SAND2017-11450C

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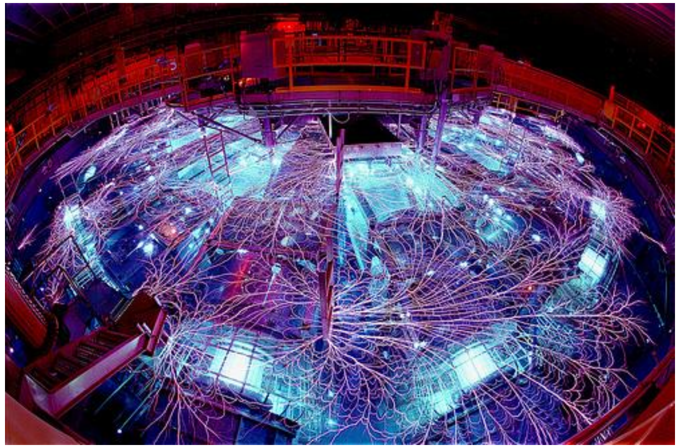

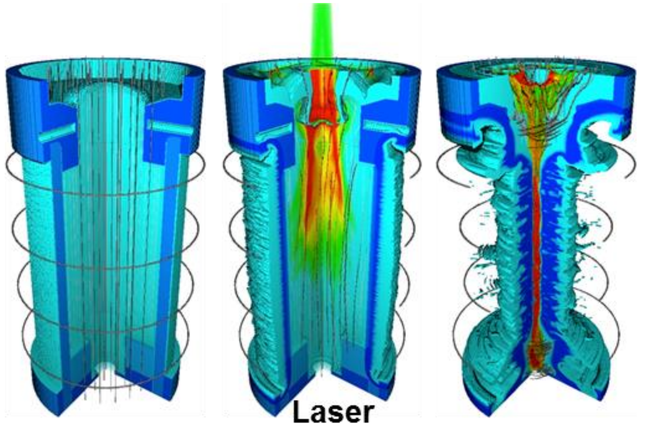

3D stagnation instabilities in Maglif Loads

C. A. Jennings

Steve A. Slutz, M.R. Gomez, E.C. Harding, A. Harvey-Thompson, P. F. Knapp, M. Geissel, M.R. Weis, T.J.Awe, D. J. Ampleford, S.B. Hansen, G. R. Laity, M.E. Glinsky, K. Peterson, M. Hess, M.R. Martin, P.F. Schmit,
Sandia National Laboratories, Albuquerque, NM, USA

J. Chittenden,
Imperial College, London, UK

59th Annual Meeting of the APS Division of Plasma Physics

October 25, 2017

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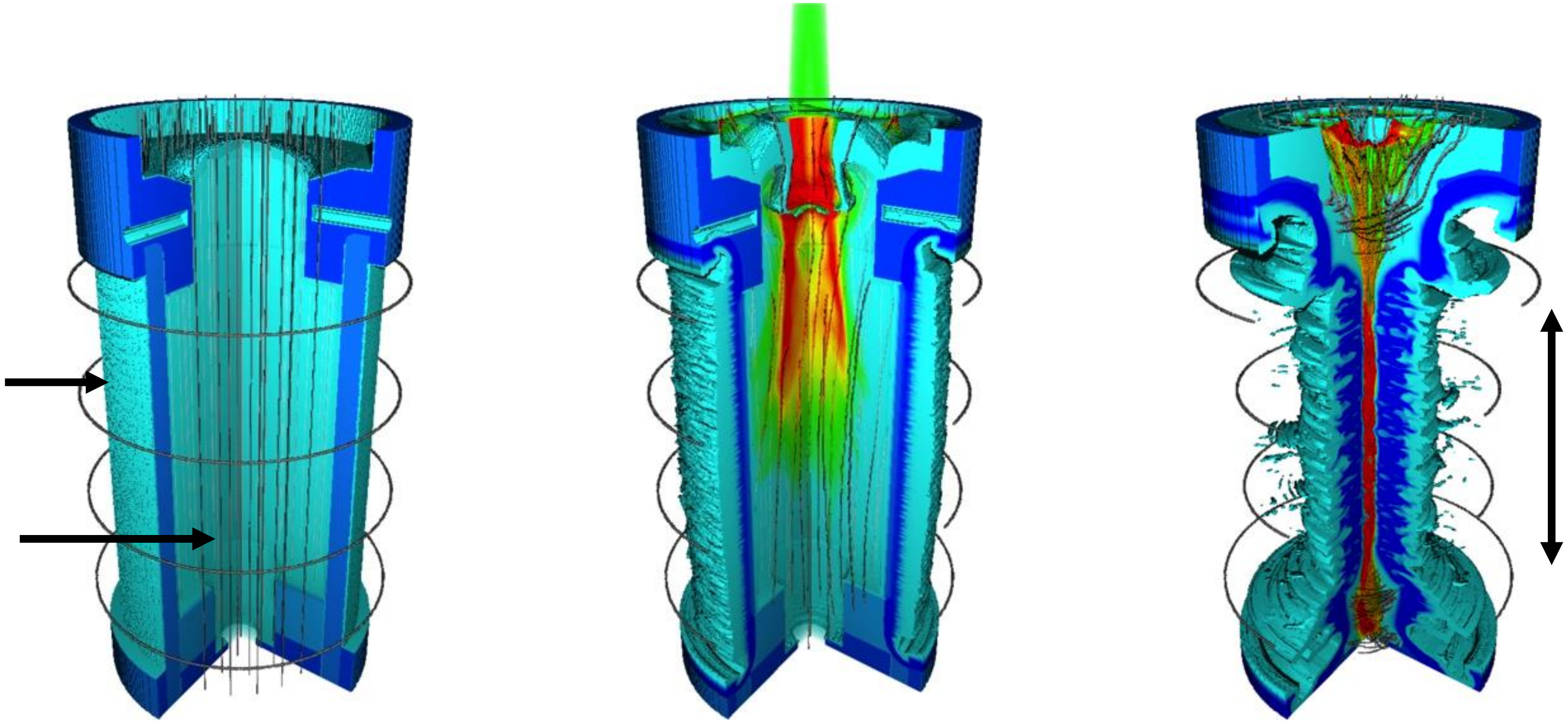
U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Magnetized Liner Inertial Fusion relies on three stages to produce fusion relevant conditions

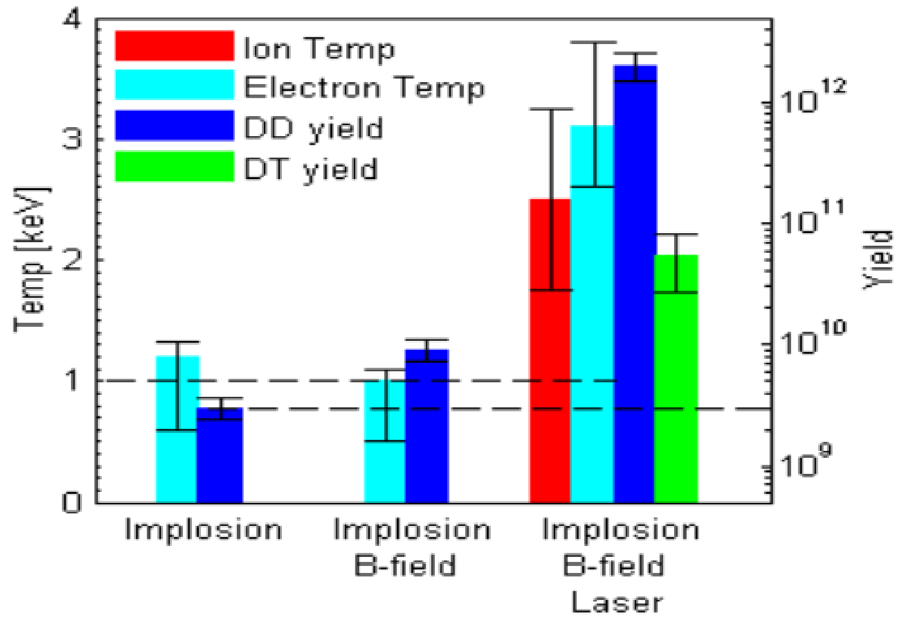


*S.A. Slutz *et. al.*, PoP (2010)
S.A. Slutz and R. A. Vesey, PRL (2012)
M.R. Gomez *et. al.*, PRL (2014)
P.F. Schmit *et. al.*, PRL (2014)
A.B. Sefkow, *et. al.* ,PoP (2014)
M.R. Gomez, *et. al.*, PoP (2015)
S.B. Hansen, *et. al.* , PoP (2015)
R.D. McBride, *et. al.*, PoP (2016)

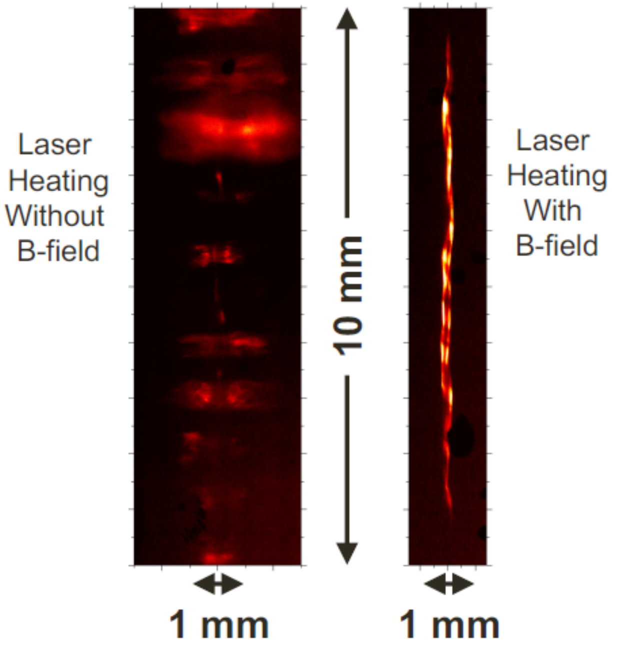
S. A. Slutz, et al., Phys. Plasmas 17, 056303 (2010).

Maglif has successfully demonstrated the necessary elements of magneto-inertial fusion

Laser Preheat required for significant yields



Applied Bz required with preheat for significant yields



Stagnation self emission imaging with and without applied Bz

DD Neutron yield

	No B-field	B-field
No Laser Heating	$3x10^9$	$1x10^{10}$
Laser Heating	$4x10^{10}$	$3x10^{12}$

Data from M. Gomez / K. Peterson

Summary:

Maglif is presently operating close to ideal simulation expectations.

Presently, degradation of neutron yield is dominated by:

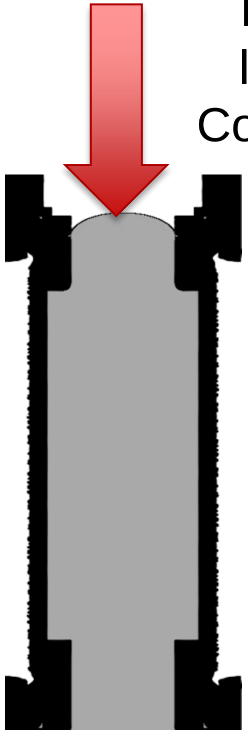
- Implosion instabilities
- Mix into fuel
- Loss of thermal insulation

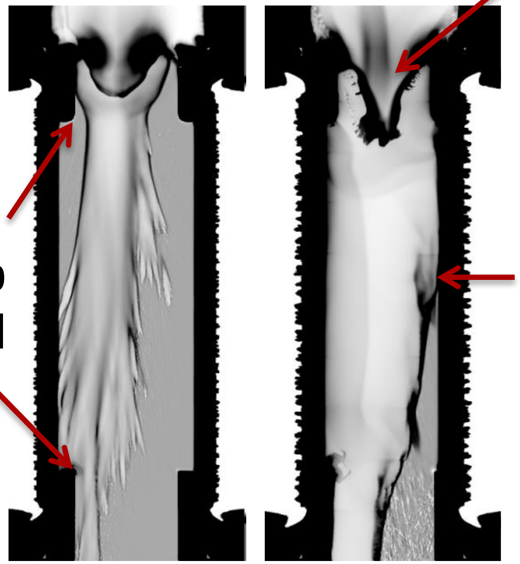
Not to:

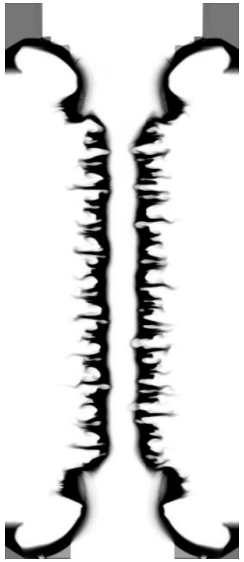
- Lack of preheat energy
- Low current delivery

Understanding relative dominance of these different processes helps define path forward

3 Main areas of concern have been: Laser Coupling, High Z Mix, Liner Instabilities







To what extent are these degradation mechanisms limiting Maglif performance ?

In reality it is likely all 3 and more are in play to some degree !

What are our expectations ?

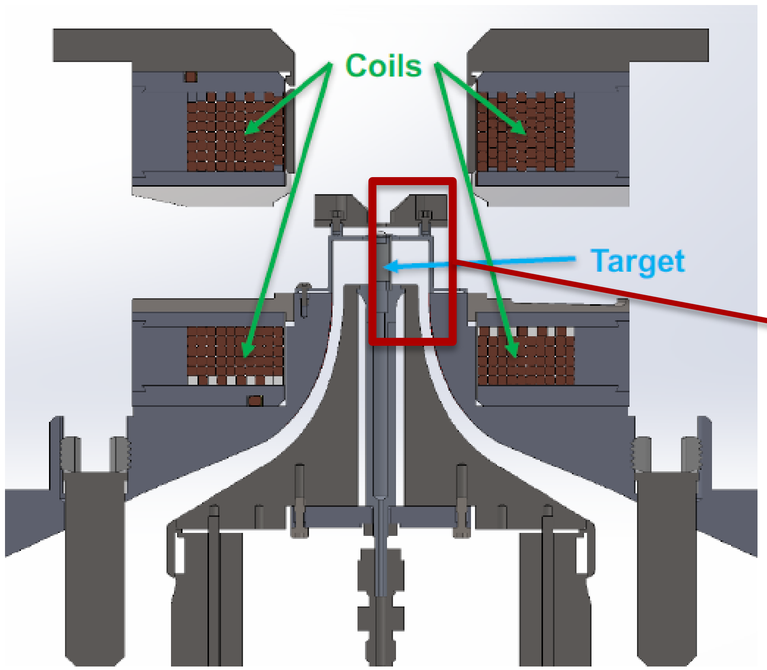
To understanding how significant different degradation mechanisms are we must first

Understand what we expected the performance to be

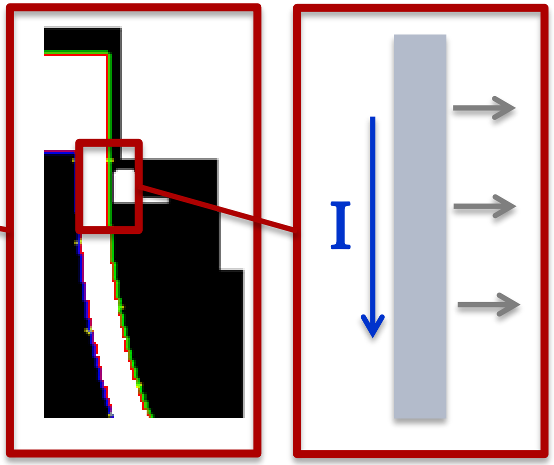
Better characterize our inputs:
What is the preheat energy delivered
What is the current

16.2 MA delivered to standard 10mm tall Maglif target (Z 2851)

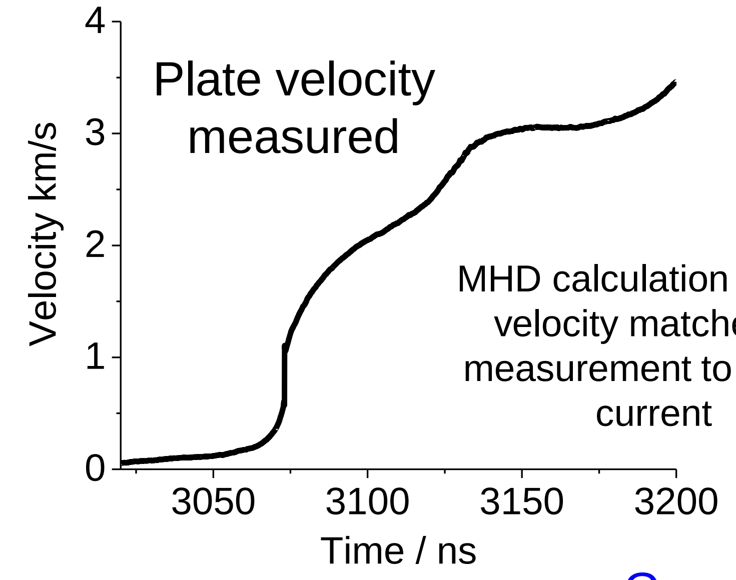
Apply techniques of the Z dynamic material properties groups

