LCLS Newsletter JULY-2000

Project Management *Lowell Klaisner, Max Cornacchia*

The SAC met on July 14-15. The experiments to be present at BESAC on October 10 are taking shape and good progress is being made, as reported by Ingolf Lindau in this newsletter. Each experiment is being analyzed and discussed by some members of the LCLS team with a view to better understand the experimental requirements and to ensure that they can be met.

The Working Group on "Ultra Short Bunches" has issued a report of the study. The report is titled “Ultrashort Optical Pulses in the Linac Coherent Light Source” and can be found on the Web at (http://www-ssrl.slac.stanford.edu/lcls/technotes/LCLS-TN-00-8.pdf).

The preparations for the Arcidosso Workshop (Sept. 10-15) on "The Physics of, and the Science with, X-Ray Free-Electron Lasers" are proceeding. About 75 people have registered, of which about 2/3 from the accelerator and FEL community, and 1/3 from the users.

LCLS General Seminar

There will be a LCLS Seminar on Monday, July 31st, starting at 3:00 pm in the LOS 2nd floor conference room. Carl Schroeder will talk on "Quantum Effects in High-Gain Free-Electron Lasers".

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

See attached Powerpoint presentation for some of the work being done in the FEL Physics Section. (Pages 8-42 of this PDF file)

Photoinjector R&D News *J. Clendenin/J. Schmerge*

GTF

So far with 0.5 nC of charge with a transversely clipped (2 mm diameter) and temporal Gaussian laser pulse shape we have measured 3.0 mm-mrad with a 2 ps FWHM laser pulse and 2.6 mm-mrad with a 4 ps FWHM laser pulse. The later measurement was repeated over two days and we have an additional data point at a different solenoid field which is much lower but the quality of the data is not good. We are attempting to repeat this measurement today to get a good set of data. So far we have not had good success measuring the emittance at 1 nC because the beam is not well behaved so it is very difficult to transport. This is probably because at the high charge the laser energy has to be maximized and this means minimizing the laser pulse length which leads to very high peak currents and thus space charge is a big problem. Therefore in order to make 1 nC emittance measurements we need to use longer laser pulses on the cathode to reduce the space charge force.

Thus starting on Friday we will be installing the laser pulse stacker (based on a Michelson Interferometer) which will allow us to stack 1, 2 or 4 pulses. This will allow us to produce long shaped pulses and at the same time maintain the laser conversion efficiency since the pulse stacking is done in the UV. We expect to have the pulse stacker installed and characterized (using a streak camera) by August 9th. The GTF will be shut down the first part of August due to a building water outage. The water will be turned back on by August 9th. Thus the long laser pulses will be ready at the same time the beam comes back on.

Linac *Vinod Bharadwaj*

A major effort is underway in developing the cost estimate for the linac (and the injector, both are being done together). At present, the draft cost estimate for the linac is about 50% complete. There are some significant differences in cost between now and the previous cost estimate made at the time of the Technical Design report, which will have to be discussed in detail. An effort is underway to quickly get a “draft” draft total to see how different the final cost is going to be. We do not anticipate any difficulty getting a draft estimate by the end of September.

The conclusion of the “Shorter Bunches” study and the subsequent discussion of the scientific experiments show extreme interest in the shorter (50 fs) optical pulses. Further refinements to the calculations in the linac enabling these shorter pulses will be done.

Undulator *Efim Gluskin/Liz Moog*

The prototype undulator section (with fake magnets) is nearly complete and expected to be delivered next week.

A test version of the mover system to align the undulators and quadrupoles is on order.

A prototype version of the quadrupole lens has just been ordered.

The design work is being completed for a full-size prototype undulator. The titanium bar that will become the strongback holding the magnets and poles will be a special-order item because of its size and cost. The smaller mechanical parts to hold the poles and magnets are in the final stages of production. Purchases of magnets and poles will be separate. The request for a quote on the material for the poles has been sent out.

N. Vinokurov will be at APS for two weeks at the beginning of August. One goal of his visit is to make significant progress on the CDR sections that discuss the undulator line and the inter-undulator FEL diagnostics.

Work is also beginning on calculations of the energy that will be deposited in the crystals used in the diagnostics. The results of these calculations will be used to investigate the effect that the power load will have on the crystals.

X-Ray Optics *Art Toor*

Bending Magnets and Beam Dump

Technical review of the new bending magnet design by D. Walz and S. Mao had concluded that this design is superior to the design presented in the LCLS Design Study. The new design uses 5 permanent magnets and two DC magnets and will deflect the electron beam with energies between 1.5 GeV and 15 GeV into a smaller beam dump that will not require additional muon shielding. D. Walz and S. Mao are developing a cost estimate for electron dump system which includes the bending magnets, vacuum chamber, electron dump and the dump shielding. They have completed estimates for bending magnets, electron dump and the dump shielding. Cost estimates for the vacuum chamber will be completed after D. Walz finalizes the layout design for the magnets.

Energy Deposition at Photon Stopper

The energy deposition at the photon stopper due to high-energy electron beam losses has been calculated by A. Fasso and S. Mao using FLUKA and EGS4. The photon stopper position for these calculations was 20 meters downstream from the first bending magnet (upstream of the electron beam dump). Three beam loss sources were calculated:

1) the two collimators upstream from the undulator,
2) the e-beam position and profile monitors located upstream of the undulator and distributed throughout the length of the undulator, and
3) the x-ray beam position and intensity monitors located in the undulator at a spacing of ~ 10 meters.

The two collimators were assumed to be separate by 4 m with an inside diameter of 0.2 cm and 1% of the electron beam power was lost in the collimators. The e-beam position and profile monitors include button-type BPMs rf-cavity BPMs and wire scanners. No losses result from the button type or rf-cavity BPMs and the wire scanners were assumed to use 20-μm diameter tungsten wire and that 20% of the beam power is intercepted by the wire. The x-ray monitors were assumed to be 0.5-mm thick diamond according to an e-mail from E. Gluskin. The energy deposition at the beam stopper from these three sources can be summarized as:

1) $\sim 2 \times 10^{-5}$ W
2) $\sim 4 \times 10^{-4}$ W
3) $\sim 4 \times 10^{-2}$ W

To limit the deposition from the x-ray monitors to 4 x 10^{-2} W will require an interlock control that allows the diagnostic to be inserted into the beam at a 1-Hz or lower rate.

Experiment Hall

The plan view of the Experiment Hall that has been discussed since May is the layout that will be described in the CDR. The length of the Hall is about 70 m. The hall consists of one x-ray optics room, 13 experiment hutches, one photon dump room and several user rooms. S. Mao and W. Kroutil have completed a draft PPS design for the LCLS Experimental Hall. The PPS design includes 16 pairs of Photon Stoppers, 12 pairs of

Photon Dump/BTM and 15 PPS doors. The PPS design and cost estimate will be discussed in the LCLS Hutch Safety Meeting on July 31.

CAMEL (Capillary-Magneto-Electrostatic) Optics

LDRD funding has been obtained to study and develop CAMEL optics consisting of thin liquid films. D. Ryutov and A. Toor are studying a range of LCLS relevant applications where CAMEL optics offer unique advantages over conventional x-ray optics.

Experimental Program *Ingolf Lindau*

On July 14 SAC met at SSRL. The main purpose of the meeting was for the spokespersons of the first scientific experiments at LCLS to present the first draft of the report, to be submitted to DOE by September 1, 2000, and rehearse their presentations in preparation for the BESAC meeting on October 10, 2000. Drafts of all proposed experiments were available at the time of the meeting and are now sent to a few reviewers for informal input. The drafts will be finalized by August 15, then edited, printed and sent to DOE by the September 1 deadline. Copies will be distributed to those interested. As the next step in the preparation of the presentations for BESAC October 10 the spokespersons for the six experiments will meet at SSRL on September 7-8, 2000 to decide and work out the final format of the talks.

