S2E Simulation of THz FEL at PITZ with Bunch Compressor

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Abstract: The PITZ accelerator comprises a radiofrequency photogun and an RF booster cavity, capable of generating electron beams with bunch charges of several nC and momenta of up to 22 MeV/c. To achieve higher beam current which is a key parameter for the single-pass high-gain THz FEL, bunch length compression using a four-dipole chicane installed upstream of the undulator has been studied. Using a gaussian photocathode laser, much higher beam current with flattop and spike-at-tail profiles has been obtained. In this poster, we report the strong seeding effects from the steep trailing edge of the current profile observed from Genesis simulations. The limited improvement of the radiation energy due to the longitudinal phase space smearing from strong short-range longitudinal space charge forces will also be discussed.

Ming-Xie Parameterization for THz SASE FEL

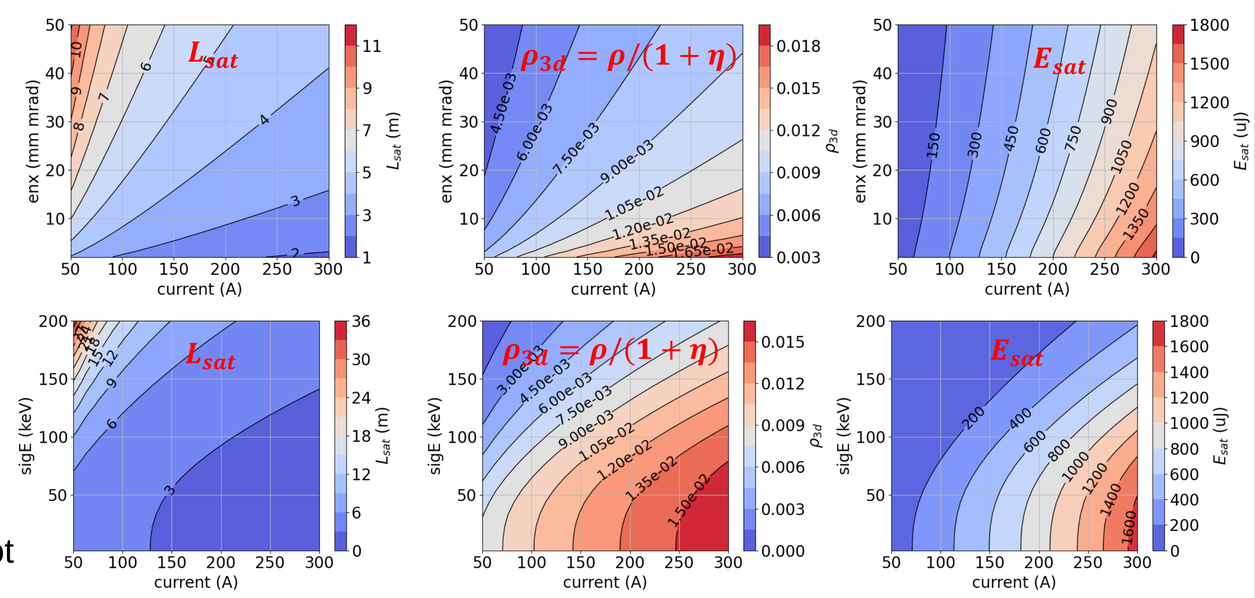
Beam and undulator parameters used in the scan:

- $E_{beam} = 16.7$ MeV, $\sigma_E = 50$ keV
- $\varepsilon_{xn} = 5\ um\ rad$, $\beta_{x,y} = 2$ m, $L_{beam} = 20\ ps$
- Planner undulator, $K = 3.49, \lambda_w = 30$ mm
- $\lambda_s = 100\ um$

$$L_{sat} = L_g \ln\left(\frac{P_{sat}}{\alpha P_n}\right)$$

$$\rho = \left[\left(\frac{I}{I_A}\right)\left(\frac{\lambda_w A_w}{2\pi\sigma_x}\right)^2\left(\frac{1}{2\gamma_0}\right)^3\right]^{1/3}$$

$$P_{sat} \approx 1.6\rho\left(\frac{L_{1d}}{L_g}\right)^2 P_{beam}$$



Results from scanning *beam current, emittance and energy spread* show that:

➢ For electron beam ε_{xn}~5 um rad, σ_E~50 KeV, I~100 A:

$$L_{sat}\sim 3.5\ m, \rho_{3d}\sim 0.01, E_{sat}\sim 300\ \mu J$$

➢The output radiation energy is much more sensitive to beam current, not so sensitive to beam emittance & energy spread => **Higher beam current from Bunch Compression !**

Bunch Compression for Gaussian Beam

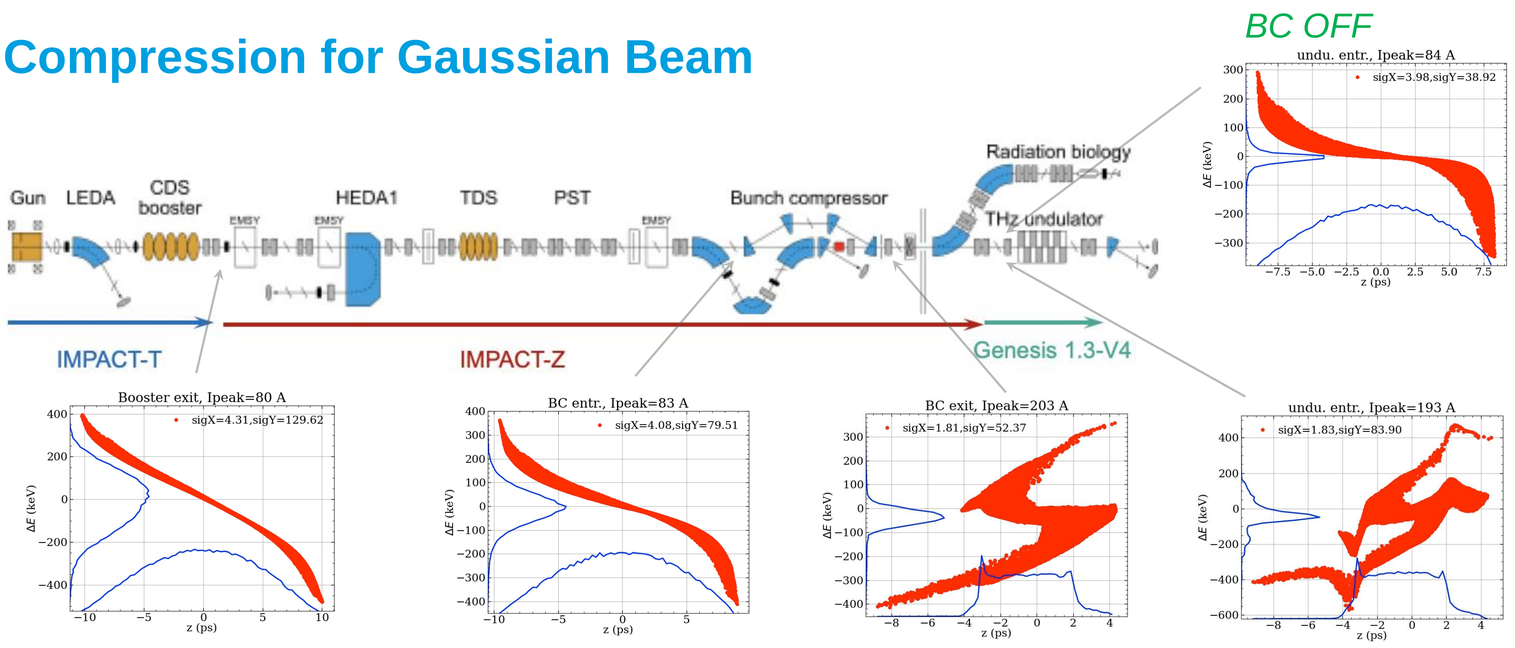
Settings for beam and chicane:

➢ Electron beam $Q = 1$ nC, $\sigma_{x,y} = 0.83$ mm (BSA = 3.5 mm), $\sigma_z = 2.97$ ps

➢ $R_{56} = 215$ mm (fixed for Chicane at PITZ), only booster phase is scanned:

beam core section $I = 84$ A $\rightarrow$ 170 A

Flattop & spike-at-tail current profile can be obtained (due to the s-shape energy chirp from LSC)



Genesis Simulation Results

Genesis simulation results show:

➢The gain curve for BC ON starts much faster than BC OFF

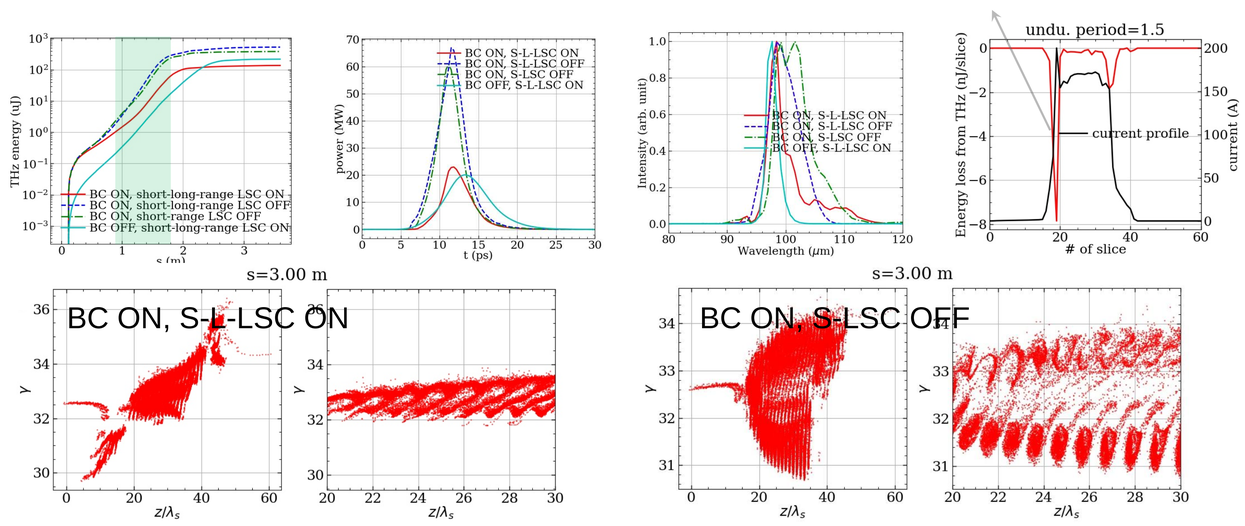
➢ However, the final THz energy is smaller than BC OFF

➢ Short-range LSC tends to smear out the micro-bunching structures when beam current is too high after bunch compression

➢ strong seeding from the sharp edge of current profile & peak at tail is observed in the simulation

➢ *For higher current, we need higher beam energy, or larger beam size inside the undulator to mitigate the S-LSC smearing effects!*

Strong seeding from current peak at tail



Summary

➢ THz SASE FEL is much more sensitive to beam current, not so sensitive to beam emittance & energy spread

➢ However, for higher beam current, the S-LSC will introduce strong phase space smearing effects => limited improvement from BC

➢ Flattop & spike-at-tail current profile can be obtained with BC for gaussian beam, strong seeding from the coherent radiation of the beam tail is observed in the Genesis simulation

References

[1] Xie, Ming, Proceedings Particle Accelerator Conference. Vol. 1. IEEE, 1995.
[2] McNeil et al., Optics communications 165.1-3 (1999): 65-70.
[3] Mikhail Krasilnikov et al., PHYSICAL REVIEW ACCELERATORS AND BEAMS 28, 030701 (2025)

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