Enhancement of radiative energy extraction in a FEL oscillator by post saturation beam energy ramping

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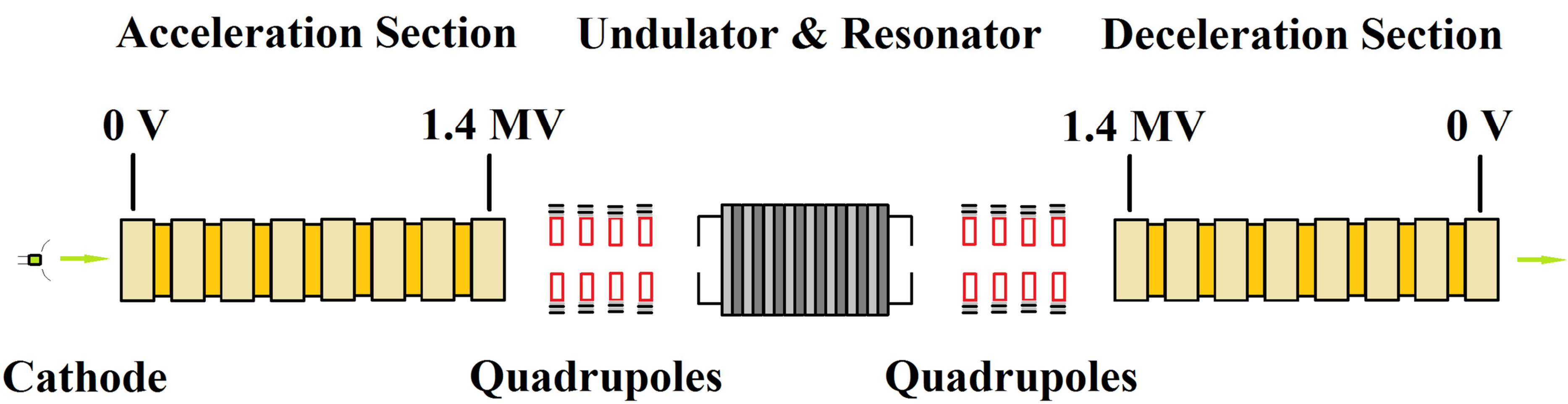
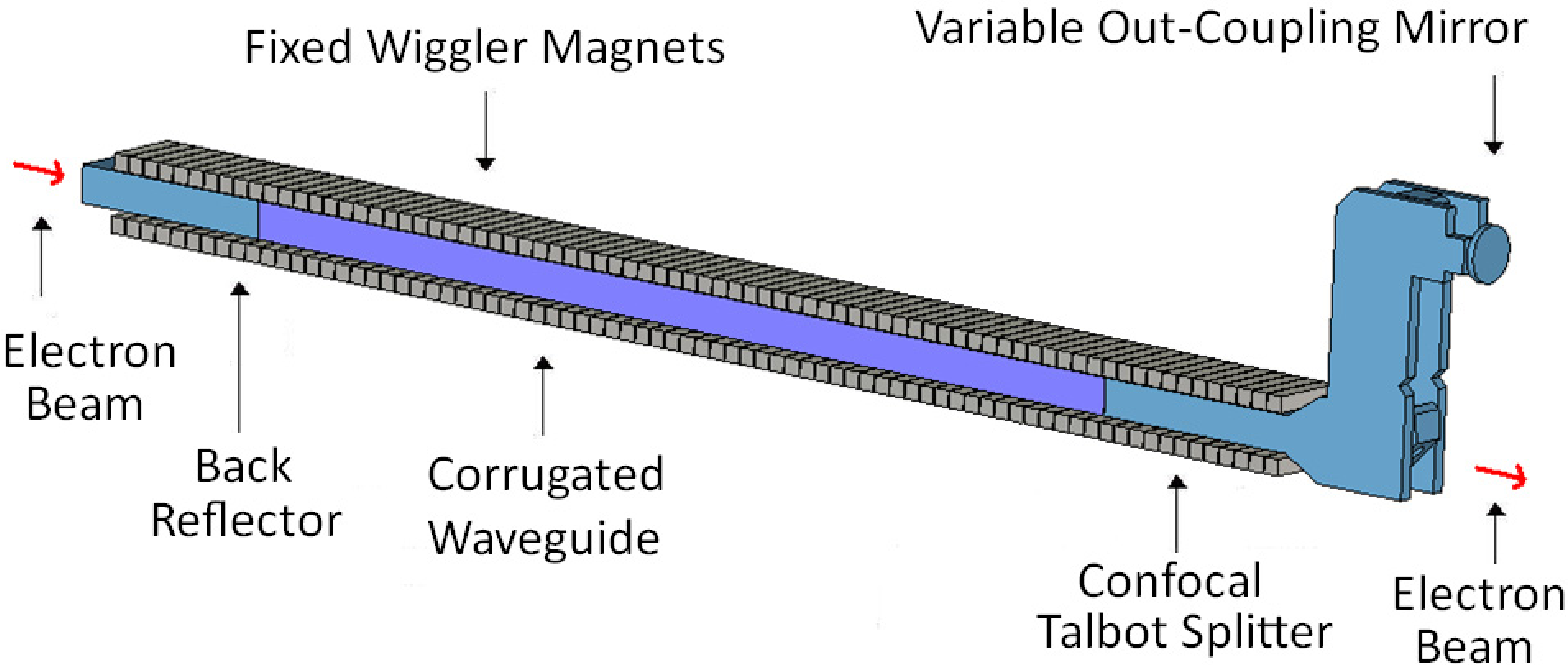
Santa Fe

