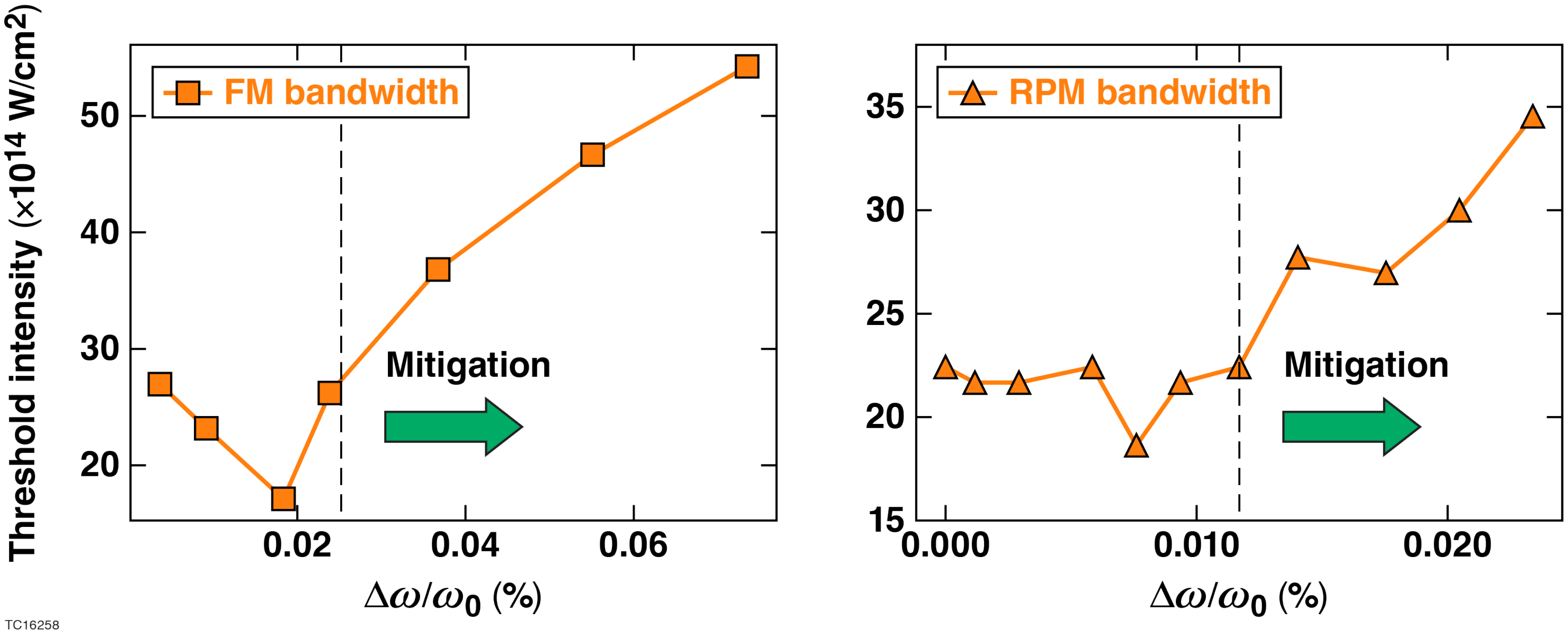
The Effectiveness of Different Laser-Smoothing Techniques for Mitigating Inflationary Stimulated Raman Scattering



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The three-wave coupling model that incorporates the kinetic frequency shift can capture the behavior of inflationary stimulated Raman scattering

- **Stimulated Raman scattering (SRS) can inhibit laser-target coupling and generate hot electrons that preheat the target fuel, impacting the performance of inertial confinement fusion (ICF) implosions**
- **The frequency of a large-amplitude SRS plasma wave is downshifted due to trapped particles, which expands the resonance region in an inhomogeneous plasma, greatly enhancing SRS**
- **Laser bandwidth can enhance SRS when the resonance moves with the same velocity as one of the SRS daughter waves**
- **The movements of the SRS resonance caused by different bandwidth types have different characteristics, leading to distinct scaling of the inflationary SRS thresholds, and these differences can be captured by a simple three-wave coupling model**

