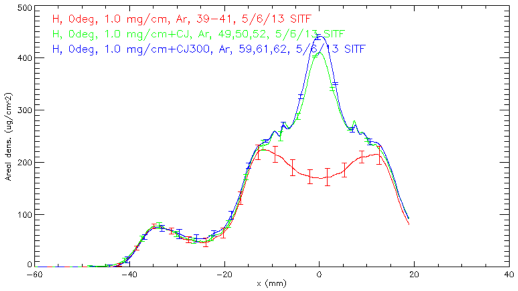
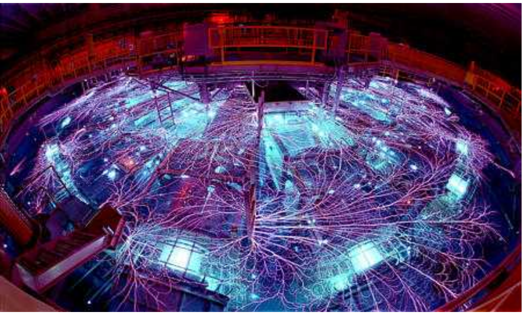
SAND2015-5028C

Investigating The Effects of Adding a Center jet to Argon gas puff implosions at the Z facility





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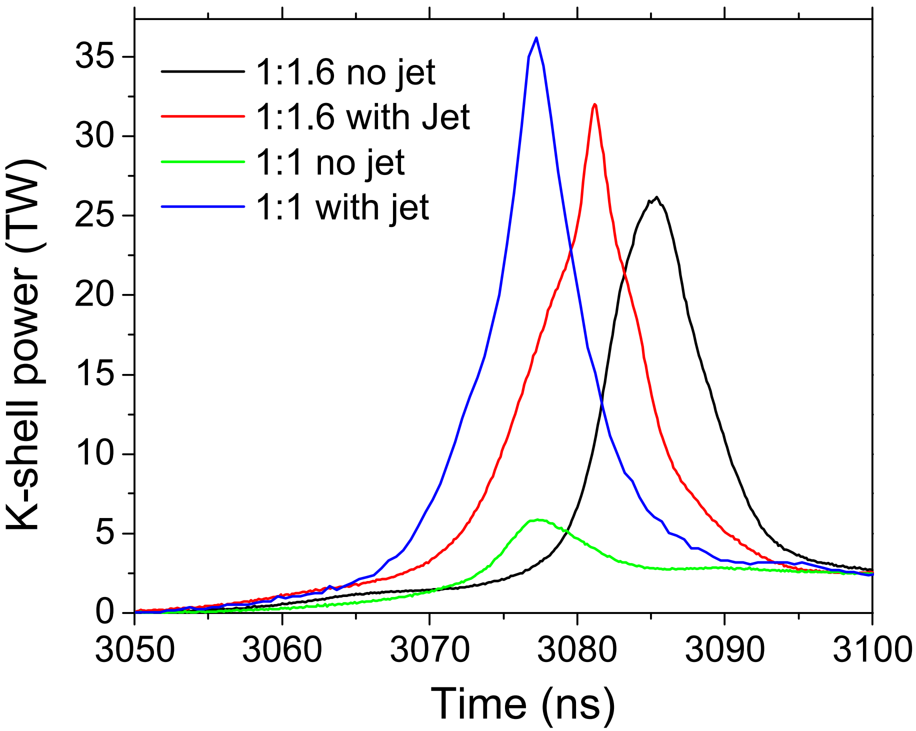
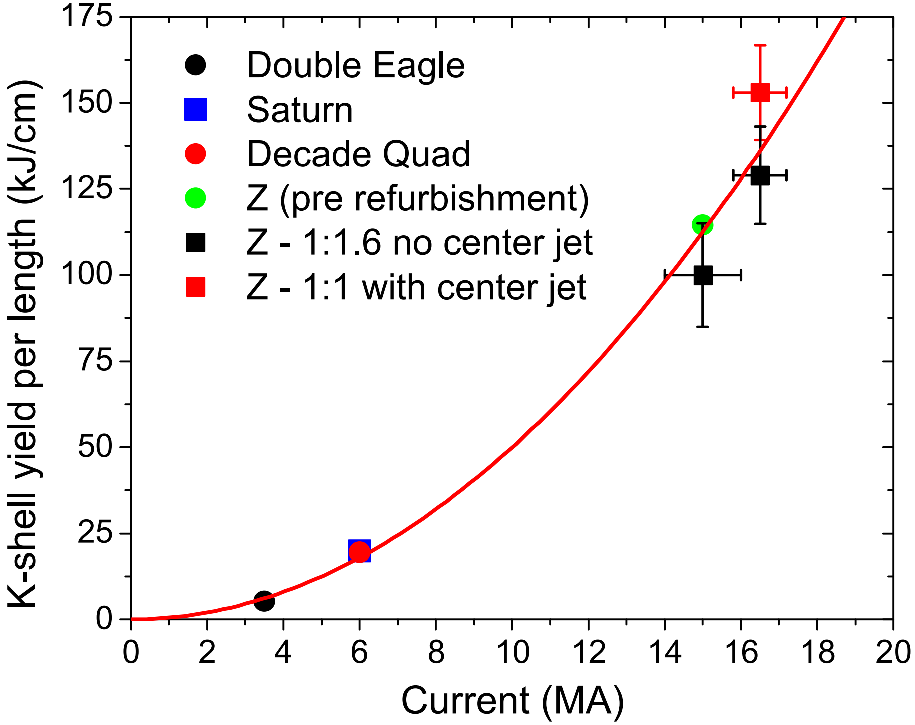
Summary – Adding center jets to Ar gas puffs on Z increases the K-shell yield – slightly





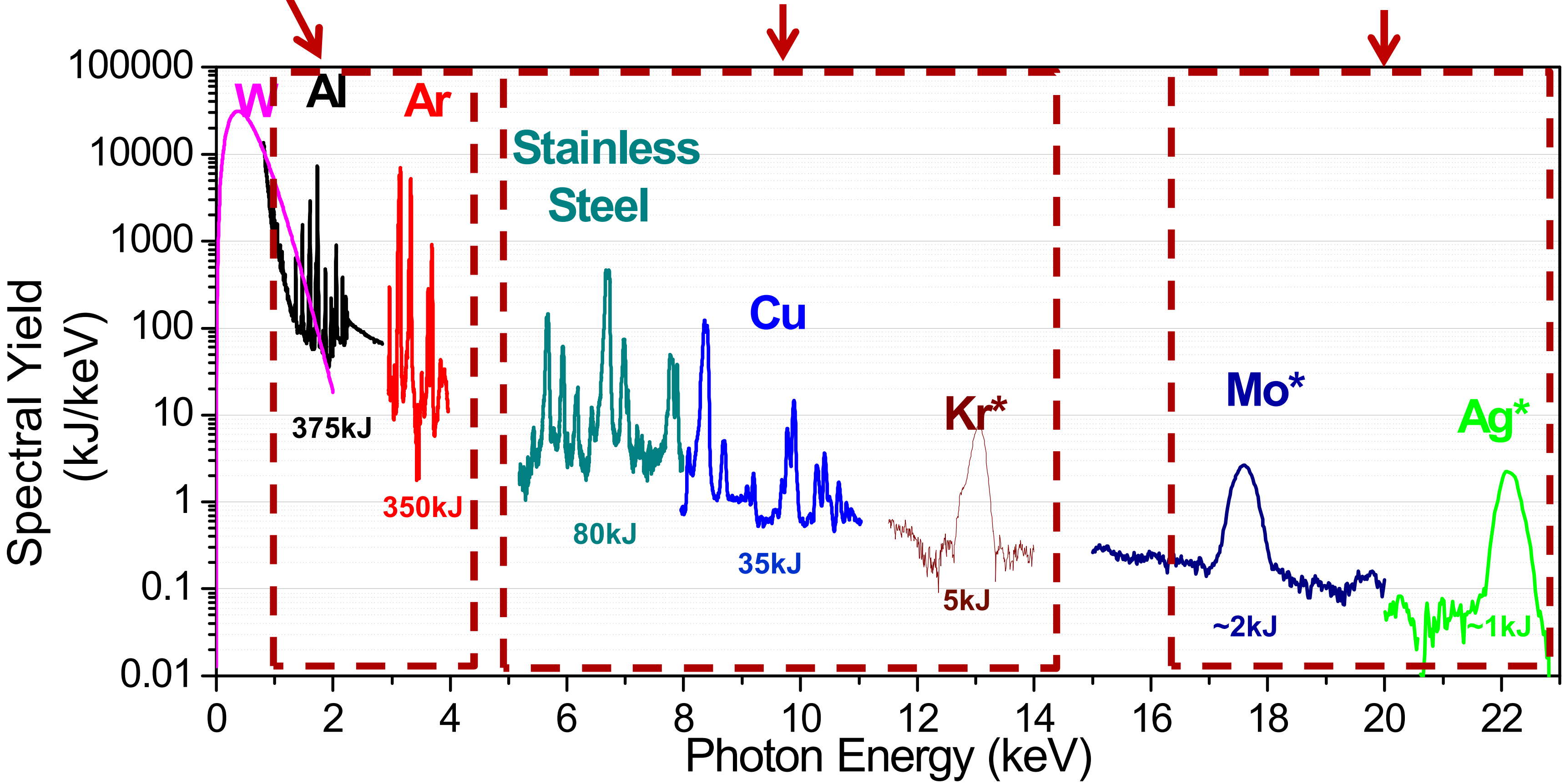
- Adding a center jet increases K-shell yield from 330 kJ to 375 kJ
- Results match simulated predictions
- Argon is an efficient K-shell source on Z – yields are in line with those expected

The Z radiation effects sciences program uses a variety of sources to cover a wide energy range of line emission

Z achieves very high yields – opacity can be a concern

Emission requires high temperatures and implosion velocities. Stability a concern.

