Stair-step Tapered Wiggler
A Novel Concept for High-Efficiency FEL

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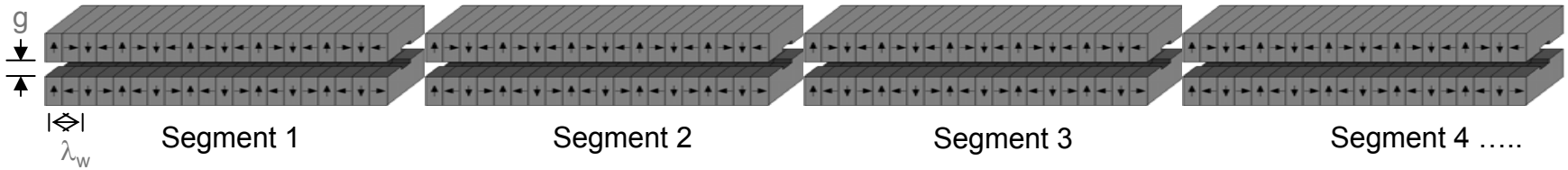
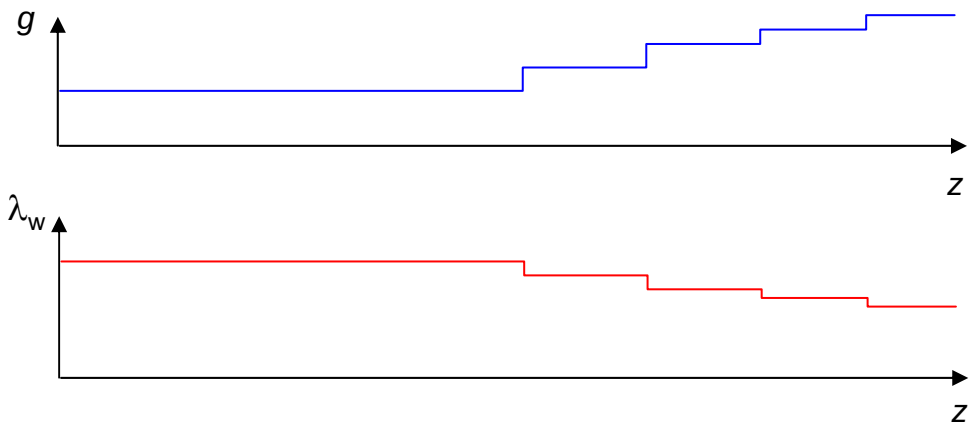
A stair-step tapered wiggler consists of multiple uniform segments with different gaps or periods



- Can be tapered in gap or period or both.
  - Taper in gap
  - Taper in period



- Each segment's gap can be independently adjusted while in operation.
- A stair-step tapered wiggler is easier to build and optimize than a continuous one.