Collaborators

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Density gradient, kinetic frequency shift, and laser bandwidth can all affect the resonance for stimulated Raman scattering

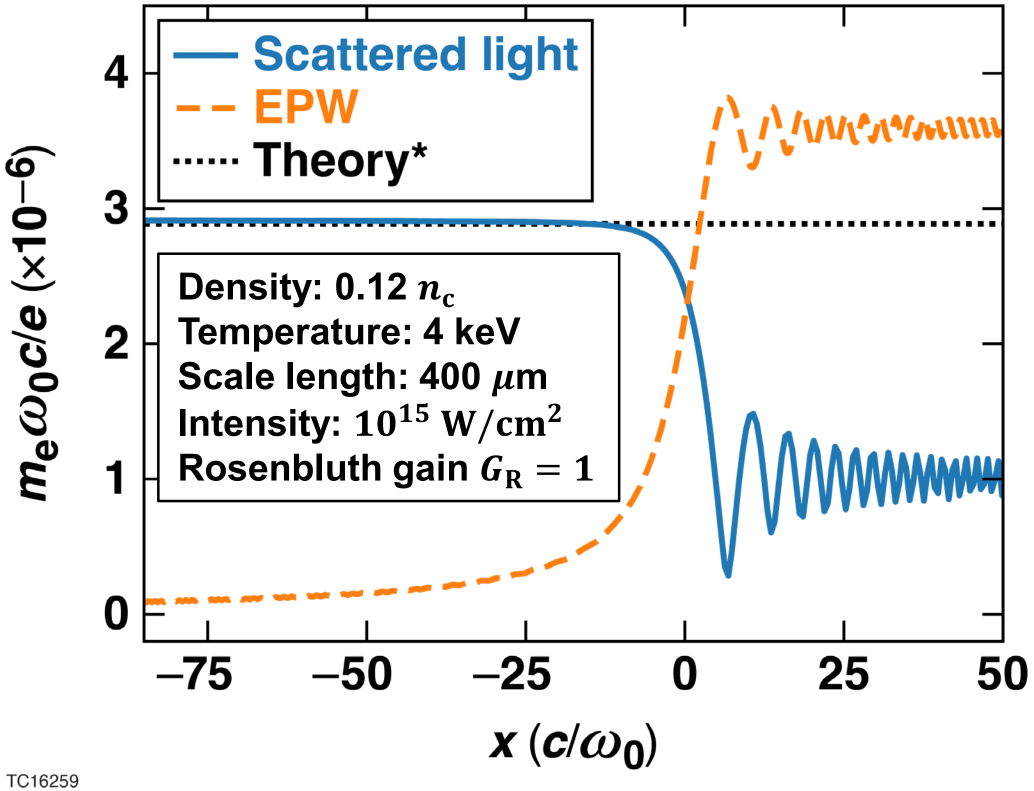
- Three-wave coupling equations
  - laser
    - $(\partial_t + c\,\partial_x)a_0 = -\Gamma_0 f a_1$
  - scattered light
    - $(\partial_t - c_1\,\partial_x)a_1 = \Gamma_1 f^* a_0$
  - electron plasma wave (EPW)
    - $\left(\partial_t + c_\mathrm{L}\,\partial_x + i\,c_\mathrm{L}\kappa' x - i\beta\sqrt{|f|} + i\delta\omega(x,t)\right) f = \Gamma_\mathrm{L} a_0 a_1^*$

