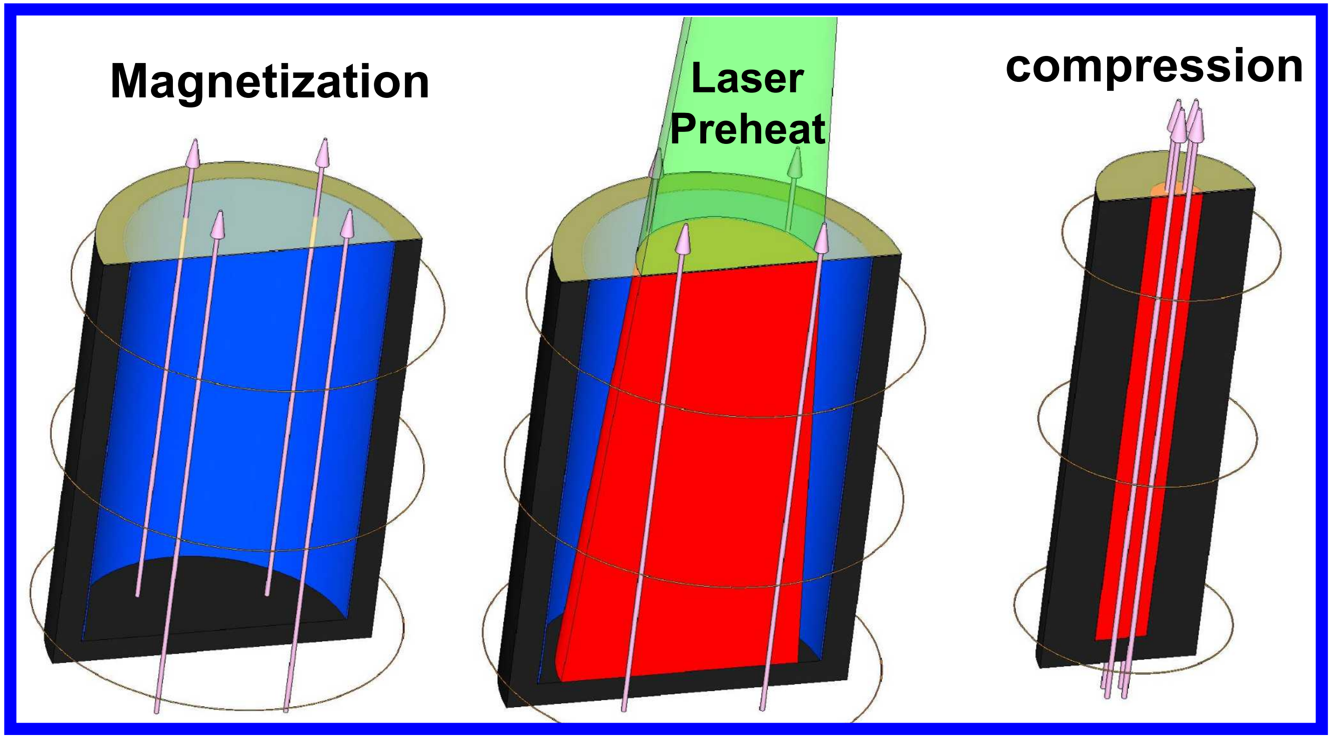
Low-Convergence Magnetized Liner Inertial Fusion and laser preheat scaling



APS Plasma Physic

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S. A. Slutz, R.A. Vesey, D.B. Sinars, and A.B. Sefkow

