

TWO-BEAM TUNING IN THE CLIC BDS

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Abstract

Beam tuning in the beam delivery system (BDS) is one of the major challenges for the future linear colliders. In those colliders, due to fast detuning of the final focus optics both beamlines will need to be tuned simultaneously. An initial two-beam tuning study for the Compact Linear Collider (CLIC) BDS had been performed, but was not fully satisfactory. In this paper a more extensive study is presented, as well as several improvements to the tuning algorithm. A comparative study between two competing CLIC final focus systems (FFS), the traditional and the compact FFS, will be discussed.

INTRODUCTION

CLIC

CLIC is an international study for a potential future linear lepton collider, colliding positrons and electrons at up to 3 TeV centre of mass energy [1]. The design is based on normal conducting elements, making use of a novel two-beam acceleration scheme in order to have a reasonable power consumption. CLIC requires a small vertical emittance, and the beam size at the interaction point (IP) must be in the nanometer range to achieve its nominal luminosity. This is an unprecedented small beam size for linear colliders, which imposes strict alignment tolerances for the machine. The pre-alignment has a transverse misalignment requirement of about 10 μm (also called static imperfections), while the dynamic imperfections can only be fractions of a nm for the most sensitive magnets [2].

Final Focus Systems for CLIC

One of the main tasks of the CLIC BDS is to focus the beam to the small sizes required at the IP. To achieve this, the last part of the BDS, the Final Focus System (FFS), forms a large and almost parallel beam at the entrance of the Final Doublet (FD), which contains two strong quadrupole lenses. For the nominal energy, the beam size at the IP is $\sigma = \sqrt{\beta^* \epsilon}$, where ϵ is the beam emittance and β^* is the betatron function at the IP. However, for a beam with an energy spread σ_δ , the beam size is diluted by the chromaticity of these strong lenses. The chromaticity is defined as:

$$\xi = \frac{d\beta^*/\beta^*}{dE/E} \quad (1)$$

and it scales approximately like $\xi \sim \frac{L^* + L_q/2}{\beta^*}$, where L^* is the distance from the IP to the last quadrupole and L_q is the quadrupole length. Thus the chromatic dilution of the beam size, $\sigma_\delta \frac{L^* + L_q/2}{\beta^*}$, may be very large. The design of the

FFS is driven primarily by the necessity of compensating the chromaticity of the final doublet.

There are two different approaches to the compensation of the chromatic effects: the traditional scheme, based on dedicated chromatic correction sections for each plane [3]; and the local correction scheme, based on the local correction of the chromaticity [4] using extra higher order magnets for the cancellation of aberrations [5]. In Table 1 the key parameters are shown for both approaches. While the total luminosity is slightly higher for the local scheme, the luminosity for the particles within 1% of the design energy is similar for both schemes. The main difference is the considerable longer length for the traditional FFS.

Table 1: Key Parameters for the Traditional and Local FFS

Parameter	Unit	Local	Traditional
Total lumi.	$10^{34} \text{cm}^{-2} \text{s}^{-1}$	7.8	7.5
Peak (1%) lumi.	$10^{34} \text{cm}^{-2} \text{s}^{-1}$	2.4	2.4
Beam energy	TeV	1.5	1.5
L^*	m	3.5	3.5
Total length	m	447	1503

BEAM TUNING STATUS

The correction of the static imperfections of the FFS is not straightforward. Besides the challenging target specifications, the synchrotron radiation caused by the high beam energy creates a highly non-linear correction response. Advanced simulations have been developed in order to try to achieve the required tuning performance [6, 7]. The baseline design allows for a 10% reduction of the luminosity due to static imperfections (compared to a theoretical perfectly aligned machine), and another 10% reduction from dynamic imperfections. For the local scheme the best results are achieved using a combination of beam-based alignment techniques (BBA), a simplex algorithm optimising the luminosity, and orthogonal sextupole knobs [6, 8]. For the traditional scheme it was shown in [3] that this scheme is easier to tune than the local one and does not require the simplex algorithm which needs a large number of luminosity measurements. Some of these techniques have been applied successfully at the Accelerator Test Facility 2 (ATF2) [9], which is a single beamline scaled demonstrator of the local correction FFS for both the International Linear Collider (ILC) [10] and CLIC.

Motivation for Two Beam Tuning Studies

In the beam tuning simulation studies and experiments performed so far, beam tuning has been performed with a single beamline. For the luminosity determination in simulation the beam is collided with its mirror image with opposite charge. This is done to reduce the simulation time. However, in future linear colliders, due to fast detuning of the final focus optics, both beams will need to be tuned simultaneously. As self-collision is often optimal, the luminosity at the start of the tuning will be lower when simulating two beamlines compared to a single beamline. And since the luminosity measurement is typically less precise for lower luminosity, tuning with both beamlines might take considerably longer time than for each beamline individually.

