Picosecond Thermal Dynamics in an Underdense Plasma Measured with Thomson Scattering

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Summary

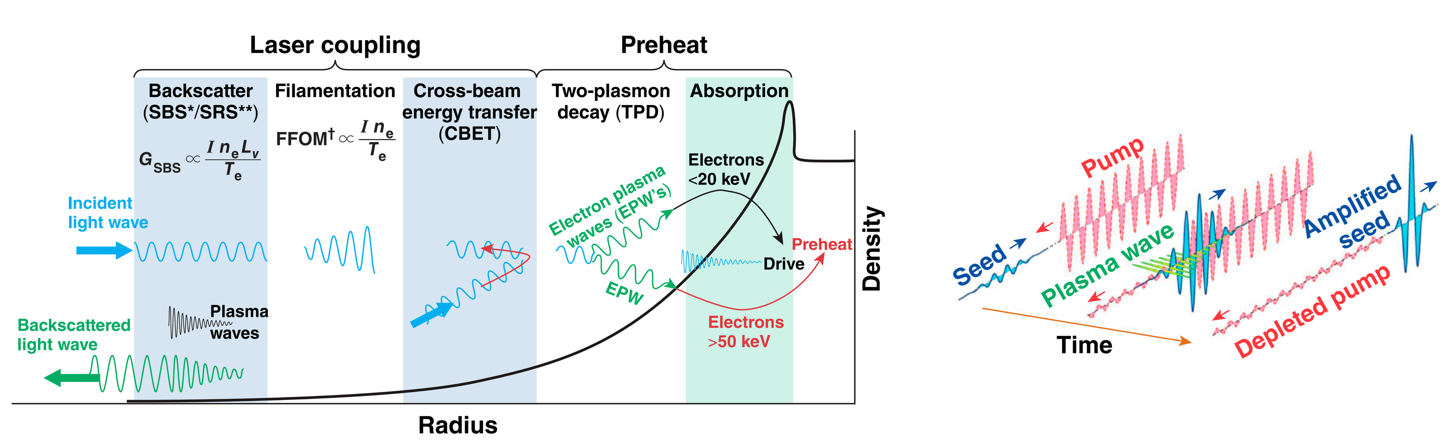
Time-resolved Thomson scattering was used to characterize the temperature and density of a low-density plasma on a picosecond time scale

- A pulse-front tilt compensated streaked spectrometer was utilized for the first time to measure underdense plasma thermal dynamics
- The electron heating rate and plateau temperature are found to increase with higher densities
- The electron temperature was observed to rise from an initial 5 eV to a plateau temperature in 23 ps

E26204

Motivation

Underdense plasmas have many promising applications within the laser–plasma interaction field: nuclear fusion, particle accelerators, x-ray sources, and laser-plasma amplification



Having complete knowledge of the plasma dynamics is essential to establishing optimal parameters for a given application.

*SBS = stimulated Brillouin scattering
**SRS = stimulated Raman scattering
†FFOM = filamentation figure of merit

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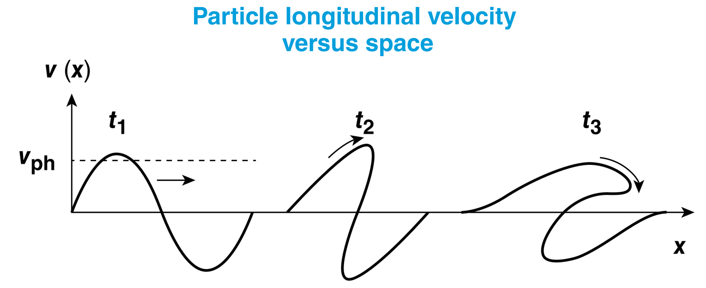
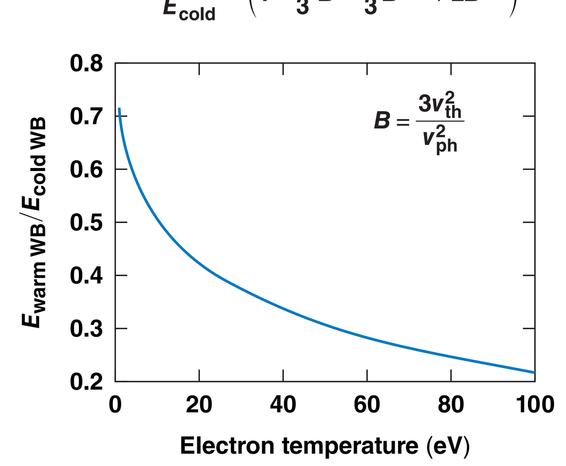
At high amplitudes, the electron plasma wave can break if the particle velocity carrying the wave approaches the wave's phase velocity



Prevention

$v_{osc} < v_{ph}$

$\frac{n_e}{n_c} > 2.5\,(a_{pump})^{4/3}$



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E25524b

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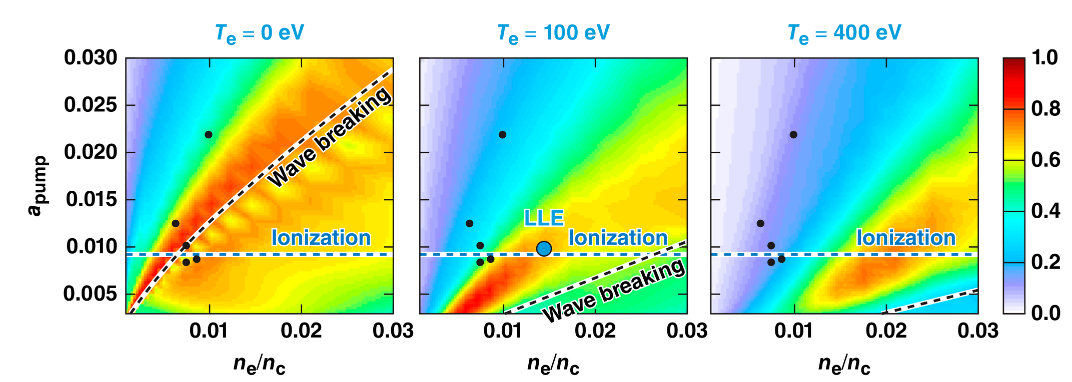

Wave breaking changes the parameter regime for optimal efficiency in a Raman amplifier.

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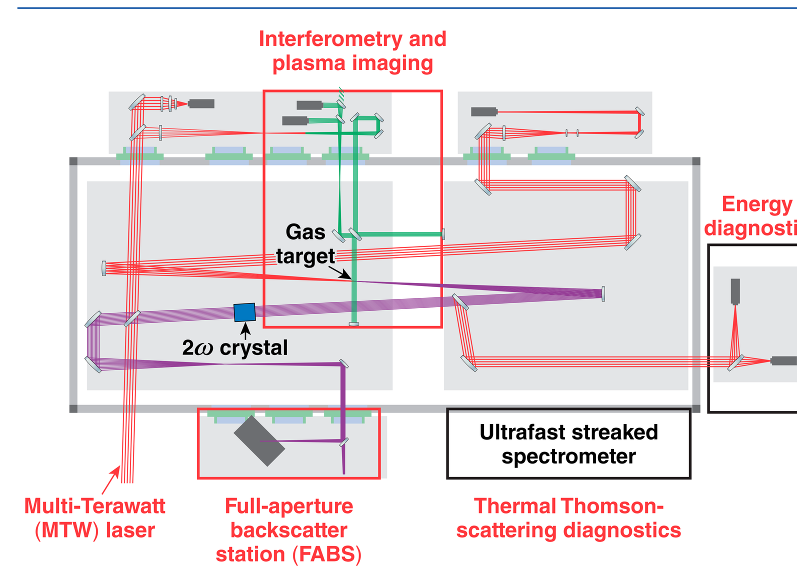

- Pump
  - λ = 1053 nm
  - E = 1.27 J
  - Δt = 55 ps
- Thomson-scattering probe
  - λ = 527 nm
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  - Δt = 40 ps

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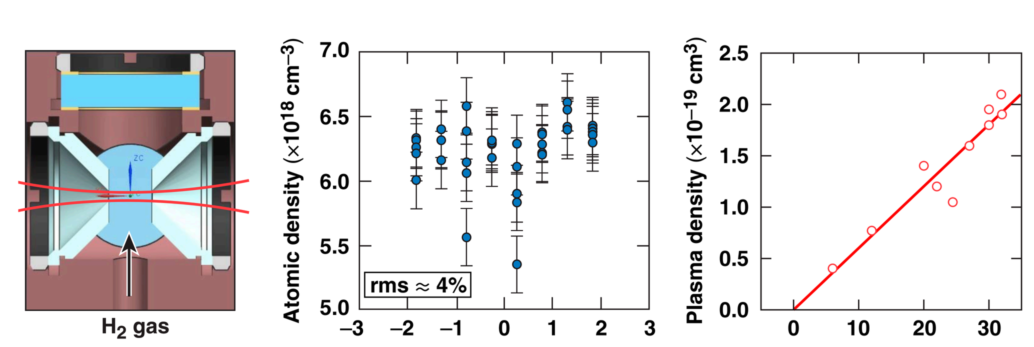
A H_2 gas cell was used to create a 4-mm-long homogenous plasma and characterized using interferometry and Thomson scattering

