Simulations of seeded THz FEL at PITZ

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HELMHOLTZ

DESY.

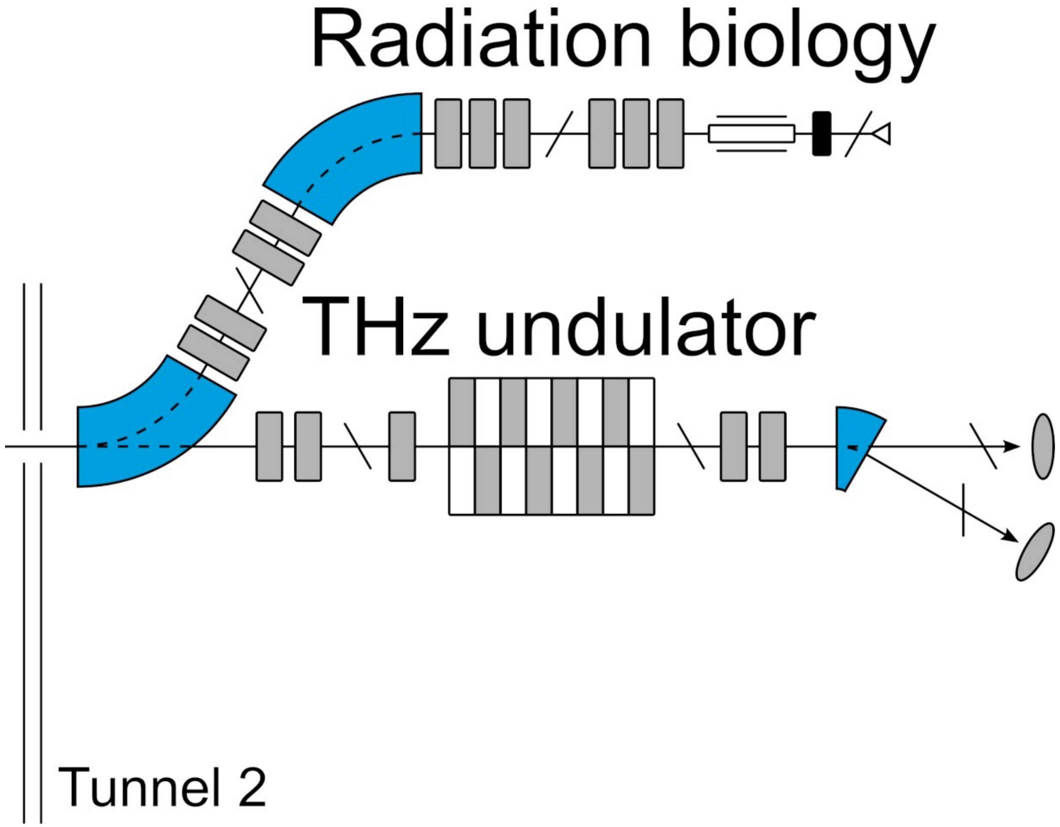
Introduction

- Ideal THz source for pump-probe experiments
  - High power
  - High repetition-rate
  - Tunable
  - CEP stable

⇨ **SASE FEL** (High power, High repetition-rate, Tunable)

⇨ **Seeded FEL** (CEP stable)

