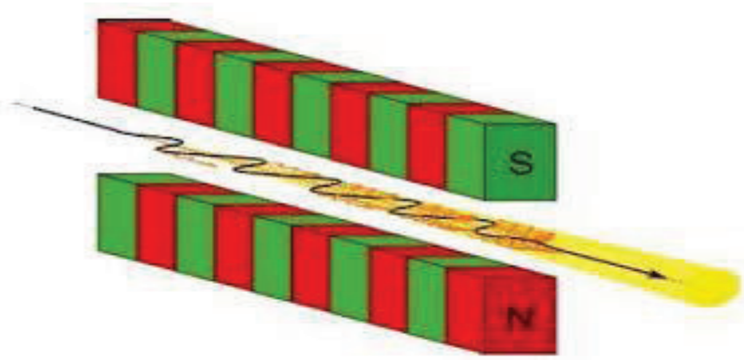
The beamlet method

Methods to improve FEL output from “dirty” beams



James Henderson, Lawrence Campbell and Brian McNeil

Outline

- Motivation Plasma accelerators
- Potential beamlet solution modulate and disperse
- Chicanes to maintain resonant interaction
- Simplified Model
- The beamlet method
- Conclusion

Motivation

- Plasma accelerator have accelerating gradients of 10^3 greater than conventional accelerators, potential for “table top” FELs.

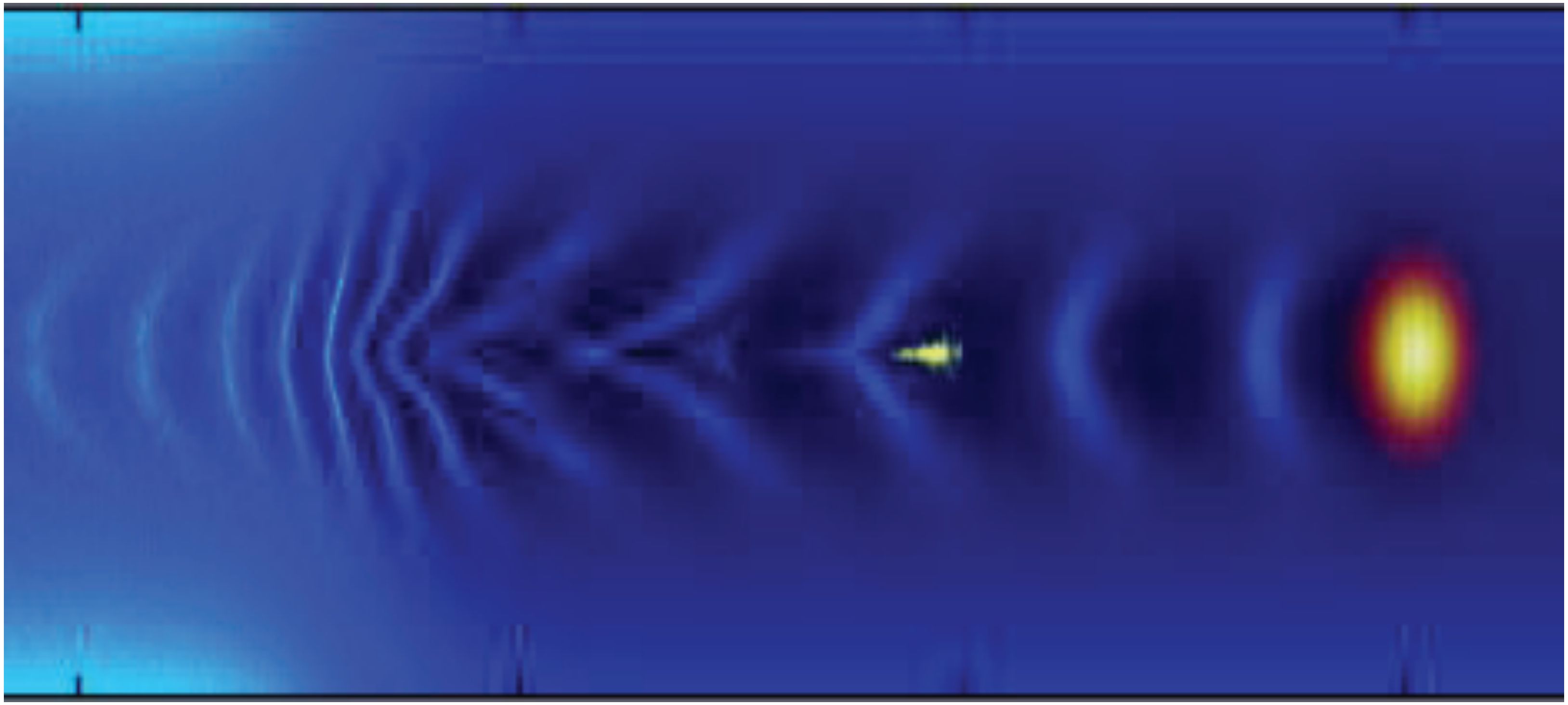
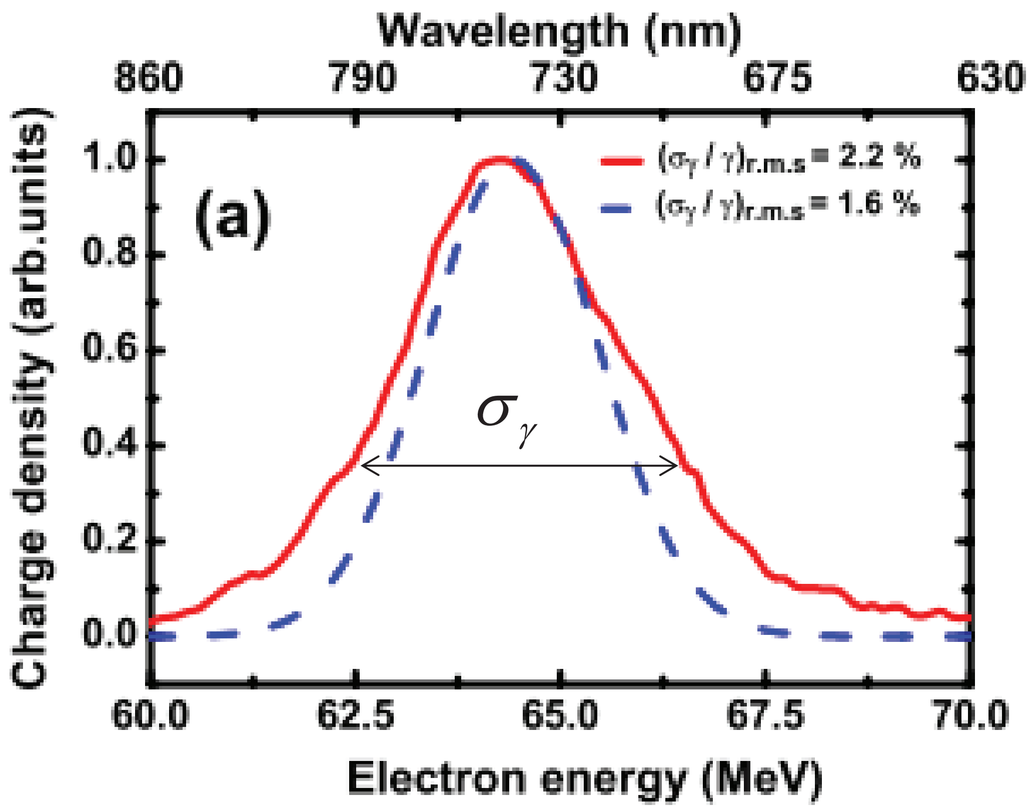


Image credit - https://www2.physics.ox.ac.uk/research/plasma-accelerators
Front page image – http://lpap.epfl.ch/page--en.html

Motivation

- Plasma accelerator have accelerating gradients of 10^3 greater than conventional accelerators, potential for “table top” FELs.
- However electron pulses from plasma accelerators typically have a large energy spread