FEL - ISRAEL



Beam Current	0.7-3 A
Beam Energy	1.35-1.45 MeV
Wiggler Period	44.4 mm
Effective No. of Wiggler Periods	24
Wiggler field Amplitude	1.93 kG
Waveguide Fundamental Mode	HE11
Radiation Frequency	95-110 GHz
Optical Length of Resonator	1.514 m
Free Spectral Range of Resonator	100 MHz

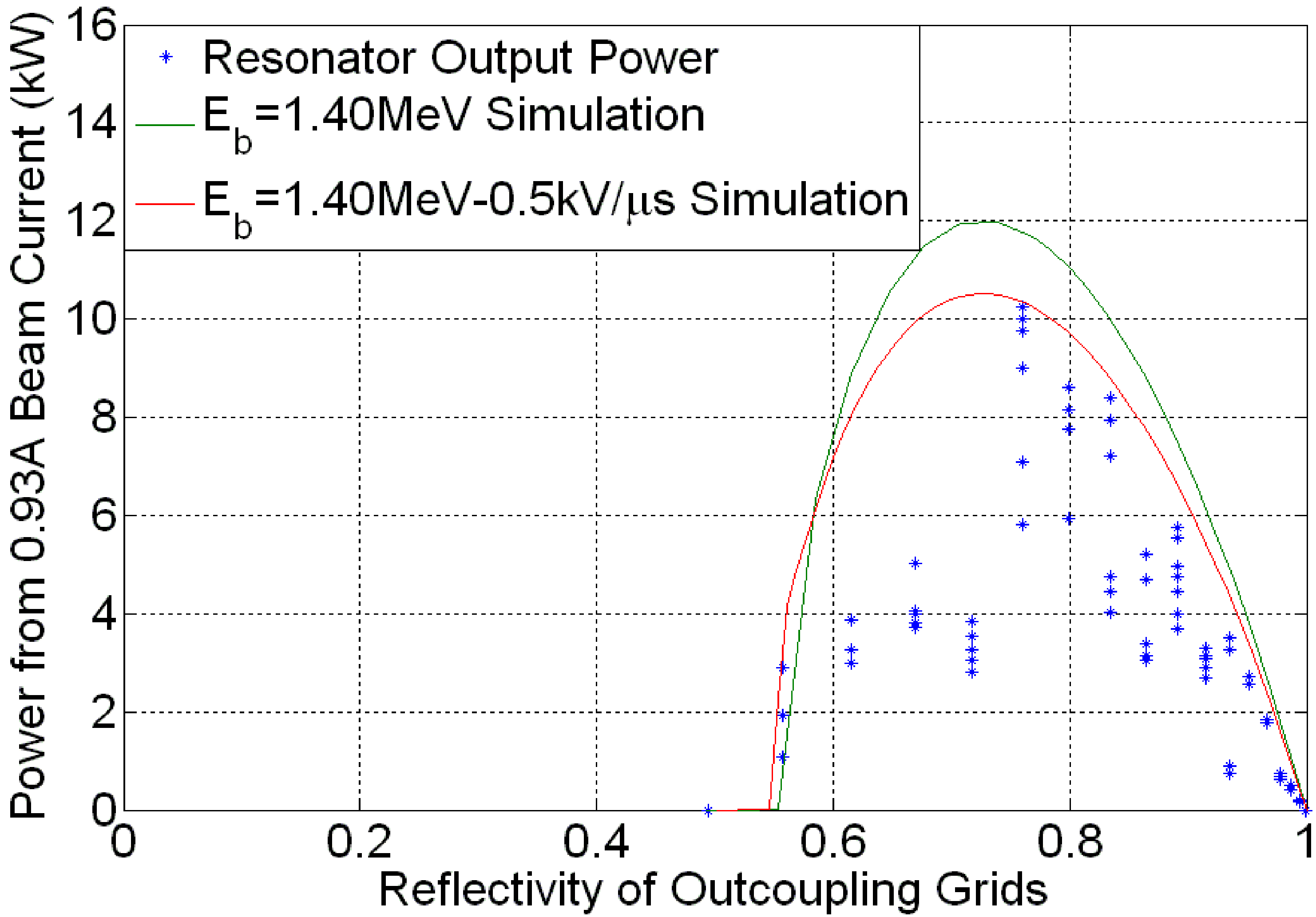
Corrugated Waveguide Confocal-Talbot Resonator



