Status of Fusion Research on the NIF

Presented to Fusion Power Associates

Washington, DC

M. John Edwards

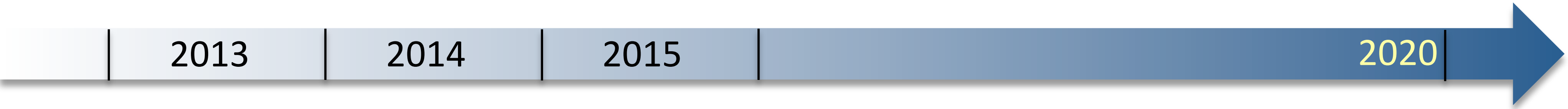
Director ICF Program

December 16th, 2015

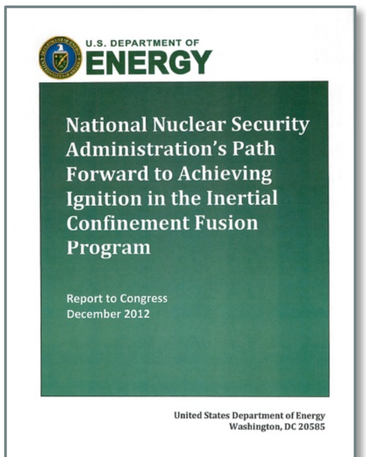
LLNL-PRES-680286

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory


2013
2014
2015
2020

Post NIC
“Path Forward”


U.S. DEPARTMENT OF ENERGY

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Report to Congress
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3 yr “Path Forward” program

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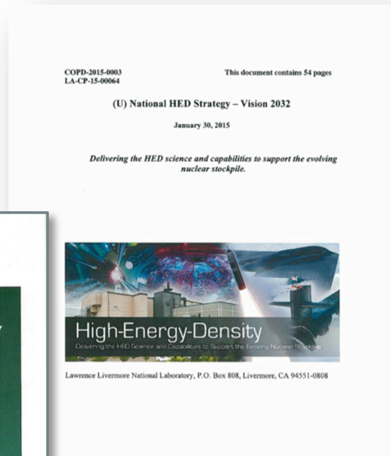
Understand NIC, less stressing implosions
Further develop direct drive
and magnetic drive

HED Vision 2032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January 30, 2015

Delivering the HED science and capabilities to support the evolving nuclear stockpile.

Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551-0808

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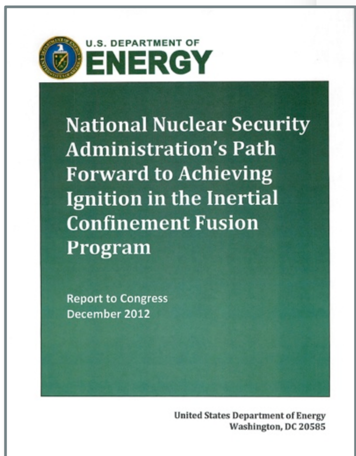
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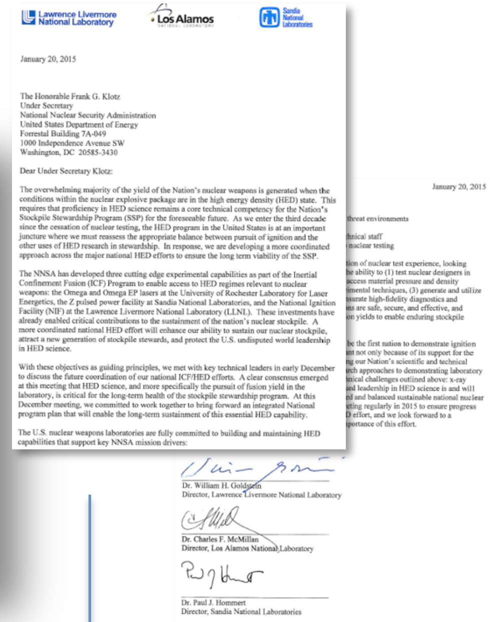
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January 20, 2015

The Honorable Frank G. Klotz
Under Secretary
National Nuclear Security Administration
United States Department of Energy
Forrestal Building 7A-049
1000 Independence Avenue SW
Washington, DC 20585-3430

Dear Under Secretary Klotz:

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Dr. Charles F. McMillan
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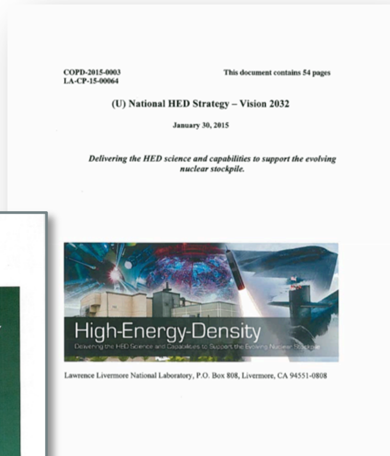
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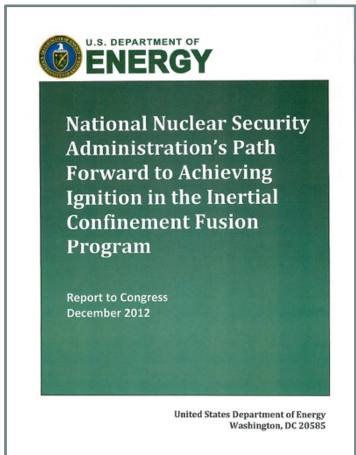
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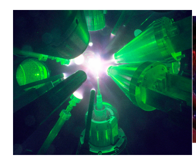
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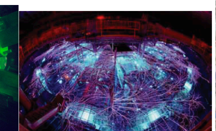
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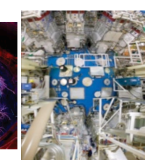
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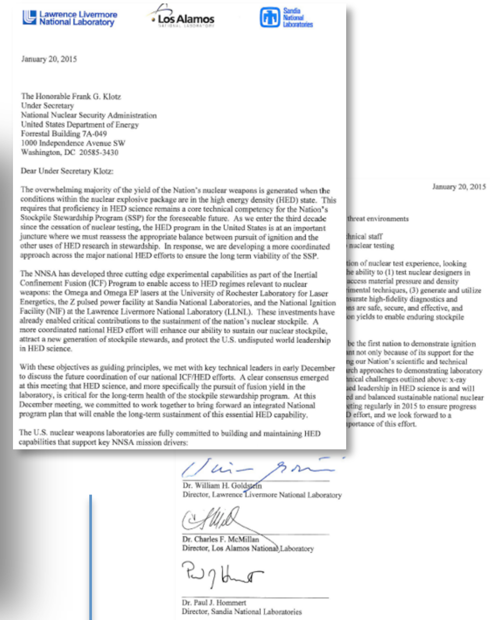

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The NNSA has developed three cutting edge experimental capabilities as part of the Inertial Confinement Fusion (ICF) Program to enable access to HED regimes relevant to nuclear weapons: the Omega and Omega EP lasers at the University of Rochester Laboratory for Laser Energetics, the Z pulsed power facility at Sandia National Laboratories, and the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL). These investments have already enabled critical contributions to the sustainment of the nation's nuclear stockpile. A more coordinated national HED effort will enhance our ability to sustain our nuclear stockpile, attract a new generation of stockpile stewards, and protect the U.S. undisputed world leadership in HED science.

With these objectives as guiding principles, we met with key technical leaders in early December to discuss the future coordination of our national ICF/HED efforts. A clear consensus emerged at this meeting that HED science, and more specifically the pursuit of fusion yield in the laboratory, is critical for the long-term health of the stockpile stewardship program. At this December meeting, we committed to work together to bring forward an integrated National program plan that will enable the long-term sustainment of this essential HED capability.

The U.S. nuclear weapons laboratories are fully committed to building and maintaining HED capabilities that support key NNSA mission drivers:

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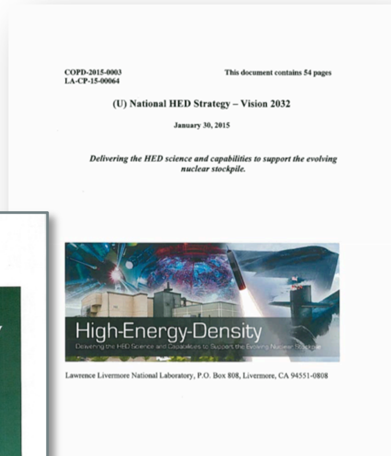

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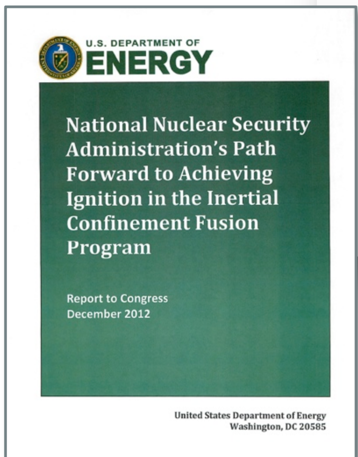

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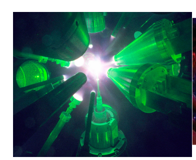
FY15 Review



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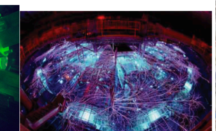

