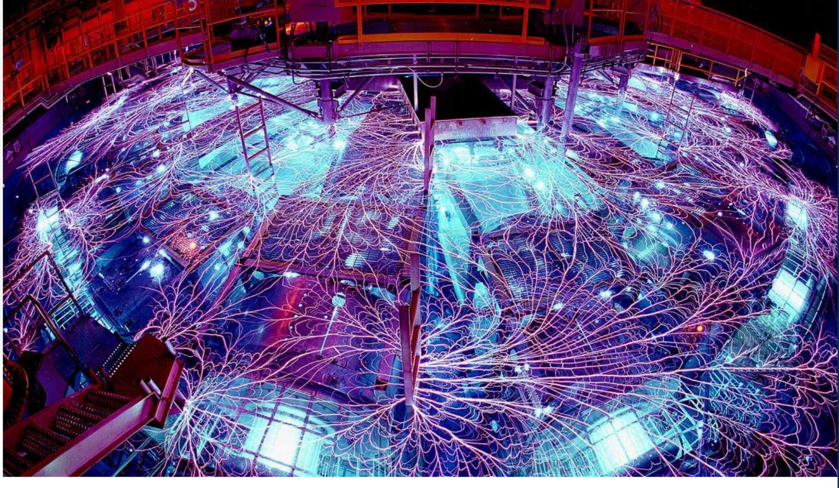

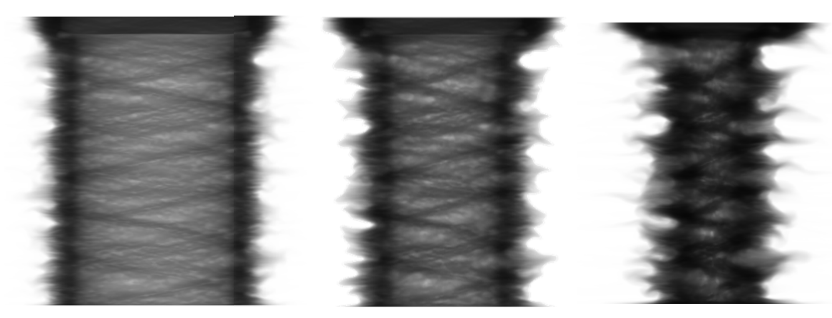

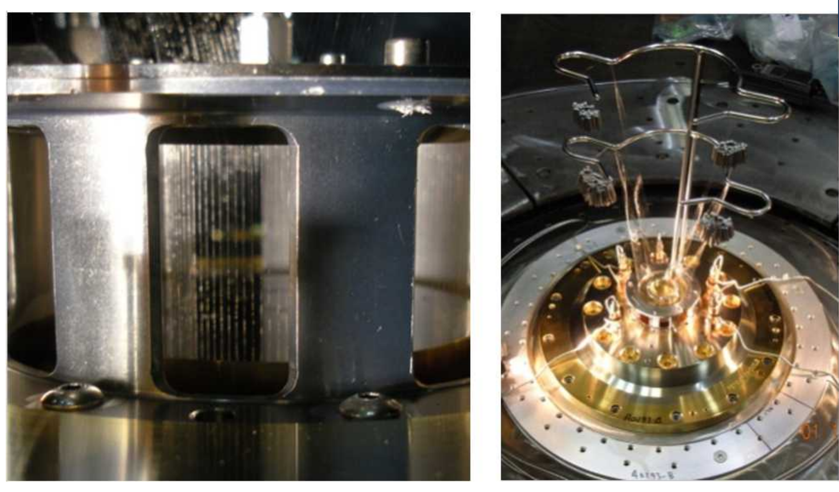

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Connecting simulation to data analysis in MagLIF fusion experiments

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Abstract

Experimental measurements are used to infer plasma conditions and characterize each MagLIF experiment, but the accuracy of these inferences is unknown. Simulation results of the MagLIF fusion experiment are often compared directly with quantities derived from experimental measurements, despite that simulation and experimental values are calculated differently. Synthetic simulation diagnostics will be developed to mimic measurements an actual diagnostic in experiment would see. The synthetic diagnostic data and the real data can be processed in the same way, to assess the accuracy of the experimentally derived quantities. Using one synthetic diagnostic, we can calculate the pressure at many times, and compare these calculations with the single value an experiment would infer to see how time-dependence affects the accuracy of our pressure determination. Synthetic diagnostic tools will test a broad range of simulations, with varying input parameters. This project will evaluate the diagnostics used in experiments to ensure that MagLIF experiments are accurately characterized.

Background

The Magnetized Liner Inertial Fusion (MagLIF) experiments utilize inertial confinement fusion (ICF) concepts to achieve thermonuclear fusion conditions.