Density gradient

Kinetic frequency shift

Laser bandwidth

Wave amplitude



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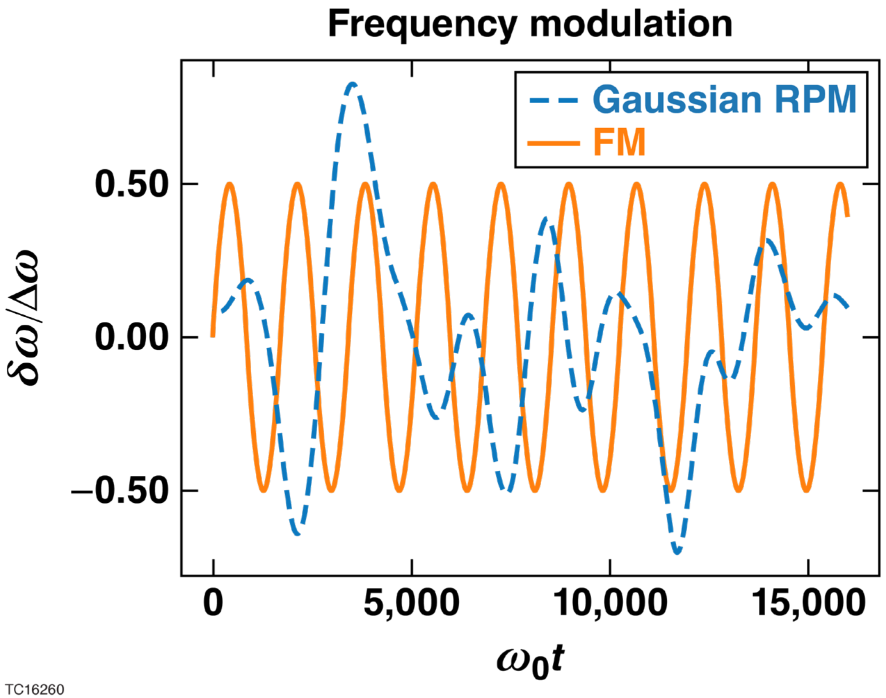
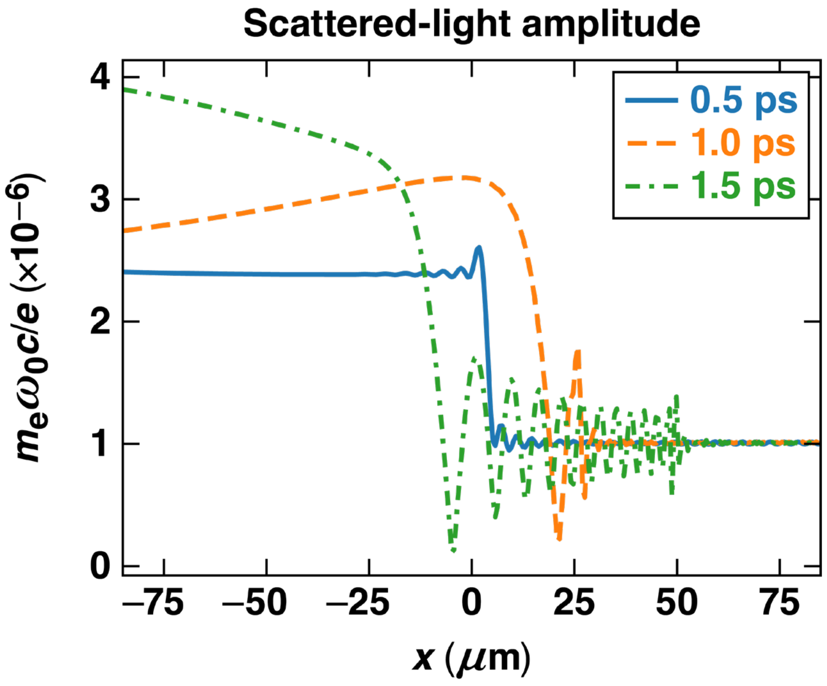
*M. Rosenbluth, Phys. Rev. Lett. 29, 565 (1972).

Laser bandwidth in the form of frequency modulation causes the resonance region to expand along the density gradient

- **Sinusoidal (FM) modulation:** $\delta\omega(t) = \frac{\Delta\omega}{2}\sin(\omega_{\mathrm{m}} t)$
- **Random phase modulation (RPM)***