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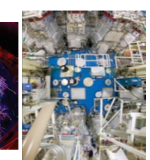

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"Determine the efficacy of NIF for ignition and credible physics-scaling to multi-megajoule yields for all ICF approaches"

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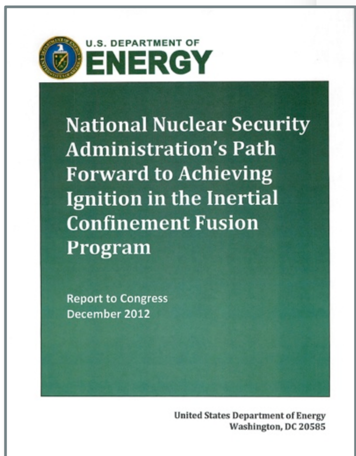

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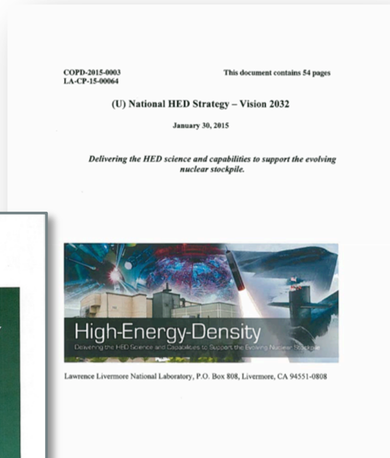

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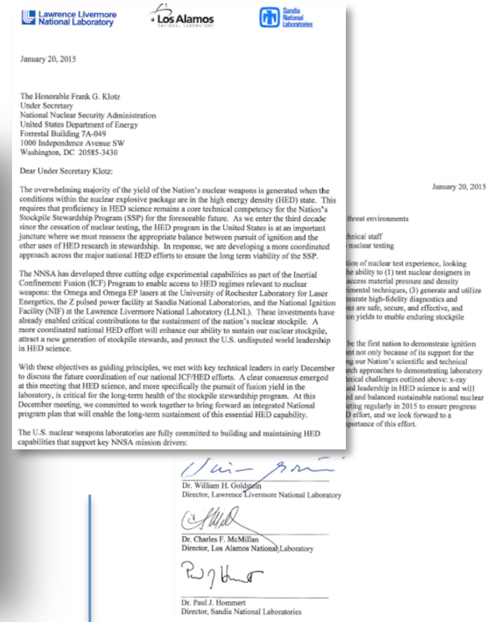

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5 yr National ICF Roadmap

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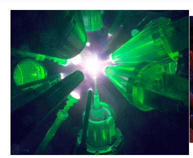
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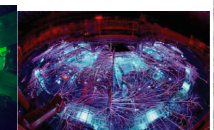
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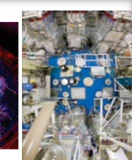
NIF

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Understand NIC, less stressing implosions
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Summary of X-ray drive ignition on the NIF

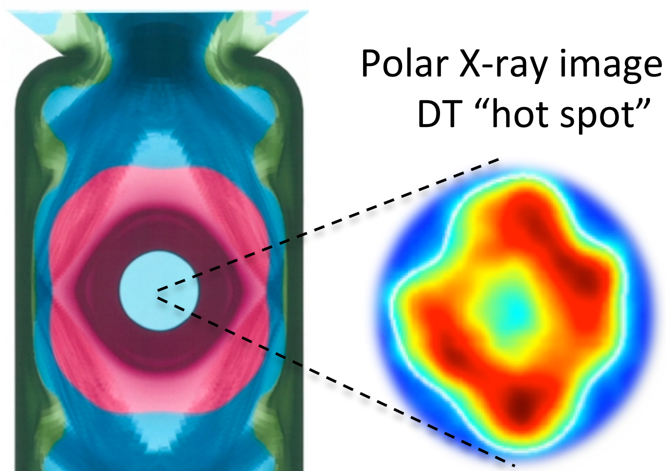
- High foot hit a ceiling approaching 10^{16} neutrons, ~50% from alpha heating (GLC ~ 0.65)
  - Major culprits appear to be:
    drive asymmetry from LPI dominated hohlraum + capsule support
  - Can't yet rule out other factors
- Ongoing engineering effort to address the capsule support
  - Challenging
- Attention turned to the hohrlaum –> simple, low LPI designs
  - Present their own challenges, can be made to work on paper – time will tell
  - Ideas to further improve

These new directions need a methodical, scientific approach, new diagnostics, improved models and time to evaluate

Major factors degrading NIC[1] - appear to conspire (again) to limit performance of high foot

Poor control of **time dependent** drive symmetry in **LPI dominated** hohlraum

Polar X-ray image of DT "hot spot"

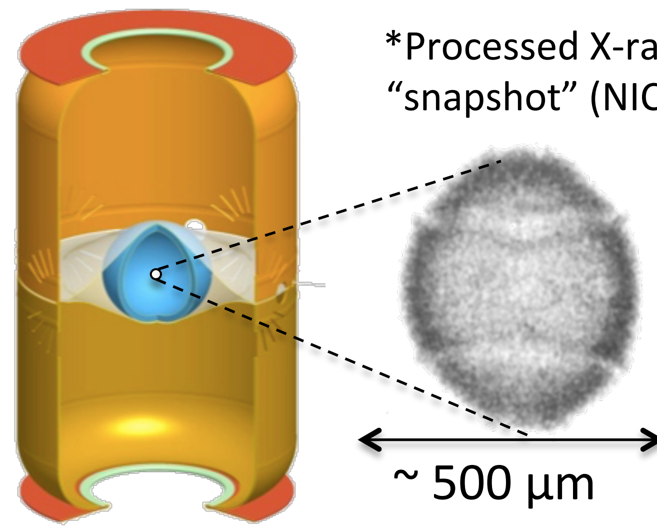


~ 50 µm

~ 5000 µm

Hydrodynamic instability seeded by the **capsule support, "tent"**

*Processed X-ray "snapshot" (NIC)



~ 500 µm

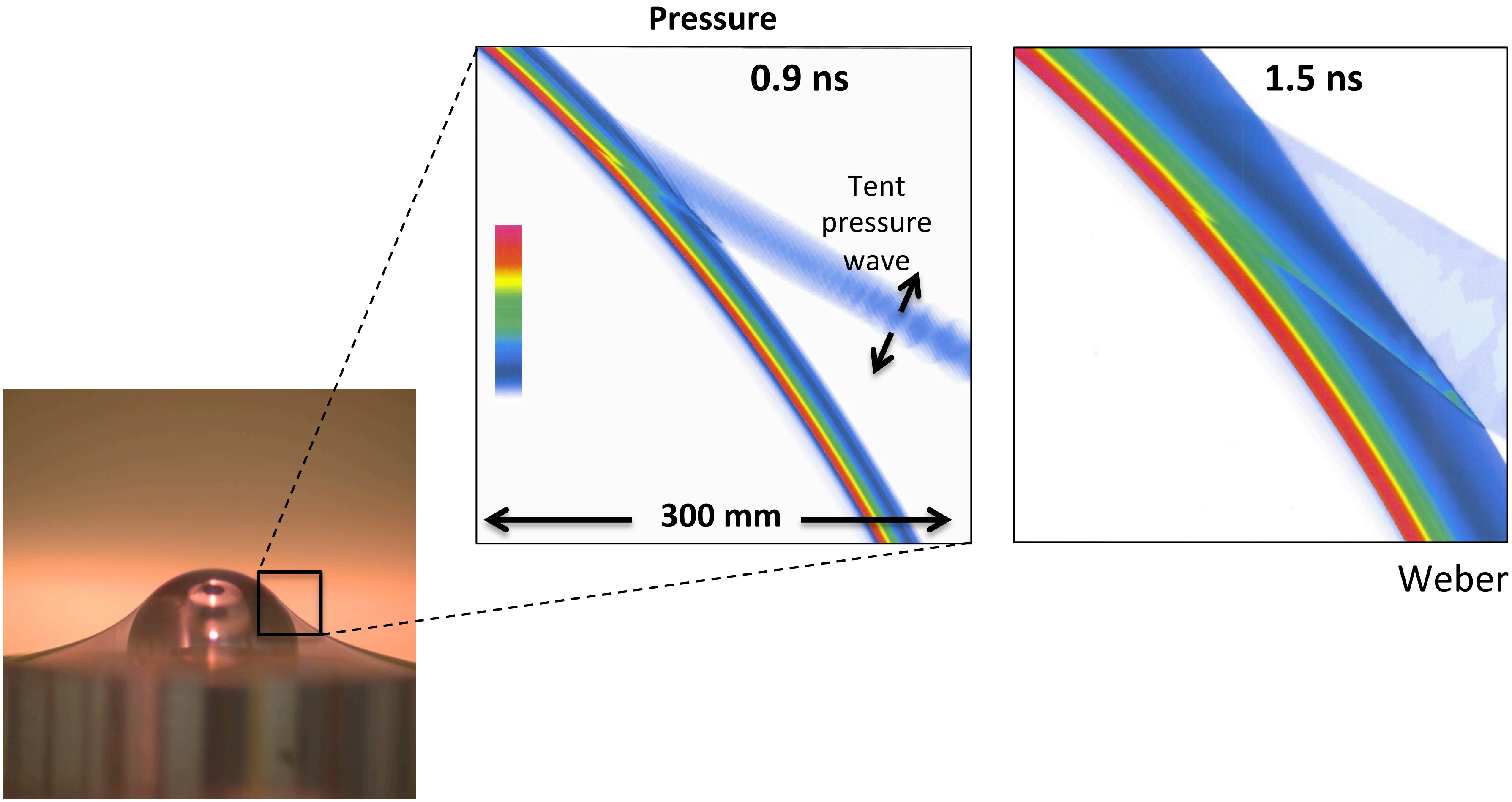
High foot mitigated this, but predict becoming important again

