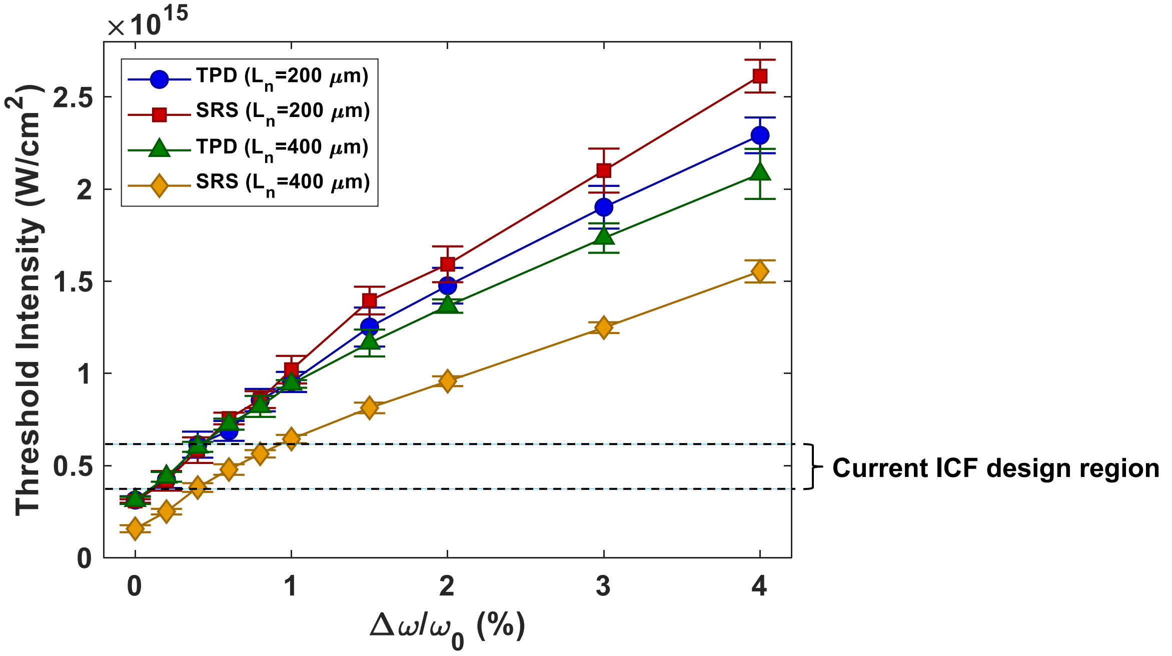
Broadband mitigation of the multibeam two-plasmon decay and stimulated Raman scattering instabilities

Multibeam absolute instability thresholds



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Summary

Temporal incoherence of the drive lasers can be used to suppress laser-plasma instabilities (LPIs)

- Laser-plasma instabilities limit the laser intensity that can be used in inertial confinement fusion (ICF) implosions
- A quantitative assessment of the viability of using broadband lasers to mitigate LPI in ICF requires multibeam 3-D simulations
- Broadband lasers are more effective at mitigating multibeam absolute instabilities than their single-beam counterparts

A future broadband laser based on optical parametric amplifiers is currently being developed at LLE

Collaborators

J. G. Shaw, C. Dorrer, D. H. Edgell, D. H. Froula, H. Wen, J. Bromage, E. Hill, T. Kessler, A. Maximov, A. Solodov, M. Campbell and J. P. Palastro

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University of Alberta

J. W. Bates, J. L. Weaver

Naval Research Laboratory

To assess their viability for use as an ICF driver, we need to determine the impact of broadband lasers on the three predominant LPIs: CBET, TPD, and SRS

