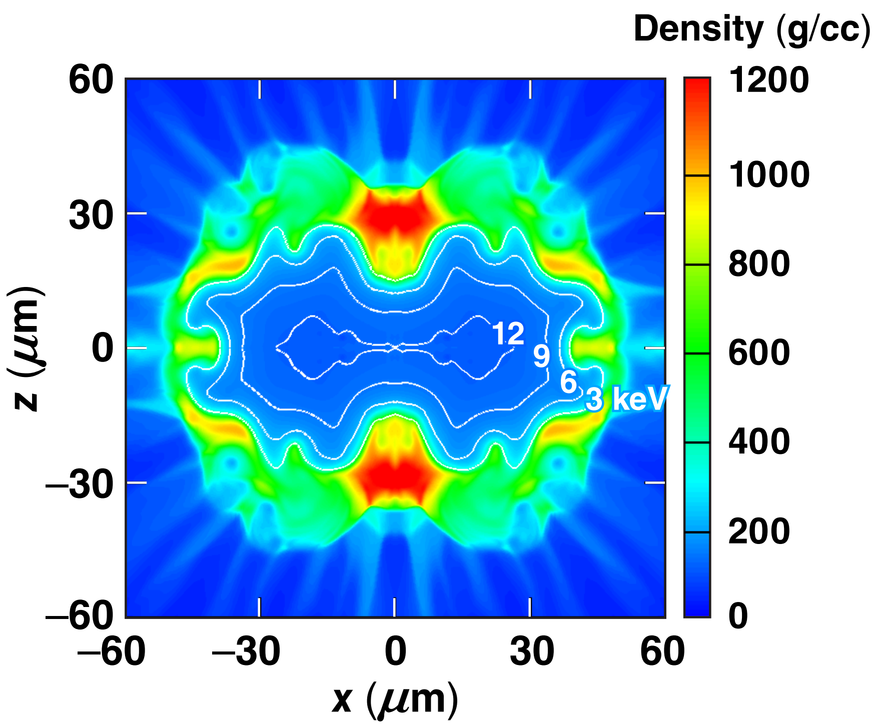
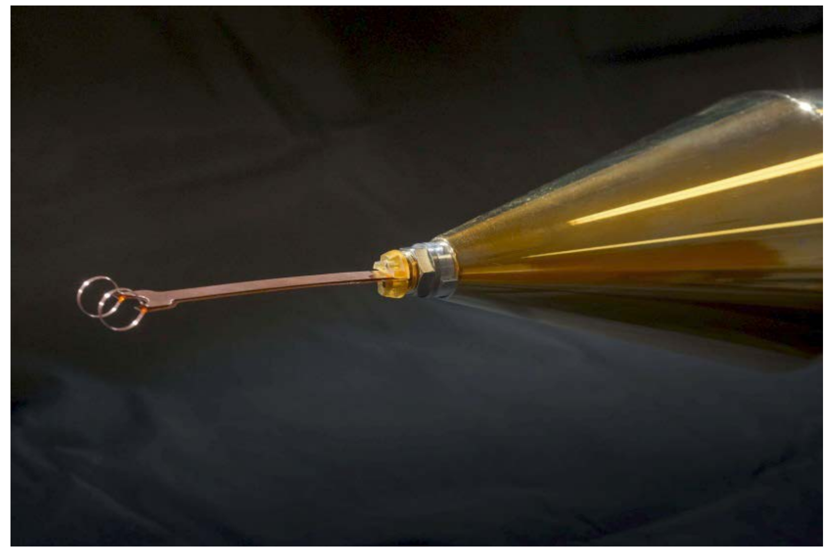
Fusion Science Center Activities on Advanced ICF Ignition





R. Betti
Fusion Science Center
University of Rochester
Laboratory for Laser Energetics

Fusion Power
Associates Meeting
Washington, DC
5–6 December 2012

The Fusion Science Center includes nine institutions: UR, MIT, UCSD, OSU, UNR, UCLA, GA, LLNL, ILSA

FSC FSC

The FSC is funded by the DOE - Office of Fusion Energy Sciences with matching funds from LLE/NYSERDA and U. Rochester

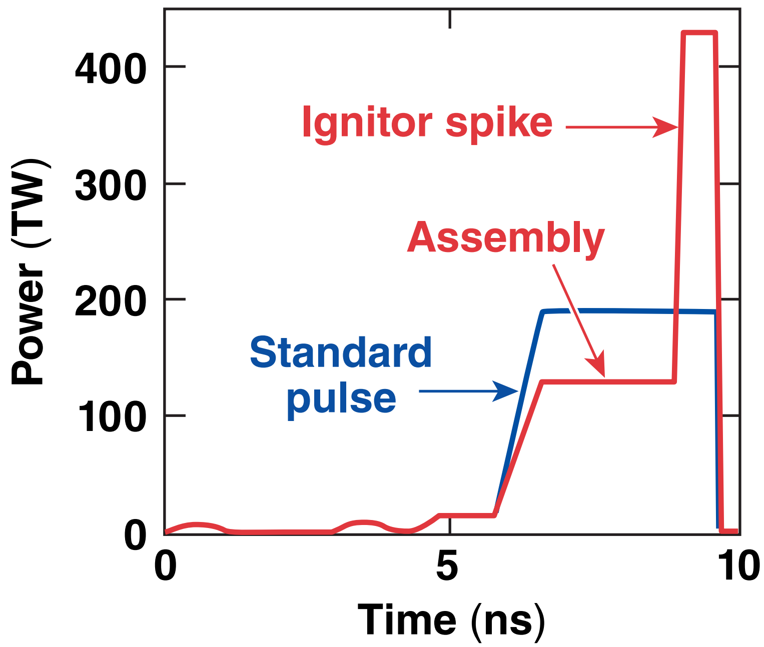
Summary

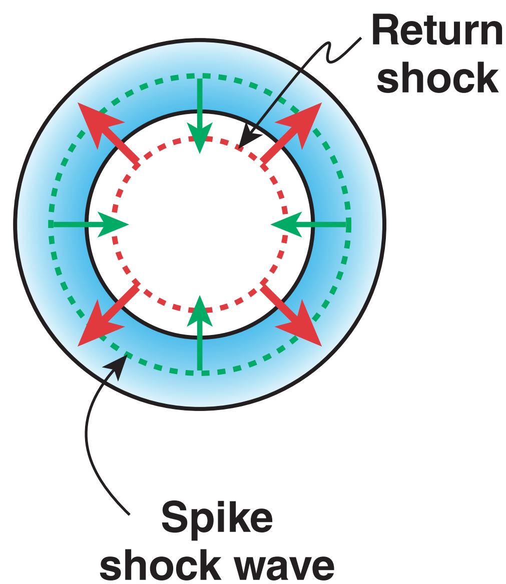
The Fusion Science Center is exploring new HED physics to facilitate ignition at NIF energies: strong shocks (Gbar level), high-Z plasmas, and magnetized HED plasmas

- Shock-ignition (SI) experiments on OMEGA show limited reflectivity and relatively cold hot electrons during the shock-launching power spike
- A polar-drive, shock-ignition design for the NIF shows robust ignition at 700 kJ and 430 TW of total laser energy/power; there are still possible showstoppers—electron preheat during the assembly pulse and cross-beam energy transfer
- High-Z ablators (SiO_2, Si, Al) reduce laser–plasma instabilities during the assembly pulse
- Magnetic fields improve hot-spot temperatures and facilitate ignition; when used in hohlraums, B fields can increase the plasma temperature and reduce laser–plasma instabilities

Shock ignition

Shock ignition separates the fuel assembly phase from the ignition phase using a single laser system





- Low implosion velocities, higher fuel mass lead to higher gains at a fixed laser energy

TC10153

R. Betti *et al*., Phys. Rev. Lett. 98, 155001 (2007).

Shock ignition makes use of massive shells ignited by the final shock leading to high energy gains

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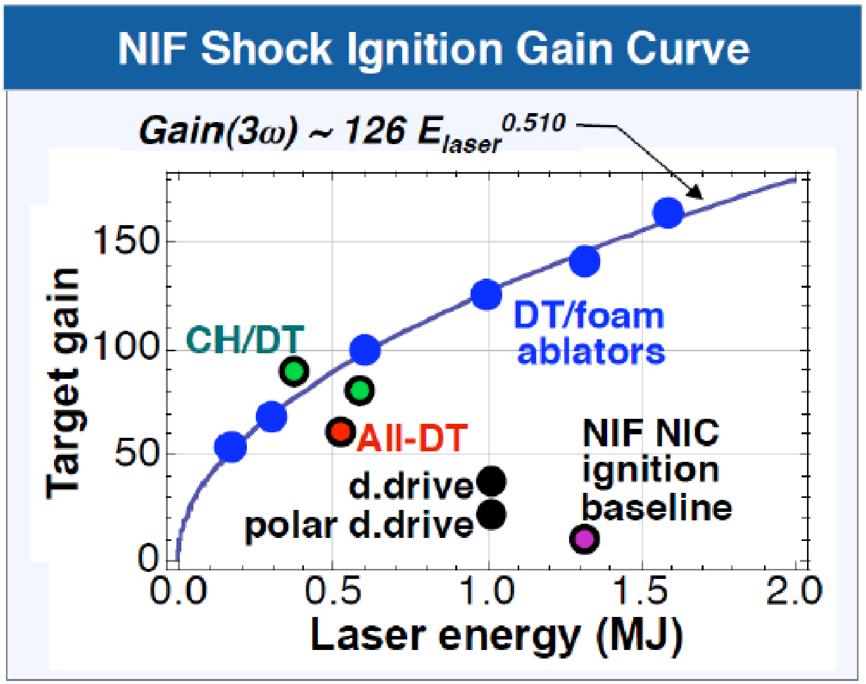
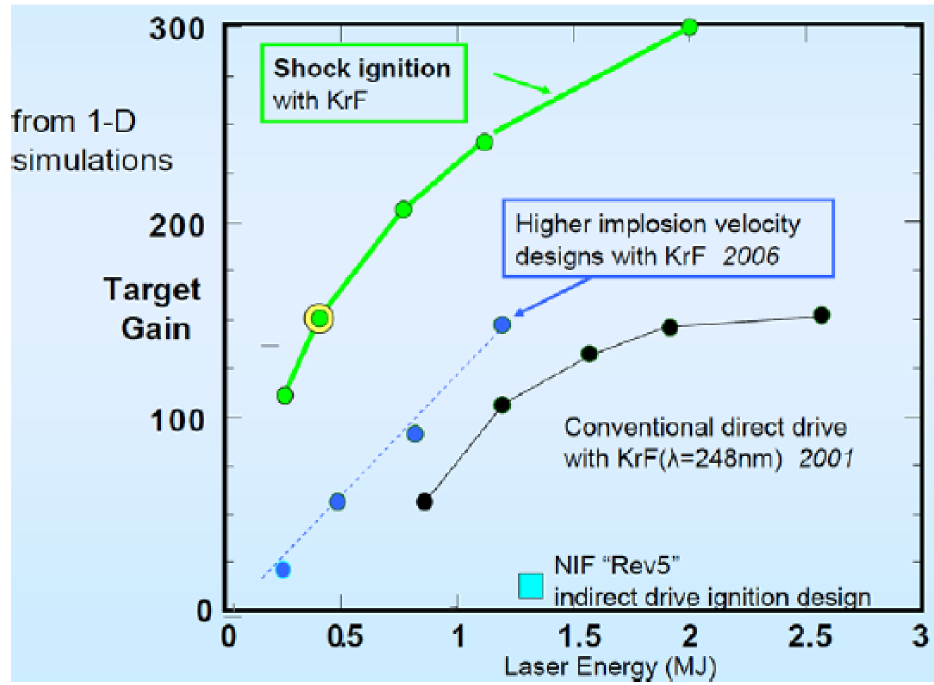
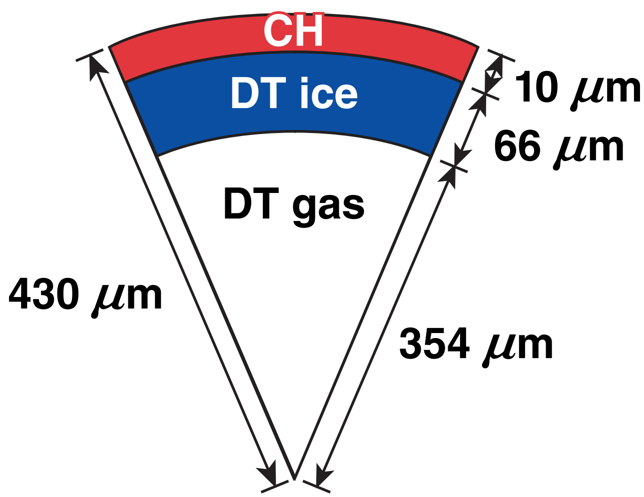


