ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-OPEN-2005-007
14 April 2005

CLIC NOTE 625

A SUMMARY OF THE ACTIVITIES OF THE CLIC STUDY TEAM FOR THE YEAR 2004

I. Wilson

(For the CLIC Study Team)

Abstract

This report describes the progress made by the CLIC Study Team during the year 2004 on the design and development of the various sub-systems of the Compact Linear Collider (CLIC), the results obtained from the CLIC test facilities, the initiatives taken to expand the CLIC collaboration to obtain additional resources for the accelerated CLIC R&D programme, and the CARE and EUROTeV activities within the EU FP6 programme of studies.

Geneva, Switzerland
8 April 2005

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Introduction

This report describes the progress made by the CLIC Study Team during the year 2004 on the design and development of the various sub-systems of the Compact Linear Collider (CLIC), the results obtained from the CLIC test facilities, the initiatives taken to expand the CLIC collaboration to obtain additional resources for the accelerated CLIC R&D programme, and the CARE and EUROTeV activities within the EU FP6 programme of studies.

Damping ring

The design and the mode of operation of the damping ring has been modified during the course of this year to respond to an anticipated change in the official CLIC design parameters which call for a reduction of the charge per bunch from 4.2×10^9 to 2.6×10^9, an increase in the normalised transverse emittances in the damping ring before extraction from $\gamma\varepsilon_x$ = 450 nm and $\gamma\varepsilon_y$ = 3 nm respectively, to $\gamma\varepsilon_x$ = 500 nm and $\gamma\varepsilon_y$ = 5.5 nm respectively, and a reduction of the interval between bunches at the IP from 20 cm to 8 cm. The design is still based on 100 compact TME (Theoretical Minimum Emittance) arc cells but the period of the 76 two-metre long 1.8 T wigglers in the two long straight FODO sections has been reduced from 20 cm to 10 cm. Taking into account intra-beam scattering for a bunch population of 2.6×10^9, the 2.42 GeV ring with a circumference of 360 m now gives transverse equilibrium emittances in the horizontal and vertical planes for a perfectly aligned machine of $\gamma\varepsilon_x$ = 550 nm and $\gamma\varepsilon_y$ = 3.3 nm respectively for a betatron coupling of 0.6%, an rf voltage of 2.39 MV, and an rf frequency of 1875 MHz. This lower rf frequency corresponds to a bunch spacing in the damping ring of 16 cm and results from the new way that the damping ring will operate for the new parameters. The longitudinal emittance of 4724 eVm is smaller than the design value of 4800 eVm.

Studies of alignment tolerances and beam-based tuning have continued. The effect of misalignments was simulated by the BETA code of SOLEIL/ESRF and by a MAD-based dispersion-free steering routine previously used for LEP operation. With rms displacements of 100 microns for quadrupoles and 30 microns for sextupoles, a combined closed-orbit and dispersion correction reduced the rms orbit distortion to less than 50 microns and the rms vertical dispersion to 4 mm. The vertical emittance for these conditions is however still larger than 20 nm. The design emittance of 5-6 nm would correspond to an rms orbit offset at the sextupoles of less than 10 microns. To reduce the vertical emittance in the presence of errors towards its target value, a number of options are being explored, these include (i) an optimization of the BPM locations as well as an increase in the number of BPMs or correctors, (ii) beam-based alignment of BPMs with respect to adjacent quadrupoles, and (iii) a correction of both residual vertical dispersion and betatron coupling by means of a large number of distributed skew quadrupoles, as used at the KEK/ATF.

An alternative damping-ring lattice was investigated. The main features were a larger dispersion and an increased difference of vertical and horizontal beta functions at the sextupole locations, which reduces the sextupole strengths and increases the dynamic aperture. Unfortunately, it was found that the simulated equilibrium emittance with IBS increased significantly, so that this development was discontinued.

An estimate of the potential of various alternative non-standard schemes to produce low-emittance electron / positron beams has been made and has been compared with the performance of the present design of CLIC damping ring. The options include (i) the use of rf-wigglers or rf-undulators instead of magnetic wigglers, and (ii) the integration of radiation damping into the main linacs by interleaving high-field wigglers with main linac accelerating structures. The advantage of (i) is that very short wiggler periods are possible. It was shown that for an rf power of 200 MW at 30 GHz, wiggler periods of about half a centimetre appear feasible. The advantage of (ii) is that there are no arcs contributing to quantum excitation and, at higher energies, intra-beam scattering can be neglected. A disadvantage is the additional linac length and rf power required, and that for fast damping times super-conducting wiggler magnets are required. In both cases CLIC target emittances could in principle be achieved.

Main beam booster linac

A first attempt has been made to study the wakefield effects in the booster linac, which accelerates the beam between the two bunch compressors after the damping ring and before the main linac. A design has been made based on 15 GHz rf structures that can be powered by the same drive beam as used for the main linac. It has been shown that the emittance growth can be limited to an acceptable value, using ballistic alignment and an emittance tuning bump. These studies assumed that the bunch-to-bunch distance is twice as large in the booster linac than in the main linac; this would naturally be the case for mixed-charge operation (see next section) but could also be achieved otherwise. For the same bunch spacing in the booster and main linac, the beam has been found to be stable but the margin for avoiding the multi-bunch beam instabilities was too small.

Main linac beam dynamics

A study has been made of the electron-cloud effect in the CLIC positron linac. Electron multipacting may occur inside the rf structures under the combined influence of the beam field and the electro-magnetic rf wave. The multipacting can lead to an electron-cloud build up along the bunch train. Rates for the production of primary electrons from both collisional and field ionization of the residual gas were calculated. The primary ionization electrons are either trapped near the centre of the chamber by the beam field and rf fields, possibly accelerated in the longitudinal direction, or they escape radially towards the wall, where they can induce multipacting. It was found that the high CLIC rf fields can accelerate the primary electrons longitudinally up to ~200 keV. The electron cloud build up is modeled by a modified version of the code ECLOUD. This build up of electrons near to the beam can drive beam instabilities, change the single-particle optics, and cause particle losses by scattering. The simulation models showed that at elevated vacuum pressure, collisional ionization can lead to electron densities which degrade the beam quality. Without multipacting, the possibility of beam break up due to ionization electrons appears remote, thanks to rapid acceleration.

