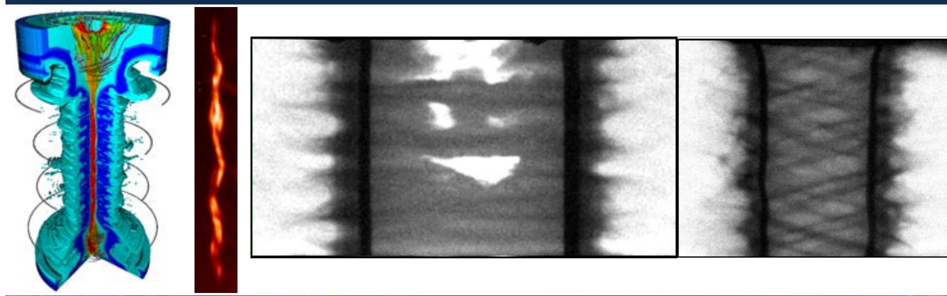
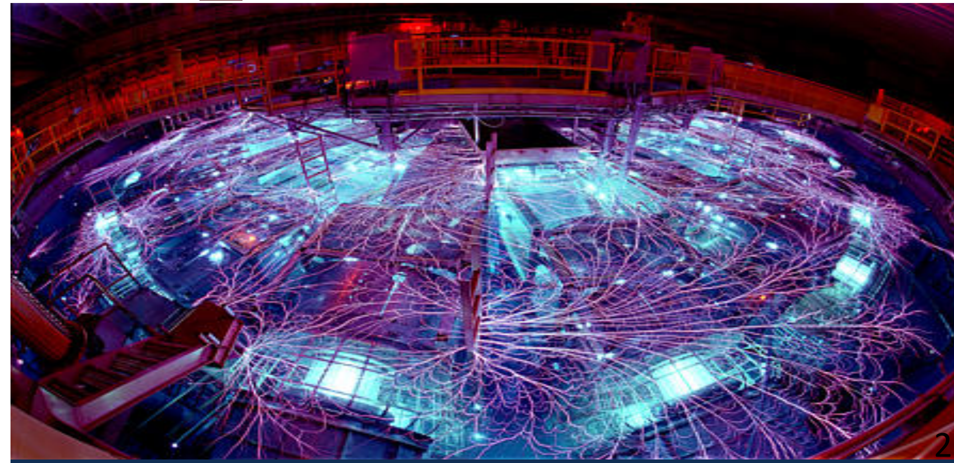
Plans for addressing MagLIF hypotheses in 2017 and beyond





Patrick Knapp representing the MagLIF team

NISP Working Group

Washington D.C.

September 13, 2016

Exceptional service in the national interest

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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As always, many people contributed to this talk….

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… And many many more

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[6] *Laboratory of Laser Energetics, Rochester, NY*
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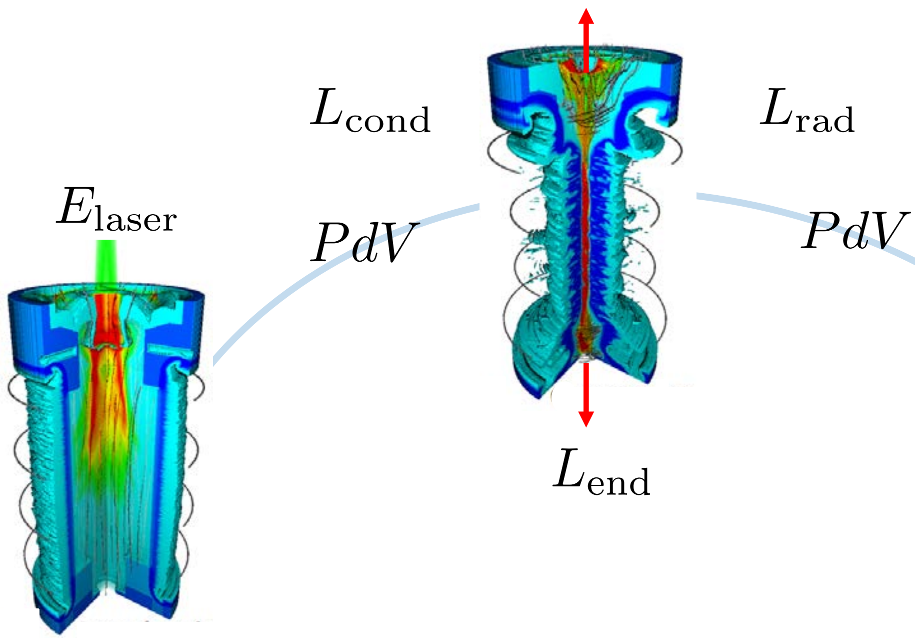
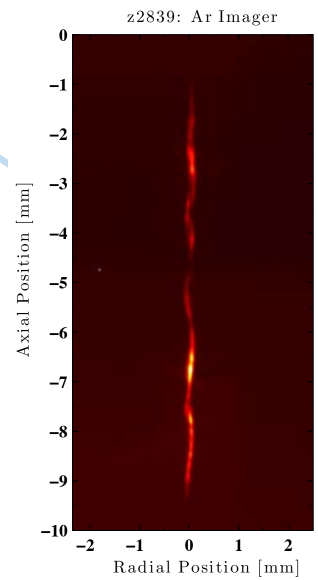
The broad theme for addressing existing hypotheses is energy balance

- What is the radiation loss in flight
- How effective is magnetic insulation
- What are the end-losses





- What is the hot-spot pressure, mass, volume
- What is the drive pressure near stagnation
- How well is the liner confining the fuel
- Is there residual kinetic energy

- How much energy is absorbed
- How much energy is scattered
- How much mix is generated, where does it go

Detailed accounting of the energy in the system at each phase is critical to distinguish between hypotheses

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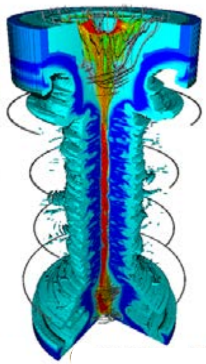
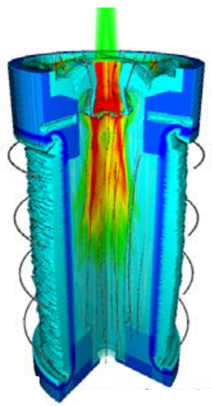


Laser Heating



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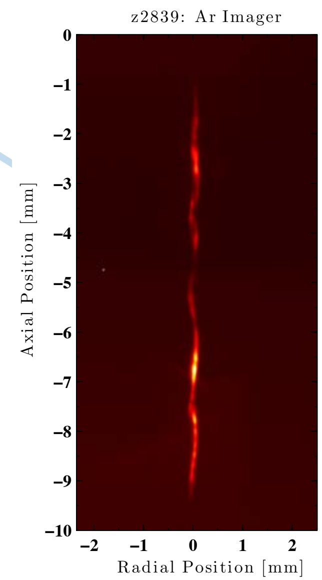

- What is the hot-spot pressure, mass, volume
- What is the drive pressure near stagnation
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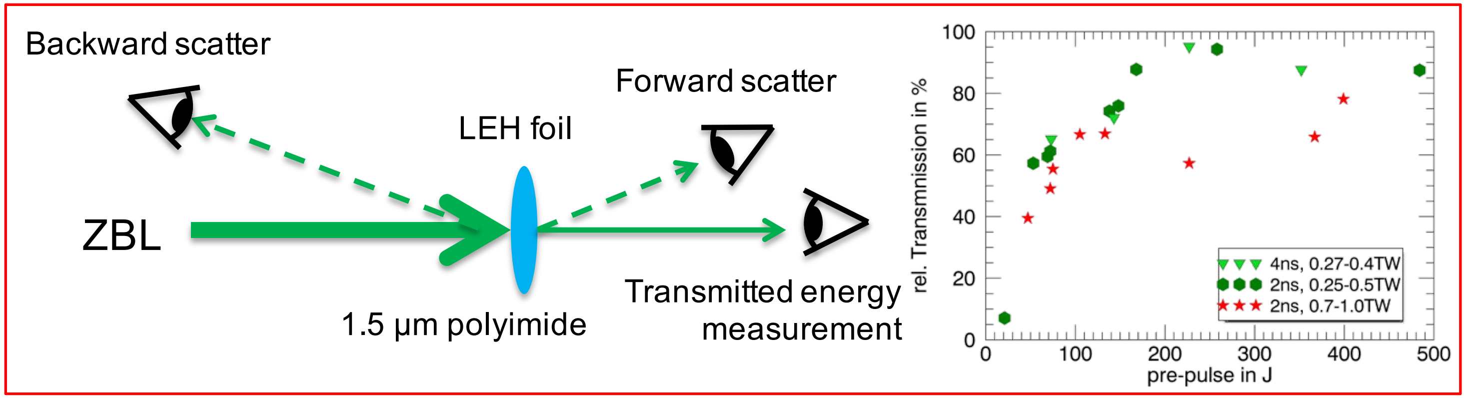
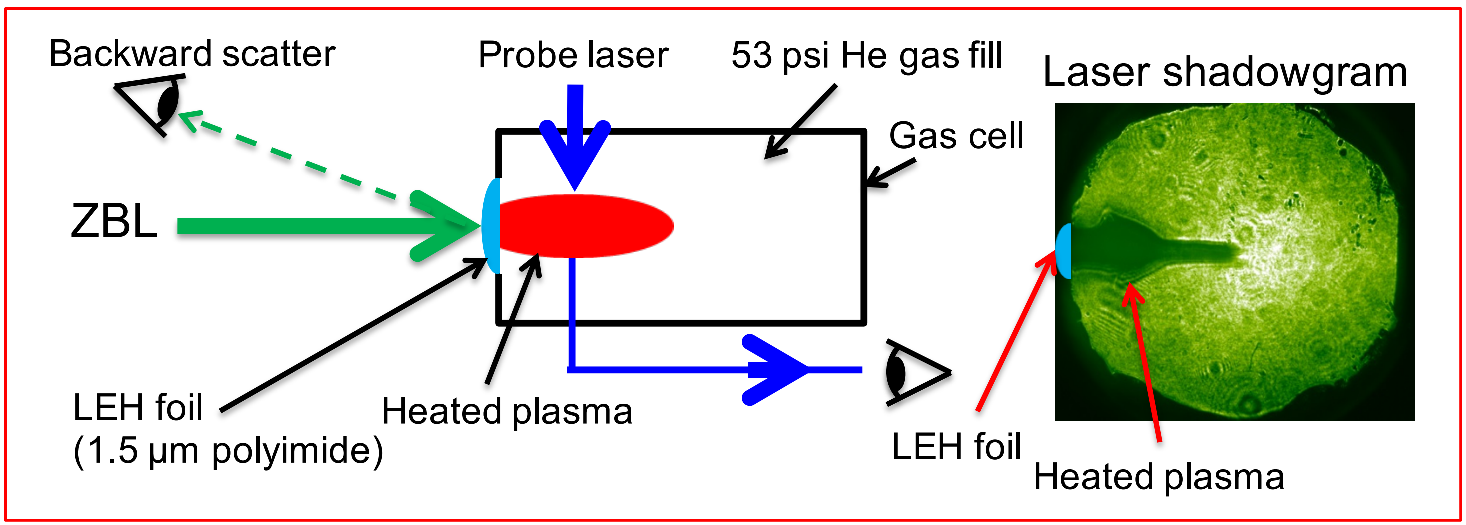
Detailed accounting of the energy in the system at each phase is critical to distinguish between hypotheses

