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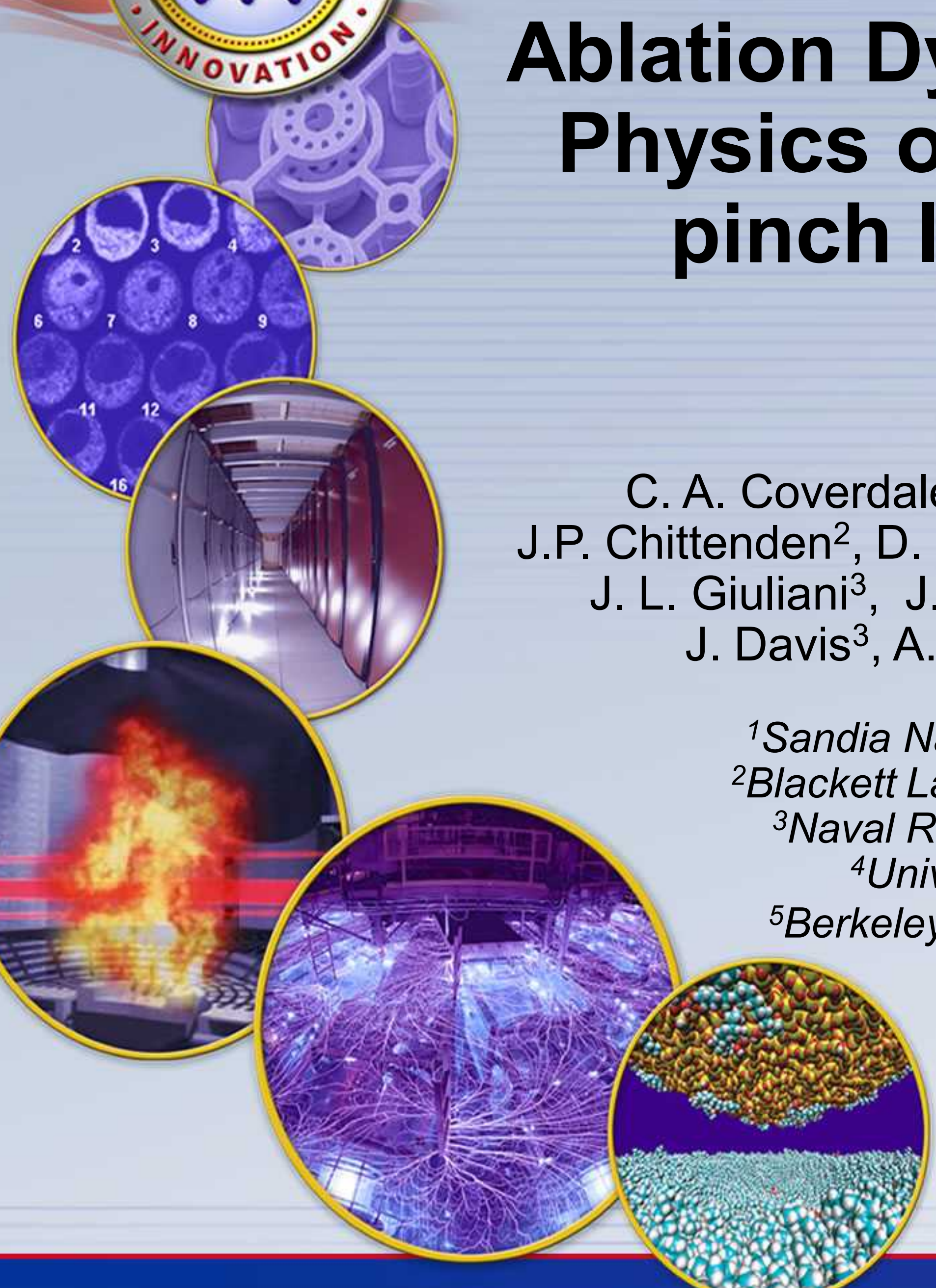

Ablation Dynamics and Stagnation Physics of Copper Wire Array Z-pinch Implosions at 20 MA

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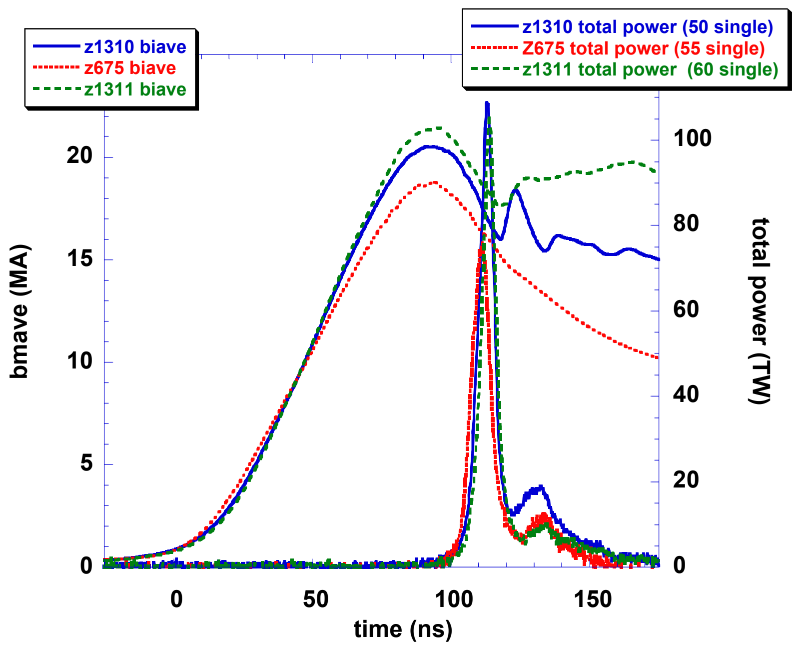
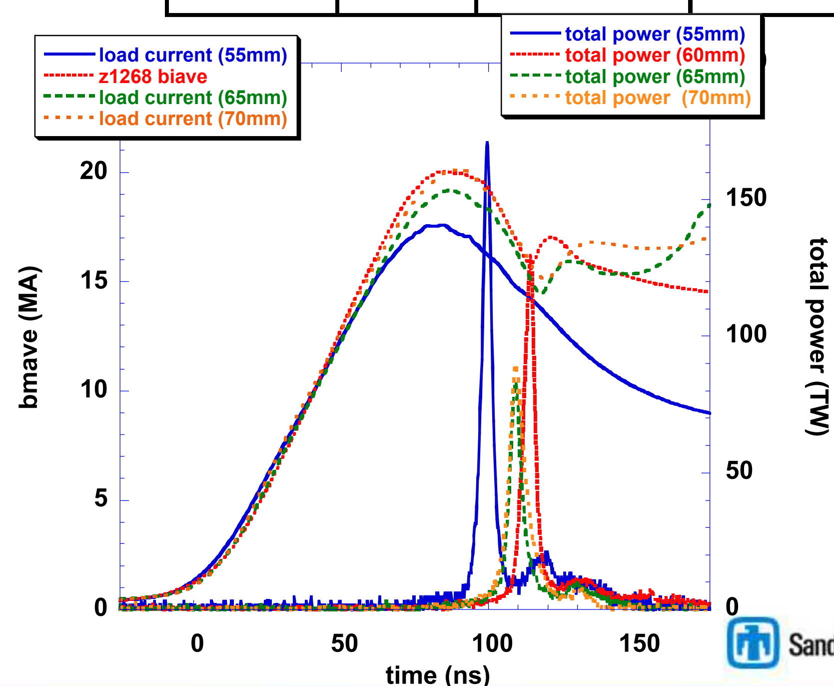
Load configurations for Cu wire arrays

- **Designed to have similar implosion times**
- **IWG large**

- **Scaling theory suggests all these loads have low η and will have trouble radiating in the K-shell**
  - **Difficult to achieve high temperature over large region with energy available**

array dia. (mm)	wire no.	interwire gap (mm)	array mass (ug/cm)	total mass (ug)
50	128	1.23		2216
55	80	2.16		1984
60	88	2.14		1524
55	92	1.88	712	
27.5	46	1.88	353	2130
60	80	2.36	625	
30	40	2.36	312	1874
65	64	3.19	609	
32.5	32	3.19	273	1764
70	56	3.93	533	
35	28	3.93	239	1544





