Measurements of Hard X-ray Emission from Laser–Plasma Instabilities on OMEGA

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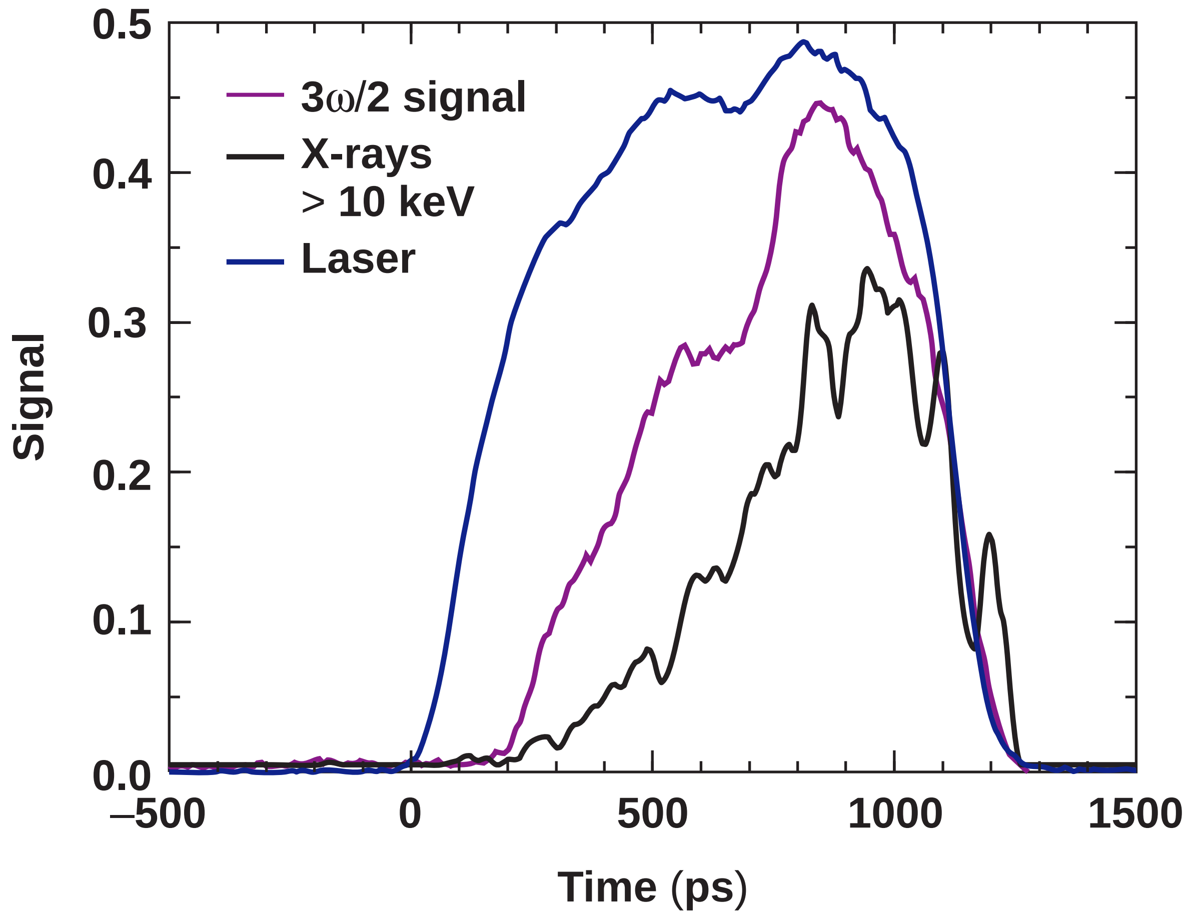
Laser–plasma instabilities producing suprathermal electrons are potentially dangerous for both direct-drive and indirect-drive laser fusion. These energetic electrons can preheat the fuel and prevent compression of the capsule to the requisite conditions for ignition. Fast-electron generation can be inferred from the hard x-ray radiation generated by the interaction of the hot electrons with the target and surrounding material. In addition, optical signatures, like the 3/2 ω emission from the two-plasmon-decay instability, provide insight into the generation processes. Using the signals from time-resolved detectors in an energy range from 10 keV to 500 keV, this paper will present an estimate of the amount and spectrum of the hard x-ray radiation. The hard x-ray data will be correlated with the 3/2 ω emission, and a first attempt to infer the amount of laser energy coupled to suprathermal electrons and to the target will be made. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority.

Hard X-Ray Emission from Laser–Plasma Instabilities



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41st Annual Meeting of the
American Physical Society
Division of Plasma Physics
Seattle, WA
15–19 November 1999

Summary

Hard x rays correlate with two-plasmon decay instability

- Hard x-ray emission was recorded time-resolved in a wide energy range from 10 keV to 500+ keV for CH-target implosions.
- The $3\omega/2$ light associated with the two-plasmon decay instability correlates with the hard x-ray emission.
- No optical signature of the SRS instability was observed.
- The radiated energy in hard x rays (> 30 keV) is of the order of 100 mJ.
- The hot-electron temperature was found to be > 100 keV.
- An energy content in hot electrons of the order of 0.1% of the laser energy can be inferred using scaling laws from previous experiments.*

*D. M. Villeneuve *et al*. Phys Fluid 27, 3 (1984).