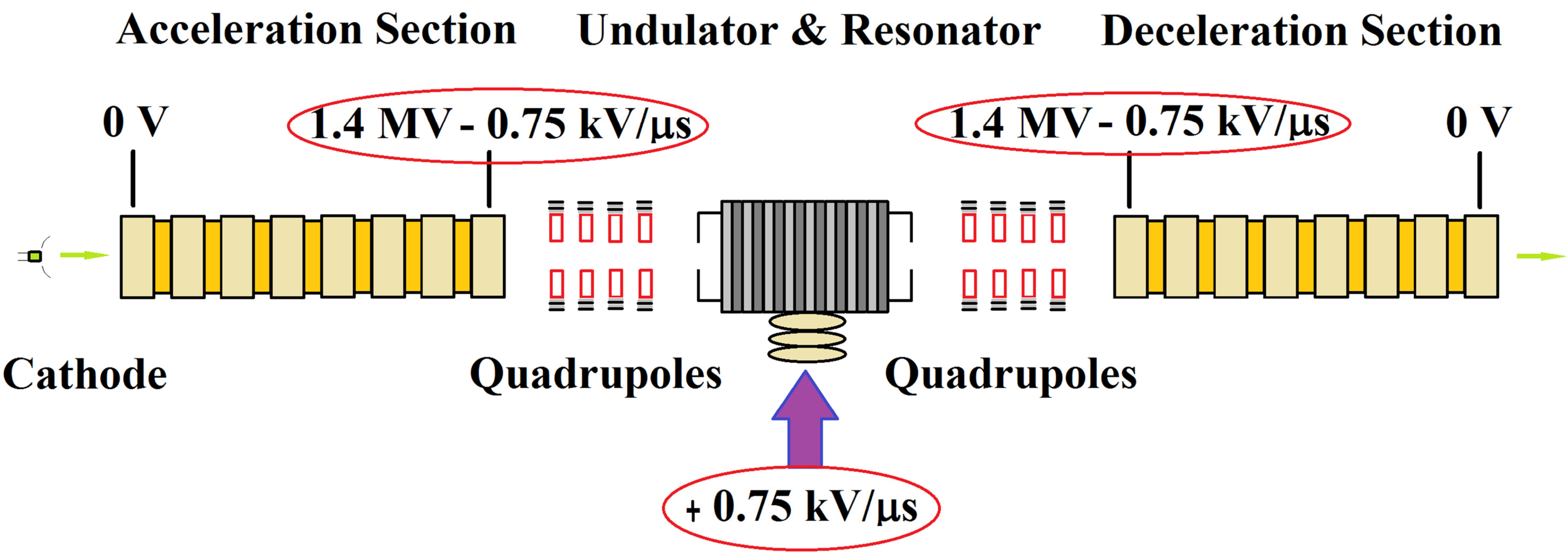
*H. S. Marks et al., "Wiggler improvement based on single axis magnetic measurement, synthesized 3-Dfield simulation of trajectories and sorting of lateral focusing magnets," *Nucl. Instr. Meth.*, vol. 660, no. 1, pp. 15–21, 2011.

**H. S. Marks, A. Gover, "Talbot Effect mm-Wave Resonator for an Electrostatic Accelerator Free Electron Laser," *Transactions in Microwave Theory and Techniques,* 2017.