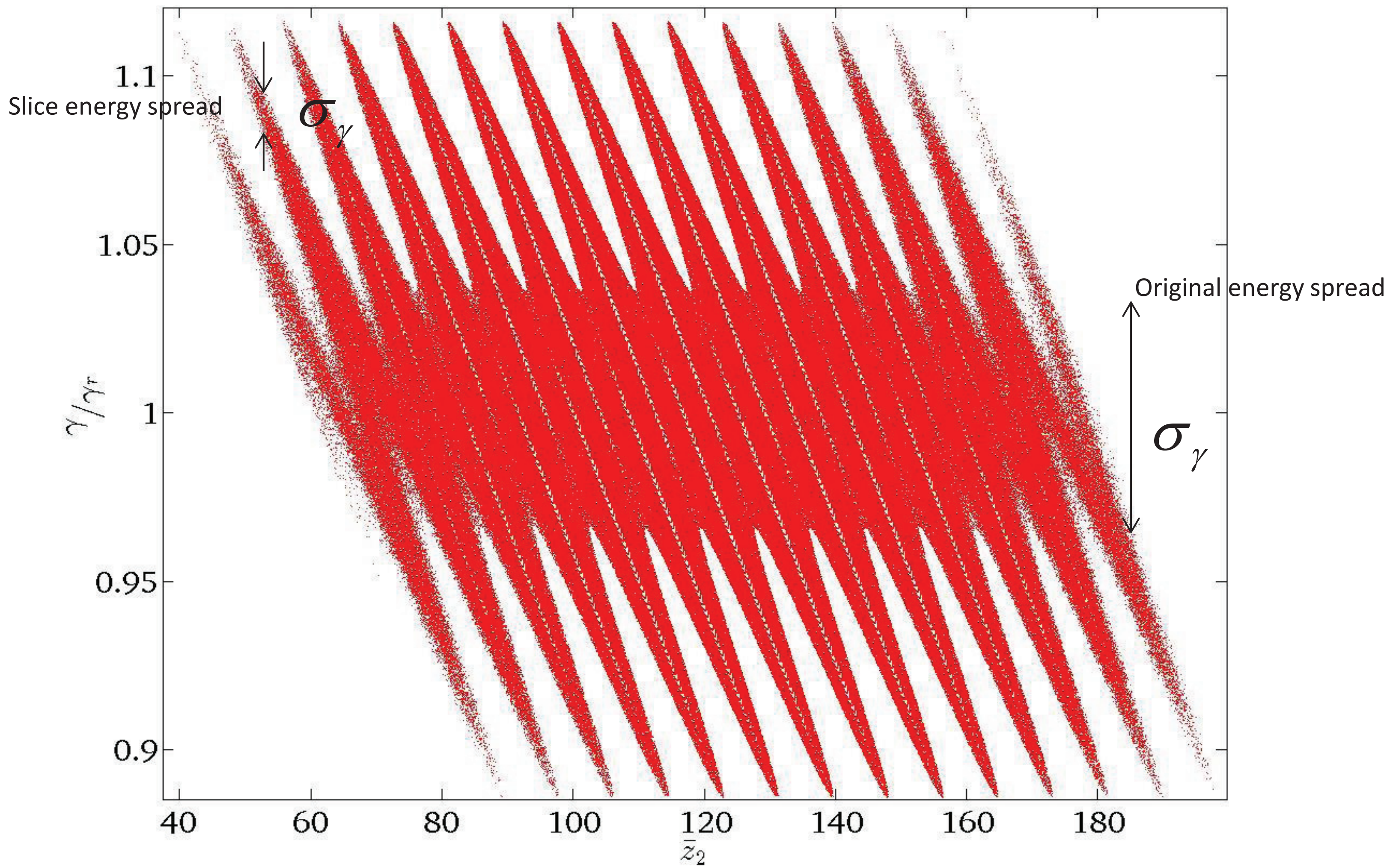
$$\frac{\sigma_\gamma}{\gamma_r} > 2\%$$

For an FEL we require $\frac{\sigma_\gamma}{\gamma_r} < \rho$ where $\rho = 10^{-2}$

A method of determining narrow energy spread electron beams from a laser plasma wakefield accelerator using undulator radiation
J. G. Gallacher,et. al. PHYSICS OF PLASMAS **16, 093102 2009**

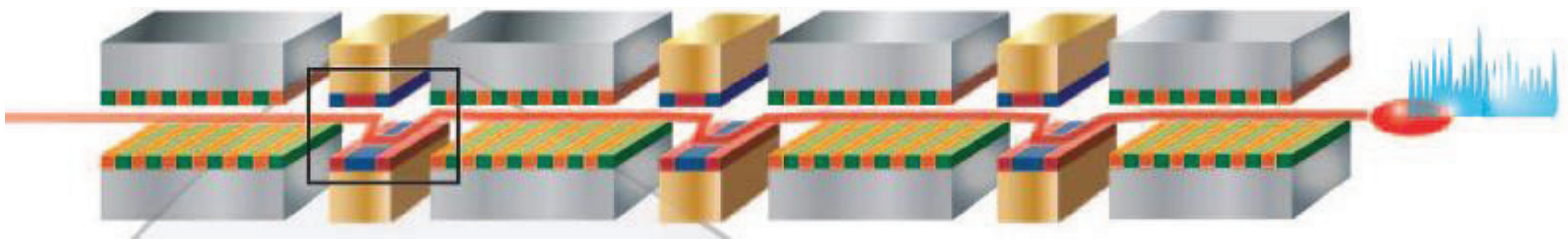
Potential Solution

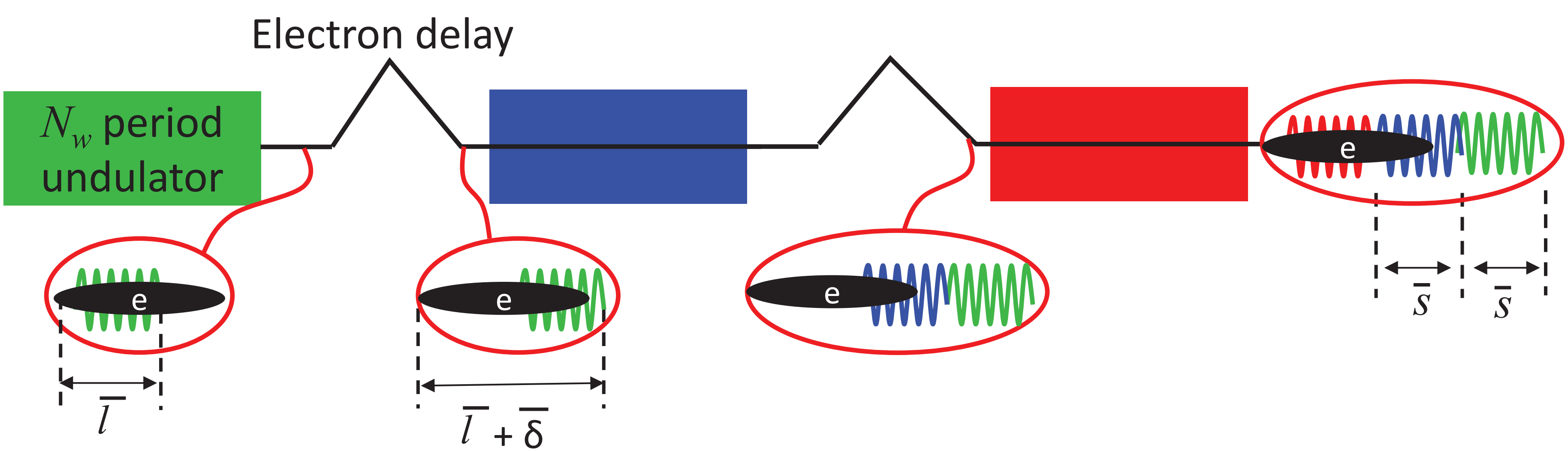
- Beamlet method – based on EEHG technique
- Electron Pulse is modulated and then dispersed