[1] D. S. Clark et al, Phys. Plasmas, **22**, 022703, (2014)

*J.E. Field et al, Rev. Sci. Instrum. **85**, 11E503, (2014)
*R. Tommasini et al, Phys. PLasmas. **22**, 056315, (2015)

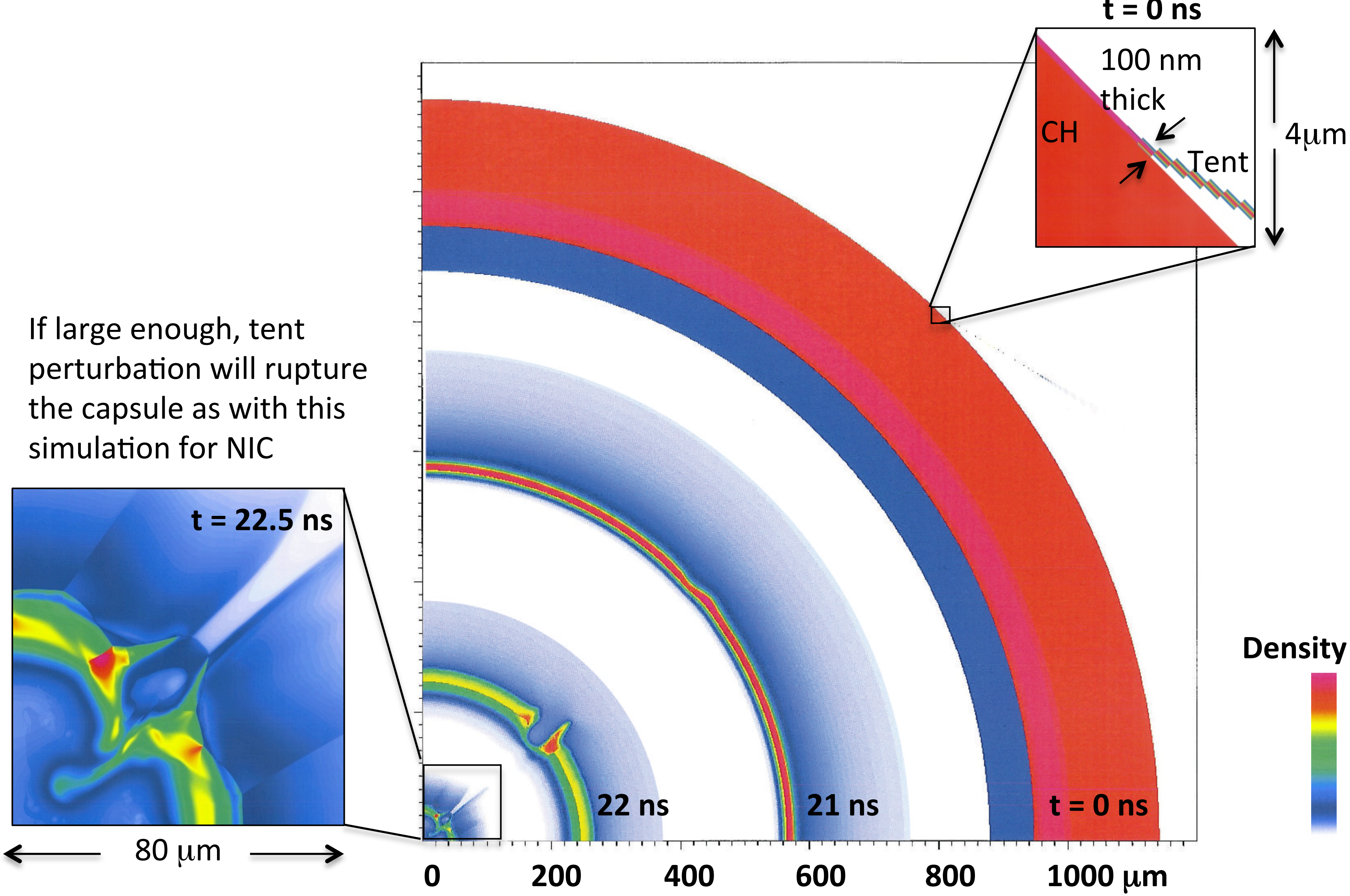
Tent and asymmetry are currently a major program focus
But may not be the only factors preventing ignition; we may find others

As the tent explodes it launches a pressure wave that impacts the capsule creating a "seed"



The tent "seed" perturbation is then amplified during the implosion (Rayleigh-Taylor instability)

If large enough, tent perturbation will rupture the capsule as with this simulation for NIC



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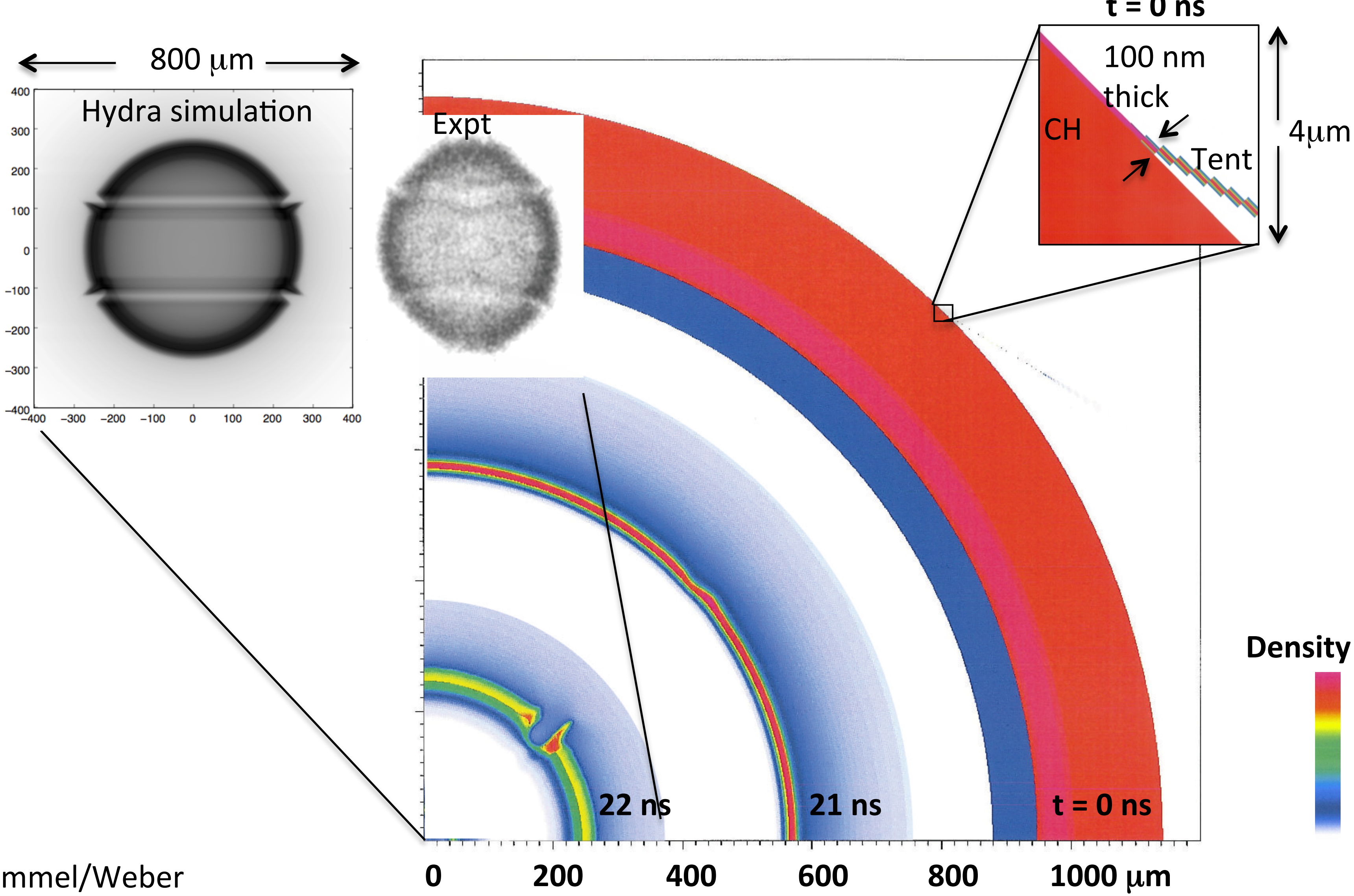
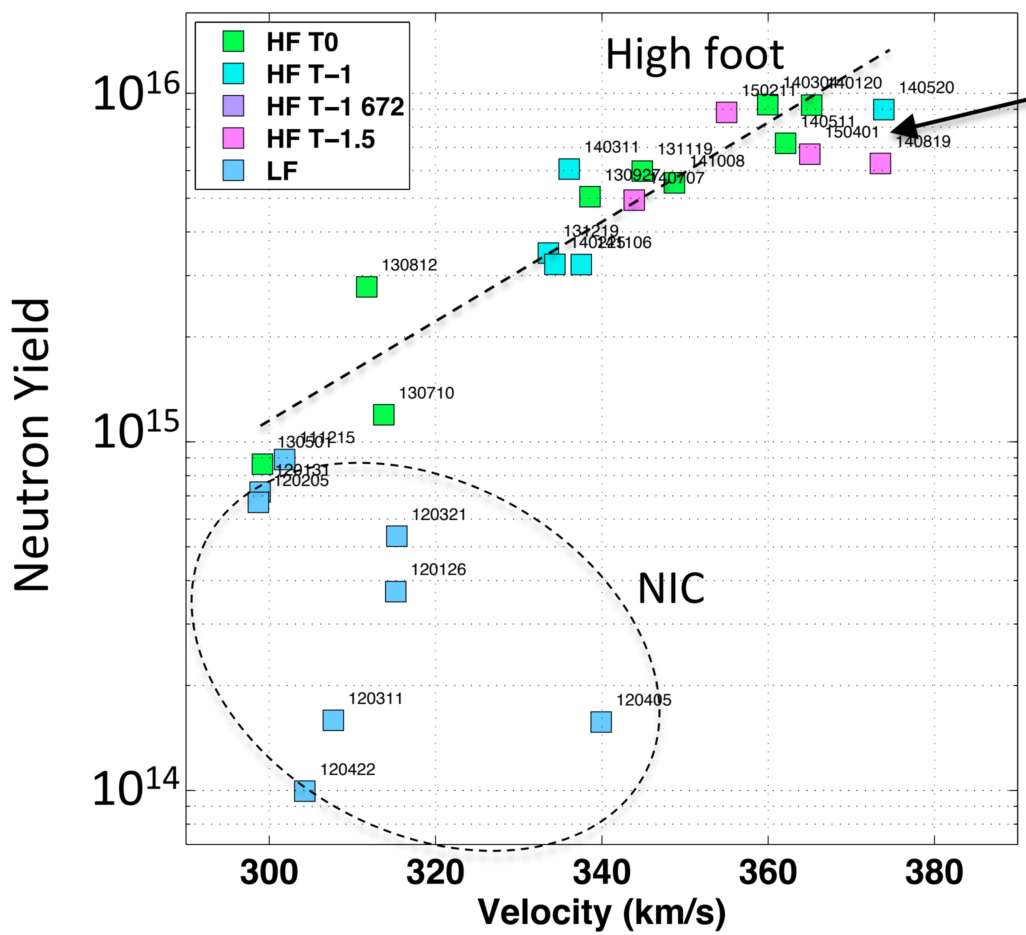