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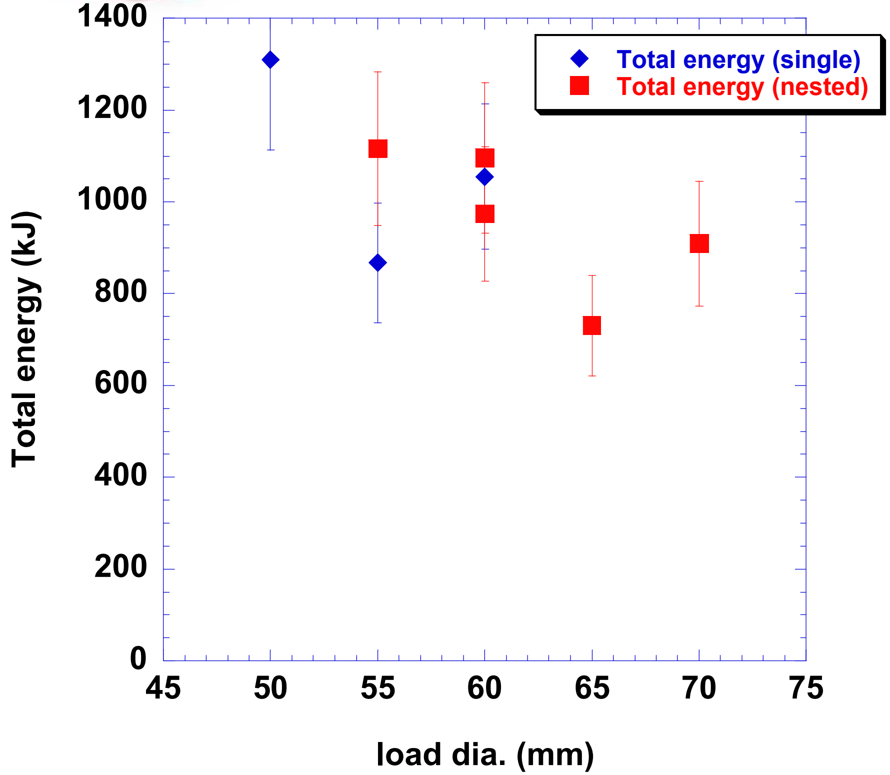
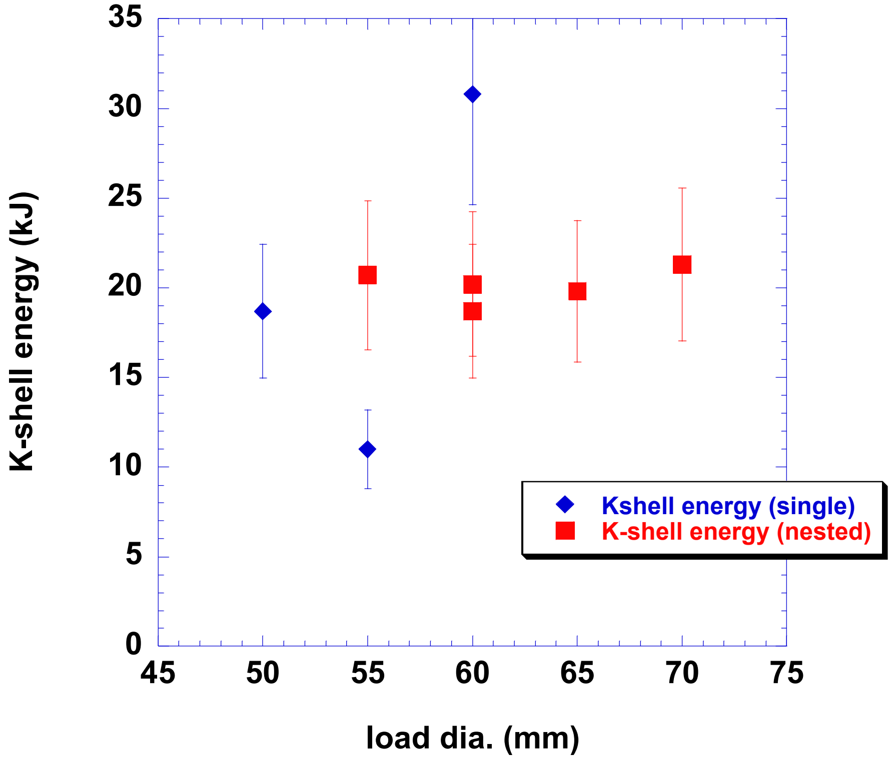
Total radiated output decreased for largest arrays, K-shell output was consistent





- **Total radiated energy trend is similar to that observed with SS wire arrays**
  C.A. Coverdale et al., Phys. Plasmas 15, 023107 (2008)
  - **Reduction in mass to maintain implosion time reduces number of radiators available**
- **K-shell output stable for nested arrays, but no specific trend as observed with lower Z materials**
  - **Single arrays less stable**

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Modified scaling theory does not replicate observed trend

$$F = j \times \mathbf{B} = ma$$

$I^2 \sim m$ or $I \sim m$

$\varepsilon \sim n^2 \sim m^2 \sim I^4$ or $\varepsilon \sim n^2 \sim m^2 \sim I$

$Y_K = \varepsilon V \Delta t \sim I^4$ or $Y_K = \varepsilon V \Delta t \sim I^2$

Modified scaling theory:

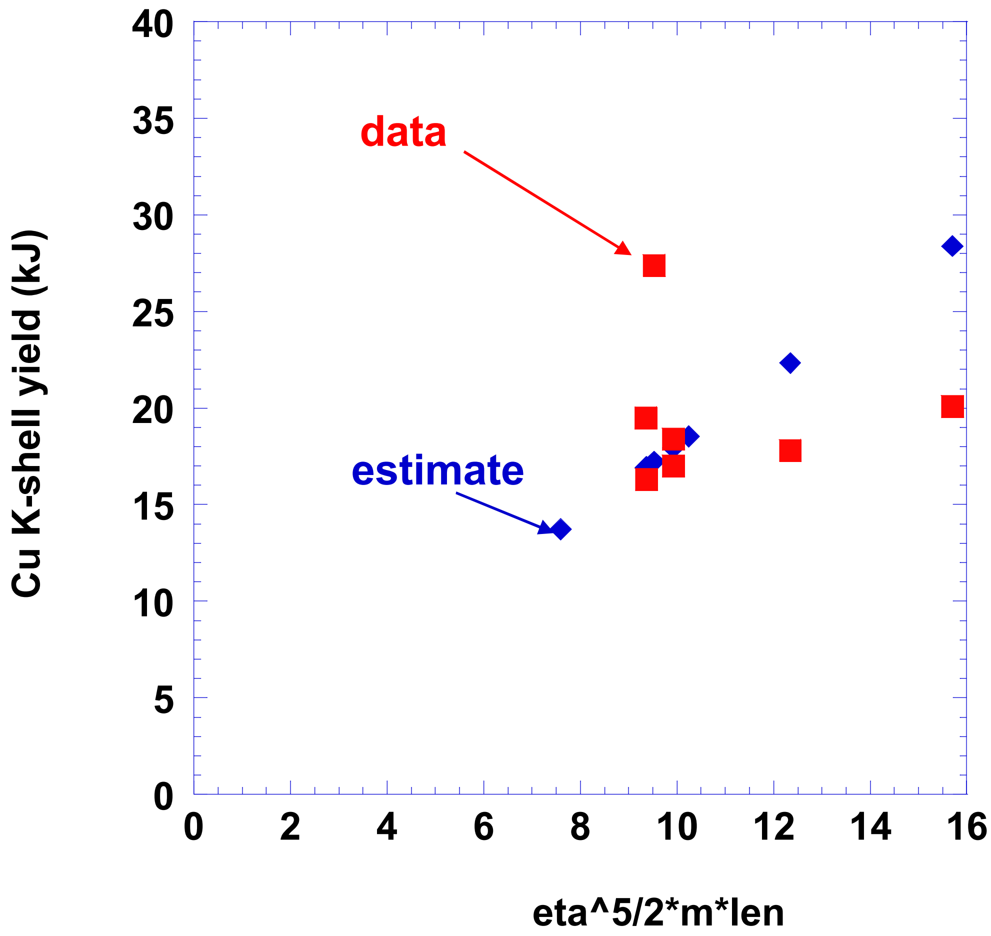
$$Y_K = f\, S\, E_{j\times B}$$
$$S = \min\left(1, m/m_{BP}(Z,\eta)\right)$$
$$f = \min\left(0.3, c(Z,\mathrm{load})\, Z^{1.2} E_{j\times B}^{3/2} / m^{5/2}\right)$$

