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Figure-8 Ion Ring – Minimum Dispersion Lattice

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Abstract

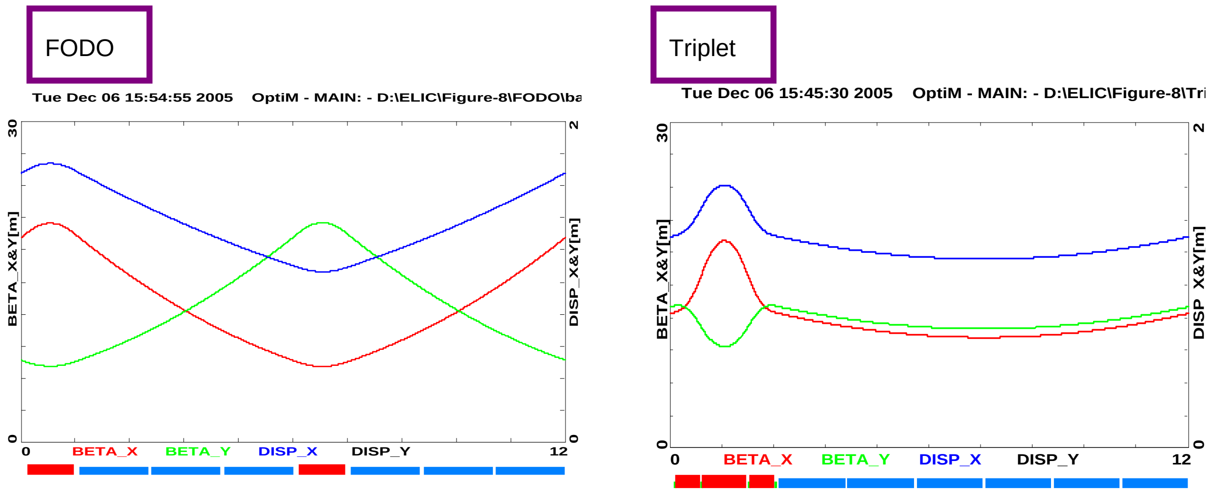
The requirement of high polarization of the colliding beams favors a Figure-8 configuration rather than a conventional circular collider ring. In the Figure-8 ring one needs to implement dispersion free straights to accommodate up to four Interaction Regions (IR), while maintaining minimum dispersion in the arcs. Two styles of focusing (FODO and Triplet) were considered as a base for building such a lattice. The FODO structure was chosen based on factor of three weaker quad strengths required for the same betatron phase advance (as for the Triplet) and much better separation of the horizontal and vertical beta functions to facilitate more effective chromaticity control. Here we will design the minimum dispersion optics for the Figure-8 lattice topology based on the 60 deg. FODO structure.

1. FODO vs. Triplet Focusing

Both the FODO and Triplet focusing styles are commonly used to build highly periodic lattices. The requirement of uniform focusing throughout the entire ring imposes consistent use of one of the styles for all lattice segments. Specific features (advantages and disadvantages) of these two focusing styles are summarized in Figure 1.

For a high energy collider ring (~150 GeV) the required quadrupole strength may become a limiting factor. Therefore the virtue of FODO focusing (factor of three weaker quads required for the same betatron phase advance per cell) makes this style more feasible. Furthermore, better separation of the horizontal and vertical beta functions in case of the FODO cell facilitates more effective chromaticity correction for the ring. Both advantages, strongly favor the FODO structure as a base for building the collider lattice.

In the next section, we will present a complete lattice design of the Figure-8 ring based on the FODO focusing.



Advantages:

- much weaker quads (~3 times)
- shorter quads (total)
- easier chromaticity correction

Advantages:

- longer straight sections
- smaller vertical beta-function
- uniform variation of betas and disp.

