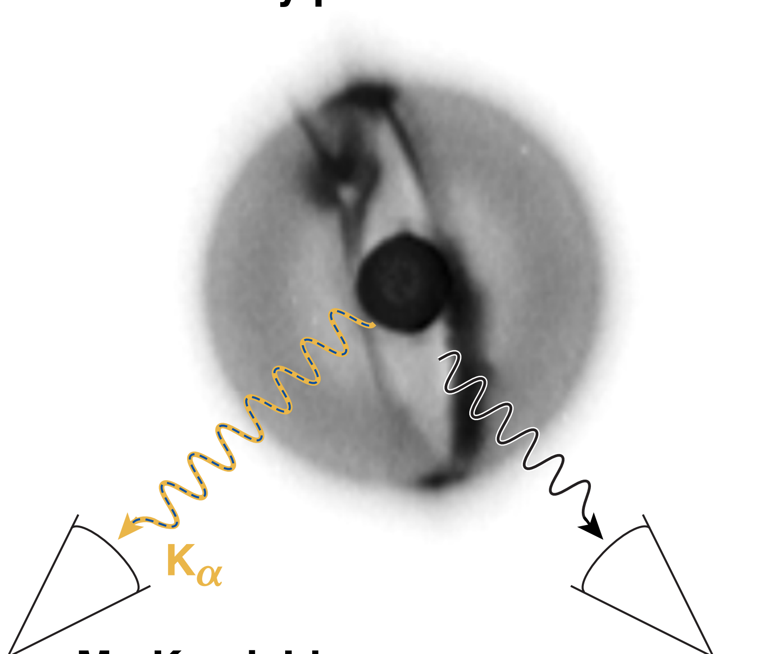
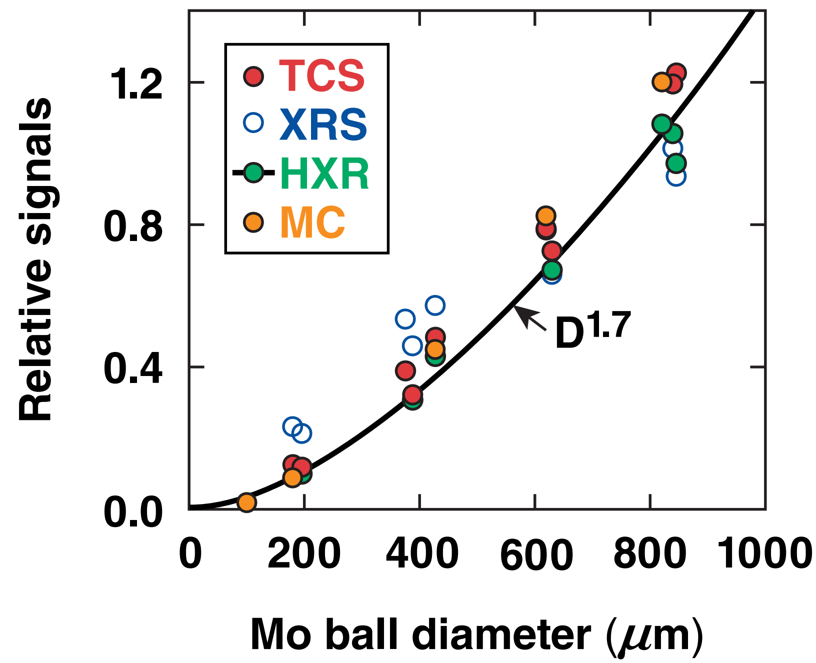
Measurements of the Divergence of Fast Electrons in Laser-Irradiated Spherical Targets





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43rd Annual Anomalous Absorption Conference
Stevenson, WA
7–12 July 2013

Summary

Measurements indicate that only 25% of the hot electrons produced by two-plasmon decay (TPD) would preheat the fuel in direct-drive experiments*

- In direct-drive experiments on OMEGA, the energy in fast electrons was found to reach ~1% of the laser energy at an irradiance of $\sim 1.1 \times 10^{15}$ W/cm^2
- The divergence of fast electrons was deduced from experiments where Mo-coated shells of increasing diameter (D) were embedded within an outer CH shell
- The intensity of the Mo-K_α line and the hard x-ray radiation increased approximately as $\sim D^2$, indicating a wide divergence of fast electrons
- Alternative interpretations of these results (electron scattering, radiative excitation of K_α, and an electric field caused by the return current) are shown to be unimportant

*B. Yaakobi, A. A. Solodov, J. F. Myatt, J. A. Delettrez, C. Stoeckl, and D. H. Froula, submitted to Physical Review Letters.