J. W. Thornhill et al., IEEE T. Plasma Sci. 34, 2377 (2006)

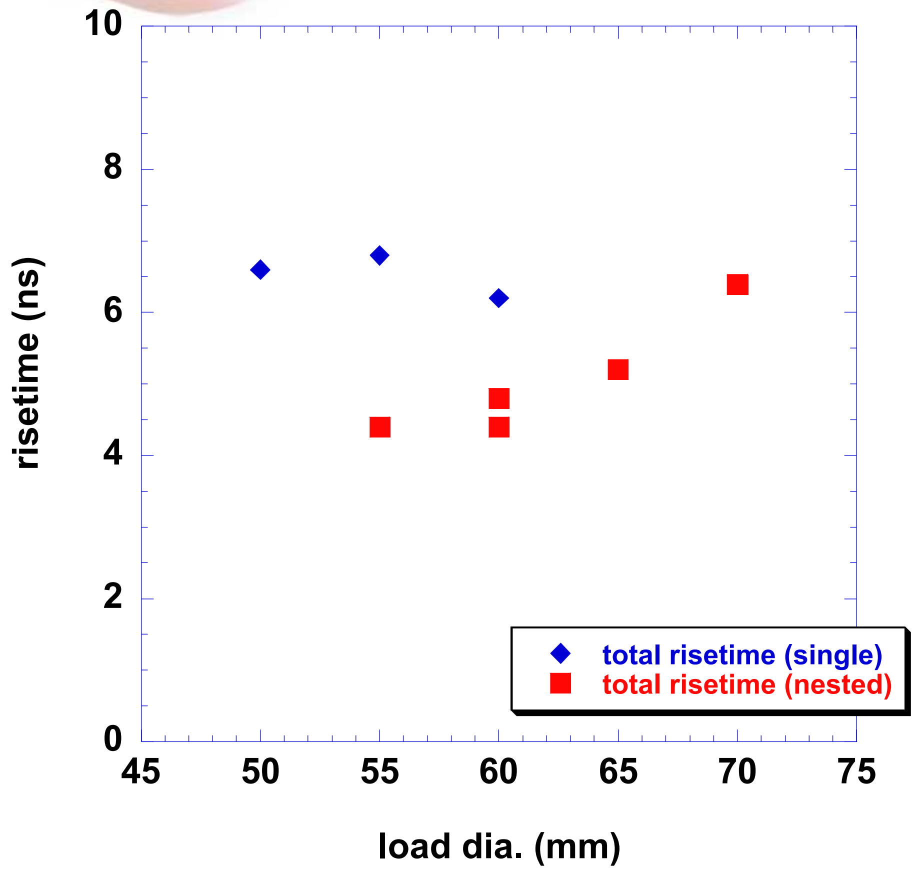
K-shell scaling for Fe at Z was reduced to a simple expression

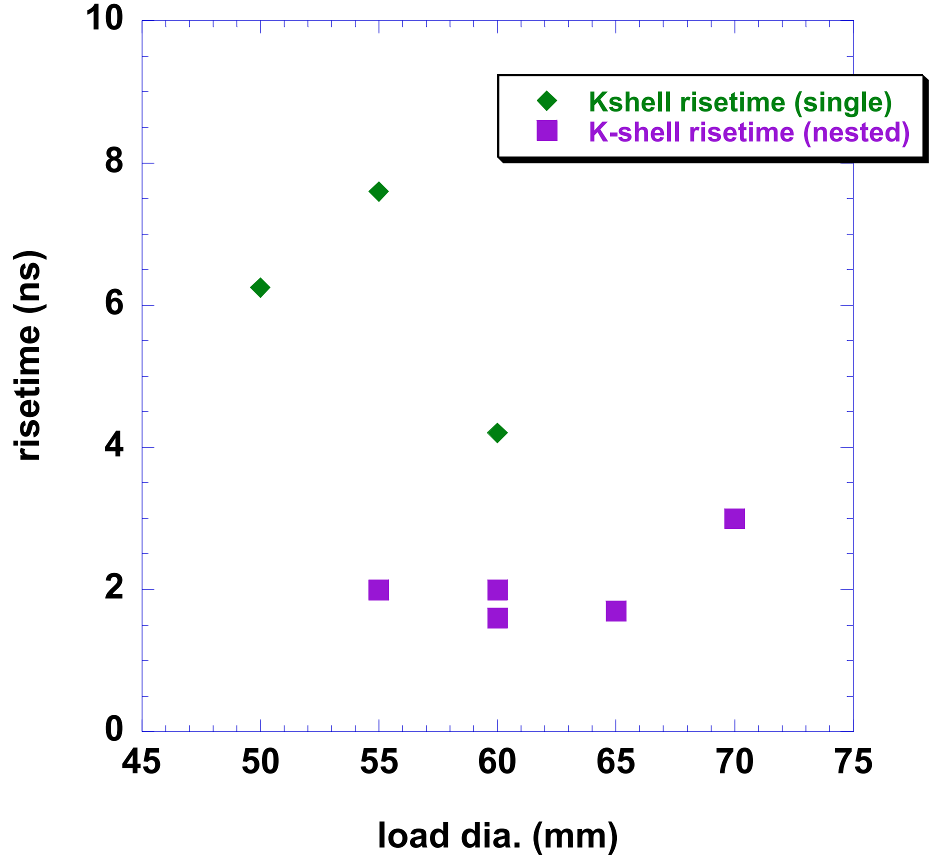
$$Y_K = c(Z,\mathrm{load})\, F(Z)\, \eta^{5/2} m l$$

B. Jones et al., Phys. Plasmas 15, 122703 (2008)



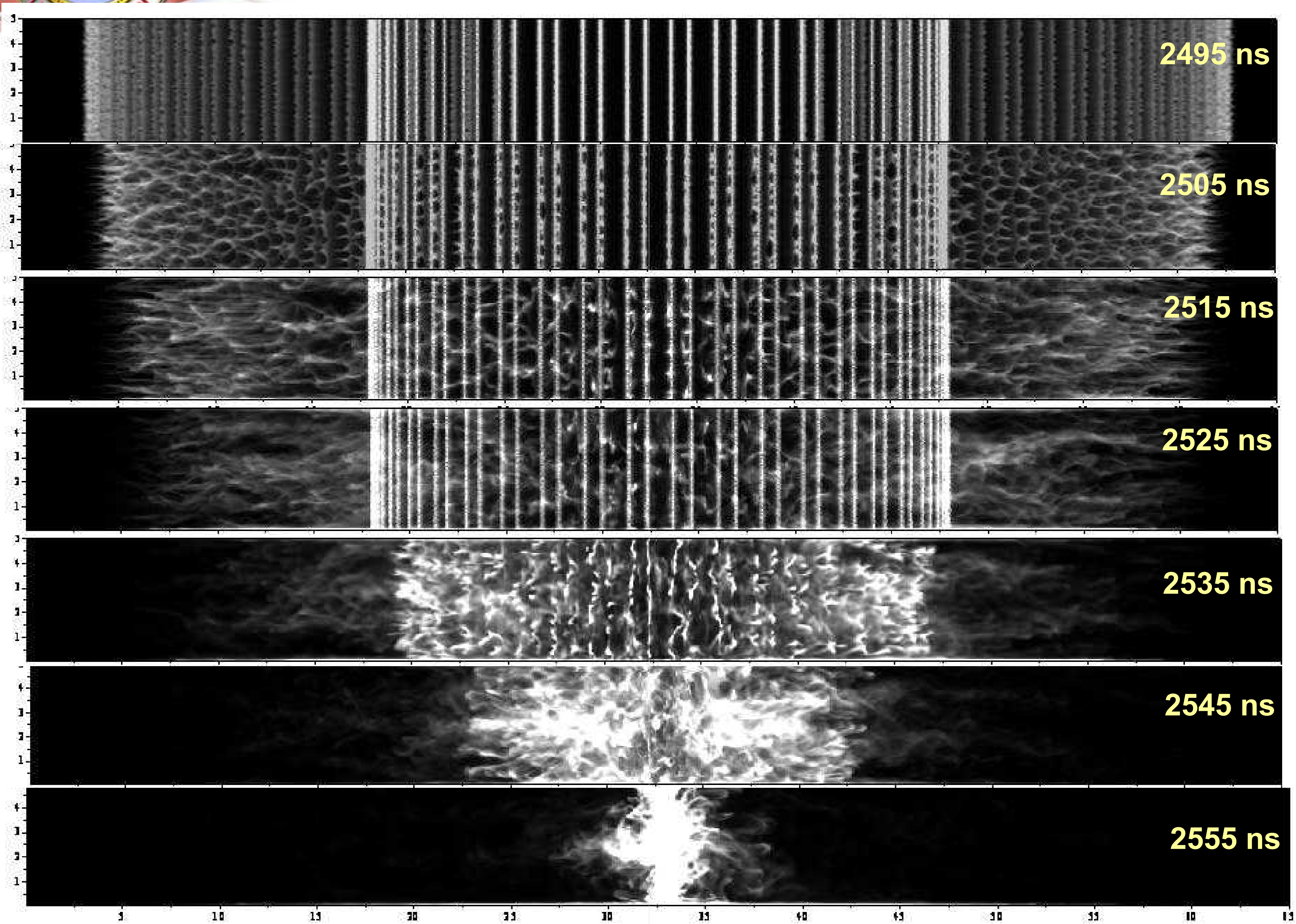
Larger diameter arrays and single arrays have longer risetime





