SAND2011-3813 C

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3-Dimensional modeling of large diameter Wire Array high intensity K-shell radiation sources imploded on the Z generator

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Outline

Implosion and Stagnation of a Large Diameter Stainless Steel Wire Array

- Describe the implosion and stagnation of stainless steel large diameter k-shell source
- Outline processes responsible for high photon energy emission
- Describe the effect this has on the interpretation of certain diagnostics

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GORGON code well suited to model discrete wires in the full array volume

GORGON – 3D Resistive MHD

Fixed square grid finite volume hydrodynamics

Single fluid – separate electron and ion temperatures

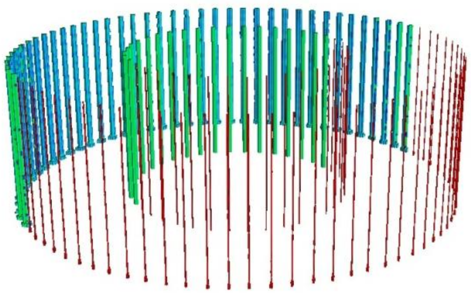
Explicit electro-magnetic field solution (wave equation in vacuum / diffusion equation in plasma)

Van Leer Advection

Constrained Transport for Magnetic Field Advection

Driven from measured voltage to account for current losses

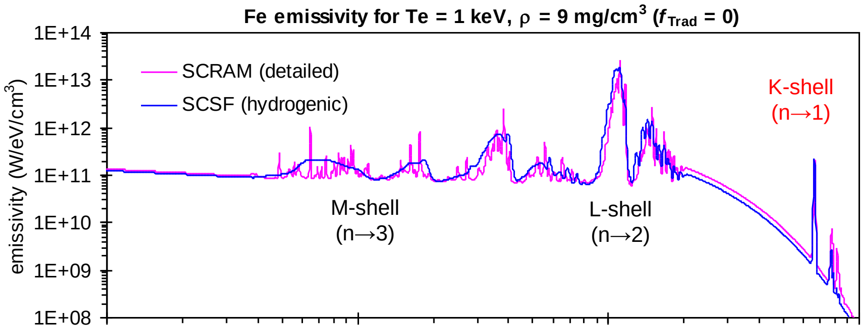
Full array modeled as discrete wires



Radiation is flux limited diffusion out of a zone then lost

Emissivity's ε and Rosseland/Planck opacities are tabulated on ρ, T_e, and f_{Trad} ($T_{rad}=T_e$).

Tables are based on the screened-hydrogenic/ UTA non-LTE model SCSF [1], which, like LLNL's DCA [1], compares well to more detailed atomic codes (*e.g*. SCRAM [2], [3])



[1] H. Scott and S.B. Hansen, HEDP 6, 39 (2010)

[2] S.B. Hansen *et al*., HEDP 3, 109 (2007)

[3] Brown, Hansen *et al*., PRE 77, 066406 (2008)

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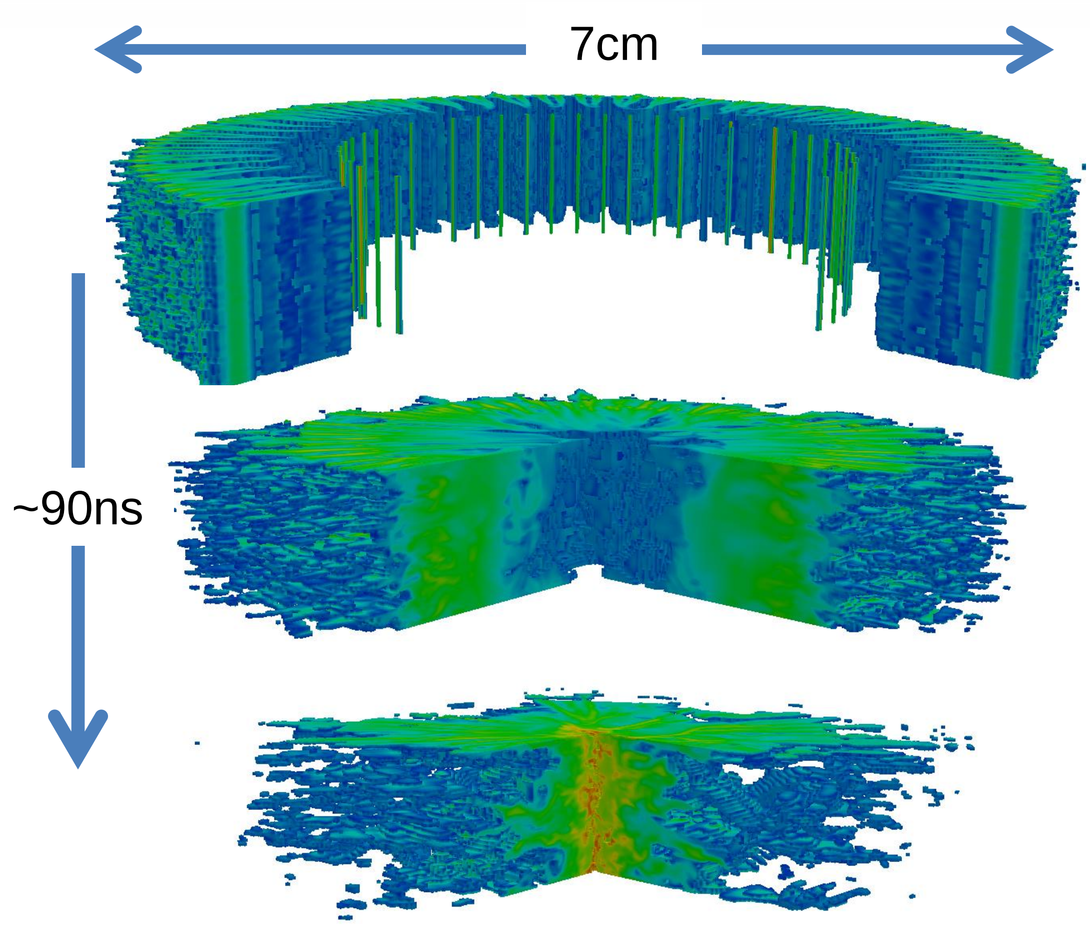
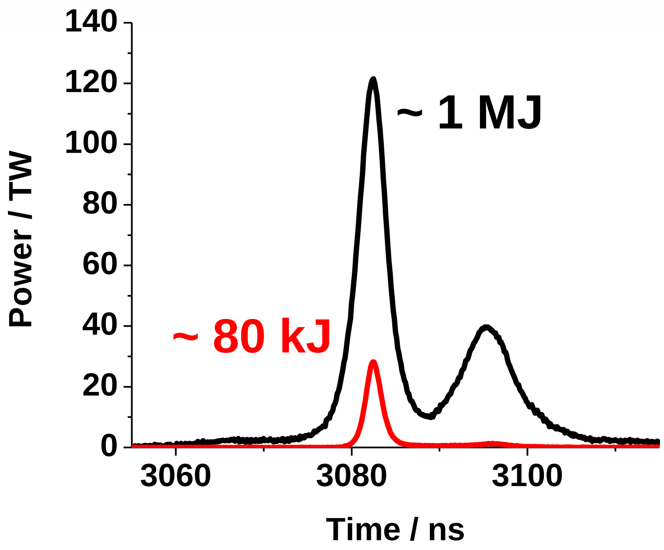
70mm Stainless Steel, nested arrays radiate ~80kJ at photon energies > 5keV



Log(density) of 81M cell calculation of a stainless steel array imploded on Z



~1.2mg total mass, with 2:1 inner to outer mass ratio
~80kJ emitted in photon energies > 5keV