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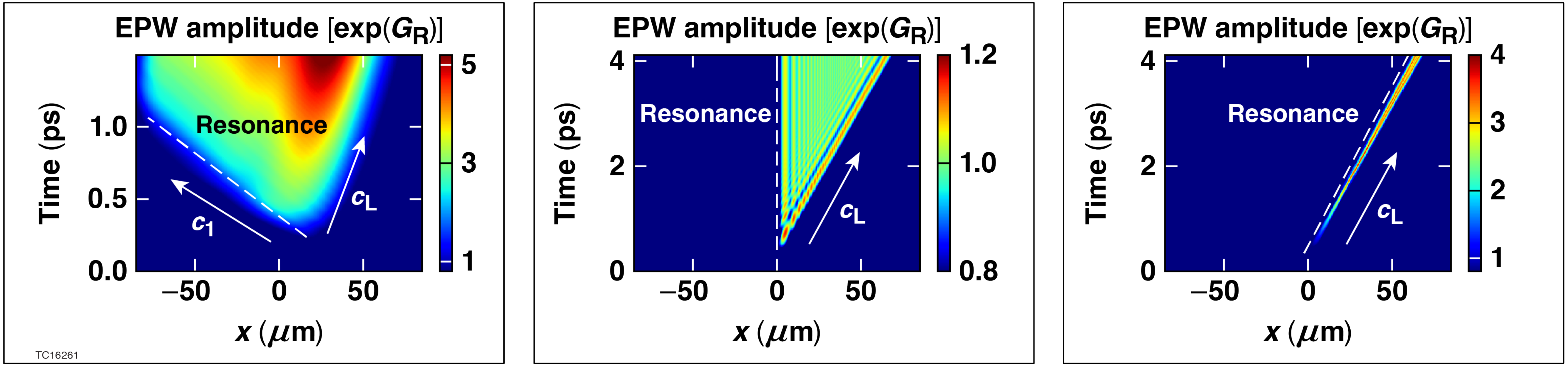
* Bandwidth $\Delta\omega$: Full width half maximum of the spectrum

The convective SRS gain can be enhanced when the resonance moves with the same velocity as one of the SRS daughter waves

$$\frac{\mathrm{d}\delta\omega}{\mathrm{d}t} \approx c_1 c_\mathrm{L} \kappa' \quad *$$

$$\frac{\mathrm{d}\delta\omega}{\mathrm{d}t} = 0$$

$$\frac{\mathrm{d}\delta\omega}{\mathrm{d}t} \approx c_\mathrm{L}^2 \kappa' \quad **$$