Chicanes

Pass radiation between beamlets using a undulator-chicane lattice

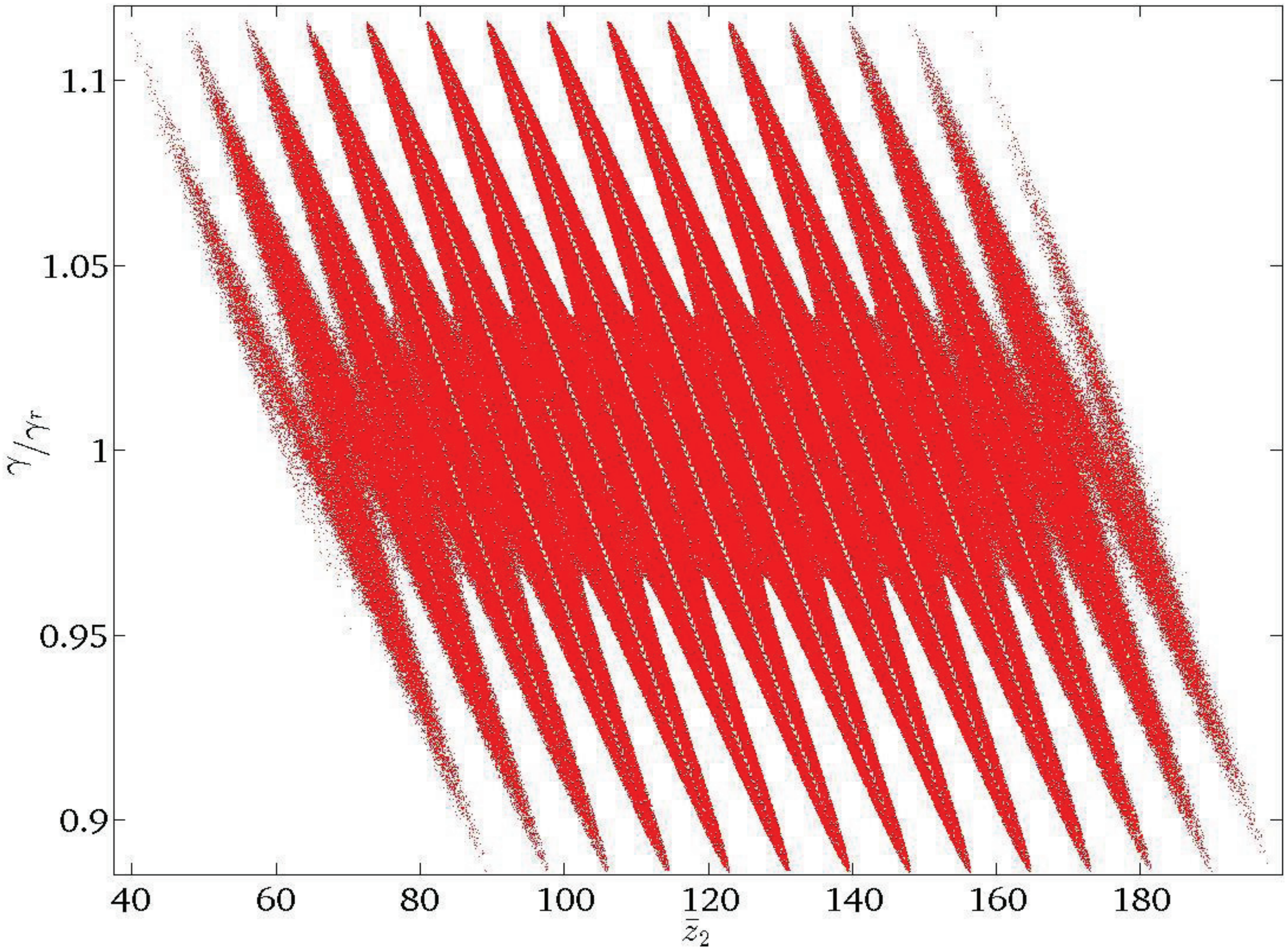




$$\bar{s} = \bar{l} + \bar{\delta}$$

$$\frac{\Delta\omega}{\omega_r} = \frac{4\pi\rho}{\bar{s}}$$

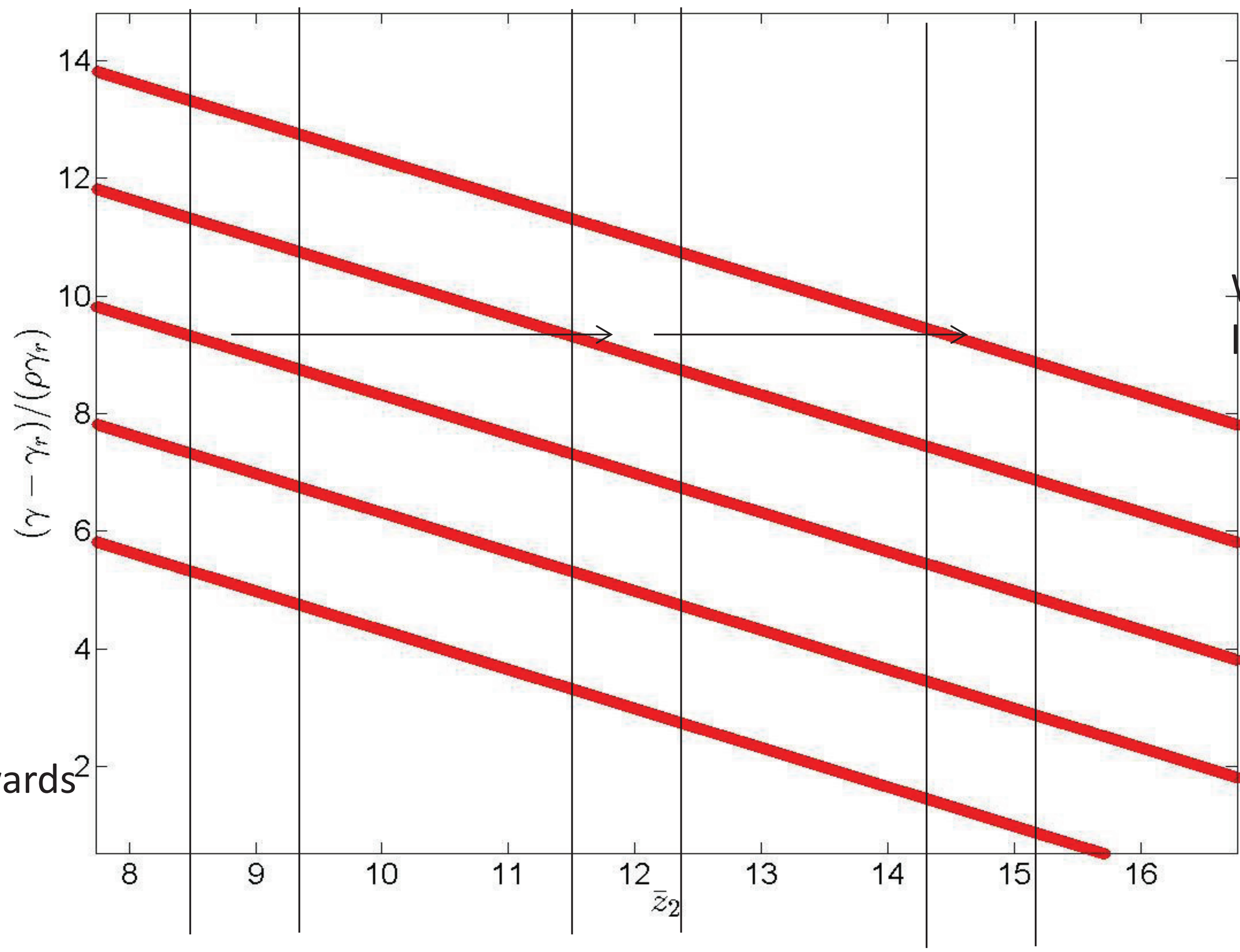
Real Beamlets



Simplified Model

Approximating the beamlets

Front of
light pulse



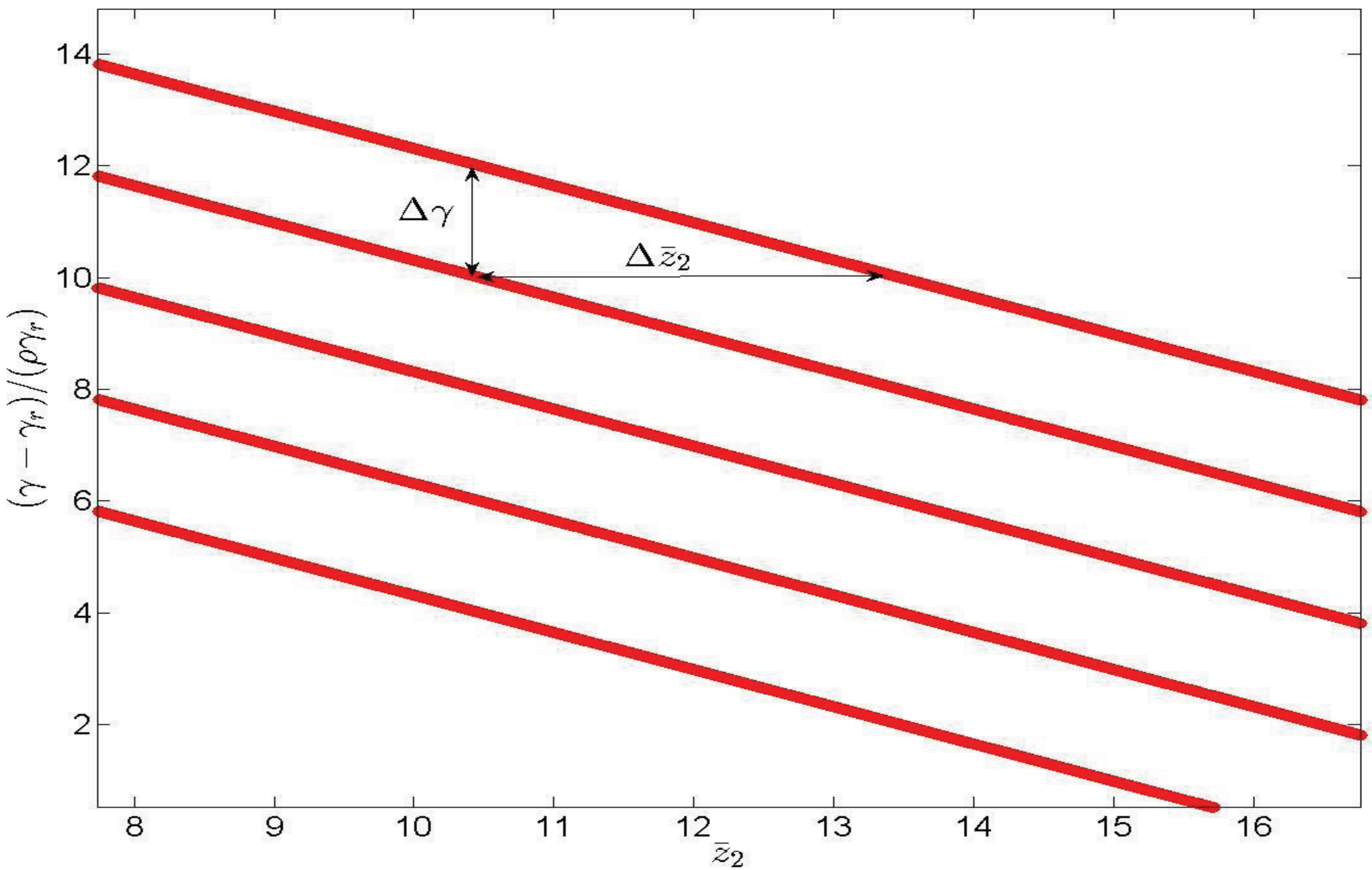
Window in
light frame

Electrons slip backwards
in the chicane

Units of cooperation length

-electrons

Simplified Model

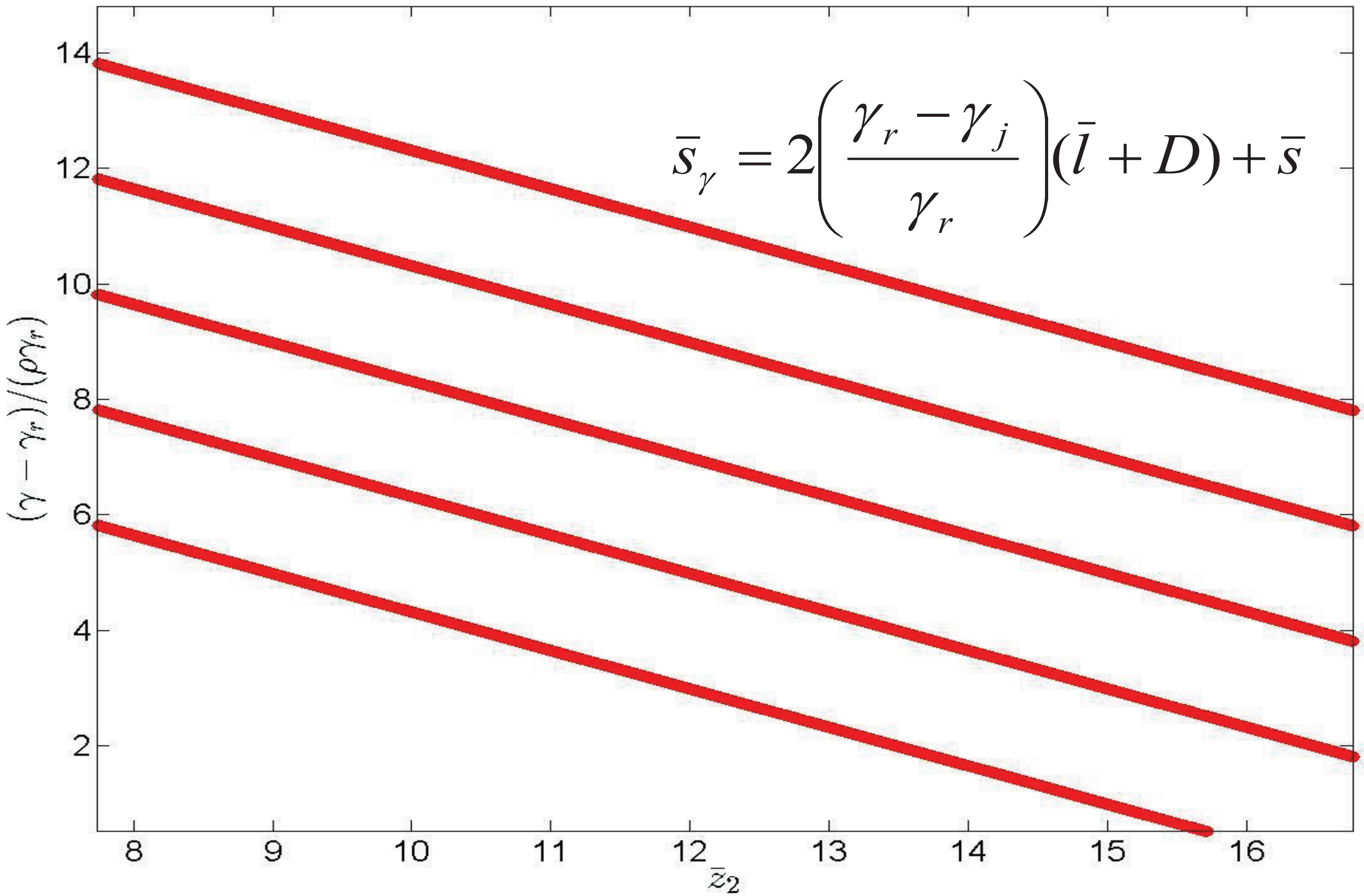


