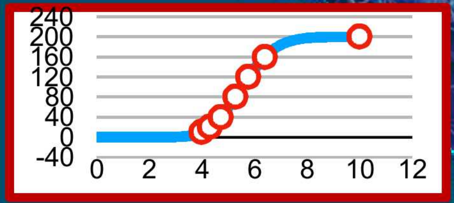
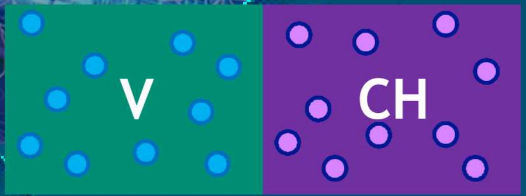
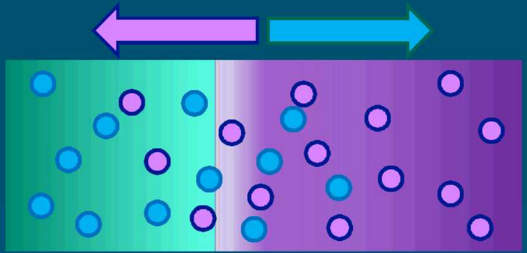
SAND2020-7960C

Experimental Validation of Dense Plasma Transport Models using the Z-Machine







PRESENTED BY

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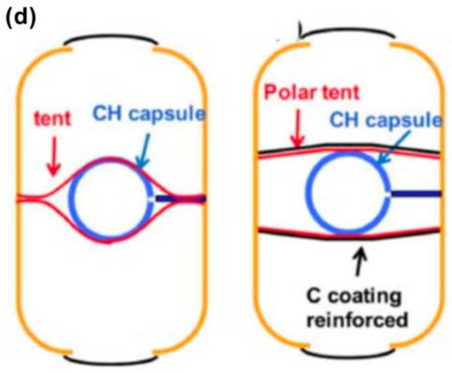
This project has been a large interdisciplinary effort

- Diagnostic Development
  - E.C. Harding, M. Schollmeier, G.P. Loisel, S.B. Hansen
- Sample Development
  - S.B. Hansen, P.J. Christenson, P.F. Knapp, T. Mattsson
- Target Fabrication
  - Haibo Huang, Reny Paguio, Brian Stahl
  - *General Atomics, La Jolla, CA*
- Modeling and Source Development
  - R. Vesey, P. J. Christenson, T. Mattsson, K. Beckwith, C. Kopenhafer, L. Stanek, R. Clay III, M. Murillo
- Multi-species BGK theory and code development
  - J. Haack (LANL), L. Stanton (SJSU), M. Murillo (MSU) and C. Hauck (ORNL)

Predictive Modelling in High Energy Density Physics



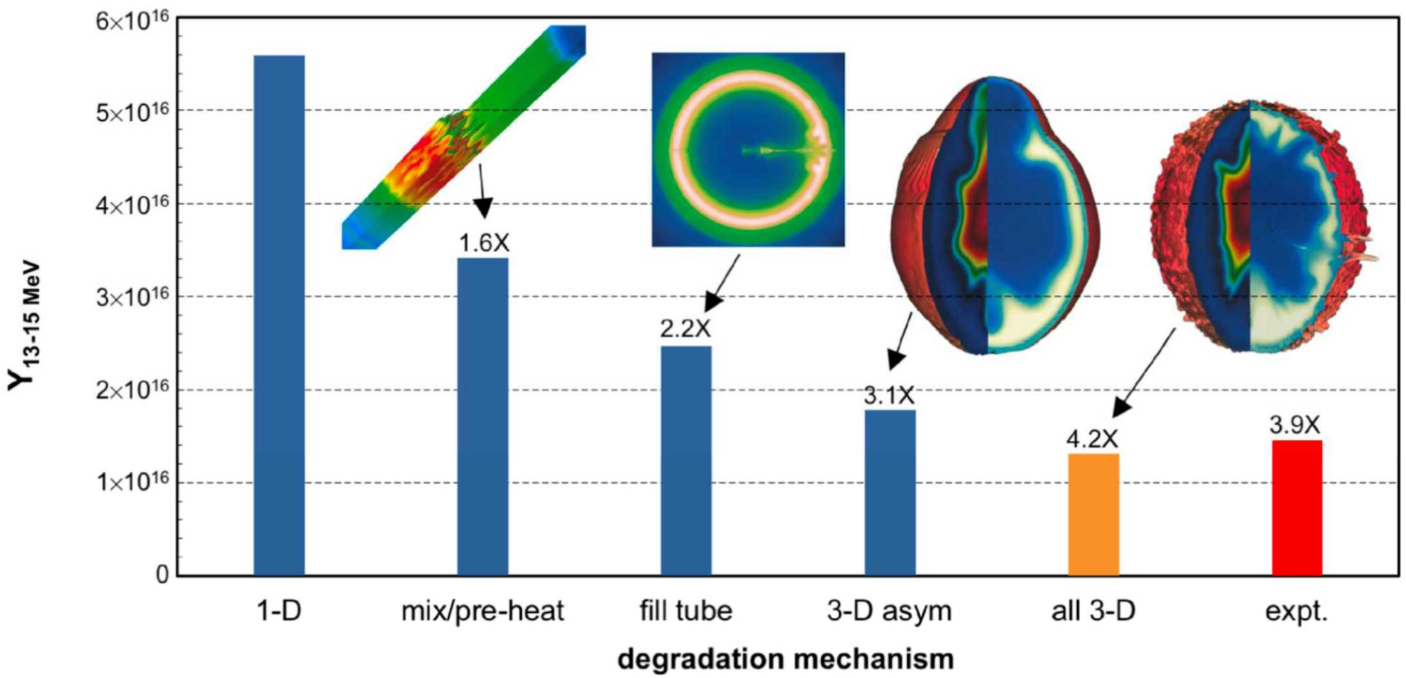


FIG. 5. Single effect simulations of N170601 showing the relative importance of different degradation mechanisms. The largest degradation sources are the 3-D x-ray flux asymmetries and the fill tube resulting in yield degradations of 3.1 and 2.2 relative to 1-D, respectively. The high-mode fuel-abaltor mix results in only a 1.6 yield degradation relative to 1-D. When all effects are combined the yield degradation relative to 1-D is 4.2 and compares favorably with the experimental total degradation of 3.9.

Multiphysics codes based on magneto-hydrodynamics++ and beyond play a critical design and analysis role in ICF.

A correct understanding of the underlying physics means we can

1.) Explain experimental behavior. *Why is our yield so low/high?*

2.) Optimize target designs to achieve a desirable result. *How can we get **more** yield?*

