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Project Title: Development of Beam Instrumentation for CLIC at the CTF3

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A. OVERVIEW

This work is focused on the design and construction of novel beam diagnostic and instrumentation for charged particle accelerators required for the next generation of linear colliders. Our main interest is in non-invasive techniques.

The Northwestern group of Velasco has been a member of the CLIC Test Facility 3 (CTF3) collaboration since 2003, and the beam instrumentation work is developed mostly at this facility[1]. This 4 kW electron beam facility has a 25-170 MeV electron LINAC.

CTF3 performed a set of dedicated measurements to finalize the development of our RF-Pickup bunch length detectors. The RF-pickup based on mixers was fully commissioned in 2009 and the RF-pickup based on diodes was finished in time for the 2010-11 data taking. The analysis of all the data taken in by the summer of 2010 was finish in time and presented at the main conference of the year, LINAC 2010 in Japan[1].

B. RF-PICKUP FOR SINGLE SHOT NON-DESTRUCTIVE BUNCH LENGTH MEASUREMENT DEVELOPMENT IN 2009/10 AND 2010/11

The research work at CTF3[2] has been focused on understanding in detail the CTF3 single bunch profile and the bunch length along the pulse train (see Fig. 1a-b), both effects of which are important in order to study the systematic effects of the RF pickup response[3]. To do this, new optical lines to transport synchrotron light to a new Streak Camera laboratory were commissioned in 2009 and the last missing Diode Oscillator was purchase and commissioned on 2010. The bunch length profile shape was measured to be a Skew Gaussian distribution with a FWHM that changed along the pulse train and for the first time we were able to performed a proper simulation and calibration of the of the RF pickup calibration, see Fig. 1c-d. This work was used to measure and then minimized the longitudinal variation along the pulse. This is intrinsic to CTF3 because of the RF pulse compression system in the Klystrons. In addition, the bunch length variation along the pulse train, introduces some additional harmonics to the frequency spectrum of the RF pickup[4]. Hence additional waveguide filters have been purchased to better isolate the beam harmonics of interest, before the down mixing stage. This will also eliminate the beating caused by two or more frequencies and enable the envelope in of the signal in the time domain to be used as an additional bunch length diagnostic. In order to calibrate the RF pickup detector board, Gunn Oscillators of fixed frequencies, corresponding to the beam harmonics of interest, have been purchased. This will also enable the electronics components mounted on the detector to be routinely checked for stability and correct functionality against a calibrated source.

