LCLS Memorandum

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Subj: Final Report: FY2003 LCLS-Supported Work on the GINGER FEL Simulation Code

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This report documents the work done on a 34K$ contract between SLAC/SSRL and LBNL to improve and extend the GINGER free-electron laser numerical simulation code. The agreed-upon specific tasks were as follows:

Task 1: Implement wake field numerical model based upon software routines provided by H.-D. Nuhn of SLAC into an auxiliary, stand-alone code to provide $E_z(t)$ for input into GINGER code. This stand alone code will be able to import the time-dependent current profile from either **`elegant`** tracking code output or from a simple ASCII table.

Task 2: Improve and extend the start-to-end modeling capabilities of GINGER with significant emphasis toward: **a)** ability to import time-dependent, beam envelope parameters derived from macroparticle output of the **`elegant`** code, including certain higher order correlation's (*e.g.* x vs. γ) **b)** develop a "segmented run" capability with which GINGER could simulate an entire LCLS pulse via division into a series of shorter pulse runs **c)** ensure that the start-to-end capabilities work properly for both single processor (*e.g*. desktop computer) and multi-processor platforms (*e.g.* the NERSC IBM-SP) **d)** extend the post-processor abilities to analyze output from multiple segment runs

Task 3: Develop and implement an algorithm for GINGER to compute and propagate higher harmonic emission from a microbunched electron beam including effects of refraction and diffraction. In the initial formulation, ignore effects of harmonic radiation back upon beam electrons --- this approximation should be quite accurate for the nonlinear harmonic emission expected up to nominal saturation from LCLS-like FEL's.

Task 4: Update the GINGER user manual to include the various new capabilities as described above.

The majority of the work done on the above tasks (with the exception of Task #3 which was not begun in FY03) was accomplished in the July – September 2003 time frame. In addition to work on tasks #1, 2, and 4, a significant amount of effort was applied in both preparing for and attending the ICFA workshop in August 2003 at Zeuthen Germany on “Start to End Modeling”. We now present some details on the work accomplished under this contract.

Task 1 - Working in collaboration with H.-D. Nuhn, the physics package of the **`xwake_gen`** numerical wakefield code was extensively updated. In particular, the models for the synchronous and geometric wakes were improved and now no longer show undue sensitivity to the value of output temporal spacing. In its present state (version #1.32), electron beam data can either be input via an SDDS-file (as would be produced from the **`elegant2genesis`** code) or from standard current longitudinal profile choices (*e.g.* Gaussian or parabolic). There are various input “switches” (via a Fortran 90 namelist in the input file) to allow the user to turn on/off the various wake contributions such as synchronous mode, geometric wakes, roughness wakes, and resistive wall wakes. The source code is written in standard Fortran 90 and should run on nearly all platforms including Windows. The output wake file is written as an ASCII-formatted SDDS file and can be directly input into the GINGER code. In Fig. 1, we show a plot of the calculated wake for a 1-nC LCLS pulse produced by P. Emma using the **`ELEGANT`** code with CSR losses included.