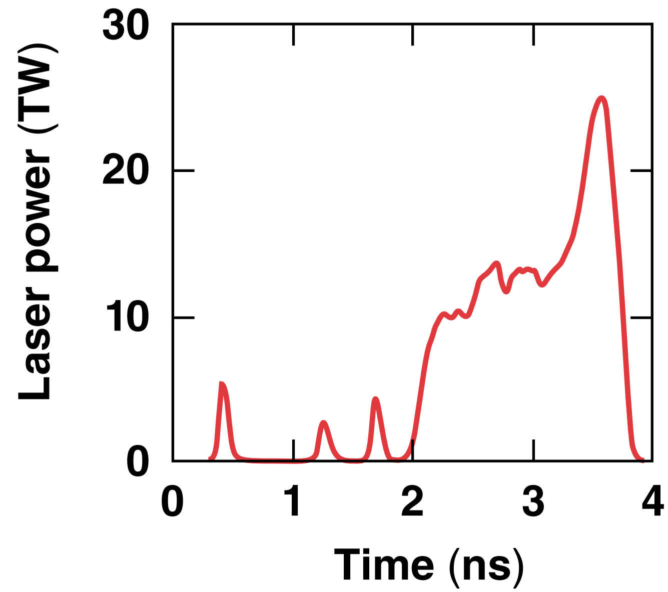


JL Perkins (LLNL)

A. Schmitt (NRL)

Cryogenic experiments* with spike pulses have achieved good performance relative to 1-D simulations



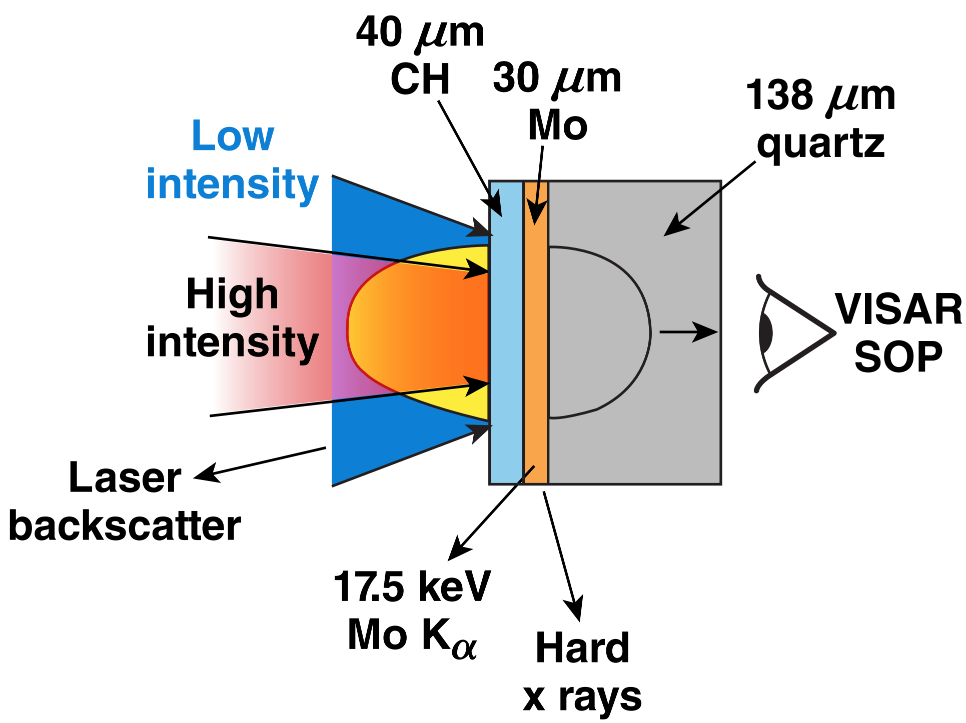


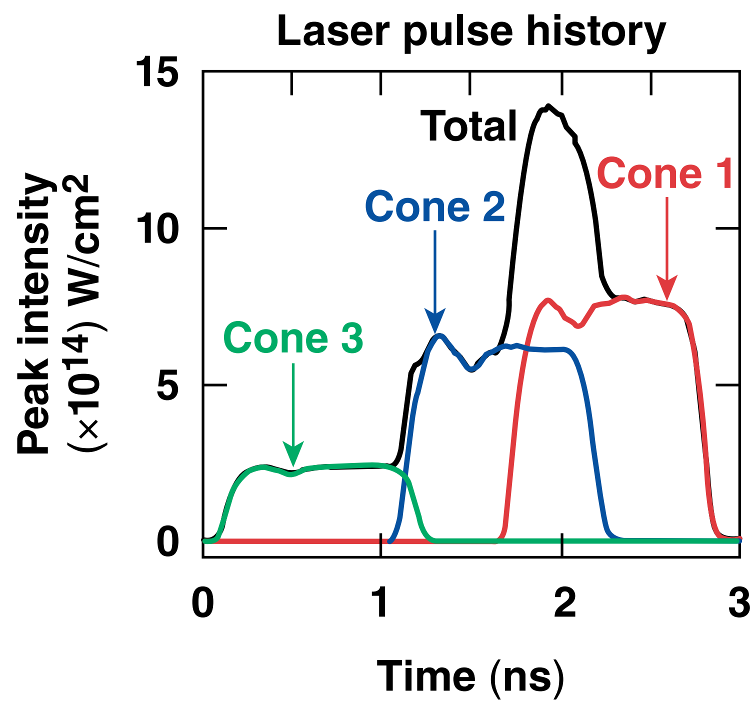
Adiabat	3.5
Neutron yield (experimental)	5.6×10^{12}
YOC (%)	33
ρR (mg/cm^2)	200

TC10347

*R. Nora *et al.*, Bull. Am. Phys. Soc. 56, 327 (2011).

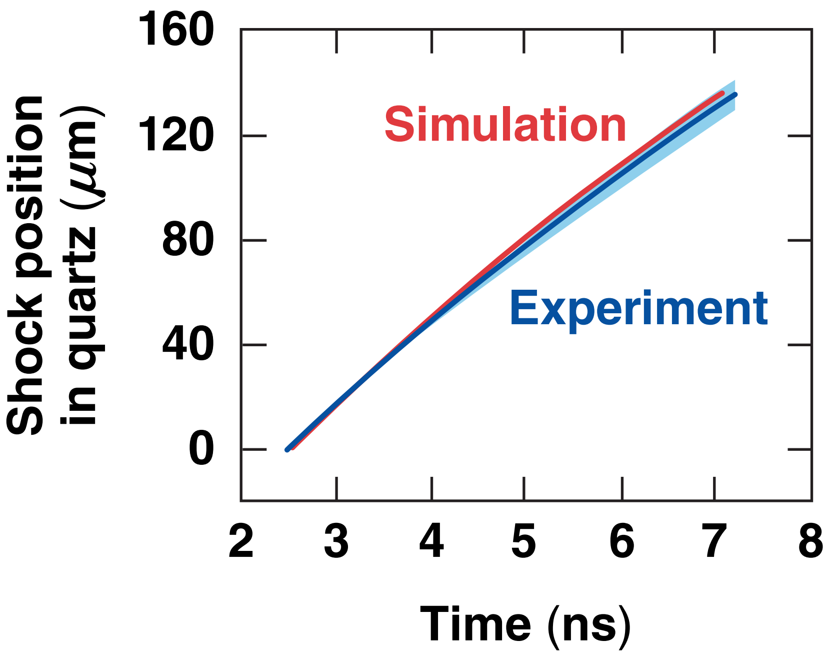
Planar experiments have validated the simulated shock pressures generated by high-intensity laser pulses in a long-scale-length plasma

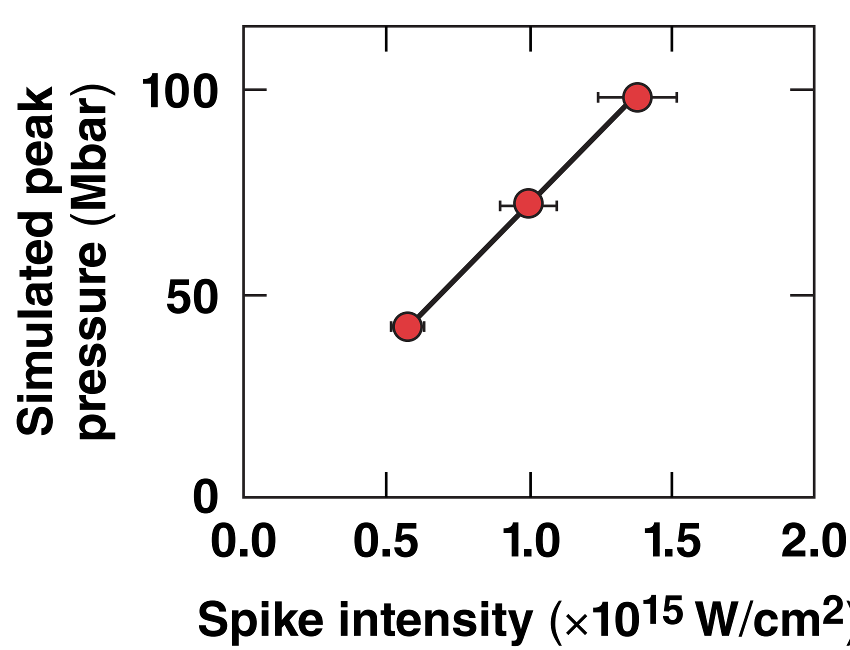




M. Hohenberger *et al.*, "Shock-Ignition Experiments with Planar Targets on OMEGA," submitted to Physical Review Letters.

Trajectories of high-pressure shocks driven at intensities up to ~1.5 × 10^{15} W/cm^2 are in good agreement with simulation





Up to 100 Mbar shock pressures are inferred.

M. Hohenberger *et al.*, "Shock-Ignition Experiments with Planar Targets on OMEGA," submitted to Physical Review Letters.

TC10156a

Hot-electron generation and capsule preheat must be well-characterized and controlled

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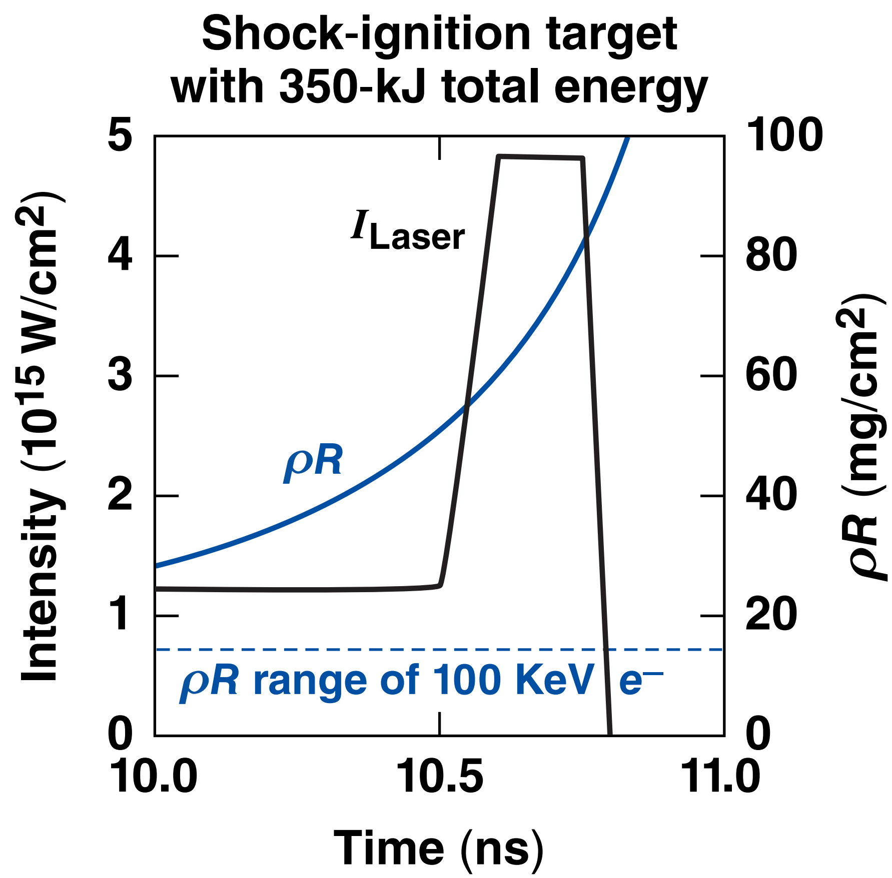
- Hot electrons at moderate temperatures and conversion efficiencies during the spike may improve margin*
- Preheat during the main drive can raise the shell adiabat, ruining compression