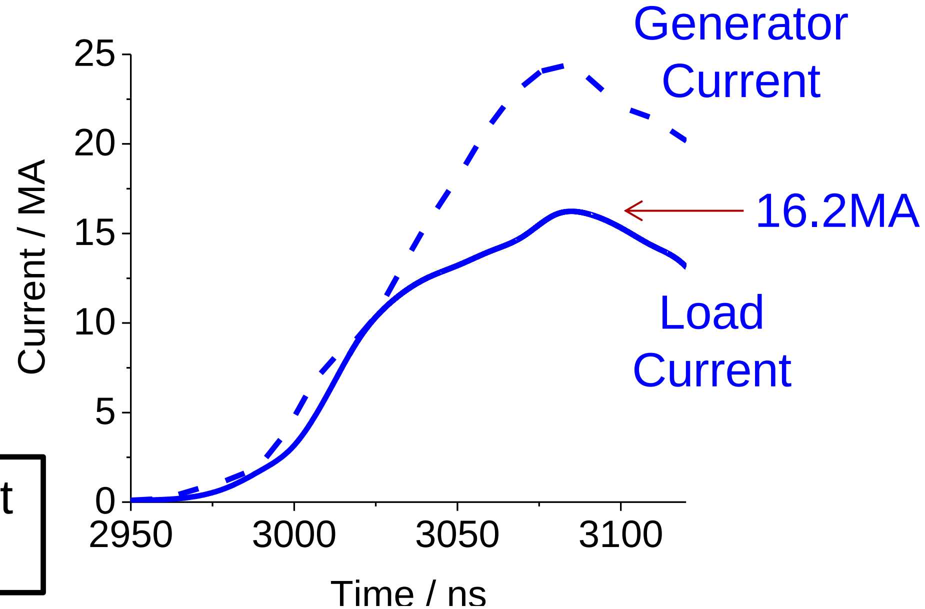


~400 micron
Al plate



Accelerated
by return
current

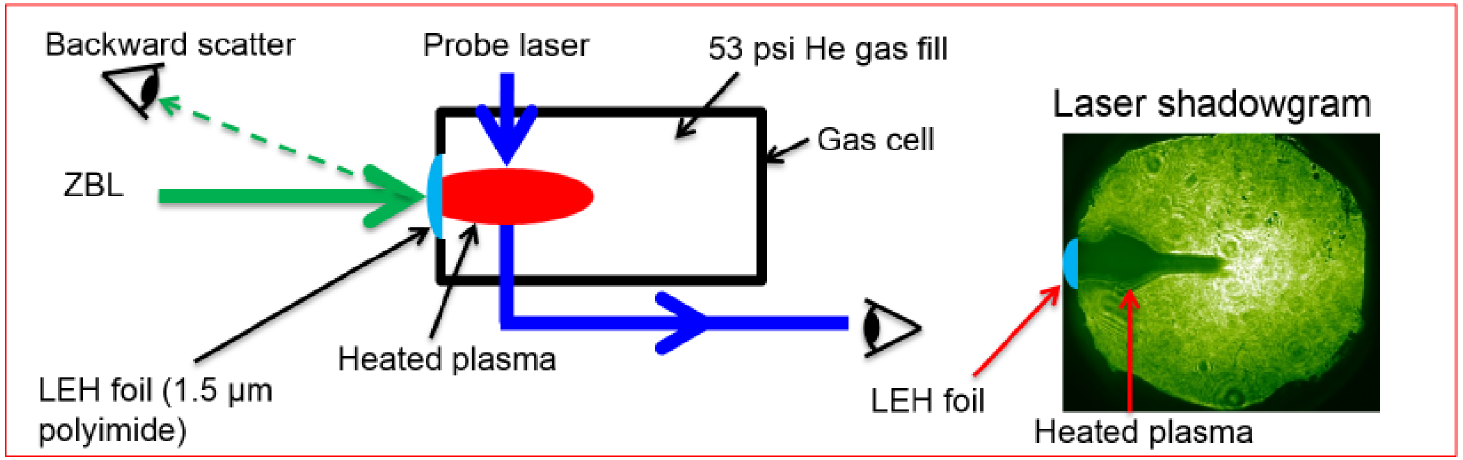




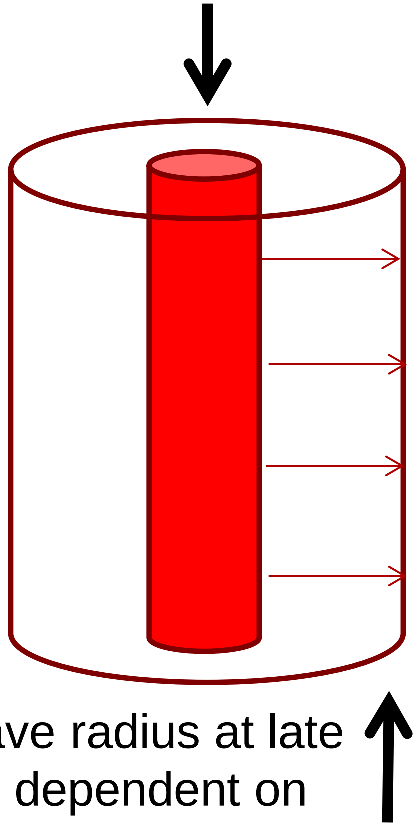
This level of current loss is atypical for Z. Likely resulting from high target inductance and extended feed used to bring electrodes into field coil

Laser energy deposited in gas determined by shadography of surrogate experiments

Gas cell experiments



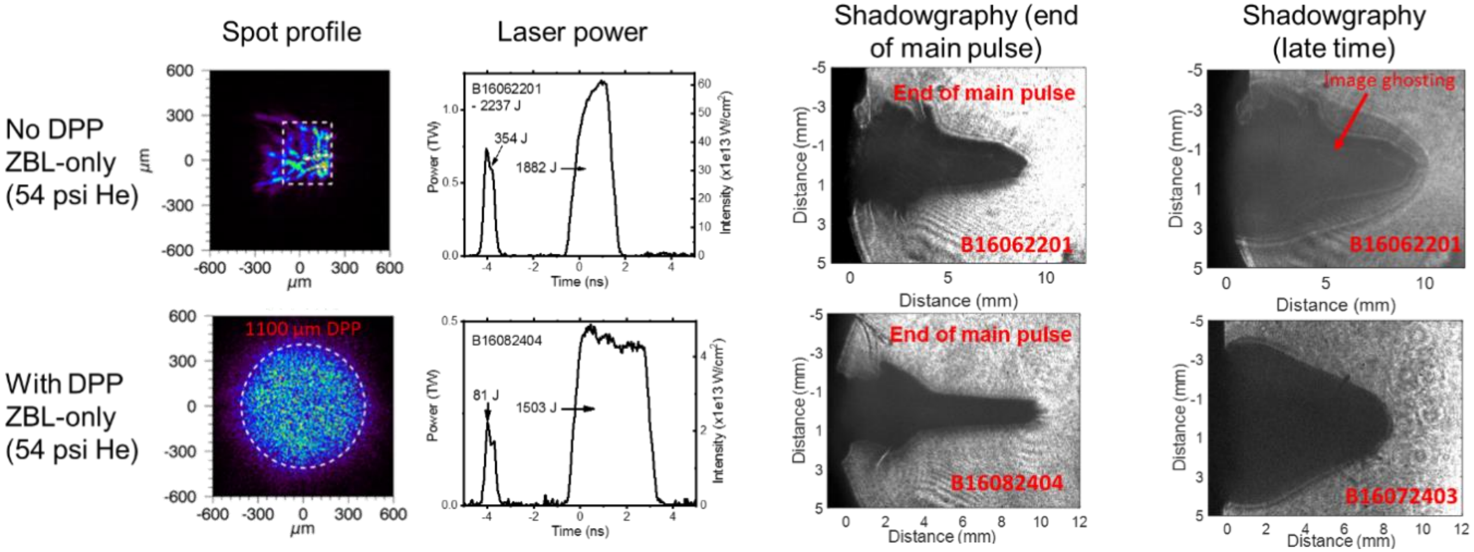
Energy deposited drives the expansion of a blast wave



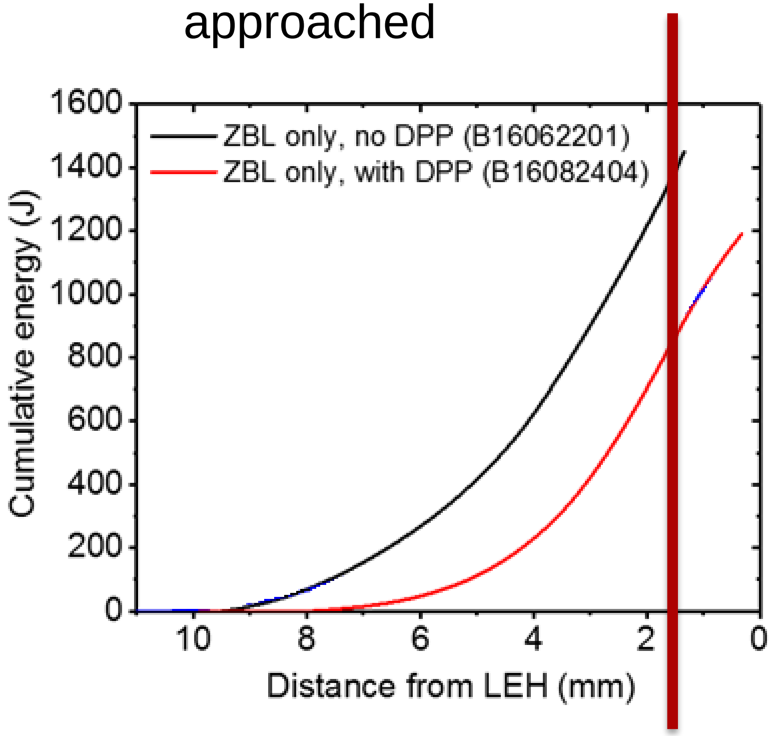
Blast wave radius at late time is dependent on energy deposited

Data / images provided by M. Geissel / A. Harvey-Thompson

Shadography used to infer deposited energy and axial distribution of deposited energy



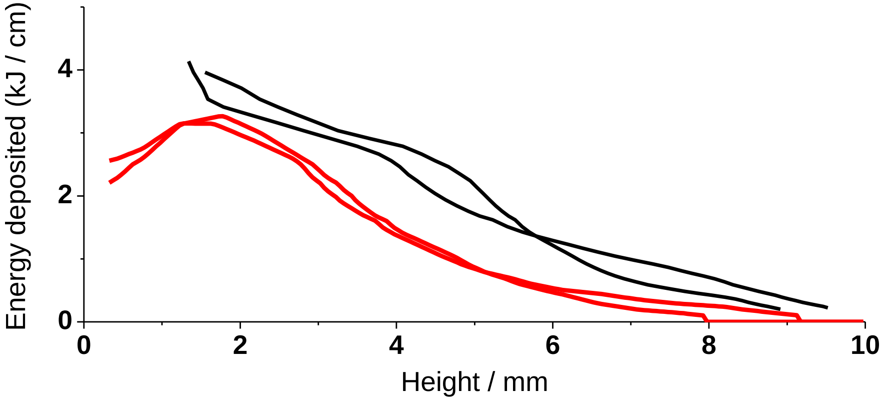
Cumulative energy as laser entrance hole is approached



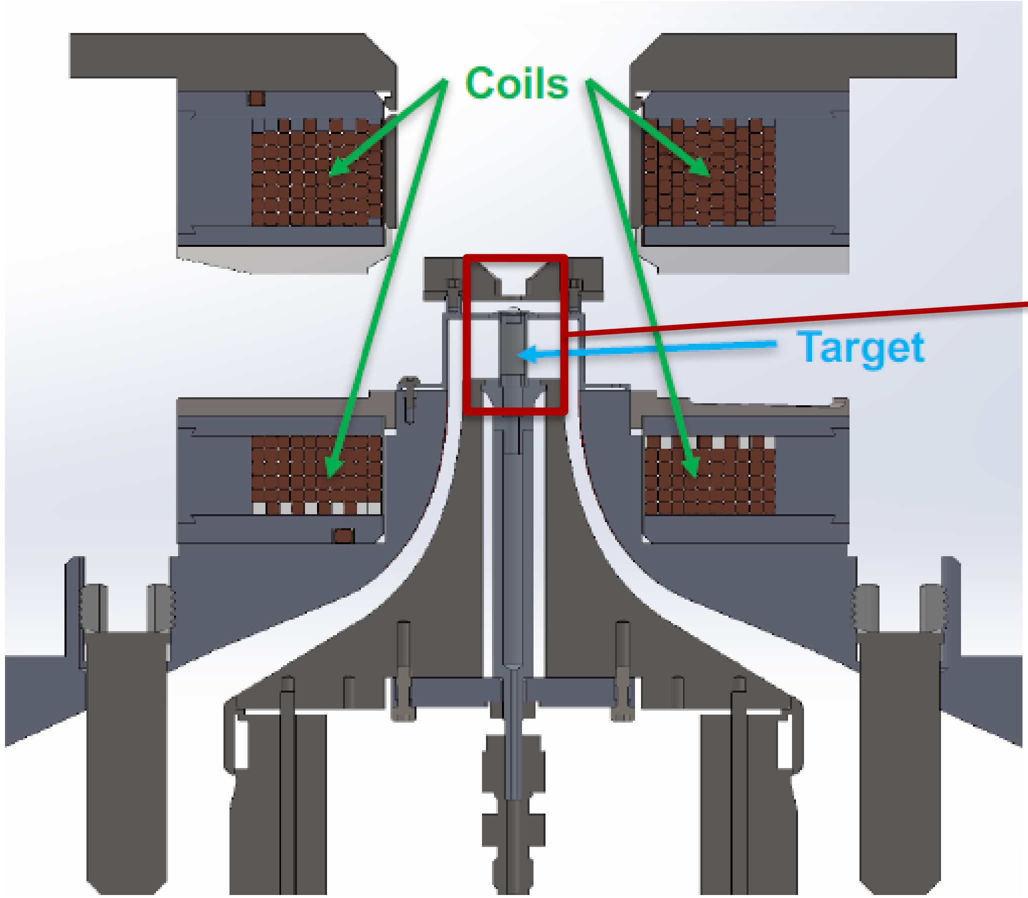
Start of imploding region in Maglif target

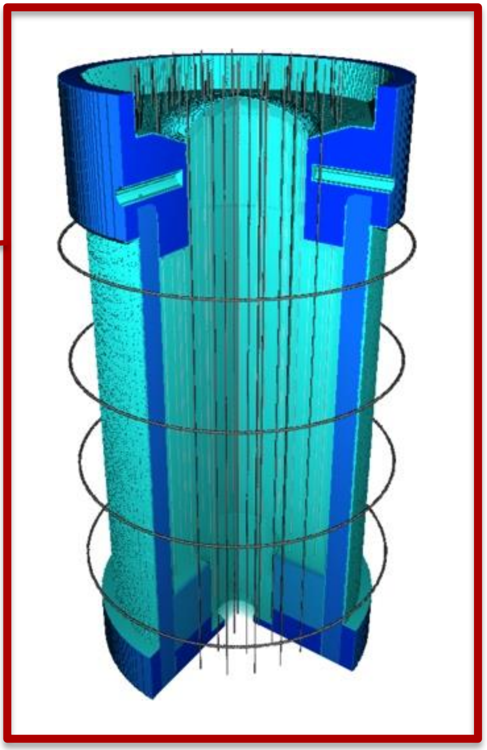
Axial distribution of energy deposited inferred from shadography

Targets used surrogate He gas, but more recently deposit into D2



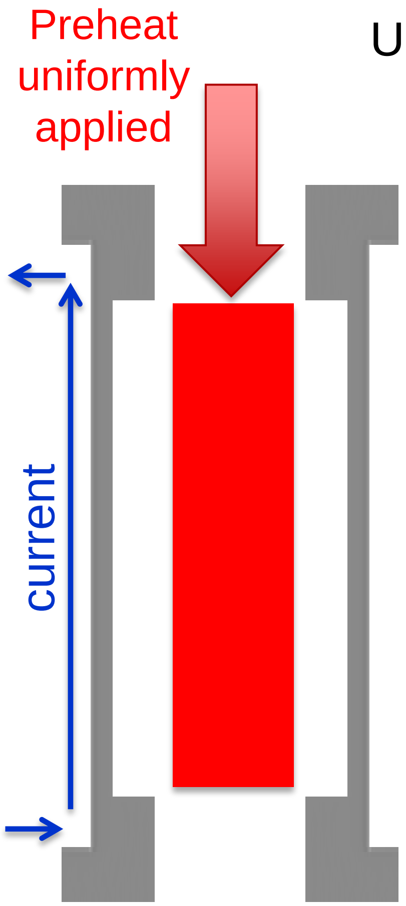
Standard Maglif Target parameters have been largely determined by engineering capabilities and historical precedent





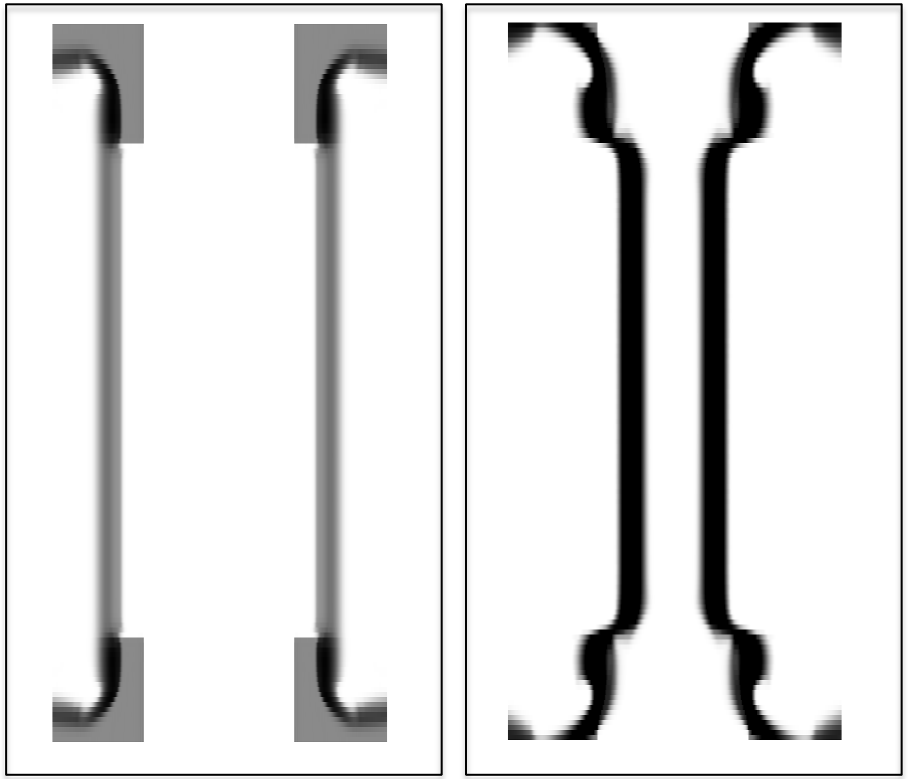
- 10T applied Bz
- 1.8 micron polyimide window
- 0.7 mg/cc D2 gas density
- 10mm tall target

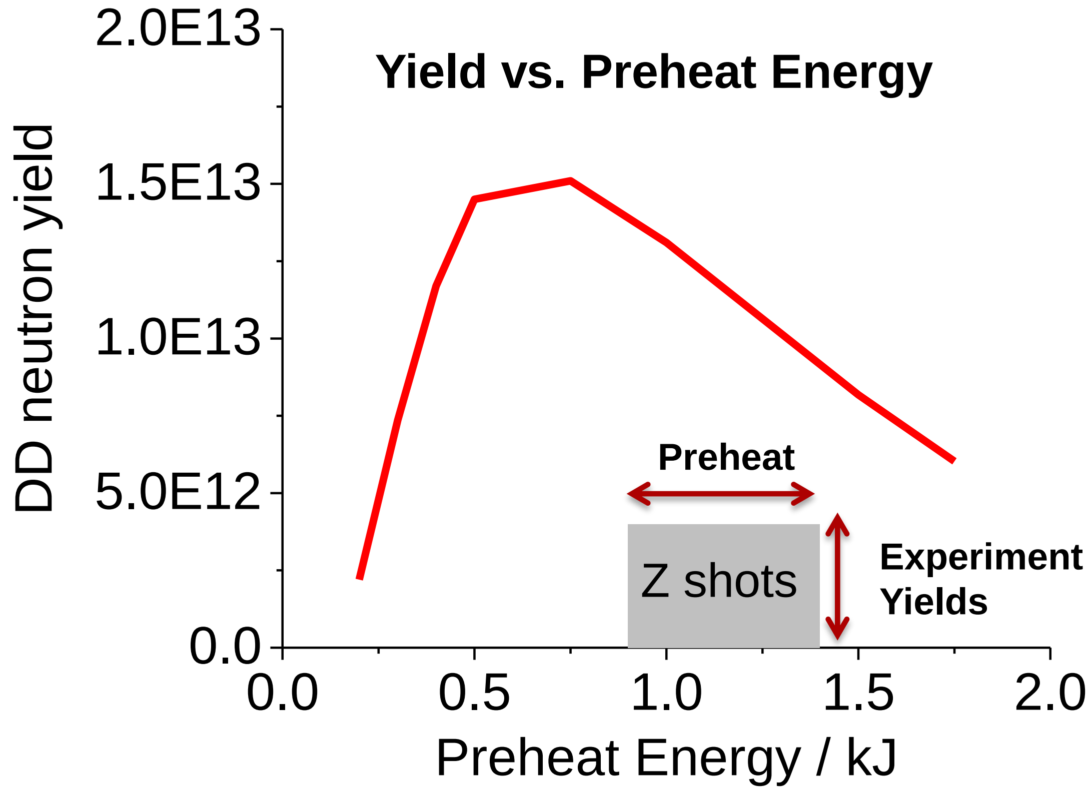
Given measured current and preheat ideal performance within a factor of ~3 or ~ 4



