The CLIC STUDY of a MULTI-TeV $e^{\pm}$ LINEAR COLLIDER

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ABSTRACT

The progress of the Compact LInear Collider (CLIC) study of a multi-TeV (0.5 - 5 TeV) high-luminosity (5×10^{33} to 1.5×10^{35} cm^{-2} sec^{-1}) $e^{\pm}$ linear collider based on Two-Beam Acceleration (TBA) is presented. The length and, in consequence, the cost of the overall complex is reduced by the use of high accelerating fields (150 MV/m), which are generated by specially damped 30 GHz normal-conducting accelerating structures. The large amount of RF power (400 MW/m) required to generate these high fields is provided by a novel RF power generating scheme which is potentially both cost and power efficient. After summarising the progress made in the developments of 30 GHz components and the performance obtained in the present phase of the CLIC Test Facility (CTF2), the design of a new test facility (CTF3), which will demonstrate the feasibility of the RF power generating scheme, is described.

1 INTRODUCTION

The Compact Linear Collider (CLIC) [1] has been optimised for a 3 TeV $e^{\pm}$ colliding beam energy to meet post-LHC physics requirements [2]. It covers a centre-of-mass energy range for $e^{\pm}$ collisions of 0.5 – 5 TeV and can be built in stages without major modifications. An overall layout of the complex is shown in Fig.1. In order to limit the overall length, beam acceleration is performed by using normal conducting travelling wave accelerating structures operating at high frequency (30 GHz) and developing fields of 100 to 200 MV/m. The RF power to feed the accelerating structures is extracted by transfer structures from high-intensity/low-energy drive beams running parallel to the main beam (Fig. 2). A single tunnel, housing both linacs and the various beam transfer lines without any modulators or klystrons, results in a simple, cost effective and easily extendable arrangement.

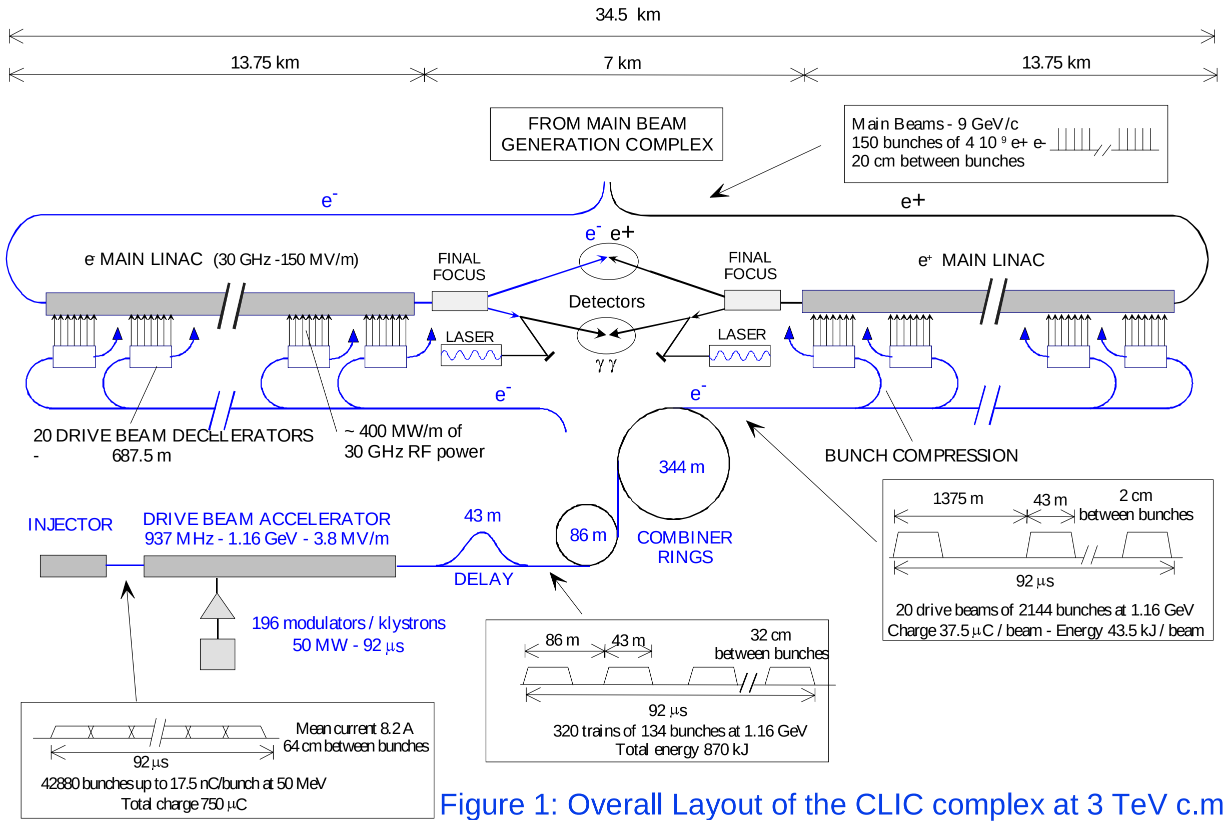

Figure 1: Overall Layout of the CLIC complex at 3 TeV c.m.