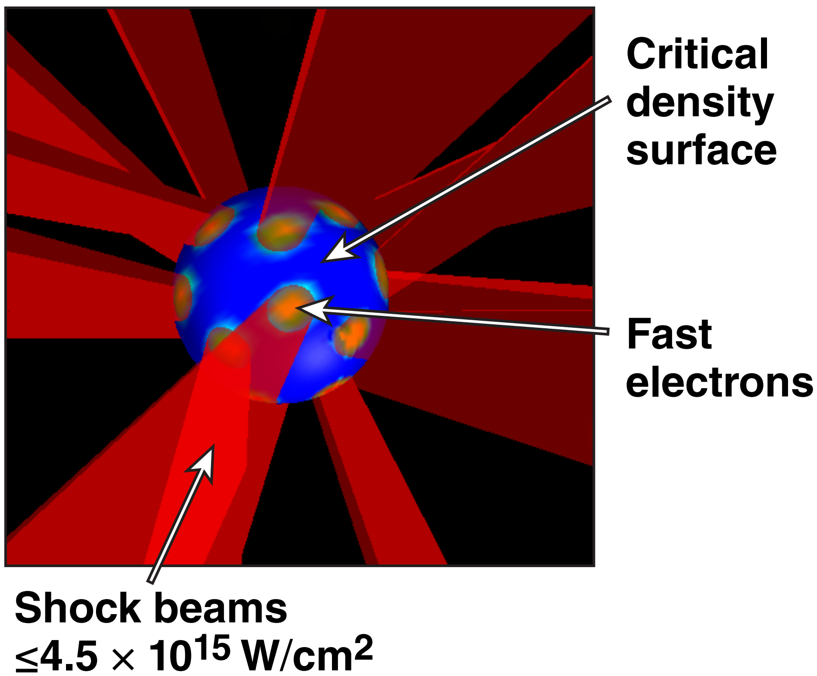


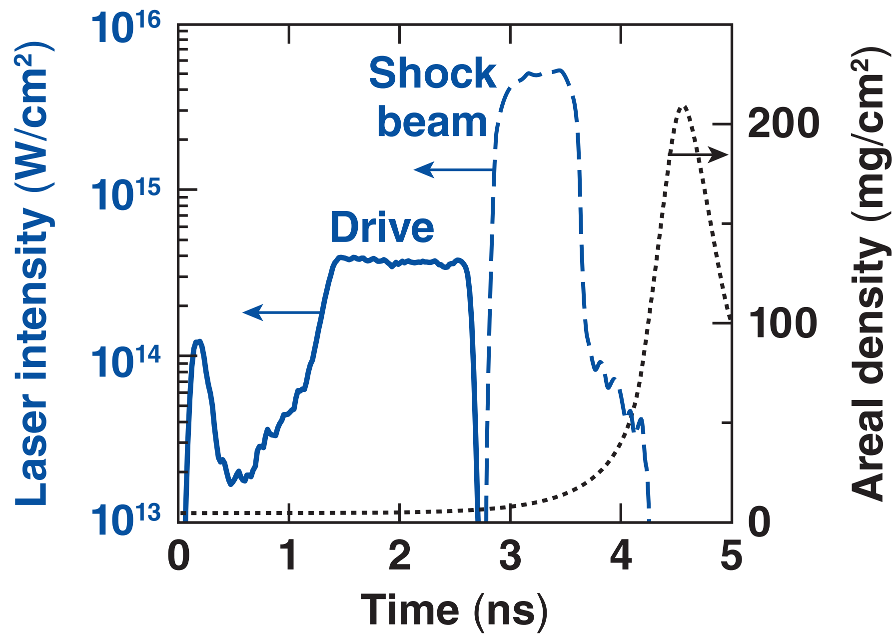
At moderate hot-electron energy, electrons are stopped in the ablator, increasing the shock pressure during the spike pulse.

TC9111a

*R. Betti *et al.*, J. Phys., Conf. Ser. 112, 022024 (2008).

Spherical implosions were performed on OMEGA using 40 beams to compress and 20 tightly focused beams to shock the target



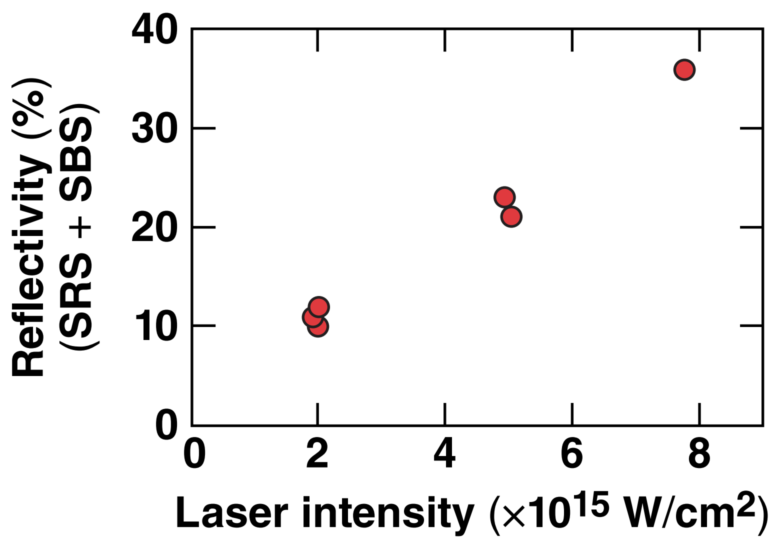


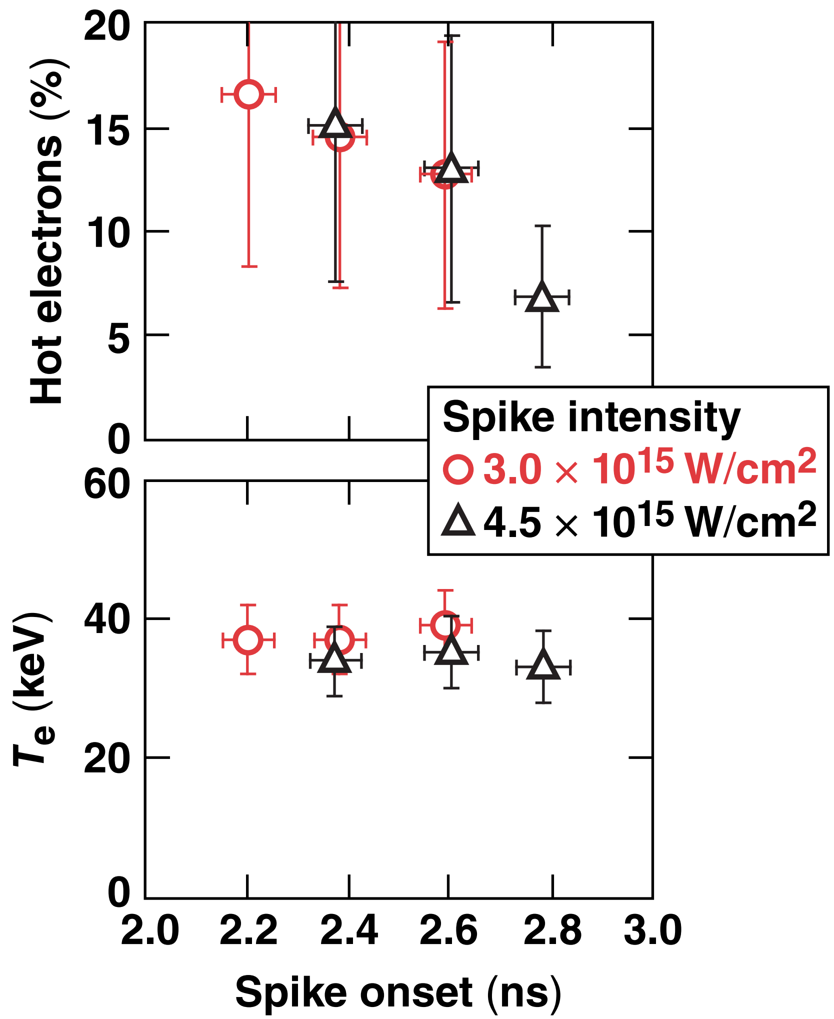
- The delay and intensity of the tightly focused beams are varied

E17863f

W. Theobald *et al.*, Phys. Plasmas 19, 102706 (2012).

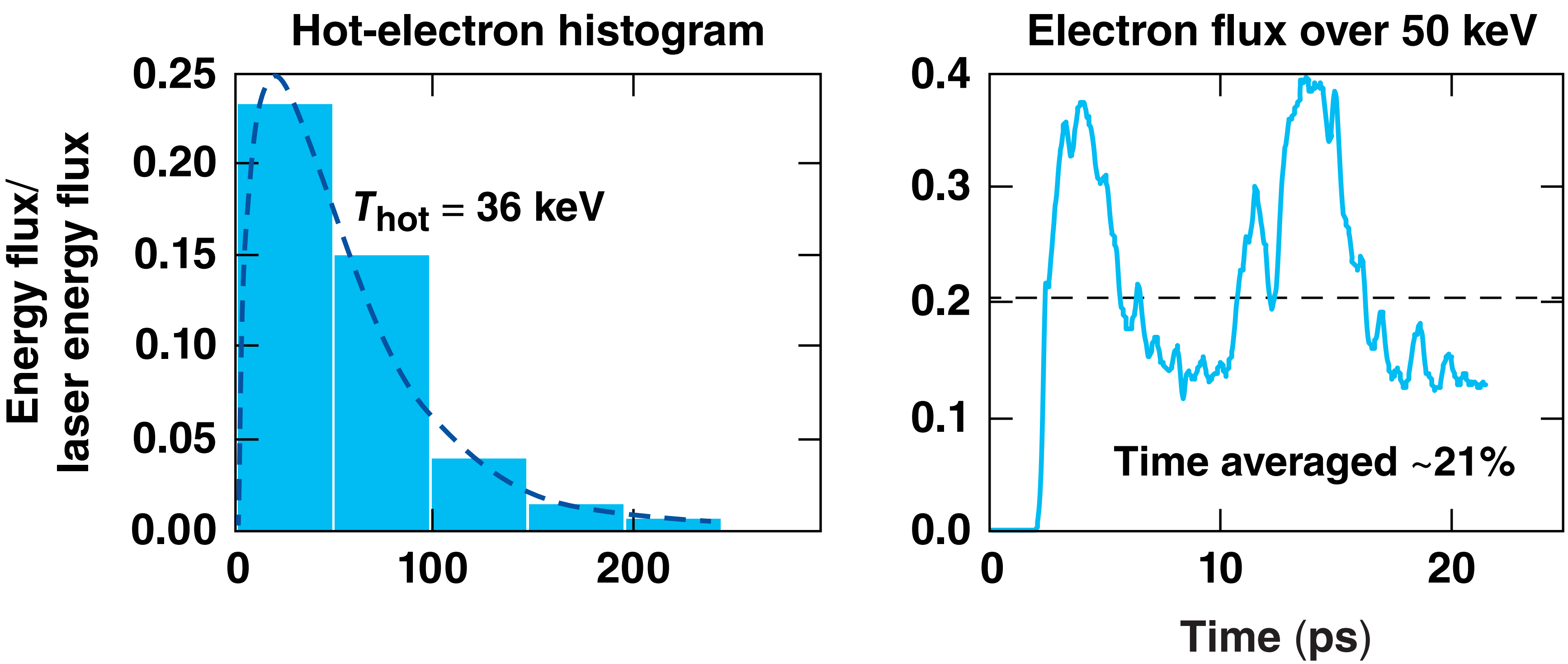
Up to 16% of the shock-beam energy is converted into 40-keV hot electrons





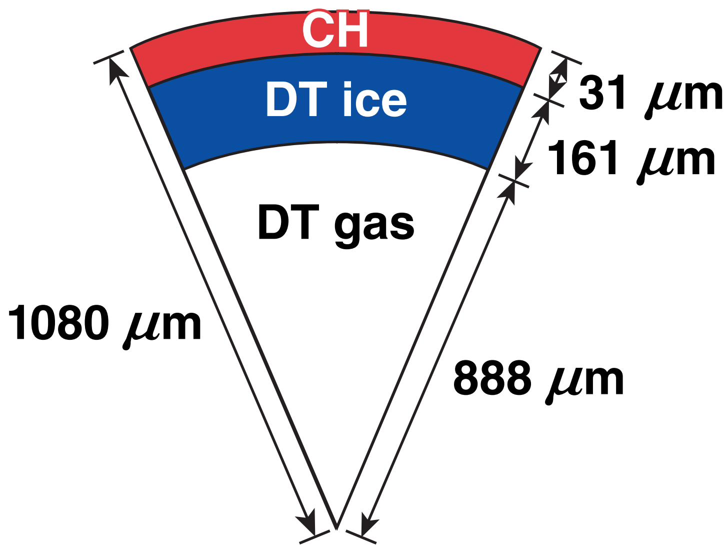
- Hot electrons are from stimulated Raman scattering
- No two-plasmon-decay (TPD) hard x-ray signal is measured

Two-dimensional particle-in-cell simulations predict similar hot-electron temperature and conversion efficiency

