Letter of intent for a program of measurements for the CLIC study at the FACET facility

Geneva, 5-7-2010

The FACET facility at SLAC has the capability to make a series of measurements of crucial importance to the CLIC study. Consequently the CLIC study will prepare and submit a formal proposal for the approval of the following experiments to be made in FACET:

1. Experimental verification of the performance of linear collider final-focus feedbacks and alignment algorithms.
2. Direct measurement of the long-range transverse wakefields of CLIC main-linac accelerating structures.
3. Direct measurement of the transverse wakefields of linear collider final focus collimator geometries.

More details of the experiments are presented in the following sections.

Experimental verification of the effectiveness of linear collider final-focus feedbacks and alignment algorithms.

The performance of future linear colliders will depend critically on beam-based alignment and feedback. Experimental verification of the proposed algorithms is essential to validate them and to prepare the commissioning of such a machine. We propose to test the CLIC and ILC main linac correction procedure at FACET. We also propose to test feedback procedures at FACET, in particular the system identification algorithm.

In ILC and CLIC it is planned to perform dispersion free steering in the main linacs [1,2]. To this end the beams are accelerated with different gradients. The steering is then performed by minimizing the average offset of the different beams in the beam position monitors and at the same time minimizing the difference between the beam trajectories. We propose to implement this method for FACET. We are in contact with Gerald S. Yocky (SLAC) to understand the details of the instrumentation and control system. If this proposal were accepted we would send a CERN expert to SLAC to help in the preparation and execution of the experiment. The expert would explore the control system needs and develop the automatic procedure to implement the steering. This would be an important contribution to linear colliders and could also be beneficial in the operation of FACET.

We also propose to test system identification procedures at FACET. The very small emittances in linear colliders require fast correction of dynamic imperfections, e.g. ground motion. The optimum control of these dynamic effects can be achieved with a single integrated feedback that covers the whole machine from the damping ring to the interaction point and beyond. The speed of these feedback systems is limited by the knowledge of the system. In the CLIC main linac the total phase advance is 200 betatron wavelengths. Small changes in acceleration gradient and phase or in magnet strength can change the overall phase advance significantly. In this case the feedback starts to introduce additional noise. This problem can be overcome by the use of an online system identification algorithm. Such an algorithm measures the response of the beam orbit to correctors during normal operation. In a linac this procedure is more difficult than in a ring. Due to the large beam energy spread the beam oscillation is damped along the linac. We have developed a model that can describe the machine using a limited number of free parameters. We also developed an algorithm to determine the parameters of this model from almost parasitic measurements.

The algorithm takes in every cycle (train to train) all available BPM measurements. With this data it performs the estimation, which involves some matrix multiplications. At the moment the algorithm is programmed in Matlab, but can be ported to another language if necessary. After the calculation, the corrector setting are changed to create the next beam bump. In case speed limitations (e.g. communication delays, computational limitations or actuator dynamics) prohibit a train-to-train operation, just every nth beam train can be used by the algorithm to slow the operation artificially down. The identified machine model can be used for feedback applications as well as for diagnostics purposes.

The participants in this experiment will include

1. New CERN staff, that is currently being hired
2. Daniel Schulte, CERN staff, <daniel.schulte@cern.ch>
3. Jürgen Pfingstner, CERN PhD student, juergen.pfingstner@cern.ch
4. Guido Sterbini, CERN post doc, guido.sterbini@cern.ch

We expect that more interest to use FACET for beam-based alignment and feedback exists and we will start a collaboration on the subject. Phil Burrows from the John Adams Institute expressed interest in joining these efforts.

Possible reviewers include

1. Nicolay Solyak, FNAL
2. Andrea Latina, FNAL
3. Tor Raubenheimer, SLAC

4. Kiyoshi Kubo, KEK

Direct measurement of the long-range transverse wakefields of CLIC main-linac accelerating structures.

