Undulator gap error tolerances for wakefield compensation in XFEL

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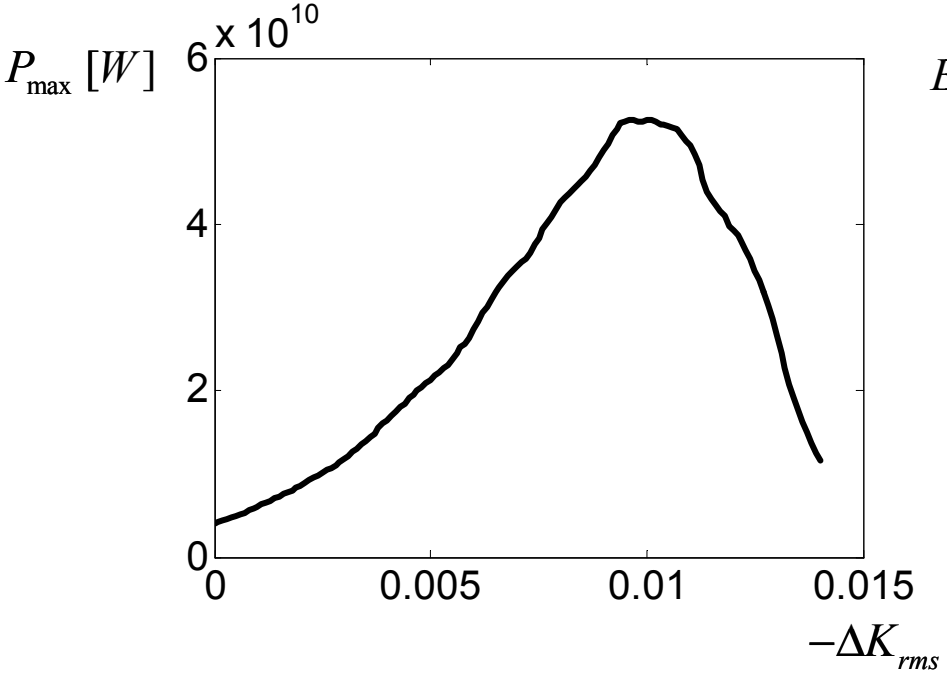
SASE 2 parameters

Parameter	symbol	unit	Value
radiation wavelength	λ	nm	0.1
Energy	E	GeV	17.5
energy spread	σ_E	MeV	1
undulator parameter	K_{rms}		1.97
Emmitance	ε_n	mm*mrad	0.7
peak current	I	kA	5
average beta function	β	m	17.25
undulator section length	L_{sect}	m	5
intersection length	L_{inters}	m	1.1
total length	L_{total}	m	260
undulator period	λ_u	m	0.048

$$\rho = 7.1 \cdot 10^{-4}$$

Steady-state



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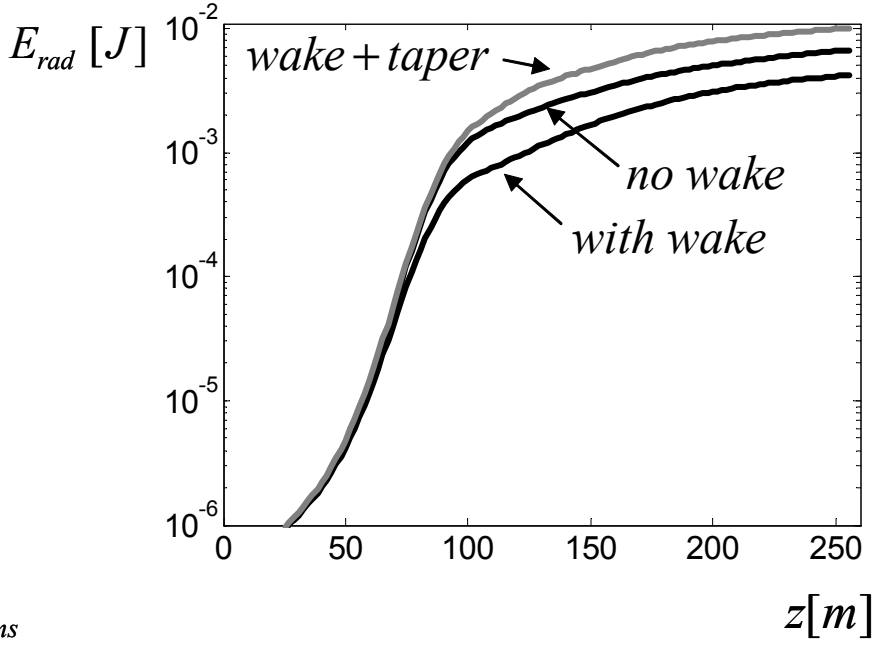


