NIF: Recent Progress and Future Plans

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Presentation to The NIF Management Advisory Council

LLNL-PRES-647817

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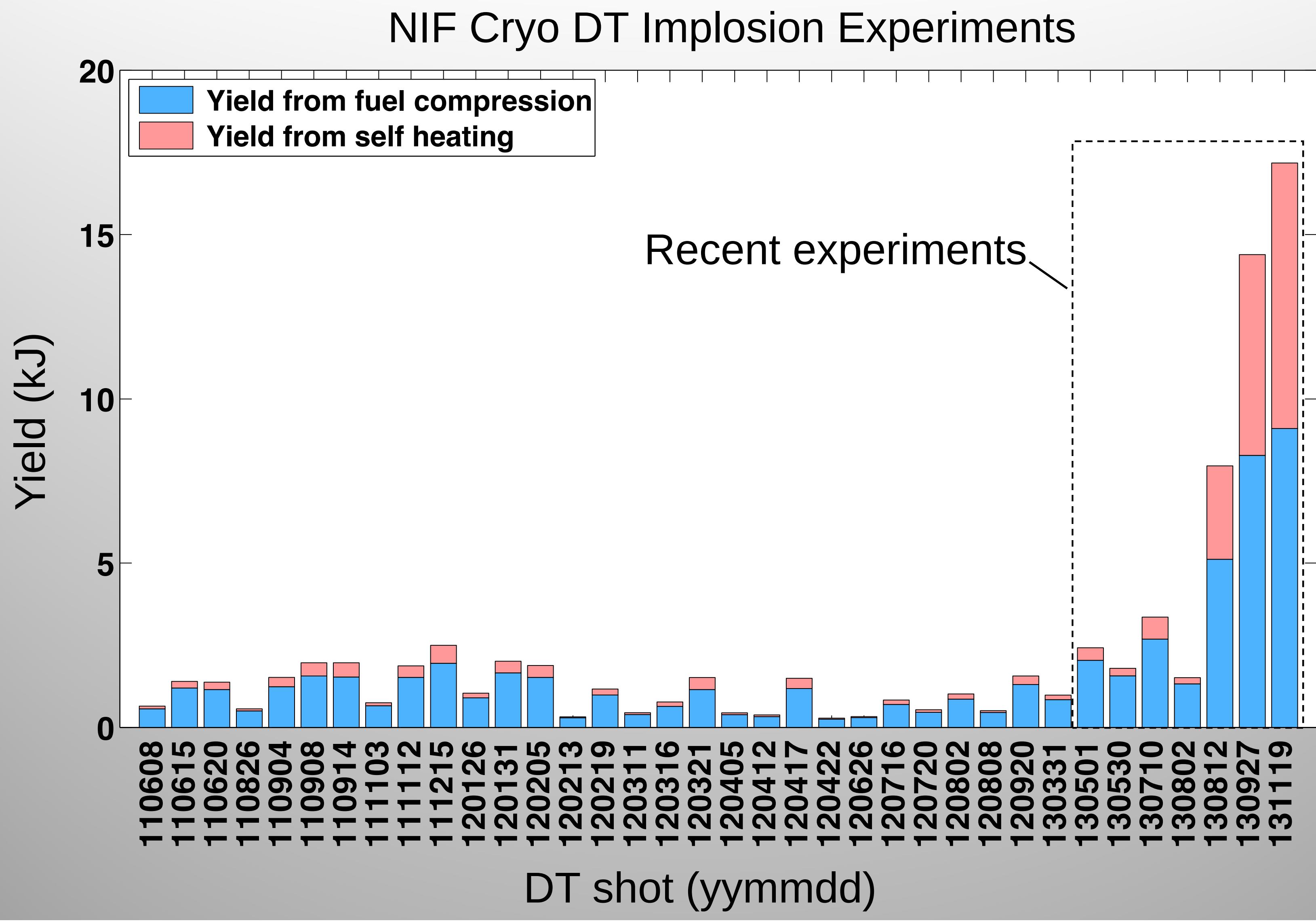
John Edwards for the ICF Team

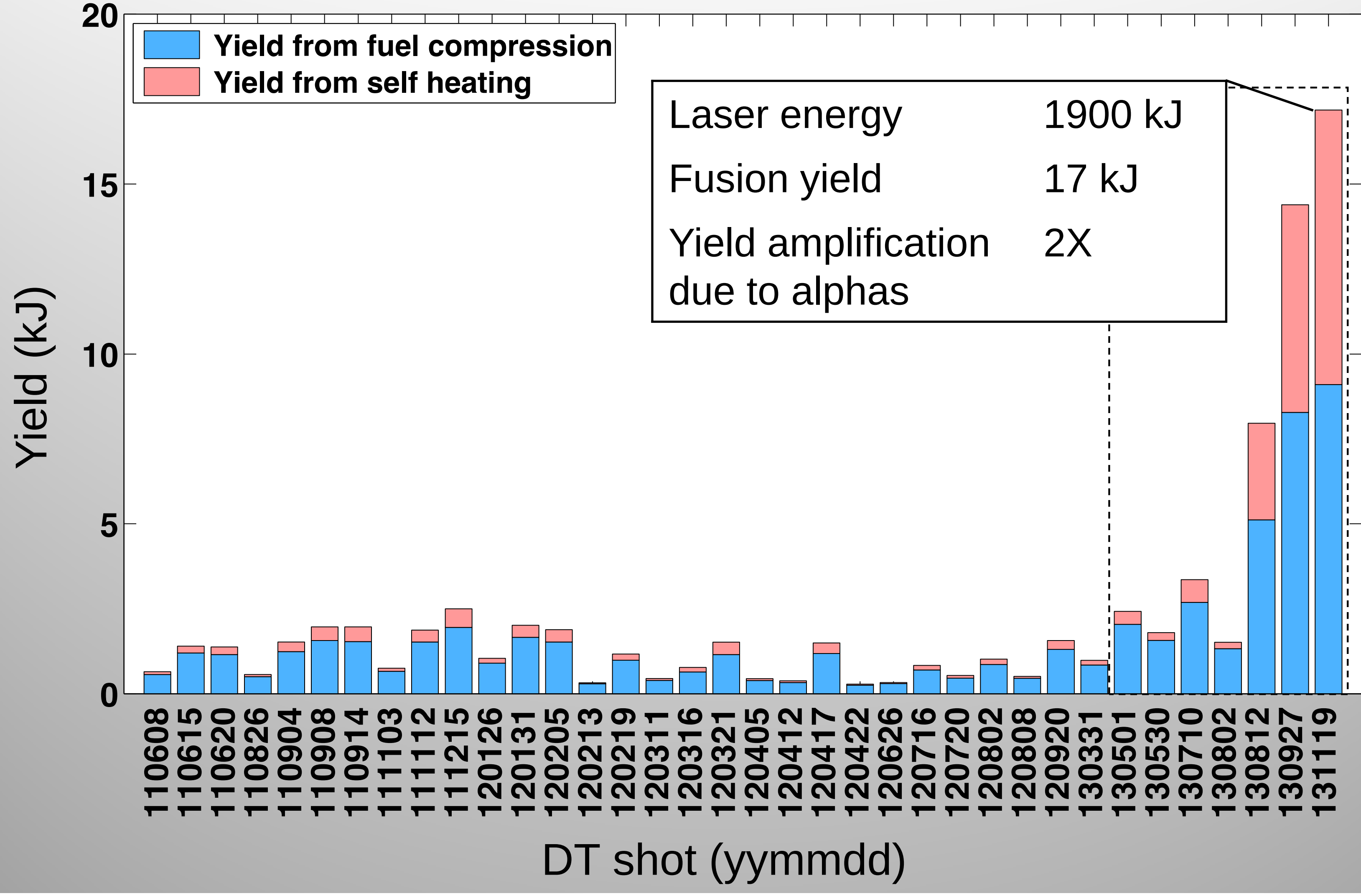
ICF Program Leader, Lawrence Livermore National Laboratory