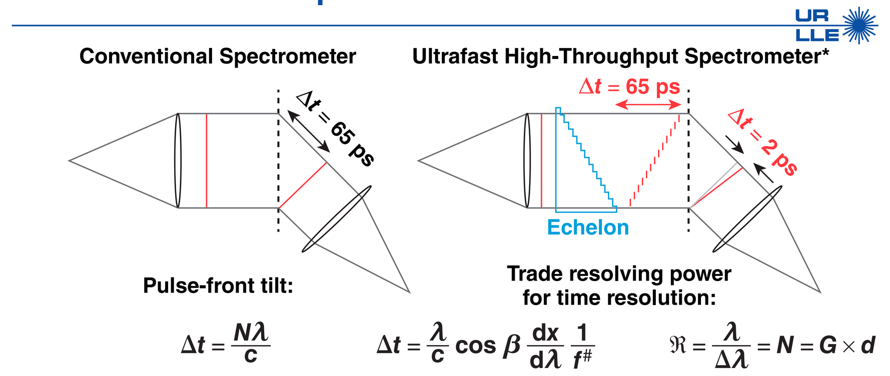


Interferometry indicates a neutral gas uniformity of less than 4% rms.

rms = root mean square

E24636c

A novel high-throughput (f/5), ultrafast picosecond Thomson-scattering system* was required to measure the evolution of the plasma conditions



	Resolving power	G (ll/mm)	dx/dλ (mm/nm)	d (mm)	f#	Δt (ps)
Conventional	20,000 (0.025 nm)	300	0.125	65	5	65
Ultrafast	600 (1 nm)	300	0.125	2	5	2

*J. Katz et al., Rev. Sci. Instrum. 87, 11E535 (2016).

E25791b

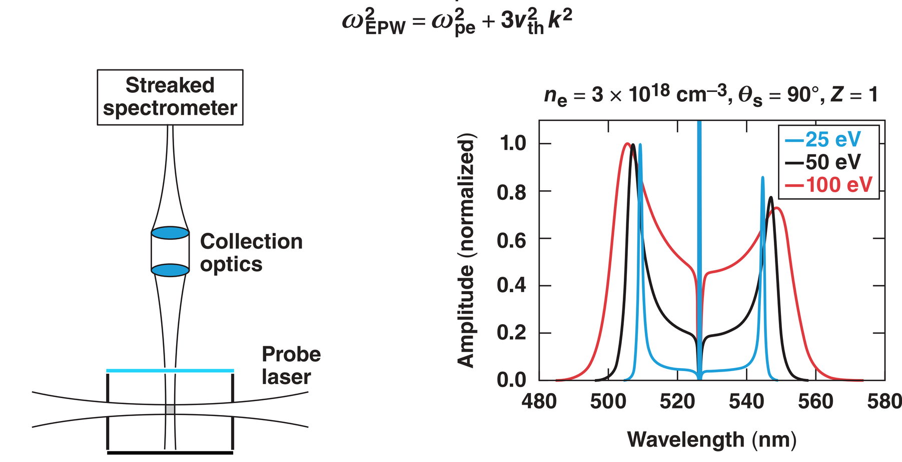
The electron temperature and density can be determined by scattering from thermal electron plasma waves

Expect to see

$\omega_{ion\ feature} = \omega_{probe} \pm \omega_{IAW} \sim \omega_{probe}$

$\omega_{electron\ feature} = \omega_{probe} \pm \omega_{EPW}$

$\omega_{EPW}^2 = \omega_{pe}^2 + 3v_{th}^2k^2$



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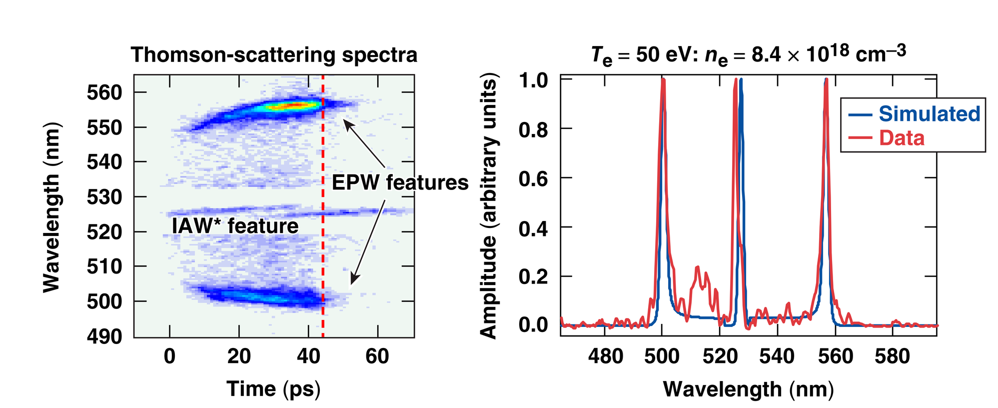
The Thomson-scattering data were fit late in time to find both the election temperature and density



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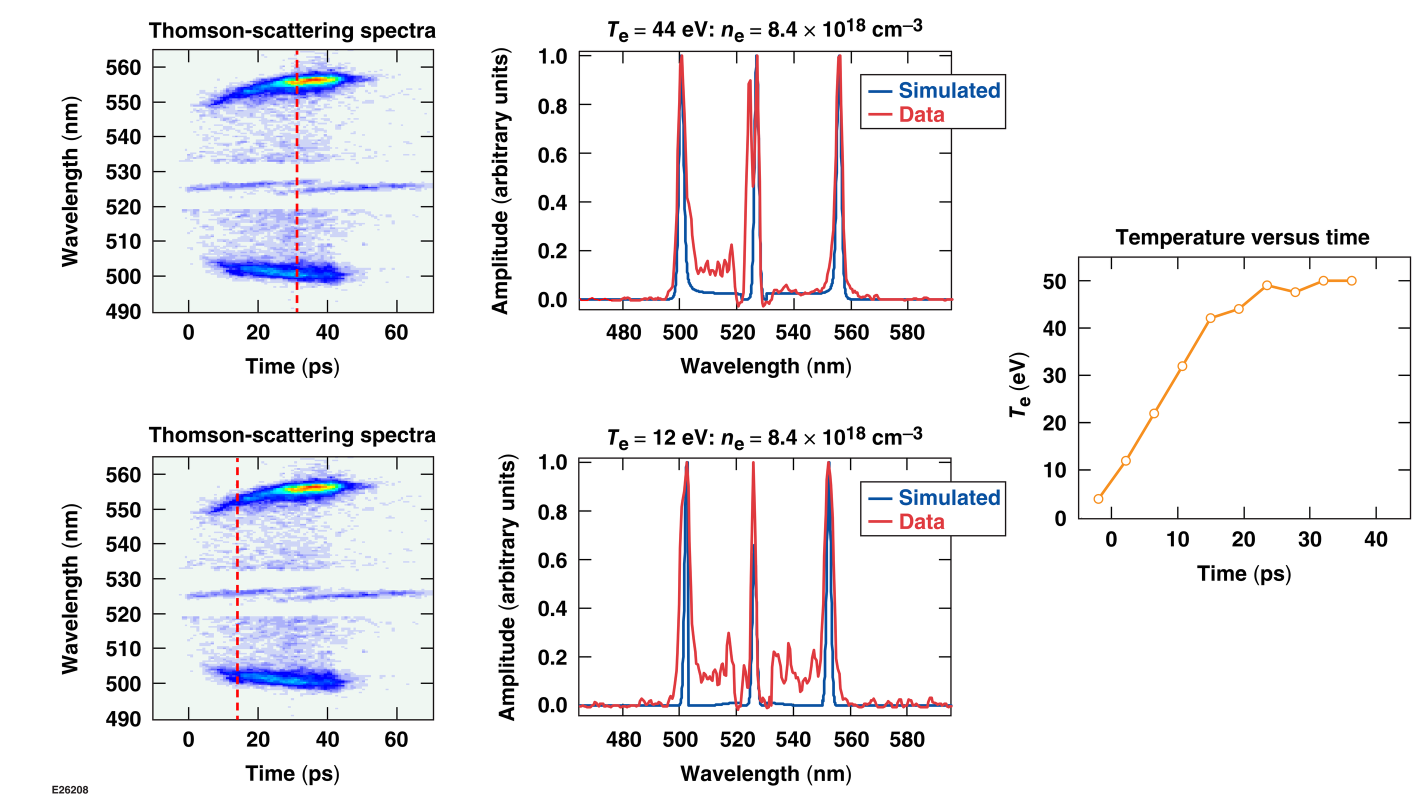
Keeping the electron density constant, the Thomson spectra were fit for all earlier times by changing the plasma temperature