- CEP stability → stable pulse + stable phase
  - Difficult to achieve



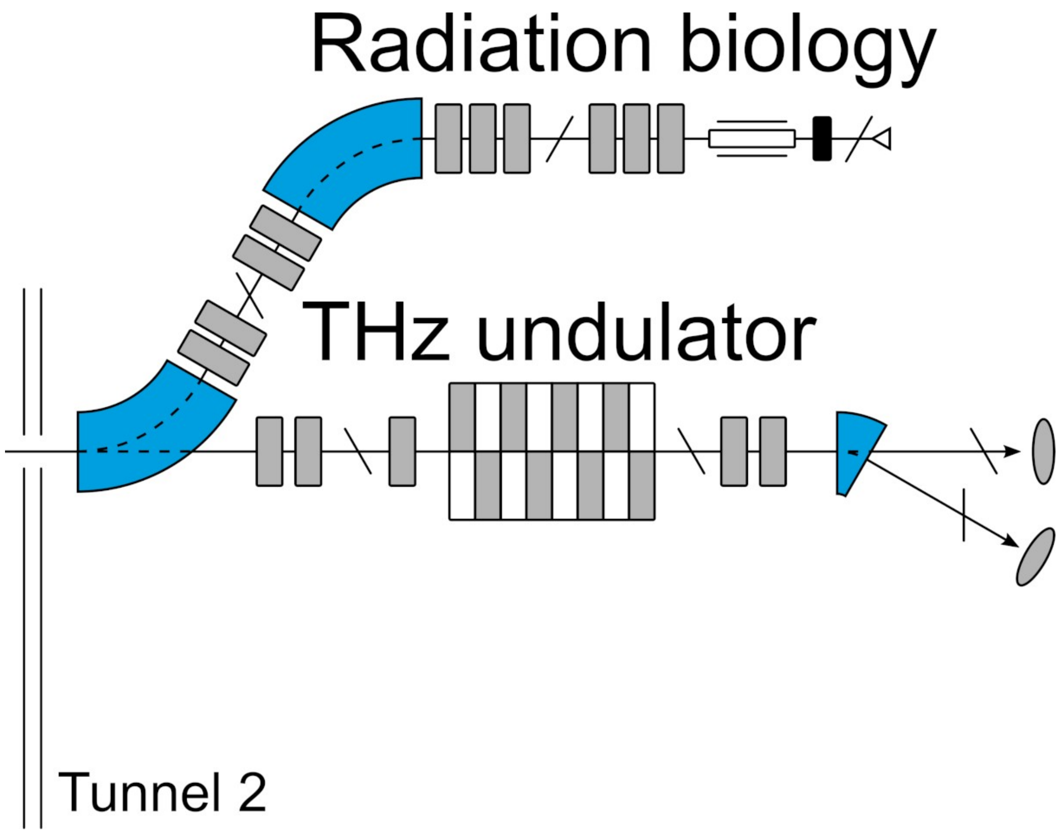
Introduction

- Ideal THz source for pump-probe experiments
  - High power
  - High repetition-rate
  - Tunable
  - CEP stable

→ **SASE FEL** (High power, High repetition-rate, Tunable)

CEP stable ⇨ **Seeded FEL**

- CEP stability → stable pulse + stable phase
  - Difficult to achieve
- Improved shot-to-shot stability
  - Energy variation
  - Arrival time jitter
  - Spectrum

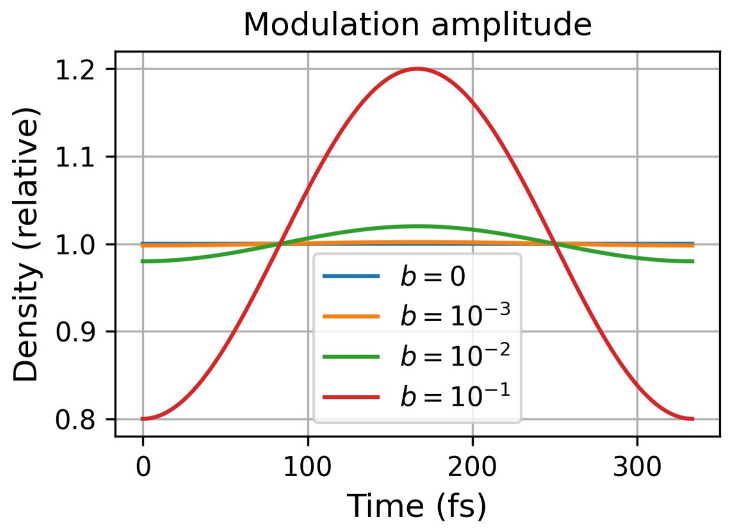


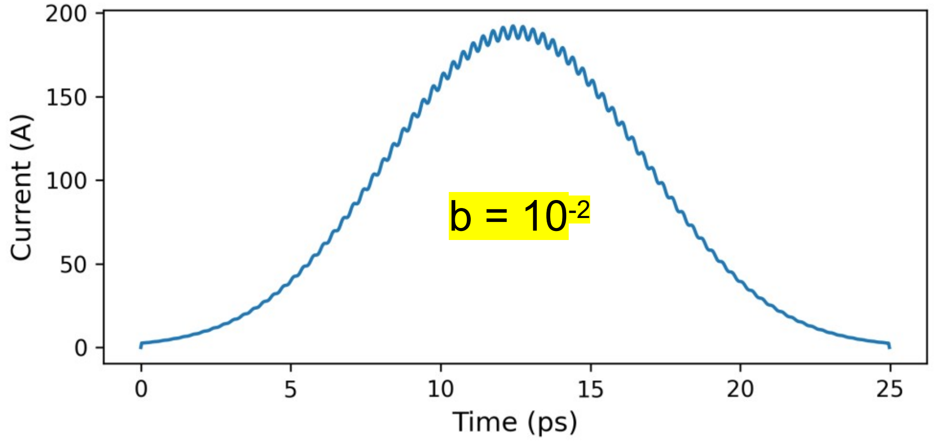
Seeding by pre-bunched beam

Introduction

- Single LCLS-I undulator
- Considered seeding methods at PITZ
  - Seeding laser
  - **Pre-bunched beam** (with experiments)
  - Short spike in beam current
- Modulated photocathode laser pulse
  - Temporal modulation at sub-THz frequency
  - Beam evolution with space-charge forces
  - More from beam dynamics simulations

