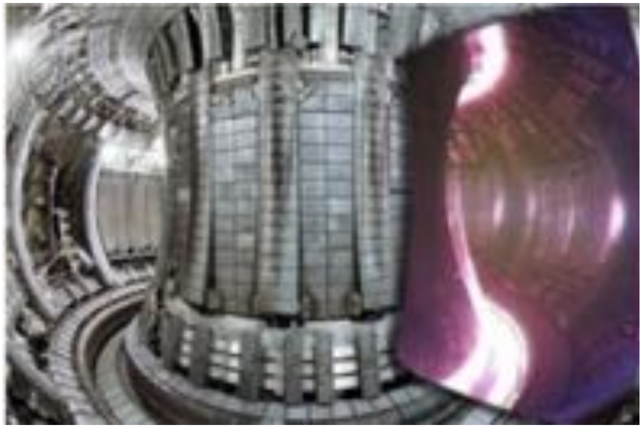
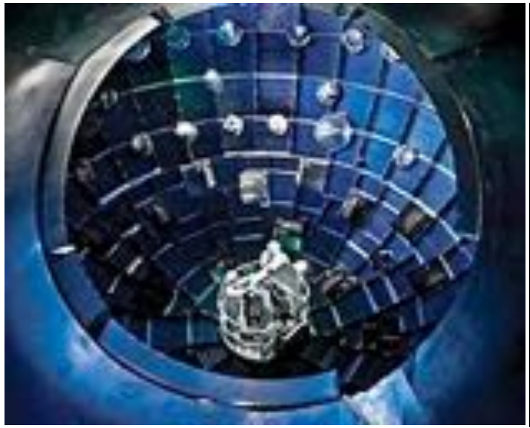
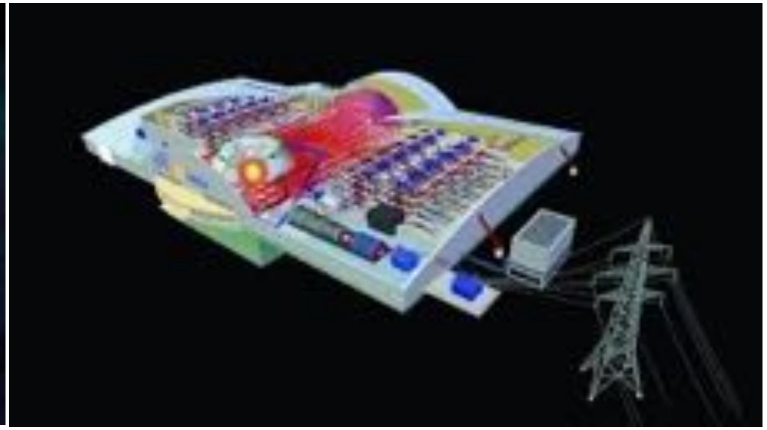
XXI Seminar on Software for Nuclear, Subnuclear and Applied Physics

9–14 Jun 2024, Hotel Porto Conte







Laser-Plasma Interaction Studies for Inertial Confinement Fusion

Leonida Antonio GIZZI
Consiglio Nazionale delle Ricerche
Istituto Nazionale di Ottica,
Pisa, Italy

