Short High Charge Bunches in the SLAC Linac

F.-J. Decker, S. DeBarger, R.H. Iverson, P. Raimondi,
Stanford Linear Accelerator Center, SLAC*, CA 94309, USA

Abstract

These days the linac at the Stanford Linear Accelerator Center (SLAC) is mainly an injector for the PEP-II rings. But besides the electrons and positrons for PEP-II, it provides a 30 GeV electron or positron beam to the end of the linac into the FFTB (Final Focus Test Beam) area or creates a test beam for the A-Line. In the FFTB tunnel there are two plasma experiments installed, which have demonstrate plasma focussing and plasma acceleration up to 0.5 GeV/m. The acceleration goes linear with the current and is inversely proportional to the square of the bunch length. Therefore we are pushing the bunch length to shorter and shorter values adjusting the R_{56} in the RTL (Ring-To-Linac) compression section and pre-compressing the bunches in the damping ring. The non-linearity of the RF and the higher order dispersion are becoming more important for bigger compression factors. Then the high-charge, short bunches will create strong longitudinal wakefields in the linac. They create a double-horned energy profile and have different beam dynamics than a long bunch in the linac. Measurements of the beam properties, like stability, distributions, tails, and backgrounds are discussed in this paper.

1 INTRODUCTION

Combining plasma physics and accelerators has led to two interesting experiments at the end of the SLAC linac. Plasma focussing of a high energy beam is studied by the E-150 group. They demonstrated a focusing via a plasma lens, by about a factor of two (from 5 μm to 3 μm) of an electron beam as well as a positron beam [1]. The E-157 group studies plasma acceleration. They demonstrated an acceleration of up to 0.5 GeV/m over 1 m distance [2]. For these experiments a low emittance, intense beam with short bunch length is required. They used an SLC-like beam with $2{\cdot}10^{10}$ particles per bunch and an emittance with 5 in x and $0.3 \cdot 10^{-5}$ m-rad. The bunch length is a critical factor for the plasma acceleration and 0.6 mm gives a 4-times higher acceleration than the typical 1.2 mm long SLC beam. These shorter bunches will generate not only a plasma wakefield, but also a strong longitudinal wakefield in the conventional accelerator giving the beam a larger energy spread. This problem is increased since only 2/3 of the linac is accelerating the beam to 30 GeV instead of 45 GeV for power saving reasons. The typical beam set up is described first, then we discuss how to reduce the bunch length further and what problems were encountered and their explanation with simulations.

*Work supported by Department of Energy contract DE-AC03-76SF00515.

2 BEAM SET UP AND EXPERIMENTAL OBSERVATIONS

Typically the longitudinal beam parameters were set up somewhat differently than during the SLC era. Instead of $4{\cdot}10^{10}$ particles in a 1.2 mm for SLC, $2{\cdot}10^{10}$ particles in a 0.6 mm long bunch were delivered for the plasma experiments. This will still give about the minimal energy spread at the end of the linac. Trying to shorten the bunch length will increase that energy spread [3], but also showed unexpected difficulties with achieving shorter bunches.

2.1 Energy Spread

The energy distribution consists typically out of a core with a spread of about 0.15-0.2% with some energy tails. By changing the overall linac phase these tails can be pulled in to the core region while the core starts to separate into two horns, giving finally a double horned distribution with very sharp edges (Fig. 1). Besides the fact that the 1% wide distribution might hit some energy defining apertures, it was quickly noticed that there was some dispersion in the plasma region giving the beam an undesired tilt. Although the dispersion was carefully corrected both experiments ran mostly with the minimum energy spread. A shorter bunch length will have a not-reducible bigger energy spread which will make the experiments trickier.

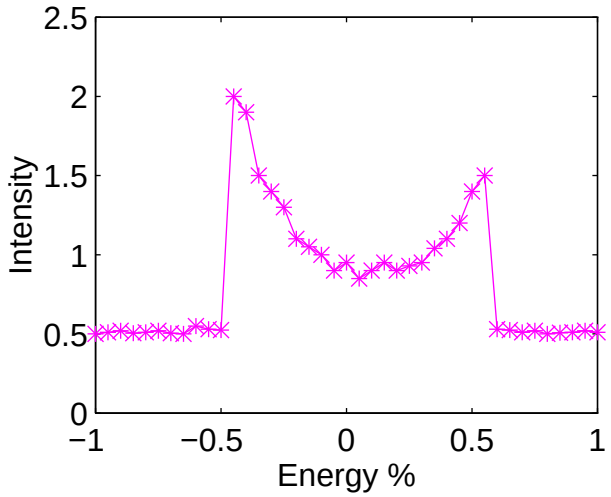

Fig. 1: Double-horned energy distribution measured at the end of the linac with a wire scanner at high dispersion.

