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INTRA-BUNCH ENERGY SPREAD MINIMISATION FOR CLIC OPERATION AT A CENTRE-OF-MASS ENERGY OF 350 GeV

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Abstract

The first stage of the electron-positron Compact Linear Collider (CLIC) is designed with a centre-of-mass energy of 380 GeV. A dedicated threshold scan in the vicinity of 350 GeV is envisioned with a total integrated luminosity of 100 fb^{-1}. This scan calls for a very small intra-bunch energy spread in order to achieve an excellent collision energy resolution. This paper presents an optimised assignment of RF accelerating gradients and phases in the CLIC main linac for operation at 350 GeV, which minimises the energy spread at the end of the main linac whilst preserving a small emittance growth. Variation of the bunch length and charge is studied in order to further reduce the energy spread; the effect on both the peak and total luminosity is discussed.

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Abstract

The first stage of the electron-positron Compact Linear Collider (CLIC) is designed with a centre-of-mass energy of 380 GeV. A dedicated threshold scan in the vicinity of 350 GeV is envisioned with a total integrated luminosity of 100 fb^{-1}. This scan calls for a very small intra-bunch energy spread in order to achieve an excellent collision energy resolution. This paper presents an optimised assignment of RF accelerating gradients and phases in the CLIC main linac for operation at 350 GeV, which minimises the energy spread at the end of the main linac whilst preserving a small emittance growth. Variation of the bunch length and charge is studied in order to further reduce the energy spread; the effect on both the peak and total luminosity is discussed.

INTRODUCTION

The Compact Linear Collider (CLIC) is a proposed electron-positron collider, with an ultimate centre-of-mass collision energy of 3 TeV [1]. A first-stage design at a lower energy of 380 GeV (Fig. 1), aimed at top quark and Higgs particle production, is currently being proposed [2]. CLIC can be operated at different centre-of-mass energies so as to perform scans. This can be achieved by operating the main linacs with reduced accelerating gradients. Currently, the only request from the physics community is to scan the top threshold, i.e. around 350 GeV, with an integrated luminosity of 100 fb^{-1} [3]. At the top threshold, a small intra-bunch energy spread tends to be beneficial since it allows one to resolve the onset of the cross section better. Achieving the smaller energy spread at an operating energy of around 350 GeV is illustrated below, but other operating energies would also be possible.

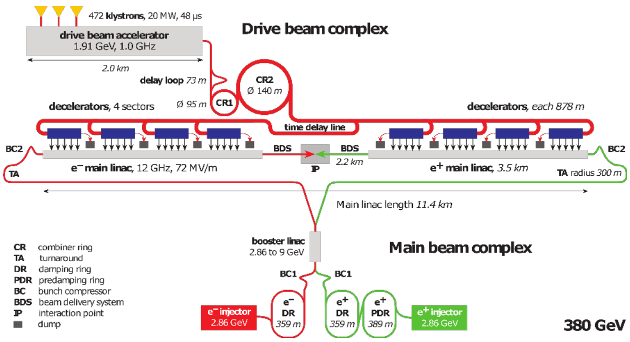

Figure 1: Overview of the CLIC layout at a centre-of-mass collision energy of 380 GeV [2].

INTRA-BUNCH ENERGY SPREAD

The intra-train energy spread is governed by the sinusoidal profile of the radiofrequency (RF) accelerating field and the short-range intra-bunch longitudinal wakefields. Figure 2 show the bunch energy profile due to the two contributions, simulated in PLACET [4], and their combined effect. The results for RF phases between 0° (accelerating on-crest) and 25° (accelerating off-crest) are shown. In each case, the cavity accelerating gradient has been adjusted such that the mean bunch energy is 175 GeV at the end of the main linac, with an incoming 9 GeV at the start of the main linac.

The effect of changing the bunch charge and length on the RMS energy spread is shown in Fig. 3. Increasing the bunch length and reducing the bunch charge lead to a reduction in