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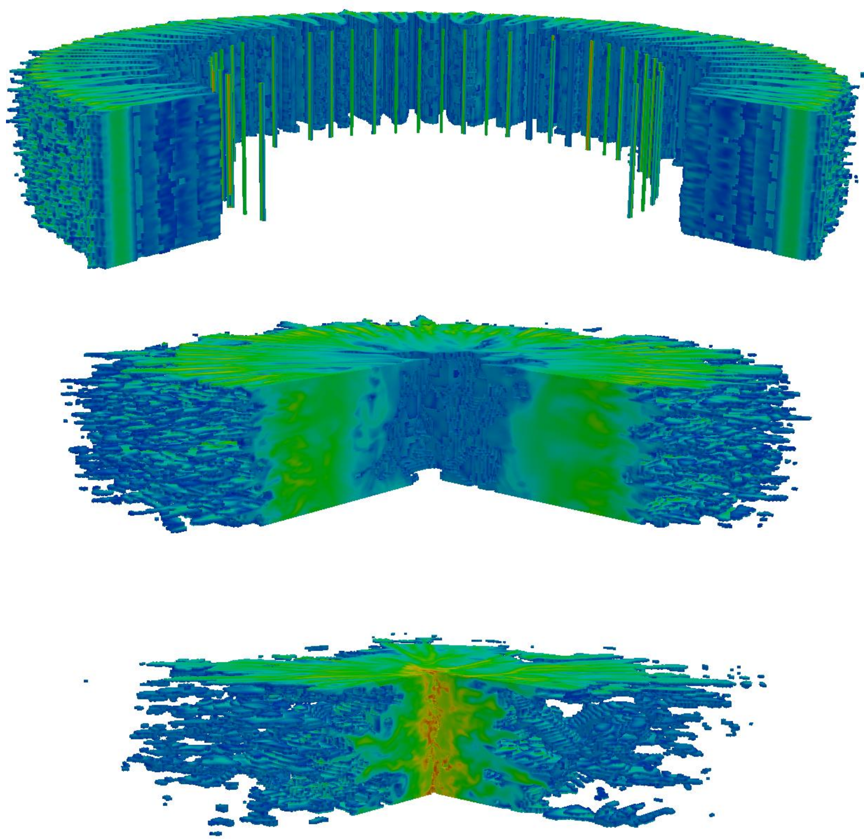
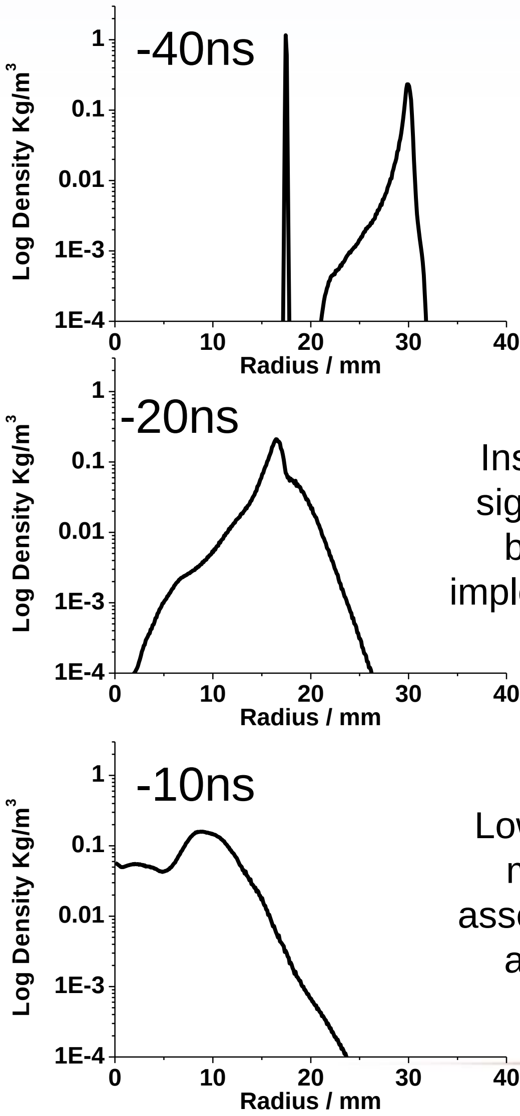
The first material to reach the axis is the lower density leading edge of the imploding array

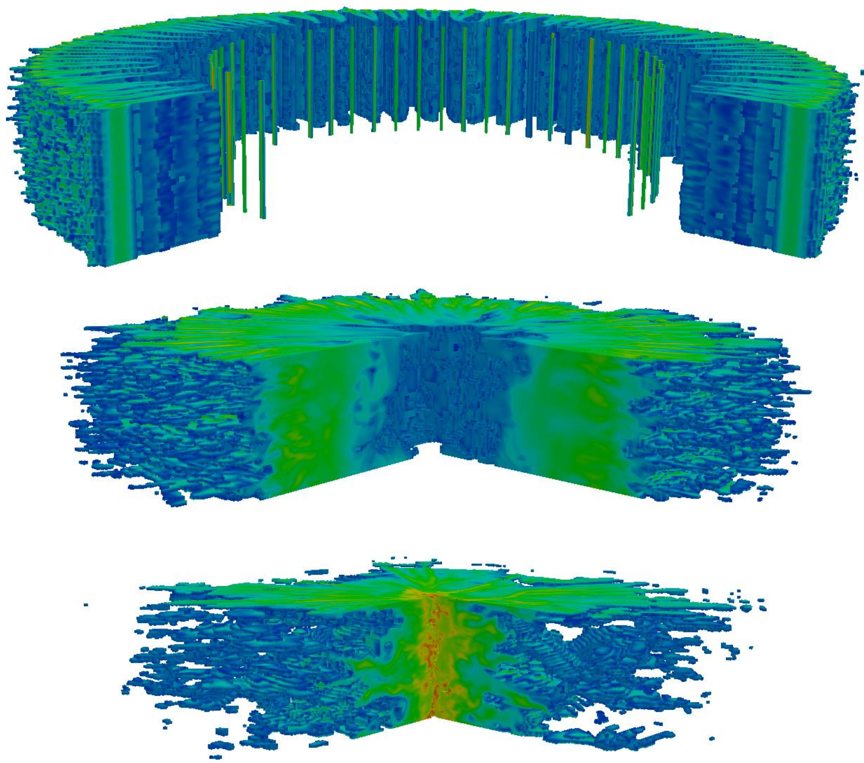


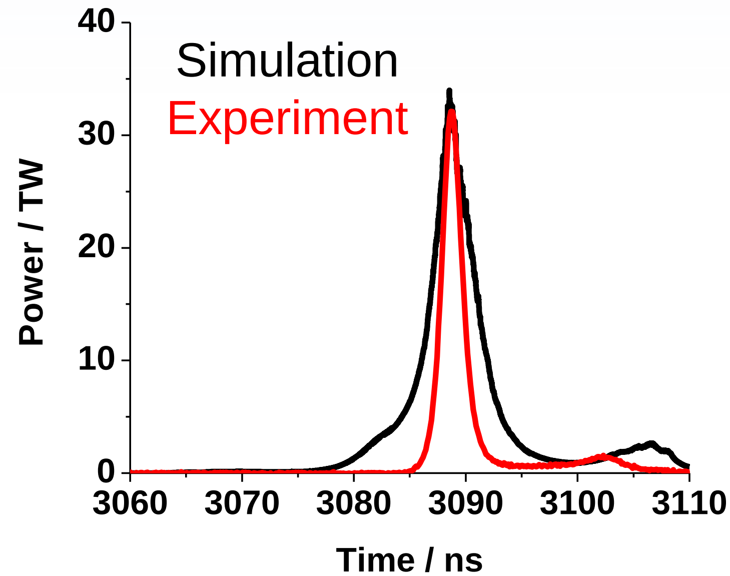


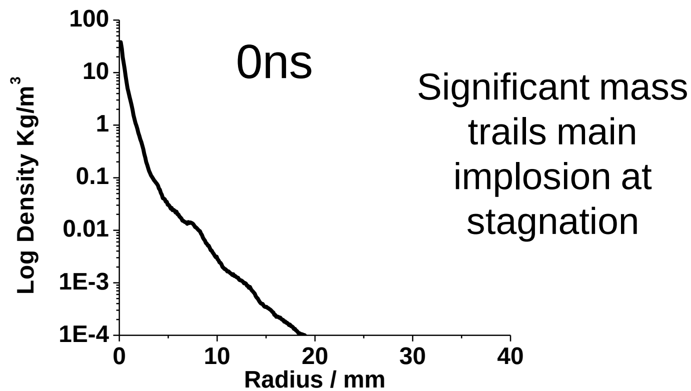
Instabilities significantly broaden imploding shell

Low density material assembles on axis first

The first material to reach the axis is the lower density leading edge of the imploding array