CNR Campus in Pisa

CNR – Istituto Nazionale di Ottica

Intense Laser Irradiation Lab

Pisa, Italy

A node of the Italian ELI Network

A founding member of the EuPRAXIA ESFRI infrastructure

http://www.ilil.ino.it

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Federico AVELLA (PhD)
David GREGOCKI (PhD)
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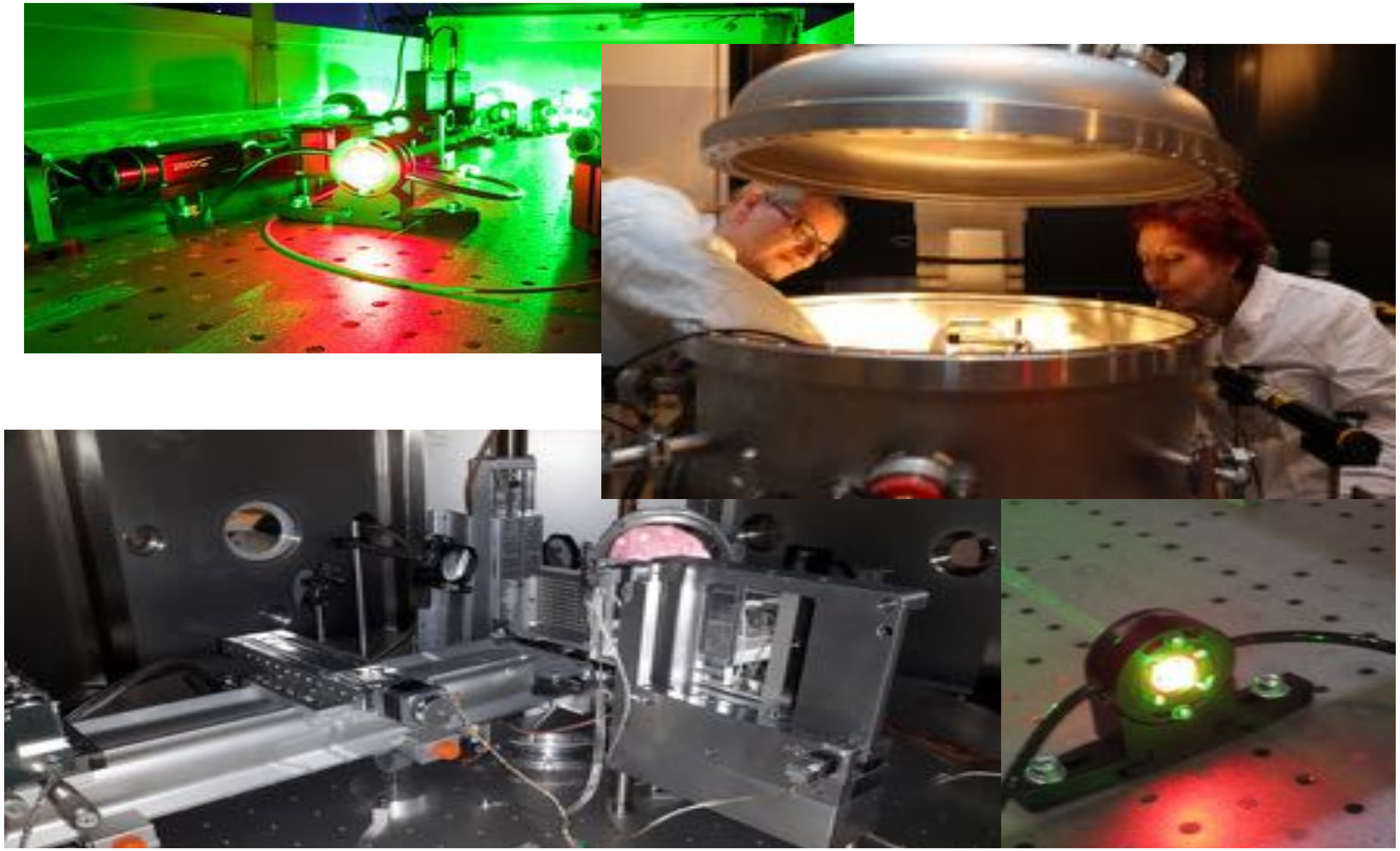

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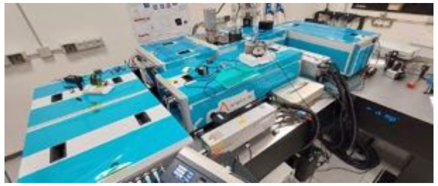

NEW HAP LASER DEV. LAB

LASER CAPABILITIES:

- 220 TW, Ti:Sa, 5 Hz, 27 fs (upgrade in progress);
- 1kHz, >20 mJ, Ti:Sa + OPA
- 100 Hz, >1J, TiSA (procurement in progress)

A member of Laserlab-Europe-AISBL

Laserlab Europe

USER CONTROL ROOM

TESTING AND PROTOTYPING

LASER FRONT END 10 TW, 10 Hz

POWER AMPLIFIER Up to 240 TW

SHIELDED TARGET AREA FOR PARTICLE ACCELERATION

NEW BEAMLINE for PRE-CLINICAL STUDIES

NEW HIGH DOSE UNDERGROUND BUNKER

THE Tuscany Health Ecosystem

iFAST

I-PHOQS INTEGRATED INFRASTRUCTURE INITIATIVE IN PHOTONIC AND QUANTUM SCIENCES

eli

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EuPRAXIA Advanced Photon Source

CONTENTS

- Recap on ICF status
- Physics of laser-plasma interactions
- Experimental platforms and Roadmap
- HiPER+ programme outlook
- Summary

CONTENTS

- **Recap on ICF status**
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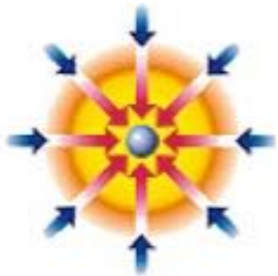
A LONG-LASTING JOURNEY

- The journey of nuclear fusion has started about 80 years ago (Sacharov, Teller, …) with many highs and lows;
- 60 years ago, the laser was invented, opening the field of "Inertial Confinement Fusion (ICF)" (Basov, Nuckolls, …);
- In December 2022, experiments performed at the National Ignition Facility (NIF) in the U.S. have demonstrated a "net energy gain" from an inertial confinement fusion (ICF) experiment;
- Today, for the first time in history, we have the demonstration of ignition, the scientific feasibility of laser fusion, which concludes the first part of this journey.

