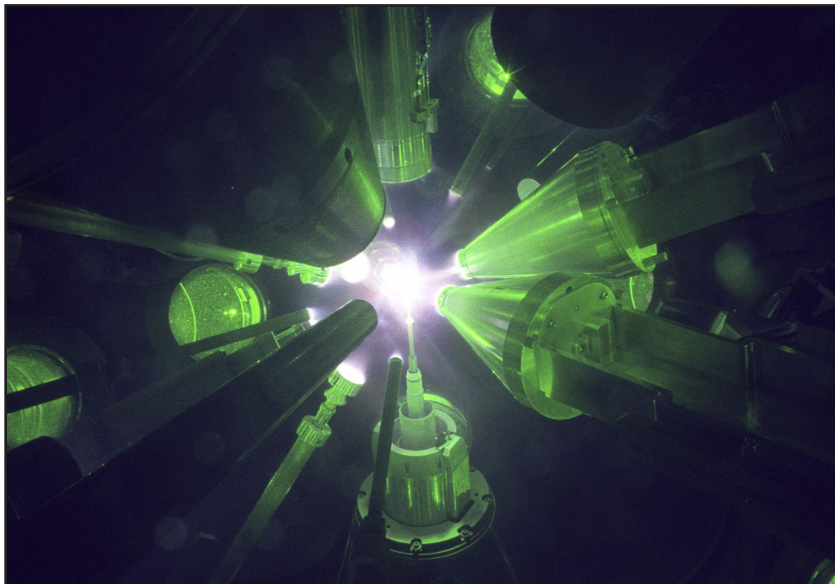
Near-Term Issues for Inertial Confinement Fusion

Cryogenic DT implosions on OMEGA



... and LPI/symmetry on the NIF

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Fusion Power Associates
34th Annual Meeting
Washington, DC
11 December 2013

Summary

This is the time to promote innovation in achieving ignition and gain in the laboratory for the first time

- The high foot design for indirect-drive ignition has led to progress toward understanding what is required to demonstrate ignition on the National Ignition Facility (NIF)
- Direct drive is a viable option for inertial confinement fusion (ICF) ignition
  - relatively modest improvements to the NIF are required to validate the concept
- Magnetically driven implosions on Z will validate an important alternate path to ignition and high gain
- There are many other options on the path to ignition that should be explored
  - shock ignition
  - magnetically insulated implosions
  - fast ignition
  - next new idea???

The most important thing is to demonstrate ignition on the NIF!!!!

This is the time to promote innovation in achieving ignition and gain in the laboratory for the first time

- Igniting thermonuclear fuel in the laboratory has been a worldwide scientific quest for the last 60 years
- We are at a point in time with unprecedented capabilities and unique facilities to finally ignite DT fuel (NIF, Z, and OMEGA)
- Thinking outside the box pays off (see latest Hi-foot results)
- There are multiple options available for ignition and high gain
  - conventional approaches: indirect drive, direct drive
  - advanced schemes: shock ignition, MagLIF
- All of the above can be tried on existing facilities
- It is crucial to take advantage of these opportunities and strengthen the ICF program to test all of the approaches

The path to ignition can be understood using scaling laws that are applicable to x-ray and direct-drive

$$\chi \equiv \frac{P\tau}{(P\tau)_{ig}} = \left(\rho R_{g/cm^2}\right)^{0.61} \left(\frac{0.24 Yield_{16}^{no-\alpha}}{M_{DT}^{mg}}\right)^{0.34} YOC^{0.06}$$

Betti et al Phys. Plasmas 17, 058102 (2010)
Chang et al, Phys. Rev. Lett 104, 135002 (2010)
Zhou-Betti, Phys. Plasmas 15, 102707 (2008)

$$\chi \sim E_{kin}^{0.37} YOC^{0.4} P_{abl}^{0.4} IFAR$$

Best indirect-drive shot to date → $\chi_{hi-foot} \approx 0.6$

Options for achieving ignition:

E_{kin} up by 4× ← **Can't do it**

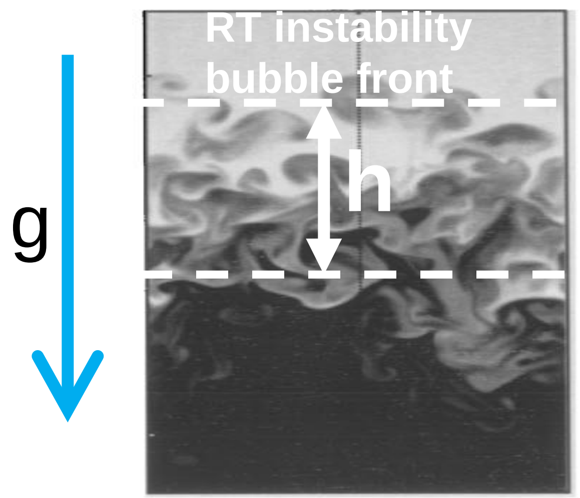
YOC up by 3× (YOC is already > 50% in hi-foot)

