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LUMINOSITY TUNING AT THE INTERACTION POINT

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Minimisation of the emittance in a linear collider is not enough to achieve optimal performance. For optimisation of the luminosity, tuning of collision parameters such as angle, offset, waist, etc. is needed, and a fast and reliable tuning signal is required. In this paper tuning knobs are presented, and their optimisation using beamstrahlung as a tuning signal is studied.

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INTRODUCTION

In the future linear colliders it will be very important to tune the collision parameters, eg. offset, angle and waist, in order to optimise the luminosity. For this optimisation a fast tuning signal is required. The most relevant signal is the luminosity, however, the luminosity cannot be directly measured fast enough. For CLIC, potentially useful signals are instead beamstrahlung, coherent pairs and incoherent pairs [1]. In this note a comparison between the beamstrahlung signal and the ideal luminosity signal is presented.

First simulations were performed in a simplified way; the tracking was left out and knob changes were emulated by directly changing the particle coordinates at the interaction point. The initial beams were obtained by taking ideal beams and randomly changing offset, angle, waist and dispersion with amounts that respectively gave luminosity reductions of the order of 10%. An optimisation procedure was then used to tune the knobs to recover nominal luminosity. During these simulations either luminosity or beamstrahlung was used as a tuning signal. This would indicate if the beamstrahlung signal might be useful for the more realistic tuning. Next, realistic tuning knobs were designed and tested. These knobs are based on movements of the FFS sextupoles, in a similar fashion as in [2].

The tracking through the CLIC main linac and BDS was performed using PLACET [3]. Each beam consisted of 10000 macro-particles and the simulations of collisions were carried out using GUINEAPIG [4].

In order to optimise the collision parameters a set of orthogonal linear knobs has been constructed. During the optimisation, knobs are independently varied until the optimal signal is found.

BEAMSTRAHLUNG AS A TUNING SIGNAL

In order to identify the signals that are useful for tuning the collision parameters, an initial study was carried out using "artificial" knobs. Each knob change was realised as a direct change of the particle coordinates of the beam. Luminosity and beamstrahlung were both studied as tuning signals. Previous studies had shown that beamstrahlung could be used when tuning the waist position assuming no other errors [1]. Scans showing that luminosity and beamstrahlung signals are correlated when tuning different collision parameters were shown in [5]. These scans show that for the horizontal parameters maximisation of the sum of beamstrahlung energy losses in the two beams also maximises luminosity. For the vertical parameters, except the waist, the sum of the energy losses should instead be minimised. For the waist we need to maximise/minimise the difference in energy loss from the two beams [1].

One disadvantage of the beamstrahlung signal is that it has lower resolution than the luminosity signal. Simulations were carried out to see whether the signal could actually be used. Artificial offset, angle, waist and dispersion knobs were used during these simulations. The corresponding IP parameters were initially randomly changed with an amount of the order of the change needed to reduce luminosity by 10%.

Using the luminosity as a tuning signal the performance of the knobs is excellent. The beamstrahlung signal also works well, see Fig. 1.
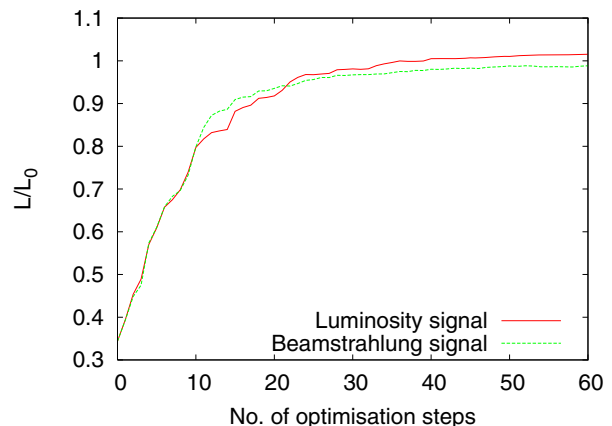

Figure 1: Optimisation of luminosity using luminosity and beamstrahlung as tuning signals respectively. Artificial offset, angle, waist and dispersion are used for the tuning.

