Anisotropic Distribution of Hard X Rays from the Two-Plasmon-Decay Hot-Electron Distribution

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Summary

Hot electrons produced by two-plasmon decay (TPD) have a strong anisotropy

- A new 180° viewing image-plate diagnostic measures the angular distribution of hard x rays emitted from a target
- The x-ray distribution from the two-plasmon-decay instability has a strong forward anisotropy, indicating that the hot electrons produced by the TPD are directed anisotropicaly
- The diagnostic indicates an unexpectedly low hot-electron temperature of 20 keV
- Extended Zakharov TPD modeling supports the measurements

The hot electrons are accelerated along the axis of the shared TPD plasma wave.

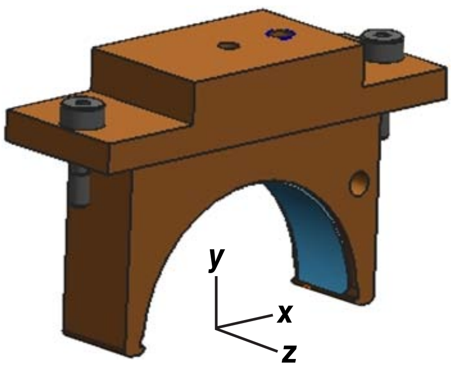
Background

Target preheat by hot electrons may reduce the areal fuel density ρR in some direct-drive implosions

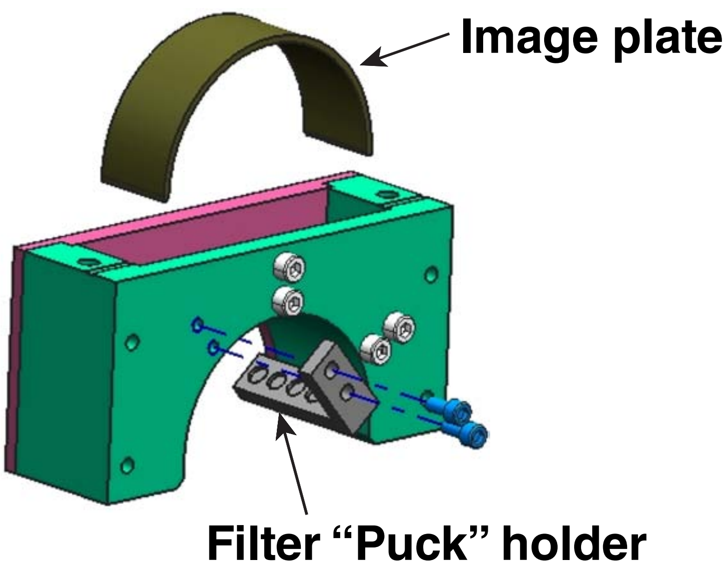
- Fast electrons can be produced during the laser pulse by laser-plasma instabilities (LPI) such as the two-plasmon decay (TPD)
- Implosion performance will be degraded if significant "preheat" energy is deposited in the fuel by the fast electrons
- The directionality of the hot electrons is important for the simulation of target preheat
- Theory and preliminary measurements using HXRD suggest that the hot electrons have a strong forward anisotropy and travel in the direction of the shared TPD plasma wave
- The nonlinear nature of TPD and shot-to-shot variations in laser performance make it difficult to quantify the anisotropy using multiple shots

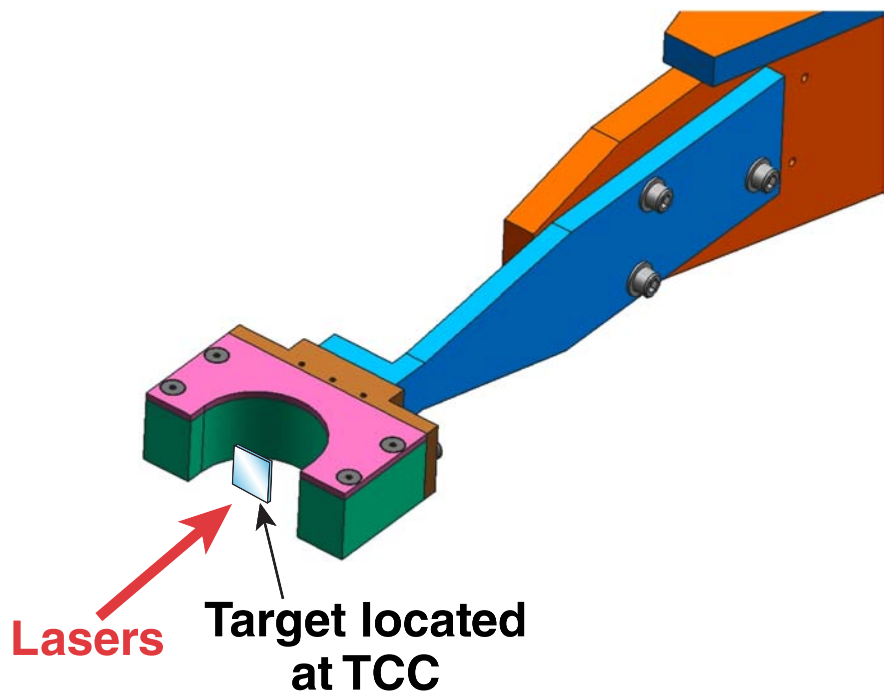
Experimental Measurements

An image-plate–based diagnostic (XIMP) was fielded to measure the anisotropy in a single shot

