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C LIC DRIVE BEAM GENERATION
A FEASIBILITY STUDY

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The CERN Linear Collider, CLIC, study explores the technologies that will be needed to build a two-beam linear collider in the center-of-mass energy range from 500 GeV to 2 TeV. The relatively low energy drive linac (a few GeV) delivers a 12 ns burst of electron bunchlets, of total charge 7 mC, to a 30 GHz transfer structure from which microwave power is drawn to feed the main linac. The duration of the burst equals the filling time of the main accelerating cavities and it is split into four or more trains of bunchlets separated by the RF period (350 MHz). The burst repetition rate is 1.7 kHz. To generate and handle these intense bunchlets several solutions are being studied. The source can be a conventional cathode or a laser photocathode. Pre-acceleration options range from Induction Accelerators to boosted S-band RF guns. One way to create the required 30 GHz time structure of the drive beam is to assemble many individual bunchlets from multiple sources, each compressed in length to 1 mm, into trains of bunchlets spaced by 10 mm. Sequential combination in momentum space is the main tool for this purpose, but a variety of optional hardware solutions exist, including the use of an isochronous collector ring. Alternatively, the 30 GHz time structure may be generated by the bunching process inherent to the operation of a Free Electron Maser, FEM. This attractive "in line" technique is now studied experimentally. Other studies include the generation of high charge from laser photocathodes, harmonic RF acceleration with compensation of beam loading and control of extraneous modes, and the specification of beam quality and stability.

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Abstract

The CERN Linear Collider (CLIC) study explores the technologies that will be needed to build a two-beam linear collider in the centre-of-mass energy range from 500 GeV to 2 TeV. The relatively low energy drive linac (a few GeV) delivers a 12 ns burst of electron bunchlets, of total charge 7 μC, to a 30 GHz transfer structure from which microwave power is drawn to feed the main linac. The duration of the burst equals the filling time of the main accelerating cavities and it is split into four or more trains of bunchlets separated by the RF period (350 MHz). The burst repetition rate is 1.7 kHz. To generate and handle these intense bunchlets several solutions are being studied. The source can be a conventional cathode or a laser photocathode. Pre-acceleration options range from induction accelerators to boosted S-band RF guns. One way to create the required 30 GHz time structure of the drive beam is to assemble many individual bunchlets from multiple sources, each compressed in length to 1 mm, into trains of bunchlets spaced by 10 mm. Sequential combination in momentum space is the main tool for this purpose, but a variety of optional hardware solutions exist, including the use of an isochronous collector ring. Alternatively, the 30 GHz time structure may be generated by the bunching process inherent to the operation of a Free Electron Maser, FEM. This attractive "in line" technique is now studied experimentally. Other studies include the generation of high charge from laser photocathodes, harmonic RF acceleration with compensation of beam loading and control of extraneous modes, and the specification of beam quality and stability.

1. INTRODUCTION

The CERN Linear Collider (CLIC) is based on the two-beam linac principle, by which a relativistic drive beam, bunched at 30 GHz, provides the microwave power at this frequency for the main high-energy linac [1]. Before being fed into the power transfer structures of the two-beam assembly, the drive beam must be produced and accelerated up to a few GeV. Superconducting 350 MHz cavities of the type developed for LEP, provide an economical means to this end, but the cost still represents a significant part of the total hardware cost of CLIC and, of course, the majority of the electrical power consumption. We are consequently studying various options for the generation and acceleration of the drive beam leaving open as many variables as possible in the desire to seek the lowest cost solution. Nevertheless, some parameters are set by the choice of 30 GHz for the main linac and that of 350 MHz for the superconducting linac, and by the overall luminosity requirement.

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Table 1
Drive beam parameters

Total charge per burst	7 μC
Maximum charge per bunchlet	40 nC
Number of bunchlets per train	22 to 43
Bunchlet separation (30 GHz)	10 mm
Bunchlet length (rms)	1 mm
Number of trains per burst	4 to 16

The total charge is limited to 7 μC by beam loading in the accelerating cavities. The maximum allowable electric field strength within the transfer structures of 200 MV/m fixes the charge per bunchlet at around 40 nC. Twenty two bunchlets can be accelerated per 350 MHz period if the RF voltage is flattened over one quarter period by using a second harmonic cavity [2]. Consequently, one way in which the total charge requirement can be achieved is by grouping several trains of 22 bunchlets at 2.84 ns intervals within an interval that is related to the filling time of the main linac cavity, using microwave pulse compression if needed. A possible time-structure of the drive beam is illustrated in Fig. 1.