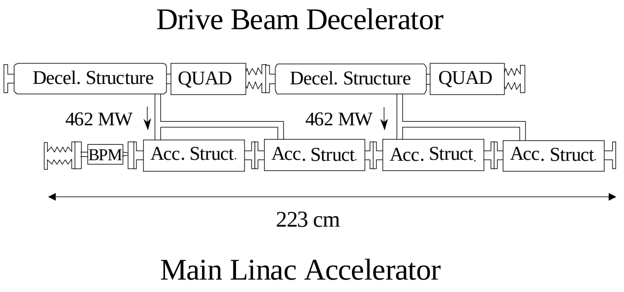

Figure 2: One main beam and drive beam module.

2 MAIN BEAM - LINAC PARAMETERS

The main beam and linac parameters are listed in Table 1 for various collision energies. They are deduced from general scaling laws [3] covering more than a decade in frequency. These laws agree with optimised linear collider designs [4] and show that the beam blow-up is independent of frequency for equivalent beam trajectory correction. To preserve the vertical emittance ε_{nv} at high frequency requires small charge per bunch N, short bunches, strong focusing and large accelerating gradient. A high RF to beam transfer efficiency results from multibunch operation with a close bunch spacing. Above 1 TeV, the vertical beam emittance is decreased and a high beam-strahlung regime retained, to limit the power consumption. Thanks to the short bunches however, the luminosity spectrum does not deteriorate significantly with the energy [5] and the increase of the number of emitted gammas is limited (Table 1). Hence, the effects of the 30 GHz transverse wakefields W_T can be kept moderate by choosing N to be $4x10^9$ and σ_z at the limit of the momentum acceptance of the final focus. The overall blow-up $\Delta\varepsilon_{ny}$ remains below $\approx$100 % at all energies [6]. The required luminosities impose a reduction in the injected ε_{ny} from $5x10^{-8}$ rad.m at 0.5 TeV to $0.5x10^{-8}$ rad.m at 5 TeV. The focusing optics, scaled as $(\text{energy})^{0.5}$, is generated by a FODO lattice made up of sectors with equi-spaced quadrupoles and matching insertions between sectors. The RF cavities and quadrupoles are pre-aligned to 10 and 50 μm respectively using a stretched-wire positioning system. Limiting $\Delta\varepsilon_{ny}$ relies in part on the use of bumps which are created locally at 5 to10 positions along the linac by mis-aligning a few upstream cavities. The measurement of the misalignments of the beam position monitors (BPMs), is crucial for emittance control [7]. A section of 12 quadrupoles is switched off, and with the beam centred in the two end BPMs of this section, the relative mis-alignments of the other monitors are measured with an accuracy of 0.1 μm. The beam trajectory and ground motion effects are then corrected by a 1 to 1 method. BNS damping is achieved by running off-crest of the RF-wave by 6° to 10°. For the sake of multi-bunch beam stability, each cell of the 150-cell structure [8] is damped by its own set of four radial waveguides giving a Q of 16 for the lowest dipole mode. A simple linear taper of the iris dimension provides a detuning frequency spread of 2 GHz (5.4%). Transverse wakefield calculations in this structure with non-perfect loads show a short-range level of about 1000 V/(pC·mm·m) decreasing to less than 1 % at the second bunch and a long time level below 0.1 %.

Beam param. at I.P.	0.5 TeV	1 TeV	3 TeV	5 TeV
Luminosity ($10^{34}cm^{-1}s^{-1}$)	0.5	1.1	10.6	14.9
Mean energy loss (%)	3.6	9.2	32	40
Photons /electrons	0.8	1.1	2.2	2.6
Rep. Rate (Hz)	200	150	75	50
$10^9 e^{\pm}$ / bunch	4	4	4	4
Bunches / pulse	150	150	150	150
Bunch spacing (cm)	20	20	20	20
H/V ε_n (10^{-8}rad.m)	188/10	148/7	60/1	58/1
Beam size (H/V) (nm)	196/4.	123/2.7	40/0.6	27/0.45
Bunch length σ_z (μm)	50	50	30	25
Accel.gradient (MV/m)	100	100	150	200
Two linac length (km)	7	14	27.5	35
Accelerating Sections	10802	21604	43736	54802
Power / section (MW)	116	116	231	386
RF to beam effic. (%)	35.5	35.5	26.6	19.4
AC to beam effic. (%)	14.2	14.2	10.6	7.8
AC power (MW)	68	102	206	310

