Antonio Giulietti

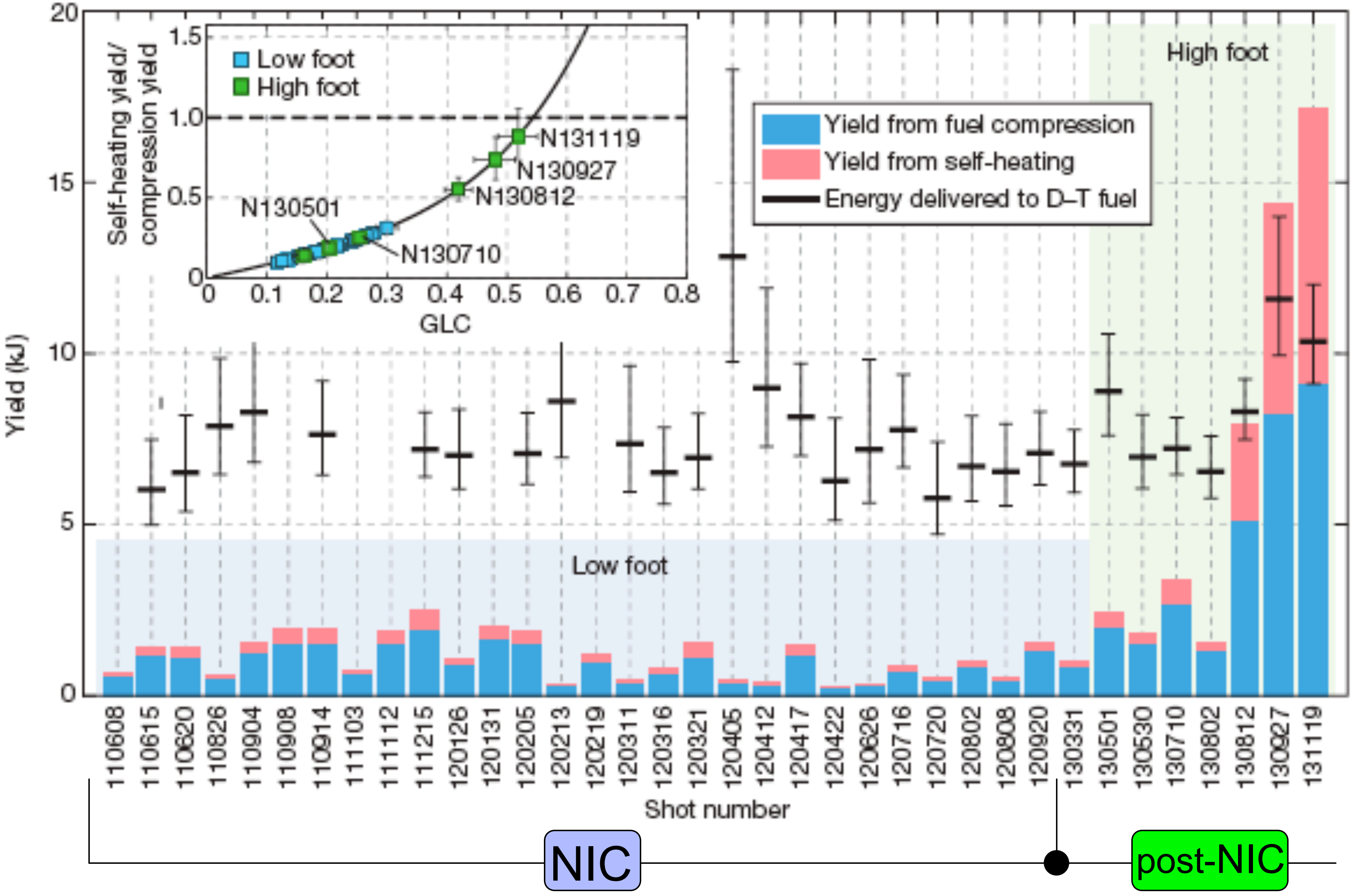
Review on latest experiments at the National Ignition Facility

Istituto Nazionale di Ottica

Area della Ricerca CNR di Pisa

aula 33 ore 10:00

O. A. Hurricane *et al.*, Nature 506, 343 (20 February 2014)



September 29, 2013

NIF Breaks Yield Record and Reaches Scientific Breakeven

At 5:51 this Saturday morning, we successfully completed our next Deuterium-Tritium (DT)cryogenic layered fuel implosion experiment. All 192 beams delivered 1.82 megajoules of ultraviolet light into the Laser Entrance Holes (LEHs) in the target. The peak power was 395 trillion watts. Excellent target diagnostic data was obtained and data analysis has started.

Initial indications are this shot provided a record neutron yield of ~5x10^{15} neutrons (~14 kJ), almost 75% higher than the last record DT implosion yield.

More importantly, the self-generated energy of this target exceeded the input energy of the imploding DT fuel. This is called ***scientific break-even*.** The amplification of the yield by nearly a factor of two as a result of "self-heating" is a clear demonstration of the mechanism that is needed to achieve ignition.

Saturday's shot was the latest in a series of carefully designed and incremental ignition experiments that have increased the yield more than five-fold since the first high foot DT experiment in May of 2013. This increase in yield has resulted both because the hydrodynamic compression energy going into the hot spot has gone up, and because of yield boost due to the additional "self-heating". This comes about because the alpha particles, helium nuclei that are a by-product of the fusion process, deposit energy into the burning core increasing the rate of burn. This feedback process – more alphas result in more yield producing more alphas - is the mechanism that leads to ignition. This series of experiments has clearly demonstrated the beginnings of this process.

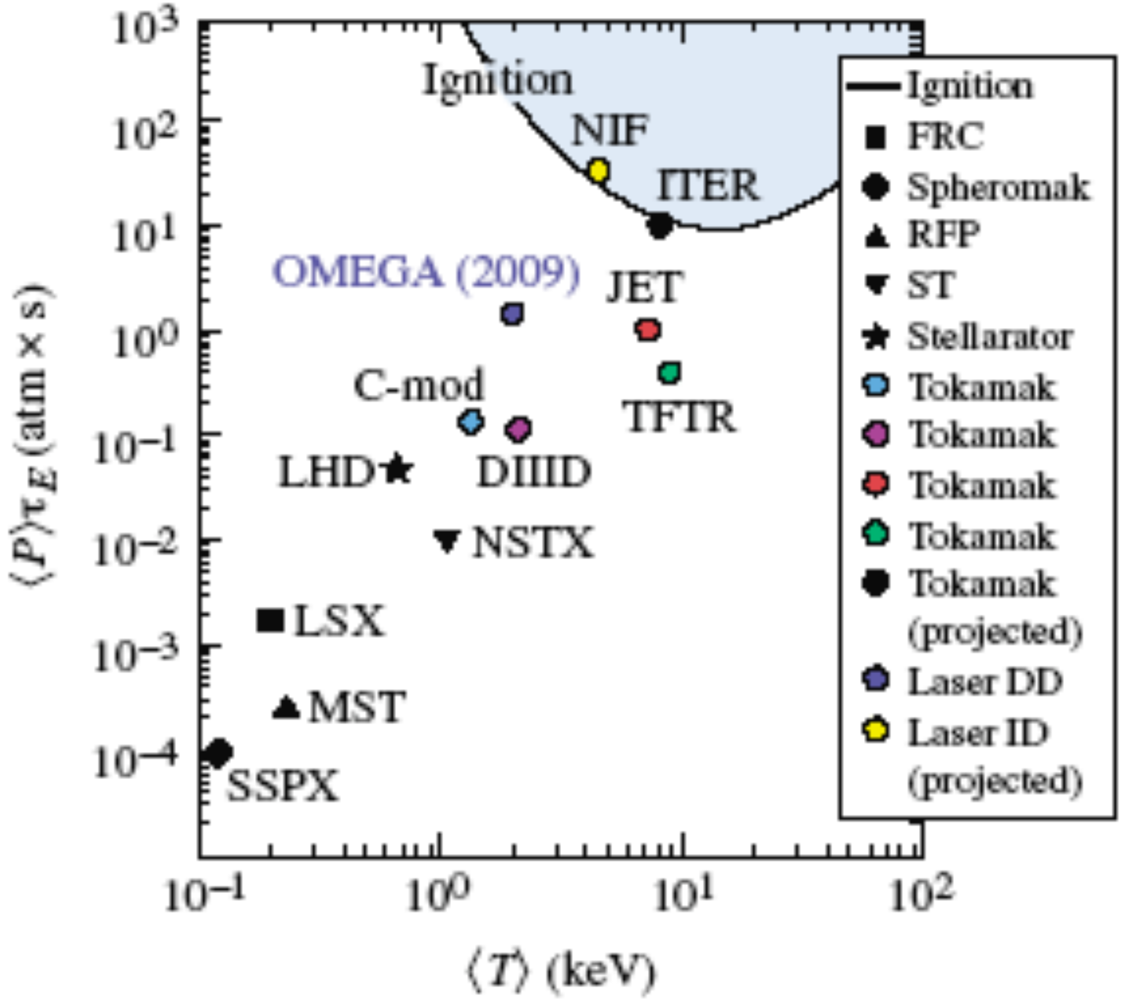
Two memorable quotes are from leading fusion researcher Riccardo Betti, University of Rochester, saying simply, "Holy Cow!' and from Omar Hurricane, this campaign's lead scientist, "It's going to be a while before the smile comes off my face". I think that we all agree.

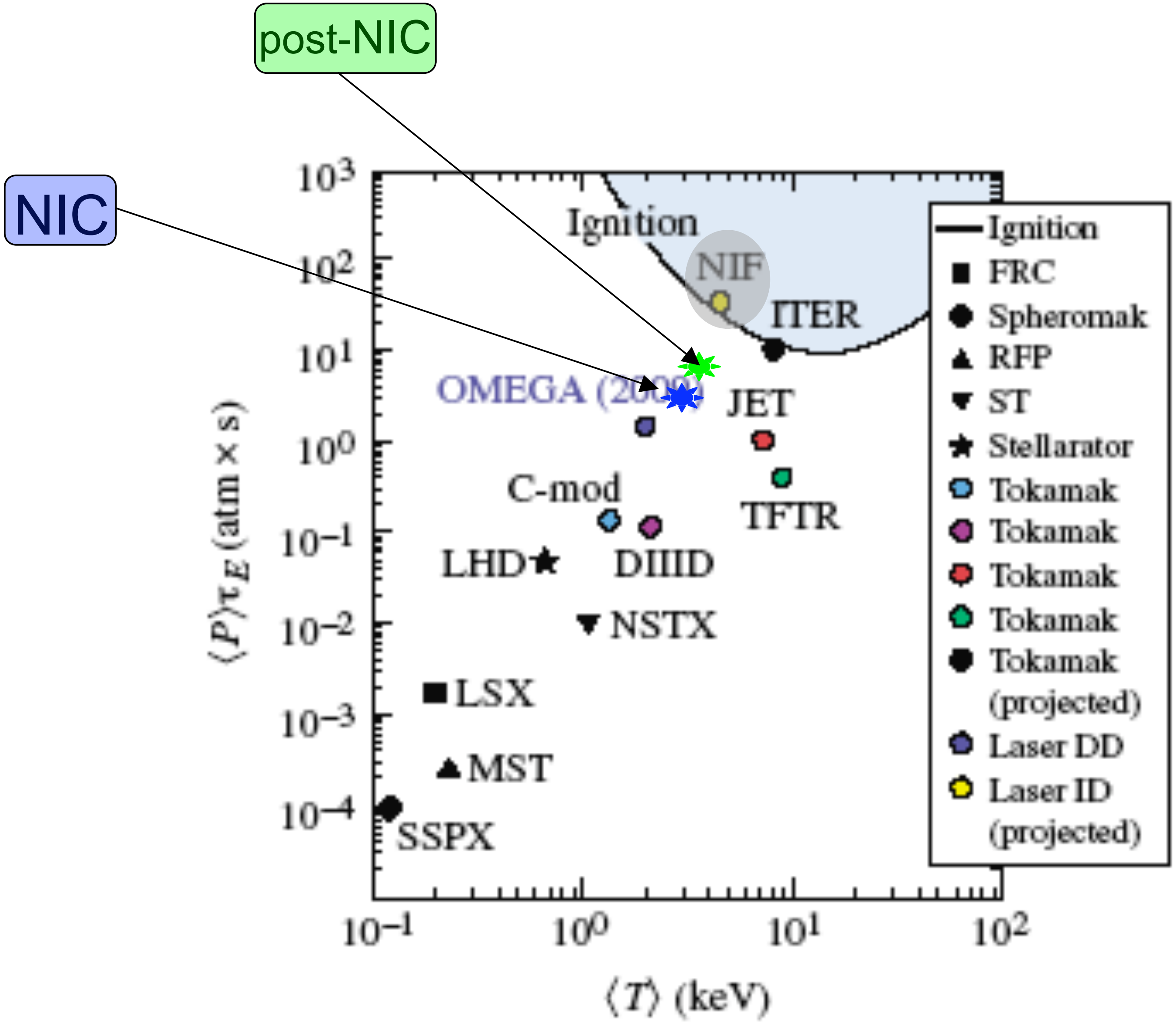
The experiment is part of the ongoing "high foot" series of shots designed in a close collaboration between LLNL's NIF and WCI scientists. Some interesting facts are that the DT ice layer was nearly flawless and all aspects of the laser and diagnostics worked as well as ever. There are many other interesting aspects of this experiment that we will be reporting on as the
data is processed.

Stay tuned.
emoses

[Ed Moses, Associated Director at NIF]

R. Betti *et al.*, PoP 17, 058202 (2010)





post-NIC
NIC
Ignition
NIF
ITER
OMEGA (2009)
JET
C-mod
TFTR
LHD
DIIID
NSTX
LSX
MST
SSPX
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\langle P \rangle \tau_E$ (atm × s)
10^{-1}
10^0
10^1
10^2
$\langle T \rangle$ (keV)
Ignition
FRC
Spheromak
RFP
ST
Stellarator
Tokamak
Tokamak
Tokamak
Tokamak
Tokamak (projected)
Laser DD
Laser ID (projected)

Energy balance of NIC and post-NIC

NIF

Electrical energy: $E_{el} \approx 600$ MJ

Laser energy: $E_L \approx 1.8$ MJ

En. delivered to fuel: $E_f \approx 6$ to 12 KJ

FUEL

En. content: $E_N >> 1$GJ

Expec. yield: $E_y \approx 20$ MJ

Ignition: $E_y \approx E_L \approx 2$ MJ *

Best NIC shots:

Total Yield: $E_T \approx 2.5$ KJ

$E_T / E_f < 1/2$

$E_T / E_L \approx 1.4\ 10^{-3}$

$E_T / E_{el} \approx 4\ 10^{-6}$

α-yield: $E_\alpha < 0.8$ KJ $E_\alpha / E_T < 1/3$

$E_\alpha / E_f < 1/6$

$E_\alpha / E_L < 5\ 10^{-4}$

$E_\alpha / E_{el} < 1.3\ 10^{-6}$

*empirical def. of **IGNITION** in the 1997 NRC report on NIF:

$E_T/E_L \approx E_\alpha/E_L = 1$

Best post-NIC shot ($E_f \approx 10$ KJ):