The maximum power dependence on tapering (left) and the radiation power along the undulator (right)

$$W_{sh} = 3\rho \frac{W_b}{N_c \sqrt{\pi \ln N_c}} = 11800[W]$$

$$W_{\parallel} = 150 kV / nC / m$$

$$B_u = 3.694 \exp\left(-5.068 \frac{g}{\lambda_u} + 1.52 \left(\frac{g}{\lambda_u} \right)^2 \right)$$

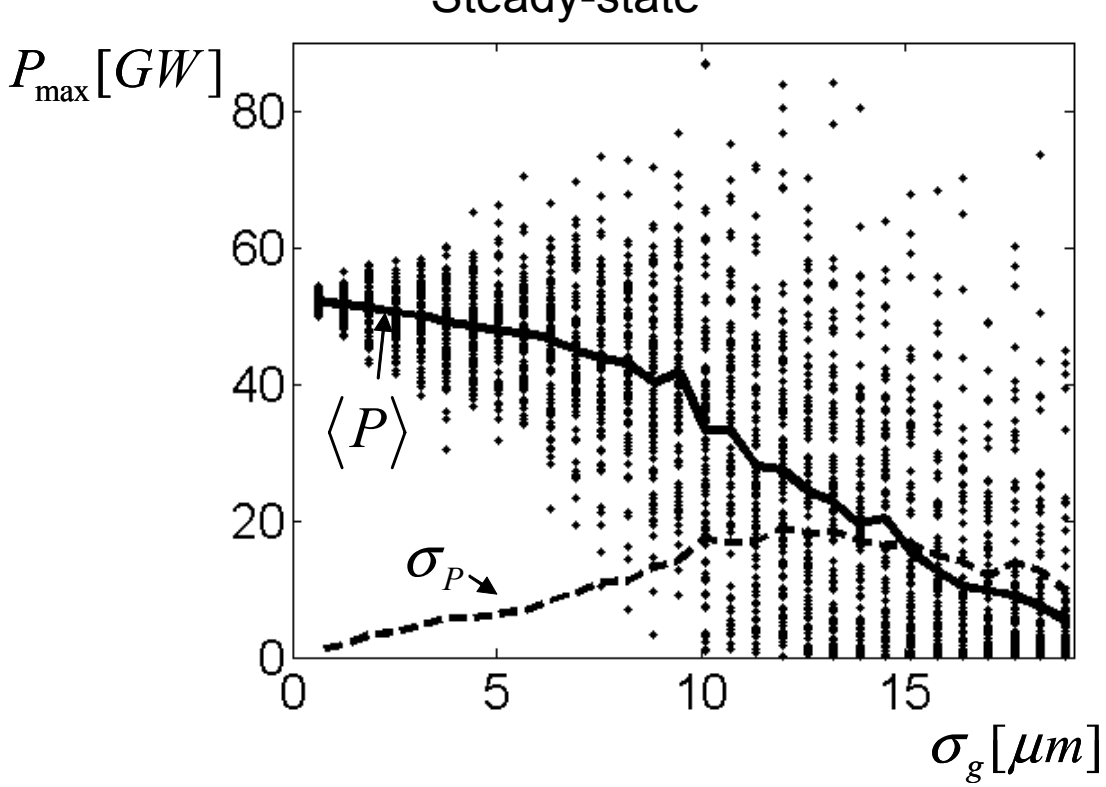
$$\frac{\Delta K_{rms}}{K_{rms}} \approx -\frac{\Delta g}{g} \left(-5.068 \frac{g}{\lambda_u} + 3.04 \left(\frac{g}{\lambda_u} \right)^2 \right)$$

