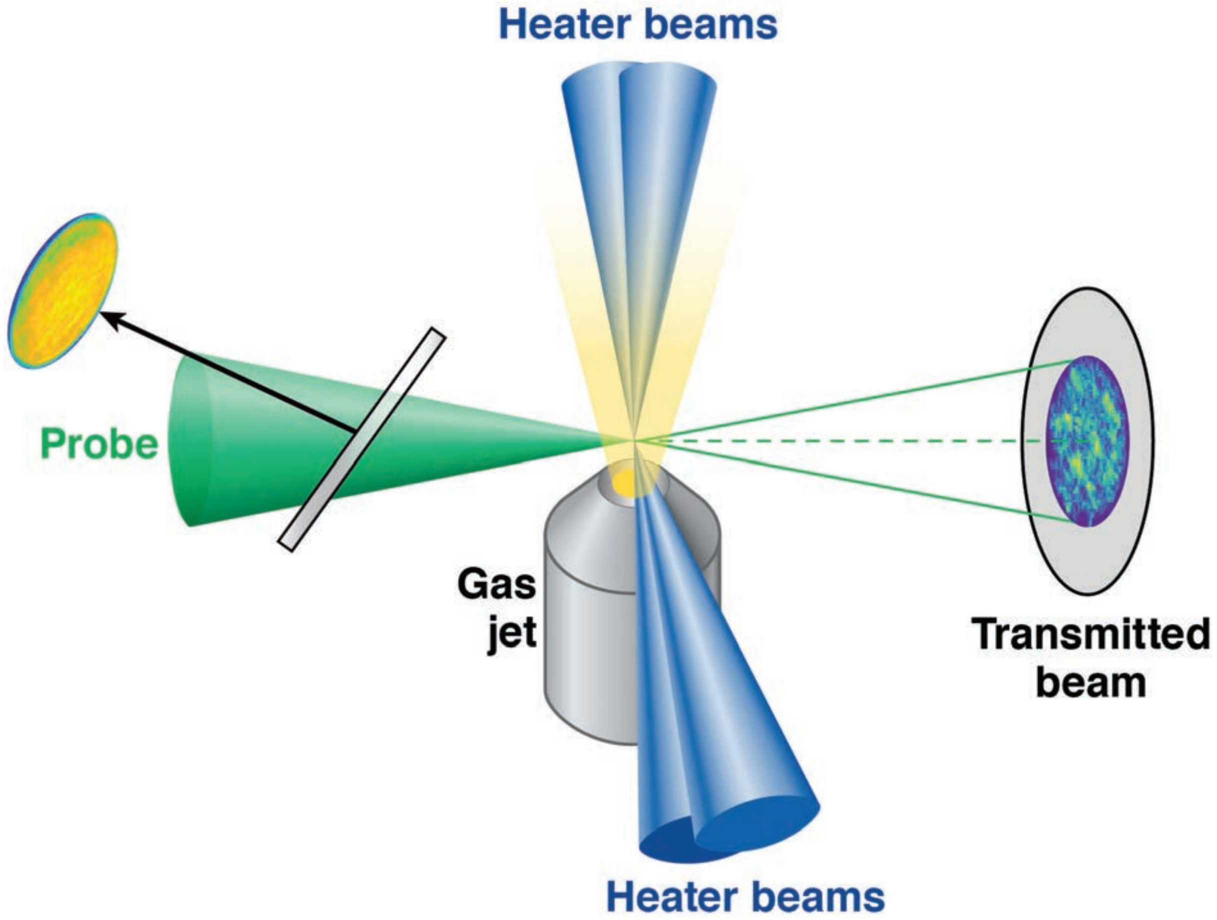
Direct Measurements of Laser Absorption in Underdense Plasmas on OMEGA



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A comprehensive suite of optical diagnostics on OMEGA provide a platform for the study of laser absorption in underdense plasmas

- Absorption can be inferred in well behaved, underdense plasmas by precisely measuring incident and transmitted-beam energies
- Backscatter and sidescatter diagnostics are used to confirm that laser–plasma instabilities (LPIs) are sufficiently suppressed
- Initial experiments demonstrate the ability to measure absorption of the order of 1% to 10% with $\pm$0.2% accuracy
- Imaging Thomson scattering spatially resolves key plasma conditions along the propagation length of the absorbed beam under test

