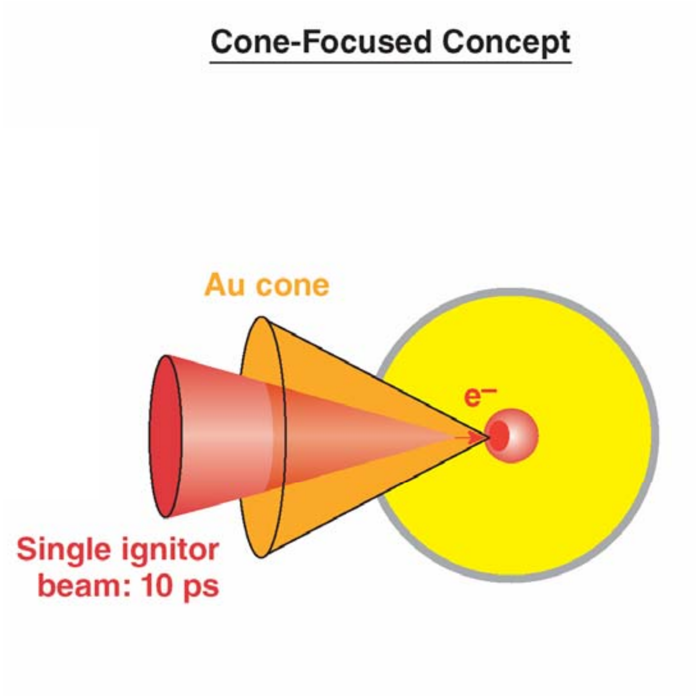
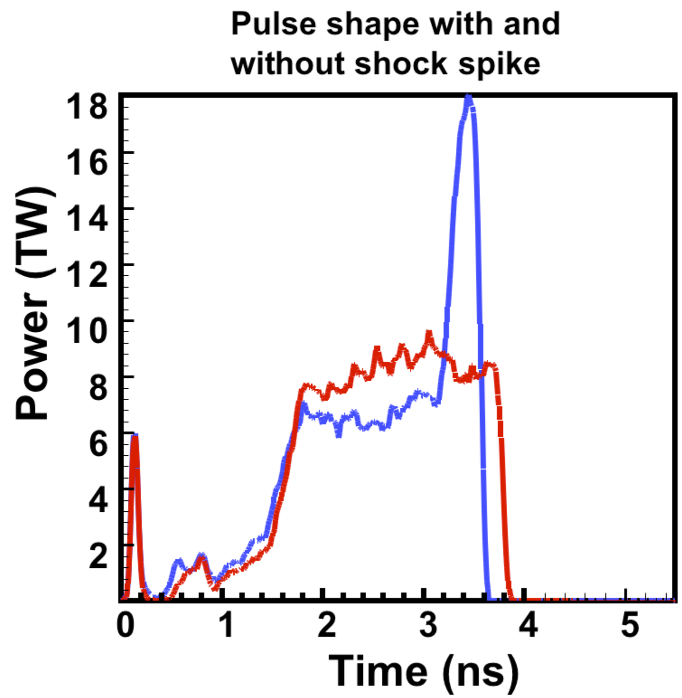
Shock ignition and Fast Ignition hydro-experiments on OMEGA





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6th FSC Meeting
San Diego CA, August 4-5, 2007

Collaborators

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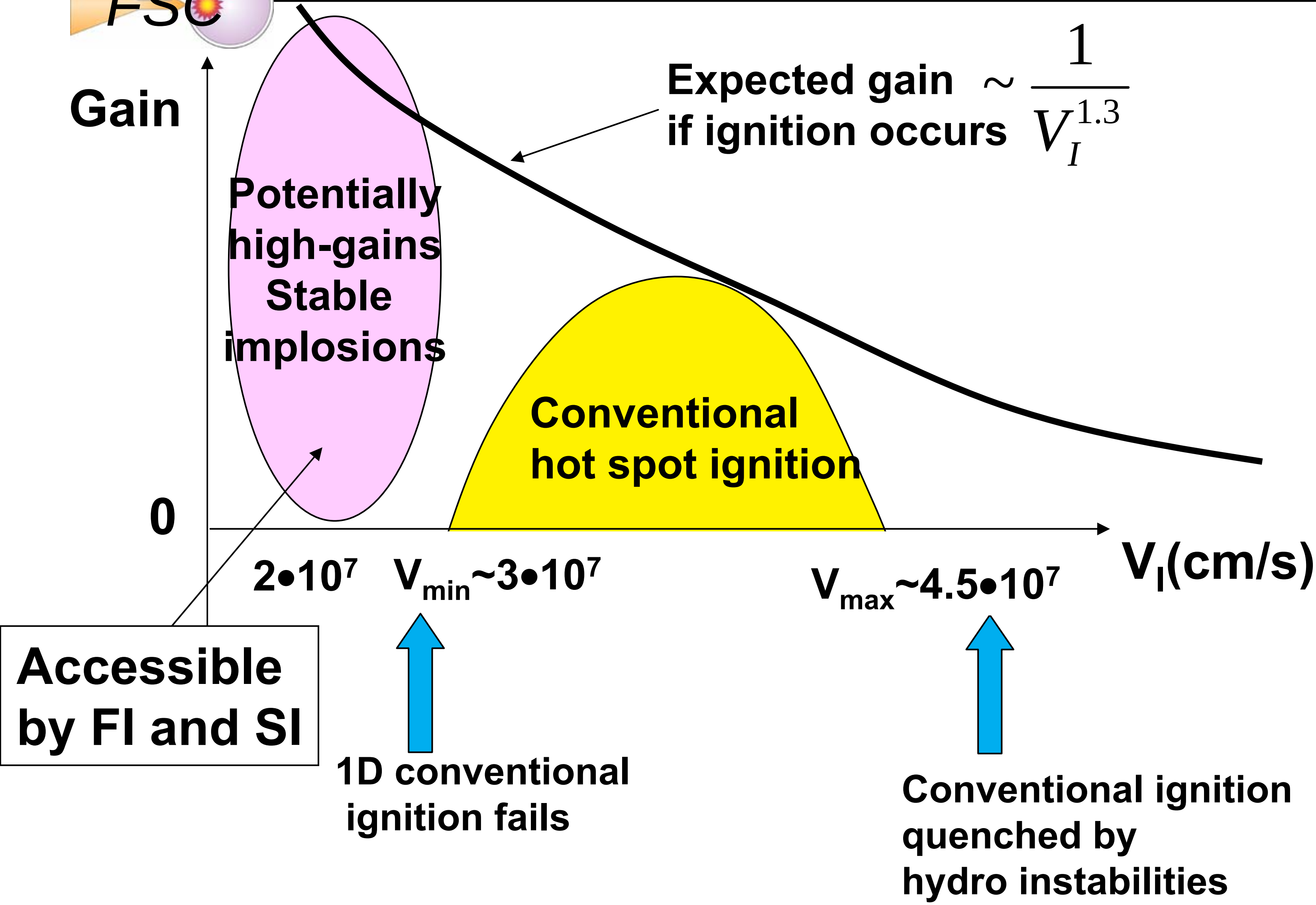
Fast and Shock Ignition can trigger ignition in massive (slow) targets leading to high gains

