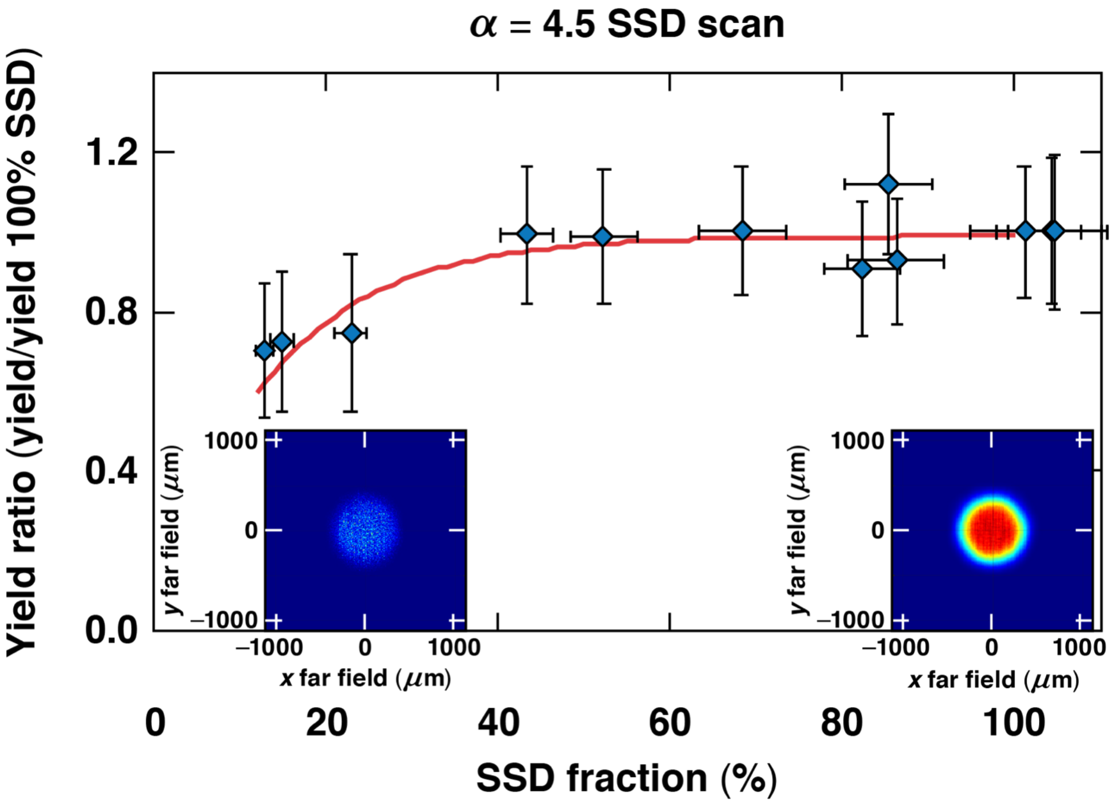
The Effect of Laser Bandwidth on High-Performance Cryogenic Implosions



J. P. Knauer
University of Rochester
Laboratory for Laser Energetics

61st Annual Meeting of the
American Physical Society
Division of Plasma Physics
Fort Lauderdale, FL
21–25 October 2019

Summary

The performance of current high-adiabat (α = 4.5) cryogenic implosions would not improve by increasing smoothing by spectral dispersion (SSD) bandwidth

- **SSD bandwidth was varied to change the Rayleigh–Taylor instability "seed" due to laser imprint**
- **Areal density and yield values versus SSD bandwidth are fitted with a "saturation"-type model**

$$\text{Ratio} = A + B\left[1 - e^{-\alpha_{\text{ratio}}\left(\text{SSD}_{\text{fraction}} - \text{SSD}_0\right)}\right]$$

- **Both *DRACO* 2-D and *ASTER* 3-D simulations of ρR and yield fractions show improving performance as bandwidth increases**
  - ***ASTER* results are a better match to the measured ρR**
  - ***ASTER* simulations that include a 20-μm target offset show agreement with the measured yields**

Collaborators

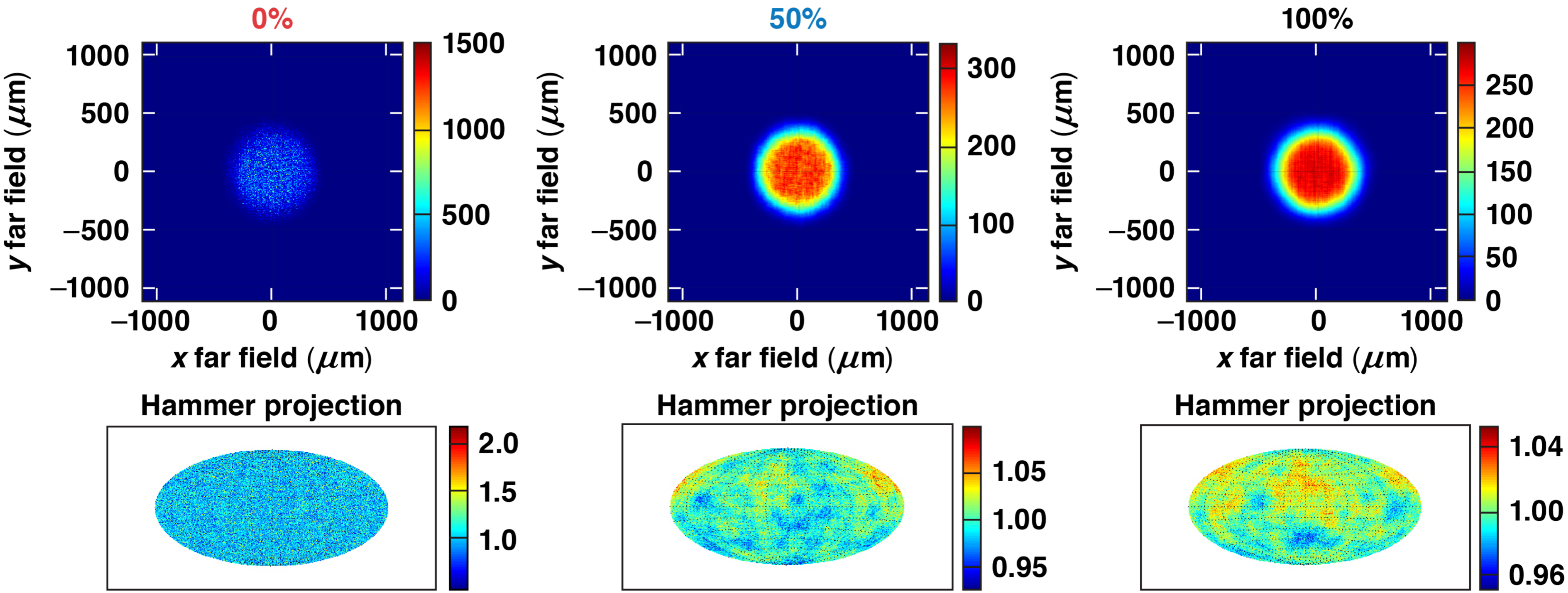
R. Betti, V. Gopalaswamy, D. Cao, I. V. Igumenshchev, A. Shvydky, D. Patel, A. Lees, M. J. Bonino, E. M. Campbell, T. J. B. Collins, C. J. Forrest, V. Yu. Glebov, V. N. Goncharov, D. R. Harding, J. A. Marozas, F. J. Marshall, P. W. McKenty, P. B. Radha, S. P. Regan, T. C. Sangster, and C. Stoeckl

