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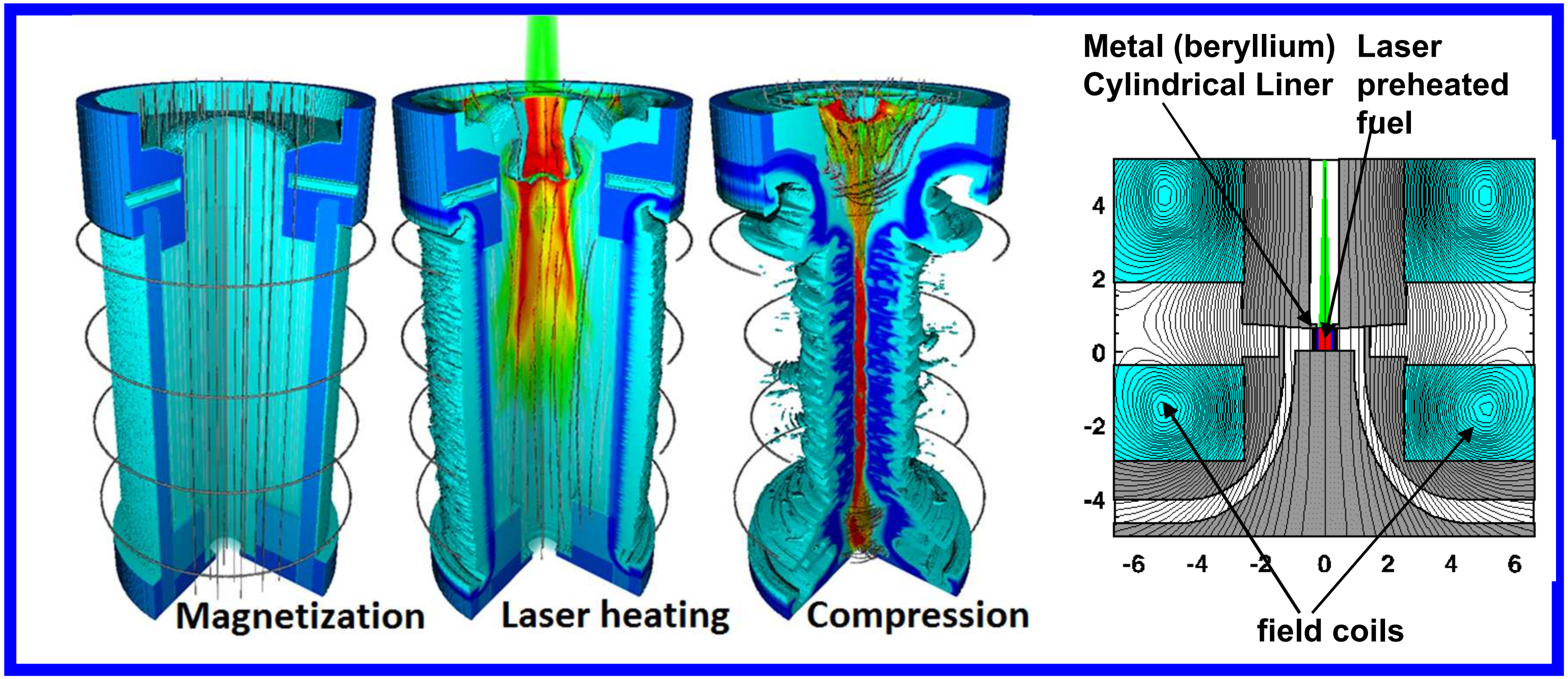
Scaling Magnetized Liner Inertial Fusion (MagLIF) on Z and Future Machines



Inertial Fusion Science & Applications

Seattle, Washington, September 20-25, 2015

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U.S. DEPARTMENT OF ENERGY
National Nuclear Security Administration

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The MagLIF concept[1] is being tested[2] on the Z facility. Higher drive currents could be provided by future machines[3]

