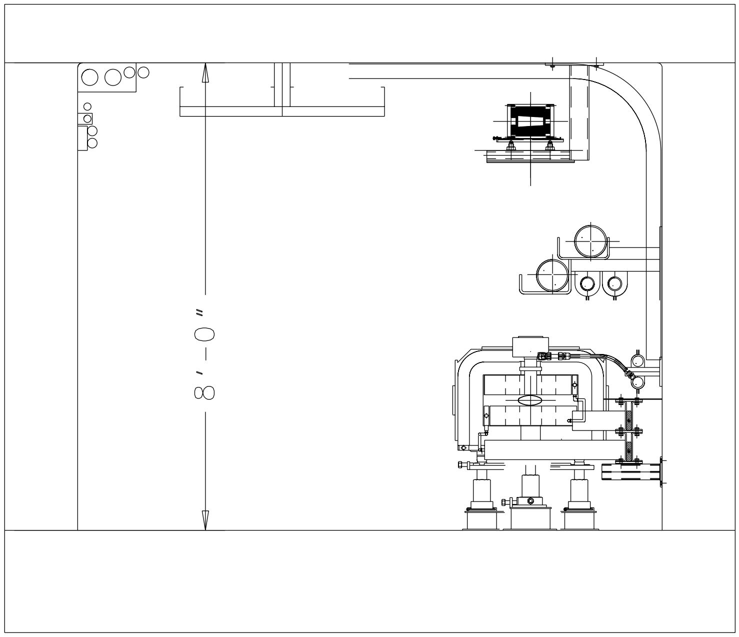

Figure 2.2.1: Tunnel cross-section in a standard arc cell showing a Main Injector dipole near the floor and a Recycler gradient magnet above it and near the ceiling.

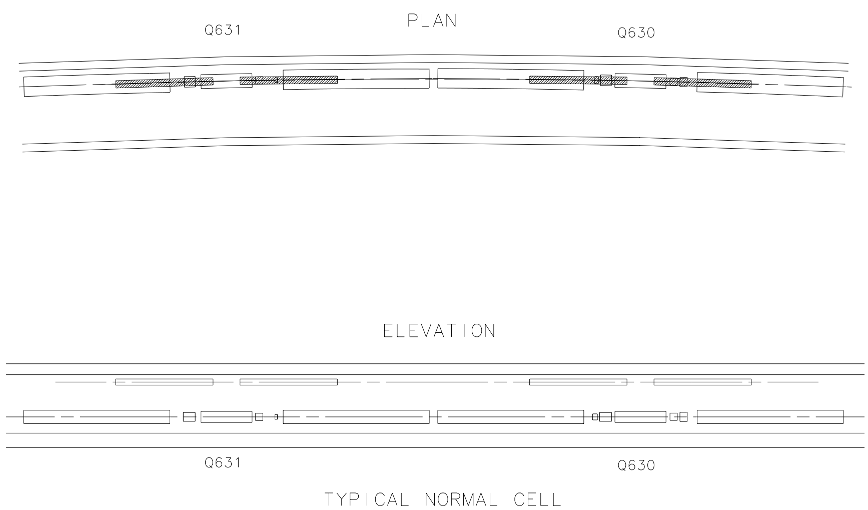

Figure 2.2.2: Plan and elevation views of both the Recycler and Main Injector beamlines. Note that the top magnets (shaded magnets in the plan view) are the Recycler gradient magnets.

