

TOWARDS A MULTI TEV LINEAR COLLIDER; DRIVE BEAM GENERATION WITH CTF3

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Abstract

The 3 TeV compact linear collider, CLIC, foresees an RF source based on a high current drive beam running parallel with the main linac. To generate this drive beam of very high instantaneous power a sophisticated complex consisting of a fully beam-loaded linac and several stages of beam compression is used. Although this scheme is very promising in terms of cost and power efficiency, it needs demonstration in a scaled version before construction of CLIC can be envisaged. This is the aim of the CLIC Test Facility CTF3, built by an international collaboration. CTF3 is constructed and exploited in several phases. Here we report present status, experimental achievements and future plans for CTF3.

INTRODUCTION

The CLIC study develops the technology for a linear electron-positron collider with a centre of mass energy reach of $E_{CMS} = 3$ TeV [1]. This energy is chosen to complement the discovery potential of LHC Hadron collider with a Lepton collider capable to perform crucial precision measurements in the whole energy range accessible by LHC [2]. The luminosity requirement for these measurements is $L_I > 3 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, where L_I denotes the luminosity available in a 1% energy bin. To reach 3 TeV in a reasonable length high accelerating gradients are essential. These gradients are in excess of the fundamental limitations for superconducting RF at about 50 MV/m. Therefore normal conducting, high frequency RF is the technology of choice for CLIC. As a consequence of the high gradient, high peak RF power is required to feed the accelerating structures. This power is extracted from a second beam of high intensity and low energy, running parallel with the main beams. Such a two beam scheme provides the required RF peak power with good efficiency. Since the drive beam is produced in a central area no active high power components are required along the linacs and a single tunnel scheme with an inner diameter of 4.5 m as shown in fig. 1 can be used [3].

Recently combined results from RF structure testing [4], an overall optimisation of parameters [5] and the introduction of a scalable cost estimate in the optimisation lead to a major parameter revision for CLIC. The main modification are the reduction of the main linac RF frequency from the former value of 30 GHz to now 12 GHz and the reduction of accelerating gradient from 150 MV/m to 100 MV/m. This leads to an overall length including beam delivery system of 47 km for 3 TeV CLIC.

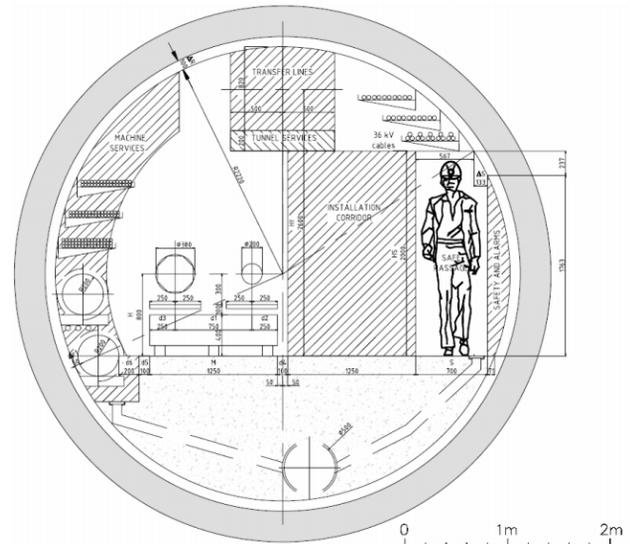


Figure 1: CLIC tunnel layout.

CLIC TEST FACILITY CTF3

The two beam scheme has been successfully demonstrated in the former CLIC test facility CTF II achieving accelerating fields of almost 200 MV/m [6]. However, in CTF II the drive beam was not produced in a manner representative for CLIC. In consequence the RF pulse length was limited to 16ns and the power efficiency of drive beam acceleration was poor.

The present CLIC test facility CTF3 aims to demonstrate the nominal CLIC drive beam production scheme [7] together with most other technical feasibility issues [8] as raised by the International Linear Collider Technical Review Committee ILC-TRC in 2003 [9]. CTF3 is build by a collaboration of institutes (table 1), with an organisation structure similar to large particle physics experiments.