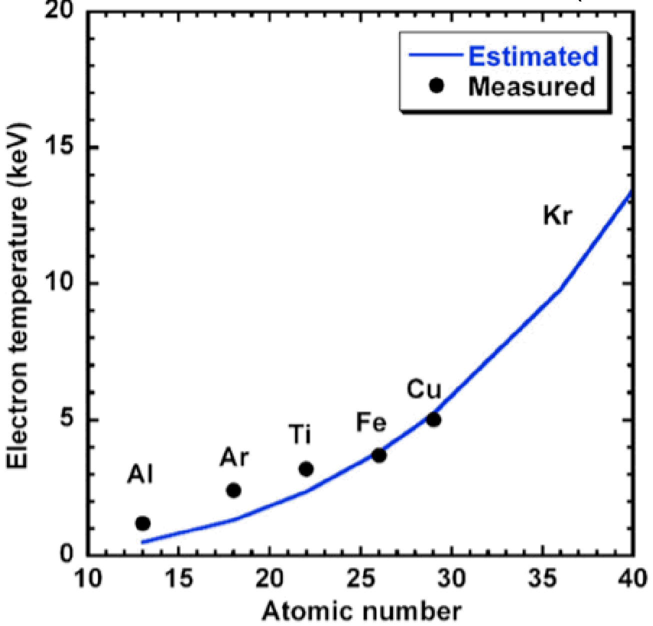
Temperatures required too high – rely on inner shell ionization



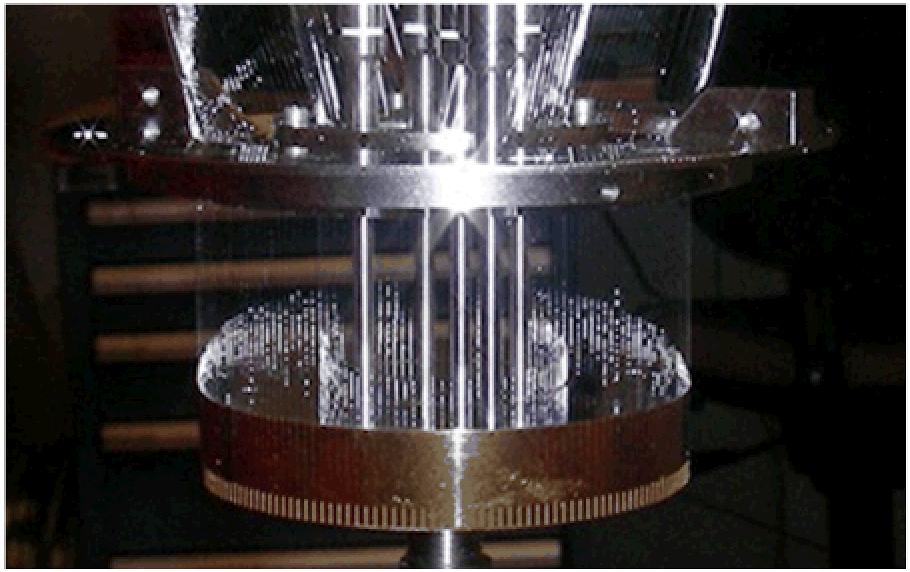
Taken from D. Ampleford et al., APS DPP 2013

Z pinch implosions use tailored mass profiles to reduce instability growth – particularly important to get to high vel.

Taken from Coverdale et al., HEDP 6 (2010)



Nested Al wire array

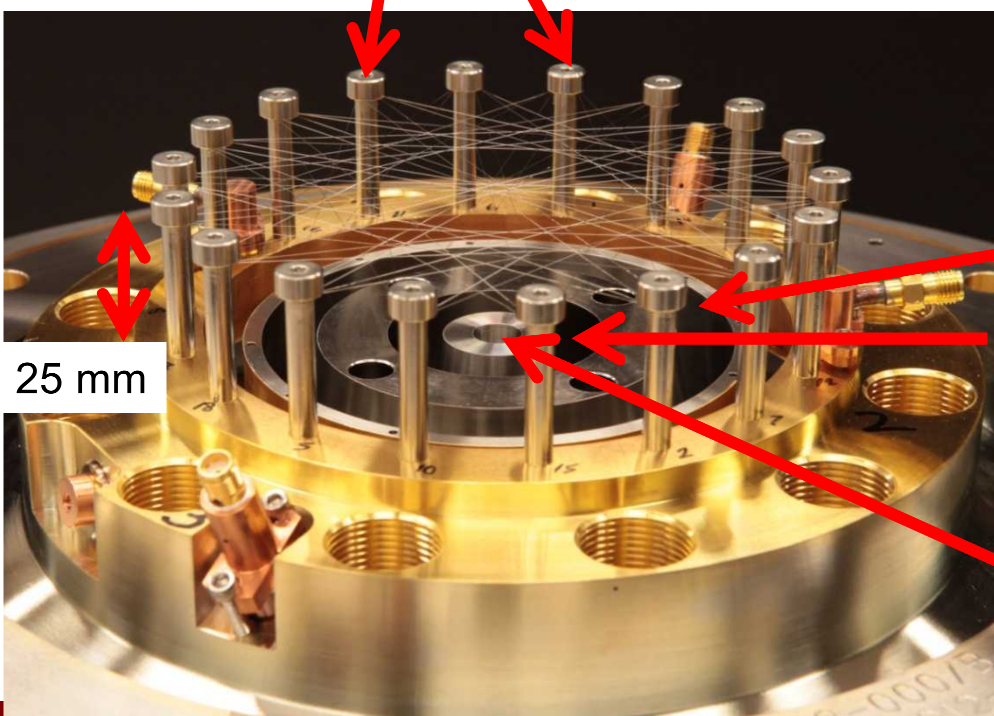


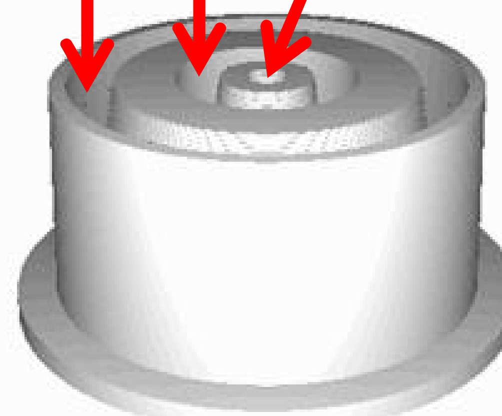
- Temperature needs to be high enough for efficient K shell radiation (T_e~$0.3*Z^{2.9}$ eV) – determines implosion velocity and initial radius required
- MRT growth disrupts larger diameter, higher velocity implosions – stabilization methods (nested arrays, double-shell gas puffs) increase yield

We have established a multi-shell gas puff capability on Z[1]

- 8 cm outer diameter
- Nozzle has outer and middle plenum with the option of a central jet
- Developed by Alameda Applied Sciences
  - M. Krishnan *et al.*, RSI **84**, 063504 (2013)

[1] B. Jones et al., IEEE Trans. Plas. Sci. (2013)



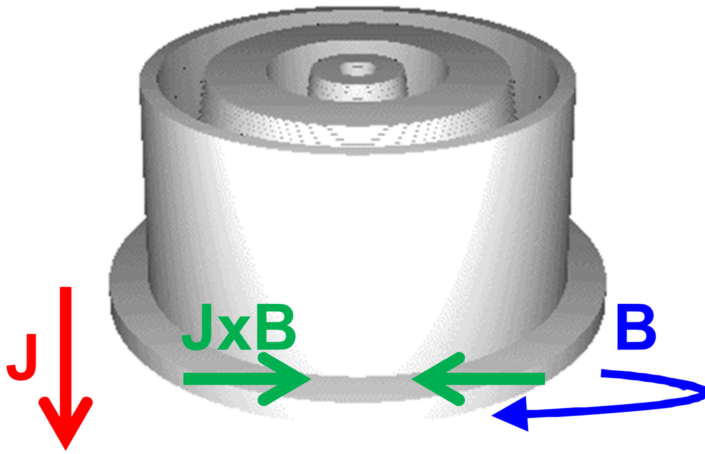


The Z generator implodes the Argon gas to produce large amounts of Argon K-shell emission at stagnation

- Supersonic jets establish azimuthally symmetric shells of Argon gas[1]
- The Z generator current implodes the Argon towards the axis
  - 25 mm pinch height – height of wire mesh
- Stagnated plasma radiates efficiently in the K-shell (>3 keV photons) – 80% of K-shell emission in lines
- We are able to alter the mass released in each shell to control the implosion – we can add mass to a center jet

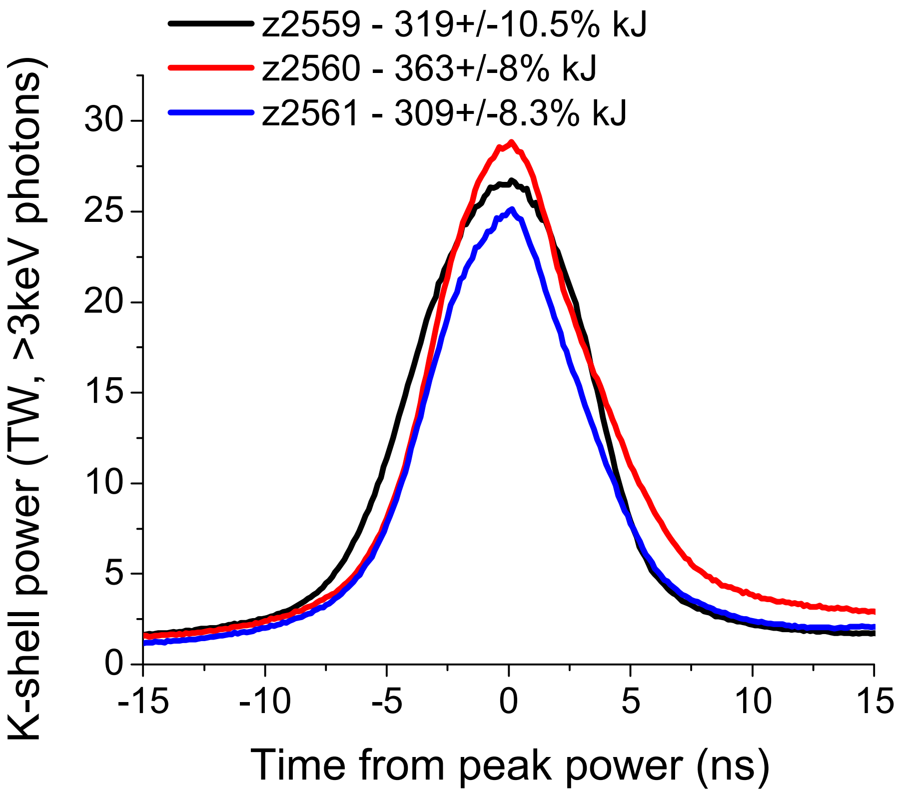
[1] Developed by AASC: M. Krishnan et al., RSI 84, 063504 (2013)