Absolute instabilities (bandwidth increases thresholds):
- **TPD**
- **SRS**

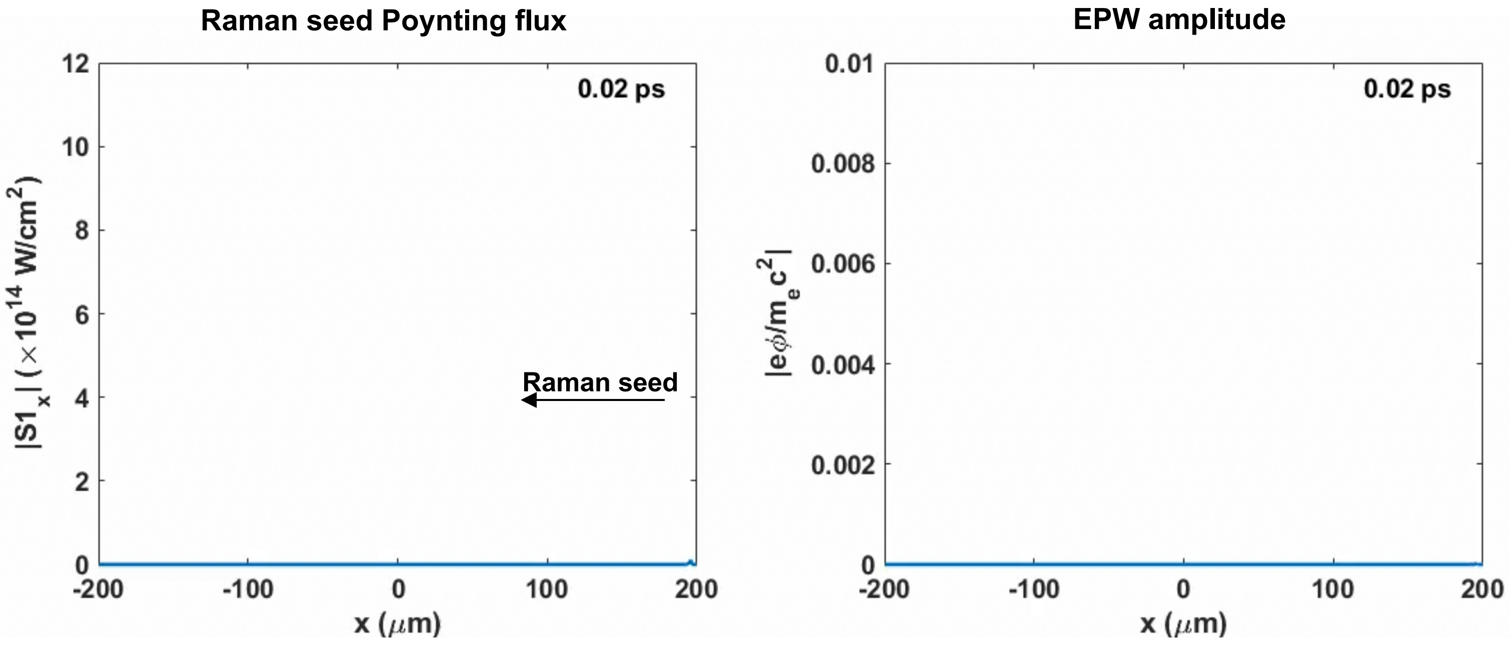
Convective instabilities (gains are not directly impacted by bandwidth):
- **CBET**
  - **Can be indirectly suppressed by pushing the resonance outside of the plasma with ~1% bandwidth[1]**
- **SRS**
  - **Backscatter gains are modest,[2] sidescatter needs further investigation**

[1] J. W. Bates et al., Higher Energy Density Physics 36, 100772 (2020).
[2] H. Wen et al., "Kinetic inflation of convective Raman scattering driven by a broadband laser," submitted to Phys. Plasmas

Broadband lasers can be used to increase absolute instability thresholds but not to reduce convective gains

Monochromatic convective SRS (n_e/n_c=0.15)

