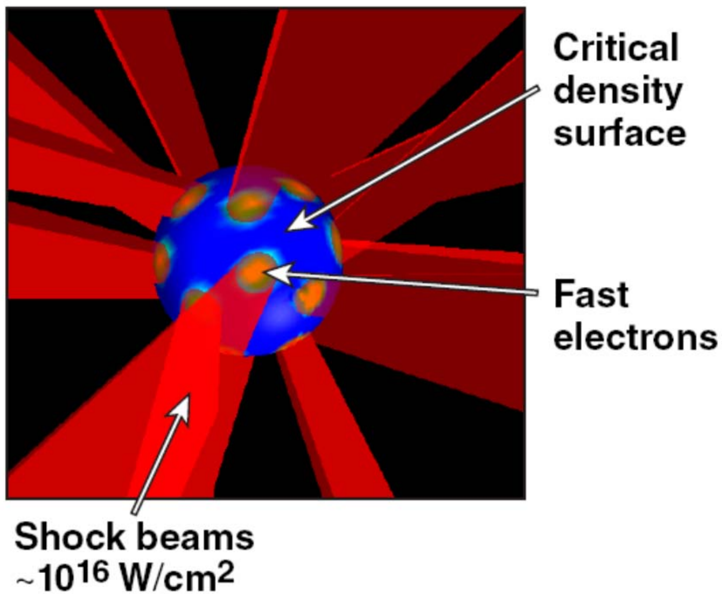
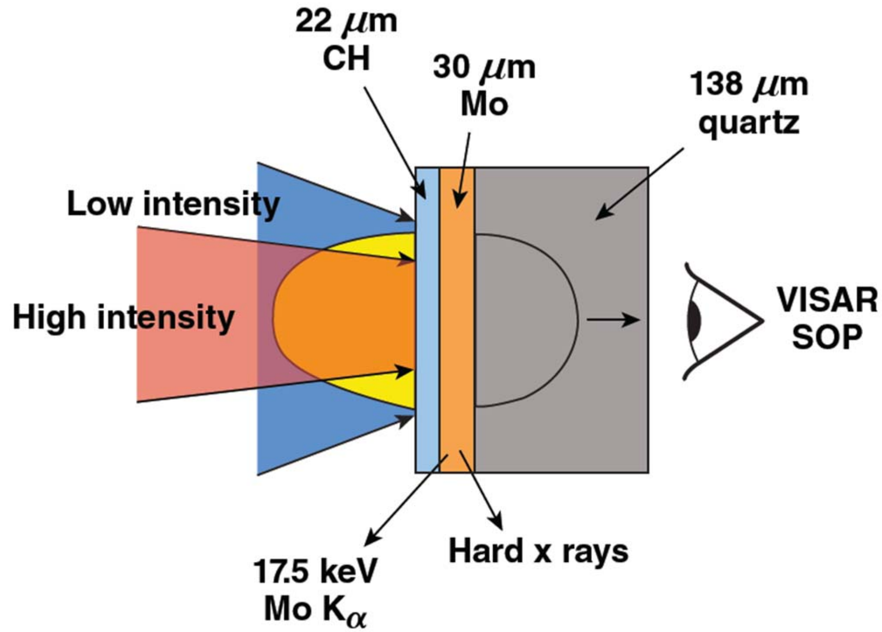
Shock Ignition Experiments on OMEGA





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LLE, Rochester NY
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High intensity laser-plasma interaction experiments on OMEGA provide valuable backscattering, fast electron, and shock wave timing data

- The 40 + 20 experiment showed strong laser backscattering and a significant energy transfer into fast electrons.
- The drive symmetry in 40 beam implosions was improved by repointing the beams.
- Triple picket implosions with 15 kJ in 40 beams on D_2 filled CH shells achieved $\langle\rho R\rangle_{n\text{-rate}} \sim 170$ mg/cm^2.
- Planar-target experiments measured $T_{hot} \sim 150$ keV and up to 6% conversion efficiency into hot electrons.

Collaborators

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Laser–plasma interaction during the spike pulse and hot-electron generation are important issues for shock ignition

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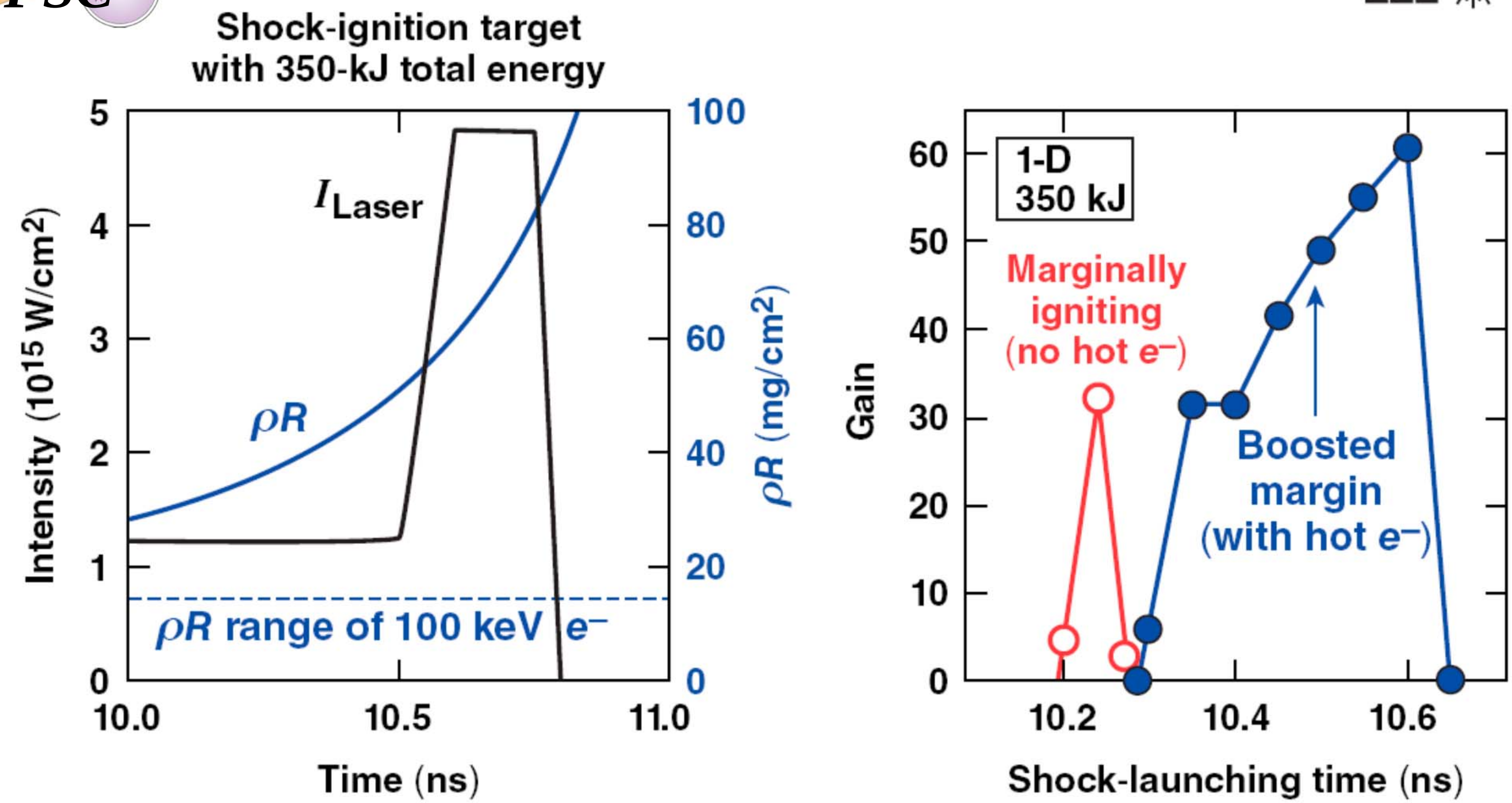
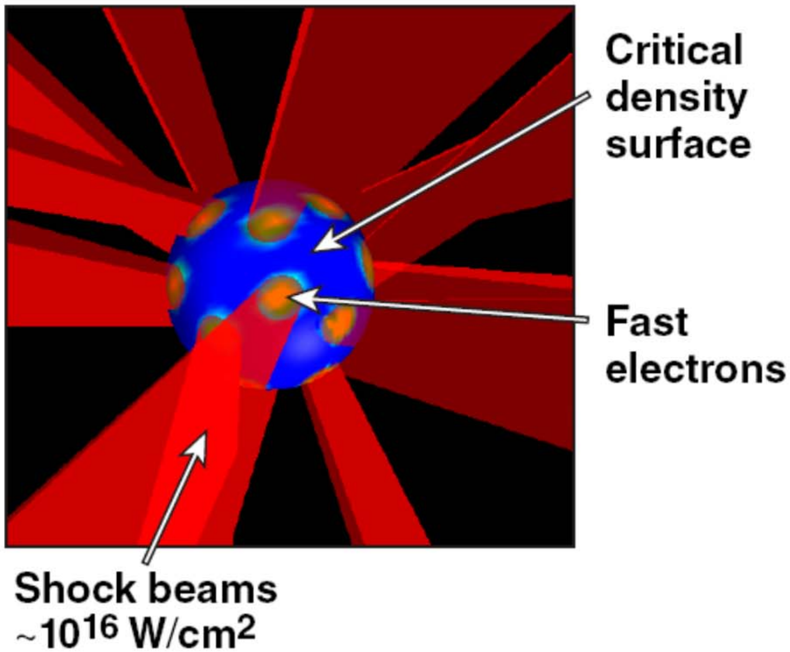


