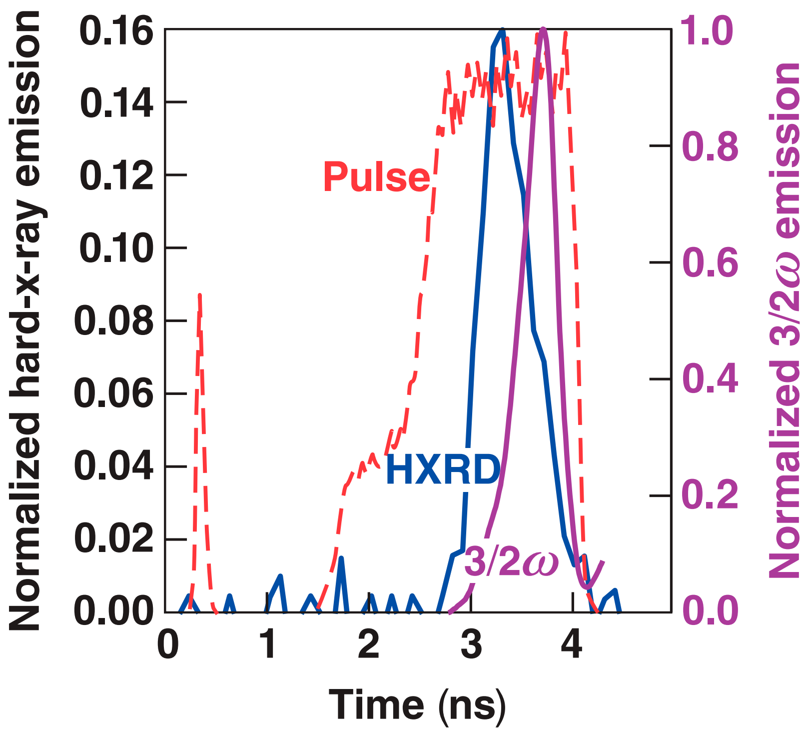
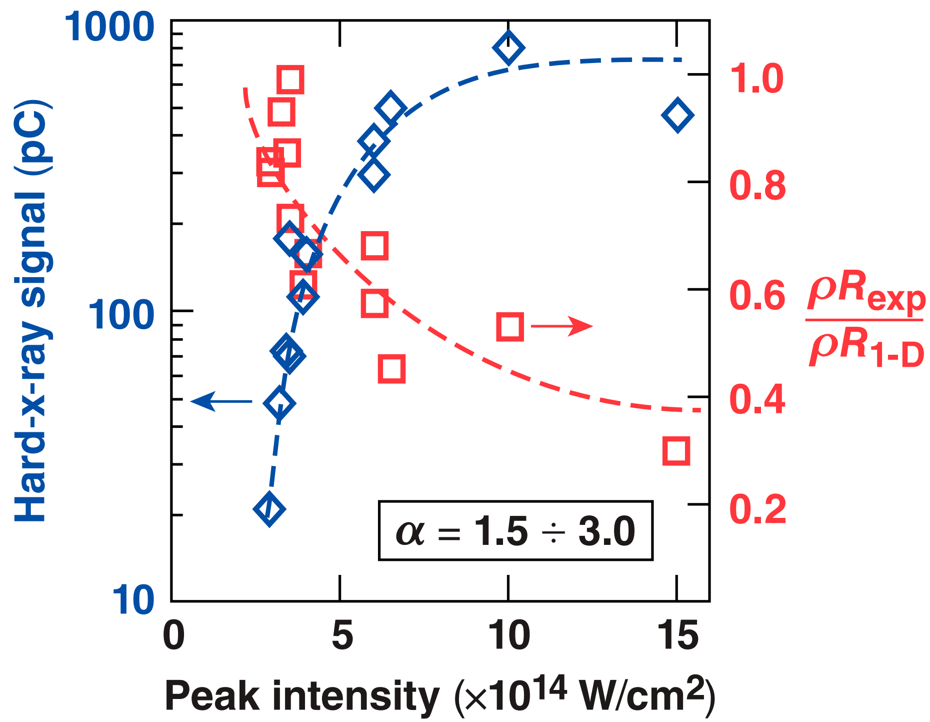
The Role of Fast-Electron Preheating in Low-Adiabat Cryogenic Implosions on OMEGA

Typical measured hard-x-ray and 3/2ω emission



Hard x-ray and ρR degradation



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Summary

High areal densities (140 to 200 mg/cm^2) close to 1-D predictions were obtained when the TPD instability was mitigated in cryogenic implosions

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- Severe areal-density degradation in high-laser-intensity cryogenic implosions are likely due to fast electrons from the two-plasmon-decay (TPD) instability
- TPD fast-electron preheating can be mitigated with
  - low laser intensities for thin CD ablator shells OR
  - a thicker CD ablator shell at mid-laser intensities
- High compression in low-adiabat cryogenic implosions is adequately modeled by 1-D models when fast-electron preheating is mitigated
- Current preheat estimations are within a factor of about 2 of the required preheating level, mainly due to physical uncertainties in the fast-electron production and transport models
  - further calibration and new methods are needed

Understanding compression of cryogenic D_2 and DT targets is important for both DDI and IDI.

