ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

CLIC-PLO/2006-017/Rev. 20 October 2006

CLIC 2006-2015 Long Term Plan (LTP) Work Plan and Resources

The CLIC Study Team

Edited by the Extended CLIC Steering Committee:
H.H. Braun, R. Corsini, J-P. Delahaye, J. Ellis, G. Geschonke, A. De Roeck, D. Schlatter, D. Schulte, W. Wuensch

Abstract

This report summarizes the Long Term Plan (work and necessary M&P resources) concerning the CLIC study in the period 2006 to 2015. The plan during the first part of the period from 2006 to 2010 is well defined and focuses on the demonstration of the feasibility of the CLIC technology. The plan during the second part of the period from 2010 to 2015 strongly depends on the results of the CLIC feasibility study, the LHC physics results and world-wide decisions on Linear Colliders. The exercise is made assuming the most demanding scenario, namely a Linear Collider based on the CLIC technology to be built at CERN as rapidly as possible.

Contents

Executive Summary

The report describes the Long Term Plan (2006 to 2015) concerning the CLIC study, namely the work to be done and the corresponding estimated M&P resources.

The plan concerning the first period up to 2010 is well defined and focuses on addressing the feasibility of the CLIC technology to be possibly used in the future for a linear collider in the Multi-TeV range. It mainly consists of building and commissioning a scaled version of the CLIC RF power source, the CLIC Test Facility, CTF3, as well as developing and testing RF structures with RF power provided by CTF3. The rate of progress of the structure performances strongly depends on the number of structures that will be able to be designed, fabricated and tested with power in CTF3. The R&D program on RF structures is currently being reviewed in order to explore other or complementary possible avenues and increase the number of structures being tested. It could require additional resources. In parallel, the CLIC design is continuously updated taking into account the progress of theoretical studies and experimental tests. Based on the accumulated knowledge, a review of the major parameters, namely the nominal accelerating gradient and the RF frequency are being considered.

Thanks to a multilateral collaboration of presently 15 volunteer's institutes providing extra resources, the basic work program should be completed on time but necessitates an extra 3 MCHF material budget every year in addition to the present budget foreseen in the MTP. Additional collaborations are under discussion in order to reduce the CERN load. Some margin could then be made available for participation to EU FP7 bids in order to address the less critical but still important issues. Man power is more critical with presently about 46 FTE and 13 visitors but with a strong reduction of the available man-power from 2008 partly due to the termination of the EU co-funded activities. Such a reduction, if confirmed and if not compensated by man-power possibly liberated from LHC, is not compatible with the anticipated workload. It is essential that the overall presently available man-power is maintained up to 2010 including the addition of a few well identified experts.

Concerning the second period from 2010 to 2015, the work program strongly depends on the results of the feasibility demonstration, the Physics perspectives following LHC results and the decisions concerning ILC. The report focuses on the preferred and most demanding scenario for CERN. It assumes that the CLIC technology has been successfully demonstrated, and that a Linear Collider based on the CLIC technology is to be built at CERN as soon as possible. A success oriented schedule (SOS) is suggested together with a description of the corresponding work to be performed during the period up to 2015. The necessary CERN resources are roughly estimated with a gradual increase from the present level to about 200 FTE and 50 MCHF/year. It is assumed that outside collaborators would add resources of similar magnitude.

The necessary CERN resources to fulfill the CLIC program under the assumptions above are summarized in the table below. The MTP and LTP figures should be corrected accordingly:

Resources		2006	07	08	09	10	11	12	13	14	15
Material (CHF)	Accelerator	6.1	6.5	6.5	6.5	6.5	25.0	40.0	50.0	50.0	50.0
	Physics&Detector	-	1.25	1.25	1.25	1.25	2.0	4.0	6.0	6.0	2.0
	Total	**6.1**	**7.75**	**7.75**	**7.75**	**7.75**	**27.0**	**44.0**	**56.0**	**56.0**	**52.0**
Man-power (FTE)	Accelerator	46	50	50	50	50	120	200	200	200	200
	Physics&Detector	-	5	7	10	15	45	60	70	80	85
	Total	**46**	**55**	**57**	**60**	**65**	**165**	**260**	**270**	**280**	**285**

Finally, a CLIC Advisory Committee (CAC) will be set-up in order to regularly review the overall CLIC study and CTF3 project. Following the recommendation of the CERN management, it would be composed of a few external and CERN experts and report to the CERN Research Board as all other Physics experiments. A draft of mandate and possible candidates will be proposed for endorsement to the CTF3 Collaboration Board at the next meeting in January 2007.

1 Introduction

The purpose of the note is to describe the necessary work to be done from 2006 to 2015 in the framework of the CLIC study and evaluate the necessary M&P resources.

It is based on the mandate clearly defined by the DG to test the feasibility of the CLIC concept and technology in order to arrive before 2010 at a firm conclusion on its possible use for a Linear Collider. The CERN Council, in its special 129th Session[1] held in Rome on 19 July 2004, confirmed its endorsement of these R&D activities to demonstrate the feasibility of the key issues of the CLIC scheme, before 2010 and which have been described in a dedicated report[2].

1.1 Schedule for physics inputs into key CLIC design choices

It is expected that physics developments, principally the initial discoveries made with the LHC, should provide by around 2010 key inputs into the choice of linear-collider technology. By this time, there are good prospects that the LHC will have determined the mass of the Higgs boson, and it may have identified a threshold for the appearance of new physics beyond the Standard Model.

Our planning hypothesis here is that, on the basis of these physics and other considerations, the choice made will be to build CLIC as rapidly as possible. Even assuming this choice, further issues concerning the range of CLIC energies, its luminosity and beam characteristics such as energy spread and polarization will need to be resolved. All the necessary information relevant to these subsidiary choices may not be available by 2010, and there will be a need to continue monitoring developments in physics during the period 2010 to 2015 before the TDR is finalized.

Since the planning hypothesis is that the ILC is not being built, the CLIC TDR may need to include the low-energy running options currently foreseen for the ILC, such as running at the top threshold and above the threshold for associated Z + Higgs production, if the Higgs boson is relatively light. We assume that there will not be a strong demand, at least initially, to use the CLIC technology for a low-energy, high-intensity photon-photon collider Higgs factory, nor for colliding CLIC and LHC beams.

However, we do assume that there will eventually be strong physics motivations for the highest possible CLIC energies. Even in scenarios with a light Higgs boson and new physics at low energies such as super symmetry or extra dimensions, high-energy running will provide unique physics opportunities. Examples include detailed measurements of rare Higgs decays and of the triple-Higgs coupling, and/or the detection of higher states above the threshold for the new spectroscopy. The case for going directly to high energies would be compelling if the Higgs boson is heavy and/or the threshold for physics beyond the Standard Model appears at higher energies.

Physics developments may also clarify the optimal trade-off between luminosity and energy resolution. For example, the appearance of narrow resonances would place a premium on fine energy resolution, whereas luminosity would be at a premium for studying the associated production of Higgs bosons and/or the continuum production of lighter states.

We assume that electron beam polarization will be available. The case has been made that positron beam polarization would also be valuable. This is another issue whose priority may depend on the additional physics information available after 2010. The choices of other options such as electron-electron and photon-photon collisions may also be deferred beyond this date.

In summary, we propose the following tentative deadlines for the physics inputs into key CLIC design choices:

2010: Initial CLIC energy range

2015: Trade-off between luminosity and beam energy resolution,

Positron beam polarization,

Electron-electron collisions,

Photon-photon collider

1.2 Organisation of this report

The first part of this report (Chapter 2) deals with the period up to 2010, while the second part of the report (Chapter 3) deals with the period from 2010 to 2015. The work program up to 2010 is pretty well defined and the resources can be estimated quite accurately. The work program after 2010 strongly depends on the results of the feasibility demonstration, the Physics perspectives following LHC results and the decisions concerning ILC. The second part of the report is based on the preferred and most demanding scenario for CERN. It assumes that the CLIC technology has been successfully demonstrated, and that a Linear Collider based on CLIC technology is to be built at CERN as soon as possible. In order to set the scene, a tentative long term CLIC scenario based on a success oriented and not resource limited schedule is presented in fig. 1. It assumes a Conceptual Design report addressing all key issues and describing the various sub-systems by 2010, a Technical Design Report following design optimisation and industrialisation end 2014. Assuming an approval of the project one year later, the construction could start early 2016 and a first beam could possibly be available from 2023 after 7 years of construction.

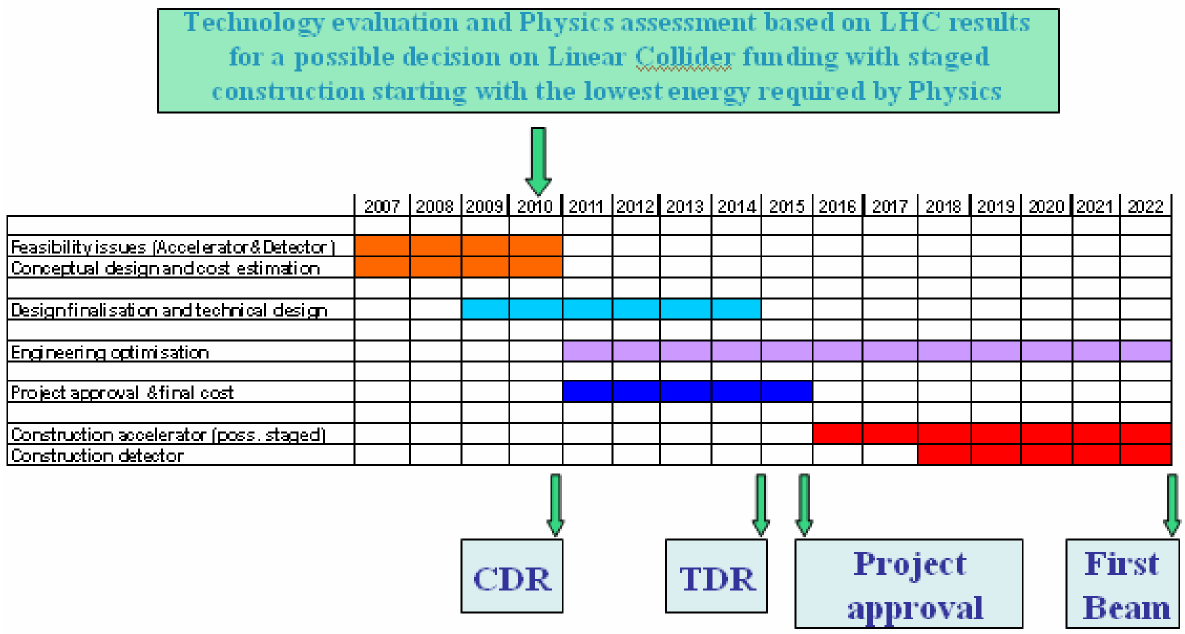


Figure 1 - CLIC possible long term schedule

2 The period 2006 to 2010

The mandate of the CLIC study, as defined by the DG for the period 2006 to 2010 and confirmed by the CERN council in 2004[1], consists in providing the HEP community in 2010 with the information if the CLIC technology can be used for a Linear Collider. The necessary work to fulfill this mandate is distributed in five categories:

- Demonstrate feasibility of the CLIC technology
- Design, optimization of a Linear Collider based on the CLIC technology and estimation of its cost
- CLIC Physics study and detector development
- Preparation of a Conceptual Design Report to be published in 2010
- Preparation of the work to be done after 2010 in case the technology is feasible

2.1 Feasibility demonstration

2.1.1 Key issues

The International Technical Review Committee[3] has identified a number of crucial items for which the feasibility of the CLIC technology has still to be demonstrated (the so-called R1 items) and a number of issues (R2 items) which must be investigated in order to arrive at a Conceptual Design. They can be divided in three categories:

- the one which are common to all linear colliders independently of the technology and colliding beam energy:
- the one which are specific to the CLIC technology
- the one which are related to the Multi-TeV regime

The issues which are common with ILC are presently studied in collaboration with ILC experts in the frame of the EU co-funded EUROTEV design study and with a limited participation to the ATF2 facility at KEK addressing low emittance generation and strong focusing to small beam dimensions.

The CLIC study team focuses its efforts and resources on the issues specific to the CLIC technology and the Multi-TeV operation. They are listed in Table 6.1 together with how and when they are foreseen to be addressed.

2.1.2 How and when to address the key issues

The 3 key issues concerning the specific feasibility of the CLIC technology as well as the first two issues concerning the design finalisation are all addressed in the CLIC Test Facility (CTF3) presently being built following the schedule below.

That requires not only to build and commission the CTF3 facility but also to operate it as a 30 GHz power source for RF structure test and conditioning during a large part of the year.

