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Integrating Microbunching and Intrabeam Scattering into OCELOT

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DESY-STFC-XFEL Collaboration Meeting

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Motivations

High-brightness FELs rely on the understanding and mitigation of collective effects in order to achieve ultimate performance.

Two such effects that merit further study are:

- Microbunching instability (MBI);
- Intrabeam scattering (IBS).

A full understanding of these effects requires harmony between:

- Theory / semi-analytic calculations [1-3];
- Simulations [4-5];
- Measurements [6-8].

Many XFEL facilities could benefit from a systematic campaign of measurements and simulations to develop our understanding of these phenomena, and the interplay between them.

MBI

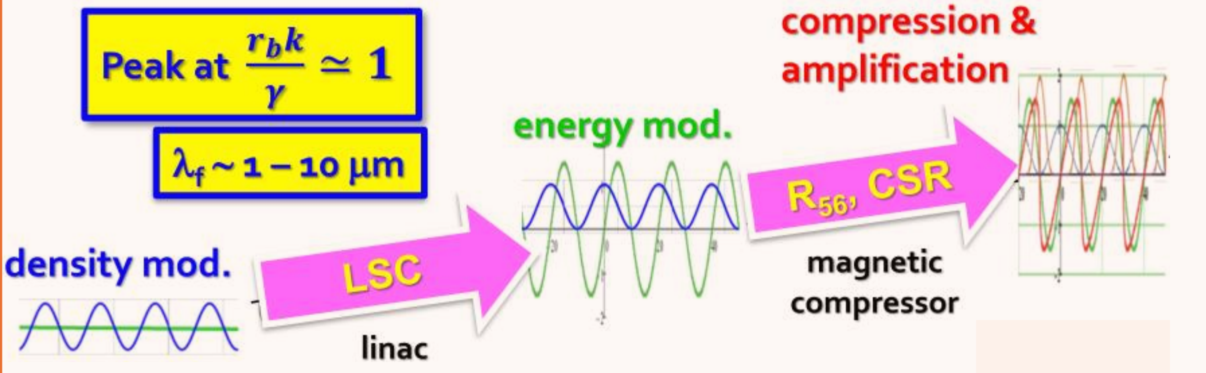


Figure from [9]

IBS

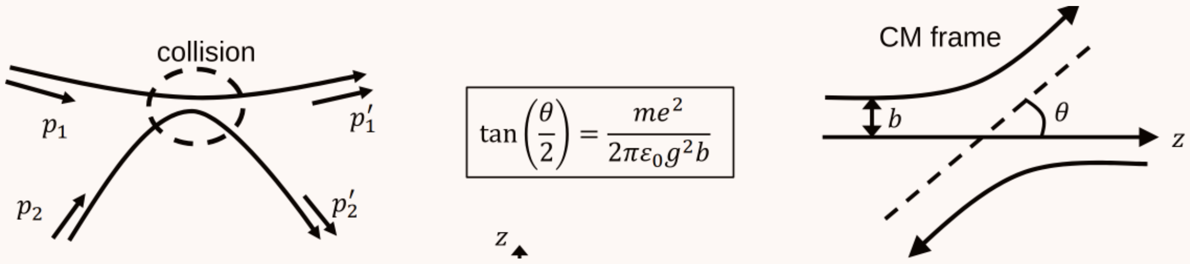
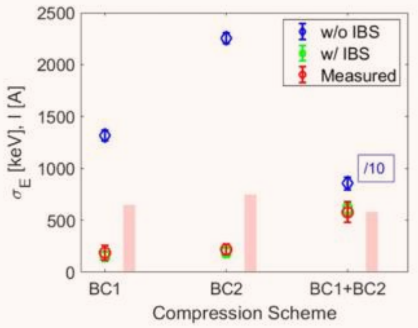
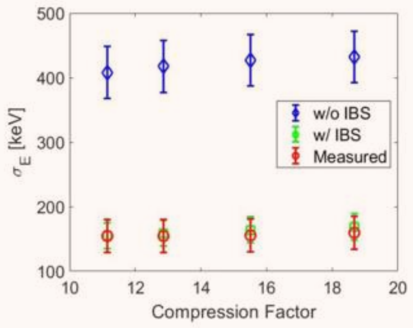


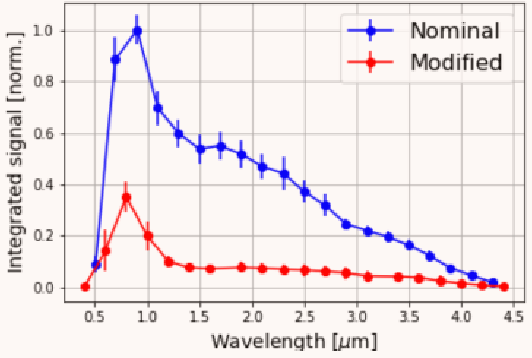
Figure from [10]

