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Short High Charge Bunches in the SLAC Linac for Plasma Experiments [*]

F.-J. Decker, P. Chen, R.H. Iverson, R.H. Siemann

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA

Abstract

The linac at the Stanford Linear Accelerator Center (SLAC) can provide beams to different experiments during PEP-II operations. It is planned to have a 30 GeV beam to the end of the linac into the FFTB (Final Focus Test Beam) area, where there will be two plasma experiments installed. They will demonstrate plasma focussing and plasma acceleration up to 1 GeV/m. The acceleration goes linear with the current and is inversely proportional to the square of the bunch length. These high charge, short bunches will create strong longitudinal wakefields in the linac. They create a strong double-horned energy profile and have different beam dynamics in the linac. Therefore we made a test run in Fall of 1998 to measure and quantify the beam properties, like stability, distributions, tails, and backgrounds, which will be discussed in this paper. The actual plasma experiments are planned for the spring of 1999.

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The linac at the Stanford Linear Accelerator Center (SLAC) can provide beams to different experiments during PEP-II operations. It is planned to have a 30 GeV beam to the end of the linac into the FFTB (Final Focus Test Beam) area, where there will be two plasma experiments installed, which will demonstrate plasma focussing and plasma acceleration up to 1 GeV/m. The acceleration goes linear with the current and is inversely proportional to the square of the bunch length. These high charge, short bunches will create strong longitudinal wakefields in the linac. They create a strong double-horned energy profile and have different beam dynamics in the linac. Therefore we made a test run in Fall of 1998 to measure and quantify the beam properties, like stability, distributions, tails, and backgrounds, which will be discussed in this paper. The actual plasma experiments are planned for the spring of 1999.

1 INTRODUCTION

The combination of plasma physics and accelerators is studied in two experiments at SLAC. E-150 plans to focus a small high energy beam by a factor of about two (e.g. 5 μm to 3 μm) via a plasma lens, and E-157 plans an acceleration of up to 1 GeV/m over 1 m distance. For these experiments a low emittance, intense beam with short bunch length is required. An SLC-like beam with $4{\cdot}10^{10}$ particles per bunch and an emittance with 5 in x and $0.3 \cdot 10^{-5}$ m-rad in y seems ideal (or $2.5 \cdot 10^{-5}$ m-rad both). The bunch length is a critical factor for the plasma acceleration and 0.6 (or 0.4) mm will give 4-times (9-times) the acceleration than a 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 large 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. How an initial test run performed, which checked mainly the compatibility with PEP-II is discussed first and then simulations follow, which show how the energy spread develops.

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

2 TEST RUN

2.1 Compatibility with PEP-II

A test run together with PEP-II operation [1] showed that several features of running an accelerator had to be separated, or a combined solution found. The timing scheduling and the beam shut off system needed a further separation, and a combined energy profile and betatron lattice made some compromise to the FFTB energy (28.5 instead off 30 GeV).

2.2 Bunch Length and Energy Spread

The bunch length was estimated with a 36 GHz cavity and optimised to about 0.55 mm at 29.5 MeV compressor amplitude. Figure 1 shows the inverted cavity signal after normalising it to a toroid reading (stars:*) and scaling it to the expected curve (solid line, for an R_{56} = 0.7 m).

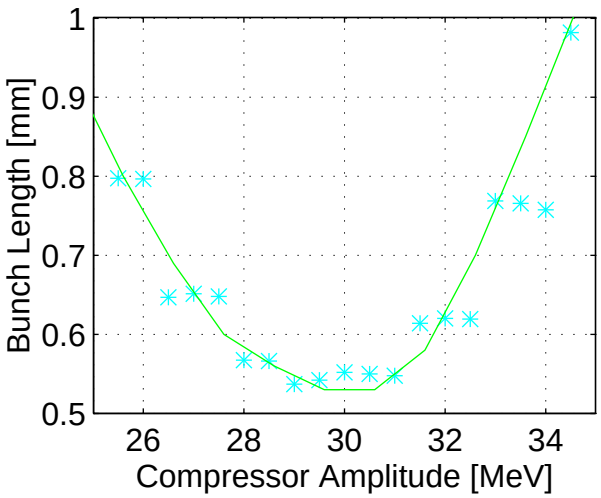


Fig. 1: Linac bunch length versus compressor strength.