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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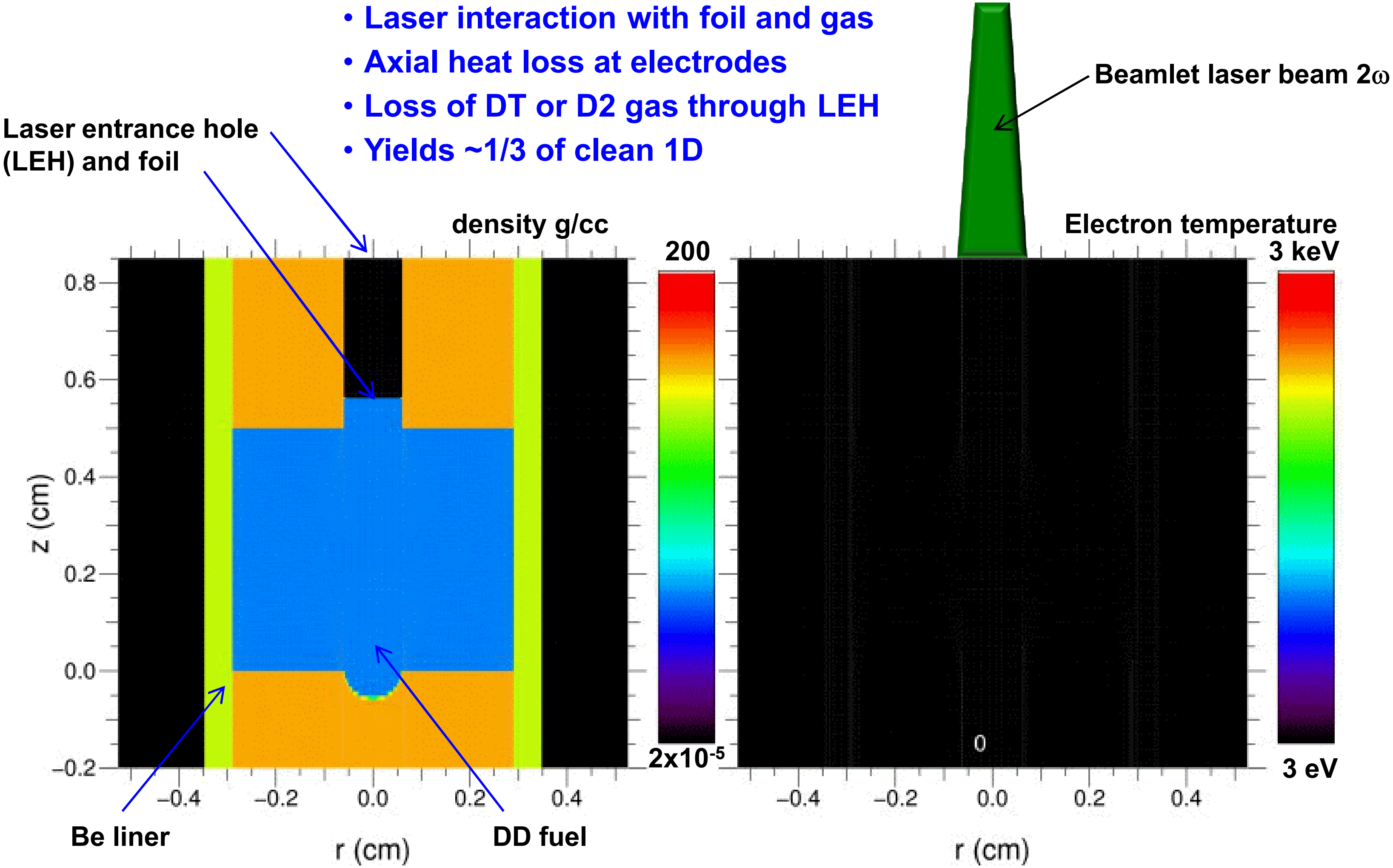
Fully integrated 2D simulations[1] have been performed using both Lasnex and Hydra

Integrated simulations include:
- Laser interaction with foil and gas
- Axial heat loss at electrodes
- Loss of DT or D2 gas through LEH
- Yields ~1/3 of clean 1D



1) see invited talk 2:00 today by Adam Sefkow on integrated MagLIF simulations

Direct magnetically driven implosions are about 20 times more efficient than indirect laser drive

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Laser driven indirect (radiation) implosions could be about 0.13% efficient

- Diode pumped lasers are about 10% efficient.
- The NIF capsule kinetic energy[1] peaks at 22 kJ from a laser energy of 1640 kJ
- Simulations predict 3% conversion to kinetic energy for MagLIF on Z
- Pulsed power has demonstrate 10% conversion of the Marx energy into radiation from wire array implosions.

