Implosion and Ignition Physics

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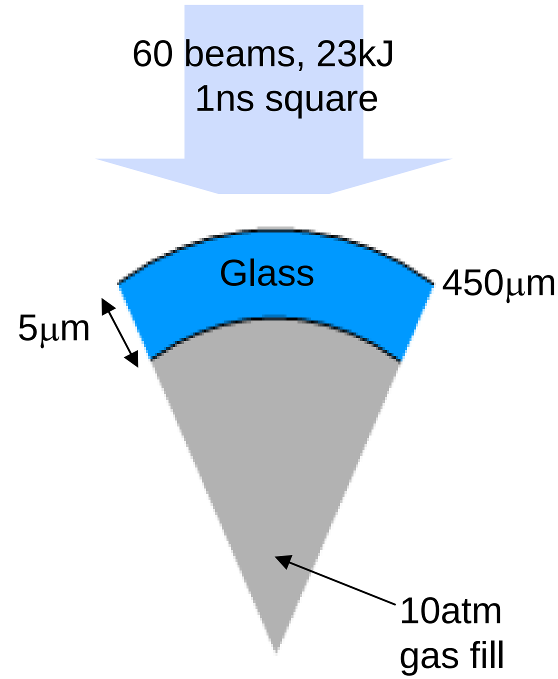
Introduction

- For the last decade AWE has maintained a small effort on ICF implosions and ignition as part of a broader plasma physics programme
- The imminent prospect of ignition at the US National Ignition Facility (NIF) has stimulated increased interest at AWE in a formal UK approach to ICF & IFE
- An understanding of, and the ability to model, ICF implosions and ignition is a core capability for a fusion programme
- In addition NIF will offer exciting opportunities to study ignition physics and access new experimental regimes
- A broad range of fundamental plasma physics and nuclear physics experiments may be possible
- This talk presents an overview of some of the implosion research undertaken by AWE

High-Z doped capsule experiments

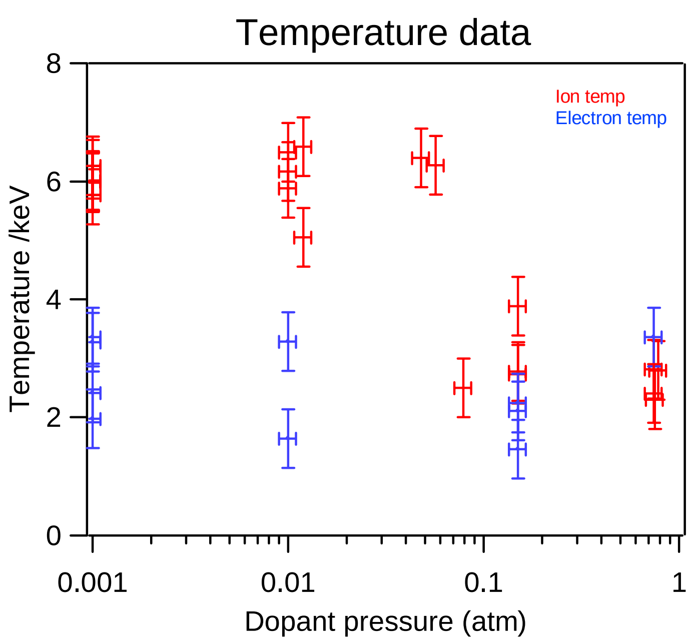
- Collaborative experiments performed with LANL at the Omega laser
- Thin-shell glass capsules fielded in direct drive with variety of gas fills
- Experiments intended to guide modelling of fuel dopants ahead of future applications on NIF.
  - use as spectroscopic diagnostic of fuel conditions,
  - study of hydrodynamic mix
  - study NLTE physics.
- Experiments also intended to develop in-house expertise in direct drive implosions