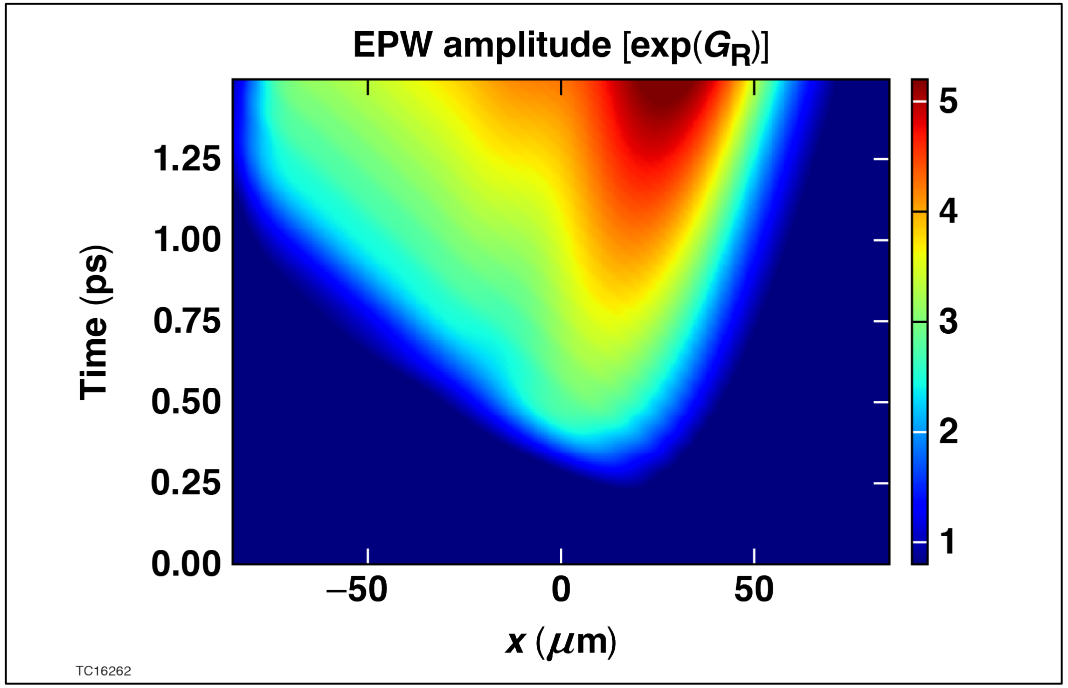


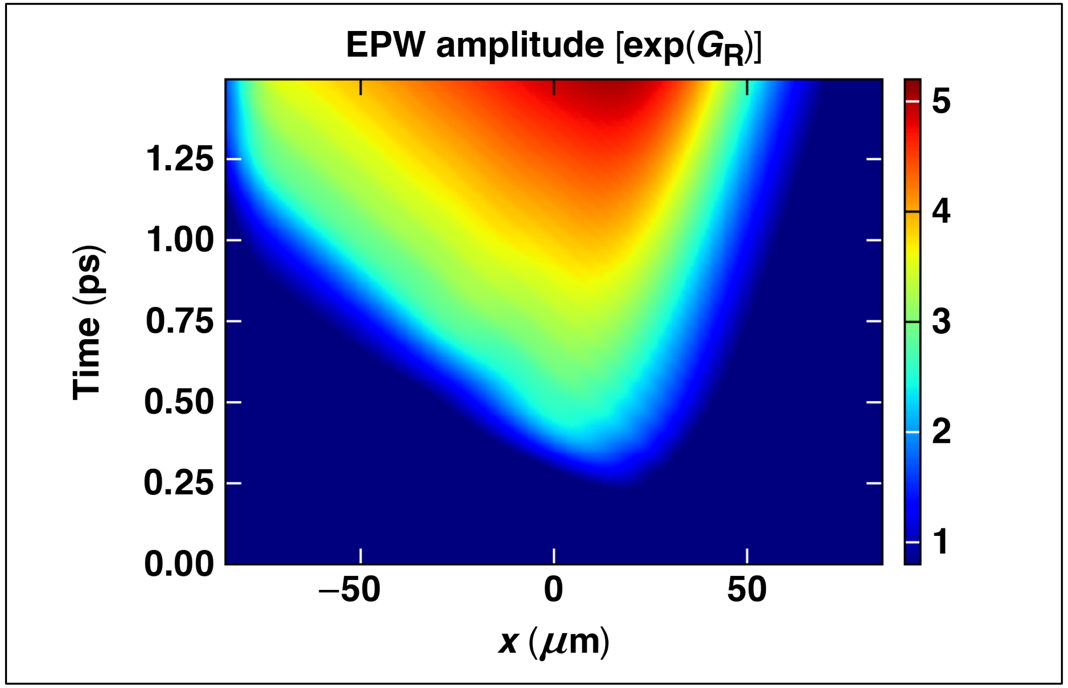
This enhanced convective gain does not require kinetic physics.

* H. Wen *et al.*, Phys. Plasmas 28, 042109 (2021)
** M. Luo *et al.*, Phys. Plasmas 29, 072709 (2022)

