

# Performances obtained with the CERN Linear Collider Test Facility (CTF)

R. Bossart, H. Braun, J.P. Delahaye, K. K. Geissler, J.C. Godot, J.H.B. Madsen,  
A. J. Riche, L. Rinolfi, S. Schreiber, J. Sladen, G. Suberlucq, I. Wilson, W. Wuensch

CERN  
CH-1211 Geneva 23

### Abstract.

The CTF serves to study some aspects of a possible future two-beam linear collider such as the production of a train of high charge, short electron bunches with a laser driven RF gun; the generation of 30 GHz power with a structure excited by the bunch train and the testing of beam position monitors. The main components of the CTF are briefly described: the 3 GHz gun and the different photocathodes used, the laser system producing trains of ps long pulses at 209 or 262 nm and the beam layout. Beam performances obtained are presented and compared with computations. The limitations encountered due to beam loading in the gun and accelerating section, due to wake fields and space charge effects are discussed.

### 1. Operation of the CTF

The beam for testing CLIC prototype structures is produced by a 3 GHz RF gun and an accelerating section. The present layout of the beam line is shown in Fig. 1. The RF gun has 1-1/2 cell, is equipped with a laser driven photocathode and operates at 100 MV/m resulting in a beam momentum of 4.5 MeV/c. With a solenoid put close to the gun outlet the beam is focused and then accelerated to 10.5 MeV/c in a 4 cell standing wave structure called the gun booster. In the travelling wave section - a spare of the LEP Injector Linac - the momentum is increased to 68 MeV/c. The beam then interacts with a CLIC structure which converts the energy extracted from the beam into 30 GHz RF power. This RF power is coupled to a second, identical CLIC structure and produces there high 30 GHz field gradients. The beam exciting the first structure is turned round and guided through the second structure and the acceleration by this structure measured. To generate high peak powers in the 30 GHz structure the e<sup>-</sup> bunches

should be short - around 10 ps FWHH - and have a high charge. Short bunches are made by hitting the photocathode in the gun with 8 ps long laser pulses.

To approach the 30 GHz power in the CLIC structure (60 MW, required to obtain a field of 80 MV/m, a train of bunches at 333 ps (3 GHz) intervals is used. For a train of eight bunches with 12 ps length at FWHH the required charge per bunch is about 11 nC. The wakefields induced in the accelerator section are too strong for getting such a charge per bunch. As the filling time of the 30 GHz structure is 11 ns, we could opt for trains of many bunches. So far, the best result was obtained with a train of 24 bunches. The bunch trains are produced by splitting one laser pulse into a train of pulses. The splitting technique employed is described below, section 2.

CsI was used as photocathode up to summer last year. This cathode can be exposed briefly to air, thus facilitating the handling between the production lab and the gun. However, to get high bunch charges the quantum efficiency of the cathode needs to be high - about 2% - implying the use of a laser wavelength of 209 nm. The laser energy was not enough at this wavelength and the optics found to be difficult. CsI itself has shortcomings as it saturates if the laser energy density increases. In autumn last year a transfer system became available to keep the cathodes under vacuum from the lab to the gun in the CTF. We therefore switched to Cs<sub>2</sub>Te and used the laser at 262 nm. The first experiences with Cs<sub>2</sub>Te photocathodes are good. One cathode had an initial quantum efficiency-QE- of 1.6% (assuming no losses in the gun) and 0.5% after 120 beam hours. With RF on, the vacuum in the gun is estimated at 10<sup>-9</sup> Torr.

