COMPARISON OF PARMELA SIMULATIONS WITH LONGITUDINAL EMITTANCE MEASUREMENTS AT THE SLAC GUN TEST FACILITY

C.Limborg*, P.R. Bolton, J.E.Clendenin, D.Dowell, S.Gierman, B.F. Murphy, J.F.Schmerge
MS 69 SLAC 2275 Sand Hill Road, Menlo Park CA , USA

INTRODUCTION

At the Gun Test Facility (GTF), we have been testing an S-band RF gun similar to the one to be used in the Linac Coherent Light Source (LCLS) Photo-Injector. The beam transverse properties have been extensively characterized on that gun and it was shown that this gun is capable of providing slice emittances of less than 1 mm.mrad for 100A slices [1]. The longitudinal beam properties are now also being investigated for 2 principal reasons:

- the transverse beam properties are correlated to the longitudinal one; an excessively large correlated energy spread at the gun exit would damage the emittance compensation
- the uncorrelated rms energy spread as small as 10keV at the gun exit is required for a good lasing in the LCLS

To measure the longitudinal emittance, the booster phase scan technique has been used at the GTF as described in [2]. We have now performed simulations of this experiment to better understand the non-linear effects and to reconstitute the longitudinal emittance.

Set-Up

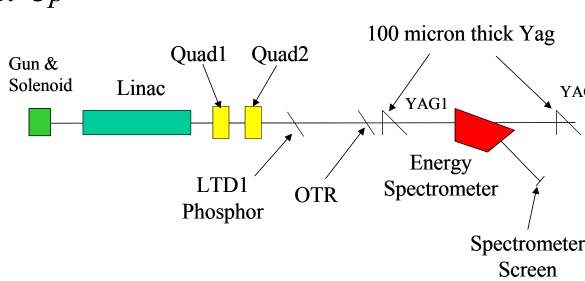

Figure 1: Layout of the GTF- The 1.6 cell S-Band RF Gun is operated at 110MV/m; the Linac is located at 89cm from the cathode.

LOW CHARGE

We first studied the low charge case. At 16 pC, the space charge effects are very small for a bunch with a FWHM close to 2ps. The RF effects in the gun are dominant. By comparing with PARMELA simulations, we could deduce the initial injection phase and bunch length. Those values were then compared with experimental parameters.

Bunch Compression

In figure 2, the evolution of bunch length and energy spread as a function of injection phase shows that:

- the bunch is compressed for injection phase smaller than 70 degrees (from zero-crossing)
- the rms bunch length does not depend on the shape of the bunch
- the energy spread (correlated) is very small for phases between 0 and 35 degrees

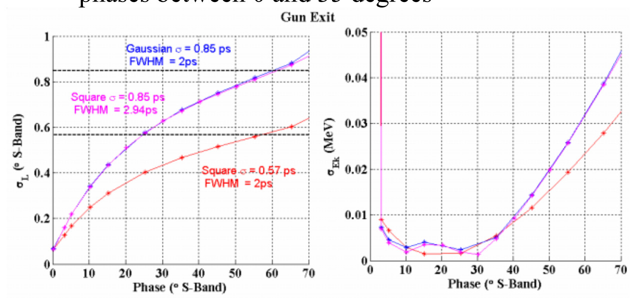

Figure 2: rms bunch length and energy spread as a function of injection phase

The rms bunch length reconstituted from the linear analysis of the booster phase scan at low charge, as shown in figure 5 of reference [2], was 0.4 ps. The experimental injection phase is 30 degrees. We conclude that the initial UV laser pulse had an rms close to 0.57 ps.

Booster Phase Scan

The booster phase scan measurement technique is described in detail in [2]. We use a reference phase of zero for the crest of the Linac RF sinusoidal field. This phase corresponds to the case where a maximum energy is reached for any particle. This is equivalent to the definition used in the experiment.

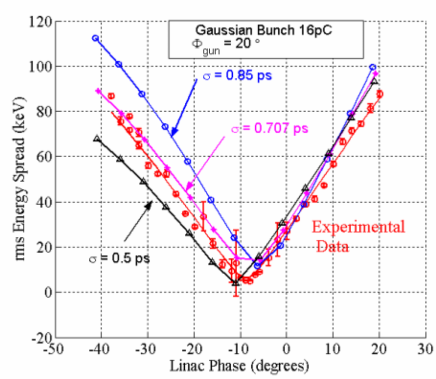

Figure 3: rms energy spread vs booster phase; Comparison experimental data with PARMELA simulations for 20° injection phase, for different initial laser pulse lengths

The 20 degrees injection phase seemed to give a better agreement for longer pulses as shown in figure 3. It was checked experimentally that the injection phase was 30 degrees, by measuring the output charge vs injection

(*) Contact: C.Limborg
e-mail: limborg@slac.stanford.edu

phase at low current. Rms bunch length of between 0.5ps and 0.6 ps gave a good match to the experimental data as shown in figure 5. It was also checked that the rms energy spread only depends on the initial rms laser pulse laser and not on its shape.