Recent experiments
- entering a different regime

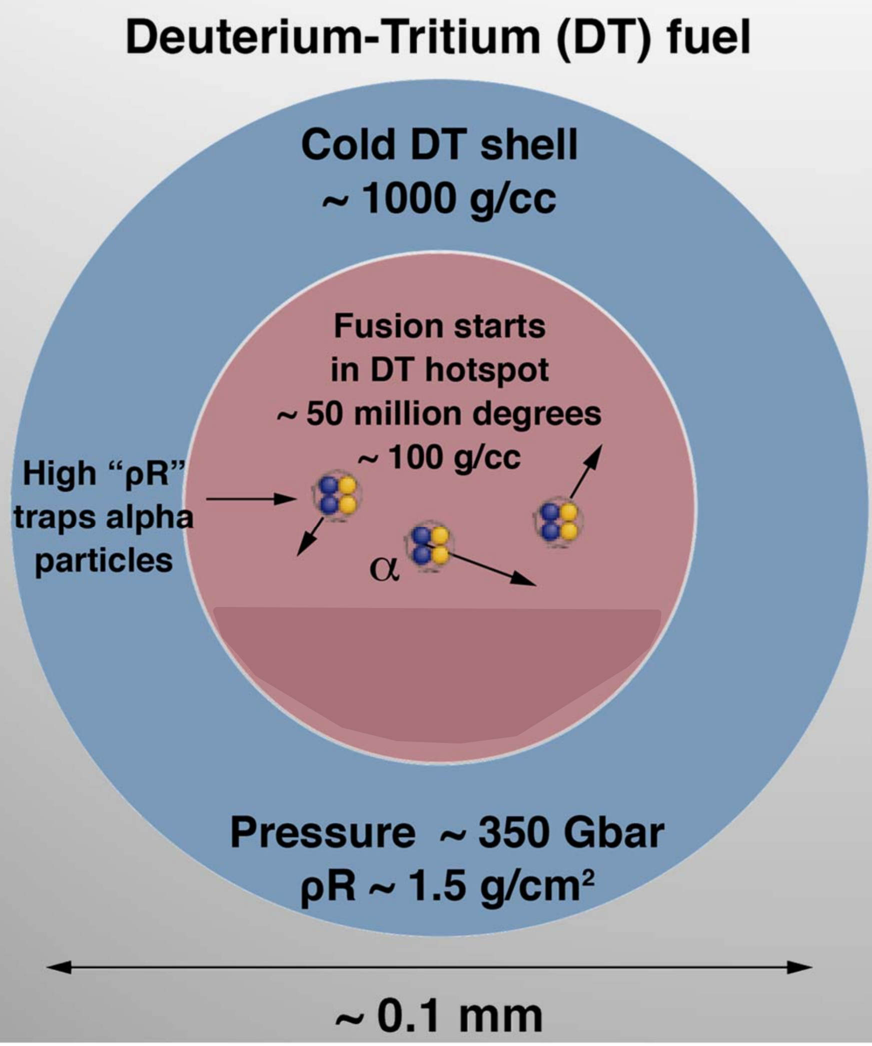


Recent experiments
- entering a different regime

NIF Cryo DT Implosion Experiments

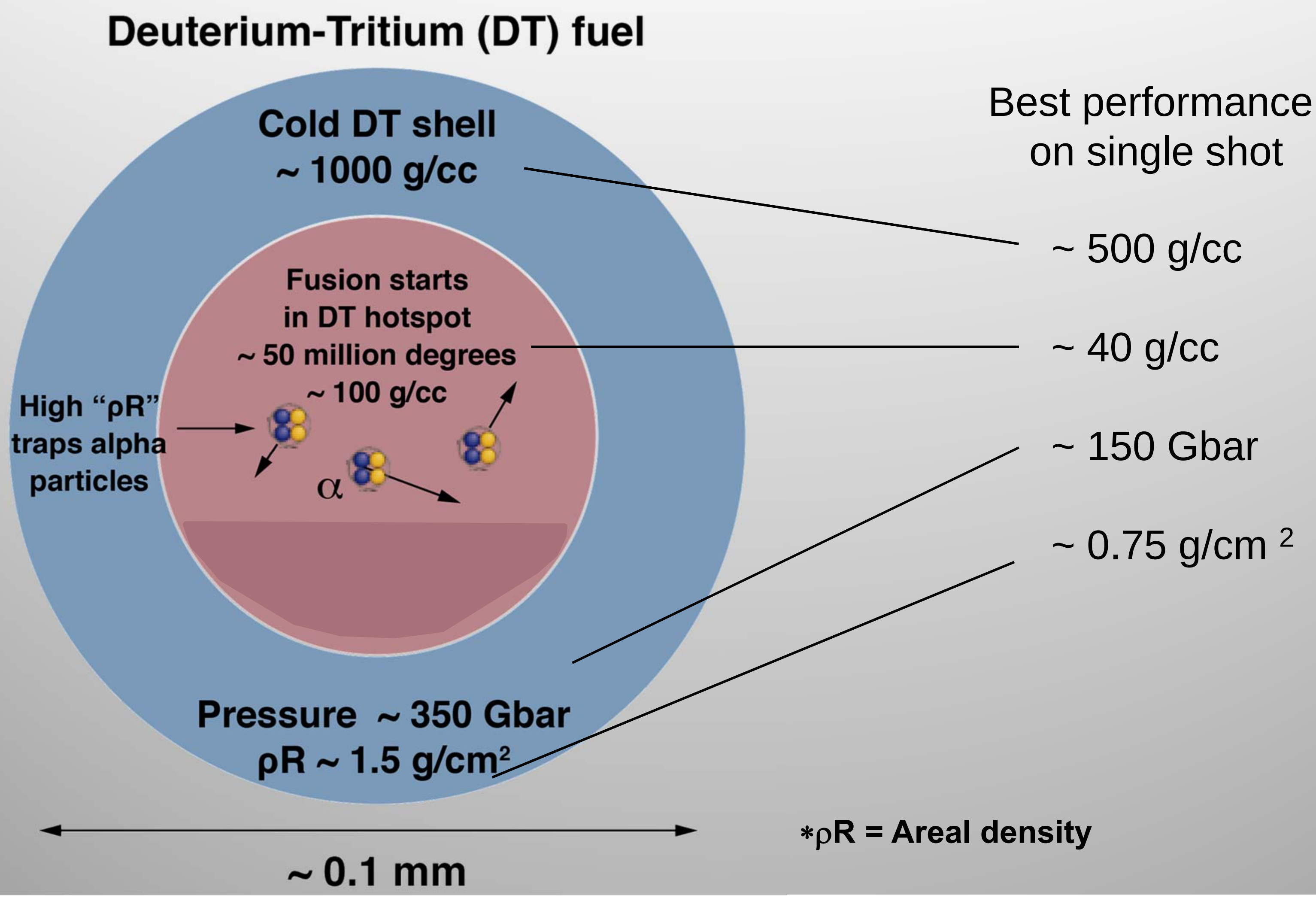


Ignition on the NIF requires extremes in pressure, density and temperature



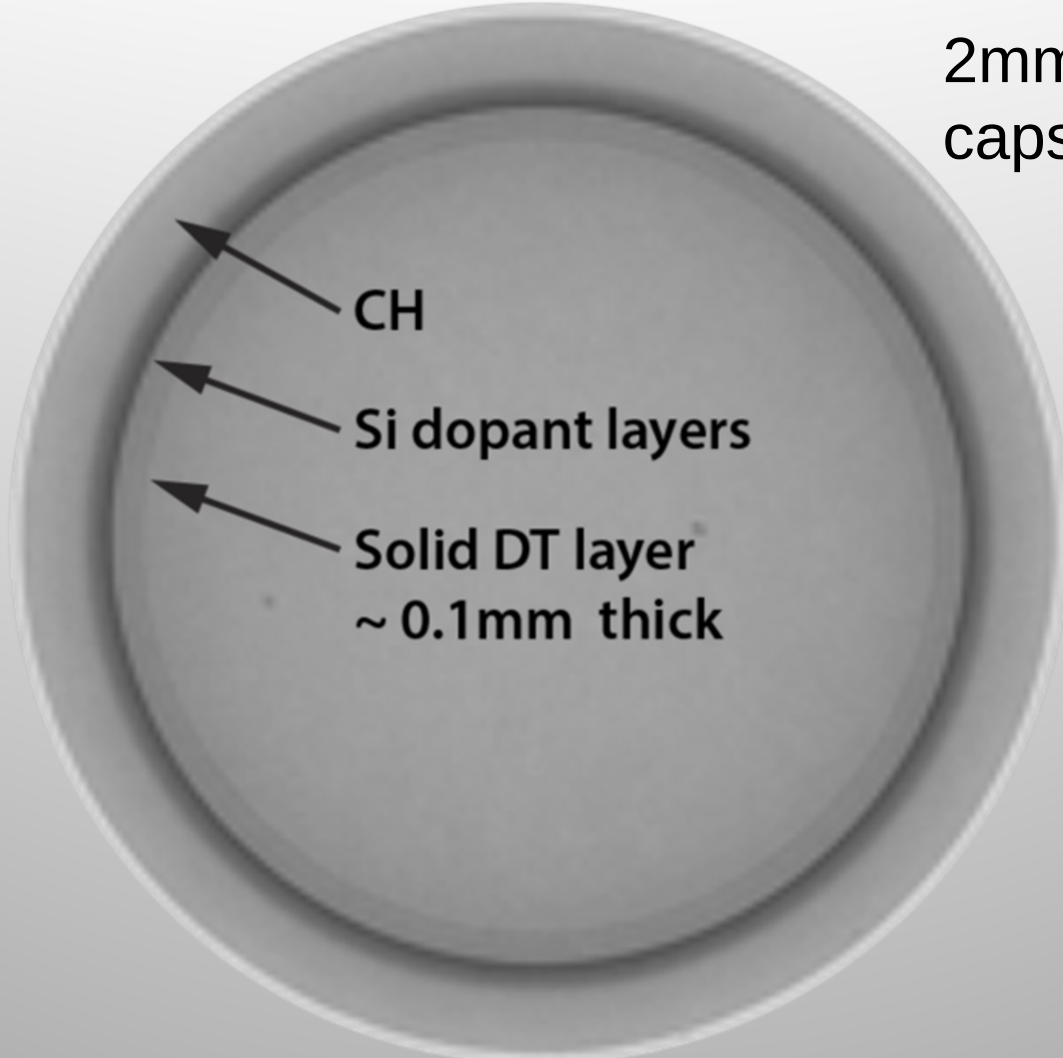
*ρR = Areal density

Ignition on the NIF requires extremes in pressure, density and temperature

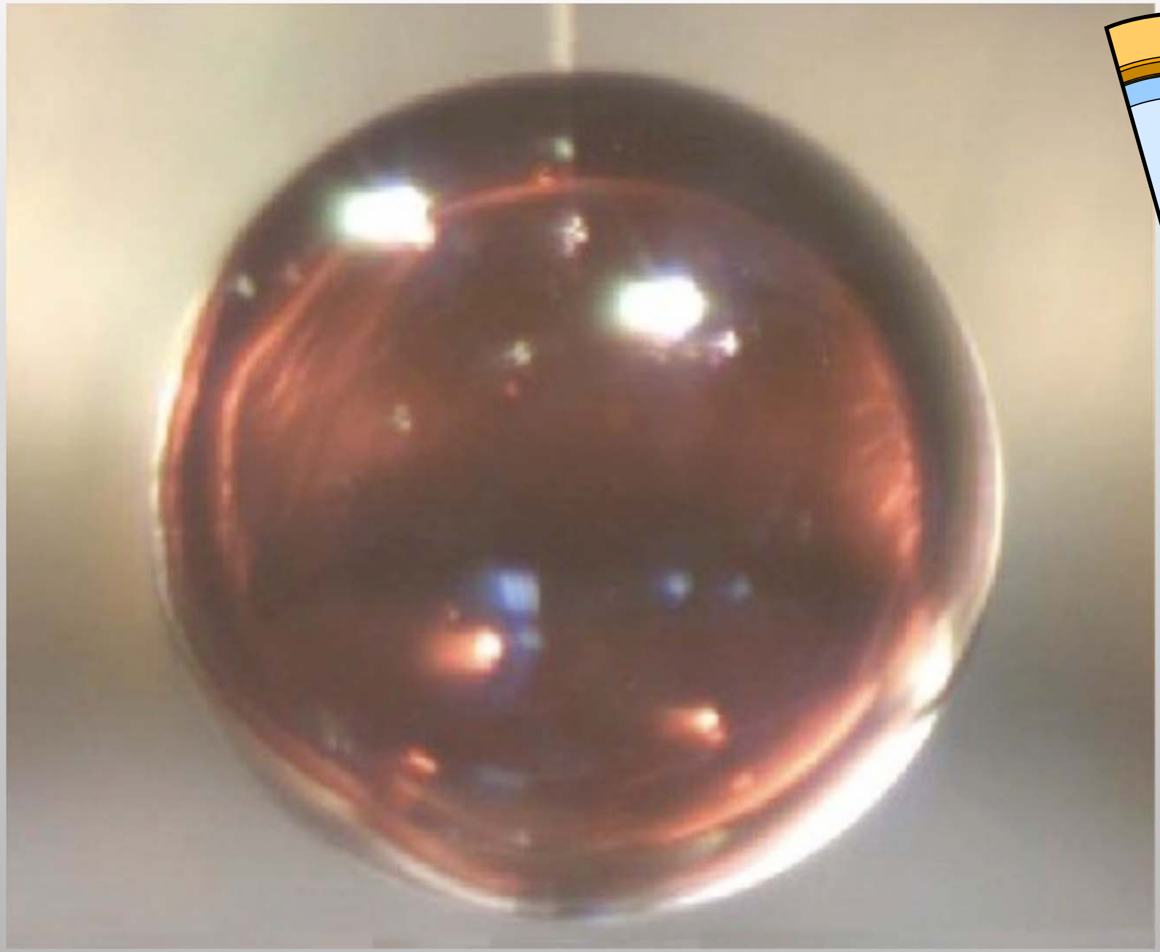


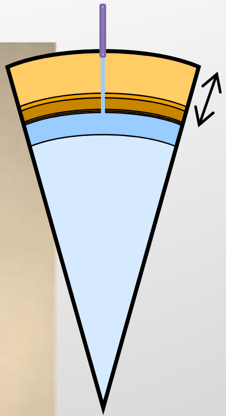
X-ray picture of capsule taken down axis of the hohlraum just before a shot

2mm diameter capsule



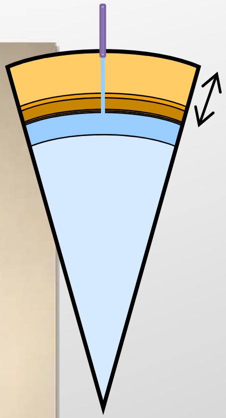
Plastic Ignition Capsule





~2 mm diameter

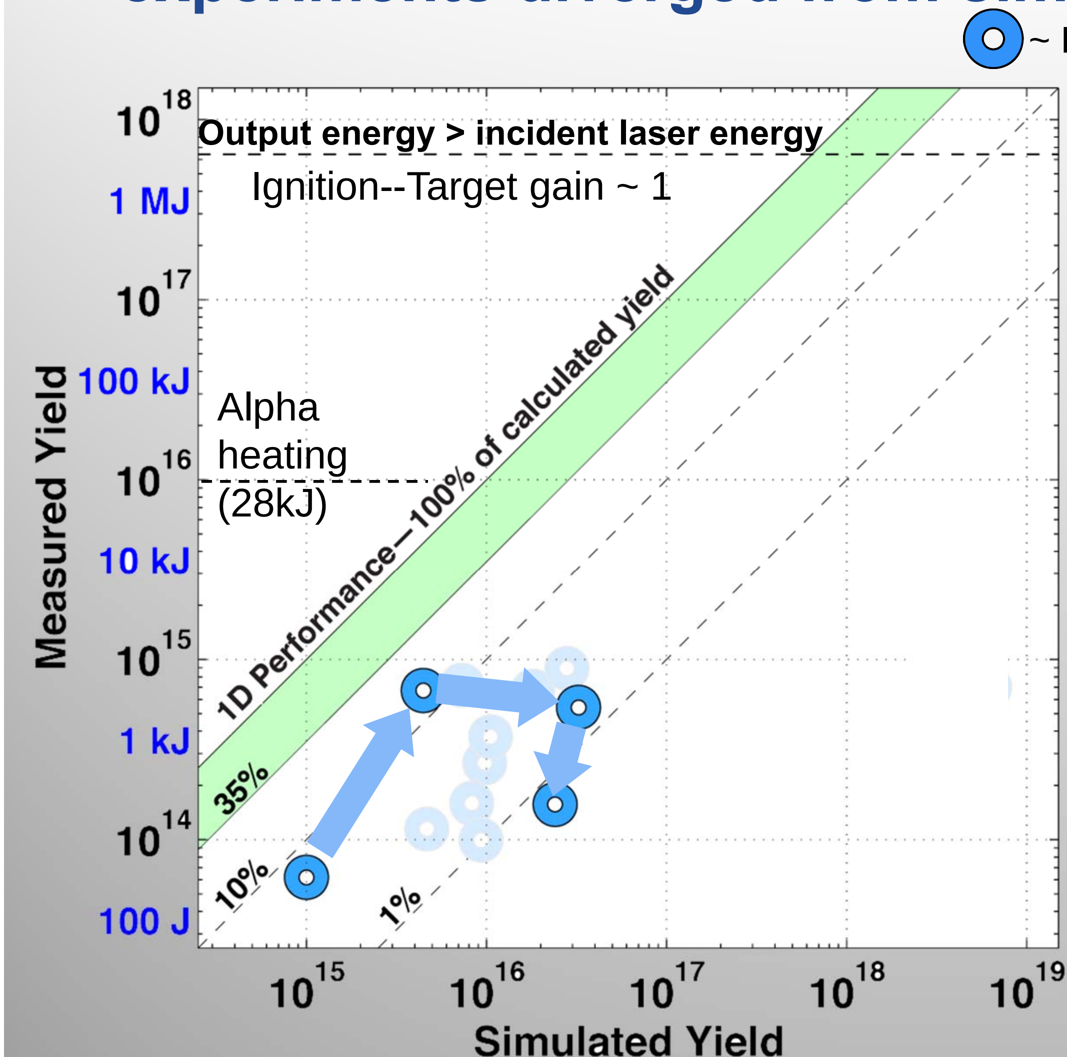
The Challenge — near spherical implosion by ~35X



DT shot N120716
Bang Time

~2 mm diameter

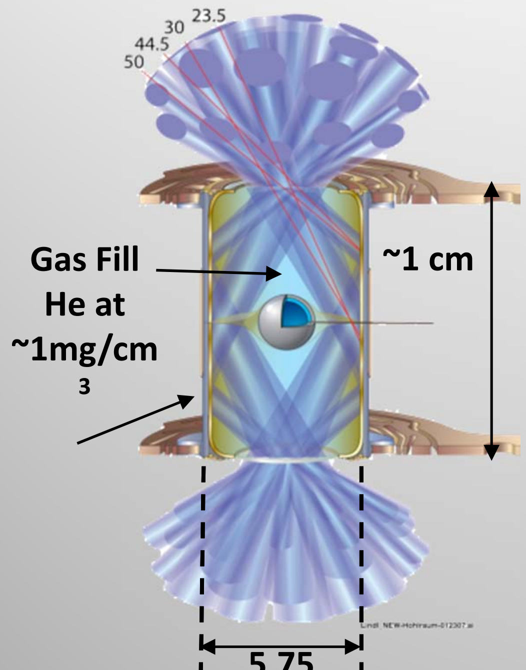
During the NIC we found that implosion experiments diverged from simulations



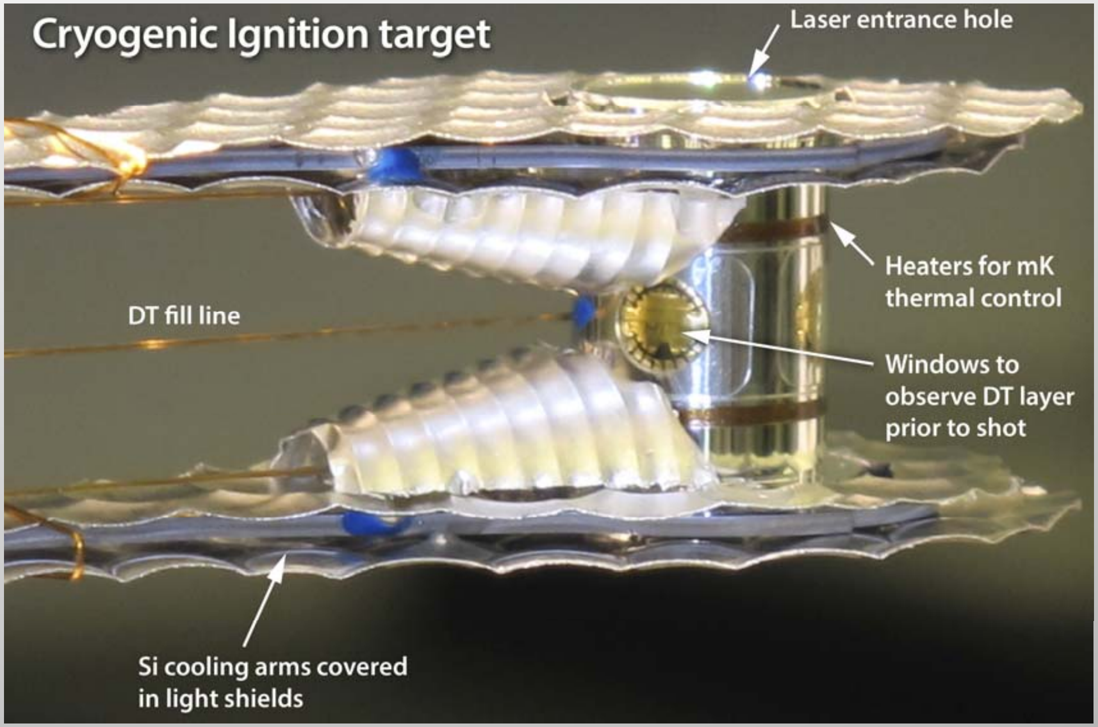
- NIC experiments were focused on a "point design":
  - Hohlraum and capsule
  - Low adiabat ~1.5
  - High fuel velocity ~370μm/ns
  - Acceptable hydro-instability
  - Good implosion symmetry
- Experiments were expected to "tune" to these design points
- It didn't work as expected…
  Why not?

