INTRA-BEAM IP FEEDBACK STUDIES FOR THE 380 GEV CLIC BEAM DELIVERY SYSTEM

R. M. Bodenstein†, P. N. Burrows, John Adams Institute – University of Oxford, Oxford, UK
J. Snuverink, John Adams Institute – Royal Holloway University of London, Egham, UK
F. Plassard, CERN, Geneva, Switzerland

Abstract

In its currently-envisaged initial stage, the Compact Linear Collider (CLIC) will collide beams with a 380 GeV center of mass energy. To maintain the luminosity within a few percent of the design value, beam stability at the interaction point (IP) must be controlled at the sub-nanometer level. To help achieve such control, use of an intra-pulse IP feedback system is planned. With CLIC's very short bunch spacing of 0.5 ns, and nominal pulse duration of 176 ns, this feedback system presents a significant technical challenge. Furthermore, as part of a study to optimize the design of the beam delivery system (BDS), several L* configurations have been studied. In this paper, we will review the IP feedback simulations for the 380 GeV machine for two L* configurations, and compare luminosity recovery performance with that of the original L* configuration in the 3 TeV machine.

INTRODUCTION

As part of the planned phased commissioning of the CLIC facility, an initial stage with an electron-positron collision energy of 380 GeV is under investigation. Being a new lattice with new requirements, the 380 GeV machine must be studied in detail, particularly in regards to the capabilities of the machine to deliver the required luminosity to the particle physics program.

In order to deliver maximal luminosity, a feedback (FB) system is required which interacts directly with the machine to correct perturbations of the beam from the nominal orbit. The beam delivery system (BDS), located in the region immediately adjacent to the interaction point of the collider, contains an IP feedback system (shown in Fig. 1, from [1]) which is capable of iteratively correcting the beam position several times within a single train, increasing the luminosity with each iteration.

There are several versions of the new 380 GeV lattice, two of which will be discussed in this paper. These versions differ in the distance between the final quadrupole and the IP, a distance called L*. In one version, the L* is 4.3 meters (identical to the 3 TeV lattice design from 2010 [1]). In the other, this distance has been increased to 6 meters.

In this paper, the authors will investigate the ability of the intratrain IP feedback system to recover the luminosity lost due to five different models of ground motion (GM). These results will be compared to those previously obtained by Resta López, et. al. [1, 2].

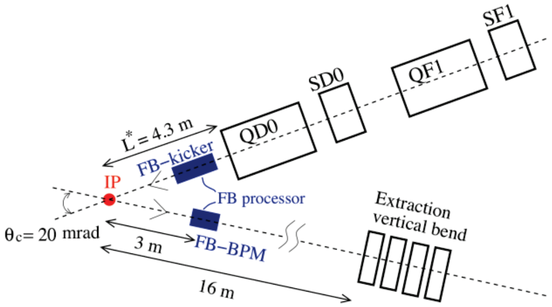

Figure 1: IP Feedback system at CLIC. L* is indicated.

BACKGROUND

In the previous studies for the 3 TeV system, the effects of 4 models of ground motion (A, B, C, and K) were investigated [3]. At this energy, the length of the train of particles was optimized to be 156 ns. Additionally, a BPM resolution of 1 μm was used for the simulations.

Using the simulation programs PLACET and GUINEA-PIG [4-6], 100 random seeds of ground motion were applied to the BDS and the luminosity recovery due to the IP feedback system was simulated. The FB BPM would detect the outgoing offset angle, which is directly related to the incoming position offset (see [1] for a full discussion). This signal is then sent to the electronics of the FB system, and the kick required to correct the beam offset is calculated and applied at the FB kicker, located upstream of the IP. Due to particle time of flight and electronic delays, a system latency of 37 ns is assumed [1]. Given this latency, and the 156 ns train length, the IP feedback system is capable of applying four iterations of corrections to the beam within a single train.

Figure 2 (from [1]) shows the average luminosity loss recovered at various IP kicker gain settings when 100 random seeds of GM model C are applied to the BDS. The error bars shown are the standard deviation divided by the nominal luminosity. The peak of this plot shows that the system can be corrected to better than 45% total luminosity loss from the initial 70% loss caused by the ground motion.