$$b = \frac{1}{N_e} \left| \sum_{k=1}^{N_e} \mathrm{e}^{-i\omega t_k} \right|$$

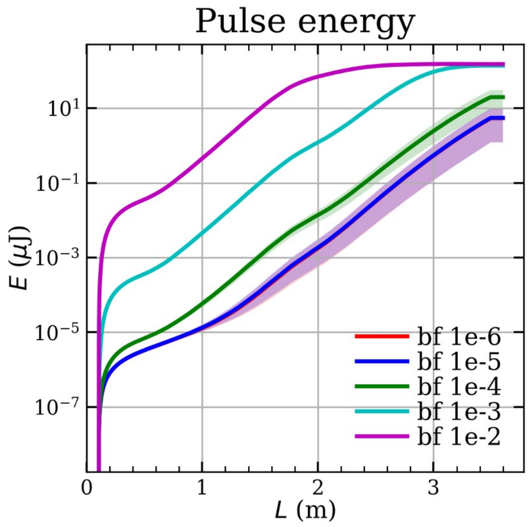




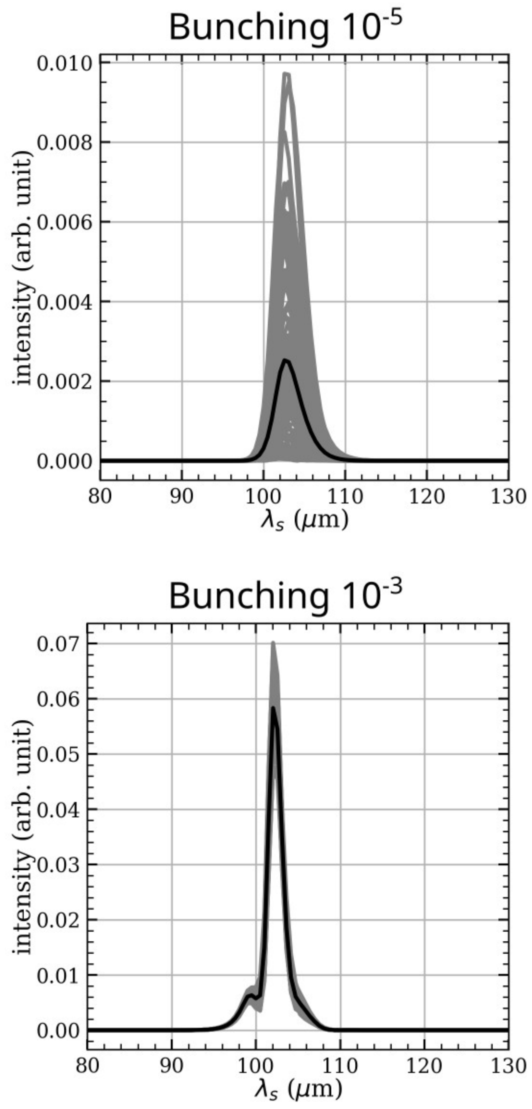
Seeding by pre-bunched beam

Seeding effect

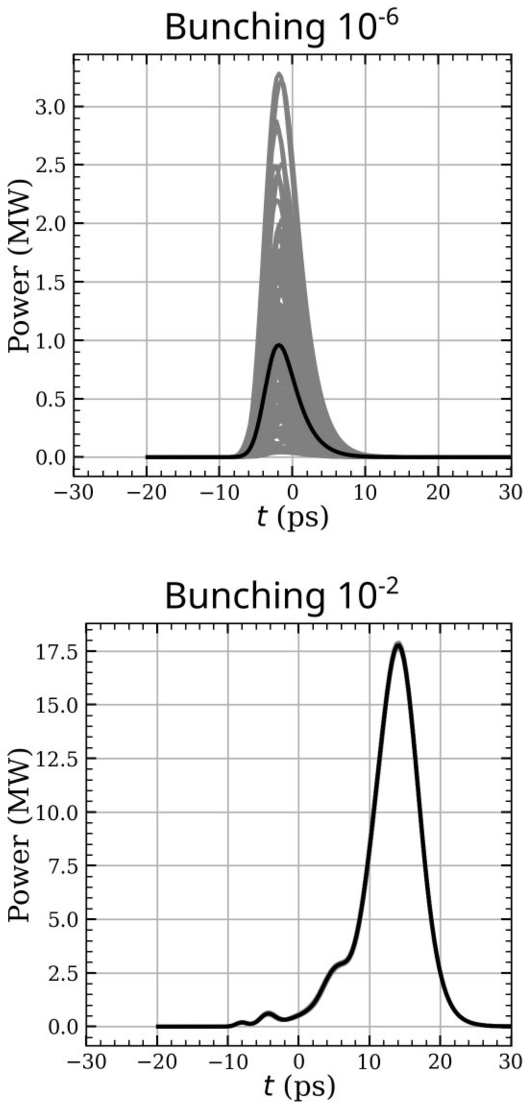
- Gray lines → 100 shots
- Black line → average
- Seeding effect
  - Stable envelope
  - Stable spectrum
  - Early exponential growth and saturation