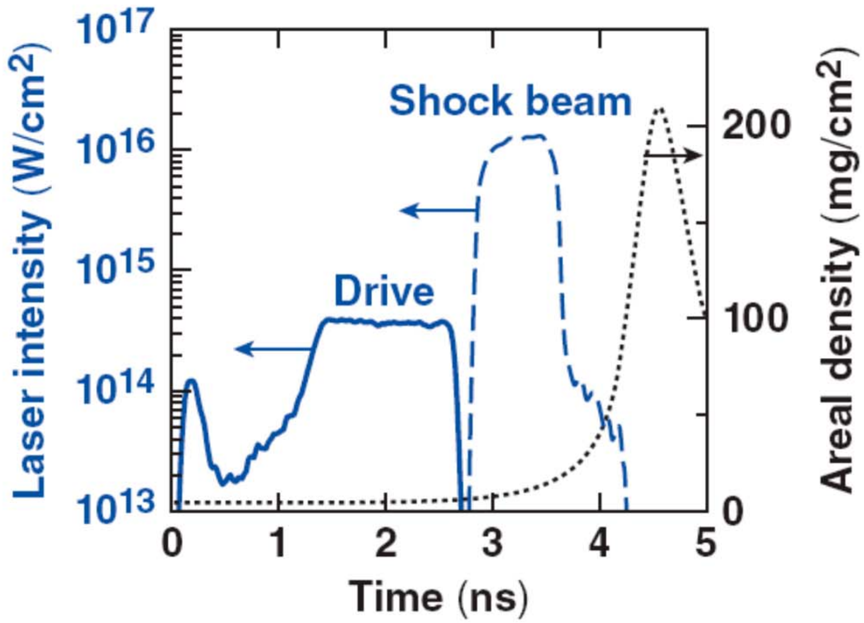
Hot e⁻ with Maxwellian T_{hot} = 150 keV, E_{hot} = 17% of spike energy, treated using a multigroup diffusion model*

TC7870d

*LILAC simulations by C. D. Zhou and R. Betti

60 OMEGA beams are split into 40 low-intensity drive beams and 20 tightly focused, delayed beams





- 35 μm thick CD shells filled with 25 atm of D2
- Density scale length (@1/4 n_c) ~90 μm
- The delay and intensity of the tightly focused beams are varied
- Laser backscattering and hot-electron generation are studied

Up to 35% of the shock-beam laser energy is lost due to backscatter

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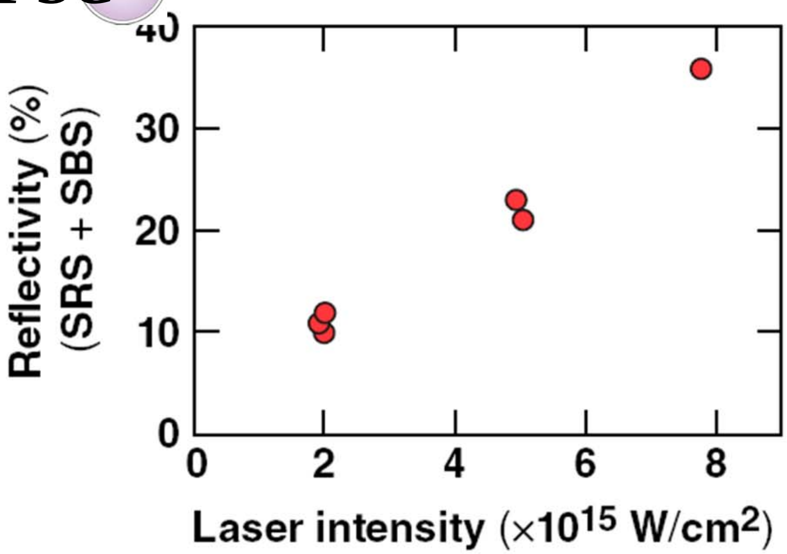
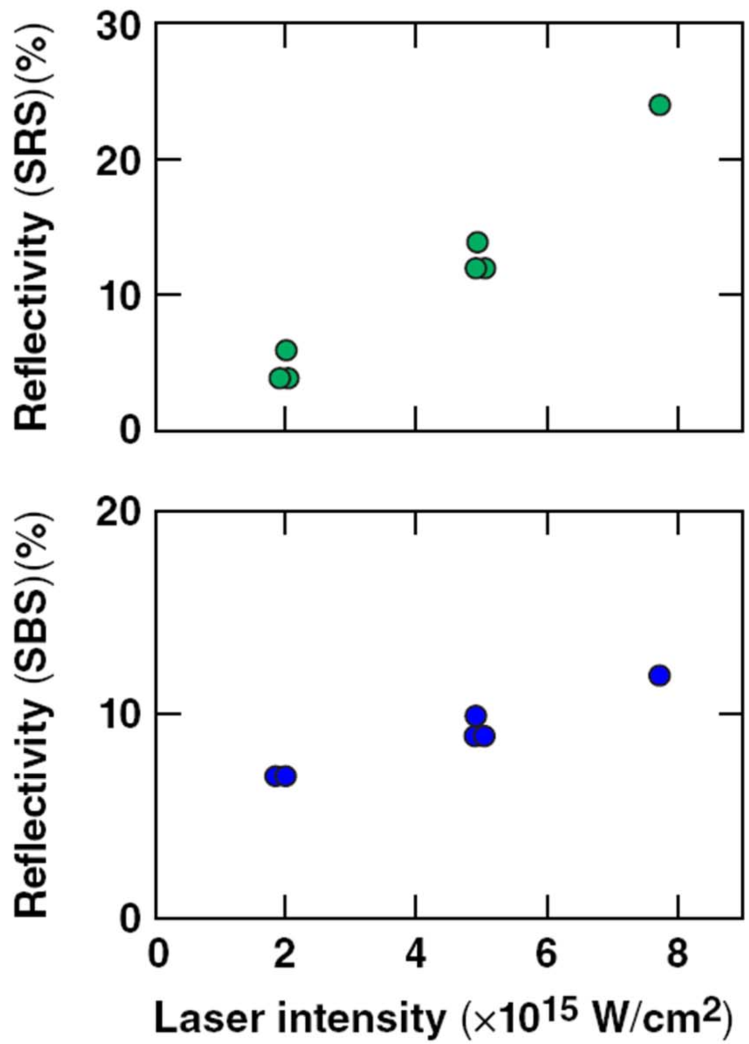
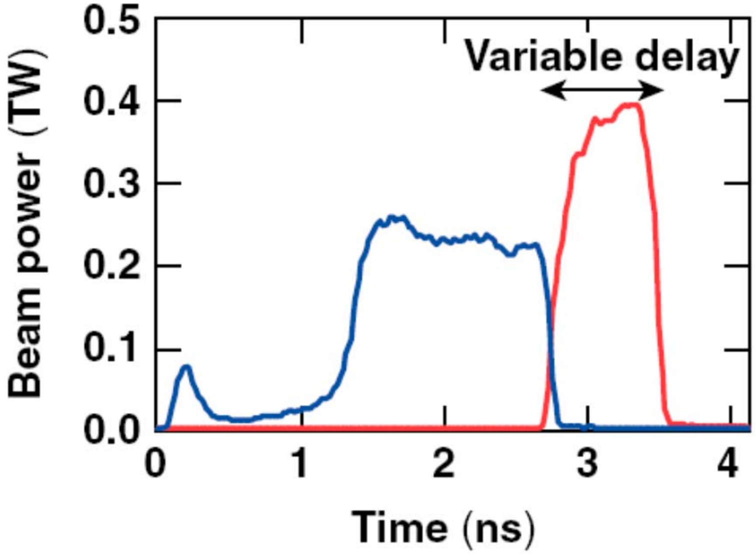


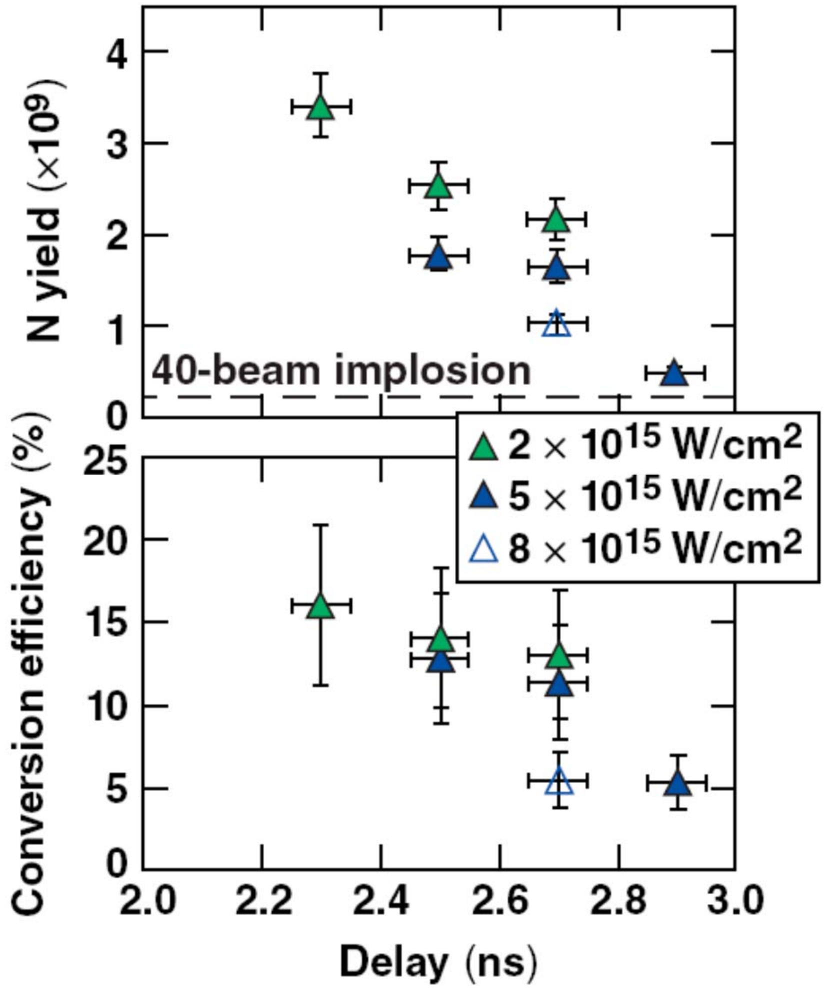


- No measurable signal of the 3/2 harmonic
- SRS dominates back reflection at highest intensity
- SBS reflection is relatively stable at ~10%

E18435

Up to 16% of the shock-beam energy is converted into hot electrons of 45-keV temperature

