Showcase of idealized seeding methods for THz LCLS-I

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HELMHOLTZ

PITZ Photo Injector Test Facility Zeuthen

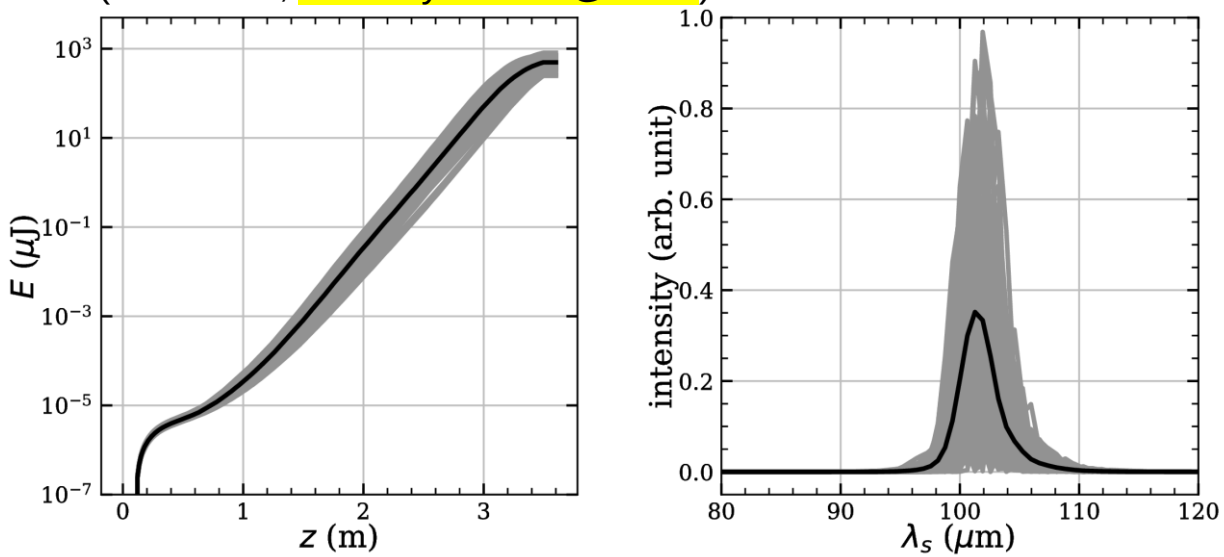
DESY.

Introduction

- Accelerator-based THz source
  - Pump-probe experiments at Eu-XFEL
- Free-electron laser
  - High power & tunable
  - Unstable shot-to-shot performance (SASE)
- Seeding – introduction of coherent signal
  - FEL as amplifier – seed determines final radiation

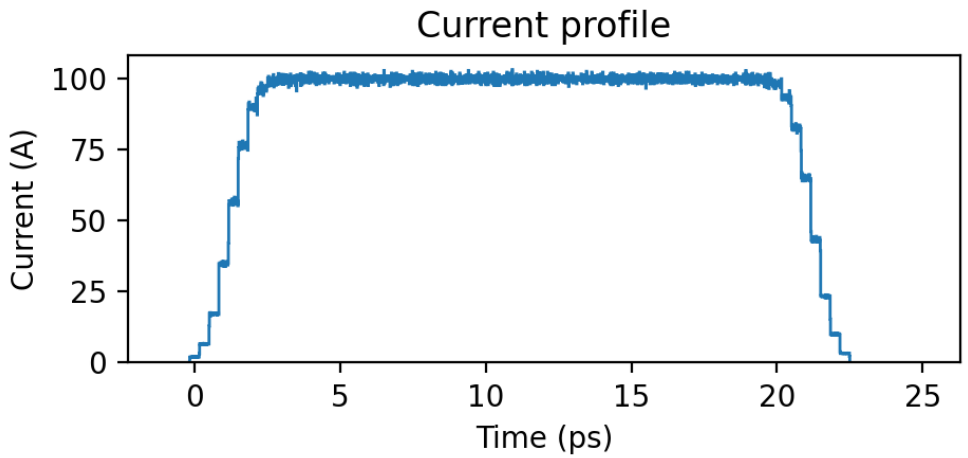
- SASE performance (2 nC, details on next slide)
  - Low FEL efficiency
  - Shot-to-shot energy deviation of 86%
  - Arrival time jitter of 1.6 ps

