High Energy Density Physics Modelling at Imperial College.

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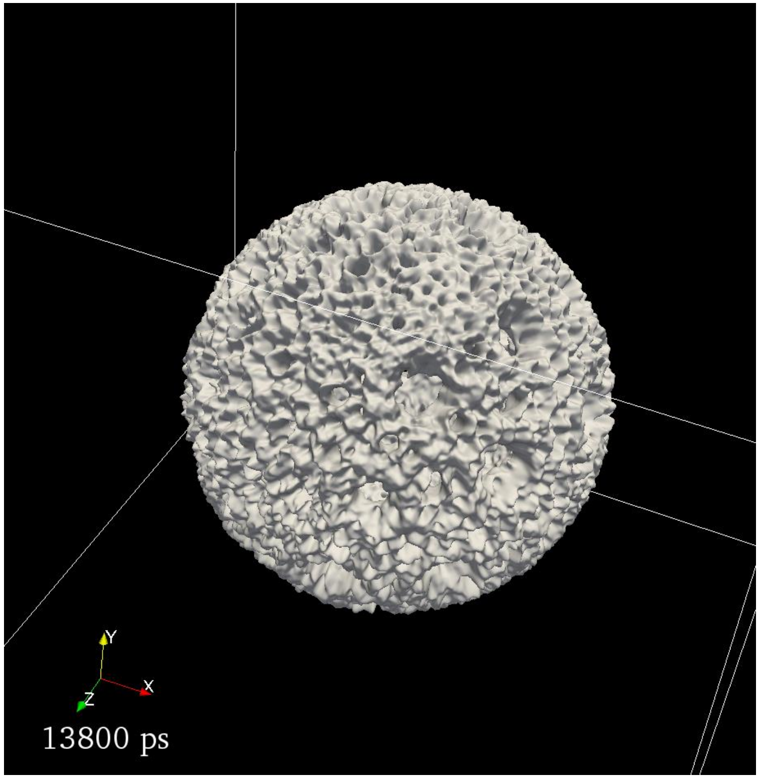
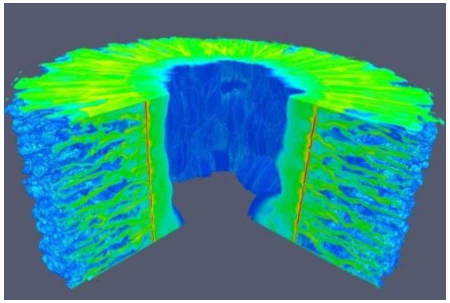


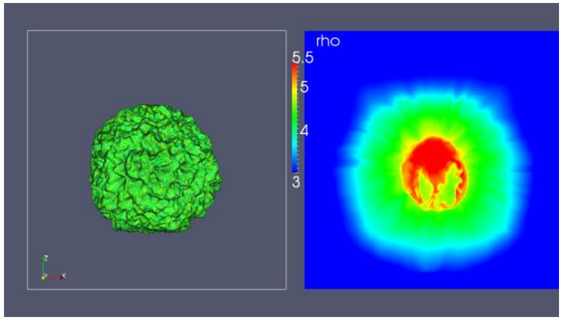
Warwick - November 2015

HEDP modelling suite



Gorgon

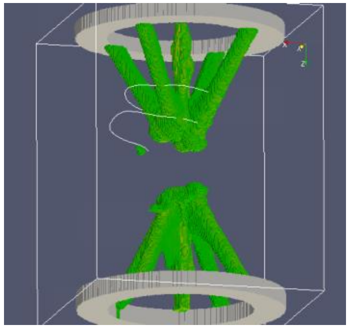
3D (x,y,z) or (r,z,θ) Eulerian, resistive MHD code.
Fully explicit version using vector potential representation.
Parallel via domain decomposition.
Detailed equation of state and transport data.
non LTE DCA atomic & radiation loss model.



Chimera

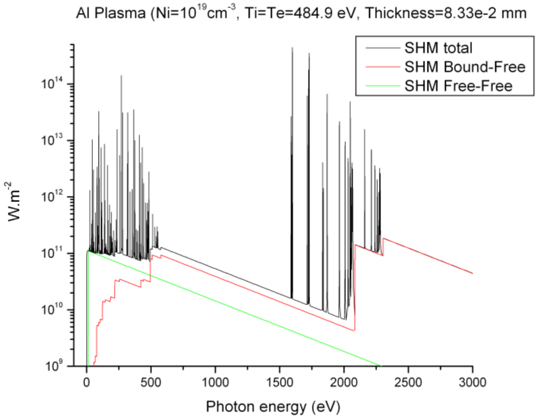
3D (x,y,z), (r,z,θ) or (r,θ,ϕ) Eulerian, rad-hydro code.
Fully explicit version with parallel domain decomposition.
Detailed equation of state and transport data.
Multi-group diffusive radiation transport using non-LTE opacity data

All codes share common solvers and can be used in combination



Melinda

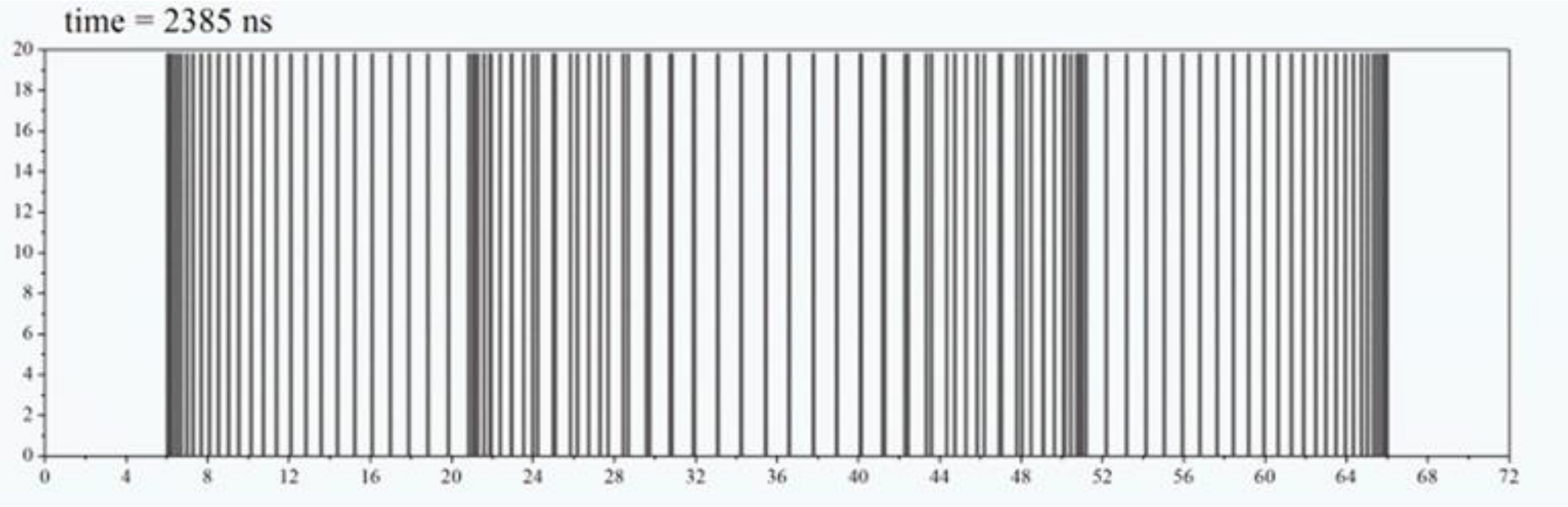
3D, relativistic, electromagnetic, explicit, PiC code:
Models non-thermal particle species – runaway electrons, fast ions, alphas, tritons, etc.
Parallel via domain decomposition.
Energy conserving force interpolation.
Relativistic binary Coulomb collision model.
Space charge limited and electrode plasma desorption particle creation models.



SpK

Multi-material CRE DCA emissivities and opacities based on a modified Saha model
including n-l splitting with up to 10m excitation level
Inline resolution of ionization populations, and radiative cooling rates, using tabulated data.
Offline generation of detailed synthetic spectra and other diagnostics using detailed line profile radiation transport including Stark, lifetime, ion temperature and motion Doppler broadening.

Wire array Z-pinches are intense (200TW) sources of soft x-rays used for inertial confinement fusion research



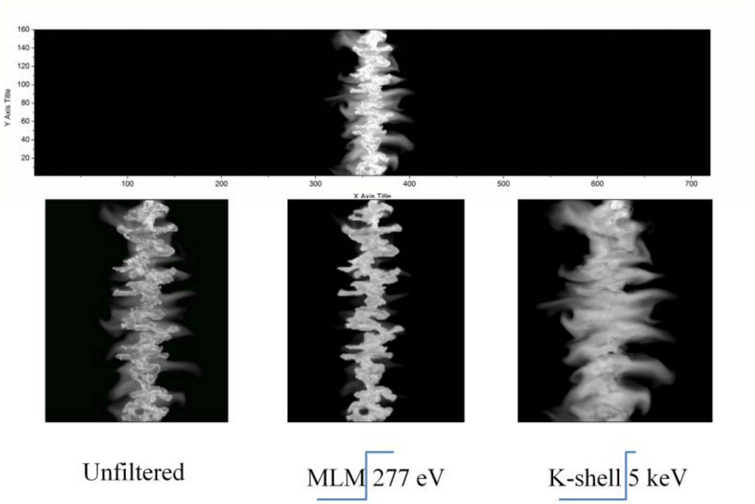
Z shot 1284 (60mm/30mm) nested Copper (80 wires / 40 wires) 10.97um

4608 processors, 2880*2880*800= 6,635,520,000 computational cells,

24.7 Gigabytes per output, 2.7 Terabytes for this animation:

K-shell radiation sources require detailed spectral modelling

Spk - a simple atomic model for large scale parallel HEDP simulations



Kernel:

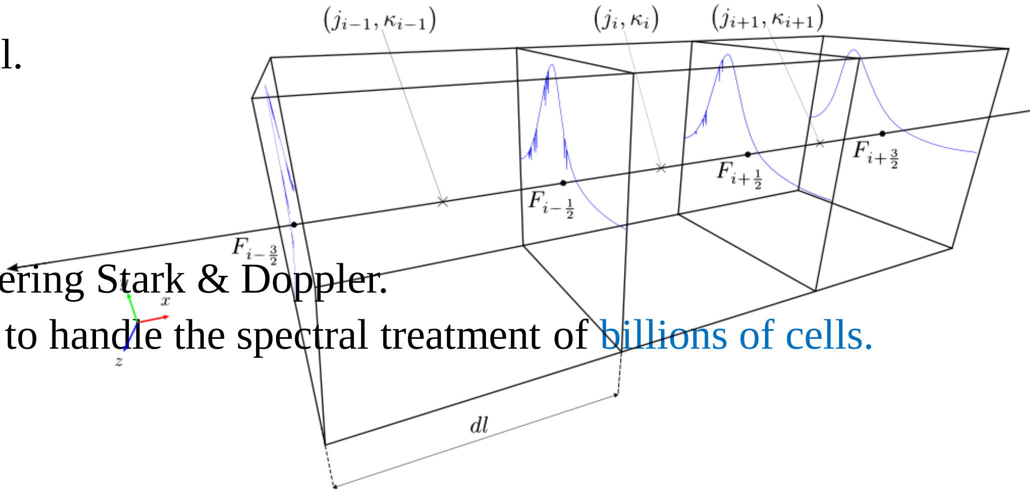
- SHM + DCA with nl splitting.
- Experimental energy levels from NIST atomic database.
- Multi-material for mixed opacities and emissivities.
- Self-consistent EOS (very experimental for the moment).

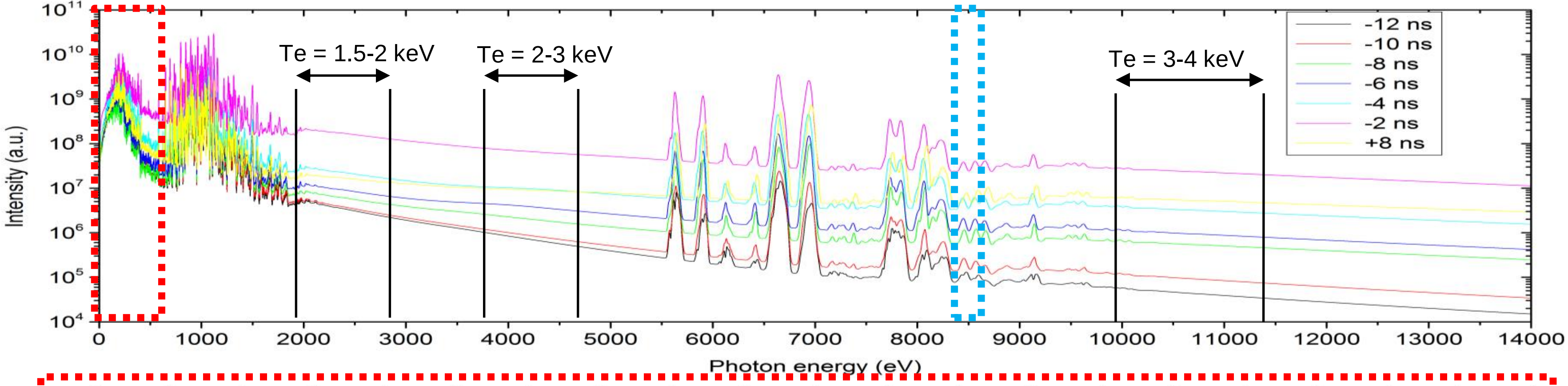
Inline:

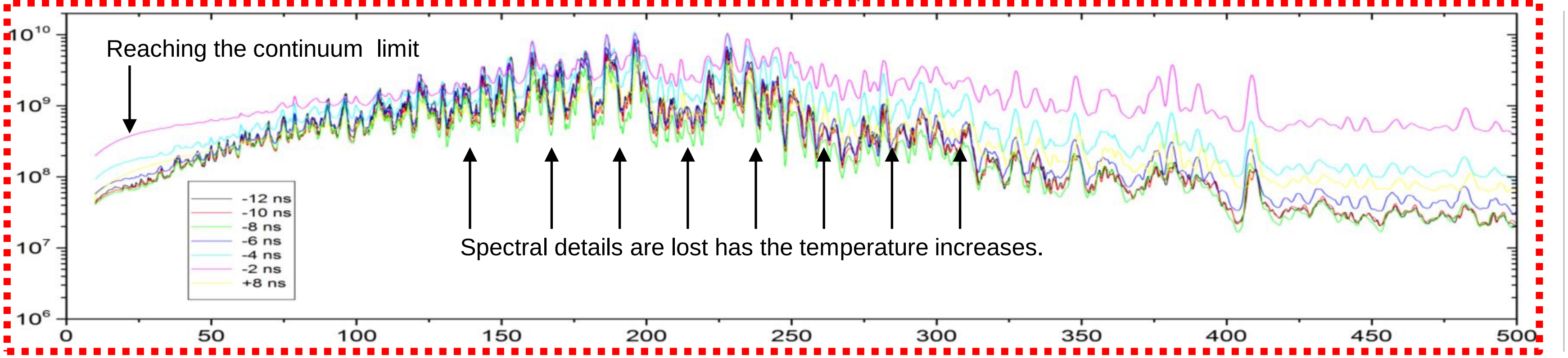
- Highly optimized.
- Run in parallel with Gorgon 3D / Chimera.
- Radiation transport: $P_{1/3}$ approximation.
- Fast pre-tabulation of Voigt profiles.
- Filtered synthetic bolometers and PCD signal.
- Self-consistent non-LTE Te and zbar .