Recently, progress has been made in resolving the laser energy deposition problem

LEH transmission studies



Gas cell experiments



- A combined approach of laser transmission studies and gas-cell studies is being used now
- We have already made tremendous progress in understanding transmitted and scattered energy
- More work needed on understanding energy *deposited*

Material courtesy Matthias Geissel and Adam Harvey-Thompson

We will develop the capability to measure the gas temperature as a function of time

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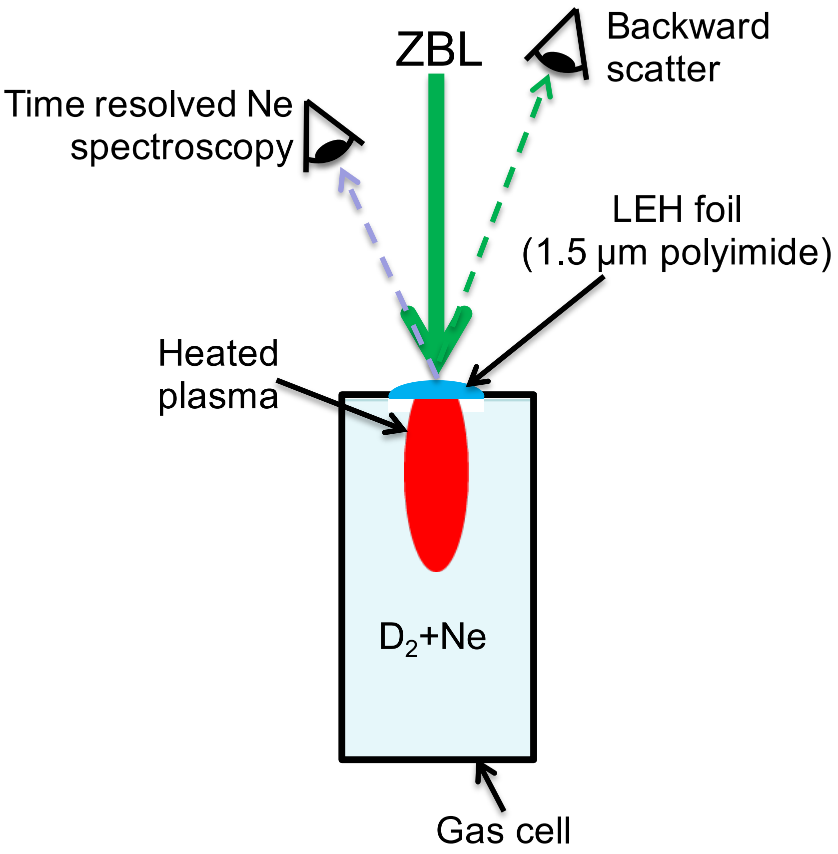
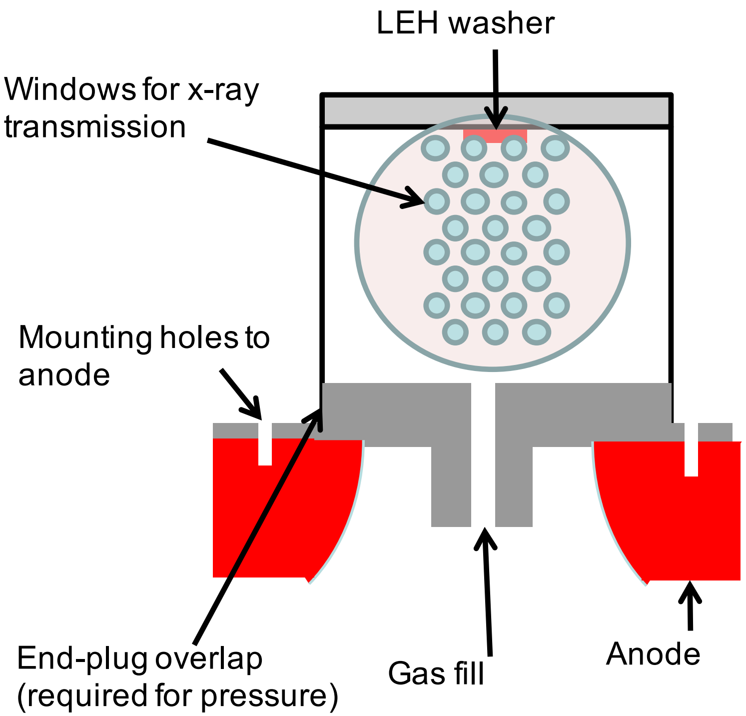
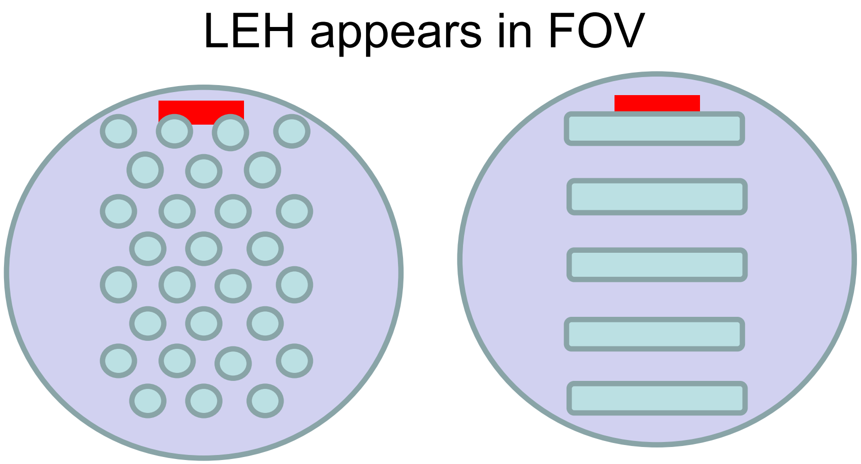


- Neon is believed to be sensitive to sufficiently low temperatures to track the increase in Te and subsequent decay as the energy redistributes and radiates away
- The spectrometer will view the heated gas through the LEH
- The proposed instrument is compatible with downline as well as ZBL only shots on Z and in PECOS

Material courtesy Matthias Geissel and Adam Harvey-Thompson

We are also developing new target designs to enable side-on imaging and spectroscopy of Ne emission



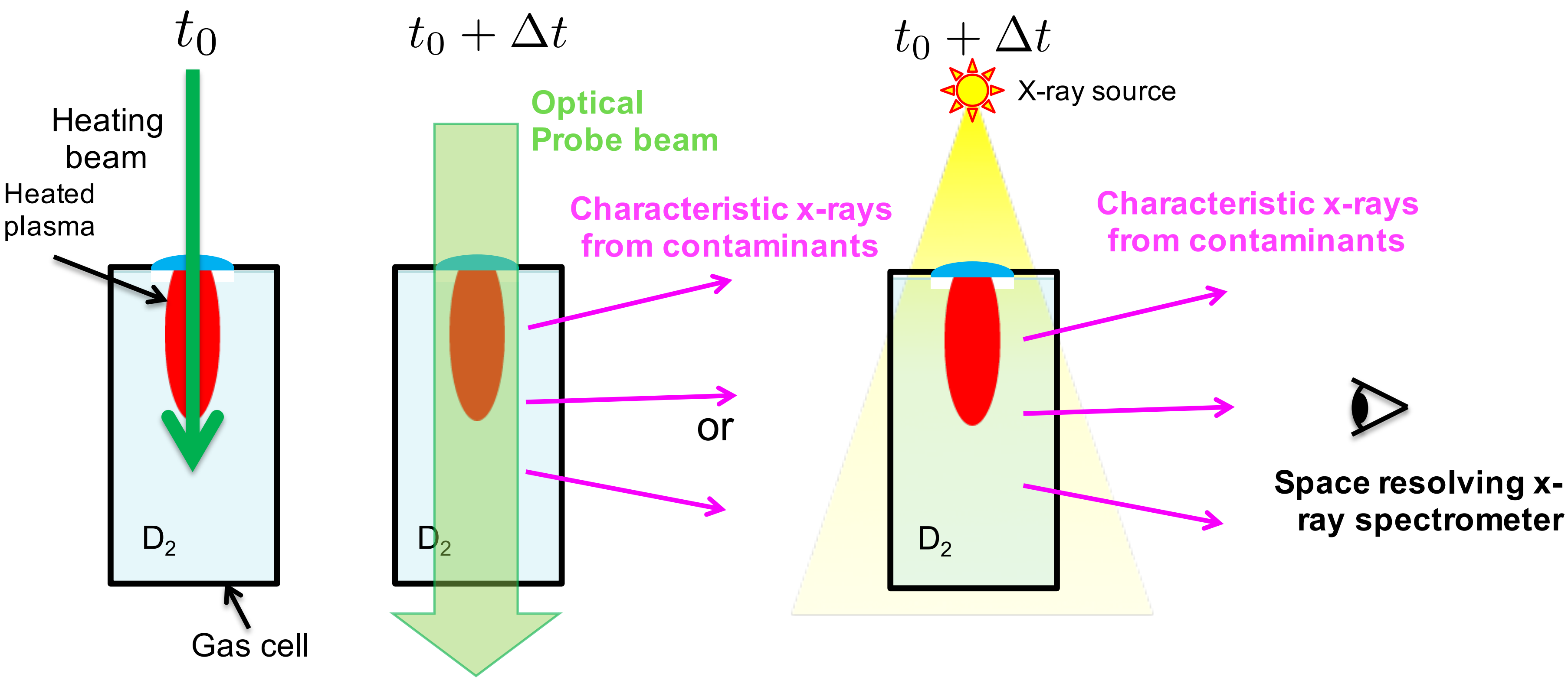


Different window designs for different applications

Compatible with a variety of in-chamber imaging and spectroscopy diagnostics

Material courtesy Adam Harvey-Thompson and Matt Gomez

We are exploring various pump/probe experiments to track the evolution of mix generated during preheat