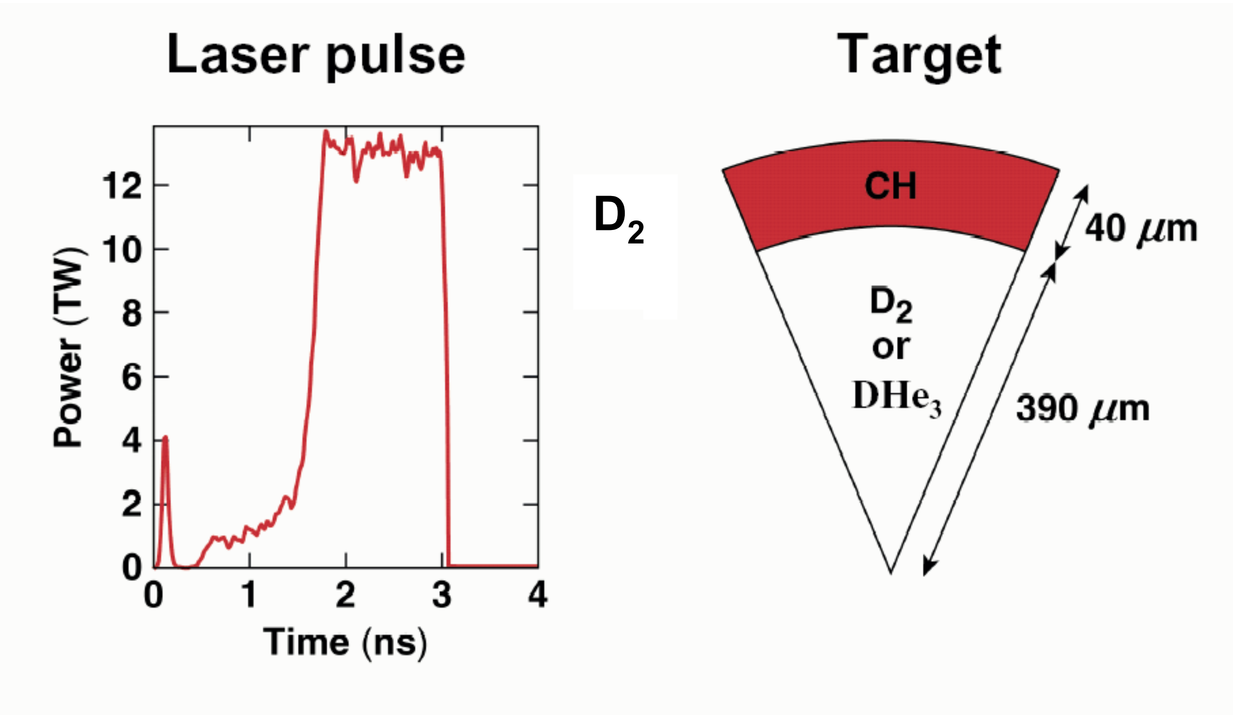


Implosion experiments on OMEGA for Fast Ignition fuel assembly

Low velocity, low adiabat implosions for Fast Ignition fuel assembly were tested on OMEGA

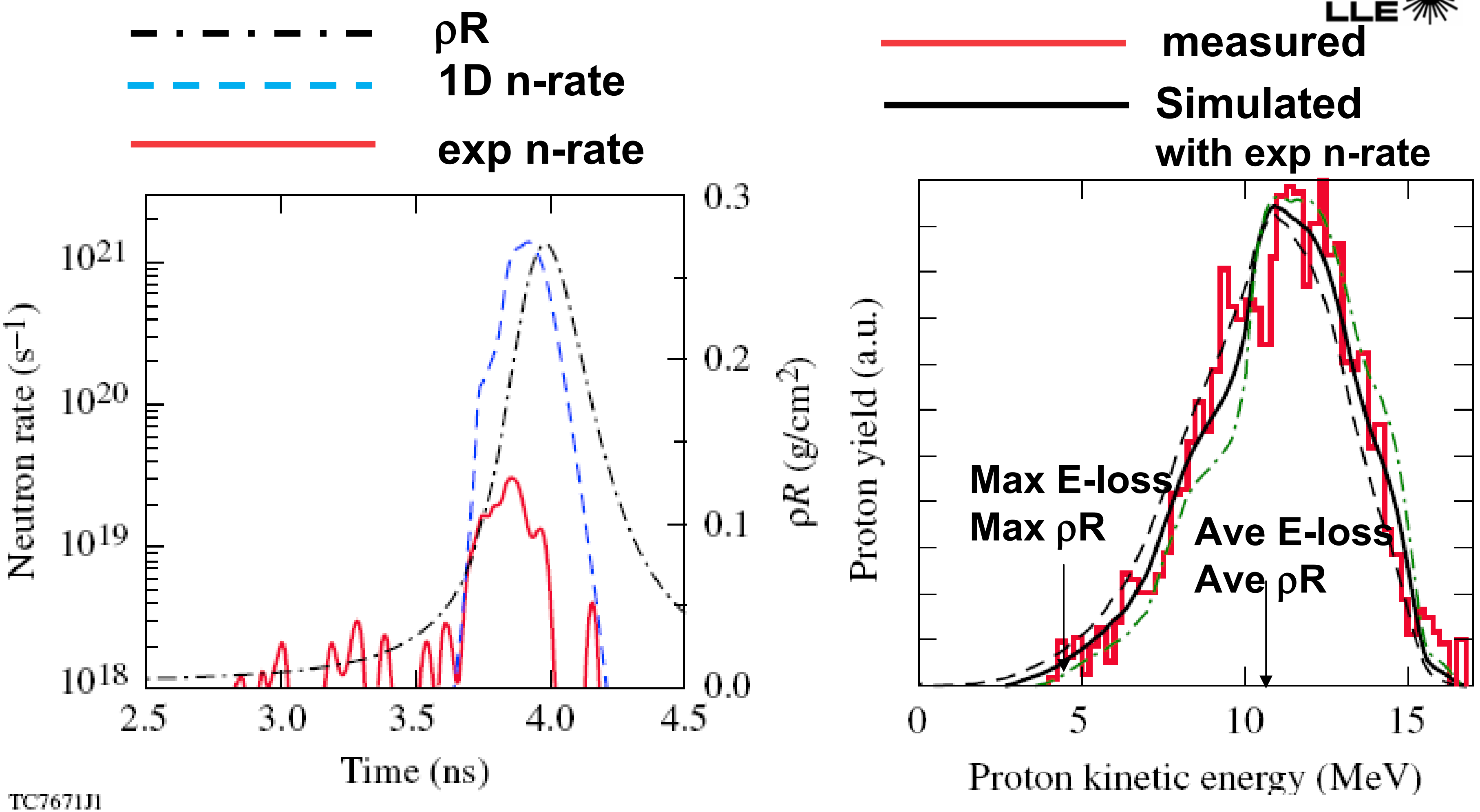
FSC — MIT — UR LLE

$E_L \approx 20kJ$	$P \approx 25atm$	$\alpha \approx 1.3$	$V \approx 2 \cdot 10^7 cm/s$



