Recent Progress in Muon Collider Storage Ring Lattice Design

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Abstract— **A new lattice for a Muon Collider storage ring with a design collision energy of 750 on 750 GeV will be discussed. The important building blocks of the lattice: the Final Focus Section, the Chromatic Correction Section and the Arc Module are described in detail. These components of the collider have been designed keeping in mind that the storage ring must approximately match the footprint of the Tevatron Ring in order to take advantage of existing services and tunnels. The model presented here relies heavily upon a previous, highly optimized 50×50 GeV storage ring lattice design. The current design value for β^* is chosen to be 1 cm, which has the advantage of lower chromaticities and longer bunch lengths (due to the hour-glass effect) as compared to the previous standard lattice with a β^* of 3 mm.**

I. Introduction

The idea is to design a lattice for the storage ring that fits or matches approximately the footprint of the Tevatron Main Ring tunnel with all its bends and straights. Taking into account the current status of the Tevatron project, Muon Collider might be a logical next step in utilizing the existing tunnel with its infrastructure, thus saving a large amount of expenses connected to building a new accelerator complex for muons.

II. Magnet strengths

Currently we use 50% dipole packing fraction, which results for the arclength of 5.85 km (6.28 km - 432 m of straights) in the dipole field of 5.3 T. At 750 GeV the magnet strengths are reasonable, in fact, the ultimate energy might be up to 1×1 TeV.

III. 50×50 GeV lattice

We use the 50 × 50 GeV lattice [1], [2] as a baseline, and scale its components to 750 GeV according to the scheme in Fig. 1. 50 × 50 GeV is a highly optimized lattice which is in turn based on the 1×1 TeV lattice [3], so there is a strong reason to assume the 750 × 750 GeV design shares most of the advantages with its "little brother".

IV. Final Focus section

The low beta function values at the IP are mainly produced by three strong superconducting quadrupoles in the Final Focus Telescope with pole-tip fields of 9 T. Because of significant, large-angle backgrounds from muon decay, a background-sweep dipole is included in the final focus telescope and placed near the IP to protect the detector and the low-β quadrupoles [4]. Bend starts at 35 meters, so the FF system fits the Tevatron straight section footprint.

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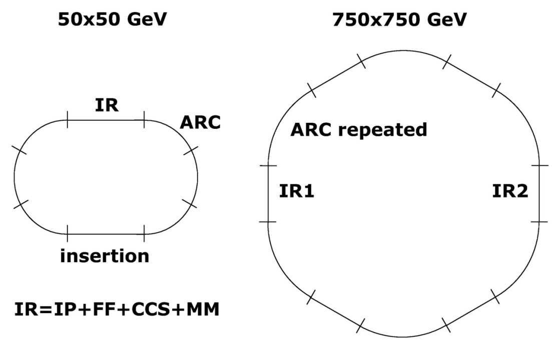

Fig. 1. Baseline 50×50 GeV lattice scheme compared to the 750×750 lattice scheme

V. Chromatic Correction Section

Local chromatic correction of the muon collider interaction region is required to achieve broad momentum acceptance. The CCS contains two pairs of sextupoles, one pair for each transverse plane, all located at locations with high dispersion. The sextupoles of each pair are located at positions of equal, high beta value in the plane (horizontal or vertical) whose chromaticity is to be corrected, and very low beta waist in the other plane. Moreover, the two sextupoles of each pair are separated by a betatron phase advance of near π, and each sextupole has a phase separation of $(2n+1)\frac{\pi}{2}$ from the IP, where n is an integer. The result of this arrangement is that the geometric aberrations of each sextupole is canceled by its companion while the chromaticity corrections add. The sextupoles of each pair are centered about a minimum in the opposite plane ($\beta_{min} < 1$), which provides chromatic correction with minimal cross correlation between the planes. A further advantage to locating the opposite planes minimum at the center of the sextupole, is that this point is $\frac{\pi}{2}$ away from, or "out of phase" with, the source of chromatic effects in the final focus quadrupoles; i.e. the plane not being chromatically corrected is treated like the IP in terms of phase to eliminate a second order chromatic aberration generated by an "opposite-plane" sextupole. Repetitive symmetry and the fact that the transfer map of the section is unity implies that the important aberration $(x|\delta\delta)$ vanishes as well. The layout of the CCS is shown in Fig. 2.