Figure 1 FODO vs. Triplet focusing – Comparison of two perodic cells of the same length and the same phase advance per cell ($\Delta\phi_x = 60^0 = \Delta\phi_y$)

3. Figure-8 Ring – Minimum Dispersion Lattice

The natural chromaticity of a high energy collider ring needs to be compensated and controlled through appropriately distributed families of sextupole magnets. Independent control of chromaticities in both the horizontal and vertical planes requires minimum of three families of sextupoles. Their effectiveness in a periodic lattice is highly enhanced by choosing 60 deg. betatron phase advance per cell in both planes [1]. Here we will present linear optics design for the Figure-8 lattice topology based on the previously described 60 deg. FODO cell.

First, on needs to construct the bending 'loops' of the Figure-8 ring, so that entire loop is horizontally achromatic and it is naturally matched to individual 60 deg. FODO cells with removed dipoles – the so called 'empty' cells. The empty cells will be used to construct the straight sections of the Figure-8 ring. The achromat could be configured as super-period of 6 cells. Starting with zero dispersion and its derivative at the beginning of the achromat the betatron phase will advance by 2π (as given by a simple numerology: $6\times\pi/3 = 2\pi$). This in turn will create a periodic dispersion wave across the achromat (zero dispersion and its derivative at the achromat end). The resulting achromat super-period is illustrated in Figure 2.

