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A CLIC INJECTOR TEST FACILITY

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1. Introduction

The Advisory Panel on the Prospects for e^+e^- Colliders in the TeV range concluded that the approach based on a normal conducting linear accelerator at a frequency of 30 GHz seems to give the promise of leading to a real project in 3 to 5 years if enough manpower and money are invested in research and development (ref.1). In this scheme (ref.2,3), the drive power is obtained from an auxiliary, high-intensity beam of a few GeV.

The generation of this drive beam seems to be the most challenging problem as far as the injectors are concerned. The beam is composed of 4 bunch trains, each consisting of 10 high-intensity bunches. The head of two consecutive trains are spaced by 85cm, and the bunches within the trains have a distance of 1cm. The first distance corresponds to 350MHz, the second spacing is the wavelength of 30 GHz. The charge per bunch is 64nC (4x10e11 particles) and the bunch length is about 3 to 4ps. The whole pattern repeats at 1.7kHz.

At present, the only device capable of producing such a beam seems to be a photo-cathode illuminated by a train of short laser light pulses and embedded in a r.f.cavity producing an electric a.c.field of about 100MV/m at the cathode. This high gradient is needed to overcome the strong longitudinal space-charge forces in the bunch when it emerges from the cathode.

After some further acceleration, a magnetic compression system provides then the reduction to the final bunch length.

Such r.f.-laser guns have been built in Los Alamos where bunches of 27nC with 50ps FWHH have been obtained (ref.4). Similar guns are under study and development for lasertrons, wake-field accelerators and FEL injectors in the US (BNL, Texas Univ.), in France (LAL, CEA) and in Japan.

Since the present performance of these systems is still far from the performance required by CLIC, and since experience with such a critical system must be built up in-house, it is proposed to start at CERN as soon as possible a vigorous research programme on this type of injectors in order to get a solid basis for the elaboration of the design concept of the CLIC injectors. This CLIC Test Facility (CTF) also allows for testing of CLIC transfer structures and of CLIC main linac structures.

In order to minimize the design work and cost, it is proposed to start with a gun operating at 3GHz, which is the standard frequency of the LEP Injector Linac (LIL). Although a somewhat lower frequency would be preferred for the gun from the point of view of beam dynamics (ref.5), this choice has the advantage that in-house expertise with 3 GHz systems already exists and that the major components could become also spare parts for LIL.

The gun would provide single bunches with a low repetition rate at the beginning, but the creation of bunch trains with 10cm spacing (corresponding to 3GHz) between the bunches would be attempted as soon as possible. The length of the train can be as long as the filling time of the CLIC structures to be tested. The nominal filling times are 3ns for the transfer structure and 12ns for the main linac structure but structures with other filling times could be chosen for the test if this yields a better match with the available bunch trains.

The CTF would also be used for tests of LIL spares as, for example, the electron gun, acceleration sections etc. Such tests are impossible at the moment as no test stand is available. It is obvious that the activity around CTF will positively influence our knowledge of 3GHz systems which in turn will help to improve the reliability and the performance of LIL.

This note gives a brief description of the facility and the scope of the research programme. Of course, a detailed study of the gun, the magnetic compressors and the beam transport elements is necessary but these hardware items are small and can be constructed relatively quickly. It is now more important to initiate the ordering of the major 3GHz components: the 4.5m long LIL accelerating section, the klystron and its modulator, which have long construction times (about 1 year). Since they are standard LIL components their specifications are well known, so they can be ordered relatively quickly. It is the purpose of this note to pave the way for a rapid decision on purchasing and construction of those components which have a long lead time.

It is obvious that the facility can also be used for the study of an e- injection system of the main linac (ref.6). Although the bunch intensity is much lower (0.8nC) in this case, this system has to provide a very small emittance beam. If this could be achieved, the electrons would not have to pass like the e^+ through the damping ring, which would reduce cost and simplify operation.

2. Description

Fig.1 shows a possible layout of CTF. The dimensions are based on the space requirements of the LIL components as detailed in Appendix I. The test facility proper is in the shielded area in the middle. The first element is the gun which could consist of 1 1/2 r.f.cells with the photocathode in the half-cell, on axis at the boundary where the electric field is maximum. The time distribution of the current pulse is determined by the duration of the laser pulse impinging on the photo-cathode. The laser beam is transported by suitable optical elements from the laser room to the gun. Fig.2 show as example the BNL gun design (ref.7).