Total Yield: $E_T \approx 18$ KJ

$E_T / E_f \approx 1.8$

$E_T / E_L \approx 10^{-2}$

$E_T / E_{el} \approx 3\ 10^{-5}$

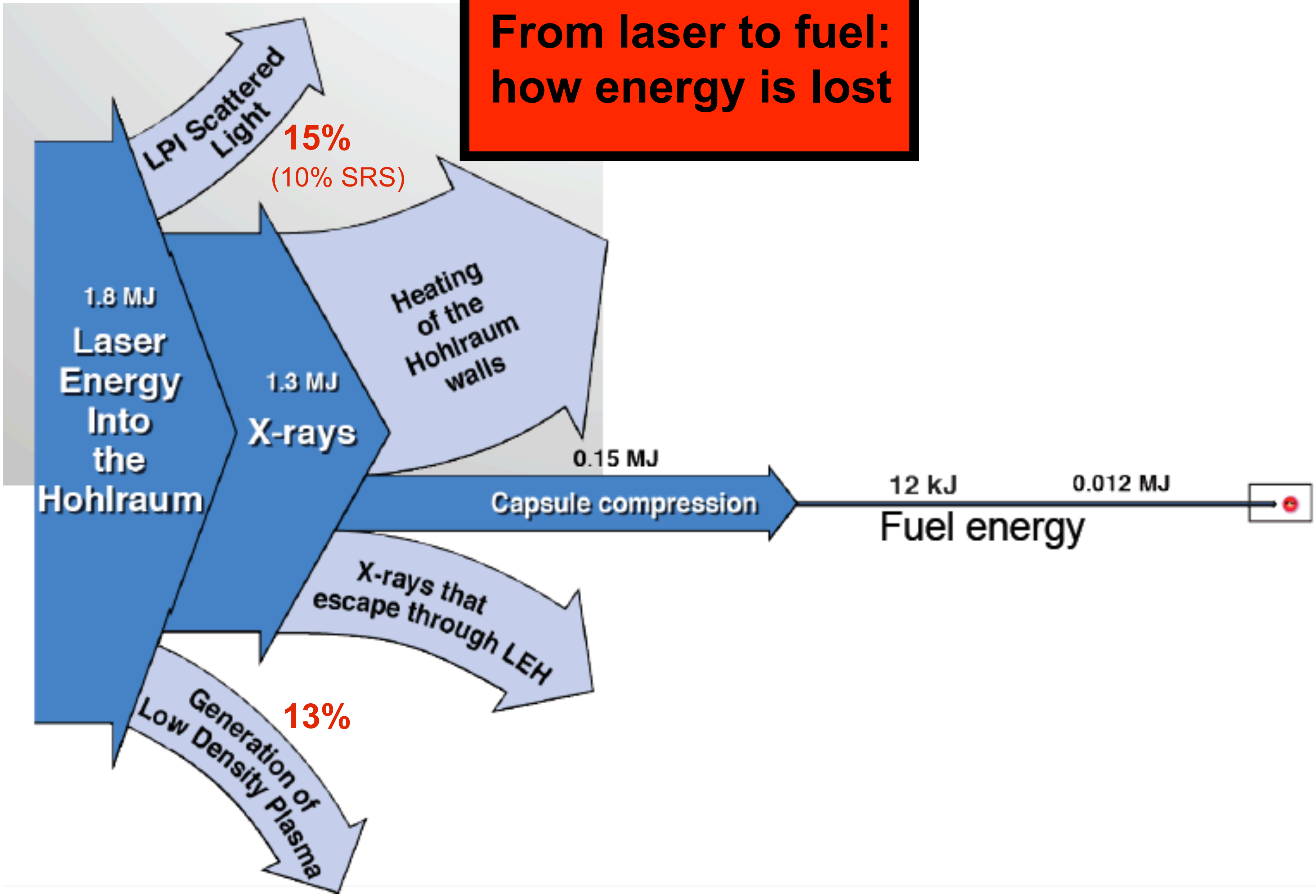
α-yeld: $E_\alpha \approx 9$ KJ

$E_\alpha / E_f \approx 0.9$

$E_\alpha / E_L \approx 5\ 10^{-3}$

$E_\alpha / E_{el} \approx 1.5\ 10^{-5}$

From laser to fuel: how energy is lost

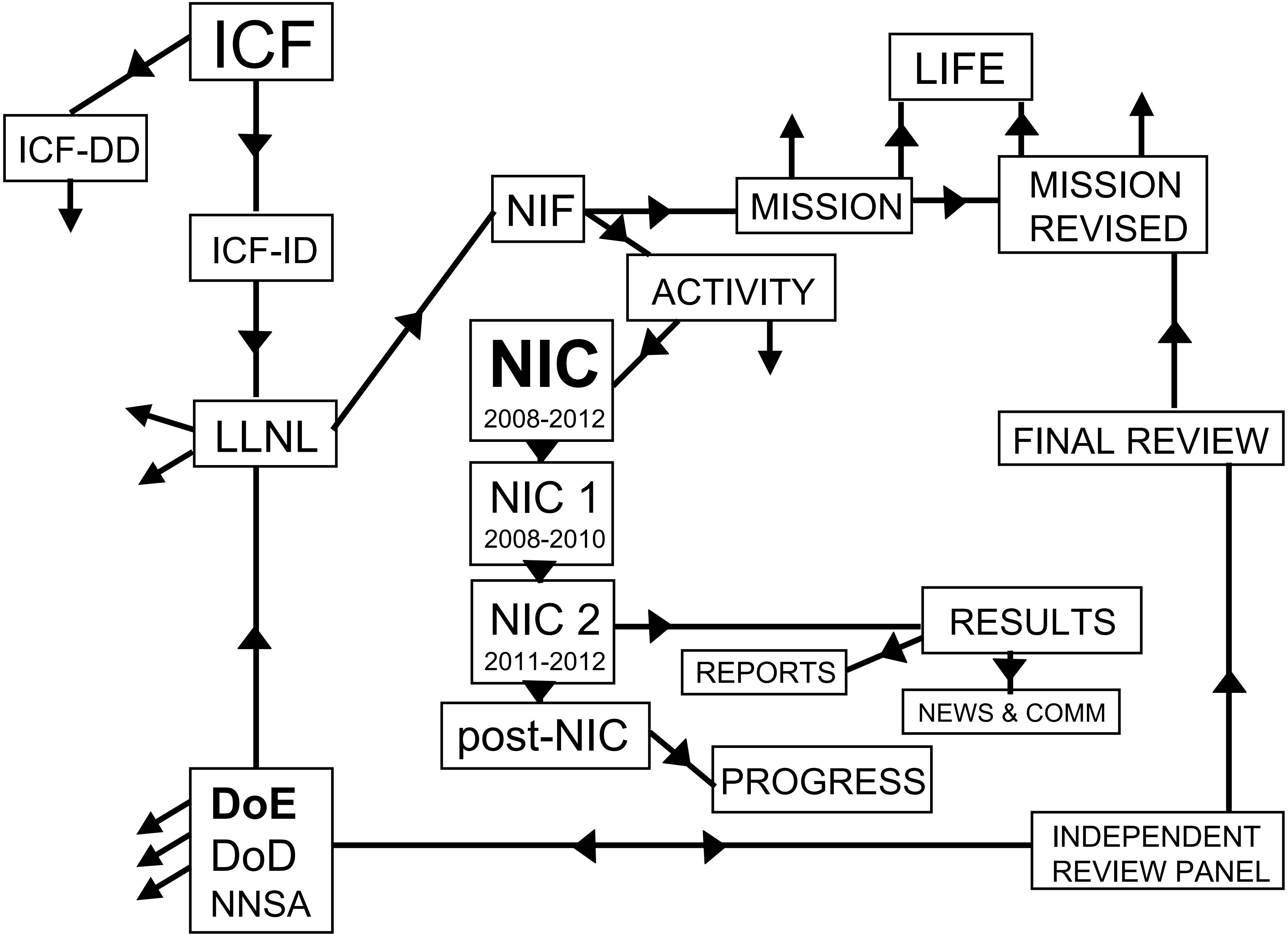


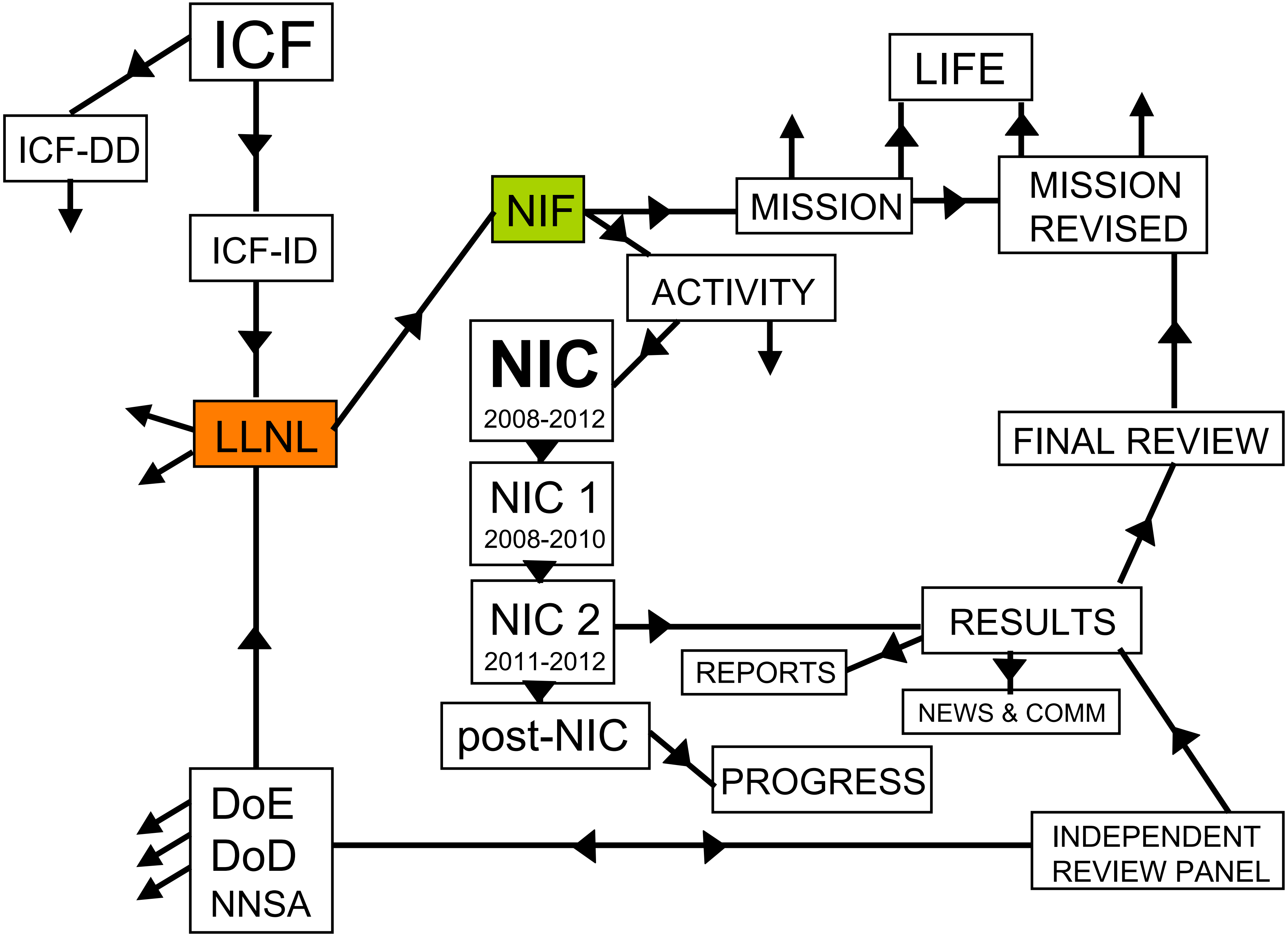
15%
(10% SRS)

13%

0.012 MJ

Fuel energy


ICF
ICF-DD
ICF-ID
LLNL
NIF
MISSION
LIFE
MISSION REVISED
ACTIVITY
NIC
2008-2012
NIC 1
2008-2010
NIC 2
2011-2012
post-NIC
PROGRESS
RESULTS
REPORTS
NEWS & COMM
FINAL REVIEW
DoE
DoD
NNSA
INDEPENDENT REVIEW PANEL



ICF

ICF-DD

ICF-ID

LLNL

NIF

MISSION

LIFE

MISSION REVISED

ACTIVITY

NIC
2008-2012

NIC 1
2008-2010

NIC 2
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post-NIC

PROGRESS

RESULTS

REPORTS

NEWS & COMM

FINAL REVIEW

INDEPENDENT REVIEW PANEL

DoE
DoD
NNSA

Lawrence Livermore National Laboratory

Looking west

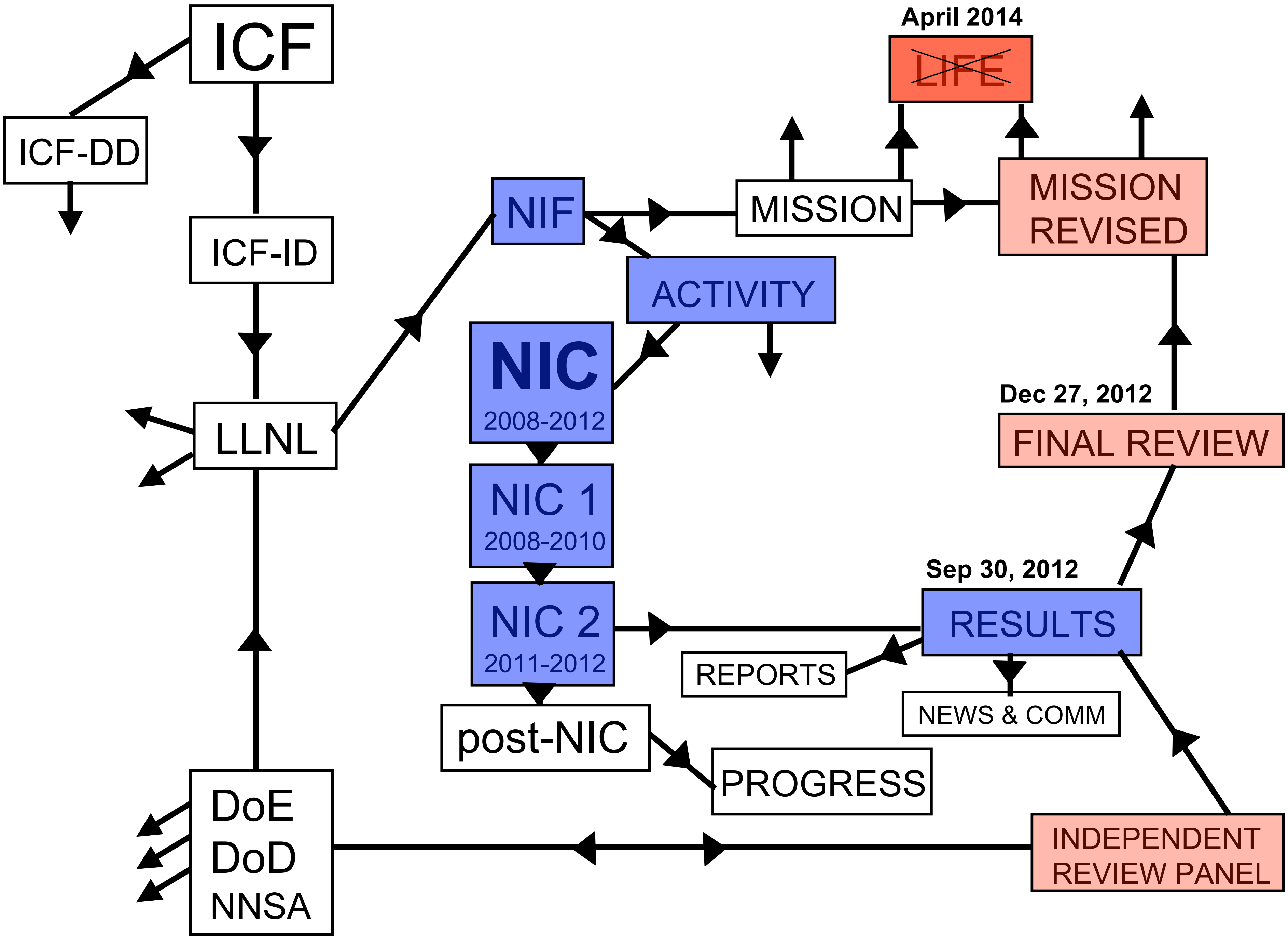
National Ignition Facility

Looking west

Lawrence Livermore National Laboratory

National Ignition Facility

National Ignition Facility (NIF)



ICF

ICF-DD

ICF-ID

LLNL

DoE
DoD
NNSA

NIF

ACTIVITY

NIC
2008-2012

NIC 1
2008-2010

NIC 2
2011-2012

post-NIC

PROGRESS

MISSION

April 2014

~~LIFE~~

MISSION
REVISED

Dec 27, 2012

FINAL REVIEW

Sep 30, 2012

RESULTS

REPORTS

NEWS & COMM

INDEPENDENT
REVIEW PANEL

Department of Energy
Office of Science
Washington, DC 20585

December 27, 2012

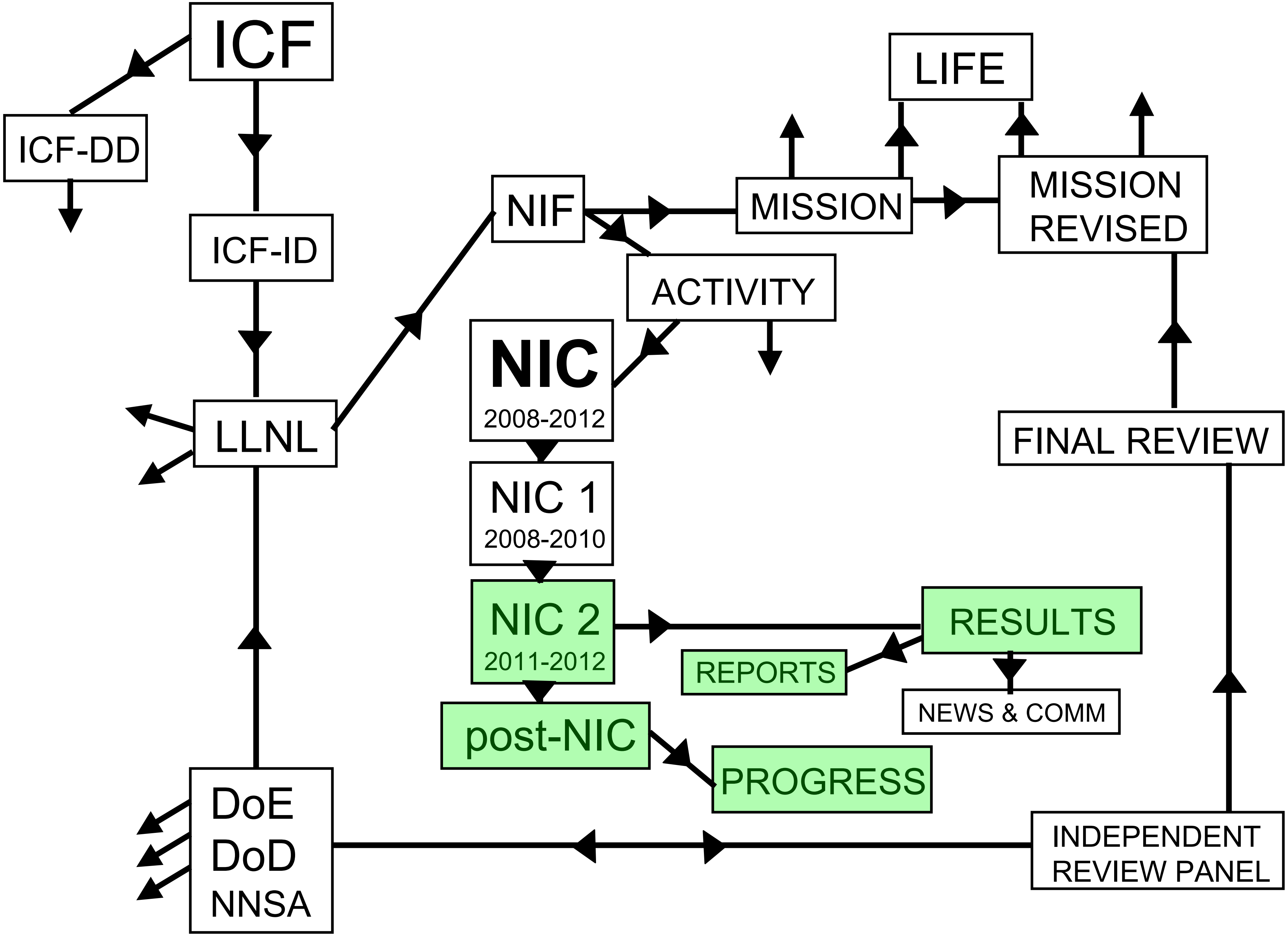
MEMORANDUM FOR DEPUTY ADMINISTRATOR OF NNSA FOR DEFENSE PROGRAMS
DON L. COOK

FROM: ADVISOR ON NATIONAL SECURITY AND INERTIAL FUSION
DAVID H. CRANDALL

SUBJECT: Final Report of the External Review of the National Ignition Campaign Final

Some reviewers were optimistic while others remain highly skeptical as regards the prospects for future ignition. Reviewers were in broad agreement that the national ICF program should be continued in a direction aimed at gaining a more complete scientific understanding of the phenomena associated with the observed capsule performance.

More generally, the reviewers support the view that future efforts should be driven by a diverse community of scientists to ensure adequate scientific breadth in future investigations of ignition.