$$K_{rms} = 93.4 \lambda_u B_u / \sqrt{2}$$

$$\Delta g = -0.0124 \, \Delta K_{rms} / K_{rms}$$

Optimal taper

$$\Delta g = -0.0124 \, \Delta K_{rms} / K_{rms} = 60 \cdot 10^{-6} [m]$$

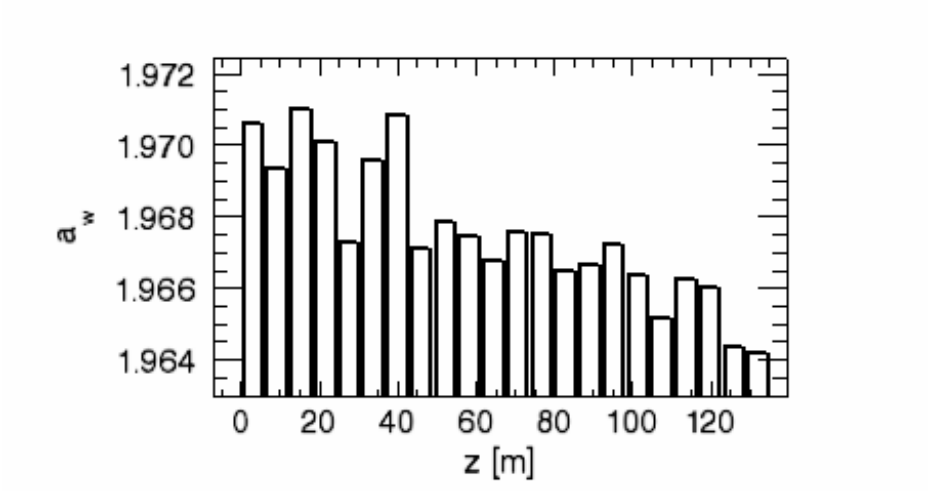


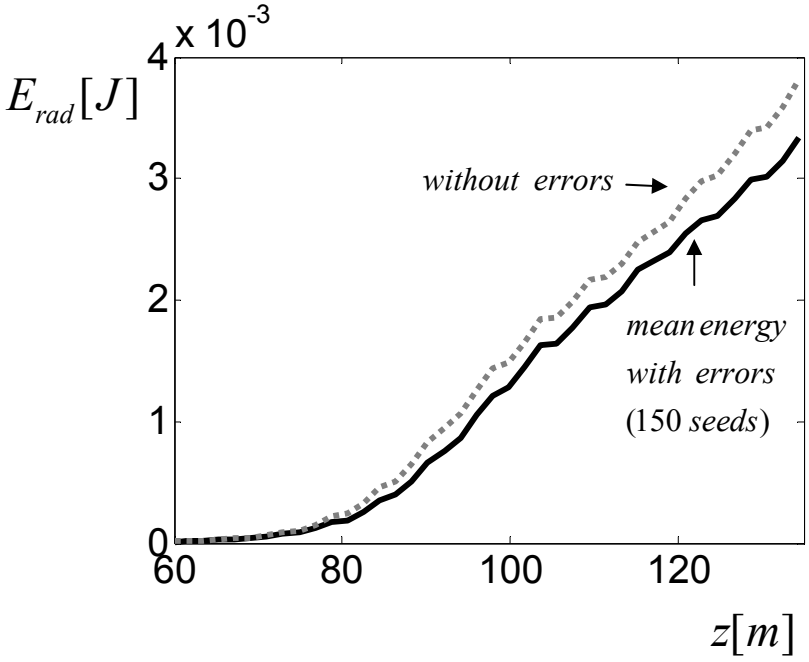
$$f(\delta g) = \frac{1}{\sqrt{2\pi}\sigma_g} \exp\left(-\frac{\delta g^2}{2\sigma_g{}^2}\right)$$

Impact of statistical errors of undulator gap on power gain.

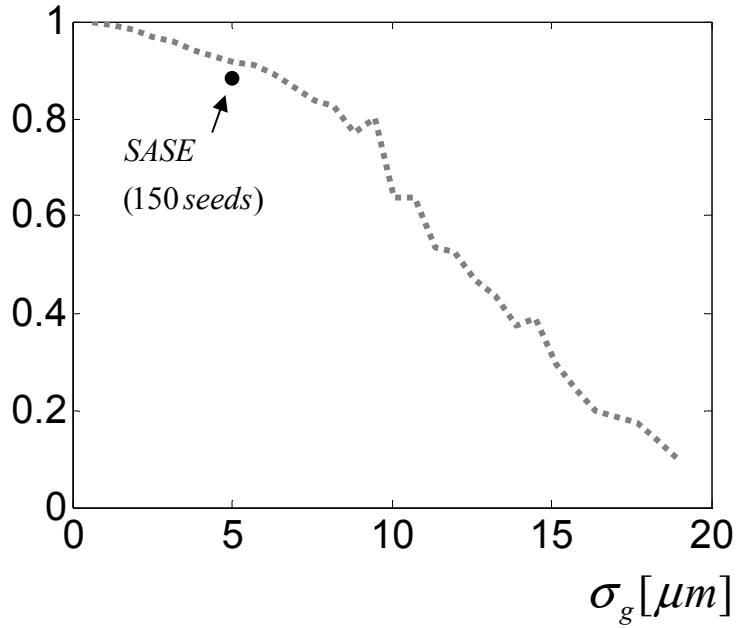
$$\frac{P_0 - \langle P \rangle}{P_0} 100\% \approx 20\% \qquad for \quad \sigma_g = 10\mu m$$

$$\frac{P_0 - \left[\langle P \rangle - 3\sigma_p\right]}{P_0} 100\% \approx 20\% \qquad for \quad \sigma_g = 2\mu m$$

