# NON-DESTRUCTIVE SINGLE SHOT BUNCH LENGTH MEASUREMENTS FOR THE CLIC TEST FACILITY 3

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## *Abstract*

A non-destructive bunch length detector has been installed in the CLIC Test Facility (CTF3). Using a series of down-converting mixing stages and filters, the detector analyzes the power spectrum of the electromagnetic field picked-up by a single waveguide. This detector evolved from an earlier system which was regularly used for bunch length measurements in the previous CLIC Test Facility, namely CTF2 [1,2]. Major improvements are increase of frequency reach from 90 GHz to 170 GHz, allowing for sub-ps sensitivity, and single shot measurement capability using FFT analysis from large bandwidth waveform digitisers. The results of the commissioning of the detector in 2006 are presented.

## INTRODUCTION

In parallel to the development of single pass Free Electron Lasers (FEL) and electron-positron linear colliders, several techniques for the measurement of ps and sub-ps electron bunch length have been successfully investigated during the past 10 years. State of the art streak cameras [3], the use of RF deflecting cavities [4] and Electro-Optic techniques [5] provide longitudinal profile measurement with resolution better than 200 fs.

In the framework of the Compact Linear Collider (CLIC) project [6], a test facility named CTF3 [7] is constructed at CERN by an international collaboration. The CTF3 complex shall demonstrate by 2010 the key technological challenges for the construction of a high luminosity 3TeV $e^+$-$e^-$ collider. The overall machine, as depicted in figure 1, starts with linac delivering a 3.7 A, 1.5 µs long electron beam with an energy of 150 MeV. The bunches are then injected in two consecutives rings [8] where the beam average current and the bunch frequency are multiplied by a factor 8. With a current of 30 A and 2.5 cm distance between bunches, the resulting beam is finally sent to the CLIC experimental area (CLEX) where it will be used to test all the relevant CLIC components.

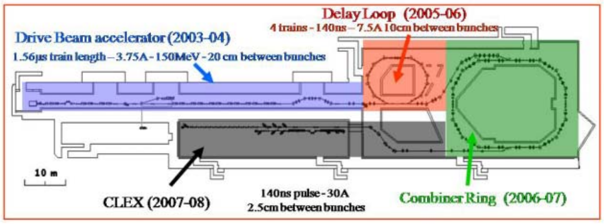

Figure 1: Overview of the CTF3 complex

The performances of the accelerator depend directly on the control of the electron bunch length. In the linac the bunches must remain short (2 ps r.m.s.) to keep the energy spread as low as possible, but need to be stretched (6 ps r.m.s.) before the rings to minimize emittance dilution due to coherent synchrotron radiation. Therefore, two magnetic chicanes have been implemented, the first downstream of the injector and the second upstream the first ring. A sketch of the second magnetic chicane, composed of 4 bending magnets, is presented in Figure 2. Normally, bunch shortening or lengthening is obtained by changing the phase in the last accelerating structures. Bunch length measurements can be performed using Optical Transition Radiation screens coupled to a streak camera [9], but the present system limits the time resolution to 2 ps. Shorter bunches are measured with the 1.5 GHz RF deflector [10], normally used to inject the particles in the Delay Loop.

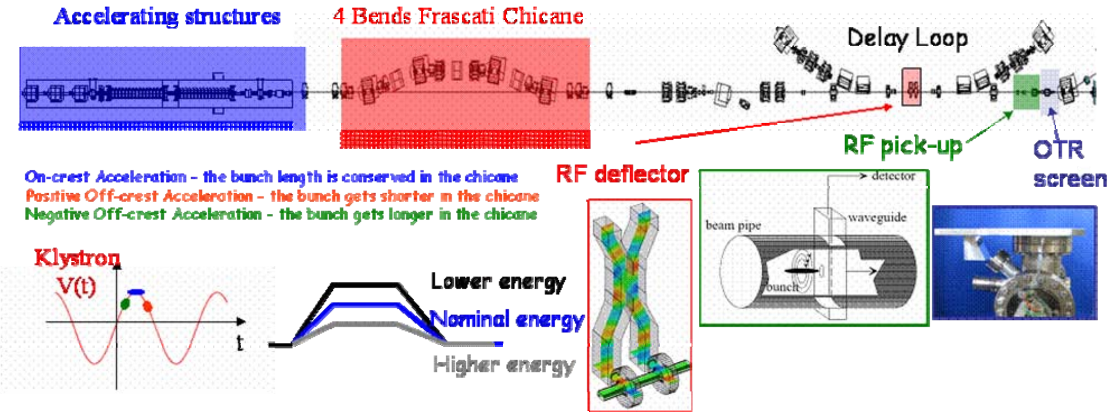

Figure 2: Layout of the Frascati chicane and locations of the bunch length monitors

