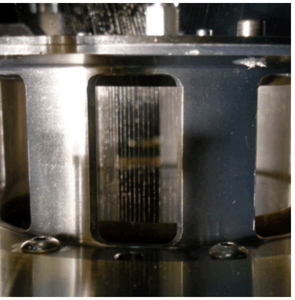
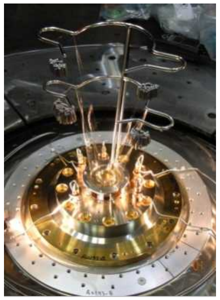
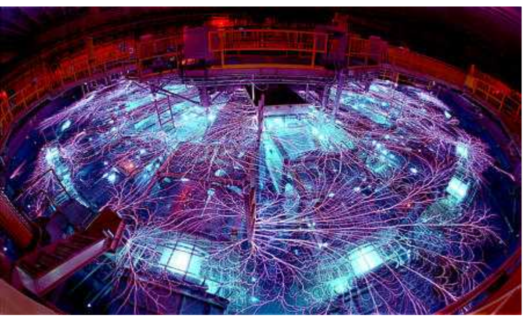
11/12/2014

SAND2014-19456C

Computational Modeling of Kr Gas Puffs on Z







Sandia National Laboratories

Exceptional service in the national interest

C. Jennings

Experimenters:
Dave Ampleford, Brent Jones, Adam Harvey-Thompson

SITF (gas puff assembly and characterization)
D.C.Lamppa, M. Jobe

Gas Puff Z integration
M. Jones, D. Johnson, T. Strizic. J. Reneker

Radiation Physics
S. B. Hansen

Alameda Applied Sciences (Gas Puff)
M. Krishnan, P.L. Coleman

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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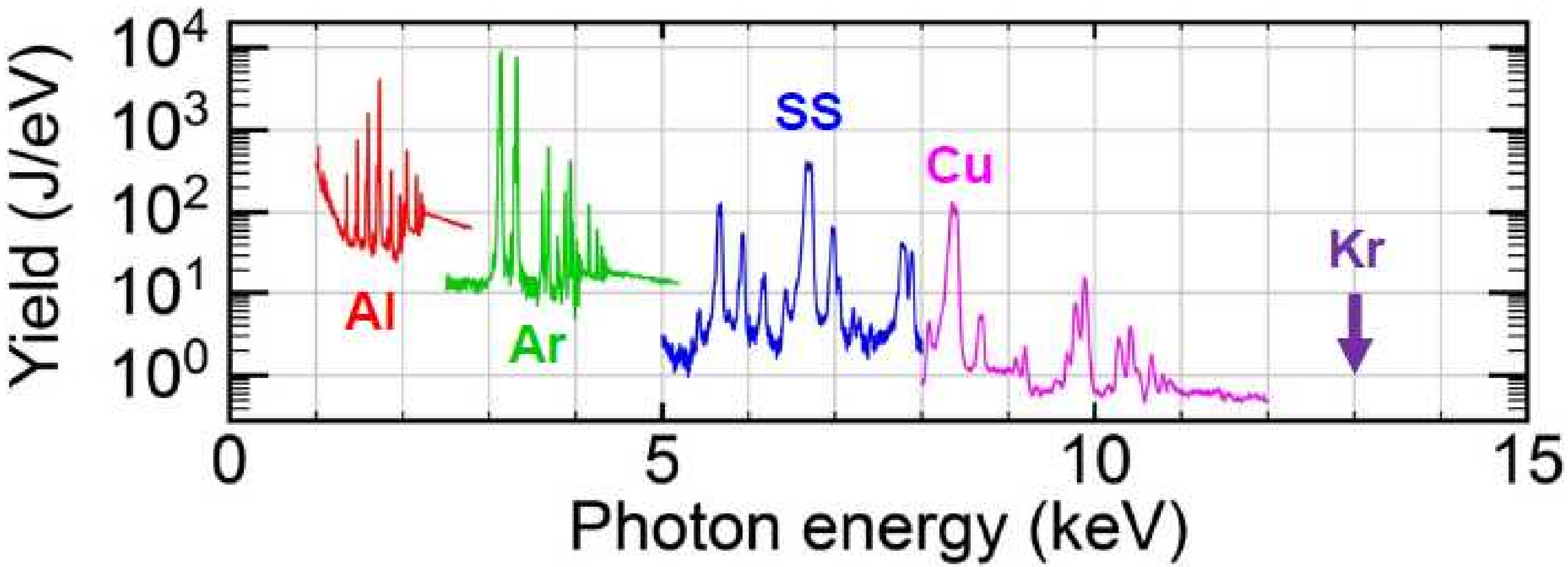
Z Generator ~20MA in ~100ns

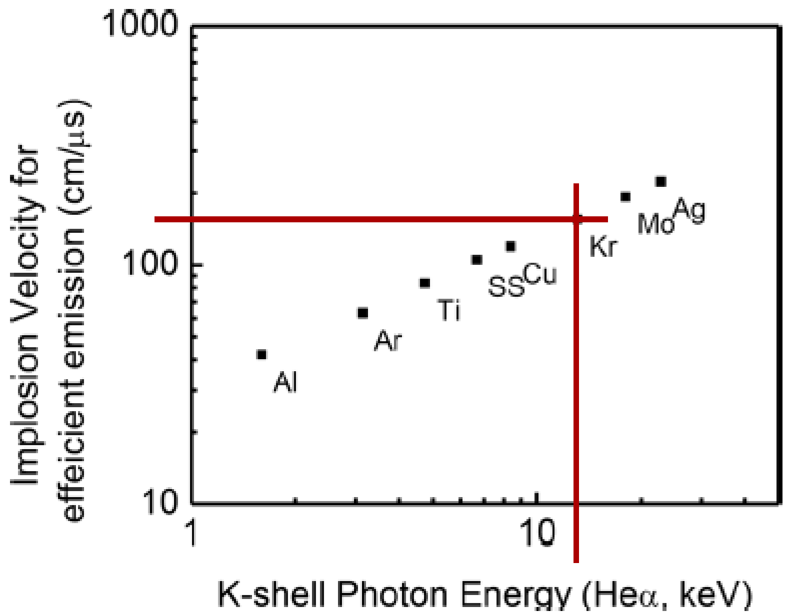
Bright Laboratory Thermal Source of Soft X-rays



Higher Photon Energies ← **Higher Electron Temperatures** ← **Higher Kinetic Energy Thermalized** ← **Larger Initial Radius**

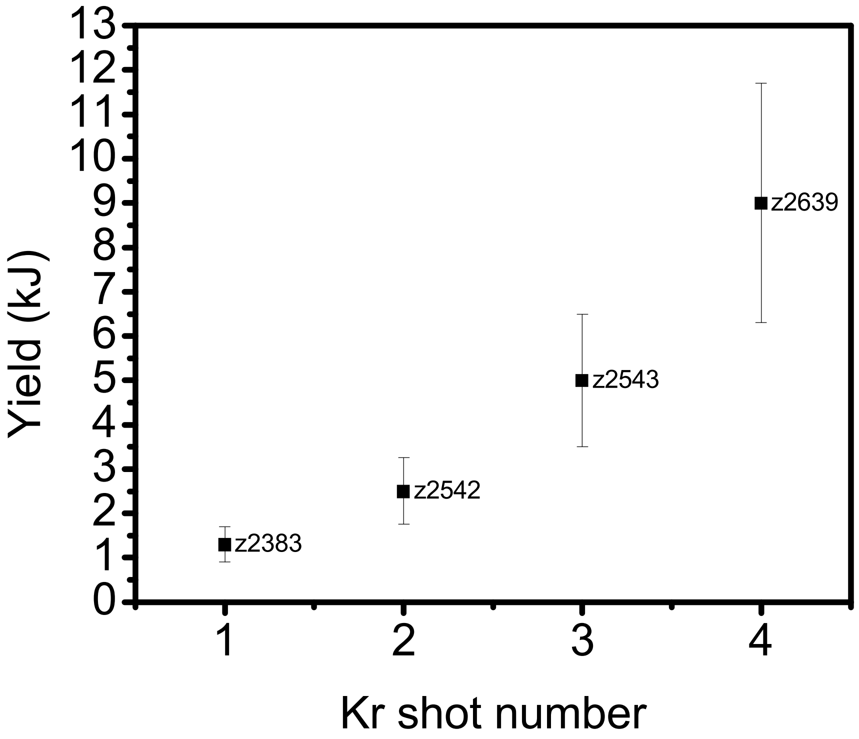
We need to magnetically accelerate ~1mg to 1000km/s over many cm's and keep it stable !

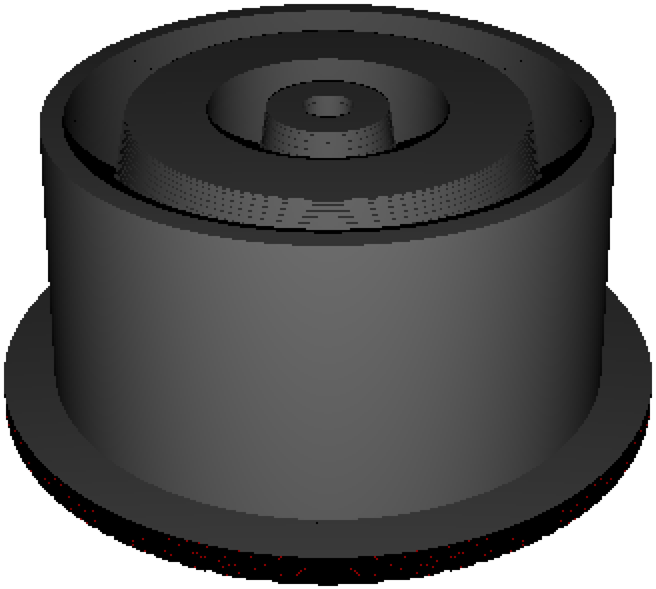
We need implosion velocities in excess of ~1000km/s to make this work



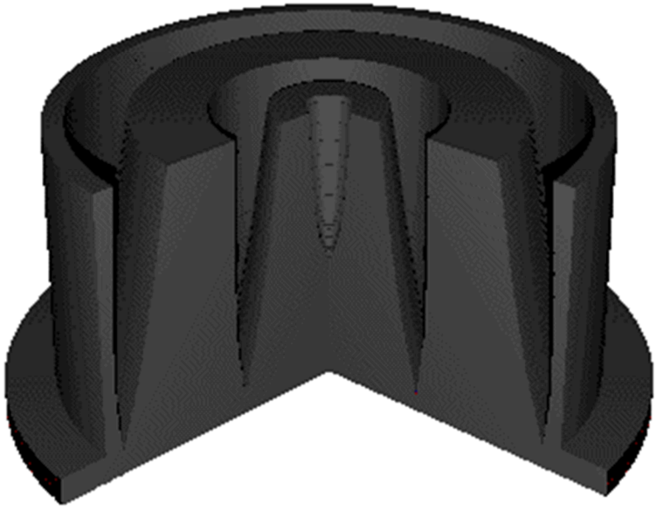
PHYSICS OF PLASMAS **21**, 056708 (2014)

Using the tools and methodology described here we achieved a factor of ~8 increase in K-shell yield in our first 4 shots.