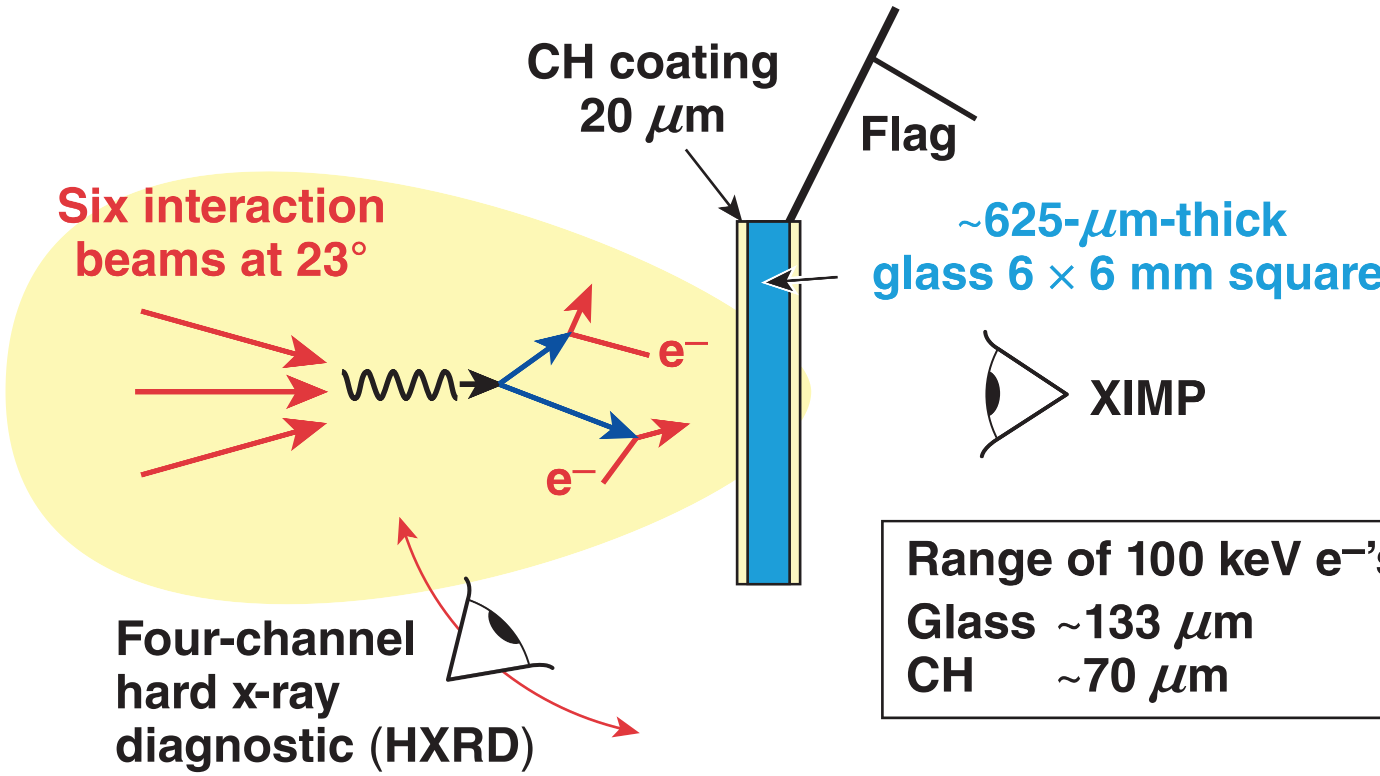


- Curved x-ray image with a 2-cm radius is placed around the target at TCC
- Measures x-ray intensity over a range ±90° from laser incidence





TPD hot electrons are produced by six OMEGA interaction beams incident on a planar glass target



Range of 100 keV e⁻'s	
Glass	~133 μm
CH	~70 μm

- Six symmetrically arranged interaction beams
- The angular dependence of the x-ray emission was also diagnosed with XIMP and a time-resolved, four-channel hard x-ray detector (HXRD) multi-shot measurements.*

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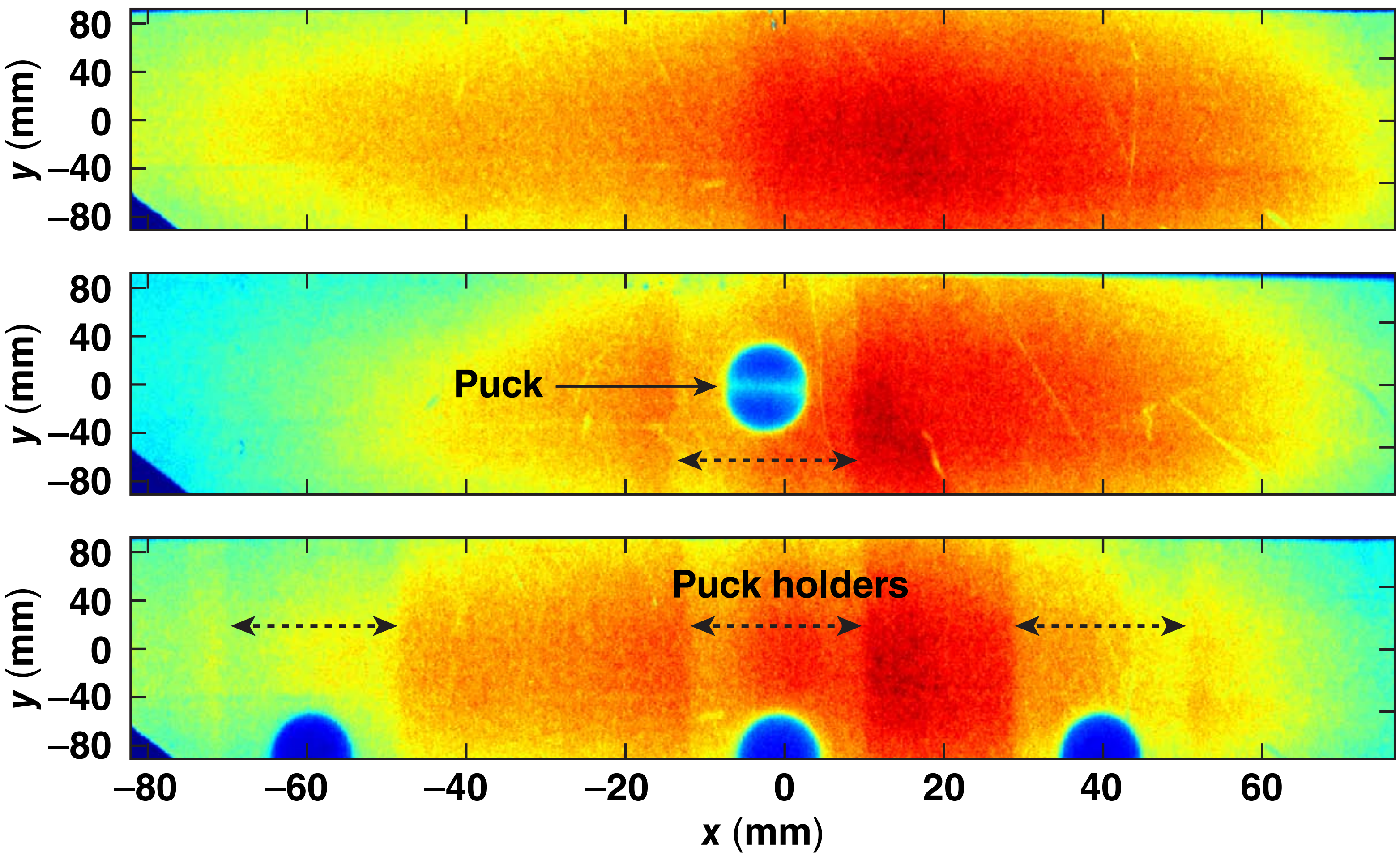
*C. Stoeckl *et al.*, Rev. Sci. Instrum. 72, 1197 (2001).

