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EXPERIMENTAL RESULTS FROM THE TEST BEAM LINE IN THE CLIC TEST FACILITY 3

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Abstract

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energy. We correlate the measured deceleration with predictions from the beam current and the rf power produced in the PETS.We also discuss recent bunch length measurements and how it influences the deceleration. Finally we look at the evolution of the transverse emittance.

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INTRODUCTION

In the future proposed Compact Linear Collider (CLIC), two low-energy electron drive beams are used as power sources to accelerate the two main beams before collision. The rf fields used for acceleration are extracted from the drive beams using 24 decelerators, each of which comprise a FODO lattice with a large number of Power Extraction and Transfer Structures (PETS), and which extracts 90 % of the drive beam energy. The PETS are constant impedance, passive microwave devices with a fundamental mode at 12 GHz.

In the CLIC Test Facility 3 (CTF3) at CERN, the Test Beam Line (TBL) is built as a prototype decelerator. Two of the main purposes of TBL are to demonstrate stable beam transport after significant deceleration and to study the consistency with theoretical models, and these topics will be addressed in this paper.

EXPERIMENTAL SETUP

The TBL has a similar lattice as the CLIC decelerators, and consists of 8 FODO cells with space for up to 16 Power Extraction and Transfer Structures (PETS). Figure 1 shows the current lattice. Currently 12 PETS are installed in the line. Since TBL has a 4 times lower beam current than the CLIC drive beam, the PETS are 4 times longer to compensate, and produce roughly the same amount of power. The 12 GHz rf power produced by the PETS is coupled out and measured with Schottky diodes. One PETS is measured with IQ demodulators, which also provides information about the rf phase. Since the power is attenuated by around 90 dB before entering the electronics, and the attenuation is measured piecewise [2], the accuracy of the measured amplitude is estimated to be around 10 %.

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The quadrupoles in the FODO lattice are placed on moving tables made by CIEMAT [3], which allow micrometer positioning. The quadrupole focusing is tapered along the line to provide a constant phase advance for the most decelerated particles, normally 90°.

The BPMs are high precision inductive wall current monitors designed and constructed by IFIC Valencia and UPC Barcelona [4], and have a resolution of 5 μm. The beam current can vary between 3.5 and 28 A, because of different bunch combination schemes using the delay loop and combiner ring in CTF3. This affects the TBL deceleration linearly and the PETS power production quadratically.

At the end of TBL a segmented dump spectrometer [5] provides time-resolved energy measurements with an accuracy of a few percent. The start of the line is equipped with a more simple spectrometer with a single slit. The other diagnostic devices are OTR screens, and a streak camera that images an OTR screen and allows bunch length measurements.

EMITTANCE EVOLUTION

In the CLIC decelerators, the 3σ beam envelope can according to simulations fill around half the aperture [1]. It is therefore important that the transverse beam dynamics through deceleration is well understood, and that there are no unknown effects on the transverse beam size.

One important parameter which we can verify experimentally is the transverse emittance. We can compare the phase space (including the Twiss parameters) in one transverse plane by

1. performing one or more quad scans at the beginning of the TBL,
2. using the quad scan results as input to a simulation code, in this case the tracking code Placet [6],
3. performing one or more quad scans at the end of the TBL and comparing the results with the expected values from the simulation.

This comparison has been performed for different beam currents in TBL. Figure 2a shows a comparison for a factor 4 bunch combination, corresponding to a beam current of 13.5 A and 25 % deceleration. The plot is similar to a standard quad scan plot, where the beam size is shown as a function of the focusing of one quadrupole.

Based on the uncertainties in the Twiss parameters and emittance at the beginning of TBL, a number of Placet simulations were run with different input parameters. The resulting beam size at the end of TBL has an uncertainty,

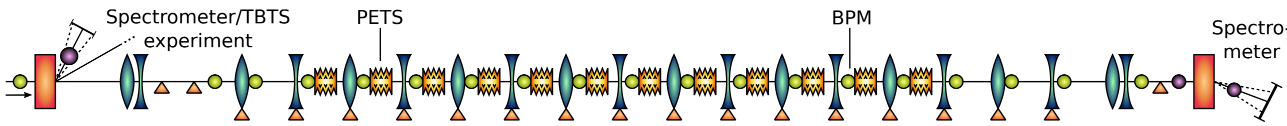
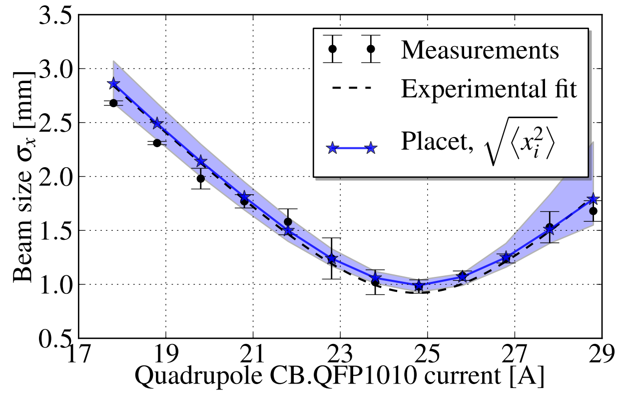