ICF

ICF-DD

ICF-ID

LLNL

NIF

MISSION

LIFE

MISSION
REVISED

ACTIVITY

NIC
2008-2012

NIC 1
2008-2010

NIC 2
2011-2012

RESULTS

REPORTS

NEWS & COMM

post-NIC

PROGRESS

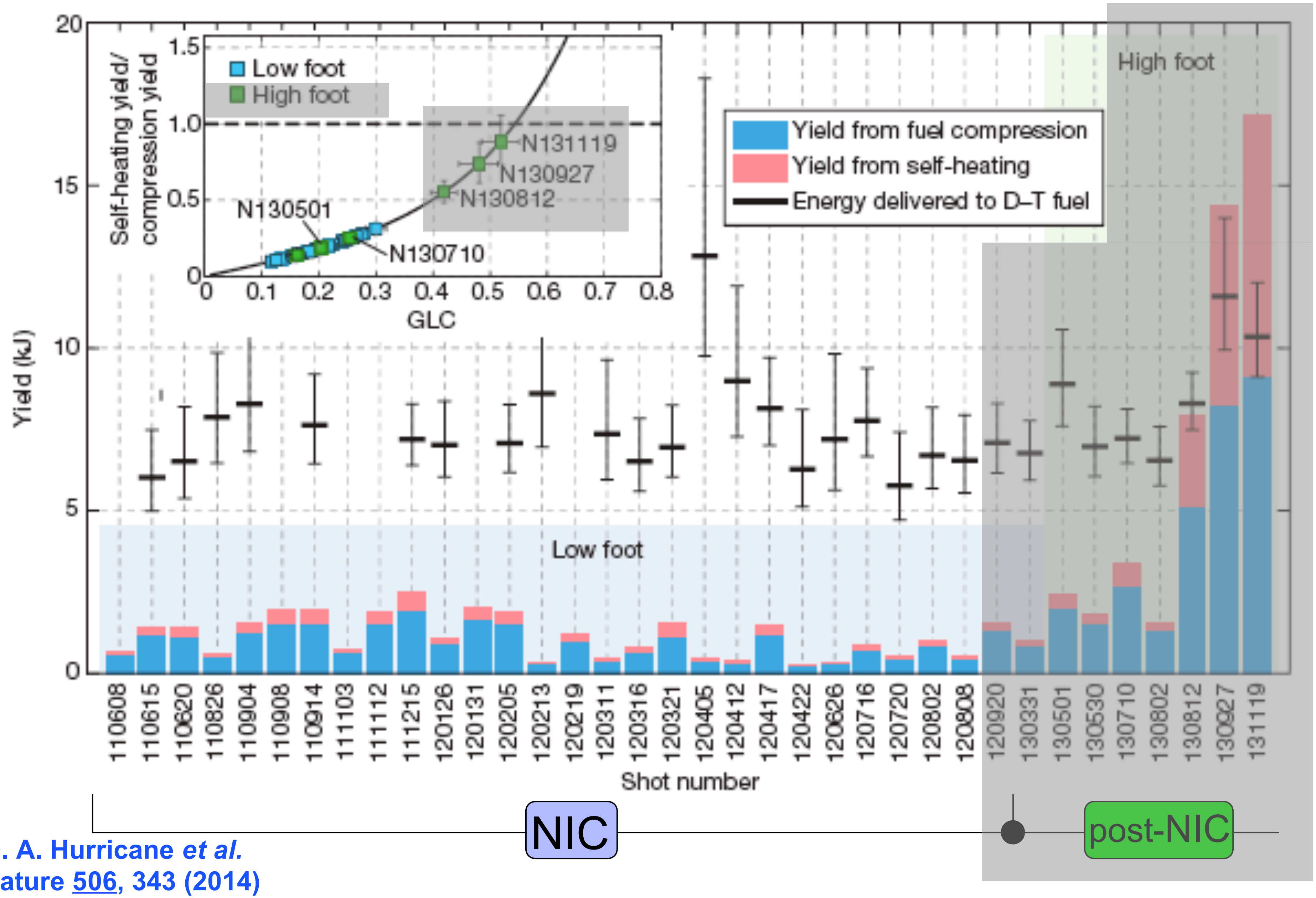
FINAL REVIEW

DoE
DoD
NNSA

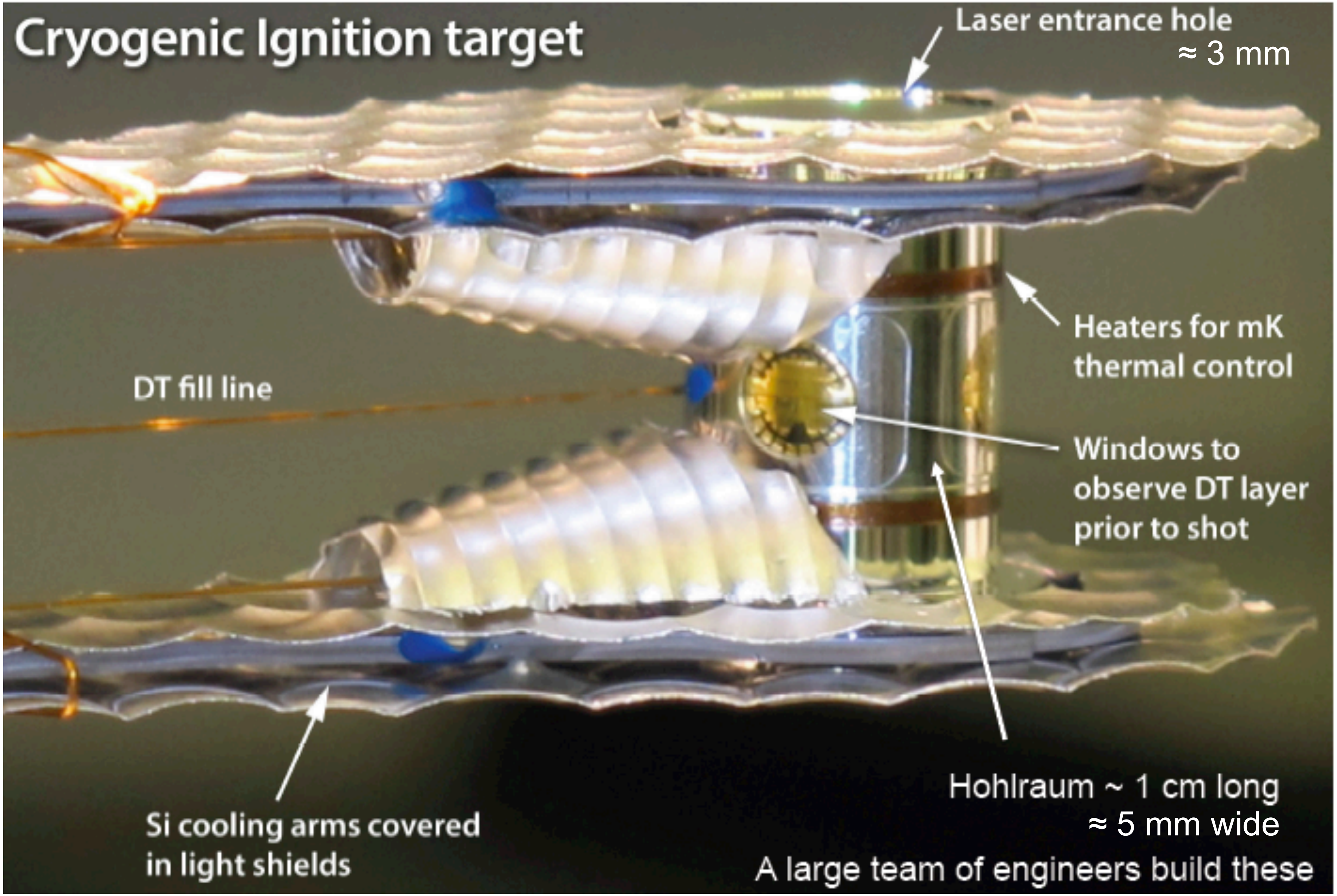
INDEPENDENT
REVIEW PANEL

NIC implosion-yield experiments

May 2011 - September 2012



O. A. Hurricane *et al.*
Nature 506, 343 (2014)



Cryogenic Ignition target

Laser entrance hole
≈ 3 mm

Heaters for mK thermal control

DT fill line

Windows to observe DT layer prior to shot

Si cooling arms covered in light shields

Hohlraum ~ 1 cm long
≈ 5 mm wide

A large team of engineers build these

John Lindl, Otto Landen, John Edwards, Ed Moses, and NIC Team

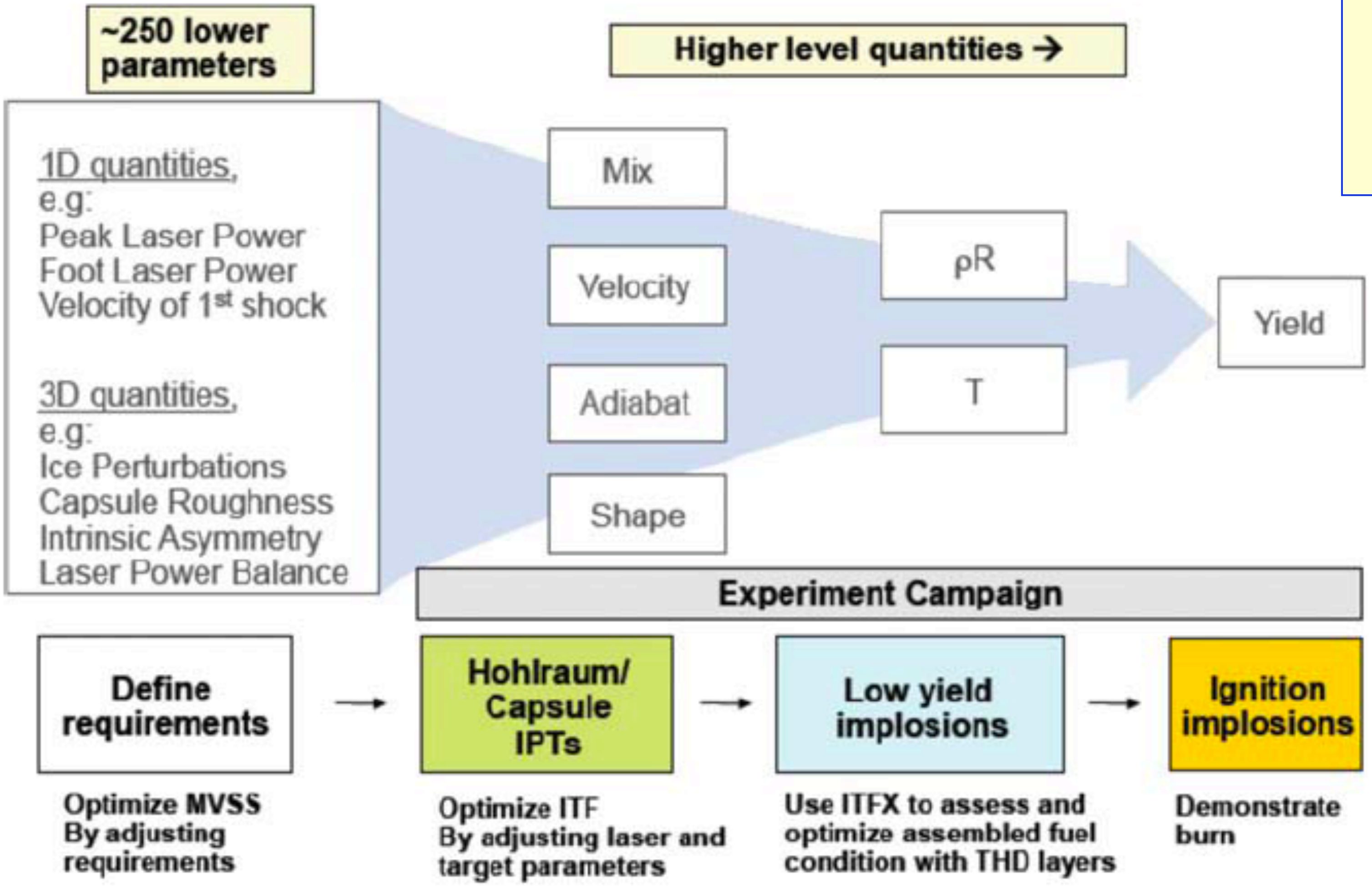
Review of the National Ignition Campaign 2009-2012

Physics of Plasmas 21, 020501 (2014)

-72 pages-

NIC Team:
235 LLNL
9 LLE
11 LANL
3 SNL
16 GA
7 MIT
4 AWE
4 CEA

developing an approach to reducing the effective dimensionality of the ignition campaign



~250 lower parameters

1D quantities, e.g:
Peak Laser Power
Foot Laser Power
Velocity of 1st shock

3D quantities, e.g:
Ice Perturbations
Capsule Roughness
Intrinsic Asymmetry
Laser Power Balance

Higher level quantities →

Mix
Velocity
Adiabat
Shape

ρR
T

Yield

Experiment Campaign

Define requirements → **Hohlraum/ Capsule IPTs** → **Low yield implosions** → **Ignition implosions**

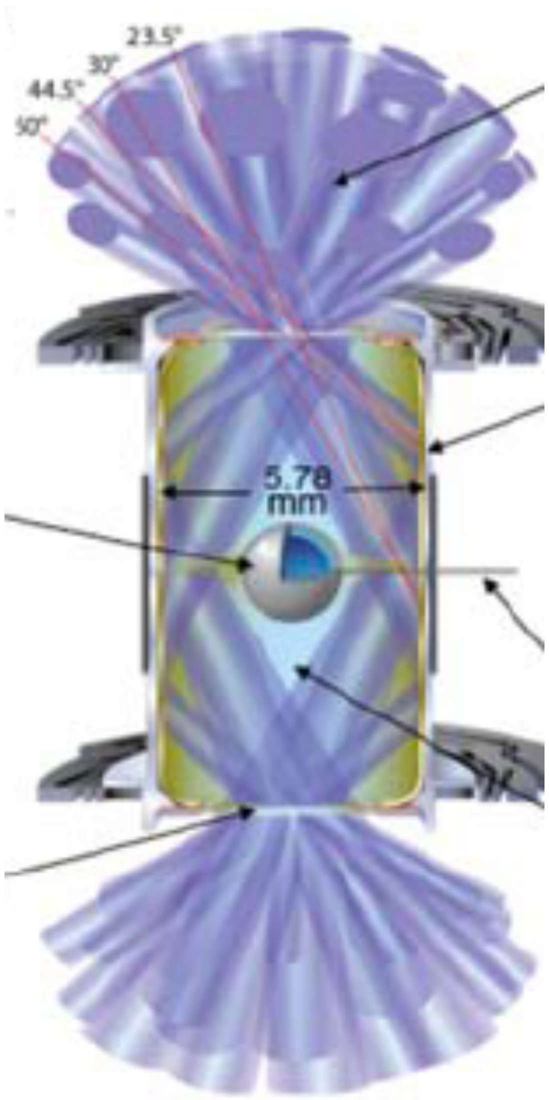
Optimize MVSS By adjusting requirements

Optimize ITF By adjusting laser and target parameters

Use ITFX to assess and optimize assembled fuel condition with THD layers

Demonstrate burn

192 NIF-beams arrangement



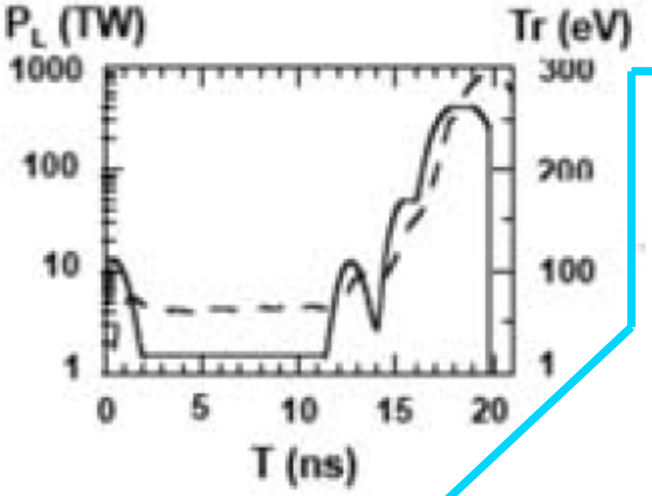
There are 192 beams in NIF, which enter the target chamber in 48 "quads." For most purposes, a quad can be considered as a single ∼f/8 beam. These beams are arrayed in 8 cones, forming angles with the hohlraum axis of 23.5°, 30°, 44.5°, and 50° from each side. These cones of beams contain 4, 4, 8, and 8 quads, respectively, on each side. Beams coming in along 23.5° and 30° have a wavelength or color that differs by a few angstroms and a pulse shape that differs from the color and pulse shape for the 44.5° and 50.0° beams. The 23.5° and 30° beams can also have different wavelength. The relative brightness of the two sets of cones allows time-dependent control of the symmetry of the x-rays irradiating the capsule. The slightly different color of the different cones makes it possible to transfer energy from one set of beams to another, providing an additional technique for controlling long wavelength radiation flux symmetry. The hohlraum is filled with He gas which is confined by a ∼0.5 μm thick window of polyimide over the LEHs.