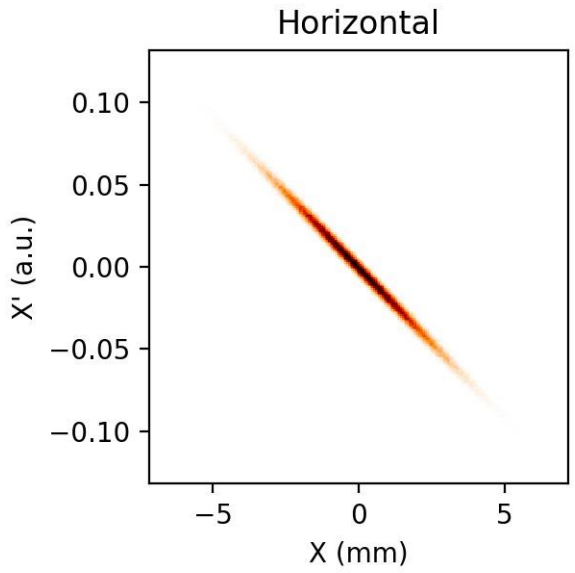
General example: pulse energy along undulator and final spectrum (simulation, courtesy X.K. Li @ PITZ)

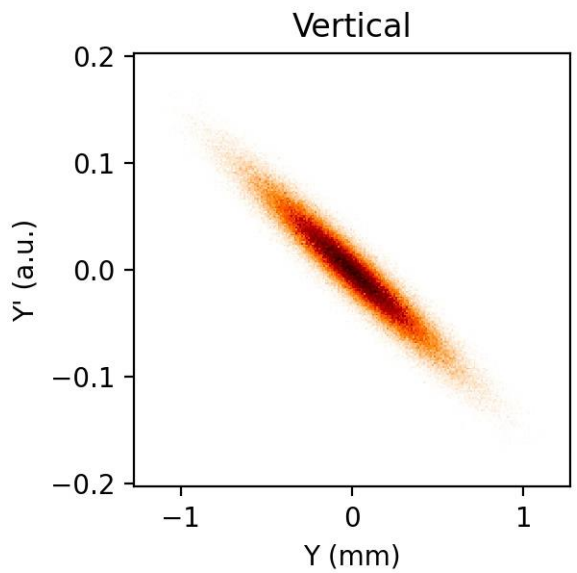


Simulation setup

- Performed with Genesis v2
- Beam current - 100 A for 20 ps (2 nC)
  - Quiet loading – reduce noise at **resonant frequency**
- Transverse emittance - 4.0 mm mrad
- Beam momentum – 17 MeV/c (gamma=33.4)
  - 3.0 THz resonant frequency
  - 0.5 % uncorrelated energy spread
- Longitudinal space charge forces included
  - **Previous sims with Genesis v4 have no SC!**
- Macro particles – 8192 per wavelength