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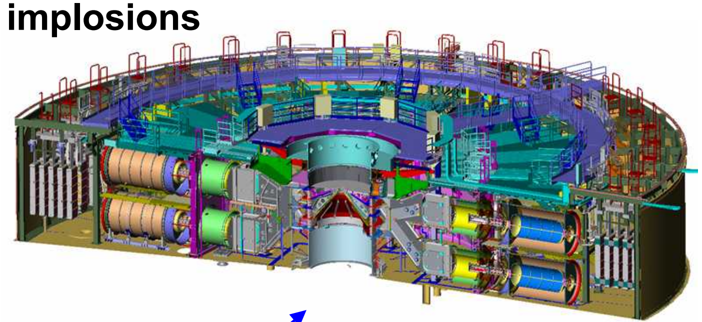
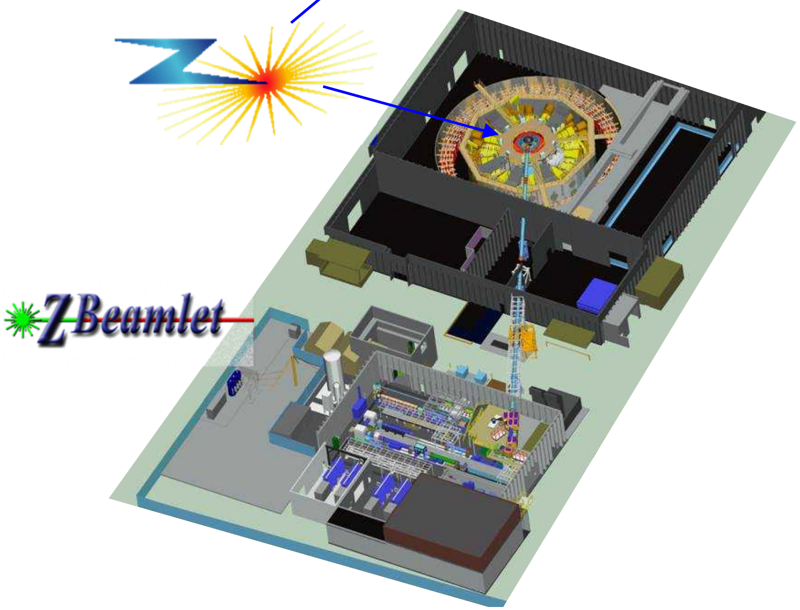
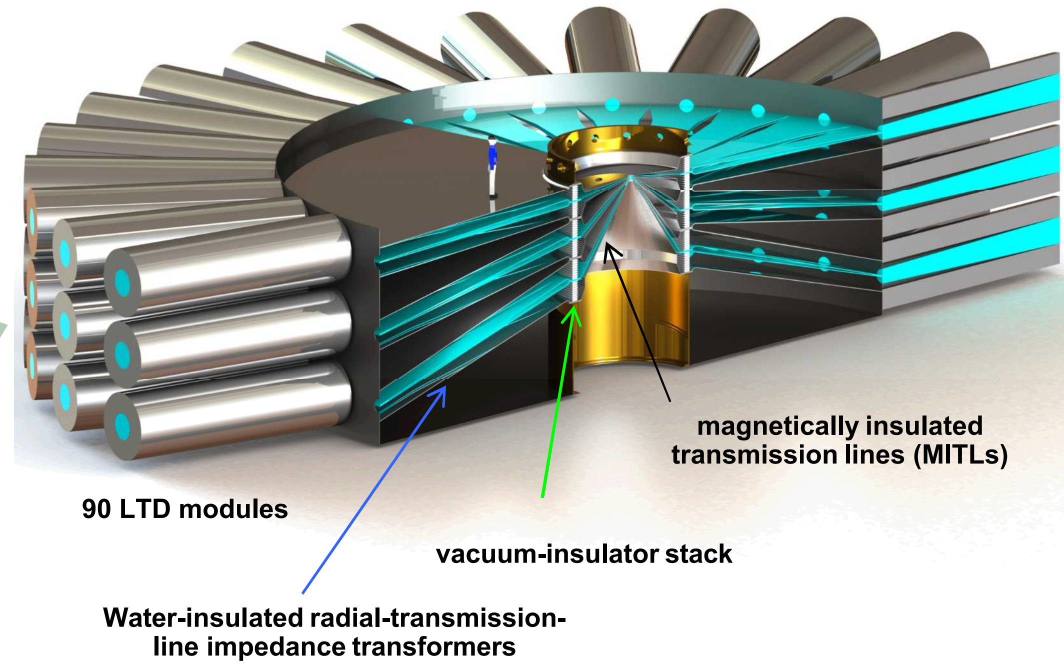
Z can generate high magnetic pressures to drive cylindrical implosions





Z-Beamlet provides fuel preheat

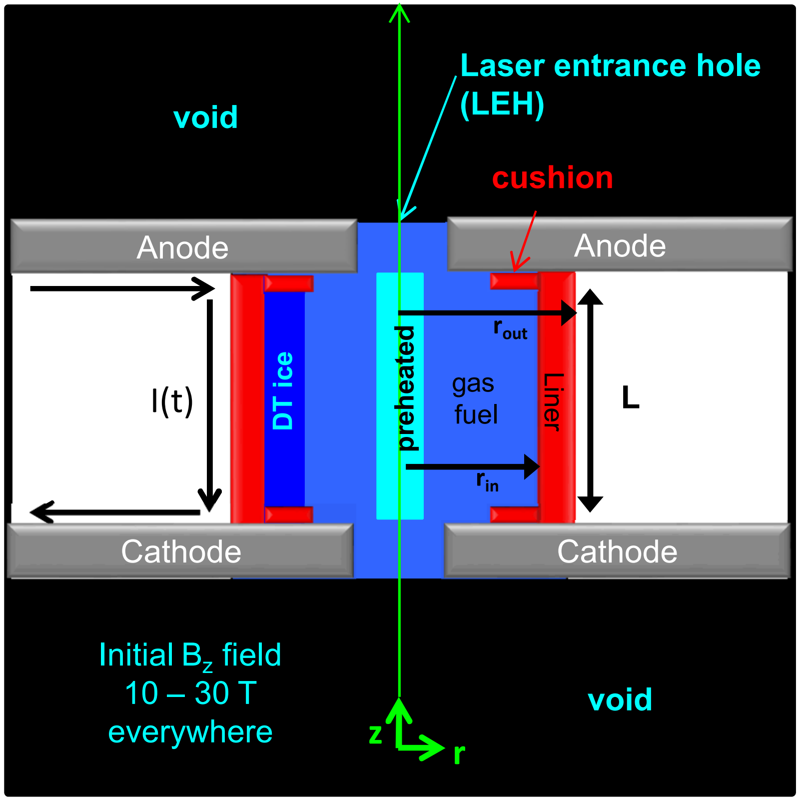
Z 300 employs Linear Transformer Driver (LTD) technology to deliver 48 MA to a MagLIF load, and would fit within the existing Z building.

