SCENARIOS FOR THE ATF2 ULTRA-LOW BETAS PROPOSAL

E. Marín, R. Tomás (*CERN*), B. Parker (*BNL*), P. Bambade (*LAL*), S. Kuroda, T. Okugi, T. Tauchi, N. Terunuma, J. Urakawa (*KEK*), A. Seryi, G. White, M. Woodley (*SLAC*)

Abstract

The current ATF2 Ultra-Low beta proposal was designed to achieve 20nm vertical IP beam size without considering the multipolar components of the FD magnets. In this paper we describe different scenarios that avoid the detrimental effect of these multipolar errors to the beam size at the interaction point (IP). The simplest approach consists in modifying the optics, but other solutions are studied as the introduction of super-conducting wigglers to reduce the emittance or the replacement of the normal-conducting focusing quadrupole in the Final Doublet (NC-QF1FF) with a super-conducting quadrupole one (SC-QF1FF). These are fully addressed in the paper.

INTRODUCTION

ATF2 is a test facility with the aim of testing the FFS design that has been proposed in [1]. To prove the CLIC 3TeV chromatic level, it has been proposed the ATF2 ultra-low β^* [2] lattice in which the β_y^* has been reduced by a factor of 4 with respect to the ATF2 β^* designed one, see Tab. 1.

The ILC project and the ILC low-power [3], would also strongly benefit from this test, in particular by gaining experience in exploring larger chromaticities and facing increased tuning difficulties for this smaller beam size.

The ATF2 UL β^* Proposal aims for a vertical beam size close to 20nm if no errors are considered. At this chromaticity level, the lattice aberrations dominate the beam size at the IP. In fact, when the measured multipolar components of the current final doublet are considered in the simulations, the horizontal IP beam size (σ_x^*) increases considerably, and the vertical IP beam size (σ_y^*) suffers from a dramatic increase as the horizontal emittance ϵ_x increases. The plot in Fig. 1 shows this undesired situation.

These values of σ_x^*, σ_y^* are obtained as rms values, however in ATF2, a beam shintake monitor (BSM) is installed at the IP in order to measure the nanometer beam, see [4]. The beam size obtained by the BSM is smaller than the RMS, because the tails are less weighted in the calculation, this effect is even more accentuated when the beam is measured fitting a Gaussian, the last method is named the core method.

The MAPCLASS code [6] is a very useful tool that allows to study the beam properties order by order. It shows that both, octupolar and dodecapolar skew components of the final doublet focusing quadrupole (QF1FF) are the responsible for this behaviour, as can be seen from Fig. 1.

Table 1: Relevant parameters of the different projects [7, 8, 9, 10]. 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$^*/\beta_y^*$, not shown but the β_x values are equally scaled between the FFSs. 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

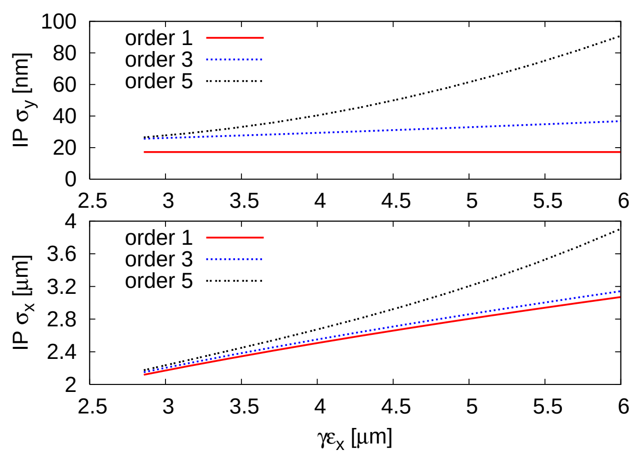

Figure 1: (top):Vertical beam size σ_y at the IP versus horizontal emittance for three different orders:first, third and fifth. Clearly the fifth order amplify dramatically the beam size. (bottom):Horizontal beam size σ_x at the IP versus horizontal emittance

DIFFERENT SCENARIOS

To overcome the described problem, different solutions can be considered:

- To use super-conducting quadrupole
- To run the machine at lower horizontal emittance
- To reduce the β-function at QF1FF

Super-conducting quadrupole

The super-conducting magnet has a better performance than the normal-conducting ones, taking advantage of the

Table 2: Normal (b_i) and skew (a_i) harmonics of integral field quality at 10mm radius for the normal and superconducting quadrupole.

n-pole	SC-Quadrupole		NC-Quadrupole	
	$b_i[10^{-4}]$	$a_i[10^{-4}]$	$b_i[10^{-4}]$	$a_i[10^{-4}]$
2	-	-	-	-
4	10^4	-	10^4	-
6	0.49	-0.49	-2.72	-0.28
8	-0.2	-0.35	-0.573	-0.04
10	0.025	-0.016	-1.26	0.19
12	0.018	0.001	-3.47	0.77

