Fusion mit Laser und Teilchenstrahlen für die Stromerzeugung - Stand und Perspektiven

TECHNISCHE UNIVERSITÄT DARMSTADT

Aktualität

NIF Fertiggestellt 2009

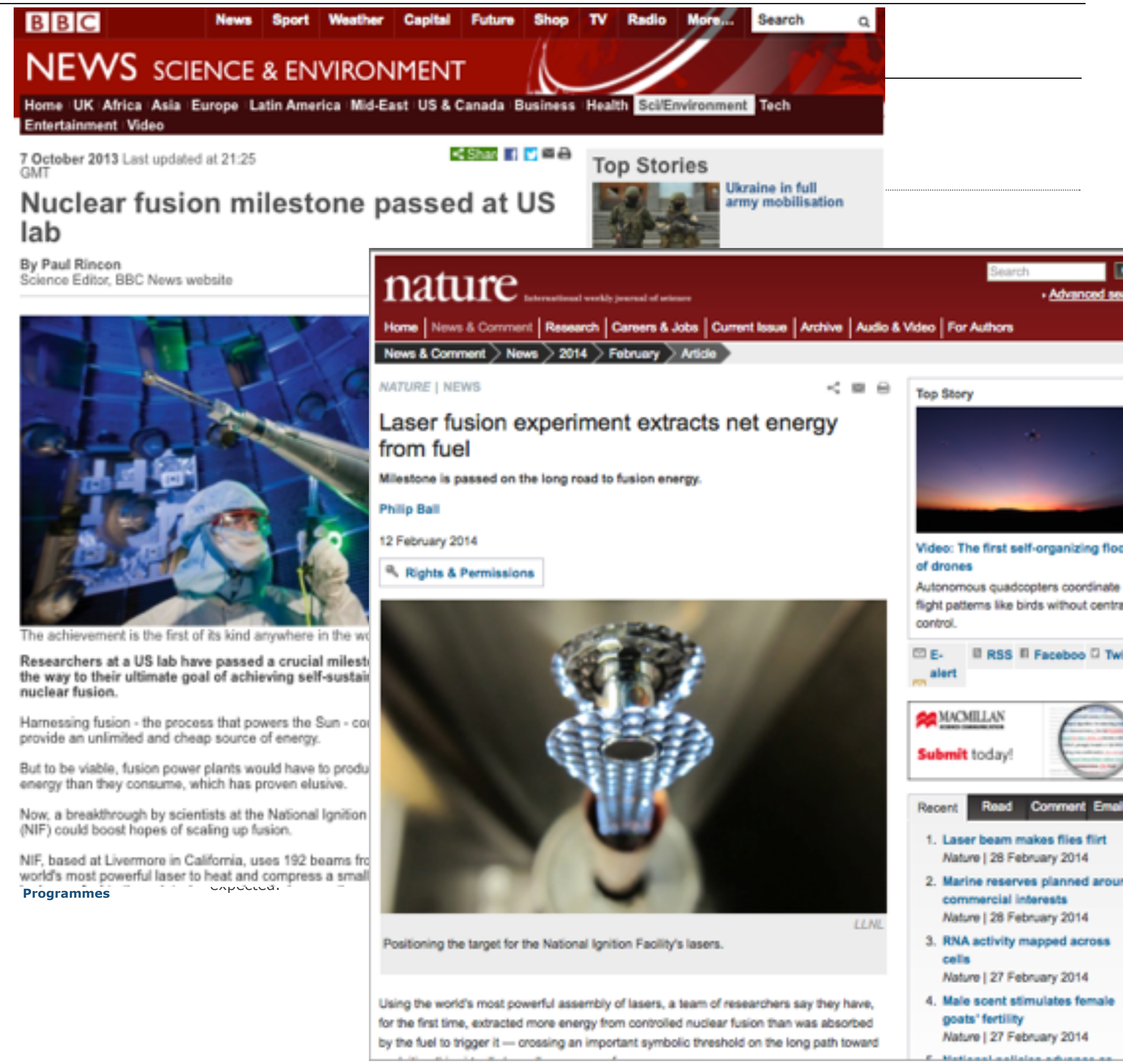
Beginn Experimente 2009

Erste Kampagne 2010

Ende der ersten Kampagne 2012

Workshop Science for Ignition @ NIF

High-Foot Kampagne 2013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7 October 2013 Last updated at 21:25 GMT

Nuclear fusion milestone passed at US lab

By Paul Rincon
Science Editor, BBC News website

Top Stories
Ukraine in full army mobilisation

The achievement is the first of its kind anywhere in the wo

Researchers at a US lab have passed a crucial milest the way to their ultimate goal of achieving self-sustai nuclear fusion.

Harnessing fusion - the process that powers the Sun - co provide an unlimited and cheap source of energy.

But to be viable, fusion power plants would have to produ energy than they consume, which has proven elusive.

Now, a breakthrough by scientists at the National Ignition (NIF) could boost hopes of scaling up fusion.

NIF, based at Livermore in California, uses 192 beams fro world's most powerful laser to heat and compress a small

Programmes

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NATURE | NEWS

Laser fusion experiment extracts net energy from fuel

Milestone is passed on the long road to fusion energy.

Philip Ball

12 February 2014

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LLNL

Positioning the target for the National Ignition Facility's lasers.

Using the world's most powerful assembly of lasers, a team of researchers say they have, for the first time, extracted more energy from controlled nuclear fusion than was absorbed by the fuel to trigger it — crossing an important symbolic threshold on the long path toward

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Video: The first self-organizing flock of drones

Autonomous quadcopters coordinate flight patterns like birds without central control.

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Trägheitsfusion

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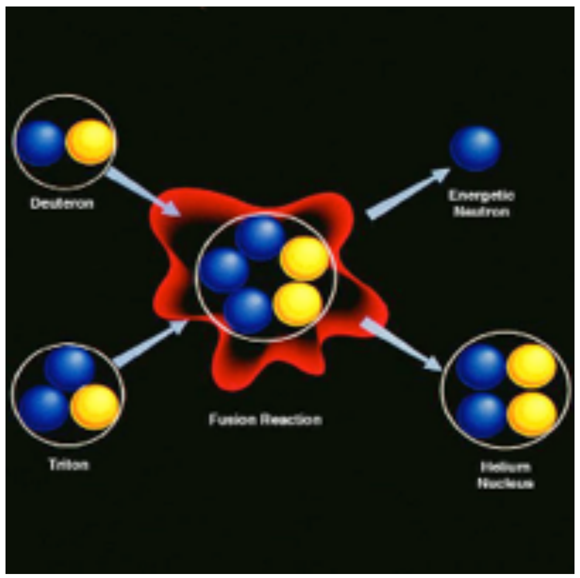
Plasma Einschlussbedingung: Lawson Kriterium: $n\tau = 10^{14}$

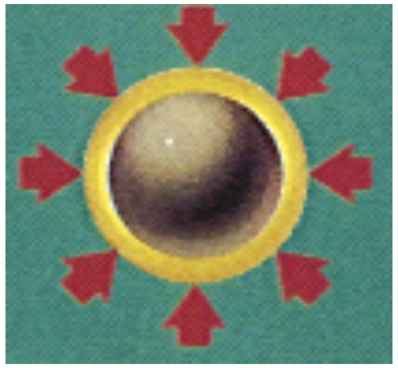


Magnetic Confinement Fusion

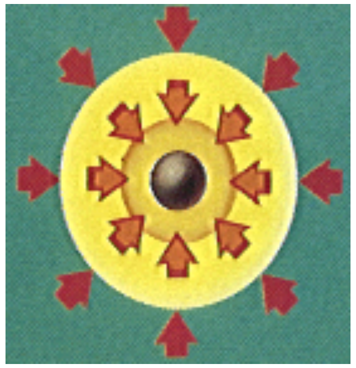
Dichte = 10^{14} cm^{-3}
Einschlusszeit = 1 Sekunde

Inertial Confinement Fusion

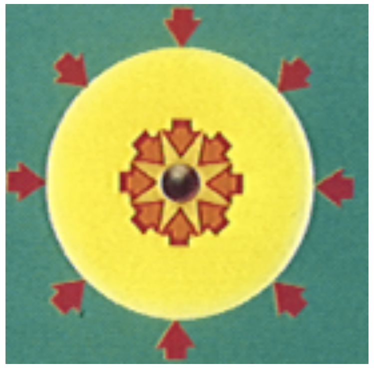
Dichte = 10^{25} cm^{-3}
Einschlusszeit = 10 Pikosekunden



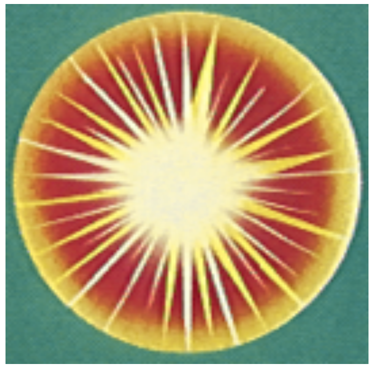
Bestrahlung der Oberfläche



Kompression (Raketen-prinzip)



Zentrale Zündung



Burn

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Einige Zahlen

$$n \cdot \tau \geq 10^{14}\ s/cm^3 \rightarrow \rho R > 1 g/cm^2$$

n: Particle number density [cm^{-3}]
ρ: density [g/cm^3]
τ: Confinement time [s]
T: Temperature [keV]
R: compressed fuel radius

- Bei ρR=3 g/cm² i.e. f_b=30% Y=100 MJ/mg
- 1 mg DT muss komprimiert werden zu 336 g/cm^3 oder 1680 x Festkörperdichte (0.2 g/cm^3) für ρR=3 g/cm^2.

Um die enormen Anforderungen an die Symmetrie zu gewährleisten wird in der ersten Kampagne die indirekte Zündung versucht

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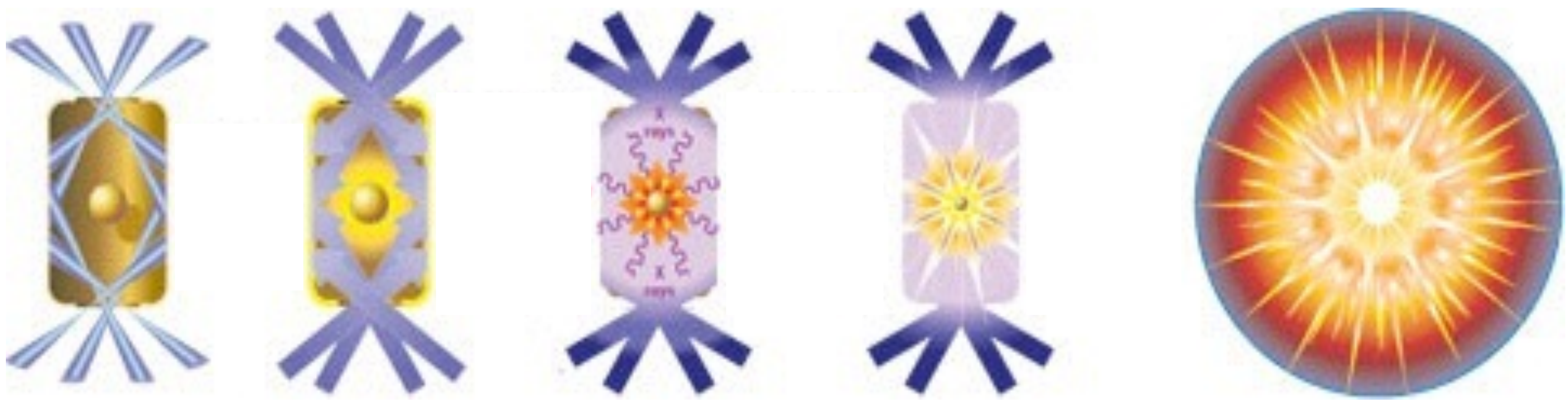
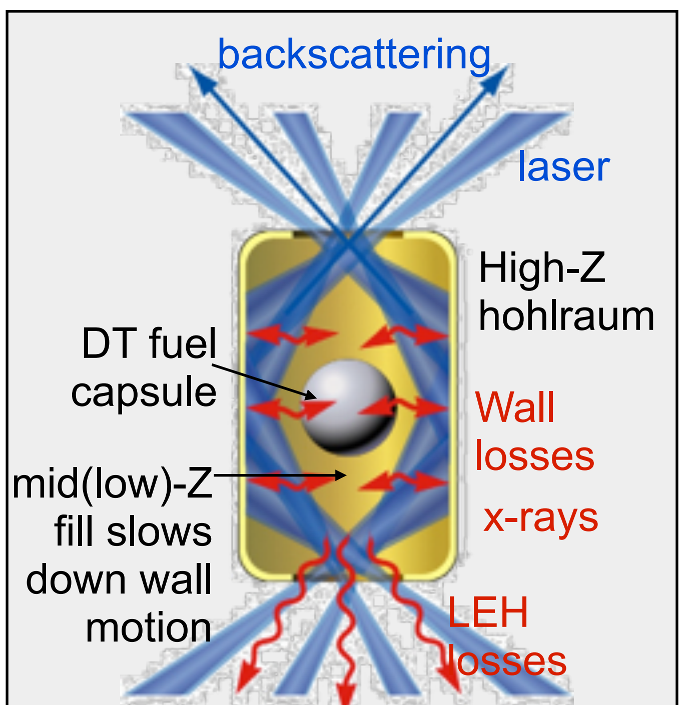


indirect Illumination by x-rays

fuel capsule compression (200-1000 g/cc)