Collaborators

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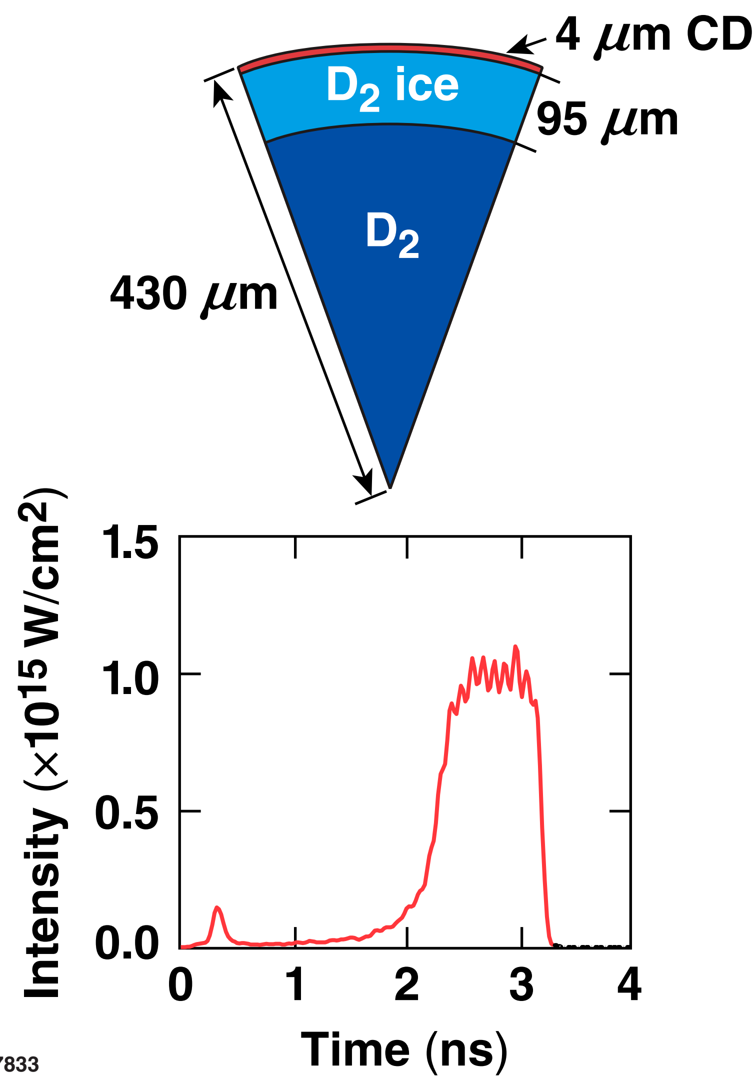
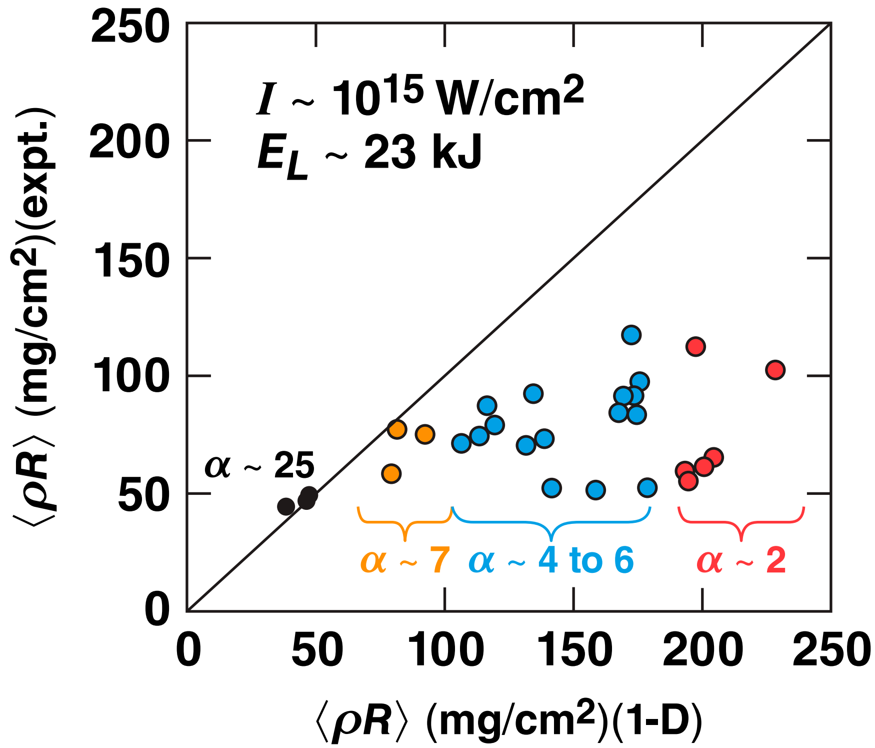
A severe degradation of ρR, up to 40% of 1-D predictions, was observed in high-intensity mid- and low-adiabat cryogenic implosions on OMEGA





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Several possible causes of the areal-density degradation can be shown to be unlikely

- Hydrostability of the imploded ice shell
  - mid-α, high-I, and low-α mid-I implosions are predicted to be highly stable
- Shock mistiming due to absorption discrepancies, mainly in picket
  - degradation happens in all pulse shapes and pickets (type and strength) including no picket cases
- Radiation preheating
  - D_2 is almost transparent to thermal x rays $\rightarrow \Delta T \lesssim$ few eV
- Nonlocal thermal electron preheating
  - $T_c = 2 \div 3$ keV $\rightarrow \lambda(6 \times kT_c) \sim 10\ \mu m \ll d(D_2) \sim 80\ \mu m$ (at solid density)
- Fast electrons from resonance absorption
  - $T_h = 2 \div 5$ keV $\rightarrow \lambda(6 \times kT_h) \sim 25\ \mu m \ll d(D_2) \sim 80\ \mu m$

