CHAPTER 4

Upgrade Paths to Higher Energies

4.1 TESLA

The TESLA linac design for 500 GeV c.m. energy with an accelerating gradient of 23.8 MV/m is based on the technology developed and proven during the first phase of the R&D program at the TTF. While an upgrade to higher energy could in principle be done by extending the linac length, we do not consider this option here, mainly because of cost reasons. It should also be noted that the detailed planning and the legal procedure for land acquisition and construction permission (in German: *Planfeststellungsverfahren*) for the TESLA site at DESY do not include the possibility of an extension of the length beyond the foreseen 33 km for the baseline 500 GeV design. An energy upgrade for TESLA will thus require to increase the beam energy gain per unit length of the accelerator:

- By further reduction of the inter-cavity spacing the linac fill factor can be increased. The concept presently under development (so-called superstructures) uses pairs of 9-cell cavities with spacing reduced to half rf wavelength. The rf power is transmitted through this interconnection so that only one high power input coupler is needed per cavity pair—thus reducing the number of couplers by a factor of 2. Building the linac with superstructures improves the fill factor—and hence the maximum energy for a fixed accelerating gradient and site length—by about 6%.
- The fundamental limit for the gradient in niobium structures at 2 K is above 50 MV/m, and at the TTF several 9-cell cavities have already reached gradients around 30 MV/m. Electropolishing followed by low-temperature bake-out has yielded systematically high performance single-cell cavities, with gradients up to 42 MV/m. The maximum gradient achieved with an electropolished 9-cell cavity is 35 MV/m.
- The Lorentz force detuning (which increases as the square of the accelerating gradient) can be compensated by active mechanical stabilization using fast piezo tuners; this removes the need to increase the regulation rf power overhead at higher gradients. The method was successfully demonstrated at the TTF at 24 MV/m.

As a reasonable estimate for the maximum gradient in the TESLA linac we assume E_{acc}=35 MV/m at Q_0=5×10^9. Using superstructures, the energy reach of the machine is

TABLE 4.1
TESLA parameters for an upgrade to 800 GeV. It is assumed that the linac is built with 2 9-cell superstructures and the rf power has been doubled (see text).

		TESLA-800
Accelerating gradient	E_{acc} [MV/m]	35
Fill factor		0.79
Repetition rate	f_{rep} [Hz]	4
Beam pulse length	T_P [μs]	860
Number of bunches per pulse	n_b	4886
Bunch spacing	Δt_b [ns]	176
Charge per bunch	N_e [10^{10}]	1.4
Emittance at IP	$\gamma\varepsilon_{x,y}$ [10^{-6} m·rad]	8, 0.015
Beta at IP	$\beta^*_{x,y}$ [mm]	15, 0.4
Beam size at IP	$\sigma^*_{x,y}$ [nm]	391, 2.8
Bunch length at IP	σ_z [mm]	0.3
Beamstrahlung	δ_E [%]	4.3
Luminosity	L [10^{34} cm^{-2}s^{-1}]	5.8
Power per beam	$P_b/2$ [MW]	17
Two-linac primary electric power	P_{AC} [MW]	≈160

then E_{cm}=800 GeV. A parameter set for this energy is shown in Table 4.1. The beam delivery system and the magnets in the main linac are designed to be compatible with operation up to 400 GeV beam energy. Obtaining high luminosity at maximum energy requires upgrading of the cryogenic plants (approximately doubling the 2 K cooling capacity) and of the rf system (doubling the number of rf stations). The higher beam pulse current and the reduced bunch spacing also require an upgrade to the injection system (*e.g.*, increased rf power in the 5 GeV pre-linac and in the damping ring, faster kickers for damping ring injection/extraction).