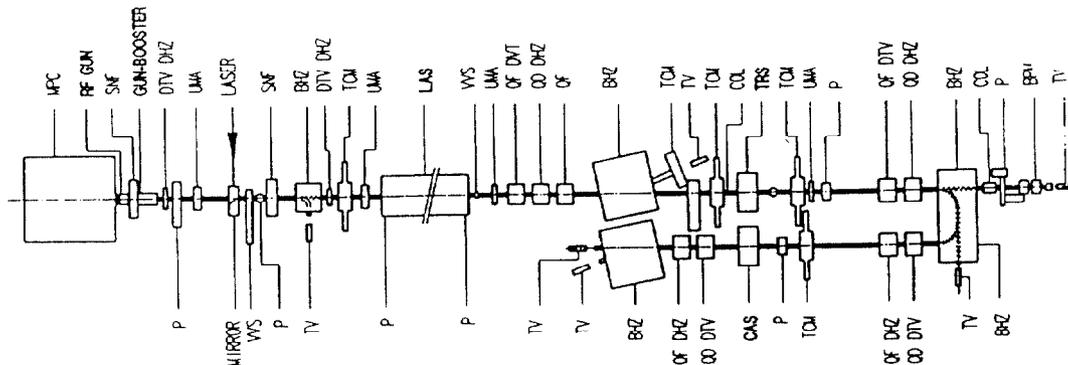


Fig. 1: Layout of the beam line SNF-solenoid, QF, QD-quadrupoles, BHZ bending magnets, DTV, DHZ-vertical and horizontal steering; MPC device for introduction of cathodes under vacuum in the RF gun; LAS-LIL accelerating section, TRS, CAS - two identical CLIC structures; UMA - beam position and charge monitor; TCM-transition radiation or a Cerenkov monitor; TV-screen in air viewed by camera; VVS-valve, P-vacuum pump

The storage life in a vacuum of  $10^{-11}$  Torr is long as no decay in QE was observed over three months. The RF gun and the gun-booster with the intermediate focusing solenoid are described in ref. 3. The duration of the RF power pulse to the sections is  $2.5 \mu\text{s}$  long and the repetition rate is 10 Hz. The nominal field gradient in the gun of 100 MV/m is reached after a conditioning time varying from a couple of hours to a few days and depends mainly on the quality of the RF contact of the cathode. In the gun-booster the field attained so far is 60 MV/m.

## 2. The Synchro Laser and the Pulse Train Generator (PTG)

The synchro laser system (ref. 4) has been optimized on the fourth harmonic (262 nm) providing a maximum of 0.5 mJ per pulse. As for the beam experiments 0.15 mJ/pulse is sufficient we have an operational margin. One or two pulses (at 4 ns) from the CW laser oscillator are selected by fast switching of a Pockel Cell. With a grating compressor used in combination with a stretcher the laser pulse length is 8 ps FWHH.

As is shown below, to increase the 30 GHz power generation a train of  $e^-$  bunches has to be used. This is achieved by splitting one laser pulse into a train of pulses spaced by one 3 GHz wavelength or 333.5 ps. The train generator using 49/51 transmission/ reflection mirrors - principle shown on fig. 2 - has been used for most of the beam experiments. The pulses leaving the pulse train generator (ptg) on different paths hit the photocathode on the same spot. The ptg for 24 pulses has 12 optical paths. A ptg providing pulses on one path has been developed as well (ref. 5).

## 3. Beam Performances

### 3.1 Single bunch.

The charge from the gun, measured with a magnetic pickup, depends on the energy of the laser pulse, the spot size of the laser on the cathode and the laser phase (LPh: time the centre of the laser pulse hits the cathode minus the time the field is zero in the gun). Three effects can limit the extractable charge: electric field cancellation by space charge on the pc if the laser spot is small, by aperture restrictions if the spot is large and by photocathode saturation. The beam charge measured downstream of the gun and booster starts to saturate above 10 nC, maximum charge 14 nC if the laser spot on the PC is  $10 \times 10$  mm and the length 8 ps FWHH. The transmission through the accelerating section and the 30 GHz structure entails losses; an example : from the gun, the section and the structure 10.5 / 8.7 / 7.5 nC, respectively. The bunch length is measured with a streak camera which receives the photon beam produced by interaction of the bunch with a transition radiation or a Cerenkov monitor. Results are 14 ps behind the booster and 16 ps after acceleration to 60 MeV/c.

### 3.2 Train of 8 bunches.

Wakefields in the accelerating section limit the charge per bunch which can be focused through the structure

generating the 30 GHz. The transverse profile and position of the bunches in the train are observed in front of the structure with a transition radiation monitor and the streak camera. The distortions due to the wakefields are shown on fig. 3. By applying a solenoidal magnetic field in the section and beam steering it is possible to counteract the wakefield effects. Even the individual position of the bunches is optimised by steering the laser pulse position on the PC while looking at the transverse characteristics in front of the structure. For a train charge from the gun of 20.6 nC only 65% passed the structure.