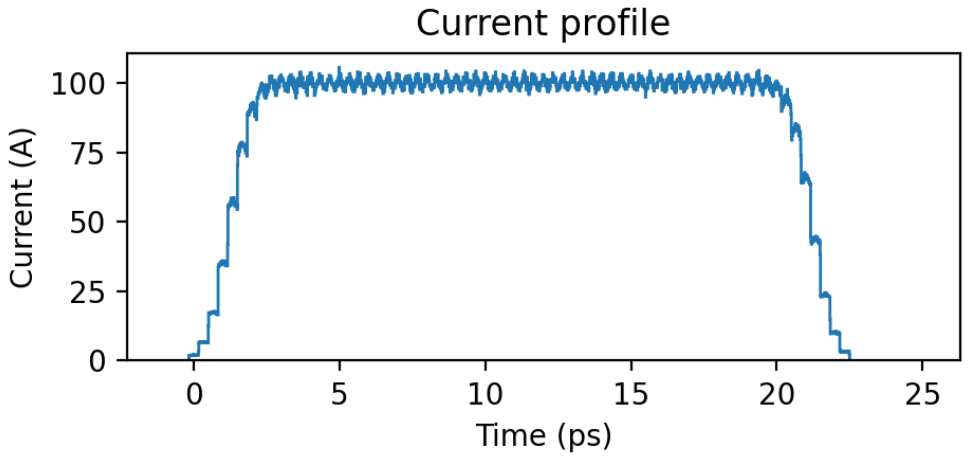


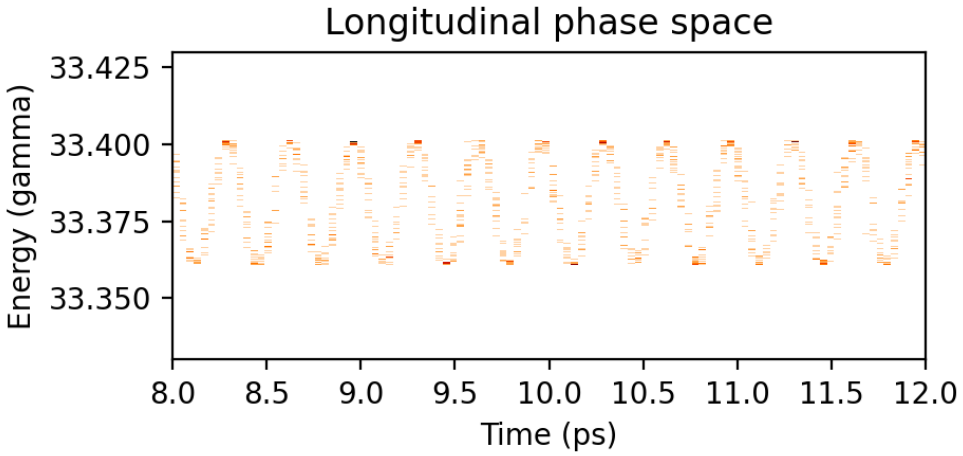




Four seeding options

- Laser seeded FEL
  - Seed signal is radiation from external source
  - Main parameter is power
- Pre-bunched beam
  - Seed signal is initial microbunching of the beam
  - Main parameter is bunching factor
- Energy modulated beam
  - Seed signal is periodic long. energy modulation
  - Main parameter is modulation amplitude
- Short seeding spike
  - Super-radiant spike emits coherent radiation
  - Old results only, few parameters to tune

