Report on the 2007 CTF3 collaboration meeting.
Status of CTF3 at the end of 2006

G. Geschonke
(for the CTF3 Team)

CERN, Geneva, Switzerland

Abstract

A collaboration meeting of the CLIC Test Facility, CTF3, took place at CERN on 16th and 17th of January 2007. The present summary of the CTF3 status, results obtained in 2006 and plans for the year 2007 is based on presentations given during this meeting.

1. Introduction

The CTF3 collaboration now consists of 21 partner institutes. All of them were represented at the collaboration meeting and reported the status of their contributions. The talks can be found in Ref. 1. This report summarizes the contents of these presentations.

2. Project status

The overall planning of the different stages of CTF3 is shown in Fig. 1. The major milestones indicated in this schematic view were reached.

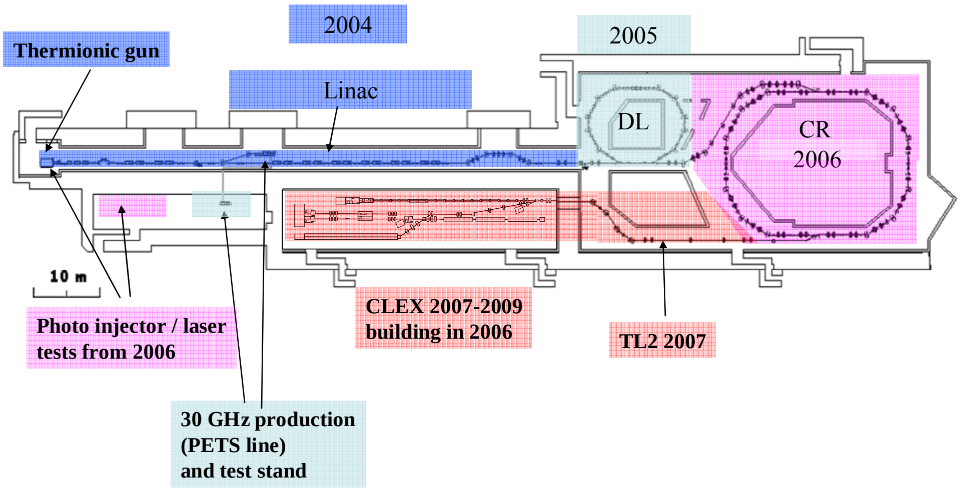

Fig. 1 Installation programme for CTF3

The main objectives of CTF3 were:

a) Commissioning of the Delay Loop with bunch interleaving using the phase-coded beam. This included commissioning of the 1.5 GHz bunching system.
b) Operation for 30 GHz CLIC component testing
c) Installation of Transfer Line TL1 and Combiner Ring

2.1 Commissioning of the Delay Loop with "phase coded" beam

The principle of bunch-train compression with the Delay Loop is shown in Fig. 2. A system of 1.5 GHz bunchers "phase-codes" the beam, i.e. every 140 ns the phase of the 1.5 GHz system is rapidly switched by 180 degrees. The bunch train is 1.4 µs long and consists of ten 140 ns long phase-coded sub-trains. This beam is then further bunched and accelerated in a 3 GHz RF system up to 150 MeV. The beam is then sent to the Delay Loop, where an RF deflector at 1.5 GHz injects every second 140 ns long sub-train into the Delay Loop. After one turn of 140 ns, this delayed train is then interleaved between the bunches of the following 140 ns long train.

