Indirect-Drive Ignition at NIF: Where We Have Been, and Where We Are Going

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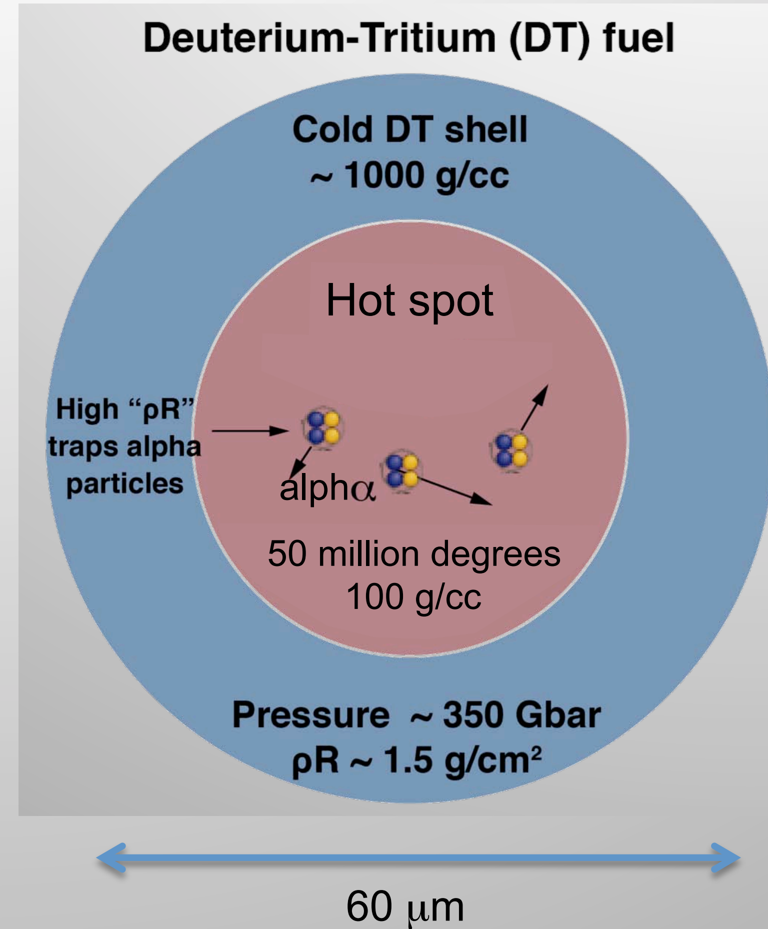
Ignition is a grand challenge



Convergence ratio of ~ 35

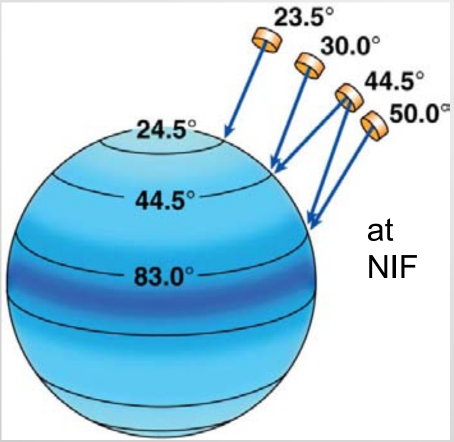
We must do this with a limited energy driver, finite number of shots, very precise laser & target specifications, in a regime where no one has been before in the laboratory

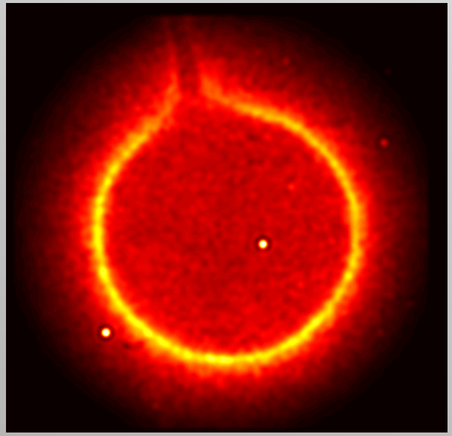
Three approaches to ignition are being pursued, with implosions that are Laser, Magnetically or X-ray driven

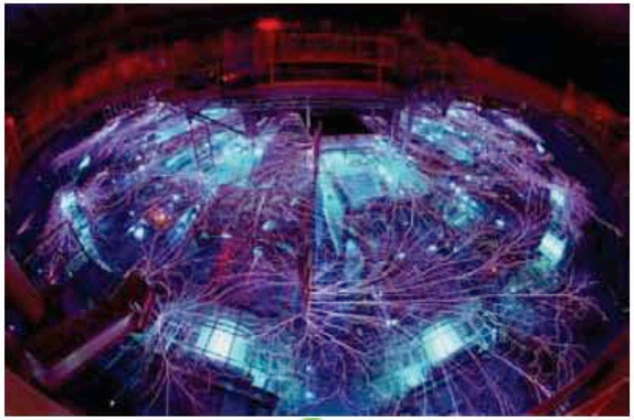
Laser: Directly Driven (Spherical on Ω, Polar on NIF) led by URLLE

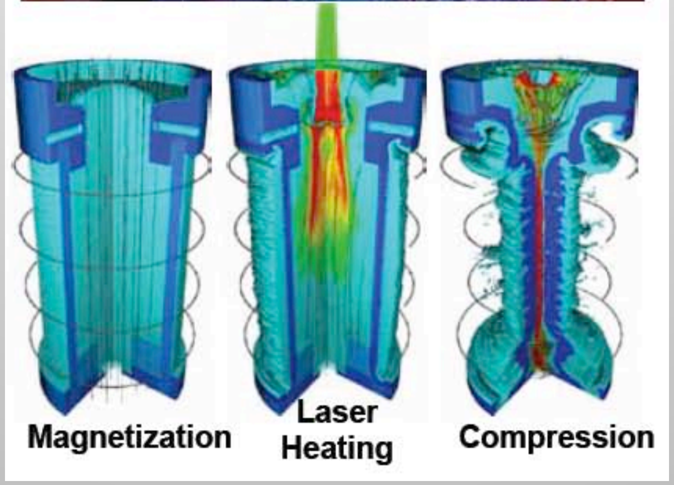
Magnetically: Magnetized Liner Inertial Fusion at Sandia Nat'l Lab

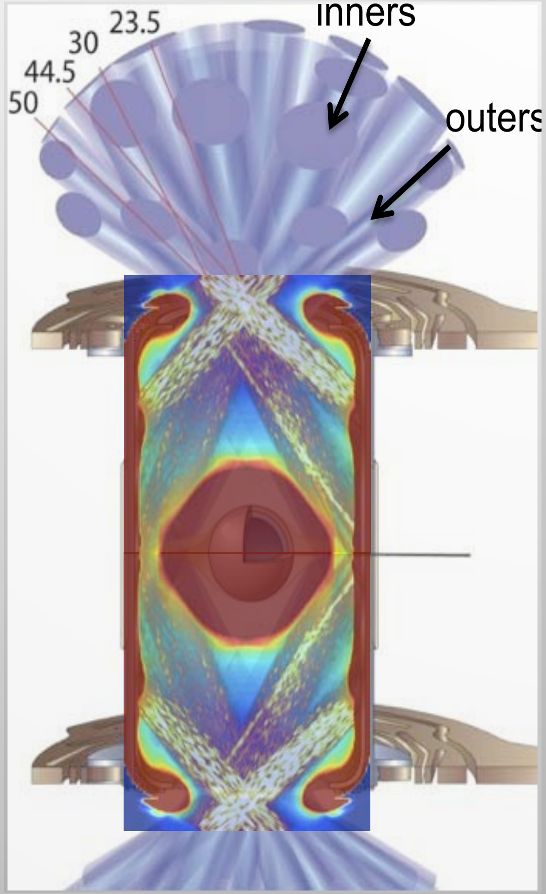
X-ray: Produced by NIF laser at LLNL with an Internt'l team











This talk deals exclusively with x-ray driven implosions, aka "Indirect Drive"

Current "traffic report" of the road to indirect drive ignition

- **Hydrodynamic Instabilities: 2012:** When pushed to higher velocity, the Pt. Design hit a roadblock: **Mix** of CH ablator into the hot spot, & severely degraded performance
  - **2014:** Less stressing, more stable, CH implosions successfully pushed to higher velocity
    - Yield improvements of > 10x, and significant self heating due to alpha deposition
  - Improved understanding of Pt. Design's initial perturbations that can lead to the mix
  - Modified designs that show promise of improved performance

- **Complex Hohlraum Physics: 2012**: Long pulse, gas filled hohlraum with >16% Laser Plasma Instabilities (LPI): Reduced **drive**, complicated **symmetry** control, hot electron (**preheat**)
  - **2014**: Potentially better hohlraums, with shorter pulse & less gas fill, show reduced LPI, reduced hot electrons, better understood drive, & possibly better symmetry control
    - These are natural choices for alternate ablators like High Density Carbon (HDC) or Be
      - After 2 DT shots, HDC has > 3x more yield than 2012 CH, so far, – with "head-room" for improvements

Recent progress shows the benefits of innovation, and exploration of broad approaches. This can lead to even better performance, and we've barely begun to innovate !

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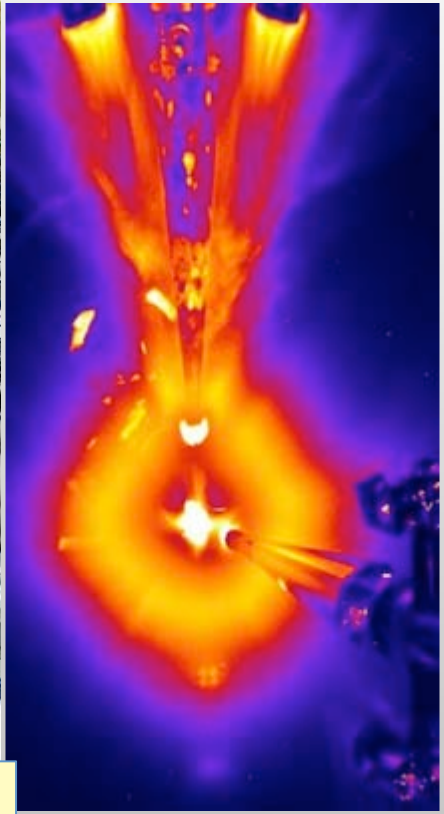
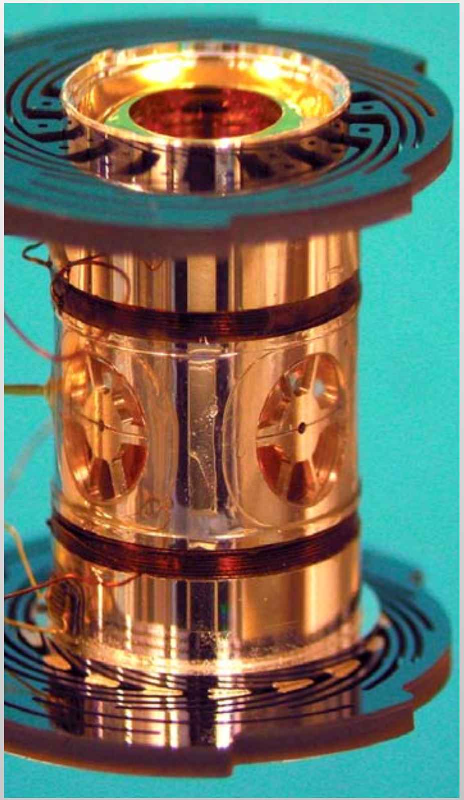
- Acknowledgements

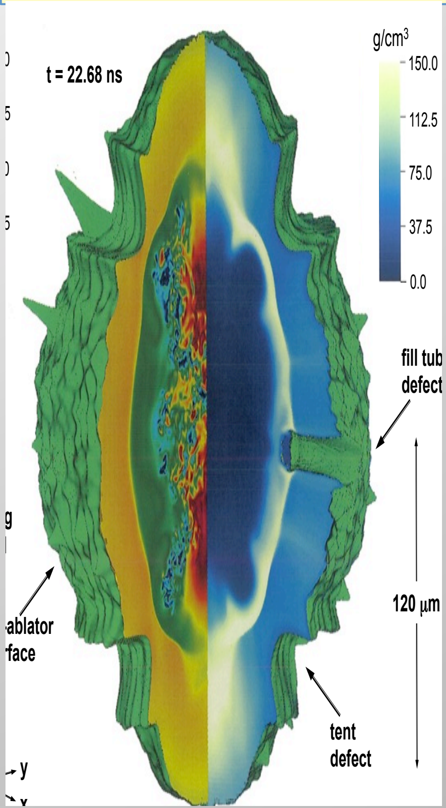
For the grand challenge of ignition we need awesome:

NIF Laser Systems*	Diagnostics	Targets	Design Codes

*Now with enhanced shot rate!

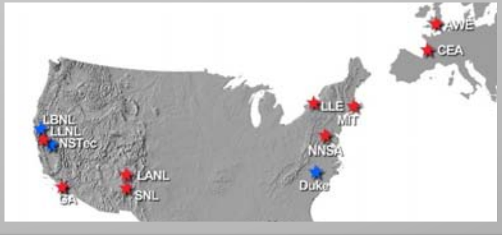




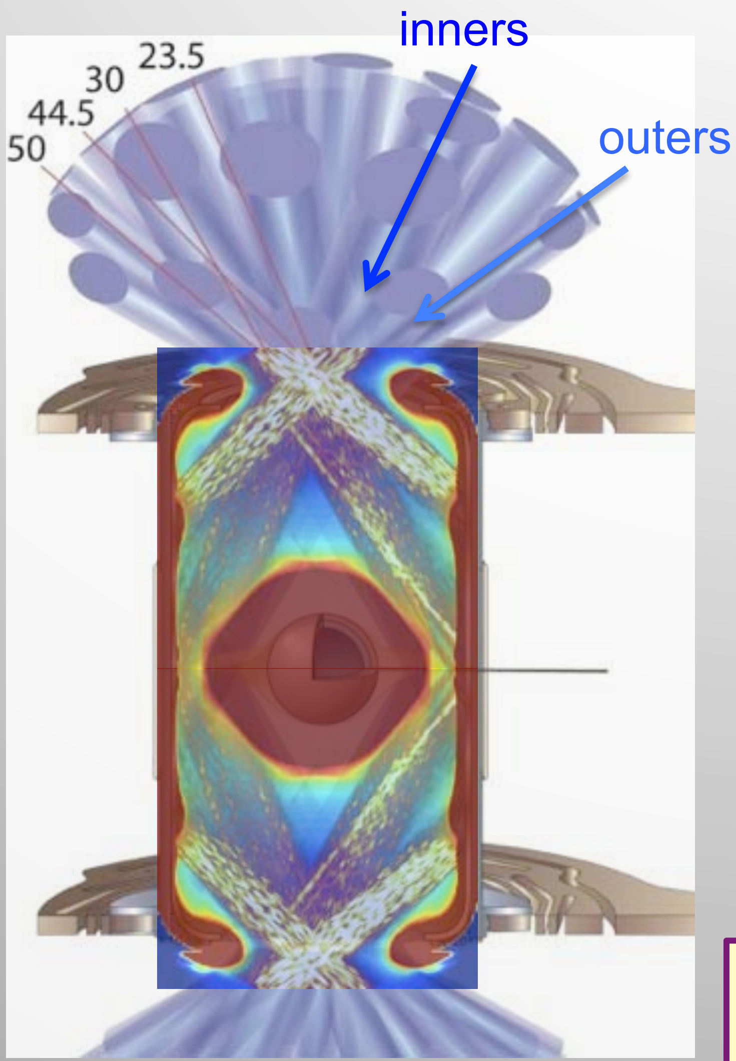


…and National & International partners in research:

AWE, CEA, Duke, GA, GSI, IC, LANL, LBNL, LLNL, LANL, MIT, NNSA, NRL, NSTec, Oxford, SNL, U of M, URLLE



A hohlraum indirectly drives capsule implosions at the 1.8 MJ National Ignition Facility (NIF)



It needs to Provide Sufficient Radiation Drive:

- - 0.2 MJ: LPI losses, mostly Raman on inners
- ~ 1.6 MJ couples to the hohlraum wall
- ~ 1.3 MJ converted to x-rays. (Tr ~300 eV)
- ~ 150 kJ absorbed by capsule ablator
- ~ 15 kJ, 370 km/s imploding rocket payload

It needs to Provide that Drive Symmetrically:

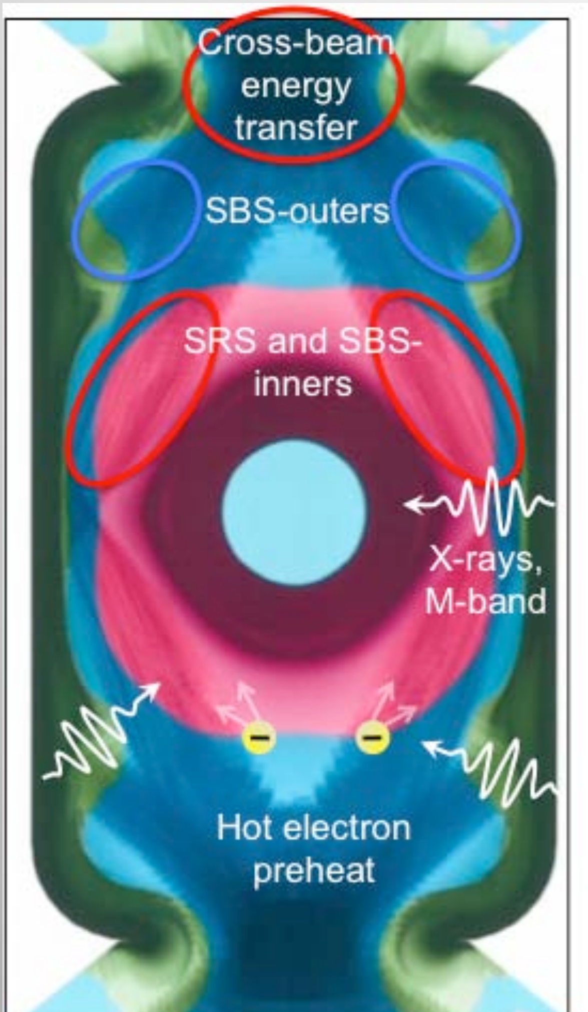
-Short wavelength modes smooth geometrically.

-P2, P4 control by inner vs. outer beam power & by Cross Beam Energy Transfer (CBET)

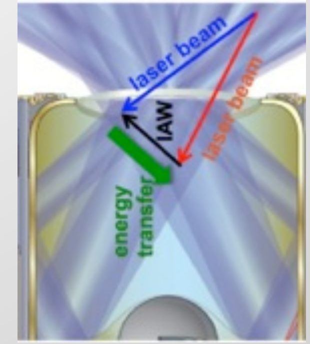
Kinetic Energy of the imploding payload converts to Internal Energy at stagnation

LPI & CBET are time dependent and complex, making drive and symmetry accuracy a challenge

The primary LPI in NIF hohlraums is cross-beam energy transfer and stimulated scatter



- **CROSS-BEAM ENERGY TRANSFER (CBET):**
  - occurs where beams overlap (at LEH)
    - Used to control symmetry



- **STIMULATED BRILLOUIN SCATTER (SBS):**

$$\vec{k}_0 \rightarrow \vec{k}_1 + \vec{k}_{iaw}$$

  - occurs in wall plasma along the outer beams
  - can cause damage to NIF optics

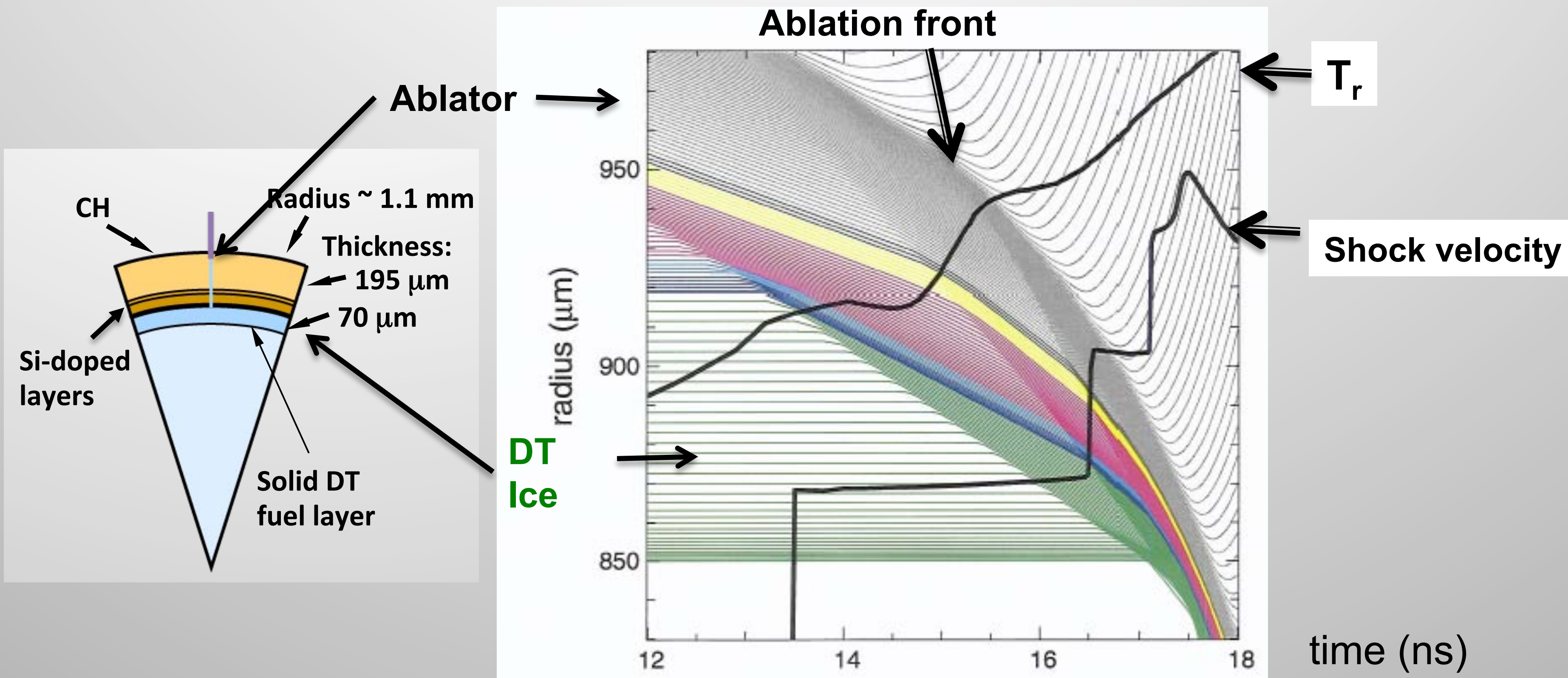
- **STIMULATED RAMAN SCATTER (SRS):**

$$\vec{k}_0 \rightarrow \vec{k}_1 + \vec{k}_{epw}$$

  - occurs along the inner beams
  - poses a challenge to symmetric implosions
  - generates hot electrons (capsule preheat threat)