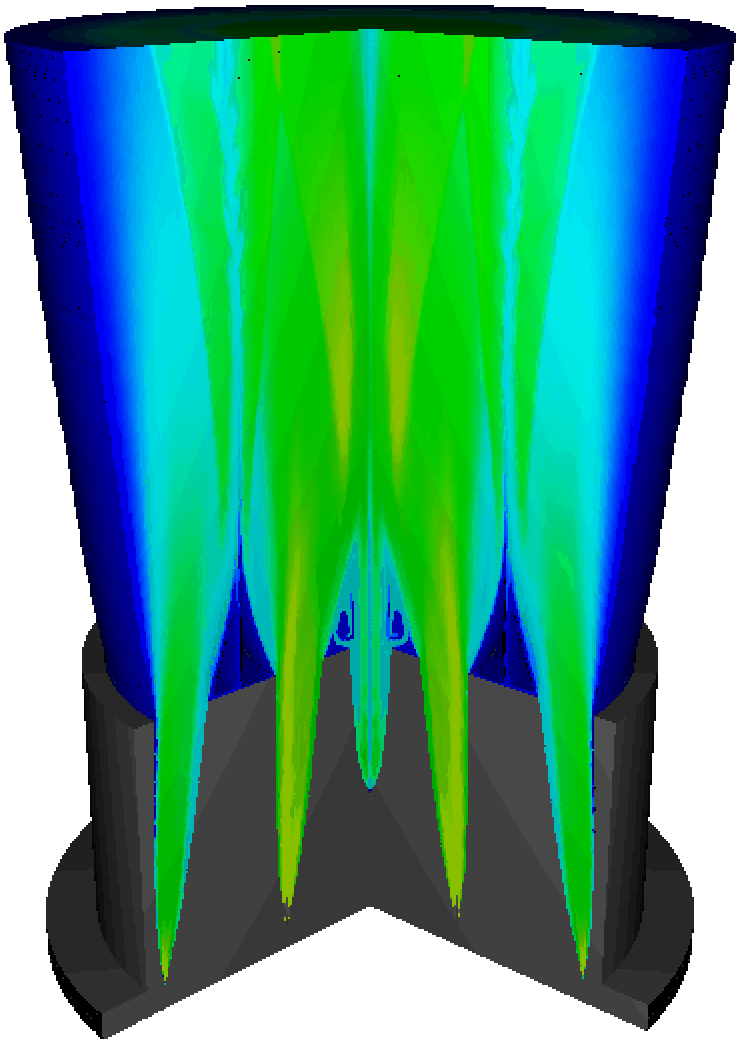


Hydrodynamic Gas Flow



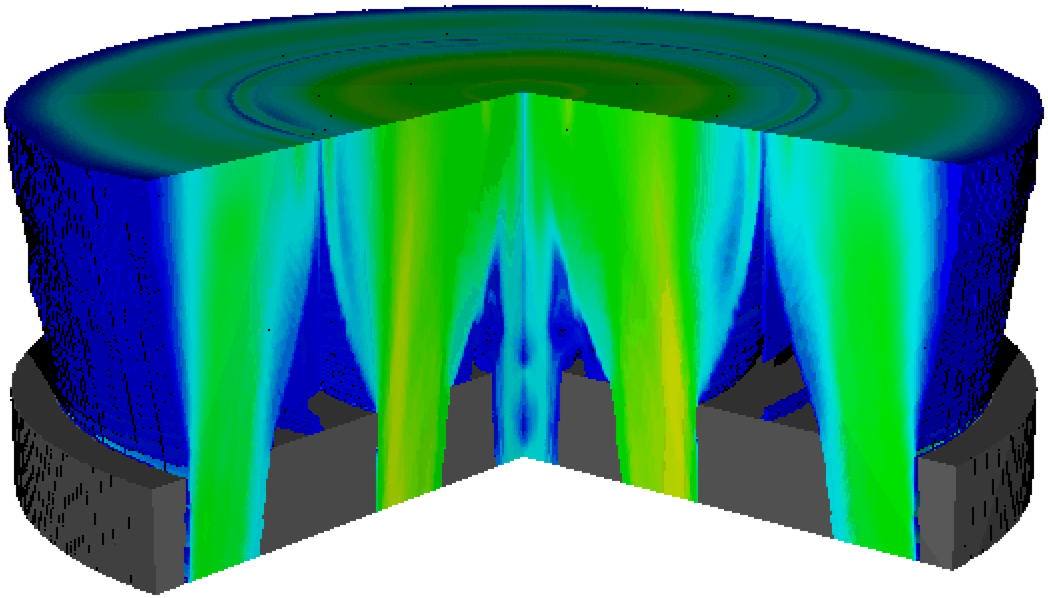
~m second

Hydrodynamic Gas Flow



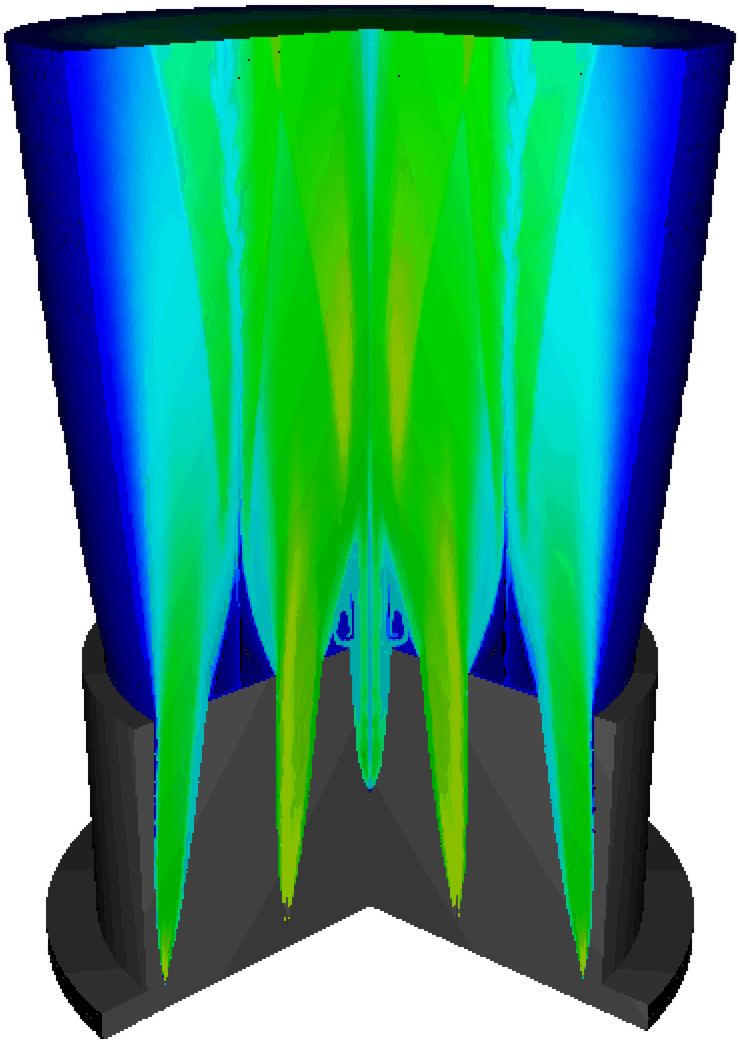
~m second

Radiative Magneto-hydrodynamic Implosion



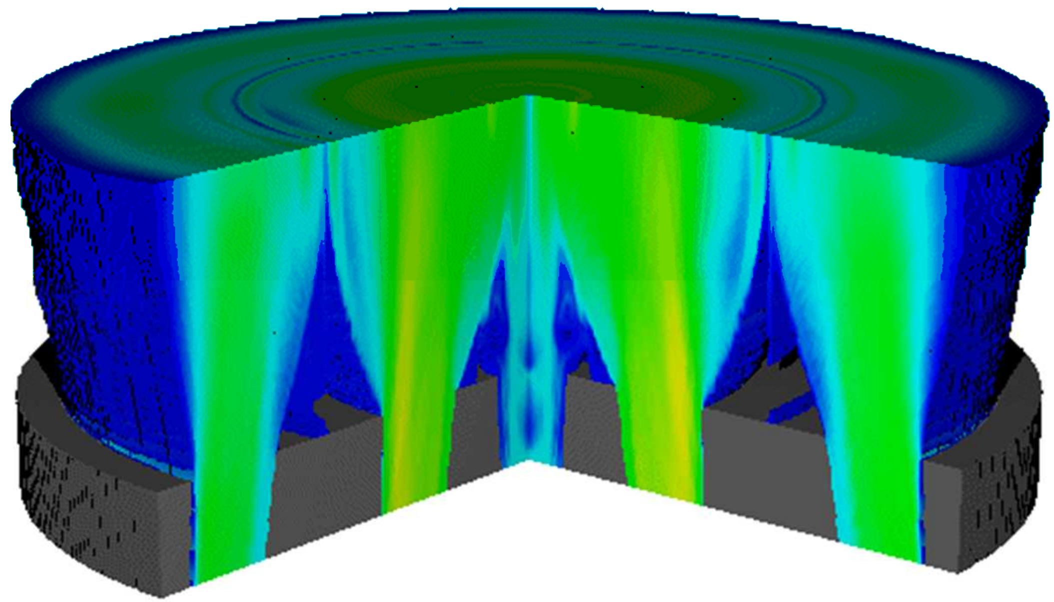
Imploded by ~20MA in ~100ns

Hydrodynamic Gas Flow



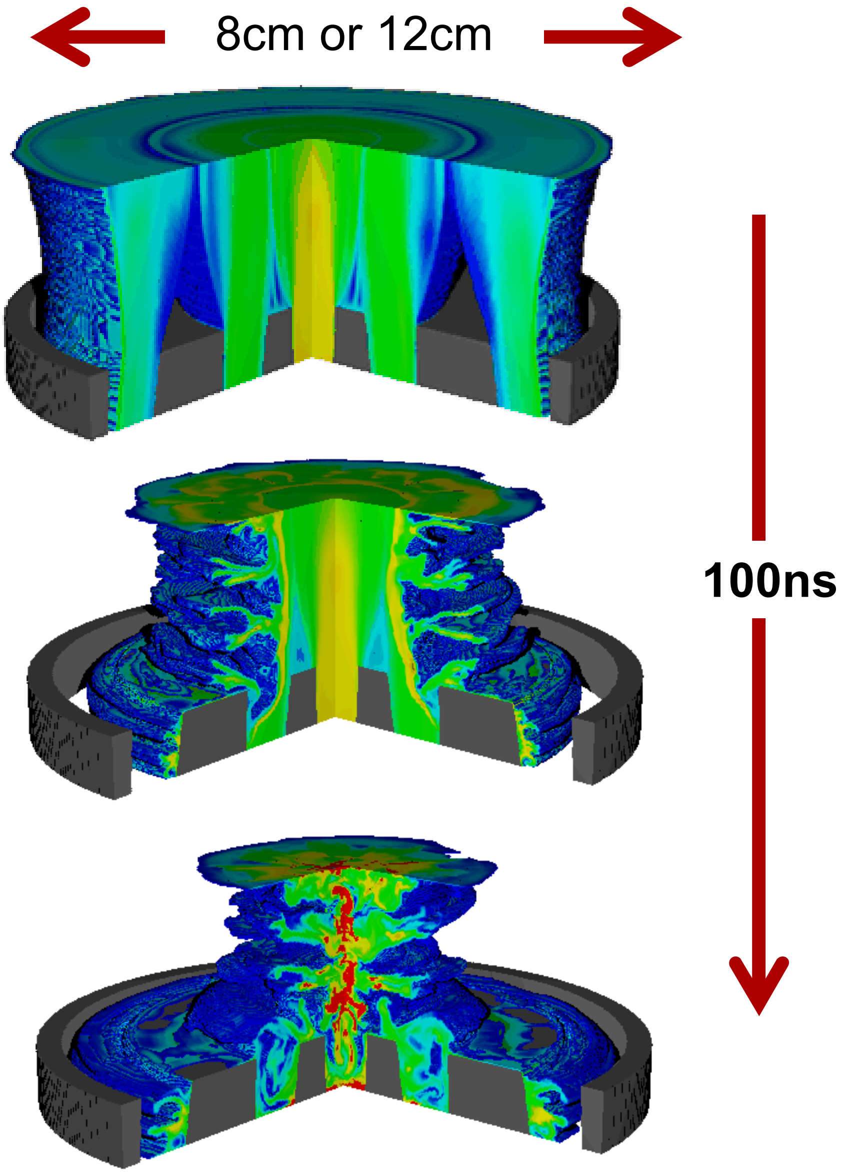
~m second

Radiative Magneto-hydrodynamic Implosion

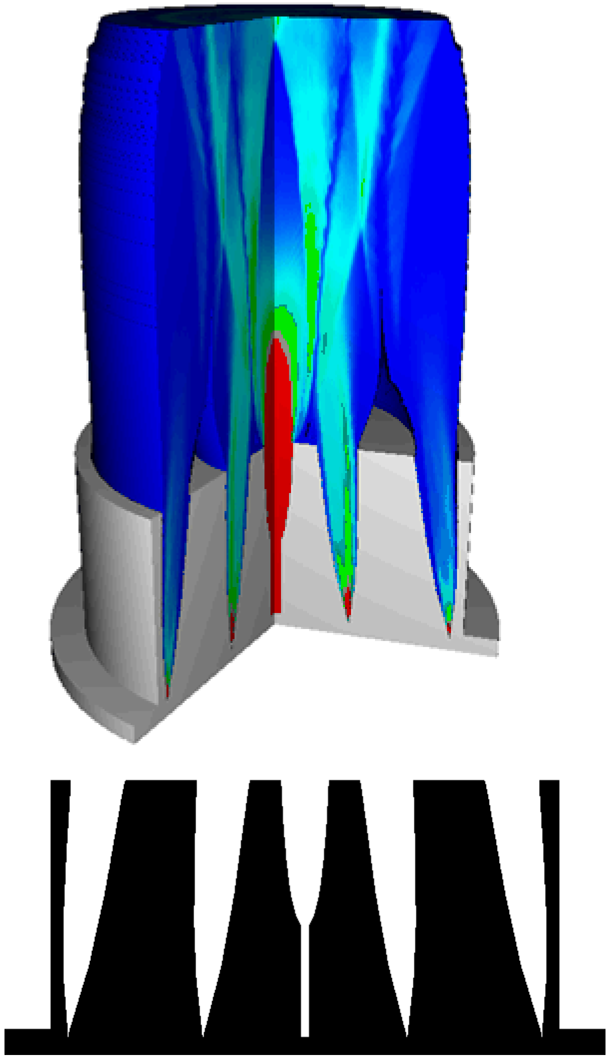


Imploded by ~20MA in ~100ns

Implosions disrupted by instabilities



Can control with mass distribution



Previous work on gas puffs indicate some promising directions to follow

Gas Puffs have been used extensively for many years:
Review Paper B. Comiso, J Guiliani (find reference)

We will explore on Z two approaches

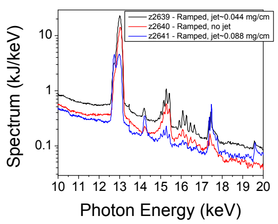
- **A shaped density profile that rises towards the axis to inhibit instability growth:**
  Hammer *et al* PoP 3, 2063 (1996)
  Velikovich *et al.*, PRL 77 853 (1996), PoP 5 3377 (1998)
  H. Sze *et al* PoP Lett. 8 3135 (2001)

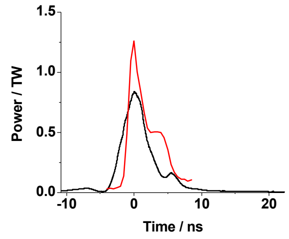
- **Use of a central jet (mass on axis) to increase K-shell yield:**
  - Successful at 200ns rise time, 2-6MA facilities
    H. Sze et. al., Phys. Plas., (2007)
    H. Sze et al., Phys. Rev. Lett. (2005)

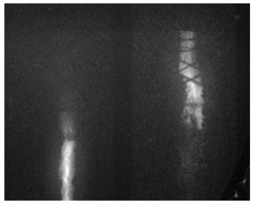
- Finite number of shots available on Z so investigating these approaches, and optimizing to Z is something we want to do this computationally.
- Modifying gas flow requires us having control over how profiles are produced

Many steps to the process

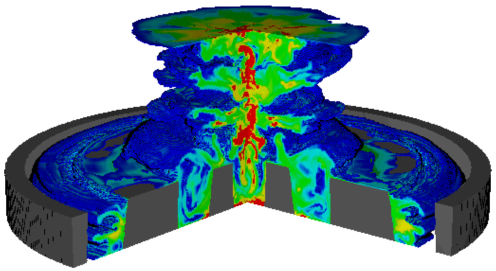
Field Gas Puff experiments. Assess and characterize output







GORGON – 3D Radiative-Resistive MHD

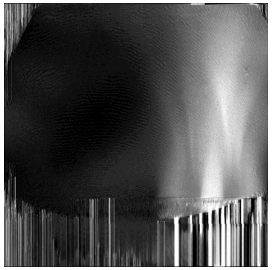


Radiation Model: S.B. Hansen

screened-hydrogenic/ UTA non-LTE model SCSF

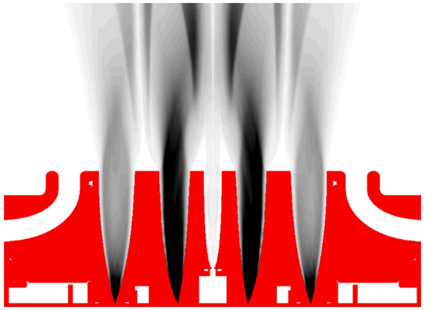
Nozzle Assembly & profiles measurement (SITF)