At the July 14 SAC meeting there was also a presentation by Dr Toshi Tajima on possible fundamental physics experiments at LCLS. The basic ideas by Dr Tajima are well summarized in the June 2000 LCLS Newsletter under the X-ray optics section. The day before the SAC meeting, July 13, Drs. Pisin Chen and Claudio Pellegrini had organized a mini-workshop on High Field, High Intensity Physics with LCLS. The program is given below. Copies of transparencies can be obtained by contacting Pisin Chen at SLAC.

Mini-Workshop on High Field, High Intensity Physics with the Linac Coherent Light Source (LCLS). SLAC, July 13, 2000.

The very large peak power of the LCLS, and the theoretical possibility of focusing the x-ray beam to nanometer spot size, open the possibility of producing in the laboratory extremely large electric fields and energy densities. The purpose of the workshop is to explore the possibility of using these unique characteristics of the focused LCLS X-ray and electron beams to study the physics of systems subjects to very large fields, pressure, and accelerations. The workshop will start with a review of the LCLS properties. It will then discuss three main categories of experiments, the X-ray optics and instrumentation needed to produce the required focused beam and particle beam physics with the very high density LCLS electron beams:

1. State of matter and the physical processes under extremely high density and pressures on materials;
2. Laboratory astrophysics;
3. Experimental tests of nonlinear QED and QCD;

4. X-ray optics and other instrumentation;
5. Physics with the LCLS electron beam.

We plan to have these introductory and overview talks in the morning, and leave the afternoon for contributed presentations.

Pisin Chen and Claudio Pellegrini (Co-organizers for the Min-Workshop)

Agenda

09:00-09:30 am	Introduction to the LCLS.
09:30-10:00 am	Extreme state of matter and physical processes under high intensities
10:00-10:15 am	Coffee Break
10:15-10:45 am	Laboratory astrophysics with high fields
10:45-11:15 am	Nonlinear QED and QCD under intense fields
11:15-11:45 pm	X-ray optics and other related instrumentation
11:45-12:15 pm	Physics with the LCLS electron beam
12:15-13:30 pm	Lunch Break
13:30-16:30 pm	Contributed presentations and discussion
16:30-17:00 pm	Summary

VISA Report from ATF Newsletter

Ilan Ben-Zvi, Aaron Tremaine

Run of June 9th:

Data taken from the last runs indicate little correlation to the proposed correct trajectories sent out by Robert. This could indicate the presence of other uncertainties in the fiducialization numbers. The trajectory data taken also shows a huge kick, 12.5mrad, near the beginning of Section 3. This kick is on the order of a missing dipole magnet. (A steering magnets at full strength gives a kick of ~4.5mrad.) Heinz-Dieter has done simulations showing that the proposed correct trajectory by Robert could not fix this kick. Also, a kick of this magnitude would have to be a gross mis-alignment of the undulator. For results please view the pdf file:
http://www.nsls.bnl.gov/AccTest/R0/6_9_VISA_run.pdf

Run of June 13th:

We performed more systematic and accurate studies in the x-direction, and also briefly recorded a couple of y-trajectories. The attached PDF file has all the relevant details:
http://www.nsls.bnl.gov/AccTest/R0/6_13_VISA_run.pdf

Run of June 20th:

The important result of this run is that we can straighten the trajectory with the intra-undulator magnets. By using three magnets (before, after and at junction 2-3) we compensated the kick and brought the trajectory down to a few hundred microns walk-off. As Vitaly suggested, we simulated with MathCad the undulator sections offset and its effect on the trajectory. The best fit to the non-steered trajectories occurs when we assume a sudden offset of about 300-400 microns at the junction of section 2 and 3. Visual observations confirm such a possibility. In addition, the simulated steering scheme to compensate for the offset was implemented during today's run, and worked fairly well. Also, for the first time since the shut down we turned on the detector. We measured a steady spontaneous emission of 300 pJ at 400 pC charge.

Run of July 13-17:

We had run days last Thursday, Friday, Sunday, Monday, and Tuesday. Not much noticeable gain was seen, but interesting trajectory measurements were done. Heinz-Dieter from SLAC came out and through his simulations we were able to analyze the trajectories. We horizontally moved the undulator and with the monitoring system were able to move the undulator to <15 microns of the desired position. At first the peak-peak trajectory was >1.5mm and after several iterations of undulator movement (using Heinz-Dieter's simulation) it was down to <500 microns. The agreement between simulation and undulator movement/ trajectory measurement is quite encouraging. This shows we believe that the undulator was not straight for this last set of runs, but we do have the ability to accurately move the undulator in the horizontal plane. This week the undulator was pulled and moved to the magnetic measurements lab. Robert and his team arrived and with George's help are setting up the pulsed-wire measurement and will teach Alex and Aaron to re-fiducialize and interferometrically align the undulator sections. If all goes well the fiducialization should be finished the last week in August at which time it will be moved back to the ATF.

Run of July 13-17 (from H-D. Nuhn)

The last VISA run days before the start of the re-fiducialization, were used for VISA trajectory studies and beam based alignment of undulator segments.

It was found that the linear regime of the VISA quadrupoles is rather small, about +/- 1 mm in the horizontal as determined by studying the response of BPM signals to changes of the correctors that are separated by phase advances of 90 degrees or more. Above and below the linear range, the sign of the response changes following an "S" curve. The edges of the linear range can be used for a rough trajectory correction. It was found that the misalignment of the third section was so great that it was impossible to keep the beam within the linear range of all quadrupoles.

It was decided to move the third undulator section to reduce its misalignment. The movement of the undulator could be done in a very controlled way.

The actual movement procedure was carried out in several steps. The required amplitude for the moves for each end of section #3 was estimated and checked, based on orbit measurements and model fitting. The total movement applied to segment #3 was 470 microns for the upstream end and 350 microns for the downstream end, both in the horizontal plane away from the wall and towards the HGHG beamline. After the alignment of segment #3 it became clear that segment #4 needed adjustments, as well. It was moved using the same procedure, 160 microns towards the wall for the upstream end and 600 microns towards the HGHG beamline for the downstream end. The trajectory improvements agreed very well with the predictions. The positions of all section ends were monitored using 5 cameras and 5 TV-monitors. Movements could be controlled to better than 15 microns.

After the realignment, the horizontal trajectory stayed within a band of 500 microns when only using upstream correctors to adjust the launch condition but leaving the correctors along the vacuum tank de-Gaussed. This amplitude is down from 3 mm before the realignment.

The last run day was spent tuning the ATF and VISA for gain, unfortunately with little success. The maximum SASE gain that was achieved was less than what had been achieved in May, in spite of the improved trajectory. The reason is very likely to be found in problems with the gun-linac system that could not be brought to its best performance in the available time.

In the coming months improvements will be added to the system, including the re-fiducialization and realignment of the undulator and a major tuning effort of the gun-linac complex. It is also planned to increase the automation of the trajectory data aquisition. All these efforts should get us into a much better position during the next VISA runs.

Report of the FEL Physics Section

- Section members:

  C. Pellegrini 30%

  Heinz-Dieter Nuhn 100%

  Sven Reiche, Post-Doc 50%

  Carl Schroeder, Post-Doc

FEL Physics section

Outline:

- ✓ Commissioning and diagnostics
- ✓ FEL Optimization
- ✓ Quantum theory of FEL

LCLS commissioning: electron beam and X-ray optics instrumentation

The **LCLS commissioning** consists of 3 steps:

a. measure the electron beam properties at the undulator entrance as a function of charge and compression;

b. propagate the electron beam through the undulator, align the undulator and the beam with beam based alignment;

c. measure the beam transverse distribution inside the undulator to match the beam into the undulator and avoid envelope oscillations;

c. measure the X-ray radiation intensity, line width, and angular distribution as a function of electron beam parameters, to determine the FEL gain, intensity fluctuations, spectral properties, and coherence properties, and compare it to the theoretical expectations.

LCLS Instrumentation

During commissioning and operation the electron beam and X-ray characteristics should be monitored for each pulse whenever possible. The system fluctuations can have an important effect on the FEL gain, and it is important to understand them. Measuring each pulse is also necessary in order to separate the FEL intensity fluctuations due to the SASE start-up from noise -of the order of about 7% for the reference LCLS case- from those due to system fluctuations in the drive laser-electron source-linac system, which can be much larger, about 35%.

