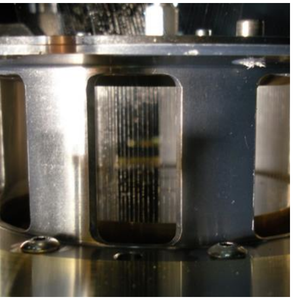

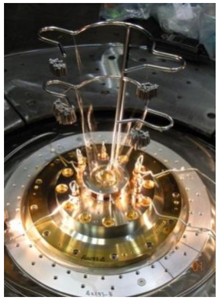

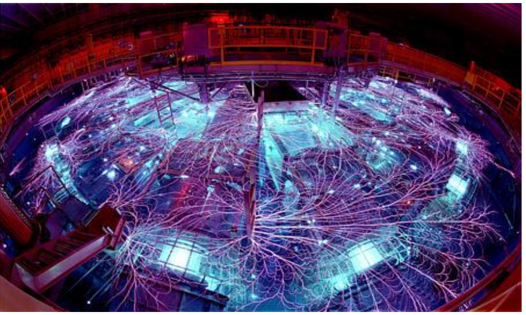

SAND2014-19457PE

THREE DIMENSIONAL MODELING OF MAGLIF LOADS ON THE Z GENERATOR USING THE GORGON MHD CODE

C.A. Jennings, M.R. Gomez, S.B. Hansen, E.C. Harding, R.D. McBride, D.B. Sinars, T.J. Awe, S.A. Slutz, A.B. Sefkow, K. Peterson

Sandia National Laboratories, Albuquerque, NM, USA

J.P. Chittenden

Blackett Laboratory, Imperial College, London, UK

Sandia National Laboratories

Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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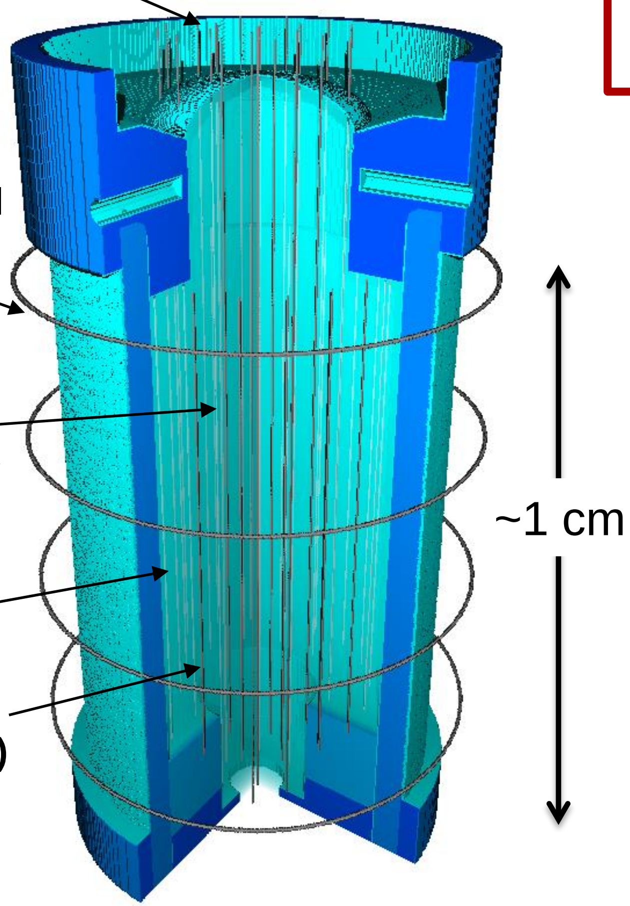
We are working toward the evaluation of a new Magnetized Liner Inertial Fusion (MagLIF)* concept



Be Liner AR6
(4.65mm-5.58mm diameters)

Integrated experiments have been performed (Matt Gomez) producing 1e12 – 2e12 neutrons

- An initial ~10 T axial magnetic field applied
- Laser preheat applied when inner surface starts to move
  - ~400J Pre-pulse to disassemble window followed by ~2kJ main pulse
  - Likely that poor coupling of laser energy is presently limiting performance (A. Sefkow APS 2014 invited)
- Implosion instabilities have the potential to disrupt fuel compression and confinement
  - Have been heavily diagnosed in stand alone experiments

*S.A. Slutz *et al.*, Phys. Plasmas 17, 056303 (2010). S.A. Slutz and R.A. Vesey, Phys. Rev. Lett. (2012).

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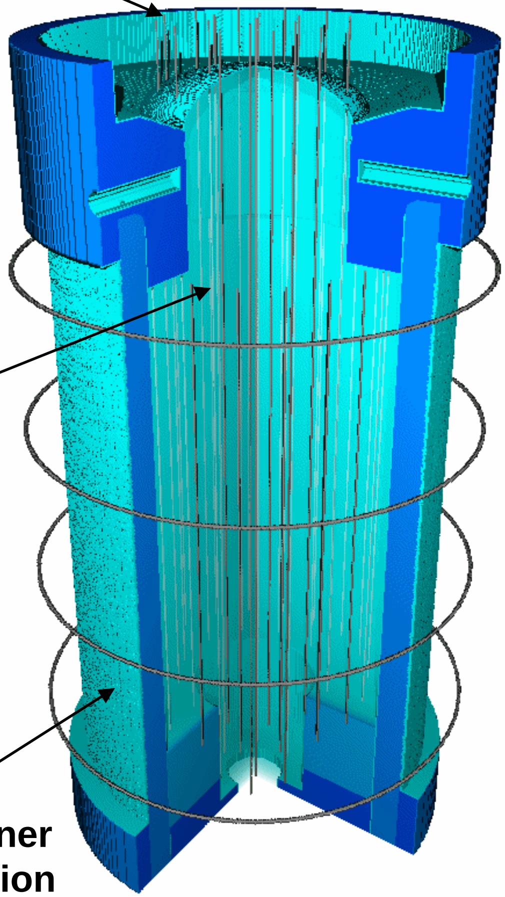

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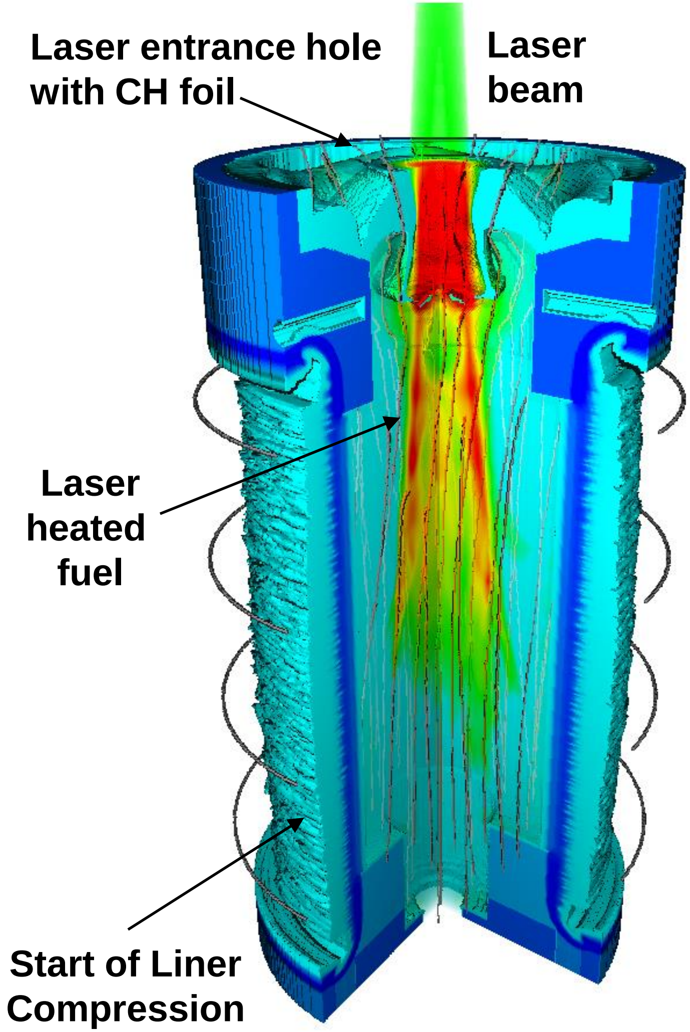

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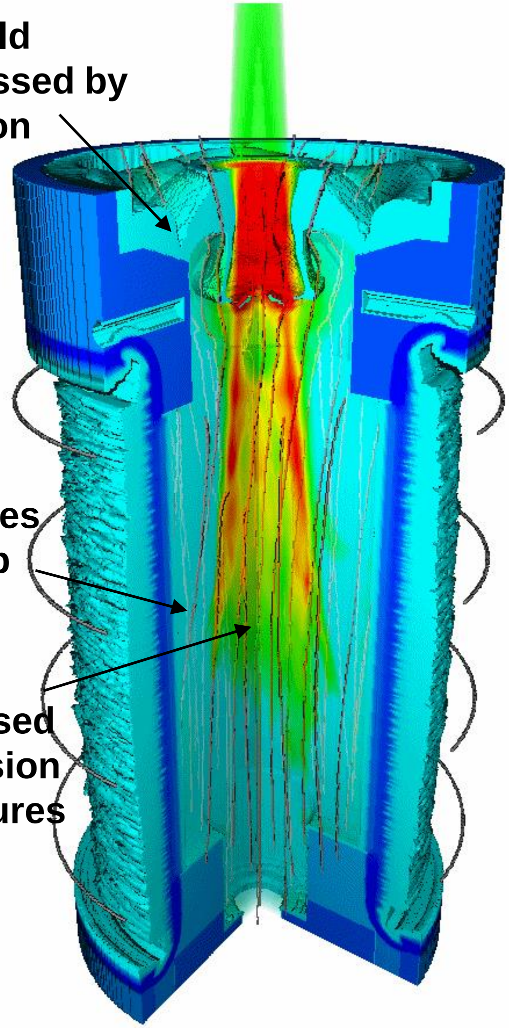

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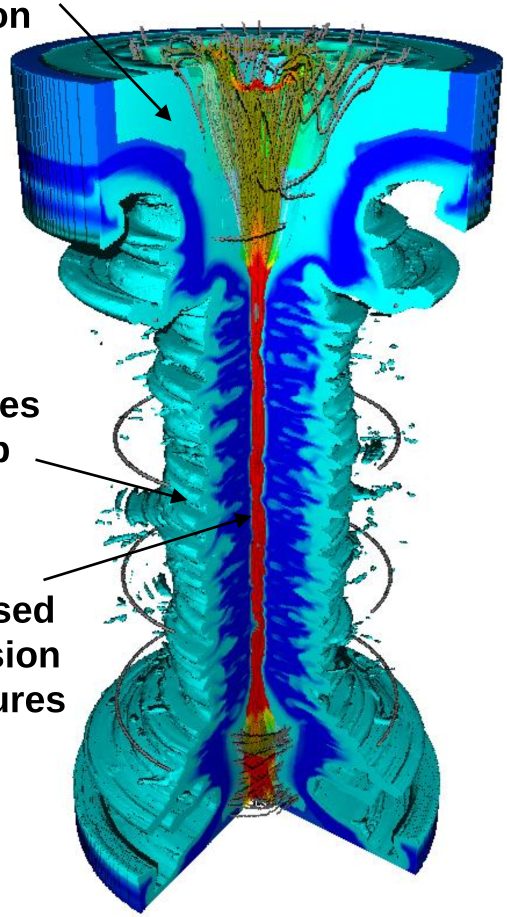

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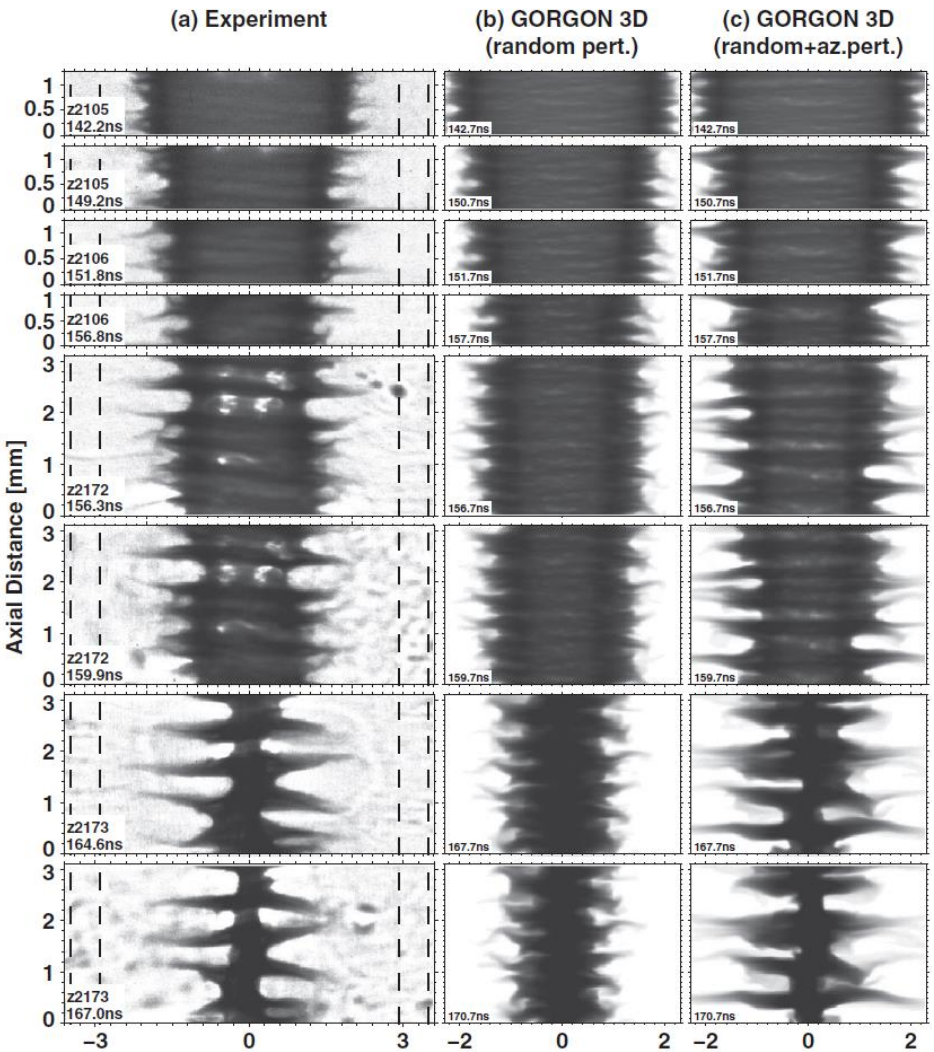
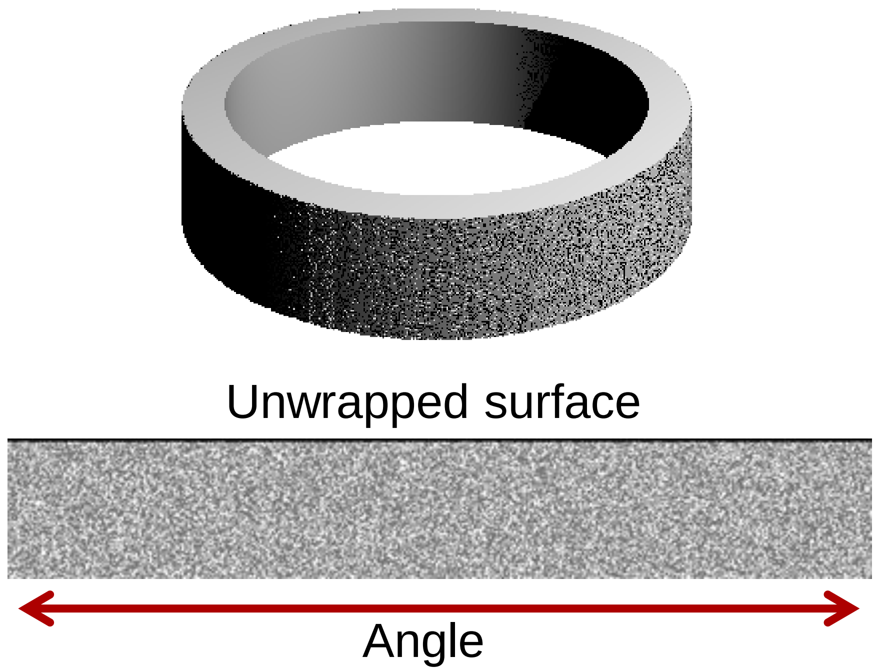
Previous work to reproduce instability structure observed during implosion required an imposed azimuthal correlation