It should be noted that operation above the 500 GeV reference energy is already possible without any hardware modification. The cooling plant capacity has a 50% overhead in the baseline design, which allows an increase of the gradient by 20–30%[1], depending on the variation of Q_0 versus g. With constant rf power, the beam current decreases as $I_b \propto 1/g$; this effect is counter-balanced by a stronger adiabatic damping of the emittance, so that one might expect a constant luminosity. However, since the cavity filling time increases as $g/I_b \propto g^2$, the beam pulse length and thus the luminosity goes down, putting a reasonable upper limit on the initial energy reach of the machine at about 700 GeV. The luminosity as a function of energy calculated for the 500 GeV baseline design without any hardware modifications is shown in Table 4.2.

---

[1] Only the rf wall losses scale as g^2/Q_0, the other contributions to the 2 K load (static losses, wakefields, about one half of the total load) remain unchanged.

TABLE 4.2
Luminosity achievable with the TESLA-500 baseline design at higher center-of-mass energies without any upgrade of installed hardware. The numbers quoted take into account the reduction of beam current with increasing energy, the increase in cavity filling time, and a reduction of the repetition rate to 4 Hz at 600 GeV and 3 Hz at 700 GeV.

c.m. Energy [GeV]	Luminosity [10^{34} $\text{cm}^{-2}\text{s}^{-1}$]
500	3.4
550	3.06
600	2.16
650	1.89
700	1.17

4.2 JLC-C

As is described in Section 3.2.2 the energy upgrade scenario for the C-band JLC starts from a 400-GeV c.m. collider, consisting of two 200-GeV C-band linacs in the upstream ends of a tunnel that is long enough to accommodate the 1-TeV machine. The upgrade itself consists of filling the remaining downstream parts of the tunnel with X-band linacs to reach 1 TeV c.m.

The advantages of this "C+X" scenario over that of X-band alone are:

(a) It allows an early start of the first stage because of the maturity of C-band rf technology.

(b) The initial buildup of the luminosity after the construction is expected to be faster owing to the looser tolerances.

(c) The actual integrated luminosity over years can be greater in spite of the lower instantaneous luminosity, owing to the more reliable hardware system.

An obvious disadvantage of the C+X scenario is:

(d) Discontinuity of the R&D between the first and second stages.

In this respect, one could start out with low-gradient X-band linacs instead of C-band (an "X+X" scenario). The luminosities of these two scenarios are similar (depending on the initial X-band gradient) and are slightly lower in the X+X scenario. The choice between the C+X scenario and the X+X scenario depends on how one evaluates the advantages of (b) and (c), and the disadvantage of (d).

The beam parameters for the C+X scenario are basically identical to those of the X+X scenario. This fact does not sacrifice the C-band performance as described in Section 3.2.2. One problem in the compatibility of the beam parameters is the bunch length. It has to be about 200 μm in the C-band linac and about 100 μm in the X-band linac for the control of the energy spread and BNS damping. For the 1 TeV operation of the C+X collider we shall choose $\sim$100 μm. In this case we choose the off-crest phase $\sim -10^\circ$ (BNS damping side) in the C-band section and the resulting energy spread will be eliminated in the X-band section. We believe, though detailed studies are still on the way, that we can choose an appropriate bunch length between 200 μm and 100 μm for operation anywhere between 400 GeV and 1 TeV.

Thus, the constraints coming from the frequency compatibility requirement are:

- The bunch compressor system must be capable of controlling the bunch length over the wide range between $\sim$200 μm and $\sim$100 μm. (Although the megatable quotes the C-band main linac injection energy as 8 GeV, the same as for the X-band case, this value can presumably be lowered for the C-band case. Then the second bunch compressor will be easier to design.)
- The accelerator structure must be designed so that the wake function has a node at 1.4 ns.

4.3 JLC-X/NLC

As described in the Overview (Section 3.3), the JLC-X/NLC linear collider has been designed to facilitate the upgrade to energies greater than 1 TeV. The baseline upgrade is accomplished by installing additional rf modules into the second half of the linac tunnel which is empty in the initial Stage I (500 GeV) configuration. The upgrade could either be completed using modules of the baseline rf system, identical to those for 500 GeV, or it could use higher efficiency rf units which will likely be developed over the next few years. To ensure the feasibility of the upgrade, all of the luminosity studies have been performed for the Stage II (1 TeV) configuration and the component tolerances have been specified for the Stage II design. In particular, the beam properties for the Stage II operation are identical to those for Stage I. Thus, no modification of the injector system is required and only the permanent magnet final doublet needs to be replaced in the beam delivery system. The expected cost for the full energy upgrade is roughly 25% of the initial total project cost (TPC).

