USPAS – *Simulation of Beam and Plasma Systems*

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Lecture: Slice Energy Spread

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U.S. Particle Accelerator School sponsored by **Old Dominion University**

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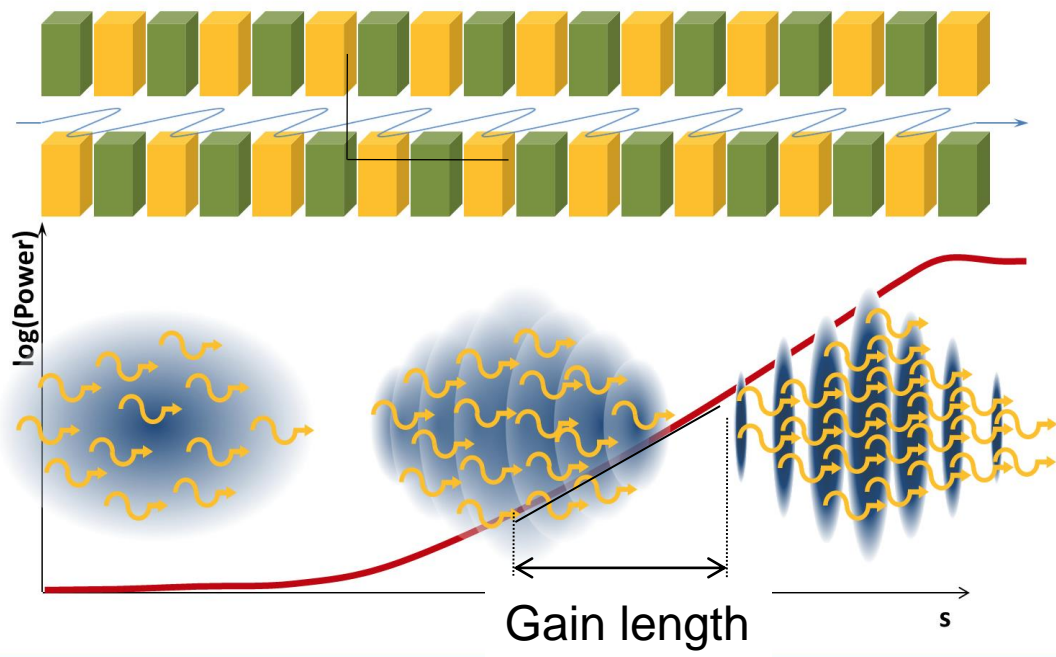
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Goals

- 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

log(Power)

Gain length

s

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

Charge / duration

Pierce parameter $\rho = \left(\dfrac{1}{16} \dfrac{Q/\tau}{I_A} \dfrac{K_0^2 [JJ]^2}{\gamma^3 \sigma_r^2 k_u^2} \right)^{1/3}$
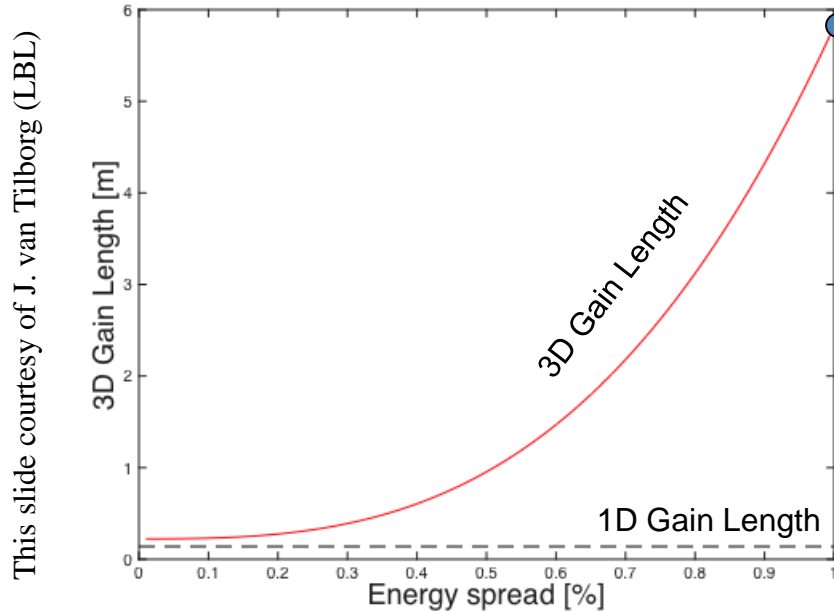
E-beam energy