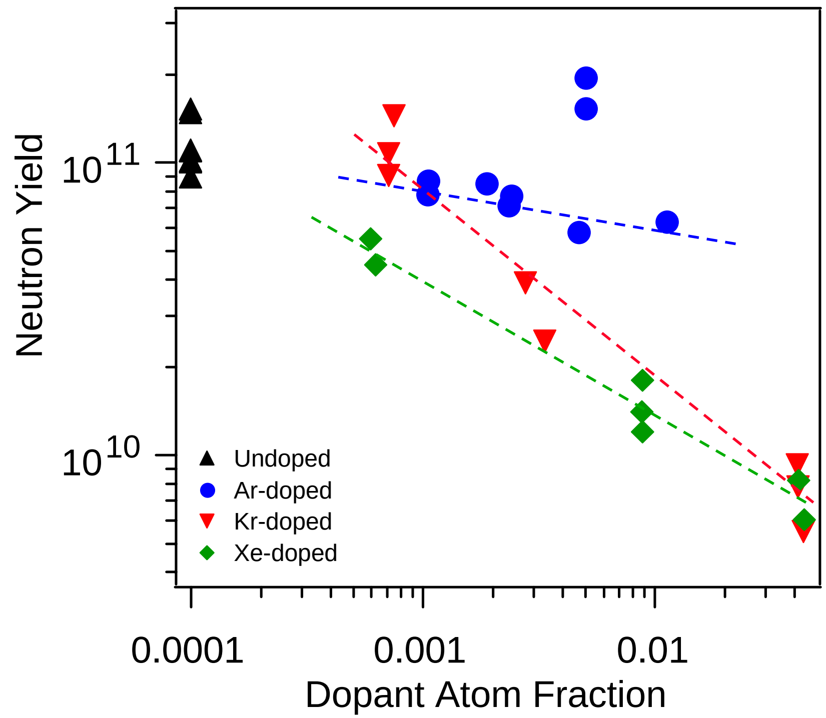


High-Z experiment results

- A large database of doped capsule data now exists at a range of concentrations and dopant Z.

- Even small amount of high-Z dopant produces significant degradation.

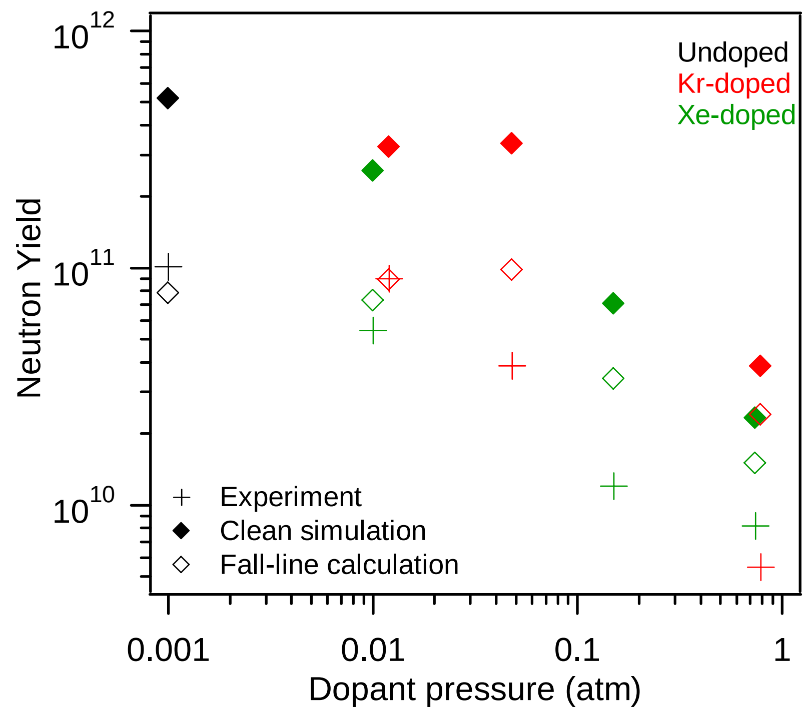




- Experimentally determined ion and electron temperatures show transition to equilibrium as Kr dopant is increased

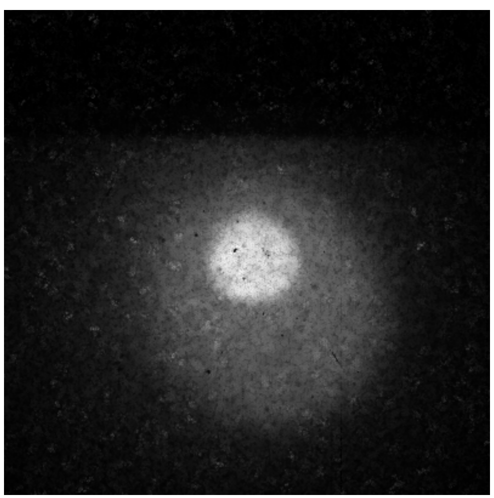
Comparison to simulations

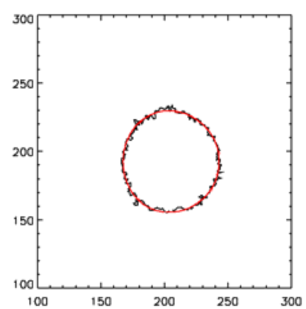
- Experiments have been simulated using Nym rad-hydrocode.
- Neutron YoC ranges over 10-35%, consistent with that achieved in other high convergence implosions
- Fall-line calculations provide a worst-case estimate of mix degradation
- At high dopant levels performance cannot be accounted for by hydrodynamic mix or experimental uncertainty
- Suggestive of errors in dopant modelling