The Stage II parameters can be found in Table 3.14 of the JLC-X/NLC Overview. As in Stage I, the beams consist of bunch trains with 192 bunches separated by 1.4 ns. The repetition rate would be decreased to 100 Hz in Japan and would remain at 120 Hz in the US. The luminosity would be 2.5×10^{34} cm^{-2}s^{-1} (3.0×10^{34} cm^{-2}s^{-1}) in Japan (US) at the nominal center-of-mass energy of 1 TeV. Although not listed, the collider is also designed to operate with 96 bunches of 1.5×10^{10} particles and a 2.8 ns bunch spacing—this latter option provides higher luminosity but also more beamstrahlung and emittance dilution.

The energy reach of Stage II is roughly 1.3 TeV without modification of the rf system. This is possible because the JLC-X/NLC traveling-wave accelerator structures are tested to a full unloaded gradient of 65 MV/m; this differs from the testing of the standing-wave superconducting structures which are only tested to the maximum *loaded* gradient of 23 to 35 MV/m. The luminosity versus energy for the Stage II JLC-X/NLC is plotted in Figure 4.1. Thus, as discussed in the Overview, the JLC-X/NLC linear collider is designed to fully cover the energy region between 90 GeV and 1.3 TeV.

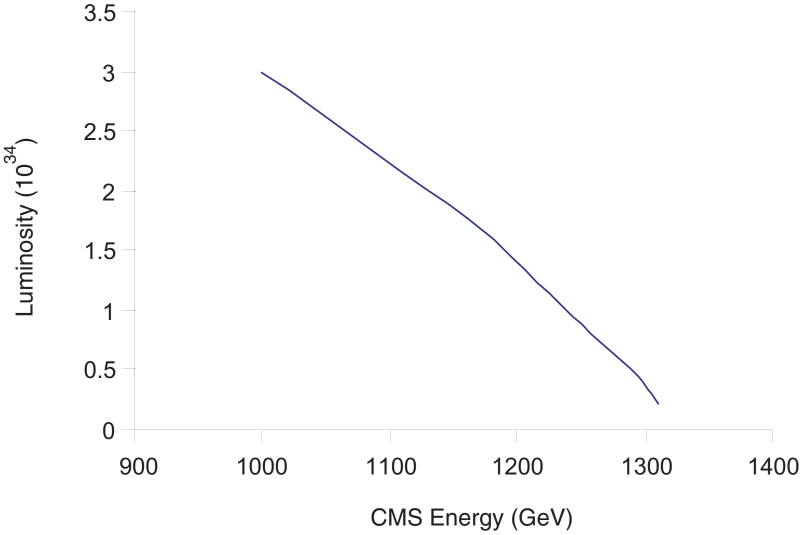

FIGURE 4.1. Energy versus luminosity for the Stage II NLC rf system

To accommodate the physics demands for energy flexibility, the design includes two interaction regions. One is optimized for high energy, 250 GeV to 1.3 TeV, and is configured so that it is ultimately upgradable to multi-TeV. This final focus can actually accommodate beams of up to 2.5 TeV in the length of about 800 m. The other interaction region is designed for precision measurements at lower energy, 90–500 GeV, although it could be upgraded to operate at ∼1 TeV as well.

To capitalize on the multi-TeV potential of the new design, it was also necessary to eliminate other bending between the linac and the high energy IP. In the NLC design, a 20 mrad crossing angle at the IP is used to avoid parasitic interactions of one bunch with the later bunches in the opposing train and to ease the extraction line design. The linacs are not collinear but are oriented with a shallow 20 mrad angle between them to produce the desired crossing angle at the high-energy IR without additional bending. The beams to the second IR are bent by about 25 mrad, which is acceptable for energies up to 1 TeV. The low-energy IR has a larger 30 mrad crossing angle for compatibility with a possible γ/γ option. Finally, in the JLC design, the primary IP has a crossing angle of 7 or 8 mrad and the non-collinear linac layout has not been planned. However, the crossing angle of the second IP is 30 mrad as in the NLC design.