Six detectors measure x-ray timing, energy, and spectrum

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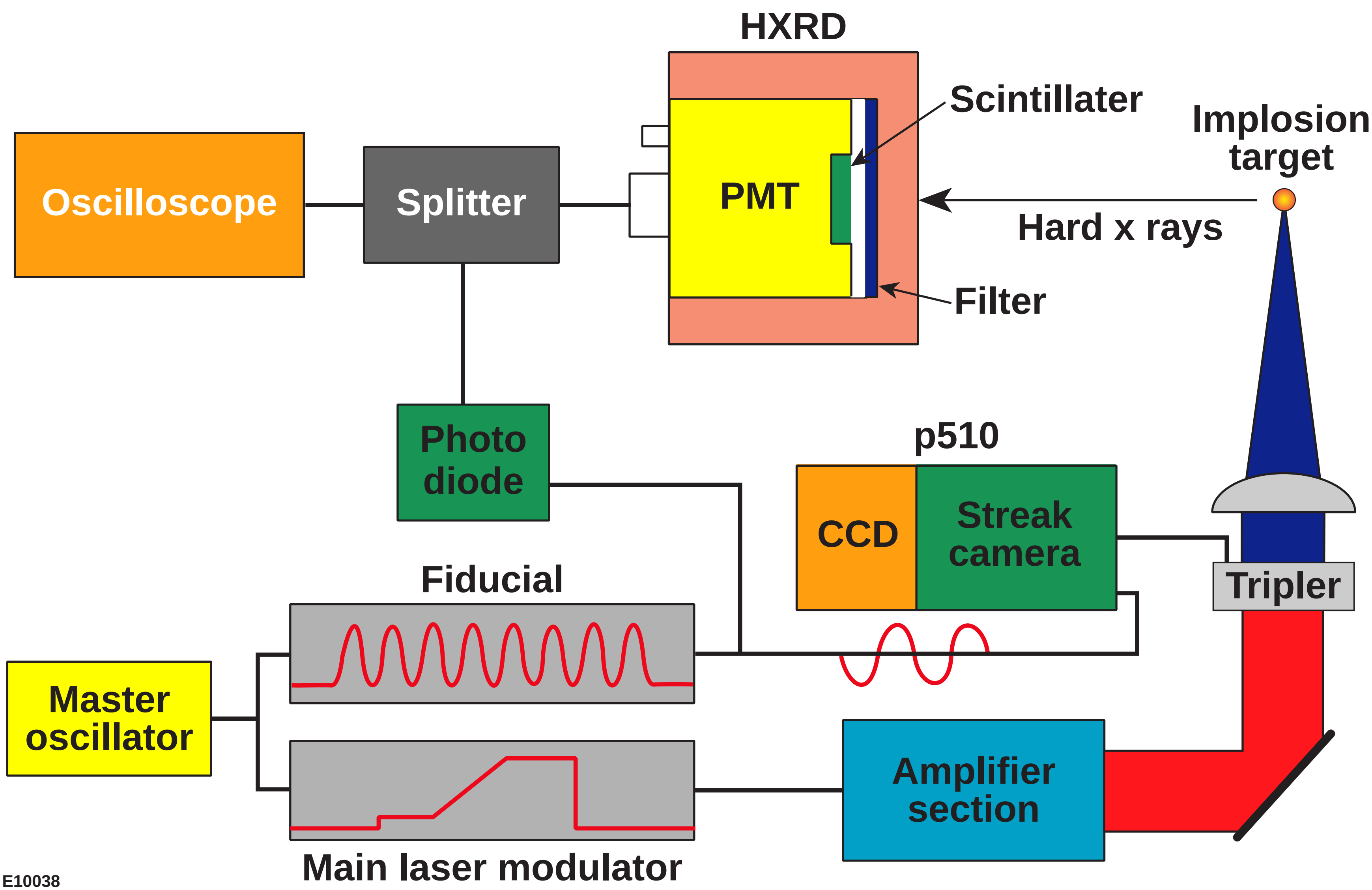
- Two detectors designed for neutronics applications – the Neutron Temporal Diagnostic (NTD) and the Neutron Bang Time Detector (NBT) – were used to measure soft >10-keV and relativistic >500-keV x-rays.
- A dedicated set of four x-ray detectors was set up using a fast scintillator (800-ps fall time) combined with a fast microchannel-plate photomultiplier (70-ps rise time) from x-ray energies for 20 to 200 keV.
  - The energy band of the x rays is determined by a single edge-type filter.
  - Two 1-GHz digital oscilloscopes (350-ps rise time) record the signal.
  - An optical fiducial establishes absolute timing.
  - The four detectors are calibrated relative to each other.
  - The high dynamic range of the detectors (> 10,000) enables their use on 1- to 60-beam shots.

