Determination of Hot-Electron Conversion Efficiencies and Isochoric Heating of Low-Mass Targets Irradiated by the Multi-Terawatt Laser

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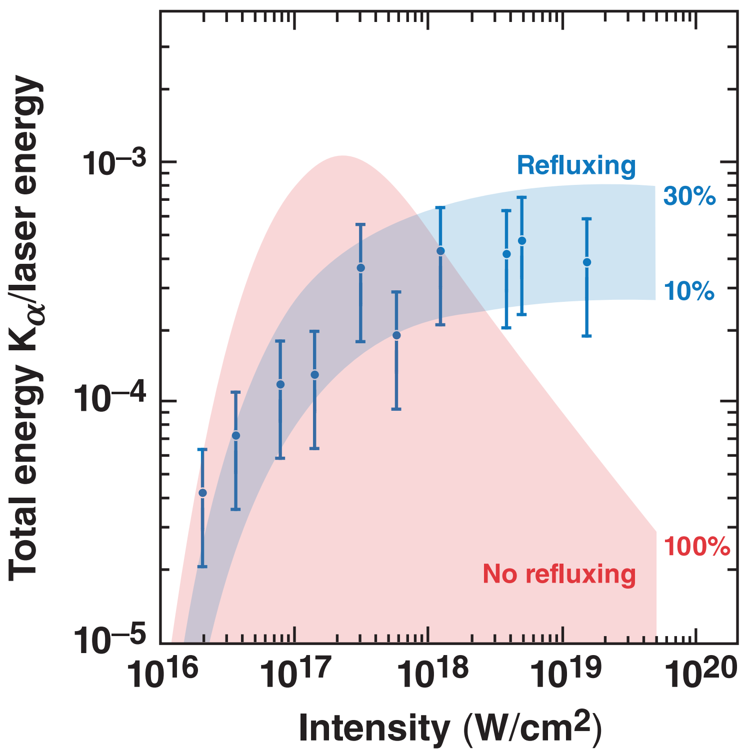

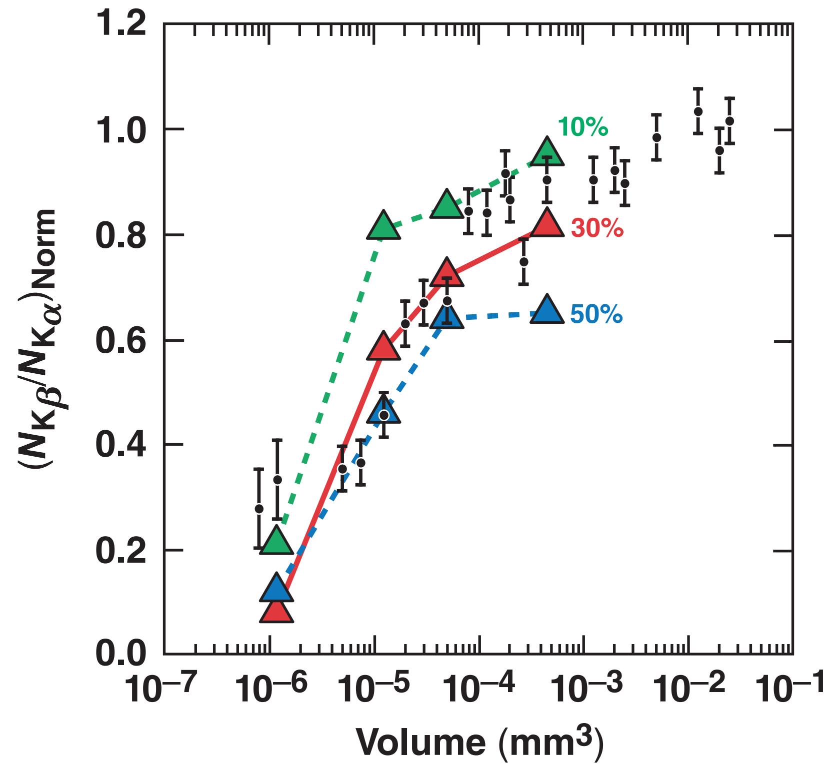

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Summary

Isochoric heating of low-mass foils to a few hundred eV has been observed in LLE's MTW laser system[1], consistent with 20% of laser energy into MeV electrons

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- Measurements of the absolute K_α-photon yield and the ratio of K_β-to-K_α yields have been made for >100 target shots
- Both a semi-analytic model and implicit-hybrid PIC calculations (*LSP**) agree with the observed absolute K_α yields for hot-electron conversion efficiencies of between 20% ± 10%.
- Ratio of K_β to K_α signal is compared with *LSP* calculations of fast heating by MeV electrons
- Also consistent with 20% ± 10% conversion efficiency for a wide range of target volumes

*D. Welch *et al.*, Nucl. Inst. Methods Res. A 464, 134 (2001).
[1]P. Nilson *et al.*, in preparation.