As stated, the luminosity listed for the Stage II design is based on the same injector and beam delivery system as for Stage I. Of course, it will likely prove possible to further increase the luminosity by upgrading the performance of the injector systems to decrease the extracted vertical beam emittance. It is expected that the emittance transport through the linacs will perform better than required as described in Section 3.3.6. In this case, the primary limitations will be stabilization of the pulse-to-pulse jitter due to the high disruption parameter which will start to approach the values in the TESLA design. An estimate of the ultimate luminosity from the collider can be found in Table 3.17 of the JLC-X/NLC Overview.

Finally, ongoing R&D at KEK, SLAC, FNAL, and LLNL is aimed at improving the efficiency of the rf units. The three places where significant improvements might be expected are the modulator, the klystron, and the pulse compression system which have design efficiencies of 80, 55, and 75%, respectively, in the baseline design. Working in collaboration with the IGBT manufacturers, the modulator efficiency might be increased to 85% by improving the rise and falls times of the IGBTs. Similarly, simulations have indicated that ∼65% efficiency for the klystrons may be possible either with improved single beam PPM klystron designs or by developing a sheet beam or multibeam klystron; the sheet beam concept is being pursued at SLAC while the multibeam klystron design is being studied at KEK. Lastly, the biggest improvement might come from improvements to the pulse compression system. The SLED-II baseline system has an efficiency of roughly 75%. An optimized Delay Line Distribution System (DLDS) or Binary Pulse Compression system (BPC) might have efficiencies of ∼90%. Work investigating the viability of a four times single-moded DLDS compression system will begin at SLAC and KEK after the demonstration of the SLED-II compression system. If found viable, then this DLDS system could simply replace the SLED-II without changes to the other rf system components.

Similarly, ongoing R&D at many laboratories, including SLAC, KEK, and CERN, is aimed at higher acceleration gradients. The maximum gradient that can be supported in copper accelerator structures is not clearly known. With the development of a new coupler design, a recent X-band test structure has operated at 90 MV/m with a breakdown rate of less than 1 per 24 h—the maximum allowable rate for JLC-X/NLC operation being 1 per 10 h. Additional design modifications might support still higher gradients. In addition, R&D at CERN and SLAC studying different materials has shown that as much as a 50% increase in the gradient may be possible by using Tungsten, Molybdenum, or Stainless Steel in the accelerator structure irises.

If structures that support ∼100 MV/m can be developed over the next decade, then the upgrade to Stage II could have an energy reach well in excess of 1.5 TeV and approaching 2 TeV. Looking further in the future, as described in the Overview, the JLC-X/NLC facility has been configured to simplify the evolution to a multi-TeV collider with c.m. energies of roughly 3–5 TeV. It is likely that much of the infrastructure could be reused and the injectors and beam delivery systems would need relatively straightforward upgrades. Only the main linac structures and rf sources would need to be replaced. Furthermore, and perhaps more importantly, the knowledge gained from operating a normal conducting linear collider would be indispensable for the design and construction of a multi-TeV linear collider.

4.4 CLIC

The CLIC design aims at reaching multi-TeV c.m. energies as stated in the introduction of the 500 GeV-CLIC description. These high energies can be reached in natural steps of about 140 GeV center-of mass (c.m.) which correspond to a typical gain of 70 GeV per beam in a 625 m long unit with an average accelerating gradient of 150 MV/m. It has to be mentioned that adjusting the rf structure layout in these units allows to vary the energy gain per step and hence tune the final c.m. energy. Studies of low emittance transfer and beam characteristics for a luminosity of the order of 10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ indicated that beam dilution and sensitivity to vibration in the last doublet are limiting the plausible maximum c.m. energy to around 5 TeV. This is true even though the wakefield effects of 30 GHz structures are controlled by a judicious choice of bunch length, charge and focusing strength. The accelerator physics limitation comes mainly from the fact that the vertical geometric beam size at the IP becomes critically small for the requested performance and imposes very tight jitter as well as vibration tolerances in the final focusing system.