Some work has been done to see if the CLIC main linacs can be used for mixed-charge acceleration i.e. to accelerate trains consisting of alternating electron and positron bunches. The idea is to merge an electron and a positron bunch train and to separate them later using a dipole magnet. Before merging each of these trains would consist of half as many bunches at twice the inter-bunch spacing compared to the case where one type of particles is used. This configuration would have a number of advantages. In the main linac dispersion-free steering could be permanently applied during luminosity operation. This scheme would allow both interaction points to be run simultaneously at half the luminosity and would halve the background per unit time in the detectors. Simulations have confirmed that the dispersion-free steering works efficiently and that the optimization of the emittance tuning bumps is in principle possible. More detailed studies of the implications of running with mixed charges is required before it can be considered a viable option.

Accelerating structure design

The new HDS design of CLIC main-linac accelerating-structure has a new geometry which includes fully-profiled rf surfaces optimized to minimize surface fields, and hybrid damping using both iris slots and radial waveguides. The slotted irises allow a simple structure fabrication in quadrants with no rf currents across joints. The new structure is also constructed from two different metals, molybdenum is used for the tips of the irises and copper zirconium is used for the cavity walls. A newly-developed structure-optimization procedure has been used to simultaneously balance surface fields, power flow, short and long-range transverse wakefields, rf-to-beam efficiency and the ratio of luminosity to input power. This procedure is based on the interpolation of structure parameters and allows millions of structures to be analyzed taking into account the full and extremely complex interplay between rf and beam dynamics parameters. For a 30 GHz structure with a loaded accelerating gradient of 150 MV/m this procedure results in a bunch spacing of eight rf cycles, an rf-to-beam efficiency of 31 %, a total rf pulse length of 42 ns for 125 bunches, and a bunch population of 3.1×10^9. The optimized structure has a length of 263 mm (158 cells) and has a phase advance per cell of 60 degrees. This novel accelerating structure design and assembly gives a number of advantages compared to traditional structures in which individual cells are brazed together - these include (i) reduction of the number of pieces per structure to four and a significant decrease in surface area to be machined (ii) free choice of joining technique because there are no rf currents between quadrants (iii) no water/vacuum joints nor brazed-on cooling channels (iv) excellent vacuum pumping and (v) the slots can be as narrow as needed and can be profiled. The structure developments have in part been made possible by the purchase and installation at CERN of GdfidL. The code runs on a cluster of 20 parallel processors with 40 GB RAM, and can run very large jobs (300-500 million mesh points). It is now the primary tool for wakefield calculations and, along with HFSS, is the main code used in structure design.

CLIC Power Extraction and Transfer Structures (PETS)

Good progress has been made with the design of the CLIC PETS. It is designed to produce 800 MW from a 164 A drive beam and the peak surface electric field in the structure does not exceed 100 MV/m. Eight radial 1.3 mm wide slots cutting the PETS all the way along its length, channel out the disruptive higher-order-mode energy to SiC loads. The structure is made up of a 23 mm long matching section at the front, a 700 mm long main body, and a 61 mm long matching section and a 70 mm long power extractor at the end. The main body has an octagonal cross-section (~22.5 mm diameter) composed of 8 identical racks with shallow (~1.3 mm deep) sinus-type corrugations with 140 degrees phase advance per period (3.8885 mm). Eight HOM damping slots are placed symmetrically around the circumference. The damping slot width (2 mm) and the slot's rounding radii (0.8 mm) provide a quasi-constant distribution of surface electric field. The power can be turned OFF or just attenuated by inserting thin (~1.6mm) corrugated metal wedges into the PETS through four of the eight damping slots. These wedges detune the synchronous mode frequency and prevent coherent build up of the excited field. The frequency and group velocity of the first transverse HOM are practically identical to the fundamental decelerating mode and the only way to damp it is to use its symmetry properties. The PETS damping mechanism can be explained as a coherent radiation of many RF sources spaced by the period of the corrugations into an infinite radial slot – for practical reasons the infinite slot is replaced by a broad-band RF matched load. The angle of radiation depends on the phase advance and distance between them. The higher the phase advance, the smaller the angle and less the damping. The radiation (damping) is strongest when the phase advance and the period are matched. Since the PETS is very over-moded, any geometrical perturbation will provoke coupling of the decelerating mode into unwanted HOMs. As a result, a long adiabatic matching section with a number of gradually reduced corrugations is needed to extract the RF power into the smooth waveguide in an efficient manner. The matching section has a total length of 58 mm (15 periods) and has a reflection and mode conversion better than – 40 dB. A new broad-band 8-channel quasi-optical extraction coupler based on the multi-mode mixing approach has been designed to couple out the power from the CLIC PETS with an efficiency of 98%. The coupler consists of three parts, a mode launcher, a diffractor section, and a combiner/extraction section; these units provide an efficient step-by-step conversion of the energy from the E_{01} mode of the over-moded circular waveguide to the fundamental H_{10} mode of the standard rectangular waveguides. A low power prototype has been built and rf tested and shown to be in good agreement with HFSS simulations.

Material test facilities

The two new experimental facilities, the dc-spark test stand and the laser pulsed-surface-heating test stand, which were developed for CLIC by the TS Department became fully operational in 2004. These facilities will speed-up technical development in areas such as materials studies and preparation techniques.