We are currently collaborating with SLAC (Chris Adolphsen) on gradients tests of the CLIC accelerating structures and PETS and on the calculation of the wakefields in these structures. In the past, the long-range transverse wakefield of a heavily damped CLIC accelerating structure, scaled to 15 GHz, was successfully measured in the ASSET facility at SLAC in October 1999, and the results are shown in fig. 1 [3]. This measurement was of vital importance in validating the concept higher-order-mode suppression by heavy damping and has provided an important experimental benchmark for transverse wakefield computational techniques developed in subsequent years. The CLIC baseline accelerating structure is now however significantly different than the structure tested in ASSET, with for example 24 cells rather than 150, much stronger geometrical tapering, a modified cell geometry, modified power couplers, a different silicon carbide supplier and a more compact load design [4,5]. A program of high-power testing the current design is well under way and prototype structures are operating in the required 100 MV/m range, and a test structure is shown in fig. 2. Another crucial validation of the CLIC baseline structure is to demonstrate that the computed transverse wakefield behavior is achieved in a prototype structure. The computed wakefield and impedance spectrum for the CLIC main linac accelerating structure are shown in figs. 3 and 4. In addition to validating the CLIC structure design, the measurement will provide important addition benchmarking data for the rapidly developing electromagnetic simulation codes like SLAC's own ACE3P. Finally the possibility to test wakefield suppression in a PETS (power generating) structure scaled up in frequency is being investigated. The frequency scaling is necessary because the PETS aperture is large, 23 mm, and the corresponding wakefields are low, below Z V/pC/mm.

We propose to measure the transverse wakefield of a fully-featured accelerating structure prototype, very similar to the structure shown in fig.2, as a function of distance behind a driving bunch. A number of prototype structures will be available by mid 2012, the expected time such an experiment would be made. The prototype structures have an overall length of about 30 cm with a restricted aperture 23 cm long and a radius of 2.35 mm. Ideally the kick measurement should be sensitive down to a level of around 0.1 V/pC/mm in order to directly demonstrate that the CLIC wakefield suppression specification has been met. It is expected that the driving and probing bunches must be separately positrons and electrons in order to separate trajectories to achieve sufficient resolution in the BPMs which measure the kick. The wakefield measurement should extend out to a distance of around 1 m in order to ensure that there are not any trapped parasitic modes or re-coherence effects. The separation between measurement points should be of the order of 1mm in order to resolve the third dipole band, which shows up as a peak around 40 GHz in the impedance spectrum. This experiment is expected to take one week with an ideal run consisting of: two days of installation and removal time, four days of beam and data taking set-up and one day of data taking.

The experimental team will include

1. Alexej Grudiev, CERN staff, <Alexej.Grudiev@cern.ch>
2. Walter Wuensch, CERN staff, <walter.wuensch@cern.ch>
3. Tatiana Pieloni, EPFL postdoc, <tatiana.pieloni@cern.ch>
4. PhD student from EPFL to be recruited in late 2010.

Possible reviewers for this experiment include:

1. Toshi Higo, KEK staff, <toshiyasu.higo@kek.jp>
2. Roger Jones, Manchester University professor, <roger.jones@stfc.ac.uk>
3. Nikolai Solyak, Fermilab staff, <solyak@fnal.gov>

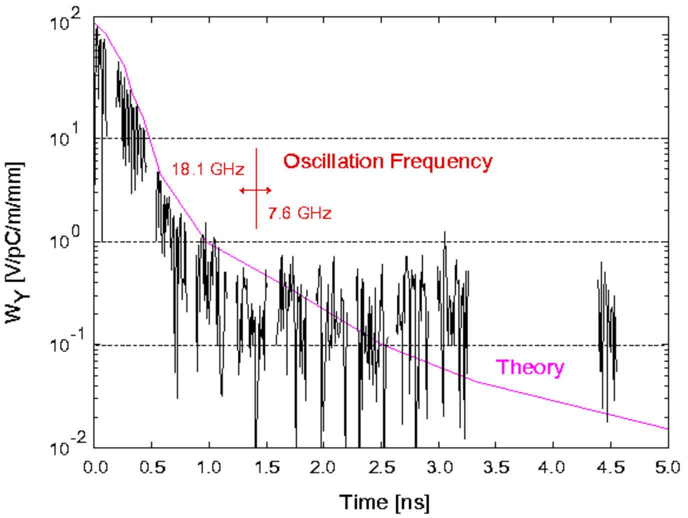

Figure 1: Long-range transverse wakefield of a heavily damped accelerating structure measured in ASSET.