HIGH CHARGE

The next series of measurements compared with the simulation corresponds to 290pC. It corresponds to a peak current close to 130 A for the core of the bunch. This is slightly larger than the LCLS requirements [1].

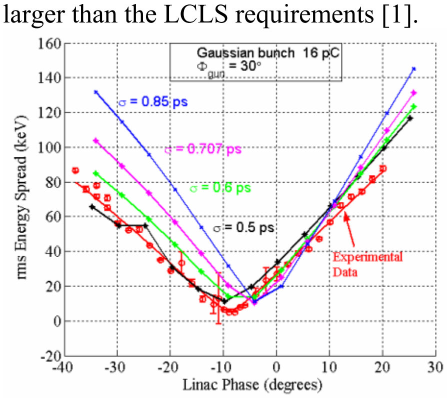

Figure 4: same as Figure 3 but for 20° injection phase.

Bunch Length

In figure 5, the evolution of bunch length and energy spread as a function of phase, for 200pC (not 290pC) shows:

- bunch lengthening occurs within the gun
- strong bunch lengthening and energy spread increase appears in the drift between the gun and entrance of the linac
- again the rms bunch length and rms energy spread are independent of the shape of the bunch and depend only of the initial rms laser pulse length; this is not true for the total energy spread which gets larger for a square pulse than for a Gaussian pulse having the same initial rms value

For 30 degrees injection phase, the bunch has lengthened by 40% at the gun exit and by 70% at the linac entrance with respect to the laser pulse length.

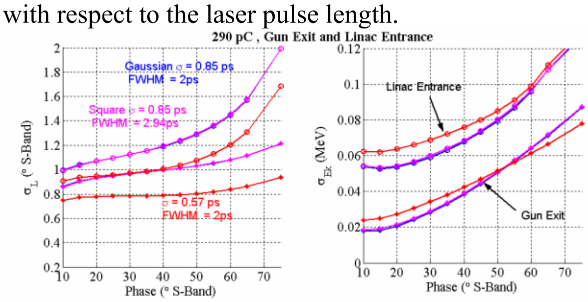

Figure 5: rms bunch length and energy spread as a function of injection phase for 290pC

Booster Phase Scan (no wakefield)

A first analysis was done ignoring the effect of wakefield in the linac. It could be concluded, as in the low charge case, that the evolution of rms energy spread as a function of booster only depends on the original rms bunch length but not on the shape of the bunch. This is illustrated in figure 6. For all the pulse lengths chosen, the slopes of the PARMELA curves do not match the measurements.

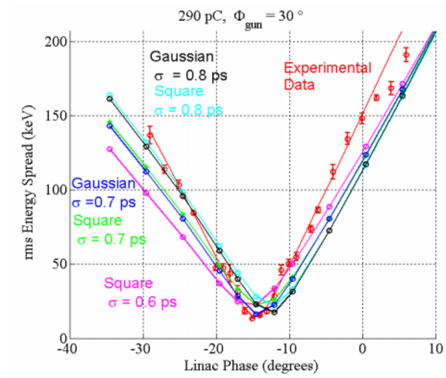

Figure 6: rms energy spread vs booster phase

Booster Phase Scan (with wakefield)

In any event, for peak currents close to 100 A, wakefields cannot be neglected anymore. The longitudinal wakefield in the SLAC S-Band section can be approximated by:

$$W(s) = \frac{Z_o c}{\pi a^2} e^{-s/s_o}$$

$$\text{with } Z_o = 377\ Ohms, \text{a} = 11.6\text{mm and } \text{s}_o = 1.32 \text{ mm}$$

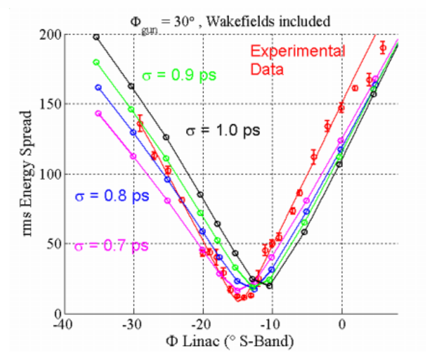

Figure 7: rms Energy spread vs booster Phase for various initial rms bunch length; wakefields are included

Longitudinal wakefield calculations were added to the PARMELA computations. It was checked that there was little difference applying the wakefield at a single point either at the end of the linac or at 20 locations along the linac. When including wakefields, it was not possible either to obtain a good match of PARMELA results with the experimental curve by varying the pulse length as shown in figure 7.

None of the solutions were satisfactory. However, we knew that we were negledcting wakefield effects in the drift from gun to linac. More particularly, we fear that the entrance port for the laser beam located at 50 cm from the cathode, generates strong longitudinal wakefields. This port hosts the last mirror for steering the laser beam to the RF gun cathode. We plan to compute this wakefield using ABCI. But, in the meantime to include some additional energy spread on the bunch, we simply unbalanced the gun field ratio between the two cells. This generates some additional energy spread on the bunch as plotted in figure 8.