TC10660

Collaborators

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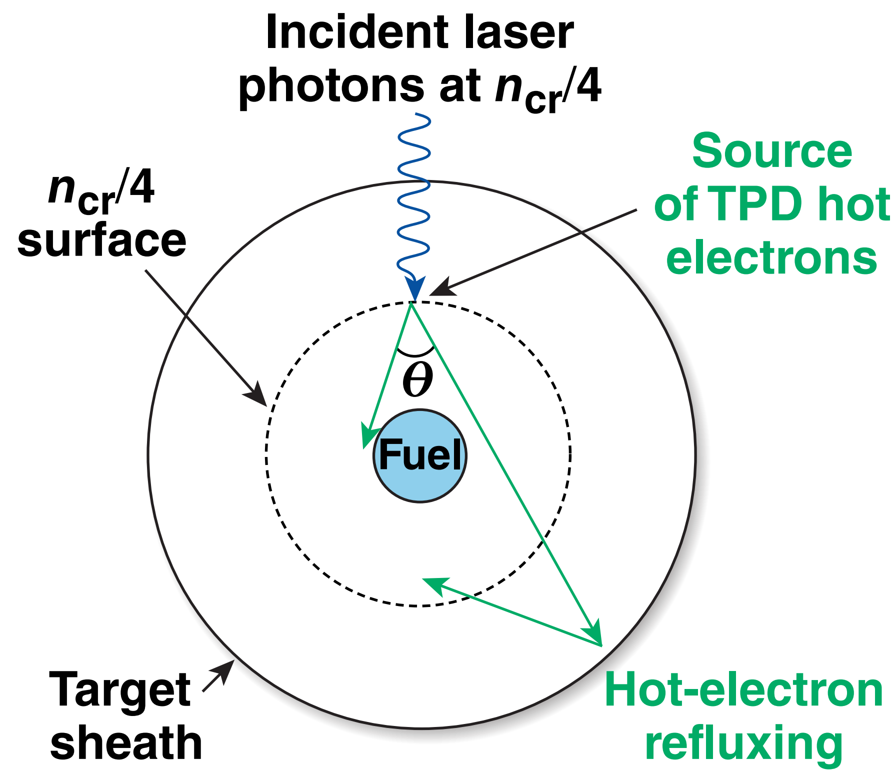
TPD generates hot electrons that can couple energy to the imploding shell, raising the adiabat and potentially quenching ignition

- Calculating the energy coupled to the fuel (preheat) requires
  - T_{hot}, f_{hot}
  - angular divergence (θ)
  - energy lost to the sheath



Direct-drive ignition requires that less than ~0.1% of the laser energy be coupled to the unablated fuel.