- uses a slow (100 ns) cylindrical implosion
- axial magnetic field limits heat loss due to thermal conduction
- Fig.1 depicts the three stages MagLIF utilizes to produce fusion conditions: the applied magnetic field, laser heating of the fuel, and compression of the liner
- Diagnostic tools measure x-ray and neutron emission, to infer ion temperature and plasma density

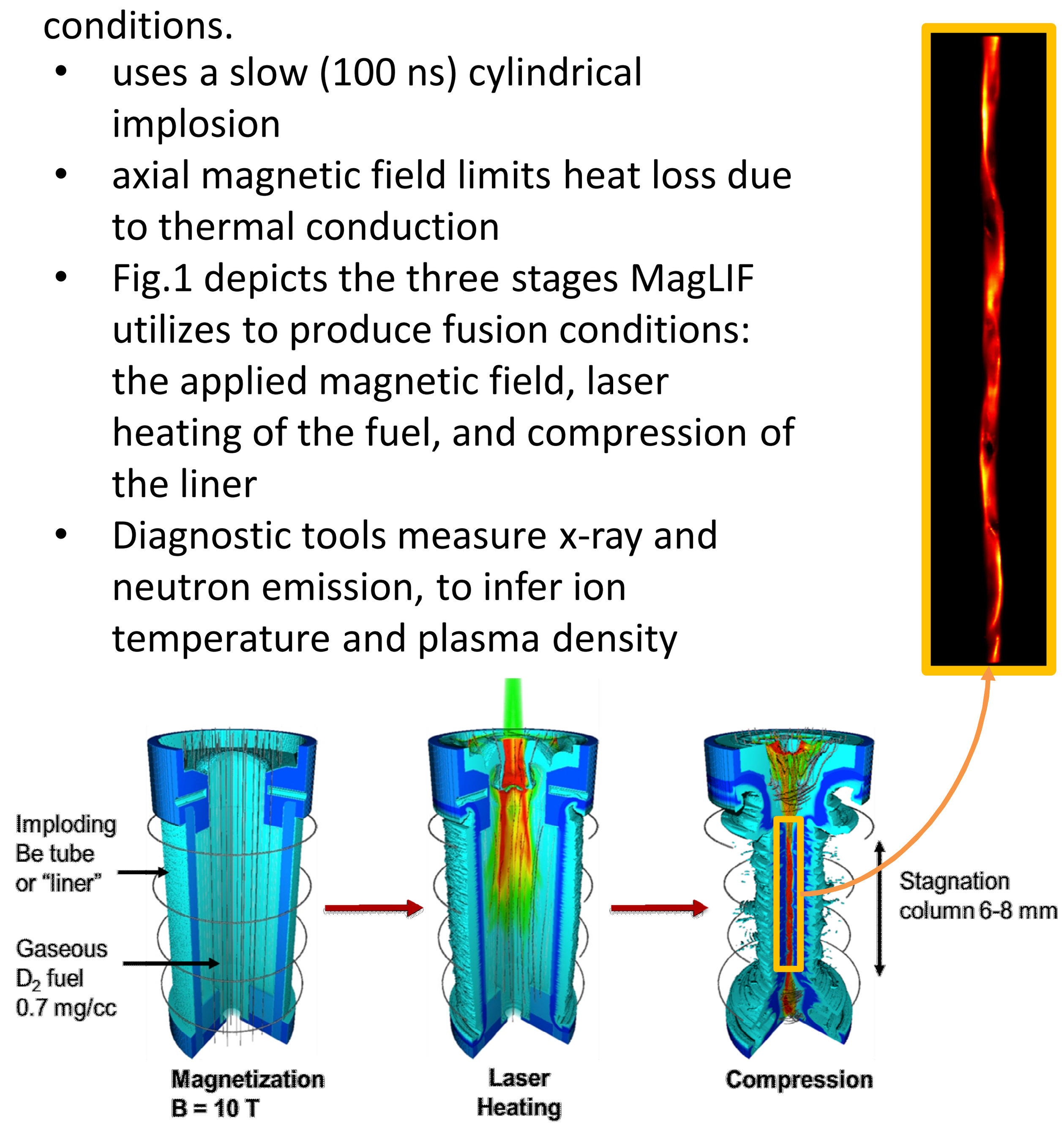
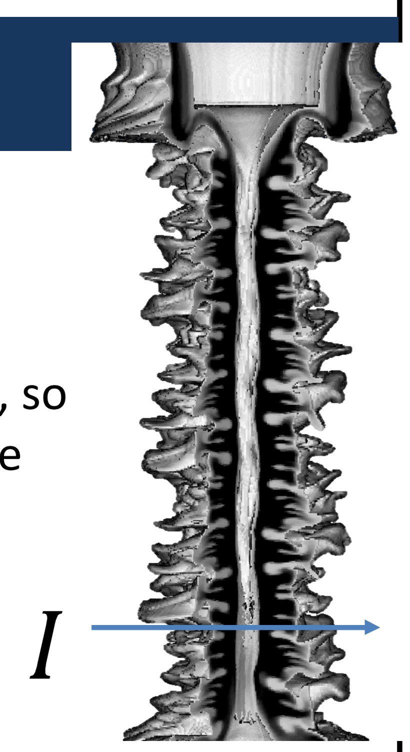


Figure 1: Stages of MagLIF

Methods

1D Simulations



Fusion experiments are complex systems effected by many conditions and conditions, so the associated multiphysics simulations are similarly complex.