Phys. Plasmas 26, 050601 (2019); doi: 10.1063/1.5091449

Problem with "Predictive" Modelling

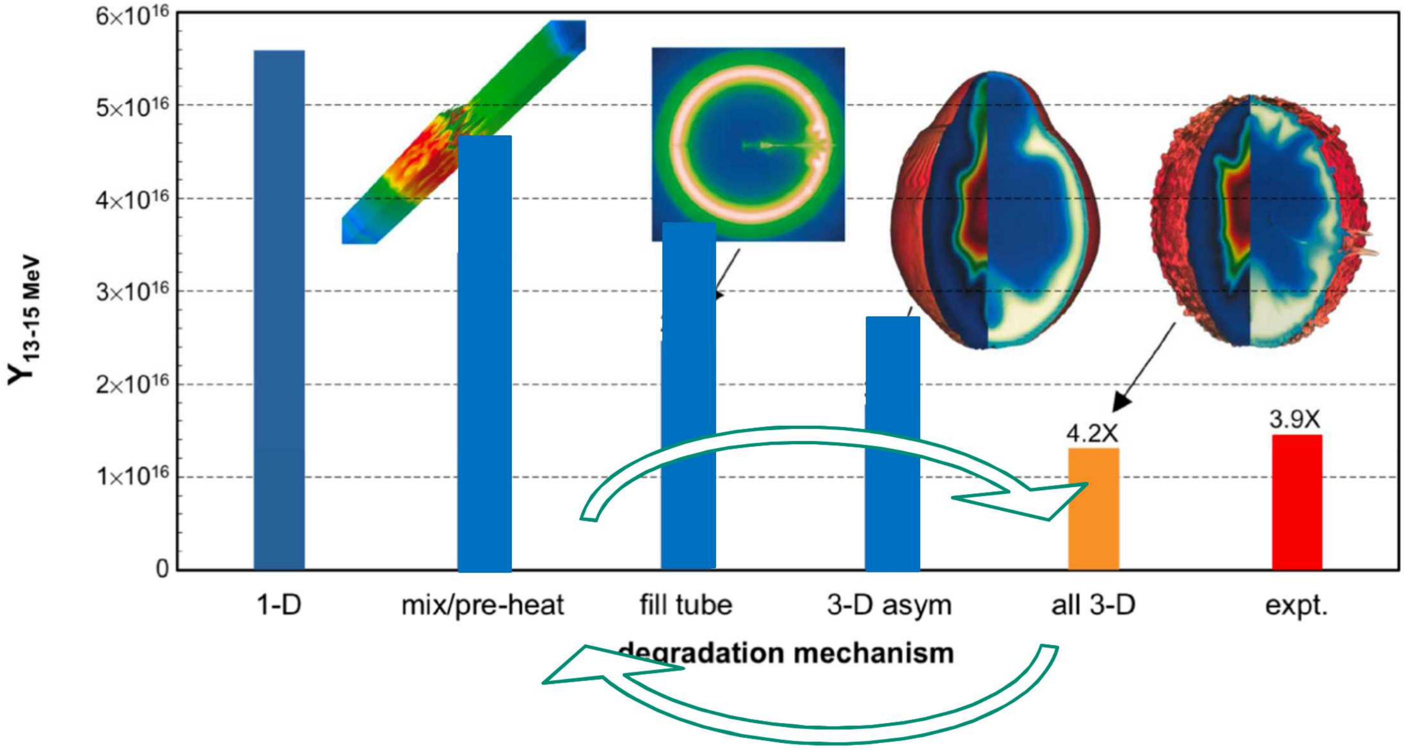


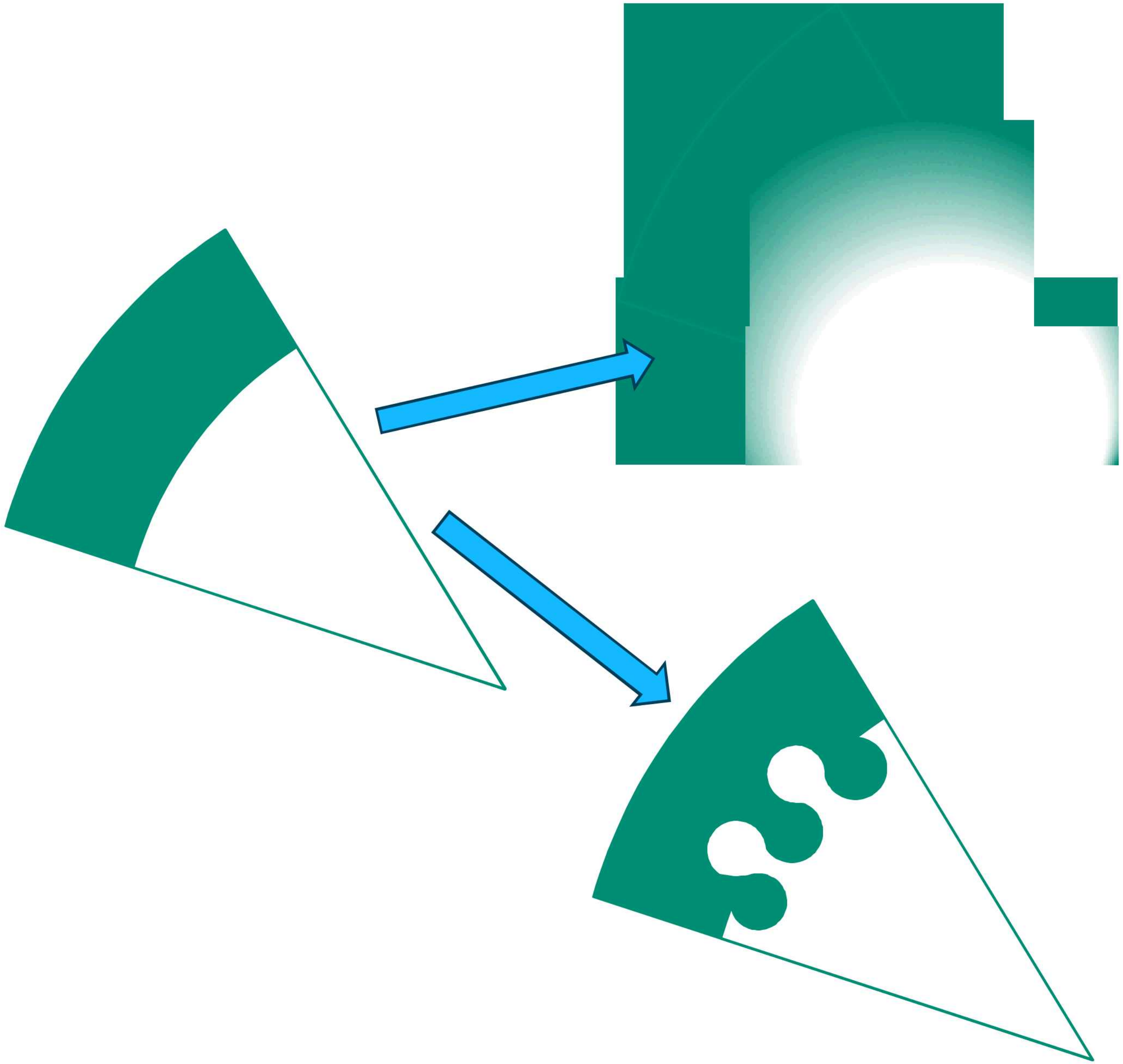
FIG. 5. Single effect simulations of N170601 showing the relative importance of different degradation mechanisms. The largest degradation sources are the 3-D x-ray flux asymmetries and the fill tube resulting in yield degradations of 3.1 and 2.2 relative to 1-D, respectively. The high-mode fuel-abaltor mix results in only a 1.6 yield degradation relative to 1-D. When all effects are combined the yield degradation relative to 1-D is 4.2 and compares favorably with the experimental total degradation of 3.9.

When looking at massively integrated quantities (e.g. yield), you can the right answer for the wrong reasons.

For example, if we downplay mix and pre-heat effects but over-emphasize 3D effects, we can get the same result for yield with different physical pictures for what's driving the mechanism.

Each component of our model must be **tested** and **validated**. We are going to focus on *transport* models.

Understanding Inhomogeneous Material Transport: Interfaces



- **How does an interface evolve macroscopically/microscopically when**
  - It is driven by a strong shock?
  - It is exposed to an intense radiation environment?
  - There are large microfields near the interface?
  - There are large temperature gradients in the vicinity?

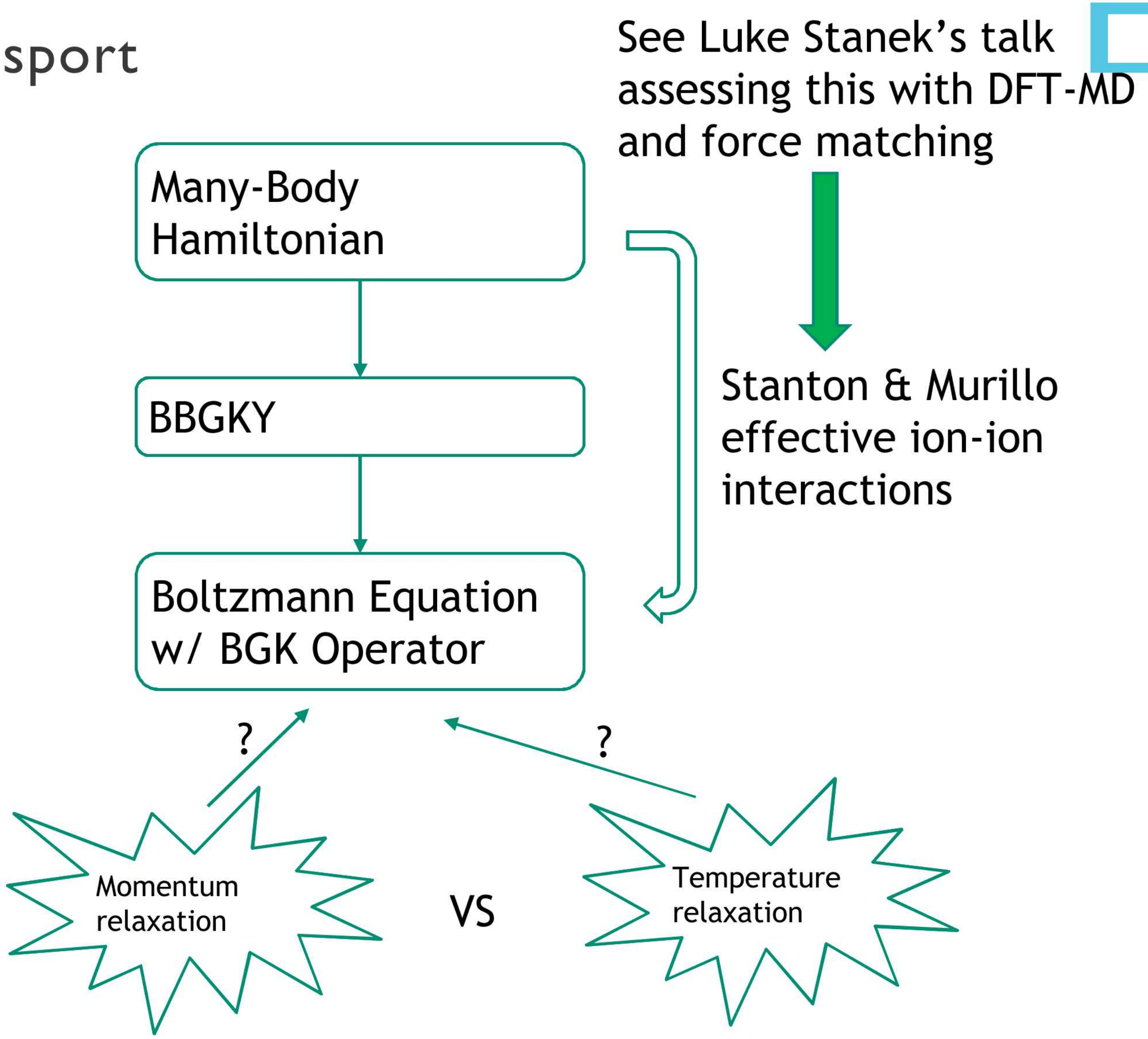
- **How this is described is very important for ICF.** Does the fusion fuel get poisoned by liner material? Does the presence of turbulence dissipate energy or hinder the formation of a hotspot?
- Unfortunately fluid models by themselves don't account for transport processes well, particularly in strongly coupled plasmas.
- Use of kinetic models is a proposed and promising way of handling these effects beyond standard hydrodynamics assumptions.


Turbulence
Non-LTE
Mixing
OH MY!