fusion ignition (~ 10 keV)

fusion burn



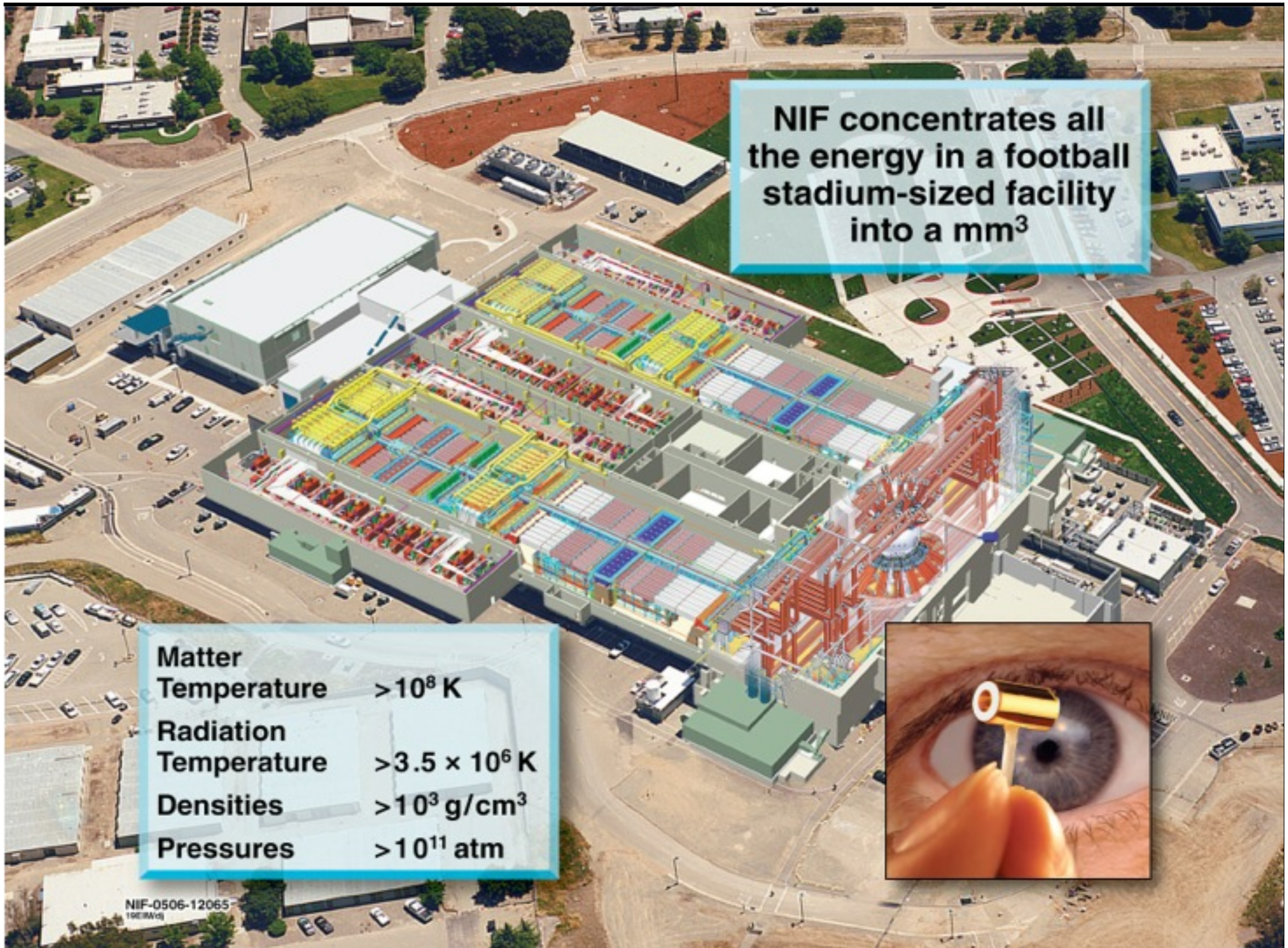
Zündung bedarf der Optimierung von:

- **Hohlraum Design:**
  - Laserabsorption/ -propagation, backscattering
  - Laser Konversionseffizienz in X-rays
  - Hohlraum Re-emissionseffizienz (Wand+LEH Verluste)
- **Implosiondynamik der Kompression**
  - shock timing, EOS ablator studies
- **Kompressionssymmetrie der Kapsel**

NIF

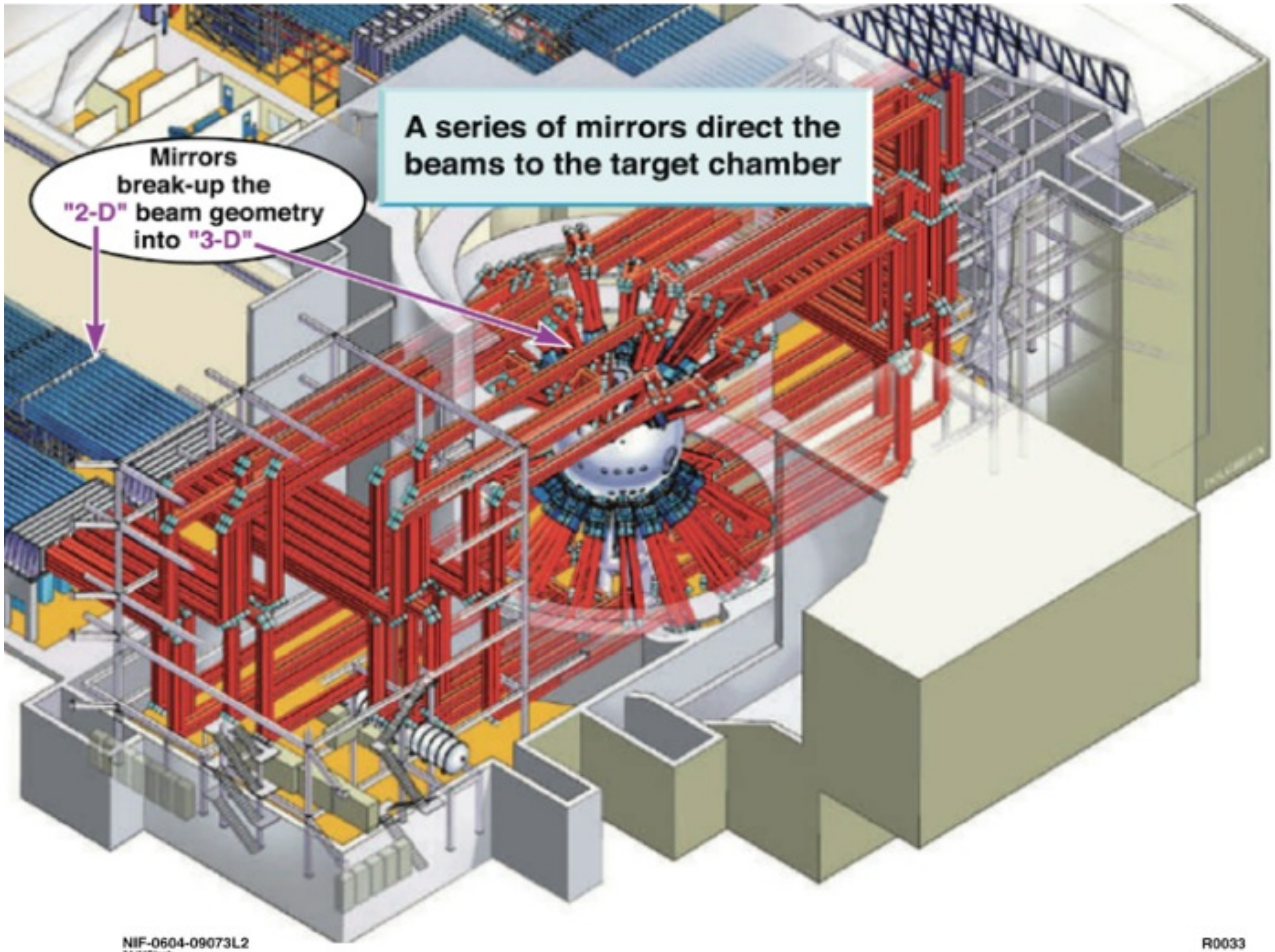
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

Aufgabe: Verlässliche Zündung einer Fusionsreaktion mit Gain bei niedrigster möglicher Laserenergie


NIF concentrates all the energy in a football stadium-sized facility into a mm³
Matter Temperature >10⁸ K
Radiation Temperature >3.5 × 10⁶ K
Densities >10³ g/cm³
Pressures >10¹¹ atm
NIF-0506-12065