The other issues cconcerning the design finalization are addressed in collaboration with other institutes in the frame of the present EU FP6 design study EUROTEV and in possible future bids to the EU FP7 program.

	2004	2005	2006	2007	2008	2009
Drive Beam Accelerator	■					
30 GHz high-gradient test stand	■	■				
30 GHz high-gradient testing (4 months per year)		■	■	■	■	■
R1.1 feasibility test of CLIC accelerating structure						▨
Delay Loop	■	■				
Combiner Ring	■	■	■			
R1.2 feasibility test of drive beam generation					▨	
CLEX				■		
R1.3 feasibility test of PETS* structure					▨	
Probe Beam			■	■		
R2.2 feasibility test of relevant CLIC linac sub unit					▨	
Test beam line		■	■	■	■	
R2.1 Beam stability bench mark tests					▨	▨

Figure 2 - CTF3 schedule

2.1.3 CTF3

CTF3[4] is presently being built by an international multi-lateral collaboration[5] of 15 institutes providing extra resources which are listed in Table 6.2. It is well on schedule. The overall resources for construction are summarized in Table 2.1 . Extra collaborations are presently being envisaged to reduce the CERN contribution, especially India concerning TL2 and Pakistan concerning TBL components.

As described in the paragraph below, CTF3 is operated continuously up to 10 months per year alternating between commissioning of newly installed systems and RF power source mode for structures conditioning and tests. The specific aspects of equipment reliability and operation are analyzed respectively in Annex 1 and Annex 2. They clearly point out that such an extended operation is feasible but requires substantial resources. It strongly relies on the support of the various technical groups in AB, AT and TS.

Table 2.1 - overall CTF3 resources

		Status March 04		Status Nov 05	
		Budget	Manpower	Budget	Manpower
		MCHF	p-y	MCHF	p-y
TOTAL TO COMPLETION		95.4	393.3	101.1	395.8
CERN	Existing Equipments	40.0		40.0	
	Contrib. 2000-2003	16.0	100.0	16.0	100.0
	Pledged 2004-2009	17.4	150.0	14.9	125.0
	Contingency	0.0	0.0	5.5	25.0
COLLAB	Contrib. 2000-2003	4.8	48.3	4.8	48.3
	Pledged 2004-2009	0.0	0.0	9.4	59.0
Missing		17.2	95.0	10.5	38.5

2.1.4 Structure development, conditioning and tests

A very important and critical R&D about the various necessary RF components at the unusually high RF frequency of 30 GHz is being pursued and analyzed. Human resource issues are addressed in Annex 3. The R&D program consists in development and tests of:

- The accelerating structures aiming at an exceptionally high average accelerating field of 150 MV/m with a maximum breakdown rate of 10^{-6}. That implies that the structure should be able to stand fields substantially higher than 150 MV/m (about 20% more in peak power at the structure entry and about 30 MV/m more at high breakdown rate during conditioning).

- Power Extraction and Transfer Structure (PETS) producing up to 600 MW of RF power at 30 GHz in order to feed 4 accelerating structures with ON/OFF capabilities

- Integration in a Two Beam Test Stand of all the relevant components including a representative vacuum systems and a fully engineered RF network with waveguides, couplers and power loads

- Demonstration of RF power production with high extraction beam efficiency and bench marking in the CTF3 Test Beam Line (TBL) producing up to 2.5 GW of RF power

This important program relies on an inter-departmental effort including AB/RF and TS/MME. The program of rf testing relies on CTF3 for testing at 30 GHz and to a limited extent on SLAC for testing at 11 GHz. In addition a dc spark test, a laser pulsed surface heating and an ultrasonic fatigue apparatus are used for technology developments.

CTF3 began producing 30 GHz rf for high power testing accelerating structures at the end of 2005. This is the first time that long-pulse (CTF2 was limited to 16 ns) high-power 30 GHz has become available. A circular molybdenum-iris structure, a circular iris copper structure and a copper HDS structure have been tested so far. Although the analysis of the results is ongoing a number of key features have emerged from this first data:

- Although molybdenum confirms its high-gradient potential, the breakdown rate variation with field was measured for the first time and was found to be much lower than for copper, as shown in fig. 3. As a consequence, the gradient, at an operational breakdown rate, is much lower than expected. The upcoming tests of molybdenum HDS's should help to determine if this is a basic property of molybdenum or if it is a consequence of clamping or surface finish of the circular clamped iris structure. The dc spark test is being upgraded to allow measurement of breakdown rate.

- A new gradient limit scaling[6] based on power flow and structure circumference has emerged from an analysis of existing and new data. New structure designs (test accelerating structures, CLIC accelerating structures and PETS) based on this new limit are being prepared. The test accelerating structures will be ordered soon and run in the coming year to further verify the precision of the scaling and if any additional parameters are required. Structures optimized with the correct high-gradient constraints would give the best performance.

- Comparisons of accelerating gradients achieved in tests at 30 and 11 GHz consistently show a higher gradient at the lower frequency when normalized to the same pulse length.

Predicted gradients based on a full optimization indicate a maximum gradient in the region of 18 GHz.

- Practical operating gradients derived from the data all point to values well below 150 MV/m for breakdown probabilities of 10^{-6} as shown in figure 3
- And more generally we have observed that:
- Development of structures is clearly limited by the rate with which the structures can be fabricated and tested in CTF3. The most fundamental limit is that only one structure can be tested at a time in CTF3 as it is currently configured. It should be noted that the available testing time in CTF3 and the efficiency of its use has considerably improved with the successful introduction of automatic conditioning. The development rate is also limited by the turn-around time between an understood test result and the fabrication of the next-generation of prototype. Manufacturing the micron precision and exotic material HDS structures is state-of-the-art and can only be made by a select group of outside firms (operating themselves in a development mode) consequently delays are often encountered. We have attempted to speed the process by ordering structures with new ideas in parallel, but this is quickly expensive. Finally it is clear that the preparation of new experimental areas (as opposed to the structures themselves) is very time consuming and resource intensive. The mid-linac test stand is now operational and only minor changes are needed to continue testing. On the other hand, almost all of the work for the two-beam test stand remains to be done. The extra resources needed to keep this from becoming a problem are outlined in Annex 3.
- We urgently need to begin testing PETS structures. This will first occur when the two-beam test stand in CLIC is brought on line.

These preliminary conclusions are based on experiments where not all variables have yet been brought under control. The next round of structure testing will emphasize removing the remaining ambiguities and on increasing the achieved gradient. A list of the structures to be tested in the foreseeable future is presented in table 2.2 .

Table 2.2: Structure testing program in 2006 and 2007

2006	HDS11 large Mo
	HDS11 small Cu (with targeted gradient conditioning)
	HDX11 Cu (11 GHz at SLAC)
2007	2% v_g HDS Cu
	2% v_g HDS Mo
	Thick-iris HDS Cu
	Thick-iris HDS Mo
	HDX11 Mo (11 GHz at SLAC)
	Efficiency optimized HDS for 11 GHz (small a) (at SLAC)

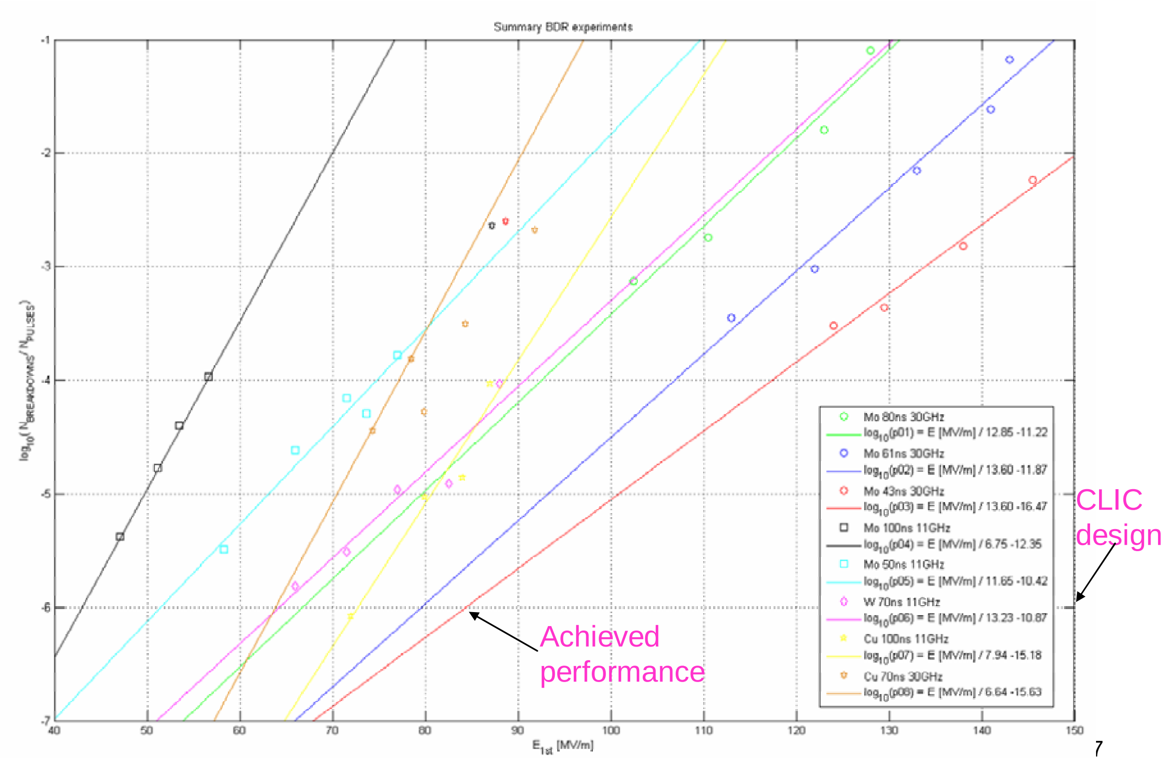


Figure 3: Achieved performances in Accelerating Structures

The R&D program on structures is currently being reviewed in order to explore other or complementary possible avenues and increase the number of structures being tested. It will certainly necessitate additional resources.

2.1.5 Beam dynamics

A strong beam dynamics support is necessary to address the key issues and validate the CLIC design by bench-marking the simulation tools with other codes and in CTF3. The necessary program is described in Chapter 2.2.2 below and analyzed in Annex 4. The current main beam activity is largely integrated into the EU co-funded EUROTEV design study which will be terminated end 2007.

2.1.6 EU related programs

A significative participation to EU co-funded activities is presently being pursued:

- to develop a possible photo-injector as a more performing electron source for the drive and probe beam of CTF3 in collaboration with LAL and RAL in the frame of the JRA PHIN of CARE partially funded by the EU FP6.
- to study common issues with ILC mainly beam dynamics and beam instrumentation in the frame of the Design Study EUROTEV partially funded by the EU FP6.
- to participate in the EU FP6 network, ELAN,

Possible future bids to EU in the frame of FP7 starting 2007 with funding from 2008 or 2009 to 2013 are foreseen to address issues which are presently not fully covered. They would form a common Integrated Activity (I3), so called “MuTeV” described in Table 6.3 and composed of 6 Joint Research Activities (JRA). The overall integrated cost is estimated at 35 MCHF (158/FTE and 17 MCHF) from which the CERN contribution is estimated at 15.8 MCHF (52 FTE and 7 MCHF) over 4 to 6 years. That corresponds to a yearly commitment of 11.5 man-year and 1.5 MCHF from which about 1/3 is available in the already foreseen program.

2.2 CLIC design

2.2.1 CLIC parameters

A new set of parameters has recently been published[7]. It is mainly derived from an overall optimization of a figure of merit[8] derived from the Luminosity per Power. It takes into account the scaling laws and limitations of structures as known middle of 2005. The optimization is currently continuously being reviewed and adapted to the evolving knowledge of the scaling laws and especially of the RF structures[6] with tests at CTF3 and SLAC at various frequencies. The figure of merit is presently being extended to include the cost and will lead to a global re-optimization of the design and parameters.