- The idea of externally probing the preheated plasma is being explored
- In principle, this can be done with a separate laser or x-ray source
- Let the plasma evolve, then excite the contaminants to produce Kα emission
- By spatially resolving the emission, we can track where the mix goes as a function of time
- Does not rely on material being hot in order to detect it

Additional ongoing effort on mitigation strategies

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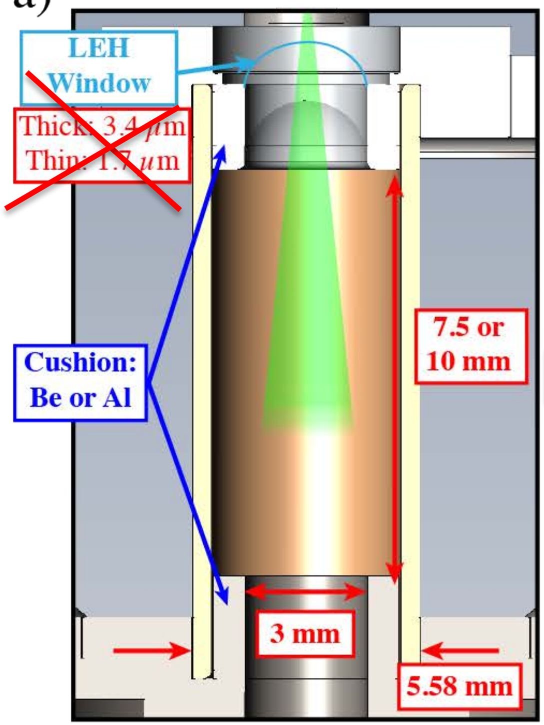
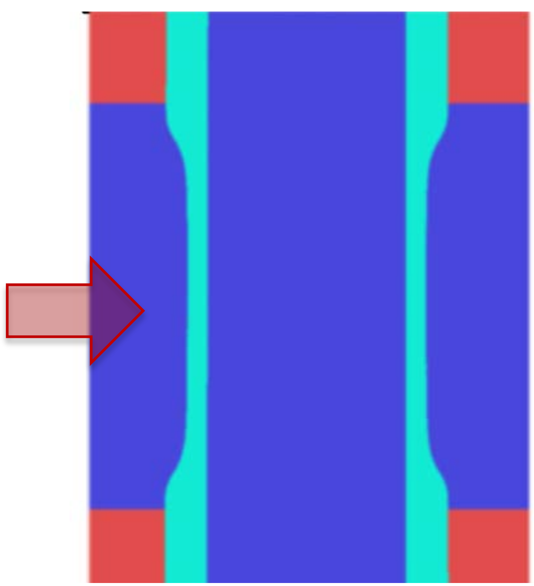
Cryogenic Gas fill platform

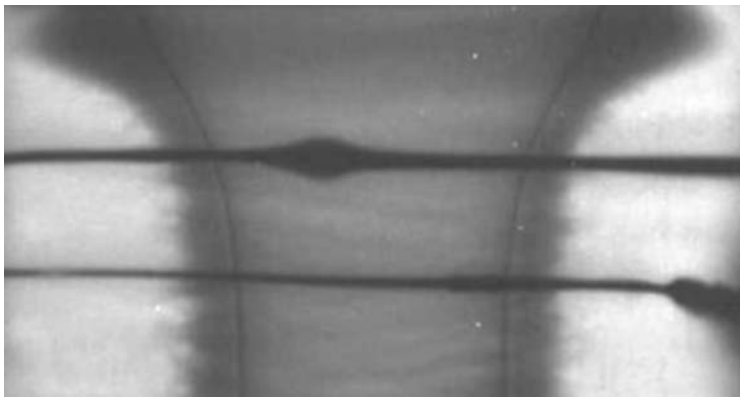
~100 nm window

➔ allows cushionless "thick-end" liner

a)



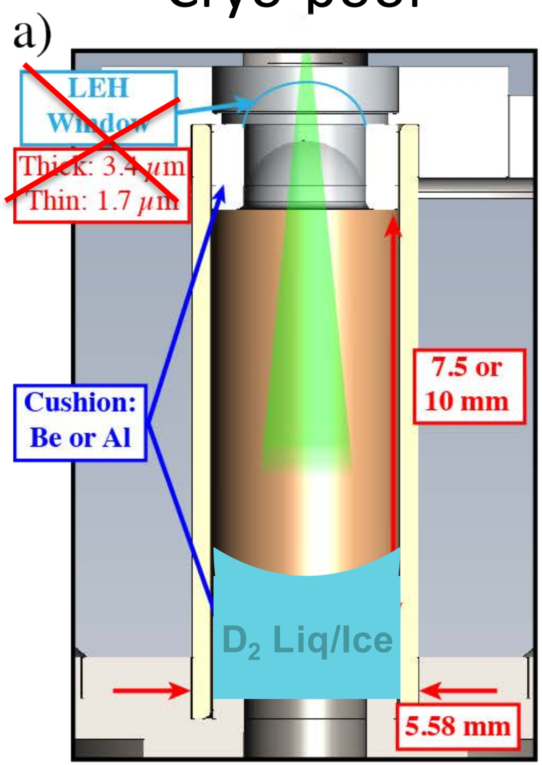




Initial radiography campaign showed agreement with early time behavior, but some problems with shots

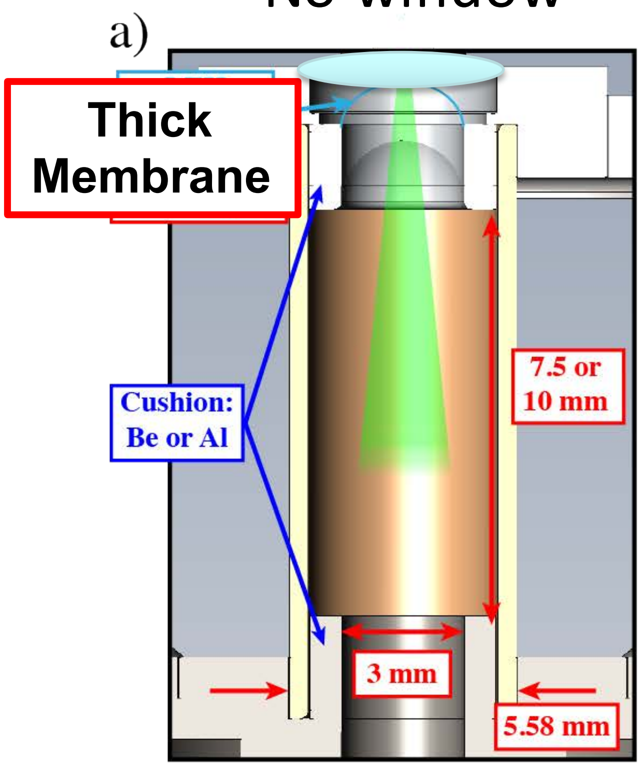
Two high risk windowless designs are being explored at a low level

Cryo-pool



Form a pool of liquid, or disk of ice
Use the preheat laser to create a plume that dynamically generates your hot spot fuel
Foam shot on EP to scope this

No window



Use a thick membrane
Mechanically burst the membrane ~1μs before preheat
Heating beam propagates through the gas rarefaction, into the imploding region

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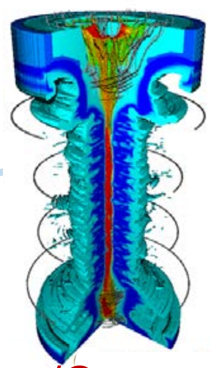
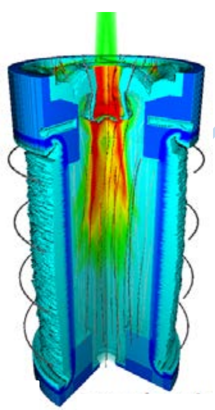
- What is the radiation loss in flight
- How effective is magnetic insulation
- What are the end-losses



Implosion/Compression



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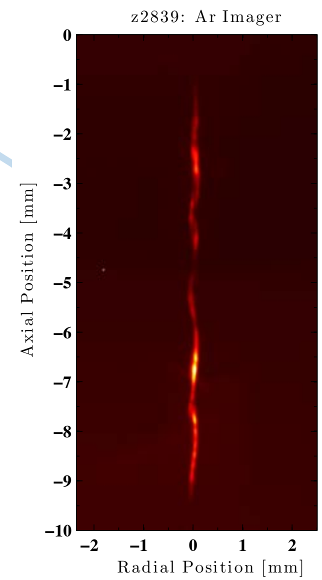

- What is the hot-spot pressure, mass, volume
- What is the drive pressure near stagnation
- How well is the liner confining the fuel

Detailed accounting of the energy in the system at each phase is critical to distinguish between hypotheses

In CY17 we will extend previous work on the stagnation dynamics to magnetized liners

