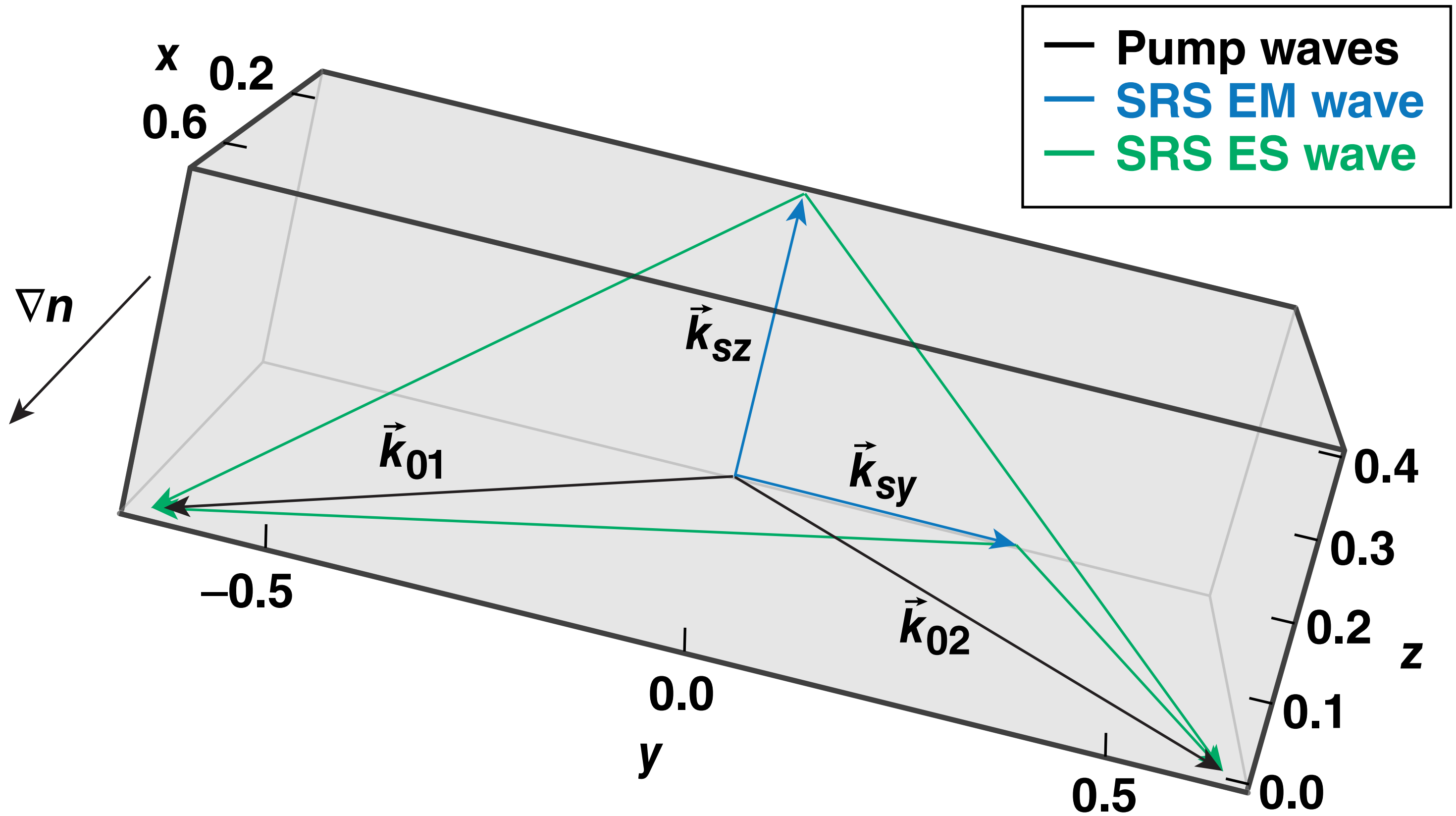
Absolute Stimulated Raman Sidescattering in Direct-Drive Irradiation Geometries



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Summary

Unlike absolute stimulated Raman scattering (SRS) at quarter-critical density, absolute SRS sidescatter is strongly affected by geometry and temperature

- SRS sidescatter is expected to become the dominant form of the instability for NIF*-scale direct-drive experiments
- Since for sidescatter the scattered-light wave vector is comparable in length to k_0, its orientation relative to the pump wave vectors significantly affects the coupling of the instability
- The absolute thresholds depend on plasma and beam geometry in a complicated way
- While general trends can be discerned from one- and two-beam examples, quantitative multibeam thresholds require specific calculations; the formalism presented here is readily extended to such calculations