Spectrum

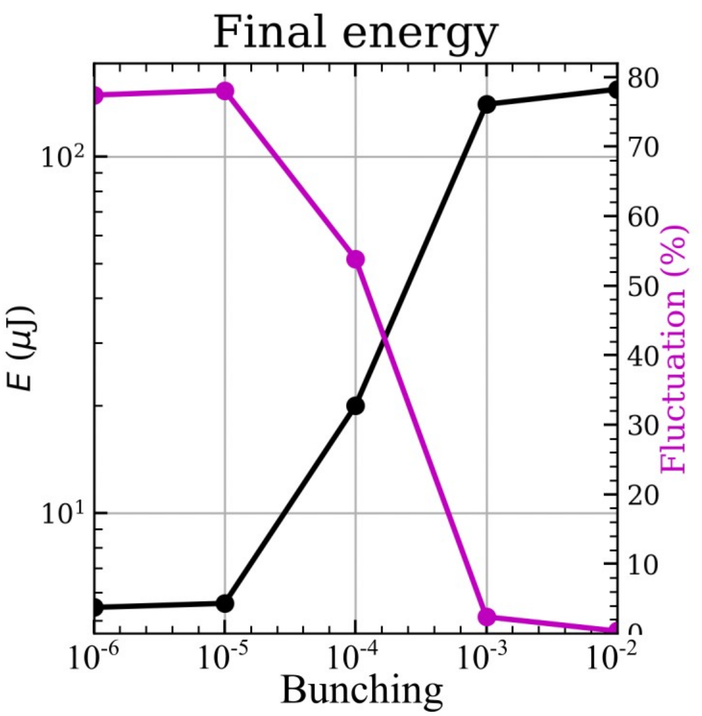


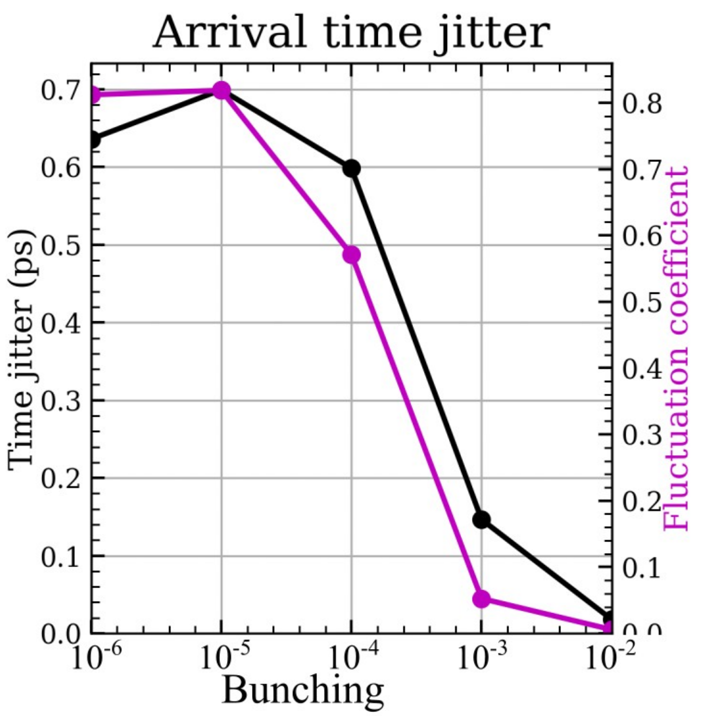
Envelope

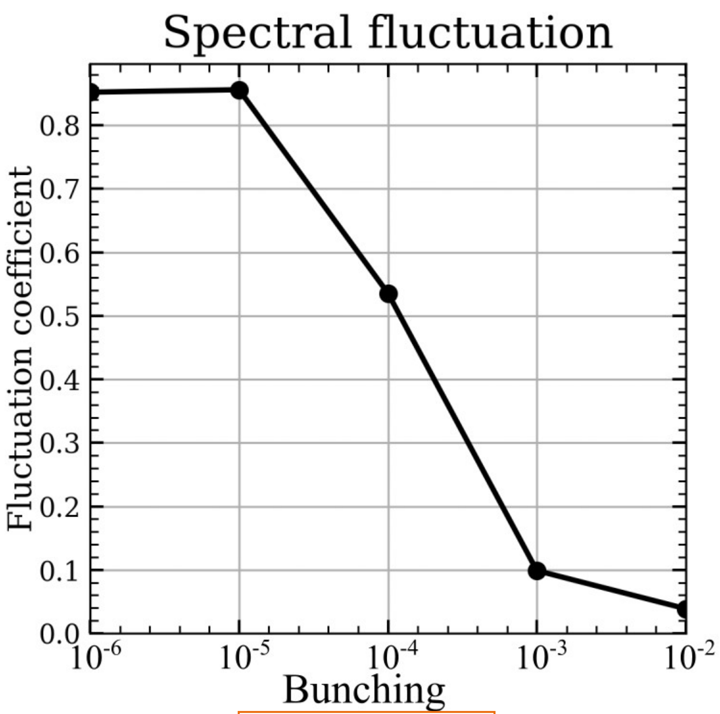


Seeding by pre-bunched beam

Overview







$$\Delta_s = \frac{\sum \sigma_i}{\sum a_j}$$

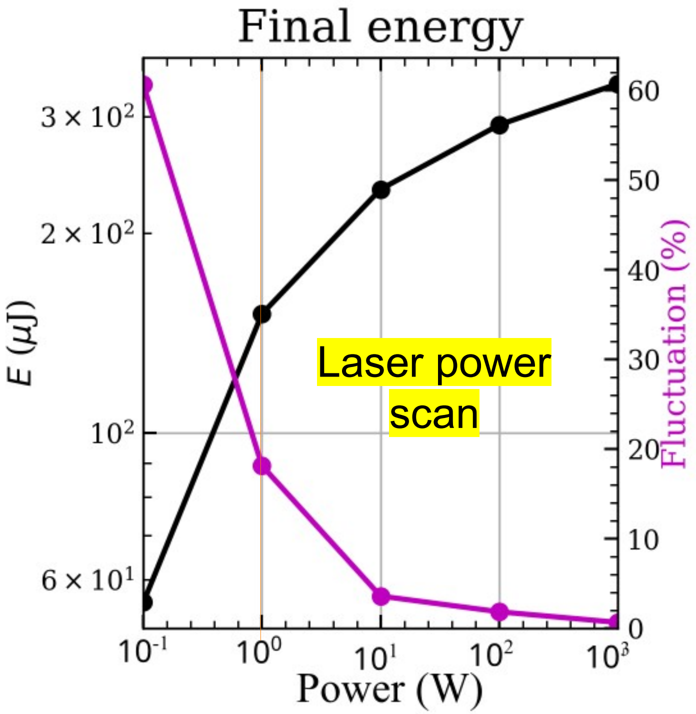
Other seeding methods

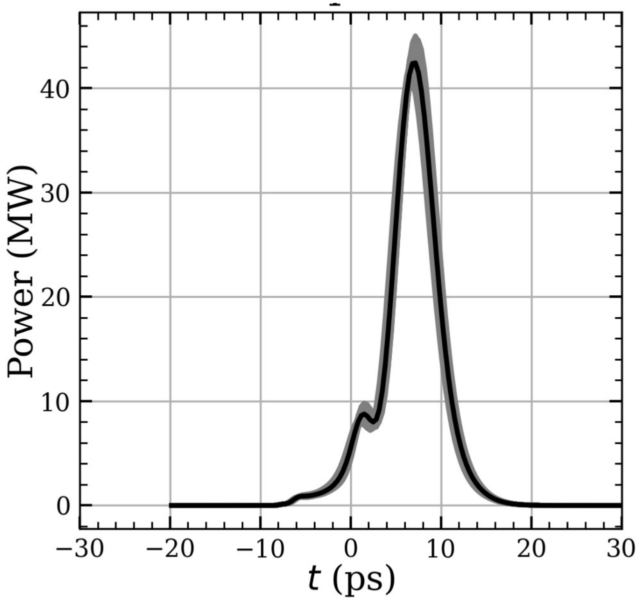
Seeding laser and short spike

- External coherent pulse copropagating
- Single super-radiant spike on top
- Seeding effect
  - Similar trends as with pre-bunched beam
  - Gain curve, arrival jitter, spectrum

Summary of seeded FEL simulations

- Significantly better shot-to-shot stability over SASE regime
- No seeding below b=10^{-5}
- Efficient seeding above b=10^{-3}