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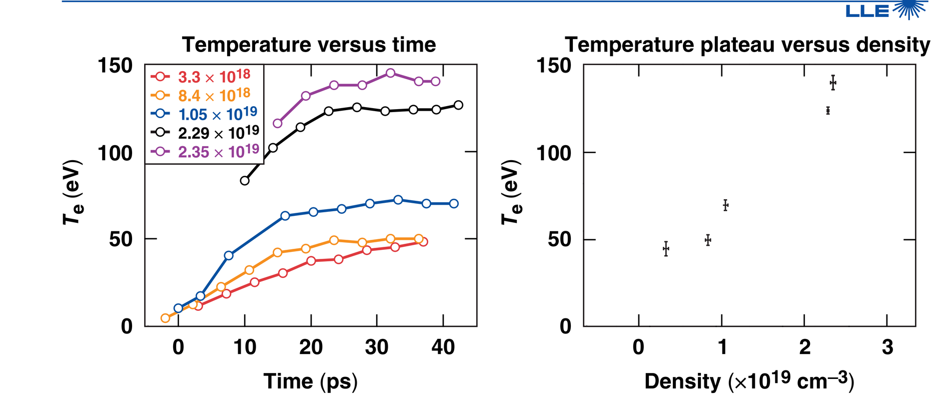
The heating rates and temperature plateaus were measured as a function of density for a 2×10^{14} W/cm^2 pump laser



The electron heating rate and plateau temperature are found to increase with higher densities.

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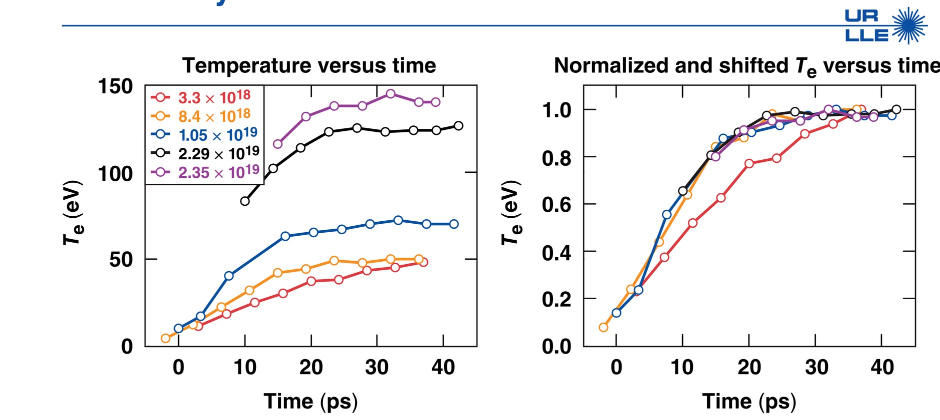
The inverse-bremsstrahlung heating pattern held during the density scan for four out of the five shots



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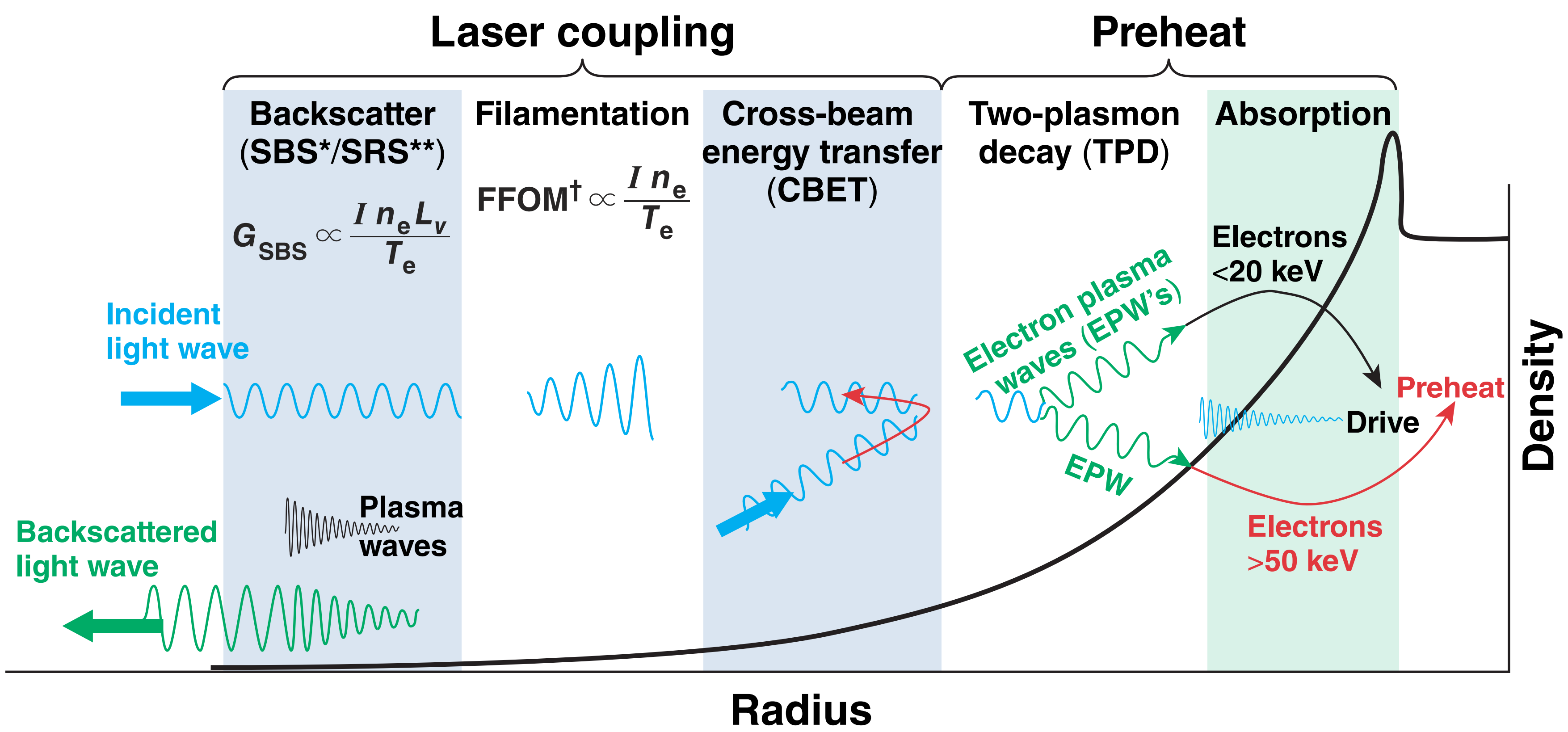