The image-plate angular-distribution measurements show similar anisotropy on all similar shots



The forward anisotropy is a reproducible feature of the TPD experiments.

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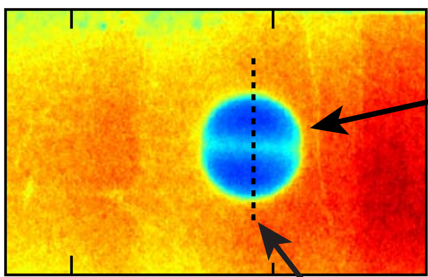
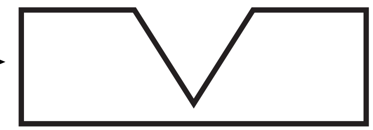
The hot-electron temperature is estimated using the transmission through various material/thicknesses

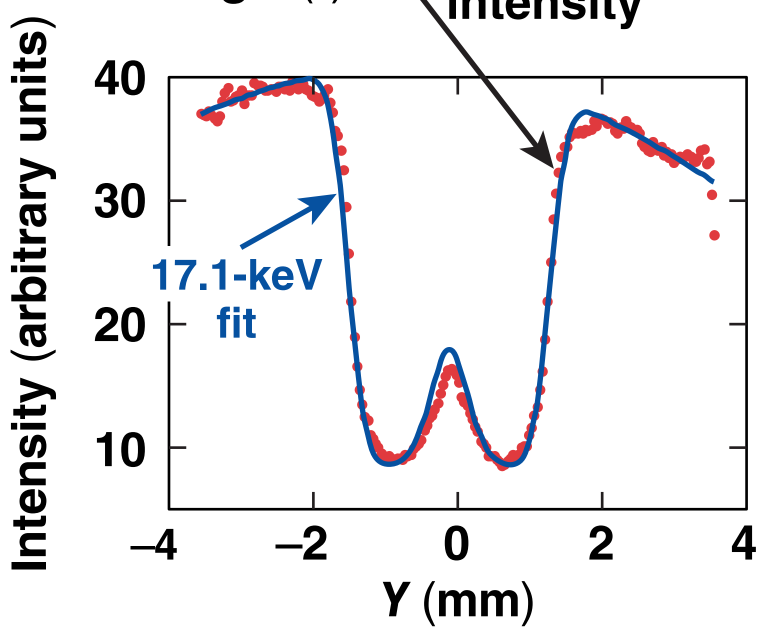
Raw image plate



Tungsten Filter Puck
3-mm diam, 1-mm thick
with 0.9-mm deep "V" groove



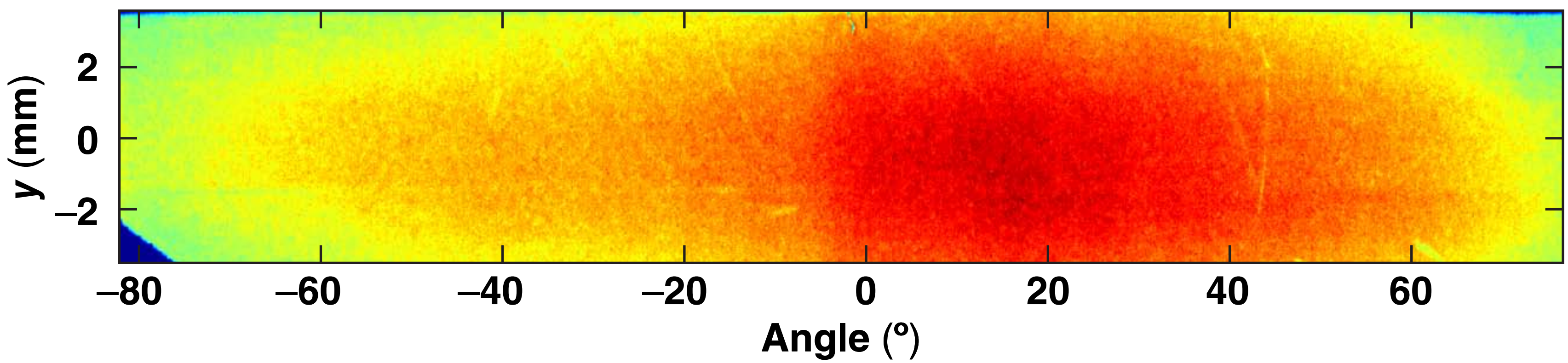
Lineout of intensity



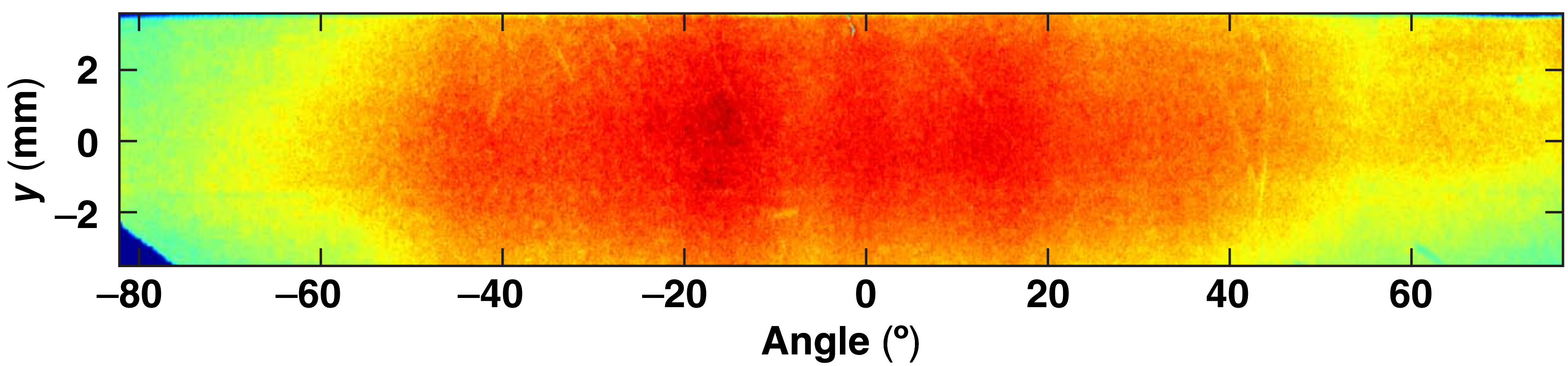