The NIC point design

Gas-filled hohlraum

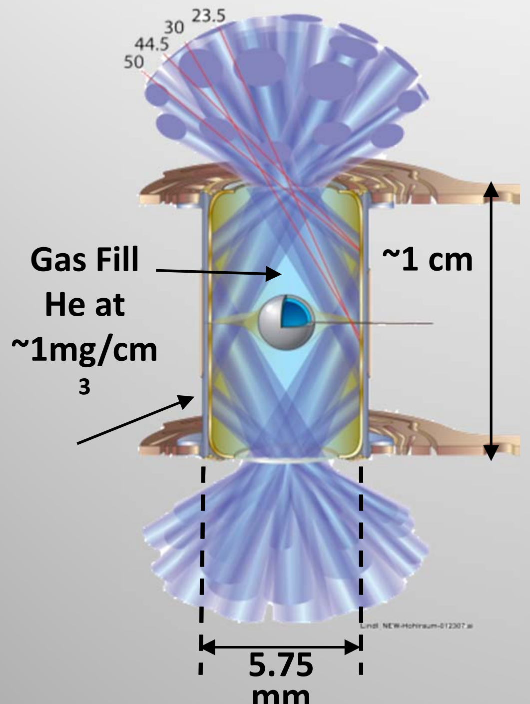


Symmetric x-ray drive
at required velocity



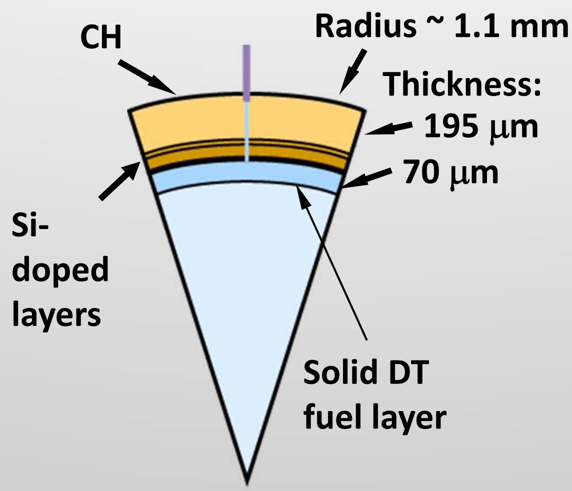
The NIC point design

Gas-filled hohlraum



Symmetric x-ray drive at required velocity

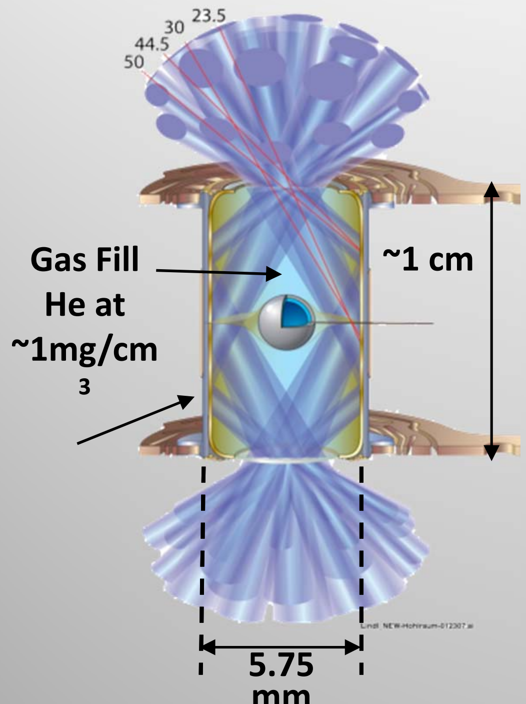
Doped CH capsule



Acceptable hydrodynamic instability at required velocity and convergence

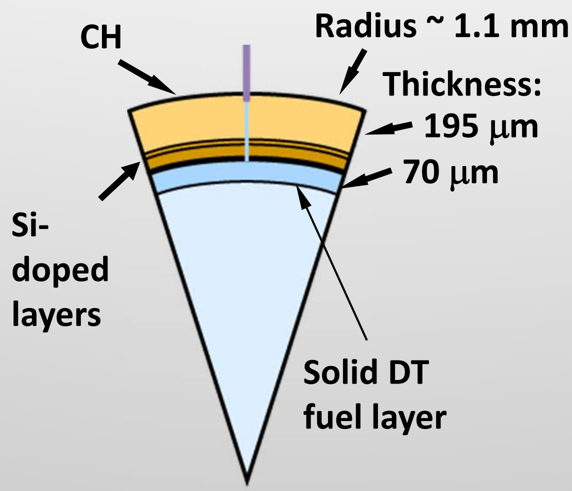
The NIC point design

Gas-filled hohlraum



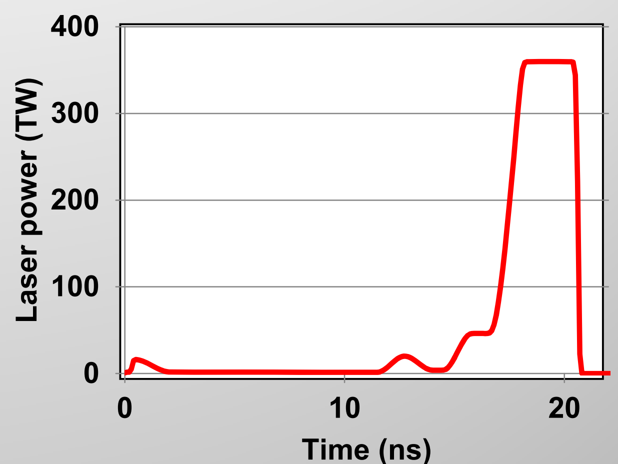
Symmetric x-ray drive at required velocity

Doped CH capsule



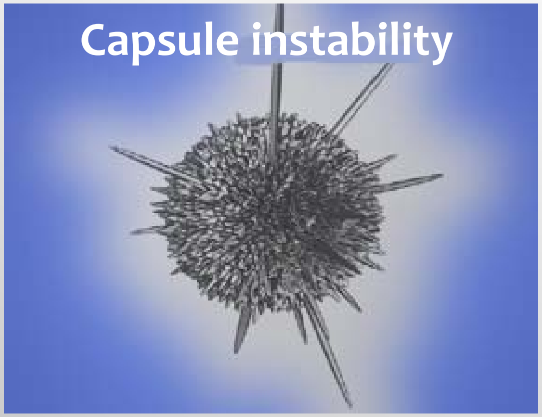
Acceptable hydrodynamic instability at required velocity and convergence

Shaped laser pulse



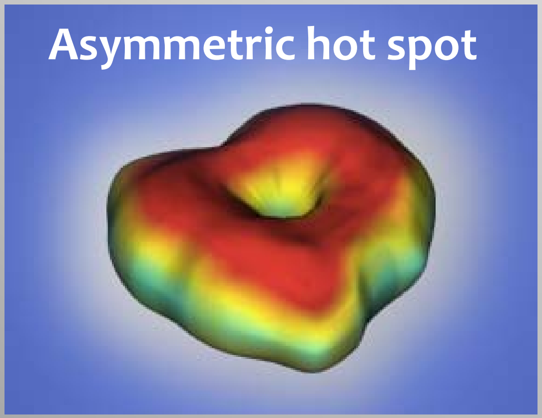
Low fuel adiabat for high compression

Towards the end of the NIC two main issues began to emerge



(Capsule surface roughness) x (Growth)

Too large

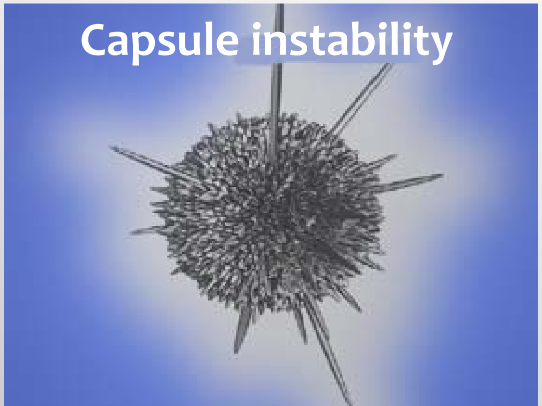


X-ray push on the capsule

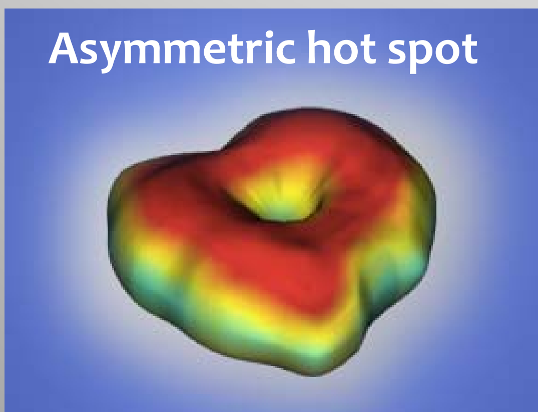
Not symmetric enough

Attention turned towards developing a deeper understanding of target behavior, improved predictive capability – can ignition be achieved on the NIF?

Post-NIC Path Forward key element 1: Focused experiments



Growth x Surface seeds is too large

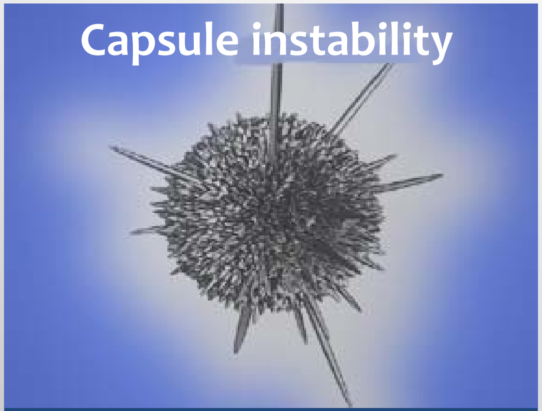


X-ray push on the capsule is not symmetric enough

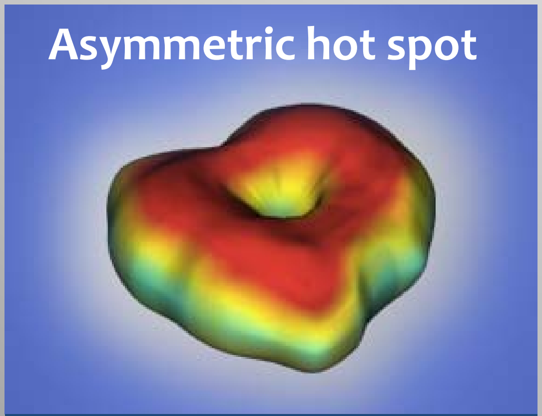
- Intense study of key aspects of capsule and hohlraum physics have begun:
  - Hohlraum x-ray drive, LPI and hot electrons
  - Shocks
  - Implosion trajectories, rocket efficiency
  - Growth of capsule perturbations
  - Ablator and hot fuel shape vs time
  - Stagnation, hot fuel motion
- Still to come:
  - Better mix measurements
  - Cold fuel shape at stagnation
  - Hohlraum plasma conditions and x-ray spectra

New experimental platforms were needed to make these measurements

Post-NIC Path Forward key element 2: Integrated experiments



Growth x Surface seeds is too large

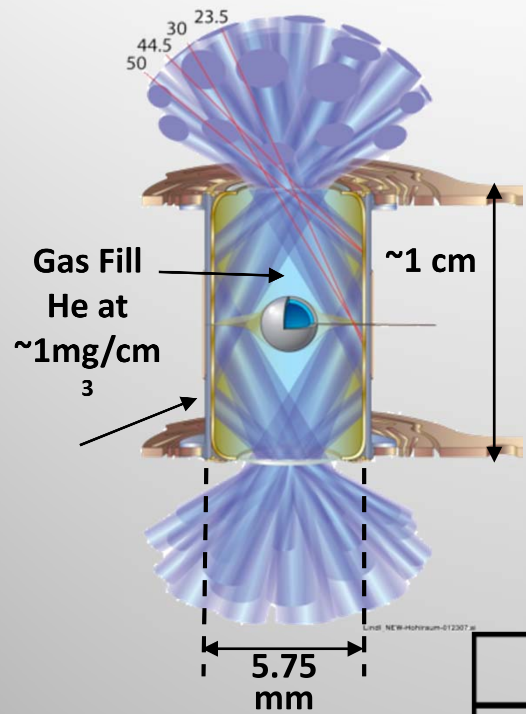


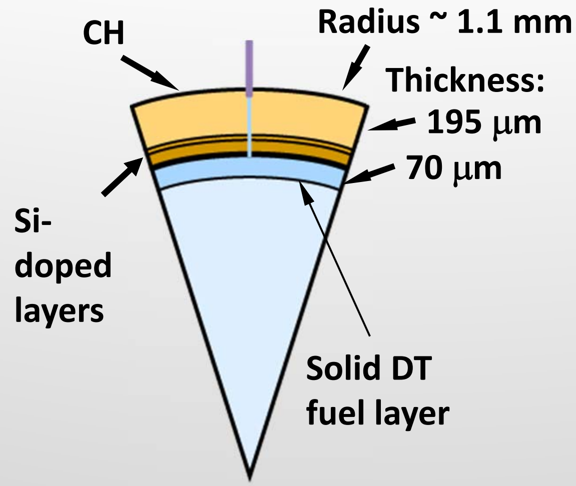
X-ray push on the capsule is not symmetric enough

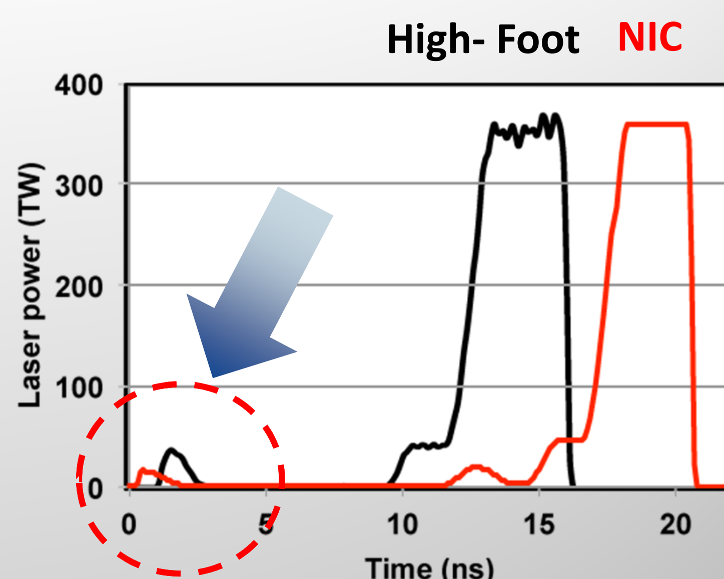
- Step back from ignition…
- Put emphasis on a less stressing implosion:
  - Reduced hydrodynamic instability
  - Performance closer to predictions
- Once achieved, build on new insights to incrementally push the envelope toward higher performance – staged goals towards ignition

Insert Omar's slides here?

A new "High-foot" design uses same target but higher initial laser power to reduce growth of surface perturbations





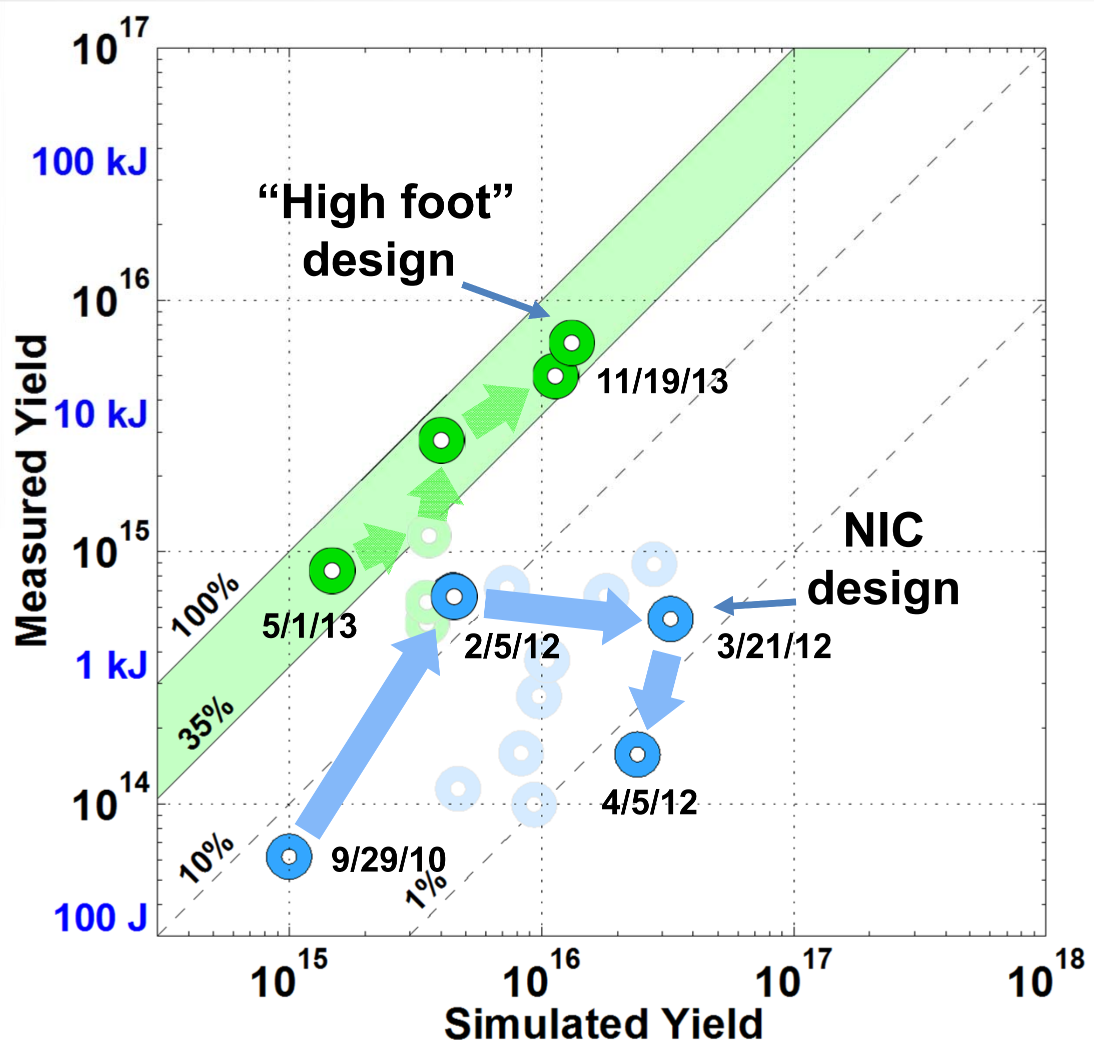


	NIC Low-foot		High-foot
Adiabat	~1.5	Increased to:	~2.5
In-flight aspect ratio, (IFAR)	~30*	Reduced to:	~10*
Convergence	~45	Reduced to:	~30