These highly resolved measurements experimentally constrain important physical processes such as inverse bremsstrahlung heating, the Langdon effect, and the coulomb logarithm

Collaborators

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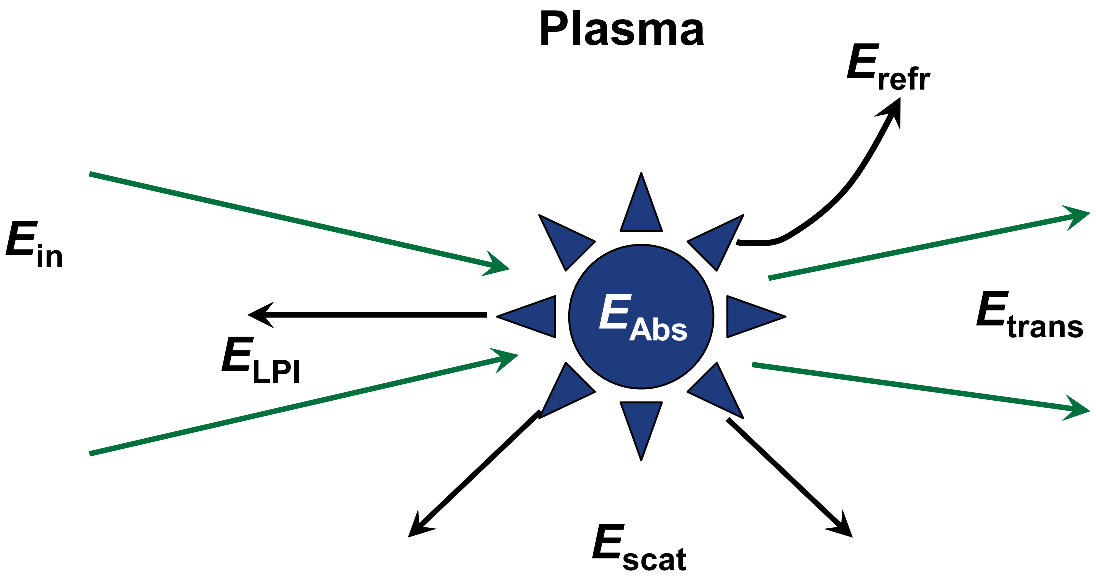
Careful accounting of input and output mechanisms provides a path to infer absorption