Use standard target: 0.7mg/cc gas fill, 10T applied Bz

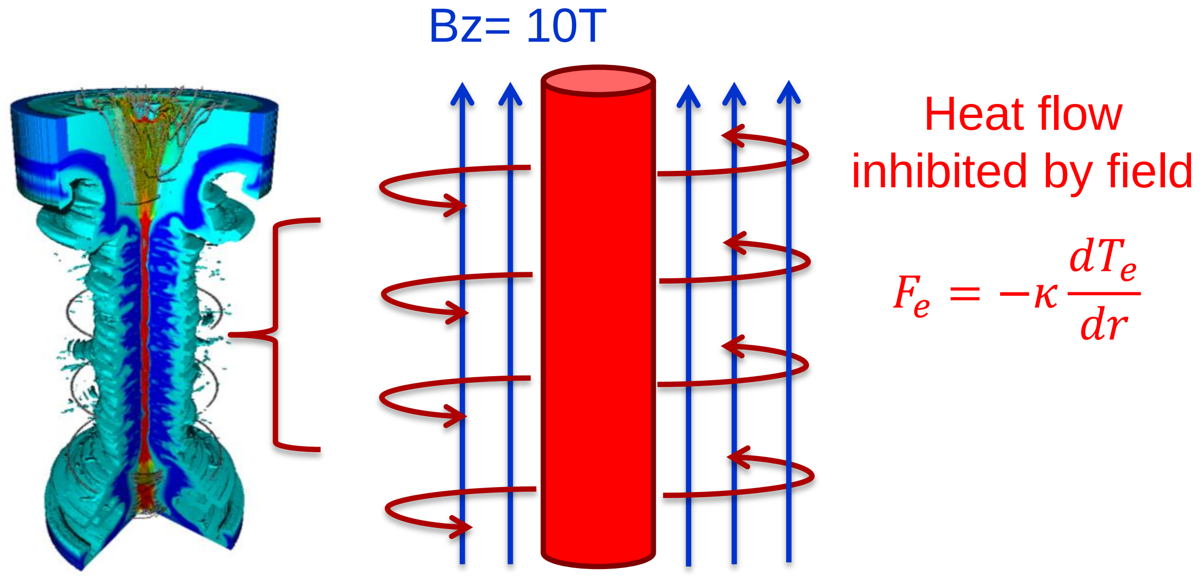
Implode Unperturbed Liner

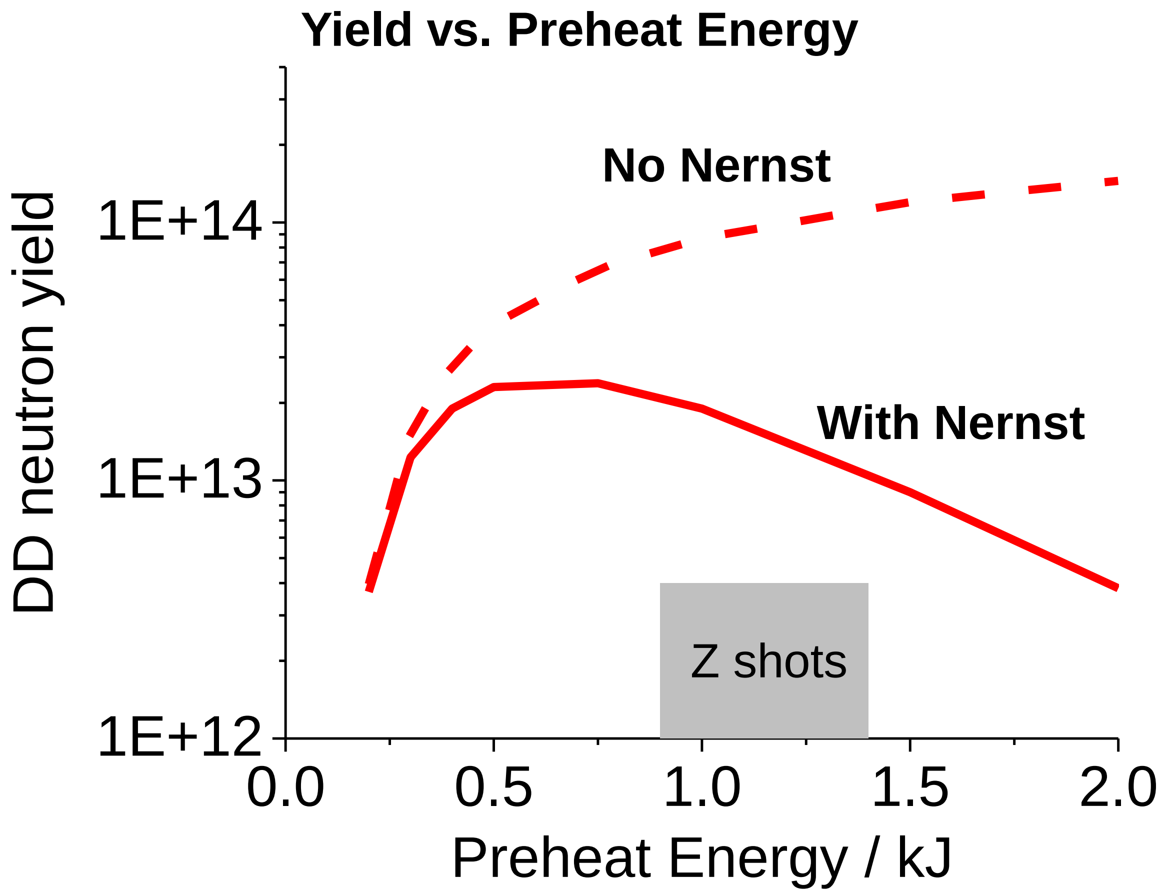




Following method used by S Slutz, conduct ideal 2D Maglif implosion calculations in GORGON.
Equivalent to 1D + end losses

Optimum laser preheat energy defined by loss of magnetic insulation through Nernst advection





Ohms law modified:

$$\boldsymbol{E} = \boldsymbol{\eta j} - (\boldsymbol{v} + \boldsymbol{v_T}) \times \boldsymbol{B}$$

Magnetic field preferentially frozen into hotter electrons also responsible for thermal diffusion (Nernst)

This has important implications for the effect of implosion instabilities.

M.G. Haines
Plasma Physics and Controlled Fusion Vol. 28 No. 11 pp 1705-1716, 1986

Optimum laser preheat energy defined by loss of magnetic insulation through Nernst advection

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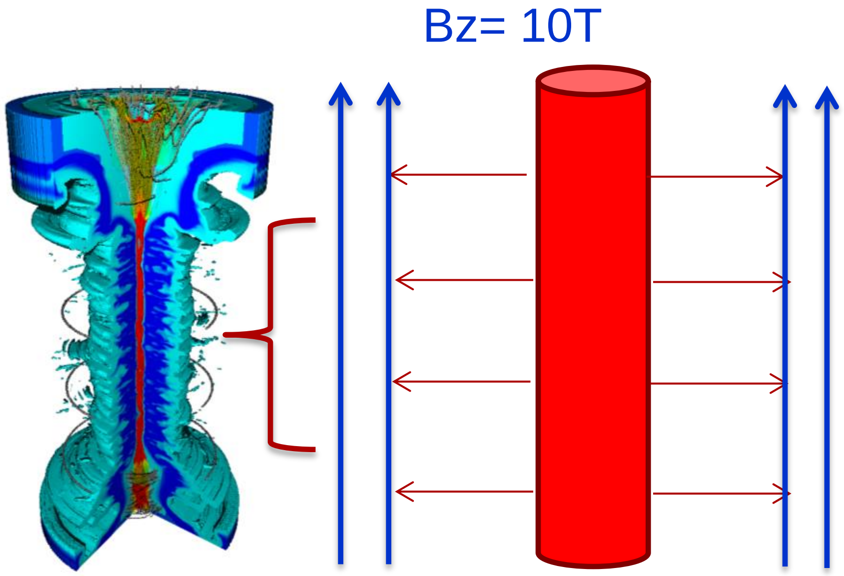

Heat flow inhibited by field

$$F_e = -\kappa \frac{dT_e}{dr}$$

Field pushed out by heat flow

$$v_T \approx \frac{F_e}{5/2 n_e T_e}$$

Ohms law modified:

$$E = \eta j - (v + v_T) \times B$$

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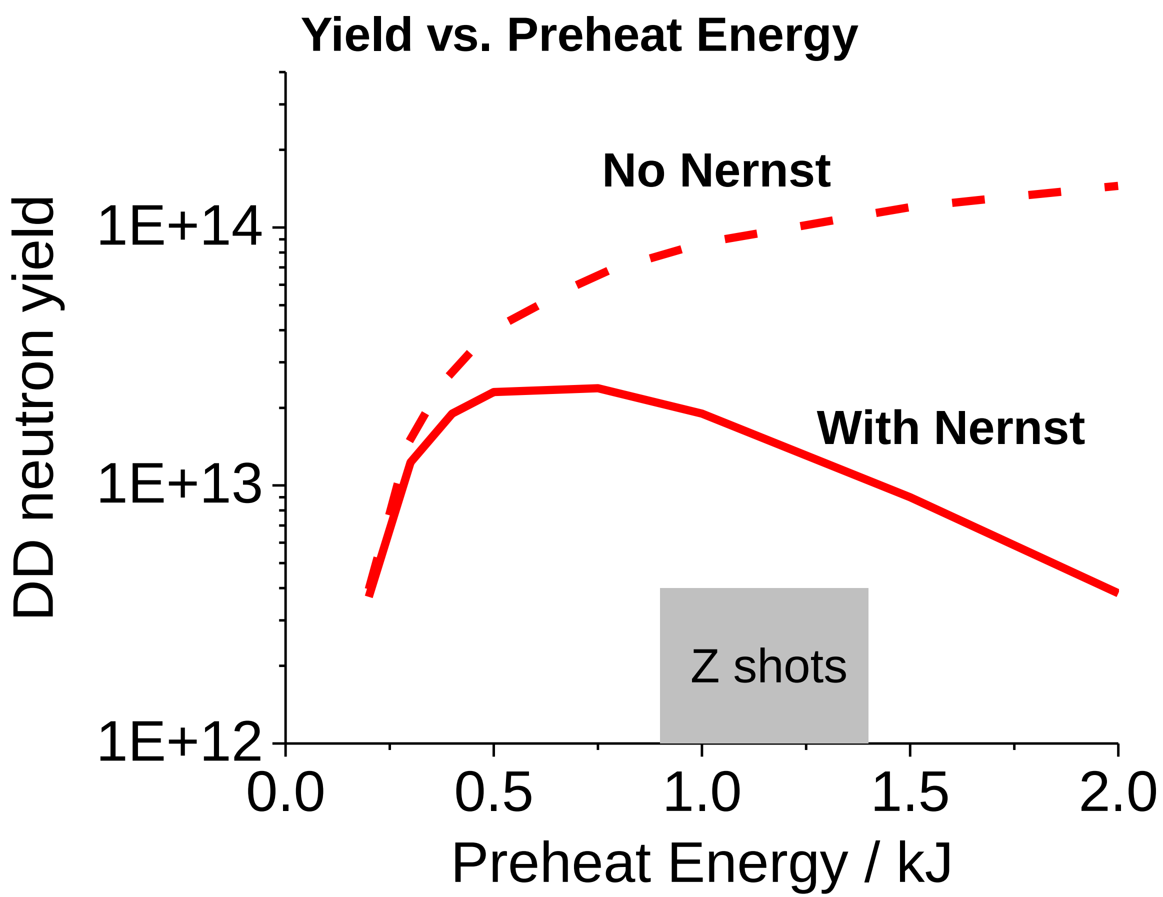
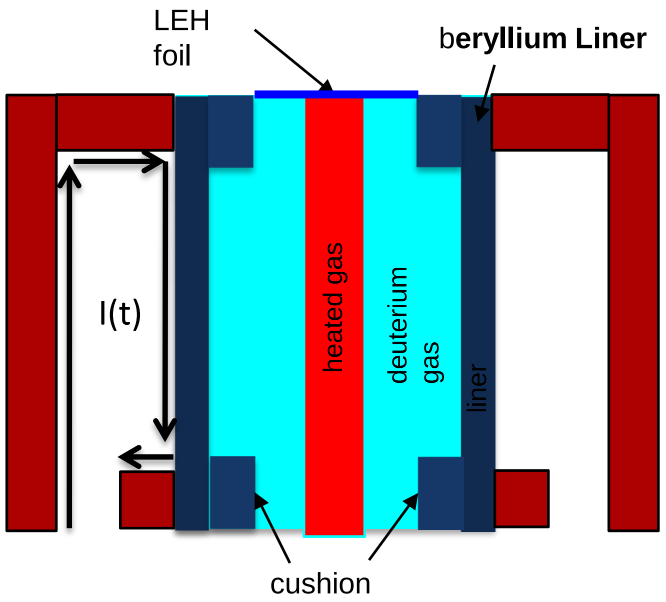
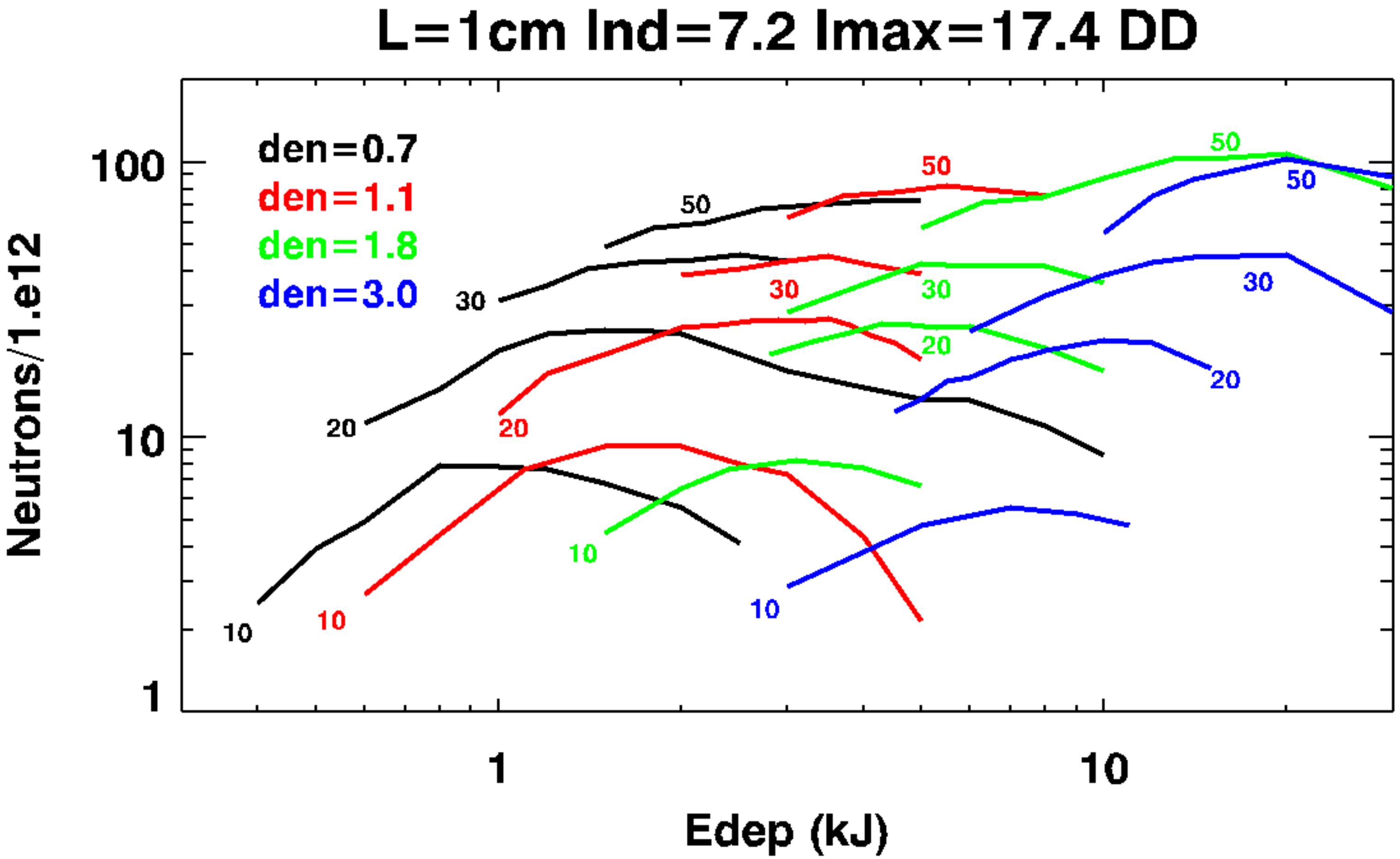


This has important implications for the effect of implosion instabilities.

Optimizing performance requires raising preheat / fuel density and magnetic field together

Uniform 2D lasnex scaling calculations
- graphs provided by Steve Slutz





Further discussion on possibilities for Z in upcoming publication by S.Slutz et al

Optimizing performance requires raising preheat / fuel density and magnetic field together