University of Rochester
Laboratory for Laser Energetics

M. Gatu Johnson, J. A. Frenje, and R. D. Petrasso

Massachusetts Institute of Technology
Plasma Science and Fusion Center

Single-beam and overlapped far-field intensity versus bandwidth was calculated for SG5-850 phase plates and a target diameter of 900 μm

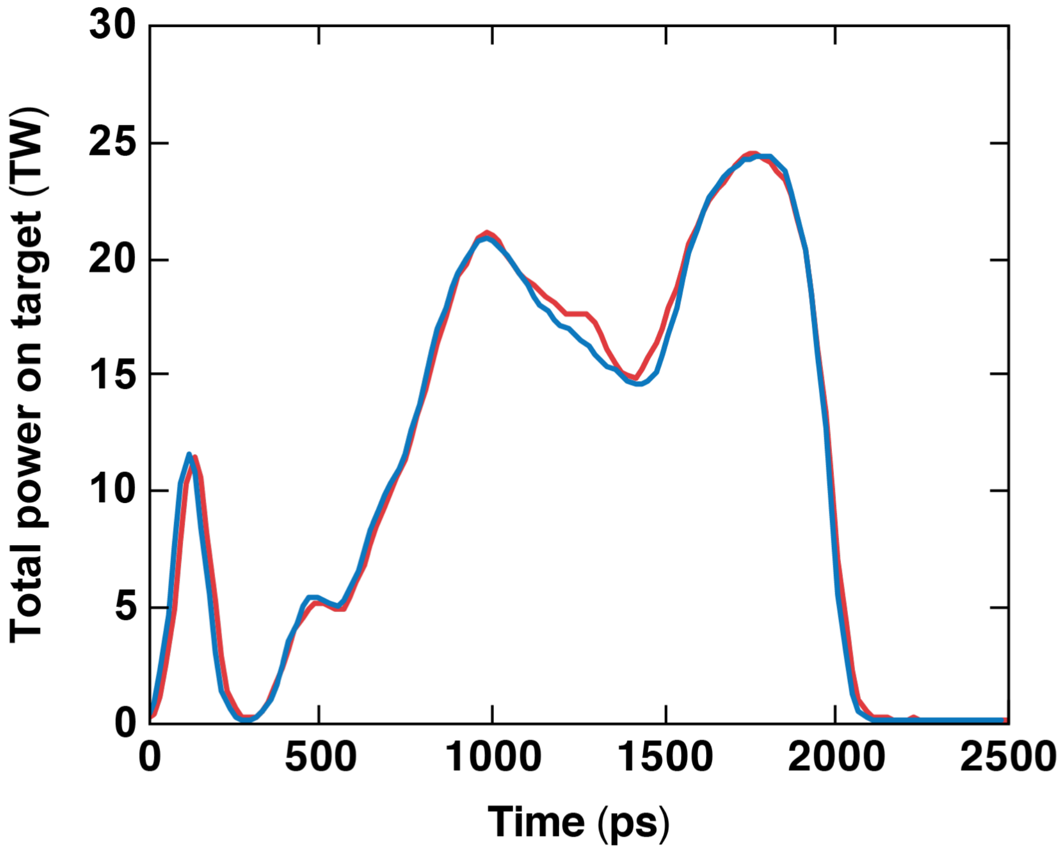


E28532a

SSD modeling done by A. Shvydky
Single-beam far fields are calculated by convolving the DPP far field with the SSD kernel
A "hard sphere" model is used to calculate the overlap intensity

DPP: distributed phase plate

The laser pulse shape and target from the best-performing implosion were used for the SSD scan



