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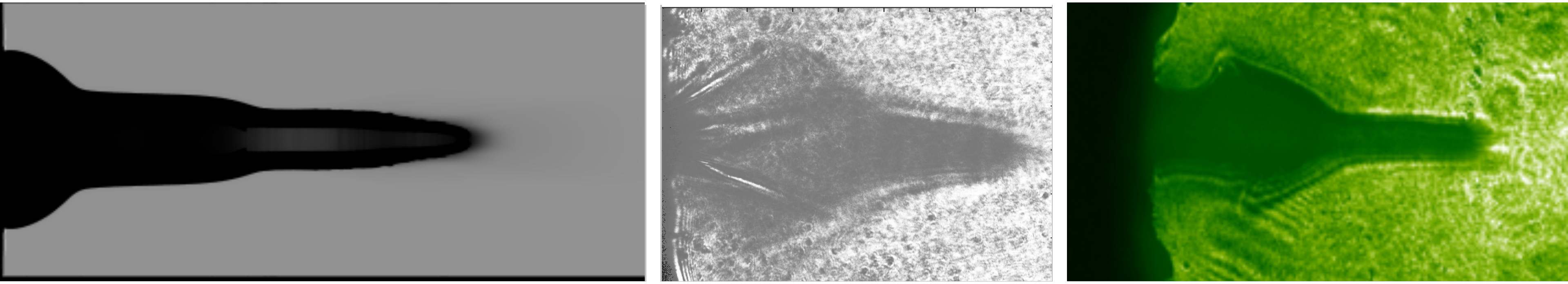

Analysis of laser preconditioning experiments on Z-Beamlet Laser (ZBL) for MagLIF

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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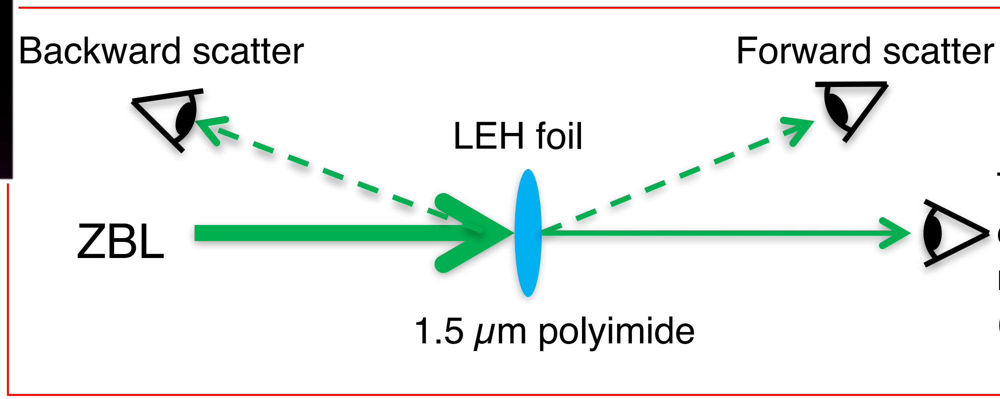
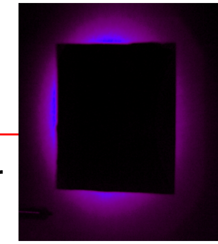
Outline

- description of experimental situation
- planned approach to experimental analysis
  - Bayesian with uncertainty and value of information
  - forward models
  - synthetic diagnostics
  - software infrastructure
  - design optimization with risk assessment
- example of deposition
- preliminary sensitivity assessment using HYDRA and Gorgon