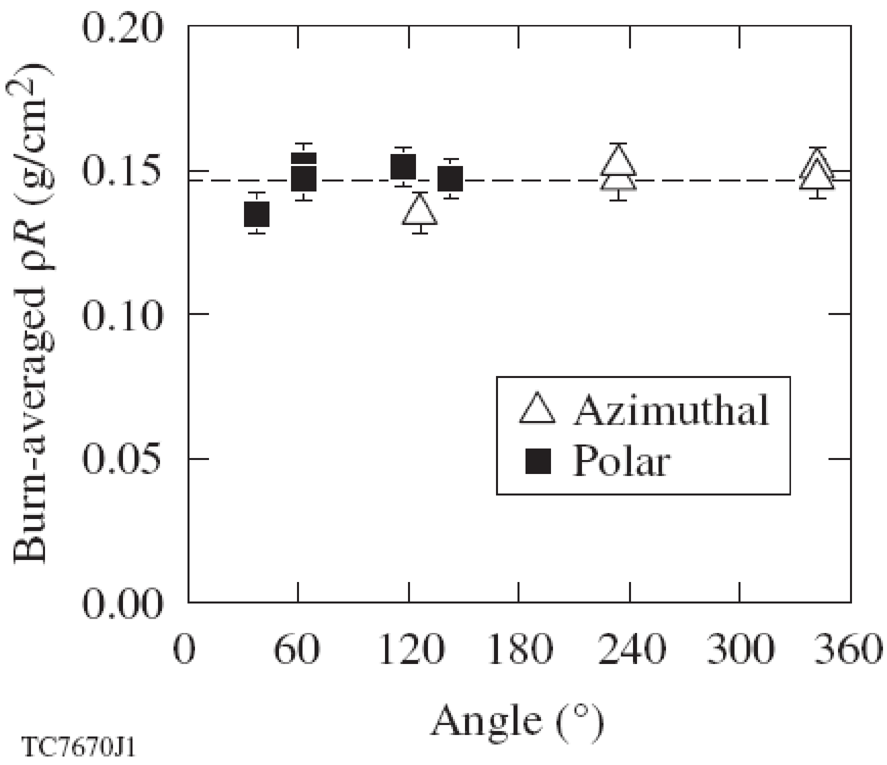
C. Zhou, W. Theobald, R. Betti, P.B. Radha, V. Smalyuk, *et al*, Phys. Rev. Lett. 98: 025004 (2007)

D-^{3}He fusion proton energy loss measured the high ρR, The peak ρR is the among the highest in CH implosions



- Average ρR=0.15g/cm^2, peak ρR is 0.26g/cm^2,
- Empty shells would achieve ρR≈0.7g/cm^2 and stop 4MeV electrons

Modulations in the areal density of the compressed core are small. The compressed core is uniform



Shock Ignition Experiments on OMEGA

SHOCK IGNITION

As a tool to improve the ignition conditions of conventional ICF

Shock Ignition

SI

Requires a relatively weak shock

As a true two-step ignition process.

Shock FAST ignition

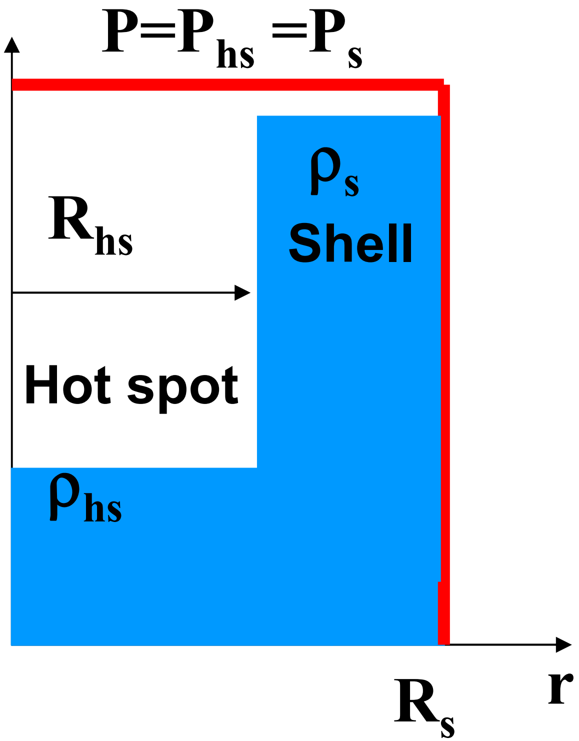
SFI

Requires a strong shock

The energy required for isobaric ignition depends on implosion velocity and adiabat

α= shell adiabat
V= implosion velocity

Isobaric Fuel Assembly

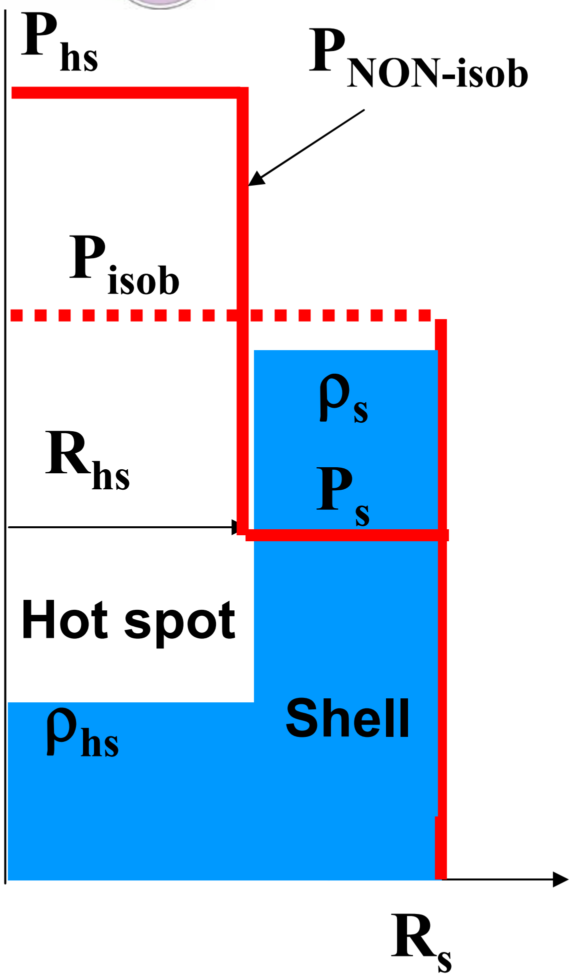


Laser energy scaling for direct-drive isobaric ignition

$$E_{Laser}^{isob.-ign.} \sim \frac{\alpha^{1.8}}{V^{6.6}}$$

Herrmann, Lindl, Tabak, Phys. Plasmas (2001)

The ignition condition is more favorable for a non-isobaric fuel assembly with a peaked pressure