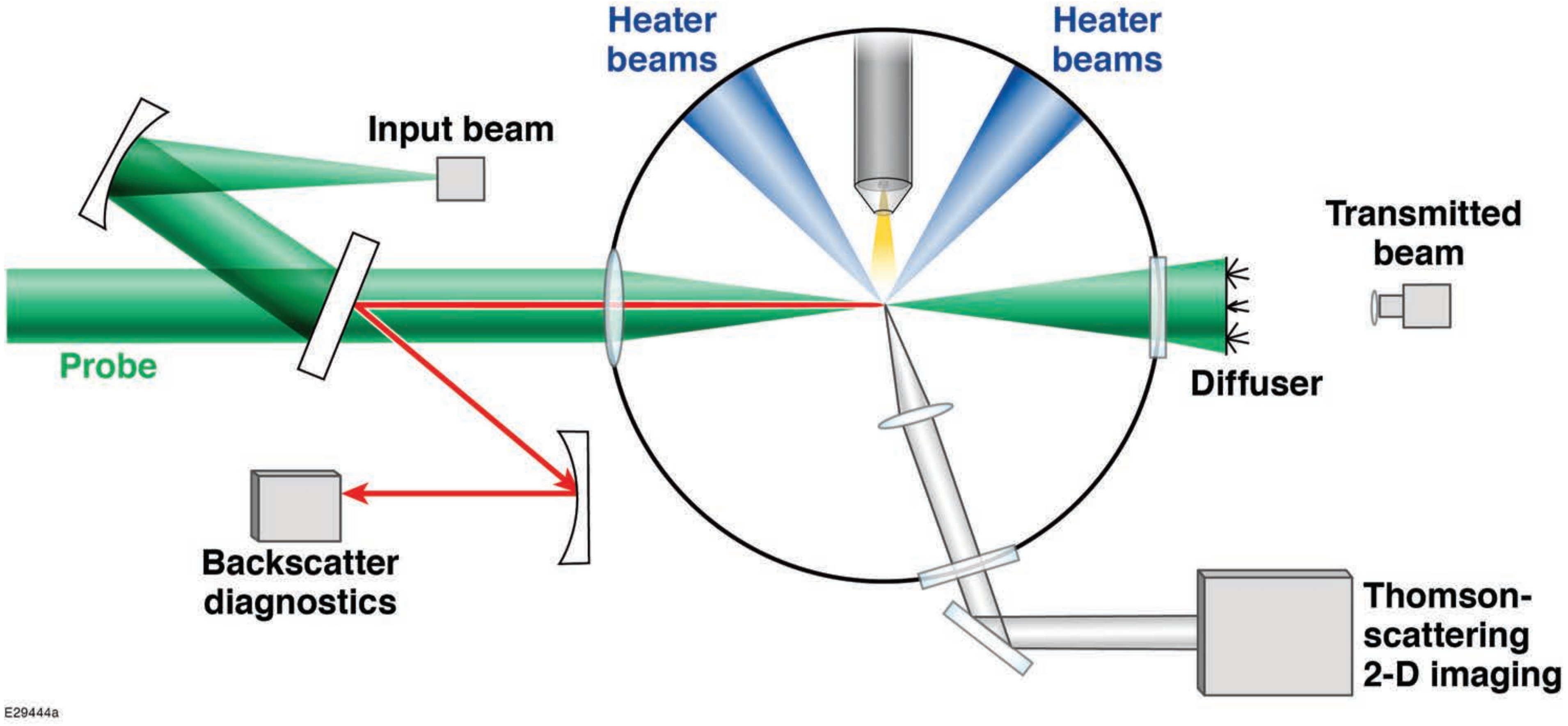


$$E_{in} = E_{abs} + E_{out}$$

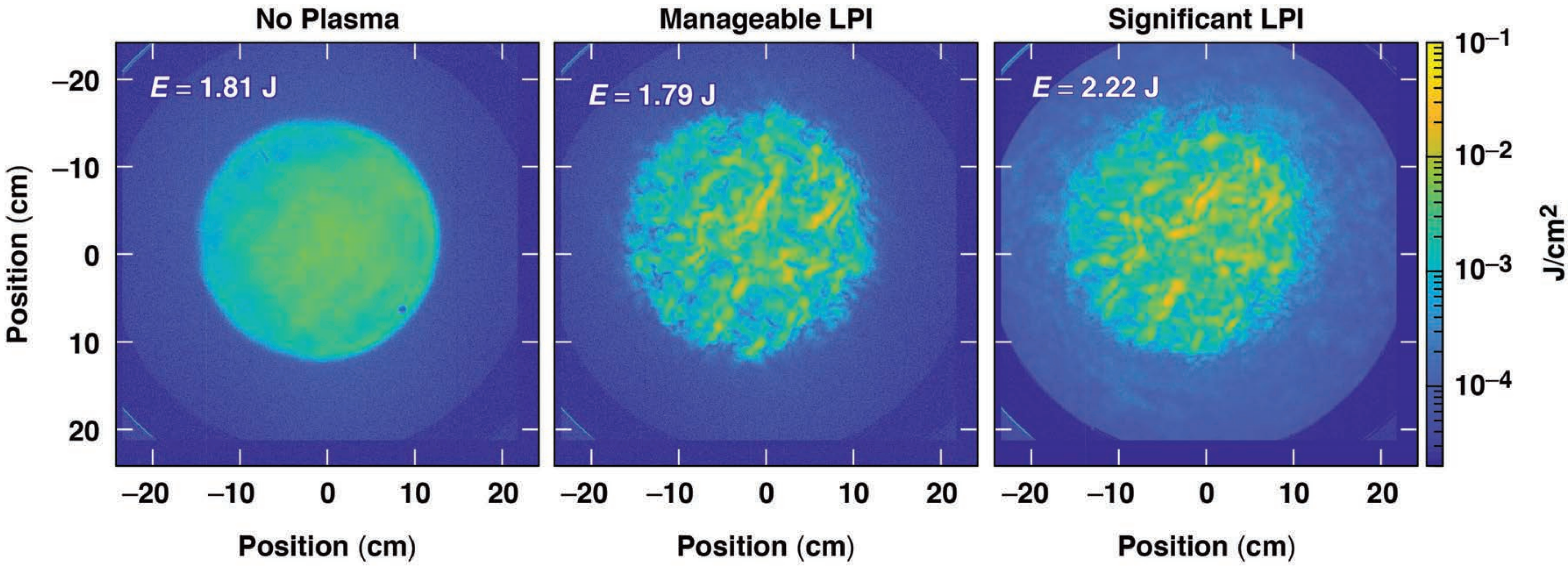
$$E_{out} = E_{trans} + E_{scat} + E_{refr} + E_{LPI}$$