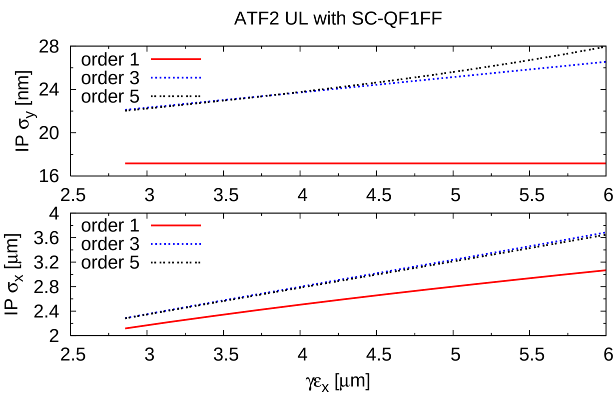

Figure 2: (top): Vertical beam size σ_y at the IP versus horizontal emittance for three different orders:first, third and fifth.(bottom): Horizontal beam size σ_x at the IP versus horizontal emittance

winding construction scheme. This allows at every construction stage to measure the present components and to adapt the following windings to minimise or emphasise specific components. BNL is designing a dedicated superconducting quadrupole and sextupole for ATF2, see [5]. In the last measurement data, excellent results were obtained, which are summarised and compared to the normal-conducting multipoles in Tab. 2.

Modelling these multipoles, and after re-matching the sextupoles strengths by MADX, the obtained results are presented in Fig. 2.

Horizontal emittance reduction

In the ATF2 proposal it has been foreseen to run the machine at a horizontal emittance value equal to 2.3nm in order to satisfy the beam Shintake monitor intensity requirement. If a lower emittance is desired without reducing the intensity, a super-conducting wiggler could be inserted in the damping ring for this purpose. In this sense an specific study was carried out for the ATF damping ring, see [11]. In this study two situations were considered, the insertion of 1 Wiggler of 4 Tesla in which the horizontal emittance was reduced down to 1.6nm. In the second case, the insertion of two Wigglers of the same strength reduced the horizontal emittance down to 1.2nm.

Applying these new emittance values to the ATF2 Ultra-Low with the normal-conducting or the super-conducting QF1FF, the obtained beam sizes are plotted in Fig. 3.

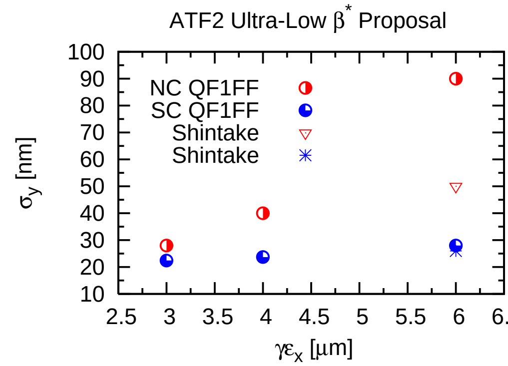

Figure 3: Red and blue points correspond to σ_y at the IP for different $\gamma\epsilon_x$, implementing a normal-conducting or superconducting QF1FF respectively. The inverted red triangle and the blue asterisk represent the respectively simulated Shintake monitor measurements at higher horizontal emittance.

Reducing the β_x-function at QF1FF

The strategy to design an effective lattice, is to reduce the β_x-function at QF1FF by half, thus the impact of the QF1FF multipoles on the IP beam size is reduced. However, the horizontal beam size at the IP increases a factor $\sqrt{2}$, since a parabolic behaviour describes the β-function along the drift between the FD and the IP.

To work out the new lattice, all quadrupoles and sextupoles strengths of the Final Focus are matched using MADX and MAPCLASS-CODE to reach the new β^* value. In order to reduce the σ_y at the IP, no constraints are given to the β,α,η, functions at the IP. The obtained results are presented in Figure 4, 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. Further information can be found in [12]

TUNABILITY OF THE ULTRA-LOW β_Y^*

As the vertical β^*-function is reduced the chromaticity rises up, therefore the *tuning difficulty* of the FFS increases. The tuning procedure is the process of bringing the system to its ideal performance under realistic lattice errors conditions.

A statistical study formed by a hundred of seeds of the ATF2 ultra-low β^* has been carried out, where the following Gaussian random distribution has been assumed:

- Transverse misalignment: 30 μm to all magnets.
- Tilt: 50 μrad for the final doublet magnets.
  300 μrad for sextupoles.
  100 μrad for quadrupoles

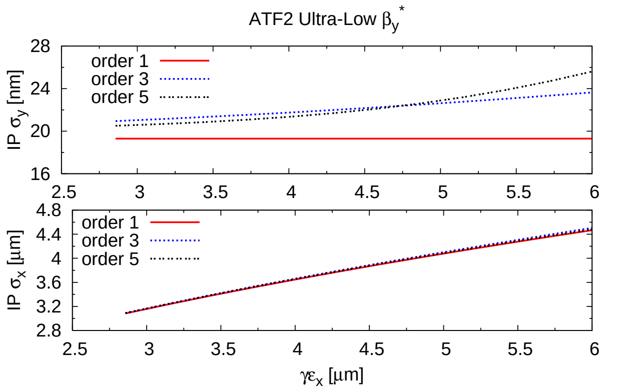

Figure 4: (top):Vertical beam size σ_y at the IP versus horizontal emittance for three different orders:quadrupolar, octupolar and dodecapolar. (bottom):Horizontal beam size σ_x at the IP versus horizontal emittance for the same orders.