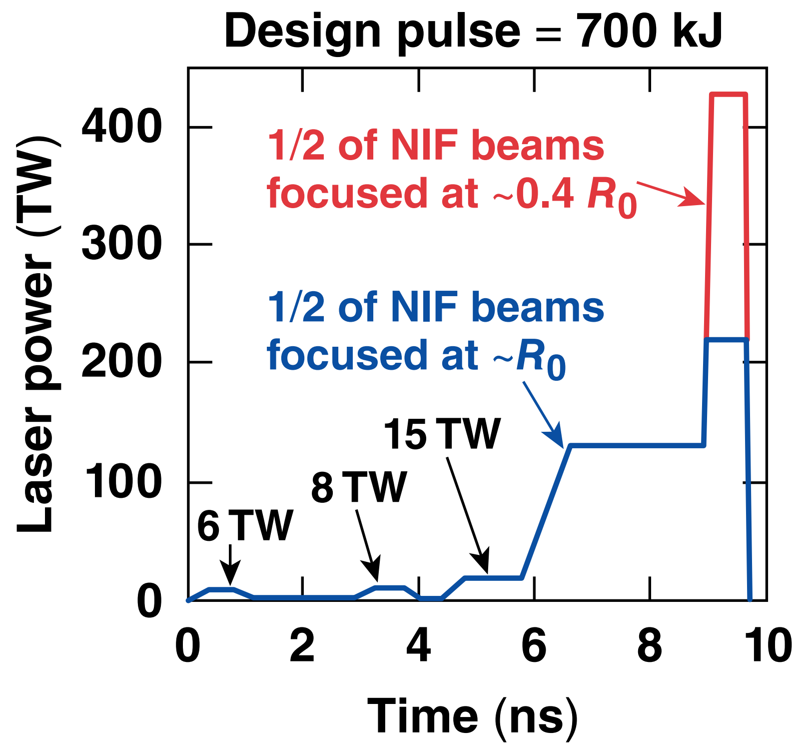


TC10382a

A two-picket shock-ignition pulse has been designed for the NIF at 700 kJ



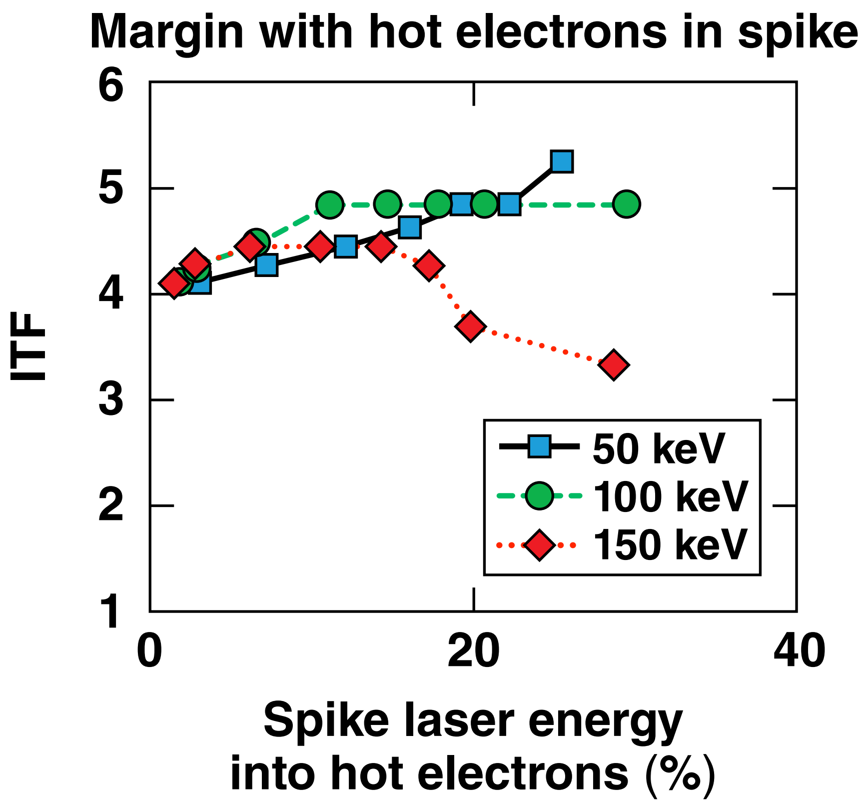
Gain (1-D)	58
ρR (g/cm^2)	1.6
V_{imp} (μm/ns)	305
$IFAR_{2/3}$	22
Average adiabat	1.8
ITF	4.1



Peak power is 85% of demonstrated NIF performance.

TC10158

One-dimensional simulations predict the target is robust to laser-spike–generated hot electrons up to 150 keV



Hot electrons below 100 keV may increase the ignition margin.

TC10157

Initial polar-drive pointing schemes use split–quads, two beams from each quad for the main drive, and two beams for the shock pulse

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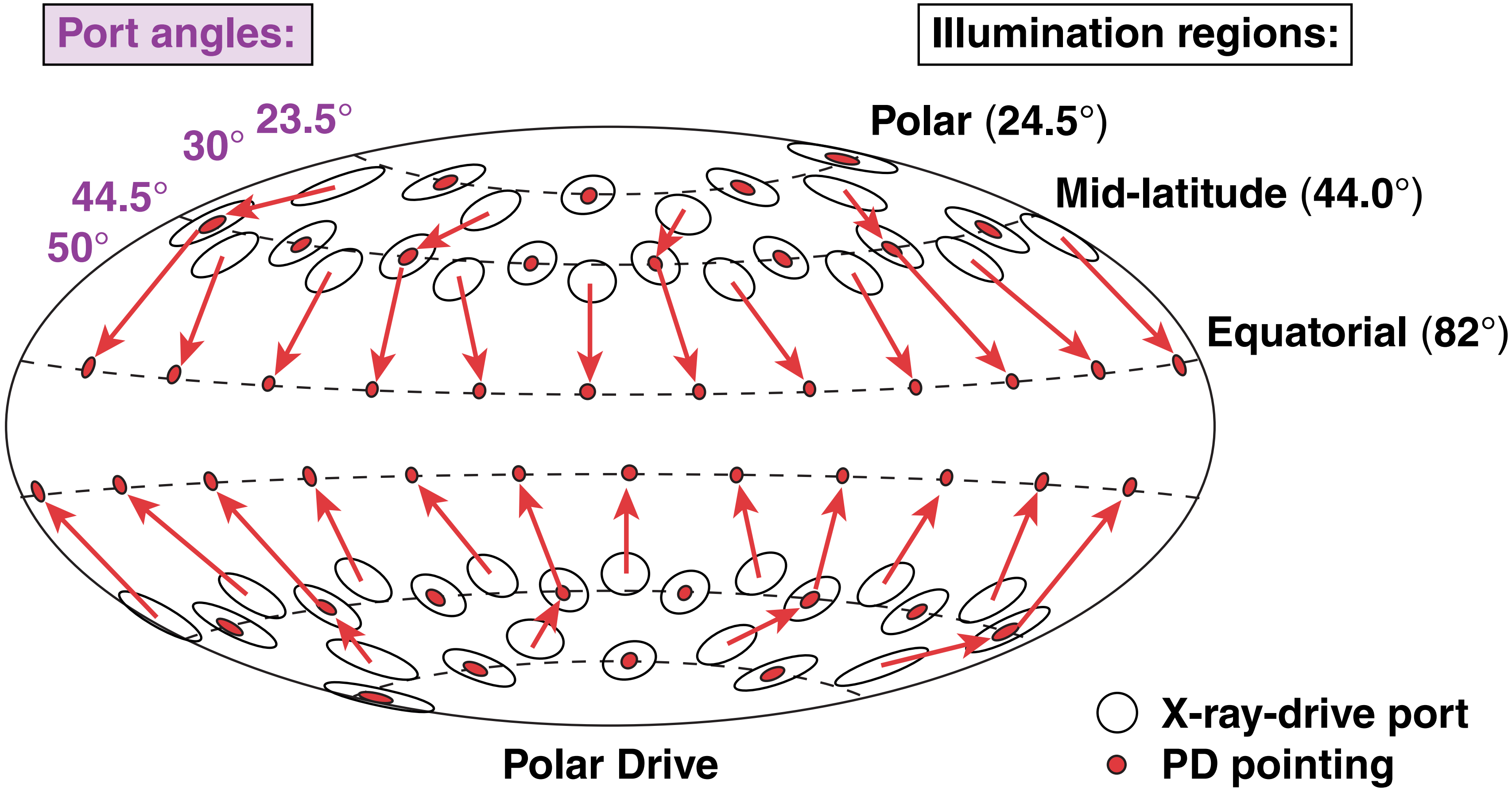


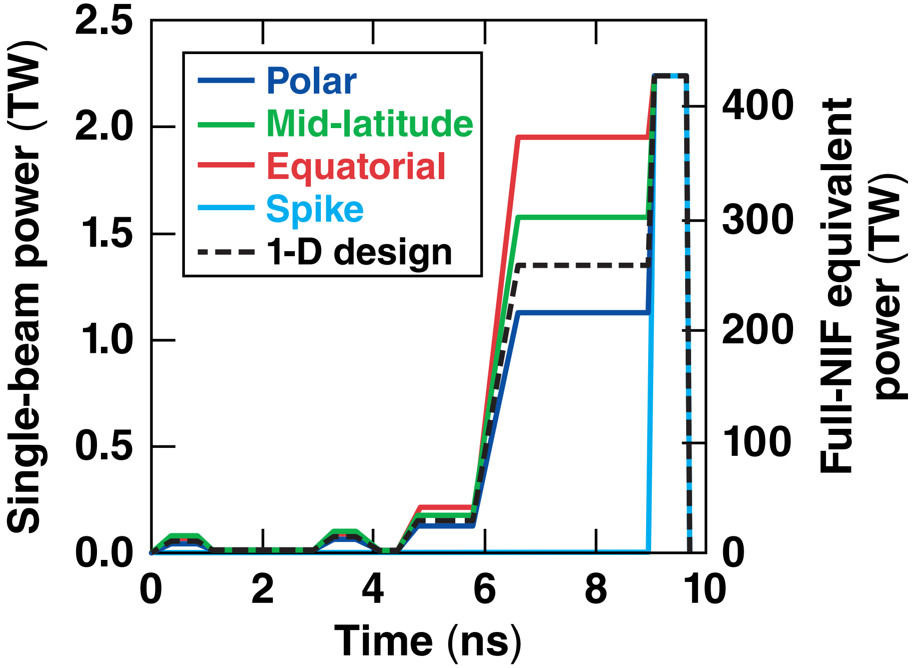
Polar Drive

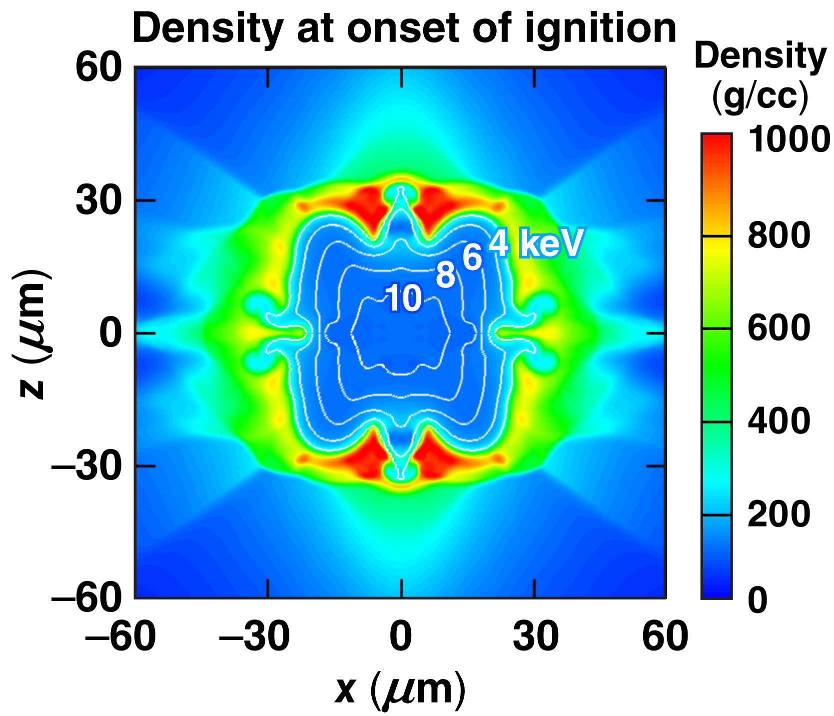
A full-quad repointing shows ignition—further refinement is underway.

E19817a

*S. Skupsky *et al.*, Phys. Plasmas 11, 2763 (2004).

The two-picket shock-ignition point design gives a gain of 52 in split-quad polar drive at 750 kJ





TC10229

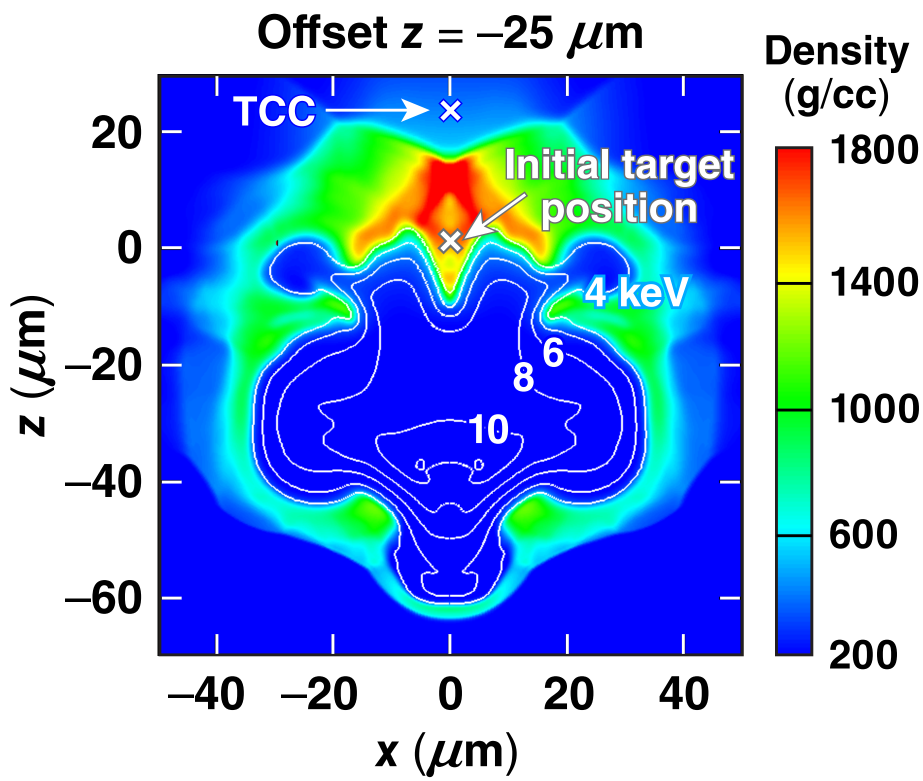
The polar-drive SI design can tolerate high levels of 2-D nonuniformities

FSC

UR LLE

Ignites in polar drive with

- 5× NIF-spec inner ice roughness
- 5× NIF-spec outer surface roughness in modes 2 to 50
- 10% rms beam-to-beam power imbalance
- 100-ps rms beam-to-beam mistiming
- 100-μm rms beam mispointing
- Expected level of imprint with multi-FM*-SSD in modes 2 to 100
- Target offset up 25 μm



Ignites with gain 38 with all expected levels of non uniformity and system uncertainty.