- Risetime previously shown to be correlated to Rayleigh-Taylor instability growth
  - Shell thickness ~ risetime * velocity
- Larger diameter arrays are expected to have higher instability growth
- Single arrays should have higher instability growth
  - Nesting of arrays should partially mitigate MRT

3D Gorgon simulations show substantial instability

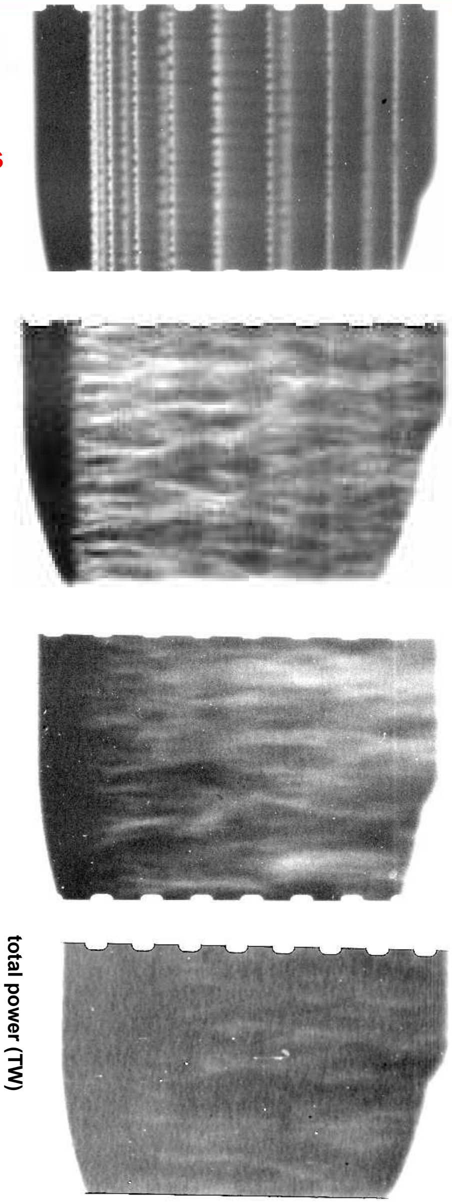


Radiographs can be compared with the Gorgon results