Offline:

- Detailed spectra (FF, BF, BB [with ∆n = 0]).
- High resolution line profiles, continuum lowering Stark & Doppler.
- A modified self-balancing binary search tree to handle the spectral treatment of billions of cells.
- Multi-material opacity tables generation.
- Filtered synthetic MCP images.
- Spatially integrated spectra.

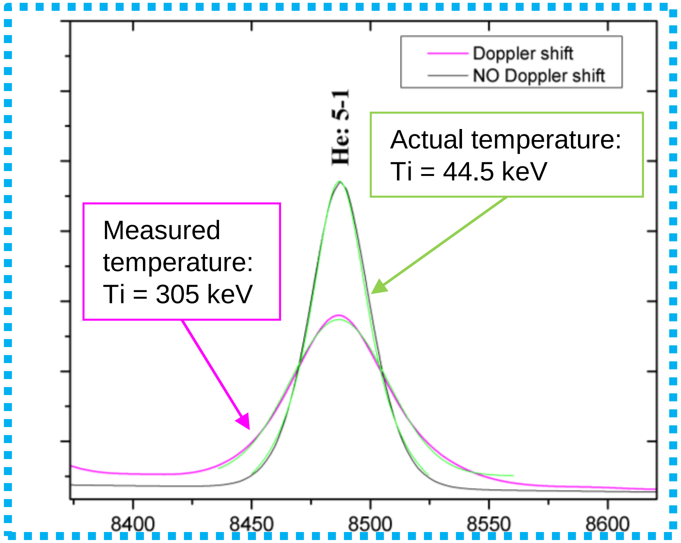






Reaching the continuum limit

Spectral details are lost has the temperature increases.

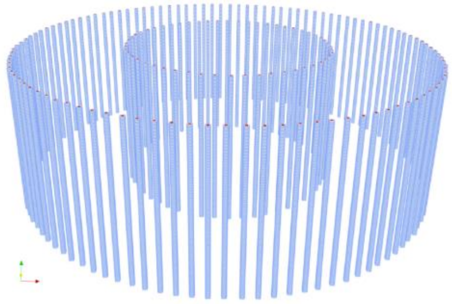


Actual temperature: Ti = 44.5 keV

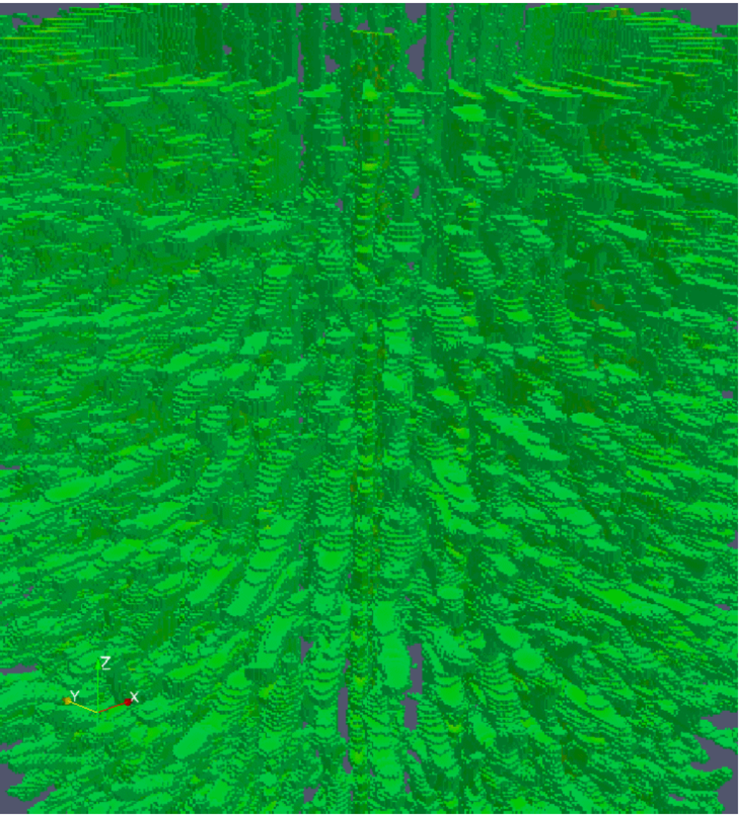
Measured temperature: Ti = 305 keV

Spk spatially integrated time-dependent synthetic SS spectra, obtained by post processing the results of a ZR cylindrical wire array Z-pinch simulation performed by the Gorgon code.

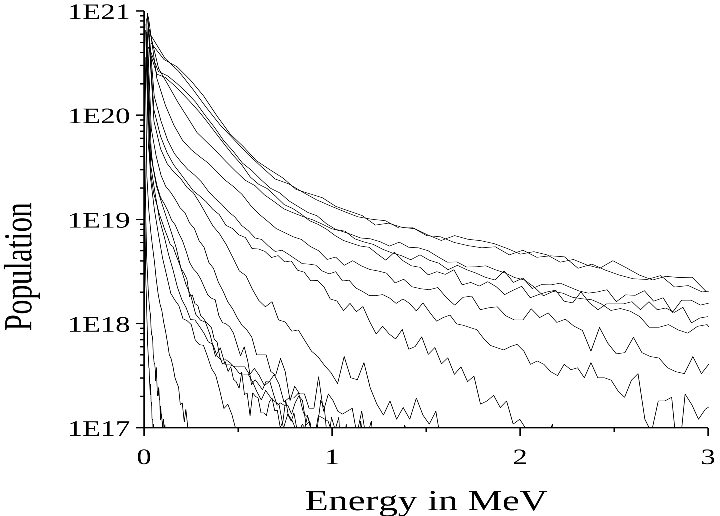
YIELD	Total	L-Shell (>1keV)	K-Shell (>5KeV)
Experimental [3]	940 kJ	470 kJ	85 kJ
SHM (old Spk)	994 kJ	370 kJ	89-73kJ
ΔX/X	5.4%	21%	4-14%



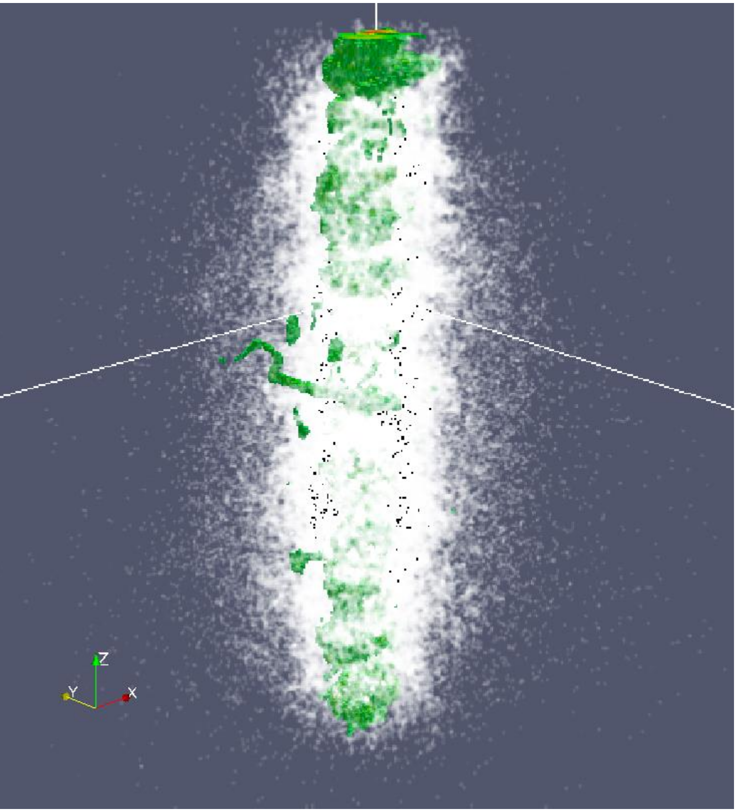
Electrons increase in number & energy and their trajectories become increasingly eccentric in the convoluted field of caused by instabilities

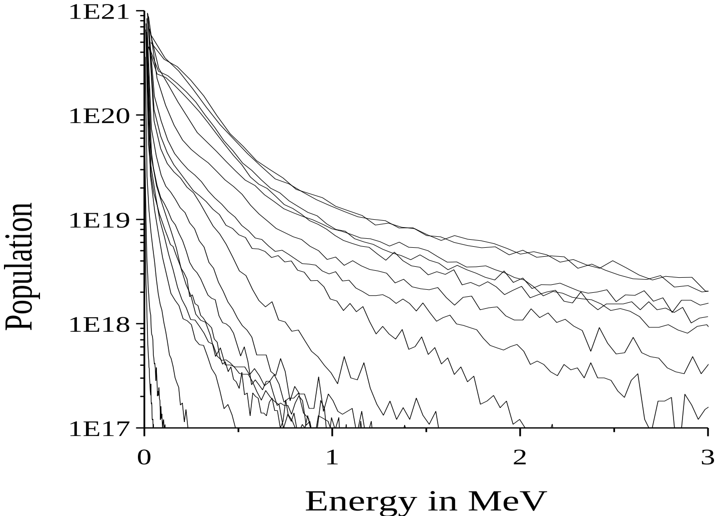


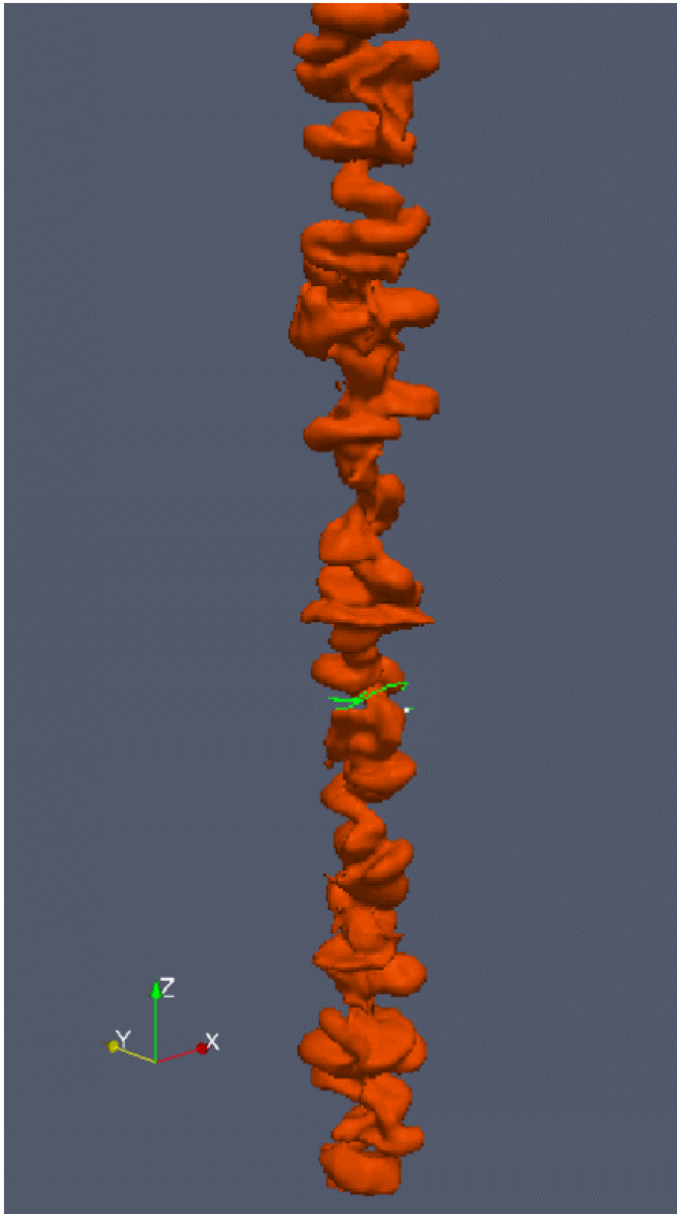
Results were generated using 3000 cores on the ARCHER UK National High Performance Computing Facility



Electrons increase in number & energy and their trajectories become increasingly eccentric in the convoluted field of caused by instabilities



