Compact ring FEL as a source of high power infrared radiation

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Outline

1. Introduction
2. General concept of the ring FEL (brief review)
3. Possible layout of the infrared ring FEL
4. Lattice of isochronous bends
5. Simulation of the ring FEL operation
6. Conclusion

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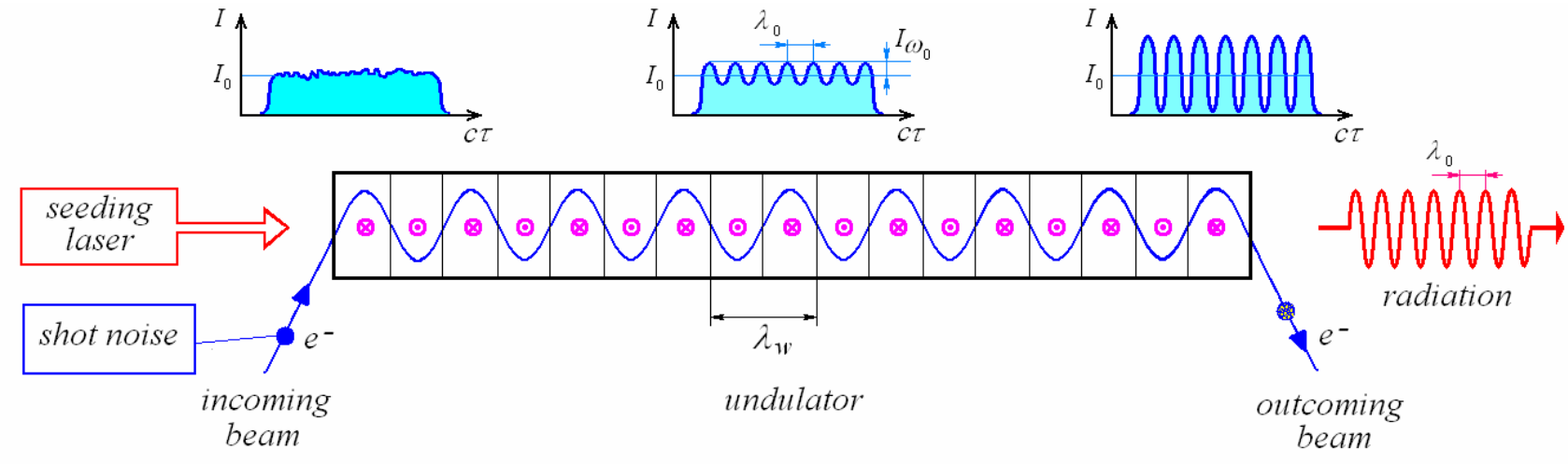
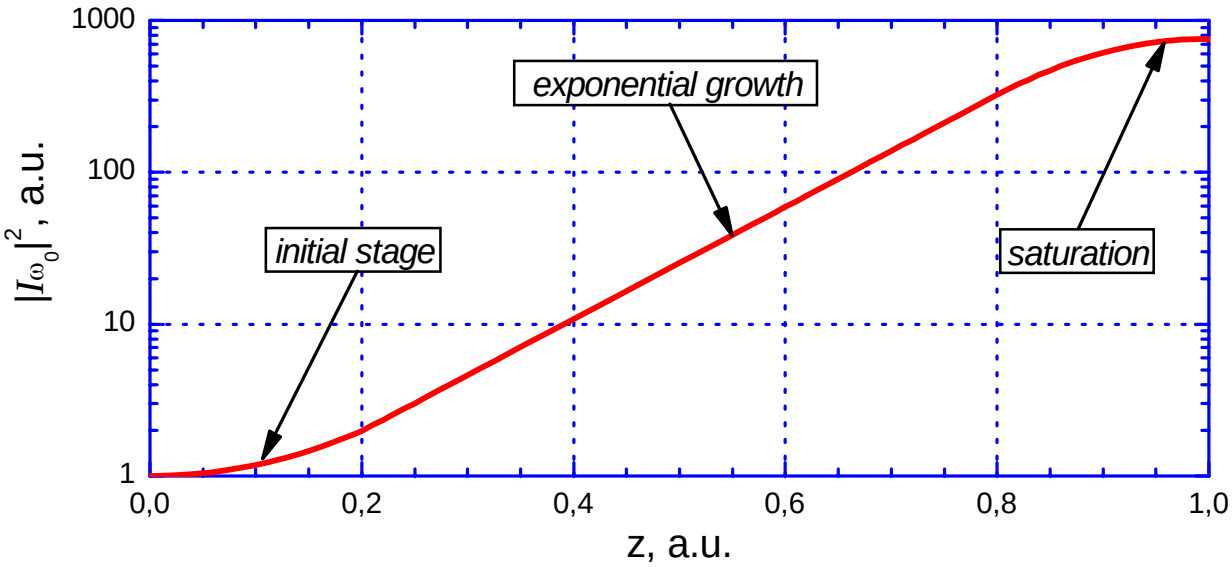
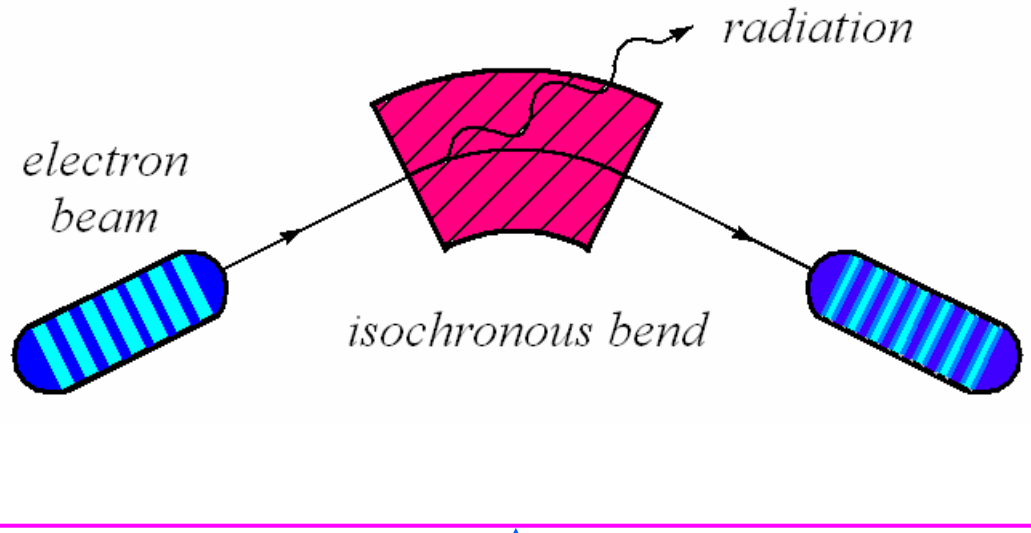
The scheme of the single-pass high gain FEL amplifier





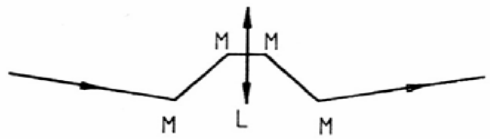
General scheme and principles of operation of ring FEL