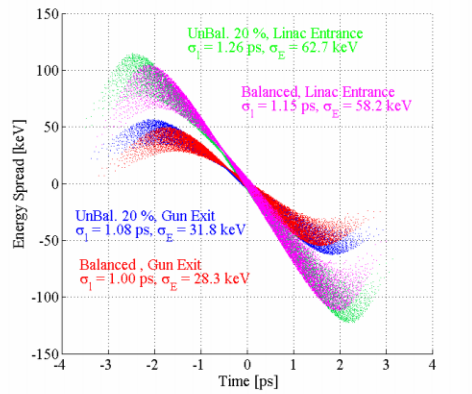

Figure 8: Longitudinal phase space from PARMELA output at gun exit and entrance Linac for Balanced and Unbalanced cases initial; the rms pulse length is 0.9ps

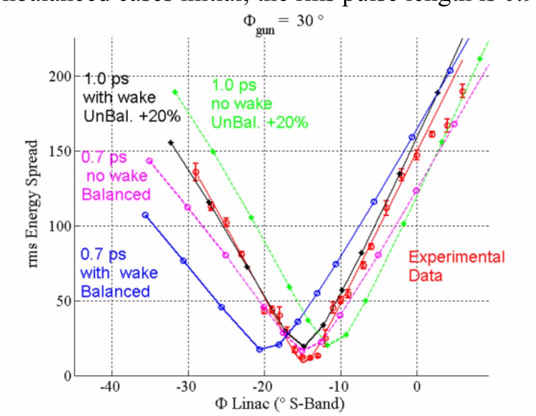

Figure 9: rms Energy Spread vs booster Phase w/o wakefields, w/o additional energy chirp. (UnBal. = ratio field amplitudes of the 2 cells different by 20 %)

The most satisfying fit corresponds to the case of an initial pulse of 1ps and a gun unbalanced by 20%. Thorough measurements of the gun field balance on the GTF gun have been performed and show that the gun was not unbalanced when the experiment was done [3]. However, we believe that an additional wakefield effect increases the correlated energy spread of the bunch in the drift between the gun exit and the linac entrance.

We deduce that the rms bunch length and the rms energy spread are respectively 1.26 ps and 62.7 keV at the entrance of the linac. The measurement of the bunch length will be performed at the entrance of the linac using an Electro-Optic device next summer and the booster phase scan experiment will be repeated.

The uncorrelated energy spread along the bunch can be extracted after removal of the correlation as plotted in figure10. All the slices have an uncorrelated rms energy spread smaller than 10 keV. This confirms what has been measured at other facilities[4].

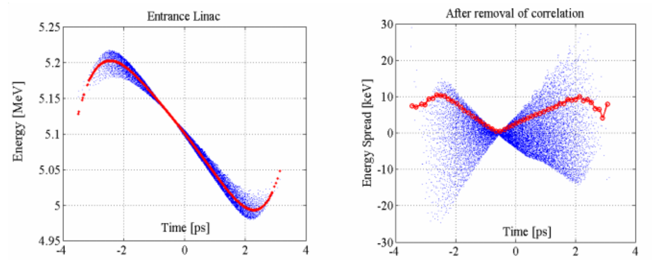

Figure10- Longitudinal Phase Space at linac entrance (1) – Uncorrelated energy spread (2)

CONCLUSION

From the low charge studies, we reconstitute the initial rms bunch length to be 0.5-0.6 ps. The high charge case leads us to an initial rms close to 1ps. This increase in uv pulse duration with pulse energy is possible since the uv conversion (from ir) is a two stage second harmonic generation process. Furthermore, we had not fully implemented uv pulse energy control that was independent of the ir pulse energy. Producing electron bunches with 15 pC and 290 pC charge levels required uv pulse energies of 1.2 µJ and 23 µJ respectively. At lowest ir and uv energy levels, the uv pulse duration can be half of that for higher ir and uv levels. The temporal profile of single uv pulses needs to be directly measured. Measuring the temporal profile of a single ir laser pulse is done using a FROG technique. A similar technique will implemented to enable single uv pulse measurements.

REFERENCES

[1] C.Limborg "New Opitmization for the LCLS injector", EPAC02, Paris, June 2002

[2] D.Dowell et al. "Longitudinal Emittance Measurements At the SLAC Gun Test Facility " D.Dowell, FEL02, ANL,Chicago,August 02, (SLAC-PUB-9541)

[3] S.Gierman, Private Communications, LCLS Tech note to be released

[4] H.Schlarb, Private Communications, Measurements of energy spread on L-Band Gun at the TTF

SLAC is operated by Stanford University for the Department of Energy under contract number DE-AC03-76SF00515