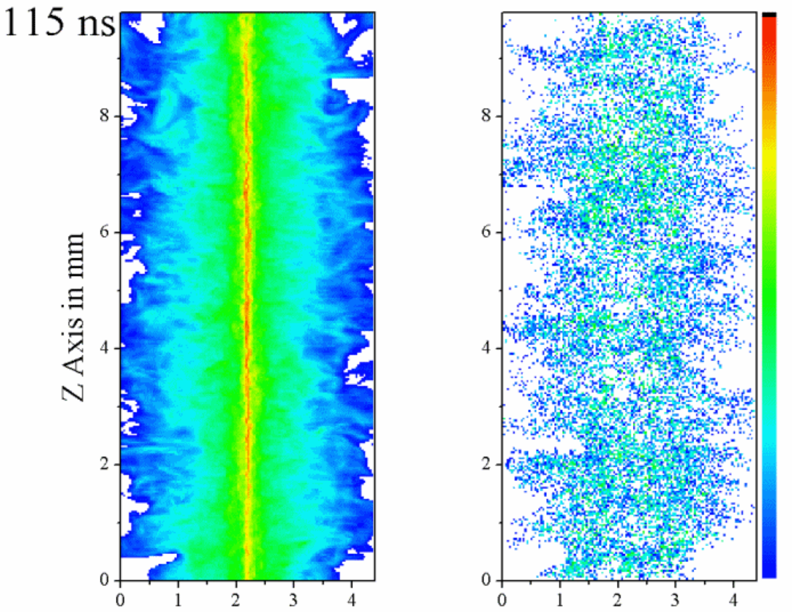


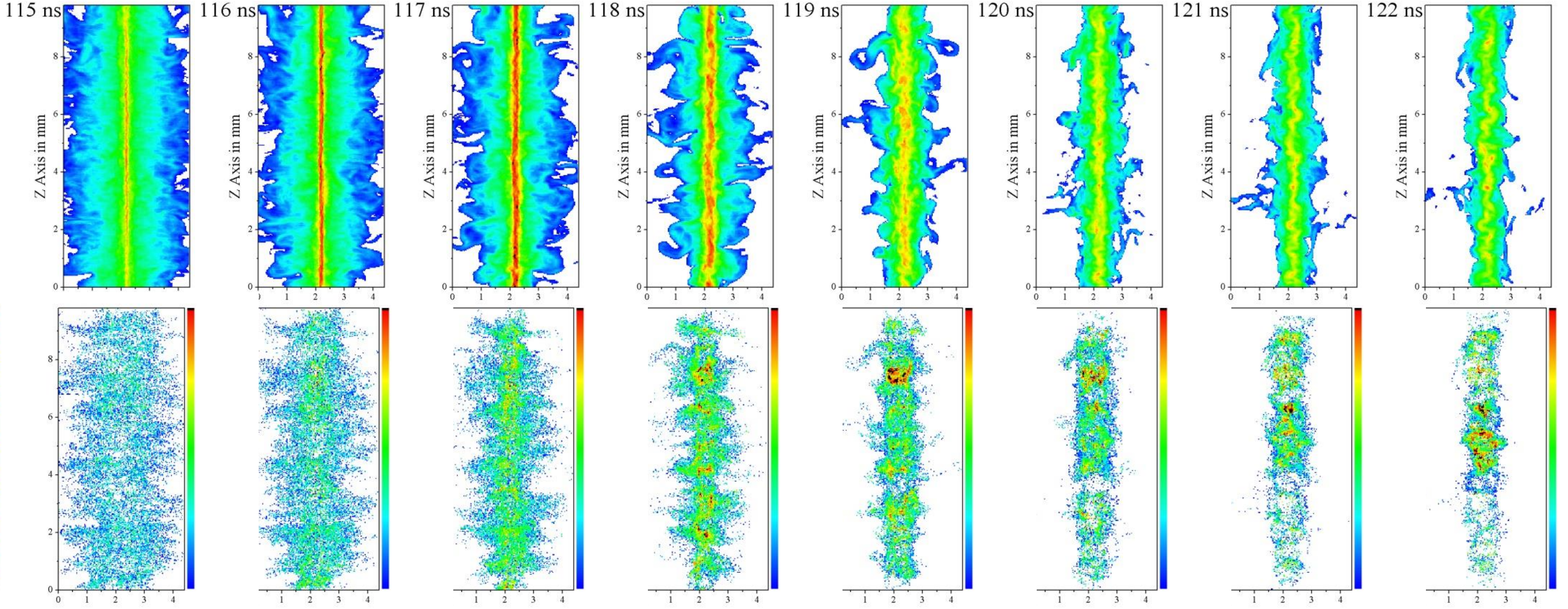


K-alpha emission peaks after thermal soft X-ray and typically coincides with regions of strong MHD instability

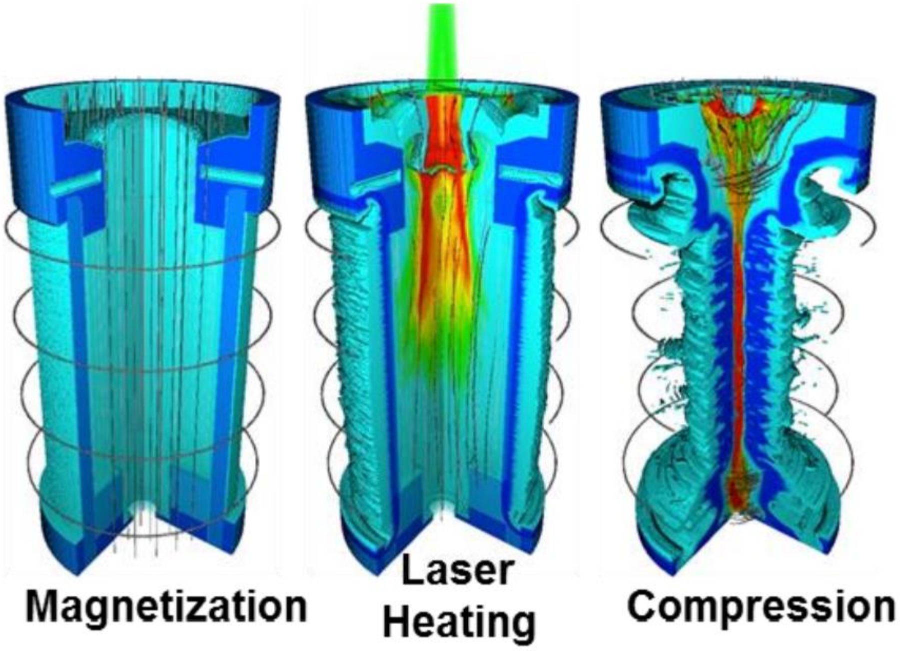
Here the product of fast electron density and background ion density provides a rough estimate of the probability of K-alpha emission – assuming a constant cross-section above a few times the ionization potential …

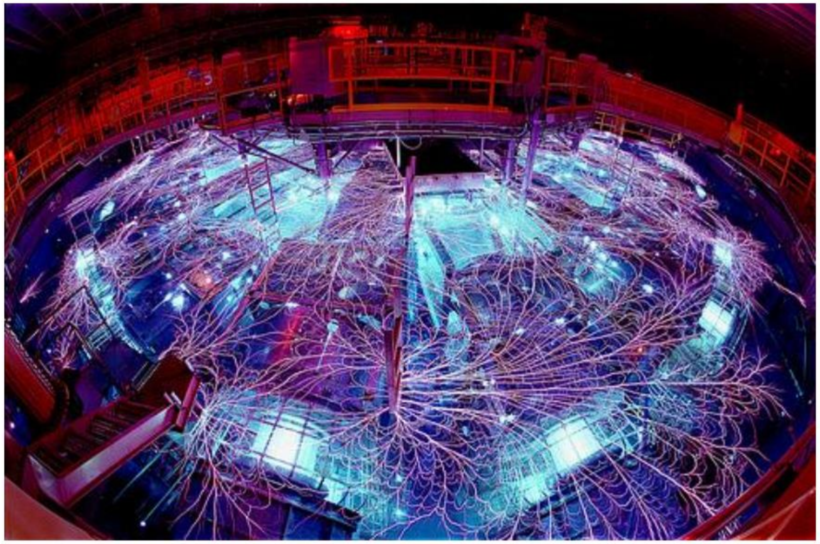
$$P_{k\text{-alpha}} \sim n_{fast}\, v_{fast}\, n_i\, \sigma\, E_{k\text{-alpha}}$$

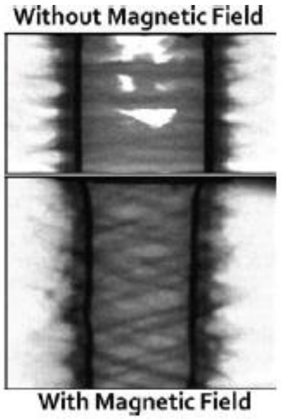


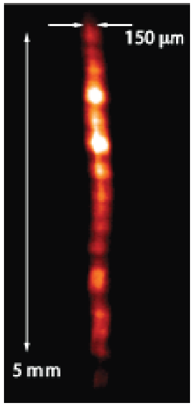


Magnetised Liner Inertial Fusion (MagLIF) research at Sandia National Laboratory







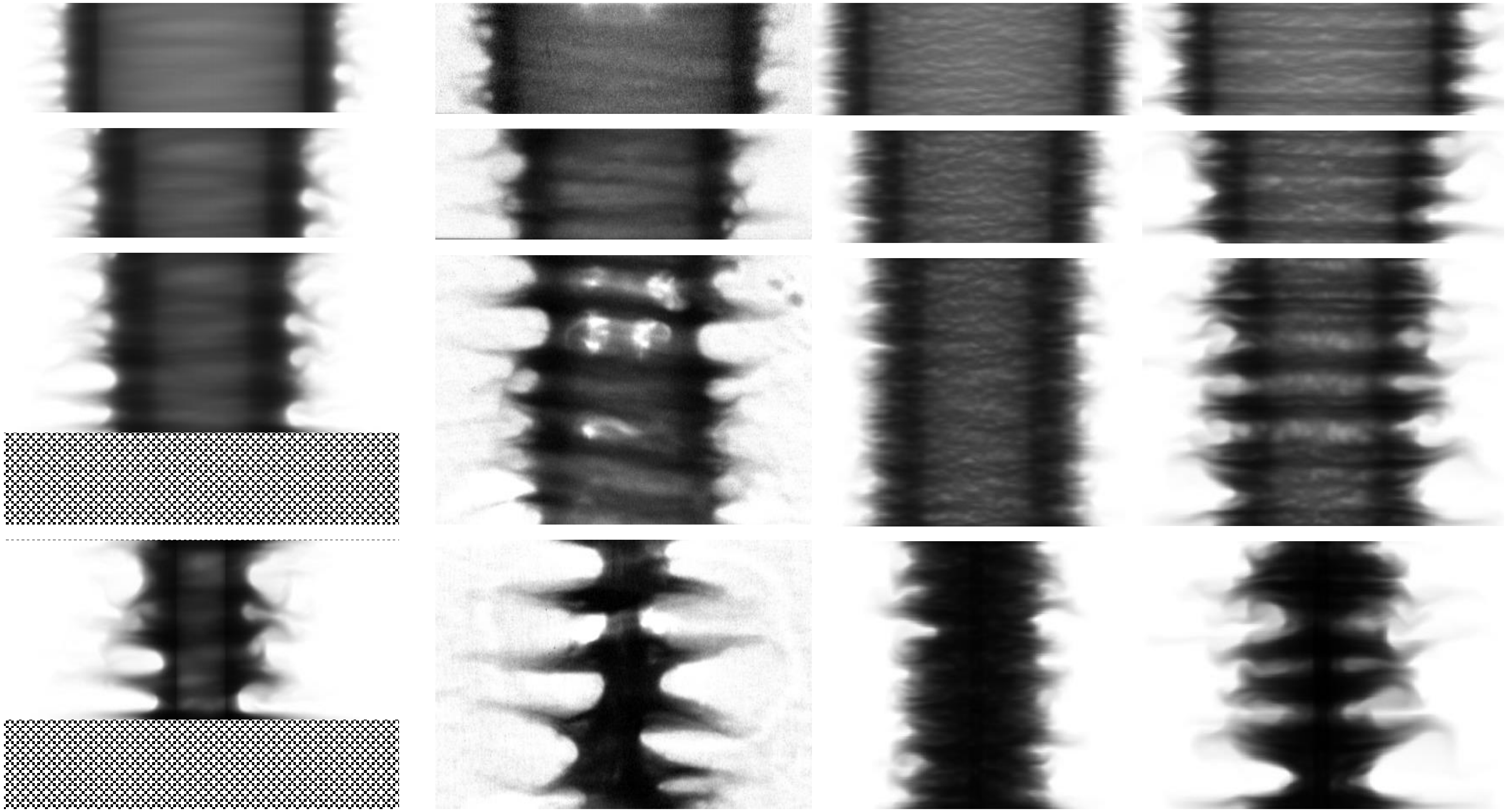


3123 eV
imager
data
from
z2584

Z2591
Beryllium liner, Deuterium filled
20MA current, 10 Tesla field, 2 kJ laser preheat
2×10^{12} neutron yield

Material strength affects early phase instability amplitude and correlation in MagLIF liners

Synthetic radiography compared to experiment



3D Gorgon: random,
4 μm
inc. strength model

Experimental results
from McBride *et al*

3D Gorgon:
random, 20 μm

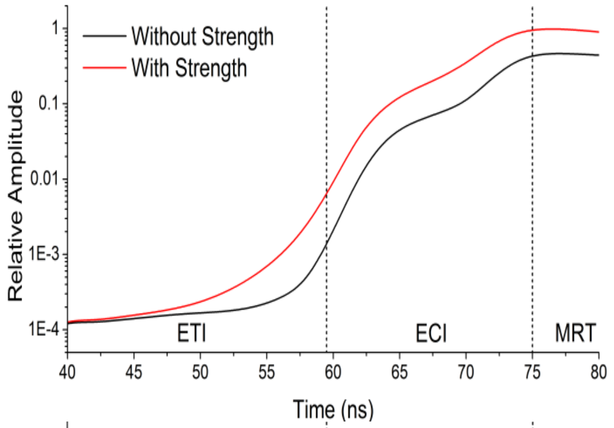
3D Gorgon:
correlated, 20 μm

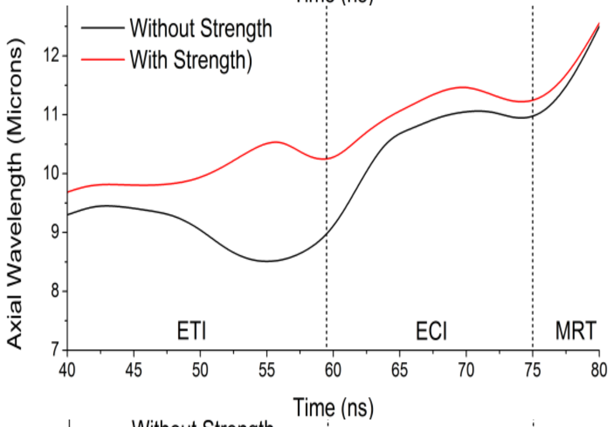
Material strength affects early phase instability amplitude and correlation in MagLIF liners

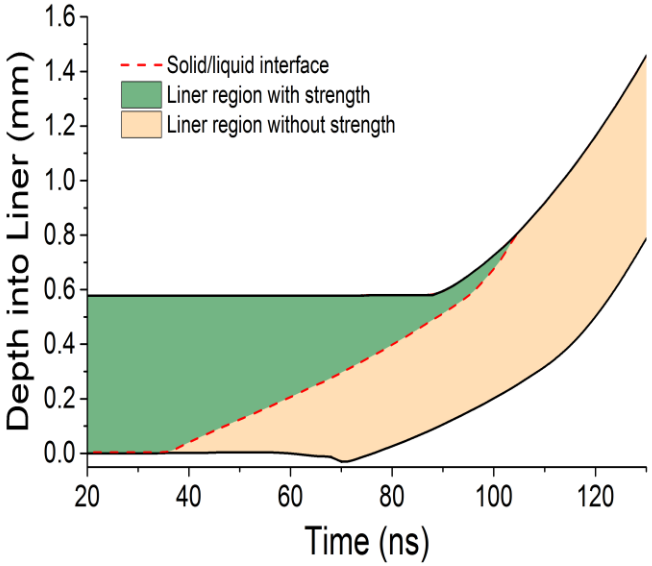
Material strength added to Gorgon: liner loses strength by the time the ECI is seeded, has no effect in ECI or MRT phases.