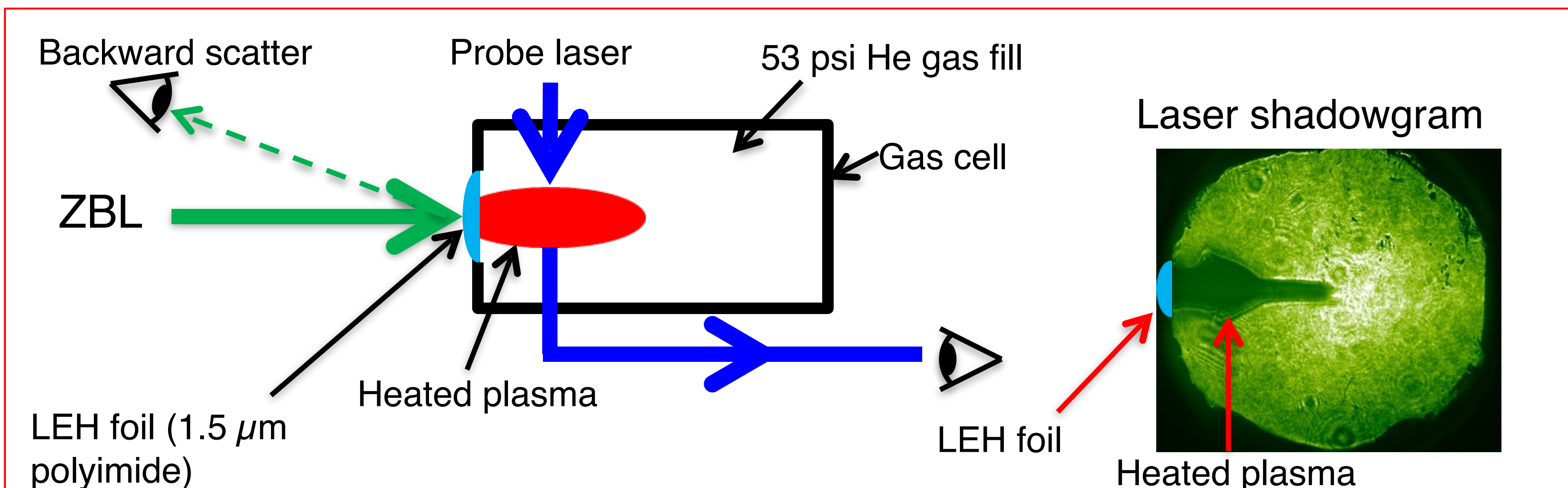
The situation

LEH transmission studies





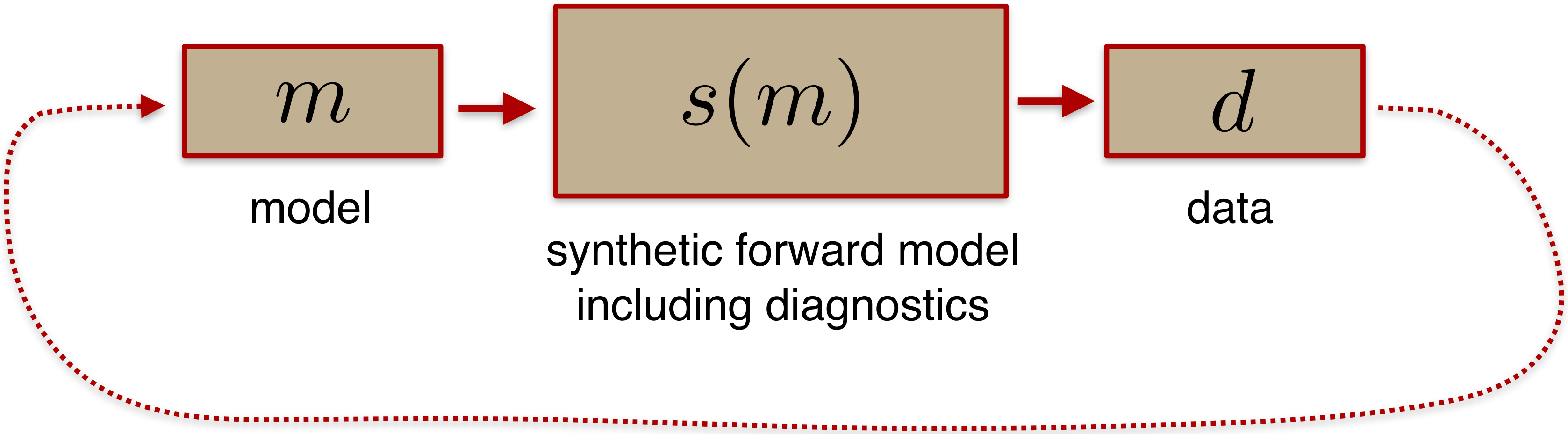
Gas cell experiments



Basic parameter ranges of ZBL experiments

- parameters:
  - frequency doubled Nd:glass laser, 540 micron wavelength
  - 750-1100 micron phase plate, f10 optics
  - 10-500 J, 1 ns prepulse, 3 ns gap (dwell time) to
  - 800-3000 J, 4 ns main pulse
  - gas pressures up to 70 psi (He, Ne, Ar)
  - 2 micron Laser Entrance Hole (LEH) window thickness
- future capabilities:
  - magnetic field (transport inhibition)
  - D2 gas
  - cryogenic (greater gas densities)
  - independent pre-pulse co-injection to increase well time
- goal:
  - maximize energy absorbed into gas (> 1 kJ)
  - minimize LEH window and sidewall mix

Bayesian framework for analysis



- ➡ inversion or
- ➡ optimization or
- ➡ distribution estimator

$$P(m,d) = P(d)P(m|d) = P(m)P(d|m)$$

$$P(m|d) \propto P(m)P(d|m) = P(m)P(d - s(m))$$

Key covariances for value of information — big data analysis (dimensional reduction)

$$C^{-1}(m,m) \stackrel{\text{SVD}}{=} U_m^T \Sigma_m^{-1} U_m$$

combination of model parameters being determined

$$C(m,d) \stackrel{\text{SVD}}{=} U_m^T \Sigma_{md} V_d$$

what model parameters are being determined by what data (value of data)

$$\Sigma = \begin{pmatrix} \sigma_0^2 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \sigma_n^2 \end{pmatrix} \qquad U = \begin{pmatrix} \hat{u}_0 \\ \vdots \\ \hat{u}_n \end{pmatrix}$$

Model parameterization

- controllable (design parameters for optimization)
  - window shape
  - window thickness
  - laser energy, pre-pulse & main pulse
  - laser pulse lengths
  - dwell time between pre-pulse and main pulse
  - laser spotsize
  - magnetic field
  - gas content & pressure
- no control
  - opacity multiplier (physics estimation bias)
  - density multiplier (experimental uncertainty)
  - laser intensity multiplier (LPI physics surrogate)
  - laser divergence and focal plane (LPI physics surrogate)
  - thermal conductivity multiplier (plasma turbulence surrogate)
  - low temperature atomic physics and EOS
- other
  - measurement error
  - rad-hydro modeling error (including different programs)
- outputs not directly measured, but fundamental quantities to be estimated
  - sidewall mix
  - deposited energy
  - deposition volume
  - laser entrance hole kinetic energy
  - SBS, SRS, filamentation growth
- **multiple experiments**

note: these divisions are grey, it may be just differences in uncertainty of prior, P(m)