- The difference in transmission through the grooved disc suggests a hot-electron temperature of ~20 keV
- This is much less than the ~60 keV indicated by the HXRD channels for similar shots

The unblocked image plate shows the expected forward anisotropy with the 20-keV hot-electron temperature

Raw image plate's apparent off-centered intensity peak is due to manufacturing variations in the thickness of the tungsten shield in front of the image plate



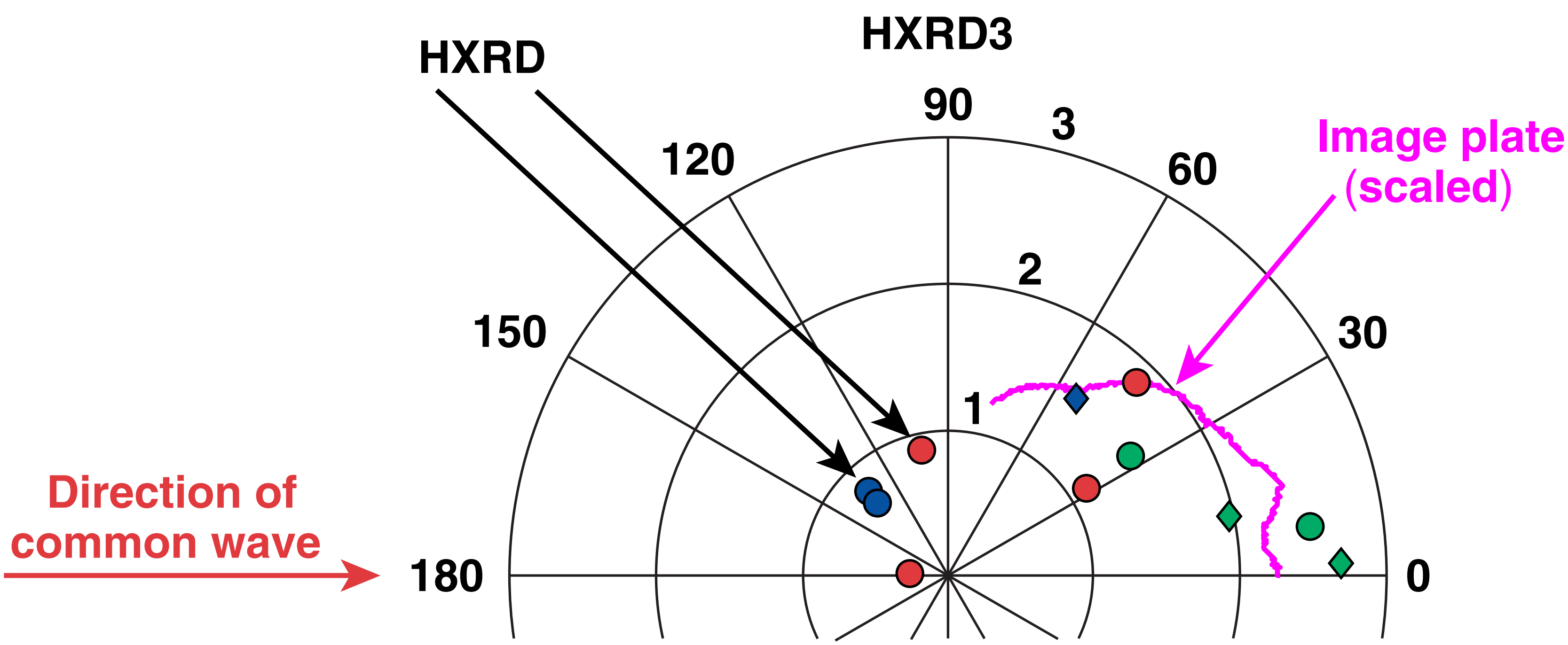
Forward-peaked intensity distribution is recovered when 20-keV distribution is convolved with the measured shield-thickness variations