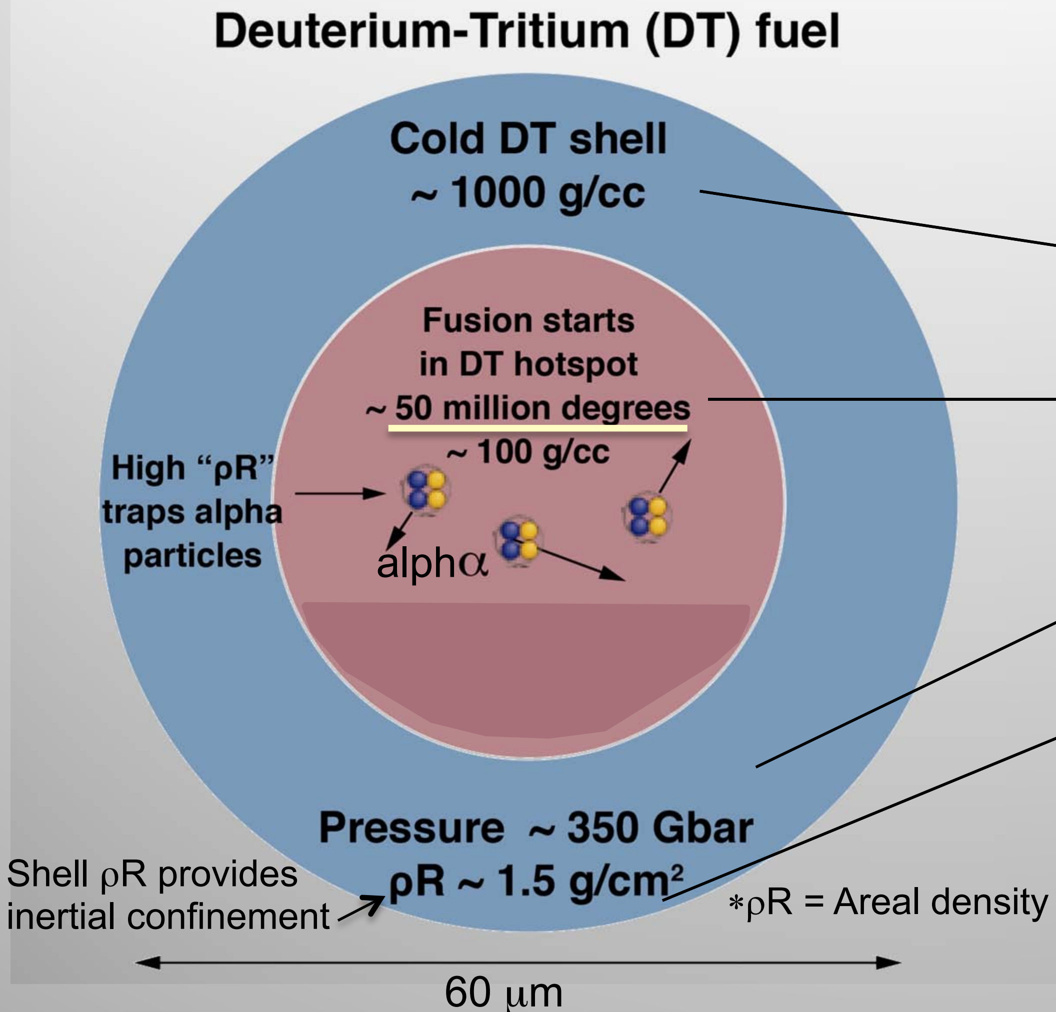
Shock timing compresses the shell to high density: Allows ~ 100 MB drive to accelerate it "cold" (= low adiabat)

The higher the adiabat, the more difficult it is to compress the target to high density



Changing the # / sequence / size of shocks can raise the adiabat. That can help stability: Puffier shell, & with higher first shock, ablatively stabilize more.

We're ~ 2x away from required ignition conditions



Best simultaneous
performance
on single shot

~ 27kJ

~ 500 g/cc

~ 40 g/cc

~ 180 Gbar

~ 0.75 g/cm ^{2}

50 million degrees achieved

$$E_{ignition} \sim \rho R^3 T \sim \frac{(\rho R)^3 T^3}{P_{stag}^2}$$

At the end of NIC in 2012, we were > 10x lower in Yield, and P_{stag} ~ 130 Gbar

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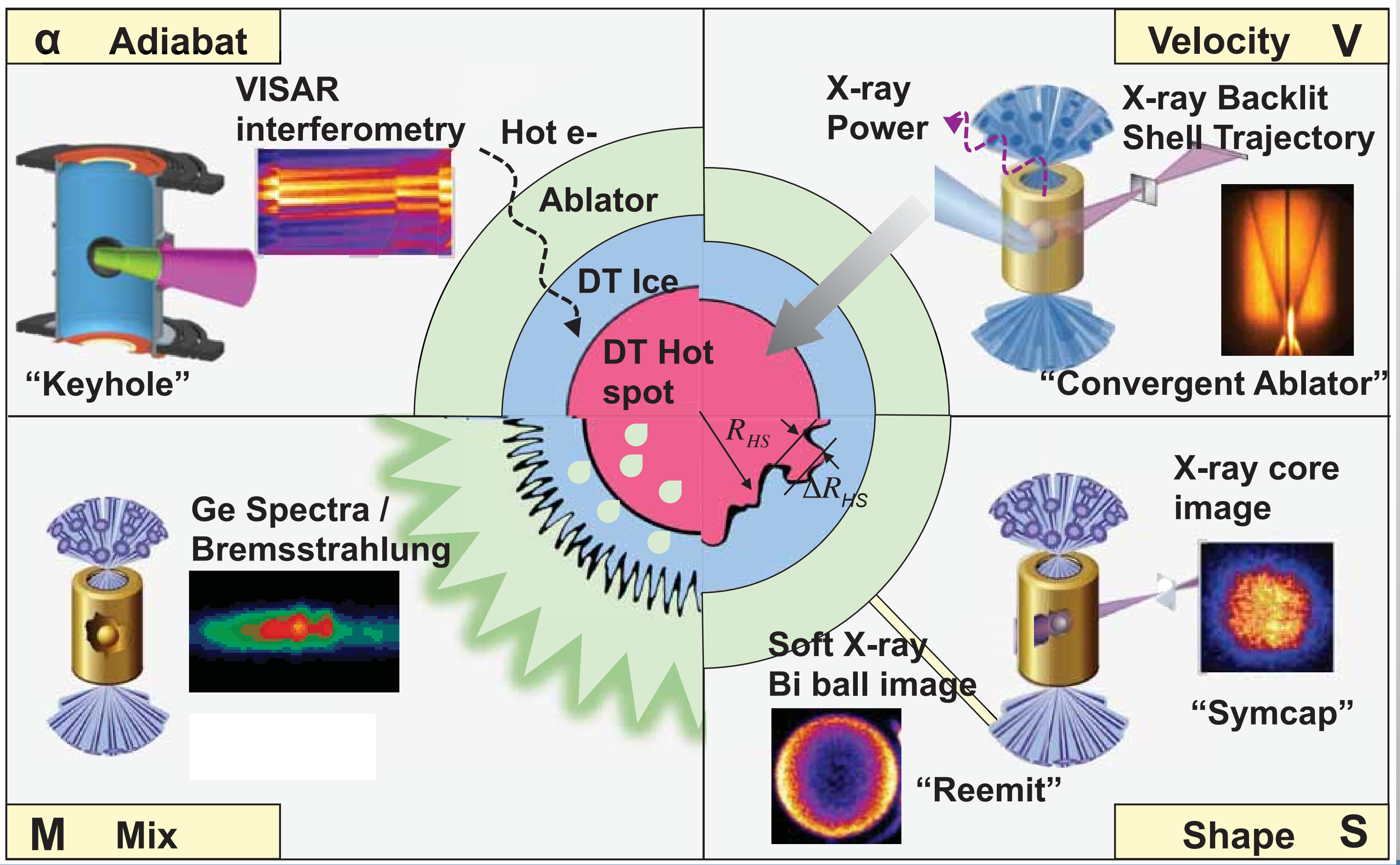
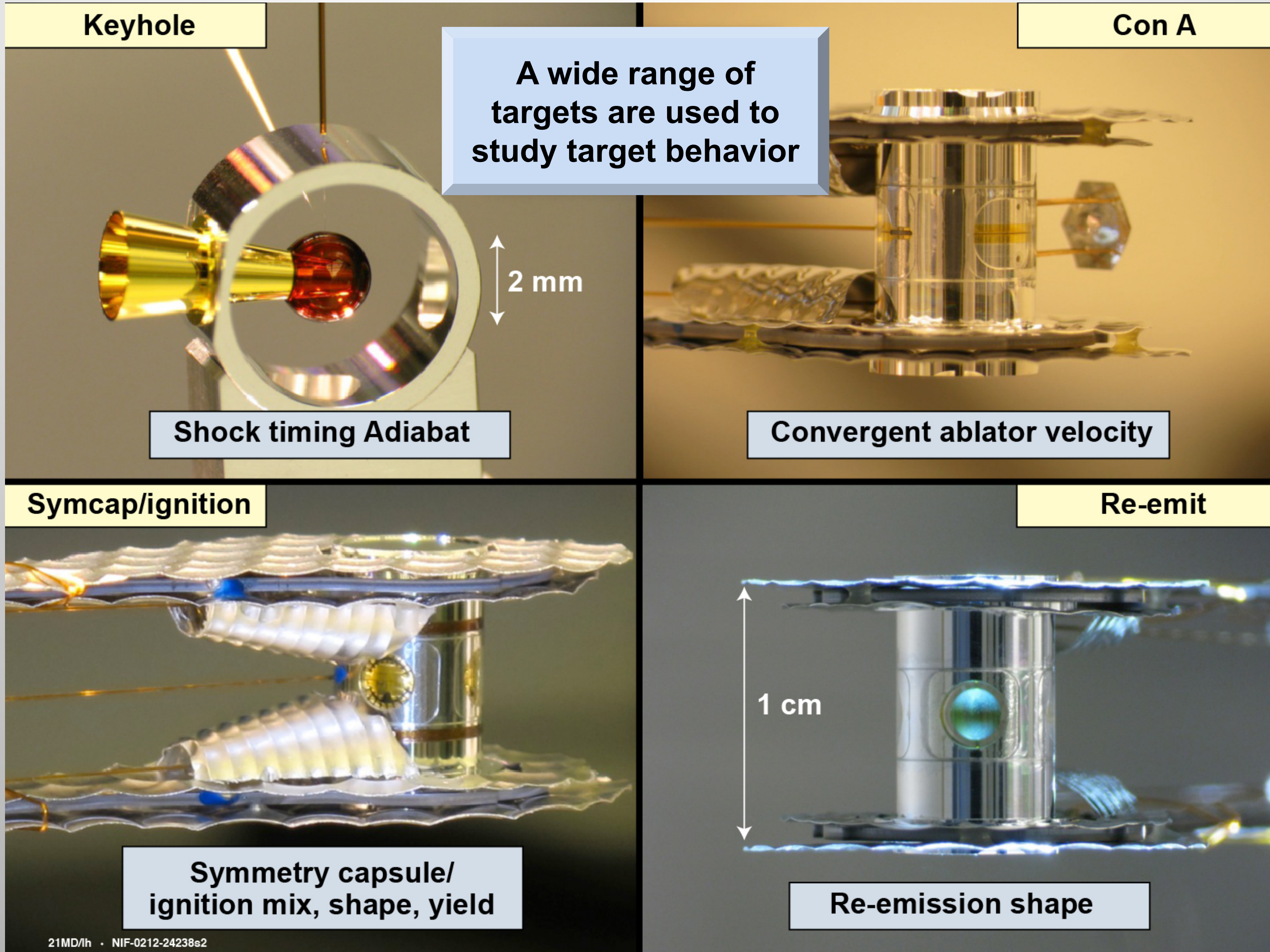
NIC developed many platforms needed for progress



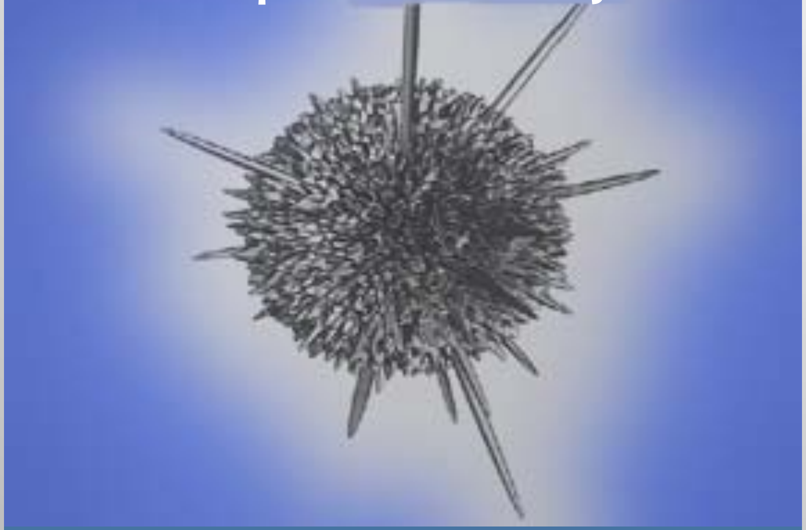
Previous work on the URLLE Omega Laser expedited these developments.
Since NIC, we've added more: e.g. 5 axis keyhole, 2-D time gated backlit images.

Thank you – target fabrication wizards !



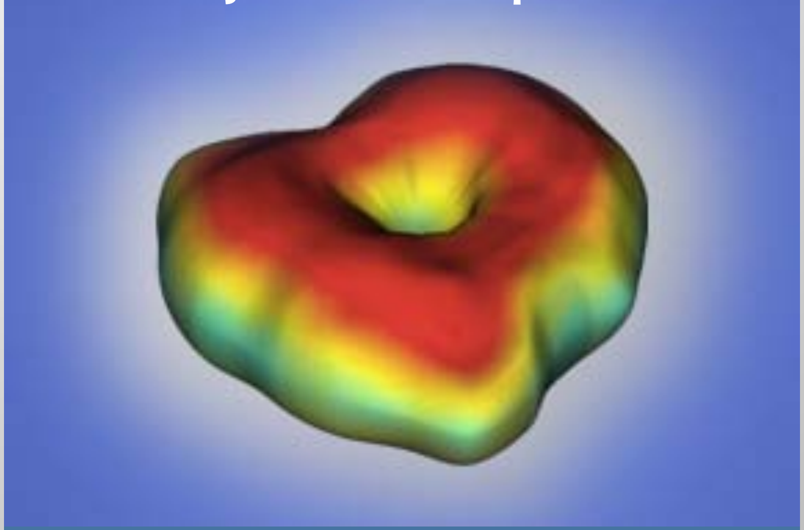
We think 3 major issues caused the degraded performance of the NIC point design ("Low foot", 4 shock CH capsule)

Capsule instability



Growth x Surface seeds is too large leading to mix at lower velocity than predicted

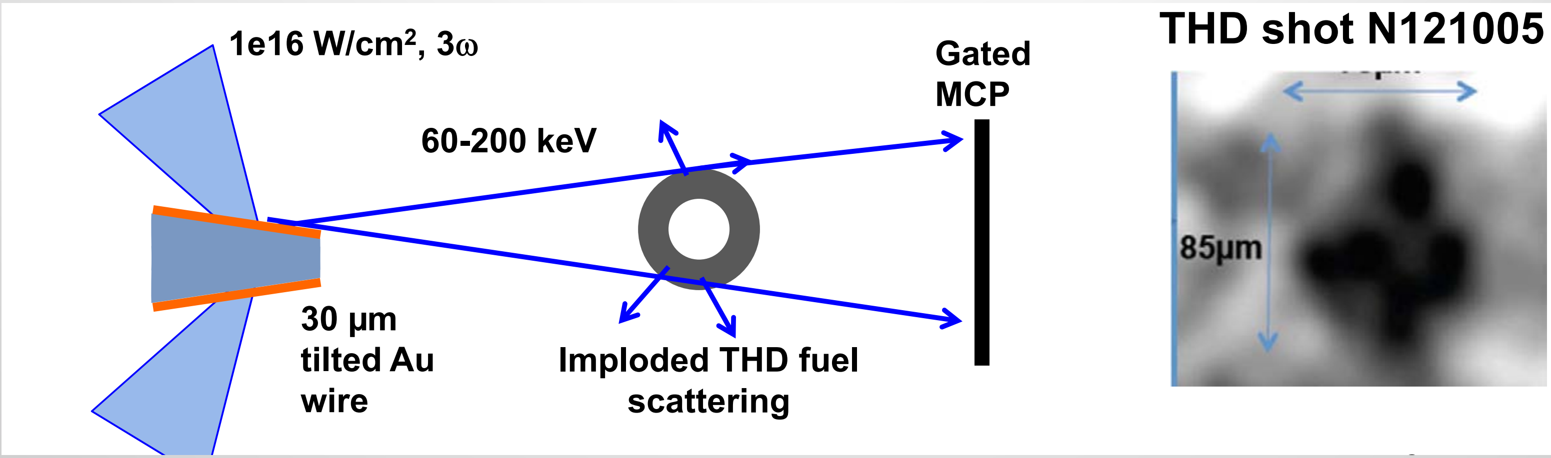
Asymmetric implosion



X-ray push on the capsule is not symmetric enough resulting in loss of efficiency at stagnation

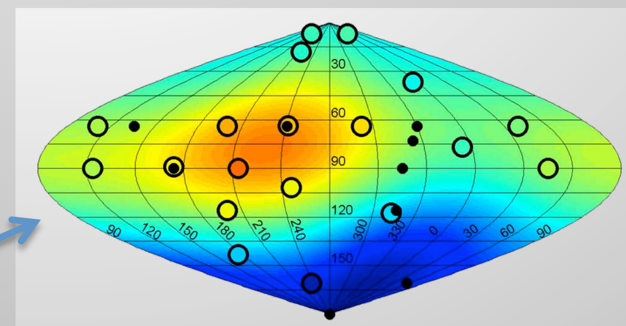
The hohlraums were complicated by Raman (SRS) on the inners: This then required CBET & each affects the other. Unexplained "deficits" in drive, and hard to calculate symmetry ensued. SRS also made hot electrons, which may have affected performance.

2012 Preliminary Compton Radiography implied a low mode asymmetric imploded core, as does nuclear data



(*caveat: Large background subtraction required)

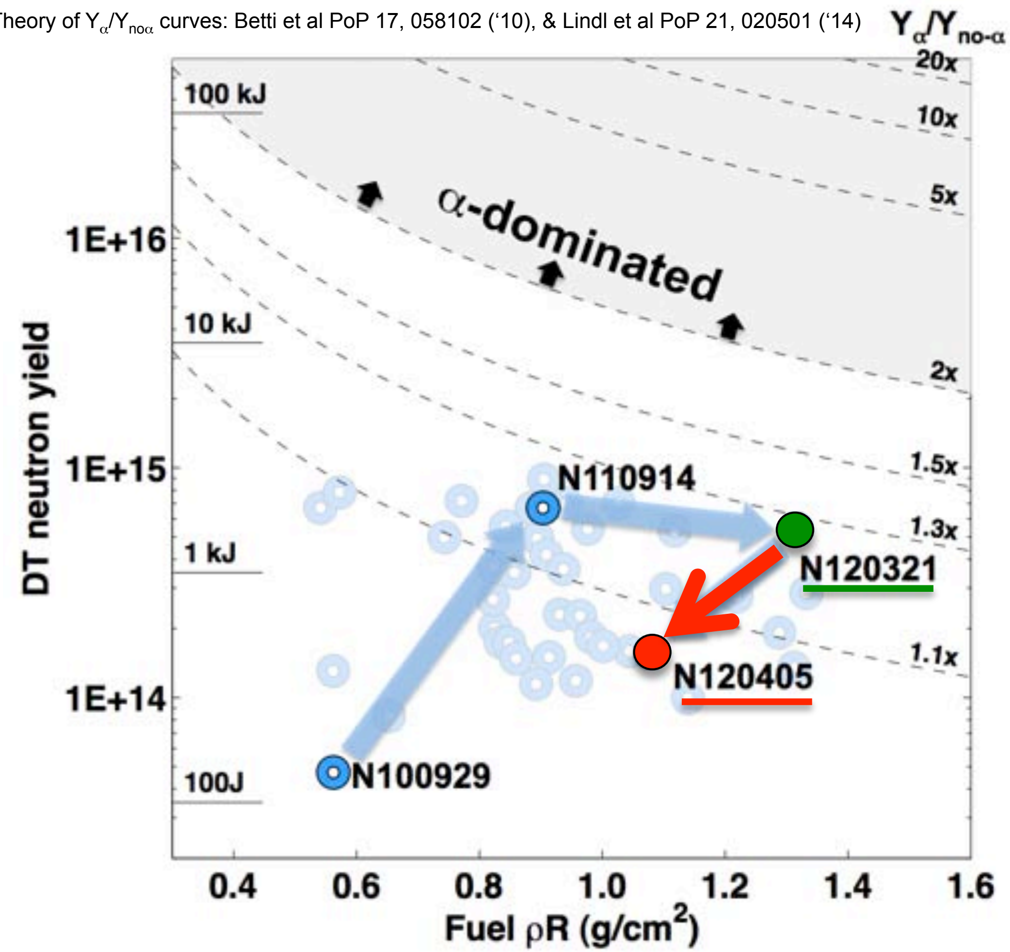
2014: Nuclear diagnostics also imply core asymmetries:
- Bulk velocity flows within the hot spot: "Residual kinetic energy" (RKE)
- ρR variations in the dense ice shell



For more on RKE & nucler diagnostics: B. Spears et al PI1.2, & A. Zylstra et al PI1.6

A major mystery is the CH mixing into the hot spot as we tried to go to higher velocity by using higher power

Theory of $Y_{\alpha}/Y_{no\alpha}$ curves: Betti et al PoP 17, 058102 ('10), & Lindl et al PoP 21, 020501 ('14)



Improving shock timing, & reducing the coast time, led to:

N120321: highest ρR for a DT implosion

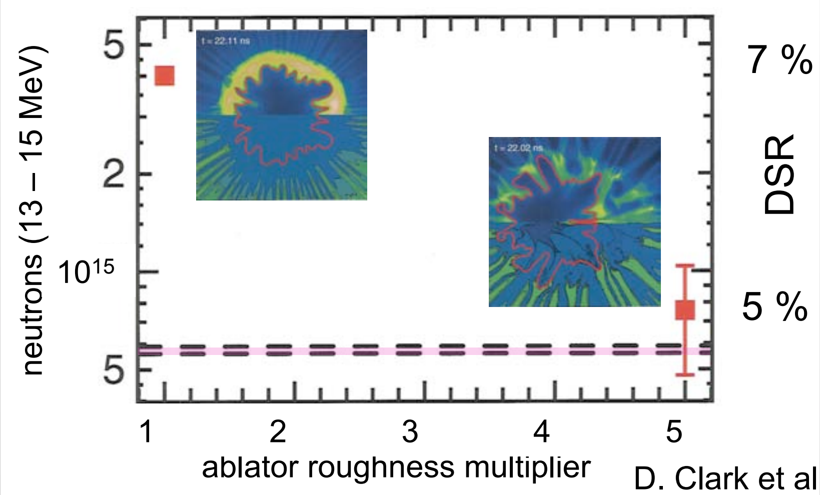
(but ρR 25% less than expected, & yields well below 1-D)

Increased the power for shot N120405 in order to increase ρR & enhance alpha deposition, by imploding faster.

