Report of the 1st CLIC Advisory Committee (CLIC ACE)

June 20-22, 2007

Committee

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Introductory Comments

First, the committee would like to thank the presenters for well-prepared materials and for informative and interesting discussions, and administrative staff, especially Sonia Escaffre, for assisting the committee with travel arrangements and hospitality.

This report summarizes the first meeting of the CLIC Accelerator Advisory Committee (CLIC ACE). The meeting provided a comprehensive overview of the CLIC design. The main goals of the meeting were to review the recent changes in the CLIC rf and beam parameters and the overall R&D program that would support a conceptual design report on the 2010-timescale. The detailed charge is attached in Appendix A and the meeting agenda is listed in Appendix B. Overall the reviewers were very impressed with the CLIC development and R&D plans. The CTF-3 is an impressive linear collider test facility and although relatively small, the CLIC team is very enthusiastic. Reviewing the program was a pleasure for the reviewers. Detailed comments will follow on the parameter choices, the R&D program, and plans to complete both CTF-3 and a CDR by 2010. The next ACE meeting in January 2008 will focus on the detailed accelerator structure development plans.

Parameters

Findings:

The CLIC rf and beam parameters were recently modified. The rf frequency was reduced from 30 GHz to 12 GHz and the acceleration gradient was reduced from a loaded gradient of 150 MV/m to a loaded gradient of 100 MV/m. The change in parameters was motivated by three main points. First, experimental data was presented that shows damage to the accelerator structures with the present rf parameters and little or weak dependence of the maximum acceleration gradient on frequency. Second, a detailed cost model had been developed that predicted a weak cost minimum at a frequency of roughly 14 GHz – well below the starting value of 30 GHz. The cost model includes detailed scaling laws for the beam dynamics and the accelerator structure parameters. Third, stand-alone power sources can be constructed at 12 GHz which would further the structure testing program.

A scaling law, referred to as the P/C scaling, was used to optimize the accelerator structure design. This scaling relates the local power density to the gradient limit and appears to agree (within a factor of two) with measured limits over a large range of parameters. The ability to predict the gradient limit would be a very important step in accelerator design.

Finally, beam parameters were presented for a 3 TeV collider based on the new rf parameters which provide a total luminosity of $7x10^{34}$ at 3 TeV ($2x10^{34}$ in 1% of the peak energy).

Comments:
The committee strongly endorses the reductions in the rf frequency and the acceleration gradient. The committee did not fully understand the details of the cost model however the optimization appeared to be reasonable. The committee would recommend further development of the detailed cost model and using this to understand variations in the design parameter space.

The P/C scaling, which was used to optimize the structure design, appears to agree well with experimental data but there is still a lot of scatter about the scaling law predictions. The committee was concerned that the detailed structure design, and thereby the CLIC parameters, rely heavily on these predictions of the scaling. Thus, the committee recommends additional experimental verification of the scaling and the desired structure gradient performance. In doing so, it is important to separate fundamental gradient limitations from gradient limits that may arise from the structure fabrication or testing procedures. It would be advantageous to make these measurements quickly as many of the CLIC design parameters are tightly coupled to the structure design. The committee would recommend working with collaborators to perform these studies as rapidly as possible.

While the committee agrees that the potential of the CLIC technology to reach multi-TeV is very important, it would recommend developing a staged approach to a 3 TeV collider. The committee felt that the beam parameters at 3 TeV are based on relatively aggressive assumptions of the damping ring and emittance preservation performance and would suggest starting from beam parameters more similar to those experimentally demonstrated.

R&D Program and Key Issues

Findings:
The CLIC design is unique in that it is based on a two-beam acceleration concept and utilizes accelerator structures operating at 100 MV/m loaded; this implies a geometric

gradient, i.e. the average accelerating gradient per meter along the linac, that is roughly four times higher than that in the ILC superconducting accelerator design. Although there are significant advantages of these rf parameter choices, there are also many critical issues associated with the parameter choices that must be demonstrated; no other accelerator or test facility has been operated with similar rf parameters.