The beam having an energy of about 5 MeV after the gun then enters a first bunch compressor before being accelerated again by a 50cm long S-band structure to 10MeV. The next short S-band structure prepares the beam for the next compressor by giving the head of the bunch a higher energy than the tail of the bunch. The energy-dependent flight-time created by the magnetic deflecting elements of the compressor makes the head and tail coincide in time at the output yielding a short bunch. Whether the existing 0.3m S-band SW structure (former buncher W) could be used to save the fabrication of one of these short structures remains to be studied.

The following LIL accelerating section provides an energy gain of 60MeV for 15MW input r.f.power. The beam has then enough energy so that the strongly decelerating CLIC structures can be tested with a beam being relativistic with a confortable margin even at the output of these structures. This accelerating section is at the same time an additional spare for LIL.

The spectrometer after the section allows for a precise measurement of the beam energy and of the energy spread. Fig.1 shows the CLIC structure in a position where the beam energy before and after the structure can be measured. The straight beam line at the end contains beam monitors and the dump.

Space is left between the components for instrumentation (cf.appendix I) which must be rather elaborate in order to allow for full exploitation of the test results.

The 3GHz LIL-type 35MW klystron with its modulator and the ancillary equipment is separated from the beam area by a 1.6m thick shielding wall so that access is possible to the r.f.source during operation as in the case of LIL. The roof of the beam area must also provide radiation shielding. In order to minimize radiation, effective composite beam dumps will be used.

If in addition to the 15MW for the accelerating section the two short structures require 2MW each and the gun needs 6MW as does the BNL gun, the power reserve is still 6.5MW asuming 10% losses in the waveguides as in LIL. Provided the acceleration section stands the higher gradients, which is not yet proven, the reserve power could be used to increase the energy gain to 72MeV; if on top of this the section tolerates the power increase by a peak power multiplication system (LIPS type) , an energy gain of 100MeV appears conceivable. Recent experiments at LAL with high power dissipation in LIL-type structures are very encouraging in this respect (ref.8).

The maximum repetition rate of the modulator is 100Hz, the actual repetition rate is likely to be limited by the laser or the shielding to 10 or 30Hz but this rate is not important; it should only be not too low, otherwise beam observation becomes tedious.

In order to simplify the setting-up of the facility with beam, it is advisable to use a conventional thermo-ionic gun. The former LIL W-gun could be suitable for this; it provides a low-emittance beam with 1A peak current and with a pulse length adjustable between 10 and 20ns.

In order to study the photocathodes and the space-charge problems under simplified conditions, it is necessary to perform a number of tests with a d.c.voltage. For this reason, space is reserved on the left side of the klystron room for a d.c. HV generator (HV), the resistance (R) and a d.c.gun (G) with a small spectrometer attached. Since the maximum conceivable voltage is only a few hundred kV, a 0.8m thick shielding wall is sufficient.

The laser beam can be delivered to either of the two guns from the laser room by means of an optical switch. The laser itself remains stationary on its temperature and vibration controlled base in the laser room.

For the start a prototype of an excimer-pumped dye laser is under development in the EF Division. It will be a fixed wavelength UV dye laser based on cascade pumping of short cavities. Tail quenching methods will yield 5 ps long pulses. The maximum repetition rate is 30Hz.

3. Research for CLIC with CTF

3.1 Gun

* Interaction laser-photocathode

Study the influence of the following parameters: energy of laser pulse, laser wave-length, angle of light incidence, effect of polarisation; Investigate: lowering of effective work-function by an auxiliary laser (ref.9), laser stability, spotsize, homogeneity of illumination, delay between light and beam pulse, comparison of width of light pulse to width of beam pulse.

* Technology of photo-cathodes

Material, handling, lifetime, reliability. It is likely that we start as everybody else with a Cesium-Antimony cathode which yields a high current density with a negligible broadening of the pulse. However, this electrode must be prepared and re-activated in situ under vacuum; its lifetime is less than days. Hence, there is a strong incentive to develop robust metal cathodes with a long lifetime though they probably need a laser pulse of shorter wavelength and a higher pulse energy, which seems to be at the limit of present technology.