Power Out-Coupling Maximisation at 102 GHz

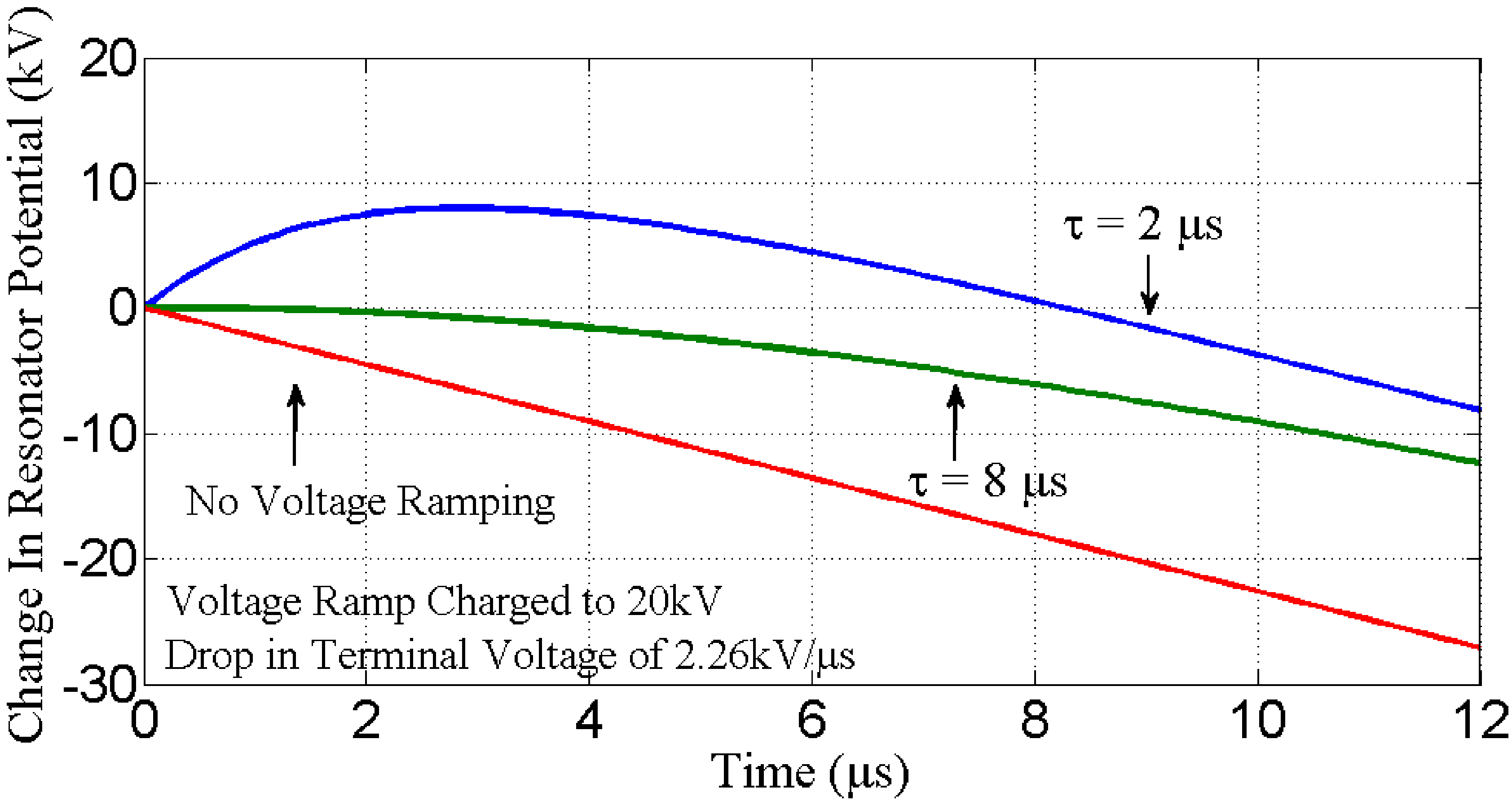


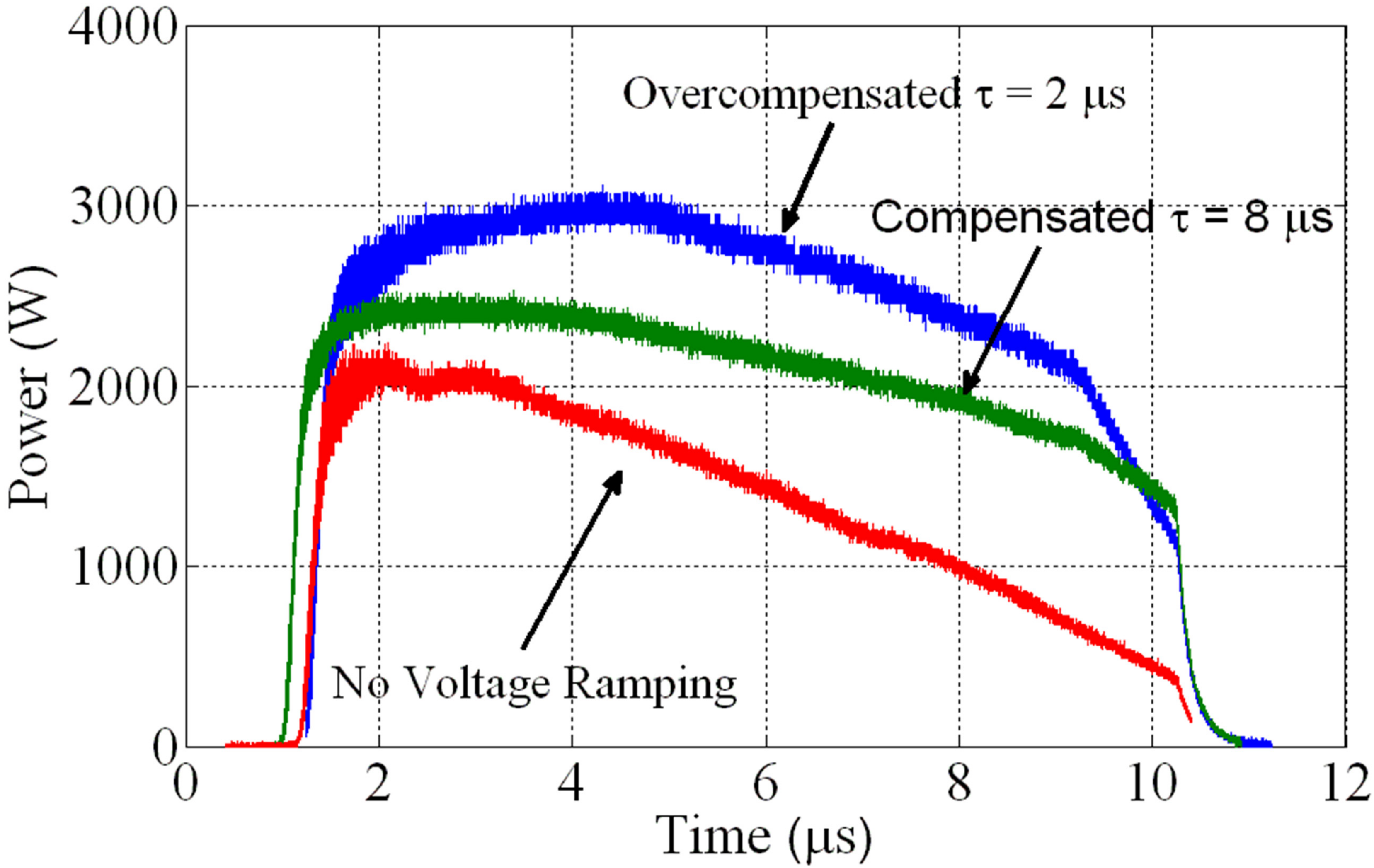
* H. S. Marks et al., "Radiation Power Out-Coupling Optimization of a Free Electron Laser Oscillator", *IEEE Trans. Microwave Theory and Techniques*, vol. 64, no. 3, pp. 1006-1014, Mar. 2016.