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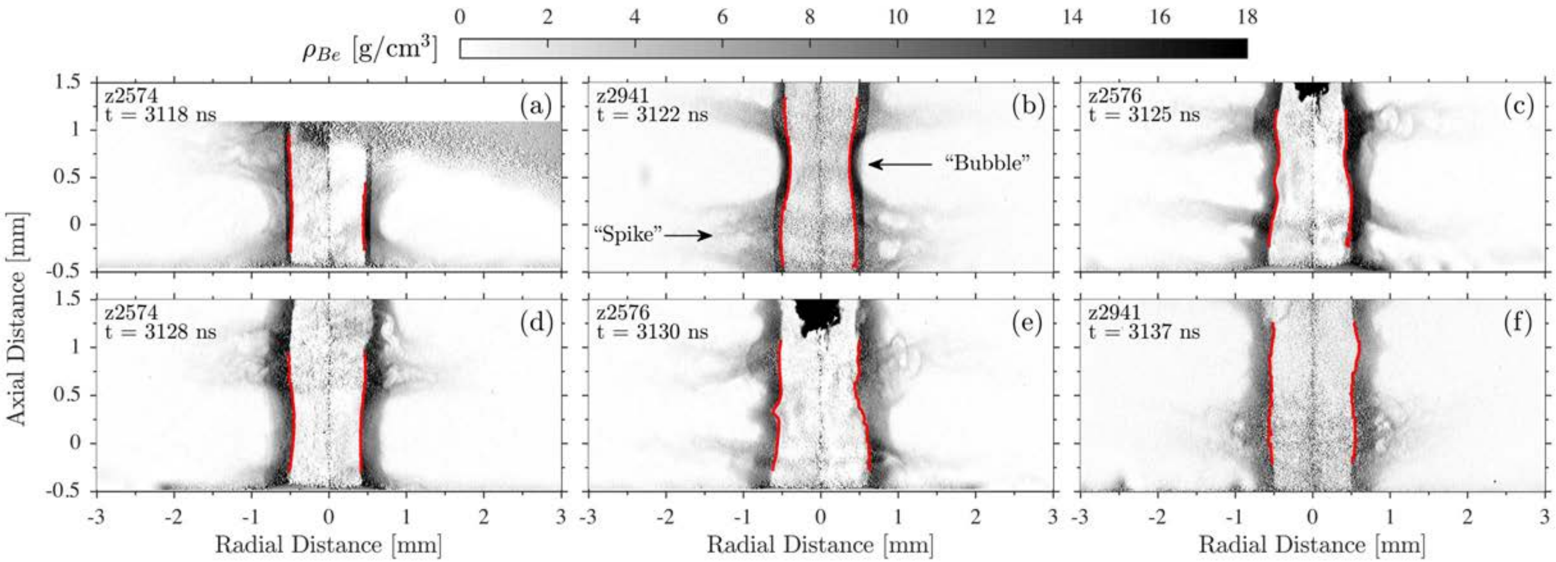
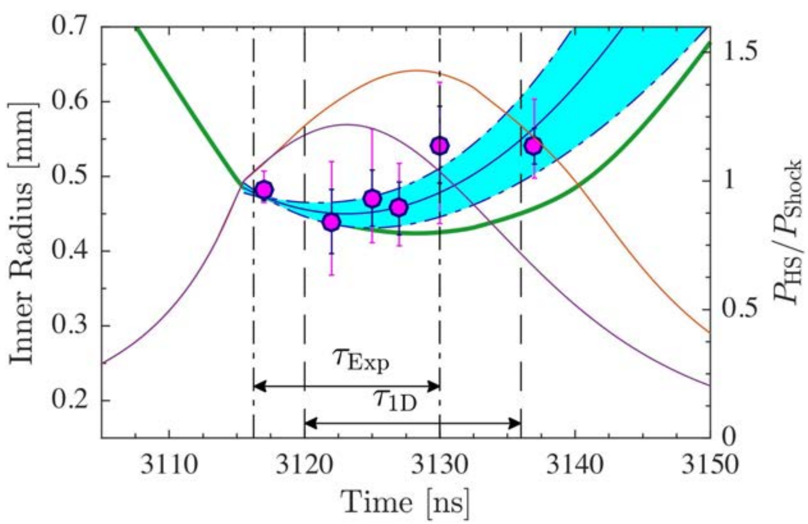
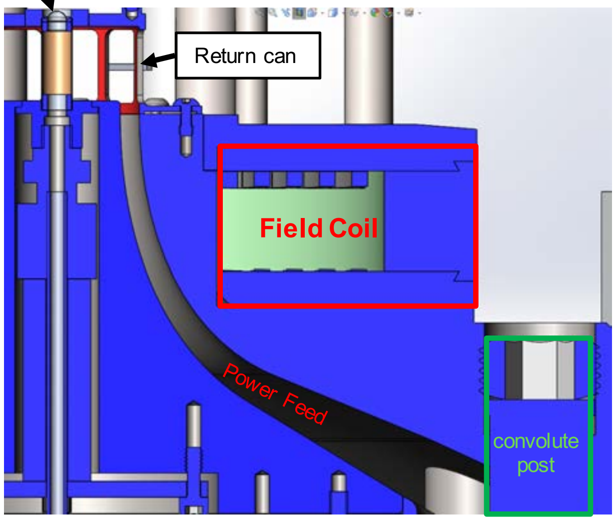


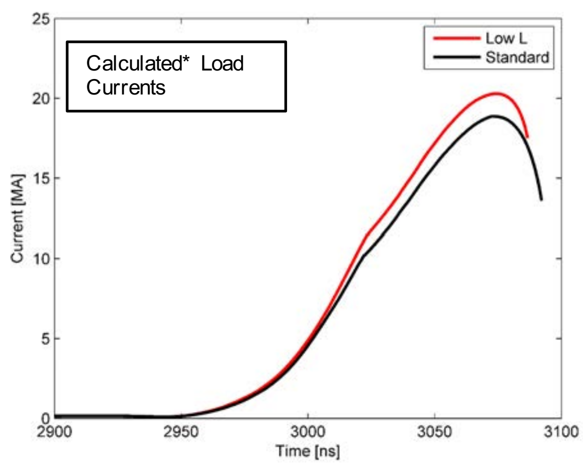


- We have demonstrated the ability to radiographically map out stagnation in moderate convergence (CR~8) implosions with unmagnetized liners
- We will apply this methodology to liquid D2-filled MagLIF liners w/ applied Bz
  - "standard" AR=6 liner
  - Mass-matched liner with ETI mitigation

Power feed modifications are being pursued to improve driver energy coupling

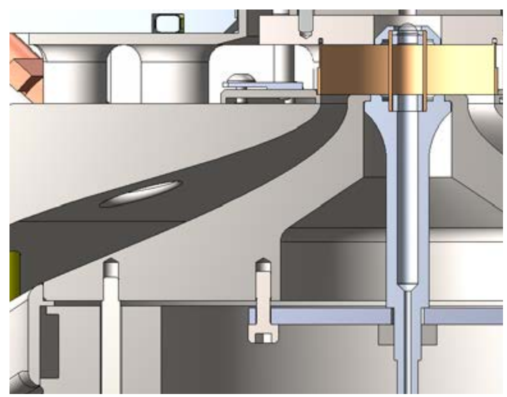
Standard Feed



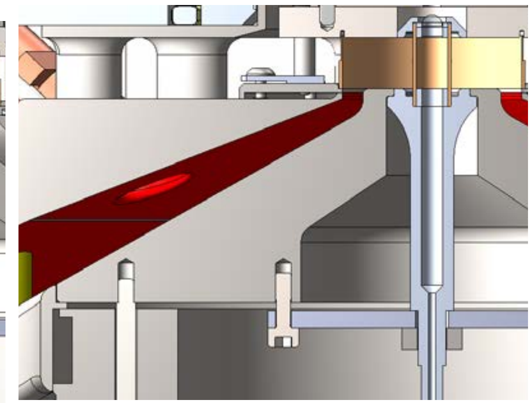


Low Inductance Alternatives**

Lincoln feed – 4 mm minimum gap



Conical feed – 3 mm minimum gap

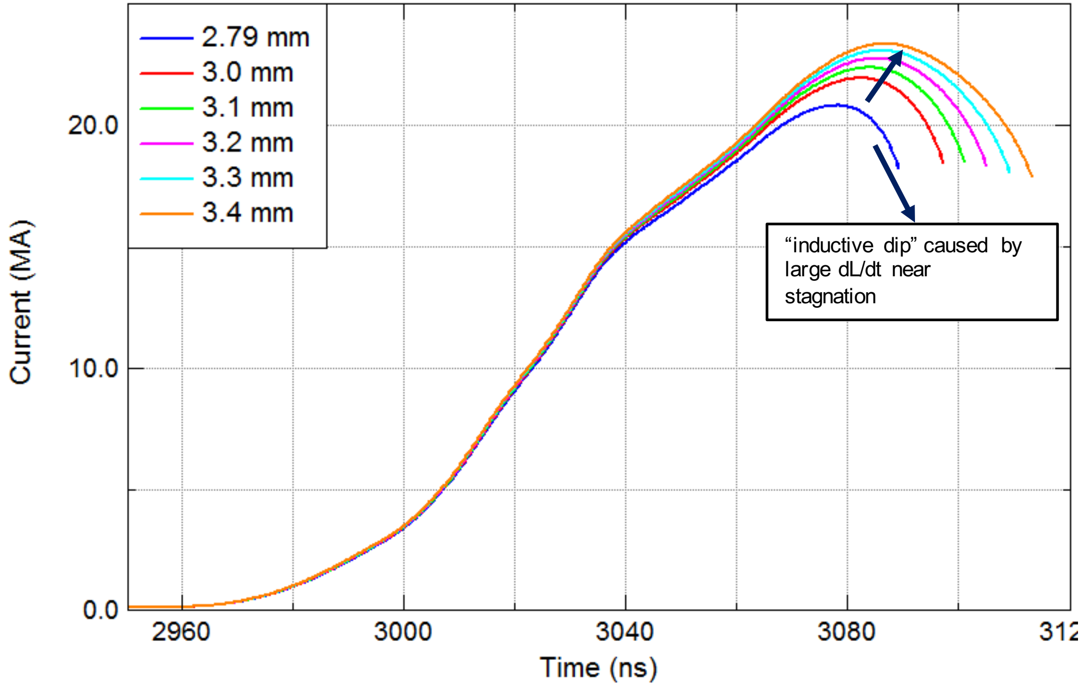


- The power feed inductance has a dramatic influence on coupling driver energy to the load
- Higher inductance feeds drop the available current and increase the voltage at the convolute, exacerbating losses
- Lower inductance feed likely needs to be accompanied by target modifications to fully realize the benefits
- Increasing current is important to test scaling

*Circuit model developed by Brian Hutsel, **power feeds designed by Matt Gomez

We will be testing the effectiveness of modifying the target diameter at increasing current delivery

