Studies of Undulator Tapering for the CLARA FEL

I.P.S. Martin[1], R. Bartolini[1,2], D. Dunning[3], N. Thompson[3]
[1]Diamond Light Source, Oxfordshire, UK
[2]John Adams Institute, University of Oxford, UK
[3]ASTeC, STFC Daresbury Laboratory, UK

Summary

- *The suitability of the CLARA FEL layout for undulator tapering is investigated*
- *The modified-KMR technique for calculating the taper profile is compared to direct, optimisation of a quadratic taper profile*
- *Simulations are carried out for both seeded and SASE mode at 266 nm*
- *Both methods are found to improve the FEL pulse energy and spectral brightness*
- *A significant contribution to the increase in pulse energy comes from sideband growth*

INTRODUCTION

Undulator tapering is a well-known technique for improving the performance of FELs. It works by keeping the resonant wavelength matched to the bunching that develops in the electron beam, despite the changing energy of the electrons as they travel along the undulator. The topic is currently one of interest for study at the CLARA FEL, as this facility aims to provide a location at which a wide range of current and future FEL schemes can be tested experimentally. As such, the suitability of the proposed layout for effective tapering needs to be established at an early stage. Both seeded and SASE operation at 266 nm are studied. For each case, the effectiveness of undulator tapering as a method to improve the final FEL pulse energy and spectral brightness is determined.

TAPER OPTIMISATION METHODS

Modified Kroll-Morton-Rosenbluth (KMR) Technique

In this technique, a Hamiltonian method is used to define a fixed synchronous phase Ψ_r that relates the rate of energy-extraction to the particle energy, field amplitude and a_u. The selection of Ψ_r is a trade-off between capturing the greatest number of particles (small Ψ_r) and maximising the rate at which energy is extracted (large Ψ_r). A modification was recently proposed, in which Ψ_r varies along the radiator. We investigate a linear increase of Ψ_r of the form:

$$\Psi_r(z) = \frac{\pi}{2L_d} z$$

where L_d is the detrapping length (bucket area shrinks to zero at $z = L_d$). The taper profile is found by iteratively solving the equation:

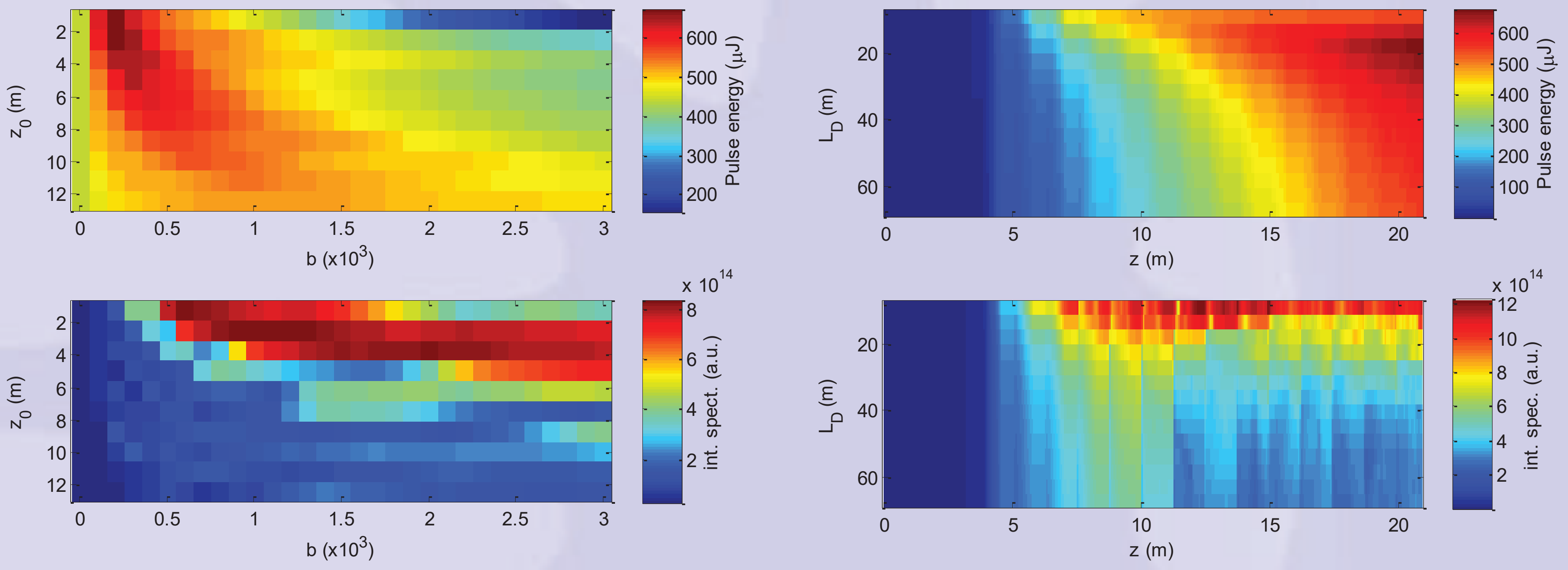
$$a_u(z+\Delta z) = a_u(z) - \frac{\sqrt{2}e}{m_e c^2}\frac{\lambda_r}{\lambda_u} f_B(z) E_0(z) \sin\Psi_r(z)\Delta z$$