Following figure of merit optimization summarized on Figure 4 based on the current knowledge and test results, a more realistic design in term of structure capabilities and performances would be expected from a review of the RF frequency and accelerating gradient in the range:

$$100 \text{ MV/m} \geq \text{Accelerating gradient} \geq 120 \text{ MV/m},$$

$$15 \text{ GHz} \geq \text{RF frequency} \geq 24 \text{ GHz}$$

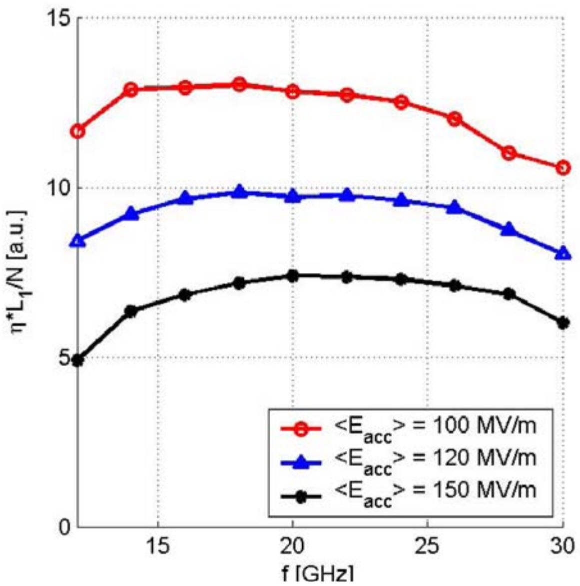


Figure 4 - Figure of Merit optimization

Such an optimization imposes to review the overall CLIC design as well as all sub-systems, especially the main beam and drive beams injectors, the main linac and drive beam decelerators and their various components.

2.2.2 Beam dynamics

The necessary program concerning beam dynamics is analyzed in Annex 4. It includes a source to end simulation of the beam behavior and a continuous optimization of the various sub-systems in terms of beam performances and final luminosity, namely.

- The injectors of the drive and main beams
- The Damping Ring and bunch compressors both especially critical for the luminosity and challenging beam parameters
- The preservation of beam quality along the linac with especially strong transverse and longitudinal wake-fields
- The Beam Delivery System (BDS) focusing the beam to unusually small dimensions in the nm range, including beam stability and feedback for long term luminosity preservation
- The post collision line with extreme momentum and angular spread due to the high beamstrahlung regime during collision
- The drive beam stability all along the whole chain of accelerators and transport, especially along the decelerator during RF power production. The final part of the drive beam decelerator with 100% energy spread is a specific key issue of the CLIC scheme and especially critical for power beam efficiency

With such high beam power in the main beam (135kJ/pulse, 20 MW per beam) and in the drive beam (30kJ/pulse 4.5MW/individual beam) the machine protection and reliability issues are specially analyzed.

The tools developed to analyze the various systems of the CLIC linear collider will also be used for CTF3, thus bench marking them were possible. Main systems are:

- The drive beam source, linac, bunch compressor, delay loop and combiner ring
- The drive beam decelerator in the Test Beam line generating up to 2.2 GW of RF power
- The probe beam injector and Two Beam Test stand

The key issue consists in validating the tools in CTF3 in order to guarantee the validity of the simulation in the real CLIC conditions and parameters.

2.2.3 Structures

The development work for the CLIC design coincides with the one addressing the key issues described in Chapter 2.1.4 above. In addition, a module working group is studying the integration of all necessary components of a standard Two-Beam module namely the RF components (Accelerating Structure, PETS, waveguides, couplers, dumps, etc) but also the beam position monitors, the magnet including movers and the alignment. It is composed of experts of the various technologies from the corresponding groups in AB, AT and TS.

2.2.4 Alignment and stability

The alignment and component stability is especially critical for the performance of the CLIC scheme. Various techniques of alignment are presently being reviewed by the TS-SU experts in collaboration with experts in other laboratories, NIKHEF, LAPP, etc. A test stand is being considered to be built in TT1 in order to validate the chosen technology.

Excellent performances of component stabilization in the nanometer range have already been successfully demonstrated. The R&D is being pursued, mainly by LAPP, in the frame of the FP6 co funded EUROTEV design study and could be pursued in a new FP7 JRA, so called LED. CERN experts could possibly join next year when liberated from LHC.

2.2.5 Cost estimation

The cost of a Linear Collider on the CERN site is currently being estimated with the aim of identifying the major cost drivers. It is done in parallel and takes advantage of the cost estimation of ILC on the same site using the same tools by the same persons. It involves cost estimation of the various technical groups of the three departments AB, AT and TS. A first estimation is expected by early 2007 but will continue to be refined in the following years.

2.3 Preparation of a CLIC Conceptual Design Report

By 2010, a report summarizing the studies and tests done to address the key issues specific to the CLIC technology will be published with a conclusion on the feasibility of this technology. It will include an optimized design of a Linear Collider based on the CLIC technology and the description of the various sub-systems including a first estimation of the cost.

2.4 Preparation of the work from after 2010

As already pointed out, the work program during the period 2006 to 2010 focuses on the technology demonstration and on the preparation of the CDR. All other work is being postponed until after the successful demonstration of the CLIC technology.

One activity could be worth pursuing, namely the development of a stand alone RF power source at the appropriate frequency. If the CLIC technology proves to be feasible, the program during the period 2010 to 2015 would imply fabrication and conditioning of a large number of structures. It will be very important in this case to increase our capacity of structure testing, which can be done either by upgrading CTF3 for high repetition rate operation with multiple testing ports, or by using a limited but substantial number of stand alone RF power sources. Such a power source does not exist today. A new bid for a Joint Research Activity (JRA) within the FP7 work program, so-called SAPS (Table 6.3), is envisaged for its development in a collaboration of interested industries and laboratories.

2.5 Resources

The work to be done is defined in Work packages following a Work Breakdown Structures. Each Work Package is under the responsibility of a well identified Group. Each work package is described and constitutes a contract between the CLIC study/CTF3 project and the corresponding group of the various departments (AB, AT, TS and PH). The material budget is allocated from the CLIC budget and the man power is estimated and allocated by the corresponding group leader.

2.5.1 Material

The CLIC spending material budget is summarized on Table 2.3 . Thanks to the collaborations providing extra resources, the material budget is sufficient to complete the project if 3 MCHF extra allocated in addition to the budget foreseen in the MTP.

Table 2.3 - CLIC material budget

		2004	2005	2006	2007	2008	2009	2010	Total
	CLIC TOTAL (including EU)	**6780**	**4385**	**6869**	**9077**	**6454**	**6383**	**3200**	**43148**
	EU funded			779	385	30			1194
	EU CERN (without PHIN) (FP6&7)			406	153	20	1000	1000	2579
	CTF3 (with PHIN)	5725	3225	4314	7169	5034	4013	1430	30910
	CMS: General&Structures	1055	1160	1370	1370	1370	1370	770	8465
	CLIC CERN TOTAL SPENDING	**6780**	**4385**	**6090**	**8692**	**6424**	**6383**	**3200**	**41954**
Material									
	MTP	3400	3400	3400	3490	3485	3485	3485	24145
	Corrections		790	-270					520
	Additional	3000		3000	3000	3000	3000	3000	18000
	CLIC CERN ALLOCATED	**6400**	**4190**	**6130**	**6490**	**6485**	**6485**	**6485**	**42665**
	BALANCE	**-380**	**-195**	**40**	**-2202**	**61**	**102**	**3285**	**711**

Extra collaborations are being considered in order to reduce the CERN load. Some margin could then be made available for participation to EU FP7 bids in order to address the less critical but still important issues. The most critical year is 2007 with an over commitment of about 2 MCHF.

2.5.2 Man-power

The present allocation of 46 FTE and 13 visitors as recorded in APT under the PPA FRC for the whole CERN (this includes 3.5 FTE for TS support,which is presently not registered in APT) and displayed on Figure 5 below, is just about adequate. In spite of the heavy load and the corresponding high priority of the LHC, the support of the technical groups is generally appropriate. Nevertheless, it is strongly conditioned by the availability of experts with commitments elsewhere. This can lead to delays especially during the critical year 2007 with the completion and start up of the LHC. Collaboration with external institutes provides welcome additional resources, but requires substantial efforts by CERN experts for the necessary support and follow-up.

The man-power allocated in APT from 2011 is only minimal as the work program has not yet been defined, but the strong reduction of the allocated man-power especially from 2008 to 2010, is not compatible with the work load described above. The recorded reduction is partly due to missing data from some groups and is presently being reviewed with the corresponding group leaders. On one hand, some reduction of man-power is expected due the progressive completion of the CTF3 construction and the termination by end 07 of the EU FP6 co-funded activities (EUROTEV, PHIN, and ELAN). Moreover, a large part of the 13 present visitors are paid by EU which will also not be available from 2008. On the other hand, the overall operation of the CTF3 complex with increasing complexity, the CLEX commissioning and structure tests as well as the preparation of the CDR will require extra resources. In addition, bids for complementary activities in EU FP7 could provide extra resources from 2008 or 09 but will also require substantial CERN involvement.

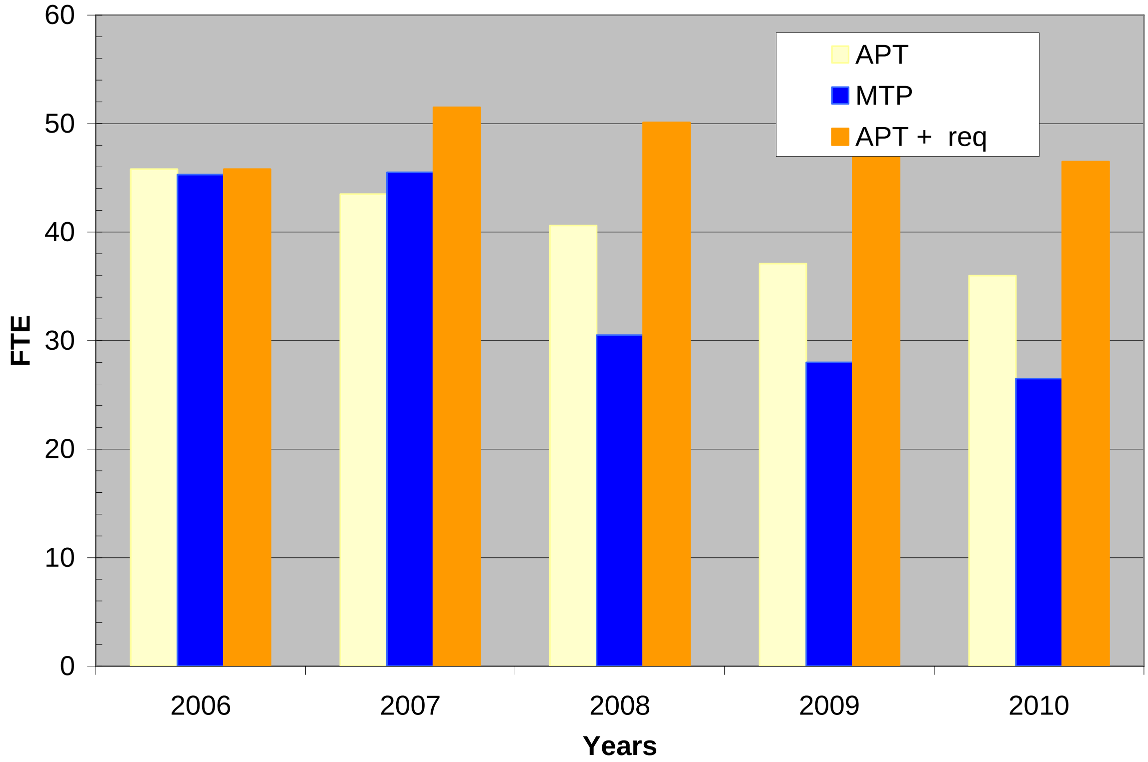


Figure 5 - Evolution with time of the staff allocated to the PPA FRC, as recorded in MTP and APT

As summarized in Table 2.1 concerning the necessary resources for CTF3 completion and operation, 43 FTE (integrated up to 2010) are lacking from resources foreseen to be provided by external collaborations. This is the reason why five operators to run the overall CTF3 facility have been tentatively defined missing. After analysis of the CTF3 operation as described in Annex 2, a more efficient way of CTF3 operation for 30 GHz production has been defined relying on automatic operation with supervision from the CCC. The allocation of the 5 operator posts has therefore been redefined accordingly.

It is essential that the overall man-power is maintained up to 2010 including well identified experts presently missing as explained in the Annex 1 to 4 and summarized in the Table 2.4 below. Table 2.5 shows the previsions as recorded in APT and MTP together with our projection of requirements.

Some of these experts could possibly be provided by man-power liberated from LHC.

Table 2.4 - Missing man-power

Job description	category	requested	2007	2008	2009	2010	Total
Structure production	E	WW	1	1	1	1	4
Systems integration	D/E	GG	1	1	1	1	4
Expert core team	D/E	RC	1	2	2	2	7
Structure tests	E	WW	1	1	1	1	4
Electronic expert	C/D	GG	1	1	1	1	4
CTF3 software	D/E	RC/FT	1	0.5	0.5	0.5	2.5
Beam dynamics	E	DS	2	2	2	2	8
Installations	C	GG	0	0	1	1	2
Vacuum	C	GG	0	1	1	1	3
TOTAL			8	9.5	10.5	10.5	38.5

Table 2.5 CLIC staff previsions in MTP and APT in comparison with projected requirements.