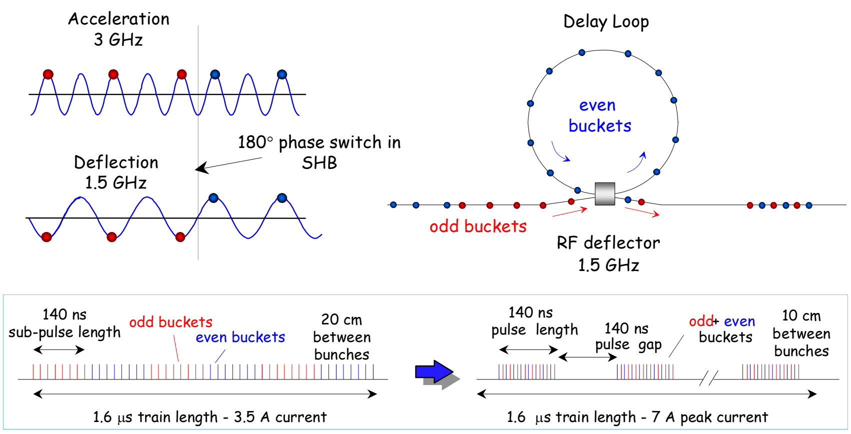

Fig. 2: Principle of Delay Loop operation

All three 1.5 GHz traveling wave tube amplifiers and the associated sub-harmonic bunchers were installed and commissioned. They produce 40 kW output power each. The beam was successfully phase-coded. Fig. 3 shows the bunch switching. The upper picture was taken with a streak camera from light produced by an OTR screen. The lower part is the response of an RF pick-up in the beam line. One sees, that the switching transient is about eight 1.5 GHz RF periods long, i.e. 6 ns, as foreseen.

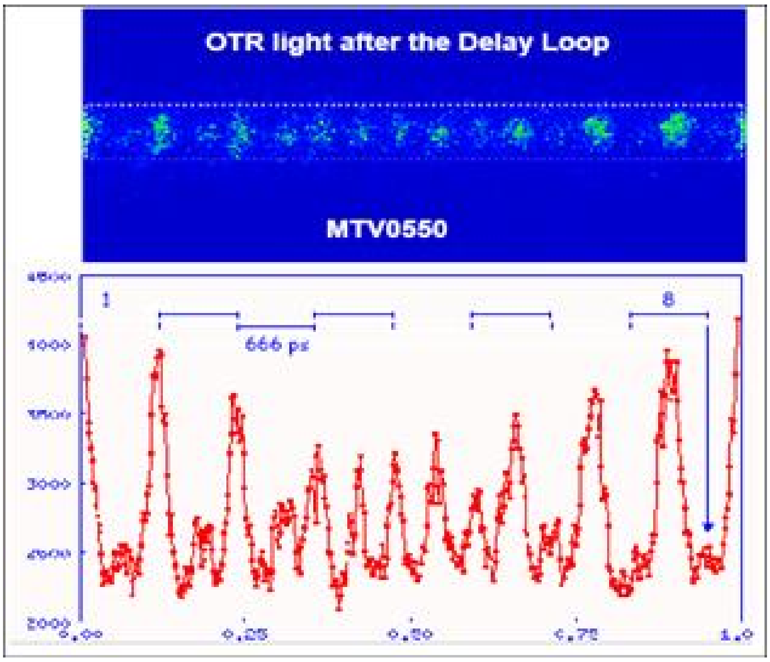

Fig. 3 "Phase coding" of beam bunched with 1.5 GHz bunchers. The upper trace shows a picture of light from an OTR screen taken with a streak camera. The lower part shows the response of an RF pick-up. The transient is about 6 ns long.

The Fig. 4 below shows the beam current measured with beam position monitors at various positions before, inside and after the Delay Loop.

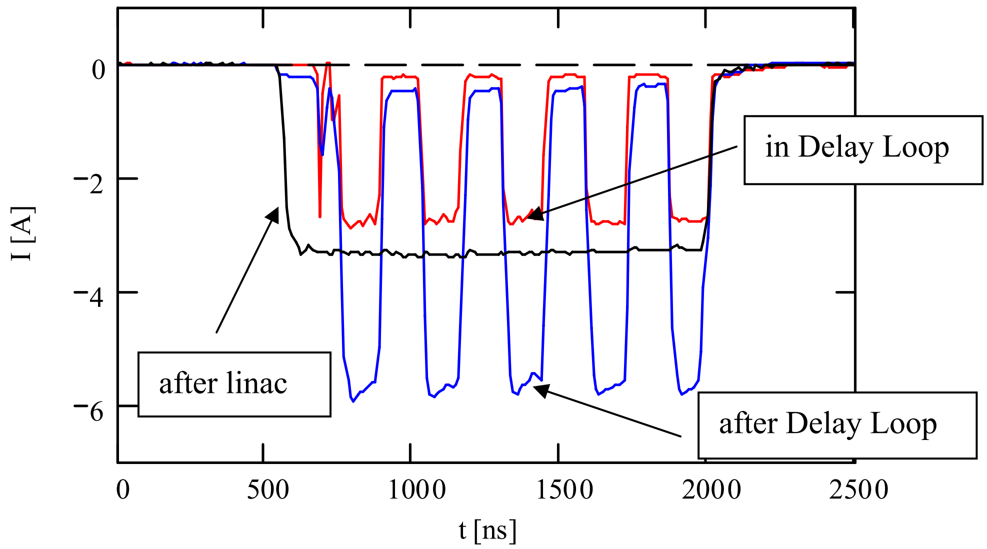

Fig. 4: Demonstration of bunch interleaving using an RF deflector, which injects every second 140 ns long sub-train into the Delay Loop and interleaves the bunches between the following sub-train after one turn in the Delay Loop.