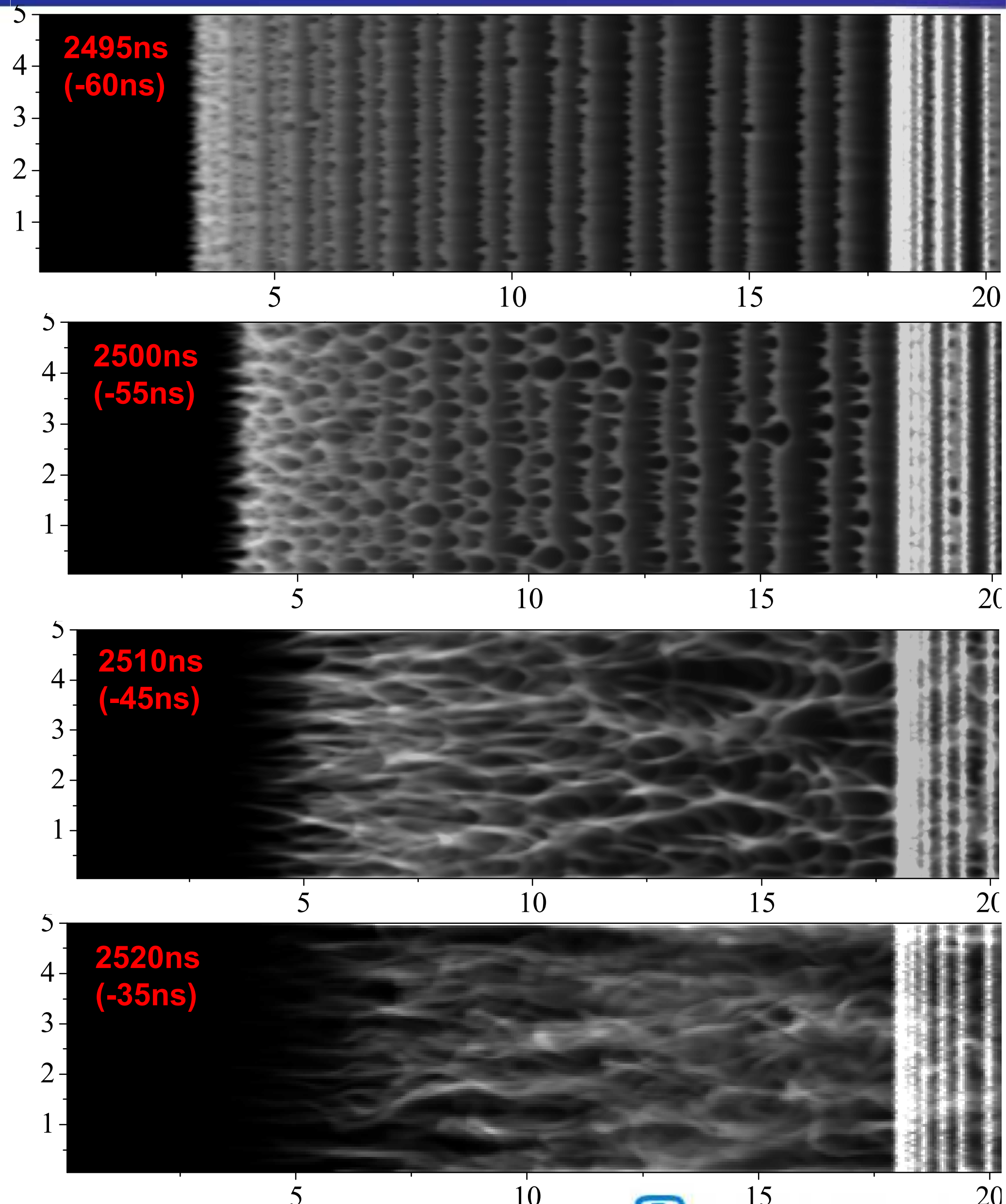
Z1284
t~ -61.4 ns

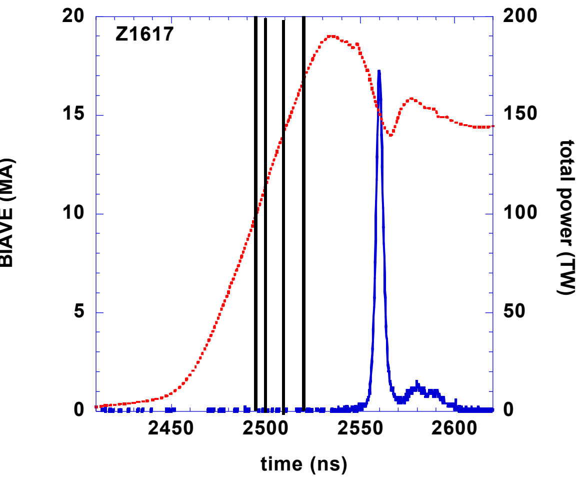
Z1270
t~ -54 ns

Z1268
t~ -44 ns



Z1269 t~ -34 ns





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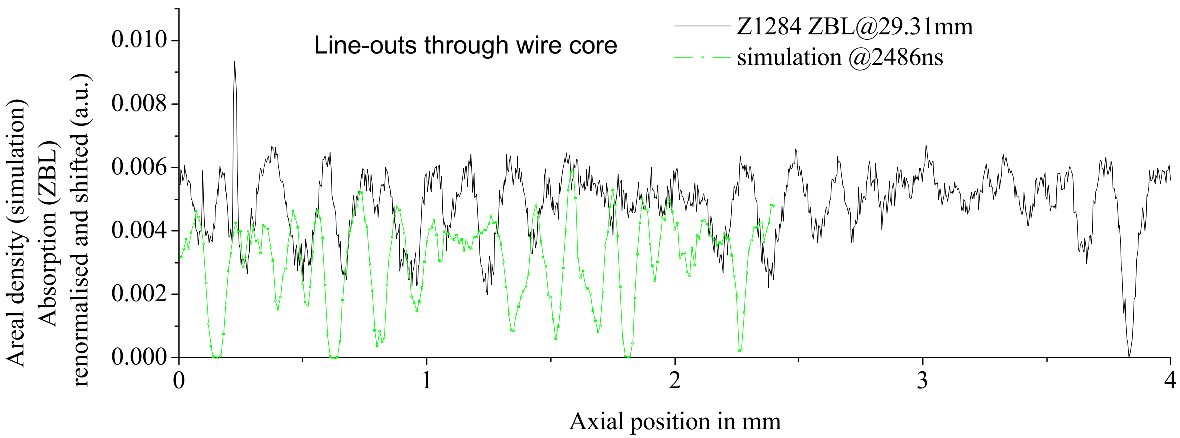
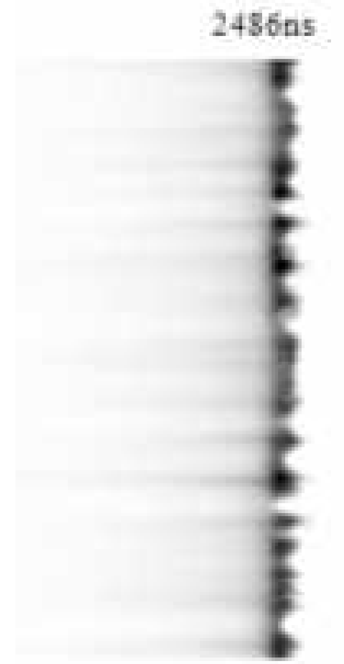
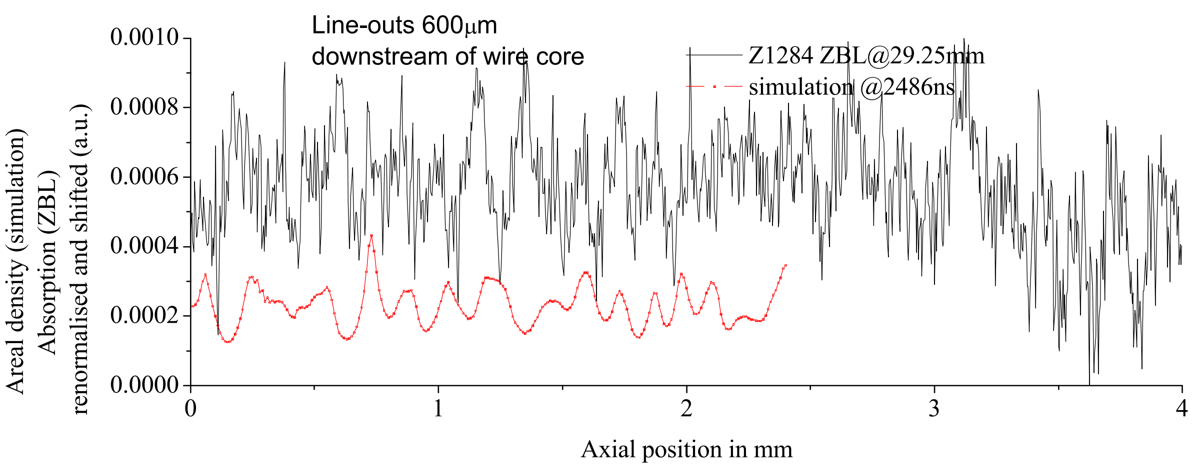
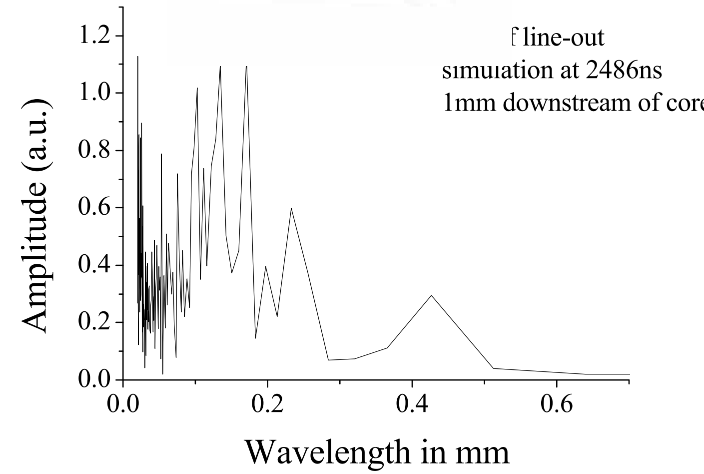
Data has noise which makes quantitative comparison more complicated