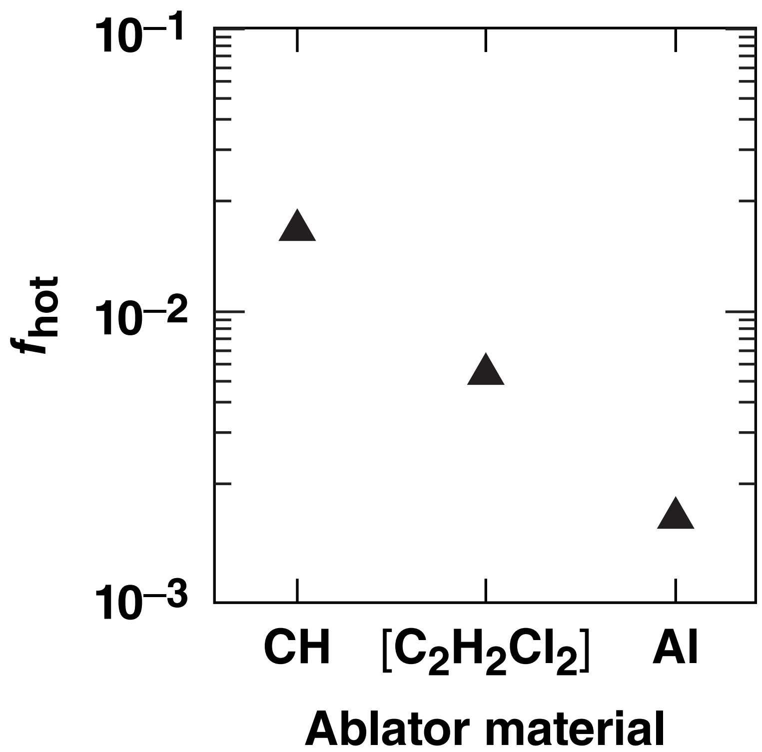
*LLE Review Quarterly Report 114, 73, LLE Document No. DOE/NA/28302-826 (2008).

TC10162a

High-Z ablators

High-Z reduction of TPD is seen in experiments and simulations

- Hard x-rays (HRX) reduced by more than 40× in glass with respect to plastic at 10^{15} W/cm^2*
- Confirmed:
  - on multiple materials in planar targets**
  - in particle-in-cell (PIC) simulations
  - in quasilinear Zakharov model simulations

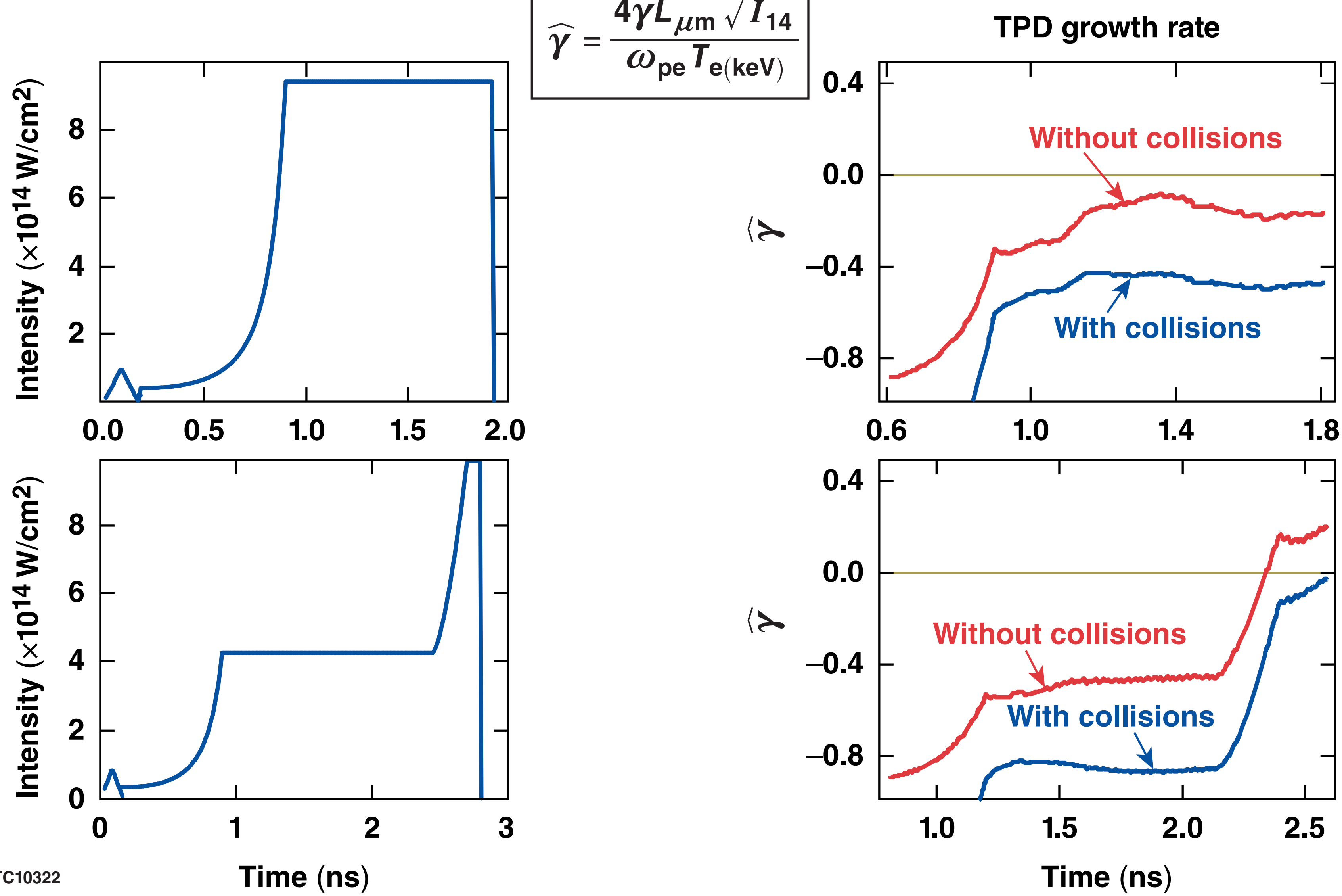


*V. A. Smalyuk *et al.*, Phys. Rev. Lett. 104, 165002 (2010).
**D. H. Froula *et al.*, Plasma Phys. Control. Fusion 54, 124016 (2012).

TC10315a

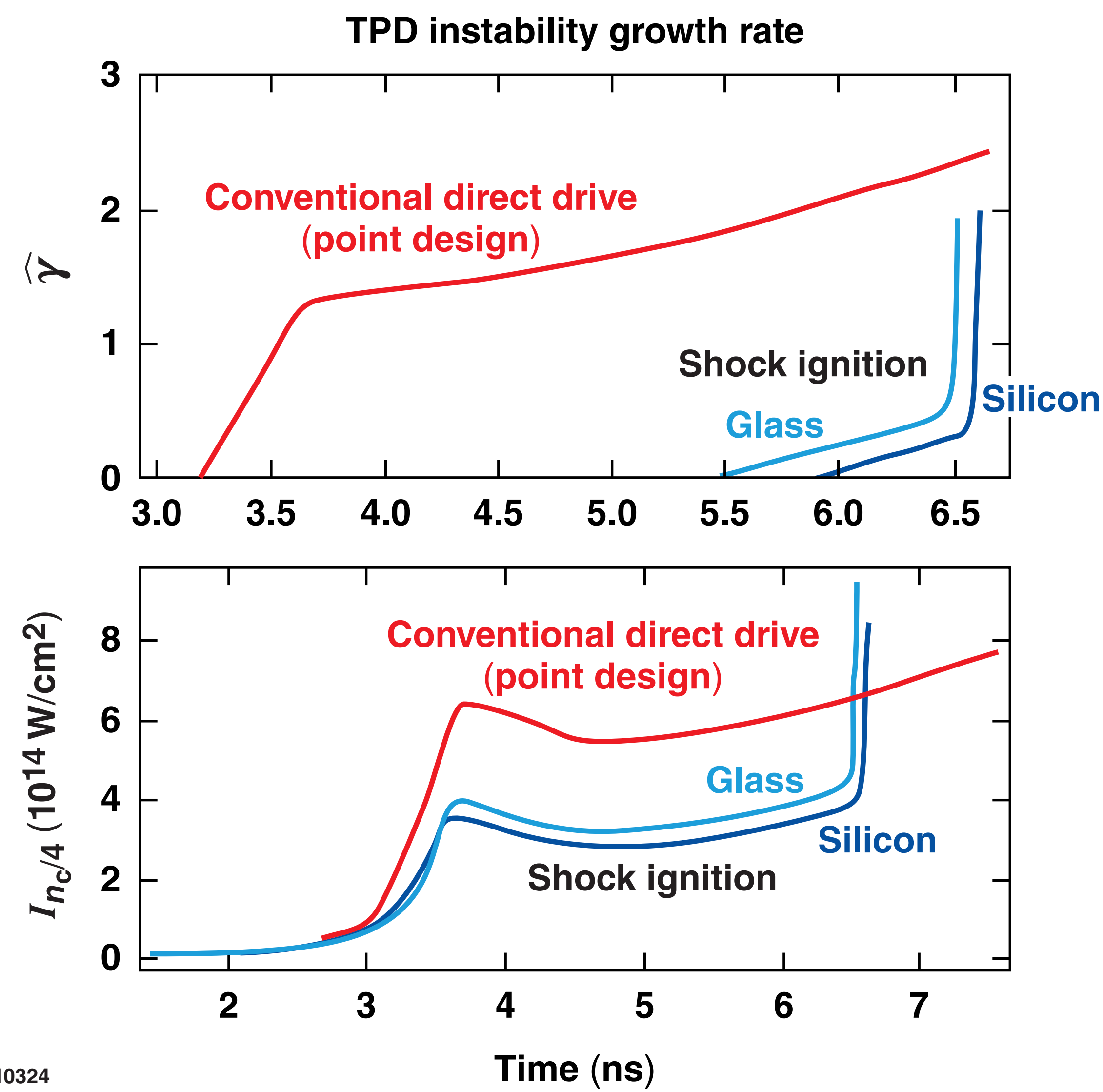
The TPD cannot be driven above the linear threshold in SiO_2-ablator targets on OMEGA at 10^{15} W/cm^2

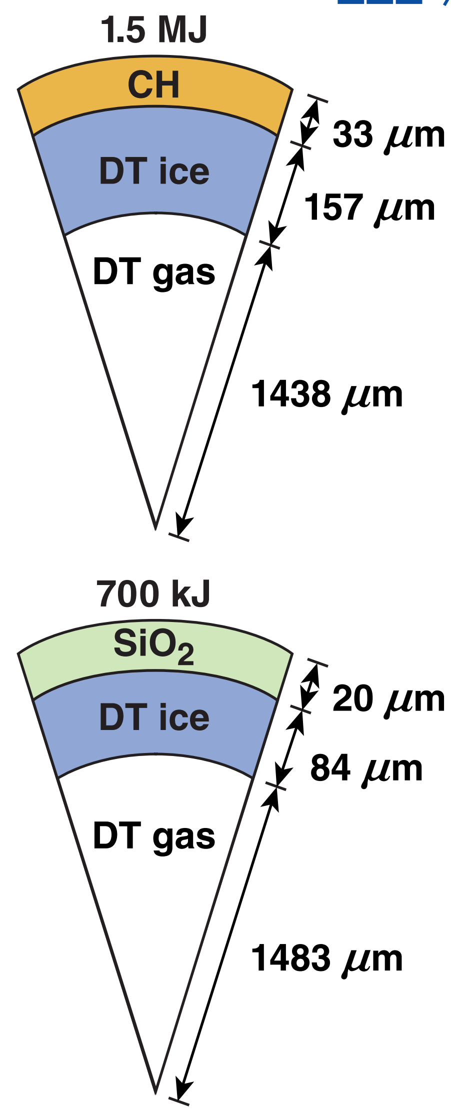
$$\hat{\gamma} = \frac{4\gamma L_{\mu m}\sqrt{I_{14}}}{\omega_{pe} T_{e(keV)}}$$