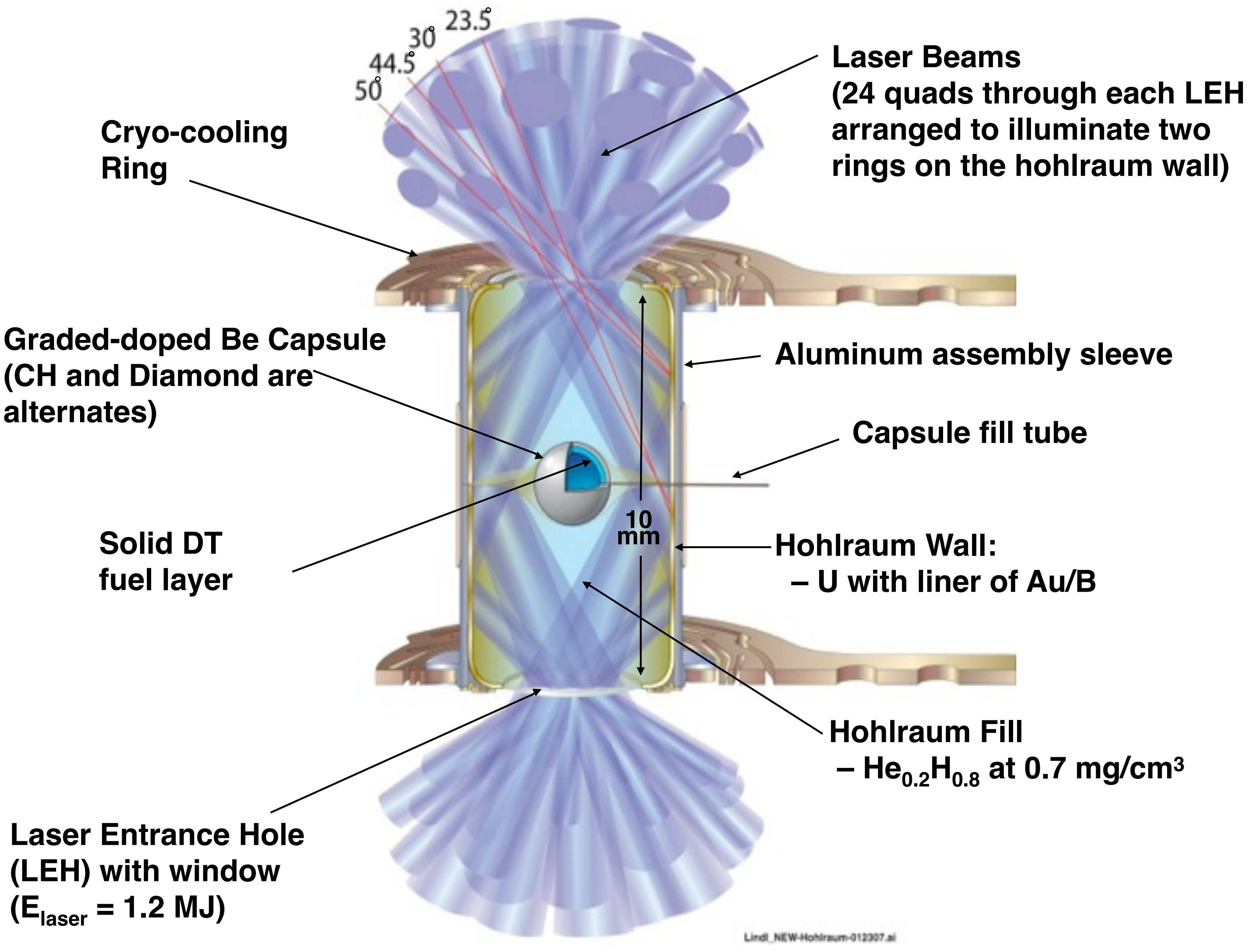
Eine von zwei Laserbays

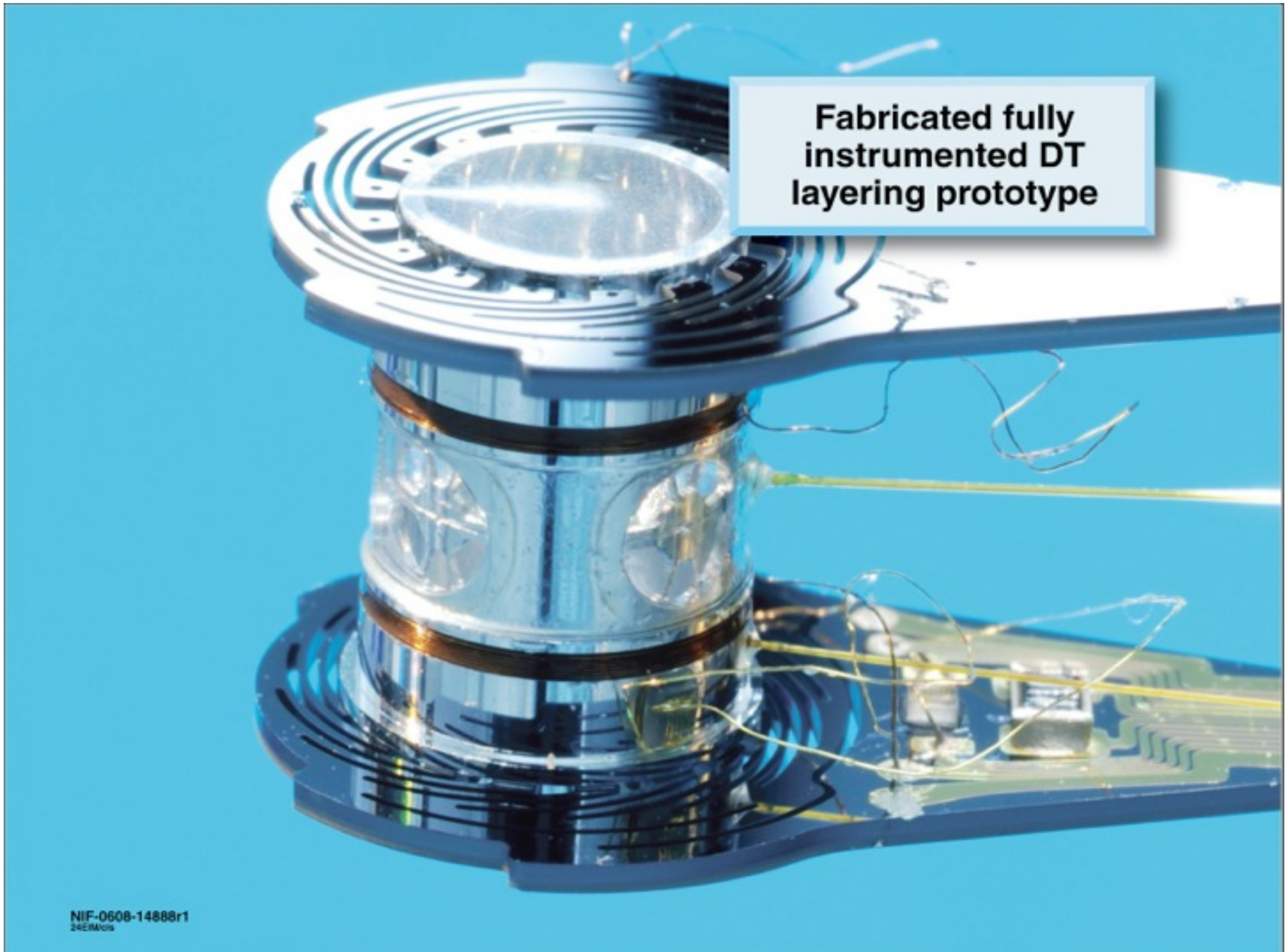
NIF-0506-1195


Mirrors
break-up the
"2-D" beam geometry
into "3-D"
A series of mirrors direct the
beams to the target chamber
NIF-0604-09073L2
R0033

Targetkammer

The NIF point design has a graded-doped, plastic capsule in a hohlraum driven at 285 eV




Fabricated fully instrumented DT layering prototype
NIF-0608-14888r1

The NIC is structured to develop a robust burning plasma platform by the end of 2012

NIC
The National Ignition Campaign

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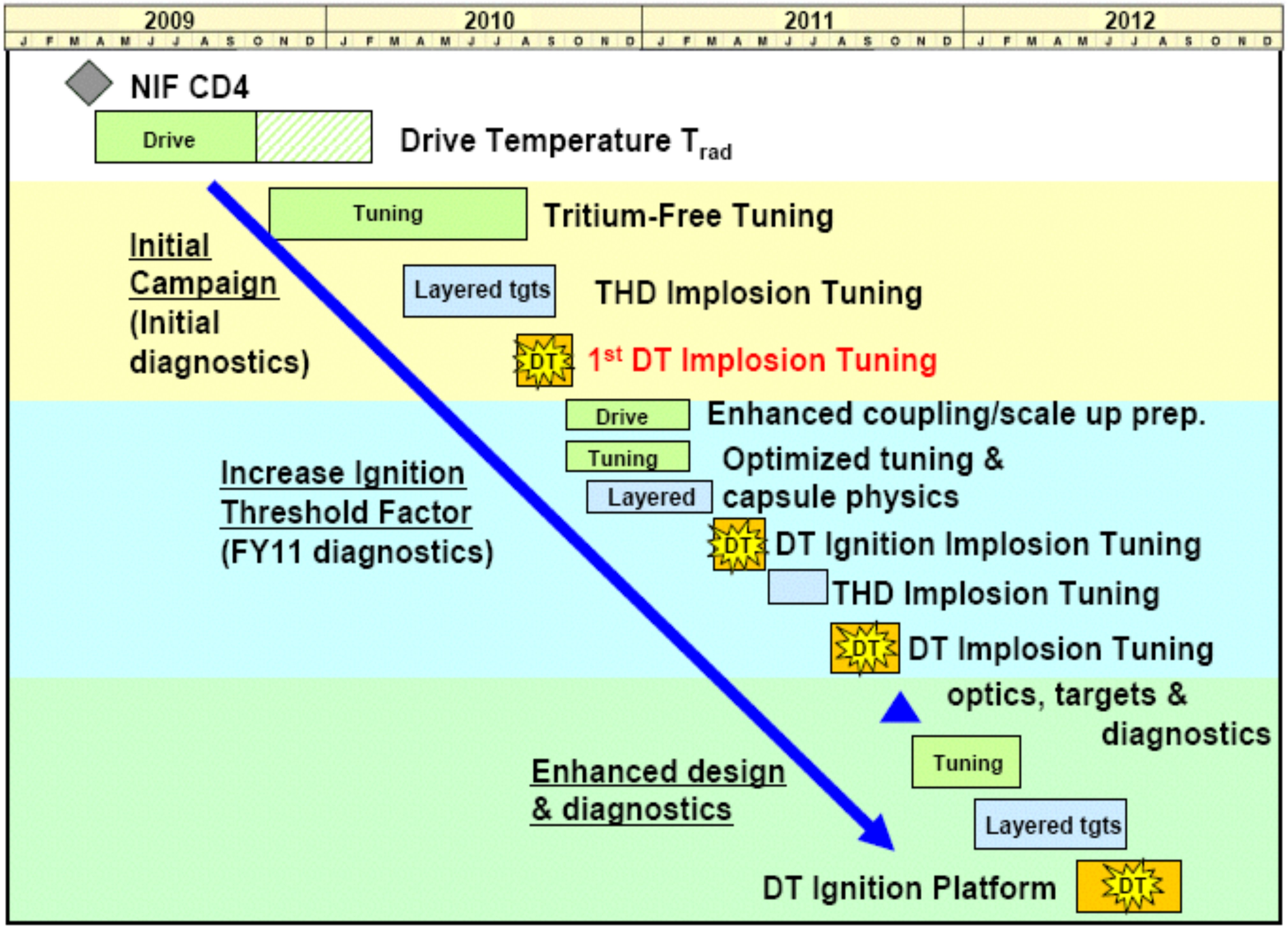

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NIF hat bislang keine Zündung erreicht was ging schief? wo stehen wir?….

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NIF

Update on the pathway to ignition at the National Ignition Facility (NIF)

Presentation to
LANSA, Yokohama
April 23, 2013

Dr Mike Dunne

Program Director, Laser Fusion Energy, LLNL

Lawrence Livermore National Laboratory • National Ignition Facility & Photon Science

NIF

Progress Toward Ignition at the National Ignition Facility

Presentation to
European Physical Society Meeting
Espoo, Finland
July 1, 2013

D. E. Hinkel

LLNL-PRES-640041

Lawrence Livermore National Laboratory • National Ignition Facility & Photon Science

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

The High-Foot Implosion Campaign

APS DPP Meeting QI3.00004

Nov. 13, 2013

Omar A. Hurricane
Distinguished Member of the Technical Staff

Lawrence Livermore National Laboratory

LLNL-PRES-645894

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

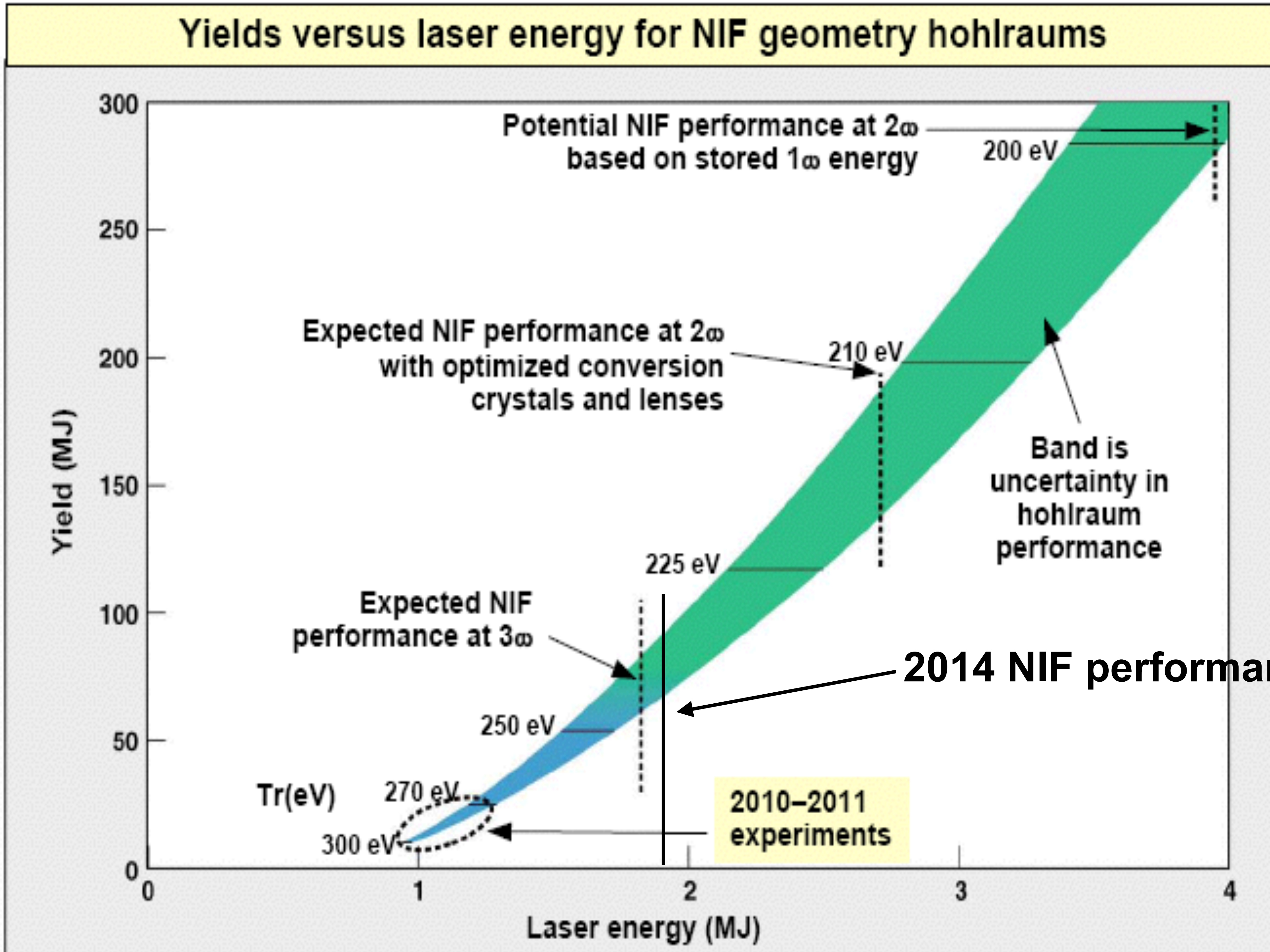
Quicklook for N140304-003-999 I_Abl_DT_HfootDU_S02 (March 4, 2014)

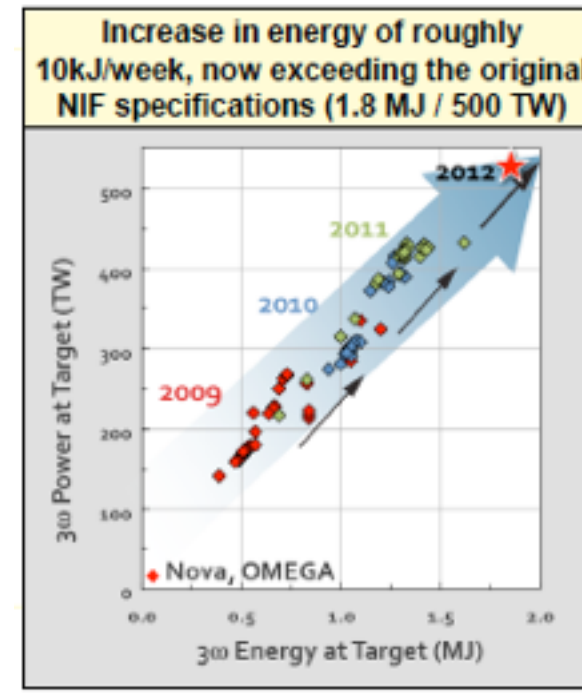
WCI NIF

H. –S. Park, D. Casey, T. Ma, T. Doeppner,
O. Hurricane, D. Callahan, D. Hinkel, T. Dittrich
+ High-Foot team

Lawrence Livermore National Laboratory

NIF hat seine Designparameter inzwischen weit übertroffen





alle drei Monate wird das bislang stärkste Lasersystem der Welt (NOVA) addiert

NIF Tests erfüllen (und oft übertreffen) die Design Spezifikationen, die für die Zündung erwartet werden