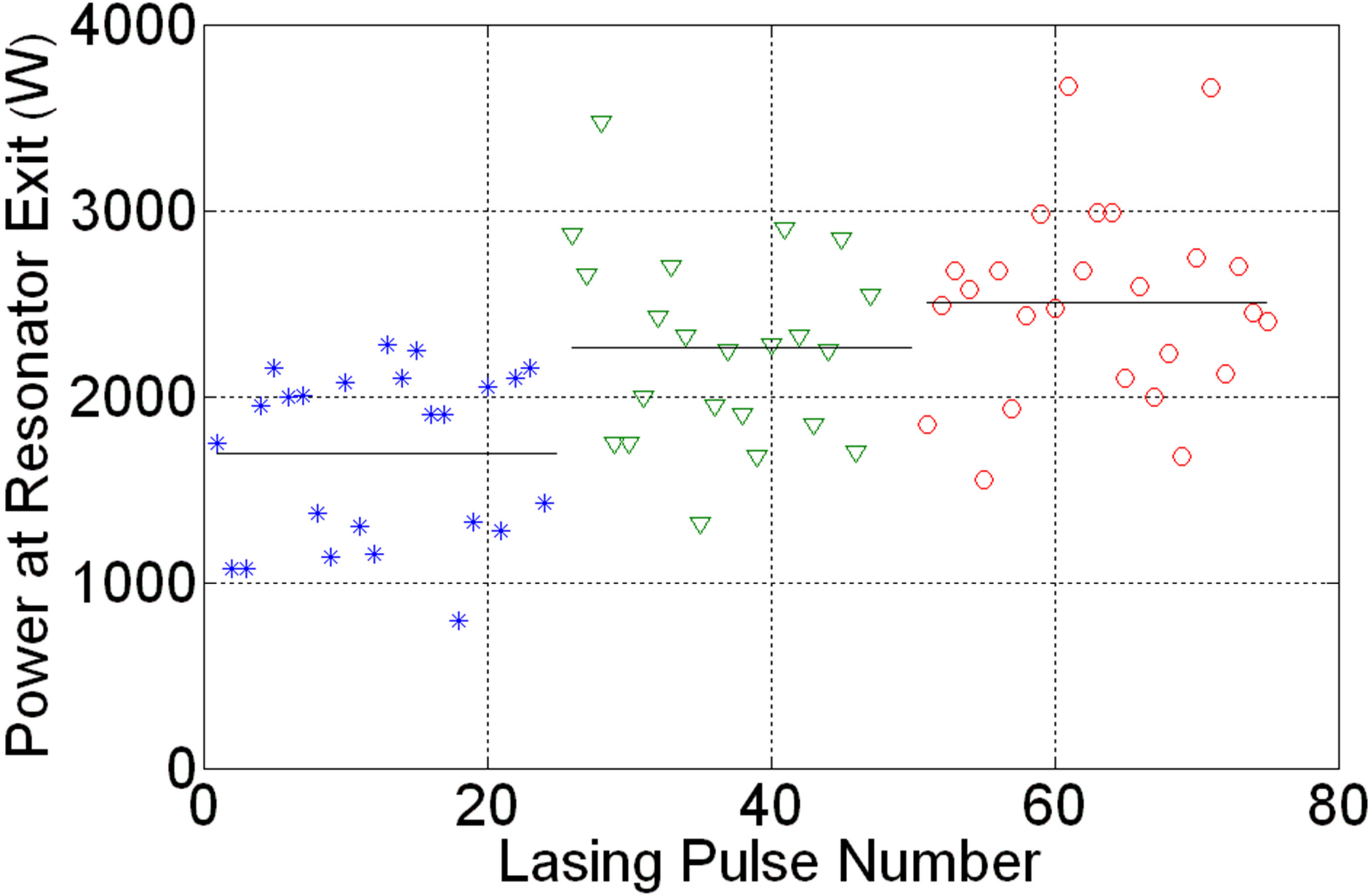


Acceleration Section
Undulator & Resonator
Deceleration Section
0 V
1.4 MV - 0.75 kV/µs
1.4 MV - 0.75 kV/µs
0 V
Cathode
Quadrupoles
Quadrupoles
+ 0.75 kV/µs

Voltage Correction and Control:

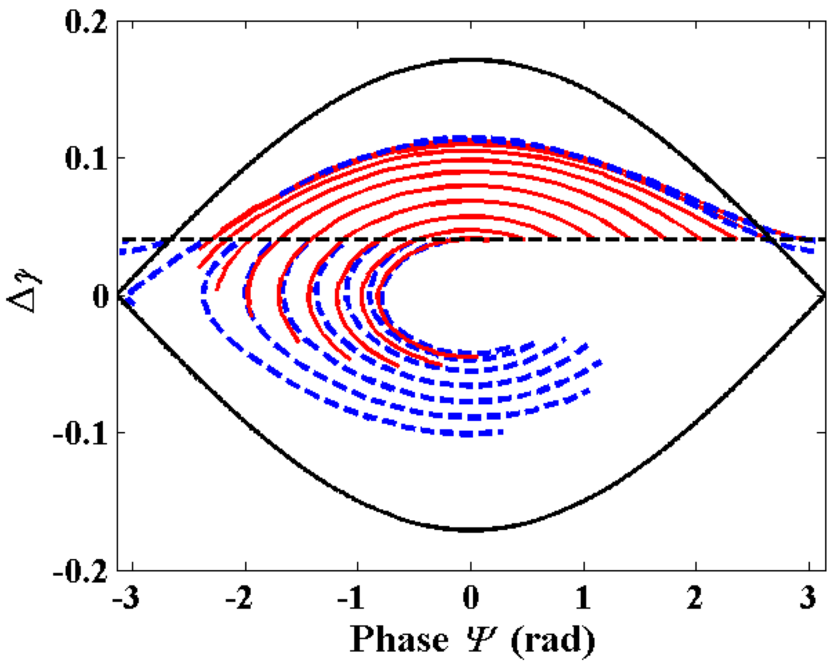



Overcompensated τ = 2 μs
Compensated τ = 8 μs
No Voltage Ramping
Power (W)
Time (μs)
0
1000
2000
3000
4000
0
2
4
6
8
10
12