	2006	2007	2008	2009	2010	Grand Total
APT (international and local staff)	45.8	43.5	40.6	37.1	36	203
MTP (international and local staff)	45.3	45.5	30.5	28	26.5	175.8
projected need	45.8	51.5	50.1	47.6	46.5	241.5
missing in APT	0	8	9.5	10.5	10.5	38.5
missing in MTP	0.5	6	19.6	19.6	20	65.7

3 The period from 2010 to 2015

3.1 The context

The work program after 2010 strongly depends on the results of the CLIC feasibility demonstration, the Physics perspectives following LHC results and the decisions concerning ILC. The various options are summarized in Table 6.4 .

Only the preferred and most demanding scenario 1 is considered here. It assumes that the CLIC technology has been successfully demonstrated, and that a Linear Collider based on CLIC technology is to be built at CERN as soon as possible following the Success Oriented Schedule (SOS) described on Figure 1. All other scenarios are sub-sets of the first one and can easily be deduced. As the scenario 1 assumes no ILC construction, the CLIC facility is supposed to be constructed in phases with a first phase defined by the lowest energy requested by Physics at the time and certainly much below the nominal of 3 TeV, possibly in the 500 GeV range.

Following the previous chapter, a Conceptual Design Report (CDR) addressing all key issues and describing the various sub-systems would be available by 2010. A large amount of work, mainly related to the optimisation of design and industrialisation would have still to be done before such a technology can be used. It will have to be described in a Technical Design Report in parallel with the preparatory phase for the authorisation of the project. Based on the experience of previous projects like the LHC or the ILC, this period is estimated to 4 years leading to a detailed Technical Design Report end of 2014. Assuming an approval of the project one year later, the construction could start early 2016 and a first beam could possibly be available from 2023 after 7 years of construction.

The period 2010 to 2015 would then be especially critical with the preparation of the construction starting the year after with all steps to go from a technology feasibility demonstration to the start of a real project.

3.2 Estimate of required resources for accelerator R&D

Following the feasibility demonstration up to 2010, it is assumed that no other major facility is necessary before the construction of a Linear Collider based on the CLIC technology. However, the CTF3 will still be operated and upgraded in order to fulfill the requirements during the period 2010 to 2015 for the preparation of the project. In particular, the two beam test stand should be extended and upgraded as a succession of CLIC nominal modules used to optimize the integration of the various components including active alignment, vibration control, beam diagnostic and nominal quadrupoles. The test beamline would be equipped with PETS with ON/OFF capability and would take advantage of the overall RF power production of about 2.5 GW for conditioning a large number of accelerating structures in parallel. An evaluation of the necessary work on the various sub-systems is described in Table 6.5 starting from the assumed results in 2010. The projection is done for an only technically limited schedule. In case of limited resources the schedule has to be stretched accordingly. Furthermore we assume that collaborating institutes will contribute at least at a relative level similar to the present CTF3 situation, i.e. one third of the total effort.

Starting from the work required for a complete technical design and preparation for construction as defined in 6.5, we estimate the required manpower and material using the following assumptions:

- The construction of CLIC will last only seven years. This implies that all technical components needed in large numbers have to be fully engineered, prototyped and tested before start of construction in 2015, so that key contracts can be placed very early in the construction phase. This concern all items required for the two beam modules of the main linac, as well as the components of drive beam accelerator.

- For small number items only those which are technologically very demanding and critical for the machine performance (for example final focus quadrupoles) need prototyping and testing during the TDR phase, while the final engineering of other small number components (for example magnets of injector complex) can be performed during the construction period.

- Large scale RF power testing will be required to develop high frequency RF structures to readiness for mass production. For this power testing we assume an upgrade of CTF3 to use all 16 power producing structures in the TBL line (located in the CLEX building) as structure testing ports. This implies that the whole CTF3 complex has to be adapted for running at a high repetition rate of a least 100 Hz (presently 5 Hz).

- For quality assurance and pre-conditioning of high frequency structures during mass production even more testing ports will be required. We assume that novel stand alone RF high power sources will be better adapted for this purpose than a CTF3 like facility. Therefore the development of such stand alone power sources has to be undertaken in the period 2010-15, so that a number of these devices can be ordered and installed early in the construction period.

- To keep the ambitious construction schedule the procedures with the host states authorities for approval of tunnel construction have to be started early in the TDR phase. This implies a considerable amount of civil engineering and consultancy work during this phase.

- The CLIC bids to FP7 (see table 11) are all focused on key CLIC R&D. Therefore successful bidding will reduce the requirements on CERN budget assumed here.

Figures 6 and 7 show our estimated spending profiles for manpower and budget respectively. Figure 8 shows the combined M&P spending profile for CERN (without collaborating institutes). Figure 9 shows how the spending is distributed across the various activities as listed in Table 6.5 . Table 6.6 gives detailed information of the data used for Figures 6-9.

We would like to emphasize that the required R&D resources as shown below are higher than those which were needed for LHC, but still of comparable magnitude.

