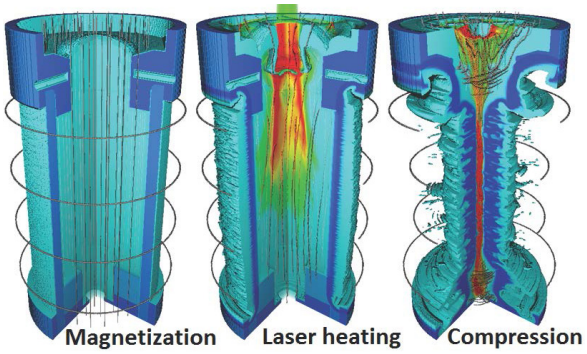
DEMONSTRATING FUEL MAGNETIZATION AND LASER HEATING TOOLS FOR LOW-COST FUSION ENERGY

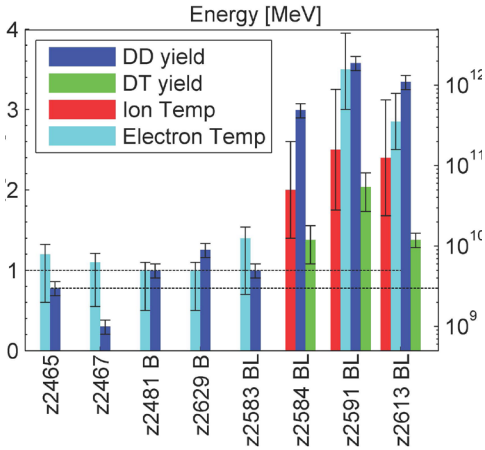
A joint SNL/LLE project funded by the ARPA-E ALPHA program

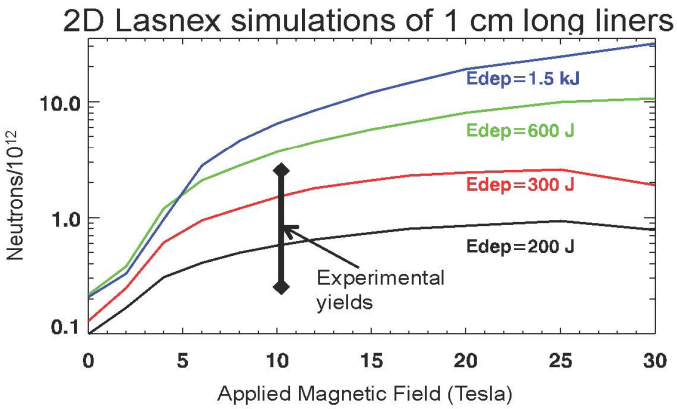


Schematic of MagLIF

Magnetized liner inertial fusion (MagLIF) [1] is an inertial confinement fusion (ICF) scheme using cylindrical compression of magnetized, preheated DT gas. A 10 – 30 T axial magnetic field reduces electron thermal conductivity allowing near-adiabatic compression at implosion velocities of order 100 km/s, much lower than the 300 km/s or more required for conventional ICF. Preheating to at least 100 eV ensures that keV temperatures are reached with a convergence ratio no greater than 30. The compressed magnetic field confines alpha particles in the radial direction, replacing the ρR > 0.3 g/cm2 requirement of conventional ICF, which requires high convergence ratios, with a BR > 0.6 T m requirement[2]. The ignition temperature of low ρR, magnetized DT is about 7 keV, slightly higher than the 4.5 keV required at high ρR. The confinement time is provided by the inertia of the target, as in conventional ICF.

Temperature and yield measurements from Z experiments in 2013. B indicates a 10 T axial magnetic field was applied, L indicates laser preheat was applied.





Example of simulation results for Z experiments showing DD neutron yield as a function of initial axial magnetic field for different levels of energy deposition in the gas

MagLIF experiments on Z [3] started in 2013 using 5.58 mm outer diameter, 0.465 mm thick, 7.5 mm long Be liners filled with 0.7 mg/cc D2 in a 10 T axial magnetic field, imploded at a velocity of 70 km/s using a 19 MA, 100 ns rise-time current pulse. The gas was preheated using the Z beamlet laser (ZBL), delivering 2.5 kJ in 2.5 ns at a wavelength of 0.53 µm. Temperatures just under 3 keV and a BR of at least 0.4 T m have been achieved, close to the 7 keV and 0.6 T m required for ignition, giving DD neutron yields up to 3.2 x 10^{12}. Magnetic confinement of fusion products, a key requirement of any magnetized fusion scheme, has been demonstrated by DT neutron yields resulting from T production in DD fusion. Subsequent experiments will be used to optimize performance and improve statistics.