lattice and the resonant frequency difference of the beamlets

$$\frac{\Delta\omega_{\text{beamlet}}}{\omega_r}=2\frac{\Delta\gamma}{\gamma_r}\qquad \frac{\Delta\omega_{\text{modal}}}{\omega_r}=\frac{4\pi\rho}{\bar{s}}\qquad \Delta\omega_{\text{modal}}=\Delta\omega_{\text{beamlet}}$$

Potential Solution

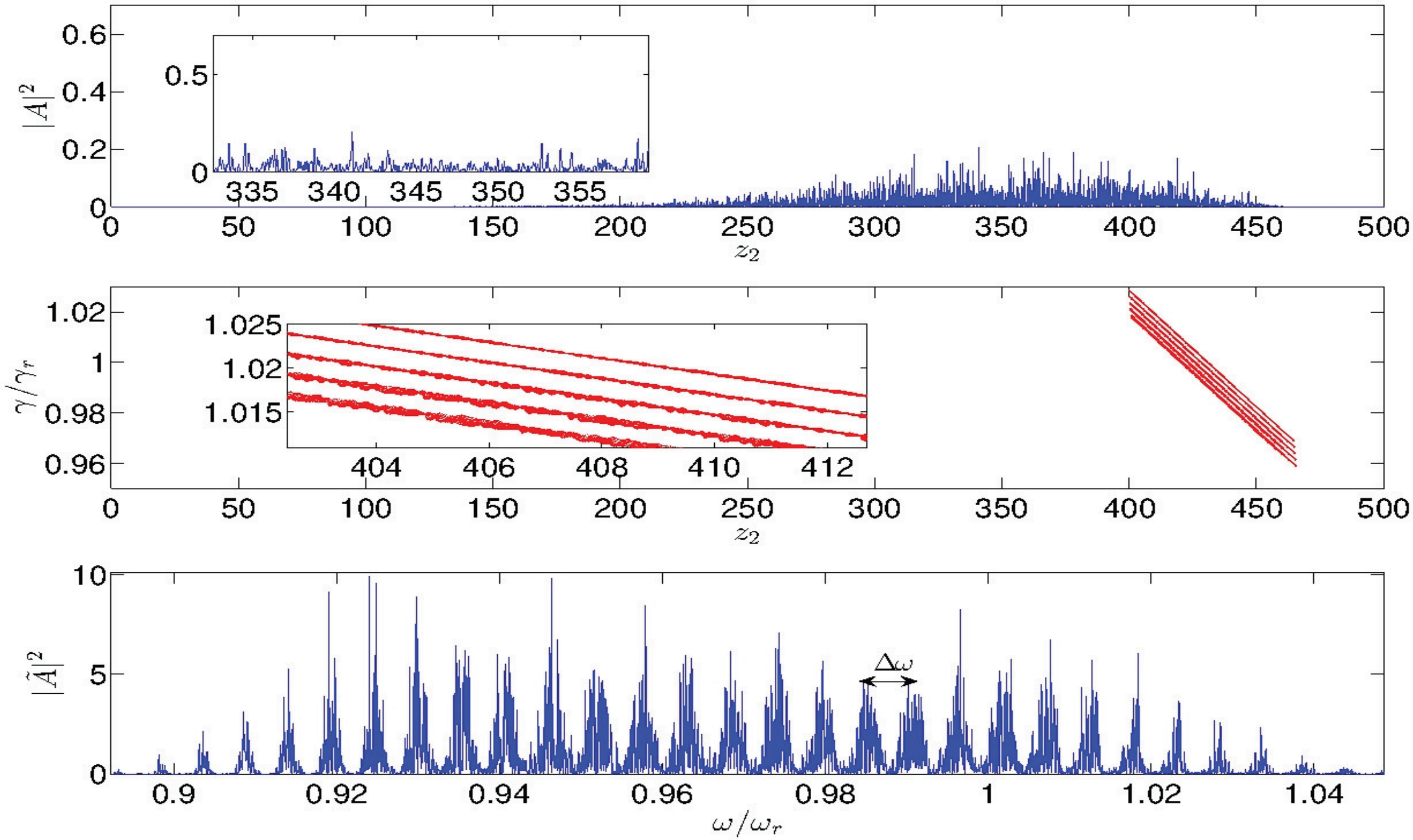
- Electron pulses with a large energy chirp exhibit an energy dependent slippage



- Electron of different speeds will take different paths from undulator and chicane
- Can lead to mismatching when passing radiation from beamlet to beamlet