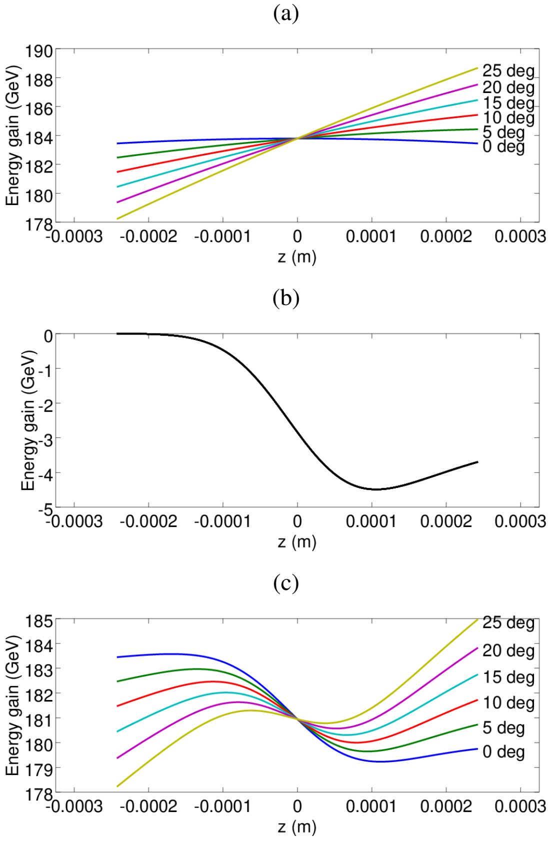

Figure 2: Energy gain in the main linac as a function of the bunch length z for (a) RF accelerating field, (b) short-range longitudinal wakefield and (c) combined contributions. The head of the bunch is towards negative z. The RF phase was varied from 0° (accelerating on-crest) to 25° (accelerating off-crest), in steps of 5°, as shown.

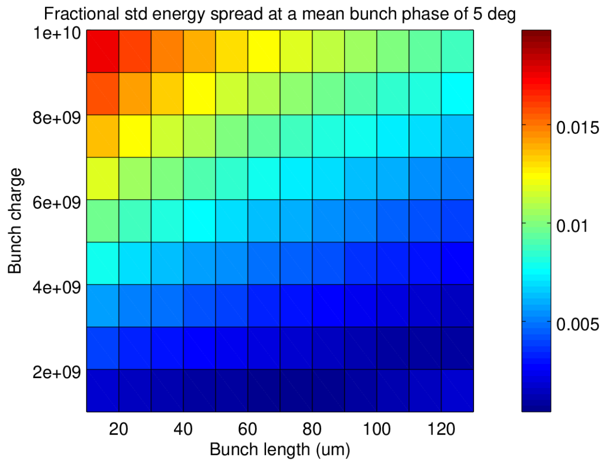

Figure 3: Fractional intra-bunch energy spread (colour coded according to the colour bar on the right) as a function of the bunch charge and length, for a mean RF bunch phase of 5°.

the beam energy spread. Two scenarios were explored in detail. The first uses the same bunch charge (5.2×10^9 particles) and length (70 μm) as at 380 GeV and the second a bunch that is 10% longer and has only 90% of the nominal charge.

At the beginning of the linac the phase ϕ_1 is set to introduce an increasing correlated energy spread while the uncorrelated part is naturally decreasing. At the end the phase ϕ_2 is set to reduce the energy spread. This choice takes advantage of the so-called BNS damping [5]. The correlated energy spread counteracts the transverse wakefields induced by a jittering beam. This suppresses beam break-up.

RESULTS

Figure 4 shows the energy and energy spread along the main linac for operation at the nominal 380 GeV and for the two options at 350 GeV. The incoming RMS energy spread is 1.6% and an RMS vertical quadrupole position error of 10 nm is assumed throughout the main linac. The emittance growth due to an artificially large quadrupole jitter is also shown and demonstrates that the beam stability is the same in the different cases.

For the 380 GeV case, $\phi_1 = 8°$ is used for the first three-quarters of accelerating structures and $\phi_2 = 29.6°$ for the last quarter. This gives an RMS energy spread of 0.36%, which is acceptable for the beam delivery system (BDS) [1].

For the first 350 GeV case, $\phi_1 = 6°$ is used for the first half and $\phi_2 = 30°$ for the second half of accelerating structures, allowing a larger energy spread in the middle of the linac, hence producing a more stable low-emittance beam; this energy spread is removed by the end of the main linac. The RMS energy spread at the end of the main linac is 0.31%. The resulting luminosity, calculated using GUINEA-PIG [6], is 1.52×10^{34} cm^{-2} s^{-1}, where 60% of collisions take place above 99% of the design energy.