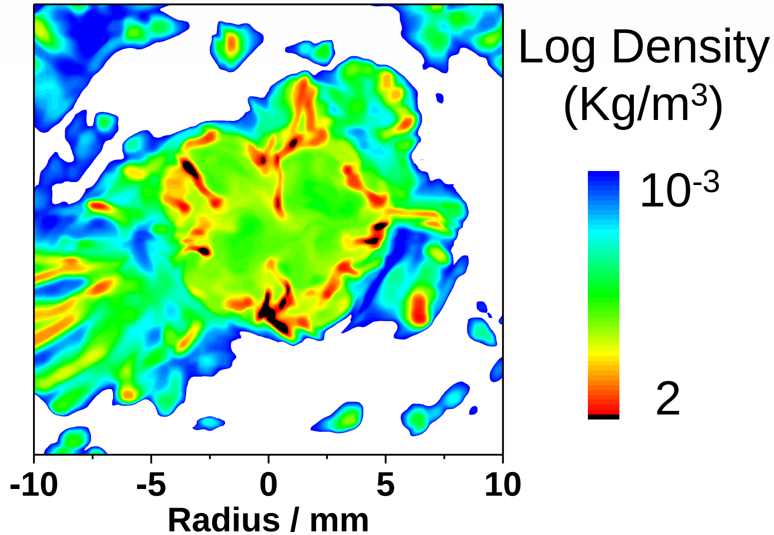


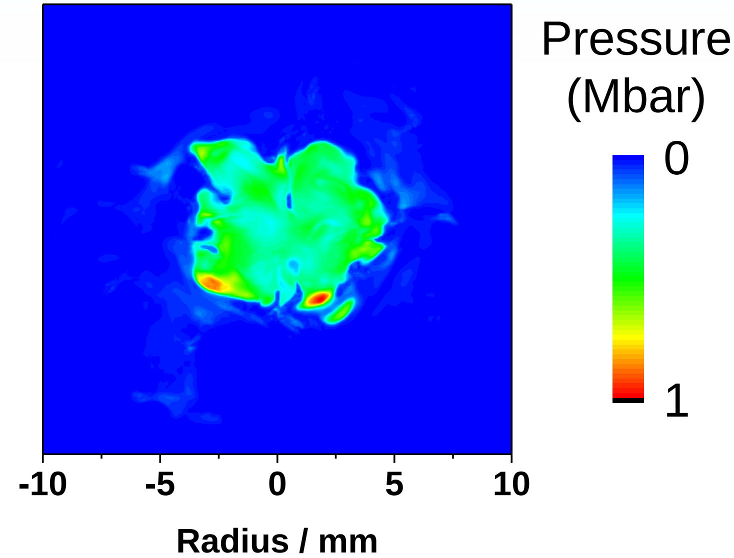


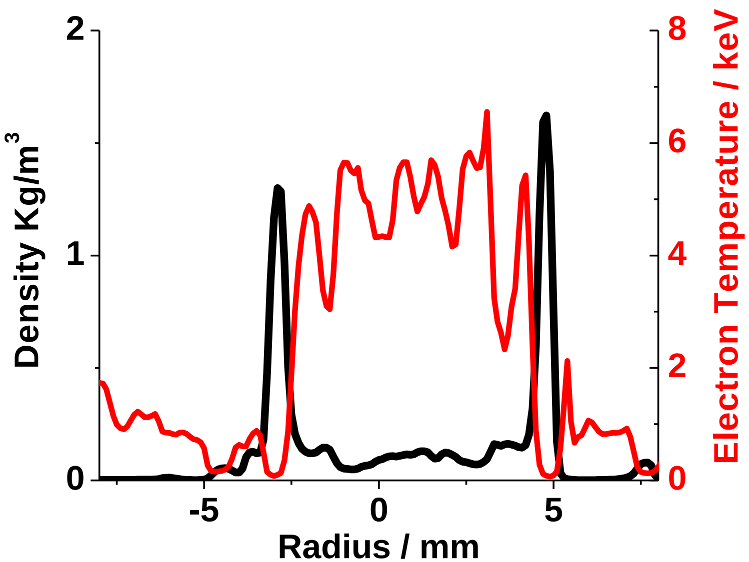


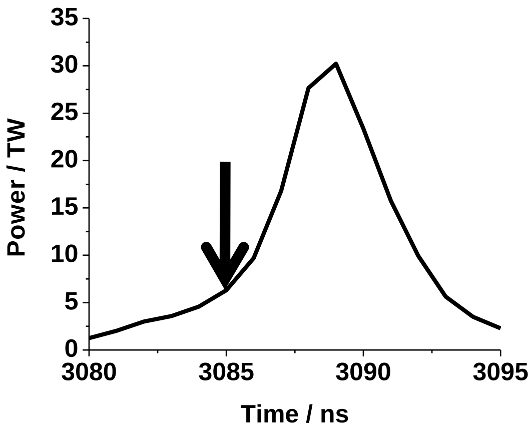
Dense imploding shell stagnates on low density, high pressure material that first arrives on axis

At foot of power pulse 'shell' implodes on top of hot, high pressure low density material









K-Power

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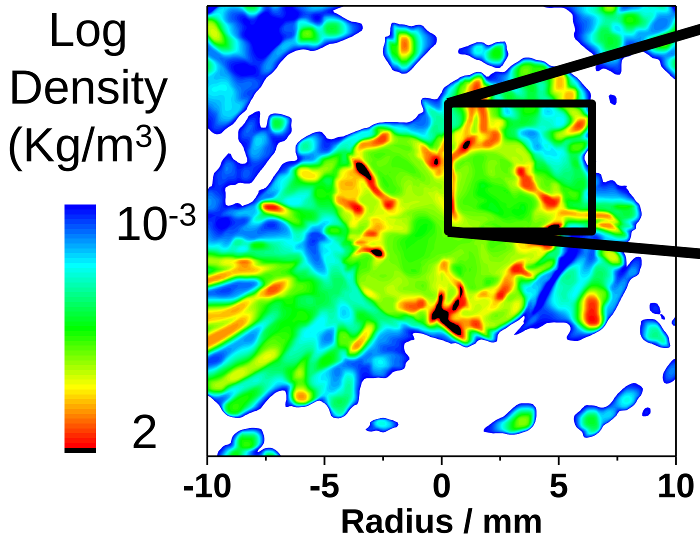
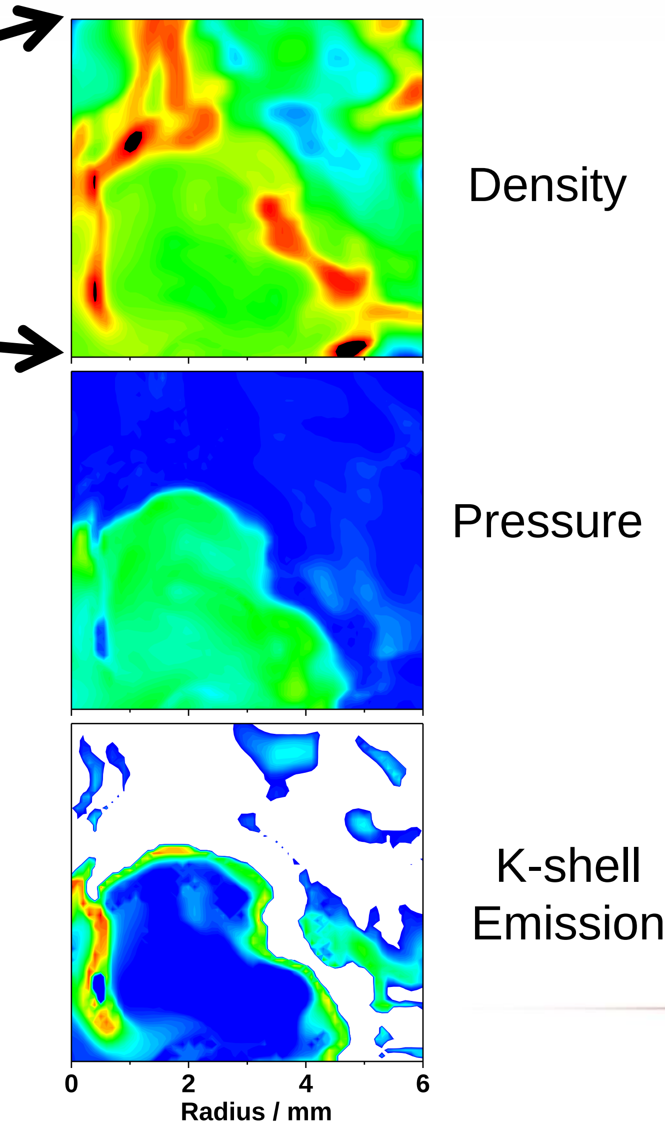
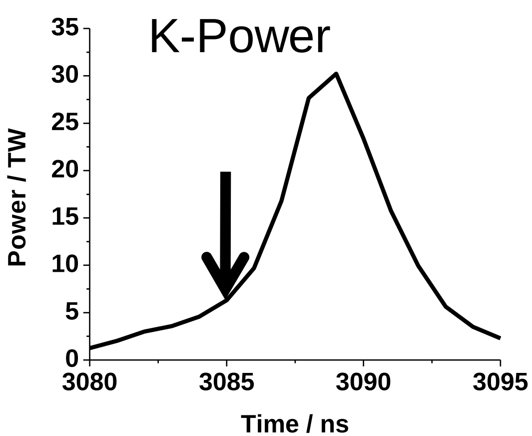
K-shell Emission Predominantly comes from leading edge of stagnating shell impacting high pressure on axis