Kinetic effects further enhance the SRS gain

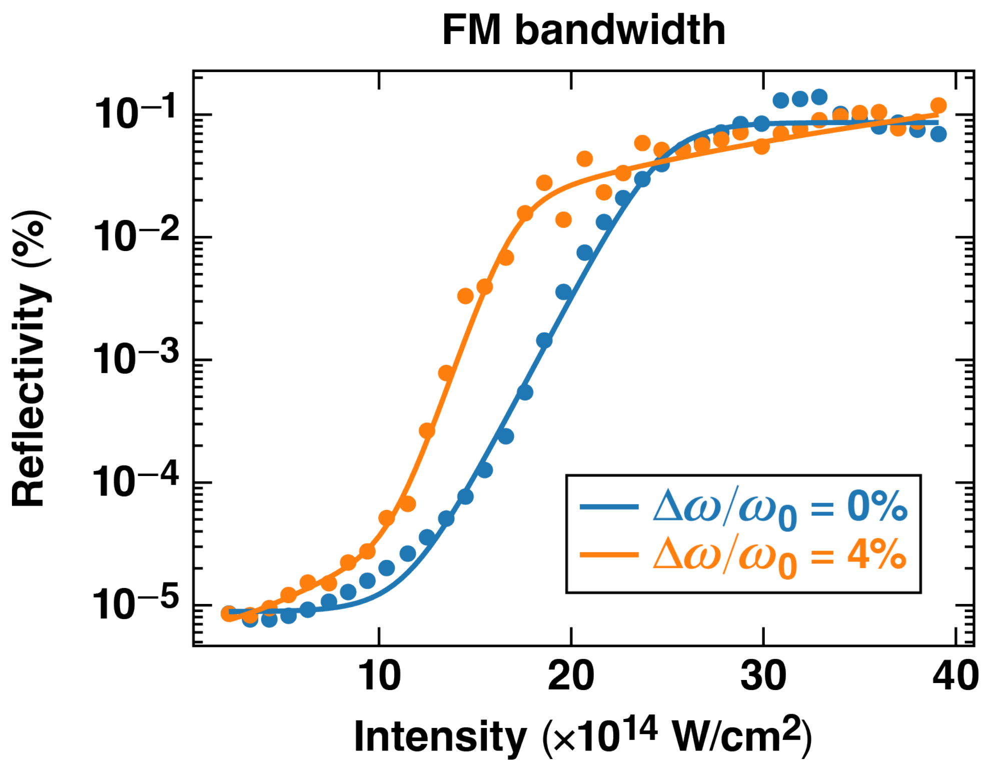
$\beta = 0$	$\beta = 0.25$





Reflectivity is 45% higher when $\beta \neq 0$.

The three-wave equations were solved numerically to infer the inflationary SRS threshold



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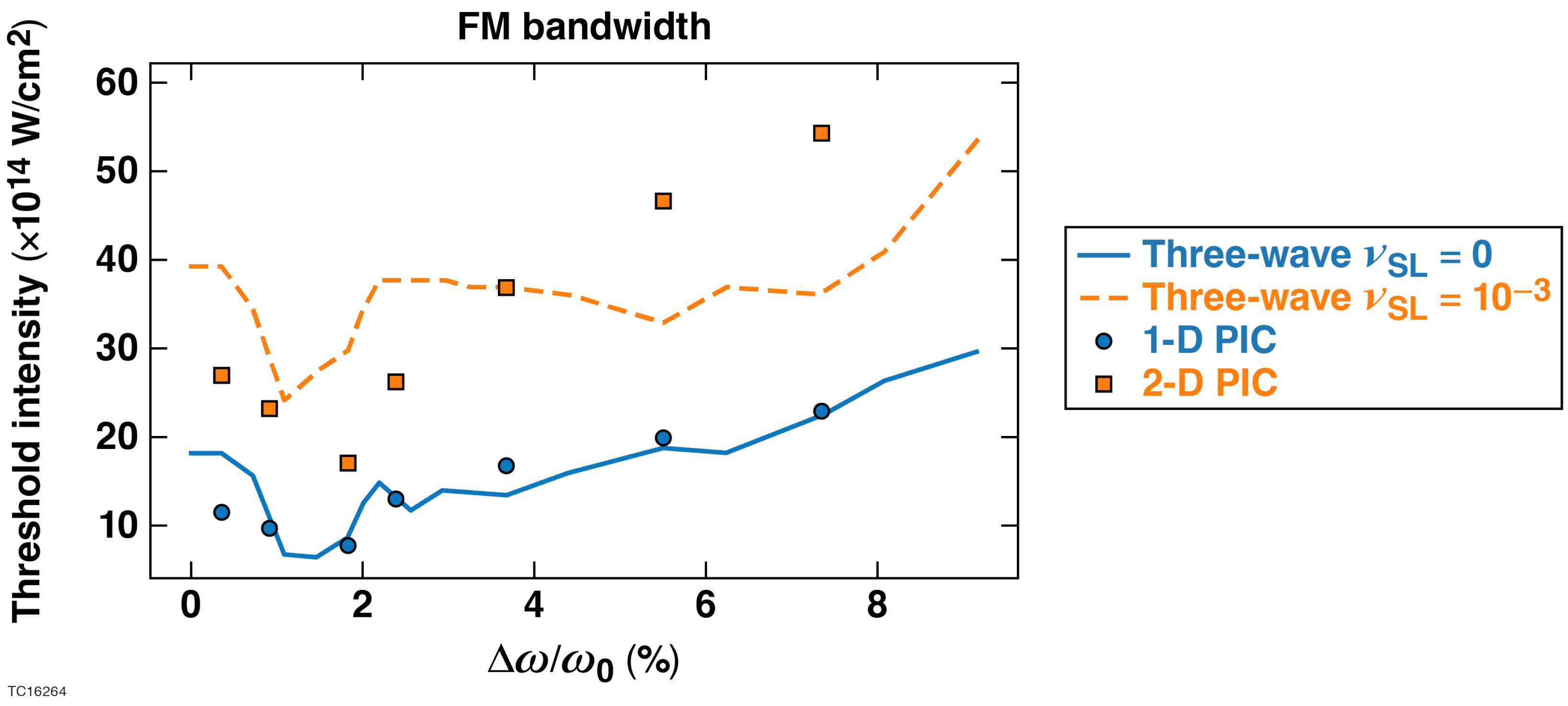
The same fitting process was carried out for particle-in-cell (PIC) simulations.