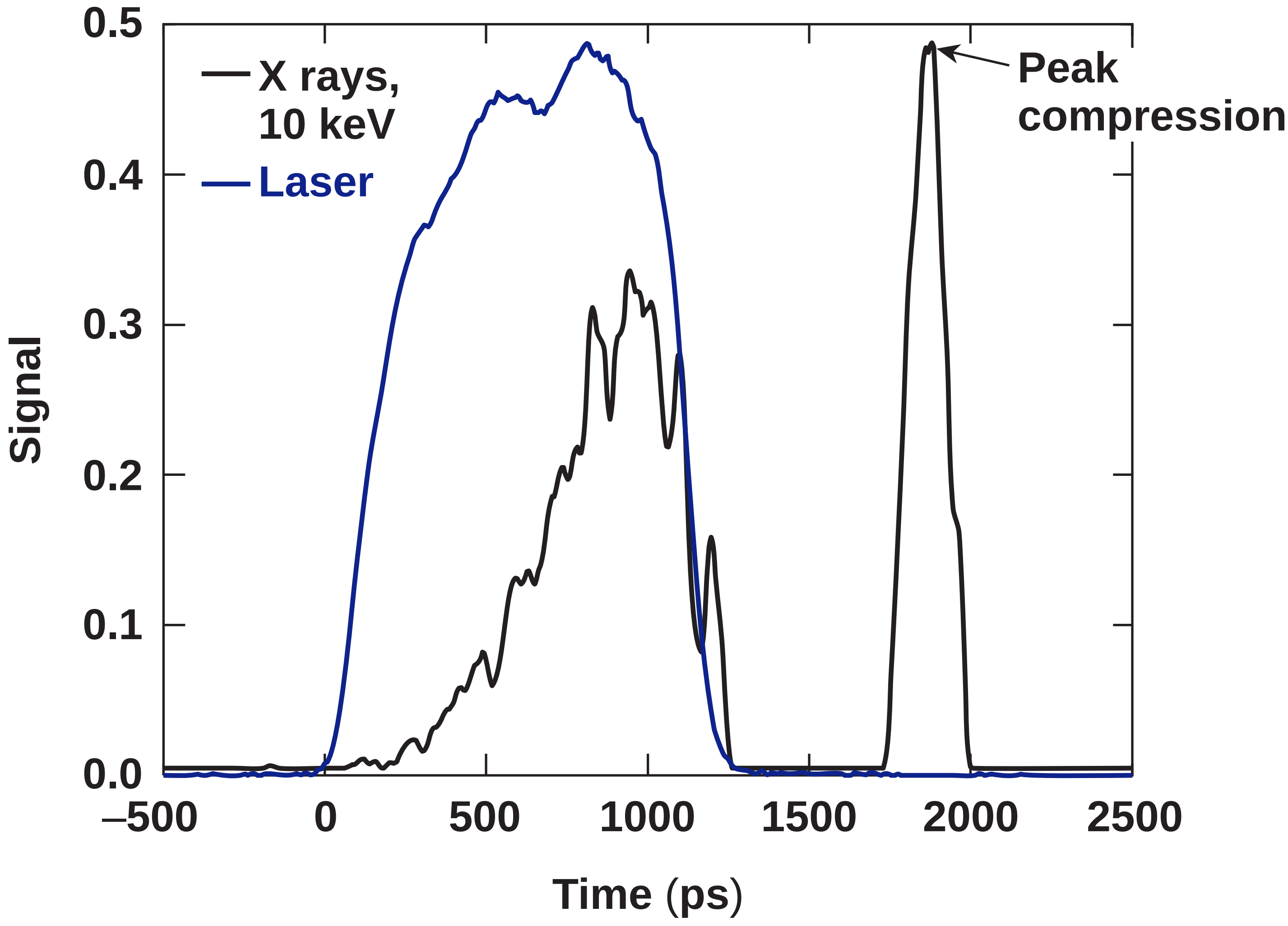
A simple design was used for the HXRDs



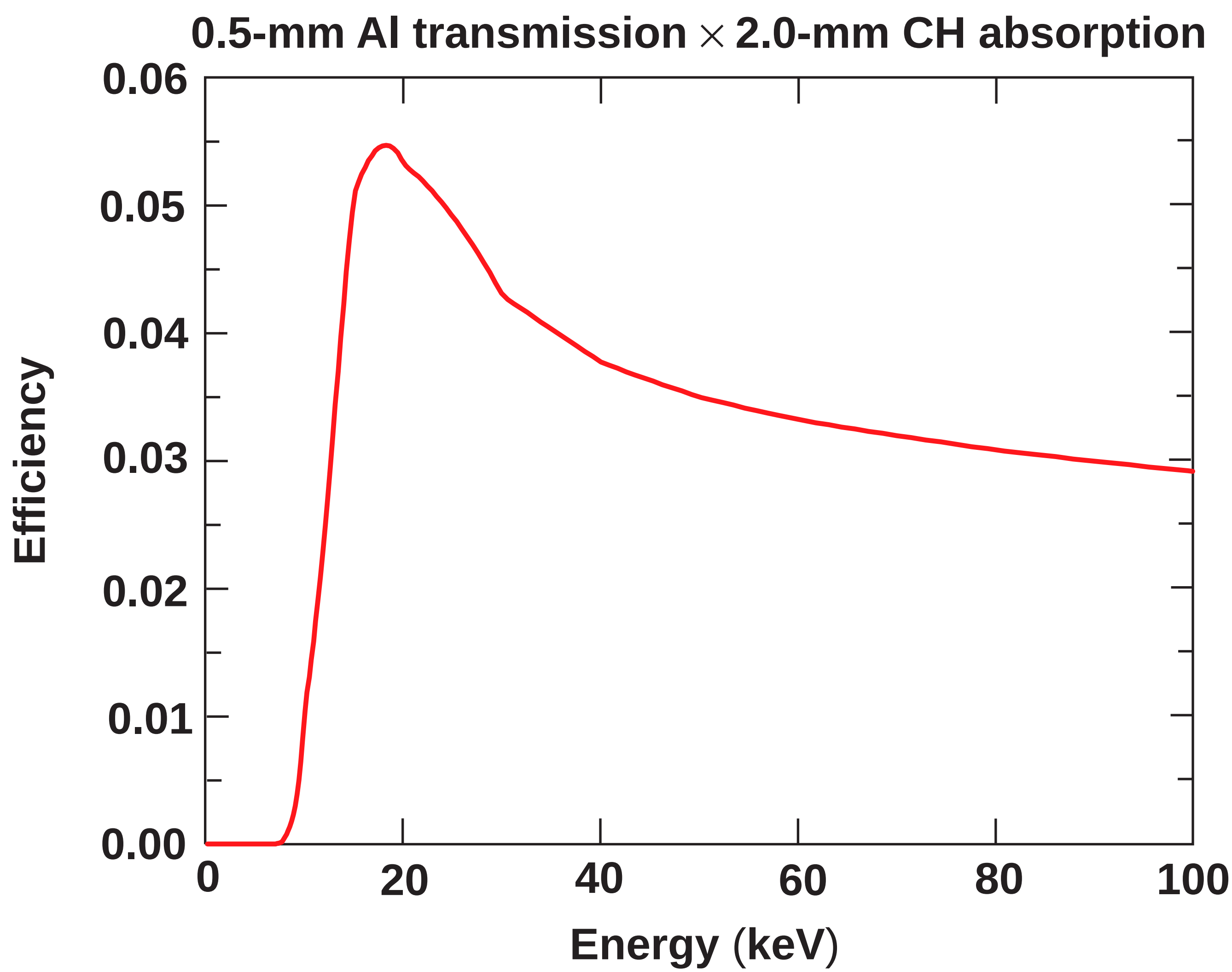
E10038

NTD shows x-ray emission above 10 keV

- 20-μm CH shell, 1-mm diam., 8×10^{14} W/cm^2, 1-ns square