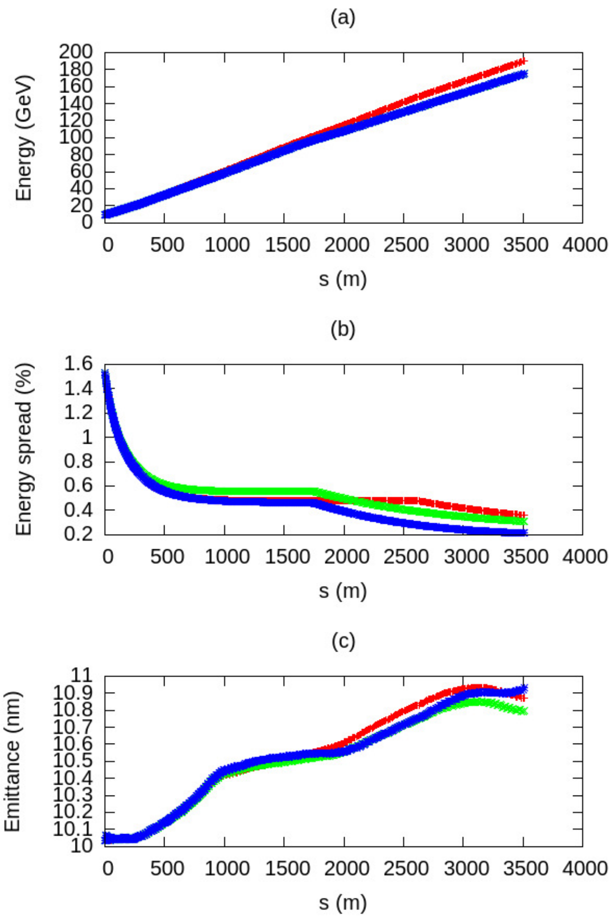

Figure 4: (a) Energy, (b) RMS fractional energy spread and (c) vertical emittance versus length s of the main linac, operating with nominal bunch length and charge at 380 GeV (red) and 350 GeV (green), and at 110% of the nominal bunch length and 90% of the nominal bunch charge at 350 GeV (blue).

For the second 350 GeV case, the same phases are used but the charge is reduced to 90% and the bunch length increased to 110%. This reduces the energy spread at the end of the main linac to 0.21%, whilst preserving the same beam quality. The luminosity achieved is 1.18×10^{34} cm^{-2} s^{-1}, where 64% of collisions are above 99% of the design energy. The reduced charge and increased bunch length, with the resulting smaller overall energy spread, leads to a 10% re-duction in the emitted beamstrahlung photons, increasing the luminosity quality. Figure 5 shows the luminosity spectrum for both cases. The results are summarised in Table 1.

CONCLUSIONS

Optimised assignments of RF accelerating gradients and phases in the CLIC main linac have been identified for operation at a centre-of-mass energy of 350 GeV, at the top production threshold, which minimise the energy spread at the end of the main linac whilst preserving a small emit-

Table 1: Energy spread and vertical emittance at the end of the main linac, and resulting total and peak luminosities, for the three sets of operating conditions in Fig. 4.

Design centre-of-mass collision energy	(GeV)	380	350	350
Bunch length	(μm)	70	70	77
Particles per bunch	(10^9)	5.20	5.20	4.68
RF gradient	(MV/m)	67.62	64.04	63.92
RF phase[a]	(°)	8/8/8/29.6	6/6/30/30	6/6/30/30
RMS fractional energy spread[b]	(%)	0.36	0.31	0.21
Vertical emittance[b]	(nm)	10.87	10.80	10.93
Total luminosity $\mathcal{L}_0$	(10^{34} cm^{-2} s^{-1})	1.5	1.52	1.18
Peak luminosity[c] $\mathcal{L}_{0.01}$	(10^{34} cm^{-2} s^{-1})	0.9	0.91	0.76
$\mathcal{L}_{0.01}/\mathcal{L}_0$	(%)	60	60	64
Beamstrahlung photons per beam particle		1.44	1.43	1.29

[a] RF phases in the 4 sectors of the main linac (Fig. 1).

[b] Given at the end of the main linac.

[c] Luminosity at collision energies above 99% of the design energy.

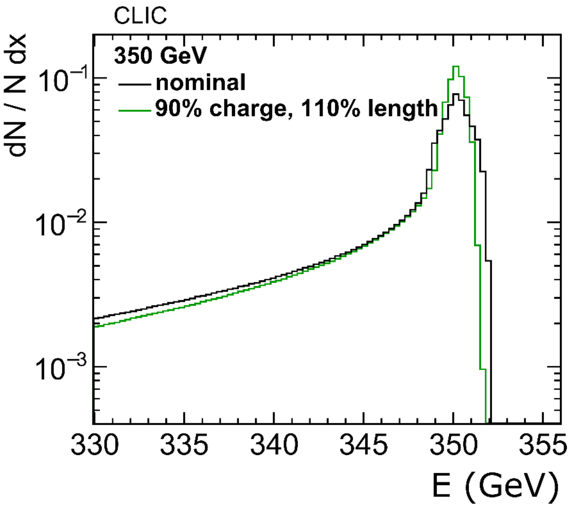

Figure 5: Luminosity versus collision energy, operating with nominal bunch length and charge (black), and at 110% of the nominal bunch length and 90% of the nominal bunch charge (green).

tance growth. Two scenarios were explored in detail. The first uses the same bunch charge and length as at 380 GeV; delivering a luminosity of 1.52×10^{34} cm^{-2} s^{-1}, like that at 380 GeV, with an RMS energy spread of 0.31% at the end of the main linac and in which 60% of collisions are above 99% of the design energy. In the second case, the charge is reduced by 10% and the bunch length is increased by 10%; reducing the energy spread to 0.21%, yielding a luminosity of 1.18×10^{34} cm^{-2} s^{-1} and with 64% of collisions above 99% of the design energy.

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