

Beam Dynamics in Undulators: wakefield estimates

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Outline

- Model for wakefield in undulator region.
- SIMPLEX simulation results for 4.6 GeV for 0.1 nm FEL and 9 Ge V for 0.05 nm FEL.
- Genesis simulation results for 6 GeV electron beam with real beam distribution.
- Conclusion and future studies.

Effect of the wakefield

- Wakefields such as the resistive wall wakefield and the surface roughness wakefield inside an undulator can cause beam energy loss and energy spread growth.
- Such energy loss inside an undulator can induce energy variation along the bunch length
- That will limit the performance of the undulator and the quality of the final FEL radiation.
- In this presentation the effect of the resistive wall wakefield to the FEL performance is investigated for some draft parameters.

Model for resistive wake potential

- The wake potential can be calculated from Bane's paper formula (Resistive wall wakefield in the LCLS undulator beam pipe, SLAC-PUB-10707, LCLS-TN-04-11, 2004).
- The wakefield is

$$W(s) \approx \frac{4}{a^2} \text{Exp} \left(-\frac{s}{4 \Gamma s_0} \right) \text{Cos} \left(\left(\frac{8}{\Gamma} \right)^{1/4} \frac{s}{s_0} \right) \quad \Gamma = \frac{\tau}{s_0}$$

τ is relaxation time and s_0 is characteristic distance. The characteristic distance is

$$s_0 = \left(\frac{c a^2}{2 \pi \sigma} \right)^{1/3}$$

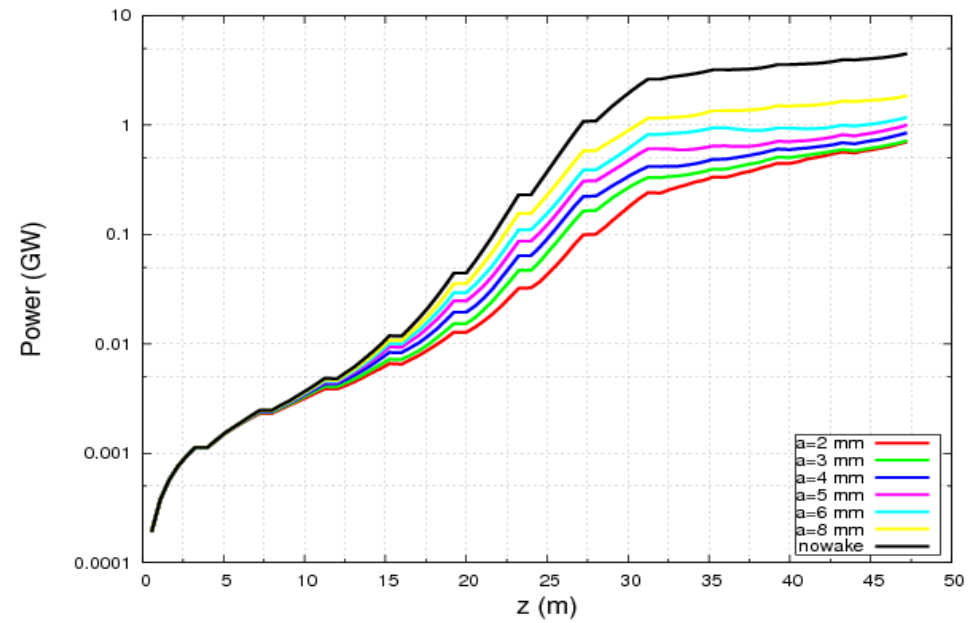
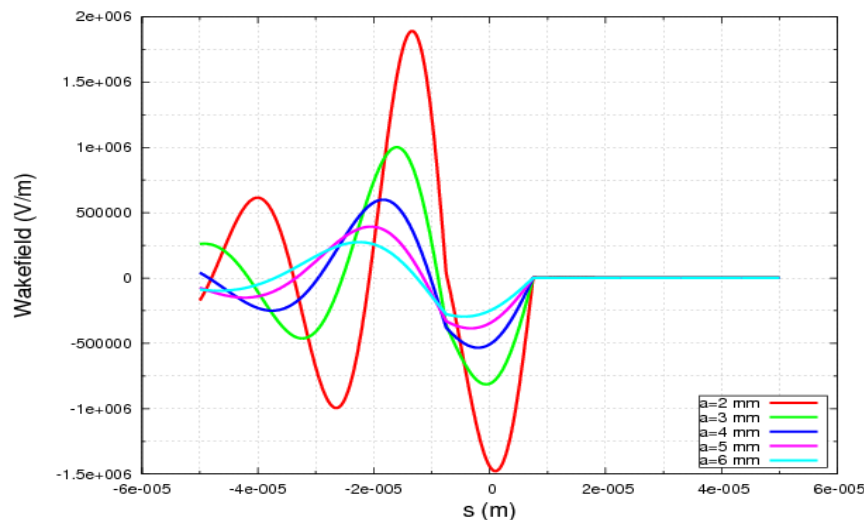
where a is beam pipe radius and σ is conductivity.