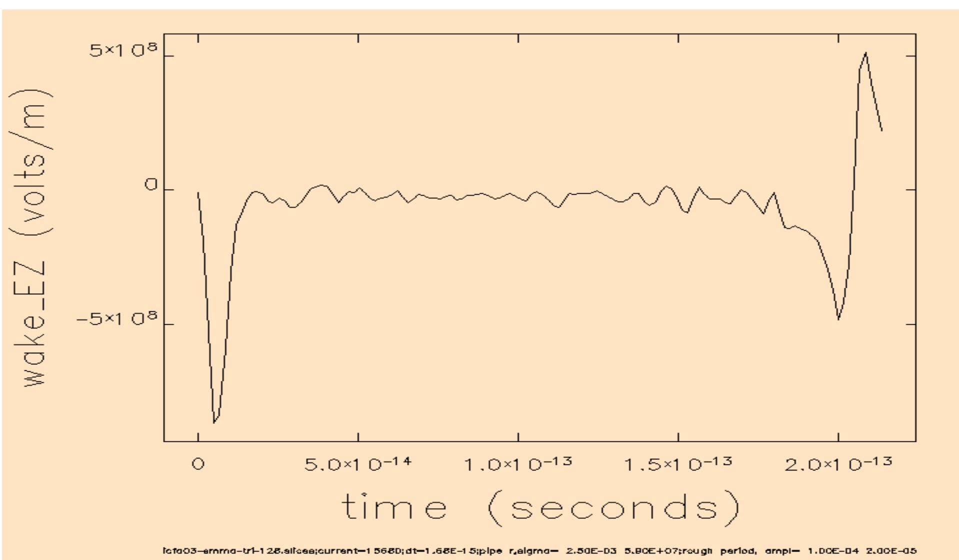

Fig. 1 – Longitudinal wake field E_z plotted vs. time for a 1-nC LCLS pulse with undulator parameters from the Zeuthen 2003 S2E workshop LCLS benchmark.

The **`xwake_gen`** code and its output were extensively used in the investigations performed for the ICFA Zeuthen workshop and is felt to be in a reasonably mature state at present. If and when improved physics models for wake generation are developed, it should be reasonably easy to include them in future versions of the code.

A great deal of work was also spent on Task #2 involving the generation and use of detailed phase space information from the **ELEGANT** tracking code. This work, too, benefited from and contributed to the effort spent on LCLS modeling for the ICFA Zeuthen workshop. In particular, the auxiliary numerical code **xconv_elegant** was improved and extended to produce highly detailed, time-dependent "summaries" of basic electron beam envelope parameters such as transverse centroids, angular tilts, mean energy and RMS energy spreads. These summaries together with the actual **ELEGANT** macroparticle data are used by GINGER to create individual slices whose 5-D phase space details can capture such phenomena as bimodal energy distributions and transverse centroid-energy correlations. The code uses a moving window method whose "center-of-mass" always remains fixed on the actual temporal output position. It also calculates instantaneous time-derivatives for the various centroids, tilts, and the mean energy. These are needed by GINGER when it is necessary to construct a macroparticle slice at $t=t_n$ using actual **ELEGANT** macroparticles whose temporal positions are many "cooperation" lengths away. This method appears to be reasonably robust and has been used to date to reconstruct the entire (*i.e.* 200-fs) LCLS pulse from an Emma-produced **ELEGANT** tracking run.

A second part of Task #2 was to develop a "multi-segment" run capability with GINGER. This was felt necessary because the CPU time and output storage requirements to simulate a full LCLS pulse are rather large. This capability required significantly improving GINGER's I/O code with regards to the reading and writing of z-dependent radiation field restart files inasmuch as these files must pass along sufficiently detailed parameter information so that a new segment run can begin seamlessly with minimal user-supplied information.

This effort was completed in time for the ICFA workshop in which results for ~30 fs of the beam head were shown. A slice-to-slice temporal spacing of 12 at was used; thus ~2500 individual slices were simulated. After the ICFA workshop, the remainder of the LCLS pulse was simulated in multi-segment mode for a grand total of ~17500 slices. These runs were done in "massively parallel" mode on the NERSC IBM-SP, typically with each segment run using 32 processors for 1024 slices. Total CPU time for the complete LCLS pulse was ~240 hours. In single-processor mode, the segmented run capability also worked correctly.

