NUMERICAL SIMULATION OF A SUPER-RADIANT THz SOURCE DRIVEN BY FEMTOSECOND ELECTRON BUNCHES

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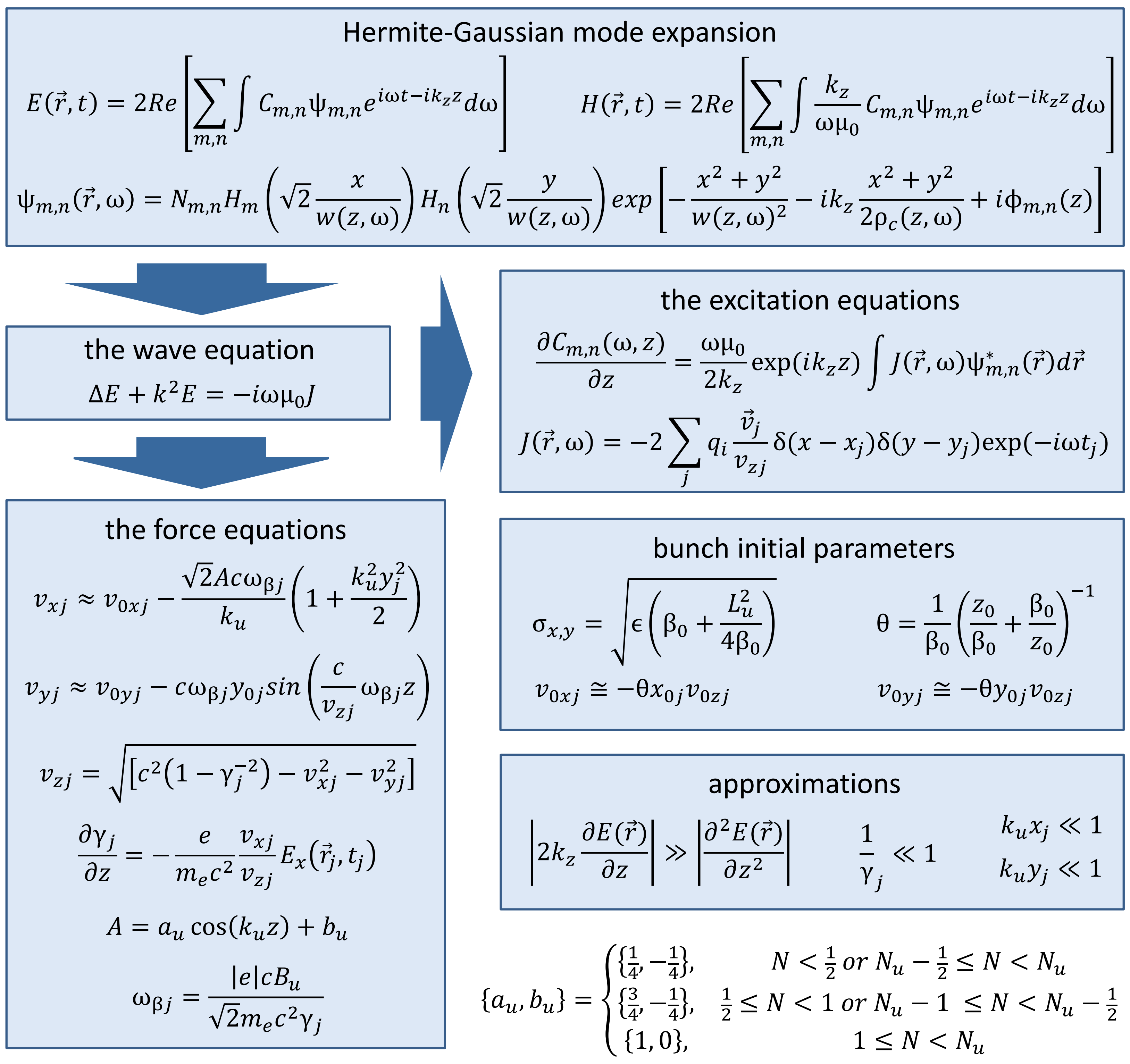
THE MODEL



Hermite-Gaussian mode expansion

$$E(\vec{r},t) = 2Re\left[\sum_{m,n}\int C_{m,n}\psi_{m,n}e^{i\omega t-ik_z z}d\omega\right] \qquad H(\vec{r},t) = 2Re\left[\sum_{m,n}\int \frac{k_z}{\omega\mu_0}C_{m,n}\psi_{m,n}e^{i\omega t-ik_z z}d\omega\right]$$

$$\psi_{m,n}(\vec{r},\omega) = N_{m,n}H_m\left(\sqrt{2}\frac{x}{w(z,\omega)}\right)H_n\left(\sqrt{2}\frac{y}{w(z,\omega)}\right)exp\left[-\frac{x^2+y^2}{w(z,\omega)^2} - ik_z\frac{x^2+y^2}{2\rho_c(z,\omega)} + i\phi_{m,n}(z)\right]$$

the wave equation

$$\Delta E + k^2E = -i\omega\mu_0 J$$

the force equations

$$v_{xj} \approx v_{0xj} - \frac{\sqrt{2}Ac\omega_{\beta j}}{k_u}\left(1+\frac{k_u^2y_j^2}{2}\right)$$

$$v_{yj} \approx v_{0yj} - c\omega_{\beta j}y_{0j}sin\left(\frac{c}{v_{zj}}\omega_{\beta j}z\right)$$

$$v_{zj} = \sqrt{\left[c^2\left(1-\gamma_j^{-2}\right) - v_{xj}^2 - v_{yj}^2\right]}$$

$$\frac{\partial\gamma_j}{\partial z} = -\frac{e}{m_ec^2}\frac{v_{xj}}{v_{zj}}E_x(\vec{r}_j,t_j)$$

$$A = a_u\cos(k_uz) + b_u$$

$$\omega_{\beta j} = \frac{|e|cB_u}{\sqrt{2}m_ec^2\gamma_j}$$

the excitation equations

$$\frac{\partial C_{m,n}(\omega,z)}{\partial z} = \frac{\omega\mu_0}{2k_z}\exp(ik_zz)\int J(\vec{r},\omega)\psi_{m,n}^*(\vec{r})d\vec{r}$$

$$J(\vec{r},\omega) = -2\sum_j q_i\frac{\vec{v}_j}{v_{zj}}\delta(x-x_j)\delta(y-y_j)\exp(-i\omega t_j)$$

bunch initial parameters

$$\sigma_{x,y} = \sqrt{\epsilon\left(\beta_0+\frac{L_u^2}{4\beta_0}\right)} \qquad \theta = \frac{1}{\beta_0}\left(\frac{z_0}{\beta_0}+\frac{\beta_0}{z_0}\right)^{-1}$$

$$v_{0xj} \cong -\theta x_{0j}v_{0zj} \qquad v_{0yj} \cong -\theta y_{0j}v_{0zj}$$