Figure 3 (from [1]) shows the performance of the IP FB system with the application of a single seed of GM model C to the BDS. In this case, the gain is chosen at the peak of the curve in Fig. 2. The nominal luminosity of this 3 TeV system is 6.223×10^{34} $\mathrm{cm^{-2}s^{-1}}$. The first iteration shows the greatest recovery in luminosity, with each successive iteration continuing to improve, but by smaller amount.

---

† ryan.bodenstein@physics.ox.ac.uk

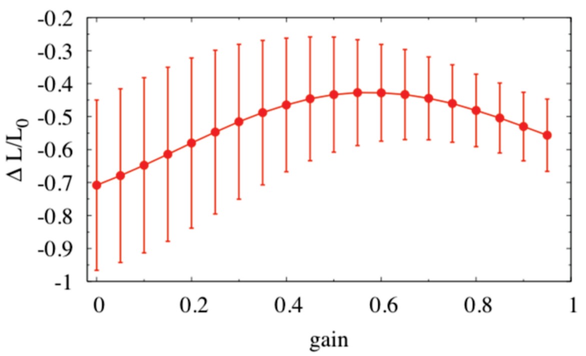

Figure 2: Relative luminosity loss vs. kicker gain.

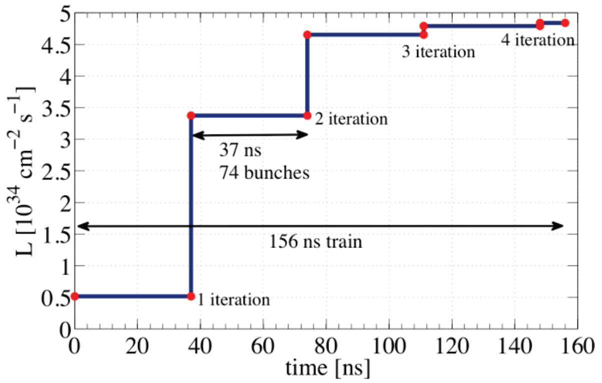

Figure 3: Luminosity recovery for single seed of GM.

CURRENT INVESTIGATION

Using the LinSim [7, 8] framework of PLACET and GUINEA-PIG, 5 GM models were investigated. In addition to the four models investigated previously, model D has been included in the study. Model D is a variation of model B with an amplified peak to match technical noise, and should be the worst case that the CLIC project would experience. However, in order to compare the previous studies with the present, the more extreme ground motion model C will be the focus of this work.

Determination of Gain

In a manner similar to that shown in Fig. 2, the value of the gain applied to the IP kicker is determined by simulating 100 random seeds of ground motion for each model. The value, or range of values, which shows the greatest luminosity recovery is used as the IP kicker gain setting for the final simulation of the IP feedback system.

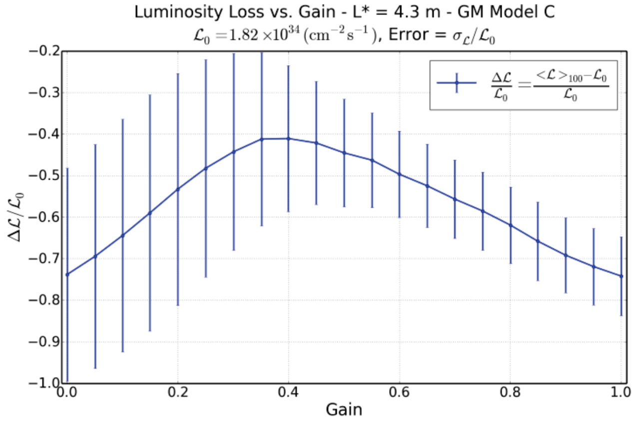
Luminosity Loss vs. Gain - L* = 4.3 m - GM Model C
$\mathcal{L}_0 = 1.82 \times 10^{34}\,(\mathrm{cm}^{-2}\mathrm{s}^{-1})$, Error = $\sigma_{\mathcal{L}}/\mathcal{L}_0$

Figure 4: Relative luminosity loss vs. kicker gain for the 380 GeV BDS with an L* of 4.3 meters.