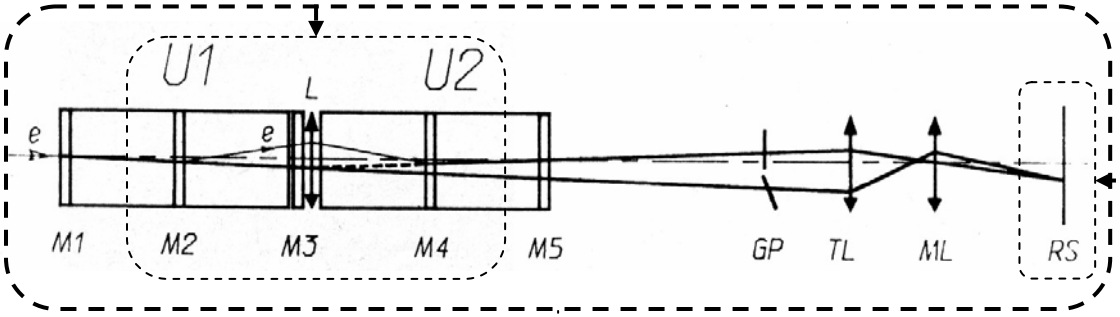
The beam microbunching is partly conserved in the isochronous bend

Experimental observation of the coherency of radiation from two undulators

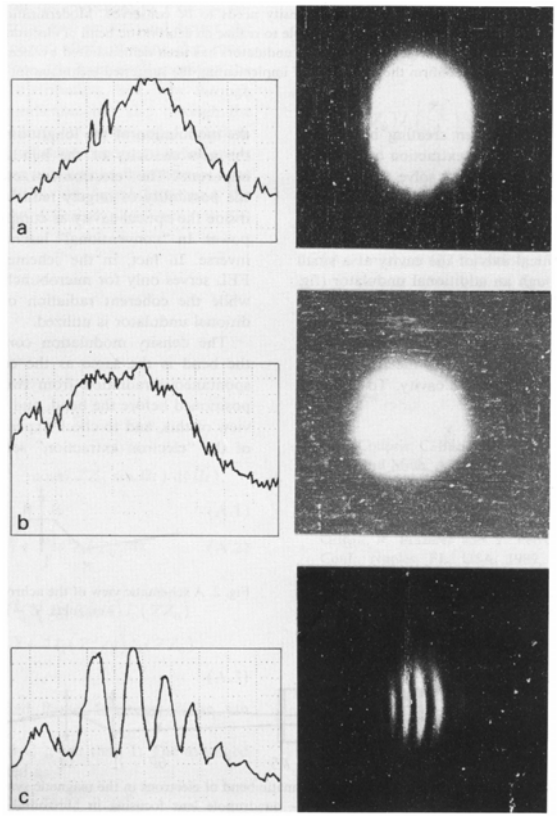
A schematic view of the achromatic bend: M – bending magnets, L -lens