Effort has been made at CTF3 to develop a non destructive single shot bunch length monitor. This device, the RF pick-up, measures the frequency spectrum of the electromagnetic field emitted by the particles and collected by a rectangular $K_a$ waveguide. The RF pickup was installed 50cm upstream of the OTR screen, and hence cross calibrations can be performed between all the different devices. This monitor sensitive to sub-ps time resolution also has the advantages of being self calibrating and relatively inexpensive compared to the other techniques.

## EXPERIMENTAL SETUP

The RF pickup consists of a single WR-28 waveguide connected to the beam pipe, see Figure 2. A 3.5 mm thick $Al_3O_2$ window is used to isolate the vacuum in the beam pipe from the atmospheric pressure in the waveguide. Signal frequencies above the cut-off of the WR-28 waveguide (21.2 GHz) are transported in a continuous WR-28 waveguide for about 18 m to the detection station in a technical gallery, in order to avoid radiation damage. The attenuation is ~ 0.1dB/m for signals at 30 GHz. Frequencies higher then 40GHz also propagate in the waveguide but they are not only coupled to the fundamental mode and they presumably split into extra TE/TM propagating modes. Based on our past experience [2] this effect is small and is not considered as a major concern.

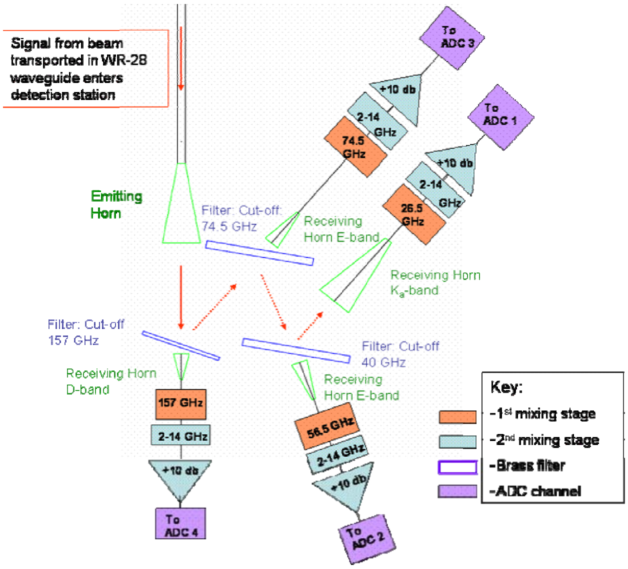

Figure 3: Schematic of the detection system

After transportation to the detection station, the RF signal from the beam is emitted using a $K_a$ band horn antenna, as shown in figure 43 The detection system is designed to to measure the amplitude and phase of the RF signals, simultaneously in four frequency bands, namely 26.5-40 GHz, 45-69 GHz, 75-90 GHz and 157-170 GHz. The incoming RF signal is sent consecutively to the 4 detecting chains using a series of brass grids, consisting of cylindrical holes [11] as shown in figure 3. Depending on the wavelength of the signal and on the diameter of the holes, the grids act as either high pass filters or reflectors. Only frequency higher than the cut-off frequency of the holes passes through the grid. Lower frequencies are reflected towards the next detection stage.

Two down-mixing stages in series are required in order to measure the RF signals using fast ADC's. The first down mixing stage is unique to each frequency band, namely 26.5 GHz, 56.5 GHz, 75 GHz and 157 GHz. The second down mixing stage is in common to the four detection bands, obtained using a synthesizer with a variable frequency range from 2-14 GHz. The signals are amplified after the second down mixing stage, and then digitized using a fast Acqiris digitizing scope with a bandwidth of 2 GHz per channel. The data acquisition is controlled remotely by a LabView program, which stores, displays and analyses the signals in real time.

## EXPERIMENTAL RESULTS

For each machine condition, which corresponds to a particular setting of the phase of the last Klystron, ten successive measurements are stored and their Fourier transforms performed. Typical examples of signals are shown in figure 4, for both the time and frequency domain. The lines in the frequency domain are well above the noise, and correspond to the frequency expected after down-conversion.