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Liu, Rosenbluth, and White pointed out in 1974 that SRS sidescatter can be absolute in the density-gradient direction*

- The scattered-light wave propagates perpendicular to the density gradient in the interaction region, minimizing convection and allowing absolute growth
- The instability remains convective in the transverse direction, but if the growth is fast enough, and the transverse scale length long enough, the instability will saturate through nonlinear effects rather than convection
- Their condition for this is $\left(\frac{v_0}{c}\right)\left(\frac{\omega_p}{\omega_0}\right)k_0 L_y > 1$ or $\sqrt{I_{14}}\, L_y\,(\mu\mathrm{m}) > 47$
- This condition is readily satisfied in modern laser–plasma interaction experiments
- Recent experiments and simulations indicate that SRS sidescatter may be the predominant form of SRS in direct-drive experiments**

*C. S. Liu, M. N. Rosenbluth and R. B. White, Phys. Fluids 17, 1211 (1974).
**M. J. Rosenberg *et al.*, WeI-2 (invited); P. A. Michel *et al.*, WeO-4; W. Seka *et al.*, WeO-5, this conference.

In a linear gradient, the coupled equations for SRS sidescatter become a set of first-order ordinary differential equations (ODE's)

UR LLE

- For a gradient in the *x* direction, it is found that the interaction occurs over a very small range of density
- The equations in *k* space become (for two beams)

$$\left.\begin{aligned}\frac{\partial}{\partial k_x}u_{d1} &= -\frac{1}{2}\left(\frac{iL}{\omega_{p0}}\right)u_s D_1 e^{iL/\omega_{p0}^2\int_0^{k_x}\left(\omega_d^2-\omega^2+c^2k^2-3v_T^2k_{d1}^2\right)dk_x} \\ \frac{\partial}{\partial k_x}u_{d2} &= -\frac{1}{2}\left(\frac{iL}{\omega_{p0}}\right)u_s D_2 e^{iL/\omega_{p0}^2\int_0^{k_x}\left(\omega_d^2-\omega^2+c^2k^2-3v_T^2k_{d2}^2\right)dk_x}\end{aligned}\right\}\ \text{Plasma waves}$$

$$\left.\begin{aligned}\frac{\partial}{\partial k_x}u_s = &-\frac{1}{2}\left(\frac{iL}{\omega_{p0}}\right)u_{d1} D_1 e^{-iL/\omega_{p0}^2\int_0^{k_x}\left(\omega_d^2-\omega^2+c^2k^2-3v_T^2k_{d1}^2\right)dk_x} \\ &-\frac{1}{2}\left(\frac{iL}{\omega_{p0}}\right)u_{d2} D_2 e^{-iL/\omega_{p0}^2\int_0^{k_x}\left(\omega_d^2-\omega^2+c^2k^2-3v_T^2k_{d2}^2\right)dk_x}\end{aligned}\right\}\ \text{SRS light}$$

