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Abstract

The Linac Coherent Light Source (LCLS) at SLAC requires the rf photo-injector to produce a beam with a normalized, projected emittance of 1 micron in a 10 ps long bunch with a charge of 1nC. In addition, a small longitudinal emittance is needed to attain the desired 3 kiloamperes peak current after compression in two chicane bunchers. To achieve this excellent beam quality, we are performing systematic studies of both the transverse and longitudinal beam properties from the rf photocathode gun at the SLAC Gun Test Facility (GTF). Time resolved emittances (slice) are determined by using a bunch with a linear energy chirp which is dispersed by a magnetic spectrometer. By varying the strength of a quadrupole lens upstream of the spectrometer allows measurement of the individual slice emittances. Spectrometer images at the various quadrupole settings are binned in small energy/time windows and analyzed for the slice parameters. Our measurements indicate a temporal resolution of approximately 100 femtoseconds. In addition, the longitudinal phase space distribution is determined by measuring the energy spectrum over a range of linac phases. The correlated and uncorrelated components of the phase space distribution are determined by fits to the energy spectra analogous to a quad scan in the transverse dimension. The combined analysis of the transverse and longitudinal data gives not only the slice and longitudinal emittances, but also any correlations due to wakefields or other effects.

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Abstract
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INTRODUCTION

The first measurements of the slice emittance at GTF showed a large difference in value and behavior between the projected and slice emittances for low and high charge bunches [1,2]. At low charge they were in good agreement with each other and with thermal emittance measurements [3]. While it appeared obvious that most of the additional projected emittance was due to relative offsets between the slices, it had not be proven quantitatively. This paper describes further analysis of the data presented in ref [1] to quantify the slice offsets and their effect on the projected emittance.

EXPERIMENTAL TECHNIQUE

The SLAC Gun Test Facility consists of a 1.6 cell s-band gun with a copper cathode followed by a 3-meter SLAC section to produce beams at 30 MeV as shown in Figure 1. Details of this facility can be found in ref [4] and references therein. The slice emittance is measured using the chirped bunch technique, in which the linac is phased off crest to produce a bunch with a nearly linear energy-time correlation. The bunch is then dispersed by the energy spectrometer onto the spectrometer screen. The energy spectrometer is a vertical bend. The quadrupoles Quad1 and Quad2 are used to prepare the beam for a quadrupole scan determination of the slice emittance. In detail, the Quad1 is defocusing in the horizontal plane and focusing in the vertical. Therefore the beam in the vertical plane is small at Quad2 and the beam size on the spectrometer screen is only slightly affected by changes in Quad2. In the horizontal plane the beam is defocused by Quad1 making it large at Quad2. Thus changes in Quad2 strongly affect the beam size at the spectrometer screen. The result is that Quad2 can be varied to make large changes in the horizontal beam size on the spectrometer screen, while leaving the beam nearly unchanged in the spectrometer bend plane. This arrangement allows measurement of the slice emittance without disturbing the energy spectrum over the entire range of the quadrupole scan.

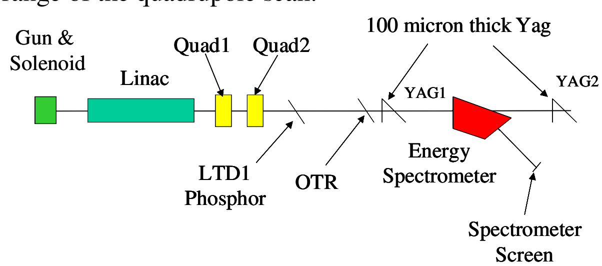

Figure 1: The SLAC/SSRL Gun Test Facility beam line components used for slice emittance experiments.

The emittance scan is done by varying Quad2 and collecting beam images on the spectrometer screen. The quadrupole range chosen includes the beam waist or minimum size on this screen. A typical image near the beam waist is shown in Figure 2. Each image is divided into 10 equal slices in energy/time, the transverse rms beam size is computed for the slices, averaged over 5 images at each quadrupole setting and then analyzed with the standard quadrupole scan technique to obtain the emittances transverse to the spectrometer bend plane. Additional energy spectra data are taken over a wide range of linac phases to obtain the longitudinal phase space. This is used to convert the energy scale to time[4]. The results of this analysis for three gun solenoid settings are shown in Figure 2.

These data show the projected emittance is approximately twice the typical slice emittance, and results from a combination of twisting and offsets of the slices in transverse phase space. The emittance and Twiss parameters along the bunch are plotted in Figure 3.