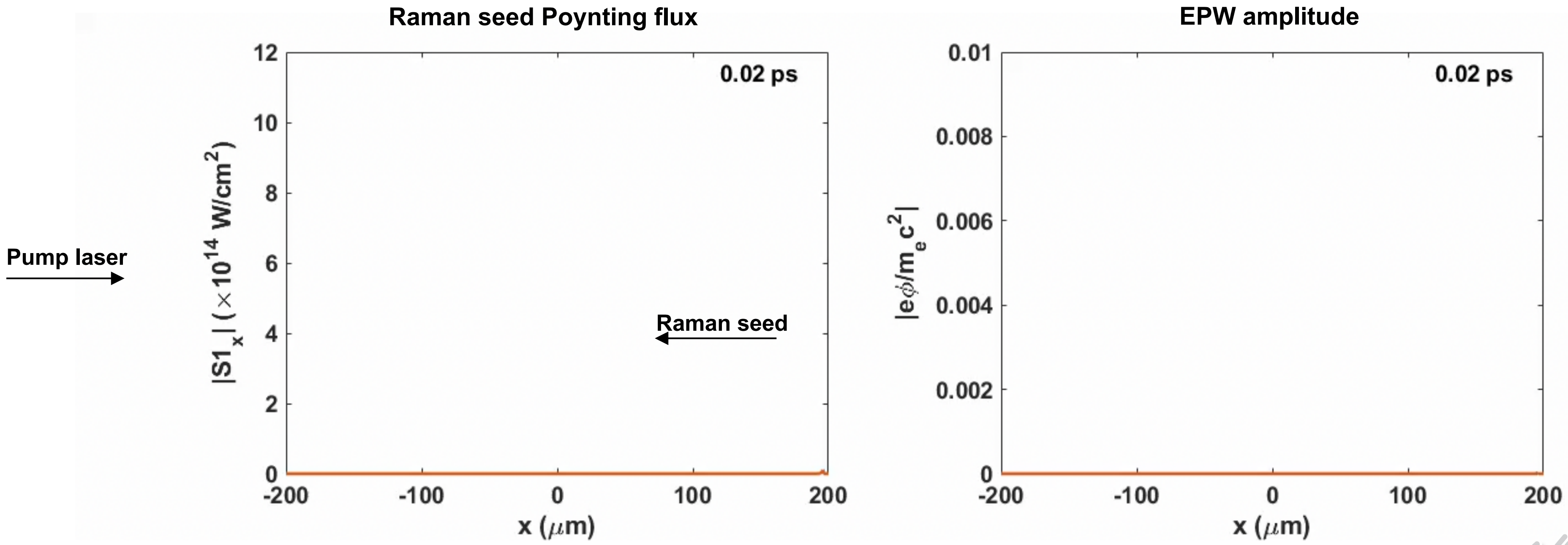
Pump laser (monochromatic)



Density gradient

Broadband lasers can be used to increase absolute instability thresholds but not to reduce convective gains

Three-color and monochromatic convective SRS (n_e/n_c=0.15)



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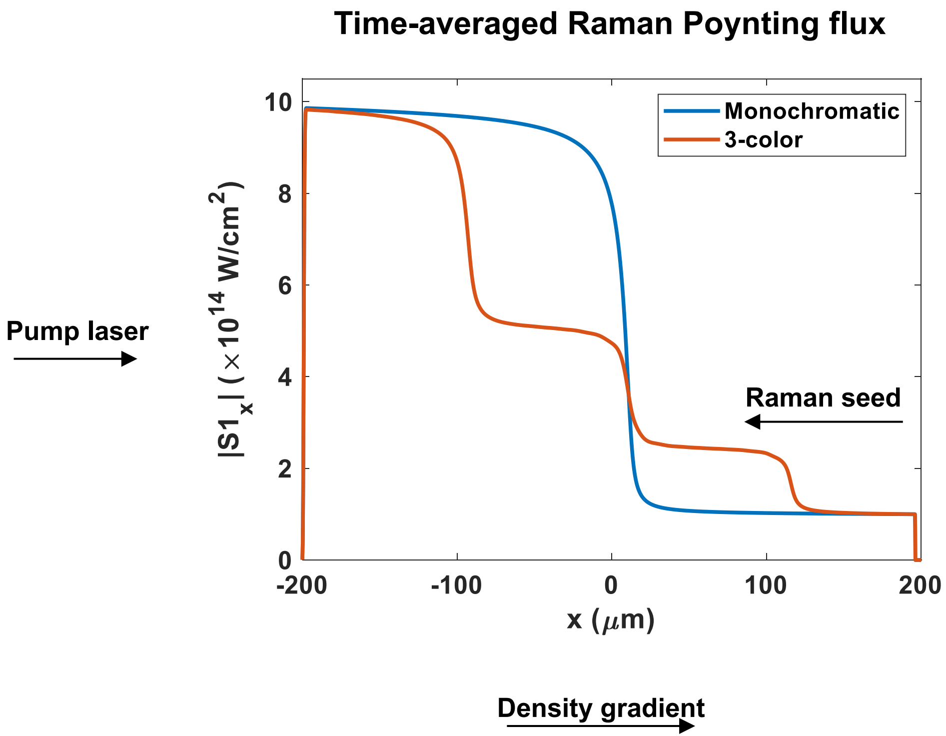
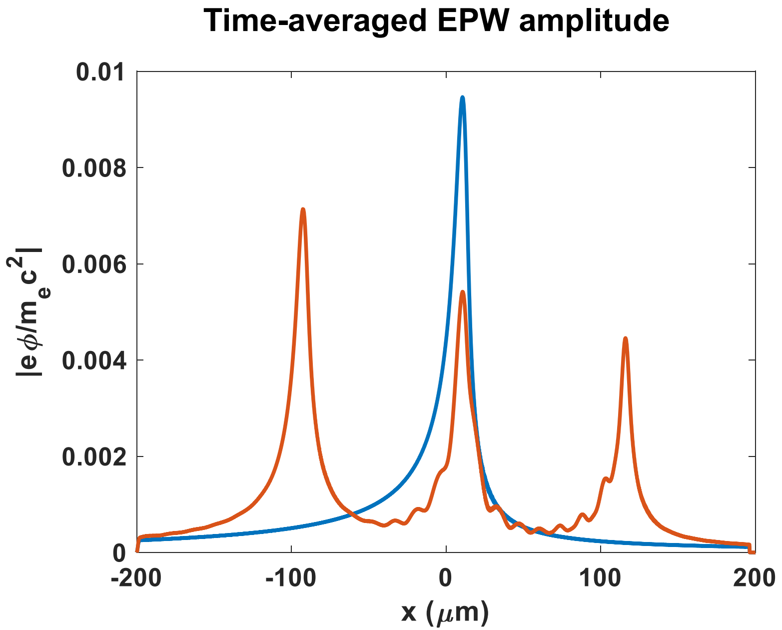


