# A PROPOSED INJECTOR FOR THE LCLS LINAC*

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*Abstract*

The Linac Coherent Light Source (LCLS) will use the last portion of the SLAC accelerator as a driver for a short wavelength FEL. The injector must produce 1-nC, 3-ps rms electron bunches at a repetition rate of up to 120 Hz with a normalized rms emittance of about 1 mm-mrad. The injector design takes advantage of the photocathode rf gun technology developed since its conception in the mid 1980's [1], in particular the S-band rf gun developed by the SLAC/BNL/UCLA collaboration [2], and emittance compensation techniques developed in the last decade [3,4]. The injector beamline has been designed using the SUPERFISH, POISSON, PARMELA, and TRANSPORT codes in a consistent way to simulate the beam from the gun up to the entrance of the main accelerator linac where the beam energy is 150 MeV. PARMELA simulations indicate that at 150 MeV, space charge effects are negligible.

## 1 BEAMLINE

The injector beamline for LCLS consists of a 1.6 cell S-band photocathode rf gun, 4 SLAC type 3 m S-band constant gradient traveling wave accelerator sections, emittance compensation solenoids at the gun (after accelerator section 2 and after accelerator section 3), a 14° achromatic, isochronous translation bend system (dog-leg) into the main linac, and instrumentation for beam diagnostics as shown in Fig. 1.

The rf distribution system is also shown in Fig. 1. Two un-SLEDed 5045 klystrons will be used: one to power the gun and the first two accelerator sections and the other for the last two accelerator sections. High power rf attenuators and phase shifters will allow independent control of the rf power, phase and amplitude for the gun and each of the first two accelerating sections.

Many diagnostics have been designed into the injector to characterize the beam and to aid in tuning the injector. In the drift section from the gun to the first accelerator there will be a beam position monitor (BPM) a current monitor, and a profile screen/Faraday cup pop-in device. A mask in the laser beam into the photocathode can be used to produce beamlets in various patterns to study emittance trends from the gun, or just as a tuning aid to optimize the steering. After each accelerator section there is a BPM, a current monitor, and a screen. After the second accelerator section there is a bunch length monitor which is an x-band cavity outside the beamline near a ceramic gap in the beamline [5]. While this monitor will not characterize the longitudinal bunch profile, it will be a useful tuning aid to minimize the bunch length.

A full transverse emittance diagnostic section is included prior to the dog-leg which consists of four wire-scanners [6] separated by 45° of $x$ and $y$ betatron phase advance. The matched input beam produces an $x$ and $y$ rms beam size of 67 $\mu$m at each wire. A fifth wire scanner in the dog-leg allows the energy spread measurement. Emittance and energy scrapers are also planned in this region.

## 2 SIMULATION

Emittance growth and compensation in the LCLS injector from the gun to the end of the fourth accelerator section has been thoroughly studied using PARMELA simulations. The electric field map of the rf gun was obtained with SUPERFISH and directly used in PARMELA. SUPERFISH was used to simulate the fields in the traveling wave accelerator sections and space harmonics were calculated for use in PARMELA. The rf fields were assumed to be cylindrically symmetric. Much care has been taken to symmetrize the dominant dipole rf fields in the gun [2] thus assuming cylindrical symmetry in the rf fields is not unreasonable.

A magnetic field map for the solenoid magnets at the gun was produced using POISSON and passed to PARMELA. Single coils were used to represent magnetic fields from solenoids between accelerator sections.

Space charge effects were included assuming cylindrical symmetry. For these simulations, the thermal emittance at the cathode and the emittance growth due to multipole electric fields were ignored. The magnetic and electric fields in the gun and the accelerator region were optimized to minimize the emittance at 150 MeV at which point the normalized emittance is virtually constant.

The peak electric field in the gun is 150 MV/m at the cathode and the laser is injected at 23 degrees ahead of the rf crest. In the first and second accelerator sections the centroid of the beam is about 5 degrees ahead of the crest and the gradient is 7 MV/m. This introduces about a 1.5% energy spread for the full beam at the exit of the second accelerator but helps slightly in emittance compensation. This energy spread is removed by the third accelerator section by phasing the rf such that the beam arrives