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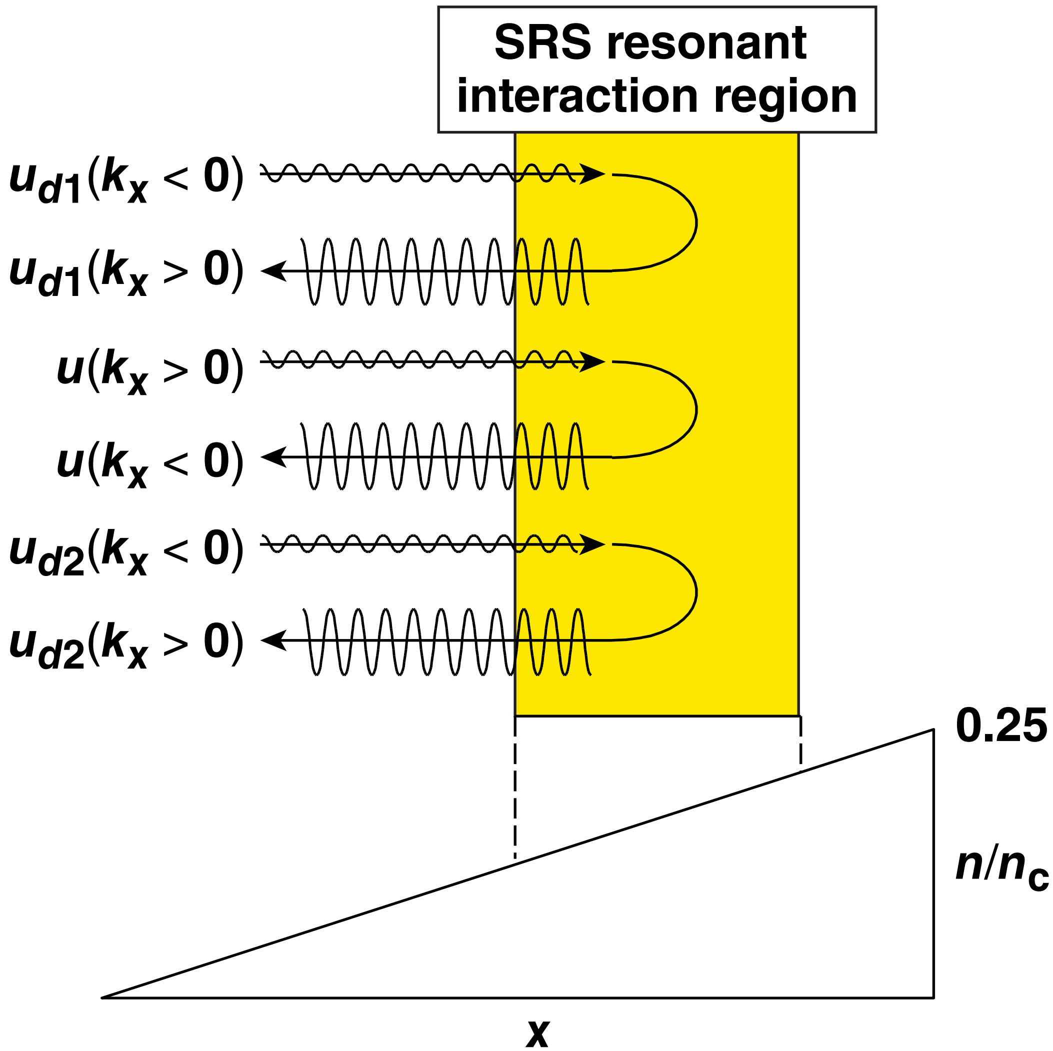
Numerical integration of these equations gives spatial gain; divergent gain indicates absolute threshold



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The coupling coefficients depend on the geometry and polarization of the pump and scattered waves

p-polarized pump $\tilde{v}_{0z} = 0, \tilde{v}_{ez} = 0$	*p*-polarized SRS in the *x–y* plane $k_z = 0$, in *x–y* plane:	$D = \left(k_x v_{0y} - k_y v_{0x}\right)\frac{k_d}{k}$
	p-polarized SRS in the *x–z* plane $k_y = 0$, $\vec{k}$ and $\tilde{v}_e$ in the *x–z* plane:	$D = \left(k_x v_{0z} - k_z v_{0x}\right)\frac{k_d}{k}$
	s-polarized SRS $k_y = 0$, $\vec{k}$ in the *x–z* plane: $\tilde{v}_e = \tilde{v}_{ey}\hat{y}$	$D = k_d v_{0y}$
	s-polarized SRS $k_z = 0$, $\vec{k}$ in the *x–y* plane $\tilde{v}_e = \tilde{v}_{ez}\hat{z}$	$D = 0$
s-polarized pump v_0 in *z* direction $\tilde{v}_{0x} = v_{0y} = 0, \tilde{v}_{ey} = 0$	*p*-polarized SRS, $k_y = 0$, $\vec{k}$ and $\tilde{v}_e$ in the *x–y* plane	$D = \frac{k_x k_d}{k} v_{0z}$
	s-polarized SRS, $k_z = 0$, $\vec{k}$ in the *x–y* plane and $\tilde{v}_e$ in *z* direction	$D = k_d v_{0z}$
	p-polarized SRS, $k_z = 0$, $\vec{k}$ and $\tilde{v}_e$ in the *x–y* plane	$D = 0$
	s-polarized SRS, $k_y = 0$, $\vec{k}$ in the *x–y* plane and $\tilde{v}_e$ in the *y* direction	$D = 0$