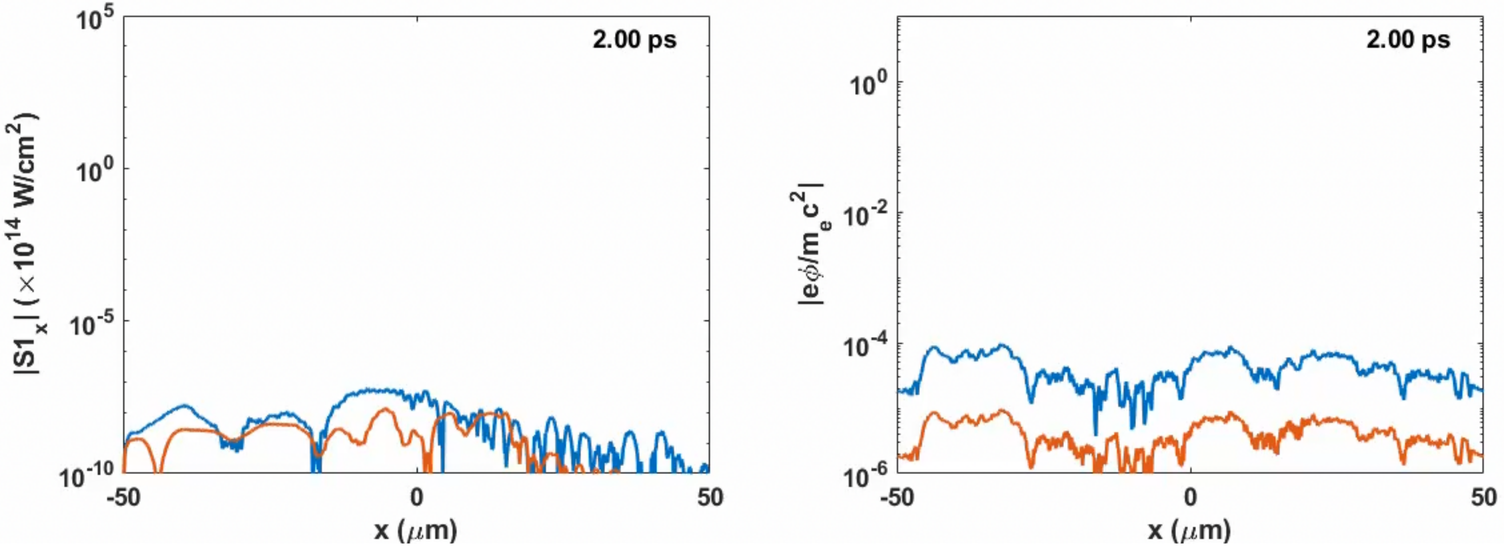


Broadband lasers can be used to increase absolute instability thresholds but not to reduce convective gains

Three-color and monochromatic absolute SRS (n_e/n_c=0.24)

Raman Poynting flux | **EPW amplitude**

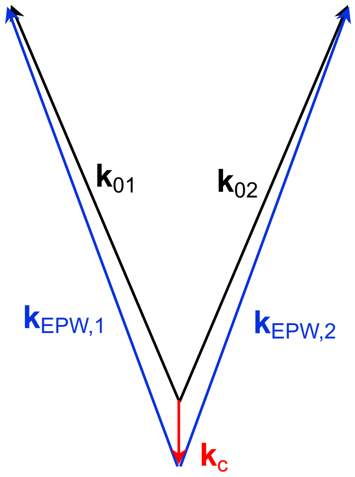
Pump laser
(Monochromatic, I=0.5e14 W/cm^2)
(3-color, I=1.5e14 W/cm^2)