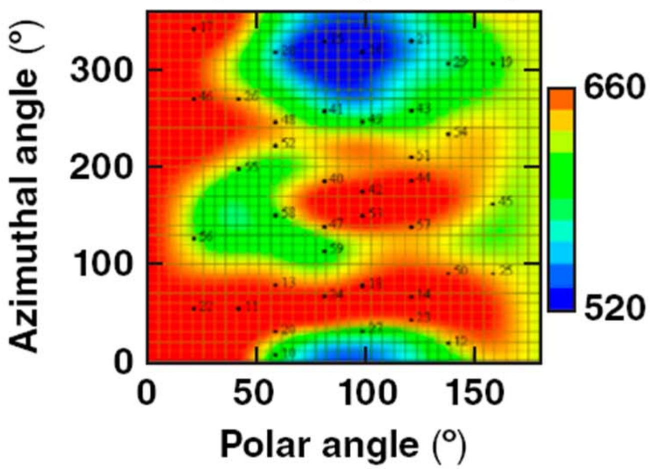




Initial 40 beam implosions suffered from a poor power balance

Calculated 40-beam drive power

Direct laser power deposited (TW/cm^2)



- ~11% power imbalance

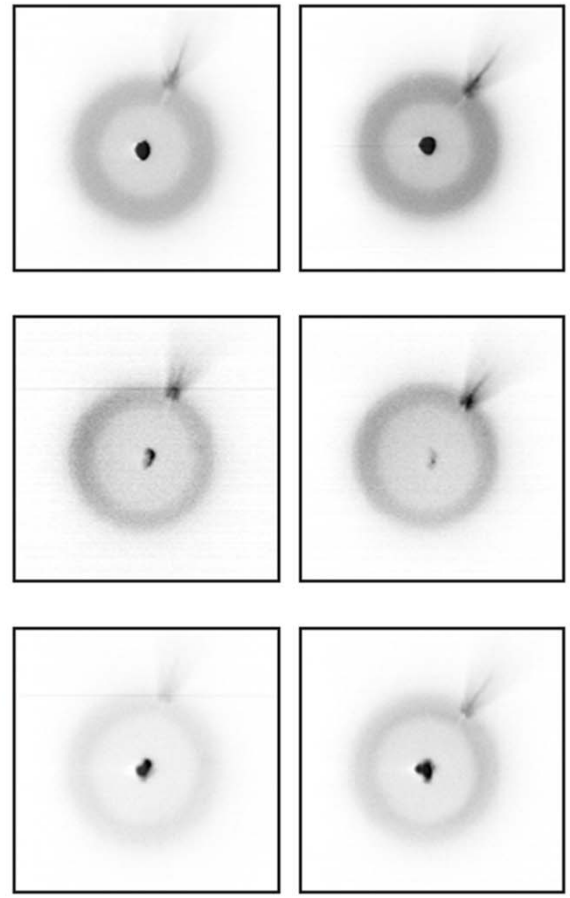
X-ray pinhole images

View 1 View 2

60 beam, 20.8 kJ
uniform illum.
N yield: 1.3×10^{10}

40 beam, 13.7 kJ
nonuniform illum.
N yield: $\sim 2 \times 10^{8}$

40 + 20 beam,
13.6 + 4.8 kJ = 18.4 kJ
nonuniform illum.
N yield: 3.7×10^{9}



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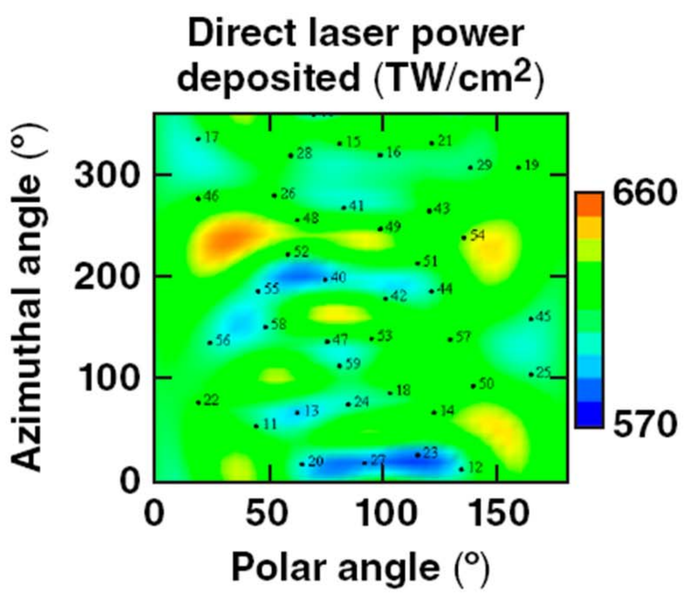
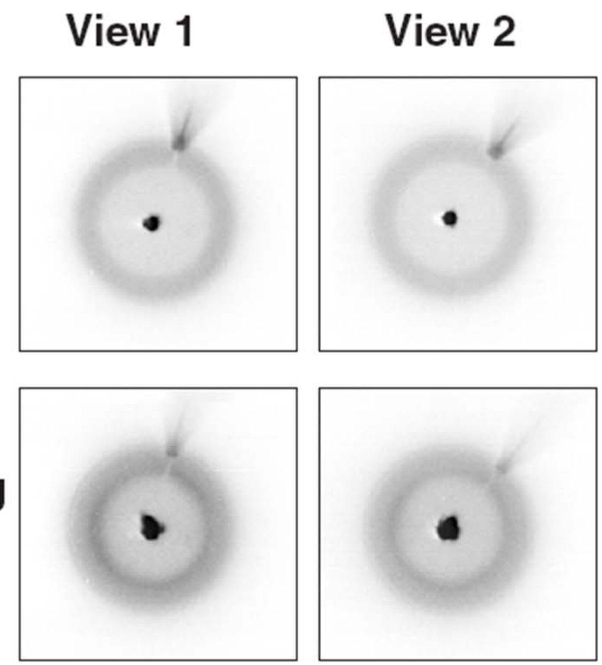
The drive symmetry in 40 beam implosions was improved by repointing the beams

Calculated 40-beam drive power



- ~2.6% power imbalance with repointed beams

X-ray pinhole images



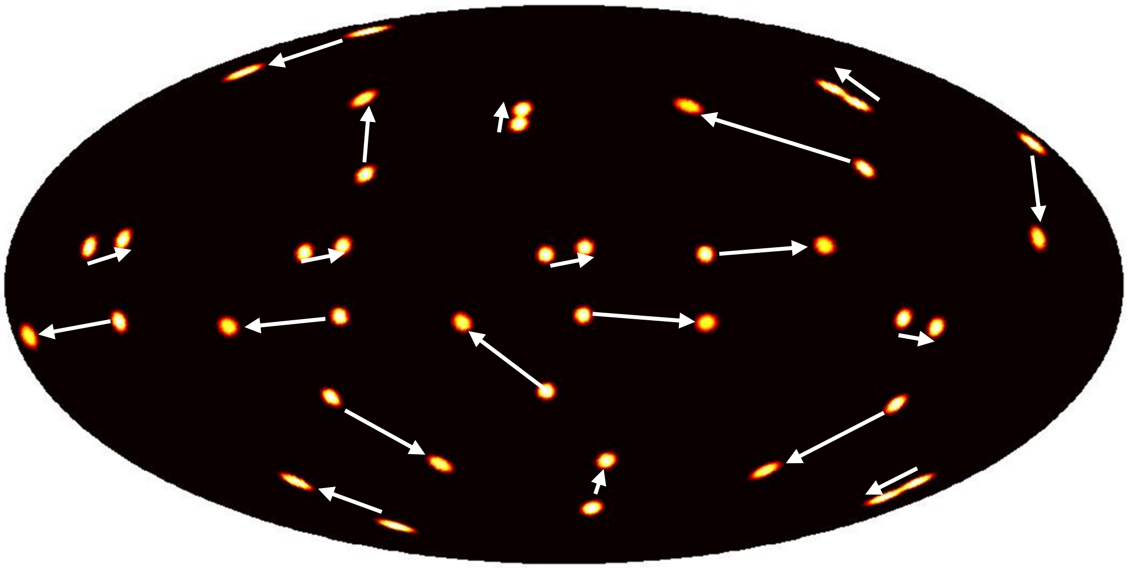
40 beam, 13.5 kJ
improved illum.
N yield: 1.6×10^9

40 + 20 beam,
13.9 + 5.6 kJ = 19.5 kJ
improved illum.
N yield: 3.3×10^9

The 20 high intensity beam were also repointed

Beam ID	Polar Angle (°)	Azm Angle (°)
30	142.62	18.00
31	37.38	342.00
32	79.19	77.94
33	37.38	270.00
34	100.81	257.94
35	100.81	41.94
36	79.19	293.94
37	79.19	5.94
38	142.62	306.00
39	100.81	329.94
60	79.19	221.94
61	37.38	198.00
62	142.62	162.00
63	100.81	185.94
64	142.62	234.00
65	79.19	149.94
66	37.38	54.00
67	100.81	113.94
68	37.38	126.00
69	142.62	90.00

Beam displacements
(parallel displacement)

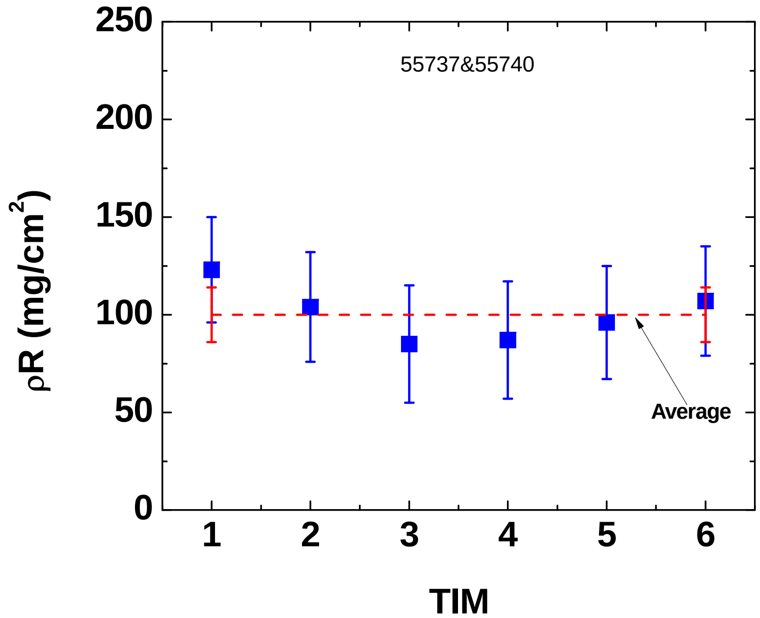


Aitoff representation

The 20 shock beams form a dodecahedron pattern

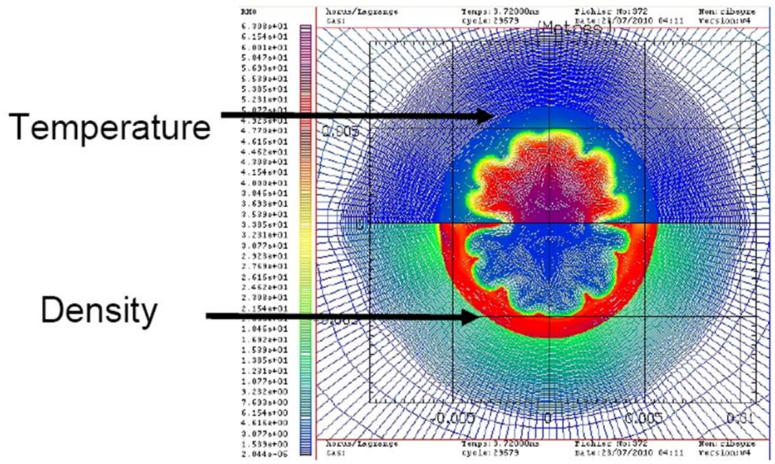
The measured areal density varies with observation direction