* Analysis ongoing

GOAL: Performance that is understood and well matched to calculations

The new “high foot” design achieved the goal of an implosion that performs closer to simulations

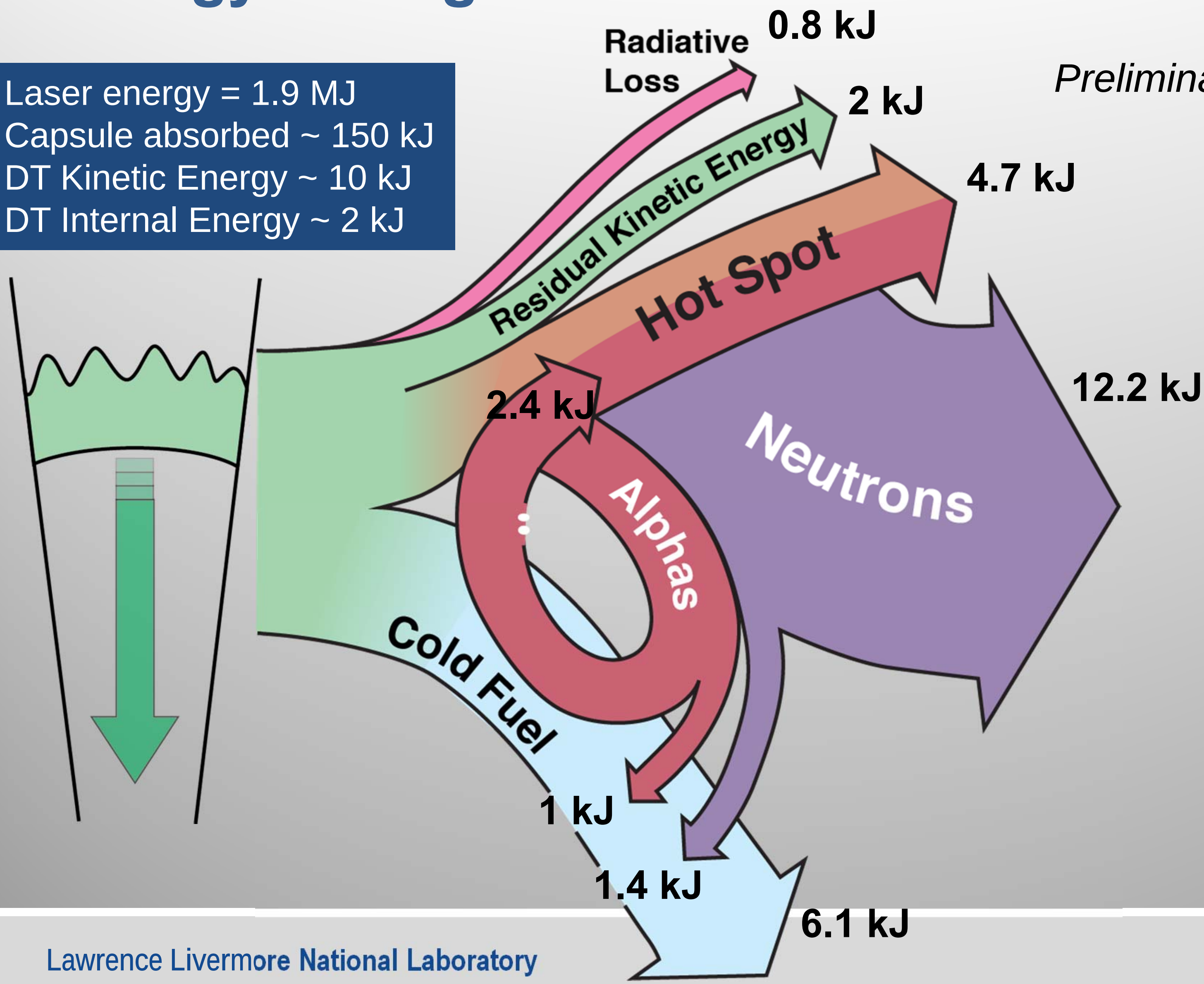


- The “high foot” design is:
  - More tolerant of hydrodynamic instabilities
  - At the expense of compression and potential gain

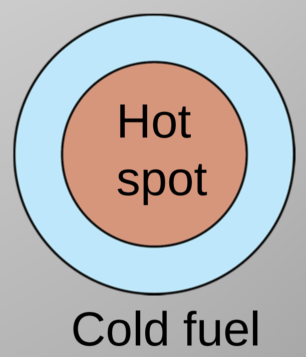
Alpha energy contributed ~ 50% of the hot spot energy at stagnation for DT shot N131119

Laser energy = 1.9 MJ
Capsule absorbed ~ 150 kJ
DT Kinetic Energy ~ 10 kJ
DT Internal Energy ~ 2 kJ

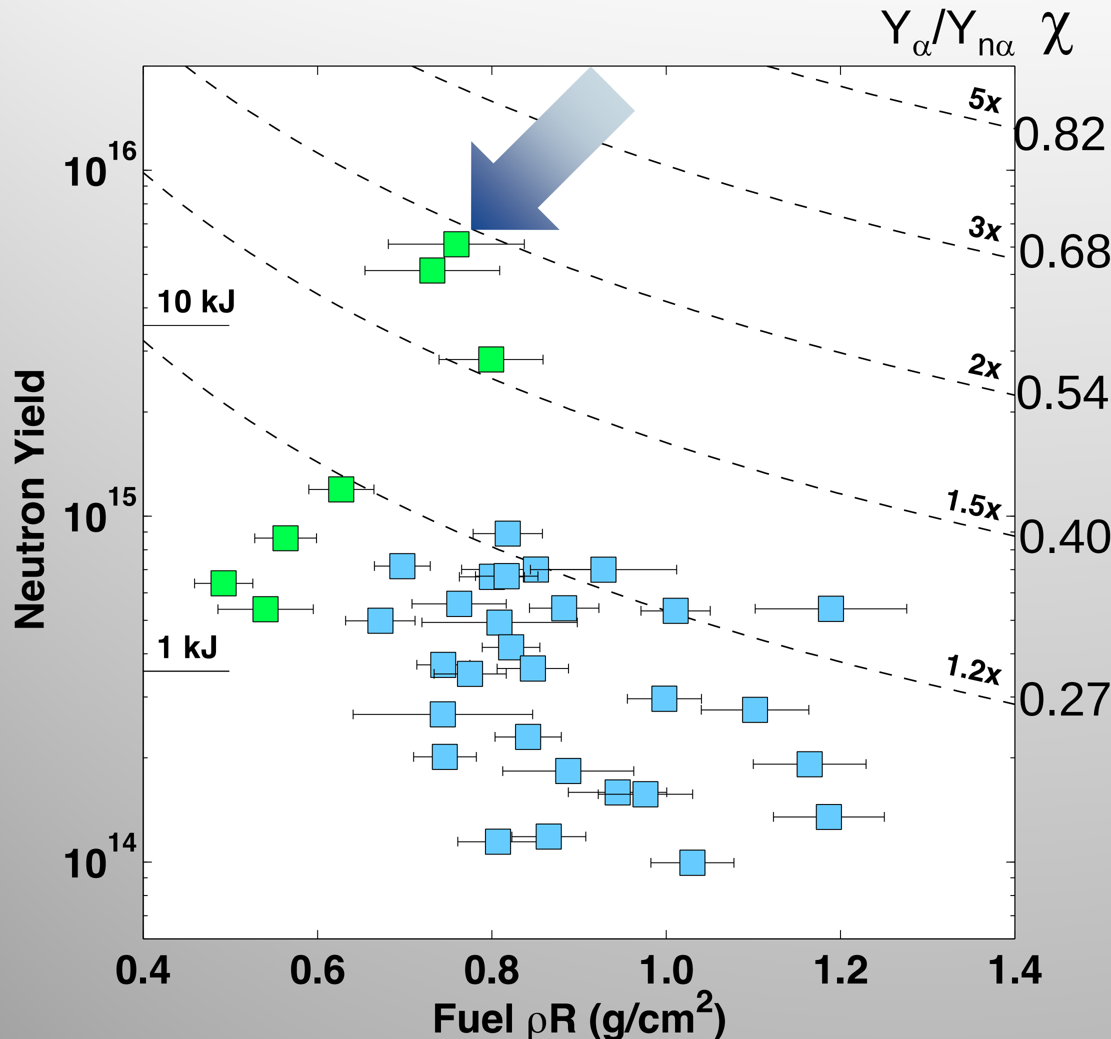
Preliminary analysis



Total yield ~ 17kJ



Status of "high foot" implosions



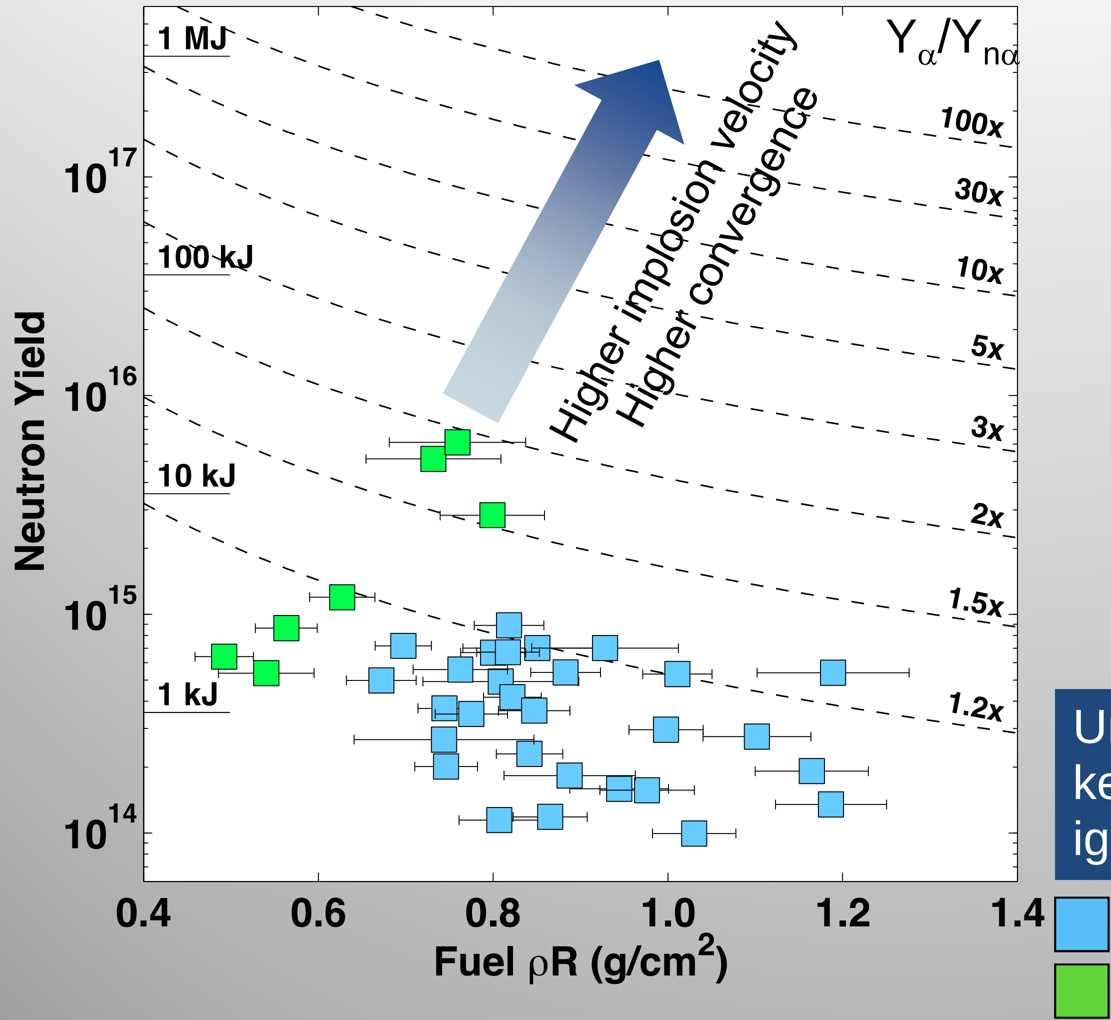
Nov 19 High-foot experiment

- V_{Fuel} ~ 330 km/s
- χ ~ 0.5
  (ITFX ~ 0.25)
- Yield amplification ~ 2X

Low foot (NIC)

High foot

Path to ignition



This requires

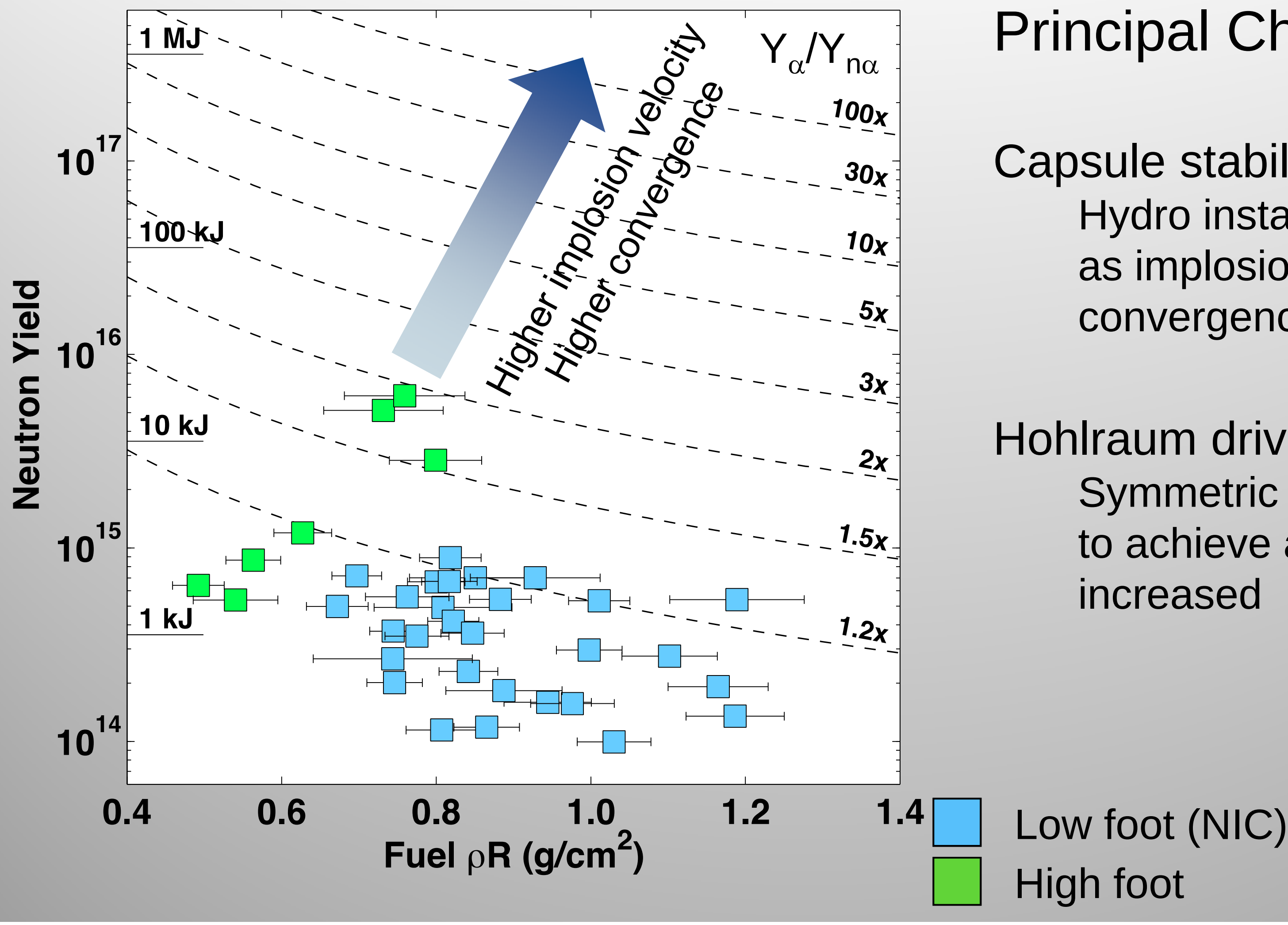
- higher implosion velocity
- higher convergence ratio
- improved symmetry
- significant alpha heating