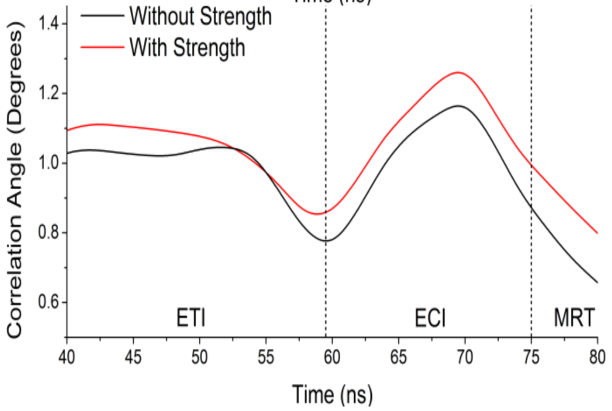
Strength results in longer ETI wavelength, higher amplitude and larger correlation angle

This difference remains through ECI and MRT phases



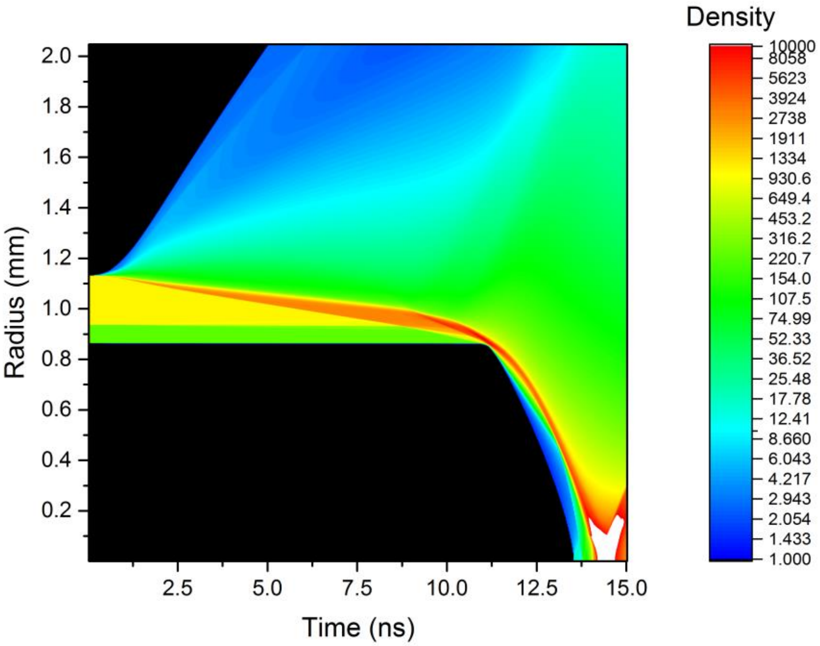


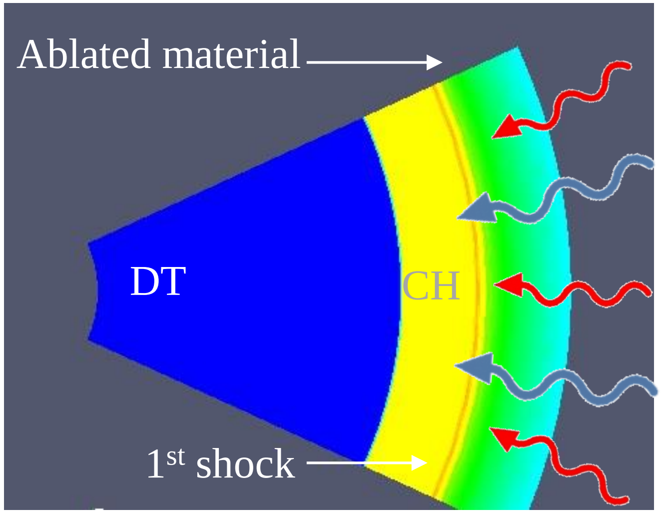


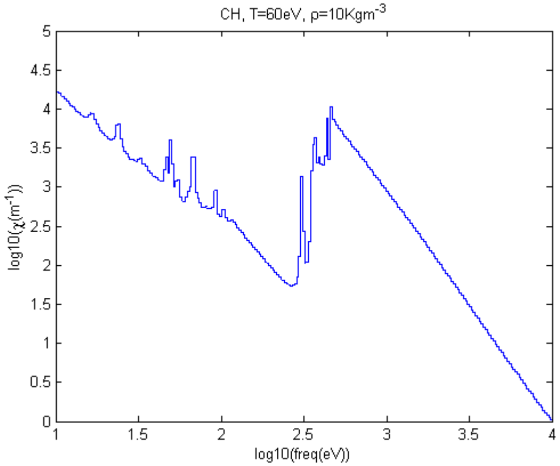


X-ray ablation using a multi-group radiation diffusion approximation

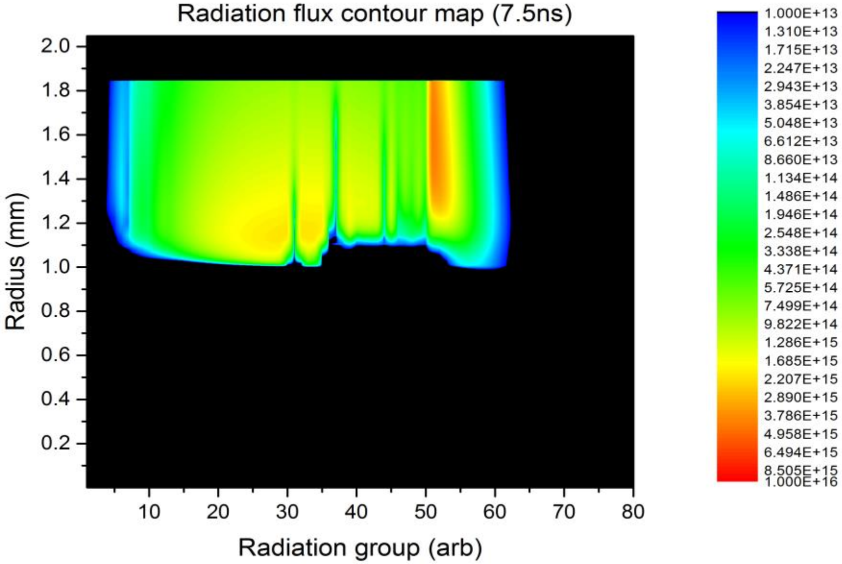
see Niasse et. al. Tu.Po.21







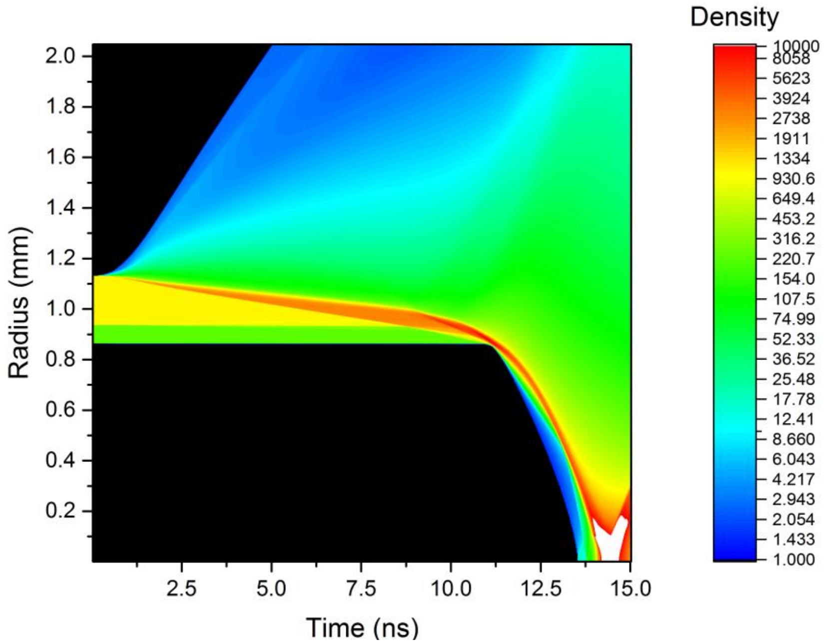
Tabulated CRE DCA opacities for CH from the SpK code are condensed into 80 radiation energy groups

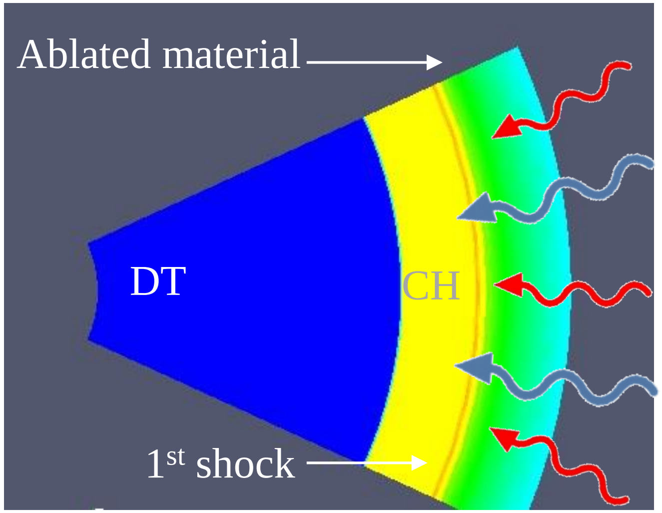


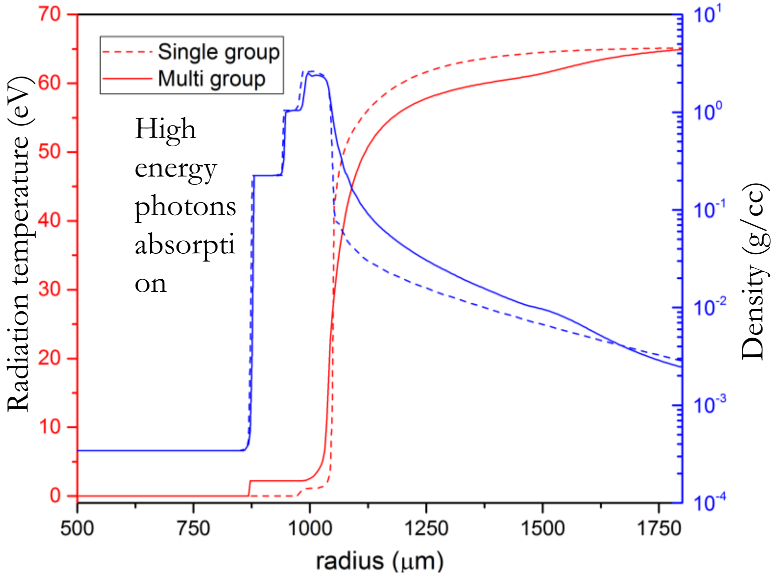
Absorption of different photon energies at different densities smooths out the density gradient at the ablation surface

X-ray ablation using a multi-group radiation diffusion approximation

see Niasse et. al. Tu.Po.21

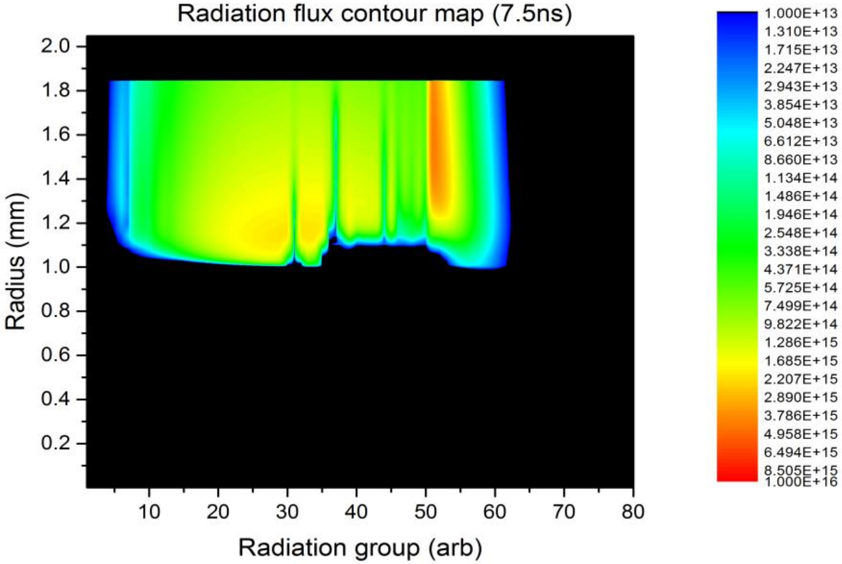






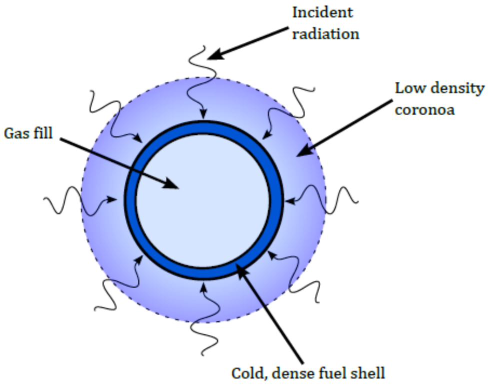
High energy photons absorption

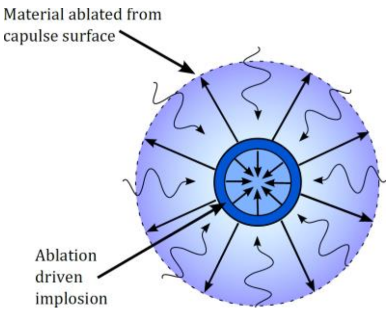
Multi-group affects ablation scale length and adiabat(s)