Since something was wrong with the beam line (see below) we ran most of the time at 32 MeV compressor strength which lengthens the bunch to about 0.6 mm and gives a very small energy spread of about 0.15 %.

2.3 Emittance Odyssey

After years of watching over the last 10 or 20% emittance growth in the SLC era, it was an eye-opening experience to see emittances changing from roughly 100% to 2000% in a matter of days. This was the initial excuse for a noisy beam in the FFTB tunnel tripping protective ion chambers. After getting different rf phase adjustments

working for FFTB and PEP-II [1] and therefore being able to get BNS-damping [2] in place, the emittances came down and the orbits could be steered down to less than 150 µm rms, see Fig. 2.

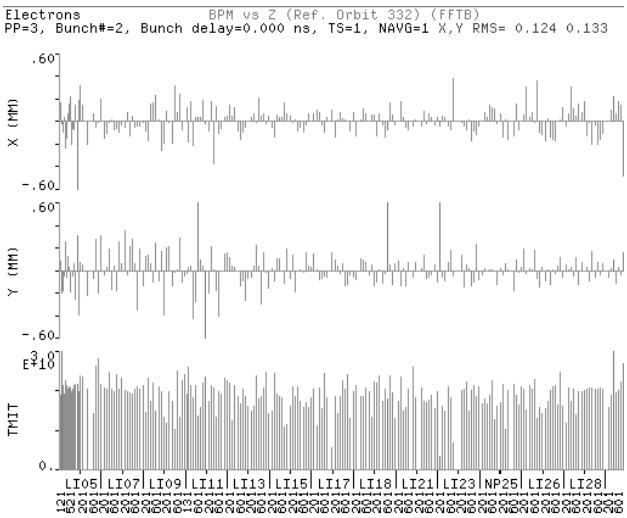
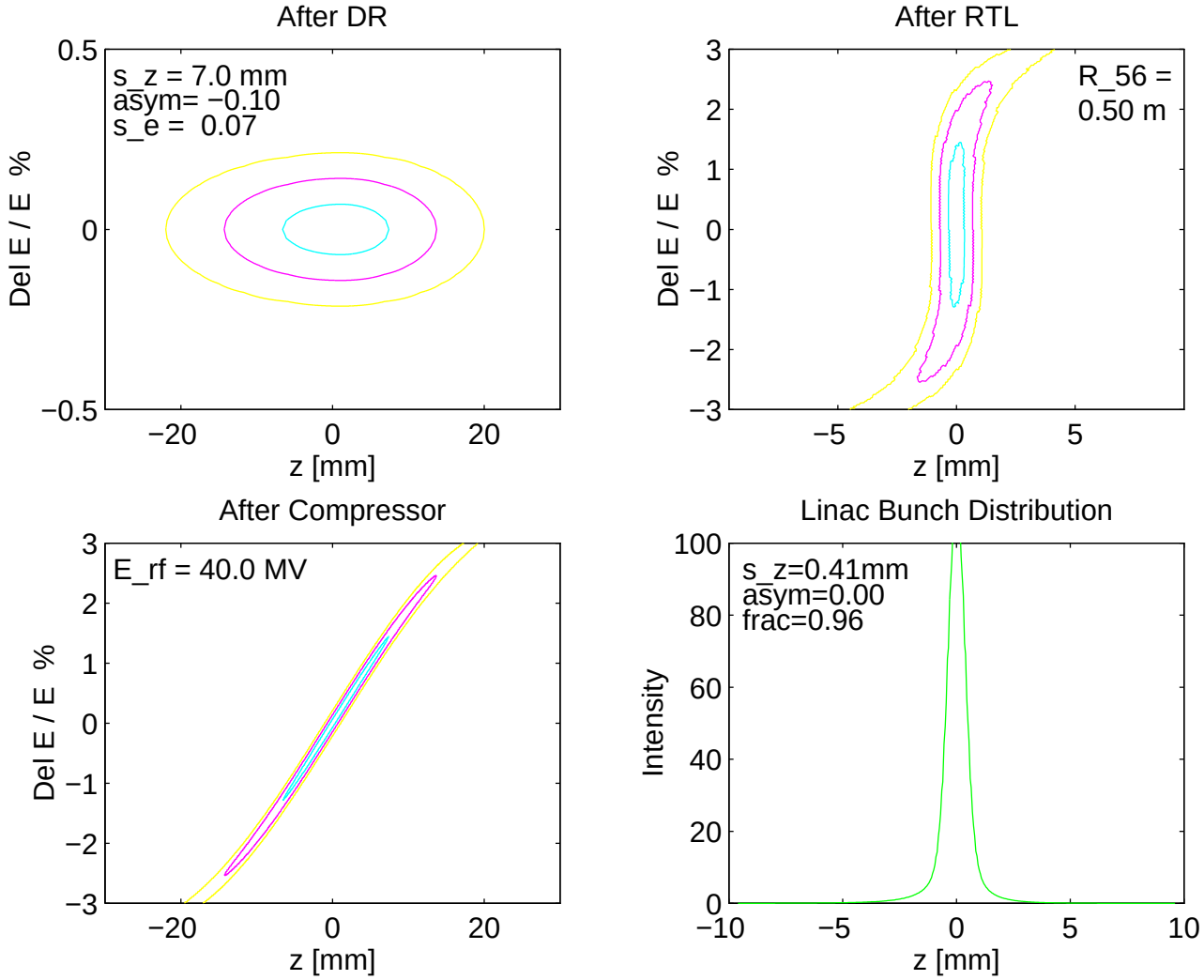


