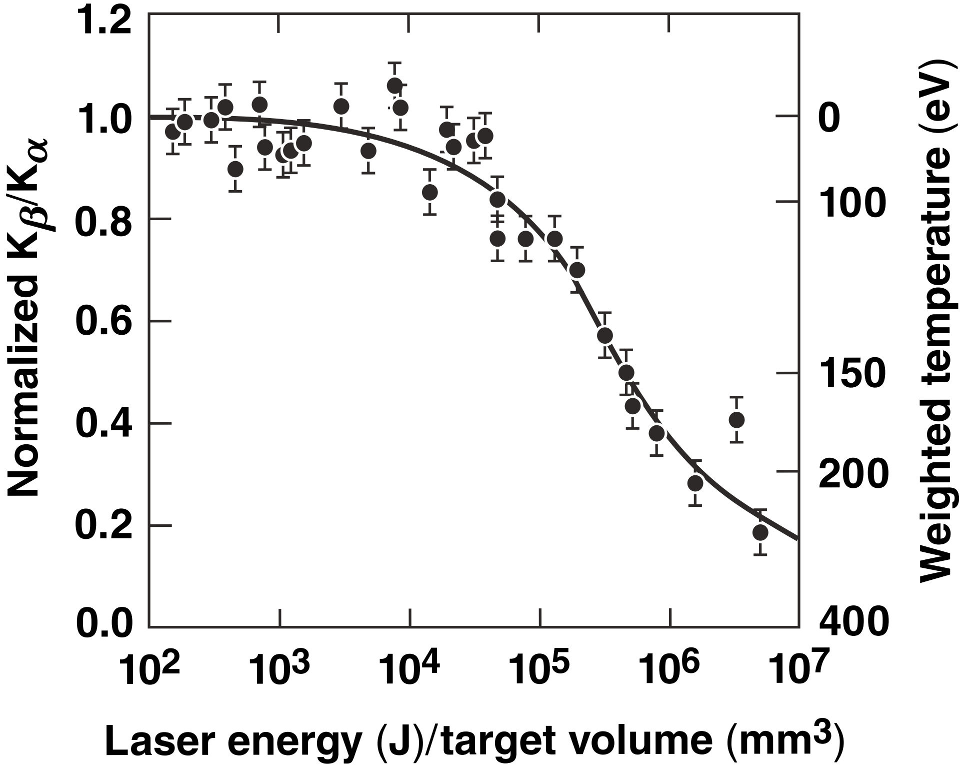
Fast-Electron Source Characterization on OMEGA EP

MTW: $E_L = 1$ J, $\tau_L = 1$ ps



Increasing energy density →

P. M. Nilson
University of Rochester
Fusion Science Center and
Laboratory for Laser Energetics

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Summary

OMEGA EP experiments have demonstrated a minimum 20% conversion efficiency of short-pulse laser energy into fast electrons

- The energy-conversion efficiency $\eta_{L \rightarrow e}$ into fast electrons is important for fast ignition and various HEDP applications
- Comparison of K_α yields from solid targets to a K_α production model infers $\eta_{L \rightarrow e} = 20 \pm 10\%$
- Electron-energy deposition in small-mass solid targets is consistent with numerical target-heating calculations for $\eta_{L \rightarrow e} = 20 \pm 10\%$ over a wide range of target volumes

$\eta_{L \rightarrow e}$ is independent of the laser pulse duration $\tau_P \leq 10$ ps at fixed laser intensity.