Direct Optimisation of a Quadratic Taper Profile

In this method the optimal taper profile is found by direct optimisation using time-dependent GENESIS simulations. The stepped taper has the form:

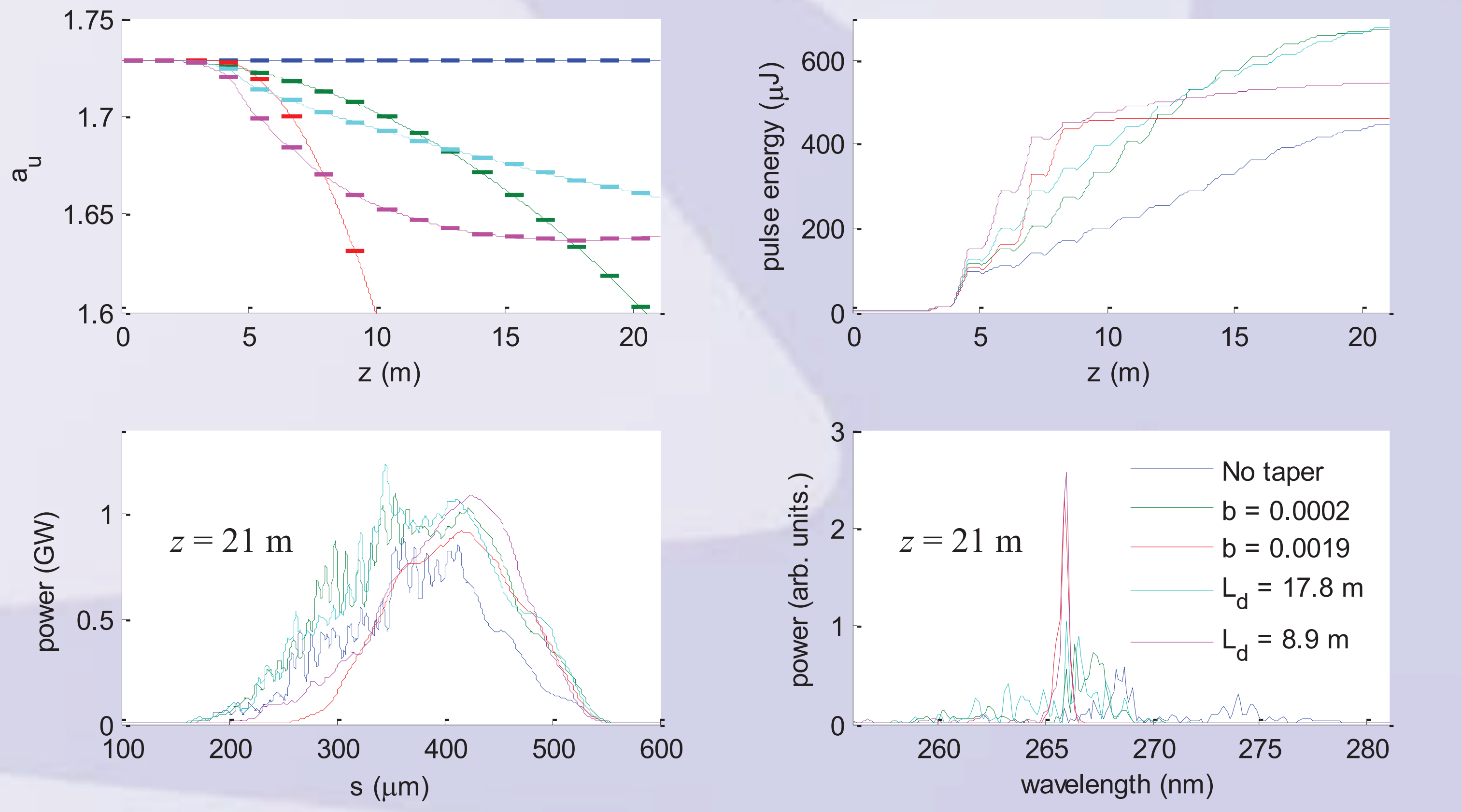
$$a_u(z) = \begin{cases} a_u(0), & \text{if } z \le z_0 \\ a_u(0) - b(z-z_0)^2, & \text{otherwise} \end{cases}$$