Uniform 2D lasnex scaling calculations
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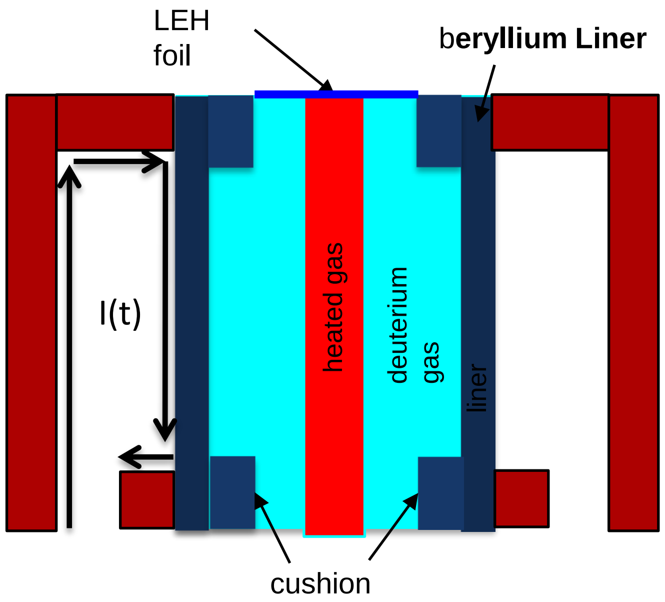
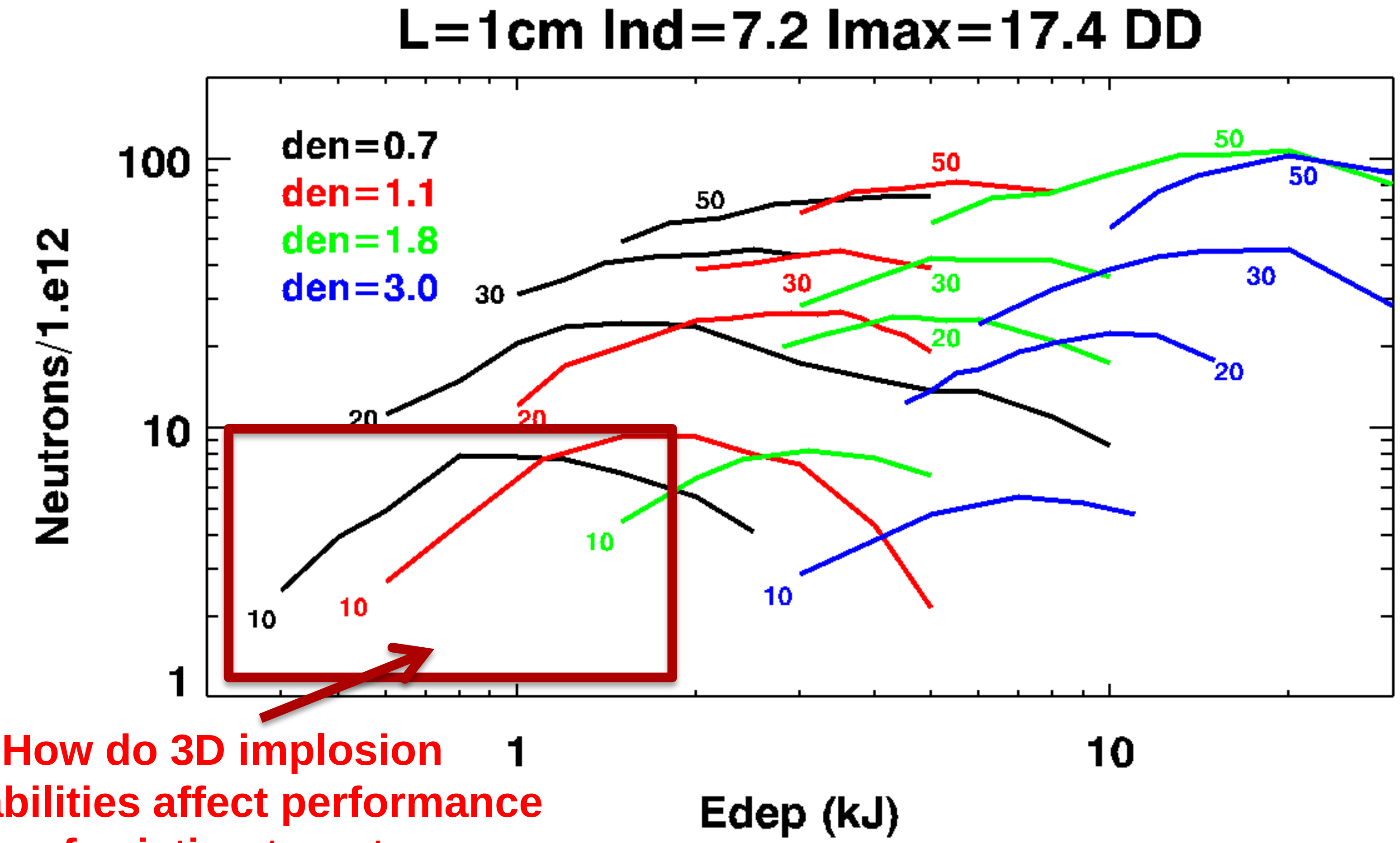
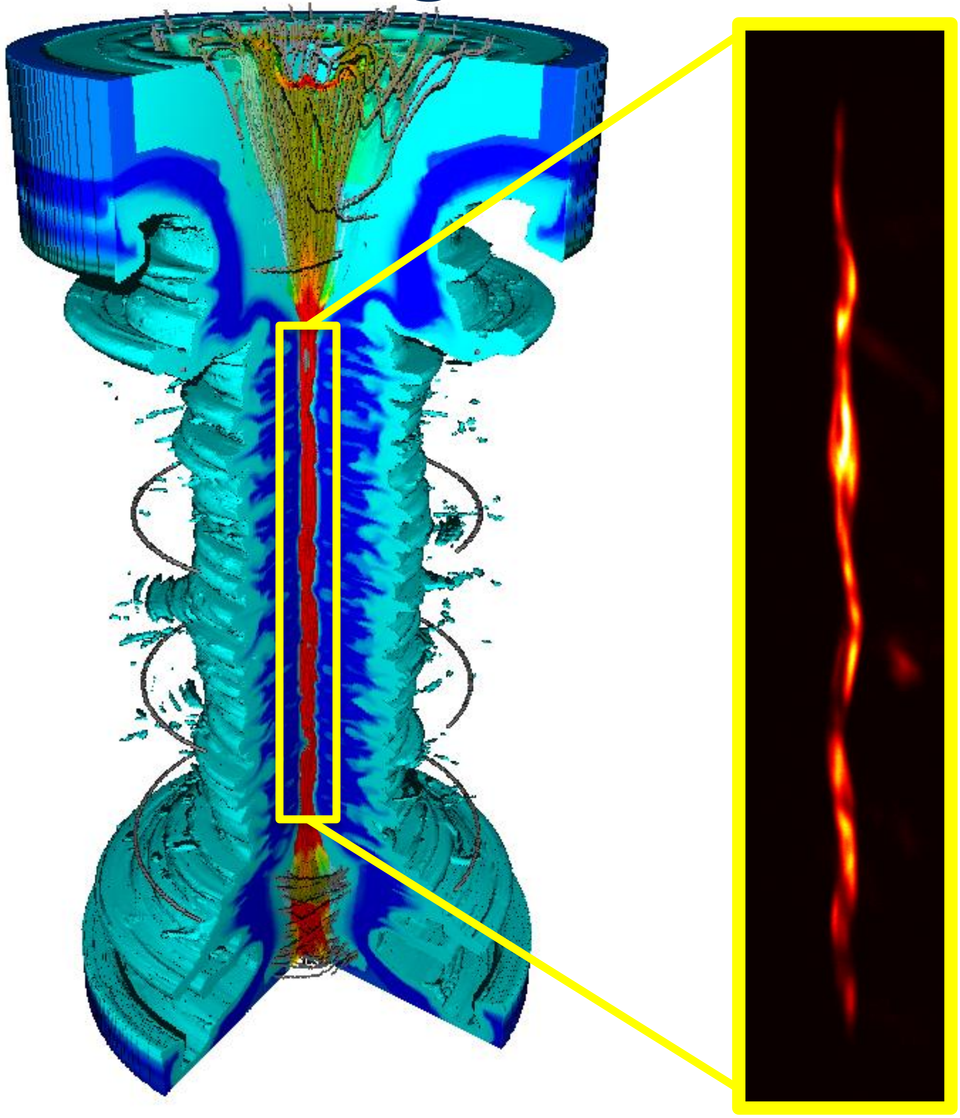




Further discussion on possibilities for Z in upcoming publication by S.Slutz et al

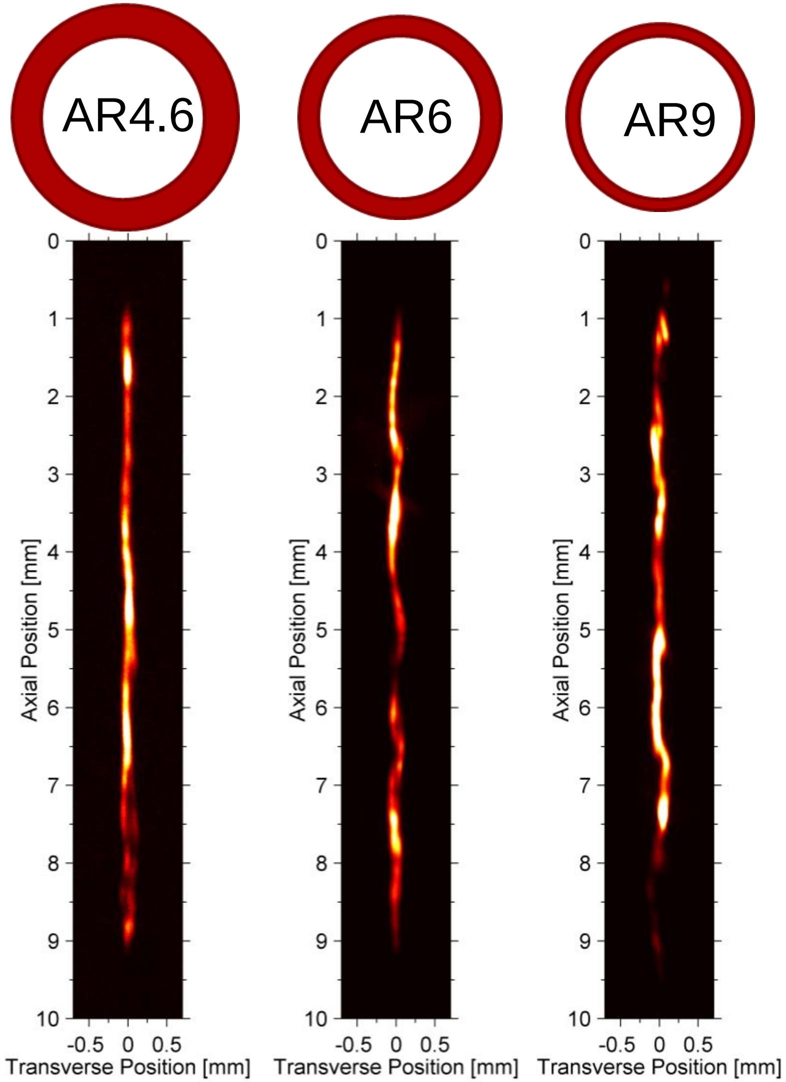
How do 3D implosion instabilities affect performance of existing targets

Stagnation instabilities principally diagnosed in time integrated self emission imaging



Helical structure / bifurcations and intensity variations indicative of feedthrough of implosion instabilities

Reduction in structure when liner thickness is increased also indicates instability feedthrough



4mm load height modeled, with perturbation applied consistent with liner radiography

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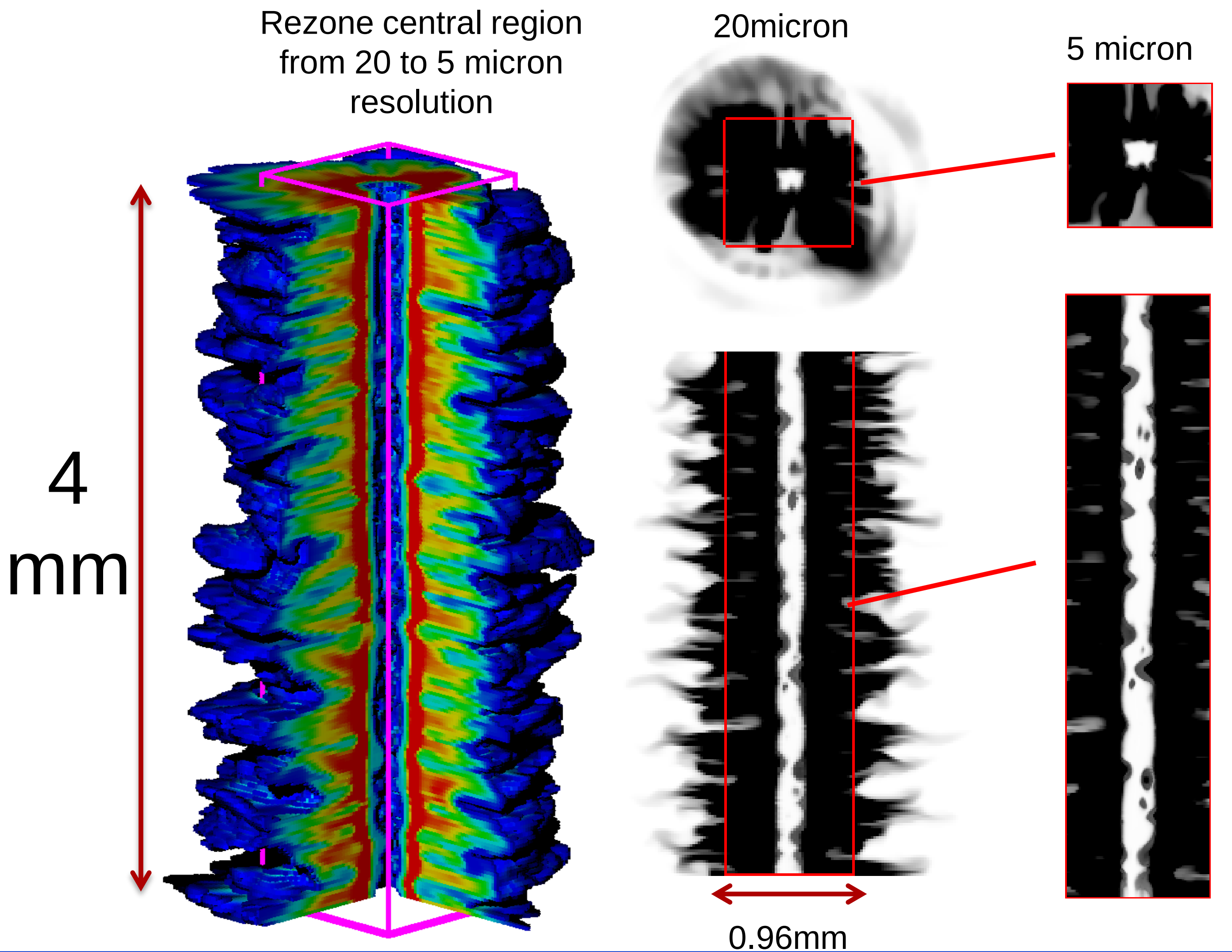
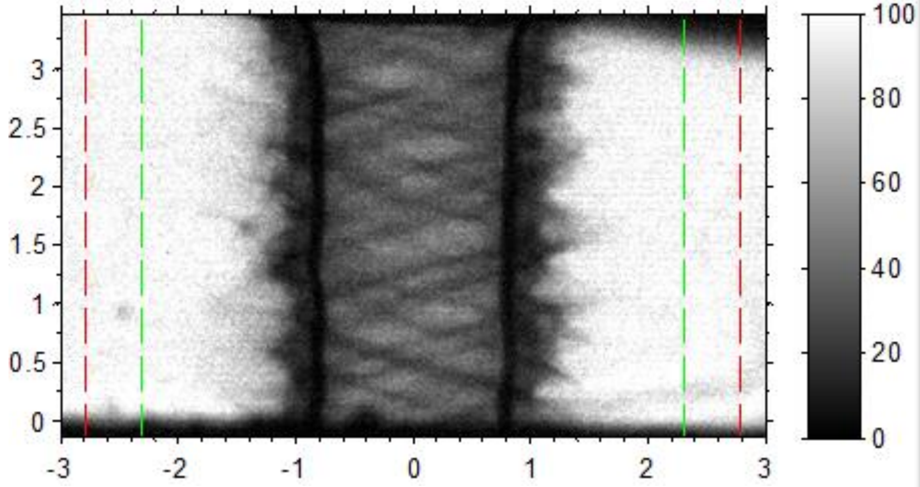
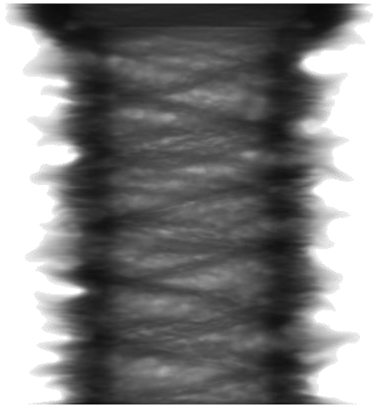