Circuit model predictions* for new Low-L design with various diameter targets

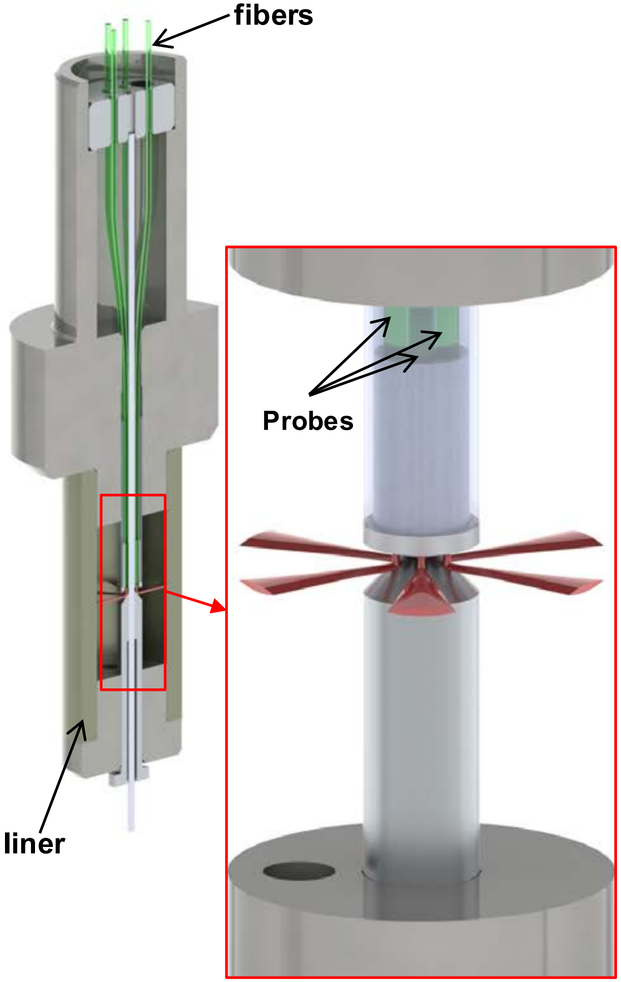


- Increasing target OD at fixed AR has a paradoxical effect
  - Initially slows the implosion (bad)
  - This reduces the dynamic (dL/dt) voltage (good)
  - This in turn increases the drive current, allowing the peak velocity to be largely recovered
  - Also moves inner surface away from laser interaction region
- Net effect is that the driver is able to more effectively couple to the load (better matched impedance)

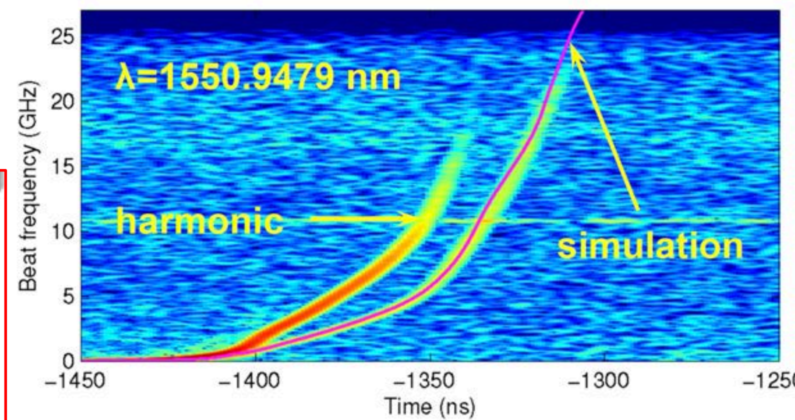
*Circuit model developed by Brian Hutsel

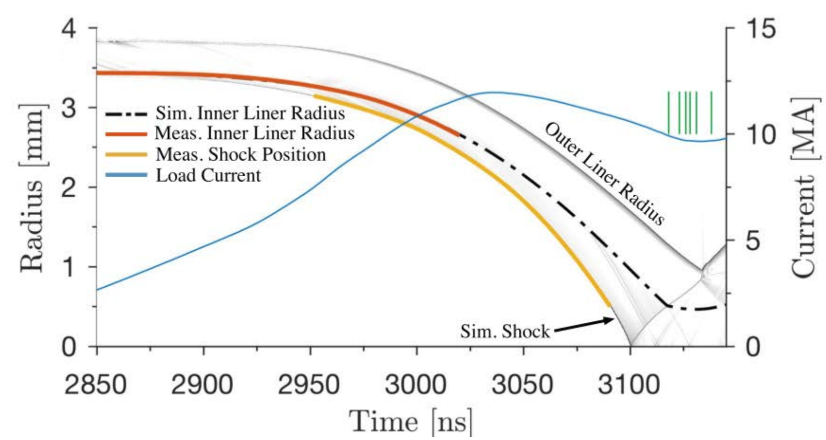
We are also exploring several ways to accurately characterize current delivery

- We have developed the cylindrical analog to the NIF “key-hole” experiments to compliment electrical diagnostics
- Multi-point radial PDV (MPDV*) allows us to measure the liner velocity at up to 6 azimuths
- Currently goes to ~40 km/s, but extension to >100 km/s in progress
- The velocity history is a direct probe of the drive pressure history
- Can be converted to drive current through MHD simulation



Example Velocity Spectrum





Example Velocity Compared to Simulation

*MPDV developed by Dan Dolan in conjunction w/ Ray Lemke, Matt Martin and Patrick Knapp

In addition to increasing PdV work, we aim to measure and mitigate losses

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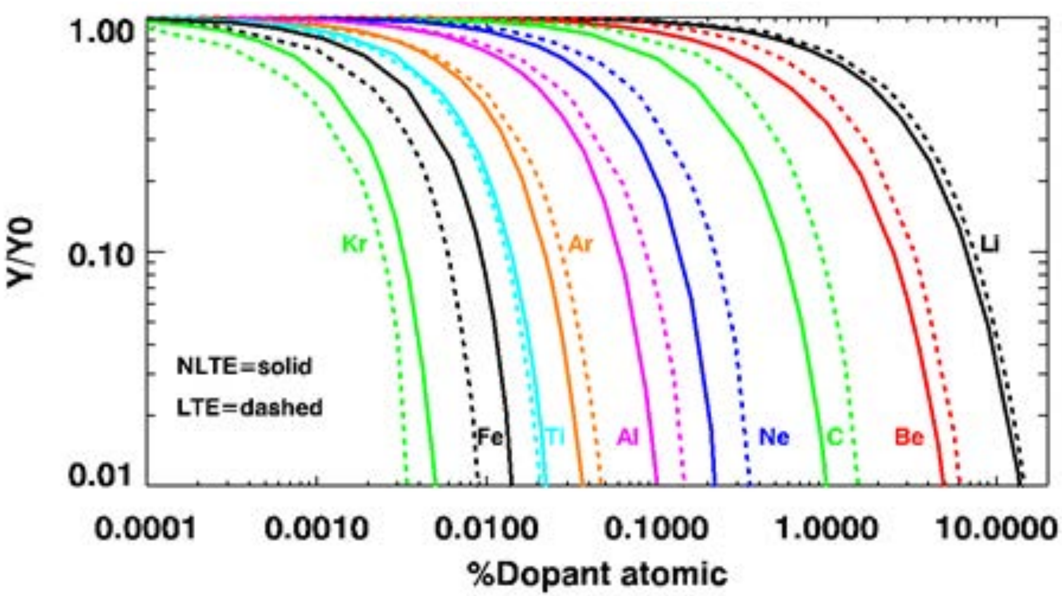
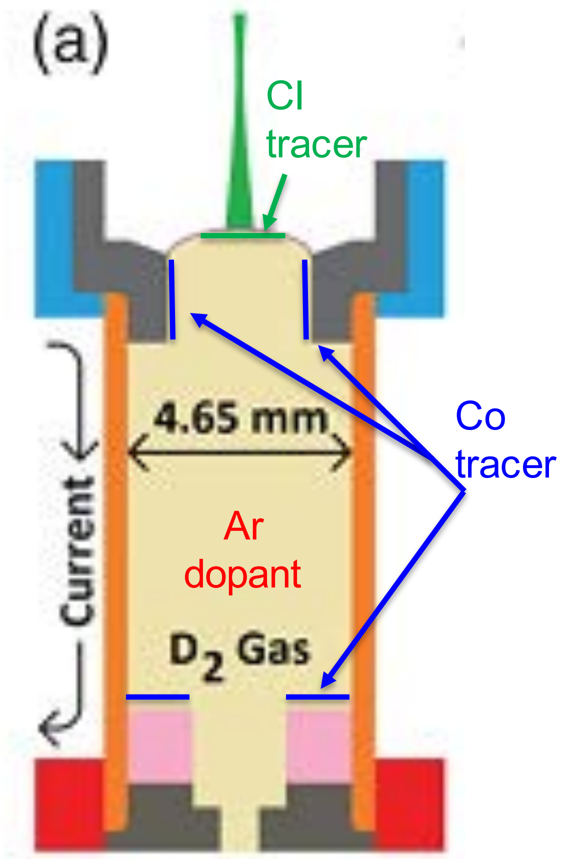
- Early-time mix from laser-window and laser-wall interactions can be devastating: we believe that ~0.1% endcap mix and few-% window mix are introduced during preheat
- Mix near stagnation (~1% wall mix) is much less harmful
- Spectroscopic tracers have been used to track endcap material
- Time-resolved heating, window mix, and rad loss diagnostics are possible with 100 ppm Ar and chlorinated plastic; time-resolved spectrometers required for fielding on integrated shots





*Calculations courtesy Steve Slutz

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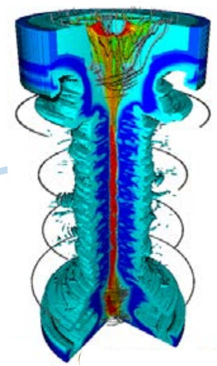

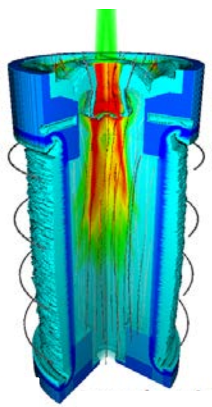

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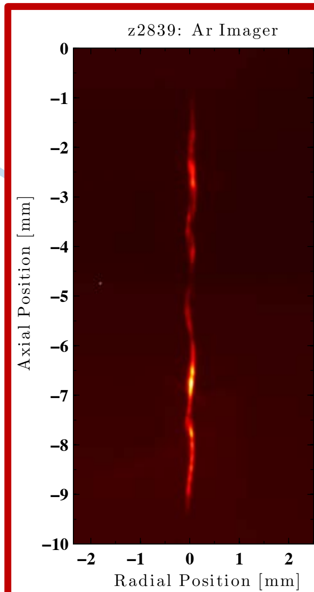


Stagnation

- What is the hot-spot pressure, mass, volume
- What is the drive pressure near stagnation
- How well is the liner confining the fuel

Detailed accounting of the energy in the system at each phase is critical to distinguish between hypotheses