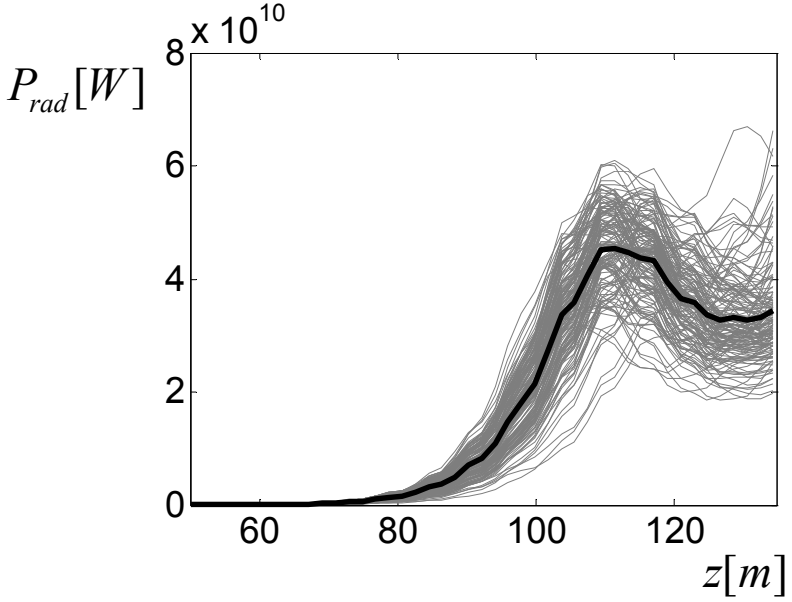


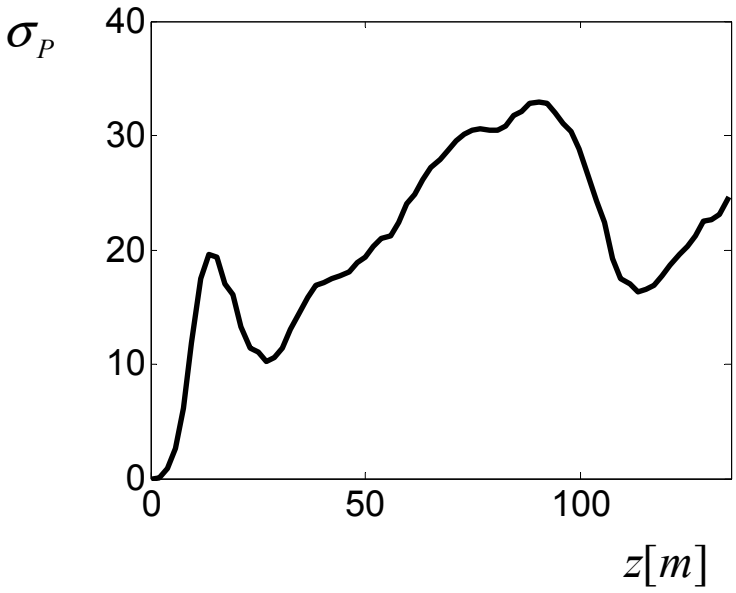


$$\frac{\left\langle P_{\max}^{\sigma_g} \right\rangle}{P_{\max}^{0}}$$



Steady-state





