Dual RF Cavity Monochromatization

Towards Higher Resolution Time-Resolved Electron Energy Loss Spectroscopy

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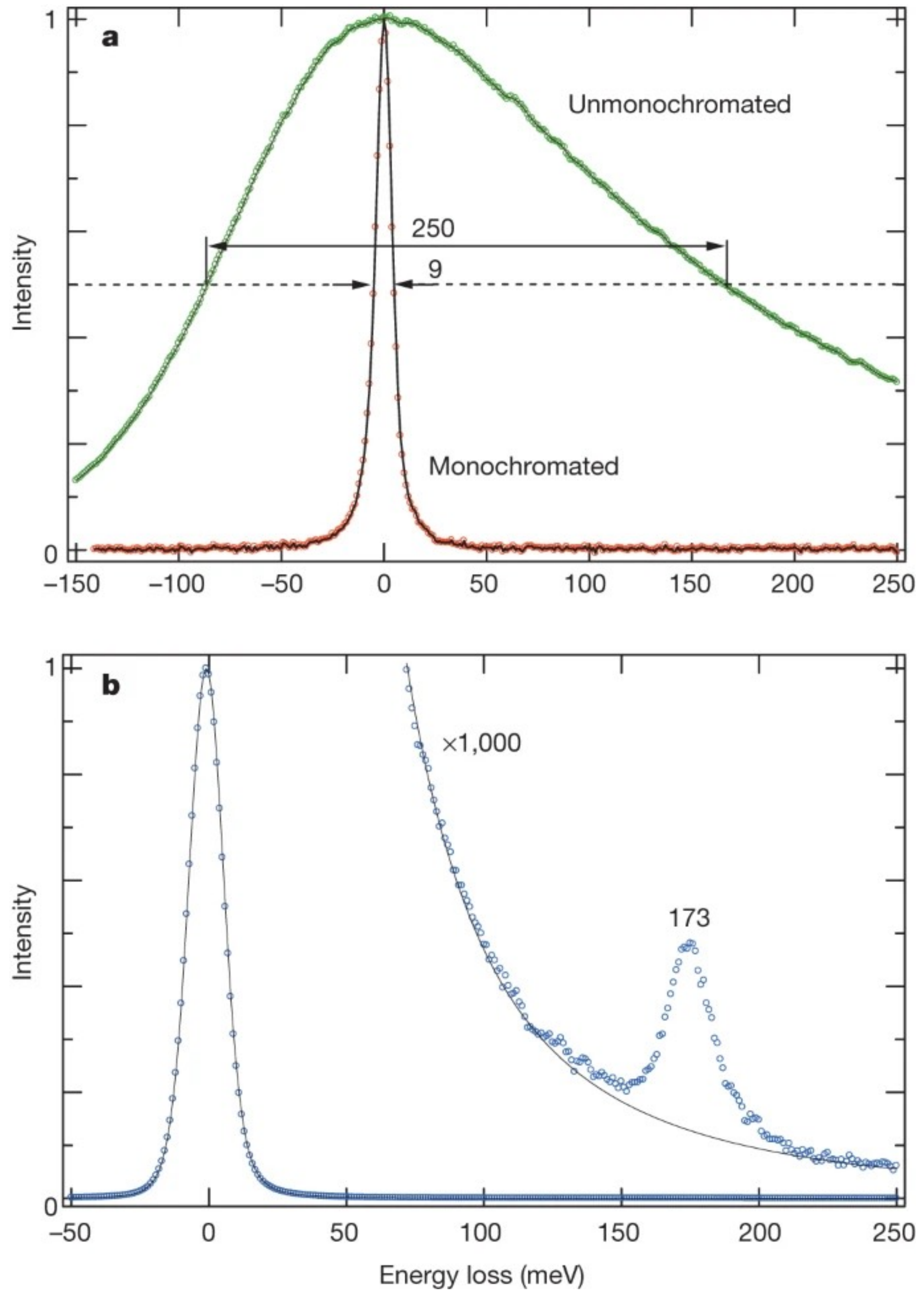
Electron Energy Loss Spectroscopy

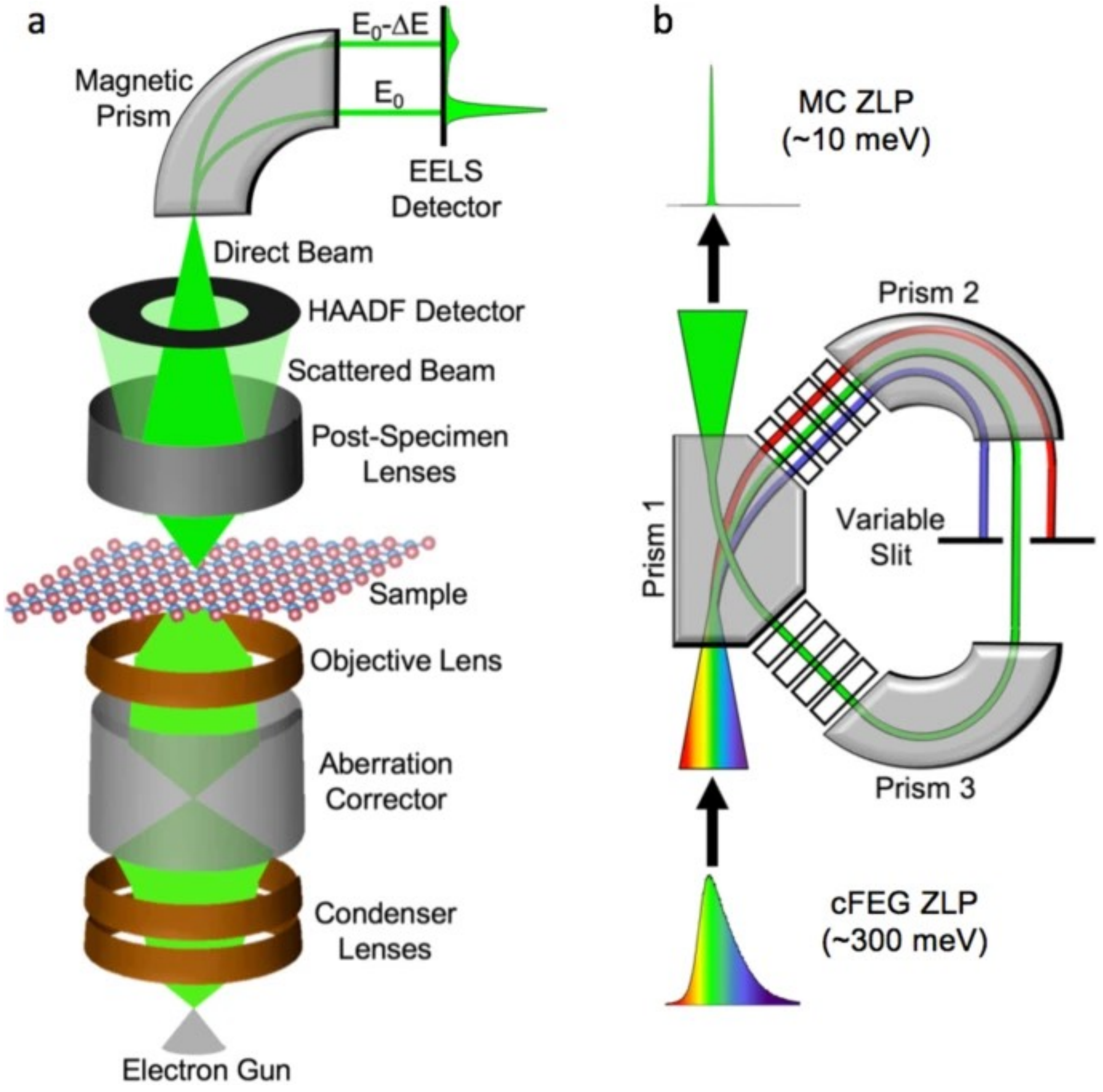
- Modern condensed matter relies on inelastic scattering techniques
- Recent advances have shown electron energy loss spectroscopy (EELS) to be promising to investigate dispersion relations
- For high-resolution EELS, we require small energy resolution (meV) which requires a monochromator