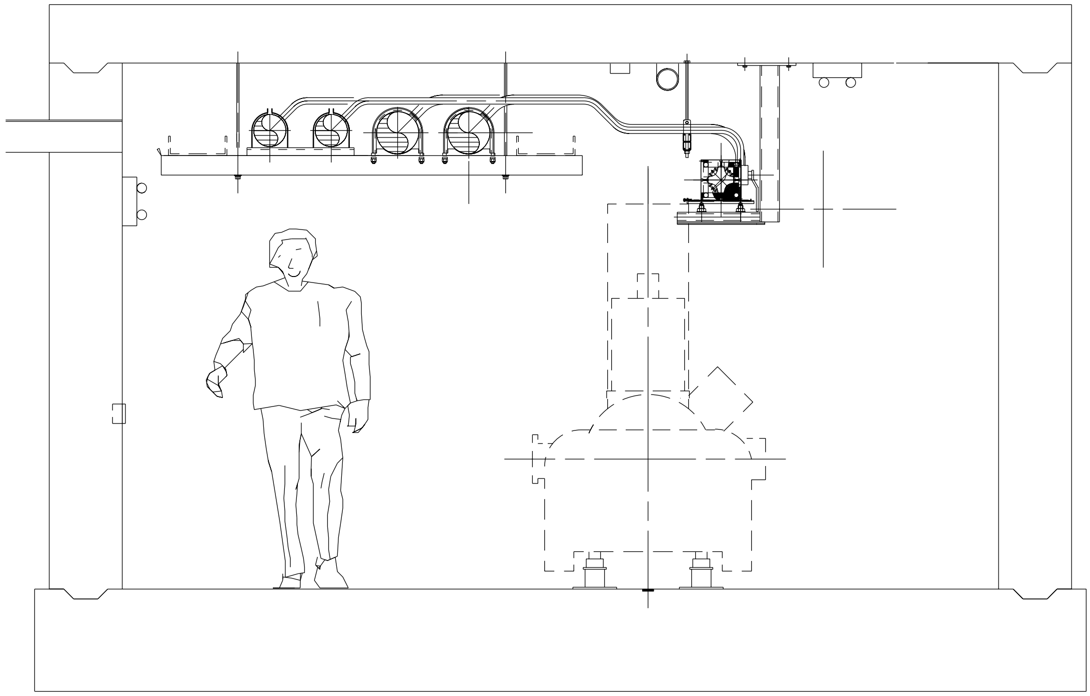

Figure 2.2.3: Tunnel cross-section at the MI-60 straight sections showing the Main Injector RF cavities with the Recycler ring quadrupoles above and to the radial outside.

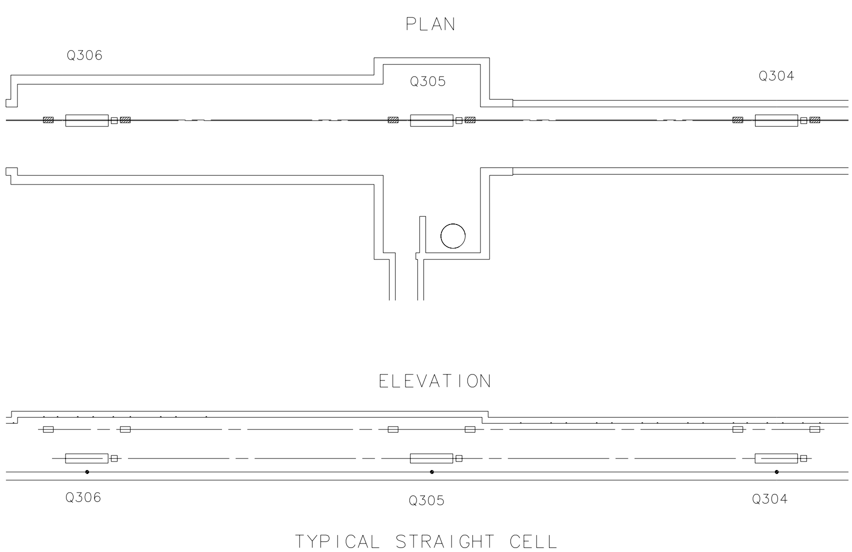

Figure 2.2.4: Plan and elevation views of the Main Injector (open frames) and Recycler (shaded rectangles) magnet deployments in a standard straight section.

