LCLS Newsletter June-2001

Project Management *John Galayda*

There will be the following visitors to SLAC in June and July

Richard Walker (ELLETRA) 14 June
Will present a seminar on FEL activities at ELETTRA

Eberhard Jaeschke (BESSY) 26-29 June
Will present a seminar on the BESSY-FEL proposal

Rene Bakker (BESSY) 2 July
Will present a seminar, topic TBD

Photoinjector R&D News *J. Clendenin*

The present Gun Test Facility (GTF) R&D team consists principally of John Schmerge, Steve Gierman, Paul Bolton, Brendan Murphy, Franz-Josef Decker, Rick Iverson, and Cecile Limborg.

Since the last Newsletter there has been significant progress at the Gun Test Facility. The very large integrated emittances that were reported in the September 2000 Newsletter have now been found to be due principally to two factors: cathode non-uniformities and poor laser-beam profiles. The single-crystal Cu cathode installed last fall has consistently demonstrated a relatively uniform QE (at the level of 5×10^{-5} for our operating conditions) and in addition very low dark current. So far only one field emission site has developed. Fortunately it is outside the area illuminated by the laser.

The Nd:glass laser system is now routinely in operation without regular optical damage. To maintain this performance, the regen output energy must be limited to 5 mJ, which is significantly lower than the design value of 8 mJ. The beam spatial uniformity was greatly improved by expanding the beam before it goes through the imaging aperture. The resulting UV beam at the cathode is limited to about 30 (20) μJ for a 2-ps (4-ps) FWHM Gaussian temporal distribution. The photocharge is then limited to about 300 pC, although as much as 400 pC is sometimes achieved. (The values quoted here for UV energy at the cathode and resulting photocharge are composite numbers observed over many days of operation. All other factors being the same, the UV energy in the 4-ps case will be no more than 25-30% of the 2-ps.)

Normalized rms emittance measurements were made under these conditions, resulting in values in the range of $1\text{-}2\times10^{-6}$ m that appear to be consistent with PARMELA simulations. These results are summarized in LCLS-TN-01-4 (April 29, 2001), which is available from the web at http://www-ssrl.slac.stanford.edu/lcls/technotes/LCLS-TN-01-4.pdf.

In addition, the mystery of the strange spatial profiles of the electron beam has been at least partially solved. A small quadrupole component is introduced by the gun solenoid, most likely as a result of a too-abrupt crossover of the windings in all or some of the 8 pancakes. There is some evidence that the effect is strongest near the exit of the solenoid. The effect can be canceled to first order by placing iron of the appropriate shape at the solenoid exit. In our case, we placed our iron-wound corrector coil right at the solenoid end plate and rotated it until the beam shape in the drift region after the solenoid was round for all values of solenoid current. We are still in the process of determining if this cancellation makes a significant difference in the measured emittance.

The principal effort at present is to complete the pulse-stacker arrangement that will give the optical pulse a uniform temporal distribution. This has proven to be a challenging task. With the stacker, the input 2-ps FWHM beam is split into 4 beamlets. The beamlets have been aligned and their energy balanced. The spatial profile of each beamlet now duplicates the input profile. The input profile is being corrected by using an improved pinhole in the UV air spatial filter. Unfortunately this will limit us to about 17 μJ at the cathode or <200 pC charge. However, this should be adequate to demonstrate the difference between Gaussian and uniform temporal shaping.

Over the next few months we will increase the laser energy first by recycling the unconverted green light (expect up to 40% increase in the UV) and second by adding another amplifier stage (expect a factor 2 increase in the IR).

The striking achievement (with respect to emittance) of the VISA experiment in recent weeks followed by the extremely low emittance measurement results at ATF made without the limitation of tightly focused beam on a screen (see Vitaly Yakimenko's report in the May, 2001, BNL Accelerator Test Facility UPDATE) has provided additional encouragement for us to reexamine the way we calculate the emittance from our measured data. First, both the ATF and the DUFEL exclude pixel values that are less than 10% of the peak whereas we have been defining an area within which all pixels are included. For a comparison, we are recalculating some of our emittance values using the 10% technique. Second, we note that during an emittance measurement our focused beam spot is on the order of 100 μm or less. If the resolution of our YAG screen is only 50 μm or more, then it will significantly increase the resulting emittance value. We plan to measure the resolution of both our camera system and separately our screen. Screen resolution is discussed in detail in A. Murokh et al., "Limitations on the Resolution of YAG:Ce Beam Profile Monitor for High Brightness Electron Beam," in *The Physics of High Brightness Beams*, World Scientific (2000), p. 564. (http://www-ssrl.slac.stanford.edu/visa/documents/YAGweb-apr-2000.pdf)

For our emittance measurements, the GTF is operated with zero temporal compression. Our Hadlon sub-picosecond streak camera has recently been returned from the manufacturer after having the streak tube replaced, so we should now be able to better verify the pulse length. We are also developing a procedure to measure the longitudinal emittance as a regular part of the transverse emittance measurements. Dave Dowell is contributing to this effort.