### 3.3 Train of 24 bunches

The experiments with trains of bunches showed that for passing the highest possible charge through the structure a continuous train of many bunches has to be used to reduce the effect of wakefields. The laser pulse train generator giving 24 pulses at 3 GHz gave the best results. A 24 bunch train total charge of 43.0 nC or 1.8 nC pb could be accelerated without losses and 76% passed the structure.

## 4. The 30 GHz Power Production and the Field Gradients

20 ns long, 30 GHz power pulses are generated by passing the CTF bunch train through a prototype CLIC structure. The pulses feed a second structure which accelerates a probe beam. Transmitted and reflected power levels from both structures are measured with directional couplers by mixing the signals down to 500 MHz and capturing on a 2 Gs/sec scope, fig. 4. Field levels in the structures are computed from transmitted powers. With 40 MW generated, a maximum peak field level of 80 MV/m was achieved in the decelerating structure, and 65 MV/m in the accelerating structure. The driving train is turned through  $180^\circ$  to form the probe beam. The flight time is adjusted to ensure that the second structure is filled with RF power when the first bunch of the train arrives. The accelerating field in the second structure is determined from the difference between maximum and minimum energy gain of the probe beam as its phase between the beam RF varies. The fields derived from reacceleration agree with those derived from power measurements to within 10%. These two field levels agree with that computed from measured bunch lengths and charges for single bunches. However, bunch trains seem to produce power levels up to 20% higher than those expected from measured bunch charges and lengths.

## 5. Further Increase of the 30 GHz Power Generation

We expect to reduce the effects of the wakefields in the accelerating section by raising its gradient. This will be achieved by a second 35 MW klystron feeding the section via an RF pulse compressor. The higher gradient will also lower the energy spread due to beam loading. Besides increasing the train charge through the 30 GHz structure we aim at shorter bunches. A magnetic bunch compressor put in front of the section is under construction [6]. Not related to 30 GHz optimisation but as part of the CTF objectives, a new RF gun will be designed to give up to 100 nC/bunch.

## 6. References

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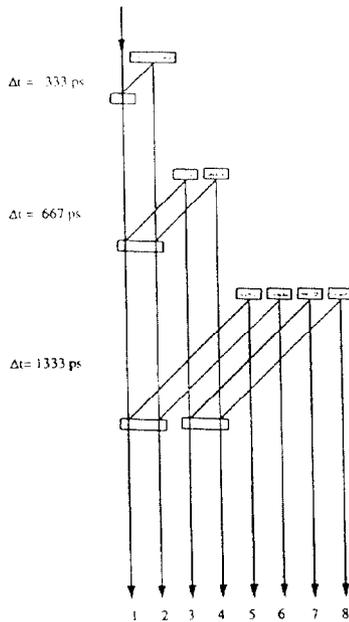


Fig. 2: The eight laser pulse train generator



x ←  
↓  
y  
and  
time

The slit in front of the camera is wide open.  
width If bunches seem to be closer then it is a position shift in y, not in time.

Fig. 3: Streak camera picture of the transverse bunch positions.

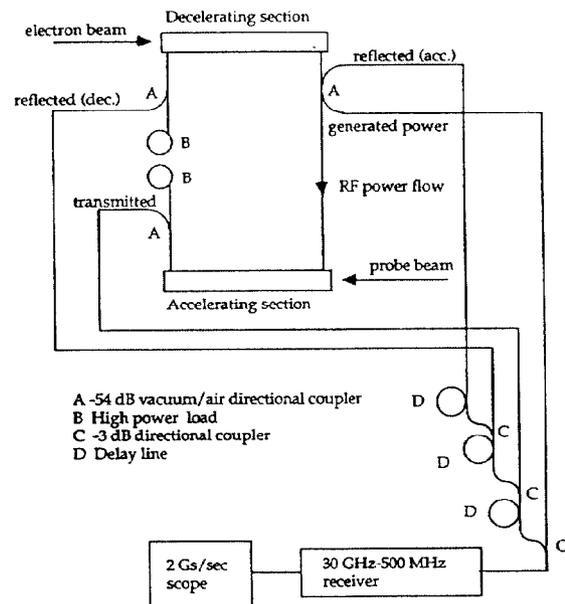


Fig. 4: RF measurements on the CLIC structures