Kinetic Theory for HED Plasma Transport

Radiation Hydrodynamics

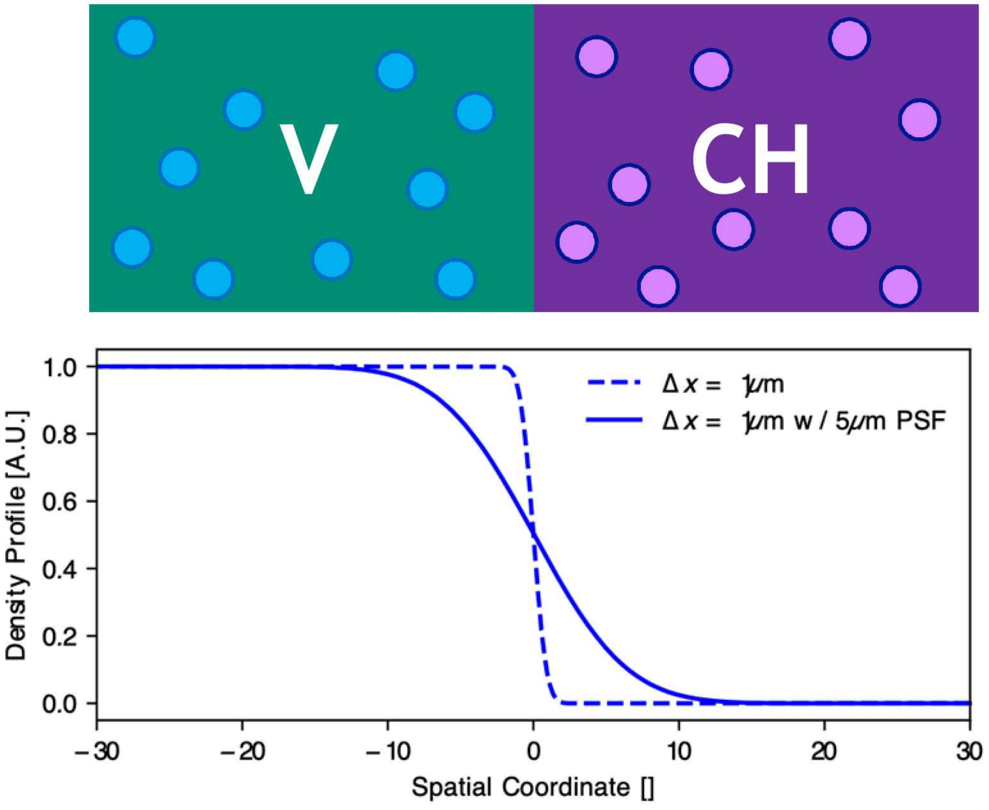
VS

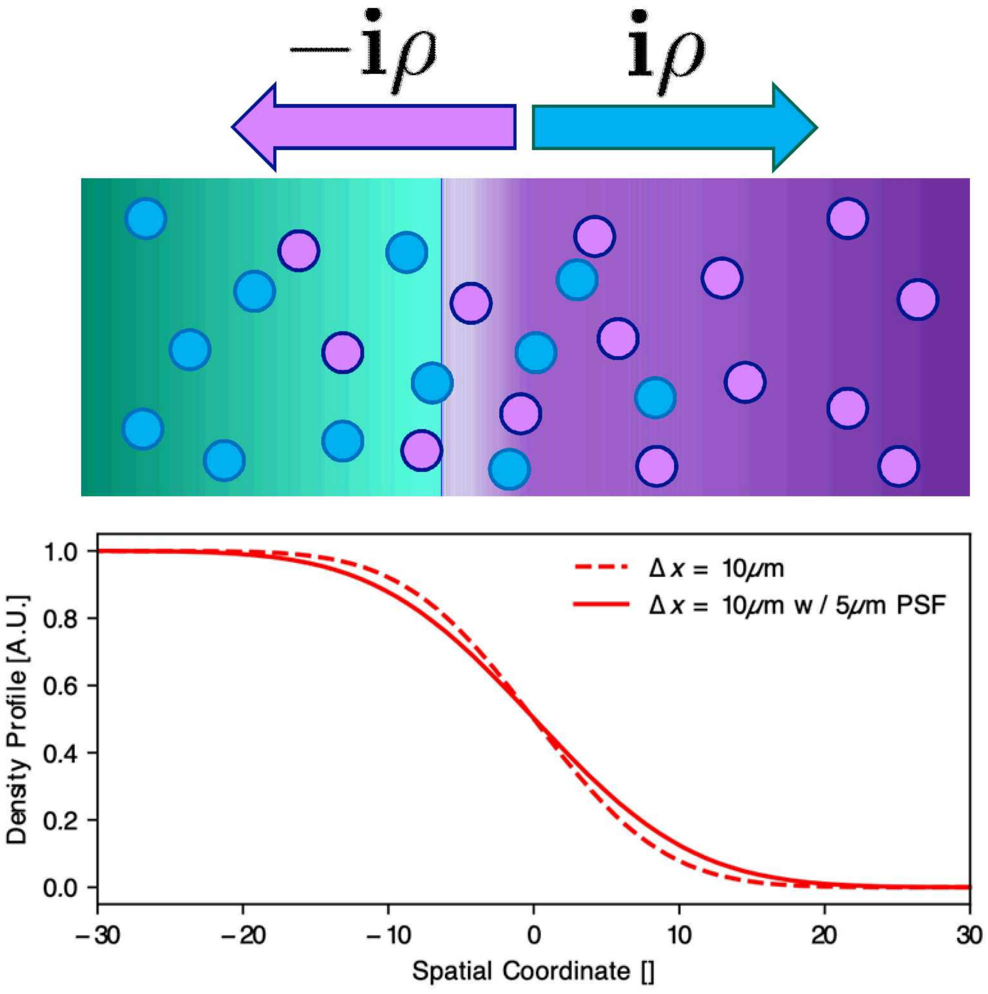


- A natural way to improve transport is to move to kinetic theory:
  - Much more graceful handling of non-diffusive transport & strongly coupled systems.
  - More direct/accurate treatment of atomic level physics.
- How do we know that this is physically the correct thing to do? Do various approximations in the kinetic theory impact predictions?

- Haack et al. (2017b): 10.1103/PhysRevE.96.063310
- Stanton & Murillo (2016): 10.1103/PhysRevE.93.043203

Experimental Test of Transport at HED: Evolution of an Interface





- We can set up a low Z/high Z interface
- Isochorically heat it to 100's of eV.
- Watch the evolution of the interface with radiography, and compare to transport models.

Plasma Transport Sample and Diagnostic Concept

Half moon sample allows transmission to be obtained from the attenuation

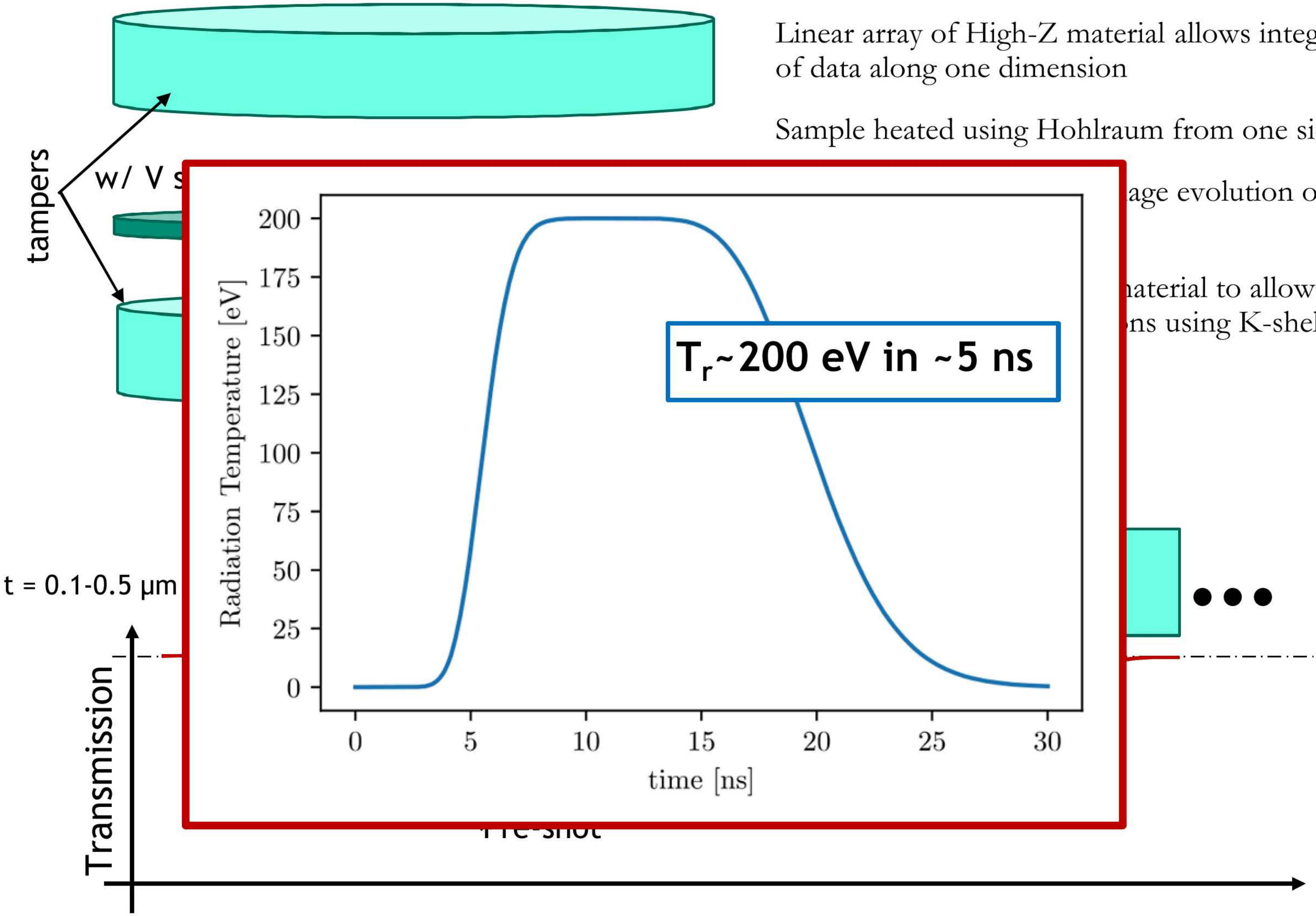
Linear array of High-Z material allows integration of data along one dimension