Shell-on-shell profile – no center jet



Illustrative 3D MHD GORGON sim. by Chris Jennings

We have established a 1:1.6 outer:inner mass ratio, 1 mg/cm configuration as a reliable, well performing load[1]



- 3-shot average K-shell yield (>3 keV photons) for 1:1.6 without center jet config:

  330 kJ ± 9% (3 shot Av. yield)

- Average peak power: 26.7 TW
- Average FWHM: 7.85±0.56 ns

The remainder of the talk will discuss the performance of other configurations including central jets

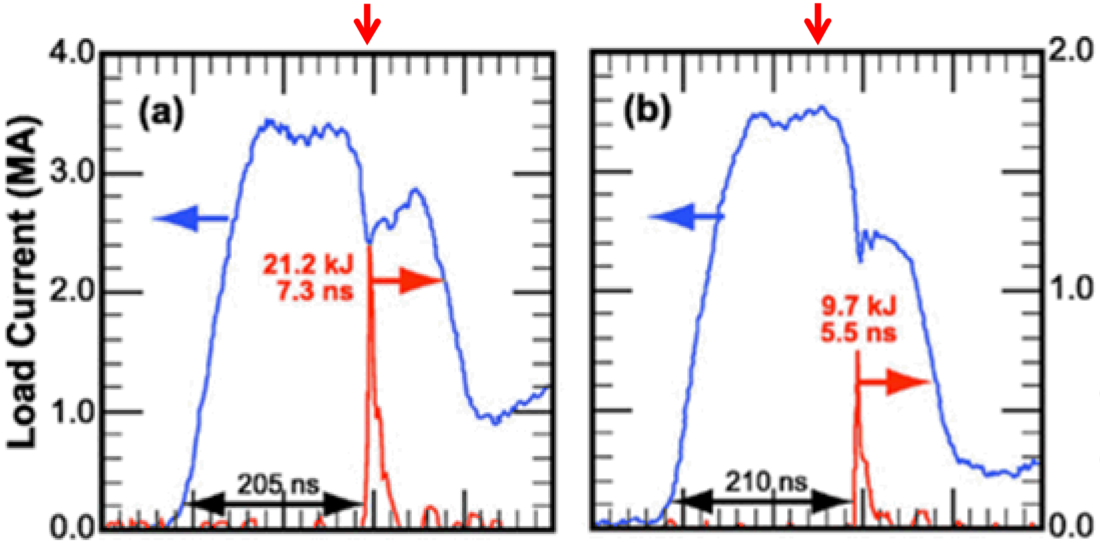
Shot	2559	2560	2561
K-shell yield, >3 keV	319 kJ ± 10.5%	363 kJ ± 8%	309 kJ ± 8.3%
K-shell peak power	26.4 TW	29.0 TW	26.9 TW
K-shell FWHM	8.5 ns	7.6 ns	7.5 ns

[1] B. Jones et al., Phys. Plasmas 22, 020706 (2015)

In 2-6 MA, 200 ns rise-time experiments adding a central jet produced yields comparable to 100 ns experiments

Results from 200 ns rise time experiments

Jet-middle-outer 21.2 kJ   Middle-outer 9.7 kJ



Experiments on Double-Eagle, H. Sze et al., PoP, 2007

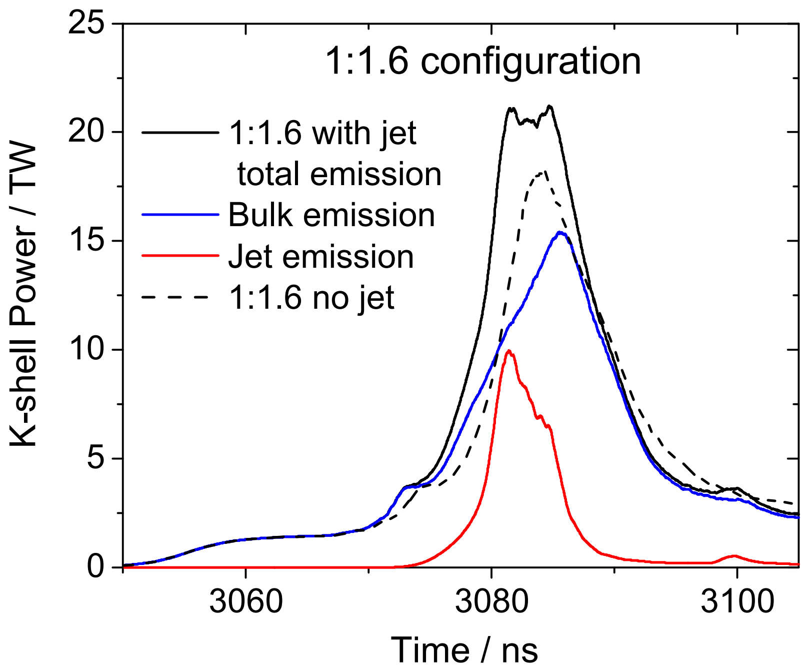
- Experiments conducted at the 2-6 MA, 200 ns risetime facilities Double-Eagle[1], Decade-Quad[2] and Saturn
- All experiments used 12 cm diameter 1:1 mass ratio nozzles

[1] H. Sze et. al., Phys. Plas., (2007)
[2] H. Sze et al., Phys. Rev. Lett. (2005)

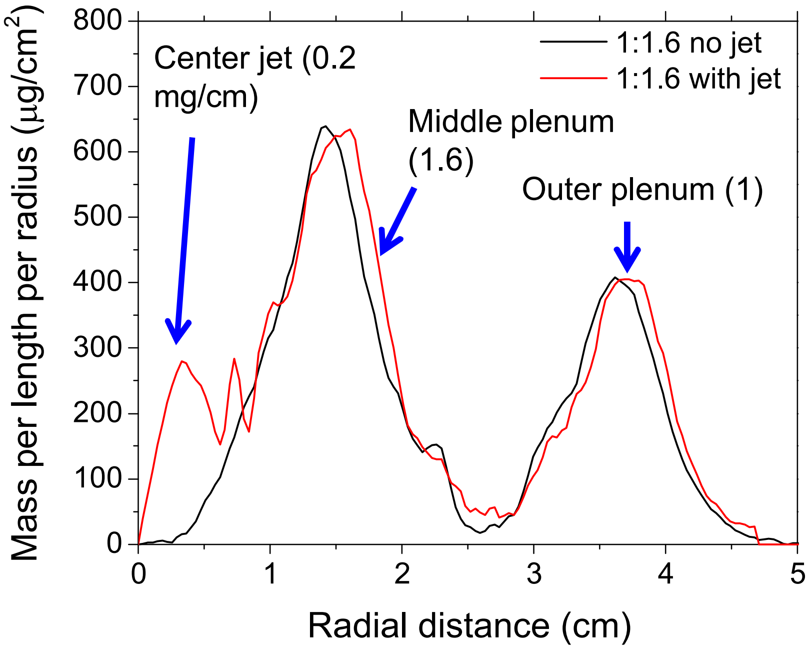
- 200 ns implosions should not perform as well as 100 ns implosions!
  - Require larger diameters for same implosion velocities and hence more instability growth
- Experiments suggest that adding a center jet reduces the impact of MRT growth beyond just using a double shell puff

2D and 3D MHD simulations are used to design and help understand the experiments

Emission from 3D MHD GORGON simulations of 1:1.6 with jet



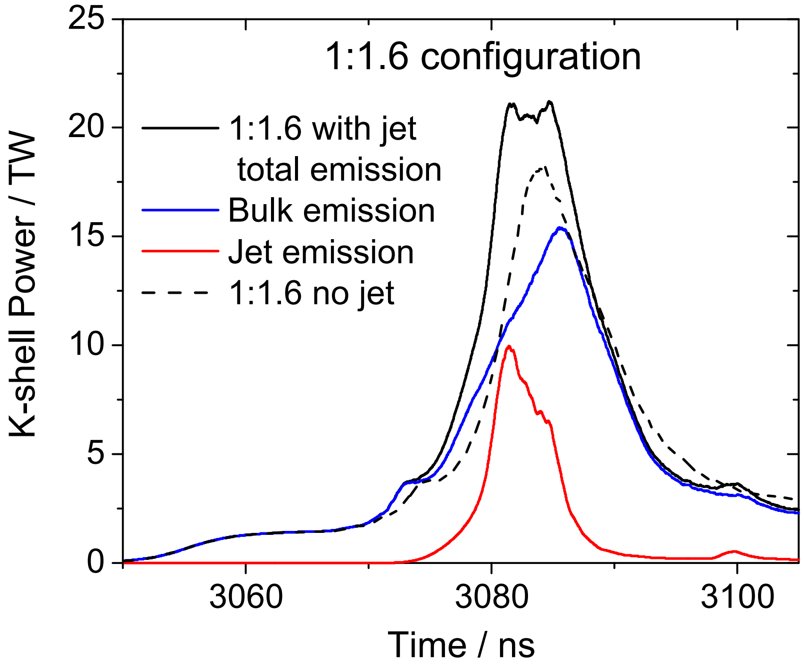
Measured mass profiles used in sims



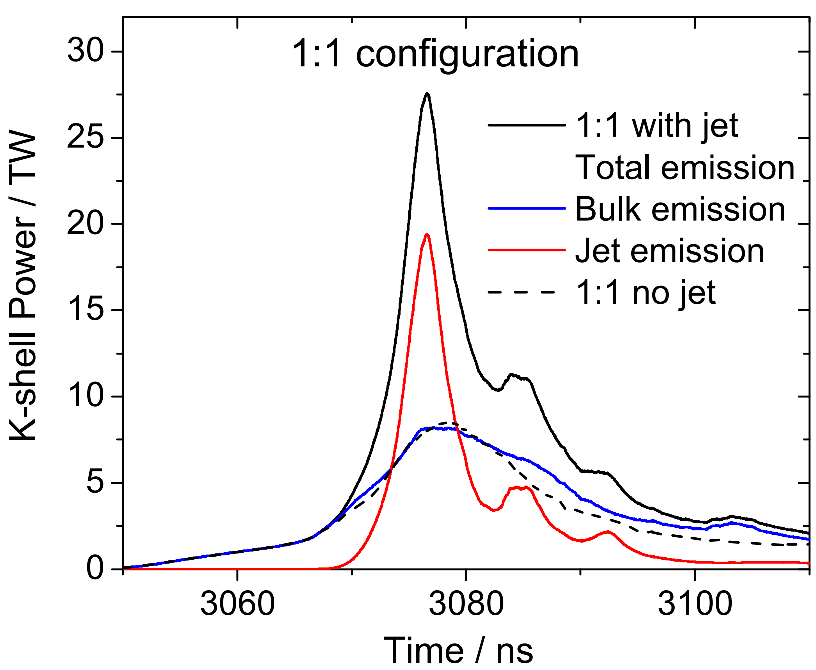
- GORGON suggests a 0.2 mg/cm central jet does not add much emission to the 1:1.6 configuration – the implosion is too slow and the jet not heated effectively