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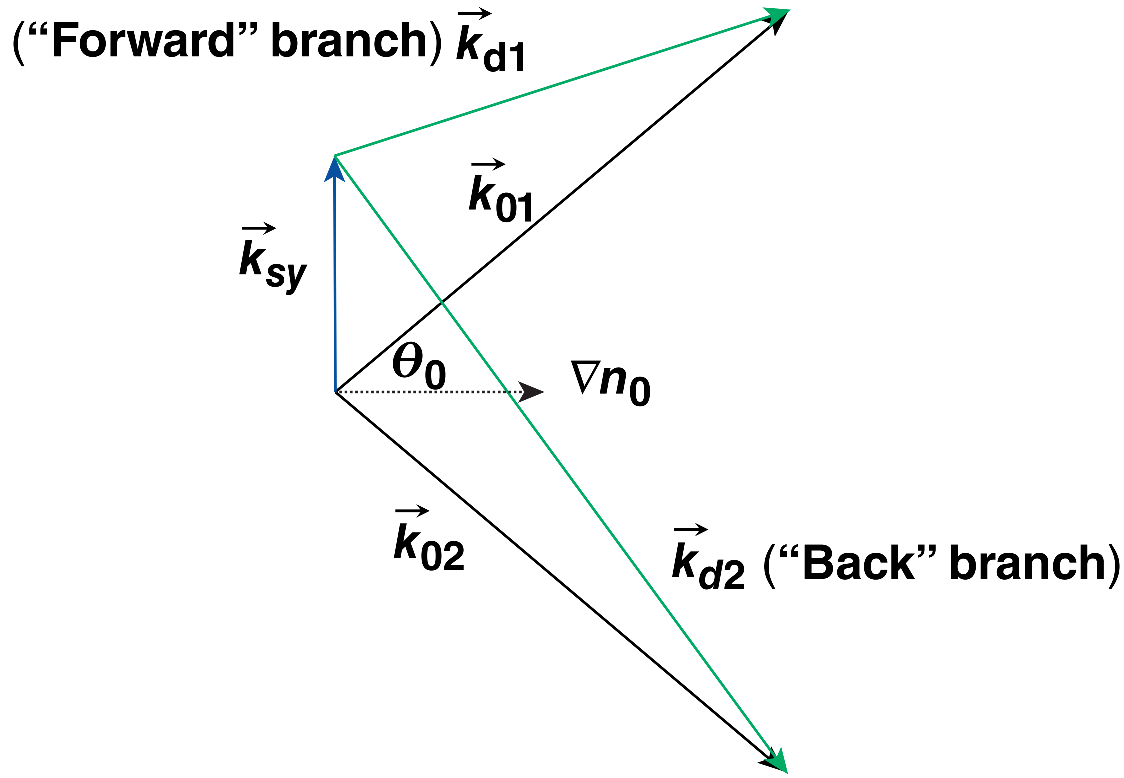
Temperature affects in-plane SRS for oblique incidence



- $\vec{k}_d$ increases with angle between pump and $\vec{k}_s$, increasing SRS gain
- Phase mismatch between $\vec{k}_{d1}$ and $\vec{k}_{d2}$ increases with angle and temperature, so SRS becomes single beam
- Landau damping increases with temperature and $\vec{k}_d$, suppressing the long-$\vec{k}_d$ branch and also making SRS single beam

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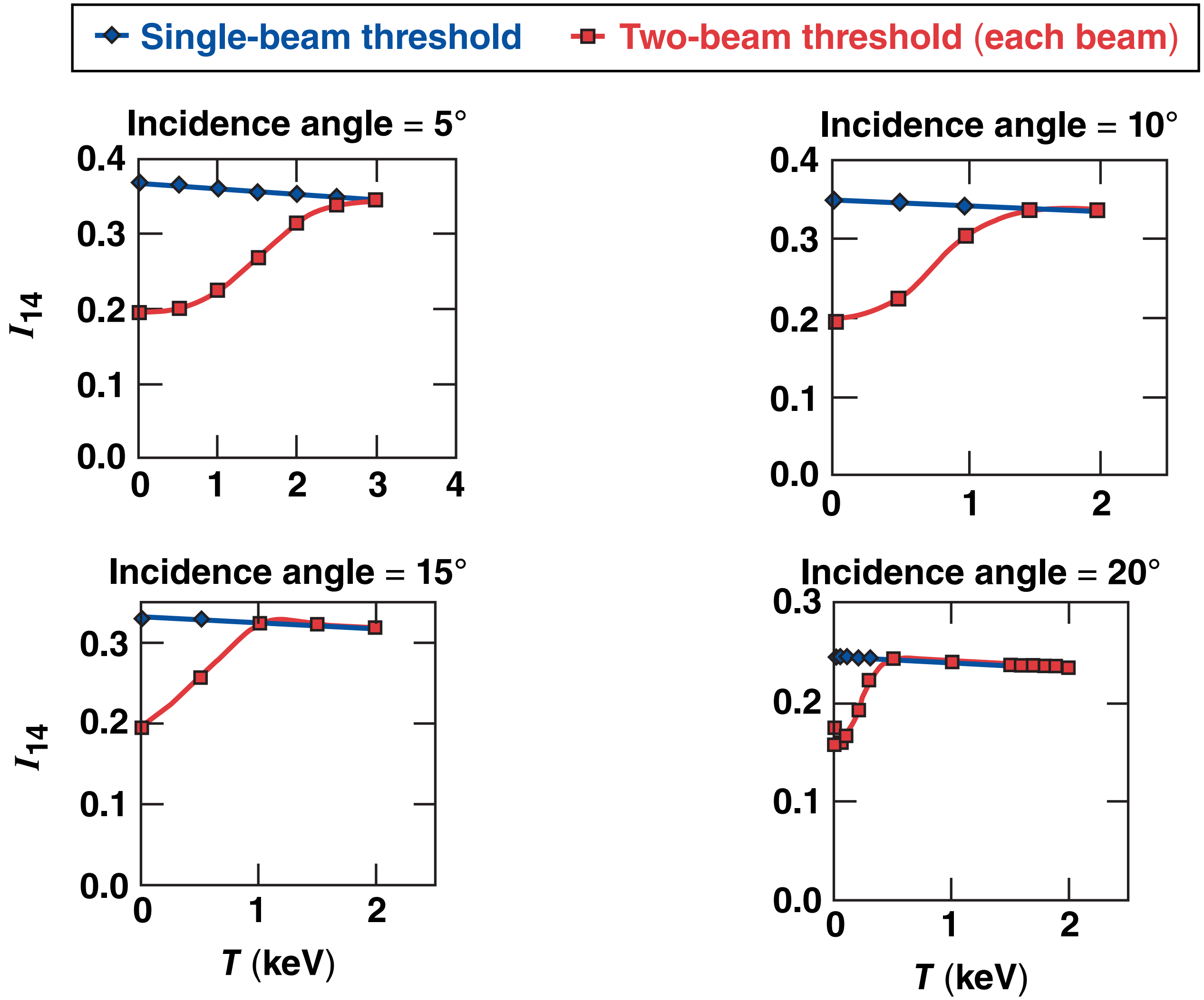
Increasing temperature inhibits two-beam in-plane SRS