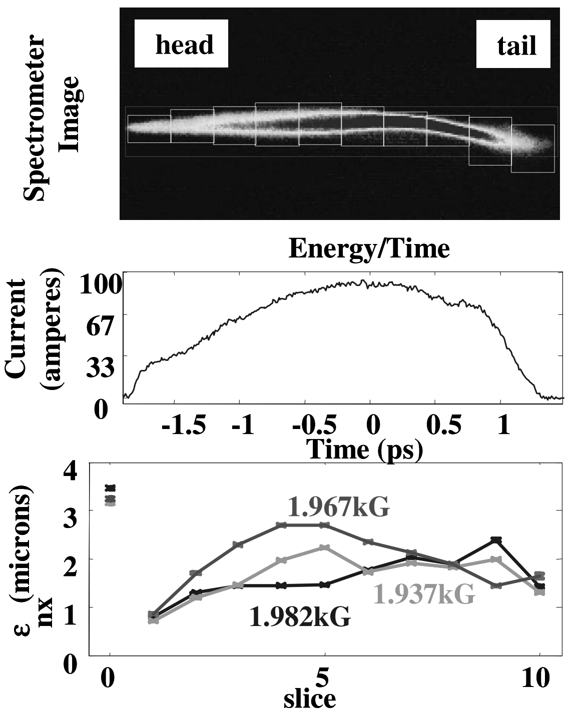

Figure 2: Slice emittance data from the GTF for three gun solenoid fields.

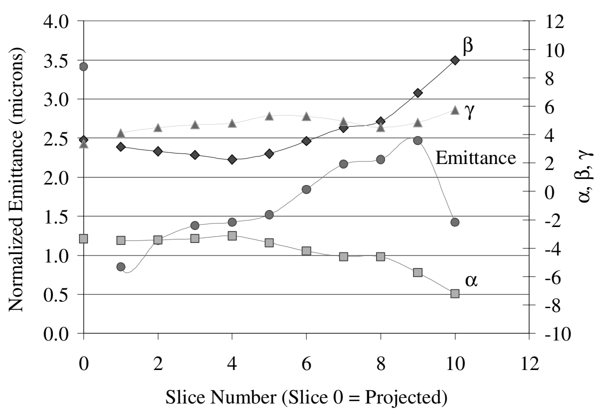

Figure 3: The slice emittance and Twiss parameters along the 300 pC bunch. The units for β and γ are meters and inverse meters, respectively.

DETERMINATION OF SLICE OFFSETS IN TRANSVERSE PHASE SPACE

In addition to the slice variation in Twiss parameters as given in Figure 3, there are also slice centroid offsets along the bunch due to wakefields and other effects. Experimentally, the slice ellipse offsets in transverse phase space are determined at the entrance to Quad1 by fitting the slice centroid as a function of the Quad2 strength. The slice centroids are computed relative to the full projected centroid. The basic concept is to determine the transverse position and angle of each slice by measuring the steering due to Quad2, similar to the standard method of beam-based alignment. The analysis includes the focusing properties of the spectrometer magnets. A typical fit to the centroid data is shown in Figure 4.

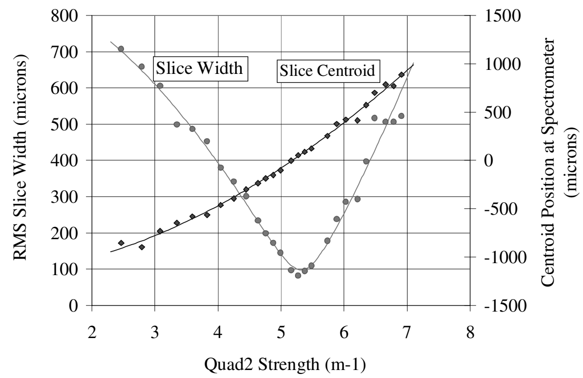

Figure 4: Rms width and centroid of a typical slice at the spectrometer screen as a function of Quad2 strength. The curves are fits to the data. The width fit gives the slice emittance and the centroid fit gives the slice offset in position and angle at the entrance to Quad1

The results of this analysis are summarized in Figure 5 where the emittance and slice position and angle offsets are given along the bunch. The X_0 and X_0' quantities are the position and angle offsets of each slice relative to the projected bunch center at the entrance to Quad1. The data show a significant oscillation of the slice offset from one side to the other near the tail of the bunch. The slices are offset by ~200 microns at Slice 6 and then shift to the other side of the bunch center to -700 microns at the tail. The position and angle offsets may be due to a single kick from the near-normal laser injection mirror located between the gun and linac section.