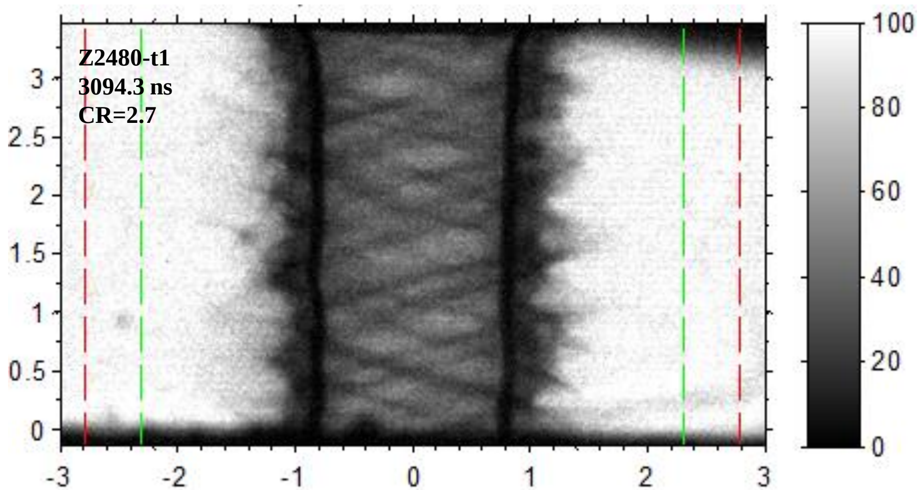
Data from Ryan McBride (PRL)

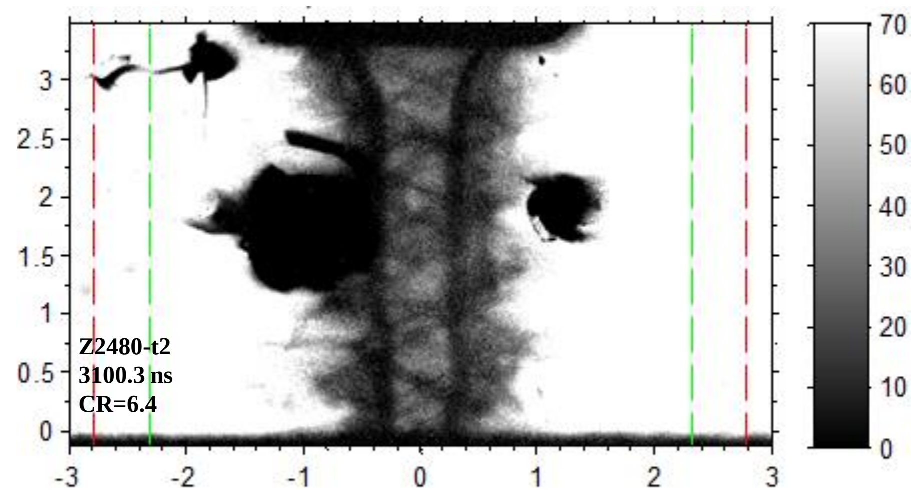
To match radiography data required imposing some azimuthally correlated component to a random 20 micron surface roughness.



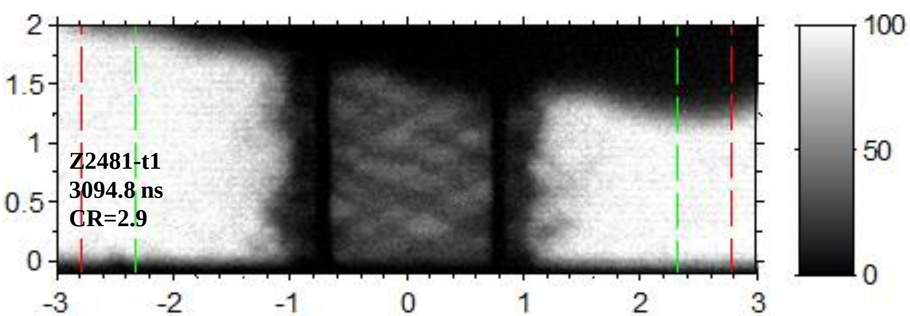
Tom Awe experiments imposed an axial magnetic field (~10T)

Helical structures were clearly observed to develop in the imploding liners





Z 2480 (7T applied Bz field)



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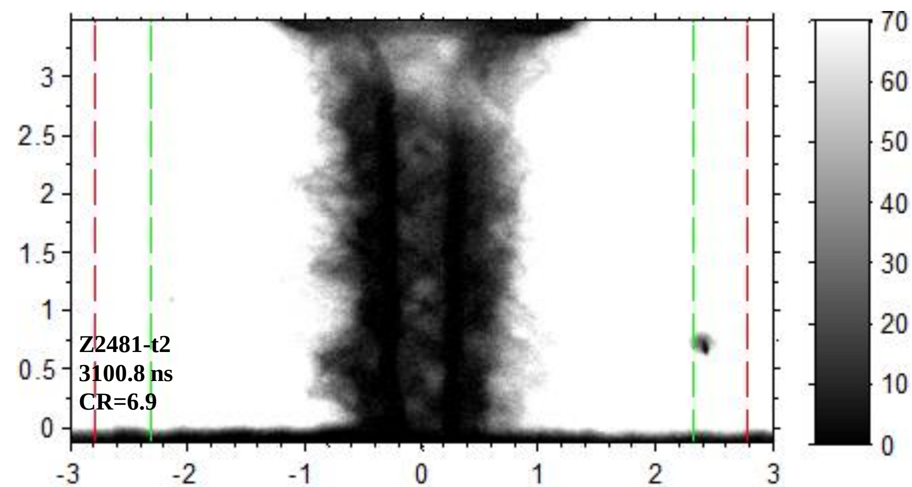
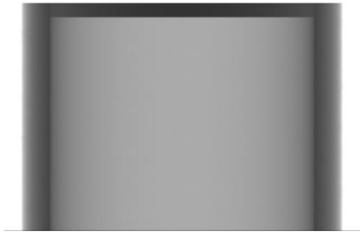
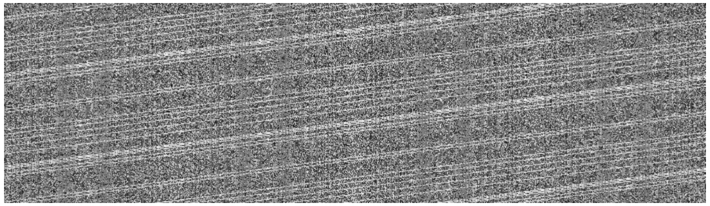


We can impose helical perturbation as a small amplitude initial surface perturbation

Initial Conditions

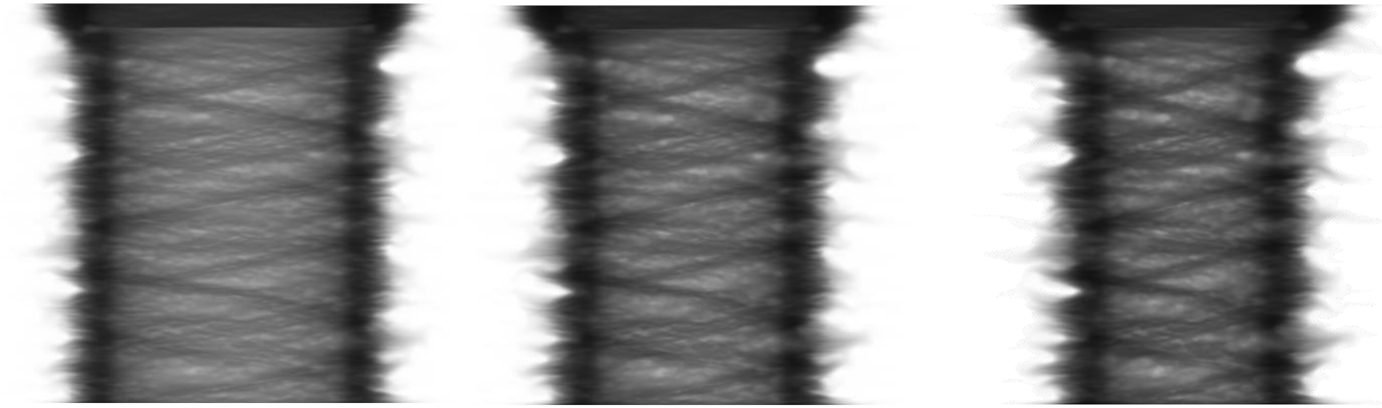




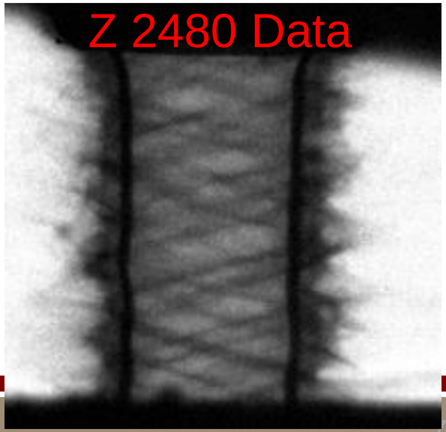
7.2 degree helix etched onto liner surface at 20 micron grid resolution

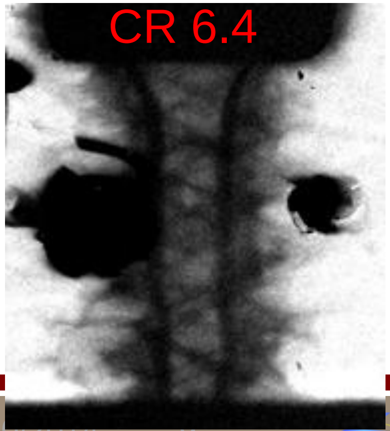
Density slice

Convergence of 6.4



Simulated Radiographs

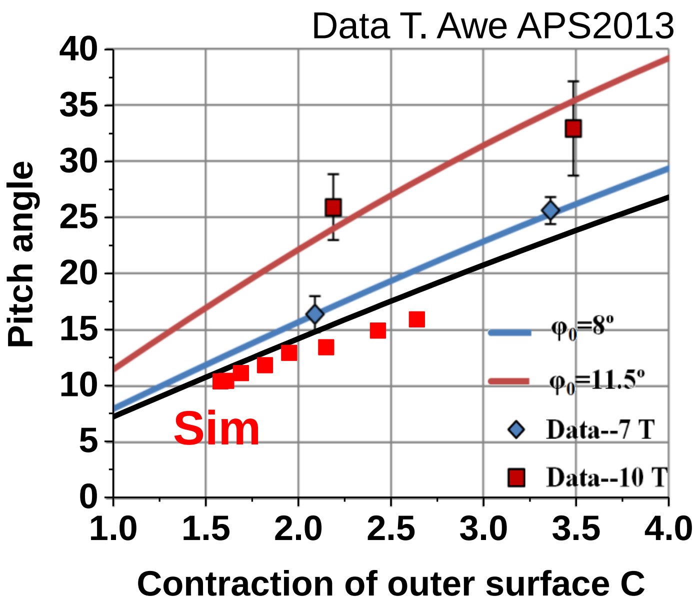




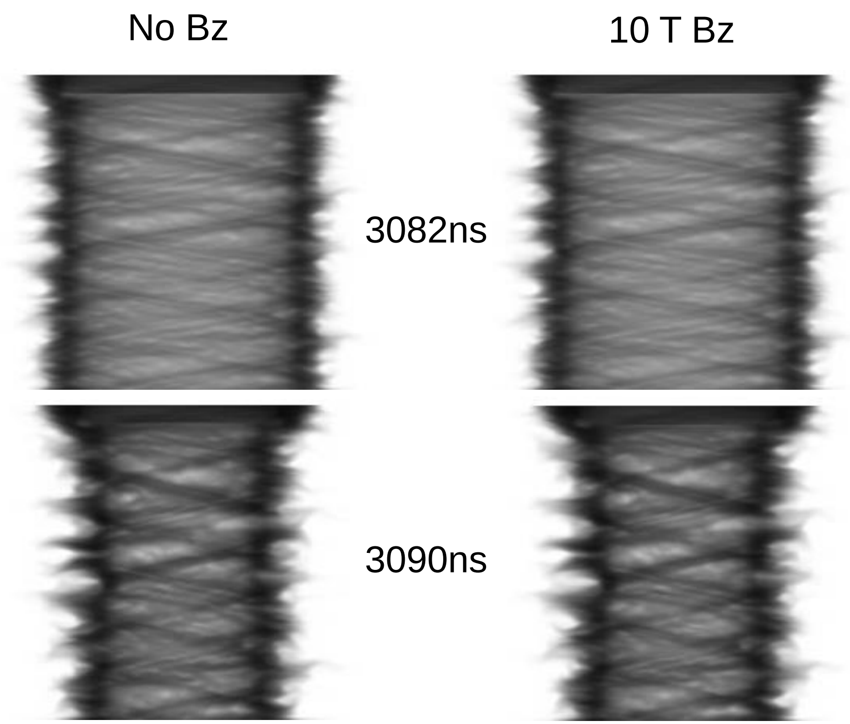
- Helical structure grows enough to be retained in radiographs during implosion.
- These calculations did not include initial 10T Bz field. It is not required for initial perturbation to persist

Observed helical structure consistent with evolution of an initial surface perturbation.

Evolution of Pitch Angle



Changes in pitch angle are consistent with contraction of a helical structure in simulation and experiment.



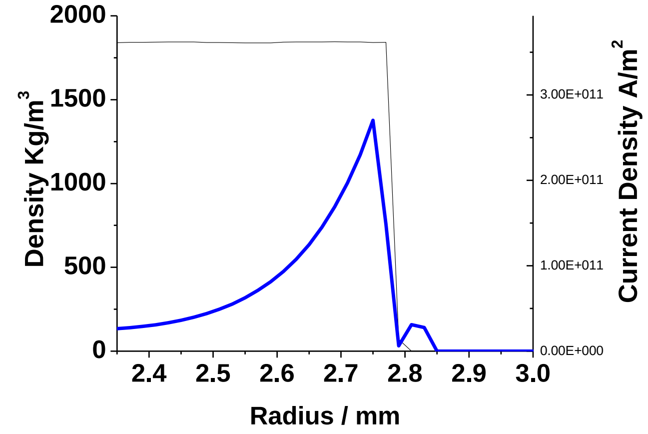
Bz field helps set the initial conditions, but beyond that it is not dynamically significant

Perturbation structure imprinted at very early time

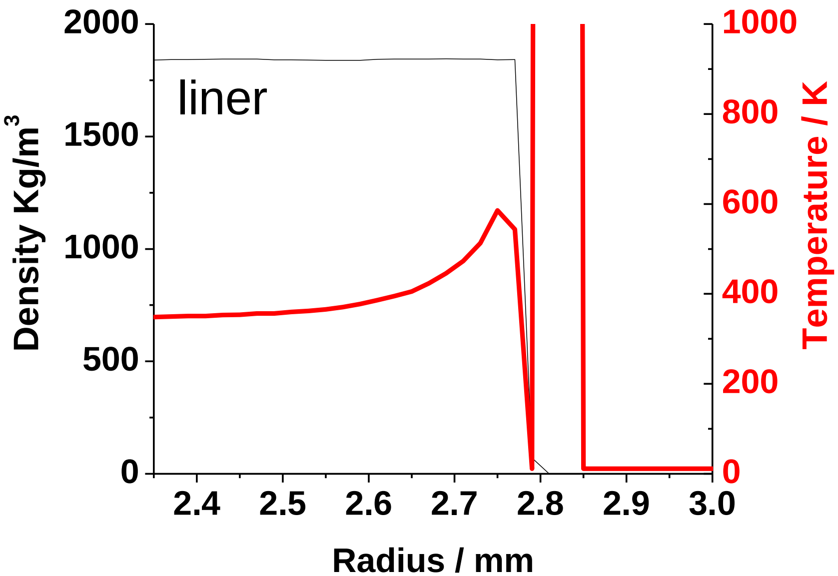
Pitch angle does tell us the field magnitude at which the correlation gets imprinted. For 7 T Bz field, assuming the 7.2 degree angle used in simulation magnitude of field ~56T

Profiles at which outer B at edge of liner reaches this point:

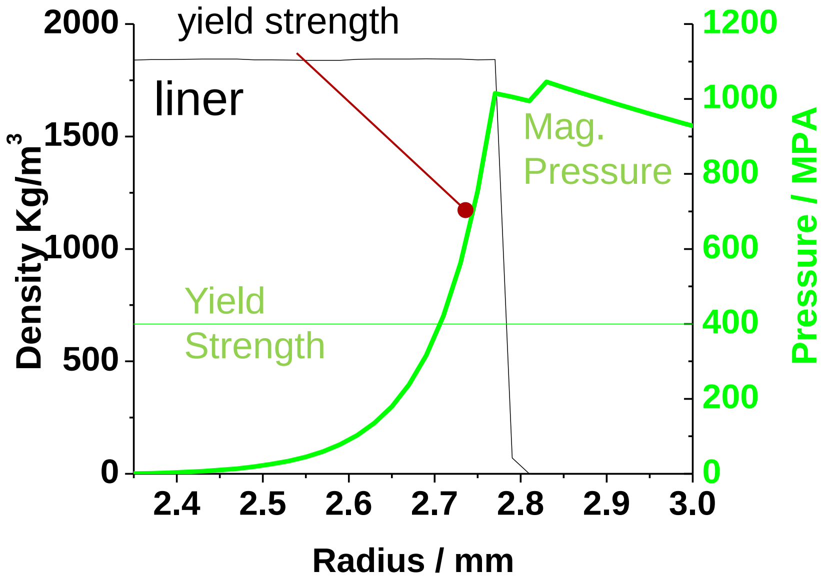
Current is flowing predominantly in liner surface