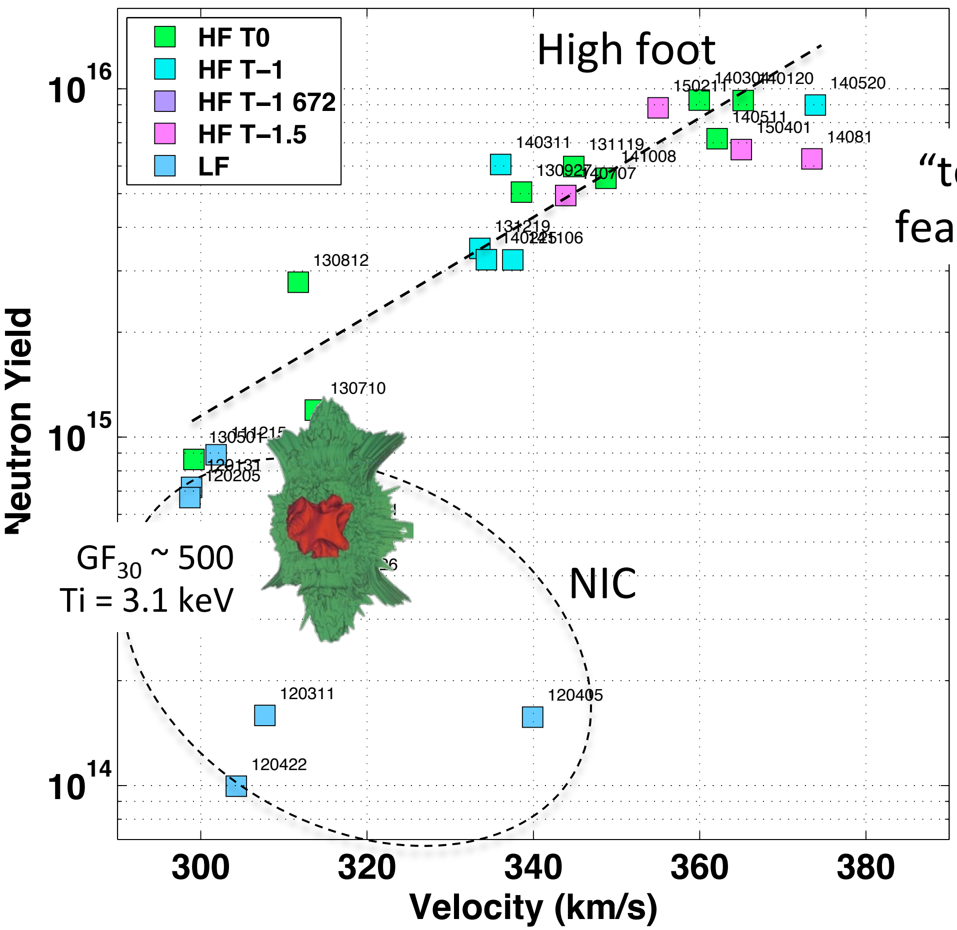
Hammel/Weber

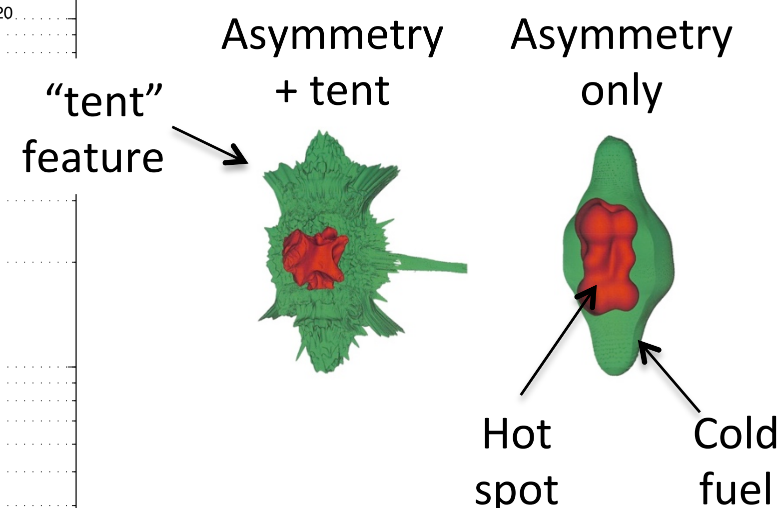
More stable high foot pulse resulted in behavior more consistent with theoretical scaling, but..



Indication higher velocity implosions deviating from predicted performance
– in simulations some start to ignite

*(Partially) Validated 3D simulations "explained" NIC – tent and asymmetry degraded hot spot formation