Experiment



Preliminary CHIC 2D simulations

Without radiative transport



The stagnation is perturbated

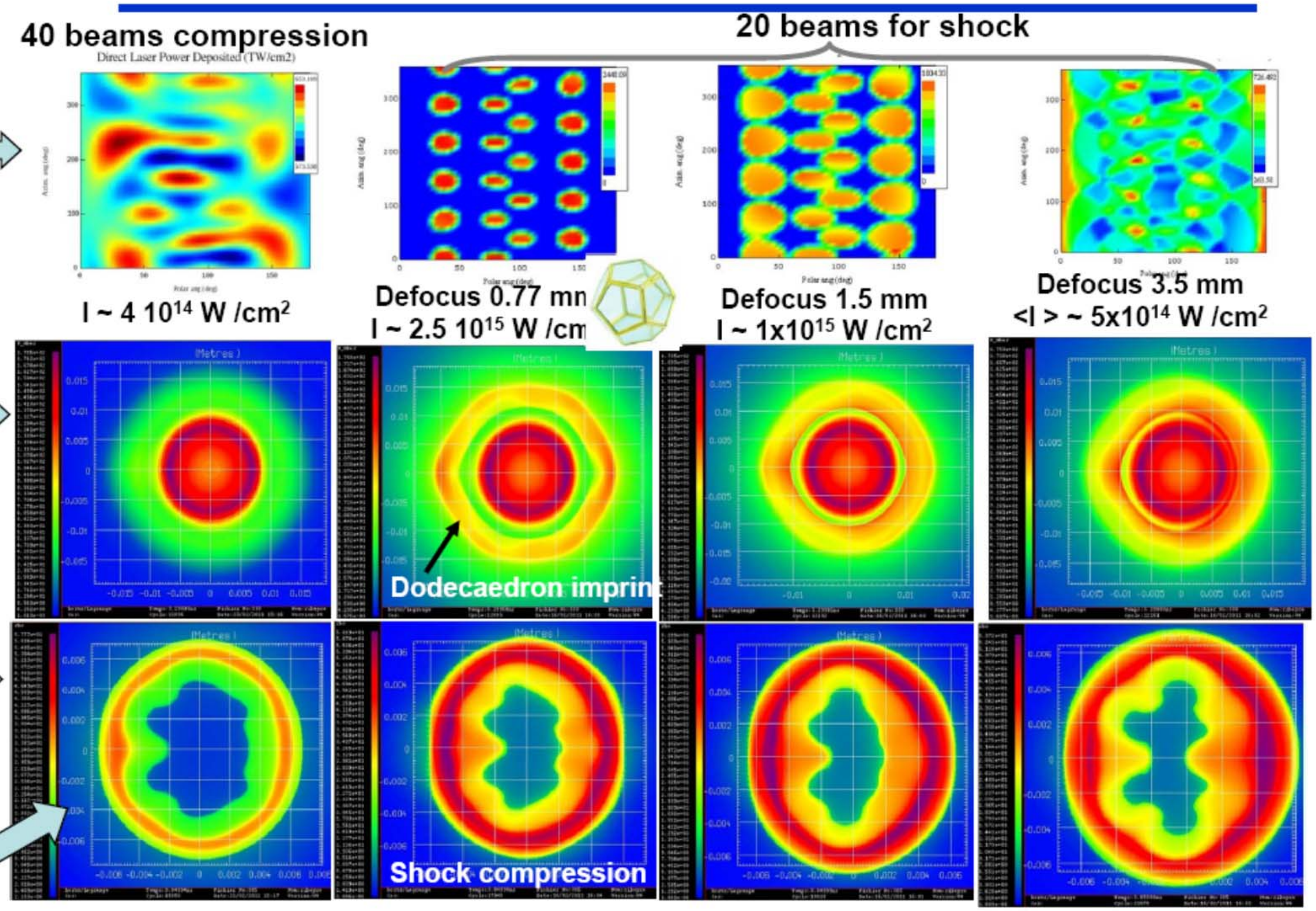
1D predicted peak ρR: 130 mg/cm^2

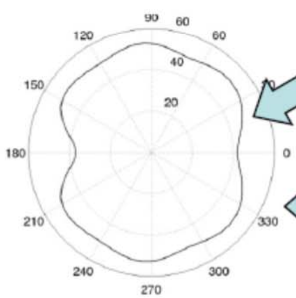
Effects of low shock asymmetry on the fuel assembly are evaluated in 2D CHIC calcs.