Sample heated using Hohlraum from one side

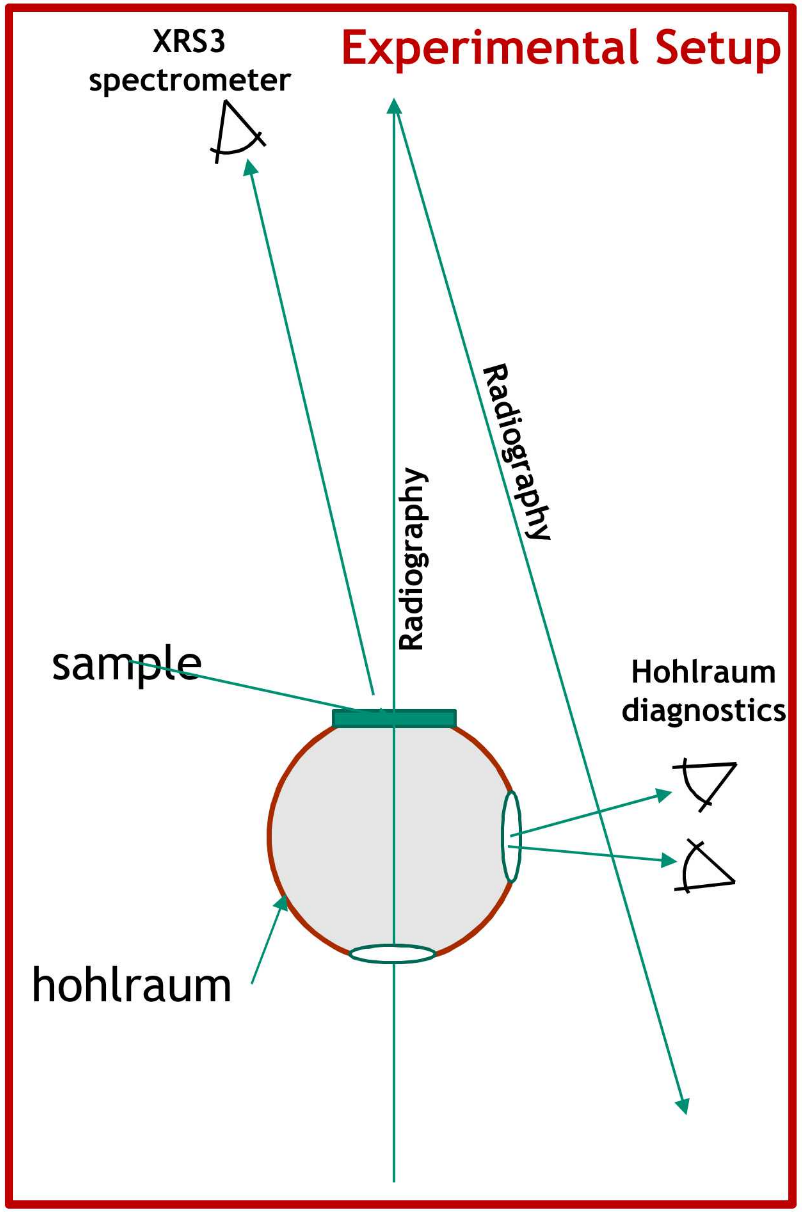
…age evolution of high

…aterial to allow …ns using K-shell

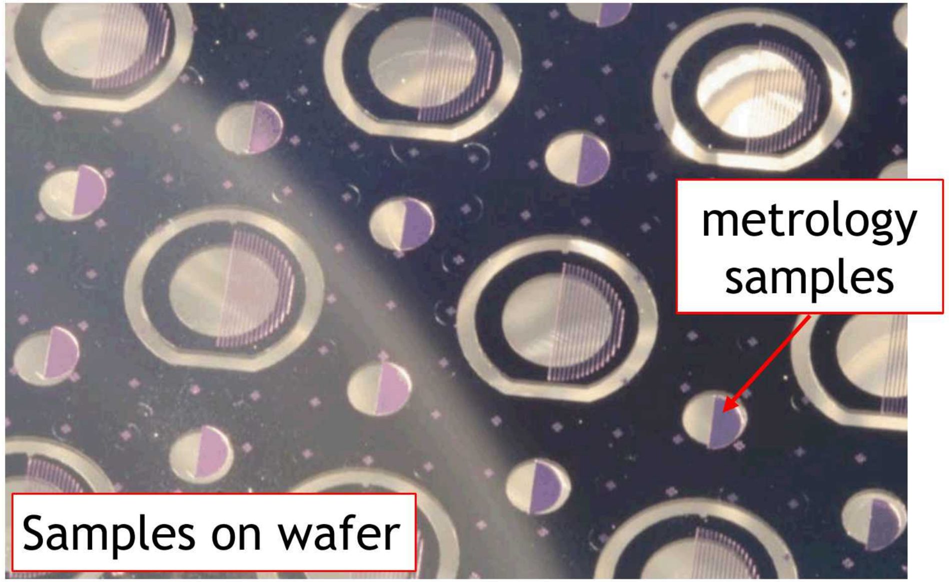
Conceptual Sample

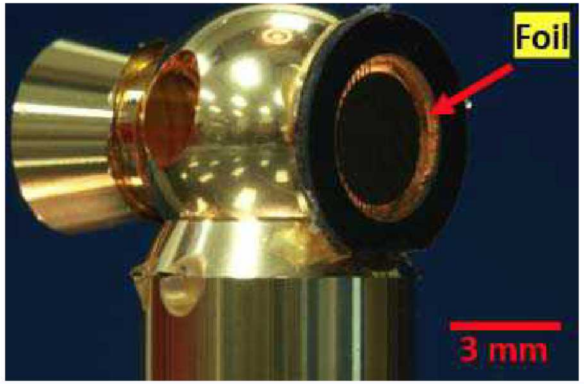


Experimental Setup

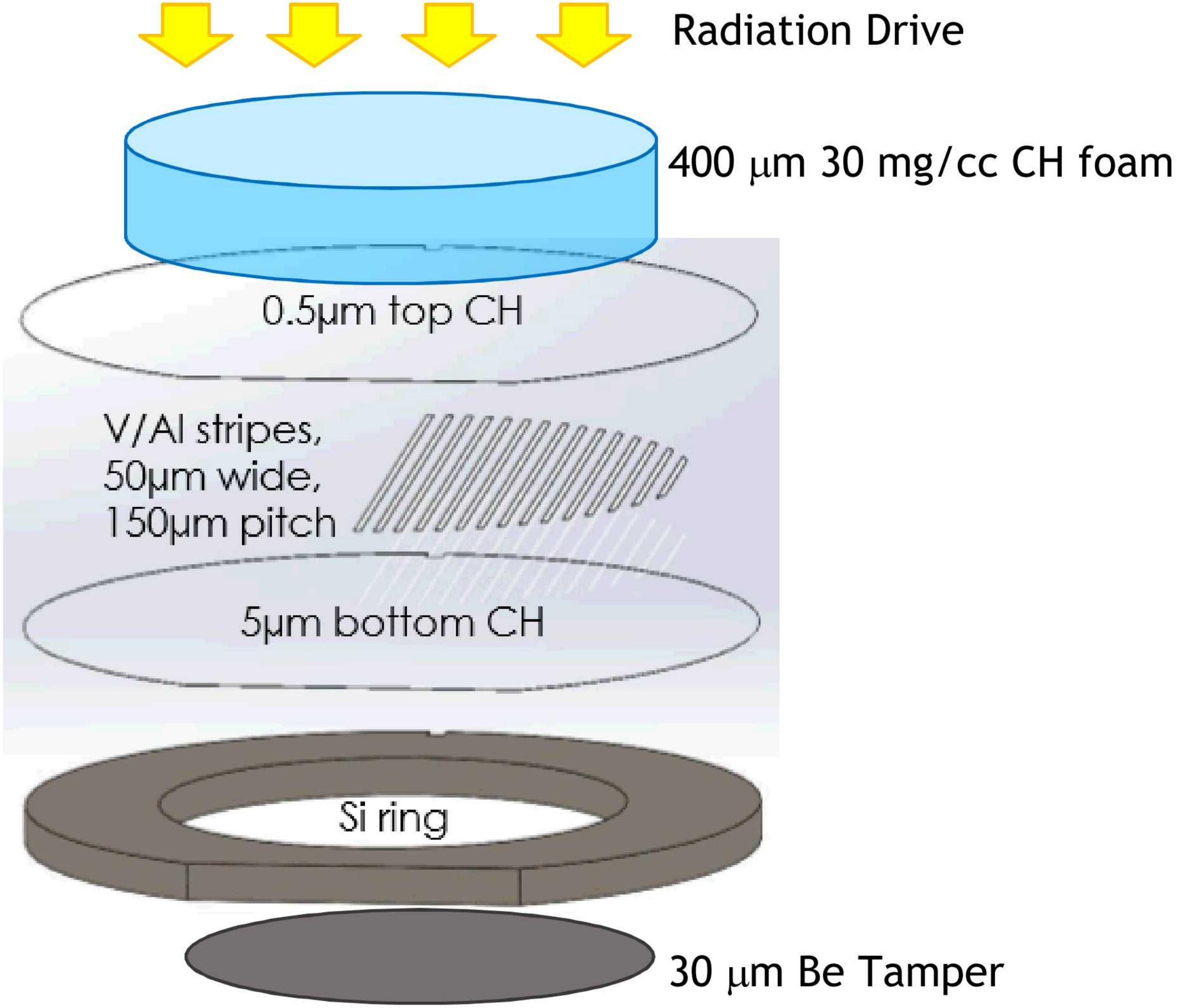


Fabrication of the sample required significant R&D by general atomics





Sample on hohlraum w/ Be tamper attached

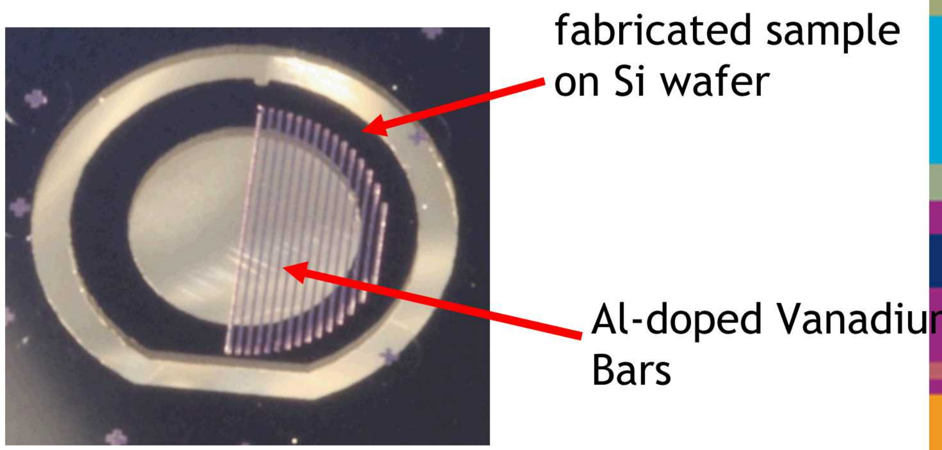


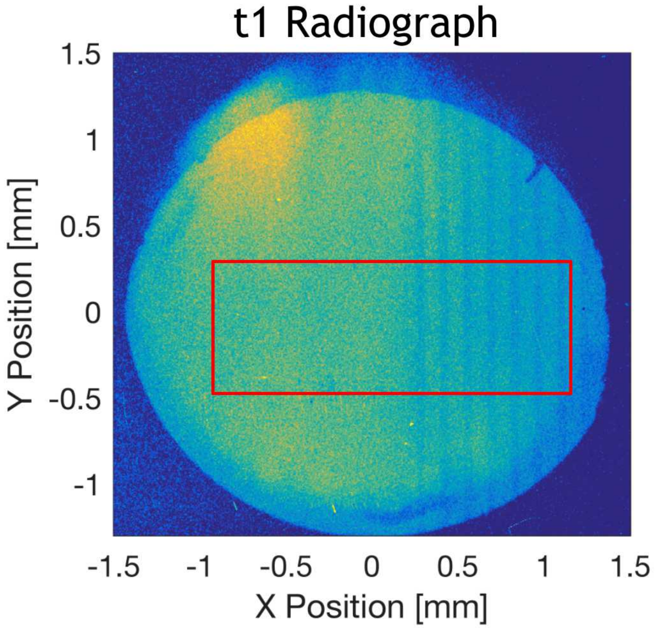
- Requirement of sharp interface led to use of lithographic technique
- Significant effort in metrology for areal density, mixture properties, and edge widths