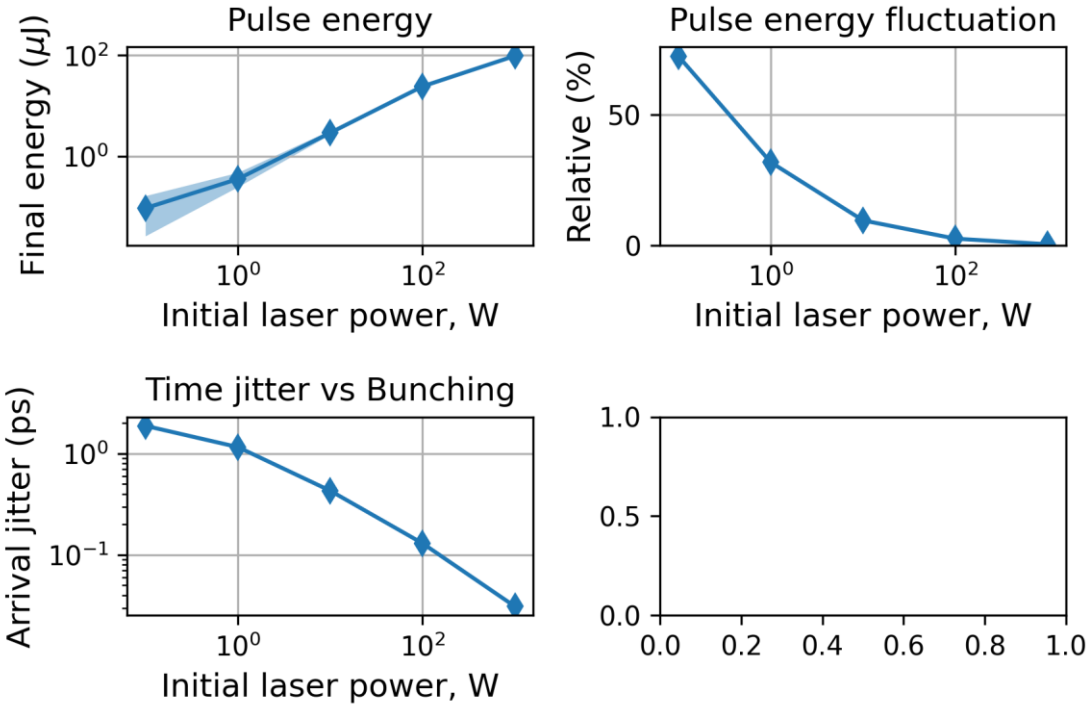




Laser seeded FEL

Seed signal is radiation from external source

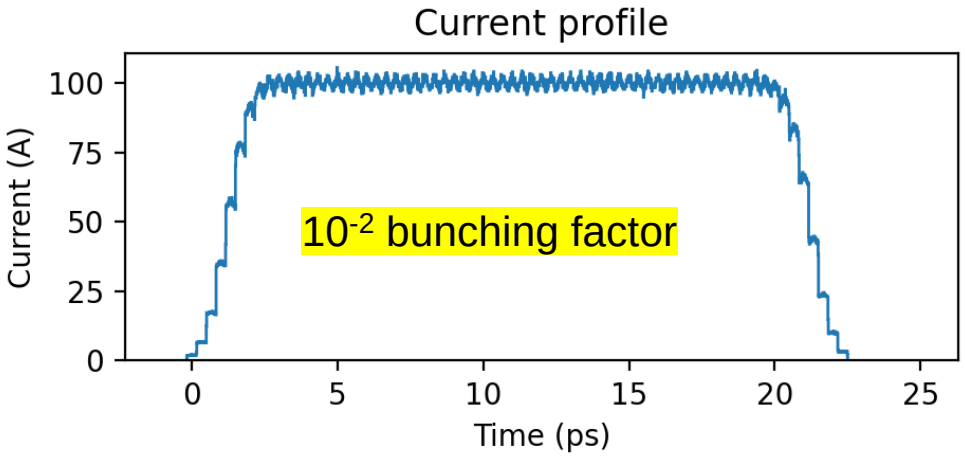
- Seeding effect of the method
  - Improved efficiency – final radiation energy
  - Reduction of shot-to-shot energy fluctuation
  - Orders of magnitude lower time jitter
- Effect monotonously increases with power