O. L. Krivanek et al., *Nature*, 2014.

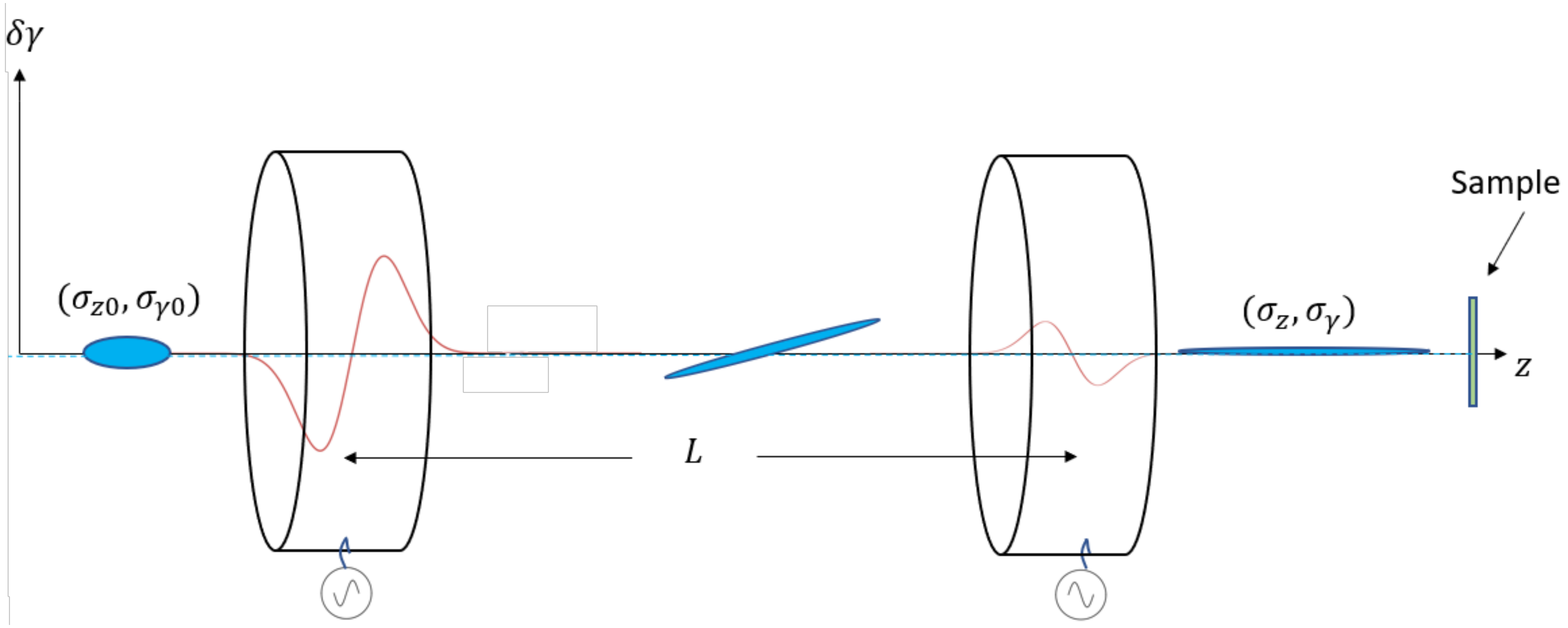
Current Monochromators

- Typically, energy spread mainly comes from thermal spread from the cathode (0.1-0.5 eV)
- Currently, we trade current for fine energy resolution
- If the initial beam is pulsed, we can trade off bunch length for energy resolution (Duncan et al., *Physical Review Applied*, 2020)



J. A. Hachtel et al, *Scientific Reports,* 2018.

Our Scheme



- Pulsed photoemission yields an initial electron bunch
- Liouville Theorem | Phase space area must be conserved
- Can provide meV energy resolution in exchange for temporal broadening

Theory

- Transport matrix for the longitudinal dynamics $(z_0, \Delta\gamma_0)$ -> $(z, \Delta\gamma)$ for the scheme
- We set the second cavity to nullify the linear correlation
- Optimal Compensation:

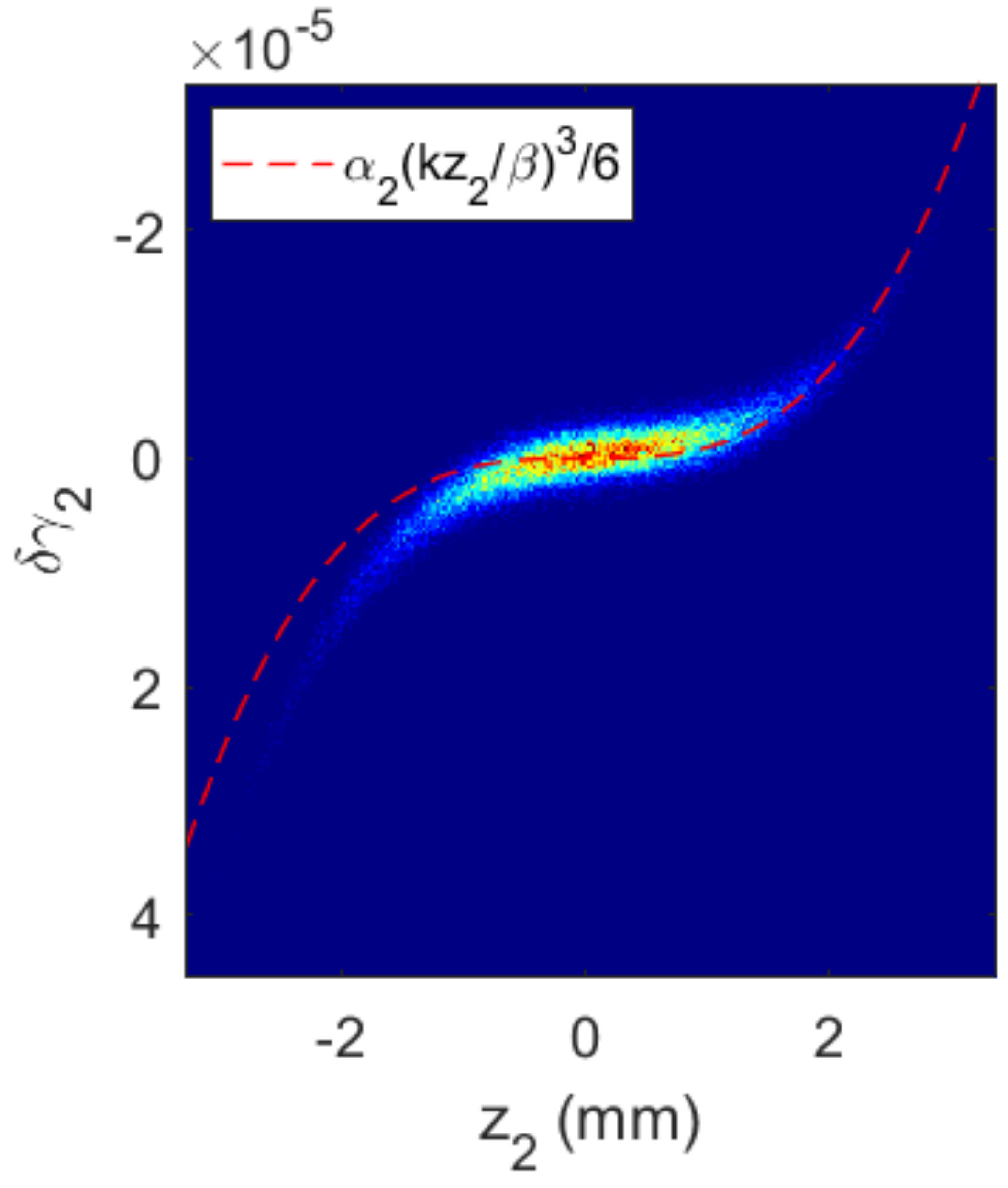
$$C = \frac{\Delta\gamma_0}{\Delta\gamma} = \frac{1}{1 + \eta_1 \alpha_1 L k_1 / \beta}$$

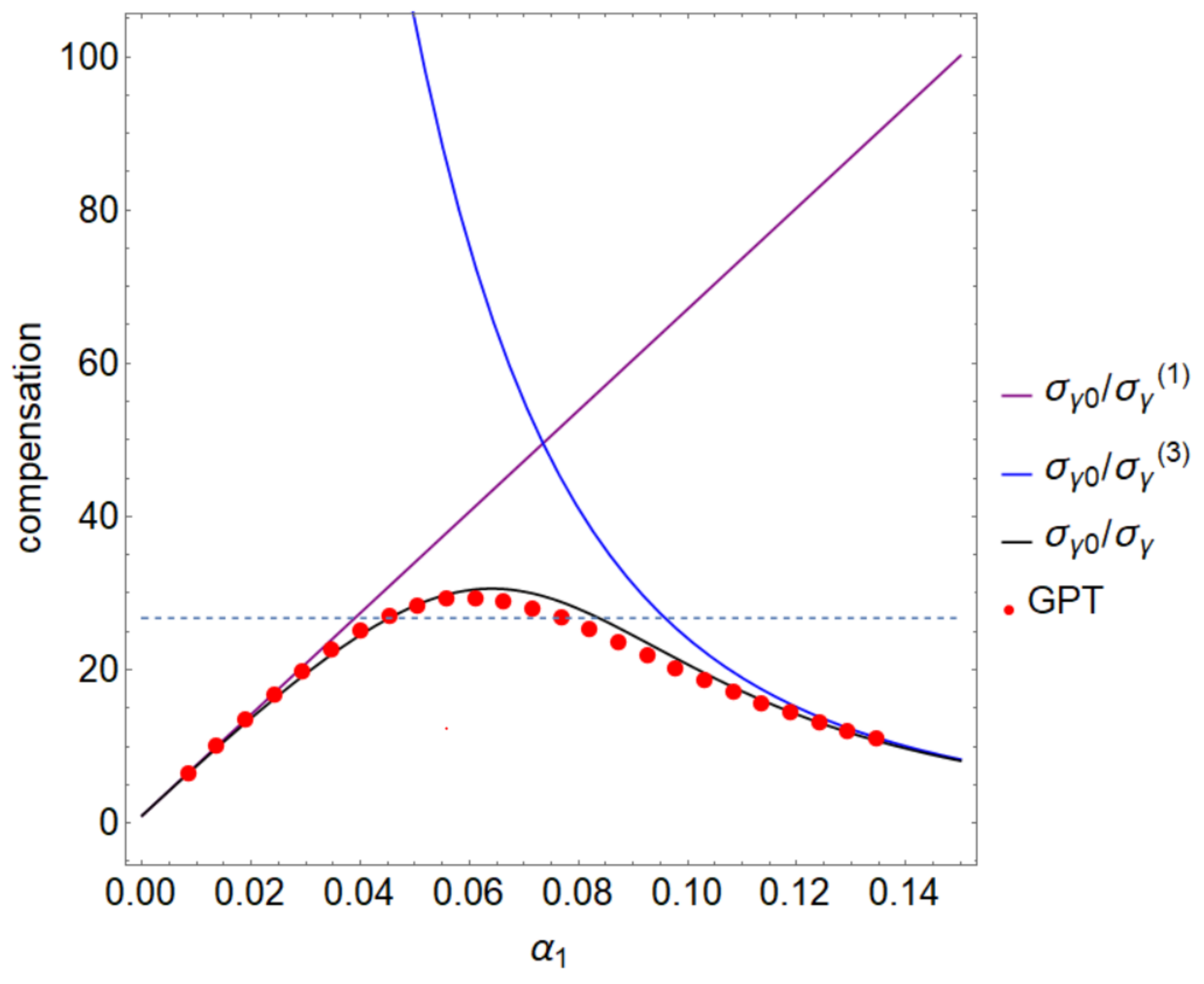
L is the drift length,
α_1 is the normalized accelerating voltage of the first cavity
k_1 is the wavenumber for the first cavity
$\eta_1 = 1/\gamma^3\beta^2$ where γ, β are the relativistic gamma and beta factors

Limits

- Tradeoff implies we want large drift length to maximize compensation
- A large bunch entering the second cavity will sample too much RF phase
- Optimal compensation is limited by the 3rd-order effects at the second cavity