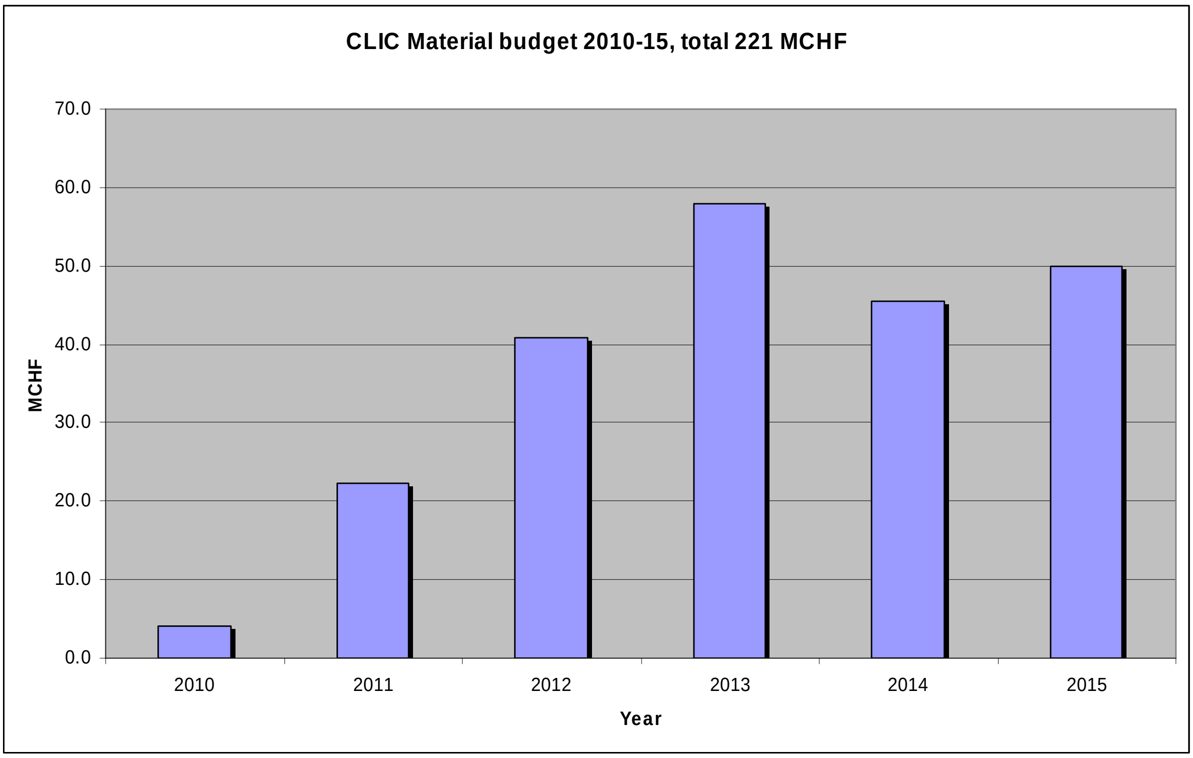


Figure 6 - Evolution of the required material budget

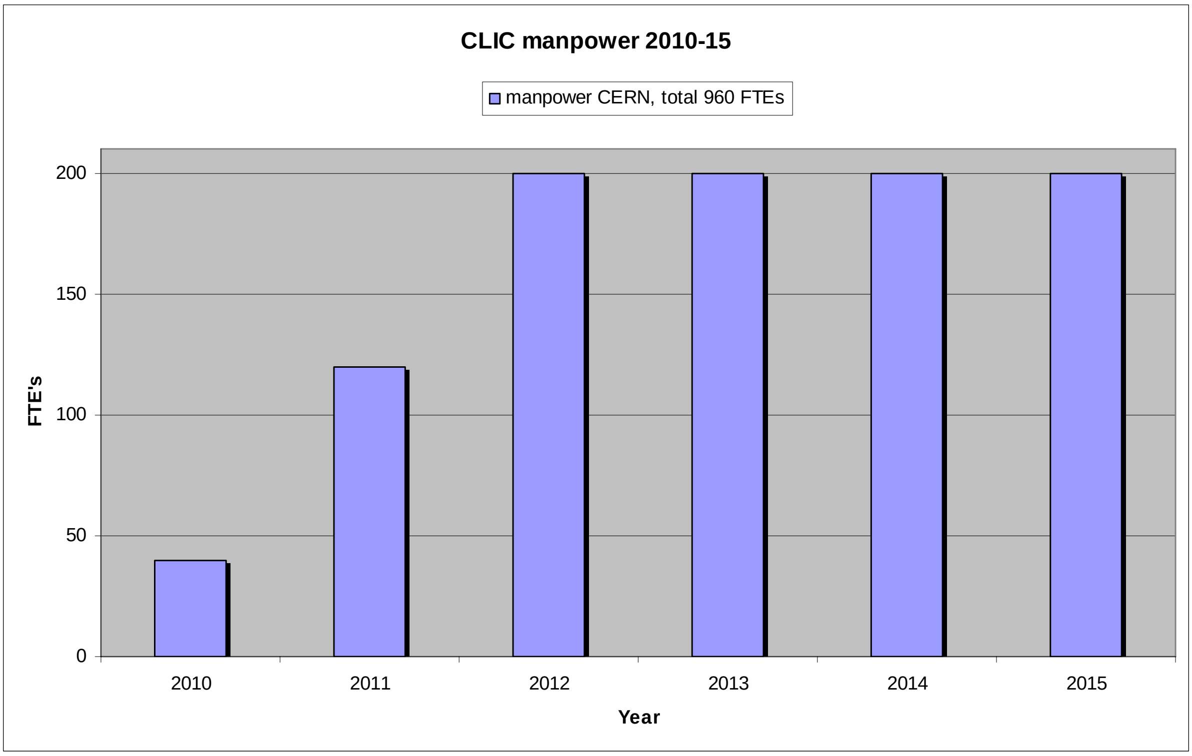


Figure 7 - Evolution of required man-power

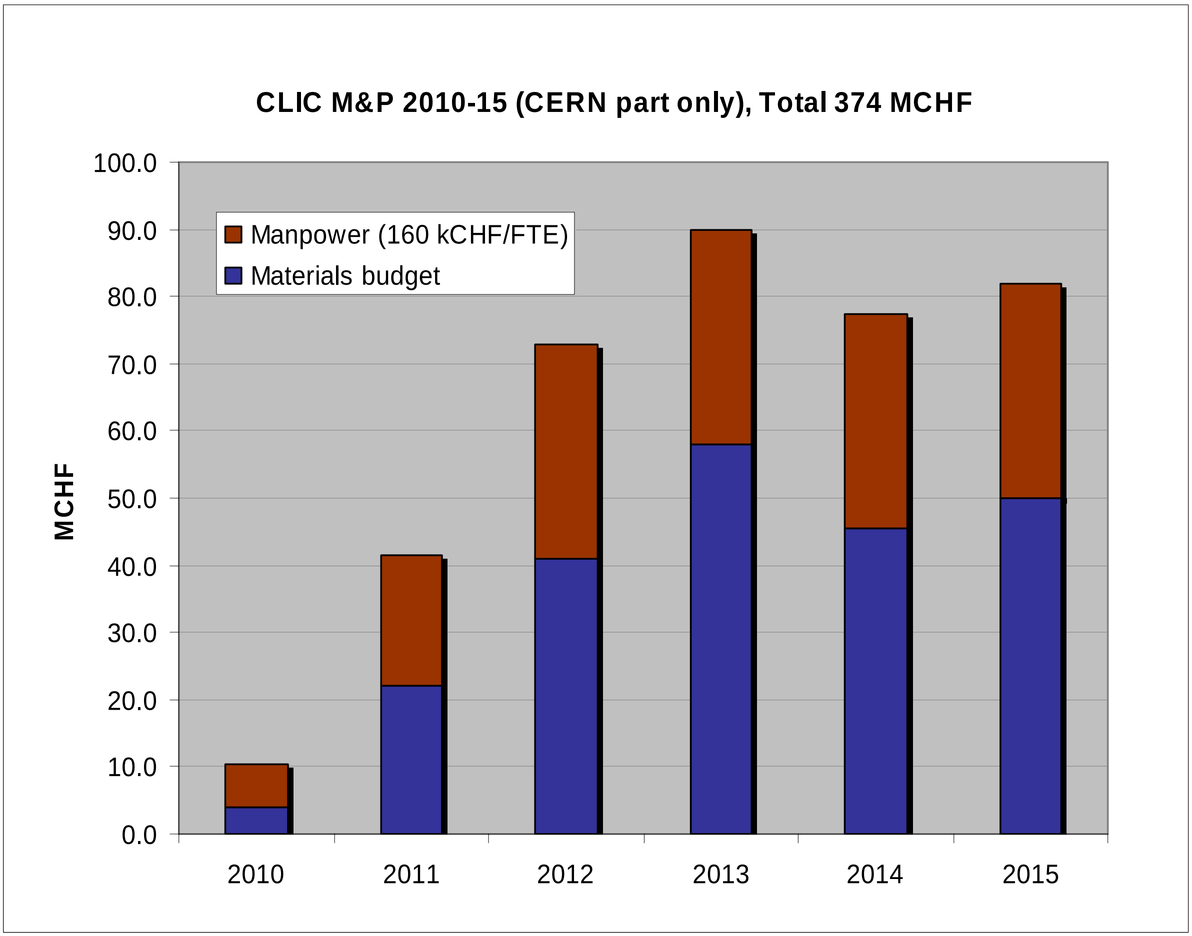
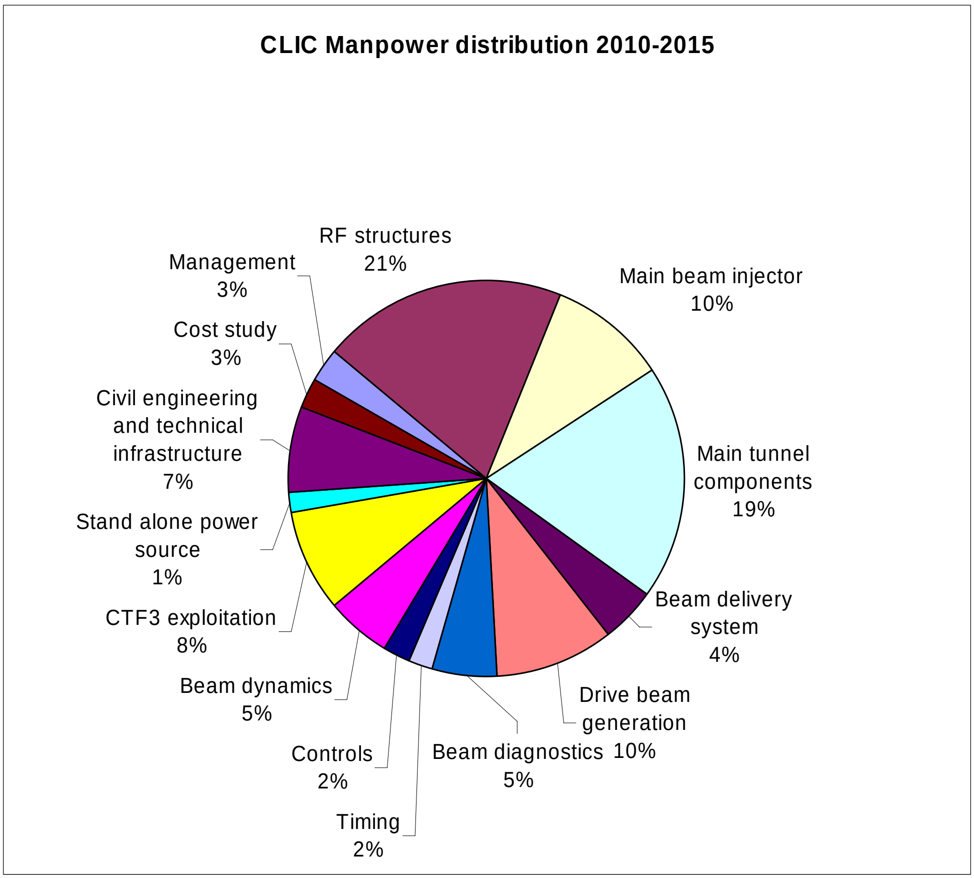


Figure 8 - Budget profile of CLIC (M&P) resources



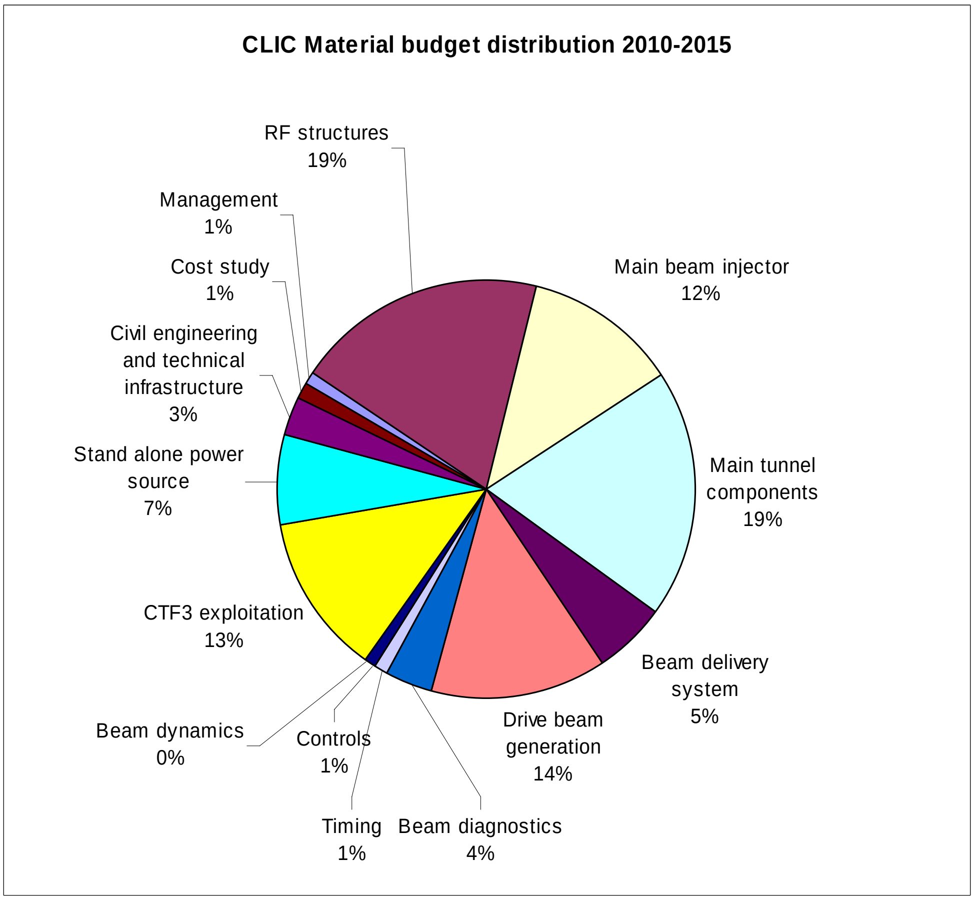


Figure 9 - Distribution of CERN part of CLIC M&P resources

4 CLIC detector preparation

4.1 The Context

To estimate the resources needed for the development of a CLIC detector at CERN in the scenario outlined in the introduction, we make the following assumptions:

- For the sake of the argument we assume that CERN/PH will participate in **one** Linear Collider detector at the **same level** as it contributed to the **LHC detectors (**20%)**.**
- Size and complexity of a LC detector are the same as for the CMS detector (see Table 4.1).
- CERN contributes to 6 sub-systems (like for CMS):

  magnet, , tracker, calorimeter, DAQ, electronics, integration

- Performance requirements for ILC and CLIC are the same (or very similar) (see Table 4.1).
- Around 2010 the energy scale for a linear collider would be known from LHC physics.
- There would be substantial support from the groups working on ILC detector development now.

Table 4.1: Some detector properties.

	CMS	ILC (SiD[1])	CLIC
Outer radius (μ chamber) [m]	7.5	6	7
Coil radius [m] B [T]	3 4	3.3 4	3 4
Pixel-VDET Minimum radius [cm] Vtx resolution 1) [μ]	4	1.5 5⊕10*f	4 15⊕35*f
Track momentum resolution 2) σ/pt^2 [GeV^{-1}]		$5\ 10^{-5}$	$5\ 10^{-5}$
ECAL X_0	25	29	28
HCAL λ_{int}	8	4	?
Jet energy resolution	<1/E	0.3/√E	0.3/√E

1) $f = 1/(pt \sin^{3/2}\theta)$

2) for LC with vertex constraint, without ×1.5

4.2 The R&D Phases and resources

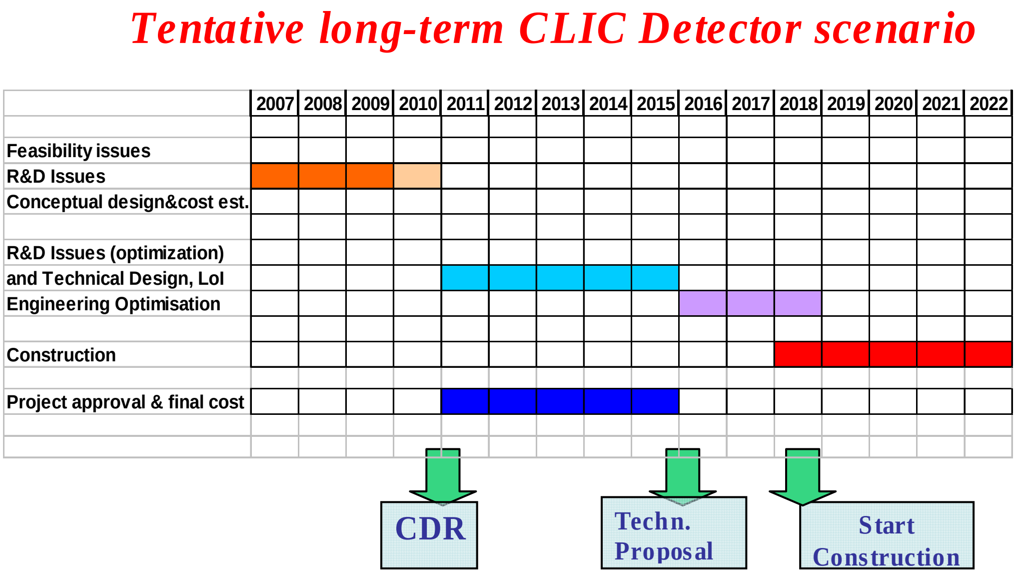


Figure 10 Tentative long-term CLIC Detector scenario

Before the start of detector construction, one can identify 3 phases (see Figure 10):

1. 2007-2010, R&D on feasibility for CLIC/ILC detector in collaboration with outside groups. The following topics are proposed:

   a. novel readout chambers for a TPC. Would a TPC be an option for a 3 TeV CLIC?

   b. pixel detector with very fast time stamping to be used in vertex detector,

   c. microchannel detectors for very fast time stamping,

   d. dual read out calorimeter with crystal fibers for high resolution jet reconstruction,

   e. engineering study of forward region. CLIC quadrupole is inside the detector, different from ILC.

   For these feasibility studies, **10 FTEs/year** are needed in PH. These are part of a request from PH Department for resources for some specific detector R&D.

   The amount of project money needed during this time, mostly for electronics (ASIC) prototyping, is about **5 MCHF**.

Table 4.2: CERN personnel in CMS before construction.

Generic CMS R&D (RD5)	1990	10 FTE
Prepare Letter of Intent	1992	30 FTE
Prepare Technical Proposal	1994	80 FTE
Pre- construction R&D	1996	80 FTE

2. 2011-2015, specific R&D to write a LoI and prepare a technical proposal.

   From past experience in PH, in particular from the R&D phase in CMS (see Table 4.2), one can estimate the need of **30 FTEs in the beginning** increasing to **80 FTEs at the end**.

   At present, no conceptual CLIC detector design exists. Therefore, we can only estimate the R&D costs in the 5 years preceding the Technical Proposal from what ATLAS and CMS did spend about 10 years ago and from a study of one of the ILC detectors (SiD) [9].

   The CERN part of detector R&D preceding the production was originally 9 MCHF each. (ATLAS/CMS) but had to be doubled later. Since the Linear Collider detector is aiming for ultimate precision, we assume that R&D costs will be similar.