E-beam size (emittance)

3D Gain length $L_g = \dfrac{\lambda_u}{4\sqrt{3}\pi\rho}(1+\Lambda) = L_{g0}(1+\Lambda)$

Huang & Kim PRSTAB 10, 034801 (2007)

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

Adding correlation through chicane de-compression:

Integrated Energy Spread = 1%

This slide courtesy of J. van Tilborg (LBL)

3D Gain Length

1D Gain Length

D=1

De-compression D>1

Chicane de-compression:
Maier *et al.* PRX 2012,
Schroeder *et al.* FEL2013
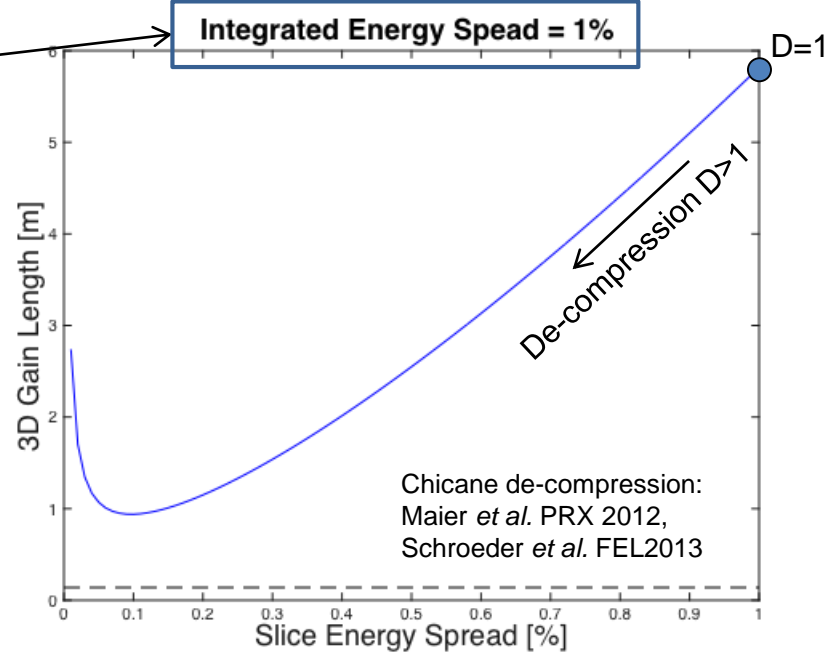
Beam parameters:
5 pC in 10 fs
250 MeV
Emittance 0.5 μm
Beam size 25 μm
Undulator:
Period 2.18 cm
Strength K=1.26

Pierce ρ=0.007

No correlation

σ_{z0}

Y

σ_γ

z

Same beam, with correlation

$D \times \sigma_{z0}$

Y

σ_γ

z

Instantaneous energy spread of slice: σ_γ/D
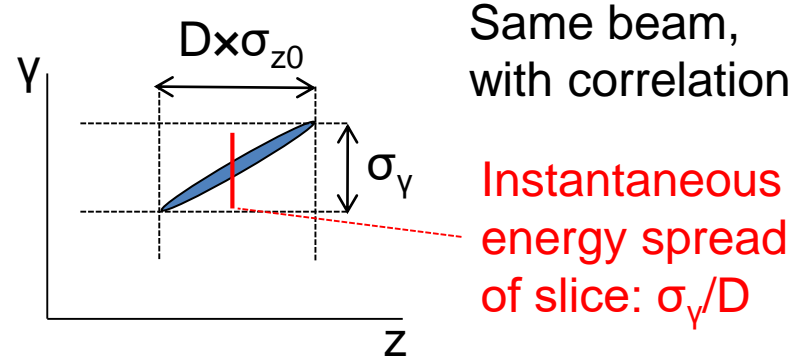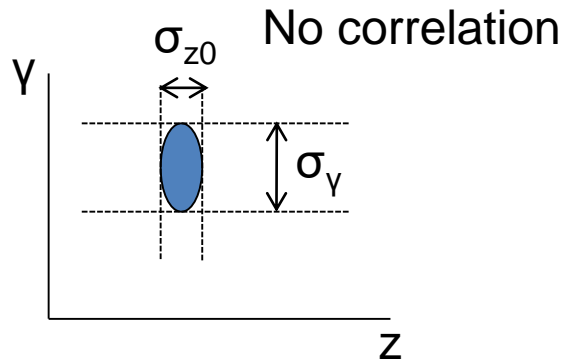
- Slippage of chirped e-beam through photon pulse is detrimental
- Length of relevant slice is several radiation wavelengths long (~5 fs)