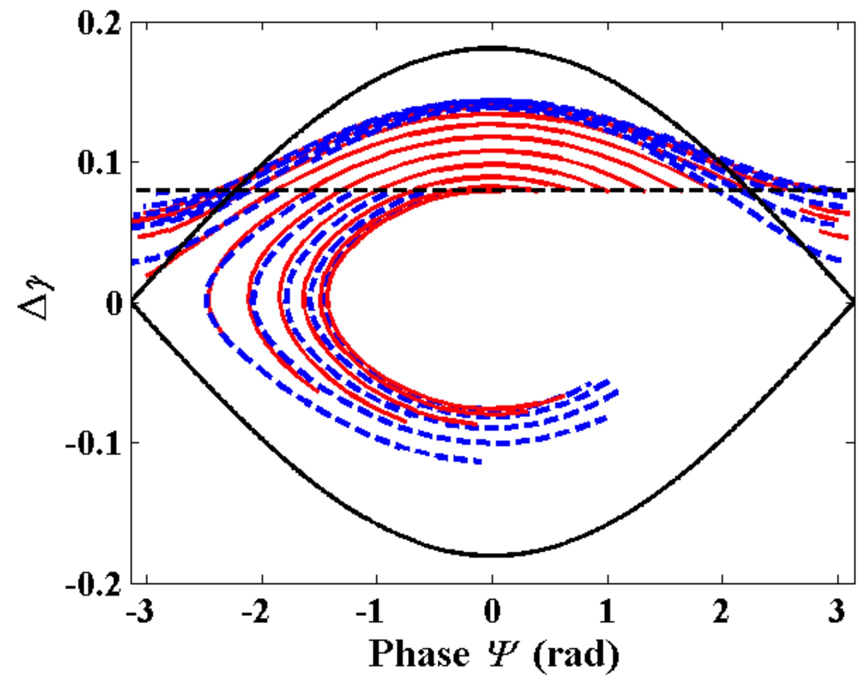
4000
3000
2000
1000
0
0
20
40
60
80
Power at Resonator Exit (W)
Lasing Pulse Number

No Voltage Ramping, Constant Beam Energy



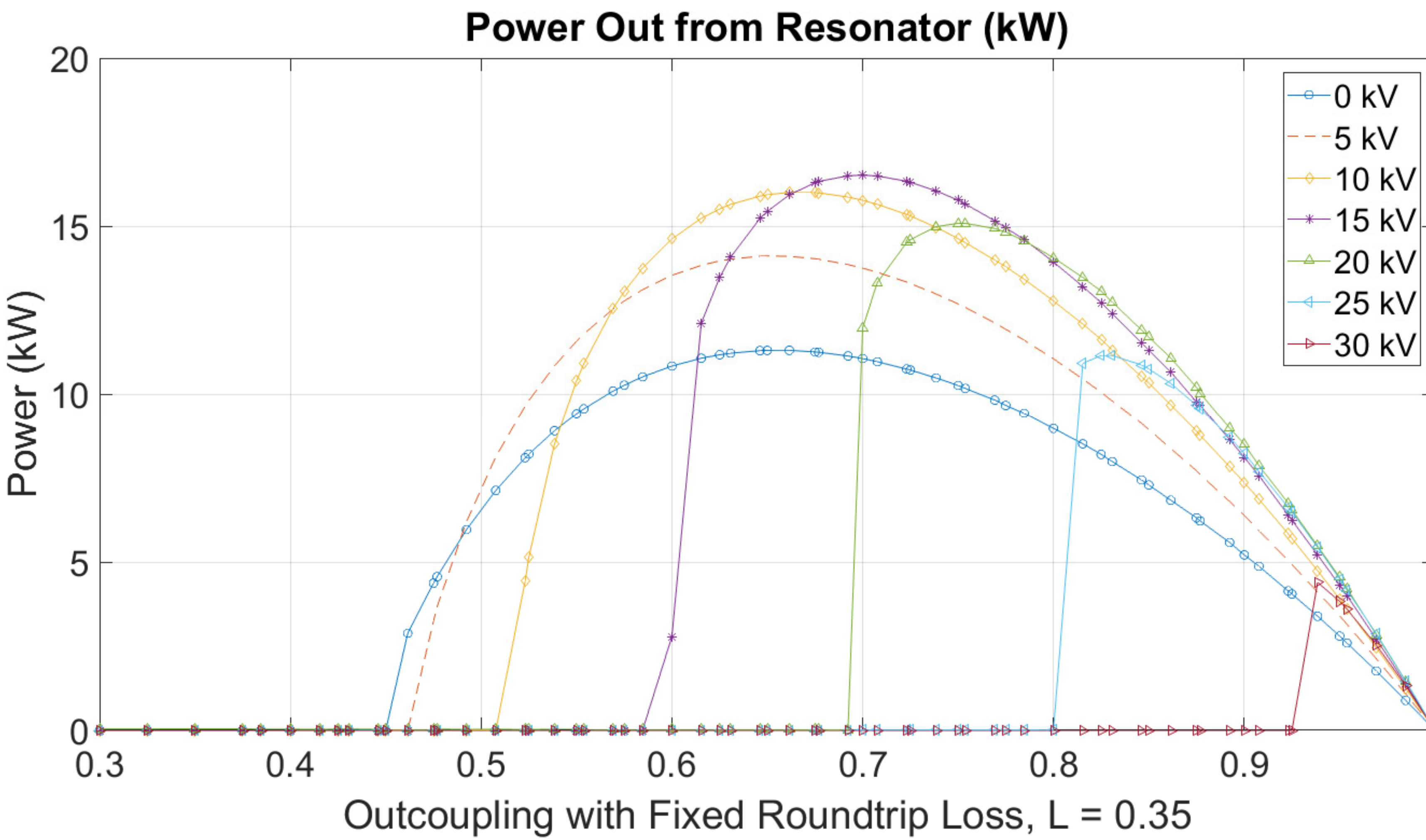
Phase-space trajectories at saturation for:
$E_{initial}$ = 1.4035 MeV, $\Delta\gamma = 0.0406$ or $\Delta E_{det} = 20.8$ keV above the synchronism energy.
Averaging the exit energy:
$\langle \Delta\gamma_i(L) \rangle = -0.0146$, which corresponds to 28.3 keV.