* Test of different gun geometries

The beam leaving the cathode is under the influence of extremely strong space charge and image forces. These effects are difficult to model analytically. Thus, testing of the computer optimized gun geometries is indispensable.

3.2 Magnetic bunch compressors

Test of different magnet layouts to optimize compression and to reduce emittance growth.

3.3 Test of CLIC transfer and main linac structure

By measuring the energy loss of the bunch in these 30GHz structures the calculated shunt impedances can be verified. By measuring the higher-order mode spectra the loss into the higher modes can be obtained. The shape of the r.f.output pulses of the transfer structured can be studied.

Although the details are far from being worked out, an acceleration test with a small probing beam in the linac structure powered by the transfer structure could be possible.

3.4 Instrumentation and triggering

It is vital for the test facility to monitor the evolution of these high-intensity bunches which are about 16 times shorter than the LEP bunches (16mm). Thus, the appropriate instrumentation needs to be developed. Since precise monitoring is also important in CLIC, CTF will also provide a good opportunity to test and develop instrumentation for CLIC.

In order to measure these short pulses in the optics lab and to monitor the beam, the purchase of a high-resolution streak camera will be indispensable.

The timing between laser pulse and r.f. has to be done with high resolution and stability as the r.f.phase at the time of cathode illumination is a very critical parameter. The resolution has to be more precise by orders of magnitude than the present timing of the LIL gun where a resolution of 1ns is sufficient.

4.Usefulness of CTF for LIL

After LIL had reached the performance required by the LEP Injector Chain, the work of the PS/LP group on LIL has been directed to obtain a high availability of LIL for LEP. Consequently, the reliability of the equipment is being improved and the stock of spare is being completed. Scrutinizing the various LIL components, three major items were identified that in case of failure would bring about a long interruption of the LEP programme because no spares exist.

The electron gun used operationally for LIL has been purchased in 1980 from industry as a prototype for the first beam tests of the LEP linac front-end. Since spares of its components designed 10 years ago are difficult to get and since its configuration does not lend itself to computer control, a modernisation and consolidation programme has been launched. After acquisition of all the new parts a complete spare electron gun can be assembled. At present, however, no test area for such a gun is available. The CTF will allow for thorough testing of this gun, permitting to improve our know-how and creating an effective spare.

The LIL-V bunching system was purchased together with the gun from industry. We can think of faults on the r.f. and the hydraulic circuits that cannot be repaired quickly in situ. In such a case, the LIL operation may be interrupted for many weeks. Therefore, we contemplate design and construction of a spare bunching system. To test this system, a 3GHz power source, an electron gun and a beam measurement system are required as offered by CTF.

The accelerating sections next to the e^-/e^+ converter are indispensable for the e^+ production. These sections are equipped over their entire length with solenoids which can be dismounted only by opening up the section. Thus, in case of a problem in one of the sections which cannot be solved in situ, the removal of the solenoids and the mounting of these coils on the spare section will take 3 to 4 weeks. Therefore, we propose to purchase an accelerating section which will be equipped with solenoids. To become an effective spare, the section should be tested with the 3GHz source of CTF. This section would be ordered at the same time as the LIL section for CLIC. Such a section is under fabrication in industry for LAL. We could get these sections relatively quickly profiting from technical support by LAL and from the fact that industry has an operational production set-up.

The tests of the gun or of the accelerating section will take something like one or two weeks; testing the complete spare front-end of LIL will need one to two months judging from experience with the testing of the present LIL front-end at LAL. Thus, the time taken by LIL tests is expected to be a small fraction of the time available for CLIC.

Most of the staff working on LIL consolidation, maintenance and improvement will be also engaged on CTF, which will provide additional motivation. The expertise and skill gained through the participation in CTF will certainly have a positive impact on the availability of LIL.

5. Other laboratory space

The techniques for the production of trains of very short light pulses at high repetition rates are not yet developed though the evolution in the field is very rapid and conceptual solutions appear to exist (ref.10). Development of lasers will continue in the EF optics laboratory with final verification on the guns in CTF. Great attention has to be paid to the stability and reproducibility of the laser pulse.