Bunch duration: 5 pC in 10 fs

Integrated Energy Spread = 1%


Correlation unknown

Chicane scan
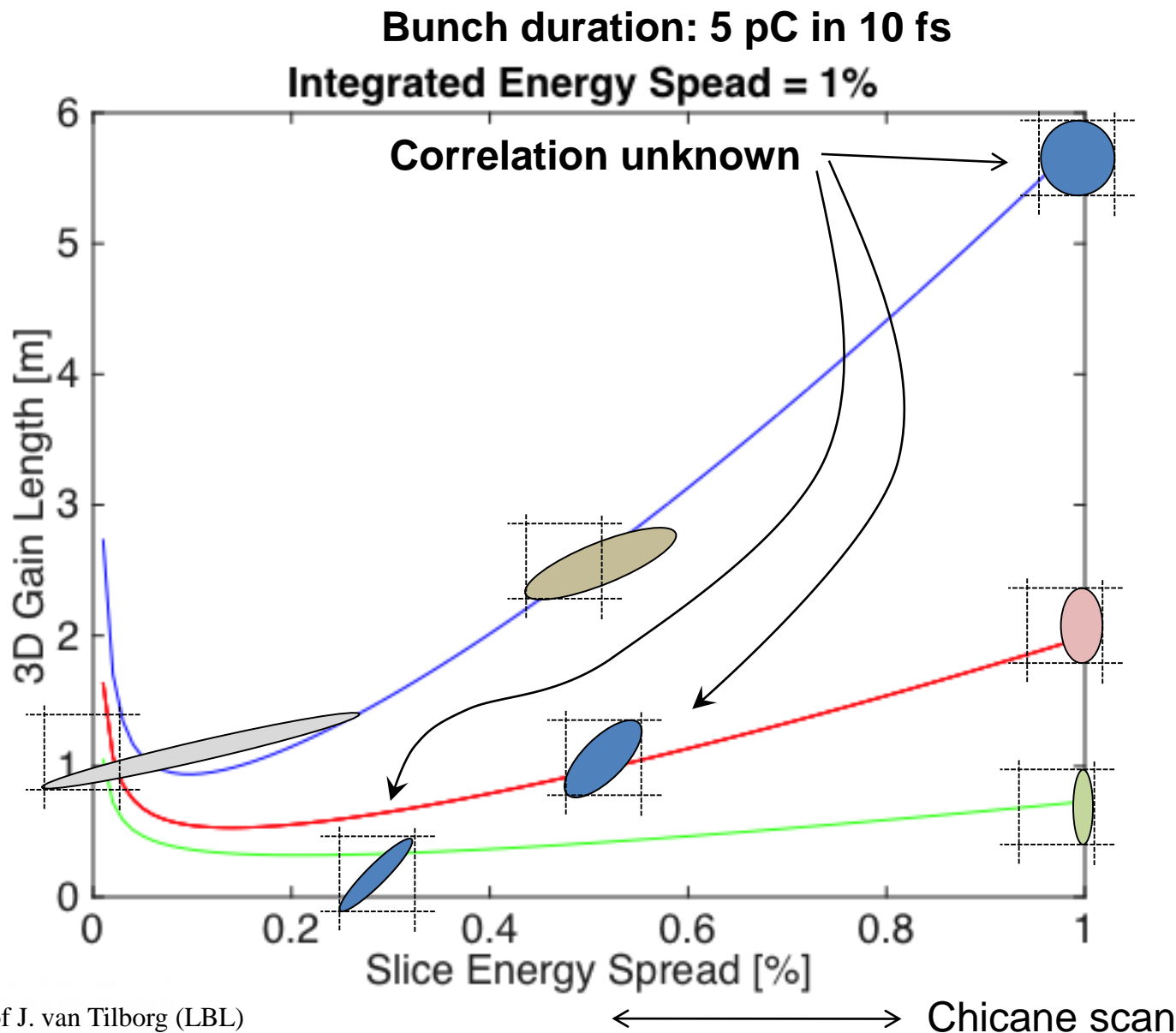
How can one quickly stretch the longitudinal phase space?

