Preliminary Simulation on Terahertz superradiation generation at PITZ

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Abstract

The photoinjector test facility at DESY in Zeuthen (PITZ) is developing a THz free electron laser using its high brightness electron beams. This poster presents a parameter study on the electron bunch for producing few-cycle high energy THz free electron lase (FEL) radiation and a start-to-end (S2E) simulation to explore the potential of generating required electron bunch using the current THz beamline.

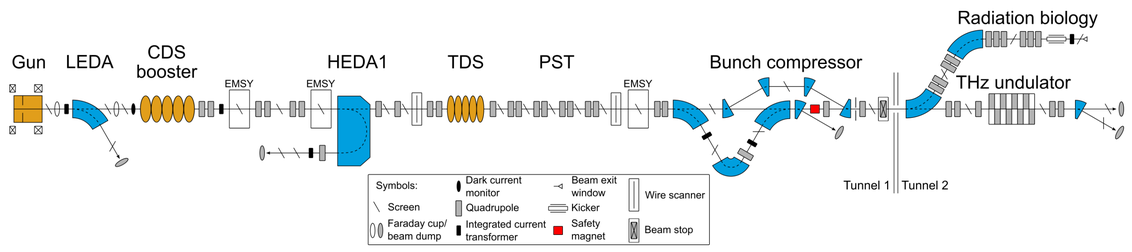

Fig. 1. PITZ beamline overview

Parameter study for short THz pulse generation

An ideal 6D-Gaussian distributed electron bunch and the current LCLS-I undulator at PITZ was used in the parameter study to find the requirement for the electron bunch at the entrance of undulator.

Table 1 shows the parameters of the 6-D Gaussian distributed electron bunch at the entrance of undulator. The FEL simulation was performed by GENESIS1.3 version 4 using the LCLS-I undulator and the result of THz pulse energy is shown in Fig. 2.

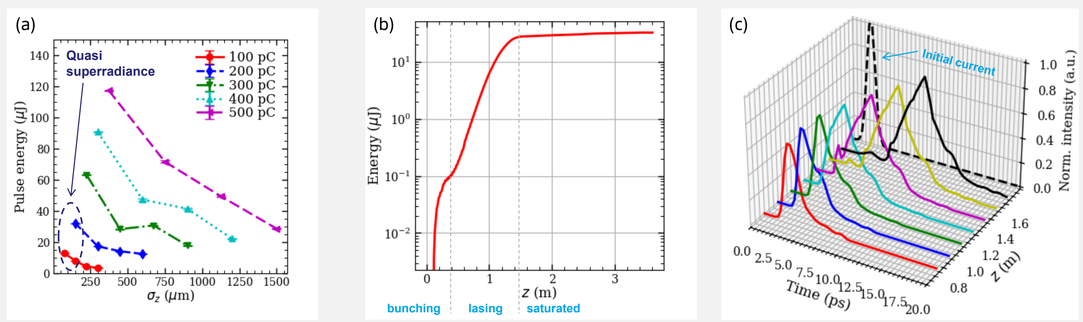

Fig. 2. Simulation results of pulse energy. (a) THz pulse energy vs. bunch charge and length; (b) Gain curve and (c) THz pulse temporal profile along the undulator for the case of 200 pC charge / 150 μm σ_z.

- bunch charge and length are critical for the energy of few-cycle THz FEL radiation.
- According to prev. studies of bunch compression at PITZ, 200 pC charge with 150 μm rms bunch length is possible and is considered in start-to-end simulations.
- 200-pC 150-μm case: The saturation length, THz pulse energy and FWHM are around 1.4 m, 30 μJ and 4.1 ps, respectively.

Table 1. Initial electron bunch parameters

α_x	10	β_x	17.5 m	ε_{xn}	2 μm
α_y	9.75	β_y	1.125 m	ε_{yn}	2 μm
$\sigma_{E,cor}$	-85 keV	$\sigma_{E,uncor}$	8.5 keV	p_z	17 MeV/c

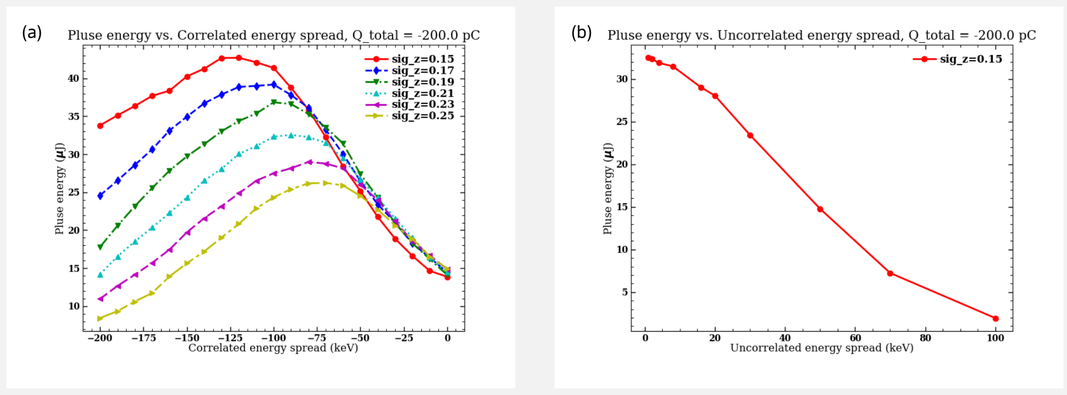

Fig. 3. Influence of correlated and uncorrelated energy spread on THz pulse energy.