- **Phase mismatch caused by Bohm–Gross frequency increases with temperature**

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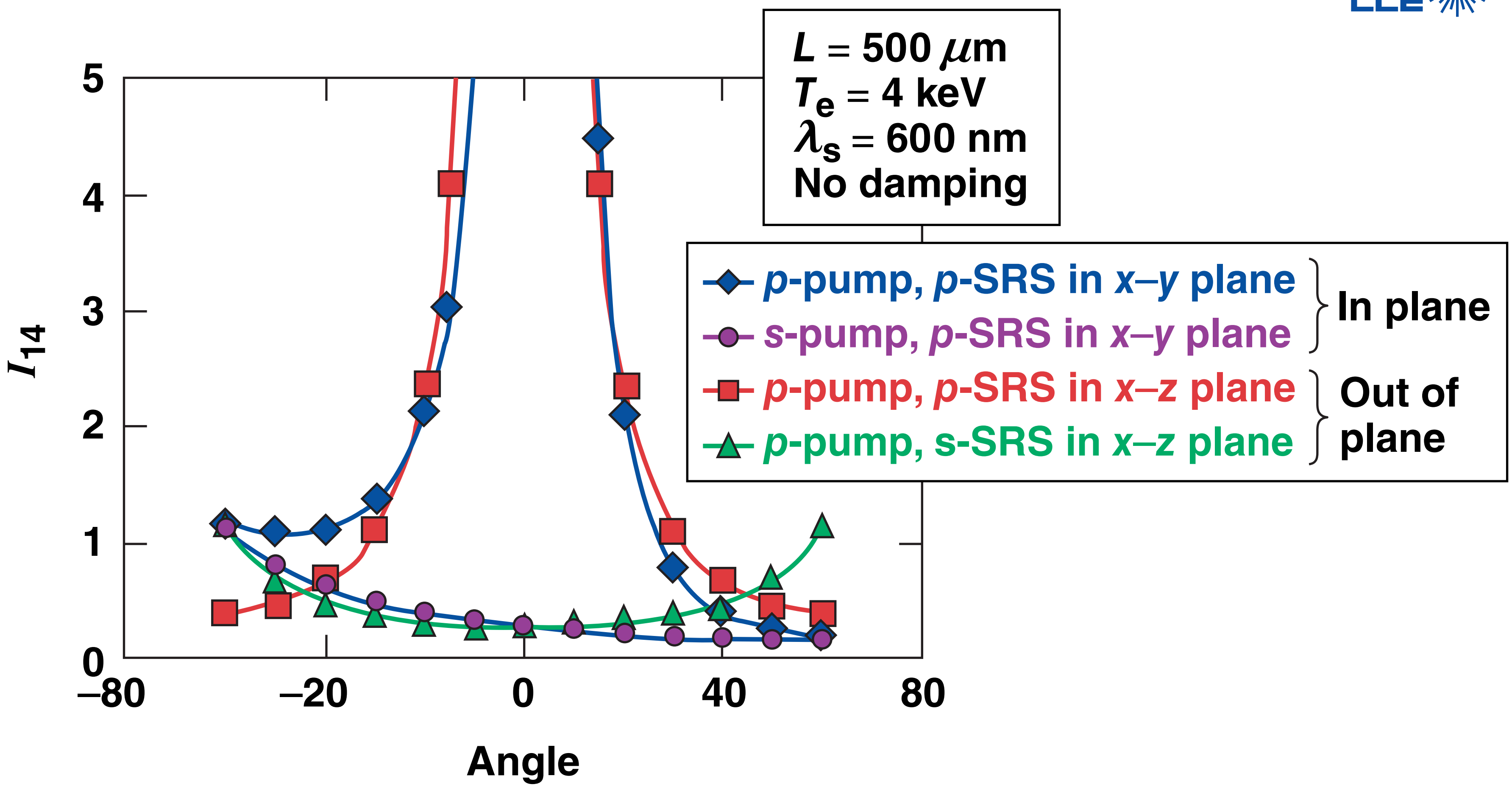
For small damping, the "back" branch of sidescatter has the lowest threshold