- Start simple, with 1D simulation data, assuming cylindrical symmetry

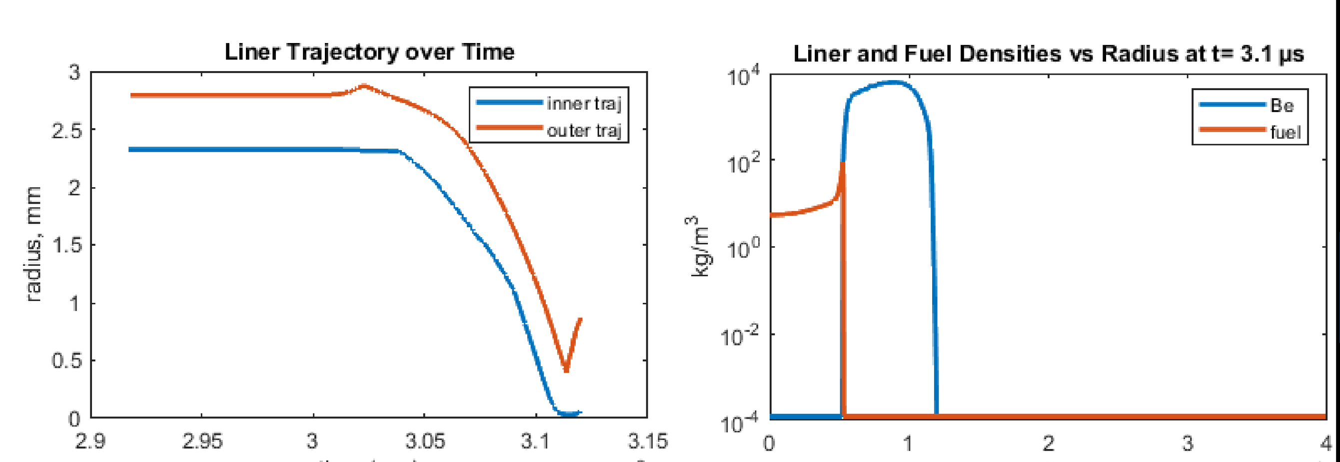


Figure 2: Plotted 1D Simulation data; liner trajectory (left) and densities of liner and fuel (right)

X-ray emissions

- Ray-trace algorithm sums intensities perpendicular to the column
- Mimics measurements taken in experiment
- X-ray emission, ϵ, is determined by the free-free and bound-free emissivity contributions:

$$j_p^{ff} = A_{ff}\frac{n_p^2 Z_p^2}{T_e^{1/2}}e^{-h\nu/T_e} \qquad \epsilon_{x_i,y_j} = g_{FF}\sum_p f_p(j_p^{ff} + j_p^{fb})$$

$$j_p^{fB} = A_{fb}\frac{n_p^2 Z_p^4}{T_e^{3/2}}e^{RyZ_i^2/T_e}e^{-h\nu/T_e}$$

- Kapton filters of varying thickness filter emission images by frequency, absorbing radiation
- Beryllium liner also absorbs radiation; for preliminary diagnostics, it is treated as a 500 micron filter.

$$I_{x_i} = \sum_\nu \left(\sum_j \epsilon_{x_i,y_j}\Delta y_j\right)(T_\nu^{Be}T_\nu^{Kap})\Delta\nu$$