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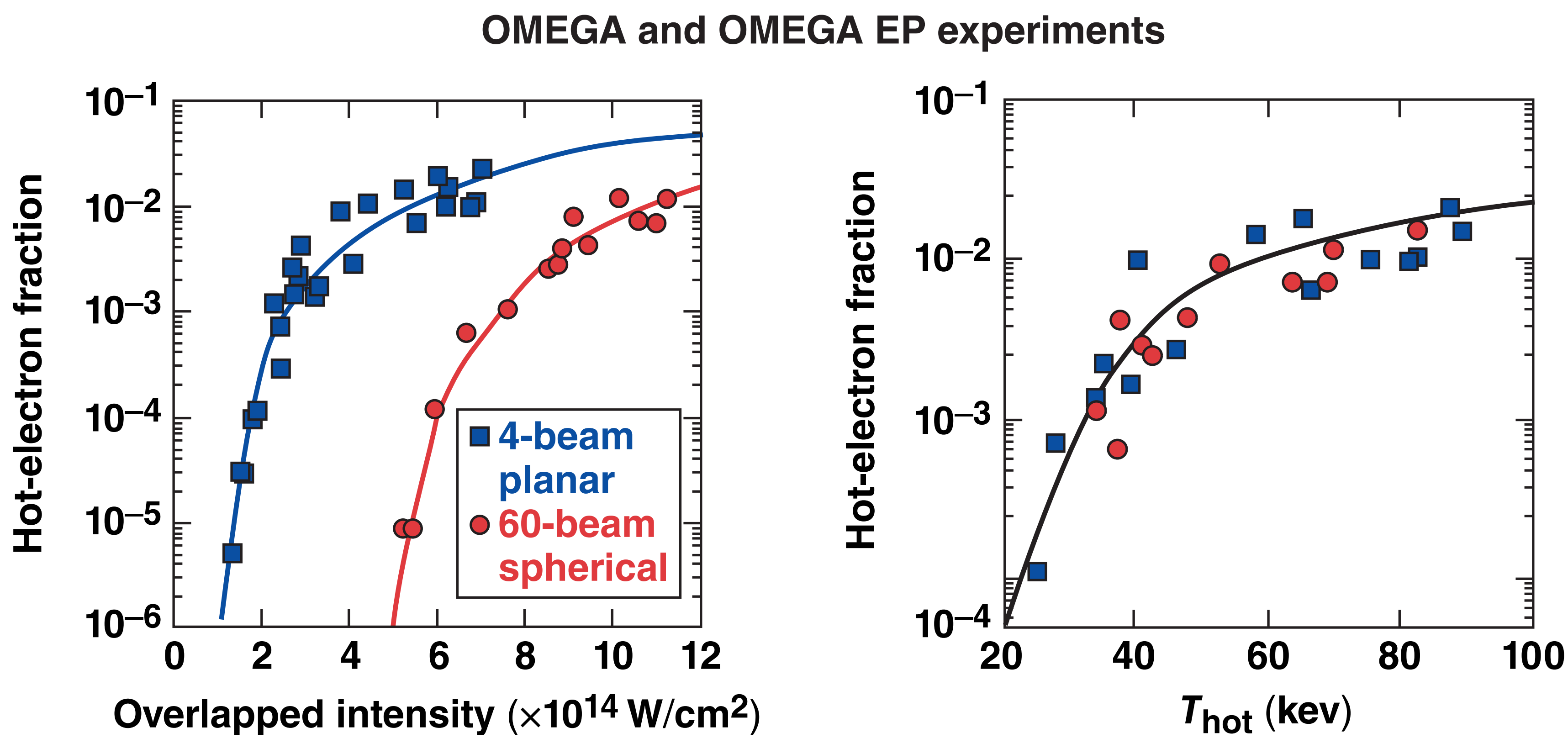
Extending the intensity to ignition conditions indicates that ~1% of the laser energy can be converted to hot electrons with a characteristic temperature of 50 to 100 keV



- The experiments suggest that the hot-electron fraction has the same scaling with the temperature in different geometries

E21309d

* D. H. Froula *et al*., Plasma Phys. Control. Fusion 54, 124016 (2012).

In typical cryogenic direct-drive experiments* only ~1/4 of the fast electrons will be intercepted by the compressed fuel if the hot electrons have a wide angular divergence