- Strength: 10^{-4} relative error to all magnets.

In order to perform as a real tuning as possible, the vertical beam size is evaluated in terms of a convolution between the shintake monitor interference field and the beam profile. A 10% random error is assigned to the σ_y^* obtained value.

Starting from this initial configuration, the tuning algorithm consists on the following steps:

- Optimisation of misalignments and tilts
- Dispersion correction: η_x, η_y
- Coupling correction: $< x, y >, < x, py >$
- Optimisation of magnet strengths

These steps are iterated several times to assure the convergence of the system. The corrections of dispersion and coupling, are carried out using dedicated knobs in order to speed up the tuning process.

The results are presented as histograms in Fig. 5, and summarized in Tab. 3.

Table 3: Tuning results in terms of different methods.

method	% seeds	$\leq \sigma_y^*$[nm]
RMS	80%	35
Shintake	80%	30
Core	80%	28

CONCLUSIONS

The progress on the ATF2 ultra-low β^* proposal has been presented. It has been shown three different possible solutions to overcome the multipoles issue, namely emittance reduction, use of a super-conducting quadrupole and ATF2 ultra-low β_y^* lattice.

The first two solutions require cryogenics equipment, this traduces into a significant increment cost.

The third solution has none cost increment, but since the lattice has been modified, it differs from the scaled ILC and

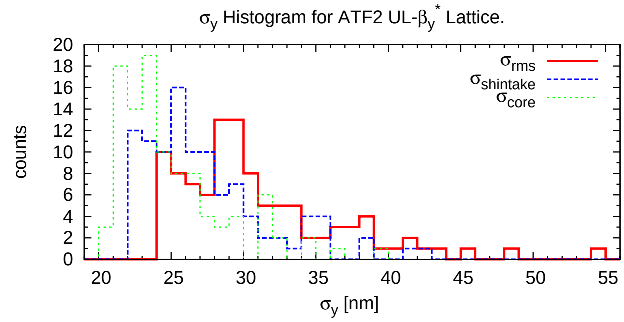

Figure 5: Histogram of the final σ_y^*. In continuous-red colour: in terms of rms, in discontinuous-green colour: in terms of the shintake monitor and in dashed-blue colour: in terms of a Gaussian fit.

CLIC horizontal β functions, which indeed is an undesired situation.

Referring to the tunability of the developed lattice and according to σ_y^* and number of required iterations for convergence (≈17000), the results are not satisfactory, therefore an improvement of the algorithm is needed. In this sense the development to intermediate lattices is ongoing in order to easily reach the goal. The following step in the tuning is to include the ground motion into simulations and to crosscheck the results with PLACET [13].

REFERENCES

[1] P.Raimondi and A.Seryi, Phys. Rev. Lett.**86**, 3779-3782
[2] D. Angal-Kalinin et al, "Exploring ultra-low β^* values in ATF2 -R&D Programme proposal", CARE/ELAN Document-2008-002. Networking/N2/ELAN/Documents/2008/ELAN-Document -2008-002.pdf
[3] A. Seryi et al "POWER SAVING OPTIMIZATION FOR LINEAR COLLIDER INTERACTION REGION PARAMETERS", SLAC-PUB-13767.
[4] Y. Honda et al, "Shintake BSM and gamma detector" at the Fifth ATF2 project meeting: http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=1806
[5] Brett Parker *et al*, "A Superconducting Magnet Upgrade of the ATF2 Final Focus" in these proceedings.
[6] R. Tomás, "MAPCLASS: a code to optimize high order aberrations" CERN AB-Note-2006-017 (ABP), and "Nonlinear Optimization of Beam Lines", Phys. Rev. ST Accel. Beams **9**, 081001 (2006).
[7] P. Tenenbaum "Expanded Studies of Linear Collider Final Focus System at the Final Focus Test Beam", SLAC-R-475.
[8] "CLIC parameters" 2008, to be published.
[9] ILC Reference Design Report:http://lcdev.kek.jp/RDR/
[10] D. Schulte, "Beam-Beam Simulations of the Proposed ILC Parameters", EUROTeV-Memo-2005-004-1.
[11] Y.Papaphilippou, "Emittance reduction by a SC Wiggler in the ATF-DR", ATF2 weekly meeting, September 2009
[12] R.Tomás et al., "ATF2 Ultra-Low β^* Proposal" in Proceedings of PAC09
[13] D. Schulte. "The Tracking Code PLACET". http://home.cern.ch/dschulte/placet.html.