We are developing the means to measure the fuel pressure using independent methods

X-rays

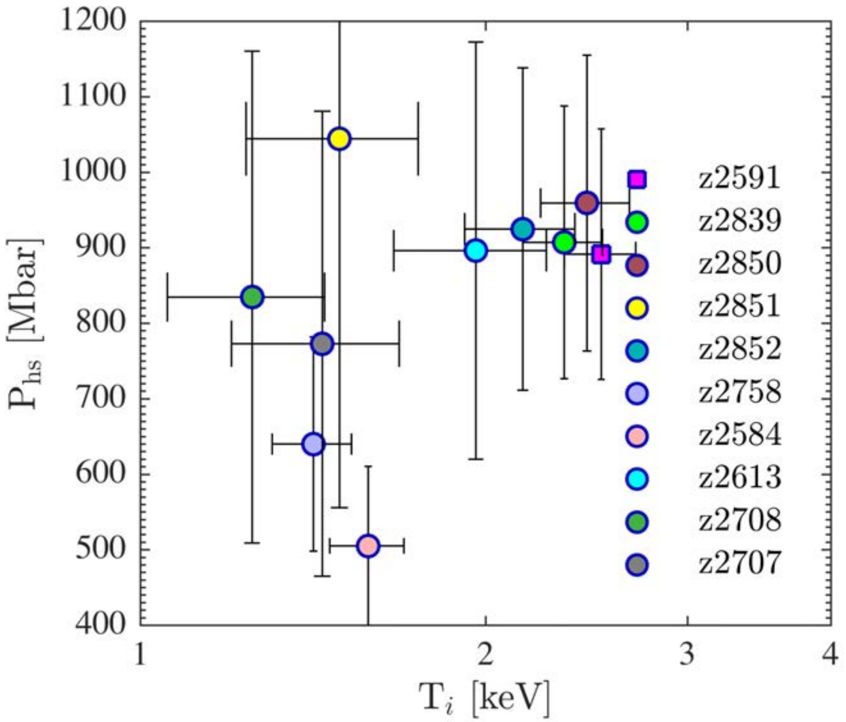
$$P_{\mathrm{HS}} = \sqrt{\frac{e^{\kappa_\nu \rho_l \ell}(h\nu)^{1/3} Y_\nu}{8\pi^2 m_{\mathrm{p}}^2 \delta h R^2 \tau (1+\sum_i x_i Z_i)\int_0^1 \tilde{r} d\tilde{r} \frac{e^{-h\nu/T_{\mathrm{e}}}}{T_{\mathrm{e}}^2}\left(1+\sum_i x_i \frac{j_i}{j_{\mathrm{D}}}\right)}}$$

Neutrons

$$P_{\mathrm{HS}} = (Z+1)\sqrt{\frac{2Y_{\mathrm{DD}}}{\tau 2V \int_0^1 \tilde{r} d\tilde{r} \langle\sigma v\rangle_{\mathrm{DD}}/T_{\mathrm{i}}^2}}$$

Necessary Measurements

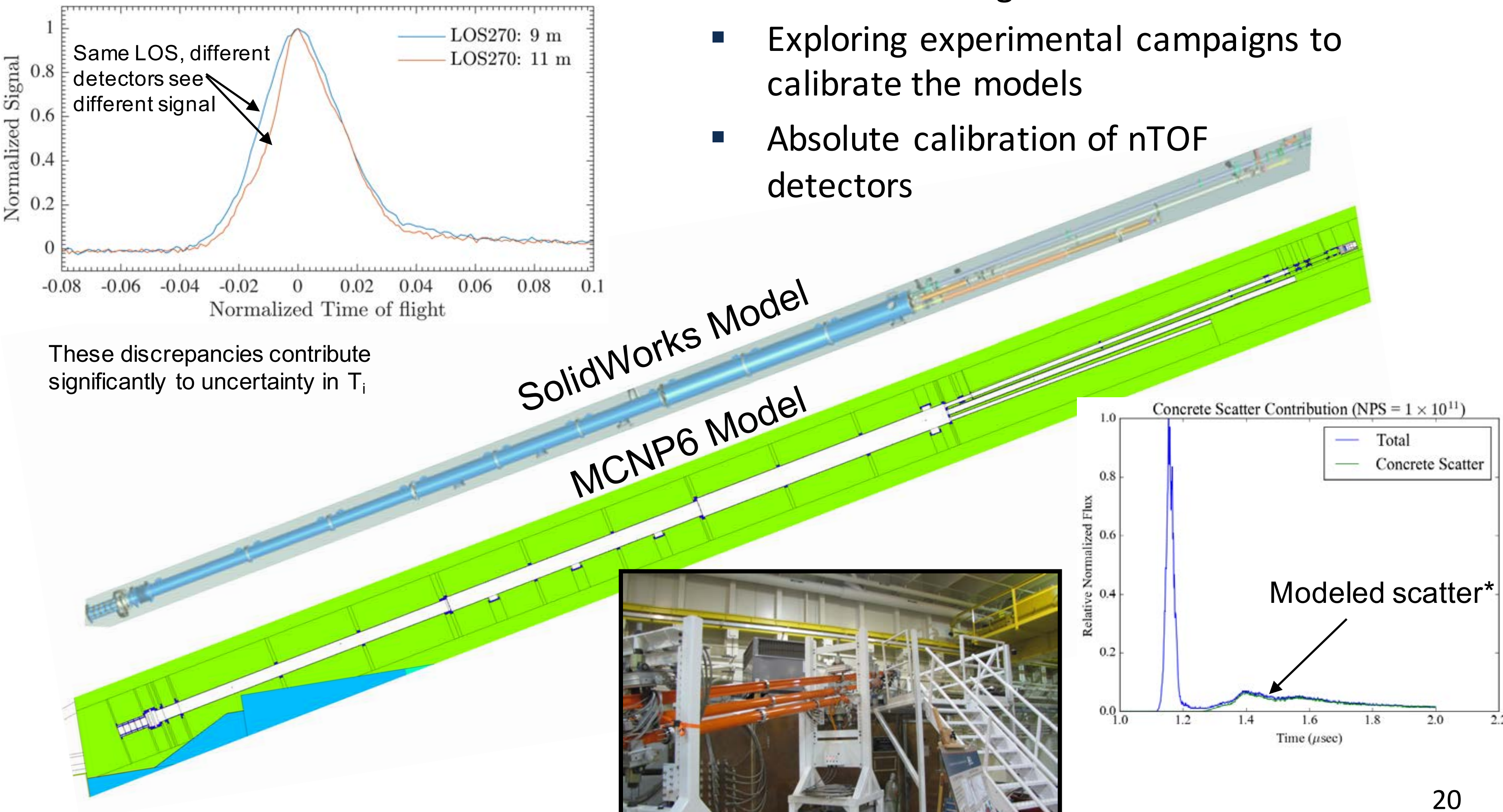
Neutron Yield
Total X-ray yield
Fuel volume
Ion temperature
Electron temperature
Liner areal density
Emission duration
Mix (Z)



Must improve uncertainties to discern trends

There is a significant ongoing effort to model the Z environment in order to improve the precision of our yield and T_i measurements

- MCNP modeling of various nTOF LOS's
- Exploring experimental campaigns to calibrate the models
- Absolute calibration of nTOF detectors



These discrepancies contribute significantly to uncertainty in T_i

*Model for LOS50 developed by Edward Norris and Kelly Hahn

Filtered pinhole images can be used to reconstruct fuel T_e, liner areal density and total x-ray yield

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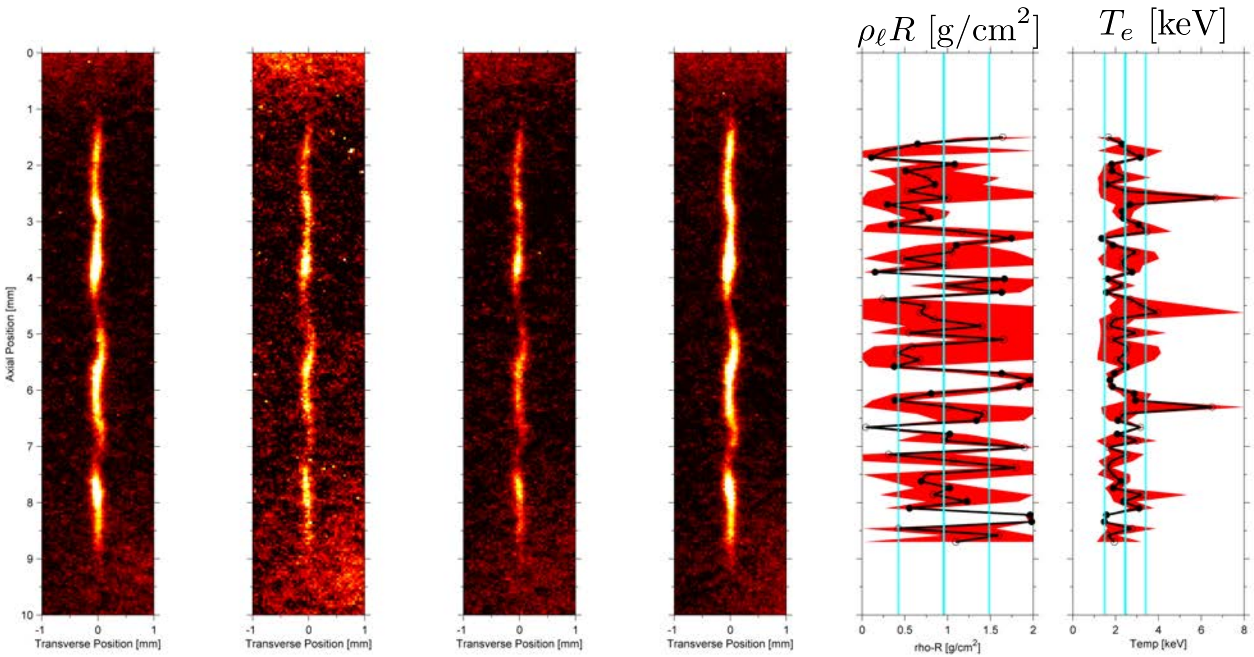
$$\zeta_j = 8\pi^2 m_{\mathrm{p}}^2 P_{\mathrm{HS}}^2 (1 + \sum_i x_i Z_i)\tau\delta h R^2 \int_0^\infty d\nu \mathcal{F}_j e^{-\kappa_\nu \rho_\ell \ell} \int_0^1 \tilde{r} d\tilde{r} \left(1 + \sum_i x_i \frac{j_i}{j_{\mathrm{D}}}\right) \frac{e^{-h\nu/T_{\mathrm{e}}}}{T_{\mathrm{e}}^2 h\nu^{1/3}}$$