TC10322

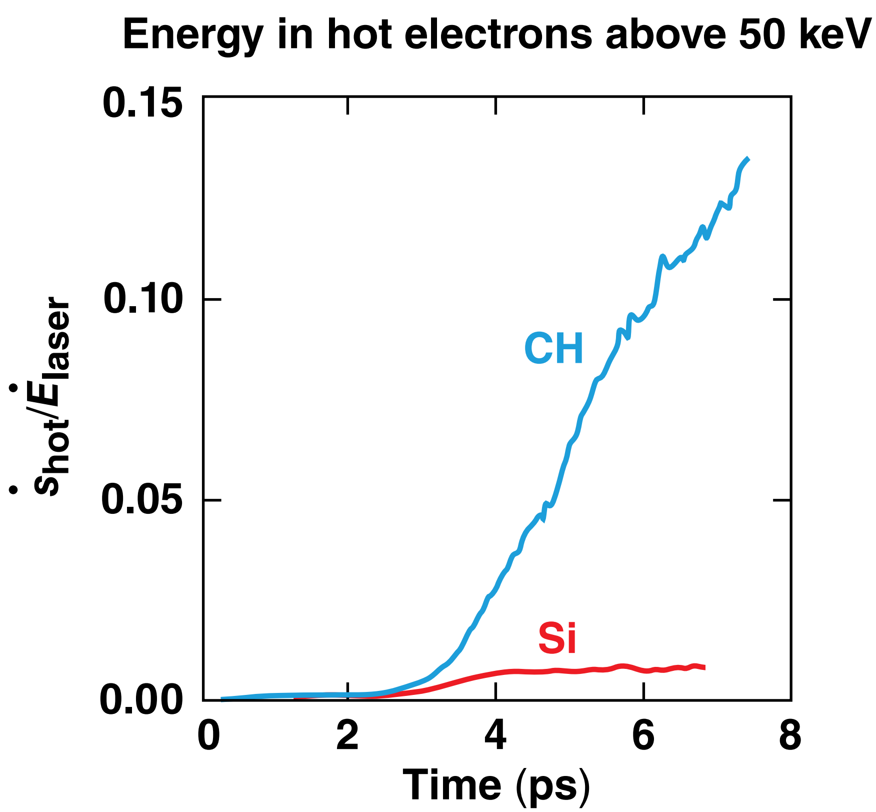
Shock-ignition, 700-kJ NIF SiO_2 targets can be designed to be almost fully below threshold during the assembly pulse

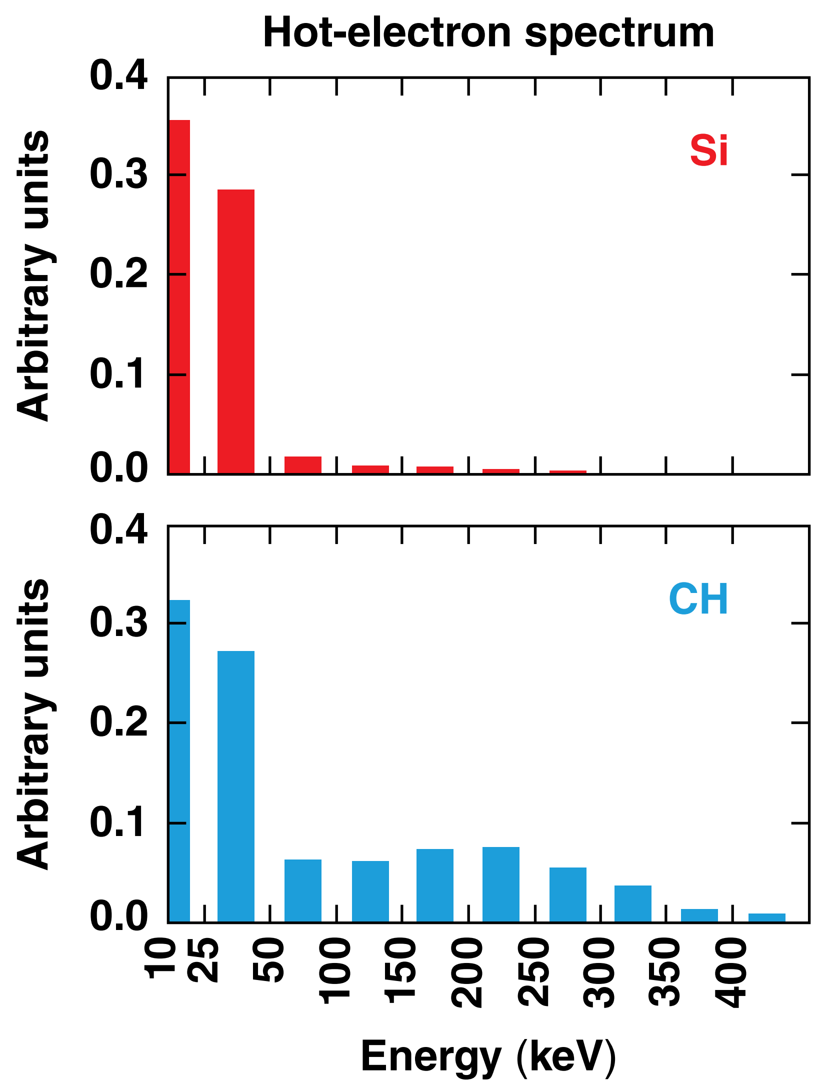




TC10324

PIC simulations show that hot-electron production in Si is negligible even at the end of the assembly pulse

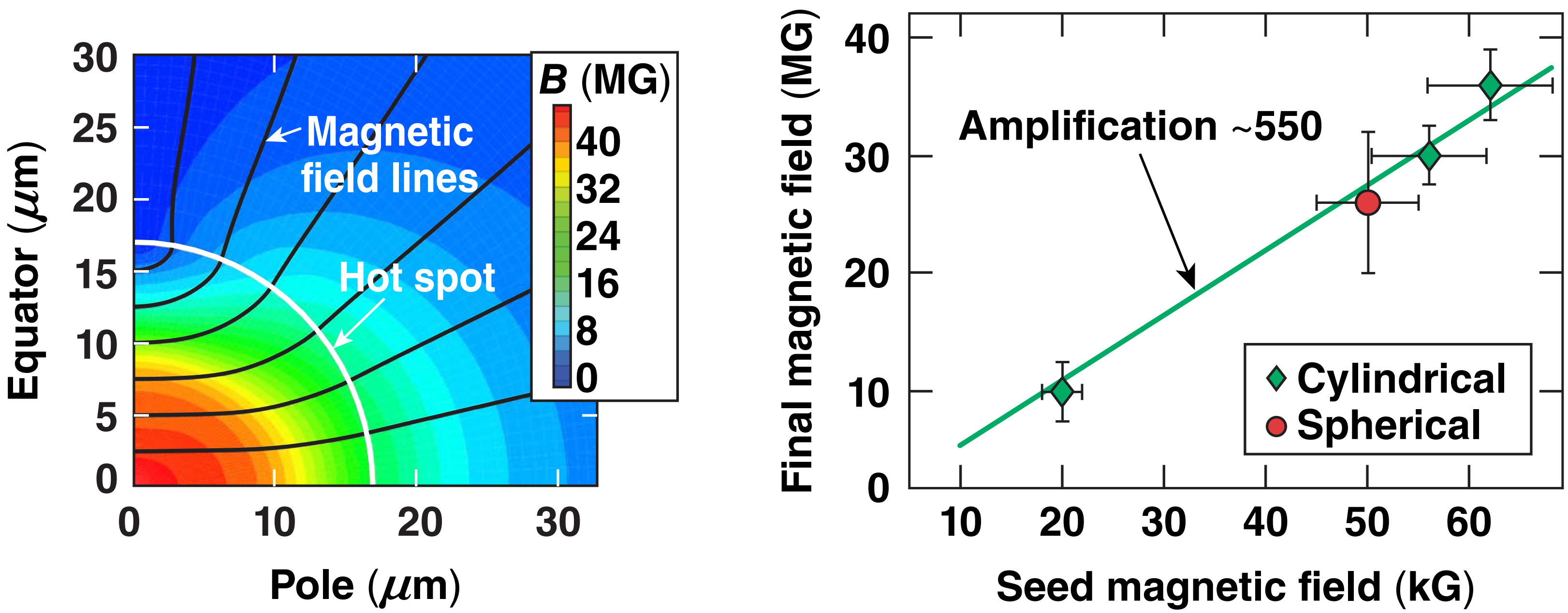




TC10325a

Applied Magnetic Fields

A magnetic field of ~25 MG was inferred in spherical implosions

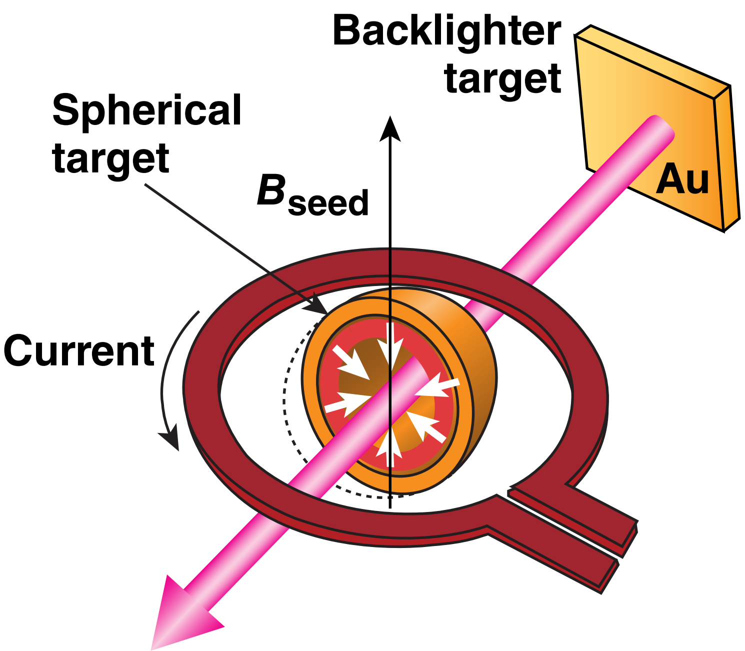


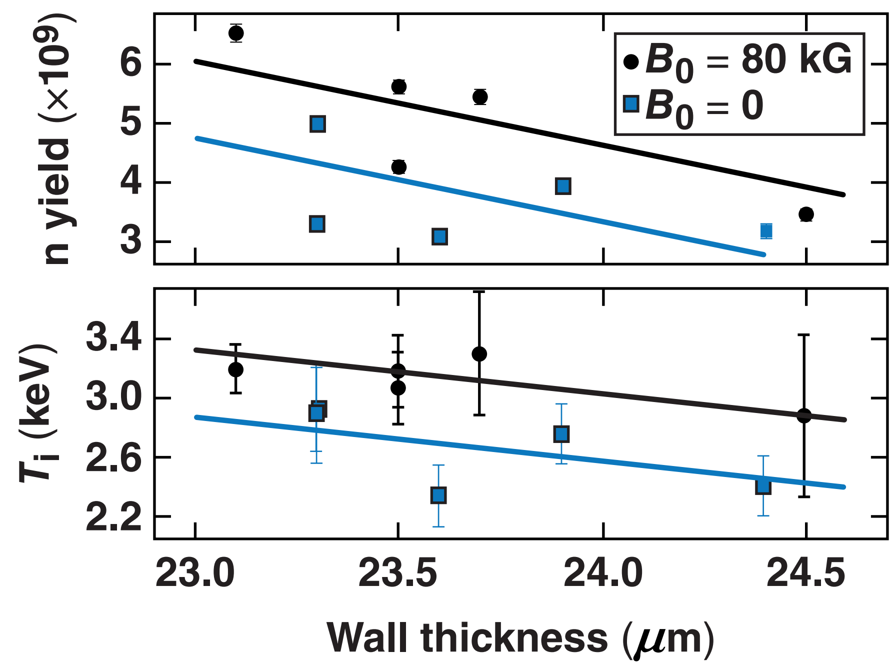
- Single-shot data indicated that the field is compressed to ~25 MG in a spherical target; more shots are needed to confirm the magnetic-field measurements