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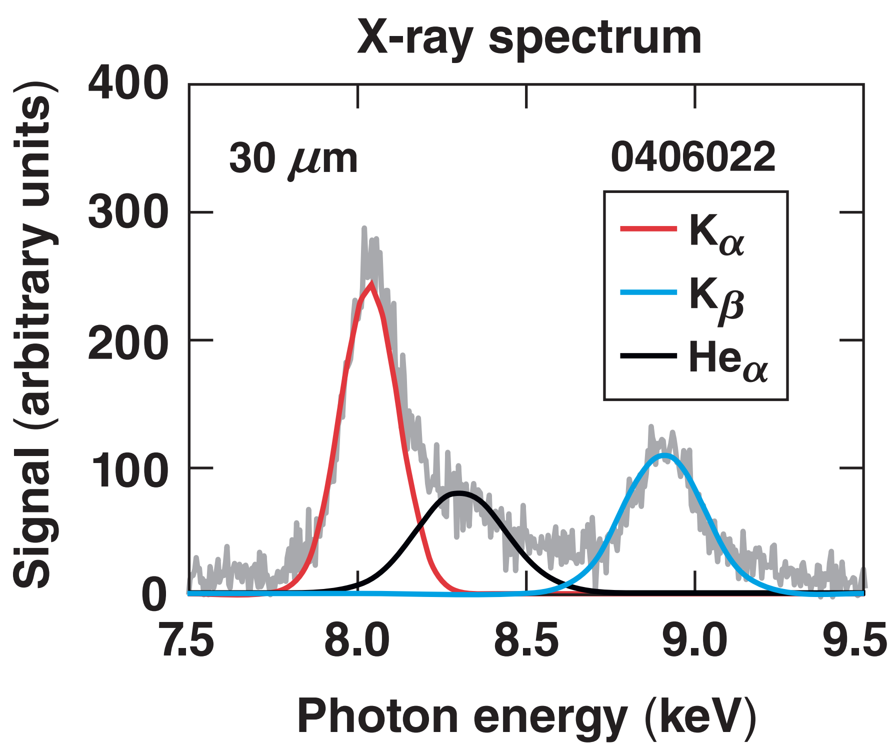
The measurements of K-shell emission performed on the MTW were scaled from earlier RAL experiments*

- Laser ~5 J in 700 fs
- Laser intensities of $10^{17} < I < 10^{19}$ W/cm^2
- A range of target volumes: $10^{-6} < V < 10^{-1}$ mm^3
- Solid copper targets



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*Theobald *et al.*, Phys. Plasmas 13, 043102 (2006).

Low-mass targets have some remarkable properties that simplify the modeling

- The majority of hot electrons stop in the target due to space-charge (refluxing)
- Secondary radiation production is simple to compute (as in infinite medium)
- Efficient K_{α}, K_{β} radiators
- Transparent to K-shell x-rays
- Access high temperatures at solid density
- Good testbed for hot-electron conversion and volumetric heating
- Can be used to benchmark codes – *LSP* can model the whole target in 3-D (implicit-hybrid mode)

Absolute K_α yields on MTW are consistent with the fast-electron refluxing model[1] and constant conversion efficiencies of between 10% to 30%