Instead, N120405 crossed a mix cliff

Understanding this mix cliff is crucial in getting past this roadblock to ignition

A “shorthand” for the capsule behavior was: Surface roughness was acting like “4x” larger than measured



D. Clark et al

With “4x”, the yield, & shell ρR* at burn time, is reduced, and is closer to data

*ρR is measured by Down Scatter Ratio, (DSR)

DSR = (10-12) MeV neutrons / 14 MeVs

However, “4x” was simply a “fudge” to reproduce some of the NIC results, - a stand-in for the unexplained degradation

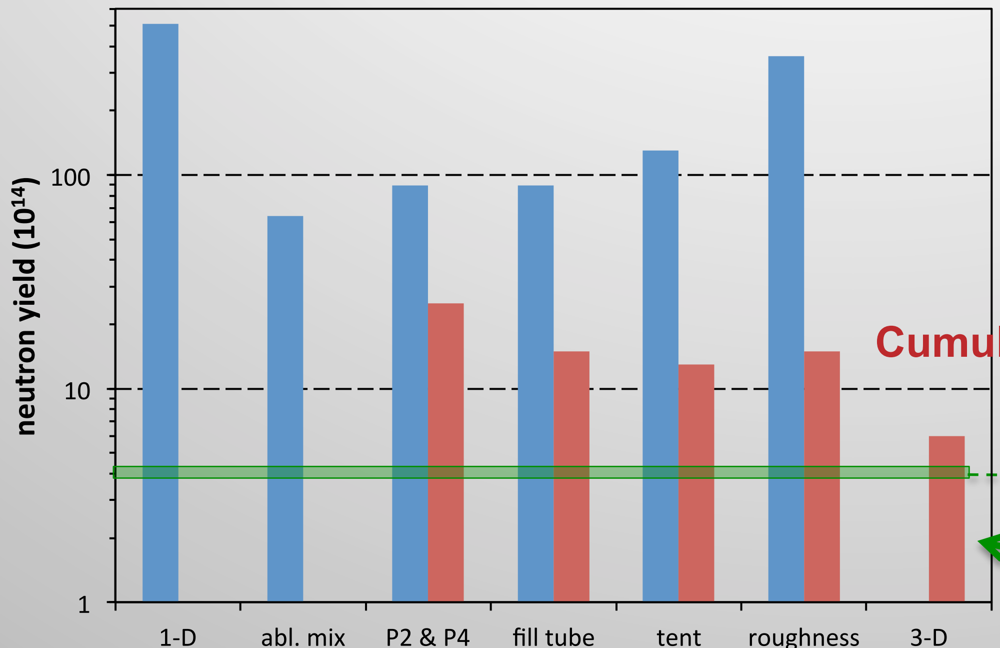
Was the unexplained mix due to errors in growth rates, or due to initial conditions?

More sophisticated 2-D & 3-D attempts are being made to explain the data, assuming "1x" surface roughness

D. Clark et al PoP 18, 082701 (2011),

D. Clark et al PoP 20, 056318 (2013),

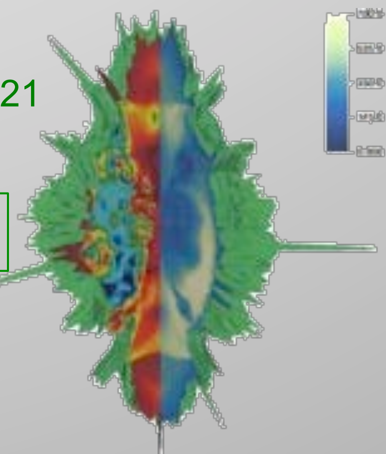
Individual contributors (in 2-D)



Cumulative sequential effect (in 2-D)

Data N120321

3D



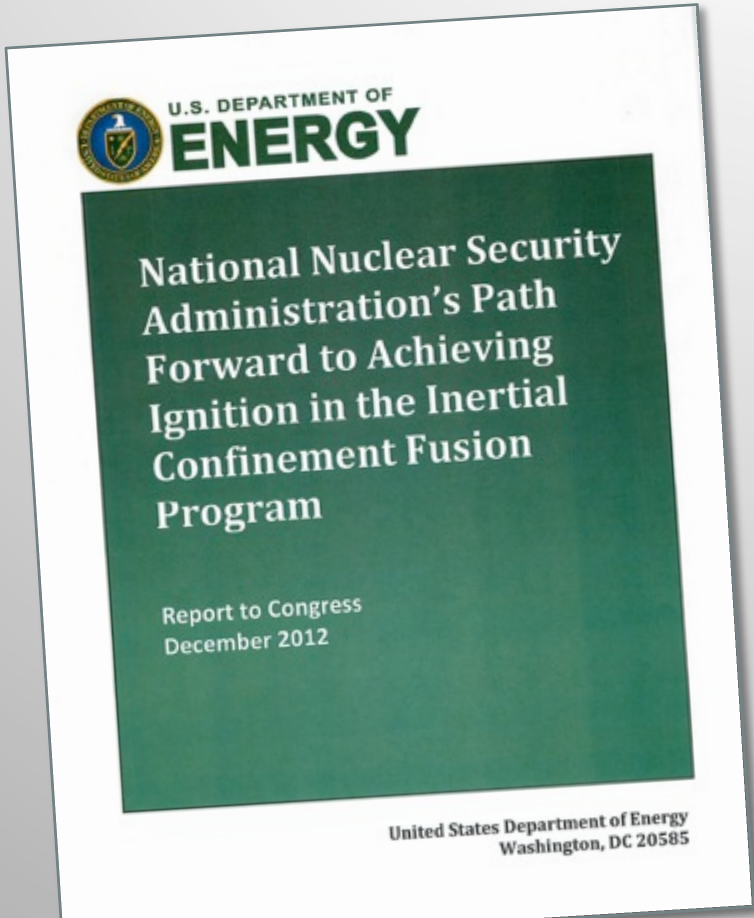
CH pre-mixed, based on early guidance of expt's

Approx. model

"1x"

These impressive 3-D calculations, with all of the effects included, had not been able to reproduce the 1000 ng of CH mixed into hot spot of N120405

At the end of the NIC in 2012, Congress directed NNSA to provide a Path Forward for Ignition


U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration's Path Forward to Achieving Ignition in the Inertial Confinement Fusion Program

Report to Congress
December 2012

United States Department of Energy
Washington, DC 20585

The report outlined a 3-year go forward strategy

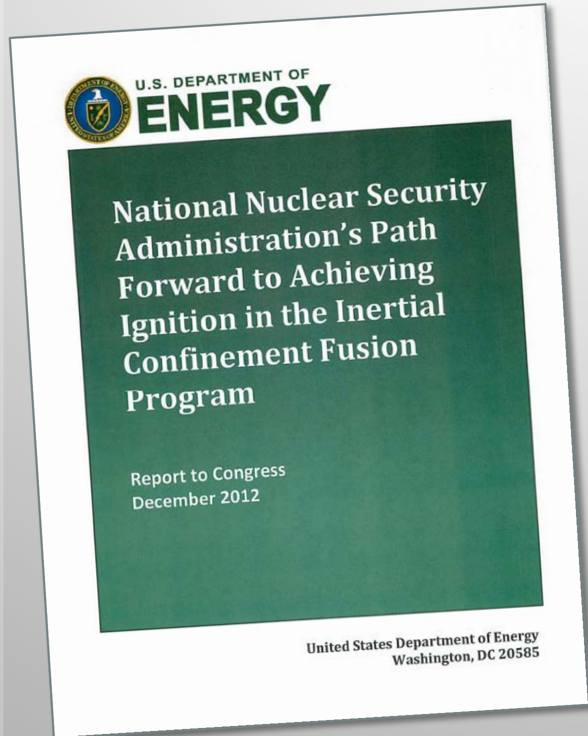
For x-ray drive identify major scientific obstacles to ignition

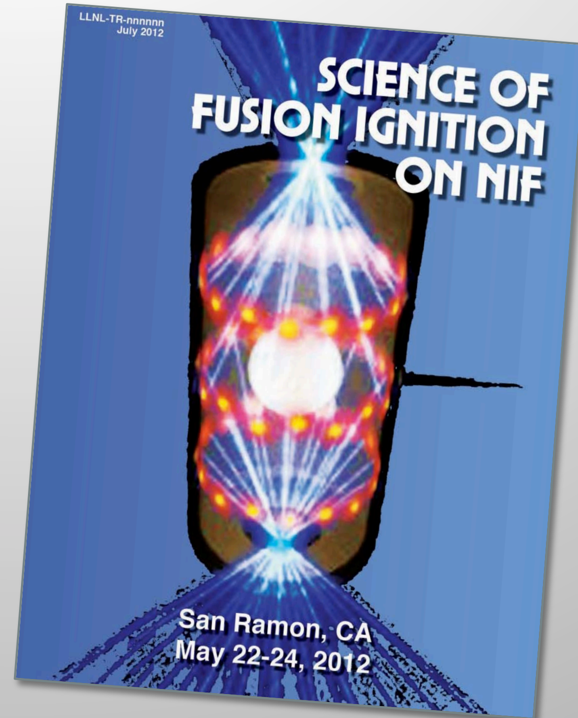
3 elements

- Less stressing integrated experiments
- Focused experiments to study individual physics
- Alternate x-ray driven concepts
  - e.g. Double Shells (LANL / LLNL)

The plan culminates in a Strategic Review at end of FY15. Includes x-ray, direct and magnetic drive approaches

The plan follows much of the guidance from a Community-wide Ignition Science Workshop in 2012





That ~ 150 person meeting was co-chaired by Bill Goldstein and Bob Rosner

We had a ~ 25 person Summer Study (8/14) to follow up, & to seek further guidance

Our successes in the last 2 years are a tribute to that broad community involvement

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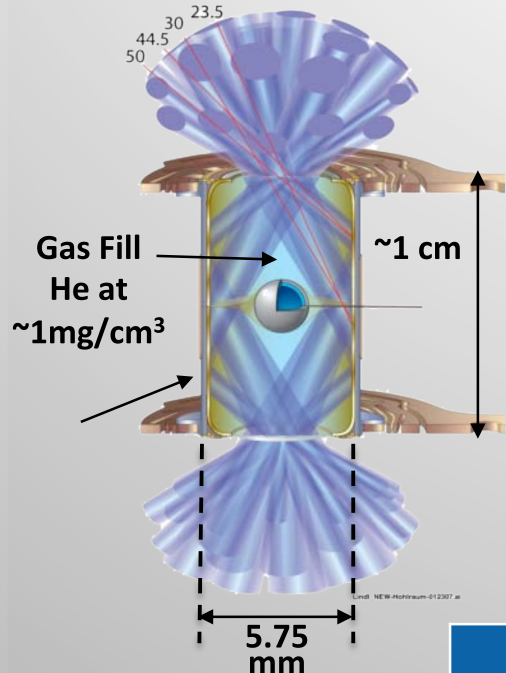
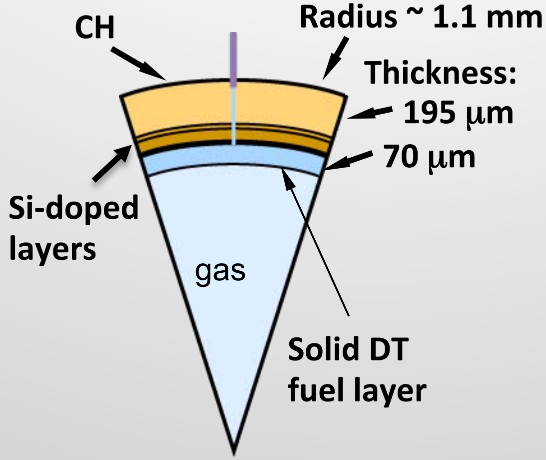
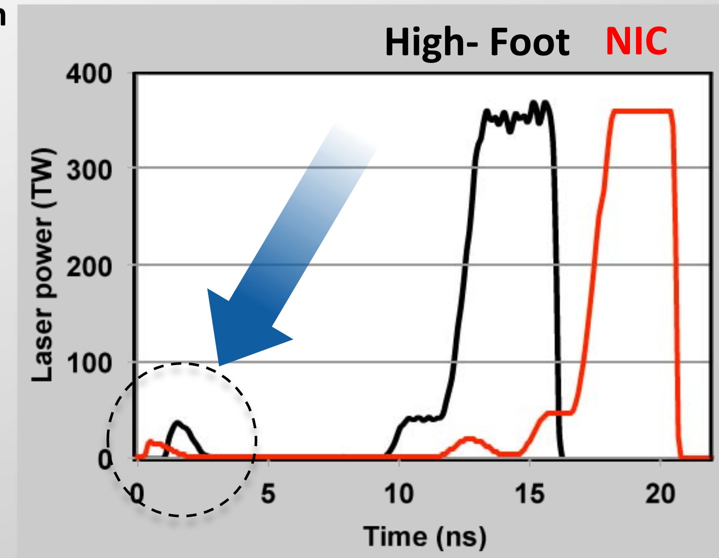
High Foot: 3-shock CH ablator at higher adiabat. Less Stress



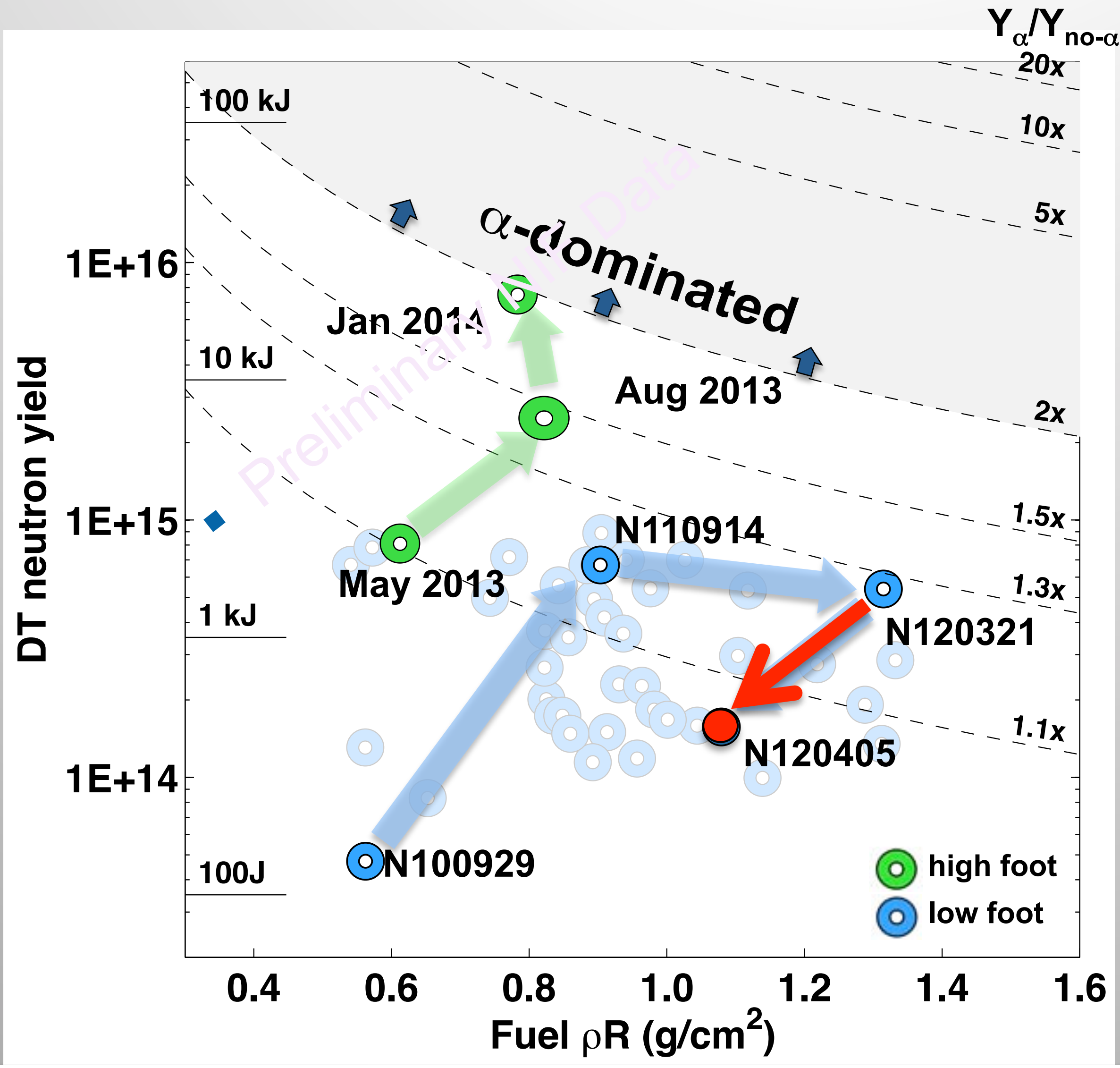




	NIC Low-foot	High-foot
Adiabat (a measure of entropy)	~1.5	**Increased to:** ~2.5
In-flight aspect ratio, (IFAR) = R/ΔR	~20	**Reduced to:** ~16
Convergence	~45	**Reduced to:** ~30

It trades ultimate performance for much greater stability and less sensitivity to shape

Whereas NIC Low Foot implosions "went down" at higher velocities, the High Foot implosions went up…

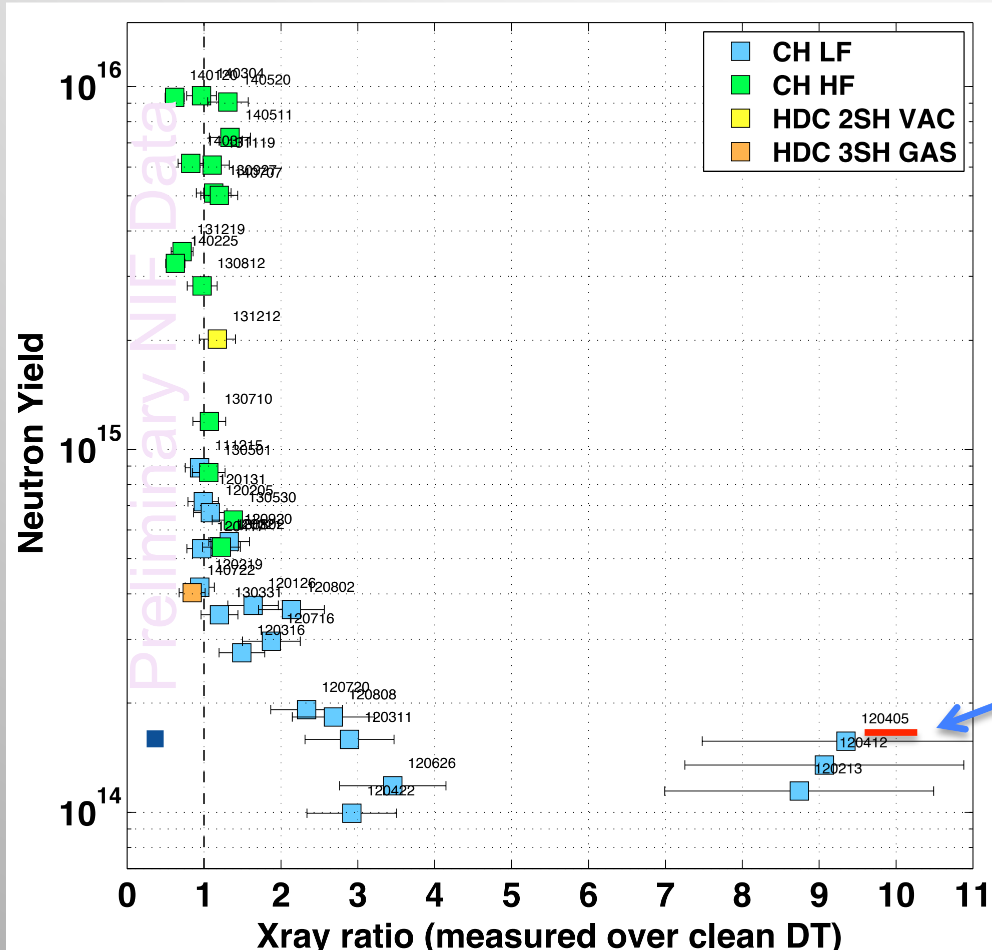


…albeit, at lower compressions,

but

more stable,
as evidenced by…

… the High Foot implosions showed no evidence of CH-into-Hot-spot Mix, while Low Foot did