D.C.Lamppa, M. Jobe

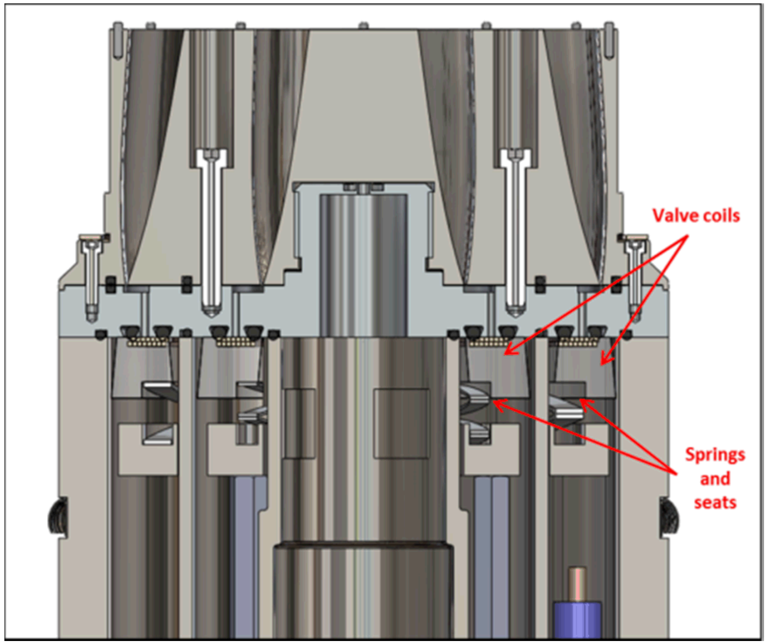


Interferometry System:
Alameda Applied Sciences (AASC) (P. Coleman et al RSI 2012) (Assisted by DTRA funding)

GORGON-HYDRO – Gas flow modeling for nozzle design



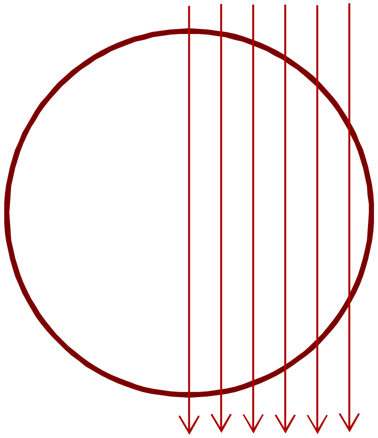
Simulated Areal Density Compared Directly of Measurement



Simulated Areal Density Compared Directly of Measurement

Density Areal Density

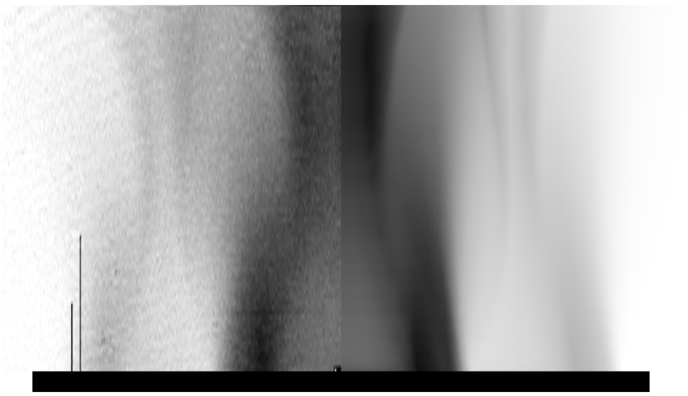
Integrate across density profile for Areal Density

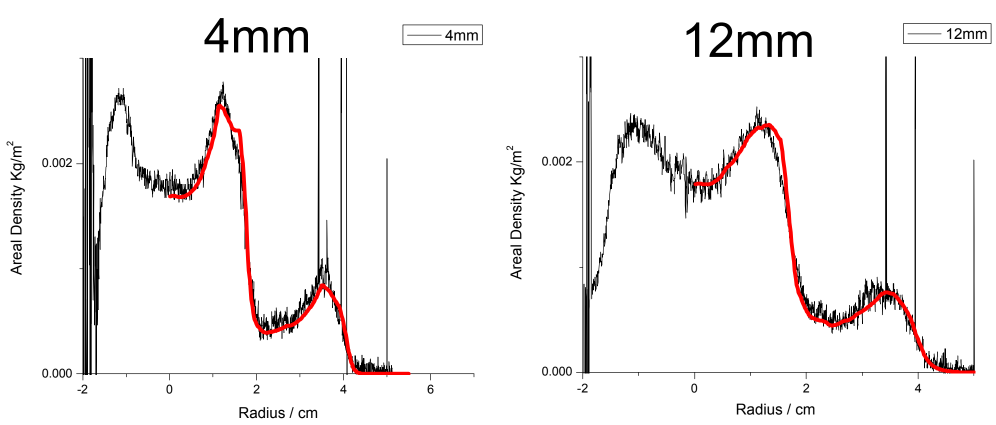


Simulated Areal Density Compared Directly of Measurement (avoids need to Abel invert)

Density Areal Density

Interferometry Simulation

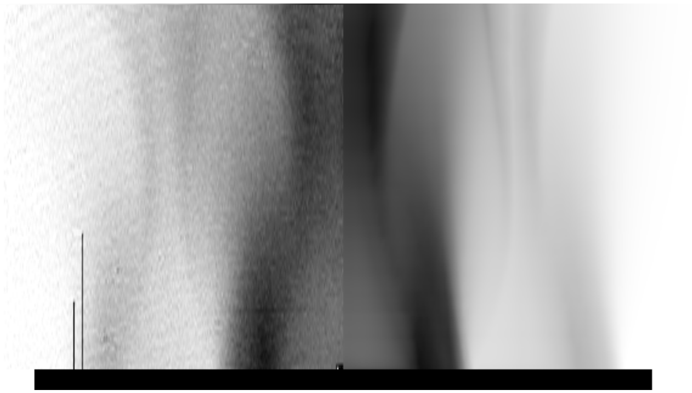




Interferometry / simulation

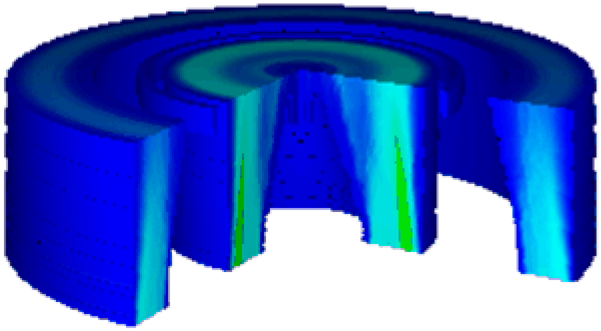
Initial perturbations may be added in controlled way to hydro model

Interferometry Simulation

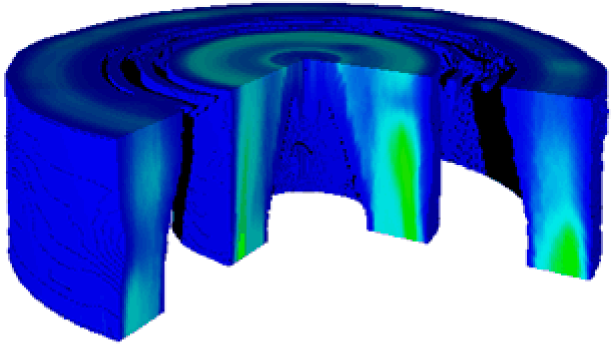


Smooth profile perturbed by volumetric Gaussian bubbles. Scale length comparable to throat plate variations. Magnitude below what would show up on areal density interferometry map.

Unperturbed Density Profile

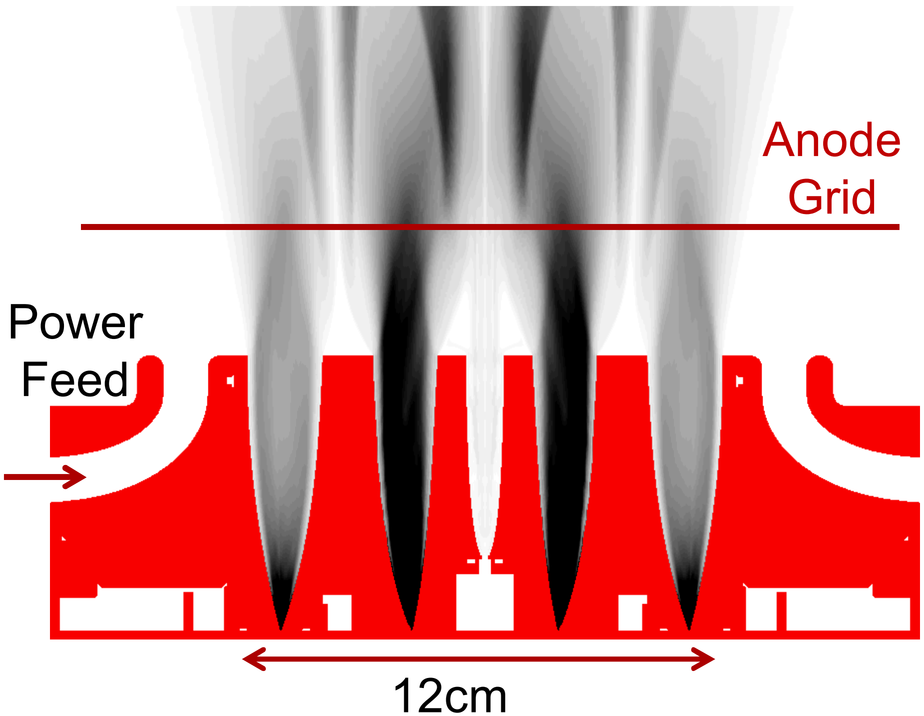


Perturbed Density Profile

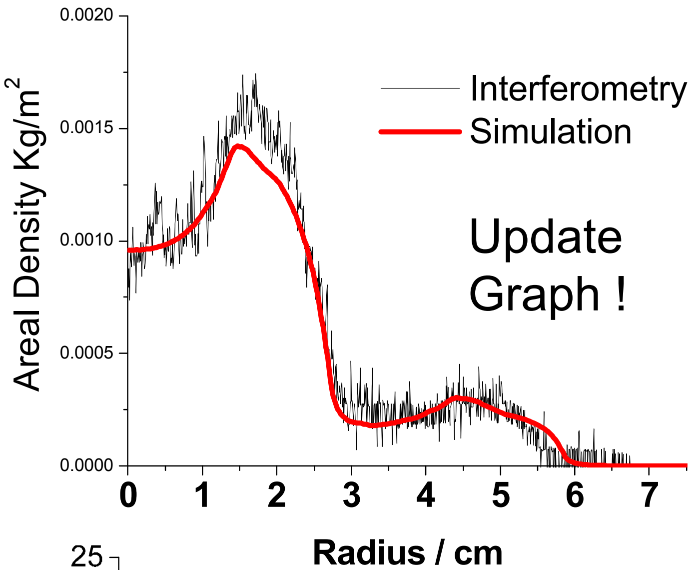


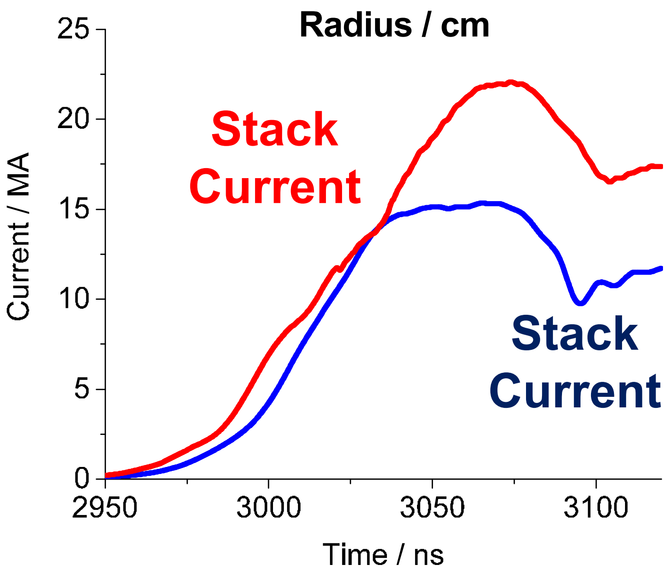
Start With a Double Shell Gas Puff and Evolve Design to Improve Performance

We will evolve design based on approaches people have previously found successful