TAPERING FOR SEEDED OPERATION



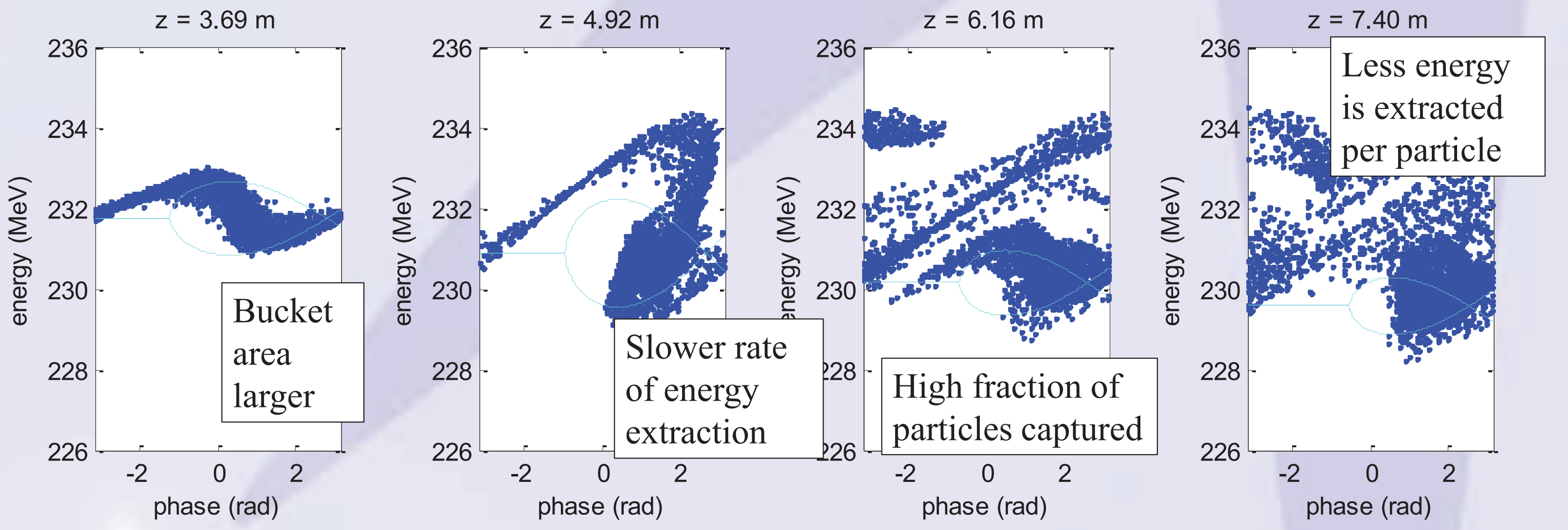
- Optimising for FEL pulse energy requires a shallow taper, starting early
- Optimising for spectral brightness required a stronger taper, starting later

