LCLS Newsletter AUGUST-2000

FEL Physics Section Report *H-D Nuhn, C. Pellegrini*

PARAMETER GOALS

A set of goal numbers for important LCLS parameters, such as emittance and energy spread have been established for the full LCLS bunch as well as for bunch 'Slices'. These are not limits of what can be achieved but numbers that we think we can achieve comfortably. Such a set of numbers is needed for the writing of CDR sections, for simulations and so on. The width of 'Slices' has been defined as 1/20 of the FWHM of the electron bunch. It is believed that this is a quantity that can be measured. The 'SLICE' width that is actually of interest is significantly smaller, but there is no experimental technique known to measure 'Slice' emittances on the fs or sub-fs scale. We believe that it does not make sense to set parameter goals that can not be verified, experimentally. Specifying emittance and energy spread numbers as integrals over the 'Slice' distance implies that the values for smaller parts of the 'Slice' distance will be at least as small or smaller.

The following table summarizes the goal numbers for a beam charge of 1 nC. The numbers at the Undulator Entrance are for a beam energy of 14.35 GeV:

Parameter	Location	LCLS Goal Value
Slice Emittance	Injector (@150 MeV)	1.0 mm mrad (RMS)
	Undulator Entrance	1.2 mm mrad (RMS)
Projected Emittance	Injector (@150 MeV)	1.2 mm mrad (RMS)
	Undulator Entrance	1.5 mm mrad (RMS)
Slice Energy Spread	Injector (@150 MeV)	0.01 % (RMS)
	Undulator Entrance	0.01 % (RMS)
Projected Energy Spread	Undulator Entrance	0.05 % (RMS)

This table of goals contains values at the 150 MeV point as well as at the entrance of the undulator. The goal for the 'Slice' emittance at the injector is set to 1 mm mrad. Recent simulations predict that much smaller emittance values might be achievable. In that sense, the 1-mm-mrad value can be considered a reasonable and comfortable goal. A 20% increase was added for the 'Slice' emittance along the linac, up from the expected 10% predicted by simulations. The projected emittance values are a bit larger, i.e., 1.2 mm rad at the injector and 1.5 mm mrad at the entrance to the undulator. Also larger is the increase of the projected emittance along the linac, i.e. 25%, because linac rf and wakefields actually act on the projected emittance they don't act on the 'Slice' emittance. For the 'Slice' energy spread, simulations show that the value at the undulator entrance can be as low as 0.006%. It is believed that values smaller than 0.01% could not be experimentally verified. The goal values are therefore set to the 0.01% both at the injector and at the undulator entrance. In comparison the Design Study Report number used for the 'Slice' energy spread was 0.02%. We decided to move to a smaller number because 0.02% is too pessimistic. Also, the number for the projected energy spread has been reduced to 0.05% from the value of 0.1%, which also was too pessimistic an estimate. The value of 0.05% is still a conservative number.

A complete document that will also include goals for the accuracy and precision of measurements will soon be published.

Ginger simulations, using these goal values for emittance and energy spread of a slice, predict a saturation length of 87 m, reduced by more then 20 m from previous results based on the parameter values in the Design Study Report. The new simulations use the new FODO optics as proposed by N. Vinokurov with two different lengths for the segment breaks. The 87 m length refers to the actual length of the device, including undulator sections as well as drift spaces.

FEL RADIATION

To provide information of the distribution of the electric field within the x-ray pulse for the entire operational range of the LCLS, the Ginger FEL simulation code was run for 10 different wavelengths using high particle numbers. All runs were made over a distance of 88.04 m or four FODO superperiods. The 1.5-Å case saturates at about 87 m. For longer wavelengths, the saturation length gets shorter quickly to arrive at about 25 m for the 15-Å case. These numbers are for the error free device.

The runs also show a special effect of SASE. After saturation there is not a clear signature of synchrotron oscillation but a continuous, although small, increase in total power. This is because, at saturation, there are still areas within the bunch, i.e., between spikes, where micro-bunching is not yet fully developed.

The ten data files, each containing values of the electric field at 768 positions along a 12288 wavelengths long part of the pulse, have been given to the X-Ray group for analysis.

Photoinjector R&D News *J. Clendenin*

Emittance measurements (Schmerge, Gierman, Bolton, Hernandez, Dowell).