The ILC-TRC issues addressed in CTF3 are:

a) *Demonstration of the CLIC accelerating structure at design gradient and pulse length.* CTF3 is already used as RF power source for 30 GHz testing. The 30 GHz CLIC accelerating structures are being tested in a well instrumented test stand. A vigorous development programme of accelerating structures is under way.

b) *Demonstration of the Drive Beam scheme.* The main issue here is the generation of the Drive Beam, i.e. acceleration of a long bunch train with conventional klystrons and subsequent bunch manipulations in order to increase the bunch repetition frequency, together with an increase in electron current in short, compressed bunch

trains. A very important feature of the Drive Beam acceleration is the operation of the accelerating structures under full beam loading. The other issue is the bunch train compression and frequency multiplication of the drive beam in isochronous delay loop and combiner ring with RF deflectors as injection kickers. CTF3 uses one delay loop with compression factor two and one combiner ring with a compression factor variable between one and five.

c) *Test of Power Extraction Structure (PETS) with on/off capability.* Special PETS are being used to provide the 30 GHz RF power for structure testing in the linac test stand, but 12 GHz PETS close to the CLIC design will be tested once the 35 A beam is available following completion of the Combiner Ring.

d) *Beam stability and beam loss control of the Drive Beam under deceleration for RF power production.* This will be tested in the Test Beam Line (TBL), where several PETS will decelerate the beam to a small fraction of its initial energy, converting the beam energy into RF power.

e) *Test of a relevant linac sub-unit with beam.* The full scheme will be tested with acceleration of a low-charge beam, the Probe Beam. Contrary to the CTF II, CTF3 allows tests with RF pulses in the 40-200ns range, covering the whole range of interest for CLIC.

As a consequence of these objectives, operation of the CTF3 facility is split between two main activities: Testing the Drive Beam generation complex and operation for high frequency RF power production for the development of CLIC accelerating structures. This second task uses presently the first part of the linac and a dedicated structure test stand. From 2008 on also the two beam test stand in the new CLEX (=CLIC EXperiment area) building will be used.

An overview of CTF3 is shown in figure 2. The drive beam is produced in a high current (10 A, 140 kV) thermionic gun. After bunching and a magnetic chicane for energy filtering a bunch train with maximum duration of 1.54 μ s and a beam current beam of up 5 A with a bunch repetition frequency of 1.5 GHz is accelerated in a fully loaded linac to 150 MeV. At half linac length a switch yard allows to take the beam either to a decelerating structure for 30 GHz RF power production or to keep it in the linac for full acceleration After passing the linac and a magnetic chicane which allows to adjust the bunch length, the beam is subject to a first frequency multiplication by a factor two using the 42m long isochronous delay loop. Afterwards the beam is transported with the isochronous transfer line TL1 to the combiner ring. This 84m circumference isochronous ring allows for frequency multiplication adjustable between two and five, leading to a maximum beam current of 35 A at extraction, with a train length of 140ns. Depending on the frequency multiplication factor bunch repetition, frequencies of 6, 9, 12 and 15 GHz can be obtained at extraction. Thus RF power at all these frequencies and their harmonics can be produced with the CTF3 drive beam. This flexibility allows easy adjustment of CTF3 to the new CLIC parameters. After frequency multiplication

Table 1: Present members of CTF3 collaboration

| Country | Institute |
|-------------|---------------------------|
| many | CERN |
| Finland | Helsinki Inst. of Physics |
| France | DAPNIA |
| | LAL |
| | LAPP |
| India | BARC |
| | RRCAT |
| Italy | LNF |
| Pakistan | NCP |
| Russia | BINP |
| | IAP |
| | JINR |
| Spain | CIEMAT |
| | IFIC |
| | UPC |
| Sweden | Uppsala University |
| Switzerland | PSI |
| Turkey | Ankara Universities |
| USA | NWU |
| | SLAC |

in the combiner ring, the high current beam is sent through transfer line TL2, where bunch compression with R_{56} variable from -0.35 to +0.35m is applied. A sophisticated sextupole scheme keeps T_{566} at zero for the whole R_{56} range. A so called tailclipper kicker in TL2 allows to adjust the train length, by kicking an adjustable fraction of the train to a dump.

