European Coordination for Accelerator Research and Development

PUBLICATION

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07 December 2010

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579.

This work is part of EuCARD Work Package **9: Technology for normal conducting higher energy linear accelerators**.

ATF2 ULTRA-LOW IP BETAS PROPOSAL

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Abstract

The CLIC Final Focus System has considerably larger chromaticity than those of ILC and its scaled test machine ATF2. We propose to reduce the IP betas of ATF2 to reach a CLIC-like chromaticity. This would also allow to study the FFS tuning difficulty as function of the IP beam spot size. Both the ILC and CLIC projects will largely benefit from the ATF2 experience at these ultra-low IP betas.

INTRODUCTION

ATF2 is a test facility with the aim of testing the FFS design that has been proposed in [5]. To prove the CLIC 3TeV chromatic level, ATF2 β_y^* should be reduced by a factor of 4, see Table 1. After the original proposal [1] there are some open questions: tuning difficulty, impact of the known magnetic errors and the compatibility of the Shintake monitor with a probably enlarged halo.

The ILC project and the ILC low-power [2], would also largely benefit from this test, in particular by gaining experience in exploring larger chromaticities and facing increased tuning difficulties for this smaller beam size.

Reference [3] studies a wide range of ATF2 β^* values.

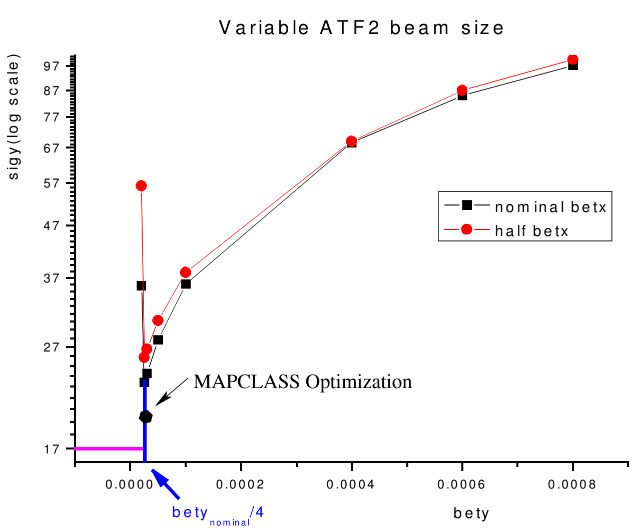

Figure 1: Vertical beam size (in [nm]) at the IP versus vertical beta function (in [m]) for two cases: nominal and half horizontal beta functions. Aberrations change the ideal trend of this curve for the very low betas and they are larger for the case with half the nominal horizontal beta. The quarter of β_y is marked on the plot together with the corresponding ideal vertical sigma.

Table 1: Relevant parameters of the different projects [8, 9, 10, 11]. ξ_y is a precise computation of natural chromaticity given by $(T_{346}R_{33} - T_{336}R_{34})/\sqrt{\beta_y^*}$. This is shown on the table to verify that the chromaticity of similar FFSs roughly scales with L*/β_y^*, the FFTB being the only FFS having a totally different design.

Project	Status	β_y^* [mm]	L* [m]	ξ_y
FFTB	Design	0.1	0.4	17000
FFTB	Measured	0.167	0.4	10000
ATF2	Design	0.1	1.0	19000
ATF2 ultra-low	Proposed	0.025	1.0	76000
CLIC 3TeV	Design	0.09	3.5	63000
ILC	Design	0.4	3.5	15000
ILC low power	Proposed	0.2	3.5	30000

The larger β^* are useful during the commissioning period in order to reduce the difficulty of the system. The previous study also shows that there is some margin to lower the vertical IP beta function. Figure 1 shows the vertical sigma versus the vertical beta functions without including radiation effects. A minimum beam size of 20nm seems possible with the magnets and power supplies presently planned in the beam line (not considering potentially increased bremstrahlung background in the Shintake monitor from reducing β_x). Lattice aberrations dominate the beam size in the lower betas regime. MAPCLASS [4] has been used to achieve the minimum beam size. Achieving the CLIC IP beam sizes in ATF2 is not possible due to the difference in geometrical emittance, but the strategy, should be reducing the ATF2 betas to the lowest feasible values. This procedure leads us to experience with another important aspect: *the tuning difficulty* of the FFS. By tuning, we understand the process of bringing the system to its ideal performance under realistic conditions of lattice errors. The experience learned can be extrapolated to both CLIC and ILC.

