CLIC - A COMPACT AND EFFICIENT HIGH ENERGY LINEAR COLLIDER

H.Braun, R.Corsini, J-P. Delahaye, G.Guignard, C.Johnson,
J.Madsen, W.Schnell, L.Thorndahl, I.Wilson, W.Wuensch, B.Zotter

CERN, CH-1211, Geneva 23, Switzerland

I. RF SYSTEM

A description of the original CLIC two-beam scheme is given in [1]. The overall layout of the 1 TeV machine is shown in Fig.1. The main linac consists of normal conducting travelling wave accelerating structures operating at a frequency of 30 GHz and a gradient of 80 MV/m. One in ten of these sections have an asymmetric geometry and act as microwave quadrupoles for BNS damping. For multi-bunch operation damped and/or detuned structures would be required. The 30 GHz RF power is supplied by transfer structures which extract energy from a 3 GeV high-intensity electron drive linac running parallel to the main linac in the same tunnel. The transfer structure consists of a 11.5 mm diameter circular beam tube coupled through two diametrically-opposite ≈5mm wide slots to two periodically-loaded rectangular waveguides. Each 50 cm long section produces two simultaneous 11.6 ns long 44.6 MW power pulses which drive two accelerating structures. This output power corresponds to 95% of the energy extracted from the beam. Two full-length (84 cell) constant impedance undamped accelerating section have been tested to an average accelerating gradient of 94 MV/m without any signs of breakdown and the periodically-loaded output waveguides of a full-length transfer structure have withstood 60 MW of 30 GHz RF power without breakdown but the structure itself has not yet been tested with a bunched beam Prototype diamond machined discs with the asymmetric geometry required for microwave quadrupole sections have been successfully produced by industry, and studies of damped structures for multibunch operation are underway. High gradient tests have also been made at SLAC on a 26-cell CERN-built X-band section [2]. Average accelerating gradients of 125 MV/m (a peak surface field of 285 MV/m) were obtained after 10^7 shots at 60 Hz with a pulse length of 150 ns. After conditioning, the dark current was 2µA at 50 MV/m and 150µA at 80 MV/m.

II. DRIVE LINAC

Each of the four drive linac has a starting energy of 3 GeV and a final energy of about 350 MeV. The total drive beam charge of 2.58µC is contained in four trains of 22 bunches per train with 1cm between bunches and an rms bunch length of 0.6mm. The first bunch of each train loses very little energy as it passes down the linac whereas the last bunch of the train is strongly decelerated. The limit to this energy extraction process is reached when the energy of the last bunch reaches about 350 MeV and the blown-up beam completely fills the 11.5 mm diameter available aperture [3].

.