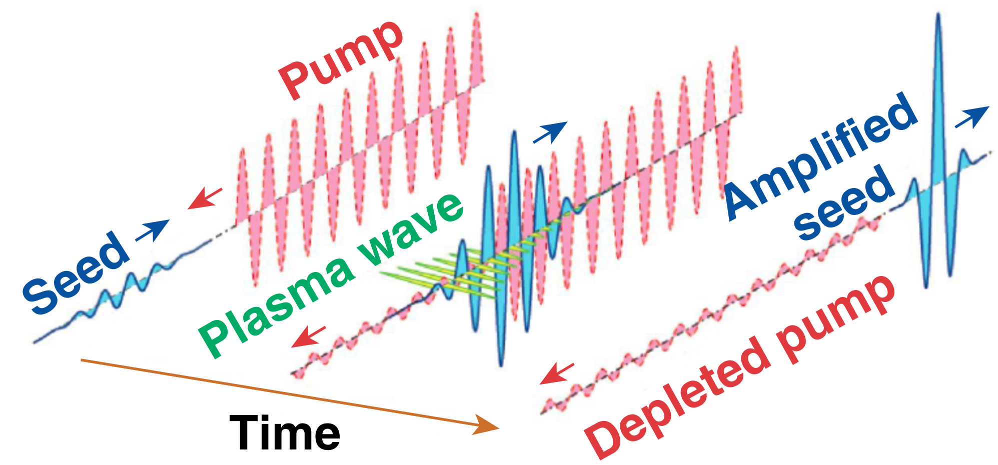

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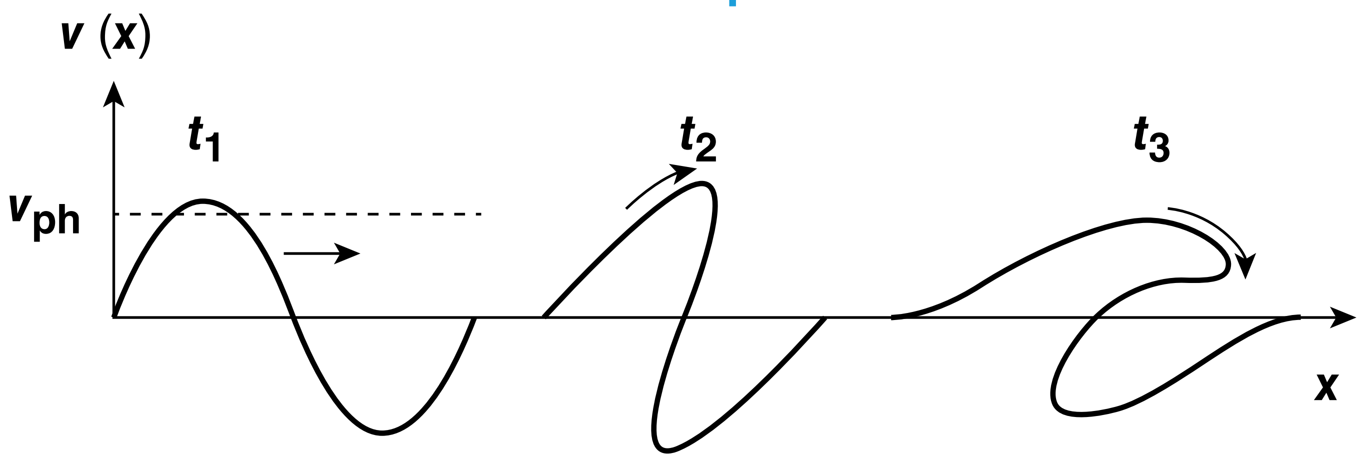
Particle longitudinal velocity versus space



Prevention

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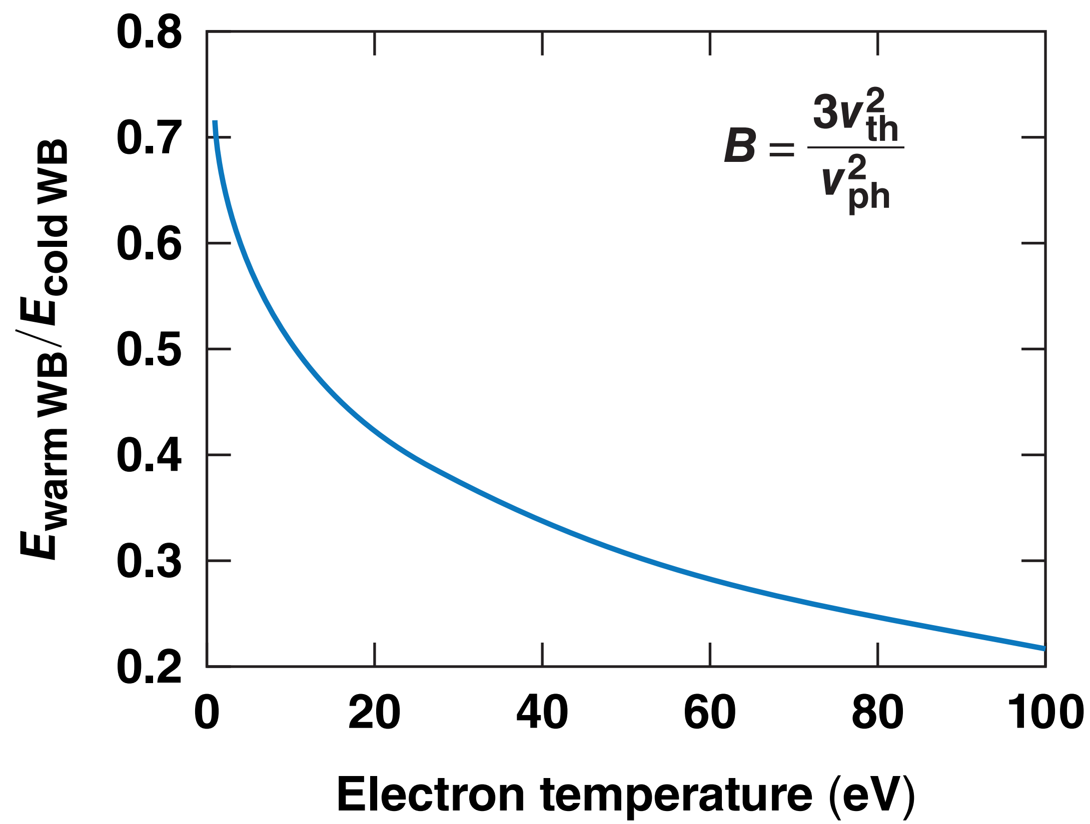
Finite-temperature effect on wave breaking

$$\frac{E_{warm}}{E_{cold}} = \left(1 - \frac{1}{3}B - \frac{8}{3}B^{1/4} + 2B^{1/2}\right)^{1/2}$$



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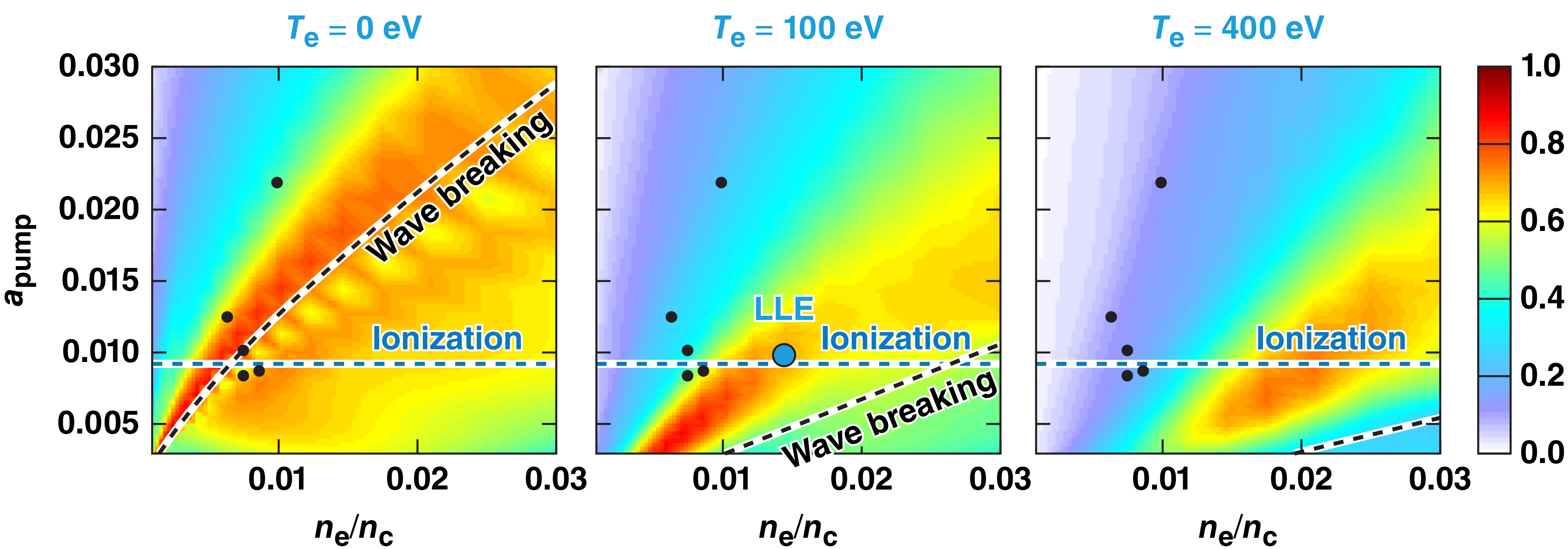
1-D, constant pump, constant density, seed meets nonlinear regime