Computer simulations and experimental diagnostics

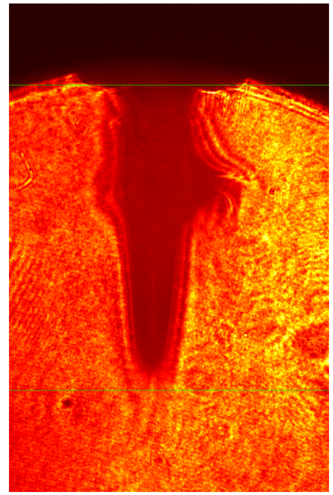
- forward models:
  - HYDRA
  - Gorgon
  - parameterization of final state
- synthetic diagnostics:
  - x-ray transport (SPEC3D, Cretin, custom optically thin code)
  - laser plasma interaction (linear growth such as DEPLETE, eikonal inline raytrace, paraxial inline and post such as pF3D)
  - simple post processing for wall velocity and transmitted energy
- diagnostics (data):
  - density shadowgram (time resolved)
  - x-ray self emission images (time resolved, filter-set & integrated)
  - axial x-ray spectra
  - backscatter & forward scatter diagnostics
  - wall velocity (VISAR & PdV) measurements
  - transmitted energy calorimeter

Example diagnostic outputs

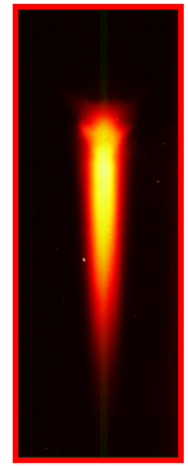
backscatter

foreward scatter

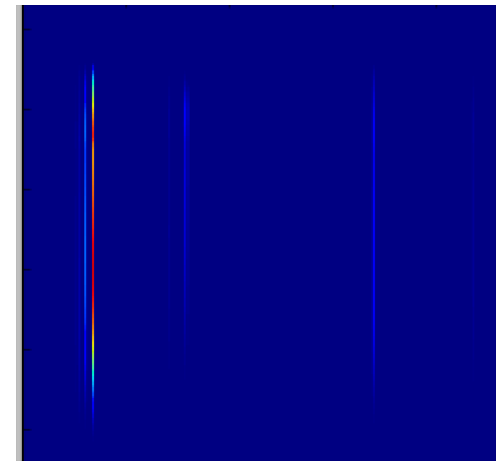
shadow gram



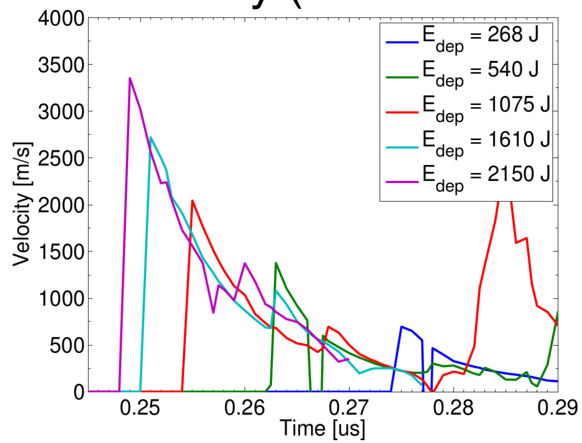
self emission



axial x-ray spectrum



wall velocity (VISAR & PdV)



Software infrastructure

- Python at the nexus
- VTK as a grid standard
- synthetic generation code being modified and wrapped to be assessable from Python
  - using pyorick (Yorick), F2PY (Fortran), SWIG (C++)
  - command line interface
  - traited wrapper object with “GUI for free” and better parameter verification
- rad-hydro program Gorgon being productized with a Python interface
- generator decks (Python programs) for HYDRA and Gorgon modularized and version controlled
- Bayesian analysis with a combination of pyMC and Dakota
- experimental data accessible from a Python interface to SMASH

significant effort to-date

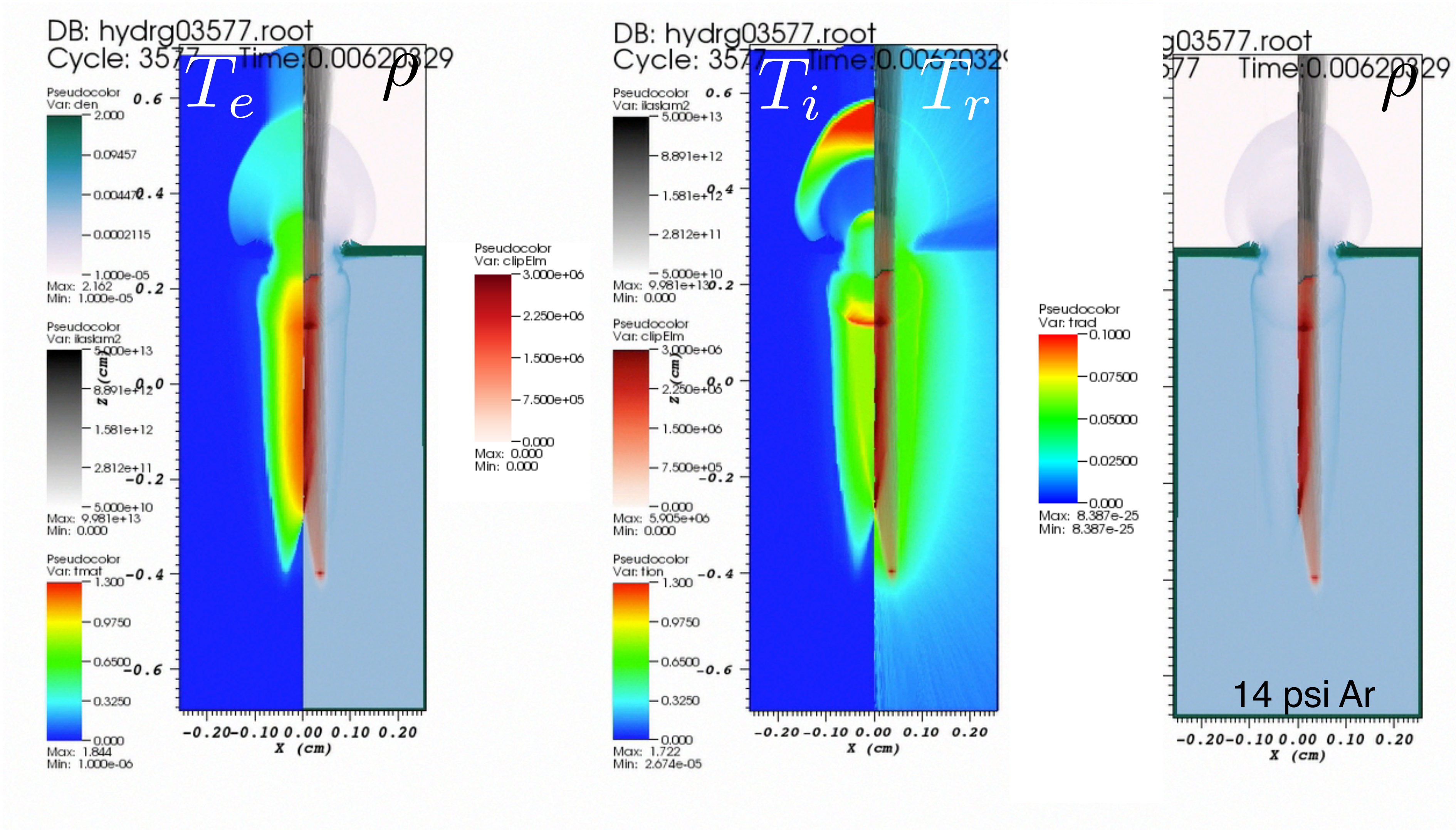
Uncertainty quantification, and design analysis with risk assessment