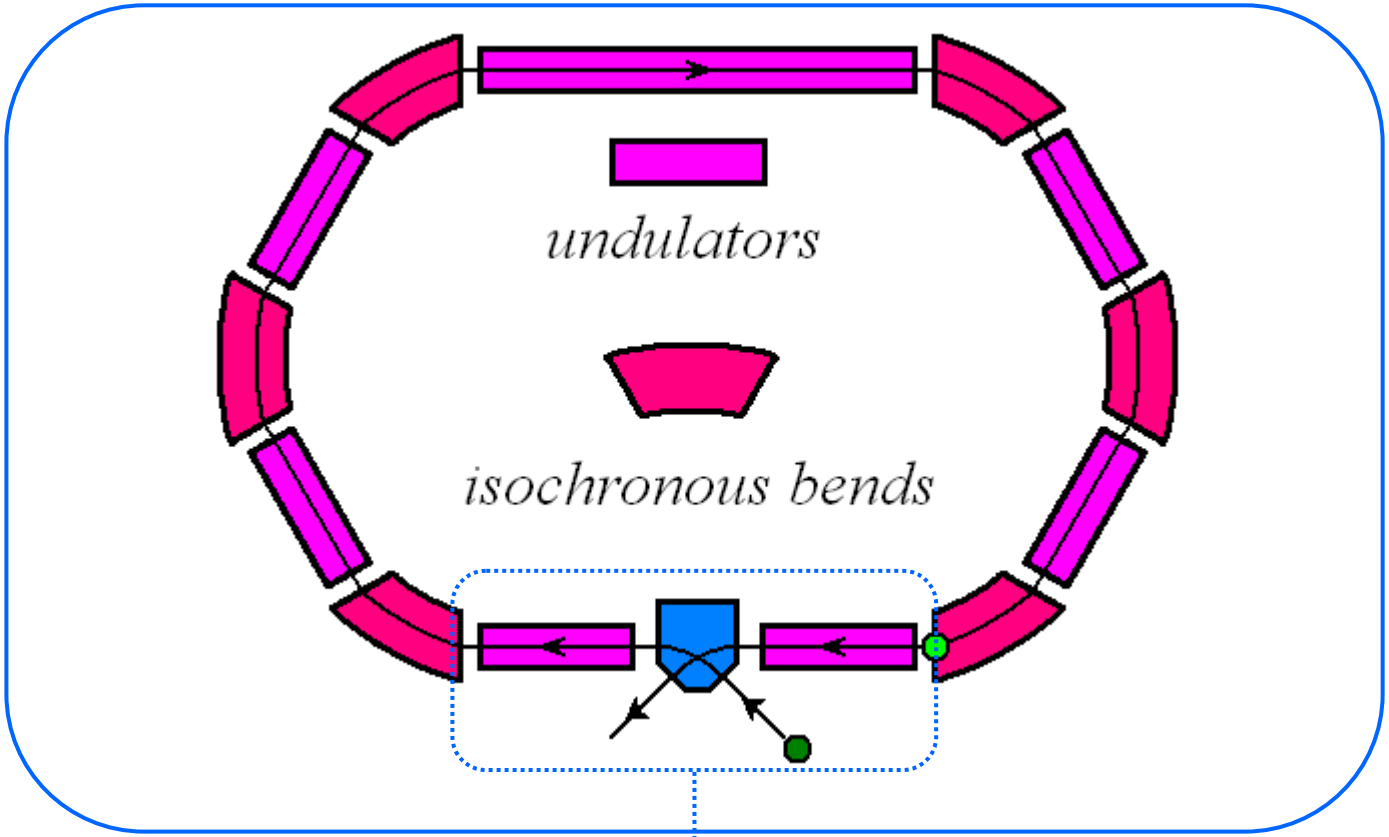
$R_{5,1}$ and $R_{5,2} = 0$

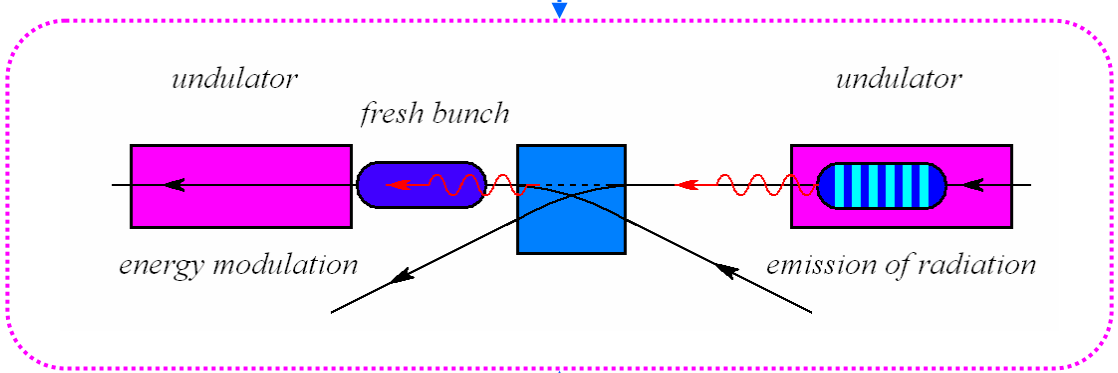


The scheme to observe radiation coherency at the achromatic bend of electrons in the magnetic system of the optical klystron on VEPP-3: M1-M5 –horizontal bending correctors; L – quadrupole lens focusing in horizontal direction; U1 and U2 undulators; TL and ML – optical telescope lens and imaging lens respectively; RS – registering screen

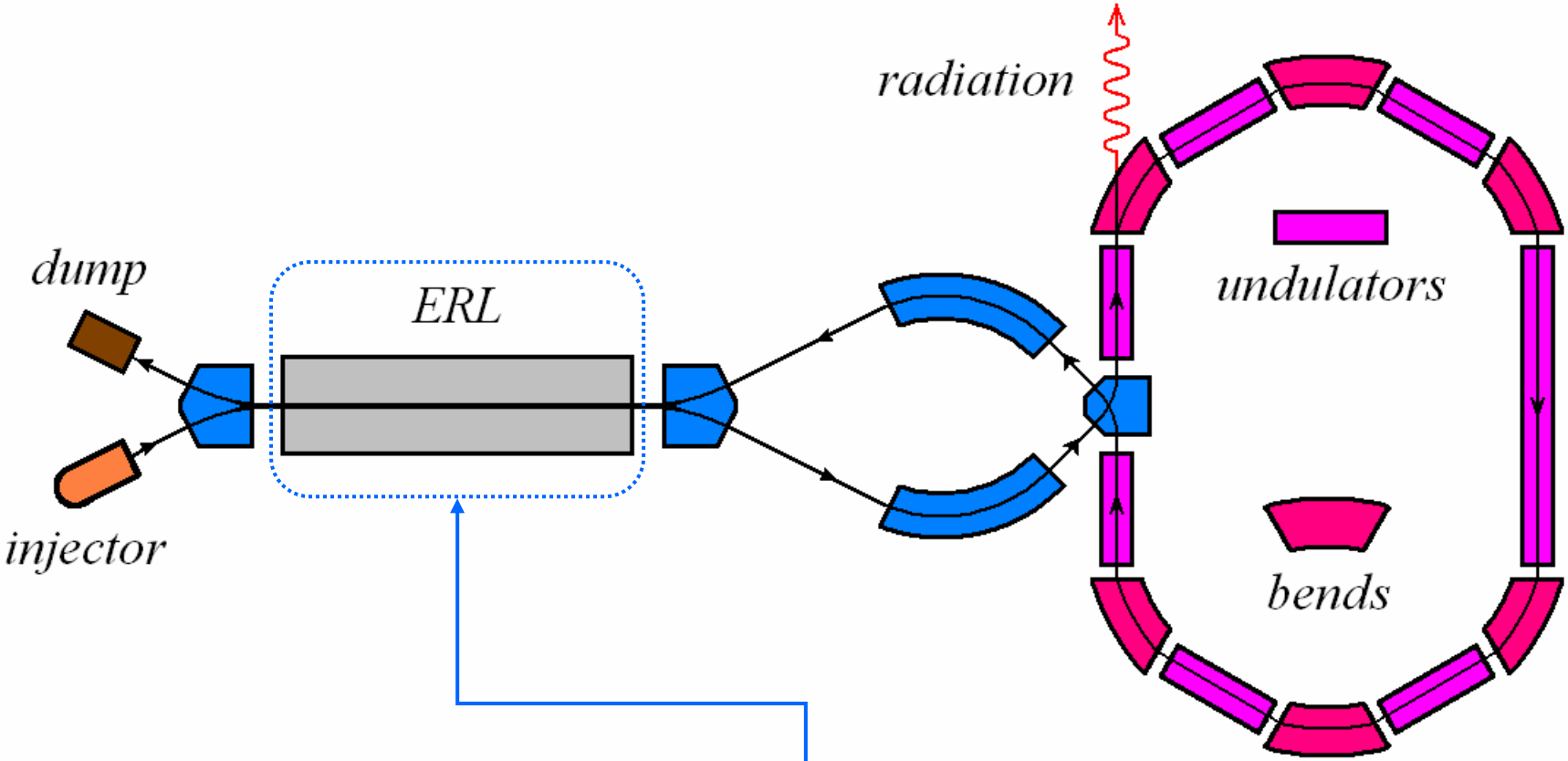


Interference pictures observed at a conventional (nonachromatic) bend (a), at an achromatic bend without the delay compensation (b) and with the delay compensation (c)