VisRad illumination

Pressure Before Shock collision

Density 100 ps After max neutron rate

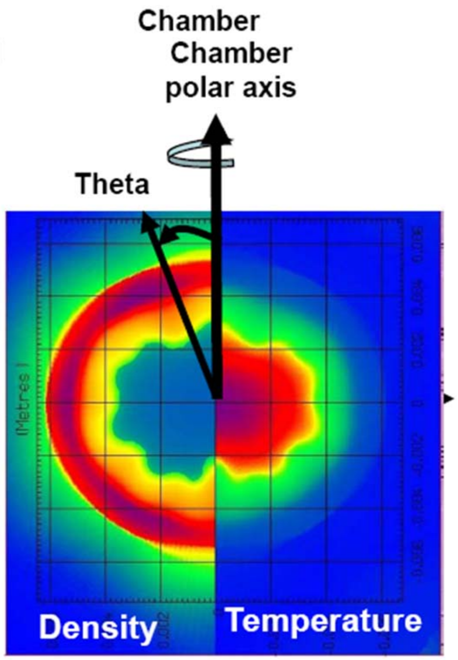


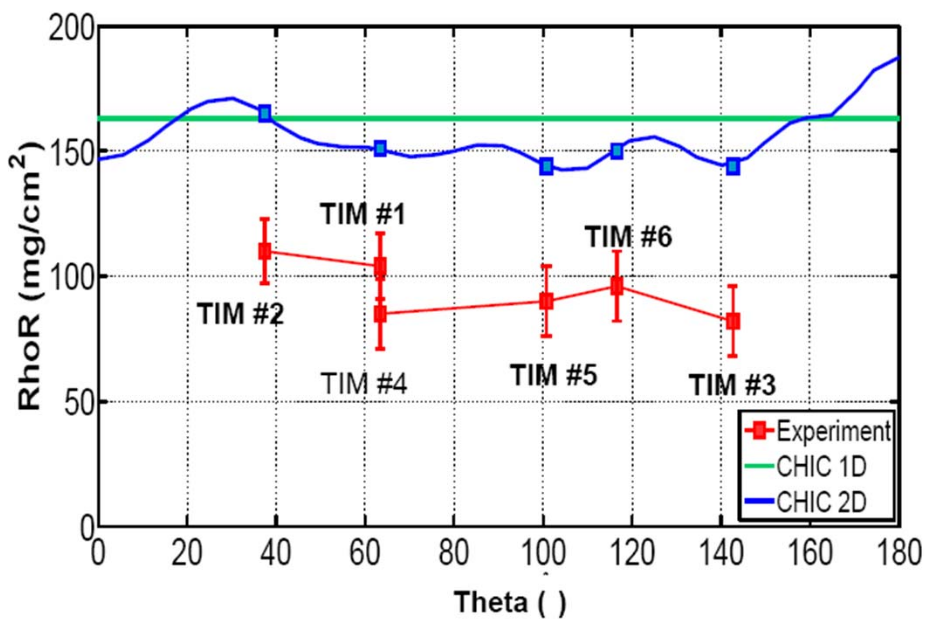


Inner interface model for compression from illumination

Dominant modes: l=2 and l=6

2D simulations roughly reproduce the measured modulations of the areal density

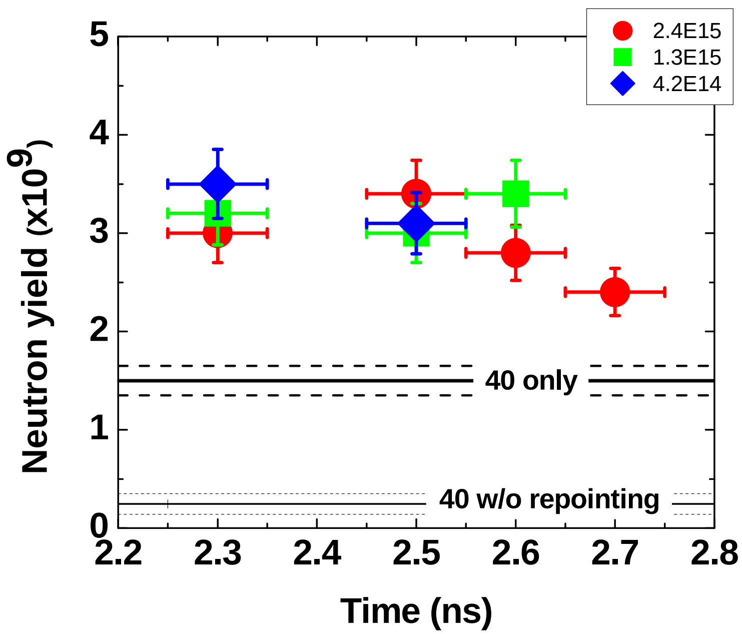




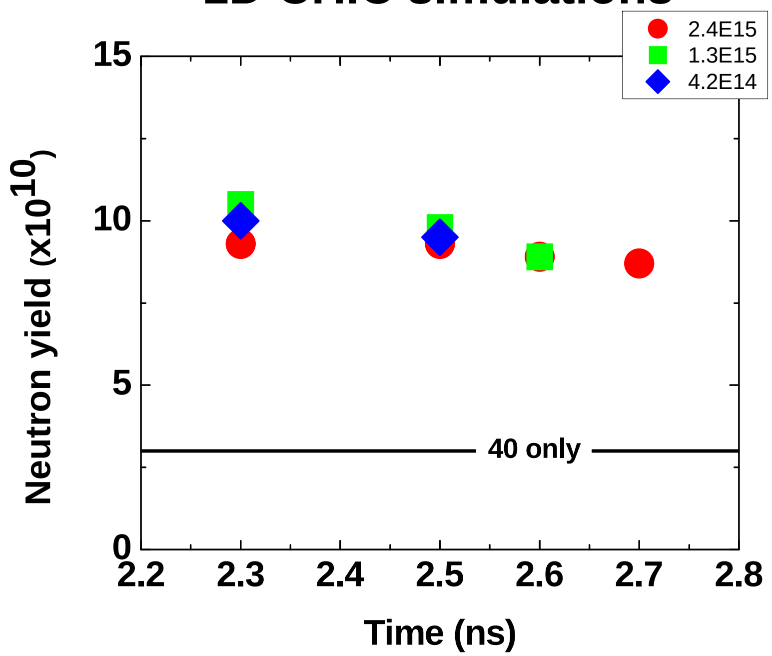
- 2D CHIC simulation ρR is ~50 mg/cm^2 higher (peak ρR)
- ρR variation with Theta agrees with simulations

The spike intensity does not significantly affect the neutron production

Experiment

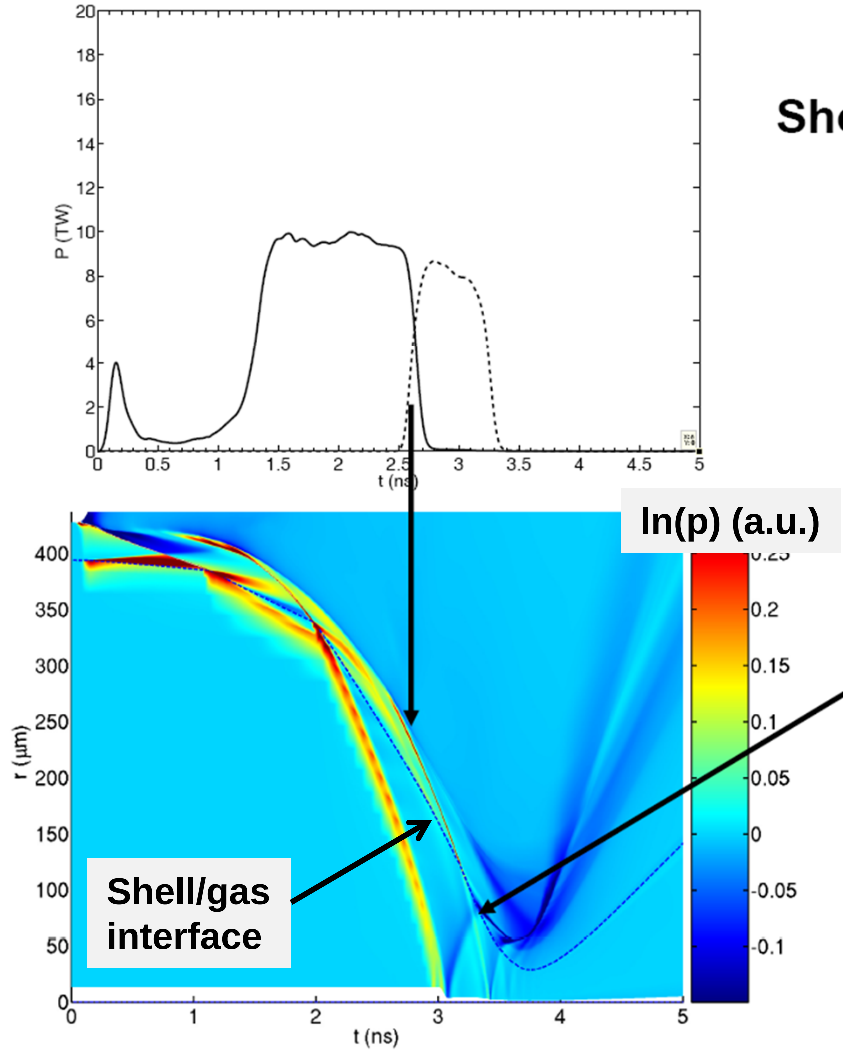


1D CHIC simulations



- YOC ~ 5% w/o spike
- YOC ~ 3% with spike
- Experimental n-yield enhancement: ~2.3
- 1D predicted n-yield enhancement: ~3.6

The laser pulse ends too early, which is detriment to the spike timing



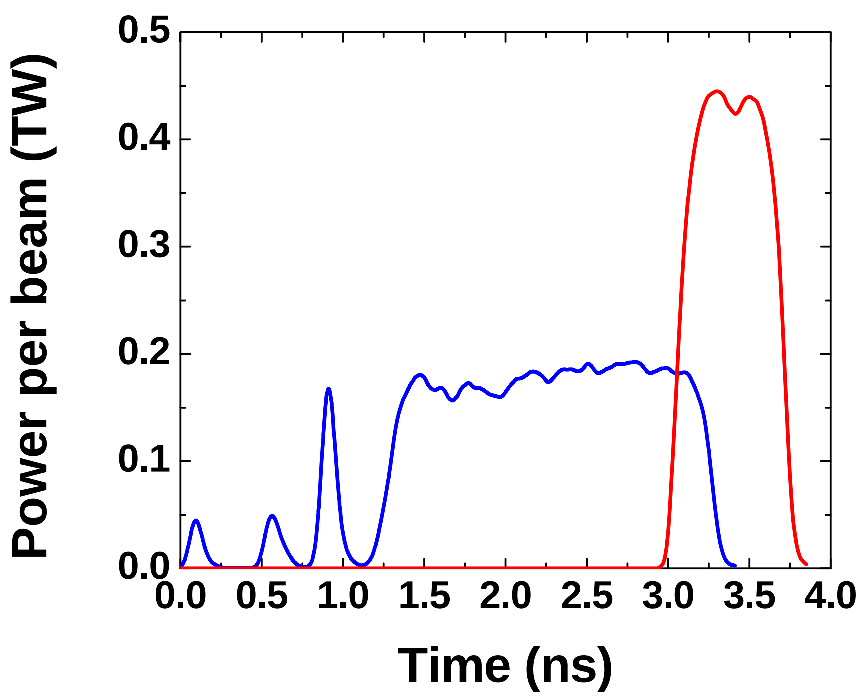
Shot #58342

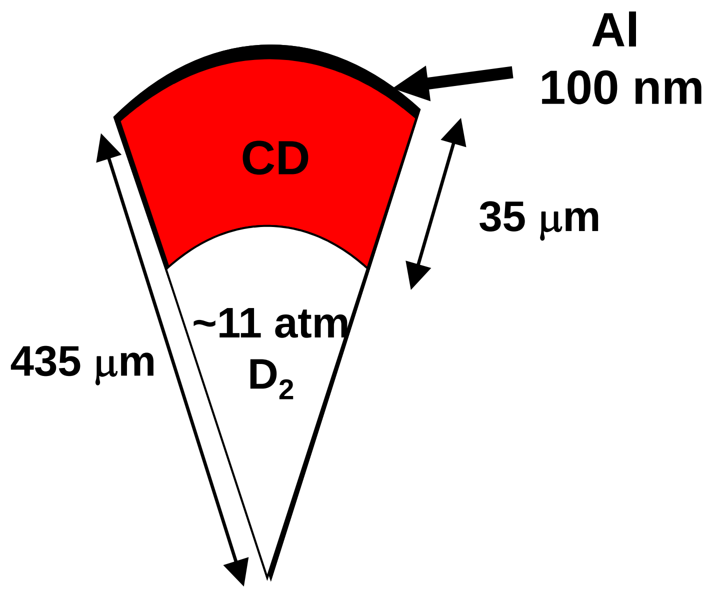
- The compression pulse ends during the acceleration phase of the target and does not allow an efficient implosion for the target

The collision between the return shock from the compression and the spike shock takes place in the gas

- The early spike timing prevents an efficient pressure amplification by the shock collision

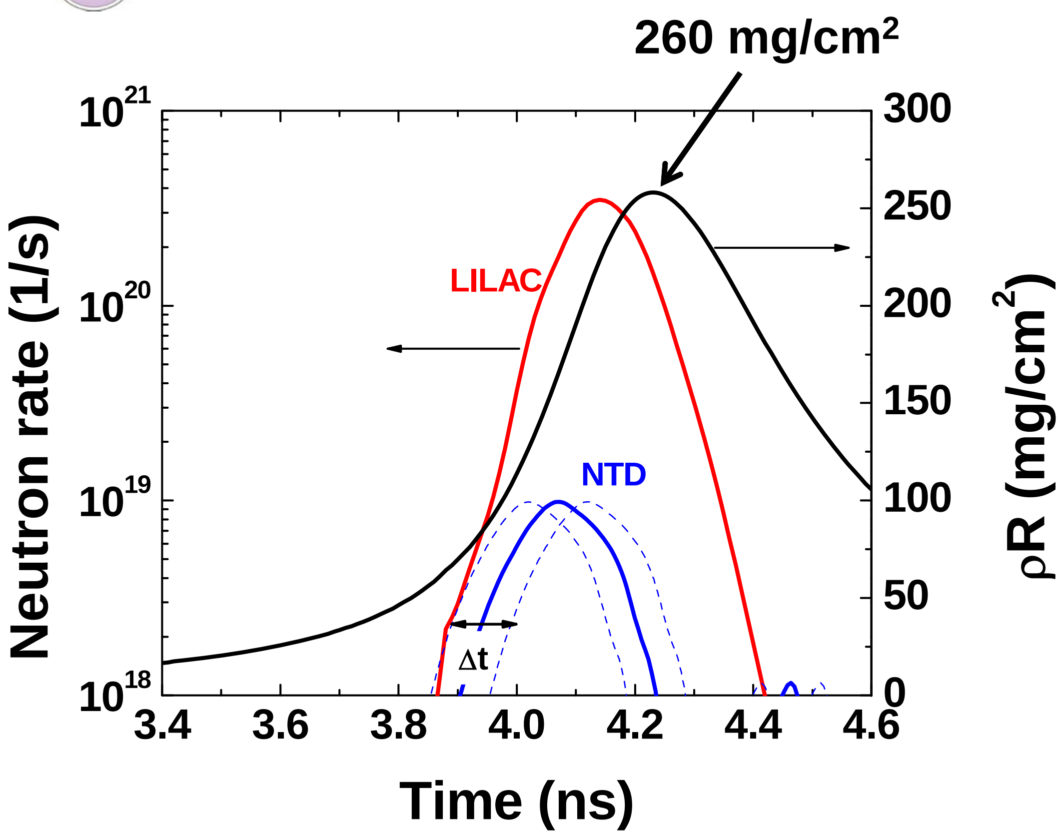
An improved design with triple picket pulse shape was used for the 40 drive beams