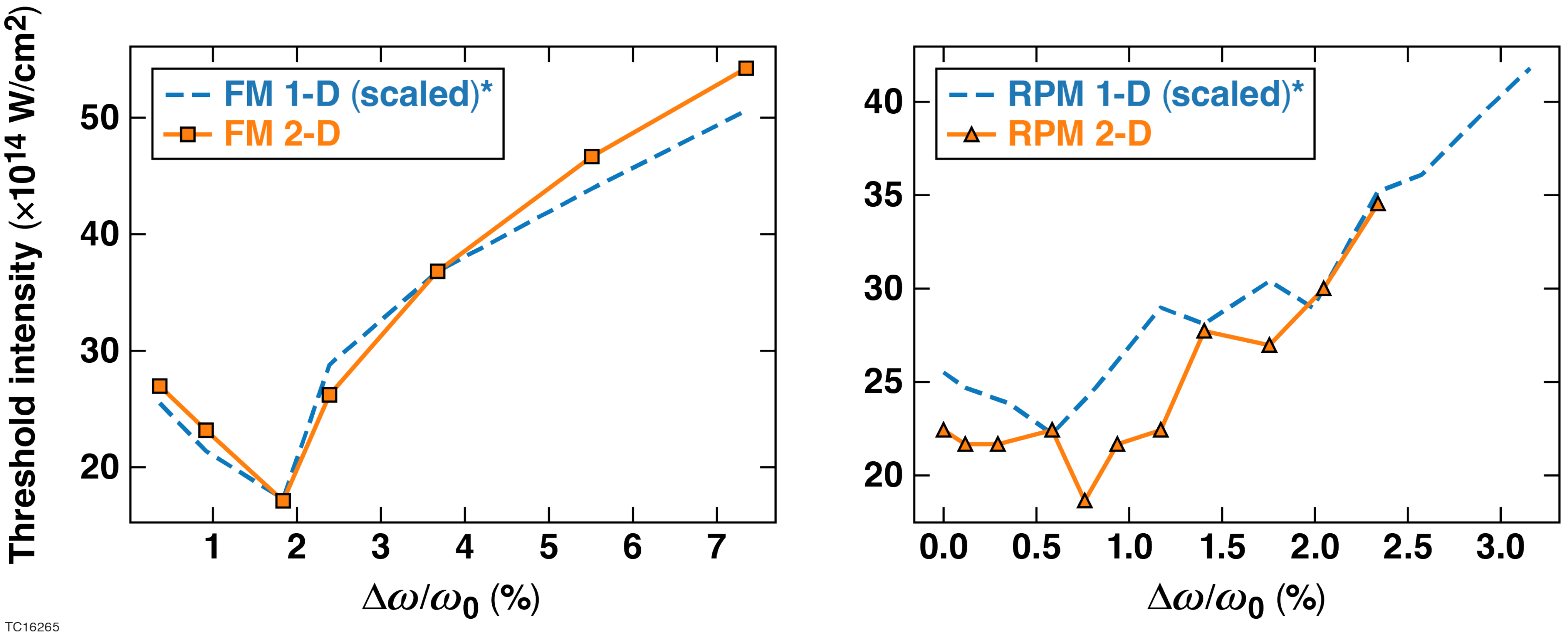
The three-wave model captures the general behavior of the inflationary SRS threshold obtained in PIC simulations