Mildly overcompensated simulation

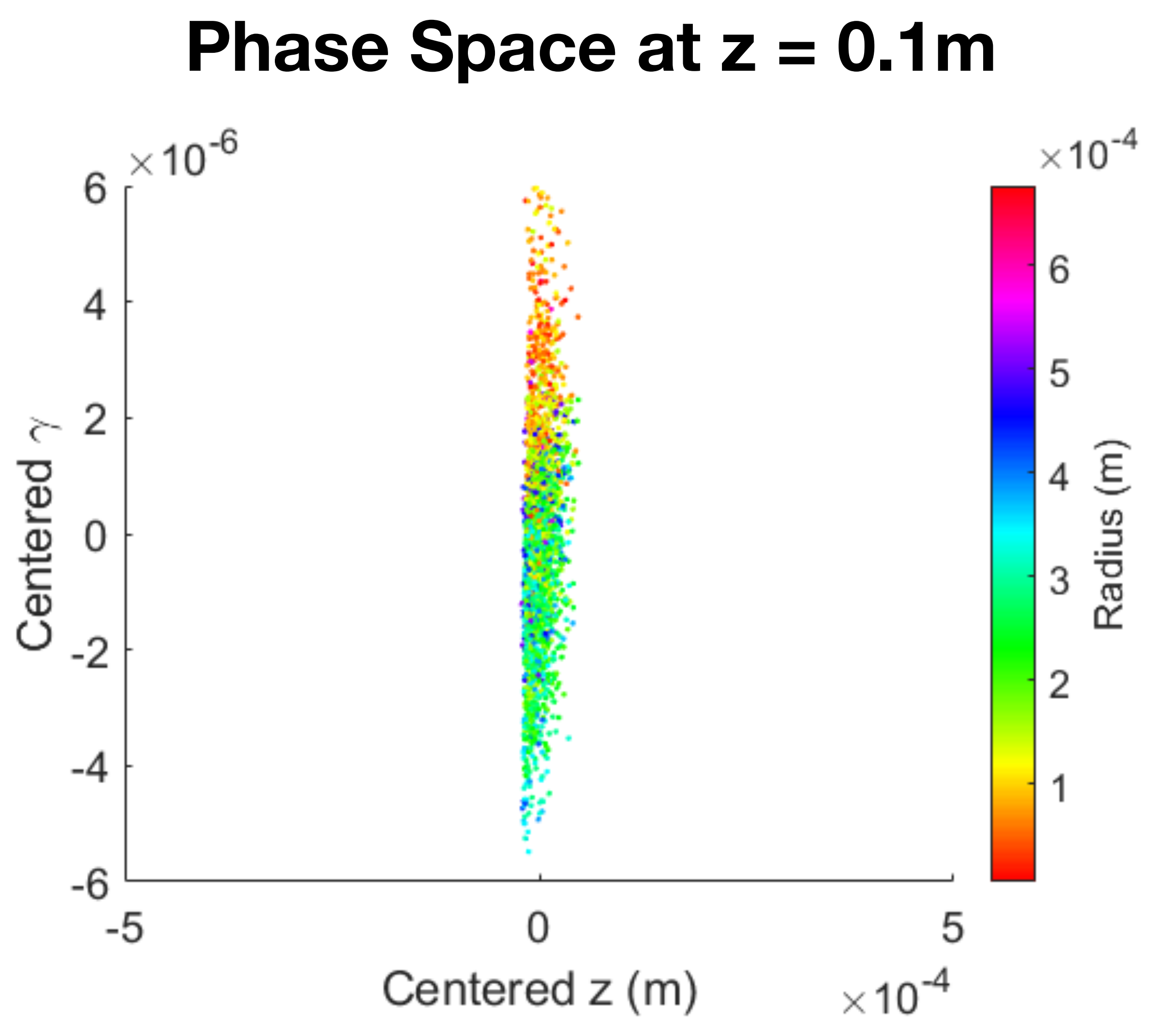


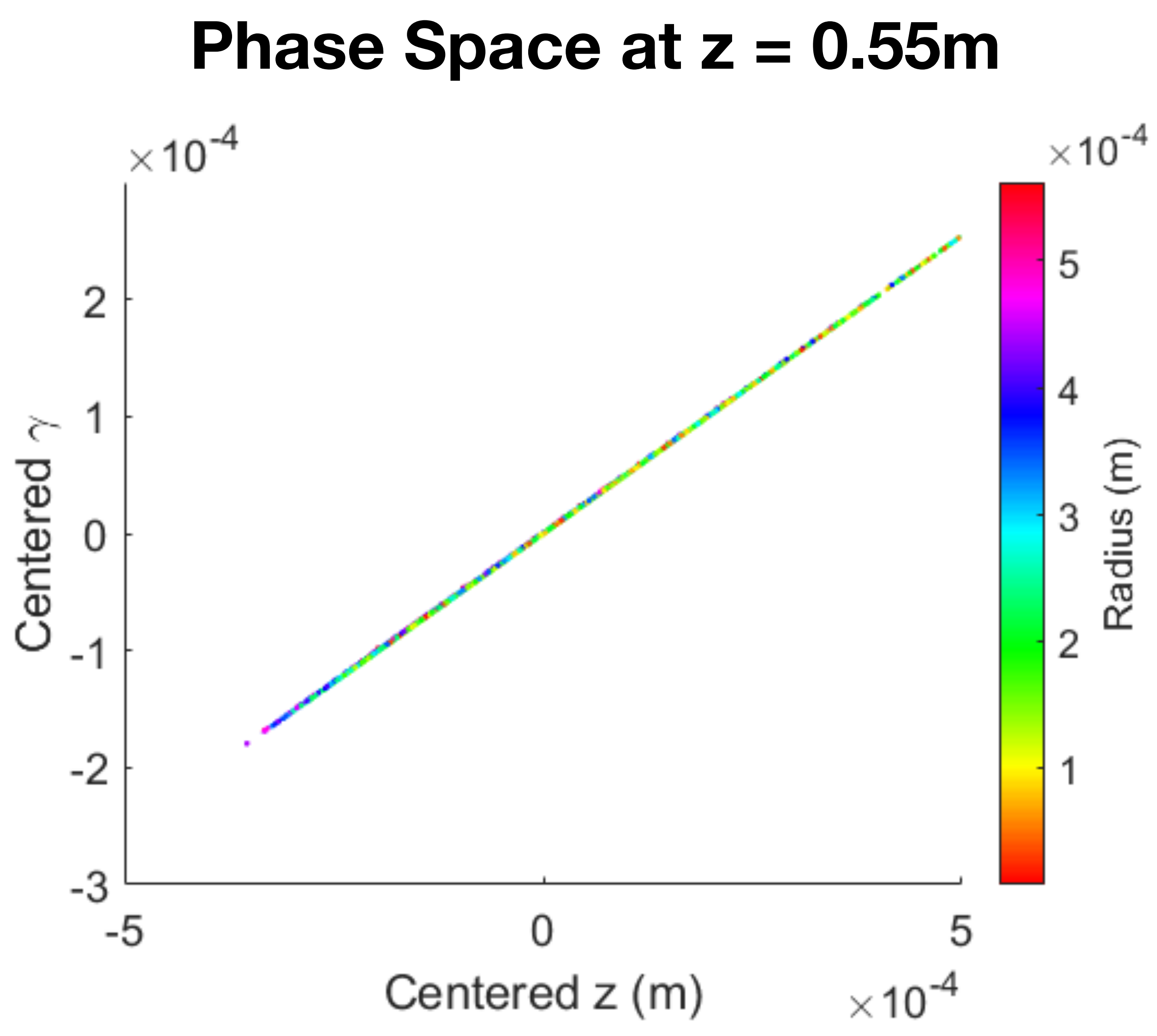


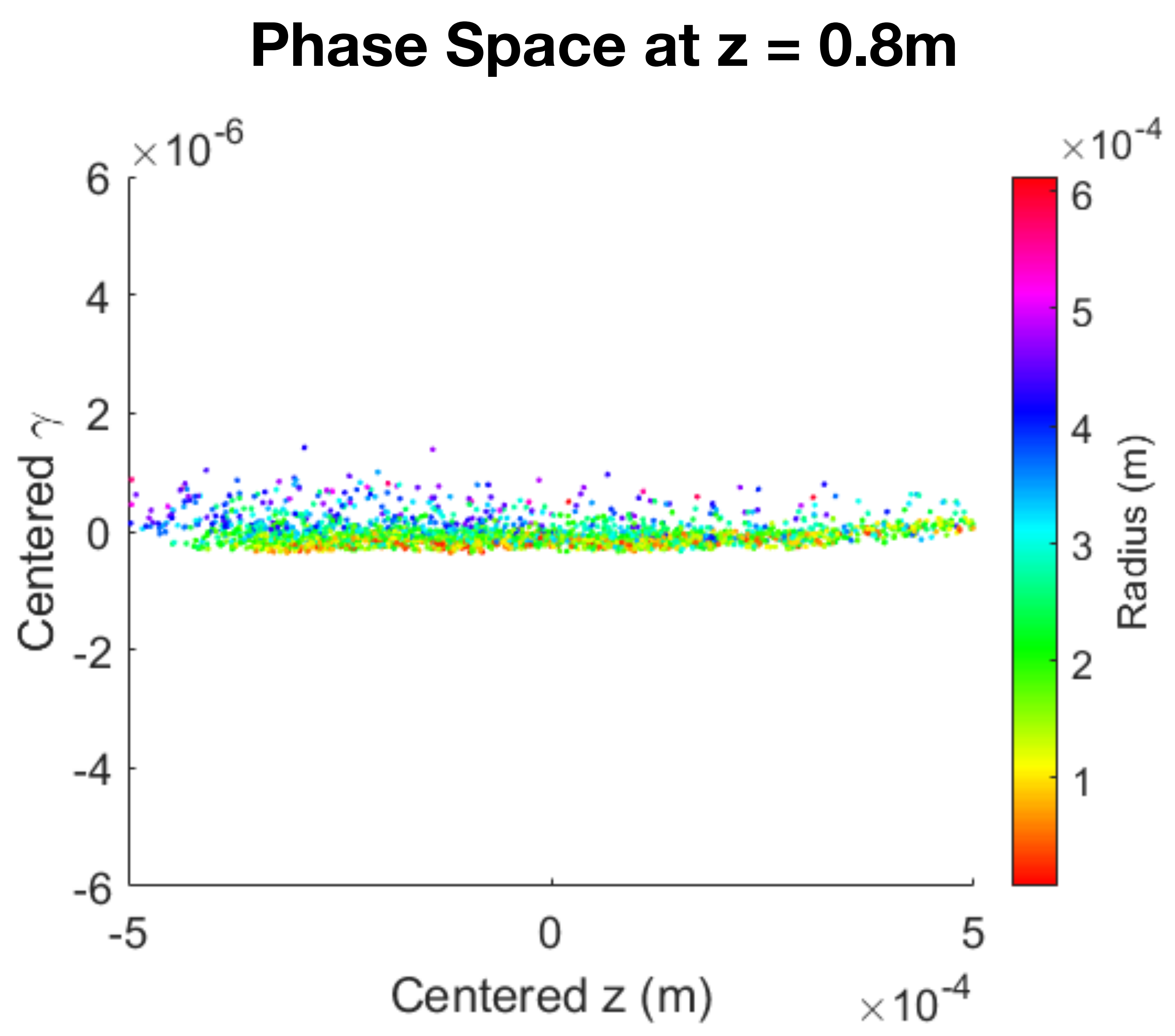
Numerical Study

- Numerical study of the 3D dynamics using General Particle Tracer