Table 1: Main beam and linac parameters

3 THE RF POWER SOURCE

The RF power for each 687.5 m section of the main linac is provided by a secondary low-energy high-intensity electron beam which runs parallel to the main linac [9]. The power is generated by deceleration of this beam through energy-extracting RF structures in the so-called “Drive Beam Decelerator”. For the 3 TeV c.m. collider there are 20 drive beams per linac. Each drive beam has an energy of 1.16 GeV and consists of 2144 bunches with a spacing of 2 cm and a maximum charge per bunch of 17.5 nC. These 20 drive beams, spaced at intervals of 1.375 km, are produced as one long pulse by one single drive beam generator. By sending this drive beam train towards the on-coming main beam, different time slices of the pulse can be used to power separate sections of the main linac (Fig. 1). All the bunches (for 20 drive beams) are first generated and accelerated with a spacing of 64 cm as one 92 μs long continuous train in a normal-conducting fully-loaded 937 MHz linac with an RF/beam efficiency ≈ 97%. After acceleration the continuous beam is split up into trains of bunches using the combined action of a delay line and a grouping of bunches in odd and even RF buckets. These trains are then combined in two stages by interleaving four bunches in odd and even RF buckets. These trains are successive bunch trains over four turns in each of two subsequent isochronous rings yielding a final bunch repetition frequency and corresponding beam energy compression by a factor 32. The energy-extracting structures consist of 4 periodically-loaded rectangular waveguides coupled to a circular beam pipe [10]. Each structure provides 462 MW of 30 GHz RF power, enough to feed two accelerating structures. For stability in the drive beam decelerator, these structures are damped to reduce long-range transverse wakefield effects. The overall wall plug to RF power production efficiency is of the order of 40%.

4 TEST FACILITIES

The first CLIC Test Facility (CTF1) operated from 1990 to 1995 and demonstrated the feasibility of two-beam power generation. It produced 76 MW of 30 GHz RF power and generated on-axis gradients in the 30 GHz structures of 125 MV/m. A new test facility (CTF2) [11] equipped with 30 GHz modules made with RF components as similar as possible to the one envisaged for CLIC and including a few µm precision active alignment system, is being commissioned. The nominal configuration is as follows: The 48-bunch 640 nC drive beam train is generated by a laser-driven S-band RF gun with a Cs$_2$Te photocathode. It is accelerated to 62 MeV by two travelling-wave sections operating at two slightly different frequencies to provide beam loading compensation along the train. After bunch compression in a magnetic chicane, the bunch train passes through four power extracting structures, each producing enough power to drive two 30 GHz accelerating sections with 40 MW, 16 ns long pulses. The two bunches of the probe beam, also generated by an RF gun, are pre-accelerated to 50 MeV at S-band before being injected into the 30 GHz accelerating linac. The installation is now complete. The drive beam RF gun has produced a single bunch charge of 112 nC and a maximum charge of 755 nC in 48 bunches. 50 MW of 30 GHz RF power have been produced so far using a 450 nC drive beam. This resulted in a 30 MeV energy gain of the 0.7 nC probe beam. The highest accelerating gradient obtained is 70 MV/m with all the power generated by one structure feeding one accelerating structure.

A new facility (CTF3) is under study (Fig.3), which would test all major parts of the CLIC RF power scheme. To reduce costs, it is based on the use of the ten 3 GHz 40 MW klystrons and modulators from the LEP injector Linac. The drive beam is generated by two thermionic guns and is accelerated to 180 MeV by 20 short fully-loaded structures operating at 7.4 MV/m with an RF to beam efficiency of 96%. The beam pulse is 1.4 µs long with a current of 4 A. The bunches are initially spaced by 20 cm (two 3 GHz buckets) but after two stages of frequency multiplication they have a final spacing of 2 cm. This bunch train is then decelerated by seven power extracting structures in the drive beam decelerator. Each structure provides 512 MW. The main beam is accelerated to 1.1 GeV by fourteen 30 GHz accelerating structures operating at a gradient of 150 MV/m.

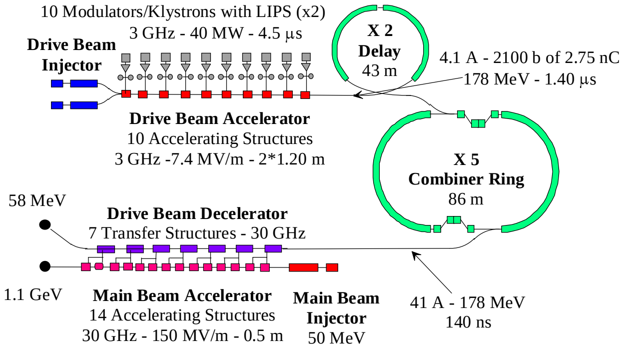

Figure 3: CTF3 schematic layout

5 CONCLUSION

The CLIC Two-Beam scheme is the ideal technology for extending the energy reach of a future high-luminosity linear collider in the multi-TeV range. The high operating frequency (30 GHz) allows the use of high accelerating gradients (100-200 MV/m) which shorten the linacs (27.5 km for 3 TeV) and reduce the cost. The effects of the high transverse wakefields have been compensated by a judicial choice of bunch length, charge and focusing strength such that the emittance blow-up is made independent of frequency for equivalent beam trajectory correction techniques. The upgrading in the multi-TeV range of the beam delivery from the linac to the detector still has to be studied. The two-beam RF power source based on a fully-loaded normal-conducting low-frequency linac and frequency multiplication in combiner rings is an efficient, cost effective and flexible way of producing 30 GHz power. The feasibility of Two-Beam power production has been demonstrated in the CLIC Test Facilities (CTF1 and CTF2). A third test facility is being studied to demonstrate the drive beam generation and frequency multiplication schemes.

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