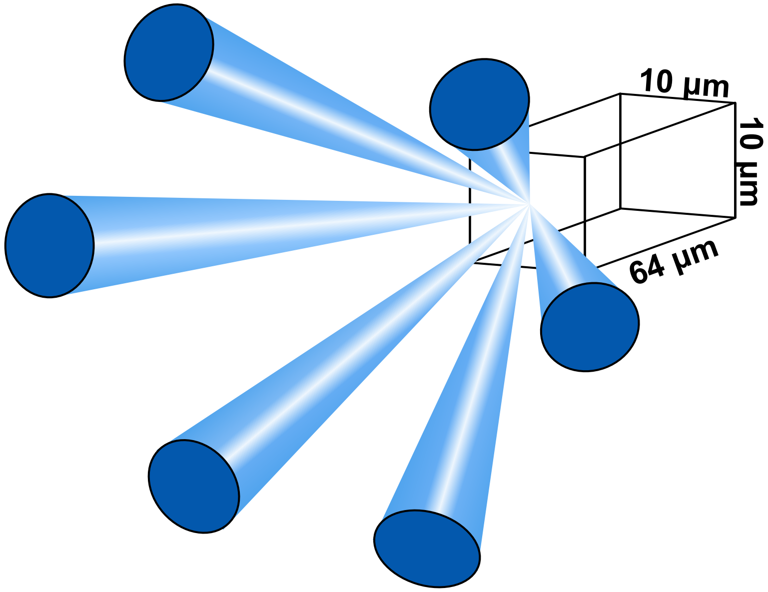
Density gradient

Multibeam 3-D simulations are required to make an accurate assessment of absolute instability mitigation in ICF implosions

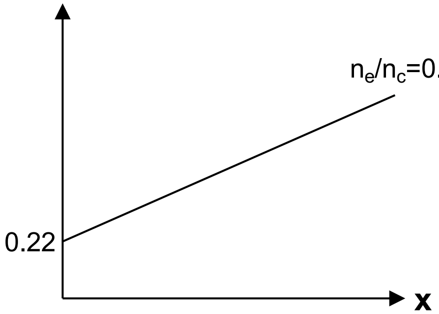
Common-wave matching condition



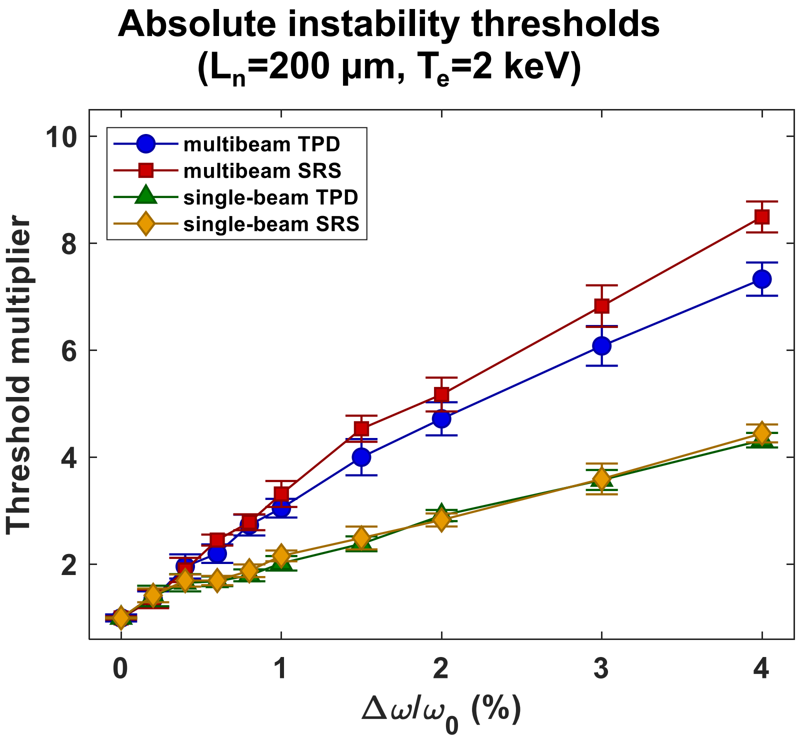
Simulation geometry (6 beams)