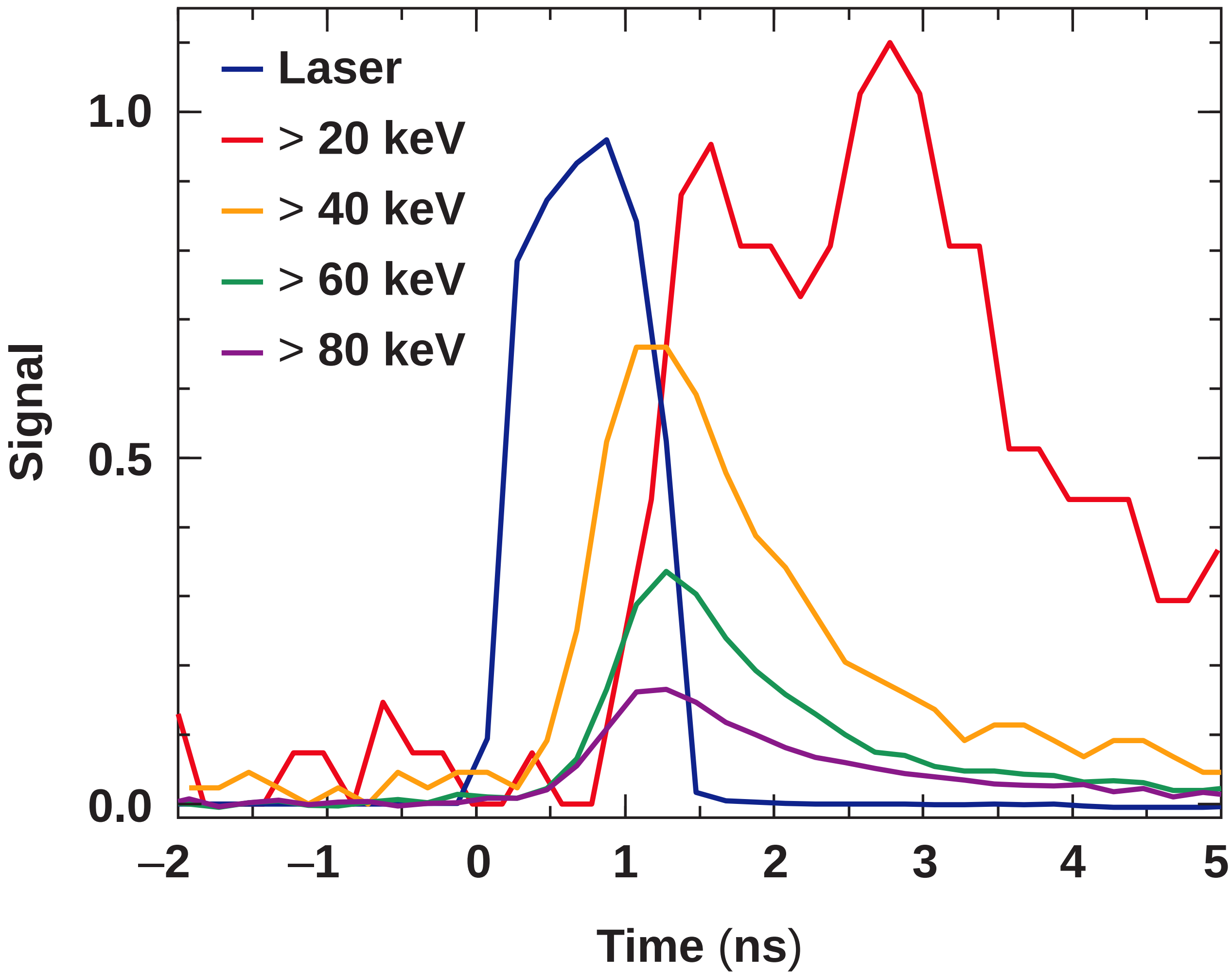


Sensitivity of NTD with Al filter is peaked at 20 keV



HXRDs show x-ray emission between 20 keV and 200 keV

- 20-µm CH shell, 1-mm diam. , 8 × 10^{14} W/cm^2, 1-ns square