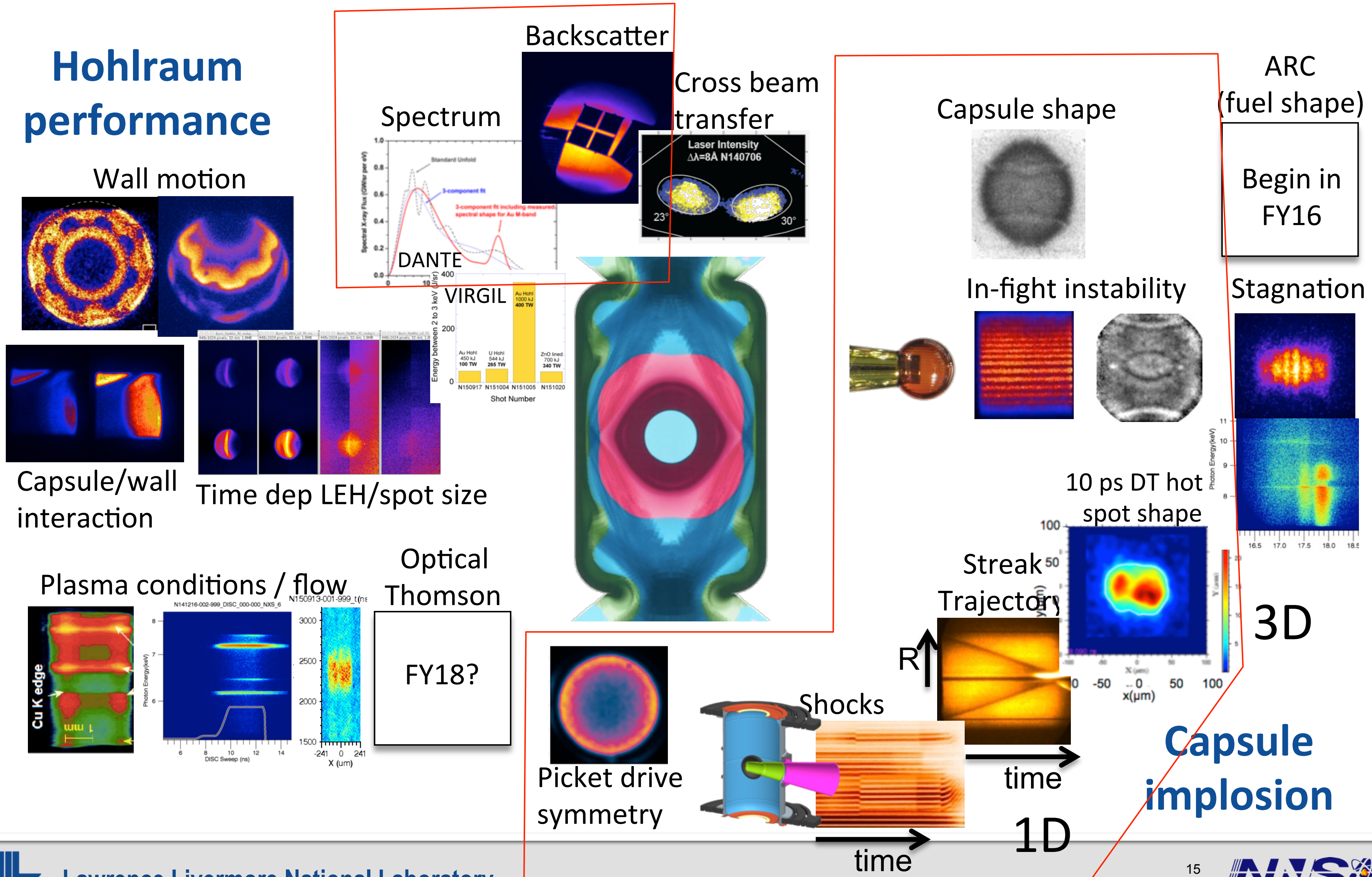




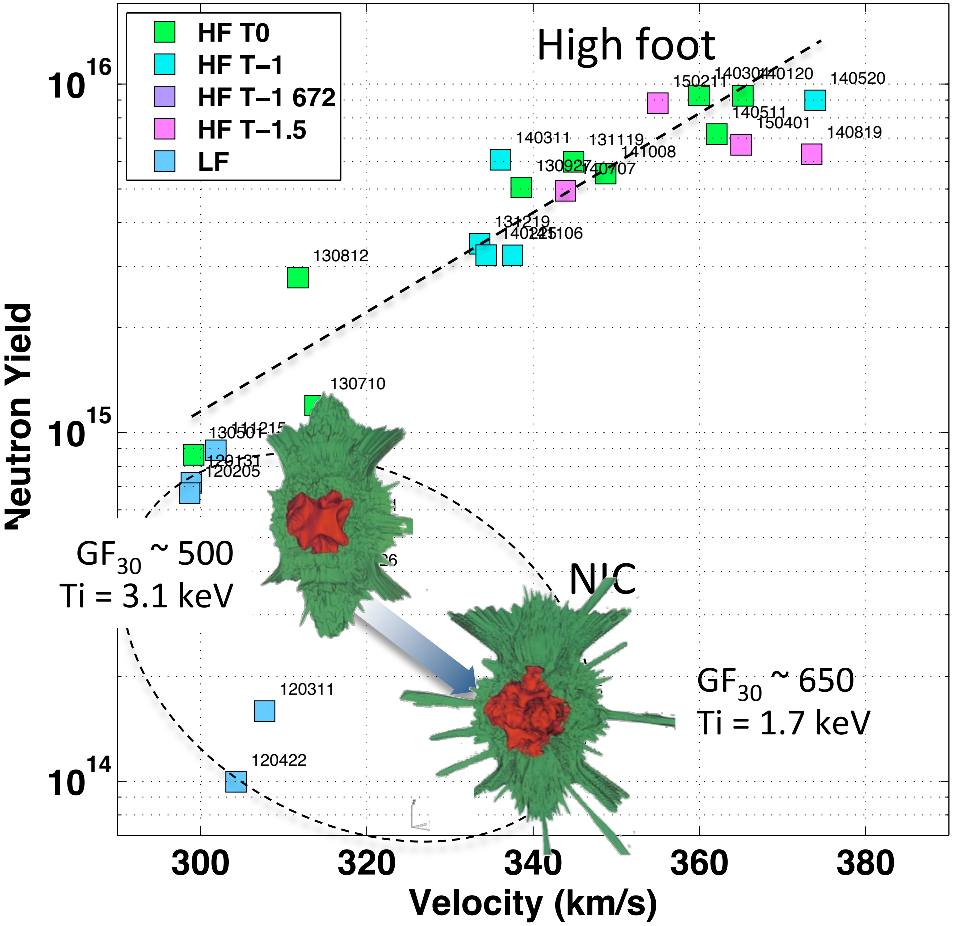
*Better visualization of the cold fuel required

*hydro growth, tent validated with HGR platform and 2DConA; implosion symmetry constrained by keyhole, 2DConA, hot spot; more refined models of symmetry desirable; hot electrons not included, D. S. Clark et al, submitted to Phys. Plasmas

Significant amount of (new) data gone into model validation, but more needed – future focus on hohlraum and cold fuel

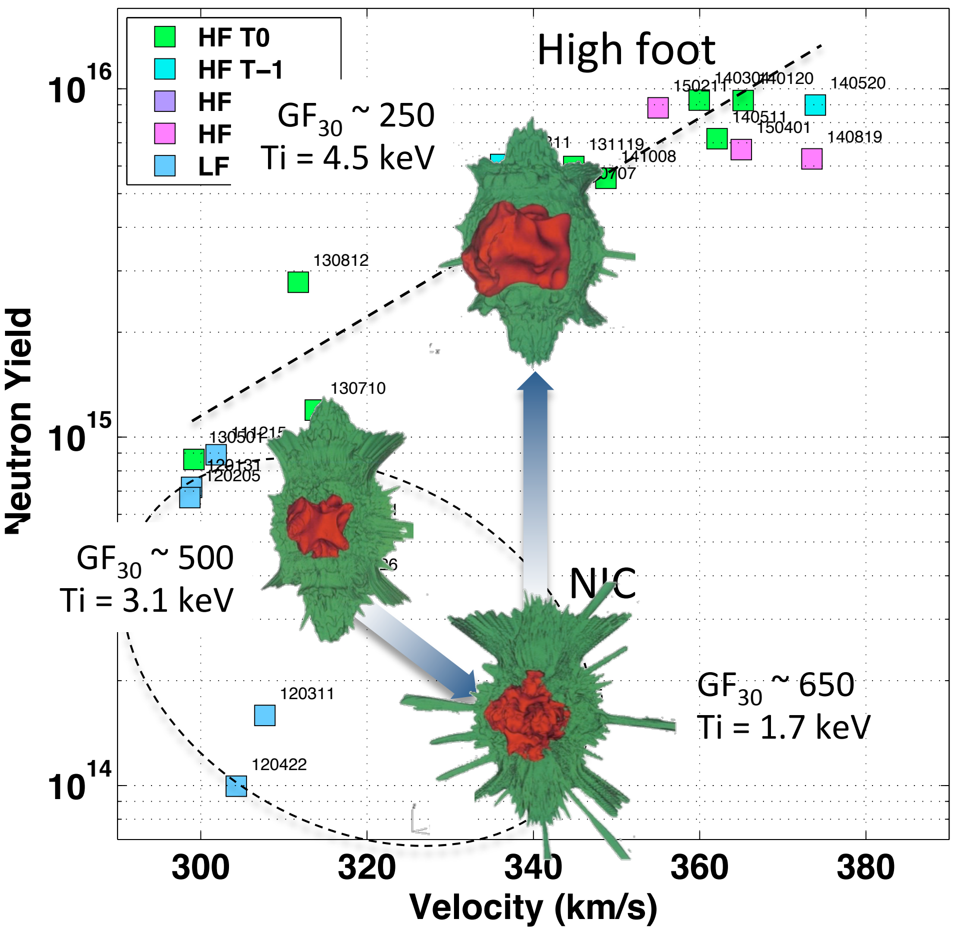


Increasing velocity resulted in mix – tent implicated



D. S. Clark et al, submitted to Phys. Plasmas

More stable high foot reduced impact of tent – larger, hotter hot spot -> more yield