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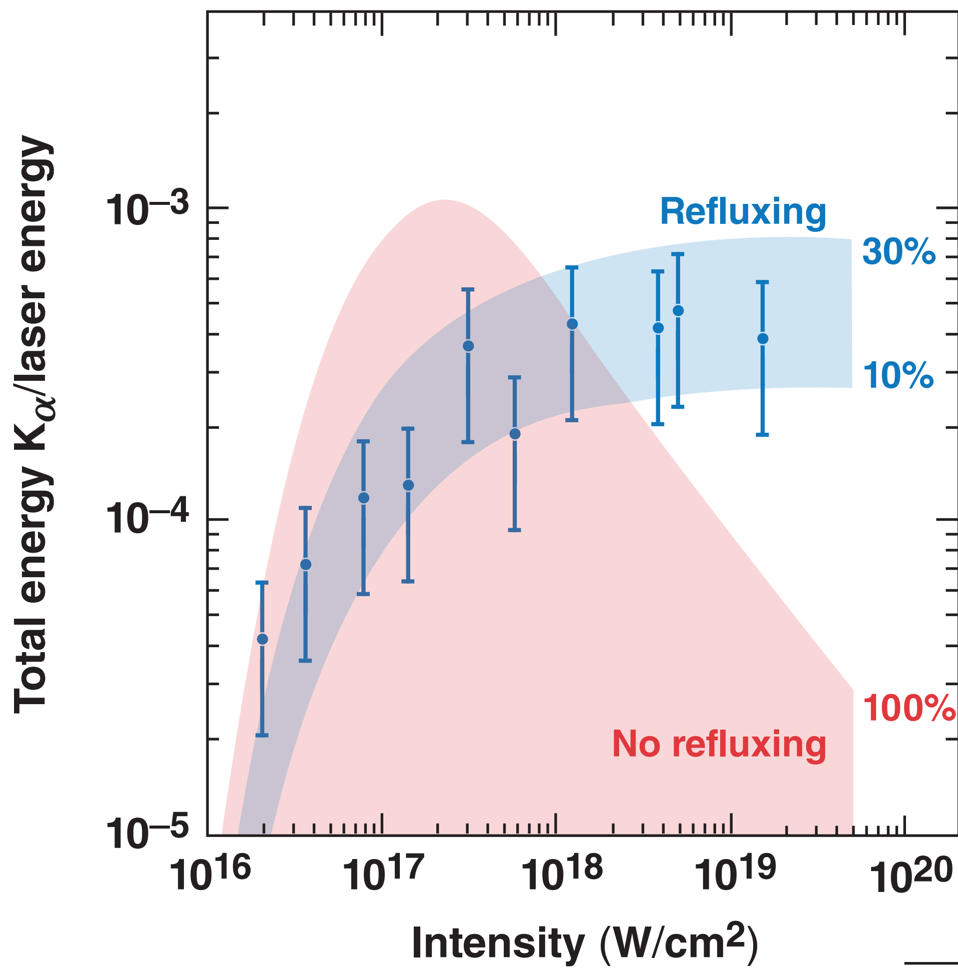

- Exponential hot electron spectrum with temperature given by ponderomotive scaling
- K_α production is essentially computed as in an infinite medium

Cu target: (500×500×20) μm
Laser: 1 J, 1 ps

[1] J. Myatt *et al.*, Phys. Plasmas, 14, 056301 (2007);
W. Theobald *et al.*, Phys. Plasmas 13, 043102 (2006).

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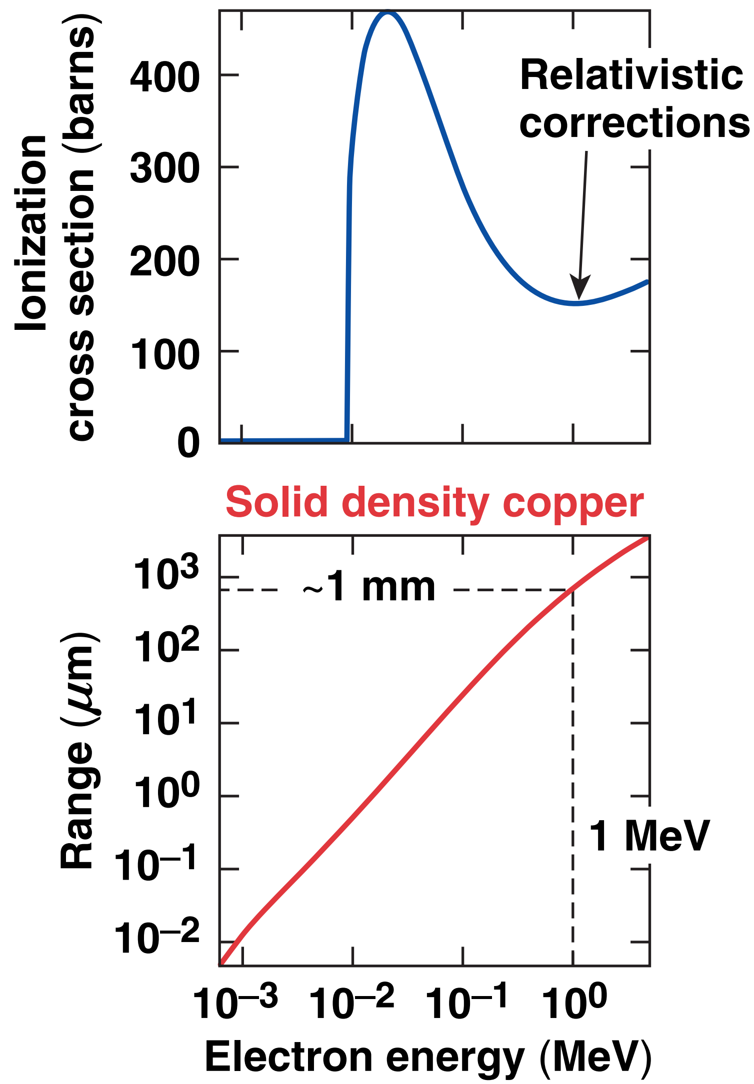
The theoretical K_α yield relies on knowing the hot-electron range, the energy dependence of the K-shell ionization cross section and the fluorescence probability