The possible increased number of tuning iterations is a concern since depending on the ground motion model, CLIC loses up to 10% of luminosity in 1 hour even with a ground motion optimised orbit feedback system [11]. Therefore, beam tuning needs to be performed almost continuously and a fast beam tuning procedure and therefore fast luminosity measurement are essential. CLIC can measure luminosity with a 1% precision in 20 trains by looking at the hadronic pair production [6].

Initial two beam simulations for the local scheme were encouraging, but more studies were definitely needed [12].

Tuning Procedure

For the tuning studies, static misalignments of all BDS magnets and beam position monitors (BPMs) are assumed with a normal distribution and a standard deviation of 10 μm and BPM resolutions of 10 nm. The following single beam tuning procedure is applied, which is an improved version [13] of the one applied in earlier studies [6, 12] and consists of the following steps:

- BBA
 - 1-to-1 correction
 - Target Dispersion Steering (Dispersion Free Steering (DFS) like method) to correct the dispersion.
- Sextupole knobs
 - First iteration of sextupole knobs
 - Hybrid DFS Knobs
 - Second iteration of sextupole knobs
 - Second order sextupole knobs

The tuning procedure is split in two parts. The first part uses the BPM signals as inputs to the BBA techniques. It can be performed simultaneously for both beams. For the first two steps, the 1-to-1 correction and first iteration of DFS, the multipoles are switched off. The second part of the tuning procedure consists of varying the position of the last five sextupoles in the FFS. For each beamline there are ten independent orthogonal sextupole knobs. Since the luminosity signal is used for optimisation, each beam has to

be optimised separately. For two beam tuning the beams are alternated after each sextupole knob to reach a high and precise luminosity signal quickly. For most of the misalignment seeds, two or more additional iterations of sextupole knobs are beneficial. The second order sextupole knobs consist of scanning the strength of the individual sextupoles. These second order sextupole knobs improve on average the luminosity by about 3% when the luminosity is already more than 60% of the nominal luminosity. The simplex algorithm has not been chosen due to the large number of iterations that it requires, but may be studied later if needed. The tuning steps are explained in more detail in [6] and [8]. A discussion on the hybrid DFS knobs can be found in [13]. To speed up the tuning simulations, an automatic centering of the beams, which means an almost ideal IP feedback system, has been assumed.

RESULTS

The results show and compare the tuning results for the local and traditional FFS for both single beam tuning and two-beam tuning. For each FFS, 110 different alignment seeds are studied with the beam tracking code PLACET [14] and the code Guinea-Pig [15] for the beam-beam interaction and luminosity calculation. Since the simulations for the local scheme have not yet been performed using the improved tuning procedure, the results for both the improved tuning procedure and the previous tuning procedure are shown for the traditional scheme, allowing for a more fair comparison of the procedure. The results are shown for a full iteration of the tuning procedure and for four iterations of sextupole knobs. The fourth iteration corresponds roughly to about 1700 luminosity measurements for single beam tuning and twice that for two beam tuning.

Single Beam Tuning

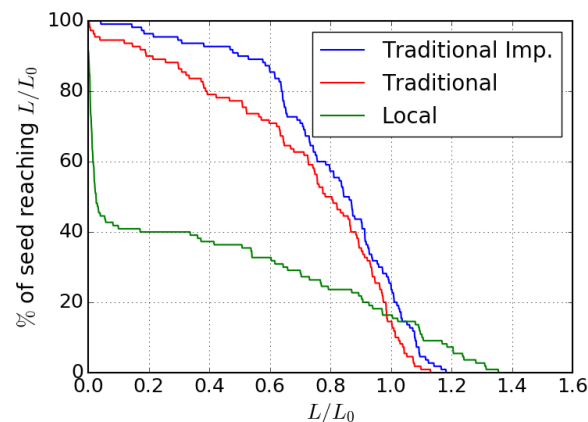


Figure 1: The survival plot for the single beam tuning after the first iteration of the tuning procedure. The vertical axis shows the cumulative percentage of machines reaching a given luminosity.