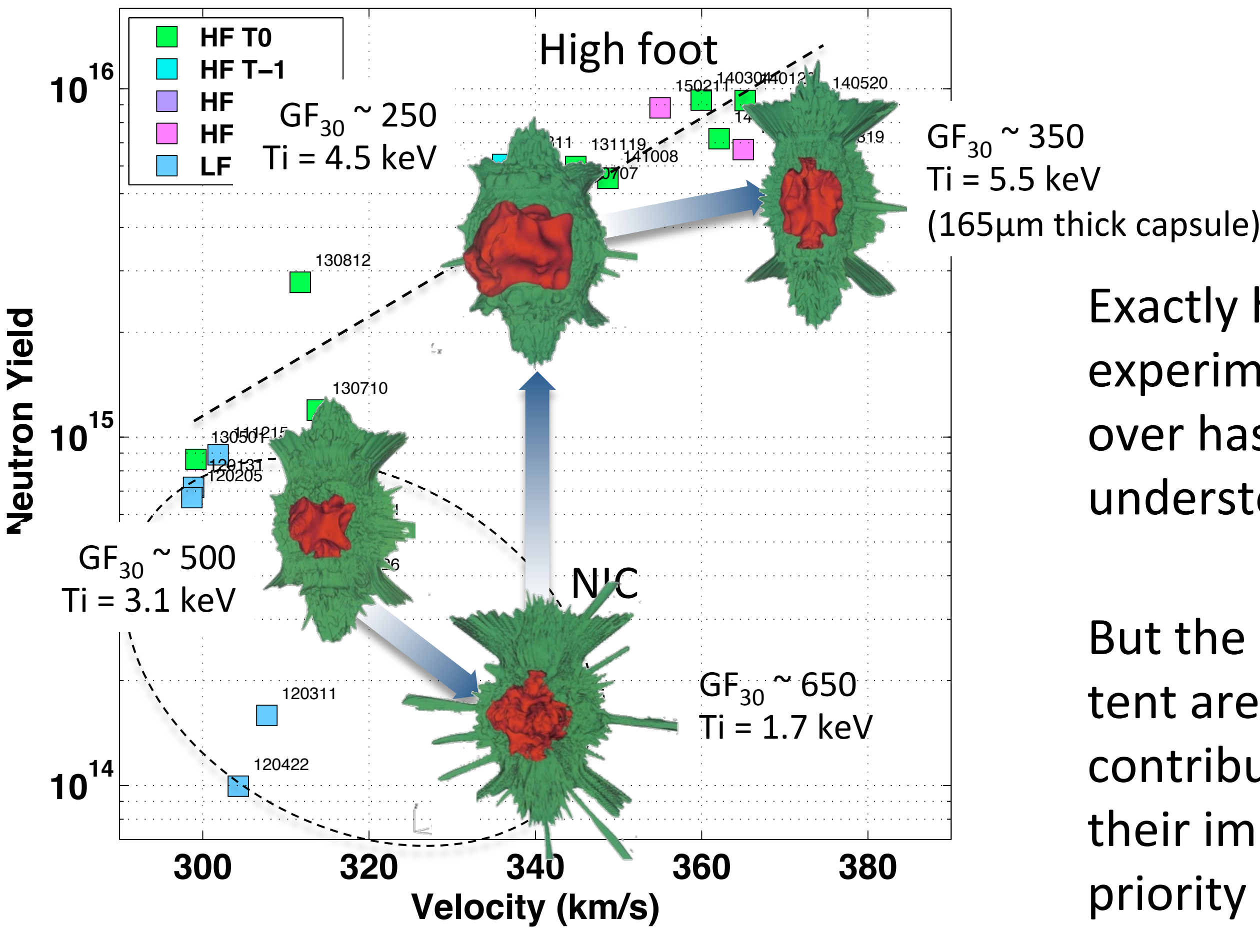
Note character of overall shape from drive symmetry not very different – predicted to dominate performance

*Improved stability verified in off-line experiments; impact of tent much less

*D. T. Casey et al, Phys. Rev. E **90**, 011102 (2014)
R. Tommasini et al, Phys. PLasmas. **22**, 056315, (2015)

D. S. Clark et al, submitted to Phys. Plasmas

Tent *predicted* to impact hot spot again as (thinner) capsule pushed harder –appears to burn-through, not mix

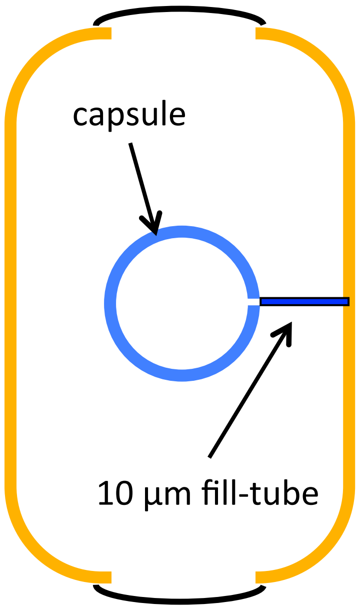


Exactly how/why the experiments are rolling over has yet to be understood

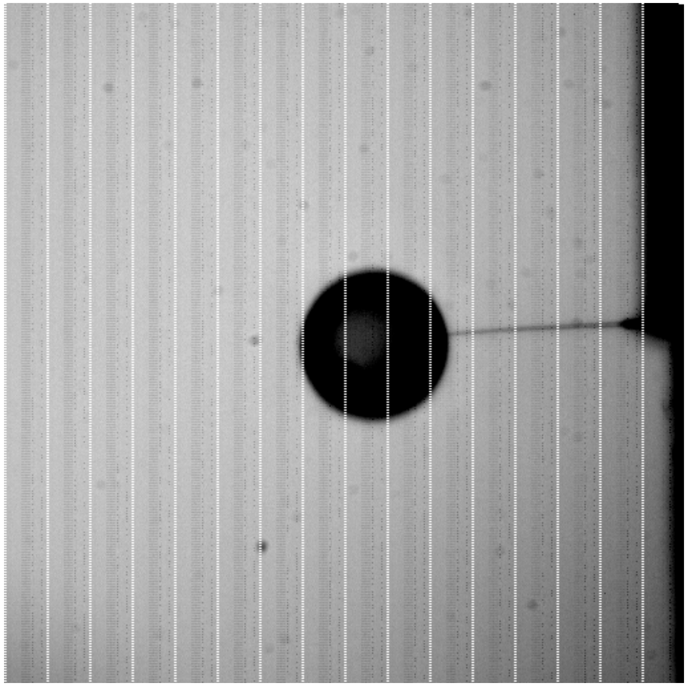
But the asymmetry and tent are (the major?) contributors – reducing their impact is a high priority

D. S. Clark et al, submitted to Phys. Plasmas

The best solution would be to eliminate the tent altogether



30 µm free-standing fill-tube vibration test



Ongoing S&T effort to improve the capsule mounting scheme
Variety of possibilities being evaluated, but challenging – report next year

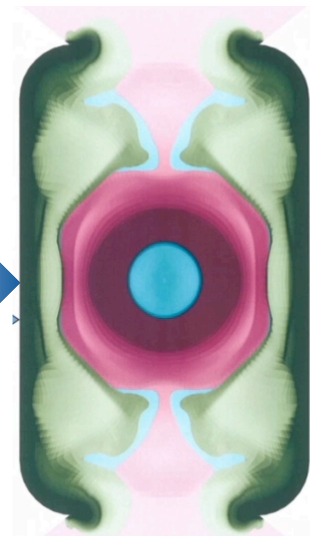
Program has moved to low fill hohlraums

–30-50% more efficient, very low LPI, but different challenge

High-gas-fill,
LPI dominated

Case-capsule
ratio ~ 2.5

Low-gas-fill,
Rad-hydro dominated



Initial experiments
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ratio >~3 needed

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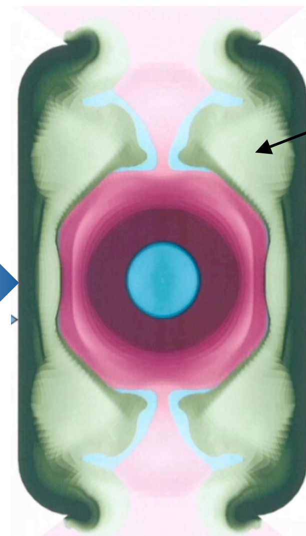