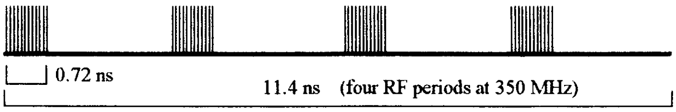

Figure 1. Basic drive beam time structure: 4 (or more) trains of 22 bunchlets. Other variants are described in section 2 of the text.

2. OPTIONS

2.1. Beam Switch-Yard

One technique for generation of the drive beam consists of producing the bunches individually in an array of RF electron guns [3] and merging them onto a single trajectory using a magnetic system called a "beam switch-yard" (Fig 2). The bunchlet separation of 10 mm is achieved by precise triggering of the guns. The final charge of 7 μC is divided into 8 trains of 22 bunches of 40 nC. Each train is 210 mm long and rides the crest of the RF wave made of the super-imposition of the fundamental 350 MHz wave and of a fourth harmonic which limits the momentum spread to ±4%. The 11 channels cover an octave of energy (25-50 MeV). Each gun emits two bunchlets per train at a repetition rate of 350 MHz via the switch-yard into a superconducting linac. The four trains are interlaced with four from a second

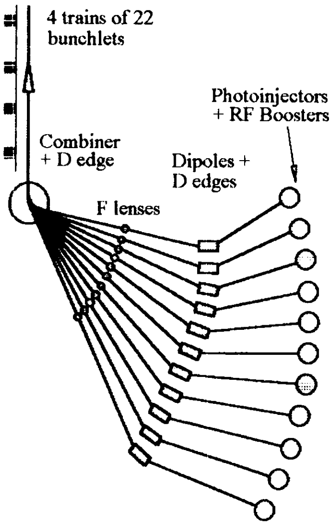

Figure 2. Merging bunches in a beam switch-yard.

switch-yard as shown in Fig. 3. After acceleration to 3 GeV the eight trains are combined into one beam of 8 times 22 bunchlets in 12 ns. This is deflected to one drive linac and after a short delay the sequence is repeated for the second drive linac. Before entering the drive linac transfer structures each of the eight trains must be given an overall initial momentum distribution increasing by 40% from head to tail. This is introduced by 700 MHz superconducting linacs in line with the drive linacs. The trains are centered around zero phase so that momentum is transferred from the head to the tail of each train.

2.2. Induction Linac plus Free Electron Maser

This technique for drive beam generation was initially proposed by Yu [4] in 1989 and then developed in greater detail by Shay et al. [5] in 1991. A long electron pulse (12 or more ns) from an induction linac is bunched in a Free Electron Maser, FEM, amplifier at 30 GHz and then chopped into the desired number of trains. The bunching operation must be performed at a high enough energy that subsequent longitudinal space-charge debunching is negligible. This would be in the range 30 - 40 MeV. Post-acceleration is accomplished as in section 2.1 (see also Fig. 3, FEM option).

Some preliminary experiments to demonstrate the feasibility of this method are under way at the Centre d'Etudes Scientifique et Techniques d'Aquitaine, CESTA [6] and these could lead to the construction of a short section of two-beam CLIC structure using a drive beam bunched by FEM action at 4 to 10 MeV. Improvements on the original scheme of Shay et al., and the means for removing the unbunched fraction of the beam are also being examined.

2.3. Pulse Train Compression

A third alternative is to generate by standard technology a long train of long bunches widely separated at low energy and to accelerate them bunch by bunch in a recirculating superconducting linac (Fig. 4). The length of the bunches is reduced in stages by conventional magnetic bunch compressors and the proper bunch sequencing for the two drive beams is made by longitudinal stacking in a single isochronous ring at the energy of 3 GeV with a circumference just equal to the distance between bunches in the injector linac. The two beam trains, separated by half the ring circumference, are then simultaneously extracted and transported for injection into the corresponding drive linacs, where the momentum correlation optimum for RF power generation is induced along the trains as mentioned in section 2.1.

This method has various attractive features. The facility comprises a single electron source, three linacs with a total energy gain of 740 MeV, all superconducting at the same frequency of 350 MHz, two stages of bunch compressor and one isochronous ring with a race-track shape and 2 km long straight sections in the same tunnel as the main linac. This provides, at a 1.7 kHz repetition rate, the two drive beams with 4 trains of 43 bunches each.