- $\sigma_K(E)$ taken from Kolbenstvedt[1] relativistic corrections are essential
- The fluorescence probability ω_K is taken for cold matter at solid density
- CDSA range[2]

Need to specify: E_e (= $\eta_{L\rightarrow e}E_L$)



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

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

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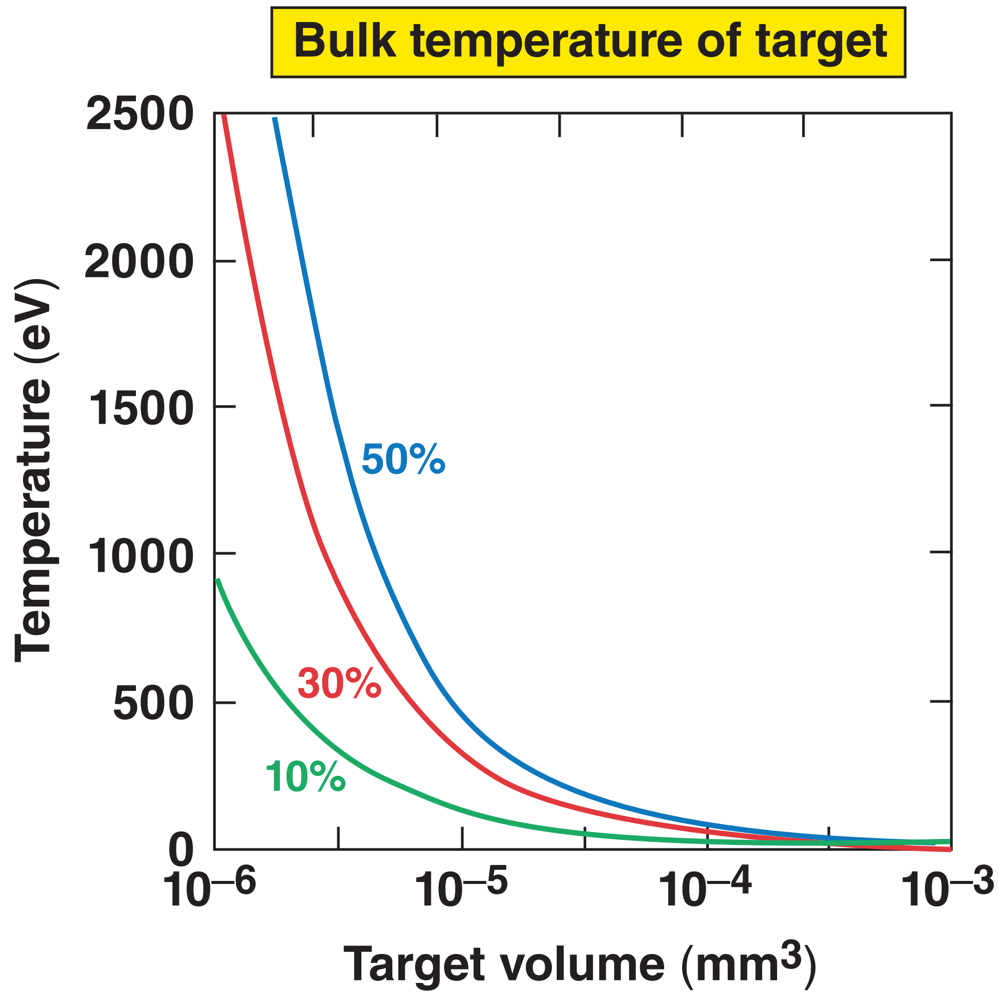
For target volumes smaller than 10^{-5} mm^3 temperatures of several hundred eV are predicted