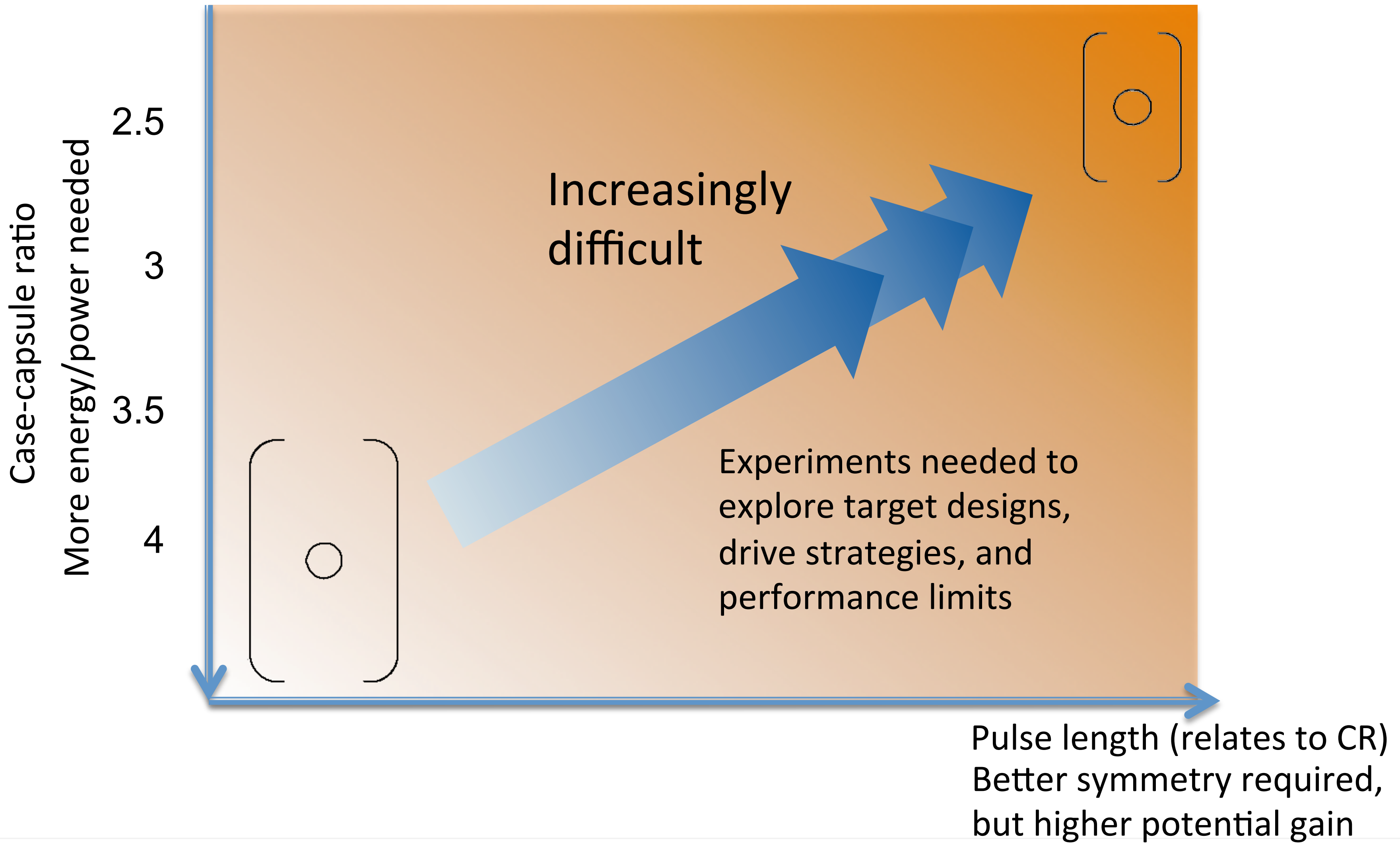
Initial experiments suggest case-capsule ratio >~3 needed

- Challenge is plasma filling (less gas pressure to hold wall back)
- Motivates bigger hohlraums and shorter pulses
- But hohlraum size constrained by available power and energy

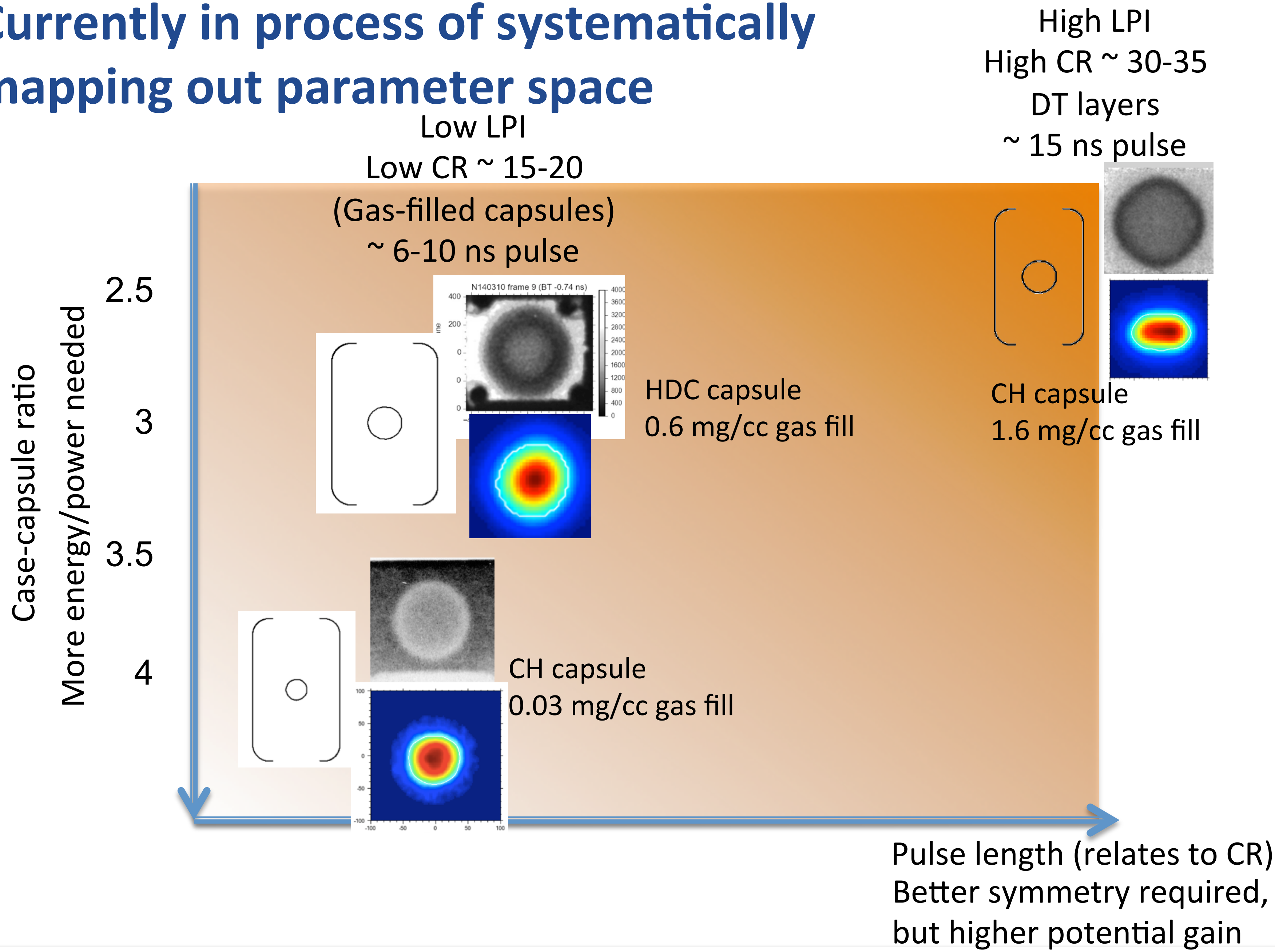
Are there designs and drive strategies consistent with ignition?
On paper yes, but experiments needed to test and guide

Emphasis on understanding, then expanding operable parameter space

Hohrlaum Case-Capsule ratio vs. Laser Pulse Length



Currently in process of systematically mapping out parameter space

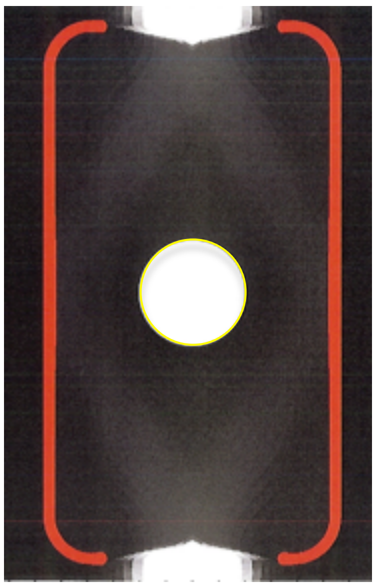


More space, better symmetry with foam liners? – experiments needed to test simulations

Regular hohlraum wall

$P_{wall} > P_{gas}$

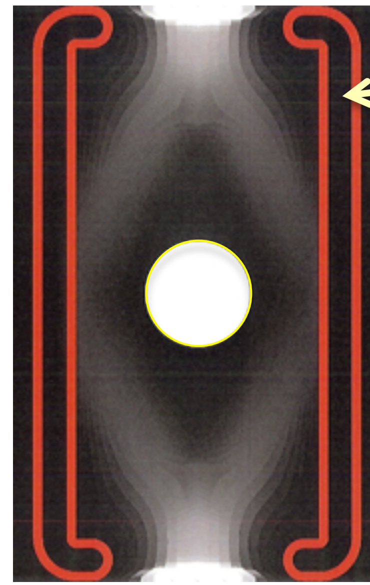
Temperature Map



0.03 g/cc gas fill

Foam lined hohlraum

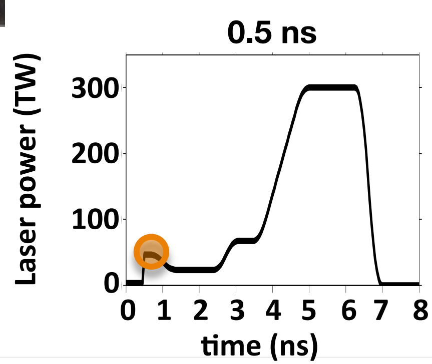
$P_{wall} \sim P_{gas}$



0.3 g/cc gas fill

20 mg/cc Ta_2O_5 Foam liner

Foams can be made, but parts not yet demonstrated



These are simulations of "0.8 scale" (850 kJ) test targets in which first tests are being done