The beamlet method (D=0)*

Mode-locked beamlet modes

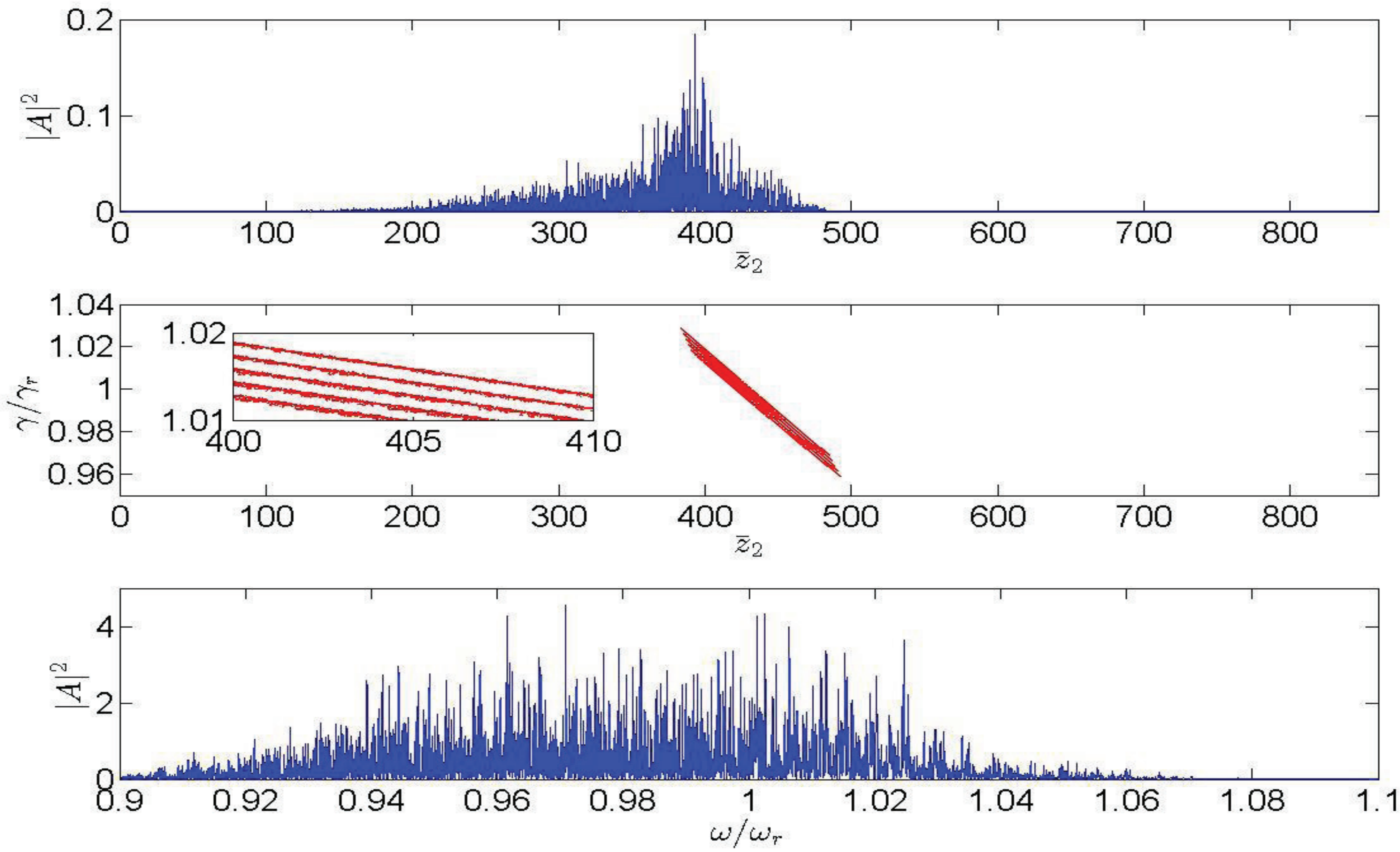


$$\bar{s} = 2.51, \bar{l} = 0.25, \bar{\delta} = 2.26, D = 0$$

$$\frac{\Delta\omega}{\omega_r} = \frac{4\pi\rho}{\bar{s}}$$

* James Jones' Ref

The beamlet method (D>0)

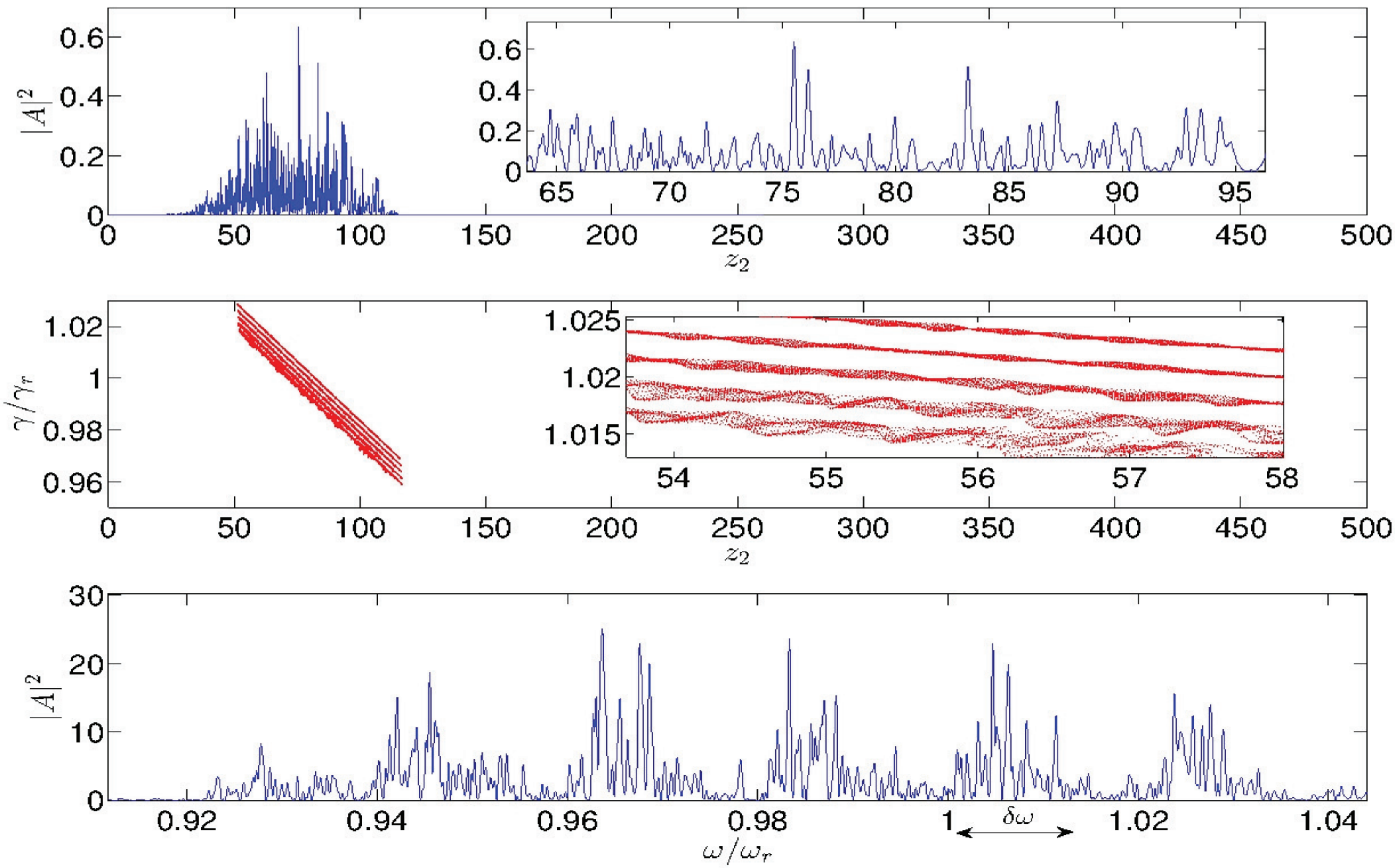


$\bar{s} = 2.51, \bar{l} = 0.25, \bar{\delta} = 2.26,$ $\boxed{\mathrm{D} = 0.3}$

$$\bar{s}_\gamma = 2\left(\frac{\gamma_r - \gamma_j}{\gamma_r}\right)(\bar{l} + D) + \bar{s}$$

The beamlet method (D=0)