Temperature is low within liner (below melt)



Pressure at peak jxB force comparable to yield strength

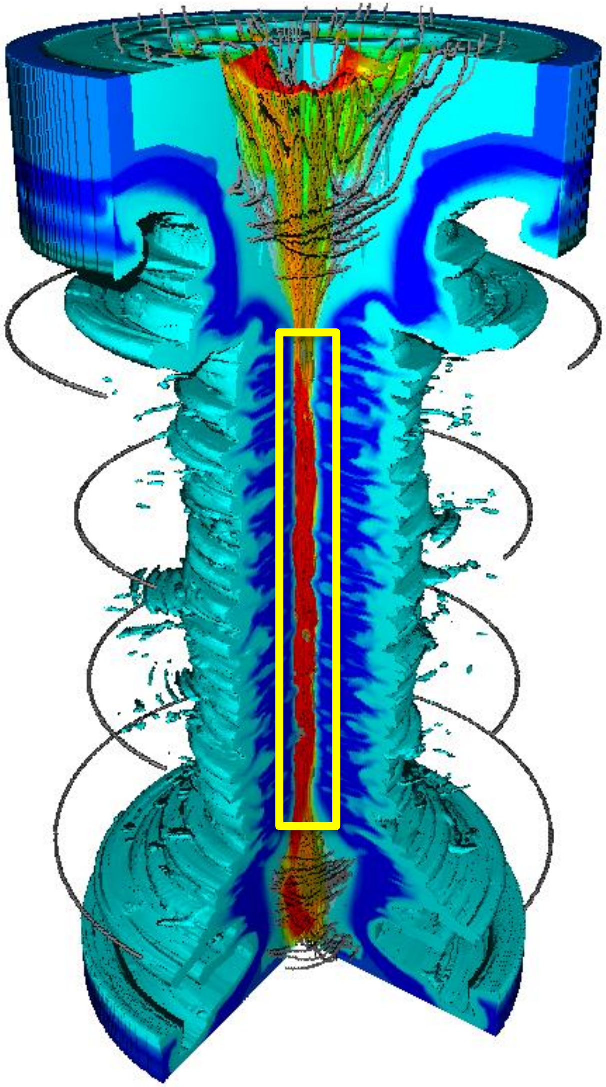


Final Pinch Structure Measured with Time Integrated Self-emission

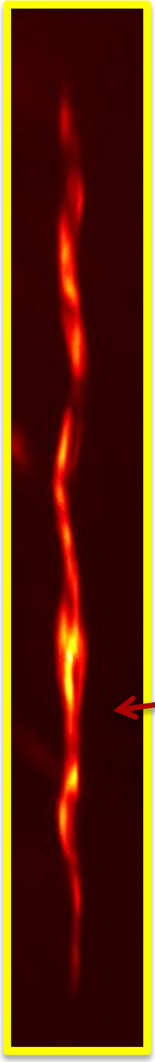
Integrated Experiments performed by M. Gomez.

DD fuel
+
Laser Preheat
+
Applied Bz

Generated ~10^{12} neutrons



Z2613



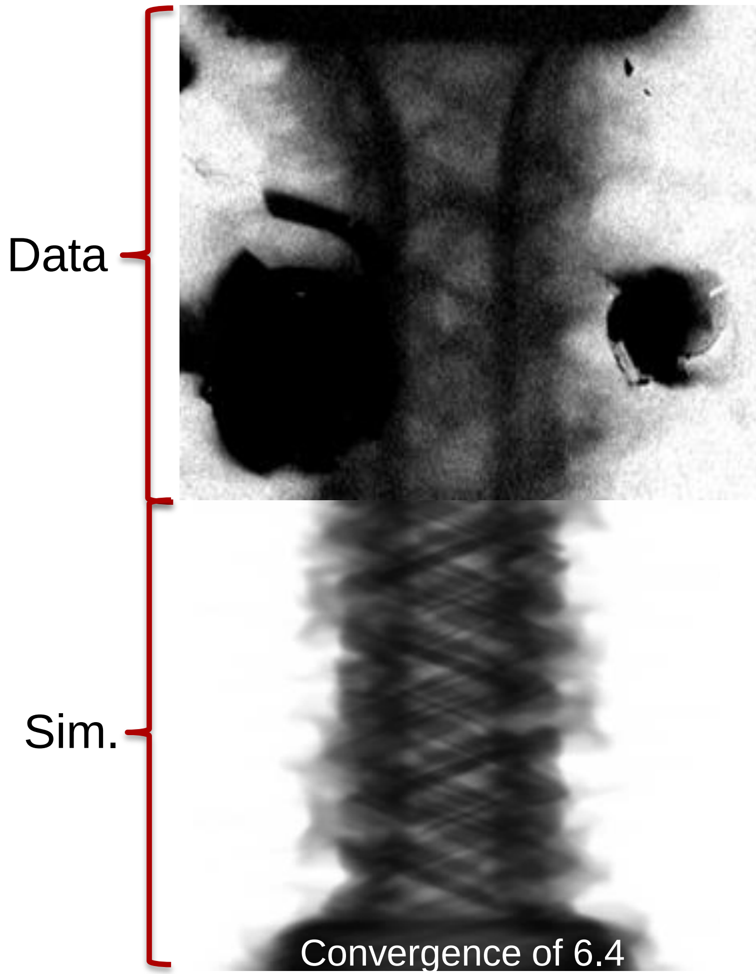
Eric Harding fielded a crystal imager, recording time integrated self emission from the assembled pinch.

Apparent helical structure

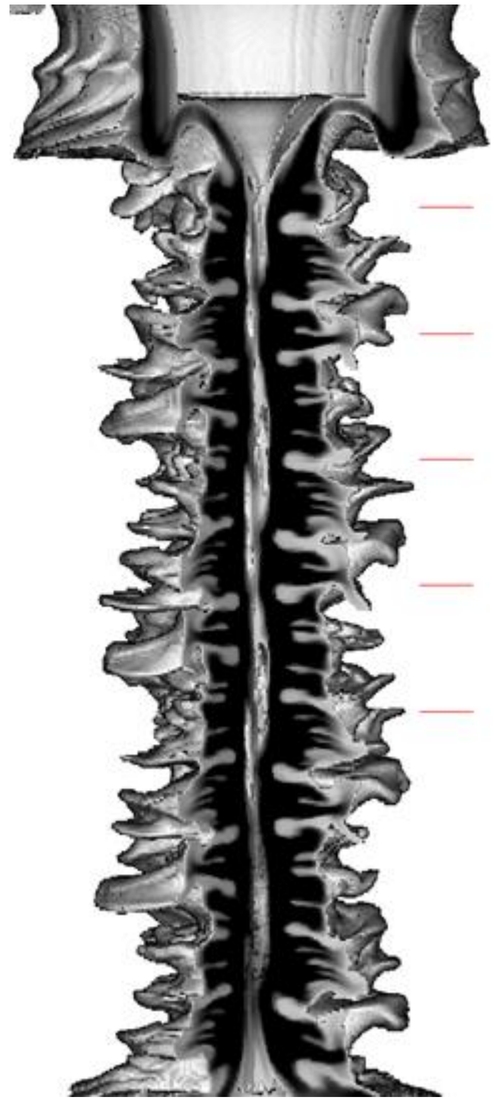
Axial variations in emission observed.

Output self emission from integrated calculation driven with helical perturbation

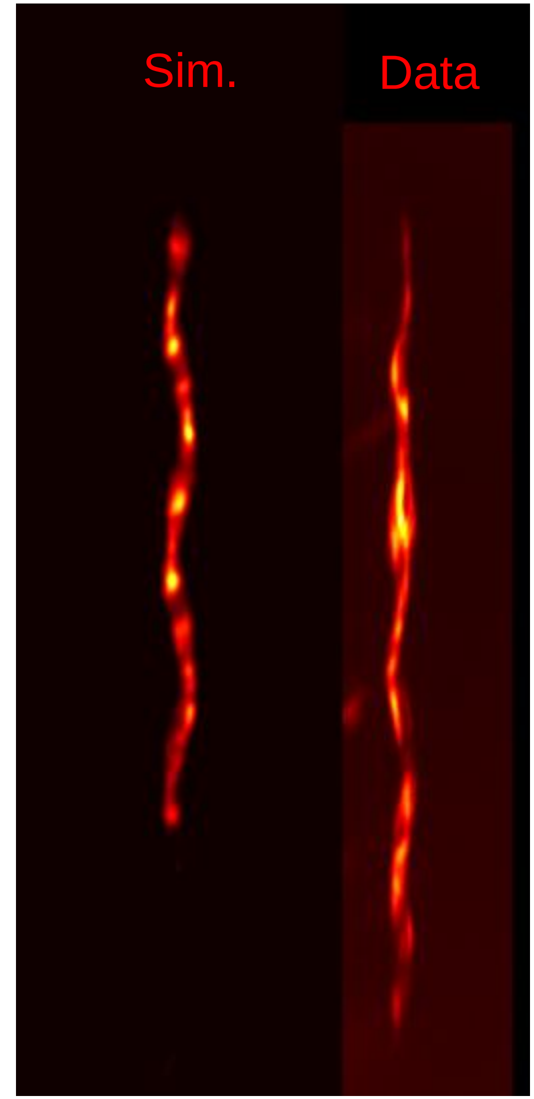
Follow match to radiography through to stagnation →