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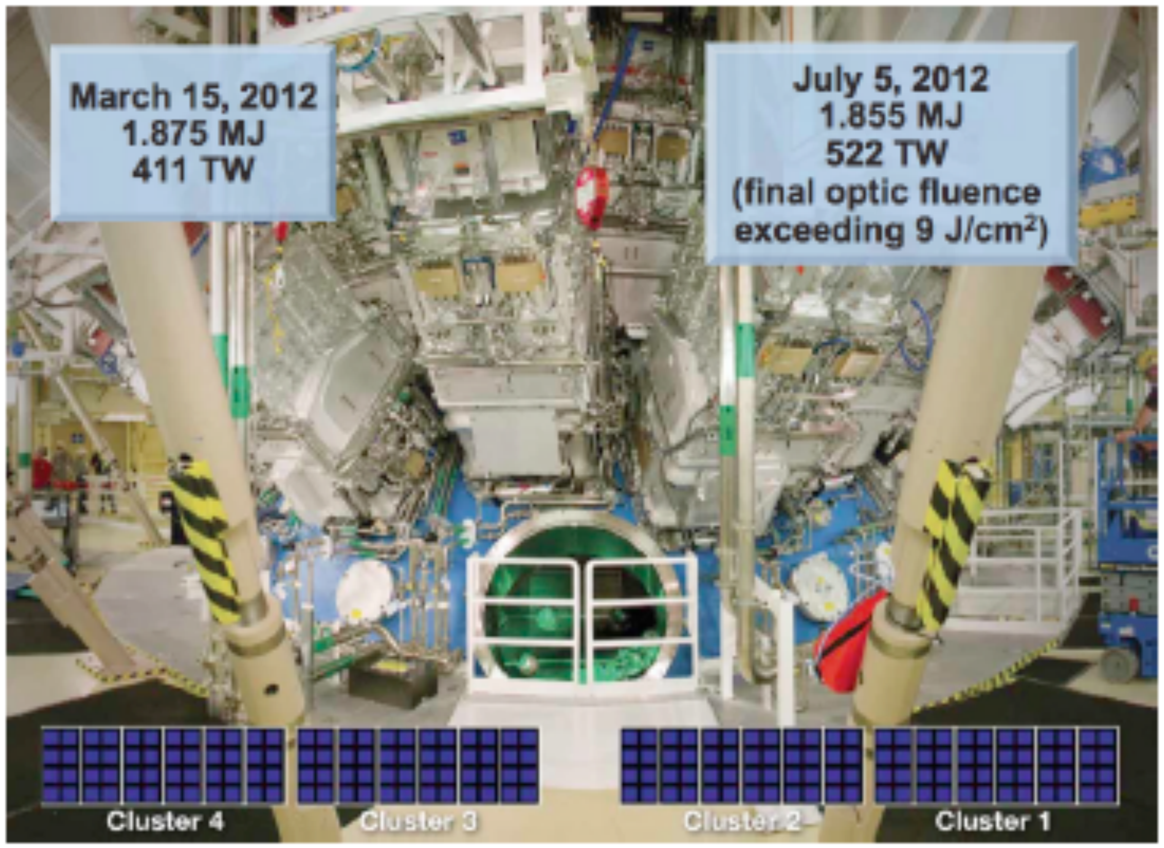
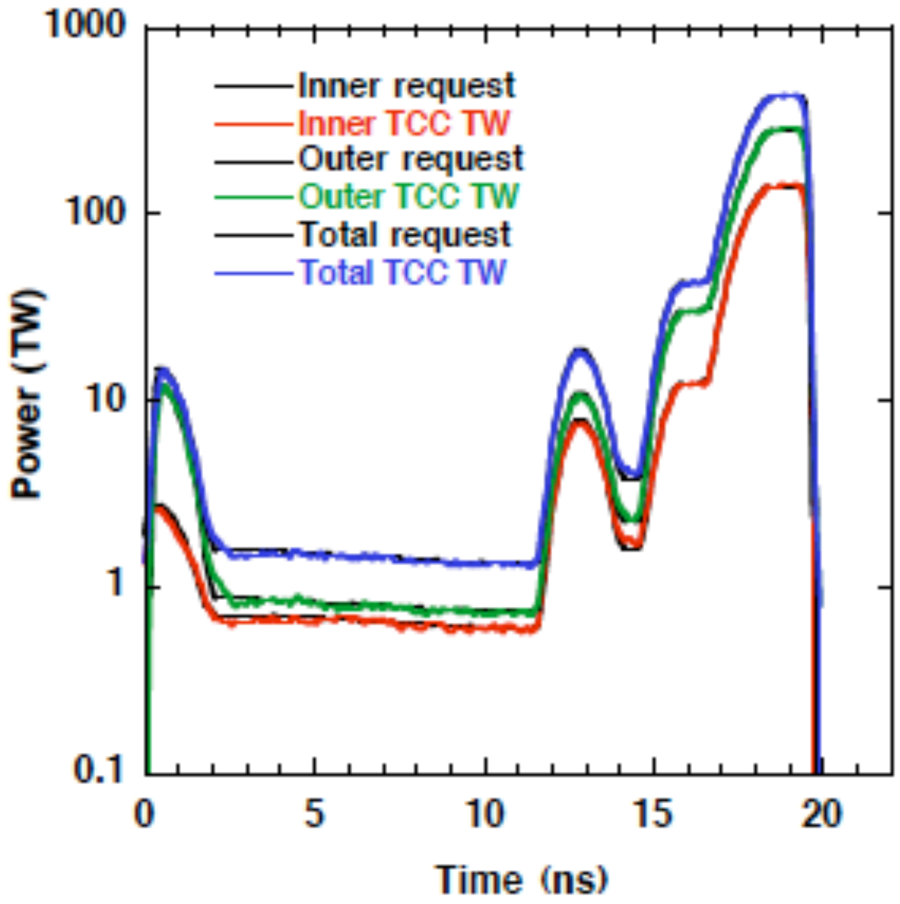
NIF surpassed its milestone of 1.8 MJ of 3ω energy, 500 TW on target



Precision at NIF enables tuning and reproducibility



NIF ist das zuverlässigste Lasersystem das je gebaut wurde

Jedes Experiment des Lasers ist exakt reproduzierbar

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Technische Universität Darmstadt
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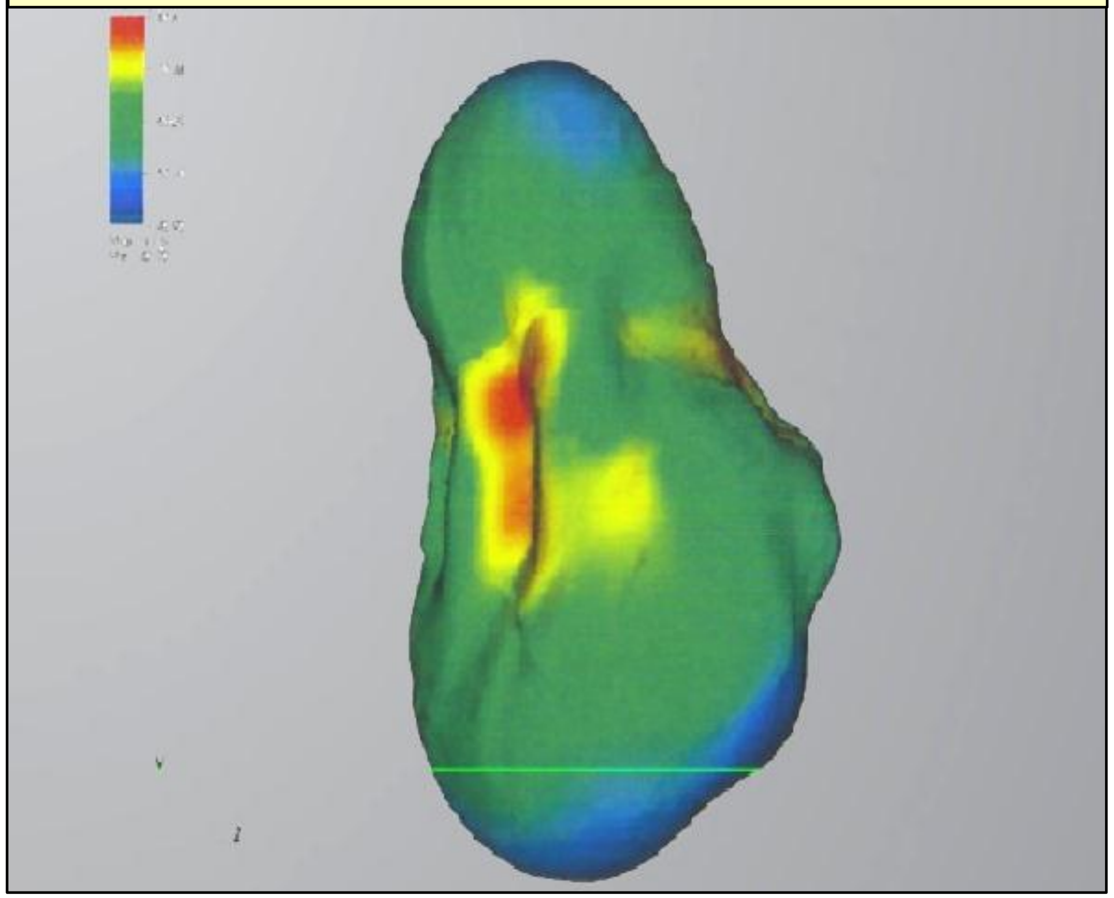
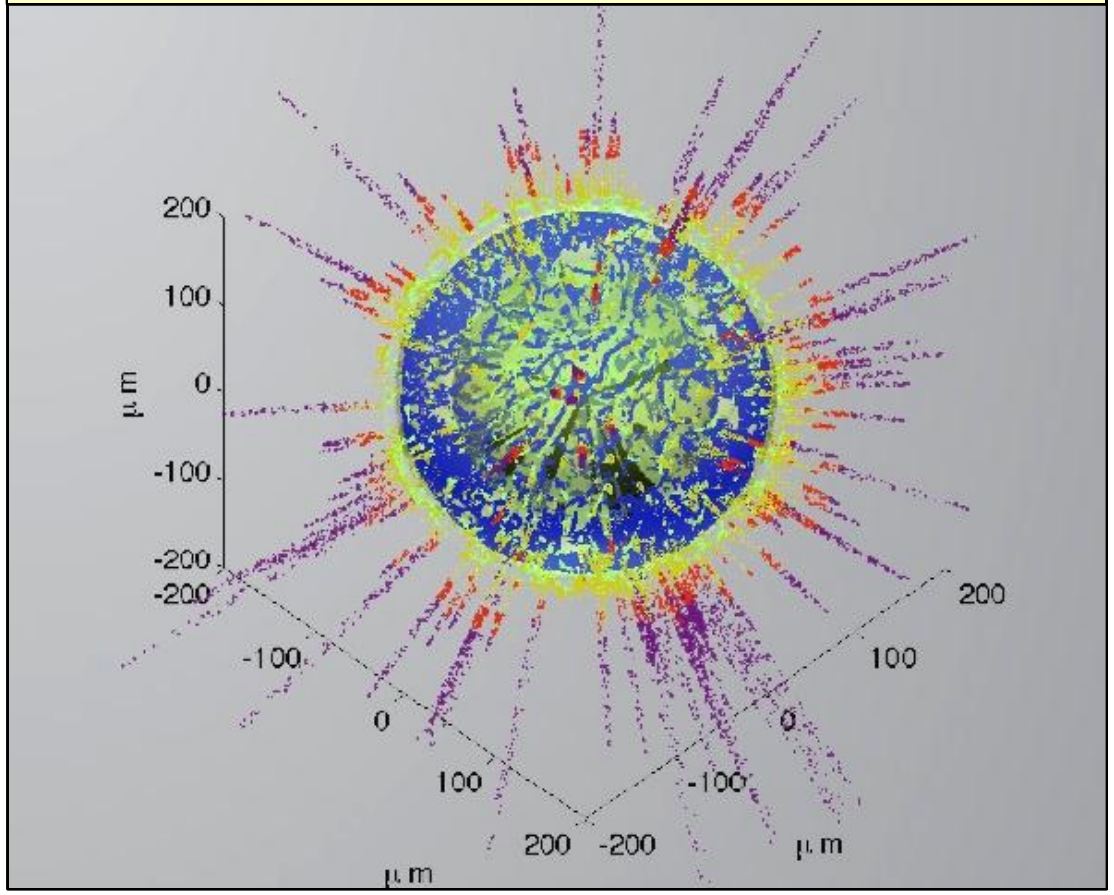
Vermutete Hauptgründe für das Versagen bei der Zündung