TC9729c

M. Hohenberger *et al*., Phys. Plasmas 19, 056306 (2012).

The neutron yields increased by ~30% in magnetized spherical targets



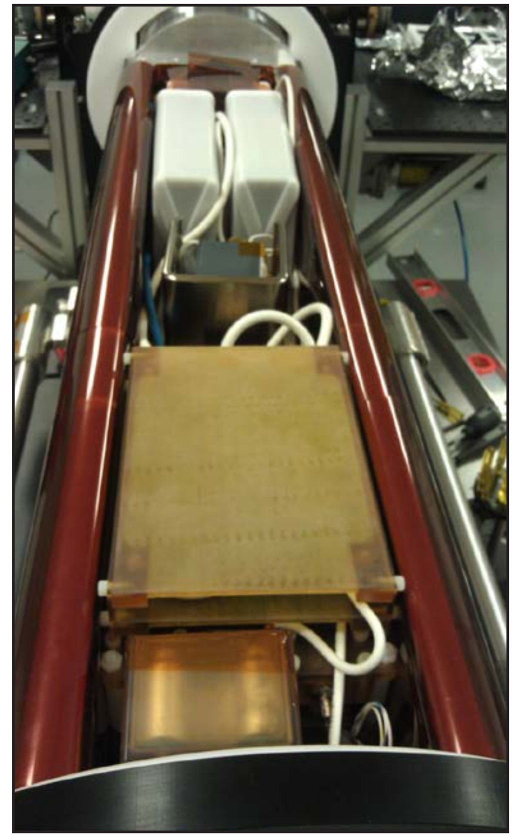


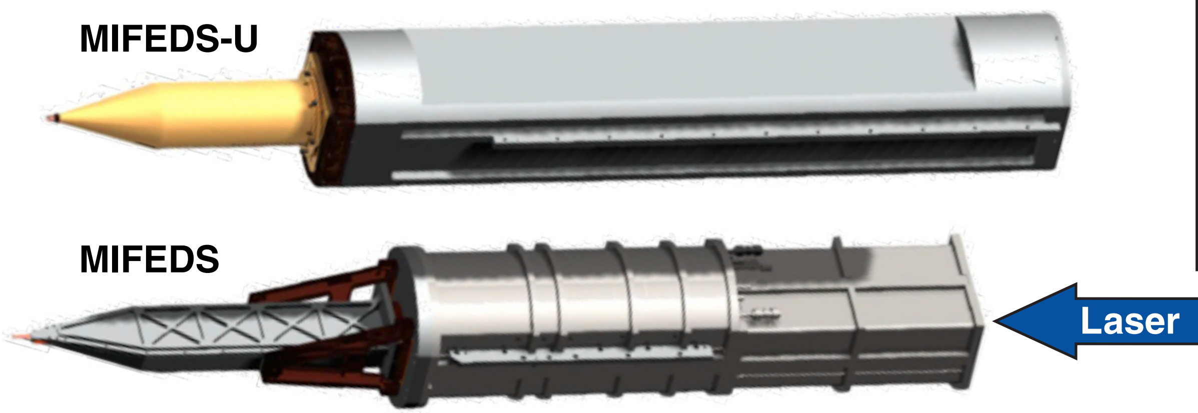
- The measured ion temperature and fusion yield were improved by 15% and 30%, respectively, when the hot spot was magnetized

E19783e

P. Y. Chang *et al.*, Phys. Rev. Lett. 107, 035006 (2011).

MIFEDS has been upgraded to be more robust and flexible in operation

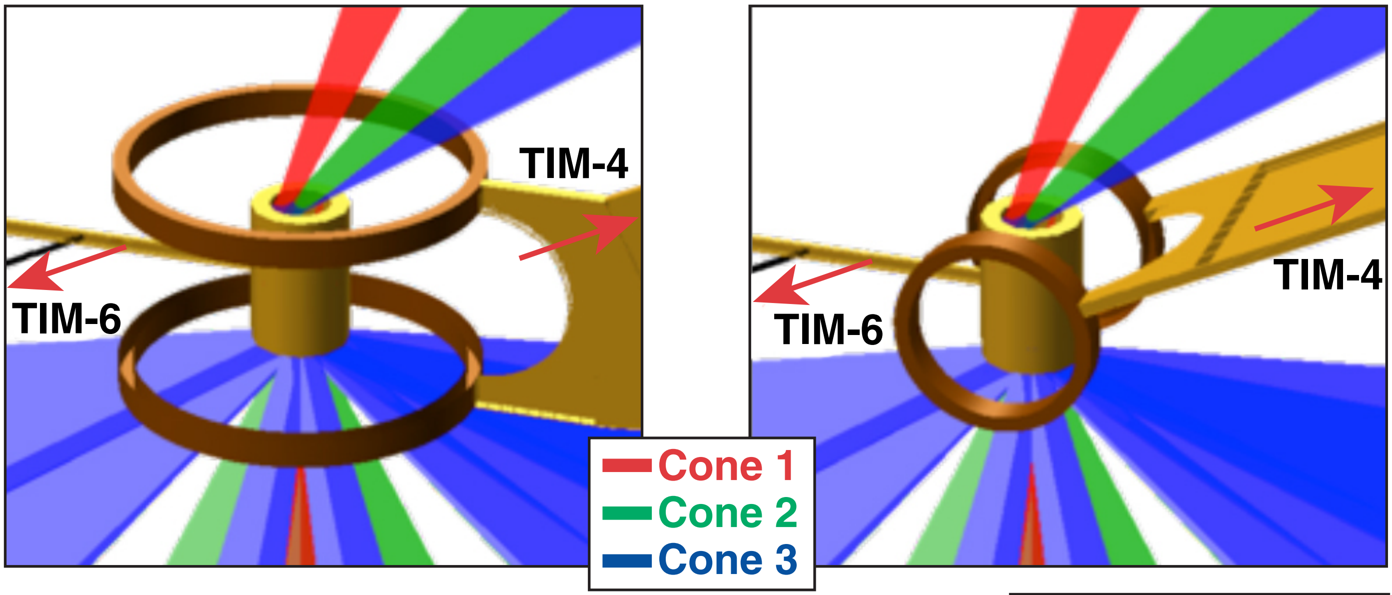


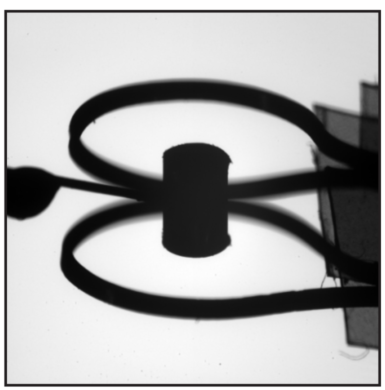


TC10282a

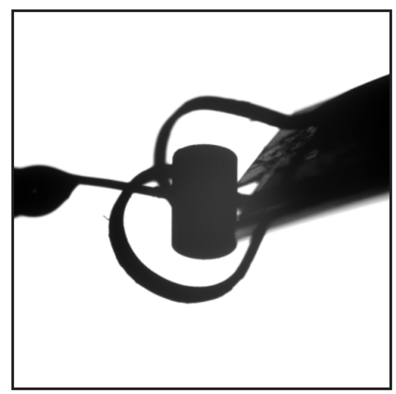
Experiments to control laser–plasma interactions with B fields in hohlraums have been carried out on OMEGA

Axial field | Transverse field





Use the B fields to magnetize electrons, decrease heat conductivity, increase temperature and supress LPI (SRS and TPD)



TC10287a

Summary/Conclusions

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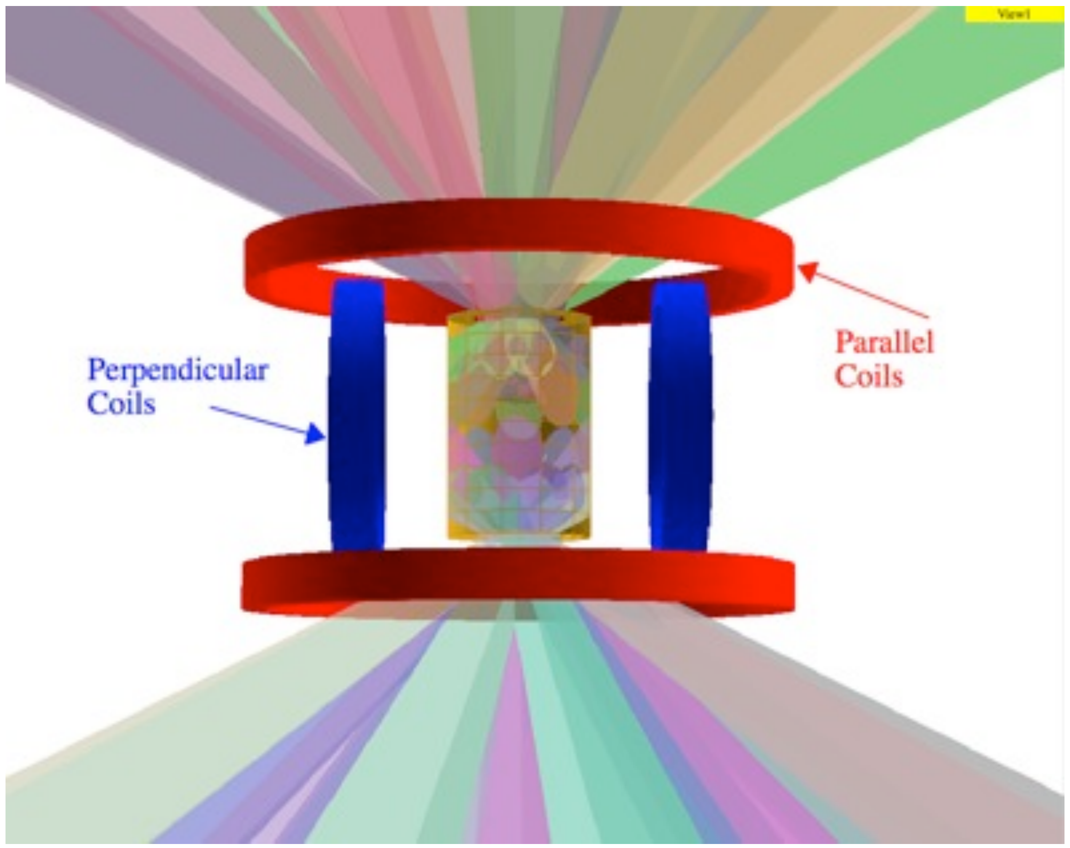
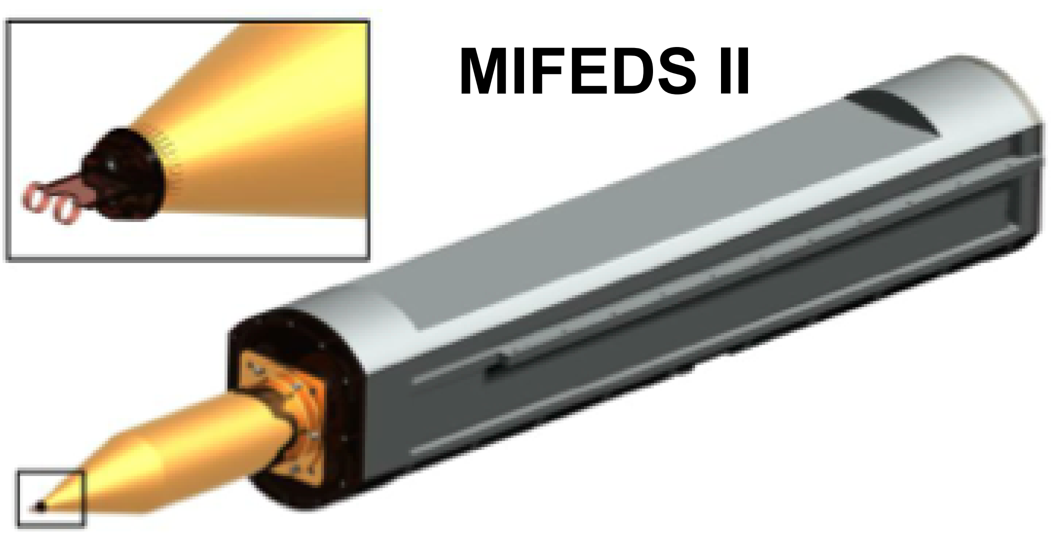
- High-Z ablators (SiO_2, Si, Al) reduce laser–plasma instabilities during the assembly pulse
- Magnetic fields improve hot-spot temperatures and facilitate ignition; when used in hohlraums, B fields can increase the plasma temperature and reduce laser–plasma instabilities

Fast electron control with magnetic field in hohlraums



Hohlraum:
wall - Au, 5 µm
l = 2.5 mm
d = 1.6 mm
d_{LEH} = 1 mm

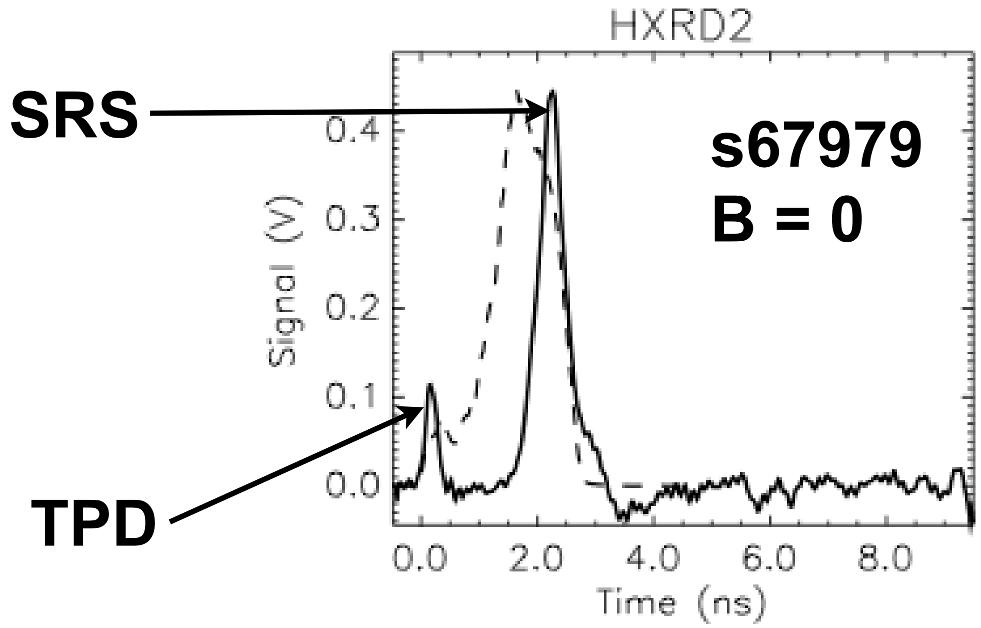
Parallel (axial) coils:
d = 6.75 mm
l = 4.0 mm
B = 10 T