Single-step Tapered Wiggler

Resonant energy

$$\gamma_R = \sqrt{\frac{\lambda_w}{2\lambda}\left(1+a_w^2\right)}$$

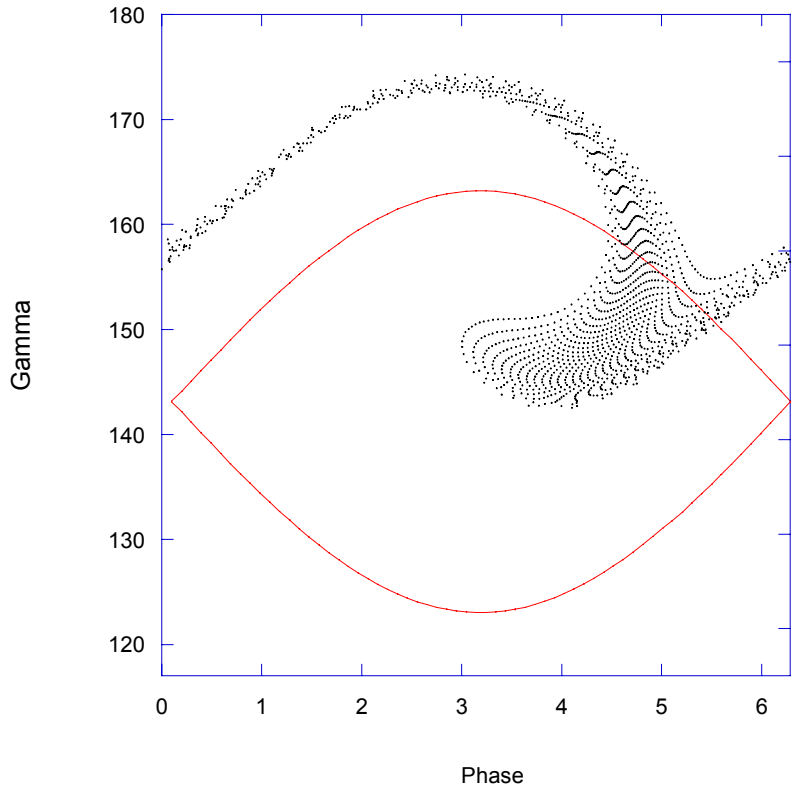
Uniform wiggler efficiency

$$\eta = 2\eta_C\sqrt{\frac{a_w a_s}{1+a_w^2}}$$

Step-tapered wiggler efficiency

$$\eta = 2\eta_{C1}\sqrt{\frac{a_{w1}a_s}{1+a_{w1}^2}} + 2\eta_{C2}\sqrt{\frac{a_{w2}a_s}{1+a_{w2}^2}}$$

Phase-space distribution at the transition



Performance of the stair-step taper is compared to a linear taper using 3-D MEDUSA simulations