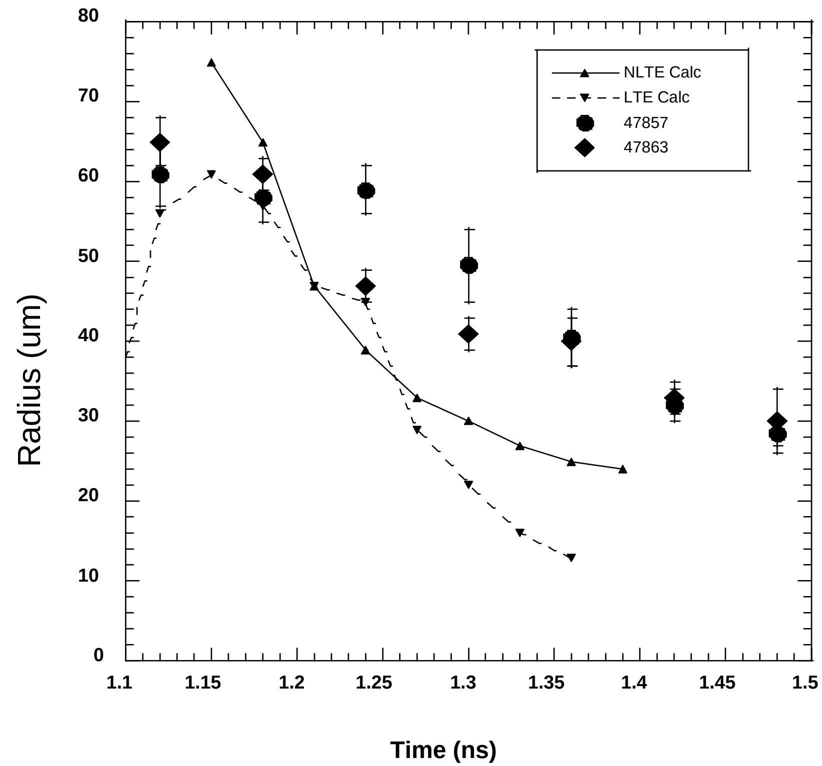


Capsule modelling

- A large range of diagnostics is being used to constrain capsule modelling
- There is some evidence that capsule compression is over-predicted by simulation:
  - Proton downshift
  - Self-emission images
  - DT/DD neutron ratio



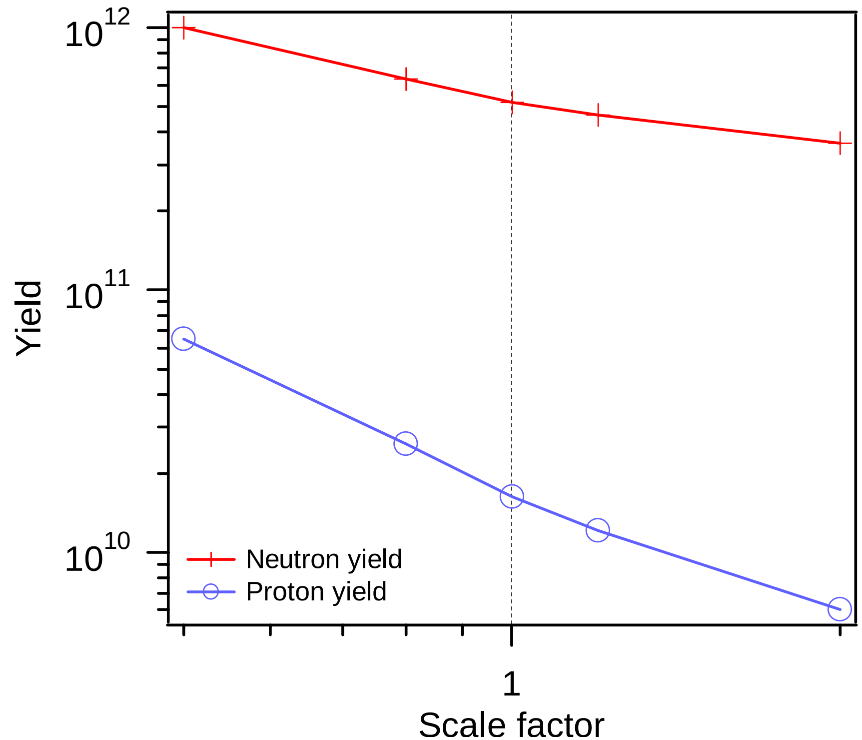




From Wilson et al., J. Phys. Conf. Series 112 022015 2007.

High-Z capsules offer a platform to study fundamental plasma physics

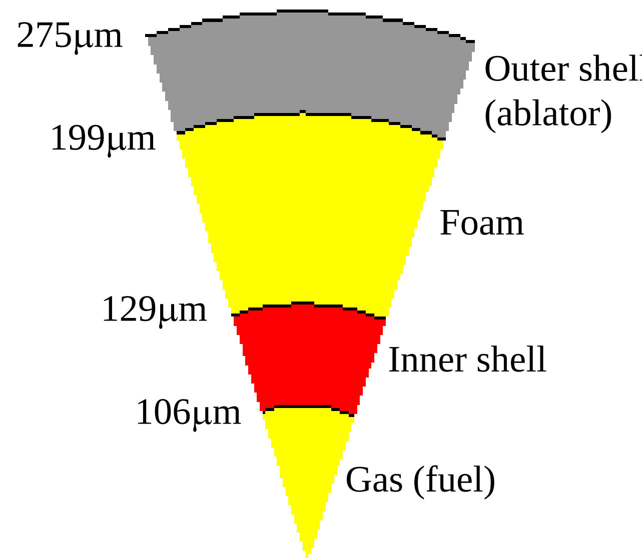
- As example have assessed capsule sensitivity to electron-ion coupling[1]
- Recent theory[2] suggests exchange rate could be in error by a factor 2 in ICF capsules
- Neutron and proton yields show different sensitivities; measuring both uniquely determines model
- Currently at Omega experimental uncertainties exceed model sensitivity
- Potential for improvement at NIF