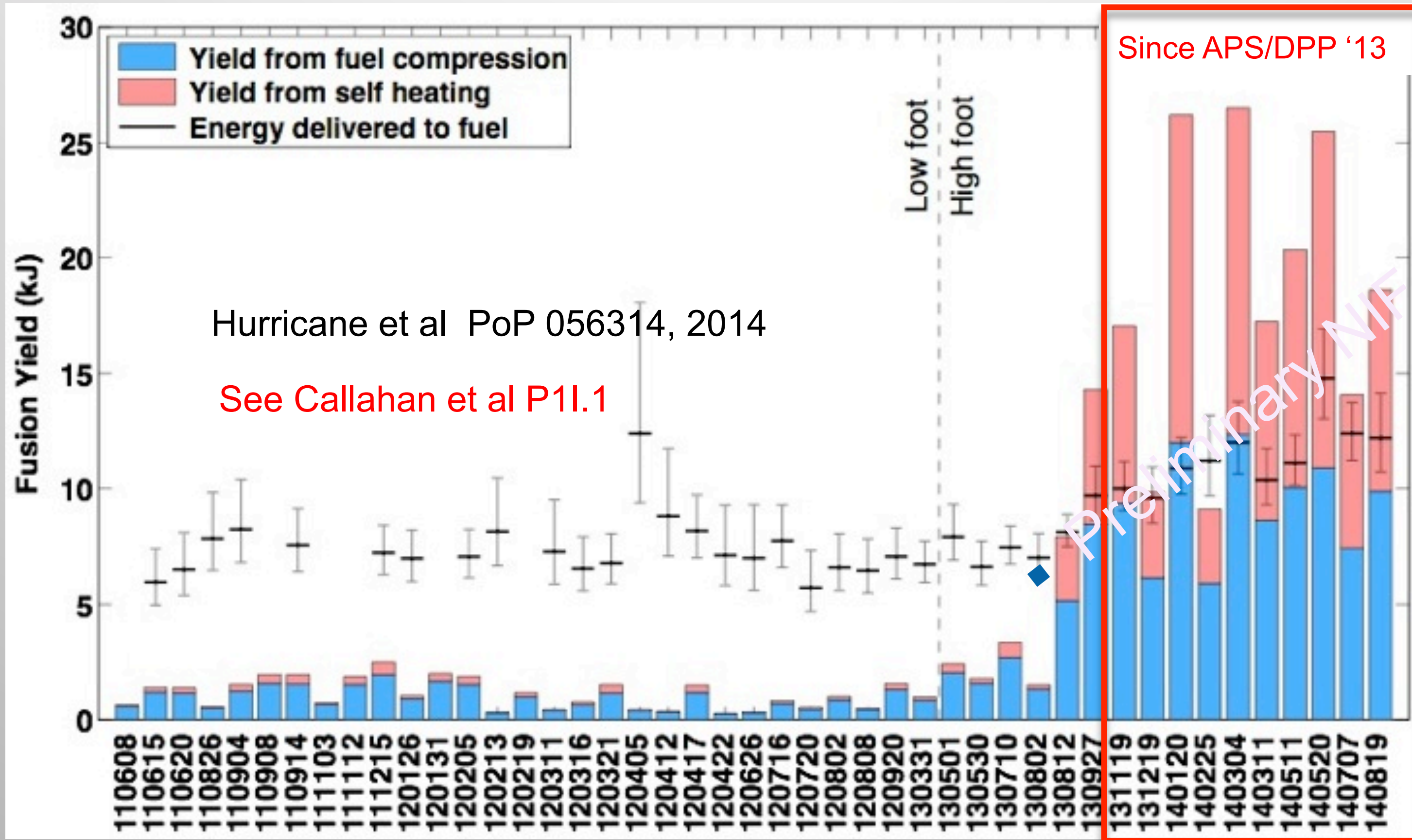


- High foots show no mix
- HDCs show no mix
- Highest Power Low Foots show ~ 1000 ng of CH mixed into the hot spot
- X-ray ratio is enhanced when higher Z CH mixes all the way into the hot spot

Mix →

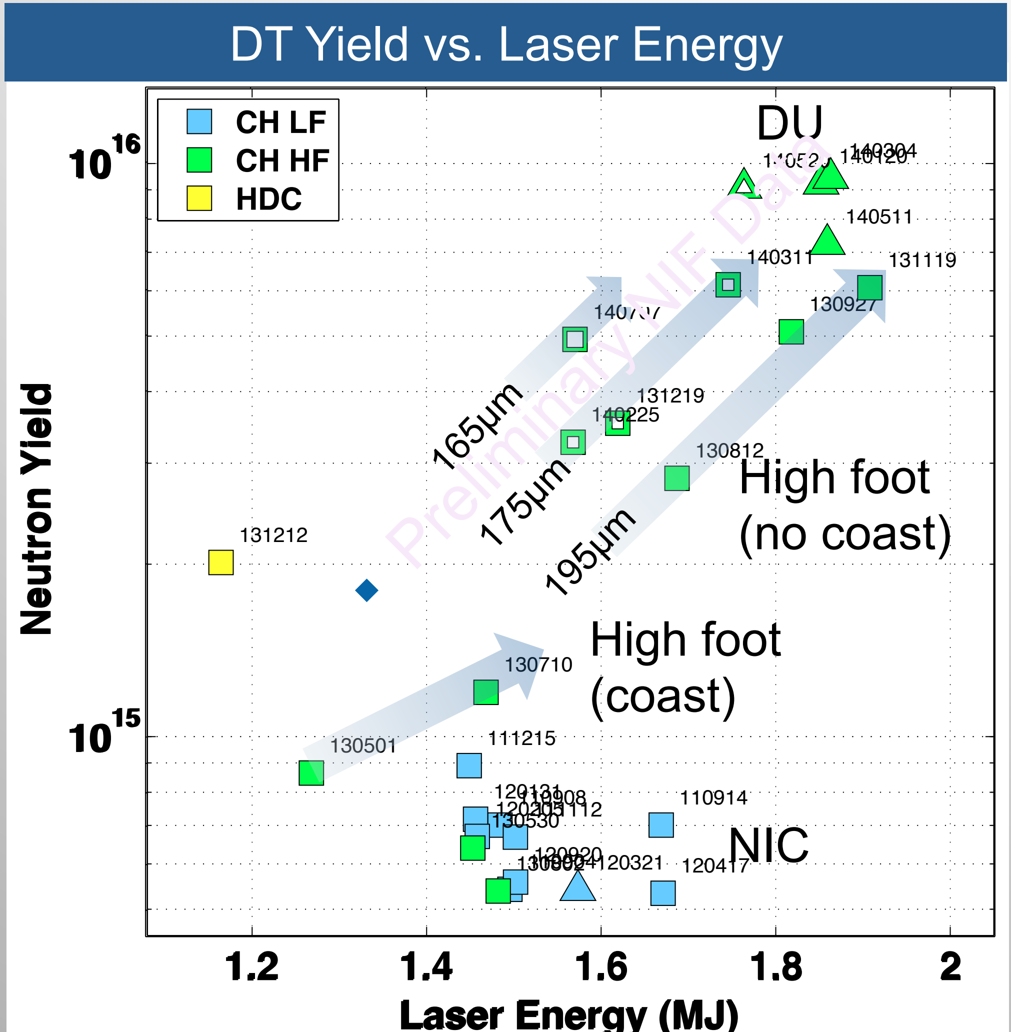
Courtesy of Prav Patel

Increasing implosion velocity has resulted in ~ 2x increase in neutron yield since last year's meeting



The best performing of these ~ double the yield due to Alpha Deposition

High Foot is approaching several limits – next will be taking steps along new axes



Approaching limits

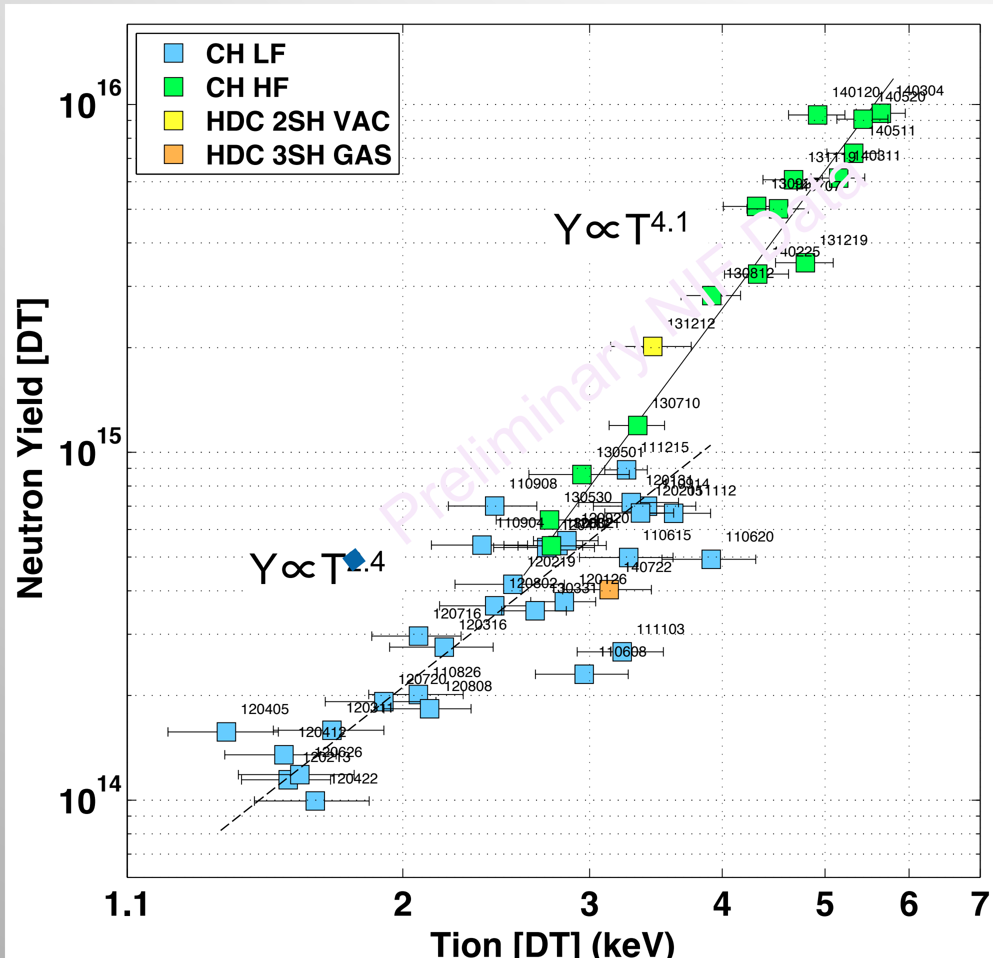
- Laser power, energy
- P2 symmetry control
- Velocity from 320 to 380 km/s:
  - Capsule burn-thru (?)

Next

- Higher convergence (ρR)
- Improved symmetry
- Better hohlraum / coupling

Hurricane, Callahan and Team:
E. Dewald, T. Dittrich,T. Doeppner, D. Hinkel, M. Barrios, D. Casey, L. Berzak Hopkins, S. Haan, B. Kirkwood, P. Kervin, A. Kritcher, J. Lee Kline (LANL), A. Kritcher, S. Le Pape, T. Ma, A. MacPhee, J. Milovich, J. Moody, P. Michel, A. Pak, P. Patel, J. Ralph, H.-S. Park, B. Remington, R. Rygg, H. Robey, J. Salmonson, P. Springer, R. Tommasini, ICF Tuning Platforms, NIF operations, NIF cryo, NIF targets, NIF Diagnostics, Code groups, LANL, GA, LLE, & M.I.T.

High Foot vs. Low Foot: Yield vs. Ion Temperature



- High Foot Yields ***do*** scale with a power law of T that would be expected for a near 1-D system
  - — Models predict High Foot yields within 2-3 x of the data
- Low Foot Yields do ***not*** scale with a power law of T that would be expected for a near 1-D system

Courtesy of Prav Patel

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High Density Carbon opens up other avenues for enhancing performance, (as does Be)

- **High density (3.5g/cc) => ~3x thinner ablator**
  - **Absorbs more energy than CH for same outside diameter**
  - **Ignition designs have ~2x shorter laser pulses than CH**

- **Short pulse => suitable for near vacuum hohlraums**
  - **40% more drive**
  - **Almost Laser Plasma Interaction (LPI) free :**
    - **No Cross Beam Energy Transfer (CBET) needed**
    - **Negligible Stimulated Raman Scattering (SRS) and hot electrons**

N. Meezan, A. MacKinnon, L. Berzak Hopkins, L. Divol, D. Ho, S. Ross, S. LePape, J. Milovitch, T. Ma, A. Pak, S. Khan, et al

HDC Yield of ~ 3 10^{15} has already exceeded that of the NIC by > 3x

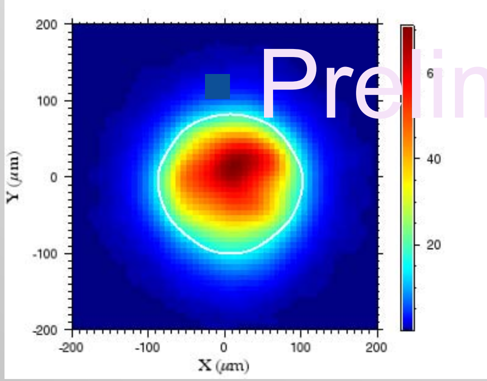
Early results on HDC show promise

See L. Berzak Hopkins PI1.4

At ~10x convergence: Still 1D performance

At ~30x convergence: Symmetry swings & prolate shape explain mild degradation

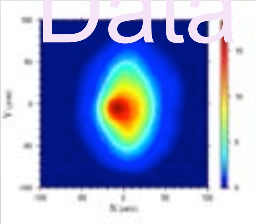
80 µm HDC "Sym-Cap" capsule
2 shock; 1.2 MJ; 6.3 ns



Y=1.5 10^{15} = 2D-Yield= 1D-Yield

- Fuel Rho*r is ~ 0.025 g/cc
- Tion ~ 3.4 keV; Te ~ Ti
- Pressure ~ 11 Gbar
- Adiabat ~ 4.5

80 µm HDC layered DT
2 shock; 1.2 MJ; 6.3 ns

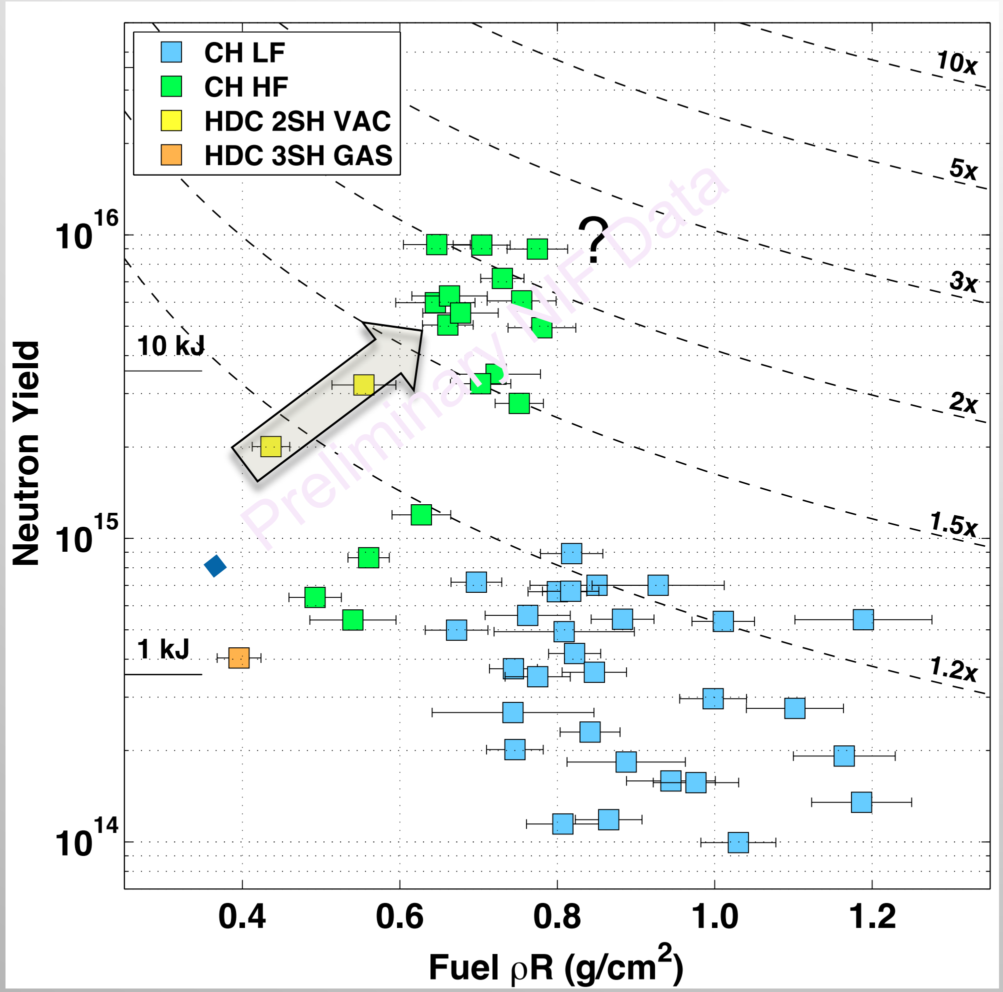


Y=2 10^{15} = 2D-Yield = 40% 1D-Yield

- Fuel Rho*r is ~ 0.77g/cc
- Tion ~ 3.84 keV; Te ~ Ti
- Pressure ~ 100 Gbar
- Adiabat ~ 3.5

The recent 8 ns DT shot, at > 30x convergence, had higher ρR, & Y~ 3 10^{15}

Going forward plan for HDC

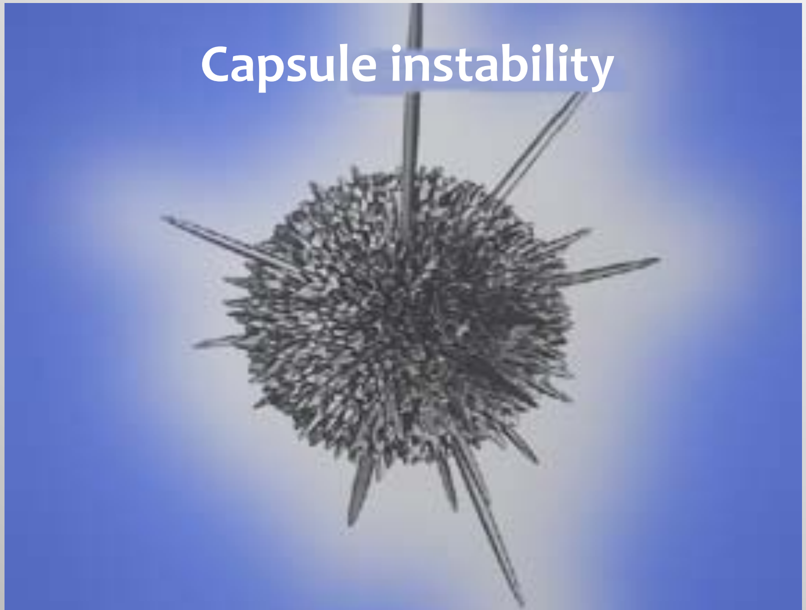


HDC has "head room" to test:

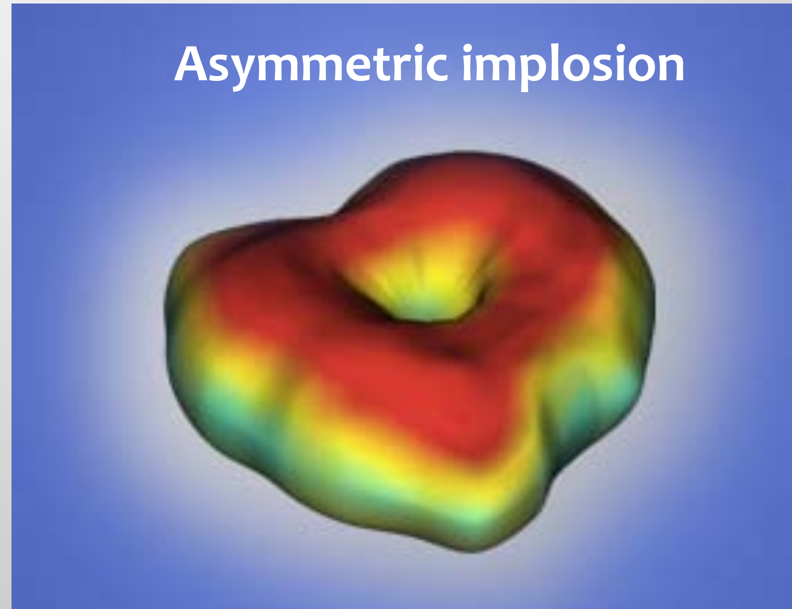
- Thinner shells – to achieve higher velocities
- "No Coasting", longer pulse shapes to achieve higher velocities and higher ρRs
- Test hydro growth (on HGR platform) to determine shell doping requirements
- Test symmetry control in Near Vacuum Hohlraums

Performance to date has been encouraging, with many more things to try

We have made progress in understanding the degraded performance of the NIC Low Foot implosion



Growth x Surface seeds is too large leading to mix at lower velocity than predicted



X-ray push on the capsule is not symmetric enough resulting in loss of efficiency at stagnation

The hohlraums were complicated by Raman (SRS) on the inners: This then required CBET & each affects the other. Unexplained “deficits” in drive, and hard to calculate symmetry ensued. SRS also made hot electrons, which may have affected performance.