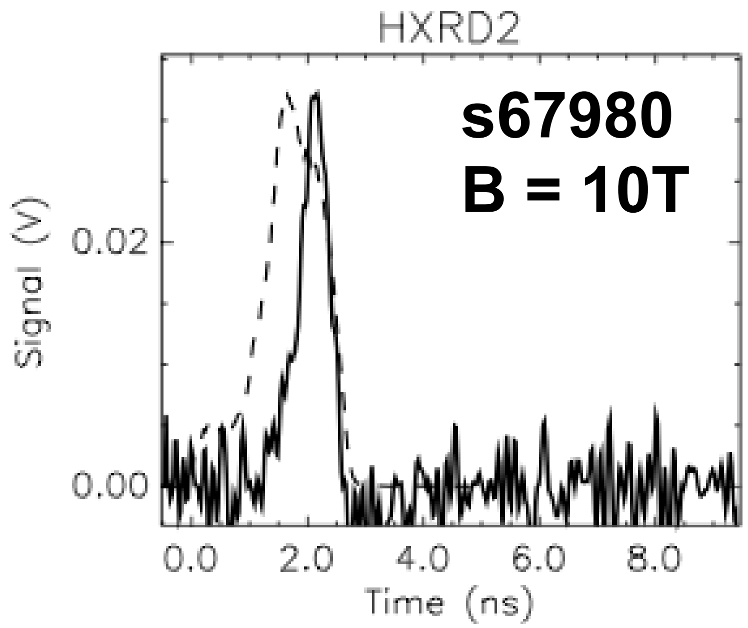


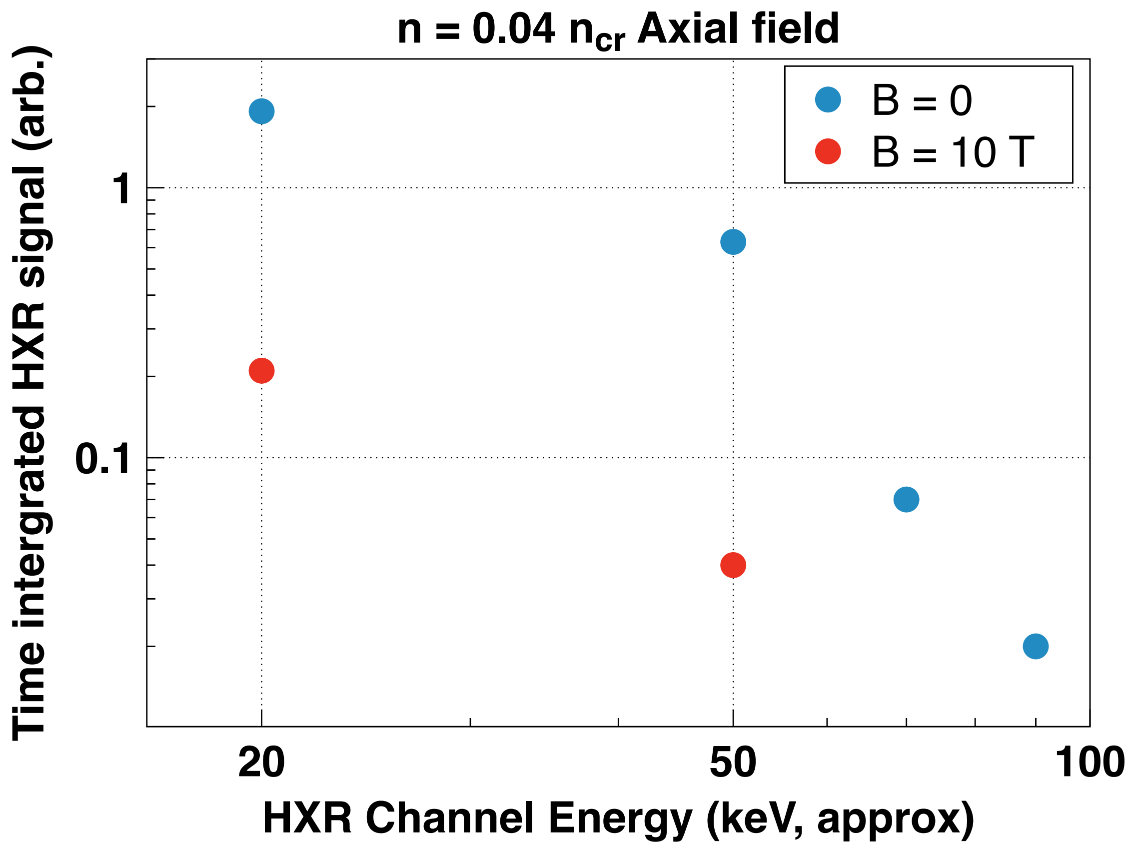
Perpendicular (transverse) coils:
d = 3.55 mm
l = 4.0 mm
B = 8 T

G. Fiksel
Dec 3 2012

In two shots with matching fill pressure at n = 0.04 n_{cr} HXR decreases with axial field



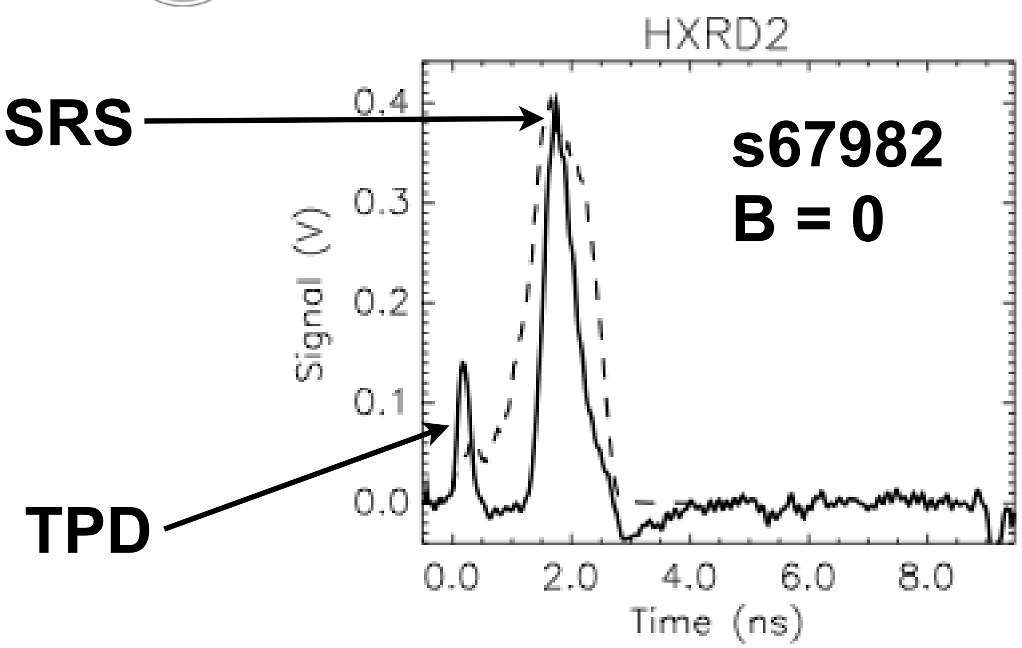


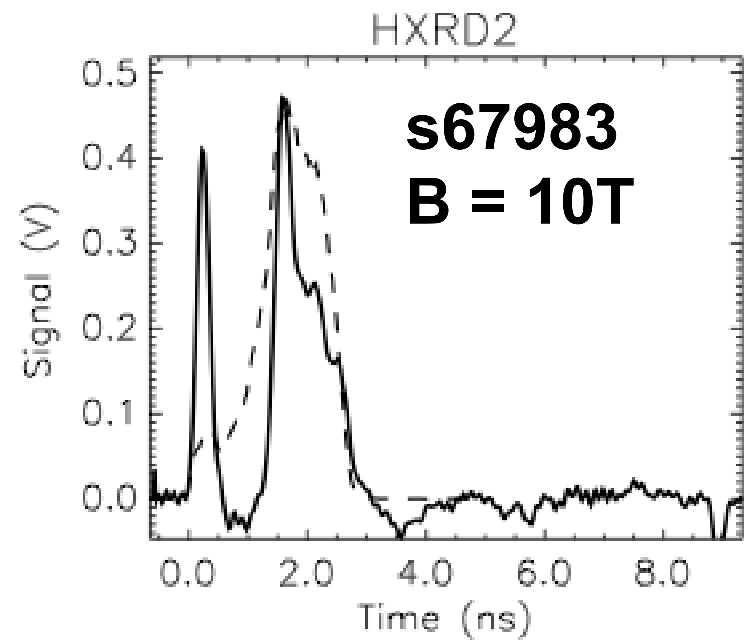


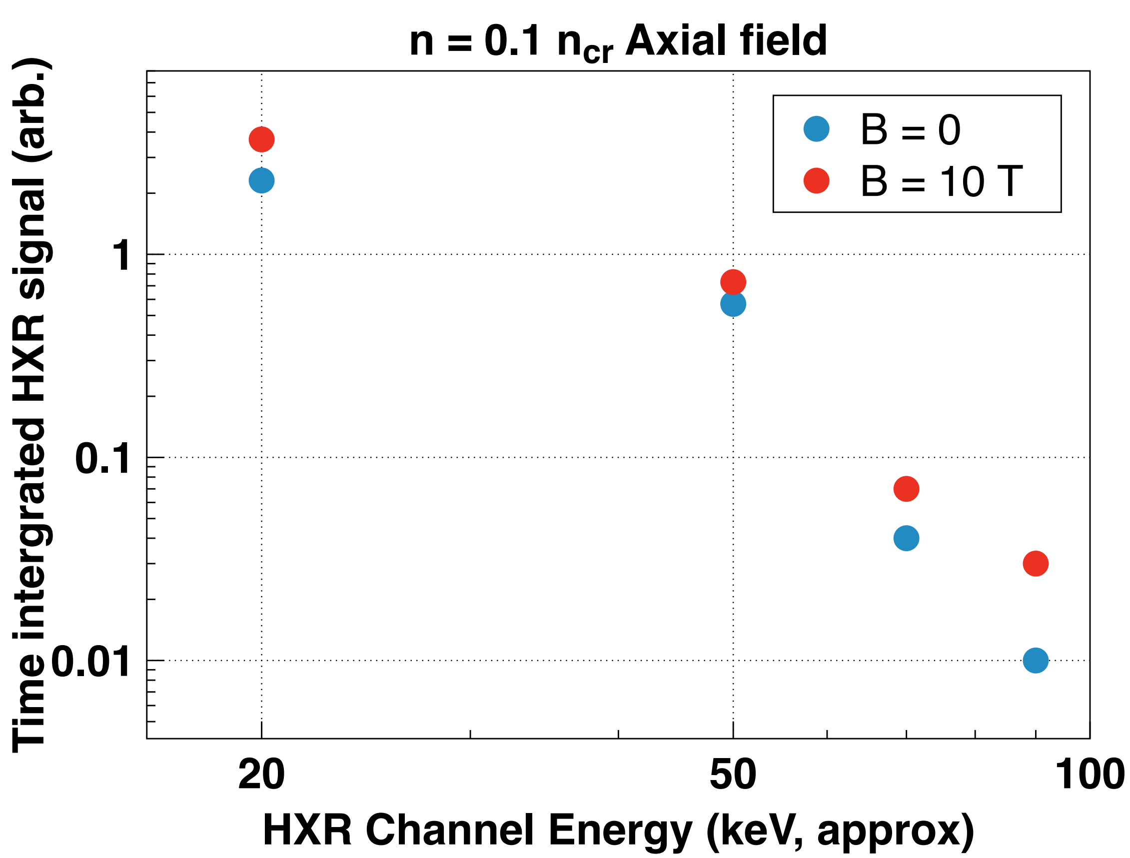
Both TPD and SRS signals are reduced

Two shots with matching fill pressure:
s67979 - 0.85 atm
s67980 - 0.90 atm

In two shots with matching fill pressure at n = 0.1 n_{cr} there is no HXR reduction with axial field







TPD is 2x higher
SRS is not reduced

Two shots with matching fill pressure:
s67982 - 0.85 atm
s67983 - 0.90 atm