

SLAC MEMORANDUM¹
LCLS Technical Note

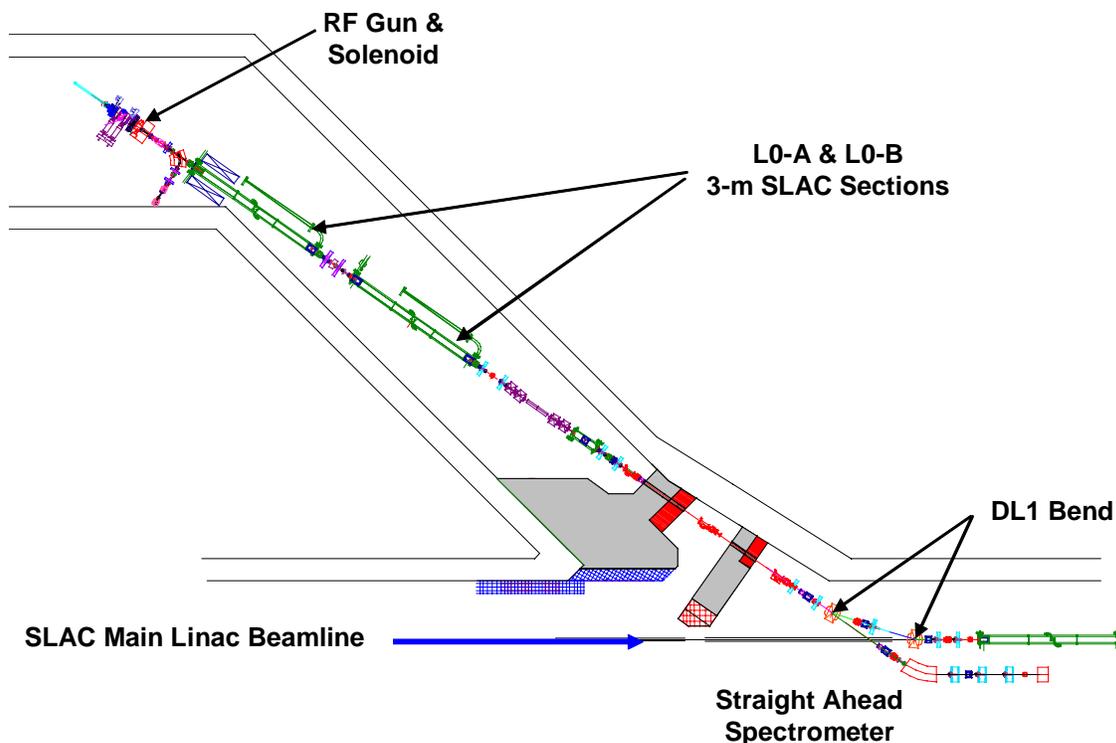
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Topic: Location of Maximum Credible Beam Losses in LCLS Injector

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The memo describes the maximum credible beam the LCLS injector can produce and lose at various locations along the beamline. The estimation procedure is based upon three previous reports [1, 2, 3]. While specific numbers have been updated to accurately reflect the present design parameters, the conclusions are very similar to those given in Ref 1. A drawing of the injector beamline is shown in the following figure for reference:



The source of the maximum credible beam results from the explosive electron emission from the photocathode if the drive laser intensity exceeds the threshold for plasma production. In this event, the gun's RF field can extract a large number of electrons from

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this plasma which are accelerated out of the gun and into the beamline. This electron emission persists until it has depleted the gun of all its energy. Hence the number of electrons emitted per pulse is limited by the amount of stored RF energy in the gun. It needs to be emphasized that this type of emission is highly undesirable, as it causes permanent damage to the cathode.

The maximum stored energy in the gun is 10.1J for operation at 140MV/m [4]. Due to beam loading the average beam energy will be reduced from 7 to 4MeV, therefore the maximum charge per pulse the gun can produce is

$$Q_{\max} = \frac{10.1\text{Joules}}{4\text{MeV}} = 2.52\mu\text{C},$$

which for a repetition rate of 120 Hz gives an average current of 0.303 mA. The previous studies [1, 2] show that 85% of this beam is lost between the gun and first linac section (L0-A), therefore the average beam power deposited in this region is 1030 watts.