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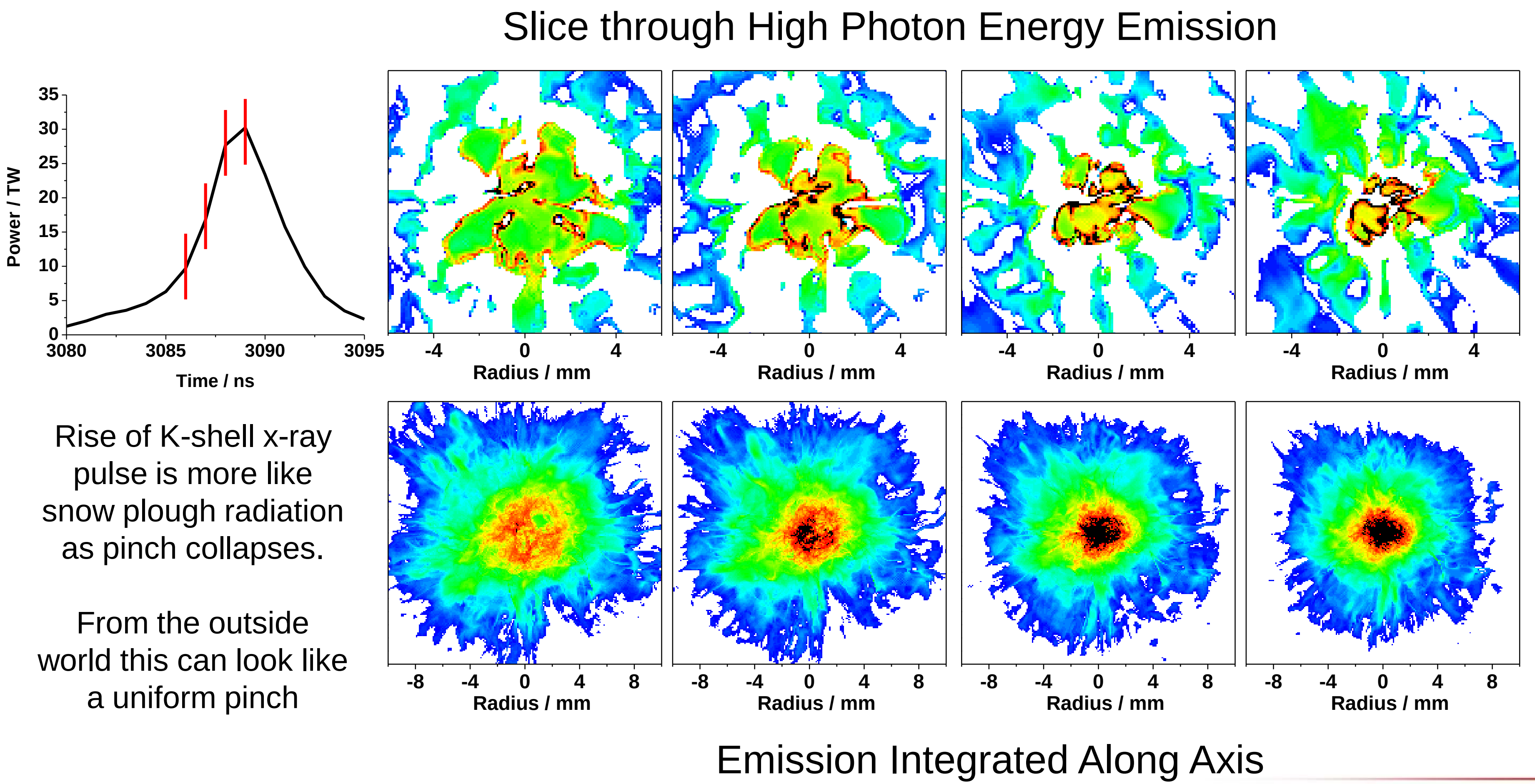
K-shell emitting leading edge can look like a uniform compressing pinch



Rise of K-shell x-ray pulse is more like snow plough radiation as pinch collapses.

From the outside world this can look like a uniform pinch

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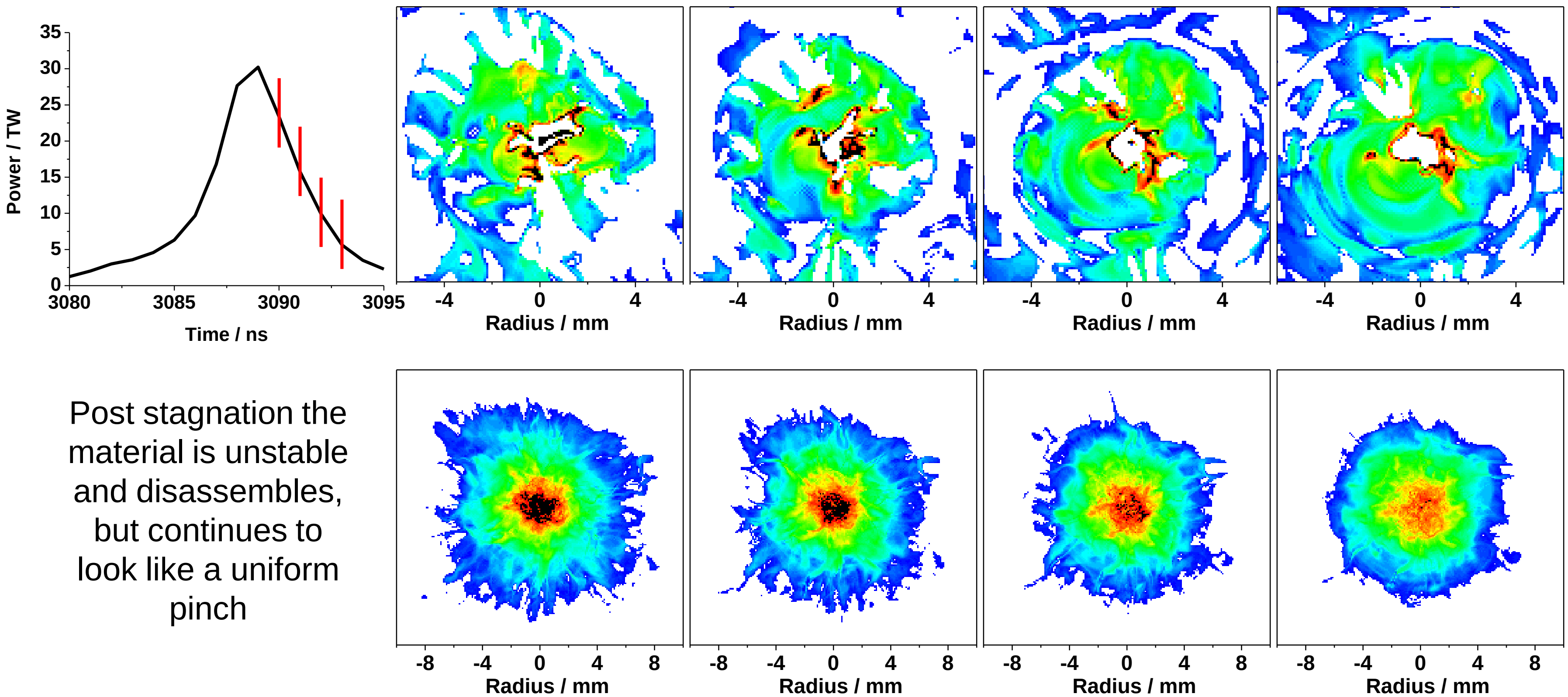
Post Peak X-ray Pinch Disassembles