Preheating by ultrafast electrons from TPD observed in cryogenic and CH implosions is the main candidate for cryo ρR degradation

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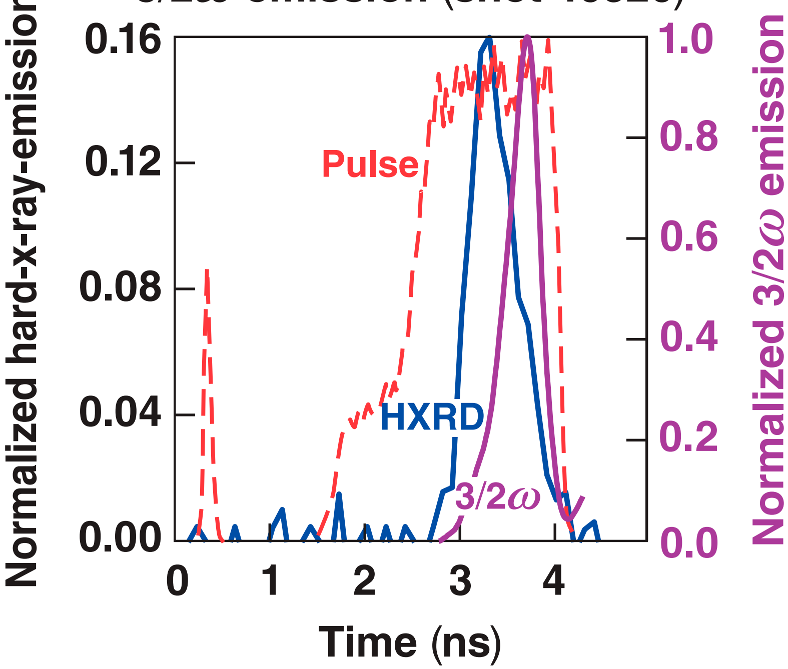
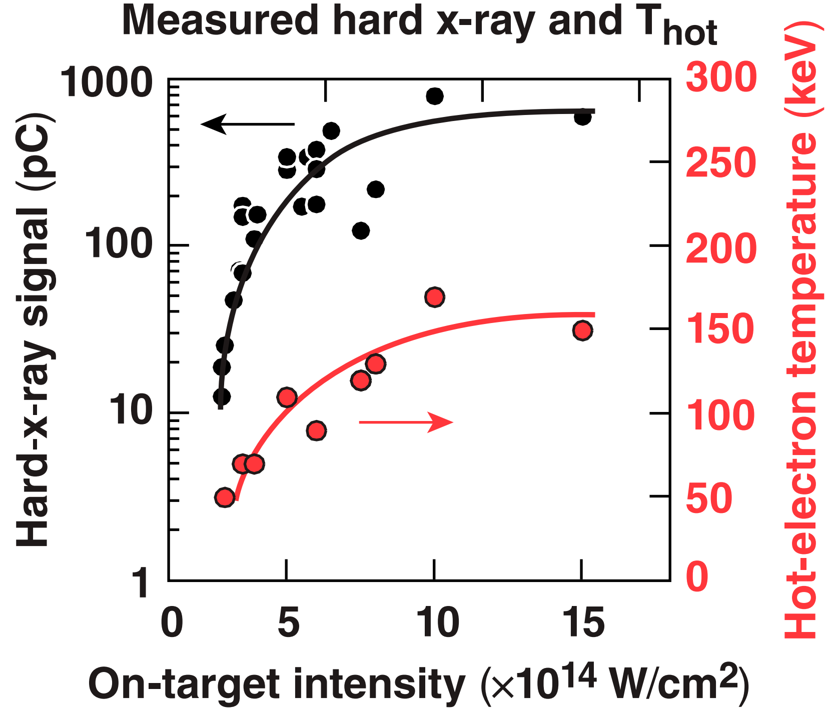
Typical measured hard-x-ray and 3/2ω emission (shot 46520)



Measured hard x-ray and T_{hot}



- $I_{\text{th},\,2\omega_p} \sim 2 \times 10^{16} \times T_c\,(\text{keV})/L\,(\mu\text{m}) \sim 2 \times 10^{14}\,\text{W/cm}^2 \;\; (L \sim 100\;\mu\text{m}, T_c \sim 2\,\text{keV})$
- $T_{hot} > 50$ keV $\rightarrow$ $\lambda e > d(D_2)$
- E_{ph}/E_L* ~ (0.3 to 3.0) × 10^{-3} $\rightarrow$ E_{ph} ~ 5 to 50 J

*B. Yaakobi *et al.*, Phys. Plasmas 12 062703 (2005).
C. Stoeckl *et al.* Phys. Rev. Lett. 90 235002 (2003).