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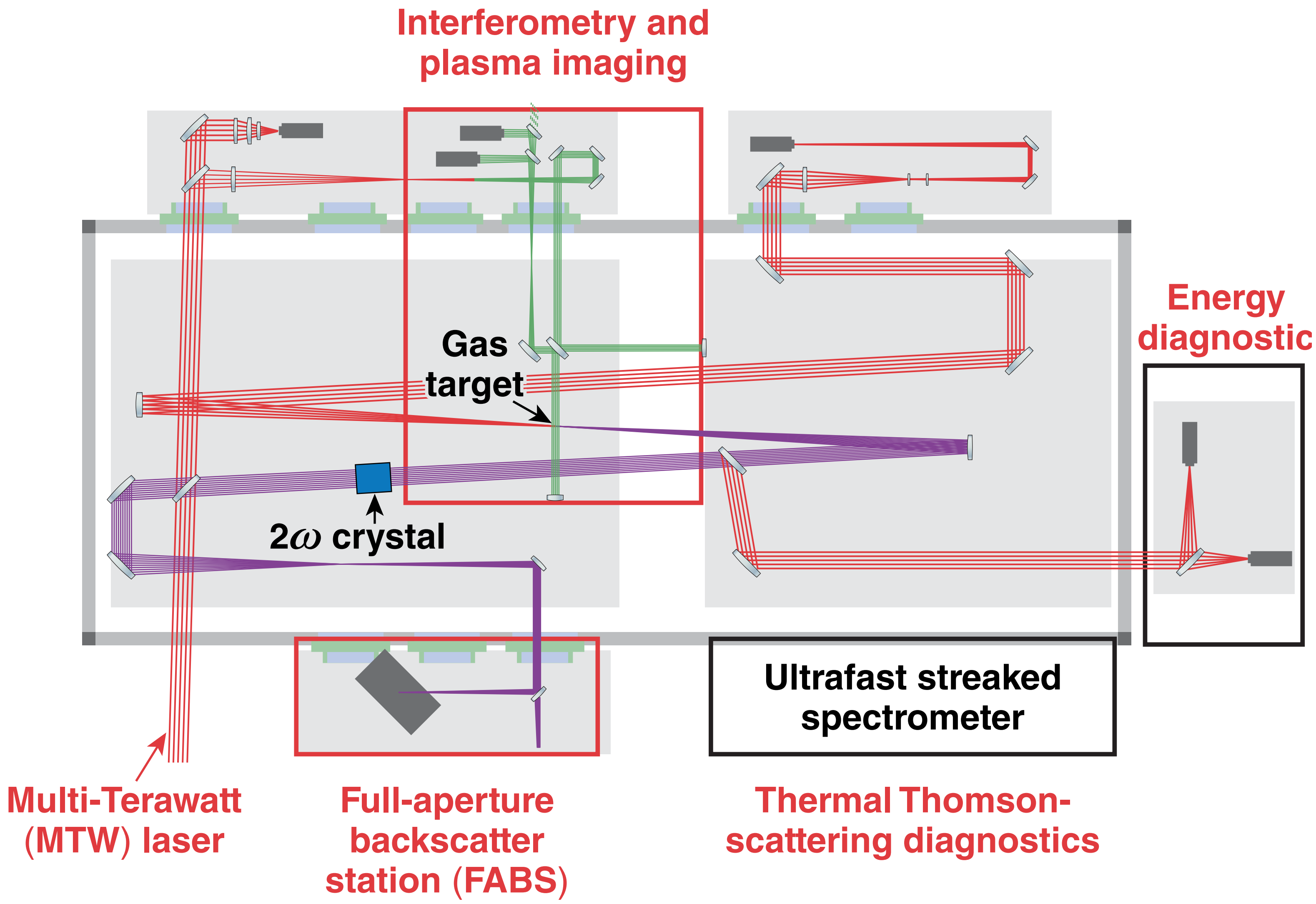

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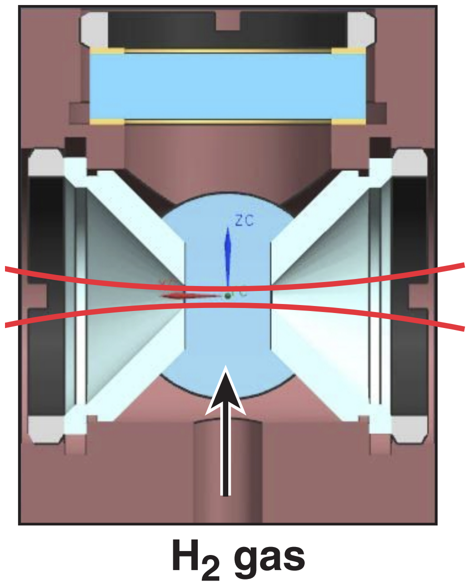

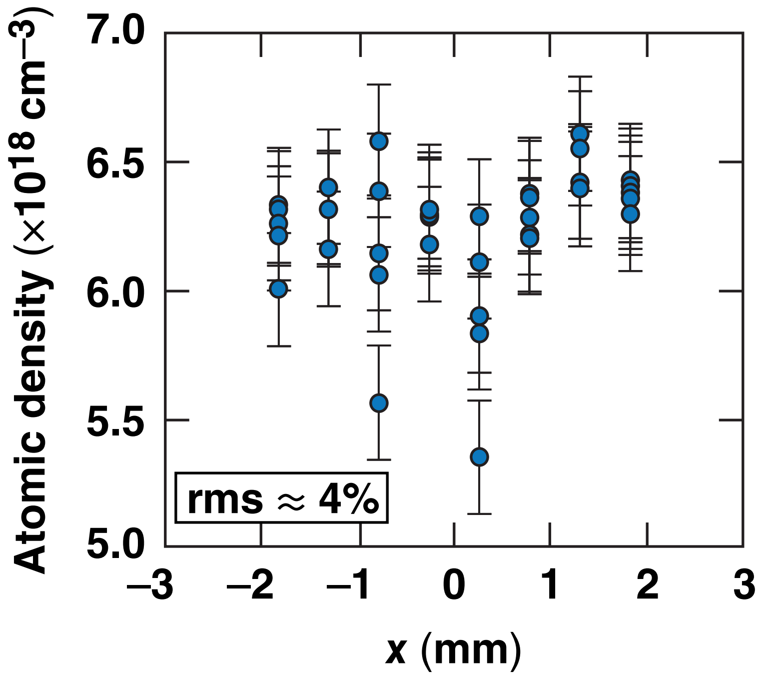

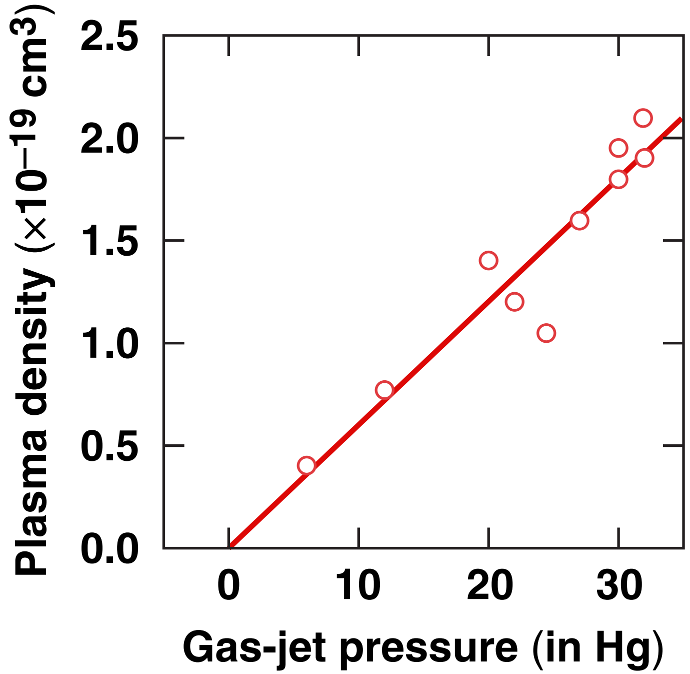

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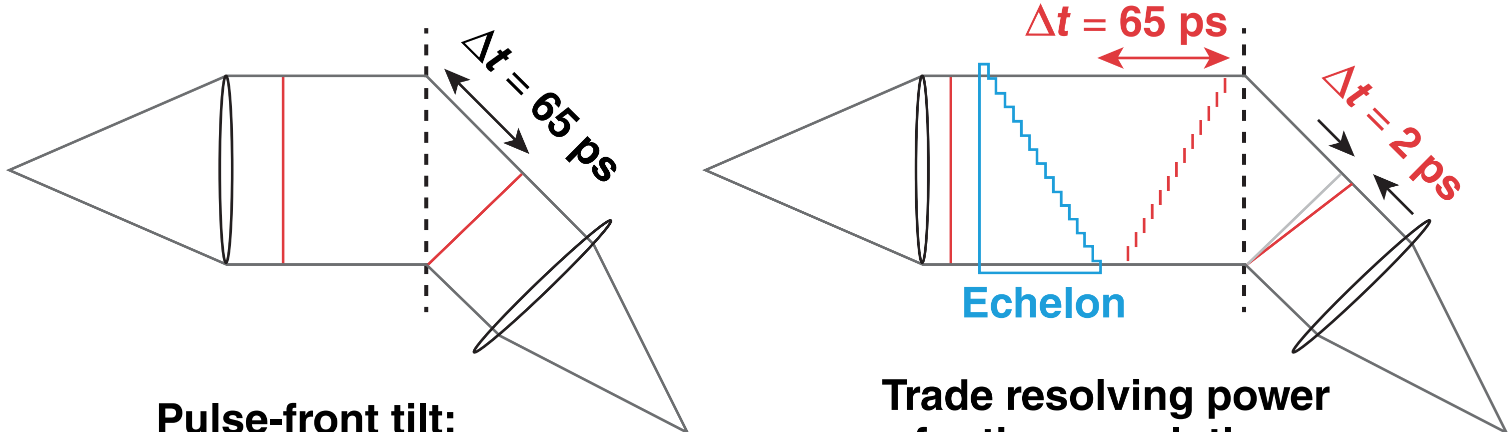
Conventional Spectrometer | **Ultrafast High-Throughput Spectrometer***



