Focusing to nm beam sizes

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Project	Status	σ_y^* [nm]	ξ_y [10^4]
FFTB	Measured	70	1
ATF2	Commissioning	37	1.9
ATF2 ultra-low β	Proposed	20	7.6
ILC	Design	6	1.5
ILC low power	Alternative	4	3
CLIC	Design	1	6.3

Table 1: Vertical IP beam sizes and vertical chromaticities for different projects. Chromaticity is computed from the elements of the transfer matrices as $(T_{346}R_{33} - T_{336}R_{34})/\sqrt{\beta_y^*}$.

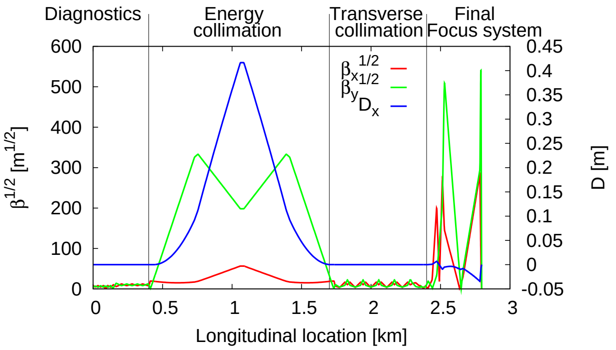

Figure 1: Optics functions along the CLIC BDS.

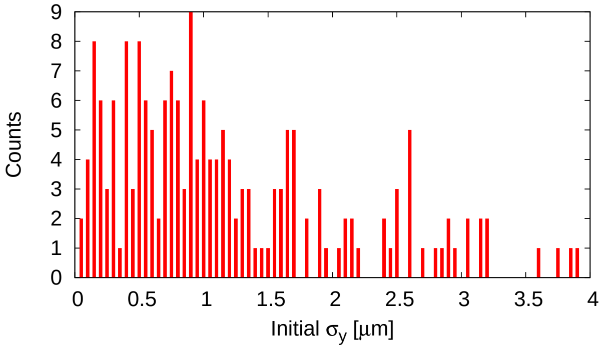

Figure 2: Probability distribution of the CLIC vertical IP beam size assuming realistic beam line imperfections.

ISSUE

Future linear colliders require Final Focus Systems (FFS) of unprecedented demagnification factors. This causes large chromatic aberrations that need to be compensated with strong sextupoles, which in turn generate geometric aberrations that require special arrangements of these sextupoles. The traditional design of such FFS consisted of two sections. The first section hosted the sextupoles compensating the chromatic aberrations generated by the second section containing the Final Doublet (FD). A more compact design was presented in [1] featuring a local chromaticity correction by placing the sextupoles at the source of the aberration, i.e., at the FD. The CLIC Final Focus System (FFS) is based on this local chromaticity correction scheme. However, residual aberrations of higher order were still limiting the performance of the CLIC FFS with target vertical IP beam size in the nm level. It was required to add extra non-linear elements, like octupoles and decapoles, to better cancel residual aberrations [2]. Table 1 reports the vertical IP beam size and the vertical chromaticity of various projects, being CLIC the most challenging.

In order to provide collisions with an acceptable background level it is mandatory to collimate the beam halo that would otherwise directly irradiate the detector or impact machine components. This is achieved within the collimation section preceding the FFS. Figure 1 shows the optics functions through the CLIC Beam Delivery System (BDS) consisting of diagnostics, collimation and FFS sections.

R&D

Achieving nm beam sizes with the current FFS designs is mostly challenged by the static and the dynamic imperfections of a realistic beam line, mainly misalignments and field errors. Figure 2 shows the probability distribution of the CLIC vertical IP beam size assuming realistic beam line imperfections. The most likely value is about 1 μm, three orders of magnitude larger than the 1 nm from the ideal design. The static beam line imperfections must be compensated by using beam-based alignment and tuning techniques. The dynamic errors must be mitigated via the use of feedbacks. The validation of the entire process to reach the nm beam size is done both via computer simulations and experiments.

The experimental verification of this type of FFS is presently being investigated in the KEK ATF2 facility [4]. ATF2 contains a scaled-down version of the ILC FFS with a vertical IP beam size of about 37 nm. However the CLIC FFS has about 4 times more chromaticity than ILC or ATF2. An ATF2 R&D proposal has been made [5, 6] to reduce the ATF2 IP vertical beta function by a factor of 4. This proposal has a two fold motivation, reduce the IP vertical size as close as possible to ILC and CLIC values,

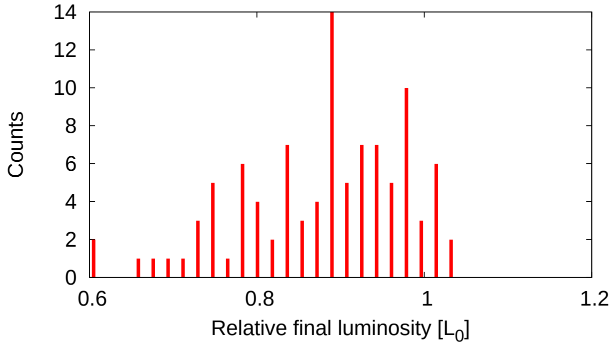

Figure 3: Probability distribution of the CLIC luminosity after tuning for a maximum of 18000 iterations.

see Table 1, and prove the CLIC chromaticity levels.