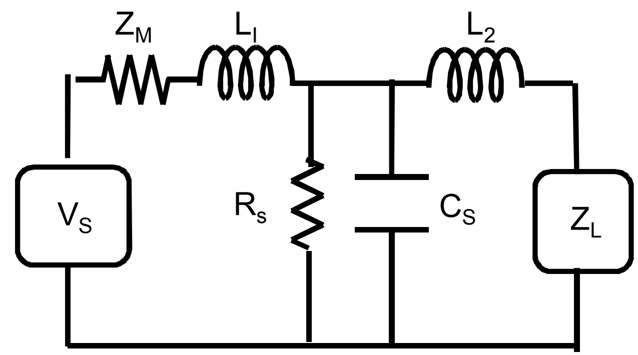


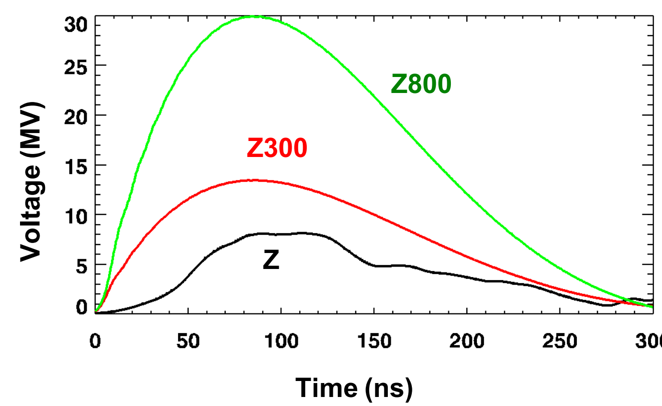
Z800 would deliver 65 MA with the same technology

[1] *Slutz et al. PoP 2010*   [2] *Gomez et al. PoP 2014*   [3] *Stygar et al Phys. Rev. ST Accel. Beams 2015*

2D Lasnex simulations based on simplified geometry and circuit model

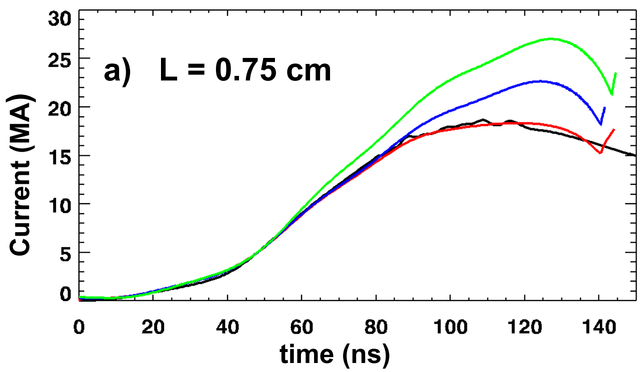


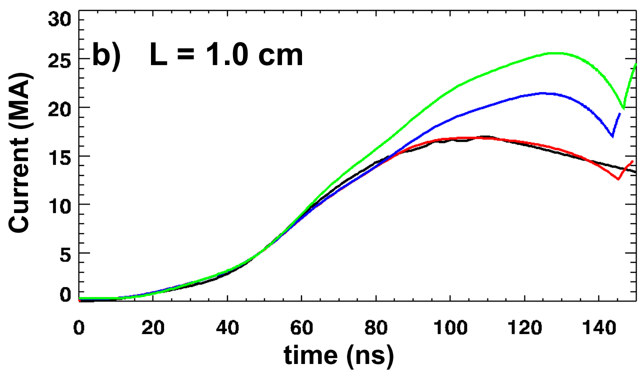




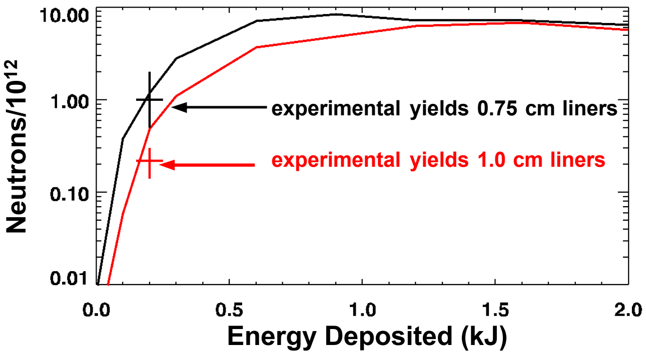
Simulated yields are comparable to experiments results

Black: 80 kV MagLIF experiments results
Red: 80 kV simulated with feed loss
Blue: 80 kV simulated without feed loss
Green: 95 kV simulated without feed loss





2D MagLIF simulations



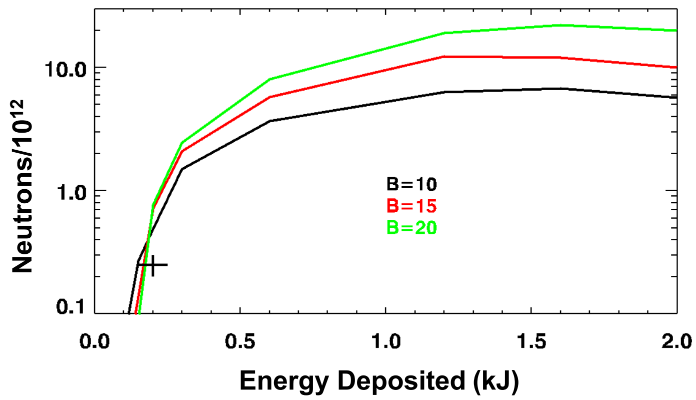
Z Beamlet produces 2 kJ of unsmoothed 0.53 mm light

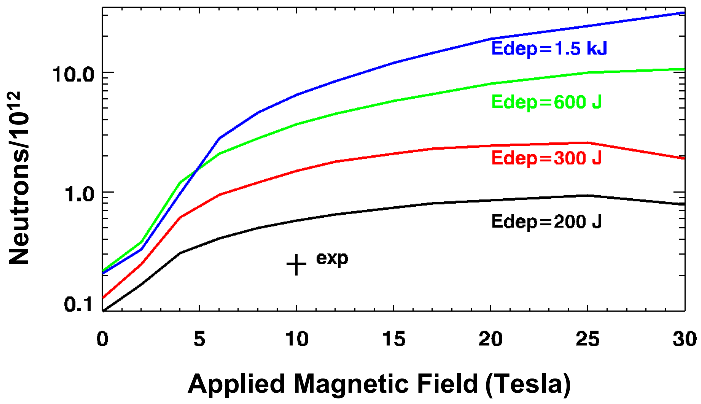
- Only ~ 200 Joules penetrates foil[1]