- What have the measurements determined?
- What measurements should we make?
- What is the probability of achieving system performance?
- What is the system that will maximize the probability of achieving a performance goal (i.e., minimize the program risk)

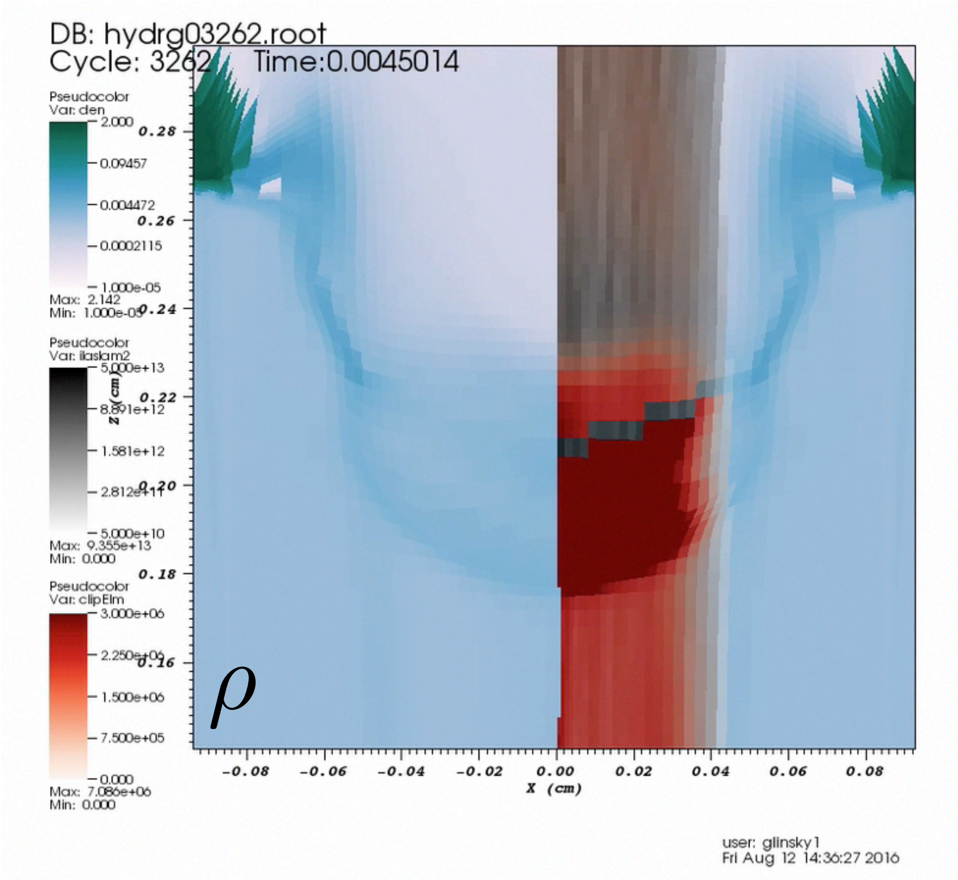
movies

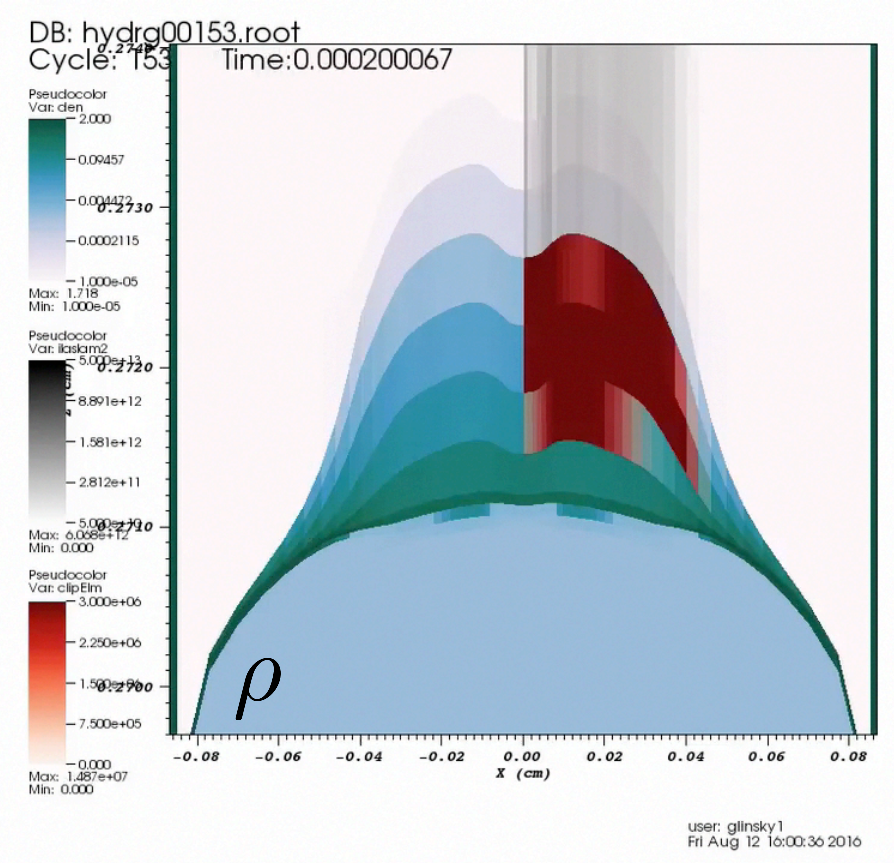
EXAMPLE DEPOSITION

Laser deposition