20 kV Voltage Ramping, Post Laser Saturation, followed by Constant Beam Energy

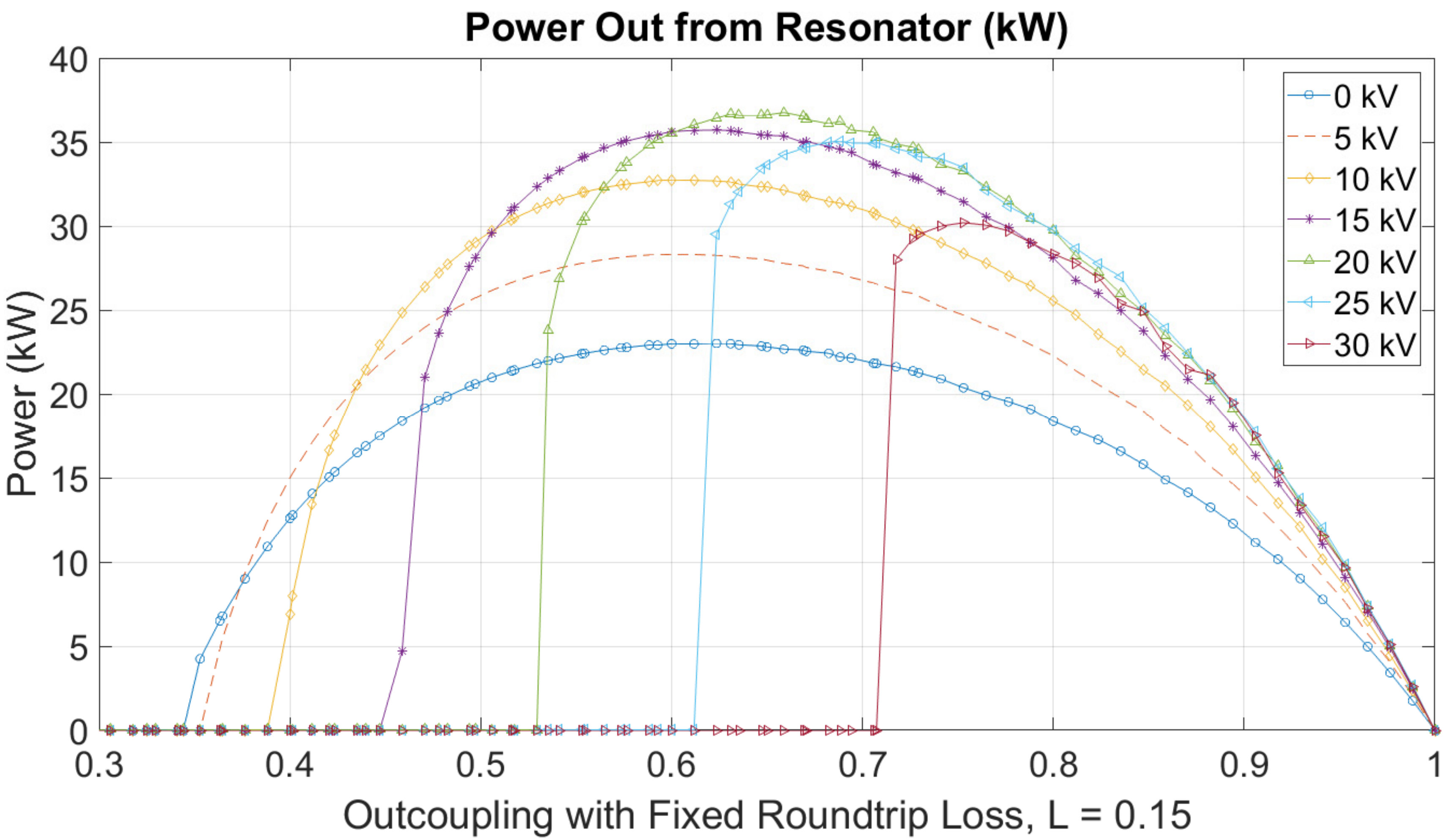


Graph generated by taking the steady-state saturation power circulating in the left graph and raising the beam energy by 20 kV to $\Delta\gamma = 0.0795$ above synchronism.
Averaging the exit energy:
$\langle \Delta\gamma_i(L) \rangle = -0.0087$, which corresponds to 45.2 keV

*H. S. Marks, Yu Lurie, E. Dyunin, and A. Gover, "Enhancing electron beam radiative energy extraction efficiency in free-electron laser oscillators through beam energy ramping," *IEEE Trans. on Microwave Theory and Techniques*, May, 2017.