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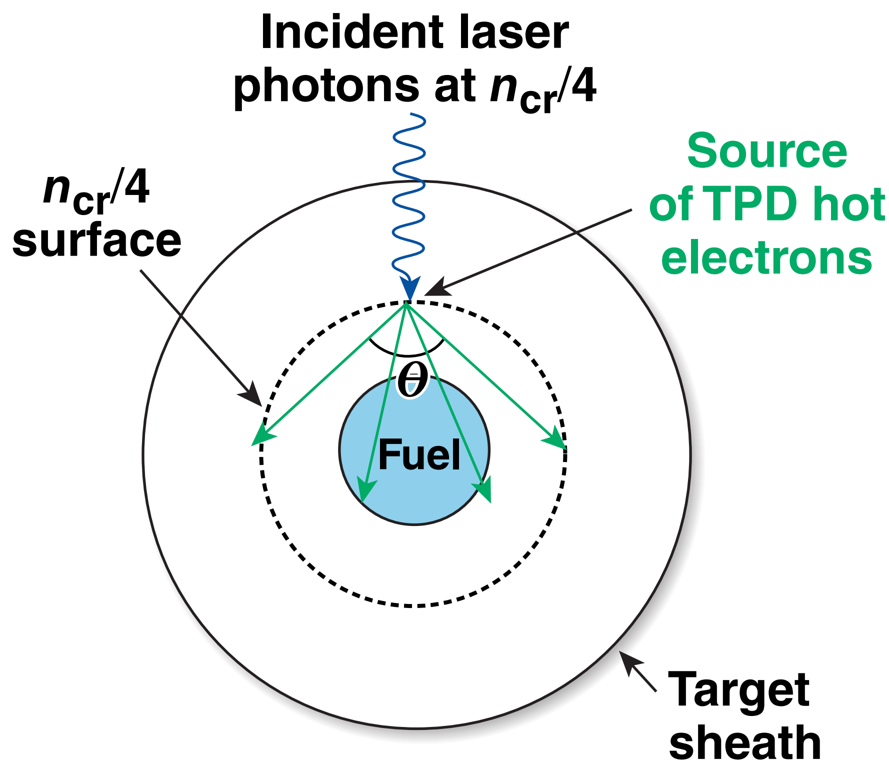
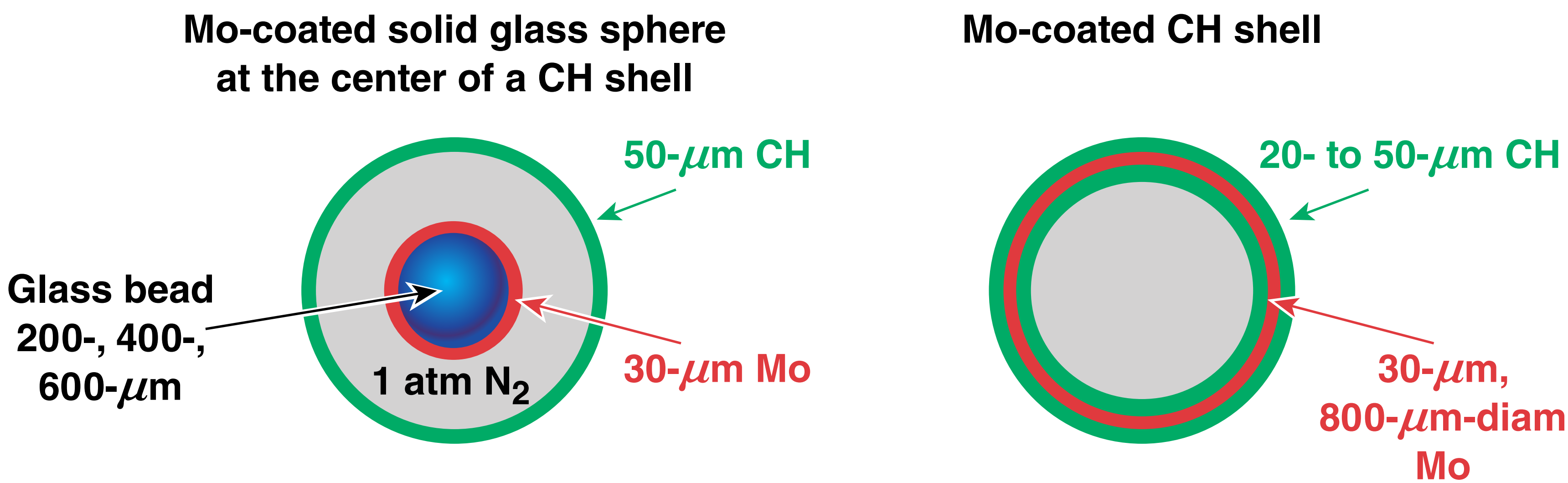
- Fast electrons are generated near the end of the laser pulse** when the density scale length is maximal
- At that time the compressed fuel shell has converged to about half the original target size*



TC10662

* V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010).
** C. Stoeckl *et al*., Phys. Rev. Lett. 90, 235002 (2003).