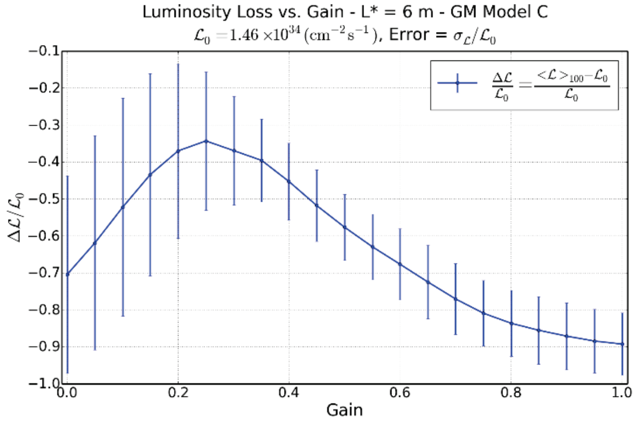
Luminosity Loss vs. Gain - L* = 6 m - GM Model C
$\mathcal{L}_0 = 1.46 \times 10^{34}\,(\mathrm{cm}^{-2}\mathrm{s}^{-1})$, Error = $\sigma_{\mathcal{L}}/\mathcal{L}_0$

Figure 5: Relative luminosity loss vs. kicker gain for the 380 GeV BDS with an L* of 6 meters.

Figure 4 shows the results of this gain scan for the 4.3 meter L* configuration in the 380 GeV machine under the application of GM model C. For this configuration, the maximum total luminosity is 1.82 × 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The highest luminosity recovery for this case is found at a gain setting of 0.4, which corresponds to a recovery of better than 42% luminosity loss from the initial loss of nearly 75%. For the 6 meter L* configuration under the application of GM model C, one can see from Fig. 5 that the peak luminosity recovery, corresponding to better than 35% luminosity loss from the initial 72%, occurs at a gain of 0.25. The maximum total luminosity for this configuration is 1.46 × 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

A similar process is performed for each of the ground motion models. For a more in-depth discussion regarding the determination of the IP kicker gain strength, including the mathematics and conversions required, please refer to the discussion in reference [1].

Luminosity Recovery

Using the gain value which corresponds to the highest recovery of lost luminosity, one can plot the luminosity against the time in the timeframe of one bunch train. This shows the effects of each correction iteration, just as in Fig. 3. However, rather than plotting the luminosity recovery for a single seed of applied GM model C, the average luminosity recovery from 100 random seeds of the same model are shown in Figs. 6 and 7. Furthermore, the shaded band around the average value represents the error on the mean. Figure 6 shows the recovery for the 4.3 meter L* configuration, where four distinct iterations can be seen within the length of one bunch train. Each iteration corresponds to an increase in luminosity. Figure 7 is the analogous plot for the 6 meter L* configuration. This procedure was completed for all five models of ground motion. The results are summarized in Table 1.

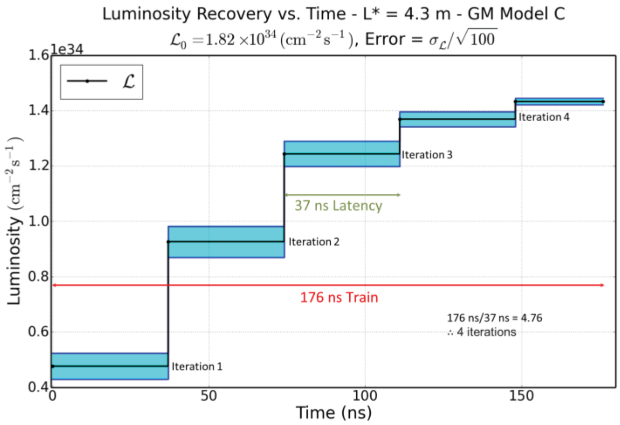

Figure 6: Luminosity recovery vs. time for the 380 GeV BDS with an L* of 4.3 meters.

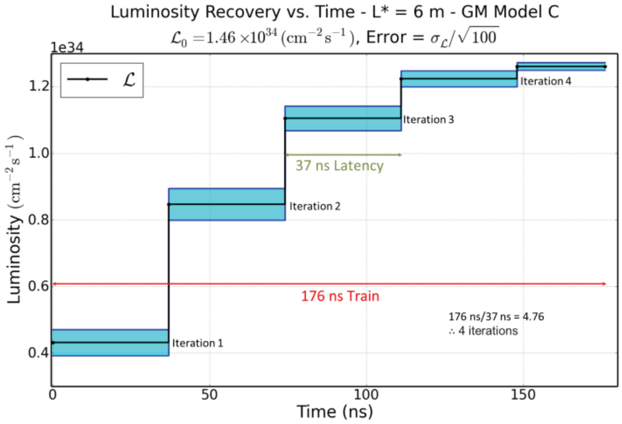

Figure 7: Luminosity recovery vs. time for the 380 GeV BDS with an L* of 6 meters.