- Hot electron heat target on the ps-time scale, before bulk hydrodynamic motion
- Figure shows back-of-envelope estimation assuming T-F EOS
- Similar temperatures to RAL experiments



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Heating of the target leads to a reduction in K_β/K_α ratio that can be used to gauge the energy in the fast electrons

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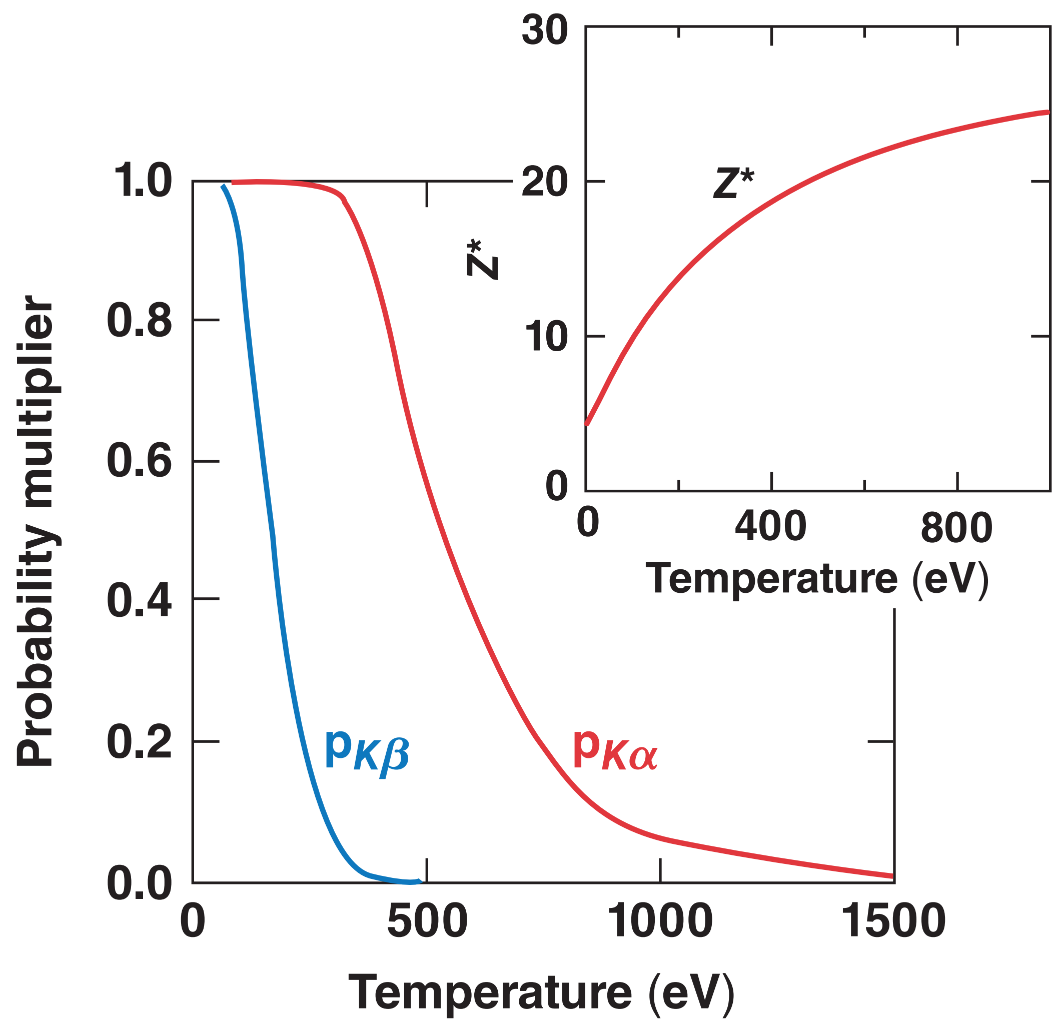
- PrismSPECT[1] is used to get ion population and modify ($p_{K\alpha}$, $p_{K\beta}$) appropriately
- Depletion of the copper M-shell reduces the K_β emission relative to K_α
- Ratio is determined by bulk temperature