Work in progress



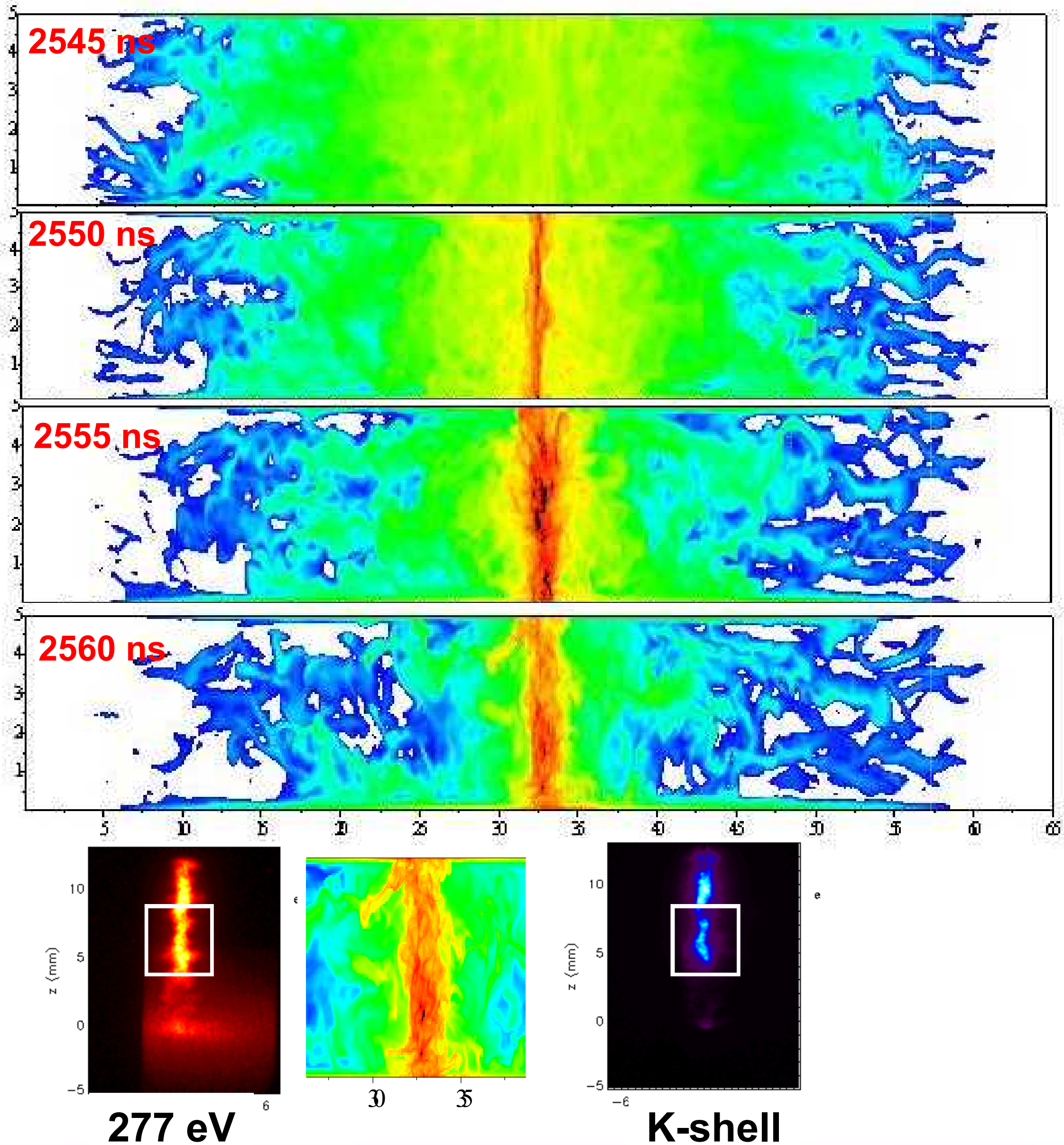


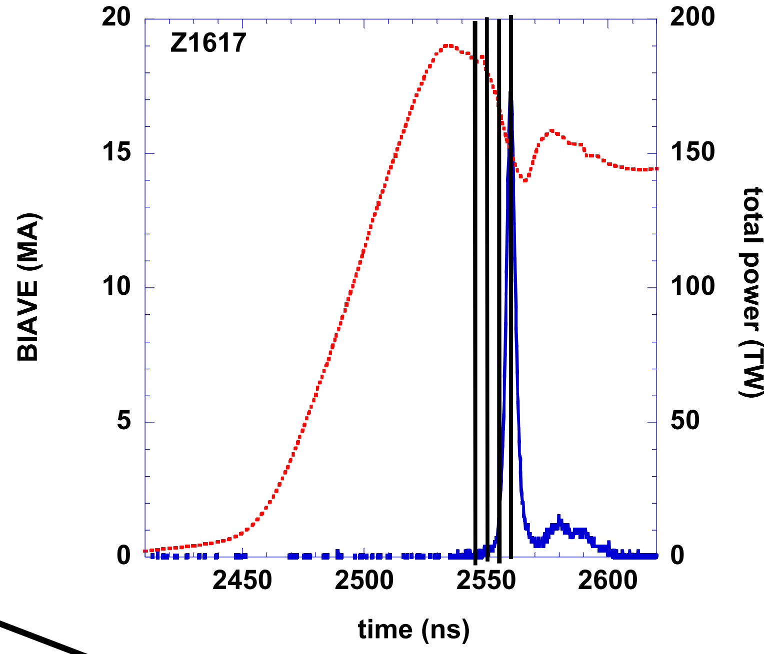


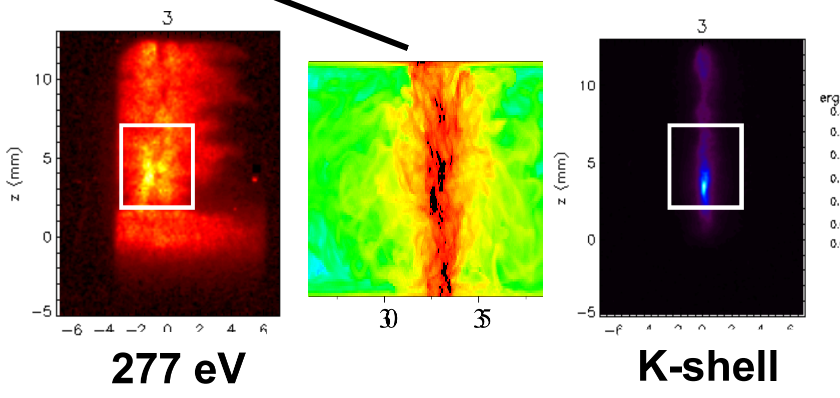


Gorgon output can also be compared with images of pinch near stagnation

Emission images (unfiltered)



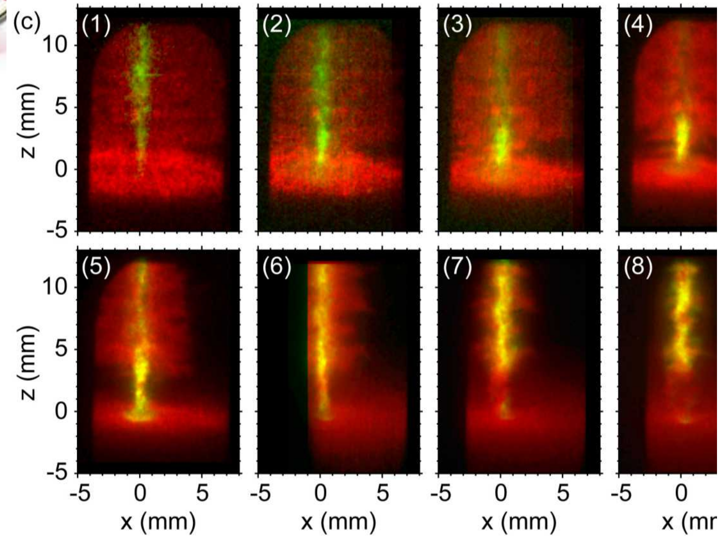


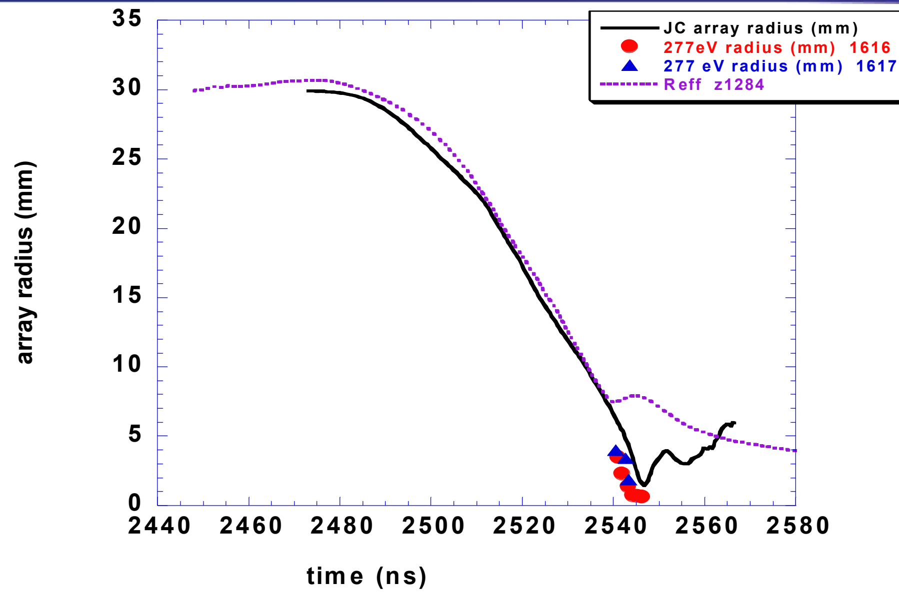


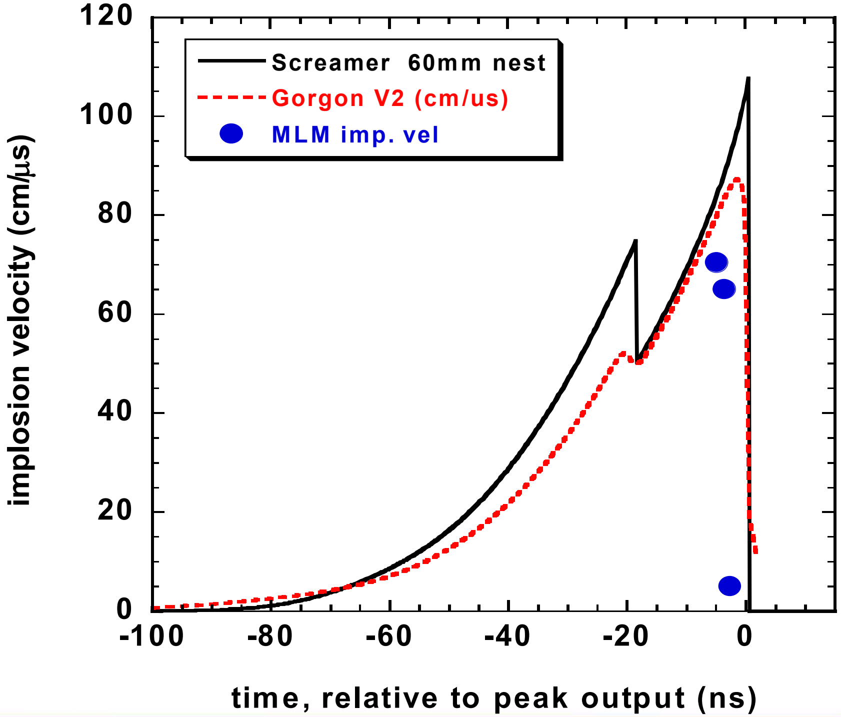
Final stage of the implosion can be studied with pinhole images