The “Two-Beam Acceleration” method of CLIC is such that the design remains essentially independent of the final energy for all the major subsystems, like the main beam injectors, damping rings, the drive-beam generators, the rf power source, the main-linac and drive-beam decelerator units, as well as the beam delivery systems. For the main linacs however, the existence of lattice sectors with different quadrupole length and spacing (see below) makes it necessary to shift the low-energy sectors toward the linac-injection points, which move apart when the tunnel is extended, and to install the new higher-energy sectors in the already existing tunnel segments. Transporting the girders equipped with up to four accelerator structures and the quadrupoles should not be difficult and could possibly be achieved within a few months. The basic differences related to the c.m. energies reside in the number of two-beam units involved in each linac and in the length of the pulse required in each drive-beam accelerator. As an illustration, these two numbers are equal to 4 units and 17 μs, 22 units and 100 μs, and 37 units and 154 μs, at 500 GeV, 3 TeV and 5 TeV c.m. respectively. These numbers correspond to two-linac lengths of 5 km, 28 km and 46.5 km as well as total collider-lengths of about 10 km, 33 km and 51.5 km, assuming that the length of the BDS system remains unchanged at the various energies while the layout and the magnet strengths may have to be adjusted. These total collider-lengths have been submitted to the engineering feasibility-study carried out using a site near CERN with the interaction point on the present CERN site. As already quoted in the 500 GeV c.m. description, a length of up to 40 km total is available in a molasse of SPS/LEP quality which corresponds to the cheapest conditions in the region and would cover an energy slightly above 3.5 TeV c.m. Going beyond this total tunnel length would imply entering into limestone on one side and/or crossing a 2 km wide underground fault on the other side. In spite of the technical difficulty, the second solution looks preferable and the extra cost would approximately correspond to doubling the cost per unit length over the 2 km crossing distance. Crossing this fault would then open the possibility of extending the tunnel to the next major fault which is not recommended to be breached. With this extension, the maximum tunnel length which can be considered is 52 km, which happens to be sufficient for a 5 TeV collider with the parameters indicated.

Given the main goal and the limitations mentioned, the CLIC design has been optimized for a 3 TeV colliding beam energy which should meet the post-LHC physics requirements. The ultimate energy considered as reachable is 5 TeV. All the subsystems listed have been initially designed for a 3 TeV c.m. energy and scaled down whenever necessary in order to satisfy the requirement at 500 GeV. This approach, together with the fact that developments continue, explain why the description of the 500 GeV collider is not entirely consistent. For more complete information, the detailed description of the 3 TeV CLIC design is given in Reference [1]. However, design modifications took place since the publication of Reference [1] and have been included in the 500 GeV CLIC chapter. The present section underlines the differences associated with an upgrade from 0.5 TeV to 3 TeV in this framework.