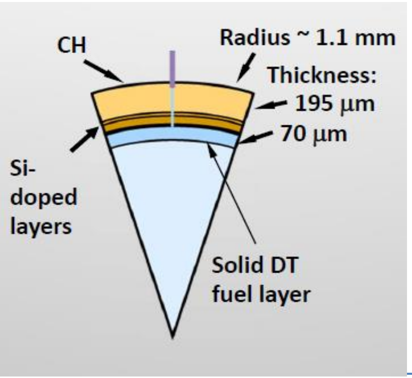


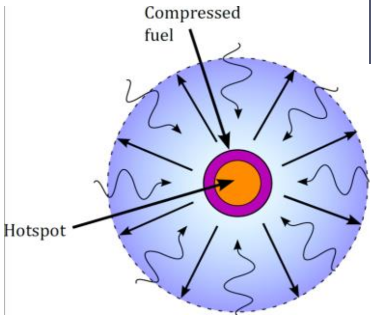
Absorption of different photon energies at different densities smooths out the density gradient at the ablation surface

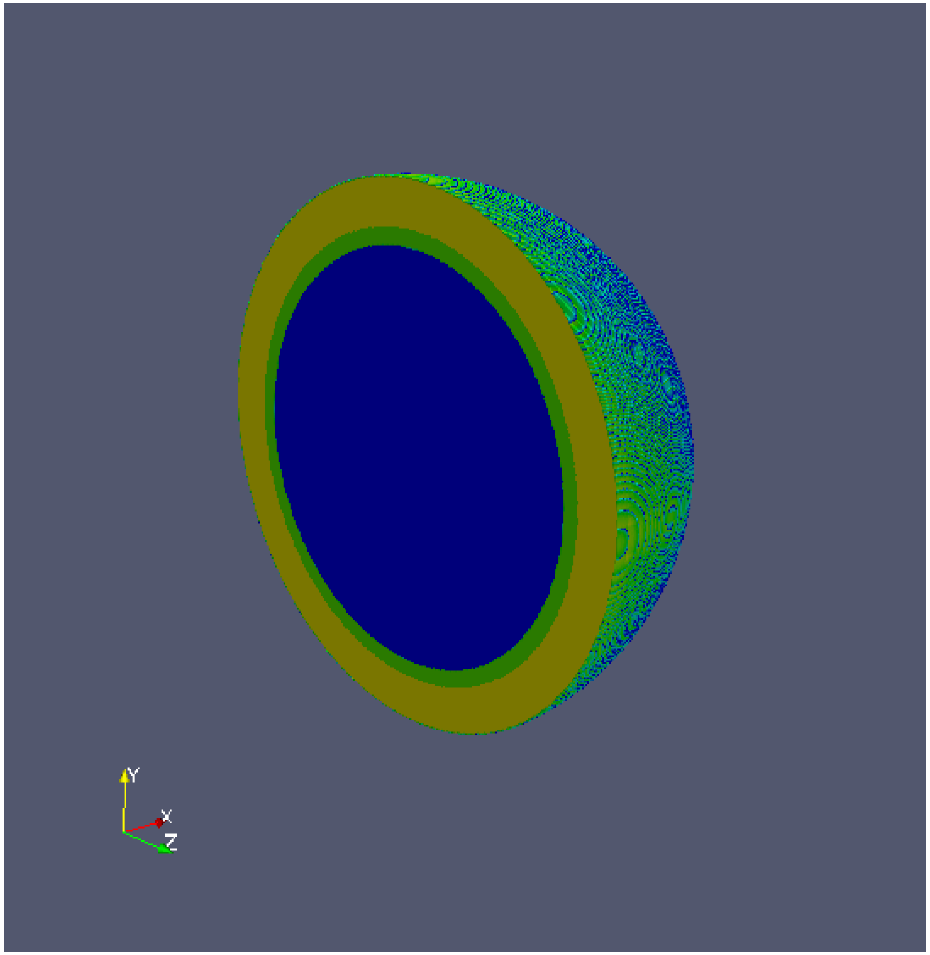
Full volume 3D radiation hydrodynamics simulations of NIF low-foot implosion



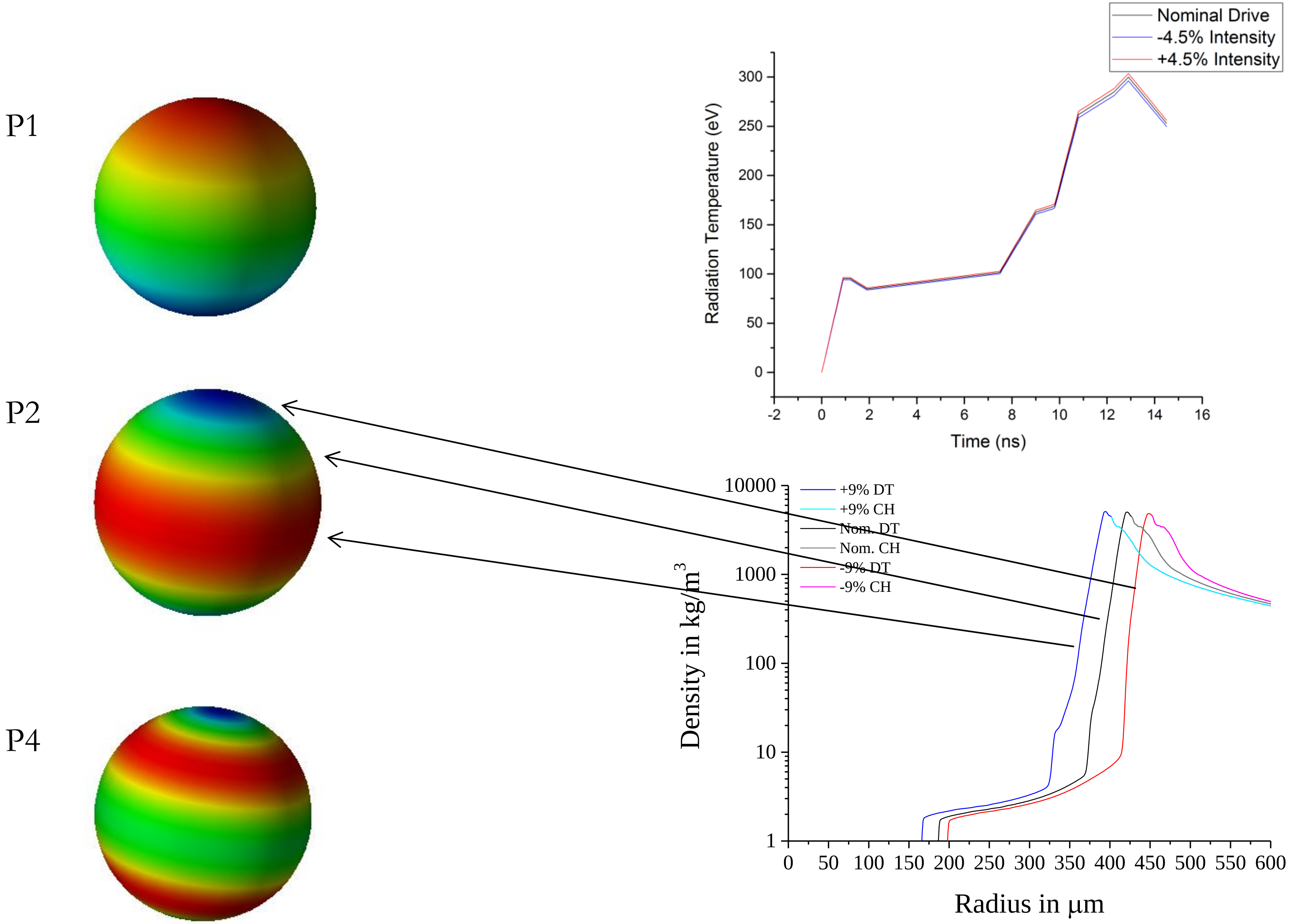








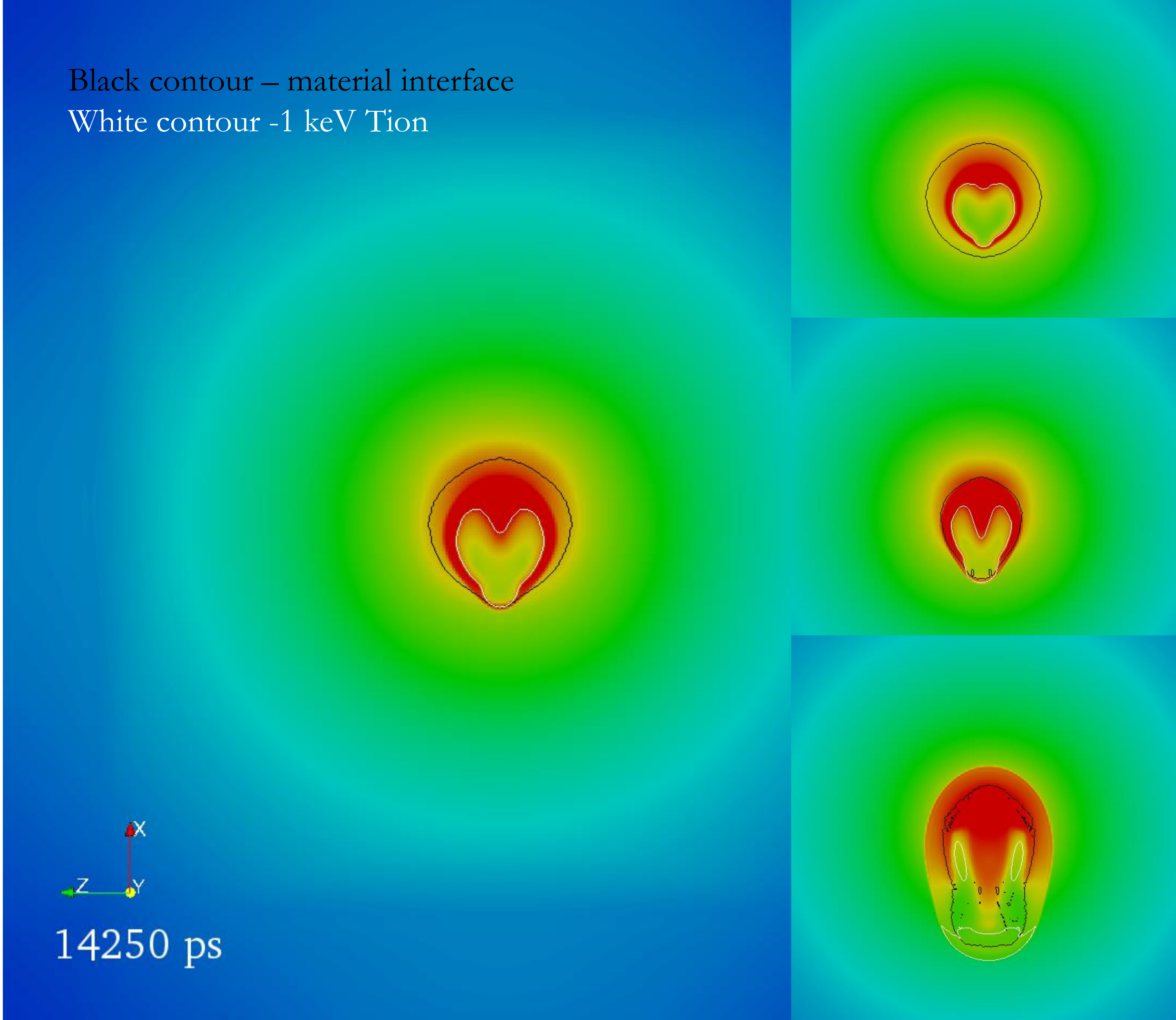
Approximating low mode radiation drive asymmetry in 3D simulations of the deceleration and stagnation phases



For radiative drive asymmetry, 3D structure is constructed from a database of 1D results

1D Chimera simulations with radiation drive multipliers at the start of the ‘coast’ phase