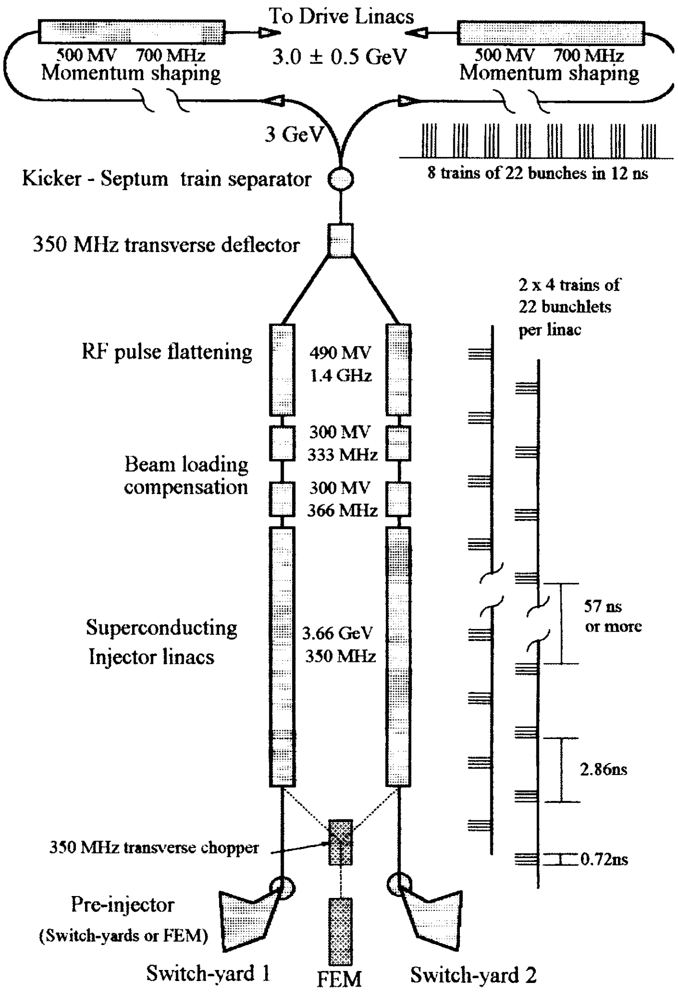

Figure 3. Suggested layout of pre-injector and post-acceleration linacs. Example given is for 500 GeV centre-of-mass collider.

Because of the long bunches at low energy (a charge of 40 nC in 30 mm FWHM), the electrons can be generated by a standard thermionic gun followed by sub-harmonic and harmonic bunchers or, preferably, by an RF gun for smaller transverse and longitudinal emittances. The acceleration of each group of 4 bunches in successive RF buckets at the crest of the RF wave in a repetitive operation at a constant rate of 145 kHz is very effective. Because of the long time interval between groups of bunches, the heavy beam loading generated in the superconducting structures can be

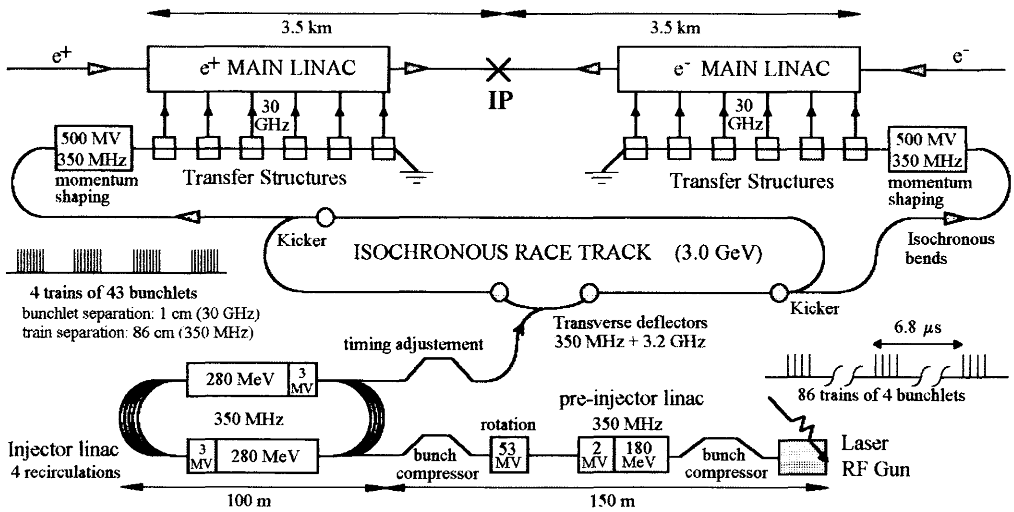

Figure 4. Drive beam generation using an isochronous race track to stack and thereby compress bunchlets into 30 GHz trains. N.B. In Figs. 3 & 4 conventional linacs are specified by the maximum beam energy in MeV or GeV, other structures (e.g. bunch rotators) are specified by the peak integrated RF voltage in MV.

compensated by RF refilling between the passage (6.84 μsec) of the 2×43 successive groups of 4 bunches.