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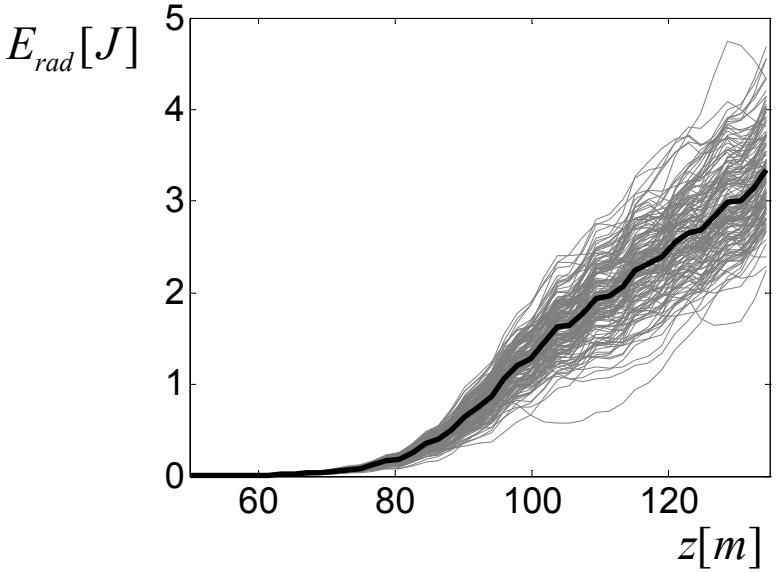

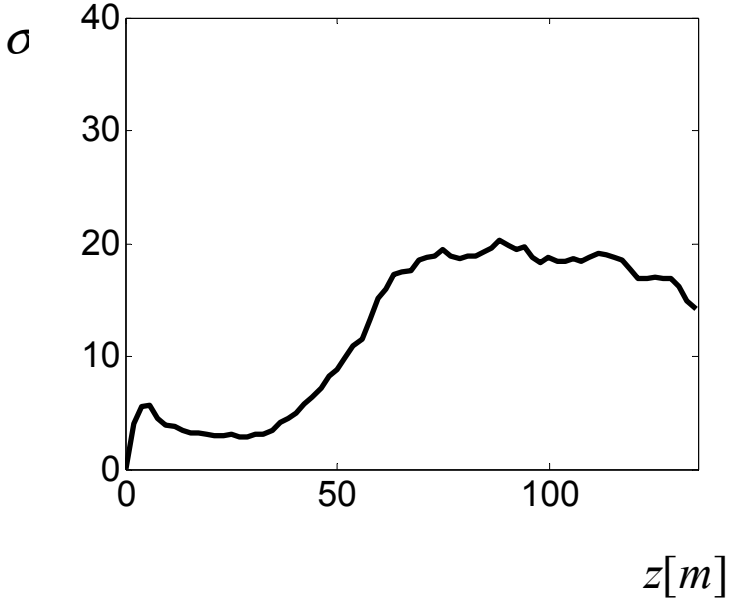

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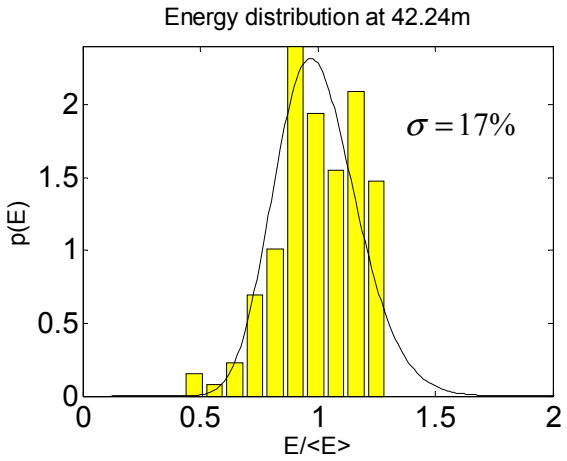

