LONGITUDINAL BEAM TUNING AT FACET*

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Abstract

Commissioning of the Facility for Advanced acCelerator Experimental Tests (FACET) at SLAC began in July 2011. In order to achieve the high charge density required for users such as the plasma wakefield acceleration experiment, the electron bunch must be compressed longitudinally from 5.6 mm down to 20 microns. This compression scheme is carried out in three stages and requires careful tuning, as the final achievable bunch length is highly sensitive to errors in each consecutive stage. In this paper, we give an overview of the longitudinal dynamics at FACET, including beam measurements taken during commissioning, tuning techniques developed to minimize the bunch length, optimization of the new "W" chicane at the end of the linac, and comparison with particle tracking simulations. In addition, we present additional diagnostics and improved tuning techniques, and their expected effect on performance for the upcoming 2012 user run.

INTRODUCTION

The FACET accelerator shown in Figure 1 comprises the first two-thirds of the SLAC two-mile linear accelerator complex. An electron beam with a bunch charge of approximately $2x10^{10}$ particles is extracted from the North Damping Ring (NDR) at 1.19 GeV with an RMS bunch length of 5.5 mm, compressed in the ring-to-linac transfer line (NRTL) to approximately 1.1 mm, and injected into the main linac. This bunch is then accelerated to 9.0 GeV approximately 20 degrees off-crest, which introduces a chirped correlation into the beam's longitudinal phase space. It is then compressed again to approximately 50 μm in the linac bunch compressor chicane (LBCC) in Sector 10. After another section of acceleration to the end energy of 20.3 GeV, a final W-shaped chicane in Sector 20 provides a final stage of compression down to 20 μm.

NEW DIAGNOSTICS

A number of diagnostics for measuring longitudinal beam parameters were included in the original FACET construction. Most useful of these were a bunch length monitor located close to the IP region, comprised of a transition radiator foil instrumented with a pyroelectric detector [1], which is sensitive at wavelengths on the order of the final 20 μm bunch length.

The experience gained during the 2011 initial commissioning run indicated a clear need for improved bunch length diagnostics earlier in the linac, to be able to maintain the compression setup at each stage. To this end, bunch length monitors (BLMs) were installed in Sectors 2 and 18 to characterize the bunch compression after the NRTL and LBCC.

Sector 2 BLM

The first stage of bunch compression at FACET occurs in the NRTL transport line. After extraction from the NDR, the bunch is sent through a short section of S-band accelerator which is operated at 90° off-crest. This imparts the bunch with a linear energy chirp, and the R_{56} of the NRTL over-compresses the bunch. Varying the amplitude of the compressor klystron RF allows adjustment of the compression and therefore the longitudinal phase space distribution entering the linac.

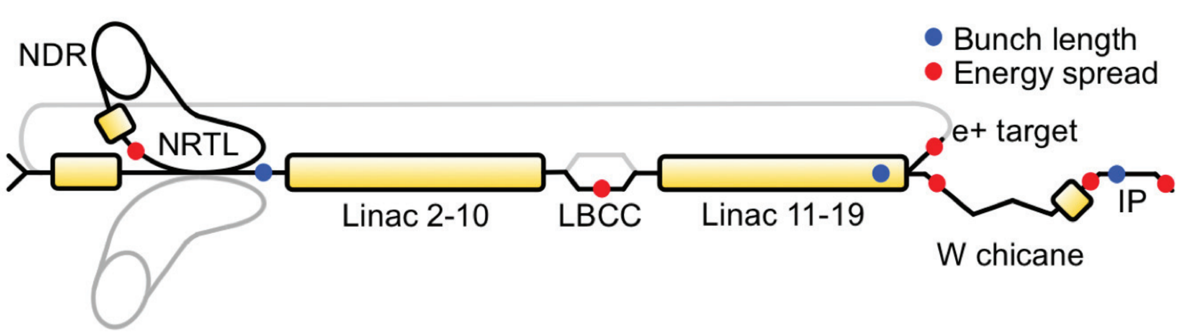

Figure 1: The FACET accelerator complex. Yellow boxes represent accelerator sections, including those in the injector, the NRTL compressor, Sectors 2-10, Sectors 11-19, and the eventual location of the X-band transverse cavity to be installed in the W chicane. Blue dots show the location of bunch length diagnostics in Sectors 2, 18, and 20, and red dots show the locations of energy spectrometers.