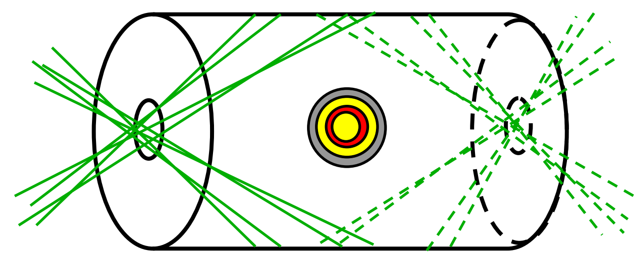


1. W J Garbett et al., J Phys Conf Series 112 022016 (2007)
2. M. Dharma-wardana Phys Rev E 64, 035401 (2001).

Double shell capsule experiments

- AWE were involved in early work on double shell capsules with LANL at Omega[3]
- Double shells provide an alternative non-cryogenic route to ignition that avoids many complexities of the single-shell approach
- Much of our effort was aimed at explaining the varied performance of different double shell targets
- Improved understanding has allowed development of designs which control and mitigate mix
- LLNL now have credible ignition designs[4]

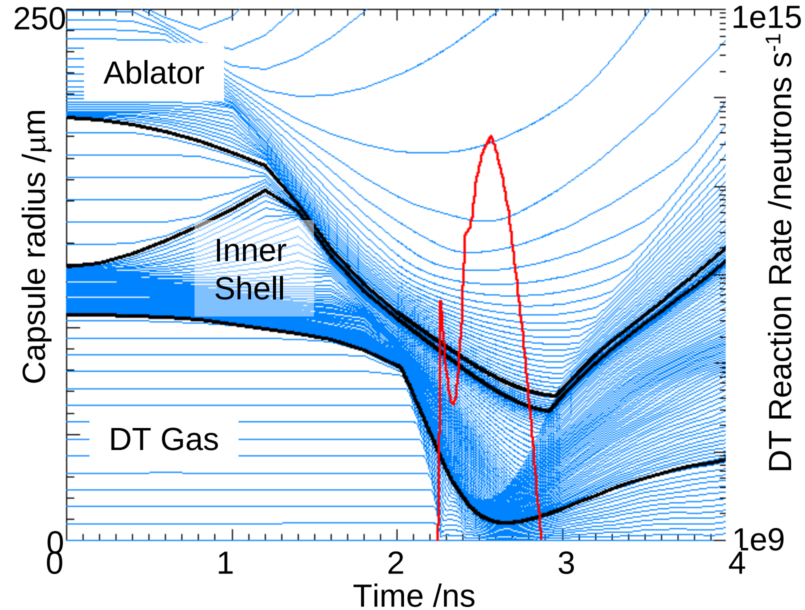




3. W S Varnum et al, PRL 84, 22 (2000)
4. P Amendt et al PRL 94 (2005)

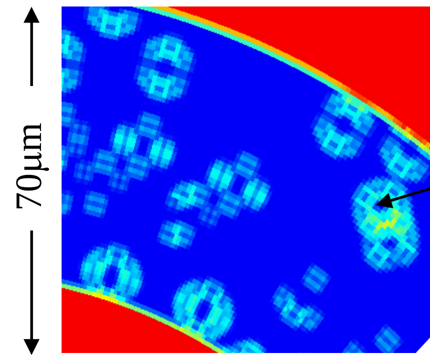
Double shell capsule modelling

- Simulations provide an understanding of double shell dynamics
- The main design challenge is to control the effects of mixing between the high-Z inner shell and the DT fuel.
- Detailed modelling was undertaken using the 2D Eulerian code Petra, to study the impact of different perturbations
- Multimode perturbations using modes up to 100 showed increased mix degradation compared to 1D models



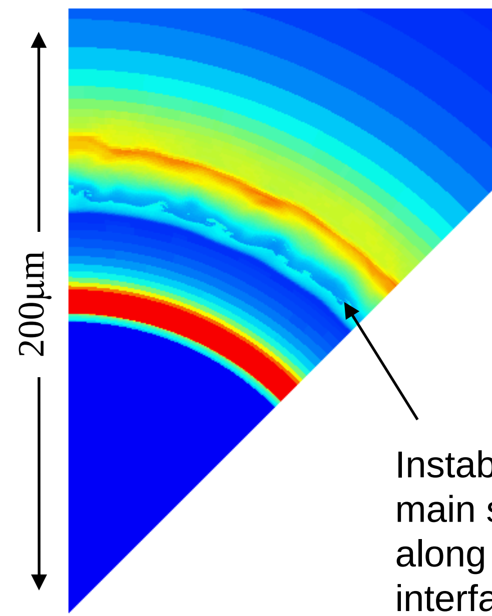
Double shell capsule modelling (2)

- Various degradation mechanisms were explored through detailed 2D modelling
- Perturbations due to foam pore structure were expected to seed mix at the outer surface of the inner shell
- This was calculated to have a significant effect on capsule performance
- Effect on yield was later confirmed experimentally using two different types of foam



t=0.3ns

Expansion of high density foam regions during preheat phase.