The divergence of fast electrons was studied using targets with Mo spheres of different diameters



- 26-kJ, 1-ns square-shaped OMEGA pulses with $I_L \sim 1.1 \times 10^{15}$ W/cm^2 were used
- Mo K_α and hard x-ray (HXR) energy dependence on the diameter
  - is unchanged for directed electrons
  - increases for divergent electrons

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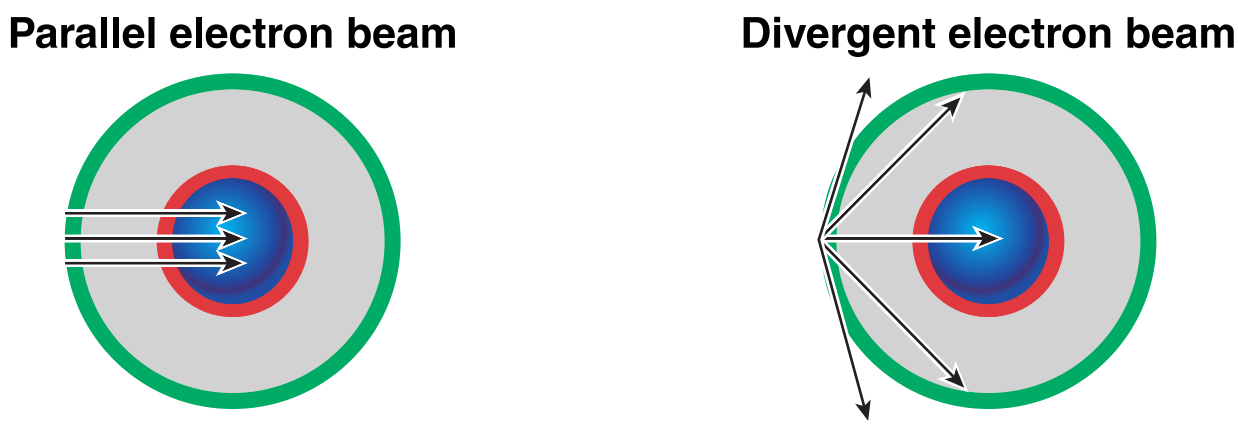
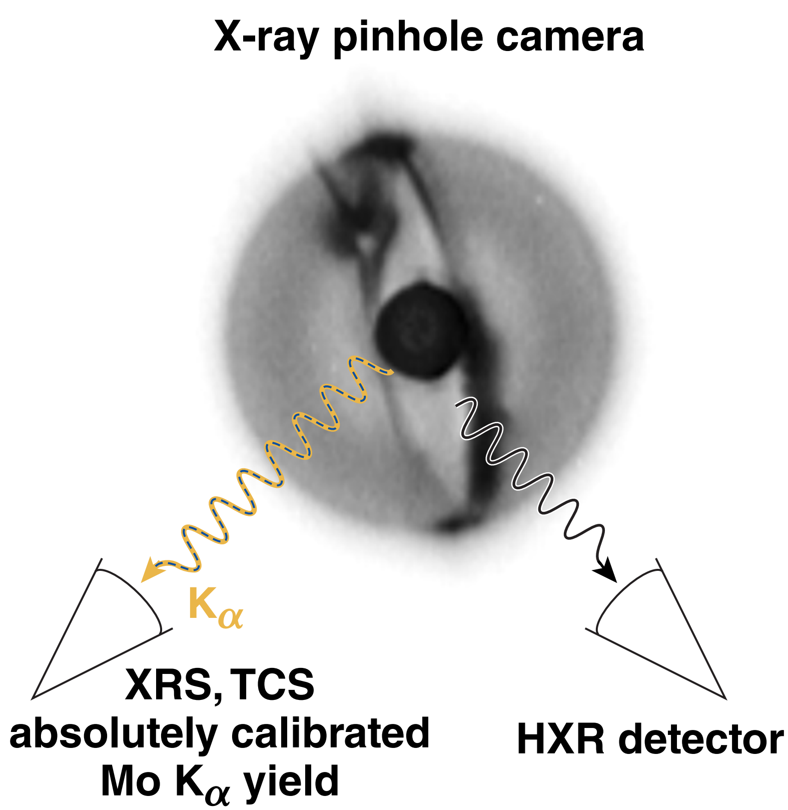
The transport of hot electrons was modeled with the Monte Carlo code *EGSnrc**