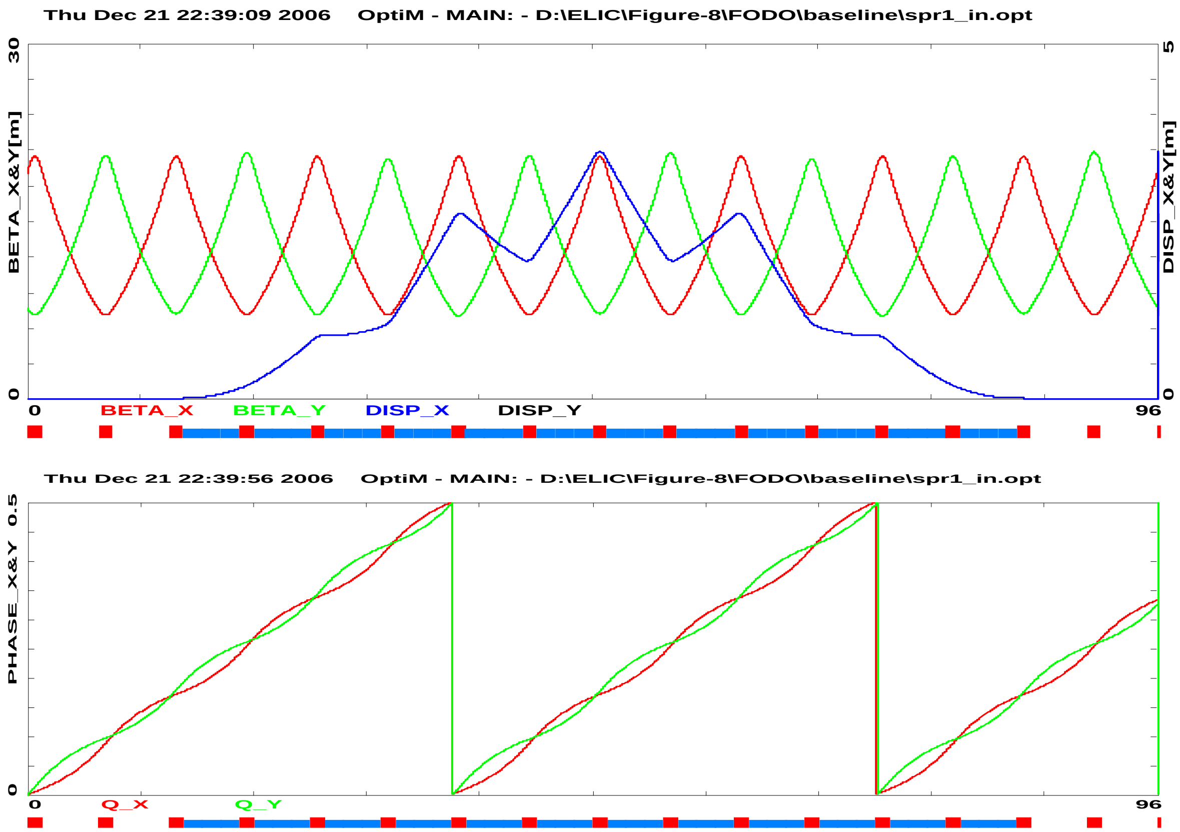


Figure 2 Achromat super-period – Twiss functions (top) and betatron phase advance in units of 2π (bottom)

In principle, one could build the entire arc as a sequence of the above achromat superperiods, which are inherently matched to the straight sections (sequence of empty cells). However, his solution would end up with rather large average dispersion and large momentum compaction. One may observe that the minimum dispersion is reached for a periodic solution as illustrated in Figure 1. Therefore, to minimize the average dispersion in the ring it would be beneficial to build the Figure-8 bends out of periodic FODO cells and then suppress the dispersion at the transitions to the straight sections. This can be accomplished by removing specific dipoles from the transition cells. The process of dispersion suppression based on pure geometry is illustrated in a sequence of lattices with removed dipoles (evolutionary pattern) as shown in Figure 3.