SIMPLEX simulation

- For FEL sources, Resistive wall wakefield is much more dominant than surface roughness.
- The SIMPLEX can calculate the wake potential for given aperture and material itself.
- In simulations the resistive wall wake field with parallel plat configuration is taken in account .
- In the calculation the resistivity and relaxation time for Copper (Cu) are used ($\rho=1.68 \times 10^{-8} \Omega\text{m}$, $\tau=2.4 \times 10^{-14} \text{ s}$).

SIMPLEX Simulation results for 4.6 GeV electron beam energy (parameters of CompactLight proposal)

Parameter	Value
Energy (GeV)	4.6
Bunch length (μm)	15
Current Profile	Boxcar
Bunch Charge (pC)	250
Peak Current (A)	5000
Emittance (mm mrad)	0.5
Undulator Period (cm)	1
Undulator Parameter	1.13
Und. Length (m)	3.35
Rad. Wavelength (nm)	0.1

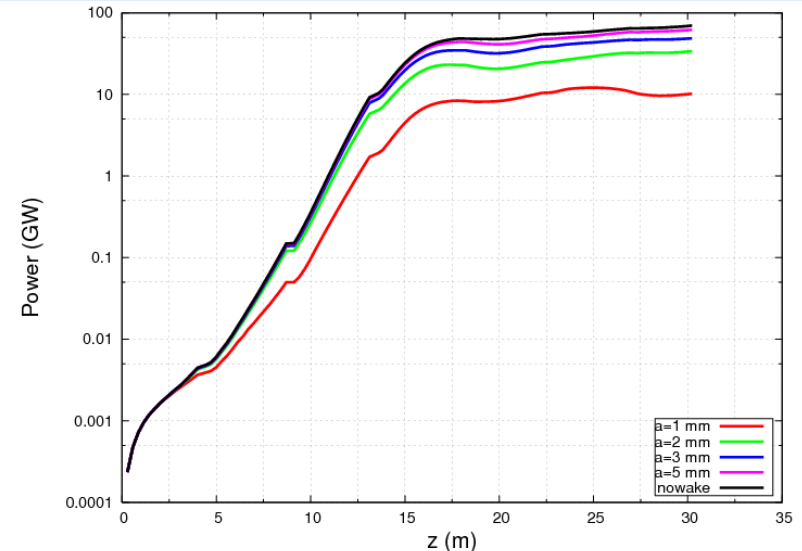
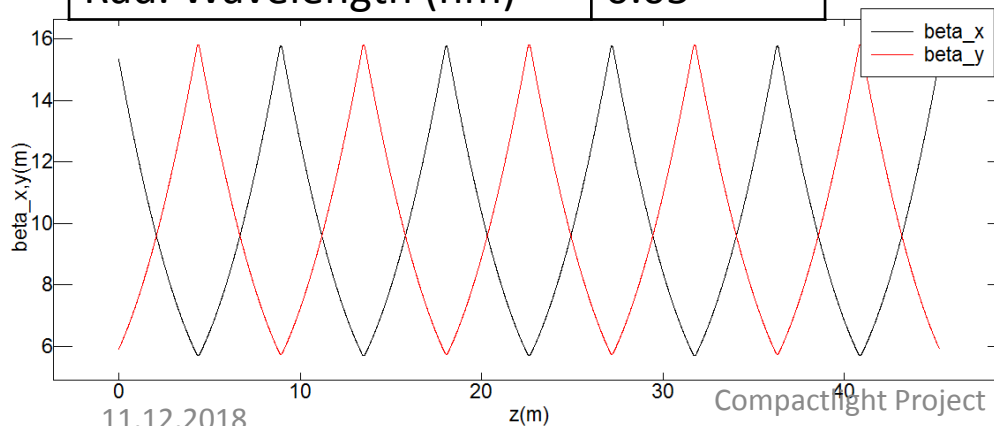