$$P = \sum_i I_{x_i}\Delta x_i * height$$

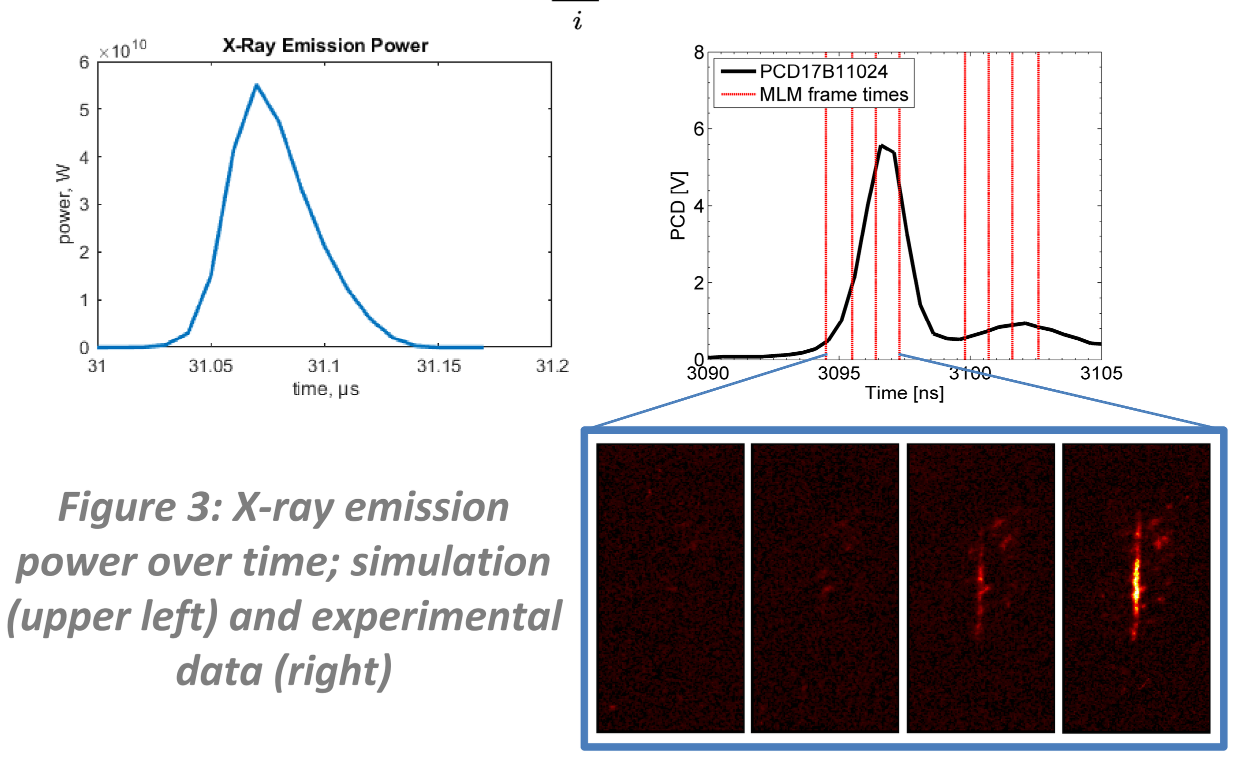


Figure 3: X-ray emission power over time; simulation (upper left) and experimental data (right)

Synthetic Diagnostics

- Pressure calculation requires several diagnostics:
  - *Synthetic PCD yield:* Power and burn duration calculated using X-ray emission intensity
  - *Synthetic volume:* Using intensity calculations, approximate volume of column
  - *Synthetic neutron emission* (also gives burn weighted temperature)

$$P_\nu = A_{ff}4\pi P_{HS}^2\, e^{-\tau_\nu}\int_{V_{HS}}\frac{g_{FF}\langle Z\rangle}{(1+\langle Z\rangle)^2}\sum_i f_i\tilde{j}_i\,\frac{e^{-\frac{h\nu}{T_e}}}{T_e^{5/2}}dV$$

Analysis Approximation

- *Isobaric, time-independent approx.* to test synthetic diagnostic and infer pressure from data
- By varying input parameters, we can study how this approx. affects pressure and mix inferences
- Assumes
  - Profile is constant for burn duration
  - Temp distribution: $T(r) = T_c\left[1-\left(\frac{r}{R}\right)^\nu\left(1-\frac{T_b}{T_c}\right)\right]$
  - Density: $n_i\,[cm^{-3}] = 0.1\,\frac{P_{HS}[Bar]}{(1+\langle Z\rangle)k_B T[eV]}$

	Filters:	No filter	Be	Be + 1mil Kap	Be + 10 mil Kap	Be + 20 mil Kap
Mix:	*3% Be*	296.94 J	44.52 J	43.59 J	36.58 J	30.86 J
	0% Be	244.32 J	36.67 J	35.91 J	30.13 J	25.42 J

Table 1: X-ray emission energies for varying filters compositions in the isobaric, time-indep. approx.

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Hansen, S.B. (2015/05/01). Diagnosing magnetized liner inertial fusion experiments on Z. *Physics of Plasmas*, 22, 056313-. doi: 10.1063/1.4921217

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Simulation Output

Radially and time dependent:

- Ion temperature
- Fuel density

Synthetic Diagnostics

Experiment and Simulation Derived Values

- PCD yield + burn duration
- Neutron yield
- Burn weighted temperature
- Volume

Isobaric approx.

Pressure Data

Evaluated using:

- PCD yield
- Neutron yield
- Varied input parameters

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