TUNING PERFORMANCE VS β^*

It is expected that the tuning difficulty should roughly scale inversely to the beam size at the IP. Tuning simulations have been performed for three different IP vertical beta functions of ATF2. The simulation takes into account ground motion, H & V displacements, transverse rolls and mispowerings of the magnets. The Simplex-Nelder algorithm [7] is used to minimize the IP beam sizes. The results

Table 2: Tuning performance of the ATF2 ideal lattice for decreasing values of the vertical IP beta function.

case	Max. tuning time	Ratio of success
β_y=0.1mm	5.5 days	100%
β_y=0.05mm	8 days	90%
β_y=0.025mm	10 days	80%

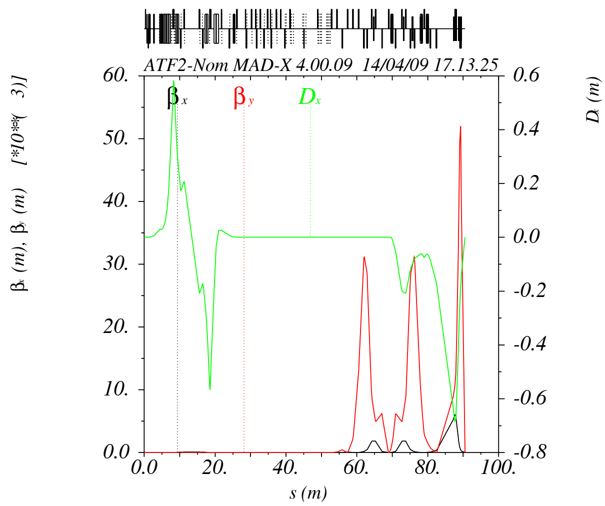

Figure 2: Nominal β_x, β_y and horizontal Dispersion D_x functions for the ATF2 ultra-low β proposal. It should be noted the present symmetry around 70m concerning β_y.

obtained are summarized in Table 2. Clearly, lower betas require more tuning time and show a lower success ratio. Improved algorithms will be used in the future in order to reach a better performance.

EFFECT OF MULTIPOLAR ERRORS

The ATF2 ultra-low initial β and dispersion functions, are presented in Fig. 2. The recently measured magnetic errors in (mainly in QF1 and QD0) have been added to the MAD model. This has considerably deteriorated the IP beam sizes. The size of the beam at the IP is computed using MAPCLASS [4]code. This code performs an order by order analysis allowing the identification of the most important contributions to the beam size. The horizontal normalized emittance $\epsilon_{x,n}$ is varied within the range [2.8μm,6.0μm], while the vertical normalized emittance $\epsilon_{y,n}$ is fixed at 3nm. From the results presented in Fig. 3 (top), it is clear that the fifth order (dodecapole error) is responsible of blowing up the beam size at higher emittances. In addition, a non-negligible contribution from the third order (octupole error) is present. A less important contribution comes from the second order, not shown on the graph. From the results presented in Fig. 3 (bottom), again the dodecapole error rises up considerably the σ_x as the horizontal emittance increases. And a negligible contribution from the rest of the orders is observed. This emittance blow-up is mostly due to the multipolar errors in QF1, where the

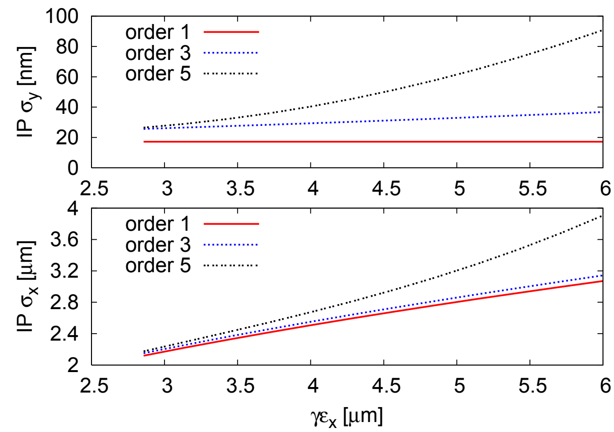

Figure 3: (top): Vertical beam size σ_y at the IP versus horizontal emittance for three different orders: first, third and fifth. Clearly the fifth order amplify dramatically the beam size.
(bottom): Horizontal beam size σ_x at the IP versus horizontal emittance

horizontal beam size is maximum. In order to reduce this growth either a new optics could be developed or a dodecapole magnet could be inserted nearby QF1.

MINIMIZING THE ERROR

Two possible solutions are proposed in this section. The first one is inserting a dodecapole in front of QF1. A scan over seven different strength values of the dodecapole magnet has been performed. The beam size versus the strength is presented in Fig. 4. The study is presented for two different horizontal emittances: $\epsilon_{x,n}$ =3.14μm and $\epsilon_{x,n}$=6.0μm. Parabolic curves fit the results allowing to obtain the minimum vertical beam size at the optimum dodecapole strength=1.6×10^6m^{-5}. At this strength, for

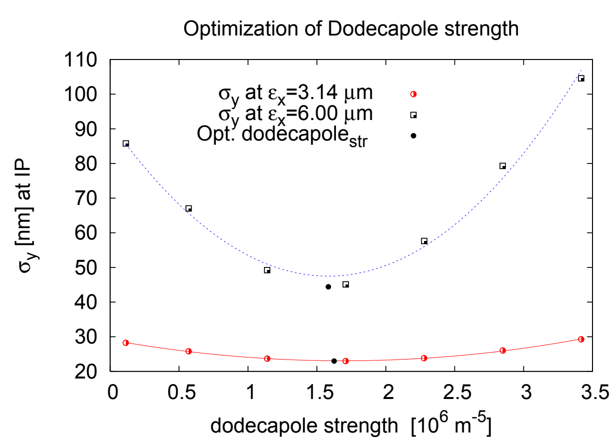

Figure 4: Qualitative study for the optimization of the dodecapole strength at lower and higher ϵ_x. Keeping the ultra-low beta lattice design unmodified. The black solid points mark the minimum σ_y at the IP for both cases.

