SILMI Report on Short Visit Grant 3467

Andreas R. Maier, Visit at Paul-Scherrer Institut starting 1. June 2010 until 11. June 2010.

Purpose of the Visit

Free-electron lasers (FEL) are well-established sources of coherent radiation of high brilliance. They have proven to be invaluable tools for various branches of science. With the rapid progress in the field of laser-driven particle beams, laser-plasma accelerated electrons are a prominent candidate to drive next generation FELs, increasing their availability to everyday science due to their lower costs and compact size. Yet, the currently achievable few-percent electron beam energy spread of laser-driven beams is not sufficient to maintain a compact FEL, or at least to demonstrate a proof-of-concept.

During the research stay at Paul-Scherrer Institut (PSI) various concepts were studied aiming to overcome the degrading effects of high-energy-spread electron beams, typical for laser-plasma accelerators. They are based on active phase-space shaping of the electron bunch.

Description of the work carried out

One of the schemes proposed in Short Visit Grant Application 3467 is a rotation of the laser-plasma driven electron beam in phase space. Laser-plasma driven electron beams are intrinsically different from conventional radio-frequency-created beams. They show currents on a 10 kA scale and a high relative energy-spread of a few percent rms, while conventionally created electron bunches usually have low currents (few kA) and an energy spread $\Delta E/E$ on the order of 10^{-4} rms.

1D FEL theory predicts a sensitivity of the FEL process to the energy spread scaling with $I^{1/3}$, with I denoting the beam current. The overall performance in terms of total emitted power and preferably low gain length, increases with beam current and lower energy spread. When debunching the electron bunch via a magnetic chicane the beam current and slice energy spread drop linearly.

With both effects competing (performance loss due to lower currents but performance gain due to lower slice energy spreads), a net reduction in gain length can be obtained. This basic principle has been studied for different parameter sets derived from electron beams currently produced in LWFA experiments.

First, an analytical aproach based on 1D FEL theory was utilized to check the overall scaling of the FEL performance with varying electron bunch paramters and to find an optimum FEL paramter set to maximize the FEL performance. Following this, the results have been checked with the full-3D FEL code GENESIS. The simulations required extensive usage of a computer cluster available at PSI. They

are self-consistent in the sense, that they included all relevant 3D effects and also a proper beam optic to transport the electron bunch. Therefore, the simulation results are directly transferable to the design of a first proof-of-principle experiment.

Results

While the elongation of the electron bunch lowers the beam current and introduces a linear energy chirp along the bunch, the degrading effect is overcome by the decreasing energy-spread. The above introduced concept significantly improves the FEL performance for laser-plasma driven FELs, and may be a promising scenario for a first proof-of-concept experiment.

Besides these scientific results, I personally have greatly benefitted from the research stay at PSI. FEL simulation codes are delicate to use. Dr. Sven Reiche supported me in properly setting up the simualtions. His unique experience in the field of Free-Electron Laser physics allowed me to improve my knowledge and to gain a deeper understanding of the underlying physics.

Future Collaboration

As already indicated in the proposal for the Short Visit Grant, several other concepts of activ phase space shaping have been proposed, which may boost the FEL performance for high-energy-spread electron beams. Due to the lack of time, it was not possible to studies these scenaios, but to investigate these concpets will be subject of an intended future visit in fall 2010.

Projected Publiations

Already the results of the first visiti to PSI have been very promising and a publication is currently being written, which will present the results from this visit.

Comments

The visit to PSI lasted from 1. June 2010 until 11. June 2010, which differs from the originally proposed schedule. The change in schedule was necessary on short notice, as the host at PSI, Dr. Sven Reiche, was called to an unexpected and urgent meeting.