LCLS Instrumentation

What we need to measure:

1. Electron bunch charge;
2. Electron bunch center of mass position along the undulator;
3. Electron bunch transverse distribution throughout the undulator as a function of charge;
4. electron bunch longitudinal distribution, and integrated and slice energy spread, as a function of charge.
5. X-ray intensity within a defined solid angle and line width as a function of electron bunch charge;
6. X-ray spectral properties.

Electron beam measurements before the undulator*.

Needed to analyze the FEL intensity and gain:

	accuracy	dynamic range
Bunch charge	1%	0.1-1nC
Bunch length	10%	50-300fs
Energy spread*	10^{-5}	10^{-5}-10^{-3}
Emittance**	20% proj., 40% slice	0.2-2 mm mrad
Electron energy	1% absolute, 10^{-5} relative	5-15GeV
Arrival time	50 fs	

*List discussed also with V. Bharadwaj, P. Emma, M. Cornacchia

** both slice and projected data are needed

Alignment requirements

The LCLS will use beam based alignment techniques. To reach the alignment required for the FEL gain, we need to measure electron beam displacements of the order of 2μm and beam angles of the order of 1μrad.

The electron beam center of mass position can be measured with a relative precision of 1μm using RF BPMs.

Measuring the x-ray transverse distribution center of mass can in principle give information of the local position and the "history" of the trajectory. For this to be useful for alignment the required accuracy is again of the order of 1-2 μm.

Alignment requirements

To match the beam to the undulator and avoid beam envelope oscillations we also need to measure the beam transverse distribution. This can be done with OTR if we can solve the signal to noise ratio problem, due to the large amount of spontaneous radiation.

Alignment: X-ray instrumentation

- The effect of a misaligned quad or section in the undulator is to produce for the electron bunch a trajectory transverse shift or an angle. Since the betatron wavelength is about 120 m the beam will appear in each undulator section corresponding to one gain length as displaced or at an angle.
- To preserve the gain the beam must be aligned to about 2 μm. The electron beam position can be measured to this accuracy using RF BPMs.

Alignment: X-ray instrumentation

A. One section

Assume that in one section, one gain length long, about 10m, the beam is displaced by about 2μm. The spontaneous radiation produced in that section has an angular aperture of $K/\gamma \sim 10^{-4}$. The spot size on a screen at the section end would be about one mm in radius.

Selecting the "coherent radiation" with an angular aperture of $\theta_c \sim K/(\gamma N_u^{1/2}) \sim 10^{-4}/50 \sim 2\times 10^{-6}$, we obtain a spot size of about 20 μm for a single electron. For many electrons this has to be folded with the angular spread in the electron beam of about 10^{-6} rad, and with the radial position distribution of about 30 μm. As a result the x-ray spot size will be larger than the electron beam spot and will overlap it.

Alignment: X-ray instrumentation

B. Two sections

- Let us look now at the trajectory history, Let us say that from a section to the next one the there is a misalignment and the trajectory is displaced by 2μm. We look at the X-ray with a detector at the exit of the second section. If we do not select in angle or frequency the x-ray spot size from the first section will be larger than 1mm.
- Putting an iris in the undulator to look only at the coherent part of the radiation is not possible. Selecting in frequency with a crystal can reduce the effective angular aperture.

Alignment: X-ray instrumentation

Selecting radiation within a frequency interval of 5x 10^{-4}, corresponds to a selection in angle of about 2 μ rad. This would give a spot size at 15m of 30 μm, that will be increased by the folding with the electron radial position distribution and energy spread. On the detector at the exit of the second section we would have to resolve the two spot sizes, 30 μm or larger in radius, to the level of 2μm.

Alignment: X-ray instrumentation

Wavelength chirping and fluctuations.

X-ray measurements frequency selective must also include the effect of the chirping of the electron energy and the corresponding chirping in frequency along the bunch, and of the central energy fluctuations. These effects would tend to reduce the selectivity in angle associated with the selection in frequency, since only part of the bunch would be within the interval selected by the monochromator.

The energy chirping is presently estimated to be of the order of 10^{-3} . The central beam energy is also estimated to fluctuate by 10^{-3}, so the wavelength will fluctuate by twice that amount.

Alignment: X-ray instrumentation

Conclusions:

A. Based on the previous discussion using x-ray diagnostic for alignment purposes along the undulator seems to be very difficult.

B. Measuring the coherent radiation intensity along the undulator, within a much larger background of spontaneous radiation, also needs careful evaluation, in particular considering the effects of chirping, and of the fluctuations of the central frequency.

LCLS Instrumentation: X-ray measurements at undulator exit

This still needs to be discussed. From the point of view of commissioning we list what is needed in the following Table.

Instrumentation	Dynamic Range	Resolution
X-ray intensity detector	10^7-10^{12} photons/pulse	1%
X-ray angular distribution	⬂1.7μrad	fraction of μrad
X-ray monochromator, $\Delta\omega/\omega$	10^{-3}-10^{-6}	⬂1%
Intensity of harmonics		

XFEL Optimization

We have looked at the LCLS performance, including synchrotron radiation and wake-field effects, for different undulators. We consider the 5 cases given in the table.

One case is the reference LCLS case. Three cases, A, B, D, use permanent magnet helical undulators, with a gap of 8.5 mm, K=2.7, and the same beam energy of the LCLS case.

Case C uses a lower field, K=1.8, permanent magnet helical undulator, and lower beam energy.

Table 1

	LCLS	A	B	C	D
Undulator period, cm	3	3	3	4	3
Undulator field, T	1.3	0.96	0.96	0.48	0.96
Undulator K	3.7	2.7	2.7	1.8	2.7
Undulator gap, mm	6	8.5	8.5	7.5	8.5
Beta function, m	18	17.7	73.5	20.5	5
Beam energy, Gev	14.3	14.7	14.7	12.0	14.7
Synch. Rad. loss, GW	90	50	50	11.6	10
Norm.emitt, mm mrad	1.1	1.1	1.1	1.1	0.3
Charge, nC	0.95	0.95	0.95	0.95	0.2
Peak current, kA	3.4	3.4	3.4	3.4	1.17
Energy spread, %	0.006	0.006	0.006	0.006	0.006
FEL parameter, $\rho \times 10^4$	5	6	4.5	6	10
Gain Length, m	4.2	2.8	3.4	4.2	1.84

FEL scaling laws: a comment on case D.

The FEL performance is controlled by:
1. the FEL parameter

$$\rho=((K/4\gamma)\Omega_P/\omega_U)^{2/3},$$

with the plasma frequency being proportional to the beam density

$$\Omega_P \sim (N_e/\varepsilon\beta\sigma_L)^{1/2}.$$

2. the ratio of the emittance to the radiation wavelength/4π. When this ratio is larger than approximately one diffraction effects increase the gain length. This is the case for LCLS where the ratio is about 4. In this situation the gain length can be made shorter by reducing the charge and the emittance, keeping ρ the same.

FEL scaling laws: a comment on case D.

In case D we reduce the charge, the emittance and also the peak current, to obtain a shorter gain length.