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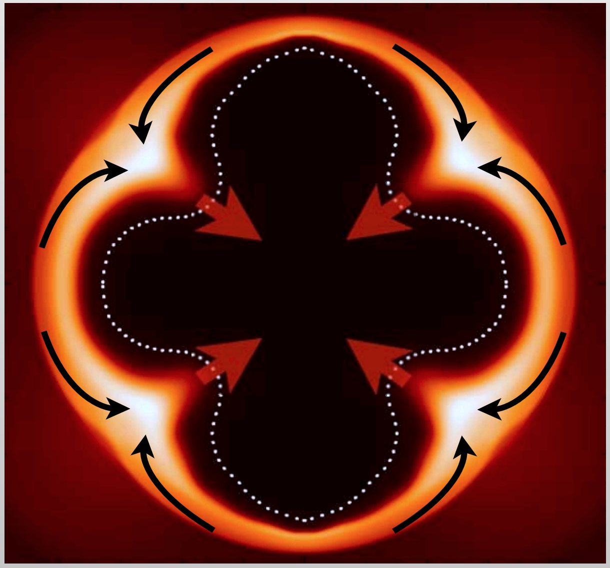
Asymmetries set up non-radial flows, whose kinetic energy will not convert to thermal upon stagnation



R. Scott, PRL 110, 075001 ('13)

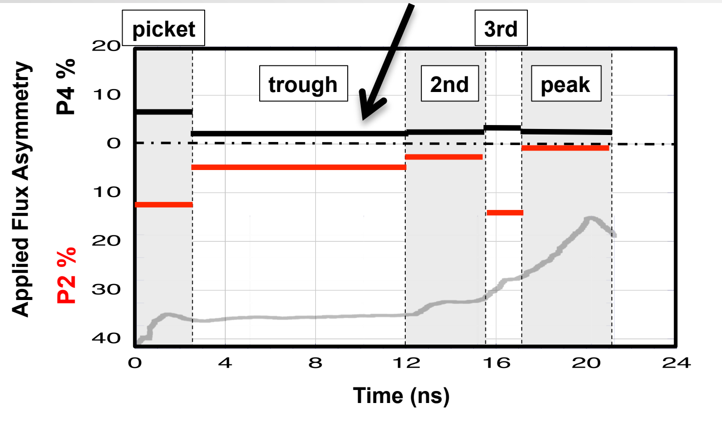
A. Kricher et al PoP 21, 042708 ('14)
R. Town et al PoP 21 , 056313 ('14)

What's worse, if the symmetry varies in time, sloshing will occur wherein the flow fields can reinforce this residual kinetic energy (RKE)

Many important symmetry diagnostics are in the pipeline

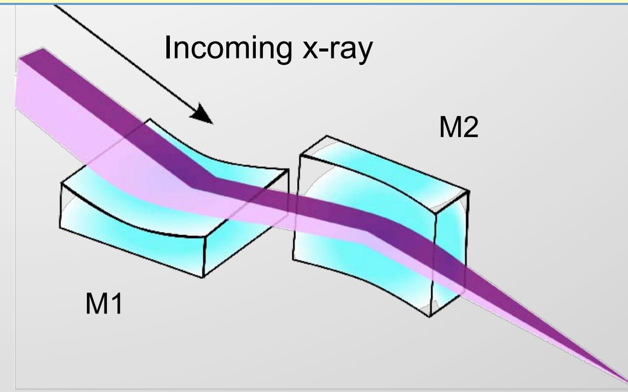
Thin shells / foam balls to diagnose symmetry during the trough

85% Yield Over Clean contour



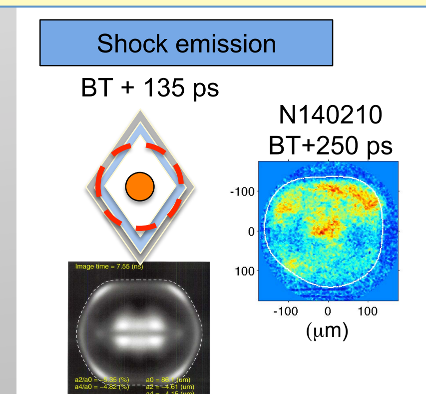
A. Kricher et al PoP 21, 042708 ('14) R. Town et al PoP 21 , 056313 ('14)

KB Microscope for better core late-time self emission resolution



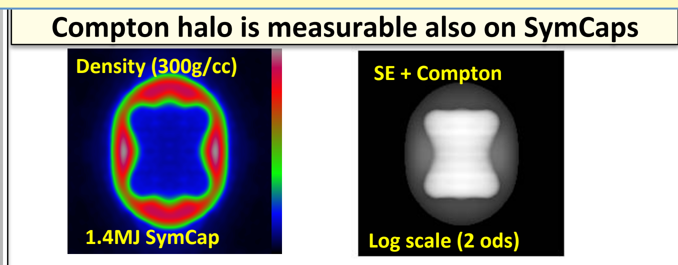
M. Barrios, R, Rygg, et al

Imaging outgoing shock to diagnose dense shell at stagnation



A. Pak et al

Pinhole camera for Compton halo of dense shell at late times



N. Izumi et al

Time dependent symmetry swings may be compromising the core symmetry

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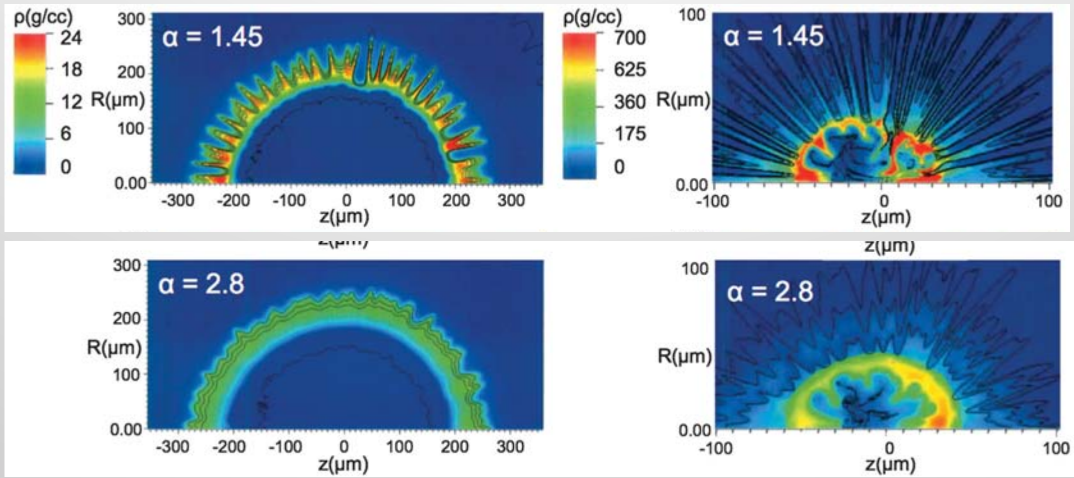
The High Foot was predicted to be more stable than the Low Foot. Confirm that directly with a focused experiment

LF vs. HF Comparison done at "4x", (because at "1x" the Low Foot did *not* mix)

Low Foot:
at 4x

High Foot:
at 4x

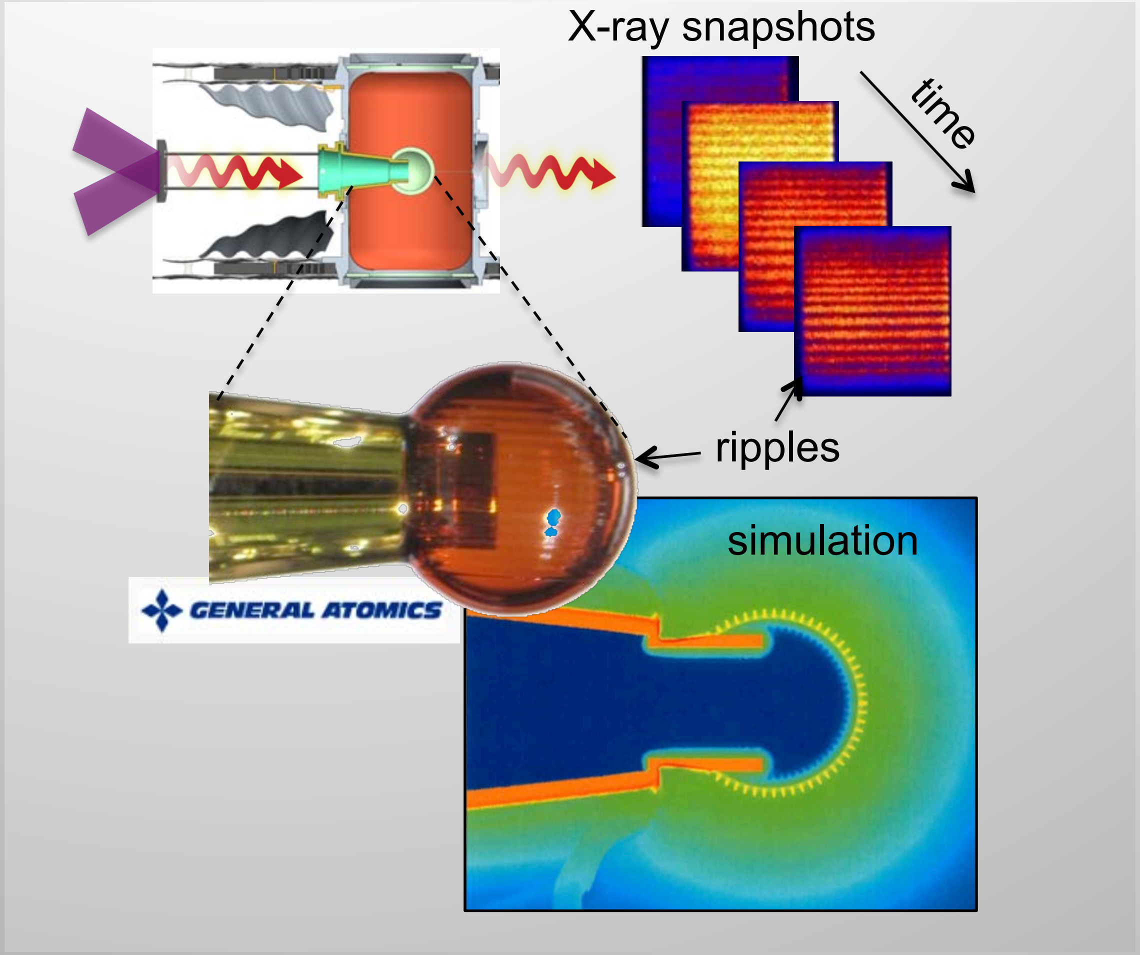


T. Dittrich et al
PRL **112**,
055002 (2014)

And more fundamentally, measure the Low Foot hydro-instability Growth Factors, to answer the question:

Was the unexplained mix in NIC due to errors in growth rates, or in initial conditions?

The Hydro-Growth-Radiography (HGR) Platform has proven invaluable for clarifying relevant ICF physics

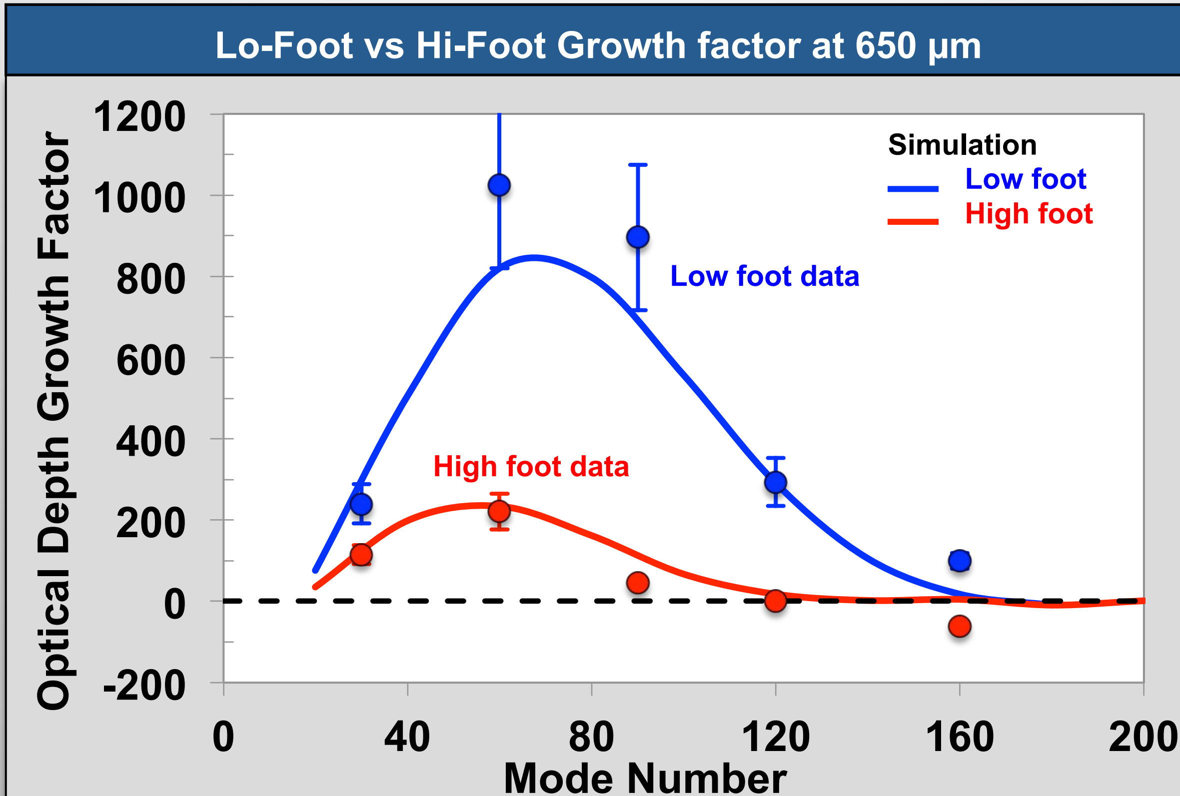


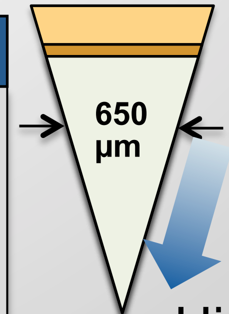
V. Smalyuk, et al,
PRL 112, 185003 (2014)

See L. Peterson PI1.3

This platform is in the midst of a long string of extremely useful studies

The Hydro-Growth-Radiography (HGR) Platform has been applied to Low Foot and High Foot drives





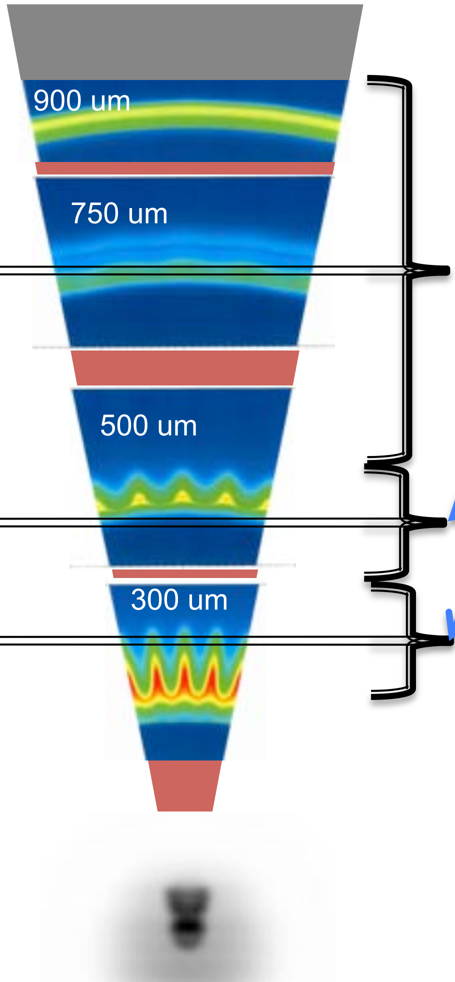
Higher convergence

See L. Peterson PI1.3

D. Casey et al, PRE 90, 011102 ('14)
K. Raman et al, PoP 21, 072710 ('14)

Confirms that High Foot is more stable, but deepens the mystery why Low Foot mixed

So far, the HGR results rule out errors in Growth Factors, at least for imposed ripples at the ablation surface.



Measure growth of 2D, 3D perturbations and native surfaces

- **Ablation front – accel phase HGR**

Besides ablation front growth, there are ***other*** hydro growth issues to pursue, as well as CH initial conditions

- **Ablator-ice interface – accel phase layered HGR**
- **Deceleration growth by self backlighting**

Is the NIC mix due to errors in *other* growth rates, or in the initial conditions?

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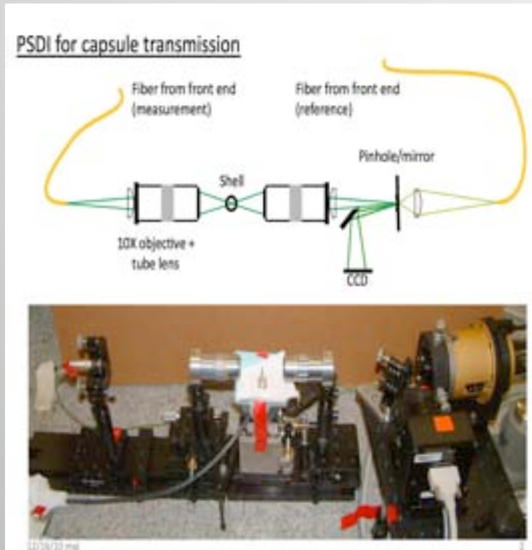
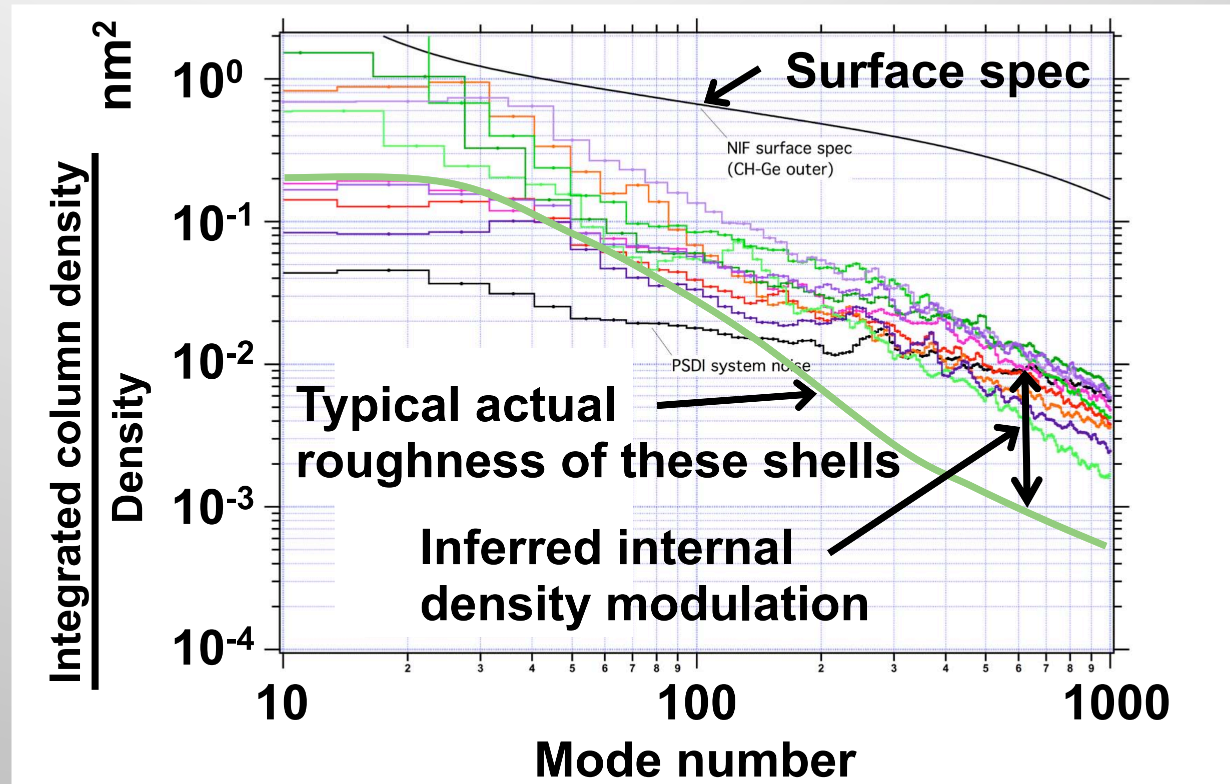
S. Haan has recently had an insight into the “4x” problem

The known internal modulations in CH were assumed to be *pure CH* perturbations
If so, they are well below Spec, and grow ~ as surface does, thus ***not*** a threat



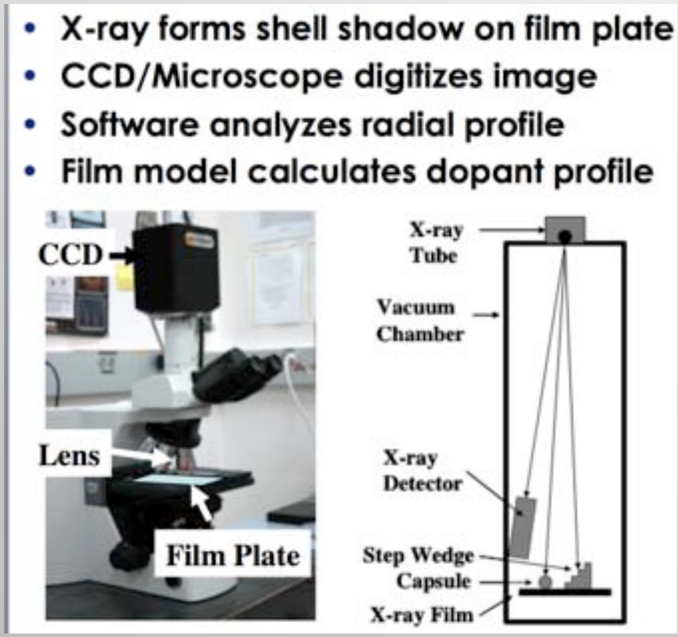
Internal density modulation data via optical deflection / index of refraction

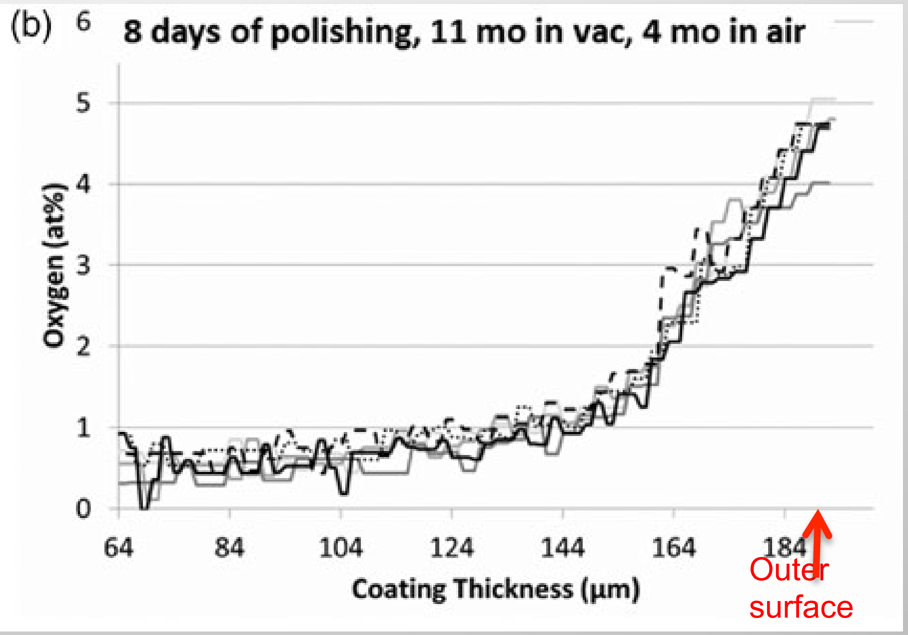


But, if these modulations are due to ***Oxygen***, not CH, growth will exceed Spec

We've known there *is* Oxygen internal to the CH

But its affect was only assessed in the *1-D* sense (velocity reduction)



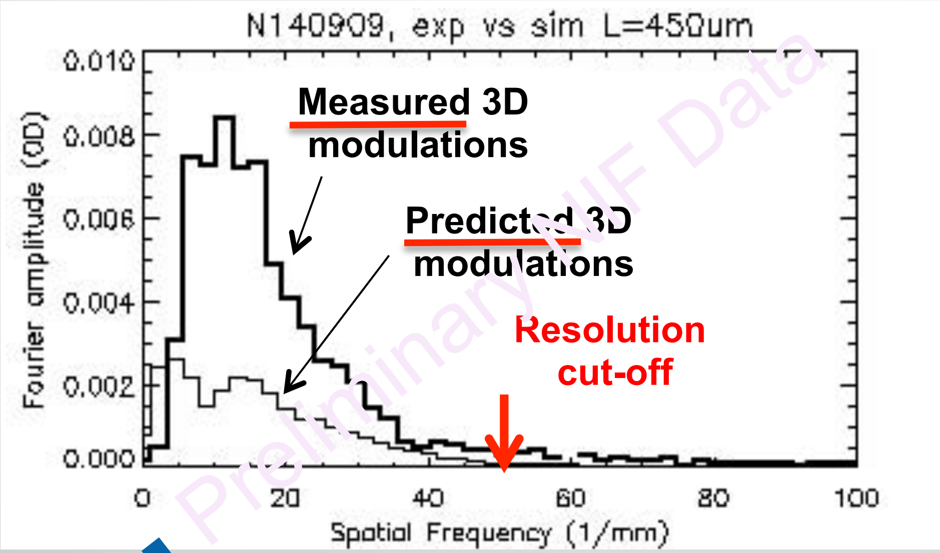


Oxygen Data via X-ray radiography

H. Huang et al Fus. & Sci. & Tech. **63**, 142 (2013)

The effect of this Oxygen as a 2-D / 3-D source of perturbation is >> than that of CH

HGR was done on a "1x native roughness", and modulations were 4x of the predictions !