λ_0 = 351 nm

John Lindl *et al.*, PoP 21, 020501 (2014)

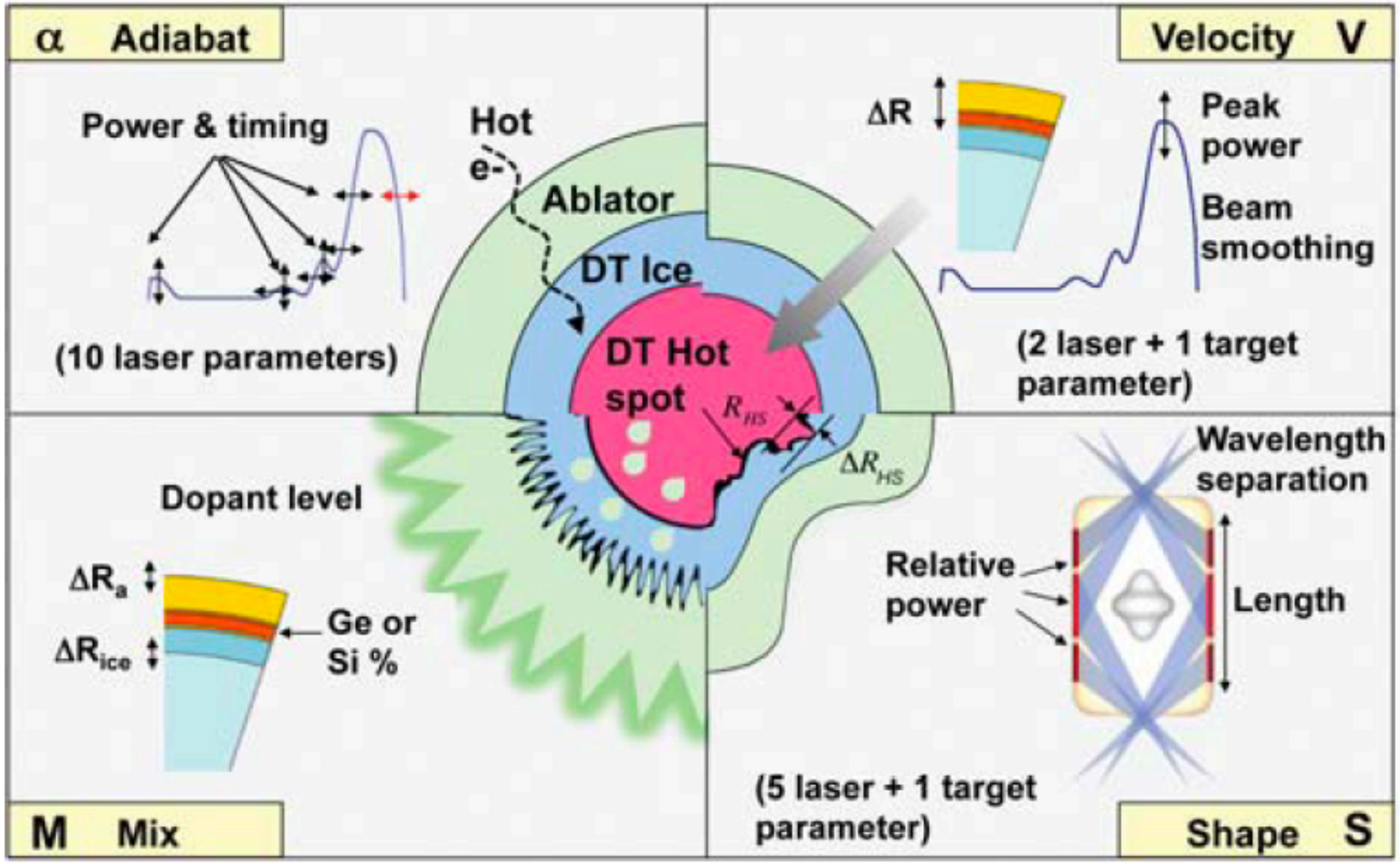
NIC 4-shocks, low-foot pulse:

energy delivered along 20 ns
in 4 peaks (4 shocks)
with a foot of 10 ns between
the first two peaks



Laser power
delivered
vs time
and

its influence
on implosion
parameters



John Lindl *et al.*
PoP 21, 020501 (2014)

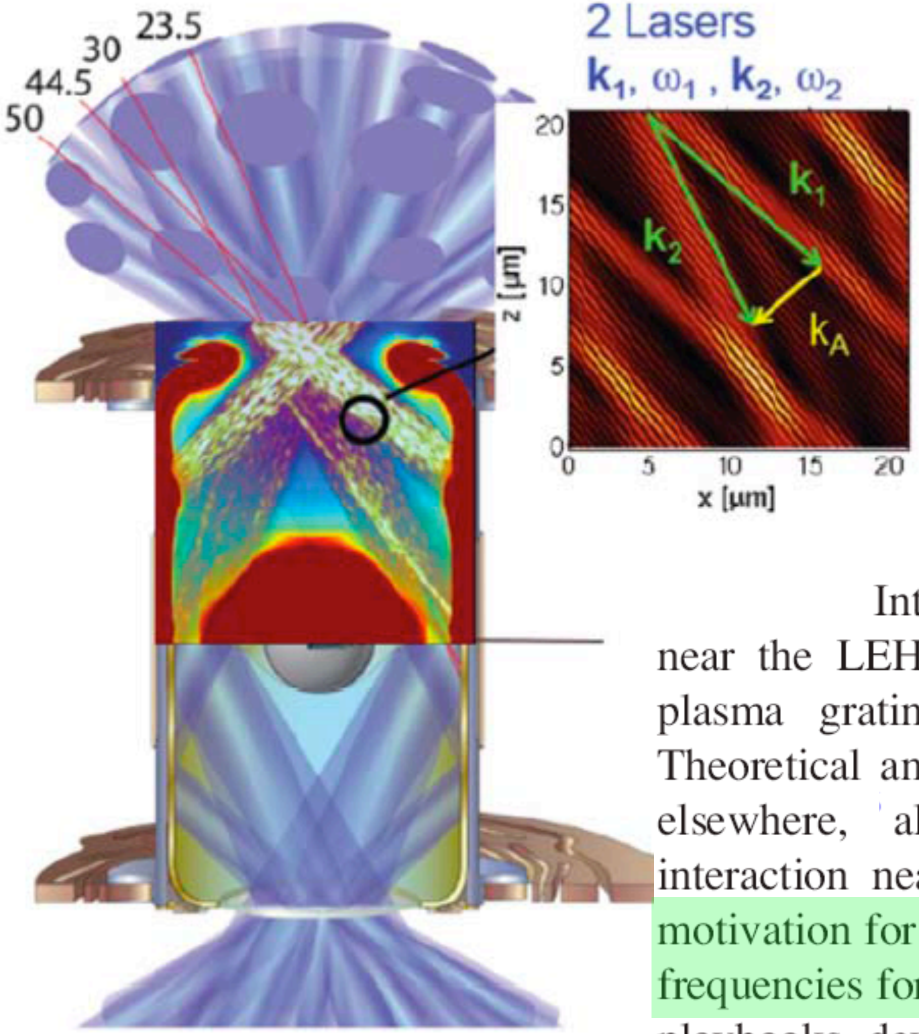
Beam-to-beam energy cross transfer and balance (1)

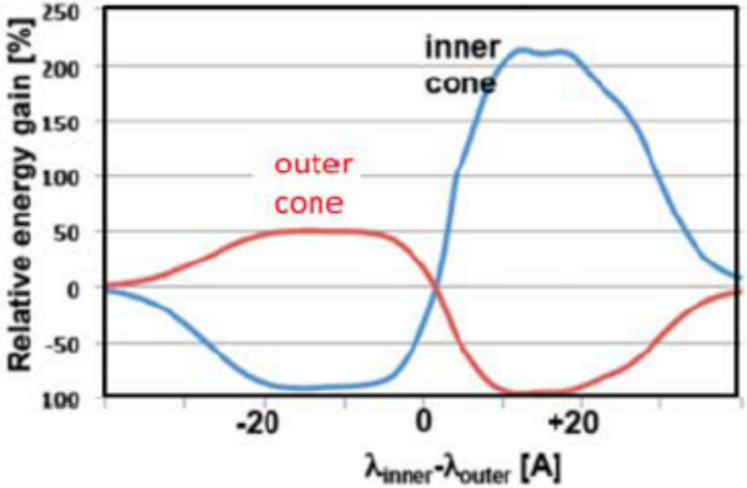
P. Michel *et al.*
Tuning the implosion symmetry of ICF targets
via controlled crossed-beam energy transfer
PRL **102**, 025004 (2009)

P. Michel *et al.*
Symmetry tuning via controlled crossed-beam
energy transfer on the National Ignition Facility
PoP **17**, 056305 (2010)

J. D. Moody *et al.*
Multistep redirection by cross-beam power
transfer of ultra-high power lasers in a plasma
Nature Phys. **8**, 344 (2012)

Beam-to-beam energy cross-transfer and balance (2)

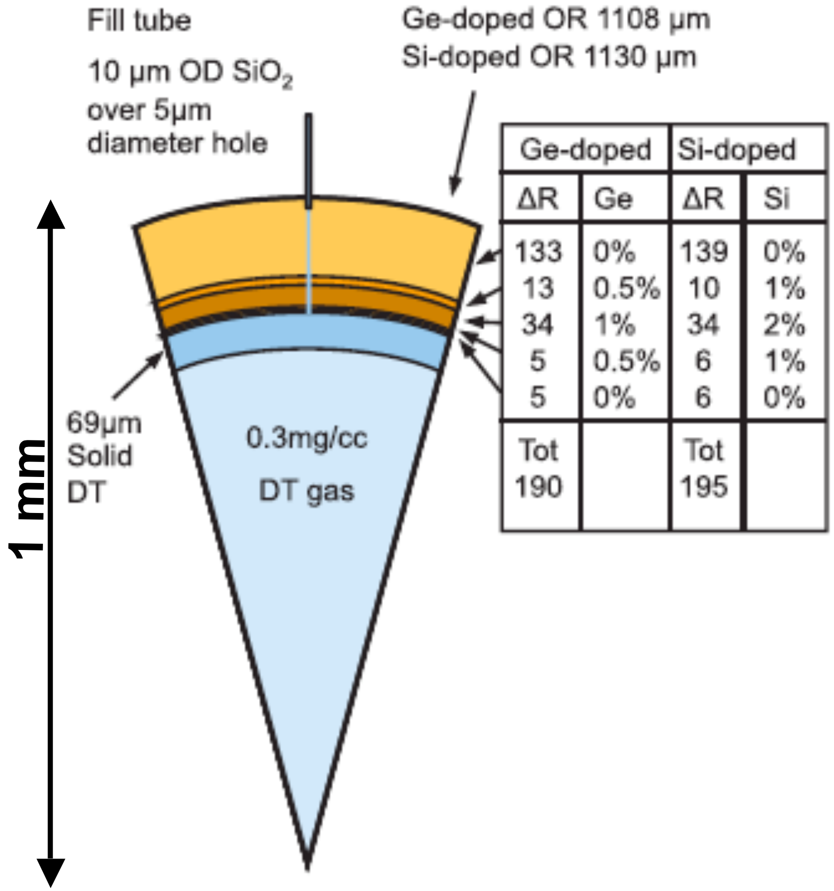




Interference between quads of beams interacting near the LEH sets up density modulations that act like a plasma grating that can shift energy between quads. Theoretical analysis and experiments on the Nova laser and elsewhere, although not exactly analogous to the multi-quad interaction near the LEH in NIC hohlraums, provided the motivation for construction of NIF with oscillators at different frequencies for inner and outer beams. This capability and the playbooks developed based on the theoretical models for cross-beam transfer allowed the NIC campaign to achieve a symmetric hot spot in these early experiments in only three shots.

John Lindl *et al.*
PoP 21, 020501 (2014)

Capsule layers



Ge-doped		Si-doped	
ΔR	Ge	ΔR	Si
133	0%	139	0%
13	0.5%	10	1%
34	1%	34	2%
5	0.5%	6	1%
5	0%	6	0%
Tot 190		Tot 195	

The outer shell can be CH plastic or Be, high-density carbon (HDC or nano-crystalline diamond) or another low-Z material, called the ablator. The layers of the shell must be very smooth, to minimize seeds of hydrodynamic instabilities. In order to minimize instability growth at the interface between the ablator and fuel layer, the ablator includes concentric layers of mid-Z dopant. These layers absorb preheat x-rays, thereby tailoring the temperature profile and hence the density of the ablator near the interface with the cryogenic fuel. The ablator encloses a spherical shell of DT fusion fuel, kept solid by keeping the entire assembly at cryogenic temperatures near the triple-point of the fuel mixture. The interior of the shell contains DT vapor in equilibrium with the solid fuel layer. The capsule is supported in the hohlraum between two films of Formvar that is 15–100 nm thick. The DT filling the capsule is fed through a 10 μm diameter fill tube and hole through the ablator. The NIC utilized a CH ablator, doped with either Si or Ge for preheat protection. Dimensions and other features of the capsules with the two different dopants are shown in Figure . The initial CH point design capsule with Ge preheat dopant was used in the NIC campaign until August 2011. Si doped capsules were found to be more efficient as described in the discussion of experiments below and were used after August 2011. Experiments have tested different thickness ablators as well as different dopant concentrations and profiles as part of the optimization process.

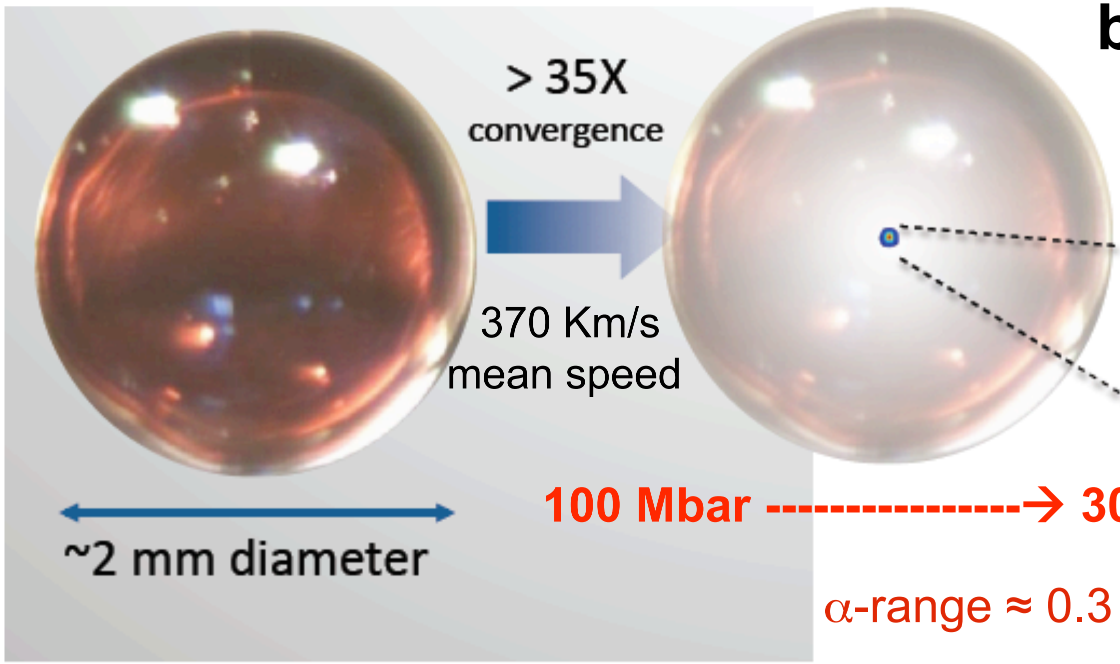
John Lindl *et al.*, PoP <u>21</u>, 020501 (2014)