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During the 2012 downtime, a ¼” ceramic break was installed at the beginning of Sector 2, just after the compressed beam is launched back into the linac. Radiation from the gap is collected into a short section of waveguide and detected with a pair of Schottky diodes operating in Ka (26.5-40 GHz) and V (50-75 GHz) bands, which are connected directly into an integrating gated ADC. The frequency spectrum of this radiation is given by

$$I_b(\omega) = \frac{Q_b}{\sqrt{2\pi}} \exp\left(-\frac{\omega^2 \sigma_z^2}{2c^2}\right) \tag{1}$$

where Q_b is the beam charge, c the speed of light and σ_z is the RMS bunch length [2].

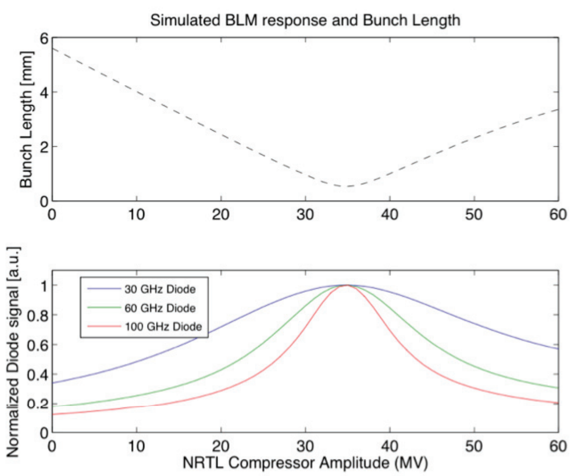

Figure 2: Simulated gap monitor response vs. compressor klystron RF voltage.

The BLM response was measured by varying the compressor klystron voltage and sampling the diode signal. At the time of the measurement, only the V-band channel (60 GHz) was working. This signal can be calibrated by simulating the detector response to such a scan. To do this, LiTrack particle tracking software [3] was used to perform a virtual compressor scan, generating a set of longitudinal bunch distributions. For each simulated bunch, Eq. 1 was integrated over the detector’s frequency range, generating an expected detector signal as a function of compressor voltage, as shown in Figure 2. The BLM data is normalized to the simulation, and plotted on top of this expected response in Figure 2. It is worth noting that the compressor voltage is known to be miscalibrated; measurements using the dispersion in the NRTL indicate the actual voltage is low by approximately 15%. Here, fudging the voltage down by a factor of 91% gives the best agreement.

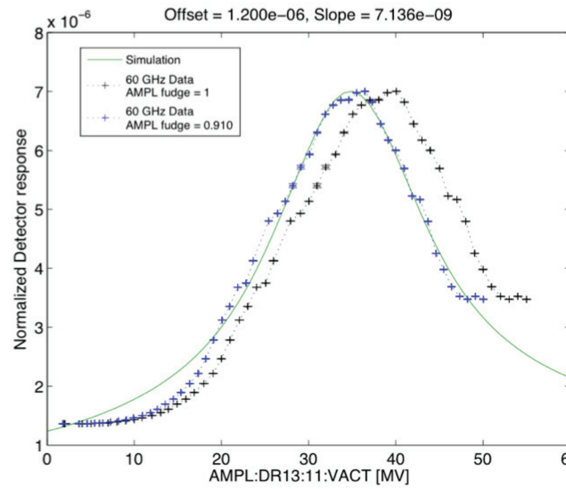

Figure 3: Simulated 60 GHz diode response and measured data from compressor voltage scan.

Sector 18 BLM

The bulk of the bunch compression at FACET happens in the Sector 10 chicane, where the chirped beam is compressed from 1 mm to 50 µm. An additional OTR foil and pyro detector was installed in Sector 18 to measure the bunch length after the Sector 10 chicane. The pyro detector signal is amplified and sampled by a gated ADC. This is a relative bunch length monitor, with a response known [4] to go like Q_b^2/σ_z, and while there is no absolute calibration of the signal, the design operational mode is to minimize the bunch length after the LBCC chicane, so maximizing this parameter is believed to minimize the final bunch length.