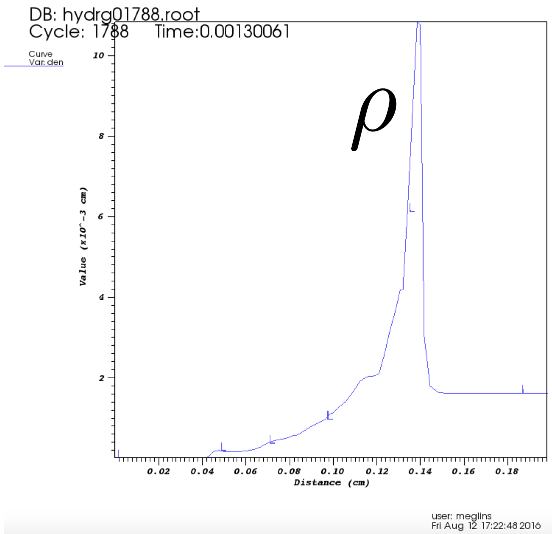


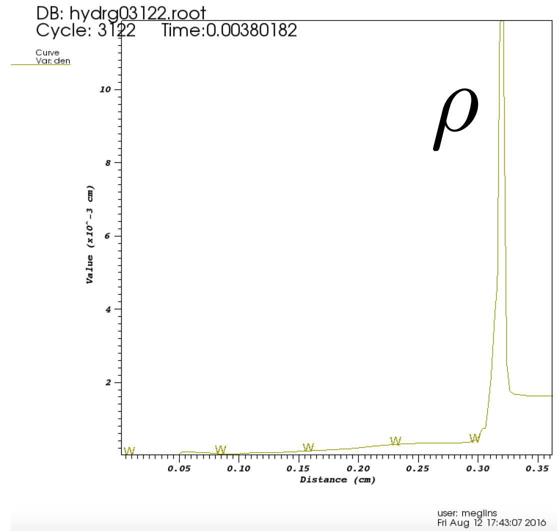
Closer look at LEH disassembly

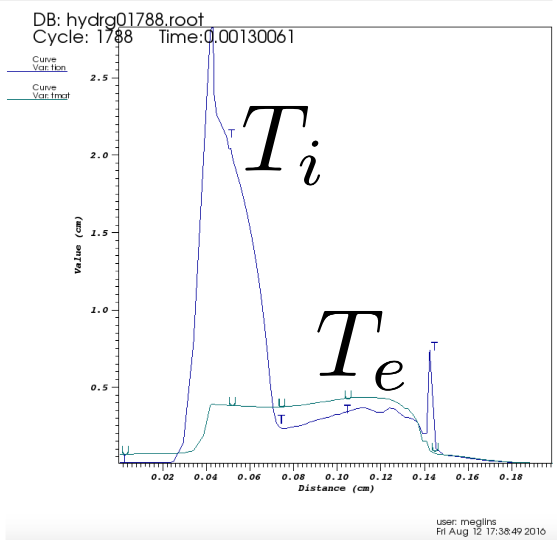




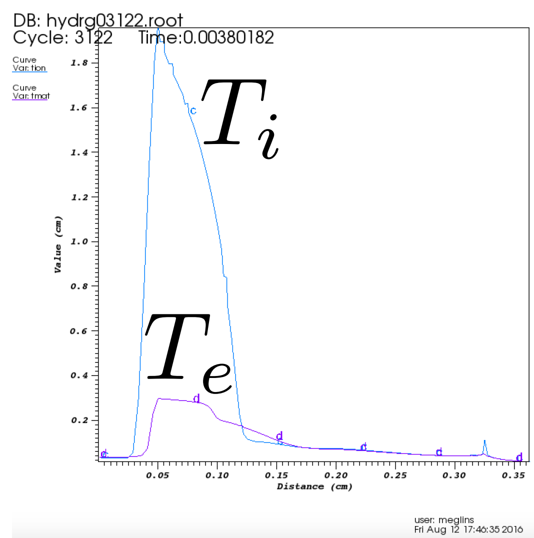
Plasma conditions







at end of pre-pulse

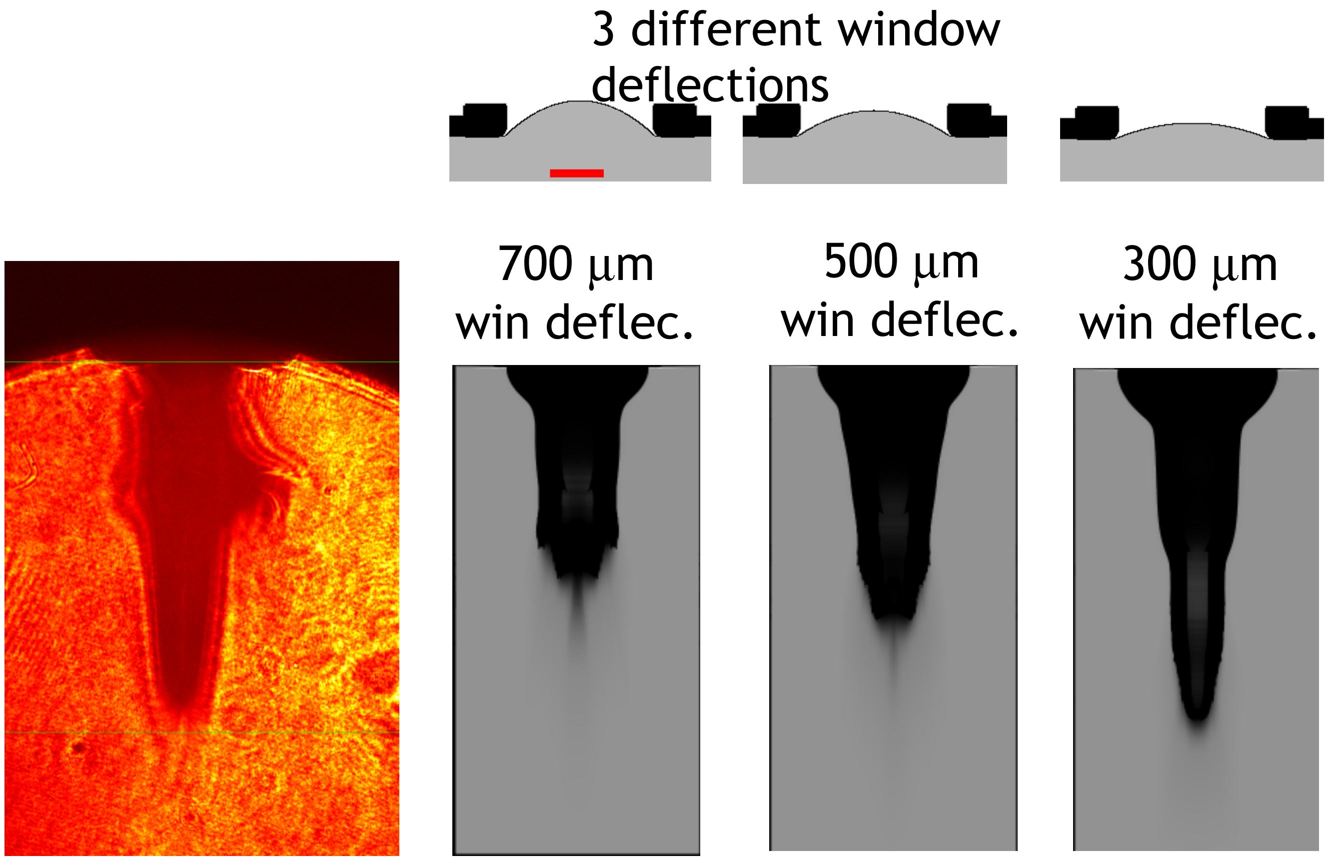


at start of main pulse

Sensitivity assessment using HYDRA and Gorgon

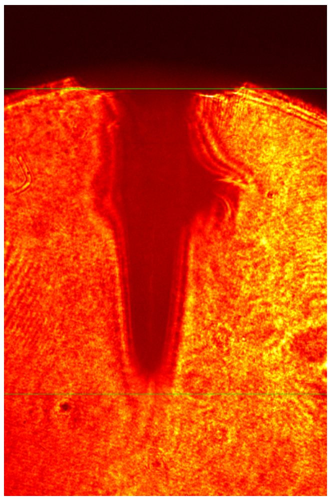
PRELIMINARY

