Introduction and Summary

The Review Panel wishes to thank the LCLS Injector Group for a very interesting, informative and impressive presentation. The presentation was comprehensive and made for a very enjoyable and enlightening day for the panel. This review is being written with the understanding that this 1.6 cell gun is probably not the ultimate electron source for LCLS and that staying on the rather aggressive schedule is very important. With that understanding it is not helpful to recommend redesigning this gun from-the-ground-up or gold plating it. Rather we will try to make recommendations which will get the most bang for the buck or the most improvement in the limited time available. In that context our panel will be happy to come back in 6 months or a year or whatever time is appropriate and review a from-the-ground-up design of a new gun. We also will not be upset if some of our recommendations are not followed because of the limitations of time and resources.

The most important question to answer is whether the LCLS Injector with this gun will meet the LCLS performance requirements. The best answer we can give is that it’s too close to call. What we can say is that the injector won’t fail to meet the emittance performance requirements because of RF design issues which we can identify short of a from-the-ground-up redesign of the gun. The biggest reason the injector may fail to meet the emittance requirements, and the major reason none of the similar guns have achieved 1 mm-mr emittance at 1 nC is not related to the RF design but rather to the temporal and spatial distribution of charge leaving the cathode. This is dependent both on the temporal and spatial distribution of the laser pulse and to the spatial uniformity of the quantum efficiency of the cathode. The load lock system proposed as an upgrade is likely to improve the uniformity of the cathode significantly. We do not imply here that the proposed improvements in the RF design are not worth doing, but rather that the biggest remaining barrier (and probably most difficult to remove) to achieving 1 mm-mr is achieving uniform temporal and spatial emission. The true symmetrizing and race tracking (or other quad correction) of each of the RF couplers will each make a small improvement in the achievable emittance and therefore should be implemented. Increasing the separation between 0 mode and $\pi$ mode certainly should be done. Similarly it certainly makes sense to over couple the Gun to shorten the filling time and thereby decrease the pulse length required, thereby increasing the ease of running high gradients. In both cases the real question is how far to go.
We think you should seriously consider whether the simplest way to achieve a viable load lock is to build a valved-off gun with an RF window. This is a detailed question beyond the scope of a short review.

**Couplers**

We have used 3 different styles of couplers we have used on accelerator sections at SLAC (developed in the NLC program), all of which deal with pulse heating and provide for dipole symmetry in the coupler. The first of these (sometimes called the “fat lipped coupler”) evolved from the original coupler used on the SLAC S-band accelerator. The SLAC coupler was first symmetrized by feeding from both sides. Then the excessive pulse heating in the NLC X-band guide was solved by thickening the irises and increasing the radius of curvature on the inside of the irises. Finally the quadrupole component of the fields in the coupler can be suppressed by “race tracking” the coupler cavity. This style coupler could be used for both the gun and for the two accelerator sections, L01 and L02. The coupling iris in the SLAC S-band accelerator structure extends the full z length (sometimes called “Z-coupling”) of the coupler cell. This feature is attractive for any coupler such as for the RF gun where excessive heating occurs around the coupling iris. A natural solution for this heating is to make the iris thick with a large radius on the inside surface of the coupler cell. With θ-coupling this radius is difficult to machine on the inside of the cell. With Z-coupling, because the iris has straight sides which extend the full Z-length of the cell, the radius can easily be milled with the axis of rotation parallel with the z axis of the cell cup.

Two other couplers were developed in the NLC program: the mode converter coupler and the waveguide coupler. They are similar in concept and appearance. The mode converter coupler and the waveguide coupler are both very good for eliminating localized heating in the coupler but both introduce at least a few centimeters of reduced acceleration so they are not appropriate for the 1½ cell RF gun, nor perhaps the input coupler of L01. Furthermore, a very satisfactory electrical design for symmetrized, quad corrected input couplers has already been completed by Li for L01 and L02. The localized heating is also very comfortable, so there seems no point in introducing a new style coupler.