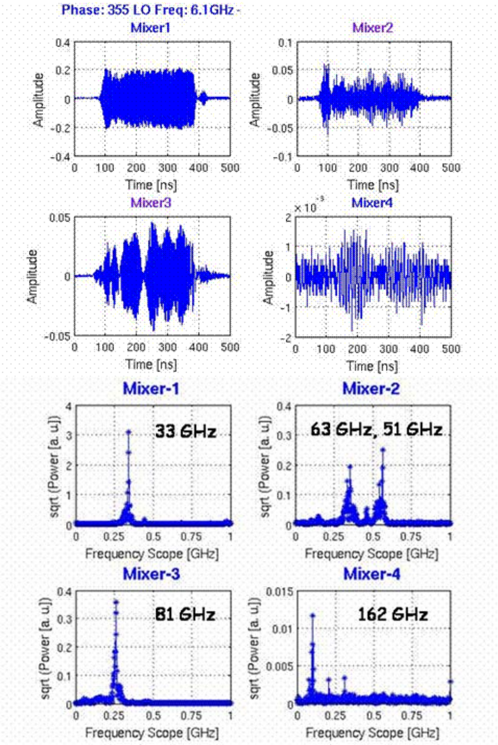

Figure 4: Signal amplitudes in the time and frequency domain from each of the four mixing stages.

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The frequency signals are averaged 10 consecutive times and the mean height of the peaks are measured and used for bunch length measurement. As an example, the evolution of the 4 signal amplitudes is presented in figure 5 as a function of a klystron phase. The amplitudes shown here are normalized to the values corresponding to the nominal klystron setting with a phase of 348 degrees.

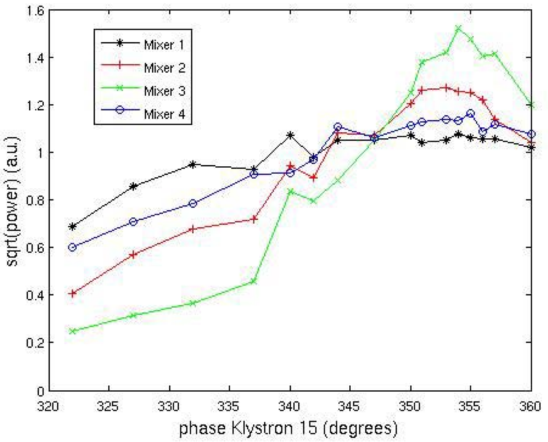

Figure 5: Signal amplitudes from the 4 selected frequencies as a function of the phase in Klystron 15.

In order to extract the bunch length, the data displayed in figure 5 are then analyzed used in the fitting procedure. The longitudinal distribution of the electrons is assumed to be Gaussian. A $\chi^2$ minimization fit, to the Gaussian function, is then performed, with the fit parameters being the r.m.s. bunch lengths at each machine setting and a response factor for each frequency, thus taking into account the variation of the system response with frequency. The extracted r.m.s bunch lengths are shown in figure 6 and the evolution of the bunch length with respect to the the phase of the last Klystron can be seen.

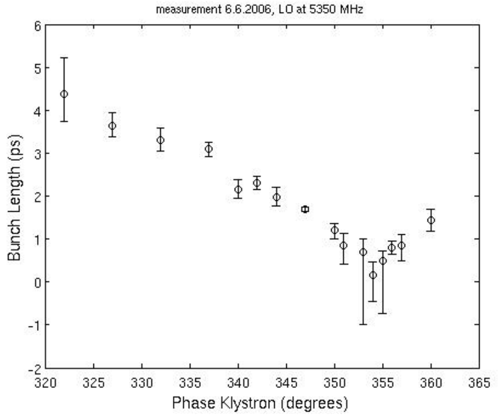

Figure 6: Bunch length measurements as a function of the phase of Klystron 15

Only the first three mixing stages were used in this analysis, because the transmission of the highest frequency signal was too low. The resolution limit is currently about 0.7 ps.

## CONCLUSIONS AND PERSPECTIVES

The RF-pickup monitor has been successfully installed at CTF3 to measure bunch lengths on a single shot, real time basis. The resolution was measured to less than a ps.

Improvements are foreseen in order to decrease the time resolution up to 0.3ps. A thin diamond RF window, which would increase the transmission for high frequency, has been already installed to replace the actual one in alumina. The waveguide arrangement will also be modified by adding a reflecting spherical surface of the first high pass filter/grid, which will focalize the RF signals and increase by more than a factor 2 the signal transmission.

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