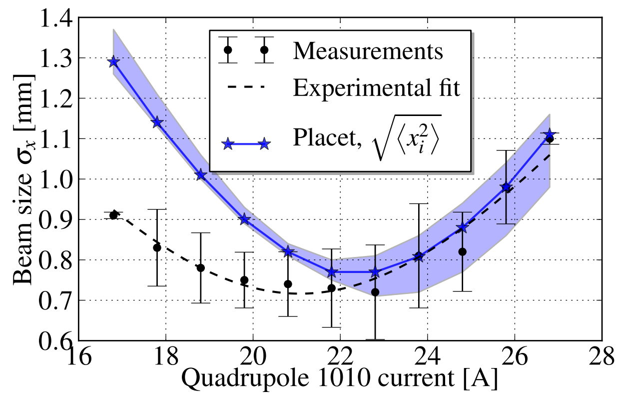
Figure 1: The current TBL lattice with 12 out of 16 PETS installed, with the CTF3 drive beam arriving from the left. Quadrupoles are shown as blue lenses, dipoles as red rectangles, correctors as orange triangles, BPMs as green circles, OTR screens as purple circles and PETS as brown corrugated structures.

given by the simulation results, that is represented by the blue band in Figure 2a. The blue line represents the simulated condition using the mean measured values from the beginning, which were also used for matching the TBL. Measured quad scans at the end of TBL are shown with black error bars and a corresponding quadratic fit. The measurements agree very well with the simulations, and we conclude that evolution of the transverse emittance is well understood.

We also show a similar comparison between measurements and simulations for an uncombined beam, corresponding to a beam current of 3.5 A and 7 % deceleration, in Figure 2b. Here the measurements disagree with the simulations. However, the beam size at the waist is roughly the same, but the waist is wider. We therefore believe that the emittance behaves as expected, but that the error lies in the Twiss parameters, maybe due to a drift of the machine. When the measurement was performed, the TBL was still matched and optimized for transporting the combined beam measured in Figure 2a, and this is a further uncertainty factor, even though the simulations were performed with the same optics. In the future we want to repeat the measurement for the uncombined beam, and also match the line for that beam.



(a) Factor 4 bunch combination, 25 % deceleration.



(b) Uncombined beam, 7 % deceleration.

Figure 2: Emittance evolution in the TBL. The plots represent quad scans done at the end of TBL. The simulations are based on the Twiss parameters and transverse emittance from the beginning of TBL. The emittance agrees well for both cases, while there is some uncertainty in the Twiss parameters for the uncombined beam.

DECELERATION

Energy measurements are regularly performed in the TBL, and the energy of the decelerated beam is compared to predictions from the measured beam current and from the rf power measured in the PETS. In Figure 3 one such measurement is shown, where the measured energy along the bunch train is shown in blue. The predicted deceleration based on the measured beam current is shown in red, while the prediction based on the measured PETS rf power is shown in green. A total of 60 pulses was used in the analysis. The means of the three measurements over the 60 pulses are shown with solid lines, while the standard deviations of the distributions are shown as colored bands.

When correlating the two predictions with the spectrometer measurements, one uncertainty is the charge distribution form factor $F(\lambda)$. This parameter takes the value of unity for infinitely short bunches with a perfect bunch phase. Based on bunch length and phase measurements, a reasonable estimate most of the time [7] is $F(\lambda) \leq 0.90$. One example of this is the bunch length measurement in Figure 4. Ignoring bunch phase effects and assuming Gaussian bunches, we can use the single bunch form factor

$$F(\lambda) = F_b(\sigma_z) = \exp\left[-\frac{1}{2}(\sigma_z 2\pi f_b/c)^2\right], \qquad (1)$$

where σ_z is the bunch length, f_b the bunch frequency and c the speed of light in vacuum. Using eq. (1) and the data in Figure 4 (including error bars), we obtain $F_b(\lambda) \in [0.81, 0.88]$.

