



## USPAS – *Simulation of Beam and Plasma Systems*

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### Lecture: **Slice Energy Spread**

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<http://uspas.fnal.gov/programs/2018/odu/courses/beam-plasma-systems.shtml>

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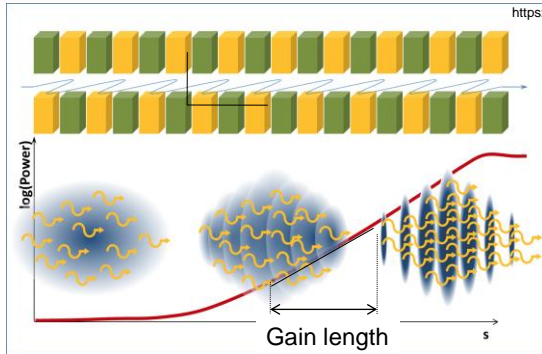
Office of Science

## Goals

- Understand slice energy spread
  - why is it important for free electron lasers (FEL)
  - what is the relevance to laser-plasma accelerators?
- Explore a real world example, using Elegant



# High-quality electron beams (high charge, short duration, low emittance) can drive Free Electron Laser



[https://www.helmholtz-berlin.de/projects/berlinpro/eri-intro/linac-fel\\_en.html](https://www.helmholtz-berlin.de/projects/berlinpro/eri-intro/linac-fel_en.html)

- Free Electron Laser:**
- Interaction undulator radiation & dense e-beam → micro-bunching → coherent undulator emission
  - Small gain length favorable
  - E-beam quality → Pierce parameter  $\rho$
  - Large  $\rho$  favorable ( $\rho$  typically of order  $10^{-3}$ - $10^{-2}$ )
  - Energy spread washes out micro-bunching
  - 1D gain length corrected with 3D effects  $\Lambda$  (energy spread, emittance, etc.)

Charge / duration

$$\text{Pierce parameter } \rho = \left( \frac{1}{16} \frac{Q/\tau}{I_A} \frac{K_0^2 [JJ]^2}{\gamma^3 \sigma_u^2 k_u^2} \right)^{1/3}$$

E-beam energy

E-beam size (emittance)

3D Gain length

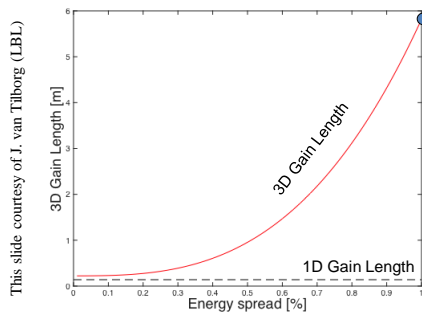
$$L_g = \frac{\lambda_u}{4\sqrt{3}\pi\rho} (1 + \Lambda) = L_{g0} (1 + \Lambda)$$

This slide courtesy of J. van Tilborg (LBL)

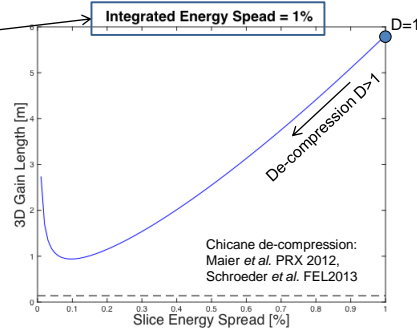
Huang & Kim PRSTAB 10, 034801 (2007)

# Each time slice can develop micro-bunching: Not integrated but slice energy spread critical to FEL: $\sigma_{\gamma, \text{slice}} < \rho$

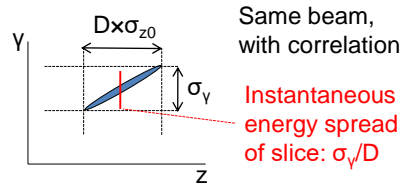
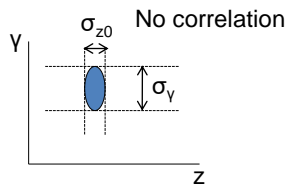
3D Gain Length as a function of energy spread in a correlation-free beam:



Adding correlation through chicane de-compression:

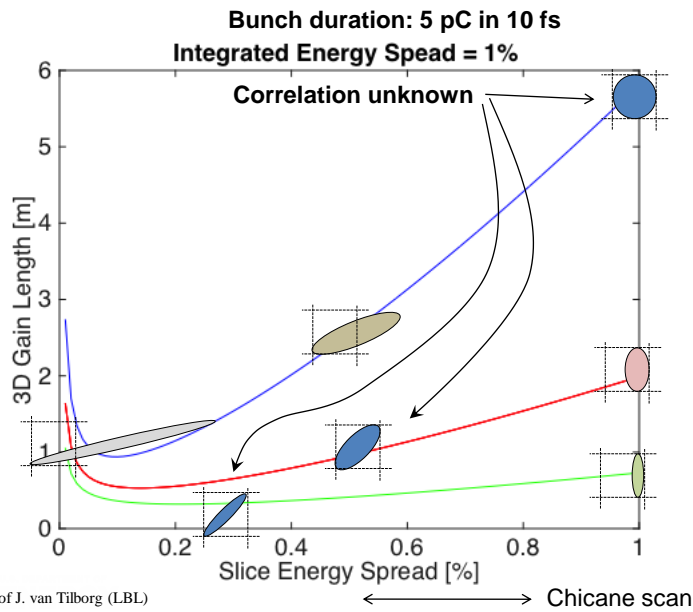


**Beam parameters:**  
 5 pC in 10 fs  
 250 MeV  
 Emittance 0.5  $\mu\text{m}$   
 Beam size 25  $\mu\text{m}$   
**Undulator:**  
 Period 2.18 cm  
 Strength  $K=1.26$   
**Pierce  $\rho=0.007$**



- Slippage of chirped e-beam through photon pulse is detrimental
- Length of relevant slice is several radiation wavelengths long (~5 fs)

## Bunch length and energy spread known, but correlation not known (longitudinal phase phase not known)



This slide courtesy of J. van Tilborg (LBL)

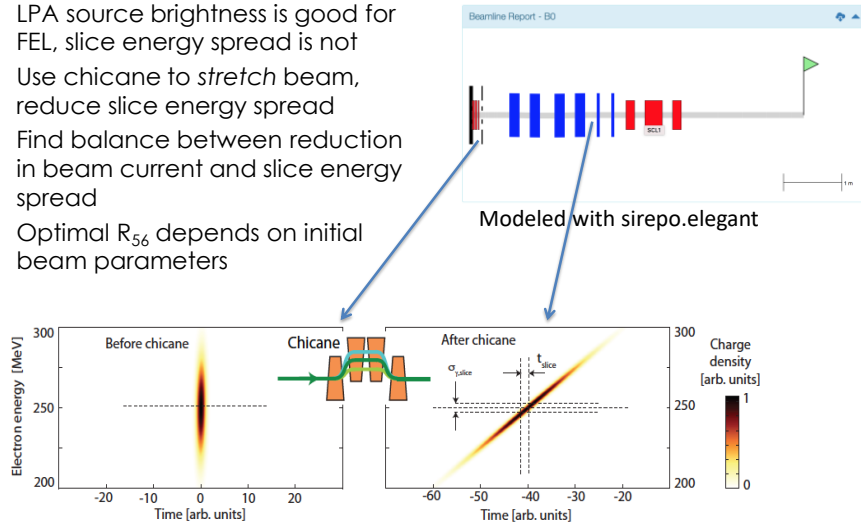
### How can one quickly stretch the longitudinal phase space?

- Use a chicane (a sequence of dipoles)
  - typically used to compress bunches
  - here, it is being used to longitudinally stretch the bunch
- Explore a real world example
  - from the ATF (Accelerator Test Facility) at Brookhaven National Lab



## User case: Chicane for LPA-FEL

- LPA source brightness is good for FEL, slice energy spread is not
- Use chicane to *stretch* beam, reduce slice energy spread
- Find balance between reduction in beam current and slice energy spread
- Optimal  $R_{56}$  depends on initial beam parameters



Courtesy S. Barber (LBNL)



D. Bruhwiler – USPASP – January 2018 – Slice Energy Spread

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