X_j - Measured intensity

$\mathcal{F}_j$ - Filter transmission & detector response

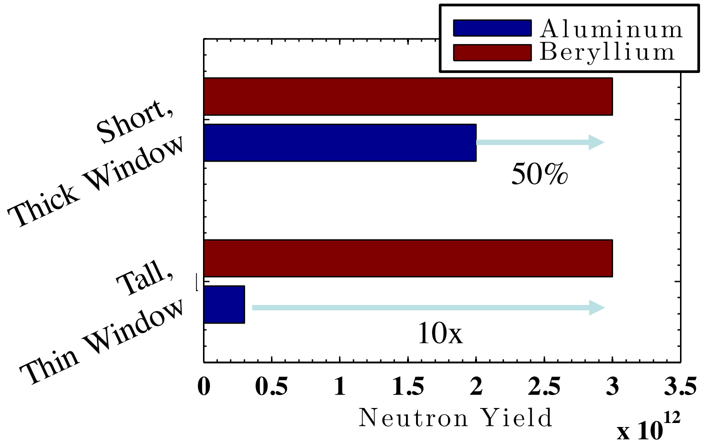
ζ_j - Simulated intensity

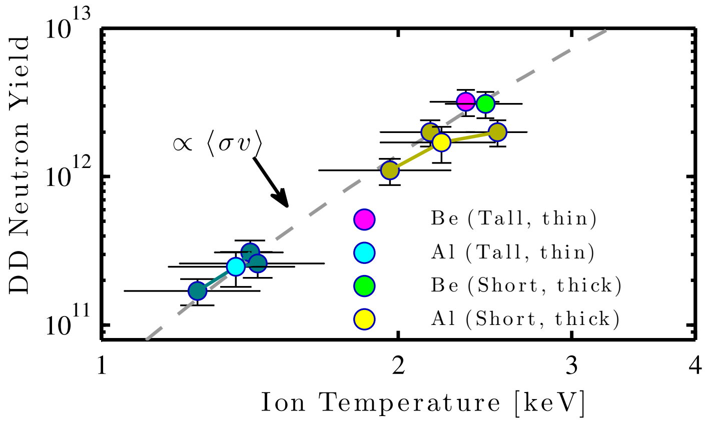
$$\chi_r^2 = \frac{1}{N-m}\sum_j \left(\frac{X_j - \zeta_j}{\sigma_j}\right)^2$$

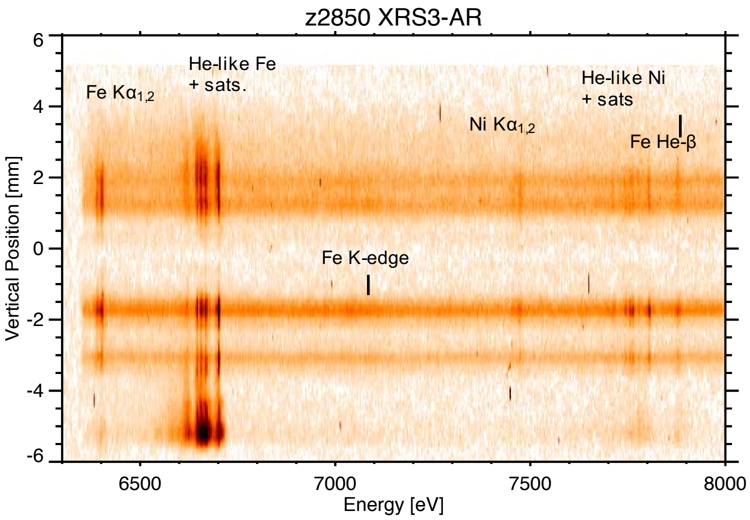
- Existing instrument has poor spatial resolution (~100 µm)
- Images are integrated radially, but resolved axially
- With absolute x-ray yield, mix, and emission radius, can also get $\langle P \rangle$, $\frac{\delta P(z)}{\langle P \rangle}$
- Working on formalizing parameter estimation and defining uncertainties

Images provided by Matt Gomez

We have shown a dependence of target performance on mix, but significant uncertainties remain





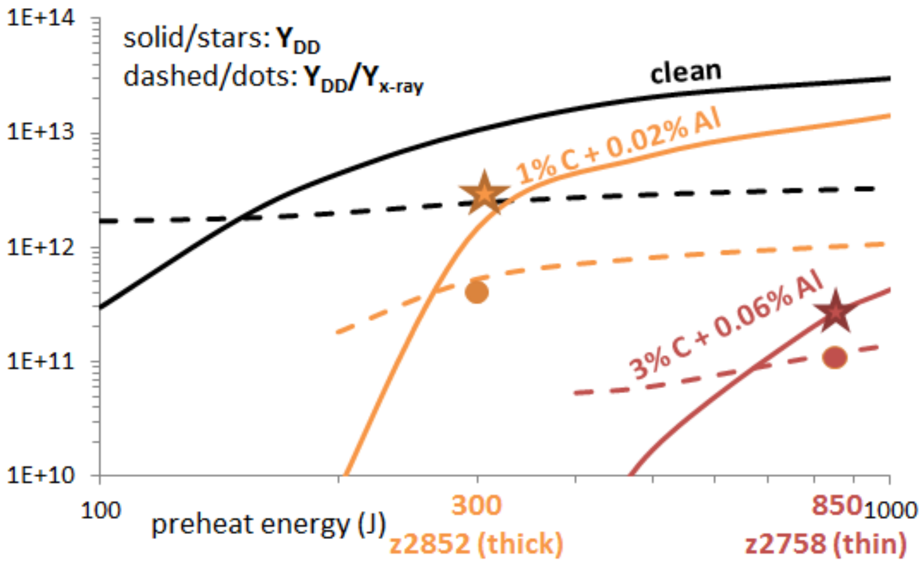


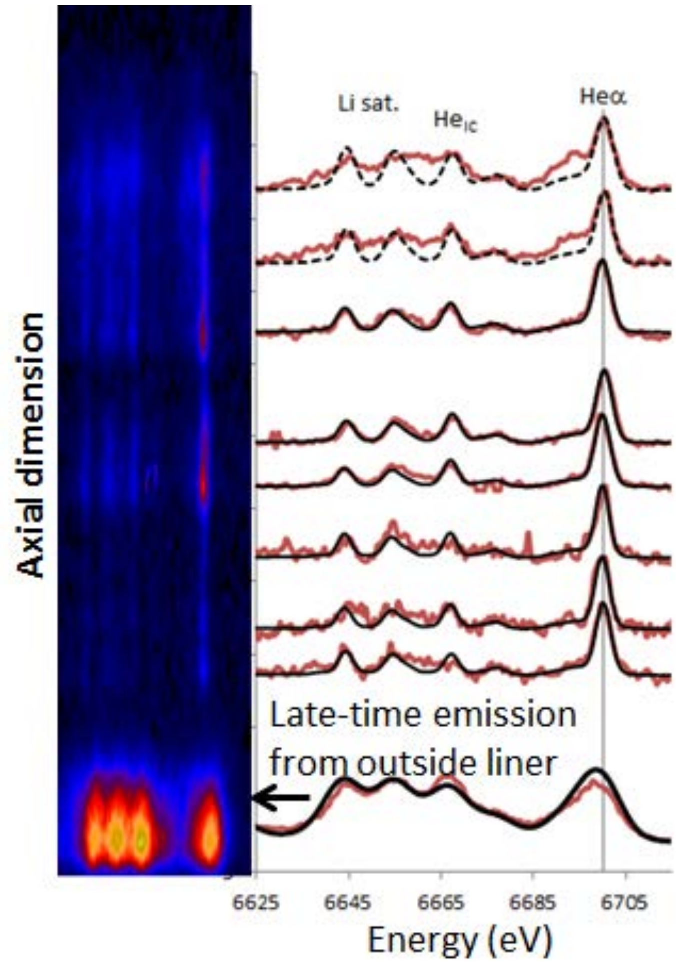
- We have clear indications of the presence of hot contaminants
  - Uncertain how much is truly mixed in the participating fuel
  - Observed hot Fe emission* could be from hot spot, or could be later in time
- Uncertain how much window material is mixed in
  - Indications that this amount scales with laser energy deposition
  - Potential solutions are degenerate with respect to window mix and preheat energy

Spectra processing and analysis courtesy Eric Harding and Stephanie Hansen

Mix is measured by impurity line emission and absolute x-ray yields

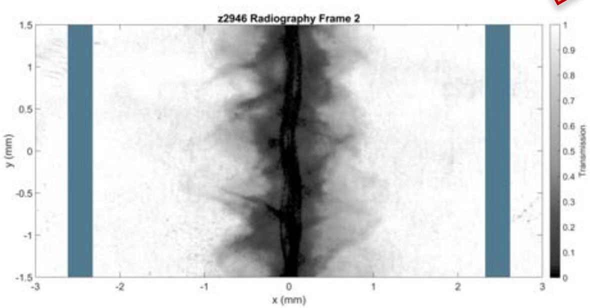
- X-ray yields from filtered silicon diodes indicate $\rho_f \sim 0.3$ g/cc (with mix), dependent on Δt and volume
- XRS3 and CRITR impurity line emission intensities indicate ~few % Be believed to be from late-time instability driven mixing
- Ratios of neutron to x-ray yields indicate that endcap and possibly window mix increase with preheat energy

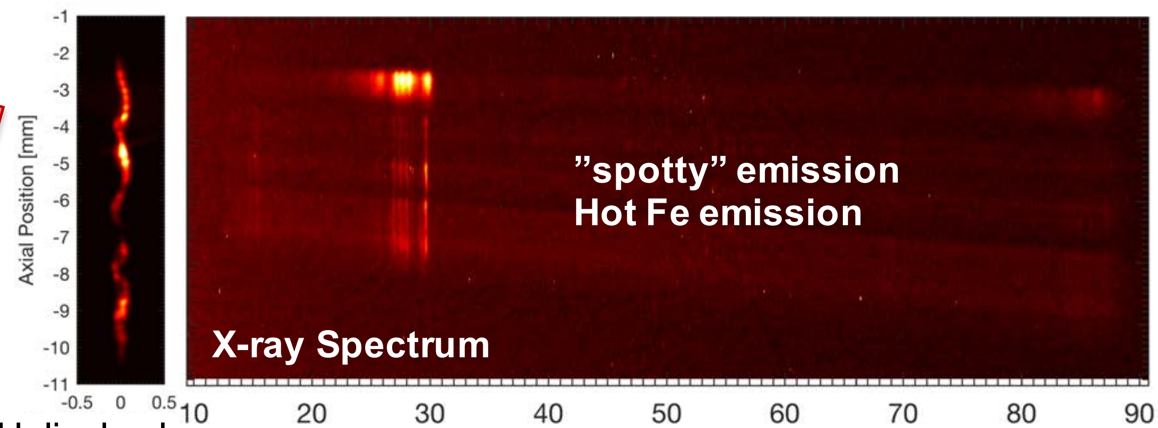




We have demonstrated the ability to impact the stagnation morphology through controlling the implosion