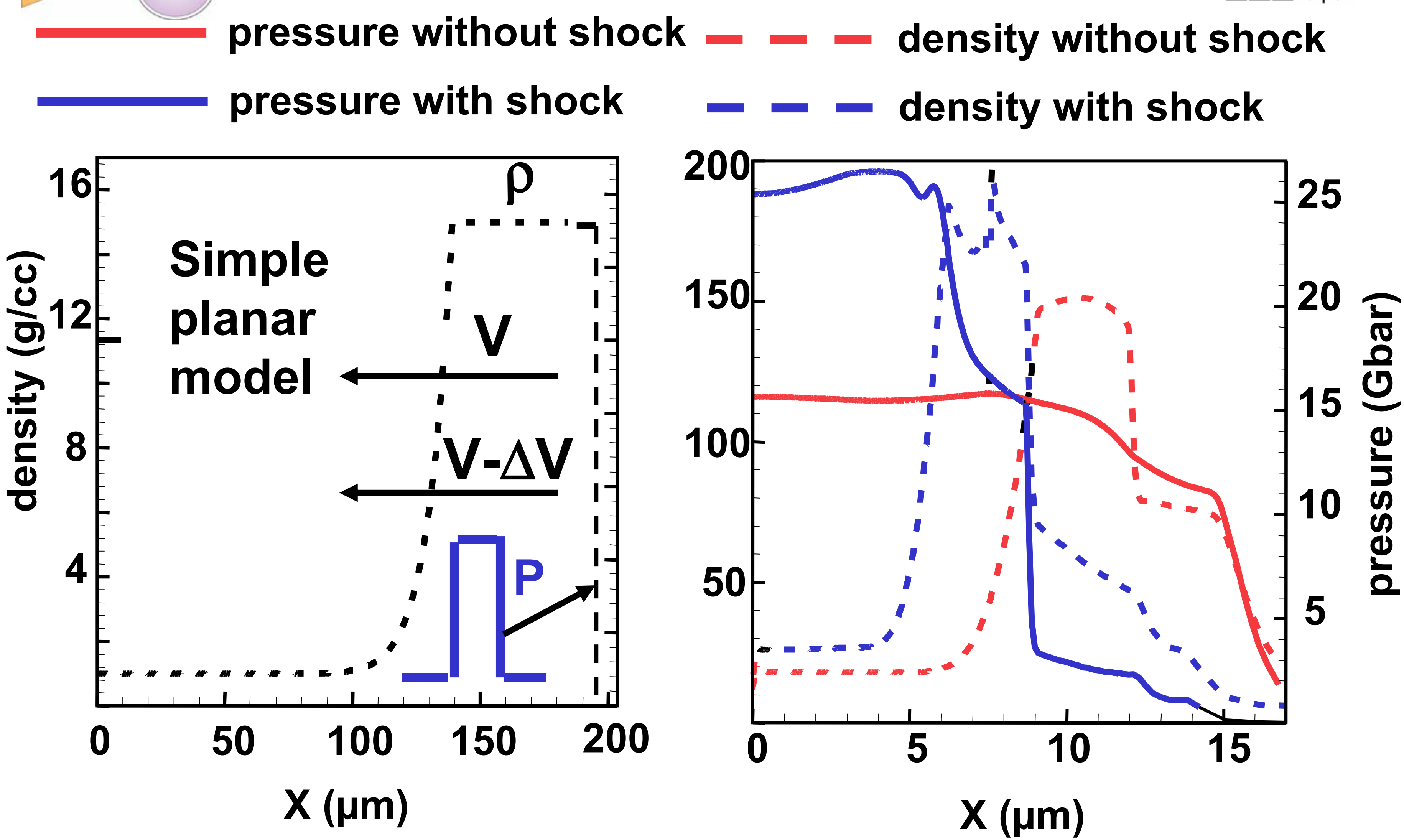


$$E_{Laser}^{NON\text{-}isob.\text{-}ign.} \sim \frac{E_{Laser}^{isob.\text{-}ign.}}{\Phi}$$

For adiabatic compression of the hot spot

$$\Phi \approx \left(\frac{P_{hs}}{P_{iso}} \right)^3$$

A non-isobaric fuel assembly can be produced by shocking the target just before peak compression



Shock ignition target design for the NIF requires ~500kJ

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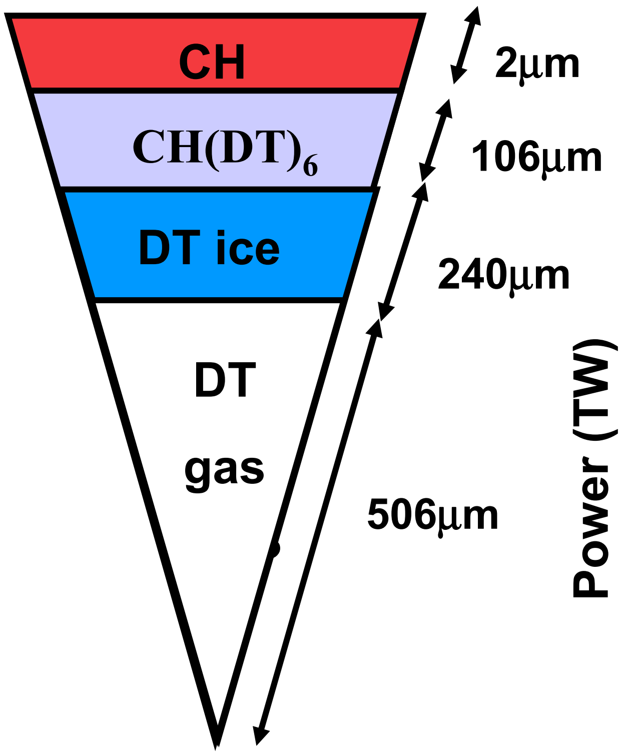
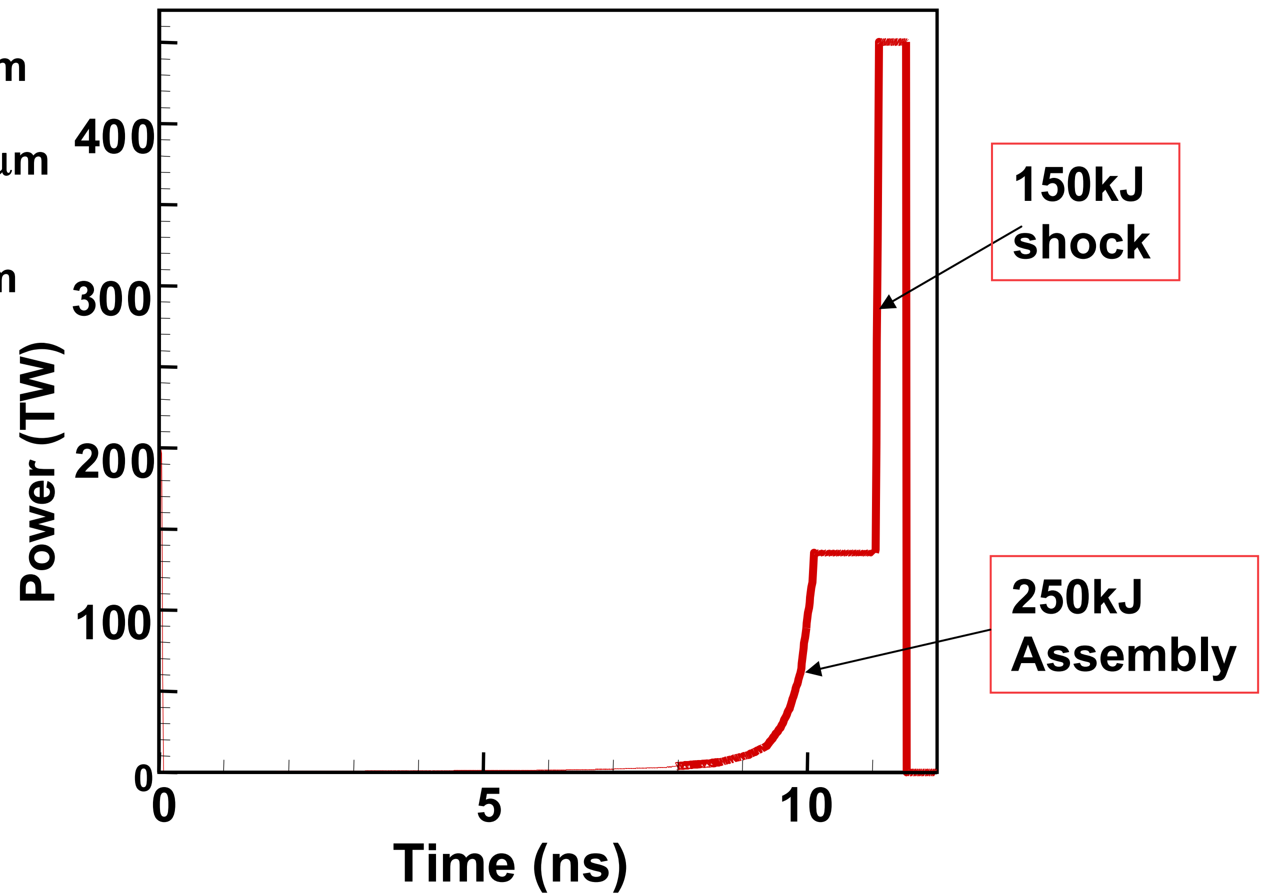
E_L=400kJ, V_i=2.4e7cm/s, α=0.7-1, λ_L=0.35μm