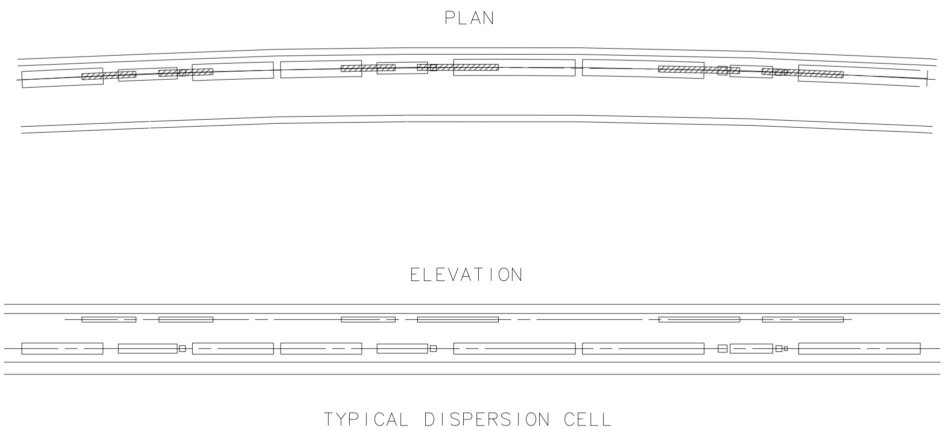

Figure 2.2.5: Plan and elevation views of the Main Injector (open frames) and Recycler (shaded rectangles) magnet deployments in a dispersion suppresser cell.

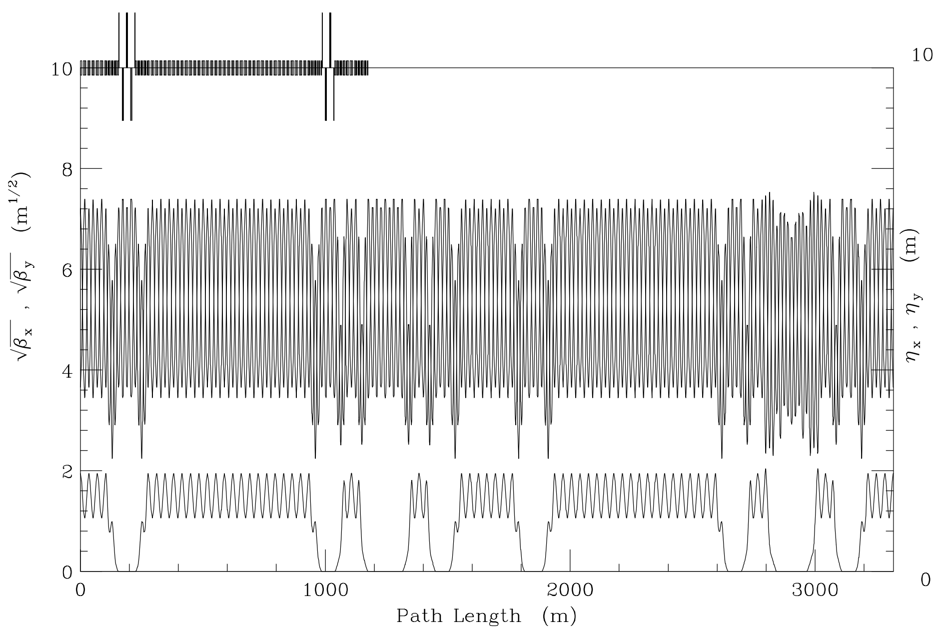

Figure 2.2.6: The Recycler lattice. Note that this lattice is virtually identical to that of the Main Injector.