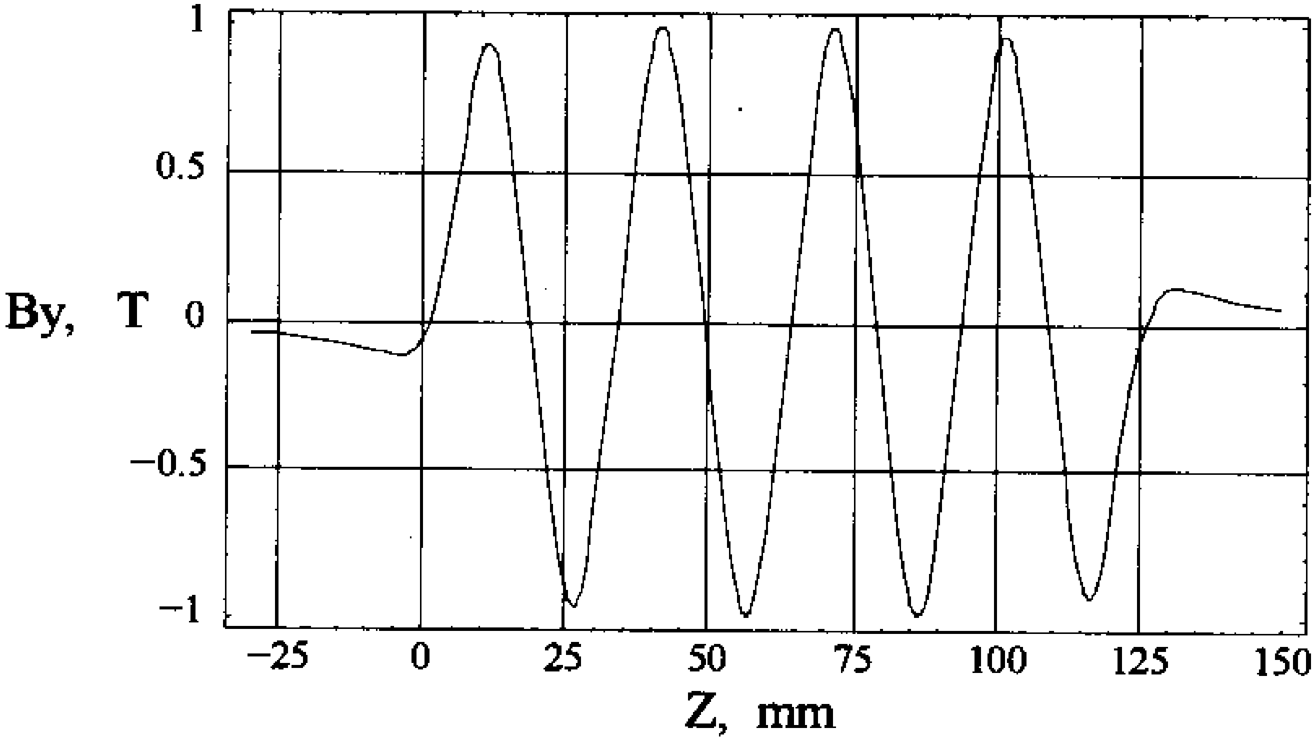
The reduction of the peak current facilitates the acceleration and compression the beam, without emittance blow-up.

The price to pay to follow this strategy is a reduced FEL peak power, which is proportional to the total charge. An additional advantage is reduced synchrotron radiation background on the X-ray optics and instrumentation.

Undulators for cases A, B, D.

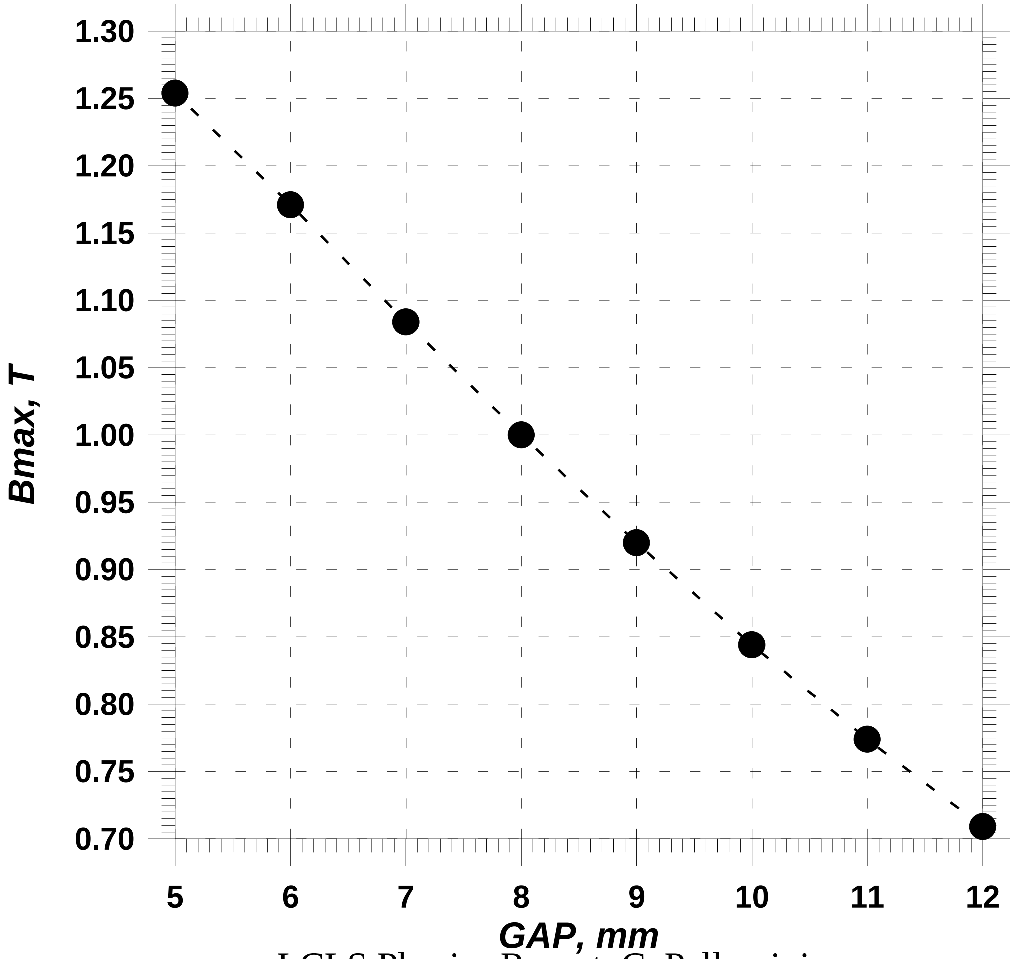
We use the hybrid helical undulator scheme of the Kurchatov Institute.

Undulator period λ_w=30 mm, Gap=8.5 mm, Field =0.96 T.



Undulators for cases A, B, D.

KI Hybrid helical undulator scheme: Field vs gap.



Effects of wake-fields in undulators

Because of the the large length of the X-ray FELs undulators, and of the large peak current of the electron beam, the wake-field effects in the undulator vacuum pipe cannot be neglected, and have been the subject of much recent work. The two main effects considered here are those due to the resistivity and the roughness of the vacuum pipe wall. Of course for a complete estimates one must also consider the wake-fields produced by discontinuities in the vacuum chamber, diagnostic elements, vacuum ports, and other possible elements.

Wall resistivity

The wall resistivity produces a longitudinal and a transverse effect. The last one is usually negligible in the cases of interest to us and will not be considered here. The longitudinal effect can be described by the wake-field

$$W_z(t) := \frac{-4\,ce^2 Z_0}{\pi R^2}\left[\frac{1}{3}e^{\frac{t}{\tau}}\cos\left(3^{\frac{1}{2}}\frac{t}{\tau}\right) - \frac{2^{\frac{1}{2}}}{\pi}\left(\int_0^{\infty}\frac{x^2 e^{x^2\frac{t}{\tau}}}{x^6+8}\,dx\right)\right]$$

where t is the longitudinal position of the test particle respect to the particle generating the field.