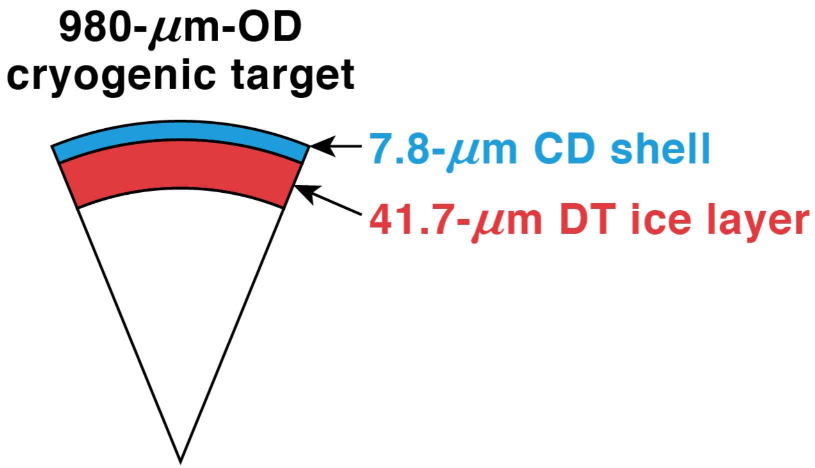
E28533a

— Red line for maximum bandwidth (100% SSD fraction) reference implosion

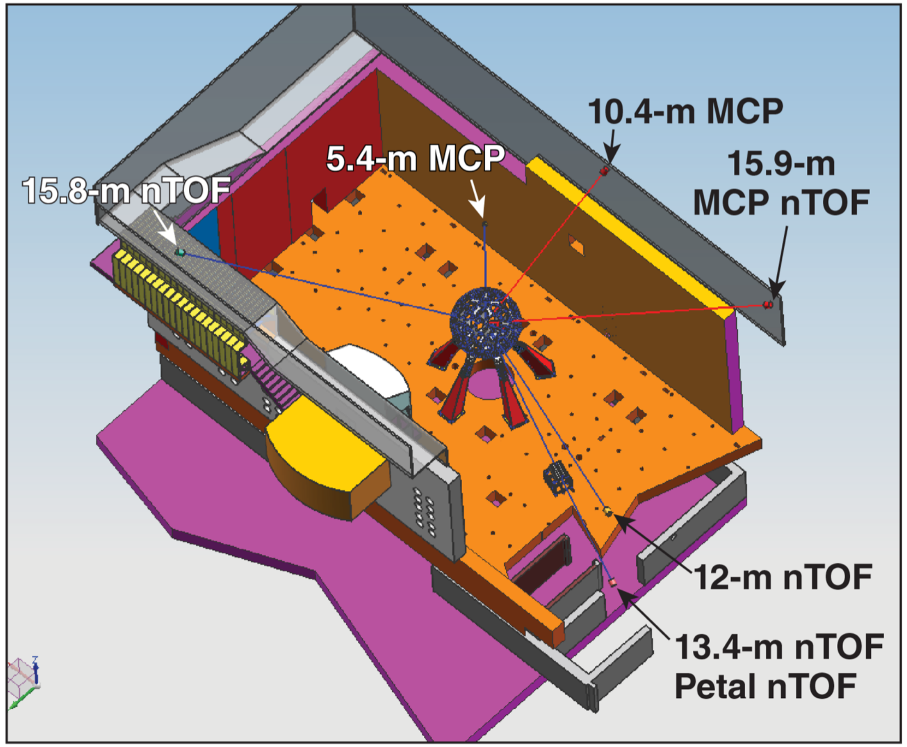
100% SSD = 0.345 THz = 1.42 Å (UV)