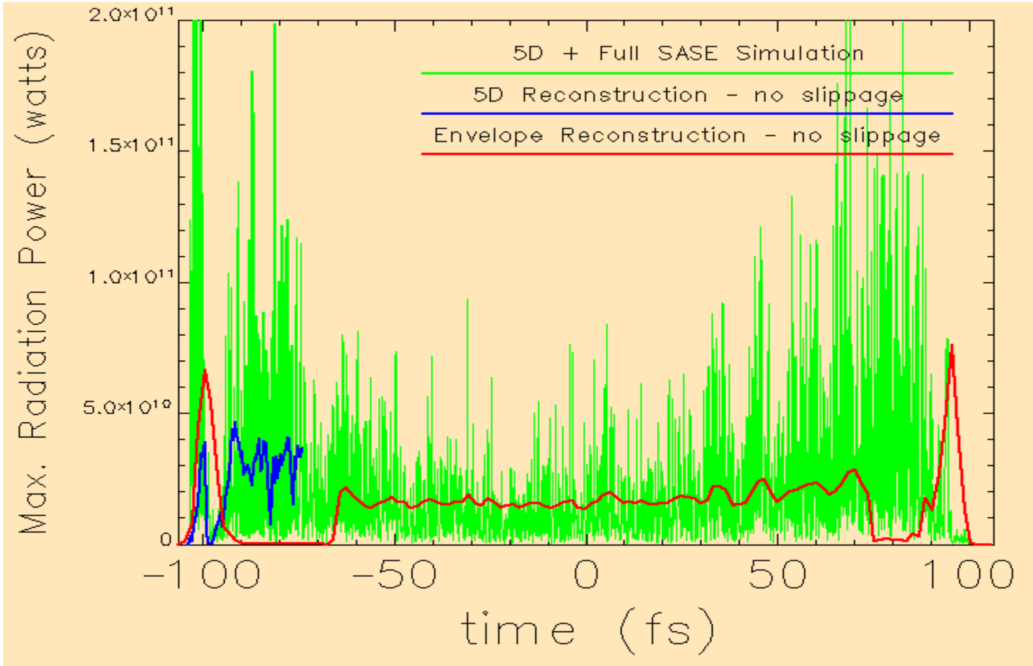

Fig. 2 – Output power vs. time for a 1-nC LCLS pulse with undulator parameters from the Zeuthen 2003 S2E workshop. The green line corresponds to a full SASE run with 5D phase space (*i.e.* macroparticle) slice reconstruction using data from the **`elegant`** code. The red line is from a series of time-independent monochromatic amplifier runs using electron beam envelope information produced by the **`elegant2genesis`** code. The blue line is from a similar series of amplifier runs but using a 5D phase space reconstruction. The green line to the output power at a z = 130 m. For the amplifier runs (red and blue lines), max *P* (approximately the saturated power) is plotted.

To date, we have not modified GINGER's post-processor to handle output from multiple segment runs simultaneously. It was felt that this effort could be postponed because the post-processor has the existing capability to generate SDDS-formatted time-dependent output files. A group of these output files can be input to SDDS routines such as **`sddsplot`** to produce the "big picture" of FEL performance such as the output radiation power. An example of this is shown in Fig. 2 for the aforementioned full pulse LCLS run.

In FY2004, we expect to completely revamp the format of GINGER's output file (the infamous *pltfile*) used by the post-processor. In particular, the output will be written in a much greater "self-describing" format (although not in "classic SDDS format) and with much greater flexibility (*e.g.,* highly detailed radial intensity information could be written at a much lower frequency in *z* than "scalar" output such as instantaneous power, microbunching, *etc*.). When this new work is completed, we expect that the post-processor will be able to simultaneously handle multiple segment output. This wanted format flexibility is also needed for the extension of GINGER's simulation capability to follow harmonic radiation generation. We expect work in this area (originally Task #3) to begin in late winter or spring 2004, initially under LBNL's financial "auspices" as the capability is needed for modeling the LBNL LUX project.

Task #4 involved updating the GINGER user manual to include the extensions and modifications made to the code since the last official release in January 2002. This work was begun in earnest in late fall 2003 and is, as of January 2004, essentially complete. New sections detailing the information needed to do multiple segment runs and the writing/reading of particle and field restart files have been written. A “beta” version of the manual has been released in early February 2004. The manual is formatted under LaTeX and available in both PostScript and PDF form. A final version will likely be released by 1 April 2004. In addition to the user manual, simple “help” instructions to most of the so-called auxiliary codes (*e.g.,* **`xwake_gen`**, **`xconv_elegant`**) are automatically displayed to a user's computer screen when these programs are run “naked” (*i.e.* without any input files).