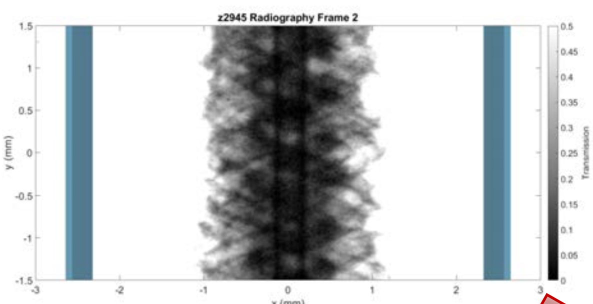
No coating





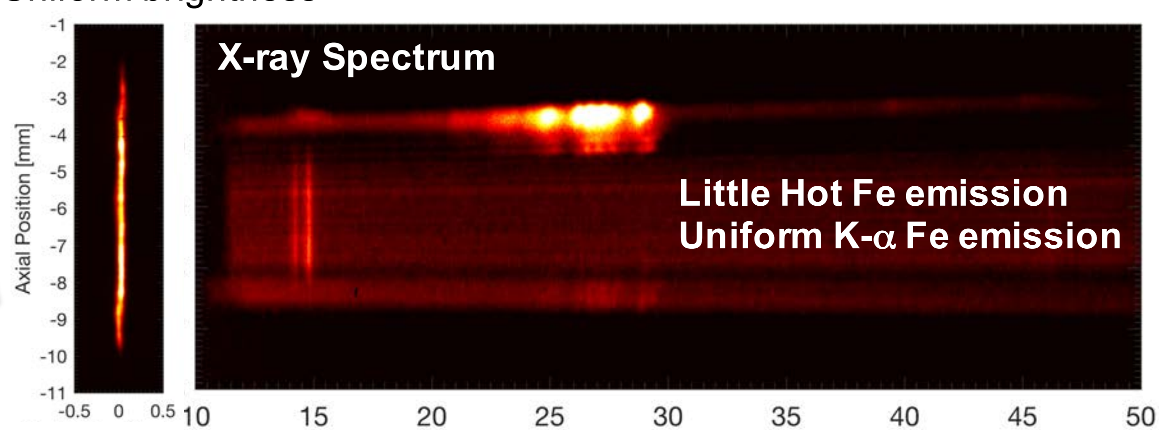
Helical column
Highly variable intensity

Despite "improved" morphology, neutron yield and ion temperature decreased



w/ dielectric coating

Much straighter column
Uniform brightness



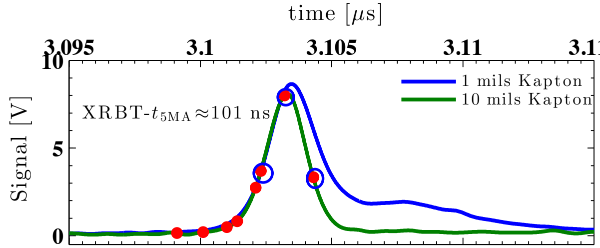
Implosion only experiments

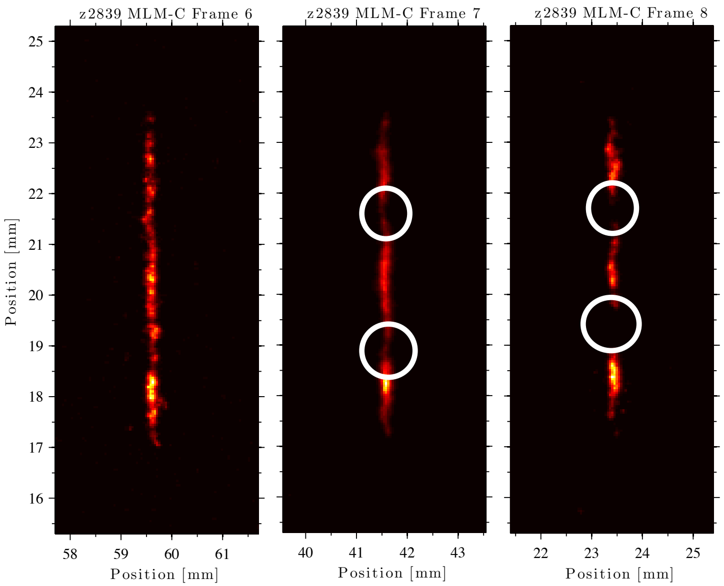
Integrated experiments

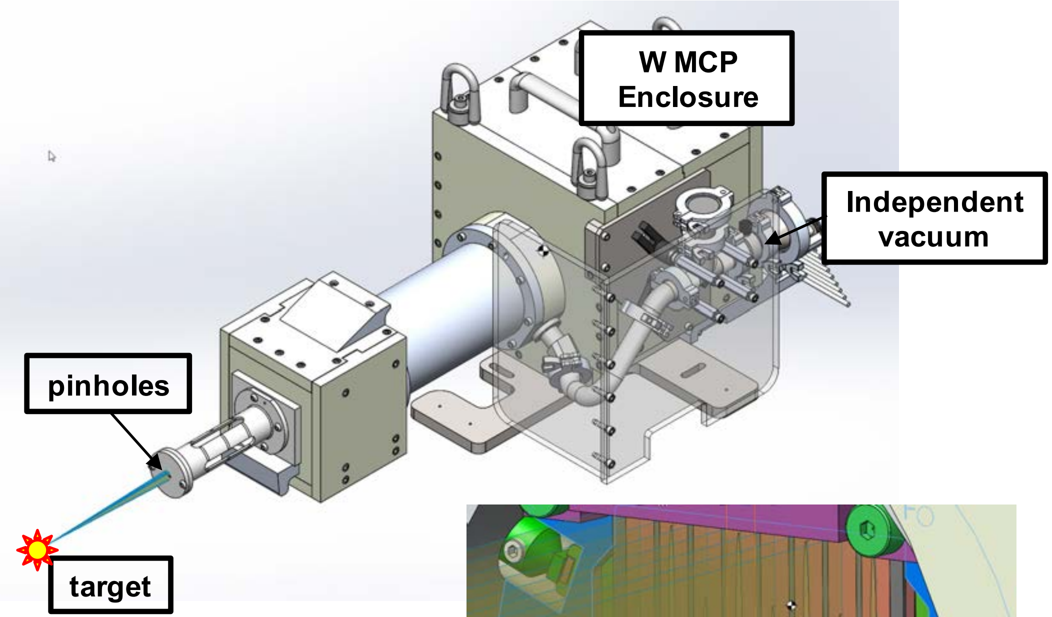
Radiographs provided by Tom Awe and Dave Ampleford

We are currently designing and building an in-chamber time resolved PHC for studying hot-spot evolution

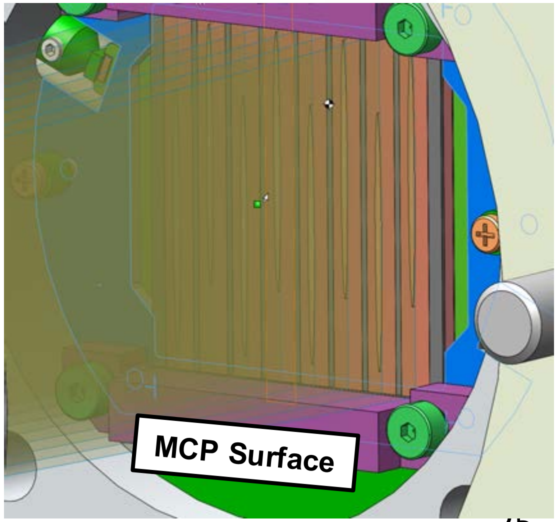
Previous measurements hint at important features in hot spot evolution, but instrument did not have sufficient resolution or sensitivity







$M = 0.5,\ 1$ or 3
$\delta x \geq 25\ \mu\mathrm{m}$
$\delta t \geq 250$ ps
8 frames

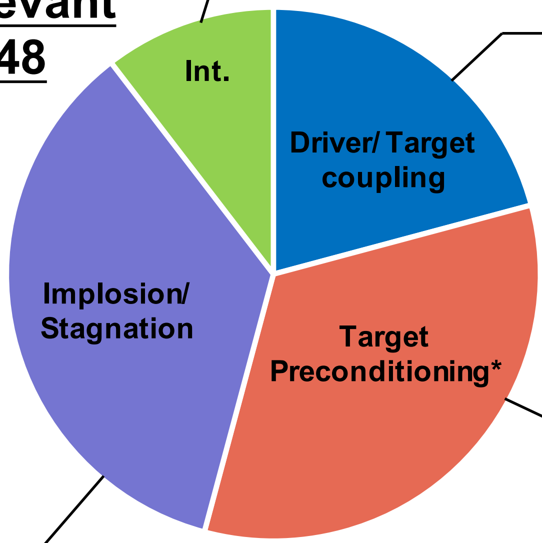


Instrument design by Christopher Ball and Matt Gomez

The CY17 Z shot allocation reflects these priorities

Sandia National Laboratories

MagLIF Relevant Shot days: 48



5 days: Integration of new platforms

10 days: split between lowering inductance to increase drive current and better diagnosing current delivery

5 days: MagLIF Cryo
8 days: Develop and characterize new baseline
2 days: Calibration
1 days: Electron temperature measurement

4 days: Stagnation Hydrodynamics
8 days: Mix techniques/characterization/mitigation
2 days: Liner diameter scan
1 days: Tritium development

Focusing heavily on preconditioning as interpretation of stagnation is predicated on understanding initial conditions

*Preconditioning shot allocation does not include PECOS or OMEGA/OMEGA-EP experiments