Symbol	Mechanism	Approximate magnitude (% of E_{in})
E_{in}	Incident laser pulse	–
E_{abs}	Inverse bremsstrahlung	1 to 10’s
E_{trans}	Transmitted through plasma	50 to 99
E_{refr}	Refraction/filamentation	0 to 10’s
E_{scat}	Thomson/Rayleigh scattering	10^{-9} to 10^{-7}
E_{LPI}	Stimulated Raman/Brillouin	0 to 10’s

Optical instrumentation on multiple lines of sight give a full picture of the plasma conditions and potential loss mechanisms



The P9 Transmitted Beam Diagnostic measures the spatial profile and energy of the probe beam after it propagates through the target chamber



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Transmitted energy (J) → $E = \varepsilon \sum \mathrm{CCDe}^-$ ← Sum of signal (CCD electrons)

↑ Instrument sensitivity (J at TCC/CCDe⁻)

CCD: charge-coupled device
TCC: target chamber center

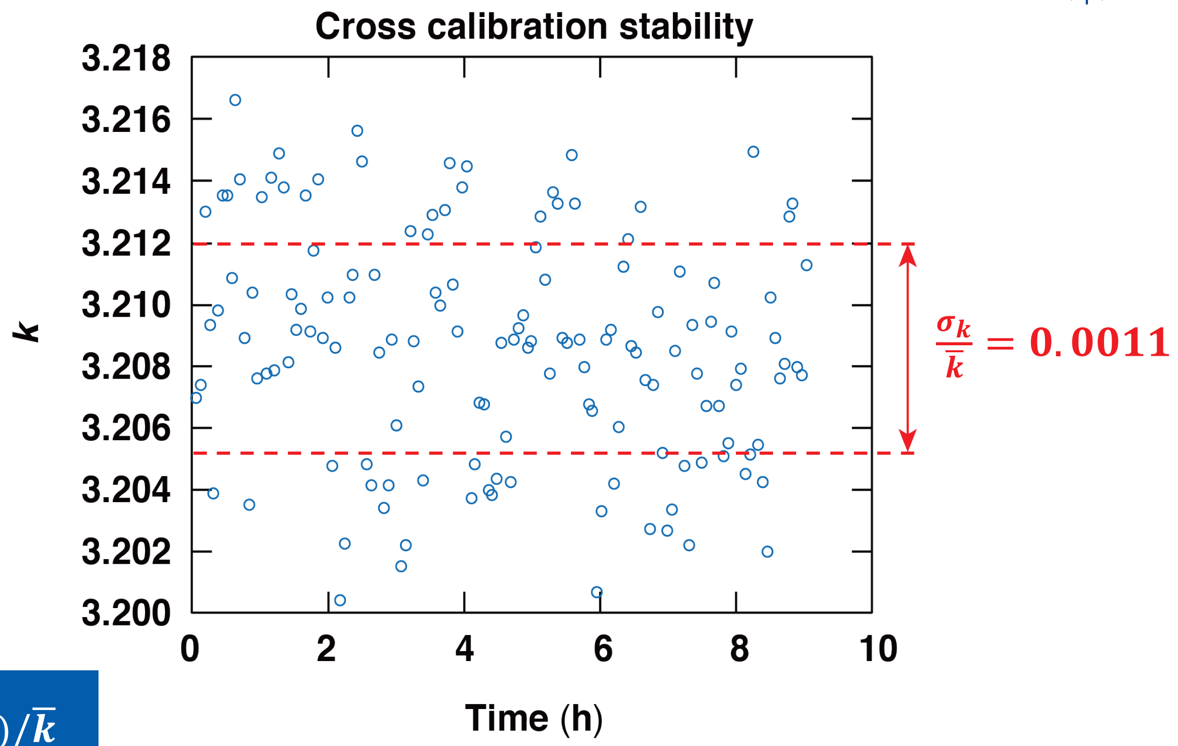
In the absence of significant LPI activity, the accuracy of the absorption ratio measurement scales with detector precision

$$E_{abs} = E_{in} - E_{trans} - \cancel{E_{scat}} - \cancel{E_{refr}} - \cancel{E_{LPI}}$$

$$\frac{E_{abs}}{E_{in}} = 1 - \frac{\varepsilon_{trans} \sum CCDe^{-}_{trans}}{\underbrace{\varepsilon_{in}}_{k} \sum CCDe^{-}_{in}}$$