— Average of all SSD scan implosions

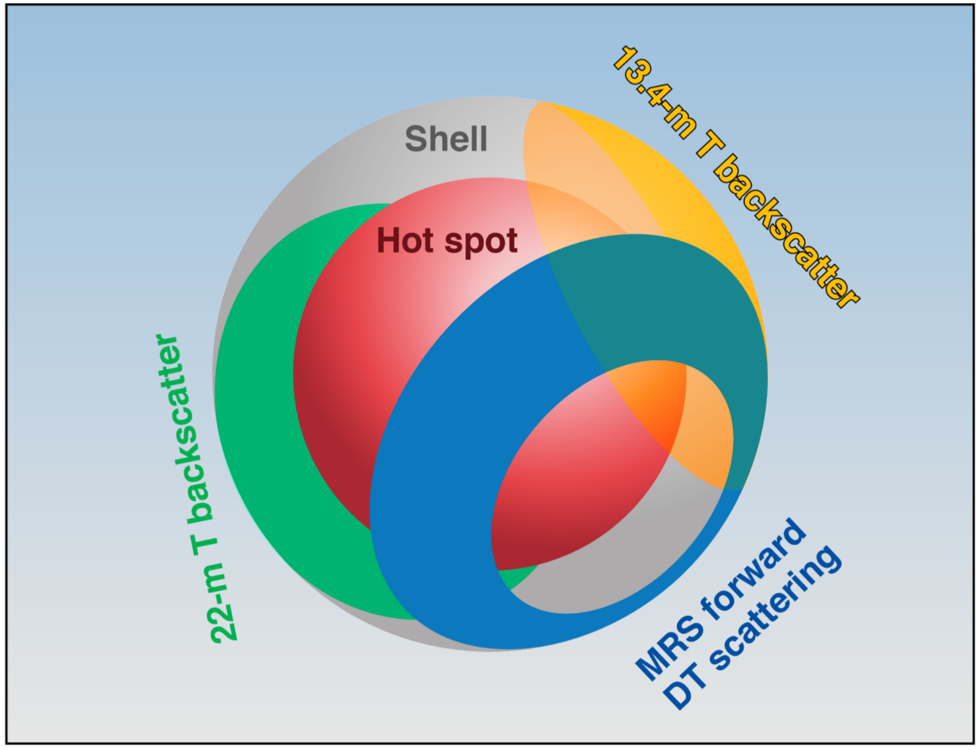
Adiabat (α) = 4.5



Yield and areal density are measured along multiple lines of sight



TC12945b



E28448a

Six lines of sight for yield measurements

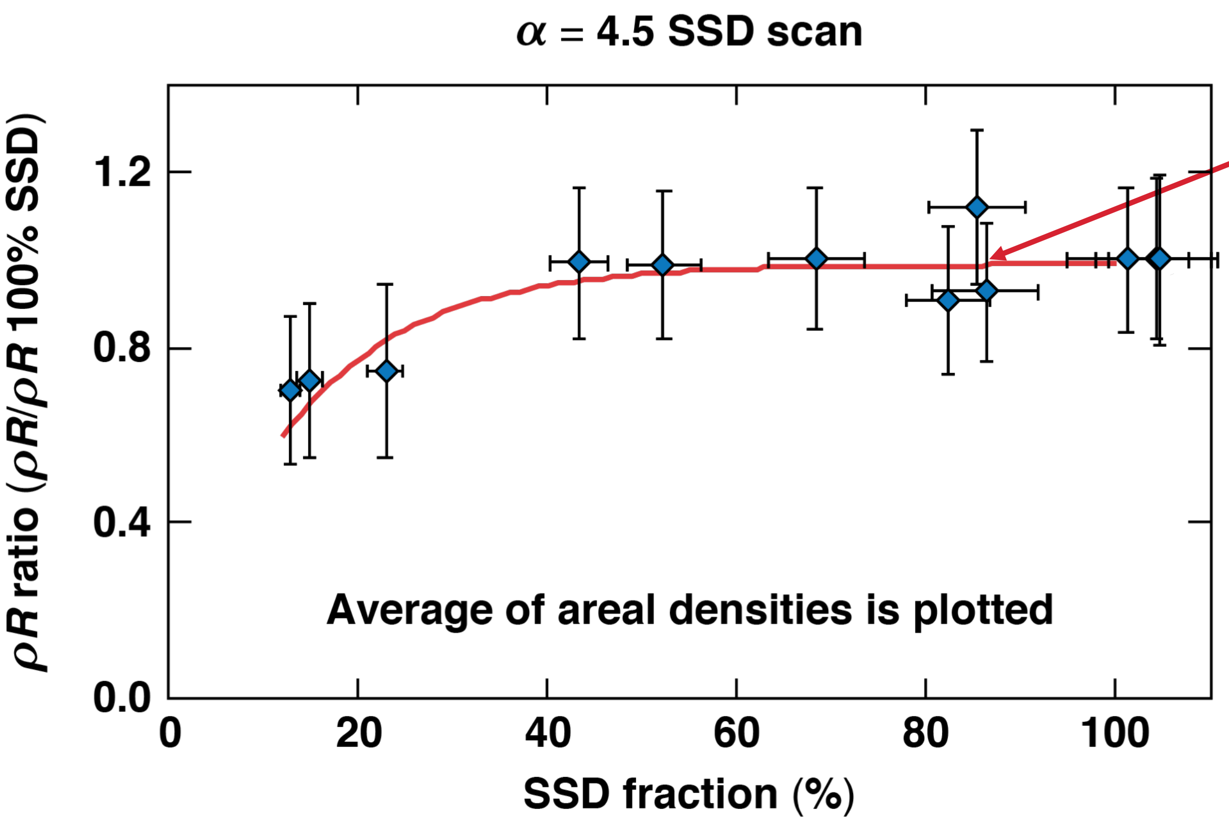
Three lines of sight for ρR measurements

nTOF: neutron time of flight
MCP: microchannel plate

MRS: magnetic recoil spectrometer
DT: deuterium–tritium

All areal density measurements were used to fit a saturation model to the data

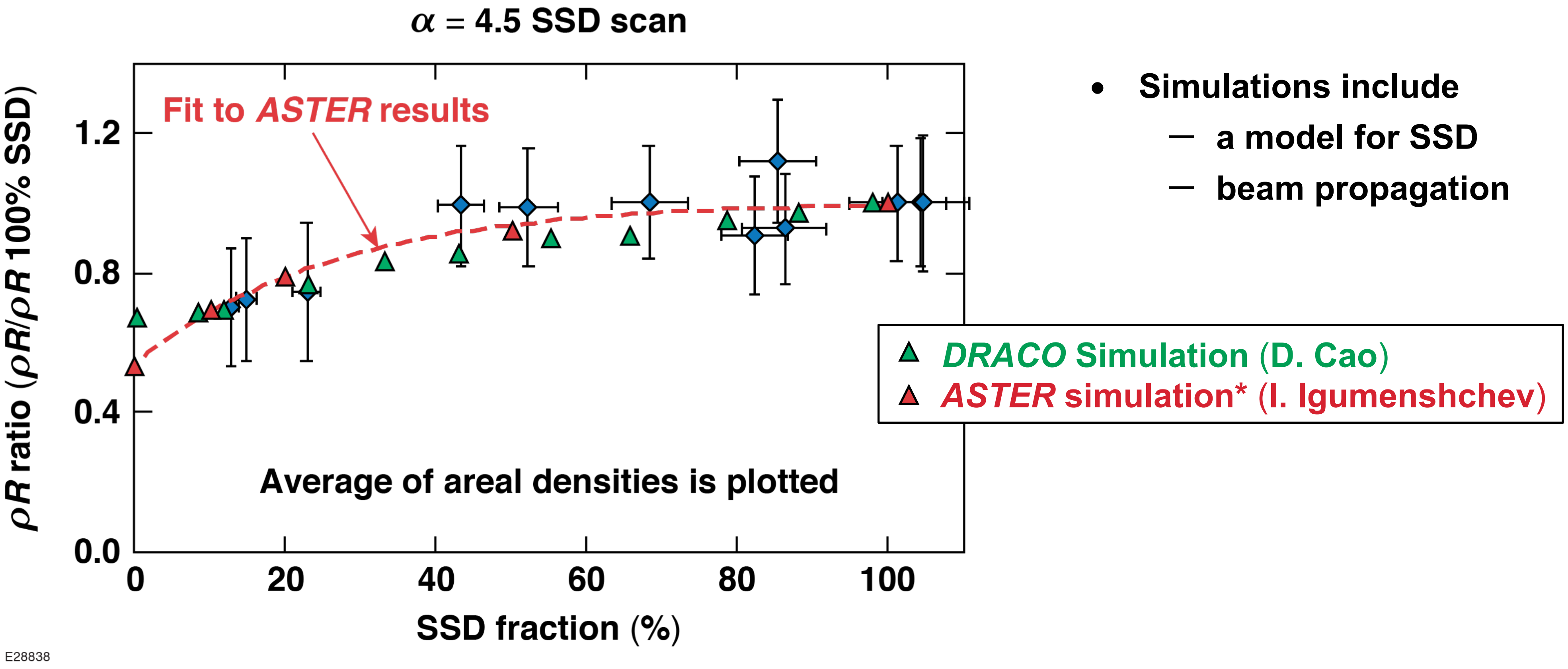
UR LLE



E28849

- **Saturation Model**
  - Ratio = $A + B\left[1 - e^{-\alpha_{\text{ratio}}(\text{SSD}_{\text{fraction}} - \text{SSD}_0)}\right]$
  - A = minimum ratio
  - B = saturation multiplier
  - α_{ratio} = SSD fraction scale
  - SSD_0 = onset of SSD effect
- **For ρR data**
  - $A = 0.023 \pm 0.003$
  - $B = 0.966 \pm 0.005$
  - $\alpha_{\text{ratio}} = 7.48 \pm 0.02$
  - SSD_0 (%) = $5 \times 10^{-2} \pm 10^{-2}$