approximations

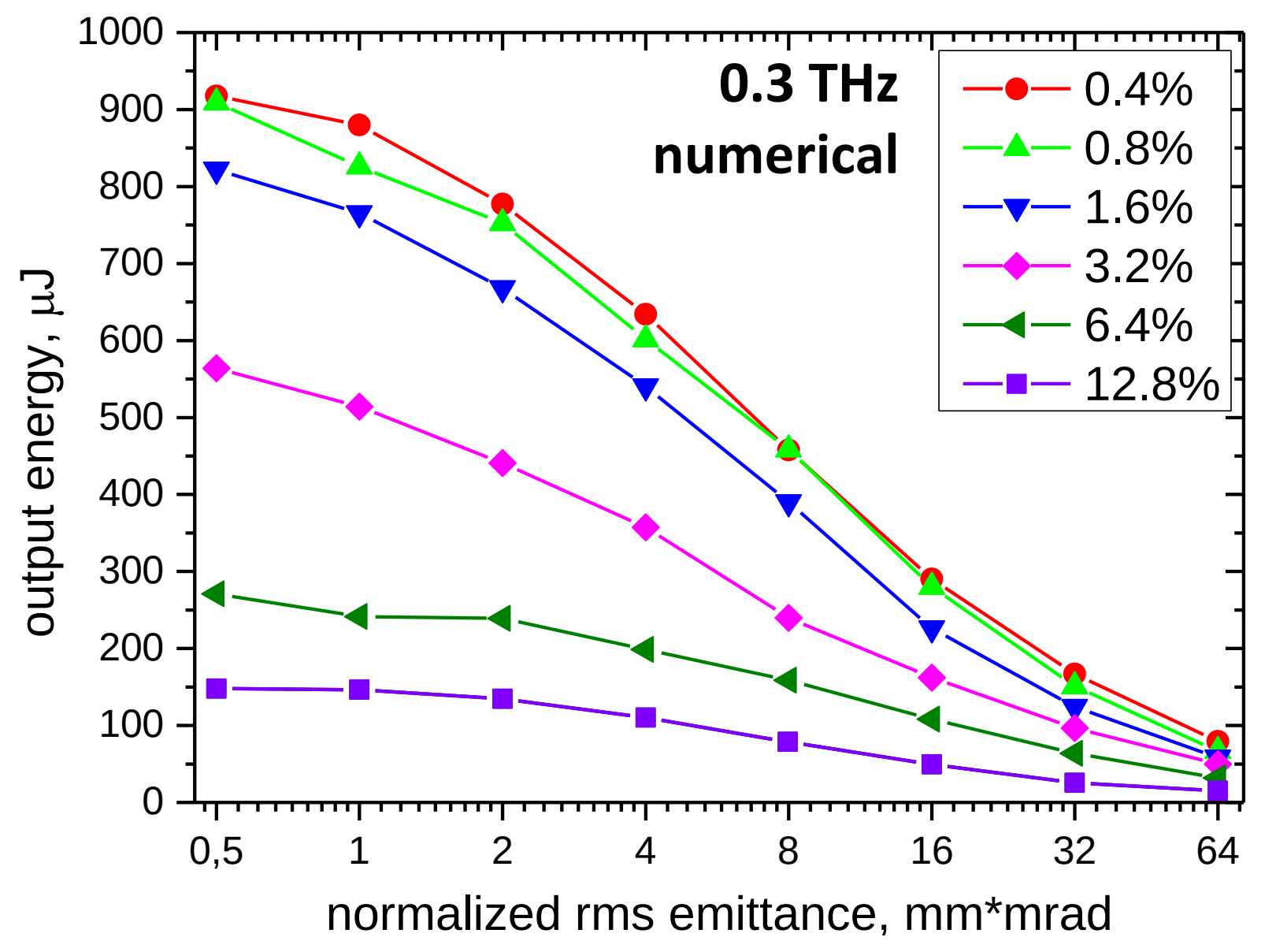
$$\left|2k_z\frac{\partial E(\vec{r})}{\partial z}\right| \gg \left|\frac{\partial^2E(\vec{r})}{\partial z^2}\right| \qquad \frac{1}{\gamma_j} \ll 1 \qquad k_ux_j \ll 1 \quad k_uy_j \ll 1$$

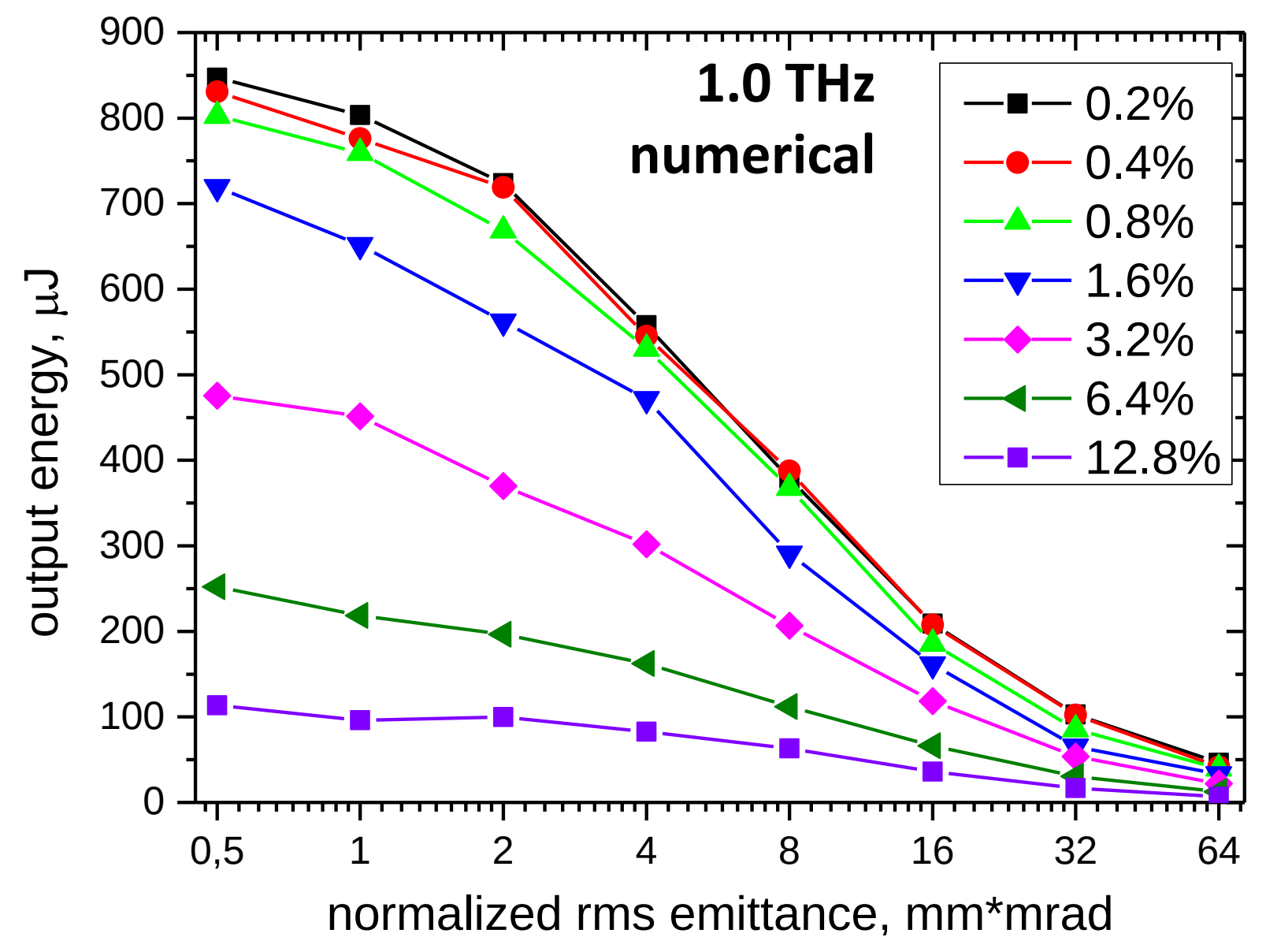
$$\{a_u,b_u\} = \begin{cases}\{\frac{1}{4},-\frac{1}{4}\}, & N < \frac{1}{2}\ or\ N_u-\frac{1}{2} \le N < N_u\\ \{\frac{3}{4},-\frac{1}{4}\}, & \frac{1}{2} \le N < 1\ or\ N_u-1 \le N < N_u-\frac{1}{2}\\ \{1,0\}, & 1 \le N < N_u\end{cases}$$