For a no-gas calibration shot $E_{in} = E_{out}$

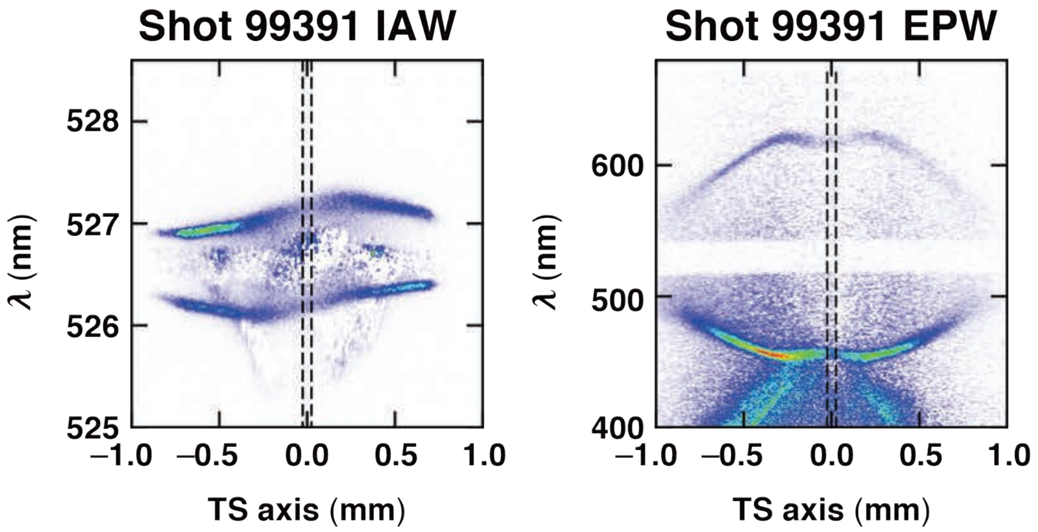
$$\frac{\varepsilon_{trans}}{\varepsilon_{in}} = \frac{\sum CCDe^{-}_{in}}{\sum CCDe^{-}_{trans}} = k$$



Full system on shot calibration stability

Calibration shot #	$\Sigma e^{-}_{in} \times 10^9$	$\Sigma e^{-}_{trans} \times 10^9$	k	$(k-\bar{k})/\bar{k}$
97347	6.728	4.447	1.5127	−0.00094
97350	6.509	4.295	1.5156	+0.00094

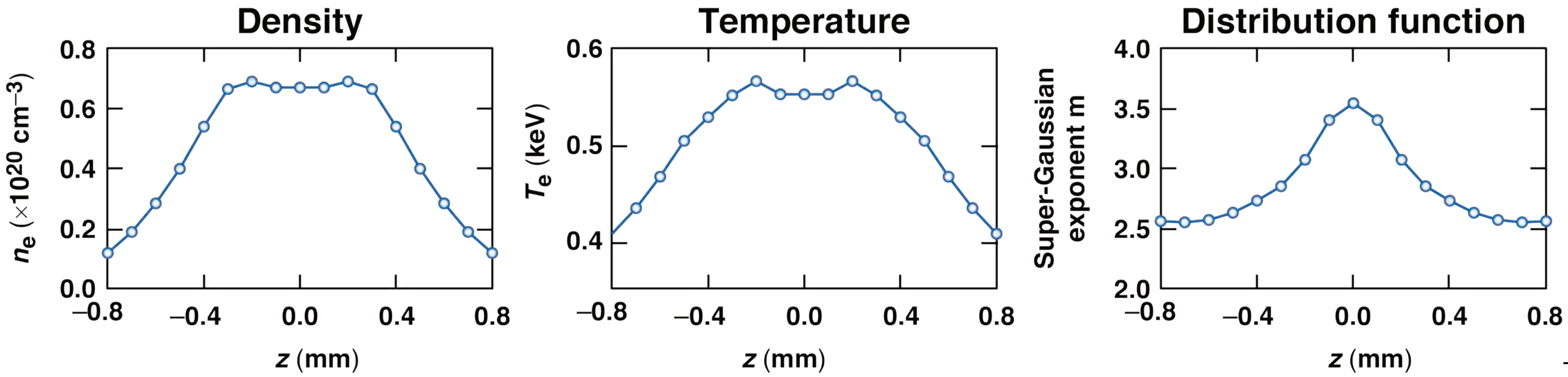
Imaging Thomson scattering spatially resolves key plasma conditions* along the propagation length of the absorbed beam under test