Pulse-front tilt:

$$\Delta t = \frac{N\lambda}{c}$$

Trade resolving power for time resolution:

$$\Delta t = \frac{\lambda}{c} \cos\beta \frac{dx}{d\lambda} \frac{1}{f^{\#}}$$

$$\Re = \frac{\lambda}{\Delta\lambda} = N = G \times d$$

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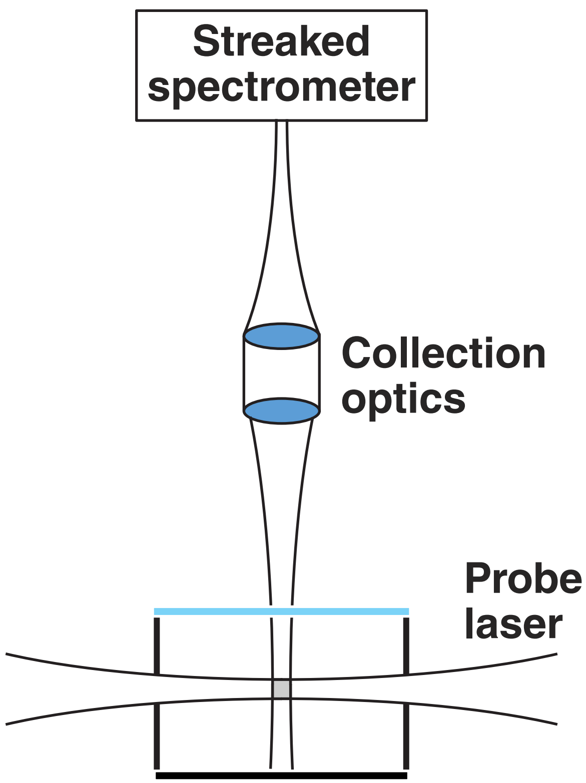

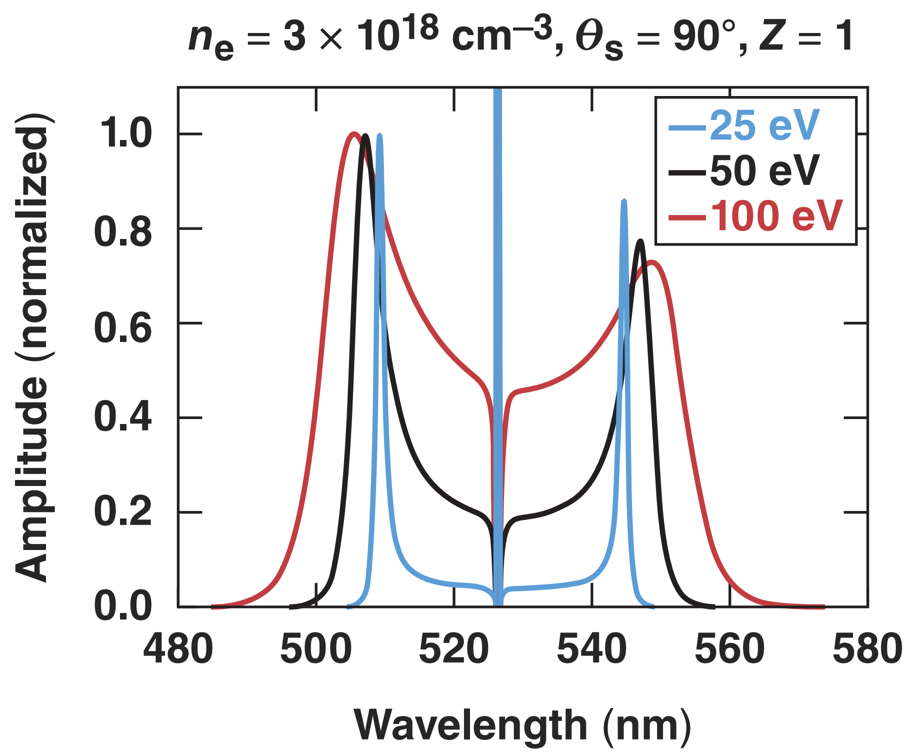

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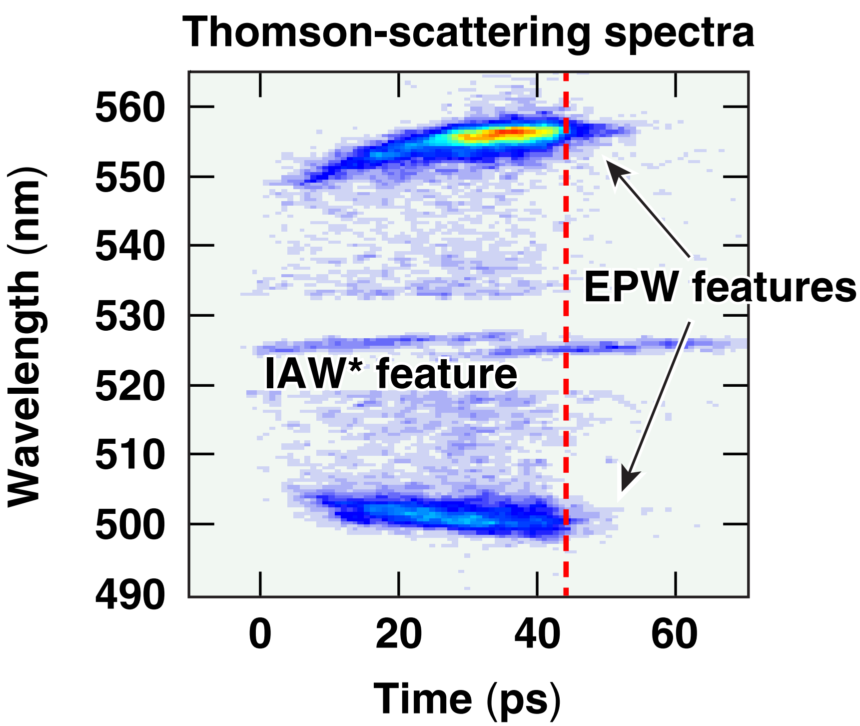