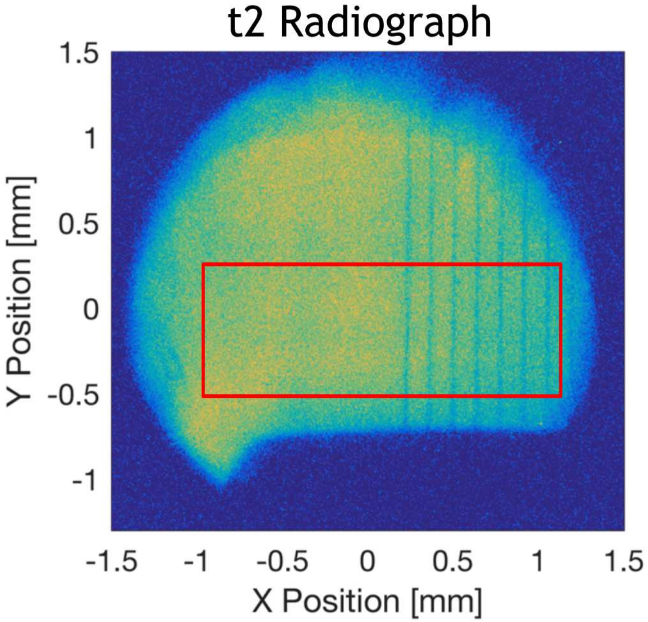
Material provided by Haibo Huang, General Atomics

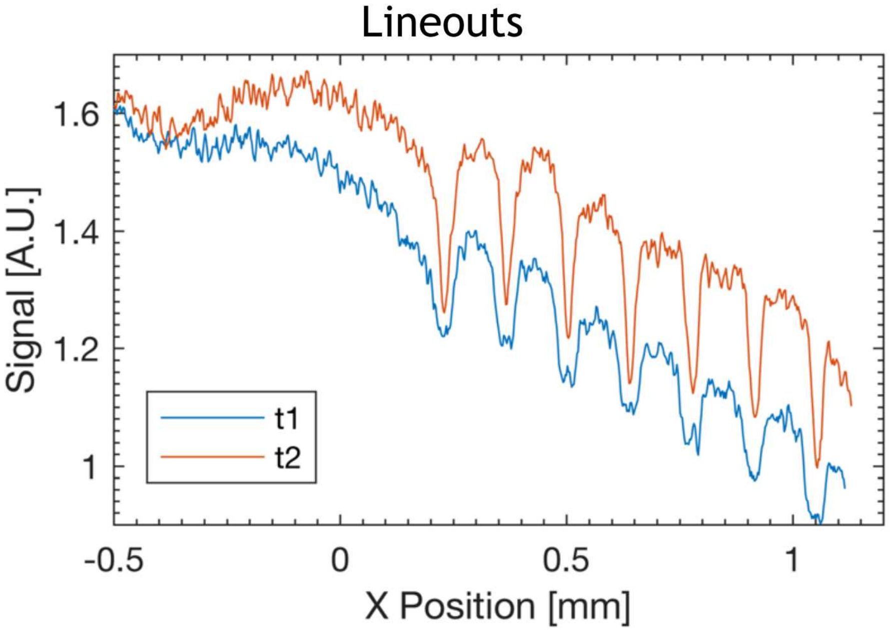
First plasma transport experiments have been executed on Z demonstrating the feasibility of the proposed measurement

- Executed two experiments in March testing x-ray heating and diagnostics performance
- Demonstrated good contrast of the sample in the radiographs on shot z3220 (6.1 keV backlighter with detector placed at closer focal position)





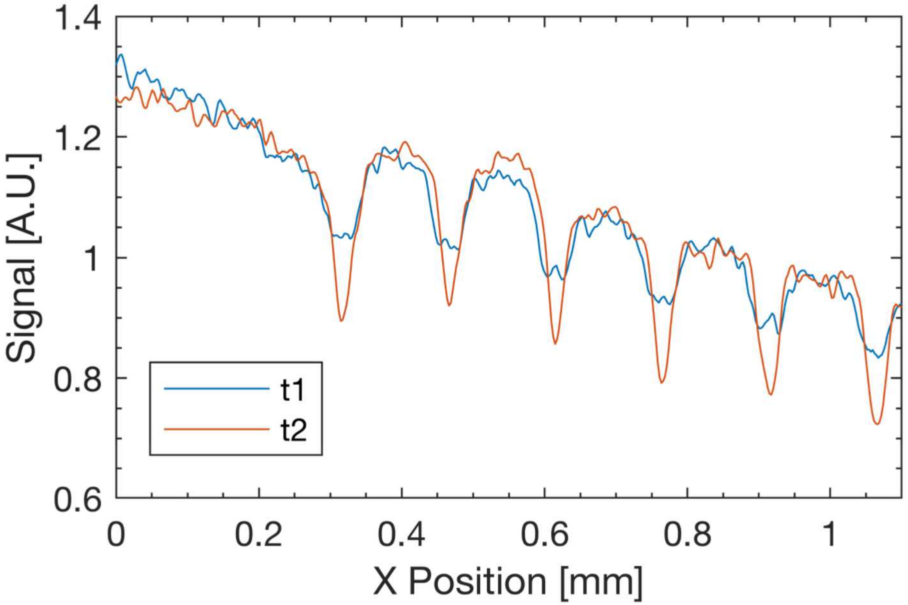


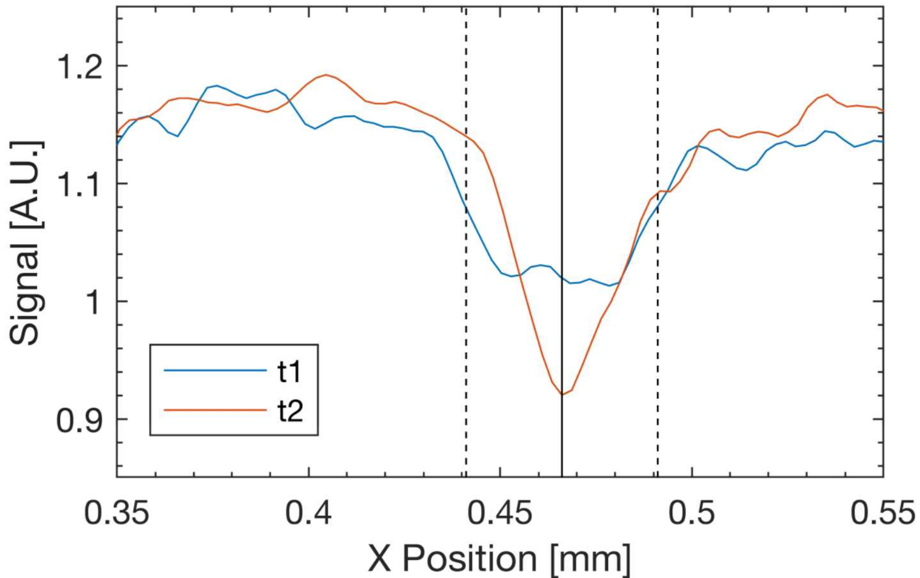


A closer look at the experimental data

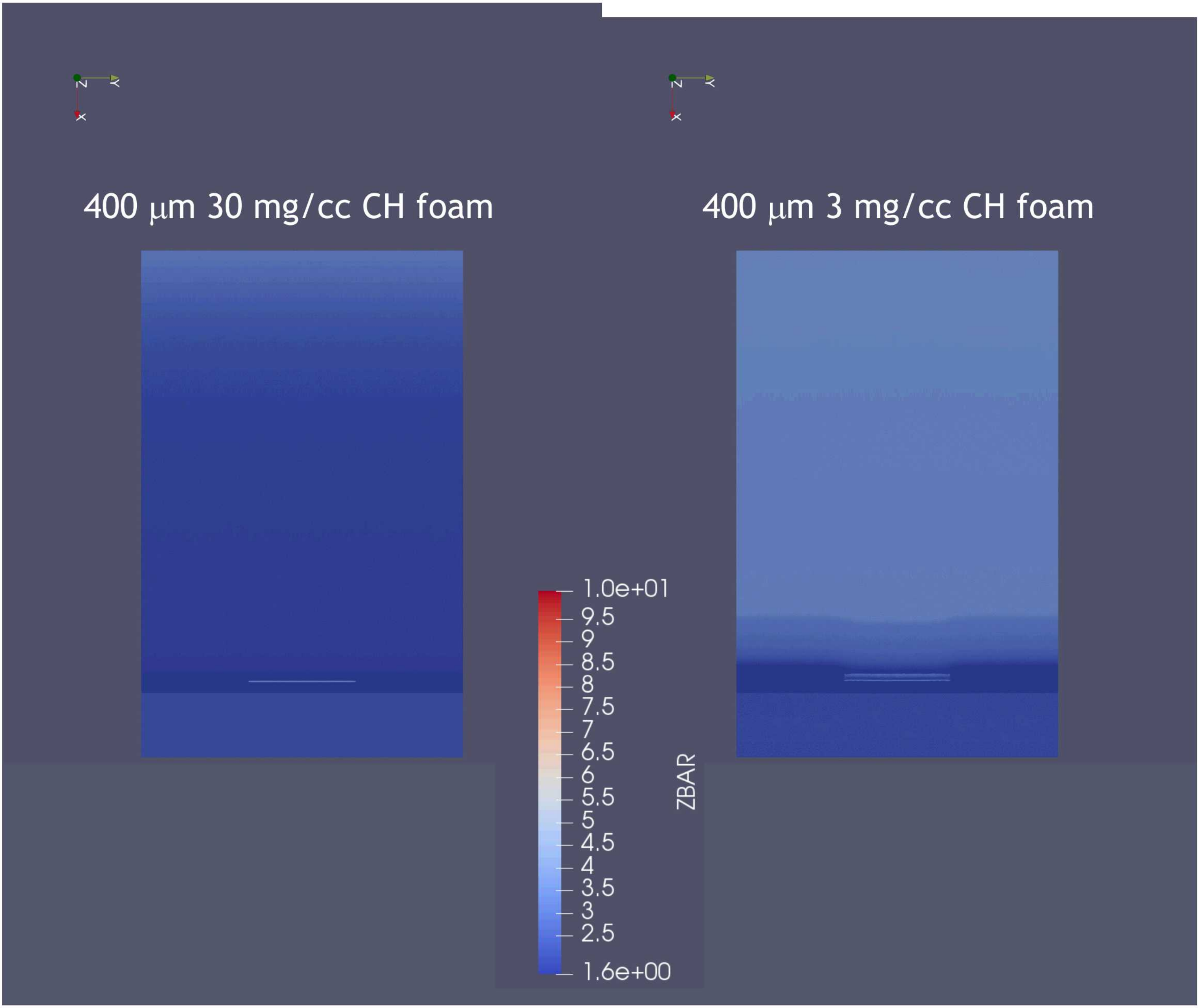
There is a clearly visible difference between the two frames