E10111

The sensitivity of the HXRDs depends on filtering

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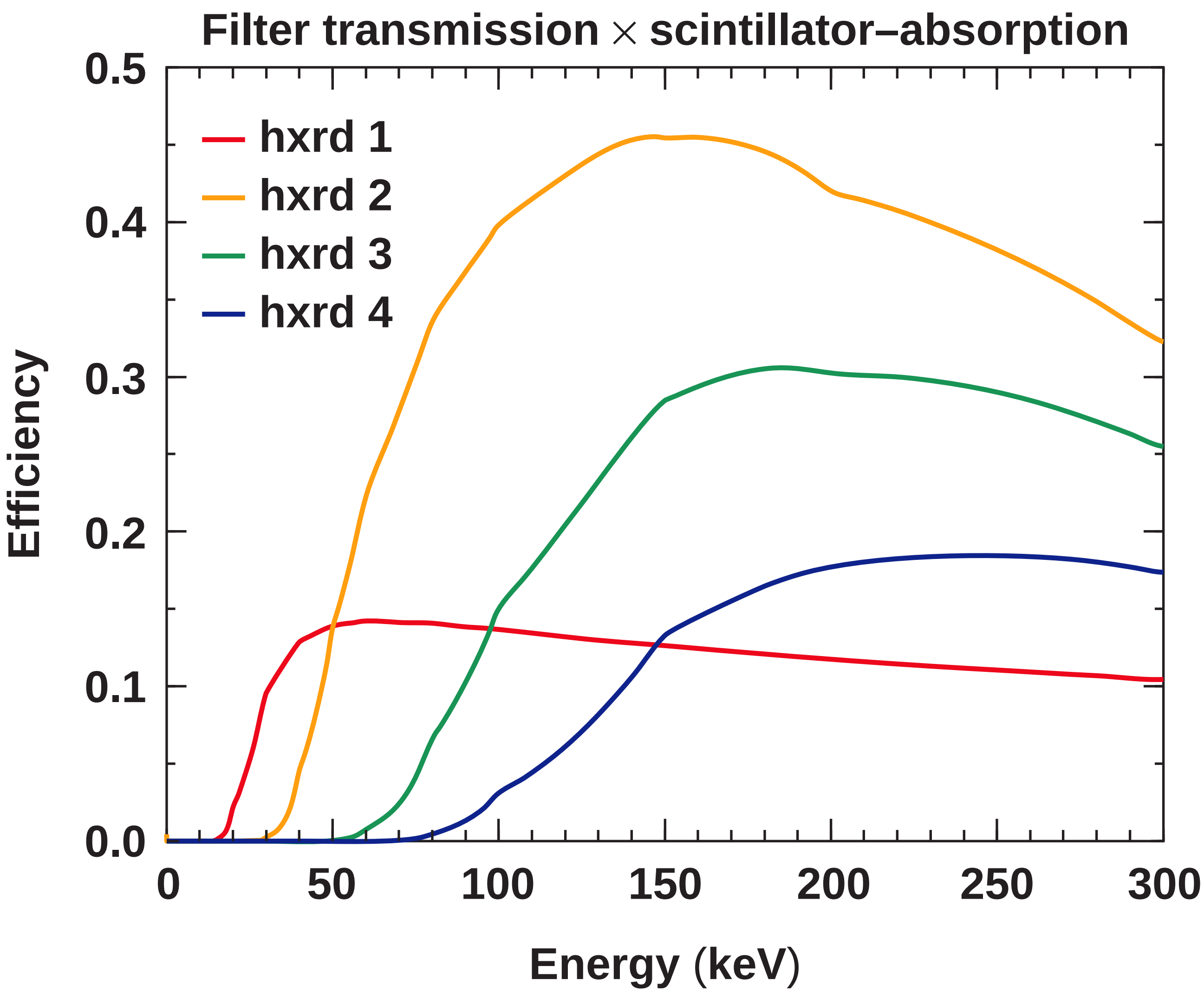
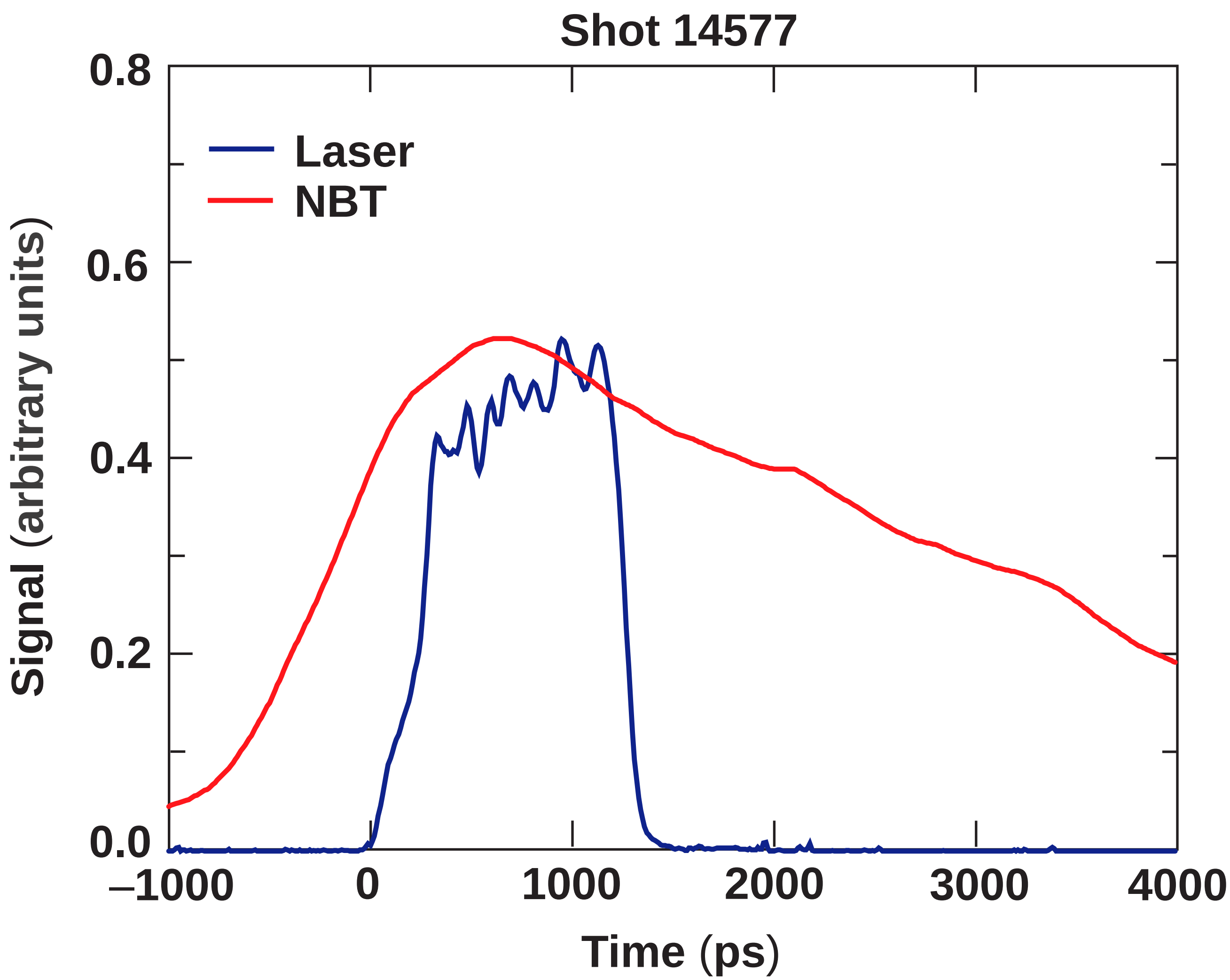