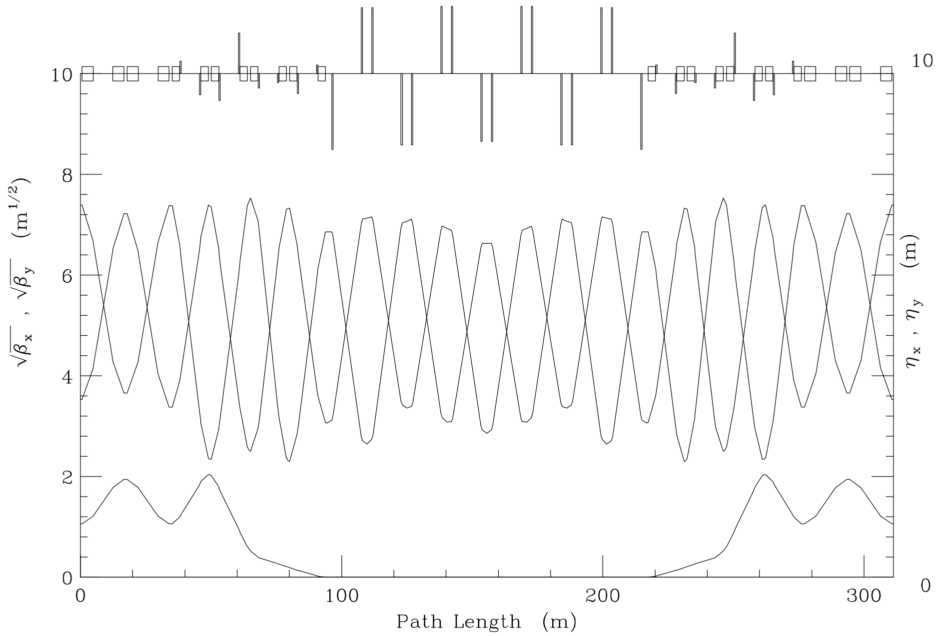

Figure 2.2.7 The Recycler lattice near MI-60. Note that 8 special quadrupoles have been placed around the dispersion suppresser gradient magnets in order to match Twiss and dispersion functions distorted by the magnet moves required to generate the 18" radial bypass of the Main Injector RF stations.

Given that there are 104 cells in the Recycler, the above cell descriptions would infer that the horizontal and vertical betatron tunes are 25.36 and 23.86, respectively. In actuality, the phase advance in the region of the MI-60 bypass is not the standard straight section or dispersion suppresser. The reason is that the half-cell length of the dispersion suppresser cells on either side of the RR-60 straight section were lengthened by 2 m and the RR-60 straight section half-cell length was shortened by the same amount to accomplish the 18" radial bypass of the MI RF stations. The shorter cell length in the straight section reduced the lattice functions in this region creating a greater demand on the dispersion suppresser insert to match between the arc and straight section lattice functions and cancel the dispersion. Figure 2.2.7 shows the lattice functions in the region of the MI-60 bypass. Note the extra 8 quadrupoles in the dispersion suppressers on either side of the straight section. These are used to aid in the match between the straight section and standard arc cells.

A special feature of the RR-60 straight section is its use as a phase trombone for Recycler tune control. Instead of distributing remotely adjustable quadrupoles around the ring, the RR-60 quadrupoles are segmented into 5 families. By adjusting these circuits, a tune variation of up to ±0.5 is attainable, although only a fraction of that is actually required and will be implemented in the initial phase of Recycler operations. The adjustments in these circuits are coordinated in such a way that the Twiss parameters at the ends of the straight section are unchanged. For the full tuning range from the base tune, the peak beta function inside the straight section can grow by about a factor of 3.

Therefore, the vacuum chamber will be round and have a 3" diameter in this region in order to preserve the Recycler aperture.