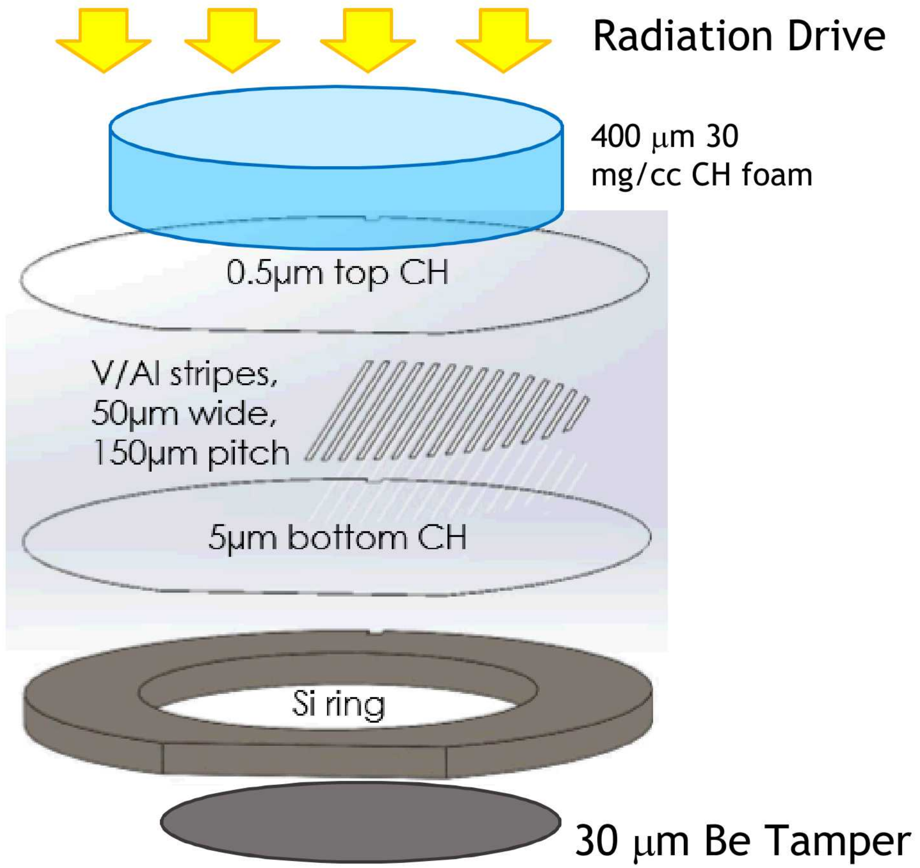
- The V strips appear to get “squeezed”
- There is a substantial absorption difference (hohlraum emission makes it difficult to assess this)
- The width of the strips is approximately correct, though the resolution is not as good as anticipated





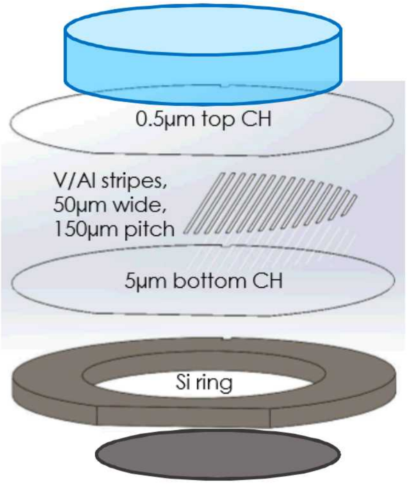
Radiation Hydrodynamics: How fast are we heating anyway?

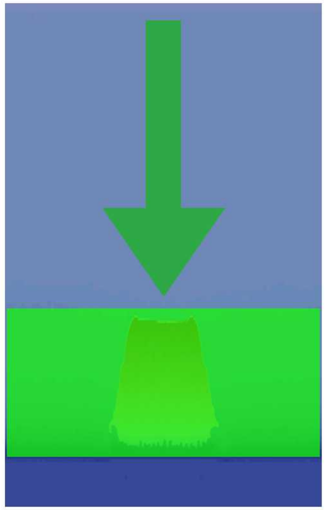




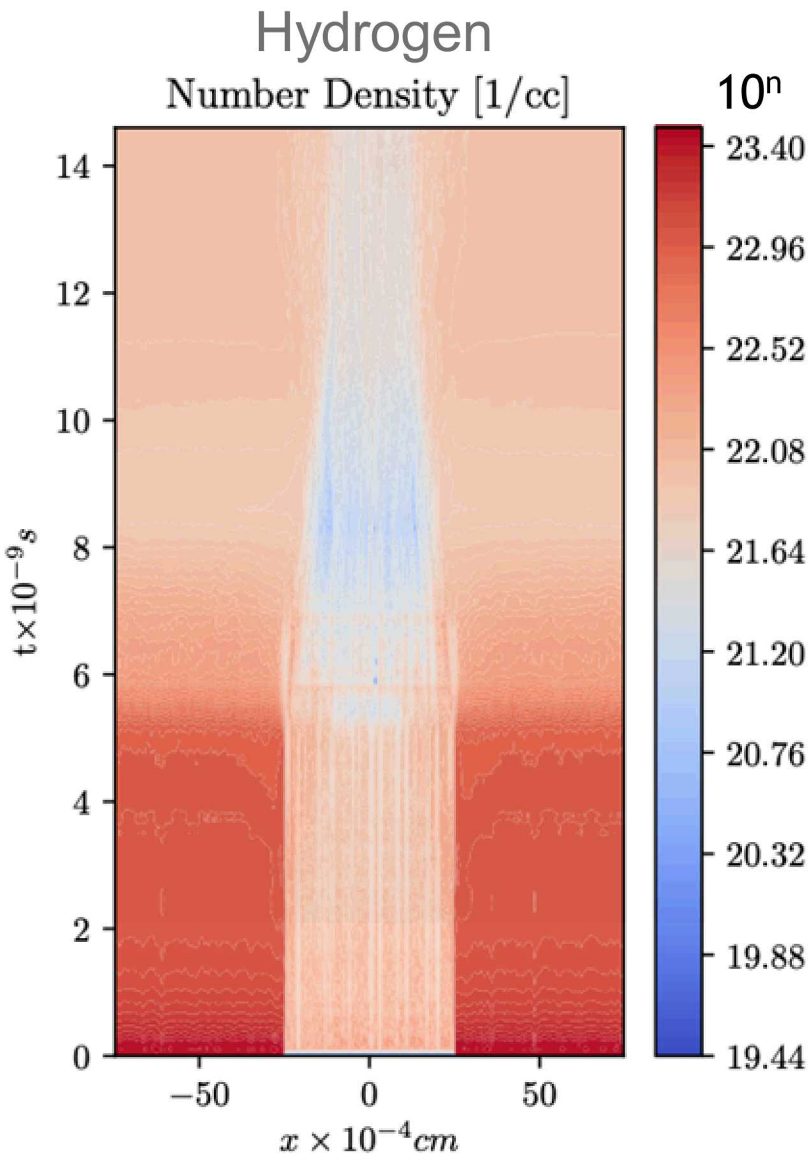
- ALEGRA Radiation hydrodynamics calculations conducted at experimental conditions reveal sensitive to CH foam properties
  - Foam optical depth at experimental densities sufficient to prevent sample from heating
  - Radiation shock at late times drives instability on sample surfaces
  - Lowering effective optical depth of foam allows sample to heat *but* exhibits significant expansion

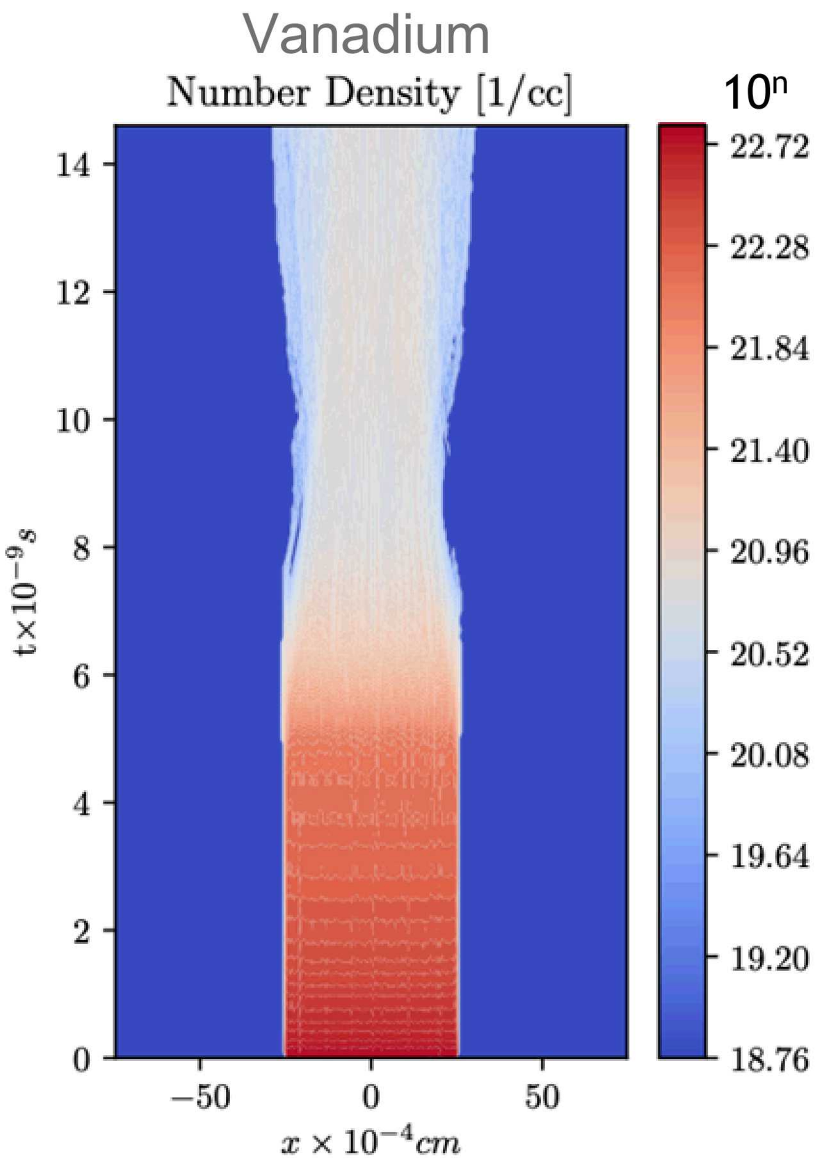
Radiation Hydrodynamics: How fast are we heating anyway?