The synchrotron light signal measured in the Delay Loop is reproduced in Fig. 5. The figure shows that the "satellite bunches", which sit between the 1.5 GHz bunches due to imperfect bunching, represent about 8% of the beam current.

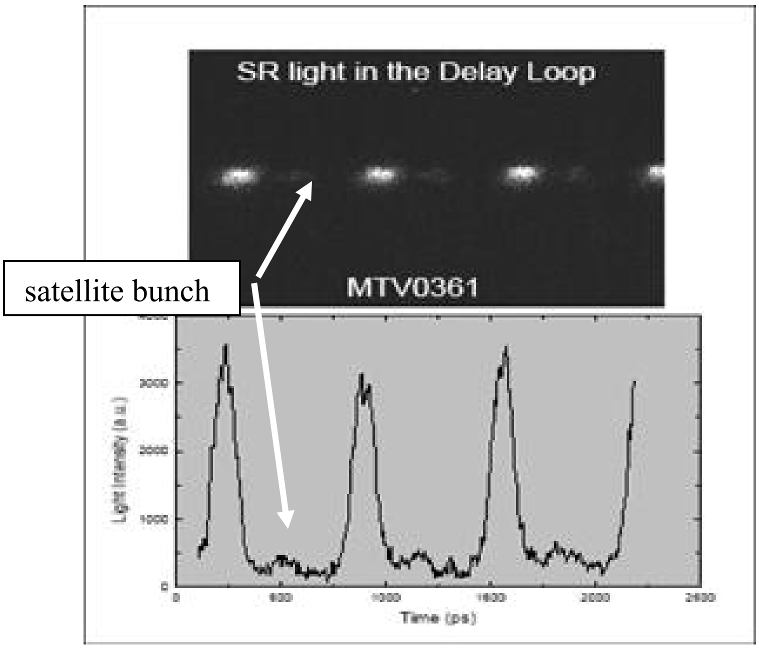

Fig. 5 Satellite bunches

The achieved beam parameters are shown in table 1. With the exception of the beam current after the Delay Loop recombination and the beam energy, the nominal parameters have been achieved. Improvements are expected from the installation of another klystron and from progress on beam instrumentation and set-up procedures.

	Nominal	achieved
Beam current	7 A after DL	3.3 A max after chicane, ≤ 6 A after combination (satellites)
Energy	150 MeV	100 MeV (still missing one klystron)
Emittance	100 π mm mrad	50 - 80 π mm mrad (consistently below nominal)
Pulse length	1.4 μs	1.4 ms after chicane, 5 × 140 ns pulses after DL
Bunch length	up to 2.5 mm	1.4 – 2.7 mm

Table 1: Beam parameters after Delay Loop

2.2. Operation for 30 GHz RF power production

In addition to the demonstration of the feasibility of the CLIC 30 GHz RF power source, the second main goal of CTF3 is to provide RF power at 30 GHz for testing CLIC accelerating structures. This is now achieved in a routine manner.
For this purpose an intense electron beam is accelerated in the first part of the linac and sent into a line parallel to the main linac at an energy of about 70 MeV. Here a "PETS" (Power Extraction and Transfer Structure) extracts 30 GHz RF power from the beam, which is sent via a circular waveguide to a test stand in a building next to the linac. A schematic view of the testing installation is shown in Fig. 6.