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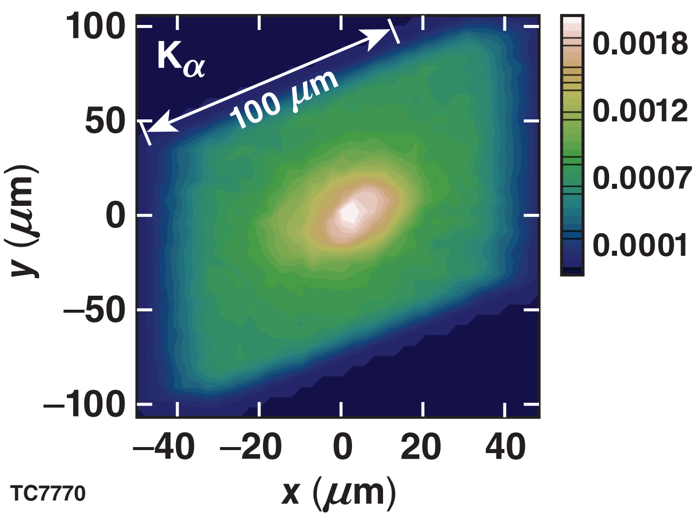
[1]Prism Computational Sciences, Inc., Madison, WI 53711

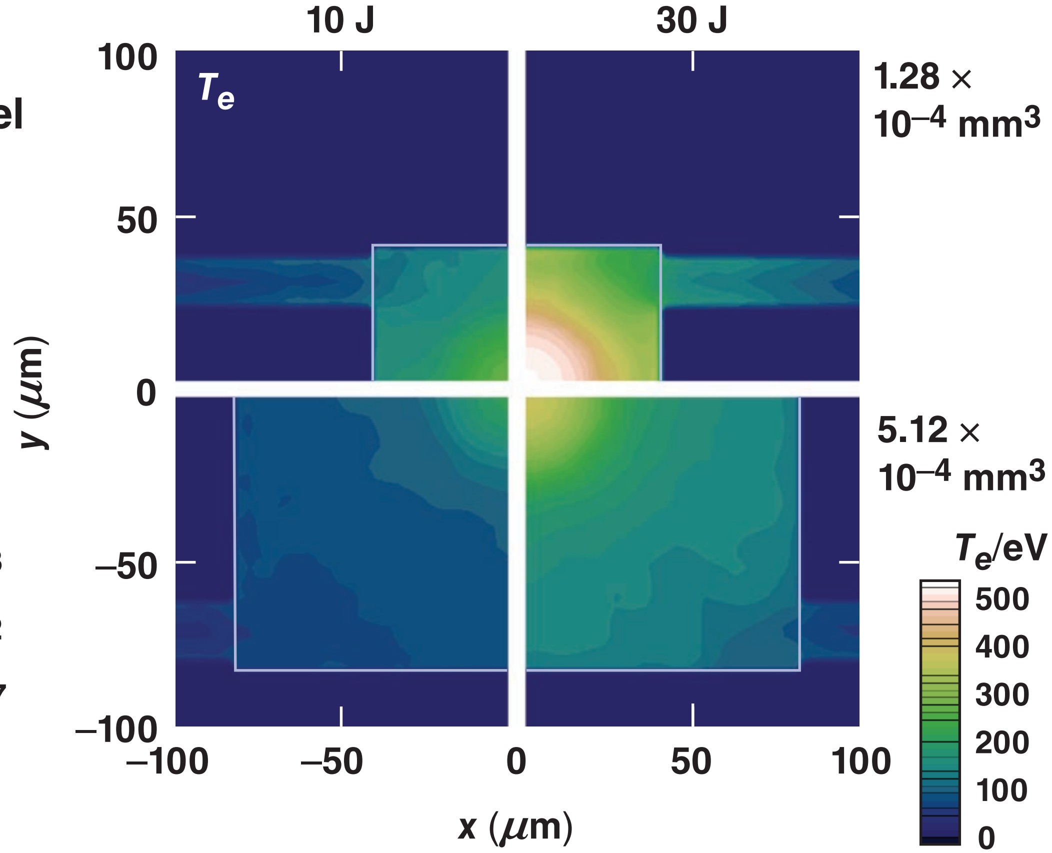
Taking into account temporal and spatial depedence, *LSP* is used to predict the effect of target heating on the K_β-to-K_α line ratio

