# LONGITUDINAL PHASE SPACE SETUP FOR THE SLC BEAMS

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*Abstract*

The longitudinal phase space distribution of the SLC beams is affected by many different machine parameters and constraints. By using a technique of over-compression [1] in the ring to linac transfer line, a small energy spread of 0.12 % can be achieved at the end of the linac for a bunch length of 1.2 mm ($\sigma$). In the final focus a small energy spread is desirable to reduce emittance dilution due to chromatic effects. Optimization of the bunch length is also important as a longer bunch of 1.2 mm can contribute up to 40 % luminosity enhancement due to disruption. If there is a correlated energy variation along the bunch, for example due to mistuning of the optimal rf phase with respect to the beam, the bunch will be further compressed as it passes through the SLC Arcs. The resulting bunch can be too short to produce the desired disruption enhancement, but will radiate more beam-strahlung during collisions giving a false indication of higher luminosity. This paper discusses the interplay of these issues from the damping ring to the interaction point.

## 1 GOALS AND PROBLEMS

The longitudinal phase space is setup to give a <u>small energy spread</u> for the limited band-pass [2] at the interaction point (IP) and to give no reason for luminosity weighted polarization [3]. No energy spread also helps to have no compression in the arcs to get a <u>long bunch length</u> at the IP. This gives luminosity enhancement due to disruption, when the hour-glass effect due to a large angular divergence is not yet limiting. – A long bunch in the linac experiences bigger transverse wakefield kicks, and a correlated energy spread would help stability (BNS-damping). Due to beam loading from the first bunch (positrons) to the second one (electrons), the accelerator structure should only be partially filled (off the PSK energy peak) to have the same energy for both bunches. This costs energy overhead and leads to a setup with a shorter positron bunch, which is further off the rf crest getting less energy. Short bunches give more beam-beam background at the IP, and have more low and high energy tails, which create other background along the way.

## 2 INITIAL CONDITIONS AND HIGHER ORDERS

The bunch length in the damping ring depends strongly on the beam current. Based on the data in [4] a 10 % in current changes the bunch length by 5 %. The dependence of the bunch length on the gap voltage is weaker at high current (fourth-root) than at low current (square root) [4]. At high current and high gap voltage a higher than expect bunch length is seen, which could be due to the microwave instability (saw-tooth) [5]. The measured energy spread varies from 0.080 % at low current to 0.092 % at $4{\cdot}10^{10}$ particles per bunch. The expected spread at low current is close to 0.071 %. There should be no dependence on gap voltage, except from the microwave instability. Increasing the gap voltage from 750 to 950 keV, the energy spread changes from 0.089 to 0.094 % at $4{\cdot}10^{10}$. The bunch length is strongly distorted by the potential well in the damping ring. The asymmetry factor is $A = (\sigma_h - \sigma_t) / (\sigma_h + \sigma_t) = -0.4$ at $4{\cdot}10^{10}$, which means that for $\sigma_z = 7.5$ mm, the head has a $\sigma_h = 4.5$ mm (40 % less) while the tail has a $\sigma_t$=10.5 mm. The centroid is 1.6 $A\ \sigma_z = -4.8$ mm shifted from the peak.

There are several higher order effects in the RTL, which are utilized to obtain the smallest possible energy spread with no energy tails at the end of the linac. These include:

### 2.1 Higher Order Dispersion

The $T_{566}$ term is about 1.5 $R_{56}$ = –900 mm, which means that higher and lower energy particles in the RTL are bent backwards (late), which is the right direction (sharp rise). This term can not be varied easily without a lattice design change. Figure 1 shows the 1, 2, and 3 sigma contour lines of the compression and the resulting linac bunch distribution.

### 2.2 Non-linear rf curvature

A similar effect can be achieved by decelerating the centroid of the beam in the compressor cavity using a phase offset.

### 2.3 Bunch Precompression in the DR

With bunch pre-compression [6] a quadrupole mode oscillation without phase oscillations is induced by successive application of two changes to the gap voltage. While advantageous for increasing the beam current, the advantages of bunch over-compression for bunch shaping are somewhat reduced. Interestingly [7] pre-compression of the bunch does not flip the asymmetry in the longitudinal beam distribution in the damping ring.