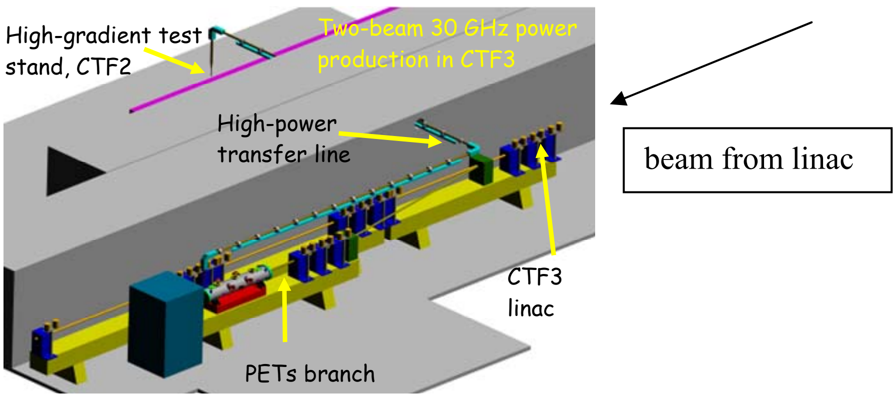

Fig. 6: Installation for testing CLIC components with high RF power at 30 GHz.

Peak RF power of 100 MW is now routinely produced at 30 GHz, operation is possible on a 24 hour basis with supervision by operators from the CERN Control Centre (CCC). The conditioning process is largely automatic.

2.3. TL1 and Combiner Ring

The transfer line TL1 which transports the beam from the Delay Loop to the Combiner Ring was installed and successfully commissioned with beam. The beam was injected into the injection region of the Combiner Ring, and dumped in a instrumentation line connected to the first dipole in the ring arcs.
Installation of the Combiner Ring is advancing well, all magnets, injection and ejection septa are installed. The vacuum chamber and the beam diagnostic elements are being produced and will be installed before the end of the winter shutdown in March 2007.

3. Hardware status

3.1. High Power RF system

A schematic view of the RF system is given in Fig. 7. Ten S-band klystrons with output powers between 35 and 45 MW at a pulse length or 5.5 µs are now operational. Nine of them have RF pulse compressors which give an increase in RF peak power of a factor 1.9 to 2 at a pulse length of 1.6 µs.
The L-band system at 1.5 GHz consists of three wide-bandwidth (200 MHz) Traveling Wave Tubes with an output power of 40 kW each at 3 µs pulse length, and a klystron giving a power of 22 MW at 5.5 µs.
This year only five out of the ten installed S-band klystrons were used. Due to the nearly continuous operation for 30 GHz RF power production, they operated for 5000 hours in 2006. Two klystrons had to be replaced because they had reached the end of their lifetime.
A program to improve the amplitude and phase stability has been started.
A major improvement in operational stability was achieved with the installation of a new water cooling system for the RF pulse compressors (BOC and LIPS). The new system allows to stabilize the temperature of individual pulse compressors to 0.02 degrees, with a fast response time of a few minutes to changes of the set-points.