[1]M. Geissel et al. 41st EPS Conference on Plasma Physics 26 June 2014, Berlin, Germany

Present experiments on Z at 18 MA do not have optimal values of preheat or applied field according to simulation

2D Lasnex simulations of 1 cm long liners

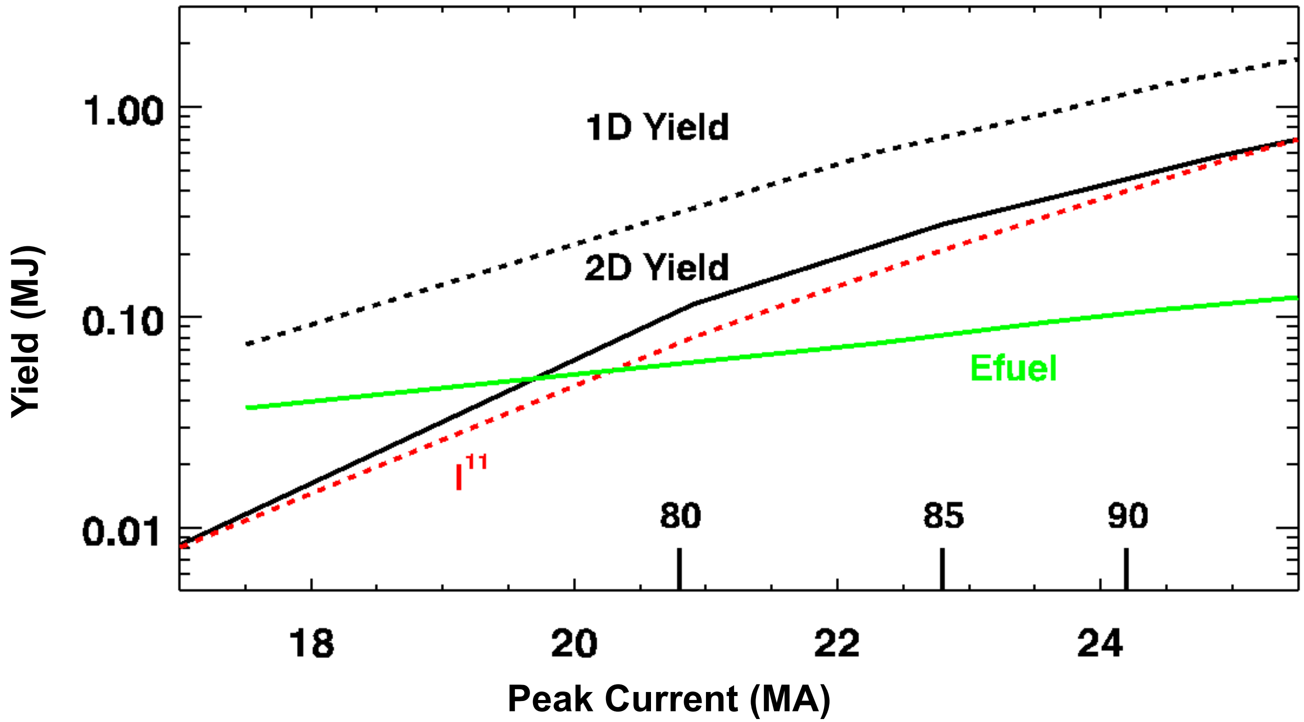




2D simulations predict yield increases with fuel preheat and applied B

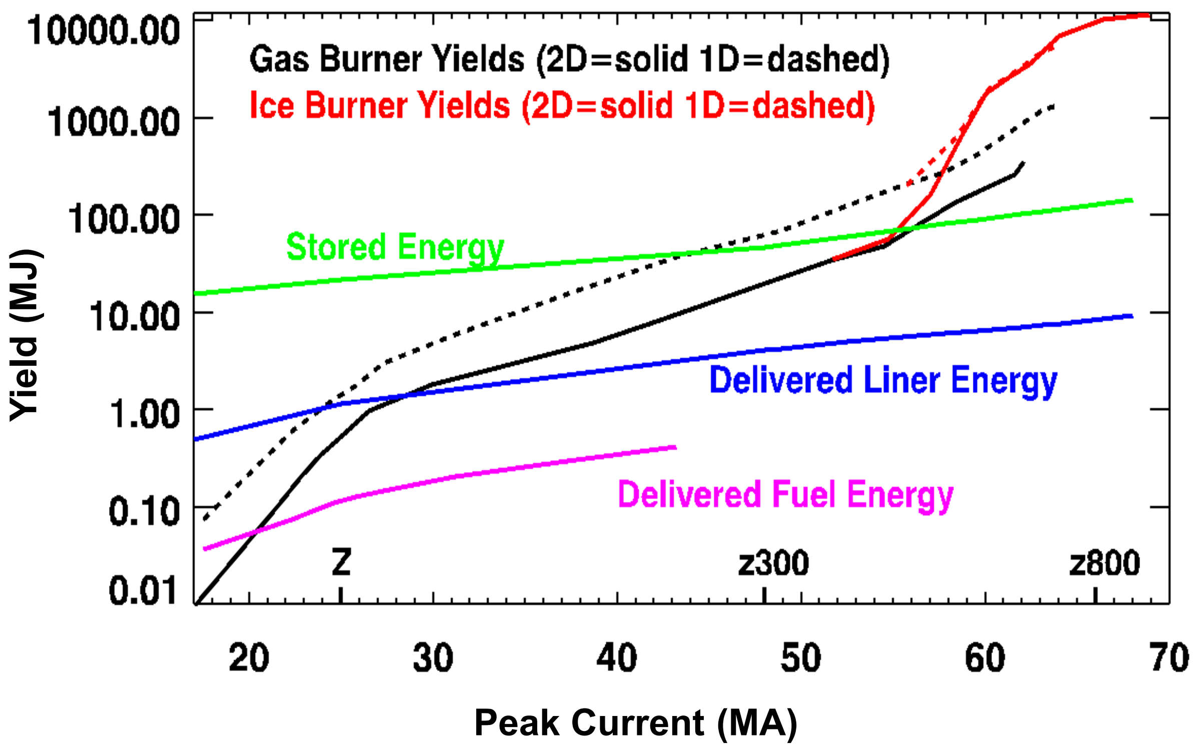
Experiments will be performed to test these predictions