Minimum shock energy for ignition = 50kJ, total energy = 300kJ

The robustness of the ignition is measured by the size of the shock ignition window

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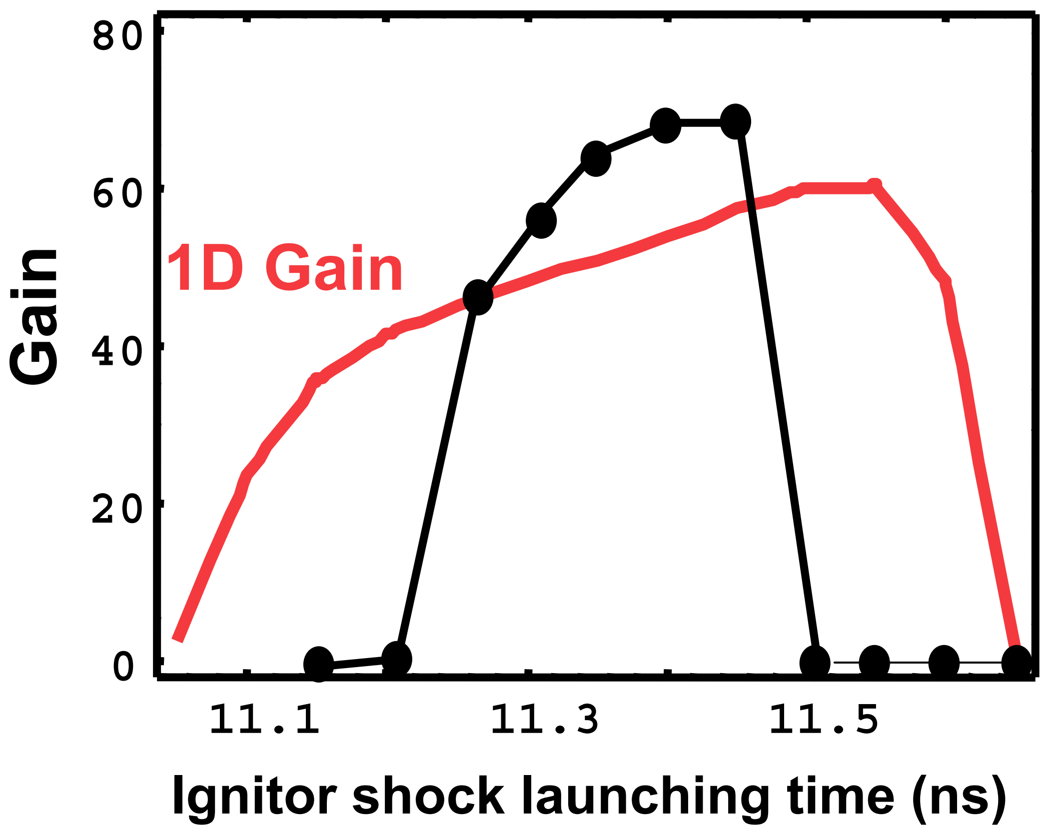
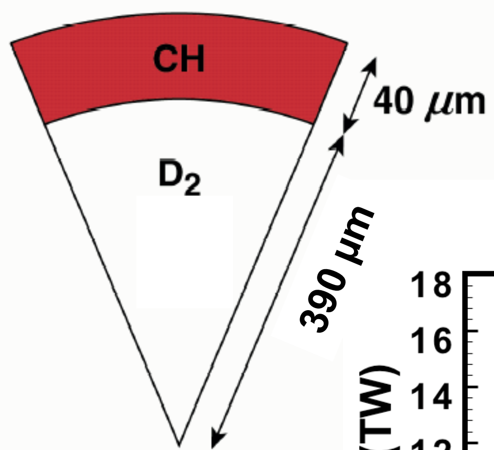


- 2D simulations
  Modes l=4-100,
  NIF 2D-SSD
  Energy = 400kJ
  Normal Incidence
  Thomas-Fermi EOS
  No radiation