Fuel shape



Mix



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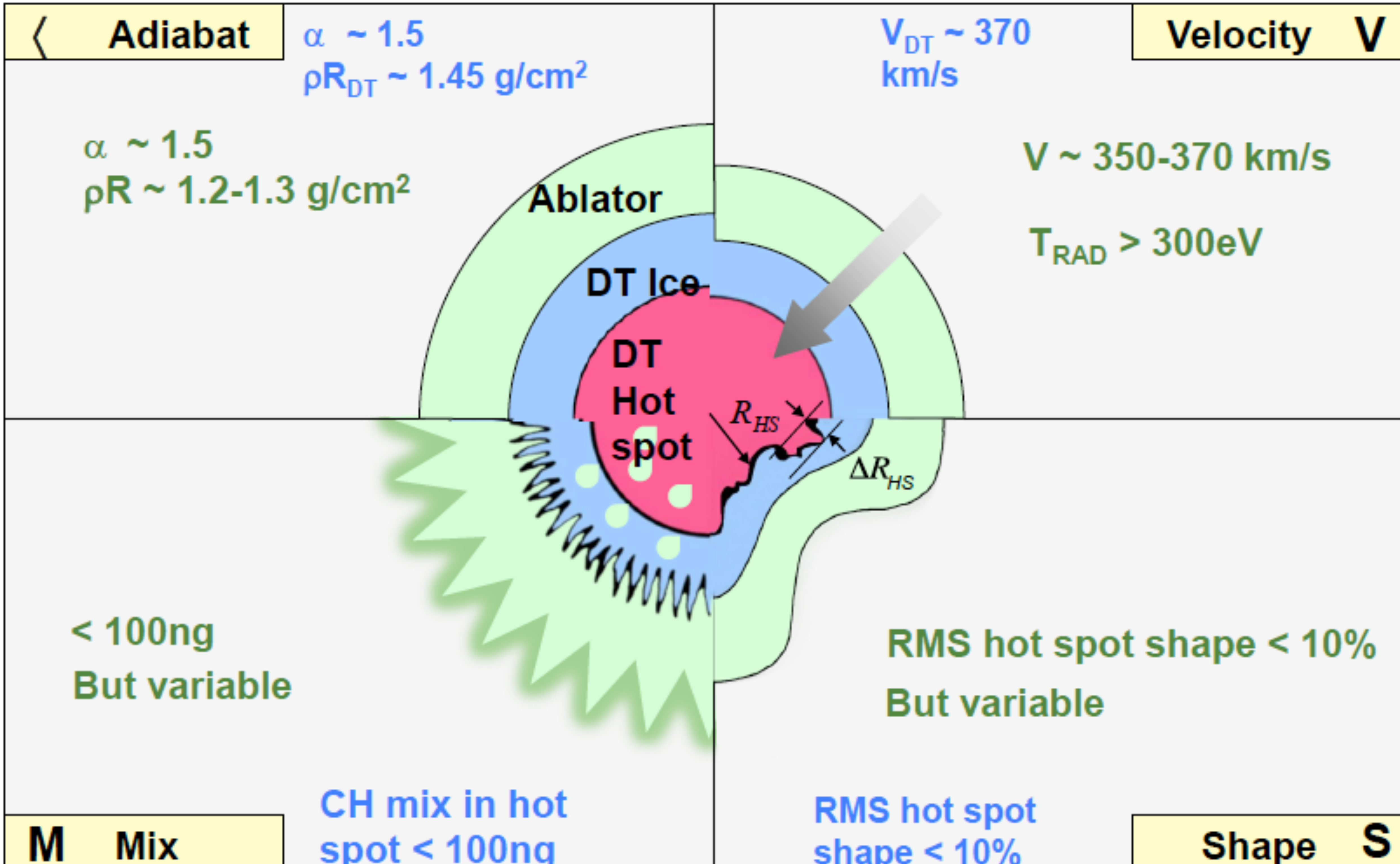
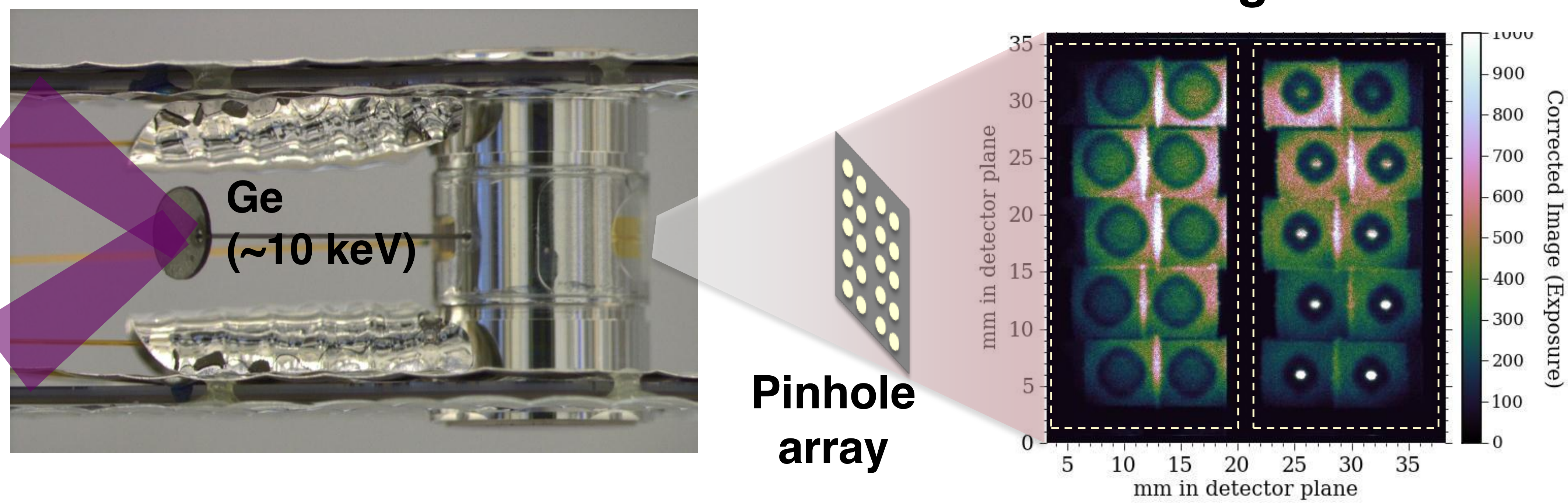
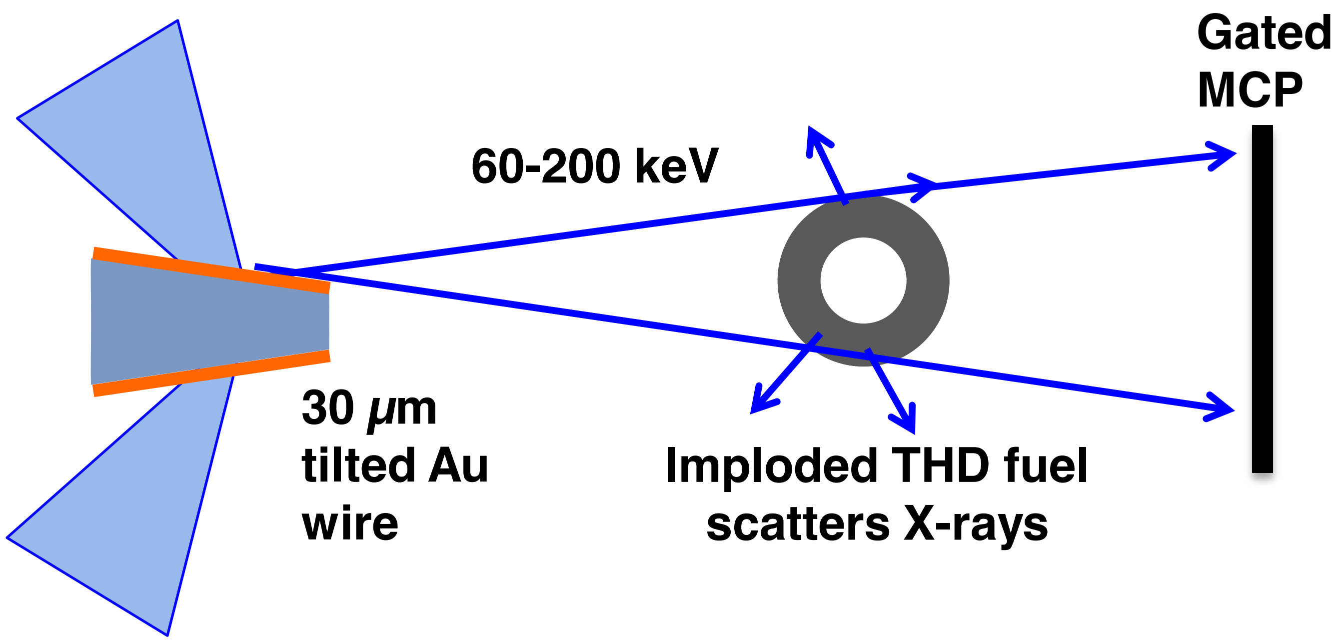
Einzeln wurde fast alle Anforderungen im Experiment erreicht



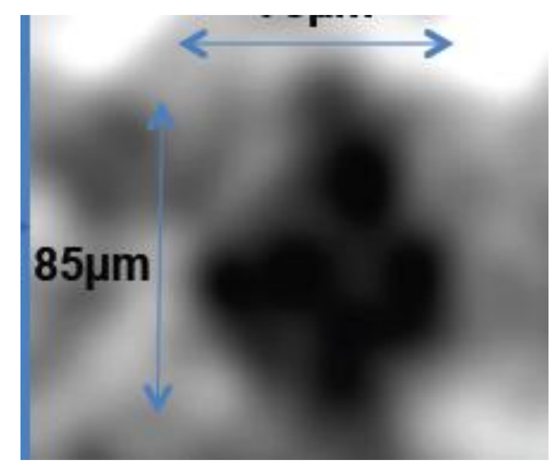
New radiography capabilities used to measure low mode fuel asymmetry (Oct 2012 - Mar 2013)