Previous Studies

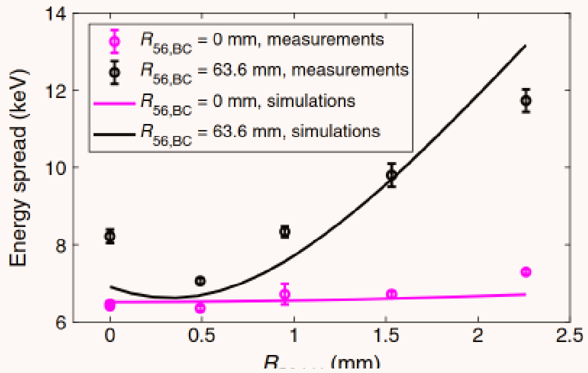
FERMI [11-12]

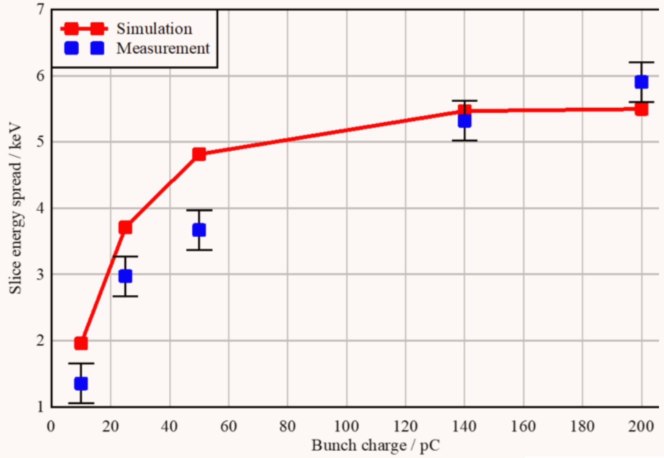






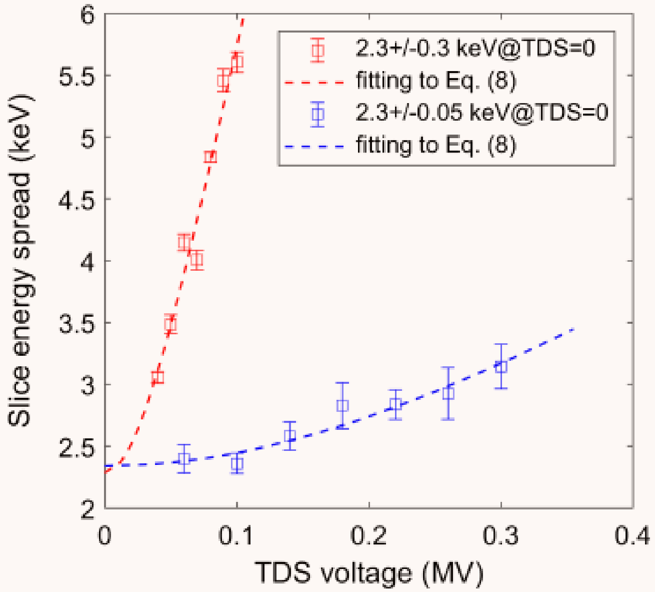
SwissFEL [10,13]





Furthermore, our evaluations indicate that standard tools to model electron beam sources, not covering the observed physics effects, are insufficient and that new approaches are required.

EU-XFEL / PITZ [14]



Our result demonstrates the expected low slice energy spread (~2 keV) from the Cs_2Te based photoinjector and indicates slice energy spread growth in the high energy photoinjector, e.g., intrabeam scattering, microbunching instability, which is worth further studies.

Implementation in OCELOT

Two new `PhysProc` classes have been added for MBI and IBS

IBS	IBS
For every `unit_step` along the beamline: • Calculate the bunching factor b_0 and the kernel of the integral equation K(t, s) (and the same in the energy plane) $$b(s) = b_0(s) + \int_0^s K(\tau, s) b(\tau) \mathrm{d}\tau$$ • This includes the LSC and CSR impedances, and Landau damping (beam and lattice properties). We can also use a realistic value of the uncorrelated slice energy spread – a fundamental improvement over post-hoc calculations as in [3]. Note: this `PhysProc` does not change the properties of the beam; it only calculates the bunching factor along the lattice.	For every `unit_step` along the beamline: • Calculate the increase in uncorrelated slice energy spread as a function of beam and lattice parameters. • Use the formalism of [15], which provides different formulae for IBS in drifts, dispersive regions, and linacs. • Apply a kick in energy to each particle in the bunch based on a Gaussian distribution Note: there are many assumptions built into the analytic theory of IBS, and investigating their limits will be complicated! This is a fundamentally simpler method of simulating IBS than full Monte-Carlo or particle-to-particle tracking, but may provide a more ‘realistic’ simulation for ultrarelativistic beams.