KNOBS BASED ON FFS SEXTUPOLES

Alignment and field errors in the BDS and, in particular, in the FFS are amplified by the strong focusing and may lead to enlargement of IP beam size and subsequent luminosity loss. Several knobs based on transverse motion of the five FFS sextupoles have been designed to correct linear aberrations at the IP: longitudinal position of horizontal and vertical beta waist, x and y dispersion, x and y orbit offset, and x' and y' angles. It is currently foreseen to place these sextupoles on mechanical movers. By selecting various combinations of horizontal and vertical sextupole displacements, linear aberrations can be cleanly corrected at the IP.

A luminosity loss due to increase of IP beam size may be caused by longitudinal displacement of focusing waist $w_{x,y}$ as well as residual horizontal and vertical dispersion $\Delta D_{x,y}$ at IP. Fig. 2 shows the luminosity loss as a function of the longitudinal displacement of the vertical waist. The
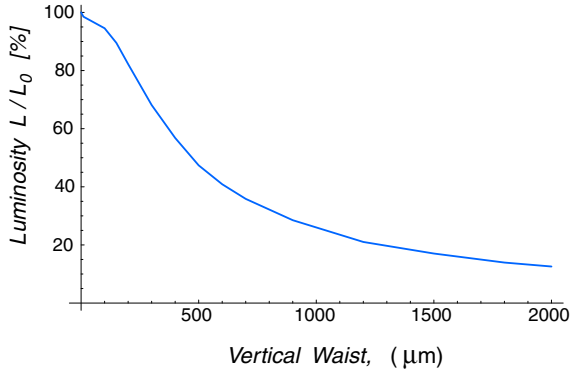

Figure 2: The luminosity loss as a function of the longitudinal displacement of the vertical waist.

longitudinal waist shift increases IP beta function as $\beta_{x,y} = \beta_{x,y}^* + w_{x,y}^2/\beta_{x,y}^*$, where $\beta_{x,y}^*$ is the ideal beta at the IP.

A horizontal displacement of a sextupole ΔX perturbs the $\beta_{x,y}$ and the D_x functions. Since the phase advance between the FFS sextupoles and the IP is $\Delta\mu^s = \pi/2 + n\pi$, a longitudinal waist shift can be estimated as $w_{x,y} \approx K_2 L \Delta X \beta_{x,y}^s \beta_{x,y}^*$, where L and $\beta_{x,y}^s$ are the sextupole length and beta function, respectively. Assuming that α_x^* and α_y^* are equal to zero at the IP, the longitudinal position of the waist is directly proportional to the change of α^* at IP:

$$\alpha_{x,y}^* = -\frac{\beta_{x,y}'}{2} = -\frac{w_{x,y}}{\beta_{x,y}^*}$$

The horizontal dispersion D_x^s through the FFS sextupoles is in order of 1 cm that also generates horizontal dispersion at IP: $\Delta D_x^* \approx K_2 L \Delta X D_x^s \sqrt{\beta_x^* \beta_x^s} \sin\Delta\mu_x^s$, where ΔX and ΔY are a horizontal and vertical displacement of sextupole relative to the reference orbit, respectively. The vertical dispersion at IP caused by vertical displacement of a single sextupole is given by $\Delta D_y^* \approx -K_2 L \Delta Y D_x^s \sqrt{\beta_y^* \beta_y^s} \sin\Delta\mu_y^s$. A vertical displacement of sextupoles introduces a skew quadrupole field which couples the motion in the transverse plane. We expect that

betatron coupling introduced by vertical displacement of sextupoles is much smaller than betatron coupling arising from tilt errors of the FFS quadrupoles. In any way, a betatron coupling can be compensated by using four additional skew quadrupoles.

The horizontal and vertical kicks produced by a sextupole are proportional to the square of sextupole displacement. The orbit offsets Δx, Δy and angles $\Delta x'$, $\Delta y'$ at IP can be linearly approximated with a good accuracy if the transverse displacement of sextupoles are in the range of $2~\mu$m.