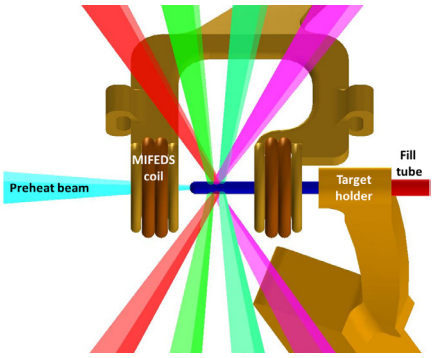
MagLIF simulations are being carried out using the MHD codes Lasnex, Hydra and Gorgon in 1, 2 and 3D. Developing a validated, predictive simulation capability that can be used for the whole ALPHA program is a key aspect of this project. Initial 2D simulations of the Z experiments predicted a neutron averaged ion temperature of 3.5 keV, BR of 0.53 T m and a DD neutron yield of 6.1 x 10^{13}, nearly 20 times higher than measured. The principal candidate to explain this discrepancy is lower than predicted laser preheat; all of the experimental observables can be matched if the energy deposited in the gas is reduced by a factor of

6 in 2D simulations[4], slightly less in 3D simulations. Laser-only experiments with ZBL have shown that the codes do over predict laser transmission through the entrance window. Laser preheat is now the subject of extensive study.

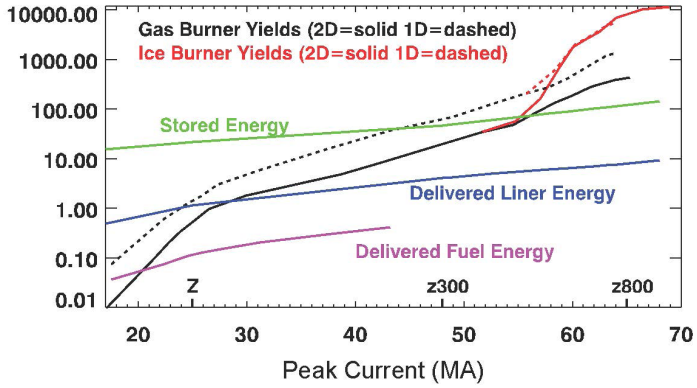
MagLIF preheat-only experiments are being carried out on ZBL, both on Z and in separate target chambers, on OMEGA-EP[5] and OMEGA at the LLE, and on the National Ignition Facility (NIF). Developing the capabilities to study preheat with ZBL in separate target chambers is a key aspect of this project.

Laser-driven MagLIF on OMEGA using targets ten times smaller in linear dimensions than Z targets is being developed by this project to provide the first experimental data on MagLIF scaling, and to provide more shots with better diagnostic access than available on Z to facilitate the study of the basic physics of compressing magnetized plasmas. In particular, the axial magnetic field can be probed with protons on OMEGA, which is not possible on Z due to the large azimuthal magnetic field from the pulsed power compression. A 9-shot day program (> 90 shots) has been drawn up that includes measurements of field compression and scans of preheat, magnetic field, implosion velocity and convergence ratio.

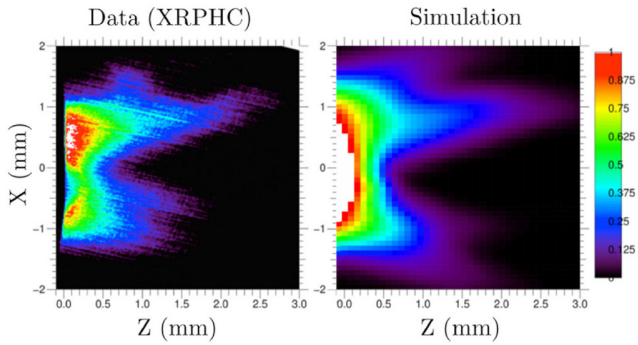
Scaling to ignition and fusion energy production is being studied at both the theoretical[6] and technical level. A next generation Z machine based on linear transformer drivers to demonstrate energy gain, on a single shot basis, appears to be a practical near-term goal. Options for high-gain fusion at repetition rates suitable for energy production are being explored.



Design drawing of the laser-driven MagLIF concept on OMEGA, only select beams are shown for clarity.



Scaling of MagLIF yield with drive current for the standard design (gas burner) and a design incorporating a layer of DT ice on the inside of the liner (ice burner).



X-ray pin hole camera image from preheating experiments on OMEGA-EP and the results of 3D simulations with Hydra.

[1] S. A. Slutz et al Phys. Plasmas 17 056303 (2010)

[2] M. M. Basko, A.J. Kemp and J. Meyer-ter-Vehn, Nucl. Fusion 40 59 (2000)

[3] M. R. Gomez et al Phys. Rev. Lett. 113 155003 (2014), P. F. Schmit et al Phys. Rev. Lett. 113 155004 (2014)

[4] A. B. Sefkow et al Phys. Plasmas 21 072711 (2014)

[5] A. J. Harvey-Thompson et al Phys. Plasmas 22 122708 (2015)

[6] S. A. Slutz and R. A. Vesey Phys. Rev. Lett. 108 025003 (2012), S. A. Slutz et al Phys. Plasmas 23 022702 (2016)

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