GORGON simulations suggest the center jet performs better with a 1:1 mass profile configuration

Emission from 3D MHD GORGON simulations of 1:1.6 with jet



Emission from 3D MHD GORGON simulations of 1:1 with jet



- GORGON suggests a 0.2 mg/cm central jet does not add much emission to the 1:1.6 configuration – the implosion is too slow and the jet not heated effectively
- A 1:1 configuration implodes faster, heats the jet more effectively and is more similar to configurations used previously

3D GORGON and 2D Mach2[1] simulations predict some potential improvements in K-shell yield with added center jet

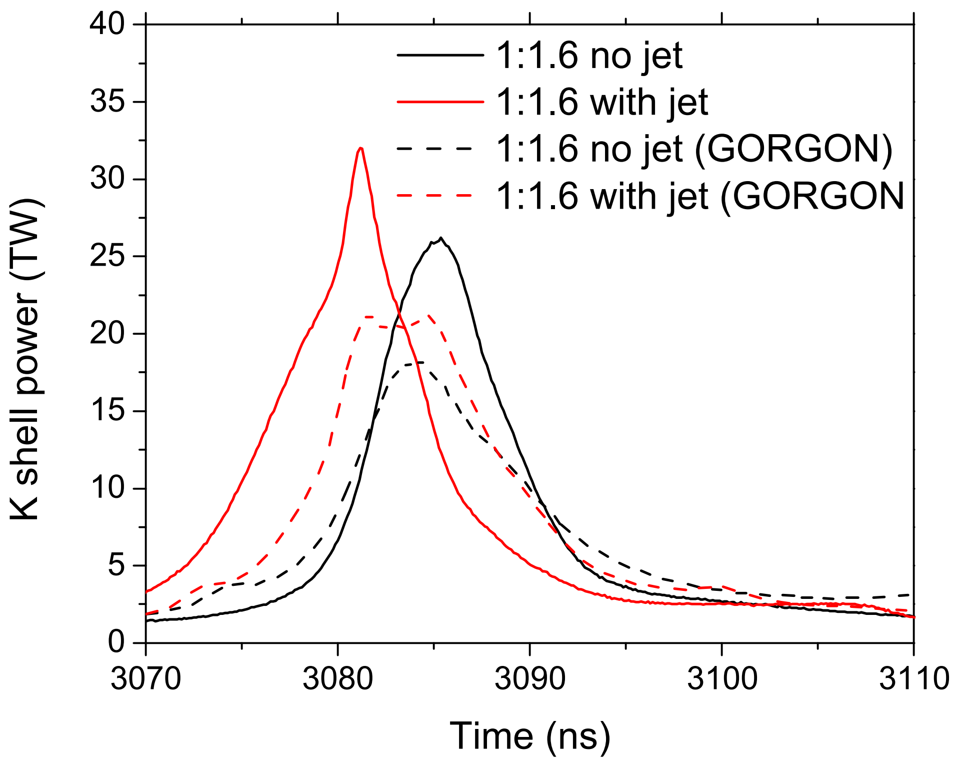
Configuration	GORGON yield	Mach2 yield
1:1.6 no center jet (1 mg/cm)	323 kJ	350 kJ
1:1.6 with center jet (1.2 mg/cm)	356 kJ	460 kJ
1:1 no center jet (0.77 mg/cm)	205 kJ	260 kJ
1:1 with center jet (0.97 mg/cm)	383 kJ	350 kJ

Simulations suggest some improvements possible with center jet – but probably not dramatic

Discrepancy in Mach2 sims. partially explained by increased energy coupled into loads in these predictions

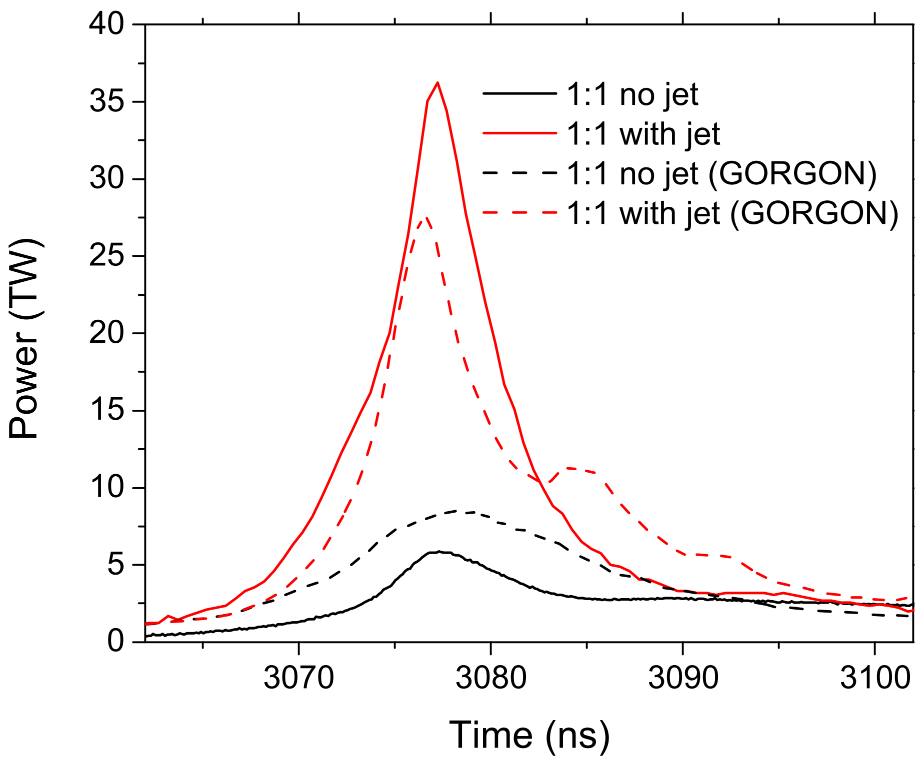
[1] W. Thornhill et al., HEDP 2012

Central jet added to 1:1.6 config. shows small improvement in K-shell yield



- Center jet increased yield from 330 kJ ± 9% to 373 kJ ± 9%
- Peak K-shell power increased from 26.7 TW to 32 TW
- GORGON agrees with yield but under-predicts power

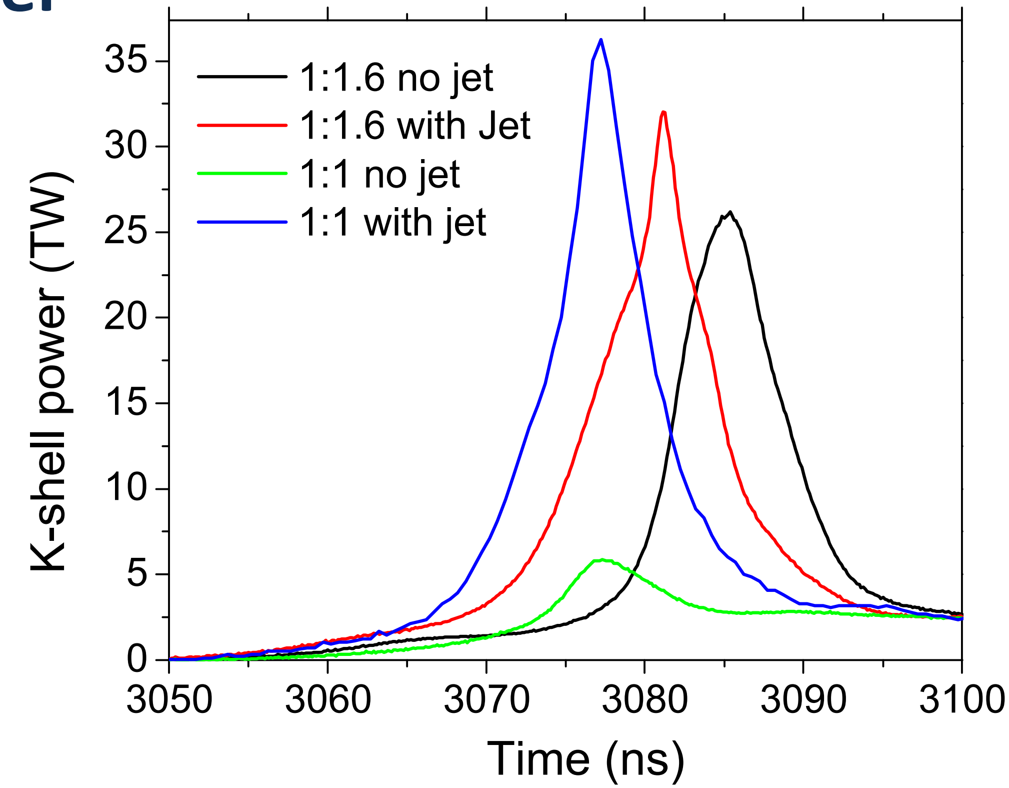
Central jet added to 1:1 config. shows significant improvement in K-shell yield and power



- Center jet increased yield from 143 kJ ± 9% to 375 kJ ± 9%
- Peak K-shell power increased from 6 TW to 36 TW
- GORGON agrees with yield again, some disagreement with power

Center jet shots show some improvement in yield, larger improvement in power

- 1:1 with center jet shows highest peak power
- Yields very similar (except for 1:1 without center jet) and in-line with GORGON simulations