Surface roughness wake-field

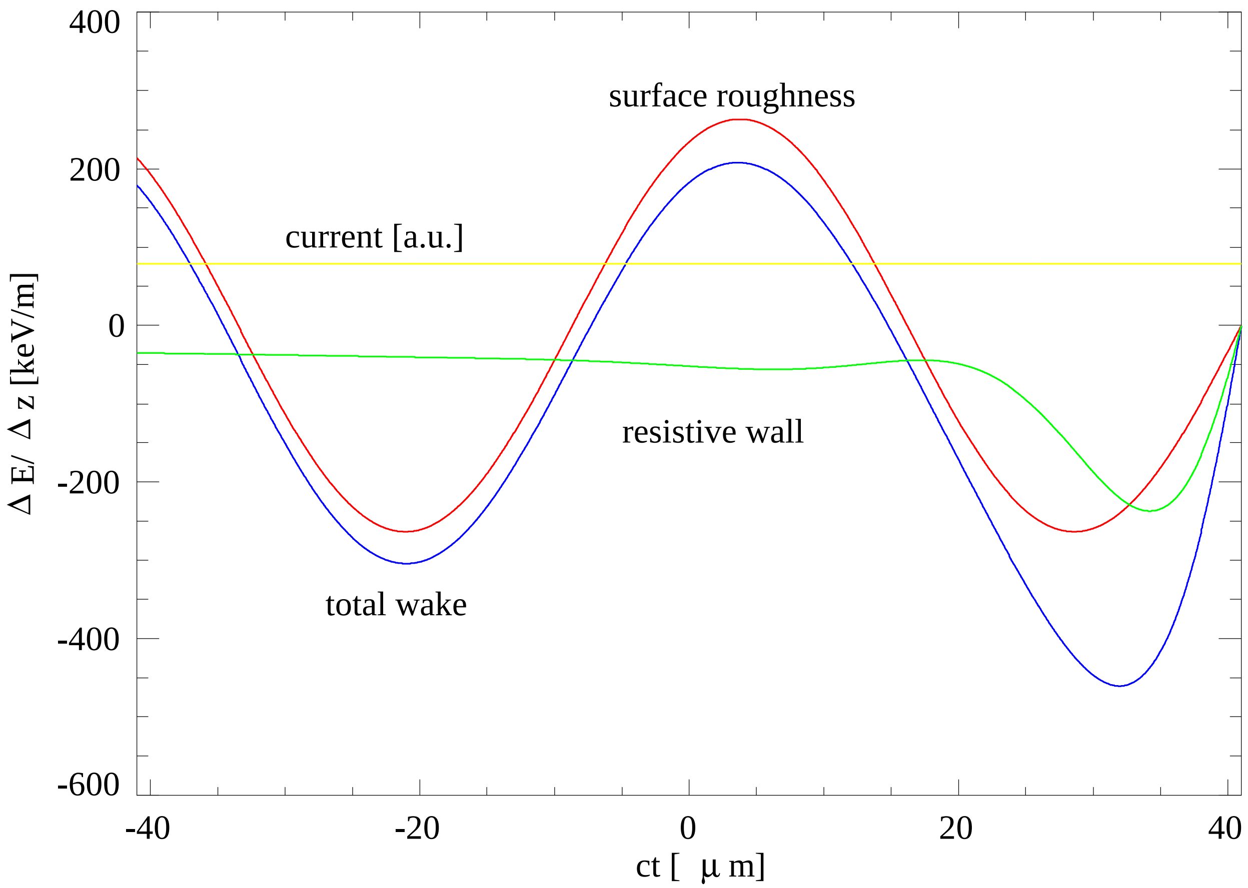
For the effect of roughness there are several models.

The one used in the calculations done in this paper is the "Darmstadt model", which simulates the effect of imperfections with a thin layer, δ, of dielectric, slowing down the phase velocity. For this model the wake field is

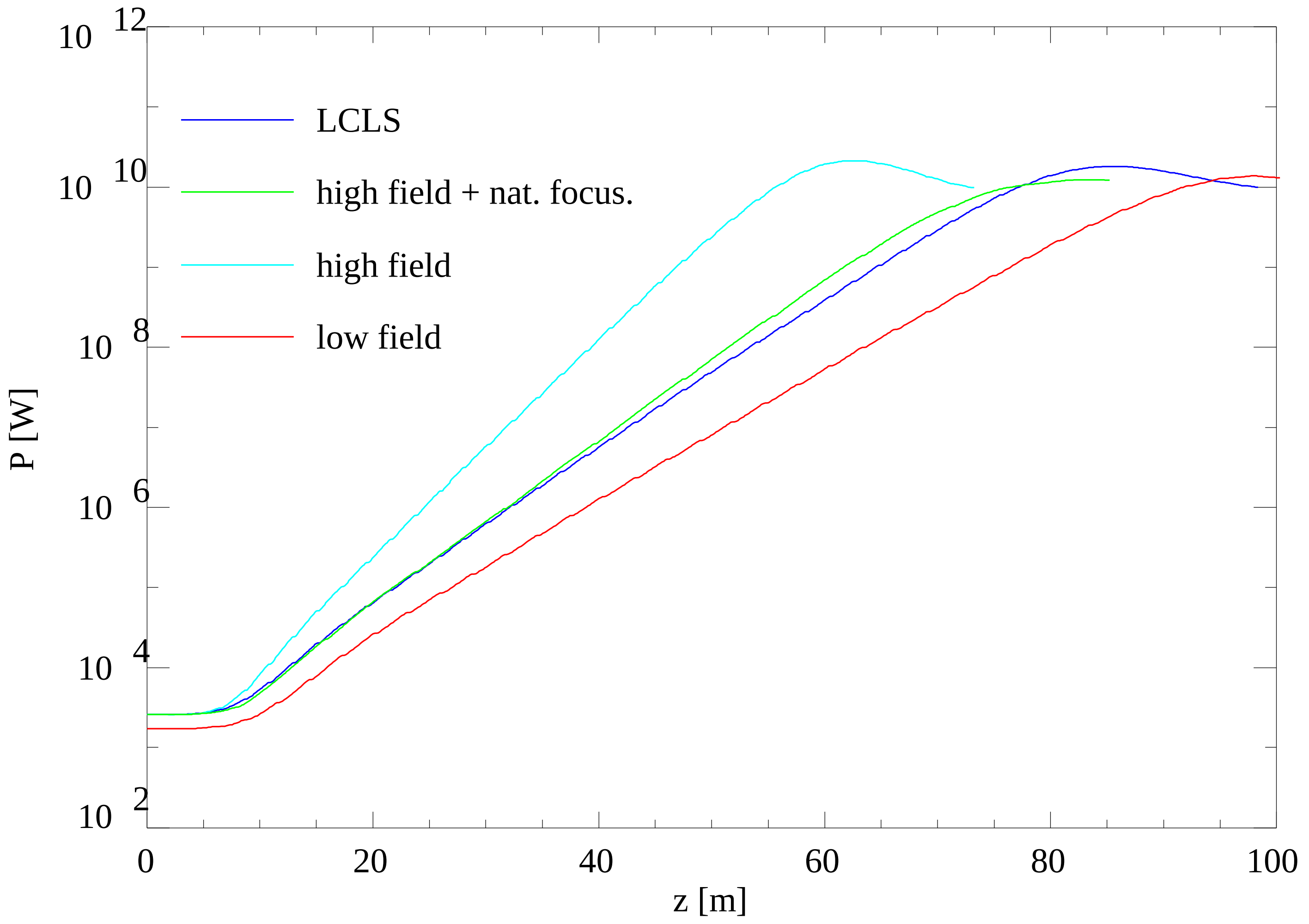
$$W\mathbf{z}(t) = -(ce^2 Z_0/\pi R^2)\cos(k_0 t)$$

Where $k_0=(2\varepsilon/(R\delta(\varepsilon-1))^{1/2}$ and $\varepsilon \sim 2$.
This model is more pessimistic than other models developed by Stupakov et al.