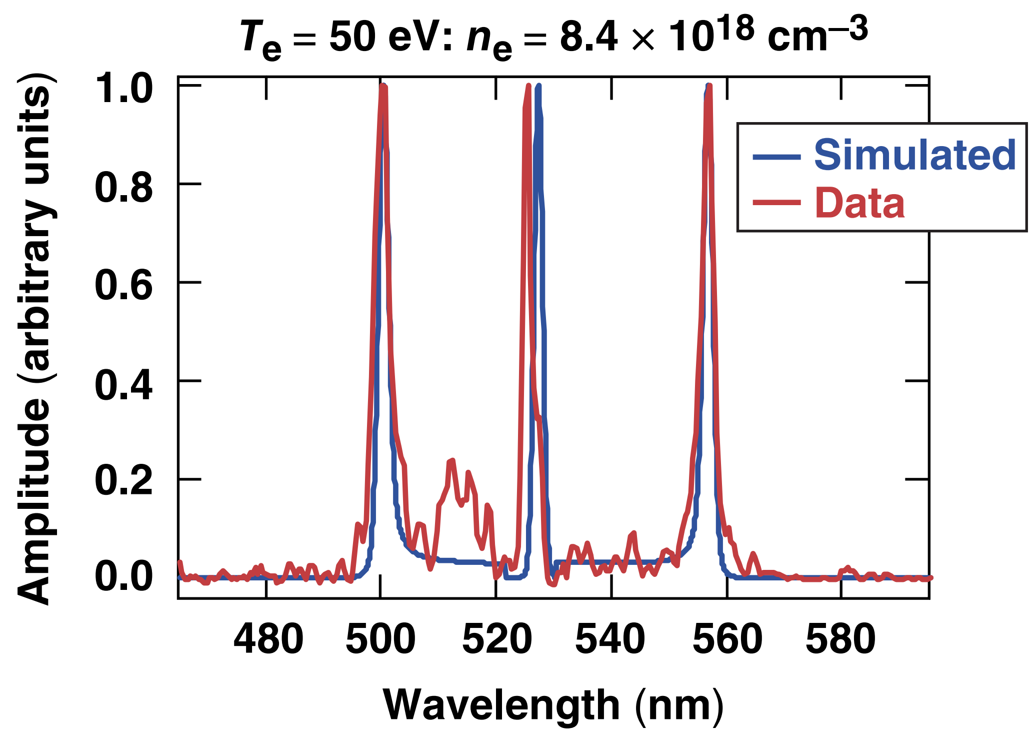

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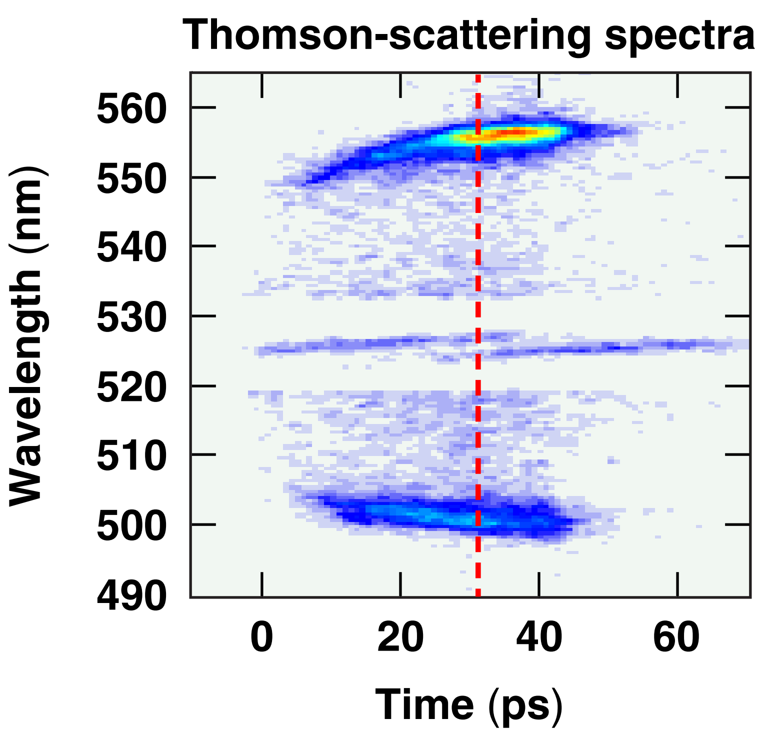