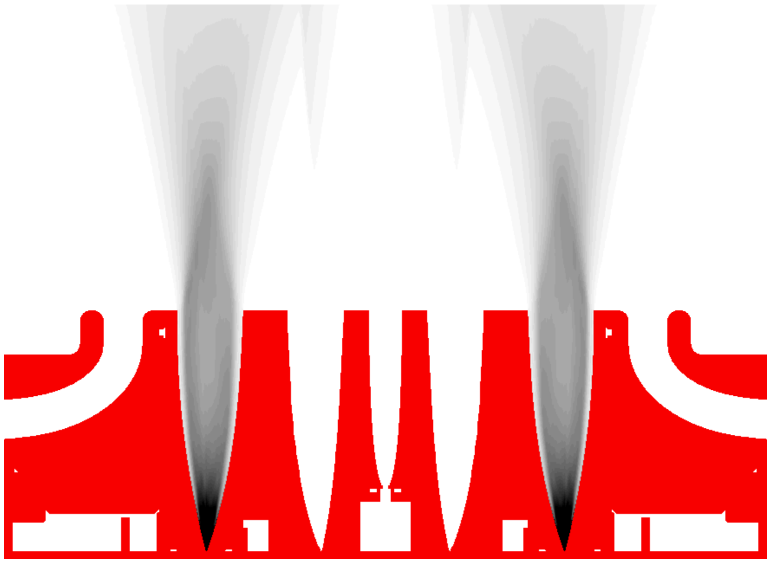


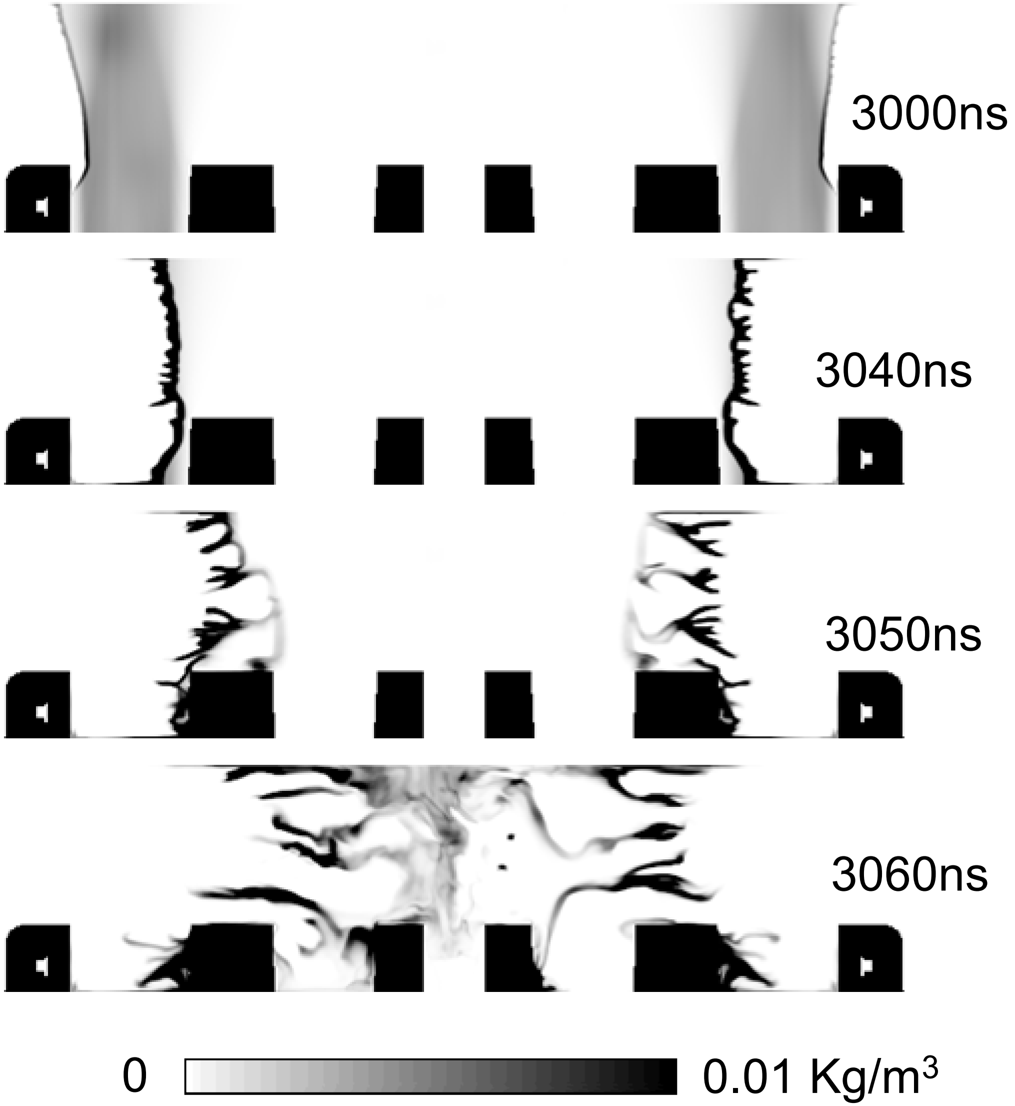
Design Nozzle Contours for a Typical Double discrete shell gas puff. Designed to be compatible with the AAS backend





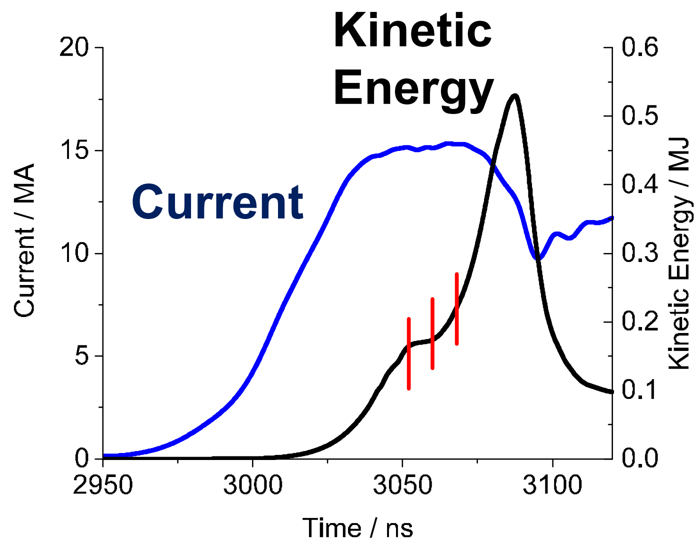
Outer Shell Only Is Catastrophically Unstable

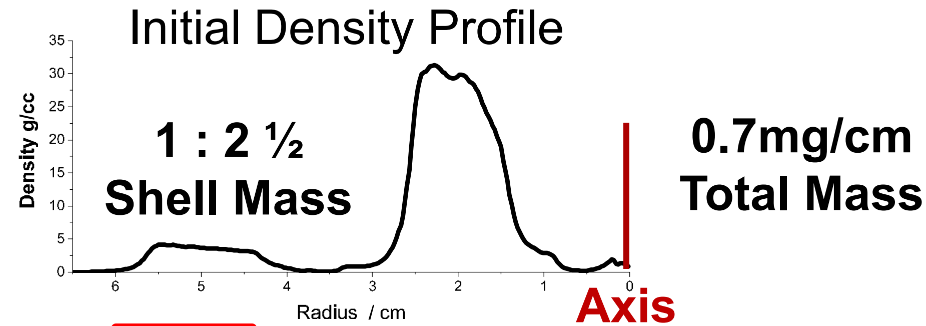


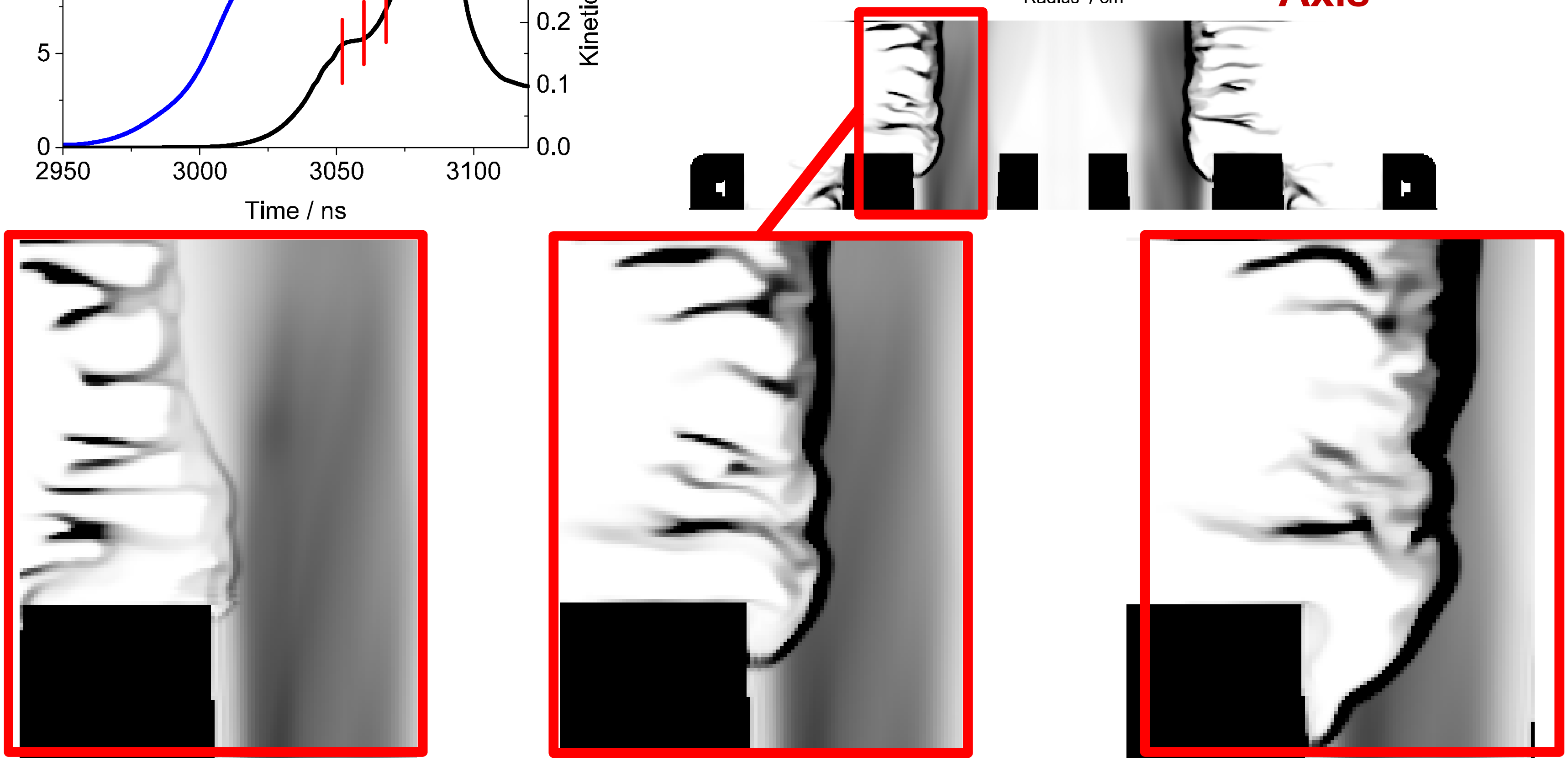


Driving a light single shell
After Shell mass is accreted
instabilities rapidly grow as
imploding surface encounters
free space

Use heavy inner shell to interfere with instability growth

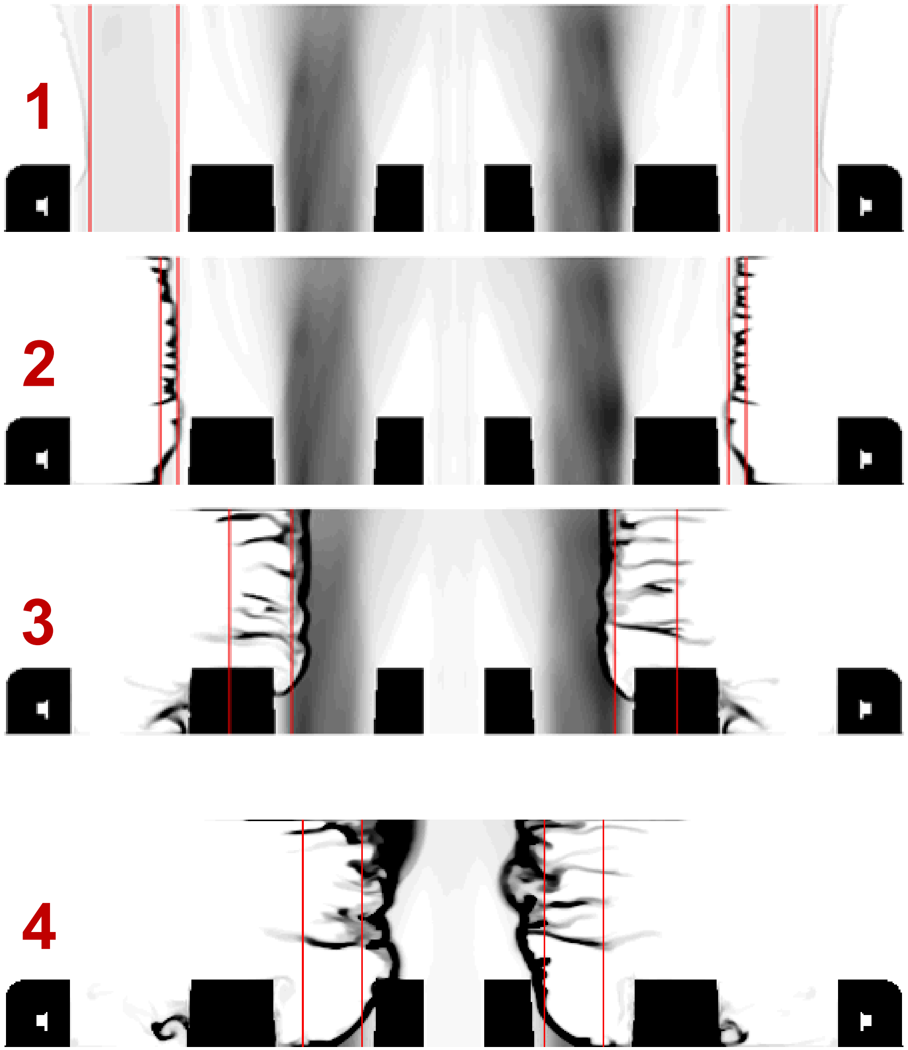


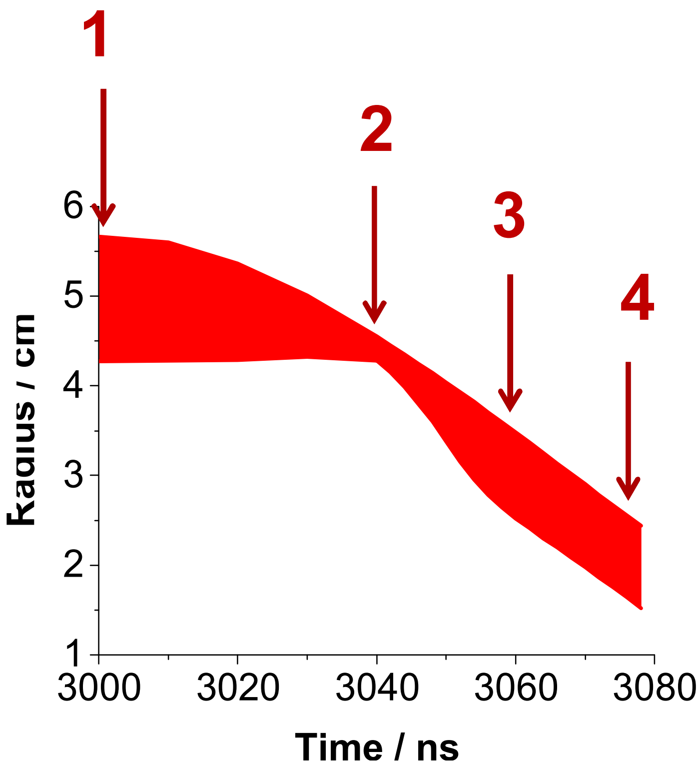




Optimum Shell Mass Ratio Determined in Similar way to NRL Ar gas puff optimization Ref. Thornhill