The natural geometry of magnetic implosions is cylindrical

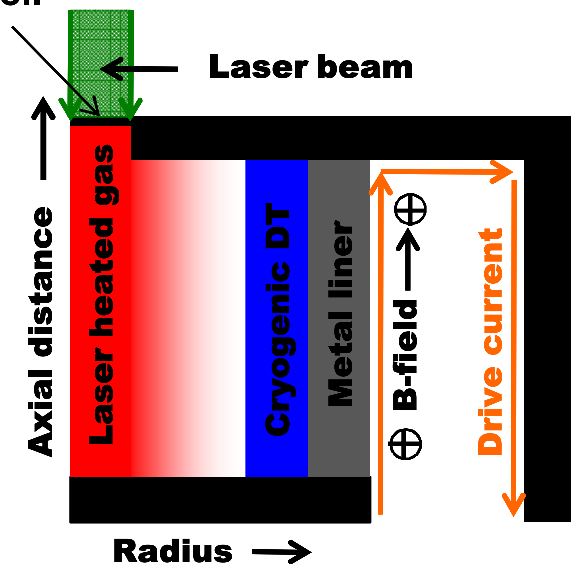
- reduced volume compression (ρr and T_{ig} more difficult than for spherical)
- implosion velocity is slow V_{imp} ~ 12 cm/μs for instability-robust liners

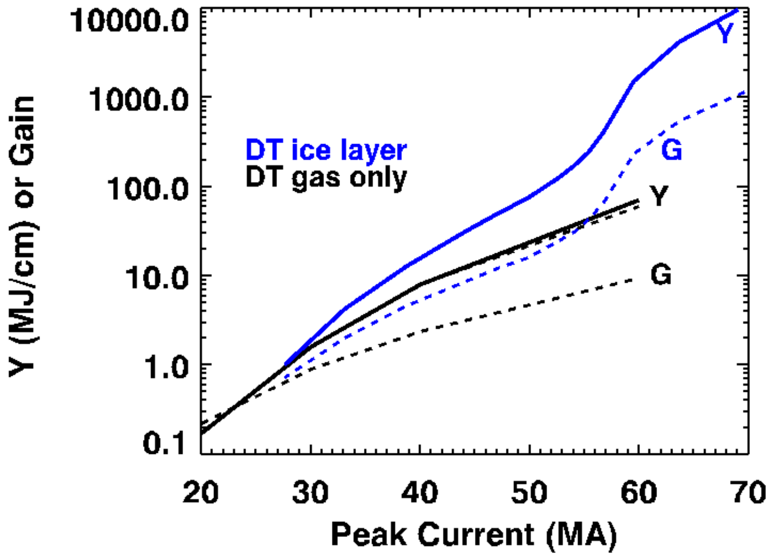
Slow cylindrical implosions can reach ignition conditions with fuel magnetization and preheat

- Magnetization reduces conduction losses during the implosion and burn
- Preheating reduces the volume compression needed to obtain ignition temperature
- Magnetization also reduces the required fuel ρr

[1] R.E. Olson et al., Bulletin American Physical Society 2012

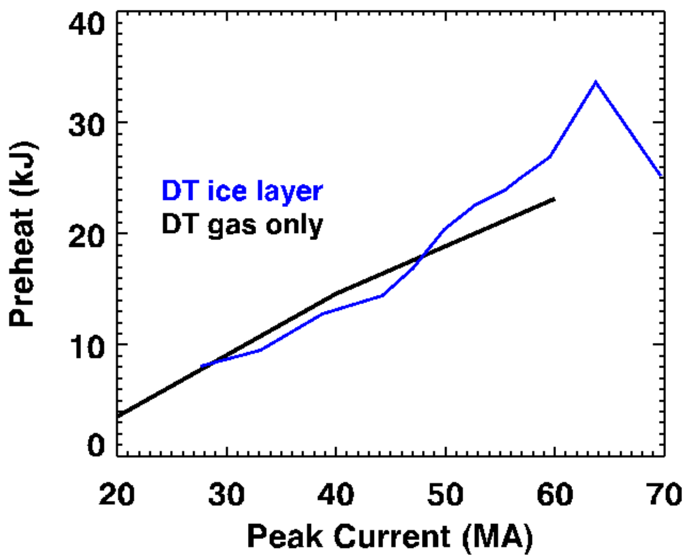
MagLIF could in principle provide high yield and gain but this requires a substantial fuel preheat





It is important to determine the limits of laser preheating for MagLIF

- the laser must penetrate the LEH foil
- the laser must be efficiently absorbed in the fuel with a length of ~ 1 cm
- the deposition must be reasonably uniform