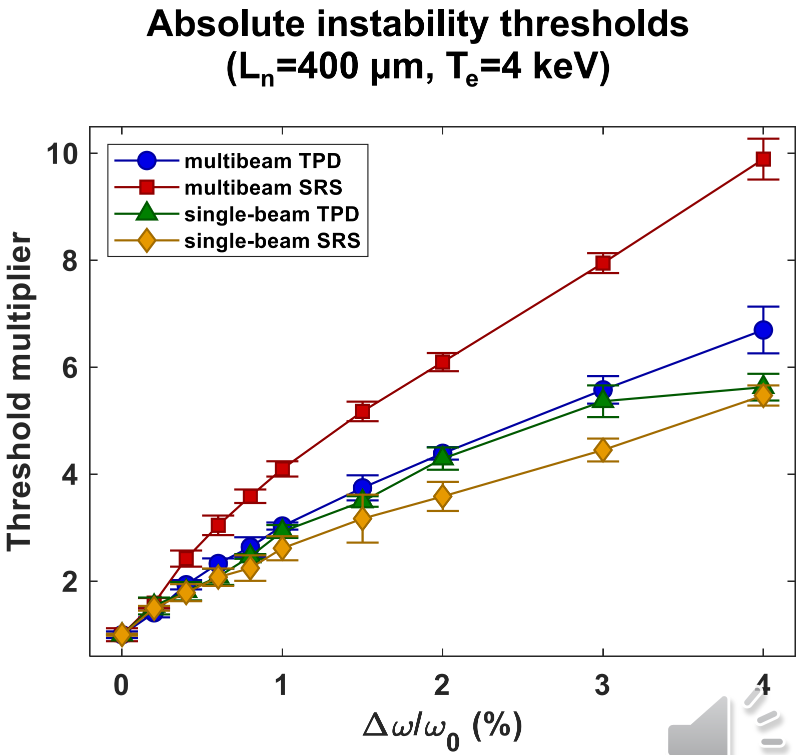


Density profile



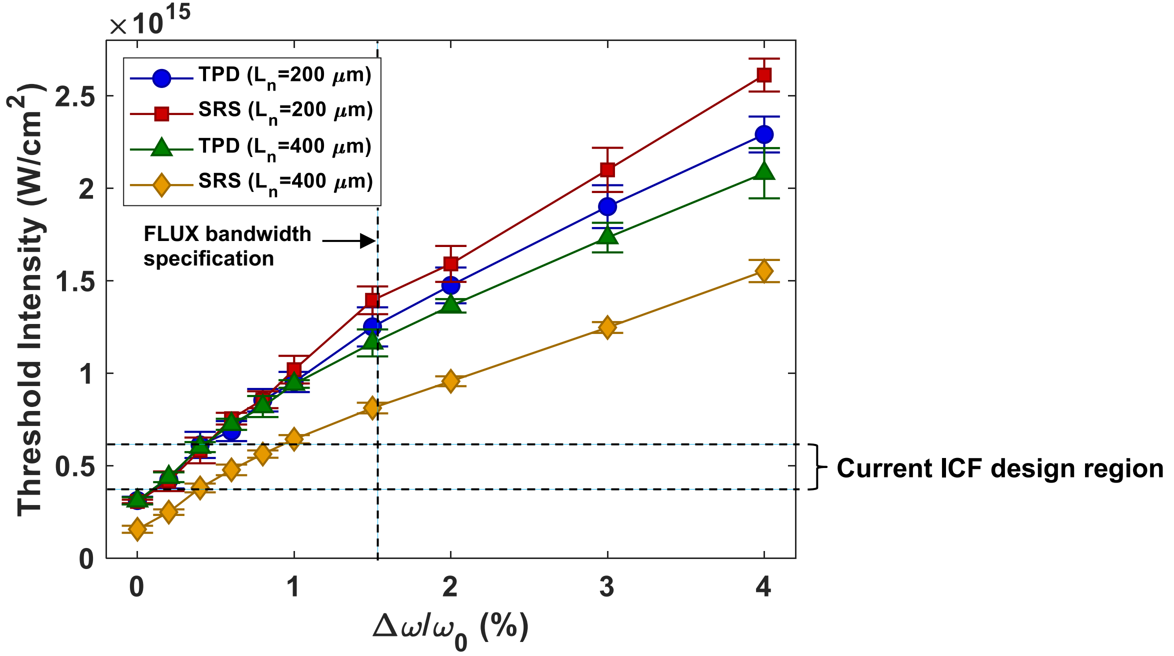
Bandwidth has a greater impact on multibeam absolute thresholds than the corresponding single-beam thresholds because of reduced multibeam coupling