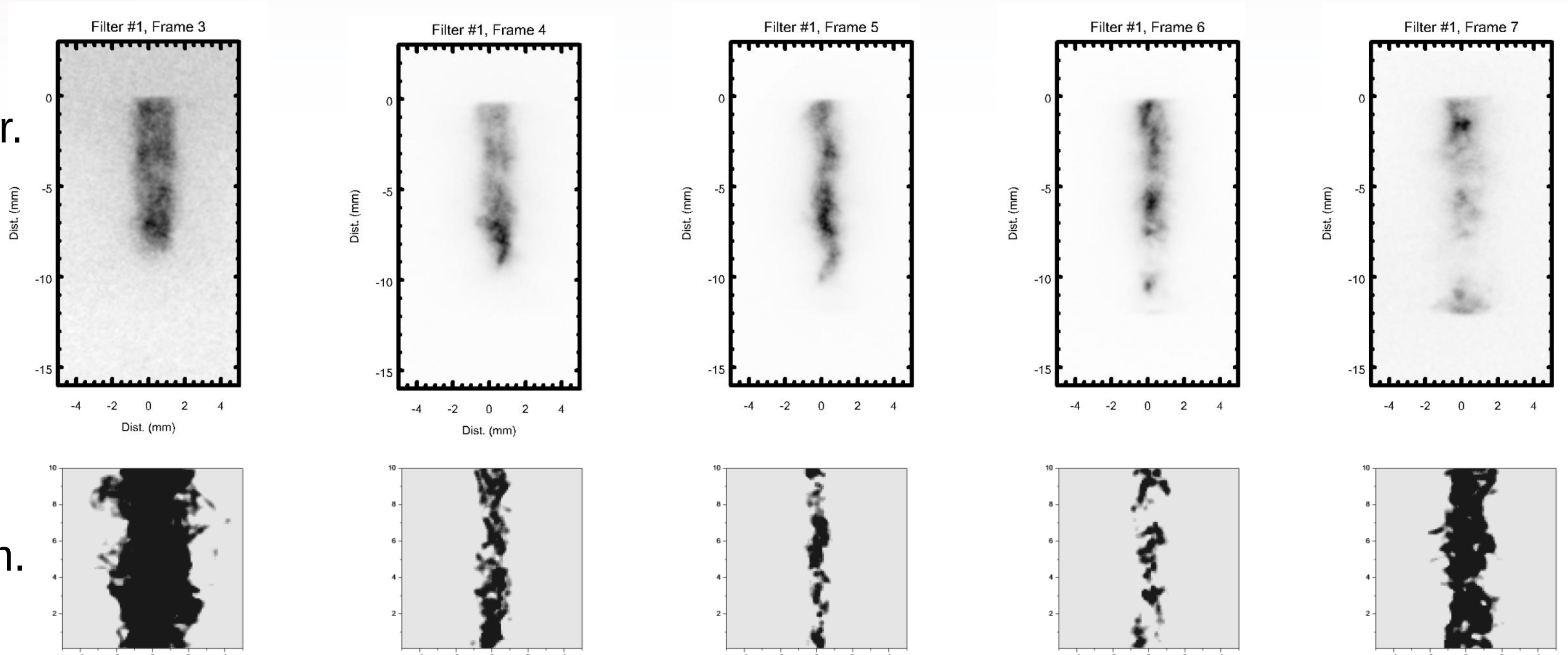
Post stagnation the material is unstable and disassembles, but continues to look like a uniform pinch

Comparison of actual and Synthetic Pinhole images

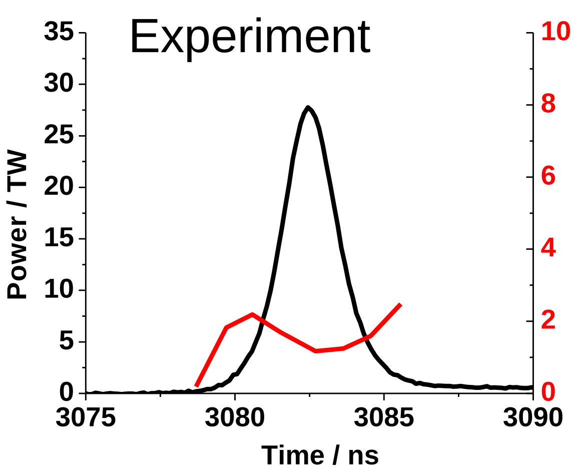
-2.2ns | -1.2ns | -0.2ns | +1.8ns | +2.7ns

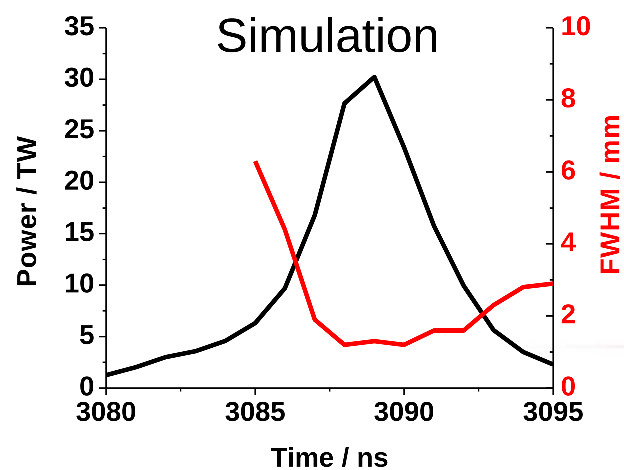
Expr.

Sim.



Calculated K-shell FWHM agrees with experiment





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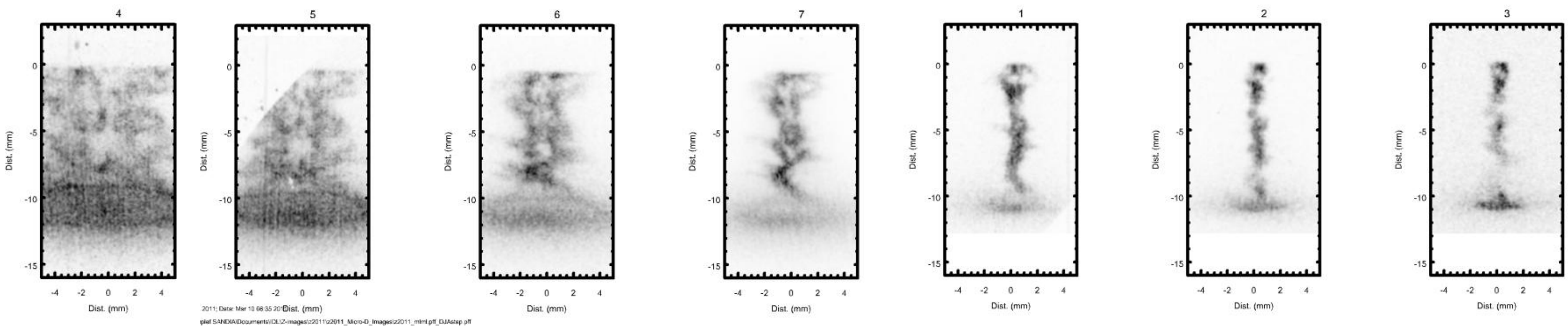
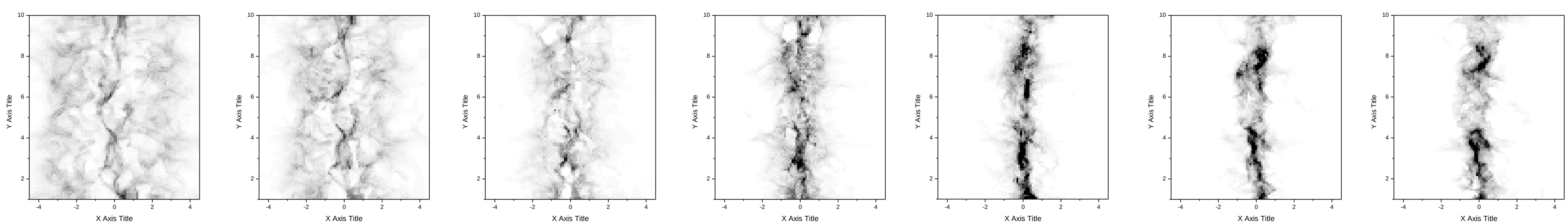
Lower Photon Energy 277eV MLM Camera shows similar structures

277eV

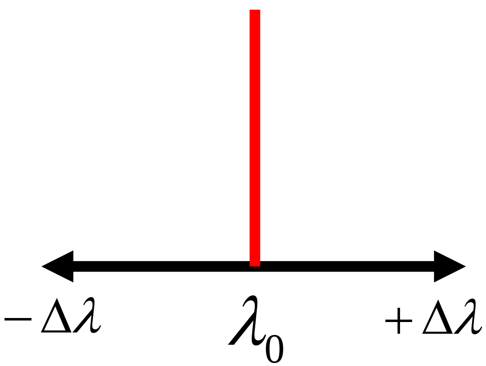
-3.2ns **-2.2ns** **-1.2ns** **-0.2ns** **+0.8ns** **+1.8ns** **+2.7ns**