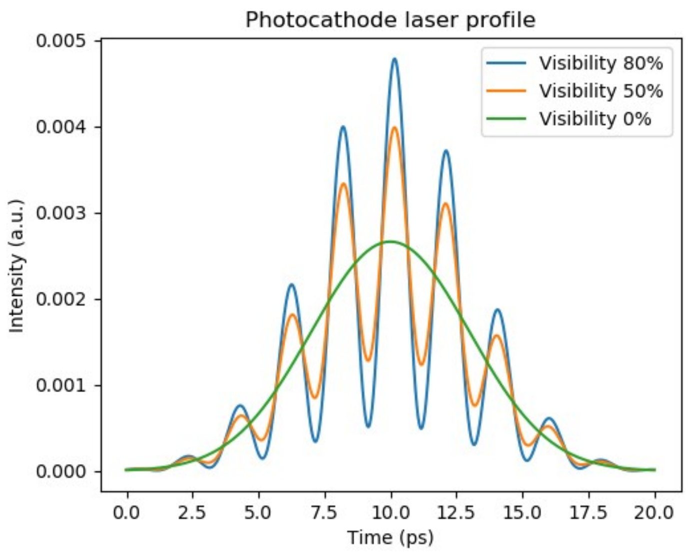


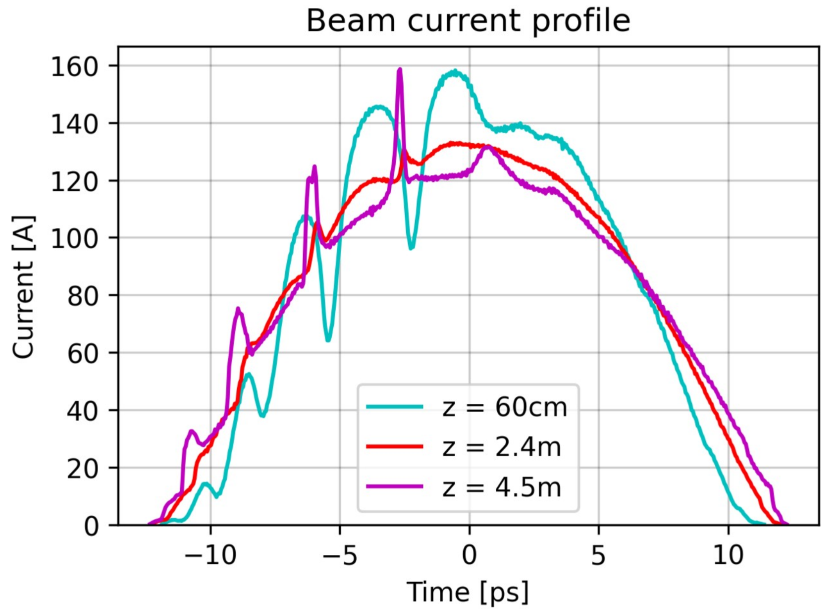
Beam dynamics and experiment

Beam dynamics simulations

Non-linear space-charge effects

- Modulated long Gaussian
  - Modulation visibility 80%
  - Main goal → high bunching factor
- Non-linear space-charge oscillations
  - Higher-harmonics appear
  - **Development of short spikes**