There is one modification of the symmetric feed, rounded iris, racetrack couplers which is probably worth considering for both the gun and the L01 and L02 input couplers. The modification is to replace coupler cavity plus the external multiple piece “magic T” splitter and rectangular waveguide pieces with a compact monolithic matched T waveguide fork and coupler cavity machined from a single piece of copper. Since the rectangular waveguide network symmetry is produced on a single piece in a milling machine it is easier to achieve and maintain equal amplitude and phase entering the coupler cavity. The compact coupler replaces 3 waveguide flange pairs with one, 2 ion pumps with one and eliminates the need for two directional couplers. For L01 use of a compact coupler on the input does require that the solenoid be slipped on from the downstream end. We have a design of such a compact coupler for the NLC X-Band structure. The X-Band compact coupler was not racetrack shaped. Regardless of what
style coupler is adopted, if the coupler is to be replaced on a structure the coupler
subassembly should comprise the coupler plus the next 3 or 4 cells.

We strongly support the use of symmetric feed, rounded iris, race track couplers to
preserve emittance. On the gun it may be worthwhile to change from an azimuthal or
theta coupling slot to a longitudinal or z coupling slot if this simplifies machining the
large radius on the inside of the iris.

The accelerator sections selected for L01 and L02 should be cold tested including a bead
pull before machining to be sure they are in good condition. The old couplers plus 3 or 4
cells should be machined off. After being brazed onto the accelerator structures, the
replacement coupler assemblies will be easily tuned for good match to the old sections.

**Recommendations for Gun**

1. The final optimization of the gun (phases, solenoid, E field, pulse shape) should
be done using RF fields calculated with lossy copper.

2. A bead pull (or drop) should be done to measure the amplitude *and relative phase*
of the fields in each cell of the gun. This information is derived by looking at the
change in the reflection from the gun (rather than the change in resonant
frequency) as the bead moves through the gun. This change in the reflection is
proportional to the square of the complex field at the bead. The phase of change
in the reflection varies as twice the phase of the field and the amplitude of the
change of the reflection is proportional to the square of the field.

3. Z-coupling coupler design should be adopted for easy and precise machining of
the thick iris with a large radius on the inside.

4. The mode spacing should be increased, possibly at least to 15 MHz.

5. Such working parameters as pulse heating, average RF losses, operating gradient
and sensitivity of RF phase to changes of the gun temperature can be improved
with increased $\beta$. Increasing $\beta$ shortens the filling time and, for a given gun
gradient, increases the incident RF power, the reflected power during the pulse
and the emitted power after the pulse. If a valved-off gun with an RF window is
chosen in lieu of a more conventional load lock, our rough estimate suggests you
should limit the beta to about 3 as a comfortable value for the window.

6. Feedback on the metal temperature of the gun with a proportional control on the
water temperature can be applied by looking at phase of RF emitted from the gun
after RF pulses. Using the emitted signal makes questionable usefulness of field
probes in the gun.

7. Remove mechanical tuners from the gun, leave only push-pull wall deforming
with studs, like usually done in X-Band structures.
**Recommendations for Gun Fabrication**

For the sake of smooth completion of the project and continuity in the development of next generation gun, we strongly recommend:

1. SLAC to maintain the engineering control and use vendors for machining.
2. SLAC to braze, assemble, RF cold test, tune, and process the gun.

**Recommendations for Next Generation Gun**

1. We suggest the near axis laser injection.
2. You should study the multi-cell gun because it may be advantageous to pass through the output RF fringe fields with a higher energy, smaller radius beam.
3. Waveguide or mode converter coupler can be adopted.
4. You should look at a valved-off gun with RF window.

**Recommendations for L01/L02**

1. We suggest using compact feed for input couplers. Whether compact or not, waveguide split assembly does not need directional couplers on each side – one coupler before split should suffice.
2. There is no need to taper input waveguide in either plane.
3. Coupler assembly should include coupler plus 3 or 4 cells in order to obtain a good match between new coupler and old section.
4. Study is needed for the necessity of quadrupole correction for output couplers. We suggest considering replacement of the present output couplers with symmetric feed couplers to meet the requirement for future improved guns. If a symmetric coupler is adopted for the output it does not need a splitter, two loads would be enough.
5. Today we can design coupler well enough that you don’t need to cold test before subassembly, but all coupler parts, especially, the RF related dimensions need to be carefully measured.
6. We recommend to making a simple bench test for the cavity tuning mechanism.