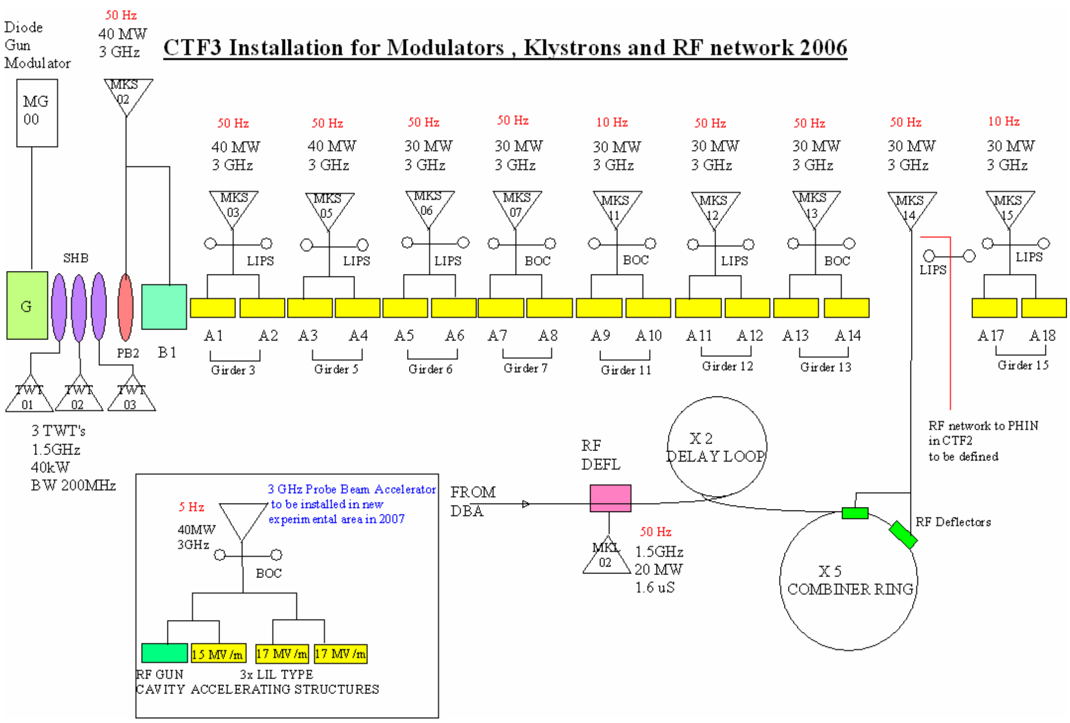

Fig. 7 RF system in 2007

3.2. Sub-harmonic bunching system

Three traveling wave bunching structures have been built and were installed inside the focusing solenoids of the injector. Fig. 8 shows one of the three traveling wave bunchers inside the solenoid during its installation.

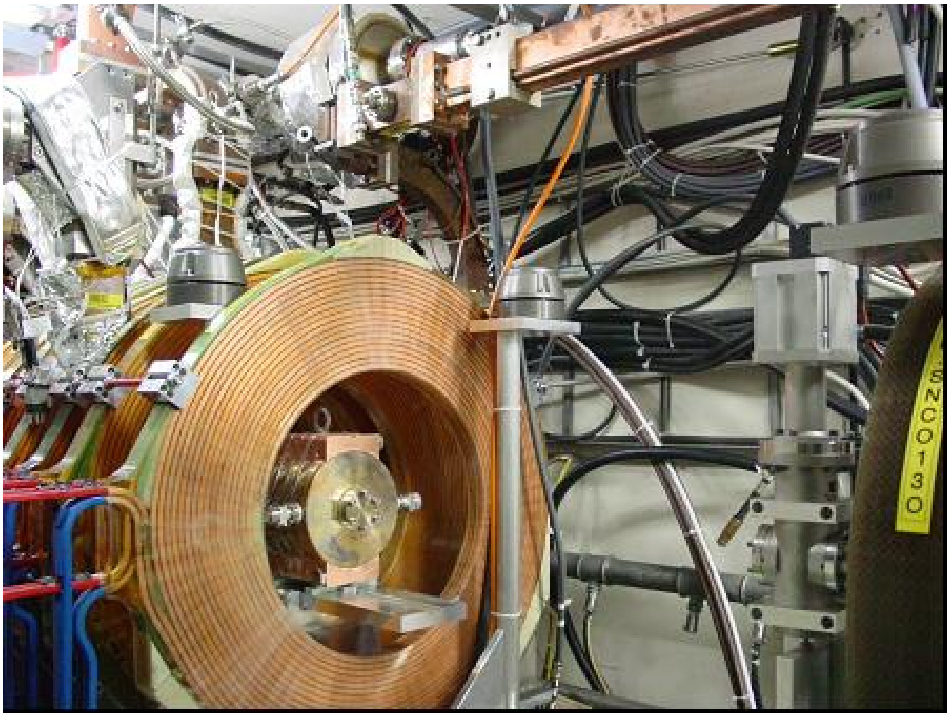

Fig. 8 Traveling-wave buncher inside the solenoid

These bunchers operate at 1.5 GHz, the RF phase is switched every 140 ns by 180 degrees. This “ phase coding” allows to selectively inject 140 ns long sub-trains into the Delay Loop and to interleave them between the bunches of the following 140 ns sub-train.
The switching time has to be as short as possible, therefore the bunching structures as well as their RF source need to have a large bandwidth. Traveling Wave tubes, which have been specially developed in the industry, are used as RF power source. They provide 40 kW at 1.5 GHz with a bandwidth of 200 MHz. All three tubes are now available. Problems during the development of the power supply system for these tubes, which have to provide HV pulses at a stability of 0.5% in amplitude to give 1 degree stability in phase during the pulse, resulted in a significant delay. Finally only one system could be installed at the very end of the run. Nevertheless we were able to demonstrate the bunch phase coding and the bunch interleaving with the Delay Loop, however with relatively large satellite bunches.