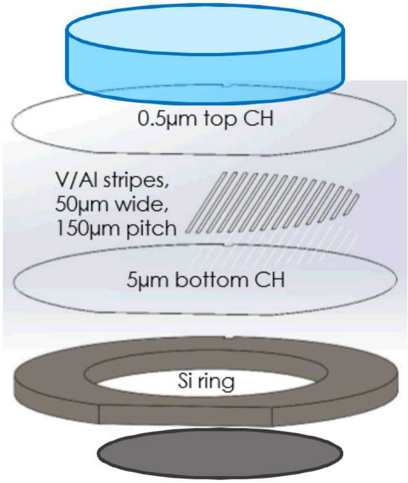


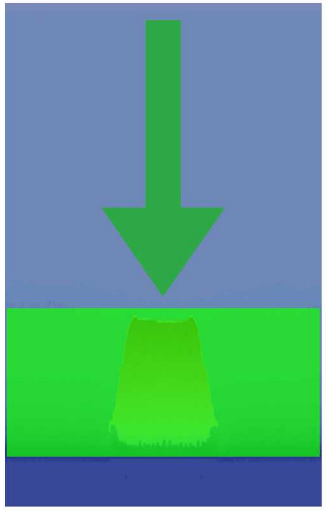
- Analyze time evolution of sample by integrating simulation along radiation path, over region adjacent to Vanadium
  - Focus attention on low density foam case
  - Plastic appears to compress Vanadium in the 8-10ns window



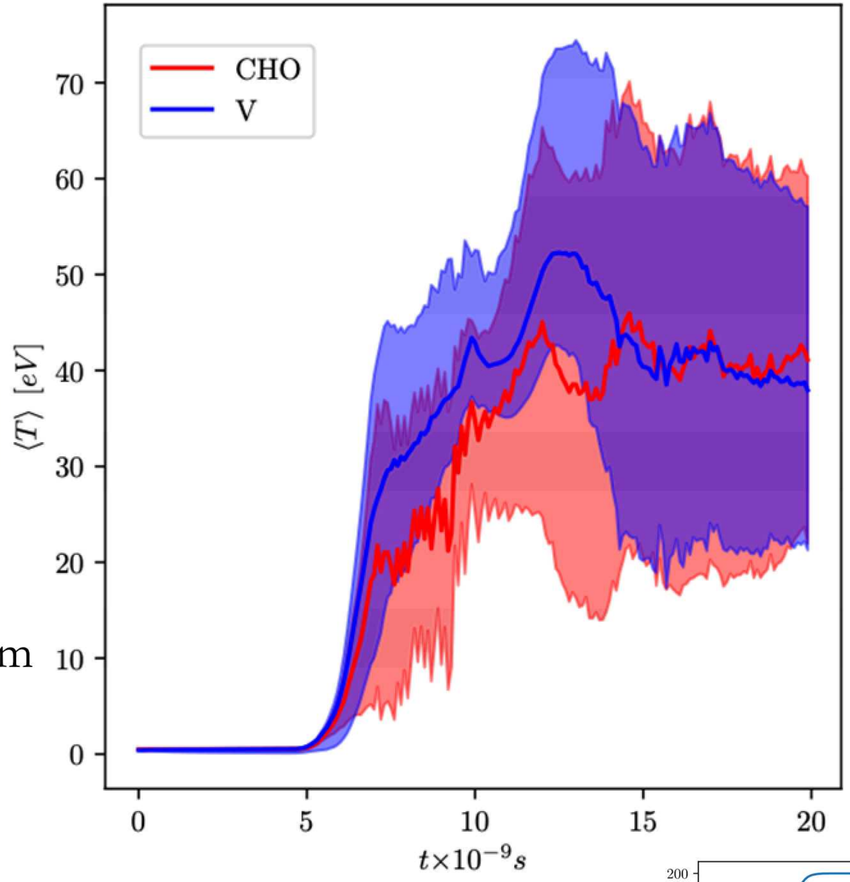


Radiation Hydrodynamics: How fast are we heating anyway?

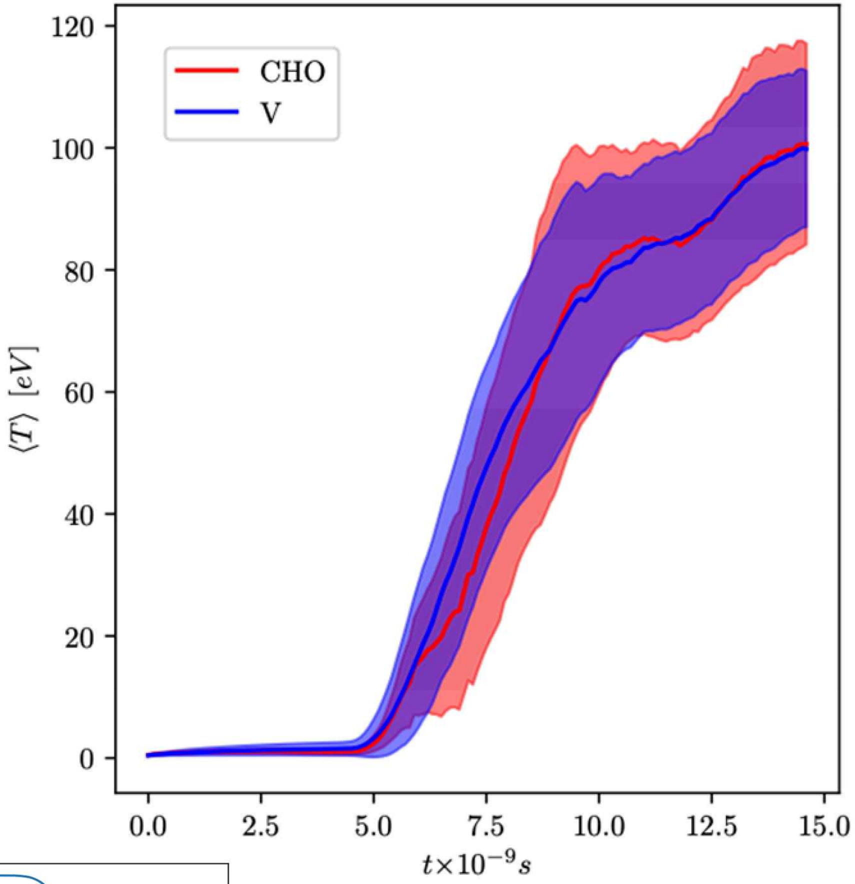


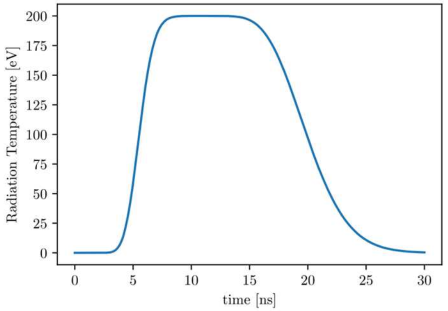


400 μm 30 mg/cc CH foam



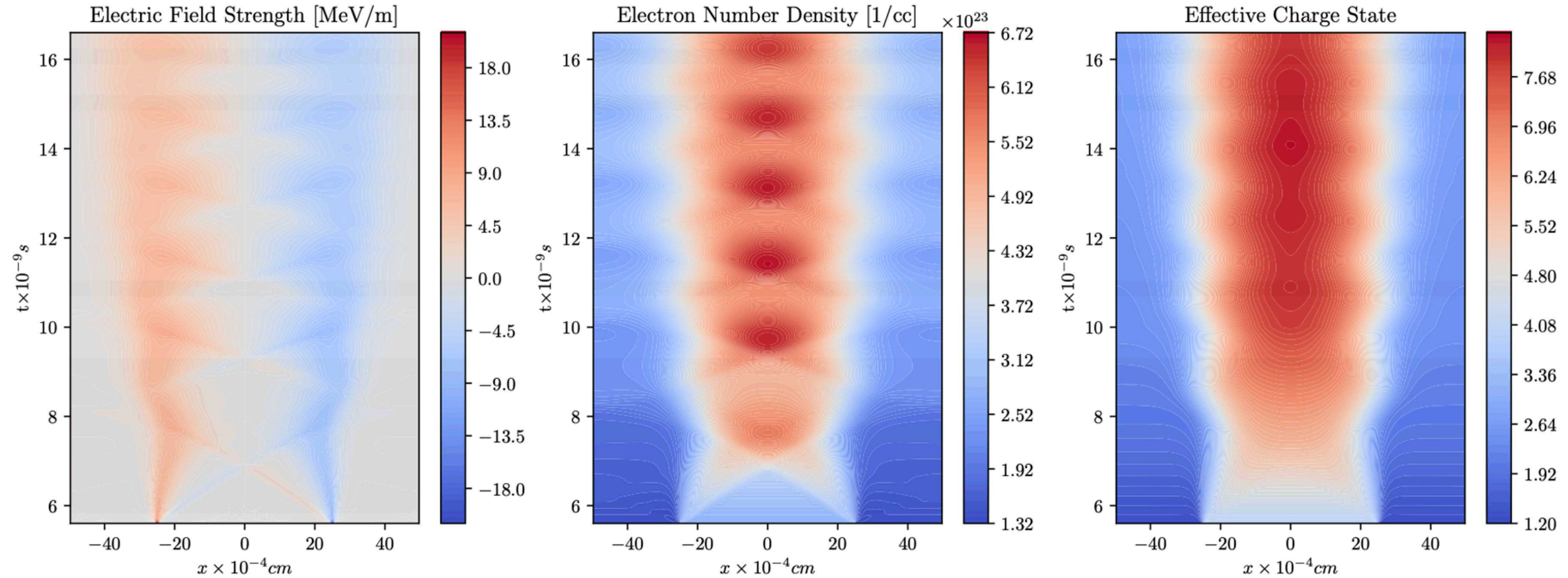
400 μm 3 mg/cc CH foam





- Analyze time evolution of sample by integrating simulation along radiation path, over region adjacent to Vanadium
  - Heating strongly dependent on effective optical depth of foam
  - Foam @30 mg/cc: V & plastic only heat to 40eV
  - Foam @3 mg/cc: V & plastic heat to 80eV by 10ns and 100eV by 15ns
  - Impacts ionization state achieved