ablation

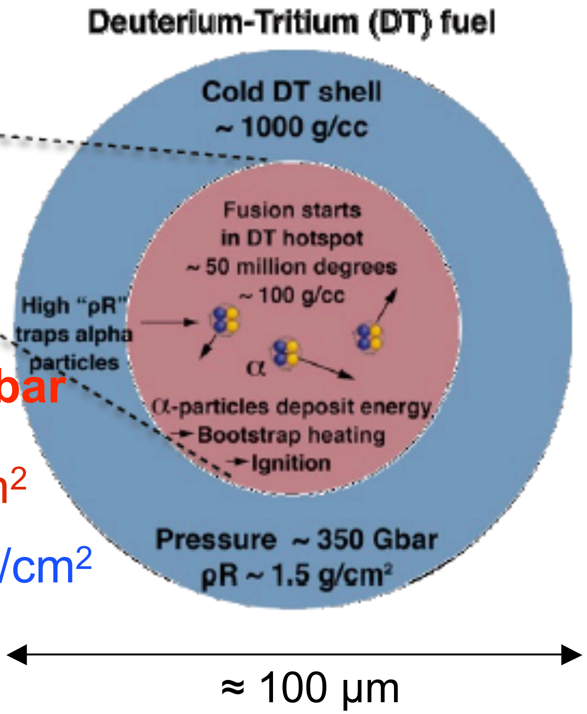
compression

stagnation

burnout & confinement

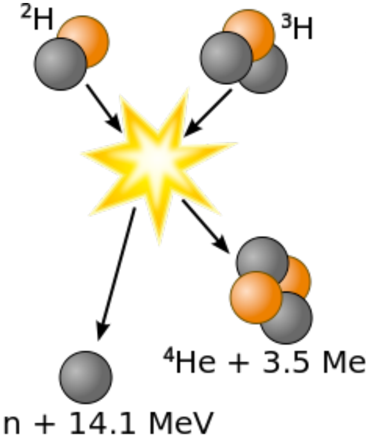


100 Mbar -----------------→ 300 Gbar

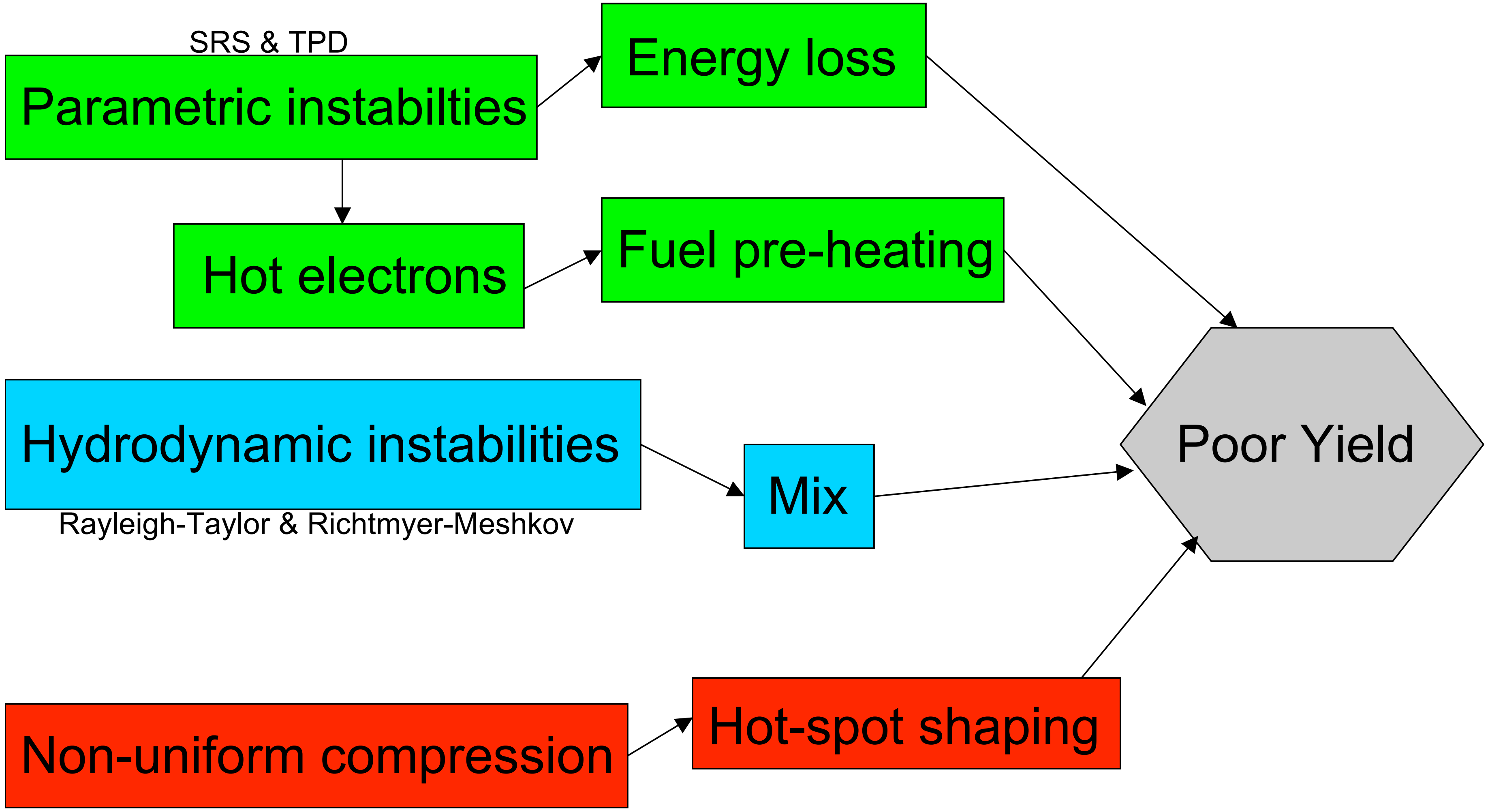


α-range ≈ 0.3 g/cm^2

GLC @ 4 keV: $\rho r > 1$ g/cm^2



Major NIC drawbacks



SRS & TPD

Parametric instabilties

Energy loss

Hot electrons

Fuel pre-heating

Hydrodynamic instabilities

Rayleigh-Taylor & Richtmyer-Meshkov

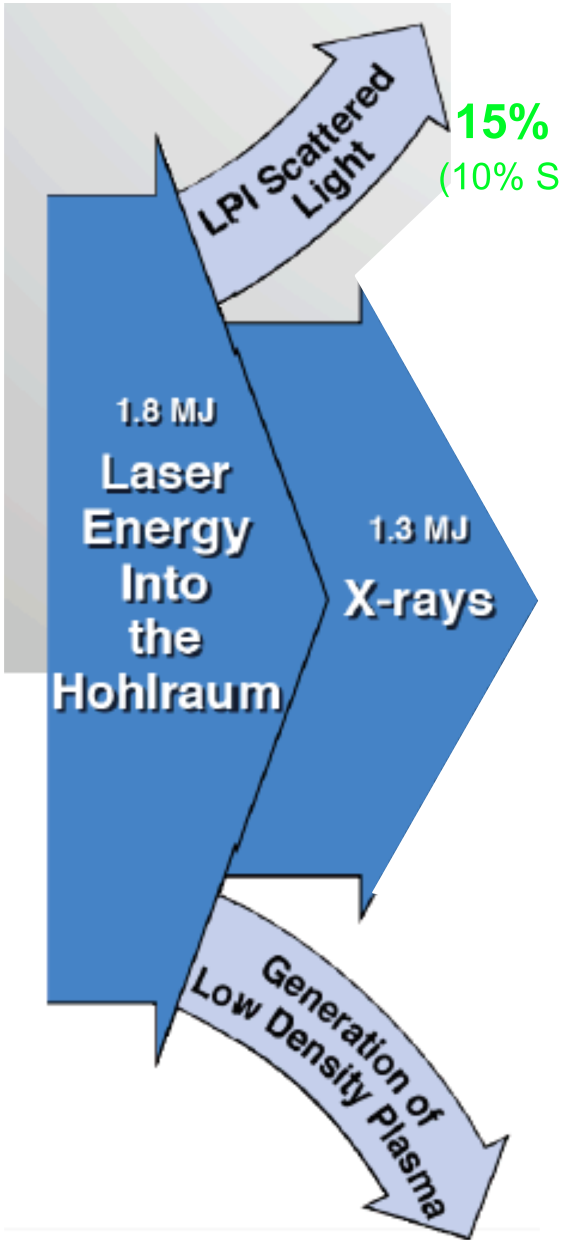
Mix

Poor Yield

Non-uniform compression

Hot-spot shaping

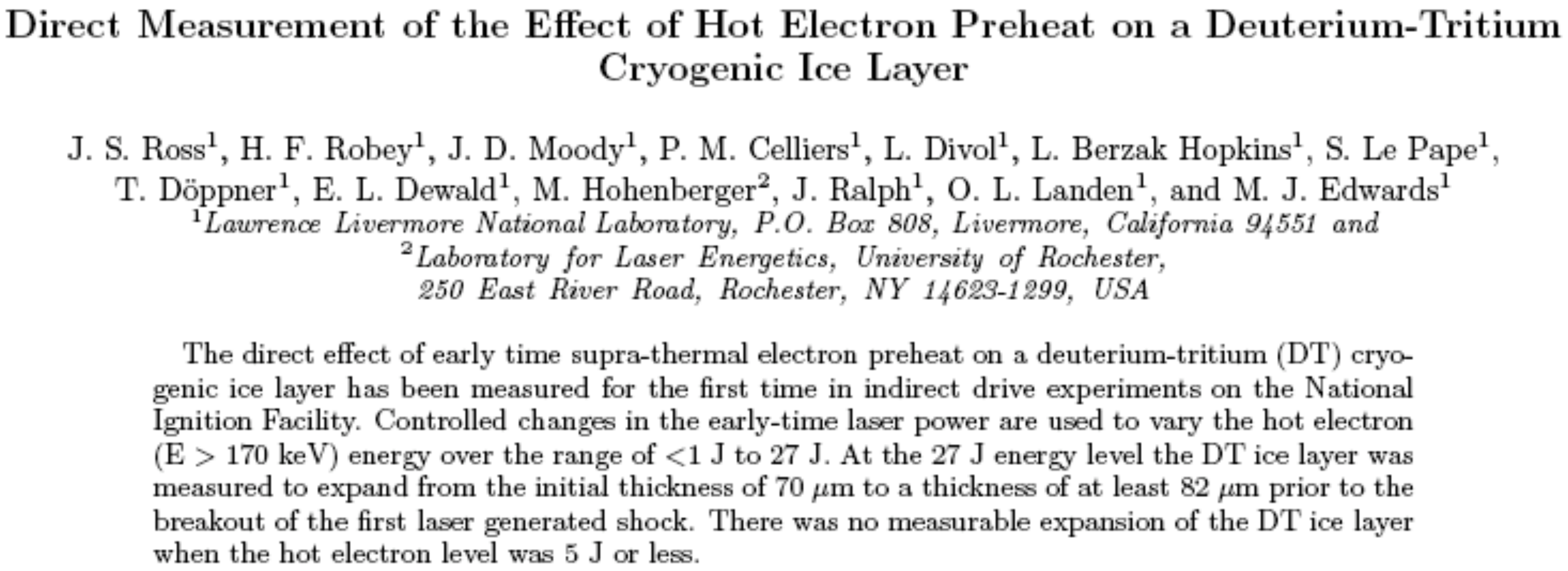
Energy loss



15%

(10% SRS)

Hot electron generation -> fuel pre-heating.1

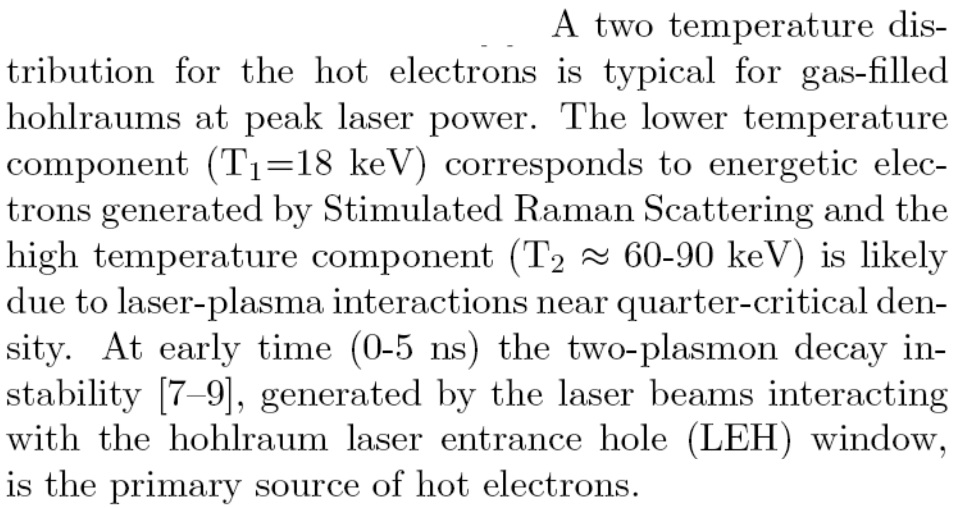


Direct Measurement of the Effect of Hot Electron Preheat on a Deuterium-Tritium Cryogenic Ice Layer

J. S. Ross[1], H. F. Robey[1], J. D. Moody[1], P. M. Celliers[1], L. Divol[1], L. Berzak Hopkins[1], S. Le Pape[1],
T. Döppner[1], E. L. Dewald[1], M. Hohenberger[2], J. Ralph[1], O. L. Landen[1], and M. J. Edwards[1]
[1]*Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551 and*
[2]*Laboratory for Laser Energetics, University of Rochester,*
250 East River Road, Rochester, NY 14623-1299, USA

The direct effect of early time supra-thermal electron preheat on a deuterium-tritium (DT) cryogenic ice layer has been measured for the first time in indirect drive experiments on the National Ignition Facility. Controlled changes in the early-time laser power are used to vary the hot electron ($E > 170$ keV) energy over the range of <1 J to 27 J. At the 27 J energy level the DT ice layer was measured to expand from the initial thickness of 70 μm to a thickness of at least 82 μm prior to the breakout of the first laser generated shock. There was no measurable expansion of the DT ice layer when the hot electron level was 5 J or less.

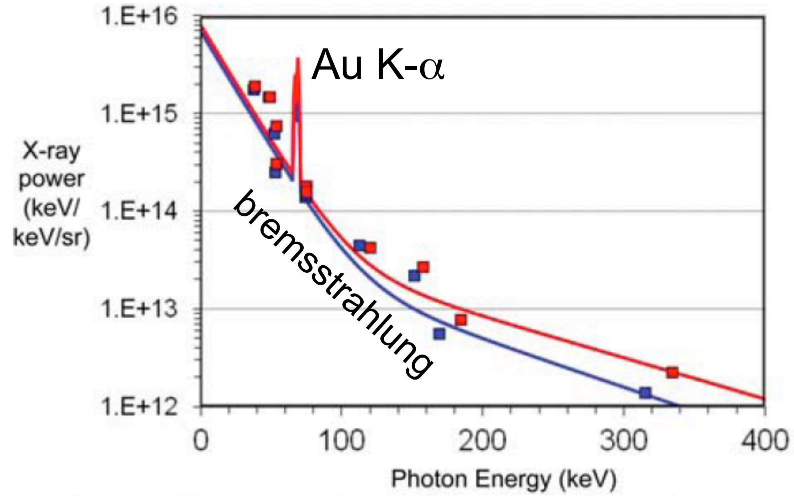
[preprint 2014]



A two temperature distribution for the hot electrons is typical for gas-filled hohlraums at peak laser power. The lower temperature component (T_1=18 keV) corresponds to energetic electrons generated by Stimulated Raman Scattering and the high temperature component ($T_2 \approx$ 60-90 keV) is likely due to laser-plasma interactions near quarter-critical density. At early time (0-5 ns) the two-plasmon decay instability [7–9], generated by the laser beams interacting with the hohlraum laser entrance hole (LEH) window, is the primary source of hot electrons.

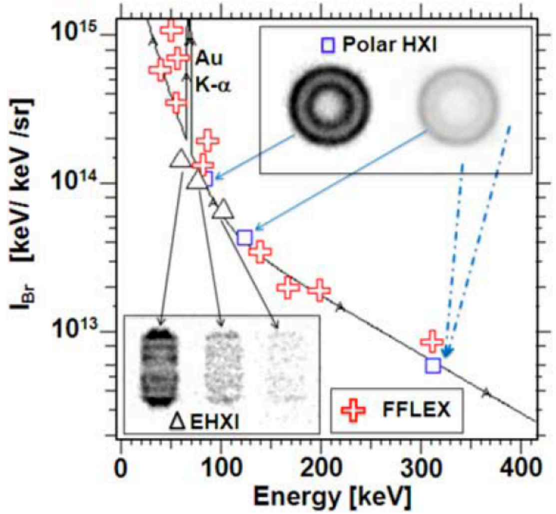
Hot electron generation -> fuel pre-heating.2

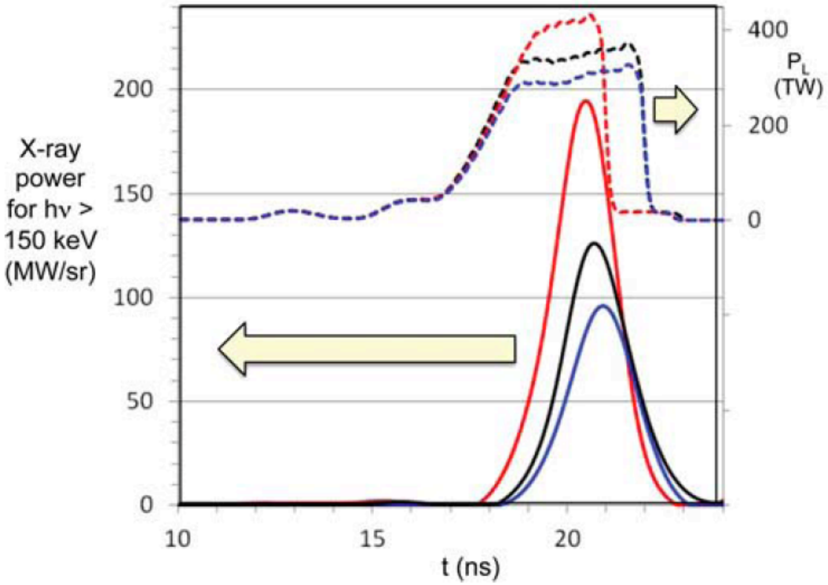
John Lindl *et al.*
PoP 21, 020501 (2014)



The spectrum has a component with $T_{Hot} \sim 20$ keV which is consistent with the observed SRS. There is also a "Superhot" component, with much less energy, which may be the result of $2\omega_{pe}$ processes or Raman scattering near $^1/_4\, n_{cr}$. Electrons with energy above ~170 keV can penetrate the ablator and are those most responsible for fuel preheat.

Shot	Peak Power (TW)	Energy (MJ)	T1 (keV)	E1 (kJ)	T2 (keV)	E2 (kJ)	E > 170 keV (kJ)
N120122	420	1.45	18	74	100	0.54	0.5
N120408	330	1.54	18	64	88	0.44	0.4

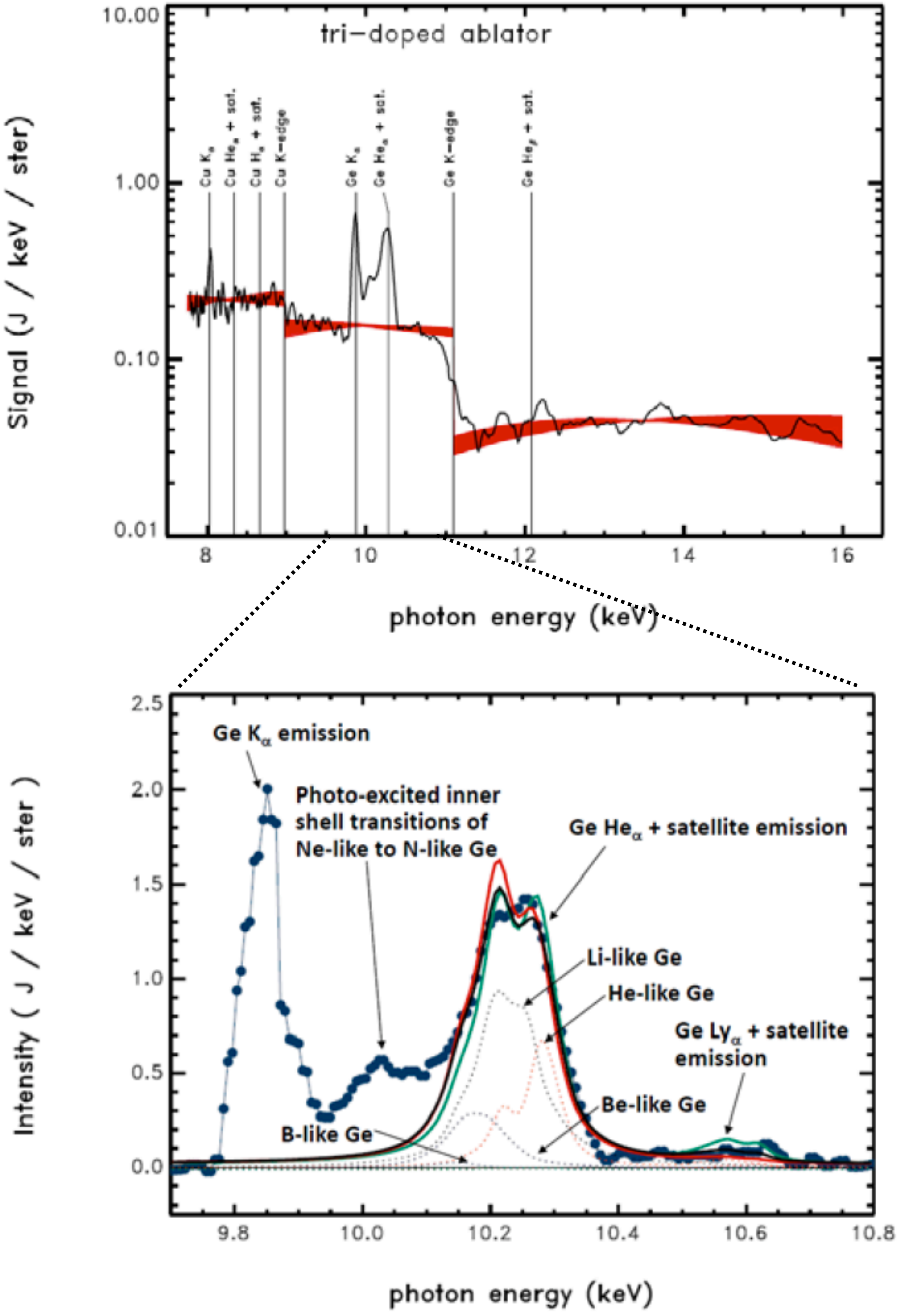




Shot, drive	E > 170 keV energy (kJ)
N120122 420TW/1.45MJ Au, coast	0.4
N120329 360TW/1.6 MJ Au, no coast	0.27
N120408 330TW/1.54MJ DU, no coast	0.23

these electrons primarily responsible for fuel preheat are being generated near the end of the pulse, at levels of 0.2–1 kJ.