$$\frac{\Delta\omega}{\omega_r} = \frac{4\pi\rho}{\bar{\delta}}$$

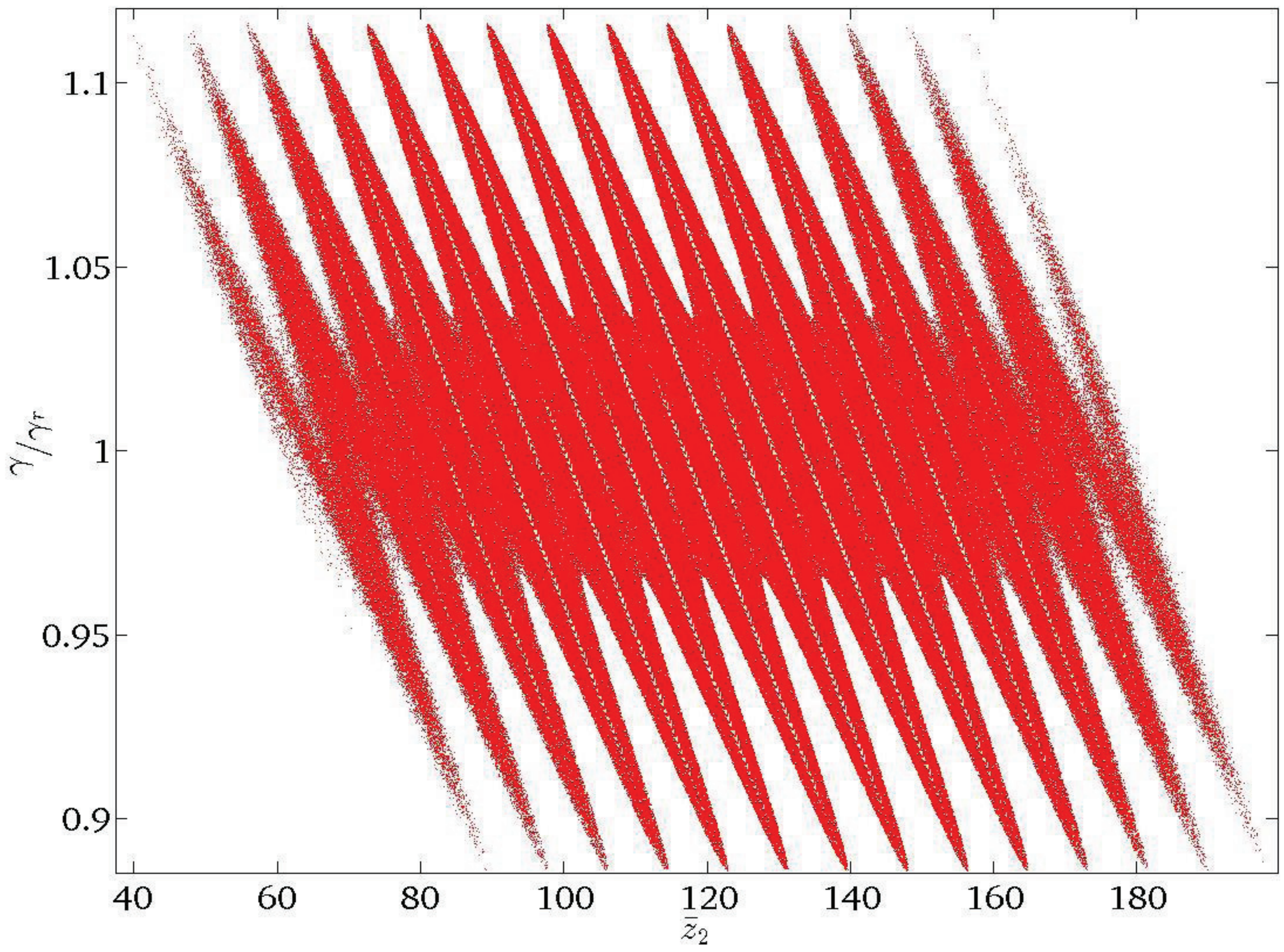


$\bar{s} = 2.51$, $\bar{l} = 1.88$, $\bar{\delta} = 0.63$, $\mathrm{D} = 0$

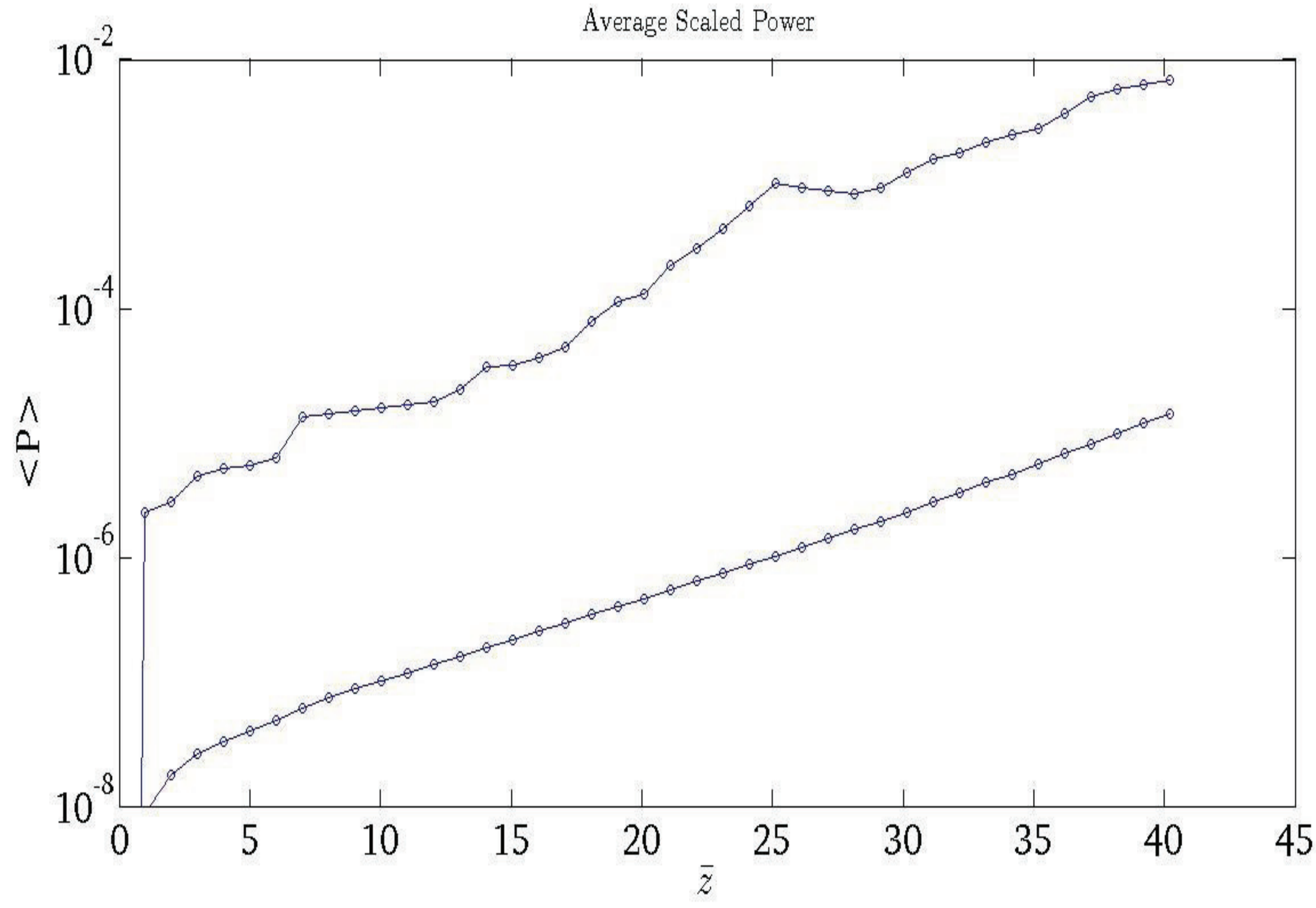
$$\bar{s}_\gamma = 2\left(\frac{\gamma_r - \gamma_j}{\gamma_r}\right)(\bar{l} + D) + \bar{s}$$