Evolution of power in undulator region for different apertures (Averaged over pulse).

Resistive wake along bunch for different aperture

Last Proposed parameters (9 GeV and 0.05 nmFEL)

Parameter	Value
Energy (GeV)	9
Bunch length (μm)	2.5
Current Profile	Boxcar
Bunch Charge (pC)	75
Peak Current (A)	9000
Emittance (mm mrad)	0.12
Undulator Period (cm)	1.3
Undulator Parameter	1.65
Und. Length (m)	4.2
Rad. Wavelength (nm)	0.05



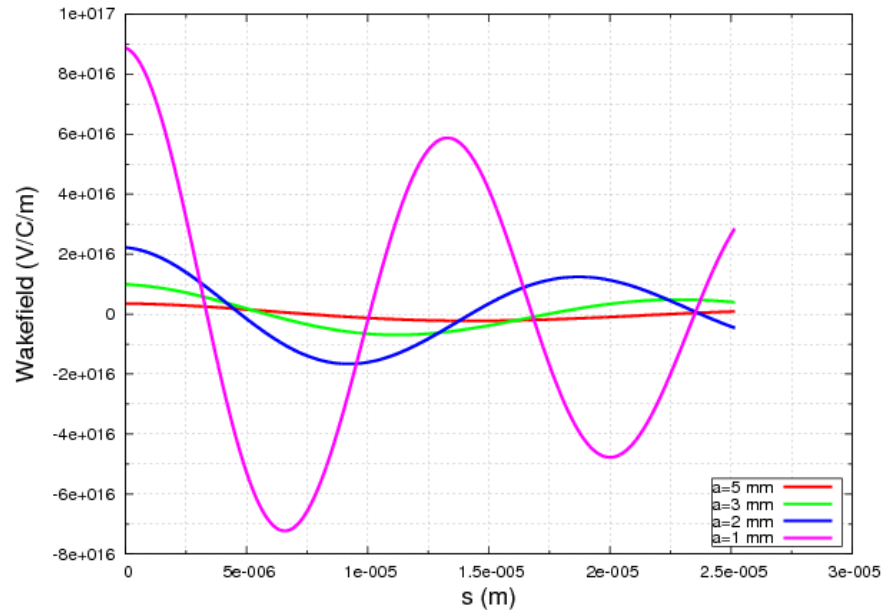
- Saturation power is 45 GW without wake
- 43 GW for aperture=5 mm;
- 35 GW for aperture=3 mm;
- 22 GW for aperture=2 mm;
- 10 GW for aperture=1 mm;
- Saturation length is around 17 m.