The design of the moveable Pepper-Pot is progressing. It will incorporate the moveable stage loaned to us by the ATF (Xijie Wang). The goal is to install this diagnostic when the booster is removed, possibly as early as late summer.

We are also in the process of upgrading the GTF control and diagnostic system. This will take several months to fully implement.

Undulator *L. Moog*

Most of the magnet blocks needed for the prototype undulator have arrived (425 of the 500 ordered). The decision was made to upgrade the Helmholtz coil magnet block measurement system, to make the motion of the magnet block within the coils smoother and more controllable. The parts for the upgrade are due from the machine shop next week. The holders for the magnet blocks are already completed.

The magnet blocks will also be measured using a scanning Hall probe. For these measurements, the magnet will be held between two poles so we can check for position-dependent variation in the magnet block strength that will affect the magnet's contribution to the overall undulator field. Some low-carbon steel poles are being made for this test fixture and should arrive soon.

We would have preferred to use real poles for this magnet block test fixture, but the manufacture of the real poles was delayed. The problems have been corrected, and the manufacture of the poles is now in full swing. The poles are due to be completed in mid-July. The assembly of the supports for the prototype undulator has begun. The movers are being installed on the supports, and holes for bolting down the supports in front of the measurement bench are being made.

Once the magnets and poles have been assembled into the upper and lower magnetic structures, the two magnetic structures will need to be assembled into the titanium strongback. The special fixture that will be needed to handle these two magnet arrays and insert them into the strongback has been made, though a few minor corrections are needed.

Per request, the prototype quadrupole magnet was shipped to R. Ruland for consideration of alignment issues.

X-Ray Optics

The following is a summary of the status of the x-ray optics and diagnostics for LCLS and the work to be done in 2001.

The work undertaken in this area will be summarized under the following headings:

Optical component design code development
Optical component design for the experiments
Optical diagnostic design for the experiments
Optical component manufacture and testing
Photon-materials interactions studies
Novel optical concepts
Conceptual Design Report

Optical component design code development

A Gaussian model of the FEL beam has been derived, and predictions compare well with the Ginger code predictions. The model is being used to derive downstream parameters relevant to optical design and material damage, such as intensity, spot size, and absorbed energy in specified materials. It is also being used for predicting the action of transmissive optics on the beam, in order to better understand the lens proposed for e.g. the warm dense matter experiments (see below).

Optical component design for the initial experiments

We have organized presentations on the initial experiments, to better understand the requirements, and thus design optics and diagnostics, and write the requirements-driven CDR. Initial requirements have been interpreted from the book of experiments; these are now being augmented after the presentations and discussions.

Atomic Physics:

Discussions with Rick Freeman and Richard Bionta have allowed Roman Tatchyn and Troy Barbee to start the design of a replicated ellipsoidal optic (equivalent to a K-B microscope). Operation at 0.85 to 1 keV is required, with focusing to ~1 μm. It will operate in specular reflection over the full range of the LCLS fundamental. The possibility of utilizing single coatings on different versions of the optic, to optimize reflectivity for selected spectral regimes and thus provide a low pass filter, is under investigation. Then the optic should remove most of the spontaneous LCLS spectrum above the third harmonic. In addition, V. Shlyaptsev has designed a related micro-lens for the same purpose that is predicted to survive if built from Be, C or Si. A general view is shown below; the central peak represents the focused light.