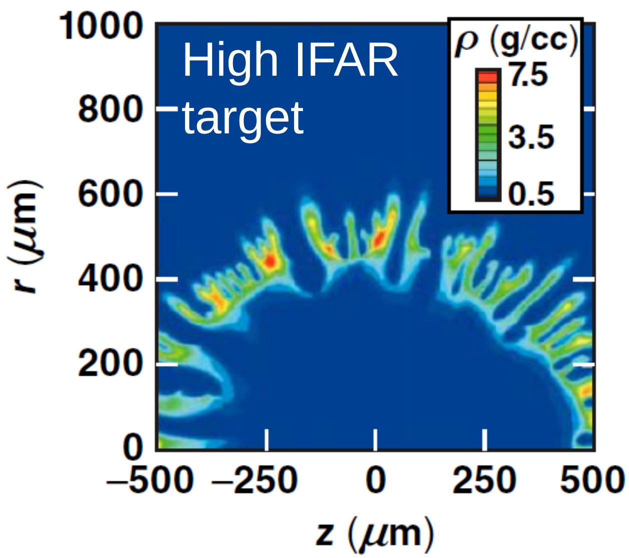
P_{abl} up by 3.6× ← **Can't do it**

$IFAR$ up by 1.6× ← **Only realistic option but challenging**

Requires reducing the in-flight thickness by 40% (adiabat by ~ 2.3)
Will hydro instabilities allow us to do that?

Increasing the IFAR by 60% is a real challenge





Δ = target thickness R_0 = target initial radius

$$IFAR \approx \frac{R_0}{\Delta}$$

Bubble front penetration

$$h \approx \beta g t^2 \approx 2\beta D \approx \beta R_0$$

D= distance travelled during acceleration~ $R_0/2$

$\beta \approx$ 0.05-0.07

Critical stability parameter

$$\frac{h}{\Delta} \sim \frac{\beta R_0}{\Delta} \propto IFAR$$

Increasing the IFAR by 60% causes the RT bubbles to penetrate 60% deeper in the target unless the RT is suppressed

There are three primary scientific/design challenges for the polar-drive (PD)–ignition campaign

1) Energy coupling to the capsule at ~8×10^{14} W/cm^2
   a) cross-beam energy transfer (CBET) leads to a reduction in drive pressure and may impact symmetry
   b) oblique beam incidence at the equator reduces thermal coupling to the ablation surface

2) Adequate implosion performance at lower fuel adiabats (<3)
   a) the two-plasmon–decay (TPD) instability at $n_c/4$ leads to the production of energetic electrons and may lead to fuel preheat
   b) mitigation of hydro-instability seeds

3) Drive/shell symmetry through acceleration
   a) symmetry demonstration is primarily a NIF objective given limited capabilities on OMEGA
   b) final symmetry assessment on the NIF will require dedicated ignition phase plates

Current experiments with the ID configuration on the NIF will focus on laser–plasma instability (LPI) physics at the ignition scale.

Our path to assessing MagLIF builds on increasing understanding and improving capabilities

Sandia National Laboratories

Improve experimental capabilities to support ~100 kJ DT yield experiments on Z

- Increase current from 20 MA to 25 MA
- Increase B field from 10 T to 30 T
- Increase laser energy from 2 kJ to >6 kJ
- Begin designs for DT capabilities on Z

Understand the physics of target magnetization and fuel preheating

- Understand and measure efficacy of magnetic flux compression by the liner implosion (e.g., Nernst effect)
- Understand the efficacy of heat loss suppression (Braginskii transport valid?)
- Understand laser-plasma coupling efficiency and dynamics

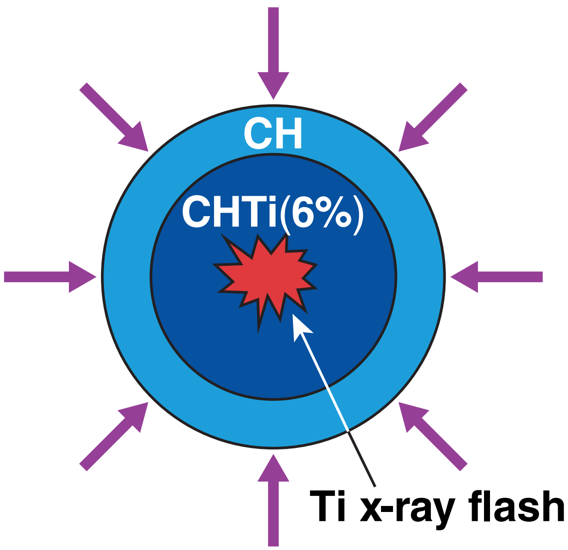
Continue to advance our understanding of liner implosions