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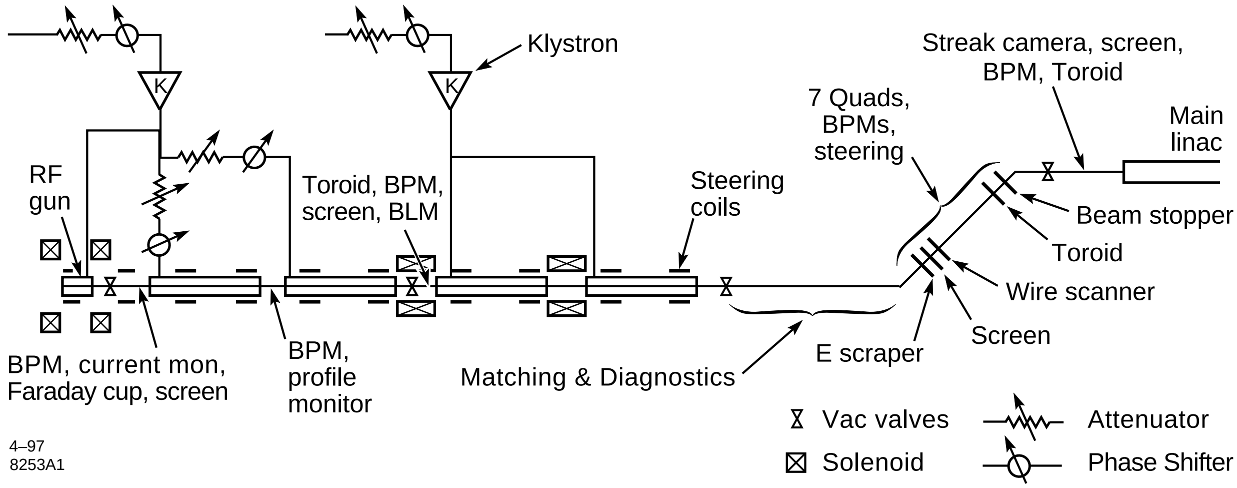


**Figure 1**. Beamline layout from rf gun to injection into the SLAC main linac. The 'matching & diagnostics' section includes matching quadrupoles, 4 wire scanners for transverse diagnostics, 4 phase space scrapers, a toroid, BPMs and a streak camera station for bunch length measurements. The two dog-leg inflector bends follow the diagnostic section.

slightly behind the crest. The gradient of the third and fourth accelerator sections is 17 MV/m.

The magnetic field at the gun is generated by two solenoids placed symmetrically up and downstream of the cathode such that the axial magnetic field at the cathode is zero. The field then rises sharply after the cathode to about 3 kG with an effective length of about 20 cm. The axial magnetic field between accelerator sections is slightly greater than 3 kG with an effective length of 70 cm. Fig. 2 shows the axial magnetic fields along the length of the beamline where $s$ = 0 is the cathode location.

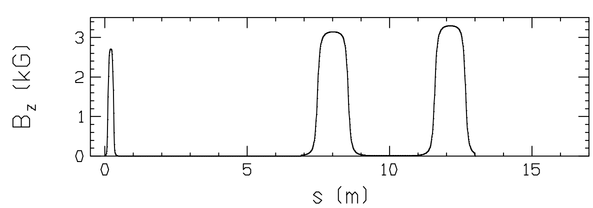


**Figure 2**. Solenoidal magnetic field along the beamline from the cathode ($s$ = 0) to the 150 MeV point.

At the cathode, the edge beam radius is about 0.9 mm dictated by emittance compensation—a balance between space charge, magnetic field, and electric field effects. At the entrance of accelerator-section-3, however, radial rf fields have a more dominant effect on emittance growth than space charge since the beam energy is nearly 50 MeV In addition, the accelerating gradient in section-3 is more than twice that of sections 1 and 2. Thus the beam radius is drastically reduced at the entrance of the third accelerator section to reduce the emittance growth due to radial electric field effects.

The transverse distribution at the cathode is assumed to be uniform, but the temporal shape is assumed to be a truncated Gaussian achieved by using a Gaussian pulse with an rms of 4.4 ps which is then truncated at $\pm 2\sigma$. The overall rms length is then 3.8 ps. In fact, a uniform temporal distribution is more desirable for optimal emittance compensation, however a truncated Gaussian results in a bunch-compression system which is much less sensitive to injection timing jitter [7].

It should be noted here that simulations indicate a 40% shorter beam at 150 MeV than at the cathode due to bunching because the laser is fired 23 degrees ahead of the rf. However there is experimental indication of bunch lengthening in the 1.6 cell S-band rf gun at these current densities which is not manifested in PARMELA simulations [8]. Thus the expected bunch length at 150 MeV may be longer than indicated in simulation by possibly 30-40%. Fig. 3 shows the temporal and energy distributions and phase space as well as an $x$-$y$ particle scatter plot of the simulated bunch at 150 MeV.