2.2 Bunch Length

The bunch length in the linac depends on the longitudinal emittance from the damping ring and the set up of the compression in the ring to linac section (RTL). The damping ring for the electrons was operated with only one cavity. This gives about 600 kV instead of the usual 900 kV gap voltage, resulting in a 20% longer bunch (8.4 mm instead of 7 mm). By quickly varying the gap voltage just before the extraction it is possible to pre-compress the bunch by up to about 30% while increasing the energy spread by the same amount.

In the RTL an RF compressor with a voltage of 37 MV introduces an correlated energy spread. This correlation with the length rotates in the following beam line due to an R_{56} term of about 0.6 m giving a linac bunch length of 0.53 mm (Fig. 2). Besides the linear terms there are higher order terms, especially the non-linear compression due to T_{566} and the RF sin curve.

In the linac a 36 GHz cavity can be used to maximise the peak current, which will minimise the bunch length if the current is constant.

The further decrease in bunch length was tested first with the positron beam. Instead of pre-compressing in the damping ring we actually de-compressed it there by varying the timing so the bunch is longer but with a smaller energy spread. This smaller energy spread should rotate into a smaller bunch length if every thing would be linear. First we observed an additional beam loss in the RTL since the energy acceptance is only about ± 2.5%.

The measured 36 GHz signal was actually lower and had to be optimised by changing individual sextupole setting to influence the non-linear T_{566} term. Finally a bunch with 10% less charge and 10% smaller length could be achieved.

The electron beam had the handicap of the larger longitudinal emittance from the damping ring. The test to further compress this beam via the de-compression in the damping resulted actually in the opposite of the expected effect, a small increase in linac bunch length with de-compression and a decrease with pre-compression. Tab. 1 shows the results with pre-compression, without, and with de-compression.