TC7835

Preheat levels of an order of 50 to 100 J are needed to severely degrade areal density at low-adiabat cryo implosions

- $\rho R \propto \alpha^{-0.6} \rightarrow$ for $\rho R_{ph}/\rho R_{1\text{-}D} \sim 1/2$ one needs:

  $\alpha_{ph}/\alpha_0 \sim 3.5$
  $\rho_{ph}/\rho_0 \sim 0.5$
  $T_{ph}/T_0 \sim 2.0$

- For a typical $\alpha_0 = 3$ shot on OMEGA:

  $T_0 \sim 25$ eV, $\rho_0 \sim 7$ g/cm^3, $\rho R_{1\text{-}D} \sim 200$ mg/cm^2

  $\rightarrow$ for $\rho R_{ph} \sim 100$ mg/cm^2, one gets:

  $\alpha_{ph} \sim 10$, $\rho_{ph} \sim 3.5$ g/cm^3
  $T_{ph} \sim 50$ eV $\rightarrow \Delta T_{ph} \sim 25$ eV

For $\Delta T_{ph} = 25$ eV and 20 μg of D_2 (cold and dense ice layer) one needs 70 J as preheating, which is 0.3% of laser energy.

This estimation compares well with 1-D simulations that include full fast-electron transport

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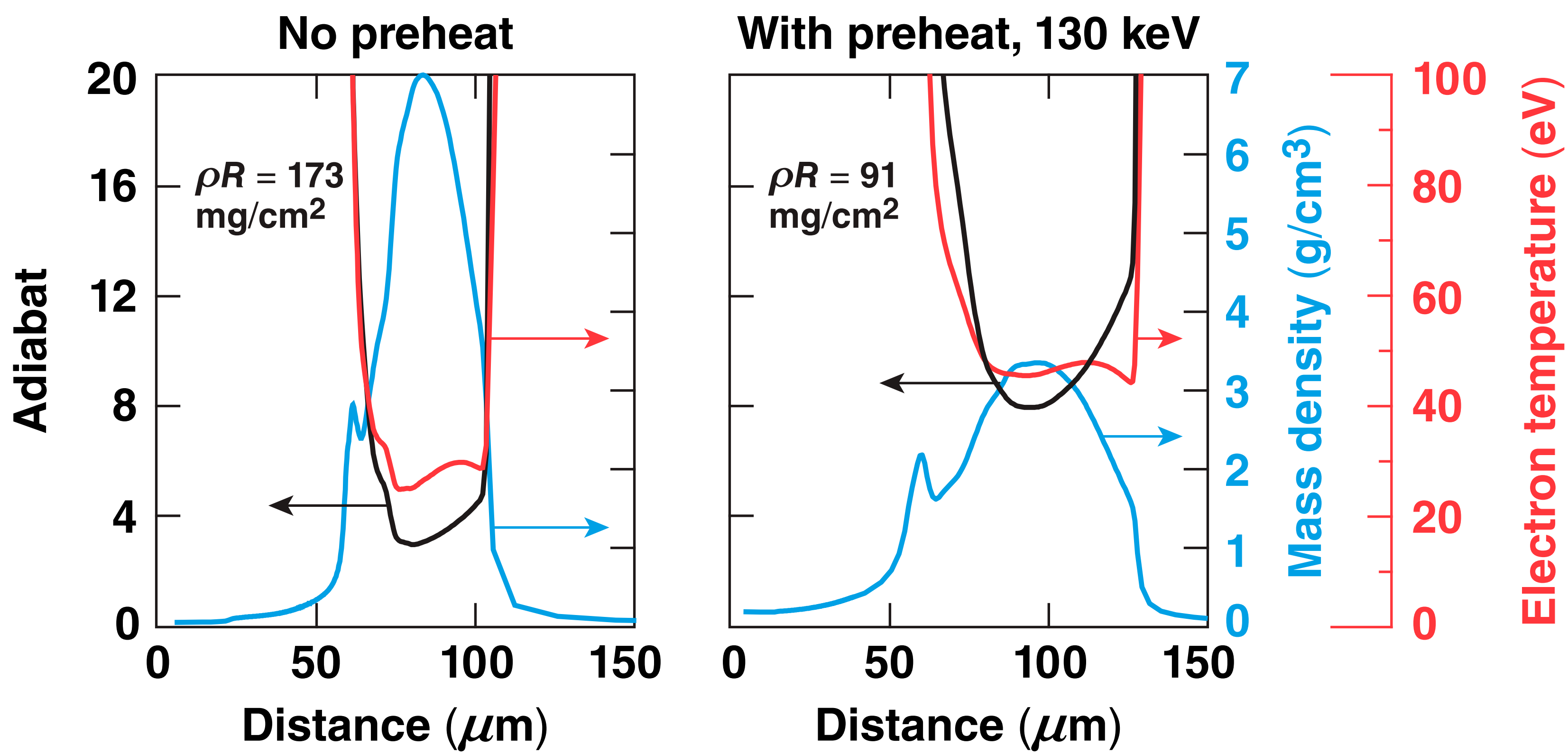
Shot 43950: $I = 1 \times 10^{15}$ W/cm^2, $\alpha = 3$ shaped pulse