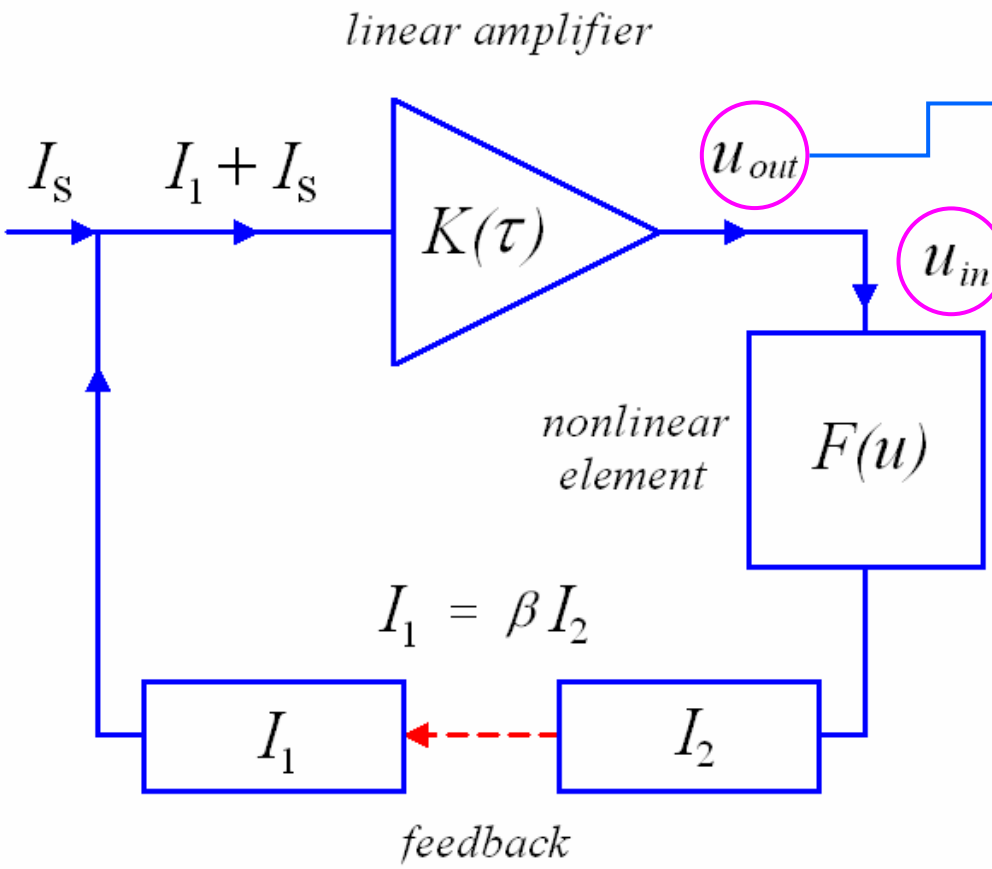


Signal from the old bunch to the fresh one is transferred by radiation



Ring FEL requires ERL as a source of electron beams, as the average beam power can be very high.

Circuit representation and linewidth of ring FEL



$$u_{out}(t) = \int_0^\infty K(\tau)\left[I_1(t-\tau) + I_s(t-\tau)\right]d\tau$$

$$I_1 = \beta\, I_2 = \beta\, F(u_{in})$$

$$u_{out}(t) = \int_0^\infty K(\tau)\left\{\beta F\left[u_{in}(t-\tau)\right] + I_s(t-\tau)\right\}d\tau$$

$$\frac{\delta\omega}{\omega} \sim \frac{e\omega}{I}\left(\frac{\Delta\omega}{\omega}\right)^2 |K(\omega)|^2 \sim \frac{2\pi}{N_{e,\lambda o}}\left(\frac{\lambda_w}{L_G}\right)^2 |K \sim 10|^2 \sim 10^{-9}$$

Natural linewidth is very small !

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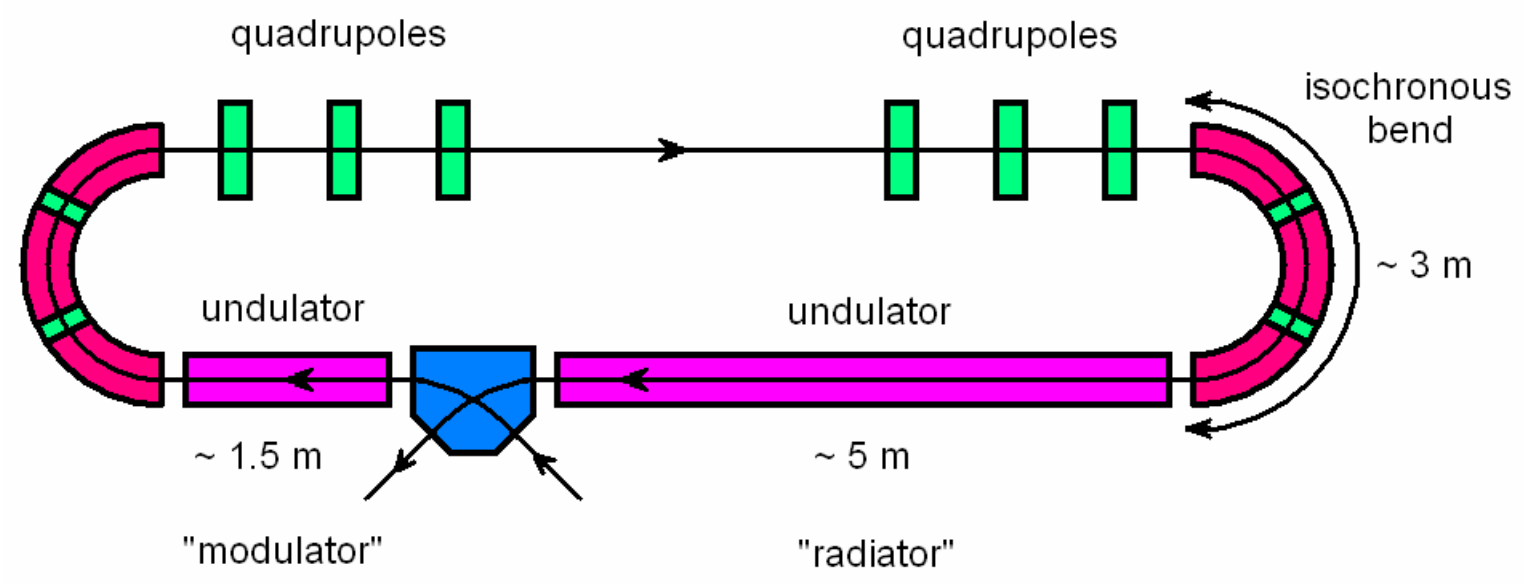
Possible layout of the infrared ring FEL



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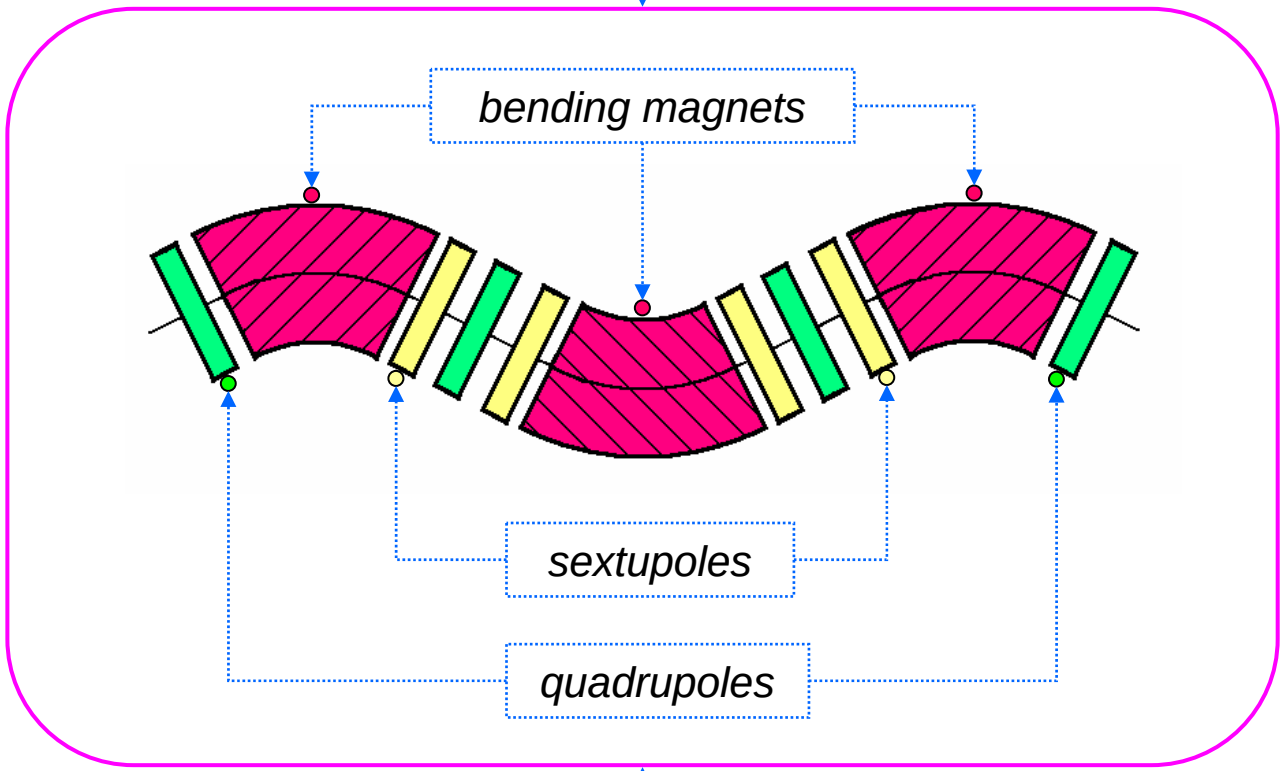
Lattice of isochronous bends