Sensitivity to window shape

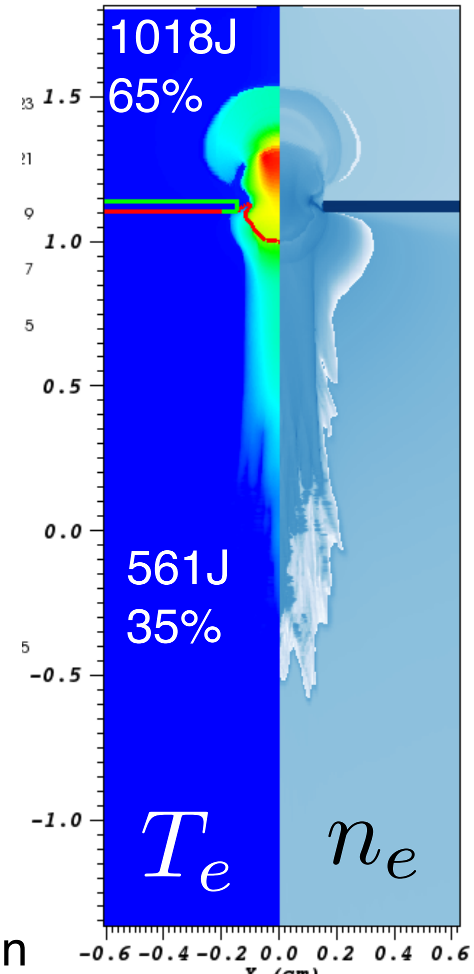


Gorgon simulation

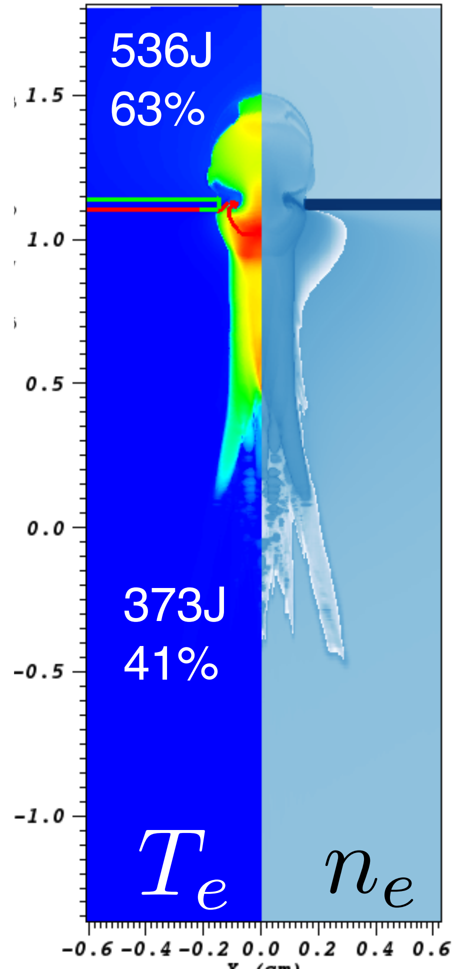
Sensitivity to main pulse energy

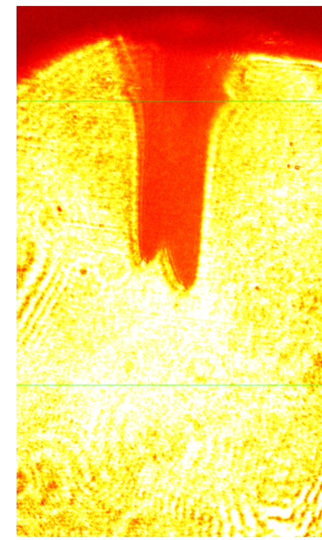


80/1500J



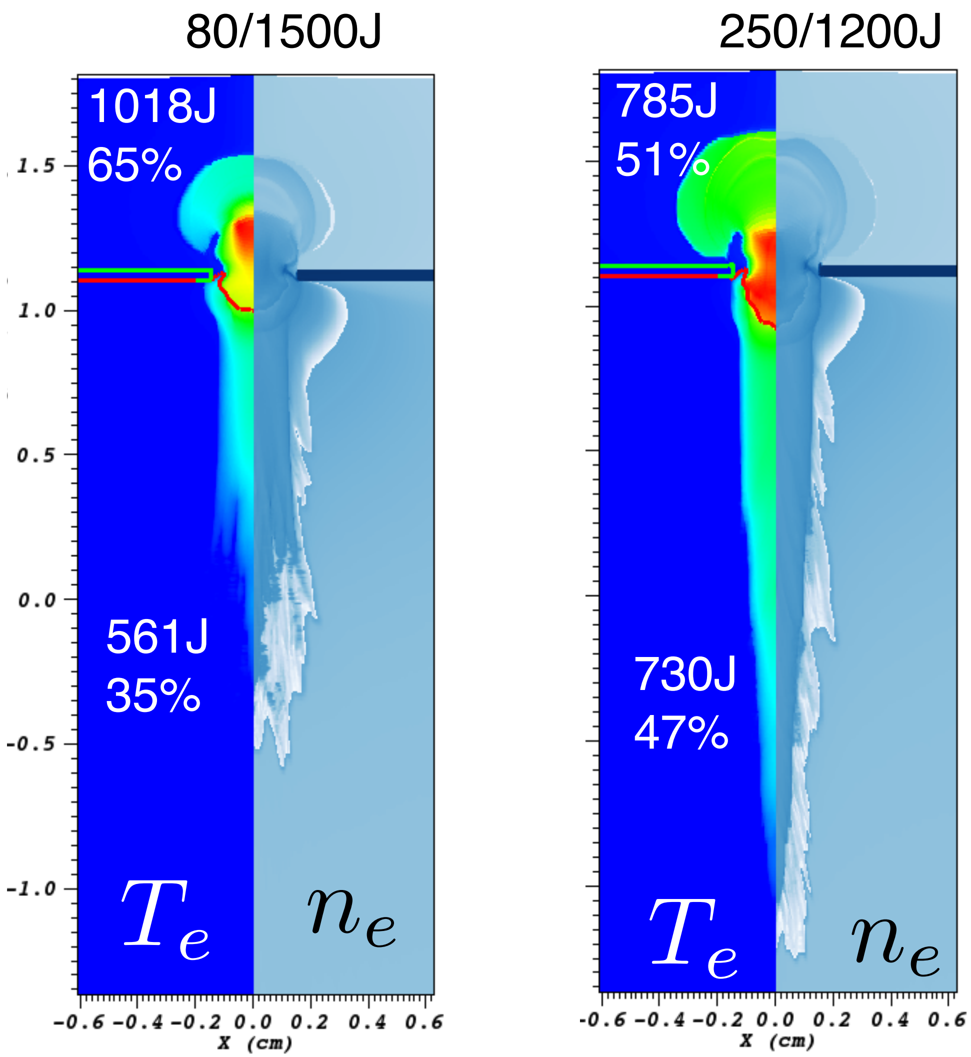
61/849J





HYDRA simulation

Sensitivity to prepluse energy



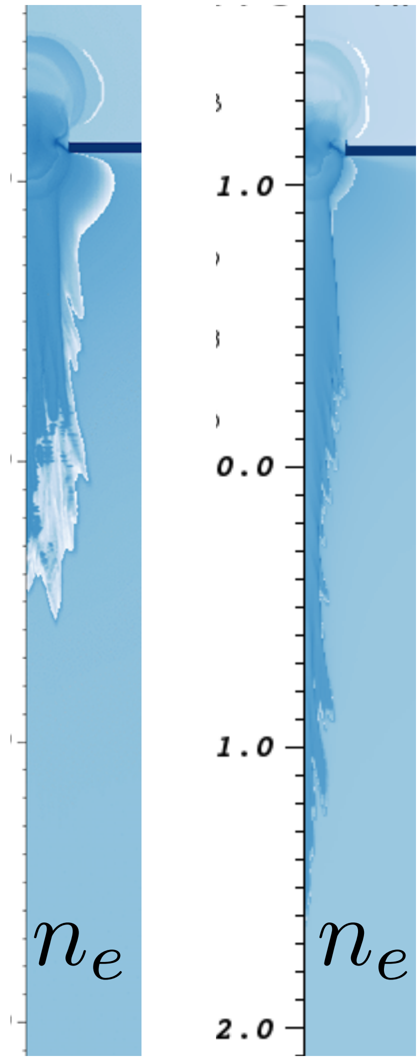
HYDRA simulation

Sensitivity to gas