In the CLEX building the drive beam can be switched either into the two beam test stand or into the decelerator test beam line (TBL). In TBL stability of the beam will be demonstrated under deceleration in a string of up to 16 PETS down to about 50% of its energy. In the two beam test stand the drive beam is sent through a PETS structure, producing 12 GHz RF power for feeding the 12 GHz accelerating structures in the probe beam. The probe beam is a low current beam of small emittance, delivered by a 180 MeV S-band linac named CALIFES. CALIFES uses a photo-injector and ballistic compression, to obtain short bunches of small emittance. The two beam test stand allows in addition to the two beam acceleration measurements, experiments on key aspects of RF breakdown phenomena and their effects on the beam and measurement of wakefield phenomena. For the probe beam there is a, not yet funded, option to add a beam line for beam instrumentation development (ITB= Instrumentation Test Beam).

The former CTF II building is used for high power RF testing and also for a test stand for a new photo injector, which will replace the thermionic injector of the drive beam. More detailed descriptions can be found in [10].

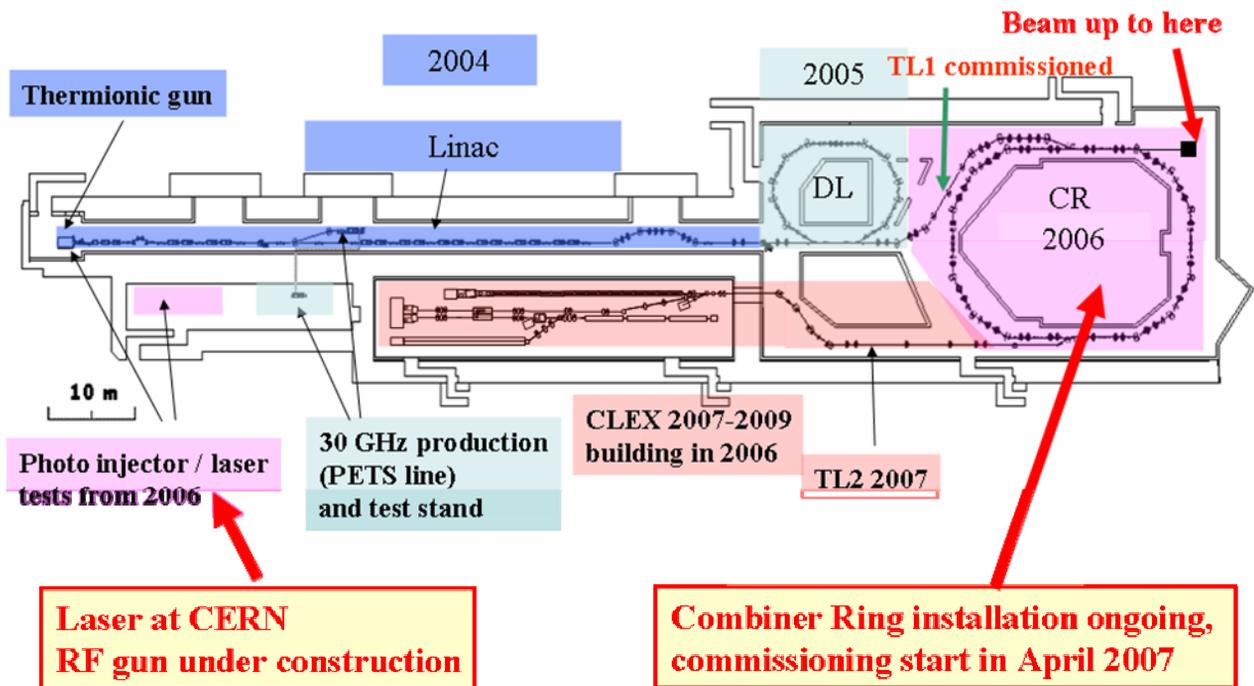


Figure 2: Overview of CTF3, indicating the present commissioning status and the different installation phases.