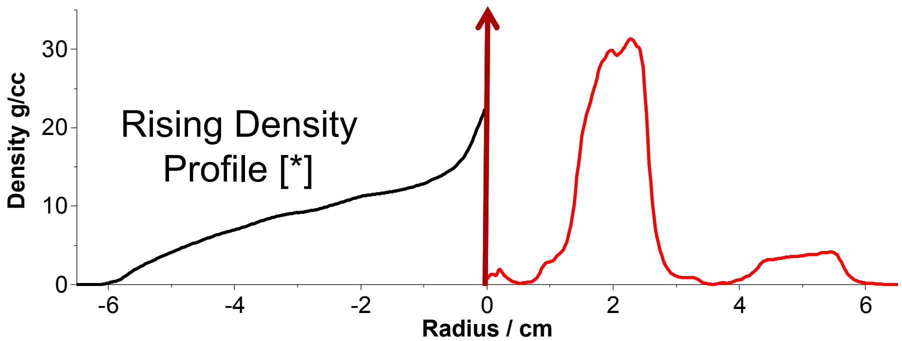
Instabilities rapidly redistribute outer shell mass as it transits space between shells

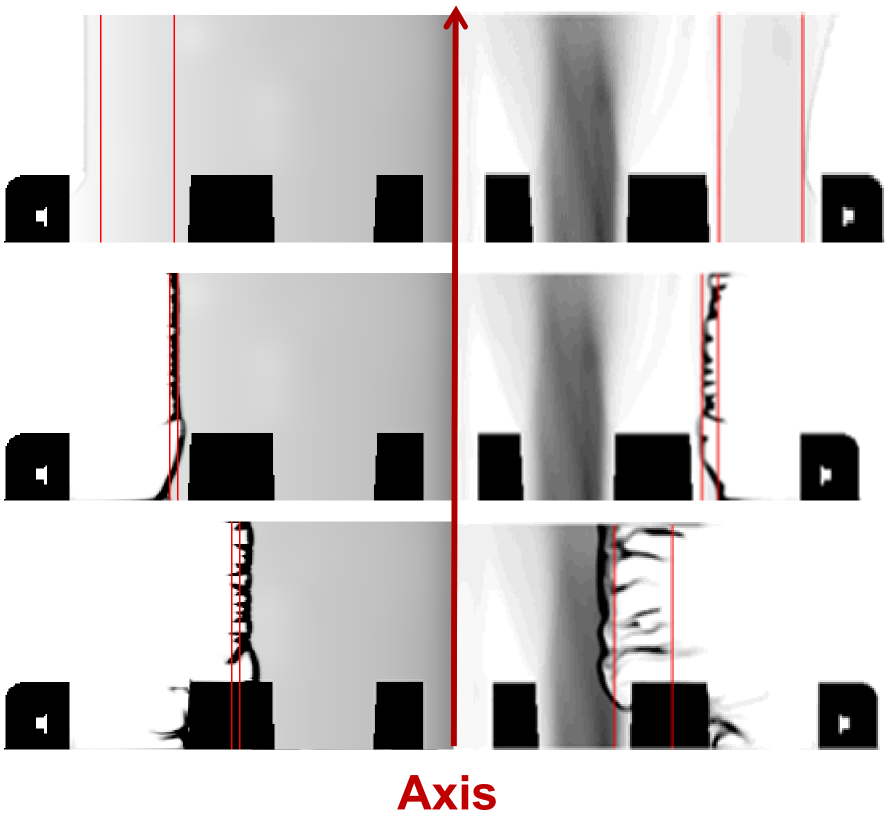




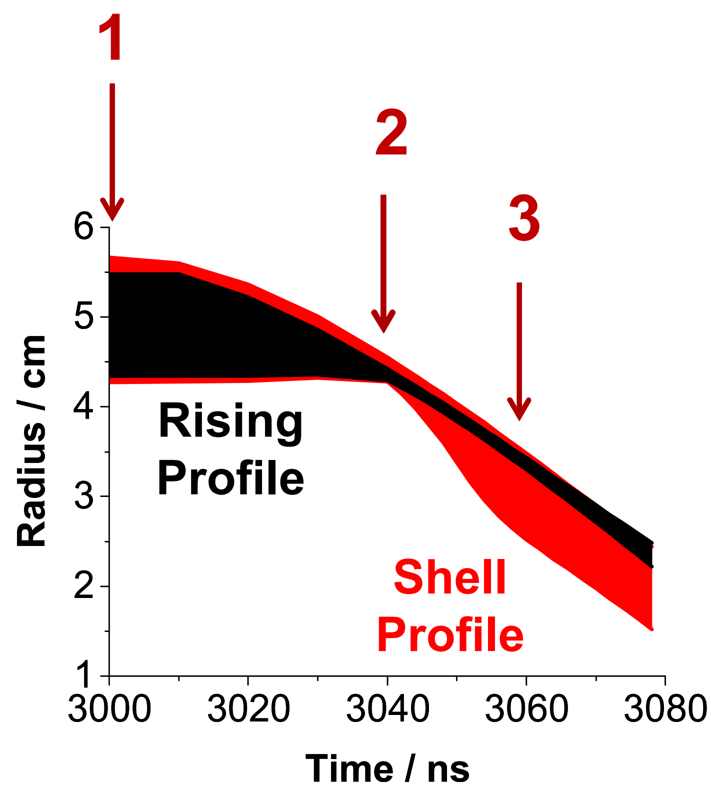
Instabilities are temporarily tamped as you transit inner shell, but reassert themselves at late time

Idealized rising density profile tamps early disruption





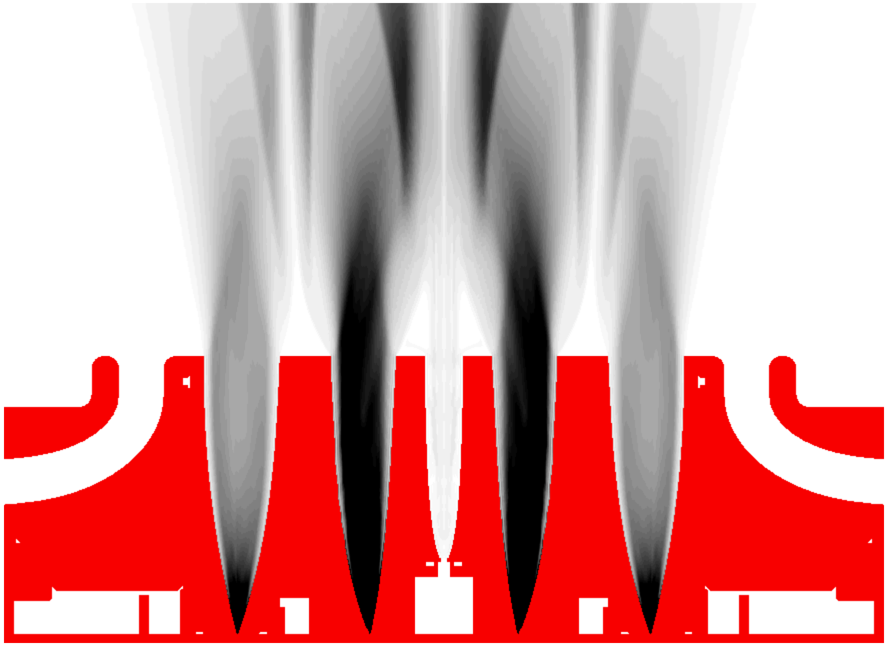
By filling space between shells rapid onset of instabilities is inhibited

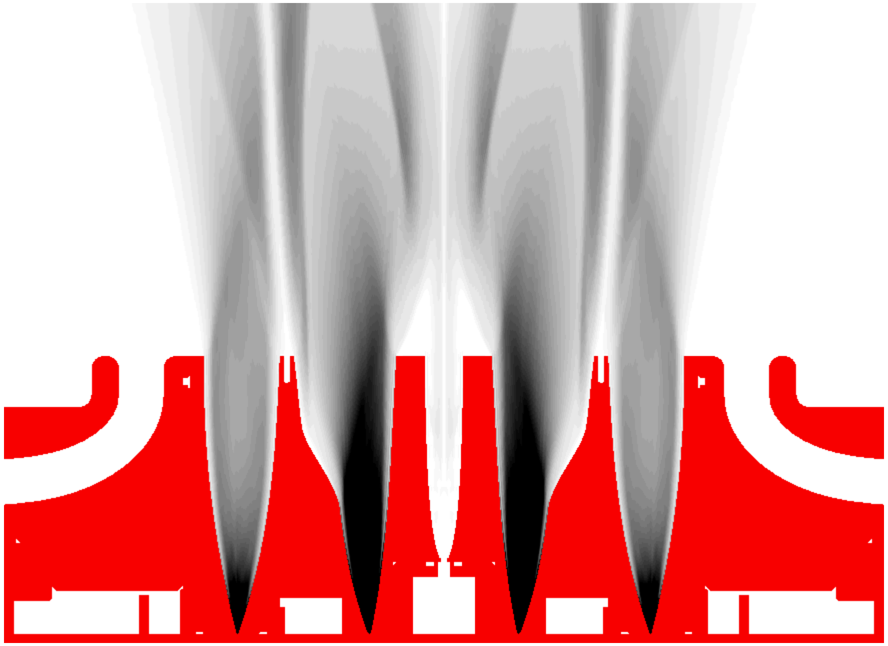


[*] Reference Hammer, Velikovich etc

Design 2 12cm nozzles to study shell like vs ramped density profiles.

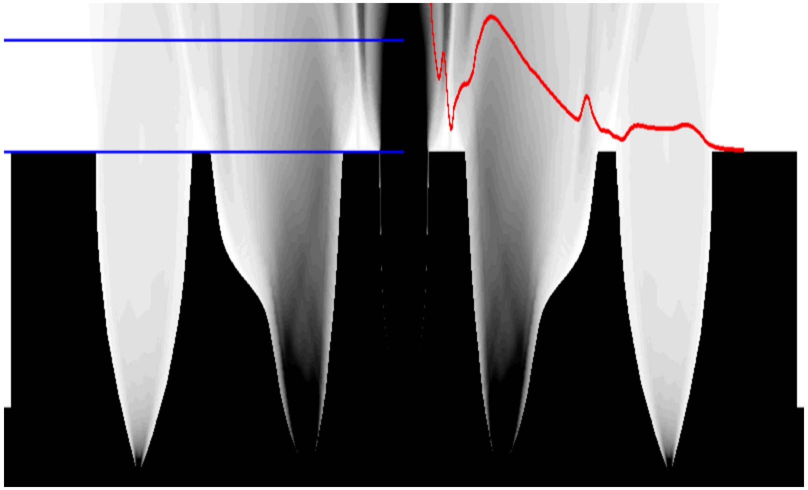
We would like to incorporate the ramped profile advantages in a gas profile we can both produce, and one we can directly compare to a double shell profile



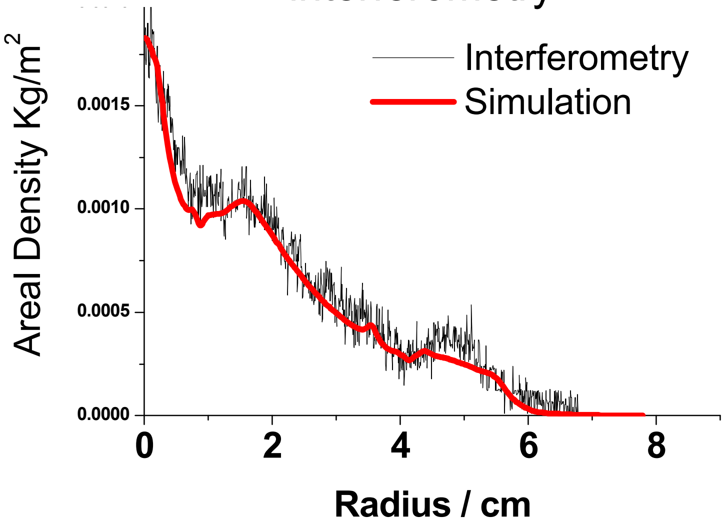


Ramped Density Profiles / Central Jet: Hammer *et al* PoP 3, 2063 (1996), Velikovich *et al.*, PRL 77 853 (1996), PoP 5 3377 (1998) , H. Sze *et al* PoP Lett. 8 3135 (2001)

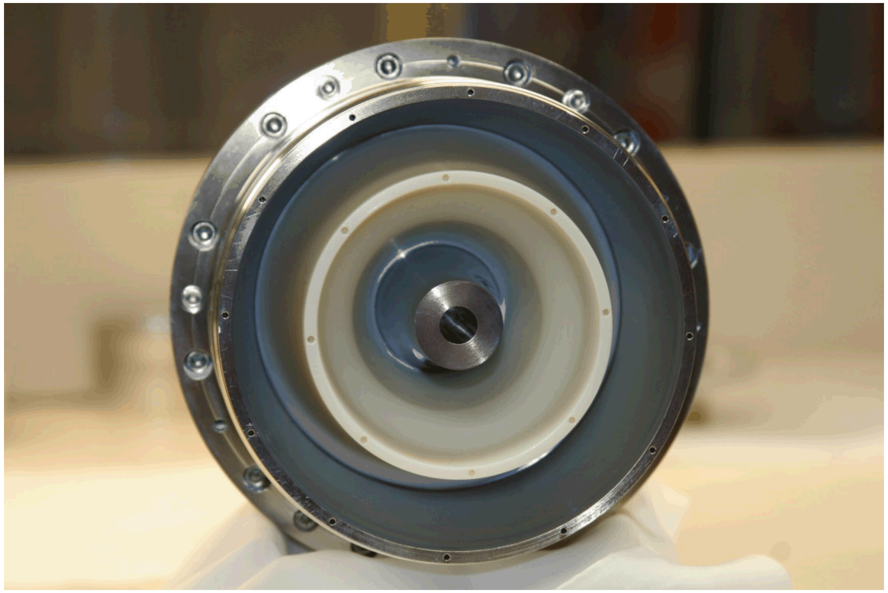
Shaped profile verified with 3D printed components