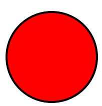


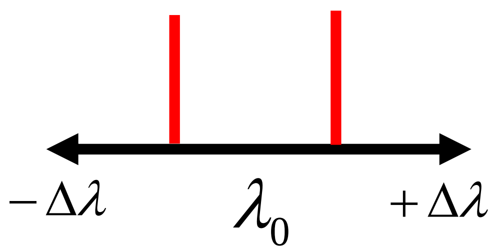
Doppler shifted emissivity is calculated from MHD model

$$\frac{\Delta\lambda}{\lambda} = \frac{(v_x)_{plasma}}{c}$$

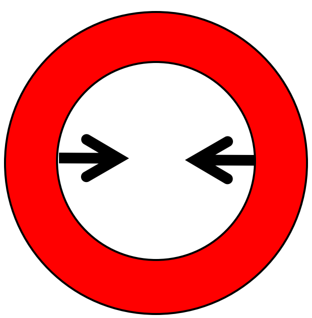


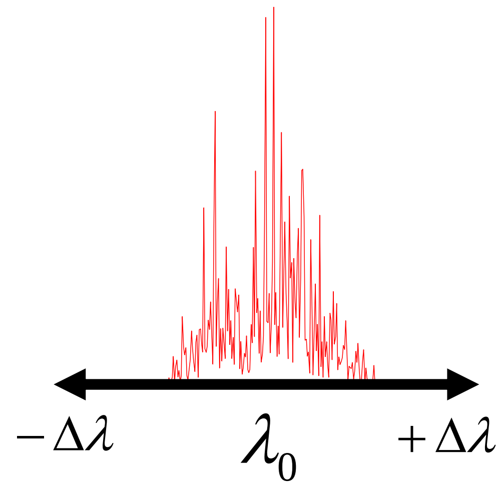
Stationary



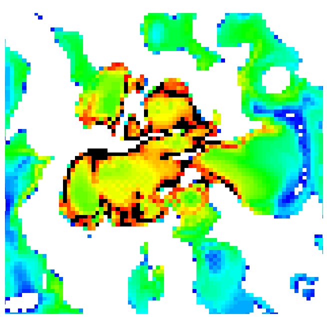


Thin Shell





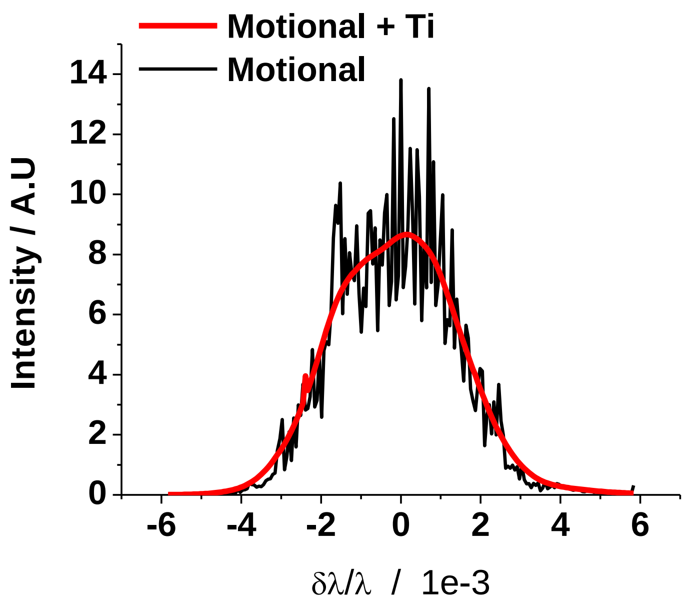
MHD model



Spectral Line Widths can be dominated by plasma motion

Line shape calculated by applying Doppler shift to each emitting zone, and summing over all plasma. To account for Doppler broadening the Doppler shifted delta function of each emitting zone can be convolved with appropriate Gaussian using that zones ion temperature.

Line shapes calculated using Mn-He-α emissivity



At peak k-shell power line width measurements are seriously compromised by motion of the plasma

Ion temperature contribution to broadening of spectral line width in negligible

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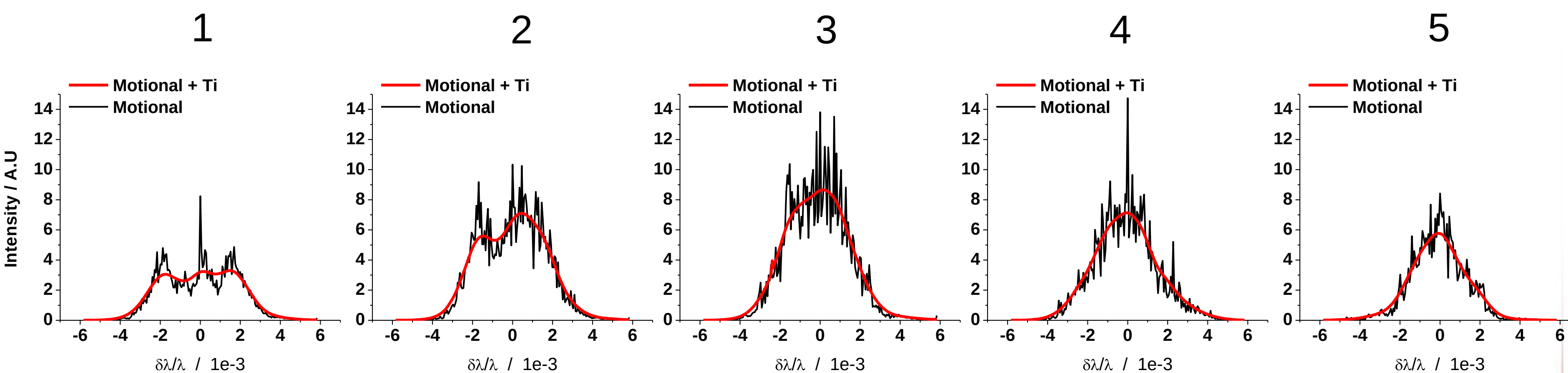
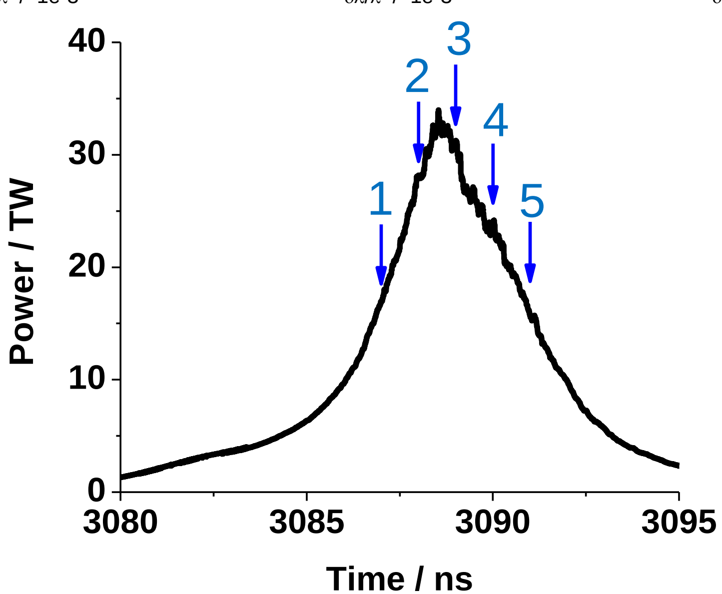
Motional Contamination of Line width measurement persists through stagnation





Line width during K-shell power pulse is massively dominated by motion in the stagnating plasma

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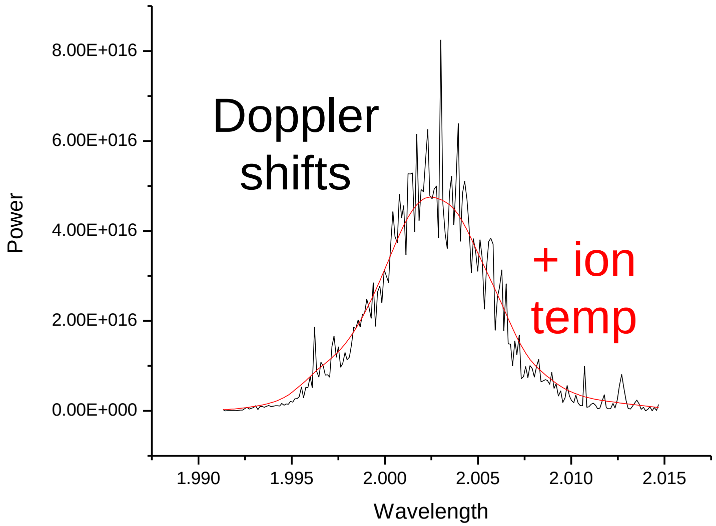
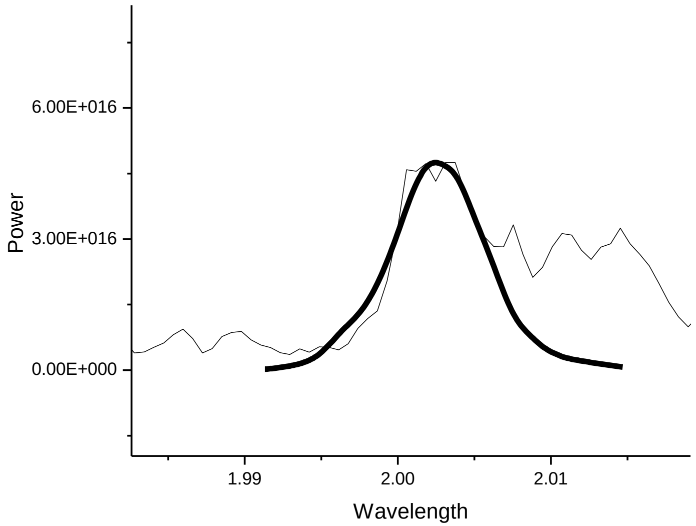
MHD simulations post-processed to compare with specific line widths appears to give reasonable fit to the experiments