Simulations indicate that optimized yields are a strong function of current over the range accessible to Z



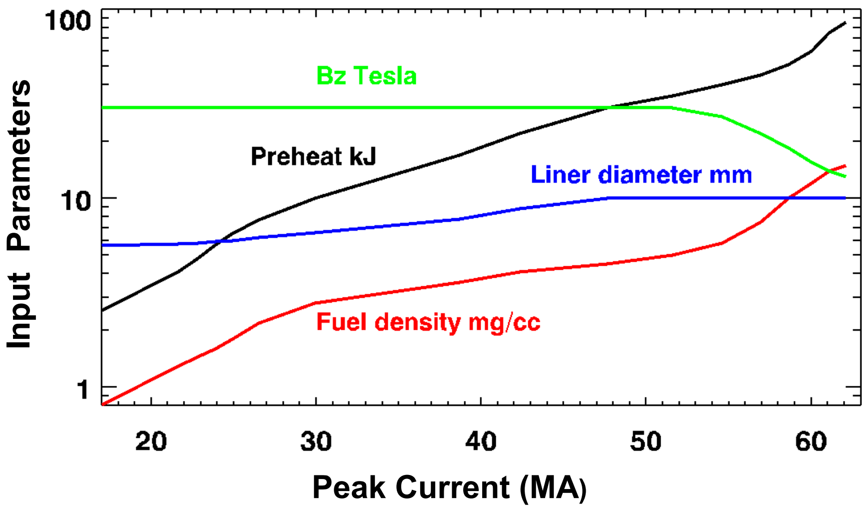
Capsule parameters (radius, fuel density, fuel preheat, and B_z) are optimized at each value of the drive current.

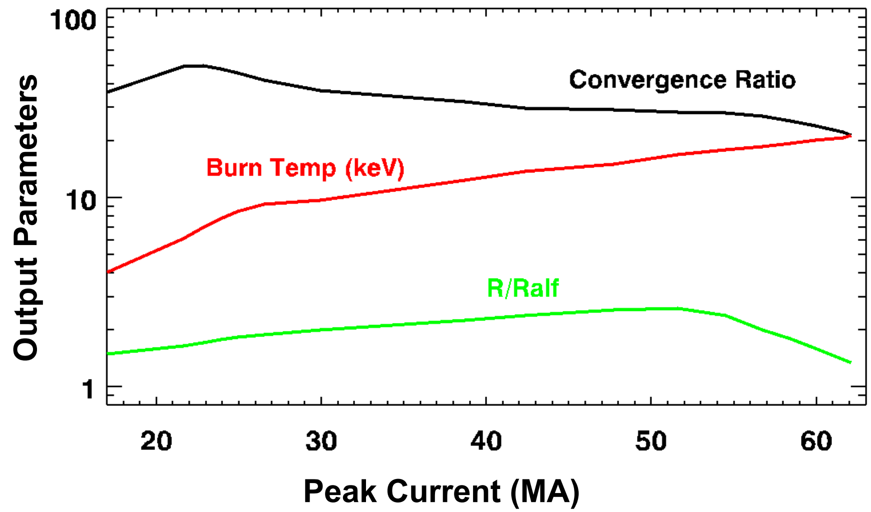
2D simulations indicate that Z300 could drive a MagLIF with gain greater than unity