Overview of Seeded Pulses for Different Taper Profiles



- Modified KMR taper far from quadratic
- Modified KMR taper produces marginally better results
- Significant sideband growth for pulses with increased energy

Electron Phase Space for Modified KMR Taper: $L_d = 17.8$ m



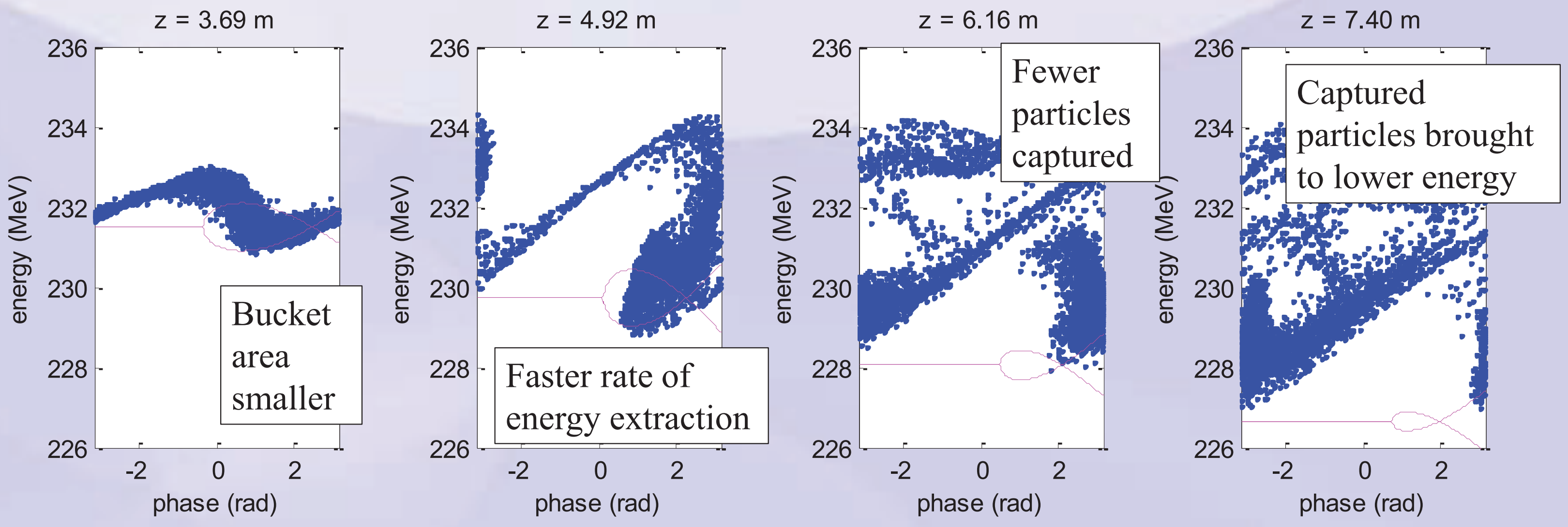
Bucket area larger

Slower rate of energy extraction

High fraction of particles captured

Less energy is extracted per particle