4. Operation

The schedule of 2006 is shown in Fig. 9.
The first period from week 11 to 20 was dedicated to Delay Loop commissioning and beam dynamics studies during the day and 30 GHz power production during nights and weekends.
The second period from week 21 to 41 was used for 30 GHz power production. In parallel the transfer line TL1 and the Combiner Ring were installed. This was possible since the buildings housing the linac and the rings are separated by a shielding wall.
In the third period from week 47 to 49 the transfer line TL1 and the Combiner Ring were commissioned, again with 30 GHz power production during nights and weekends.

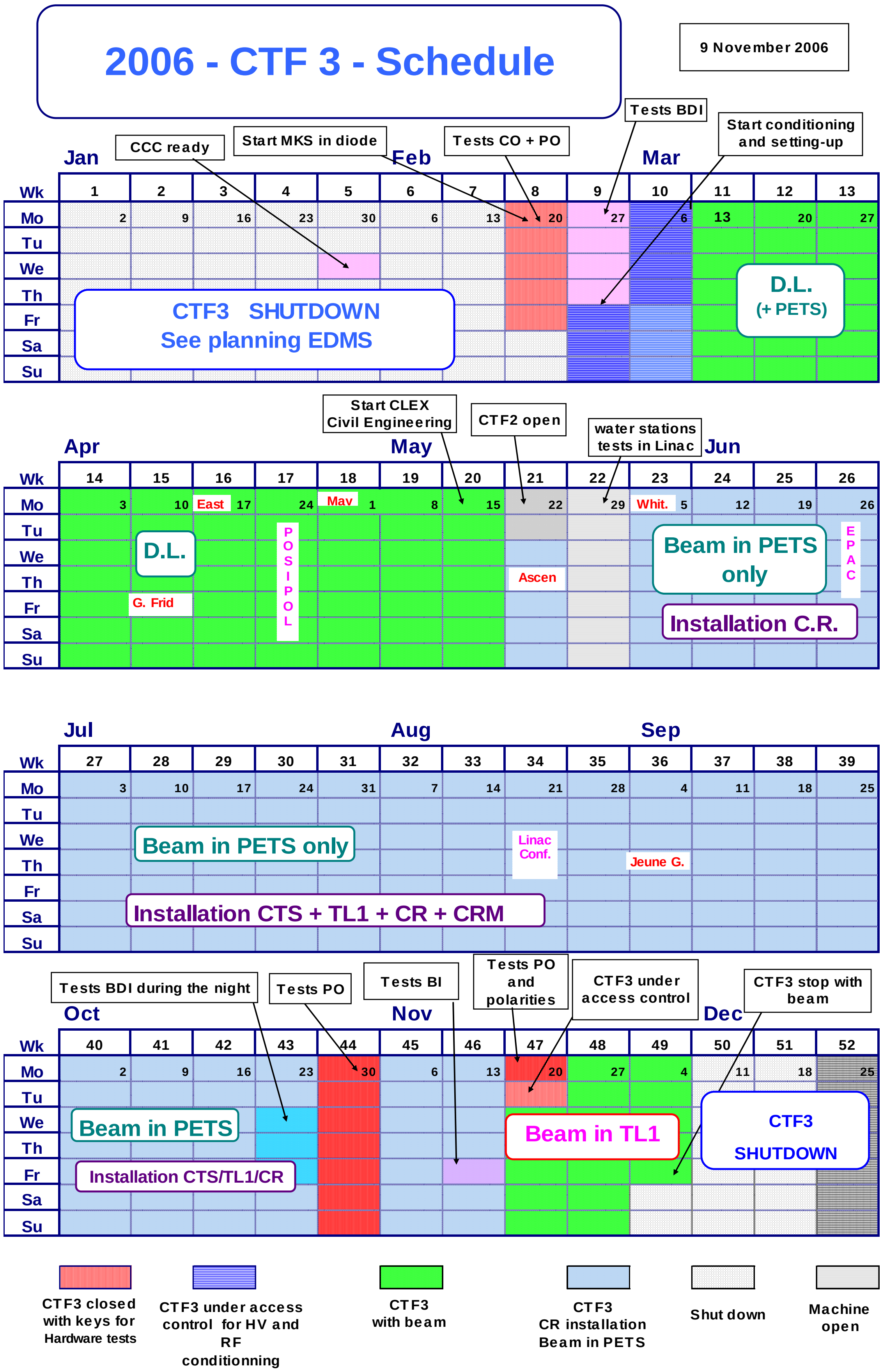

Fig. 9 CTF3 operation schedule for 2006.