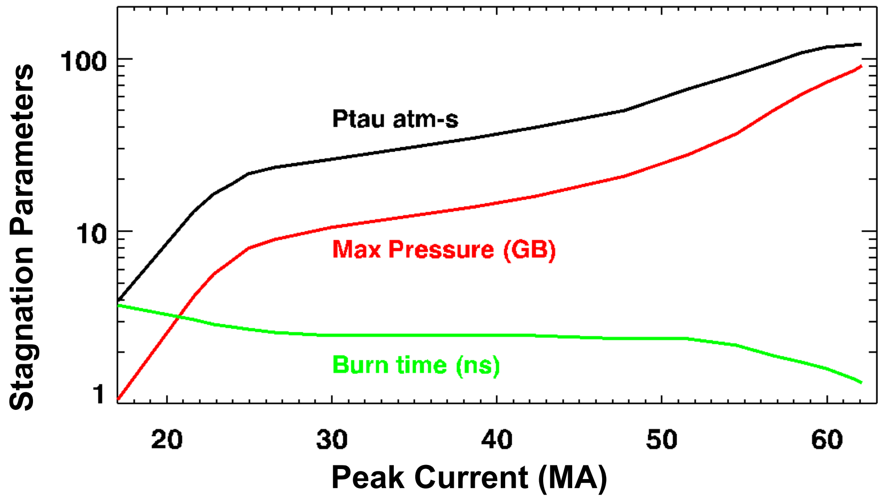


DT ice layers may significantly enhance yields for drive currents > 60 MA

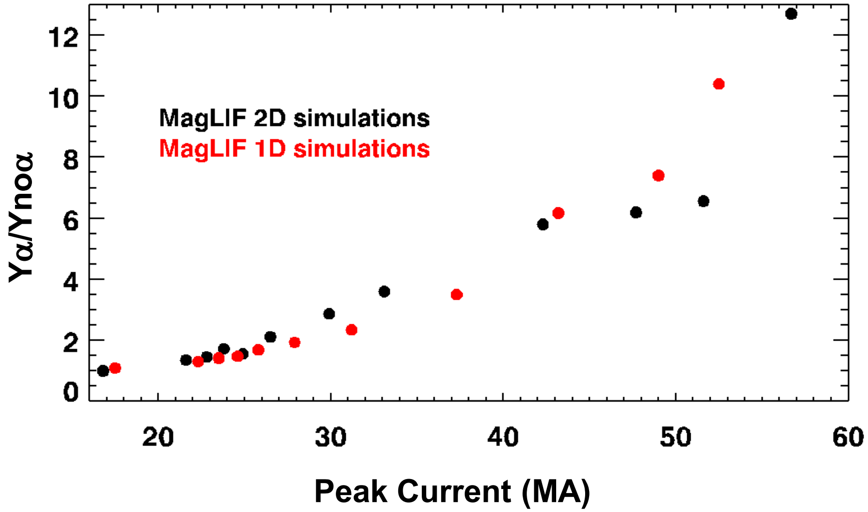
2D simulations indicate optimal design parameters and output quantities



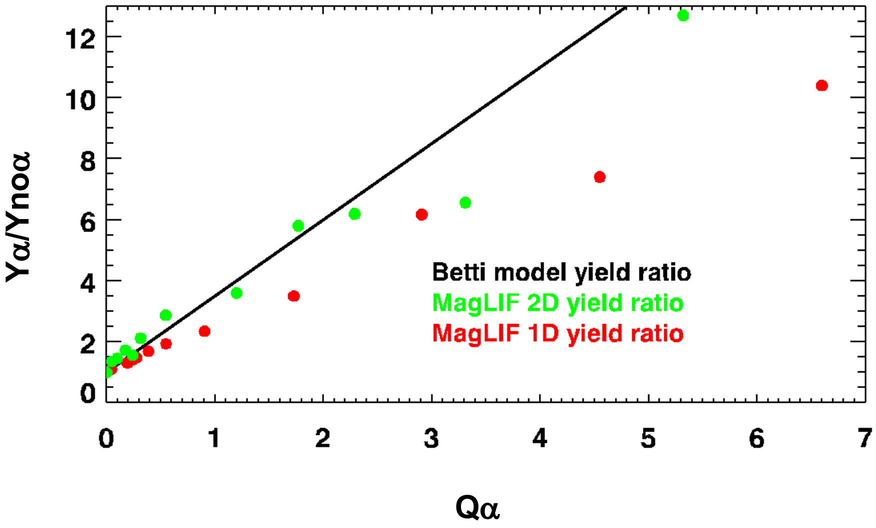




The ratio of the yield with and without alpha particle heating can be used as an ignition metric[1]



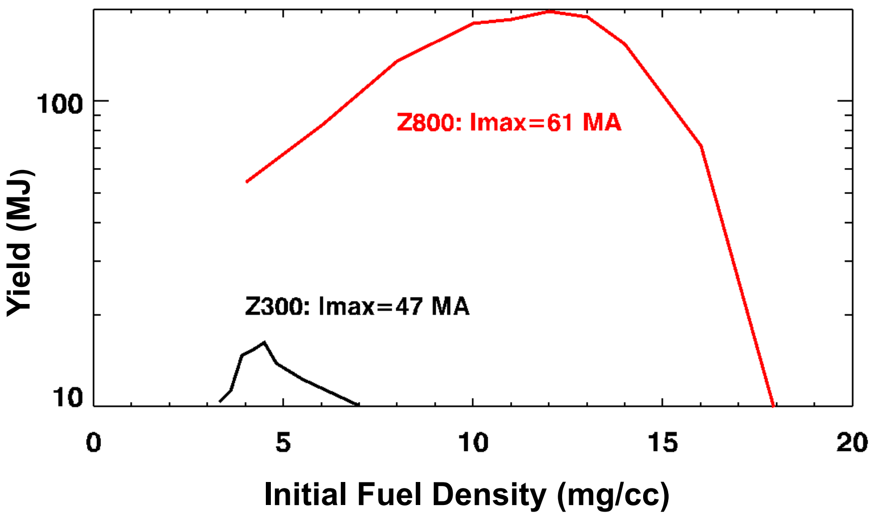
Defined Qα: as the ratio of the fuel energy at peak burn with and without alpha deposition

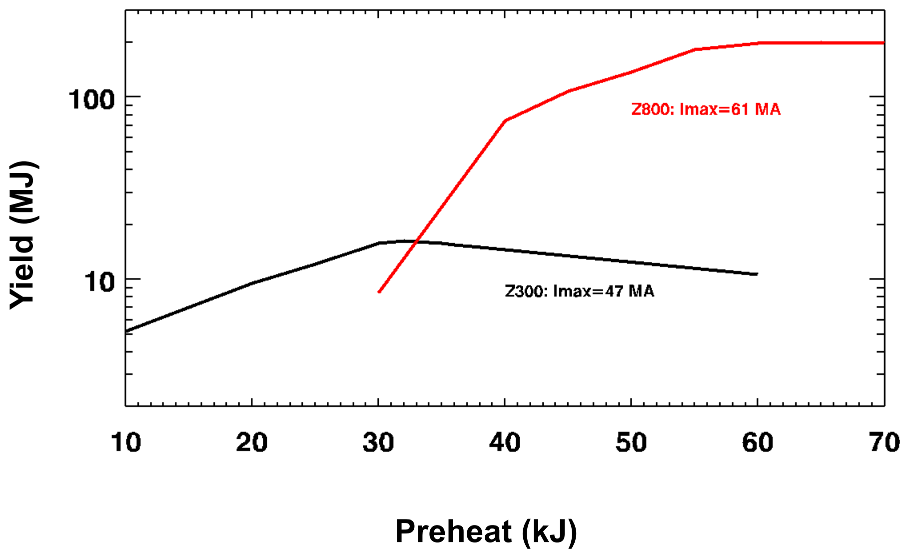


[1]Betti et al Phys. Rev. Lett. 114, 255003 2015

2D simulations indicate initial fuel density and preheat energies have broad optima

