Numerical Calculations of Laser-Generated MeV Electrons and Characteristic X-Ray Production in Copper Foil Targets

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Electron Density

Laser Spot

Normalized laser intensity

R (μm)

Z (μm)

47th Annual Meeting of the American Physical Society Division of Plasma Physics
Denver, CO
24–28 October 2005
Summary

A modified version of LSP* is able to correctly compute the characteristic K-shell emission from laser irradiated foil targets without the *ad hoc* introduction of hot electron refluxing.

- $K_\alpha$ photon production efficiencies have been computed for parameters relevant to recent Cu foil experiments† on the 100-TW and PW RAL systems for laser intensities in the range $I = 10^{18} - 10^{20}$ W/cm$^2$.

- The computed yields depend strongly on the presence of large self-fields ($B \sim 10$ MG, $E \sim 10^7$ kV/cm) that create trapped and refluxing populations of hot electrons.

- Results compare favorably with the experiment in terms of the absolute yield and its dependence on laser intensity and target thickness.

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Collaborators

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Monte Carlo (MC) models can only be made to agree with the RAL data if we allow for “refluxing”

- For exponentially distributed electrons, the best fit occurs for an 8% conversion efficiency $\eta_{L\rightarrow e}$

![Graph showing laser intensity (W/cm²) vs. total energy in Kα/laser energy for different cases: 100 TW and PW RAL data, MC Model perfect refluxing, MC model no refluxing with 20 μm Cu foil.]

*C. Stoeckl et al., Bull Am. Phys. Soc. 49 1004 (2004).*
The LSP model automatically describes refluxing because it self-consistently solves for EM fields.

- Unlike MC, hybrid PIC includes the generation of sheath fields, anomalous stopping, resistive inhibition and collimation hot current.

- K-shell photon production efficiency is a result of the interplay between electron energy loss (dE/ds) and the energy dependence of the K-shell ionization cross section \( \sigma_k(E) \).

- The LSP plasma model has been extended by using a combination of the “collisional plasma” model and ITS routines.
  - collisional slowing down and scattering *
  - produce and transport x-ray photons

- Electrons are “promoted” from the background with Wilks scaling.†

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*A. Solodov et al., QP1.138
LSP calculations exhibit complex hot electron trajectories including refluxing from the foil boundaries

- Magnetic field strength and sample particle trajectories in 20 μm Cu foil.

- Hot electrons flow radially outward along the target surface.
  \[ U_{\text{drift}} = c \frac{E \times B}{B^2} \]

- Energetic electrons reflux off the sheath at the front and back surface.
Reasonable agreement is obtained between experimental $K_\alpha$ yield and LSP yield.

- Experimental points are a compilation of 100 TW and PW data where intensity is changed by varying beam energy (100 $\rightarrow$ 500 J) and spot size for a ~1ps pulse.
- LSP collision model under-predicts stopping at high electron energy*.

*A. Solodov et al., QP1.138
$K_\alpha$ yield is insensitive to target size in both experiments* and LSP calculations

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The k-photon yield and its dependence on laser intensity can be estimated by a simple model*

- Determine production efficiency

\[ \eta_{e \rightarrow k} = \frac{t_k N_k}{\eta_{L \rightarrow e} E_L}, \quad N_k = \frac{N_{k,obs}/F_{obs}}{N_e} \]

by integrating over path

\[ N_k = N_e \int_0^{\infty} dE_0 f(E_0) \int_0^{S_{\text{max}}(E_0)} ds \omega_k \eta_{Cu} S_k \]

- Energy distribution \( f(E_0) \) is uncertain

  - e.g., \( f(e) \, dE = T \exp\left(-\frac{E}{T}\right) \, dE \), with \( T \) related to \( I \) with Wilks scaling: \( T \sim W_{\text{osc}} = 0.511 \left[ (I = I_{18} \lambda^2 \mu m/1 \cdot 37)^{1/2} - 1 \right] \text{MeV} \)