The dc-spark test stand was used to investigate the electrical breakdown behavior of Mo, W and Cu in ultra-high vacuum. The maximum stable electric field without breakdown and the field enhancement factor, beta, have been measured between electrodes of the same material in a sphere/plane geometry for anode and cathode, respectively. It was found that the maximum stable field increased as a function of the number of breakdown events for W and Mo. In contrast, no systematic increase was observed for Cu. The highest values obtained were typically 500 MV/m for W, 350 MV/m for Mo and only 180 MV/m for Cu. This conditioning behavior for the refractory metals, corresponded to a simultaneous decrease of beta and is therefore related to the field emission properties of the surface and their modification upon sparking. In contrast, for copper, the beta values remained high and no increase in field due to conditioning was found to occur after repeated breakdown. These results are qualitatively in agreement with RF breakdown experiments performed on prototype 30 GHz accelerating structures for the CLIC accelerator. It was found that the conditioning in the case of dc set-up needs a much lower number of breakdowns. This is consistent with the argument of needing a certain minimum energy per surface area since in the dc set-up the energy per pulse is higher and the exposed area is smaller.

For the CLIC main linac the amplitude of the thermal cycling due to rf surface heating is about fifty degrees, and the expected lifetime of the linac is estimated at ~ 10^{11} pulses. The laser test stand simulates this thermo-mechanical fatigue behaviour. Tests have been made on Cu and a CuZr alloy in vacuum on an area of 0.5 mm^2at a repetition rate of 25 Hz. The purpose of the experiment is to produce high-stress/low-cycle data which can be extrapolated to the very large number of cycles required for CLIC. The surface of the samples were irradiated with 40 ns pulses of UV light (308 nm) using an excimer laser. The number of laser shots needed to create a break-up of the surface was measured as a function of the peak surface temperature difference. Surface break-up was characterized by average surface roughness. The energy densities applied were between 0.15 and 0.4 J/cm^2, corresponding to temperature increases at the surface of 90 and 240 K respectively. Observations by Scanning Electron Microscope showed that the surface damage obtained was similar to that produced in RF tests. It was found that CuZr withstands a much larger number of cycles than Cu for the same peak temperature.

The collaboration between CERN, JINR (Dubna) and IAP (Nizhny Novgorod) to provide pulsed-surface-heating fatigue data has again been delayed this year by the need to replace and improve many parts of the JINR FEM. This experiment is now running more than three years late but the latest schedule foresees results by mid-2005.

Material, machining and metrology studies

The TS Department has been investigating the fabrication and machining of bimetallic HDS structures. Two bars of CuZr with a Mo core have been ordered from the Finnish firm METSO. The bars are made by HIP (Hot Isostatic Pressing) to achieve a diffusion bond between the materials. For the machining of the HDS, two techniques are being studied, high-speed 3D milling and 3D electro-discharge machining (EDM). A short prototype piece of copper HDS has been successfully machined by high speed milling to an accuracy of +/-5 µm by the Finnish firm IMTEC, and a longer piece has been ordered from the German firm Dahmen. A collaboration with the "Ecole d'Ingénieurs de Genève" has recently been started to study problems of machining molybdenum by EDM. A short low-accuracy piece of HDS made entirely from molybdenum has been produced to demonstrate the capability of the technique and to see what surface quality can be obtained. The piece revealed the presence of micro-cracks which it is believed can be eliminated by a more suitable choice of machining parameters. Interfaces between CATIA and HFSS are being developed for the accurate exchange of dimensional data for rf analysis and the subsequent CNC machining of complex 3D shapes.

Beam parameters

Recent structure developments have opened up the possibility of a modification of the CLIC main parameters. No firm decisions were taken in 2004 but the new design of structure would make it possible to reduce the bunch spacing in the main linac from 20 to 8 rf cycles and to reduce the overall rf pulse length by about half to ~ 70 ns. The implications of these eventual parameter changes are still being studied.

Luminosity at the interaction point

The CLIC collision parameters, such as collision offset, collision angle and longitudinal position of the beam waists, need to be carefully tuned in order to maximize luminosity. In order to optimize these parameters a fast luminosity signal is needed. Possible signals that can be used for this purpose include the incoherent pair creation, the beamstrahlung and the coherent pair creation. Since the strong CLIC beam-beam interaction gives rise to the emission of a few megawatts of beamstrahlung and creates very large numbers of coherent pairs (~10^9 per bunch crossing at 3 TeV), these are good candidates for such a signal. In order to use realistic bunch shapes at the interaction point the beam transport through the main linac and the beam delivery system was fully simulated using the code PLACET. The elements of the main linac were offset according to the anticipated alignment errors. Full beam-based alignment of the linac was then simulated. It was assumed that the beam delivery system was aligned perfectly but the non-linear and synchrotron radiation effects in this system were taken into account. The beams obtained in this way were collided pair-wise using the beam-beam simulation code GUINEA-PIG. Based on simulations of 50 machines, it was found that by performing an offset scan in order to minimize the total beamstrahlung or coherent pair power about 99.6% of the basic luminosity could be obtained for both vertical offsets and crossing angle using the coherent pair signal. For the optimization of the longitudinal position of the beam waist the corresponding value was 98.8%.

Stability studies

Very little effort has been invested in stability studies this year because of limited resources. The results of vibration measurements made on CTF2 quadrupoles have however been written up. Vibrations of the lattice elements, if not properly corrected, can result in a loss in performance by creating both unacceptable emittance growth in the linear accelerator and relative beam-beam offsets at the interaction point. Vibrations induced by the circulating water used to cool the lattice quadrupoles are of particular concern. Since the CTF2 quadrupoles and their alignment support structures were realistic prototypes of those to be used in the CLIC linac, the measurements carried out provide a realistic estimate of the CLIC magnet vibrations in a realistic accelerator working environment. Measurements with and without the cooling water were taken simultaneously on the floor, on the concrete support girder and on top of the quadrupoles using high-resolution seismometric geophones which have a sub-nanometer resolution in the 4 Hz to 315 Hz frequency range. With the nominal water flow (pressure of about 3.2 bar), the quadrupole vibration level is increased by between 4 nm to 6 nm depending on the measurement conditions and on the quadrupole under investigation. There are indications that the quadrupole motion is affected by vibrations generated upstream of the magnet cooling circuit which are transmitted to the magnet via the water.