The beamlet method

- Electron Pulse is modulated and dispersed

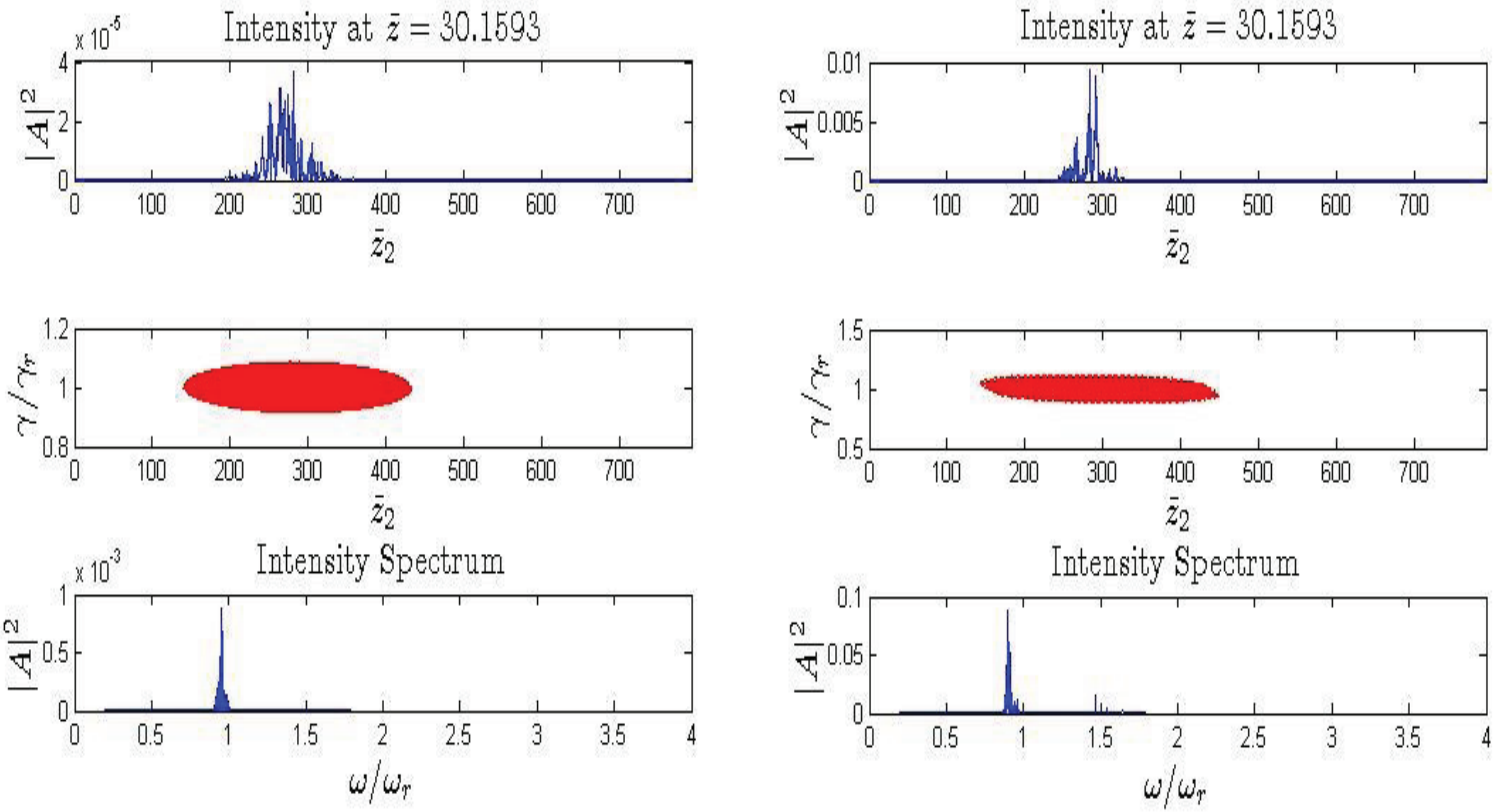


The beamlet method



The beamlet method

No Beamlets | Beamlets



Conclusion

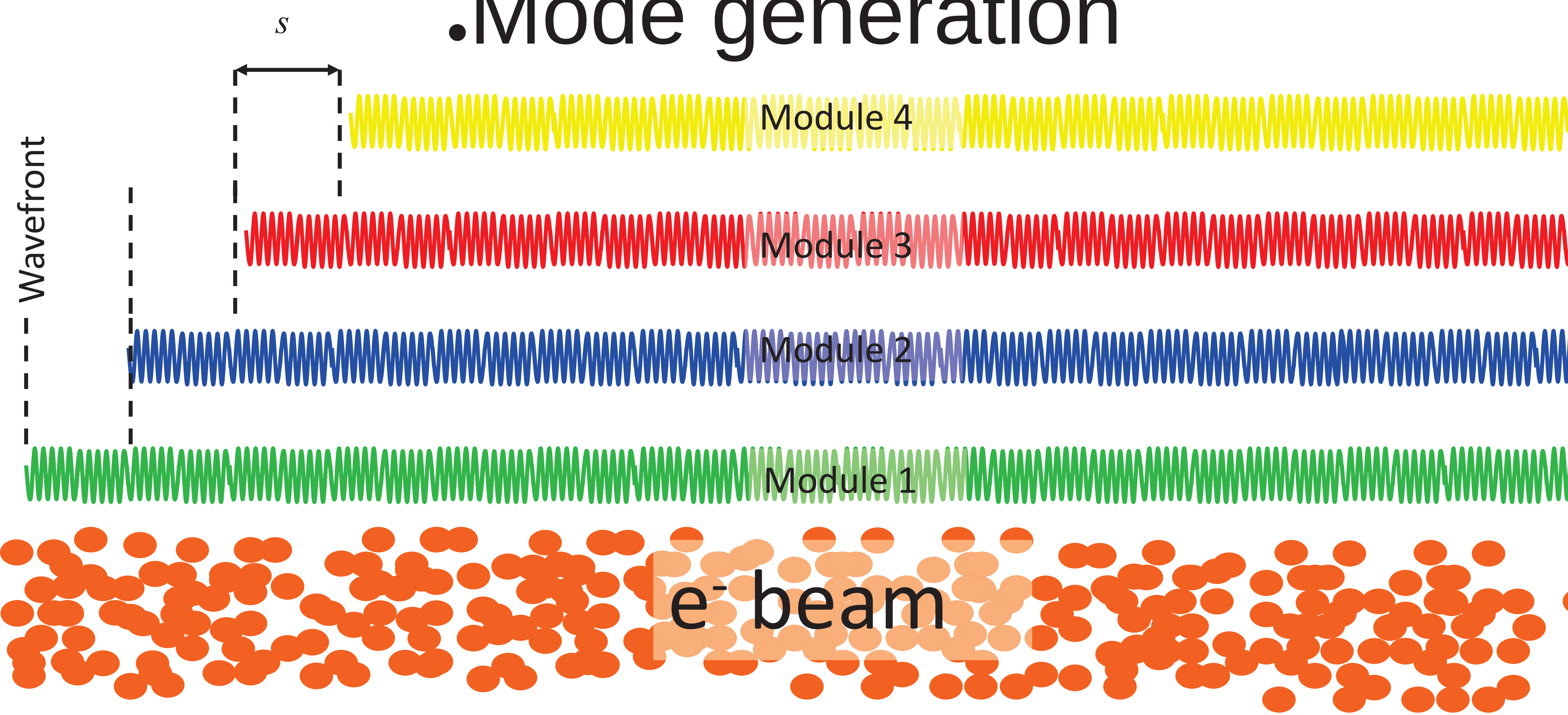
- Method to improve the FEL output was presented
- This is on-going research
- Results so far are promising with two-three order magnitude improvement

Future development

- Optimization of the beamlet parameters
- Using a taper to cancel out the beamlet chirp
- Use of these techniques for multi electron pulse schemes

Thanks for listening.
Any questions?

.Mode generation

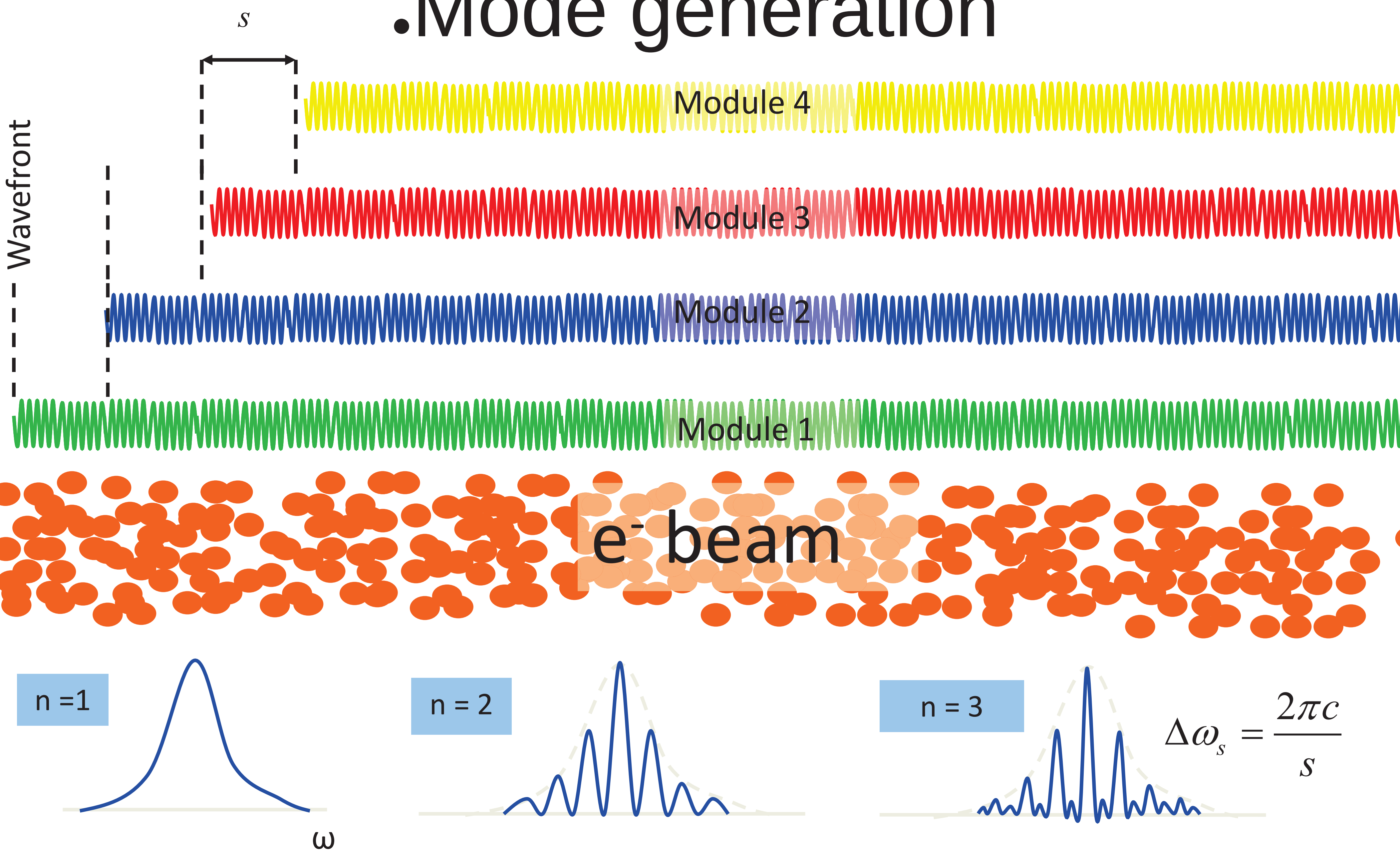


For continued slips of distance s, only those wavelengths with an integer number of periods in distance s will survive after many such slips. For s an integer of λ_j :

$$s = N\lambda_j = (N+1)\lambda_{j-1}$$

$$\Rightarrow \omega_j = \frac{2\pi c N}{s};\ \omega_{j-1} = \frac{2\pi c\left(N+1\right)}{s} \quad \Rightarrow \Delta\omega_s = \omega_{j-1} - \omega_j = \frac{2\pi c}{s}$$