Significant gains are predicted with moderate driver energies

The shock ignition concept has been tested on OMEGA

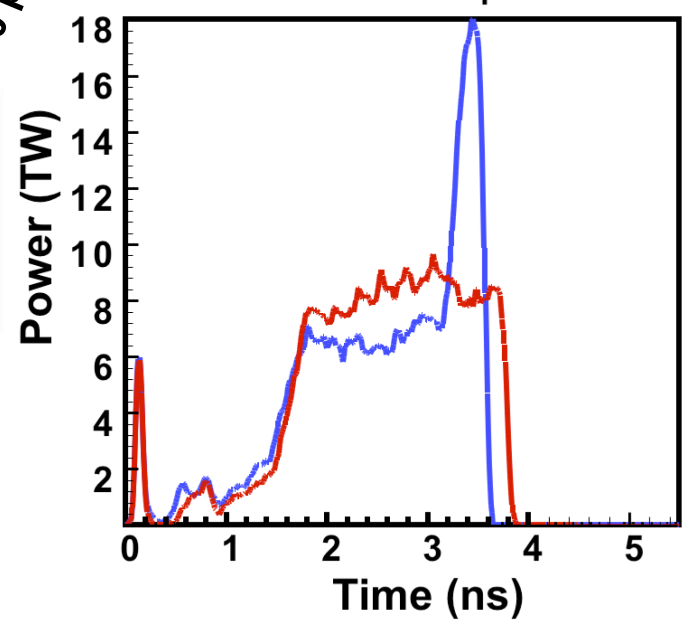
Target

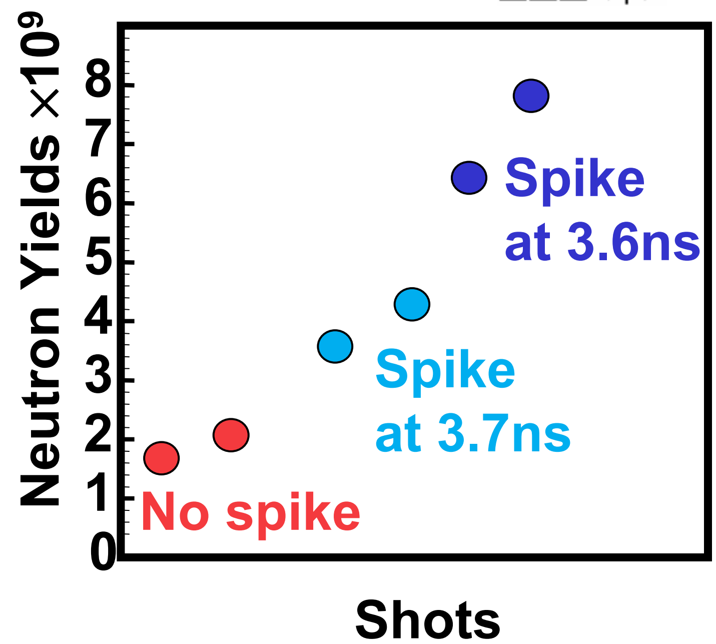


W. Theobald,,
C. Zhou,
et al
(UR-LLE)

E_L=17-18kJ
$\alpha\approx$1.3

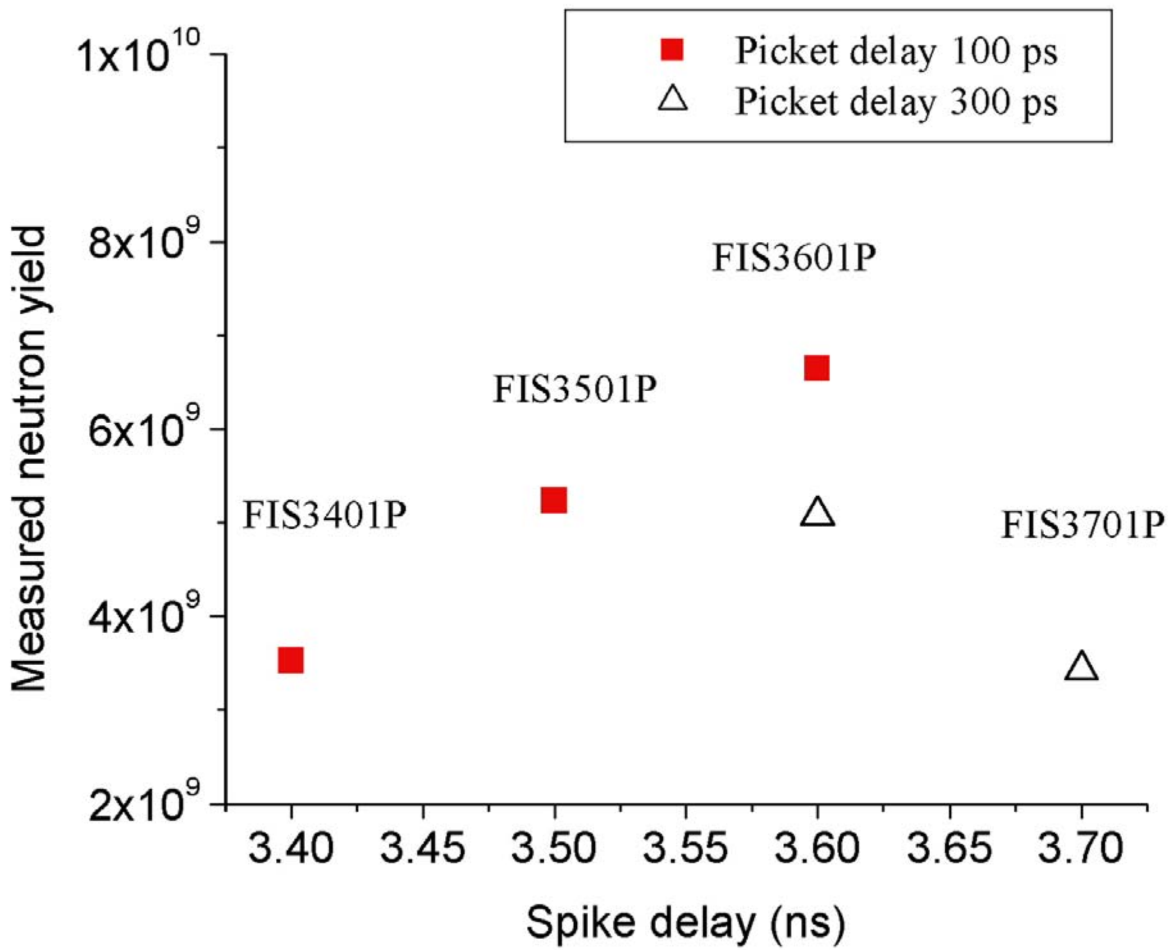
Pulse shape with and without shock spike





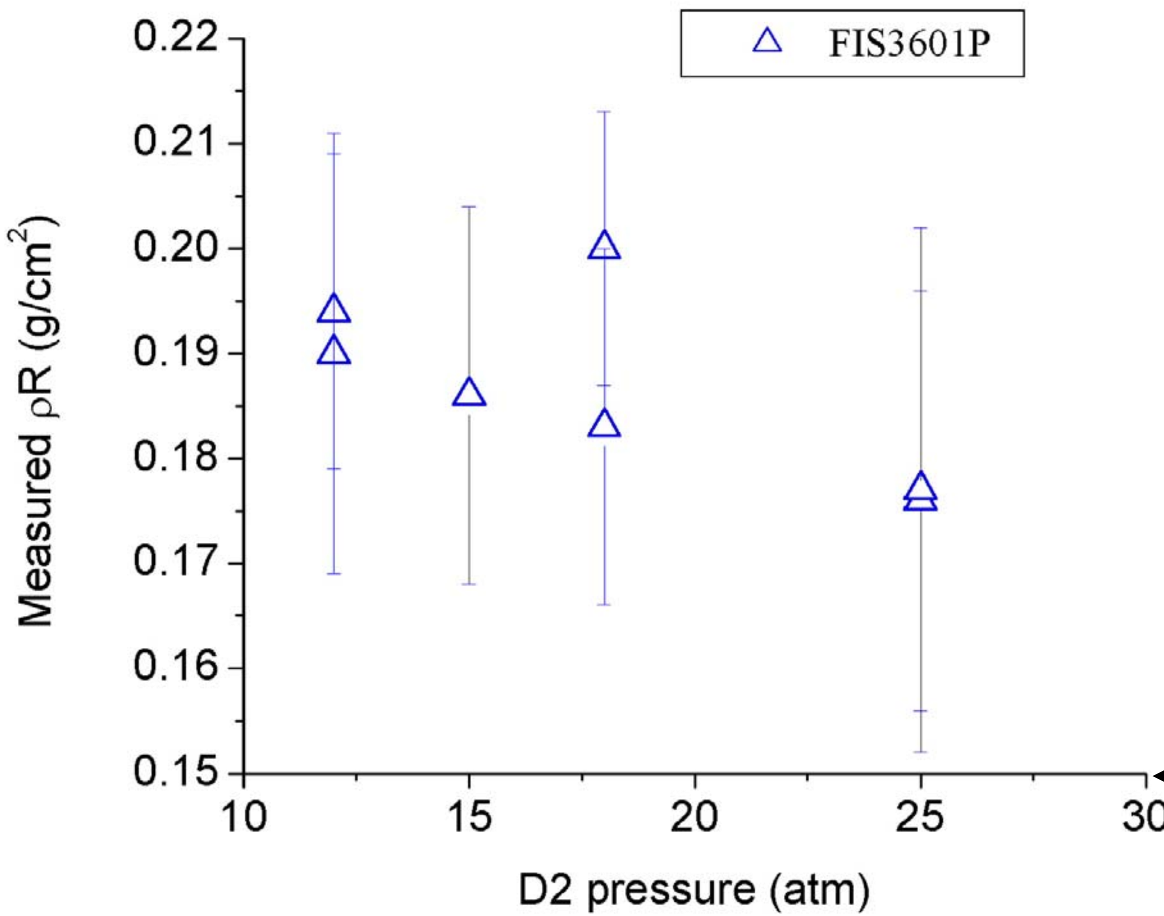
The neutron yield increases considerably when a shock is launched at the end of the pulse