Collaborators

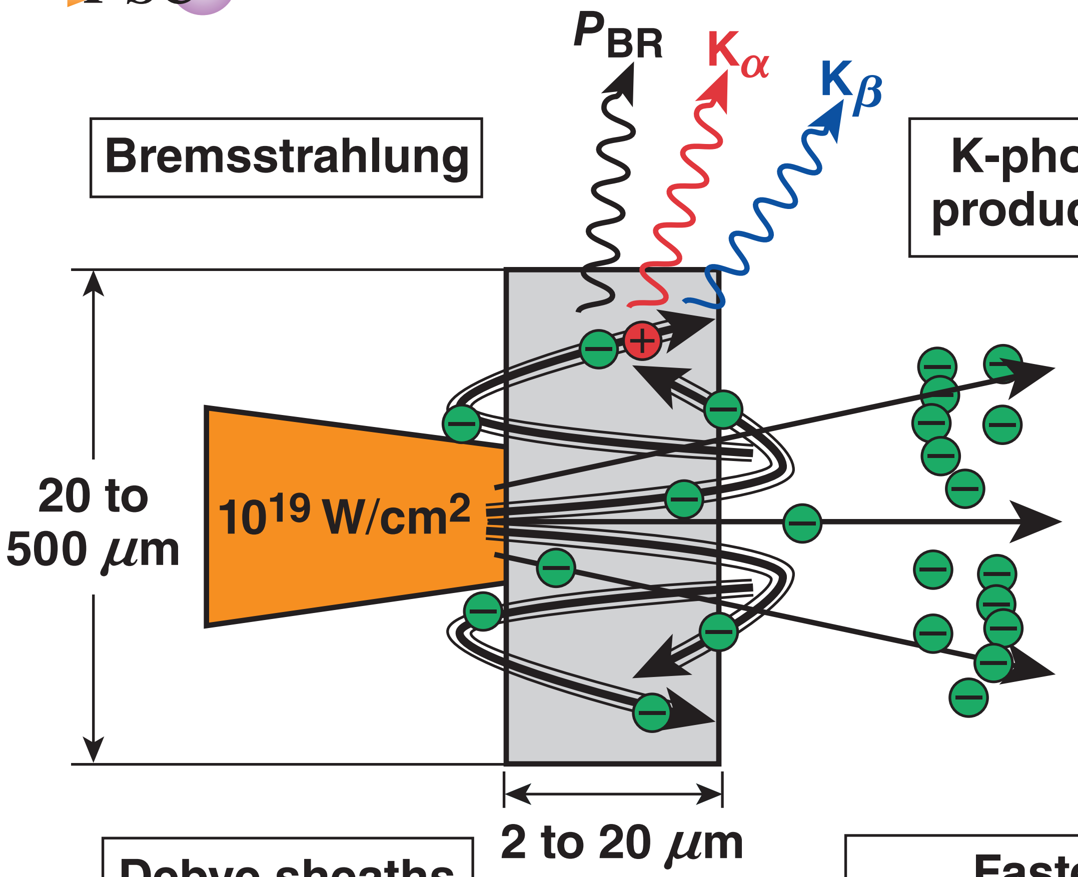
W. Theobald, J. F. Myatt, C. Stoeckl, P. A. Jaanimagi, J. A. Delettrez,
B. Yaakobi, J. D. Zuegel, R. Betti*†, D. D. Meyerhofer*†, and T. C. Sangster
University of Rochester
Laboratory for Laser Energetics

A. J. MacKinnon and P. K. Patel
Lawrence Livermore National Laboratory
Livermore, CA

K. Akli
General Atomics, San Diego

*also at Fusion Science Center for Extreme States of Matter and Fast-Ignition Physics, University of Rochester
†also at Mechanical Engineering and Physics Department, University of Rochester

Fast-electron recirculation in small-mass targets allows access to high-energy-density phenomena



Debye sheaths
$|E| \approx 10^{12}$ V/m

Fastest electrons escape

- Refluxing is caused by Debye-sheath field effects[1,2]
- Majority of fast electrons are stopped in the target
- Provides a simple geometry for testing laser-coupling, electron-generation, and target-heating models[3,4]