   One of the ILC detector concepts (SiD) has published a preliminary study of total and R&D cost. The base line detector cost is 310 MCHF [10] (assuming "M&S + labor" and 1 $=1.25 CHF). Actually, very similar to the 300 MCHF the LHC detectors were supposed to cost in 1993 (Evian Workshop).

   SiD figures the R&D cost as 15% of the total which gives 50 MCHF. Assuming the same for a CLIC detector, a 20% share of CERN would be 10 MCHF.

   We expect that the final costs of an ILC or CLIC detector will be higher than the early estimate of SiD, in fact close to the costs of an LHC detector. Therefore, R&D costs for CERN are expected to be 20 MCHF.

   In summary, R&D, leading to a Technical Proposal for a CLIC detector at CERN, we estimate the project money needed in PH to about **20 MCHF.**

3. 2016-2018, TDR done, pre-construction R&D for engineering.

Before phase 2 can start, most of the tasks of phase 1, in particular the development of fast electronics for time stamping, need to be done. Figure 11 summarizes the estimates for manpower over 10 years. From 2011 to 2015 this corresponds to **340 man-years.**

How much of this manpower could be found within PH and how much would be new, additional manpower, is not part of this study. Certainly, it depends on whether the LHC collaborations would work on a major luminosity detector upgrade for 2015 or not.

Following the above arguments, and that CERN would contribute about 20% to a CLIC detector, the resources needed at CERN for R&D for a CLIC detector in the two periods, 2007-2010 and 2011-2015, are summarized in Table 4.3.

Table 4.3 Summary, resources needed in PH for CLIC detector R&D

	2007 - 2010	2011 - 2015
Manpower (man-years)	35	340
Material (MCHF)	5	20

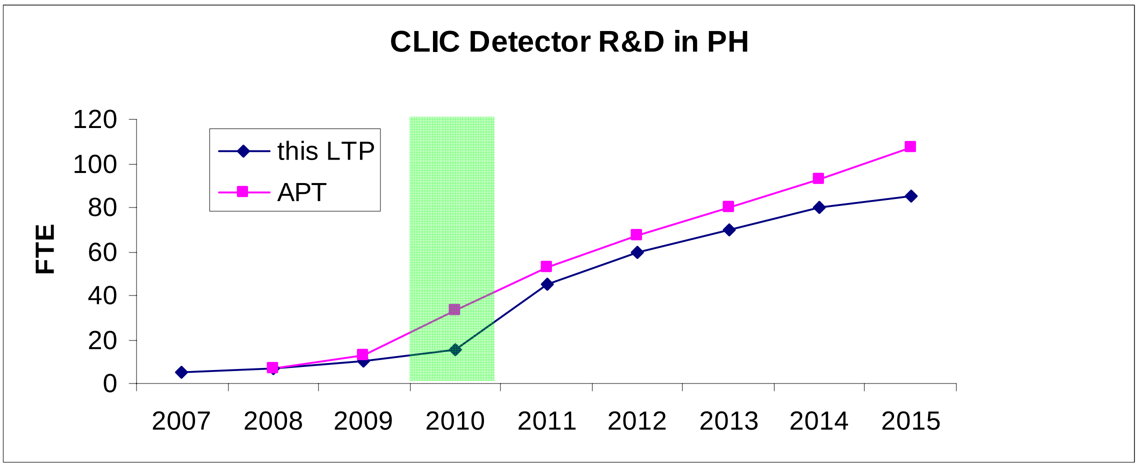


Figure 11. Manpower estimates for R&D for one CLIC detector with PH participation as was for ATLAS or CMS. "LTP" this proposal, "APT" PH estimate from Dec. 2005.

5 References

[1] CERN Council, Rome, July 2004

[2] I. Wilson, "CLIC Accelerated R&D," CLIC note 620, 2005

[3] "International Linear Collider Technical Review Committee, 2nd report," SLAC Report 606, 2003

[4] "CTF3 design report," 2002, http://doc.cern.ch/archive/electronic/cern/preprints/ps/ps-2002-008.pdf

[5] 10th CTF3 collaboration meeting, 2005. http://ctf3.home.cern.ch/ctf3/New_clic_notes.htm

[6] W.Wuensch, "The scaling of the Traveling Wave RF breakdown limit;" CLIC note 649

[7] F. Tecker (editor), "Updated CLIC Parameters 2005," CLIC note 627, 2005

[8] A. Grudiev, D. Schulte and W. Wuensch, "Optimum frequency and gradient for the CLIC main linac accelerating structure," proc. 10th EPAC, Edinburgh 2006

[9] SiD, Silicon Detector Outline Document, http://hep.uchicago.edu/~oreglia/siddod.pdf

6 Tables

Table 6.1 - CLIC Key issues

Category	Related	Nbr	Key issue	addressed	Date
Feasibility	Specific CLIC technology	R.1.1	Test of damped accelerating structure at design gradient and pulse length	CTF3: Power test stand STRUCTURES JRA (FP7)	2005-2010
		R.1.2	Validation of the drive beam generation scheme with a fully loaded linac	CTF3: Source, Linac, delay loop, combiner ring, bunch comp.	2007
		R.1.3	Design and test of a power-extraction structure, with damping and ON/OFF capability	CTF3- CLEX-TBL	2008-2009
Design finalization & machine reliability		R.2.1	Validation of beam stability and losses in the drive beam decelerator, design of a machine protection system	CTF3-CLEX-TBL EURODRIVE JRA (FP7)	2008-2010
		R.2.2	Test of a relevant linac sub-unit with beam	CTF3 – CLEX: Two beam test stand	2008-2010
		R.2.3	Precise synchronization drive beam /main beam for beam energy stability (not TRC identified)	EUROTEV WP5 LED JRA (FP7)	2007 2010
	Multi-TeV operation	R2.4	Multi-beam klystron performances	MBK proto by ILC HEMBA JRA (FP7)	08-12
		R2.5	Coherent radiation effects in CLIC bunch compressors	EUROTEV	
		R.2.5	Design of 3TeV extraction line after collision at IP	EUROTEV Des. St. LED JRA (FP7)	2007 09-12
		R2.6	Long term beam position stability, especially final quad. at nm level for collisions at IP (TRC classified as R3)	LED JRA (FP7)	09-12
Components fabrication cost optimiz. industrialization	Specific technology	R.3.1	Design of the low level RF system		
		R.3.2	Impacts of drive beam operation on main linac reliability, stability and operation		
		R.3.3	Muon and synchrotron radiation induced background tolerable?		
	Multi-TeV operation	R.3.4	Beam beam backgrounds by coherently electron/positron pairs		
		R.3.5	Efficient modulator		

Table 6.2 - CTF3 collaborations

01.09.2006		spent up to end 2004		pledged for 2005-2009	
		manpower my	cost kSFr	manpower my	cost kSFr
Addendum signed					
Helsinki Institute of Physics (HIP)	specialist in micro machining technologies for CLIC structure developments			3.00	
	establish dedicated project for development of technology with industrial and academic partners				
Budker institute of Nuclear Physics (BINP) Novosibirsk	11 quadrupoles, 26 sextupoles				270
	future: more magnets as required according to the same conditions.				
Northwestern University Illinois	one accelerating structure		100		
	beam loss monitor		100		50
	total manpower	2.00		1.00	
	RF pick-up for bunch length				100
CERN	existing facilities		40'000		
	new equipment		16'000		
	total manpower	100.00			
	power converters				860
	waveguides				100
	CLEX				2'500
	technical services				2'500
	project management				
	TL1 and CR				600
	magnets for CR				330
	vacuum equipment for CR				200
	installation TL1 and CR				1'600
	Controls CR				100
	CTF3 commissioning, testing				
	accelerating and PETS development				4'000
	total manpower			125.00	
	Probe Beam				1'950
	ISTC 30 GHz source				75
Ankara University	manpower for CTF3 operation	0.25		5.00	
IAP	30 GHz power source				1'024
	Manpower and material , ISTC 227k$ included				
SLAC	electron gun triode (long term loan)		320		
	injector design and commissioning	3.00			
JINR Dubna	Manpower for automatic conditioning		114		
Sweden	Preliminary phase participation	1.50			
	Phase monitor	1.50	150		
	Celsius magnets				150
	Phase monitor cont.				200
	Two Beam Test Stand				2'300
CEA	Probe Beam linac			30.00	1'950
CNRS IN3P3	LURE 32 quadrupoles				
	LAL				
	Thermionic guns (15 my = 2.25 MCHF)	15.00			
	probe beam photo gun			3.00	300
	LAPP BPM read-out electronics			5.00	150
Spain	15 qadrupoles for TBL + precision tables				
	2 Septa for CR				
	Extraction kicker for CR				
	HV pulser for kicker				
	32 corrector magnets for CR				
	PETS design				
	Contribution to BPM design for TBL			4.00	2'000
INFN	Delay Loop	25.00	4'000		
	vacuum chamber TL1 and CR			4.00	900
	CTF3 commissioning, operation			4.00	
	sum:	**148.25**	**60'784**	**184.00**	**24'209**
RAL	Laser for photo injector (CARE/PHIN)				

Table 6.3 - FP7 bids

Systems	Type	Subject	Total budget (MEuros) (person-year/Material)	CERN cont p-y/ MCHF	Duration FTE/MCHF/year	Comment
CLIC MultiTeV LC R&D "MuTeV" (I3)	JRA	High Gradient: **RF structures**	5.0 22 / 2.5	5.0 15/2.5	5 years 3.0/0.5	Available staff and mat. budget from "Structure R&D"basic programme: 5 FTE + 1.2 MCHF /year
	JRA	**EURODRIVE**	5.0 39 / 0.7	3.15 16/0.4	4 years 4/0.1	2 FTE available from basic prog. Mat. budget avail. from TBL project
	JRA	Luminosity Ensuring Design: **LED**	5.4 25 / 2.7	2.7 10/1.0	5 years 2/0.2	1 FTE available Mat. budget avail. from TBL project
	JRA	Generation And Diagnostics Gear for tiny EmiTtance: **GADGET**	5.9 30 / 2.6	0.9 4/0.2	4 years 1/0.05	1 FTE available from basic prog. Budget available (present collab. on wigglers with Russia)
	JRA	High Power&High Efficiency Multibeam RF Amplifier: **HEMBA**	7.0 32? / 3.5?	1.4 3/0.9	6 years 0.5/0.15	0.5 FTE available No budget presently foreseen
	JRA	3Ka-band Stand Alone Power Source: **SAPS**	6.7 10 / 5.6	2.7 4/2.0	4 years 1/0.5	0.5 FTE available No budget presently foreseen
Total CLIC	**I3=6JRA**		35.0 158/17.6	15.8 52/7.0	4 to 6 y 11.5/1.5	3.5 additional FTE from 2008 0.65 MCHF/ year additional material budget from 2008

Table 6.4 - The various scenarios from 2010

Scenario	CLIC technology (CTF3 results)	Physics perspectives (LHC results)	ILC decision	CLIC decision (@CERN or outside)	Model of work in the period 2010 - 2015
1	Feasible	E ≥ 1 TeV	No (Physics)	Yes	Preparation for construction as soon as possible at E = 1.5 to 3 TeV
2	Feasible	E ≤ 1 TeV	No (Cost)	Yes	Preparation for construction as soon as possible at E as low as compatible with Physics requests (500 GeV?)
3	Feasible	E ≤ 1 TeV	Yes outside CERN	No (possibly later in far future)	Pursue R&D at low level to prepare Multi-TeV project in the far future? Low level participation of CERN to ILC?
4	Feasible	E ≤ 1 TeV	Yes at CERN	No (possibly later in far future)	Strong participation of CERN to ILC Low level R&D on CLIC?
5	Feasible	Independent	No	No	Document and stop the CLIC study
6	Not feasible	Independent	Independent	No	Document and stop the CLIC study