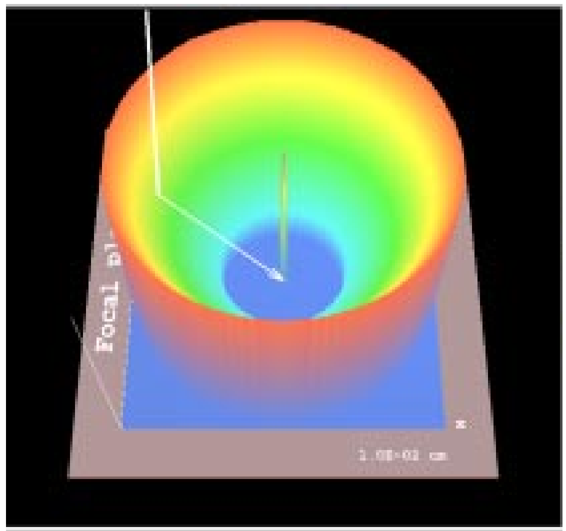


Figure: a view of a 100 mm x 40 mm x 8 mm micro-lens designed for the atomic physics experiments

Warm Dense Matter:

Discussions and presentations by R. Lee have allowed us to develop a solid conceptual design for a transmissive lens, mount, filters, and apertures. The layout of the experimental area is in hand. The figure below shows some of the details.

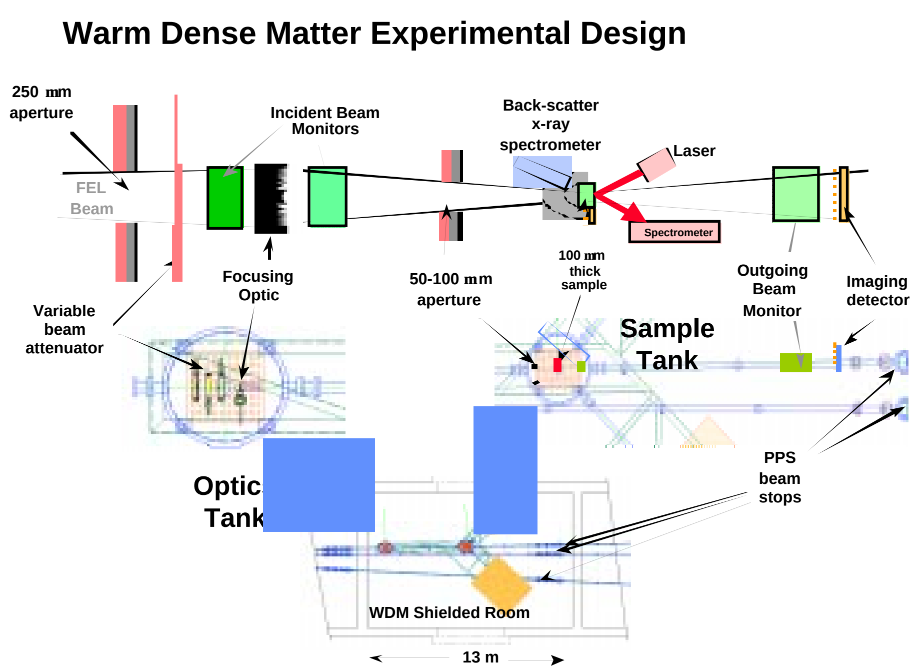


Figure: Details of the warm dense mater and plasma lens and associated components, and experimental layout

FEL physics:

Discussions are planned with J. Hastings in the near term on this topic. The objective is to finalize the sections to appear under this heading in the CDR, and assign writing tasks.

Nano-scale dynamics:

A first interpretation from the “book of first experiments has been completed”.

Femto-second chemistry:

A first presentation, by John Arthur, suggests the requirements for first experiments are comparatively simple (no lens), except for the need for the synchronization measurement between laser and FEL. We are organizing a follow-up meeting.

Biology:

A first interpretation from the “book of first experiments has been completed”. Further discussions are for February 2001.

Optical diagnostics design for the initial experiments

Following a meeting at SLAC, it was decided to organize the diagnostics into “commissioning and common”, and then “experimental specific”. The latter will appear in the experimental sections. Roman Tatchyn and John Arthur are responsible for organizing these sections; the plan is to have them complete by mid March.

