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# MODIFICATIONS OF THE LCLS PHOTOINJECTOR BEAMLINE *

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## *Abstract*

The LCLS Photoinjector beamline is now in the Design and Engineering stage. The fabrication and installation of this beamline is scheduled for the summer 2006. The Photoinjector will deliver 10 ps long electron bunches of 1nC with a normalized transverse emittance of less than 1 mm.mrad for 80% of the slices constituting the core of the bunch at 135 MeV. The calculations done to finalize the specifications of the photoinjector beamline components are described. Modifications include a new exit energy, additional focusing between the two linac modules, the insertion of a "laser heater", and a new geometry for the coupling cells of the RF structures. We also discuss two interesting tunings, one for the nominal charge of 1nC but using a longer laser pulse and the second one for a lower charge of 0.2nC. Sensitivity to field errors and misalignment for those two new configurations is compared to that of the nominal tuning.

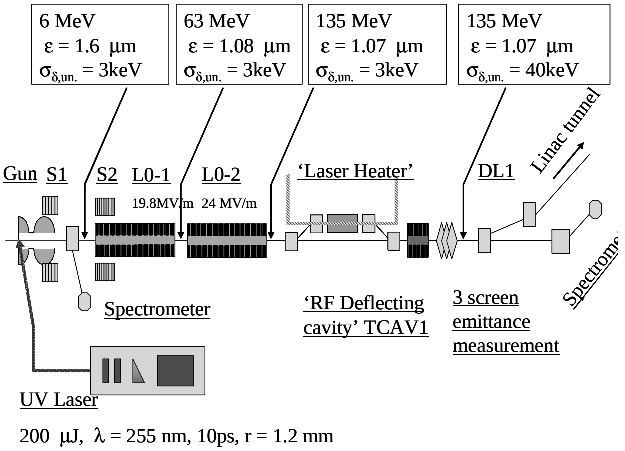

Figure 1: Schematic of the LCLS PhotoInjector.

## NOMINAL TUNING

### *Modification of final Energy*

As we are beginning the engineering and construction phase, final modifications on the beamline have been performed. In particular, the nominal exit energy was changed from 150 MeV to 135 MeV. To reach 150 MeV, the optimal tuning required running the first linac, L0-1, at 18 MV/m and the second linac, L0-2 at 30 MV/m. The operation of L0-2 at such a high gradient would have generated dark current, likely to perturb diagnostics. L0-1 will be operated at 19.6 MV/m and L0-2 at 24 MV/m. The final energy will be 135 MeV.

The rms transverse beam size becomes as small as 80 $\mu$m in the matching section at the waist of the three screen emittance station. PARMELA simulations have shown that at 135MeV, the emittance will not increase in the matching section. The emittance would increase by more than 1% or more for energies lower than 120 MeV.

### *Additional focusing in L0-1 L0-2 drift*

Two quadrupoles have been added in the drift between the two linac sections to reduce the transverse beam size at the exit of L0-2. In previous computations done with PARMELA, the rms beam size had wrongly been estimated to be about 300 $\mu$m at the end of L0-2. Space charge kicks had been applied every 5 degrees in L0-2, but to correctly include the defocusing/focusing kicks at the passage through the iris, computations need to be done at time steps separated by less than 1 degree. With the new quadrupoles, the number and the recent results show that adding a quadrupole doublet in this section allows fewer and weaker matching quadrupoles.

## LSC INSTABILITY

### *Longitudinal Space Charge (LSC)*

As described in [1], the longitudinal space charge force creates micro-structures in the longitudinal phase space from an initial modulation of the photo-electron current profile. The micro-bunching is strongly amplified in the bunch compressors. This induces a too-large uncorrelated energy spread at the entrance of the undulator, possibly preventing the saturation or even the lasing of the SASE FEL.

A "Laser Heater" has been added to the Injector beamline in the matching section [2,3]. The interaction between the laser beam and the electron beam increases the uncorrelated energy spread from 3keV to 40 keV. With this larger energy spread, the microbunching is not amplified.

## RF MODIFICATIONS

### *Time dependent kicks at entrance L0-1*

Computations have been made to evaluate the maximum tolerable amplitude of the RF time dependent dipole kick. Such a dipole kick comes from the phase term of the power flowing through the single-sided power feed of the entrance cell of the SLAC linac structure as the amplitude term has been corrected by offseting the cell axis with respect to the cavity one. The computation of the time dependent dipole kick is similar to that of a transverse wakefield for a beam entering the cavity at small angle. Wakefield-like computations have shown that if the kick exceeds 120 $\mu$rad over the 10ps bunch, the 80% emittance will increase by 2%. The dipole kick from

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a single feed exceeded that value. Accordingly, the entrance cell will be modified to accommodate a dual feed [5].