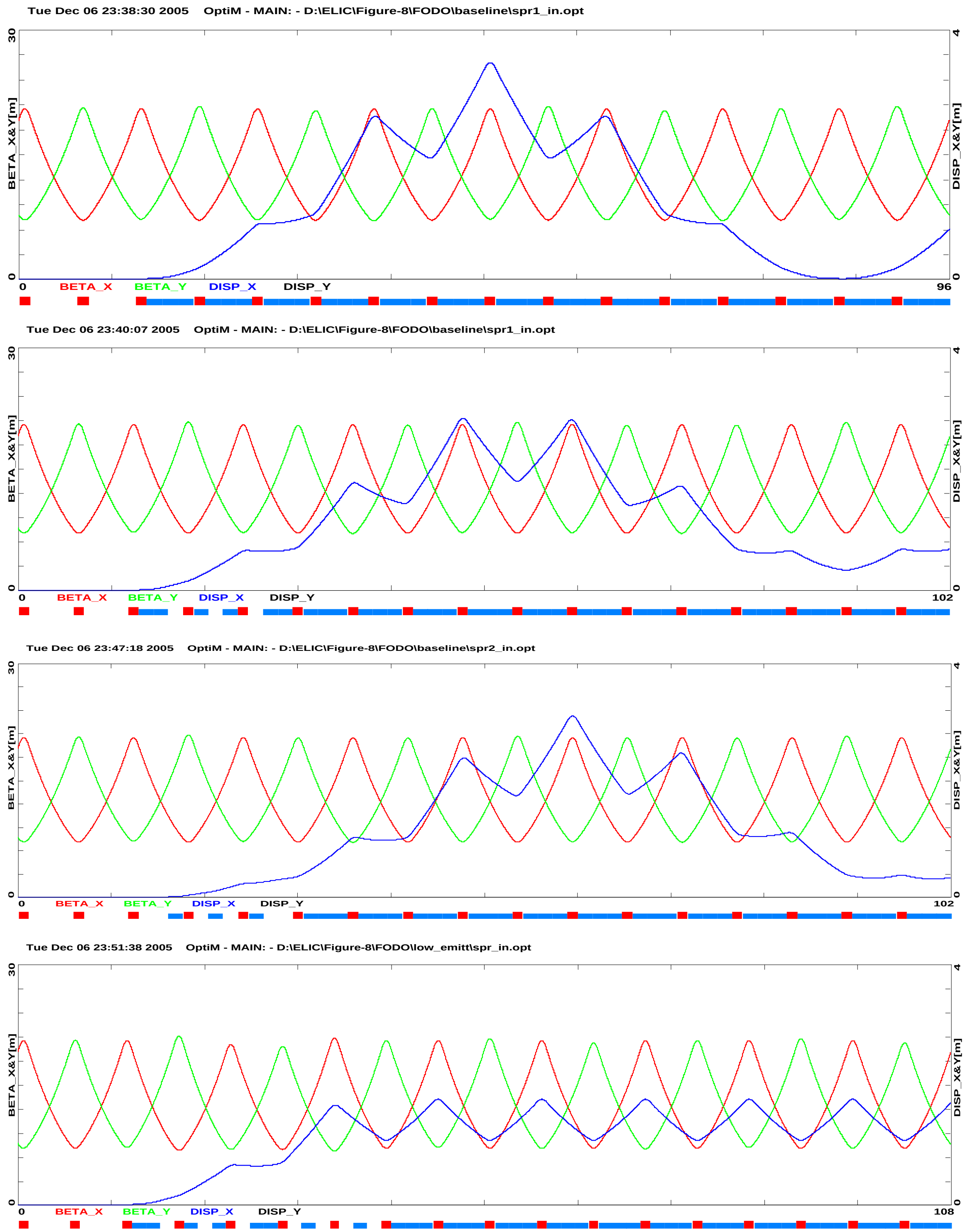


Figure 3 Minimizing the average dispersion in the ring by removing specific dipoles from the transition cells.

The bottom picture in Figure 3 illustrates the desired minimum dispersion solution for the Figure-8 loop. One can see the unperturbed periodicity of the beta functions across the dispersion suppression region, which makes this solution even more attractive.

The overall optics for one half of the Figure-8 ring (where 240 deg. bend is closed by 24 periodic FODO cells) is illustrated in Figure 4. Its geometric layout is depicted in Figure 5.

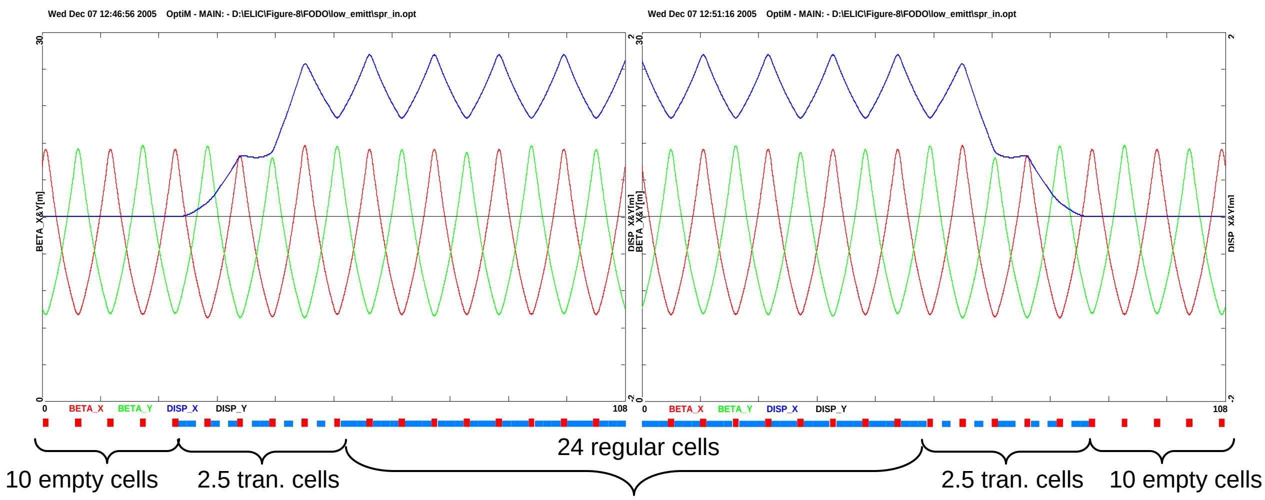


Figure 4 Linear optics at 150 GeV for one half of the Figure-8 ring with 60 deg. crossing.