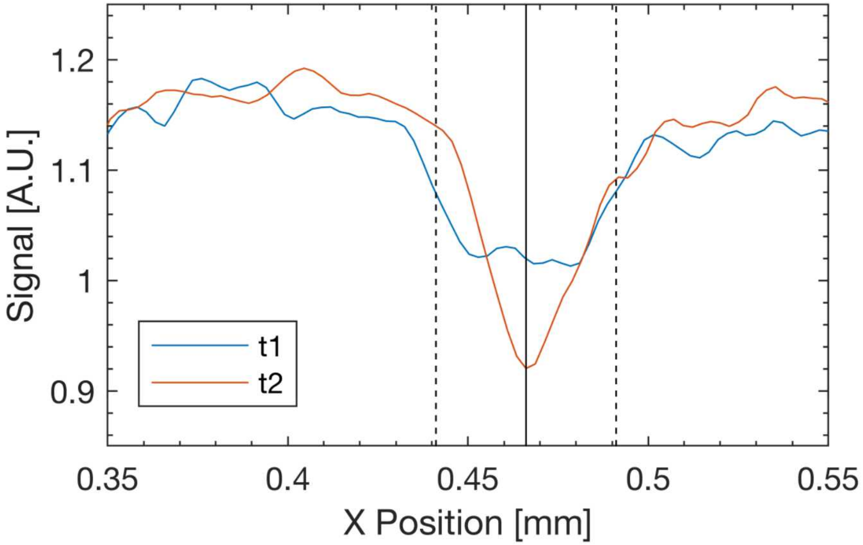
Kinetic Modeling of V/CH Interface: Electrostatic Fields



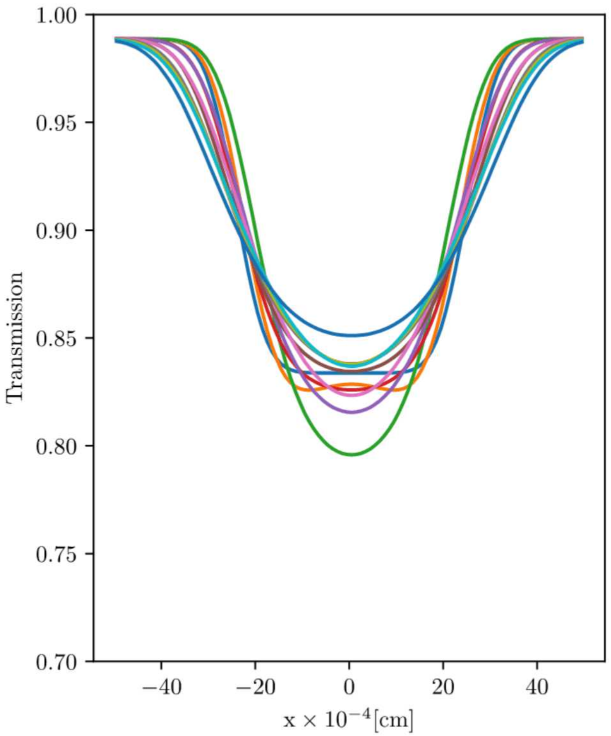
- Utilize electrostatic multi-species kinetic code to study plasma transport at CHO-V/Al interface
  - Thomas-Fermi Average Atom model for ionization state; Fermi-Dirac statistics for electrons
  - Temperature relaxation model for ion-ion collisions
- Simulation setup: V @90% solid density, 10% Al doping
  - Ions initialized at 10eV

- Electrons temperature derived from 3 mg/cc rad hydro
- Electric field & electron evolution is qualitatively the same as before:
  - Electrons remain confined within the Vanadium strip
  - Electric fields ~*9x* weaker c.f. heating to *200eV*

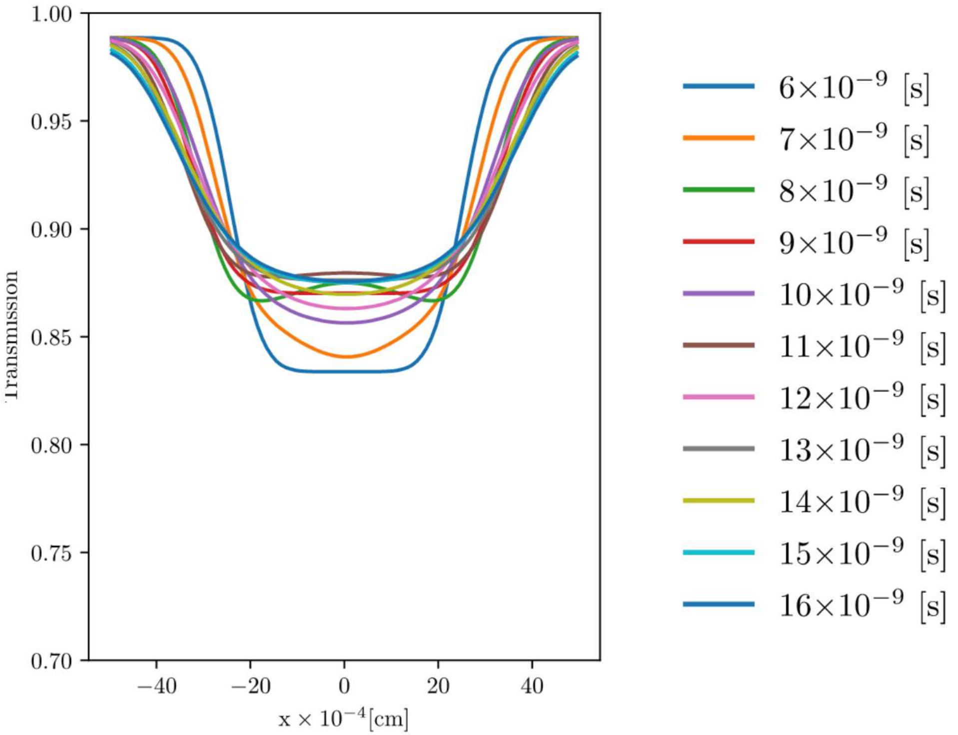
Existing radiography capability can be used to distinguish between kinetic models



Temperature Relaxation



Momentum Relaxation



- Utilize electrostatic multi-species kinetic code to study plasma transport at CHO-V/Al interface
  - Thomas-Fermi Average Atom model for ionization state; Fermi-Dirac statistics for electrons
  - Comparing Temperature and momentum relaxation model for ion-ion collisions
- Simulation setup: V @90% solid density, 10% Al doping
  - Ions initialized at 10eV

- Electrons temperature derived from 3 mg/cc rad hydro
- Synthetic radiography:
  - In temp. relaxation case Transmission profile deepens and narrows prior to 8 ns, then widens
  - In mom. Relaxation case, the profile always widens

Questions that emerged during the experiment/modelling process:

- How is the sample really heated? How does radiation propagate through the tamper to heat up the sample?
- How does the vanadium layer evolve in the transverse direction (i.e. into the tamper). We don't want to do a foam experiment.

These are open questions that prevent a direct assessment of transport models.

Experimental Plan

October 2020

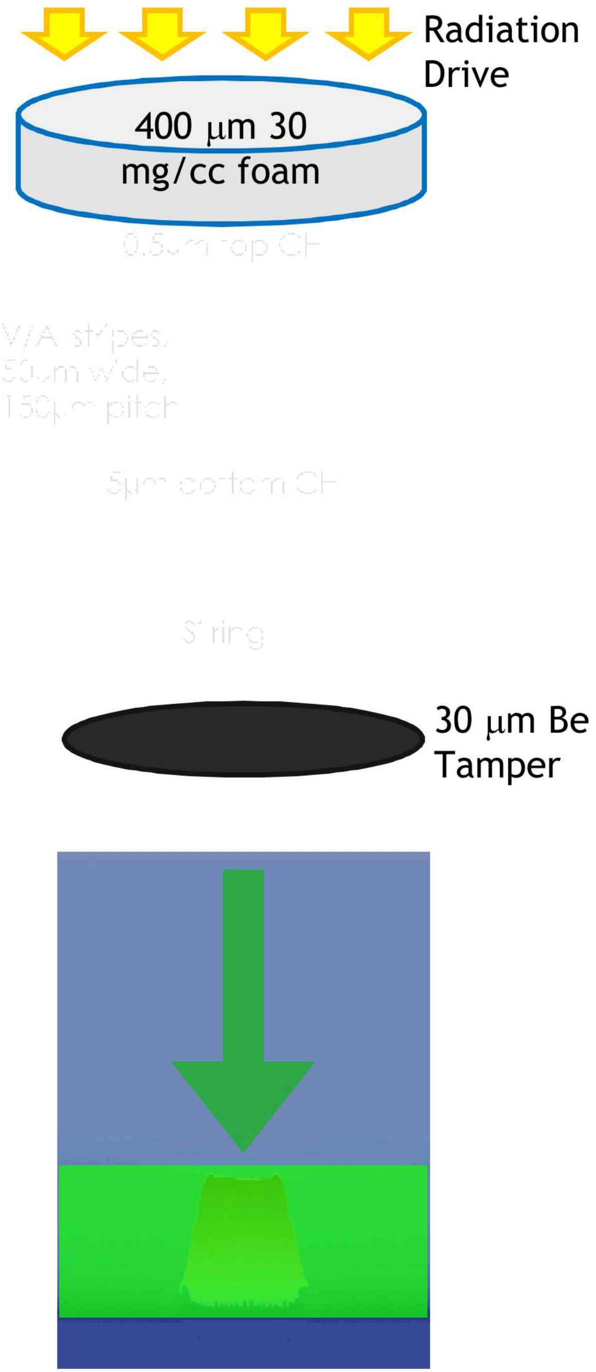
- 2 shots to test out a new harder X-ray source. The goal is to promote more volumetric heating and to avoid potential radiation driven shocks.

Quarter 1 2021

- 2 shots to quantify sample/tamper dynamics. Edge-on shots to watch expansion of vanadium in the transverse direction.

Quarter 3 2021

- 2 shots with optimized target design.



Conclusions

- The Z-machine plasma transport platform is a unique experimental capability allowing a direct assessment of transport models.
- The differences in synthetic radiography produced by different transport models is large enough to be distinguished based on already demonstrated experimental resolution.
- The upcoming shot campaign should eliminate known sources of uncertainty, and allow the clearest test of HED transport models to date.

For more information on work to validate the physics going into the Boltzmann-BGK transport equations, see Luke Stanek’s upcoming talk.