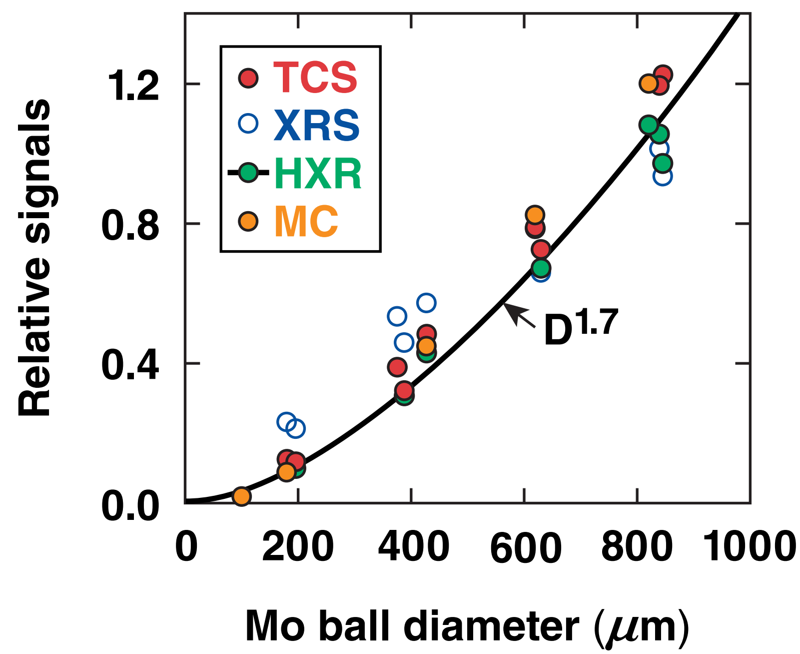


- *EGSnrc* modeled the transport of hot electrons and electron-induced HXR and Mo K-shell fluorescent radiation
- *EGSnrc* simulations assumed a 3-D Maxwellian hot-electron distribution with the temperature predicted by the four-channel HXR detector
- The divergence of hot electrons was varied from 0° (parallel beam) to 180° (isotropic beam)

* I. Kawrakow *et al*., NRC, Ottawa, Canada, NRCC Report PIRS-701 (May 2011); I. Kawrakow, Med. Phys. 27, 485 (2000).

The experiments show that fast electrons have a wide divergence extending to the original target diameter





- TCS – Cauchois-type quartz crystal spectrometer
- XRS – two identical planar LiF crystal x-ray spectrometers
- MC simulations assumed an isotropic hot-electron beam

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Three alternative explanations to the rise in signals were investigated and found to be unimportant

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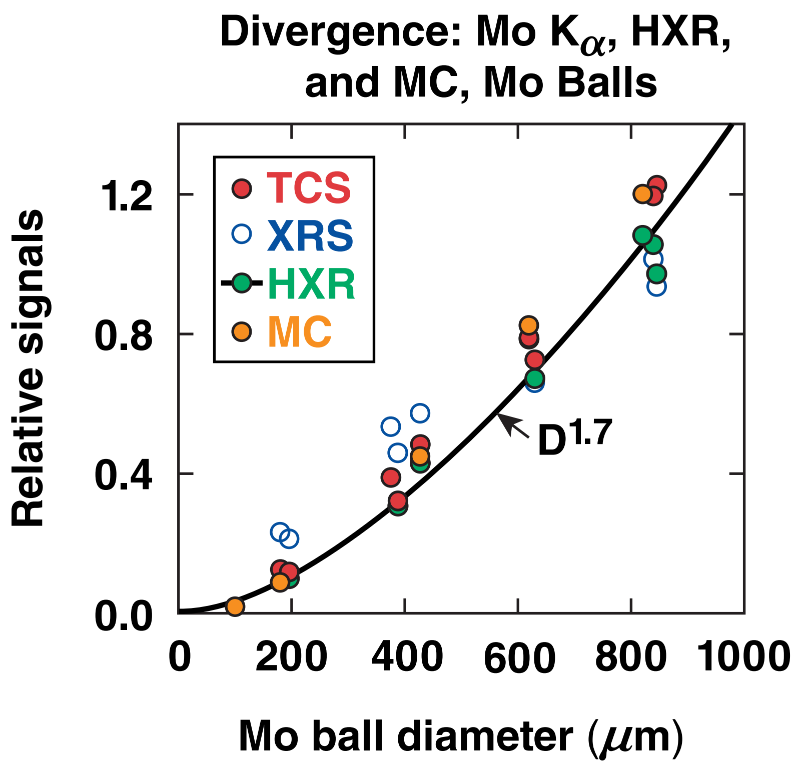
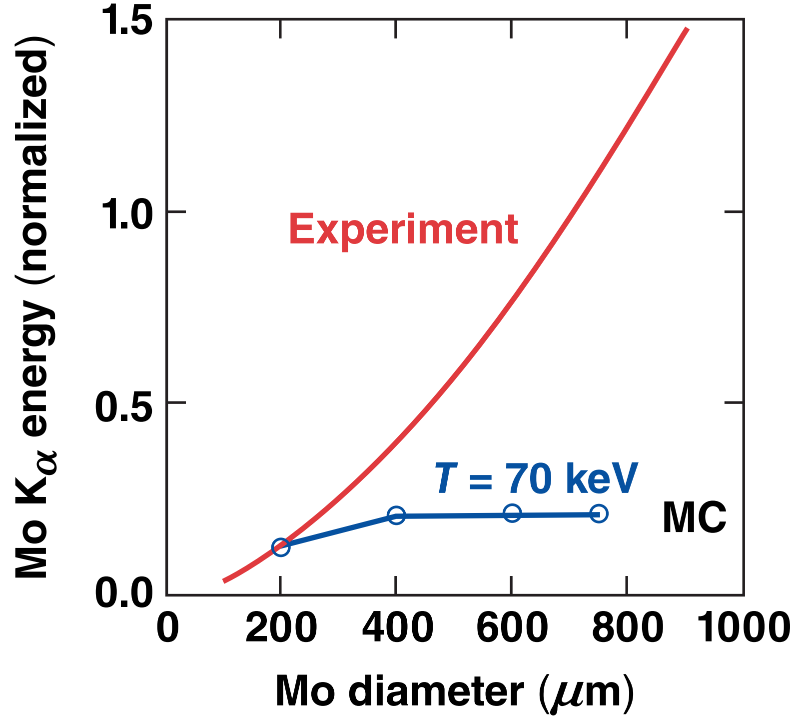