K. Baker, S. Weber, D. Casey, P. Celliers, J. Field, A. Hamza, V. Smalyuk, H. Robey,et al

Some of this 4x discrepancy may be due to insufficient 3-D numerical resolution, insufficient photon groups in 3-D, etc (~ 1.5x)

The rest may be due to the Oxygen contamination as a possible source of the non-uniformities (~ 2.5x)

P. Celliers has also seen "4x" type enhancements in velocity field perturbations on CH at Omega, though noise levels are high

CH (+ internal, modulated Oxygen) may have been ~ "4x" all along

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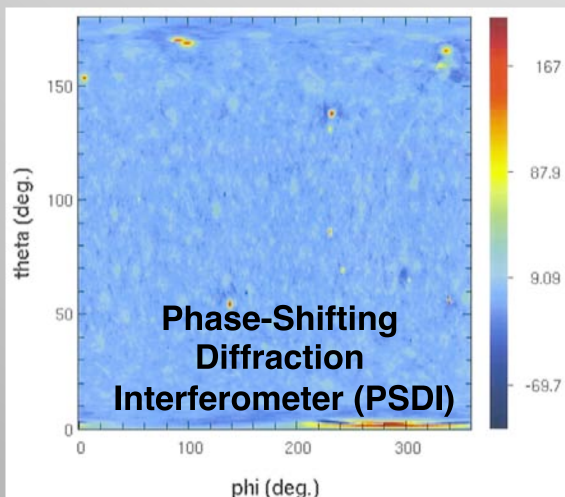
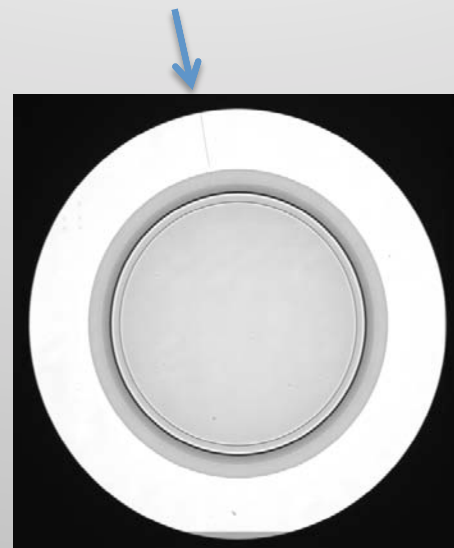
There are several other potential seeds for instability

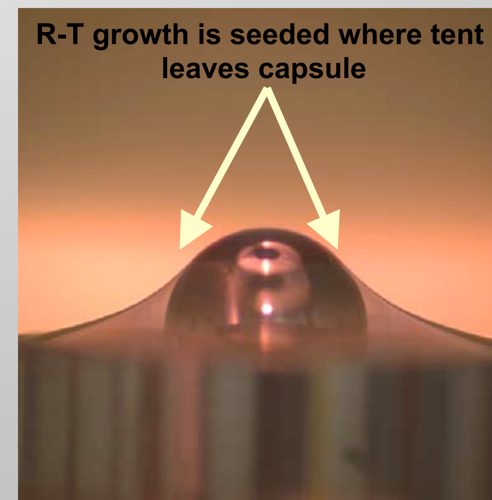
Bumps, divots, dust, bulk inhomogeneities



Fill Tube
~ 10-µm-diam SiO_2



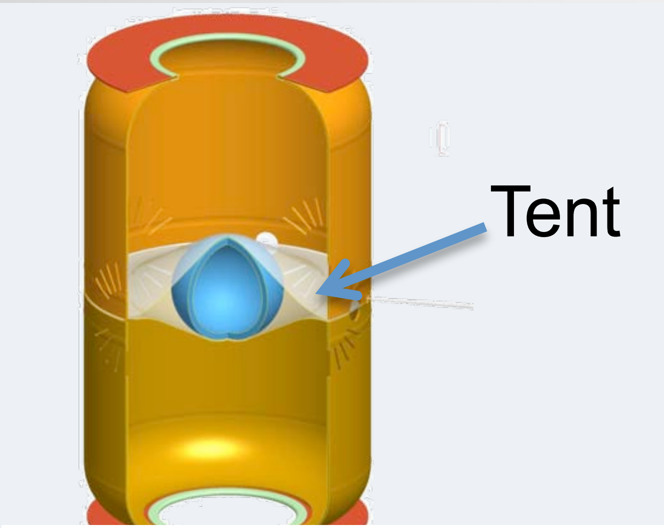
Support "Tent"
~ 50-nm-thick plastic (Formvar)



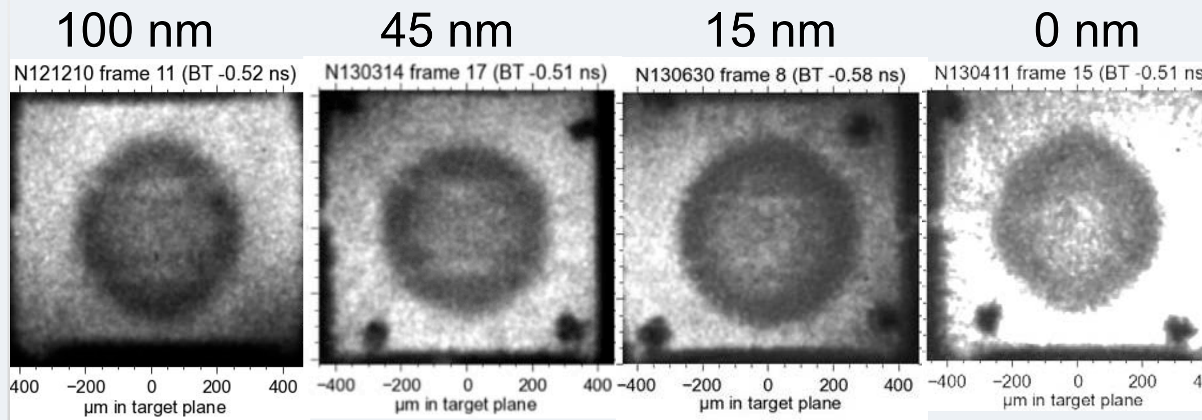
Recently, B. Hammel has had an insight into properly modeling the tent

Since NIC, the new 2-DConA platform opened our eyes to the effect of the tent

See R. Tommasini PI1.5



Backlit radiographs of imploding capsules



"tent scars" at radius = 200 μm

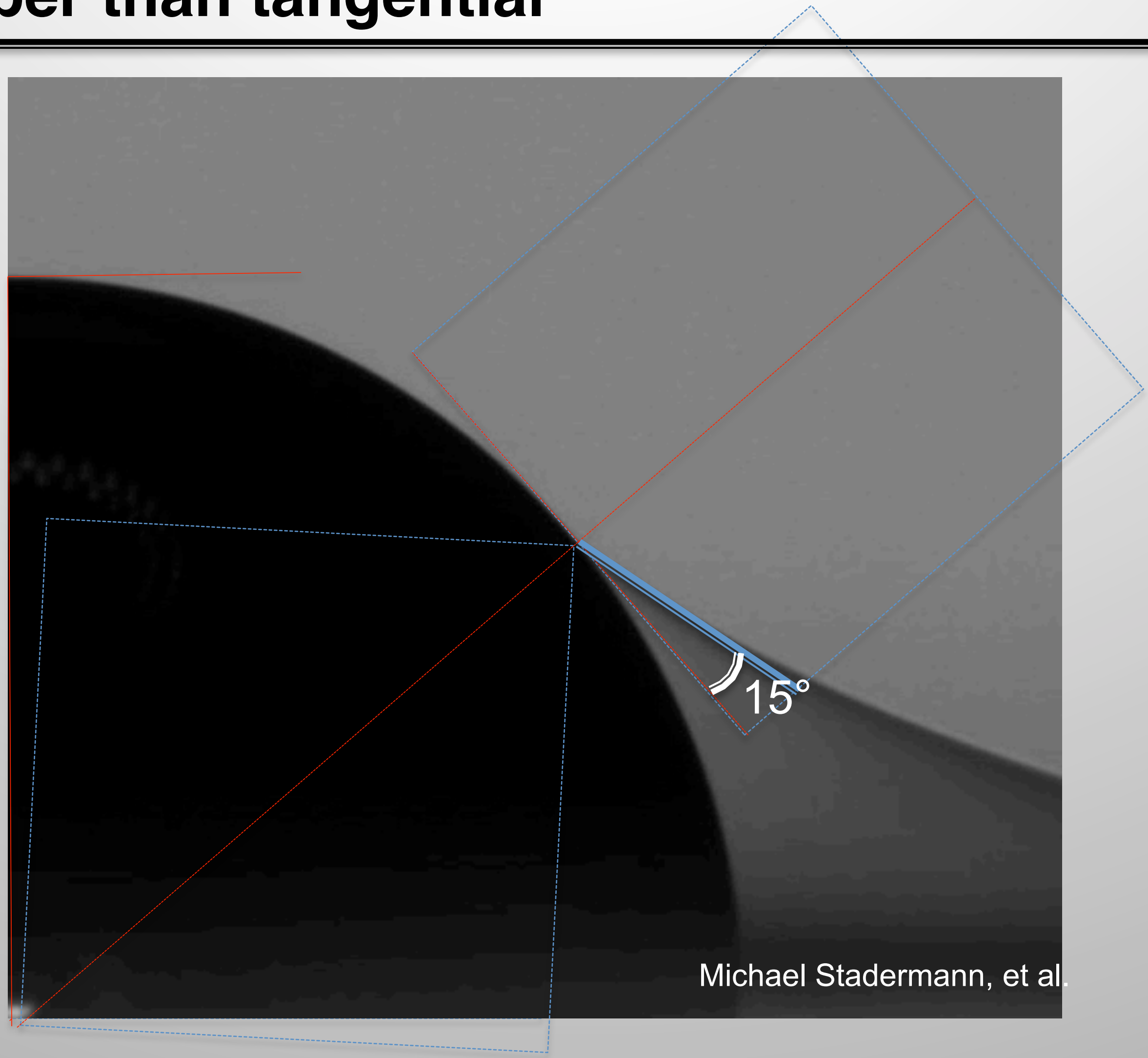
Previous high resolution tent simulations did predict that the effect of the tent was severe enough to influence the shape of the hot spot x-ray self emission

but

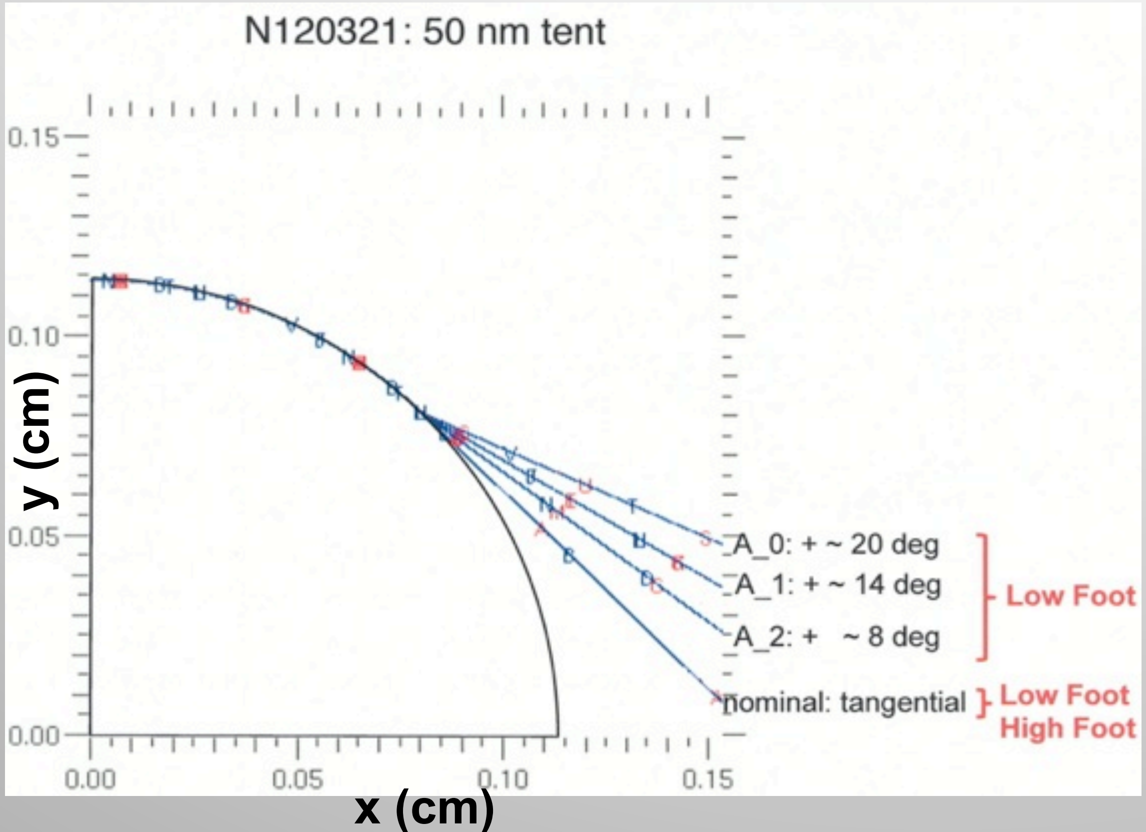
Previous high resolution tent simulations predicted "tent scars" 2-3x < than data

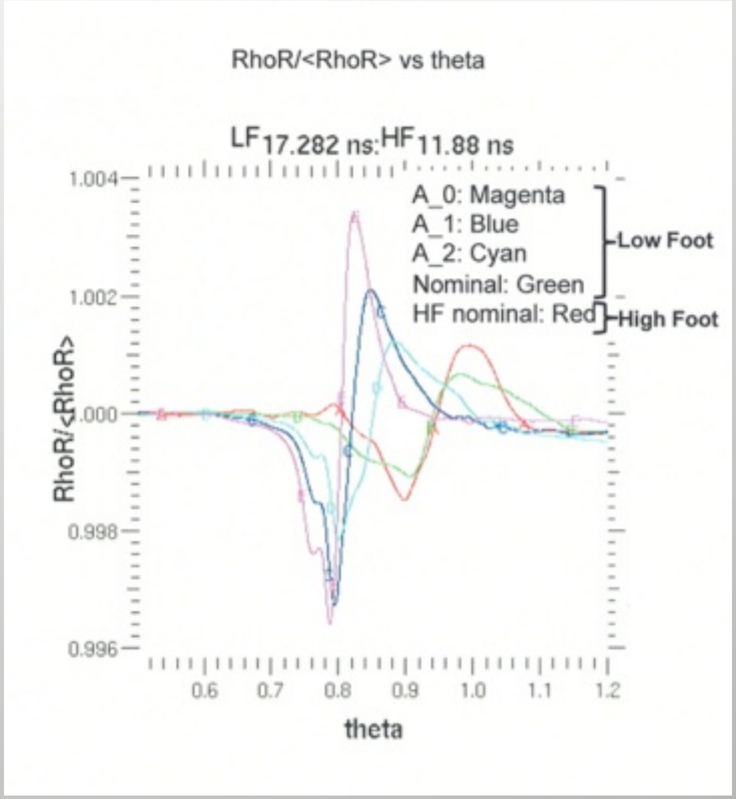
The perturbation's severity depends on the *angle* at which the tent leaves the surface

Measurements suggest that tent departure angle is steeper than tangential



Departure angles steeper than tangential lead to more growth

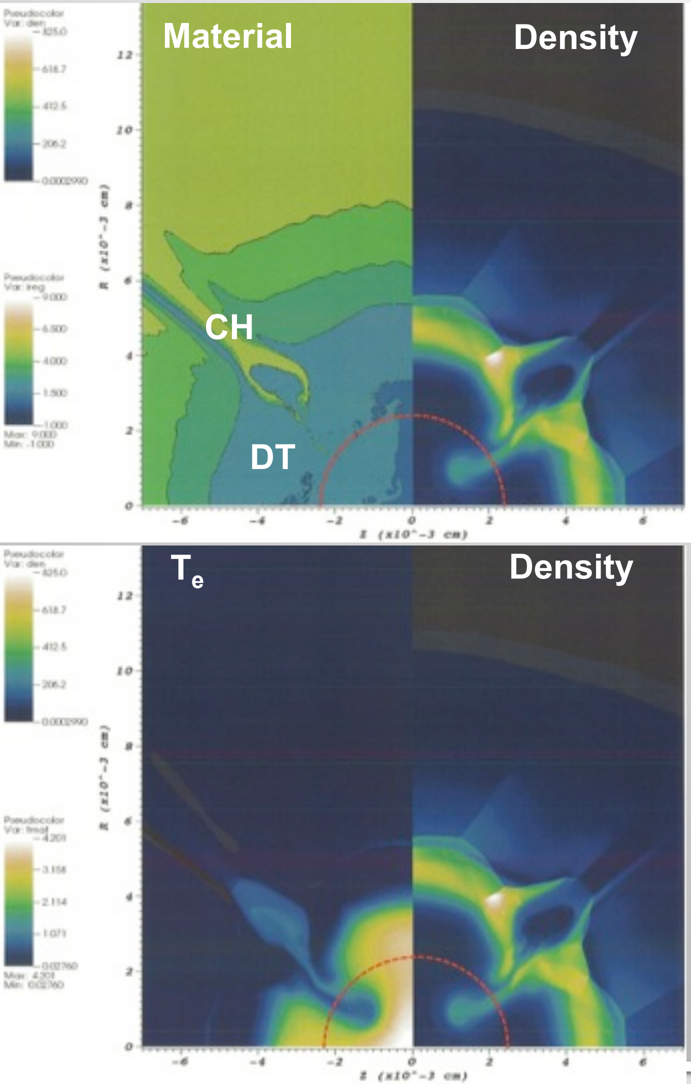




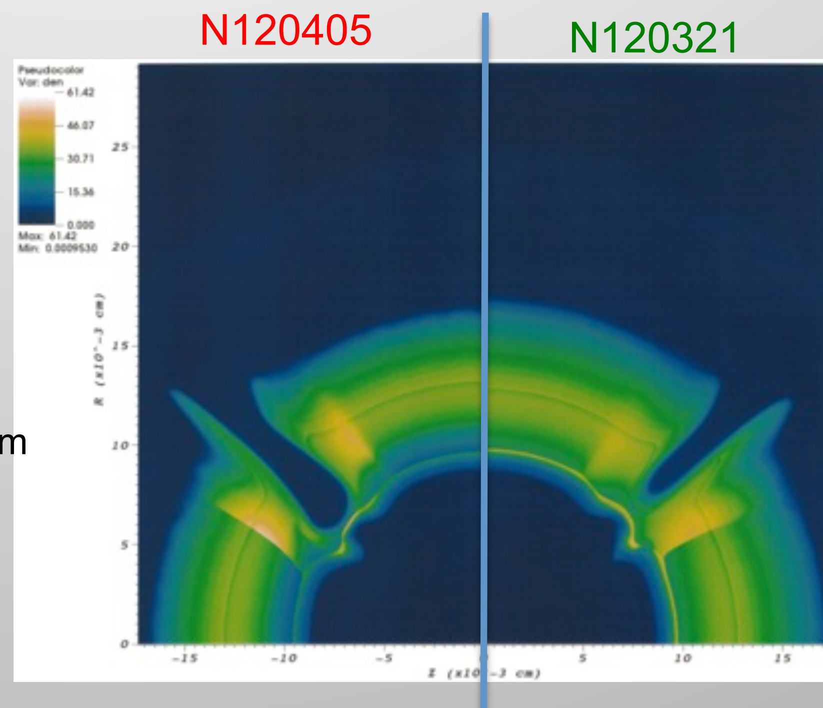
Using the correct angle now correctly predicts the tent scar in the 2DconA images

With a 100 nm tent, the high power NIC shot, N120405's tent injects ~ 500 ng of CH into the "hot-spot"

"bang time": 200 ng of CH in Hot Spot; At "b.t." + 60 ps: 500 ng (for N120405 100 nm tent +14 degree)



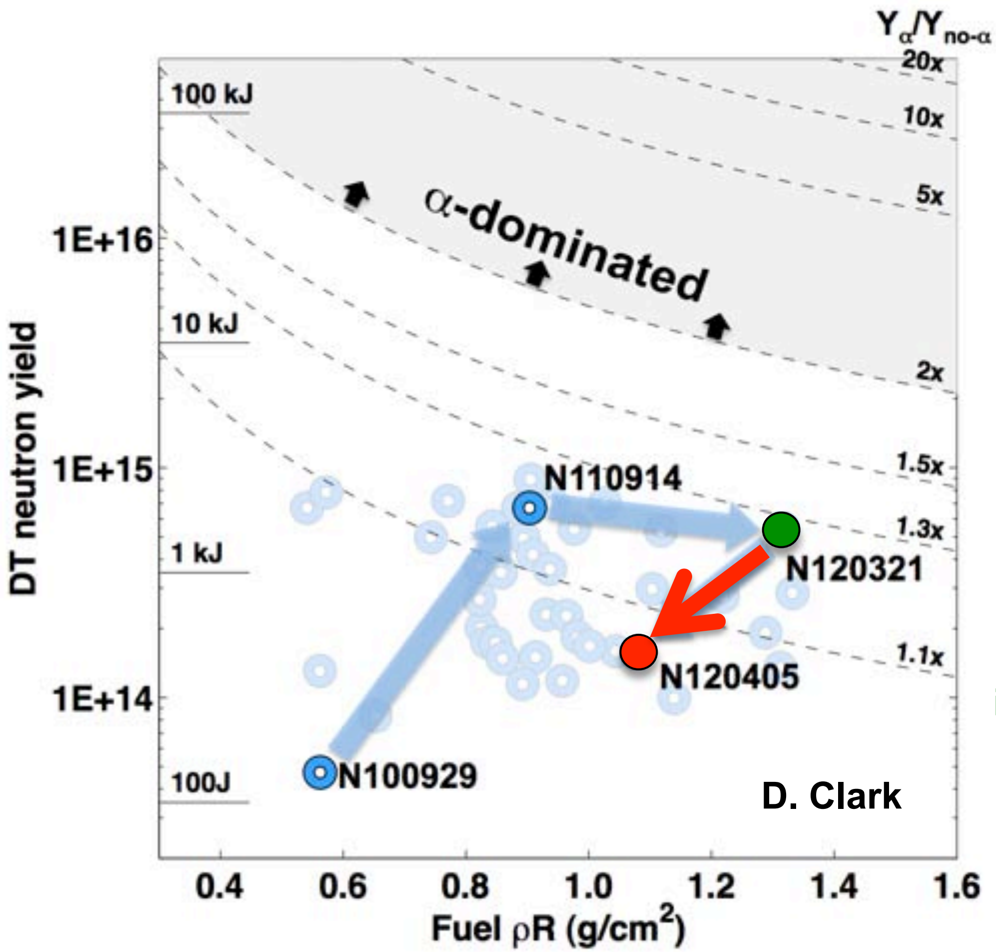
Also, predict: *No* CH into the hot spot for the lower power shot N120321