Despite the large reduction in multibeam coupling, SRS is predicted to have the lowest absolute threshold for ignition-scale designs

Multibeam absolute instability thresholds



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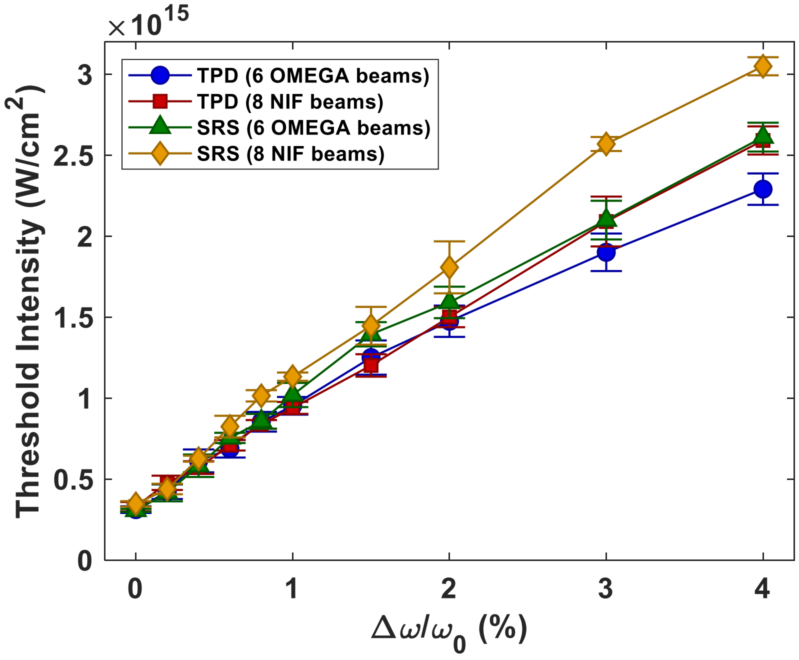
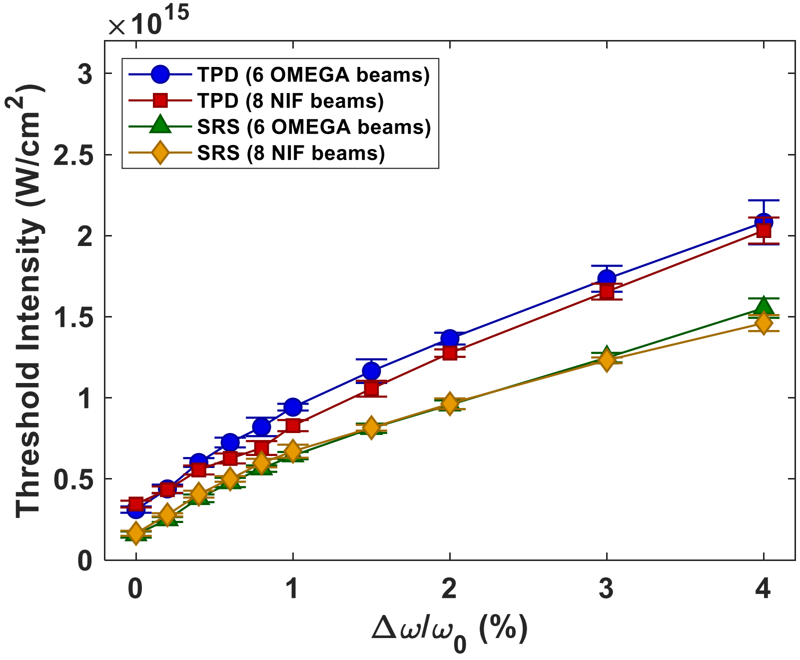
The absolute instability thresholds are only weakly sensitive to variations in beam geometry

Thresholds for different beam geometries (L_n=200 μm, T_e=2 keV)