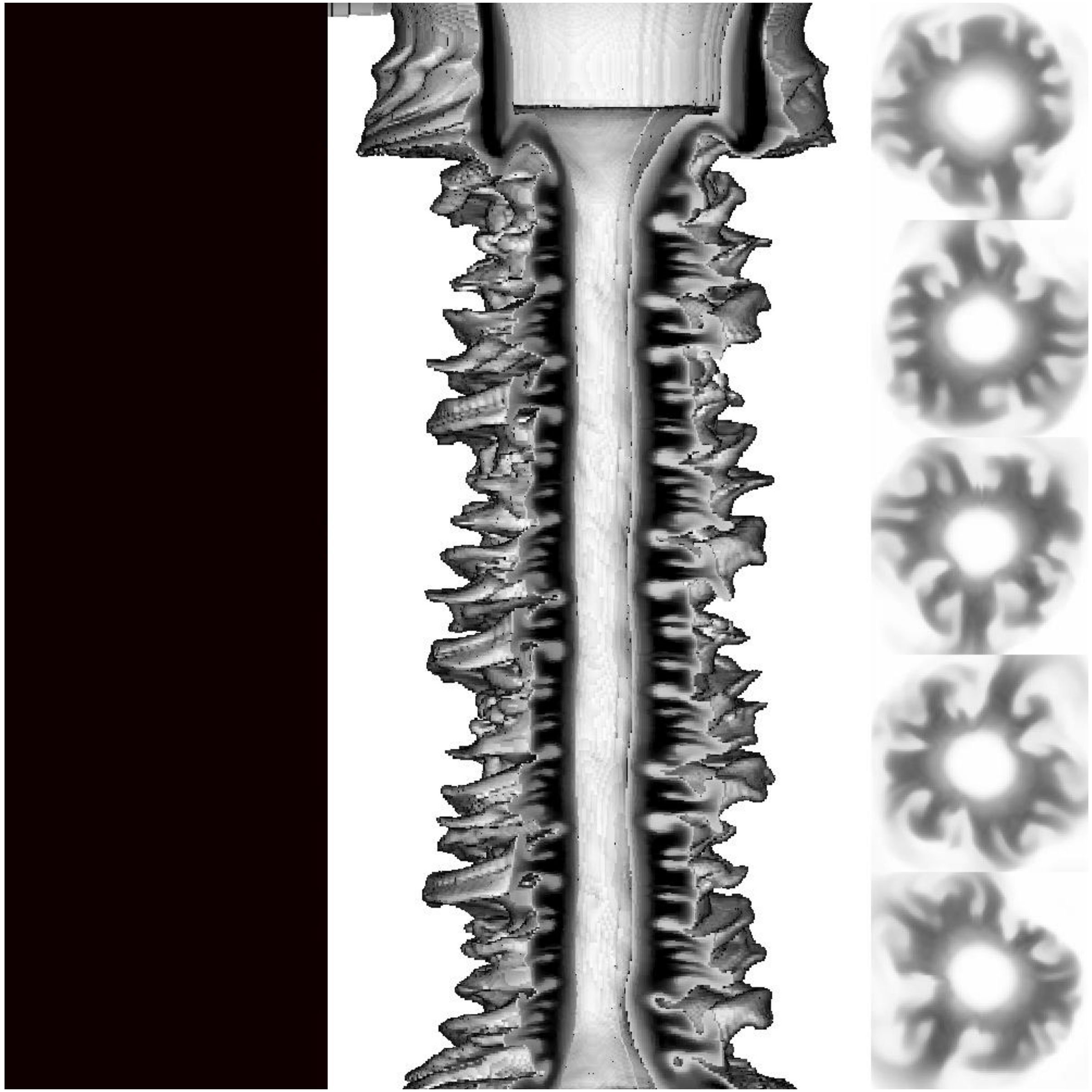
Density at Stagnation



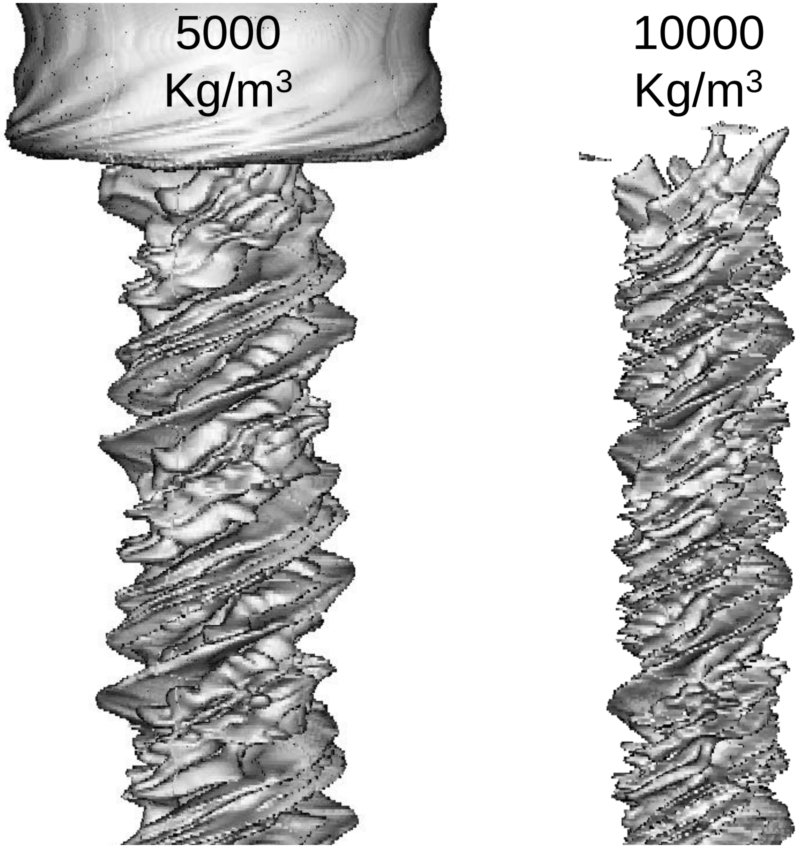
Crystal Imaging 3+6keV

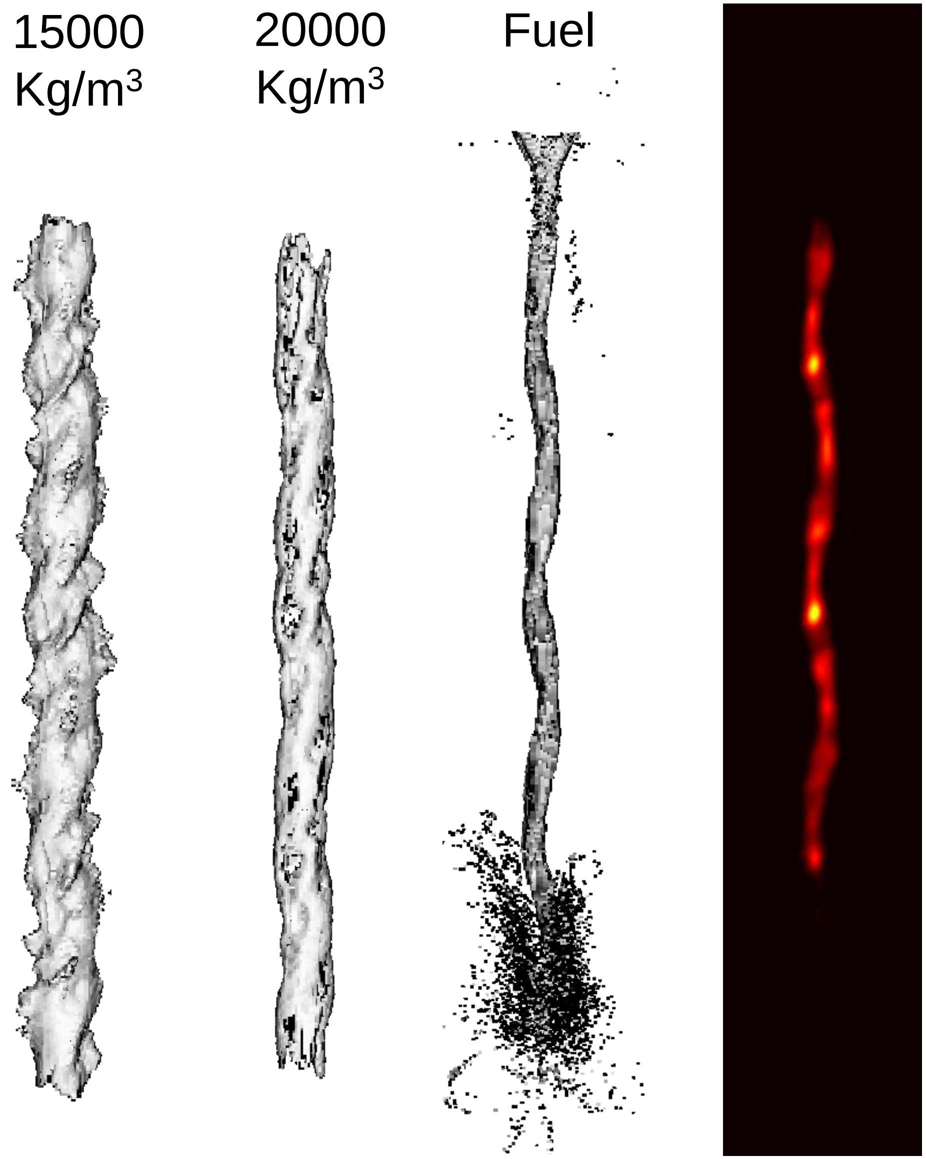


Helical structure in emission is not the result of post stagnation m=1



Helical structure is feeding through from the outer surface

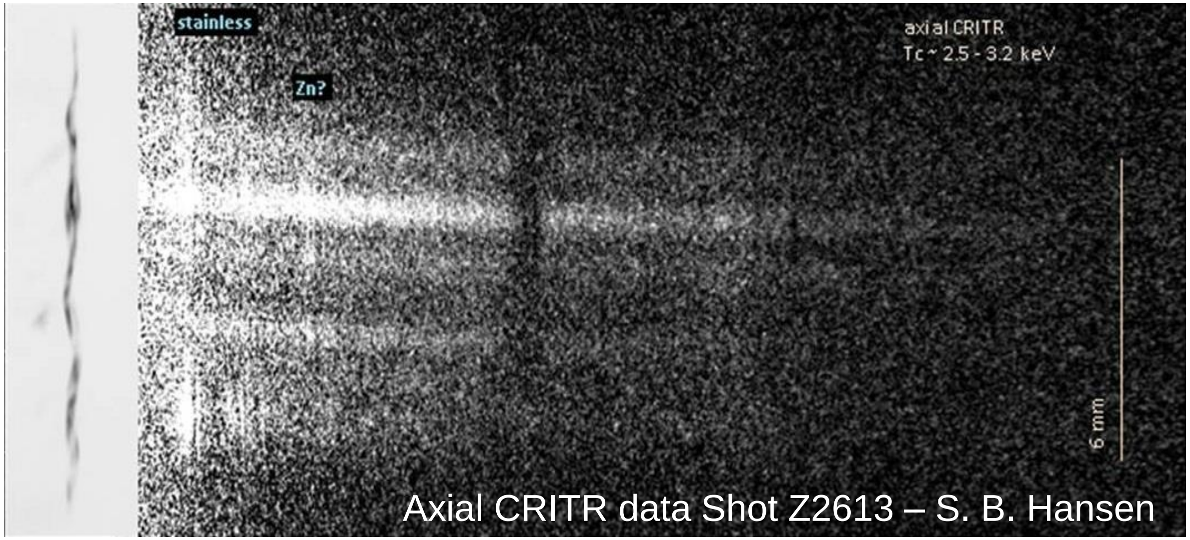


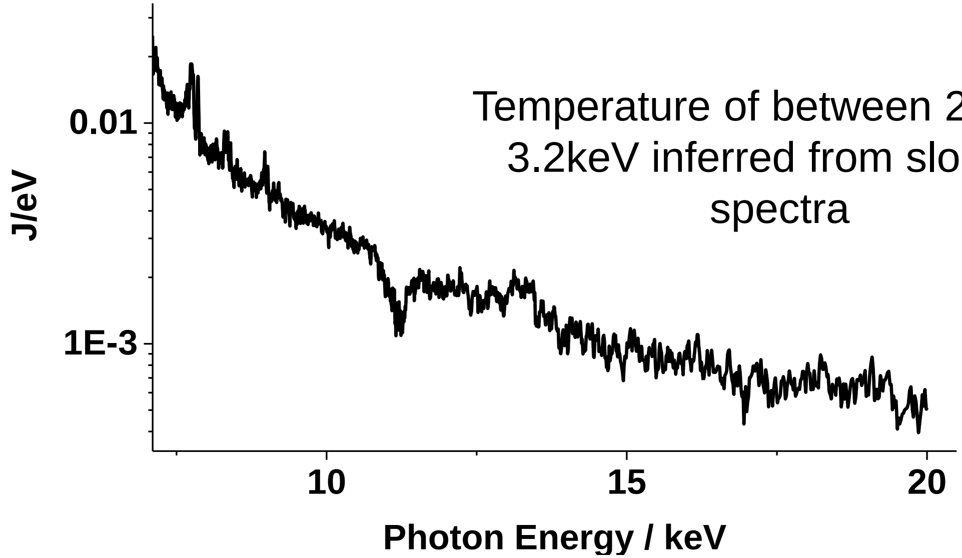


Different density surfaces 0.3ns before peak neutron.
Instability structure is feeding through from outer surface. This helix was imposed as a liner surface condition.

To better understand axial temperature variations we can appeal to the CRITR axially resolved time integrated spectrometer

Time integrated Imager

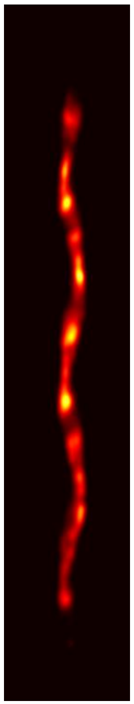




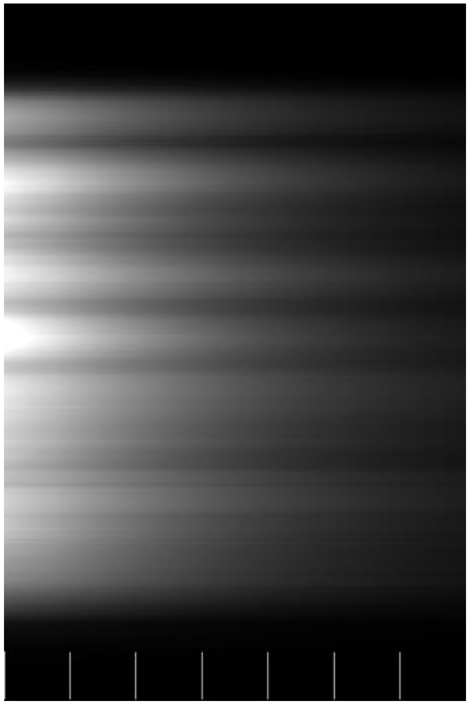
Temperature of between 2.5 and 3.2keV inferred from slope in spectra

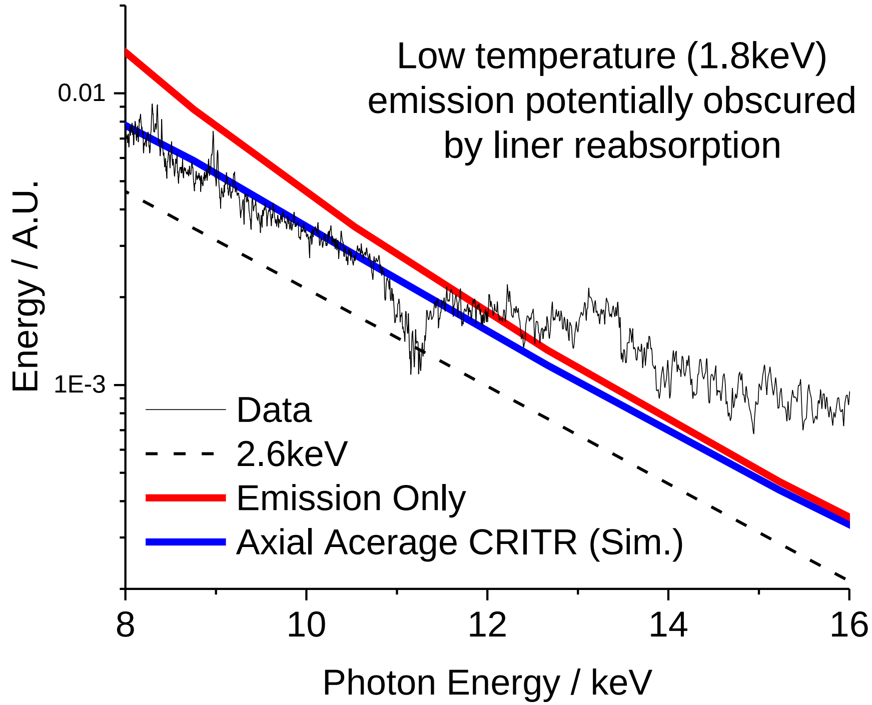
Temperature measurement from CRITR potentially influenced by reabsorption from the dense liner material

Ar Imager



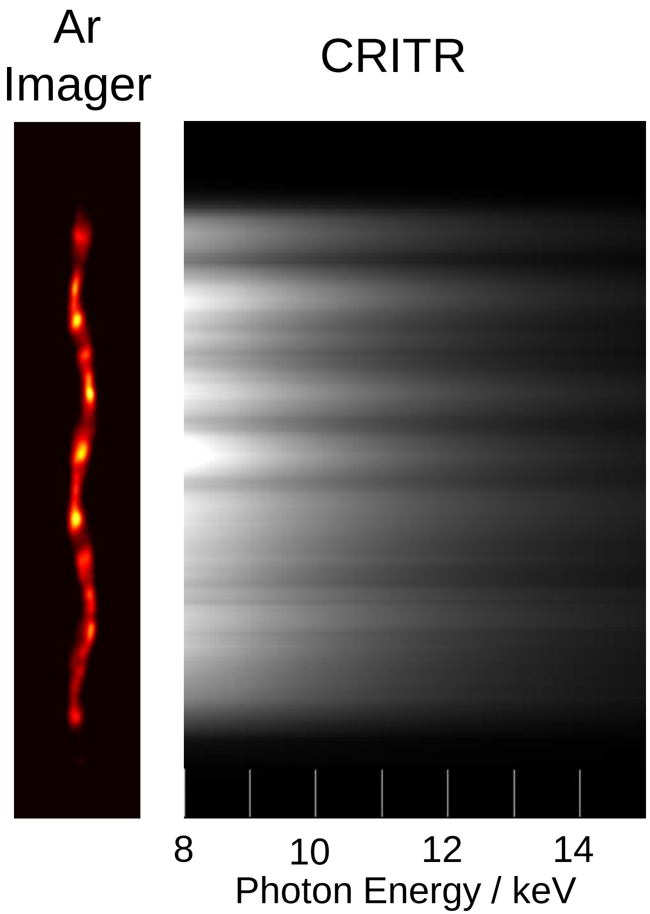
CRITR

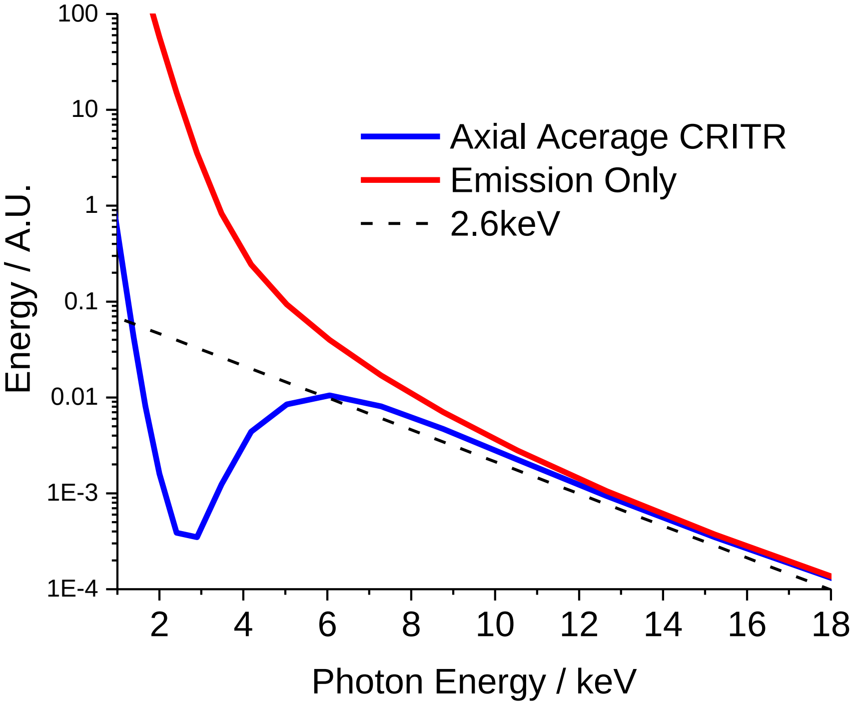




Ar imager reconstruction includes 3 and 6 keV emission.
CRITR reconstruction in range 8 – 15keV, with 400 micron geometric broadening from slit.
Simulated CRITR ~ 2.6keV.
On the low side. Although this calculation is under-resolved (20micron grid)

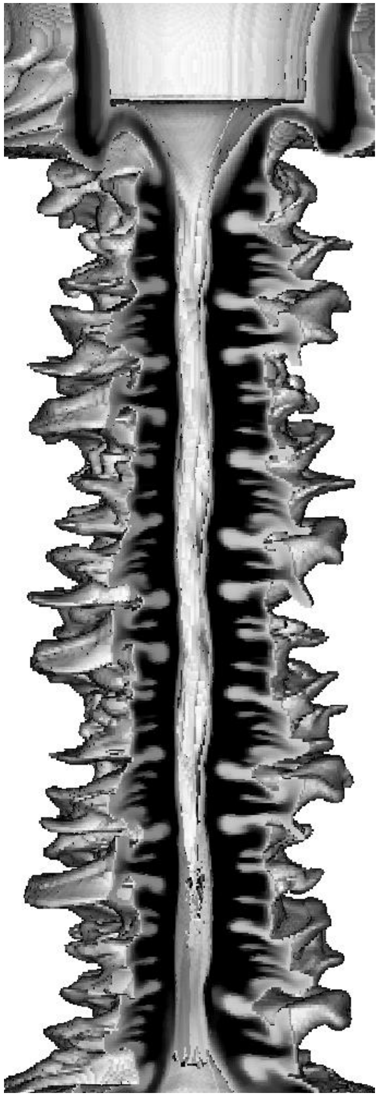
Expanding Photon Energy Range, the liner absorption is significant at lower photon energies