- Cavities placed at z = 0.2 m, 0.7 m
- Two solenoids at z = 0.05 m, 0.32 m
- Obtained a compensation of 17.6 - slightly off the analytical optimum of 20

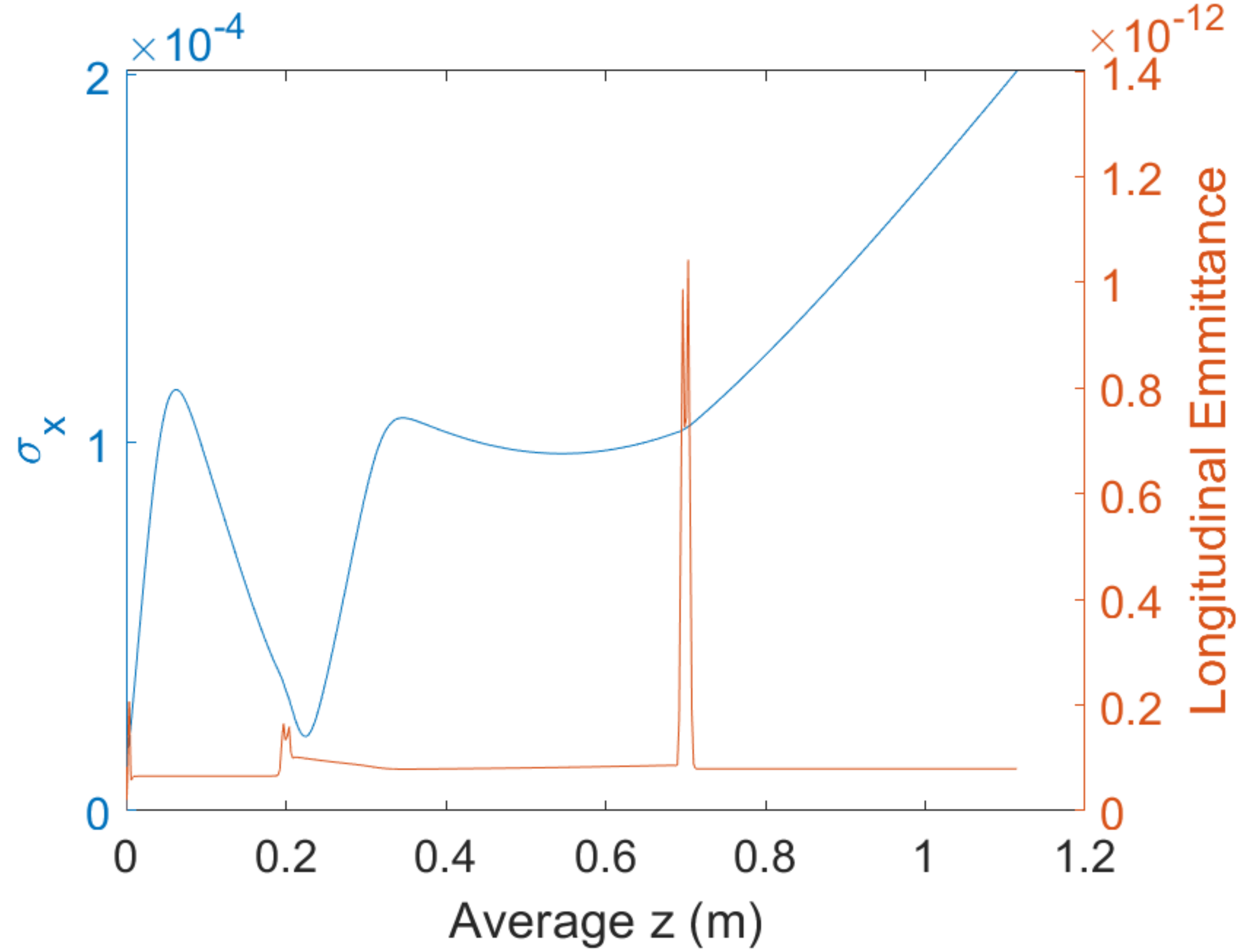
Parameter	Value
γ	36 keV
σ_{t0}	40 fs
$\sigma_{\gamma 0}$	0.22 eV
f	2.856 GHz
r	30 um