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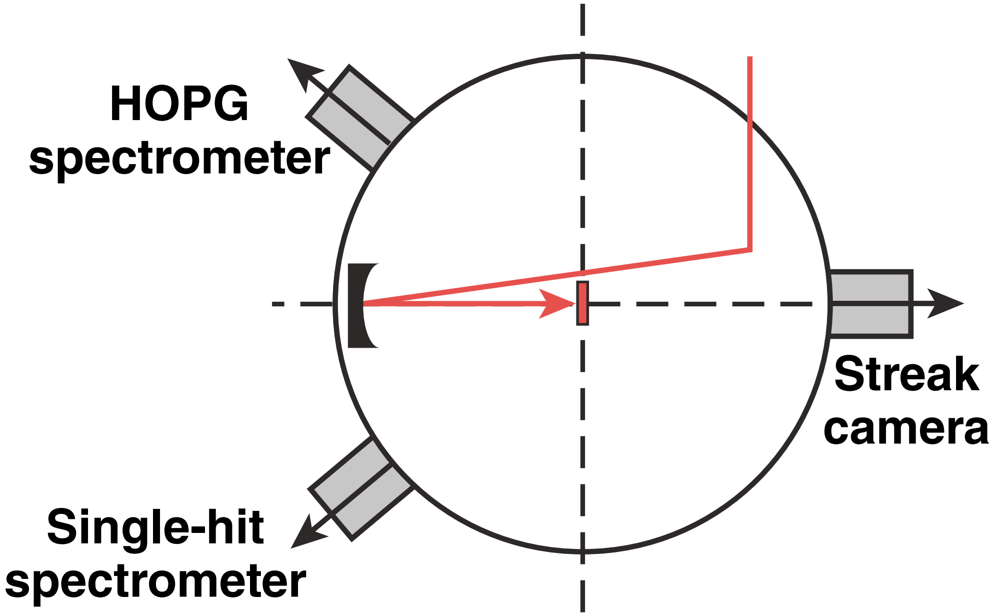
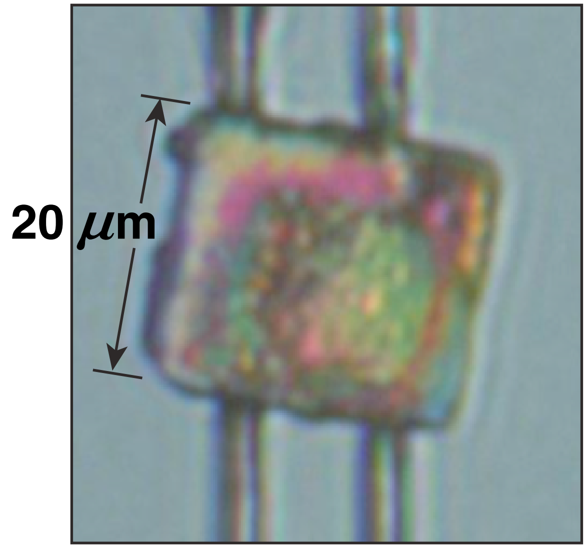
[1] S. P. Hatchett *et al.*, Phys. Plasmas 7, 2076 (2000).
[2] R. A. Snavely *et al.*, Phys. Rev. Lett. 85, 2945 (2000).
[3] W. Theobald *et al.*, Phys. Plasmas 13, 043102 (2006).
[4] J. Myatt *et al.*, Phys. Plasmas 14, 056301 (2007).

Survey experiments were performed on the Multi-Terawatt (MTW) Laser Facility at LLE

MTW laser facility: ≤10 J, ≤10 ps



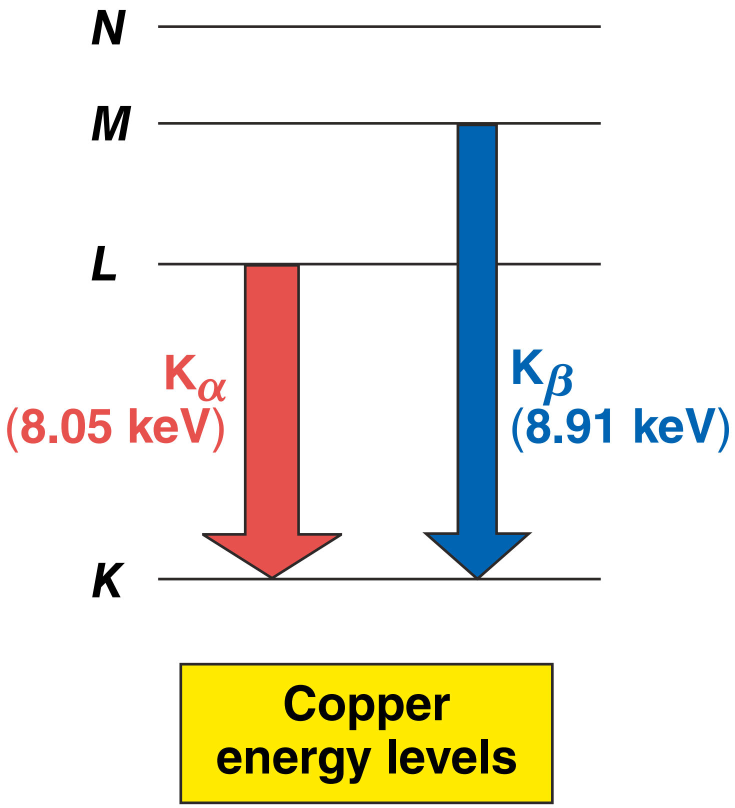


Spider-silk mounted $20 \times 20 \times 2\ \mu m^3$ copper target

- Laser intensities $I < 2 \times 10^{19}$ W/cm^2
- Copper targets
- Target volumes $V > 20 \times 20 \times 2\ \mu m^3$