Wake-field model for LCLS

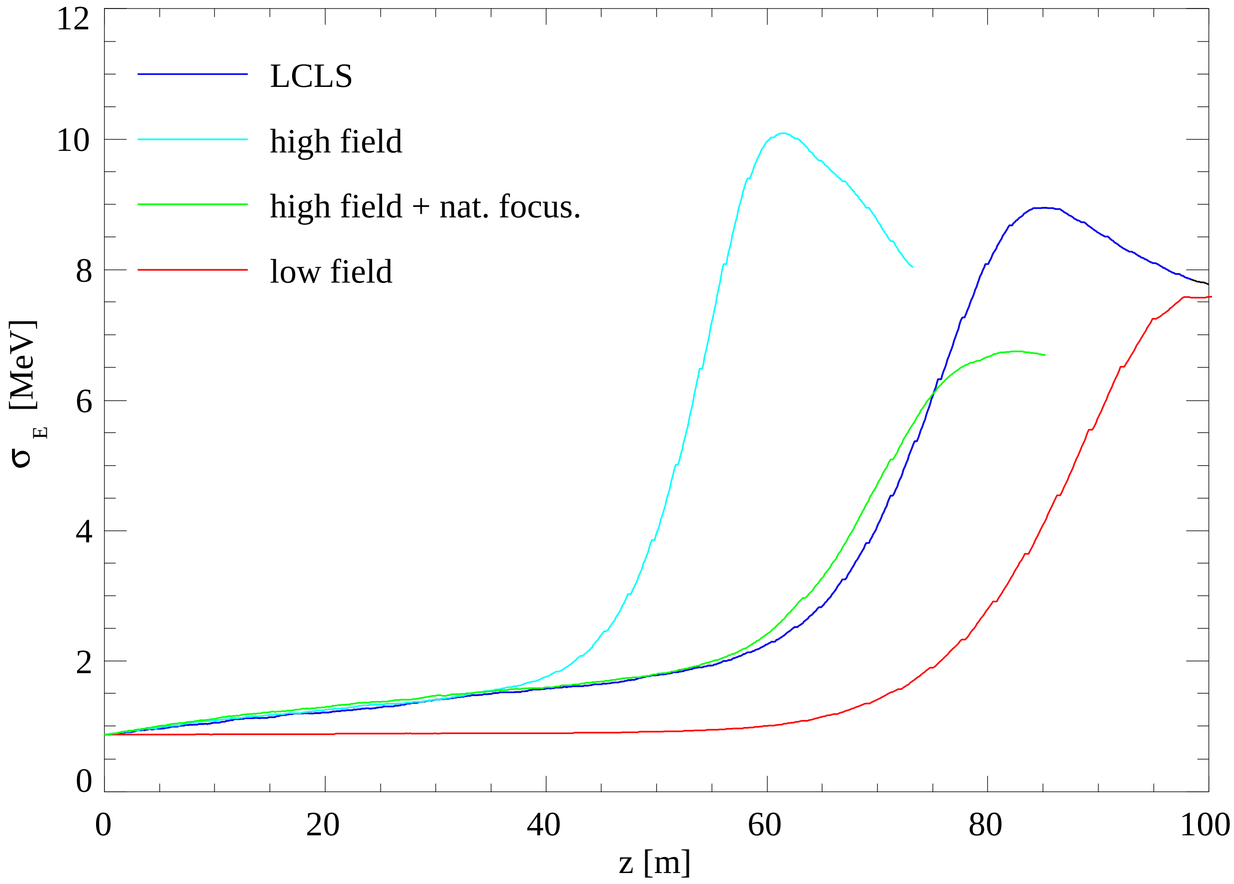


XFEL performance: no wake-field effects

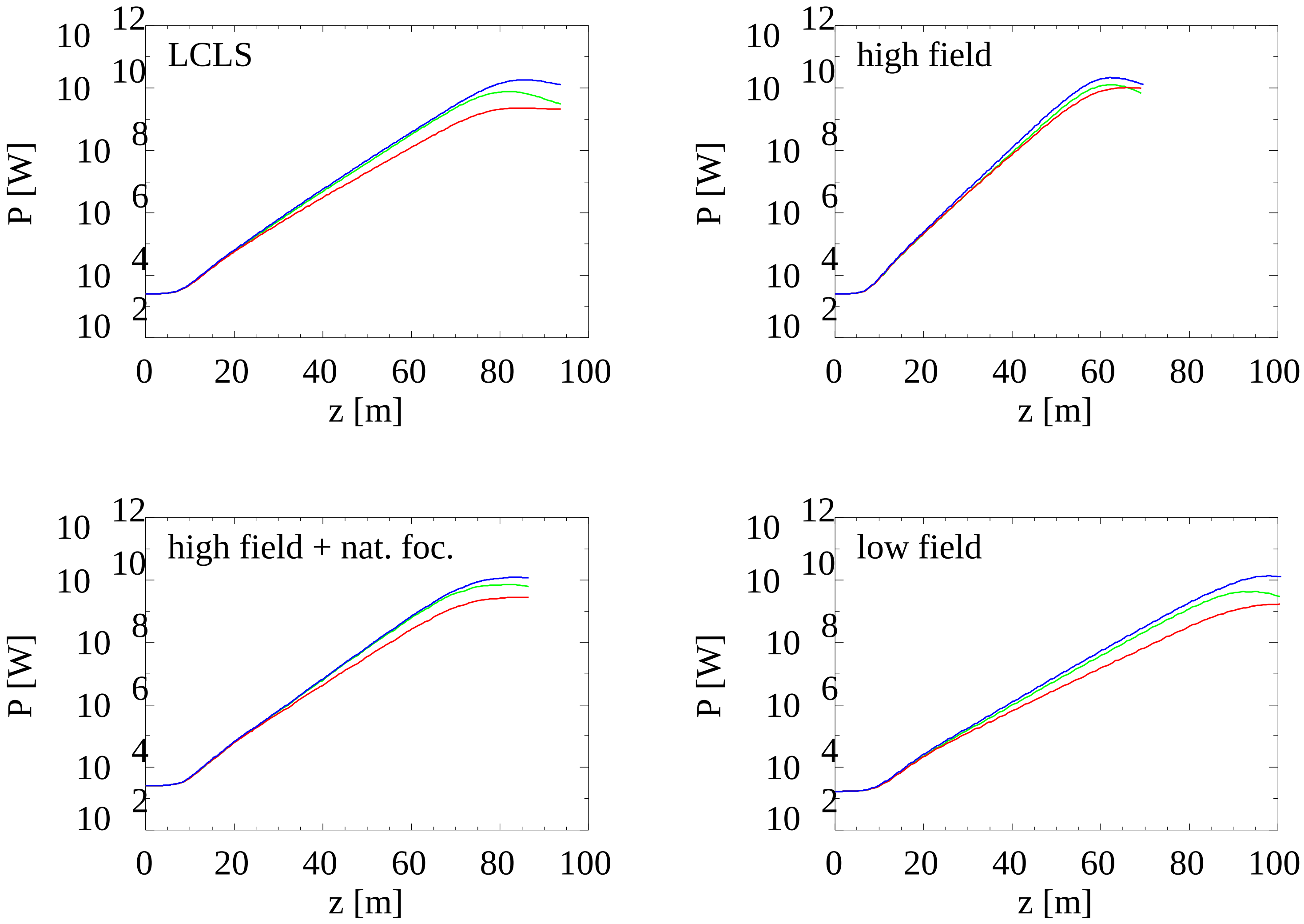


Energy spread vs length for LCLS, A, B, C.