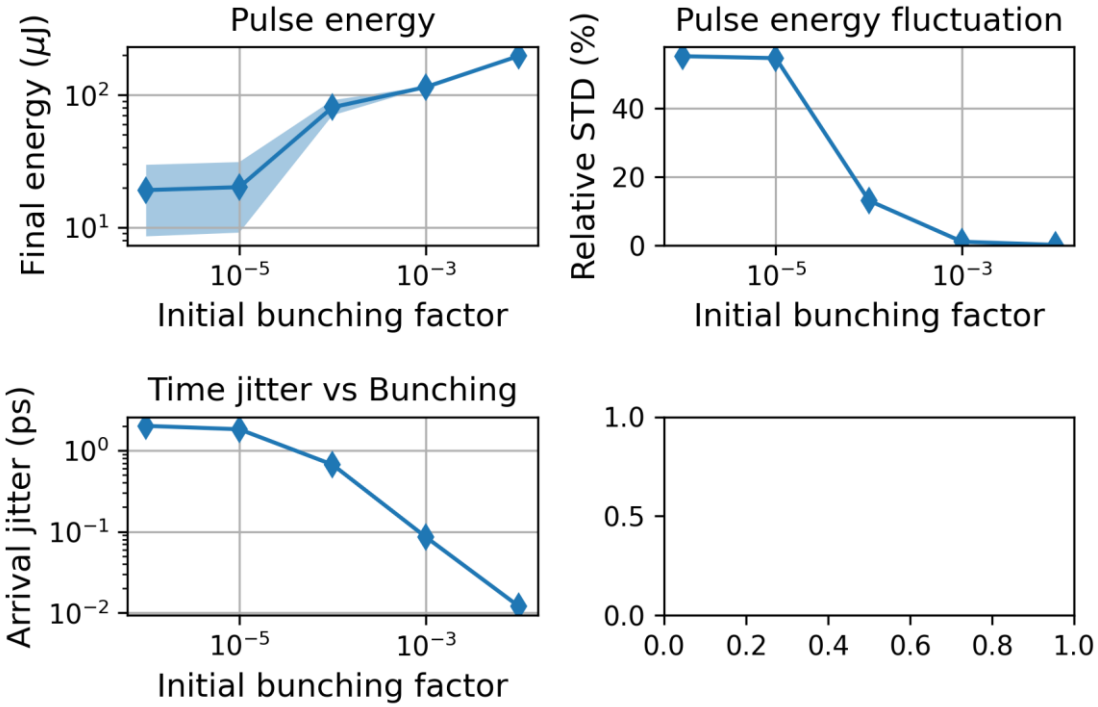


Pre-bunched beam

Seed signal is initial microbunching of the beam

- Seeding effect of the method
  - Improved efficiency – final radiation energy
  - Reduction of shot-to-shot energy fluctuation
  - Orders of magnitude lower time jitter
- Effect monotonously increases with bunching