After the damping ring (DR) the bunch is asymmetric, it gets on the non-linear rf curve of the compressor, and after the ring-to-linac (RTL) beam line the bunch is over-compressed (S-shape). This gives a linac distribution with about two times ($N$/2) sharper edges than a Gaussian.

### 2.4 Sawtooth Instability

The sawtooth instability of the new damping ring [5] is visible as bursts in a 180 kHz signal and as ±3 % changes

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in the wings of the beam distribution at about 20 % peak height (quadrupole mode). This causes the linac bunch length to change by about 10 % causing additional transverse jitter, which was observed for the positron beam [8]. Techniques to control the time of occurrence of this instability have partially successful to date, yet will be studied further.

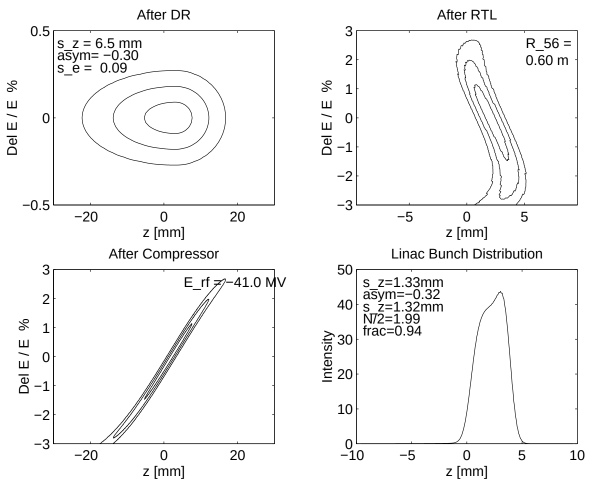


Figure 1: Bunch Compression Setup.

## 3 LONGITUDINAL PHASE SPACE TRANSPORT

The bunch length is usually adjusted using bunch compression and control of the injection phase into the linac to obtain the smallest energy spread at the end of the linac. With a typical bunch charge of $4{\cdot}10^{10}$ particles, the 7 mm bunch length [4] from the damping ring (DR) is compressed to 1.2 mm. Since 1993, the compressor cavity has been operated at a 1.4 times higher voltage in order to shape the longitudinal particle density distribution by over-compression. The goal of bunch shaping is to produce a very steep leading edge of the distribution which compensates [9] for the slope of the net voltage in the linear accelerator structures. The cancellation results in a minimum energy variation across the bunch (Fig. 2).

The SLC arcs have a compression term $R_{56}$ = 150 mm, which means that a correlated energy spread of 0.3 % would compress the bunch from 1.2 mm to 0.75 mm. If the correlation is not linear, but stronger in the core (as for the 1 mm Gaussian bunch distribution of the SLC design) the compression is even more, the 1 mm SLC-design beam at $5{\cdot}10^{10}$ would be totally compressed. To avoid additional compression in the arcs, the smallest possible incoming energy spread must be maintained. The IP bunch length sensitivity on linac injection phase is about ±20 % per degree. A small energy spread gives nearly no compression (Fig. 3).

At the interaction point (IP) the beams encounter strong beam-beam focusing forces. If the bunch length is of the order of the focal length, the luminosity may be enhanced. Up to 40 % disruption enhancement, at 100 Z/hour, is expected [10,11,12] with 1.0 mm bunch length, $4{\cdot}10^{10}$ particles per bunch. However, in tuning for high luminosity, there may be conflicting requirements.