[1] *S.A. Slutz and R.A. Vesey Physical Review Letters 108, 025003 (2012)*

Moderate Liner Convergence (CR~7) Implosions have already been demonstrated[1]

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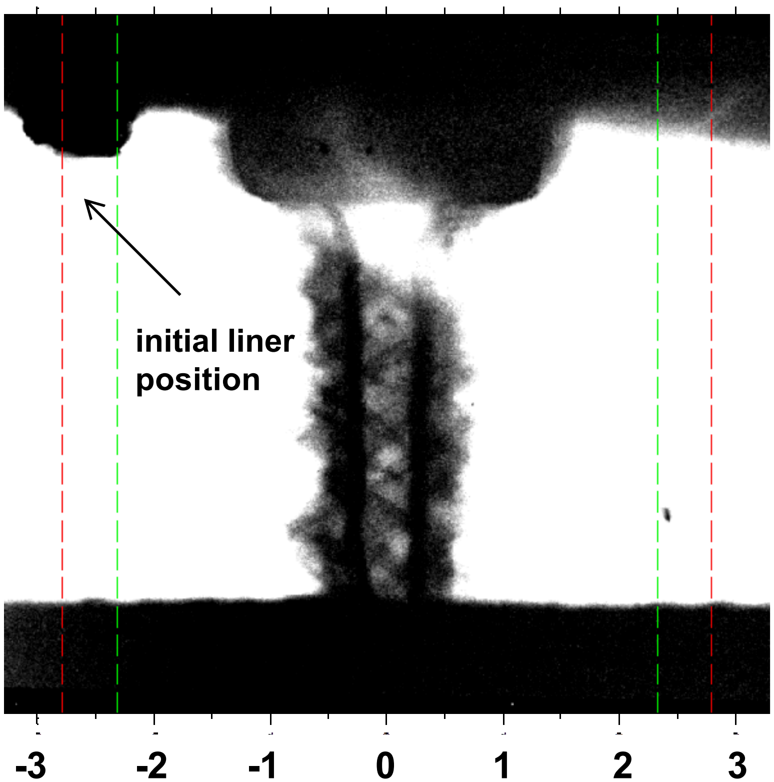
Z-Beamlet radiograph at 6 keV of Be liner with an applied Bz=10 Tesla



The image indicates a convergence ratio (CR) of about 7 at the time of the radiograph. The ultimate CR was probably much larger

Numerical simulations[2] indicate that moderate asymmetries can drive turbulence in high convergence implosions

A MagLIF system that does not require high convergence implosions should be more robust to asymmetries and instabilities

See Tom Awe's invited talk this afternoon at 2:30 for more details

1) T. Awe et al. accepted PRL

2) V. A. Thomas and R. J. Kares PRL, 109, 075004 (2012)

With sufficient preheat low convergence implosions can produce significant fusion yield