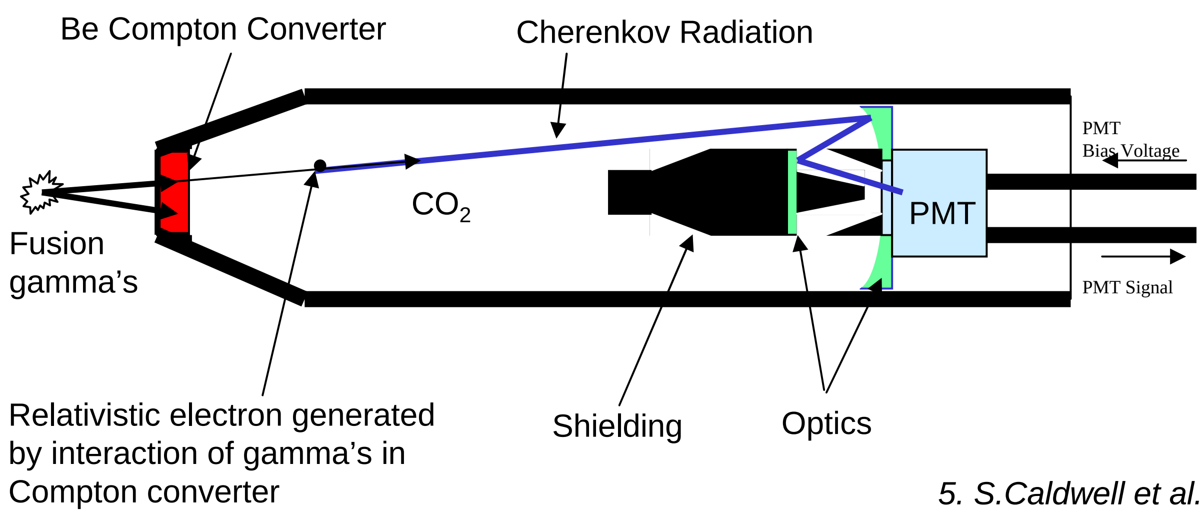


t=1.5ns

Instability occurs along main shock front, not along material interfaces as before.

Fusion diagnostic development

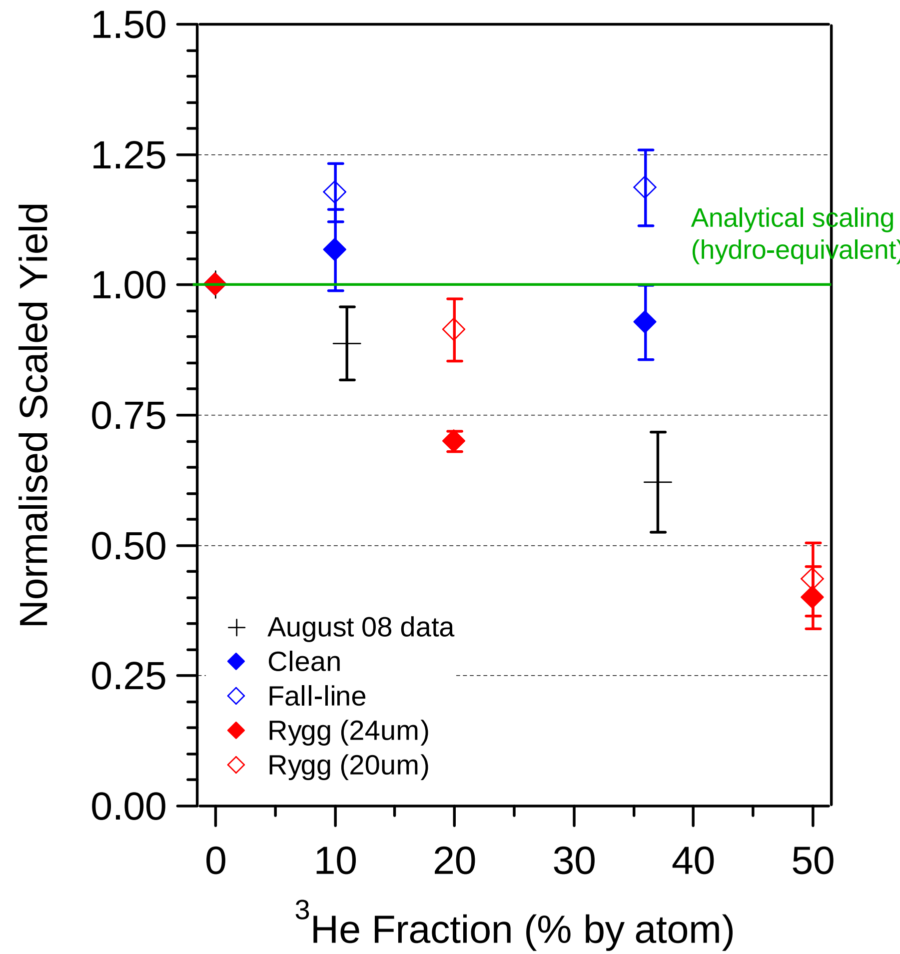
- AWE has been collaborating with LANL on the development of gamma bang time and reaction history diagnostics for Omega and NIF
- The GCD and GRH both work by detecting 16.7MeV gamma rays from an alternative DT fusion reaction.
- AWE is also involved in developing the NIF neutron time-of-flight (nToF) diagnostics, which will provide ion temperature measurements for the ignition campaign.