CLIC Test Facility (CTF3) Studies

A large fraction of CLIC resources again this year has been devoted to CTF3. This facility is being built in collaboration with Ankara and Gazi Universities (Turkey), CEA (Saclay), CIEMAT (Spain), Finnish industry, LAL (Orsay), LNF (Frascati), RAL (Oxford), SLAC (Stanford), North Western University (Illinois) and Uppsala University. The following chapters summarize the various CTF3 activities this year.

CTF3 linac

During the winter shut-down all support girders and four more SICA (Slotted Iris Constant Aperture) structures were installed in the linac. This brings the total number of SICA structures to 10. In addition a new so-called PETS line was installed parallel to the main linac. This line consists of a dog-leg transport line after the instrumentation module, and a 30 GHz power-generating PETS tank (more detail is given later in the section on 30 GHz power generation).

In the second half of the year, the Frascati team installed the variable R_{56} bunch stretcher/compressor magnetic chicane together with its vacuum chamber and beam diagnostic equipment at the end of the linac. This bunch stretcher/compressor will lengthen the short linac bunches to a σ of ~2 mm to avoid coherent synchrotron radiation (CSR) in the delay loop, but will enable very short bunches to be produced when required for CSR studies. The chicane consists of 4 dipoles and 7 quadrupoles. To be able to commission this line, the vacuum tube along the whole linac was installed and the beam line was terminated with a spectrometer. A particularly interesting part of the diagnostic equipment was a 3 GHz transversely deflecting rf cavity and its associated BPM which were used for bunch length measurement.

CTF3 beam diagnostic equipment

A comprehensive beam diagnostic system has been either developed, or adapted, to the special beam requirements of CTF3. Beam profile monitoring is done using either phosphorescent, or aluminium (or graphite) OTR (optical transition radiation) screens. Attempts to obtain time-resolved measurements of position/energy variations within the bunch train in the spectrometer lines resulted in varying degrees of success. At high beam charge, the SEMgrids did not behave as expected, one of the ceramic supports was broken by the beam, there were problems with beam induced RF noise and no credible profiles were measured. For these reasons further attempts to use SEMgrids will probably be abandoned.

More success was obtained with the two water-cooled segmented dumps consisting of 24 (2mm thick) tungsten plates spaced by ~ 1mm which were installed in the spectrometer lines on girders 4 and 7. Useful energy spread distributions were obtained with an energy spread resolution of ~ 1%.

Encouraging results were also obtained using a beam splitter and a 32-channel segmented photomultiplier in the optical line of the CT spectrometer to view OTR light produced by an aluminium screen with a gated CCD camera. With 0.8mm segments, and a distance between segments of 1mm, the system has a resolution of 2.8mm (~ 1ns). Problems linked to screen quality and optical line acceptance still have to be resolved and amplification is being considered to improve the signal-to-noise ratio.

Work by Uppsala University continued on the bunch phase monitor which is being designed to measure phase errors after bunch combination in the combiner ring. A prototype monitor was installed in the linac to test it with higher beam charge and to study its sensitivity to bunch length and beam current. The electronics have been modified to measure five beam harmonics (6, 9, 12, 15 and 18 GHz). It was found that the frequency dependence of the pick-up transfer impedance was similar to the MAFIA predictions, but the observed signals were much higher than expected. Clear signs of parasitic coupling to the RF wave guide mode were also observed.

It became clear during the 2004 runs that the screens and the MTV monitoring system will have to be improved. It was found that the phosphor screen was only good for measurement of the beam profile of dark current after the gun. Elsewhere OTR and carbon foils were preferred using gated CCD cameras for observation. Backward OTR systems with 10 micron carbon foils were used in the linac for emittance measurements, and in the spectrometer lines for energy and energy dispersion measurements. It was found that the non-perfect homogeneity of the carbon screens affected the local reflectivity of the screen, better or new materials are being investigated. Possible candidates are 300 micron silicon wafers, aluminium-coated silicon wafers (for higher reflectivity) and polished carbon or silicon carbide for high charge beams. A general problem that was encountered with the OTR systems was that the amount of light collected by the optical line (optical acceptance) was found to depend on the position of the beam on the screen and is due to the small angular aperture ($\sim 1/\gamma$) of the OTR light.

Two synchrotron light monitors were installed in the INFN chicane at the end of the linac.

Beam loss monitors

The North-Western University of Illinois is hoping to get resources to build a radiation-hard beam-loss monitoring system for the future CLEX TBL. As part of their development programme they have installed a time-resolved beam-loss monitoring system on the CTF3 linac and around the CTF3 PETS. The idea was to measure the beam loss with small ionization chambers ‘SIC chambers’ with 10mm diameter collectors. The monitors however did not work at all as expected. Both the applied voltage and the gas content (argon, helium and vacuum) had little or no effect. The chambers were found to be sensitive to both charged particles and low energy X-rays (<100keV) and it turned out that the X-ray signal (via the photo-electric effect directly on the electrodes) was the dominant signal. Since this signal depends on beam loss characteristics (position, intensity and energy) it is very difficult to get an absolute calibration of the device. The level of beam loss was therefore estimated by normalizing the SIC signals to signals from Faraday cups which were installed close to the SIC chambers for this purpose. This was not however entirely satisfactory since the Faraday cups only measure charged particles. These “secondary emission” monitors were installed at different positions along the linac (four per girder) to obtain a longitudinal beam-loss mapping along the machine. The system was able to measure a beam loss current of 1mA corresponding to ~0.03% of the nominal beam current (3.5A) with a time resolution of 2μs. The time resolution was improved by modifying the amplifier electronics. By reducing the gain of the amplifier, a 4ns time response was obtained but the monitor was then only able to resolve 1% of the nominal beam current. During normal beam operation, the beam-loss system measured an overall beam loss of 2-5% of the total beam current. This number was confirmed by beam current measurements on the linac. Girders 5 and 6 were found to be regions of high losses with 1-2%

of beam loss in less than a meter. Further along the linac, as the beam energy increases, the level of losses was found to decrease. On girders 12 and 13 for example, no beam loss was measured by the SIC system. A much more sensitive device was built for the detection of extremely small losses. This new monitor measures the Cherenkov light produced by charged particles in air with a photomultiplier (PMT), and can detect ~ 100μA (~10^{-5} of the total beam current).