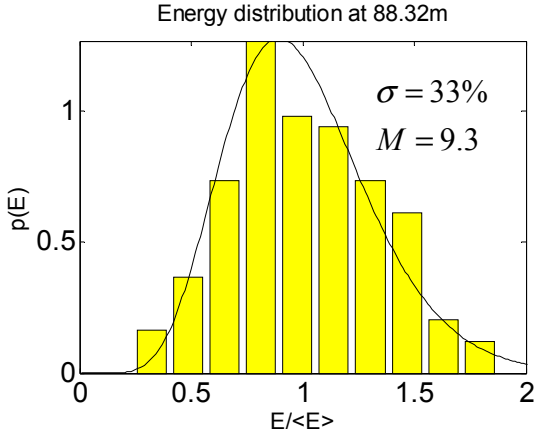

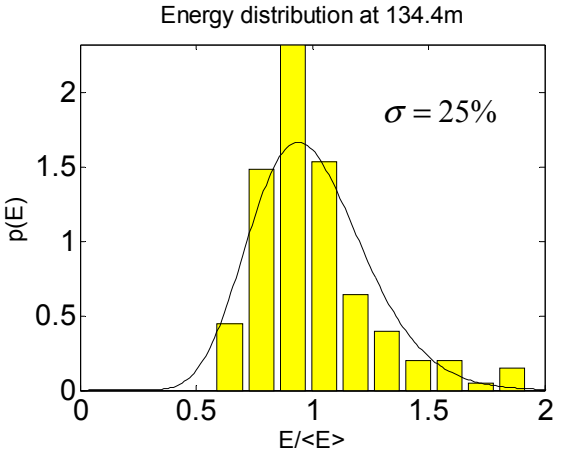

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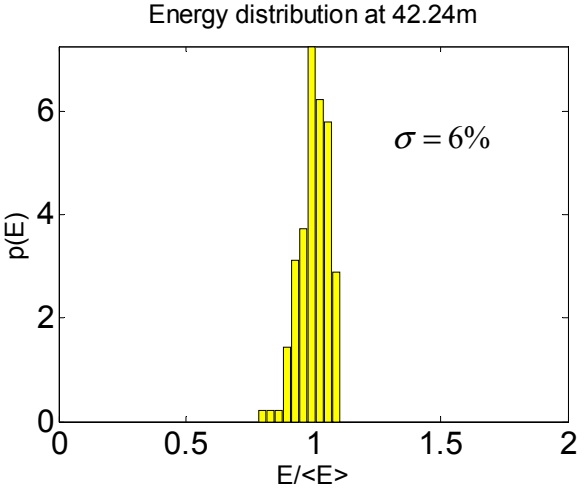
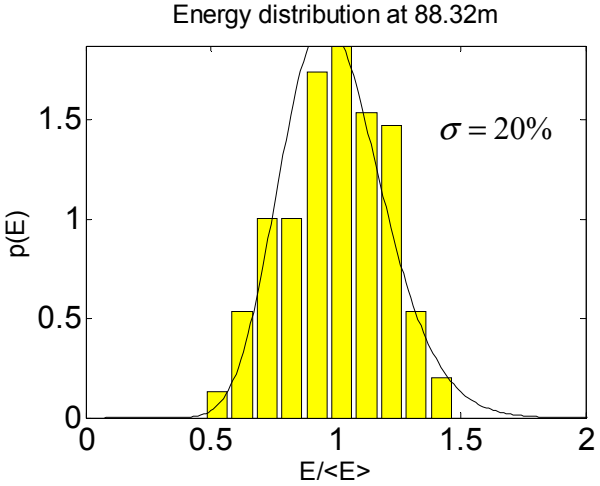
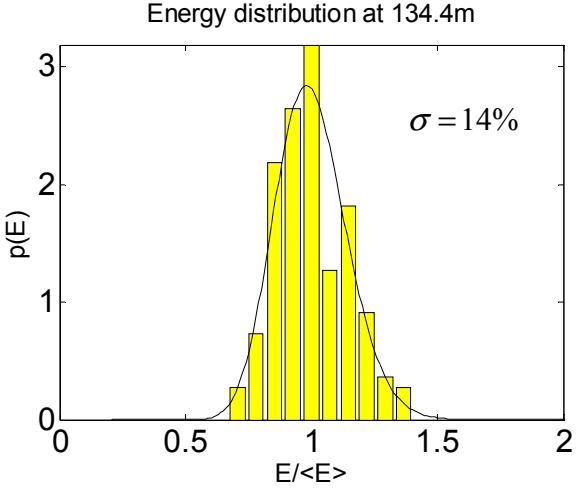
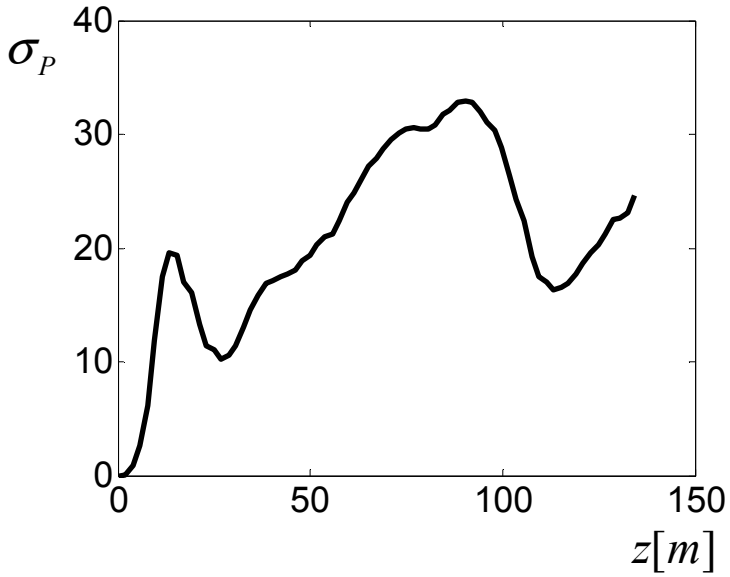






$$p(E) = \frac{M^M}{\Gamma(M)} \left(\frac{E}{\langle E \rangle} \right)^{M-1} \frac{1}{\langle E \rangle} \exp\left(-M \frac{E}{\langle E \rangle} \right)$$