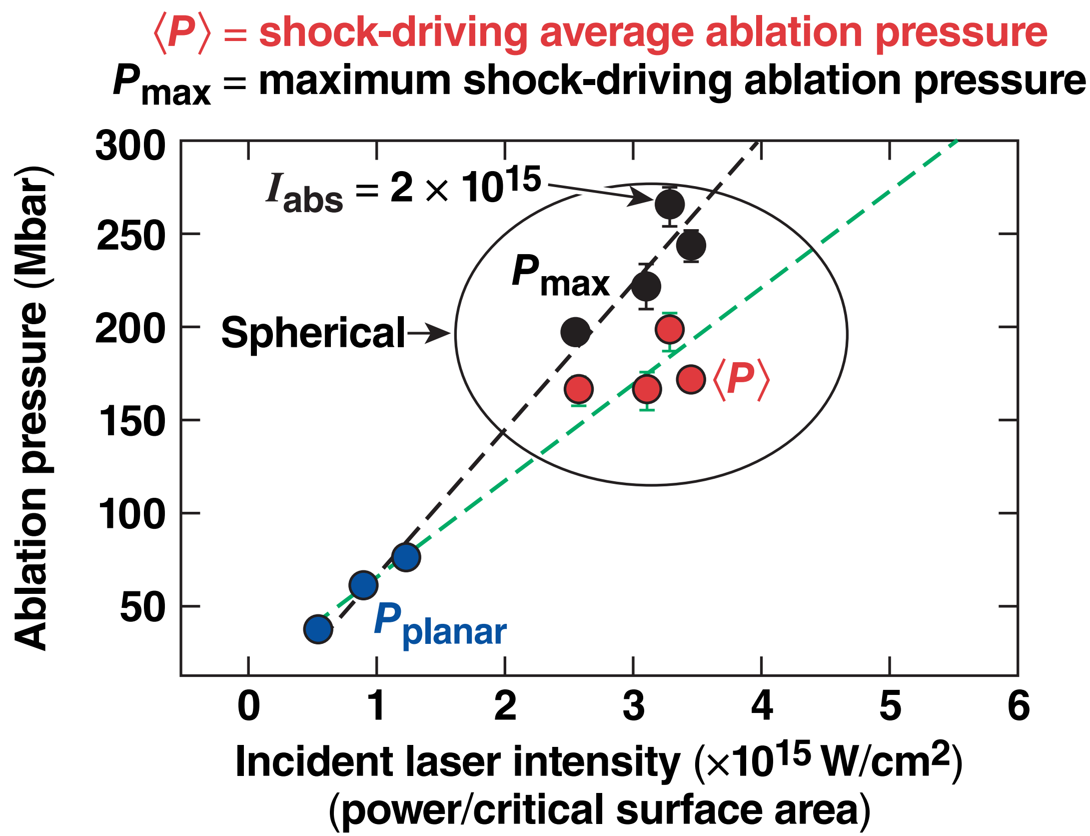
- Have a large database of radiography-based acceleration instability studies with images up to convergence ratio of 8
- Will begin working on deceleration instability studies in 2014
- Developing methods to measure liner implosion symmetry

Performing and diagnosing integrated implosions

- Apply diagnostics to understand stagnation conditions
- Study the implosion performance with changing inputs
- Begin exploring non-laser-based methods for preheating

Experiments on OMEGA are validating the physics basis for shock ignition; shock pressures >200 Mbar are produced at an intensity of only 2×10^{15} W/cm^2