Liner radiography 10T applied Bz

T.Awe PRL 111(23) 235005





Synthetic radiograph through simulation

Implosion instabilities can degrade neutron yield

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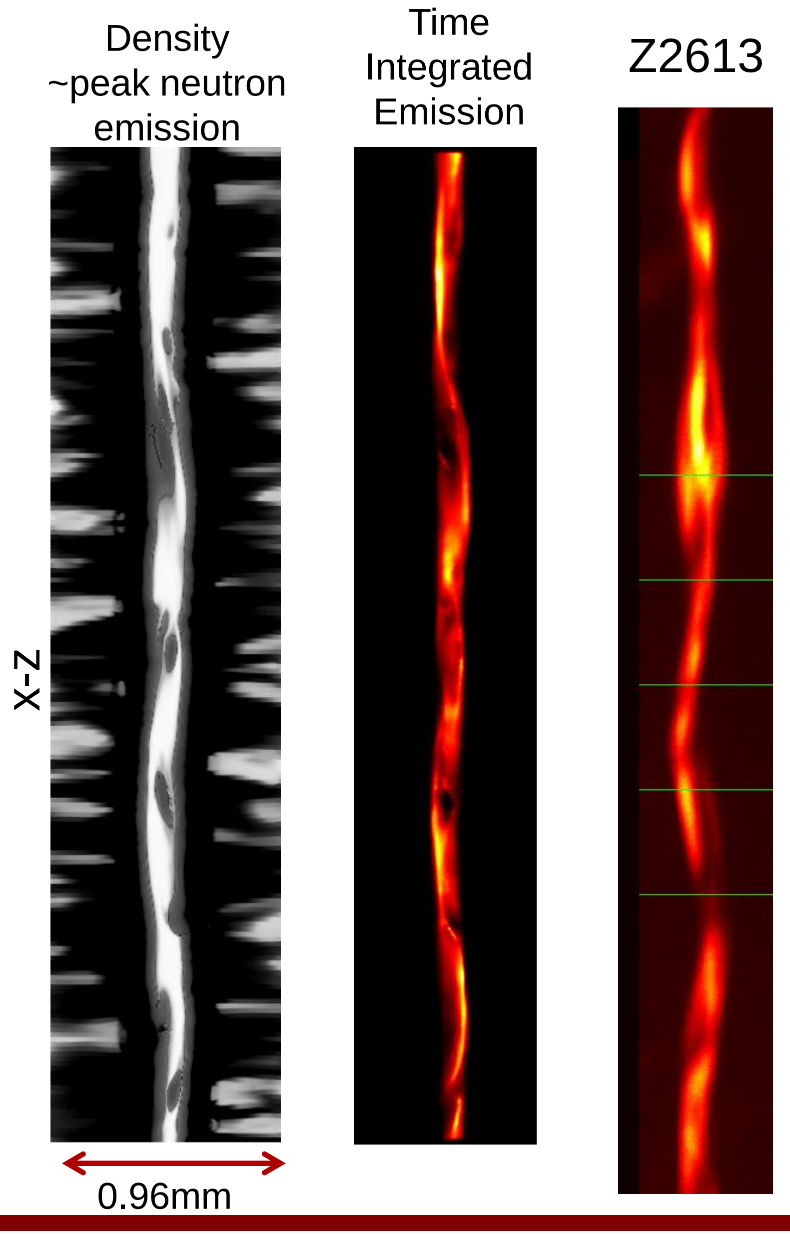
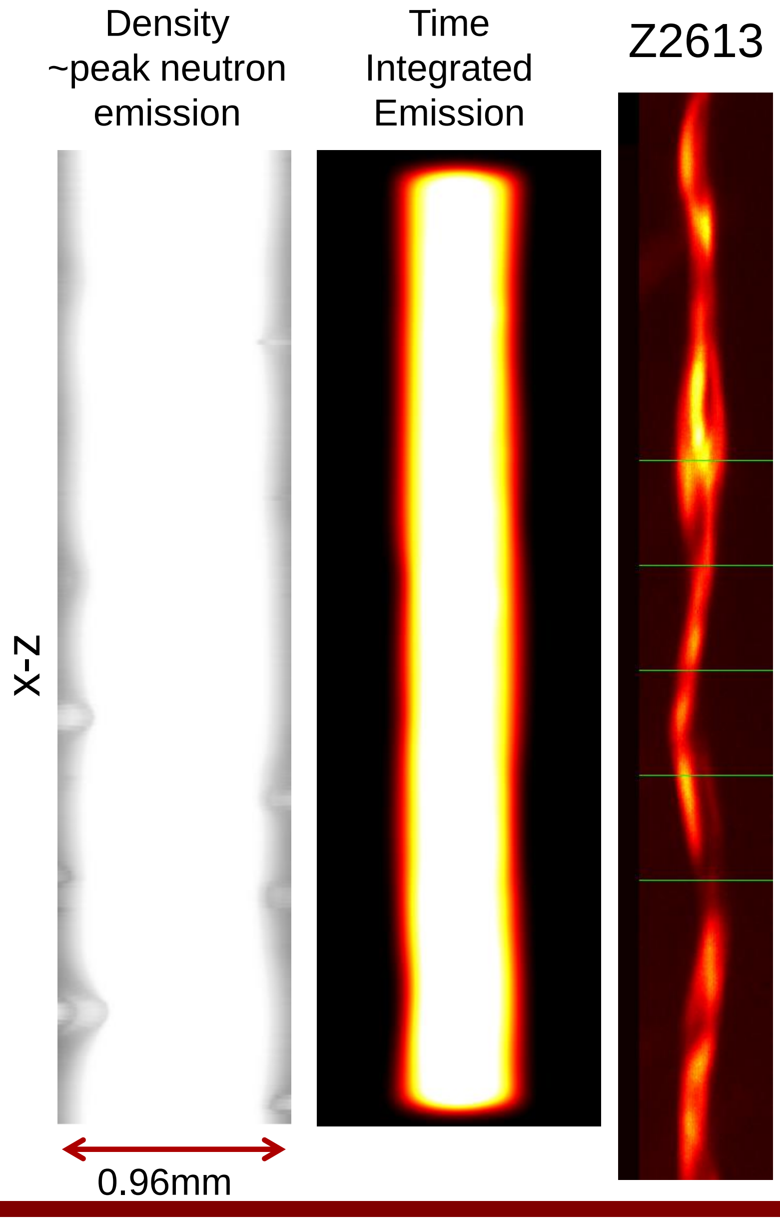
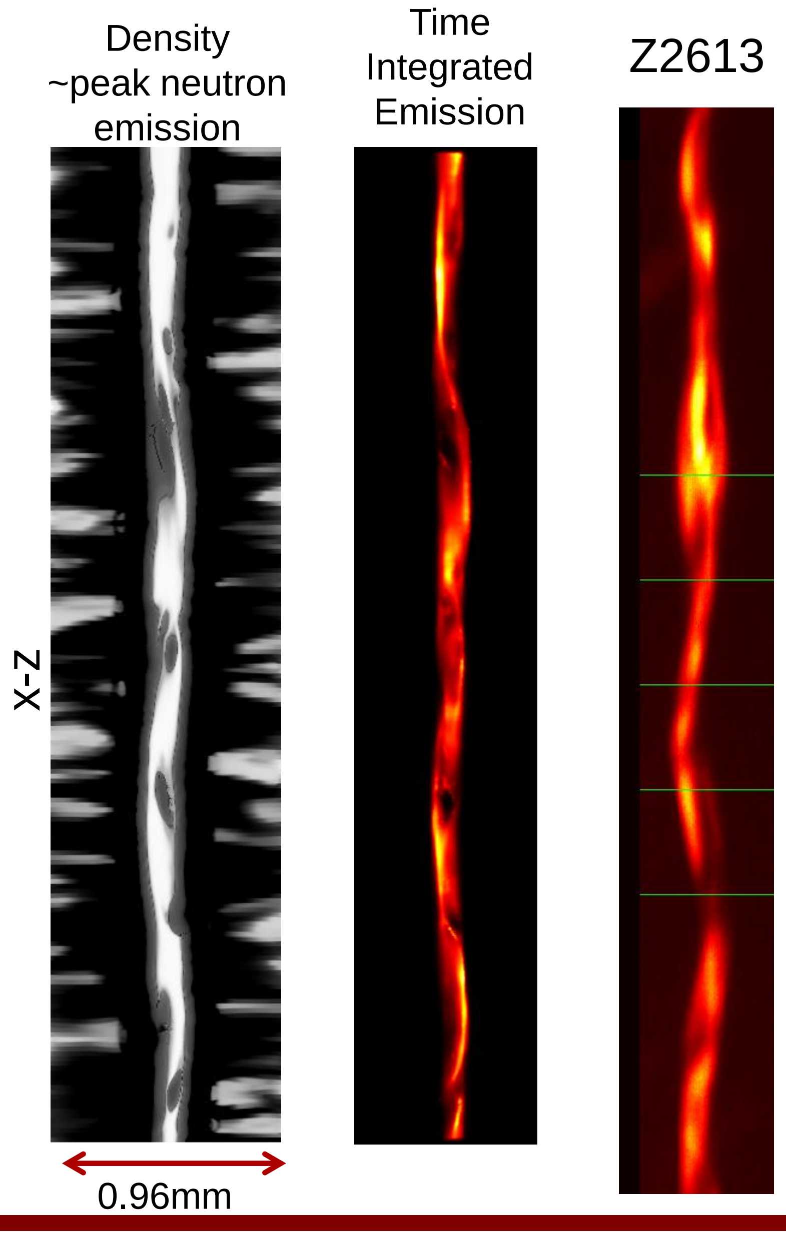
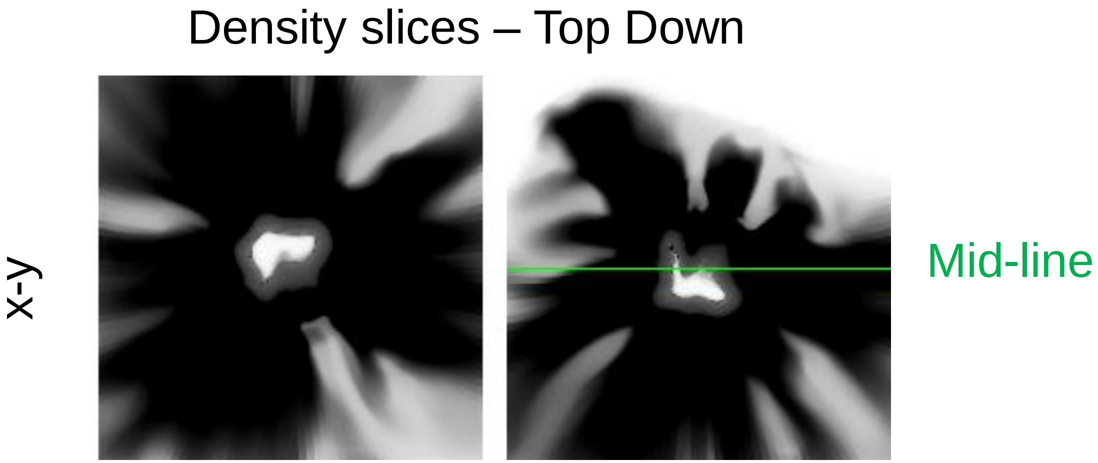


Implosion instabilities can degrade neutron yield

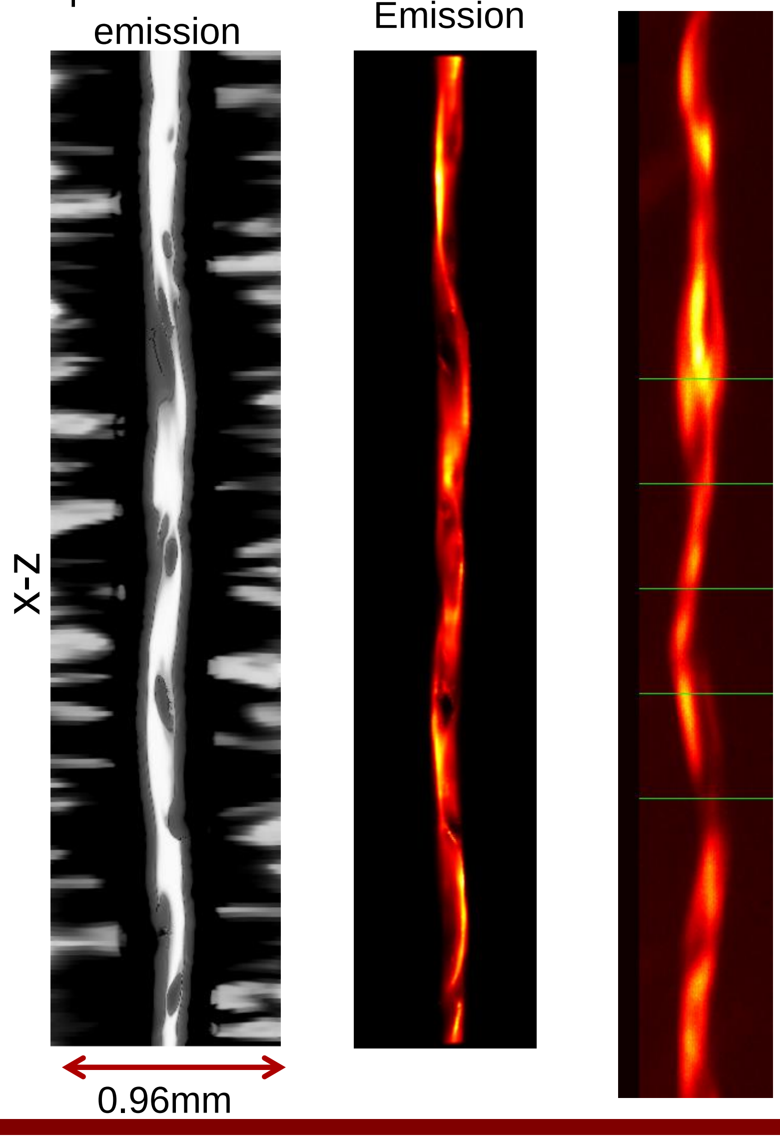


Implosion instabilities can degrade neutron yield

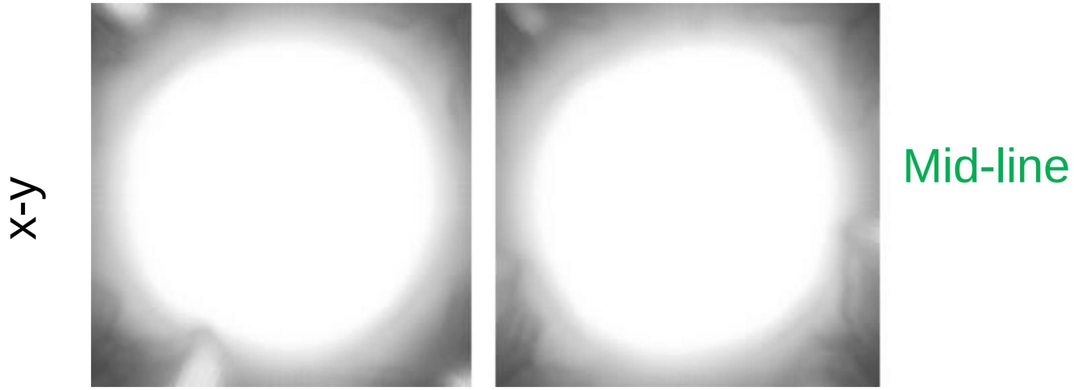




Implosion instabilities can degrade neutron yield



Density slices – Top Down



Implosion instabilities can degrade neutron yield

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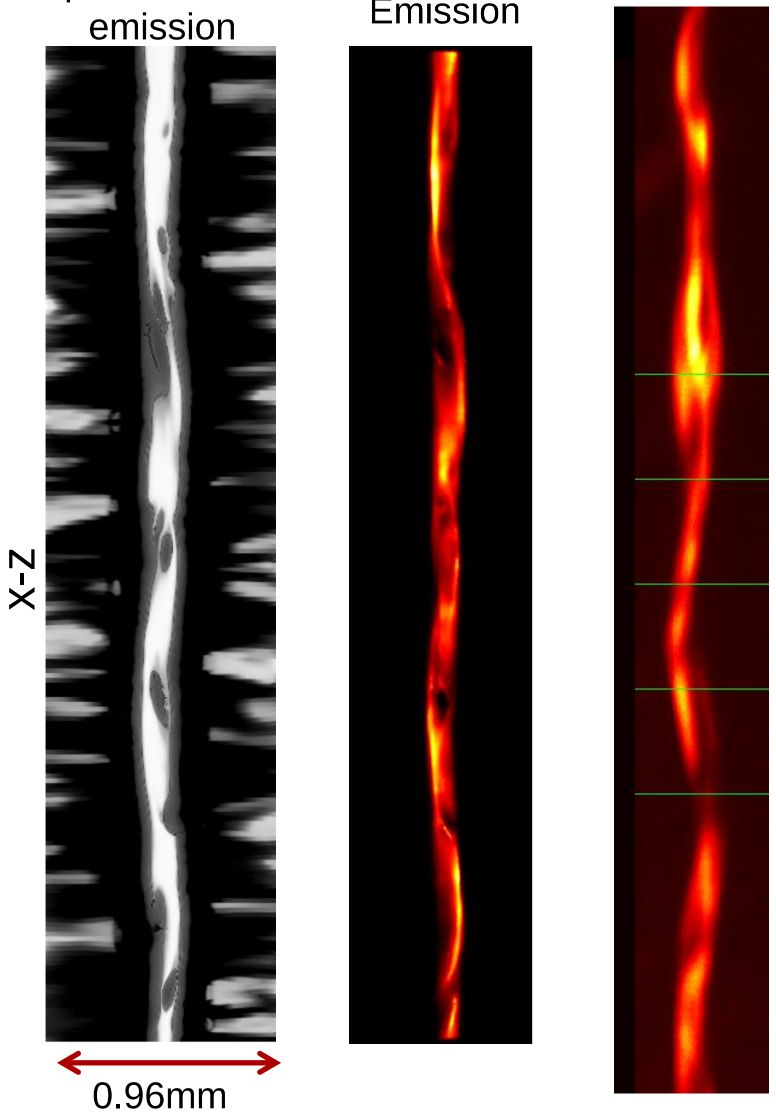
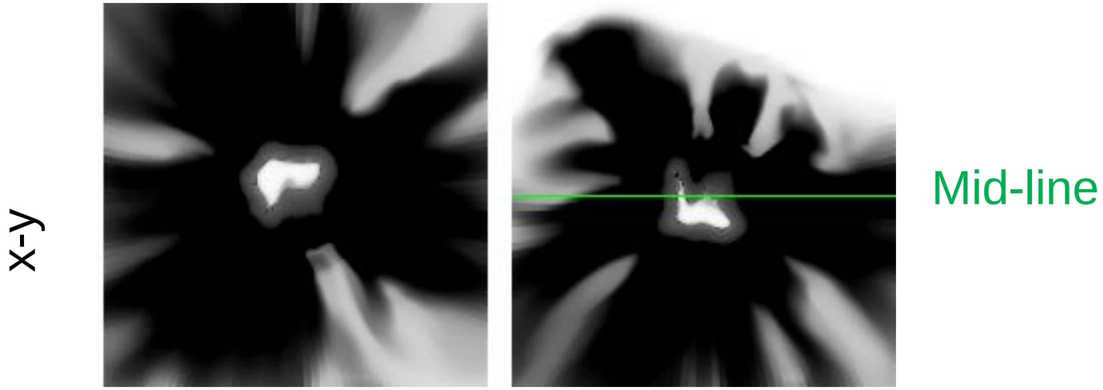
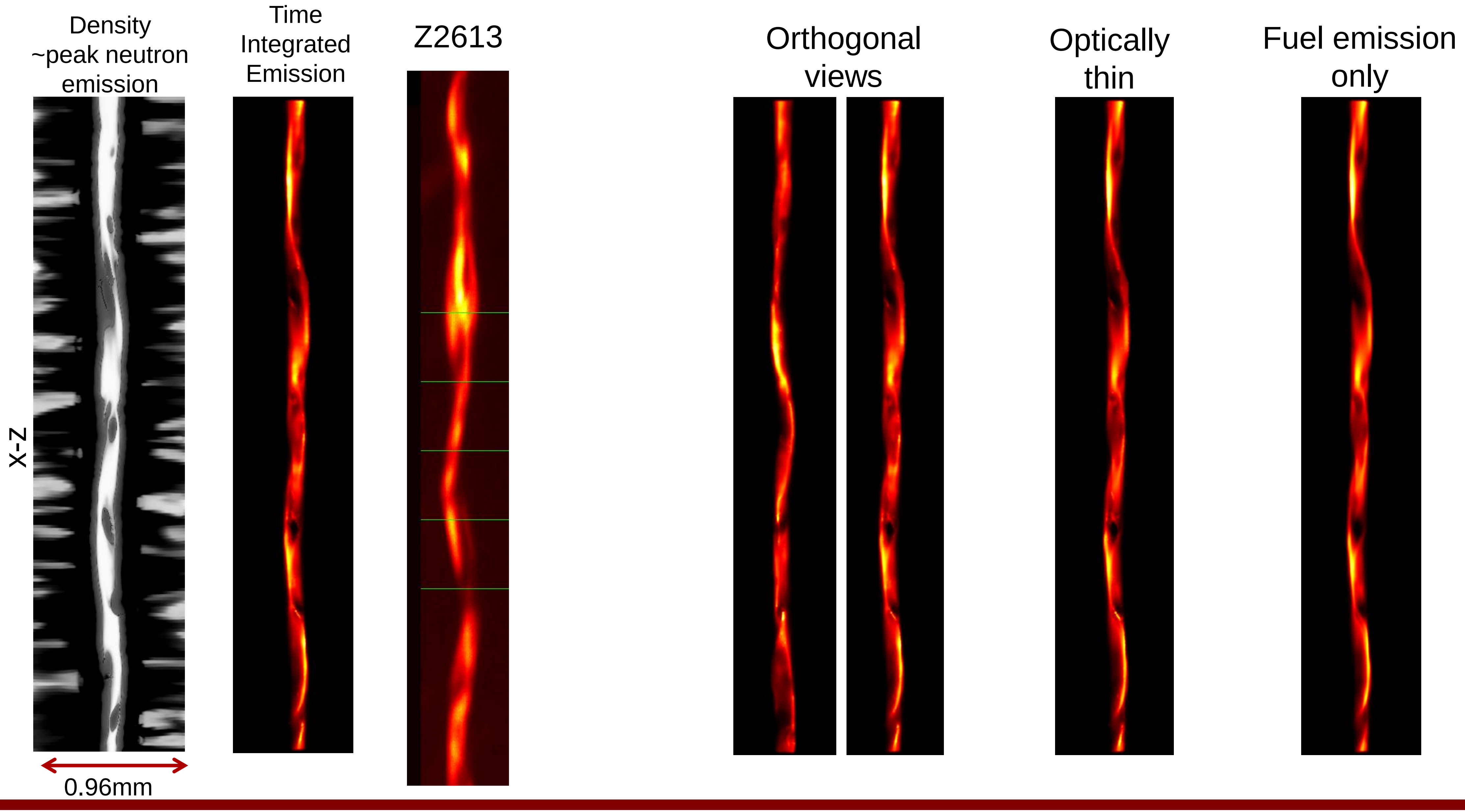