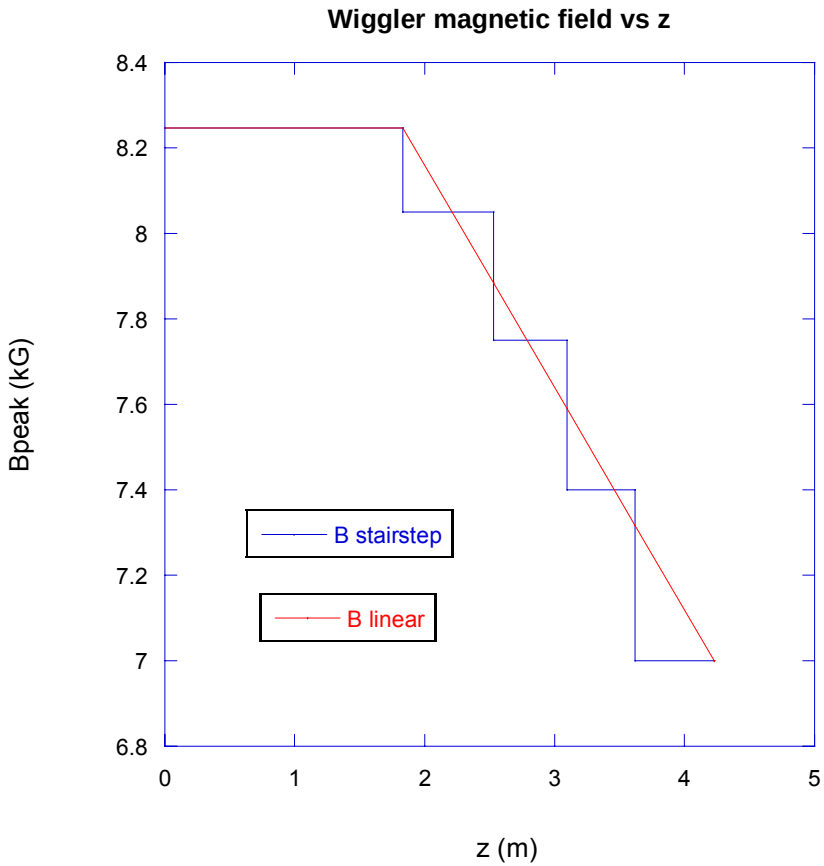
Stair-step Taper

B_0 = 8.25 kG z = 0 → 1.83 m
B_0 = 8.05 kG z = 1.83 → 2.53 m
B_0 = 7.75 kG z = 2.53 → 3.10 m
B_0 = 7.35 kG z = 3.10 → 3.66 m
B_0 = 7.05 kG z = 3.66 → 4.27 m