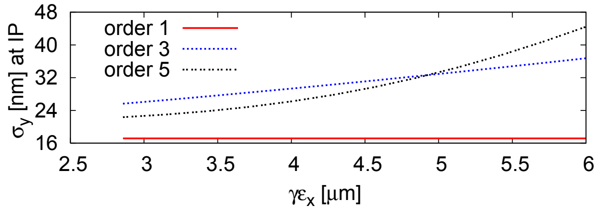

Figure 5: Resulting vertical beam size for the optimum dodecapole strength value at higher $\epsilon_{x,n}$.

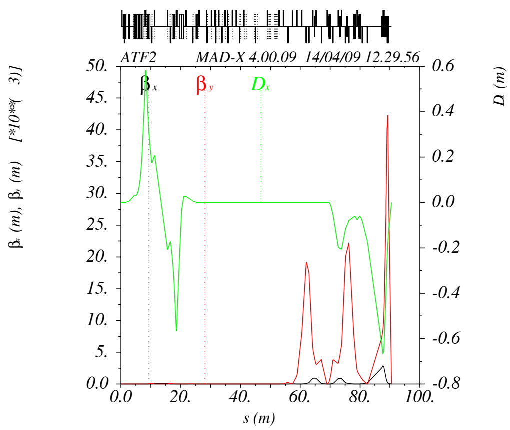

Figure 6: Representation of β_x and β_y as well as the horizontal dispersion D_x along the beam line.

$\epsilon_{x,n}$=2.85 μm, the vertical beam size is 22.36 nm, but for $\epsilon_{x,n}$=6.0 μm, the vertical beam size is 44.43nm, which is not satisfactory. As Fig. 5 shows, the dodecapole magnet can compensate the octupoloar error for lower emittance, but no longer for higher ones, where there is still large octupolar aberrations. Therefore an octupole magnet would also be required to better cancel the aberrations.

The second solution consists in reducing the beam size at QF1 by modifying the optics. MADX and MAPCLASS allow a matching for the quadrupoles and sextupoles strengths, in order to reduce the σ_y at the IP. For this purpose no constraints are given to the horizontal β functions. The results obtained are presented in Fig. 7, with the new β_x^*=8.3mm, and β_y^*=31.6μm. Approximately σ_y has been reduced 3.5 times and it is worth mentioning that also the octupolar component has been reduced. On the contrary, σ_x has increased a factor of $\sqrt{2}$ due to the increase of β_x^*. The β functions and the dispersion along the FFS for the new lattice are plotted in Fig. 6. It is important to notice the symmetry breaking of β_y around 70m with respect to the nominal β_y plotted in Fig. 2.

CONCLUSIONS

The progress on the ultra-low β proposal has been presented. It has been shown through simulations that the tuning time increases for smaller IP beam sizes. The measured multipolar errors considerably increase the IP beam sizes.

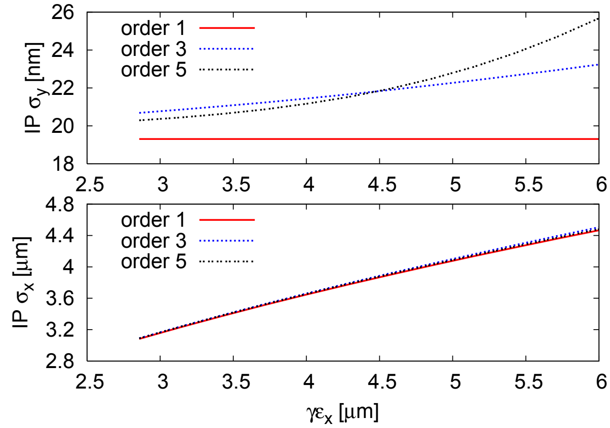

Figure 7: (top): Vertical beam size σ_y at the IP versus horizontal emittance for three different orders:quadrupolar, octupolar and dodecapolar. (bottom): Horizontal beam size σ_x at the IP versus horizontal emittance for the same orders.

The most satisfactory solution to minimize the effect from the multipolar errors is to change the IP beta functions to β_x^*=8.3mm, and β_y^*=31.6μm. This lattice features an IP vertical beam size of 25.67nm. In order to achieve similar levels of minimization by using extra non-linear magnets, both a dodecapole and an octupole magnet should be used.

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