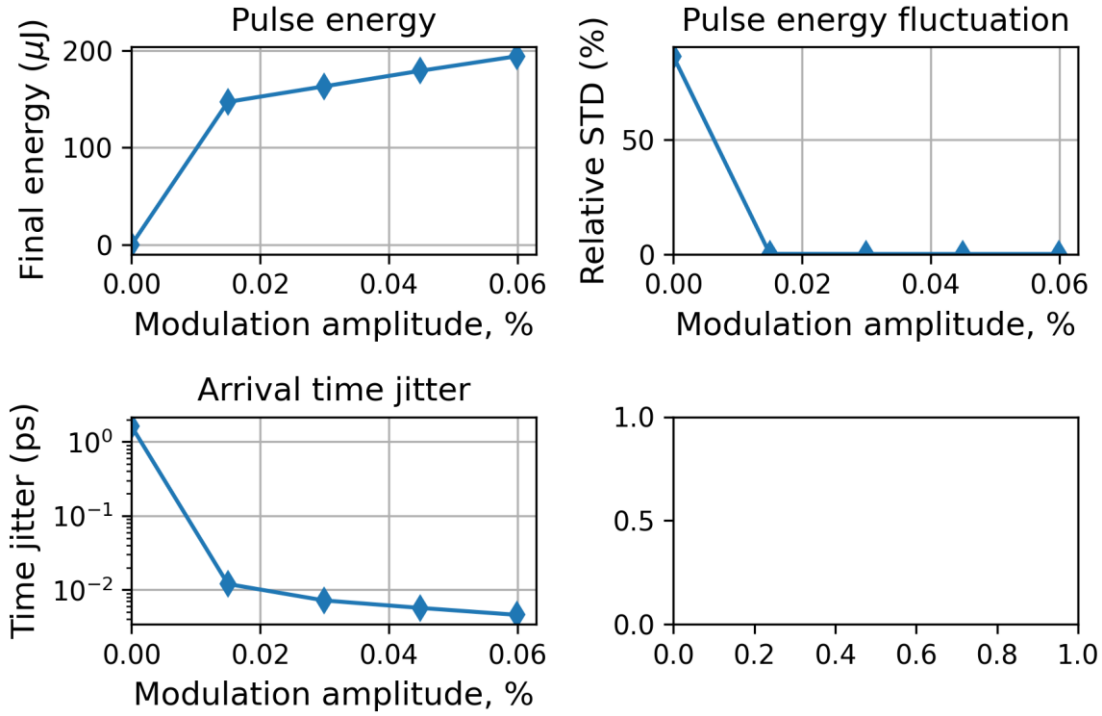




Energy modulated beam

Seed signal is periodic longitudinal energy modulation

- Seeding effect of the method
  - Improved efficiency – final radiation energy
  - Reduction of shot-to-shot energy fluctuation
  - Orders of magnitude lower time jitter
- Effect monotonously increases with amplitude
  - To a point – too much spread is harmful to FEL
- Strong seeding even with very small modulations



Energy modulated beam

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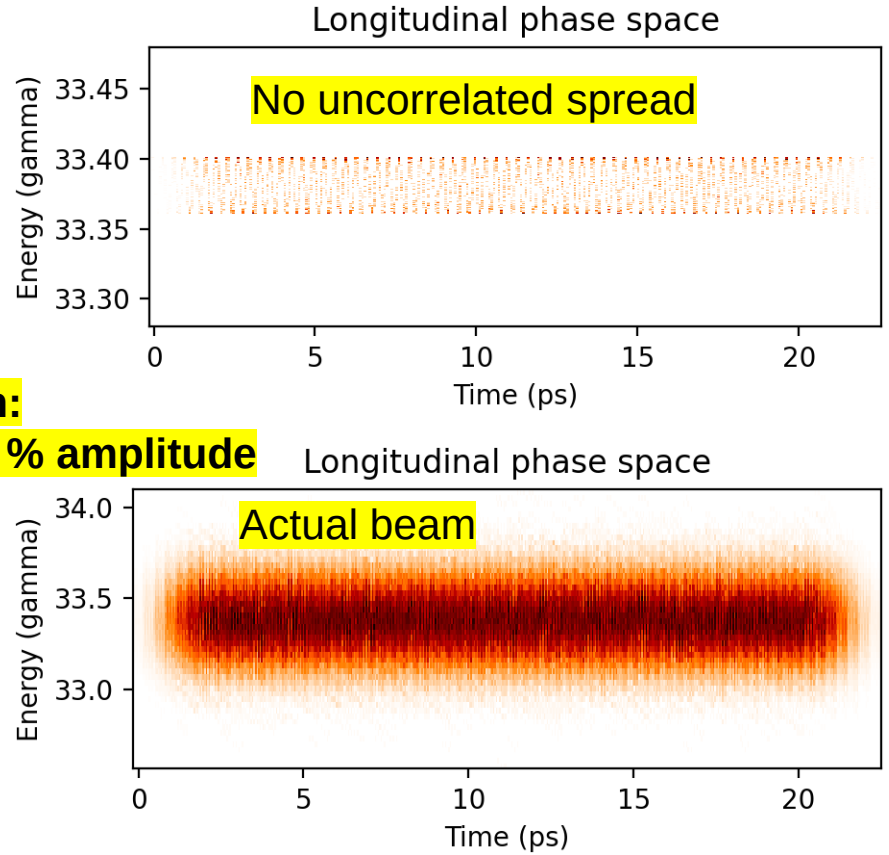
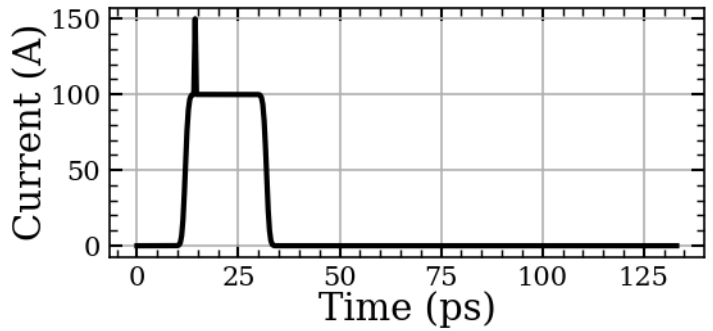
  - Improved efficiency – final radiation energy
  - Reduction of shot-to-shot energy fluctuation
  - Orders of magnitude lower time jitter
- Effect monotonously increases with amplitude
  - To a point – too much spread is harmful to FEL
- Strong seeding even with very small modulations
  - Better option than pre-bunched beam?
  - Artificially low noise from quiet loading?