Table 1: Comparison of Luminosity Loss After IP Feedback Correction for 5 GM models.

GM Model	3 TeV L* = 4.3 m (2010)	380 GeV L* = 4.3 m	380 GeV L* = 6 m
A	0.1%	0.1%	0.1%
B	3%	3%	3%
C	45%	42%	35%
D	No Data	9%	6%
K	35 %	20%	18%

RESULTS

Table 1 summarizes the results for the simulations of the IP feedback system for all 5 models of ground motion as applied to both configurations of the 380 GeV beam delivery system. It also compares these results to those from the 3 TeV study performed previously. All of the percentage values shown represent the average relative luminosity loss after recovery from the application of ground motion. The total luminosity recovery is better than the value shown.

Generally, the luminosity recovery due to the IP feedback system is able to achieve similar results for both 380 GeV configurations. Furthermore, these results are generally as good or better than those achieved in the 3 TeV study. The most marked improvement is in the case of GM model K, where both 380 GeV configurations improved by over 15% when compared to the 3 TeV luminosity recovery. Additionally, the 6 m L* configuration achieved more than a 10% improvement for GM model C over the 3 TeV system.

CHALLENGES

There are several challenges which must be addressed prior to expanding these studies. Two of these are:

- At times, the system converges to a near-maximal luminosity rapidly, and then continues to try correcting, leading to a decrease in luminosity. This has been observed in several models. Likely, this is due to the selection of a gain value which is slightly too high or too low. An extra step in the simulation process will be added to narrow down the proper gain setting prior to performing the luminosity recovery study.
- The beam distribution at the IP is not always an ideal case. The IP feedback system attempts to steer the beam offsets to the zero position. This will only achieve maximum luminosity under the assumption that the beam is distributed at the IP in a near-ideal manner. If the beam distribution is significantly different from the ideal case, collisions occurring with a slight offset could result in higher luminosities than collisions with a zero beam offset. To address this, the feedback system would need to have a method to steer to positions obtaining maximum luminosity rather than the zero position, or the beam would need to be tuned to a more-ideal distribution. Addressing this issue is a more complex challenge than the previous.

FUTURE WORK

The authors intend to expand upon this work in the future by addressing several challenges. Combining misalignments and adding more complex perturbations and realistic conditions are the obvious expansions to the current studies. However, correcting the electron and positron beamlines independently presents a much larger task, and will be addressed. Furthermore, more complex correction schemes, which are capable of greater corrections to the beam in a fewer number of iterations, shall be investigated.

ACKNOWLEDGEMENT

Many thanks to Javier Resta López for his time and assistance in this work. Additional thanks to the CLIC project and the Feedback On Nanosecond Timescales (FONT) project.

REFERENCES

[1] J. Resta López, P.N. Burrows, G. Christian, “Luminosity Performance Studies of the Compact Linear Collider with Intra-train Feedback System at the Interaction Point”, *Jour. Inst.*, Vol. 5, Iss. 09, p. 9007 (2010).

[2] J. Resta López, P.N. Burrows, “The Beam-based Intra-train Feedback System of CLIC”, in Proc. IPAC’10, Kyoto, Japan, May 2010, paper WEPEB045, pp. 2791-2793.

[3] A. Seryi, L. Hendrickson, G. White, “Issues of stability and ground motion in ILC”, SLAC-PUB-11661 (2006).

[4] Placet-project, `http://clicsw.web.cern.ch/clicsw/`

[5] A. Latina, Y. Levinsen, D. Schulte, J. Snuverink, “Evolution of the tracking code PLACET”, in Proc. IPAC2013, Shanghai, China, May 2013, paper MOPWO053, pp. 1014-1016.

[6] D. Schulte, “Study of Electromagnetic and Hadronic Background in the Interaction Region of the TESLA Collider", PhD thesis, Universität Hamburg, 1996.

[7] J. Snuverink, N. Fuster-Martinez, J. Pfingstner, “A Linear Accelerator Simulation Framework”, in Proc. IPAC2015, Richmond, VA, USA, May 2015, paper MOPJE029, pp. 341-343.

[8] J. Snuverink, J. Pfingstner, “Linear accelerator simulation framework with PLACET and GUINEA-PIG”, CERN, Geneva, Switzerland, Rep. CERN-ACC-NOTE-2016-0034, April 2016.