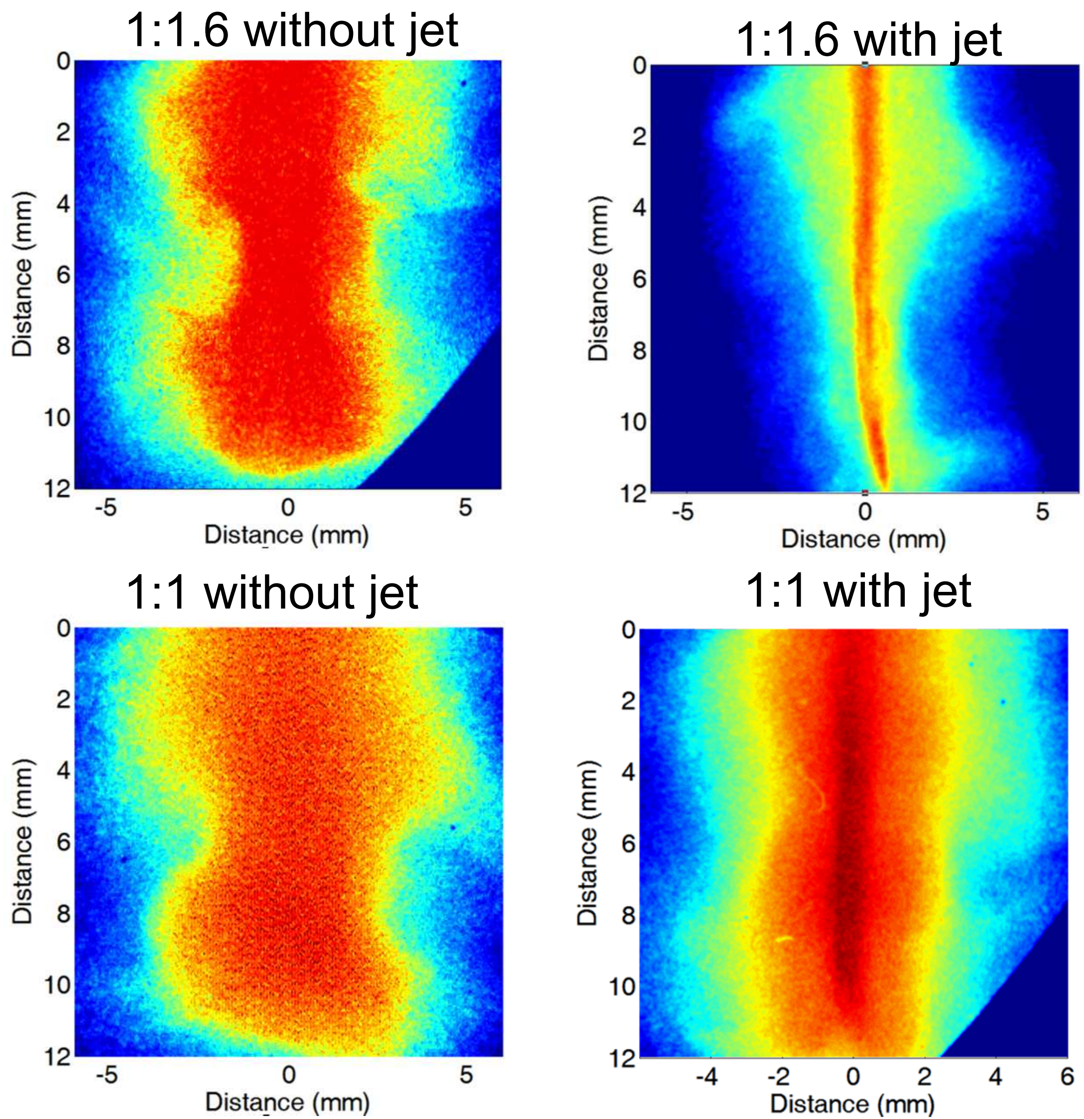
Configuration	GORGON yield	NRL yield	Experimental yield
1:1.6 no center jet	323 kJ	350 kJ	330 kJ ± 9%
1:1.6 with center jet	356 kJ	460 kJ	373 kJ ± 9%
1:1 no center jet	205 kJ	260 kJ	143 kJ ± 9%
1:1 with center jet	383 kJ	350 kJ	375 kJ ± 9%

Time resolved pinhole images near stagnation show qualitatively improved compression and uniformity in central jet shots

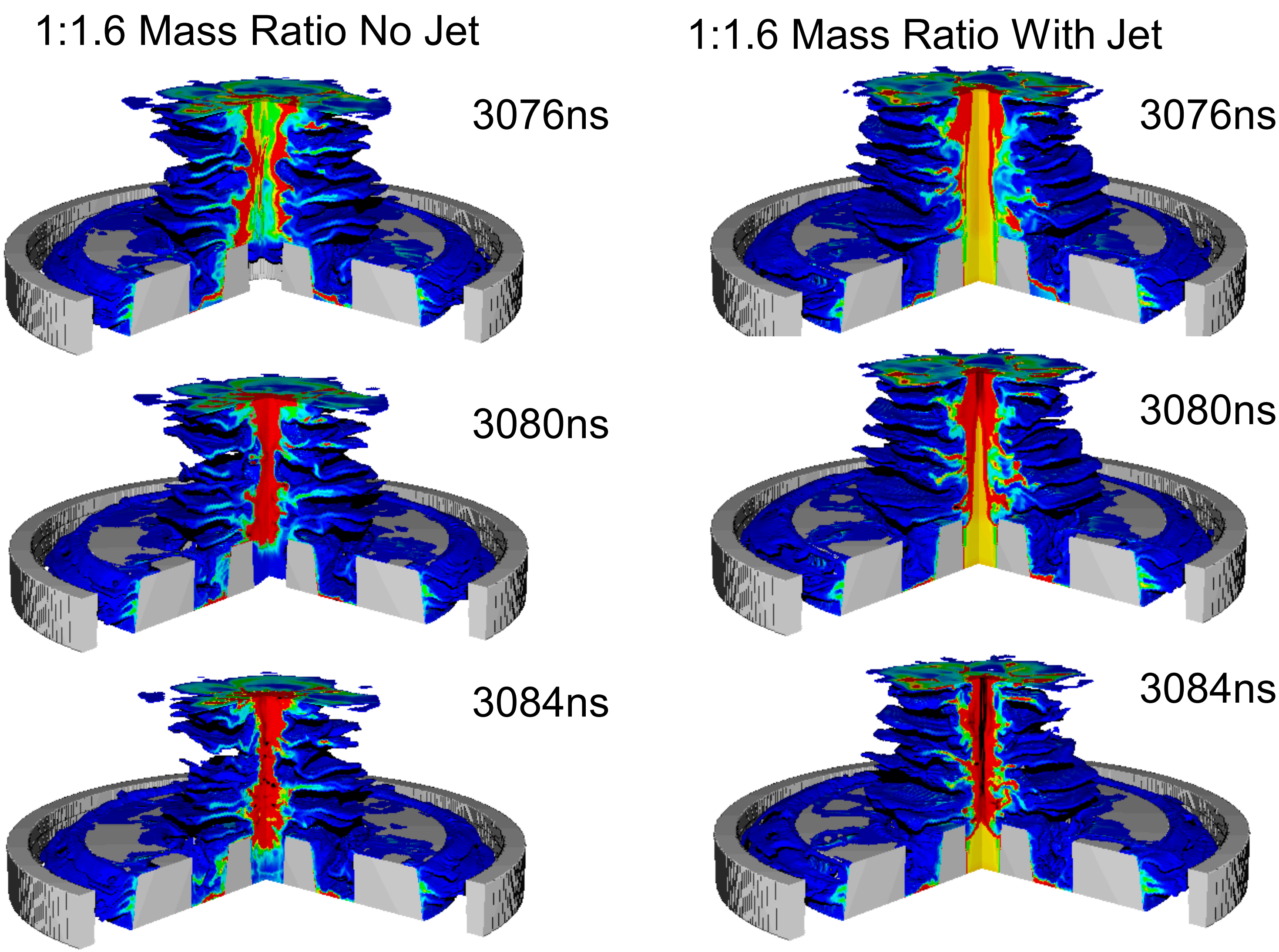
Camera sensitive to photons >3 keV

Center jet reduces pinch diameter from 3-4 mm to < 1 mm

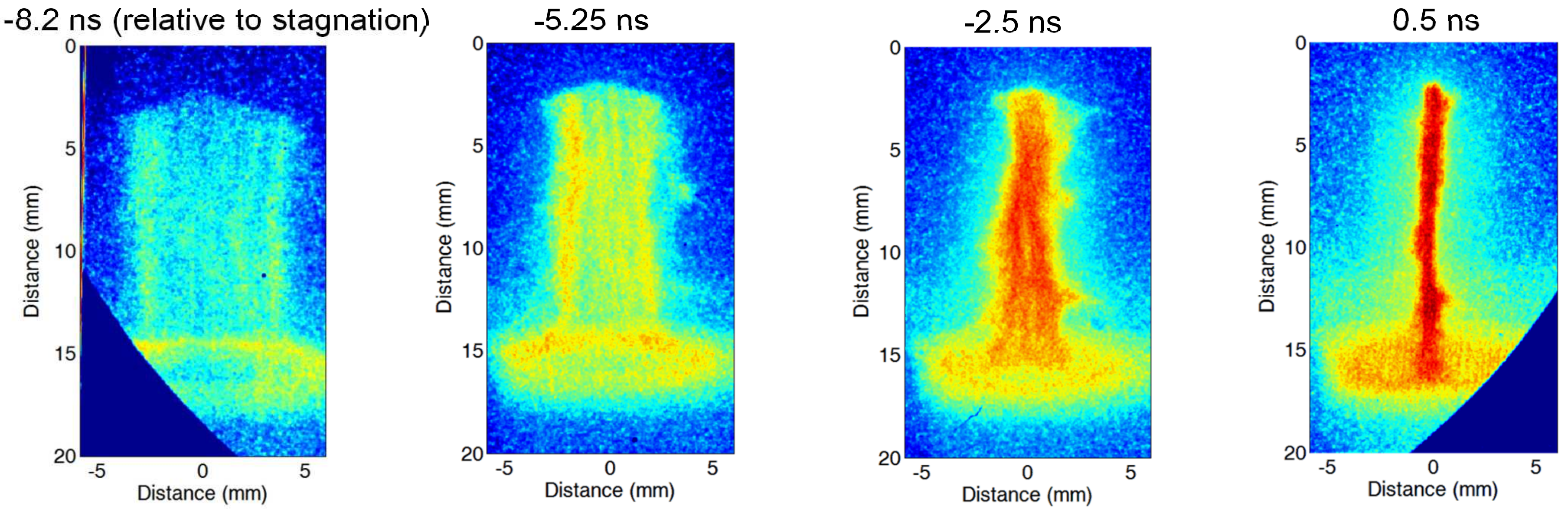
Higher convergences could indicate lower temperatures on axis