Physics understood with focused experiments

Then tested in staged goals towards ignition

Understanding how capsules fail is key to setting new requirements for ignition on the NIF

Path to ignition



Principal Challenges

Capsule stability

Hydro instabilities increase as implosion velocity and convergence increase

Hohlraum drive symmetry

Symmetric drive is harder to achieve as laser power increased

Focused experiments

- Capsule x-ray drive
- Implosion trajectories / rocket efficiency
- Shocks
- Growth of capsule perturbations
- In-flight implosion shape
- Hot spot shape vs time
- Hot spot physics
- Hohlraum LPI and hot electrons
- Hohlraum energetics

Ongoing in a number of areas

Others yet to be started

We will give a few examples today

Focused experiments

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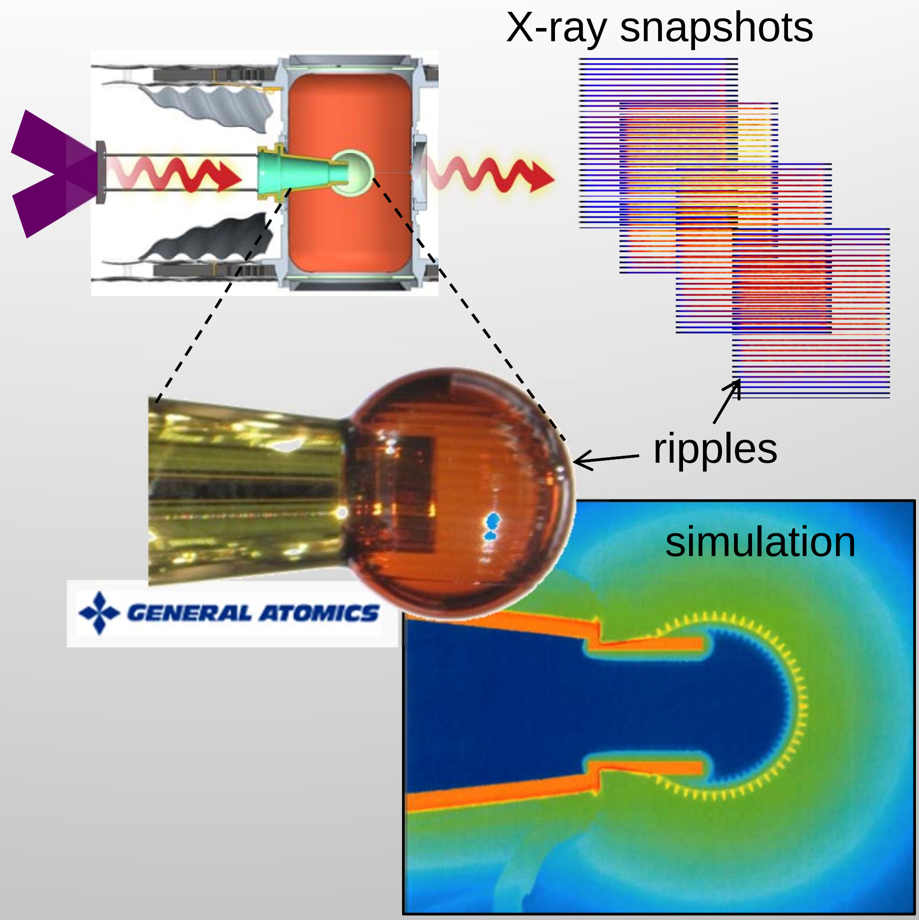
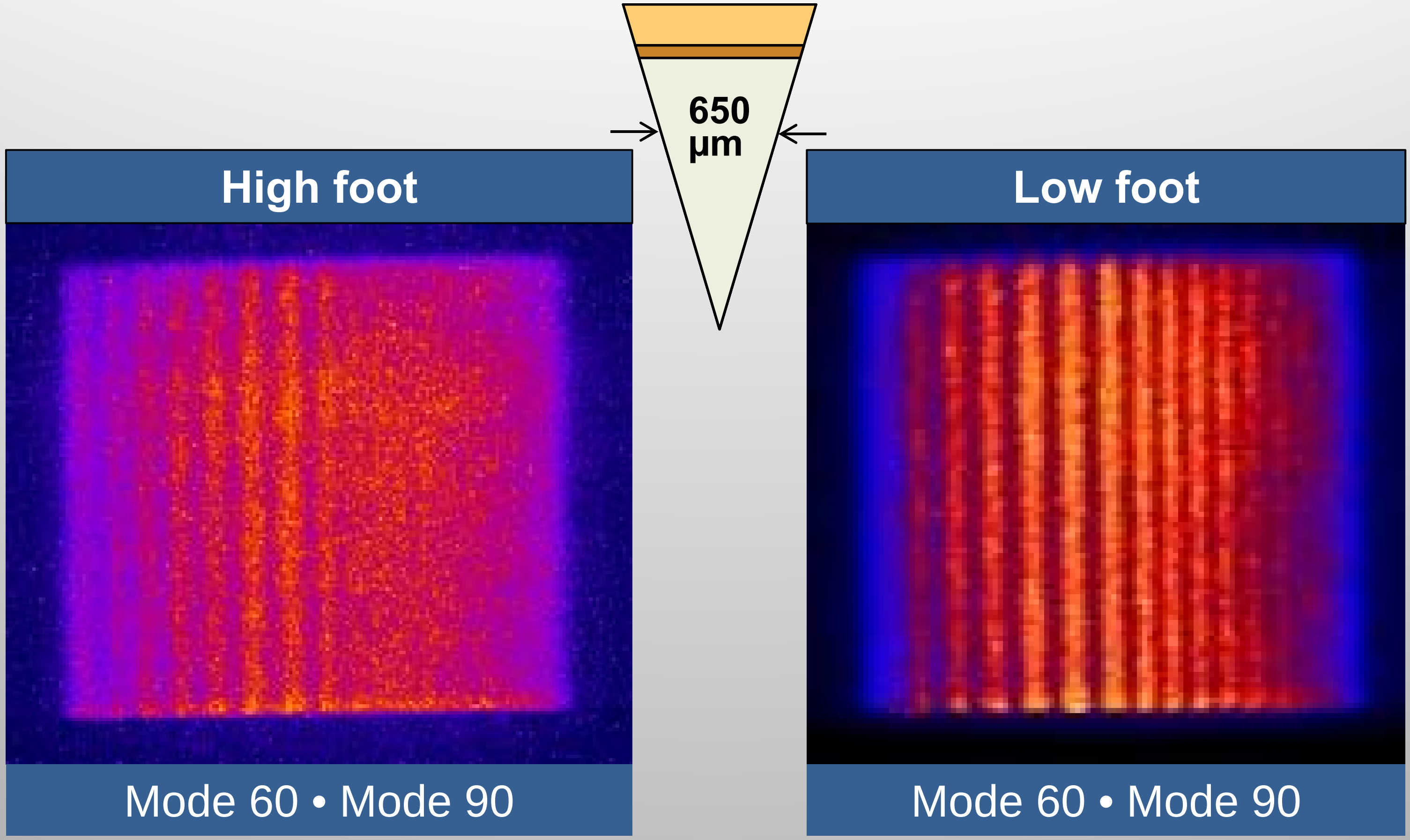
Growth of hydro instability at capsule surface

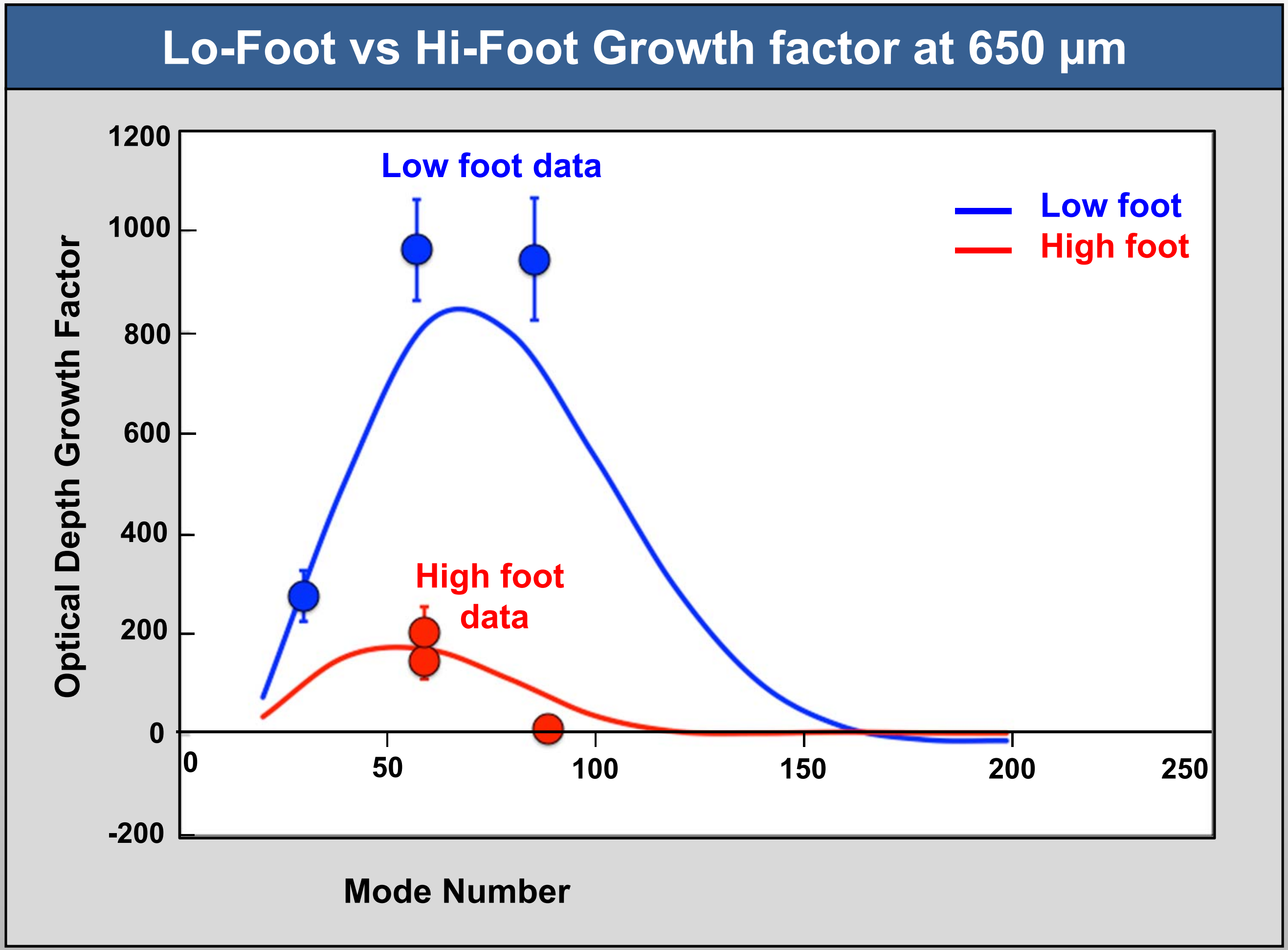


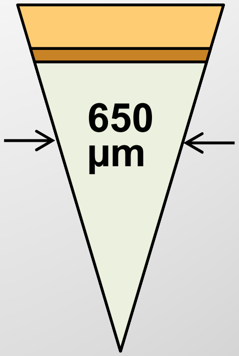
- Growth of instabilities agrees with available data to date for high and low foot drives
- More data is needed

As predicted, instability growth was confirmed lower with the high foot pulse



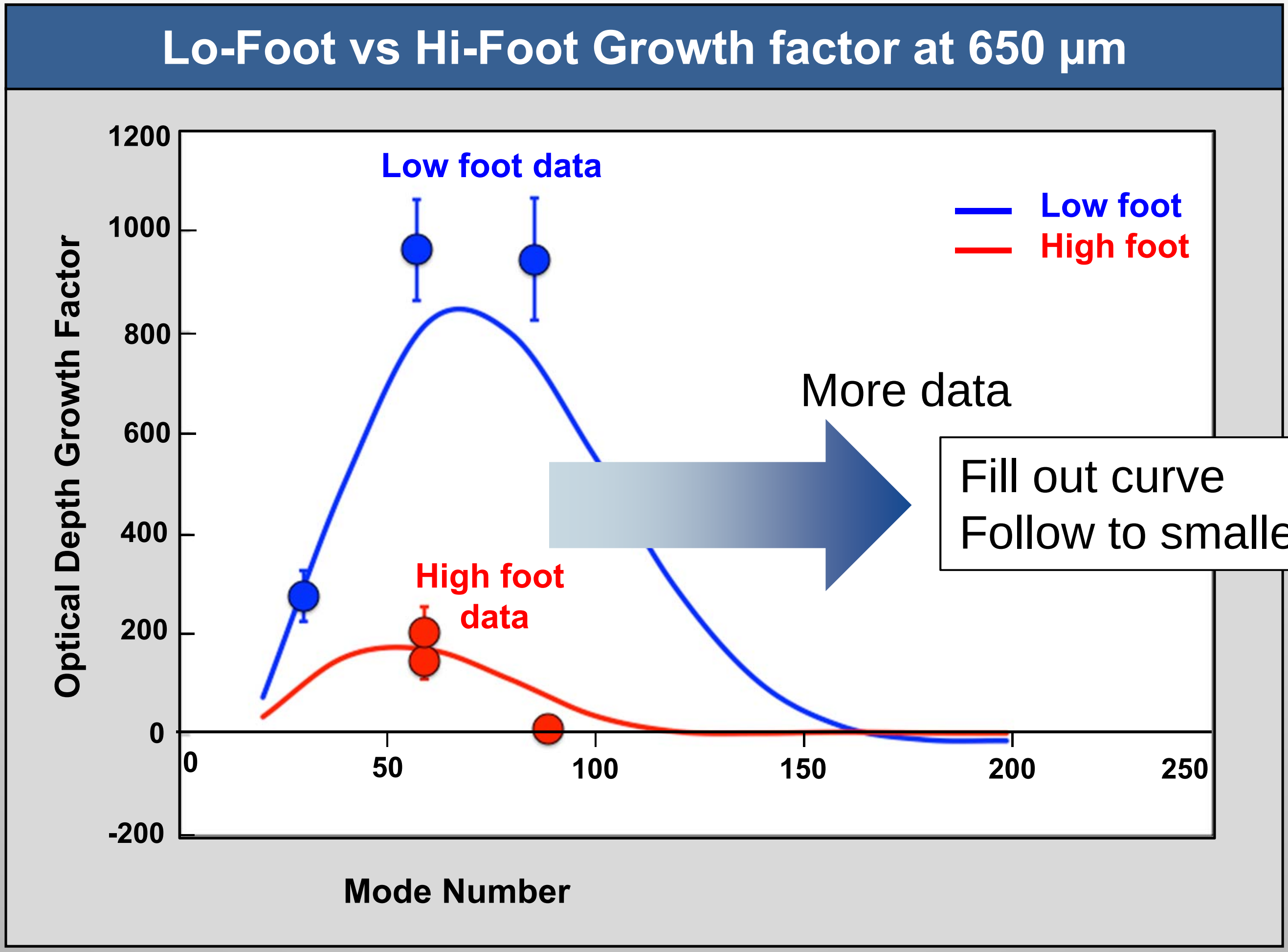
Predictive capability for implosions depends on our ability to simulate growth of perturbations