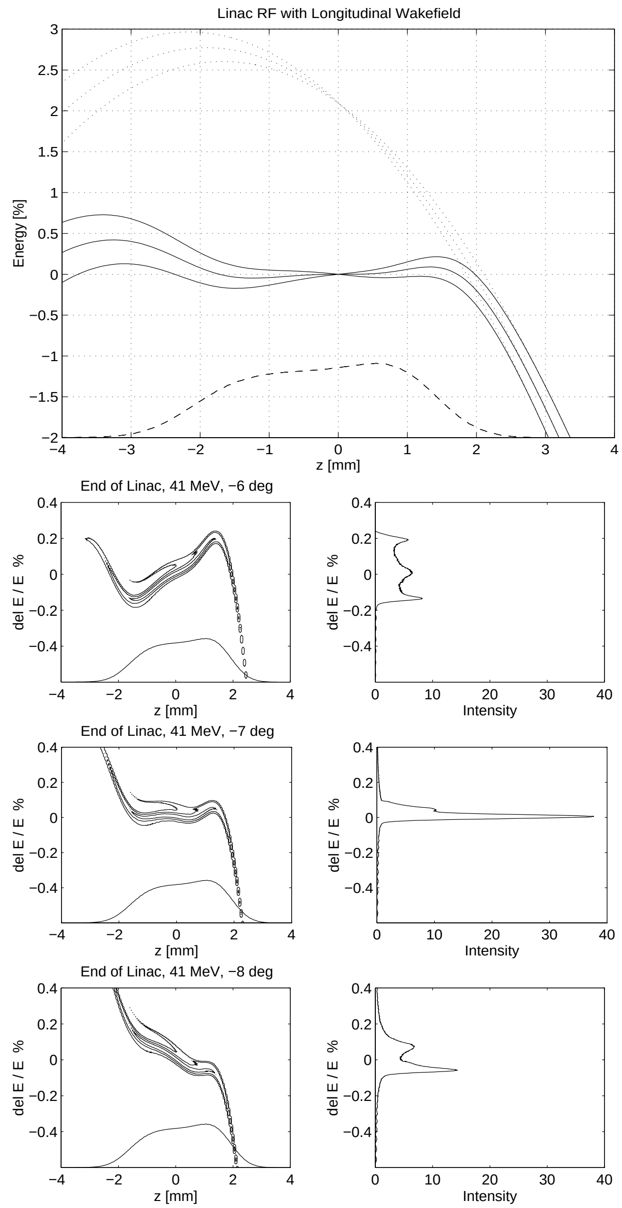


Figure 2: Energy–z correlation for different linac phase.

For example, with a very short bunch and no enhancement, the radiated beam-strahlung is higher. Detectors sensitive to beam-strahlung may therefore be difficult to interpret.

Small phase changes of ± 1° influence the energy–*z* correlation which changes the IP bunch length by 20%. The beam distribution is generated by over-compression. The lower plots show the energy distribution on the right.

The beam has to get the right bunch length and distribution in the RTL, so the longitudinal wakefield and the rf-curvature cancel each other to get a small energy spread, so that there is no further compression in the ARC.

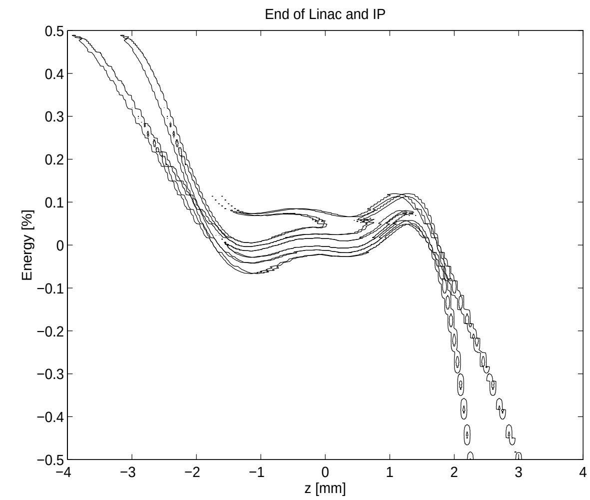


Figure 3: Setup for no ARC compression.

## 4 EQUAL BUNCH ENERGY

The two bunches in the linac can be adjusted by different means in energy, energy spread, and bunch length. The leading bunch, the positrons, produce via beam loading a change in energy gain (relative to the next pulse of electrons) of about 1.2 % at $4 \cdot 10^{10}$. This energy difference is compensated by adjustment of the time of the phase flip in the energy doubling, SLED (see Fig. 4). Due to finite available energy, however, this time cannot be arbitrarily set. It is difficult therefore to maintain positrons of large bunch length. This area needs further research since the positron bunch length was too short during the last run.