In Figure 3 the form factor is used as a fudge factor, and a value of 1.05 had to be assumed, which is non-physical. A possible explanation can be an offset in the spectrometer, either because of a calibration error or a non-centred beam. Another issue is that the dipole magnet cannot currently be demagnetized correctly. To investigate a possible system-

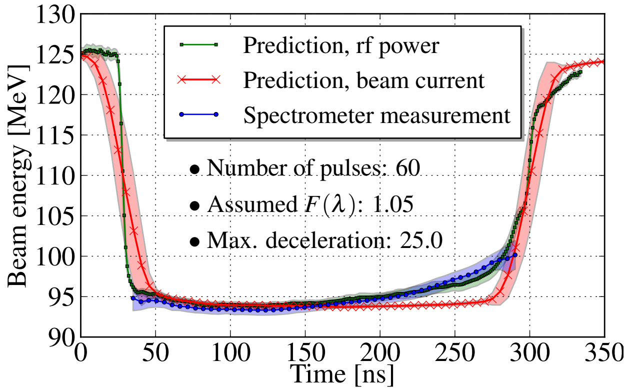


Figure 3: Deceleration of a 12.5 A beam through TBL. The measured energy along the pulse is shown, together with predictions based on the measured beam current and PETS rf power. Each colored band represents the mean ± the standard deviation.

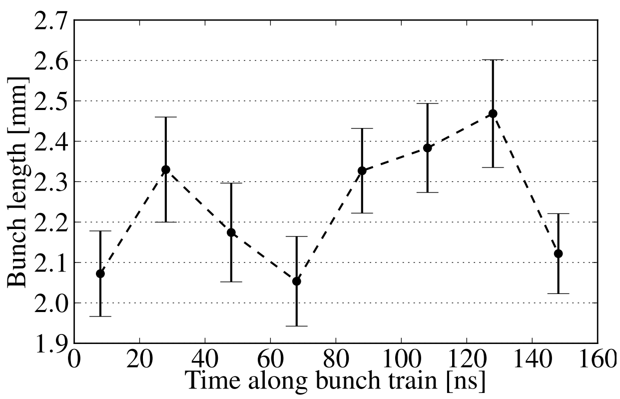


Figure 4: Streak camera measurement, where the bunch length (measured in sigmas) is shown at 8 points along the bunch train.

atic error, an experiment was performed where the the final beam energy was measured for different beam currents, and this is shown in Figure 5. A linear fit was used to find the intersect, which represents the beam energy without deceleration. This should correspond to the measured incoming energy of 125 MeV, but the intersect is 3 % lower. However, it is still inside the 95 % confidence interval of the fit, and therefore no conclusion can be made.

For the prediction from rf power there is also another uncertainty, namely the rf calibration. In Figure 3 an 8 % calibration error had to be assumed, something which is within the expected 10 % calibration uncertainty.

As seen in Figure 3, the agreement is worse at the end of the pulse. This mainly originates from a change in the form factor (bunch length and phase) along the pulse, which started upstream of the TBL. Figure 4 does not show the whole bunch train, but there is a tendency towards longer bunches at the end (except for the last point).

As shown by Figure 3 we can currently reach 25 % deceleration with a 12.5 A beam. Later this year it is expected

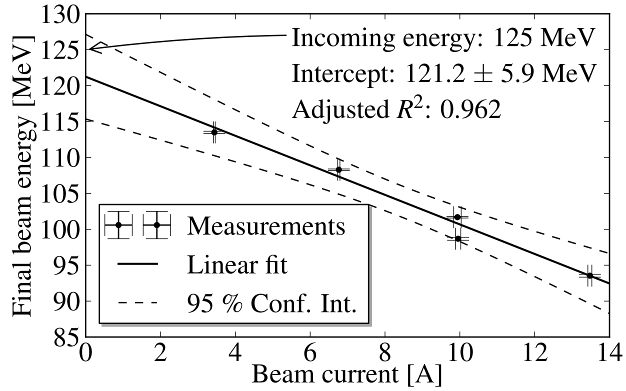


Figure 5: Measured beam energy at the end of TBL versus the beam current. A fit to the data determines the intersect, which represents the beam energy with no deceleration.

to operate with a beam current above 20 A, and it is reasonable to expect more than 40 % deceleration before the end of the year.

CONCLUSION

The TBL currently operates with 12 PETS, and has reached 25 % deceleration with a beam current of 12.5 A. There is generally good agreement with theoretical expectations, however there is a possibility of a small systematic uncertainty in the spectrometer measurement, but this is not evident from the current data.

With 25 % and 7 % deceleration we have studied the evolution of the transverse emittance through deceleration in PETS. The emittance measurements agree very well with theory, except for some difference in the Twiss parameters for one measurement.

CTF3 is now starting high-current operation, and TBL will likely reach 40 % deceleration before the end of 2013.

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