The ultra-low β^* proposal for ATF2 will also serve to investigate the difficulty of tuning the FFS for different IP beam sizes. This might allow extrapolations to the smaller beam sizes of ILC and CLIC. Simulations show that tuning difficulty increases for smaller IP beam sizes [6]. ATF2 is presently under commissioning and it is expected that first experimental data from ATF2 at relevant IP beam sizes will come before mid 2011.

ACHIEVEMENTS

Montecarlo simulations of the FFS tuning are performed to estimate the probability of success in achieving nominal parameters. The variables used during the tuning are the transverse displacements and the strengths of the FFS quadrupoles and sextupoles. The figure of merit to optimize is the luminosity. After a maximum of 18000 iterations 80% of the seeds reach 80% of the design luminosity, see Fig. 3. This result is encouraging but it is not fully satisfactory. It is desired that 90% of the seeds reach 90% of the luminosity. To this aim a large effort has been started during 2010 in which collaborators from different laboratories are sharing and comparing different alignment, tuning and feedback algorithms [10]. A first very important result was the combination of the IP feedback and the beam-based alignment techniques to estimate the machine performance at the steady state. A 59% of the design luminosity in the energy peak is achieved without having assumed any special stabilization of the final doublet.

Due to the nanometric IP beam size CLIC faces the challenge of the sub-nanometer stabilization of the last FFS quadrupole (QD0). In order to loose less than 2% luminosity the vertical jitter of QD0 has to be below 0.15 nm (for frequencies above 4 Hz) with the extra complication that QD0 is embedded in the detector at 3.5 m from the IP. There are very promising experimental results showing stabilization to these levels via active ground isolation and structure resonance rejection techniques in a laboratory environment, see Fig. 5 taken from [7]. The CLIC stabilization working group conducts the research in order to find solutions in the detector environment.

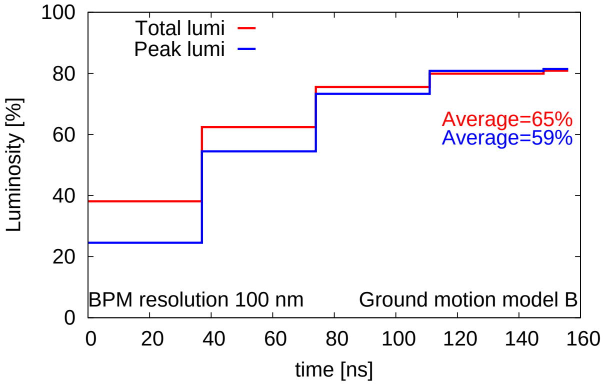

Figure 4: Performance of the IP feedback combined with beam-based alignment techniques.

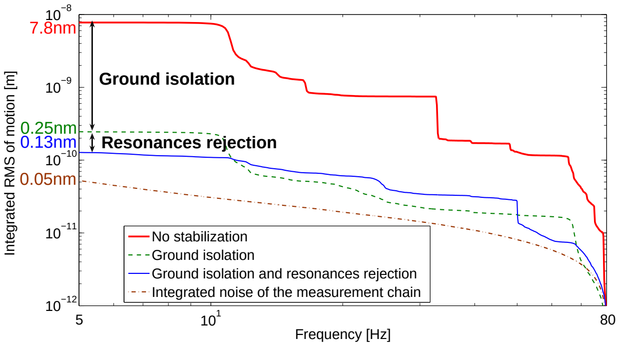

Figure 5: Demonstration of stabilization to the sub-nanometer level via ground isolation and structure resonance rejection in a quiet environment [7].

A way to considerably ease the stabilization requirement and difficulty would be to move QD0 out of the detector, thus allowing to support it on the ground [8]. Initially this required increasing L^* to 8 m and a consequent reduction of the design luminosity by 28% [9]. However, recent developments of the experiment allowed for a reduction of the end cups by 2 m. A new lattice has recently been developed with an L^*=6m that would feature only a 16% peak luminosity loss with respect to the current design (L^*=3.5 m). Table 2 displays all the existing CLIC FFS lattices with their luminosity performance. It is clear from the table that longer L^* implies lower luminosity. The new lattice with L^*=6m has proved to tune in a similar success ratio as the current design (80% of the seeds reaching 80% of the luminosity). Therefore this lattice becomes a very attractive alternative in the case that the QD0 stabilization becomes impossible.

REFERENCES

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L* $[m]$	Total luminosity $[10^{34} cm^{-2} s^{-}1]$	Peak luminosity $[10^{34} cm^{-2} s^{-}1]$
3.5	6.9	2.5
4.3	6.4	2.4
6	5.0	2.1
8	4.0	1.7

Table 2: Total and Peak luminosities for different lattices with increasing L*.

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