- E_{drive} = 15.5 kJ
- E_{spike} = 5.7 kJ
- With SSD

The triple picket pulse shape achieved an areal density of up to ~170 mg/cm² with 40 beams



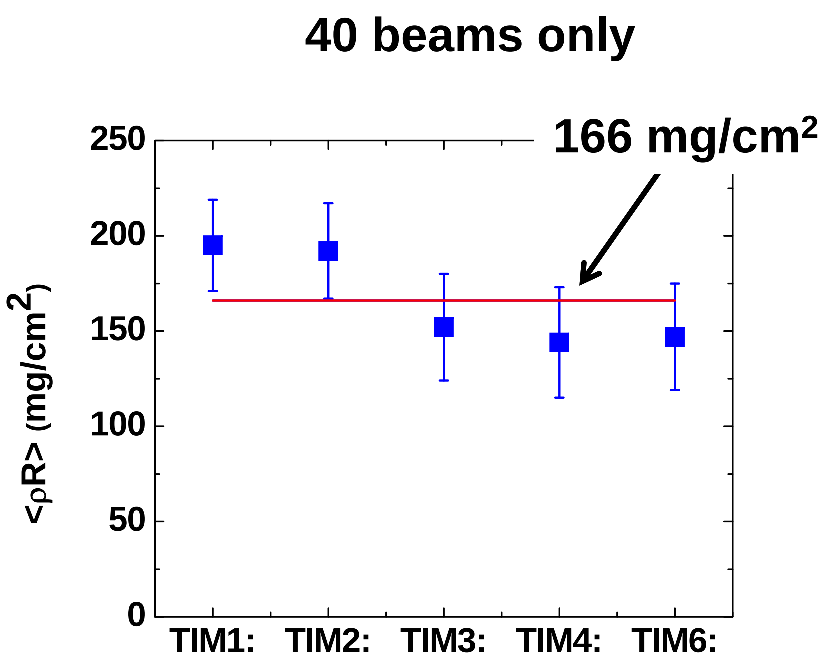
- LILAC simulation
- SBS model
- Nonlocal e- transport

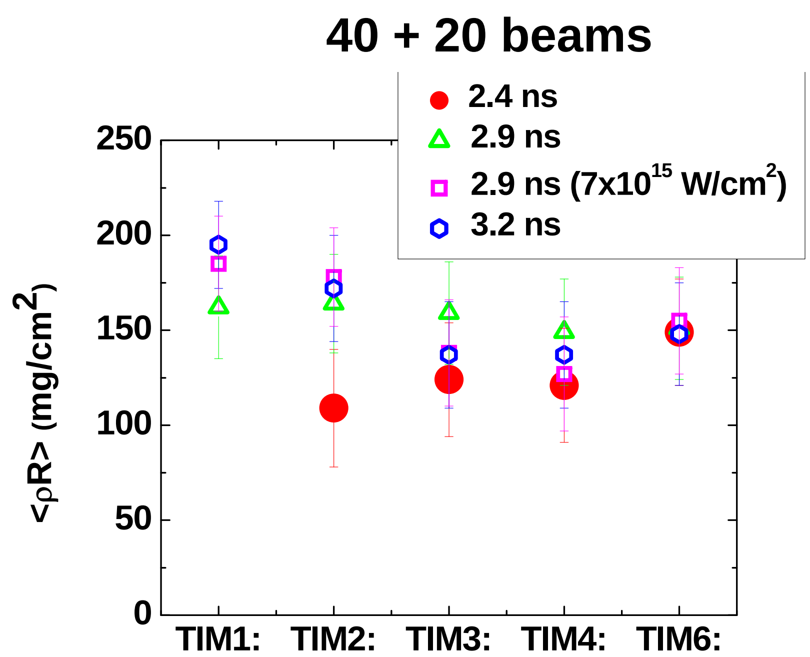
$\langle \rho R \rangle_{exp} = 166 \pm 25$ mg/cm²

$\langle \rho R \rangle_{NTD} = 174 \pm 30$ mg/cm²

YOC ~3%

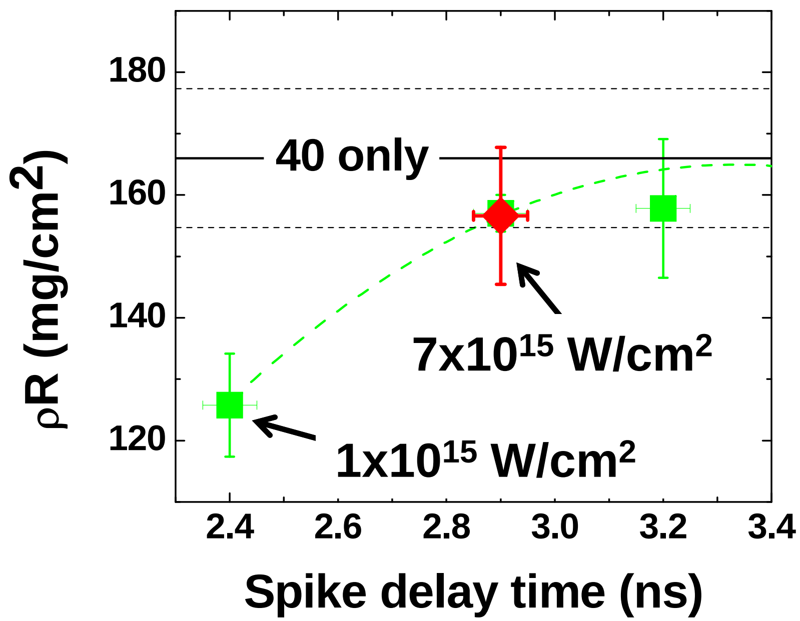
Areal densities are significantly higher than with the single picket pulse shape

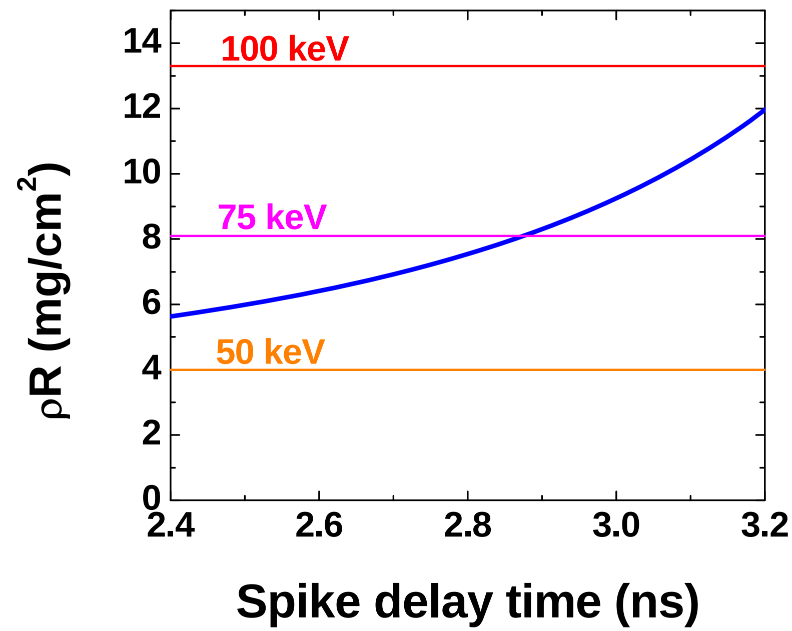




A similar ρR asymmetry is observed as in the single picket pulse shape implosions.

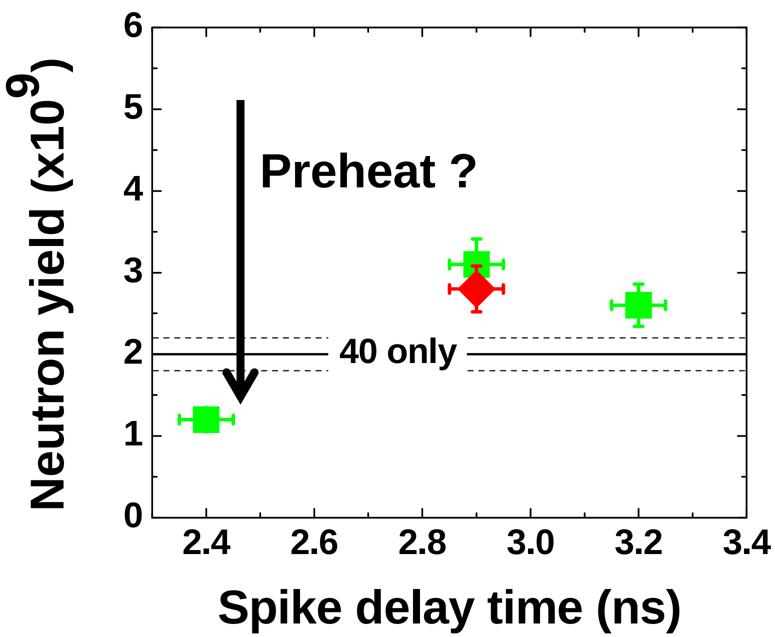
Fast electron preheat might reduce the areal density at early spike delay times