This is an indirect confirmation of the unexpectedly low hot-electron temperature

The single-shot image-plate angular distribution is consistent with the HXRD multi-shot measurements

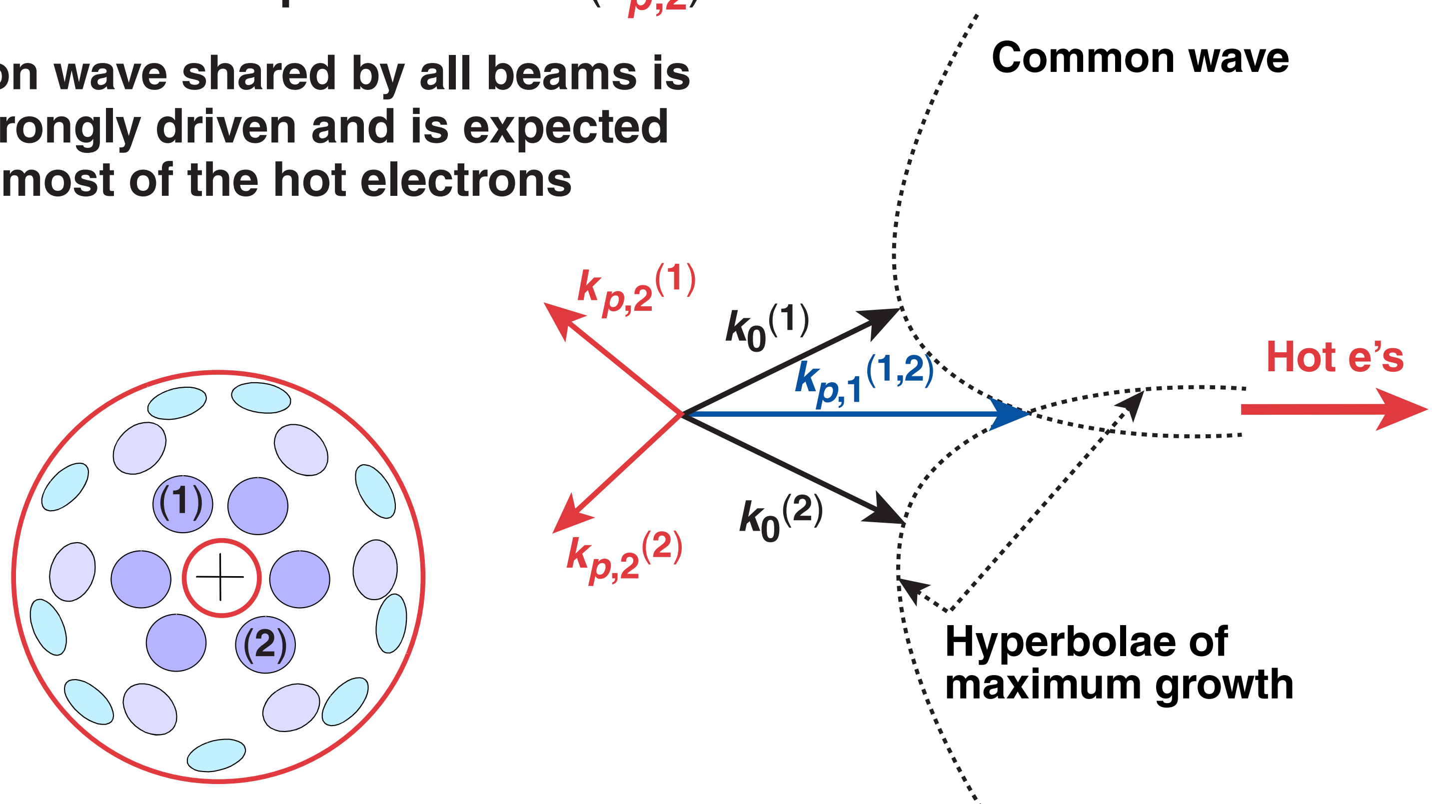
- Angular distribution of x-ray intensity with respect to angle of laser incidence



- When scaled to similar magnitudes, both distributions show variations of the same order

The two-plasmon-decay instability could produce forward-directed hot electrons

- Experiments on OMEGA show that TPD is driven by the collective intensity of overlapping beams
- Each beam (k_0) drives a common plasma wave ($k_{p,1}$) and a separate satellite plasma wave ($k_{p,2}$)
- The common wave shared by all beams is the most strongly driven and is expected to produce most of the hot electrons