Typical lattice of short isochronous bend



Second order aberrations are compensated by sextupoles

Second order aberrations

Energy spread and emittance can cause debunching

$$\frac{d}{ds}c\tau = hx - \frac{\delta}{\gamma_0^2} - \frac{hx\delta}{\gamma_0^2} + \frac{3}{2}\frac{\delta^2}{\gamma_0^2} + \frac{x'^2}{2} + \frac{y'^2}{2}$$

These terms are negligible compared to the others

$$\sigma_{c\tau}^2 \le \frac{\varepsilon_x^2}{2}\left(\int_0^s \gamma_x(s')ds'\right)^2 + \frac{\varepsilon_y^2}{2}\left(\int_0^s \gamma_y(s')ds'\right)^2$$

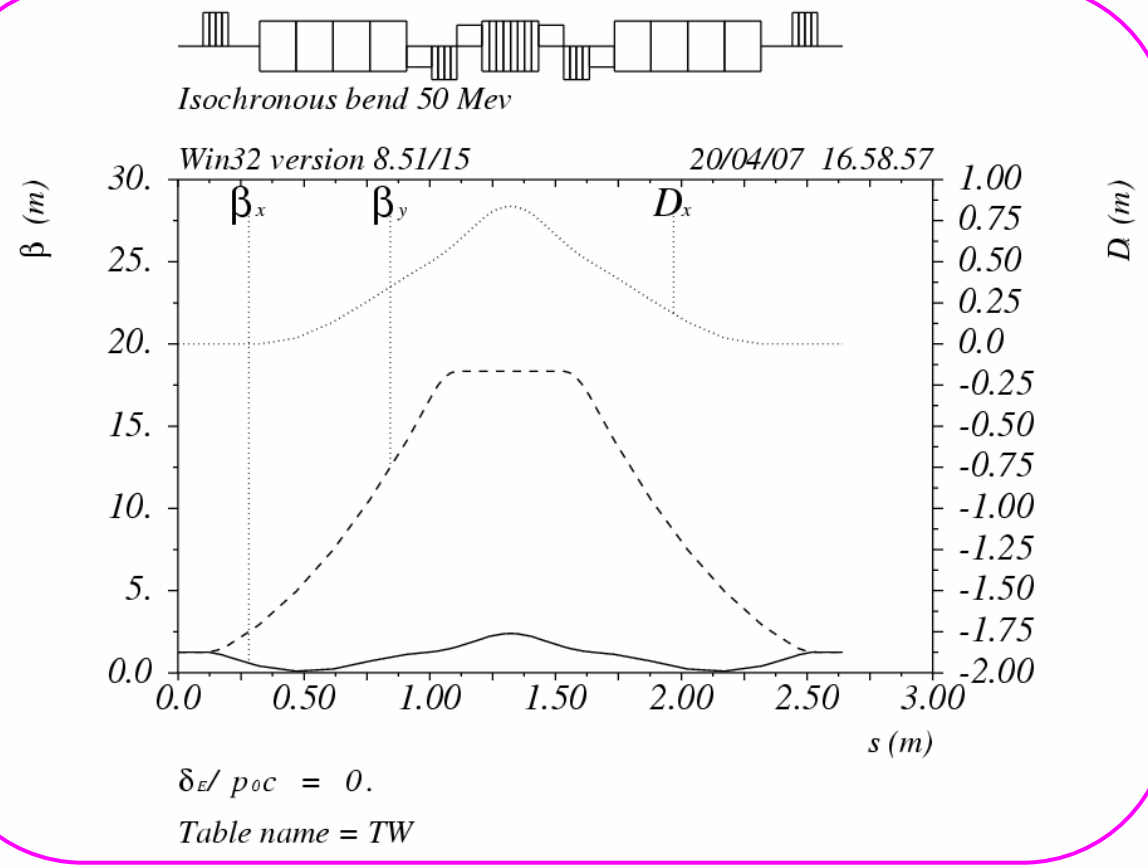
Twiss parameters

Choosing the proper values of sextupoles one can adjust $(x|x_0^2)$ to make T_{511} zero

$\frac{x'^2}{2}$ hx

$$T_{511}(s) = \frac{1}{\beta_0}\int_0^s \left(\frac{C_x'^2}{2} + h(x|x_0^2)\right)ds'$$

Linear lattice functions β_x, β_y, and D_x of the isochronous bend of the infrared (6 microns) ring FEL



Debunching induced by second-order aberrations is small

$$\left| \left\langle e^{i\omega_0 \tau} \right\rangle \right| = 0.96$$

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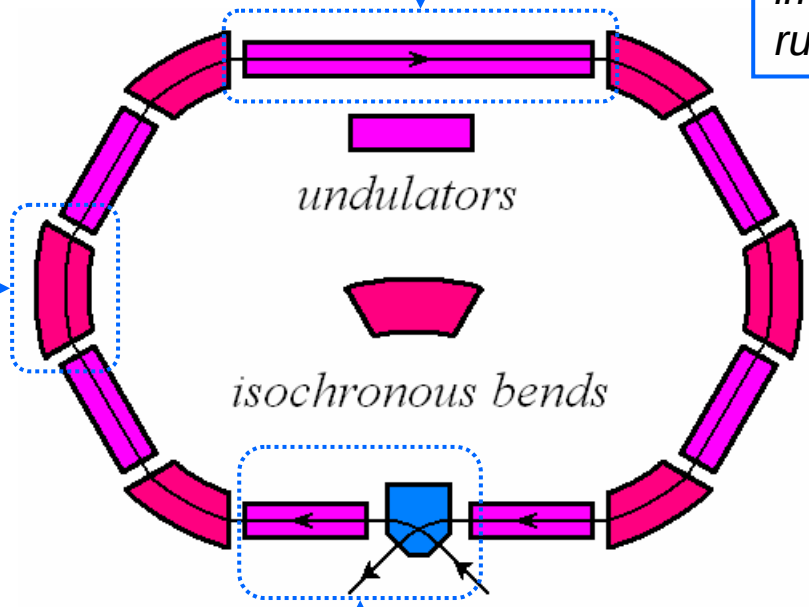
Simulation of the ring FEL operation