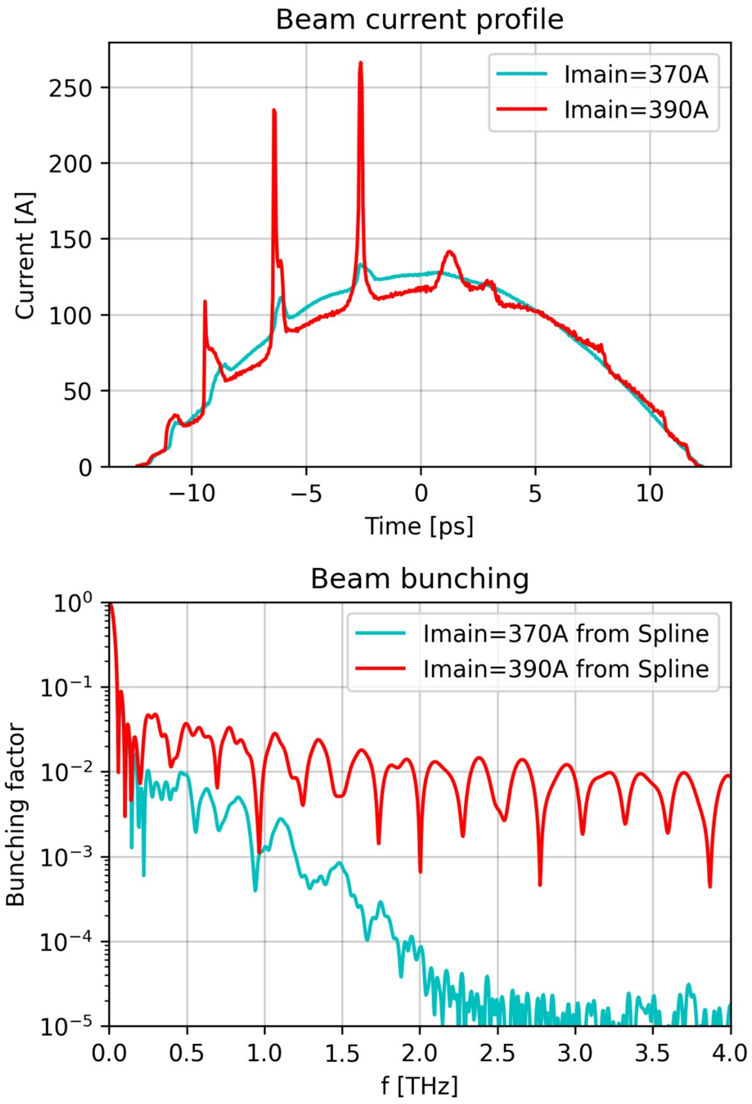




Beam dynamics simulations

Fourier analysis

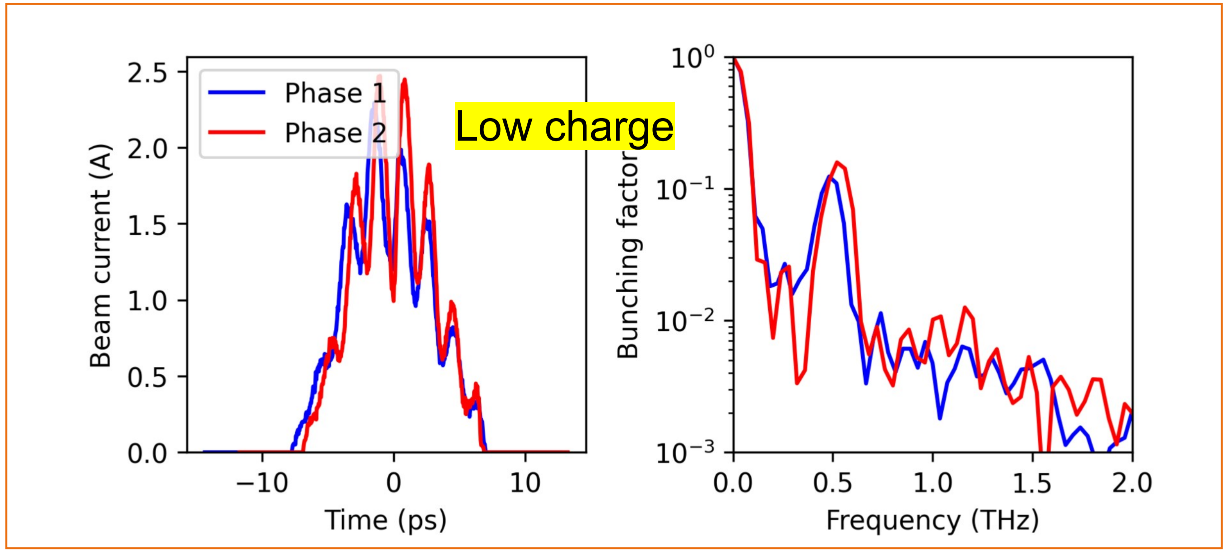
- Modulated long Gaussian
  - Modulation visibility 80%
  - Main goal → high bunching factor
- Non-linear space-charge oscillations
  - Higher-harmonics appear
  - **Development of short spikes**
- Strong focusing near the photocathode
  - Prominent short spikes
  - Bunching at high frequencies
  - Difficulties in matching to undulator (limit)

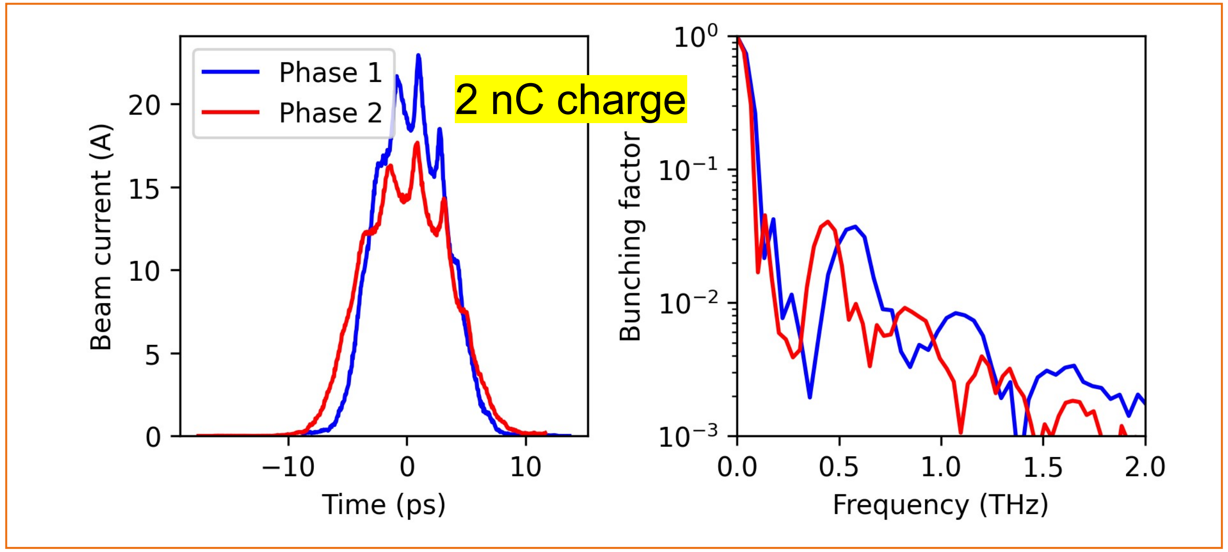


Experiment

Beam preparation

- Modulated photocathode laser at 0.5 THz
- Prepared beam for non-linear SC effects
- Limited improvement of bunching