The injection system of the main beam remains essentially unchanged at 3 TeV. However, while the klystrons of the injector linacs have to provide the same peak power, the average power they deliver is lower at 3 TeV than at 0.5 TeV since the repetition rate is two times smaller. Considering the drive beam generation, the characteristics of each bunch train (modified with respect to [1, 2]) are the same, *i.e.*, an energy of 2 GeV, an average current of 147 A and a length of 130 ns, but the number of bunch trains depends on the c.m. energy of the main beam. This means that the duration of the initial long pulse accelerated by each drive-beam linac operating at 937 MHz differs and corresponds to two times the linac length (given by the number of the rf power source units required), *i.e.*, is proportional to the energy ratio. The direct consequence is to increase the pulse length of the drive-beam accelerator klystrons by a factor of 6. However, since the repetition rate is reduced from 200 to 100 Hz, the average power to be provided by these klystrons only increases by a factor of 3 when going from 0.5 to 3 TeV c.m. and the same klystrons can be used in principle in both cases. It could however be preferable to start with klystrons designed for a shorter pulse length, which are possibly cheaper, and to exchange them later at the end of their lifetime with better performing ones. The modulator design could also be compatible with a later extension of the pulse length in order to save investment costs at the beginning. As discussed previously, the power consumption for accelerating both the drive beams goes up from $\sim$106 MW at 0.5 TeV to $\sim$319 MW at 3 TeV. The combiner rings clearly remain identical while the repetition rate of the rf deflectors is halved and their pulse is six times longer (increasing by three the average power delivered by their klystrons). Each decelerator unit then remains the same at any c.m. main-beam energy so that all the technical problems related to the drive-beam control, rf power extraction and transfer to the accelerator structures are identical at 0.5 GeV and 3 TeV for instance.

As explained in the CLIC description, the damping rings (DR) have been designed for the energy of 3 TeV, where the requirements are more stringent, and optimized with respect to IBS and radiation damping. This design doesn't yet quite satisfy the target values for the transverse emittances considered in order to reach the planned luminosity. Even though the difference looks manageable at 0.5 TeV, it becomes more difficult at 3 TeV. Therefore, investigations continue for reaching the nominal DR value of 3 nm for the extracted vertical emittance. The present design, which is a snapshot of where we now stand on the path toward a satisfying solution, gives a value of 7.5 nm for this quantity. This would correspond to an increase of the emittance at the main linac end from 10 to 14.5 nm and induce a luminosity loss of 20%. Prospecting further for an improved design of the damping ring is all the more important as the last solution proposed has still potential difficulties with the dynamical aperture after chromaticity correction and possibly with the tolerance on the impedance in order to control the collective instabilities.

It is assumed that the longitudinal beam characteristics at the exit of the DR are the same at 0.5 and 3 TeV. Under these conditions, the two stages of the bunch compressor remain unchanged when upgrading the energy and the total compression ratio is equal to 37.4. The transfer lines, the booster linac and the turn-around loops remain unchanged for the main-beam injection energy of 9 GeV is the same at any final c.m. energy. The vertical emittance blow-up taking place between the damping ring and the entrance of the main linac is estimated to be 2 nm, which brings the nominal $\gamma\varepsilon_y$ value to 5 nm at the linac-injection.

The essential characteristic of the CLIC two-beam scheme is the modularity of its power source (each module feeding 1000 accelerator structures for a nominal 70 GeV energy gain per beam, which can be adjusted). It is therefore very likely that the energy will not be raised from 500 GeV c.m. to 3 TeV at once, but via intermediate stages which will first depend on the evolution of physics, and then on the needs to learn in practice how to run such a collider under conditions which become progressively more severe. There is *a priori* nothing magic about the choice of 3 TeV c.m. from the physics point of view and this choice was arbitrary in order to be in the multi-TeV range. In the same way, the selection of 500 GeV c.m. for the present technical review is somewhat arbitrary and one might in reality take advantage of the easily upgradable two-beam technique of CLIC, for possibly starting with lower c.m. energies associated with the top-particles or Higgs-particles. In any case, the upgradability of CLIC in relatively small energy steps would allow to provide center-of-mass energies in a large range of values in response to the actual requests coming from particle physics.