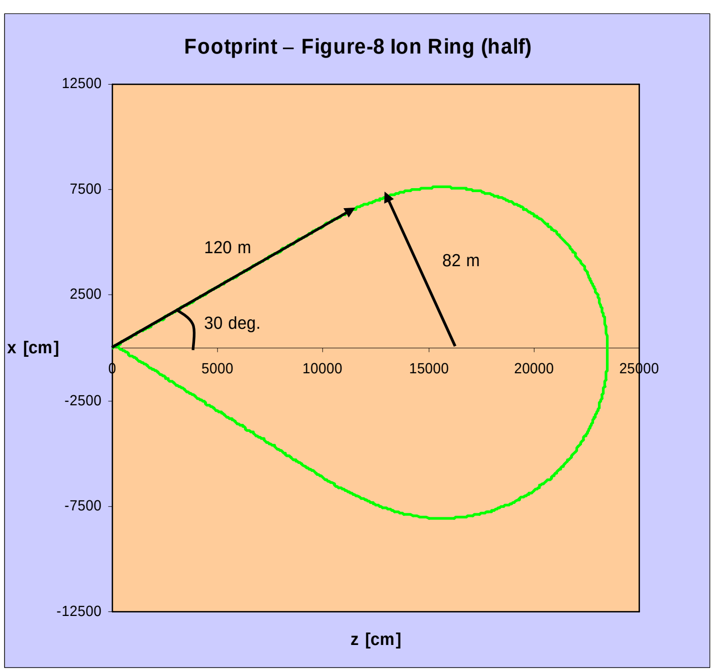


Figure 5 Layout of one half of the Figure-8 ring with 60 deg. crossing.

The long dispersion free straights (2×120 m each) will accommodate as many as four interaction regions (IR). The FODO structure of the straights is quite flexible to 'launch' matching inserts around the IRs.

5. Summary

To maintain high polarization of the colliding beams it is advantageous to use a Figure-8 configuration rather than a conventional circular collider ring. In the Figure-8 ring one needs to implement dispersion free straights to accommodate the Interaction Regions (IR), while maintaining minimum dispersion in the arcs. Two styles of focusing (FODO and Triplet) were considered as a base for building such lattice. The FODO structure was chosen based on factor of three weaker quad strengths required for the same betatron phase advance (as for the Triplet) and much better separation of the horizontal and vertical beta functions to facilitate more effective chromaticity control. To minimize the average dispersion in the ring it is beneficial to build the Figure-8 bends out of periodic FODO cells and then suppress the dispersion at the transitions to the straight sections. This was accomplished by removing specific dipoles from the transition cells making the dispersion suppression purely geometrical.

Complete lattice design at 150 GeV for the Figure-8 collider topology based on the 60 deg. FODO structure was presented. The key parameters of the Figure-8 ring, computed via OptiM [2], are summarized in the Table below [2]:

Figure-8 Ion Ring – Small Dispersion Lattice	
circumference, C [m]	1200
arc bending radius, R [m]	82
dipole bending radius, ρ [m]	59
average betas (h/v) [m]	12.5/12.5
average dispersion, D_x [cm]	168
betatron tunes (h/v)	16.69/16.69
chromaticities (h/v)	-17.85/-18.01
$M_{56} = \int \frac{D_x}{\rho} ds$ [cm]	1420
momentum compaction, $\alpha = M_{56}/C$	1.2×10^{-2}
transition gamma, $\alpha = \frac{1}{\gamma_t^2}$	9

References

1. Andrew Hutton, private communication

2. 3. http://www-bdnew.fnal.gov/pbar/organizationalchart/lebedev/OptiM/optim.htm