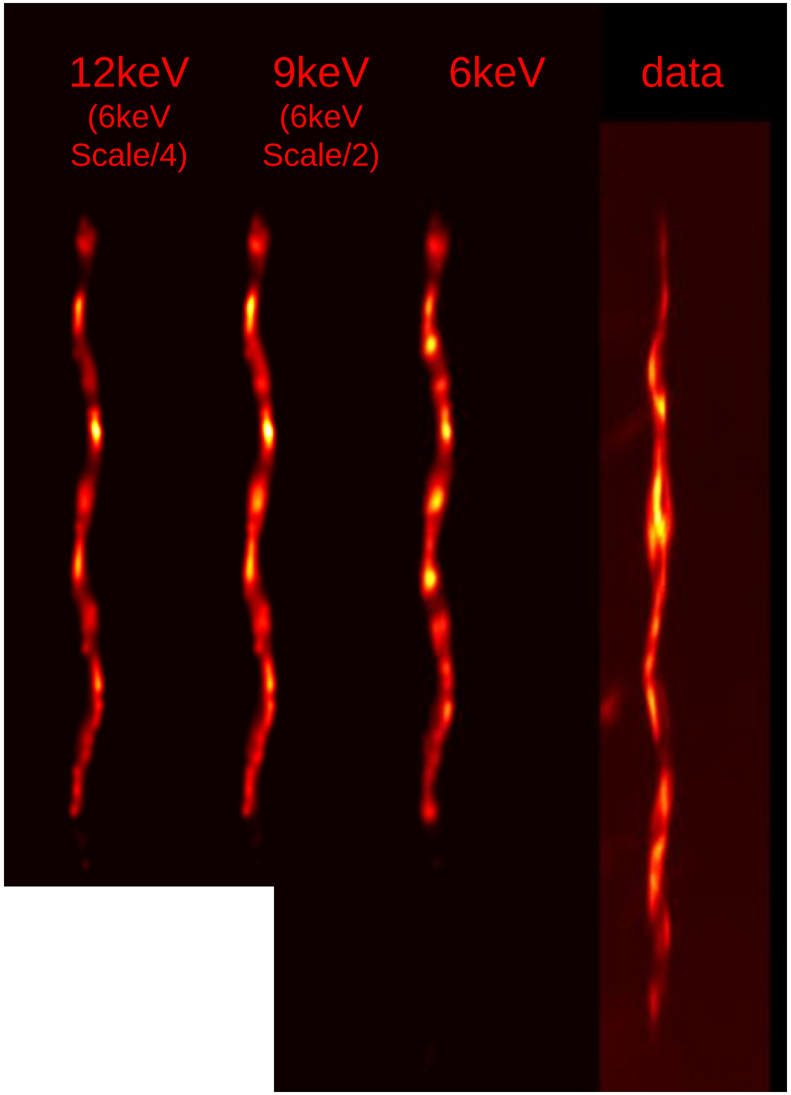




Crystal imager is sensitive to 3,6,9 and 12keV emission, so is likely getting significant contributions from the higher photon energies

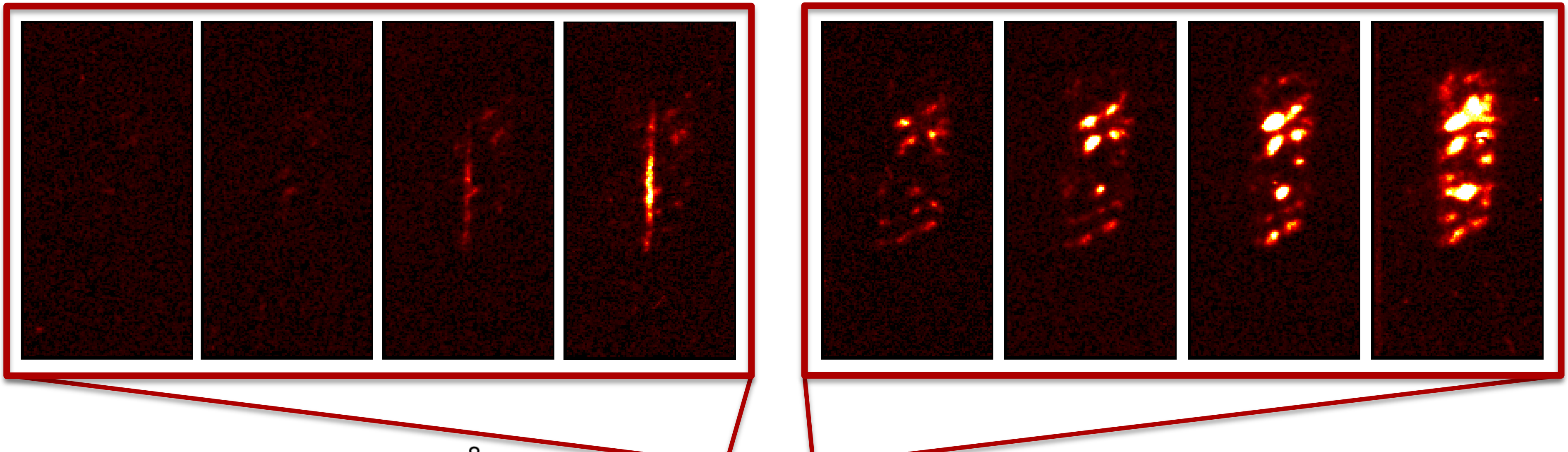
Some axial structure the result of reabsorption from liner structure, but some represents emission variations



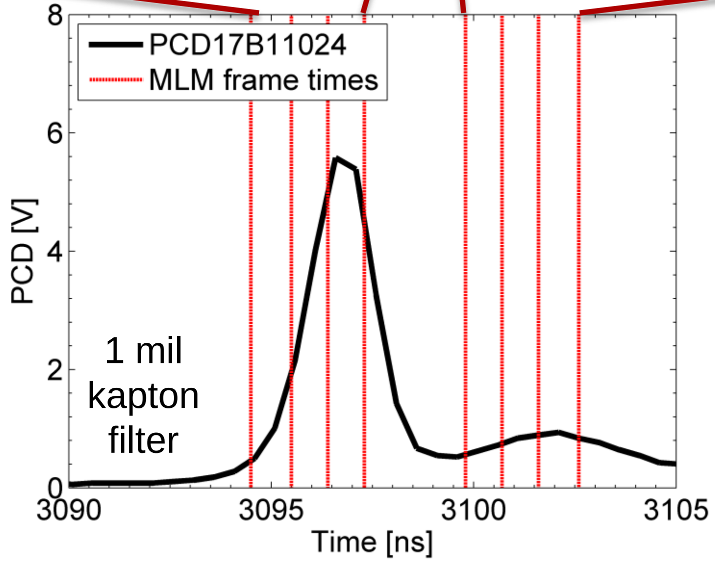


From Eric Harding's photometric calculations of this instrument, the sensitivity is comparable at 6 and 9keV

To better understand where stagnation structure we need to understand stagnation process so we appeal to time resolved imaging diagnostic MLM pinhole camera



Z2591
Output from MLM soft filtered pinhole camera



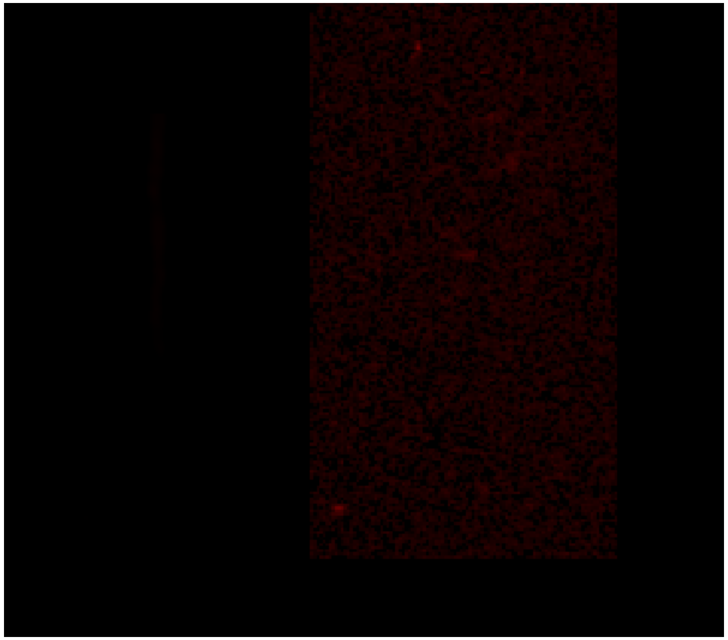
Narrow column of bright emission followed ~ 2.5ns later by emission at large diameter.

First emission peak coincident with neutron production

Neutron Production Comes and Goes While the Liner Still Implodes

MLM reconstruction – Simulation output on 13 degree LOS soft filtered (>1keV). Diffraction and geometric resolution limits applied

Simulation Data



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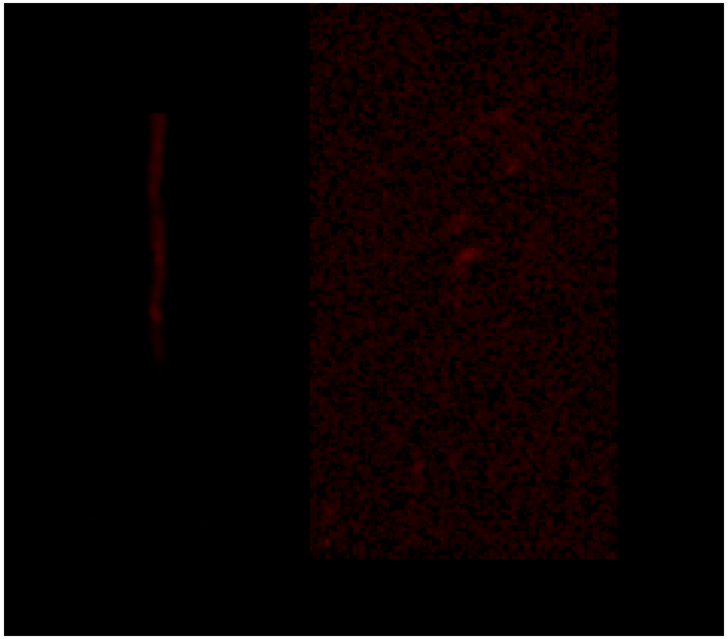
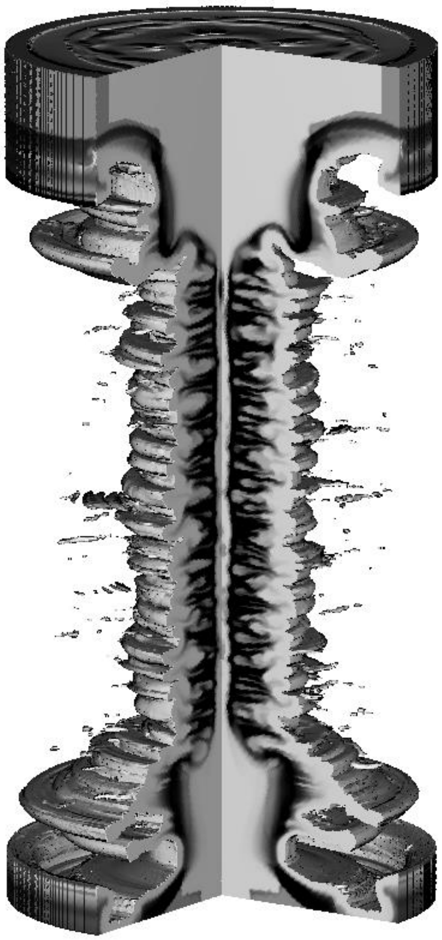


Neutron Production Comes and Goes While the Liner Still Implodes



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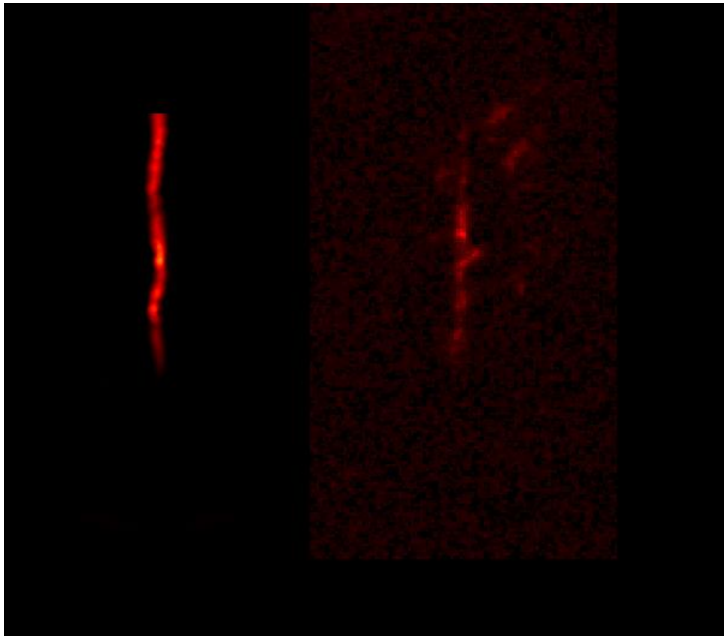

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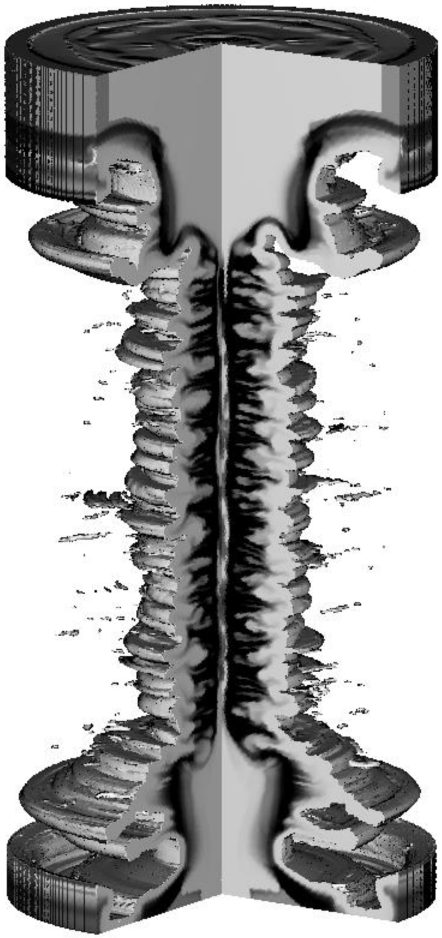

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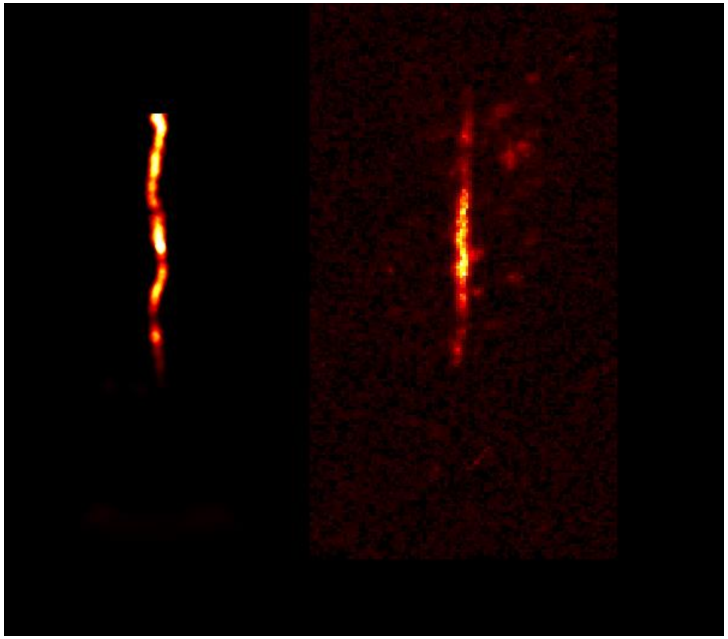

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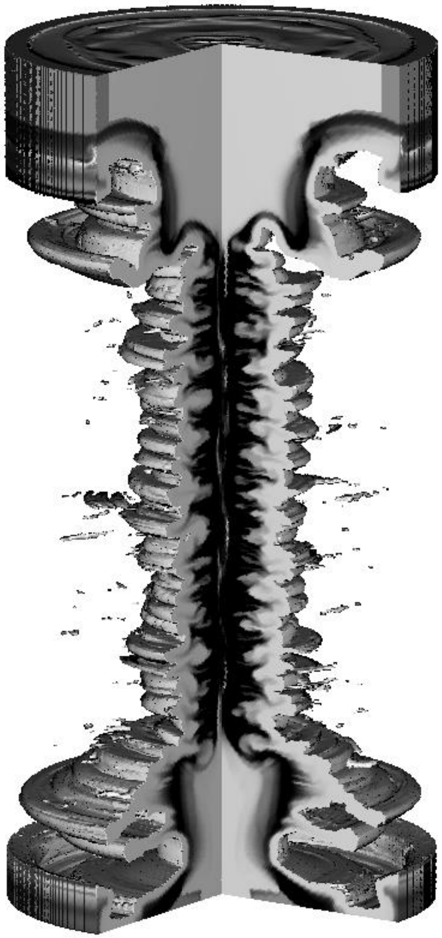

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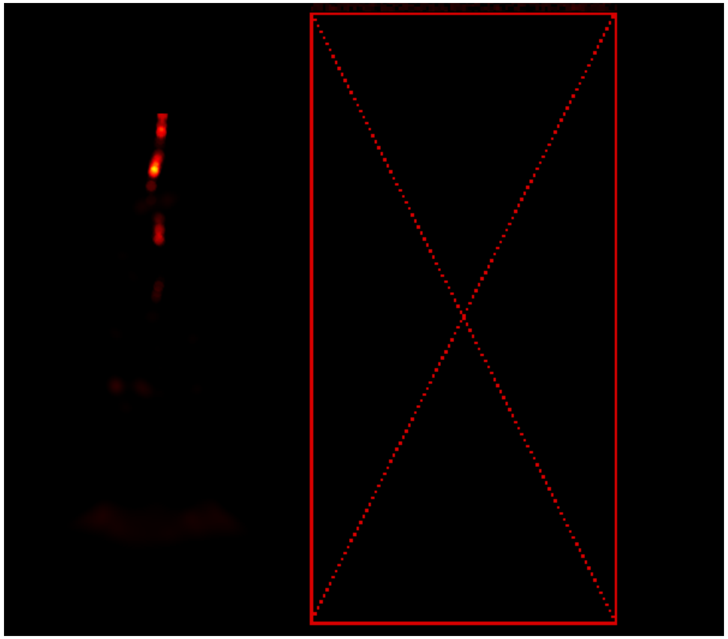