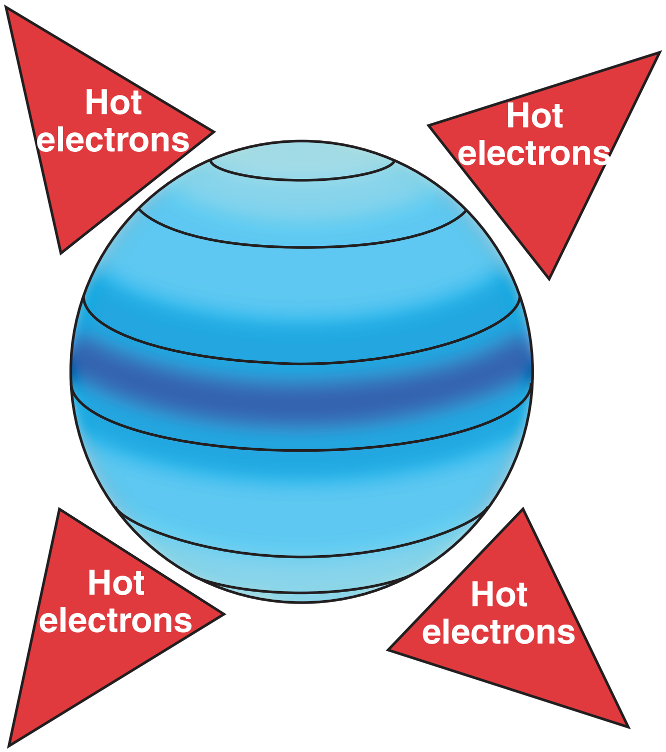


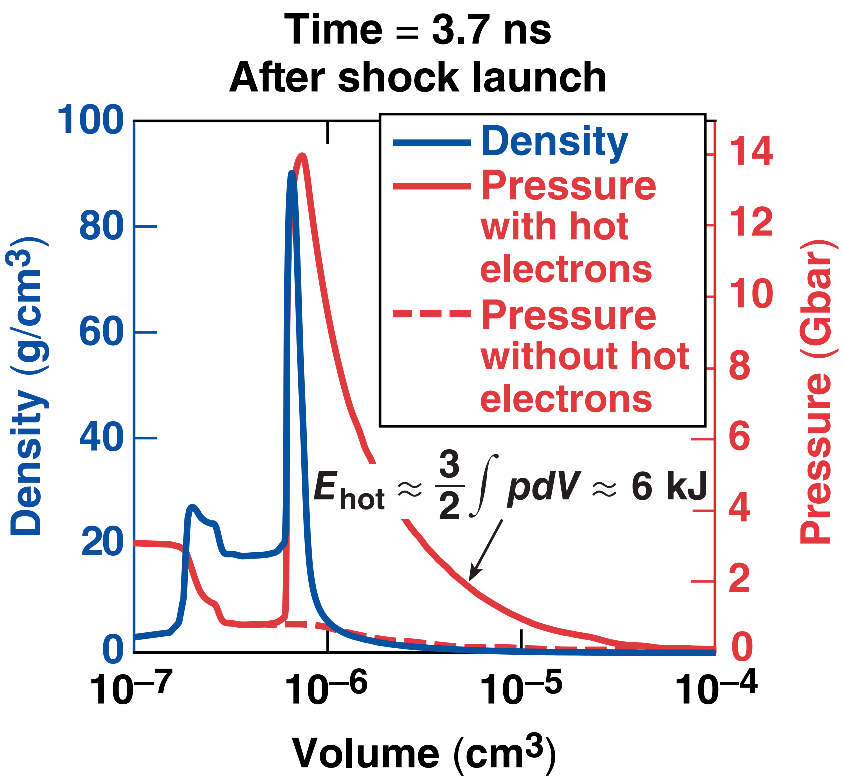


TC11077

Taking advantage of laser–plasma instabilities to launch strong shocks can be a game changer for shock ignition

- ~6 kJ of hot electrons produce multi-gigabar shocks in simulations of OMEGA size targets

