LCLS-II Technical Note

Intra-beam Scattering in LCLS-II
LCLS-II TN-15-37

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IBS in LCLS-II beam

Intra-beam scattering leads to an increase of the beam energy spread when the beam propagates through the accelerator.
I use a simplified IBS theory developed in[1] (a similar approximation was used in[2]):

- *In the beam frame* the electron distribution function is characterized by the transverse temperatures T_x, T_y and $T_{\|}$. It is assumed that

$$T_{\|} \ll T_x, T_y \ll mc^2$$

  We will verify these conditions for the LCLS-II later.
- The dominant term (now in the lab frame) is diffusion over energy

$$\text{coll. term} = \frac{1}{2} D \frac{\partial^2 f}{\partial \Delta E^2}$$

  D has dimension of $\mathrm{keV}^2/\mathrm{m}$. This term should be added to the RHS of the Vlasov equation.

[1] G. Stupakov, *Effect of Coulomb collisions on Echo-Enabled Harmonic Generation*, FEL 2011, p. 49.
[2] Z.Huang, *Intrabeam Scattering in an X-ray FEL Driver*, Report LCLS-TN-02-08, SLAC (2002).

Coulomb scattering

- The diffusion coefficient actually varies in the phase space of the beam, but we average it over x, y, θ_x, θ_y assuming Gaussian distributions over angles and transverse coordinates and then it becomes a function of a slice in the beam, z, and the location in the lattice s: $D(z, s)$.
- Formula for D

$$D(z,s) = \frac{\pi^{1/2}\Lambda}{2\gamma\sqrt{\sigma_{\theta x}(s)\sigma_{\theta y}(s)}} \frac{(m_e c^2)^2 r_e}{\sigma_x(s)\sigma_y(s)} \frac{I(z)}{I_A}$$

Λ – Coulomb logarithm, $\Lambda \approx 8$

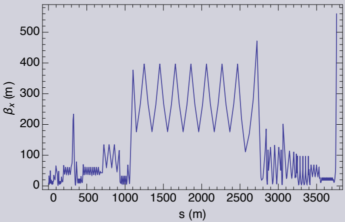
$I_A = 17$ kA

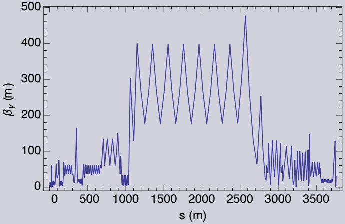
Relatively weak dependence on γ

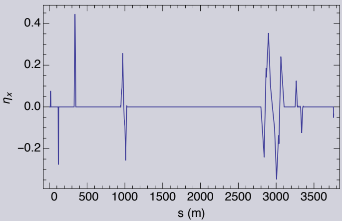
$$D \sim \frac{I}{\epsilon_N \sigma_\perp} \sim \frac{I\sqrt{\gamma}}{\epsilon_N^{3/2}\sqrt{\beta}}$$

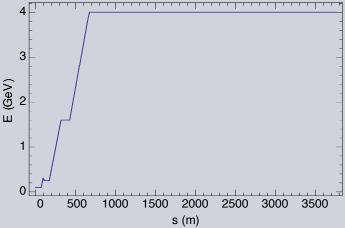
Lattice

The machine lattice "LCLS2sc (March 20, 2015)".







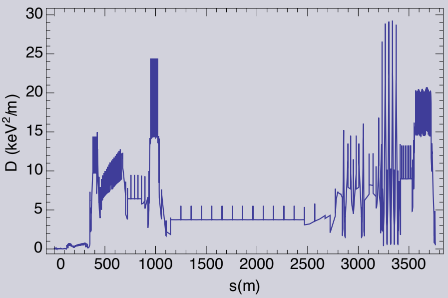


Beam parameters and lattice

Two bunch compressors with the compression factors $C_{BC1} = 5.6$ (located at $s = 124$ m) and $C_{BC2} = 9.6$ (located at $s = 352$ m).

The following beam parameters were used: $I = 1$ kA, $\epsilon_n = 0.45$ µm, initial energy spread $\sigma_E = 12$ keV. The beam current through the linac was calculated using the compression factors ($I \approx 104$ A between BC1 and BC2 and $I \approx 18.5$ A before BC1). This initial energy spread is amplified to the final value $\sigma_E = 646$ keV ($\sigma_E/E = 1.6 \times 10^{-4}$) at the end.

Dispersion was ignored in the calculations.

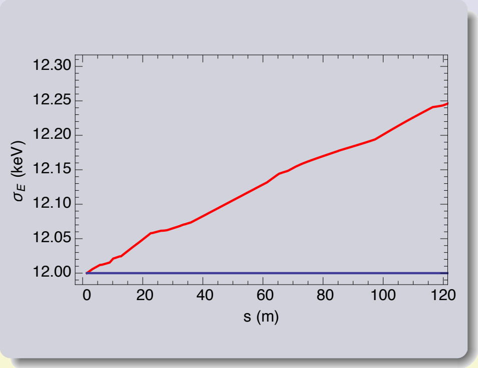


Calculation of σ_E

IBS adds to the beam energy spread in quadrature:

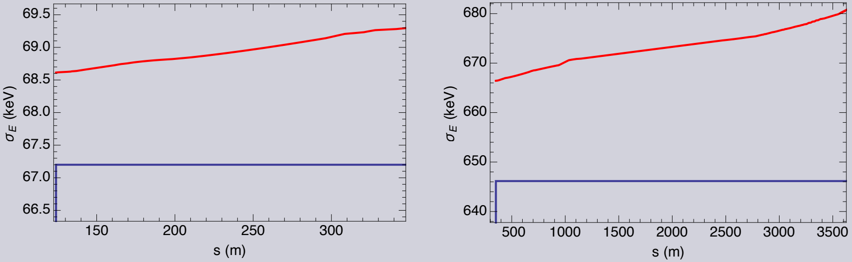
$$\frac{d\sigma_E(s)^2}{ds} = D(s)$$

This equation was integrated through the lattice with account of compression at BC1 and BC2.



Blue—σ_E without IBS, red—σ_E with IBS.

Calculation of σ_E

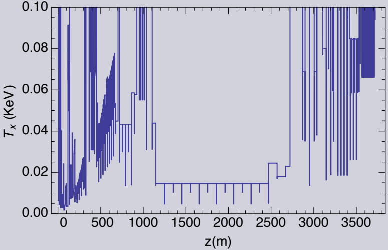


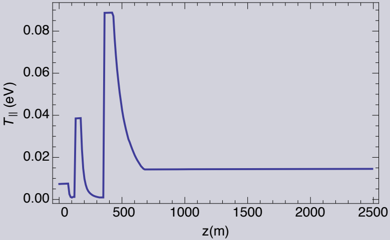
Due to the IBS the energy spread at the entrance to the undulator ($s = 3560$ m) is increased from 646 keV to 680 keV (5.2%).

Temperature in the beam frame

Show that $T_{\parallel} \ll T_x, T_y \ll mc^2$. The temperature is computed as

$$T_{x,y} = mc^2\gamma^2\sigma^2_{\theta x,\theta y}, \qquad T_{\parallel} = mc^2(\sigma_E/E)^2$$





$T_x, T_y < 15$ keV.