100 µm

N120405: 3x reduction in yield just due to tent

The "4x" initial condition, *plus* the 100 nm tent, (now properly modeled), may help explain NIC capsule performance



Together they may be able to help the full 3-D simulations:

- Match N120321 yields, ρR etc, & maybe still *not* introduce much CH into the hot spot

- Match N120405 yields, ρR etc, & introduce ~ 1000 ng of CH into the hot spot

(N120321 did *not* have significant CH mixed into the hot spot, while N120405 heavily mixed)

Focused experiments & new insights has led to this possible "parting of the clouds"

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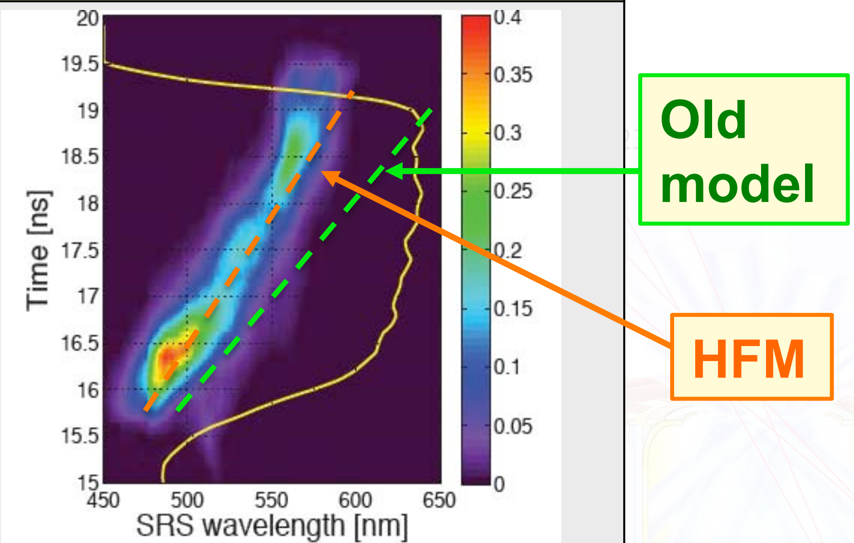
The High Flux Model (HFM) using non local e-transport & modern non-LTE atomic physics, matched bare Au sphere emission data

In 2009 MJ ignition scale gas filled hohlraum, the HFM helps match SRS spectrum & level

Coupling: Color of Raman light: λ_{SRS} vs. time

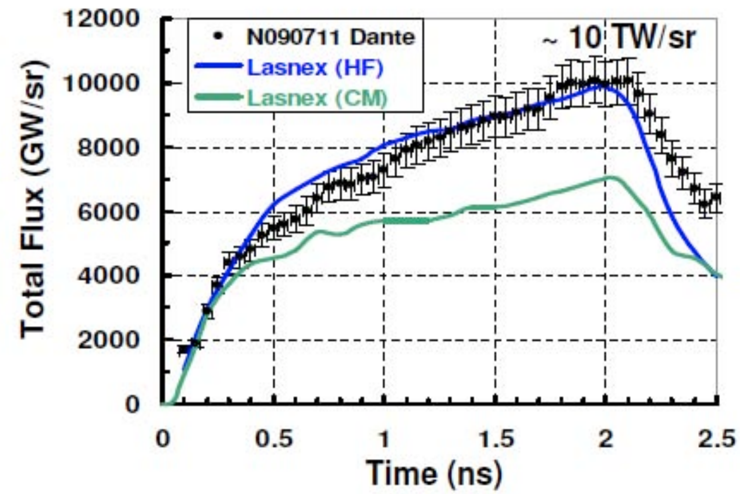


HFM leads to a cooler plasma Te

M. D. Rosen, H. A. Scott, D. E. Hinkel et al, HEDP 7, 180 (2011)
D. E. Hinkel, M. D. Rosen, E. A. Williams, et al, PoP, 18, 056312 (2011)

High flux model also agreed with NIF vacuum hohlraums* (no capsule) in 2009:

Dante x-ray drive, through Laser Entrance Hole (LEH) vs. time



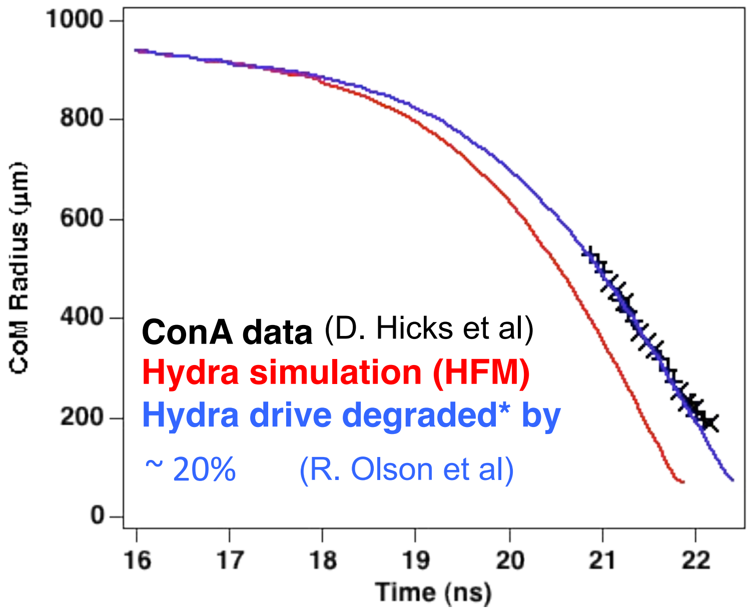
***J. L. Kline, et. Al, PRL, 106, 085003 (2011)**
R. E. Olson, et. Al, PoP, 19, 053301 (2012)

but there was a fly in the ointment…

From "day 1", the capsule imploded slower than expected (based on the HFM), requiring "source multipliers'

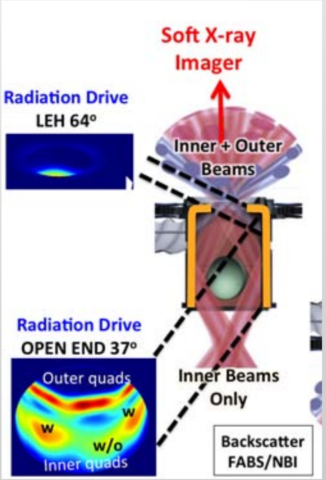
From MJ ignition scale gas filled hohlraums

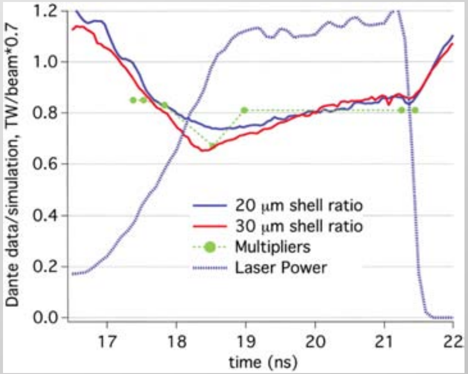
Radius vs Time



***O. Jones et al PoP 19, 056315 (2012)**
J. Moody et al PoP 21 056317 (2014)

The View Factor platform showed the discrepancy to be in the drive, *not* in the ablator



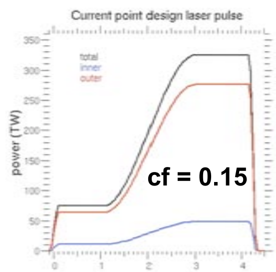


S. MacLaren, M. Schneider, K. Widmann, J. Hammer et al, PRL 112, 105003 (2014)

It seemed like it was time to pull the plug on the HFM …

But in the course of the "diversity and exploration phase" along came the Indirect Drive Exploding Pusher

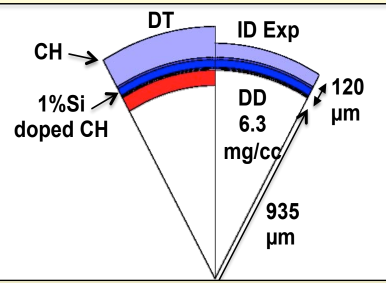
Hohlraum



9.4x5.75mm hohlraum
16Torr He

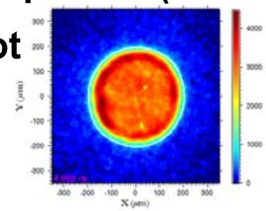
900 kJ, 325 TW
Delta lambda = (0,0)

Capsule



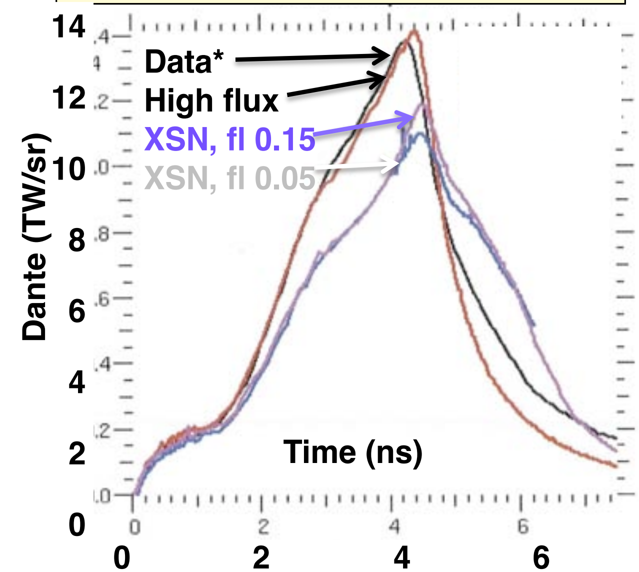
ID pusher (CR ~ 5)

Hot spot X-ray images



& ~ No LPI (99% coupling)

Near vacuum "Indirect Drive Exploding Pusher" (IDEP)



	High flux	XSN, fl 0.15	XSN, fl 0.05	*N130312 data*
n- bang time (ns)	4.5	4.8	5.0	*4.6*
X-ray bang time	4.7	5.0	5.2	*4.8 ± 0.1*

Capsule performance was also matched extremely well by the HFM: Y, Tion, ρR, etc

L. Berzak Hopkins et al, in preparation
S. LePape, L. Divol, L. Berzak, Hopkins et al PRL 112, 225002 (2014)

…The HFM (with *no* source multipliers) was back in business !

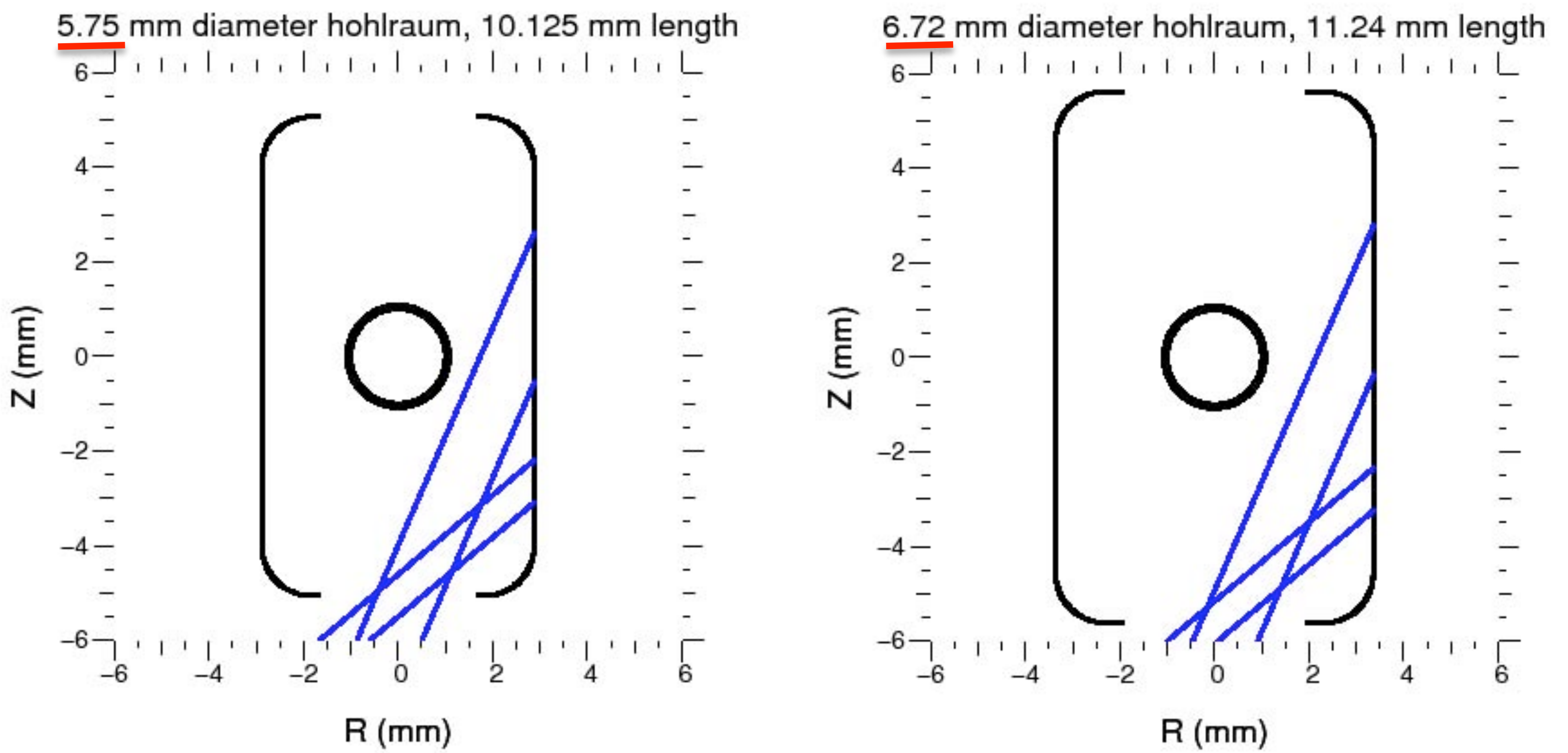
We are actively studying this non-LTE hohlraum model's "drive paradox"

	LPI loss	Multiplier "loss"	Total Loss
Gas filled, long pulse, w. CBET	16%	15 - 25%	~ 40%
Near vacuum, short pulse, no CBET	< 1%	~ 0 %	< 1%

- Investigate this paradox via **integrated experiments**:
  - Intermediate gas fills and intermediate pulse lengths
  - Au spheres embedded in a gas fill or foam at Ω, with Thomson Scattering
- Pursue theoretical ideas along with **specific hypothesis based experiments**
  - Au-gas mix/diffusion, (probe perhaps via p-beam), internal LPI, outer wall break-up, onset of flux limit in gas (B fields ?), high Z atom complexities,…
- Develop Better Diagnostics:
  - Measure plasma conditions via dot spectroscopy / Thomson Scattering
- Reduce LPI by other means: Higher T (hi Z, Imposed B fields), STUD pulses,…

We found a promising hohlraum along the way…

For the exploratory gas fill scaling, a larger hohlraum size was used: The "672": Can afford 40% more wall area



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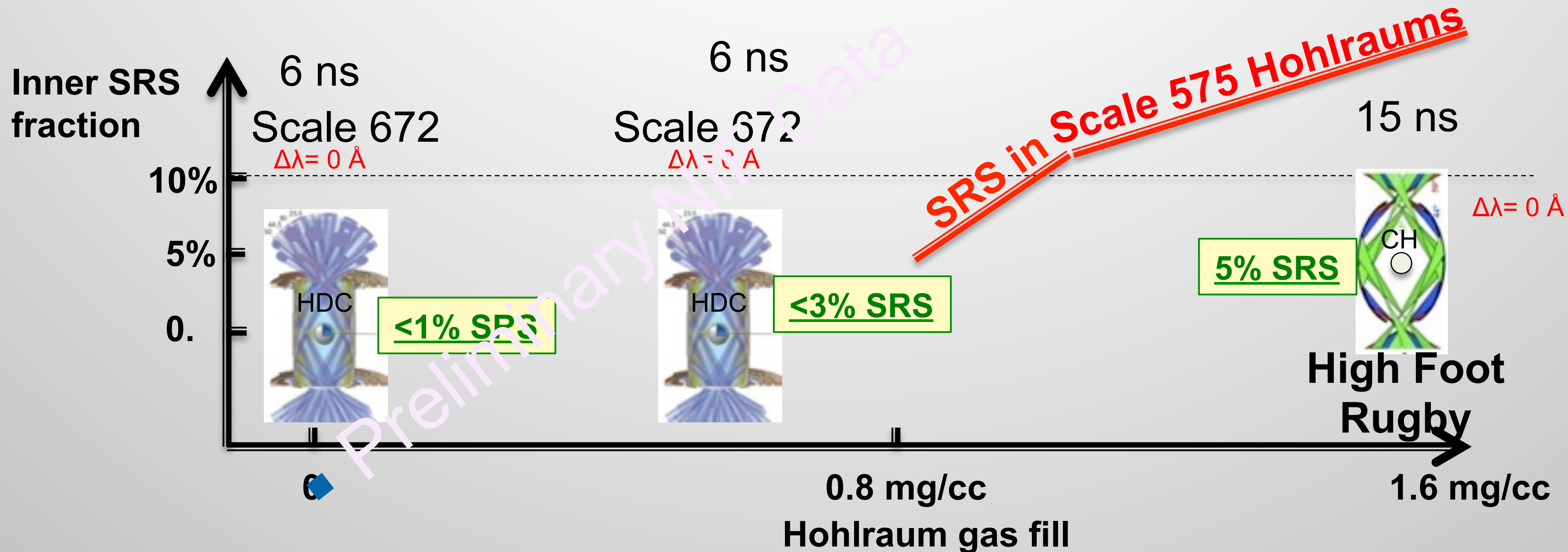
The "672" can improve clearance of inner beams from both ablator and Au bubble

We are discovering hohlraums with potentially low SRS levels to improve hohlraum performance



~0% SRS
~3% SBS

~3% SRS
~0% SBS

~5% SRS
~5% SBS

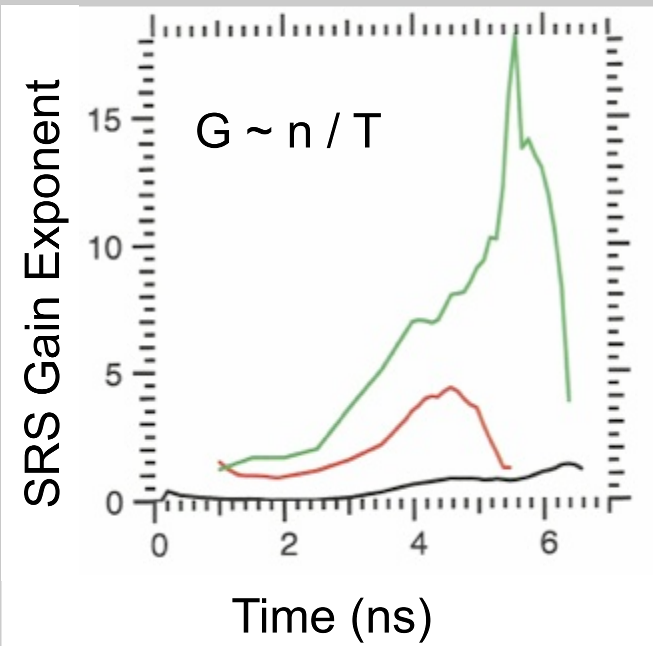
Will rugby hohlraum coupling remain at ~ 90% as we increase laser energy?