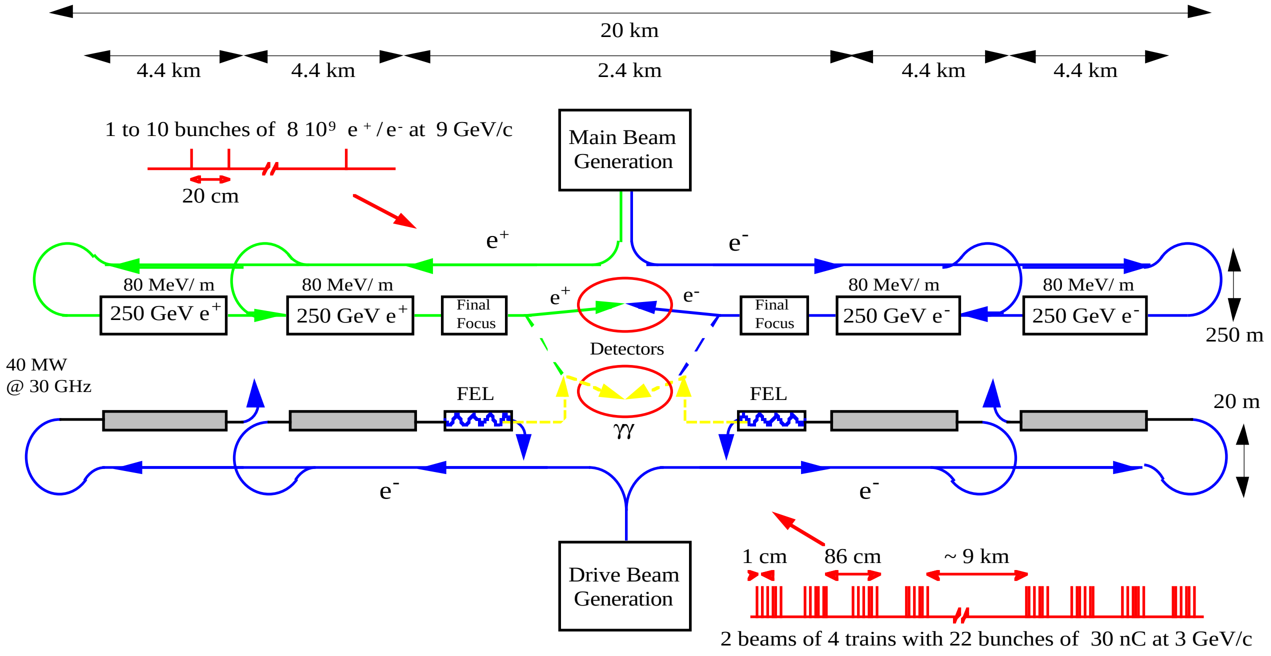

Fig.1 Schematic layout of 1 TeV CLIC machine

Half way down the linac when the mean energy of the trains is still 1.65 GeV an "energy exchange" section of 1.81GV of 700MHz SC cavities and 0.27GV of 1400MHz SC cavities is used to invert the energy distribution along the four trains to allow further energy extraction to take place. At the end of the linac when the beam is dumped the mean energies of the bunch trains are about 770 MeV for the first and about 350 MeV for the others. 72% of the beam energy is converted into RF power.

A 95 MeV drive beam consisting of a train of 24 bunches spaced at 10cm with a charge per bunch of 4.2nC and an rms bunch length of 1.3mm has been used in the CLIC Test Facility (CTF) to generate 76 MW of 30 GHz power from a single high impedance transfer structure and this power has been transmitted to a CLIC accelerating section in a two-beam configuration and has been used to accelerate a low intensity electron beam. The CTF work is reported in detail in [4].

III. DRIVE BEAM GENERATION

The 88 bunches of the drive beam are produced by a battery of 11 S-band photoinjector linacs. Each photoinjector linac consists of a laser-illuminated (262nm) photocathode (Cs_2Te) in an S-band RF gun (100MV/m) followed by an S-band RF booster. The energies of the 11 linacs (around 50 MeV) are slightly different allowing the 11 outputs to be merged in a magnetic spectrometer [5]. The resulting 12ns long bunch train is accelerated to 3 GeV using 3.8 GV of 350 MHz (6MV/m) SC cavities and 0.45 GV of 1400 MHz (10MV/m) SC cavities for RF wave flattening. Short sections (each 220 MV) of SC cavities operating at 333 and 366 MHz compensate the effects of beam loading.

One of these S-band photoinjector linacs has been built in the CLIC Test Facility (CTF) and has produced a maximum single bunch charge of 35nC with an rms bunch length of 2.4mm from the gun-booster at 11 MeV.

An alternative method to generate the 88 bunches of the drive beam directly at 50 MeV using an FEL is also being considered. Experiments to measure the degree of bunching produced by such a system at low energy (2-3MeV) are at present being carried out at the Centre d'Etudes Scientifiques et Techniques d'Aquitaine (CESTA) near Bordeaux. In a later phase it is planned to use this beam to generate power in a CLIC transfer structure.

IV. ISOCHRONOUS RING DRIVE BEAM SCHEME

A more efficient alternative to the "reference" drive beam scheme described above is being studied.