Predicted gas flow profile confirmed by interferometry



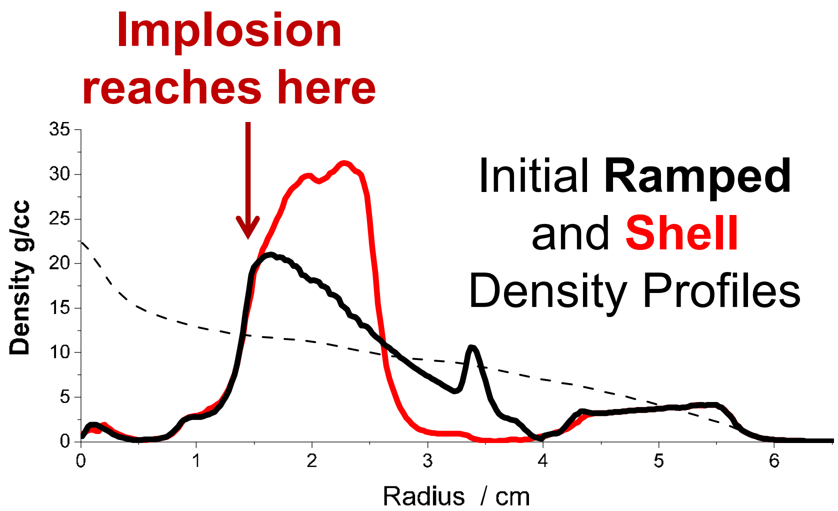
D. Lamppa and SITF team

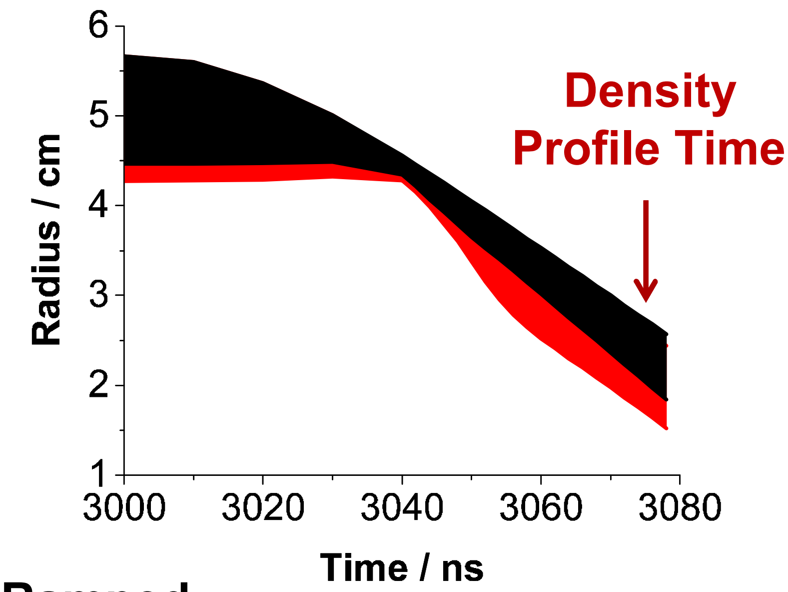


SITF team was able to rapid prototyped nozzle contour to verify design.

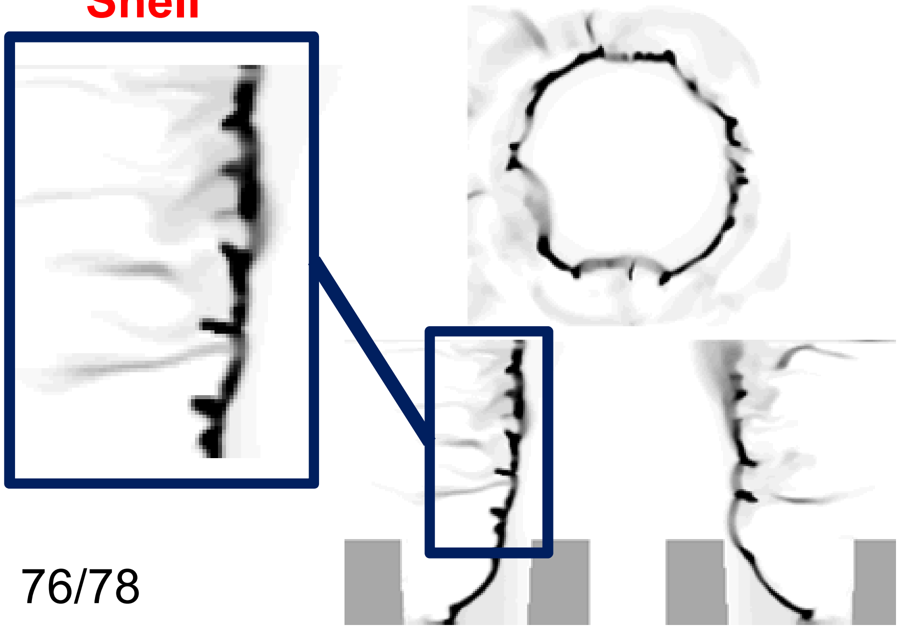
This will prove very useful as we evolve the design further

Ramp helps mitigates early time disruption

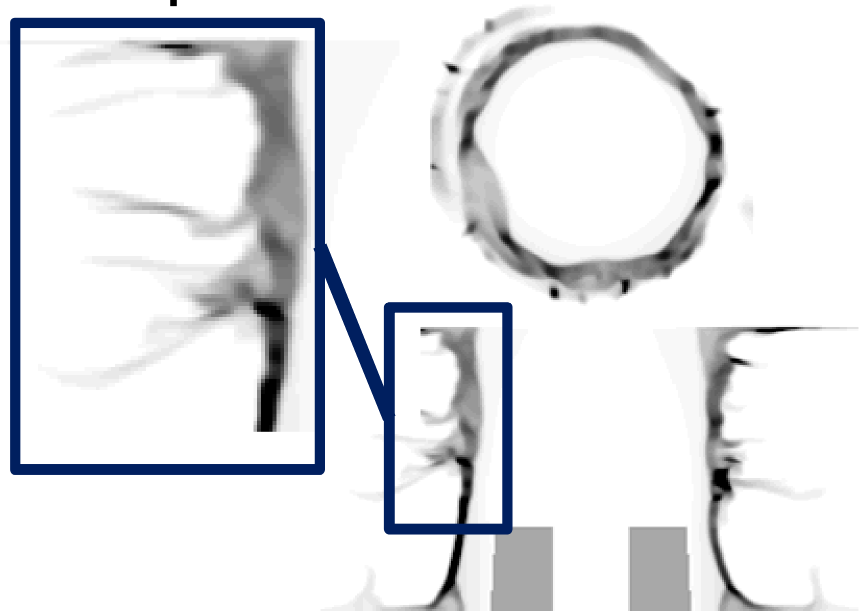




Shell



Ramped



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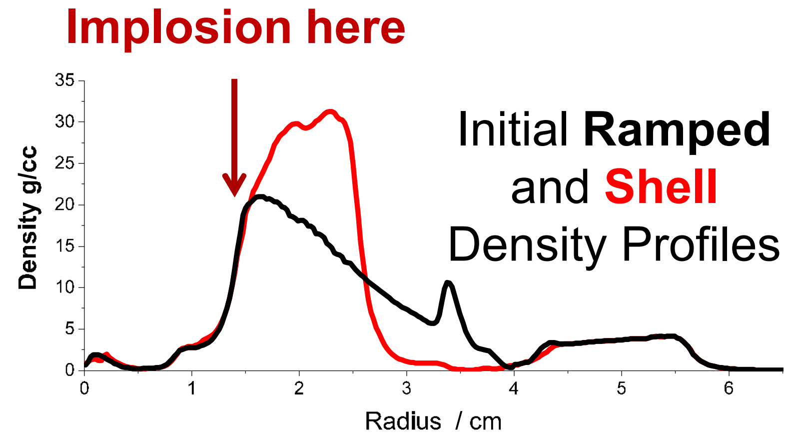
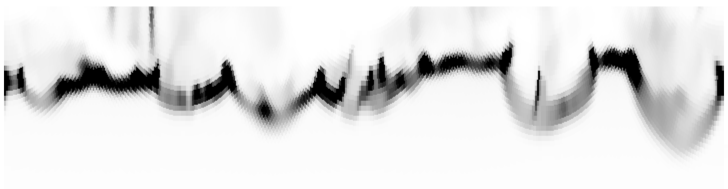
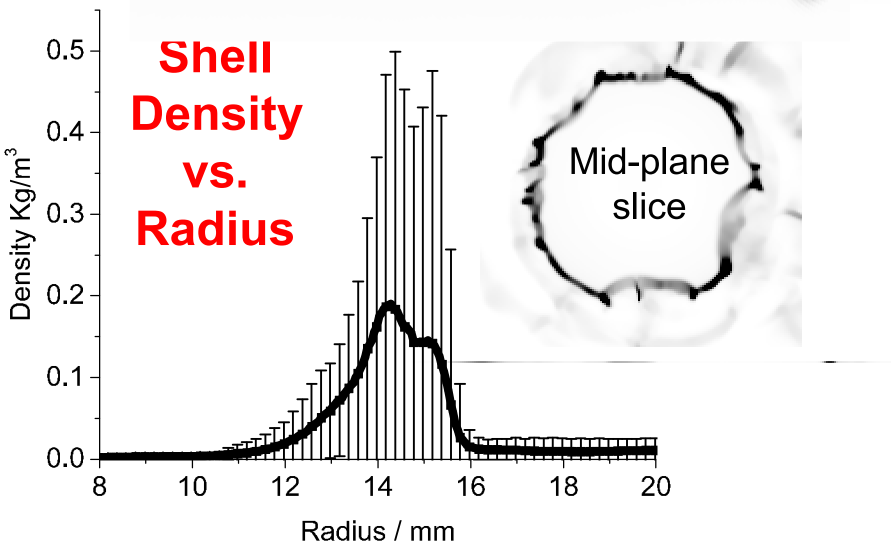
Shell Profile More Fragmented as it passes

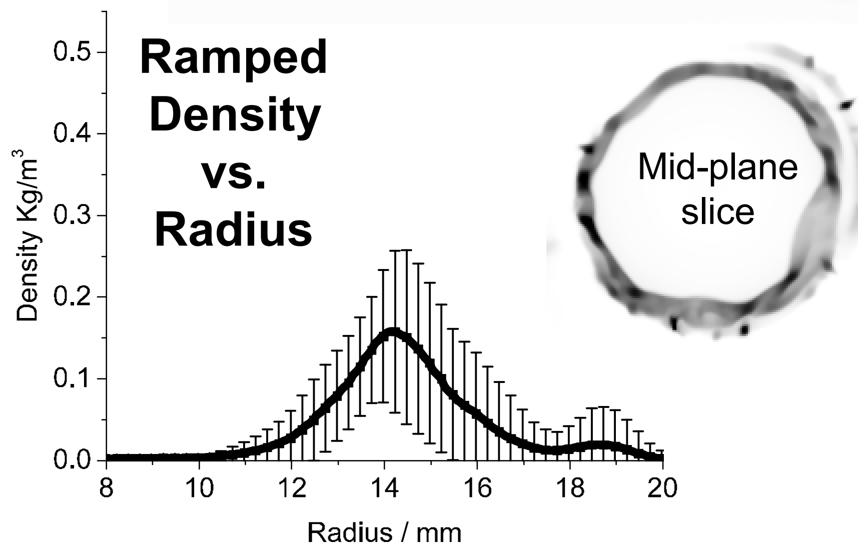
Through mid-plane the imploding shell is unwrapped to highlight azimuthal as well as axial fragmentation



360 degree circumference



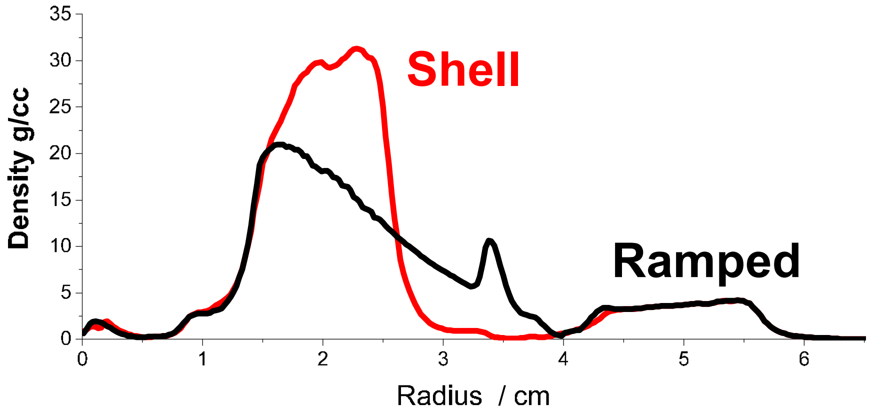




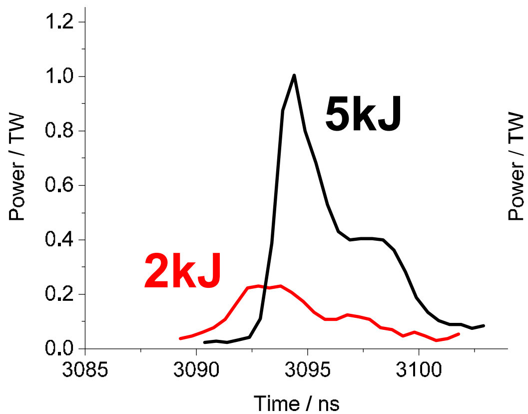
Standard deviation from average radial density significantly higher for shell profile