Lasnex simulations of Gas Burners



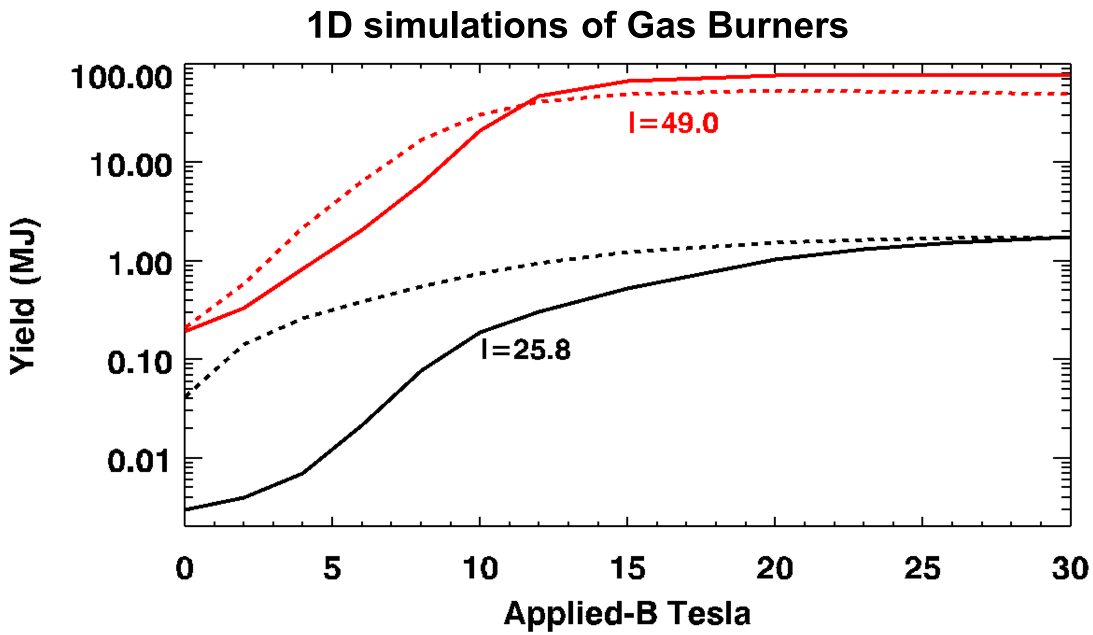


The Nernst effect can be significant

All of the preceding Lasnex simulations have included the Nernst (Ettingshausen) effect

Nernst produces an electric field E_{Nernst} proportional to B x grad(T)

- The magnetic field is advected with a velocity proportional to E_{Nernst}/B
- The magnetic field is reduced in the hot core and increased near the fuel liner interface
- The effect is decreased when $\omega\tau$ is large and is not large for optimal B
- Experiments determining the yield as a function of B will determine the importance of this effect



Simple analytic theory predicts the laser penetration can be controlled by the beam radius

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Laser absorption coefficient dominated by inverse Bremsstrahlung

$$C_V \frac{d\theta}{dt} = \frac{dI}{dz} = -kI \qquad k = \frac{\nu_{ei}\omega_p^2}{c\omega_L^2}\left(1-\frac{\omega_p^2}{\omega_L^2}\right)^{-1/2} = \frac{k_0}{\theta^{3/2}} \qquad k_0 \approx 1.23x10^6\left(\rho\lambda_L Z_b\right)^2\left(1-227\rho Z_b\lambda_L^2\right)^{-1/2}$$

$$I = I_0\left(1-\frac{z}{z_f}\right)^{2/3} \qquad z_f = \frac{5}{3}\left(\frac{2}{5k_0}\right)^{2/5}\left(\frac{I_0 t}{2C_V\rho}\right)^{3/5} \qquad R_{laser} = 5.4x10^{-7} E_{laser}^{1/2}\lambda_L^{-.67}\rho^{-1.17}z_f^{-.83}\left(1-227\rho\lambda_L^2\right)^{.17}$$

Hydrodynamics and refraction make this process more complicated

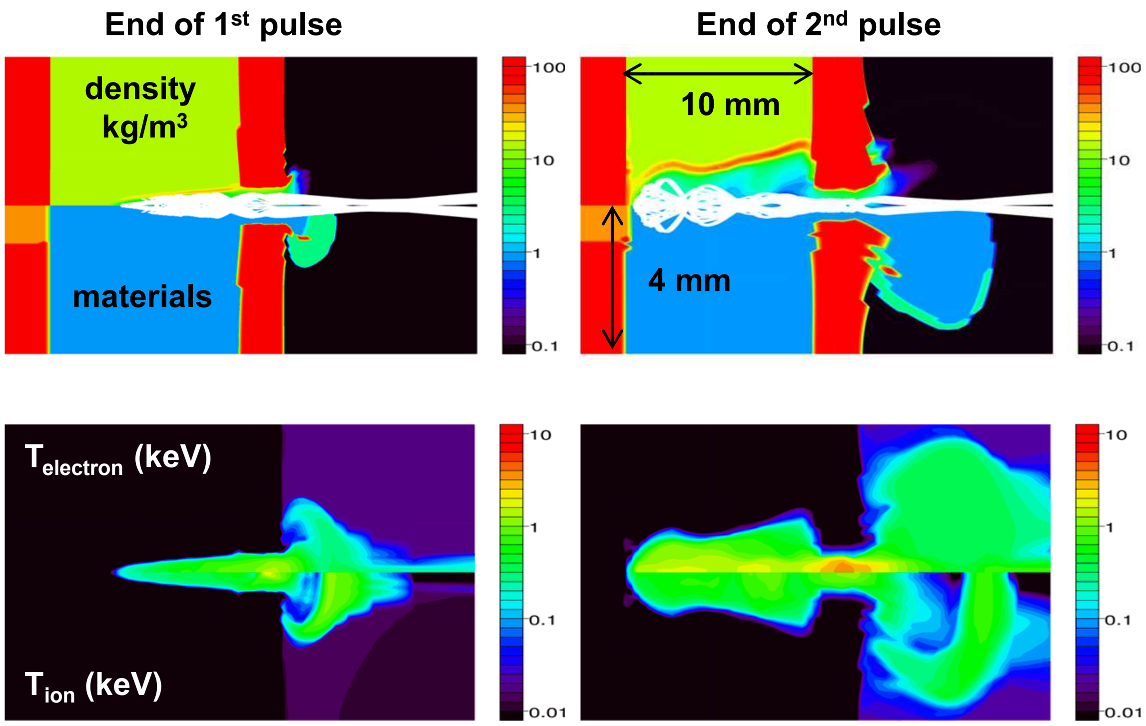
A short wavelength laser (λ ~ 0.25-0.33 μ) could be used to penetrate the initially high density DT forming a low density channel