A laser illuminated L-band RF gun supplies 2x20 trains spaced at 1.97km of 17 bunches (σ=6mm) spaced at 20cm and of relatively low intensity (17nC) to a 1.5 GHz SC linac which accelerates them singly on the crest of the wave to the top drive beam energy of 2.7 GeV. The trains are then injected using 1.5 GHz transverse deflectors into each of two 1km circumference isochronous rings to produce 10 trains of 34 bunches spaced at 10cm. After extraction and the introduction of a linear correlated energy spread along the bunch using a 140 MV 3 GHz cavity, the bunch length is reduced by a factor of 10 in a magnetic bunch compressor. Finally bunch trains from each ring are combined by a 3 GHz transverse deflector to create two beams (one for each drive linac) of 5 trains each containing 68 bunches spaced at 5cm distance. Each train is used to supply power for a 100 GeV section of the main linac.

V. MAIN LINAC INJECTOR SYSTEM

A 1.5 GHz SC linac accelerates the e- and e+ beams to 2.15 GeV for injection into the damping rings. The e- beam is supplied by a 200 MeV normal-conducting photoinjector linac. The e+ beam is created from the 2.15 GeV e- beam using a rotating conversion target and a SLC-like flux concentrator for enhanced capture. A second 1.5 GHz SC re-circulating 1.37 GV linac boosts the energy of the e- and e+ beams to 9 GeV. A predamping ring also running at 2.15 GeV is used to match the positron emittance to the acceptance of the main positron damping ring. Simulations of the positron delivery system have shown that a comfortable safety margin in positron yield can be expected. The whole injector scheme is described in detail in [6].

VI. OVERALL MACHINE PARAMETERS

The single-bunch parameters have been re-optimised to obtain an acceptable compromise between luminosity and beam-strahlung effects [7]. The new parameters are given in Table 1 and are based on simulations of the beam behaviour in the main linac and the beam-beam interaction at the collision. A luminosity of 10^{33} $cm^{-2}s^{-1}$ is obtained using 100MW of RF power with single-bunches at 500 GeV. At 1 TeV however a multibunch operation (10 bunches) is required to reach a luminosity of 10^{34} $cm^{-2}s^{-1}$.

An option to make $\gamma\gamma$ or $\gamma e\pm$ collisions in a second interaction region is planned [8]. In this case one or more bunches of the CLIC drive beam would be used to produce an intense beam of polarised light in an FEL. This laser light would be transported via mirrors into the interaction region where it would be converted into a polarised γ beam by Compton back-scattering of the photons on the incoming electron beam. The ability to generate the photon beam in this way at a relatively high repetition rate with a drive beam to photon beam efficiency of 3-4% gives CLIC a distinct advantage over other machines which rely on conventional lasers. Detailed studies show that $\gamma\gamma$ luminosities of $4x10^{32}$ $cm^{-2}s^{-1}$ and $2x10^{33}$ $cm^{-2}s^{-1}$ respectively can be obtained for single and ten bunch operation by re-optimising the final focus parameters to take into account the fact that there is no disruption.

		500 GeV	1000 GeV	
RF Frequency	f	30	30	GHz
Accelerating field	E	80	80	MV/m
Number of bunches	n	1-10	1-10	
Distance between bunches	Δ	20	20	cm
Repetition frequency	f_r	2.5-1.2	4.0-1.8	kHz
Total two-linac power	P_{ac}	100	275	MW
Beam power per linac	P_b	0.82-3.92	2.6-11.7	MW
Beam power / AC power	η	2-8	2-9	%
Particles per bunch	N	8.10^9	8.10^9	
Normalised emittances (horizontal / vertical)	$\gamma\varepsilon_{x,y}$	3/0.15	3.9/0.2	10^{-6} rad.m
RMS bunch length	σ_z	200	200	μm
RMS beam dimensions	$\sigma^*_{x,y}$	250/7.5	200/6	nm
Beamstrahlung parameter	ϒ	0.08	0.18	
Relative energy loss	δ_B	0.04	0.08	
Luminosity enhancement	H_D	1.42	1.31	
Luminosity with pinch	L	1.0-4.8 10^{33}	2.2-10 10^{33}	$cm^{-2}s^{-1}$