The short-pulse laser-energy-conversion efficiency into fast electrons is inferred from the total K_α yield

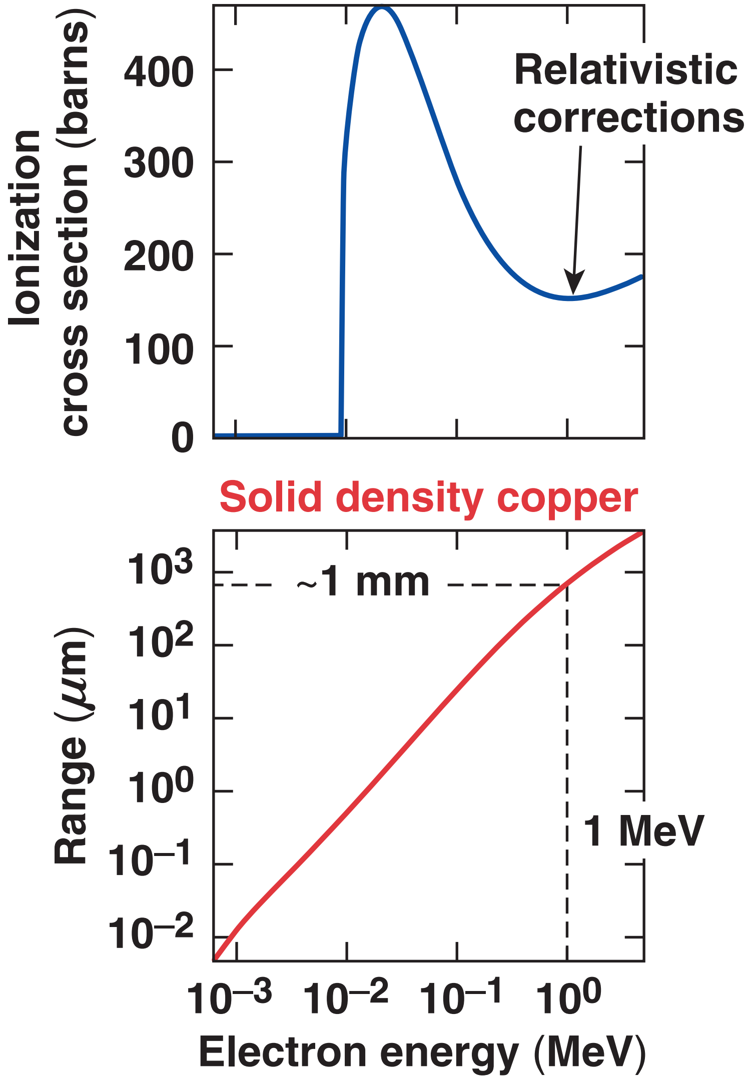
- Energetic electrons create K-shell vacancies ($E_k \approx 9$ keV)
- K-shell emission comes from the cold bulk material during the fast-electron lifetime



K. B. Wharton *et al.*, Phys. Rev. Lett. 81, 822 (1998).
R. B. Stephens *et al.*, Phys. Rev. E 69, 066414 (2004).
J. D. Hares *et al.*, Phys. Rev. Lett. 42, 1216 (1979).
W. Theobald *et al.*, Phys. Plasmas 13, 043102 (2006).