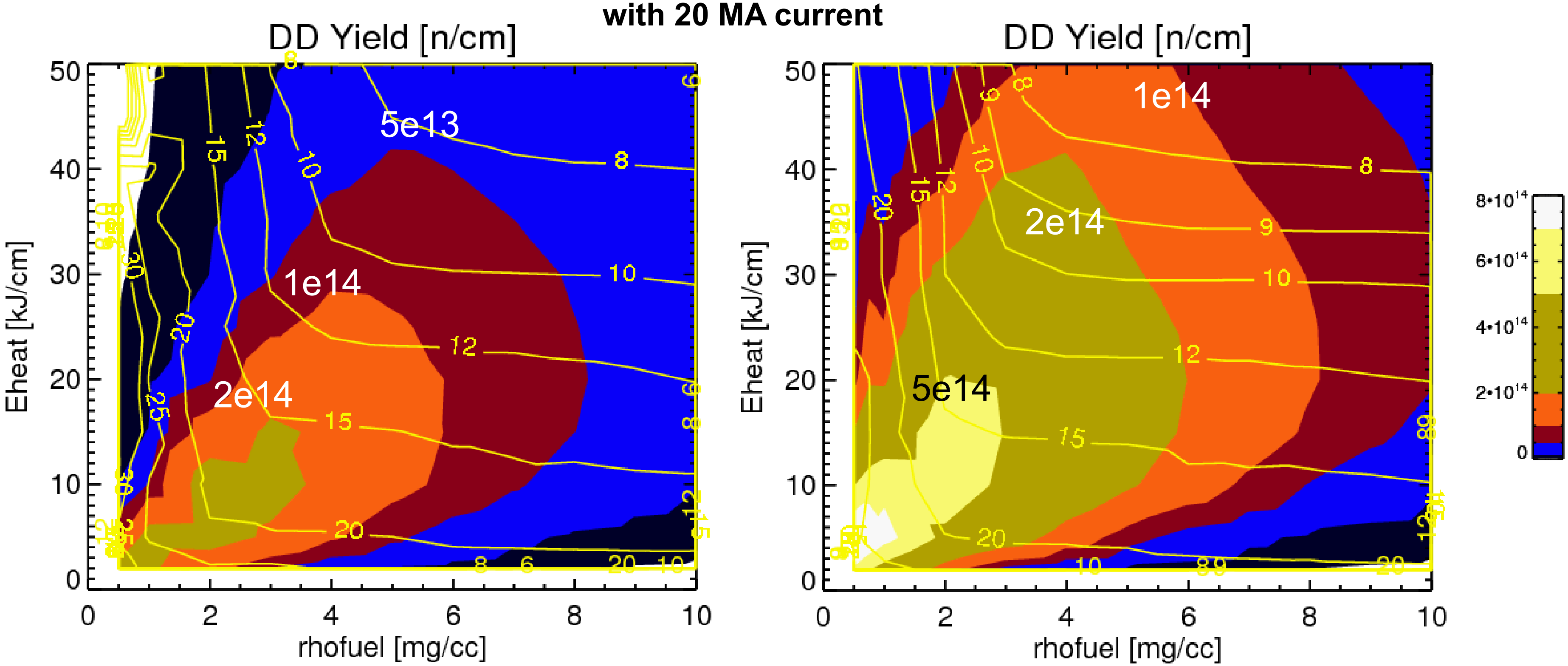
The final temperature of an adiabatic implosion is $T_f = T_0 C_R^{4/3}$

The required convergence is then $C_R = \left(\frac{T_{ig}}{T_0}\right)^{3/4}$

Bz = 15 T

Lasnex simulations with 20 MA current

Bz = 30 T



Analytic theory and simulations indicate that large preheat energies are possible with lasers

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Consider laser deposition in DD or DT without an LEH foil

Need to absorb the laser energy within the length of the liner ~ 1 cm

Laser absorption dominated by inverse Bremsstrahlung

$$C_V \frac{d\theta}{dt} = \frac{dI}{dt} = -kI \qquad k = \frac{\nu_{ei}\omega_p^2}{c\omega_L^2}\left(1-\frac{\omega_p^2}{\omega_L^2}\right)^{-1/2} = \frac{k_0}{\theta^{3/2}}$$

$$k_0 = 1.23x10^6 \rho^2 \lambda_L^2 \left(1-227\rho\lambda_L^2\right)^{-1/2}$$

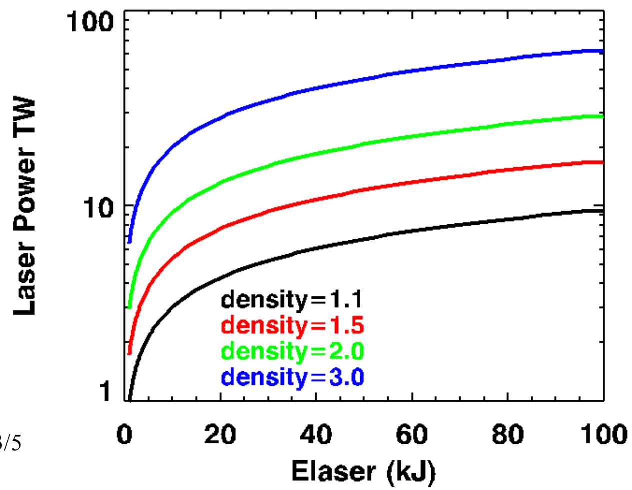
Yields the solution: $I = I_0\left(1-\frac{z}{z_F}\right)^{-2/3} \quad z_F = \frac{5}{3}\left(\frac{2}{5k_0}\right)^{2/5}\left(\frac{I_0 t}{2C_V\rho}\right)^{3/5}$