Mixing in the hot-spot studied by X-ray spectroscopy



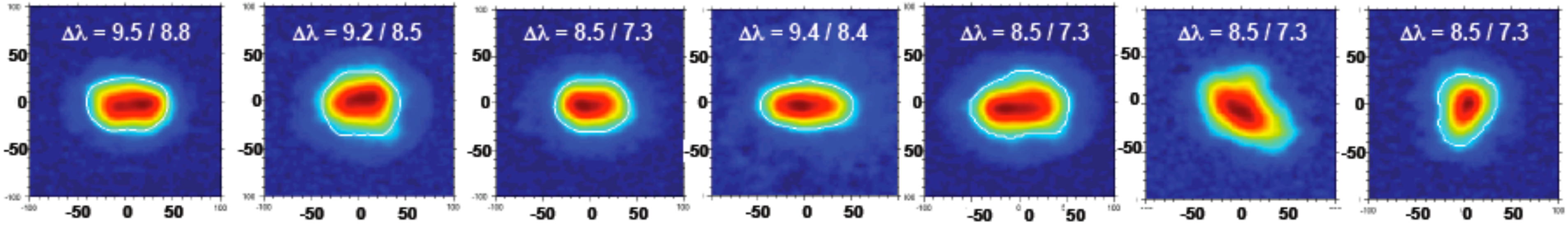
Mixing of plastic ablator material, doped with Cu and Ge dopants, deep into the hot spot of ignition-scale inertial confinement fusion implosions by hydrodynamic instabilities is diagnosed with x-ray spectroscopy on the National Ignition Facility. The amount of hot-spot mix mass is determined from the absolute brightness of the emergent Cu and Ge K-shell emission. The Cu and Ge dopants placed at different radial locations in the plastic ablator show the ablation front hydrodynamic instability is primarily responsible for hot-spot mix. Low neutron yields and hot-spot mix mass are observed.

P. Regan *et al.* (2013)
LLE Univ. of Rochester
& LLNL

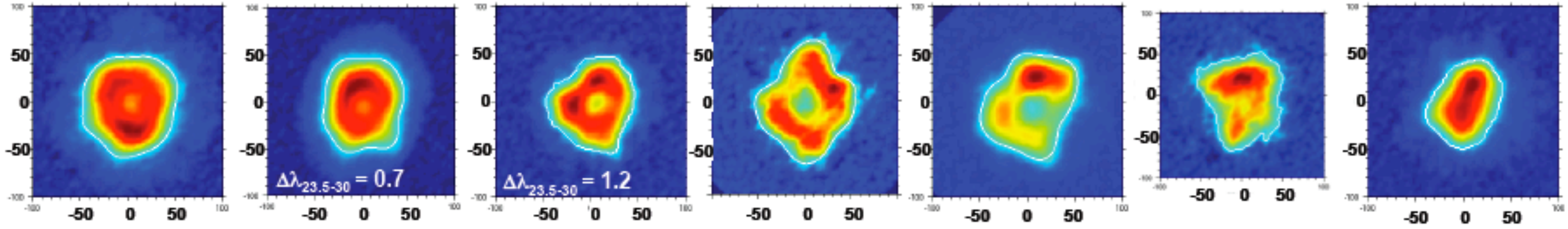
Hot-spot shaping

While instability has been controlled, controlling low-mode hot-spot shape has been a challenge

Time-integrated x-ray emission (equatorial view)

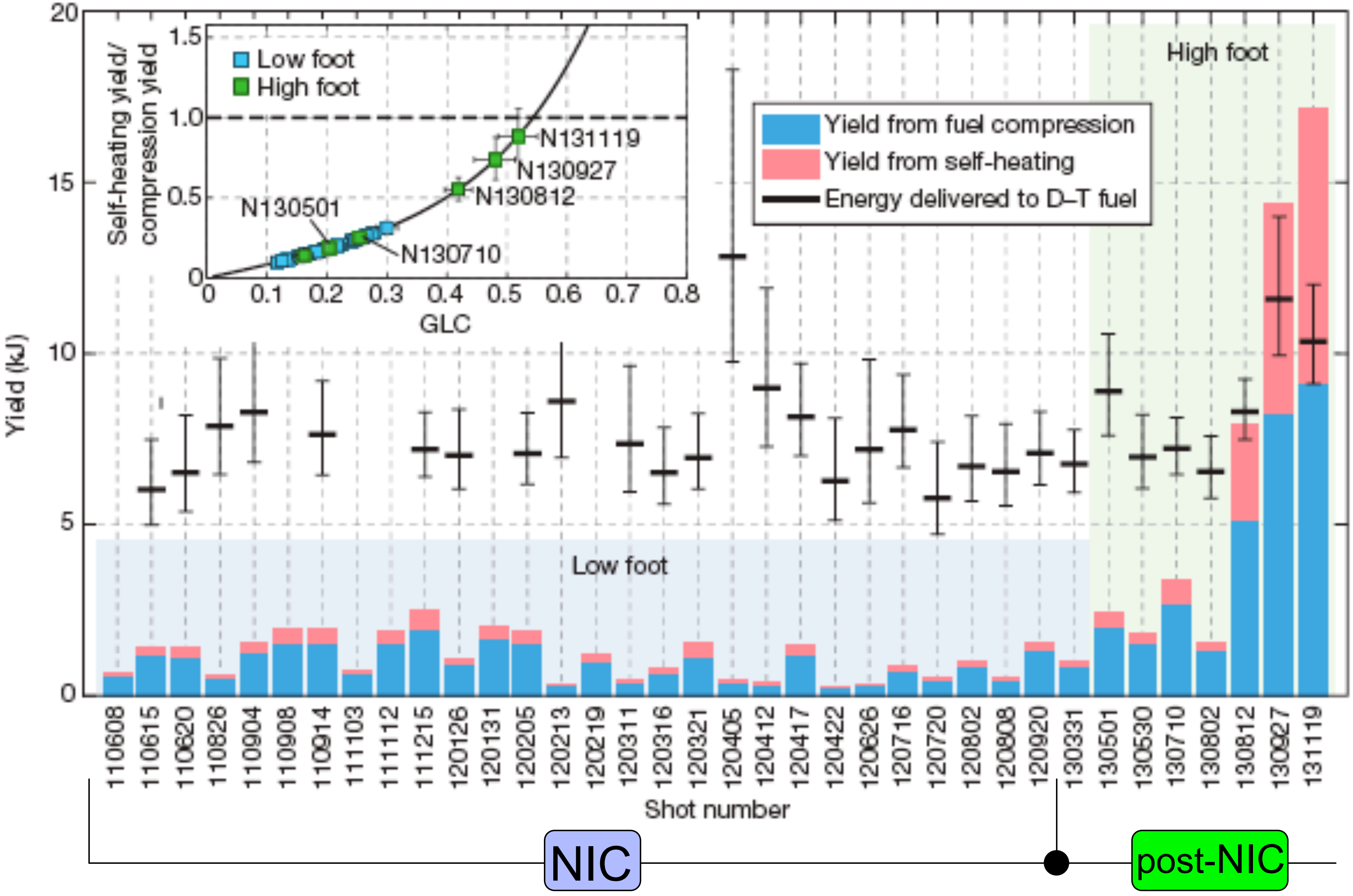


Time-integrated x-ray emission (polar view)



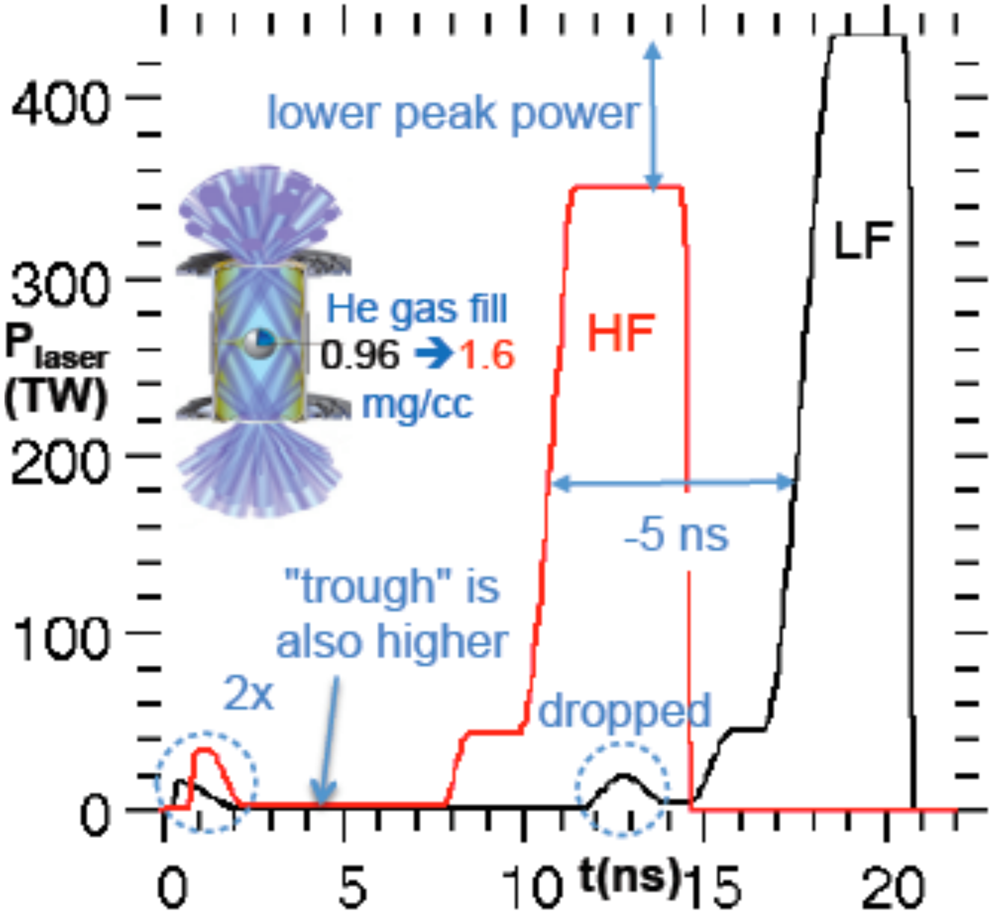
Time integrated neutron (equatorial view)

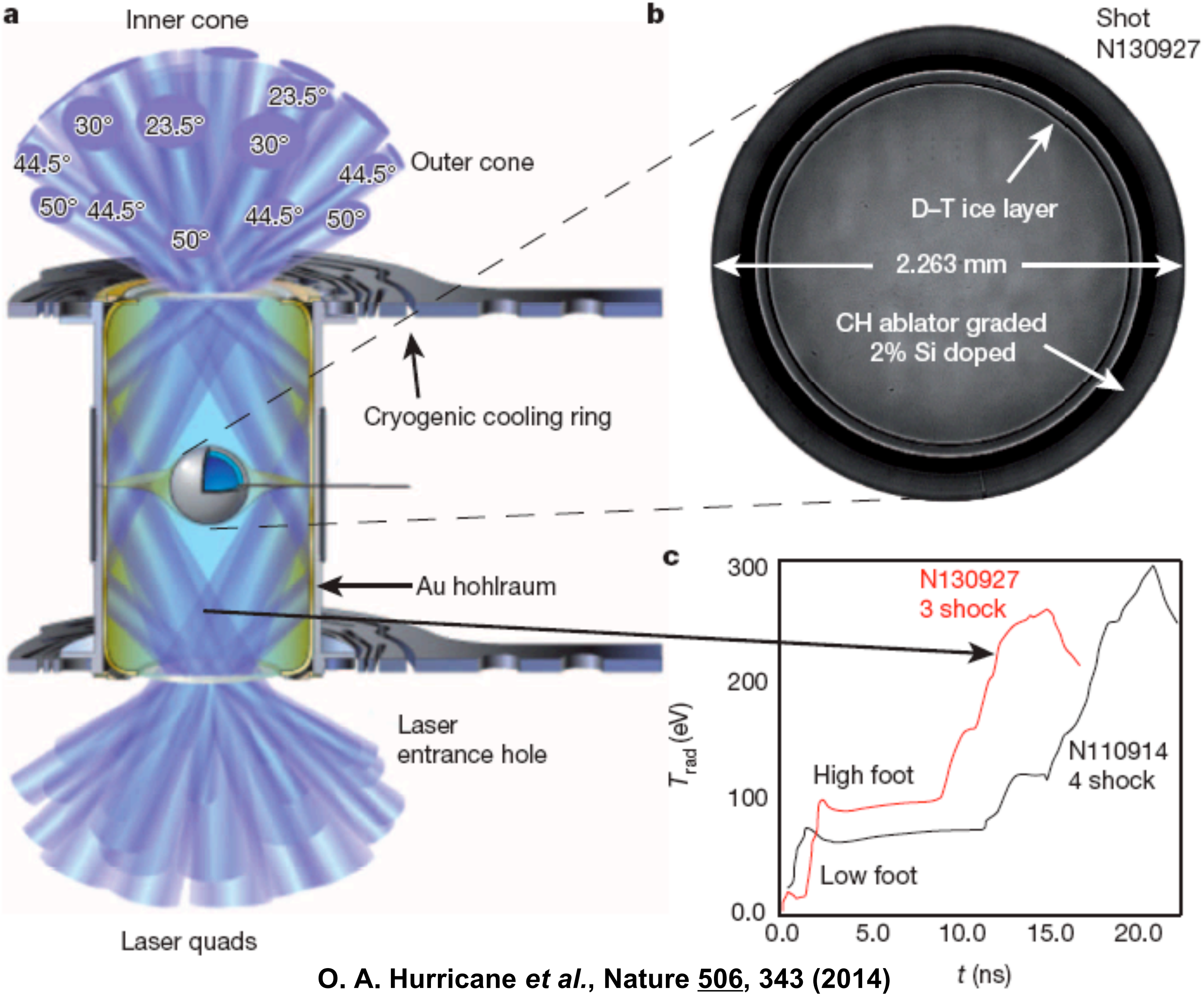
O. A. Hurricane *et al.*, Nature 506, 343 (20 February 2014)



Hurricane recipe:

1. **high-foot, 3-shocks, 15-ns**
2. improved beam balance
3. mini-quenched DT layer
4. higher He fill density





O. A. Hurricane *et al.*, Nature 506, 343 (2014)

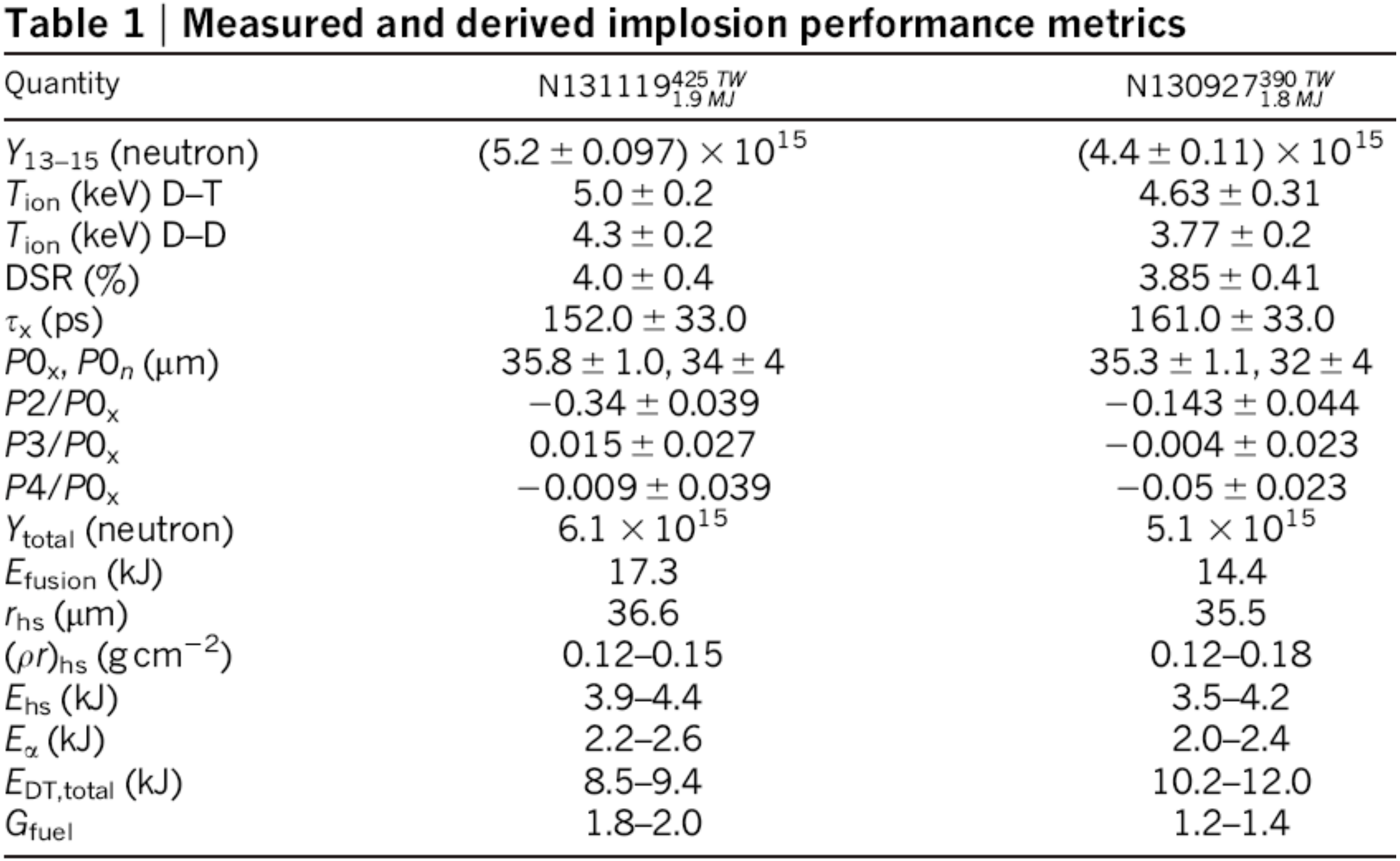
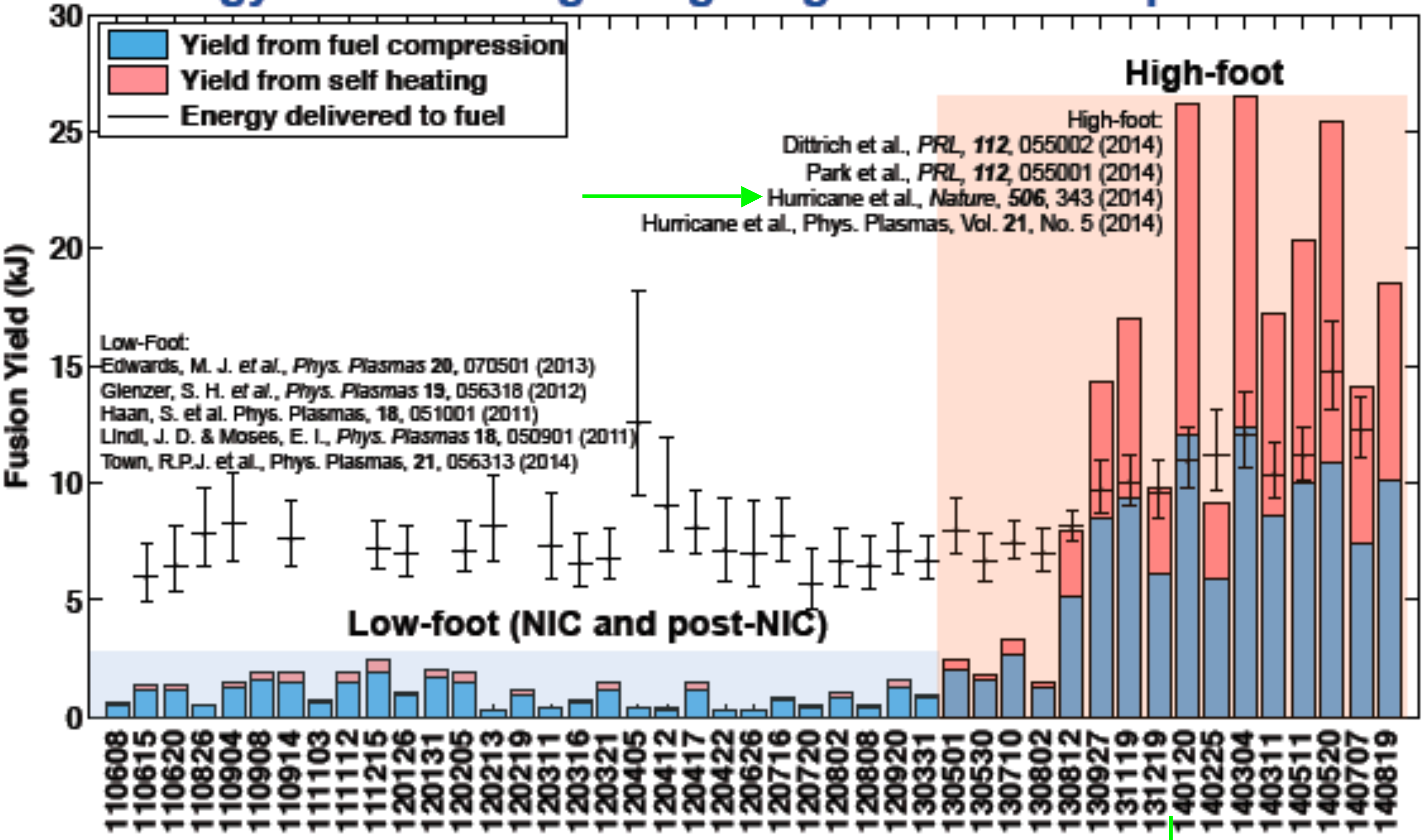