Recirculation in small-mass targets allows a number of simplifications in calculating K-photon production

- K-photon generation calculated as in an infinite medium
- Relativistic K-shell ionization cross sections[2] included
- Classical slowing down approximation (CSDA)[1]
- Fluorescence probability for cold matter is corrected for finite temperature



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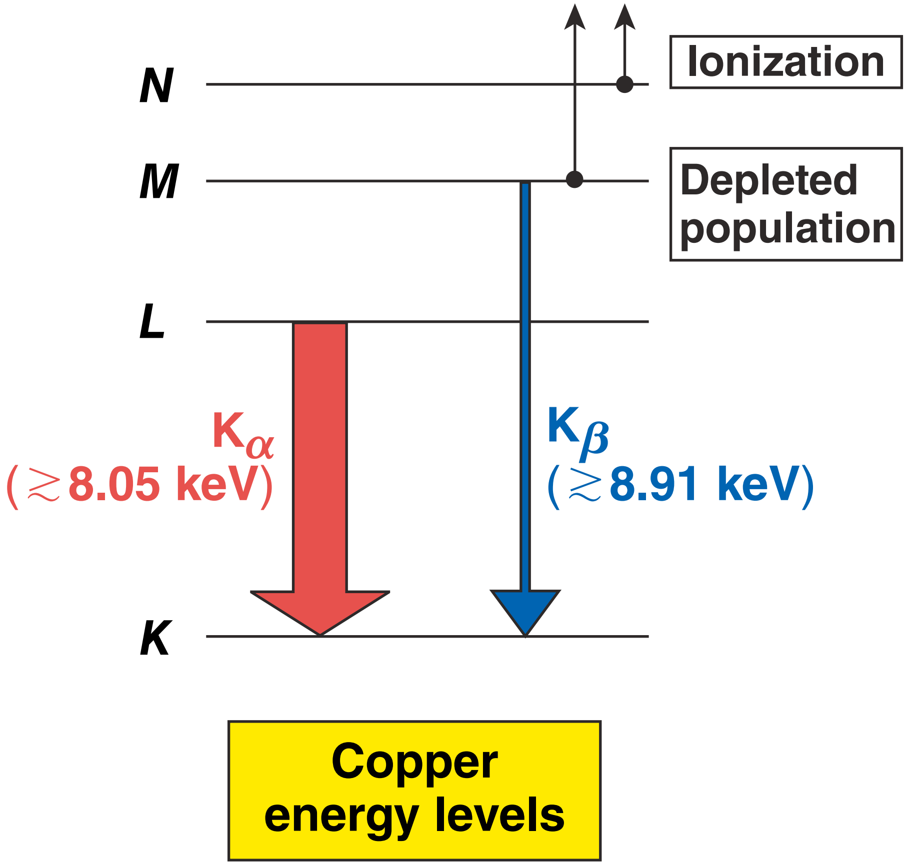
[1] H. O. Wyckoff, *ICRU Report* 37, Intern. Comm. on Radiation Units and Measurements, Inc., Bethesda, MD (1984).

[2] H. Kolbenstvedt, J. Appl. Phys. 38, 4785 (1967).

Target bulk-heating affects $L \rightarrow K$ and $M \rightarrow K$ electron transitions*

- Inelastic electron–electron collisions heat the target
- Collisional ionization with thermal background plasma occurs
- $T_e > 100$ eV causes significant M-shell depletion
- Target heating is inferred from K_β/K_α