Gated images N121004

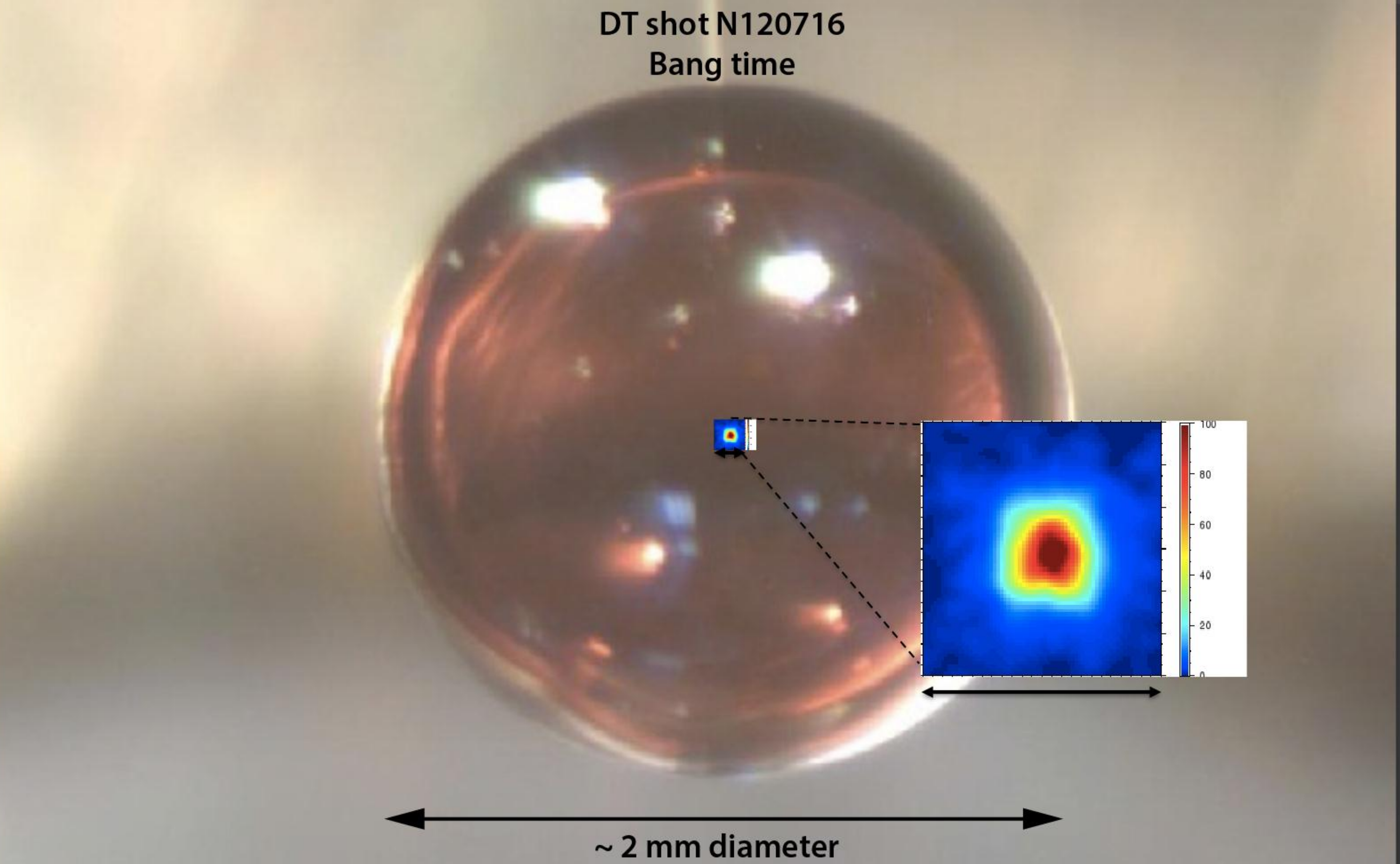




THD shot N121005

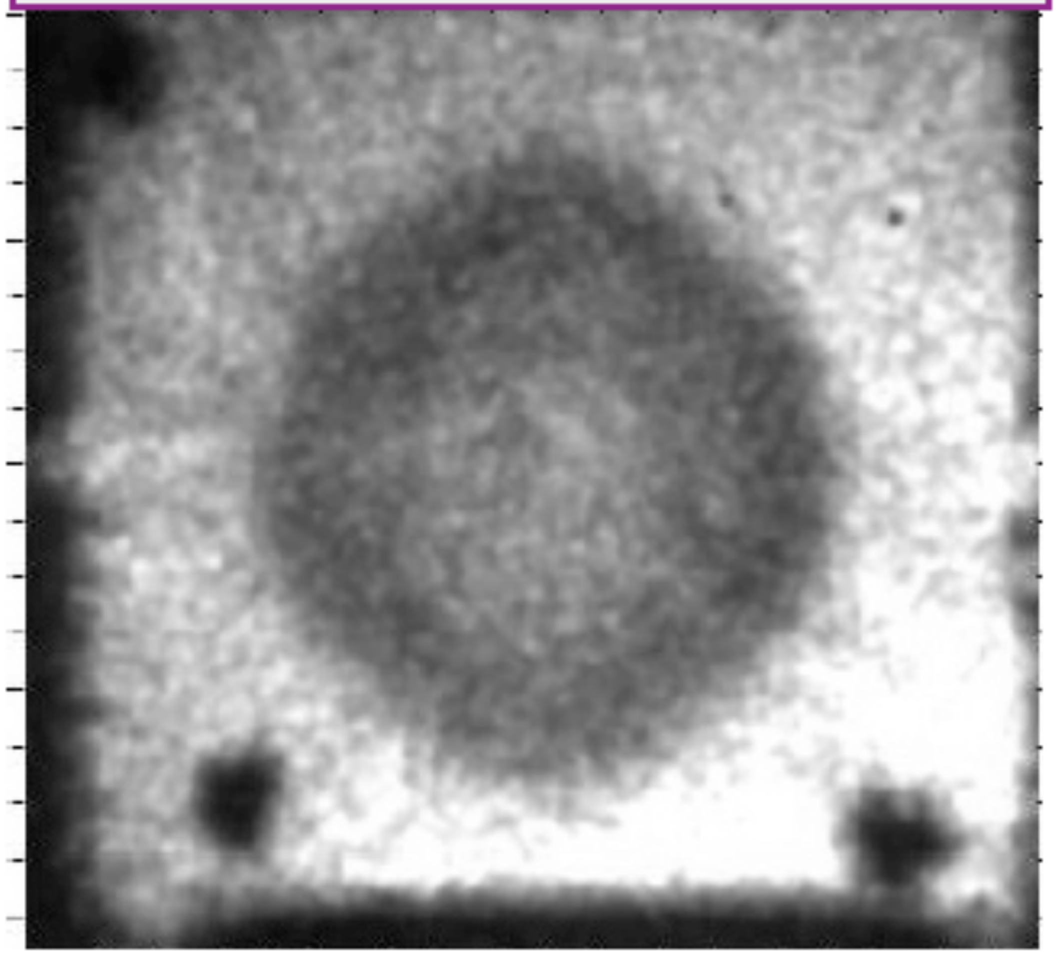


The hot spot looks quite round!

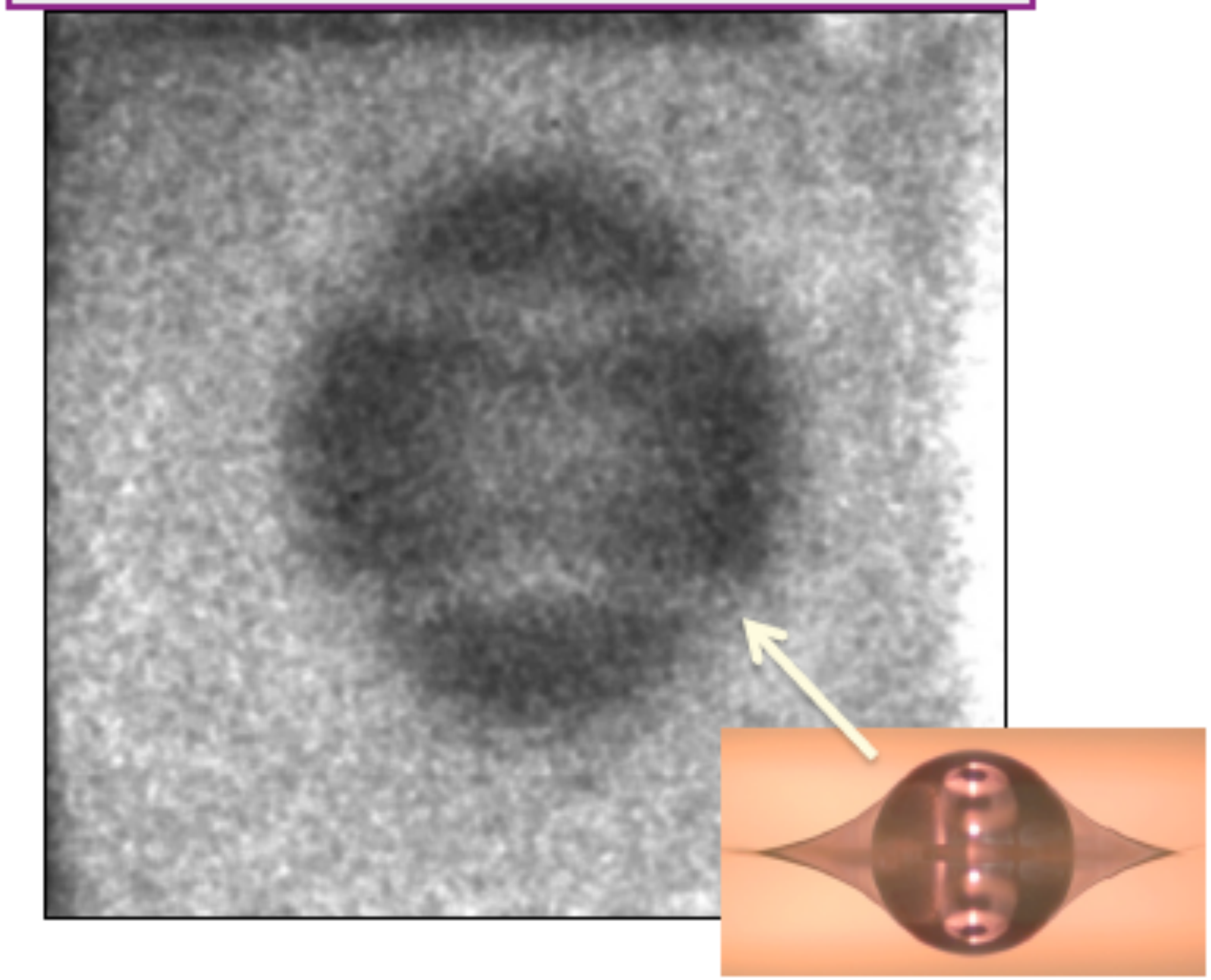


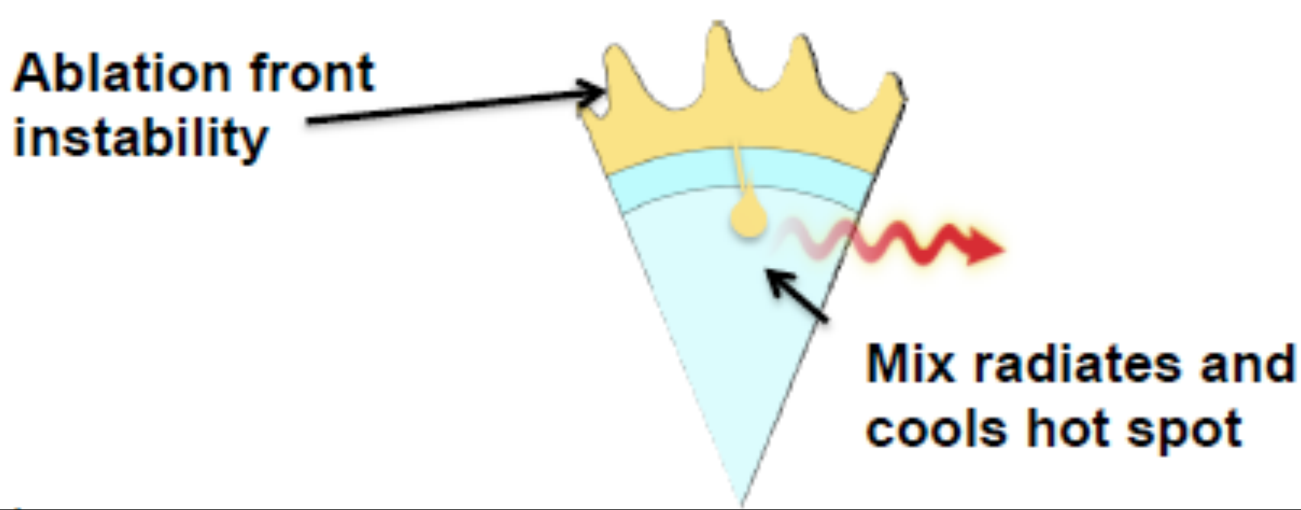
The capsule tent perturbs the implosion

Stalk-Mounted (~ 30 µm) Capsule



Tent-Mounted (~ 100 nm) Capsule





Die meisten Experimente zeigen noch Asymmetrie des hot spot reduzierte Effizienz des inneren Strahlen + P4

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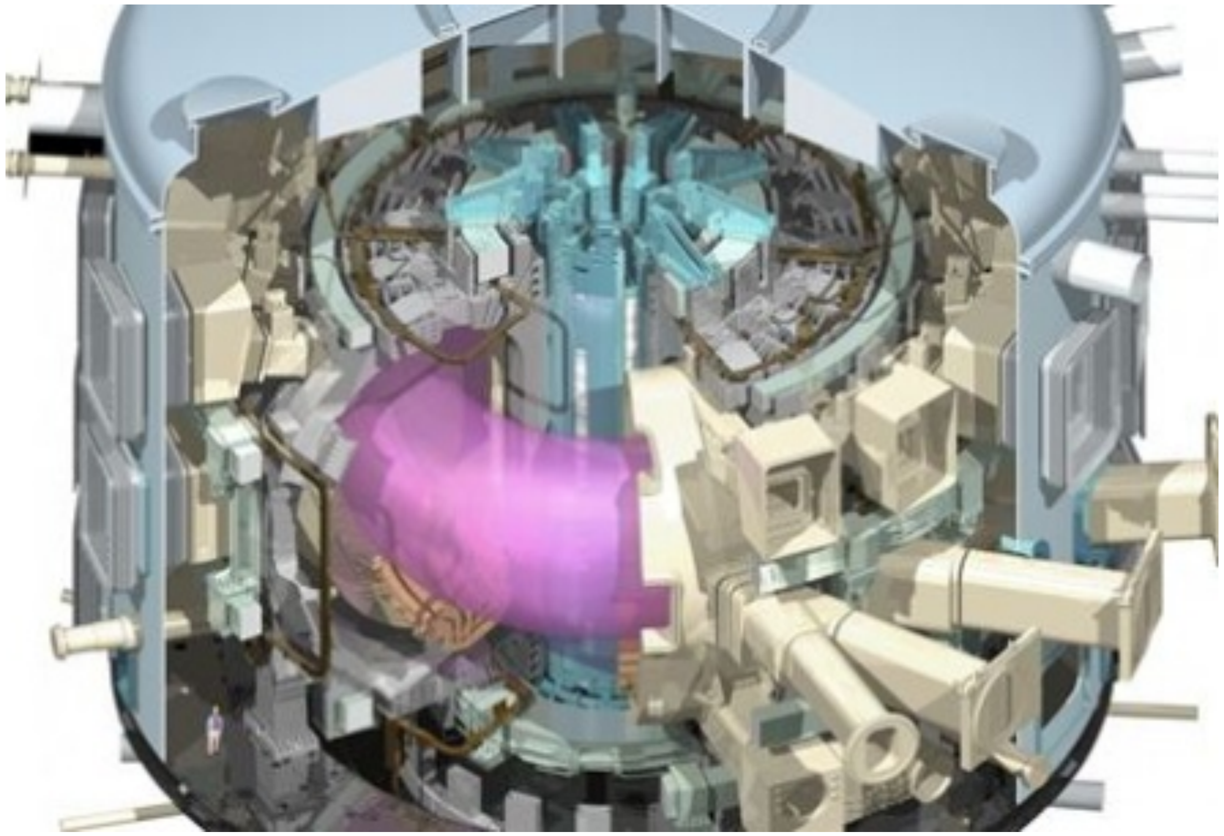
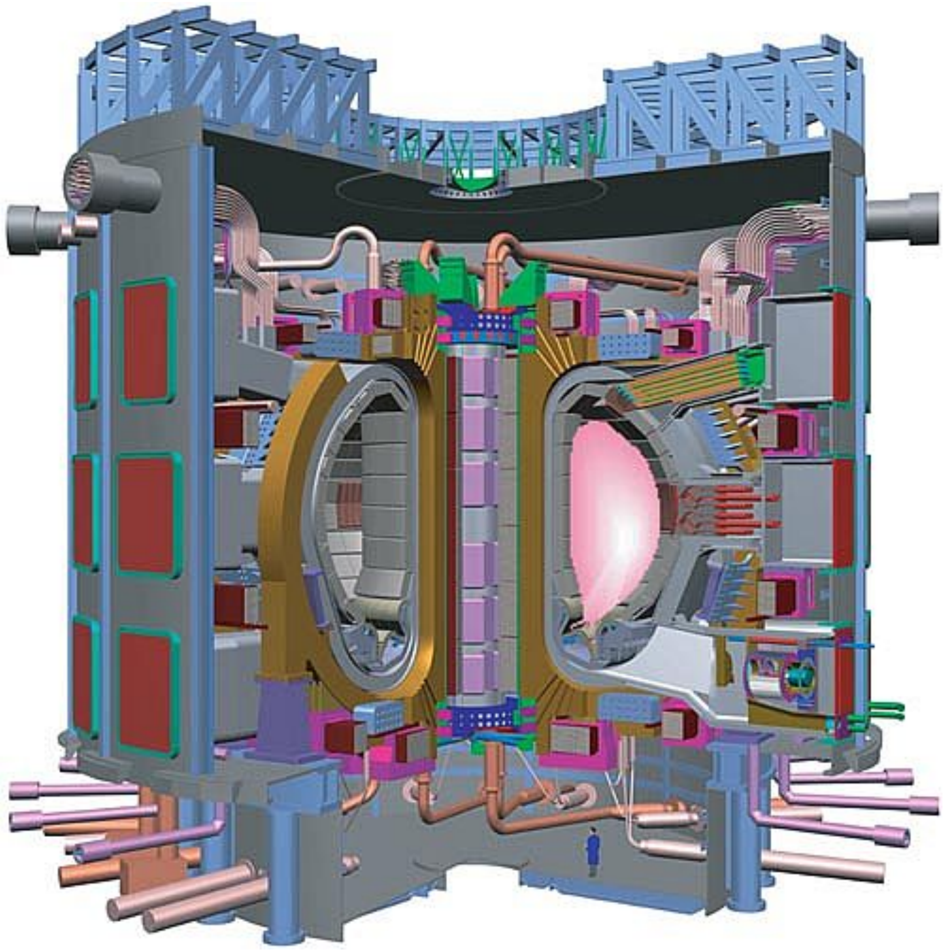
... is Mother Nature trying to tell us the right answer with these toroidal hot-spots?