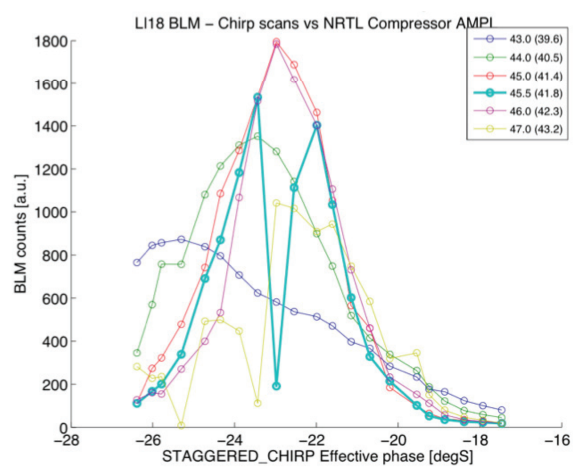

Figure 4: Data from the Sector 18 BLM. Here the phase of Sectors 2-11 is scanned at various NRTL compressor settings (fudged voltage in parentheses). The light blue curve appears to be the optimum – at the central point, saturation of the GADC causes the apparent signal to drop.

By varying the net phase of the linac in Sector 2-11, the bunch can be rotated through maximum compression and the signal optimized. The response of the Sector 18 BLM to these chirp scans are shown in Figure 4, for varying values of the NRTL compressor voltage, which sets the incoming distribution. Simulations carried out with LiTrack of these scans show qualitatively similar results.

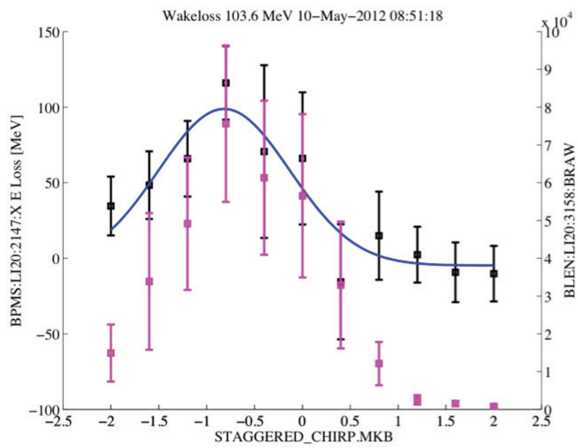

Figure 5: Chirp scan showing 103 MeV of energy loss to longitudinal linac wakefields. The purple signal is the amplitude of the THz table foil pyro detector.

THz Table BLM

Finally in addition to the upstream BLMs, another foil and pyro signal was installed at the location of the THz experimental apparatus. This proved fortunate, since as tuning proceeded and the bunch was made shorter and shorter, holes were being found after only a few pulses of beam on the OTR foils at the IP. It is speculated that the holes are caused by high electric fields due to highly compressed and highly focused bunches.

Figure 5 shows the response of the THz bunch length monitor to a chirp scan. Since the final compression stage relies on longitudinal wakefield-induced chirp, the only real tuning knob for optimizing this independently of the Sector 18 BLM is the R_{56} of the W chicane, which was adjusted to 5mm to maximize the signal on the Sector 20 BLM.

OPERATING POINT

With these bunch length diagnostics we have managed to keep the compression setup relatively consistent from day to day. However, the nominal FACET operating point that is optimal is tweaked slightly away from the design. The differences are summarized in Table 1. Many of these, such as the Sector 2-11 phasing scheme, are compromises that help improve the transverse beam sizes.

Table 1: Summary of the Major Differences in the Nominal FACET Compression Setup with respect to the Design. * The anti-BNS phase is nominally 20.2 degrees; instead we have a "staggered" phase configuration which accelerates on-crest early in the linac, and more strongly off-crest later. The vector sum of the chirp is equivalent, but strong transverse wakefield effects at low energies are mitigated.

Parameter	Design Value	Operational Value
Q_{bunch}	2.2×10^{10} e-	2.0×10^{10} e-
V_{NRTL}	40.8 MV	45.5 MV (41.5)
φ_{BNS}	20.2	[0,12,24,35,35,0,50]*
S20 R_{56}	4.0 mm	5.0 mm

FUTURE WORK

Currently underway at FACET is the installation and commissioning of an X-band transverse deflecting cavity (XTCAV), located at the downstream end of the Sector 20 W chicane. A fully operational XTCAV will allow clear and unambiguous measurements of the bunch length, as well as measurements of the energy-z correlation within the bunch.

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