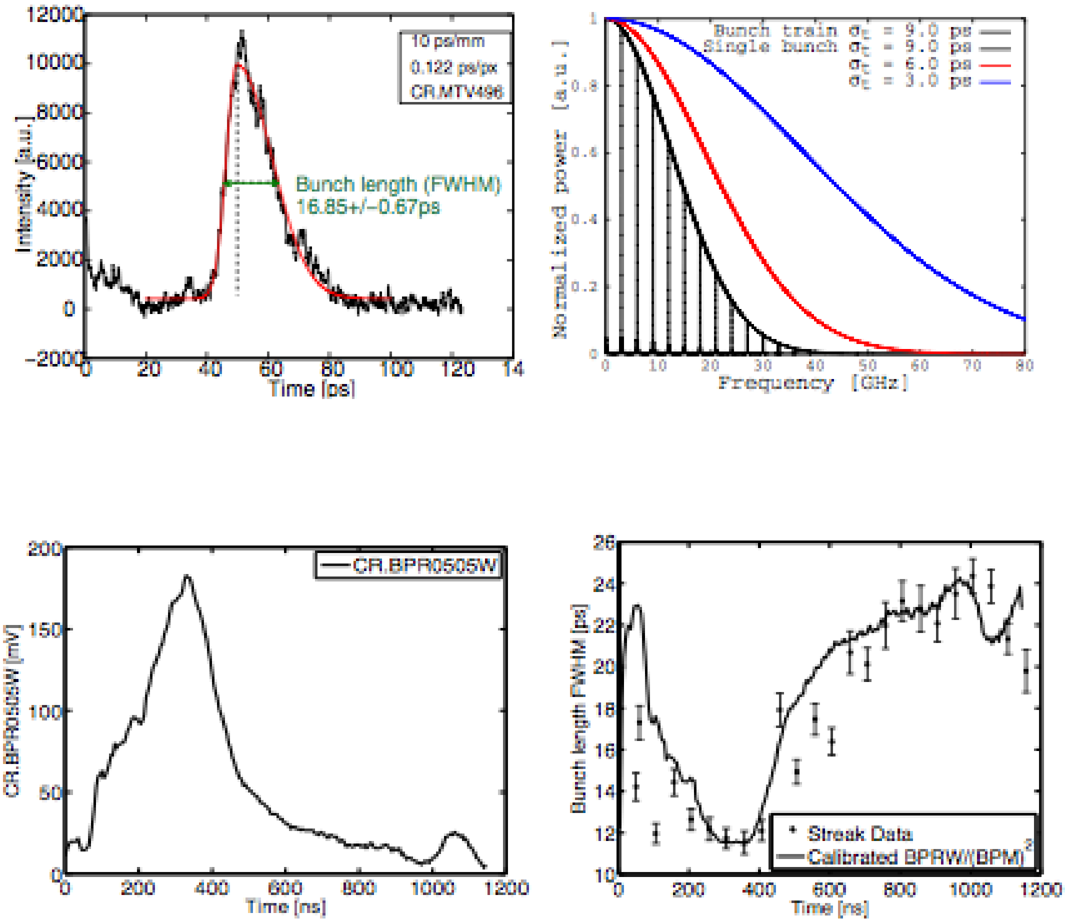

Figure 1: (a) Example of the CTF3 single bunch spectrum measured with the Streak Camera. (b) Power spectrum for a train of Gaussian bunches, with r.m.s. bunch length σ_t = 9 ps and separated by τ_i = 333.3 ps (black) and the single bunch envelope for σ_t = 9 ps (black), σ_t = 6 ps (red) and σ_t = 3 ps (blue). (c) Analog single shot response from RF-Pickup in the combiner ring. (d) Bunch Length measurement com- paring calibrated RF-pickup and the Streak Camera.

The calibration between power measurements made with the RF pickup system and with the BPR high frequency diode system against the Streak Camera measurements were show to more challenging that expected and very dependent on the beam conditions. Further work will be needed in order to increase reliability.

To understand the RF pickups sensitivity to small bunches, a dedicated test, with a beam optimised for shorter bunches took place before the machine breakdown, but we were not able to make the planned test of a cross calibration of the RF pickup with the New FESCA Streak Camera (resolution of 200-300 fs) purchased by the CTF3 collaboration.

In addition to the RF pickup, a new detector, based on high frequency diode detectors, and very narrow band pass filters was designed to measure the bunch length in CLEX, which is needed in order to optimise the CTF3 12 GHz power production. This work has been jointly funded by Northwestern University and the CLIC project.

C. EQUIPMENT

Our equipment was not affected by the breakdown of the CTF3 machine in the spring of 2010 and it is well secured.

RF pickup with mixers

The "RF pick-up" is with mixers is completed and it 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 50 cm upstream of the optical transition radiation (OTR) screen, and hence cross calibrations can be performed between the RF deflector and the RF pickup monitor.

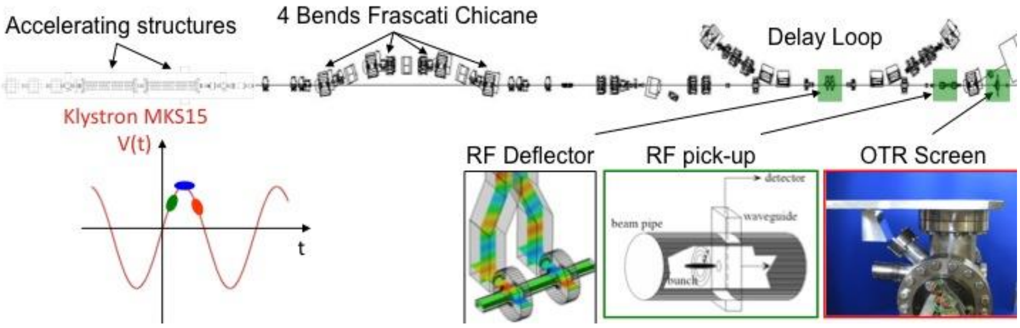

Figure 2: Layout of the Frascati chicane and locations of the bunch length monitors. By changing the Klystron MKS15 phase, the bunch length at the end of the chicane can get shorter (green), longer (red) or just be preserved (blue).