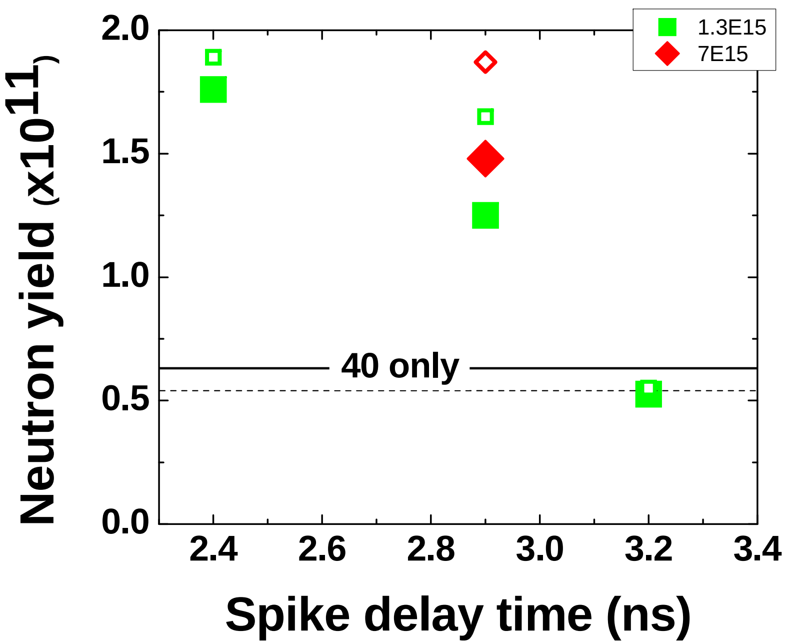


The measured neutron yield is significantly lower at early delay times

Experiment



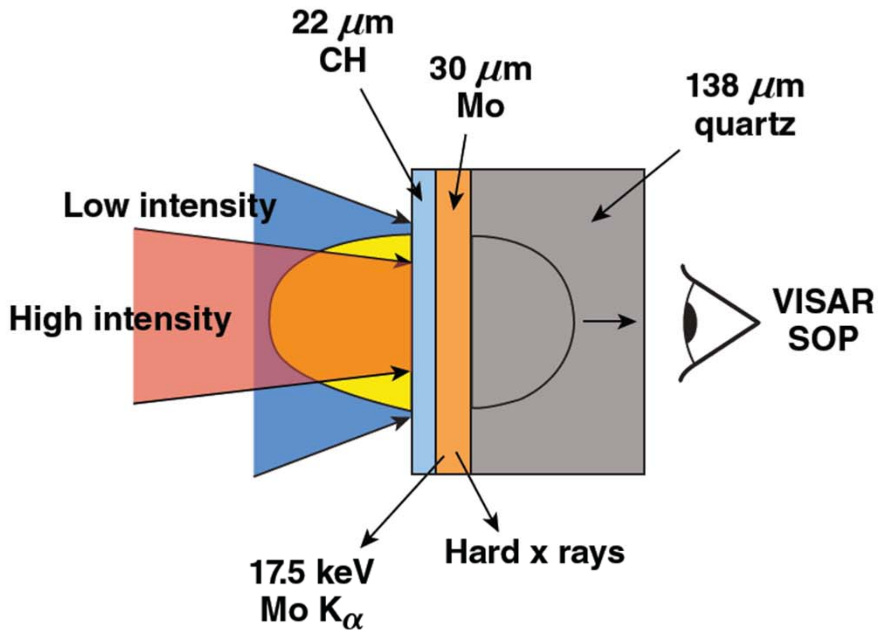
1D simulations

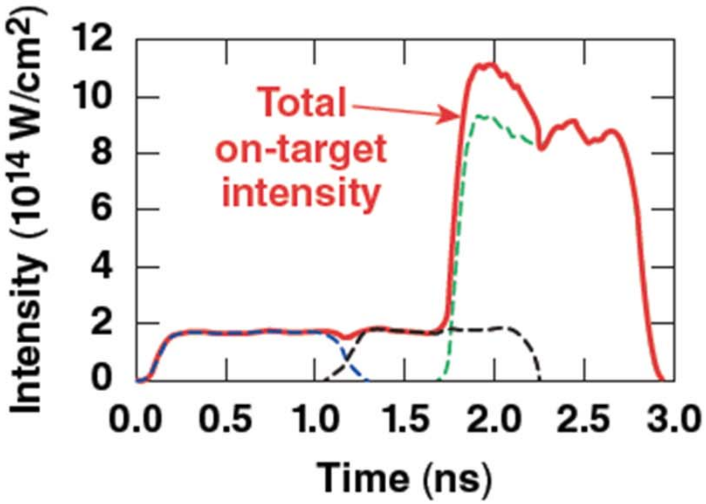


- YOC ~ 3% w/o spike
- YOC ~ 0.7 – 5 % with spike
- Experimental n-yield enhancement: ~1.5
- 1D predicted n-yield enhancement: ~3.3

Solid – LILAC
Open – CHIC

A laser-plasma interaction experiment was performed in planar geometry with overlapping beams

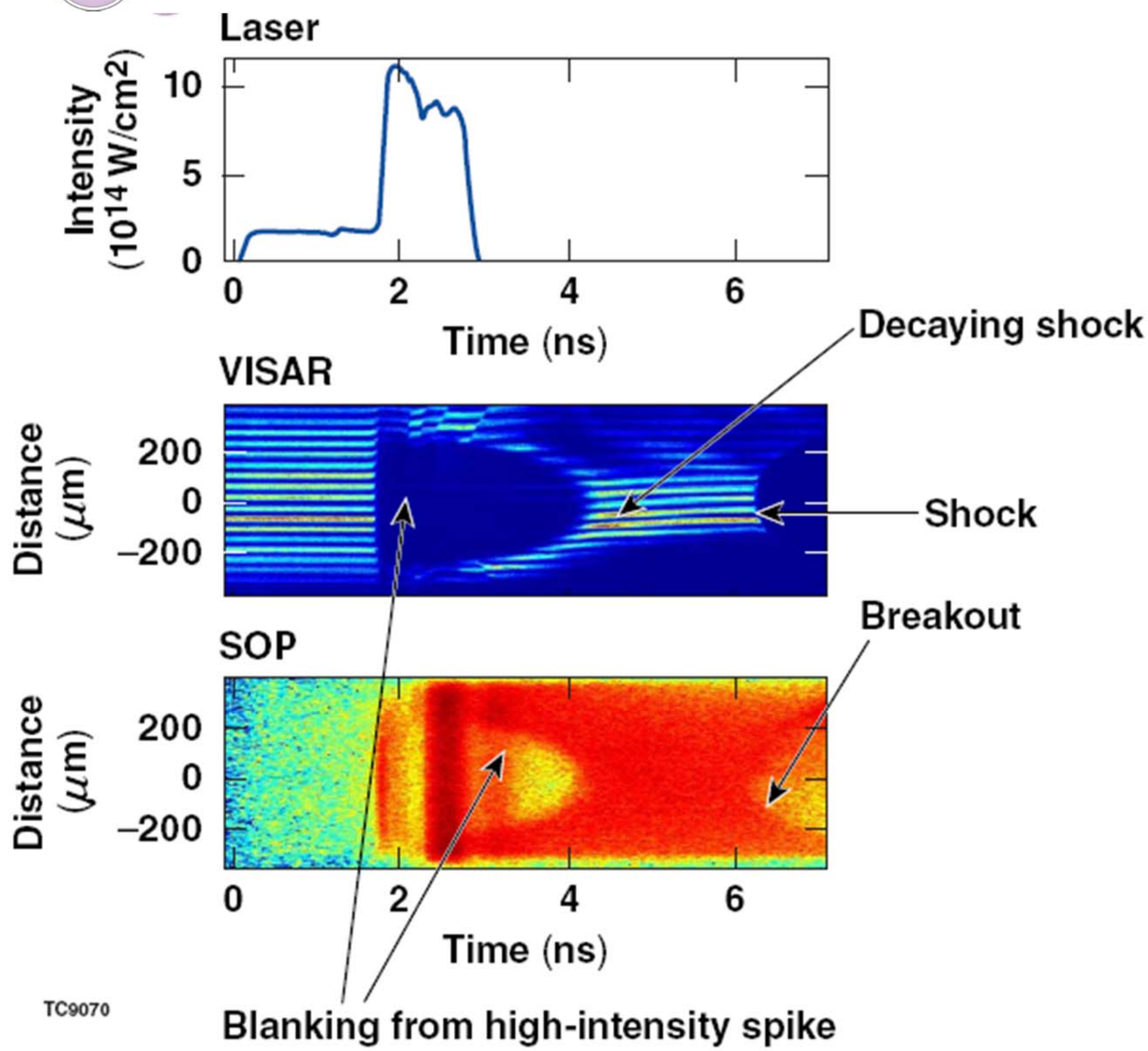




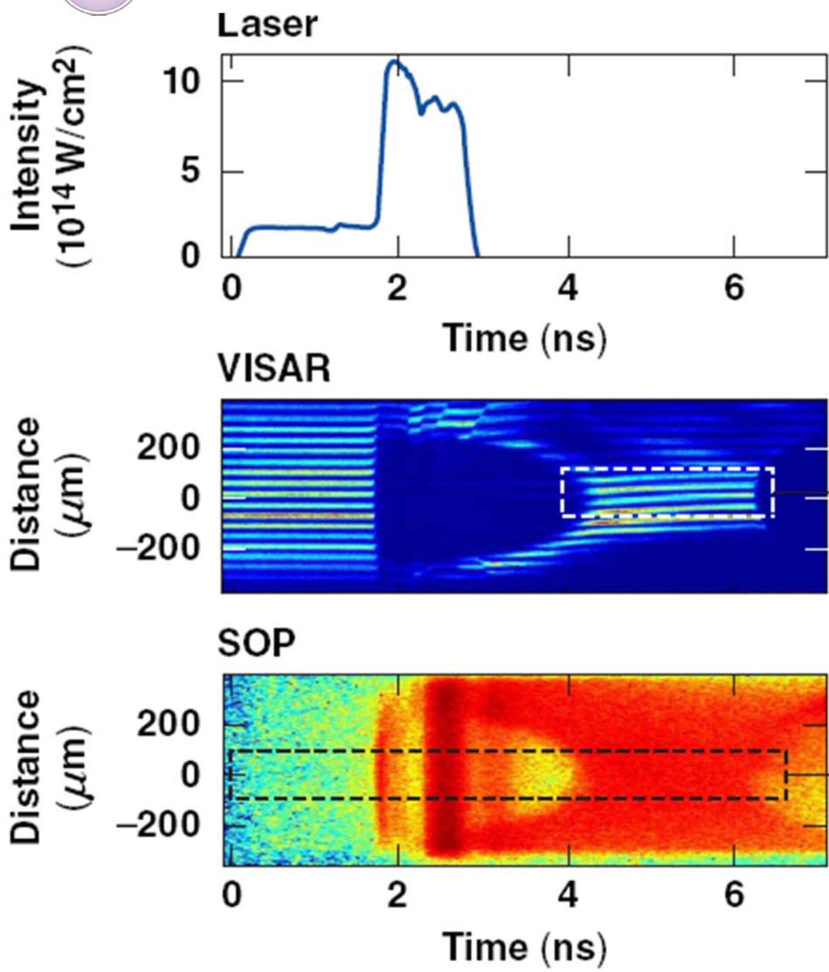
Pre-plasma pulse: ~2×10^{14} W/cm^2
900-μm spot diameter