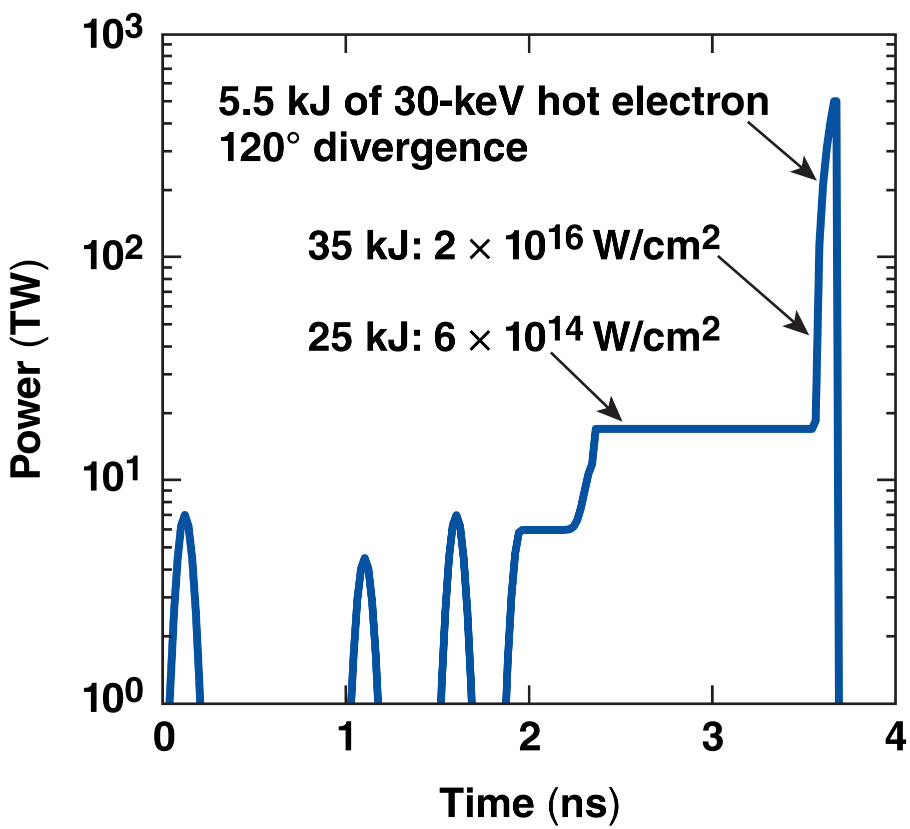


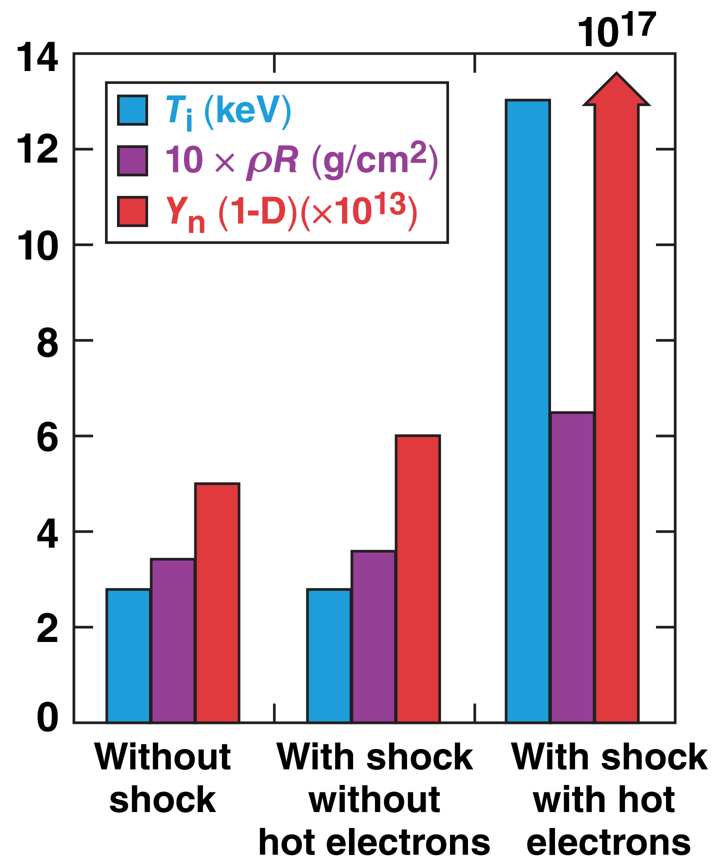


TC11078

The hot-electron–driven shock ignites a low IFAR OMEGA-size target with a 1-D gain of 6!

Target specifications: IFAR* = 15, V_i = 270 km/s, $\langle\alpha\rangle$ = 3, E_L = 60 kJ