- The mode with the lowest threshold varies with incidence angle and polarization, but the "*s–s*" mode is usually competitive

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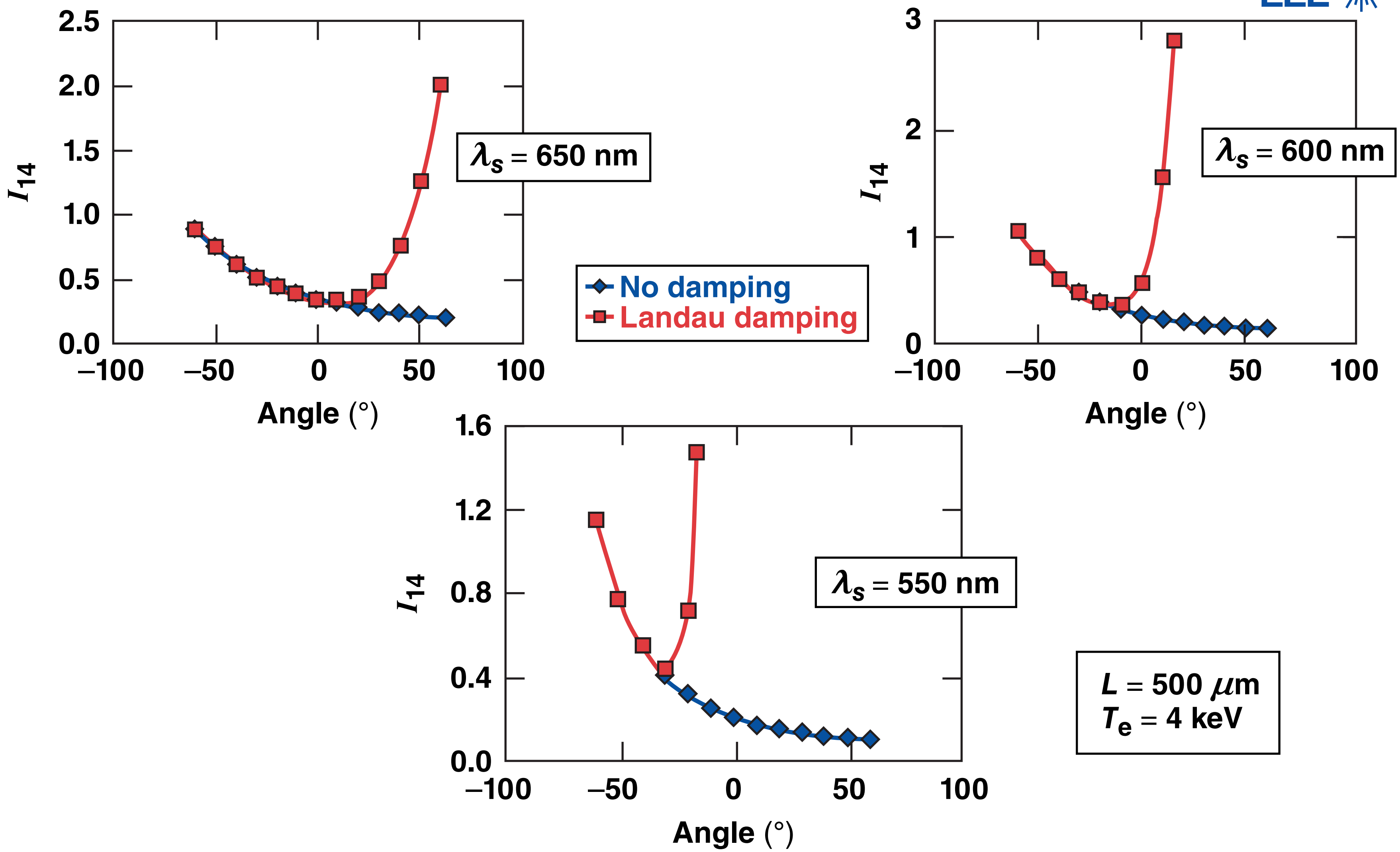
Landau damping suppresses the "back" branch of "*s*–*s*" sidescatter