Reconstructing spectral line features using specific line emissivity to compare effects of ion temperature and motional broadening



Comparison to measured Mn-He-alpha for 2011

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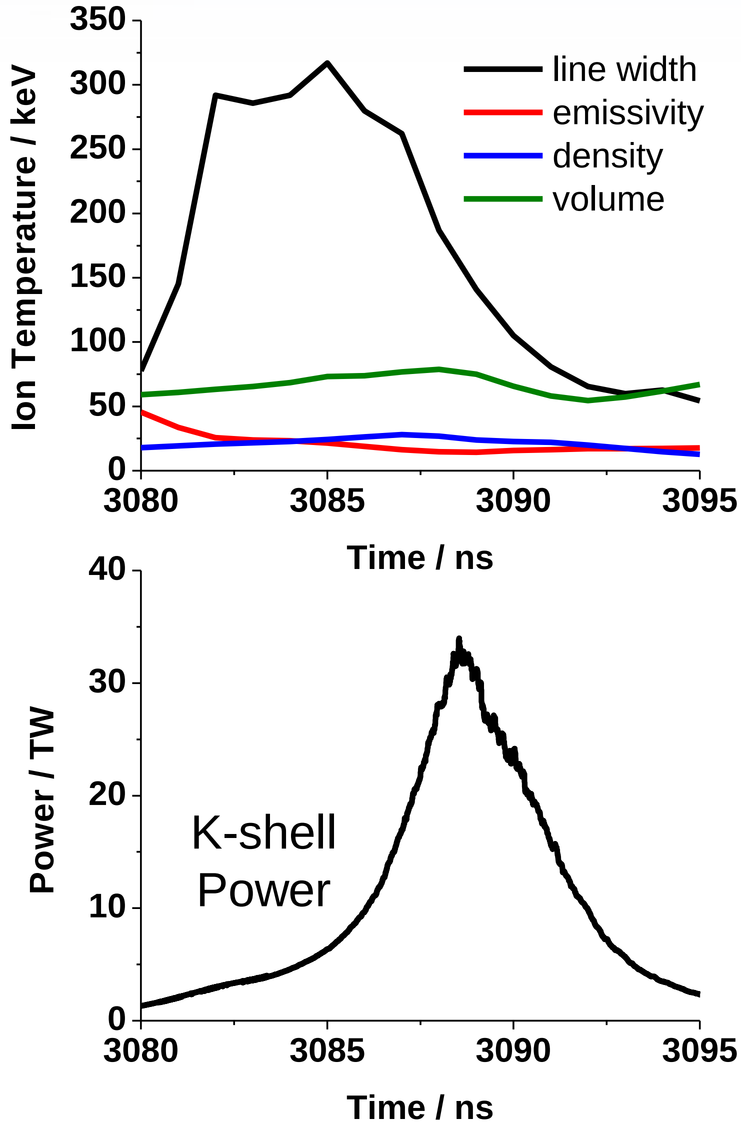
With a highly structured pinch, different measurements can sample different things



- Line width ion temperature is seriously contaminated by plasma motion, so significantly overestimates ion temperature
- Volume averaged ion temperature is skewed to emphasize very hot low density material so does not represent the temperature of material emitting
- Emissivity weighted ion temperature is ~15keV around peak k-shell power.
- The material actually radiating has a relatively low ion temperature

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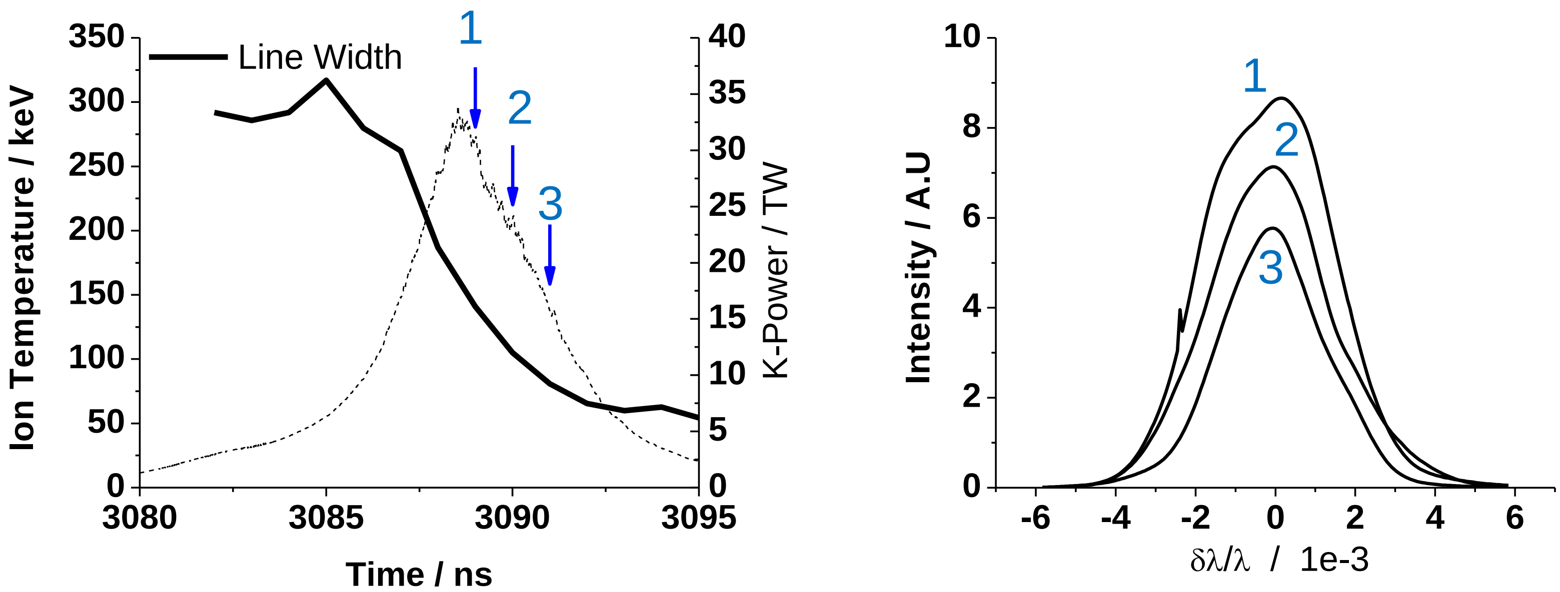
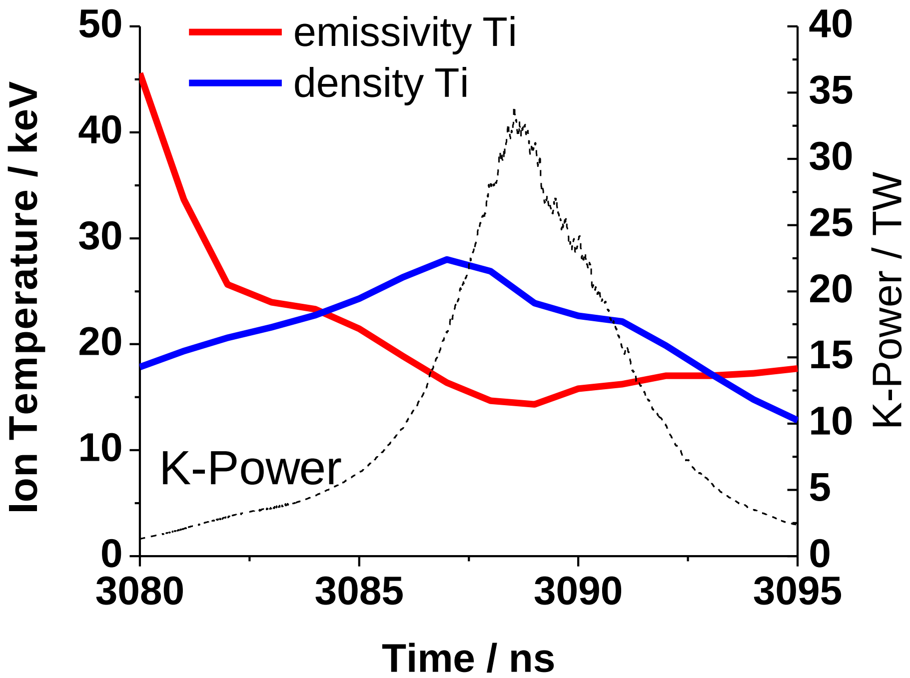
Line width narrows significantly over K-shell Power Pulse



Plasma decelerating throughout stagnation, so motional contribution to line width gets smaller. i.e FWHM gets smaller during x-ray pulse. If this were interpreted as ion temperature it would look like the plasma has cooled from ~140keV to 80keV in the 2ns after peak power.