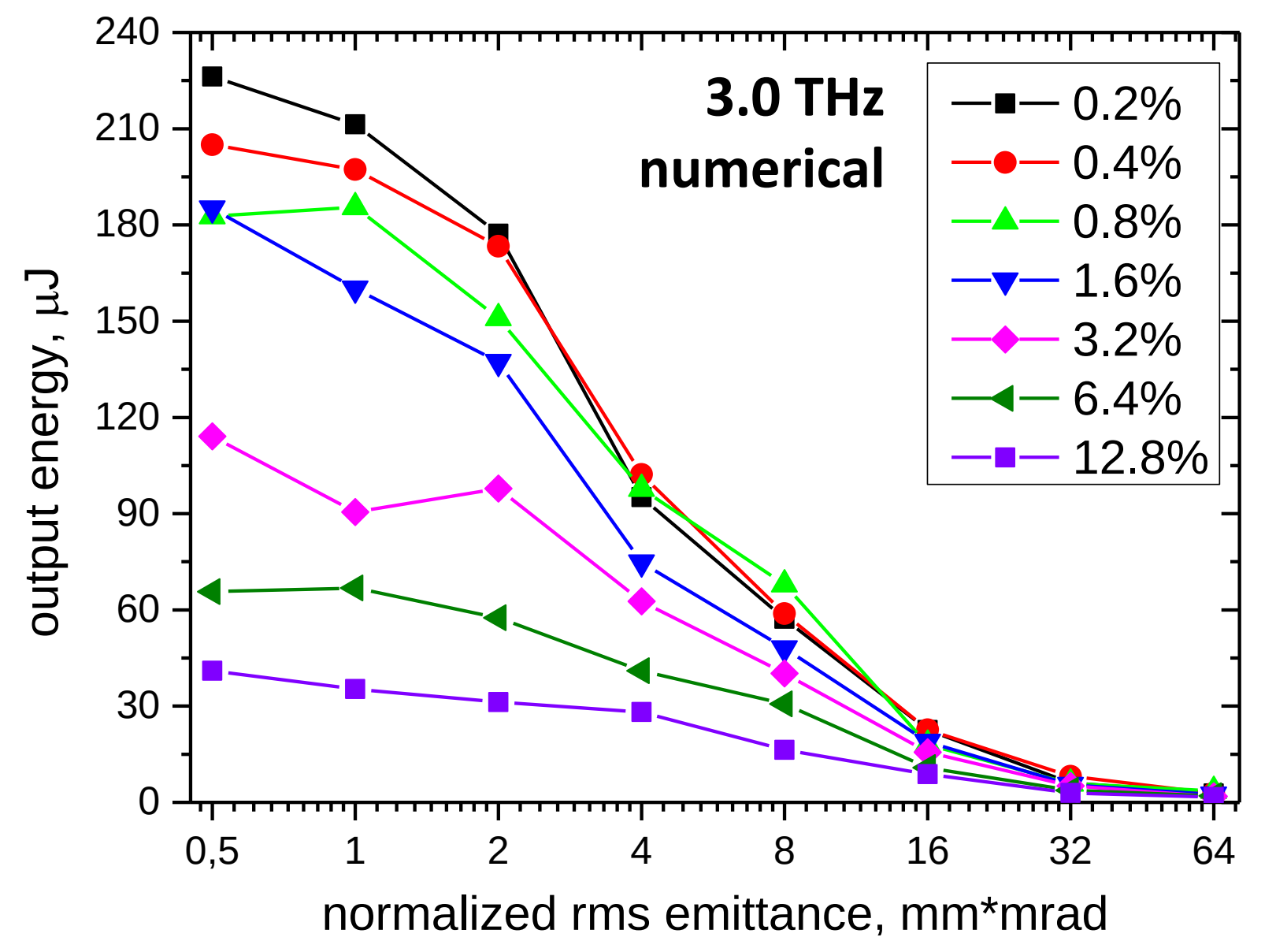
ENERGY CHARACTERISTICS

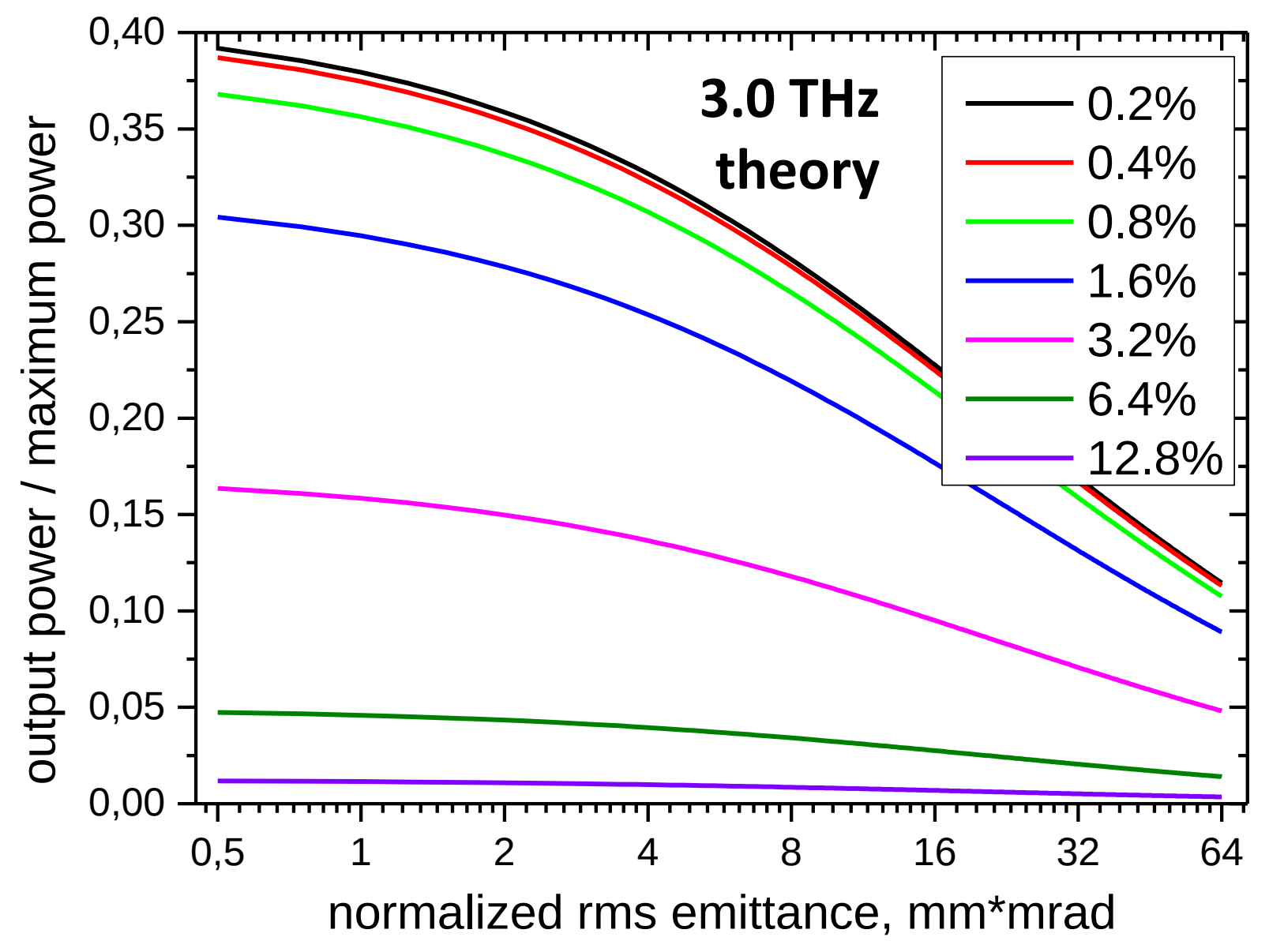
resonant frequency, THz	0.3	1.0	3.0
bunch charge, nC	1.0	1.0	0.5
mean e-energy, MeV	9.0	9.31	16.5
bunch duration, fs	150	150	100
bunch β_0 -function, m	3.0	3.0	3.0

resonant frequency, THz	0.3	1.0	3.0
magnetic flux, T	0.31	0.14	0.14
undulator period, cm	11.0	11.0	11.0
number of periods	9	9	9
undulator parameter	2.26	1.0	1.0