Linear Taper

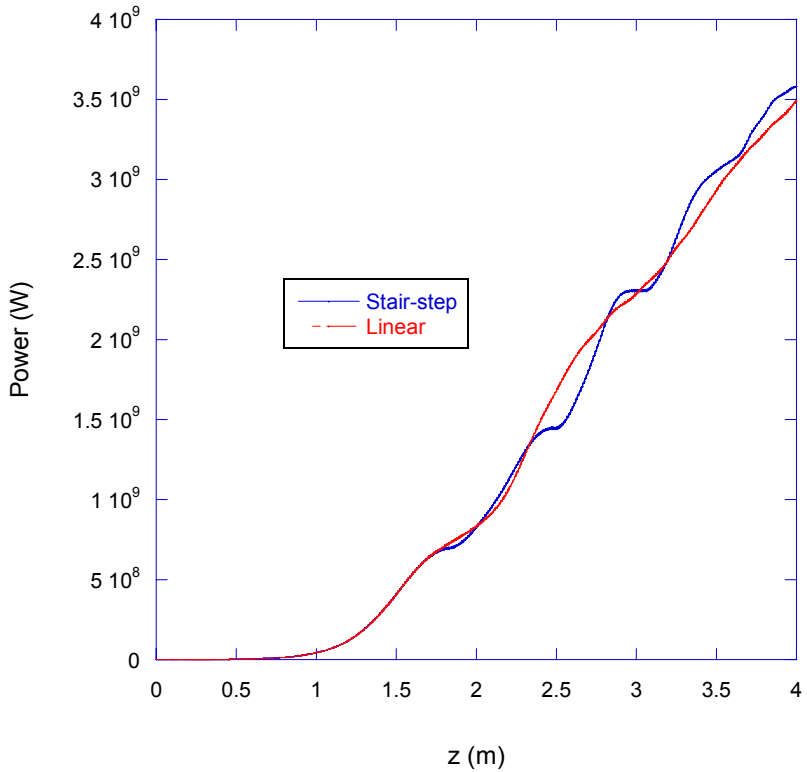
B_0 = 8.25 kG z = 0 → 1.83 m

B_0 = 8.25 kG - (0.48 kG/m) * z
z = 1.83 → 2.53 m



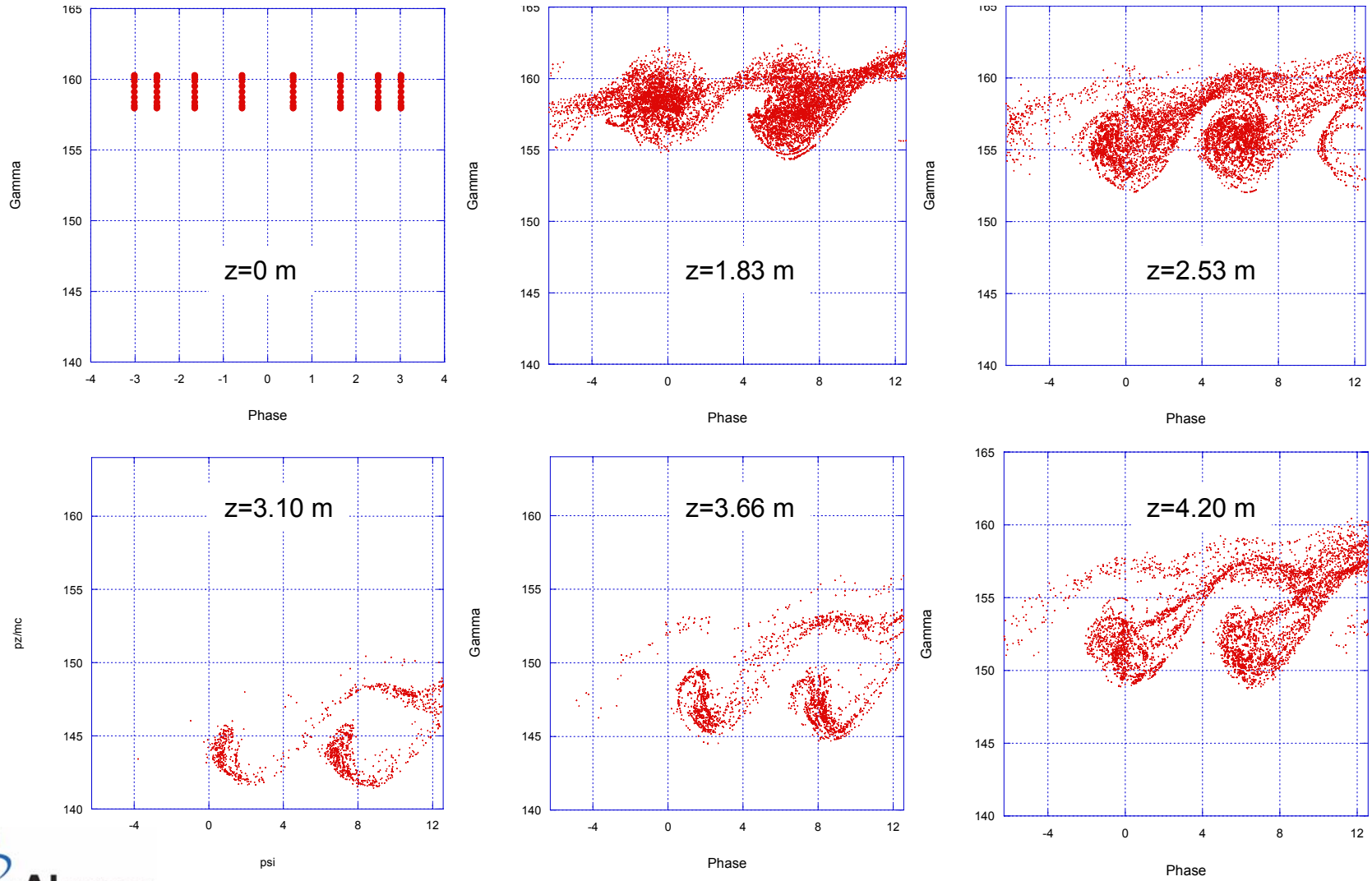
Stair-step and linearly tapered wigglers produce approximately equal power at the same taper rate

FEL Parameters	Values
Beam energy	80.8 MeV
Peak current	1 kA
Wiggler period	2.18 cm
K_{rms}	1.187
Wavelength	1.052 μ
Input power (peak)	1 MW
Stair-step taper output power	3.6 GW
Stair-step taper efficiency	4.5%
Linear taper output power	3.5 GW
Linear taper efficiency	4.4%