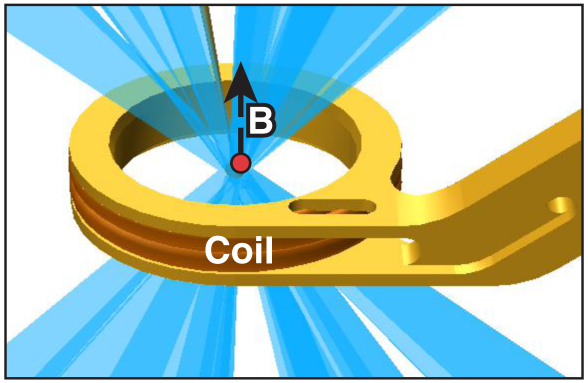


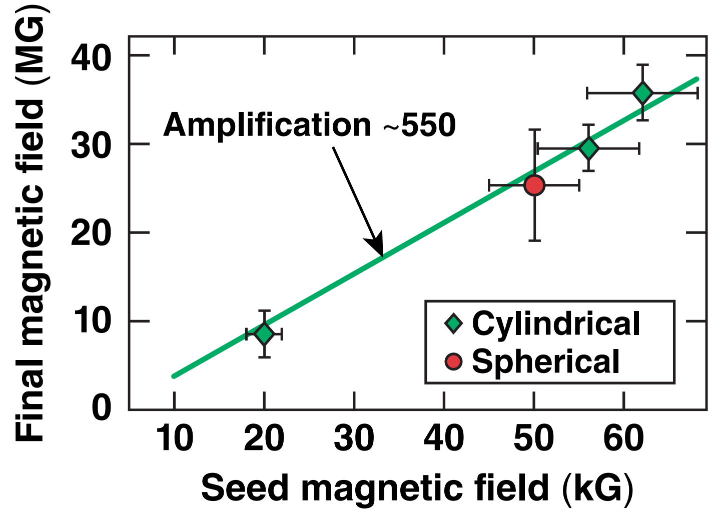
*In-flight aspect ratio

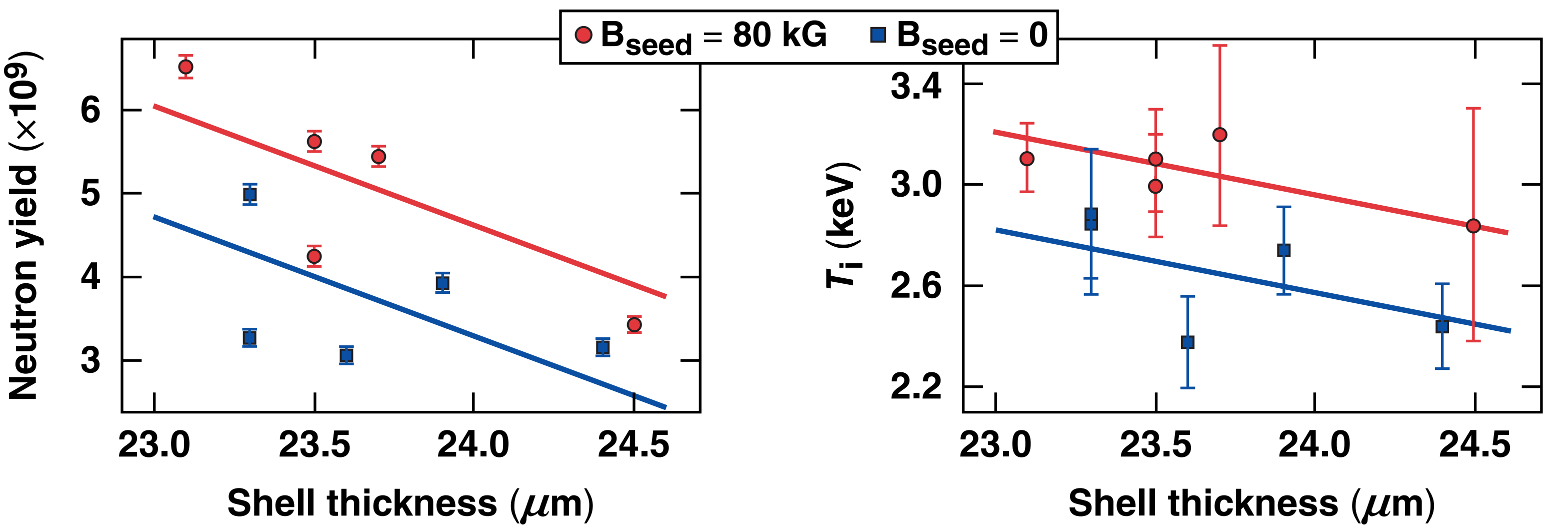
TC11037a

Magnetized target experiments on OMEGA using the magneto-inertial fusion electrical discharge system (MIFEDS) have shown that B fields increase temperature and yields