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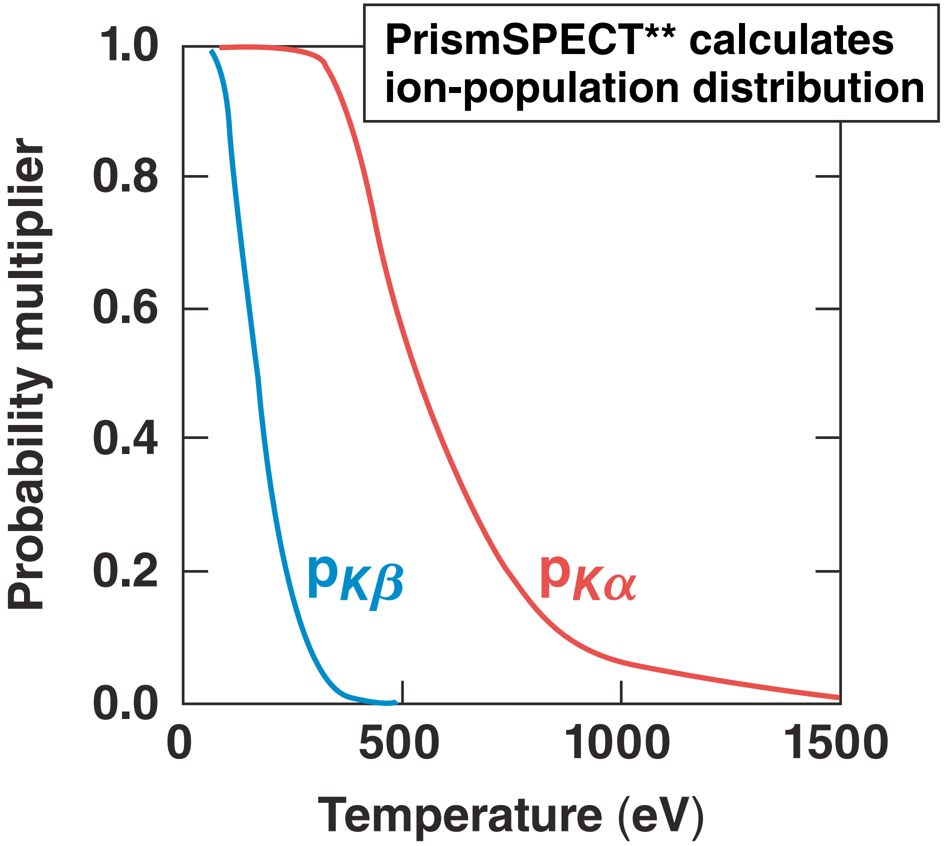
*J. Myatt *et al.*, Phys. Plasmas 14, 056301 (2007).
*G. Gregori *et al.*, Contrib. Plasma Phys. 45, 284 (2005).

Spatial and temporal variations in heating must be considered when calculating K_β/K_α

- 3-D *LSP** calculates target heating
- Fast-electron source is prescribed with varying energy
- Same target volumes and interaction timescales are modelled (no scaling)
- Assumes a Thomas–Fermi model
- Calculates EM fields self-consistently
- Emission probability calculated using the local temperature at the time of emission



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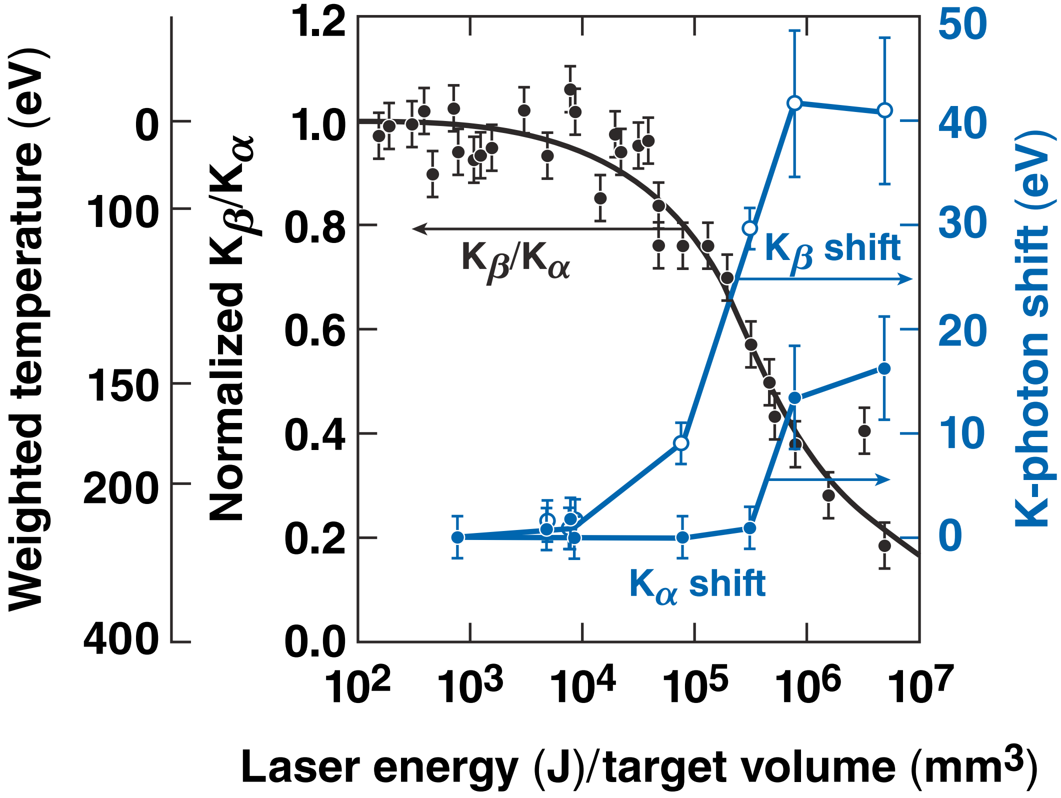
* D. Welch *et al.*, Nucl. Inst. Methods Res. A 464, 134 (2001).