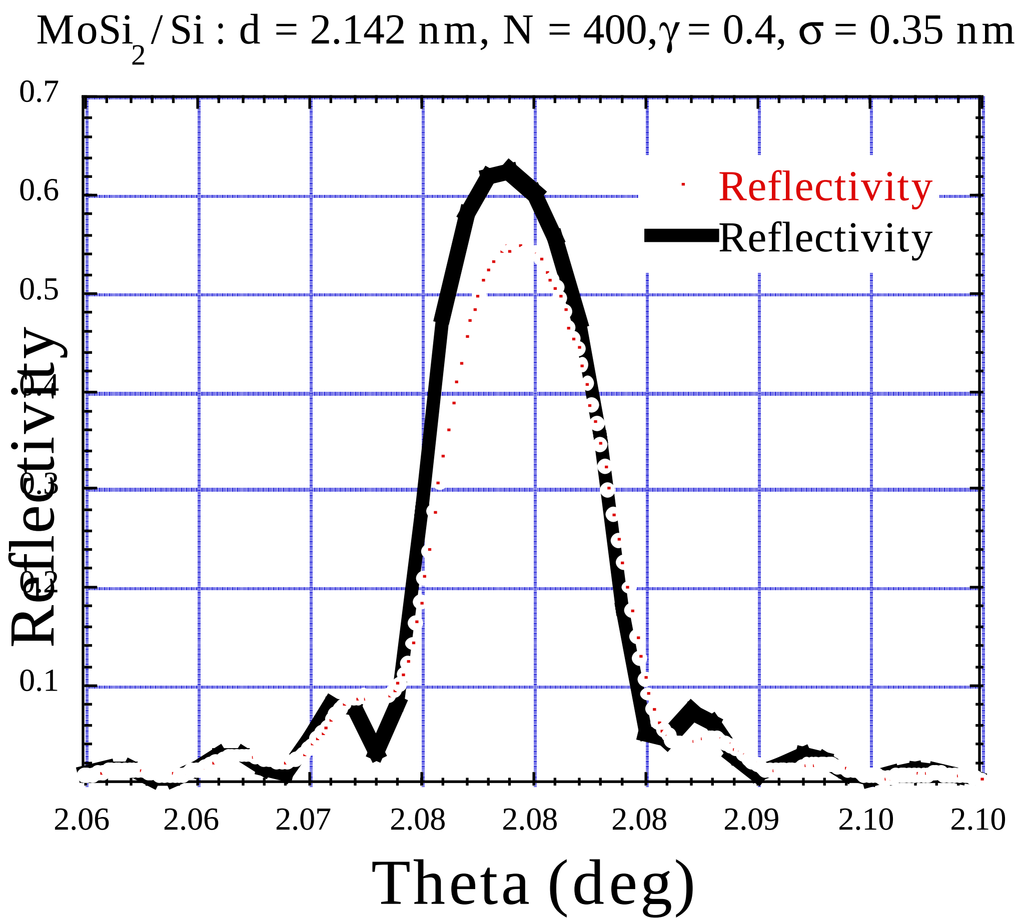
Optical component manufacture and testing

A series of multilayer optics built by Troy Barbee, were calibrated. The conclusions were:

1) The SSRL beamline could be used as a high precision calibration facility for multilayer mirrors

2) B_4C-C multilayers are not a good idea, having a half-life at room temperature of between 2 days and a month

3) A variety of WSi_2Si and MSi_2S multilayer mirrors worked almost as well as predicted at 8 keV. One MSi_2Si had a $E/\Delta E = 292$, and $55 < R < 67$. This leads Troy Barbee to expect to be able to produce mirrors suitable for wavelength filtering and time slicing for LCLS (requiring $300 < E/\Delta E < 1000$). See the figure below.



A comparison of theoretical (red) and experimental(black) reflectivities for an LCLS-relevant multilayer

A mandrel for one of Roman Tatchyn's designs (a 17 A period multilayer, ellipsoidal internal mirror for 300 minification at 8 keV) has been made previously. A single point diamond turned nickel surface was produced with rms roughness < 25 nm (prediction: this could be improved to 3 nm). This was then flow polished with 100 nm Silica to give a < 7 A rms roughness. It is now being re-polished with 50 nm Silicon, expected to produce < 3.5 A rms roughness, as required for LCLS applications.

Alan Jankowski has successfully produced BeB buttons, as might be used in place of Be on the LCLS (for easier working).