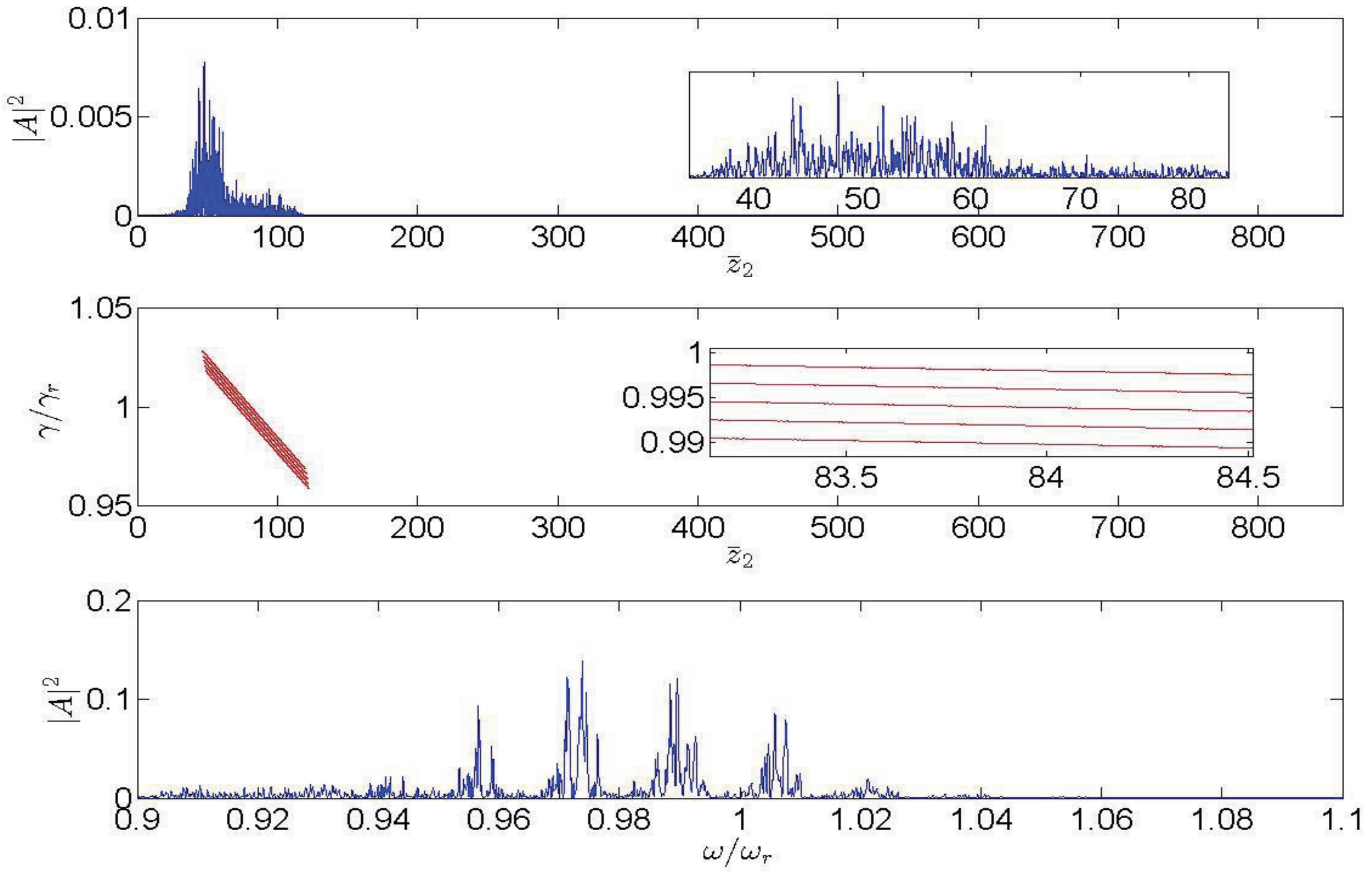
.Mode generation



$$\Delta\omega_s = \frac{2\pi c}{s}$$

The spectrum is the same as a ring cavity of length s. A ring cavity of length equal to the total slippage in each undulator/chicane module has been synthesized

The beamlet method

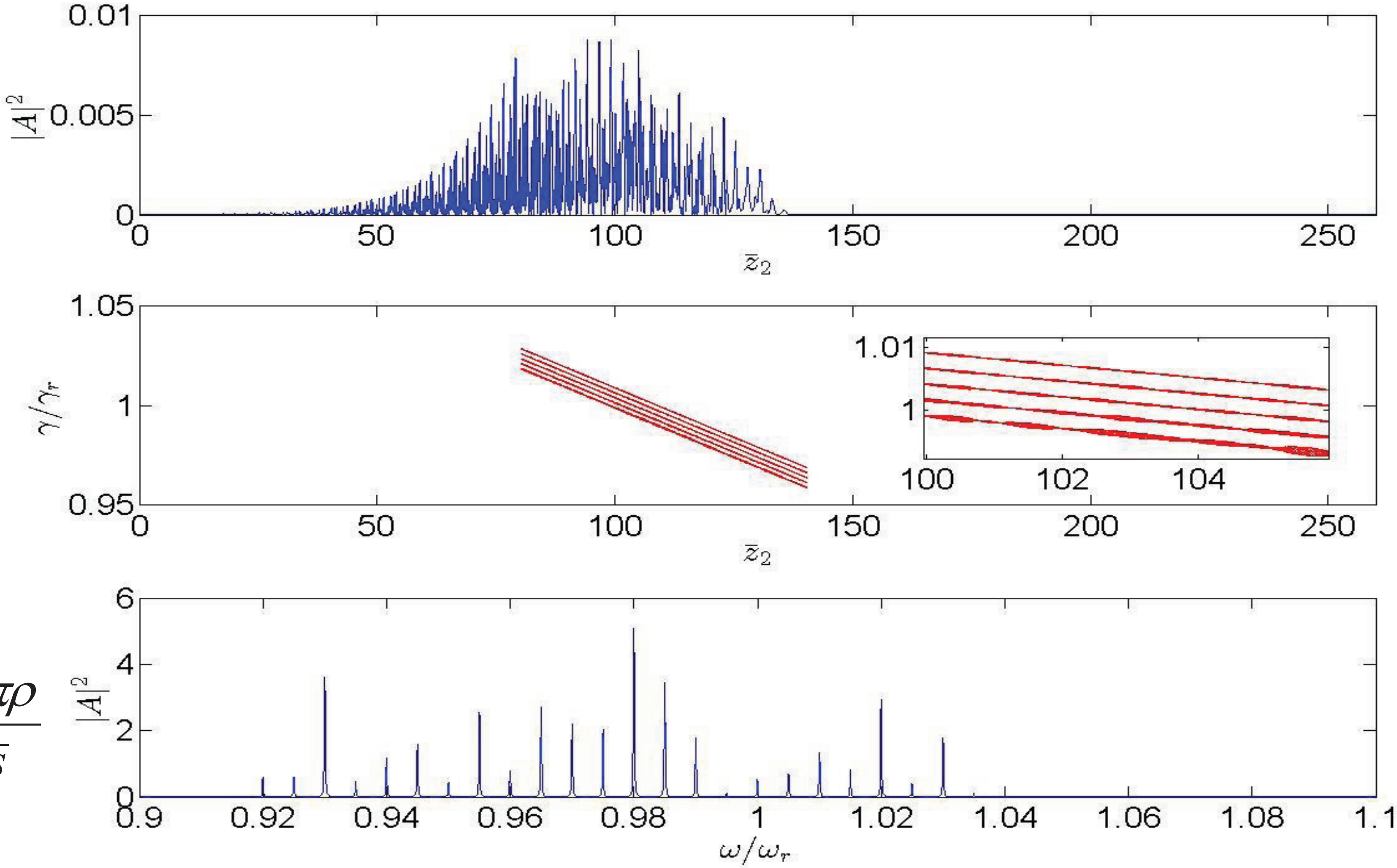


U-CD-U-CS -special undulator-chicane modules

- U – undulator
- CD – dispersion only chicane
- CS – slippage only chicane

$$\frac{\Delta\omega}{\omega_r} = \frac{4\pi\rho}{\bar{\delta}}$$

The beamlet method



$$\frac{\Delta\omega}{\omega_r} = \frac{4\pi\rho}{\bar{s}}$$

$$\bar{s} = 2.51, \bar{l} = 1.88, \bar{\delta} = 0.63, D = -1.88$$

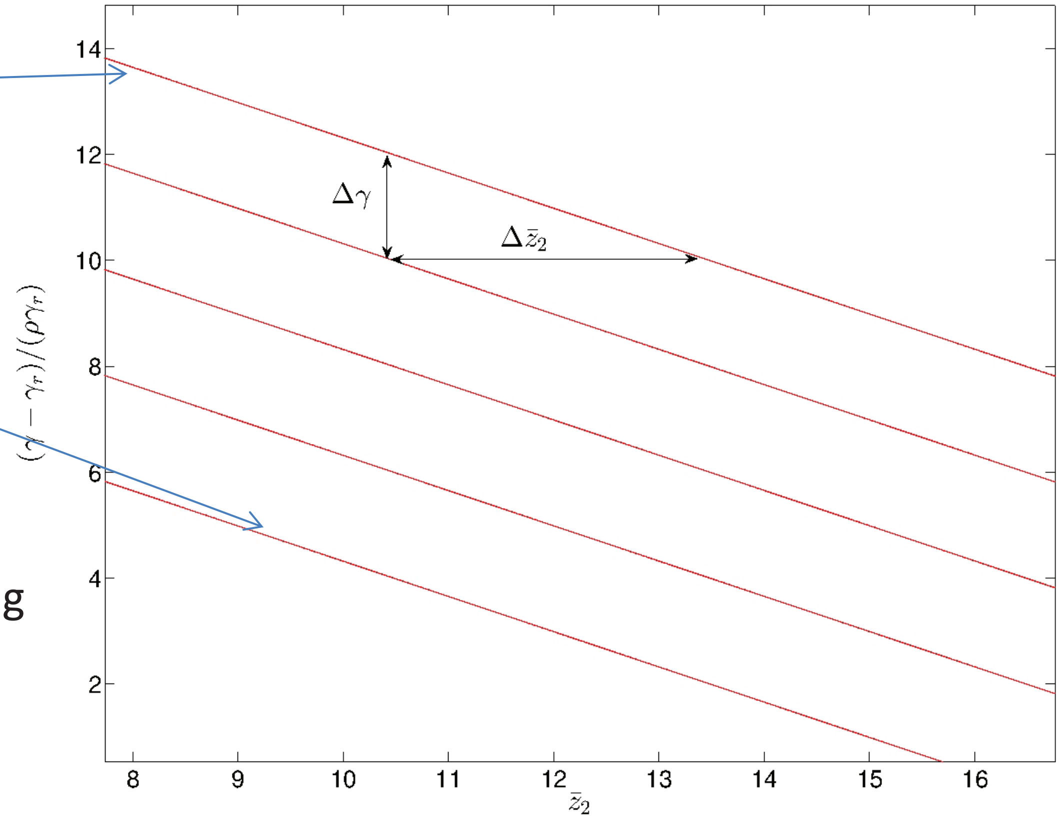
$$\bar{s}_\gamma = 2\left(\frac{\gamma_r - \gamma_j}{\gamma_r}\right)(\bar{l} + D) + \bar{s}$$

The beamlet method

- Electron pulses with a large energy chirp exhibit an energy dependent slippage

$$\bar{s}_{\gamma} = 2\left(\frac{\gamma_r - \gamma_j}{\gamma_r}\right)(\bar{l} + D) + \bar{s}$$

- These electrons take a shorter path through the undulator than lower energy electrons



- Can lead to mismatching when passing radiation from beamlet to beamlet

Potential Solution