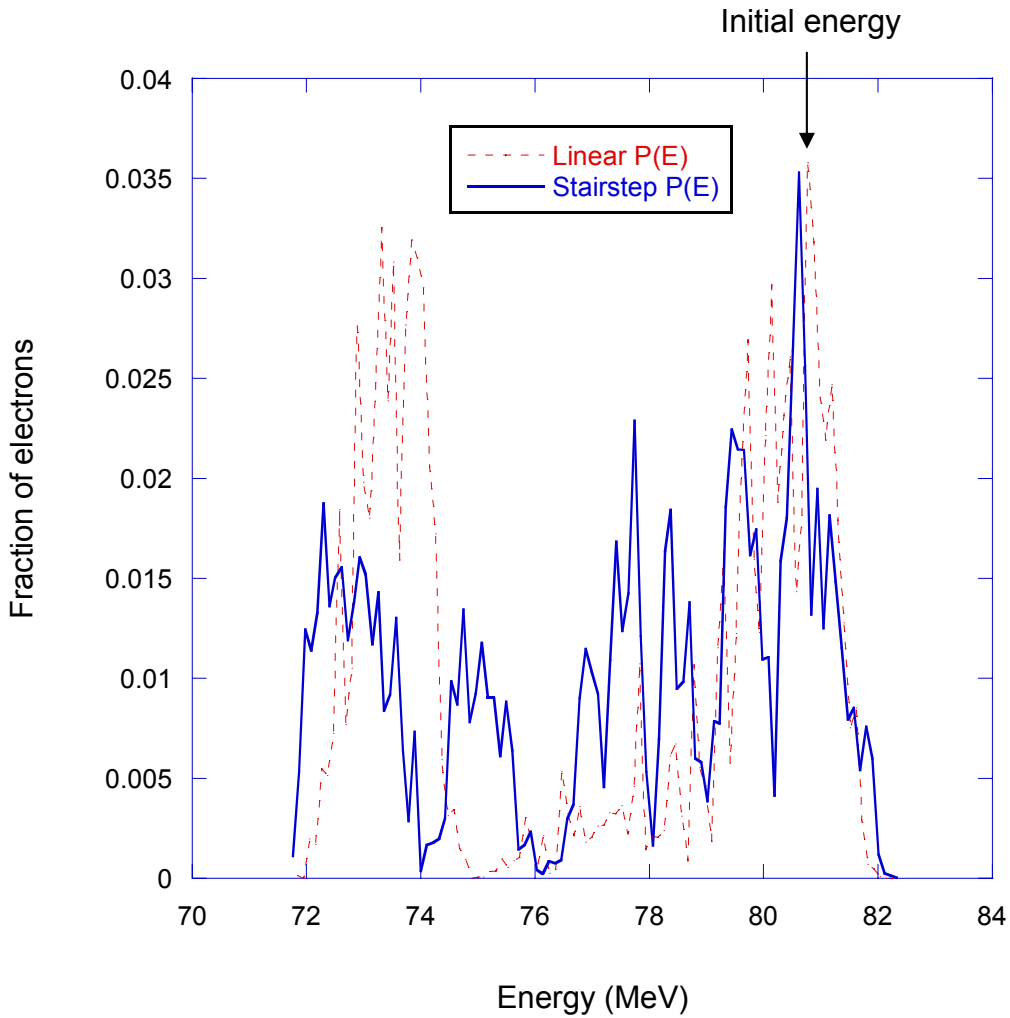


FEL power increases by approximately the same amount in each section up to five sections in the stair-step tapered wiggler.

MEDUSA-Generated Phase-space Distributions at Different Locations in Stair-step Tapered Wiggler



Energy spread of electron beams exiting a stair-step tapered wiggler is about 3X the extraction efficiency.



Summary

- We present a novel idea of stair-step tapered wiggler using multiple uniform wiggler segments with different gaps or wiggler periods.
- The stair-step tapered wiggler with the taper in gap is easier to fabricate and optimize than the continuously tapered wiggler.
- 3D MEDUSA simulations show the stair-step tapered wiggler to be as efficient as a linearly tapered wiggler and about 5 times more efficient than a uniform wiggler (4.5% instead of 0.9%).
- The non-adiabatic transitions in a stair-step tapered wiggler cause electrons to spill out of the “bucket” and fill in the energy spectrum. The total energy spread is about 3X the extraction efficiency.