HXRD2 = 800 pC, T_h = 170 keV, ρR_{exp} = 92 mg/cm^2



α_{ph} ~ 8	ΔT_{ph} ~ 20 eV
ρ_{ph} ~ 3.5 g/cm^2	ΔE_{ph} ~ 62 J

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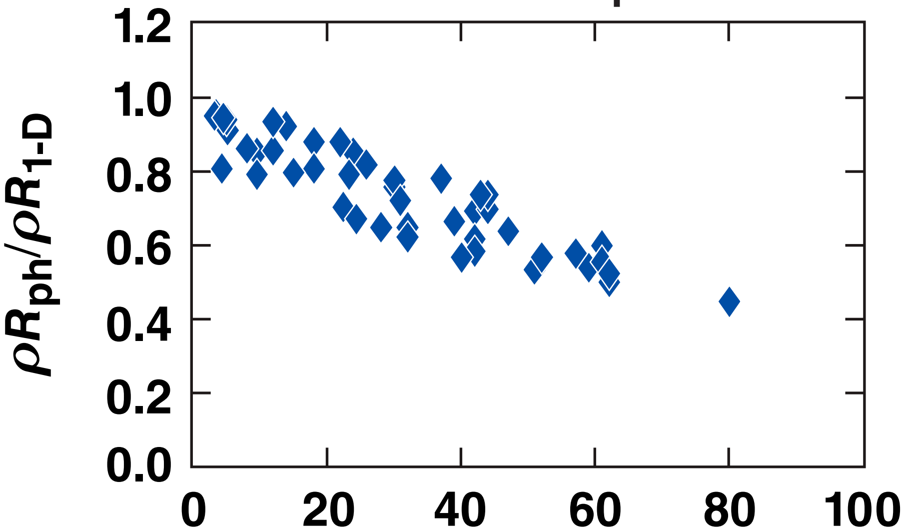
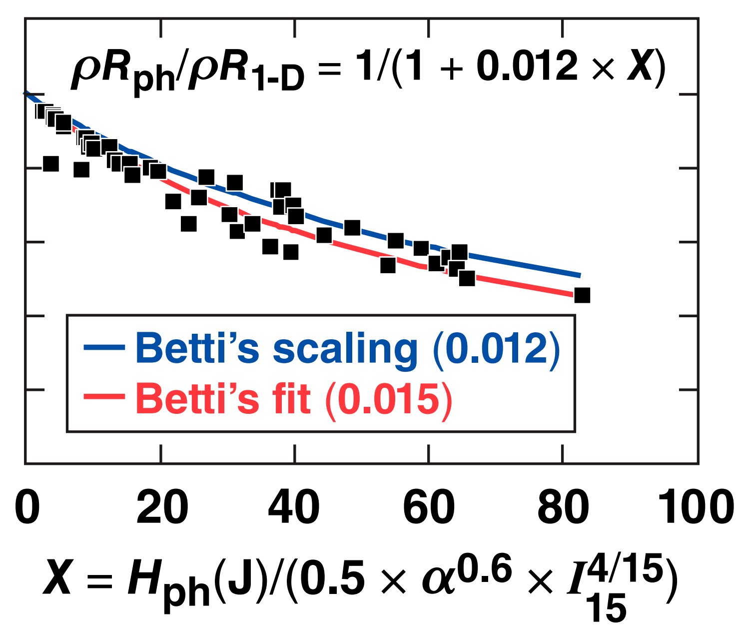
Simulations with full fast-electron transport do agree with a simple theoretical prediction for ρR degradation

LILAC simulation of ρR degradation for various targets, laser intensities and fast electron fractions and temperatures



Betti's scaling for ρR degradation



Scaling parameter: $H_{ph}/(\alpha^{0.6} \times I^{4/15})$

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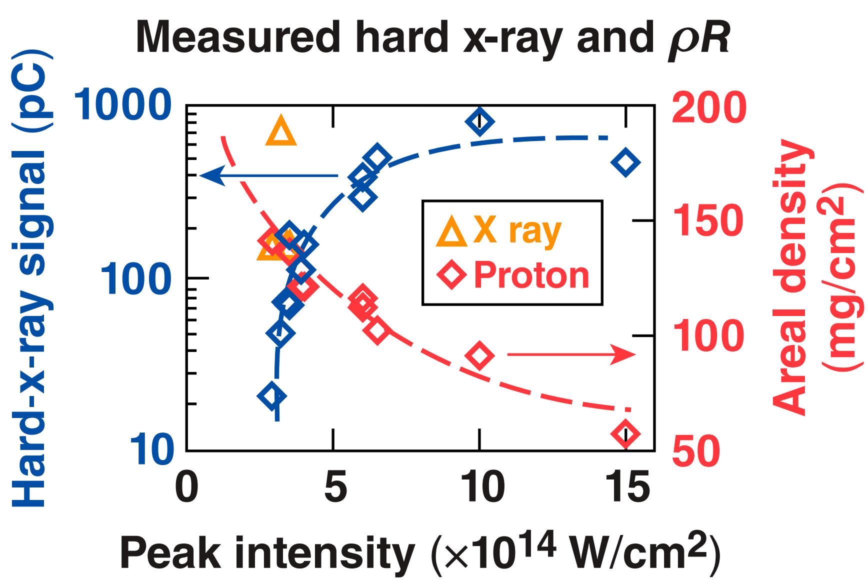
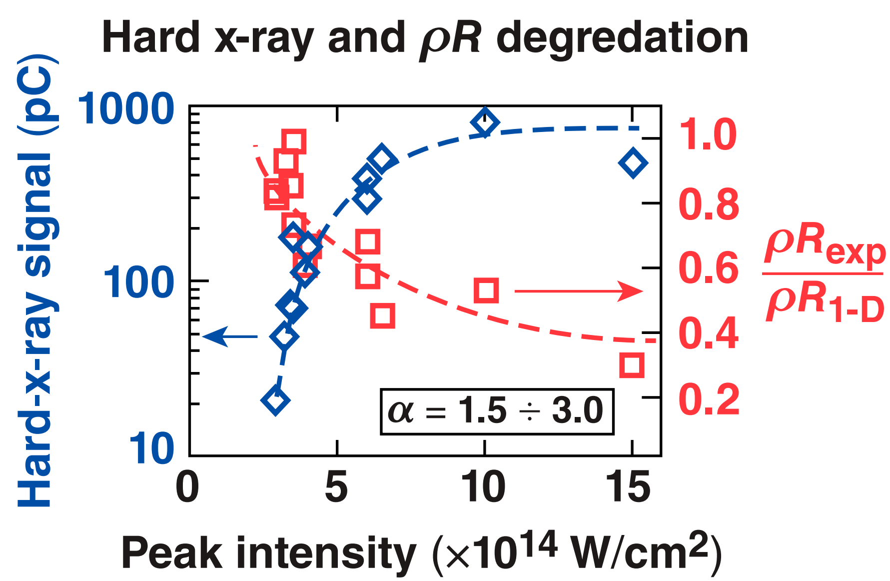
The degradation of measured ρR is highly correlated with increased hard-x-ray signal and laser intensity