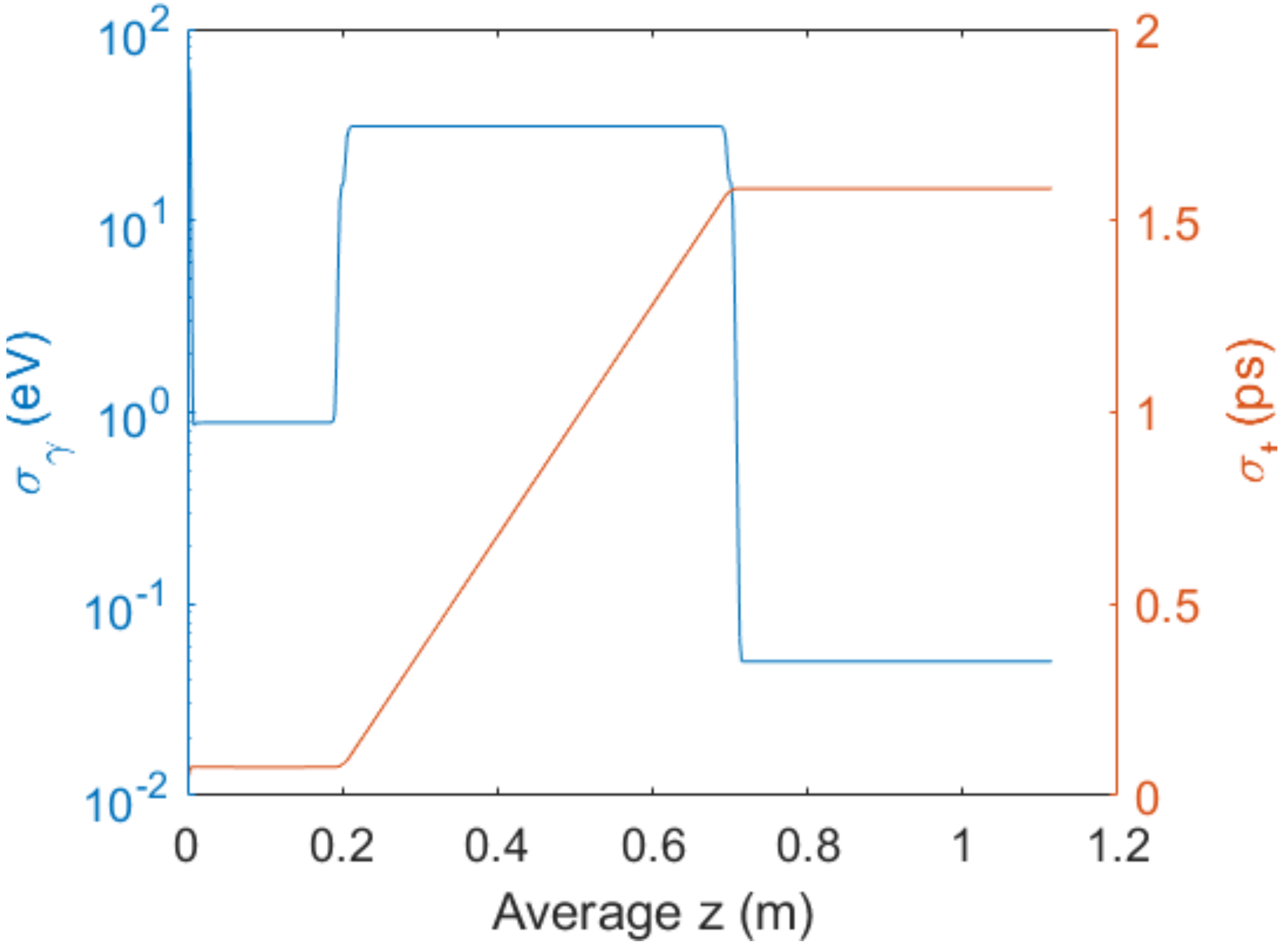

Phase Space at z = 0.1m


Phase Space at z = 0.55m


Phase Space at z = 0.8m

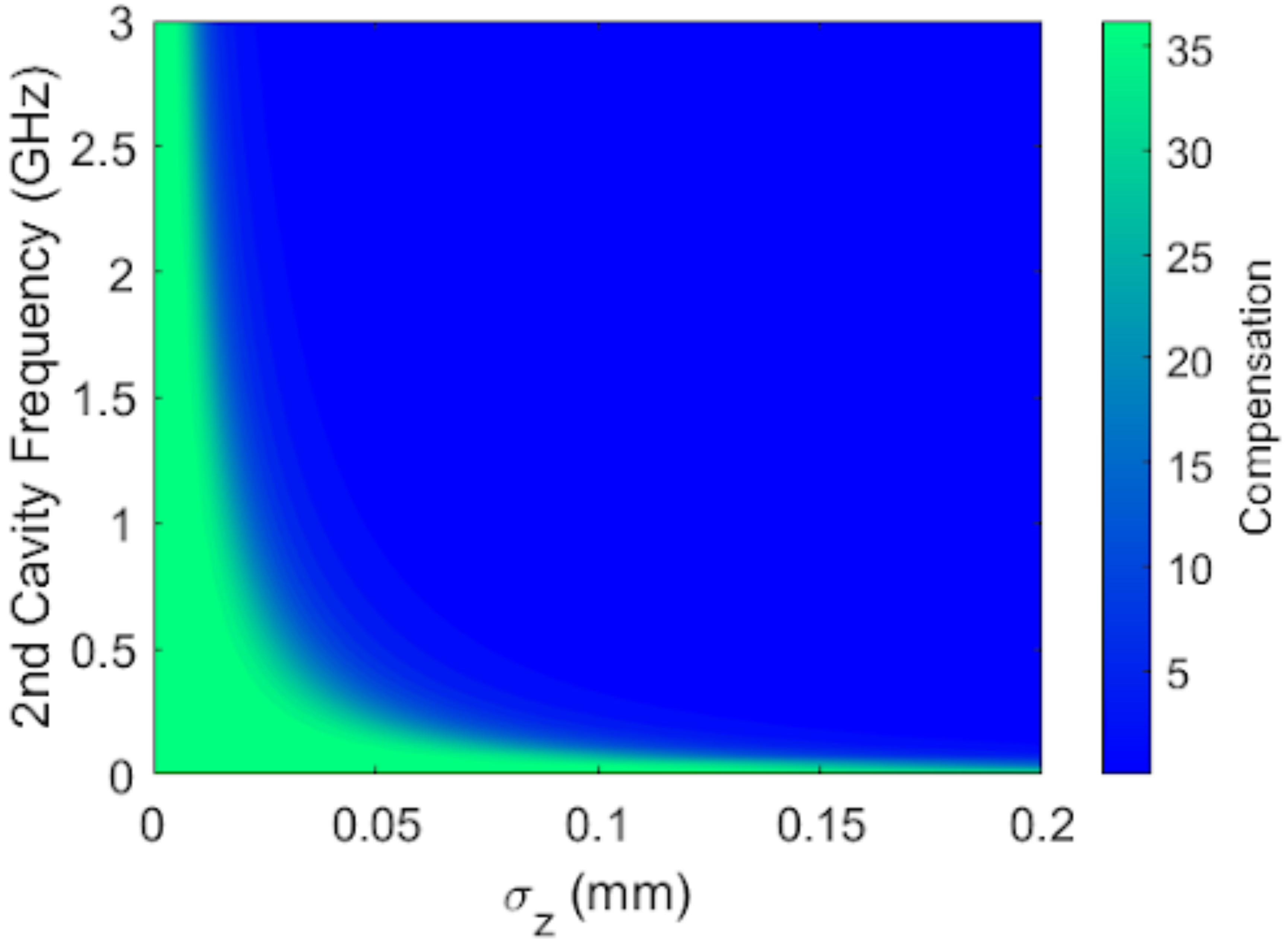
Optimal Compensation Beam Evolution





Exploring Two Different Frequency Cavities

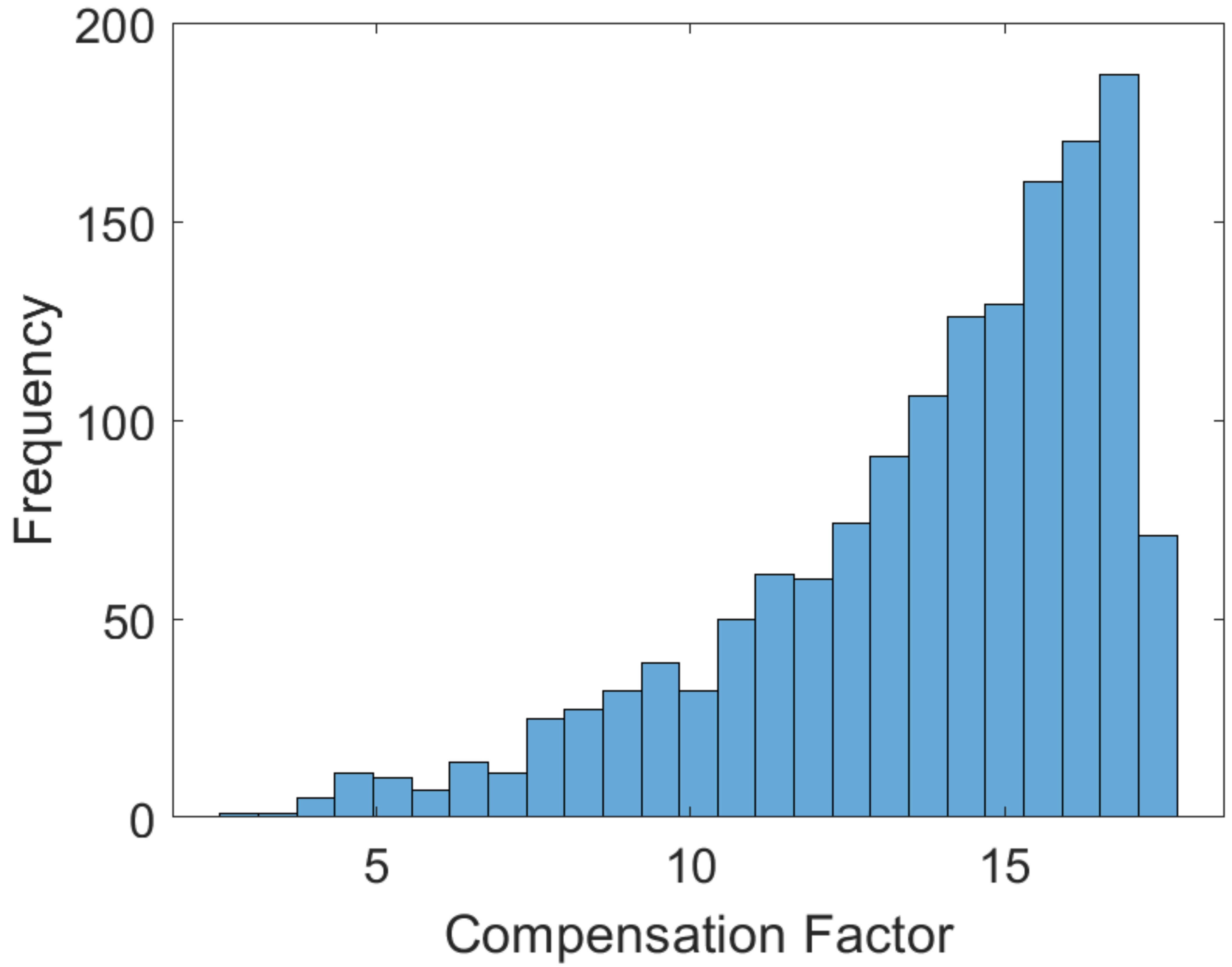
- Cavity 2 must have a lower frequency then the first cavity for the scheme to get better
- Highly dependent on the initial bunch length
- Stronger synchronization requirement to sample adequate RF phase
- Can theoretically achieve very large compensations at the expense of cavity size