5. S.Caldwell et al., Rev. Sci. Instrum. 74, 3 (2003).

GCD application

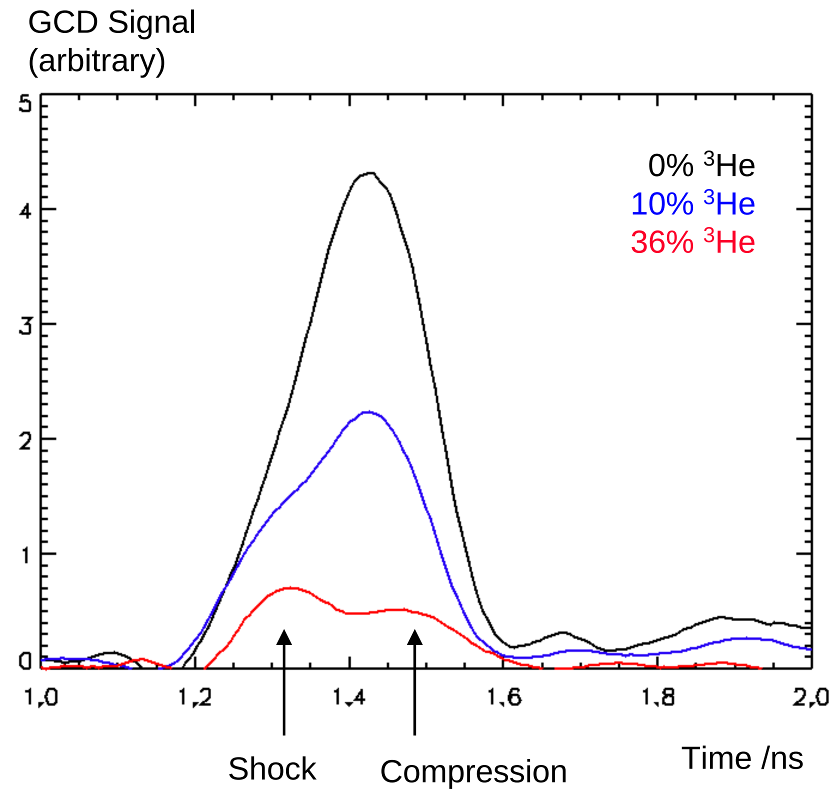
- Application of the GCD has been demonstrated in recent experiments at Omega
- We have used the GCD to explore the anomalous behaviour of ^{3}He, reported in experiments by MIT[6]
- Our experiments reproduce the anomalous yield behaviour
- GCD measurements will complement other data to help constrain capsule modelling



6. J.R.Rygg et al. Phys Plasmas 13, (2006).

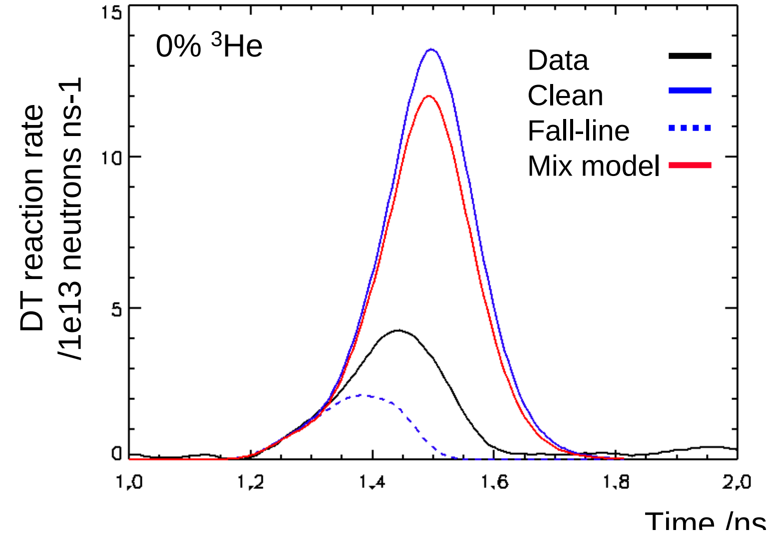
GCD burn history data

- The GCD provides low noise, time resolved measurements of the fuel burn. (~75ps resolution after deconvolution)
- Two yield phases are apparent in all curves; identified as shock and compression burn
- Signal evolves as ^{3}He fraction is increased; compression phase clearly reduced.
- Excellent shot-to-shot reproducibility gives confidence that observed features are real.