Without considering beam loading, the CLIC accelerator structure design is required to achieve gradients of roughly 90 MV/m at the structure entrance and 150 MV/m at the structure exit during the rf pulse length of 300 ns. The accelerator structure must also be designed to damp the transverse high-order dipole modes to less than 1% over their initial value after eight rf buckets. The structure has been designed using the P/C scaling law which agrees with a lot of experimental data although none the covers this parameter regime. The strong damping concepts have been demonstrated in an experiment at SLAC using a test structure operating at 15 GHz but it has not been demonstrated in a prototype CLIC structure. Finally, to minimize the structure fabrication cost, CERN has developed an innovative ‘quadrant’ design in which the structure is constructed of four separate quadrants which are then bonded together. To date, none of the quadrant prototype structures have performed as well as the conventionally machine structures.

The CTF-3 test facility is a large-scale test facility being constructed at CERN to demonstrate the high-efficiency CLIC two-beam accelerator concept. The facility has been designed to address the fundamental ‘R1’ issues identified by the 2003 ICFA ILC Technical Review Committee (ILC TRC) which include: the generation of the drive beam, the demonstration of a prototype structure operating at the design parameters, and the demonstration of the ability to turn the rf power generation of a PETS structure on and off.

The CTF-3 is designed to generate a 35 Amp beam having a pulse length of 140 ns and an energy of 150 MeV. The CTF-3 beam will be directed to an experimental area that is presently under construction. It is planned that there will be two sections: (1) an rf power generation section where the drive beam is passed through as many as 16 Power Extraction Structure (PETS) to generate over 2 GW of 12 GHz rf power and extract roughly 50% of the energy from the beam, and (2) a two-beam accelerator section where rf power from a single PETS will be directed to one or two CLIC accelerator structures which will accelerate a probe beam. There is also space for a 3rd experiment, an instrumentation beam line, but this is not presently funded.

The CTF-3 has already demonstrated many important technologies and concepts of the two-beam accelerator scheme including 94% efficient rf→beam drive beam acceleration, heavy damping of HOMs in the drive beam rf structures, and the delay loop and associated rf deflectors. At the time of the June ACE meeting, the combiner ring was being commissioned.

In parallel with the CTF-3 construction, CERN is planning to build a stand-alone 12 GHz test facility based on klystrons and rf pulse compression. When constructed, this facility will allow extensive testing of the rf properties of the CLIC accelerator structures.

The beam parameters for the 3 TeV CLIC design require significant advancement in the beam properties. This includes generation of beams with very emittances in the damping rings, preserving that emittance through the bunch compressors and the main linacs and then focusing the beams down to an IP spot size of roughly 50 by 1 nanometer while stabilizing the final magnetic elements to a fraction of the final beam spot size.

Although such beam properties have never been demonstrated, many beam dynamics issues are being addressed with simulation and theoretical studies in the European Union FP6 and FP7 proposals. Experimental studies may be possible at the ATF and ATF2 test facilities at KEK and various storage ring facilities around the world.

<u>Comments:</u>

The gradient requirements of the CLIC structure design is considerably beyond the present state of the art. The committee felt that this extrapolation was reasonable but it needs experimental demonstration. The committee urged that CERN establish collaborations to most rapidly demonstrate the structure design. The committee also supports the rapid construction of the 12 GHz stand-along test stand to further optimize the structure design and understand the impact of the fabrication techniques.

The structure design also relies on an innovative higher-order mode damping scheme. Although some preliminary tests have been performed at different rf frequencies, the committee believes that a demonstration of the HOM damping in a structure close to the design structure is required. It was suggested that this demonstration should be pursued in parallel with the gradient demonstration. CERN is also pursuing a new structure fabrication technique that has the potential for significant cost savings. At present, structures constructed with the new approach have not performed as well as conventionally machined structures. Again, the committee felt that a parallel effort should be started to understand the impact of the different construction approaches. The committee felt that by pursuing the three different issues in parallel, it was likely that a demonstration integrating all three issues could be completed on the 2010-timescale to support the CDR.