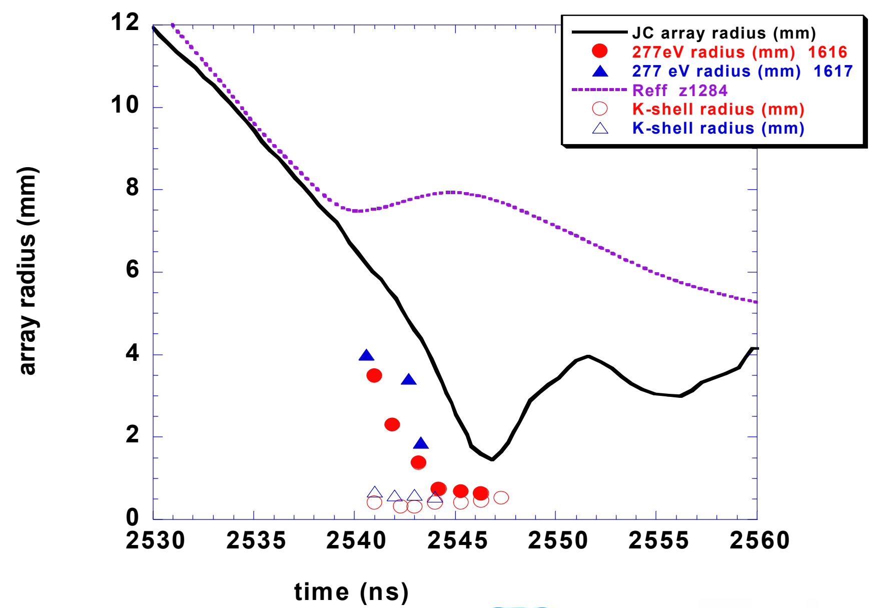
Z1616

Overlay of 277 eV (red) and K-shell (green) to produce a combined image (yellow). Frame 1 is at -6.5 ns, Frame 8 is ~ +0.5 ns









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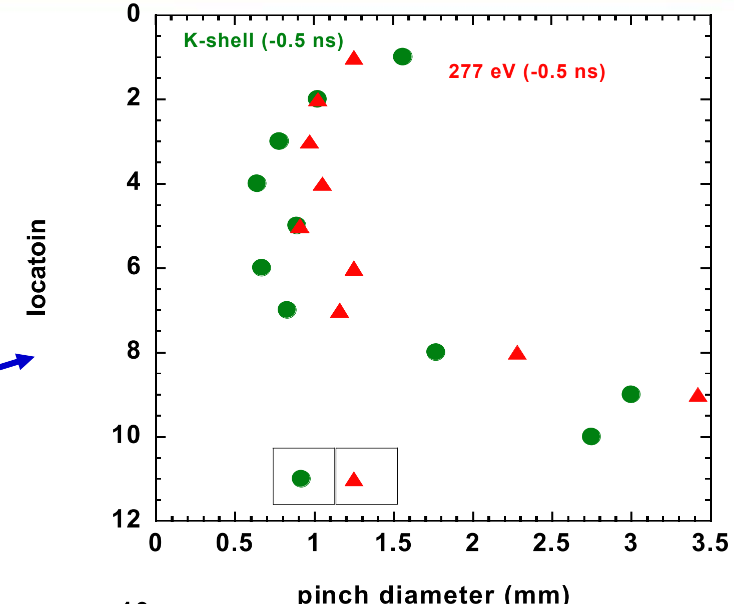
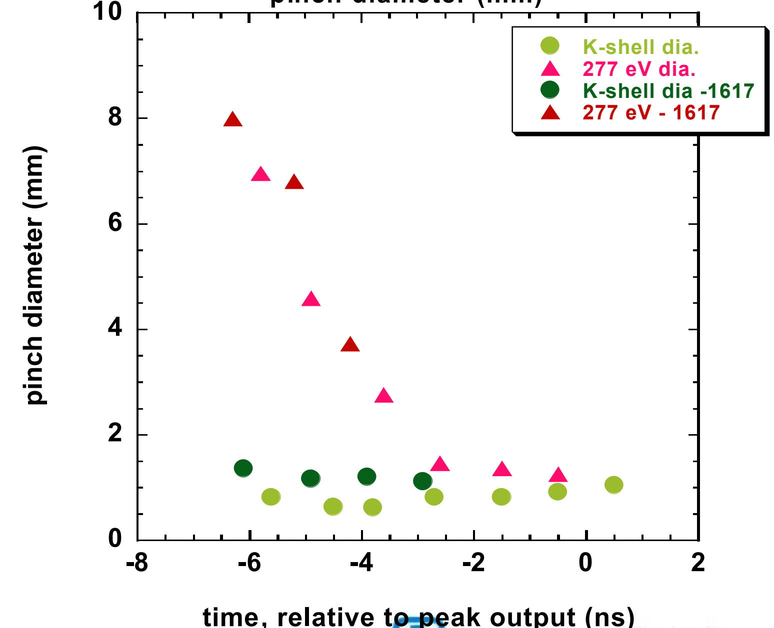
Pinhole images illustrate structure, and cool vs. warm regions

Z1616

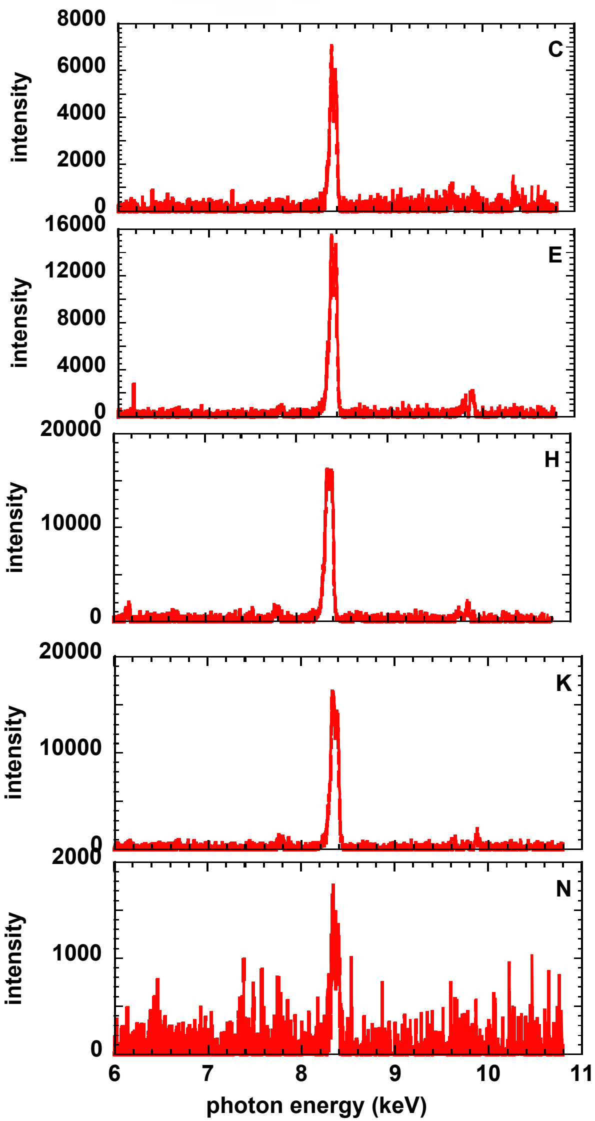
Overlay of 277 eV (red) and K-shell (green) to produced a combined image (yellow). Frame 1 is at -6.5 ns, Frame 8 is ~ +0.5 ns