5. Preparation of the next phases.

5.1. Schedule for 2007

The major milestones for 2007 will be the commissioning of the Combiner Ring and operation for 30 GHz RF power production. In parallel, the production and installation of components for TL2, TL2' and TBL prototypes, CALIFES and the Two Beam Test Stand will go on.

5.1. TL2

The design of the optics for the transfer line TL2 has started. This line has several building blocks:
Module 1, an achromat transports the beam from the Combiner Ring extraction to the first bending magnet.
Module 2 provides space for a "tail clipper", a system of kicker and collimator which will allow shortening the bunch trains for conditioning the CLIC RF equipment in CLEX.
Module 3 allows a tunable R_{56} for bunch length control and includes a matching section.
In addition the line provides a change of level in the vertical plane, because the floor level of the CLEX building is lower than the rest of the machine.
The optics is advancing well: most magnets are already available and the missing dipoles are being designed.
The plan is to install TL2 during the winter shutdown 2007/2008 to be ready for sending beam into CLEX in 2008.

5.2. CLEX

A Layout of CLEX is shown in Fig. 10.

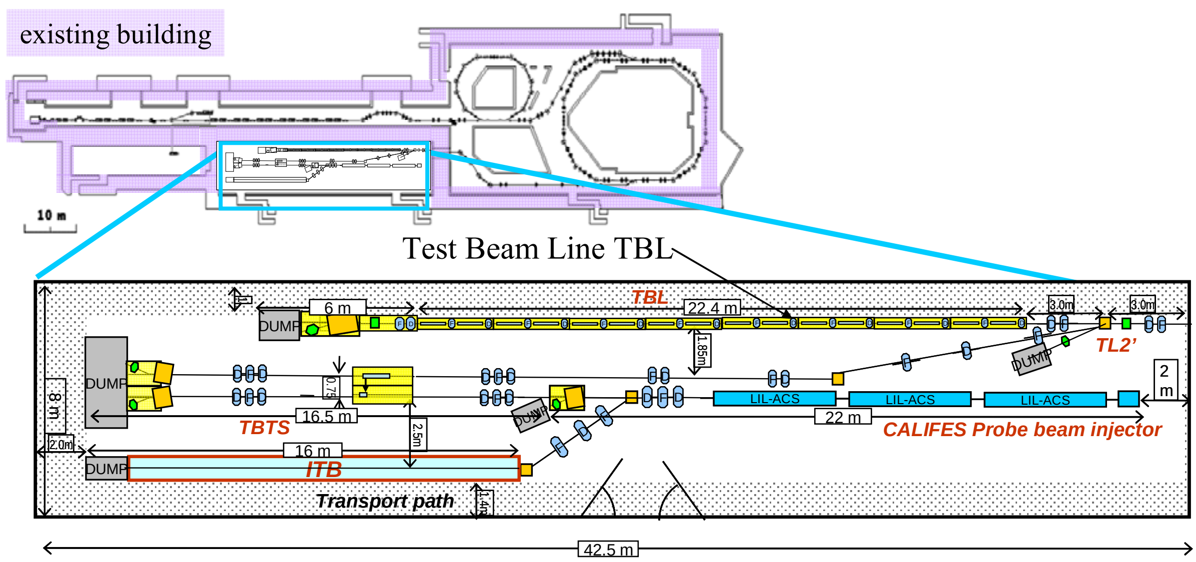

Fig. 10 Schematic layout of CLEX building

The transfer line TL2' is being designed. The layout of the Probe Beam "CALIFES" is nearly complete, production of components has started, the biggest item being the new modulator for an additional klystron.
The layout of the Two Beam Test Stand with its beam lines and diagnostics sections is advancing well and procurement of components is starting. All these systems will be installed during 2007 for operation in 2008.
The Test Beam Line TBL, consisting of 16 CLIC decelerating sections which decelerate the intense CTF3 beam to about 50 % of its initial energy is under study. Prototype work with industry on the PETS structures is going on; the magnet movers and the beam position monitors are being developed.
Construction of the building has started and is advancing according to schedule. Fig. 11 shows a view of the building. It will be ready for installation of equipment in spring 2007; beam is foreseen in 2008.