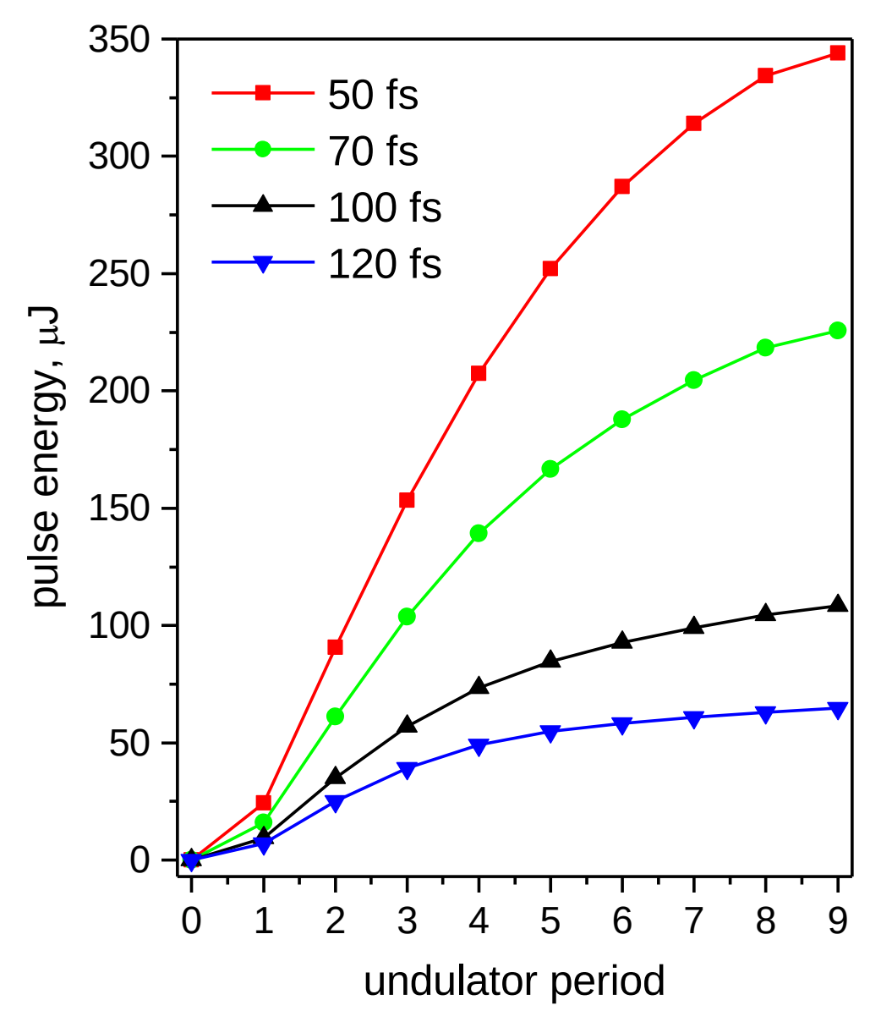


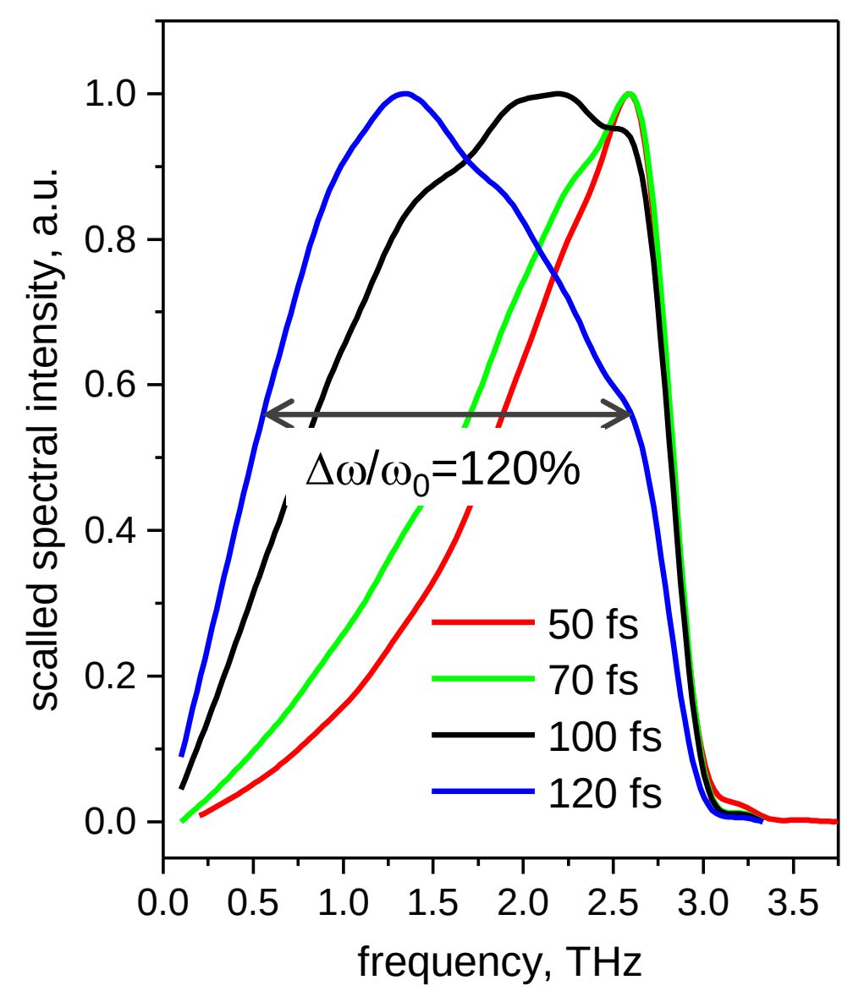
the numerical model predicts the radiation output to be more critical to the bunch emittance but less sensitive to the electron energy spread; the discrepancy is related to the bunching effect of the THz field on electrons (see bunch trajectories on the next inset) that enhances the FEL output at low emittance values.