BPM/current monitors

An Inductive Pick-Up (IPU) has been developed to measure the position and current of the beam of the linac. The pick-up construction is similar to a wall current monitor, but the pick-up inner wall is divided into 8 electrodes, each of which forms the primary winding of a toroidal transformer. The beam image current component flowing along each electrode is transformed to a secondary winding, connected to an output. The continuity of the vacuum chamber is made by a ceramic tube on the inner-side of the electrodes. The tube is coated with titanium on its inside surface and the end-to-end resistance of the layer is chosen in such a way that within the IPU bandwidth the image current flows over the electrodes. For higher frequencies the current is conducted by the coating to limit the longitudinal impedance of the device in the GHz range. The effectiveness, and optimization of the resistance of this layer have been simulated by a simple electric-network model and found to be in good agreement with the results of measurements.

CTF3 operation

There were two runs in 2004, the first from 7 June–18 July, and the second from 13 Sept–15 Nov. with a total of 14 weeks of beam operation during the normal working days with no night shifts, and in general no week-end working. Only three specialists are able to run the machine. Some members of the INFN collaboration have however started to make measurements, and some non-machine-experts helped with PETS running.A Summer shut-down period was used for further installation work. The first run was used to commission the additional linac modules (four accelerating structures), and to test the 30 GHz power production with a short PETS structure. The second run was used to commission the rest of the linac, the chicane and the final instrumentation section, and to produce 30 GHz power with the full-length PETS and the high power transfer line to CTF2. During operation the main problems came from gun current instabilities, inadequate cooling water temperature regulation, beam diagnostic screens, charging power supply faults in the new type of modulator, and broken diodes. Operation was greatly facilitated by the implementation of the time-adjusted generic sampler data acquisition software for BPMs, WCMs, the RF phase and amplitude signals, the BLMs and the segmented dumps. Also the MAD model was found to be rather accurate in predicting the optical behaviour of the line which speeded-up general progress. An automatic trajectory correction scheme has been tested and found to work very well but it has not been used regularly because the measurement is very long. A new program to optimize the flatness of the compressed rf pulses in the linac by iteration proved to be very useful and was put to good use.

For the CERN 50th anniversary Open Day more than a thousand visitors visited CTF3, some queuing for more than an hour.

Preparation for the next CTF3 stages

Good progress has been made in parallel with this year's installation and test programme, to design, build and order equipment in preparation for the next CTF3 installation phases. The following chapters summarize this preparatory work.

Preparation – linac structures, waveguides and loads

All the SICA structures for the drive beam linac have now been delivered to CERN. All waveguides and pumping ports for the rf power distribution system have been ordered. Following delays in the development of the SiC loads, an order was placed for 25 high-power (50 MW peak) rf water loads, for operation with 4.5 microsec pulses at a repetition frequency of 100 Hz. Development work on the SiC loads will however continue. A first prototype load consisting of two SiC absorber plates electrolytically-bonded to a copper waveguide was tested up to 35 MW and 2 μs. This was a very promising first result but since the nominal requirement is for 60 MW and 1.5μs more work is required to reach a final design. A second water-cooled prototype consisting of two 20 cm long profiled SiC slabs attached to the copper waveguide by a low-temperature vacuum soldering process at ~230C is currently under test.

Preparation – rf power system

Six new Barrel Open Cavity (BOC) pulse compression systems have been manufactured to complement and partly replace the existing LIPS systems. These BOC compressors have unloaded Q's of about 187000 and operate in a $TM_{10,1,1}$ whispering gallery mode. They are equipped with a mechanical detuning system to enable operation without compression if required, and a SiC absorber to remove unwanted resonances. One BOC was installed and successfully operated in CTF3 in 2004. Three of these systems are foreseen for the CTF3 linac, two for the CLEX probe beam and there is one spare.

Preparation – sub harmonic bunching system

All elements of the 1.5 GHz sub-harmonic bunching system were either constructed or ordered in 2004. This wide-band (10%) bunching system is foreseen to be installed in Spring 2005. It will allow the phase of the bunching voltage to be changed very quickly (typically 10-20 ns) so that the bunches of 140 ns-long bunch trains can be placed alternatively in even and odd RF buckets. The three 6-cell large-aperture travelling wave structures have been fabricated, and the three 40 kW travelling wave tubes and power supplies have been ordered.

30 GHz power generation

A special PETS line has been built alongside the CTF3 linac in a by-pass configuration to enable the CTF3 beam to be used for 30 GHz power production. The layout is such that a 5A beam at an energy of ~60 MeV can be switched into this line, sent through a specially-constructed 400-cell copper PETS structure and then put onto a dump. The PETS structure is made from three segments with 9, 6.7 and 9 mm diameter apertures to follow the waist of the drive beam. The interconnection between the segments is made via on-axis circular waveguides. The 30 GHz rf power generated by the PETS structure is transferred to the CTF2 building via a low-loss (<5%) line. This line which was built by the Russian firm GYCOM is basically a circular waveguide operating in the TE_{01} mode. It consists of mode-converters, pumping ports and mitred-bends and its mode of operation is quasi-optical. For the 2004 run this power was sent to an absorber but will eventually be used for high-gradient testing. By the end of the run, a peak power of 53 MW for 73 ns had been produced in CTF2, this performance was however limited by the time available for conditioning the PETS. This power was obtained with input and output drive beam currents of 6A and 3.5A respectively. This is enough power to generate a gradient of 150 MV/m for the nominal new CLIC pulse length of ~70 ns in the latest HDS design of accelerating structure. It is foreseen in a later stage to replace critical parts of the PETS by molybdenum. Unexpected generation of a 66 GHz component complicated the diagnostics in the early stages of commissioning, the impact of this unwanted power on the conditioning process is not well understood. This unwanted component will be designed out in new PETS.