Photon-materials interactions studies

A study continues of expected damage. Melting is likely the relevant threshold mechanism. Known optical constants and melt energies can be used to determine maximum fluence for a given composition. The figure illustrates timescales and energies involved

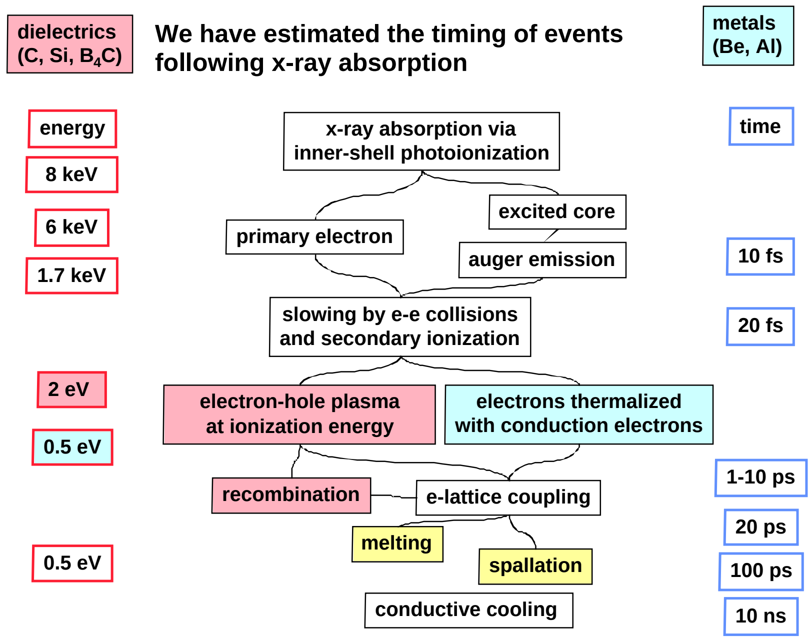


Figure: processes, timescales and energies involved in damage

Other damage processes may play a role, i.e.

average power ionization
spallation
repetitive thermal stress fracture

Integrated modeling is desired (possible codes):

Monte Carlo x-ray and electron transport (Fluka)
Molecular dynamics electron-ion coupling (XMD)
Fluid for thermal and mechanical effects (Lasnex)

Further optical laser experiments can improve our understanding of damage mechanisms.

Dmitri Ryutov is analyzing the damage that may occur on the time-scale of tens of nanoseconds and more after the passage of the x-ray pulse, related to high thermal stresses remaining near the heated spot for a long time. An aggravating factor is the pancake-like shape of the heated zone, giving rise to stress enhancement and potential for cracking. Thermal fatigue occurring during multiple pulses may further reduce the admissible x-ray flux.

To control the unprecedented peak power densities emitted by the LCLS the following methods will be employed fin the X-ray optical system:

a gas absorption cell

This component will be capable of continuously attenuating the coherent intensity at 8.3 keV from full strength to 4 orders of magnitude below peak. The attenuation range will be 6 orders of magnitude at 830 eV. This attenuator will be used to reduce the LCLS fluence to below damage thresholds for those instruments and experiments that will not require the full output power of the LCLS. Its conceptual design is complete.

multi-phase optics

To mitigate damage effects at locations where the power density is extremely large optical components whose active surfaces or interiors can be continuously replenished, for example by using liquid or gas phase materials, can be developed.

dynamic optics

For those solid-state optical components and configurations that cannot be operated at grazing incidence and are likely to sustain damage from a small number of LCLS pulses a strategy of moving the optic to a different position between pulses will be developed.

grazing incidence optics

In the near field hall grazing incidence optics will be used wherever feasible to dilute the power density by: 1) increasing the footprint of the light on the surface material, and 2) reflecting most of the incident power

low-Z optics

Detailed simulations have shown that the lowest-Z materials (i.e., Li, Be, B. C, etc.) have the least likelihood of being damaged by a normal-incidence LCLS beam in close proximity to the undulator. For this reason, a significant goal of the X-Ray optics R&D program is to develop optical components and systems out of such materials.

a far field hall

At a distance of ~380 m from the undulator exit the LCLS power density at normal incidence will be reduced to the point that low-Z materials should be able to intercept it over the entire spectral range of the fundamental without damage. Use of this hall should eliminate peak power damage issues for any experiment or optical system for which damage would be an insurmountable problem in the near field hall.

Novel optical concepts

Some renewable optics concepts have been documented, or are being developed – see the table below. The purpose of these optics is to cope with the very high energy fluences in the near hall, that preclude standard solutions. No experimental tests have been performed as yet.