Three-dimensional *ASTER* simulation ρR results agree with the data and can be fitted with the same type of model used for the experimental data

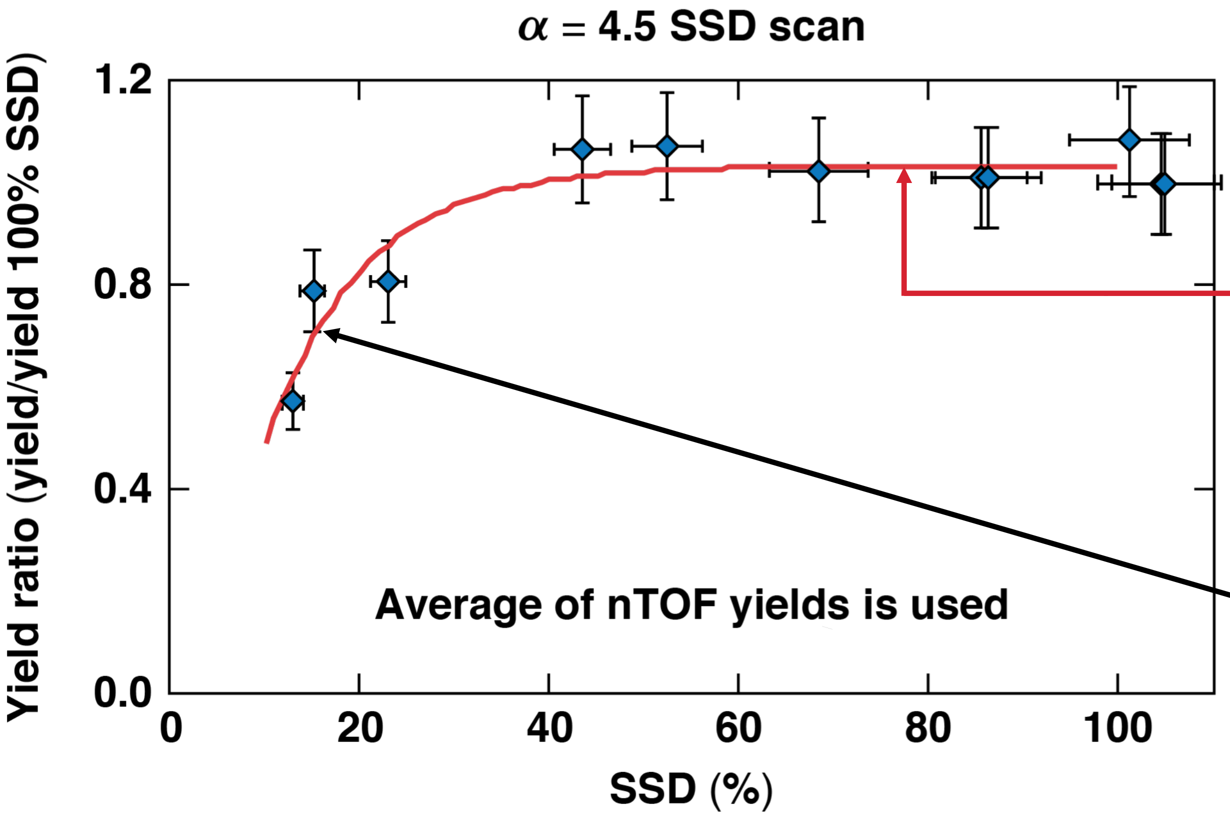


- Simulations include
  - a model for SSD
  - beam propagation

Two-dimensional *DRACO* simulations show higher ρR as bandwidth increases.

*I. V. Igumenshchev *et al.*, NO5.00006, this conference.

Yield ratio versus SSD fraction fit shows a higher minimum ratio and an onset at a larger value for the SSD fraction



