The CERN Linear Collider

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Abstract

Over the last few years, a small group of people at CERN has been studying the feasibility of building a 1 TeV on 1 TeV e+e− linear collider to satisfy the long-term requirement for a new high-energy accelerator facility. Basic parameters for such a machine have been established but assume levels of performance or achievement in many areas that are at the very limit of what is currently considered to be feasible. The main design features of the machine are described and the overall status of the various development studies is given.

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Cern is studying the feasibility of building a 2 TeV $e^+ e^-$ linear collider called CLIC to enable high energy physics experiments to be extended into a range of energies where circular machines would be crippled by synchrotron radiation.

The main difficulty associated with the design of linear colliders is the generation of adequate luminosity which should increase with the square of the energy and exceed $10^{33} \text{cm}^{-2} \text{s}^{-1}$ for CLIC. The luminosity can be enhanced by increasing the repetition rate of the accelerator (1.7kHz for CLIC) but since this raises the required mains power which is generally felt should not exceed 200MW further enhancements are achieved by increasing the number of particles per bunch to $5 \times 10^9$ and shrinking the vertical beam size at the interaction point to 12nm.

Each of the two arms of the collider is composed of an $e^+$ or $e^-$ source, a damping ring at about 3GeV to reduce the emittance, a small section for bunch compression and pre-acceleration to 10GeV, a classical travelling-wave radio-frequency main linac accelerating section and a final focus system.

An obvious design aim is to make the main linacs as short as possible to keep the cost down which implies high accelerating gradients. Since the average RF power increases with increasing gradient but is inversely proportional to the square of the frequency there is a big incentive to operate at high frequencies. The choice of 30GHz is a distinctive feature of the CLIC design. At this frequency, fabrication problems, alignment tolerances and wakefield effects seem just manageable but demand state-of-the-art technology to achieve or reduce them. In spite of this choice and a relatively modest gradient of 80MV/m, the total peak power required is 150MW per metre of main linac but only for a duration of 11ns per pulse. Rather than using individual power sources (klystrons of several hundred MW every few metres) a two-beam scheme is proposed, this is the second distinctive feature of the CLIC design.
The idea is to have a 3-5GeV high intensity electron linac or drive linac running in parallel with the main linac. The bunched drive beam is decelerated in so-called transfer structures where RF power at 30 GHz is generated and fed via WR28 waveguide to the high gradient accelerating structures. Periodic replacement of the energy lost by the beam to the transfer structures is made by short sections of 6MV/m superconducting cavities driven by 350MHz 1MW klystrons. A total length of 2.5km is required per linac. The superconducting cavities and klystrons already developed by CERN for LEP are ideal for this application.

A promising design for the transfer structure has now been found. The structure must have an extremely low shunt impedance (a few Ω/m) and be sufficiently open to avoid creating self-decelerating and self-deflecting wakefields by the intense drive beam. It consists of a 15mm diameter circular beam tube coupled to the broadside of a power collecting rectangular waveguide through a row of coupling holes. The output waveguide cut-off and coupling hole spacing are chosen to be such that the beam is synchronous with the backward TE10 wave of the output waveguide at 30GHz. The RF pulse length is controlled by the length of the coupling sections. By placing output waveguides on both sides of the beam tube, 160MW/m can be extracted from a 50cm long section.

The required 30GHz 11ns power pulse to drive the main linac accelerating sections is generated in this structure by driving it with four bunch trains each composed of eleven 1mm long bunches of 10^{12} electrons spaced by 1cm. By arranging the drain time of the transfer structure to be equal to the period of the drive linac, the four 2.8ns power pulses of each train appear at the output waveguide as a single 11.2ns continuous pulse.

It is proposed to generate this drive beam by interlacing the outputs of a battery of eleven pre-accelerators each producing one bunch per bunch train. Use of laser-illuminated photocathodes with ps pulses is expected to produce the required 10^{12} particles per bunch. Best results so far have been achieved with a CsSb photocathode and a 266nm laser. It is anticipated however that a further bunch compression stage will be necessary to obtain the 1mm bunch length. In order to study the feasibility of this relatively complex scheme, an experimental CLIC test facility (CTF) is being built. It includes a photocathode in an RF gun, a beam line acting as magnetic spectrometer, acceleration to about 60 MeV and RF power generation at 30GHz.

Generation of the drive beam by interlacing the outputs of eleven pre-accelerators and periodic re-acceleration in 350MHz superconducting cavities.

Each of the two main linacs is composed of 45750 27cm long iris-loaded travelling-wave accelerating sections. The aperture diameter is 4mm, the cell diameter 8.7mm, the group velocity 8.2%/c and the fill time 11.2ns. The rather large aperture to wavelength ratio of 0.2 enables the destructive effect of single bunch transverse wakefields which are inversely proportional to the cube of the aperture to be held within reasonable limits. The 35mm outer diameter which is machined to a precision and concentricity with the beam aperture of +/-1μm, serves as the reference for alignment. Individual cells are pumped by four vacuum manifolds through radial holes. These holes may turn out to be output waveguides or damping slots channeling out unwanted energy associated with transverse deflecting modes if a suitable design for such a scheme can be shown to be worthwhile. The damping out of long range transverse wakefield effects would enable multiple bunches to be accelerated on the same RF pulse and would result in a corresponding increase in luminosity.
It is part of our plans to use microwave quadrupoles for single bunch wakefield stabilization. Such quadrupoles - featuring simultaneous acceleration and time dependent transverse focusing - can be obtained by giving a fraction of the accelerating sections a circular aperture in a flat (quasi-rectangular) cell. The role of the quadrupole is to create a spread in the wavelengths of the transverse oscillations of the particles within a bunch with the result that the tail is focused more strongly than the head thus compensating the transverse wakefield kick (this is called BNS damping).

This sets very tight tolerances on the transverse misalignment of the components - typically 1μm for quadrupoles and 5μm for the accelerating sections - and can only be achieved using active feedback using micro-movers and a signal from a beam position monitor with micron resolution. An active alignment test facility has been built in an unused underground tunnel at CERN to study this problem and controlled submicron movements have been achieved.

A 30-cell prototype CLIC accelerating section

An important problem is matching the beam's energy spread at the end of the linac to the final focus energy acceptance of 0.6%. The beam acquires a natural energy spread of about 2.5% due to the high single bunch energy extraction of 5% from the accelerating sections. Matching at the final focus however now seems possible by cancelling the longitudinal wake with the RF voltage (flattening the resulting accelerating gradient variation over the bunch) by adjusting the RF phase for a given bunch length and population. With such energy distributions and discarding 15% of the particles from the tails, a minimum r.m.s energy spread of 0.1% has been achieved for a bunch length of 0.17mm and 6x10^9 particles.

The small emittances required in CLIC to achieve the design luminosity must be conserved through the main linacs as the beam passes from the damping rings to the final focus.

The CLIC active alignment micro-movement test facility