The experimental program at the GTF this summer has concentrated on measuring the beam emittance at 30 MeV for a nominal Q=0.5 nC beam. As reported earlier, >1 nC is quite possible, but to avoid optical damage to the laser components or the possibility of forming a plasma which might damage the cathode, we have operated the laser conservatively and kept the rf field low. The lowest measured emittance to date is still 2.6×10^{-6} m. See the figure below. If corrected to exactly 0.50 nC charge using the experimental data, this emittance would be 2.3×10^{-6} m. No PARMELA simulations have yet been run for exactly these conditions. Earlier PARMELA simulations for 1.0 nC, uniform spatial distribution with 2-mm hard-edge diameter and Gaussian temporal distribution of 6 ps FWHM gave an emittance at 30 MeV of about 2×10^{-6} m. To scale this result to 0.5 nC (see J. Rosenzweig et al., AIP Conf. Proc. 335 (1994), p. 724), we note that the beam dimensions of the GTF laser at the cathode—spatial is truncated Gaussian with 2 mm FWHM, temporal is Gaussian with 4 ps FWHM—are not scaled as $Q^{1/3}$. Nonetheless, using $Q^{2/3}$ scaling of the PARMELA emittance to 0.5 nC and also correcting for peak field —110 MV/m instead of 140 MV/m (See D. Palmer thesis (1998), p. 41) and the solenoid position (Palmer, p. 100)—leads to a predicted emittance of 2×10^{-6} m for these experimental conditions.

Figure. Transverse normalized rms emittance (ε_{nx}) vs gun solenoid current (I_{sol}) measured at GTF during July and August, 2000. Gun peak field = 107-110 MV/m, launch phase = 60°, beam energy = 30 MeV, Laser profile: diameter is 2 mm hard-edge, clipped semi-Gaussian spatial distribution. The diamonds represent 2 ps FWHM Gaussian temporal distribution, boxes 4 ps.

A measurement of 1.5×10^{-6} m was recently reported for 0.5 nC at the ATF. See X.J. Wang et al., “FEL Technologies R&D and SASE Gain Enhancement Observation at the BNL ATF," contributed to EPAC 2000.

GTF Immediate Plans.

For the next few weeks, the GTF will be able to run electron beams only a couple days per week. First, using a laser mask to image the cathode onto a screen, the e-beam rotation as a function of solenoid field will be measured to survey the emission uniformity of the photocathode and to confirm the energy out of the gun. We will also finish characterizing the new UV beamsplitters for the pulse stacker and then measure the emittance with a temporally shaped pulse. A uniform temporal shape is predicted by PARMELA to result in up to a factor of 2 reduction in emittance.

GTF Intermediate and Long Term Plans.

Although the QE of the Cu cathode is quite good as reported earlier, the surface disruption of a few microns at the center due to the tooling process affects the beam shape and presumably degrades the emittance. We plan to install a new Cu cathode during the shutdown at the end of September and then re-measure the emittance.

We still plan to measure emittance vs. z right after the gun and then relocate the booster to test the "new working point." The timing of this work depends on funding availability in FY01.

PARMELA.

C. Limborg, assisted by D. Palmer and P. Krejcik, is making good progress learning to use PARMELA. Results for optimizing the LCLS photoinjector with a temporal ramp-shaped pulse are expected soon. This study will be extended to check for emittance growth in the matching section. P. Emma reports that in fact by using an X-band section in the linac, he may be able to generate the desired temporal ramp from a uniform distribution. This will certainly simplify the problem for the injector. On the other hand, the low emittance in the injector associated with the uniform distribution will almost surely result in unacceptable emittance growth in the matching section. For this reason the matching section should be redesigned, which will probably require the source vault to be enlarged more than presently planned.

Costing for CDR.

V. Bharadwaj has been working with L. Bentson on the costing for the CDR of the photoinjector along with that of the linac. The costing of the laser system and light shack is being worked out by A. Fisher with some input from P. Bolton.

Linac *Vinod Bharadwaj*

Paul Emma presented his work on adding an x-band RF system in L1 to mitigate second order effects in the BC1 bunch compression system at the LCLS seminar on Monday August 28th. The charge distribution and timing tolerances are much more relaxed in this scheme. It is planned to modify L1 to add this x-band RF and also convert BC1 into a double chicane system.

Undulator *Liz Moog, Efim Gluskin*

The design of all the components for the prototype undulator has been completed. Almost all the orders have been placed. The cost of the prototype, not including the cost of the magnets, will be approximately $230K.

Once the magnet blocks arrive, they will be measured at APS. A new fixture for holding the magnet blocks in the Helmholtz coil in a reproducible position has been designed and is out for quotes.

Fixtures have also been designed for the assembly of the magnetic structures into the strongback support. Those drawings will go out for quotes soon.

Some progress has been made on the CDR section about the undulator line, but much still remains to be done.