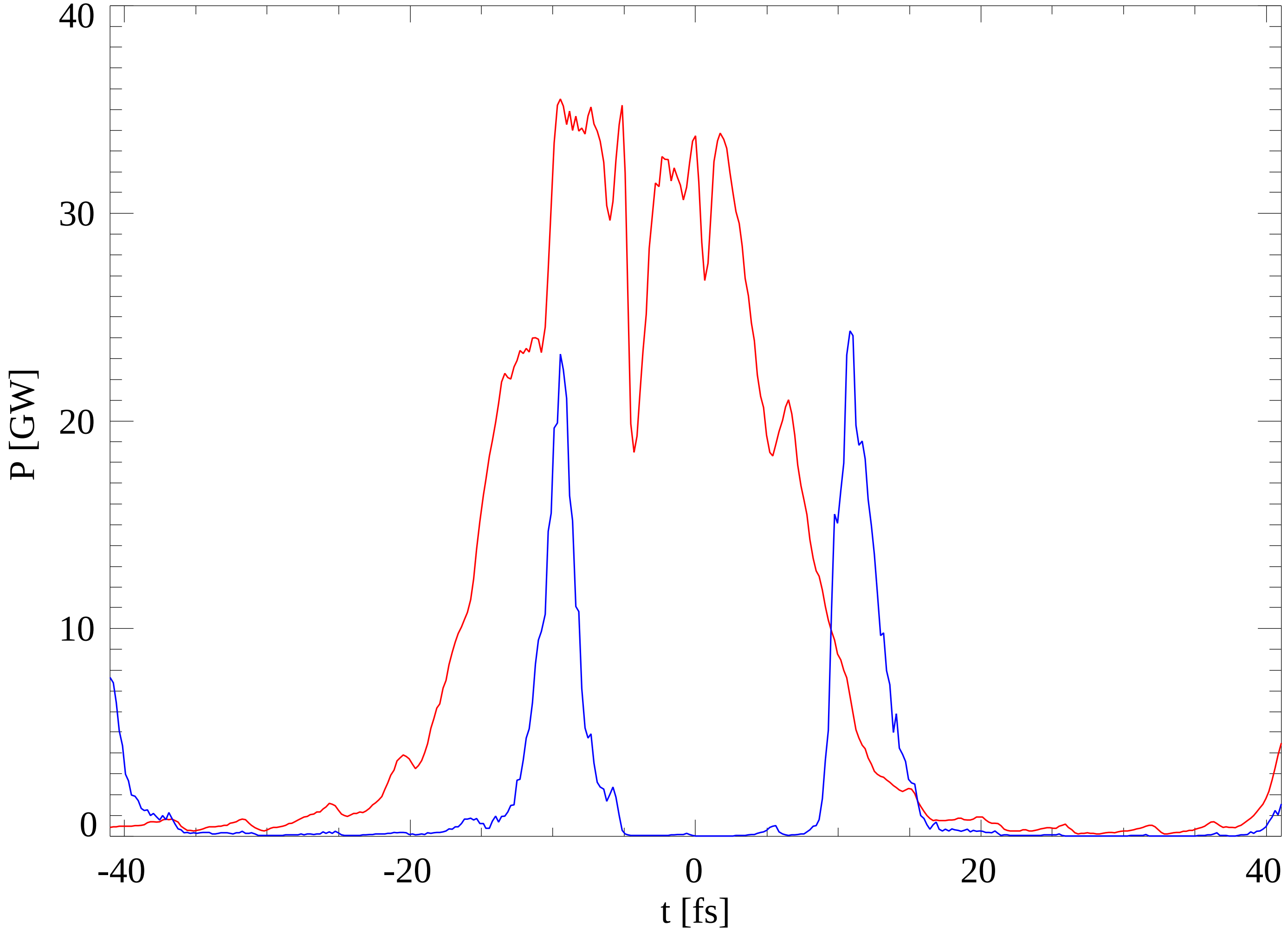
Includes synchrotron radiation emission



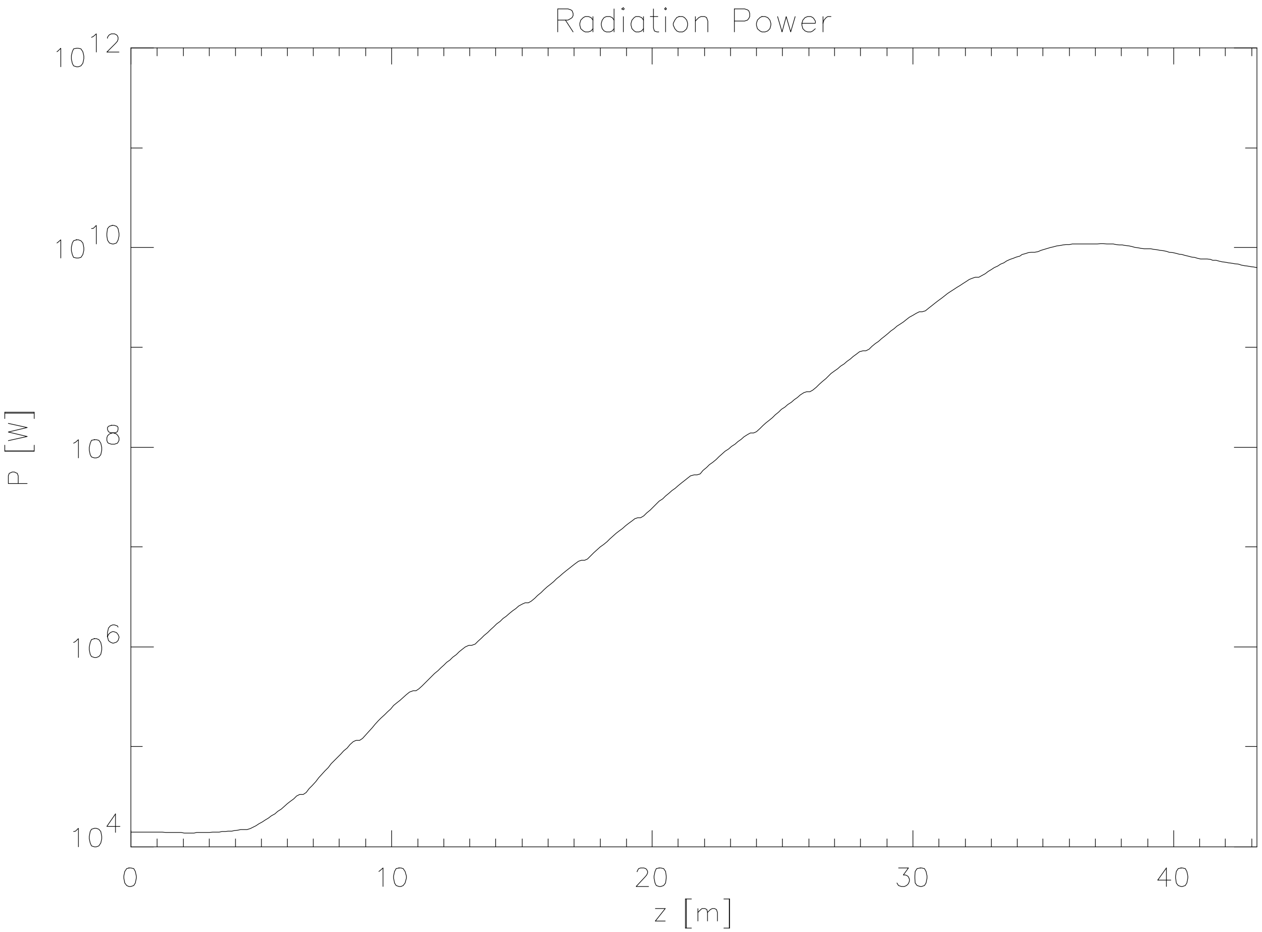
Wake-field effects for LCLS, A,B, C.



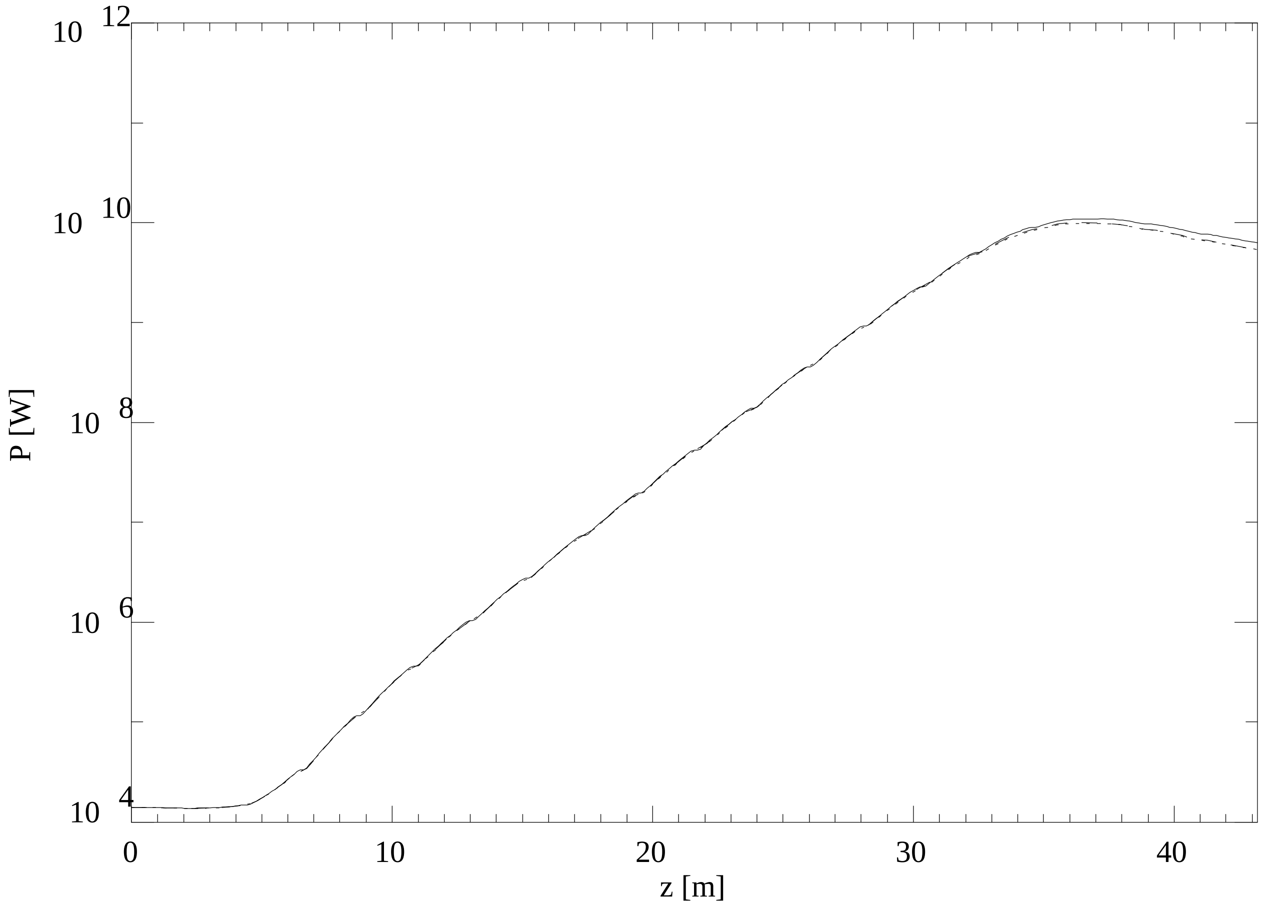
Effects of wake-fields on temporal pulse structure for LCLS and A.