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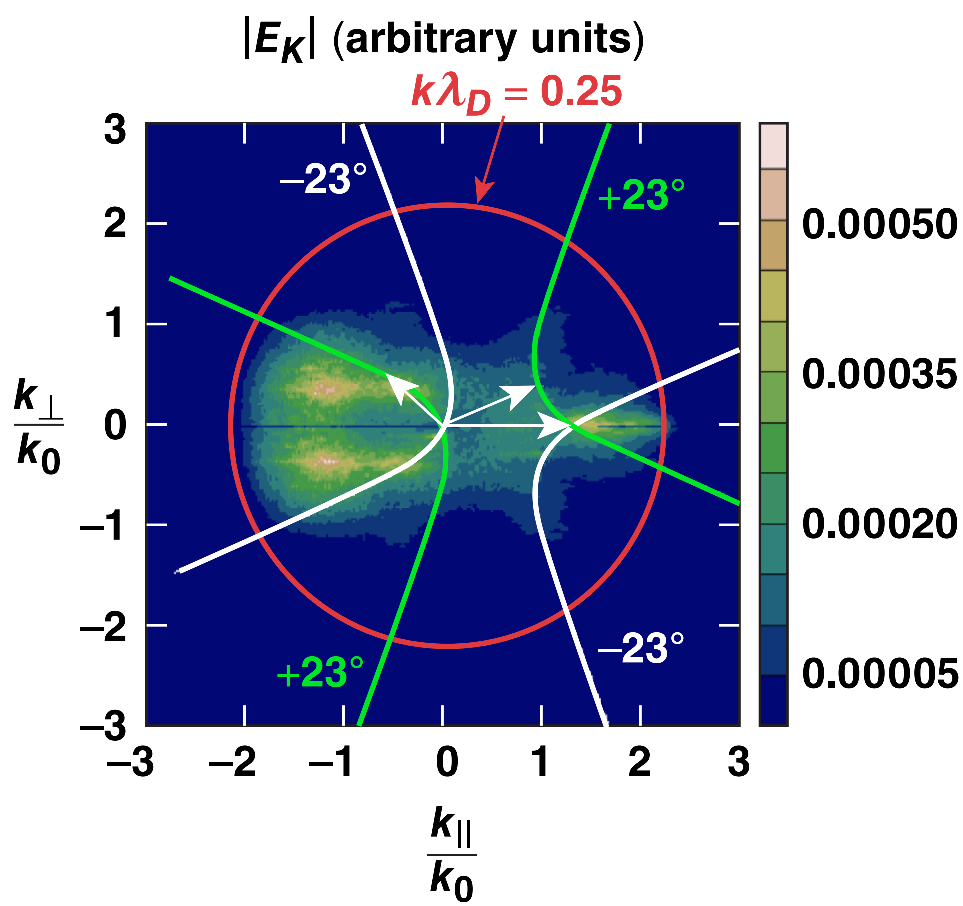
Recent two-dimensional extended Zakharov modeling[1,2] of TPD lends support to this hypothesis

- Plasma-wave k-vectors are contained within an angle of $\theta = 15°$
- The electric field is strongest in the region near the axis of the common wave ($k_{perp} \approx 0$)
- The electrons would be accelerated anisotropically in that general direction
- Some electrons are also accelerated in the direction opposite the common wave but they will be reflected back by the electrostatic sheath (see next page)

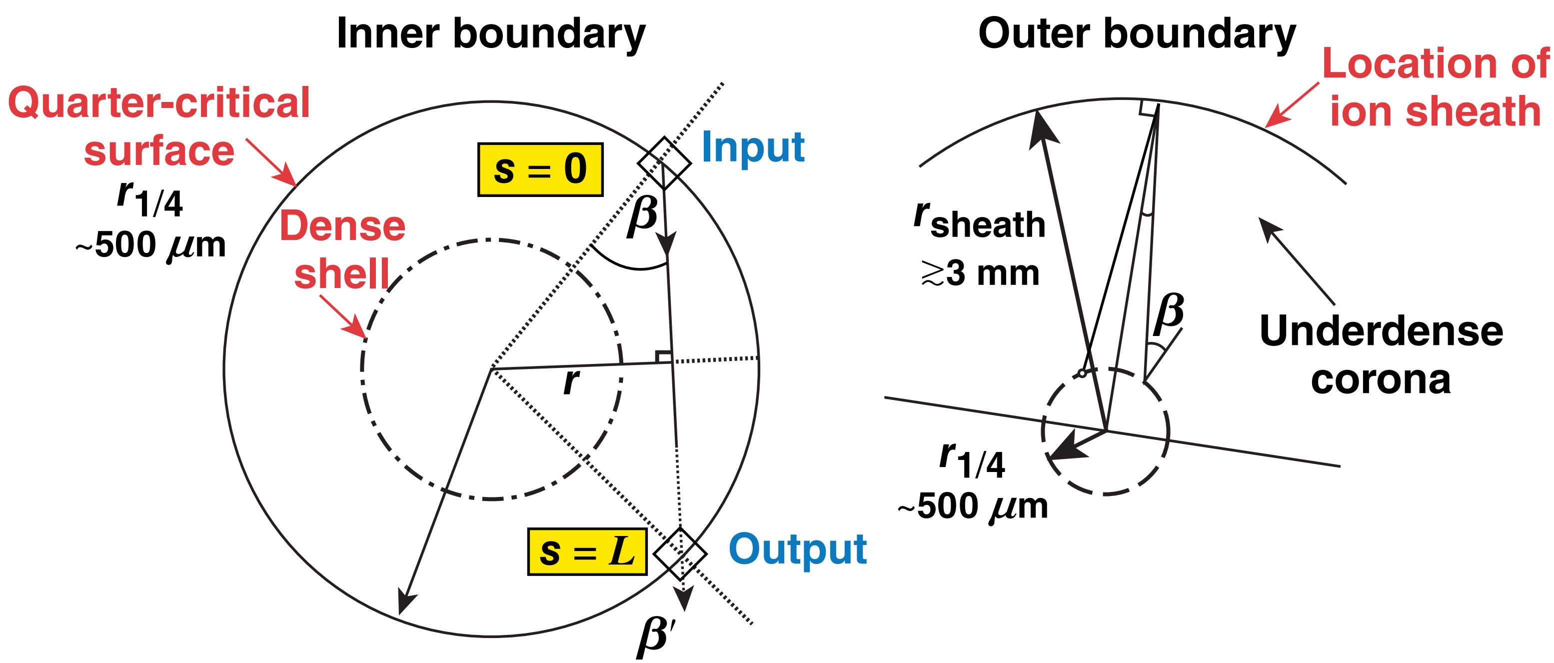


See J. F. Myatt this conference (Friday).