- Electron scattering in the outer CH shell
- Radiative excitation of the Mo-K_α line
- Radial electric field related to the return current within the ionized N_2 fill gas

Electron scattering in CH was shown to be unimportant by *EGSnrc* Monte Carlo simulations

Mo balls experiment, MC simulation with unidirectional e-beam



- Electrons that are strongly scattered in CH are also strongly absorbed

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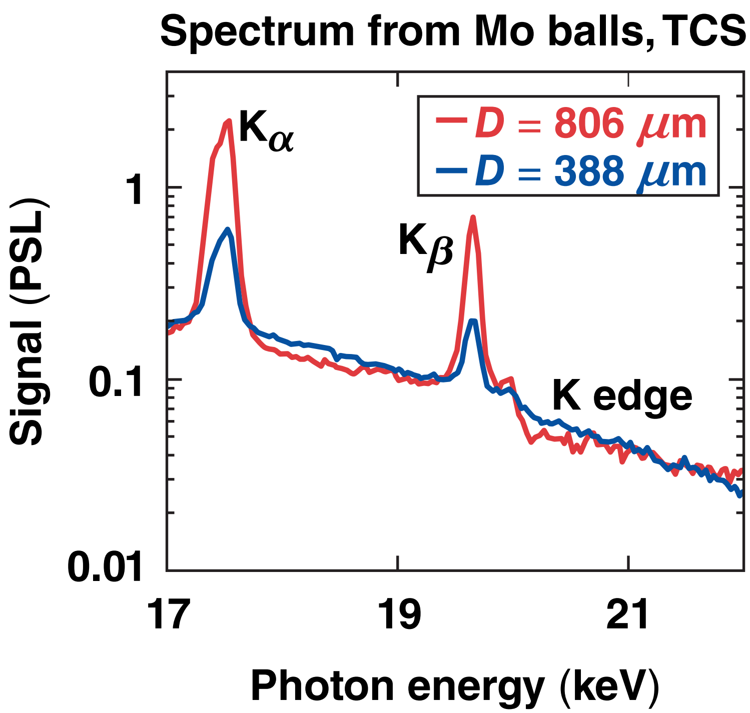
K_α line pumping by the plasma radiation from the laser absorption region in the CH is unimportant



- Radiation contribution to K_α

  $E_R = \int_{E_0}^{\infty} I_c(E)\omega_K[E(K_\alpha)/E]dE,$
  where $I_c(E)$ is the continuum spectrum,