Basic parameters used in simulations

Electron energy, MeV	50
Peak current, A	50/100
Beam charge, nC	1
Relative r.m.s. energy spread, %	0.1
Normalized r.m.s. emittance, mm×mrad	5
Undulator period, cm	6
Undulator deflection parameter *K*	1.5
Bend angle, degrees	180
Bend length, m	3

Simulation scheme

GENESIS *simulation with zero initial radiation field and particle distribution imported from previous run*

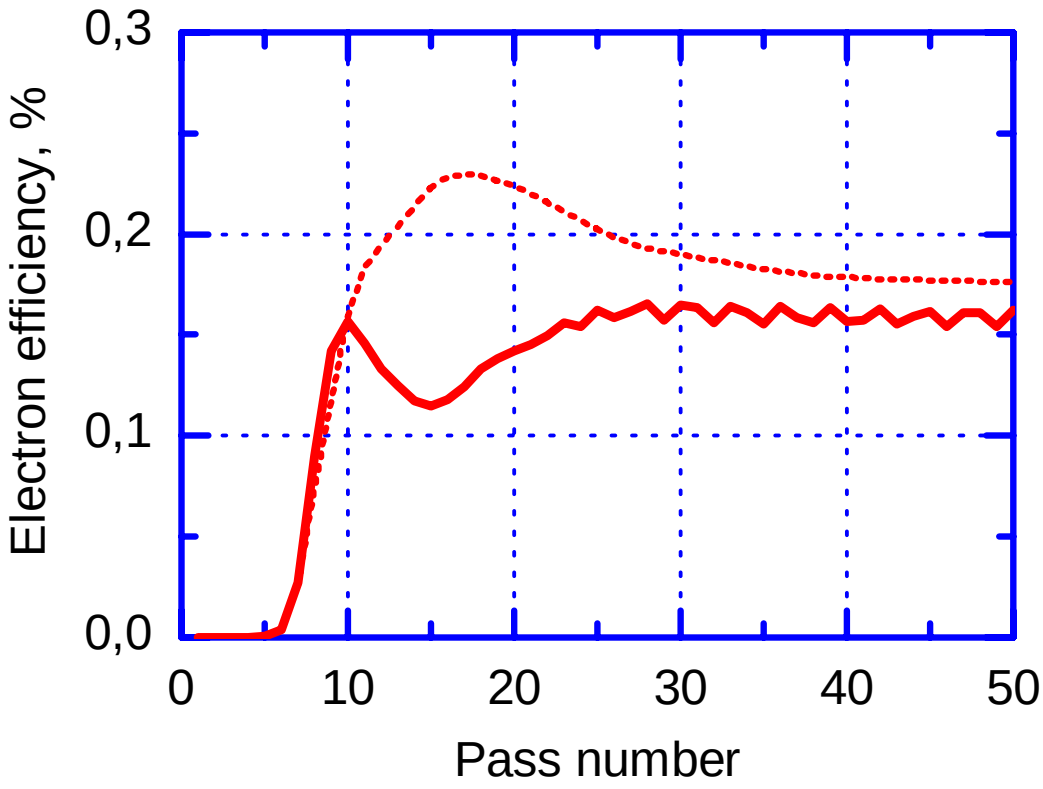


Nonlinear phase space mapping by external code. CSR *wake and quantum fluctuations are applied here.*

GENESIS *simulation with fresh particle distribution and initial radiation field imported from previous run*