Table 1 CLIC Parameter List

VII. BEAM DYNAMICS AND FINAL FOCUS STUDIES

Beam dynamics studies have focused on minimisation of the emittance blow-up in the main linac. Nominal emittances can be achieved with rms alignment tolerances of about 10μm on both accelerating structures and beam position monitors using a dispersion-free trajectory correction algorithm with three monitors between quadrupoles. Emittances below the nominal values have been obtained by applying a new correction algorithm which uses differences between trajectories for variable bunch currents and momentum [9]. The tolerance on quadrupole position jitter for a 10 % emittance dilution is estimated to be about 30 nm. A detailed layout of the scaled focusing scheme based on a division of the main linac in sectors with constant betatron function has been implemented. This required the addition of matching between sectors and a separation of the phase advances in the two transverse planes by 10 degrees to minimise coupling [10]. Shaping of the bunch particle distribution by collimation in the compressor has been introduced to minimise the energy spread.

The final focus system will have to be adapted to multi-bunch operation. It is proposed to use either a large enough crossing angle (about 10 mrad) so that the outgoing beam can exit through a separate channel in the quadrupole nearest to the interaction region, or to use a small enough crossing angle (0.25-0.5 mrad) to enable the beam to pass through the same beam hole as the incoming one. In order not to lose too much luminosity, the first option requires "crabbing" of the bunches with transverse RF fields with rather stringent phase tolerances. The second option will need somewhat larger apertures, and hence longer or stronger (SC) quadrupoles. In both cases, the incoming beam should remain on axis in order to minimise the emittance growth by radiation in the magnetic fields of the quadrupoles.

VIII. ALIGNMENT TEST FACILITY AND BEAM POSITION MONITOR TEST RESULTS

An active alignment test facility has been built in an unused underground tunnel at CERN to study the feasibility of making controlled submicron displacements and to test alignment systems. Accelerating structures are supported by V-blocks on 1.4m long silicon carbide girders. The ends of adjacent girders sit on a common platform which ensures continuity of position between units. The platforms are positioned by three stepping-motor-driven precision jacks (two in the vertical plane for vertical displacement and axial rotation, and one in the horizontal plane). Quadrupoles are positioned and moved independently of the structures by similar motors. In the test facility a stretched-wire running along the axis of the structures and passing through capacitive position transducers where the BPMs would normally be is used to simulate the beam. After deliberate misalignments of 1mm, the system which is programmed for automatic alignment with respect to the transducers, returns to its original position within <1μm.

A prototype E_{110} resonant cavity type CLIC beam position monitor has been tested with an antenna in the laboratory, and with a beam in the CTF. Resolutions down to 10 μm have so far been demonstrated in pilot data taking runs in the CTF. The antenna tests however clearly demonstrated a resolution of 5nm.

IX. REFERENCES

[1] W.Schnell, CERN-LEP-RF / 86-06.

[2] J.Wang et al. " SLAC/CERN high gradient tests of an X-band accelerating section", this conference.

[3] A.Riche, "Tracking particles with wakefield and space charge effects", this conference.

[4] R.Bossart et al.,"CTF Developments and Results," this conference.

[5] B.Autin and R.Corsini, "Generation of a 30 GHz train of bunches using a magnetic switchyard" this conference.

[6] J.P Delahaye, CERN/PS 94-14 (LP).

[7] G.Guignard and I.Wilson, "Single-bunch parameters proposed for 500 GeV and 1 TeV CLIC options", CLIC Note 264, Dec.1994.

[8] R.Corsini and A.Mikhailichenko, "The feasibility of $\gamma\gamma$ or $\gamma e\pm$ collisions for CLIC", CLIC Note 254, Dec. 1994.

[9] C.Fischer, " Improved CLIC performances using the beam response for correcting alignment errors" this conference.

[10] G. Parisi and G. Guignard, "Arrangement in Sectors of CLIC Linac Focusing", CERN SL/94-56 (AP).