From comparison with measured K-shell power the calculated rise and fall are too slow, so need to refine calculations

Ion temperature of material emitting is not the same as the ion temperature that drives the dynamics



- Emissivity weighted ion temperature is the average temperature of the material that is emitting
- Density weighted ion temperature better represents the temperature that determines the pressure and drives the dynamics – these differ by ~60% at peak power

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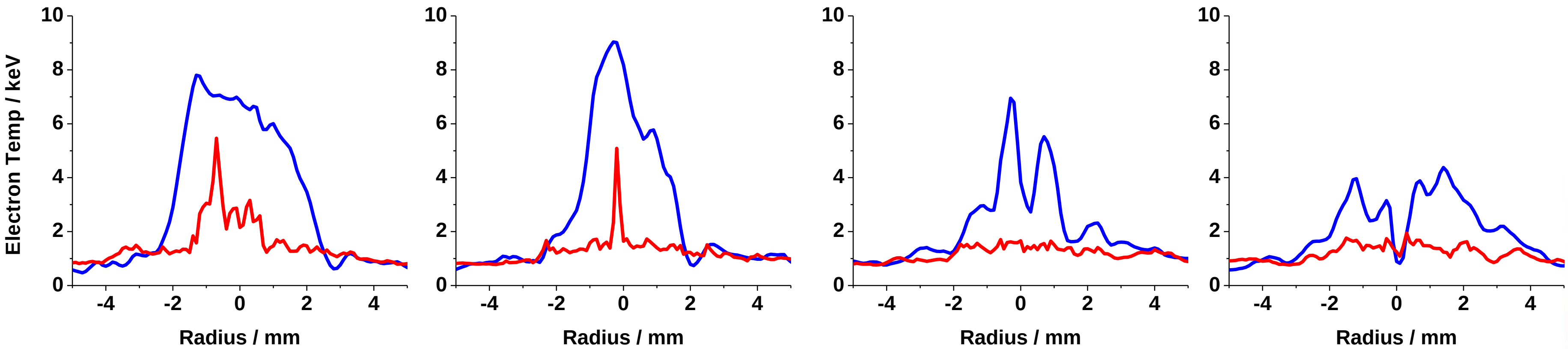
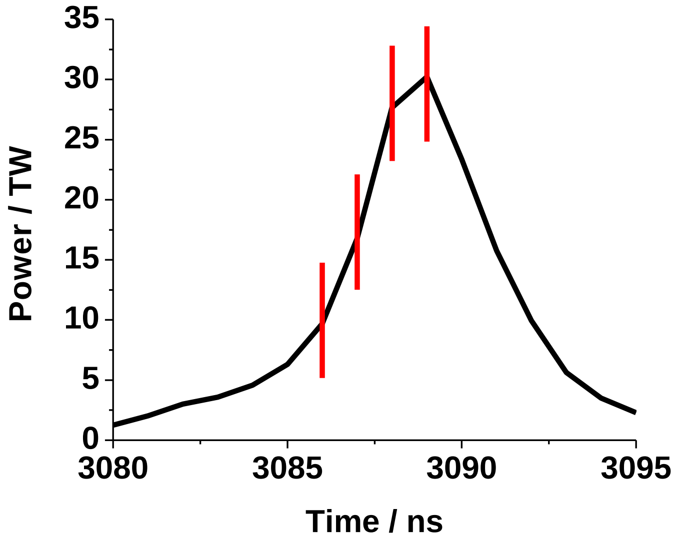
Emission diagnostics will only sample the areas that are emitting

Red=average electron temperature
Blue=emission weighted electron temperature

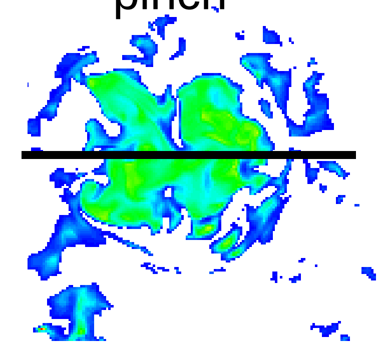
Lineout's through end on profiles integrated along z





Emission diagnostic samples the electron temperature, then it does not capture the low density hot material that can dictate the emission process, but does not itself emit very strongly

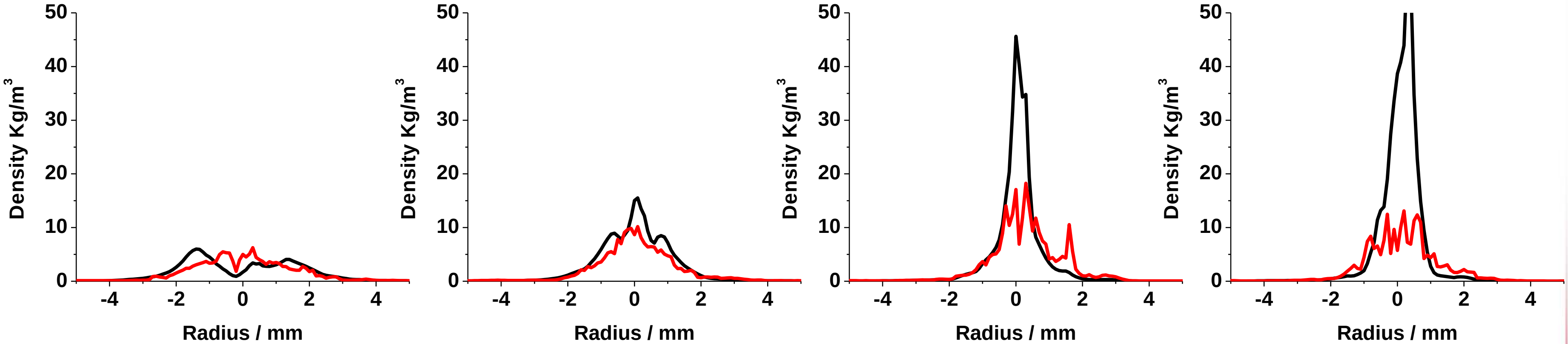
Line outs through pinch

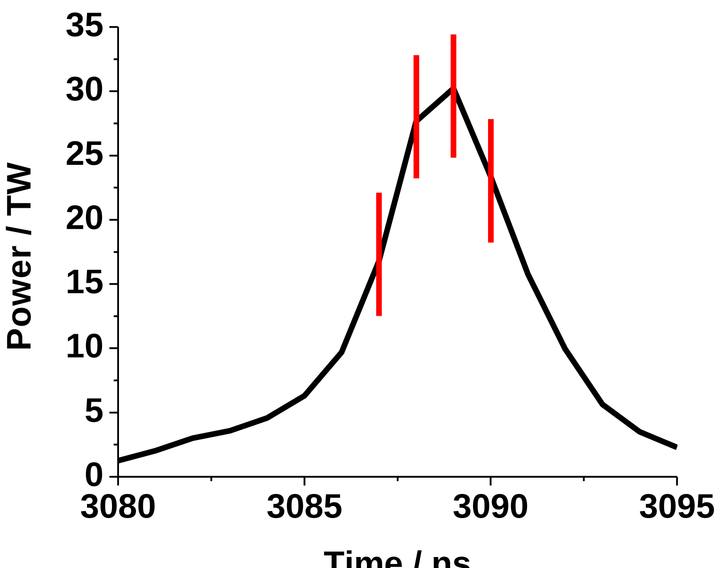


Similarly, emission features used to locate density may not represent the mass distribution

Red=emissivity weighted density
Black = average density

Lineout's through end on profiles integrated along z





At late times opaque regions will not contribute to emission, so we expect a discrepancy, but at early times an emission diagnostic preferentially samples emitting regions, so does not represent the mass distribution

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Summary

- K-shell emission predominantly comes from the inside surface of an imploding shell impacting hot, low density material assembled on axis
- Pinch is highly structured at stagnation, but integrated diagnostics do not necessarily represent this
- Large non-uniformities throughout a dynamic stagnation necessitate development and direct comparison of real and synthetic diagnostics so assumptions on plasma conditions are not introduced.

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