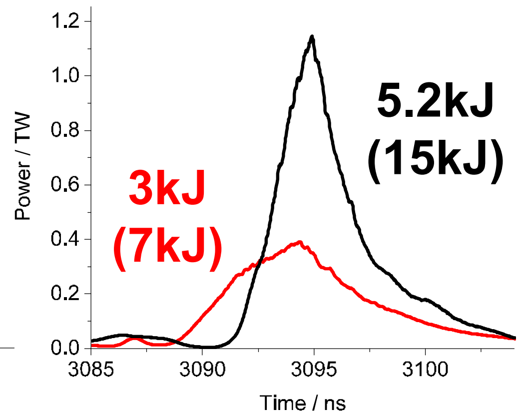
Z experiments conducted to compare ramped and shell profiles, confirming predicted x2 increase in K-shell Yield

Z2542 / Z2543



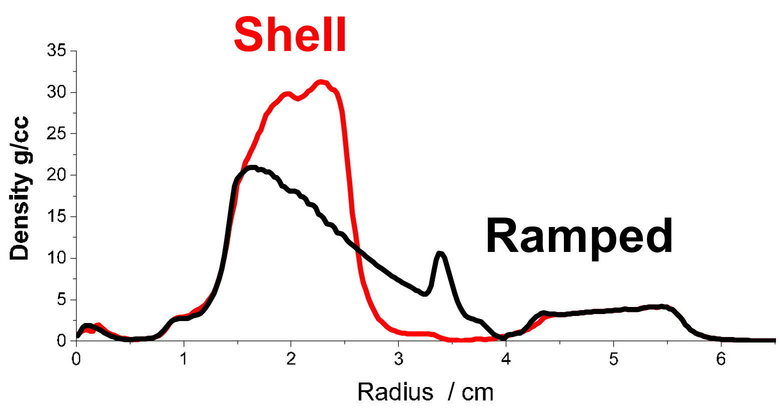
Simulated and Measured powers and yields for photon energies Kr K-shell and above

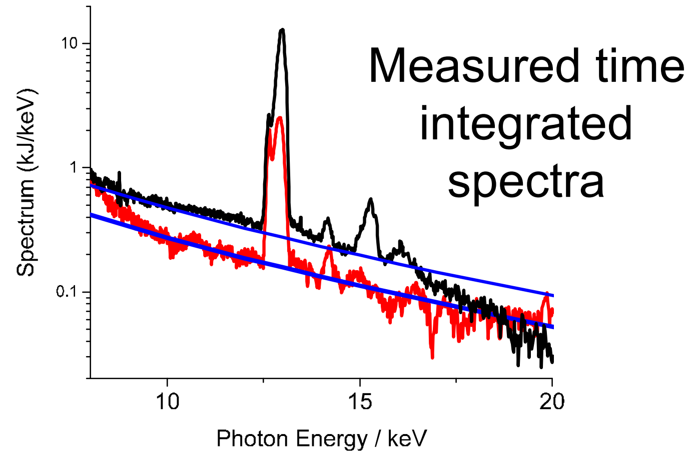




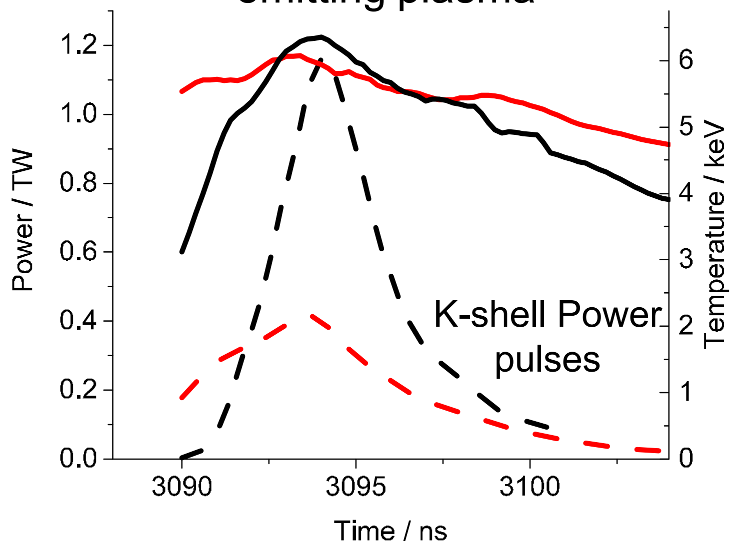
While increase from profile change recovered initial predictions of first experiments were high due to optimistic assumptions on current delivery

Emitting plasma at comparable temperatures. Changes in density account for yield changes

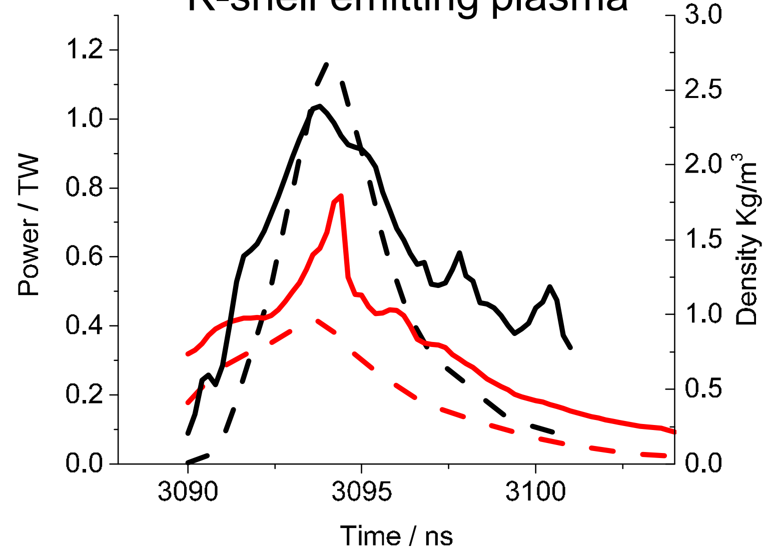




Effective continuum slope temperature of emitting plasma



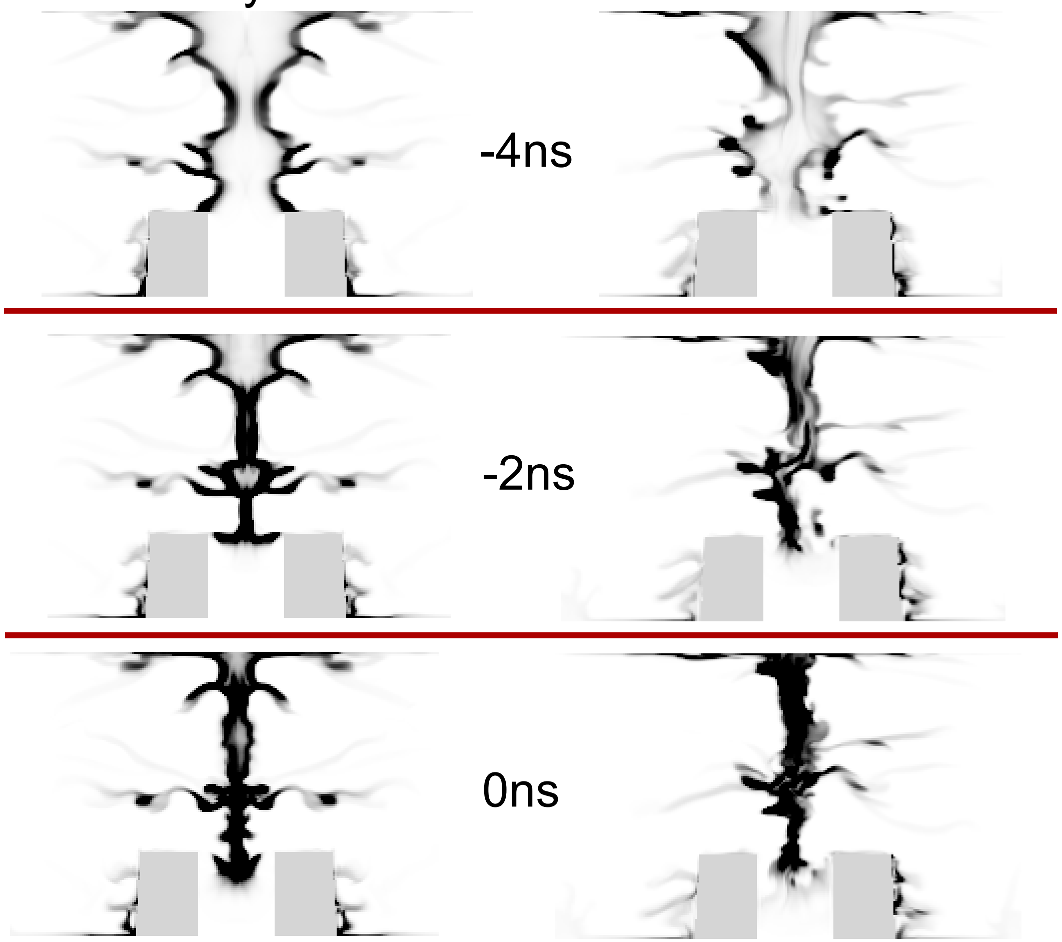
Emissivity weighted density of K-shell emitting plasma



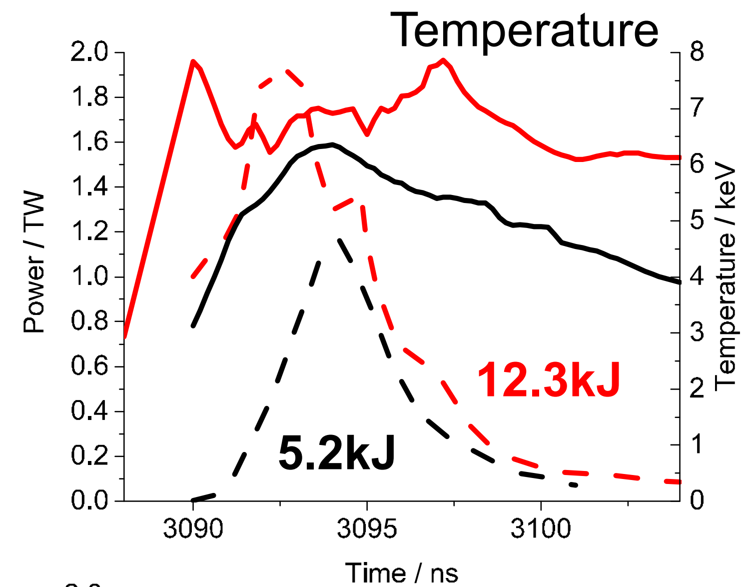
Increased yield from higher density more apparent if you force cylindrical convergence

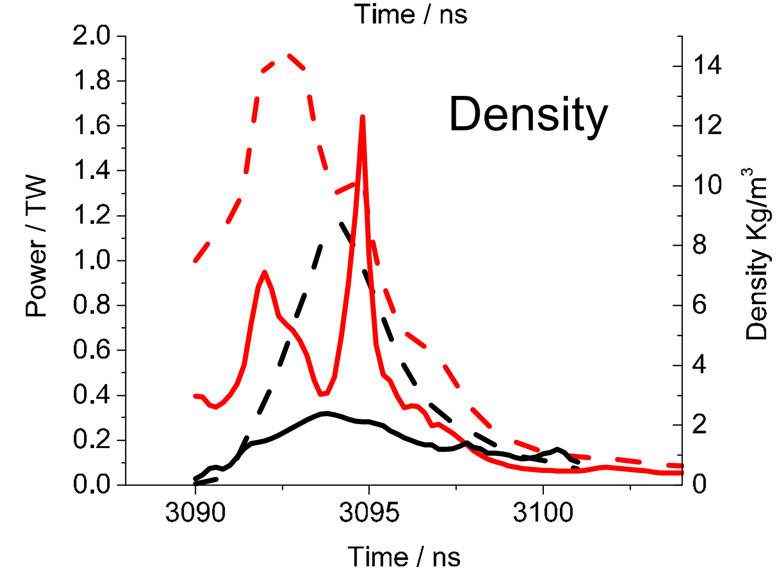
Cylindrically Symetric 12kJ yield

Asymetric 5kJ yield

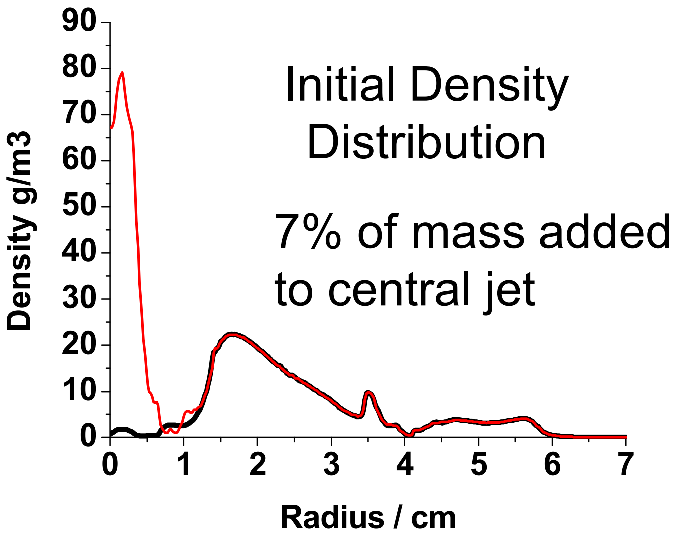


Densities at ~ peak power





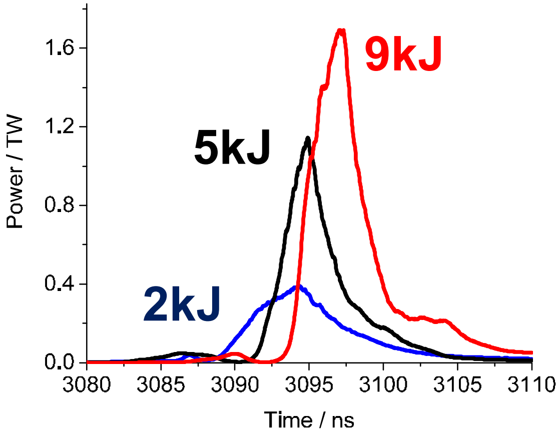
Low mass central jet predicted and confirmed to increase K-shell yield