A table of possible 'renewable optics' concepts

type	concept	status
plasma lens	capillary discharge	documented
liquid optics	controlled by magnetic, electrostatic and capillary forces	documented.
surface relief optics	controlled by auxiliary laser heating	under consideration

Conceptual design report

The major task being undertaken at the end of the period is writing the conceptual design. The organization by section is complete, and all sections except those on the specific experimental requirements (see previous sections of this report) are now complete. The list below shows the major section headings

9.0 Introduction	complete
9.1 Commissioning and common usage diagnostics	initiated
9.2 Optics and beamline components for the experiments	initiated
9.3 Facility requirements	complete
9.4 Control and instrumentation	complete
9.5 Other components	complete
9.6 optical components research and development	complete
9.7 Summary	initiated

VISA Report *Heinz-Dieter Nuhn, Aaron Tremaine*

First Saturation Measurements

On March 16, 2001, saturation of the process of Self-Amplified Spontaneous Emission (SASE) was observed at the VISA Free-Electron Laser (FEL) experiment at Brookhaven.

Saturation occurs in a SASE FEL when the maximum gain possible, for a given parameter set, has been achieved. At saturation, shot-to-shot intensity fluctuations are reduced. The LCLS is being designed to operate in the saturation regime. The distance to saturation as well as the per-pulse radiation energy at saturation have been predicted theoretically but had not been measured in an experiment until recently.

The on-set of FEL saturation after 7 orders of magnitude of gain was seen in the VISA experiment at about 3.6 m after the beginning of the undulator. The e-folding radiation power gain length, supported by 5 data points taken at 50-cm separation along the 4-m long undulator, was measured to be 18.5 cm. The wavelength of the radiation was 830 nm, i.e. in the Near Infrared spectral region. This is the second experiment that has shown SASE saturation. Saturation of a SASE FEL was first observed in September 2000 in Argonne at the Low Energy Undulator Test Line (LEUTL) FEL.

The fact that a gain length of 18.5 cm was observed for a peak current of about 75 A indicates that the electron beam's slice emittance must have been below 1 mm mrad. Slice emittance is difficult to measure directly with sufficient resolution. The electron beam parameters, present in the VISA experiment, meet the requirements of the LCLS. This is the first time that there are indications that a beam of that quality was produced.
These results are preliminary and still unpublished and will be confirmed during the upcoming runs. The official announcement of the measurement can be found at URL:

http://www-ssrl.slac.stanford.edu/visa/VISAannouncement.html

VISA Collaboration Meeting

A meeting of the VISA collaboration took place at Brookhaven on April 30, 2001 to review the recent results of the VISA experiment. At the core of the meeting were technical presentations discussing the various parts of the ATF-VISA system. The main results of the experiment are intensity as well as spectral measurements (of the fundamental as well as the second and third harmonic) taken at ports along the undulator From the intensity vs. z measurements follows a gain length of 18.5 cm associated with gain levels above 10^7. There is clear evidence that saturation occurs at the end of the undulator. The radiation spectra show less structure than expected, which could be due to the energy chirp of the electron beam or could be an indication that the electron bunch is shorter than expected. An additional result of the experiment, i.e., the measurements of slice emittance, requires further determination of the actual electron bunch length at the undulator. The slice emittance can be calculated from the gain length, the bunch length, the charge and the slice energy spread. For bunch lengths as measured in the linac the corresponding slice emittances would be significantly shorter than the measured projected emittances. J. Rosenzweig pointed out that nonlinear bunch compression in the linac-to-undulator beamline could very well be strong enough to shorten the bunch by more than a factor of two. Direct length measurements of the IR pulse after the undulator to determine the actual length of the pulses used were suggested. The agenda as well as the slides of the presentations can be found at URL:

http://www-ssrl.slac.stanford.edu/visa/visamtg_043001.html

Present Running

Optimizing the VISA gain has been quite challenging with the warming of the weather. The slow term drift of the system recently observed made the last run days less than constructive. VISA operates the ATF at maximum energy and the water-cooling has had difficulty keeping up with the demands VISA puts on it during operation. Last Thursday and Friday (May 24, 25) VISA received some running time in order to study the problem. By adding in an extra water mix and adjusting some of the low level rf, the system was much more stable than on our previous run. We were able to attain high gain and keep it with slight adjustments similar to our run days back in April. Lets hope it holds for the mid summer runs blocks.

Next week we have run days from Monday through Thursday. This will be our last run before the PAC conference. During this time, H.-D. Nuhn will come out and we hope to study the trajectory and envelop inside the undulator. If time permits, we hope to capture angular spectra.

Next steps

The LCLS funding for the VISA experiment in not extended past its present allocation covering the month of June 2001. Presently, the last scheduled run days for the VISA experiment under the VISA collaboration are June 4 - 7, 2001. The ATF management has decided to continue running the VISA experiment, even though support from LCLS funds will be discontinued.