As noted above, the CTF-3 program is focused on addressing the ILC TRC R1's. The committee agreed that a demonstration of an operating two-beam accelerator section will be crucial in demonstrating the feasibility of the CLIC concept and the CTF-3 demonstration is needed to support a CLIC CDR. For the immediate goal of supporting a CDR in 2010, the CTF-3 should focus on the demonstration of the PETS rf power extraction and the PETSonoff concept. The facility should also be used to demonstrate the drive beam stability which is necessary for reliable operation of a CLIC linear collider. On a longer timescale, the committee thought it important to develop plans for a significant two-beam accelerator demonstration; connecting the multiple PETS which are planned for the CTF-3 to accelerator structures could provide roughly 1 GeV of acceleration – this is comparable to other linear collider test facilities..

The committee was concerned that details of the CTF-3 implementation unrelated to the CLIC concept will impact overall performance at CTF-3. In particular, the low beam energy may make it impossible to reach the CLIC goal of converting 90% of the beam energy into rf power; the present goal for the CTF-3 is beam→rf 50% conversion. Simulations studies should be performed and operational considerations should be given to such implementation specific limitations

It should also be noted that the CTF-3 is not designed to operate with CLIC parameters. The CLIC drive beam has a current of roughly 100 Amps, a pulse length of 300 ns, and an energy of roughly 2.5 GeV, while CTF-3 will operate with roughly 35 Amps, 140 ns, and an energy of 100 MeV. Since CTF-3 will likely be the only two-beam accelerator demonstration on the CLIC CDR timescale, it is important to understand how to interpret the results.

Because of the relatively short rf pulse length in CTF-3, the 12 GHz stand-alone rf station will be important for the long rf pulse testing of the accelerator structures. Plans are being developed to also test the PETS with the longer pulse lengths. The committee agreed that these should be pursued. The PETs have been designed using the P/C scaling but there is little data in this long pulse, large aperture parameter regime. The committee felt that it is very important to understand how to scale these results and some benchmarking at both long and short pulse length will be necessary.

Finally, the committee felt that the CTF-3 should be designed with sufficient overhead to test rf components well beyond the nominal design parameters. The committee understood that there was substantial headroom in the CTF-3 power generation capability to address such a need while the 12 GHz stand-alone test stand will provide a capability of testing at longer rf pulse lengths.

As mentioned before, the committee was worried that the aggressive beam properties assumed for the 3 TeV design may be difficult to achieve. It was felt that the CERN team should try to develop a staged approach to 3 TeV assuming initial beam properties closer to those experimentally demonstrated.

It appeared that the CLIC team did not have sufficient people to address all of the difficult beam dynamics problems for the 3 TeV design. The committee supported participation in the EU FP6 and FP7 collaborations as a way to engage additional accelerator physicists on these difficult problems. The committee agreed that focused experiments on vibration stabilization are important and can likely be directly addressed with a reasonably scoped R&D program. An additional approach to the vibration problem may be to lengthen the beam pulse so that fast feedback systems can reduce the sensitivity to component vibration however this may lead to a reduced acceleration gradient.

Further consideration should be given to scaling issues, i.e. how to demonstrate the drive beam dynamics without a full rf unit and how to demonstrate the main beam low emittance transport without a substantial (~10 GeV) linac test facility.

Resources and CDR Development

Findings:
High-level plans to complete CTF-3 were presented to the committee illustrating the commitments from collaborators as well as additional resource needs; detailed plans and schedules were not presented. Many collaborators are contributing significant fractions to the test facility although the bulk of the work remains with CERN. It was stated that an additional 12 MCHF and 60 FTEs would be necessary to complete the accelerator structure R&D program, the 12 GHz stand-alone test stand and the baseline CTF-3. It was stated that operation of CTF-3 during a large part of the year for beam commissioning and RF power generation for structure tests is difficult for the CLIC team due to insufficient people.

Plans were not presented for the additional effort needed to complete a CDR although it was noted that some of the necessary engineering may become available as the LHC construction is completed.

Comments:
The committee felt that it is very important to complete the CTF-3 to establish the baseline technology for CLIC. Building and operating CTF-3 is a huge task and the appropriate resources should be found. Finding additional collaborators to help complete the different elements of the CLIC R&D program will be important.

Completing a CDR along with the CTF-3 effort is another large task and thought needs to be given to the scope of the effort. The committee would recommend focusing on aspects of the CLIC design that are unique to CLIC: high gradient, drive beam, single tunnel linac, etc.. Engaging the necessary engineering early will make the development of the CDR more straightforward.