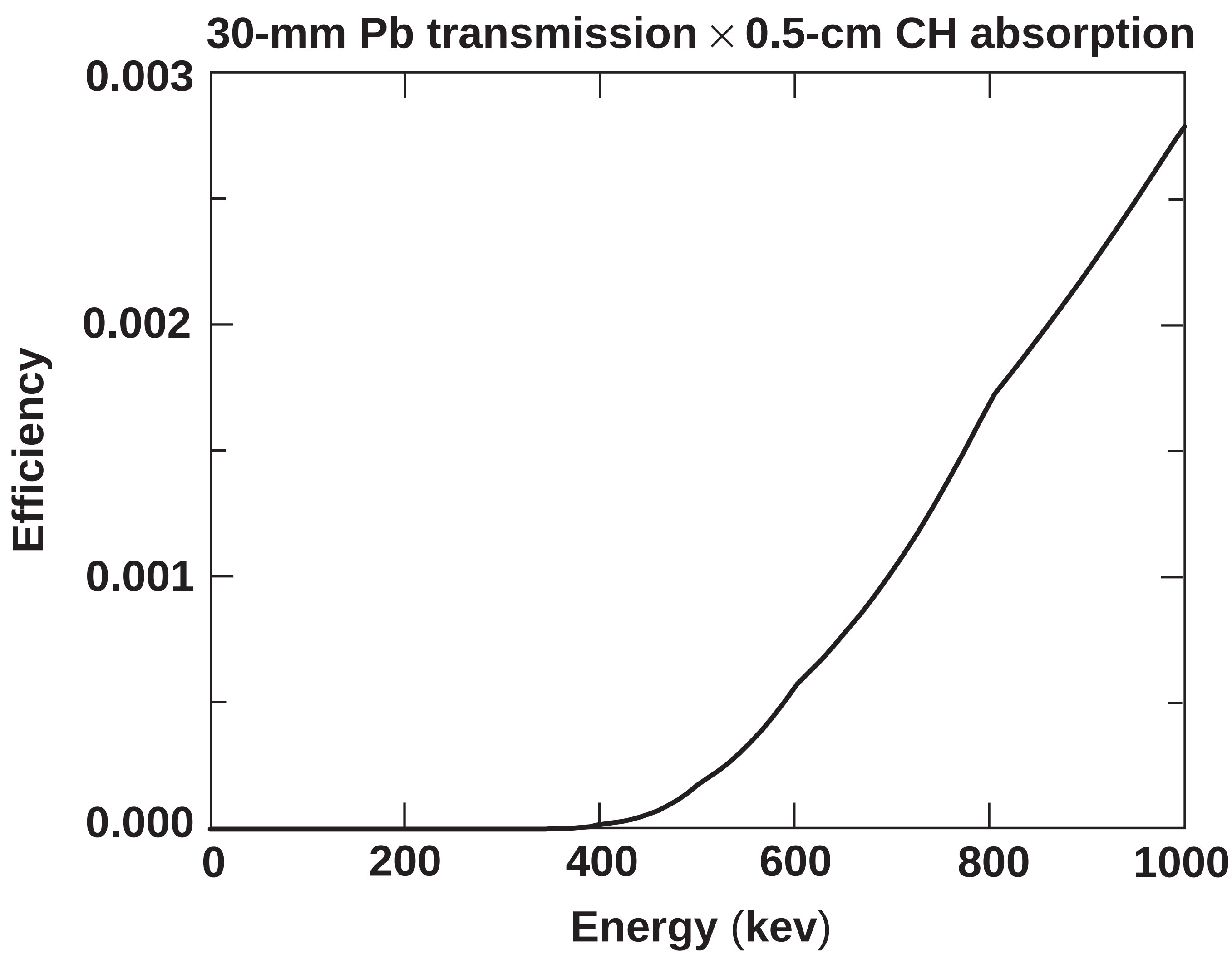
E10108

NBT shows x-ray emission above 500 keV



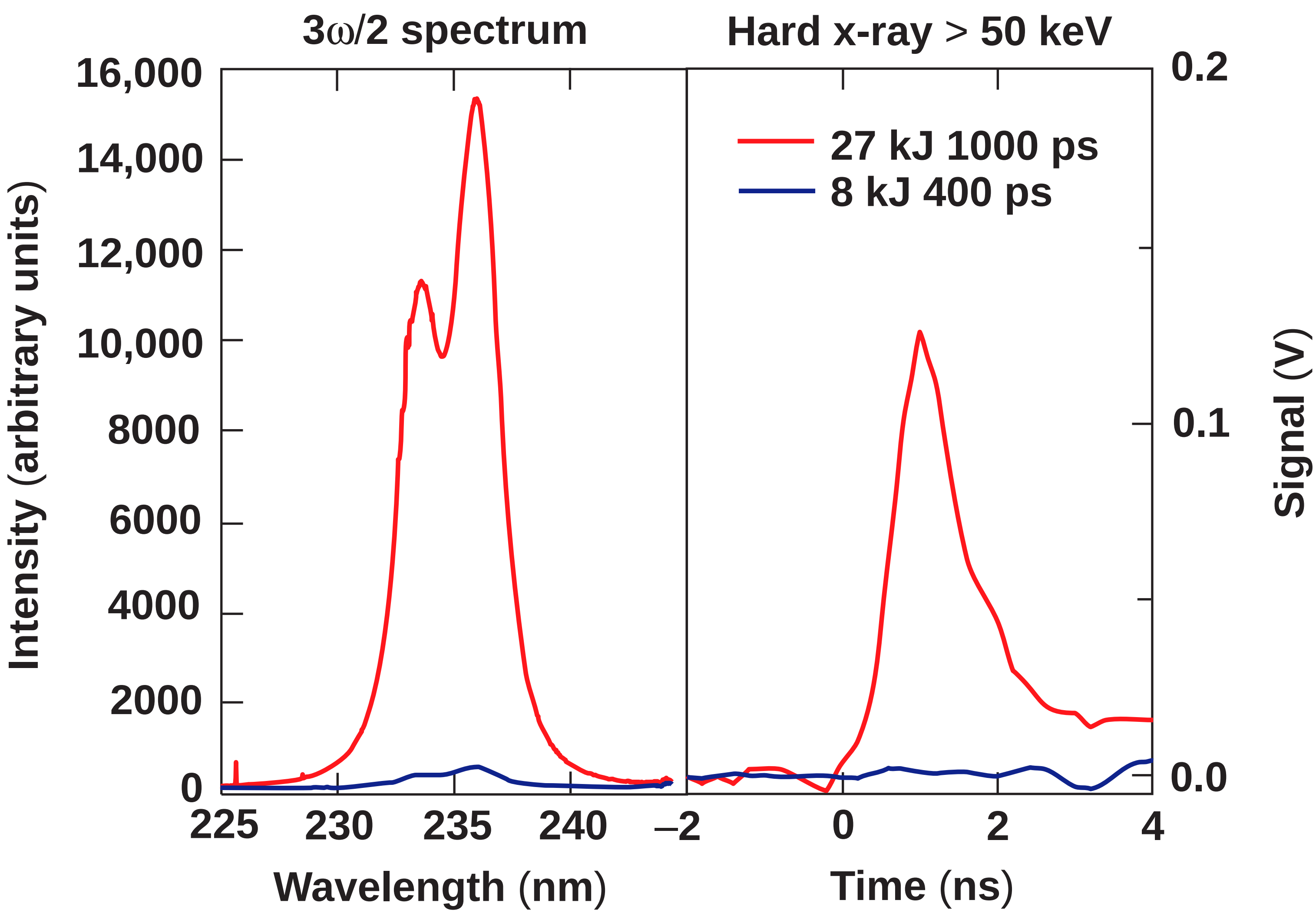
E9765

NBT shows hard x-rays produced by relativistic electrons



E9764

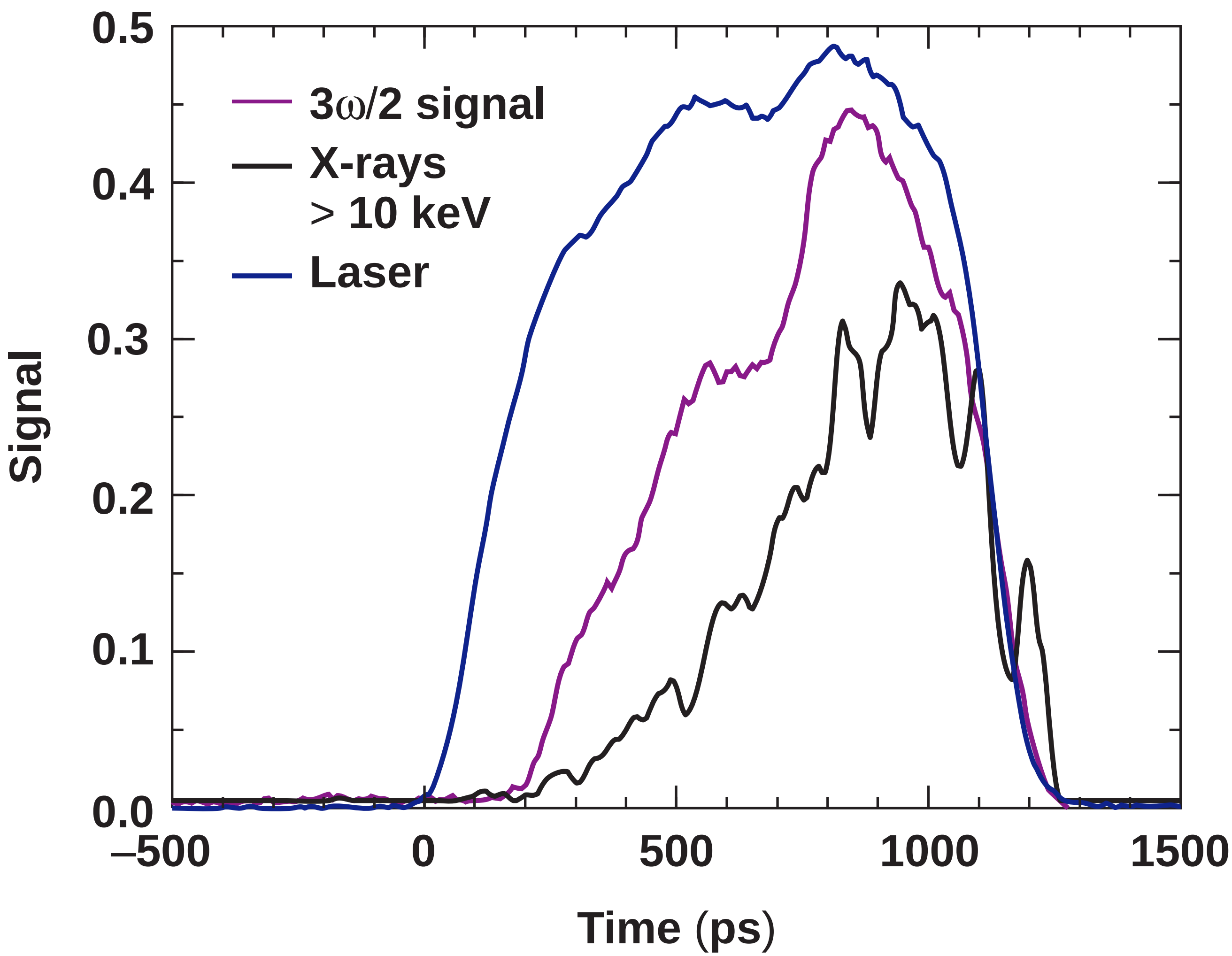
3ω/2 light correlates with hard x-ray energy