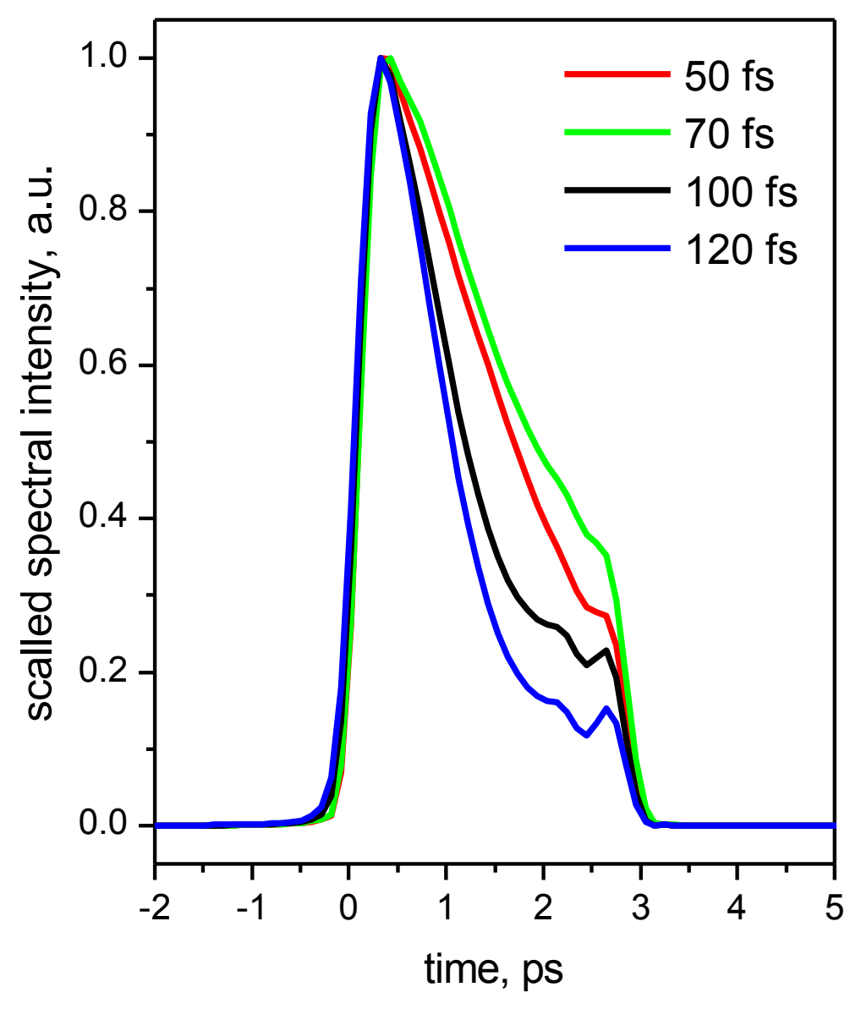
EFFECT OF THE BUNCH DURATION

resonant frequency, THz	3.0
bunch charge, nC	0.5

normalzed emmitance, mm·mrad	4.0
relative energy spread, %	1.0

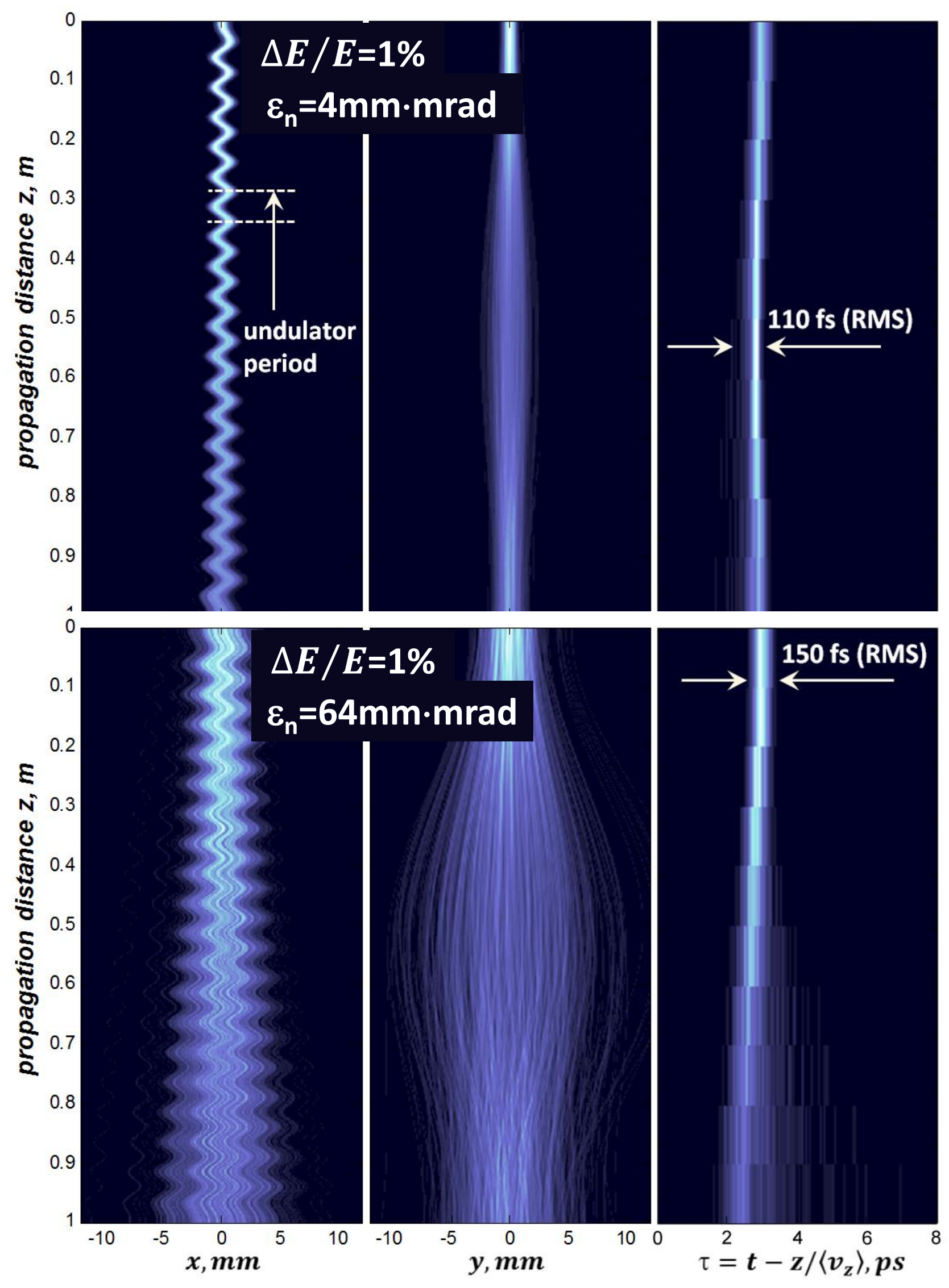


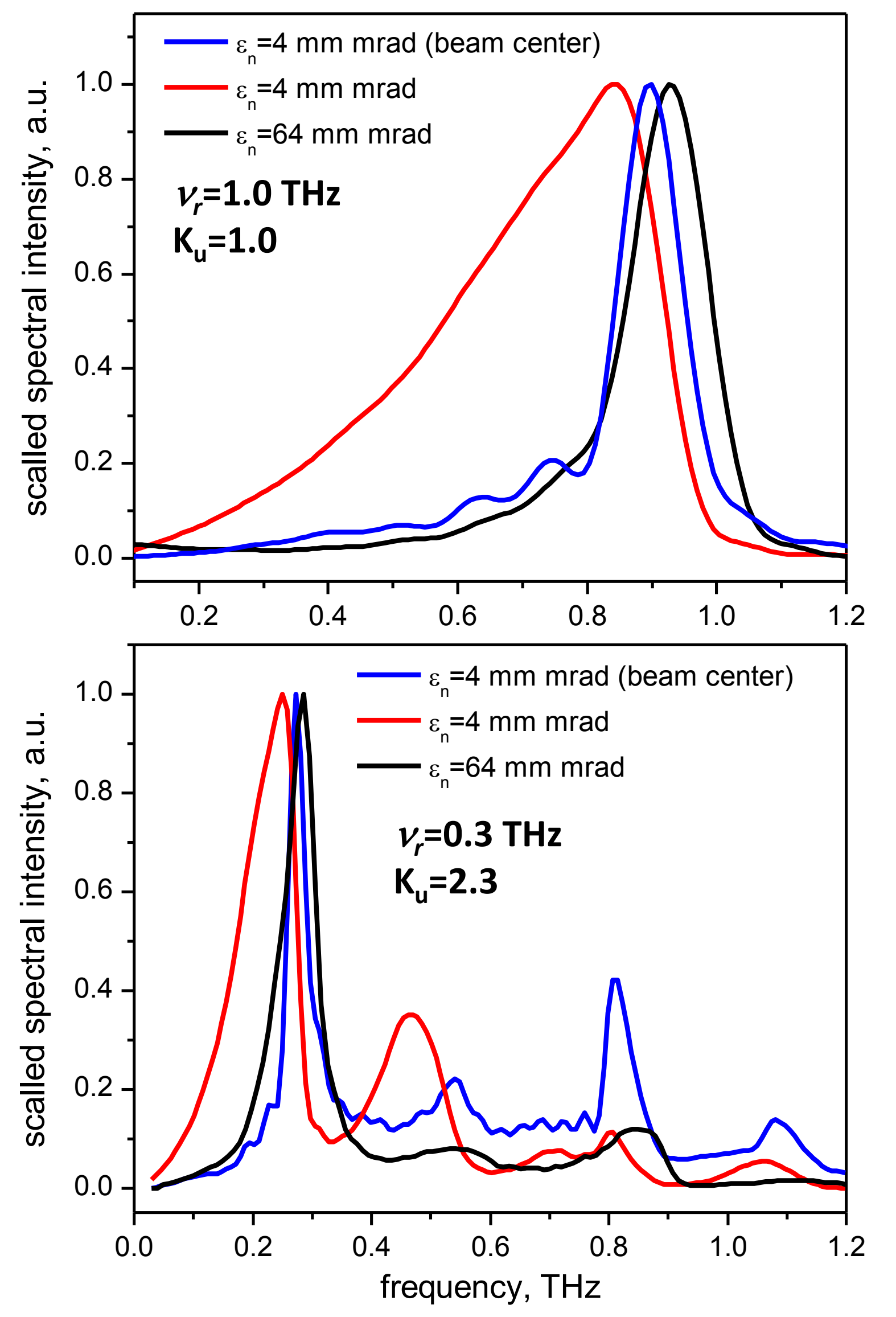




EFFECT OF THE BUNCH EMITTANCE

bunch trajectories



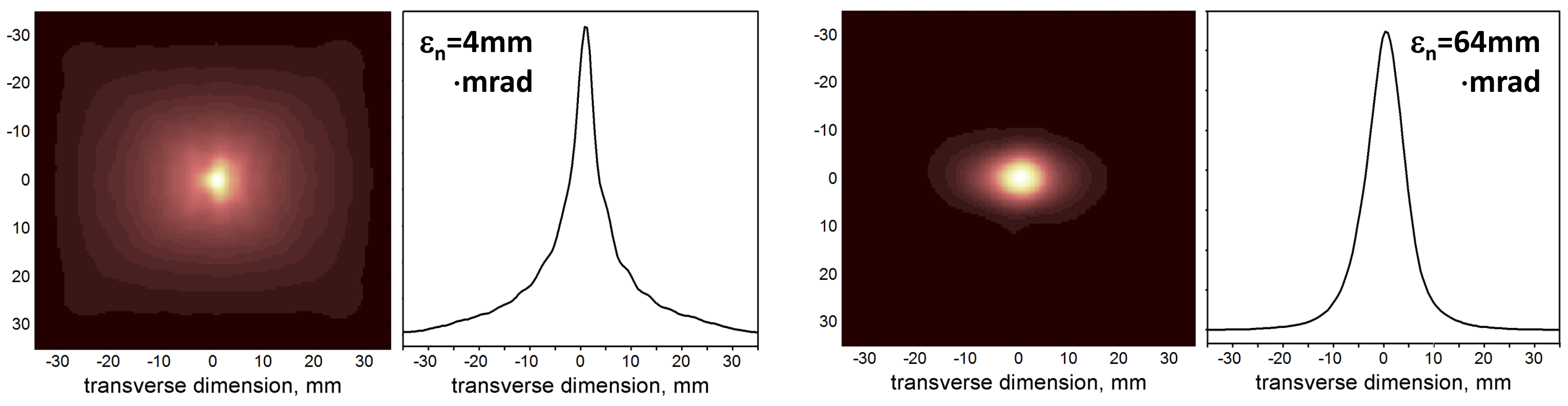


SPATIAL CHARACTERISTICS

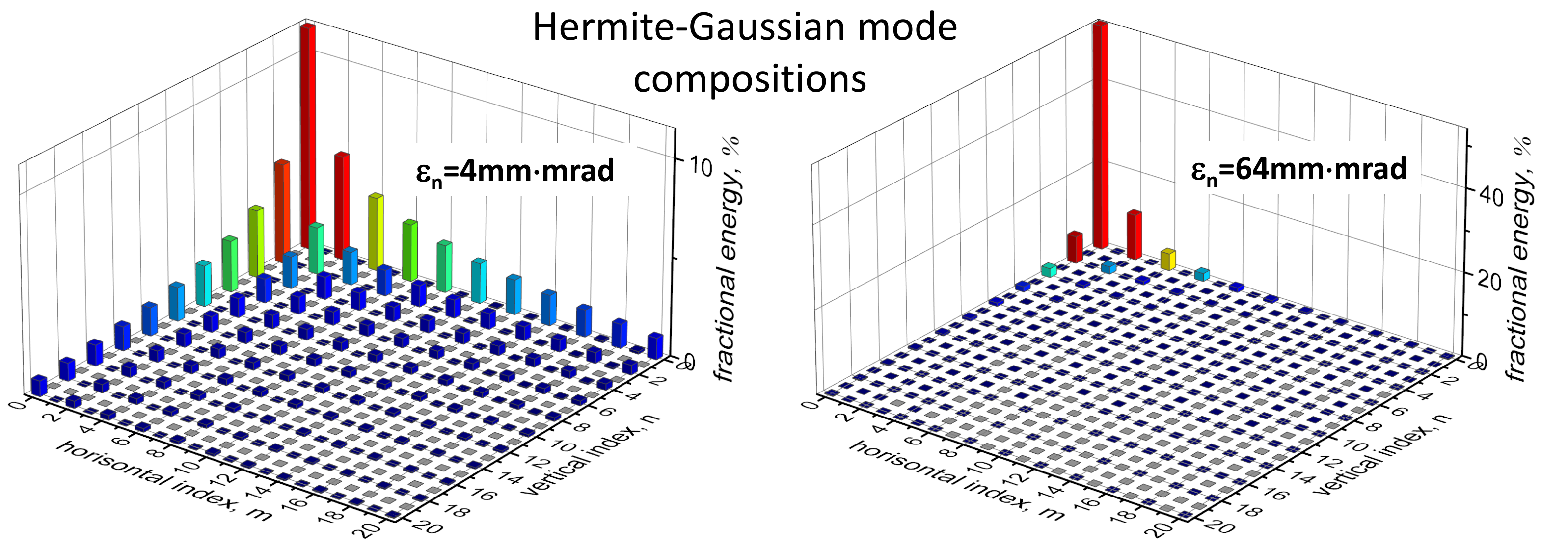
resonant frequency, THz	1.0