The time to deplete the gun of its 10.1Joules is approximately 300ns [3], giving a macropulse beam current of 8.4 amperes. As stated above, 85% of this current is lost in the gun region leaving 1.26 amperes (0.38μC) to enter L0-A.

The beam-loaded energy gain of the beam in a SLAC structure is given by [5]

$$E_{\text{gain}} = 10.59\sqrt{P[\text{MW}]} - 38.28i_b[\text{A}]$$

The maximum RF power that the L0-A structure can operate at is 42MW [6], resulting in 1.8A for the limiting current the structure can accelerate. The 1.26A is less than this limiting current and will be accelerated through L0-A, but due to beam loading will have a large energy range 20.4 to of 68.6MeV. The average energy will be 44.5MeV. The average beam power at the exit of L0-A is computed using the average energy: 44.5MeV*0.38μC*120Hz = 2030W.

The quadrupoles between L0-A and L0-B are tuned to transport 64 MeV electrons and will therefore over-focus the electrons causing them to be lost in the L0-B structure. Thus the maximum power deposited in L0-B is approximately the full beam power of 2030W.

In the event the quadrupoles are OFF, this beam can be accelerated through L0-B. In this case, the beam will exit L0-B with a range of energies between 55.6 to 152MeV as based upon the maximum available RF power [6] and beam loading producing an average beam energy of (152+55.6)/2=104MeV and an average power of 104MeV*0.38μC*120Hz= 4740W.

The beam now has one of two possible fates. If the DL1 bend dipoles are OFF, it will drift into the straight ahead spectrometer and be lost in and after the spectrometer dipole. If the DL1 dipoles are ON, then most of the beam will be lost in and immediately after the first dipole. However, electrons with energies within the energy acceptance of the DL1 bend will be transported to the main linac. The energy acceptance is +/-6.5 and for nominal operation is centered at 135MeV, thus the energy spread is +/-6.5%*135=+/-

8.8MeV or 17.5MeV, total. This 17.5MeV represents 17.5/104 or 17% of the charge which will make it around the bend and onto the axis of the main linac. Therefore the power in this transported beam will be $0.17 \times 0.38 \mu\text{C} \times 135 \text{MeV} \times 120 \text{Hz} = 1050 \text{W}$. In the situation where the DL1 magnets are at their maximum currents, the transmitted beam energy would be 180MeV [7], and in this case the power of the beam transported to the main linac would be $0.17 \times 0.38 \mu\text{C} \times 180 \text{MeV} \times 120 \text{Hz} = 1510 \text{W}$.

The following table summarizes these results:

	Ave. Energy (MeV)	Charge/Pulse (μC)	Current at 120 Hz (micro-amps)	Beam Power (Watts)
Gun exit	4	2.52	303	1210
Beam loss in gun region	4	2.14	257	1030
L0-A exit	44.5	0.38	45.4	2030
Max beam loss in L0-B	44.5	0.38	45.4	2030
L0-B exit	104	0.38	45.4	4740
Beam loss at straight ahead spectrometer	104	0.38	45.4	4740
Beam loss at DL1 dipole	97*	0.310	37.2	3610
Beam transported to main linac (nominal DL1 settings)	135	0.07	8.4	1130
Beam transported to main linac (max DL1 settings)	180	0.07	8.4	1510

*The average energy of the electrons lost at DL1 is lower than the energy of the incident beam due to the transport of the high energy electrons within the energy acceptance around the DL1 bend. This moves the average energy of electrons stopping at DL1 downward from 104 to 97MeV.

References

- [1] J.E. Clendenin et al., "LCLS maximum Credible Beam Power", LCLS-TN-01-2
- [2] E. Colby, "Explosive Electron Emission (EEE) Loss Calculations for E163", SLAC Memorandum-E163
- [3] J. Schmerge, "Radiation Safety for the Gun Test Facility at SSRL", SAPE-118
- [4] Z. Li, private communication & LCLS Gun report
- [5] H. Wiedemann, **Particle Accelerator Physics**, Springer-Verlag 1993, p42
- [6] P.A. McIntosh, "S-band waveguide reconfiguration options for the LCLS RF gun and L0 klystron feeds", LCLS-TN-05-01
- [7] R. Carr, "Design Specifications for Injector Bend Magnets", LCLS Engineering Specification Document 1.2-146