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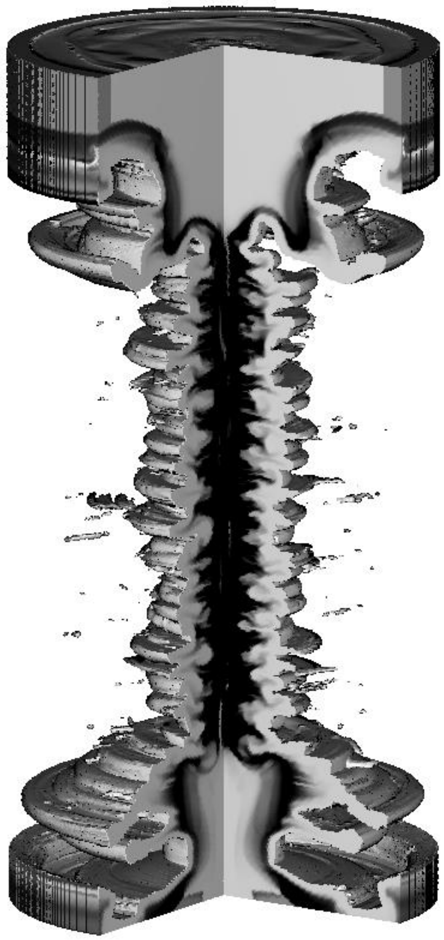

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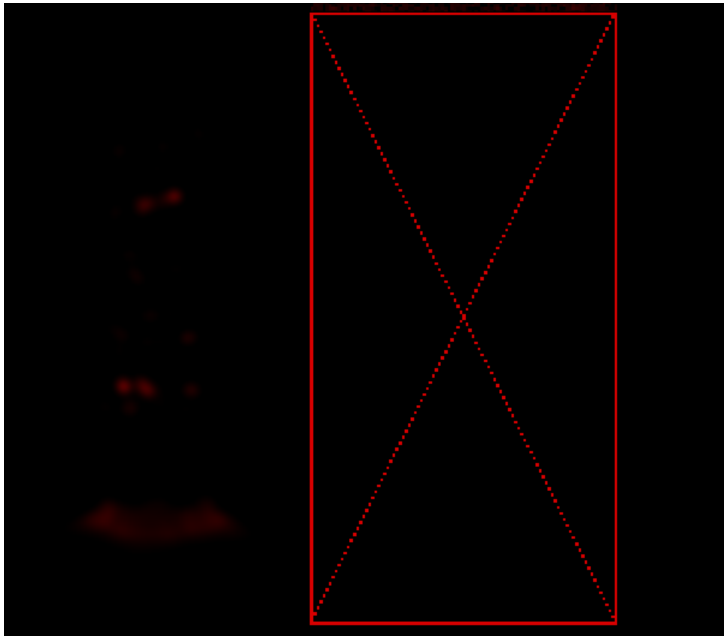
Simulation Data



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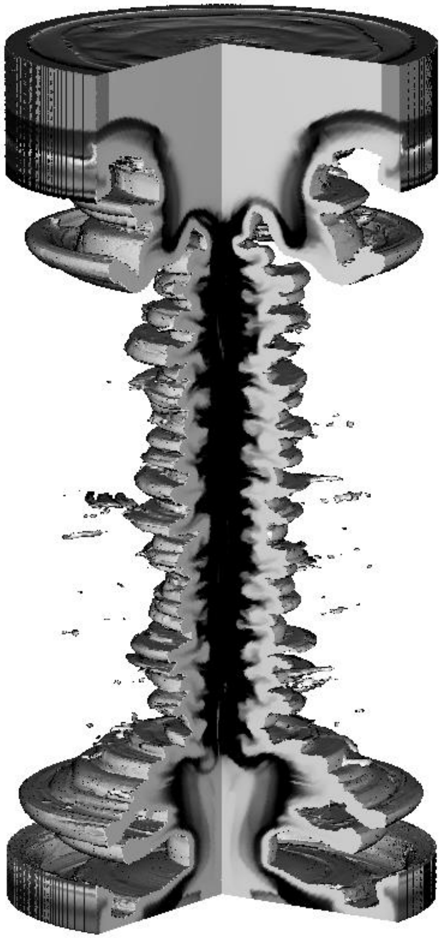
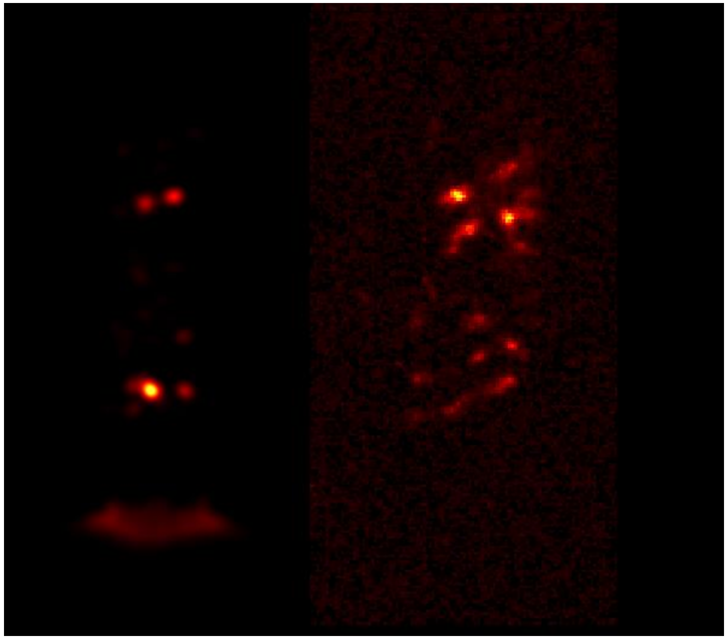
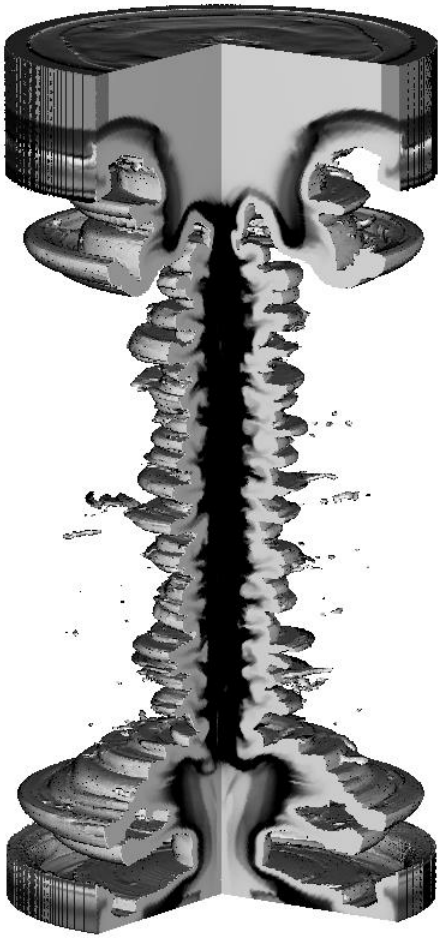


MLM reconstruction – Simulation output on 13 degree LOS soft filtered (>1keV). Diffraction and geometric resolution limits applied

Simulation Data



Neutron Production Comes and Goes While the Liner Still Implodes



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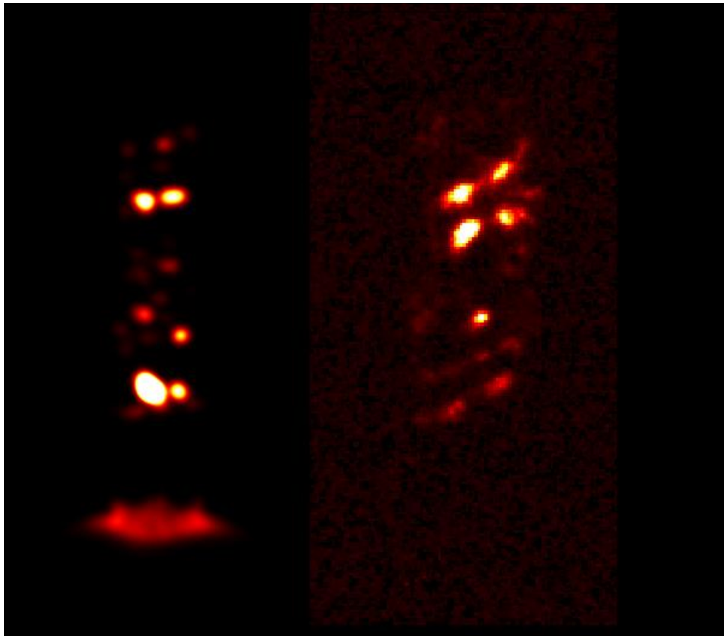

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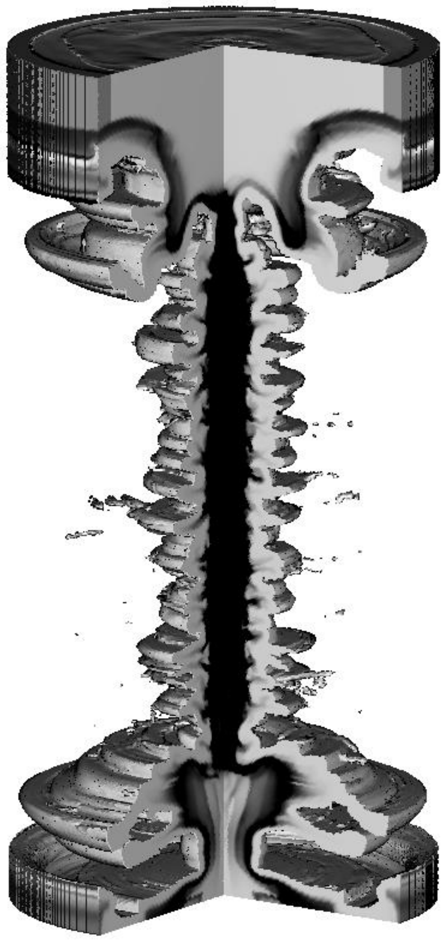

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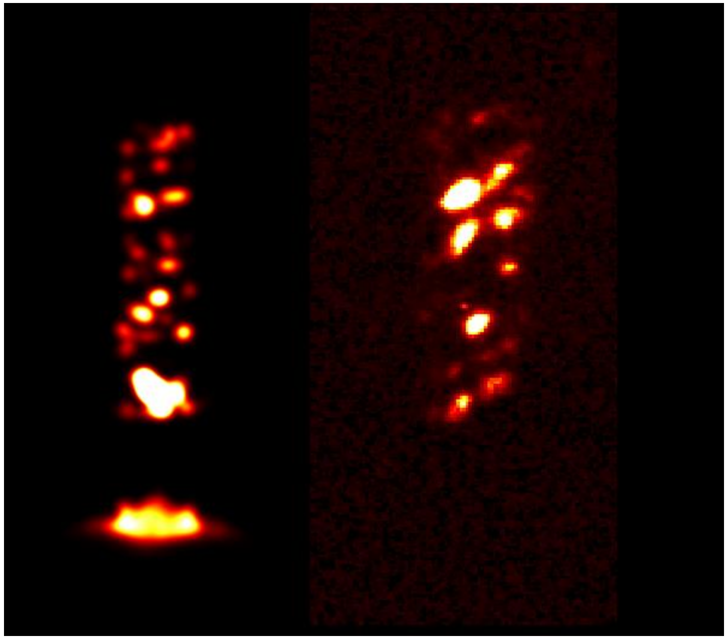
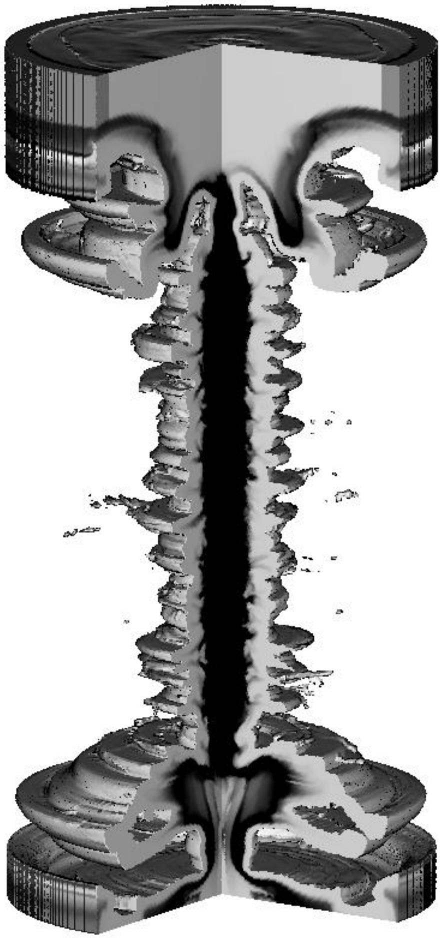


Neutron Production Comes and Goes While the Liner Still Implodes



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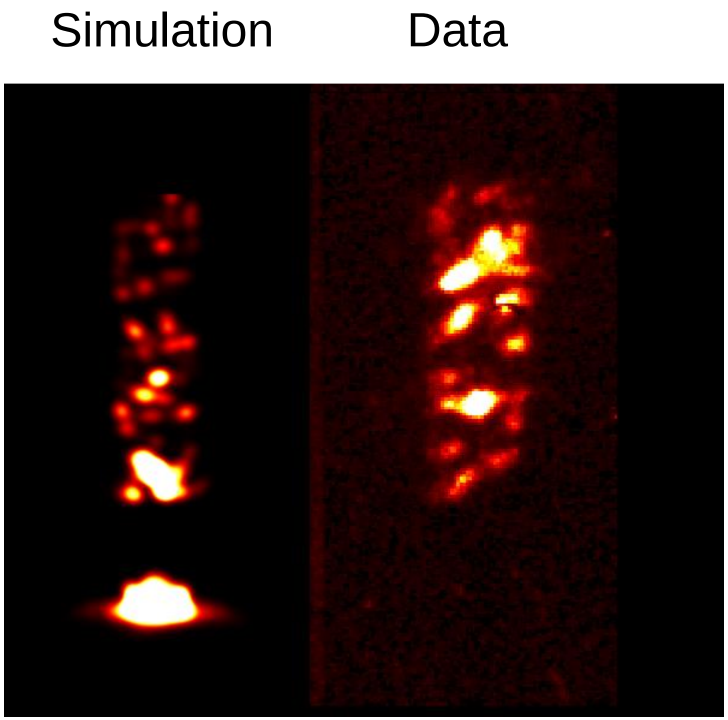
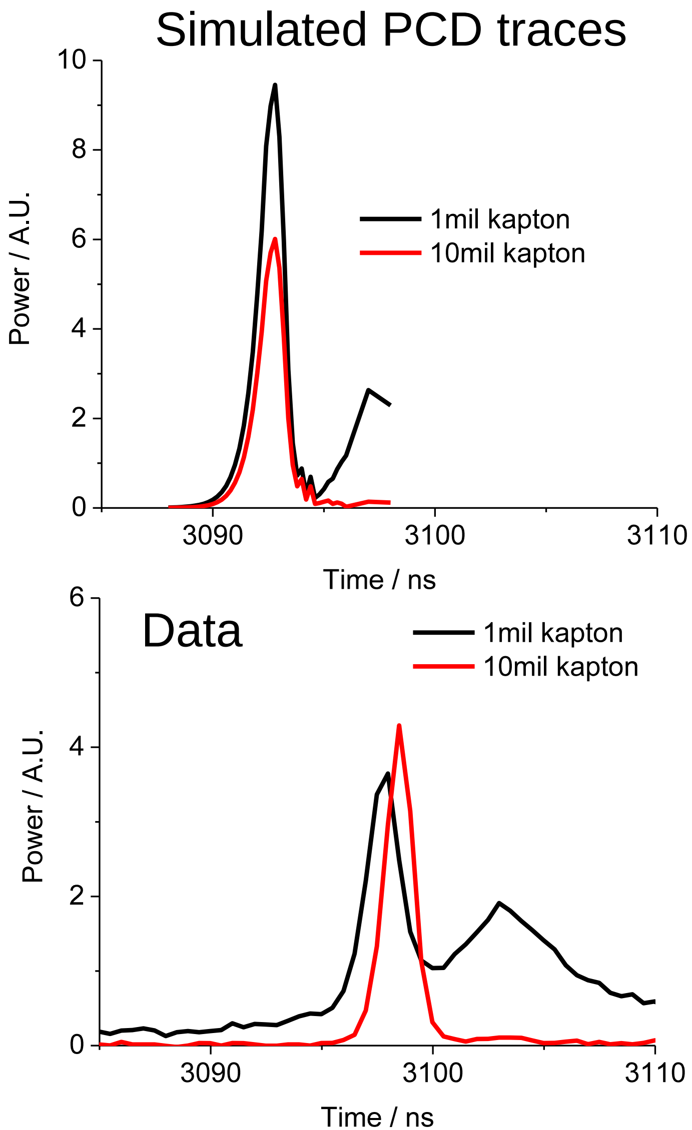


Neutron Production Comes and Goes While the Liner Still Implodes



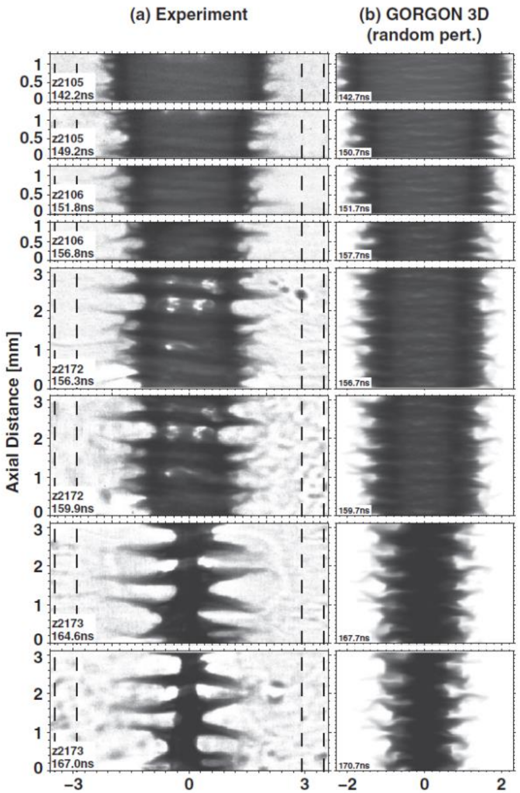
PCD traces (Z2613) S.B. Hansen

- First peak of hard radiation is the fuel compression and neutron production.
- Second peak is the final stagnation of the liner.
- Neutron production stops while the liner is still imploding.