Steady-state



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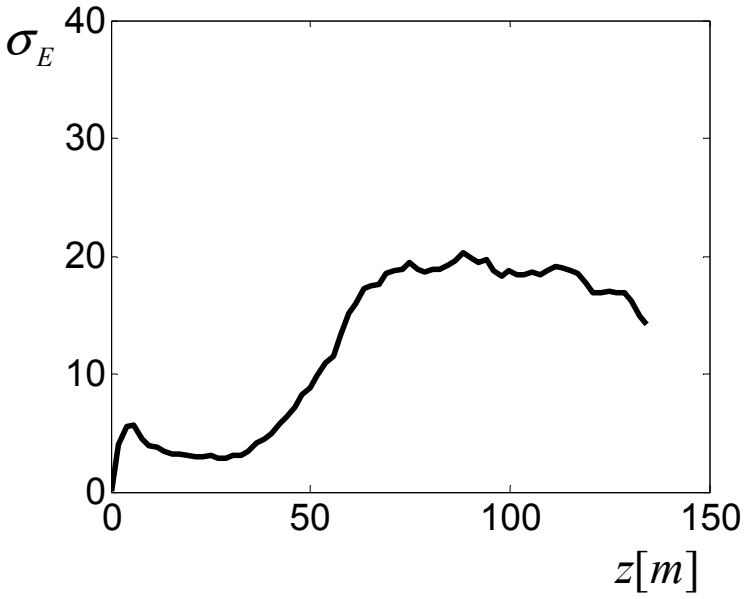
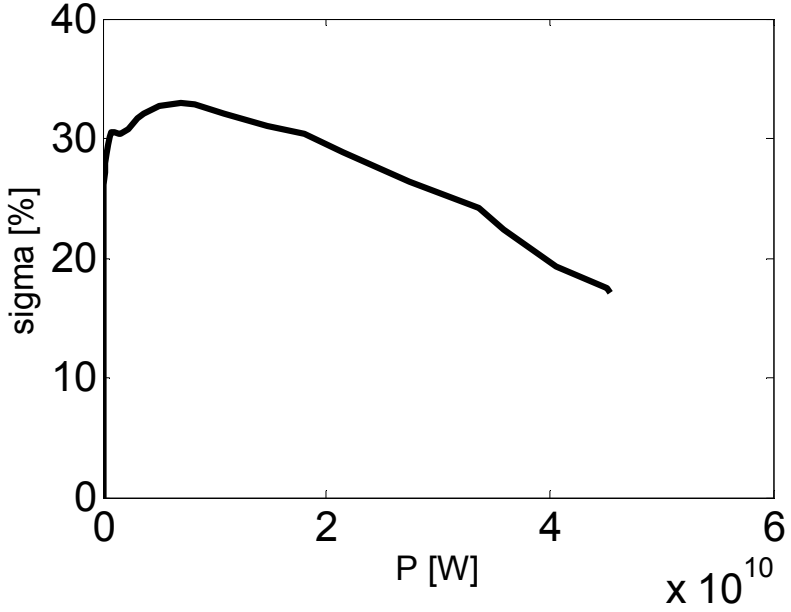
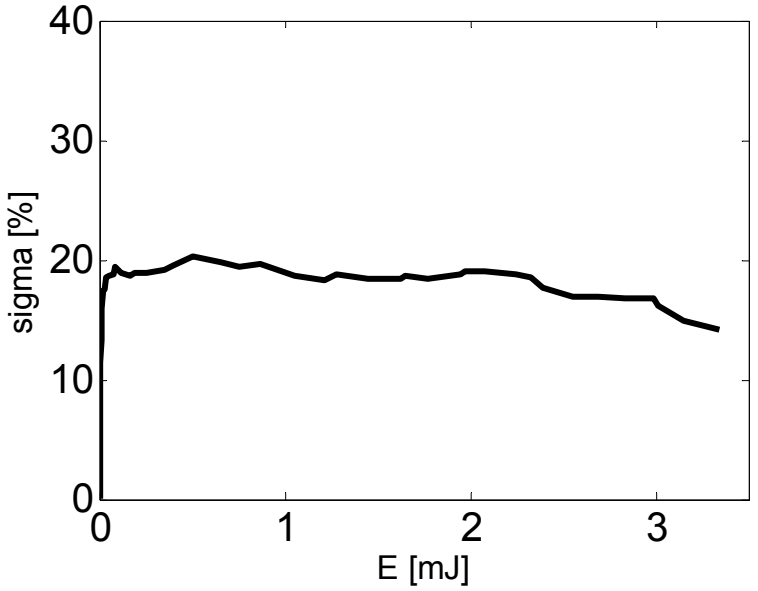