Density slices – Top Down



Implosion instabilities can degrade neutron yield



Implosion instabilities can degrade neutron yield

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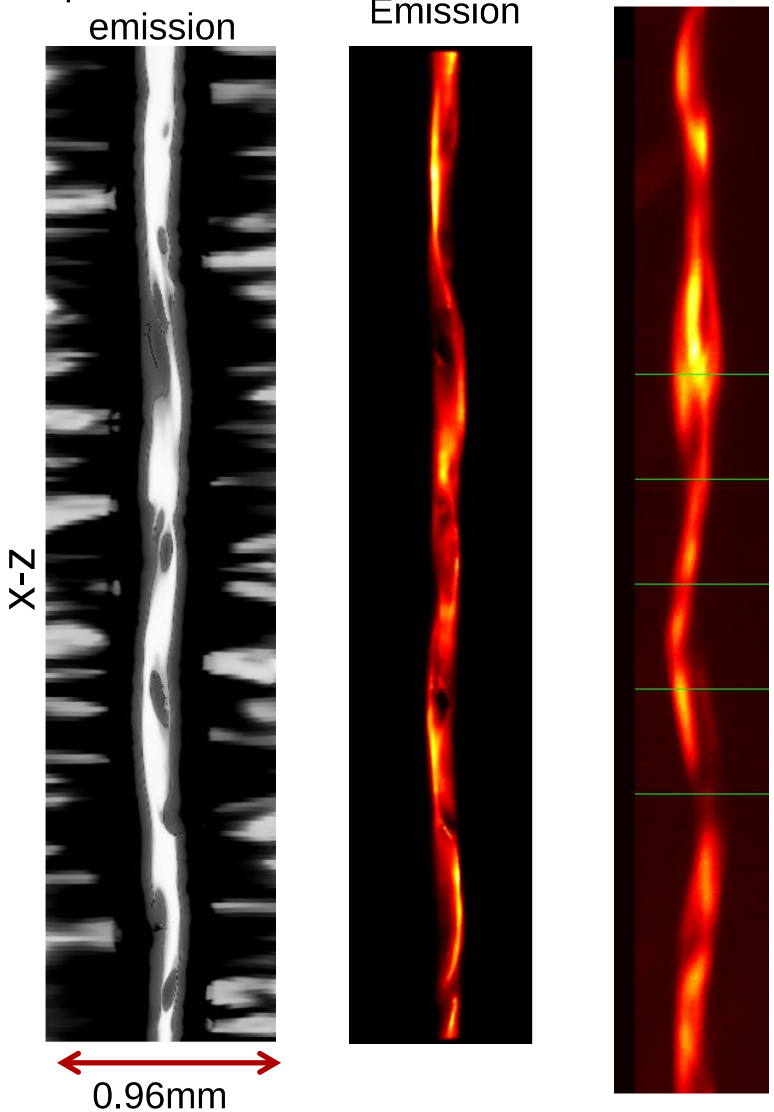
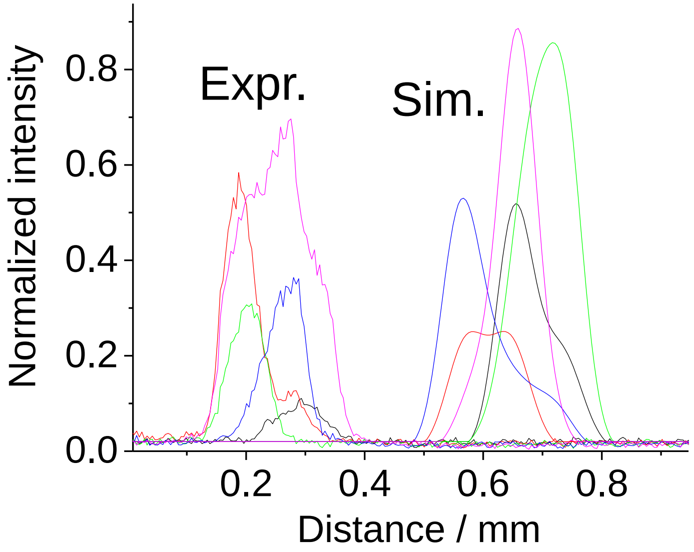
Density ~peak neutron emission

Time Integrated Emission

Z2613





Emission image Widths (microns)
Expr. 91 +/- 40
Sim. 121 +/- 23

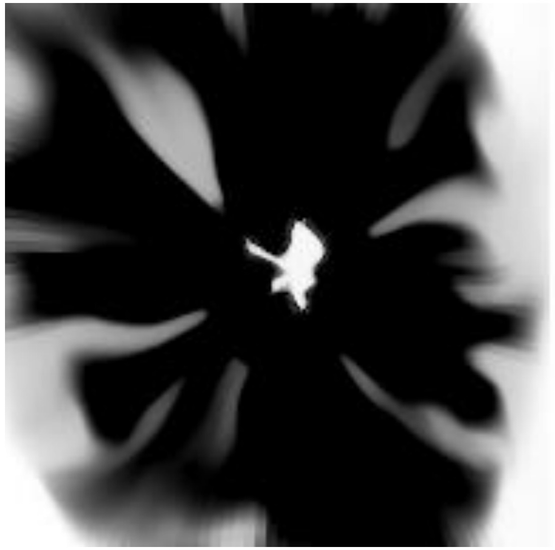
Sim. With no resolution broadening
53 +/- 26

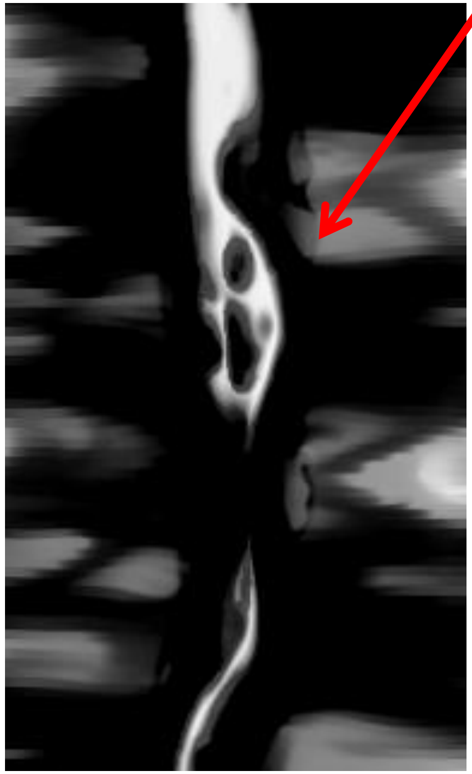
(~60 radial spatial resolution might be contributing to these widths)

Penetration of Fuel Volume can results in bifurcation of emission structure

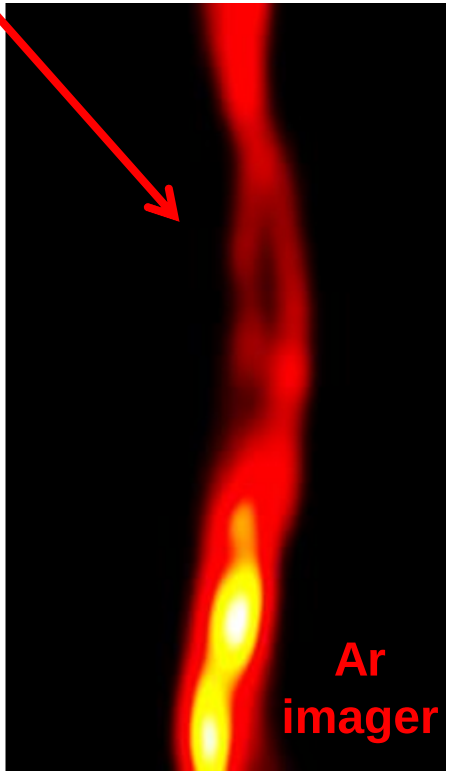
Fuel volume can be bisected creating bifurcated structures evident is some of the Ar imaging

Density slice – Top Down



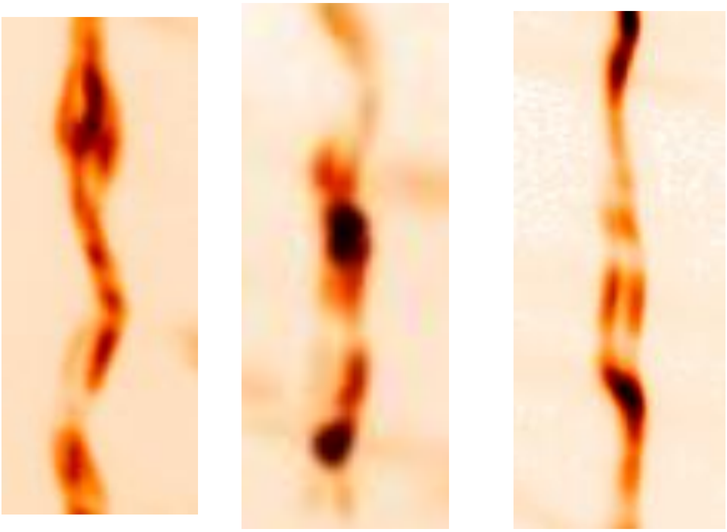


Side Density slice

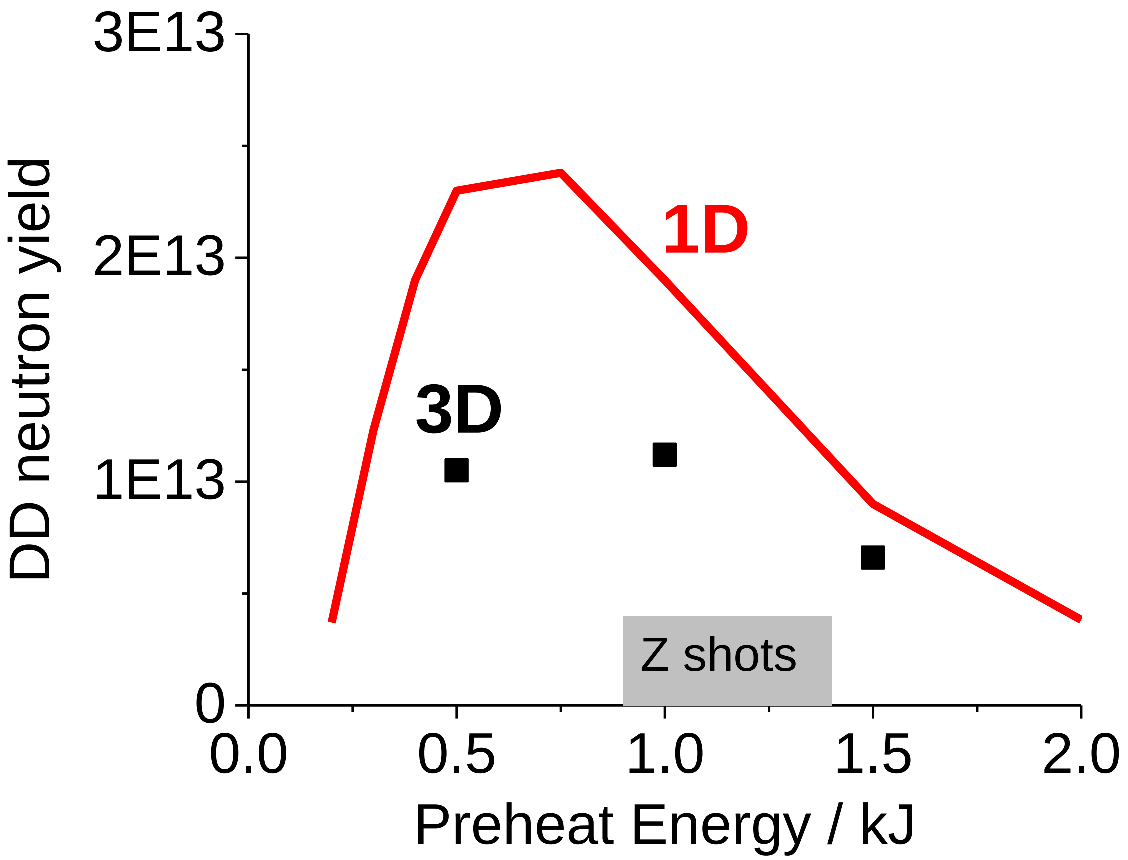


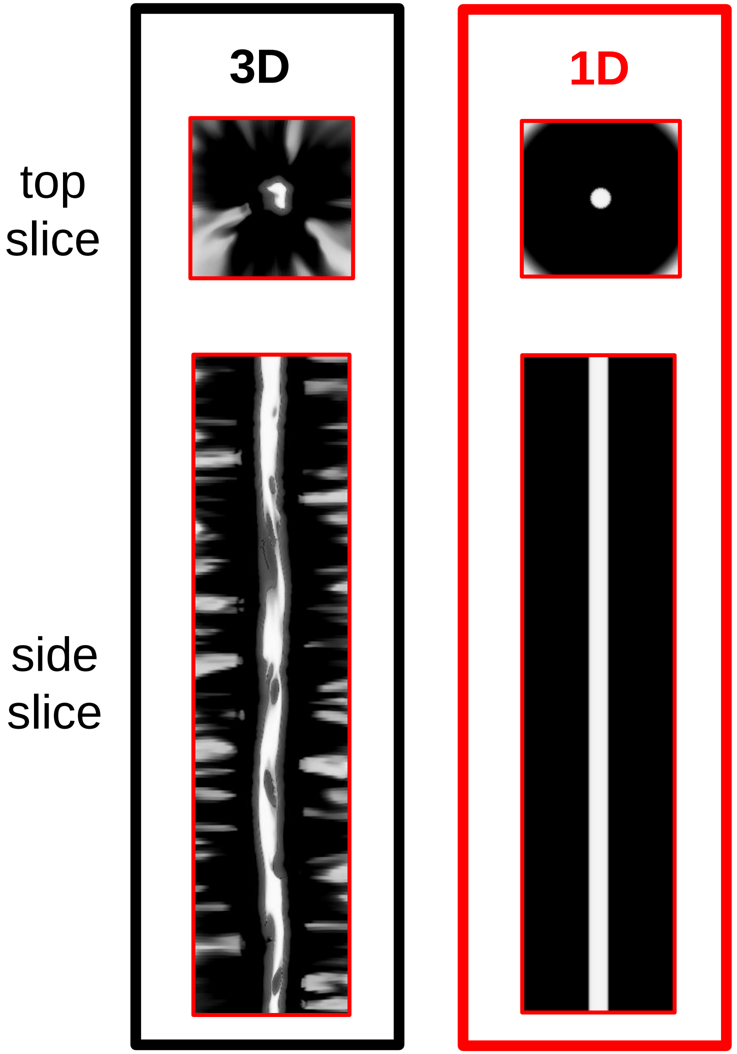
Experimental Images

2613 / 2850 / 2708

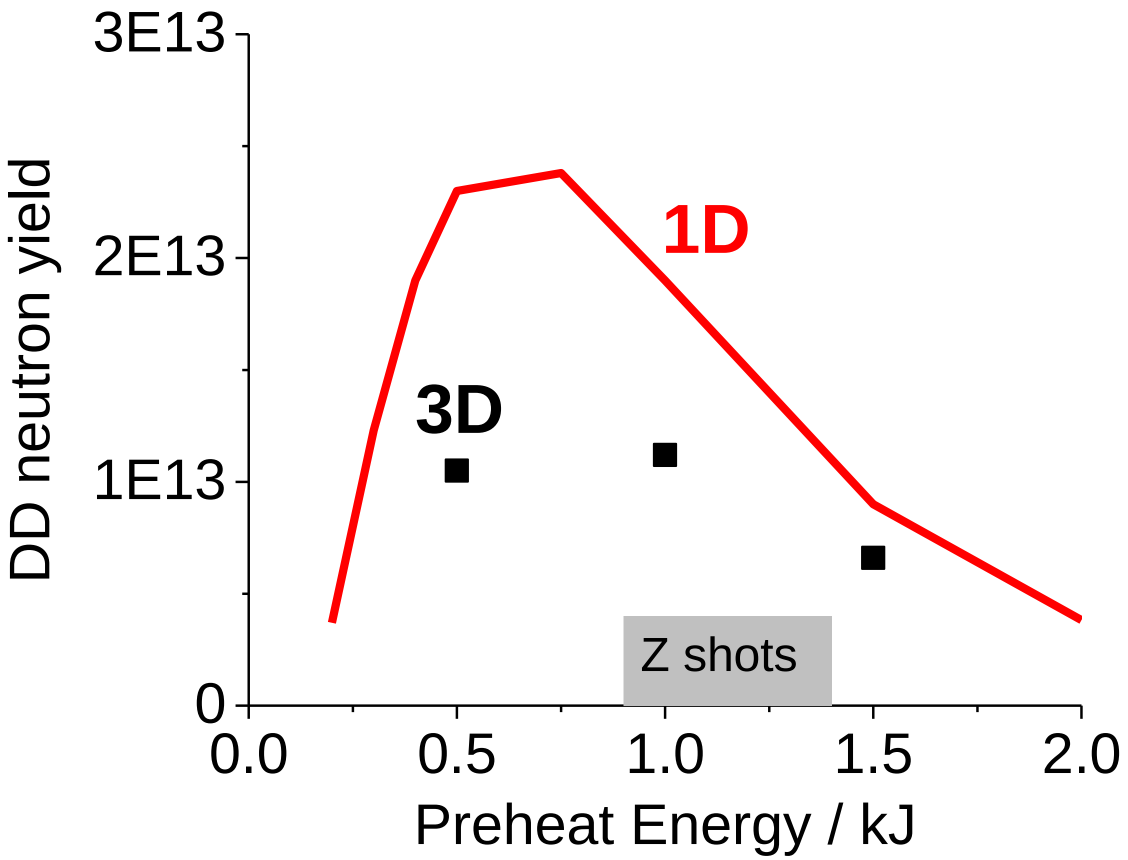


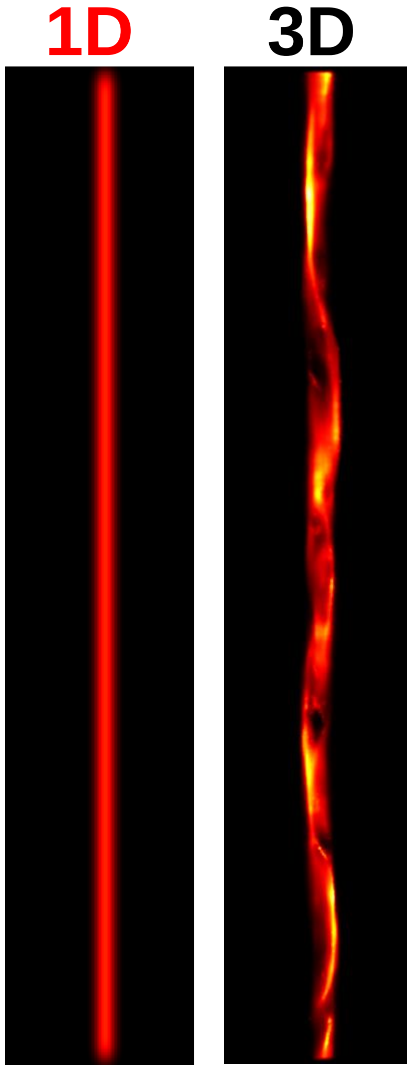
To what extent is this structure actually damaging performance ?