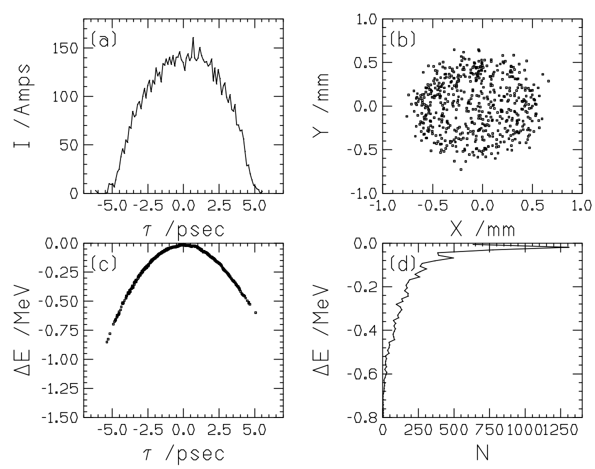


**Figure 3**. Temporal distribution (a), $x$-$y$ space (b), longitudinal phase space (c), and energy distribution (d) at 150 MeV for Table 1 parameters.

Fig. 4 is a plot of the horizontal normalized emittance ($\beta\gamma\varepsilon_x$, where $\beta \equiv v/c$) along $s$ for an optimized parameter set of the injector beamline shown in Fig. 1. Bunch parameters at the end of the fourth accelerator section are given in Table 1. The core emittance (excluding a 7.7% halo) at 150 MeV is 1.08 mm-mrad for the truncated Gaussian temporal bunch shape.

If a uniform distribution with rise and fall of less than 1 ps is used at the gun, the emittance at 150 MeV is 0.95 mm-mrad (excluding a 3% halo). We have also simulated the 1 nC, uniform transverse and Gaussian temporal bunch truncated at $\pm 4\sigma$ (i.e. nearly a full Gaussian pulse). In this case the core emittance at 150 MeV is 1.07 mm-mrad with the exclusion of 8.1% halo.

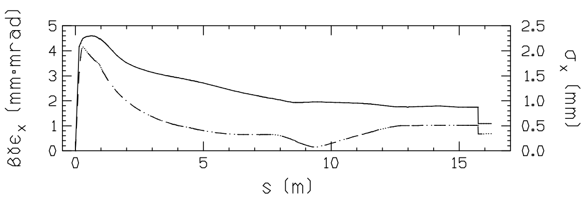


**Figure 4**. Normalized emittance (solid) and rms beam size (dash) along the beamline from cathode ($s$ = 0) to 150 MeV. The step at $s$ ~ 16 m is a 7.7% halo cut (in simulation only).

**Table 1**. Simulated electron beam parameters at 150 MeV.

| | | |
|---|---|---|
| Longitudinal distribution | — | Gaussian |
| Transverse distribution | — | uniform |
| Bunch charge | nC | 1.0 |
| Halo population | % | 7.7 |
| rms pulse length | psec (mm) | 2.3 (0.69) |
| Energy | MeV | 150.5 |
| rms relative energy spread | % | 0.13 |
| Norm. rms core emittance | mm-mrad | 1.08 |

## 3 DOG-LEG INFLECTOR

The function of the dog-leg inflector is to transport the 150 MeV electron beam from the new injector linac into the existing SLAC linac. It is possible to design the dog-leg as a first bunch compression stage, but this necessitates a large incoming correlated energy spread of 1-2% and the chromaticity of the quadrupole magnets within the dog-leg—required for linear achromaticity—generate large second order dispersion which requires sextupole compensation. Due to this, and also the need to tune the momentum compaction of the compressor (not natural in a dog-leg), the dog-leg is designed as a simple transport line, not a compressor.

The design requirements of the line are: 1) should provide a horizontal beamline inflection of ~1 meter over a few meters distance, 2) should not alter the bunch length (isochronous), and 3) should introduce no significant transverse emittance dilution. The inflection may also be made in the vertical plane or a rolled plane. However, there is no strong motivation to do so. A simple system which satisfies these conditions is composed of two dipole magnets of opposite strength separated by a +**I** optical transformer (seven quadrupoles) to produce a linear achromat. The dipoles are rectangular bends.

The beamline is 4 meters long with two 14˚, 20-cm long bends providing the ~1 meter inflection. This produces a momentum compaction, $R_{56}$, of 4 mm. An extreme electron which is off energy by 1% will move axially by 40 $\mu$m which is small compared to the ~1 mm bunch length. The effect of the second order momentum compaction, $T_{566}$, is even less. Note, the incoming rms energy spread from the injector is 0.13%. The system is therefore, for all practical purposes, isochronous with no significant chromatic emittance dilution.

## 4 SUMMARY

The injector design for the LCLS takes advantage of the present development of photocathode rf gun technology to produce 150 MeV, 1 nC, 3 ps rms electron bunches with a normalized rms emittance of 1.1 mm-mrad. The necessary beamline and rf systems have been defined to produce such beams and the design includes sufficient diagnostic components to aide in the production and characterization of the electron bunches.

## 5 ACKNOWLEDGMENTS

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