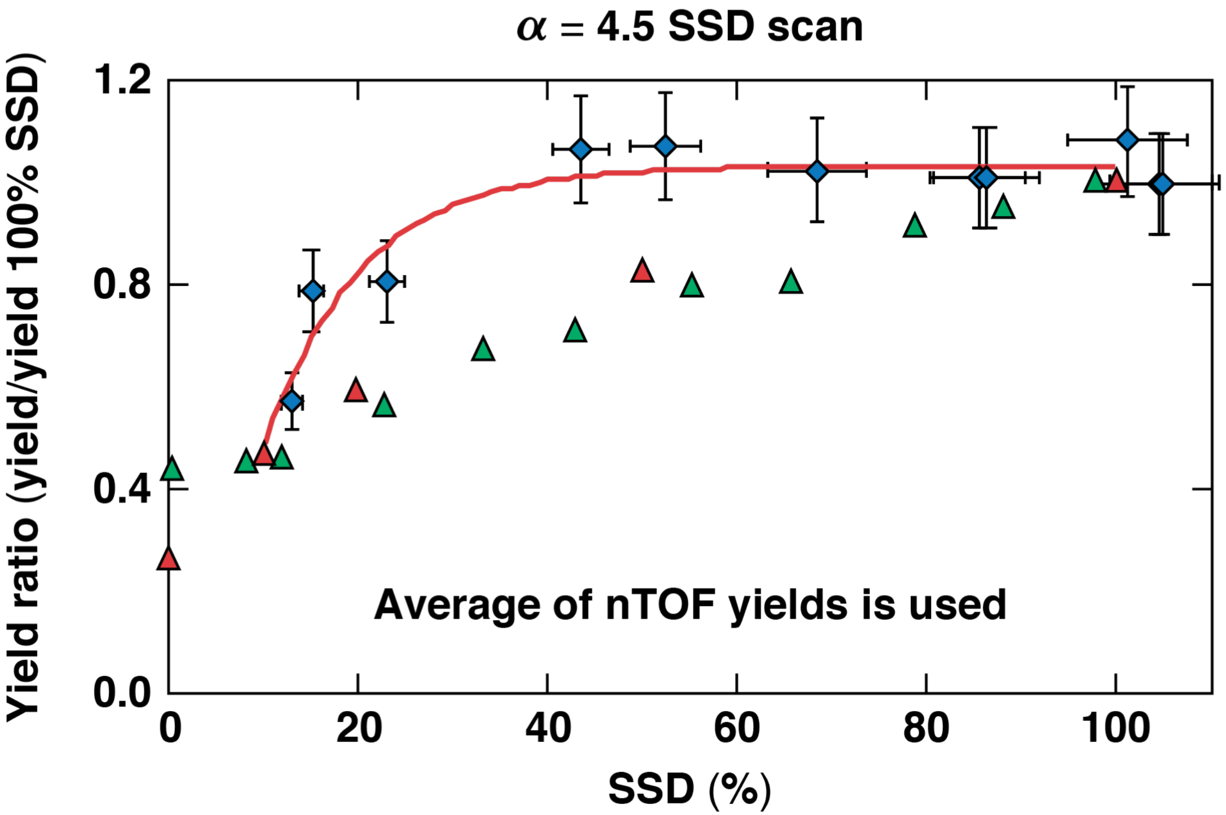
E28839

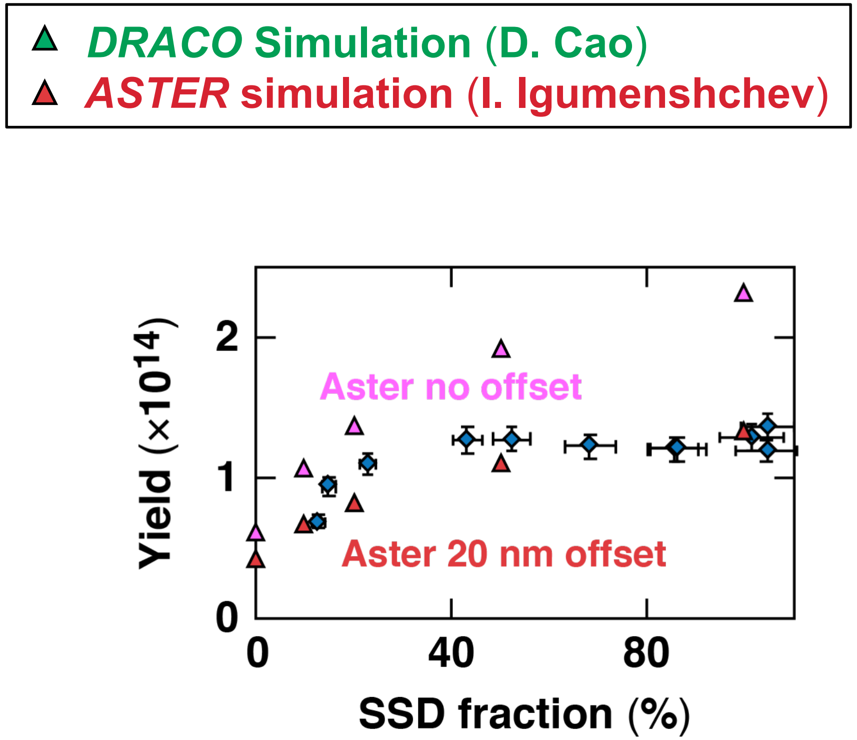
Same saturation model used for the yield ratio data

- For yield data
  - A = 0.064$\pm$0.003
  - B = 0.970$\pm$0.005
  - α_{ratio} = 9.73$\pm$0.02
  - SSD_0 = 4.09 %$\pm 10^{-2}$ %

The yield "cliff" is steeper than the ρR fit

Simulated yield fractions show improved performance as SSD bandwidth increases

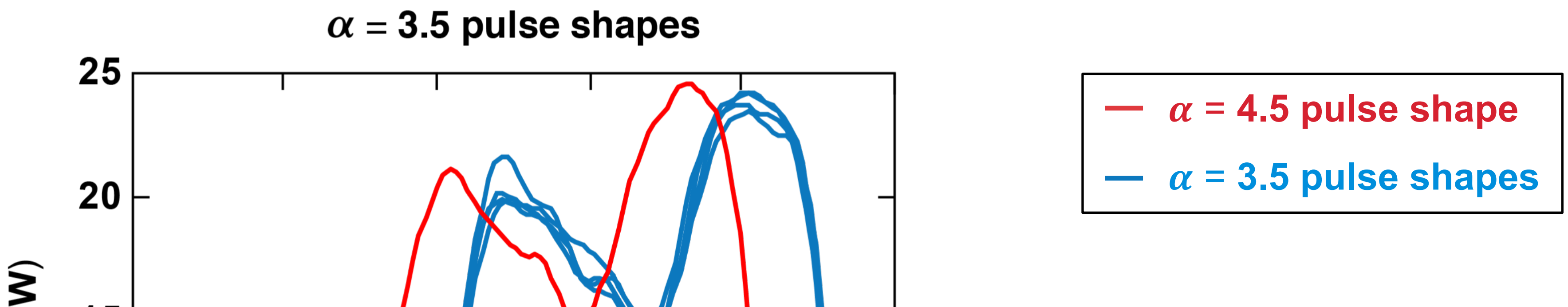


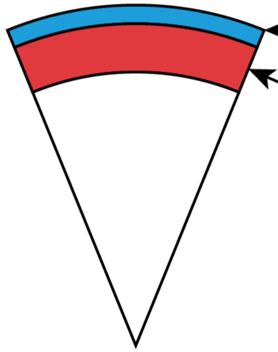


E28840

***ASTER* simulations with a 20-μm target offset match the measured yields.**

An SSD bandwidth scan has been started for α = 3.5 cryogenic implosions





E28541

The performance of current high-adiabat (α = 4.5) cryogenic implosions would not improve by increasing smoothing by spectral dispersion (SSD) bandwidth

- SSD bandwidth was varied to change the Rayleigh–Taylor instability "seed" due to laser imprint
- Areal density and yield values versus SSD bandwidth are fitted with a "saturation"-type model

$$\text{Ratio} = A + B\left[1 - e^{-\alpha_{\text{ratio}}\left(\text{SSD}_{\text{fraction}} - \text{SSD}_0\right)}\right]$$

- Both *DRACO* 2-D and *ASTER* 3-D simulations of ρR and yield fractions show improving performance as bandwidth increases
  - *ASTER* results are a better match to the measured ρR
  - *ASTER* simulations that include a 20-μm target offset show agreement with the measured yields

An SSD scan for α = 3.5 implosions is in progress.