Absorption = $\exp\left(-\int \kappa \, dl\right)$,

with $\kappa = \frac{\nu_{ei}}{v_g} \frac{\omega_p^2 \omega_p^2}{\omega^2} f_L = \nu_{ei} \frac{n_e/n_c}{c\sqrt{1 - n_e/n_c}} f_L$,

$\nu_{ei} = 2.91 \times 10^{-6} Z^* n_e T_e^{-3/2} \ln\Lambda$



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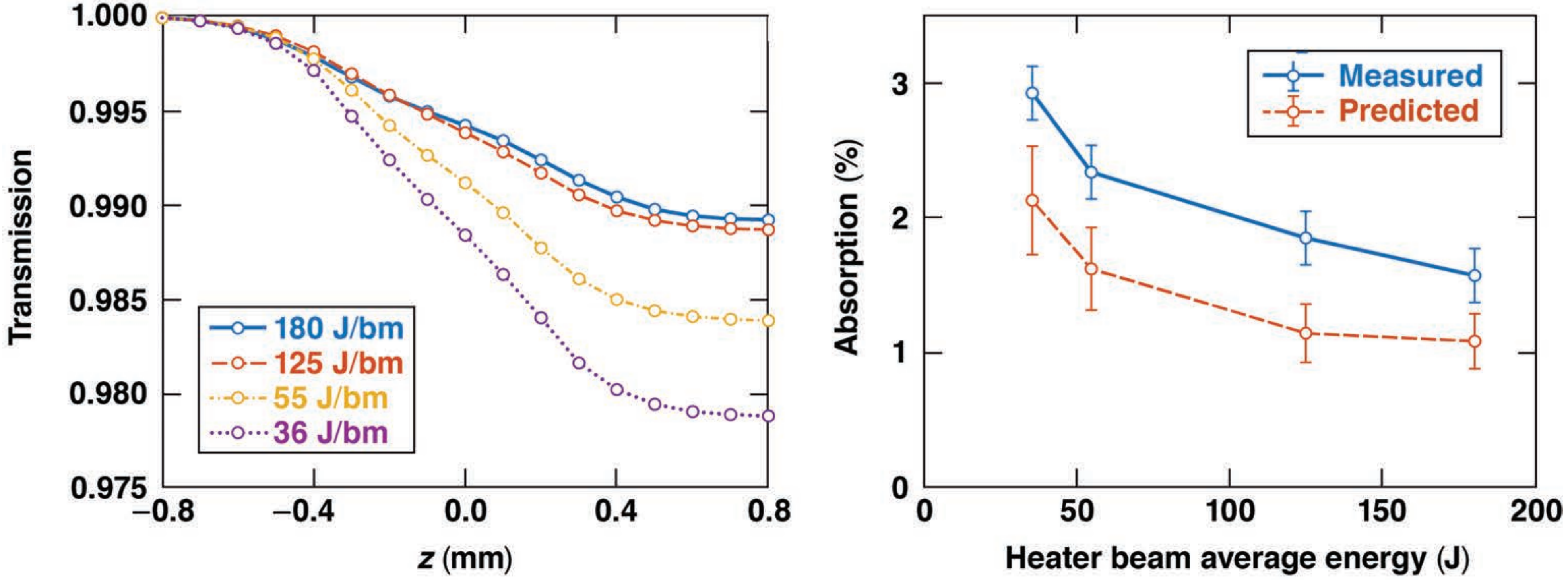
* D. Turnbull et al, Nat. Phys. 16, 181 (2020).
** J-P Matte et al., PPCF 30, 1665 (1988).

Experimentally measured plasma conditions are fed back into the models, providing constraints to physical processes



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Initial experimental results have motivated a more detailed examination of models used to calculate the coulomb logarithm. Work on this effort is ongoing.

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