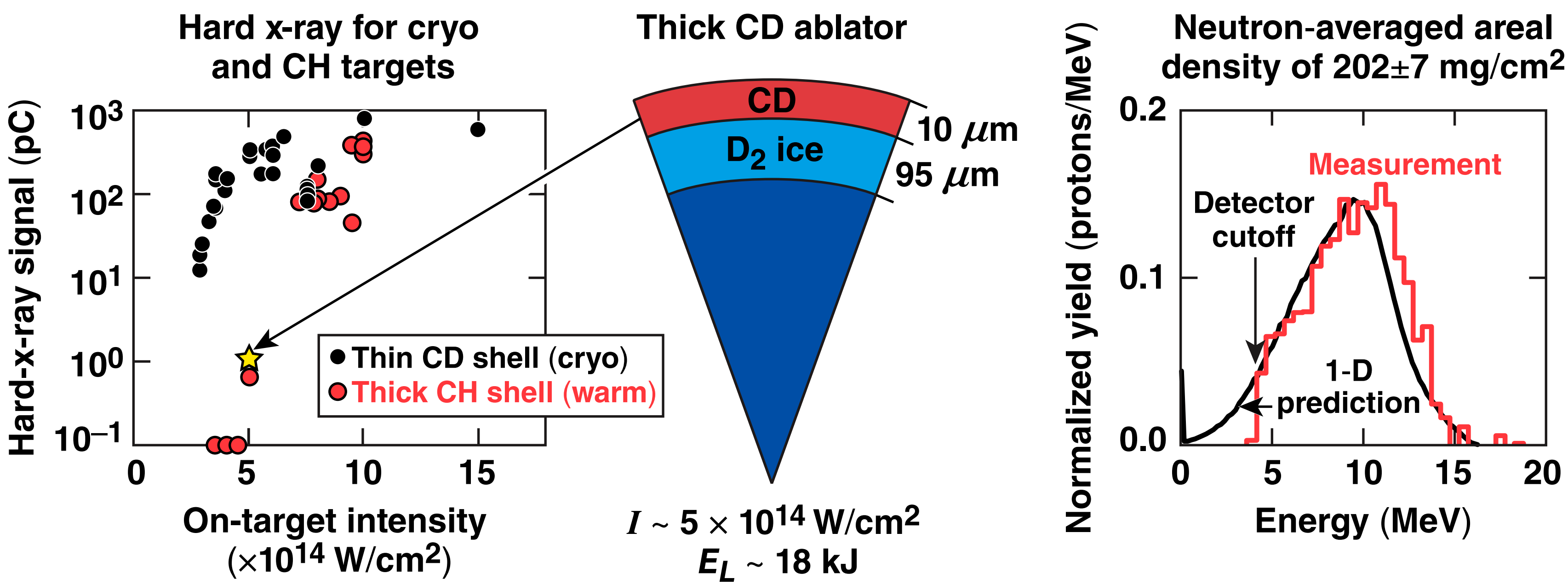
Cryogenic low-α D_2 targets with thin ($\leq$5 μm) CD ablator





The highest ρR(=140 to 160) and close to 1-D prediction was obtained using low laser intensity $I \lesssim 3 \times 10^{14}$ W/cm^2 (E_L = 13 kJ), where the HXR signal was very low.

The higher TPD threshold intensity for plastic ablators allows the laser intensity and energy to be increased when using a thicker CD ablator



A thicker CD ablator allows the use of higher intensities (5×10^{14} W/cm^2) and energy (18 kJ) resulting in record high ρR = 200 mg/cm^2.