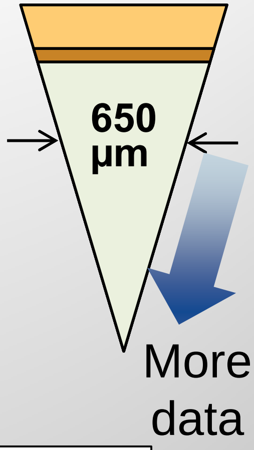




Preliminary analysis K. Raman

Predictive capability for implosions depends on our ability to simulate growth of perturbations

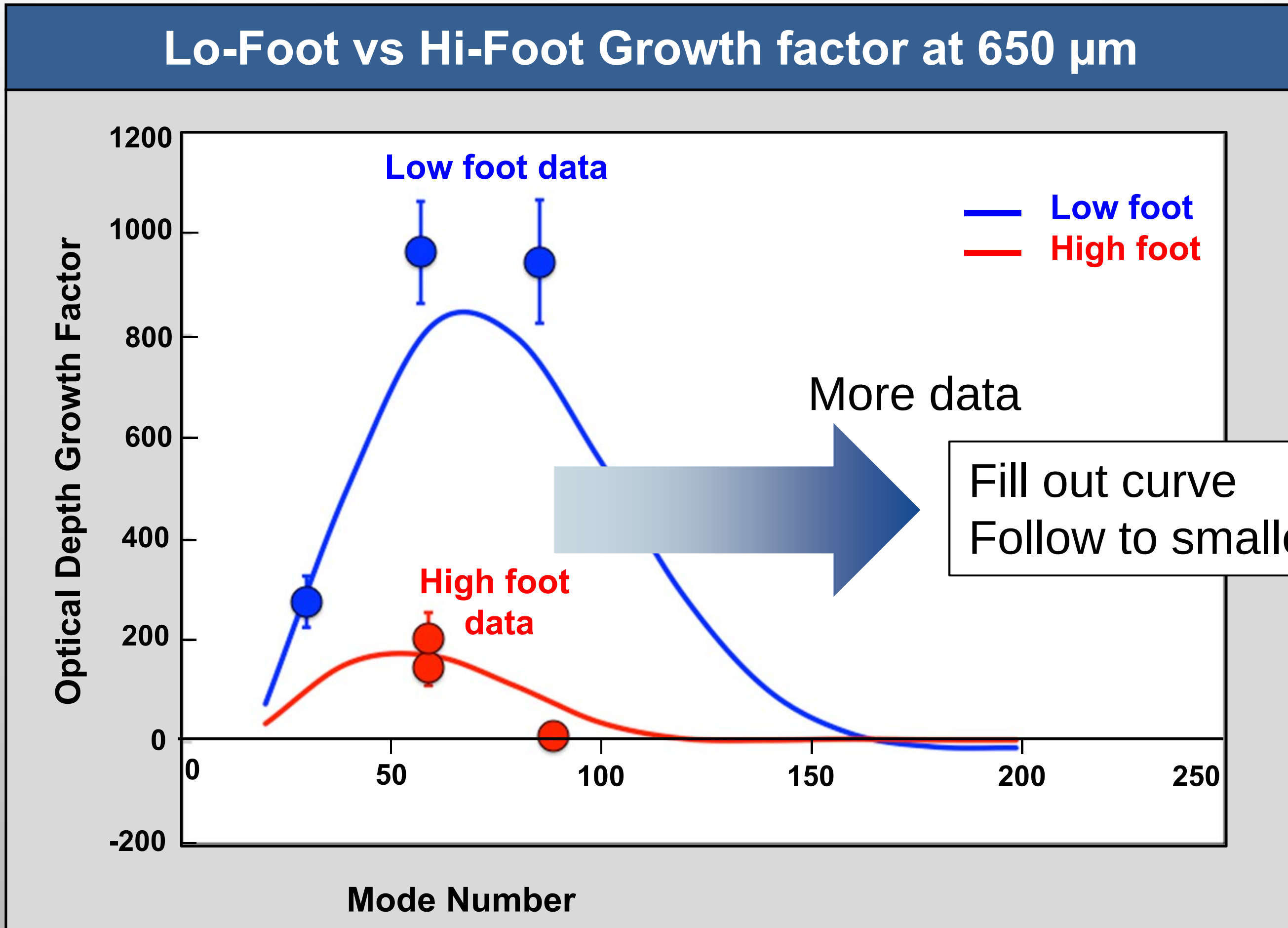


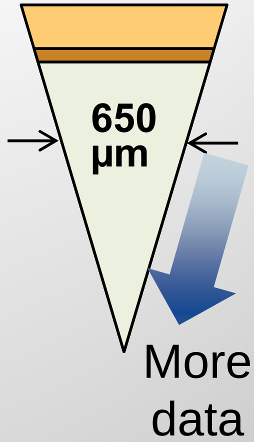


Fill out curve
Follow to smaller radii

Preliminary analysis K. Raman

Predictive capability for implosions depends on our ability to simulate growth of perturbations





Future developments:

- Native surfaces
- Mitigation schemes – e.g. adiabat shaping, drive spectrum control

Focused experiments

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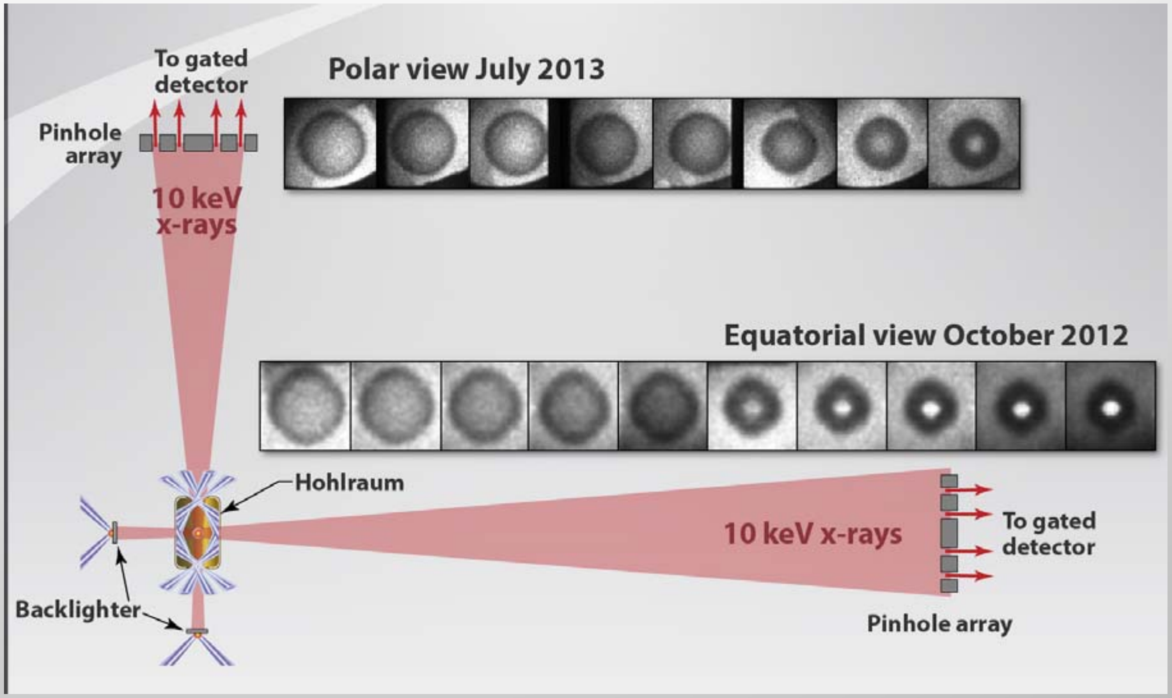
Backlit implosion technique to measure in-flight capsule shape



Revealed

- P4 implosion asymmetry
- Large perturbation due to capsule tent

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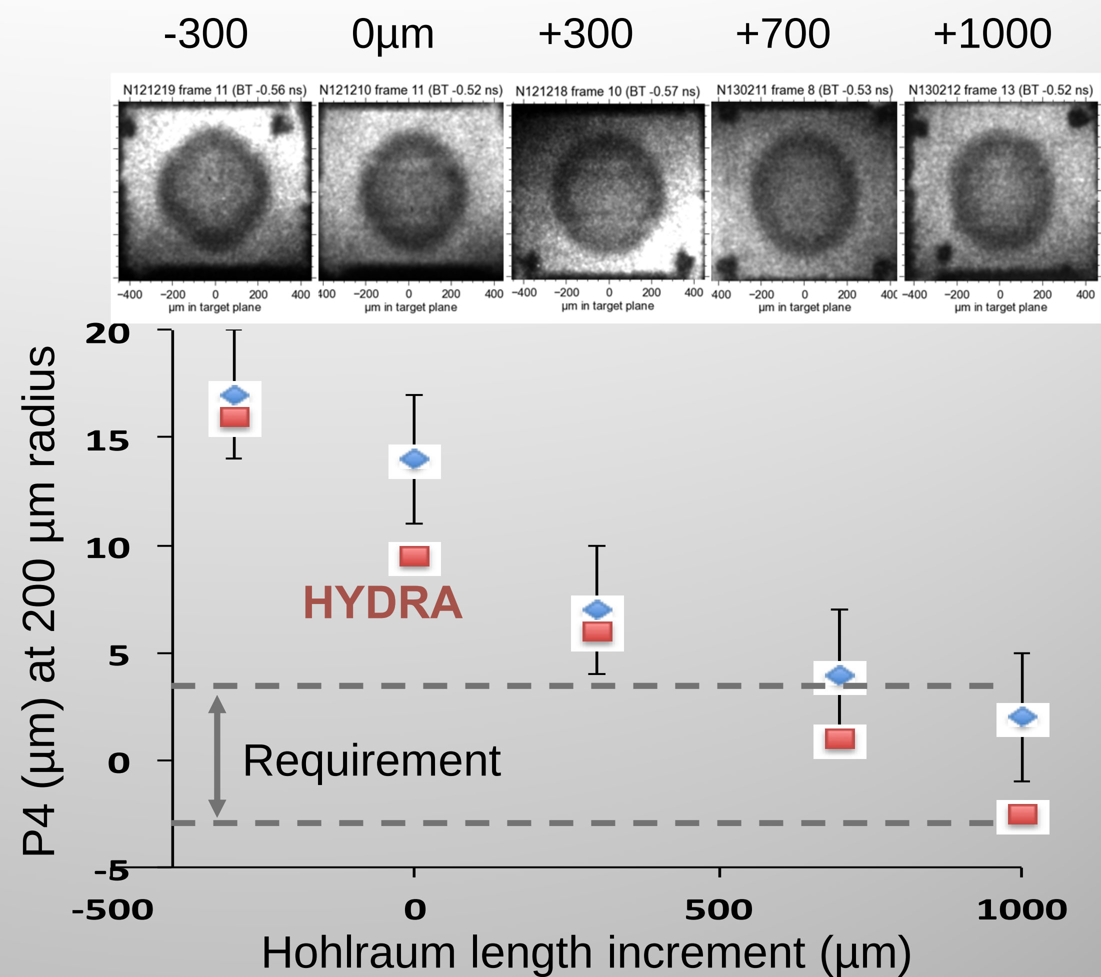
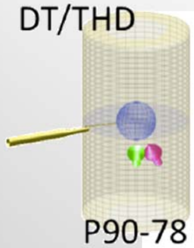
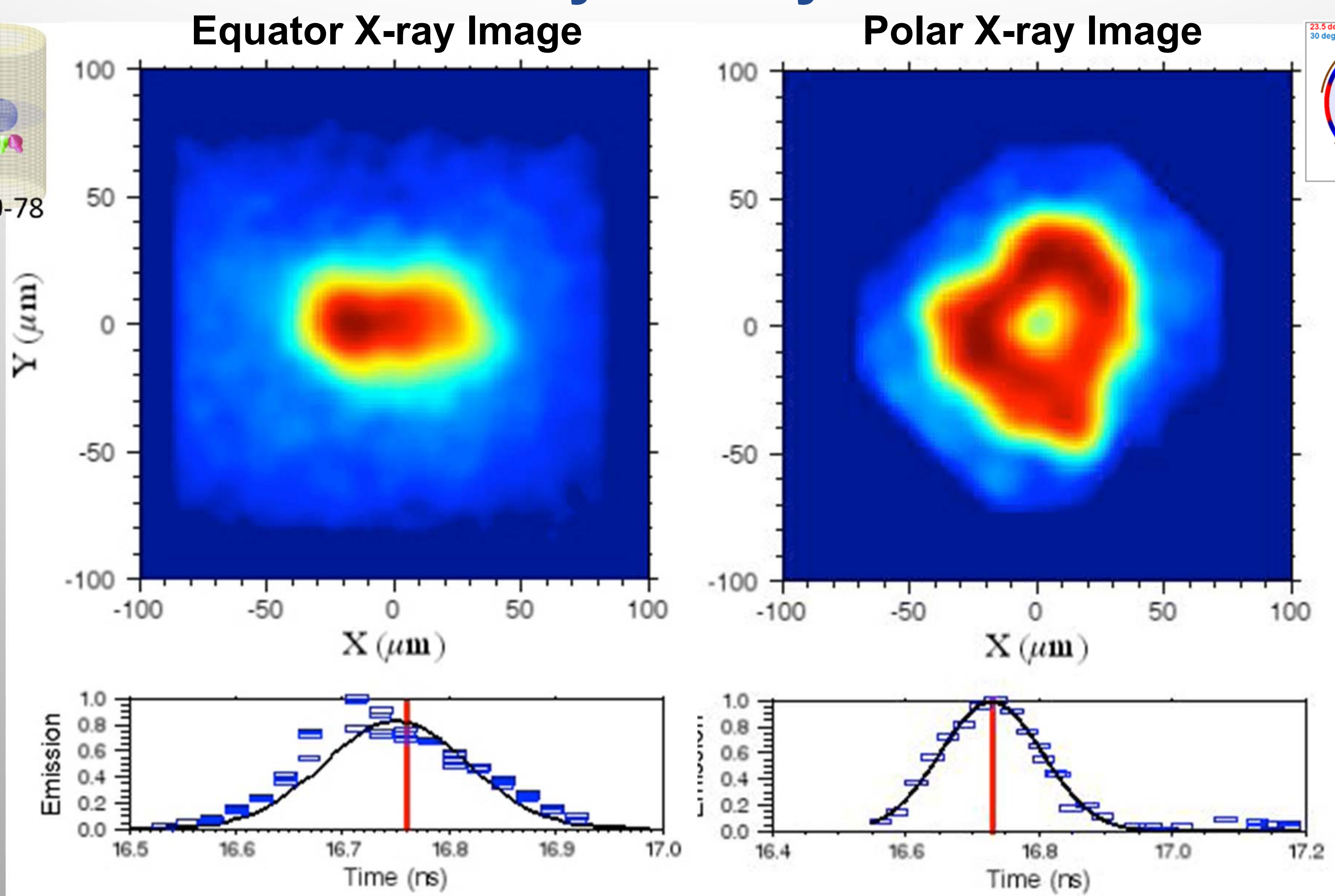
Hohlraum length experiments on P4 symmetry