E9767

3ω/2 light correlates with hard x rays for square pulse

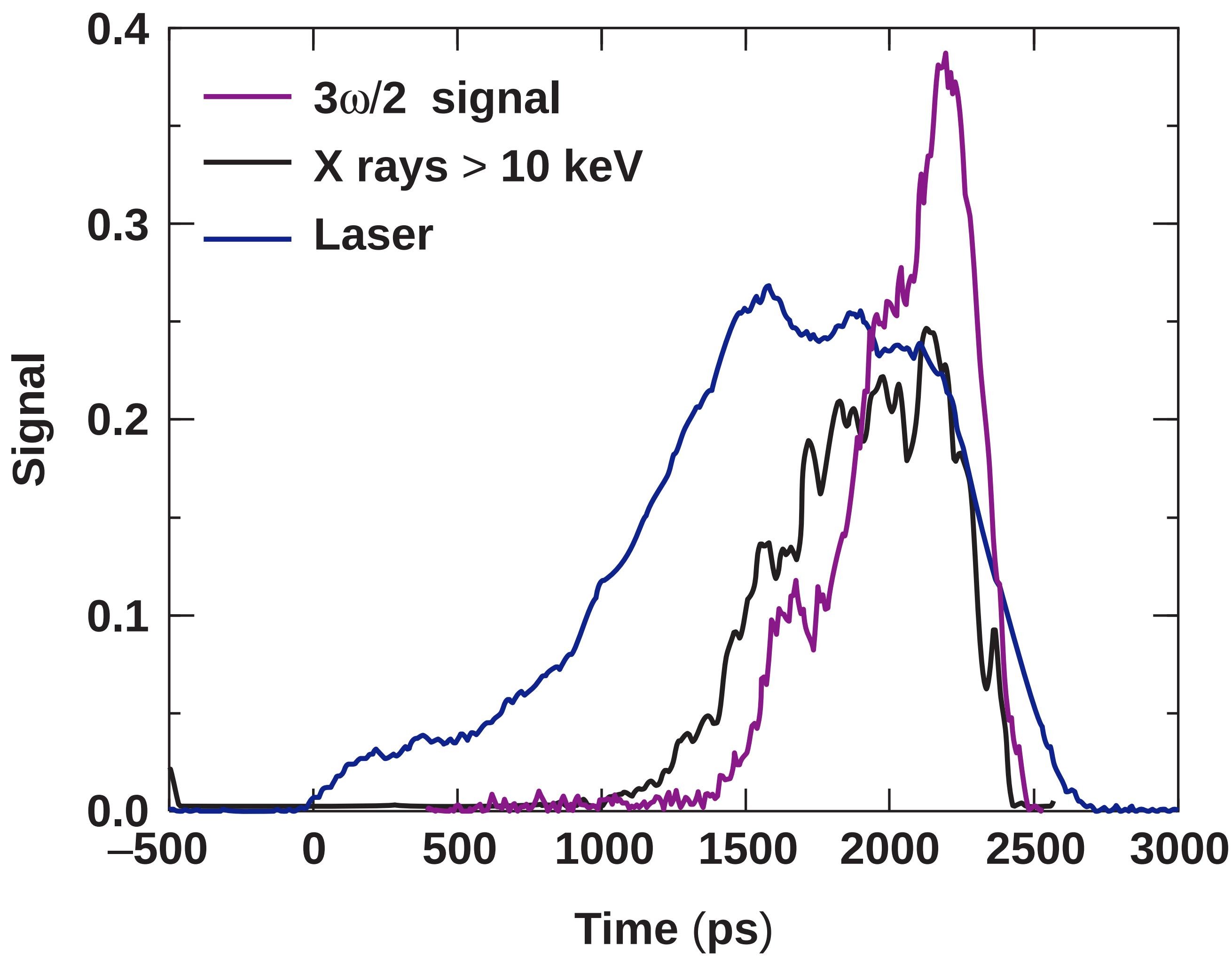
- 20-μm CH shell, 1-mm diam. , 8 × 10^{14} W/cm^2, 1-ns square



E10109

3ω/2 light correlates with hard x rays for shaped pulse

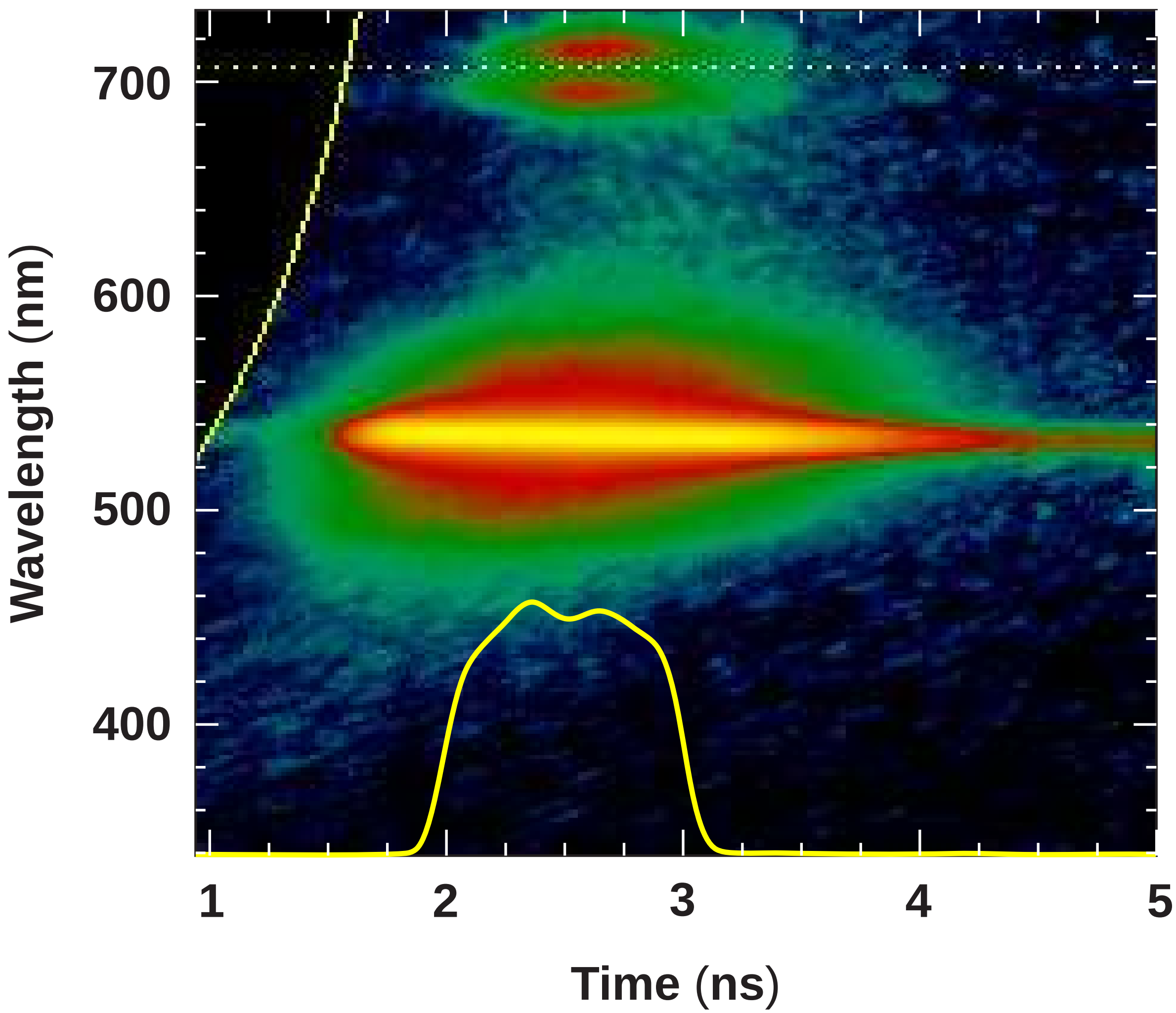
- 20-μm CH shell, 1-mm diam. , 5×10^{14} W/cm^2, 2.4-ns shaped