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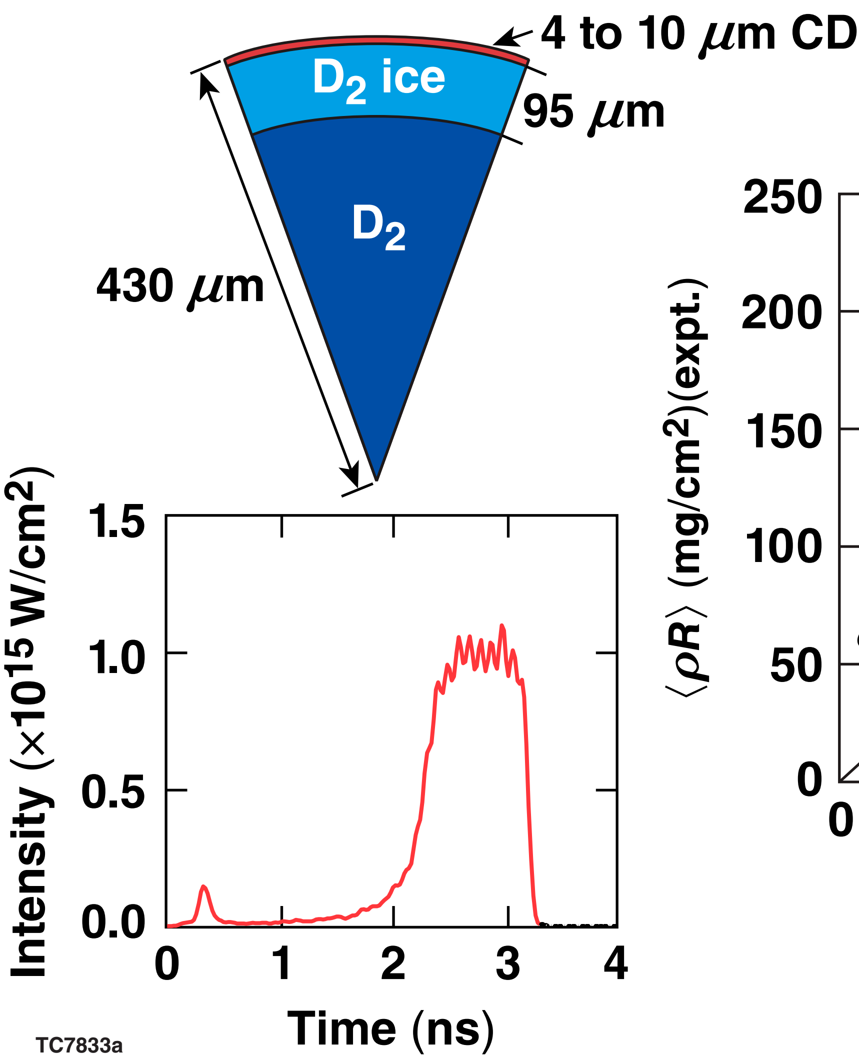
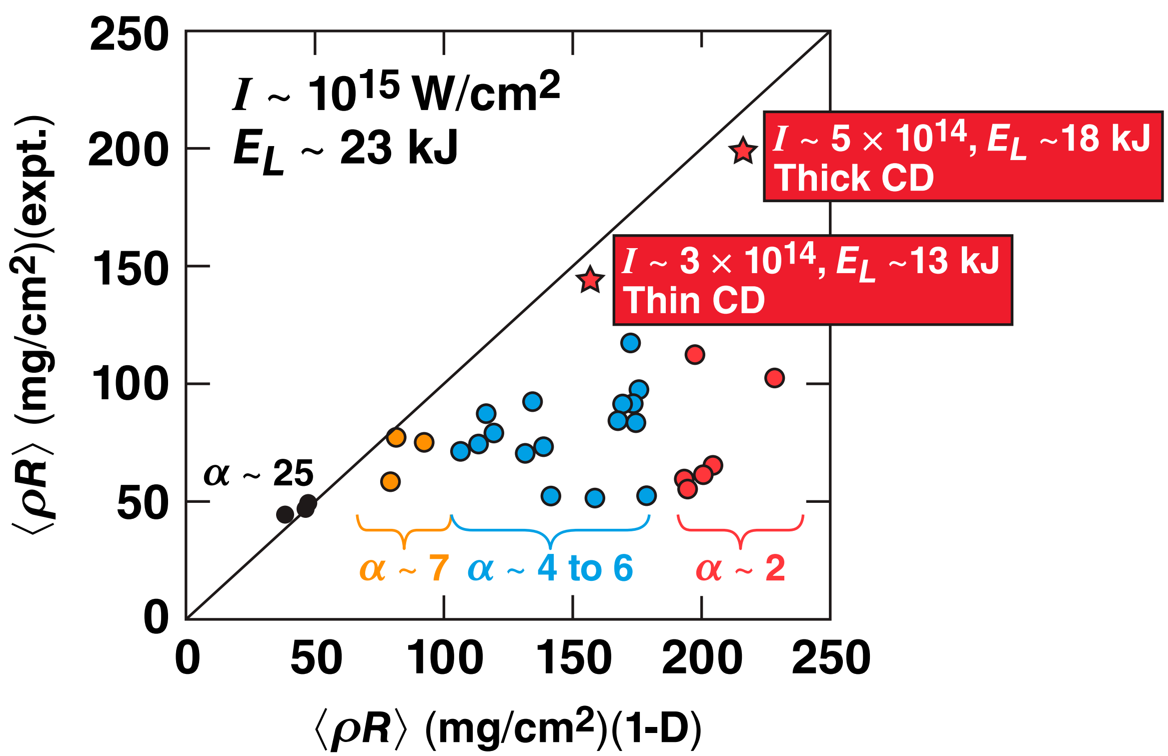
High areal densities (140 to 200 mg/cm^2) close to 1-D predictions were obtained in low-adiabat cryogenic implosions when the TDP instability was mitigated





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The preheat energy required to fit the measured ρR is highly correlated with the measured HXR signal