Sideloss of trapped electrons in the 2-D PIC simulation was approximated using a damping term* $\nu_{\mathrm{SL}} \propto \nu_{\mathrm{th}}/f\lambda_0$ in the EPW equation in the three-wave model.

*f and λ_0: f number and wavelength of the laser, respectively

The inflationary SRS threshold intensity reaches minimum at different bandwidth values for different bandwidth types



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The bandwidth value corresponding to the minimum threshold intensity can be captured by the three-wave model.

* Scale factor = 2.2

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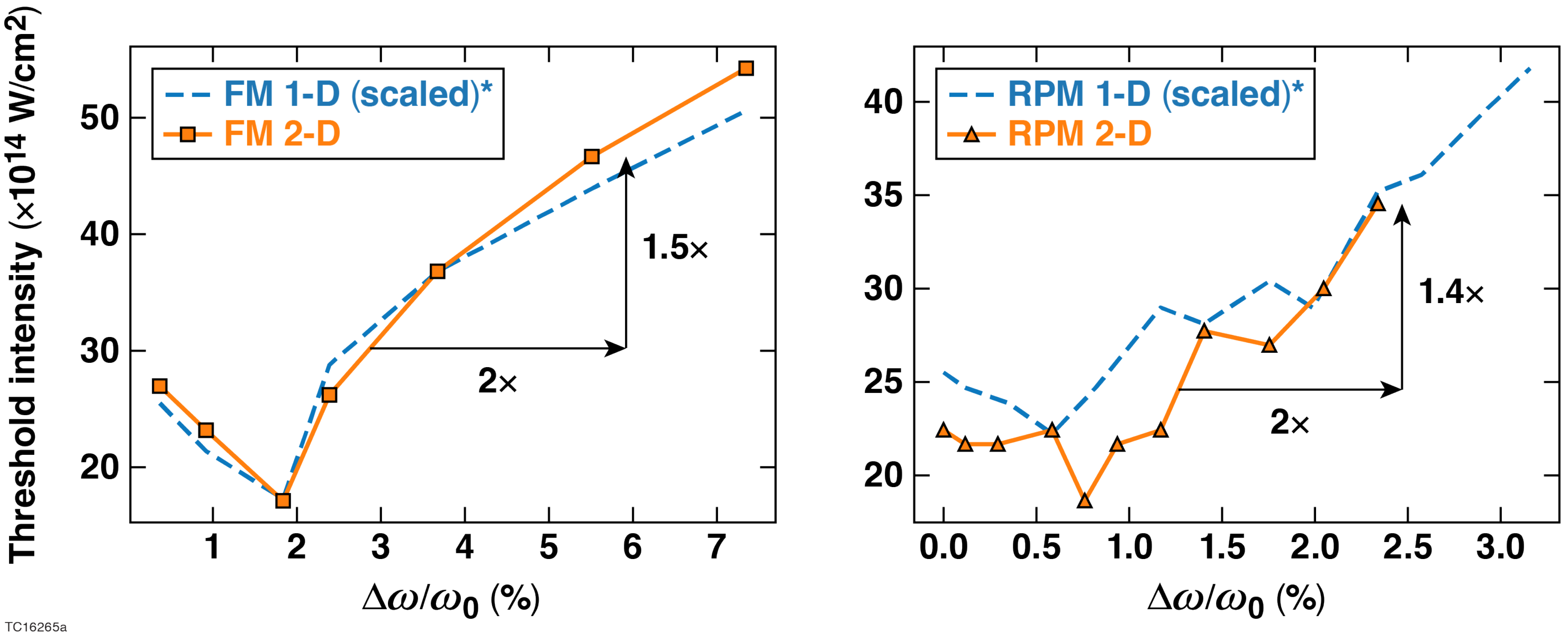

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