A short period of CTF3 operation with a phase jump of 18 degrees in the 3 GHz bunch train was successfully made resulting in a 180 degree phase jump in the 30 GHz power pulse. However, in this mode of operation which opens the way to the eventual use of a SLEDII-like rf pulse compressor, the peak power generated was limited by conditioning time of the PETS to about 16 MW. It has been calculated however that even without a phase shift, a SLEDII-like pulse compressor would increase the 30 GHz peak power from a 400 ns drive beam pulse by a factor of about 2.

Construction of a CTF3 photo-injector

The laser and photocathode activities in 2004 were directed towards the construction of the CTF3 drive-beam photo-injector. This project is being carried out within the FP6 Program of the European Union as part of the CARE Join Research Activity (JRA) entitled “Charge Production with Photo-injectors” (PHIN). The laser is being developed and built by RAL, the RF gun by LAL, and the photocathodes, installation and commissioning by CERN. The JRA also aims to improve the performance of the present cesium telluride photocathodes and to develop new photocathode materials.
The specification for the 3 GHz RF gun is for an electron beam of 2300 pulses of 2.3 nC with an emittance of 20.π.mm.mrad and a vacuum at the photocathode of 10^{-10} mbar. The construction of a cold model of this gun is in progress. The design of the main parts of the laser has been completed. The oscillator and the preamplifier which are capable of delivering a CW train of 10 W at 1.5 GHz are being built by an Austrian firm. The optical pumping of the amplifiers will be made with laser diodes with a total power greater than 35 kW QCW.
A large part of the CERN activity this year has been spent on maintenance of the photoemission lab. After more than 10 operational years most vacuum flanges of the preparation chamber were damaged and had to be changed. New clean-room compatible bake-out equipment has been defined and will be installed at the beginning of 2005. All the vacuum transfer equipment has been revised and realigned. The installation of a new co-evaporation setup is under-way. A new informal collaboration has been set-up up with the CEA-SP2A (CEA Bruyères-le-Châtel F) to study and to exchange new photocathodes of the Secondary Emission Enhanced (SEE) type proposed by BNL (Upton NY - USA).

CLIC accelerated R&D programme

The CLIC study team had already made it clear in 2003 that all the CLIC-technology-related feasibility issues could be demonstrated by CTF3 but that with the resources foreseen this could not be completed before 2014. This time frame was considered unacceptable by the management and the study was asked to study an accelerated programme to demonstrate the key issues before 2010. This was completed and a preliminary proposal was made by the DG designate to the council in December 2003 and the accelerated CLIC R&D programme was approved by Council in March 2004. Following this decision, the DG organized a special collaboration meeting on the 19th May 2004 to which he invited all the directors of the main laboratories around the world, the delegates of the member states and representatives of the main funding agencies asking them to make specific proposals in the form of voluntary contributions “a la carte”, in cash, in kind or man-power to support the programme. At this meeting the following delegations expressed their interest in making specific contributions : DAPNIA, LAL and LAPP (France), Uppsala University and the Manne Siegbahn National Accelerator Laboratory (Sweden), Finland, Netherlands, Ciemat (Spain), INFN (Italy), and the University of Royal Holloway (England). All of these proposals however were subject to approval by the respective funding agencies. Final decisions are expected to be announced at the follow-up meeting on 28th January 2005.

In particular INFN Frascati is waiting for approval of a proposal to continue its contribution beyond the delay loop to include (i) the optics design for the Combiner Ring (CR) and Transfer Lines (TL1 and TL2) (ii) the vacuum chambers and beam diagnostic equipment (without electronics) for the CR and TLs (iii) the path length wigglers for the CR.

Sweden is waiting for approval of a proposal for (i) optics design, dipole magnets and power converters, and beam diagnostic equipment for the TL2 and bunch compressor (ii) the two-beam test stand including optics, magnets, vacuum, beam diagnostic equipment and RF diagnostics and data handling.

Spain is building (i) corrector magnets and waiting for approval of a proposal for (ii) two double septum magnets and an ejection kicker (iii) quadrupole magnets with precision movers for the Test Beam Line (TBL) (iv) RF structure work with aim of building one PETS for the TBL.

Finland is waiting for approval of a proposal for (i) power converters for the CR and special technology for the fabrication of CLIC accelerating structures.

France is waiting for approval of a proposal for (i) the construction of the probe-beam linac (DAPNIA and LAL) and (ii) 32 quadrupoles from LURE for the CR.

The North-Western University of Illinois would like to build beam diagnostic equipment for the TBL but this depends on the decision concerning the US commitment.

Turkey intends to send 4 young physicists for periods of 3 months to participate in CTF3 operation.

An order has been placed with BINP (Novosibirsk) for 11 slim-quadrupoles and 26 sextupoles for CR.

The ninth CTF3 collaboration meeting was held at CERN from 23rd to 25th November 2004. All collaborating institutes participated: Ankara and Gazi Universities (Turkey), CEA (Saclay), CIEMAT (Spain), Finnish industry, LAL (Orsay), LNF (Frascati), RAL (Oxford), SLAC (Stanford), North Western University (Illinois) and Uppsala University. The CTF3 status, results obtained in 2004 and plans for the coming year 2005 were presented. For details see:
http://ctf3.home.cern.ch/ctf3/New_collab_meet.htm

CARE and EUROTeV activities

In addition to its current activities, some members of the CLIC study team now have additional commitments within the so-called CARE project (Coordination in Accelerator Research in Europe) which is part of the Sixth Framework Program (FP6) of the European Commission. In particular, for CLIC, it means participation in a European-wide network on linear accelerators (ELAN), and in a joint research activity to construct a photo injector for CTF3. As part of the ELAN activity, workshops were held at the INFN in Frascati and at DESY and resulted in several initiatives. The first was to setup a common repository for the different codes available together with working examples to facilitate their use. The necessary interfaces to simplify the exchange of machine descriptions were also discussed and it was decided to make a first attempt at creating a sample implementation of a lattice description interface in the extended mark-up language XML. The second initiative was to create a list of important beam dynamics issues. The most pressing items from this list have been included in the EUROTeV proposal (see below). Other workshops are planned including one in Frascati dedicated to wigglers. At the DESY ELAN meeting, the European involvement in the ILC was discussed to prepare the European statement for the first ILC meeting which took place in Japan in November. ELAN also associated itself with the CTF3 collaboration meeting which took place at CERN in November, and a mini workshop on the operation of CTF3 at CERN when automatic steering of the CTF3 beam was tested.