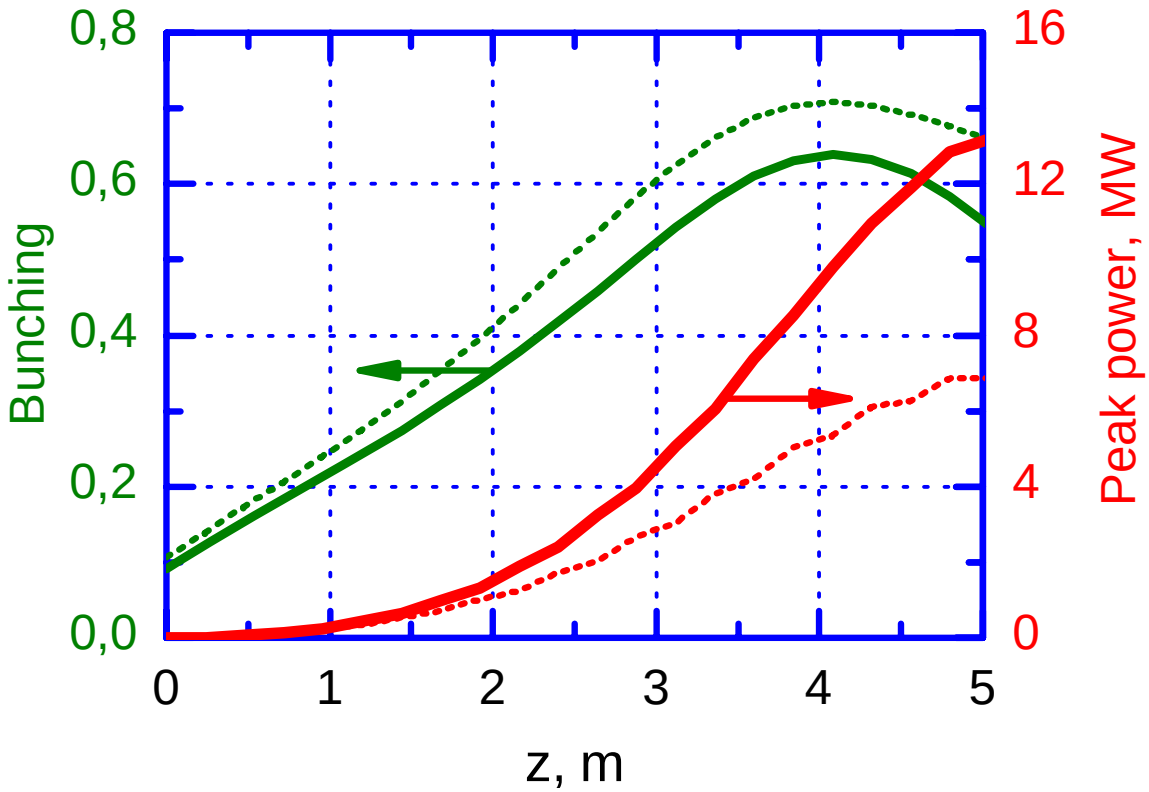
50 A peak current case

Dependence of the electron efficiency on the pass number in ring FEL



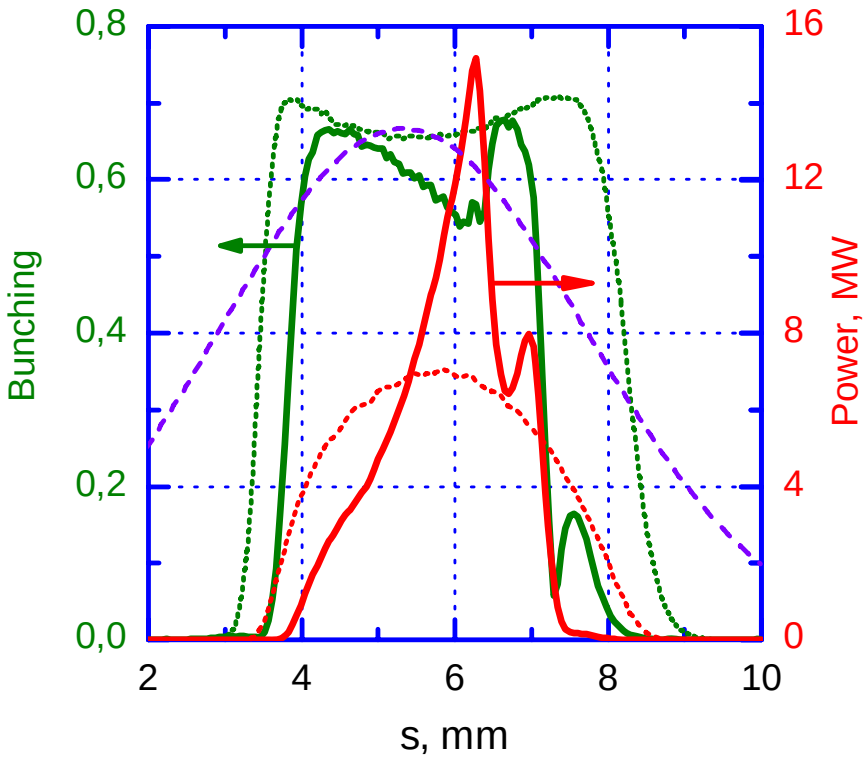
Dotted curve corresponds to ideal case without CSR effects

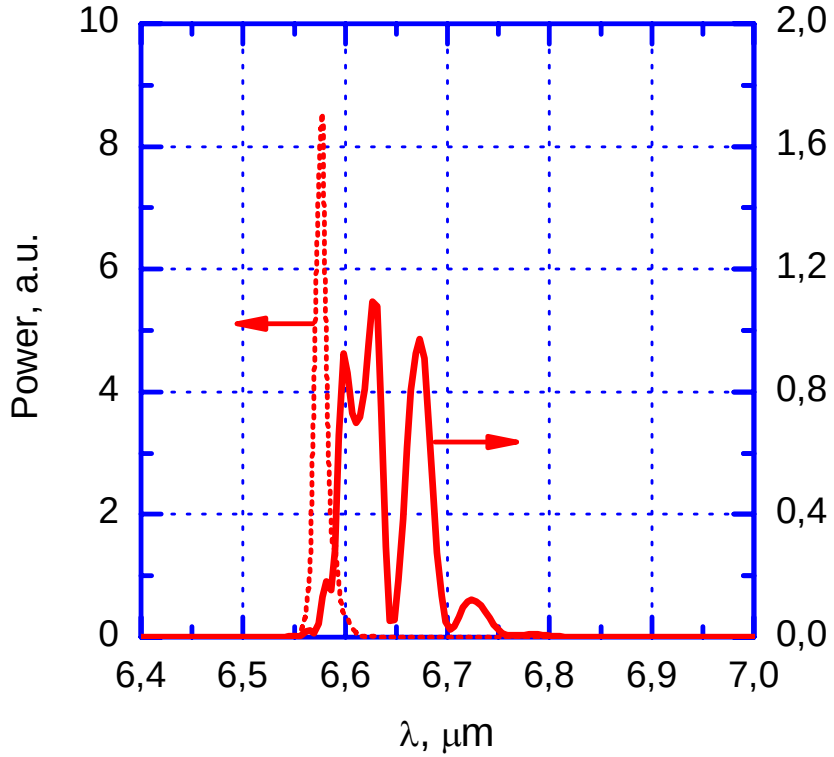
Dependence of the beam bunching factor and peak radiation power on the longitudinal coordinate in the last undulator section



Dotted curves – CSR effects are not included

Stationary beam bunching radiation power and spectral distributions at the exit from the last undulator section





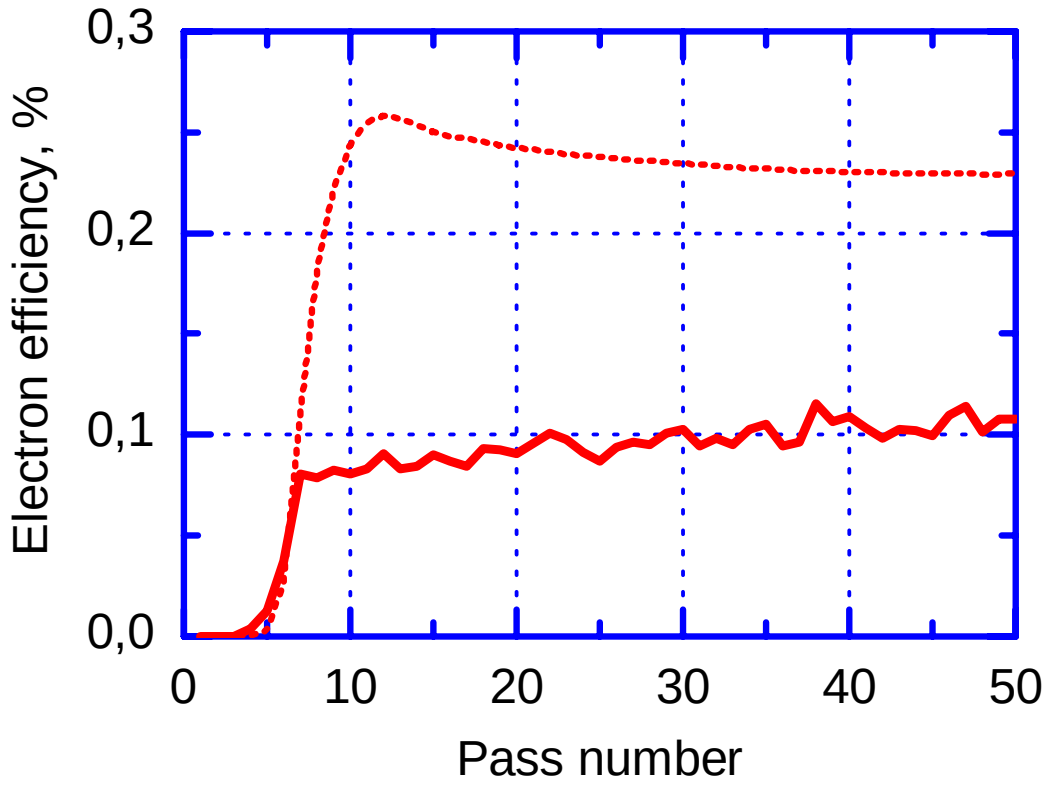
Dotted curves – CSR effects are not included,
dashed curve – beam current profile

Parameters of the output radiation

Wavelength, μm	~ 6.6
Peak power, MW	~ 10
Pulse duration, ps	~ 10
Electron efficiency, %	0.15