Optical Functions in Undulator region:

The Lattice is FODO

Average $\beta_{\text{ex}} \approx \beta_{\text{ey}} \approx 10 \text{ m}$

Calculation of wake function



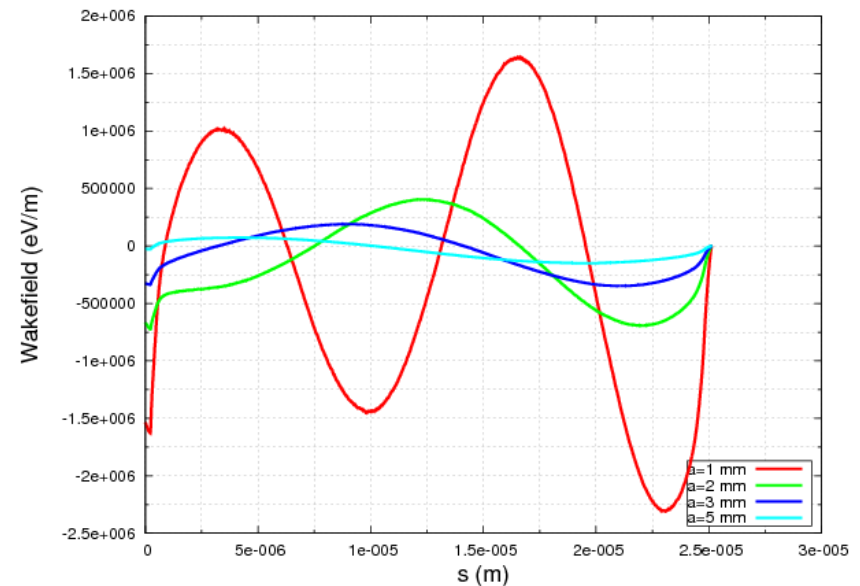
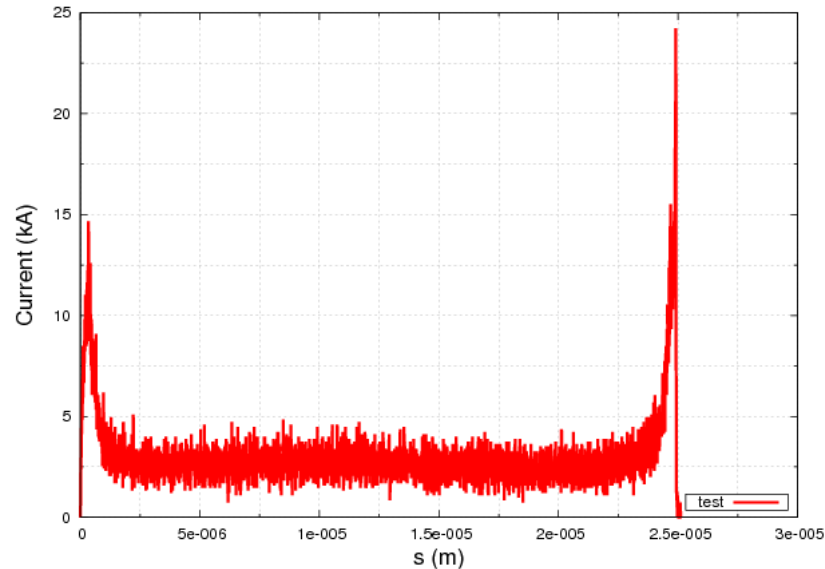
Single particle wake function inside the normal conducting undulator (Cu) for different aperture

the relative energy change induced within a bunch can be calculated by

$$\frac{\Delta E}{E}(s) = -\frac{r_e N L}{\gamma} \int_0^\infty W(s') \lambda_z(s - s') ds'$$