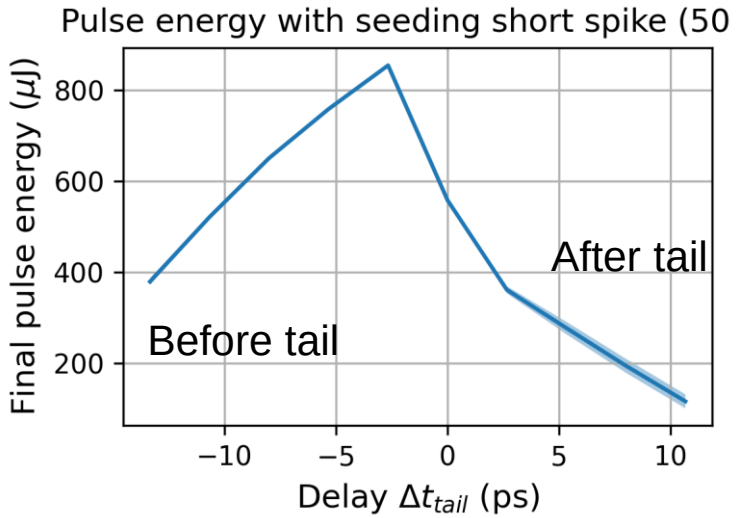


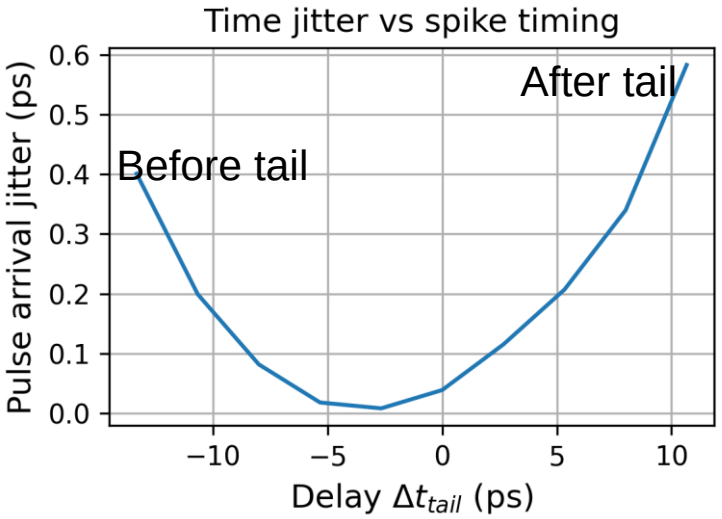
Short seeding spike

Super-radiant spike emits coherent radiation

- Old results – no space charge!
- Short spike – 500 A, 33 fs flattop
- Seeding effect of the method
  - Improved efficiency – final radiation energy
  - Lower time jitter
- Update simulation - technical challenges