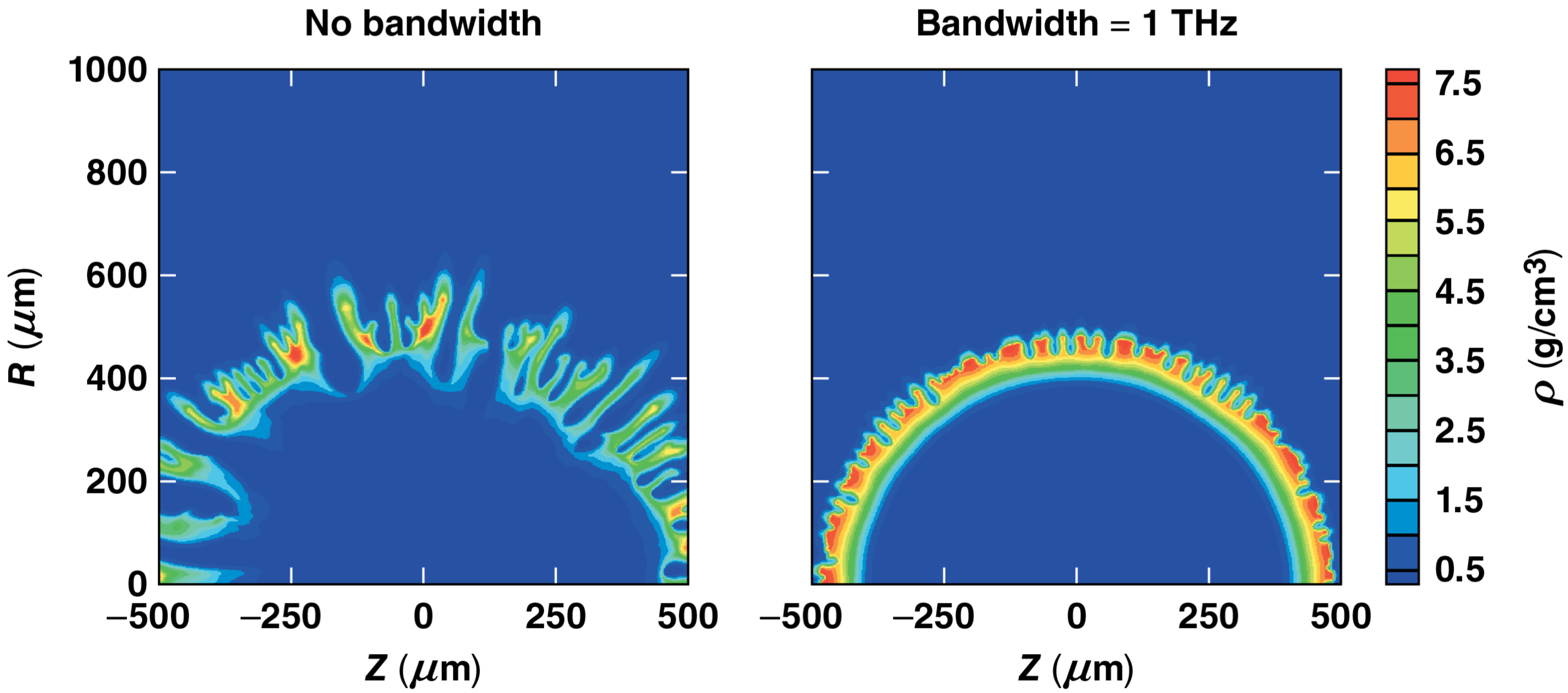
Backup

Effect of Laser Bandwidth on High-Performance, Cryogenic Implosions

The ultimate goal of the high-performance, cryogenic implosions on the OMEGA laser is to find the largest Generalized Lawson Criterion[*] that is accessible with 30-kJ, direct-drive, implosions ($\chi_{\text{no}\ \alpha}$ OMEGA).
$\chi_{\text{no}\ \alpha}$ OMEGA can then be used to extrapolate to laser driver parameters needed to achieve ignition.
A systematic study of implosion limitations is needed to meet the above goal. Implosion distortions are divided into three spherical harmonic regions: low mode, $\ell < 10$; mid mode, $10 < \ell < 20$; and high mode, $\ell > 20$. Data from a high ℓ-mode study are presented. The bandwidth imposed by SSD was varied to change the effect of laser imprint on target implosions. Neutron yield (Y_n) and areal density (ρR) were used to measure the implosion performance as a function of the SSD bandwidth. Y_n and ρR data clearly show an SSD bandwidth dependence that increases as bandwidth increases and then plateaus at the higher values of bandwidth.