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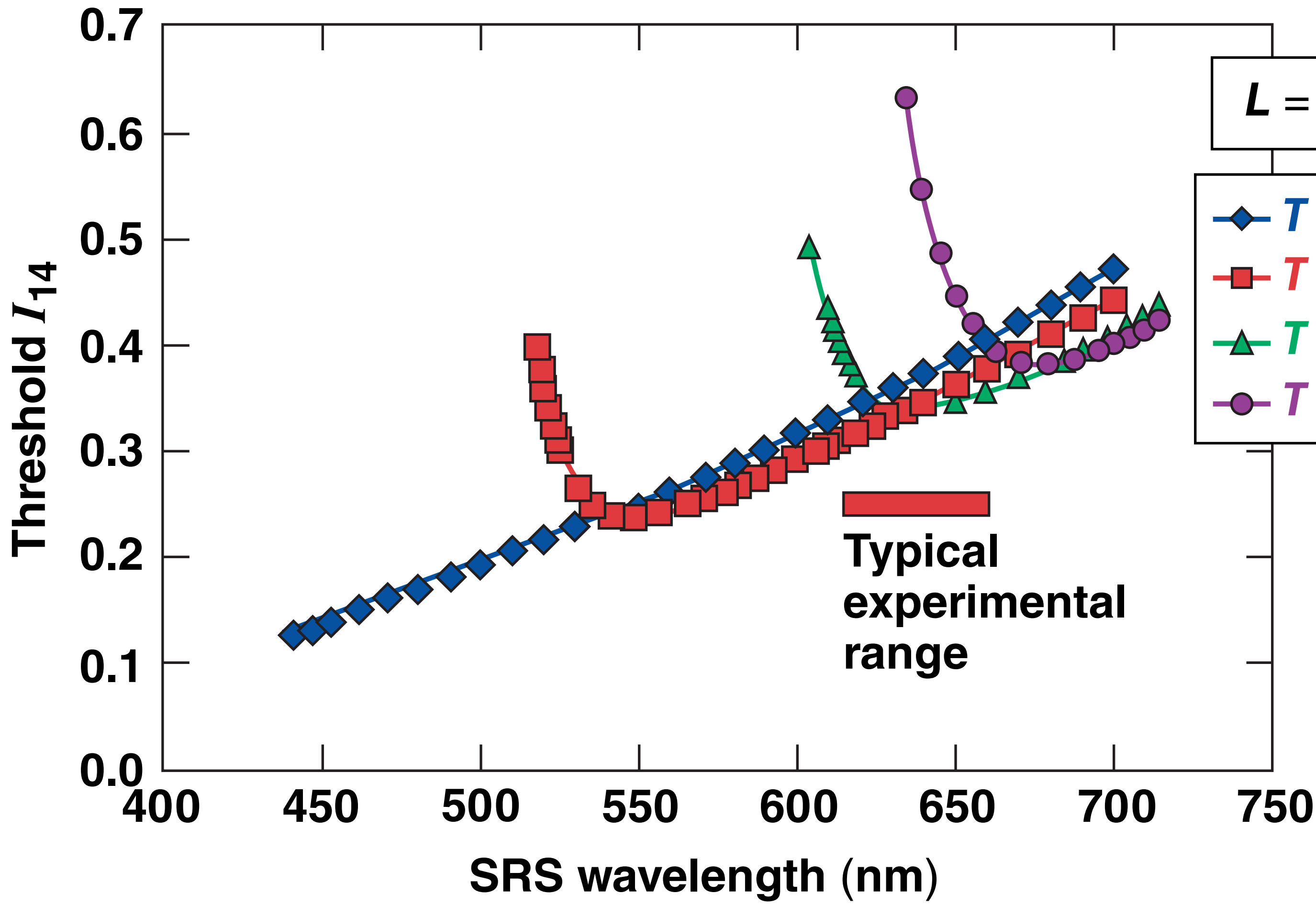
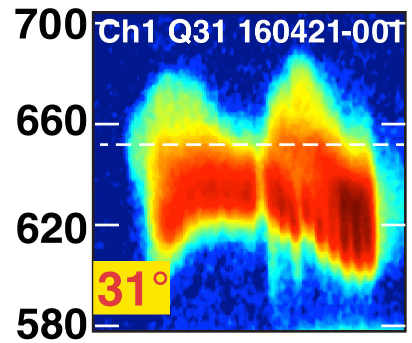
- The effect is more pronounced for shorter-wavelength scattering