E10110

SRS spectrum shows no detectable Raman instability

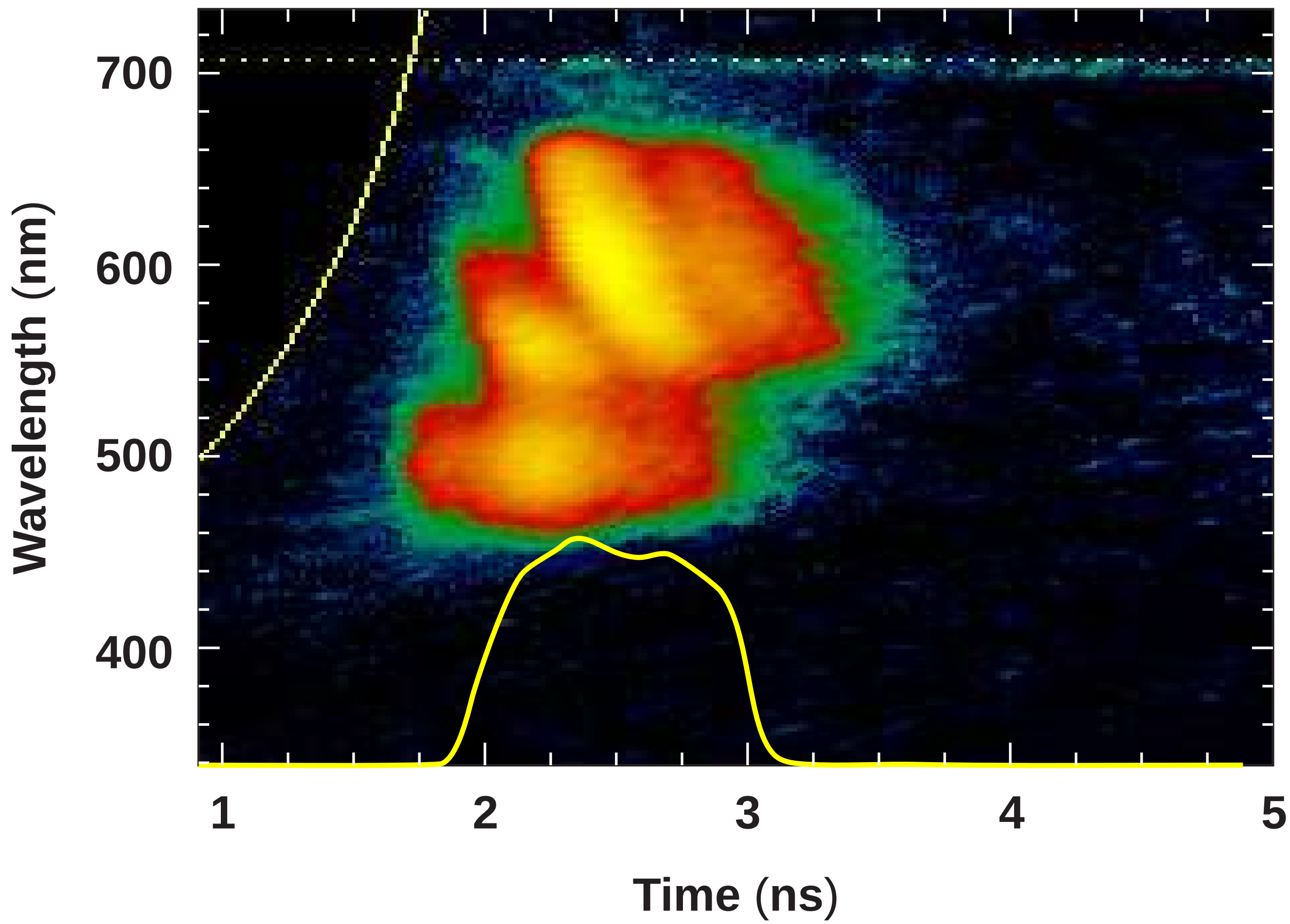
SRS spectrum for shot 17722



E10118

Experiment in planar geometry shows evidence of SRS

SRS spectrum for shot 17318



E10119

Estimating the hard x-ray energy radiated from the target

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- The number of photons emitted by the scintillator is obtained using the published sensitivity of the MCP-PMT in S (C/J):

$$N_{phot} = \text{charge}(C)/(S \times h\nu)$$

- The hard x-ray energy incident on the scintillator is calculated using the yield of the scintillator Y (phot/keV x ray):

$$E_{reg} = N_{phot}/Y$$

- Under the assumption that the x-ray spectrum is of the exponential form $E(\nu) = E_0 \exp(-h\nu/kT)$, the registered x-ray energy can be estimated by folding the spectrum with the filter transmission $F(\nu)$:

$$E_{reg} = E_0 \int_0^{\infty} \left[\exp(-h\nu/kT) F(\nu) d\nu\right]$$

- Combining the above expressions with the solid angle of the detector yields an estimate of radiated energy from the target.

Summary/Conclusions

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