Table 6.5 - Accelerator work from 2010

Year	2010 (assumed status)	2011	2012	2013	2014	2015
General	Conceptual design & Feasibility report ready. Set of parameters consistent with achieved structure performance	TDR work, Optimizing for cost, reliability and performance			Completion of TDR	Project approval
RF structures	At least one prototype of HDS and PETS with nominal performance.	Optimisation of structures for mass production Long term power testing of structure sample with statistical relevance in CTF3 Design of large scale RF signal measurement systems				Contract preparation with Industry
Main beam injectors	Concept for e^+ and e^- injector. Design of DR Conceptual design of DR SC wiggler	Detailed design of e^+ and e^- injectors. e^+ target prototype Prototype DR wiggler cell, arc cell, RF cavity.			Beam tests of DR prototypes in ATF or SR light source	
Main tunnel components	Optics design for all critical items (DR, LET, BDS…) and	Development, construction of a number of nominal Linac prototype modules with all features (quadrupoles , active alignment, vibration control, beam diagnostic …)		Test of modules with beams in CTF3 With tunnel interior mock-up around modules		
Beam delivery system	Design of BDS and post collision line ATF2 has demonstrated viability of Pantaleo scheme	Detailed design of all BDS components Prototypes for critical components (FF quadrupoles, collimators, crab cavities …)		Test of prototypes		
Drive beam Generation	CTF3 has achieved design parameters. Measurements consistent with predictions of simulation codes	Development of complete DBL module prototype. Modulator, Klystron, RF network, SICA, BPM, quadrupole, loads. Detailed design of DL's, CR's, TL's, RTL's, dumps… for nominal parameters Design of nominal injector (prototype ?)			High power test of DBL module	
Beam diagnostics	EUROTeV BPM as prototype of main beam linac BPM has demonstrated nominal performance	R&D for emittance measurement system for MB and DB (DR, BC and BDS) MB and DB BPM design and prototyping ptimized for mass production Beam loss monitoring design ptimized for mass production R&D for IP instrumentation		Tests of prototypes in CTF3, ATF, SR light source		
Timing	EUROTeV precision reference demonstrated	Detailed Timing concept, design of timing feedback – feedforward		Test of feedback / feedforward in CTF3		
Controls	Definition of control system requirements	Development of controls concept consistent with CLIC feedback and MPS requirements.			Technical choices for control system components	
Beam dynamics	Simulation results for all critical MB and DB components consistent with nominal parameters. Consistency of programs with CTF# experiment verified. Specifications for beam diagnostics, alignment, vibration control.	Detailed Optics design for all beam lines Integrated simulation of injectors and full chain			Develop operational procedures taking with control system architecture into account Tests in CTF3	
		Interaction and iteration with component design.				
CTF3 exploitation	CTF3 completed and capable of ≤5 Hz rep. rate	Upgrade to 100 Hz running for large scale RF testing	Use as high rep. rate 30 GHz RF source for RF structures and for equipment prototype testing with beam			
Stand alone power source	Preliminary design studies and tests completed	Specification and ordering of first prototype Preparation of test area		Reception and installation of 1st prototype	Testing and improvement program	Finalisation of prototype
Civil engineering and technical infrastructure	Conceptional design of tunnel and injector facilities, and surface builings	Start procedures with local authorities Detailed design, optimizing for cost, reliability, performance and environmental impact				Preparation of contracts
Cost study	Cost estimate with error margin <20% . Total cost considered to be in affordable range	Update cost estimate with improved information for mass production Interaction and iteration with component design. Update for cost indexes (raw materials, labour)			Improved cost estimate for TDR	Transition from cost estimate to cost follow-up

Table 6.6 - Distribution of CLIC manpower (CERN part) and budget as used for the graphs in chapter 3.3 .

Manpower distribution								
	2010	2011	2012	2013	2014	2015		sums
Management	2.0	3.5	5.0	5.0	5.0	5.0		25.5
RF structures	10.0	24.0	40.0	40.0	40.0	40.0		194.0
Main beam injector	1.0	10.5	20.0	20.0	20.0	20.0		91.5
Main tunnel components	4.0	21.0	40.0	40.0	40.0	40.0		185.0
Beam delivery system	1.0	5.0	9.0	9.0	9.0	9.0		42.0
Drive beam generation	2.0	11.0	20.0	20.0	20.0	20.0		93.0
Beam diagnostics	4.0	7.0	10.0	10.0	10.0	10.0		51.0
Timing	1.0	2.5	4.0	4.0	4.0	4.0		19.5
Controls	2.0	3.0	4.0	4.0	4.0	4.0		21.0
Beam dynamics	4.0	7.0	10.0	10.0	10.0	10.0		51.0
CTF3 exploitation	7.0	14.0	15.0	15.0	15.0	15.0		81.0
Stand alone power source	0.0	1.5	3.0	3.0	3.0	3.0		13.5
Civil engineering and technical infrastructur	1.0	7.0	15.0	15.0	15.0	15.0		68.0
Cost study	1.0	3.0	5.0	5.0	5.0	5.0		24.0
Total FTE	40.0	120.0	200.0	200.0	200.0	200.0		960.0
Total manpower cost (assuming 0.16MCHF/FTE)	6.4	19.2	32.0	32.0	32.0	32.0		153.6

Material budget (MCHF)								
	2010	2011	2012	2013	2014	2015		sums
Management	0.1	0.3	0.4	0.5	0.5	0.5		2.3
RF structures	1.3	4.0	8.0	10.0	10.0	10.0		43.3
Main beam injector	0.1	1.0	7.0	6.0	6.0	6.0		26.1
Main tunnel components	0.2	4.0	8.0	10.0	10.0	10.0		42.2
Beam delivery system	0.1	1.0	2.0	3.0	3.0	3.0		12.1
Drive beam generation	0.0	1.0	5.0	11.0	5.0	8.0		30.0
Beam diagnostics	0.1	0.1	2.0	2.0	2.0	2.0		8.2
Timing	0.1	0.1	0.5	0.5	0.5	0.5		2.2
Controls	0.0	0.0	0.5	0.5	0.5	0.5		2.0
Beam dynamics	0.0	0.0	0.0	0.0	0.0	0.0		0.0
CTF3 exploitation	1.8	10.0	4.0	4.0	4.0	4.0		27.8
Stand alone power source	0.0	0.5	2.0	8.0	1.5	3.0		15.0
Civil engineering and technical infrastructur	0.1	0.1	1.0	2.0	2.0	2.0		7.2
Cost study	0.1	0.1	0.5	0.5	0.5	0.5		2.2
Total material	4.0	22.2	40.9	58.0	45.5	50.0		220.6
Total M and P	10.4	41.4	72.9	90.0	77.5	82.0		374.2

ANNEX 1: CTF3 Equipment Availability

(G.Geschonke)

This annex describes additional resources required for running CTF3 on a 24 hour per day, 7 days a week basis.

The aim is to operate CTF3 for 10 months continuously, sharing the time between 30 GHz conditioning and CTF3 machine studies. A typical example is the operating schedule foreseen for 2006. CTF3 has not been designed to be a production facility with 24 hour/day, 7 days a week, 10 months per year reliable operation with high availability, therefore **extra** effort will be required.

The topic is separated into the following categories:

For material: Cost of **consumables** and repairs, provision of "**hot spares**", **improvements** to increase the availability.

For manpower: First line intervention, manpower to cope with break-downs.

Consumables and repair

Klystrons: Taking account of the available klystron stock we need to replace klystrons at a cost of about 180 kCHF per piece in addition to what was originally planned:

- In 2006/2007: 1.5 klystrons
- In 2008, 2009 and 2010: one klystron/year.

In the case that Valvo klystrons cannot be repaired and have to be replaced by Thales ones we need four sets of focusing coils at 50 kCHF each.

Thyratrons: we will need three more / year at 20 kCHF/piece.

Optical equipment – cameras, lenses – will be radiation damaged faster due to extended running. A cost of 30 kCHF per year is estimated.

For repair of failing equipment we estimate 50 kCHF/year.

Spares

In order to increase the availability "hot spares' will be needed, on-line repairs must be avoided.

We need at least two additional 3 GHz power amplifiers (40 kCHF).

Presently we have no spares for MDK charging power supplies. We need at least one (5 Hz) for about 60 kCHF.

The HV equipment for the gun has no spares. Available equipment from LEP has to be adapted. Cost: 50 kCHF.

Reliability/efficiency improvement

All modulators will be in use. A test modulator will be necessary in order to test klystrons off-line. Cost: 500 kCHF.

New end-of-line diode stacks have to be developed and implemented, four are required at 30 kCHF/each.

Manpower

One cat B or C staff for electronics development and maintenance.

It is assumed, that the groups responsible for vacuum, controls, magnets include CTF3 into their 24 hour stand-by system

Risk:

For some components we have presently no spares. Only components with long replacement/repair times are mentioned.

Electron gun. This gun is on loan from SLAC, we have spare cathodes, but if the ceramic insulator fails we have no replacement, causing several (probably 5-6) months delay. Eventually this gun will be replaced by a photo injector. We have no experience with its reliability yet; this will be evaluated in test in CTF2.

Stand-by for the RF system, low power and high power can presently not be manned to guarantee 24 hour availability. We will have to operate with a call-out list.

There is only one 1.5 GHz klystron. A repair would take 6 months.

The sub-harmonic bunching system has only three power supplies, we cannot repair them, because they are "potted". A repair by the manufacturer will take at least 3 months.

The following Table A1.1 summarizes these additional requirements.

Table A1.1

the prices are given in kSFr					
year	**2006**	**2007**	**2008**	**2009**	**2010**
Consumables					
klystrons	135	135	90	90	180
focusing coils	100	50	50		
Thyratrons	60	60	60	60	60
repairs /readiation damage	80	80	80	80	80
Spares					
power amplifier		40			
Charging power supplies		60			
HV equipment for gun	20	30			
reliability					
Test modulator	250	250			
diode stacks	30	90			
manpower					
cat B/C person	1 m*y	1 m*y	1 m*y	1 m*y	1 m*y

ANNEX 2: CTF3 sub-systems commissioning, beam operation and beam performance for RF power production

Status, perspectives and needed resources for 2006-2010

(*R.Corsini, F.Tecker)*

Background information

CTF3 beam activities are subdivided in two categories:

a) "Commissioning" – all activities aimed at obtaining the final performance of CTF3 different sub-systems. It includes as well preparation of beams for 30 GHz RF power production. Commissioning is performed by an "expert core team" (at present 4-5 people), with support from hardware specialists and technical services. Up to now commissioning took place mainly during normal working hours.

b) "30 GHz power production" – more or less routine operation aimed at high-power testing of 30 GHz structures and other RF components. It can be done by less trained operators, with some support from the core team and technical services. In 2005 part of this activity has taken place outside normal working hours (nights and week-ends).

In 2005, the total running time (CTF3 available for beam operation, not counting stops for technical failures or missing manpower) has been 13 weeks. Of these, 6 were dedicated to commissioning and 7 to power production, in which one RF structure (Mo iris) was tested.

During commissioning periods, in general beam time was available during nights and week-ends for power production. However, this meant that the core team dedicated some time every day to the "switch-over" from one mode to another (typically, from 15 min to about 1 hour). For power production, the 2nd run of 2005 (Oct. / Dec.) can be used as a "standard". There were 3 dedicated weeks for power production and 6 "commissioning" weeks with nights and week-ends available. About 24 days were actually used for power production, with 60-70% uptime.

Power production operation was provided during this period in large part by non-professional operators (about 10 people): 3 external collaborators (Ankara), 3 fellows + CERN staff. Apart from the external collaborators, these people have other assignments during normal working hours. The involvement of the core team was also important, also outside normal working hours, including initial beam set-up, adjustments to maintain performance, supervision and intervention in case of "non-standard" failures.

Beam performances for power production

Up to 2008, only the mid-linac RF power station is available. In 2005, the record peak power was about 70 MW (delivered to the DUT). Such a value was very hard to maintain, and not easy to reproduce. A level of 55-60 MW was more reproducible, and it was possible to keep the DUT fed at a constant level of about 45 MW during a long period of time using only the attenuator (no beam re-adjustments needed). Typically these power levels are obtained with a 5 A, 100 MeV beam and losses between 10% and 20% (peak current). The pulse length is limited by beam between 15 ns and 400 ns for the highest power level. At lower power, pulse lengths of up to 1.5 μs are possible.

There is a potential to improve power levels by optimizing the RF transfer efficiency (about a 10% gain), increasing the current to 6 – 6.5 A, possibly accepting higher losses and somewhat longer bunches (about 20% gain) and possibly upgrading the PETS. Considering the first two options, we can reasonably hope to get about 85 MW in the DUT. However, the power level for stable operation (margin for attenuator) will rather be in the 70 MW range.

From 2008, the CLEX power station should come online. Total power in the ~ 200 MW range, if needed, will then be available.

Scenario for 2006

In 2006 a much longer beam operation than 2005 (and previous years as well) is planned: about 40 weeks in total. We can foresee 25 weeks for power production and 15 for commissioning.

The minimum requirement to be able to cover the commissioning part is to maintain the expert core team at least to the present level. Some increased support for new operation software would also be very useful.

In order to ensure the 20-25 scheduled weeks of power production, the following scenario was chosen and is presently pursued:

Operation relies on 30 GHz automatic control and eventually remote supervision; it would be supervised from the CCC by PS or booster operators. Their task would imply to check periodically the status of the machine and of RF operation on a dedicated software panel. They should follow simple standard procedures in case of problems (initially limited to re-starting a klystron and resetting interlocks).

Resources needed from OP group in this scenario are:

a) availability of operators on shift for the task described;

b) manpower to develop the interface software with the CCC (about one person for 3 months given a good knowledge of the control system, about 6 months otherwise). It would be advisable that this person would also play a direct role in power production operation, to get a hands-on experience.