At 3 TeV, each linac contains 22 rf power source units, that is 22000 accelerator structures representing an active length of 11 km. With a global cavity-filling factor of ∼78% due to the presence of drifts and focusing quadrupoles, the total linac length is ∼14 km each. To keep the filling factor about constant along the linac, the target values of the FODO focal length and quadrupole spacing are scaled with $E^{1/2}$. For practical reasons however, the beam line consists of 12 sectors (instead of 5 at 500 GeV), each with constant lattice cells and with matching insertions between sectors. The total number of quadrupoles is equal to 1324 per linac and their length ranges from 0.5 at the beginning to 2.0 m in the last sector (where a single quadrupole replaces the four structures of a girder). The rms energy spread along the linac is about 0.55% average for BNS damping and decreases to ∼0.36% at the linac end (1% full width). The static correction of the trajectory is based on pre-alignment with a system of wires, the ballistic alignment method completed by a few-to-few correction, structure re-alignments and on emittance-tuning bumps as described for 500 GeV. The bins for ballistic correction contain 12 quadrupoles each for any final energy, but the number of tuning bumps is increased from 2 to 10 when the c.m. energy goes from 0.5 to 3 TeV. These various corrections aim at maintaining the vertical emittance growth in the linac below 5 nm or 100% relative blow-up. Simulations indicate that repeating the static corrections at times (at a repetition rate which goes from low for the ballistic, *i.e.*, every few weeks, to frequent for the tuning bumps) makes the emittance control feasible, although the wakefields at 30 GHz are high and the alignment tolerances small. Figure 4.2, left, indeed shows that emittance growth in static conditions can be limited to about 25%, thus leaving a margin for time-dependent effects. Dynamic misalignments due to element motions are dealt with in a way which depends on their frequency range. For slow motion (below a few Hz), a certain number of feedbacks (up to 40) are distributed along each linac for recentering the trajectory and an IP feedback corrects for beam separation at collision. For fast motion, it is important to have a site with low noise conditions. In this respect, the site near CERN studied for its engineering feasibility is very quiet, in particular if the whole main tunnel is located inside the molasse, although progress in stabilization techniques would permit to use the extended tunnel mentioned previously. Measurements indicate that fast motion amplitudes of the ground in the molasse remain below 4 nm for frequencies above 4 Hz (about the limit of the feedbacks). In order to cover the gap between this amplitude measured on the floor and the tolerances for the quadrupoles, and to have means

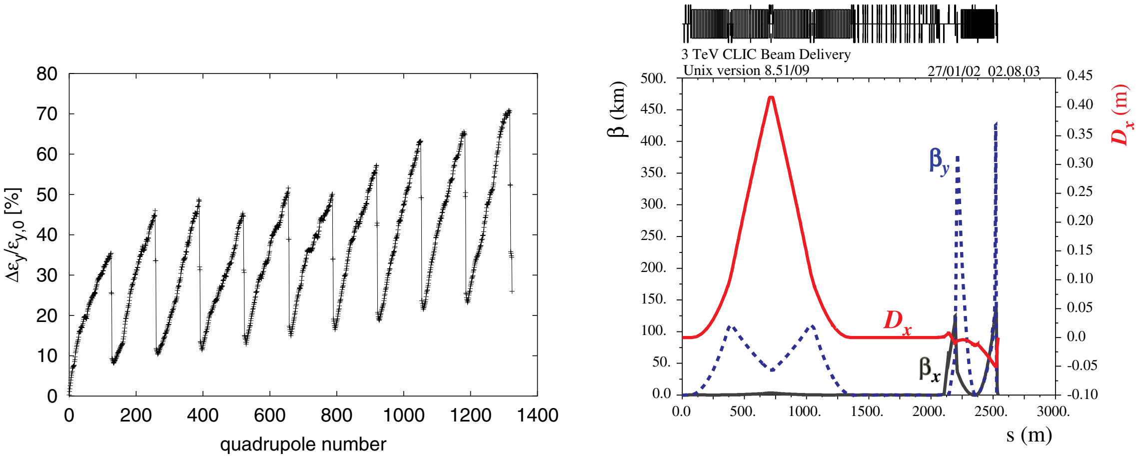

FIGURE 4.2. Left: Emittance evolution in the main linac after static correction which includes ten emittance bumps. Right: Optics of the compact beam delivery system at 3-TeV c.m.

to counteract the motion due to technical activity (like cooling), passive and active stabilization supports are considered and studied. Preliminary tests show that feet stabilized with commercial supports using rubber pads and piezoelectric movers give results which meet the requirements for the linac quadrupoles even in a noisy environment. Further reduction of the vibration amplitudes by a factor of 2–5 is investigated for the last FF doublets which predominantly contribute to the luminosity reduction. This clearly requires active stabilization, optimized by the use of permanent magnets in order to reduce their weight.