In March 2004, a consortium of 27 institutes (including CERN) submitted a new bid to the European Commission for a programme of design studies under the name EUROTeV for a linear collider in the TeV energy range. This bid received strong recommendations for funding by the referees and was subsequently approved at the level of nine million Euros. This new project has further increased the commitments of the CLIC study team members to FP6. EUROTeV will concentrate on the issues which are common to all linear collider proposals. In particular it will address some of the high ranking issues identified by the Technical Review Committee with the aim of delivering significant input to the ILC Conceptual Design Report (CDR) and thereafter the ILC Technical Design Report (TDR), but it will also investigate upgrade paths into the multi-TeV energy regime (CLIC). The design study is structured around seven scientific work-packages, covering the damping ring, the beam delivery system, instrumentation, luminosity performance simulations, the potential to stabilize the machine against ground motion, the potential to produce polarized positrons and the possibility to use computer networks for machine operation. CLIC study members will participate in a number of areas that are considered of critical importance. These include

1) the study of the electron cloud build-up in the damping ring
2) the potential to provide timing stability at the level of fifteen fs
3) development of a wide band beam current monitor
4) high precision BPMs with reduced sensitivity to beam losses
5) provision of beam time for instrumentation tests at CTF3
6) study of beam halo generation

7) study of failure modes and their impact on machine design
8) study of the integrated luminosity performance including the relevant dynamic and static effects
9) study and improvement of the beam delivery and collimation system and the spent beam lines

As well as contributing to the preparation of the bid CERN is contributing to the management of the study by participating in the overall scientific coordination and by coordinating the work-package on integrated luminosity performance studies.

ITRP activities

At the request of the International Technology Recommendation Panel (ITRP), two members of the CLIC team went to Caltech in June to present the status and future plans of the CLIC study to the panel. Although CLIC technology was not being considered by the ITRP, the panel wanted to have a complete picture of the present linear-collider activities around the world before making their final recommendation.

CLIC-based future collider options

On the initiative of the Turkish CLIC collaborators (Universities of Ankara and Gaza, & Institute of Physics, Baku), a one-day workshop took place at CERN with the CLIC study team to discuss different possibilities for colliding the CLIC beam with the LHC beam, and to review the physics potential of CLIC and CLIC-LHC based colliders in detail. The options include e-p, e-A, γ-p, and γ-A collisions to study Quantum Chromo-Dynamics (QCD) in a wide kinematical region and FEL based γ-A collisions for Nuclear Resonant Fluorescence.

QCD explorer based on LHC and CLIC

It has been argued that a linac-ring type electron-proton collider could provide important discoveries for QCD physics. A study was therefore made to find a possible parameter set for such a QCD-Explorer by colliding 7 TeV LHC super-bunches with 75 GeV CLIC bunch trains.
The nominally 2808 LHC bunches are spaced at a typical distance of 25 ns and are spread out over a revolution period of about 100 μs. On the other hand, the CLIC beam consists of 154 bunches spaced by 0.66 ns, and extending over about 100 ns. This CLIC beam could be accelerated using a single CLIC drive-beam unit. Colliding these LHC and CLIC beams would produce very little luminosity as only few bunches of either beam would participate in the collisions. However one option for a future LHC luminosity upgrade with a luminosity equal to ten times the nominal is to combine the 2808 small bunches into a few super-bunches with a total length of about 300 m. This LHC proton super-bunch with a length of about 30 m would be the ideal counterpart of the CLIC bunch train and would ensure that all CLIC bunches and a significant part of the LHC beam (10%) would contribute to the electron-proton luminosity. The estimated achievable luminosity was ~ 10^{31} $cm^{-2}s^{-1}$.

CLIC Physics Study Group

Several members of the CLIC study team contributed to the work of the CLIC physics study group which published its report on the physics potential of CLIC in June 2004.

This report summarizes a study of the physics potential of CLIC operating as an e+e- collider at centre-of-mass energies from 1 TeV to 5 TeV with luminosities of the order of 10^{35} $cm^{-2}s^{-1}$. Aspects of experimentation at CLIC, including backgrounds and experimental conditions are discussed, and a conceptual detector design used in the physics analyses is presented, most of which use the nominal CLIC centre-of-mass energy of 3 TeV. It is pointed out that CLIC contributions to Higgs physics could include completing the profile of a light Higgs boson by measuring rare decays and reconstructing the Higgs potential, or discovering one or more heavy Higgs bosons, or probing CP violation in the Higgs sector. Turning to physics beyond the Standard Model, CLIC might be able to complete the supersymmetric spectrum and make more precise measurements of sparticles detected previously at the LHC or a lower-energy linear e+e- collider: collisions and polarization would be particularly useful for these tasks. CLIC would also have unique capabilities for probing other possible extensions of the

Standard Model, such as theories with extra dimensions or new vector resonances, new contact interactions and models with strong WW scattering at high energies. In all the scenarios studied, it is made clear that CLIC would provide significant fundamental physics information beyond that available from the LHC and a lower-energy linear e+e- collider, as a result of its unique combination of high energy and experimental precision.

Technical publications of the CLIC Study Group

A list of all CLIC Notes and CTF3 Technical Notes published in 2004 is given below.