Equal energies are obtained by putting both beams, which are 60 ns apart, off the peak of the PSK energy curve to compensate the beam loading. At high current the beam loading of the positrons is so high that the offset would cost lots of energy, which makes it necessary to use other methods (like short bunch and off the rf crest).

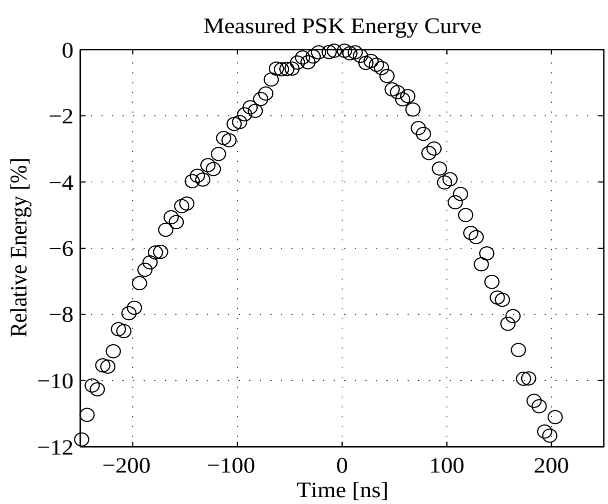


Figure 4: Equal electron – positron energies.

## 5 SUMMARY

To get the desired long bunch length at the interaction point (IP), the following has to be right:

1. compressor strength 2. linac phase

to get the smallest possible energy spread at the end of the linac. Positron bunches might get shorter to get less energy due to the right rf phase (for energy spread), to compensate for more energy due to the beam loading and rf fill-time of the accelerator (PSK).

## 6 ACKNOWLEDGMENTS

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## REFERENCES

[1] F.-J. Decker, R. Holtzapple, T. Raubenheimer, *Over-Compression, a Method to Shape The Longitudinal Bunch Distribution for a Reduced Energy Spread,* LINAC94, Tsukuba, Aug. 1994, p. 47.
[2] N. Toge et al., *Chromaticity Corrections in the SLC Final Focus,* PAC91, San Francisco, 1991, p. 2067.
[3] F.-J. Decker, J.T. Seeman, *Luminosity Polarization Correlation in the SLC,* EPAC, London, June 94.
[4] R. Holtzapple, Ph.D. Thesis, SLAC-487, 1995.
[5] K. Bane et al., *High Intensity Single Bunch Instability Behavior in the New SLC Damping Ring Vacuum Chamber,* PAC95, Dallas, TX, 1995.
[6] M.G. Minty et al., *Operation and Performance of Bunch Pre-Compression for Increased Current Transmission at the SLC*, PAC97, Vancouver, 1997.
[7] K.L.F. Bane, M.G. Minty, A.W. Chao, *Simulations of Bunch Pre-Compression at High Currents in the SLC Damping Ring,* PAC97, Vancouver, 1997.
[8] F.-J. Decker et al, *Higher Order Beam Jitter in the SLC Linac,* Linac96, Geneva, 1996, p 143.
[9] G.A. Loew, J.W. Wang, *Minimizing the energy spread within a single bunch by shaping its charge distribution,* IEEE, Vol. NS-32, No. 5, 1985, p 3228.
[10] P. Chen, *Grand Disruption: A possible Final Focusing Mechanism for Linear Colliders*, SLAC-Pub-3823 (1986), Part. Accel. 20 (1987), p. 171.
[11] P. Raimondi, P. Chen, F.-J. Decker, *Disruption Effects on the Beam Size Measurement,* PAC95, Dallas, May 1995.
[12] K.L.F. Bane, P. Chen, F. Zimmermann, *Beam-Beam Simulations with Non-Gaussian Distributions for SLC and SLC-2000,* PAC97, Vancouver, 1997.
[13] F. Zimmermann et al., *An RF Bunch-Length Monitor for the SLC Final Focus,* PAC97, Vancouver, 1997.