- The required "calibration" of HXRD (>50 keV):

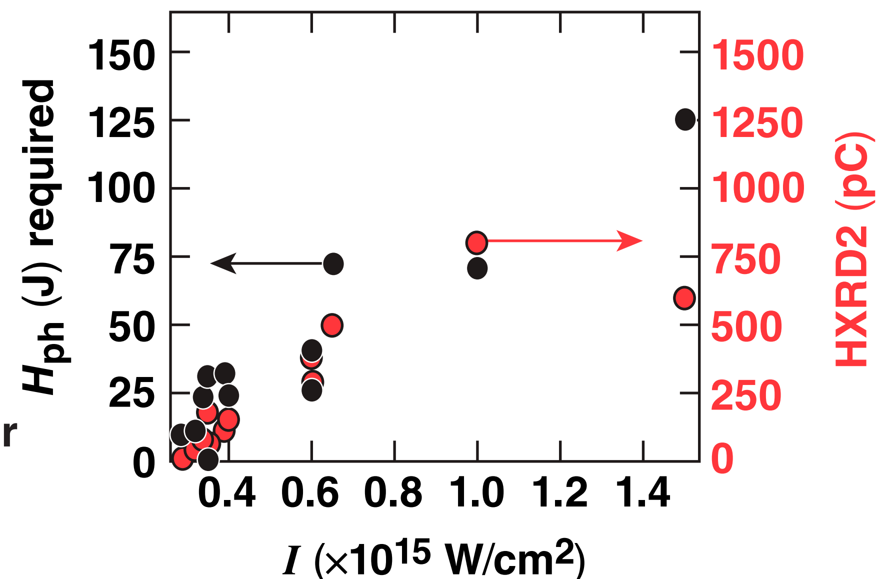
  H_{ph} (in dense D_2)/HXRD (from whole target)
  ~0.4 (J/pC) at low-I
  ~0.1 (J/pC) at high-I

- Yaakobi's "calibration" for pure D_2 (using K_α and HXR (>50 keV) measurements in a Mo/CH target with T_{hot} = 65 keV):

  H_{ph}/HXRD (>50 keV)
  ~ 0.75 J/pC × [65/T_{hot} (keV)]

- *BUT*, that calibration does not account for
  - HXR produced at the CD ablator
  - fast-electron energy deposited at the ablated (CD and D_2) parts of the target

H_{ph}(J) required (Betti's formula) and measured hard x-ray



- For that, one needs to assume/use a fast-electron transport model

TC7840

The correspondence between hard-x-ray (>50 keV) and preheat energy deposited in the dense shell is model-dependent, but can be estimated in the limit of $\rho\lambda_e \gg \rho R$

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The "calibration" of the HXR signal to preheat dense D_2 shell depends on the prediction of the assumed transport model for the partition of fast-electron-energy deposition and hard-x-ray production in the dense D_2, ablated D_2, and ablated CD regions

In the limit of $\rho\lambda_e \gg \rho\Delta R$:

$$\begin{pmatrix} \rho\lambda_e \text{ (100 keV)} \sim 20 \text{ mg/cm}^2 \\ \rho\Delta R\ (t \sim T_L) \sim 5 \text{ mg/cm}^2 \end{pmatrix}$$

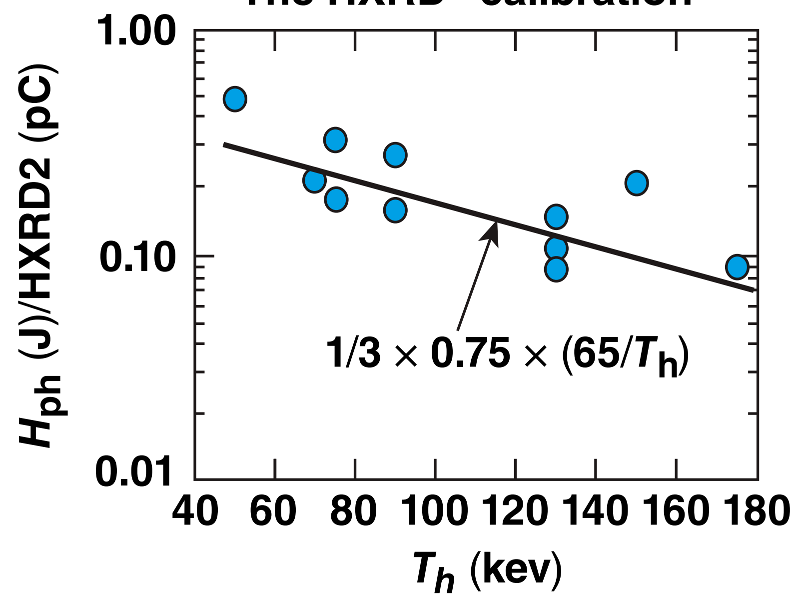
E_{dep} (dense D_2):E_{dep}(ablated D_2): E_{dep} (ablated CD) ~ 0.5:0.25:0.25 (mass ratio)

HXR(D_2)/HXR(CD) ~ 0.5:0.5 ($Z \times$ mass ratio)

$\Downarrow$

H_{ph} (dense D_2)/HXR (total > 50 keV) ~ 1/3 × 0.75 (J/pC) × [65/T_{hot}(keV)]

The HXRD "calibration"



*An error bar of an order of 2 should be assigned to calibration due to experimental and model errors

TC7832

Summary/Conclusions

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