Fig. 2: Well-steered linac orbit.

Fig. 3: Bunch length compression in the RTL.

The beam emittances of $2.2 \cdot 10^{10}$ particles was with $4.7 \cdot 10^{-5}$ m-rad in *x* and $0.28 \cdot 10^{-5}$ m-rad in *y* comparable to SLC emittances. This was measured with wire scanners in Sector 28 about 250 m away from the end of the linac. But the beam in the BSY (beam switch yard) looked still fuzzy and bigger than usual. A quadrupole emittance scan revealed a value of $40 \cdot 10^{-5}$ m-rad in *y*, which is more than 100 times bigger than just 300 m further upstream. This "smelled" like something in the beam line like a profile monitor, a stuck valve with miswired interlocks, or even "ice" built-up in a cooled section between linac and BSY. In a combined effort to solve or localise the problem, everything got adjusted and a not working beam loss monitor system revived, after which the beam was fine and small. Actually it was so "good" that it caused a vacuum to water leak near or at the dump where the beam was parked, before sending it to FFTB. After this odyssey the beam was good enough for some early test in FFTB.



3 SHORT BUNCHES CREATE BIG ENERGY SPREADS

Since the plasma acceleration goes with one over the bunch length squared and only linearly with the current, it is interesting to study the creation and limits of short bunches.

3.1 Creation of Short Bunches

In the ring-to-linac (RTL) section a compressor cavity introduces a correlated energy spread (versus z), which then compresses the bunch length. Different compression strength (R_{56}'s) will end up with different minimum bunch lengths (see Tab. 1).

R_{56}	Compressor optimum	σ_{z_min}
0.7 m	30 MeV	0.55 mm
0.6 m	35 MeV	0.48 mm
0.5 m	40 MeV	0.41 mm

Tab. 1: Lower R_{56}'s reduce the minimum bunch length.