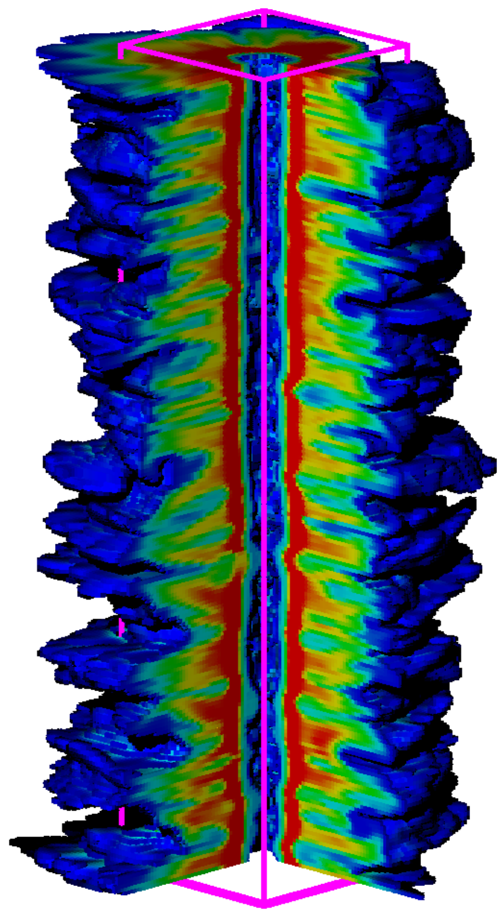
- What is the process responsible for ending the neutron production ?

Increase grid resolution on central region to study stagnation

Revert to uncorrelated initial perturbation. Assume generous 1kJ uniform spot preheat

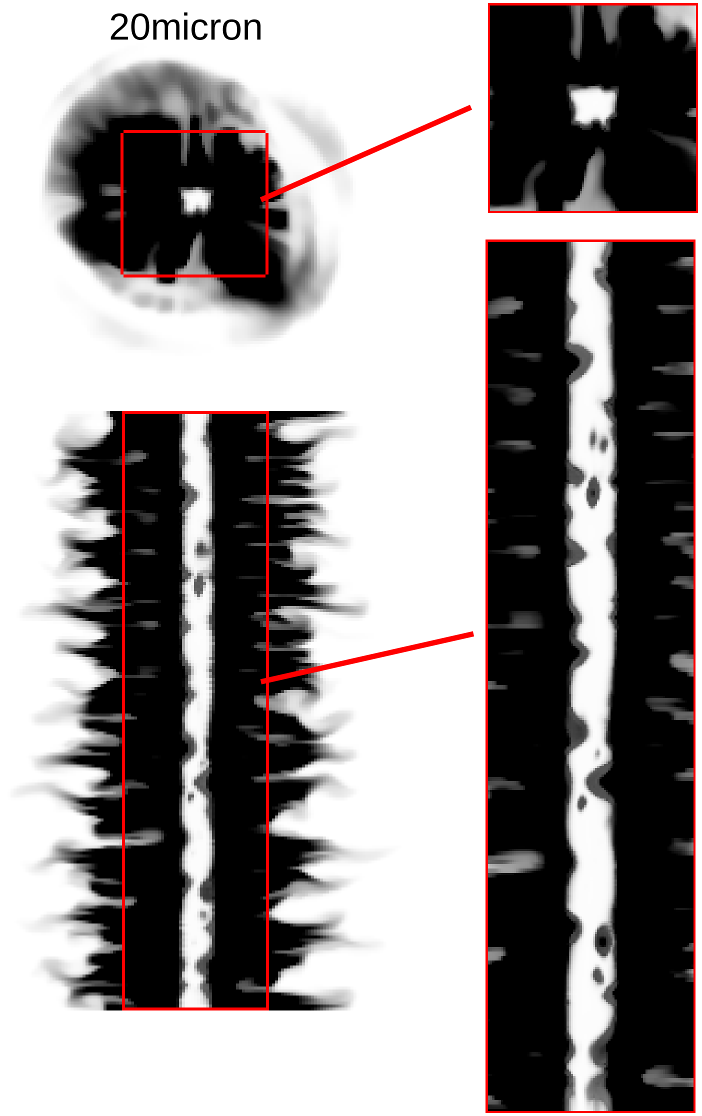


Rezone central region from 20 to 5 micron resolution

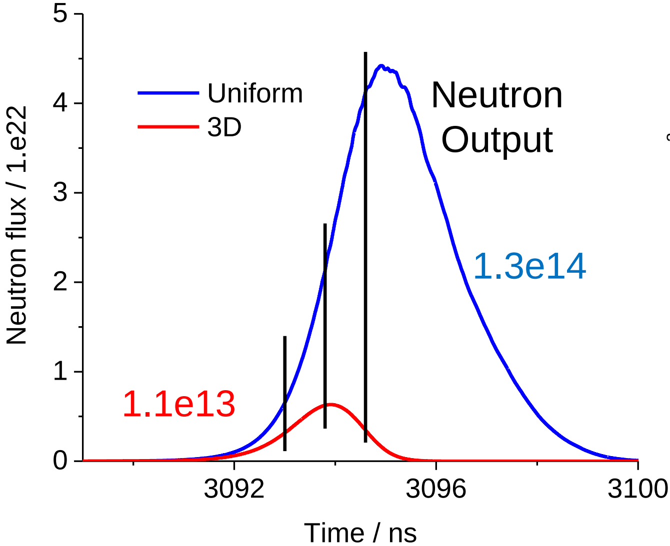


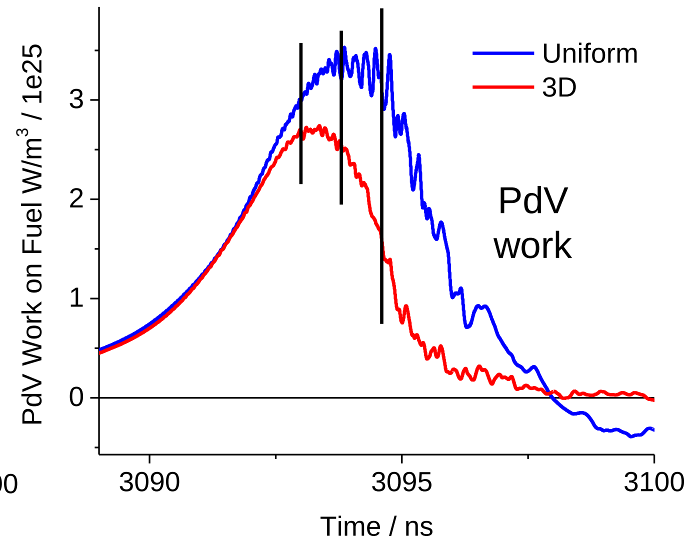
20micron

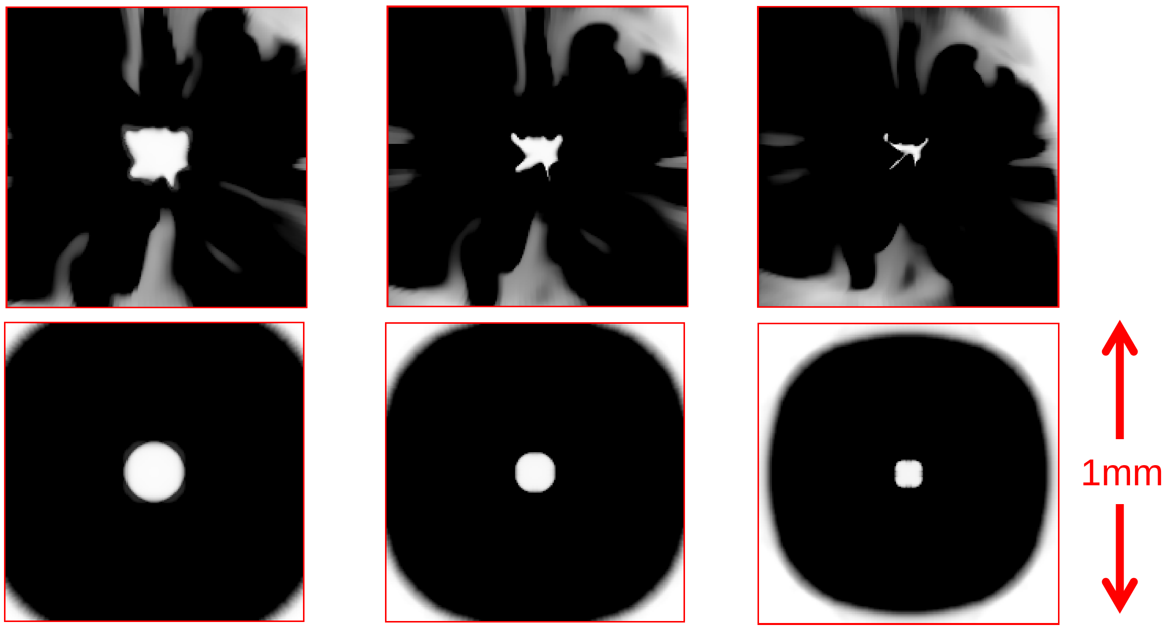
5 micron



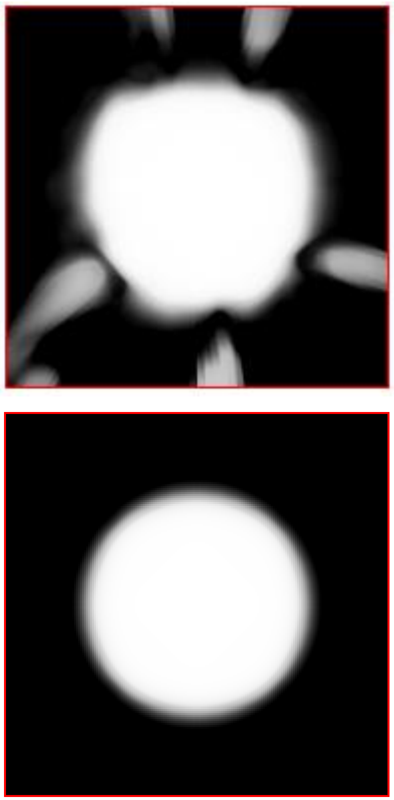
Azimuthal instabilities significantly reduce fuel confinement time.