VI. Arc Module

Flexible Momentum Compaction module (Fig. 3) provides negative momentum compaction values compensating for the positive momentum compaction generated by the Chromaticity Correction Section. The small beta functions are

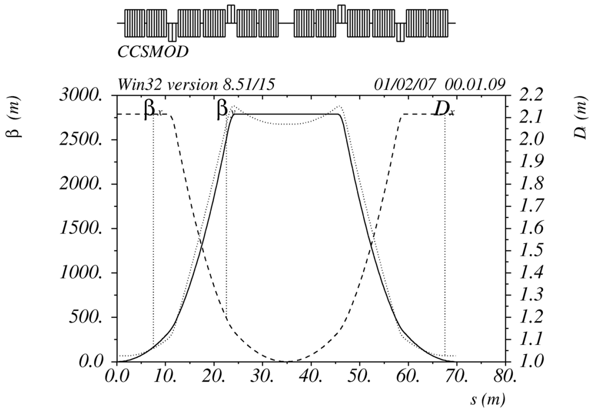

Fig. 2. Chromaticity correction section beta functions and dispersion plots

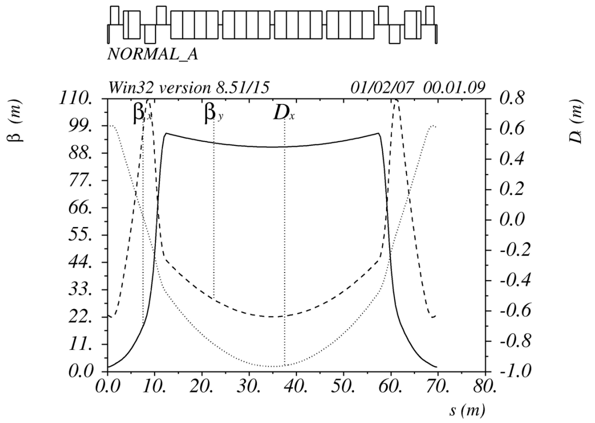

Fig. 3. Arc module beta functions and dispersion plots

achieved through the use of a doublet focusing structure which produces a low beta simultaneously in both planes. At the dual minima, a strong focusing quadrupole is placed to control the derivative of dispersion with little impact on the beta functions. (The center defocusing quadrupole is used only to clip the point of highest dispersion.) Ultimately a dispersion derivative can be generated which is negative enough to drive the dispersion negative through the doublet and the intervening waist.

VII. Lattice parameters for various designs

	4/1.5 TeV	1.5 TeV (this design)	100 GeV
β^* [mm]	3	10	40
l^* (IP to quad) [m]	4	5.5	4.5
peak β [km]	145	35	1.4
IR quad aperture [cm]	10	10	10
Poletip field [T]	12	9	8
$\epsilon_N(95\%)$ [mm mrad]	$841\pi/315\pi$	1306π	2176π
$\Delta p/p(95\%)[\%]$	.01-.08	$\geq$ .018-.144	$\geq$ .036-.288
$\xi_x(IR+CCS)$	-1500	-456	-53
$\xi_y(IR+CCS)$	-2000	-645	-73
α_{IR}	3.6×10^{-4}	1.0×10^{-3}	3.0×10^{-2}
IR length [m]	1300	506	137
α_{arc}	-2.1×10^{-3}	-9.3×10^{-3}	-9.5×10^{-2}
Arc length [m]	187	70	31

VIII. Advantages and disadvantages

Proposed design has a lot of advantages. As the lattice is isochronous, that prevents bunch length change, which is very important for controlling the hour-glass effect. β^* is chosen to be 1 cm, which has the advantage of lower chromaticities and longer bunch lengths (due to the hour-glass effect), also the apertures can be chosen smaller as compared to the 3 mm lattice. Smaller chromaticities lead to weaker chromatic aberrations and larger momentum acceptance. All these facts contribute to the larger dynamic aperture.

As for the disadvantages, the choice of larger $beta^*$ leads to undesirable decrease in luminocity. According to the following formulas

$$L \propto \frac{1}{\beta^*}$$

$\beta^* = 3$ mm $\Rightarrow$ hour-glass reduction $\eta_A = 0.76$, disruption enhancement $f_D = 1.5$.

Overall, $H_D = \eta_A f_D = 1.14$. For $\beta^*_{new} = 1$ cm we have $\eta_A \to 1, f_D \to 1, \Rightarrow$

$$\left(\frac{L_{old}}{L_{new}}\right)_{eff} = 1.14\frac{\beta^*_{new}}{\beta^*_{old}} = 3.8$$

Hence the luminosity for $\beta^* = 1$ cm is 3.8 times smaller as compared to the $\beta^* = 3$ mm. However, the loss of luminosity can be compensated by the increased momentum aperture and using the 2 IRs in the ring.

One other problem arises due to the fact that we are trying to match the lattice to the existing geometry, which puts more constraints on the building blocks of the lattice.

References

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