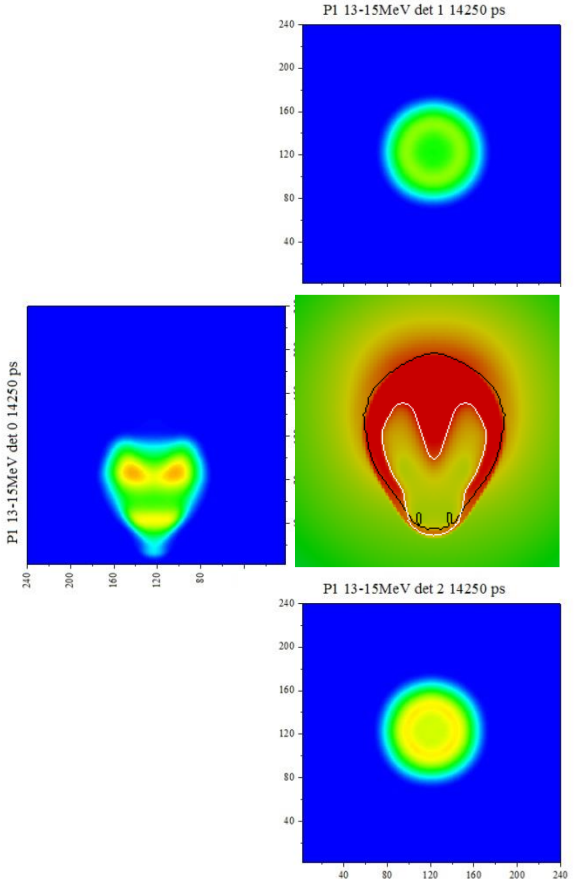
P1

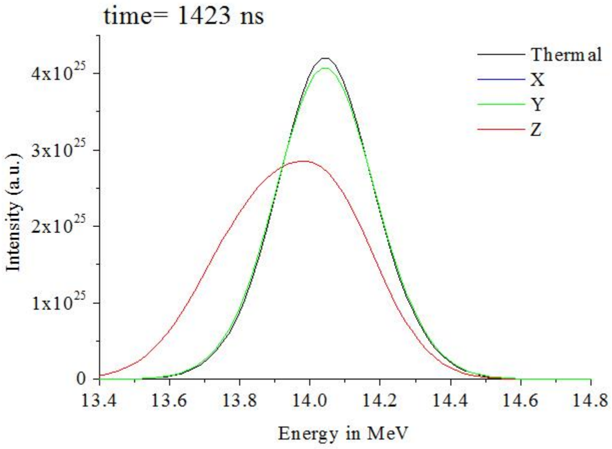


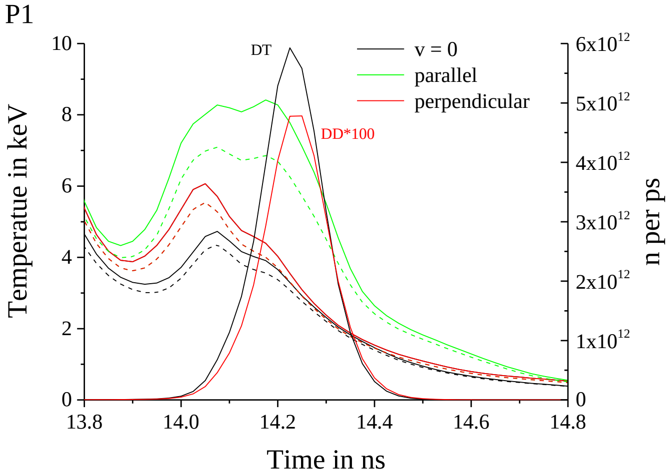
Black contour – material interface

White contour -1 keV Tion

P1 Temperatures inferred from primary neutron spectra







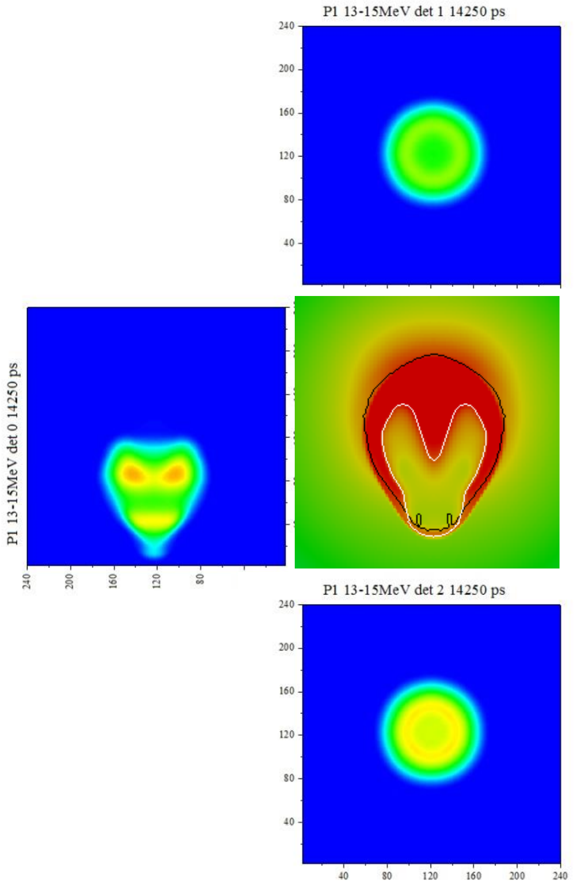
Direction	Ti (DT)
v=0	2.973
+x	3.191
+z	6.731
-z	6.971

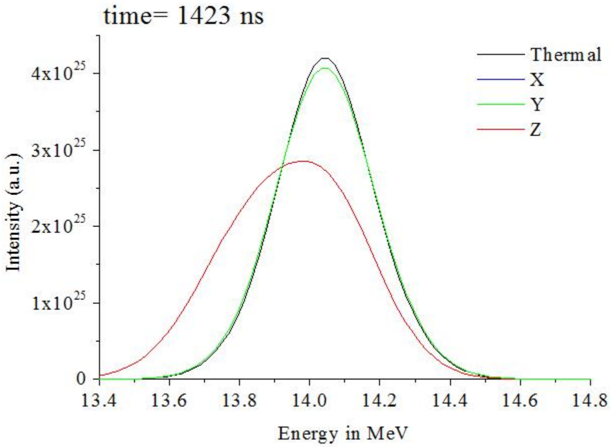
T_{DT} and T_{DD} are anisotropic

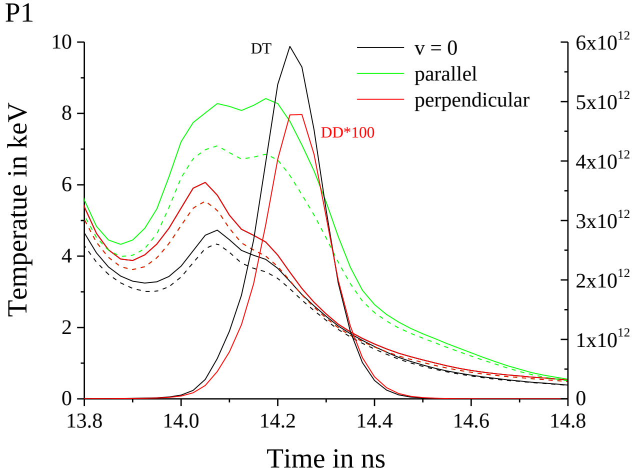
$T_{DT} > T_{DD}$ in parallel direction

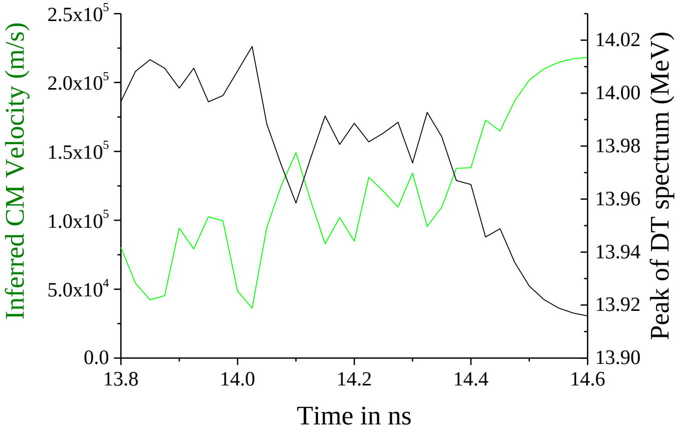
P1

Bulk velocity inferred from primary neutron spectra





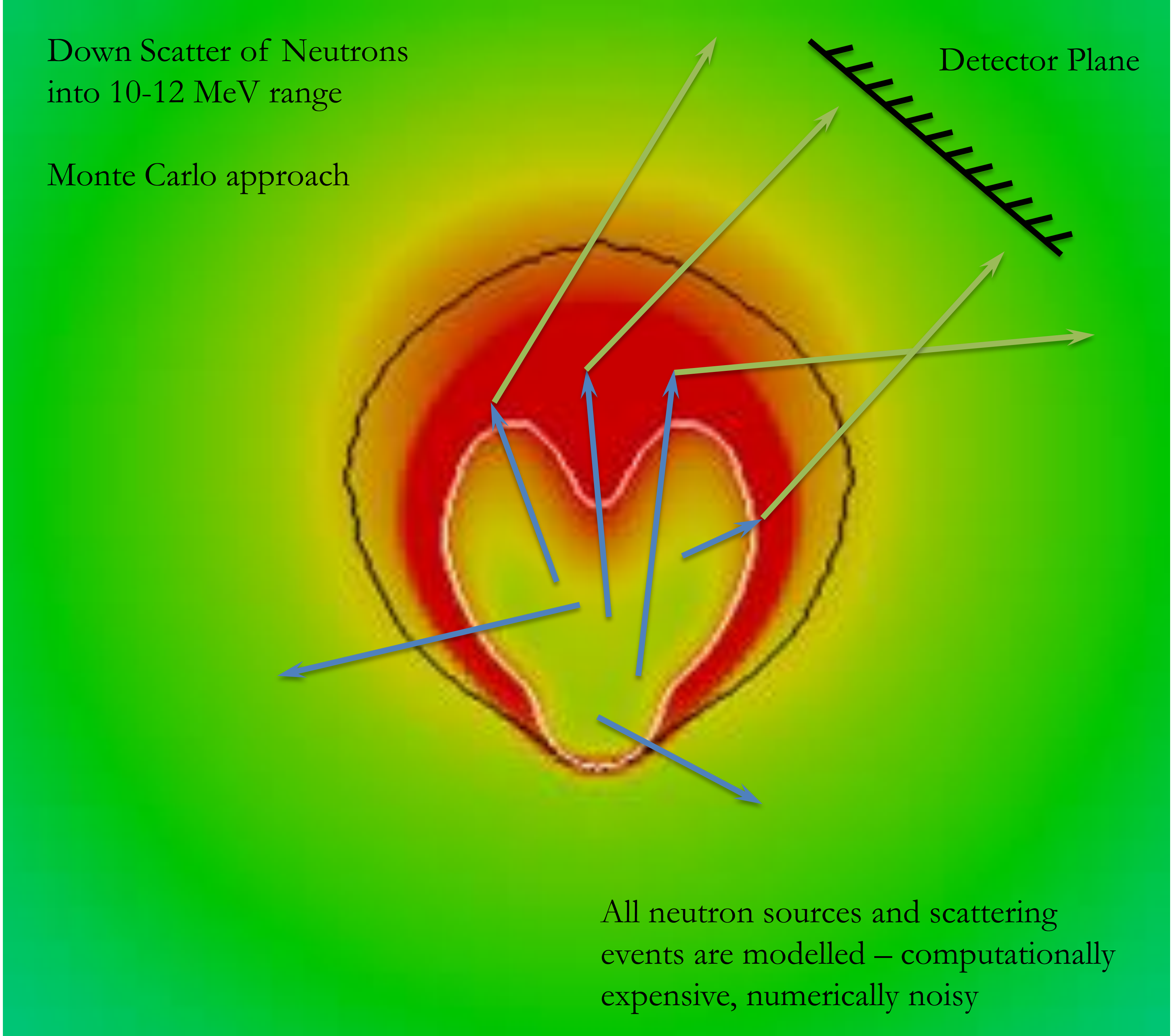




P1

Down Scatter of Neutrons into 10-12 MeV range

Monte Carlo approach

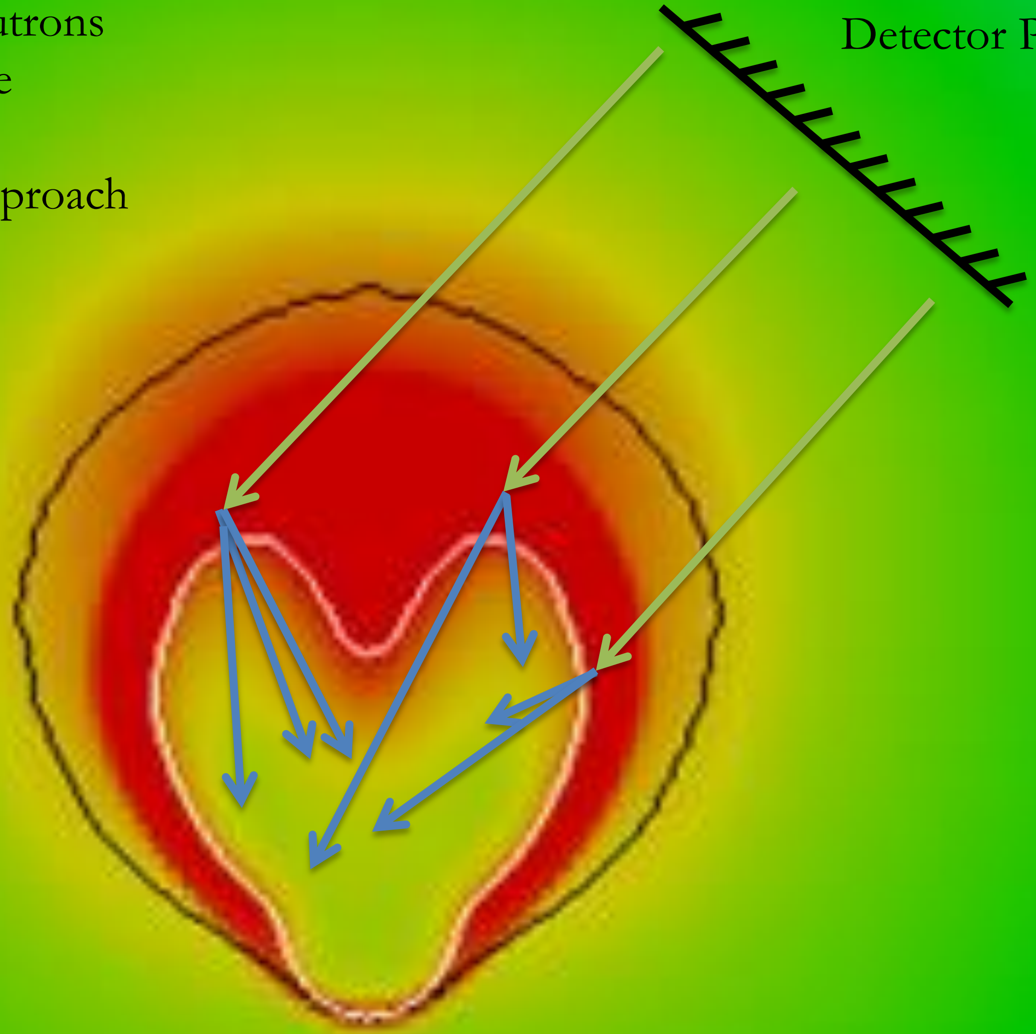


All neutron sources and scattering events are modelled – computationally expensive, numerically noisy