Table 1 | Measured and derived implosion performance metrics

Quantity	$N131119^{425\ TW}_{1.9\ MJ}$	$N130927^{390\ TW}_{1.8\ MJ}$
Y_{13-15} (neutron)	$(5.2 \pm 0.097) \times 10^{15}$	$(4.4 \pm 0.11) \times 10^{15}$
T_{ion} (keV) D–T	5.0 ± 0.2	4.63 ± 0.31
T_{ion} (keV) D–D	4.3 ± 0.2	3.77 ± 0.2
DSR (%)	4.0 ± 0.4	3.85 ± 0.41
τ_x (ps)	152.0 ± 33.0	161.0 ± 33.0
$P0_x$, $P0_n$ (μm)	35.8 ± 1.0, 34 ± 4	35.3 ± 1.1, 32 ± 4
$P2/P0_x$	-0.34 ± 0.039	-0.143 ± 0.044
$P3/P0_x$	0.015 ± 0.027	-0.004 ± 0.023
$P4/P0_x$	-0.009 ± 0.039	-0.05 ± 0.023
Y_{total} (neutron)	6.1×10^{15}	5.1×10^{15}
E_{fusion} (kJ)	17.3	14.4
r_{hs} (μm)	36.6	35.5
$(\rho r)_{hs}$ ($g\,cm^{-2}$)	0.12–0.15	0.12–0.18
E_{hs} (kJ)	3.9–4.4	3.5–4.2
E_{α} (kJ)	2.2–2.6	2.0–2.4
$E_{DT,total}$ (kJ)	8.5–9.4	10.2–12.0
G_{fuel}	1.8–2.0	1.2–1.4

O. A. Hurricane *et al.*, Nature 506, 343 (2014)

Recent progress was made possible by a change in strategy that breaks getting to ignition into steps



High-foot:
Dittrich et al., *PRL*, **112**, 055002 (2014)
Park et al., *PRL*, **112**, 055001 (2014)
Hurricane et al., *Nature*, **506**, 343 (2014)
Hurricane et al., Phys. Plasmas, Vol. **21**, No. 5 (2014)

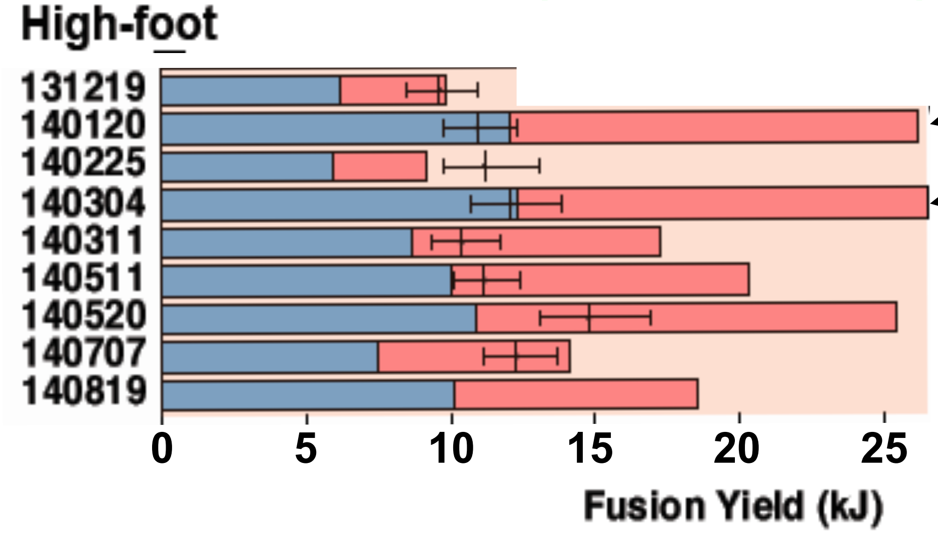
Low-Foot:
Edwards, M. J. *et al.*, *Phys. Plasmas* **20**, 070501 (2013)
Glenzer, S. H. *et al.*, *Phys. Plasmas* **19**, 056318 (2012)
Haan, S. et al. Phys. Plasmas, **18**, 051001 (2011)
Lindl, J. D. & Moses, E. I., *Phys. Plasmas* **18**, 050901 (2011)
Town, R.P.J. et al., Phys. Plasmas, **21**, 056313 (2014)

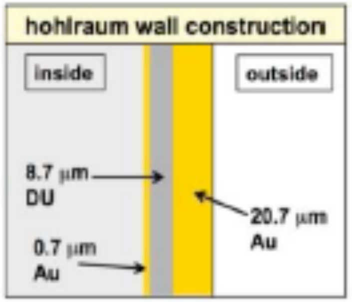
Nature

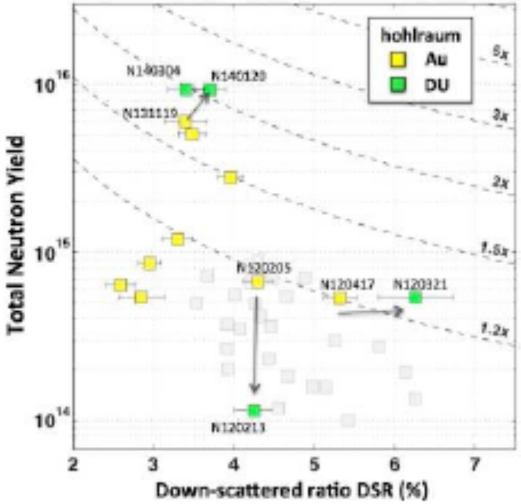
Plot from P. Patel

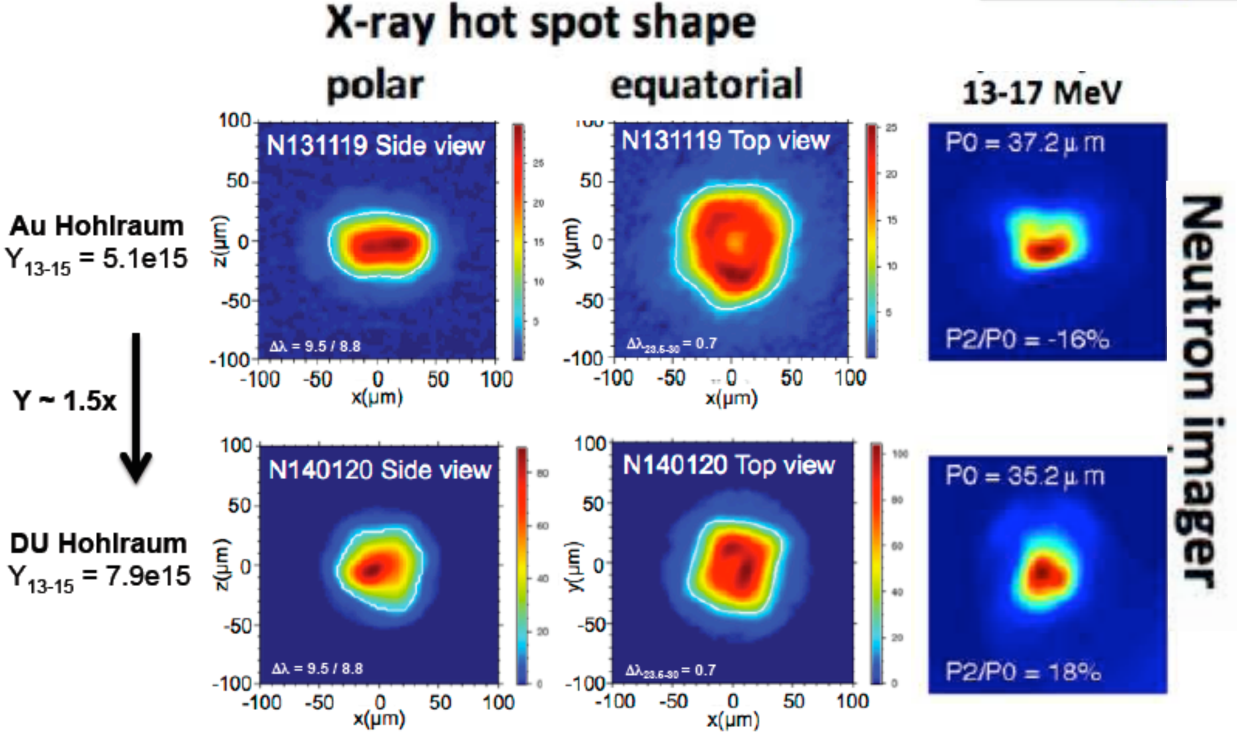
“post-Nature” progress.1

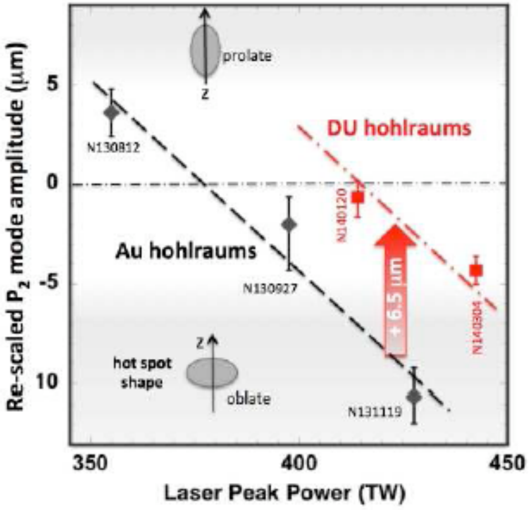
Depleted Uranium (DU) hohlraums
T. Doeppner et al., PRL submitted 2015



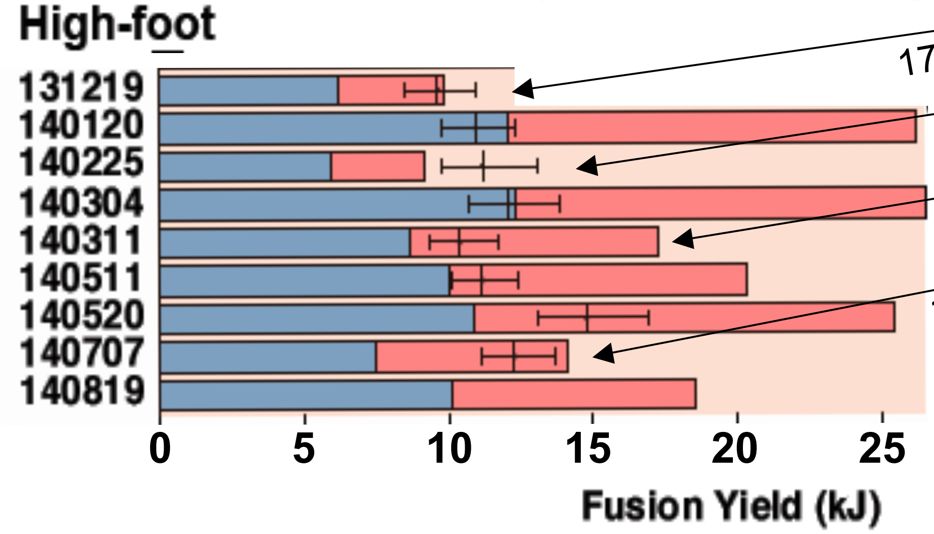




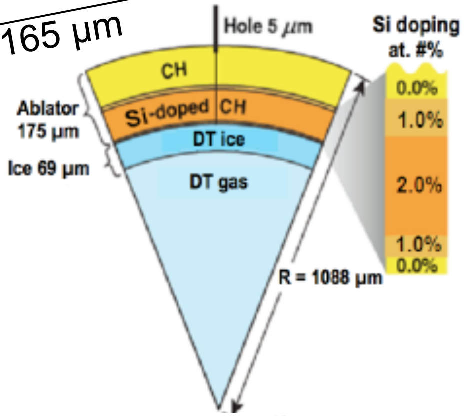


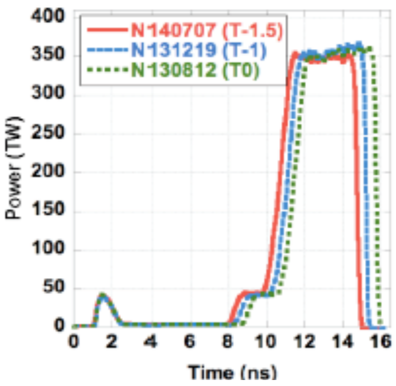


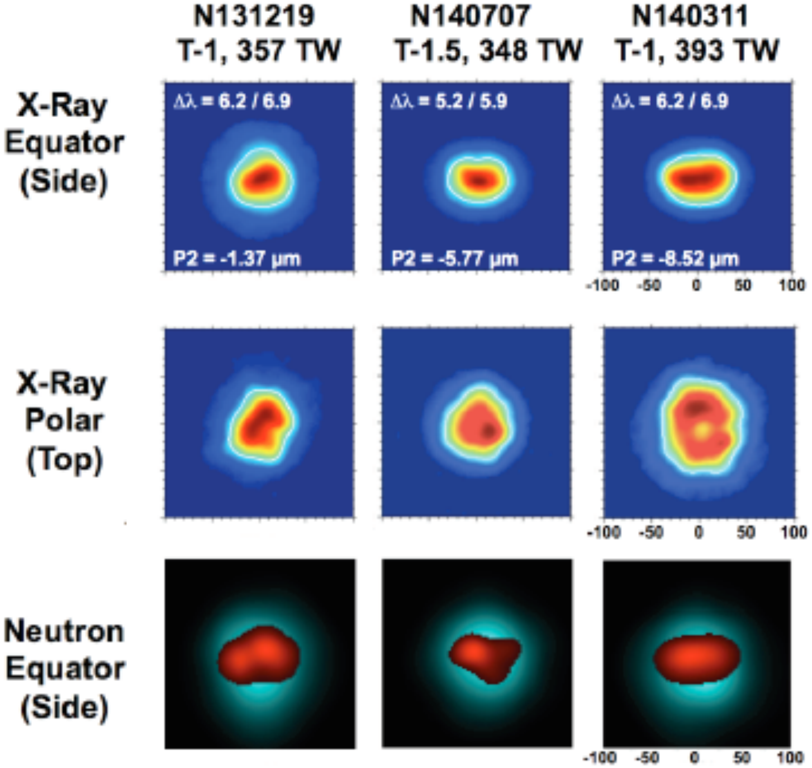
"post-Nature" progress.2



10-15% thinner ablator
Higher implosion veloc.
T. Ma et al., PRL 2015
in publication