Initial Results

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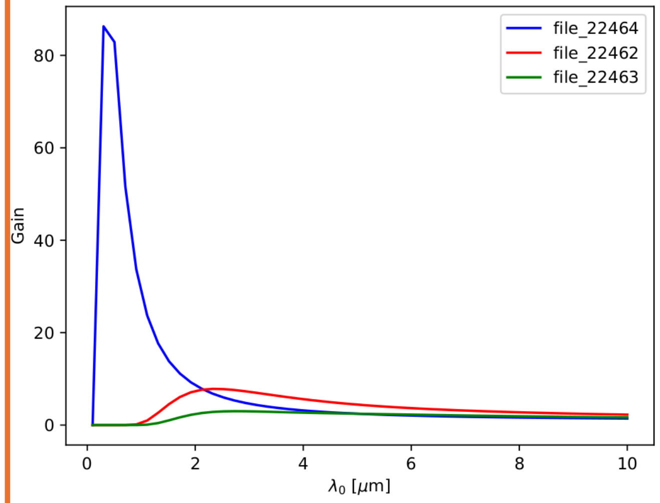
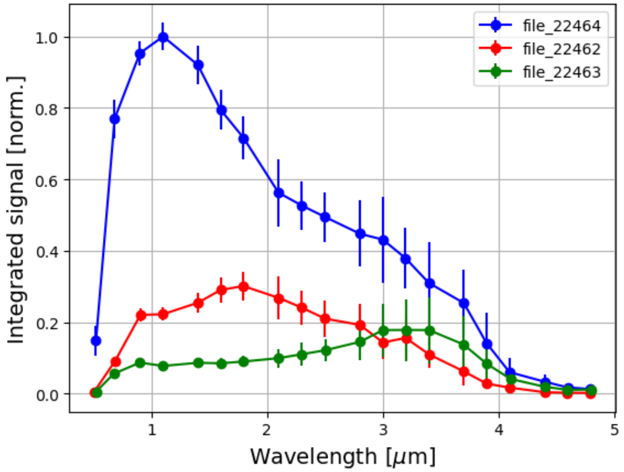
MBI



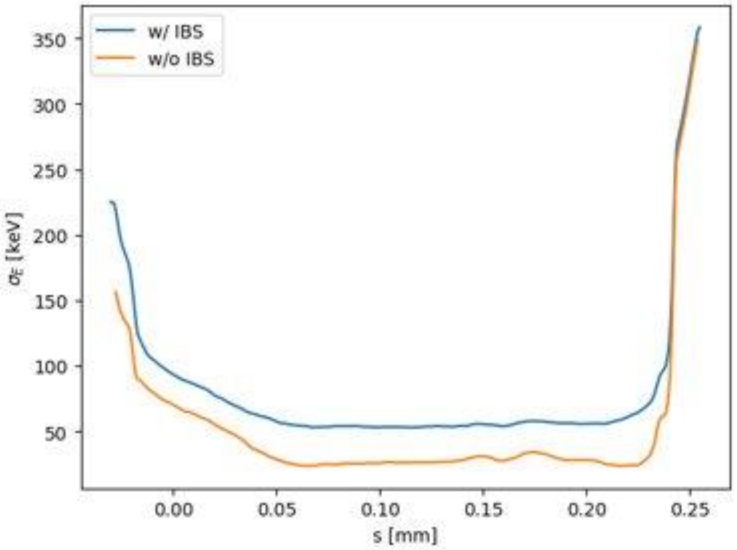


Simulated MBI gain through the FERMI spreader for different quadrupole settings in the dispersive regions

Measured IR spectrum for the same settings

Recent studies (last week) of the FERMI FEL performance have allowed some comparisons between the MBI gain simulated with OCELOT and the measured longitudinal modulations in the beam as a function of lattice optics.

IBS



Effect of IBS on the slice energy spread at the end of the FERMI linac.

This is just a first-pass test, and more work is to be done to confirm the validity of the model!

Comparisons between simulations and measurements are needed!

References

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