Fig. 11 CLEX building

6. Photo Injector

Construction of the CTF3 photo injector is progressing. This photoinjector is part of the PHIN joint research activity, financed in part by the EU within the FP6 programme. The laser, developed and partly built by RAL is now at CERN and is being finished and equipped with the phase coding system in a collaborative effort between INFN Frascati , INFN Milan and CERN.

The photocathode development at CERN has successfully started again after a few years interruption. At LAL the fabrication of the RF gun is advancing. The gun design is sketched in Fig. 12.

Testing of the photo injector in a separate building adjacent to CLEX (old "CTF2" building) is scheduled to start during 2007.

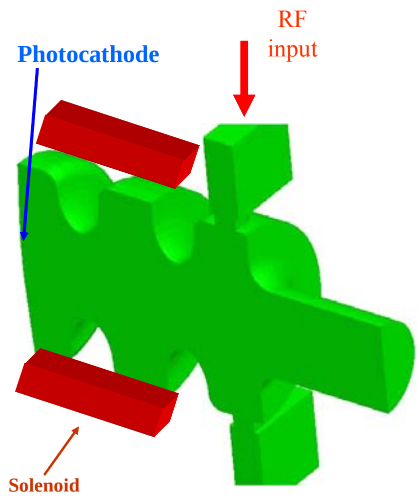

Fig. 12 Cross section of the RF gun for the photo injector.

7. Collaboration

At the time of the meeting the collaboration consisted of 16 members which had signed the Memorandum of Understanding, representing 21 institutes. A list of all members is shown in Table 2.

Countries	*Funding Agencies*	*Laboratory*
	CERN	CERN
FINLAND		Helsinki Inst of Phys (HIP)
FRANCE	CEA	DAPNIA Saclay
	CNRS/IN2P3	LAL
		LAPP
		LURE
INDIA*	Indian DAE	RRCAT, Indore
ITALY	INFN	LNF
RUSSIA		Budker Inst (BINP)
		IAP
	Dubna	JINR
SPAIN	Ministry of Education & Science (MEC)	CIEMAT
		UPC
		IFIC
SWEDEN	Swedish Research Council Wallenberg Foundation	Uppsala University
		TSL
SWITZERLAND		Paul Scherrer Inst (PSI)
TURKEY		Ankara Univ Group (2)
USA	DOE	Northwestern Univ Illinois (NWU)
		SLAC

Table 2: Collaboration members

8. Change of CLIC parameters

At the end of 2006 it has been decided to change some major CLIC parameters. The frequency of the acceleration system is now 12 GHz instead of 30 GHz, and the accelerating gradient has been lowered from 150 to 100 MV/m.
The effect of this on CTF3 is small. The bunch repetition frequency in the linac is 1.5GHz. This will be increased by a factor of 2 in the Delay Loop. An additional multiplication factor 4 gives a bunch repetition frequency of 12 GHz. This can be achieved in the Combiner Ring, which had been designed to allow combination factors of 3, 4, and 5 in any case. Changing this factor from 5 to 4 only requires small circumference changes which can be accommodated by the path length wiggler. The resulting lower beam current can be increased with a higher current in the linac and a higher RF power.
Therefore the only effect on the hardware is a different frequency for the PETS structures in the Two Beam Test Stand as well as in TBL.
For the moment the 30 GHz activity program will continue since at CERN there presently is no 12 GHz test possibility.

Conclusion

The CTF3 programme is close to the original schedule. Equipment has been commissioned up to including TL1 and the Combiner Ring injection.
The Combiner Ring will be completed in 2007 and its commissioning will follow immediately.
Beam will be sent into CLEX in early 2008. Most equipment in CLEX, with the exception of the series production PETS structures for TBL, is now covered by the collaboration.
A number of CLIC feasibility issues have already been demonstrated:

- full Beam Loading operation of the linac
- Phase coding of bunches
- Bunch Interleaving in the Delay Loop

Reference

[1] URL address of all the CLIC/CTF3 collaboration meetings and associated presentations: CTF3 Collaboration Meeting (16-17 January 2007)

Acknowledgements

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395).