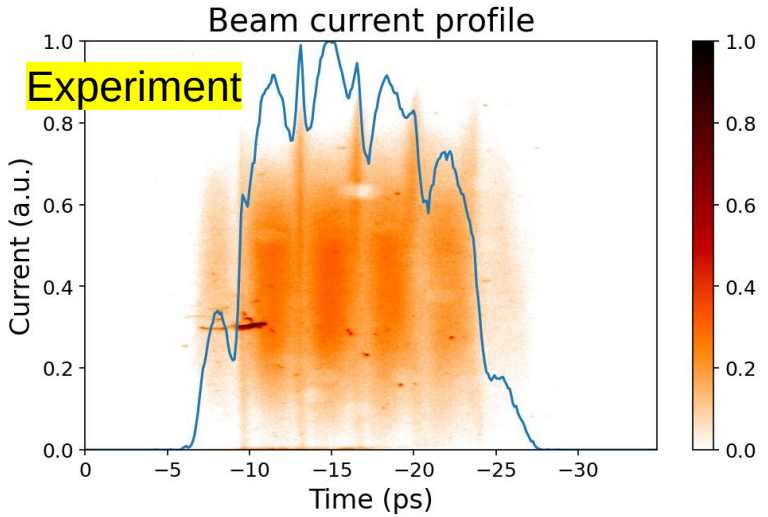


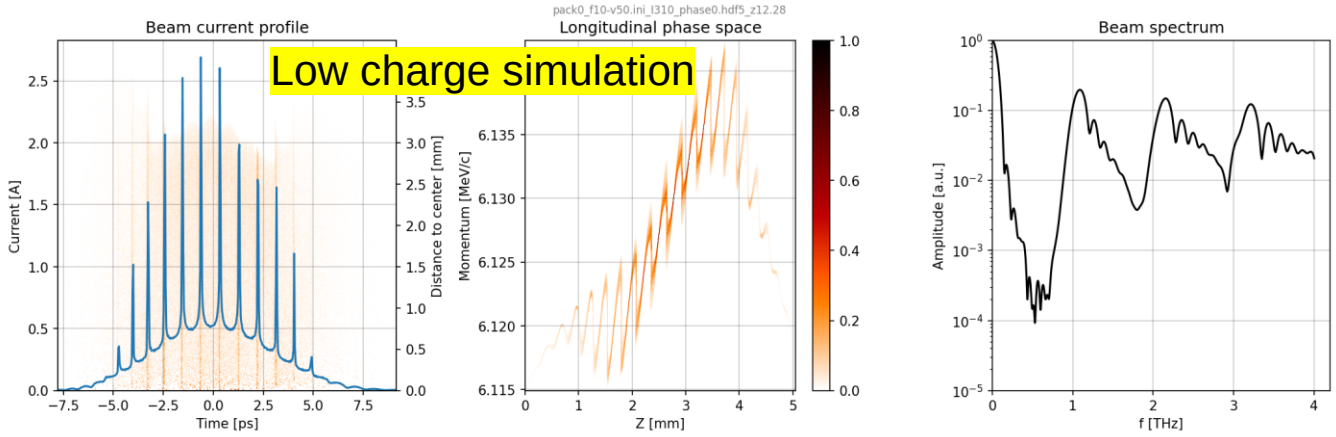


Outlook

Seeding methods in practice

- More realistic beams
  - Start to end simulation including ASTRA
  - Bunch compressor option
- Photocathode laser modulation
  - Superposition of pre-bunched and energy modulated
  - Modulation frequency limit – laser and response time
- External radiation source - hardware limits
- Short seeding spike to non-linear space-charge
  - Many spikes from higher harmonic oscillations





Summary

- Independent of seeding method
  - Improved FEL efficiency
  - Lower energy fluctuation
  - Lower arrival time jitter
- More simulations with realistic cases
  - All four methods may be applied
  - Technical and software challenges

Thank you

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