- Figure 3 shows: for correlated energy spread, the optimal value depends on the bunch length; for uncorrelated energy spread, smaller values consistently yield better performance.
- A negative chirp ($\sigma_{E,cor}<0$) can help with keeping the bunch length in undulator, which increases due to strong longitudinal space charge, while uncorrelated energy spread is harmful for the bunching in undulator.

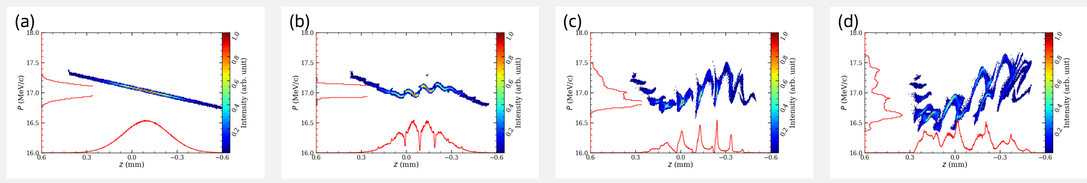

Fig. 4. Evolution of longitudinal phase space at different z position in undulator. (a) z=0; (b) z=0.6 m; (c) z=1.2 m; (d) z=1.8 m

S2E simulation for generating desired electron bunch

An S2E simulation was performed to generate the required electron bunch using the current PITZ beamline, with the photoinjector (gun & booster gradients and phases, solenoid fields) optimized by multi objective generic algorithm (MOGA) for minimizing bunch length and transversal emittance (Astra simulation). Then, the beam transport via the chicane to the undulator was simulated using ocelot.

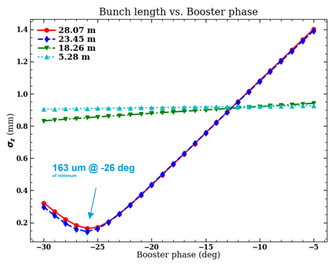

Fig. 5. Bunch length at different positions vs. booster phase

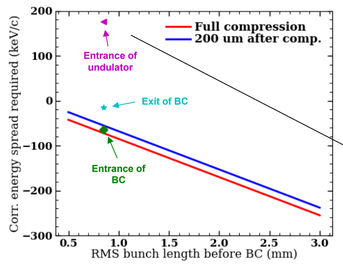

Fig. 6. Correlation of $\sigma_{E,cor}$ and rms bunch length for compression.

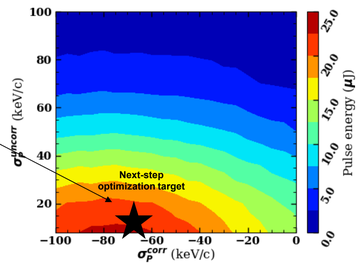

Fig. 7. THz pulse energy vs. $\sigma_{E,cor}$ and $\sigma_{E,uncor}$ for a 2.5 mm σ_z ideal Gaussian bunch.

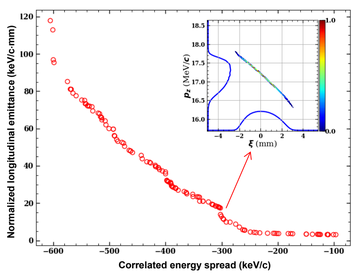

Fig. 8. MOGA result for $\sigma_{E,cor}$ and $\varepsilon_{z,n}$.

- Figure 6 shows the correlated energy spread continuously increases after the compression in the drift, flipping the longitudinal phase space at the undulator entrance.
- To reach the optimal work point in Fig. 7, more correlated energy spread should be introduced such that it remains negative at the undulator entrance.
- MOGA optimization result in Fig. 8 shows a strongly chirped linear longitudinal phase can be achieved from the photoinjector

Summary

The longitudinal space charge force was found critcial for the bunching process and can be „suppressed" by introducing a negative energy chirp to the short electron bunch:

- The photoinjector is being optimized for relatively large negative chirp;
- The bunch charge will be optimized to maximize the performance of the current beamline;
- The current work also suggests to apply the highest possible beam energy (up to 35 MeV) for the ideal machine design.