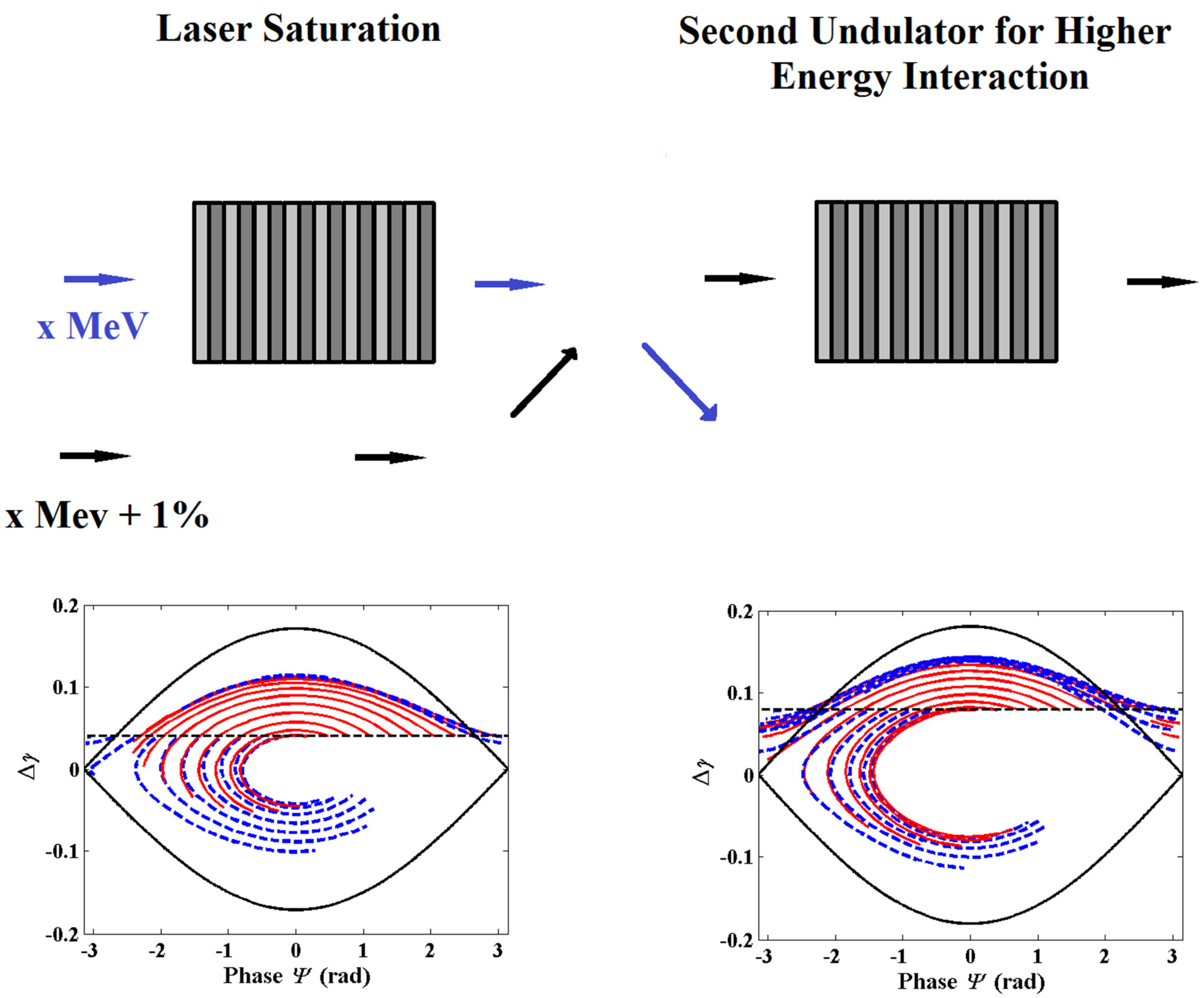


Power Out from Resonator (kW)
Power (kW)
Outcoupling with Fixed Roundtrip Loss, L = 0.35
0 kV
5 kV
10 kV
15 kV
20 kV
25 kV
30 kV
0
5
10
15
20
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Power Out from Resonator (kW)
Power (kW)
Outcoupling with Fixed Roundtrip Loss, L = 0.15
0 kV
5 kV
10 kV
15 kV
20 kV
25 kV
30 kV
0
5
10
15
20
25
30
35
40
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Perhaps this process may be employed post-saturation in an Amplifier FEL.



Conclusion

- δE of 0.7% (10 kV) ➔ 50% increase in radiative power
  - This is an experimental result backed by simulation for a resonator with an internal loss of 35%.
  - ➔ With an improved resonator it is possible to achieve an even greater extraction efficiency via the voltage ramping method.
- This may be relevant to amplifier FELs