For convenience, we denote the five final sextupoles by $S5$, $S4$, $S3$, $S2$, and $S1$. Using horizontal displacement of these sextupoles, the knobs for the longitudinal position of the beta waist $w_{x,y}$, horizontal dispersion ΔD_x, horizontal orbit offset Δx and angle x' have been constructed. These parameters are directly proportional to horizontal displacement of sextupoles. The coefficients defining linear dependence of parameters w_x, w_y, Δx, x' and ΔD_x on a horizontal displacement separately assigned to sextupoles are listed in Table 1. Note that parameters Δy, y' and ΔD_y do not depend on ΔX.

Knobs to correct the vertical dispersion ΔD_y, orbit offset Δy and angle y' at IP have been constructed using vertical displacement of the sextupoles $S1$, $S3$, $S5$. The coefficients defining linear dependence of these parameters on vertical displacement separately assigned to each sextupole $S1$, $S3$, $S5$ are listed in Table 2. The parameters $w_{x,y}$, Δx, x' and ΔD_x do not depend on ΔY.

Table 1: The coefficients defining linear dependence of parameters w_x, w_y, Δx, x' and ΔD_x on a horizontal displacement separately assigned to the sextupoles S5, S4, S3, S2 and S1.

Sextupole	S5	S4	S3	S2	S1
$w_x/\Delta X$	3022	-1444	2304	-2838	1724
$w_y/\Delta X$	-0.06	15	-226	30	-336
$\Delta x/\Delta X$	0.029	-0.015	0.023	-0.028	0.017
$x'10^3/\Delta X$	5.41	-1.68	3.37	-3.26	2.35
$\Delta D_x/\Delta X$	-0.631	0.361	-0.453	-5.458	3.317

Table 2: The coefficients defining linear dependence of these parameters on vertical displacement separately assigned to each sextupole $S1$, $S3$, $S5$.

Sextupole	S5	S3	S1
$\Delta y/\Delta Y$	0.0005	-0.007	-0.007
$y'10^3/\Delta Y$	-44.3	-0.43	-0.65
$\Delta D_y/\Delta Y$	-0.0074	0.161	-1.468

We have two linear system $\mathbf{A}\overline{\Delta X} = \overline{V_x}$ and $\mathbf{B}\overline{\Delta Y} = \overline{V_y}$ where $\overline{V_x} \equiv \{w_x, w_y, \Delta x, x', \Delta D_x\}$ and $\overline{V_y} \equiv \{\Delta y, y', \Delta D_y\}$, $\mathbf{A}$ is a 5×5 response matrix with coefficients listed in Table 1 and $\mathbf{B}$ is a

3×3 response matrix with the coefficients listed in Table 2. The vectors $\overline{\Delta X}$ and $\overline{\Delta Y}$ are the sextupole displacements $\{\Delta X_{S5}, \Delta X_{S4}, \Delta X_{S3}, \Delta X_{S2}, \Delta X_{S1}\}$ and $\{\Delta Y_{S5}, \Delta Y_{S3}, \Delta Y_{S1}\}$.
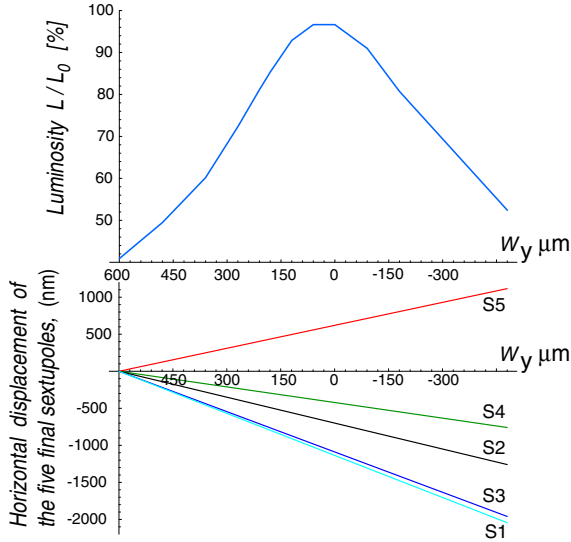

Figure 3: The recovery of luminosity loss by the horizontal movements of sextupoles.