For out-of-plane scattering Landau damping results in a short-wavelength cutoff and a minimum in the threshold





- **When Landau damping is strong, single-beam "forward" in-plane scattering becomes dominant**

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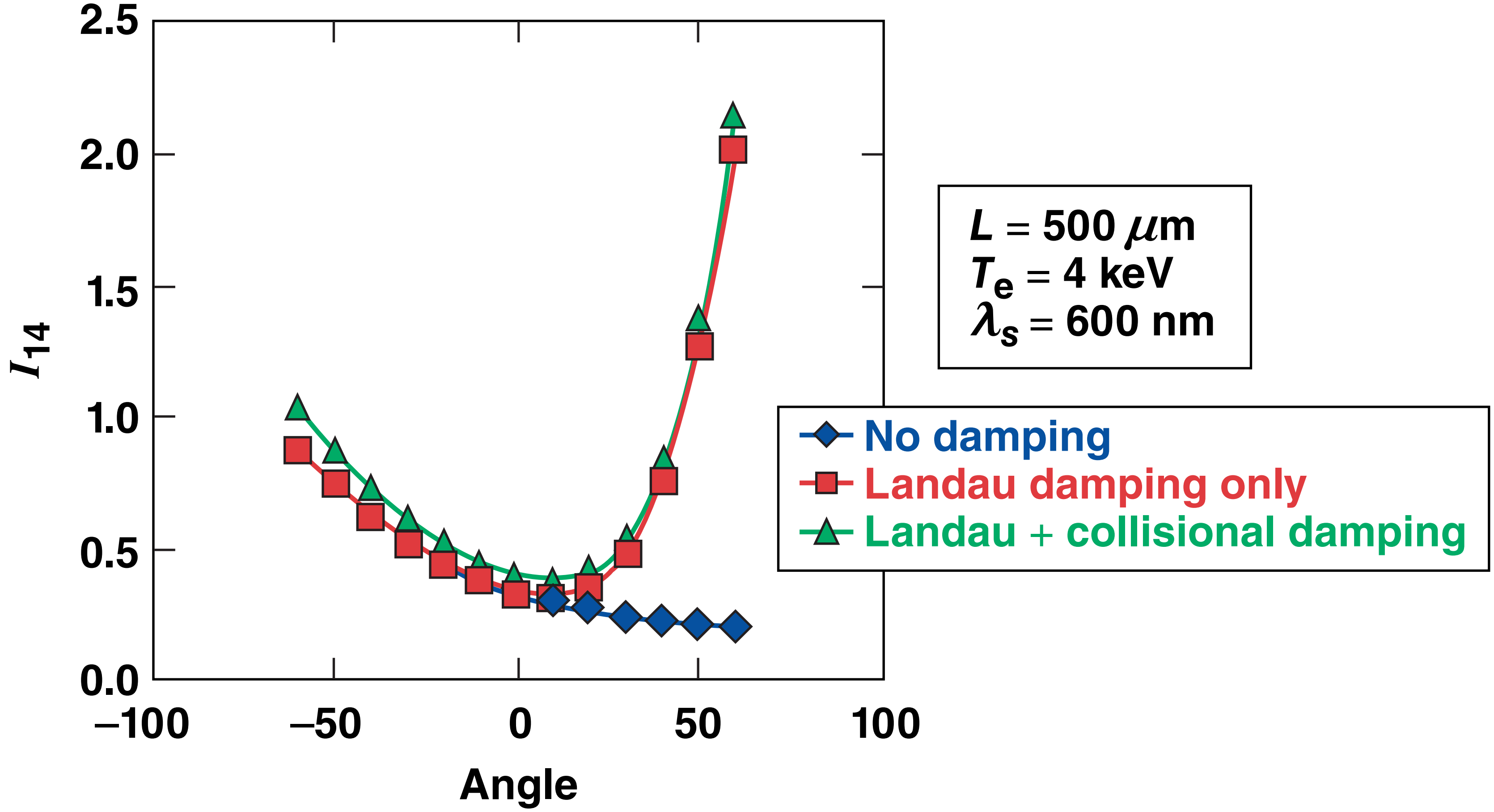
Collisional damping has little effect for these parameters



- For lower temperatures and longer-wavelength scattering collisional damping becomes somewhat more significant, but does not qualitatively alter the results

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Summary/Conclusions

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