X-Ray Optics *Art Toor*

Coherent Radiation Bandpass

Is the frequency bandpass for the FEL associated with the energy that is most damaging to optics determined by the total number of undulator periods or by the number of periods in the last two gain lengths? This question was the subject of a lively discussion at the X-ray Optics Group meeting on Aug.3rd, where Claudio Pellegrini, Heinz-Dieter Nuhn and Bill Fawley presented an informative description of the physics and the methodology used in Ginger relevant to this question. As a result, Heinz-Dieter ran Ginger at 10 different wavelengths spaced at 1.5 Å intervals between 1.5 Å and 15 Å. These runs, which took 202 hours of Cray CPT time, were for the same undulator length (88.04 m). At each wavelength, 768 slices were calculated with the temporal spacing between each slice being 16 wavelengths. At 15 Å the saturation length was 88 m and at 15 Å the saturation length was 26.7 m; thus at the end of the undulator the frequency spread at 15 Å is ~2.5 times larger than at saturation. Richard Bionta is currently in the process of analyzing the data from these runs.

Radiation Hutch Safety Meetings

The August 14th meeting discussions focused on the issue of experimental flexibility vs. the complexity of the PPS configuration control. Our initial requests had a high level of operational flexibility. Increased operational flexibility corresponds to increased costs, design complexity, and testing complexity that detracts from experimenter run time. The meeting's outcome was definition of an experimenter access system that allows access only to the experimental areas downstream from any active experimental area. An assessment will be made during the next several weeks to determine if this constraint significantly impacts various realistic user scheduling scenarios. If not, we will use this definition of concurrent user access to define the PPS system for the CDR.

The largest bremsstrahlung background in the experimental area results from the insertion of the proposed diamond FEL beam position monitors in the undulator. The background resulting from this source is orders of magnitude larger than any other source. Rather than shielding the entire central area of the Experiment Hall for this source, access will be denied whenever these beam position monitors are inserted in the electron beam. Please contact me immediately if there are concerns about this operational constraint. Because of the additional complexity this places on the PPS system, it is important to know a.s.a.p. if the diamond BPMs will be actually used.

Stan Mao and Alberto Fasso are modeling the muon and bremsstrahlung radiation from all of the upstream sources and considering stopper designs that will be discussed at our meeting on August 28.

Hydrodynamic Modeling

Max Tabak is modeling the response of transmissive multilayer optics. The first calculations are for a multilayer consisting of 100 layer pairs of B4C and Be, each layer having a height of 500 Å with the composite sliced to a thickness of 33 µm. Two fluence levels are being calculated; the LCLS baseline intensity at 1.5 Å and the intensity corresponding to 100 times the baseline. Alberto Fasso has completed the first FLUKA simulations of the energy deposition gradient resulting from 6 keV photons at grazing incidence on a beryllium mirror. The data looks fine and is consistent with our analytic estimates. Richard London will use these data to model the hydrodynamic response of mirrors. He will start on these calculations next week.

CAMEL Optics

A paper containing a complete set of engineering equations for the design of liquid film x-ray optics has been completed and submitted to the Journal of Applied Physics for publication. Hardware is being designed for seminal tests using water as the working fluid. Improved methods to characterize the temporal evolution of the film's optical quality as a function of pore size in the flat and "upside-down" configurations require further development.

Diamond Turned Beryllium Optics?

Fabricating beryllium optics has proven problematic in the past because of the large columnar grains in beryllium. We have begun a study of beryllium–boron alloys with the goal of producing a form of beryllium that is diamond turnable and can be polished to x-ray mirror quality. Our current work builds on results obtained in the late 1980's that demonstrated the grain size in beryllium could be significantly reduced by using multilayer technology to periodically interrupt the growth of columnar grains. Making large optics with this technology was both difficult and expensive. We are investigating another approach to the problem by vacuum casting beryllium alloys in a water-cooled crucible using an electron beam source. These samples are then polished and the grain size and crystalline structure is characterized with SEM/TEM and the mirror finish is characterized with AFM.

VISA Report from ATF Newsletter *Ilan Ben-Zvi, Aaron Tremaine*

We are currently pulse-wiring and re-fiducializing the undulator. Unfortunately, the pulser went bad and delayed us this week, but we found another, which we hope, will do the job. Section junctions1,2 and 2,3 look fine, and the only thing left is sections 3,4 which if we can get a working pulser should take about a day and a half if there are no gross errors in the magnet sections. Robert is coming out next week and hopefully the undulator measurements/fiducicalization will be finalized.

We are certain the undulator moved during the pumpdown process and SLAC is re-designing the undulator support, which is the most probable perpetrator. These will be finished by mid-September and installation and alignment of the undulator into the ATF will immediately commence. It looks like our first run days will be about the 2nd week of October if all goes to plan.

With other experiments coming to a conclusion at the ATF, this should allow VISA to get a significant amount of run time thus increasing the chance for high gain and eventual world domination.