** Prism Computational Sciences, Inc., Madison, WI 53711

High bulk-electron temperatures in small-mass targets is inferred by K-photon spectroscopy

- **Inelastic electron-electron collisions heat the target**
- **Collisional ionization with the thermal background occurs**
- **L- and M-shell depletion at high bulk-electron temperatures causes spectral line shifts* and K_β/K_α suppression****



MTW laser: 1 J, 1 ps

Increasing energy density →

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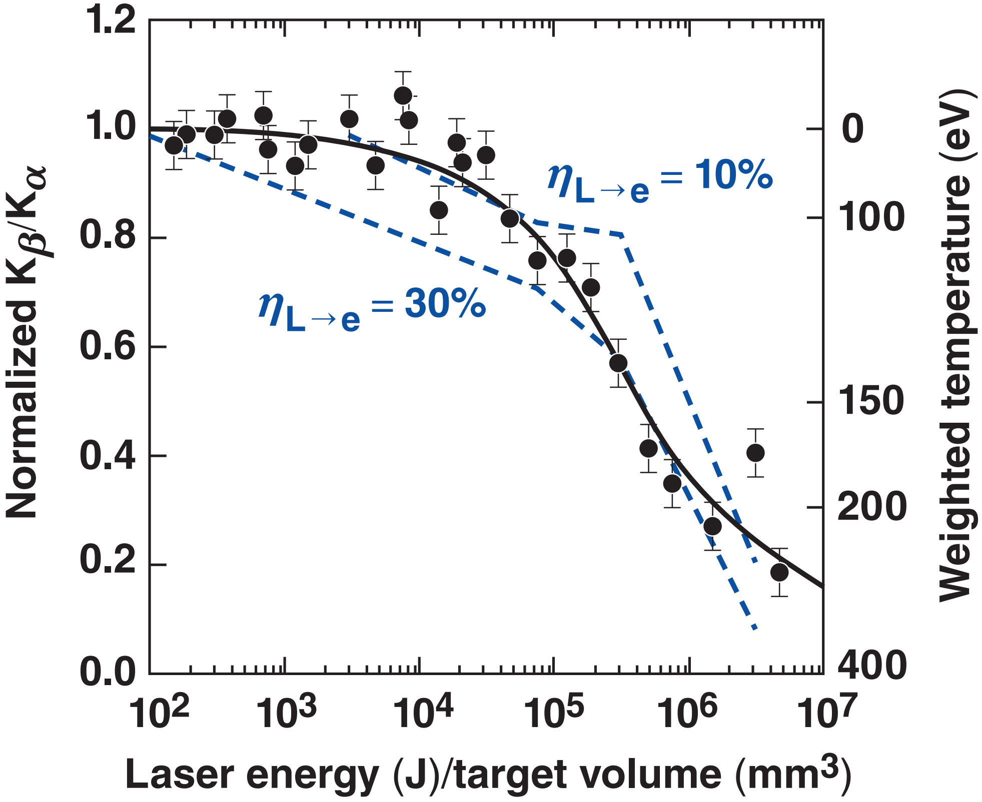
* G. Gregori *et al*., Contrib. Plasma Phys. 45, 284 (2005).

** P. M. Nilson *et al*., Phys. Plasmas 15, 056308 (2008).

A comparison of K_β/K_α to *LSP* calculations gives $\eta_{L\rightarrow e} \approx$ 20% consistent with the K_α-yield measurements*

MTW laser: 1J, 1ps

- Provides a self-consistency check on $\eta_{L\rightarrow e}$
- Confirms that the dominant physics are correctly accounted for in the simple refluxing K_α-production model



Solid density targets are heated to temperatures greater than 200 eV with 5 J of laser energy.

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*P. M. Nilson *et al.*, Phys. Rev. E 79, 016406 (2009).

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