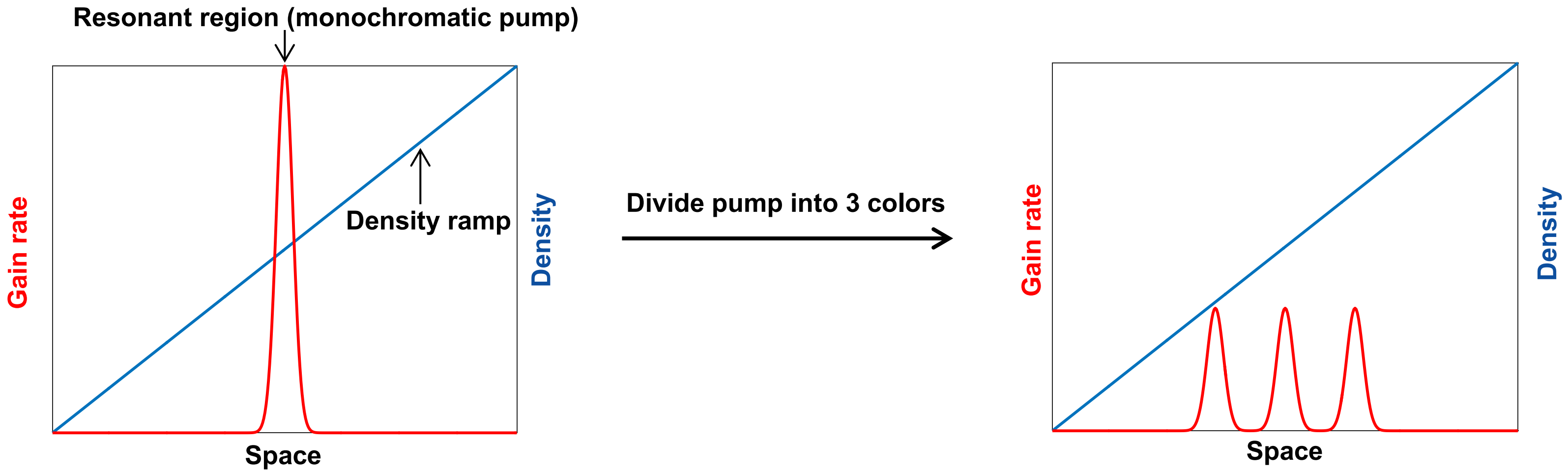


Thresholds for different beam geometries (L_n=400 μm, T_e=4 keV)



Early theoretical studies showed that laser bandwidth could be used to suppress parametric instabilities

- Thomson[1] showed that bandwidth reduces the homogeneous growth rate (γ) by a factor of $\gamma/\Delta\omega$ when $\Delta\omega >> \gamma$
- In inhomogeneous plasmas, absolute instabilities can be suppressed through spatial separation of unstable modes[2]
- Convective gains are not directly mitigated because the reduced growth rate is balanced by broadening of the resonant region[3]



[1]J. J. Thomson and J. I. Karush, Phys. Fluids 17, 1608 (1974).
[2]L. Lu, Phys. Fluids B 1, 1605 (1989).
[3]P. N. Guzdar et al., Phys. Fluids B 3, 2882 (1991).

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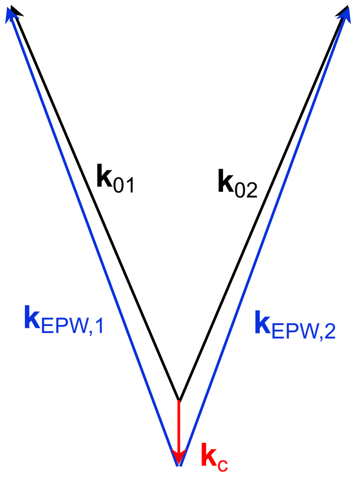

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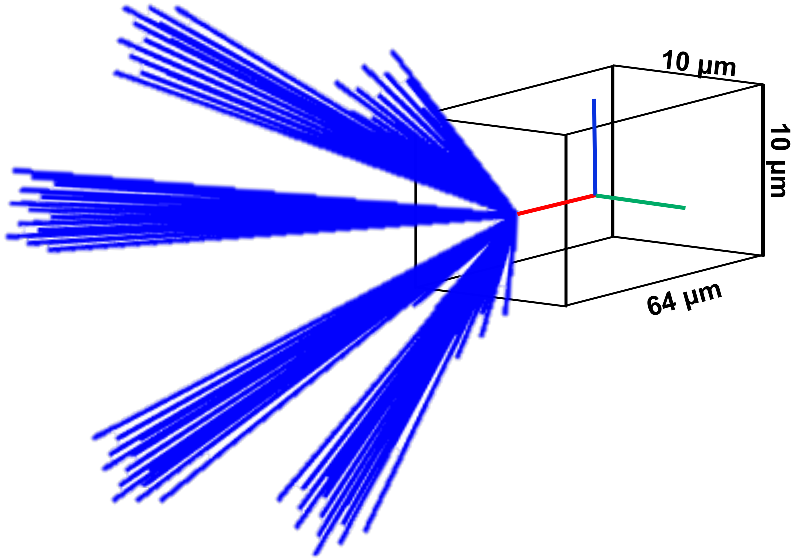

Density profile