Evidence of an optimum shock launching (spike) time was found in the latest series of SI experiments



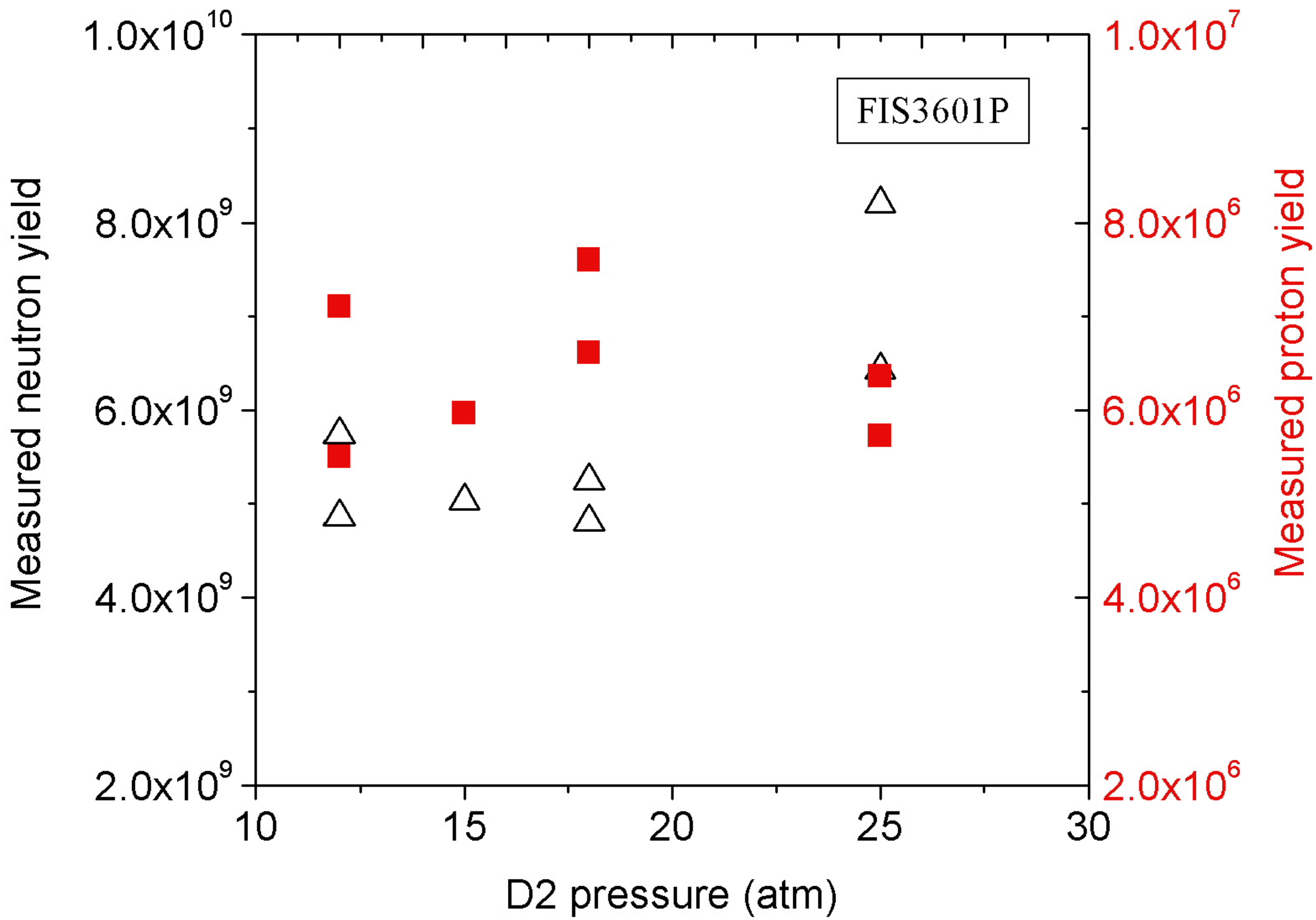
No spike "standard" Pulse shape

Shock-Ignition pulses lead to the highest average areal densities <rhoR> ≈ 0.2g/cm^2 above standard pulse shapes (0.15g/cm^2)



No spike "standard" Pulse shape

The neutron yield remains constant at low fill pressures in shock ignition targets. Areal density can be measured at low fill pressures.



SFI. A true 2-step shock-ignition scheme requires much greater energy in the shock. Conventional laser-driven thermal waves are too inefficient.