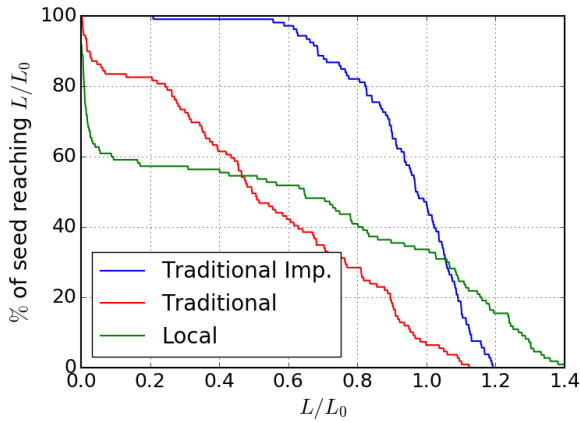


Figure 2: The survival plot for the single beam tuning after the fourth iteration of the tuning procedure.

Figures 1 and 2 show the survival plot for the single beam tuning after the first iteration and fourth iteration respectively. It can be seen that after one iteration the traditional scheme has a better performance than the local scheme, which confirms the results of [3]. The local scheme has a large number of seeds that have a very low luminosity, but also about 20% that achieve a larger luminosity than any of the traditional scheme seeds. Also the local scheme improves more in the subsequent iterations, while the traditional scheme performs worse in the fourth iteration compared to the first, see [13] for a detailed explanation. The improved tuning procedure is designed such that it does not degrade its performance and improves continuously. The improved tuning procedure performs better and almost all seeds reach 60% of the nominal luminosity after four iterations for the traditional scheme.

Two Beam Tuning

Figures 3 and 4 show the survival plot for the two beam tuning after the first iteration and the fourth iteration respectively. It can be seen that the performance is considerably lower than the single beam case with a large number of seeds reaching almost no luminosity. However, more iterations of the tuning procedure improve the results. It is expected that more iterations will still improve the luminosity since most seeds have reached 5% of the nominal luminosity at which point more iterations of the sextupole knobs will generally improve the luminosity as was shown for the single beam tuning. The fourth iteration has yet to be performed for the local scheme.

CONCLUSIONS AND OUTLOOK

The current status of the single and two beam tuning studies for CLIC has been presented for two competing final focus schemes. The local scheme is the CLIC baseline and has a compact lattice which reaches a higher total luminosity. The traditional scheme is longer and is less sensitive to beam aberrations, and therefore easier to tune. The tuning procedure has been improved and the number of luminosity

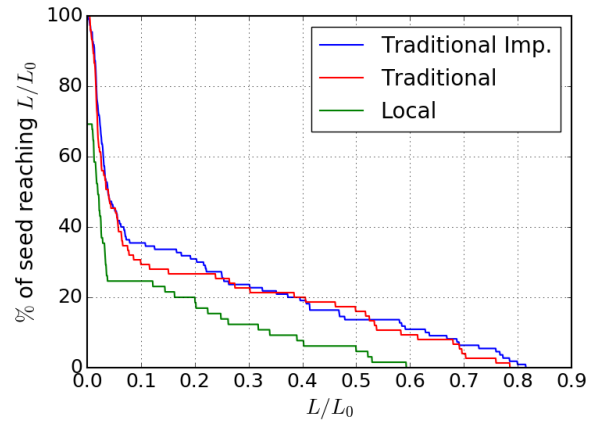


Figure 3: The survival plot for the two beam tuning after the first iteration of the tuning procedure.

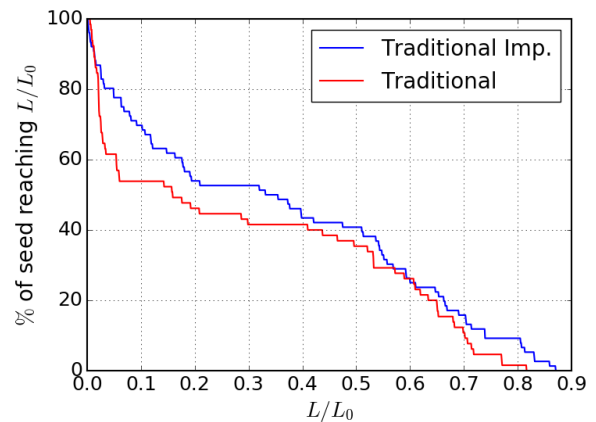


Figure 4: The survival plot for the two beam tuning after the fourth iteration of the tuning procedure.

measurements has been reduced. For single beam tuning the traditional scheme performs better than the local scheme for most seeds but does not reach as high a luminosity as some of the seeds for the local scheme. About the same percentage of seeds for both schemes reach the goal of 110% of the nominal luminosity. For two beam tuning the traditional scheme seems to perform better, but for a full comparison more tuning iterations need to be performed for the local scheme. While the results have been improved compared to previous studies, more improvements are needed and these studies will be continued.

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