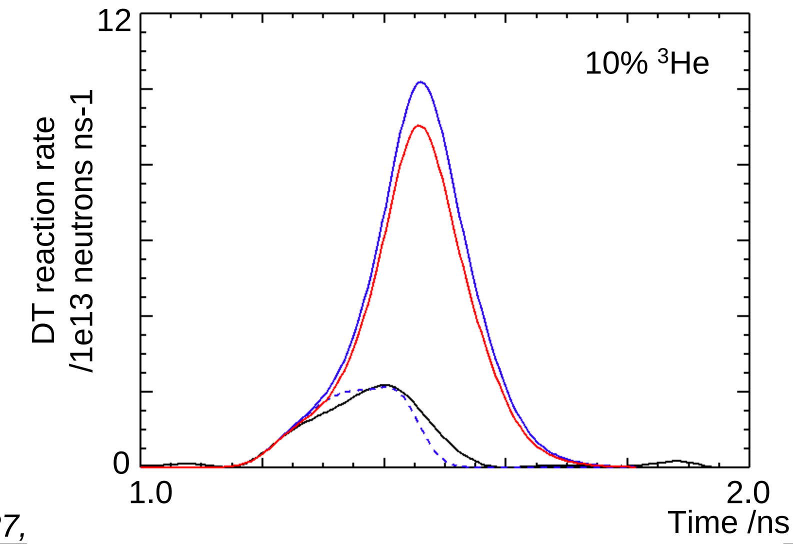


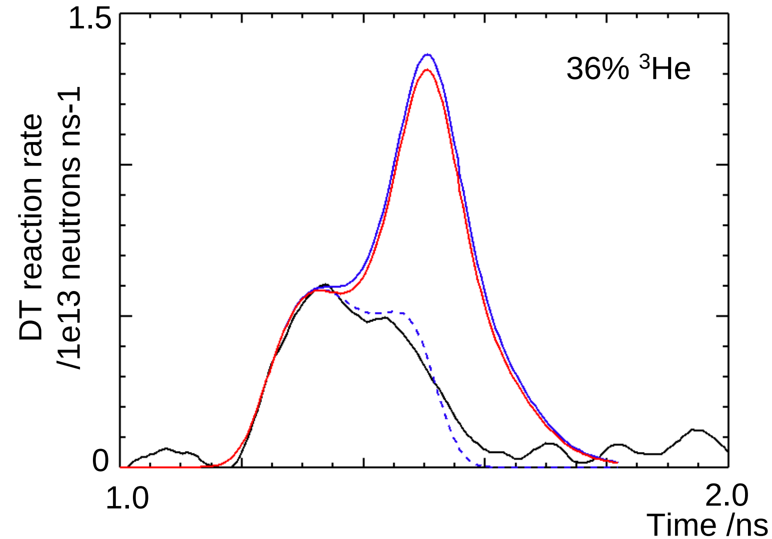
GCD burn history data

- Clean simulations match initial shock phase, but overestimate compression phase.
- Youngs' mix model[7] predicts little yield degradation
- Fall-line calculation does surprisingly well for simple model, particularly at 36% ^{3}He.



(Simulated reaction rate convolved with 75ps Gaussian to match measured GCD response)





7. D.L.Youngs, Physica D 37,

Ignition Opportunities

- NIF will offer exciting opportunities to study ignition physics and access new experimental regimes

- AWE has begun to explore potential applications of the ignition platform:

  - Physics of ignition
    - Study alpha physics / fundamental plasma physics models