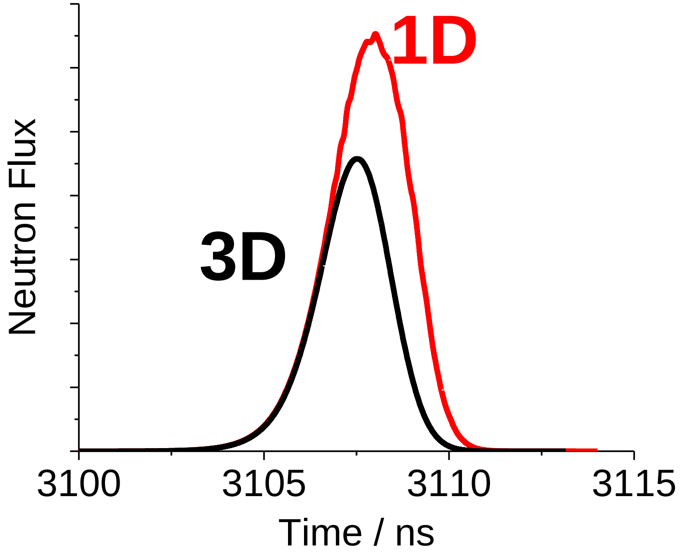




Burn partially truncated in 3d, but damage was largley done by then





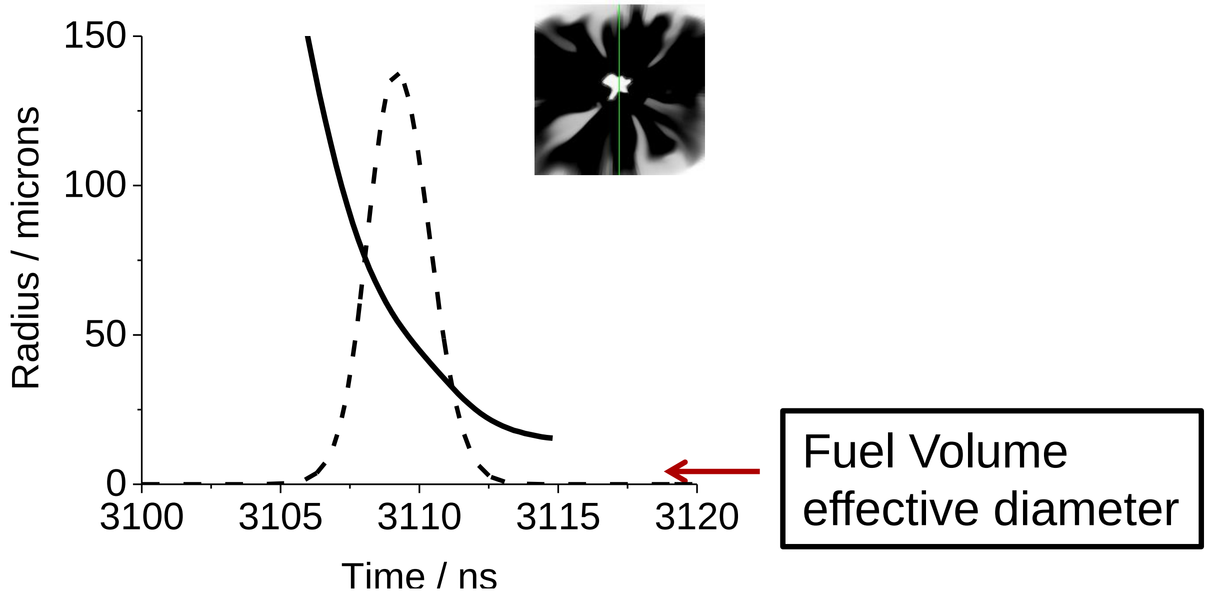


Emission structure resulting from truncating final ~60% of stagnation

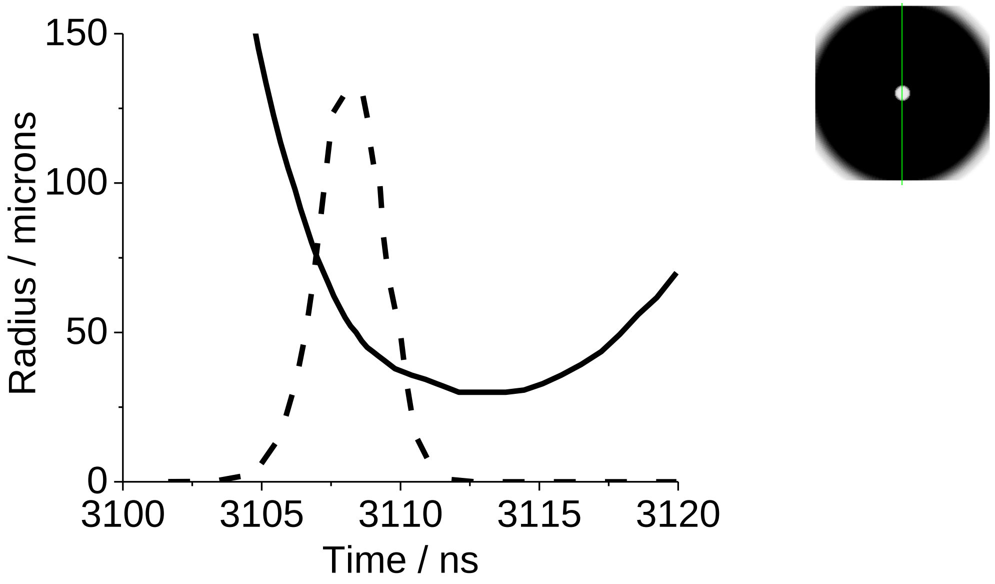
Loss of thermal insulation and disruption from instabilities compete to truncate burn.

(At 10T, ~1kJ preheat, low current, 0.7mg/cc initial gas density - loss of thermal insulation wins)

3D disruption: liner does not effectively bounce off of the fuel. Instabilities bisect fuel volume and redistribute heat.



Heat loss: liner does not effectively bounce off of the fuel. Aggressive temperature gradient redistributes field, insulation is lost, heat redistributed



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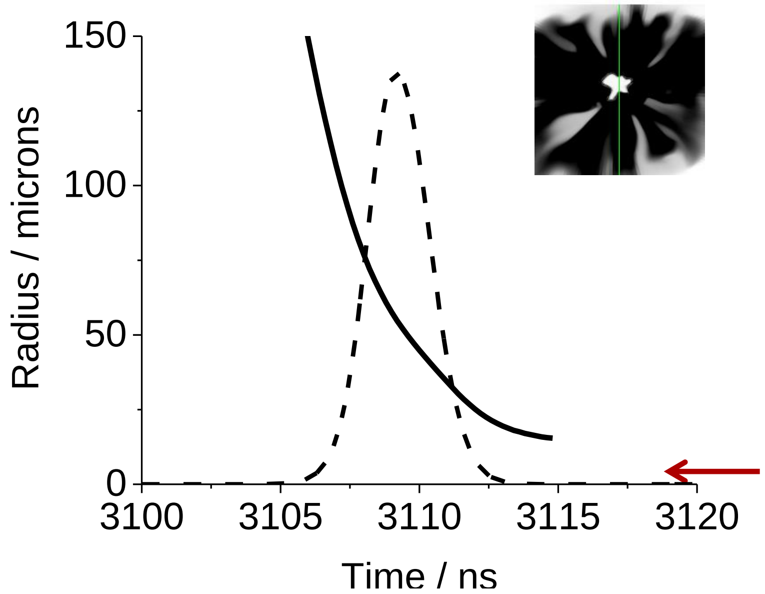
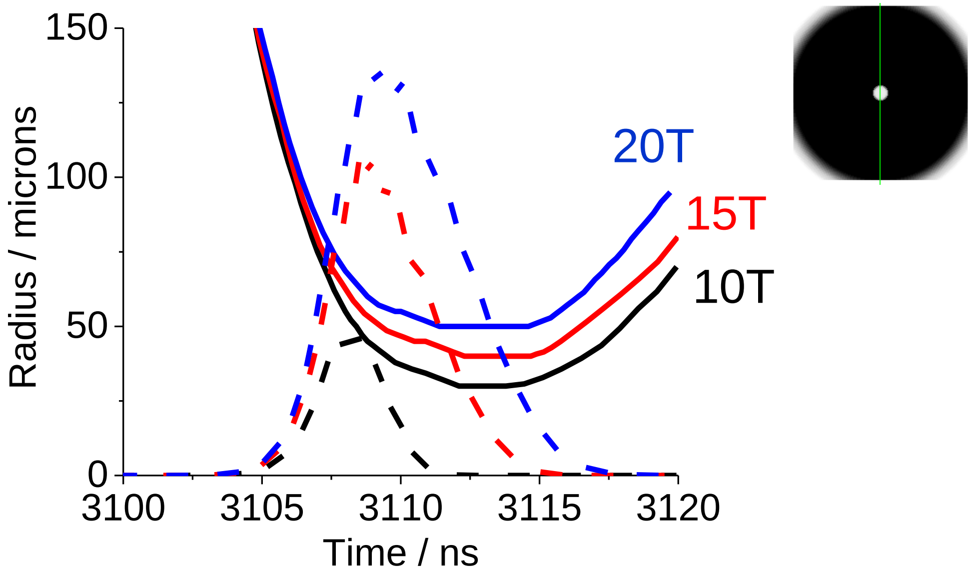


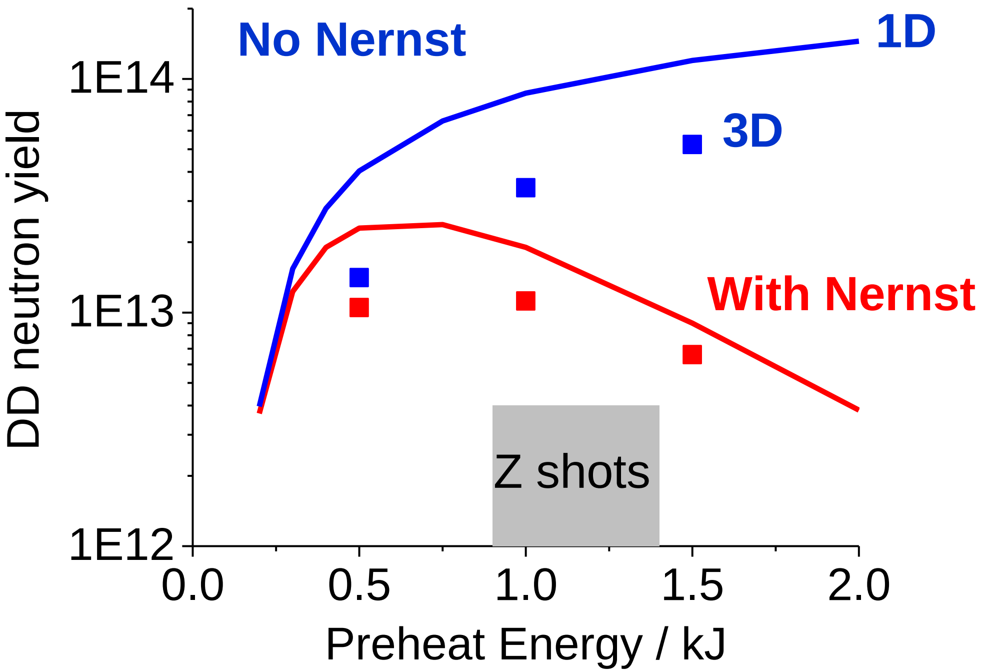
Fuel Volume effective diameter

Heat loss: liner does not effectively bounce off of the fuel. Aggressive temperature gradient redistributes field, insulation is lost, heat redistributed



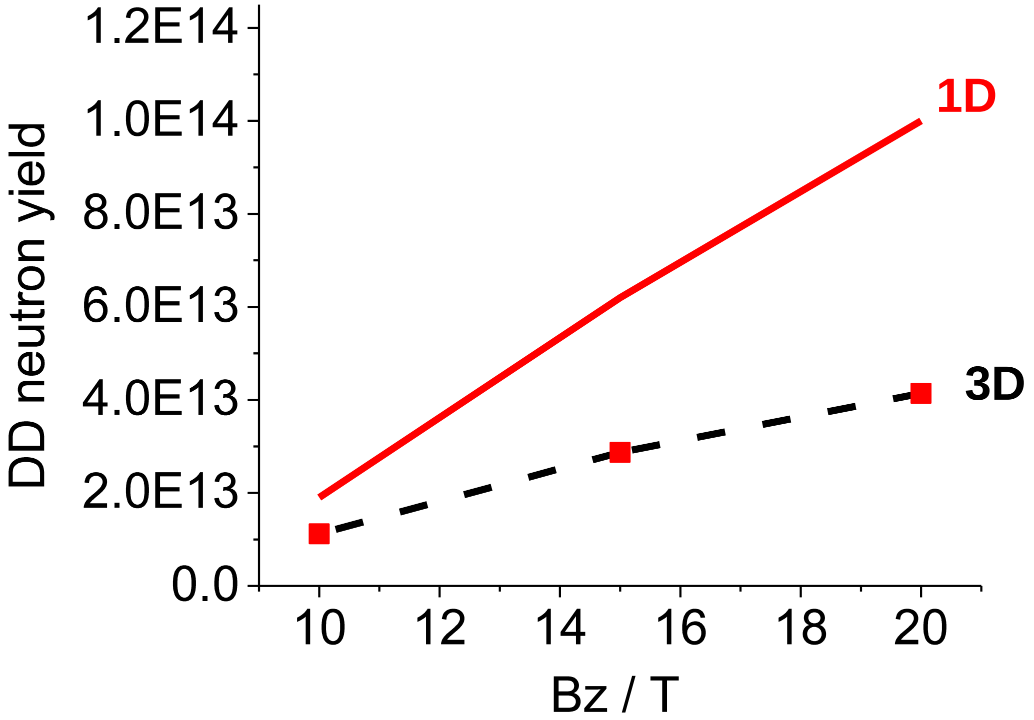
3D Instability degradation is worse as magnetic insulation improves

Yield vs Preheat Energy



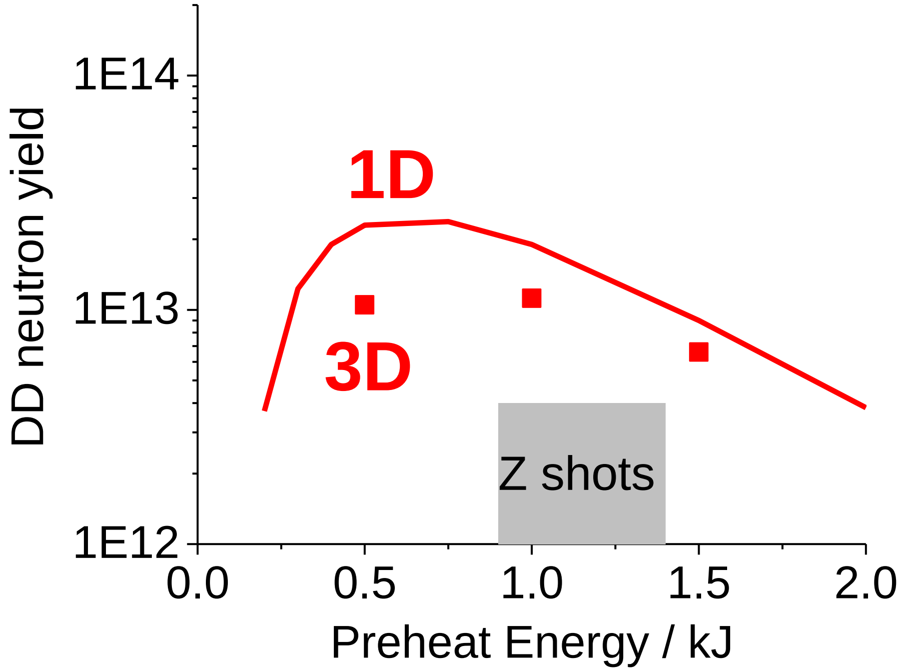
Absent Nernst, degradation from 3D instabilities more significant.
At higher currents this gets worse

Increase Magnetic field to improve insulation

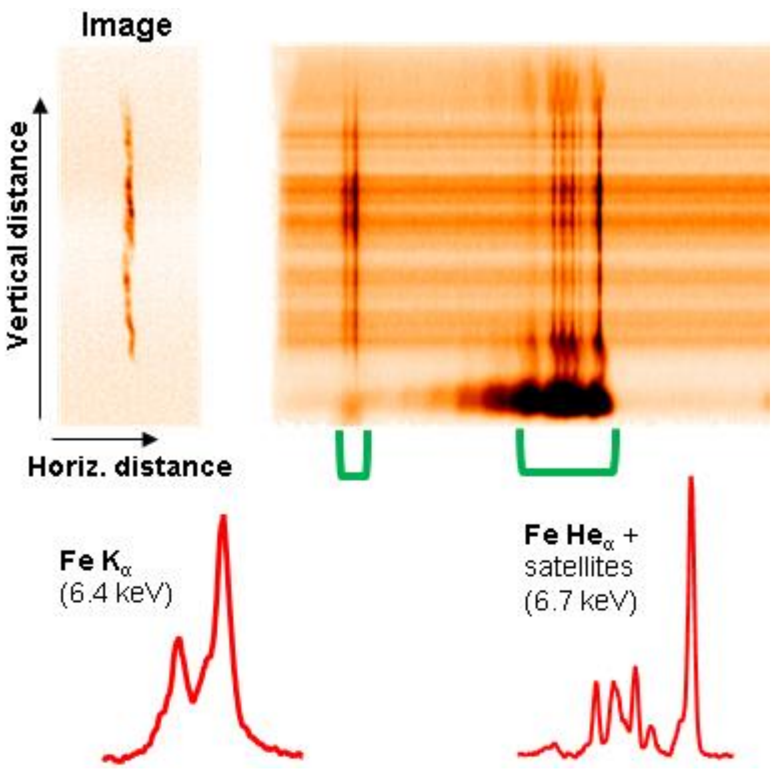


3D mitigates gains from improved insulation from higher Bz field

Instabilities appear insufficient to degrade mix alone, but mix is also observed



Axially resolved spectra indicate iron emission from stagnation column



Associated with Fe contaminant in Be Maglif liners from manufacturing

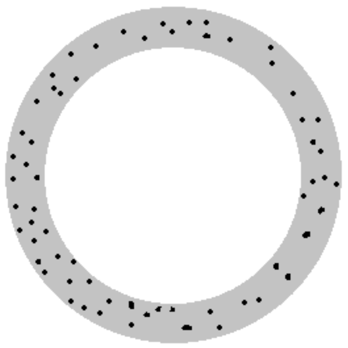


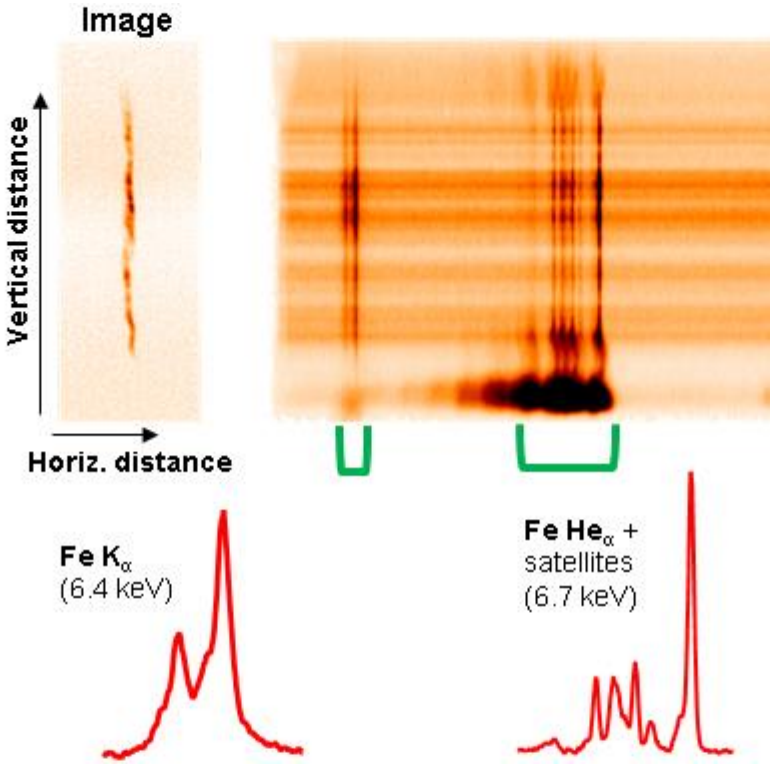
Image and data provided by Eric Harding

Instabilities appear insufficient to degrade mix alone, but mix is also observed

Spectral analysis (Eric Harding) indicates:
Be mix fraction = **7 ± 3 %**
Electron Temperature between 1.4 and 2 keV
Typically lower than the ion temperature from neutron diagnostics.