P1

Down Scatter of Neutrons
into 10-12 MeV range

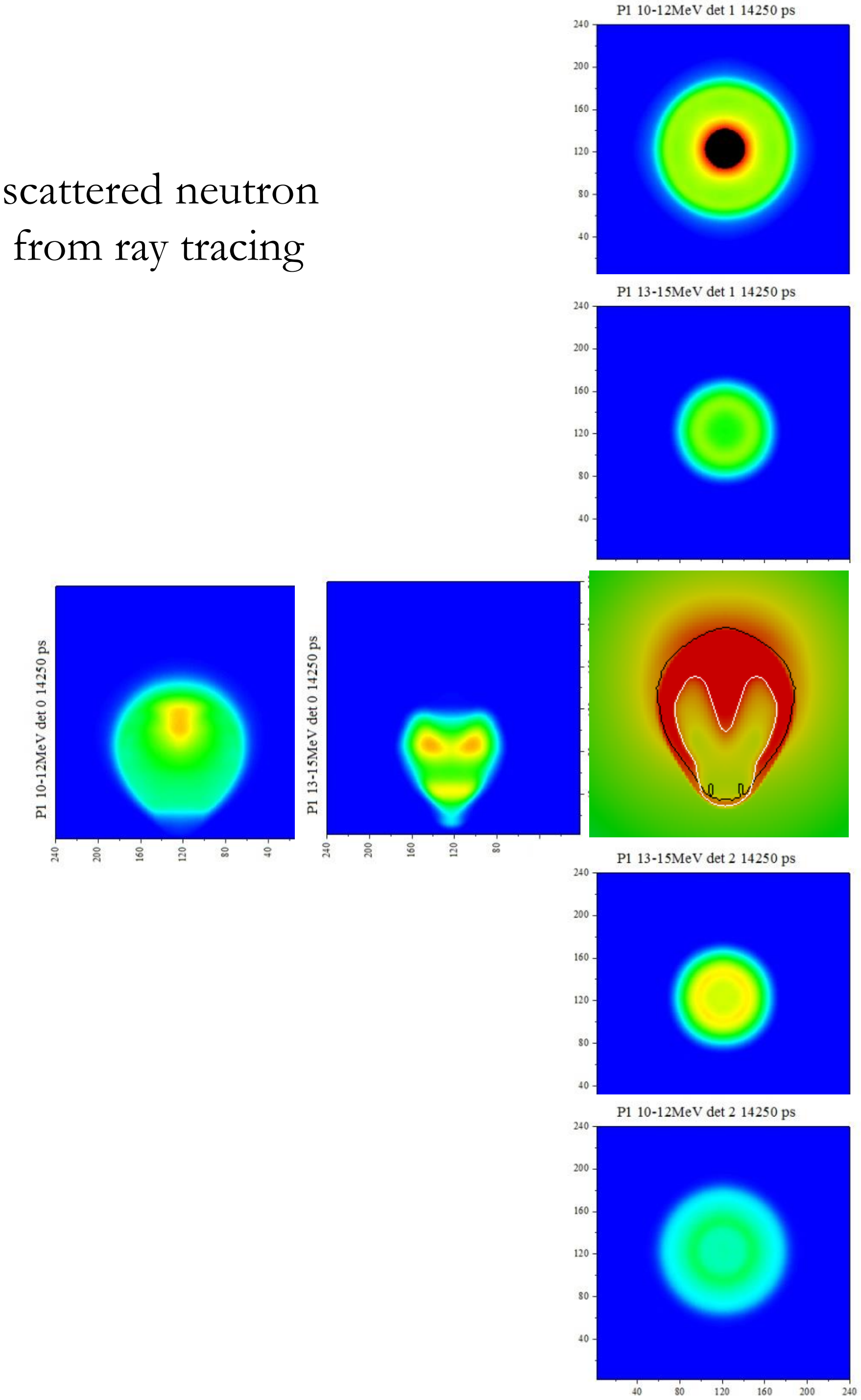
Inverse ray tracing approach

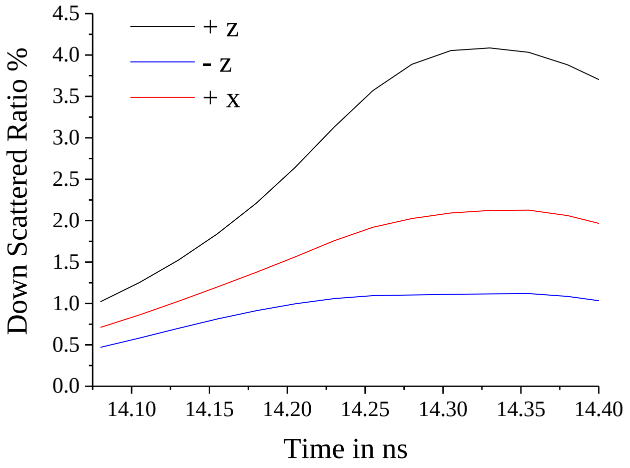


Rays perpendicular to detector plane intersect a number of scattering sites, paired with broad range of possible source sites which emit spectra drawn from database of 10^6 source spectra for different T_{ion}, velocity and angle.

P1

Down scattered neutron images from ray tracing

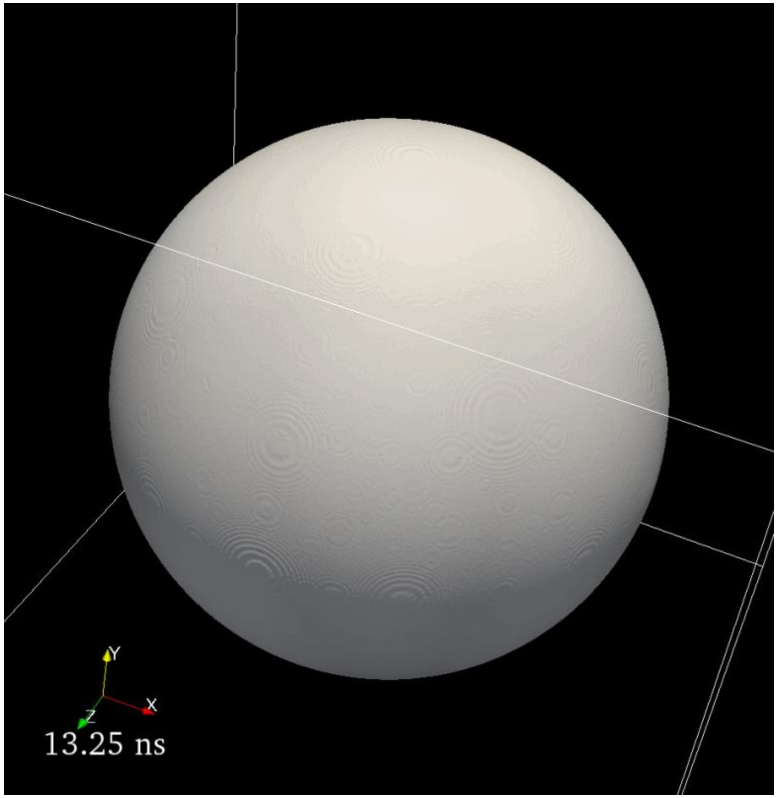


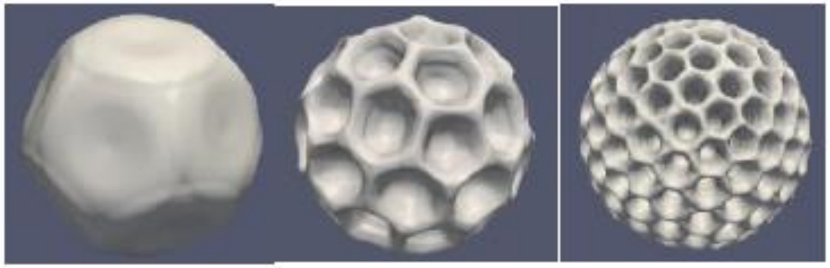


DSR from ray tracing

Multi-mode

Attempt to generate more isotropic velocity variance by inducing quasi-turbulent flow

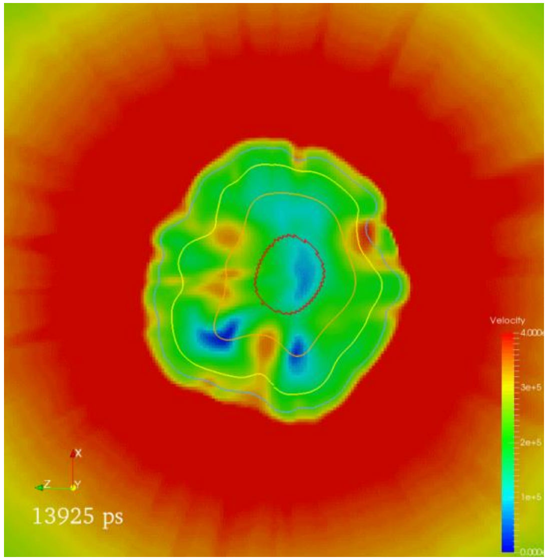


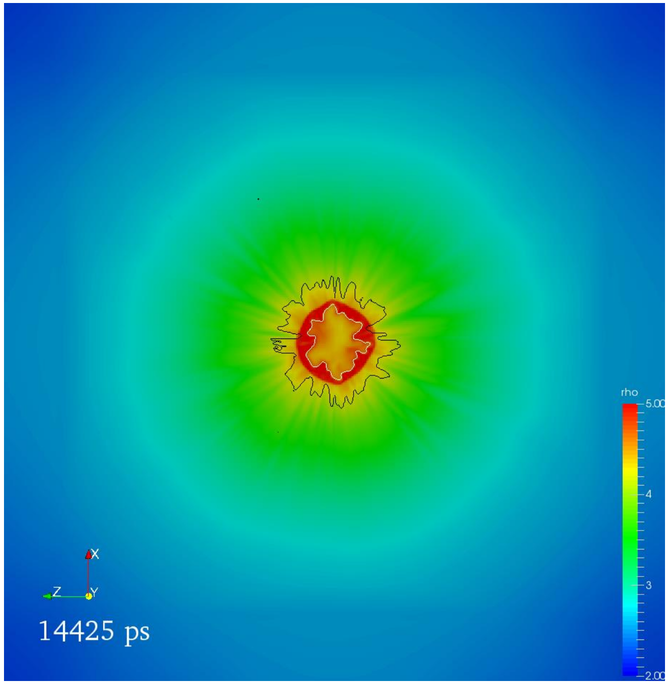


Geodesic N=12, N=42 & N=162
single-mode perturbations
S. Taylor & J. Chittenden Phys. Plasmas **21** (2014)
D. Layzer - Astrophysical J. **122** 1 (1955)

Multi-mode

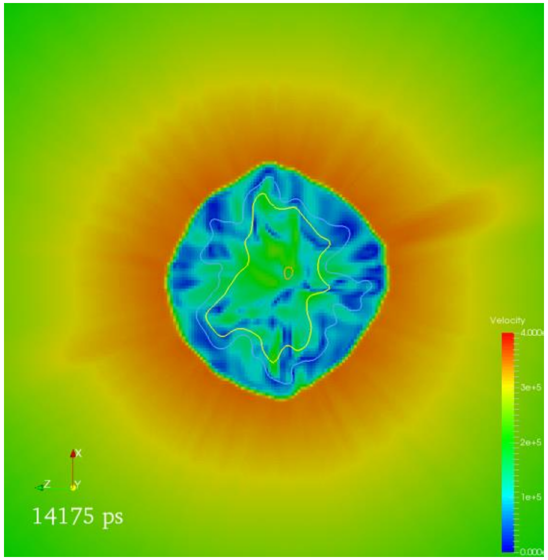
Attempt to generate more isotropic velocity variance by inducing quasi-turbulent flow



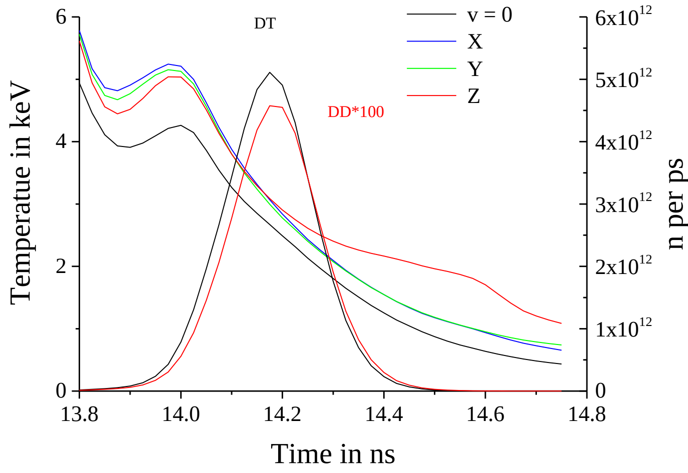


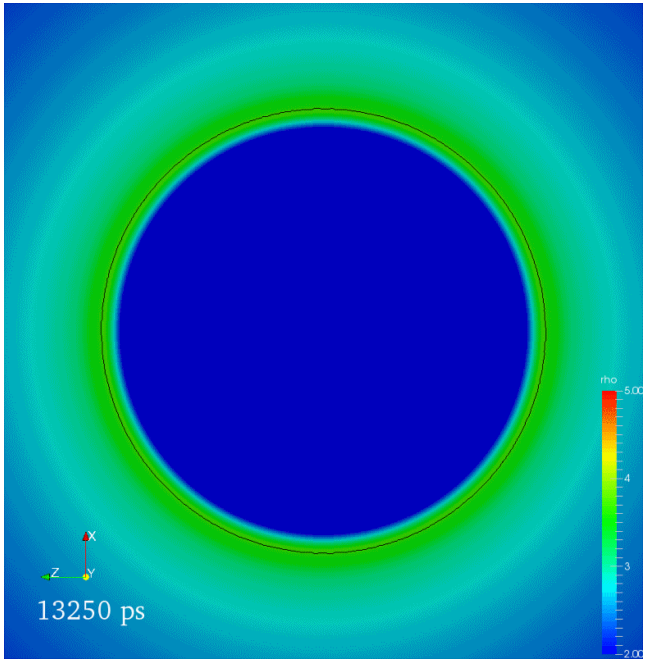
Multi-mode

Attempt to generate more isotropic velocity variance by inducing quasi-turbulent flow