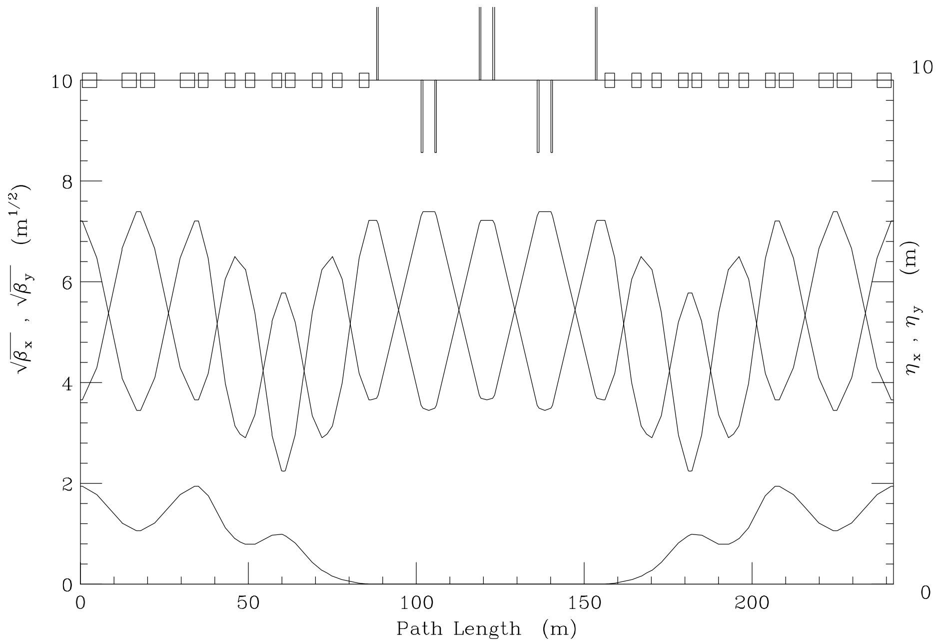

Figure 2.2.8: A standard Recycler long straight section.

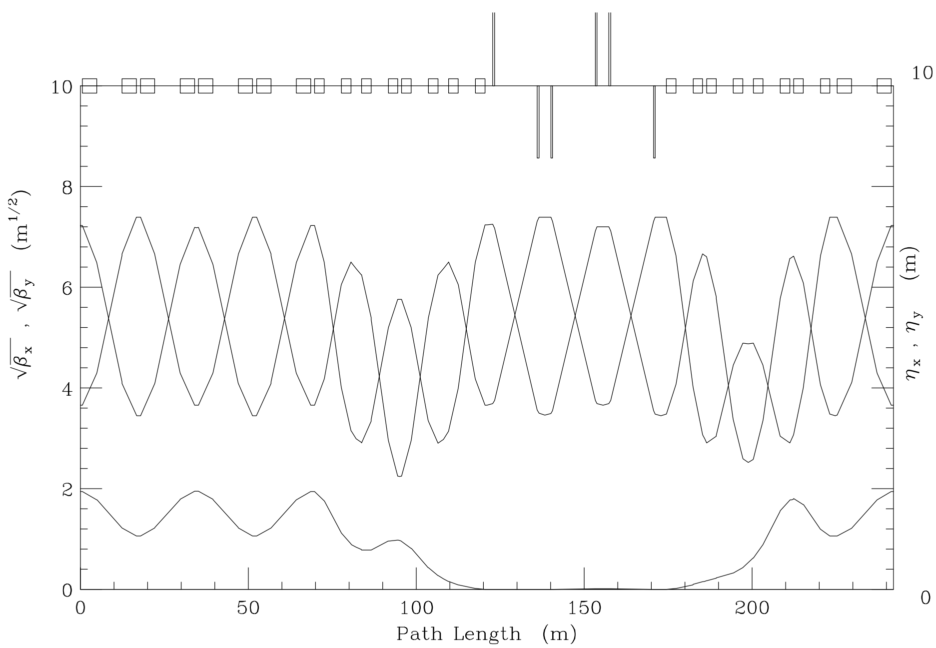

Figure 2.2.9: A standard Recycler short straight section.