e.g. shot 2977
<Te> = 1.74 keV
Tion = 2.5 keV (from nTOF)
YDD = 3.0e12

Axially resolved spectra indicate iron emission from stagnation column



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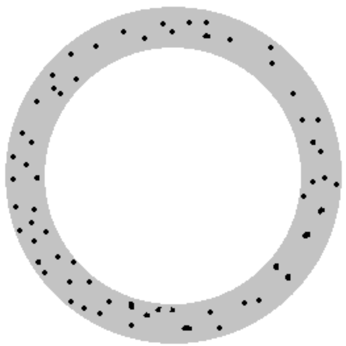
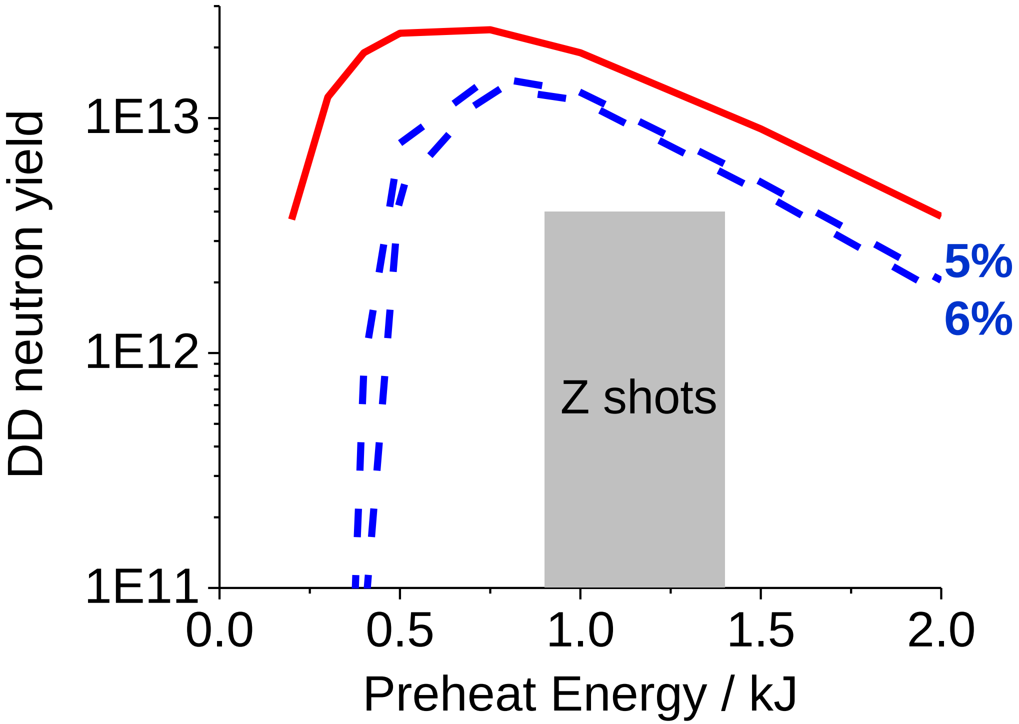
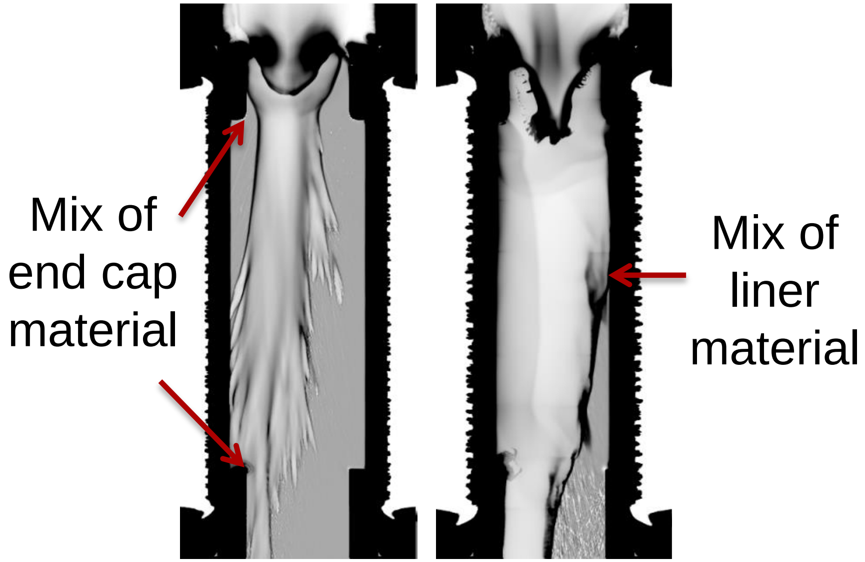


Image and data provided by Eric Harding

Maglif performance fairly robust to Be mix introduced at time of laser preheat

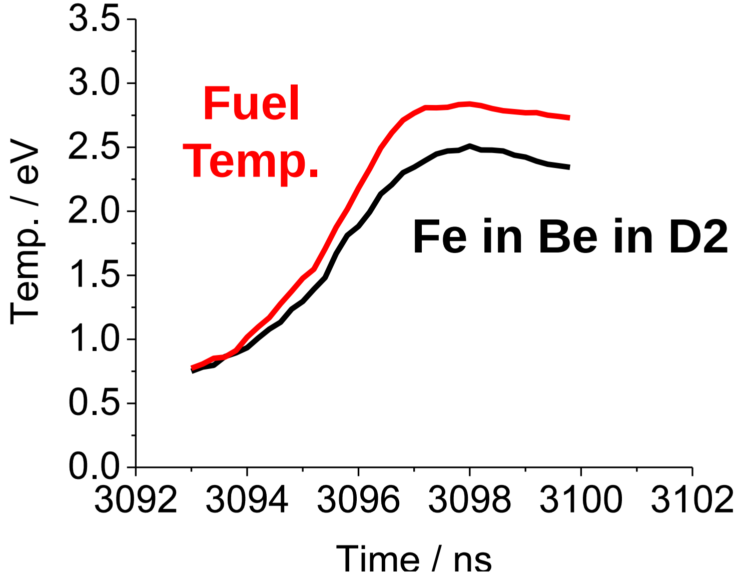




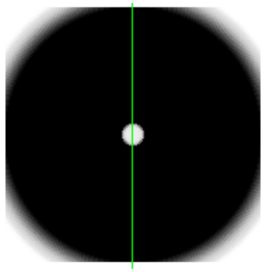
Performance is fairly robust to Be introduced at time of laser preheat

Lower temperature from iron emission indicative of late time instability injection of liner material into fuel

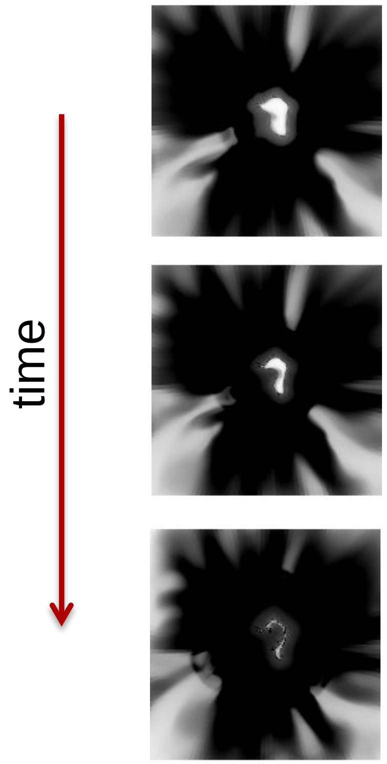
Uniform early time Be Mix



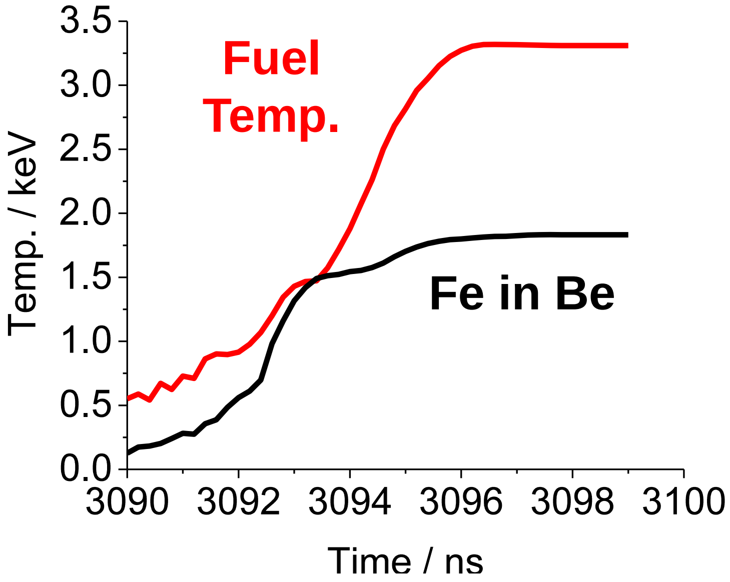
Iron emission from fuel mix weighted to colder / denser edge of fuel



S.B. Hansen, *et. al.* , PoP (2015)



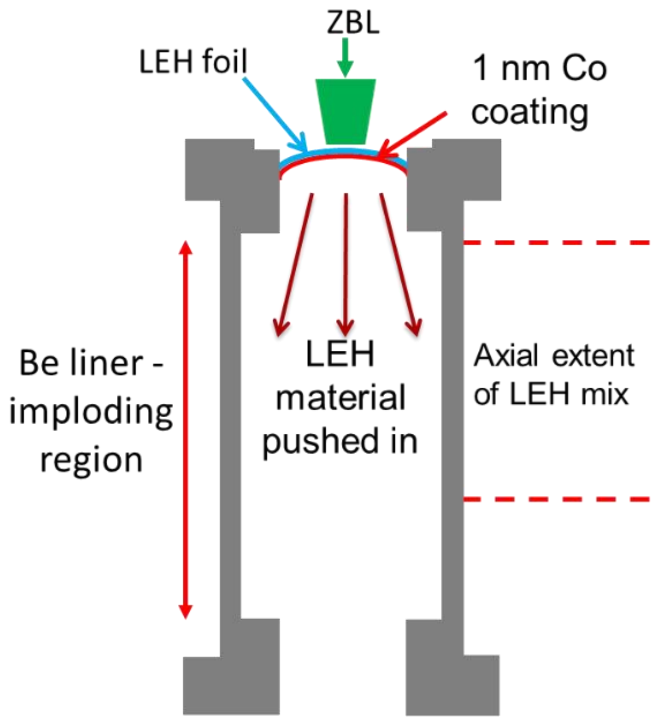
Late time liner / fuel mix



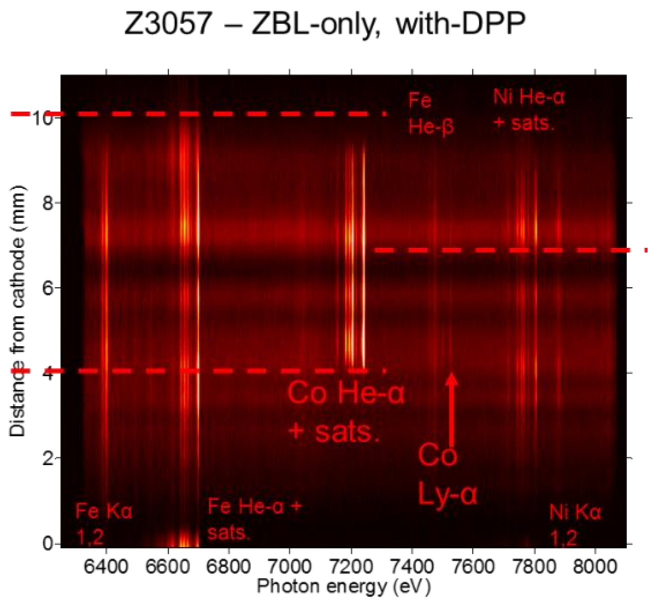
Penetration of iron carrying Be into cold fuel

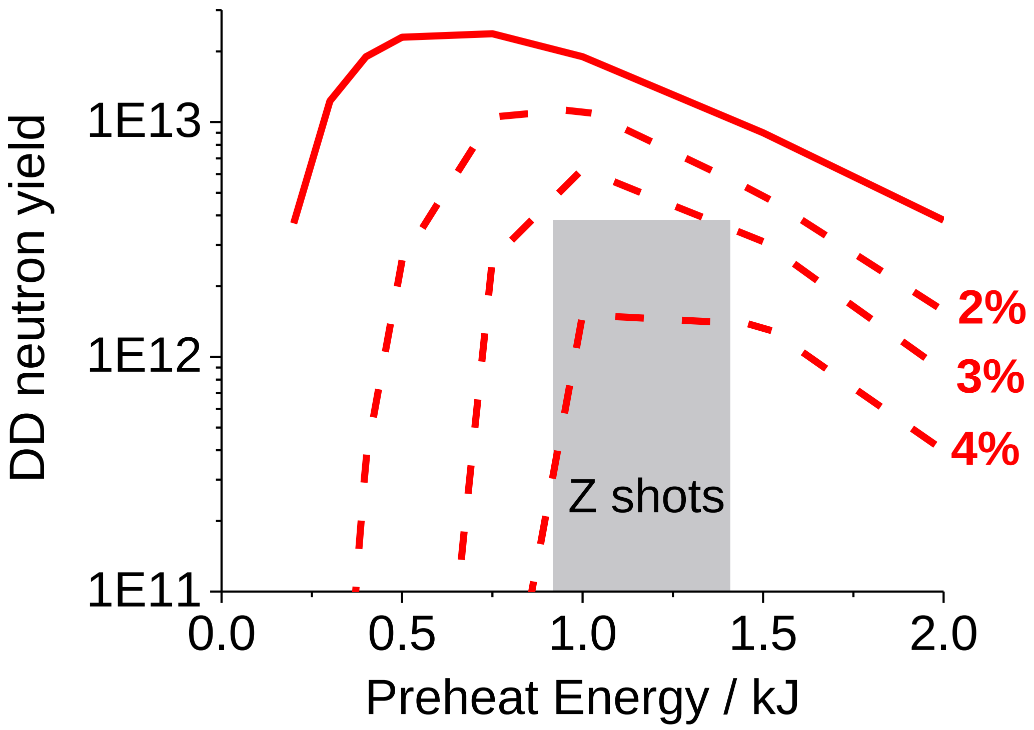
Window mix can more effectively degrade yield

Sandia National Laboratories



Axially resolved spectra show Co window tracer has migrated into fuel volume

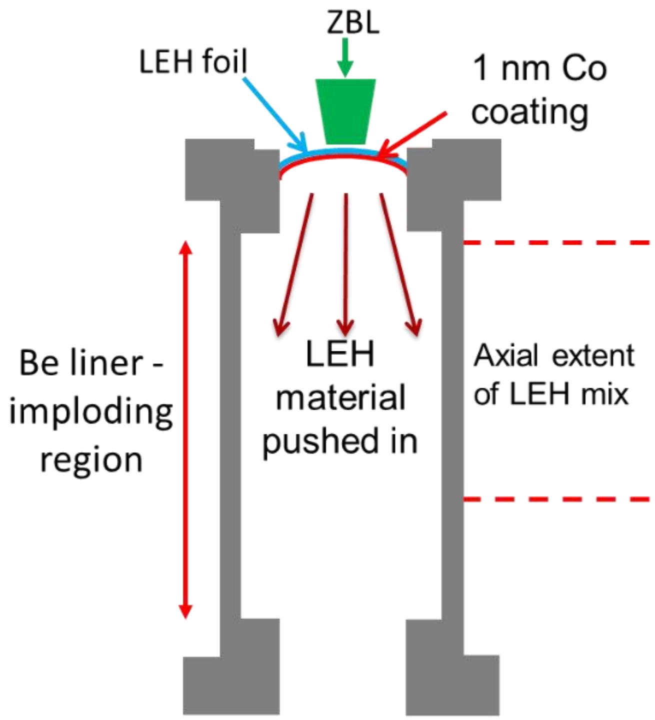




For different experiment / laser setups, assuming mix is just window plastic, values in the range of 1 – 7% have been inferred. See P. Knapp (Wed. PO8)

Image and data from Adam Harvey-Thompson

Window mix can more effectively degrade yield



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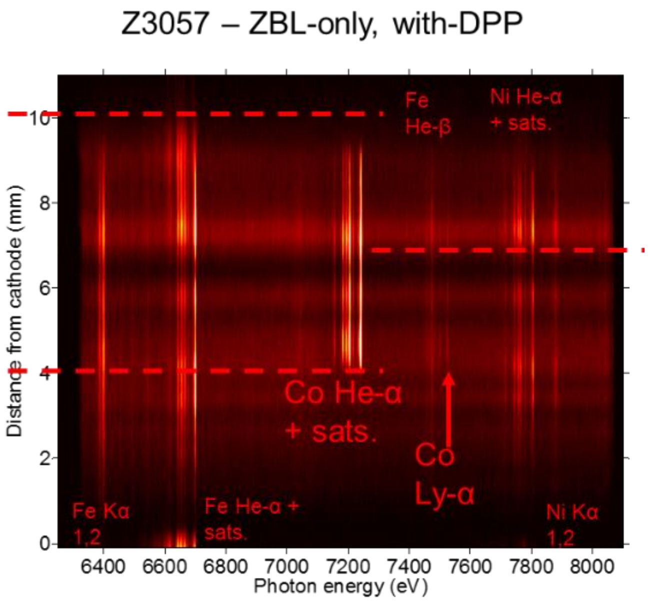

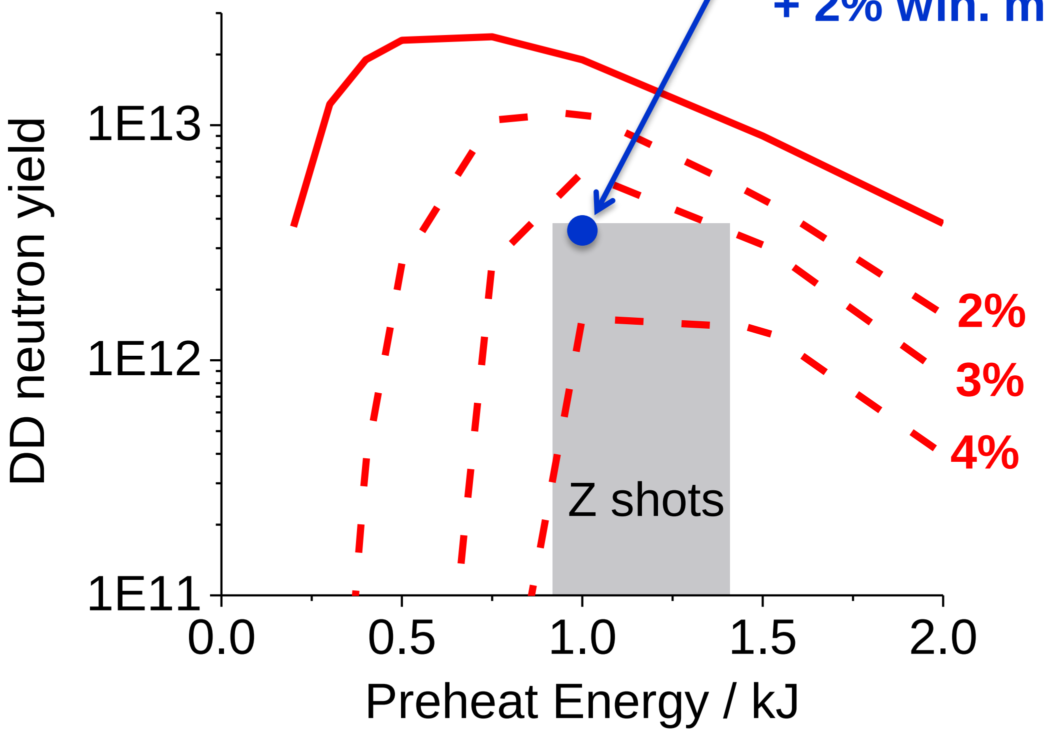

For different experiment / laser setups, assuming mix is just window plastic, values in the range of 1 – 7% have been inferred. See P. Knapp (Wed. PO8)

Image and data from Adam Harvey-Thompson

Summary:

Maglif is presently operating close to ideal simulation expectations.

Presently, degradation of neutron yield is dominated by:

- Implosion instabilities
- Mix into fuel
- Loss of thermal insulation

Not to:

- Lack of preheat energy
- Low current delivery

We have a fairly clear path forward requiring some capability development (higher Bz with higher current for higher fill densities at higher preheat energies)