The introduction of the second feed increases the quadrupole moment. The time dependent quadrupole field intoduces a head-tail quadrupole moment on the beam . PARMELA simulations indicate that the 80%-emittance will increase by 2% if the quadrupole moment is as large as 0.075 rad/m. To meet this specification, the geometry of the cell was changed to a racetrack shape [5].

A similar study has been undertaken for the gun to introduce dual power feed in the 1.6 cell RF gun. Preliminary results are described in [6].

## NEW TUNINGS

All setpoints and tolerances on components have been defined for the nominal LCLS tuning which gives an 80%-emittance of 0.9 mm.mrad at the end of the injector, leaving only a 0.1 mm.mrad margin for cumulated electro-magnetic field errors [2]. The 0.9 mm.mrad value is obtained assuming an thermal emittance of 0.6 mm.mrad per mm of radius spot size. The radius spot size being of 1.2 mm, slice emittances cannot be smaller than 0.72 mm.mrad. The present emittance compensation scheme only corrects for the linear space charge effects, so the average slice emittances is 0.85 mm.mrad for the core 80 slices. The thermal emittance can be reduced by minimizing the size of the laser spot on the cathode. The pulse length needs to be lengthened to maintain the charge density in the same range as for the nominal tuning.

### *Long Pulse*

With a radius of 0.85 mm, the thermal emittance is 0.5 mm.mrad. With a 20 ps long laser pulse, the charge density is similar to that of a 10 ps long with 1.2mm spot size radius. The optimum solenoid was found to be exactly the same as that of the nominal tuning. The optimal injection phase was 1 degree away from that of the nominal tuning.

The 20 ps long photoelectron bunch exiting the cathode is compressed in the gun and the final bunch length is 17.5 ps. Further compression in the macgnetic chicanes of the 17.5 ps long pulse is possible but tolerances on RF phases become too difficult to meet. Starting with a 17.5 ps laser pulse and a 0.85 mm radius spot size, we get a compression down to 15 ps in the gun. It has been demonstrated with a start-to-end simulation that a 15 ps bunch can be easily compressed in the LCLS to produce peak currents in the 3kA range [7]. The longitudinal phase space at the gun exit and at the linac entrance has been represented in figure 1. One will notice that the central part is very flat (nearly no RF curvature), which helps obtaining a good projected emittance.

Again due to non-linear space charge effects, the final slice emittance, which is approximately 0.65 mm.mrad, is higher than the thermal one of 0.5 mm.mrad. In Figure 2, one can see that a slightly larger radius might be beneficial for a smaller 80% emittance, however, the slice emittance will then increase.

A sensitivity study on the tuning based on the 17.5 ps laser pulse was performed and results are summarized in Table 1.

The laser system has been specified to produce pulses as long as 20 ps. This tuning still needs to be tested with respect to longitudinal space charge instability.

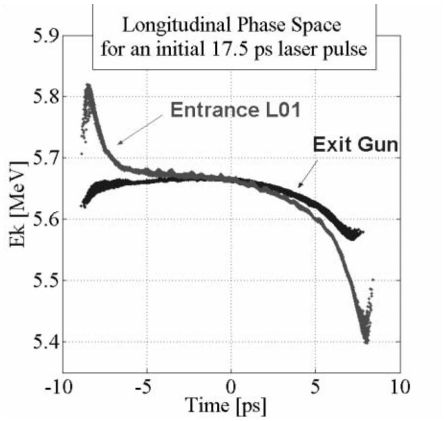

Figure 2: Longitudinal Phase Space at gun exit and Linac 1 entrance.

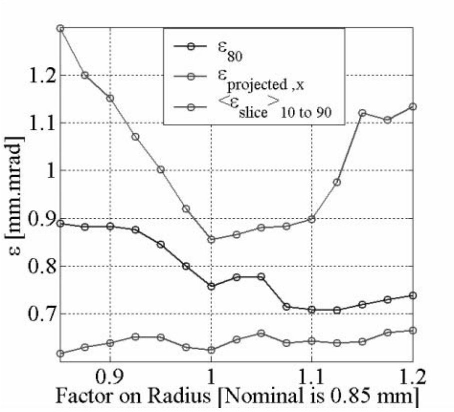

Figure 3: Evolution of emittance as a function of radius.