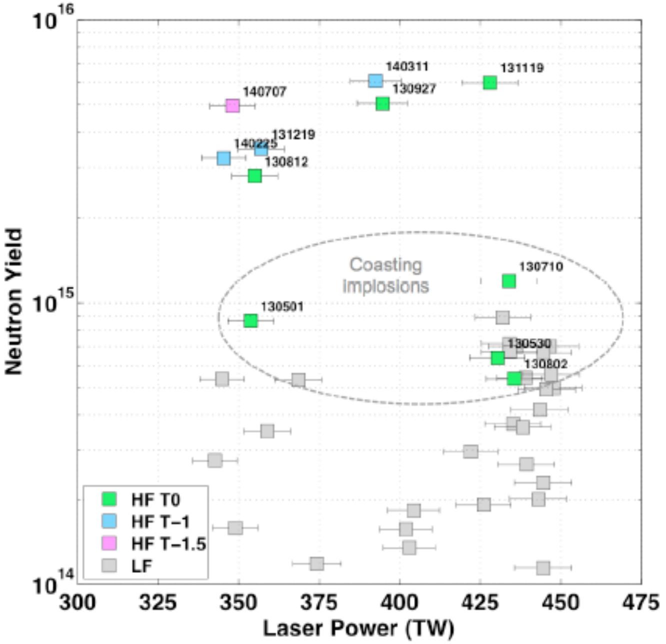




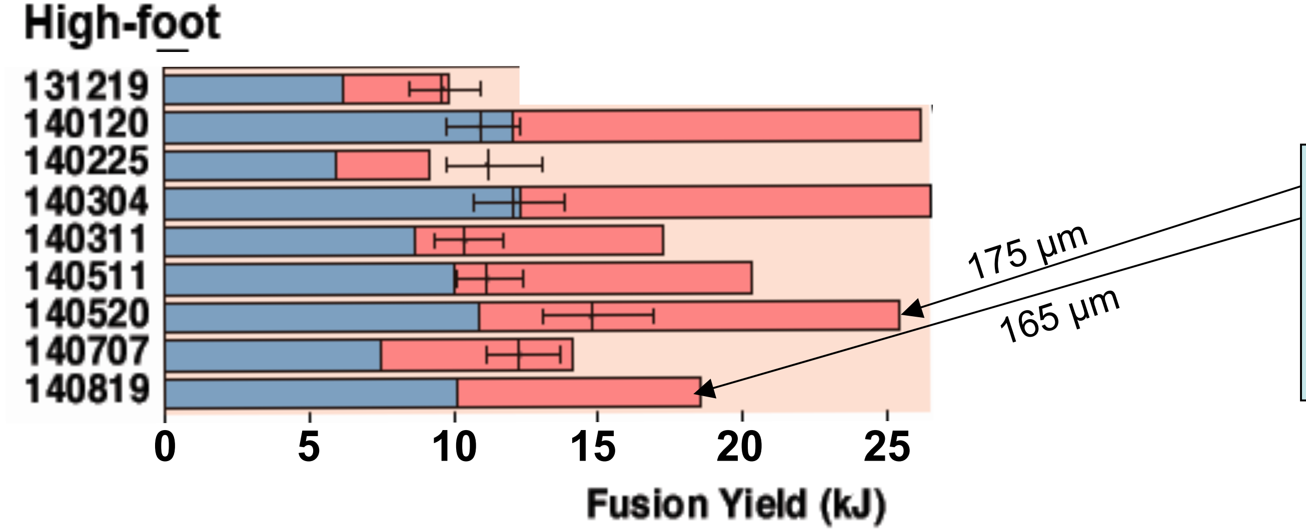


proved to be safe from instabilities & mixing

same yield with less laser energy



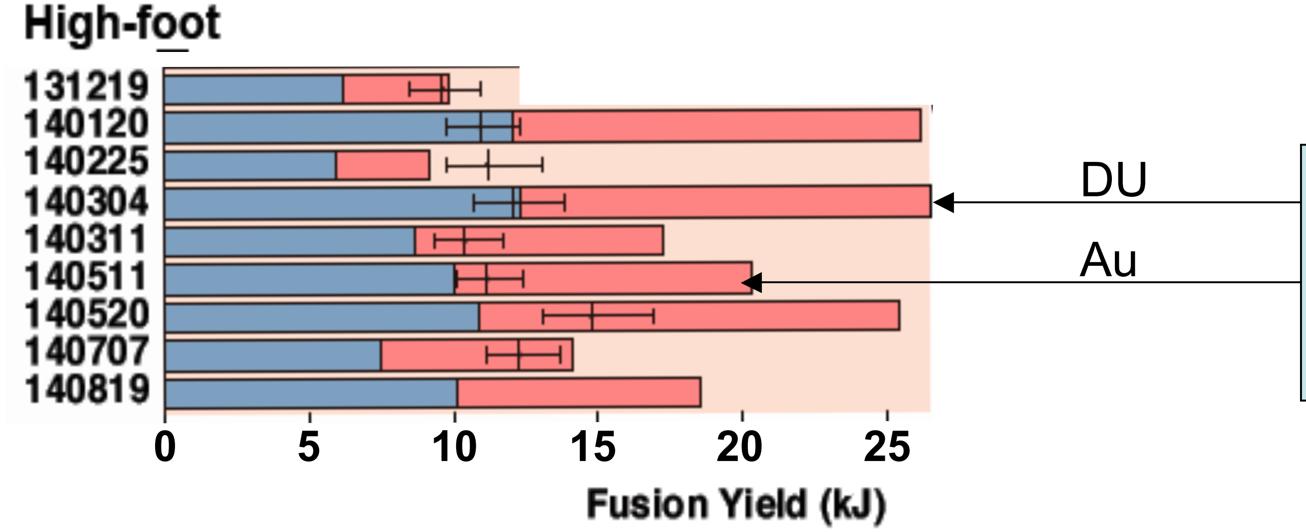
“post-Nature” progress.3



10-15% thinner ablator
& DU hohlraum

still not published

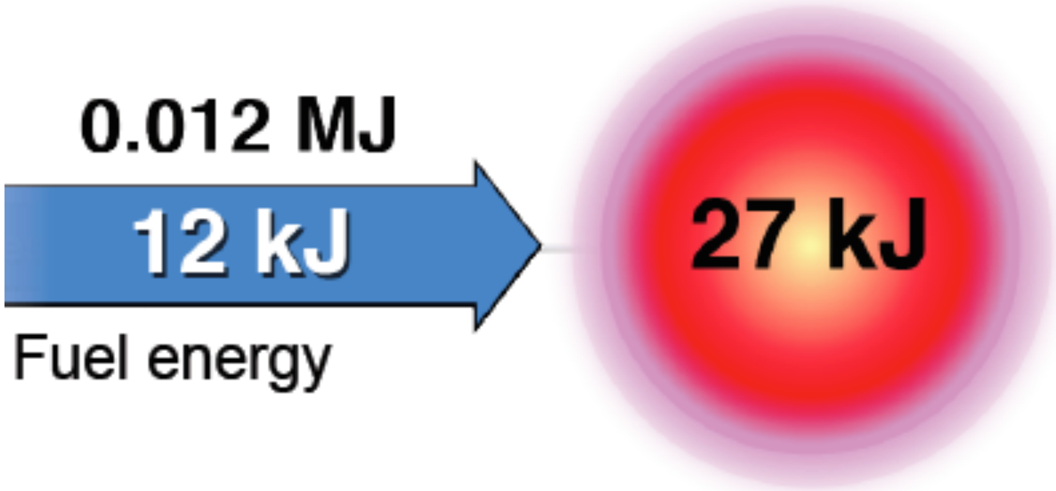
“post-Nature” progress.4



Full quenched
solid DT layer

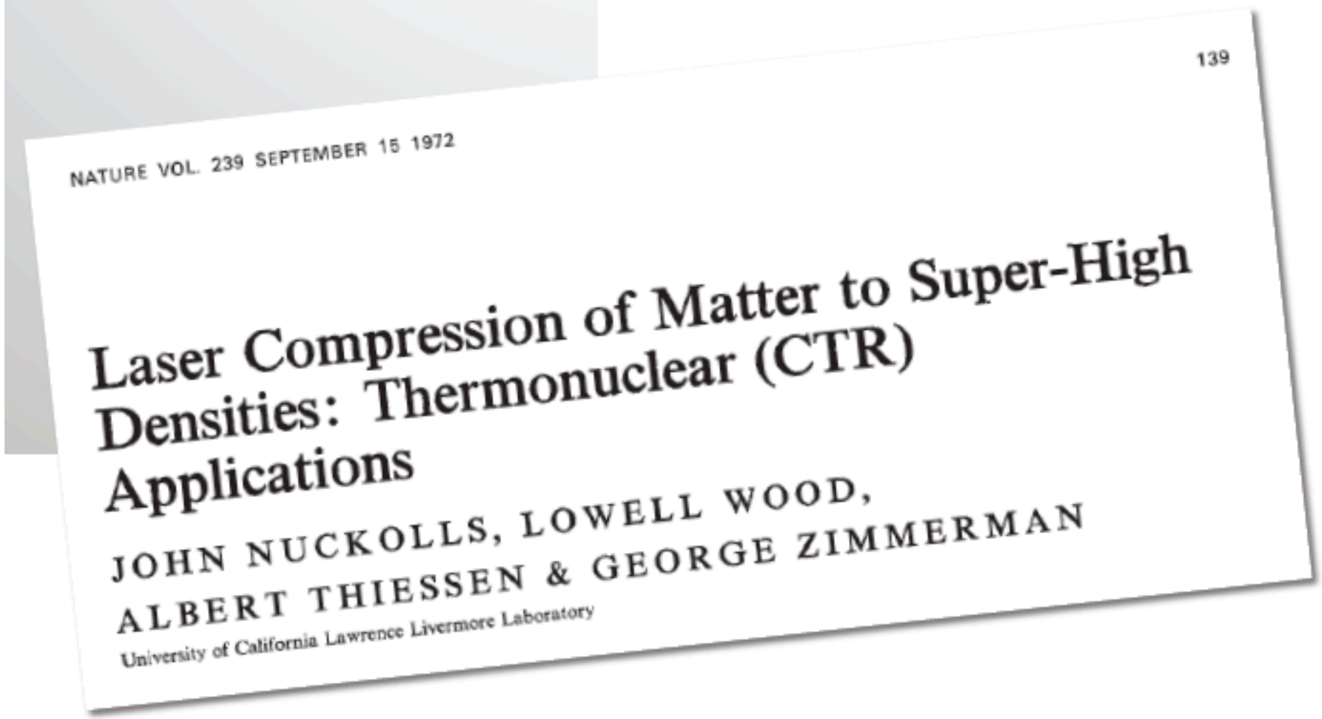
still not published

FUEL ENERGY BALANCE
best shot till Aug. 19, 2014



shot n.o 140304

- -> *high-foot*
- -> *3-shocks*
- -> *DU hohlraum*
- -> *full-quench*



NATURE VOL. 239 SEPTEMBER 15 1972

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Laser Compression of Matter to Super-High Densities: Thermonuclear (CTR) Applications

JOHN NUCKOLLS, LOWELL WOOD, ALBERT THIESSEN & GEORGE ZIMMERMAN

University of California Lawrence Livermore Laboratory

41 years later…

LETTER

20 FEBRUARY 2014 | VOL 506 | NATURE | 343

doi:10.1038/nature13008

Fuel gain exceeding unity in an inertially confined fusion implosion

O. A. Hurricane[1], D. A. Callahan[1], D. T. Casey[1], P. M. Celliers[1], C. Cerjan[1], E. L. Dewald[1], T. R. Dittrich[1], T. Döppner[1], D. E. Hinkel[1], L. F. Berzak Hopkins[1], J. L. Kline[2], S. Le Pape[1], T. Ma[1], A. G. MacPhee[1], J. L. Milovich[1], A. Pak[1], H.-S. Park[1], P. K. Patel[1], B. A. Remington[1], J. D. Salmonson[1], P. T. Springer[1] & R. Tommasini[1]

Nucl. Fusion 5 87 (1965)

Plasma compression by light pressure

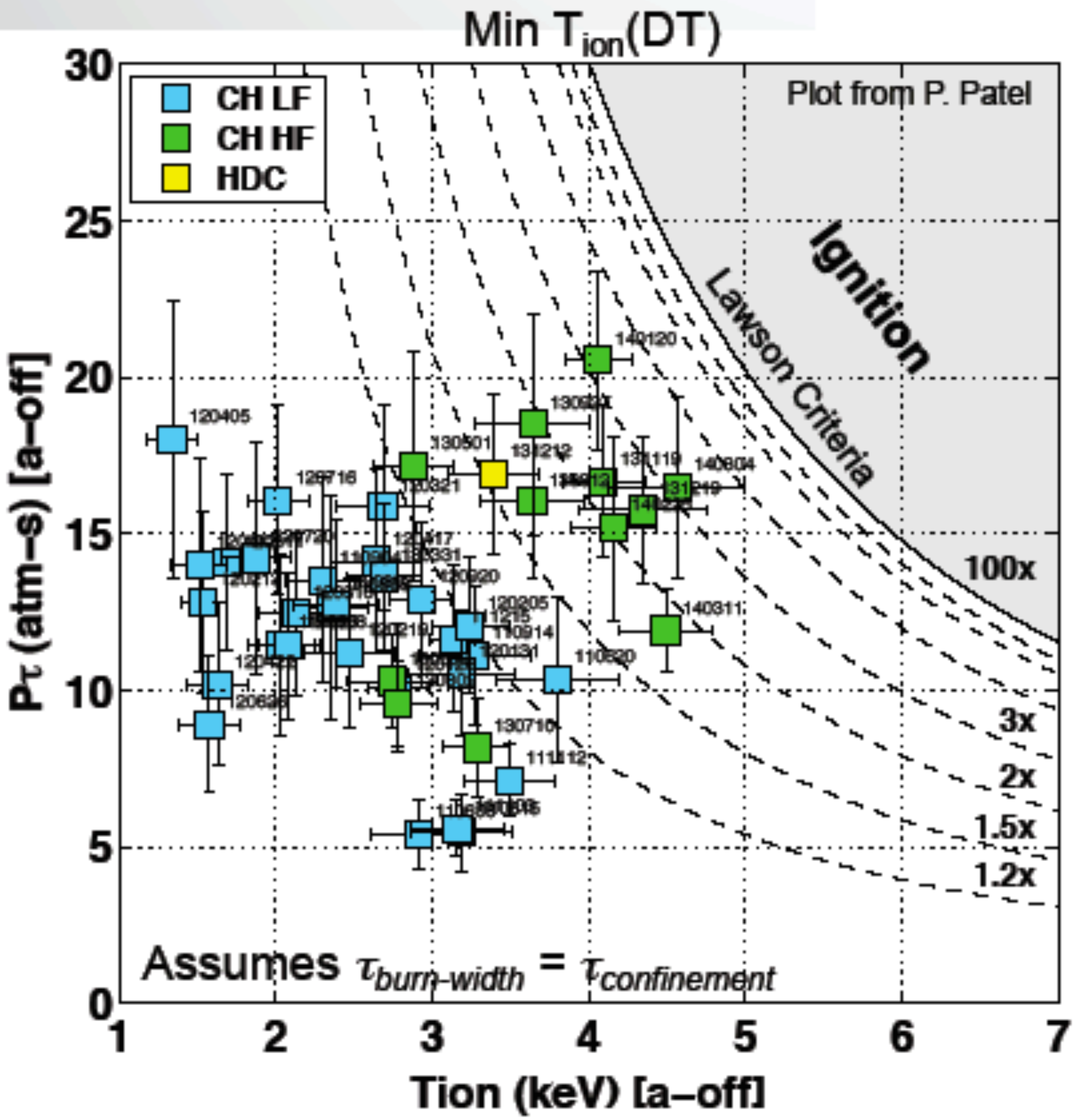
A. Caruso and F. Gratton

Laboratorio Gas Ionizzati, Euratom-CNEN, Frascati, Italy

Abstract

For giant pulse lasers with light amplifier, the rise time of the pulse is 0.001 nsec, the duration is 1 nsec. The light from the laser, focused on a speck (10 μ) of solid material, by its pressure can create near the presence of a high temperature and high density plasma. The initial stage of a plane geometry is analytically studied and, in more detail, the subsequent dynamics.

Getting ignition with facility levels of energy is not easy and not guaranteed, but we're closer than we used to be



Strategy for future:

-Better shape control
-Higher velocities
-Lower fuel adiabat (evolving laser pulse-shape)

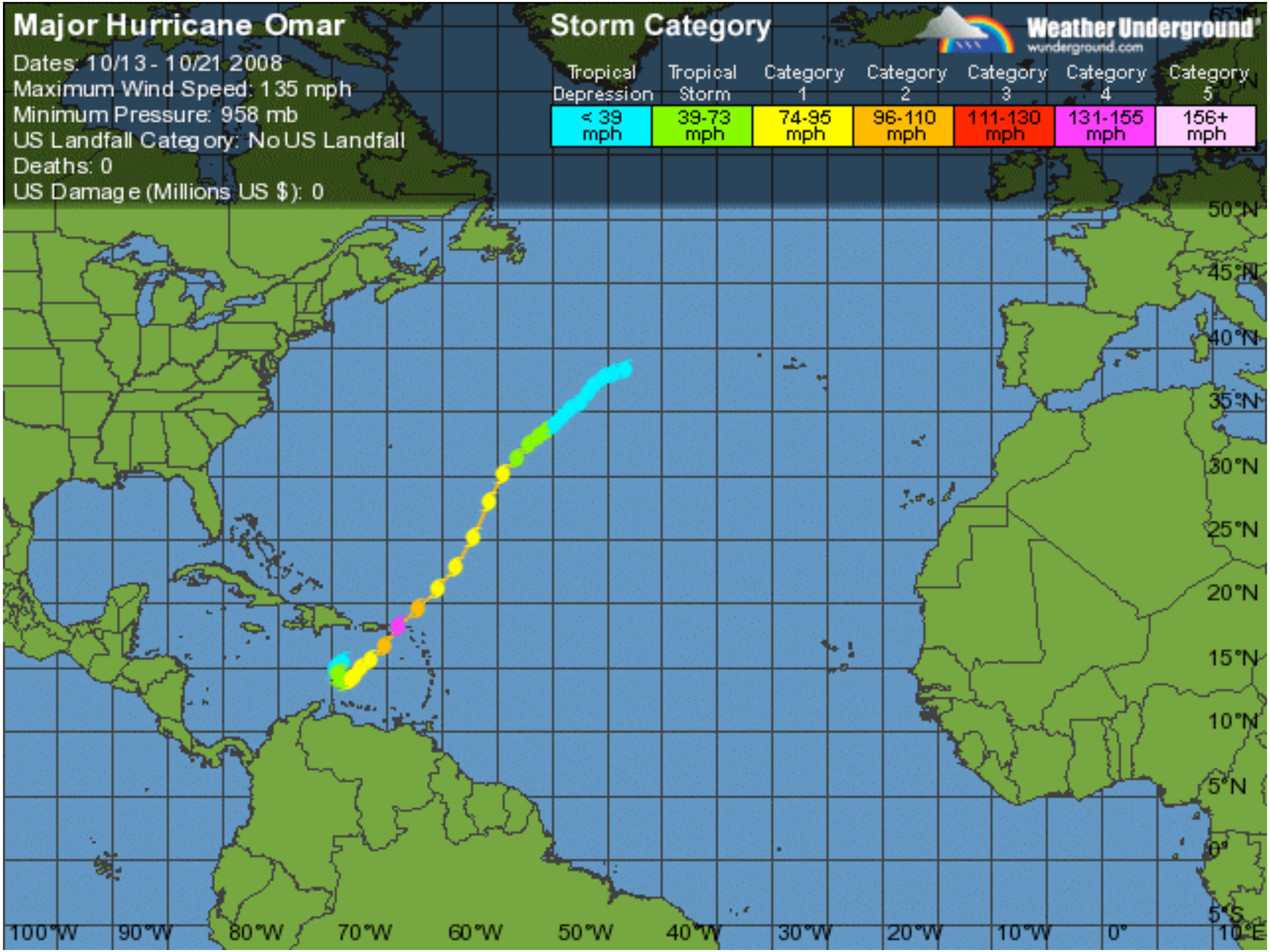
-The above all needed to get more *compression*

-Use HF implosion to test failure cliffs and models

-We are still *learning*

Performance so far:

-Alpha-heating dominated
-Fuel gain > 1
-Instability control and low mix


Major Hurricane Omar
Dates: 10/13 - 10/21 2008
Maximum Wind Speed: 135 mph
Minimum Pressure: 958 mb
US Landfall Category: No US Landfall
Deaths: 0
US Damage (Millions US $): 0
Storm Category
Weather Underground
wunderground.com
Tropical Depression
< 39 mph
Tropical Storm
39-73 mph
Category 1
74-95 mph
Category 2
96-110 mph
Category 3
111-130 mph
Category 4
131-155 mph
Category 5
156+ mph
65°N
50°N
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
5°N
0°
5°S
100°W
90°W
80°W
70°W
60°W
50°W
40°W
30°W
20°W
10°W
0°
10°E