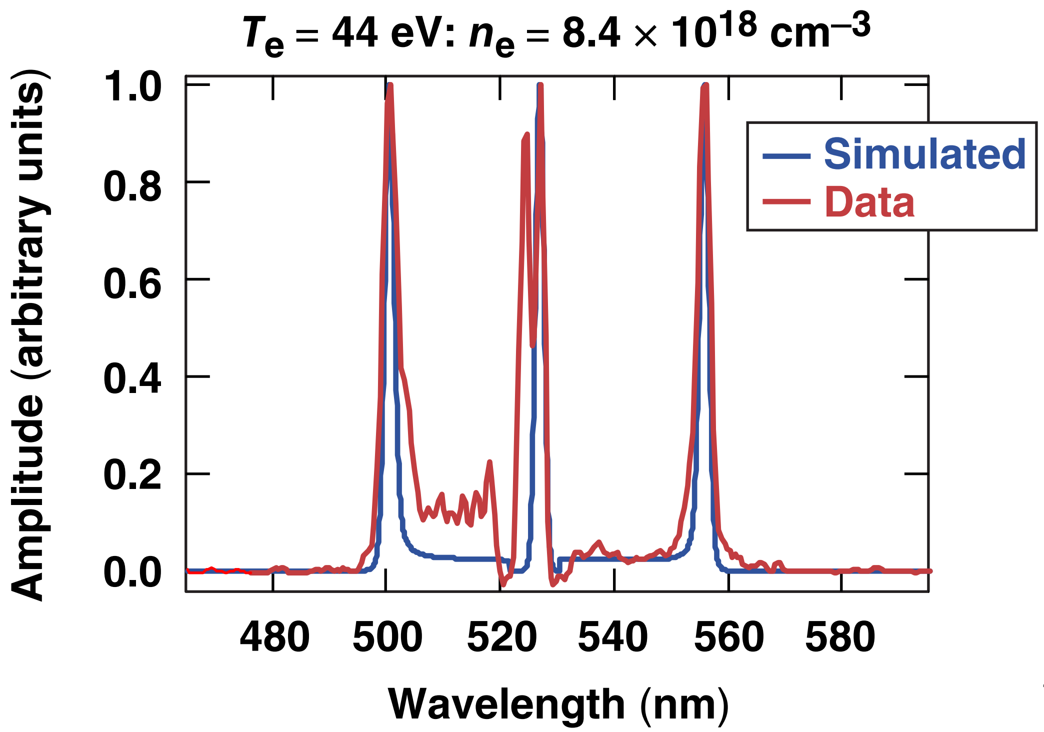

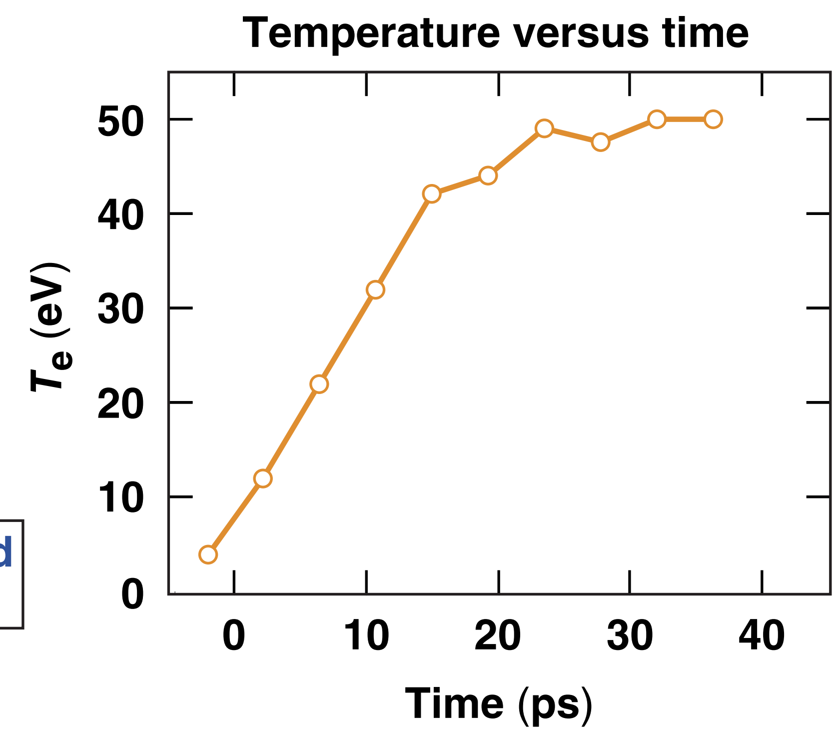

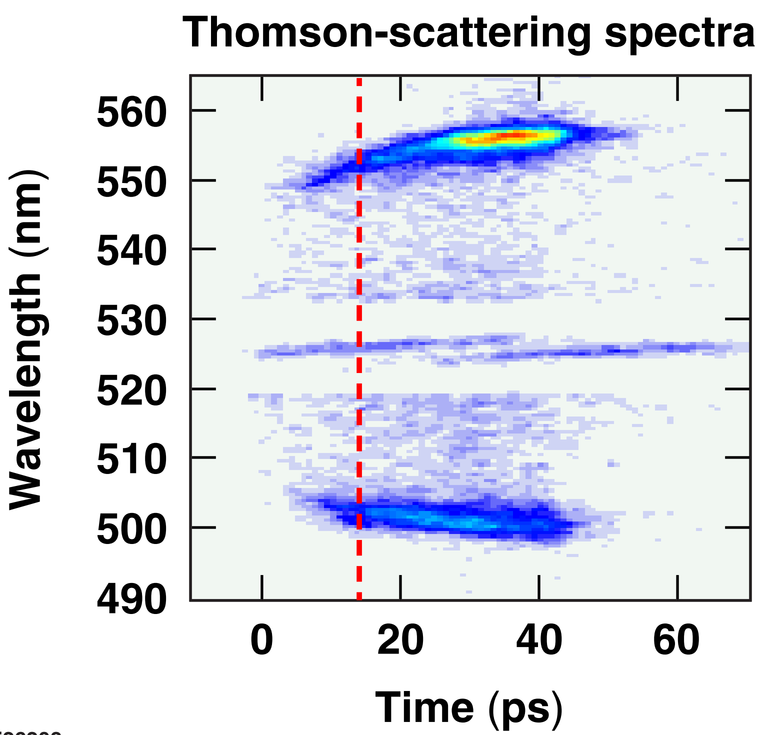

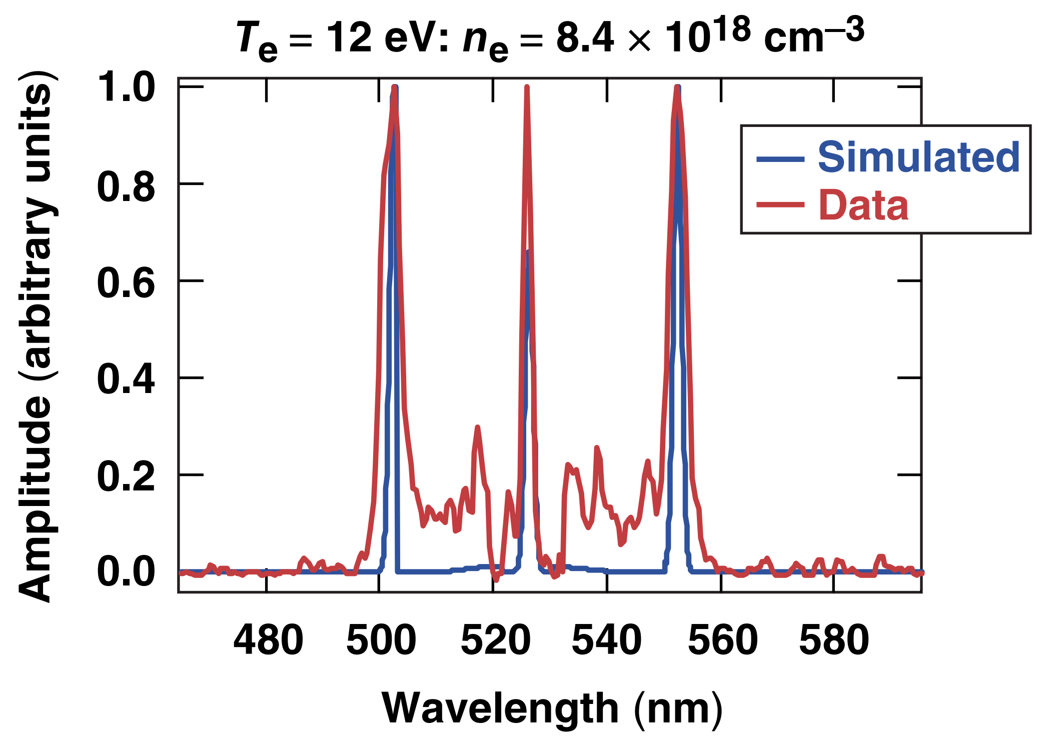

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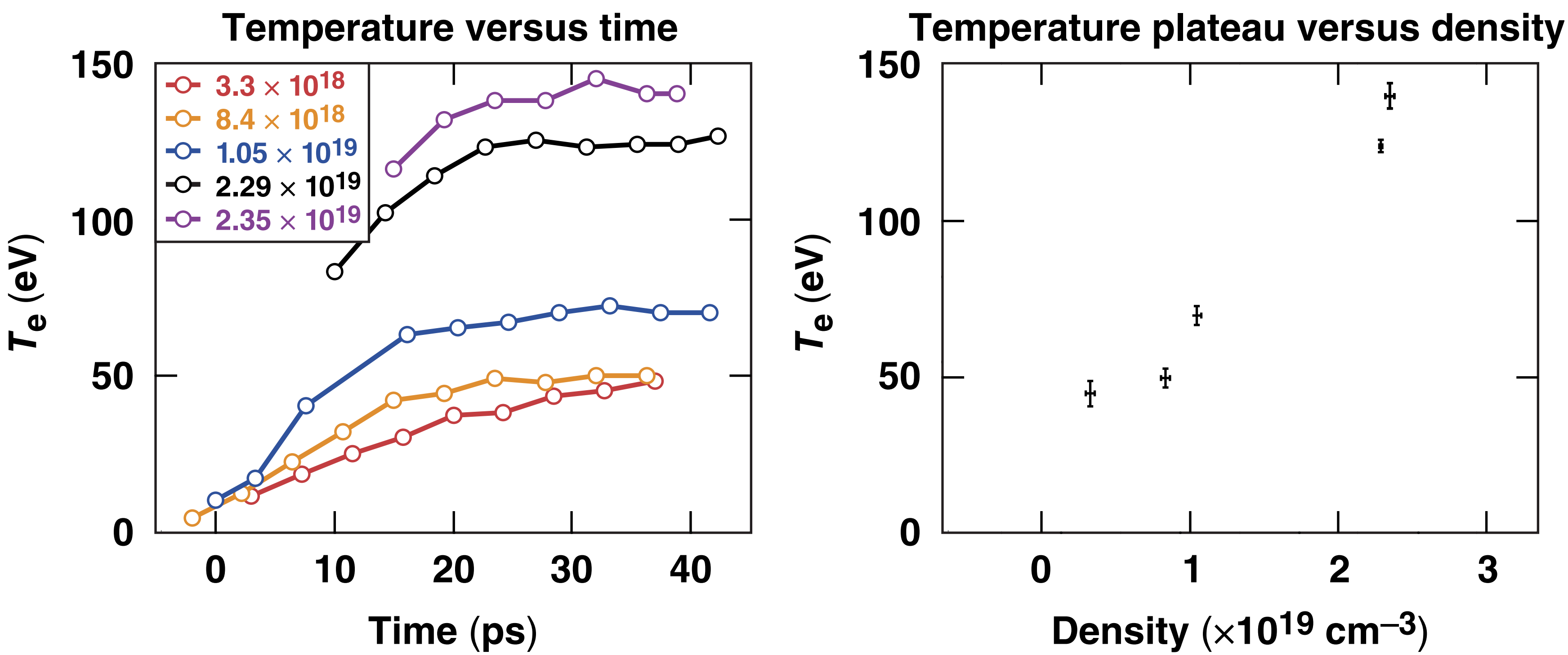

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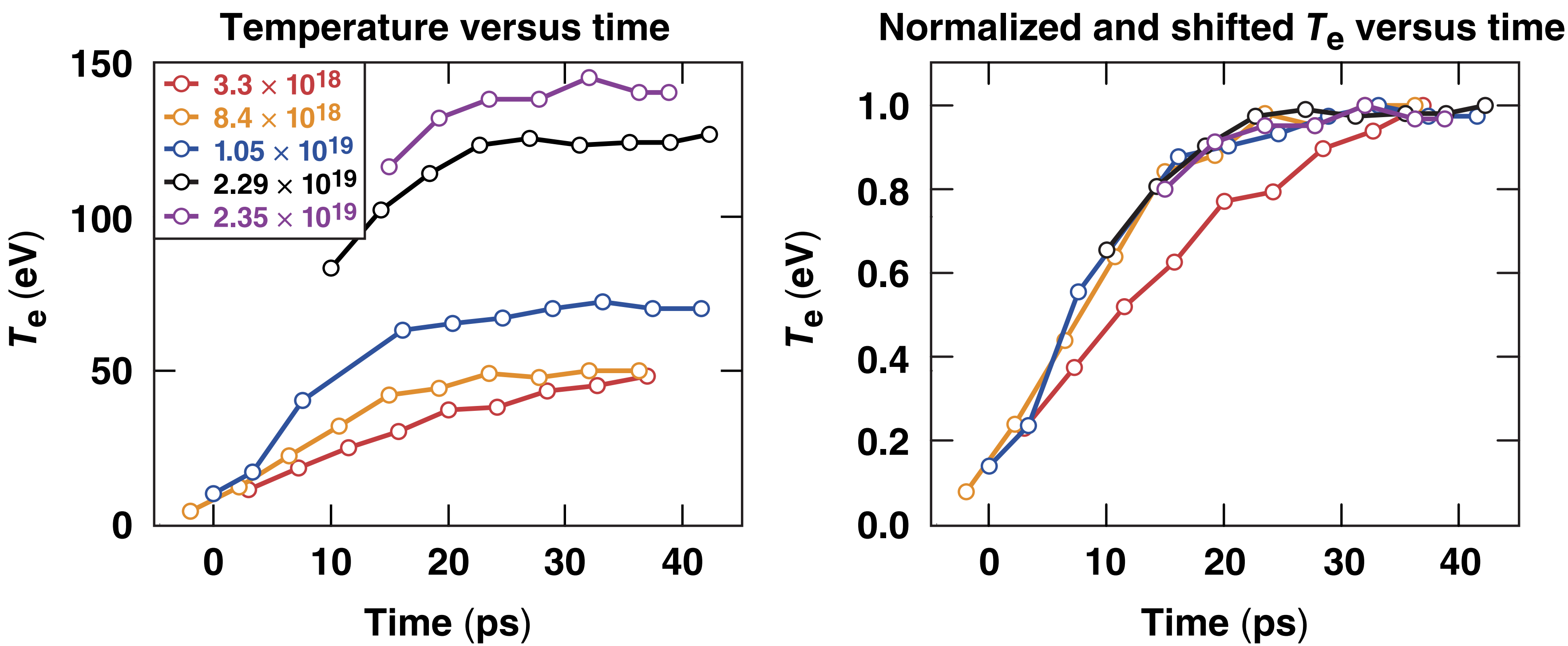

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