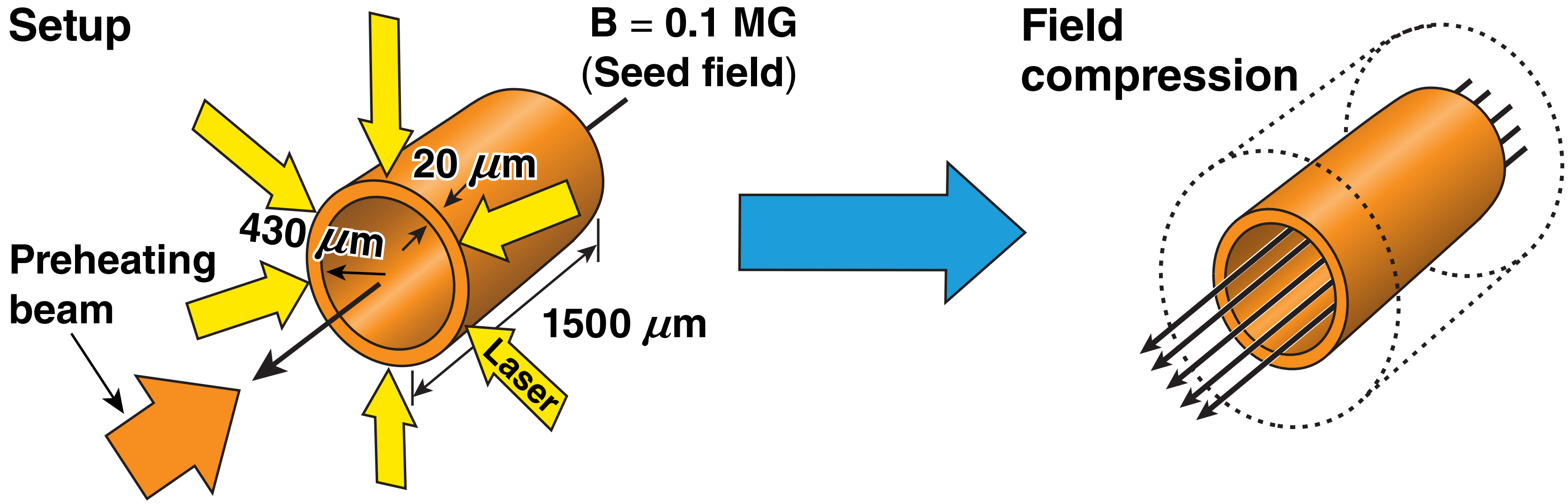
40 OMEGA beams in PD configuration*







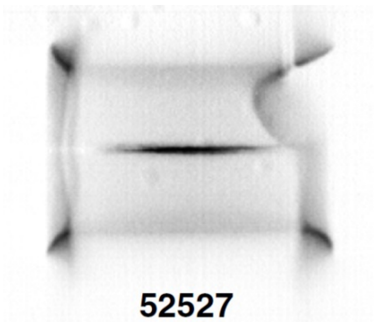
A much larger yield enhancement is predicted in magnetized cylindrical targets with preheated gas (MagLIF); OMEGA can validate the MagLIF concept



- 1-D magnetohydrodynamic (MHD) simulations of slow (~100-km/s) magnetized cylindrical implosions (MagLIF—SNL) with preheated gas (~200 eV) show a 2 to 3× enhancement of the temperature and 10 to 20× increase in neutron yield
- Scaled-down magnetized cylindrical implosions with preheated gas can be fielded on OMEGA to validate the MagLIF concept

TC11080

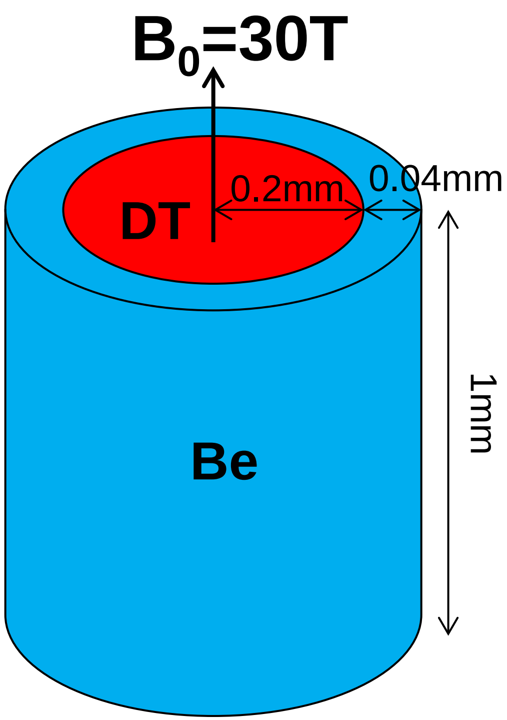
Laser-driven magnetized cylindrical implosions on OMEGA can establish the physics basis for MagLIF



52527
4T seed field
$Y_n = 2.2 \times 10^8$

- The FSC has already developed an experimental platform for magnetized cylindrical implosions (Gotchev et al, JFE 2008)
- **High neutron yields are predicted in OMEGA MagLIF targets**

Scaled-down OMEGA MagLIF
Laser energy = 18 kJ, 3 ns square
Implosion velocity = 90 km/s

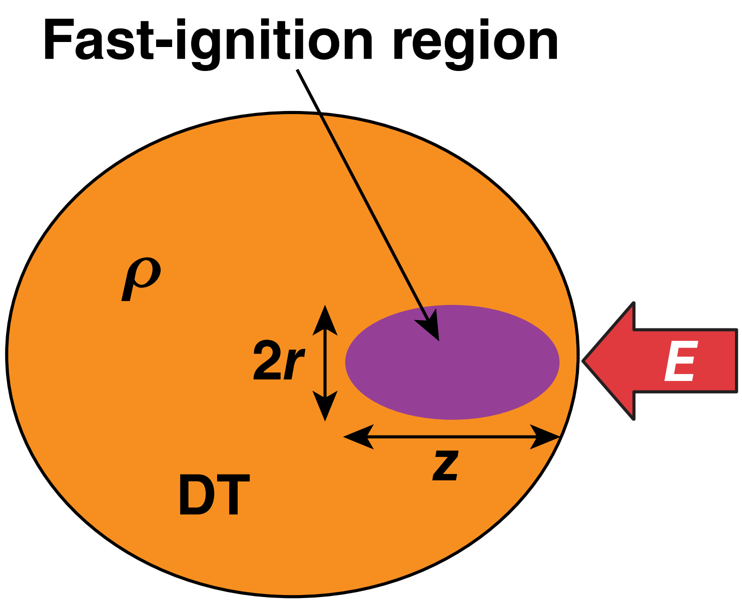


B (T)	T_0 (eV)	$\langle T_i \rangle_N$ (keV)	Yield	P (Gbar)	B_{max} (MG)
0	0	0.68	5.75×10^8	3.5	-
30	250	7.99	2.13×10^{12}	1.8	67