During the last SLC run the R_{56} was raised from 0.6 m to 0.7 m to reduce mainly the beam losses. If the adjustment range in the opposite direction is similar an R_{56} of 0.5 m is possible. This results in a 0.41 mm long bunch with 96 % throughput (see Fig. 3).

A further compression to about 0.3 mm with an inverse "pre-compression" in the damping ring seems possible, but first let's watch the resulting energy spread in the next section.

3.2 Energy Spread due to Longitudinal Wakefields

The longitudinal wakefield of a short, intense bunch will decelerate the bunch core and tail, creating a big correlation and a double-horned energy distribution. At 4 $\cdot 10^{10}$ particles and 0.4 mm bunch length the distance between the two horns is already 6% and cannot be reduced to zero anymore. Even if the beam would sit 90° off the crest, it would be still 1.5% (if the energy itself would not be zero). Being 5 mm (or 17°) off the rf crest, it will be still 4 %, see Fig. 4 and compare Tab. 2 for different currents and end energies.

The end energy of 30 GeV is achieved by not powering 1/3 of the klystrons, but whose accelerating structures will still generate wakefields, making the energy spread of $2 \cdot 10^{10}$ at 30 GeV equal to the one of $3 \cdot 10^{10}$ at 45 GeV. The limit will be set by the energy acceptance of the FFTB line.

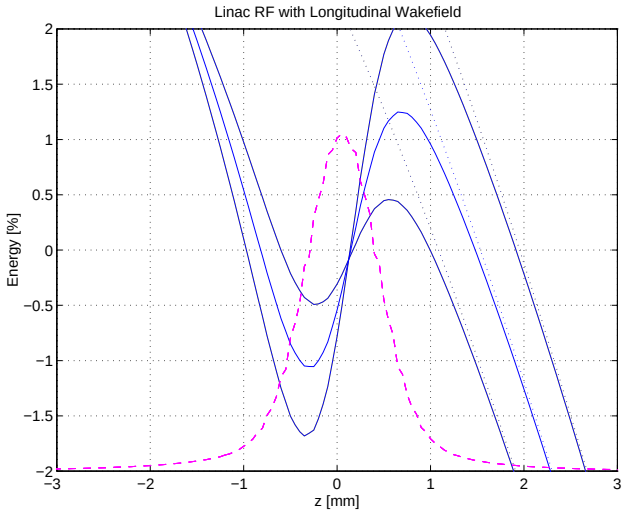


Fig. 4: Linac rf plus wakefield
for a 0.41 mm bunch with 2, 3, $4 \cdot 10^{10}$ particles.

N	$\Delta E/E$ at 30 GeV		$\Delta E/E$ at 45 GeV	
	0.41 mm	**0.54 mm**	**0.41 mm**	**0.54 mm**
$4 \cdot 10^{10}$	4.0 %	3.3 %	1.8 %	1.4 %
$3 \cdot 10^{10}$	2.5 %	1.8 %	1.0 %	0.5 %
$2 \cdot 10^{10}$	1.0 %	0.5 %	0.2 %	(-0.1 %)
$1 \cdot 10^{10}$	0.0 %	(-0.5 %)	(-0.5 %)	(-0.8 %)

Tab. 2: Double-horn distance $\Delta E/E$
for different currents at 30 GeV or 45 GeV energy
and the two bunch lengths of 0.41 mm and 0.54 mm.

4 CONCLUSION

Pulsed devices in the accelerator make a simultaneous operation of PEP-II and another beam for plasma experiments possible. Initial tests helped to improve this compatibility. Simulations have shown that short bunch lengths are possible, but the resulting energy spread will finally limit the length or the current.

5 REFERENCES

[1] F.-J. Decker, et al., *The SLAC Linac During the PEP-II Era,PAC99, New York, March 1999.*

[2] V.E. Balakin, A.V. Novokhatski, V.P. Smirnov, VLEPP, *Transverse Beam Dynamics,* 12th Int. Conf. On High Energy Accel., FNAL (1983) 119.