GORGON simulations also show better compression of material with vs. without center jet (electron density maps)



Xe dopant added to central jet in 1:1.6 configuration shows compression of jet material

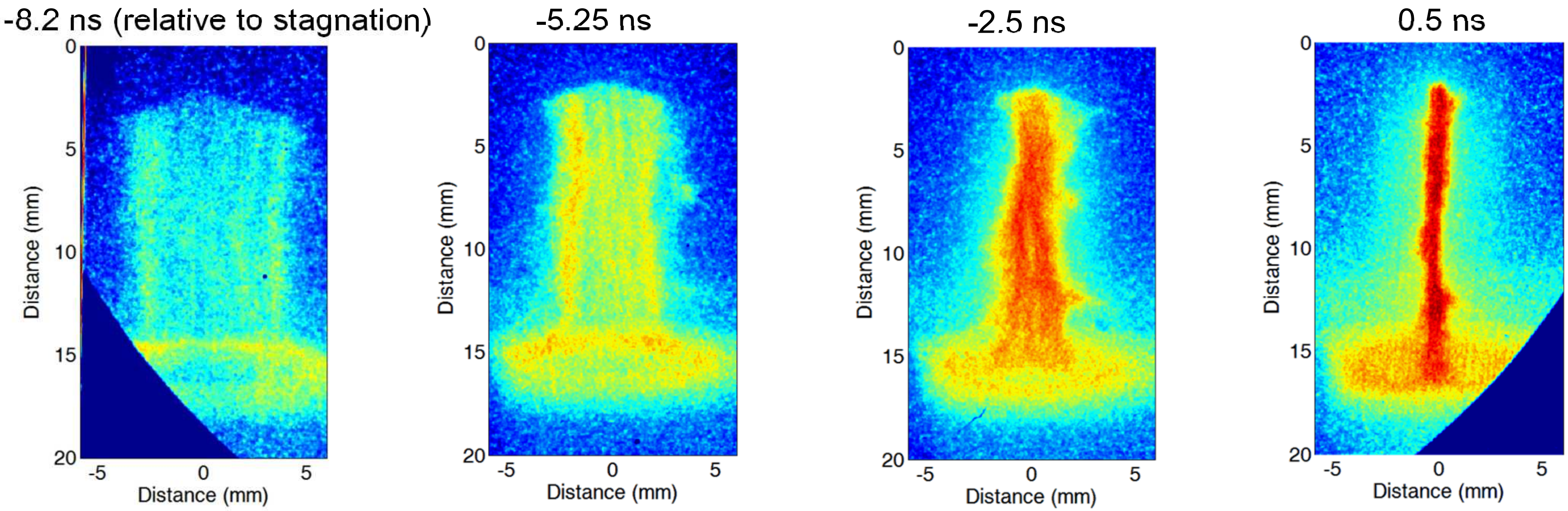


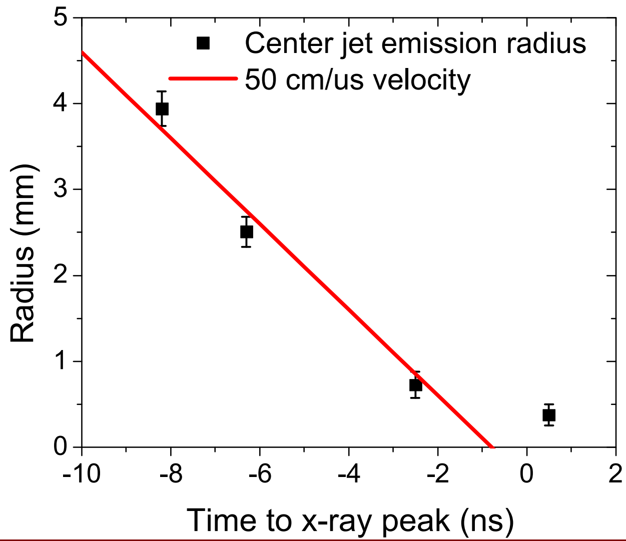
277 eV MLM time resolved camera[1] – sensitive to Xe M-shell emission

In shots without Xe, little emission seen on this camera

0.8% by particle no. Xe dopant reduced K-shell yield substantially

Compression of center jet material broadly agrees with GORGON sims.

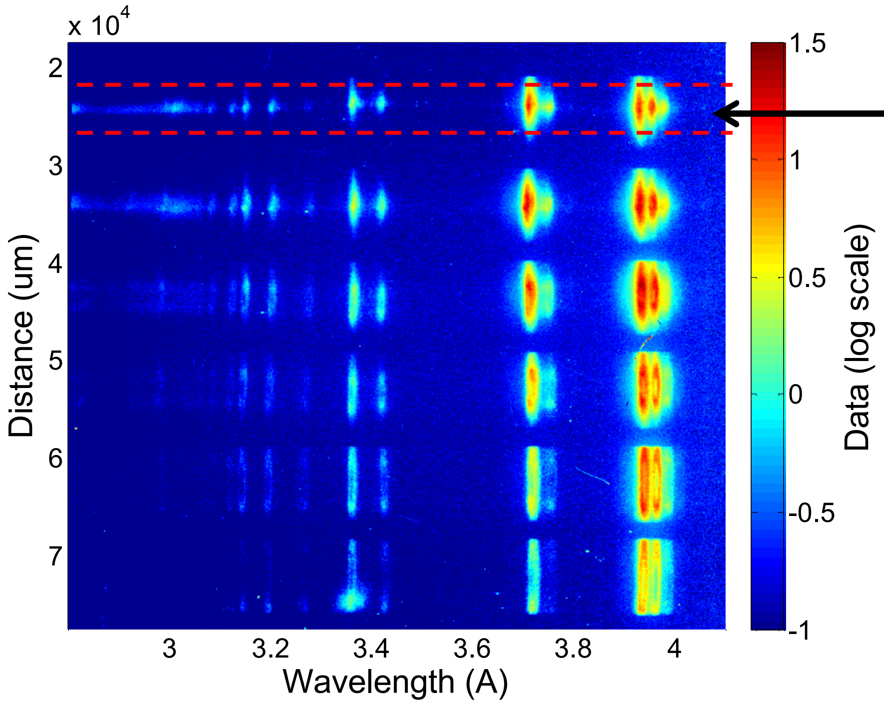


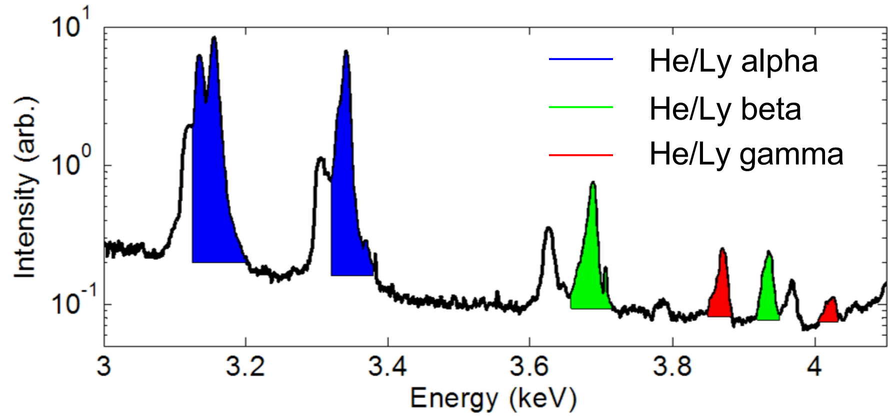


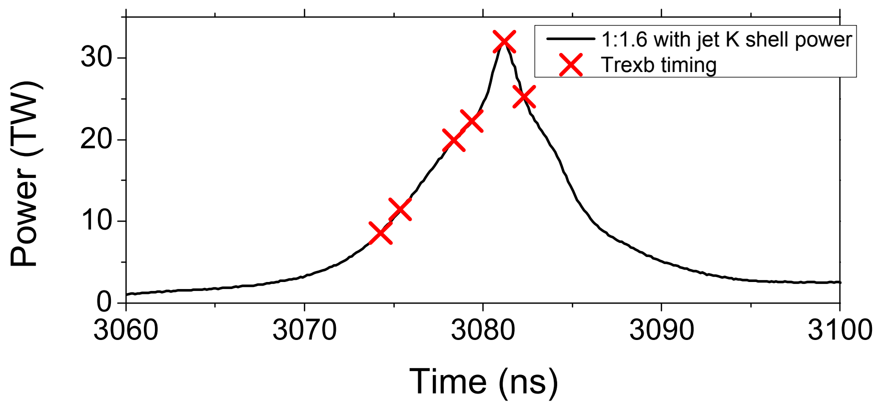
- ~50 cm/us implosion agrees with GORGON simulations

Radially resolved, time gated spectra contain information about plasma conditions at stagnation

1:1.6 with center jet time resolved spectra







- Multiple time gated (0.2 ns), radially resolved spectra taken each shot
- Doppler splitting can be used to infer velocities during implosion[1]
- Line ratios interpreted with CRE modelling can infer plasma conditions[1]

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[1] B. Jones et al., Phys. Plasmas 22, 020706 (2015)