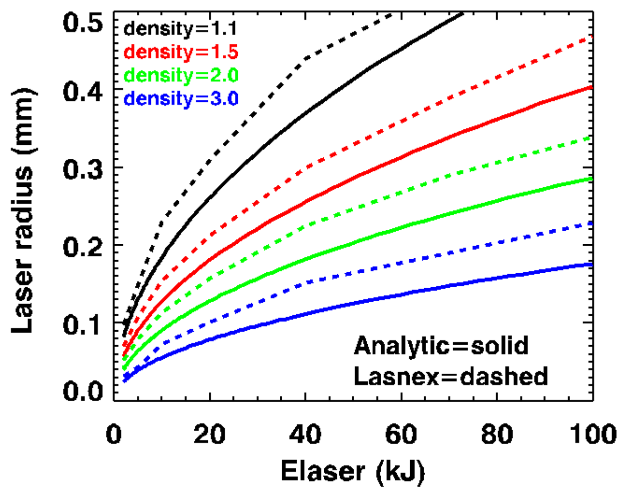
$$R_{Laser} = 5.4x10^{-7} E_{Laser}^{1/2} \lambda_L^{-2/3} \rho^{-7/6} z_F^{-5/6} \left(1-227\rho\lambda_L^2\right)^{1/6}$$

To avoid significant plasma expansion the laser pulse length needs to be less than the sound transit time

$$P_{Laser} > \frac{E_{Laser}}{\tau} \approx 7x10^{16} \rho^{11/6} \lambda_L^{4/3} z_F^{7/6} \left(1-227\rho\lambda_L^2\right)^{-1/3}$$

$\lambda_L = 0.5\mu m$





A large fraction of the laser energy can penetrate through an LEH foil and deposit in 1 cm of fuel

Lasnex simulations are used to study laser penetration through an LEH foil and deposition within the fuel

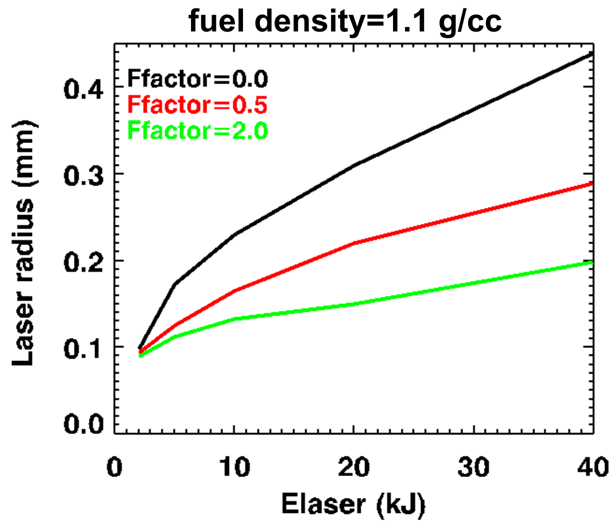
A laser prepulse with 10% of the total energy is used to disassemble the LEH foil. The main pulse is fired when the maximum foil density is one quarter critical

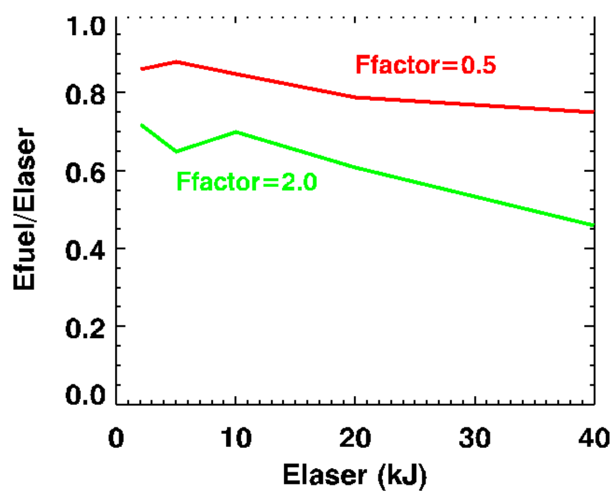
The LEH foil must be thick enough to hold the gas pressure. This can be reduced by cooling.

$$d_{foil} \geq \frac{\Pr_{foil}}{2S} \approx \left(\frac{nkT_{room} r_{Laser}}{2S}\right) F_{factor} \qquad F_{Factor} = \left(\frac{T}{T_{room}}\right)\left(\frac{r_{foil}}{r_{laser}}\right)$$