Jitter Effects

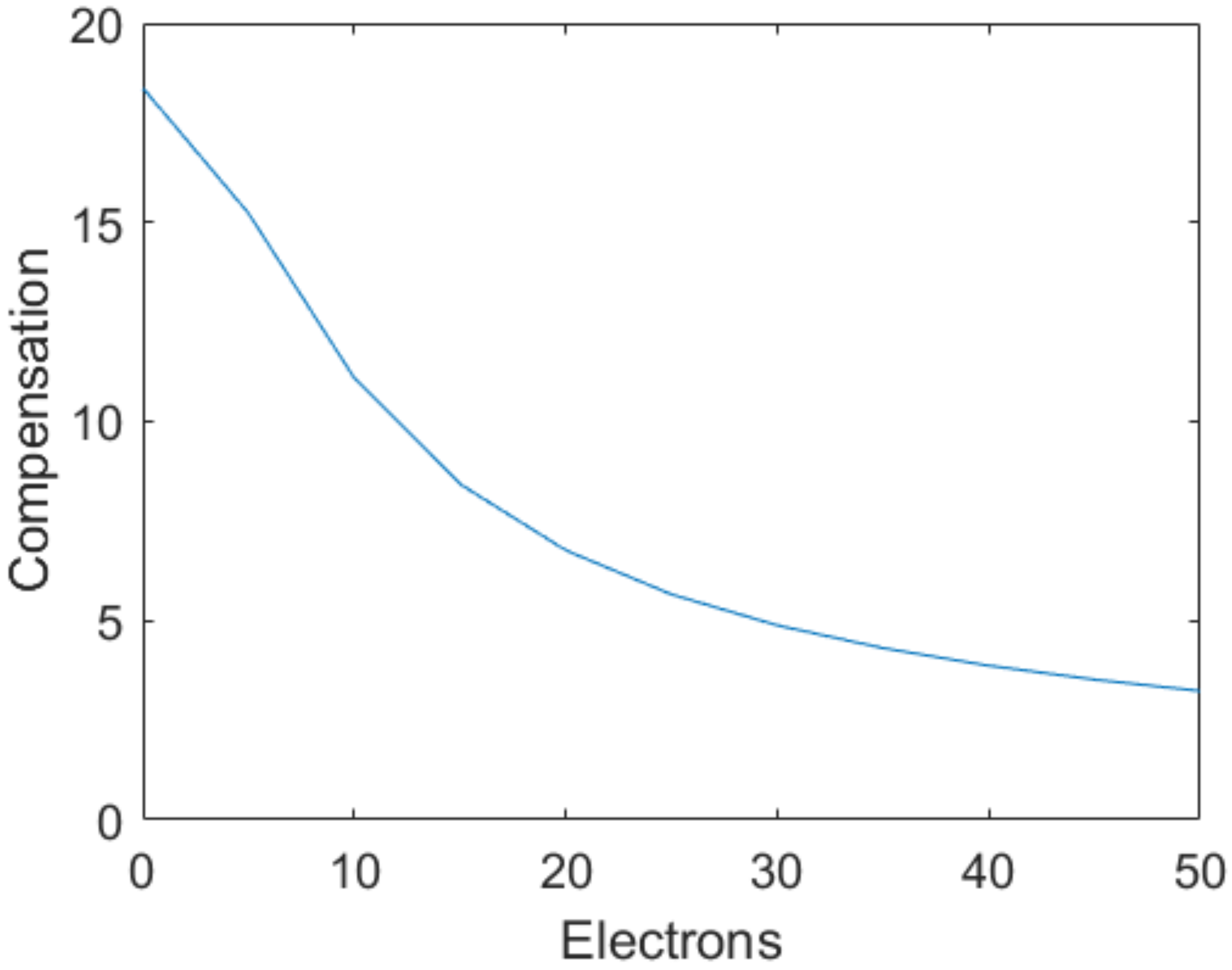
- The scheme is relatively tolerant to fluctuations in amplitude (0.1%) and phase (< 0.1 deg)
- The changes in amplitude and phase do push the scheme off optimum
- A feedback control system can be used to keep the cavities within reasonable values

500 simulations with randomly fluctuating phases and amplitudes for both cavities



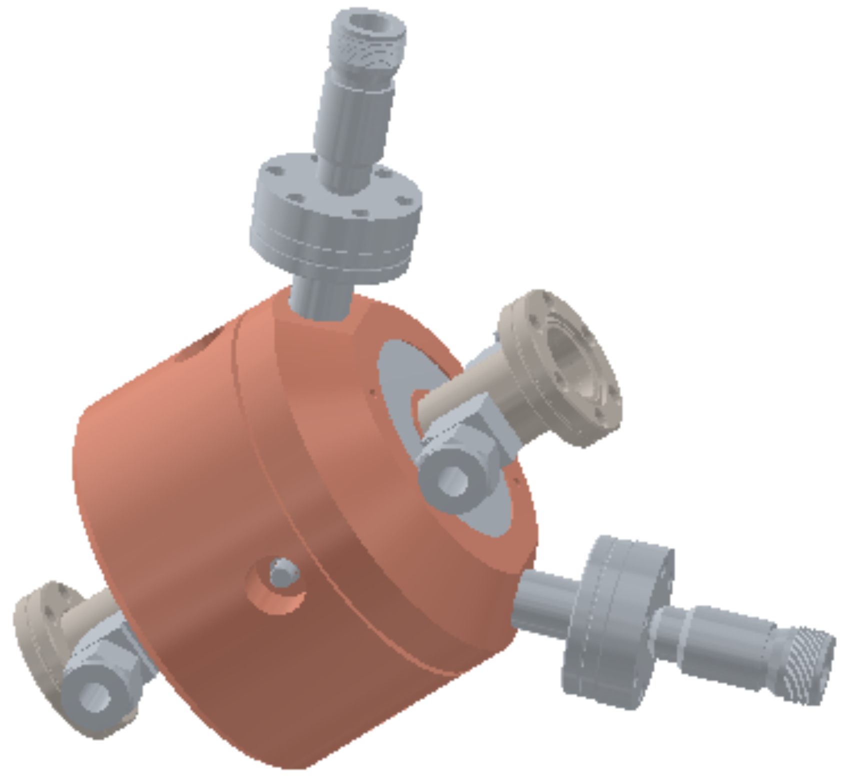
Space Charge

- Lasers tuned for single electron pulses have minimal space charge effects
- Space charge acts to shift the whole scheme off optimum by increasing the initial bunch length
- It serves to essentially add a linear chirp before the first cavity, thus the second cavity must be tuned appropriately



Conclusion

- The promising nature of the scheme in simulation begets practical implementation
- Looking forward to implement this scheme at UCLA on the KLUES beam line



RadiaBeam S-Band Buncher Cavity

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