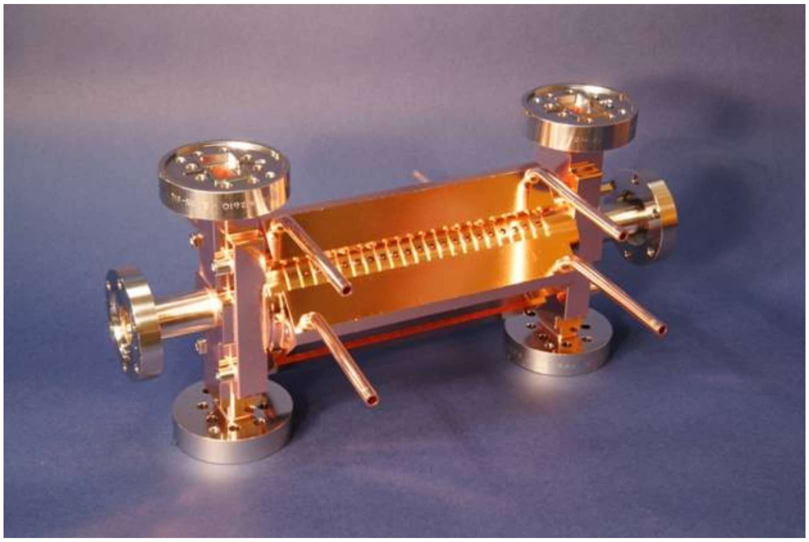

Figure 2: High-power test structure. The overall length is 30 cm.

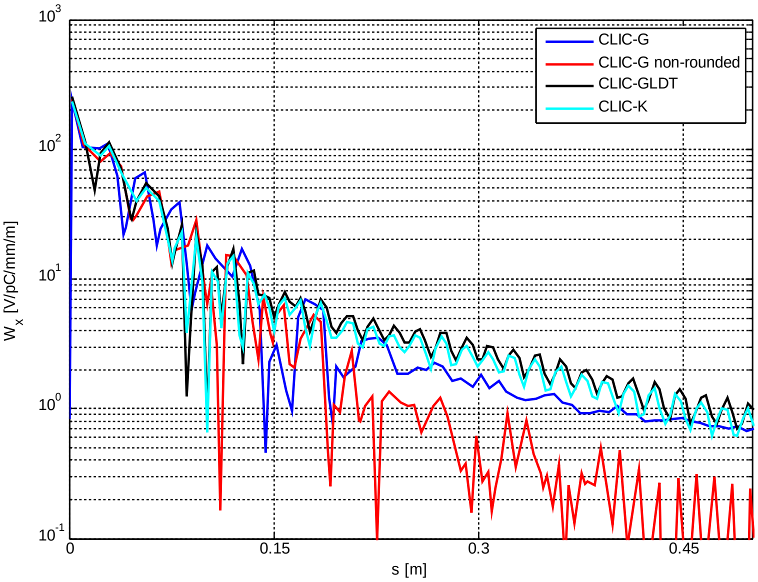

Figure 3: Long-range transverse wakefield of the CLIC main linac accelerating structure. The structure length is 2? Cm.

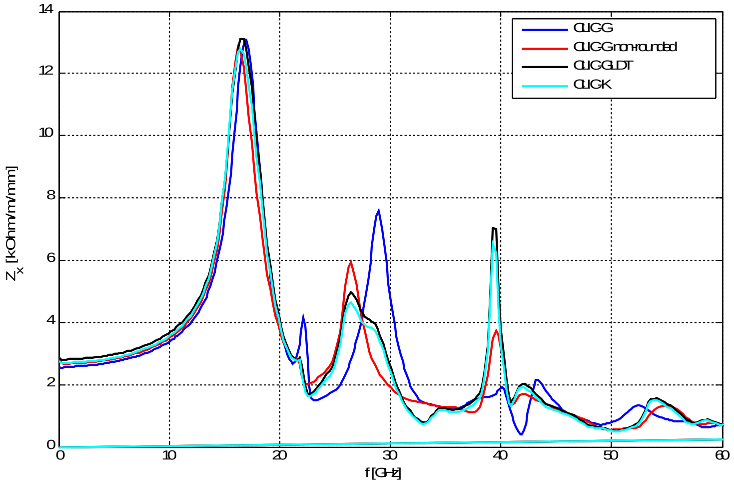

Figure 4: Transverse impedance of the CLIC main linac accelerating structure.