100 A peak current case

Dependence of the electron efficiency on the pass number in ring FEL



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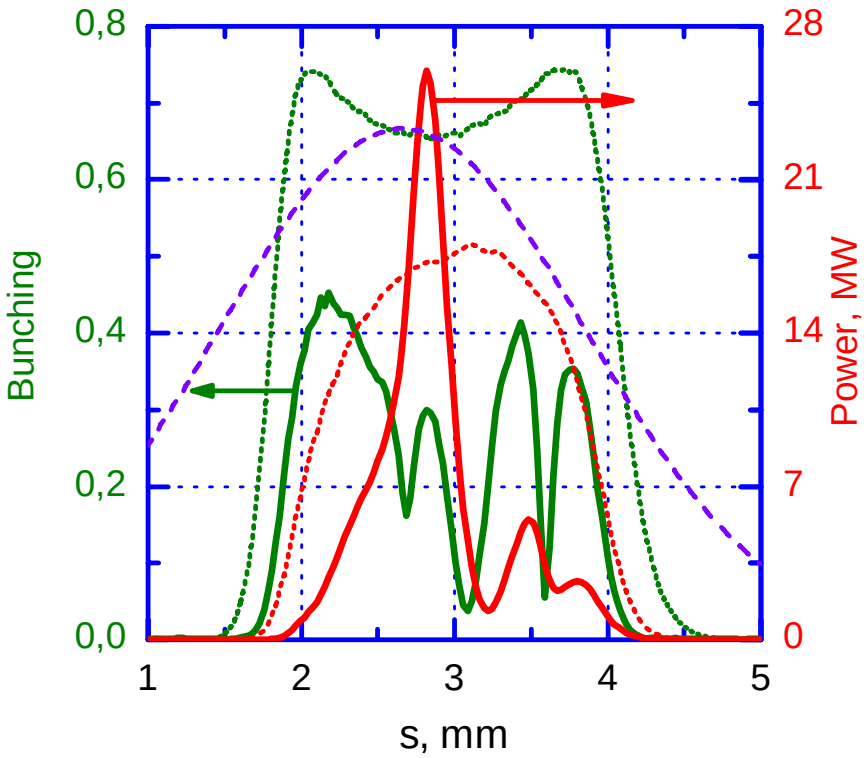
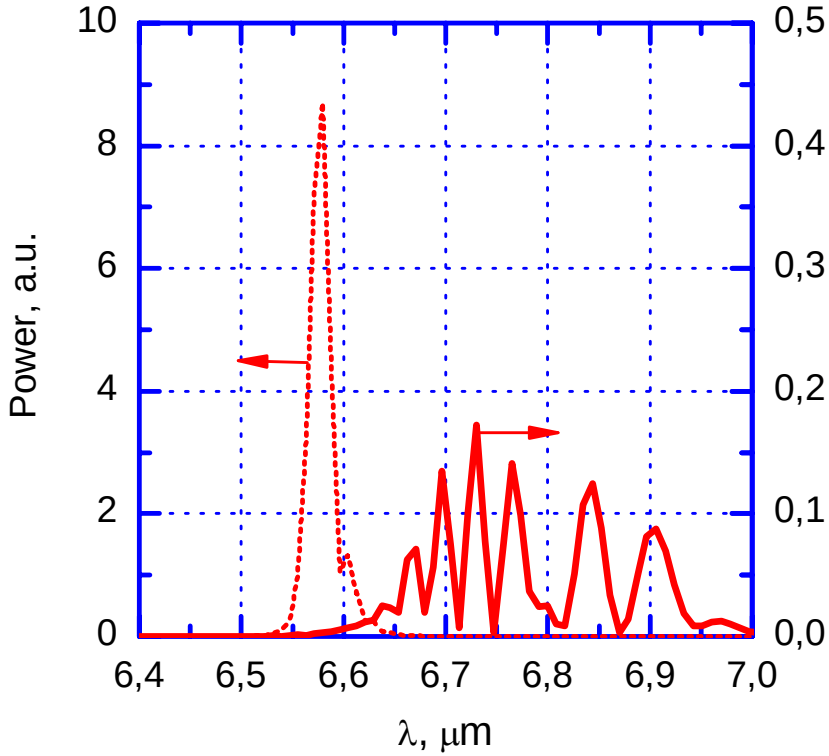
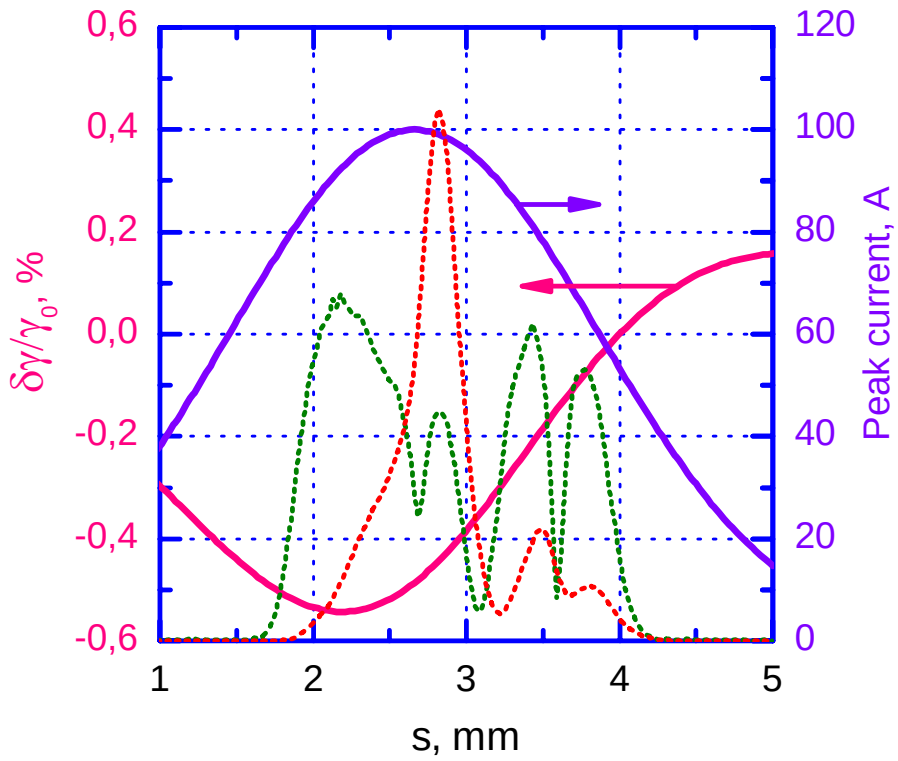




Dotted curves – CSR effects are not included,
dashed curve – beam current profile

Beam current distribution and electron energy deviation induced by CSR



Dotted curves illustrate the beam bunching (green) and radiation power (red) distributions

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Conclusion

- ✓ *We have shown theoretically the feasibility of the compact high power ring FEL for the infrared region.*
- ✓ *At that we have considered the problem of beam debunching in the bends and CSR effects.*
- ✓ *The next step should be the building of such FEL and demonstrating the feasibility of the ring FEL concept in practice.*

Thank you for your attention !

The end.