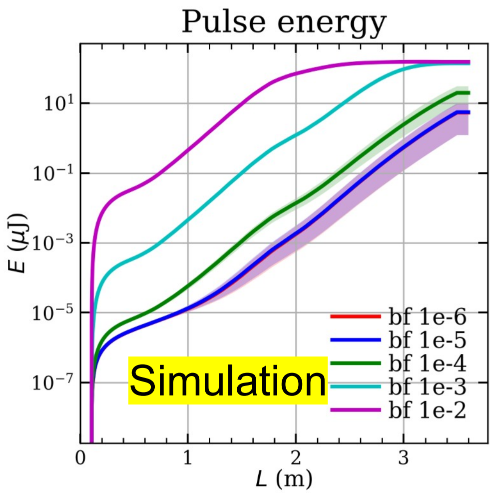


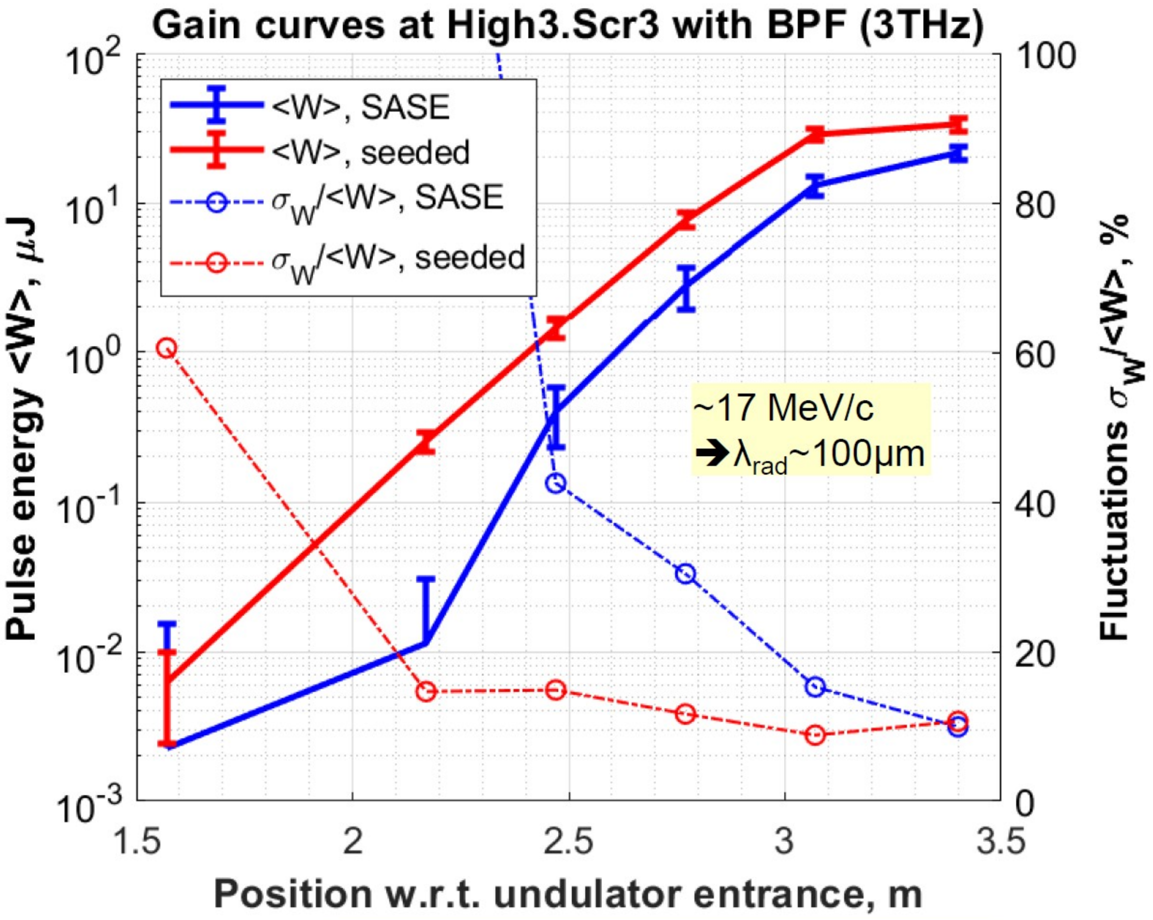


Experiment

With band-pass filter

- Modulated photocathode laser at 0.5 THz
- Prepared beam for non-linear SC effects
- Limited improvement of bunching
- Experiment with an undulator
  - Earlier exponential growth
  - Improved pulse energy and fluctuation
- Low bunching





Summary

- Seeding improves shot-to-shot stability in simulation
- Bunching factor of 10^{-3} and above for pre-bunched
- Seeding effect confirmed experimentally
  - Low bunching → low effect
- Few seeding methods available

Thank you