[1] D. F. DuBois, D. A. Russel, and H. A. Rose, Phys. Rev. Lett. 74, 3983 (1995).
[2] D. A. Russell and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001).

The Zakharov modeling includes the effects of recirculation of electrons leaving the calculation boundaries

- Electrons that exit the calculation volume on the inner boundary pass through the inner coronal plasma and possibly the dense shell before re-entering the calculation volume
- Electrons exiting the calculation volume through the outer surface travel through the outer corona and are eventually reflected by the sheath



- The delay at the inner boundary is short, with significant energy loss; the delay at the outer boundary is long, with little energy loss

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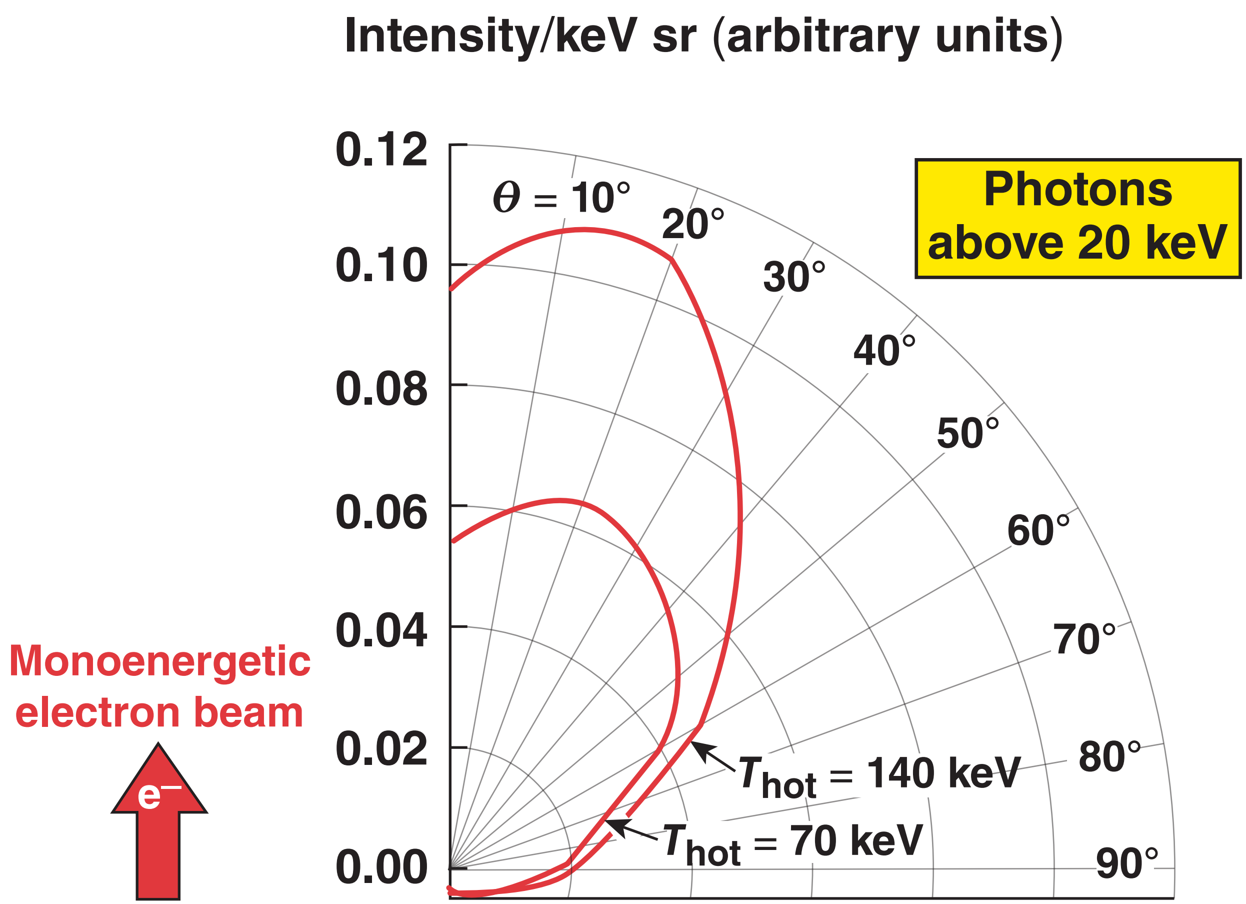
Bremsstrahlung angular distributions depend on the initial hot-electron temperature and the photon energy that is observed

- The electron is assumed to travel in a straight line, and angles are relative to the momentum p_0