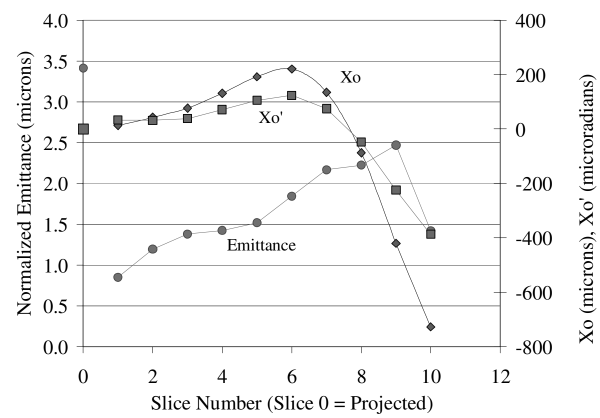

Figure 5: The slice offset in position and angle in front of the quadrupole doublet at 300 pC and a solenoid field of 1.982 kG. Slice 0 is the projected emittance and by definition the offset of the projected beam is 0.

SLICE ELLIPSES IN TRANSVERSE PHASE SPACE

With the slice ellipse parameters and offsets, their relative position can be plotted in transverse phase space, as is done in Figures 6 and 7. The figures clearly show the projected emittance is larger than the slice emittance not only due to variation in the Twiss parameters but also due to the position and angular offsets.

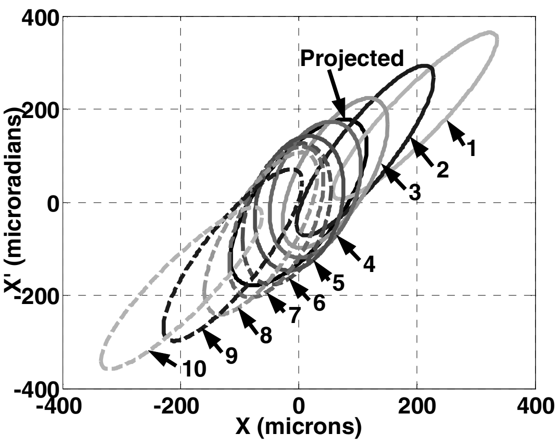

Figure 6: The slice rms emittance ellipses for slices labeled 1 to 10 in transverse phase space for 15 pC and a gun solenoid field of 1.669 kG. The projected emittance ellipse is shown in black.

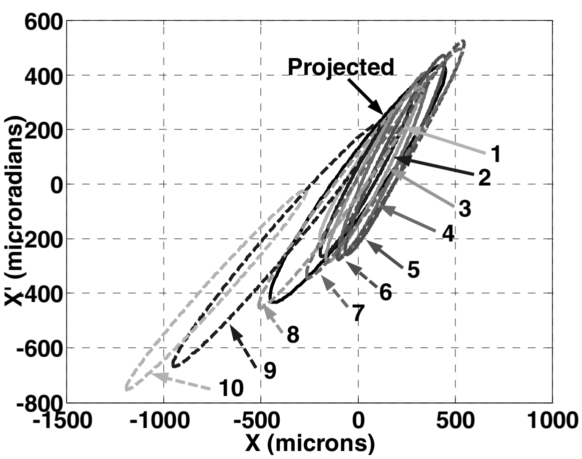

Figure 7: The slice rms ellipses in transverse phase space for 300 pC and a gun solenoid field of 1.982 kG. The projected emittance ellipse is shown in black.

In an attempt to separate these two effects, the rms Twiss parameters for each slice were used to construct Gaussian distributions in transverse phase space and the ten slices summed to produce an ensemble representing the total distribution. Computing the rms Twiss parameters for the total ensemble with and without offsets quantifies their effect.

For the case of the 15 pC data, the experimental projected emittance is 0.81 microns and the reconstructed emittance including the effect of offsets is 0.85 microns. If the offsets are artificially set to zero, the projected value becomes 0.65 microns. Since the emittance of the central slices is approximately 0.6 microns, the larger measured projected emittance is principally due to offsets.

For the 300 pC data, the experimental emittance is 3.4 microns and the reconstructed with offsets is 4.0 microns. This discrepancy is mostly likely due to an ideal Gaussian distribution used for each slice in the reconstruction while the real distribution is almost certainly not Gaussian. This is being investigated. In any case, the reconstituted emittance with no offsets is 2.5 microns. Implying ~44% of the projected emittance is due to the offsets. The average emittance of the central slices is 1.9 microns, suggesting that approximately 30% of the remaining projected emittance is due to slice misalignment. Even with the larger reconstructed projected emittance (4.0 microns vs 3.4 microns), it can still be concluded that more than half the the difference between slice and projected emittance is due to offsets with the remainder coming from slice misalignment.

ACKNOWLEDGEMENTS

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