- 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
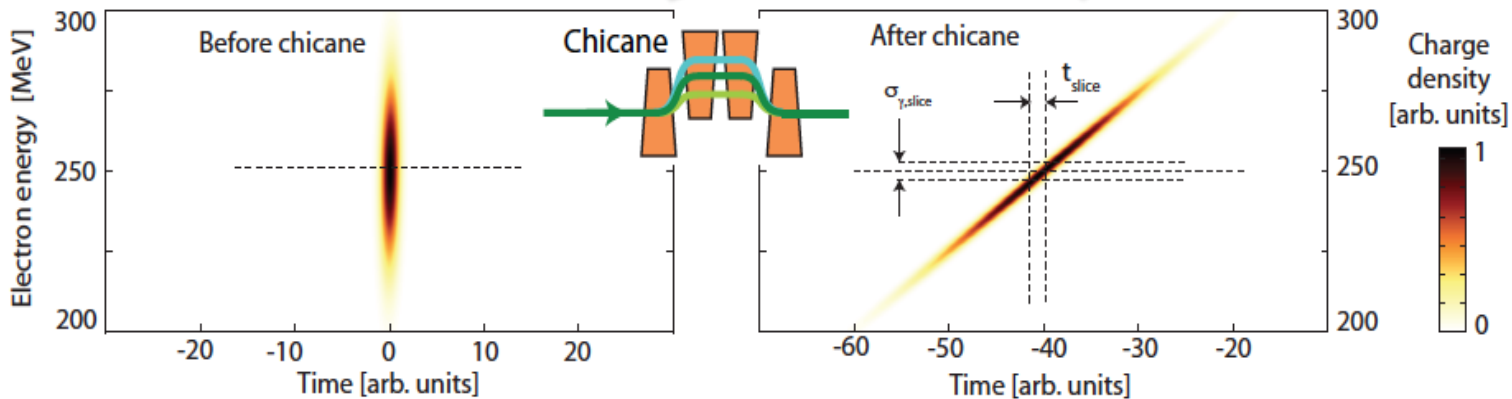 - from the ATF (Accelerator Test Facility) at Brookhaven National Lab

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
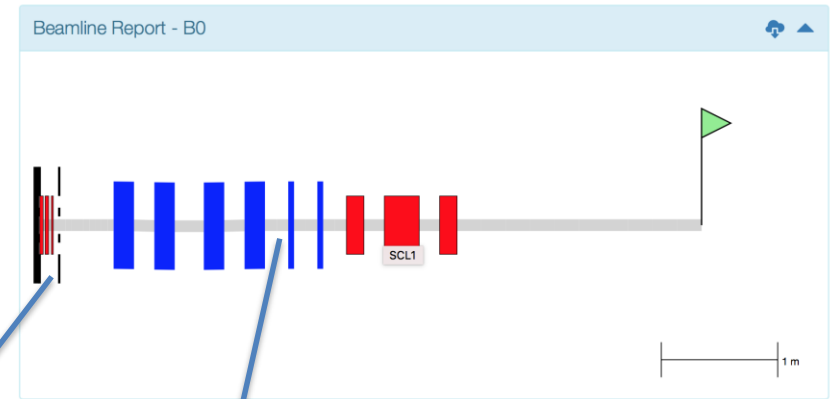
Modeled with sirepo.elegant

Courtesy S. Barber (LBNL)