In order to tune parameters at IP to desirable values, a needed set of sextupole displacements is determined as $\overline{\Delta X} = \mathbf{A}^{-1}\overline{V_x}$ and $\overline{\Delta Y} = \mathbf{B}^{-1}\overline{V_y}$. Fig. 3 shows the recovery of luminosity loss by the horizontal movements of sextupoles. The simulation was done for the case when initial shift of longitudinal position of the vertical waist at IP was assigned to 600 μm for unmoved sextupoles. The lower plot in Fig. 3 indicates the solution of the linear system $\overline{\Delta X} = \mathbf{A}^{-1}\overline{V_x}$ for the conditions $w_x = \Delta x = x' = \Delta D_x$ where w_y is variable. The maximum recovery of luminosity of 95 % is achieved at $\Delta X_{S5} = 620$ nm, $\Delta X_{S4} = -422$ nm, $\Delta X_{S3} = -1089$ nm, $\Delta X_{S2} = -700$ nm, $\Delta X_{S1} = -1135$ nm.

TUNING USING REALISTIC KNOBS

The realistic knobs are used for waist and dispersion adjustment, while the presumably trivial offset and angle knobs were still artificial. The beams were tracked through the linac and beam delivery system and its sextupoles and finally the beam coordinates were adjusted to emulate the offset and angle knobs. The initial errors were implemented in the same way as for the simplified simulations described above. In Fig. 4 the result of the optimisation using the luminosity as a tuning signal is shown. It is clear that the performance is not as good as before. The first optimisation steps, including the artificial knobs and the vertical waist and dispersion knobs improve luminosity as well as before. This indicates that the vertical waist and dispersion knobs work well, but that there might be a problem with the corresponding horizontal ones. The latter

were exchanged for the artificial ones again and new simulations were carried out where only the vertical waist and dispersion knobs are realistic knobs, see Fig. 5. It has been checked that the real horizontal knobs exceeded the linear range. A solution to this problem needs to be found.
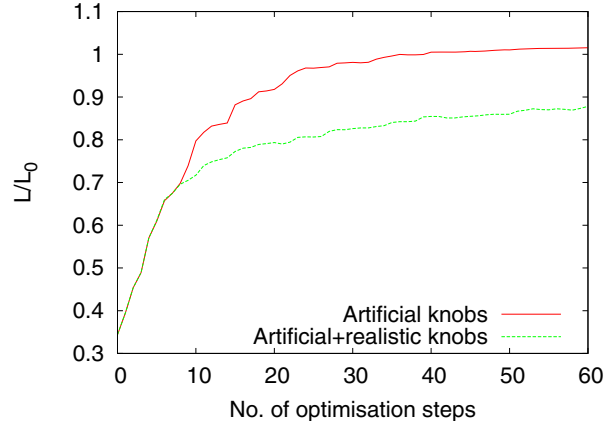

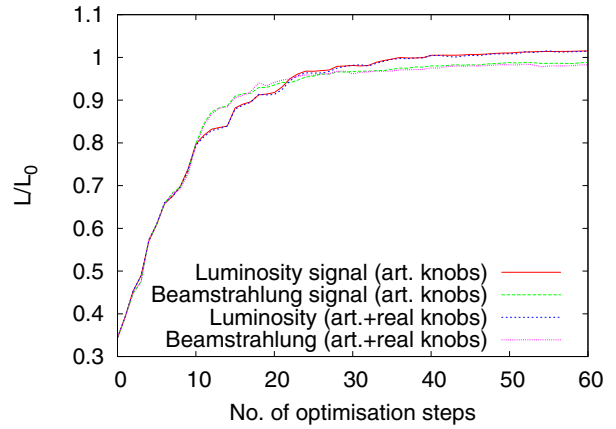Figure 4: Optimisation using real knobs.

Figure 5: Optimisation using artificial horizontal knobs.

CONCLUSION

Both the luminosity and the beamstrahlung signals can be used for the optimisation of the collision parameters. A set of knobs has been constructed based on sextupole movements. The knobs varying vertical parameters worked perfectly. However for the horizontal knobs the linear range was not sufficient.

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