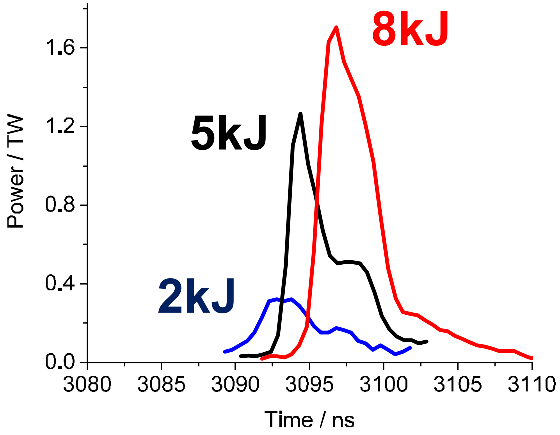
Central jet introduces additional mass on axis

Based on revised estimates on current delivery predicted factor of ~2 yield increase from addition of a light central jet was recovered in experiment

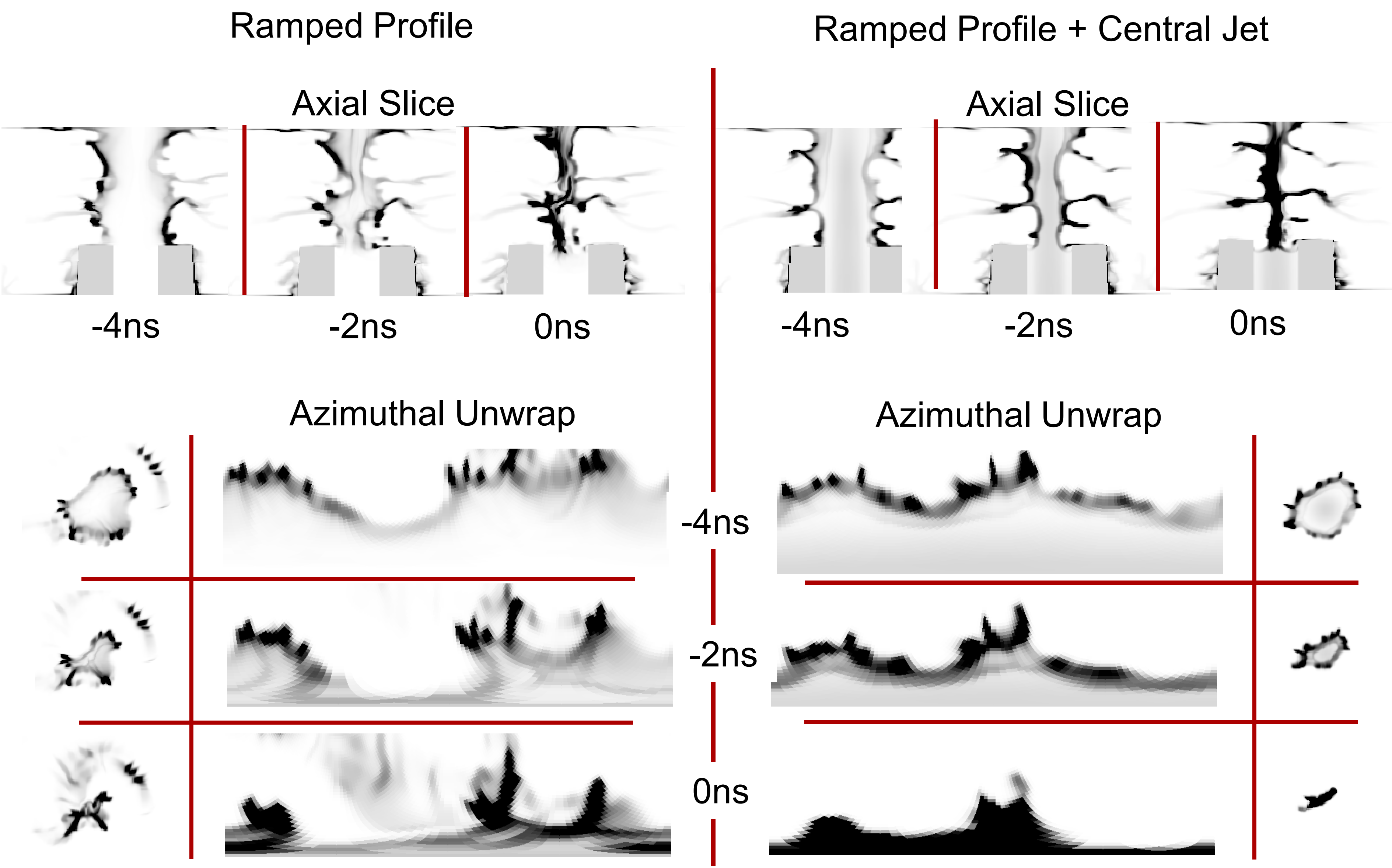
Simulation



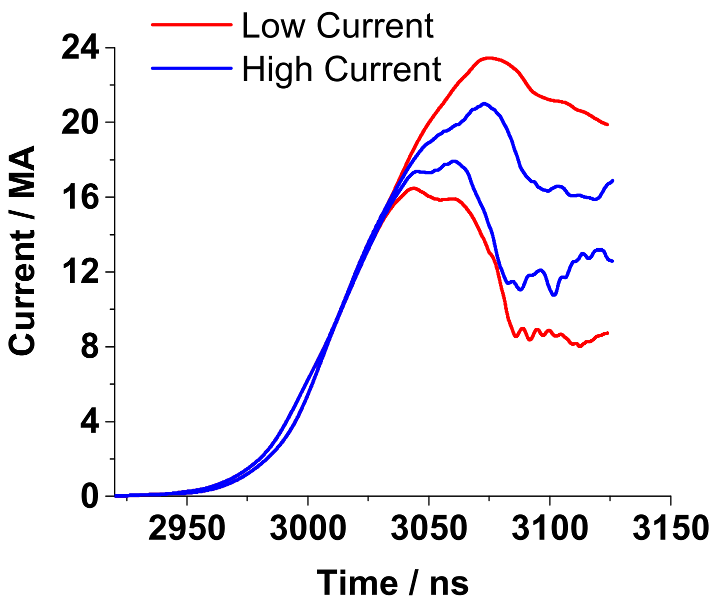
Experiment

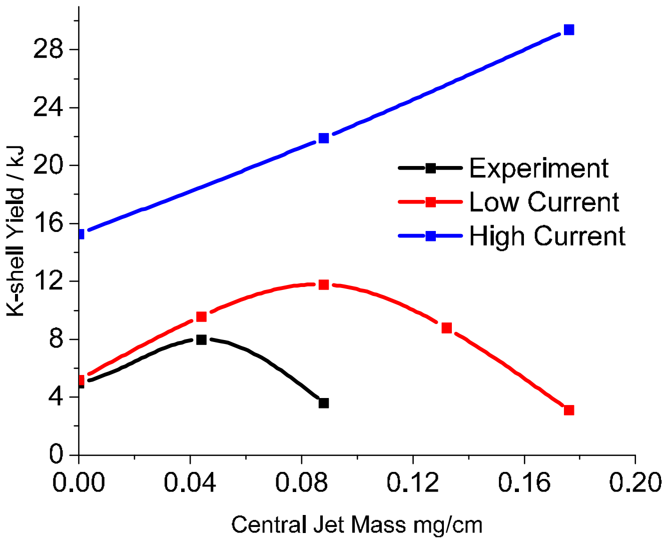


Central jet improves both axial and azimuthal symmetry



Ideal Central Jet Mass Related to how hard you drive the implosion



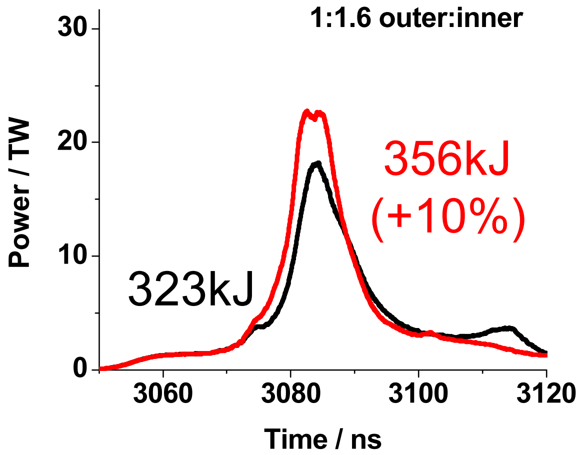


Higher current reaching the load can support significantly higher central jet masses

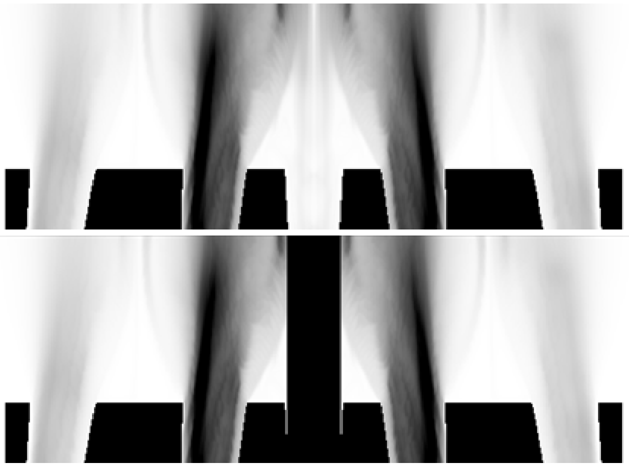
Predicted optimum central jet mass too high.

Construct a test to highlight some limits on central jet effectiveness

Addition of a 0.2mg/cm central jet to 8cm Ar gas puffs



1:1.6 outer to inner mass ratio

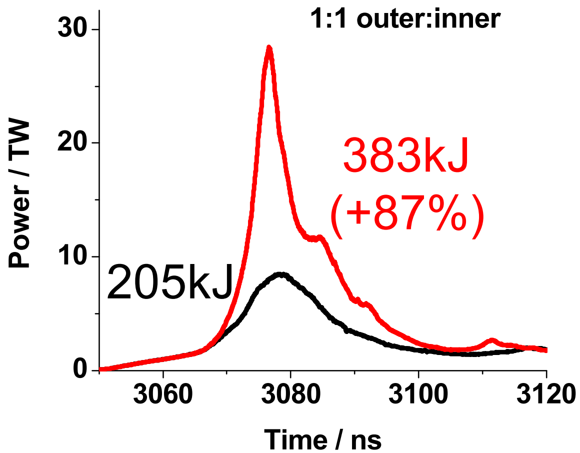


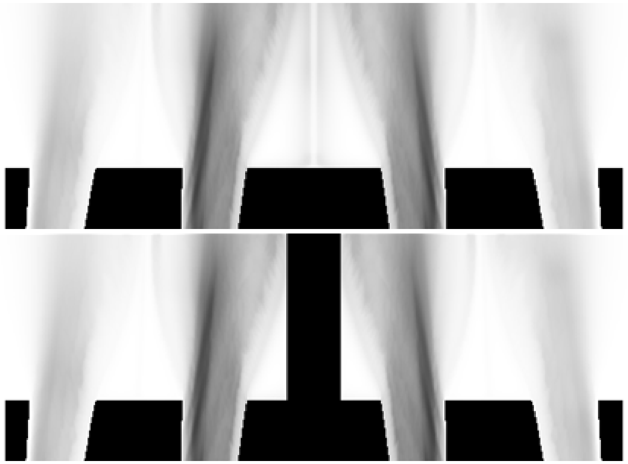
No Jet

Jet

1:1 outer to inner mass ratio

Start from 1:1.6 shell ratio baseline NRL load (ref)





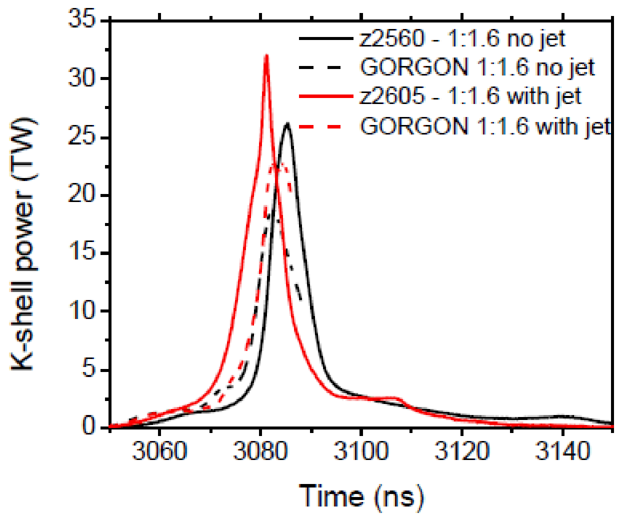
No Jet

Jet

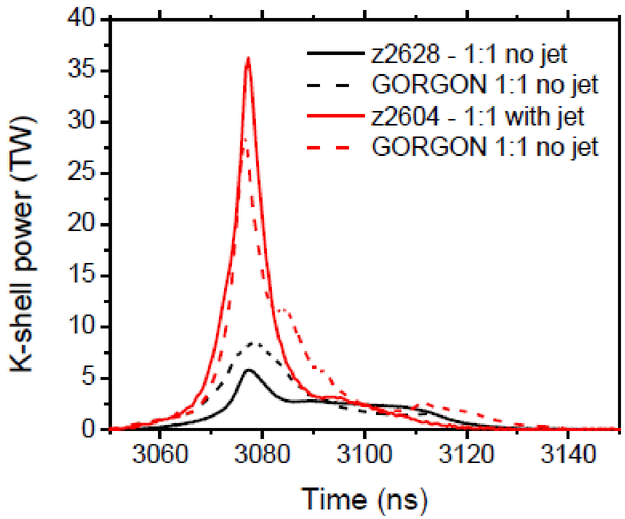
8cm diameter

Predicted behavior recovered in experiments

Experiments performed and results presented by Adam Harvey-Thompson



- 1:1.6 without center jet yield:
  330 kJ ± 9% (3 shot Av. yield)
- 1:1.6 with center jet yield:
  373 kJ ± 9% (single shot)



- 1:1 without center jet yield:
  144 kJ ± 9%
- 1:1 with center jet yield:
  375 kJ ± 10%
- Substantial increase in yield and power with central jet as predicted by GORGON

Conclusions

- Large diameter low mass implosions are very unforgiving – very little margin for error.
- Tools developed and tested to design gas profiles to optimize yield.
  - This incudes both determining distribution of mass, and shaping the gas profile
- Successfully used to increase K-shell by a factor of 8 in first 4 shots fielded.