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Erstmals gute Übereinstimmung mit den Rechnungen (YOC)

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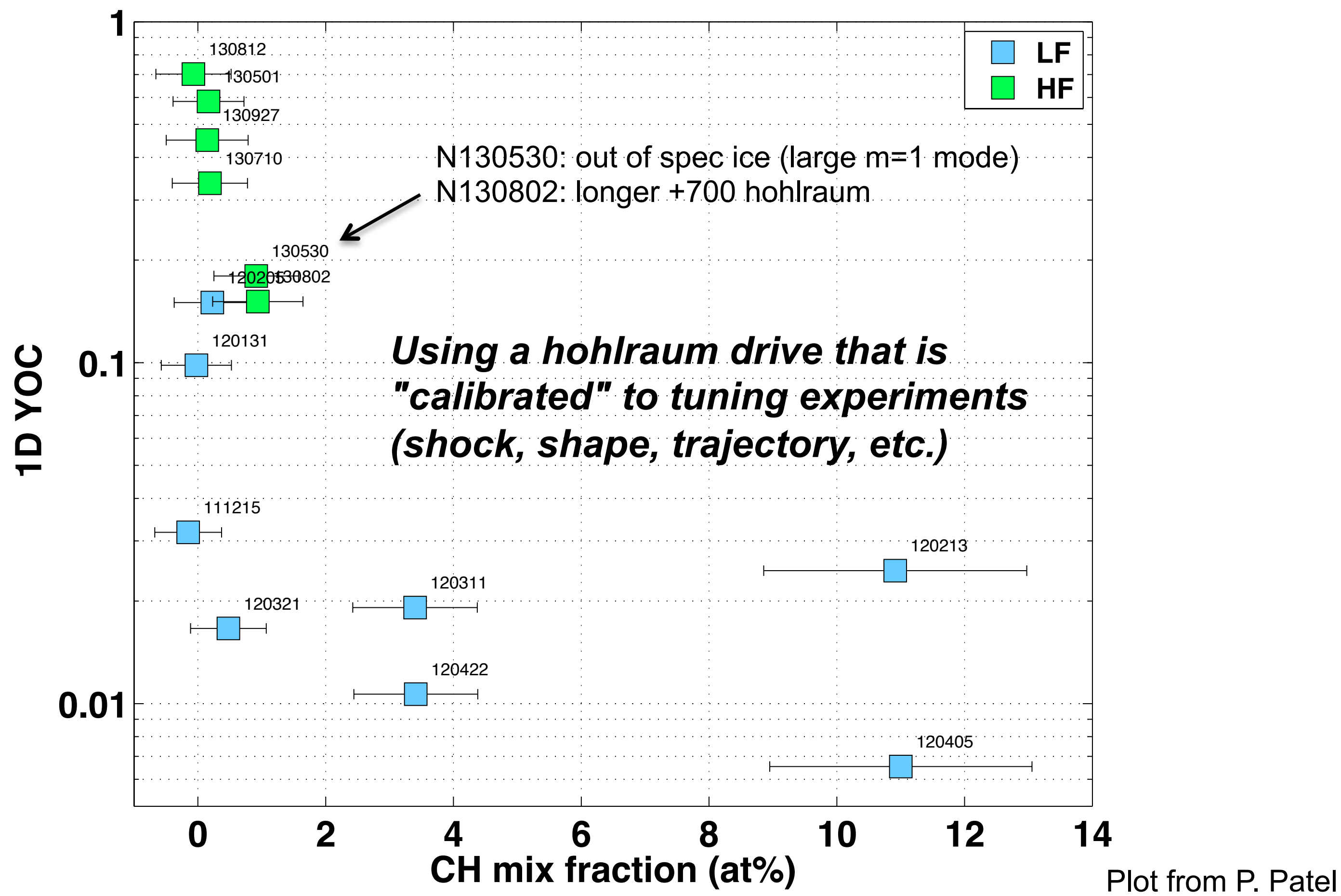
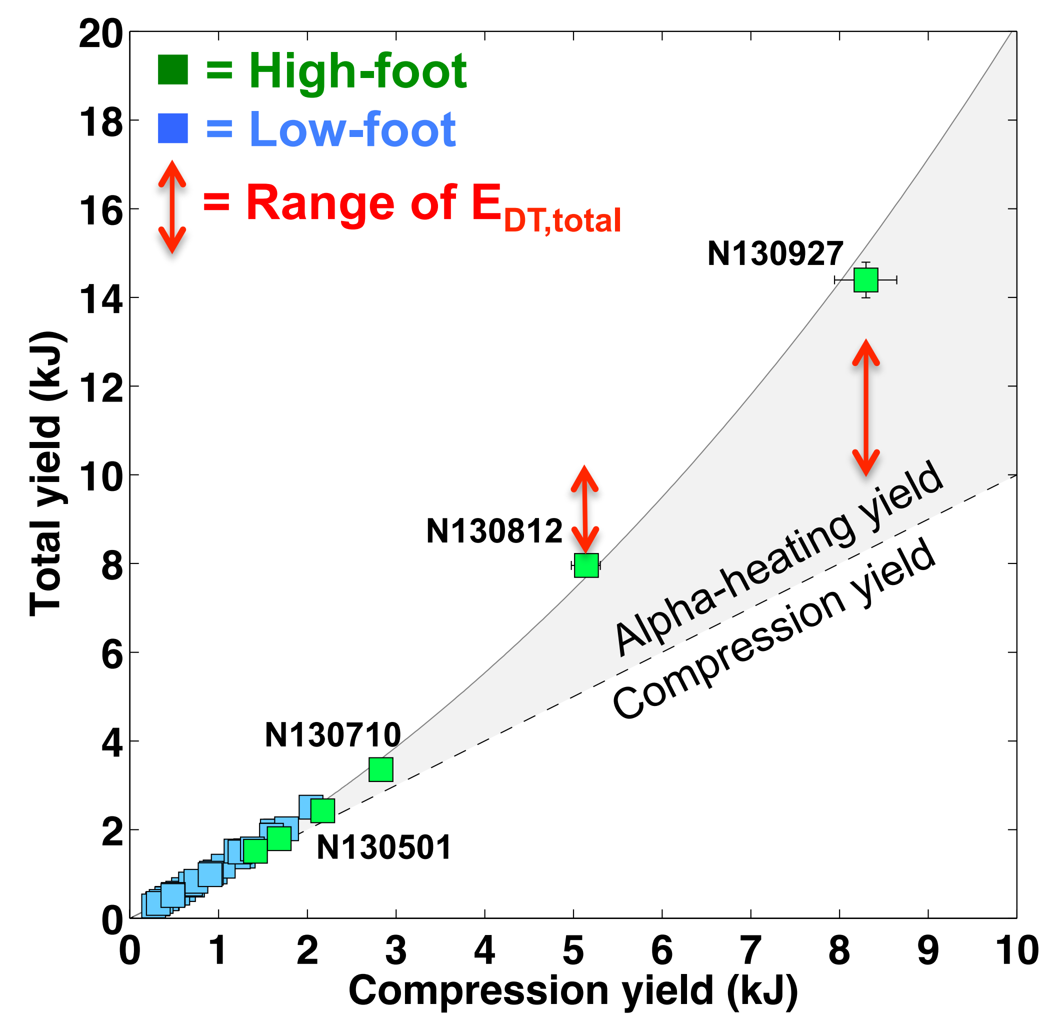


Plot from P. Patel

Beginn der alpha-Teilchen Heizung wird sichtbar



$E_{ablator\ absorbed}$ = 150 kJ

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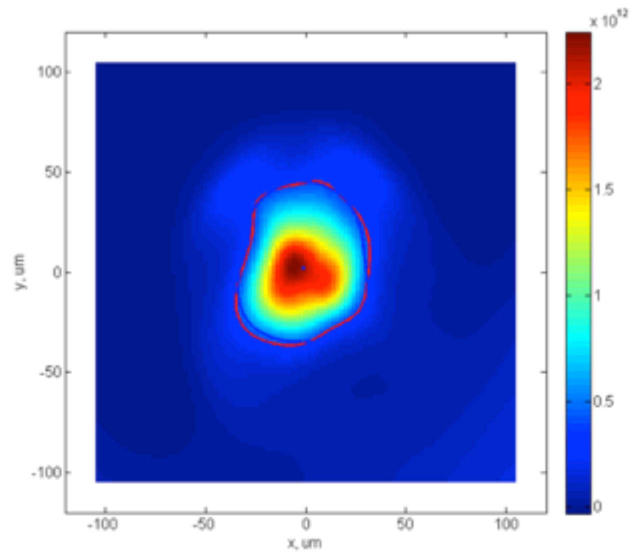
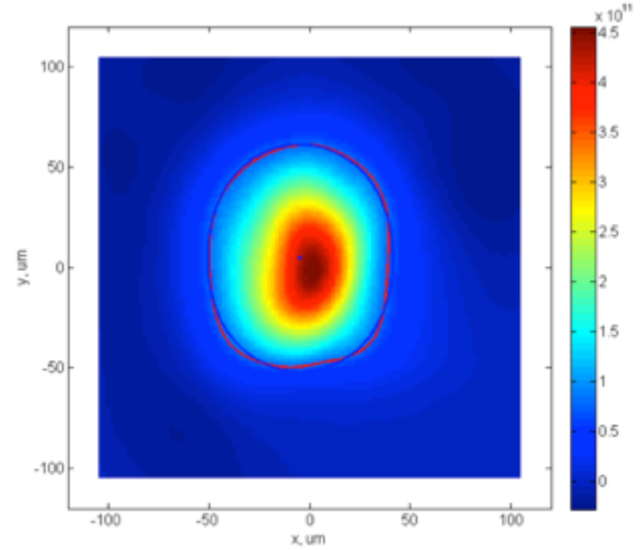
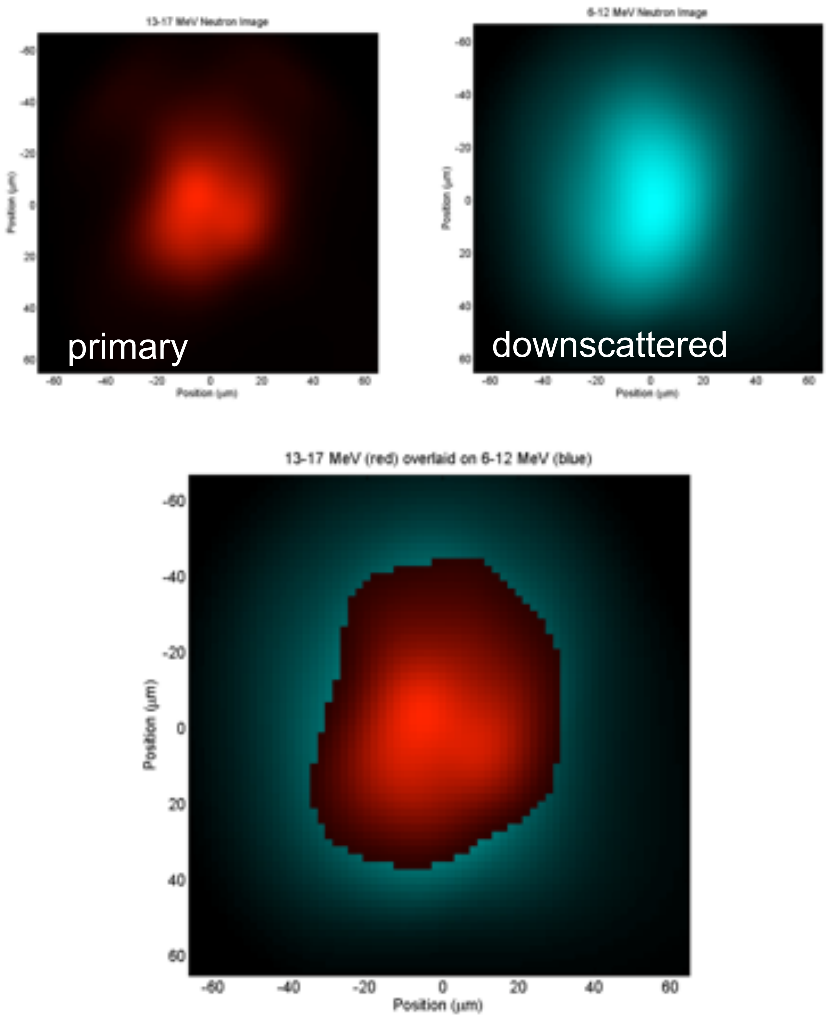
NIS zeigt Hotspot Form und Lage