Photo-cathodes need elaborate preparations such as chemical treatment, metallographic studies and surface physics investigations. Although maximum use of existing CERN facilities will be made, it seems necessary to have a proper laboratory for this activity.

6. Conclusion

The CLIC Test Facility (CTF) provides a unique opportunity at CERN to test critical components of CLIC as laser guns, magnetic bunch compressors and CLIC linac structures. It will help to build up the necessary know-how and momentum for CLIC. At the same time, CTF seems to be an appropriate test stand for all LIL components requiring testing with beam or r.f. At present, no such test facility exists.

In order to avoid undue delays it is proposed to start creating the CTF area with the required infrastructure; to purchase a LIL 35MW klystron exercising a contractual option we have until the end of the year; to start the construction of the modulator and its ancillary equipment; to purchase one LIL accelerating section from industry at the same time as the spare LIL section to be equipped with the solenoids.

A document on the cost of CTF and a possible spending profile is under preparation.

6. References

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T	Triplet focusing		11,9 m
	– Beam observation	0,3 m	
	– Quadrupole triplett	0,8 m	
			1,1 m
SP	Spectrometer		
	– Bending magnet I 30°, 7,5 kG	0,3 m	
	– Straight section for insertion of 30 GHz test structures	1,0 m	
	– Beam observation	0,3 m	
	– Bending magnet II 30°, 7.5 kG	0,3 m	
	– Drift and beam observation	1,3 m	
	– Dump	0,6 m	
			3,8 m
			16,7 m