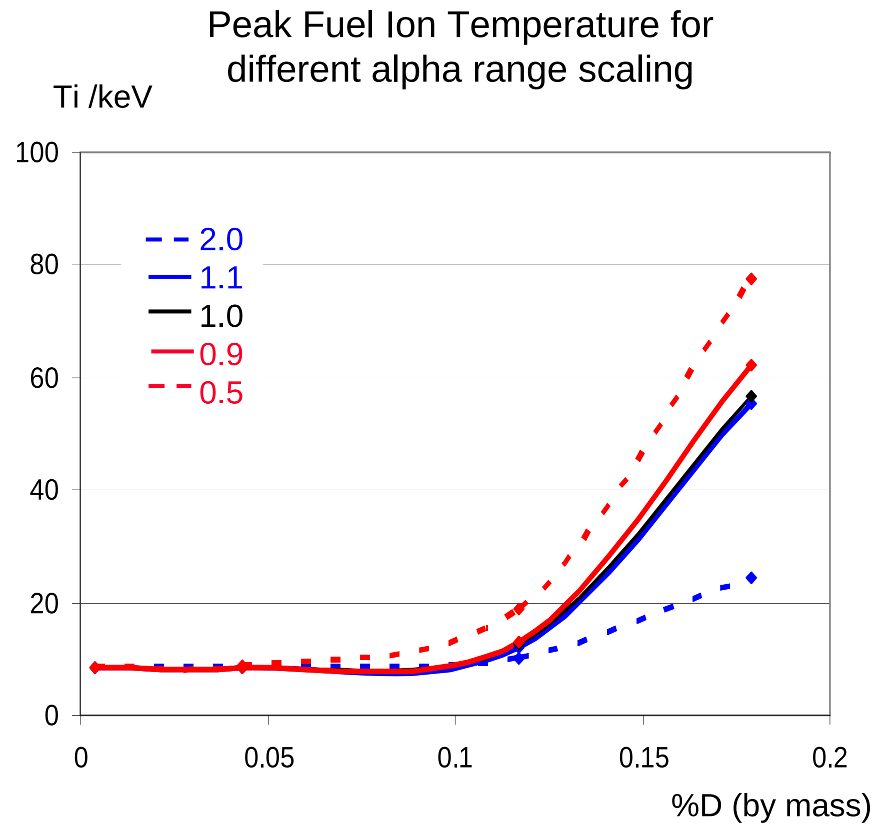
  - Improved ICF designs
    - Fast ignition, shock ignition, double shells etc

  - Nuclear physics
    - Cross-section measurements, exotic processes

  - NLTE physics

THD experiments

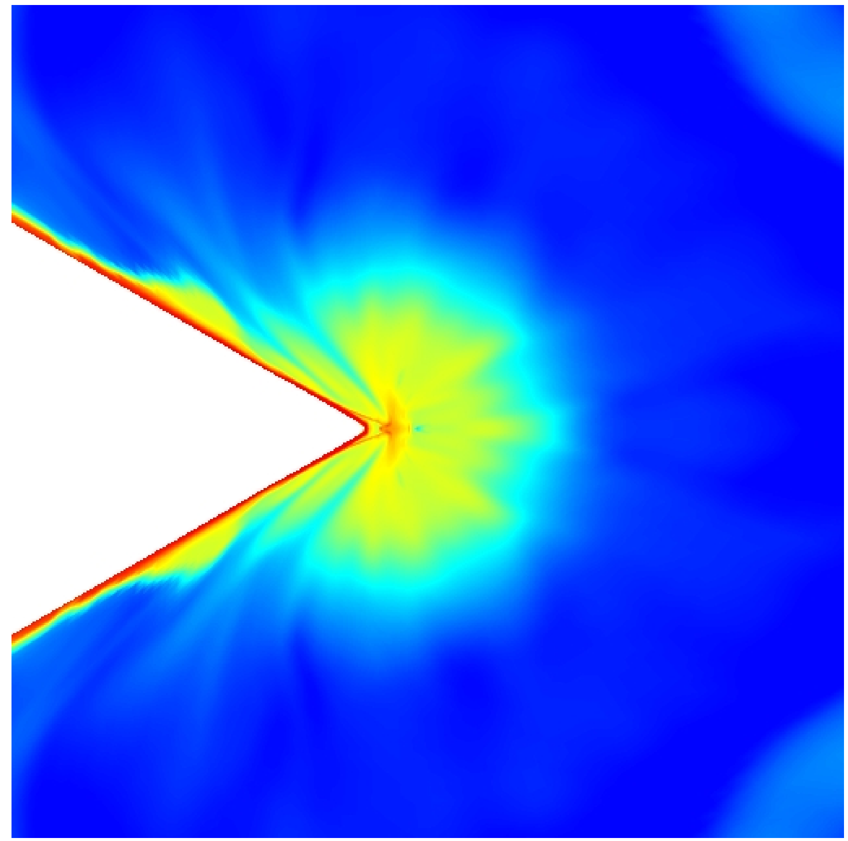
- NIC THD experiments may help constrain alpha physics models
- Recent calculations[8] suggests alpha range could be around 30% larger than Spitzer theory
- This can significantly impact self-heating; effect most obvious in marginal fuels
- THD experiments provide more comprehensive diagnostics which help confirm origin of effect.



8. Singleton, Phys. Plasmas 15, 056302 (2008)

Orion opportunities

- Orion also offers opportunities for studying ICF physics
- The combination of short and long pulse beams is ideal for studying the physics of fast ignition
- Orion will be of similar size to the Gekko XII laser, used for the integrated fast ignition experiments of Kodama *et al.*
- Will allow exploration of beam coupling to compressed matter



Summary

- AWE is looking to develop a more formal approach to ICF and IFE
- AWE has a demonstrated capability in modelling ICF implosions, which is a core capability for a fusion programme
- AWE is gaining experience in operating at NIF and is involved in several aspects of the ignition effort
- NIF and Orion will offer opportunities to study ignition physics and access new experimental regimes