3093.0ns 3093.8ns 3094.6ns



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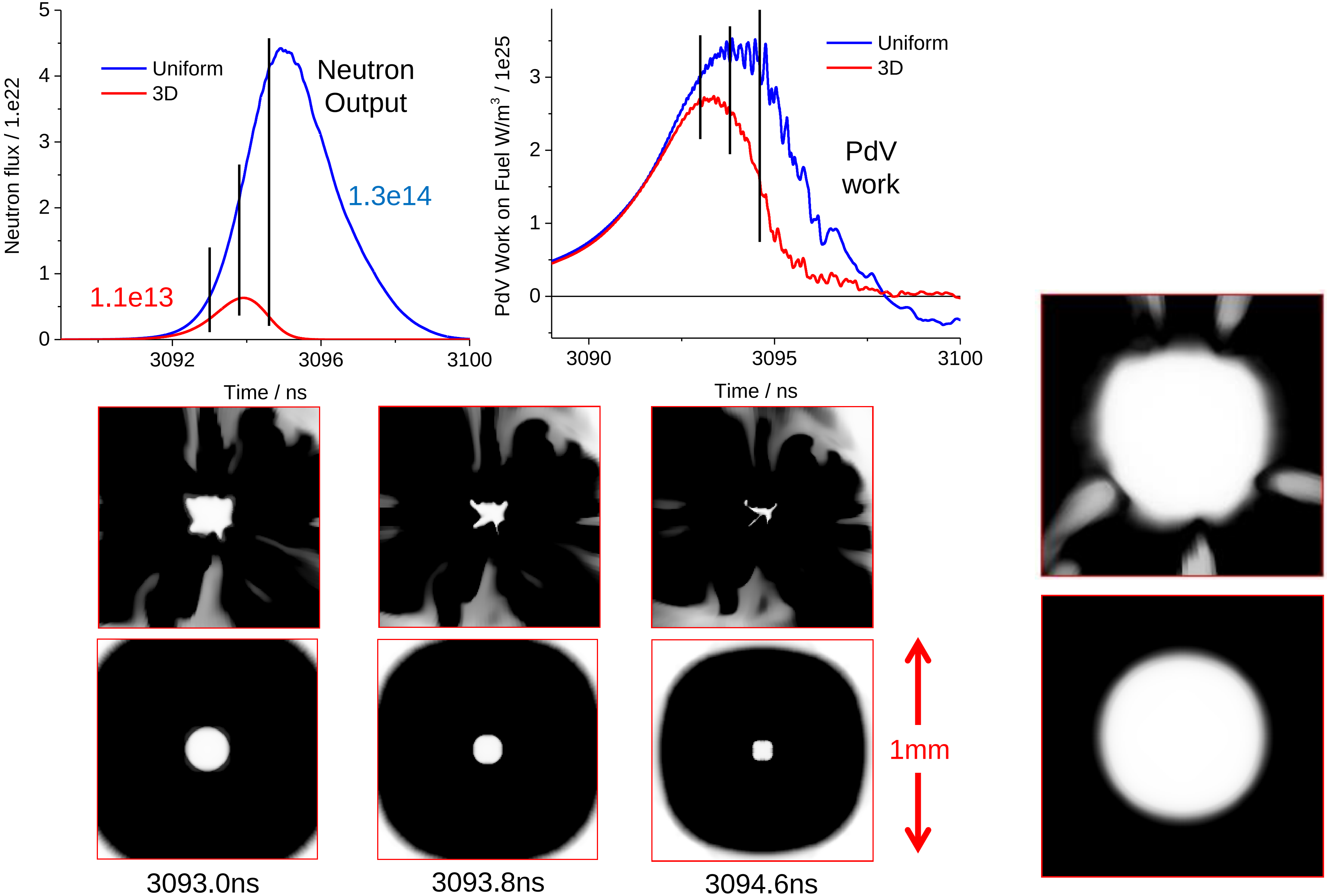
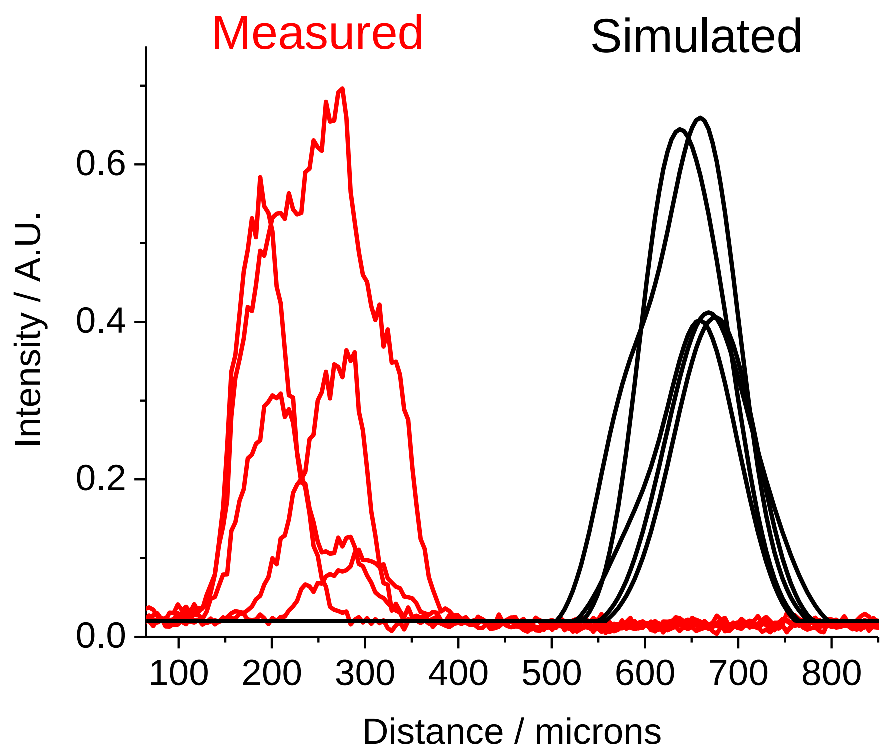
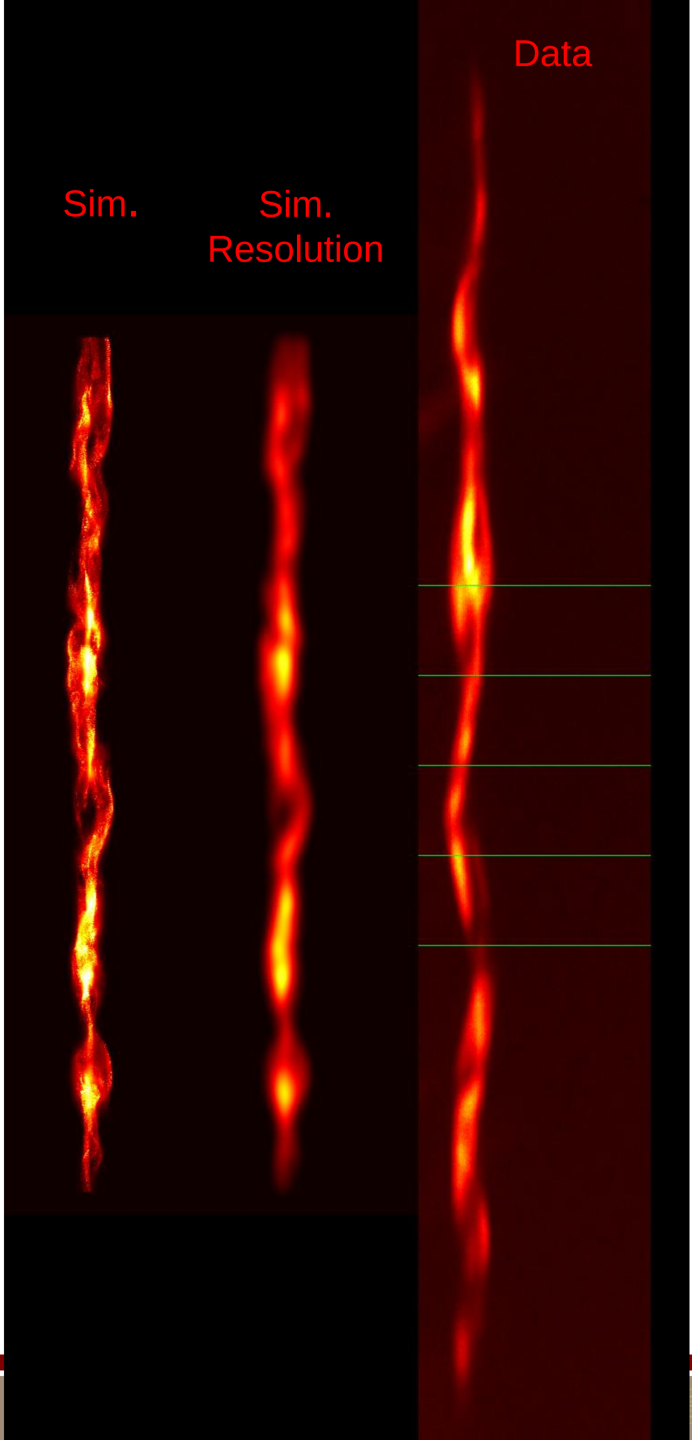


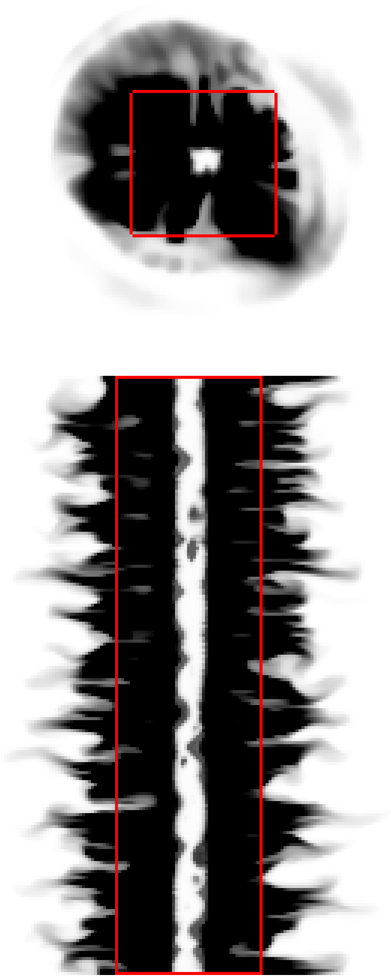
This stagnation mechanism is consistent with observed axial structure

Line outs of simulated and measured time integrated imaging



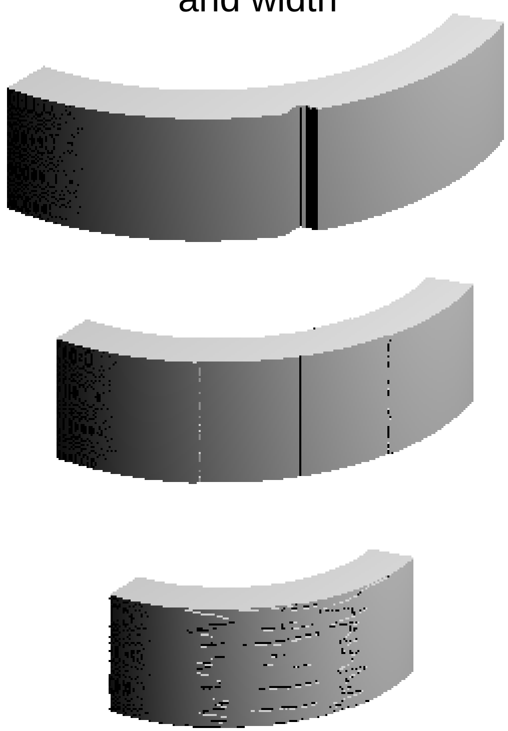


These structures are not flute modes. They have both azimuthal and axial components



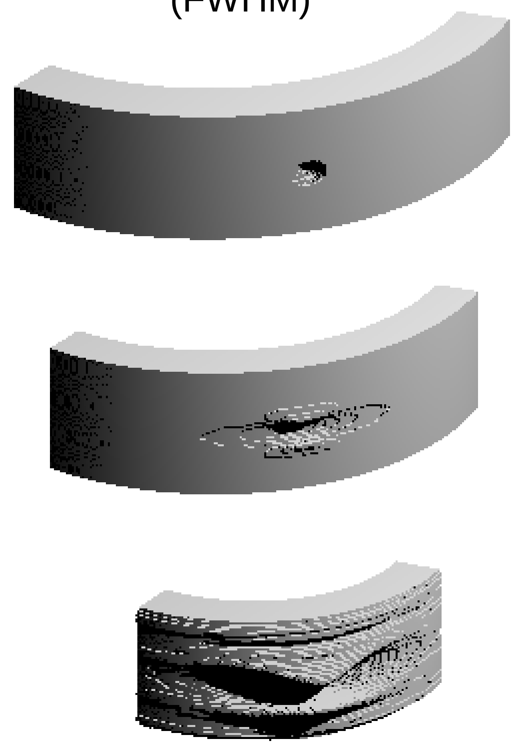
Idealized flute modes don't grow from outside

Groove of same depth and width



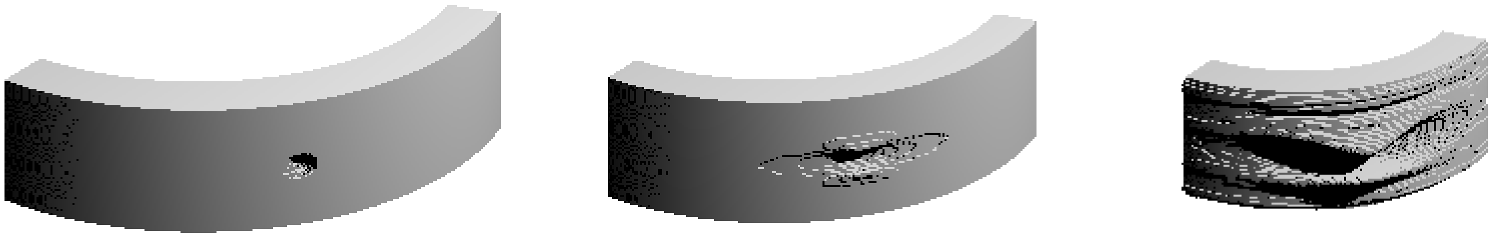
Surface defects grow and penetrate imploding shell

~100 micron hole (FWHM)

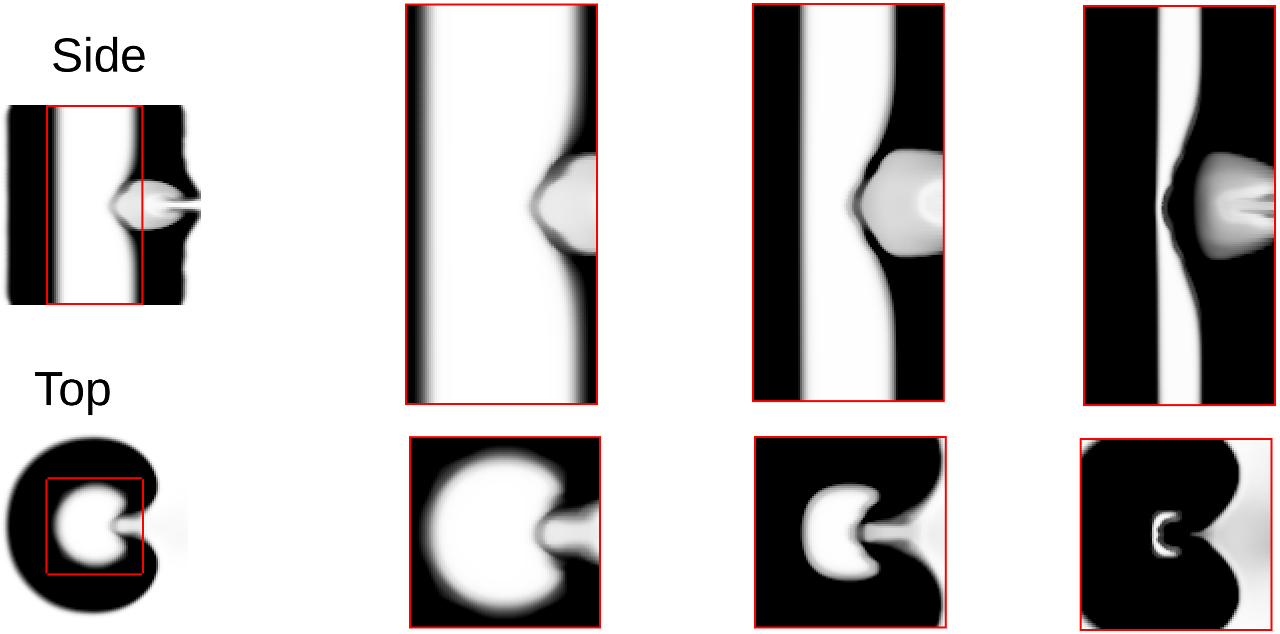


Finite axial, finite azimuthal instabilities can grow quite aggressively

Initial instability development



These azimuthal asymmetric structures are very detrimental to fuel confinement at stagnation



Conclusion

- There are a lot of unknowns concerning the performance of MagLif, but there is an increasing around of data availaibe to constrain our calculations.

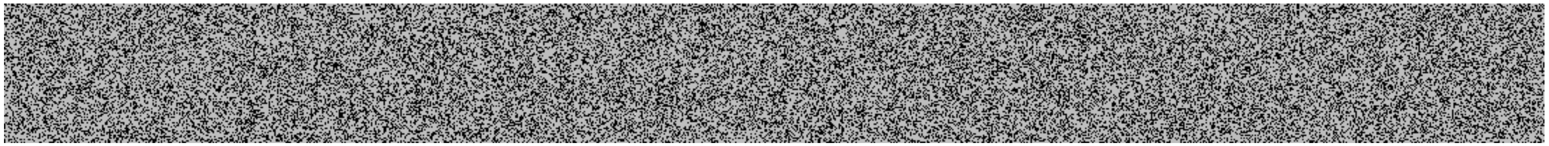
- Imaging data is consistent with helical perturbations feeding through from the outer liner surface.
  - If they're making it through, what other instabilities might be making it through with them ?

- We tend to focus on m=0 type MRT instabilities, but there are other structures that can be detrimental to fuel compression and confinement.
  - These structures are consistent with imaging diagnostics

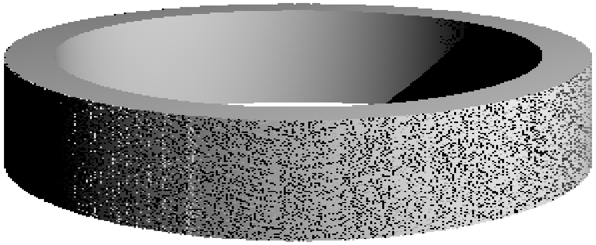
These azimuthally discrete structures arise from the long wavelength component of any random initialization

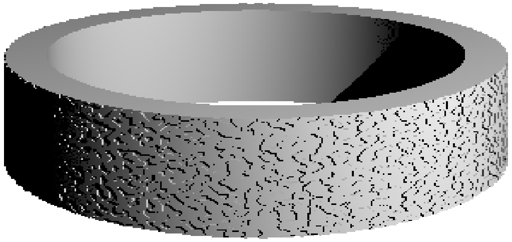
These structures are not cascading up from the short wavelength perturbations. We can test this by eliminating them from a calculation.

Standard white noise initialization



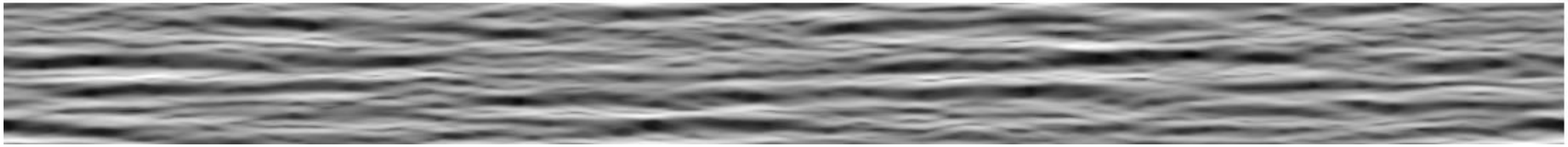
High frequency component of instabilities removed



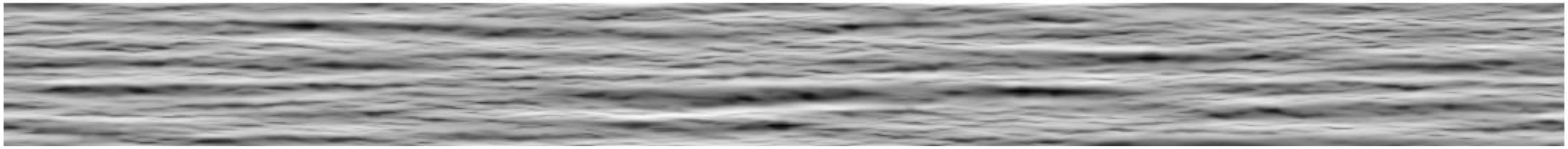


While the amplitude of resulting perturbations can be effected, the location is set by the long wavelength components that were already there

High frequency component of instabilities removed (3095 ns)



Standard white noise initialization (3110ns)



Contrast enhanced