- Hot electron source is prescribed with varying energy
- Assuming Thomas–Fermi model
- Smallest volume V~10^{-5} mm^3 targets are predicted to reach a few hundred eV

Simulated *LSP* K_α image



Predicted target heating



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Experimentally, three regimes of behavior are observed in the K_α and K_β emission that are broadly consistent with the simple estimates

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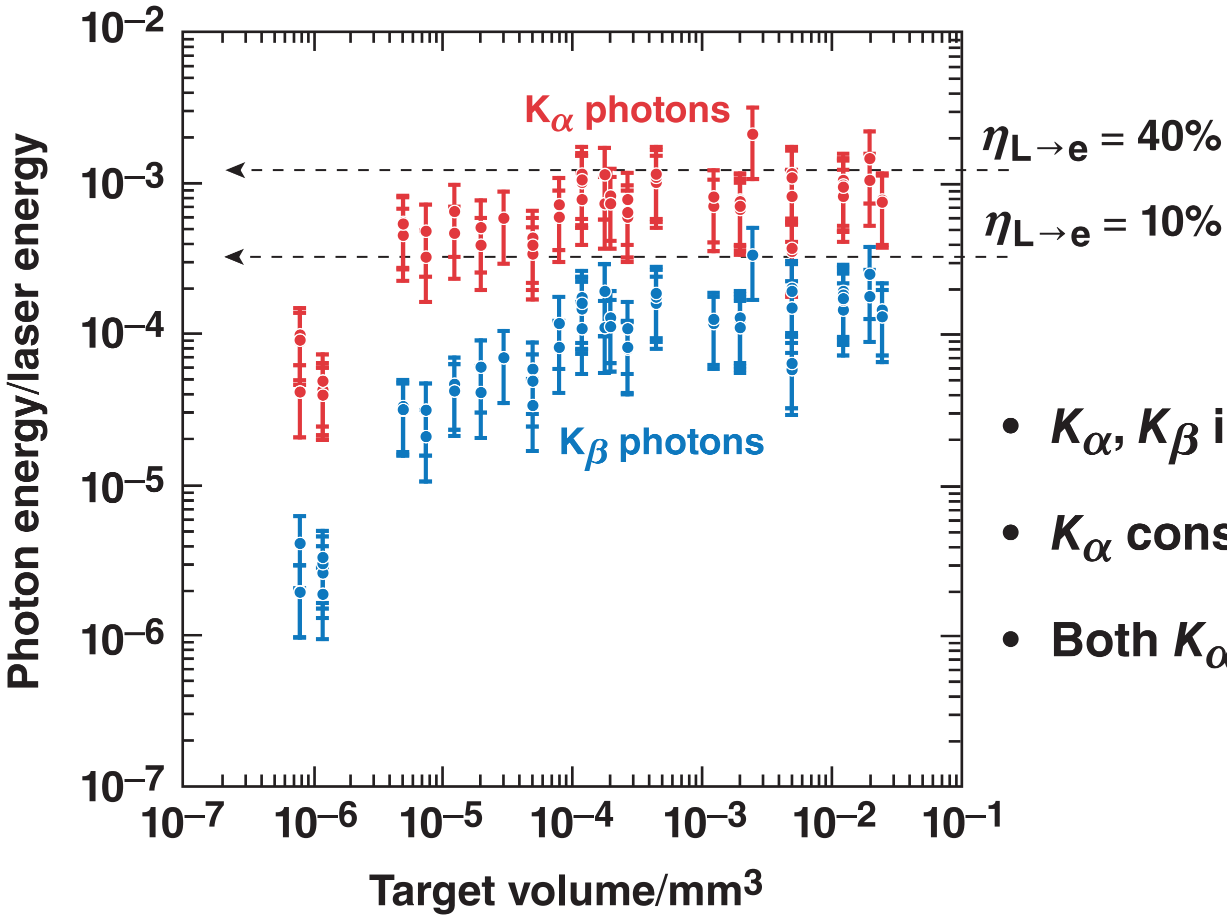

- K_α, K_β independent of volume
- K_α constant, K_β deceasing
- Both K_α and K_β decreased