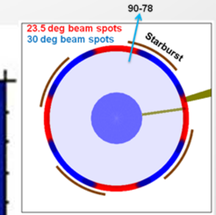


Verified P4 scaling with hohlraum length

Implosion has a torroidal shape
- P2 and P4 drive asymmetry

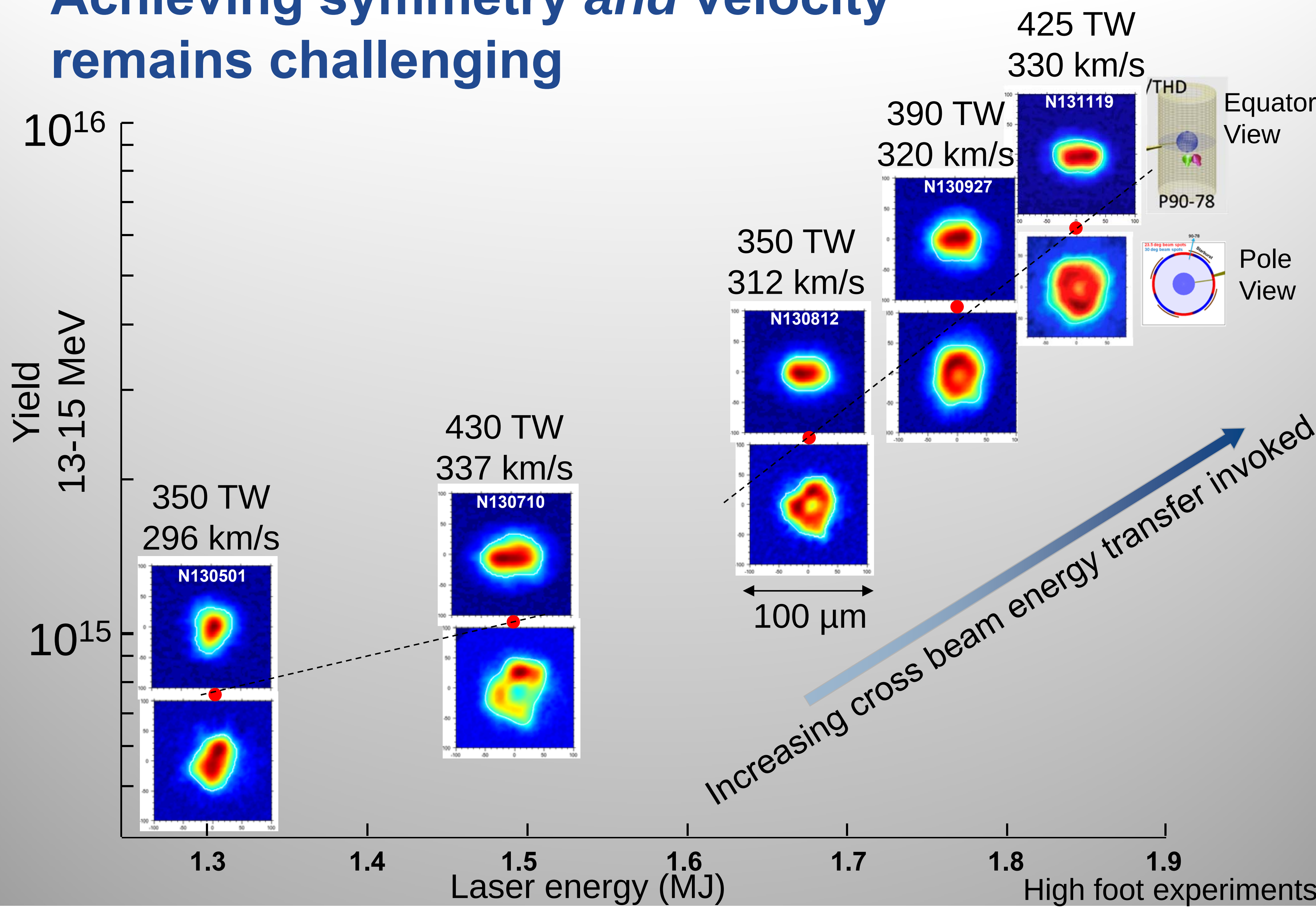




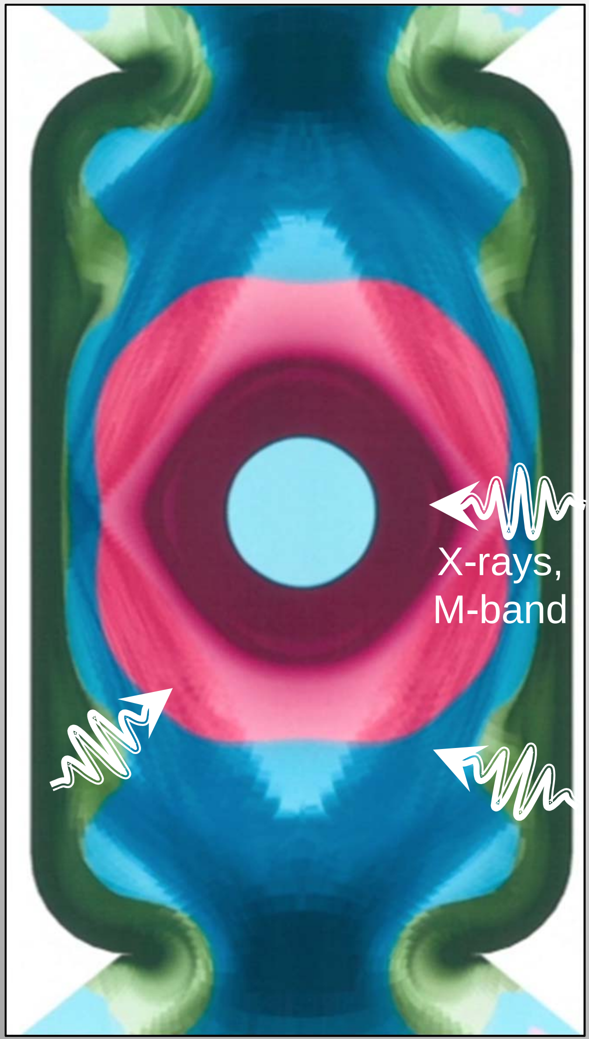


Hi foot DT N130812

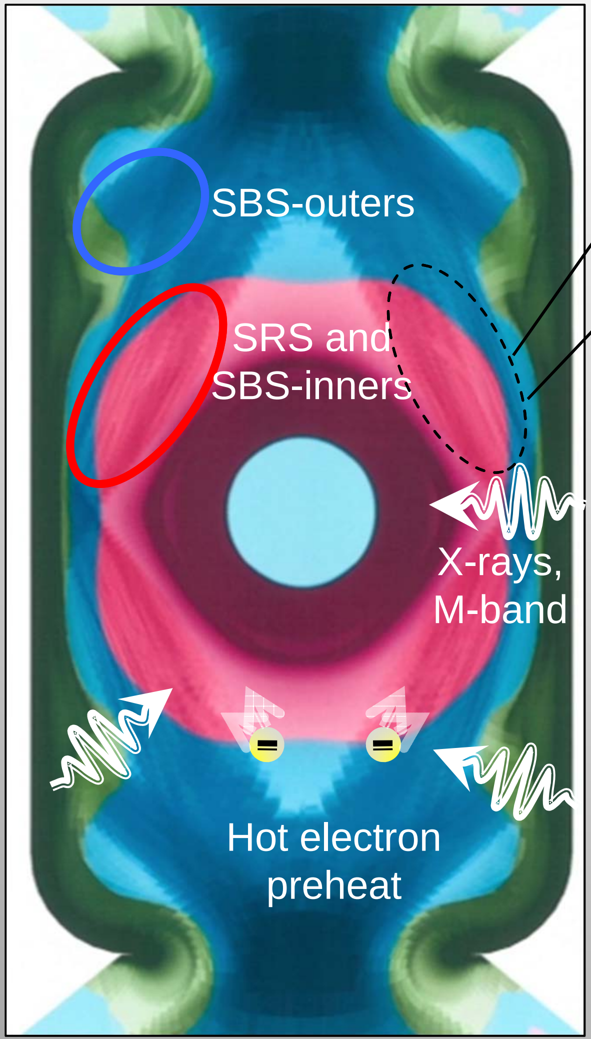
Achieving symmetry *and* velocity remains challenging



Gas-filled hohlraum dynamics are complicated

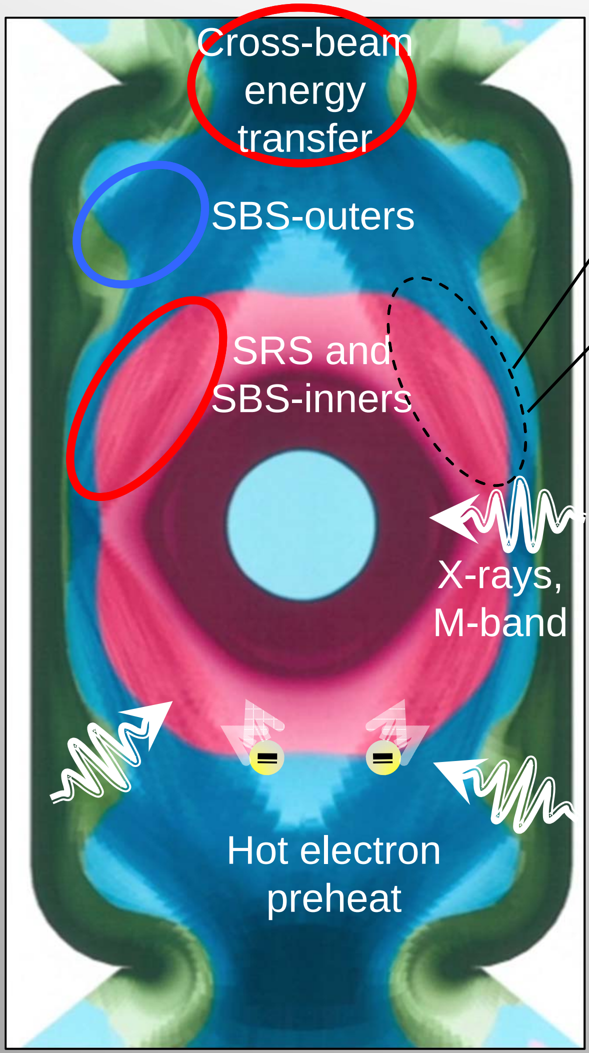


Gas-filled hohlraum dynamics are complicated



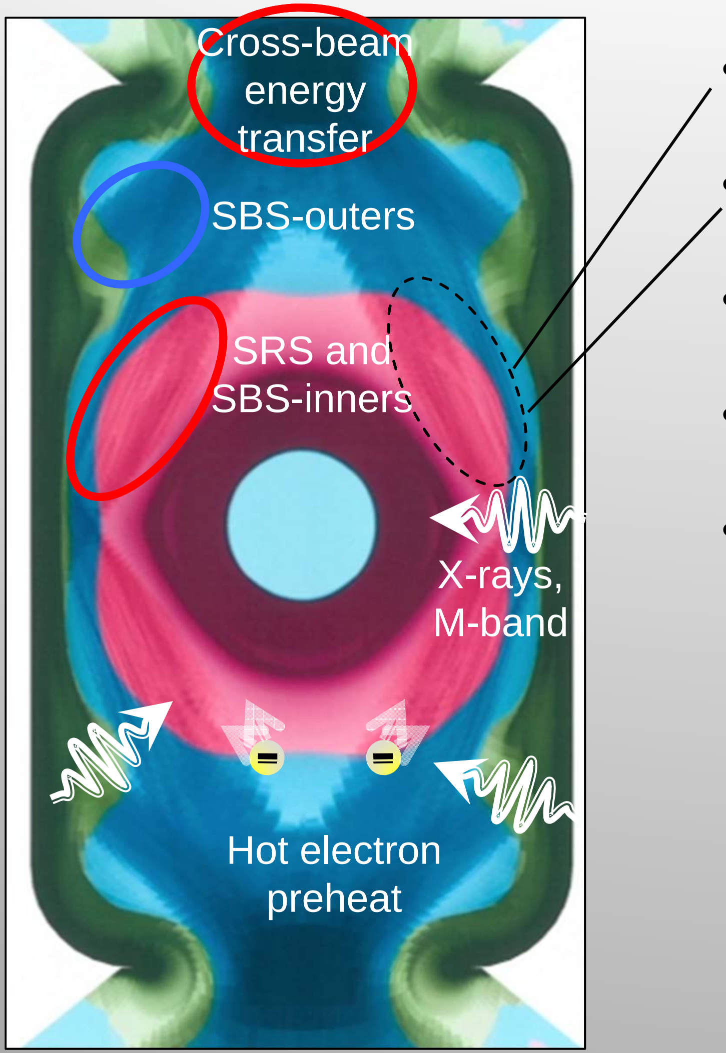
- Poor inner beam propagation
- Backscatter loss ~ 15% ~200kJ

Gas-filled hohlraum dynamics are complicated



- Poor inner beam propagation
- Backscatter loss ~ 15% ~200kJ
- Require cross beam energy transfer
- Leads to time dependent asymmetry

Gas-filled hohlraum dynamics are complicated



- Poor inner beam propagation
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- As yet unexplained drive deficit ~ 200kJ

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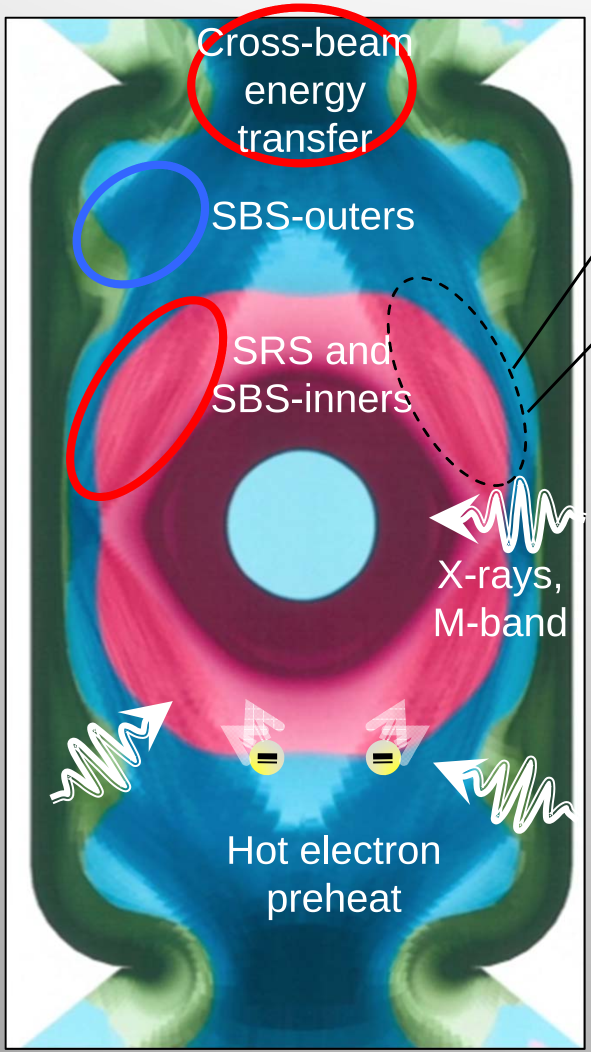

- Poor inner beam propagation
- Backscatter loss ~ 15% ~200kJ
- Require cross beam energy transfer
- Leads to time dependent asymmetry
- As yet unexplained drive deficit ~ 200kJ

Focus of future effort:
- Better understanding of all of these issues
- Develop a more predictable, more efficient hohlraum with better symmetry control