  $E_0 \sim 20$ keV is the K edge

  $\omega_K = 0.76$ is the K_α fluorescent yield of Mo

- For the largest Mo ball diameter, E_R is less than 10% of the total energy of the K_α line

- The relative contribution of the radiation is the same for all Mo diameters (but can best be determined from the largest diameter)

A negligible effect of the retarding electric fields is confirmed by the analytical model using plasma profiles from *LILAC* radiation–hydrodynamic simulations

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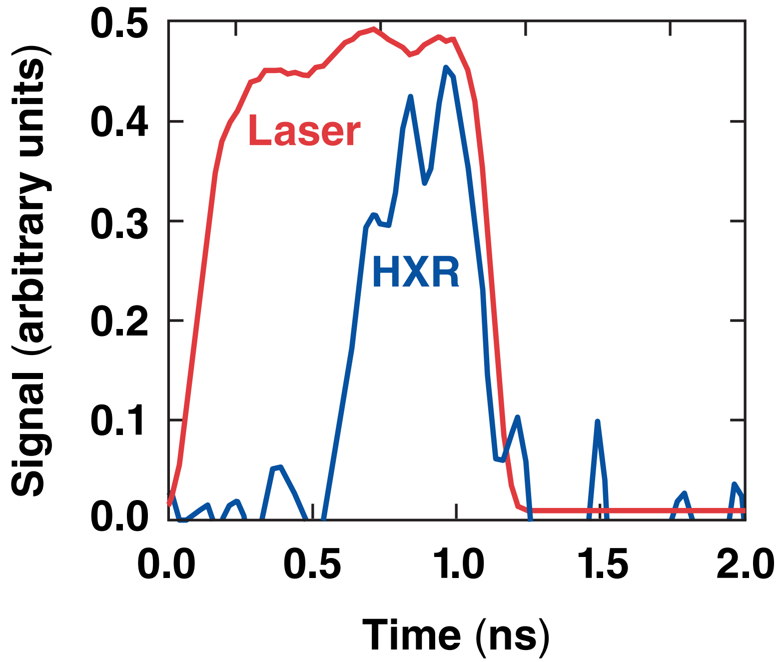
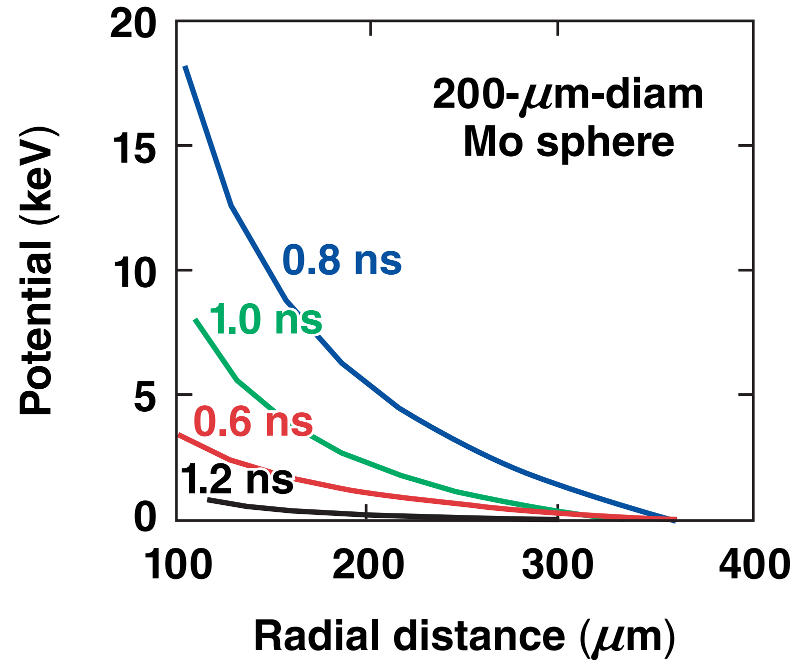
HXR for Mo ball shot 66125



Model calculation of electric field in Mo ball experiments (actual e-power)



- $E(r) = J_{hot}(r)/\sigma(r)$, with $J_{hot}(r_{1/4}) = f_{hot}\, eI_L/E_{hot}$ and $\sigma = 1.96\, Ne^2\tau_e/m_e$, $\sigma(r)$ was estimated using the temperature and ionization of the N_2 gas simulated by the *LILAC* code

E21993

Summary/Conclusions

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