13-17 MeV



6-12 MeV





Resultat seit der NATURE Veröffentlichung

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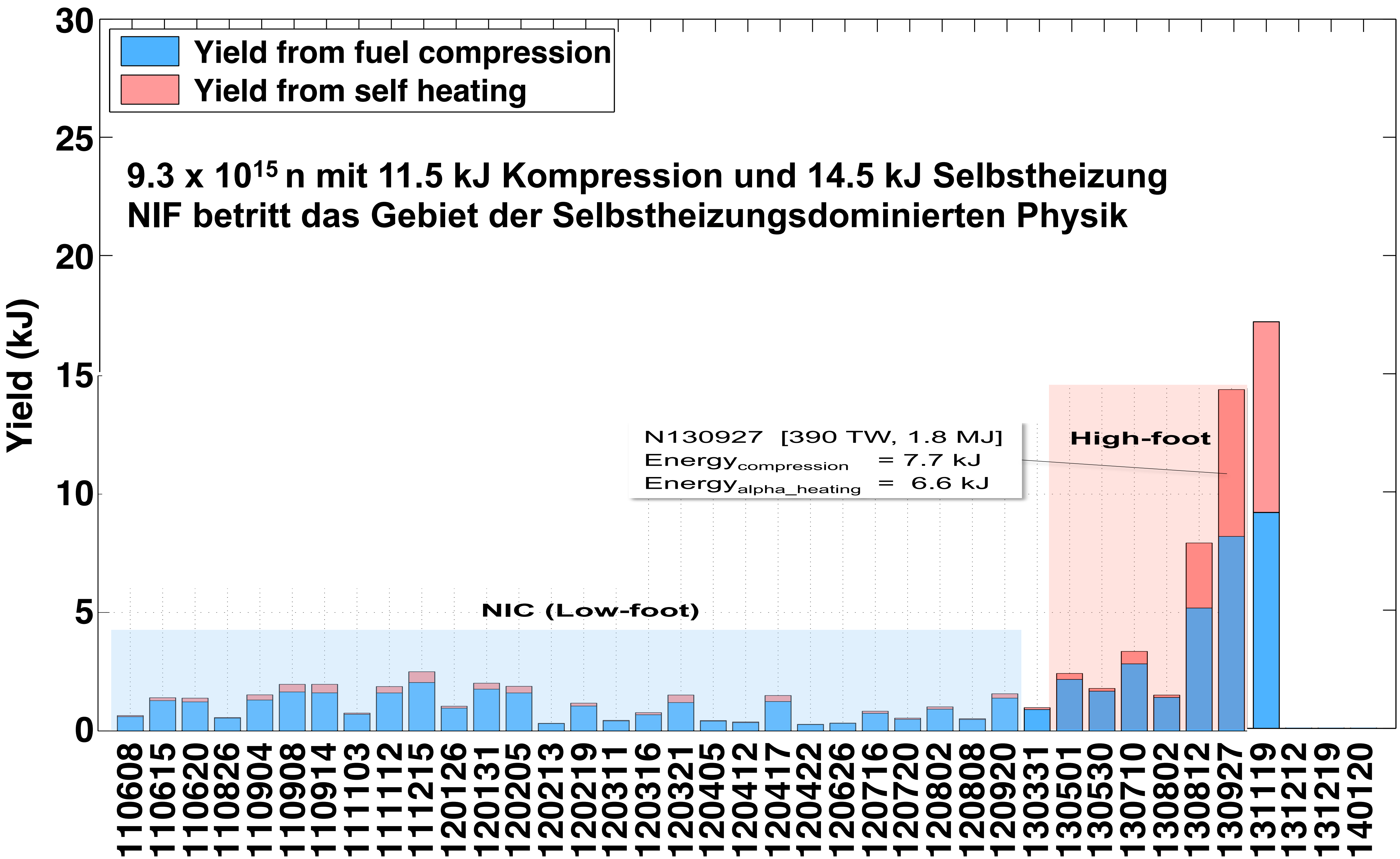

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Weitergehende Ansätze

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- Verbessertes Hohlraum Design (Rugby Hohlraum)
- Optimierter Energietransfer äussere zu innere Strahlen -> Form der Implosion
- Optimierte Adiabate (zwischen 2.6und 1.5)
- Diamant- Ablator, dünnerer Ablator
- Optimierte, isobarische Zündung (e.g. mit 2ω)
- Double shell (non-cryo solution?)
- Elektronen Fast Ignition (mit oder ohne Cone)
- Protonen Fast Ignition (2016?)

WARUM?
- kleinere Infrastruktur; höherer Gain;
- Verbesserte Toleranz gegen Laser/Target Nichtidealitäten
- Breitere Basis für Grundlagenforschung
- Möglichkeit Tritium zu vermeiden (oder zu reduzieren)

<u>Für jeden Fall zu untersuchen:</u>
- Pros/cons
- Facility (laser, targetry, delivery, reactor, waste)
- Level of confidence
- Compatibility between options (since confidence<1)
- Required R&D plan

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Als Fast Ignitor wird untersucht:
Elektronen, Protonen und Ionen, mit Konus und Schock-Ignition

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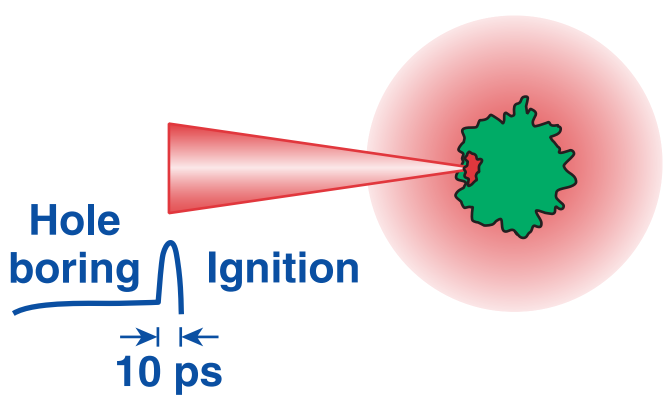
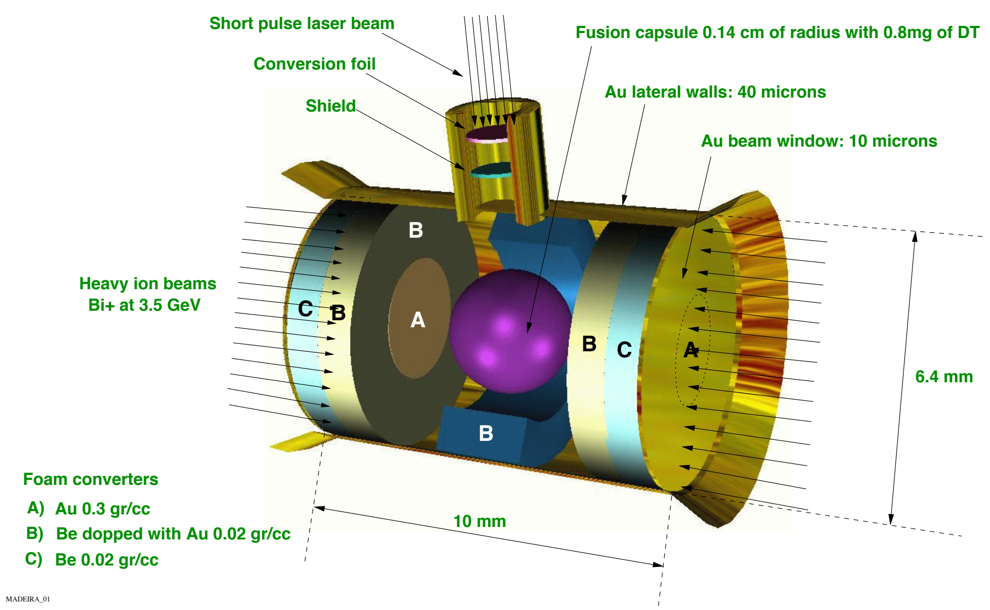
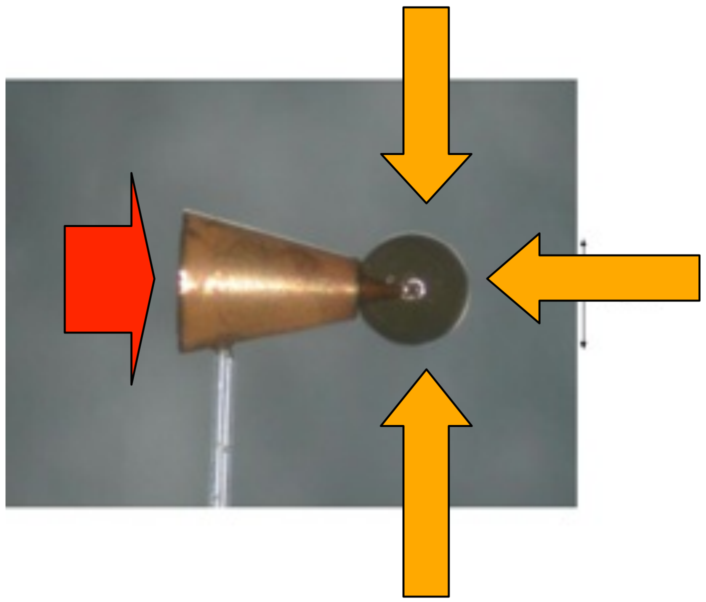
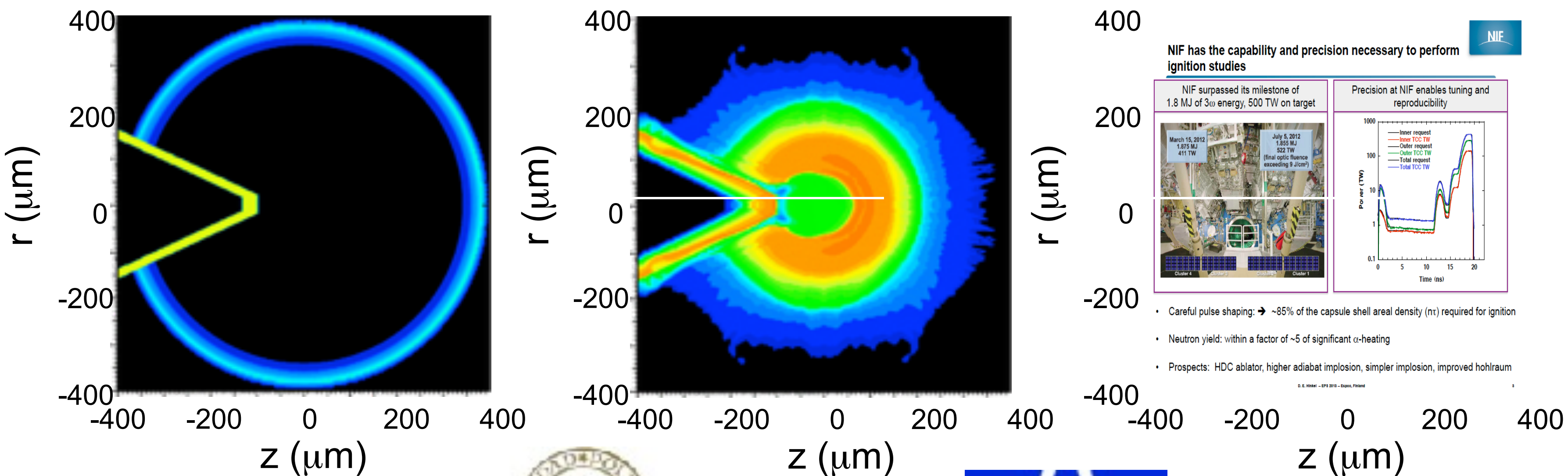
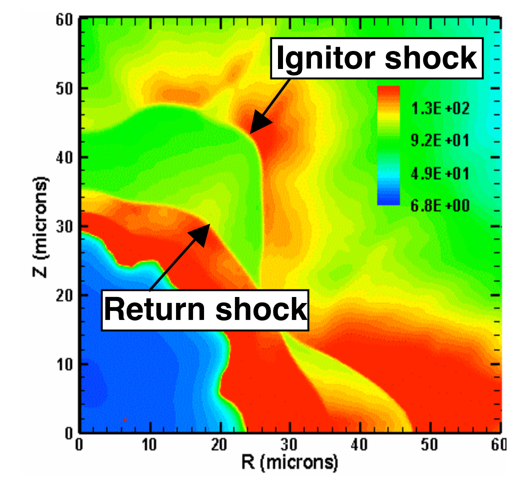
Channeling concept











Density contours at time of shock collision

Honrubia et al

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