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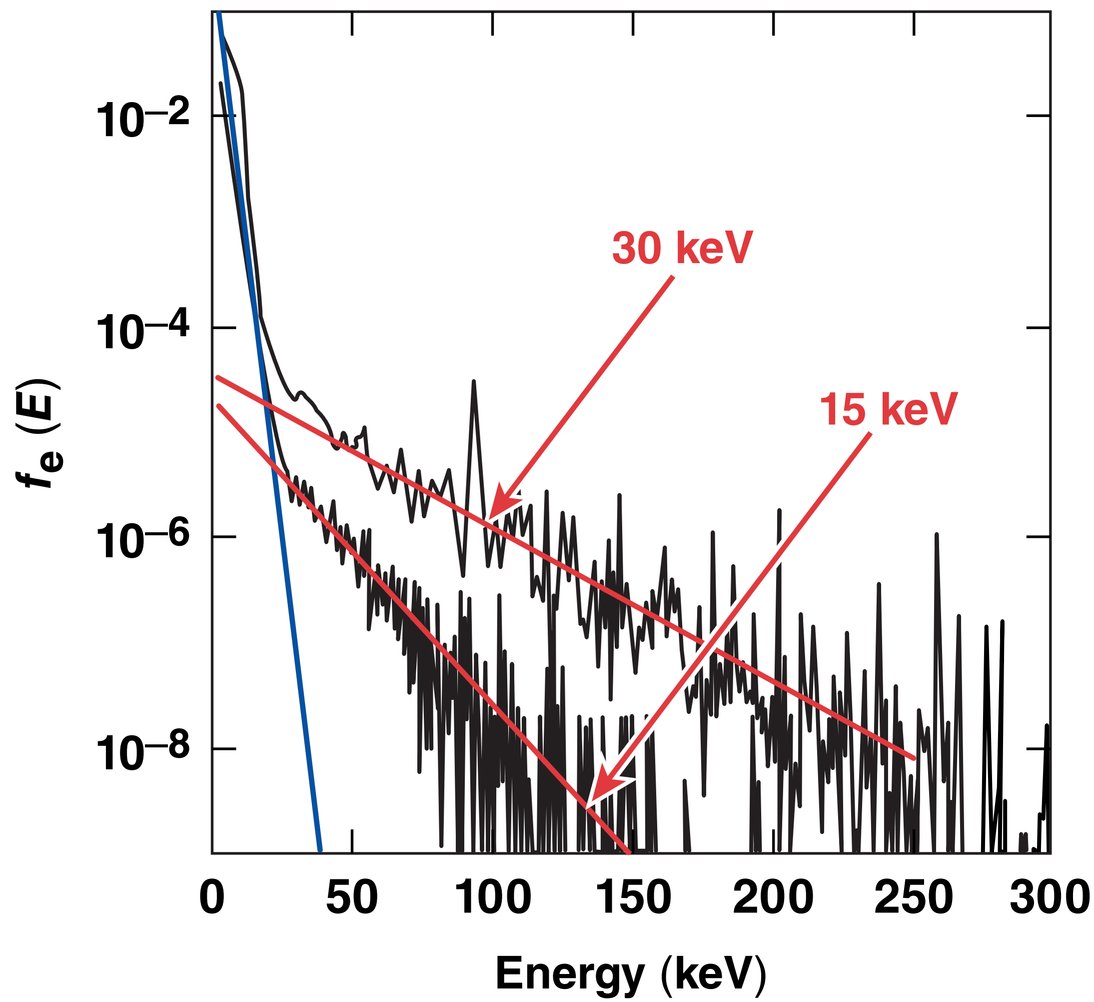
This temperature is consistent with extended Zakharov model predictions for TPD hot-electron distributions



- Extended Zakharov model for TPD predicts for spherical geometry
  - 15 keV with no-recycling
  - 30 keV with recycling
- Planar geometry with one-sided recycling should lie between these limits
  - only reflection by the sheath is appropriate since all electrons are stopped by the thick planar target

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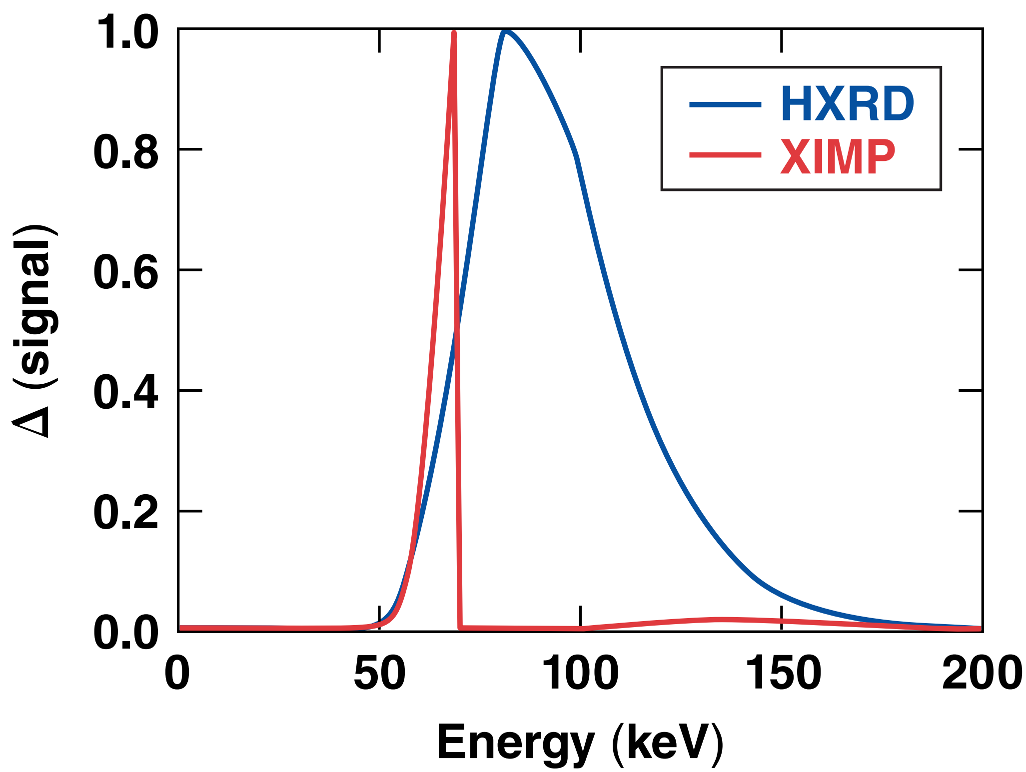
The disagreement between HXRD and XIMP may result from sampling different energy bands

- XIMP temperature measurement is most sensitive to the 50- to 70-keV range
- HXRD temperature measurement is sensitive to the higher energy portion of the distribution
- A higher energy tail to the distribution might explain the higher HXRD temperature measurements
- Experiments are planned with new filtering on XIMP to resolve the discrepancy with HXRD

Difference in signals used to determine the hot-electron temperature *S* = sensitivity

$$\left[S_2(E) - S_1(E)\right] \cdot f_e(E)$$



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