SRS is the source of hot electrons which may be affecting capsule performance

The observed low inner cone SRS is consistent with low linear gains for the larger hohlraums with 0.6 mg/cc fills

Lower fills have lower n & higher T

Calculated SRS Gain Exponent

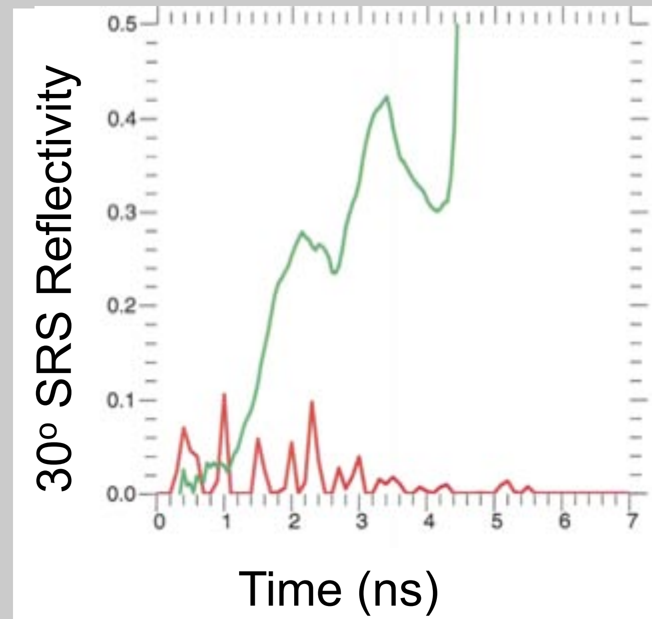


CH Ablator
0.96 mg/cc fill
Scale 575

HDC Ablator
0.6 mg/cc fill
Scale 672

HDC Ablator
0.03 mg/cc fill
Scale 672

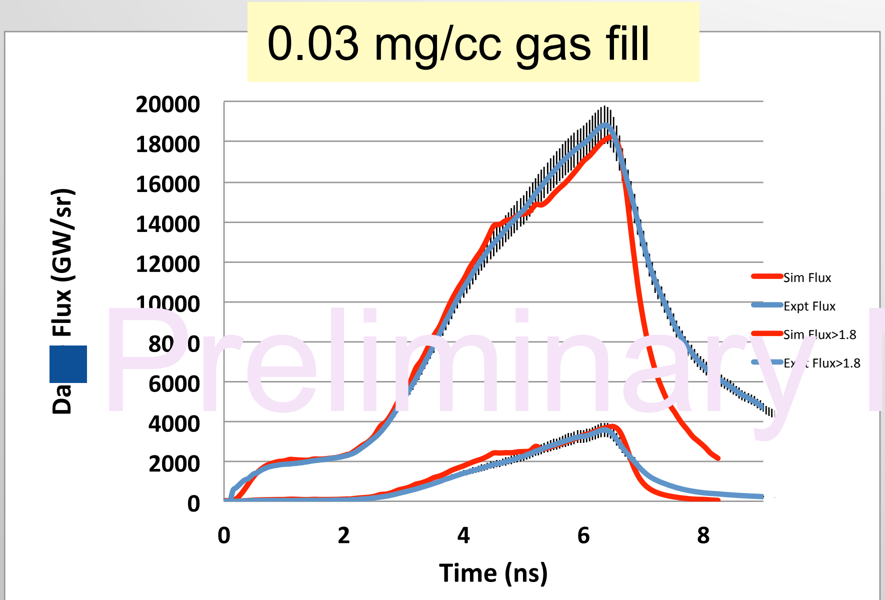
Calculated SRS Reflectivity

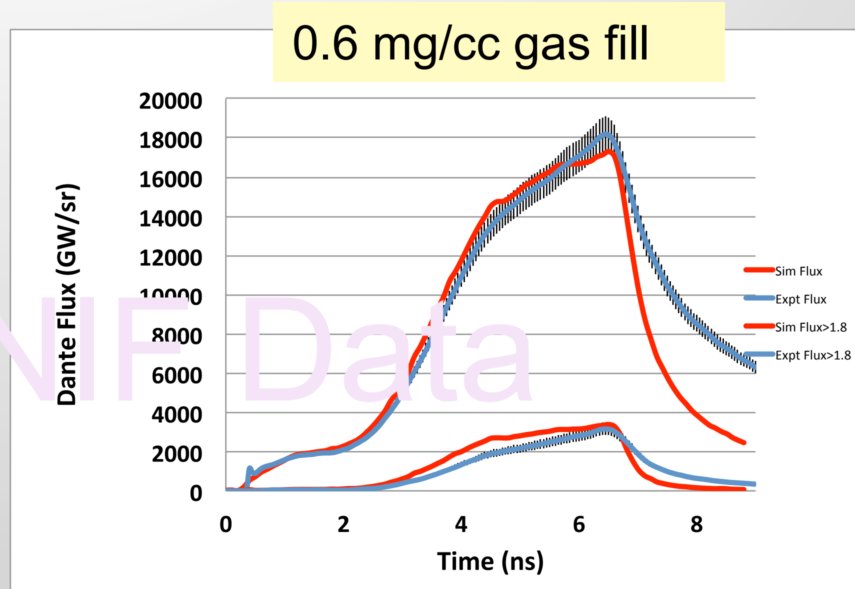


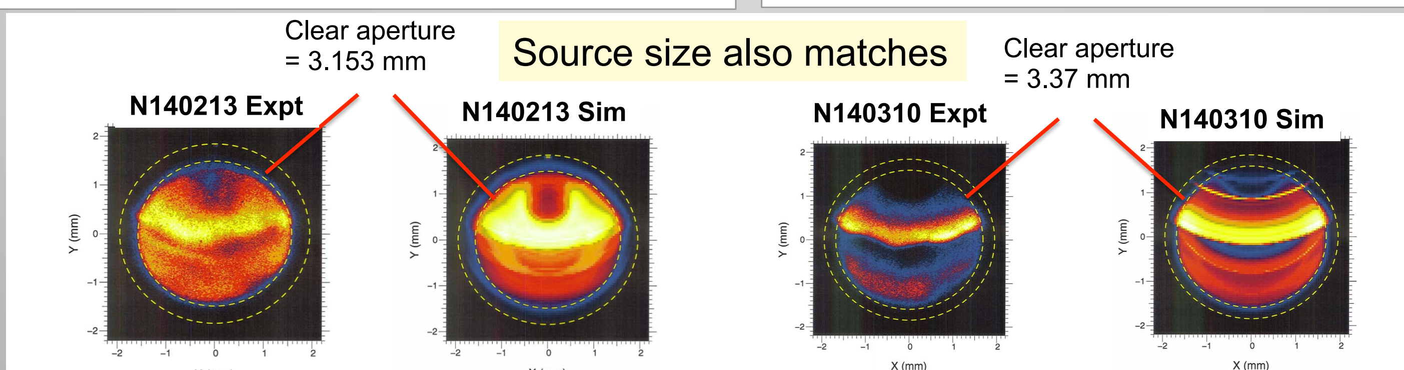
Courtesy of D. J. Strozzi

(And Rugby with no CBET has lower intensity inner beams too)

Peak Dante flux (emerging from the LEH) in agreement with HFM calculations (*__no__* **multipliers**) for 0.03 & 0.6 mg/cc fill







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Laser Entrance Hole (LEH) size also measured as calculated

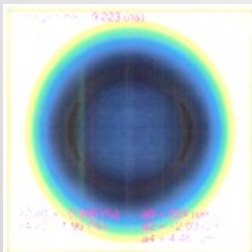
For the “672”, 0.6 mg/cc fill, both dense shell & the hot spot self emission stayed round, as predicted

Simulated inflight shape **(back-lit only)**

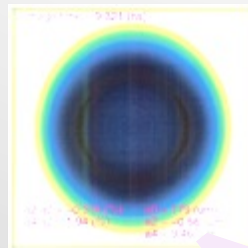
Hot Spot Self-emission

Simulated

Sim



P2 = -2 um



P2 = -0.6 um

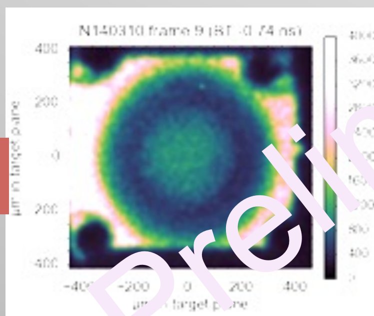
P2 = 0.02 um

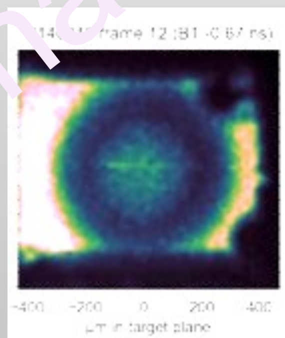
P2/P0 = -2.5%

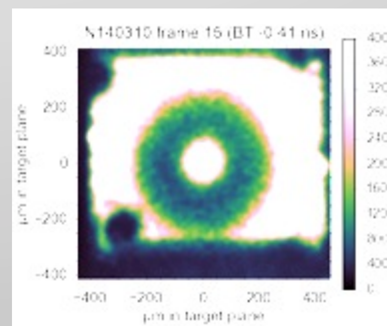
Experimental inflight shape

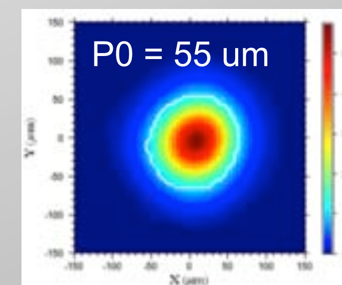
Experiment

Expt









- 740 ps **- 670 ps** **- 410 ps** **0** time

P2 = 4 um

P2 = 2 um

P2 = 5 um

P2/P0 = 3.7%

This low LPI, “round all the time” platform has great potential

Outline of this presentation

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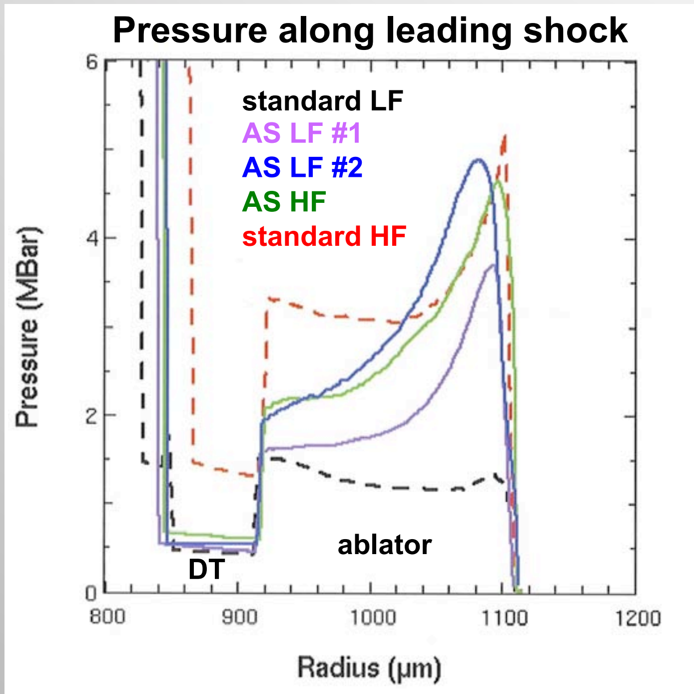
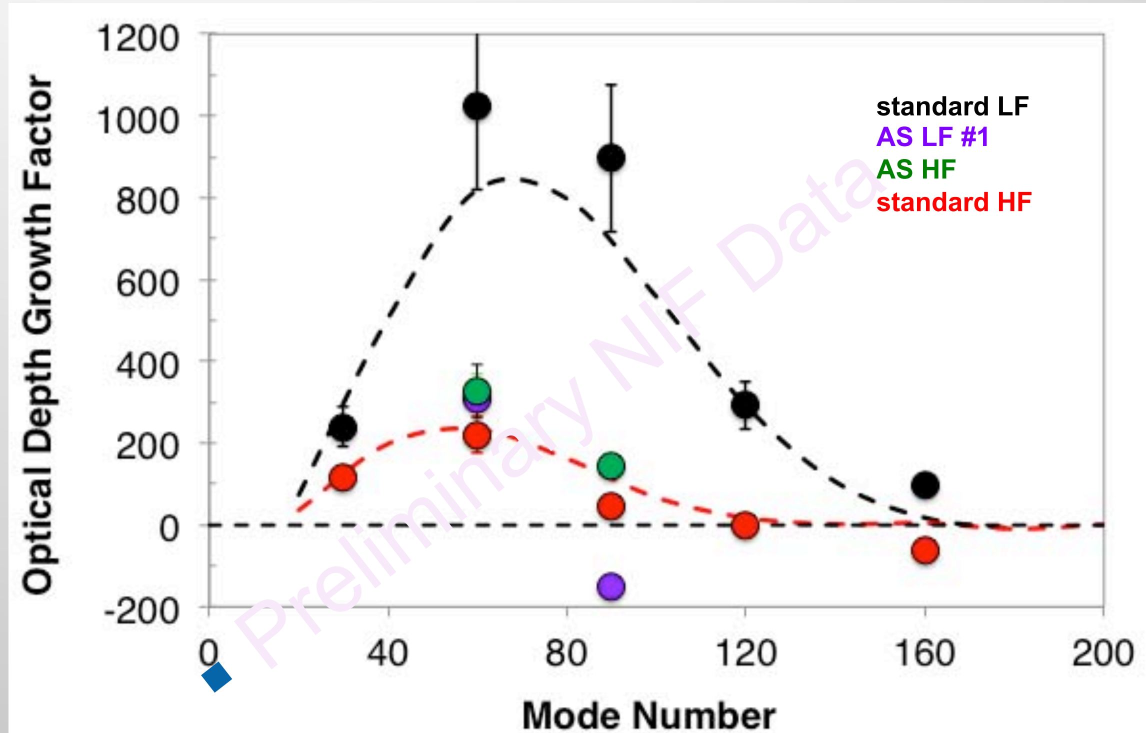
  - **Understanding**:
    - — Time dependent shape;
    - — Hydro-growth; CH initial conditions; Effects of the tent;
    - — Exploring alternate hohlraums vs. model
- **Where we are going:**
  - Lower HF (& maintain stability) / Do “adiabat shaping” on LF to improve stability
  - Improve tent & other initial conditions
  - Improved diagnostics: time dependent symmetry, stagnated core conditions, …
  - Operate in LPI free hohlraum environments (for HDC, maybe for Be & CH too!)
- Acknowledgements

HGR Platform has now been applied to Adiabat Shaped (AS) pulses that are intermediate to LF & HF drives

Adiabat shaping* stabilizes the outside with high adiabat, while keeping adiabat low inside



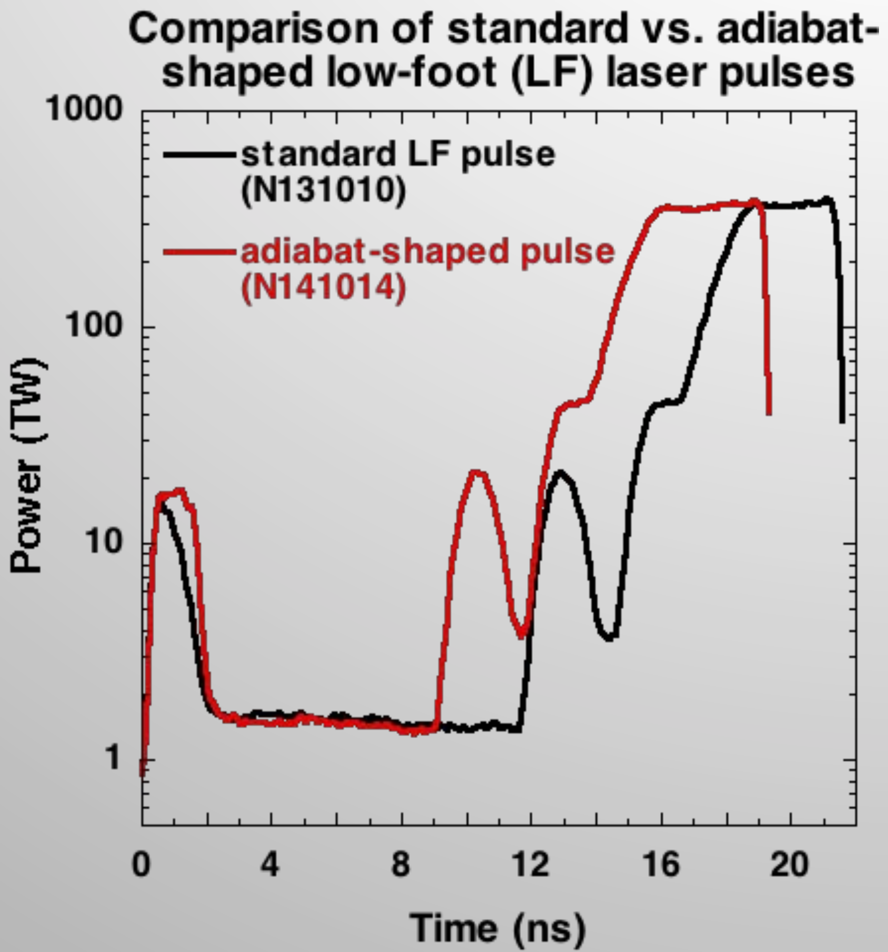


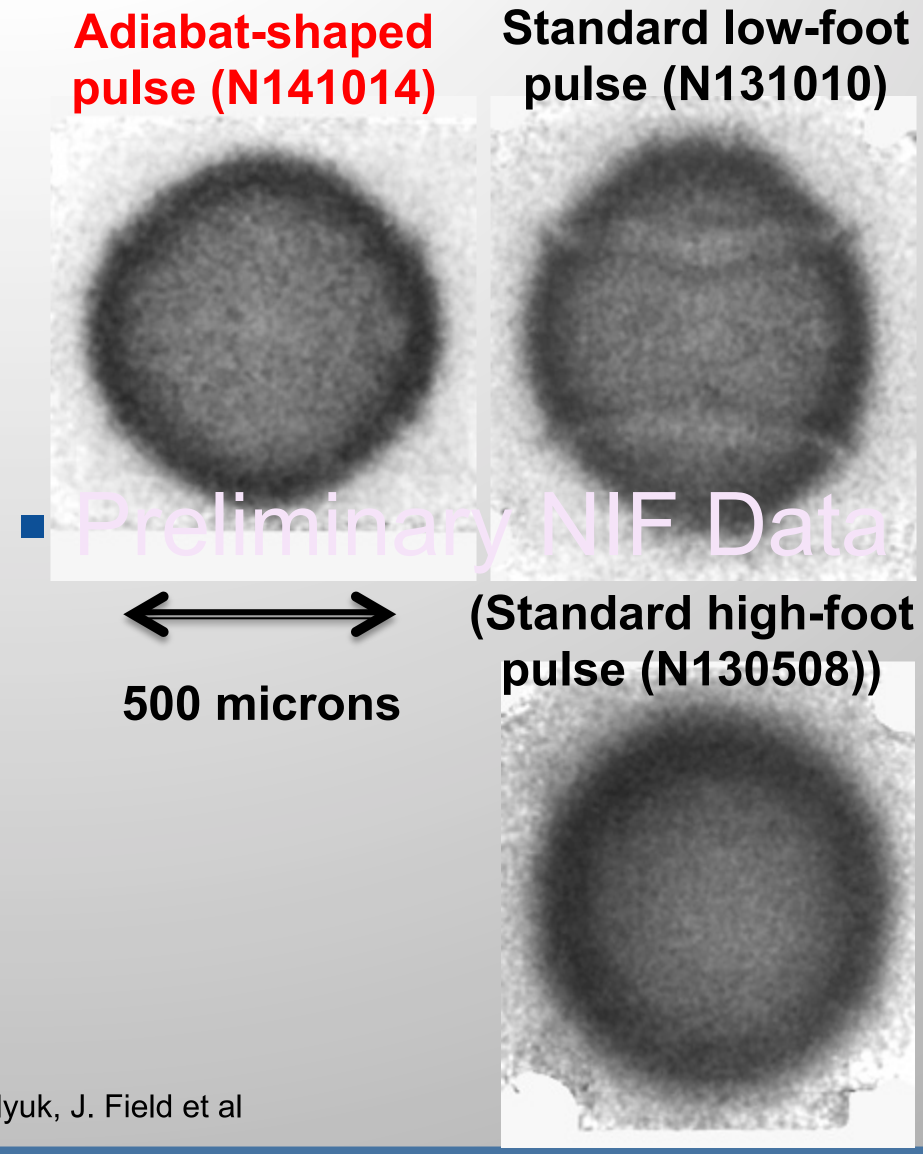
H. Robey, D. Clark, D. Casey, A. McPhee, L. Peterson, O. Jones, V. Smalyuk, Mix, Shape, Pt. Design & HF teams

*V. Goncharov et al PoP **10**, 1906 (2003)
K. Anderson & R. Betti PoP **11**, 5 (2004)

These results are close to predictions, and are quite promising for future implosions

Unstable growth of "tent" perturbation was reduced using adiabat-shaped drive





H. Robey, V. Smalyuk, J. Field et al

Both shots used the same 45-nm support membranes ("tents")

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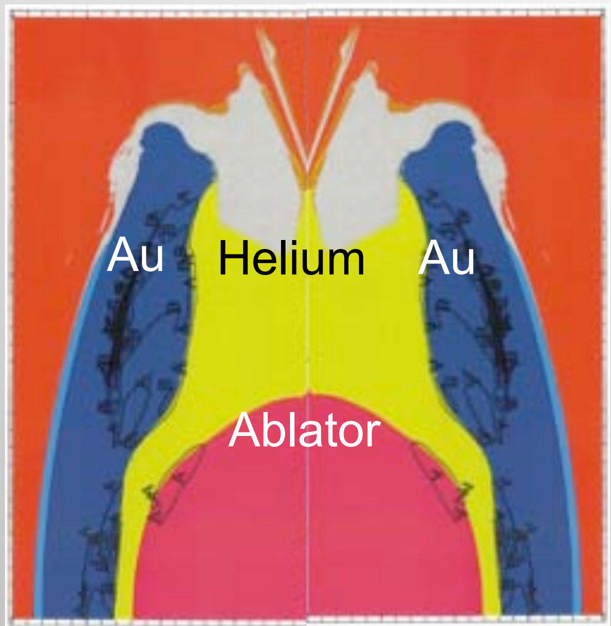
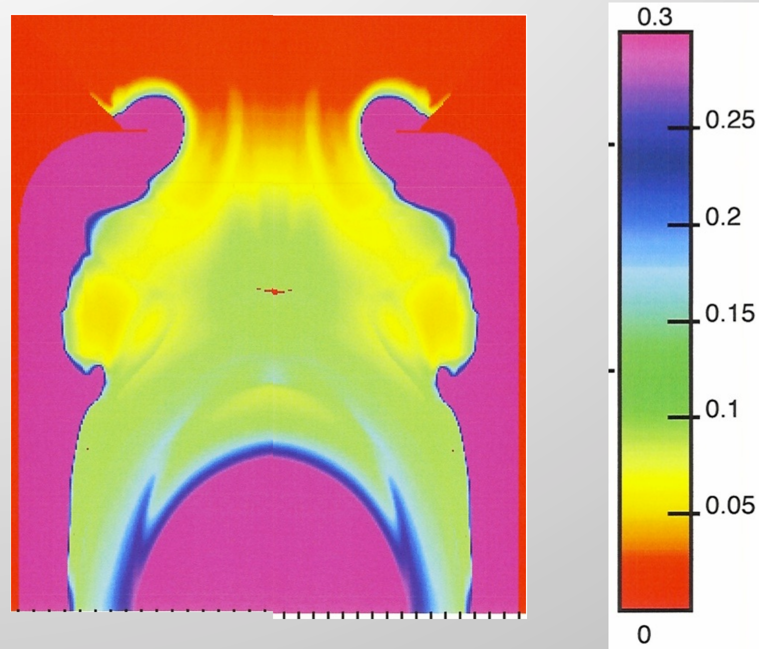
- Acknowledgements

The 0.6 mg/cc "672", low LPI, round platform has inspired several new promising designs:

P. Amendt et al Rugby for 9 ns HDC



D. Hinkel et al Cylinder for 14 ns High Foot CH



Neither rely on Cross Beam Energy Transfer (CBET)

Will the LPI remain small when these are tested?

What is the optimal size and fill density for a given pulse shape ?

Summary

- **Hydrodynamic Instabilities:** **2012:** At higher velocity, the Pt. Design **Mix**ed CH into the hot spot, & severely degraded performance
  - **2014:** Less stressing, more stable, High Foot reached higher velocities
    - Yield ~ 10^{16} : significant self heating due to alpha deposition
  - Improved understanding of tent and of surface's affect on Pt. Design, leading to mix
  - "Adiabat Shaped" designs that show promise of improved performance

- **Complex Hohlraum Physics:** **2012**: Long pulse, gas filled hohlraum with >16% SRS: Unexplained, reduced **drive**; complicated **symmetry** control; hot electron (**preheat**)
  - **2014**: Potentially better hohlraums: Rugby, Low gas fills: Reduced SRS, reduced hot electrons, better understood drive, & possibly better symmetry control
    - These are natural choices for HDC (or Be)
      - HDC Yield ~ 3 10^{15}, so far, – with "head-room" for improvements

- **The ICF Community has proven itself to be talented enough to begin to overcome the inevitable surprises that come with cutting edge, grand challenge, ignition research**

Recent progress shows the benefits of innovation, and exploration of broad approaches. This can lead to even better performance, and we've barely begun to innovate !

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- **Our families & loved ones that support us all, every day**

It takes a village !

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