A second pulse of longer wavelength light (λ = 0.5-1 μ) could then propagate down this channel and efficiently deposit its energy

2D Lasnex simulation of laser deposition indicates that 30 kJ can be absorbed in 1 cm of 12 mg/cc DT fuel

3 kJ of 4ω to bore a hole

30 kJ of 1ω to deposit energy



Laser plasma instabilities (LPI) could pose a problem for MagLIF preheat on future accelerators

LPI is unimportant if:

- the plasma density is much lower than the critical density ($n/n_{crit} << 1$)
- The laser intensity is low ($I_{Laser} < 10^{14}$ watts/cm^2)

Optimum fuel densities are larger on future accelerators

- Optimal fuel density ~ 5 mg/cc on Z300 ($n/n_{crit} \sim 0.13$) for 3ω

Optimum preheat energies are larger on future accelerators

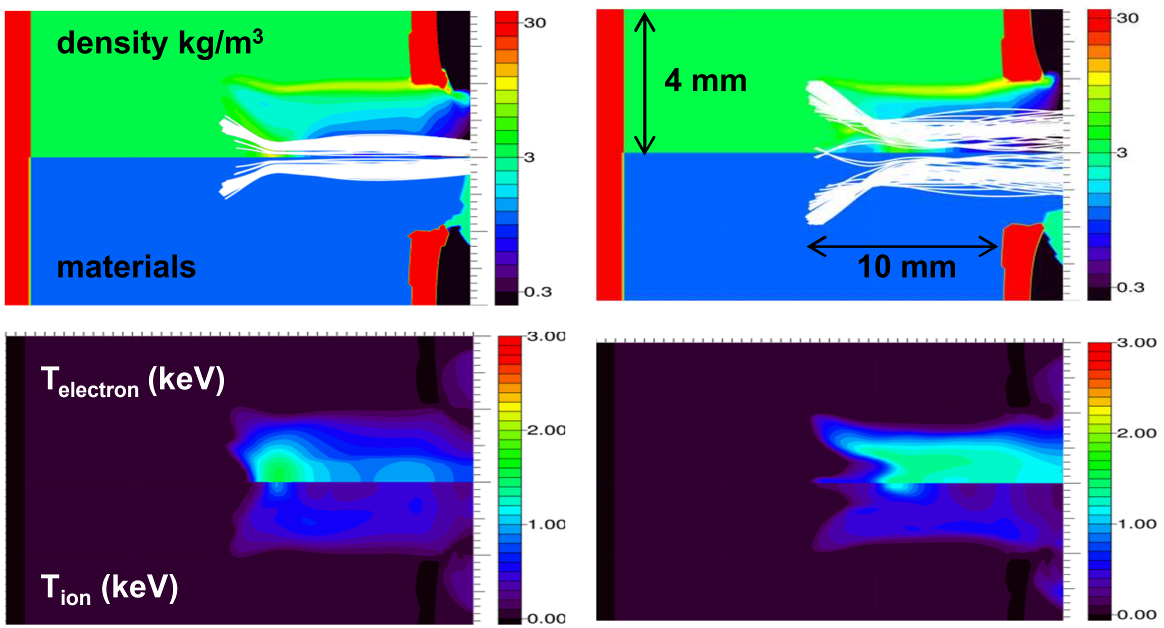
- Optimum preheat ~ 30 kJ on Z300
- Laser pulse can not be too long or gas moves out of the way. Beam intensity may need to be > 10^{14} watt/cm^2

Laser preheating at Z300 levels could be tested using a quad of NIF

30 kJ 3ω at 5 TW stopped in 1 cm of DT at 4.5 mg/cc

B=0
1.0 mm diameter focus
I_{Laser} = 6x10^{14} W/cm^2

B=30
1.8 mm diameter focus
I_{Laser} = 2x10^{14} W/cm^2



We have presented 1D and 2D simulations of MagLIF on upgraded Z and future machines

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Simulations indicate that large yields and gains may be possible on a future machine such as Z300

Simulation predictive capability is greatest when the extrapolation is not large

Present experiments have been perform at 18 MA with B=10 Tesla and low preheat ~ 200 joules

- **Phase plates have been designed of Z Beamlet to enable larger preheat energies**
- **30 Tesla fields are possible with the existing field coil system**
- **An improved convolute design will be tested with MagLIF to obtain higher drive currents on Z**

Full scale laser deposition experiments could be performed using one quad of the NIF to remove uncertainties about laser preheating

Agreement between the simulation scaling presented here and the results of experimental scaling will greatly increase our confidence to predict MagLIF performance on future machines