### *Low Charge*

The LCLS components, magnets and diagnostics, are designed to operate on beams carrying charges from 0.2nC to 1nC. With a laser radius of 0.3 mm and a 10ps laser pulse, the charge density for 0.2nC is twice that of our nominal 1nC tuning. However, a very small slice emittance can be obtained as the thermal emittance is now 0.18 mm.mrad. After optimization of electro-magnetic parameters, an 80% emittance of 0.38 mm.mrad was obtained and the slice emittance averaged over the core 80 slices is 0.25 mm.mrad. Figure 4 shows that by increasing the spot size radius the 80% emittance increases, but the slice emittance increases only slightly. Accordingly we studied the case of a 0.3 mm radius.

The sensitivity studies for this tuning show that most of the tolerances on parameters variation are relaxed.

For this small charge and with 0.25 mm.mrad slice emittance, the SASE FEL saturation length reduced by 20 m with respect to the nominal case.

Such a tuning could also be of major interest during commissioning.

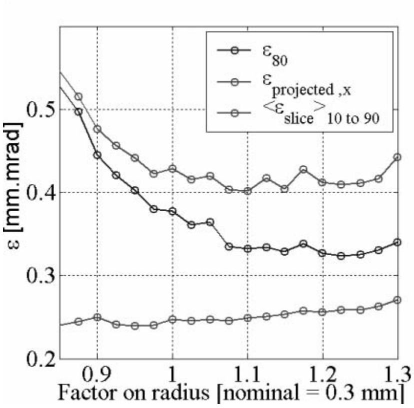

Figure 4: Evolution of emittance as a function of radius

### *Summary Sensitivity*

Comparisons of the sensitivity of the various tunings is presented in table 1. It indicates the relative variation on each of the main parameters which increases the 80%-emittance by 10% with respect to its nominal value obtained at the "optimal" operating point. The RF phase jitter becomes more critical for the longer pulse tuning than for the nominal one. The gun solenoid tolerances are the most critical for all tunings, and are all in the same range.

Table 1: Sensitivity of the 80%-emittance to various parameters for the three tunings

| **Parameter** | **Nominal tuning** 10ps, 1nC | **Long Pulse** 17.5ps, 1nC | **Low charge** 10ps, 0.2nC |
|---|---|---|---|
| RF Phase (°) | ± 5° | ± 2.5° | -2°, +4° |
| Gun field | -0.5% +1.2% | ±0.6% | -1% +0.6% |
| Balance (*) | ± 3% | -4% , +9% | -3% , +6% |
| Solenoid | -0.8% +0.6% | -0.4% +1.1% | ± 0.8% |
| Solenoid 2 | 100% | Not required | > 100% |
| charge | 14% | ±6% | ±13% |
| L0-1 field | -12% 10% | -5% | -9% |

(*) the balance is the ratio of the amplitude of electric field in the full cell over that of the half cell

For our nominal case of 10 ps and 1nC, the optimum tuning was clearly defined as the slice, 80% emittance, and projected emittance were at a global minimum for all the parameters studied. For the two new configurations, the "optimal" tuning is difficult to define. Indeed, for many parameters the minimum of the projected emittance does not coincide with that of the 80% emittance. For instance, in figure 5, the projected emittance is optimized for a balance of 1.01 , but the 80% emittance is smaller when the gun is unbalanced by 0.5%.

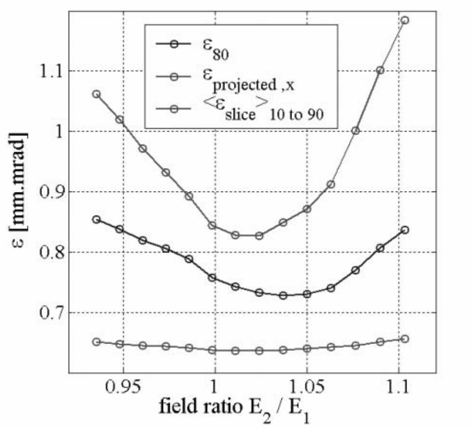

Figure 5: Evolution of emittance as a function of ratio of fields in the two cells of the gun (so called "balance").

## CONCLUSION

The components specifications for the LCLS Photoinjector are now defined as we enter the engineering phase of the LCLS project. Alternate tunings are now being studied. A long pulse tuning will allow to provide slice emittances in the 0.6 mm.mrad range, but with tighter RF phase constraints. A low charge option is being explored which could provide saturation with only 50 m of the undulator. The flexibility of the injector is now being explored.

### *Acknowledgements*

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