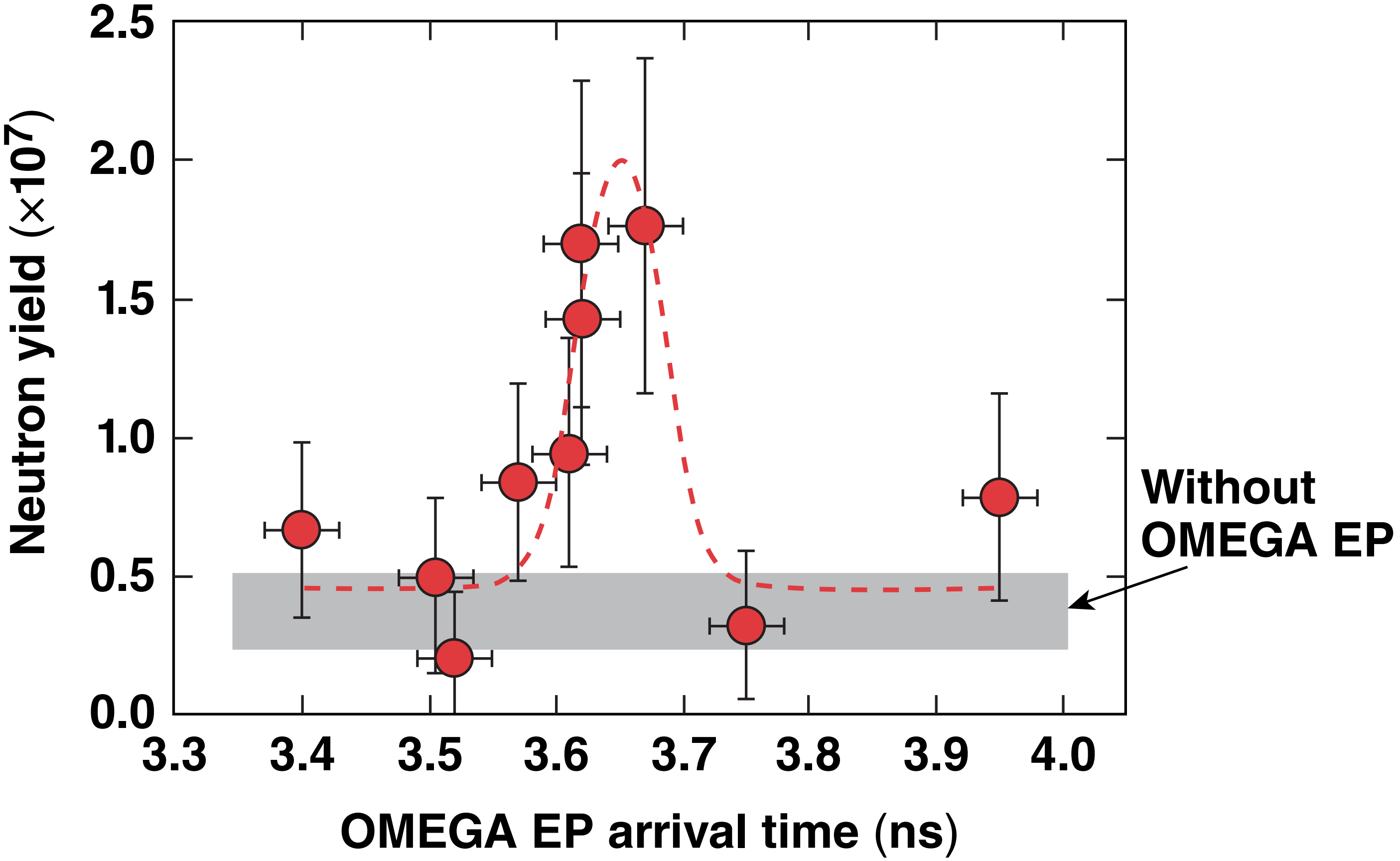
Maximizing the coupling efficiency is a challenge for full-scale fast ignition

Coupling efficiency depends on

- Laser conversion to electrons
- Energy spectrum of electrons
- Collimation of electrons
- Cone tip to dense plasma separation
- Transport efficiency through cone and plasma



The neutron yield increased a factor of 4 with an appropriately timed OMEGA EP beam



$1.4 \pm 0.5 \times 10^7$ additional neutrons were produced with the short-pulse laser.

Summary/Conclusions

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