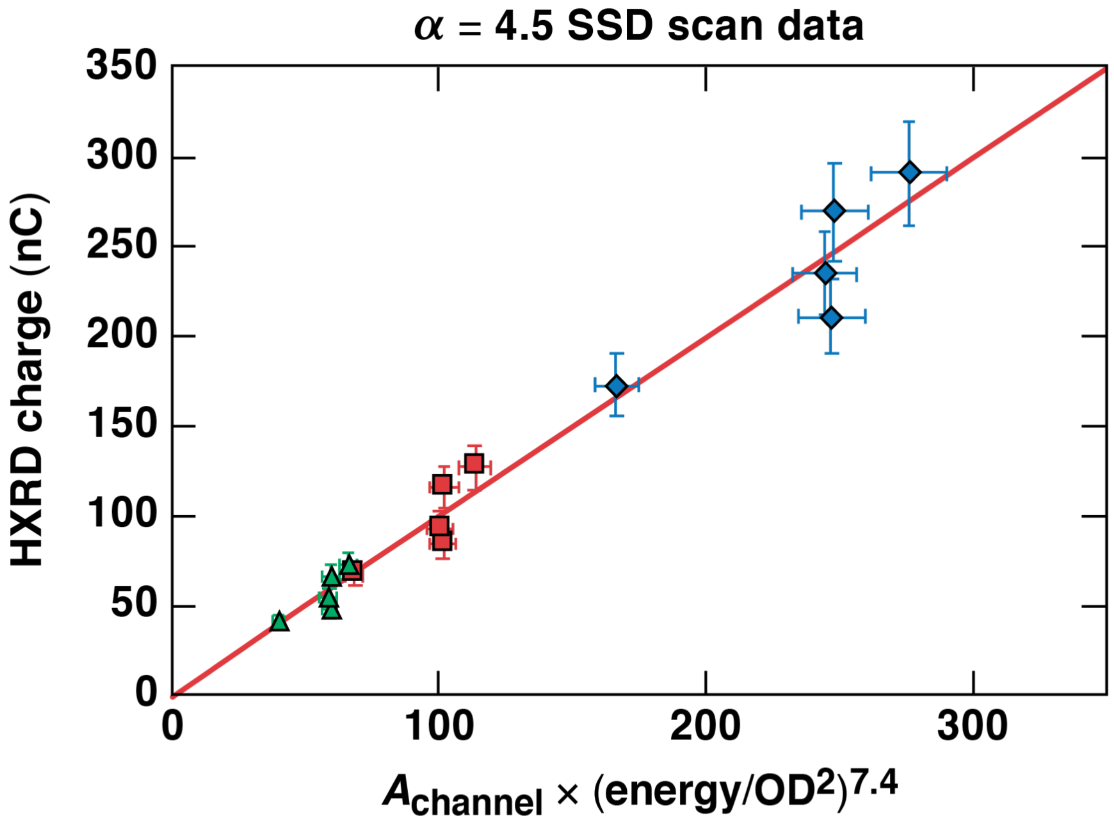
*R. Betti *et al.*, Phys. Rev. Lett. 114, 255003 (2015).

Imprint amplitude was changed by varying the SSD bandwidth



TC5587h

HXRD data for channels 2–4 show a correlation to energy/area



E28528

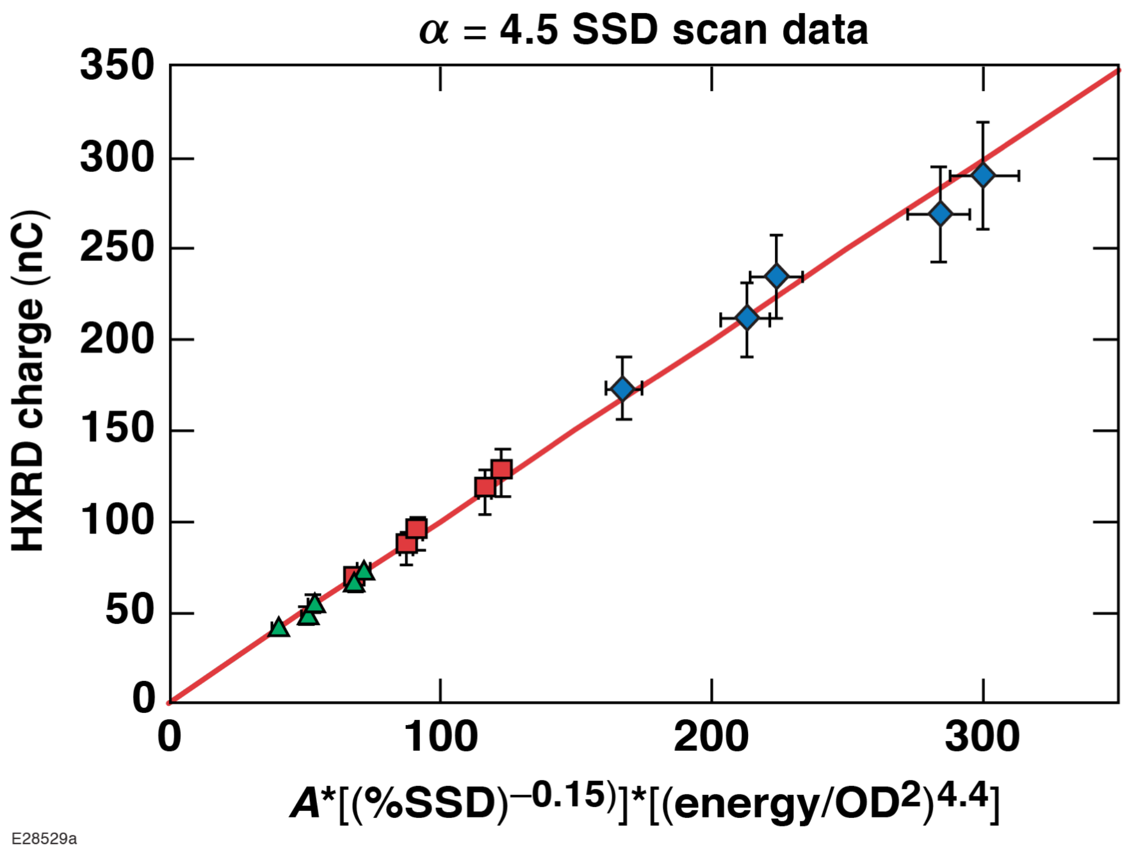
	A	σA	σA
Channel 2	4.46×10^{-9}	4.13×10^{-10}	9.3%
Channel 3	1.83×10^{-9}	2.34×10^{-10}	12.8%
Channel 4	1.07×10^{-9}	1.34×10^{-10}	12.6%

Energy/area exponent = 7.4±1.4

χ^2_{DOF} = 1.7 (10% error on HXRD charge)
R^2 = 0.97

HXRD: hard x-ray diagnostic

A predictive-model type analysis fit using both the energy/area and SSD fraction reduces the χ^2_{DOF} by a factor of 10



	A	σA	σA
Channel 2	7.48×10^{-5}	3.16×10^{-6}	4.2%
Channel 3	3.07×10^{-5}	7.55×10^{-6}	2.5%
Channel 4	1.78×10^{-5}	6.16×10^{-7}	3.5%

SSD exponent = 0.15$\pm$0.01
Energy/area exponent = 4.4$\pm$0.4

χ^2_{DOF} = 0.15 (10% error on HXRD charge)
R^2 = 1.00