Genesis Simulation for a given bunch distribution with 6.18 GeV

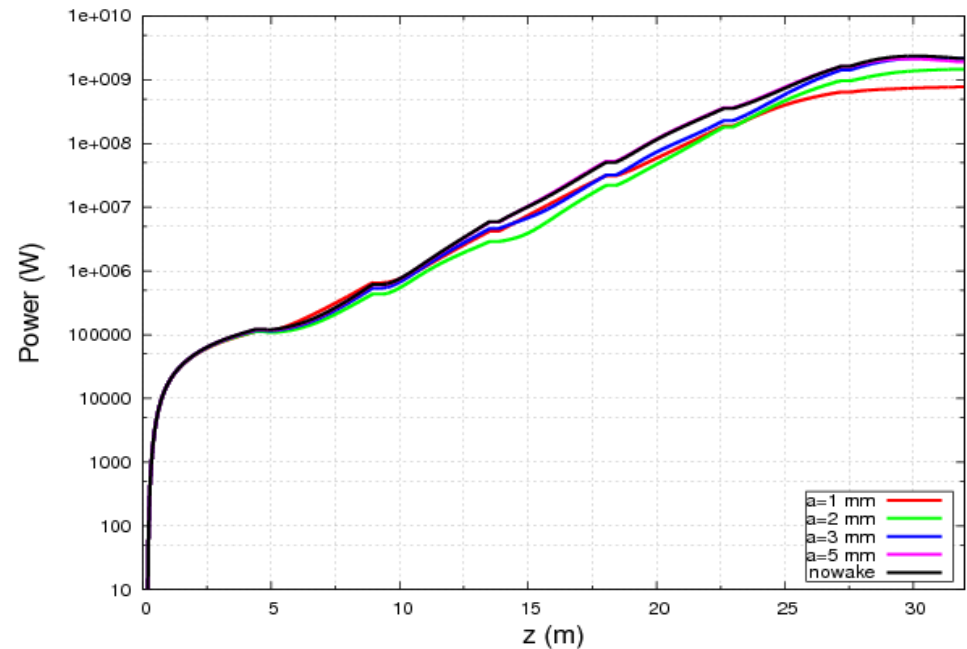
- The energy loss due to the resistive wakefield is calculated for an old beam distribution numerically by using Bane's formula is given above.



The distribution is from our past time simulations for 6.18 GeV electron beam. (2 years ago).
Our beam probably going to look likes this.

GENESIS Simulation result for 6.18 GeV beam

Parameter	Value
Energy (GeV)	6.18
Bunch length (μm)	25
Bunch Charge (pC)	250
Peak Current (A)	2600
Emittance (mm mrad)	0.5
Undulator Period (cm)	1.5
Undulator Parameter	1.41
Und. Length (m)	4.2
Rad. Wavelength (nm)	0.1