The RF pickup consists of a single WR-28 waveguide connected to the beam pipe as shown in Fig. 1. A 0.5 mm thick CVD diamond window[2] 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 (21.1 GHz) are transported in a continuous WR-28 waveguide for about 18 m to the detection station in a technical gallery. At the detection station, the RF signal from the beam is emitted using a K_a band horn antenna. The detection system is designed to measure the amplitude of the RF signals from the beam, simultaneously in four frequency bands, namely 26.5-40 GHz, 45-69 GHz, 75-90 GHz and 142-170 GHz.

As shown schematically in Fig. 2, two down-mixing stages in series are required in order to measure the high frequency RF signals. The first down mixing stage has a fixed local oscillator frequency for each band, namely 26.5 GHz, 56.5 GHz, 75 GHz and 157 GHz. The second down mixing stage is in common to each of two of the four detection bands, obtained by using two synthesizers with a variable frequency range from 2-14 GHz. From this setup, measurements of the beam harmonics of 30 GHz, 33 GHz, 36 GHz and 39 GHz are made using the K-band detection, the beam harmonics of 60 GHz, 63 GHz, 66 GHz and 69 GHz are made using the first E-band detection stage, and the beam harmonics of 78 GHz, 81 GHz, 84 GHz and 87 GHz are made with the second E-band detection stage. The D-band detection stage provides signals only for beam conditions with very short bunches, which was not the case for the measurements presented in this document. The signals are amplified by +10dB after the second down mixing stage, and then digitized using a fast Acqiris digitizing scope with 2Gs/s per channel. The data acquisition is controlled remotely by a LabView program, which stores, displays and analyses the signals in real time[4].

RF pickup with diodes

In 2009 and begin of 2010 we purchase and assembled the "RF Pickup" with diodes used at the entrance of the CLEX(TL2). Power extraction of the main CTF3 drive beam is done in two of the beam lines in the CLEX experimental hall, namely the Test Beam Line (TBL) where the power extraction and transfer structures (PETS)[5] began in 2009 and in the two beam test stand (TBTs) where a PETs structure was ainstalled in 2008.

The RF-pickup with diodes is a more compact and less expensive system than the one based on mixers. Simultaneous power measurements at 60 GHz, 90 GHz, 120 GHz and 150 GHz were made, see Fig. 1b and Fig, 3.

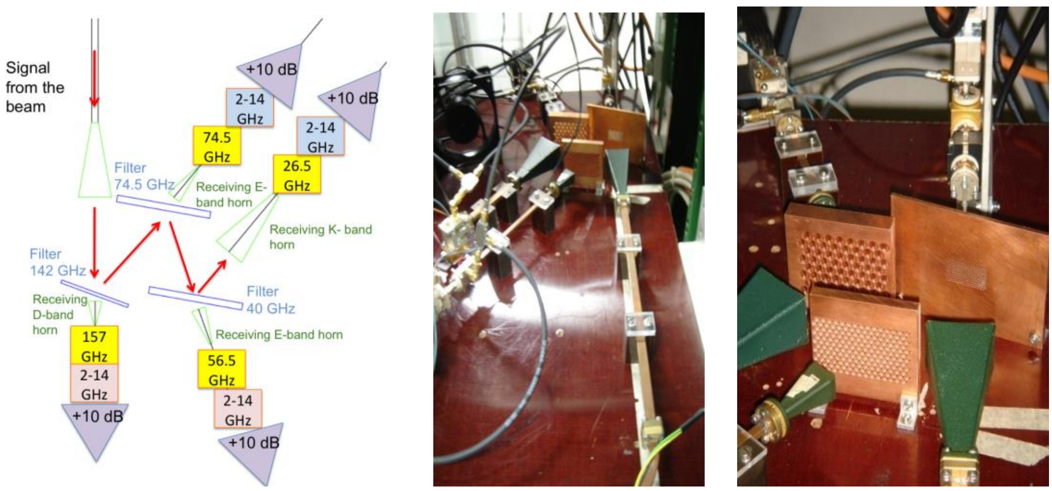

Figure 3: Schematic of the detection system. Pictures of the setup of the RF detection station in the gallery