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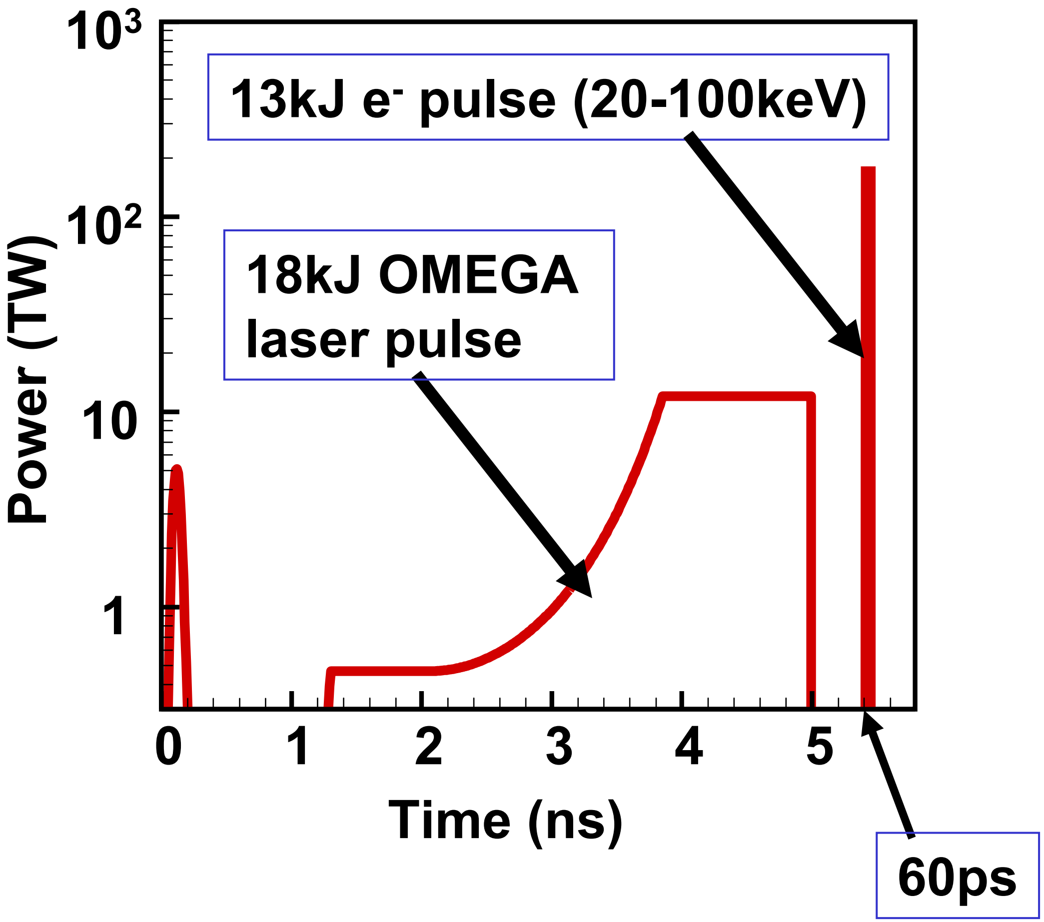
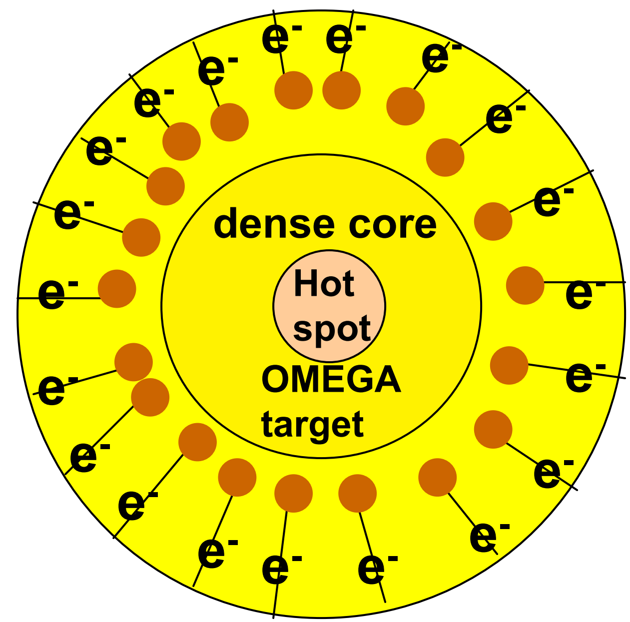
OMEGA cryo-target→95μm DT + 10μm CD





SHOCK FAST IGNITION

A spherically-convergent hot-particle driven shock is needed

SFI. Shock FAST ignition requires an ignitor shock much stronger than the return shock. OMEGA size targets can be ignited by a 13kJ shock

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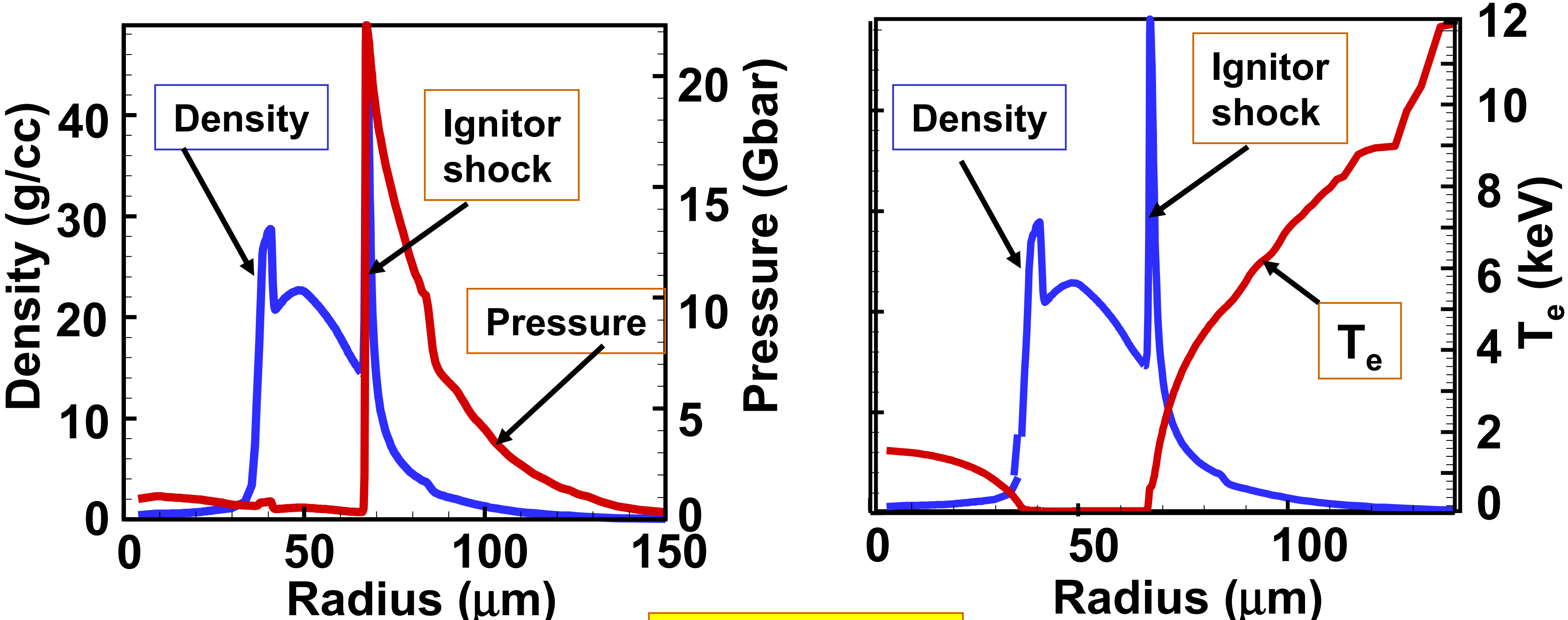

GAIN = 9

CONCLUSIONS

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- Implosions of massive shells at low velocity and low adiabat have been proven effective on OMEGA to assemble large amount of fusion fuel with high areal densities
- Shock ignition experiments on OMEGA show improvements in neutron yields well beyond the predictions of 1D codes
- A true 2-step ignition based on shock ignition requires a strong shock driven by particles (tens of kJ of 20-100keV electrons)