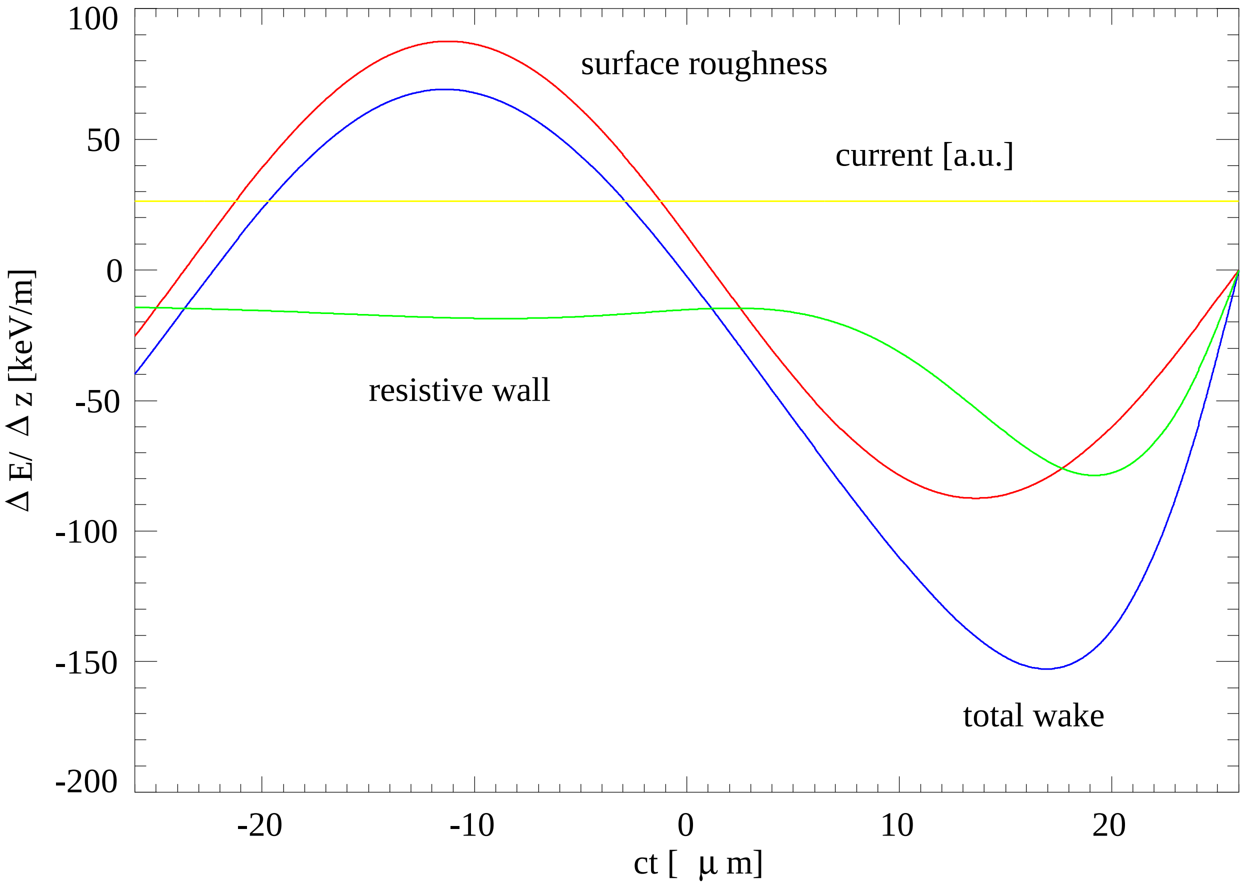
Low charge case, D; no wake-fields



Low charge case including wake-fields.



Wake-fields for the low charge case.



Injector scaling laws

We consider two ways to control the electron bunch charge and emittance. One is to use the photoinjector gun scaling laws (Rosenzweig et al).

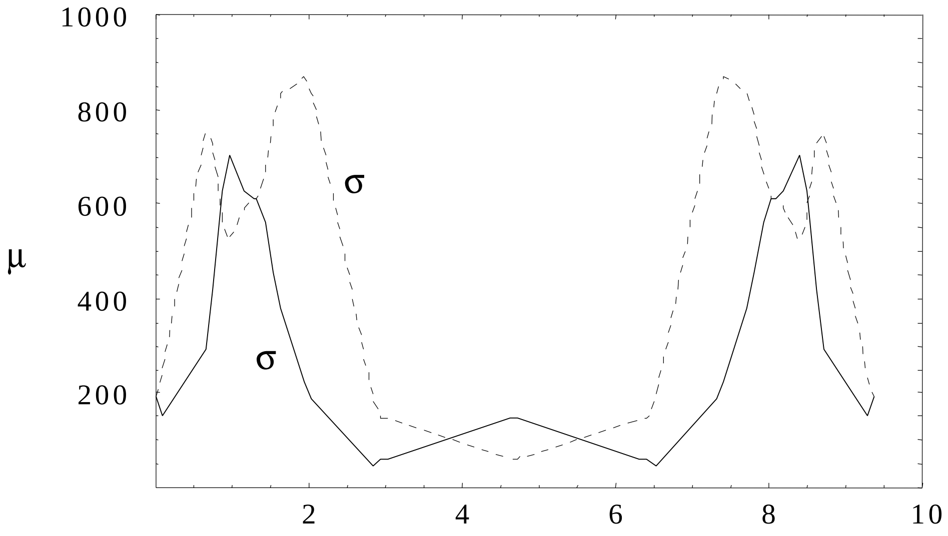
ε_N=1.45(0.38Q $^{4/3}$+0.095Q $^{8/3}$)$^{1/2}$, mm mrad, Q in nC.

σ_L =6.3x10^{-4} Q $^{1/3}$, m, Q in nC

Case D is obtained using this scaling. The reduced emittance compensates the reduced charge, and the 3D gain length becomes near to the 1D gain length.

Injector scaling laws

The second is to use a collimator system in a dedicated beam line, to reduce the charge and emittance (C. Schroeder, Nuhn and Pellegrini). We can achieve parameters similar to those of case D.



Quantum effects

A critical review of the quantum theory of FELs has been completed by C. Schroeder, and will be presnted in a seminar this afternoon.