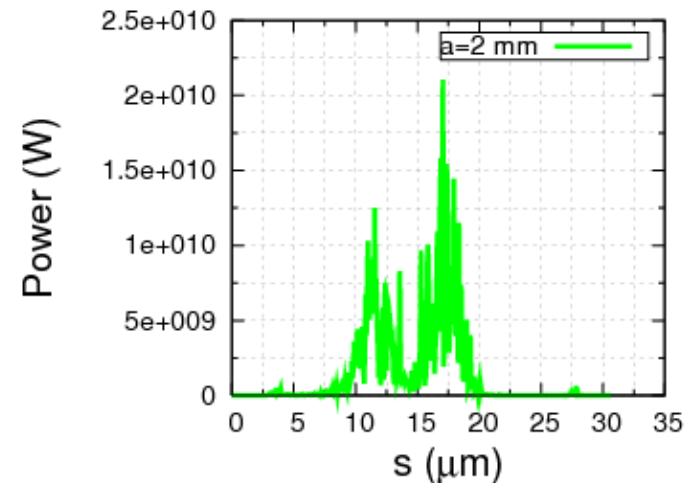
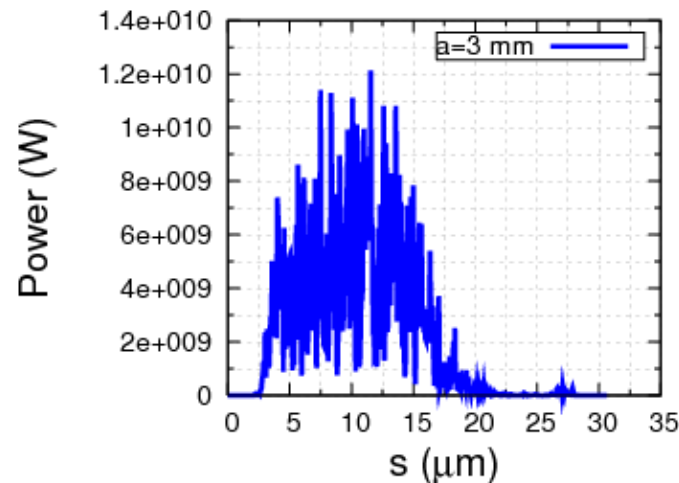
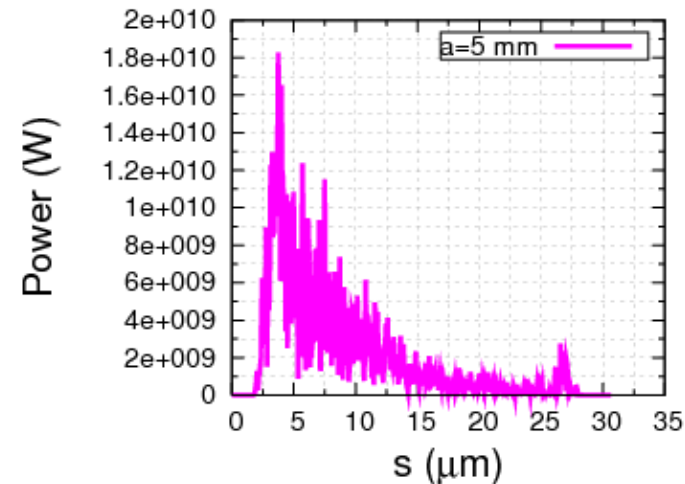
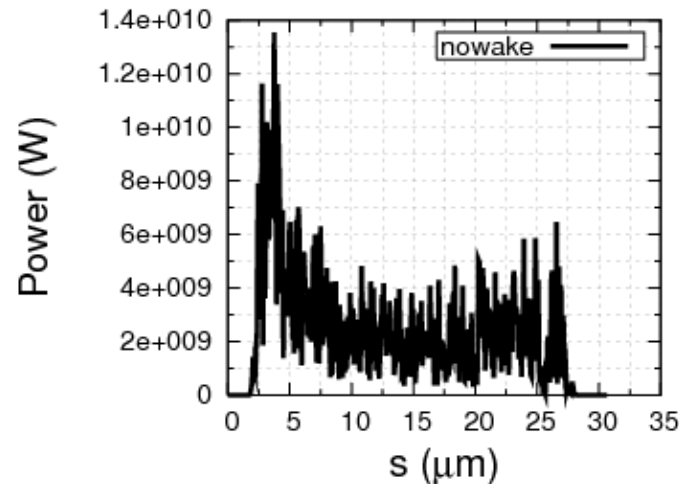
Evolution of power in undulator region for different apertures (Averaged over all pulse).

Spatial (temporal) profile of the radiation pulse

The spatial profile of pulses at saturation ($z=31\text{m}$)

The profile is disrupted at low apertures because of wake.

Tapering would be a solution and should be worked with simulations.



Conclusion

- The tools to simulate the resistive wakefield effect is ready.
- The effect of the wakefield to the FEL power become sensitive at lower energies.
- Surface wakefield effect also will be added to the simulations

Future Studies:

- The simulations and calculations will be repeated and detailed for new hard and soft x-FEL parameters.
- The effect of tapering also should be studied with simulations.
- The beam at last one layout should be simulated till undulator region and a beam distribution should be given for more realistic results.

Thank you!

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