He D2

1035J
65%

660J
42%



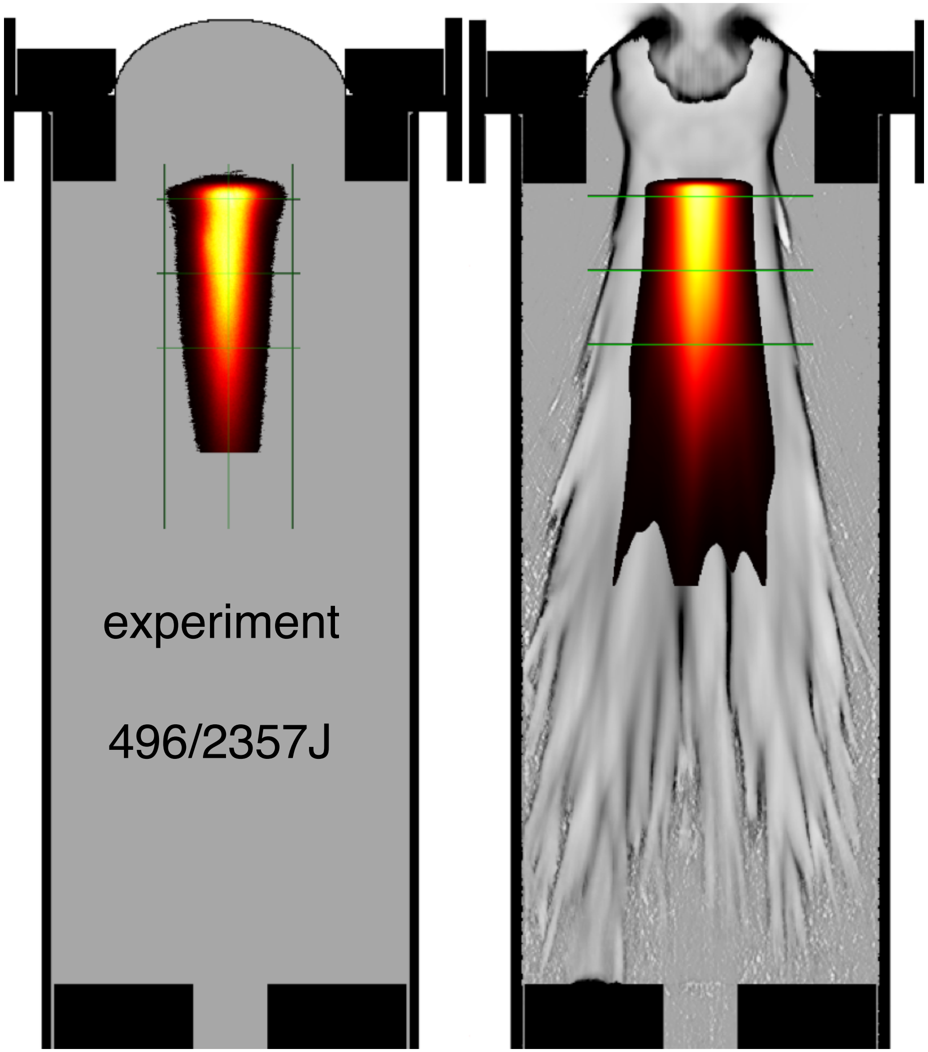
576J
32%

920J
58%

81/1503J

HYDRA simulation

Adjust laser energy to match x-ray self emission image



Gorgon simulation

best match:

77% prepulse backscattered
30% main pulse backscattered

note: shadowgram much more sensitive to lower density structure and model parameters

Summary

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- progress is being made on analysis of laser preconditioning experiments on ZBL
  - software infrastructure
  - preliminary sensitivity analysis
  - preliminary best match
- Bayesian methodology had potential to:
  - estimate performance with uncertainty
  - guide choice of experimental measurements based on Value-Of-Information (VOI)
  - allow design optimization to minimize project risk