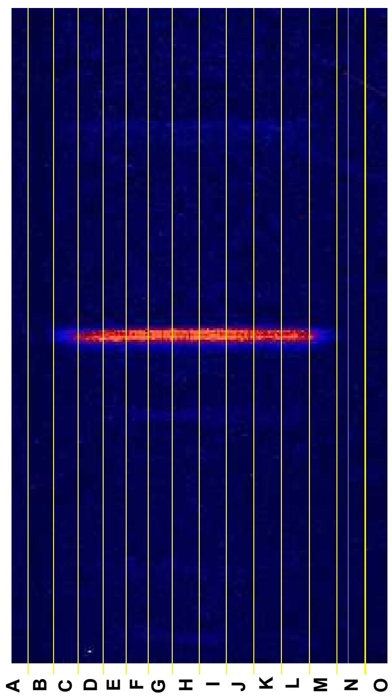


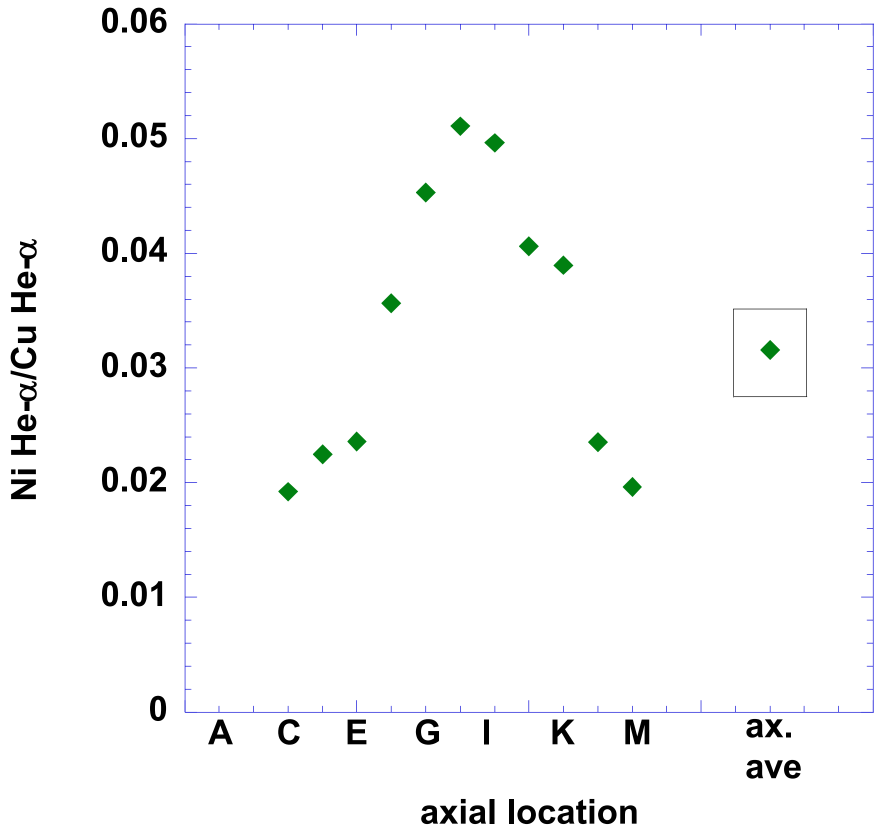
- Along the length of the pinch near stagnation, cold region is broader than K-shell emitting region
- 277 eV lineouts (at 0 ns) show consistent shape and amplitude whereas the K-shell lineouts (-0.5s) show larger variation in shape and location of peak
  - Bright spots likely due to difficulty in achieving Cu K-shell emission
  - Most of the emission comes from these bright regions, which are likely tied to instability growth

Analysis of Cu K-shell spectra also shows variation in plasma conditions along the length of the plasma



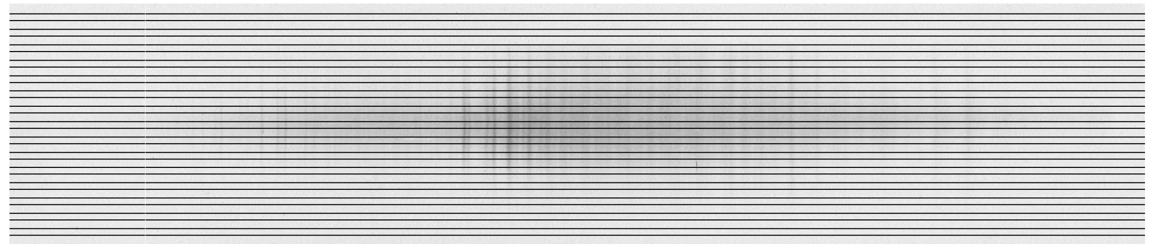
Z1617
Cu, 60mm diameter



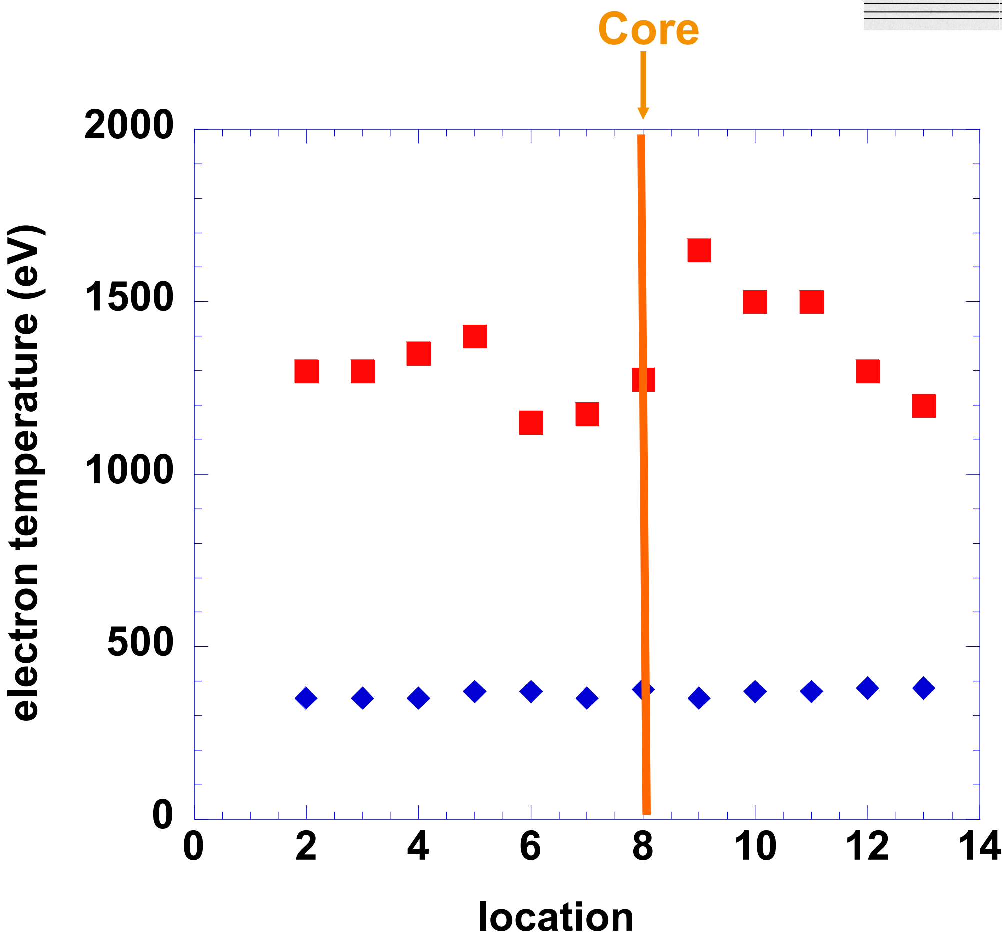


- Variation in line ratios suggests substantial non-uniformity in T_e, n_i along length of pinch
  - Reinforces that emission is localized for Cu

Cu L-shell is also being evaluated



$N_e = 10^{20} cm^{-3}$



- The temperatures inferred from the L-shell range from < 500 eV (Ne-like states) to ~ 1.3 keV (Li-like states)
- Comparison of K-shell and L-shell illustrate temperature gradients present in the plasma, and the physical extent of the hot and cold regions

Summary

- Cu wire array loads at Z have provided an opportunity to study a variety of interesting physics
- Yield and pulseshape trends illustrate the effects of instability growth on radiated output
  - Application of modified scaling theory illustrates importance of load parameters
- Radiographs show structure very similar to what is calculated with 3D Gorgon
  - Full analysis still in progress
- Pinhole images and spectra allow for detailed analysis of near-stagnation and stagnated pinch
  - Pinch size (277 eV) tracks Gorgon and Inductance Unfold estimates
  - Implosion velocity estimates similar to Gorgon values, noticeably less than 0D prediction
  - Regions of bright K-shell emission evident, with K-shell emitting regime more localized than 277 eV emitting regime
  - Axial structure in K-shell emission mirrored by time-integrated spectra, which show regions with bright emission
    - Cu K-shell emission appears to rely on instability growth