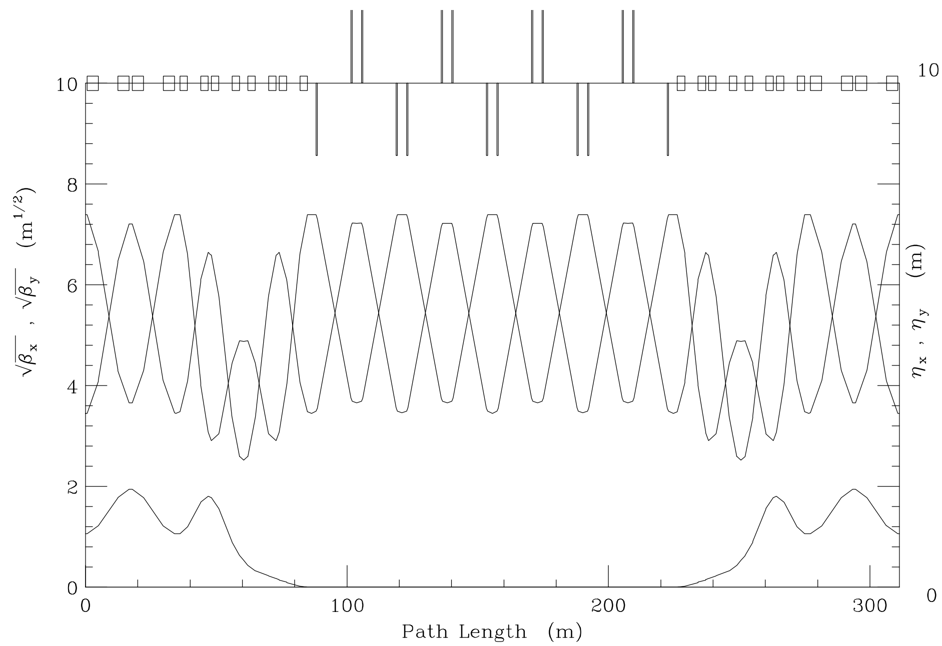

Figure 2.2.10: Lattice functions for the Recycler MI-30 straight section.

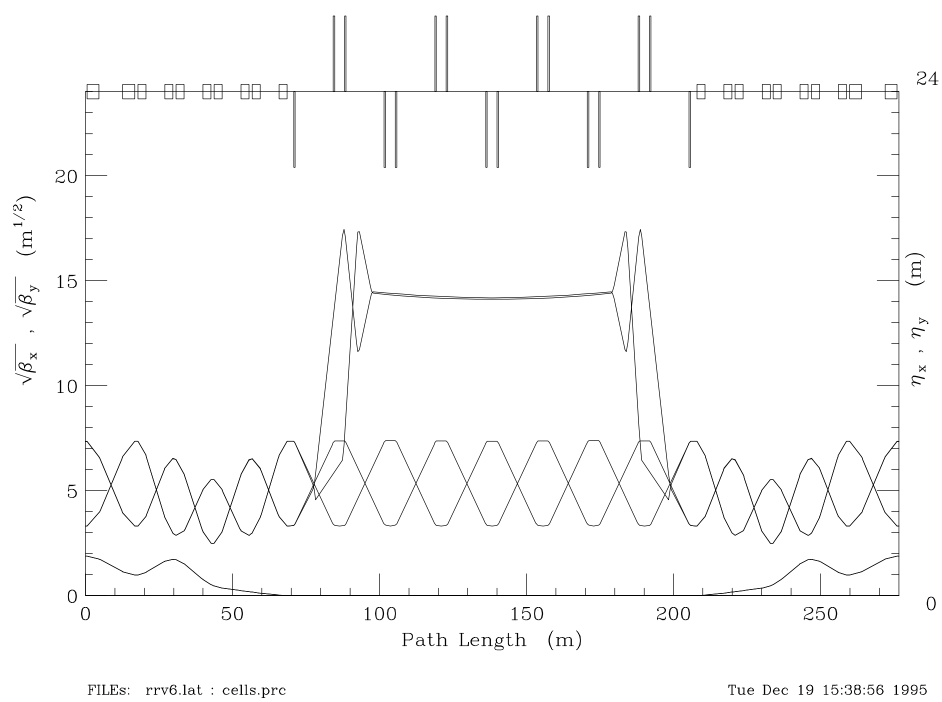

Figure 2.2.11: Lattice functions for the Recycler MI-30 straight section, with the future high-beta insertion for electron cooling superimposed.

With the exception of MI-30, the other long and short straight sections are quite unremarkable and similar to the Main Injector lattice. Figures 2.2.8 and 2.2.9 document their lattice configurations.

At MI-30 the intention at Recycler commissioning is to have the lattice shown in figure 2.2.10, which is basically identical to the Main Injector lattice. In the future, electron cooling is necessary to meet the more aggressive luminosity goals envisioned for the Tevatron Collider. Electron cooling requires a very long high-beta insertion in order to effectively transfer transverse emittance from the antiprotons to the electron beam. In figure 2.2.11 a β=200 m straight region approximately 80 m in length is superimposed over the commissioning lattice functions. In order to maintain the aperture of the Recycler ring with this high-beta insert, the round vacuum chamber at MI-30 will have to be 6" in diameter.