The trains of bunches with high peak current (6.3 kA) and short distance between bunches (1 cm) are obtained at high energy which minimizes the deleterious effects of space charge and wake fields. The whole scheme reduces to a minimum the amount of superconducting RF structures needed with substantial savings in capital cost but also in RF and consequently wall-plug power. The basic technique of beam stacking over 43 turns requires a ring which must be almost perfectly isochronous (momentum compaction factor of $\cong \pm 1\ 10^{-4}$ in a $\pm 2.5\ 10^{-3}$ momentum range) in order to avoid bunch lengthening and de-phasing during the 588 μsec long stacking process. The feasibility of such a ring has still to be demonstrated but its performance requirements could be strongly reduced by adiabatic bunching using transverse RF deflectors at 30 GHz during the stacking process [7].

3. DRIVE BEAM STABILITY

A rough estimate of the effect of transverse wakefields on he stability of the drive beam at low energies has been obtained using the daisy-chain criterion [8] and found to be more of a problem during pre-acceleration (20 MeV - 150 MeV) of the four 700 ps trains than during post-acceleration (150 MeV - 3 GeV). Detailed simulations were therefore made of the pre-acceleration phase. For a normalized emittance (both planes) of $5\ 10^{-4}$ rad m and using a 90° FODO lattice with a β of 5 m and applying the wakefields due to the two main transverse modes only, the transverse x and x' values of the four trains were calculated as a function of the initial off-sets of the first train at 20 MeV. An amplification factor of four was found for the fourth train. This normalized x, x' distribution was then used as injection error to simulate the behavior of the trains in the 3.5 km long high-energy drive linac. Expressing the amplitude of the allowable offsets in terms of the beam rms dimensions typically 0.9 mm, 170 μrad, it was found that to keep the beam inside the beam tube when applying a one-to-one correction scheme, the off-set of the fourth bunch should not exceed 3 to 4 σ_x. For a random x, x' distribution the off-set requirement is reduced to 0.5 σ_x and for a constant distribution over the four trains but with no correction (jitter) and no misalignments the value is 0.1 σ_x. These tolerances apply to the position jitter of the drive beam at the entrance to the drive linac. A tolerance of ±5° of phase jitter (between bunchlets at 30 GHz) is also desired.

4. CONCLUSIONS

A comparative analysis of these various schemes for creating the CLIC Drive Beam is now actively pursued. Because of the scale of the project this work is mainly on paper, but the CLIC Test Facility is providing encouraging experimental results (20 nC bunches) that apply to the beam switch-yard option, and the FEM solution is now studied experimentally at CESTA, with the hope that this could result in the construction of a short section of full-gradient two-beam accelerator. For a 2 TeV collider the drive beam will include re-acceleration at 350 MHz, and for this purpose a larger number of shorter trains and lower charge bunchlets are preferred, which necessitates microwave pulse compression.

REFERENCES

[1] W. Schnell, "The CLIC Study of an Electron-Positron Collider", *LC92, ECFA Workshop on e+e- Linear Colliders,* Garmisch-Partenkirchen, ECFA 93-154, pp. 267-282, 1993.

[2] L. Thorndahl, "A Multi-Frequency Pre-Acceleration System for the CLIC Drive Linac with Beam Loading Compensation", *Proc. XVth Internat. Conf. on High Energy Accelerators,* Hamburg, pp. 885-887, 1992.

[3] R. Bossart, J-C. Godot, S. Lütgert, A. Riche, "Modular Electron Gun Consisting of Two RF Sections and an Intermediate Focusing Solenoid", *Nucl. Inst. and Meth.,* A340, pp. 157-163, 1994.

[4] S. S. Yu, "Some Thoughts on a Possible Role of Induction Linacs in CLIC", BRM89-29 , 1989.

[5] H. D. Shay, R. A. Jong, R. D. Ryne, S. S. Yu and E. T. Sharlemann, "Use of a FEL as a Buncher for a TBA Scheme", *Nucl. Inst. and. Meth.*, A304, pp. 262-267, 1991.

[6] R. Corsini, C. D. Johnson, J. Gardelle, J. Grenier, "CLIC Drive Beam Generation by Induction Linac and FEL - Experimental Studies for the CERN Linear Collider", *Proc. 1993 Particle Accelerator Conference,* Washington, 1993.

[7] L. Thorndahl, Private communication , CLIC Note 224, 1994.

[8] C. Adolphsen, "Multi-bunch Motion with Nearest Neighbor Wakefield Coupling", *Proc. XVth Internat. Conf. on High Energy Accelerators,* Hamburg, pp. 867-869, 1992.