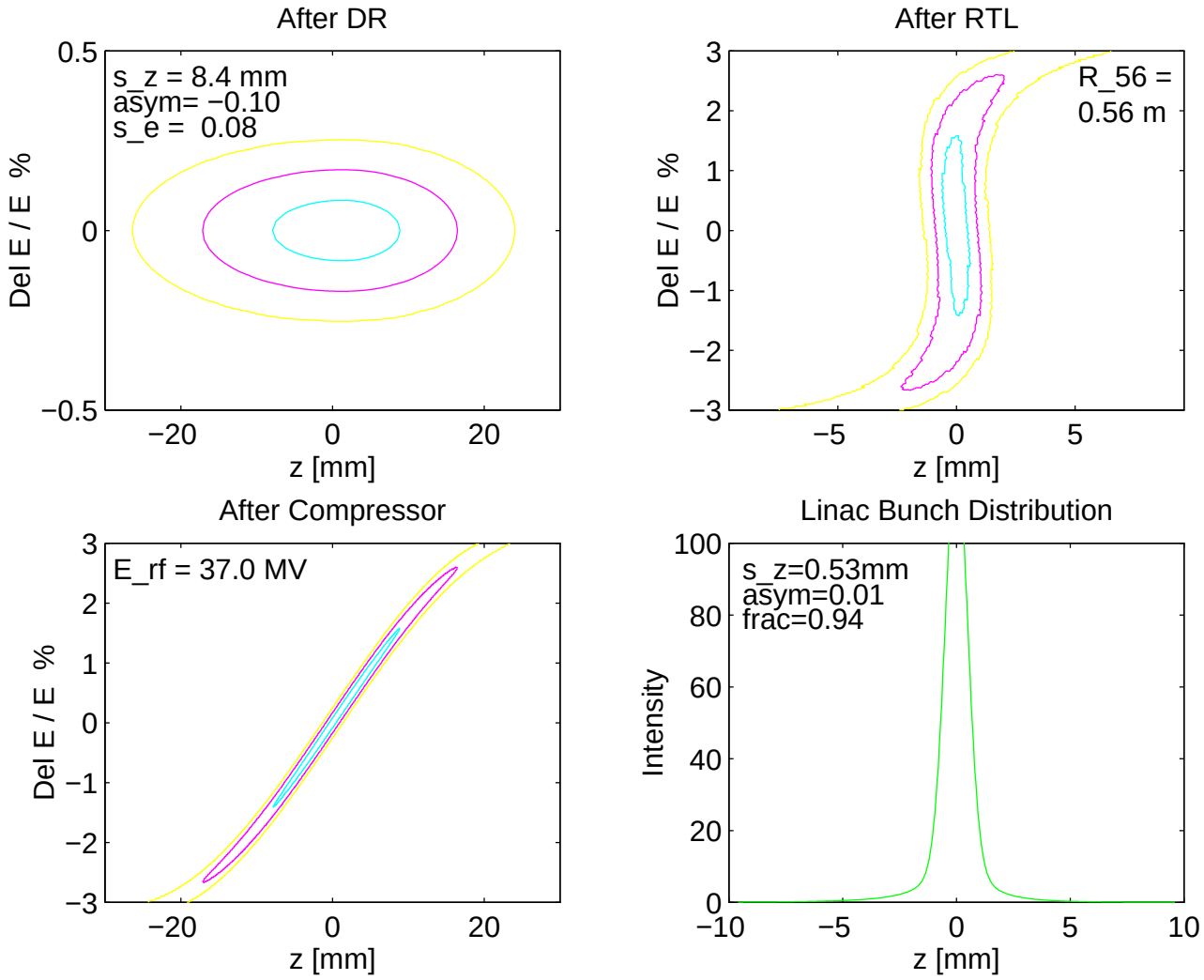

Fig. 2: Bunch length compression in the RTL.

	36 GHz	Intensity	Ratio
Off	574.4	346.7	1.657
De-compression	516.5	314.2	1.644
Pre-compression	609.0	360.0	1.692

Tab. 1: The 36 GHz signal, the bunch intensity and their ratio were measured for different damping ring pre-compression states. Although the current changes by 10% the bunch length varies less than 2%.

3 SIMULATIONS

Simulations followed to try to explain this somewhat unexpected result. With the typical running parameter including the lower damping ring gap voltage and the RTL compressor setting for minimum bunch length, we will get the result of Fig. 2. The variation due to the pre-compression is summarised in Tab. 2.

σ_{z_DR}	8.4 mm	9.8 mm	7.0 mm
σ_{E_DR} [%]	0.084	0.070	0.098
σ_{z_min}	0.53 mm	0.46 mm	0.59 mm
Fraction [%]	93.8	89.3	97.4
RMS	1.12 mm	1.56 mm	0.80 mm
RMS_t	0.61 mm	0.58 mm	0.63 mm

Tab. 2: The pre-compression in the damping ring of ±20% shows the expected behaviour when studying the sigma of a fitted Gaussian (σ_{z_min}). The RMS shows the opposite behaviour due to the long non-linear tails. Truncating the particles with an energy spread outside of ±2.5% gives barely a variation in the bunch length.

The diagnostic of the bunch length is done with a 36 GHz cavity which is optimised for bunches near 1.3 mm since the Gaussian fit to the FFT will give 36 GHz and therefore the steepest slope on that Gaussian. The 0.53mm with the non-Gaussian tails the FFT and a fit is also shown in Fig. 3. It can be seen that small improvements in bunch length will barely change the signal. This makes it hard to optimise especially when there are beam losses involved at the same time.

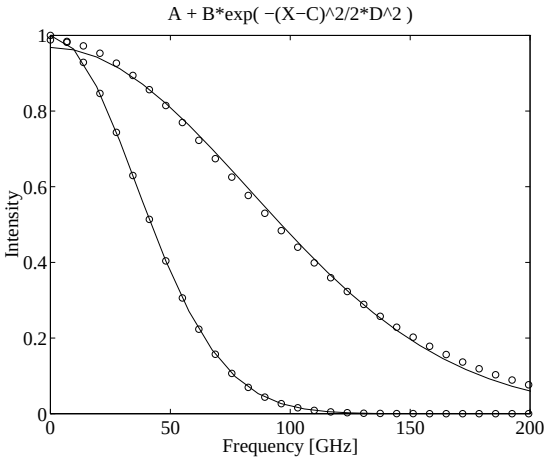

Fig. 3: FFT of 1.3mm Gaussian bunch and the 0.53 mm distribution from Fig .2

4 DISCUSSION

Comparing the experimental data with the simulation results show, that it is hard to get and diagnose much smaller bunches than 0.5 mm. The additional tails due to the lower gap voltage are mainly lost but still create some disturbing tails. Taking this into account with the truncated RMS gives roughly the observed effect of no change in bunch length. On the other hand it is obvious from Fig. 3 that there should be additional diagnostics to measure and optimise the bunch length, since the signal at 36 GHz can only be slightly raised.

5 REFERENCES

[1] J.S.T. Ng, et al., *Results on Plasma Focusing of High Energy Density Electron and Positron Beams*, LINAC2000, Aug 2000.

[2] M.J. Hogan et al., *E-157: A 1.4 Meter Long Plasma Wake Field Acceleration Experiment Using a 30-GeV Electron Beam from the Stanford Linear Accelerator Center Linac*, SLAC-PUB-8352, Apr 2000, 28pp.

[3] F.-J. Decker, et al., *Short, High Charge Bunches in the SLAC Linac for Plasma Experiments*, PAC99, New York, March 1999.