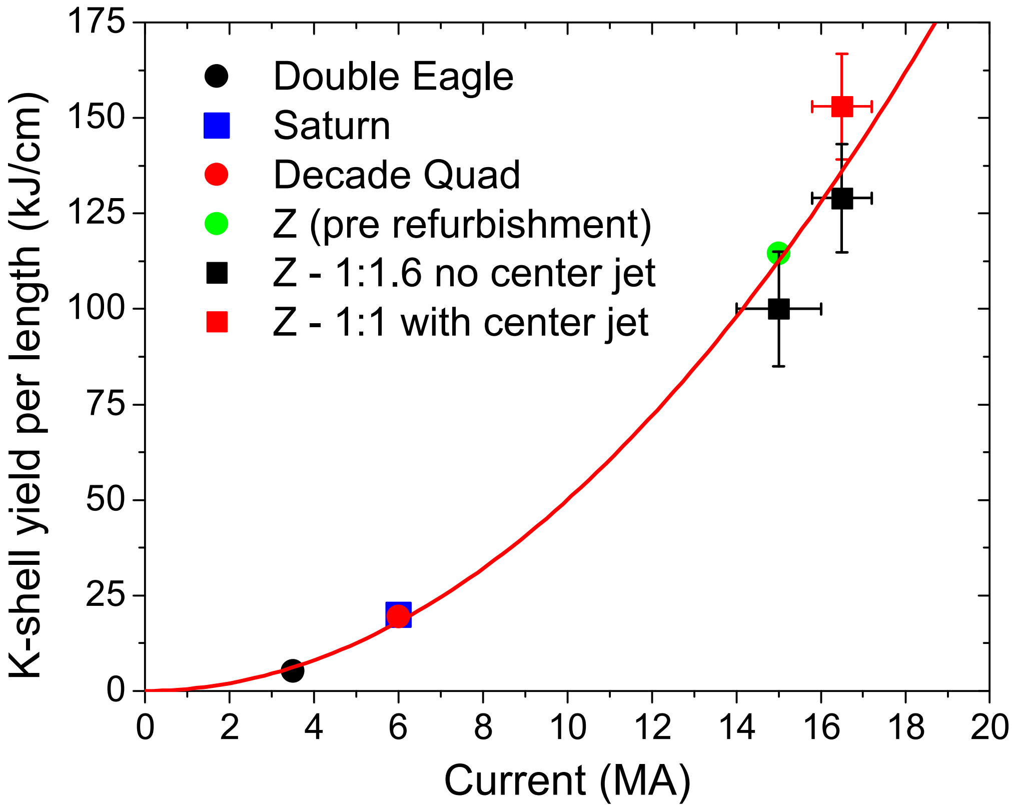
Measured parameters coupled with a two-zone collisional radiative model is used to infer parameters

Property	1:1.6 no jet	1:1.6 with jet	1:1 with jet
K-shell diam. (mm)	2.8	1.2	1.38
T ion (eff, eV)	50	29	28
T_e inner (keV)	2.45	2.00	2.00
N_i inner (10^{19} cm^{-3})	6.7	18	17
N_i outer (10^{19} cm^{-3})	2.5	3.4	2.4
X^2 for fit	1.16	0.71	0.72
Fit significance confidance level	99%	99%	99%

- Best fit is found for multiple experimentally measured parameters (including K-shell and total x-ray powers and line ratio's)
- Fitting suggests smaller emitting diameter and higher densities at stagnation in center jet shots

For more information see J. Apruzese talk next

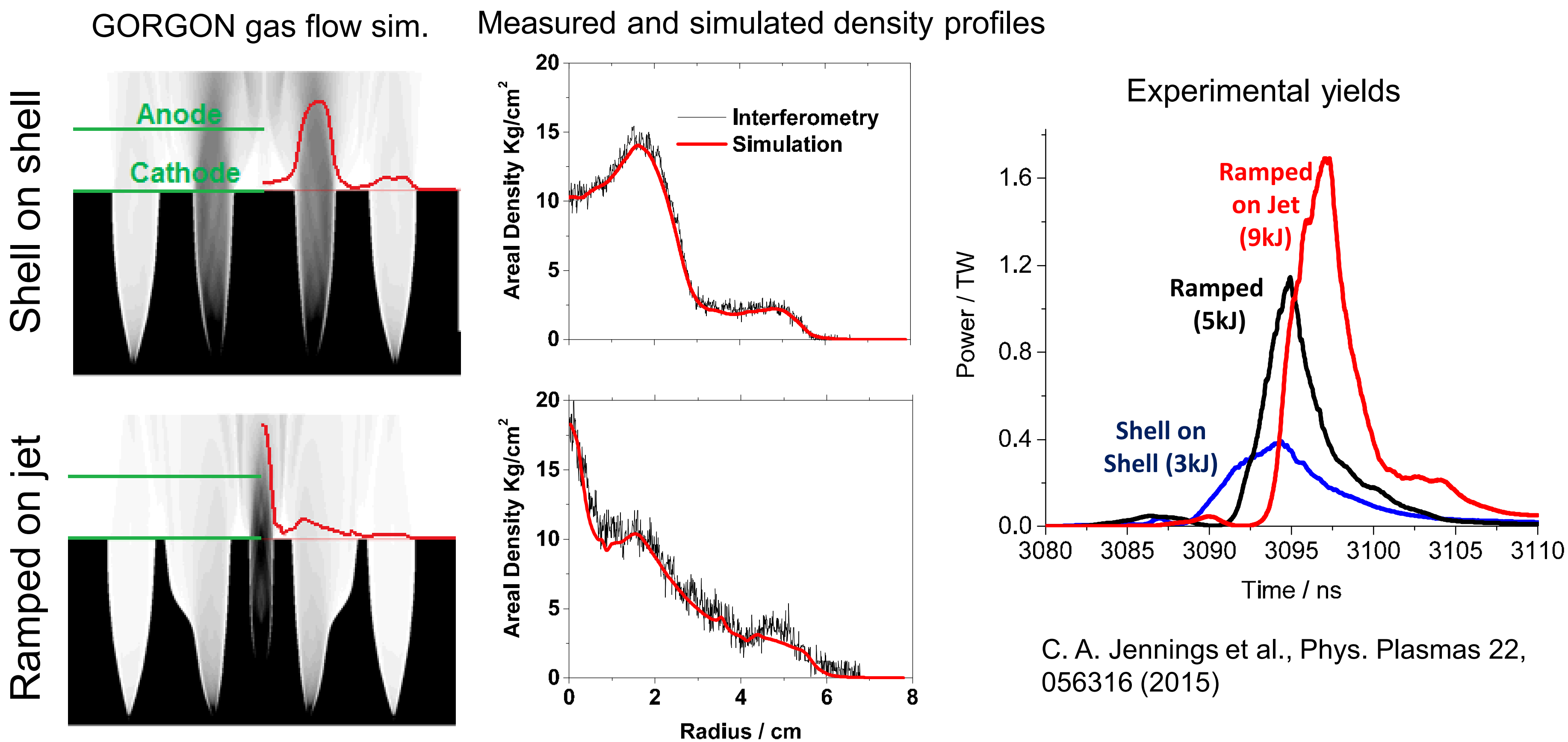
Results are in line with I^2 scaling – modest increases in current delivery may produce large increases in yield



- I^2 scaling shows we are in the 'efficient' regime – fraction of delivered energy radiated is same as earlier experiments
- Large gains in yield may not be possible from gas configuration changes alone
- Gas puffs lose current on Z due to high Ldot and a lossy convolute – need to better understand and control these losses to increase performance

H. Sze et. al., Phys. Plas., (2007)
H. Sze et al., Phys. Rev. Lett. (2005)
H. Sze et al., Plas. Phys. Lett. (2001)
B. Jones et al., IEEE Trans. Plas. Sci., (2014)
B. Jones et al., Phys. Plasmas (2015)

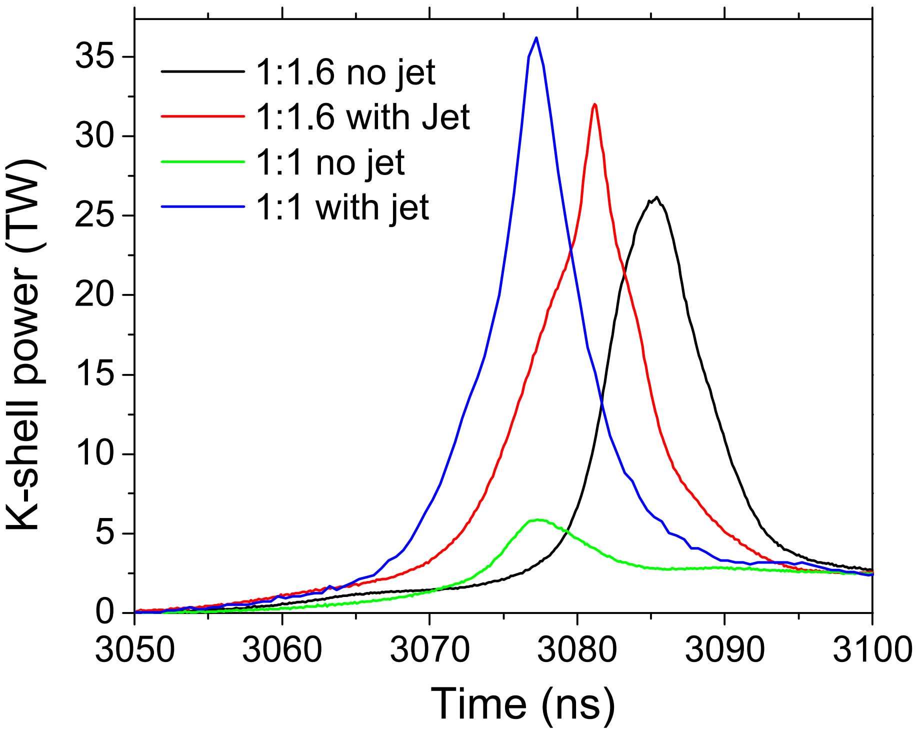
Krypton gas puffs can benefit much more from tailoring mass profiles due to higher implosion velocities[1]