CTF3 STATUS AND ACHIEVEMENTS

So far the thermionic drive beam injector, the drive beam linac, the stretcher chicane, delay loop, TL1 and the injection region of the combiner ring have been commissioned with beam. Key achievements are:

- Nominal beam production and stable acceleration of a 3.5 A beam with full pulse length in the drive beam linac [11,12] without significant emittance growth. This demonstrates the stability of high current bunch trains in the presence of strong transverse and longitudinal wakefields. The wakefields are kept under control with Higher Order Mode (HOM) damping, HOM detuning and strong transverse focusing. The measured performance is consistent with predictions from beam dynamics simulations.
- Measured RF power to beam energy transfer efficiency of 95% in fully loaded operation for a normal conducting linac [13] ! This proves that drive beam production can be as efficient as predicted.
- Demonstration of frequency multiplication by a factor two with delay loop using RF deflector cavities and phase coding with rapidly phase switched subharmonic buncher cavities [14,15]. This is a key ingredient to achieve the bunch train compression.
- Routine 24h, 7 days a week operation of the fully loaded linac for 30 GHz production in the mid linac test stand [16], demonstrating that a fully loaded linac can be operated very reliable and stable.

CTF3 PROGRAM UNTIL 2010

Early in 2007 the combiner ring [17] will be completed and commissioning will start. Commissioning of the combiner ring and beam experiments will be interleaved with running for 30 GHz power production in the linac test stand. Many machine experiments and developments will be performed to get a good understanding and control of the longitudinal and transverse dynamics in the delay loop and combiner ring. The design [18] and construction of components for TL2 is proceeding, with installation of TL2 foreseen from late 2007 to spring 2008.

The already installed parts of CTF3 including the combiner ring use existing buildings, recuperated from the LEP pre-injector. For CLEX a new concrete surface building with inner dimensions of 42x8m has been constructed in 2006 to house all the CLEX beam-lines. Figure 3 shows the layout of the experimental beam-lines in CLEX. An equipment gallery on top provides rack space for all magnet power supplies and other electric equipment for the beam-lines in CLEX as well as klystrons and modulator for the probe beam injector CALIFES [19]. The assembly of CALIFES, transfer lines in CLEX and the two beam test stand [20] will start mid 2007, with the goal to get first beams to the two beam test stand in spring 2008. The test beam line (TBL) [21] will be build up in phases, for completion in 2009.