Much of the effort on both the conceptual design and the costing could benefit from the work that is being performed for the ILC Engineering Design Report (EDR). Using the ILC EDR costing practices may make the CLIC costing more easily understood and accepted by the international physics community. To this end, the committee would recommend collaborating on the ILC EDR, especially in areas where there may be significant overlap including: conventional facilities and civil construction, controls, high-level rf power, the electron and positron sources, the damping rings and the beam delivery systems.

APPENDIX A

1st CLIC Advisory Committee (CLIC ACE)

June 20-22, 2007

Charge

The first CLIC-ACE meeting is mainly devoted to an introduction of the committee members to the present status and future plans of the CLIC study, via an extensive overview of the various aspects of the CLIC study, especially the CLIC design and plans to address the major key issues, demonstrate the feasibility of the CLIC technology and prepare a conceptual design report by 2010.

An analysis and specific recommendations by the committee concerning the following (non-exhaustive list of) subjects, would be greatly appreciated:

1) CLIC scheme and (new parameters).
2) major key-issues to be addressed before the CLIC technology can be considered feasible.
3) work programme to address the various key issues.
4) adequation of (Material & man-power) resources (including external collaborations) to the work programme.

APPENDIX B

1st CLIC Advisory Committee

Agenda

June 20-22, 2007

CERN(304-1-001 A)

Participants: M.Huening; Alban Mosnier; T.Raubenheimer, Vladimir Shiltsev

Wednesday, June 20

08:00-08:30	Executive Session	
08:30-09:10	General Introduction: Parameters, Key Issues, Programme and Resources	J.P. Delahaye (CERN)
09:10-09:30	Discussion	
09:30-10:10	Structure Issues, R&D and Limitations	W. Wuensch (CERN)
10:10-10:30	Discussion	
10:30-10:50	coffee break	
10:50-11:20	Structure Optimisation	A.Grudiev (CERN)
11:20-11:35	Discussion	
11:35-12:15	Structure Tests: Results and Programme	S. Doebert (CERN)
12:15-12:35	Discussion	
12:35-14:00	Lunch	
14:00-14:40	Overall Complex and Parameters including Injectors, Damping Ring and BDS	H. Braun (CERN)
14:40-15:50	Discussion	
15:00-15:40	Drive Beam Complex and Power Generation including CLIC Module	R. Corsini (CERN)
15:40-16:00	Discussion	
16:00-16:20	Coffee break	
16:20-16:50	Cost Model including Civil Engineering and Conventional Facilities	Hans Braun (CERN)
16:50-17:05	Discussion	
17:05-	Executive Session	
19:00	Dinner	

Thursday, June 21

08:00-08:30 Executive Session
08:30-09:10 CTF-3 Programme, Status and Collaborations including Commissioning and Operation G. Geschonke (CERN)
09:10-09:30 Discussion
09:30-10:10 Lessons Learned (Past, Present and Future) in CTF-3
F. Tecker (CERN)
10:10-10:30 Discussion
10:30-10:50 Coffee break
10:50-11:30 Beam Dynamics (Main and Drive Beams) including Alignment and Stabilisation Issues, Luminosity and Background D. Schulte (CERN)
11:30-11:50 Discussion
11:50-12:30 Visit of CTF-3
12:30-14:00 Lunch
14:00-14:40 Review of CLIC Challenges and Key Issues R. Corsini (CERN)
14:40-15:00 Discussion
15:00-15:20 Coffee break
15:20-16:00 Review of (addressed and non-addressed) key Issues including Future Activities, Technical Programme in Preparation of Conceptual Design Report H. Braun (CERN)
16:00-16:20 Discussion
16:20-16:50 Detector and Physics Issues A. De Roeck (CERN)
16:50-17:05 Discussion
17:05 Executive Session

Friday. June 22

08:00-09:30 Additional Questions of the Committee, Preparation of Report and Presentation
09:30-09:45 coffee break
09:45-11:30 Executive Session
11:30-12:30 Preliminary Report and Recommendations to CSC
T. Raubenheimer (SLAC)
12:30 Lunch