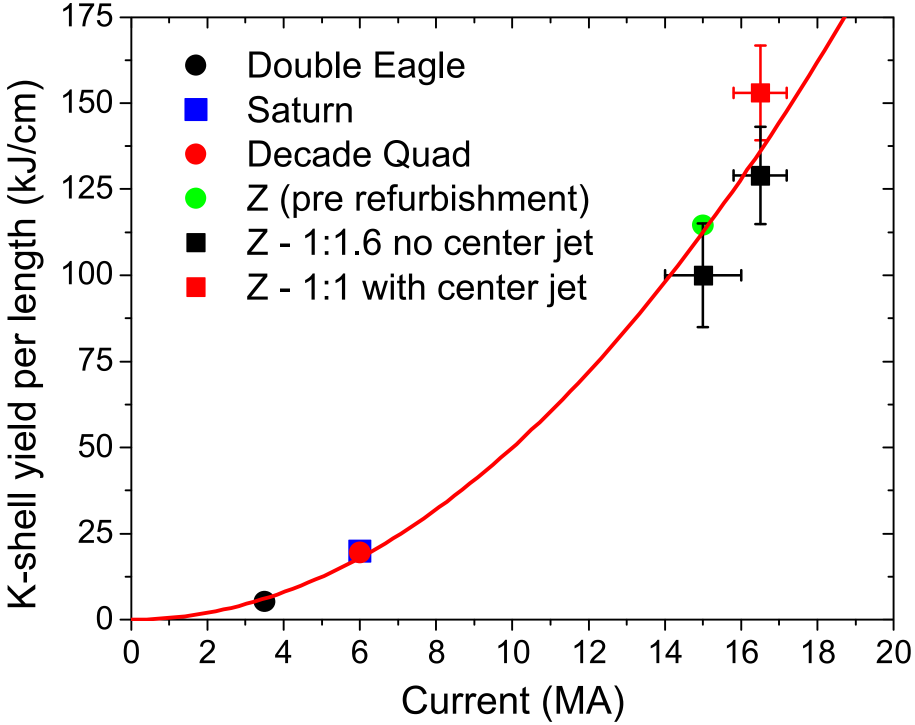


- Krypton requires higher velocities (~1000 km/s), larger diameter (12 cm) implosions on Z – these are unstable to MRT
- Improving robustness to MRT by including center jet and ramped profile increased yield significantly

[1] C. A. Jennings et al., Phys. Plasmas (2015)

Summary – Adding center jets to Ar gas puffs on Z increases the K-shell yield – slightly

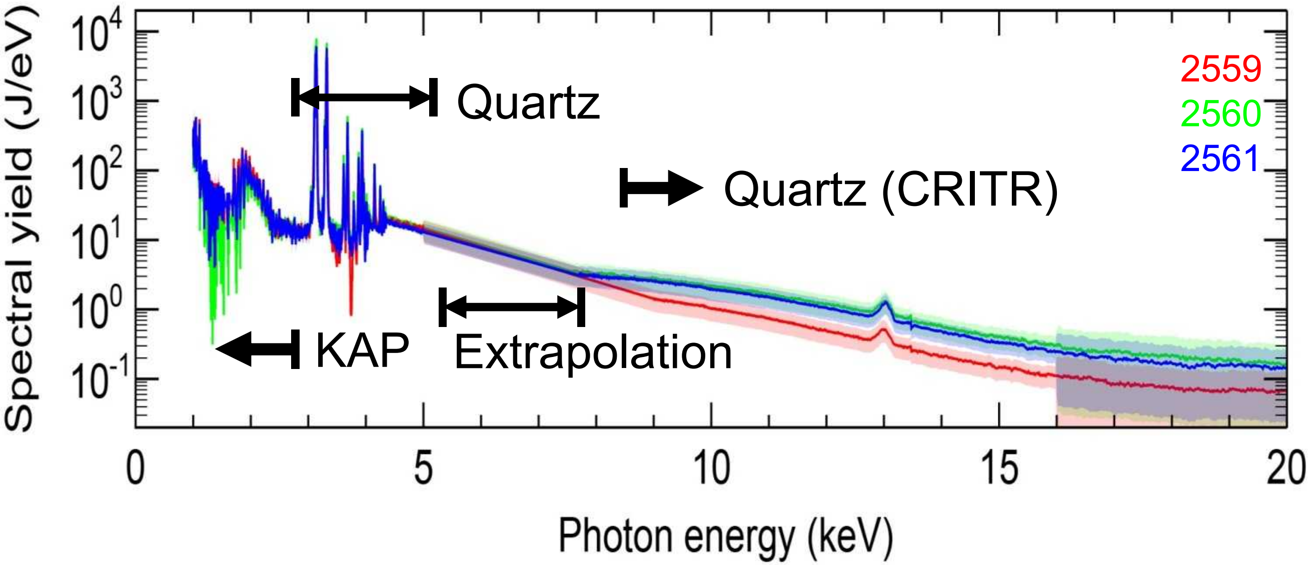


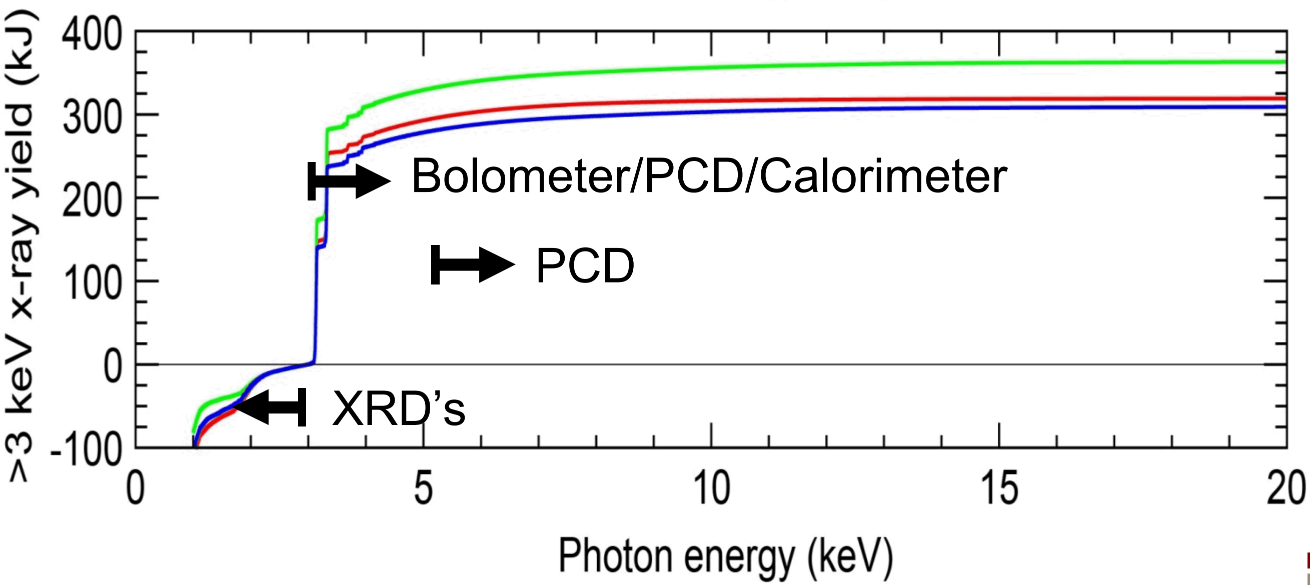


- Adding a center jet increases K-shell yield from 330 kJ to 375 kJ
- Results match simulated predictions
- Argon is an efficient K-shell source on Z – yields are in line with those expected

Backup slides

Spectrometer and power/yield diagnostics combined allow the yield in different parts of the spectrum to be assessed



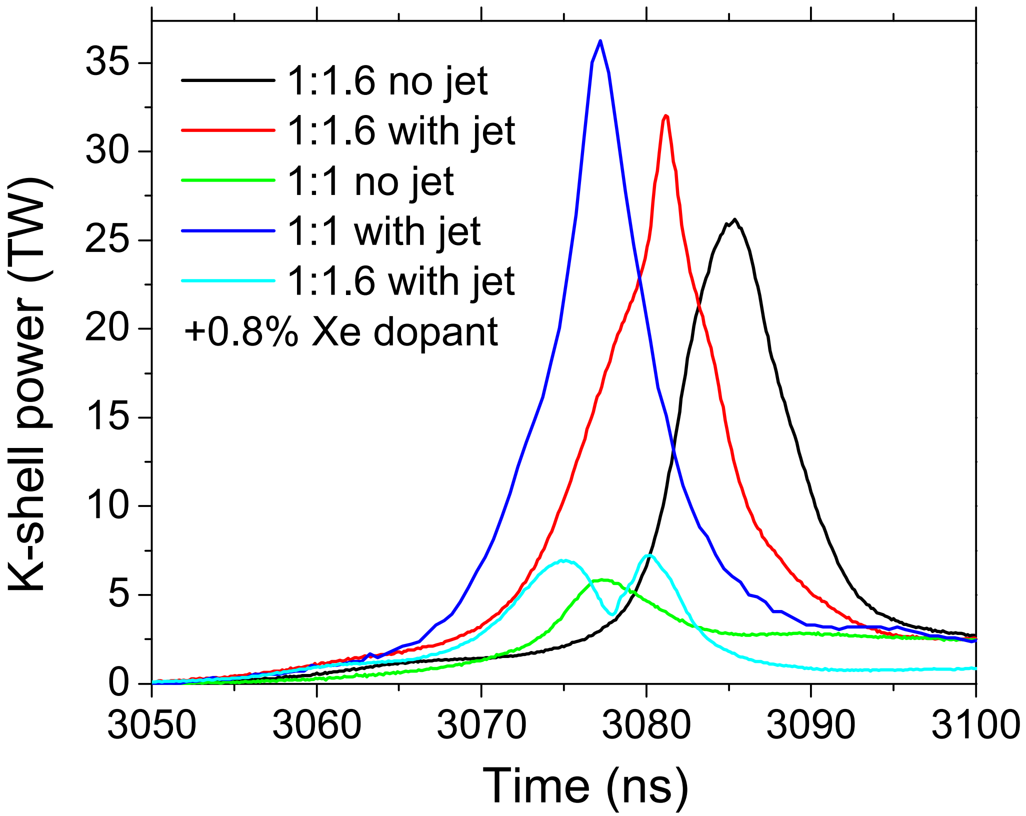


Spectrum is built from a combination of spectrometers

Different filter cuts of calorimeters, PCD's and bolo's constrain regions of the spectra

Spectrum is tweaked until best agreement is found – K-shell yield can be determined

K-shell power including Xe dopant shot



Xe dopant fraction: 0.8% by particle number just in center jet (c.j. has 0.2 mg/cm out of total 1.2 mg/cm mass in puff)

Yield of shot with Xe dopant: 129 kJ +/- 14%