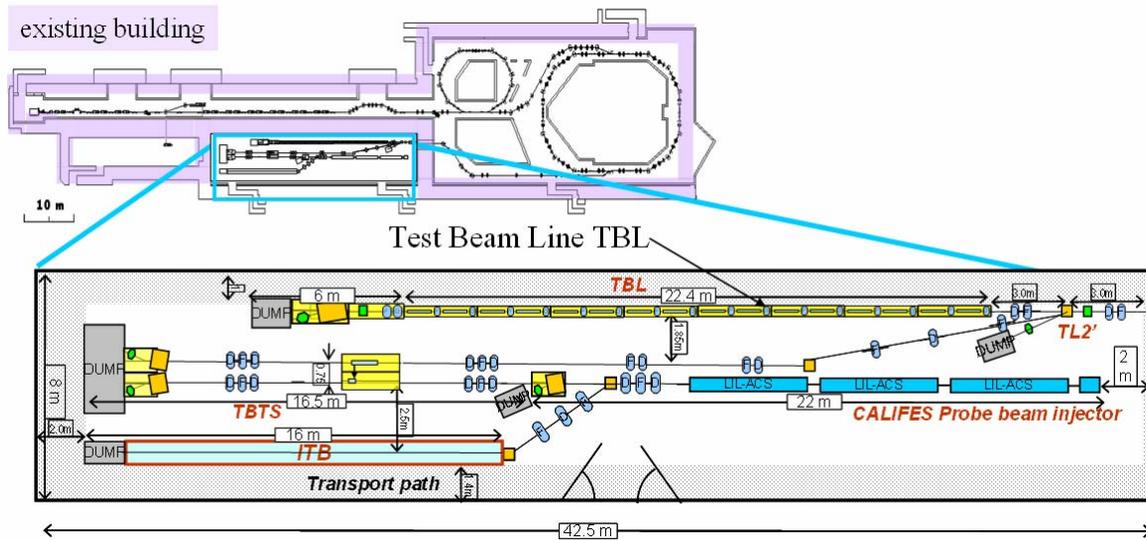


Figure 3: CLEX (=CLIC Experimental area) of CTF3

TBL=Test Beam Line
 TBS=Two Beam Test Stand
 ITB=Instrumentation Test Beam

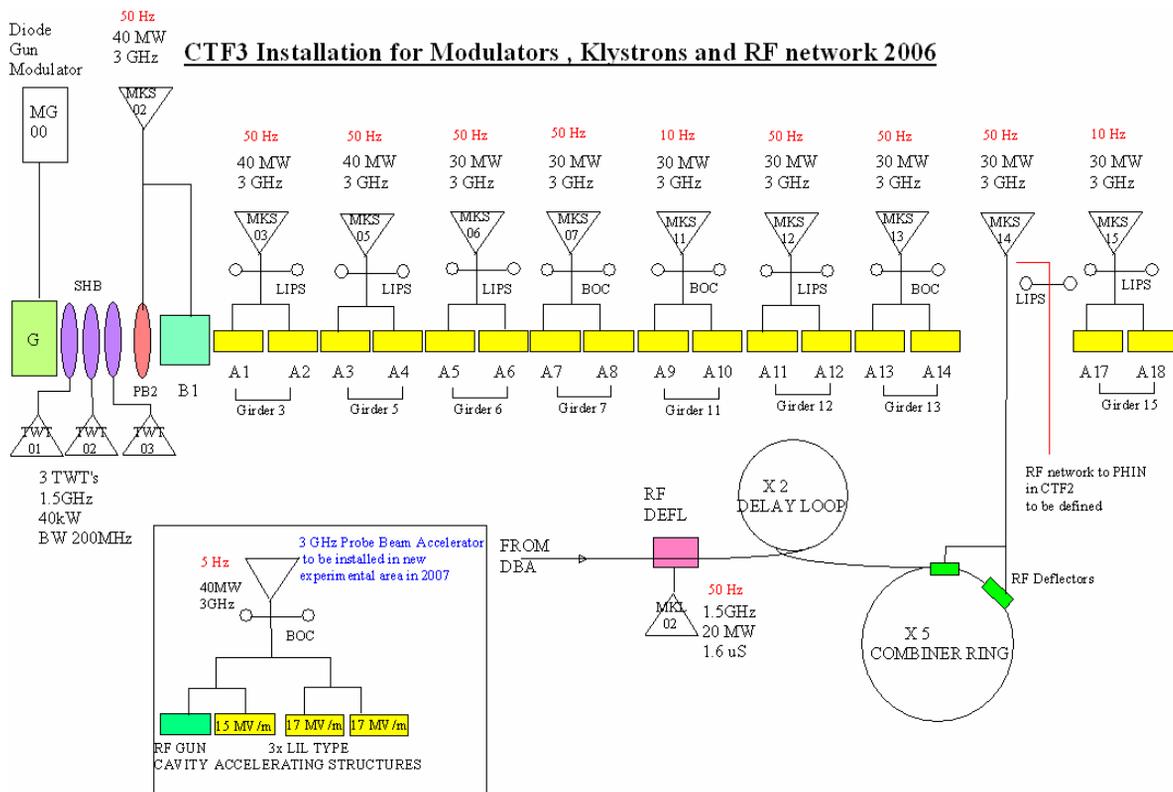


Figure 4: The 1.5 GHz and 3 GHz RF power plant for CTF3 drive beam linac and RF injector kickers.

Tests of the new drive beam photo-injector [22] consisting of a long train laser and a RF gun designed for very high beam loading will start in 2007. If successful, the present thermionic injector can be replaced with the photo injector in 2009. The laser system, however, is also used for the CALIFES RF gun and has therefore to operate from mid 2007 on. The drive beam photo-injector and its laser are financed by European Union in the framework of the joint research activity PHIN.

A key element to make all this work is the RF power plant feeding all the accelerating structures, bunchers, RF deflecting cavities and RF guns of CTF3. It consists of 11 S-band klystron modulators, one L-band klystron and three travelling-wave L-band tubes [23]. Fig. 4 shows the schematics of this power plant.

CONCLUSIONS

The program of the CTF3 collaboration to demonstrate key feasibility issues for a Multi TeV linear collider by 2010 is progressing according to schedule. Key targets like very power efficient high current drive beam acceleration without emittance growth, bunch frequency multiplication and stable long term operation in fully loaded mode have been achieved. Interleaved with commissioning and beam experiments the facility is routinely used as 30 GHz power source for accelerating structure development. The versatility of the drive beam generation scheme allows to adjust the facility readily for the new CLIC main linac frequency of 12 GHz.

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