Klystron room

Width : equal to LIL klystron gallery 6.5 m

Dimensions of RF power unit : 2.4 × 8.7 m

as a LIPS station of LIL

Laser room 4 × 5,5 20 m²

as indicated by K. Geissler

Control room 4 × 8 m 32 m²

LIL computer room has 50 m²

Auxiliary room for power supplies, instrumentation and controls 34 m²

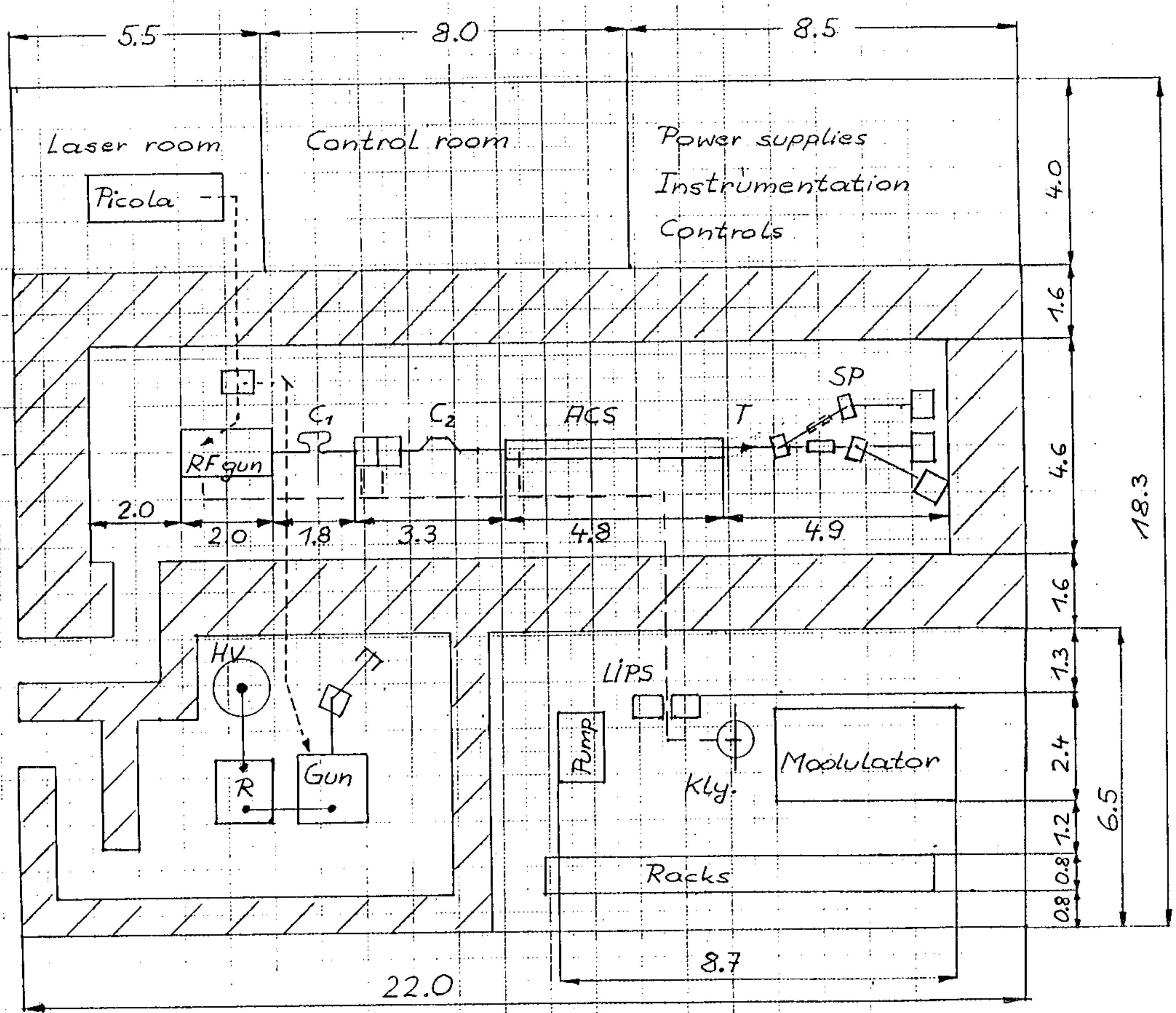
Grand total 403 m²

APPENDIX I

17.5.87
1
K.H.

Provisional layout of CLIC test

Description of elements			Length
GUN	Contains an RF gun operating at 3 GHz, triggered by the laser, and the facility for preparing a Cs_3Sb cathode behind the gun. Dimension : ≈ LIL-V gun (2 × 1 m)		2,0 m
C_1	Magnetic pulse compressor I at 4 MeV		
	– Beam observation after gun	0,5 m	
	– Ω magnet (as CEA)	0,8 m	
	– Beam observation and solenoid	0,5 m	
			1,8 m
C_2	Magnetic pulse compressor II at 9 MeV		
	– Short S-band structure (≈ LIL W buncher) for acceleration $\Delta E = 5$ MeV	0,5 m	
	– Short S-band structure for bunch rotation $\Delta E_{max} = 5$ MeV	0,5 m	
	– 4 Dipoles and 3 drifts	1.7 m	
	– Solenoid (= SNF 11)	0,3 m	
	– Beam observation	0,3 m	
			3,3 m
ACS	Accelerating structure as LIL structure $\Delta E = 60$ MeV for $P = 15$ MW		4,8 m
			11,9 m



Provisional layout   CLIC Injector Test Facility   1.6.88

Fig. 1

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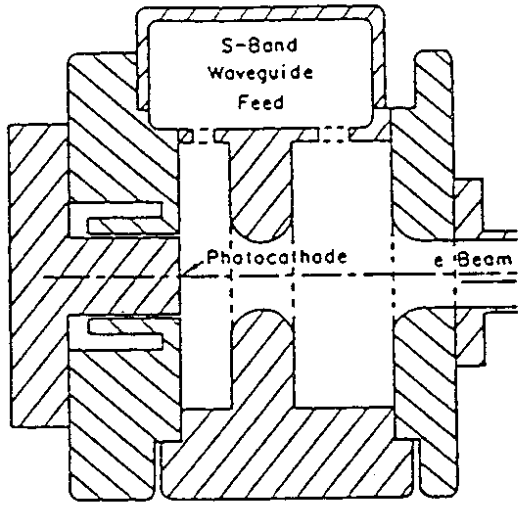

Fig. 2. Section through the rf gun. Except for the waveguide feed the gun is axially symmetric. The $1\frac{1}{2}$-cells of the gun are 8 cm long.

from K.T. McDonald, report DOE-ER-3072-43 (1988)