Electron Phase Space for Modified KMR Taper: $L_d = 8.9$ m



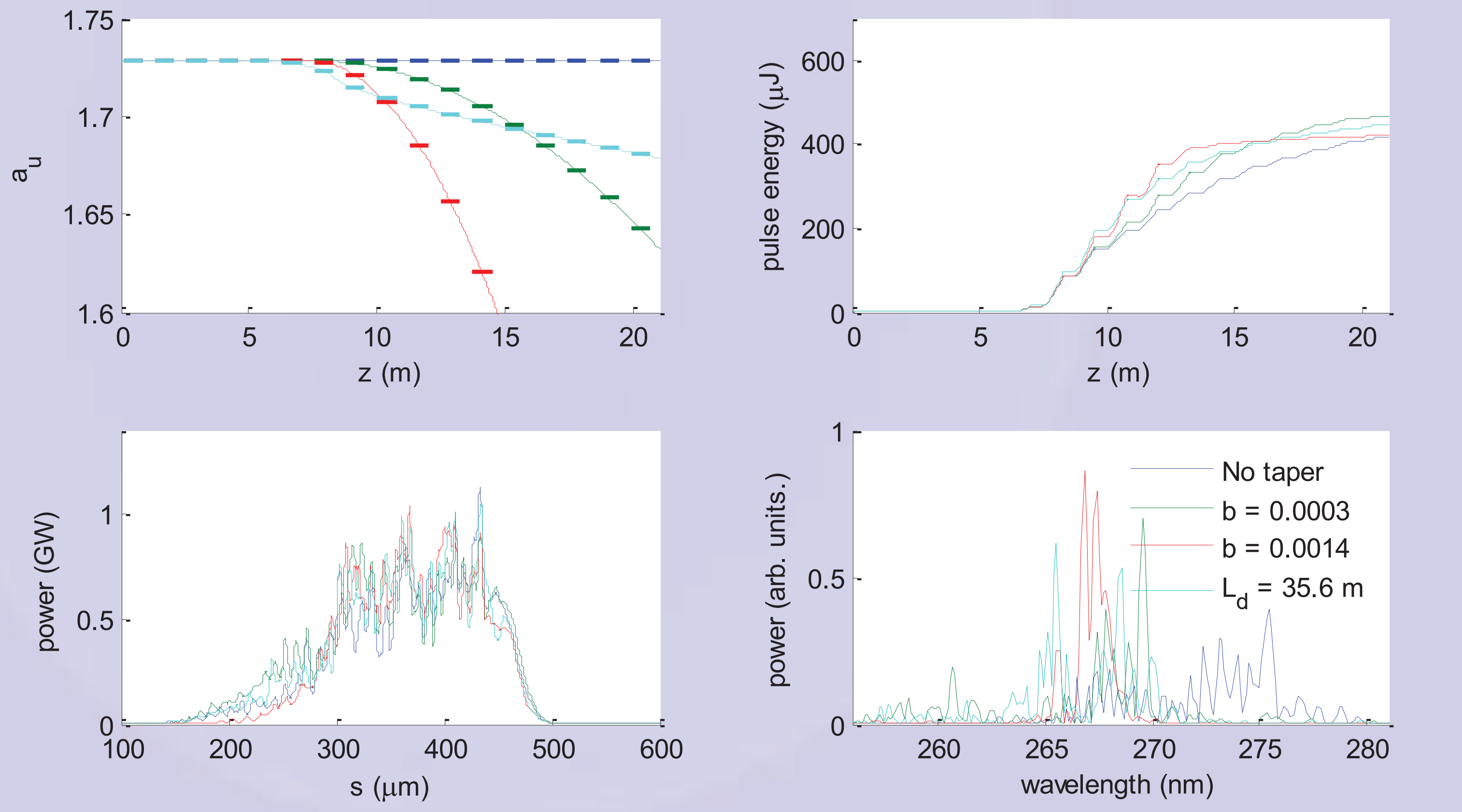
Bucket area smaller

Faster rate of energy extraction

Fewer particles captured

Captured particles brought to lower energy

TAPERING FOR SASE OPERATION



- Modified KMR maximises pulse energy and spectral brightness simultaneously
- Quadratic taper can be optimised to give better results
- Overall, tapering is less effective in SASE mode