relative electron energy spread, %	1.0

transverse profiles of the THz beams



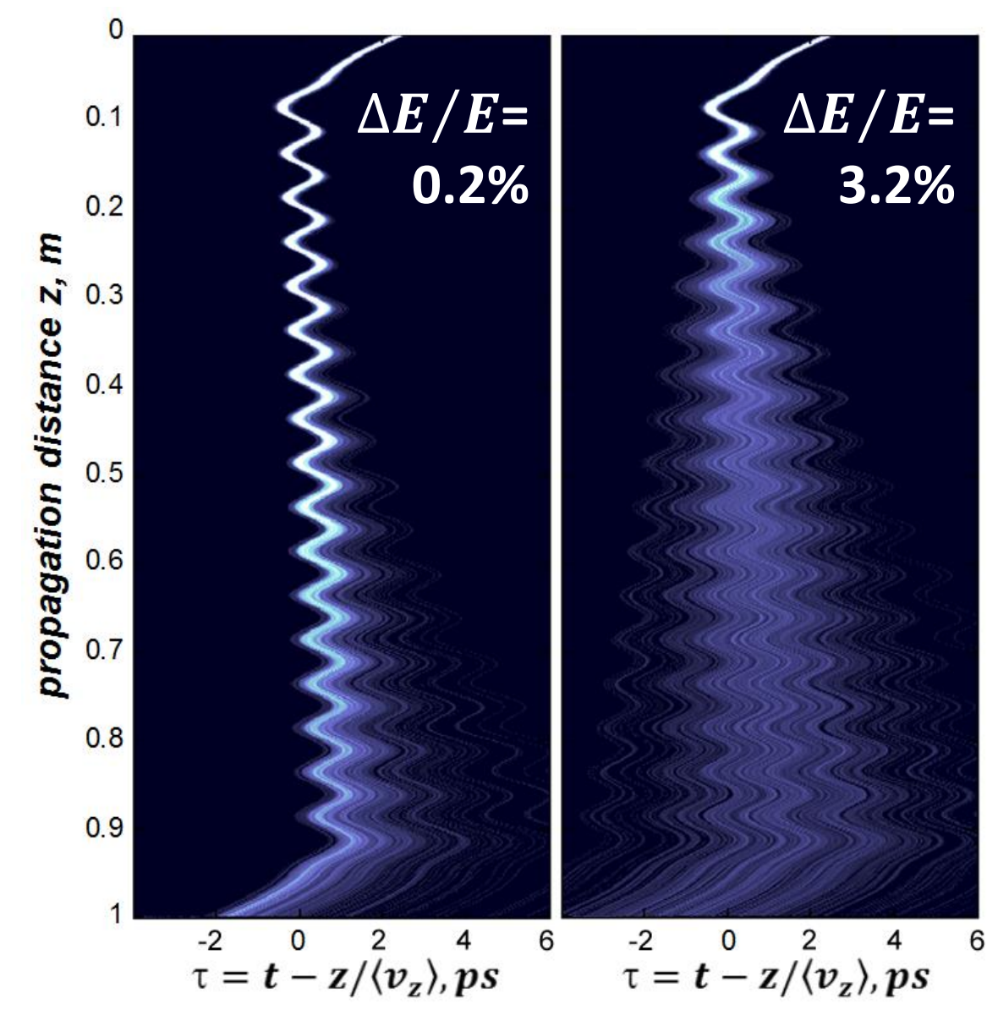
Hermite-Gaussian mode compositions

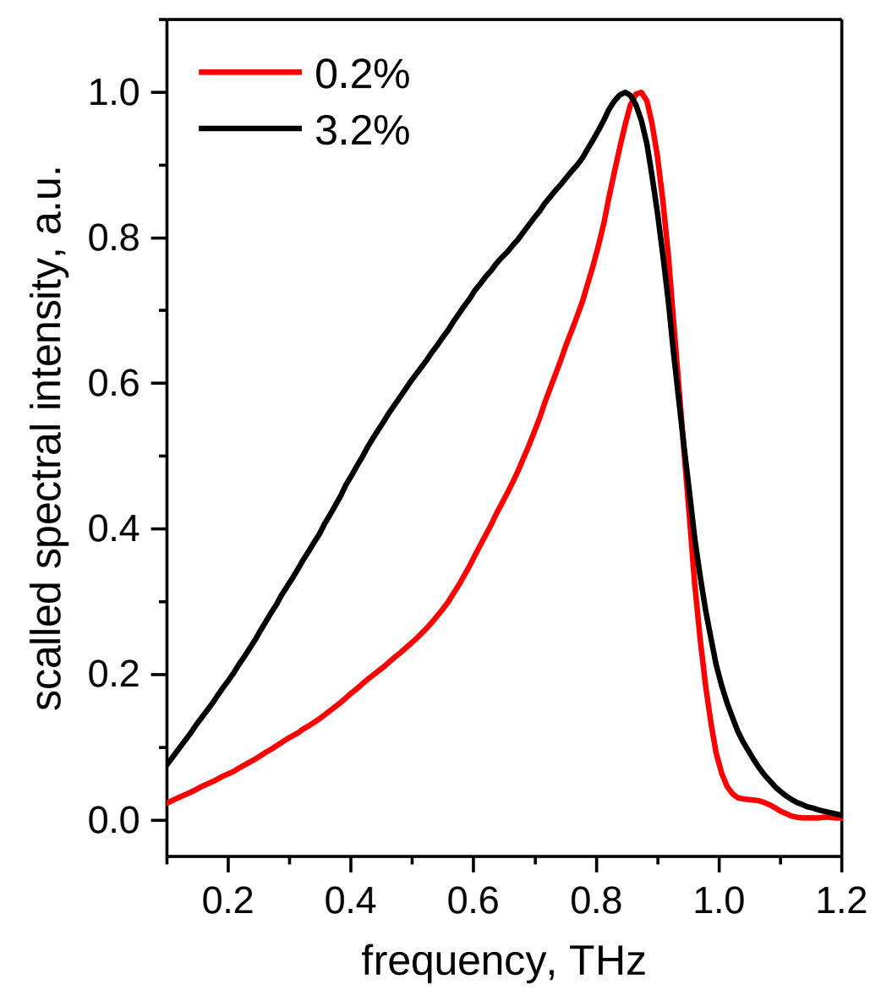


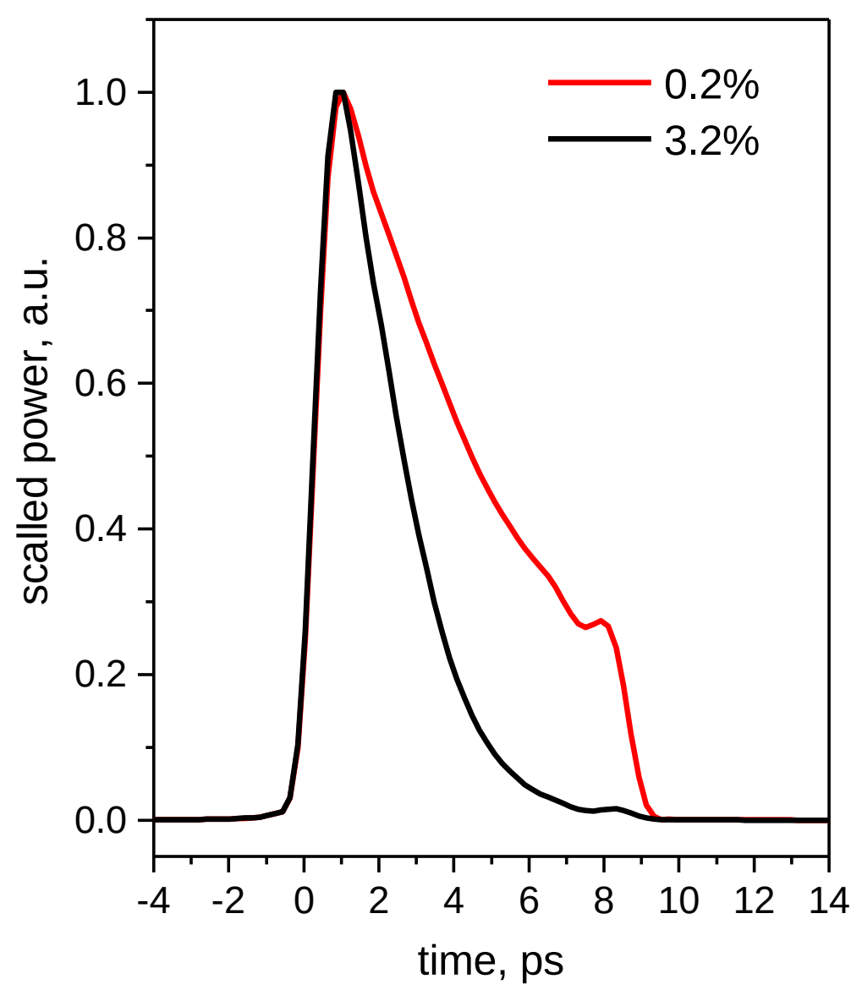
THE ENERGY SPREAD EFFECT

resonant frequency, THz	1.0

normalzed emmitance, mm·mrad	4.0







SUMMARY

- Emission properties of an open-type super-radiant THz source having a simple non-tapered undulator with plane magnets have been analyzed numerically. The calculated radiation output is more sensitive to the bunch emittance but less susceptible to the electron energy spread as compared to the known analytical theory [9]. The discrepancy is related to the bunching effect of the THz field on electrons that enhances the FEL output at low emittance values.
- Broadening of the THz spectrum due to enhanced contribution of the self-amplified spontaneous emission (SASE) has been recognized as the bunch duration and electron energy spread increase. For the considered interaction geometry, we predict degradation in angular divergence of the generated radiation and its spectral broadening as the electron bunch emittance decreases. Such degradation and broadening are directly related to the diffraction and the FEL resonance condition for off-axial light generation.

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