The BDS system has to be somewhat adjusted to the collision energy. In particular, the design scaling and the bending angles are different at 3 TeV and 0.5 TeV c.m. The design was initially done at 3 TeV, where it is most critical, and changing the energy by a large factor presently assumes some changes in the magnet positions, and in the bend and quadrupole strengths. However, the total length of the BDS remains constant as well as the total crossing angle of 20 mrad which is set from the beginning between the two main tunnels. Calculations indicate emittance growth close to the acceptable limit in the presence of sextupole aberrations and Oide effects, provided the last focusing quadrupoles are properly stabilized. Collimation efficiency remains to be checked through numerical simulations. The optics, the collimator survival and the control of wakefield effects are still being studied and improved. The final focus system is tuned on β^* values of 6 mm horizontally and 70 μm vertically, which gives a peak luminosity of $8{\times}10^{34}$ cm^{-2}s^{-1} with a good luminosity spectrum. The static luminosity optimization procedure needs further studies together with the time-dependent effects and their control via feedbacks including a luminosity-related feedback. The BDS optics at 3 TeV is given in Figure 4.2, on the right.

The main-beam injection system and the drive-beam generation system are both located in a central area. The central area also includes the underground collision point, the detector cave and the main-beam dumps. Hence most of the electrical power and a large fraction of the cooling power required must be provided there. In this configuration, upgrading the energy doesn't imply any modifications of the accelerator and ring complex. It is sufficient to make the layout suitable for a later extension of the installed electrical and cooling power in order to cope with the extra power needed for the drive-beam, and to modify the Pulse Forming Network (PFN) of the klystron modulators to cover longer pulse lengths. The distributed power required along the tunnel (mainly for the cooling systems of the rf structures) is low by comparison with the one of the central area and to first order increases linearly with its length (one service shaft per 5 power-source unit, typically). The power in the central area has a constant component (for services, detector, magnets), a component for the main-beam injectors which is constant for a constant repetition rate (but would be halved in the present assumption to reduce f_{rep} by two) and a third component for the drive-beam acceleration which basically is proportional to the ratio of the c.m. energy after and before the upgrade, divided by the reduction factor of f_{rep}.

A study of the CLIC physics prospects and of the experimental conditions is carried out for the nominal c.m. energy of 3 TeV [3]. The definition of the beam parameters and their optimization required by the physics imply close interaction between the collider design and a dedicated physics investigation. This activity aims at optimizing the experimental conditions through studies of the beam delivery and of the interaction region and the related backgrounds. In relation to machine-detector interface, it covers investigations for various beam parameters and collider characteristics of the luminosity spectra, backgrounds (muons, electron pairs, gammas, hadrons, jets, and so on) and design of the masks in front of the last quadrupole doublet. It is providing feedback to the CLIC design study on the machine parameters and has already served as a basis for proposing possible ways (see the main description) to deal with the different regimes of operation of CLIC.

BIBLIOGRAPHY for CHAPTER 4

[1] The CLIC Study Team, Ed. G. Guignard, A 3 TeV e^+e^- Linear Collider Based on CLIC Technology, Report CERN 2000-008 (July 2000).
`http://cern.web.cern.ch/CERN/Divisions/PS/CLIC/General.html`

[2] H.H. Braun, R. Corsini (Ed.), T. D'Amico, J.P. Delahaye, G. Guignard, C.D. Johnson, A. Millich, P. Pearce, L. Rinolfi, A.J. Riche, R.D. Ruth, D. Schulte, L. Thorndahl, M. Valentini, I. Wilson, W. Wuensch, The CLIC RF Power Source—A Novel Scheme of Two-Beam Acceleration for Electron-Positron Linear Colliders, CERN 99-06 (1999).

[3] CLIC - Physics Study group
`http://clicphysics.web.cern.ch/CLICphysics/`