Direct measurement of the transverse wakefields of linear collider final focus collimator geometries.

Single bunch collimator wakefields have been measured in [6] and [7] with the aim of benchmarking theory, numerical calculations and experiments in view of the importance of collimator wakefields in future linear colliders. Those studies revealed some discrepancies, specially between measurements and numerical calculations. New measurements in FACET will certainly help understand the origin of these discrepancies. A possible improvement in the future FACET experiment could be to simultaneously measure the bunch length. The uncertainty of the bunch length in [6,7] seemed to be one of the limiting factors. Electro-optic (EO) diagnostics will be employed for non-invasive, single-shot determination of the electron beam bunch profile. These techniques have demonstrated a resolution of 90fs rms [8], while more recent approach of "spectral-upconversion" has the potential to provide temporal information for the bunch length on even shorter time scales [9]. This later technique, which also has the feature of requiring only simple laser systems and minimal infrastructure, would form the baseline bunch length diagnostic for the FACET experiments. An important consideration in FACET measurements will be the applicability of EO detection in the regime of extremely high field Coulomb strength. A theoretical frame work for EO effect in this regime has been developed at [10], and indeed would aim to use FACET experiments as a means of extending our experimental confirmation of this theory to the extreme high fields available.

FACET offers the unique opportunity of measuring wakefields for a range of bunch lengths around the CLIC 44 µm bunch length. The same measurements have also been proposed for the CALIFES beam line in CTF3, which features a substantially longer bunch of about 220µ m. A sketch of the CALIFES setup with a simulated trajectory is shown in fig. 5.

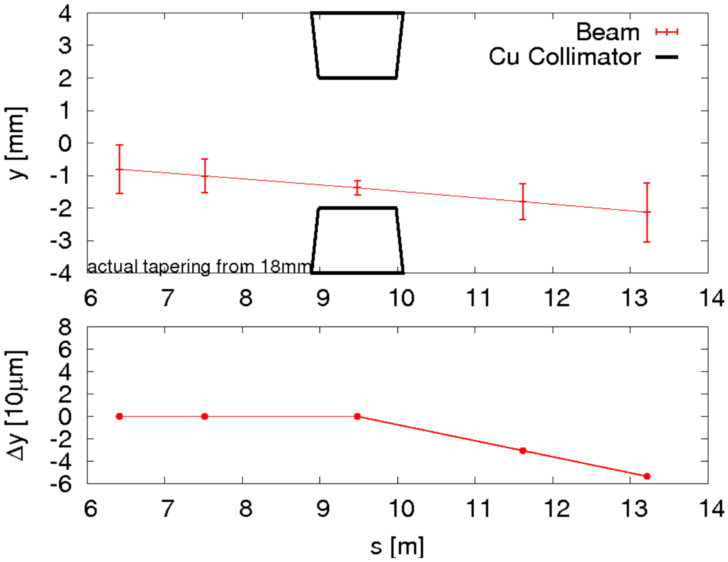

Figure 5: CALIFES beam-line experiment

A Cu collimator of 1m length induces a 20 µrad kick on the 200 MeV CALIFES beam. Two Beam Positions Monitors (BPMs) are placed at either side of the collimator in order to precisely measure the deflection caused by the collimator. This experiment can only take place in CTF3 once the main goals of this facility are achieved and high resolution BPMs are installed in the CALIFES beam line. The FACET beam is two orders of magnitude more rigid than in the CALIFES case. Therefore it needs to be investigated if the beam line dimensions and the BPM resolution suffice for this study. Eventually, compromises between the beam parameters and the collimator geometries could be found.

The collaborators: It is expected that a large number of collaborators from UK and SLAC join this measurement. Up to now the people listed below have confirmed. Many reviewers are suitable for this proposal, for example Frank Zimmermann and Kiyoshi Kubo.

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Sincerely,

Jurgen Pfingster, Alexej Grudiev,
Rogelio Tomas, Daniel Schulte
and Walter Wuensch for the CLIC
study

References:

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[5] See for example A. Grudiev http://indico.cern.ch/contributionDisplay.py?contribId=44&confId=58072

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[7] J.L.-Fernandez et al, "Measurement of Collimator Wakefields at End Station A", EUROTeV-Report-2008-045.

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