At present, CTF3 is run for power production from the local control room, using the automatic conditioning software under development and part-time supervision from experts and ad-hoc operators. Operation is mainly limited at present to normal working hours.

Scenario for 2007-2010

We expect that the scenario for the 2007 run would be the same as 2006 in terms of time dedicated to commissioning and power production.

For power production, the automatic control & CCC supervision system should be well established, enabling more beam uptime. In 2007 at least the same manpower as in 2006 would be needed to consolidate and maintain the system.

For commissioning, taking into account both the increased level support and supervision that the present core team must provide for power production operation and the new commitments (integration of new CTF3 sub-systems in terms of optics/beam dynamics and participation to the CLIC feasibility study), at least 2 additional FTE/year (engineer or physicist) would be needed in the long term, on top of maintaining the present level of 2 fellows/students.

Additional support for commissioning/operation software would also be needed (0.5 FTE/year from 2008 to 2010).

The additional manpower required in 2007-2010 for commissioning and operation is summarized below in Table A2.1.

Table A2.1. – Missing manpower for CTF3 commissioning & operation

CTF3 commissioning & operation missing staff

Job description	category	requested	2007	2008	2009	2010	Total	
Expert core team	D/E	RC	1	2	2	2	7	
Support for CTF3 software	D/E	RC/FT	1	0.5	0.5	0.5	2.5	
TOTAL			2	2.5	2.5	2.5	9.5	

ANNEX 3: An update of the human resources required for the CLIC structure development program for the period 2006 to 2010

(W. Wuensch)

The rf structures development team is comprised of roughly one third staff members, one third fellows and PhD students and one third visitors distributed mainly in the AB-RF and TS-MME groups. The current size of the team is generally sufficient for the period up to 2010 however a few weak points are apparent.

- There is the clear need for a full-time CERN staff member to take on the role of 'production engineer'. The timely and cost effective preparation of structures and especially experimental areas, with work on the two-beam test stand and TBL imminent, requires well coordinated hardware production and installation. An experienced CERN staff member is needed for this role to ensure that the many different production steps are carried out efficiently. The same person could support CTF3 testing infrastructure as well as the dc spark and laser fatigue activities.

- At least the half-time support of a talented CERN staff technician would be very valuable. We have difficulty maintaining continuity of a high-quality mechanical 'culture' in the team since the retirement of one of the key members (G. Carron).

- The current team of fellows, students and visitors is extremely strong however a number of crucial departures will occur in the coming year (2007). At the very least these individuals should be replaced in a timely fashion. Better still would be the further extension of their contracts. New members of the team are enthusiastically trained however maintaining continuity is very challenging and time consuming.

- The CTF3 conditioning software development, which is now functional, has been made by a paid associate from Dubna (A. Dubrovskey). He has recently been granted a new contract but the longer term support for the software must be ensured.

- Resources must be found to tackle the TBL. Basic guidance and limited design work can certainly be found amongst existing resource however the detailed design work, ordering and construction cannot be covered by the existing team.

ANNEX 4: Beam Dynamics

(D.Schulte)

The aim of the CLIC beam physics team is to establish until 2009 with confidence that the luminosity goal can be met. The current resources are currently largely integrated into the EUROTeV design study. They comprise

- About 3 FTE staff
- 3 FTE EU-paid fellows until end of 2007
- 2 FTE PhD students until end of 2006
- 1 CERN paid fellow until mid 2007, shared with operations
- 1 paid associate until mid 2007
- Further resources are due to collaboration with other institutes in the framework of EUROTeV, in particular PSI, Uppsala and Valencia.

Before 2010 the following reductions are expected:

- Frank Zimmermann will reduce his CLIC activities from 35% to 10% in 2006
- The PhD students Javier Resta Lopez and Peder Eliasson will leave the study at the end of 2006
- The EUROTeV paid fellows Andrea Latina, Lionel Neukermans and Maxim Korostelev will leave the study end of 2007
- The paid associate will leave mid 2007
- The collaborators will lose some of their resources with the end of EUROTeV in 2007

In addition to the studies currently carried out, a number of additional studies are needed to start during 2007 and lasting until early 2010. It is assumed that the required staff resources are needed at CERN, or in some cases be provided by collaborations. The visitors can be fellows or PhD students or collaborators from other institutes. Replacing these visitors with staff might allow decreasing the overall number of FTEs needed. The work requires very high skills, making the number of FTEs very person depending.

Significant differences between the time structure of the beams in ILC and CLIC require that a number of main beam topics are studied independently. At the time of the evaluation by the TRC, this was significantly different since other normal conducting designs existed. In the longer future, detailed investigations of the drive beam are necessary in addition to the main beam studies. The machine parameters need to be optimized and the consistency of the overall design needs to be ensured. The necessary simulation tools need to be maintained and developed. In addition a number of more specialized topics exist:

Damping Ring

We rely on a damping ring design that is dominated by intra-beam scattering. It is crucial to validate the design, since no such ring exists. For this we need to develop a self-consistent simulation of IBS in damping ring and to benchmark it with real machines. In addition, we need to study the alignment of the damping ring with superconducting wigglers and to follow the work of our collaborators. One may need to iterate on impedance requirements. In total this requires 0.5 staff until 2010 and a full time visitor to develop the simulation code. A potential candidate as a visitor could be Alexey as a PhD student.

A further important problem is the electron cloud in the damping ring. One needs to make a beam pipe design that suppresses the cloud to a sufficiently small level. Currently we develop a better simulation code to study the electron cloud. In the following time one will need to perform simulations to identify the best solution for the beam pipe. This requires resources from the technical systems design and 0.5FTE staff and 1 fellow for the electron cloud simulations and development of the countermeasures.

Another problem that needs to be addressed is the extraction kicker.

Bunch Compressor

The bunch compressor consists of

- a first section to generate a correlated energy spread
- a first chicane
- a booster linac to increase the beam energy
- a turn around to change the beam direction
- a second section to generate an energy spread
- a second chicane

The bunch compressor has significant impact on the luminosity performance of the machine due to dynamic imperfections. It also has a potential problem with coherent synchrotron radiation. The current design of the bunch compressor complex seems not feasible due to beam loading problems. A new overall design needs to be developed.

The chicanes are being designed by PSI within EUROTeV; this includes the study of the coherent synchrotron radiation. It will be important to ensure that the required expertise is transferred to CERN. In particular, modifications of the chicanes will be necessitated by modifications of the beam parameters or as a result of detailed studies.

The two energy spread generation sections and the booster linac need to be designed. The expertise on the design of the turn-around has been lost due to retirement of the staff. The turn-around has a significant impact on the system design, e.g. the fact that we have to generate the energy spread for the second compression after the turn around is due to the emittance growth expected in the current design for larger energy spreads

Finally, the alignment and tuning for the bunch compressor needs to be studied. Here, one can profit from the ILC and EUROTeV study.

The resources are about 0.2 FTE staff.

Beam Delivery System

The beam delivery system is very significantly driving our parameter choice. Further improvement of the existing design is required. The current design does not include an instrumentation section. The performance of the instrumentation, in particular the beam size measurement with a laser wire, is however crucial for the machine tuning. It is therefore necessary to establish a lattice design and to perform detailed tracking studies to evaluate the validity of the design. For this work 0.5 FTE of a lattice design expert and 0.5 FTE of a visitor are required, who can perform Monte-Carlo studies of the instrumentation performance. The visitor needs to arrive in 2007 to overlap with Lionel Neukermans who is performing studies of the halo and tail generation that are relevant for the Monte-Carlo studies.

Currently we cannot design the system from scratch but need to base ourselves of a design developed for the NLC. Given the strong impact on the final focus system on the CLIC parameters, it seems useful to attempt to develop a new design. This would allow to make modifications if so required by the physics study. It also will help to understand the ultimate performance limitations. This requires a full time experienced staff.

Post Collision Line

In order to achieve the luminosity goal in CLIC tuning of the beams at the collision point is crucial. This tuning requires a fast signal in order to be able to optimize luminosity. The detector measurements of the luminosity are too slow. A number of potential signals have been identified, which could be measured in the post collision line. Some design work is currently being done at Uppsala University but a more detailed study will need to follow. Since this tuning capability is most critical we need to be able to not completely rely on collaborations. Another related topic is the heat load in the final topic due to the spent beam. The resources needed are 0.5 FTE staff and 0.5 FTE visitor, starting in 2007 to provide overlap with the EUROTeV study.

Main Beam Studies

The preservation of the main beam emittance is much more difficult in CLIC than in ILC. It is one of the main points why the ILC-ITRP preferred the superconducting technology. A significant effort is being made within EUROTeV to address this topic by developing simulation tools and alignment, tuning and feedback strategies. This effort needs to be continued beyond 2007. In particular, different procedures can have significant impact on the cost and luminosity performance. The required resources are 1 FTE staff or 0.5FTE staff and 1 visitor.

Drive Beam Injector

A design of the drive beam injector design needs to be developed that achieves the required performance. The current design falls somewhat short of the target. The injector will be an important part of the drive beam complex and needs to be included in the integrated study. Of particular importance will be to study the phase and amplitude stability of the beam which has an important impact on the drive beam bunch compressor design. The resources for the design and the study would be about 0.4 FTE staff and a student.

Drive Beam Combiner Rings and Turn-Arounds

The drive beam combiner ring and turn-around lines need to be redesigned. A number of questions related to the design will need to be addressed, e.g. coherent and incoherent synchrotron radiation, impedances instrumentation performance. This topic could potentially be addressed by INFN. The resource requirements are 0.3 FTE staff.

Machine Protection and Reliability Issues

A study of the machine reliability is required as an R2 in the ILC-TRC. While it may not be necessary to perform this analysis in all details, the main components need to be considered. In particular the drive beam is very distinct from the main beam. For the main beam one can significantly profit from the ILC work. For the drive beam this work requires

- Understanding of hardware failure rates
- Understanding of the implications for the beam
- Understanding of the potential to damage equipment due to failures and the consequently needed interlocks. For the main beam the requirements are similar but less detail should be needed since one can rely more on ILC.

The required resources are 0.5FTE staff and 1 visitor.

Test Beam Line

The test beam line will demonstrate the principle of the drive beam decelerator. Sophisticated methods to tune up the machine will be needed. Also one expects to need extensive simulations to be able to understand the beam line during the experimental phase. The resources would be expected to be 0.5FTE staff and 1 visitor. A PhD student will start to work on this in the second half of 2006.

Drive Beam Longitudinal Studies

The drive beam longitudinal stability is of concern for CLIC. It depends to a large extent on the design of the different bunch compressor stages needed to achieve the small bunch length at the decelerator but maintaining the necessary longer bunches in the combiner rings and the turn-around. The longitudinal system needs to be designed, deciding on the position and performance of the different compressor stages. This requires study of coherent synchrotron radiation in different parts of the complex. The necessary resources are 0.5 FTE of staff and 1FTE visitor.

Drive Beam Transverse Studies

The emphasis of the drive beam studies has so far been on the stability of the beam in the different sub-systems. The alignment and tuning required to mitigate the static and dynamic imperfections has not been addressed. A study of the alignment procedures and the transverse feedback systems is essential to ensure that the drive beam can achieve the design performance. A particular problem can arise from the interplay of transverse and longitudinal effects. Small fluctuations in the longitudinal plane can couple strongly into the transverse since the will affect the energy loss in the decelerator.

The beam based alignment of the drive beam decelerator needs to be studied together with the required orbit feedback systems. Required resources are 0.5 FTE staff and 1FTE visitor.

Background and Luminosity Spectrum Studies

The aim of the CLIC study is to provide the potential of physics experiments at multi-TeV centre-of-mass energies. A new physics working group is forming to address this potential. The machine study needs to be involved in the following topics

- Background studies, since the background is largely driven by the machine design. Due to the higher energy, the background produced in the machine, at the collision point and in the post collision line is significantly higher in CLIC than in the ILC.
- Luminosity studies, since the luminosity spectrum and the potential to reconstruct it are strongly machine dependent. Due to the beam energy spread and beamstrahlung the luminosity spectrum in CLIC will be known with limited precision. It is necessary to understand how well the luminosity spectrum can be reconstructed. This requires realistic models of the machine to include the correlations in the beams, which have been shown to be very relevant.
- Detector integration, since machine components need to be integrated into the detector

Some of these topics have been addressed. The changing parameters and the expected changes in the detector require significant follow up. A number of the topics also have not yet been studied to a satisfactory level.

The required resources are 0.5 FTE staff and 1 visitor.

CTF3 support

The level needs to be discussed with Roberto.

ATF2

Limited participation to ATF2 design and commissioning by Frank Zimmermann with help of Maxim Korostelev.