Test plan gradually increases fabrication difficulty

150 mg/cc ZnO tested

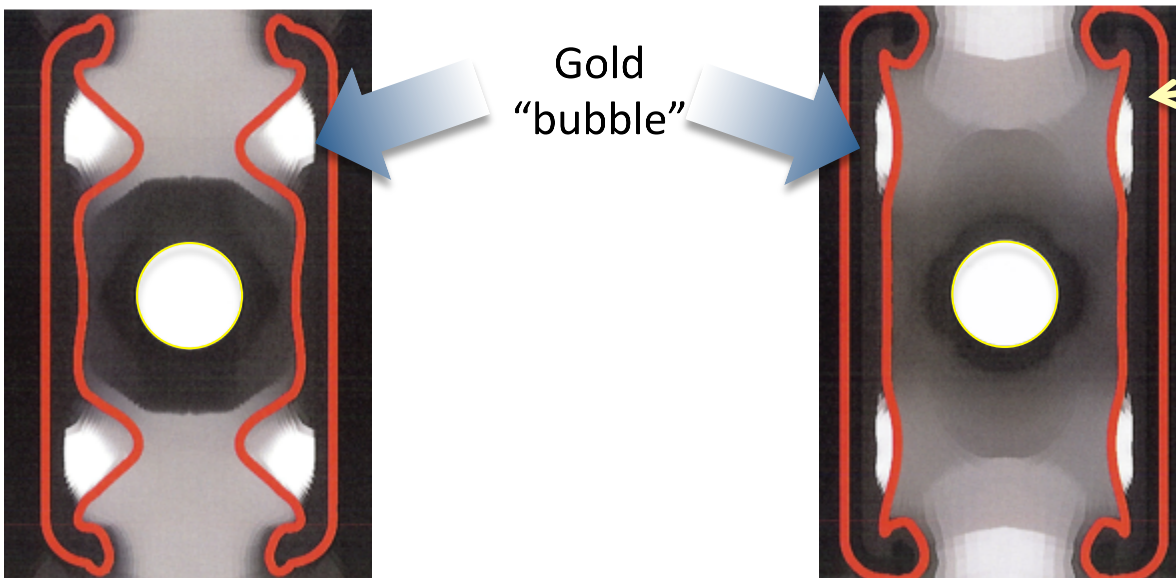
100 mg/cc Ta_2O_5 next etc

More space, better symmetry with foam liners? – experiments needed to test simulations

Regular hohlraum wall
$P_{wall} > P_{gas}$
Hohlraum begins to close

Foam lined hohlraum
$P_{wall} \sim P_{gas}$
Hohlraum remains open

Temperature Map

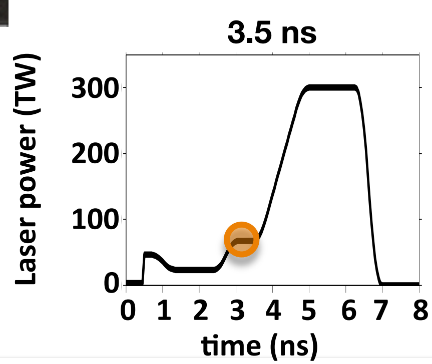


0.03 g/cc gas fill

0.3 g/cc gas fill

20 mg/cc
Ta_2O_5
Foam liner

Foams can be made, but parts not yet demonstrated



These are simulations of “0.8 scale” (850 kJ) test targets in which first tests are being done

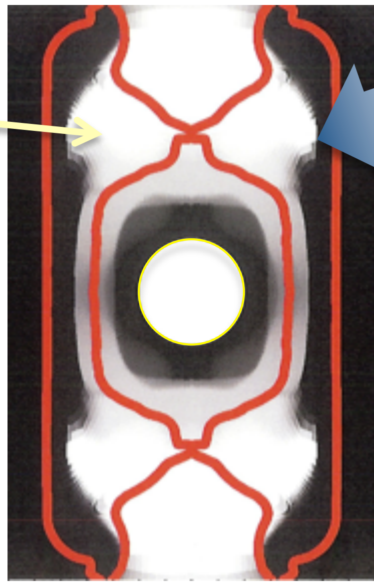
More space, better symmetry with foam liners? – experiments needed to test simulations

Regular hohlraum wall
$P_{wall} > P_{gas}$
Hohlraum closed

Foam lined hohlraum
$P_{wall} \sim P_{gas}$
Hohlraum remains open

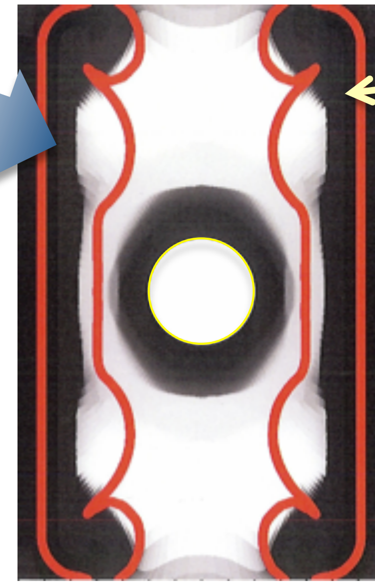
Gold "bubble"

Temperature Map



0.03 g/cc gas fill

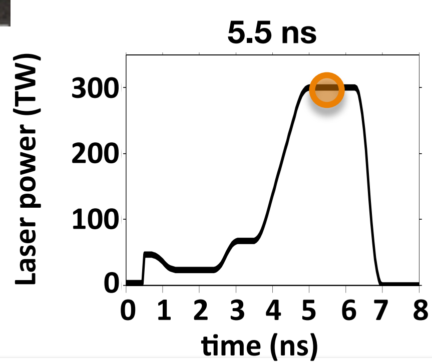
Gold "bubble"



0.3 g/cc gas fill

20 mg/cc Ta_2O_5 Foam liner

Foams can be made, but parts not yet demonstrated



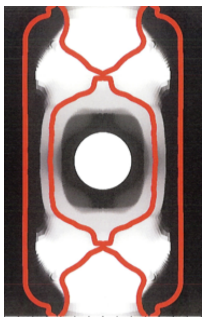
These are simulations of "0.8 scale" (850 kJ) test targets in which first tests are being done

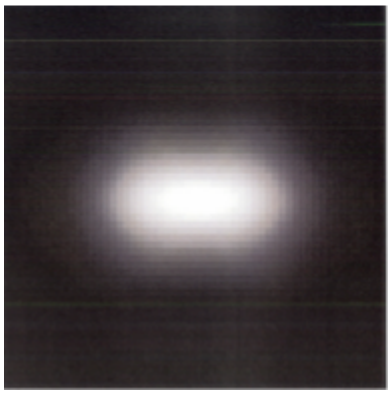
More space, better symmetry with foam liners? – experiments needed to test simulations

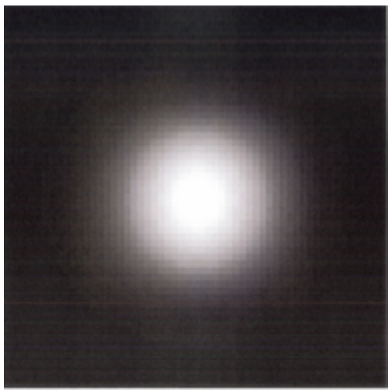
Synthetic x-ray images of hot spots for Convergence Ratio =15

Regular hohlraum wall
(0.03 g/cc gas fill)

Foam lined hohlraum
(0.3 g/cc gas fill)

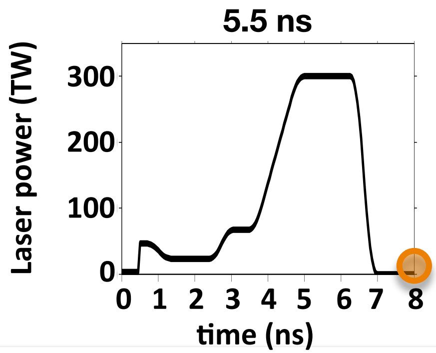






Tell-tale "donut" shape emerging

Remains symmetric to high convergence



These are simulations of "0.8 scale" (850 kJ) test targets in which first tests are being done

Summary of X-ray drive ignition on the NIF

- High foot hit a ceiling approaching 10^{16} neutrons, ~50% from alpha heating (GLC ~ 0.65)
  - Major culprits appear to be:
    drive asymmetry from LPI dominated hohlraum + capsule support
  - Can't yet rule out other factors
- Ongoing engineering effort to address the capsule support
  - Challenging
- Attention turned to the hohrlaum – low LPI designs
  - Present their own challenges, can be made to work on paper – time will tell
  - Ideas to further improve

These new directions need a methodical, scientific approach, new diagnostics, improved models and time to evaluate

Lawrence Livermore National Laboratory