Start-to-end simulations of TTF FEL, Phase 1

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Main milestone of TTF FEL, phase I: Saturation

• Phys. Rev. Lett. 88(2002)10482
• The European Physical Journal D 20(2002)149

Analysis of the FEL radiation properties leads to unique conclusion that the lasing fraction of the driving electron beam is short, about 100-200 fs

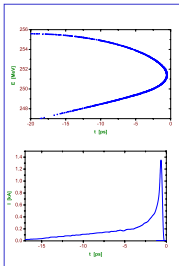
An idea for short leading spike: 2001

✓Bunch compressor forms bunches with strongly non-gaussian shape
✓Short spike in the head of electron bunch produces SASE FEL radiation

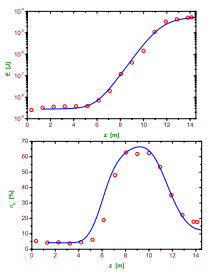
$$I_{peak} \simeq \frac{\lambda_{rf} I_0}{R_{56}\pi\sqrt{2\sigma_E}}$$

$$\sigma_z \simeq 5R_{56}\sigma_E$$

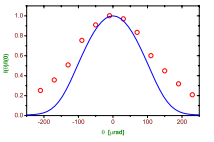
$$\delta_{rms} \simeq \frac{\lambda_{rf}\sqrt{\sigma_E}}{5R_{56}}$$



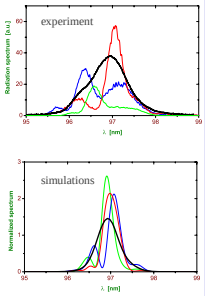
The bunch was approximated by gaussian: FWHM duration 120 fs, peak current 1.3 kA, rms normalized emittance 6π mm-mrad.



☺Good agreement between experimental and simulation results for the FEL gain, evolution of the radiation energy, and probability distributions



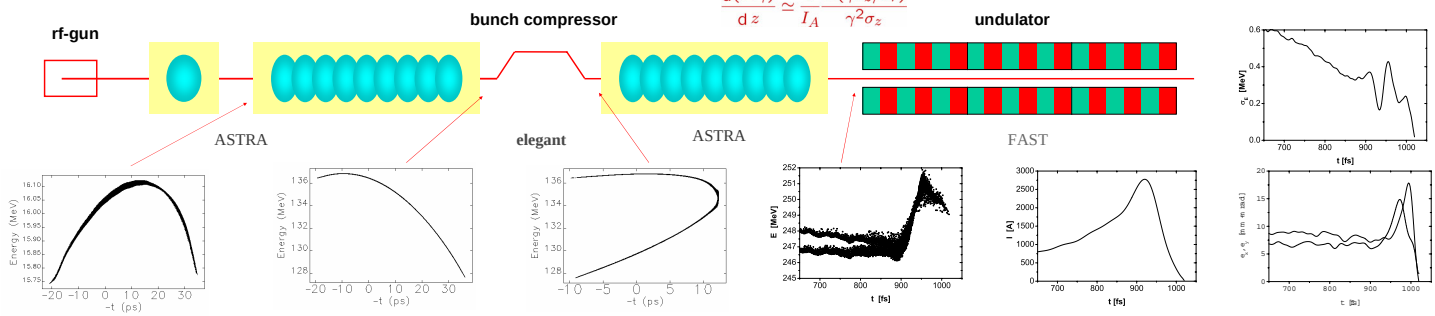
☹Difference in angular divergence indicates on difference in the spatial structure of the radiation at the undulator exit.



☹Visible disagreement between experimental and simulated spectra is a clear indication for higher value of beam current, or for large energy chirp along the bunch.

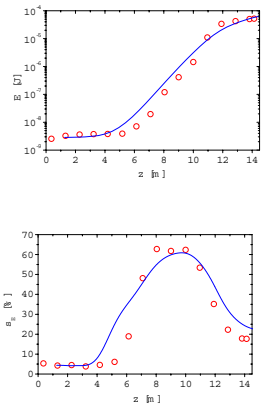
„Full physics“ start-to-end simulations: 2003

$$\frac{d(\Delta\gamma)}{dz} \simeq \frac{I}{I_A}\frac{\ln(\gamma\sigma_z/\sigma_r)}{\gamma^2\sigma_z}$$

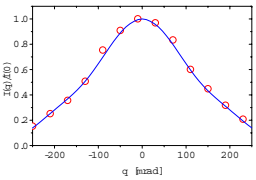


TTF FEL: experimental results (Phys. Rev. Lett. 88(2002)10482) versus start-to-end-simulations:

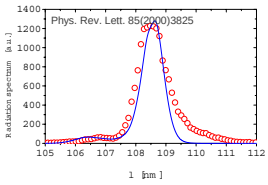
Average energy and fluctuations



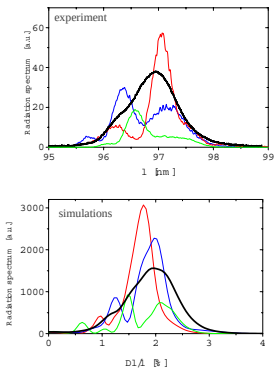
Angular divergence



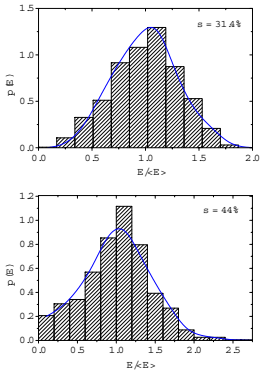
Spectra in linear regime



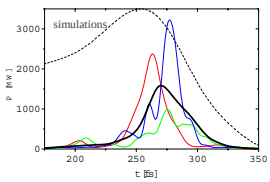
Spectra in saturation regime



Probability distributions of the radiation energy



Time structure of the radiation pulse



„Full physics“ start-to-end simulations of TTF FEL: Summary

☺Good agreement between experimental and simulation results is an encouraging message that physical models realized in codes ASTRA-elegant-FAST do not miss important physical effects, at least for parameter range of TTF FEL, Phase I.

☹Note that it is not direct benchmarking of the codes with actual electron beam parameters. None of the important slice parameters: peak current - length of leading spike – emittance - energy spread within lasing fraction of the electron bunch was measured experimentally.

TTF FEL, Phase I was driven by strongly non-gaussian bunch with short leading peak having current of about 3 kA.

Space charge is the main physical effect for beam dynamics after the bunch compressor. A large value of energy chirp of 4 MeV in the leading spike is gained in a long drift spaces due to high value of peak current and short length of leading spike:

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Radiation wavelength	80-120 nm
Radiation pulse energy at saturation	60 mJ
Radiation pulse duration (FWHM)	40 fs
Radiation peak power	1.5 GW
Spectrum width (FWHM)	1%
Divergence	diff. limited
Radiation peak brilliance up to	10^{29}