CLIC Notes 2004

http://clic-study.web.cern.ch/CLIC-Study/Publications/2004.html

589 QCD Explorer based on LHC and CLIC
LHC-Project-Note-333, D. Schulte, F. Zimmermann

590 A Novel Idea for a CLIC 937 MHZ 50 MW Multibeam Klystron
E. Jensen, P. Pearce, I. Syratchev

591 A Summary of the Activities of the CLIC Study Team for the Year 2003
I. Wilson (for the CLIC Study Team)

592 High-Power Microwave Pulse Compression of Klystrons by Phase Modulation of High-Q Cavity Resonators R. Bossart, P. Brown, J. Mourier, I. Syratchev, L. Tanner

593 The Major Issues for CLIC Accelerating and Transfer Structure Development
CERN-AB-2004-016-RF, W. Wuensch

594 Potential of Non.Standard Emittance Damping Schemes for Linear Colliders
CERN-AB-2004-017-ABP, H.H. Braun, M. Korostelev, F. Zimmermann

595 Stabilization of Nanometre-Size Particle Beams in the Final Focus System of the Compact LInear Collider (CLIC) CERN-AB-2004-026-ABP, S. Redaelli

596 R&D for the Feasibility Study of CLIC Technology
H. Braun, J.P. Delahaye, G. Geschonke, G. Guignard, K. Hübner, and I. Wilson

597 A High-Power Test of an X-Band Molybdenum-Iris Structure
CERN-AB-2004-040, C. Adolphsen, S. Döbert, A. Grudiev, S. Heikkinen, I. Syratchev, M. Taborelli, I. Wilson, W. Wuensch

598 The Impact of Longitudinal Drive Beam Jitter on the CLIC Luminosity
CERN-AB-2004-046, D. Schulte, E. J. N. Wilson, F. Zimmermann

599 Electron-Cloud Effects in the Positron Linacs of Future Linear Colliders
CERN-AB-2004-066, A. Grudiev, D. Schulte, F. Zimmermann

600 A Potential Signal for Luminosity Optimisation in CLIC
CERN-AB-2004-068, D. Schulte

601 A Newly Designed and Optimized CLIC Main Linac Accelerating Structure
CERN-AB-2004-041, A. Grudiev, W. Wuensch

602 Technological Challenges for High Brightness Photo-Injectors
CERN-AB-2004-043, G. Suberlucq

603 CLIC Magnet Stabilization Studies
CERN-AB-2004-063, R. Assmann, W. Coosemans, G. Guignard, S. Redaelli, D. Schulte, I. Wilson, F. Zimmermann

604 First Full Beam Loading Operation with the CTF3 Linac
CERN-AB-2004-057, H. Braun, M. Bernard, G. Bienvenu, G. Carron, R. Corsini, A. Ferrari, O. Forstner, L. Groening, T. Garvey, G. Geschonke, E. Jensen, R. Koontz, T. Lefèvre, R. Miller, L. Rinolfi, D. Schulte, F. Tecker, L. Thorndahl, R. Roux, R. Ruth, D. Yeremian

605 Flexibility, Tolerances, and Beam-Based Tuning of the CLIC Damping Ring
CERN-AB-2004-062, M. Korostelev, J. Wenninger, F. Zimmerman

606 Vibration Measurements at the Swiss Light Source (SLS)

CERN-AB-2004-074, R. Assmann, M. Böge, W. Coosemans, M. Dehler, S. Redaelli, L. Rivkin

607 In-situ Vibration Measurements of the CTF2 Quadrupoles
CERN-AB-2004-073, W. Coosemans, S. Redaelli

608 QCD Explorer Colliding LHC and CLIC-1
CERN-AB-2004-079, F. Zimmermann

609 Limiting High Frequency Longitudinal Impedance of an Inductive Pick-up by a Thin Metallic Layer CERN-AB-2004-090, M. Gasior

610 Beam HALO Monitoring at CTF3
CERN-AB-2004-091, H. Braun, E. Bravin, R. Corsini, T. Lefèvre, A.L. Perrot, D. Schulte

611 Beam Loss Monitoring on the CLIC Test Facility 3
CERN-AB-2004-092, H.H. Braun, R. Corsini, M. Gasior, T. Lefèvre, M. Velasco, M. Wood

612 Low Level RF Including a Sophisticated Phase Control System for CTF3
CERN-AB-2004-093, R. Bossart, J. Mourier, J.M.. Nonglaton, I. Syratchev, L. Tanner

613 Mini-Workshop on Machine and Physics Aspects of CLIC Based Future Collider Options
F. Tecker

614 New Spark-Test Device for Material Characterization
CERN-TS-2004-001 (MME) M. Kildemo

615 Fatigue Testing of Materials by UV Pulsed Laser Irradition
CERN-TS-2004-004, S. Calatroni, H. Neupert, M. Taborelli

616 Breakdown Resistance of Refractory Metals compared to Copper
CERN-TS-2004-005, S. Calatroni, M. Kildemo, M. Taborelli

617 The Compact Linear Collider CLIC
CERN-AB-2004-100, I. Wilson (for the CLIC Study Team)

618 Breakdown and Field Emission Conditioning of Cu, Mo and W
S. Calatroni, M. Kildemo, M. Taborelli

619 Ninth CLIC/CTF3 Meeting with Ankara University / CEA / CERN / CIEMAT / LAL / LNF / North Western University / RAL / SLAC / Uppsala University in November 2004
Editor : F. Tecker

CTF3 Technical Notes

http://clic-study.web.cern.ch/CLIC-Study/CTF3/Lists/2000.html#2004

066 First Full Beam Loading Operation with the CTF3 Linac
H. Braun, M. Bernard, G. Bienvenu, G. Carron, R. Corsini, A. Ferrari, O. Forstner, L. Groening, T. Garvey, G. Geschonke, E. Jensen, R. Koontz, T. Lefèvre, R. Miller, L. Rinolfi, D. Schulte, F. Tecker, L. Thorndahl, R. Roux, R. Ruth, D. Yeremian

065 CTF3 Injector Profile Monitor
C. Bal, E. Bravin, S. Burger, T. Lefèvre

064 ECL Counter Crate for CTF3 Precision Timing
J.P.H. Sladen

063 Are Beam Position Corrector Coils in Quadrupole Magnets helpful?
B. Langenbeck

062 Outline of DAQ for 30 GHz High Power Processing
H.H. Braun, J. Sladen, W. Wuensch

061 Calculation of Beam Loss Induced Particle Flux for CTF3
M. Wood