Although the gas and foil densities are below the critical density for the main pulse, there are potential problems:

- **Refraction induces filamentation**
- **The actual beam will have nonuniform intensity**
- **Brillouin and Raman scattering are not included in these simulations**





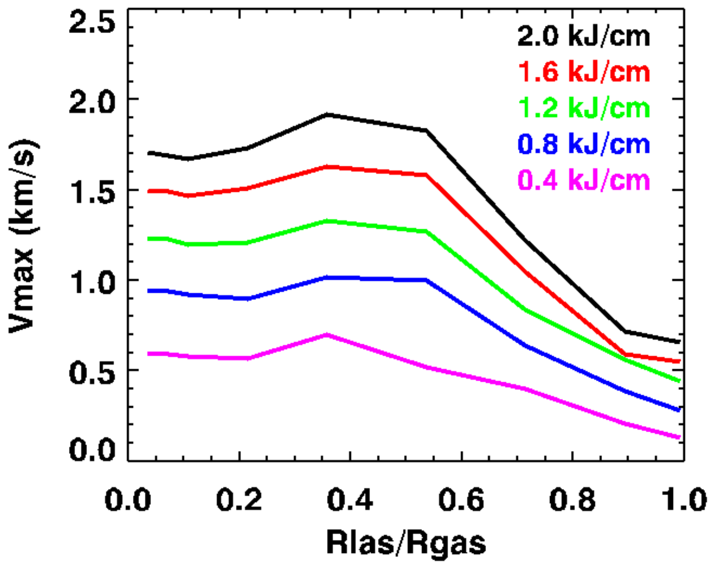
Sandia has started a campaign to study laser preheating and is planning to upgrade the Z-Beamlet laser energy

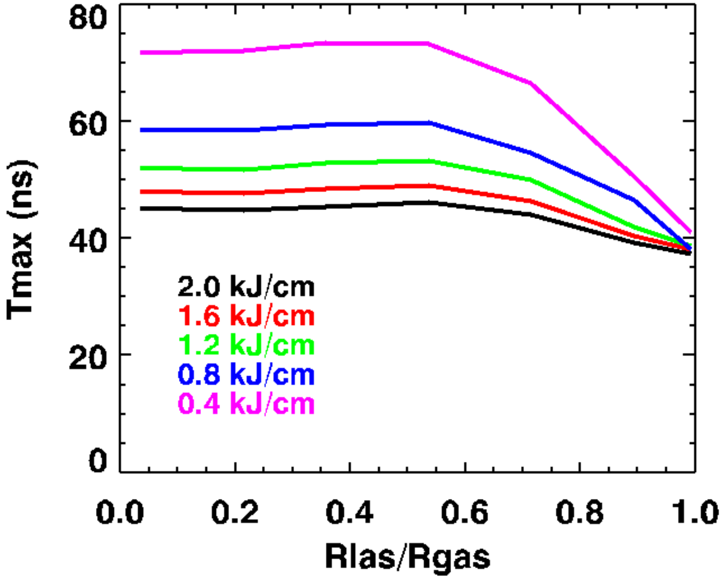
Multiple Z-Beamlet experiments are underway to determine the laser penetration of the LEH foil and the deposition within the fuel

- The total energy deposited within the fuel is being determined from the resultant blast wave (Harvey-Thompson)
- The foil transparency is being determined using an auxiliary laser beam (Geissel and Porter)
- Images of the heated plasma will be obtained with bent crystal imaging (Harding)
- Preheated fuel temperatures can be determined with spectroscopy (Hansen)

Experiments are planned using the Omega laser, which can provide more energy than Z Beamlet (Harvey-Thompson)

- cooling curves to determine the effect of an applied field on the transport





Summary

Low convergence implosions should be more robust to asymmetries and instabilities

Simulations indicate that with adequate preheat energy, low convergence MagLIF implosions could produce significant fusion yields

Lasnex simulations indicate that high gain and yields are possible with MagLIF, but substantial preheat energies are required

Analytic theory and simulations indicate that more than 40 kJ of 0.5 um laser light can be efficiently deposited within 1 cm of DD or DT at densities appropriate for MagLIF

Refraction, filamentation and scattering could pose problems. Consequently:

- We are now studying laser preheating with Z Beamlet.
- We have plans to use Omega for studies at higher laser energies