Focused experiments

- Capsule x-ray drive
- Implosion trajectories / rocket efficiency
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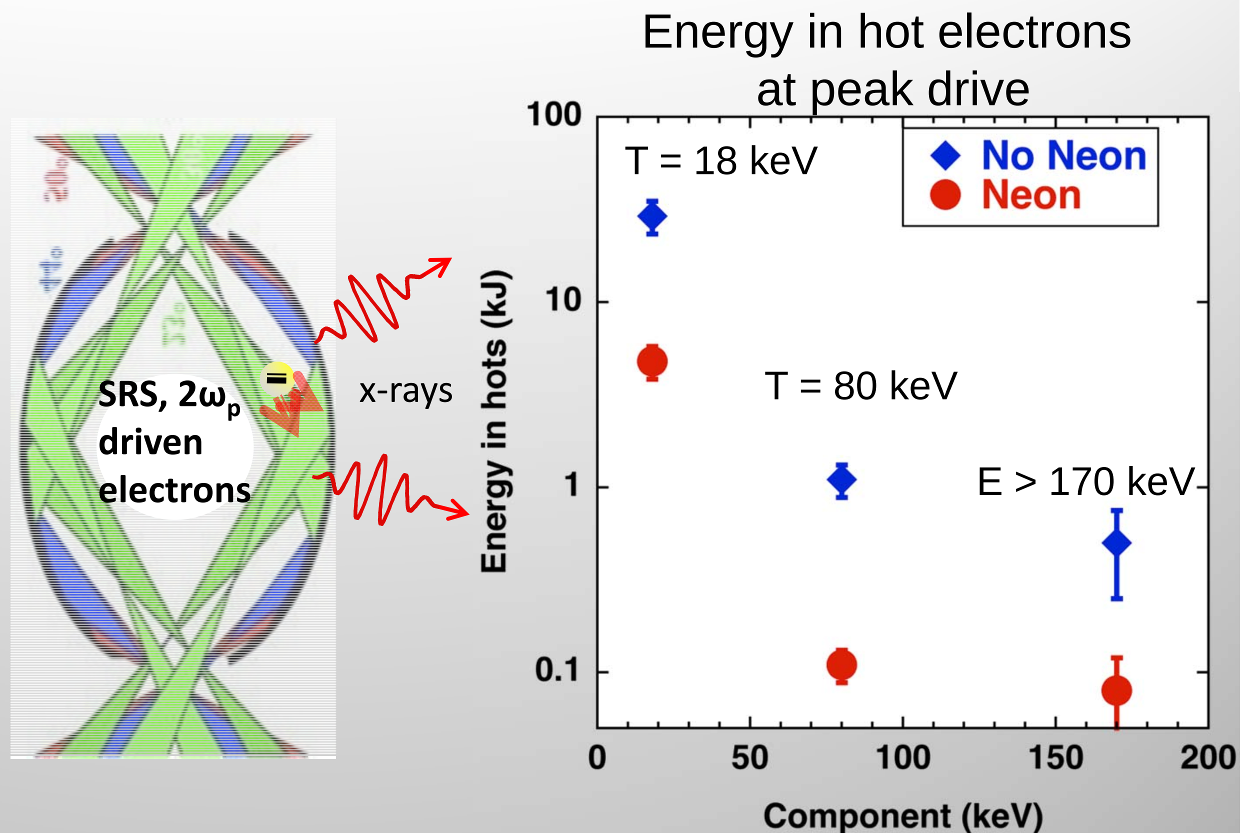
Rugby hohlraums, gas-composition and hot electrons



Preliminary analysis – work in progress

- Coupling similar to all other gas-filled targets
- Implosion symmetry with minimal cross beam energy transfer
- Factor ~ 4 reduction in hot electrons - due to Ne?

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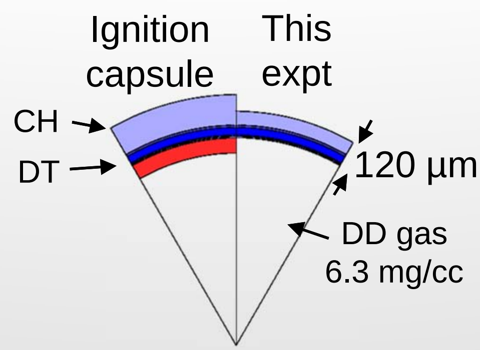
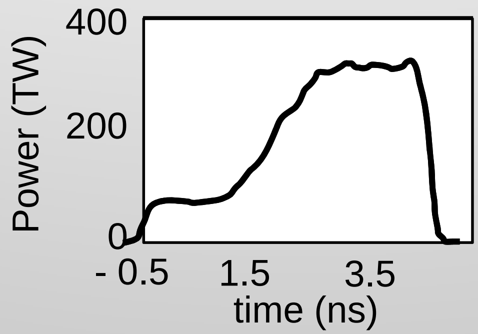
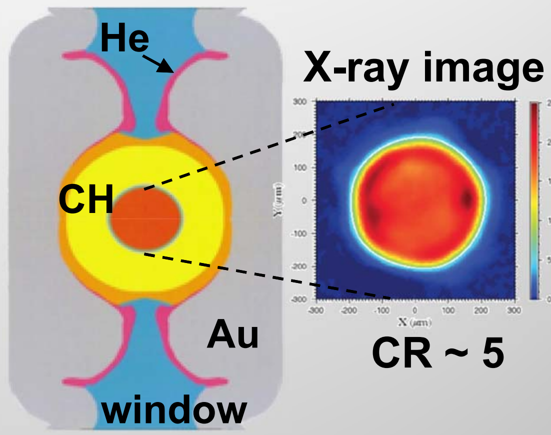
Near vacuum hohlraums – energy balance







- No LPI - ~ 1% backscatter (vs. ~ 15% in gas-filled)
- No drive deficit (vs. ~ 15% in gas-filled)
- No cross beam energy transfer

Future experiments will understand effect of gas-fill

Focused experiments

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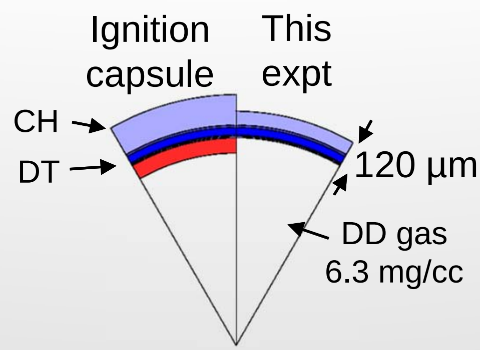
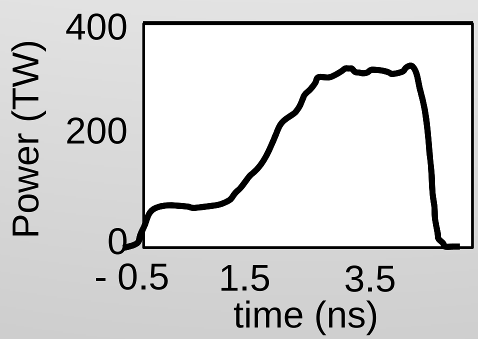
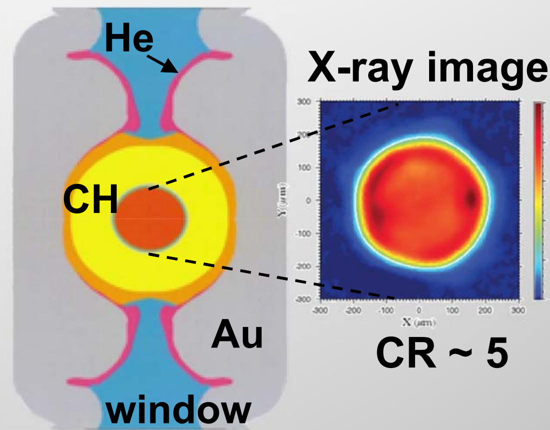
- Hot spot shape vs time
- Hot spot physics
- Hohlraum LPI and hot electrons
- Hohlraum energetics

Near vacuum hohlraums





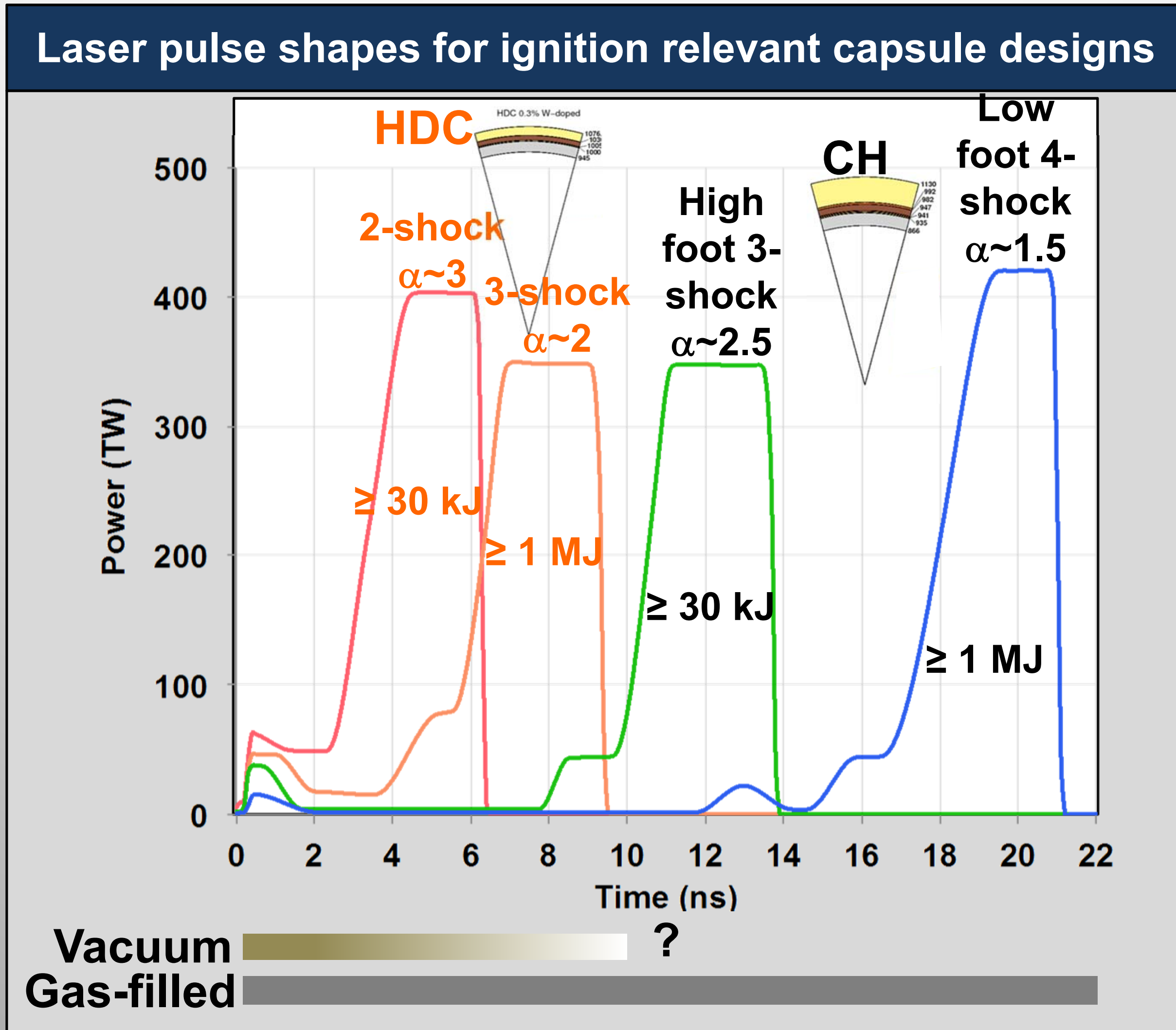


Ignition applications?

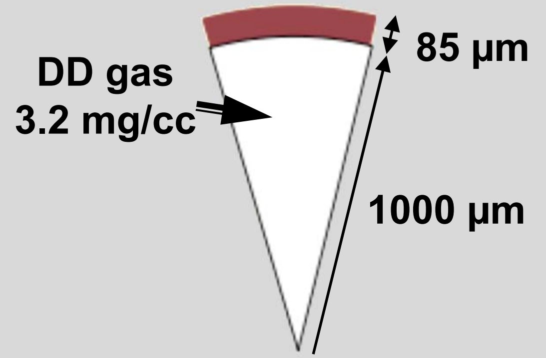
Ignition targets need long pulses

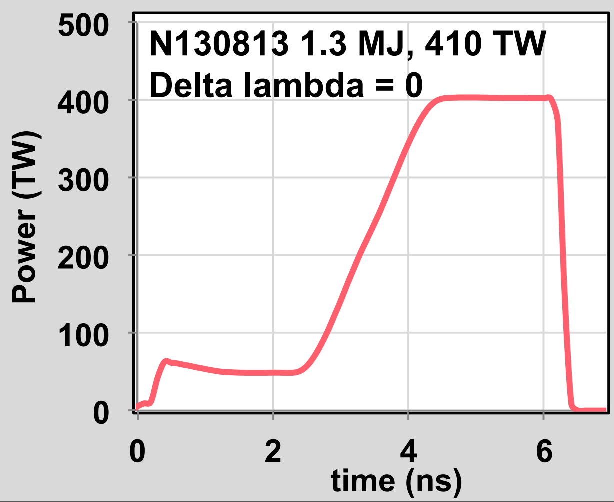
Challenge is imploding the capsule symmetrically before hohlraum fills with plasma

The high density of diamond (HDC) ablators lead to short laser pulses



Initial 2-shock experiments with HDC in near vacuum hohlraums are promising - but more work to do

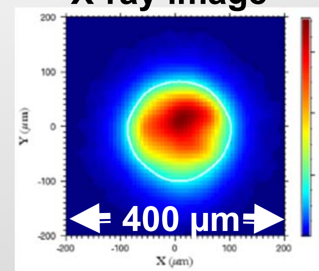




N130811 - Key experiment results

- Preserved hohlraum coupling and drive efficiency
- Near 1-D spherical implosion

X-ray image



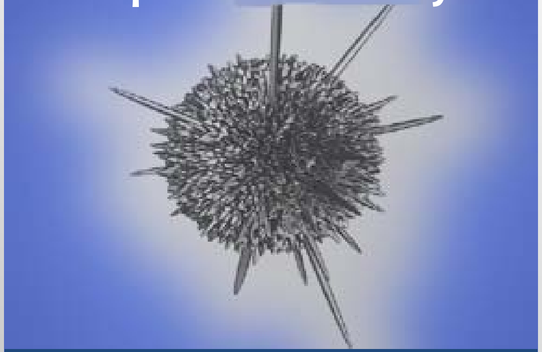
	Preshot	*Postshot drive	Expt
Mband fraction (>1.8 keV)	28%	22%	22%
Yield (DD)	1.5e13	2.4e13	2.3e13
T_{ion} (keV)	3.3	3.3	3.4
Bang time (ns)	7.35	7.75	7.77
P0 (µm)	109	101	91
Velocity (km/s)	450	430	N/A

* drive adjusted for delivered energy and observed spectrum

But symmetry swings are too large for higher convergence layered implosions
Future experiments will explore larger hohlraums and other modifications

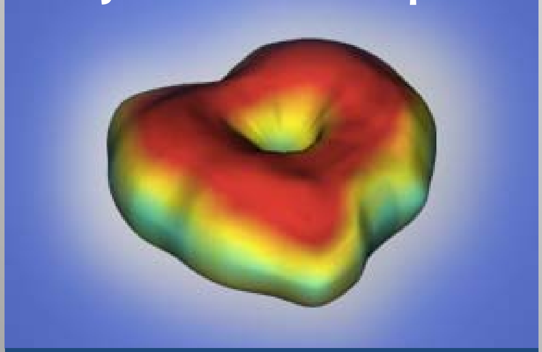
Future emphasis: improved predictive capability with staged goals towards ignition

Capsule instability



Growth x Surface seeds is too large

Asymmetric hot spot



X-ray push on the capsule is not symmetric enough

- For the Capsule
  - Understand the "mix cliff" (velocity, adiabat, surface roughness)
    - Direct measurement of growth of hydro instabilities
    - Improved hot spot mix techniques
  - Explore mix mitigation schemes
  - Verify effects of alpha heating
- For the Capsule and Hohlraum:
  - Alternate ablators – diamond (HDC), beryllium (Be)
  - Different capsule/hohlraum pros and cons vs. CH
- For the Hohlraum:
  - Understand the hohlraum energy balance
  - Explore ways to develop a more efficient, predictable hohlraum with better symmetry control (less LPI, CBET)

Development of new experiment techniques, diagnostics and analyses are key to the path forward

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