Shock pulse: ~1 to 5×10^{15} W/cm^2
250- to 600-μm spot diameter

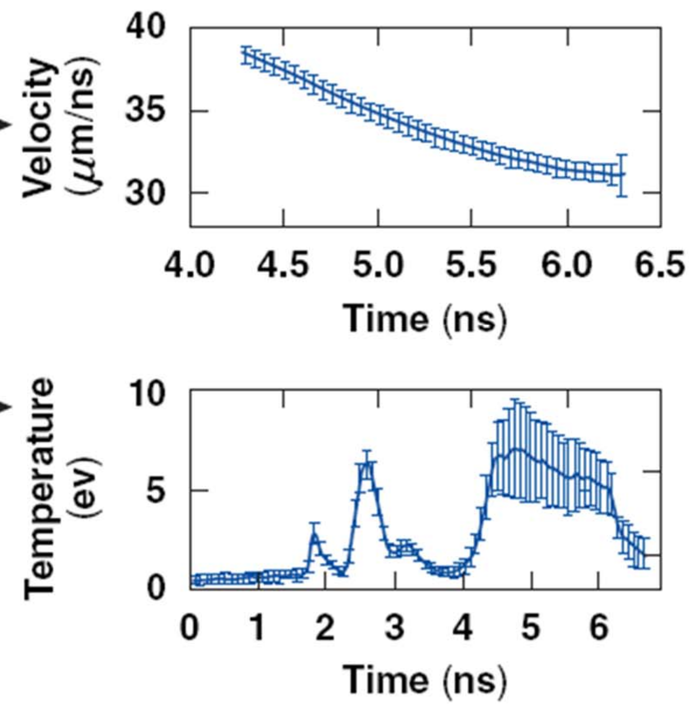
The shock propagation in quartz was observed with streaked optical pyrometry and VISAR



Because of blanking, the decaying shock front in the SiO_2 can be observed for only t > 4.2 ns



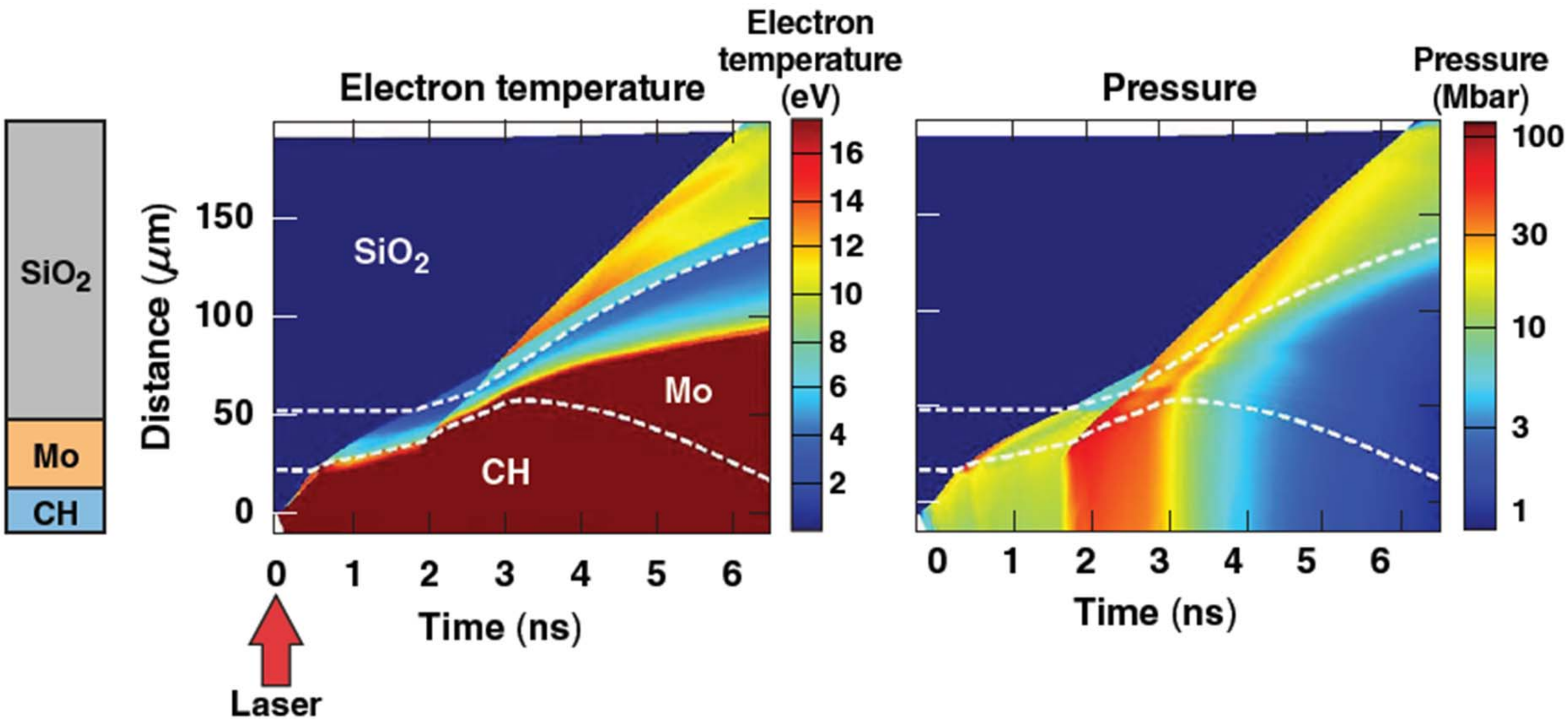
- We have extracted temperature and velocity data from the shock propagation in quartz (Shot 57529)



TC9071

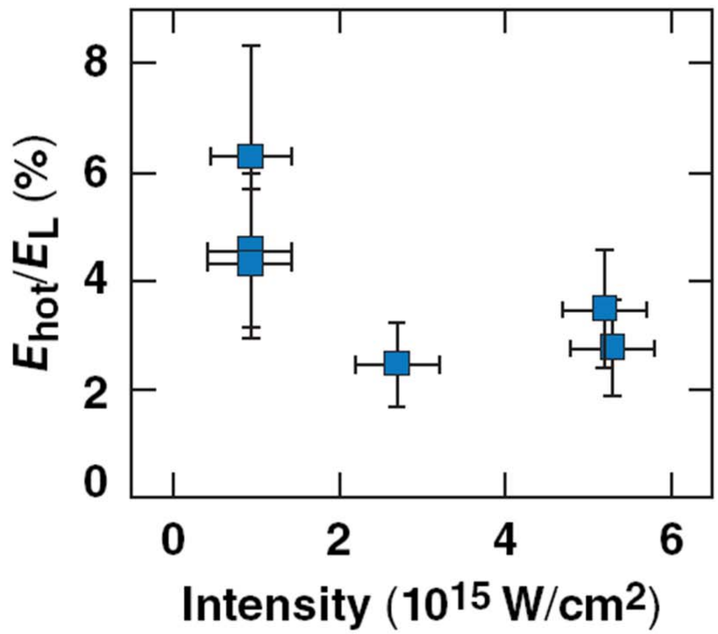
Straight early features suggest 1-D treatment of hydrodynamics is sufficient

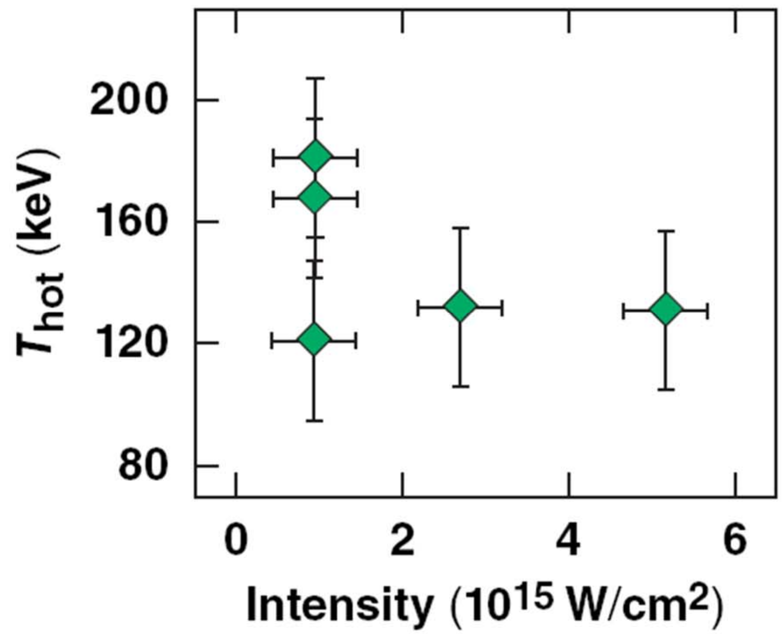
1D hydrodynamic simulations predict an initial plasma pressure of ~100 Mbar for ~1×10^{15} W/cm^2



- The spike absorption is varied to match the shock-breakout time
- 2D DRACO simulations are currently being performed

Up to 6% of the high intensity laser energy is converted into hot electrons





- The measured hot-electron temperature is ×3 higher than in spherical geometry
- >150-keV electrons can be detrimental to shock ignition

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