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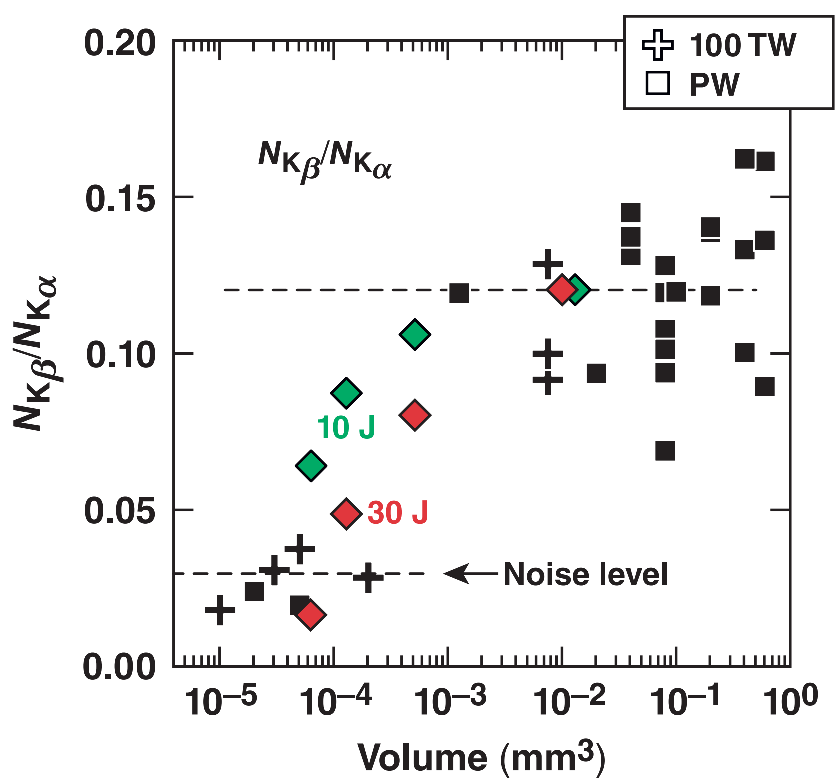
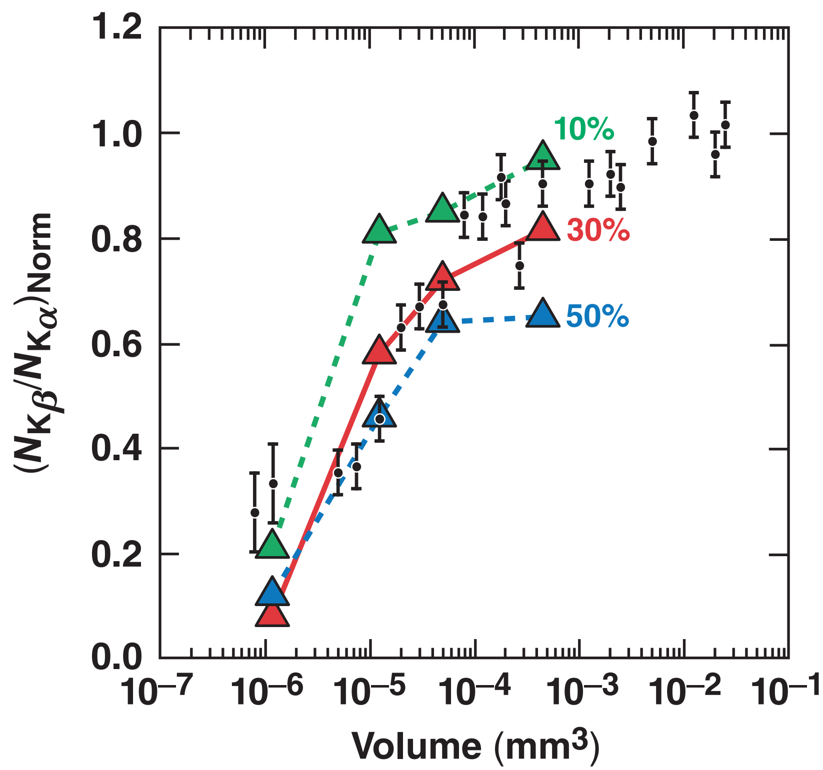
A comparison of the K_β/K_α ratio with *LSP* predictions leads to hot-electron conversion efficiencies that are in line with those obtained by fitting the absolute K_α yield

RAL Petawatt and 100 TW[1]



LLE MTW



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[1] W. Theobald *et al.*, Phys. Plasmas 13, 043102 (2006).

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