Fluctuations of the power in the radiation slice



Fluctuations of the energy in the radiation pulse



For 5 mkm gap error at position z=130m

Steady-state

$$\frac{\left\langle P_{\max}^{\sigma_g} \right\rangle}{P_{\max}^{0}} = 0.91$$

$$\sigma_P = 0.22$$

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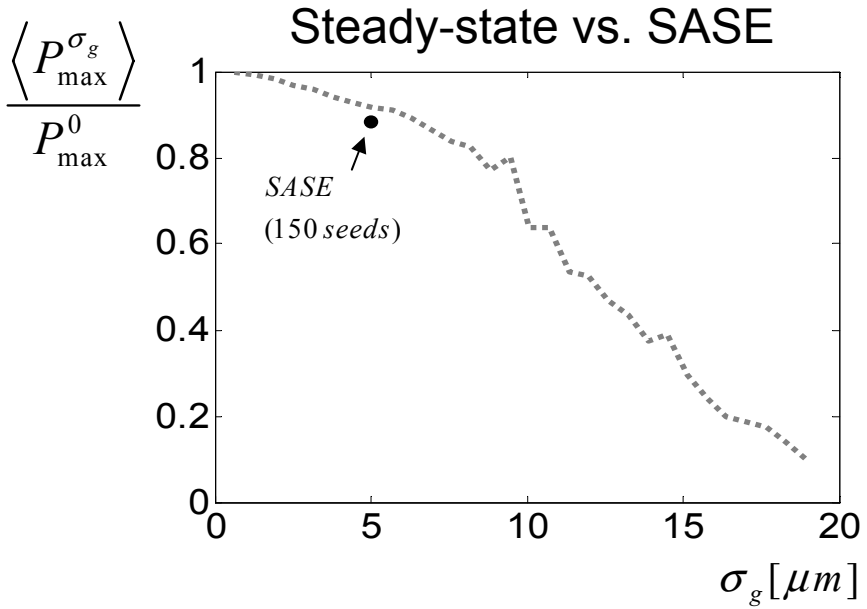
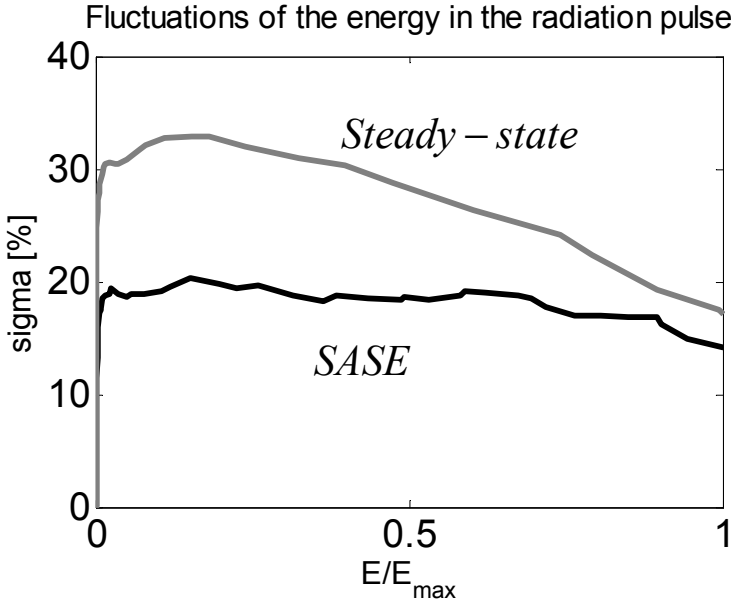
$$\frac{\left\langle E_{\max}^{\sigma_E} \right\rangle}{E_{\max}^{0}} = 0.88$$

$$\sigma_E = 0.16$$





The gap error $\sigma_g = 5\mu m$ results

- in decrease of the expected radiation energy by 10%
- in RMS deviation of the radiated energy by 16%