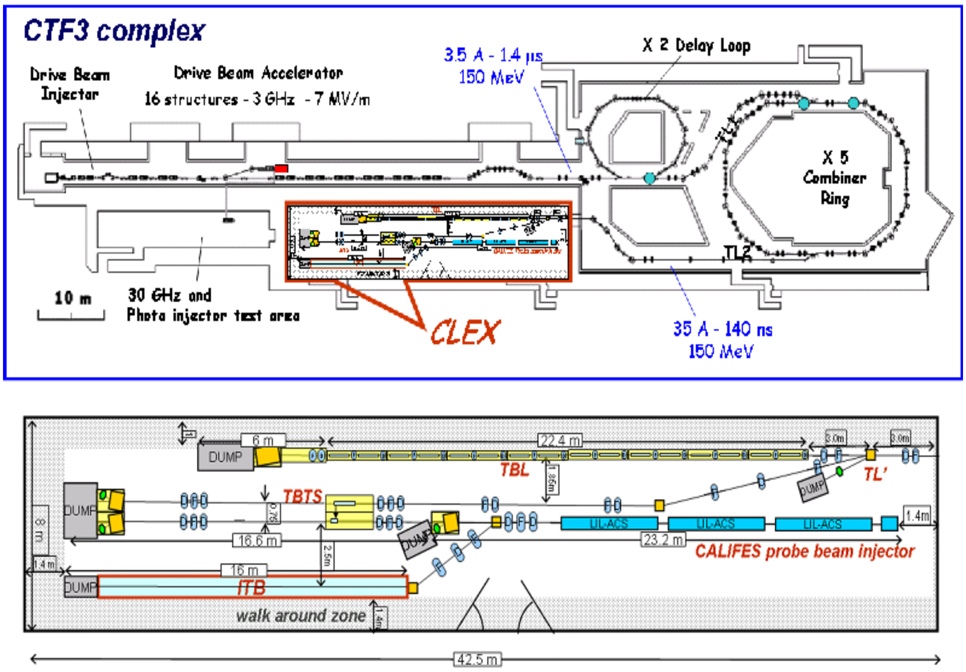

Figure 4: (a) CTF3 Complex. (b) CLEX

D. FACILITIES USED

The new CLIC Test Facility CTF3, built at CERN by an international collaboration, aims at demonstrating the feasibility of the CLIC scheme of multi-TeV electron-positron linear collider.

It is meant to demonstrate the technical feasibility of the key concepts of the novel CLIC RF power source, e.g., generation of high-charge, high-frequency electron bunch trains by beam combination in a ring using transverse RF deflectors and operation with a fully-loaded drive-beam accelerator.

CTF3 will also be used to test CLIC critical components and in particular will provide the 30 GHz RF power needed to test the main beam accelerating structures at the nominal gradient and pulse length (150 MV/m for 70 ns).

CTF3 is housed in the former LEP Pre-Injector complex building.

All our instrumentation research was performed with the 150 MeV electron linac of the CTF3/CLIC facility. This linac has high beam power, 4kW, high current, 3.5 Amps, and short beam pulse on the order of picoseconds, making it a good environment for developing beam instrumentation like the RF pick-up that we produced.

Any machining, electronics, brazing[5] and/or assembly needed were done using the facilities available at CERN and contract CERN technicians several times.

F. BUDGET

The funds from this grant were used to: (1) purchase the full RF-pickup system, which includes diode oscillators, waveguides, mixers, several amplifiers and a dedicated data acquisition; (2) build a diamond based window to minimized beam disruption; (3) contracted several technicians to help with the installation of the equipment and mounting and brazing the diamond window; (4) pay the salary and subsistence of the students that worked not only in the commissioning of the detectors and data acquisition system at CERN, but also in the data calibration and analysis; and (5) the travel expenses for the student and the PI.

Bibliography & References Cited

1. A.E. Dabrowski et al., \Measuring the longitudinal bunch pro_le at CTF3," In the Proceedings of XXV Linear Accelerator Conference (LINAC 10), Tsukuba, Japan, 12-17 Sept. 2010.

2. G. Geschonke et al, "CTF3 Design Report," CTF# note 047, (2002)

3. A. Dabrowski, talk "Bunch Length and Profile Monitoring" presented at CTF3 technical meeting 2009
http://indico.cern.ch/conferenceDisplay.py?confId=47771

4. H. Shaker et al, "Longitudinal beam dynamics studied at the Compact Linear Collider Test Facility" submitted to *Physical Review Special Topics-Accelerators and Beams*, 26 Jan 2009

5. I. Syratchev et al "HIGH RF POWER PRODUCTION FOR CLIC" *Proc PAC07.*
http://pac07.org/proceedings/PAPERS/WEPMN071.PDF