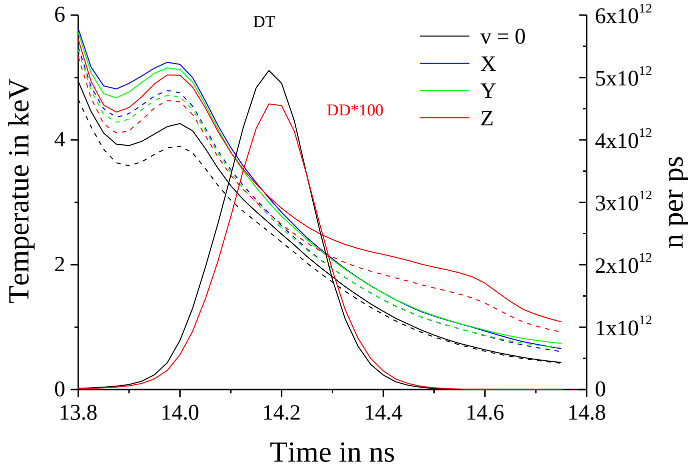


Multi-mode





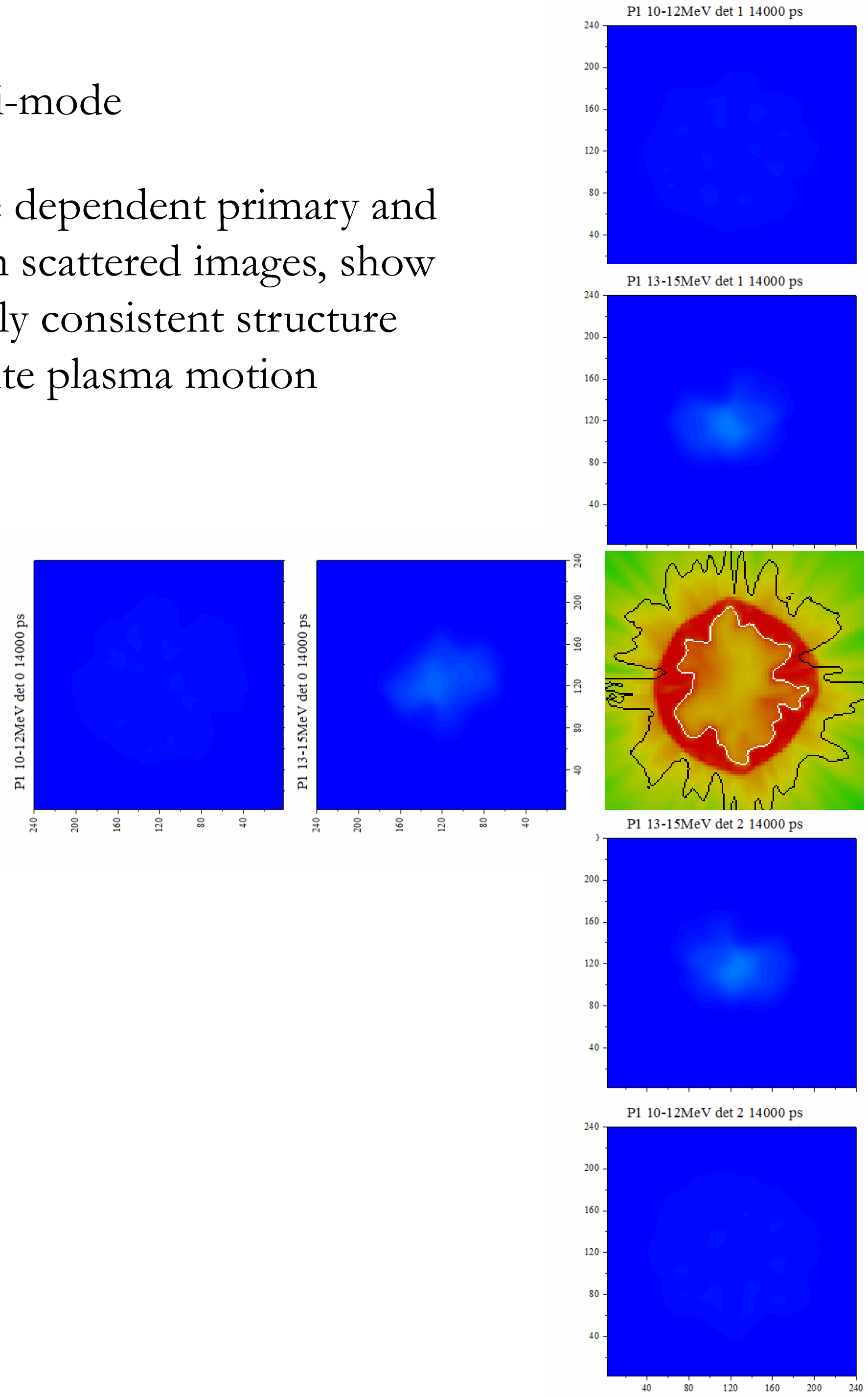
Multi-mode



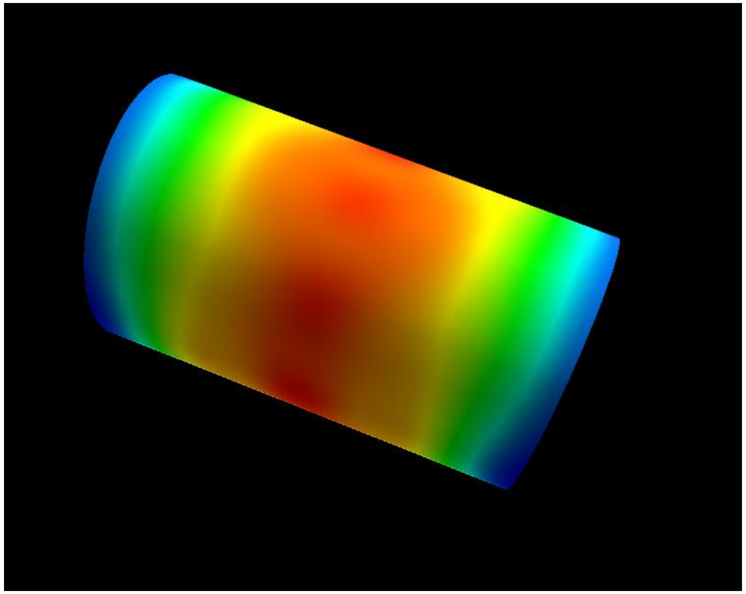
Direction	Ti (DT)	Ti (DD)
X	2.918	2.598
Y	2.865	2.569
Z	3.073	2.701

Multi-mode

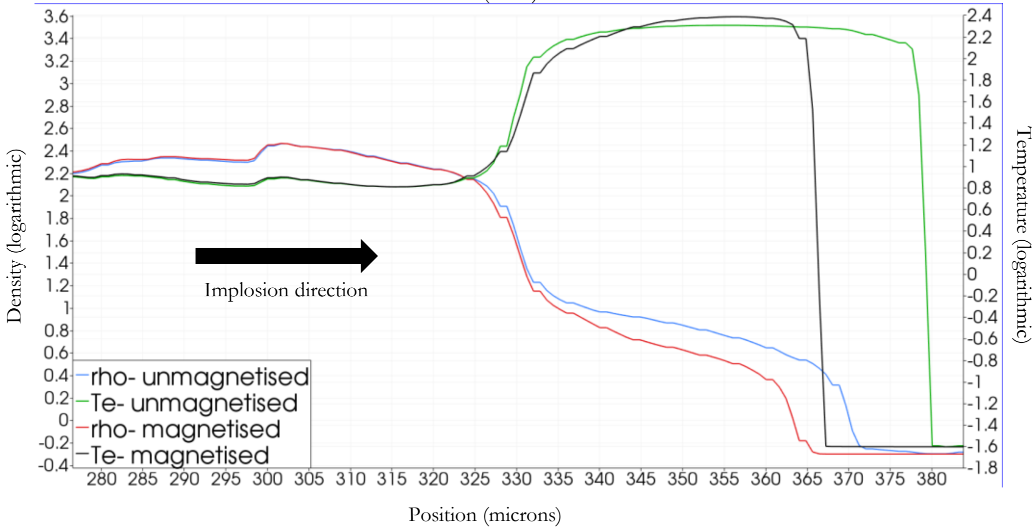
Time dependent primary and down scattered images, show a fairly consistent structure despite plasma motion

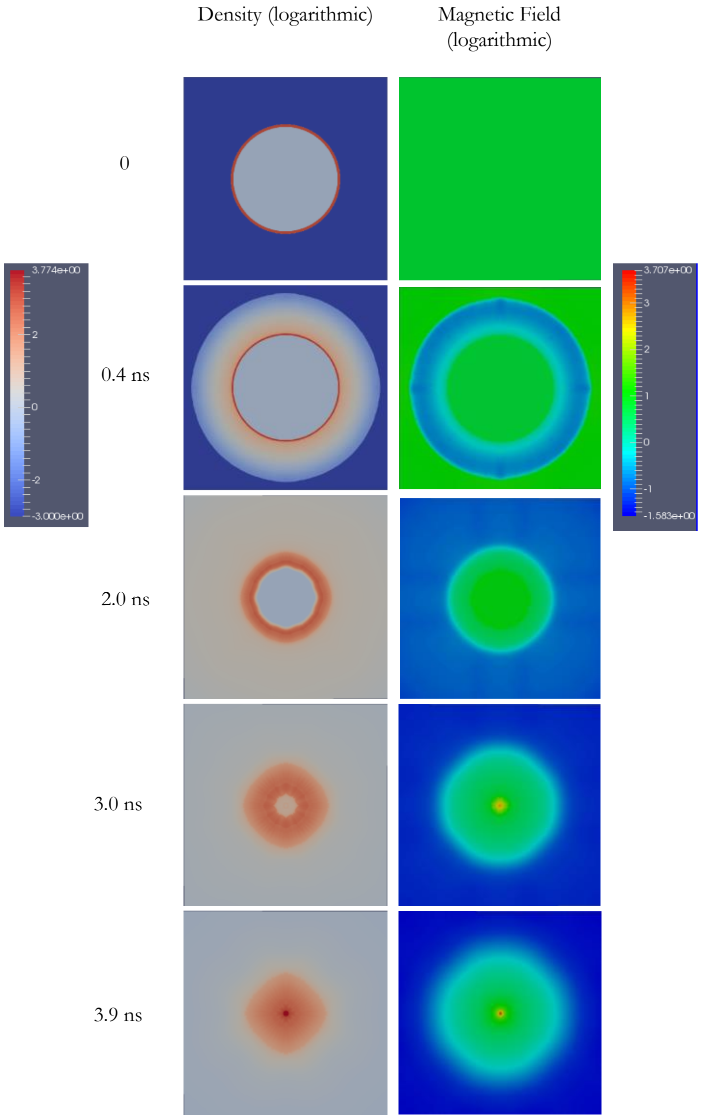


Direct drive magnetised cylinder on Omega (J. Knauer et. al.)



Deceleration Phase (2.2ns)





High Energy Density Physics modelling at Imperial College.

J.P. Chittenden, B.D. Appelbe, N.P.L. Niasse, J. Pecover, K. McGlinchey,
C. Walsh, D. Botero-Garcia, J. Tong, A. Seaton, F. Manke

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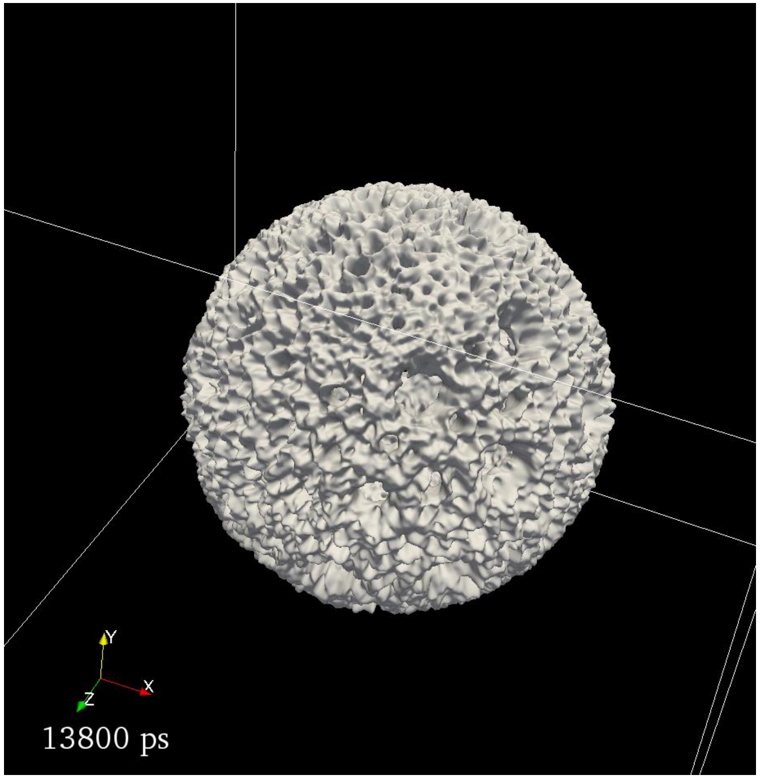

Warwick - November 2015