The original Direct Drive scheme*

Fase 1: irraggiamento tramite laser della capsula contenente DT

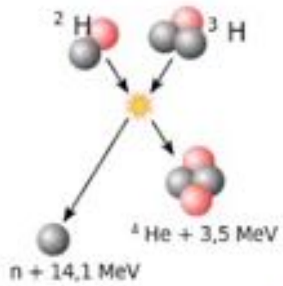
Fase 2: Compressione e riscaldamento



Fase 3: Ignizione della fusione

With ignition, the fusion process is self-sustaining with the heat generated by the fusion events themselves

Complete fusion of the fuel occurs for the short time during which the pellet remains compressed (inertia)

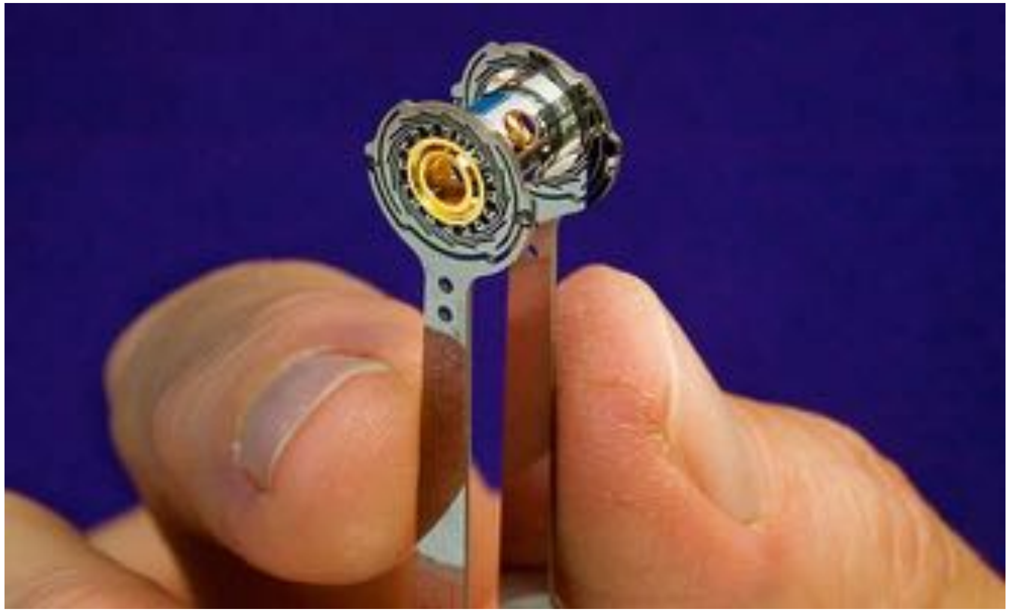


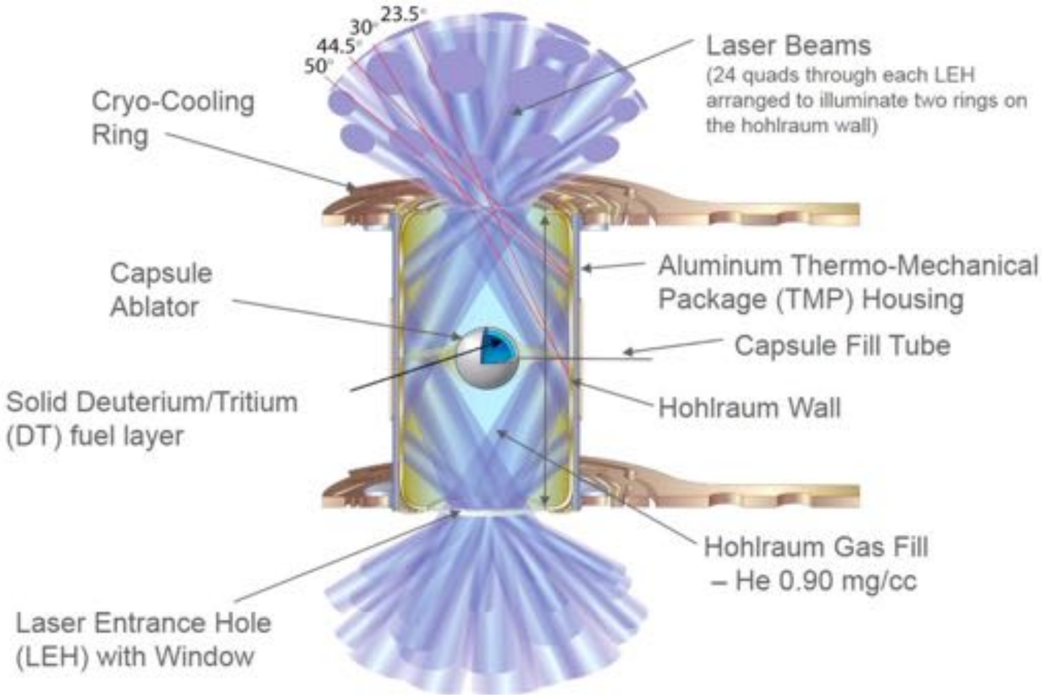
Fase 4: “Burn”

*N. G. Basov, O. N. Krokhin, and G. V. Sklizkov, in *Laser Interaction and Related Plasma Phenomena* (Springer, 1972), p. 389.
*J. Nuckolls, L. Wood, A. Thiessen, and G. Zimmerman, Nature 239, 139 (1972).

INDIRECT DRIVE

Configuration to overcome irradiation non-uniformities and seeding of Hydrodynamic instabilities

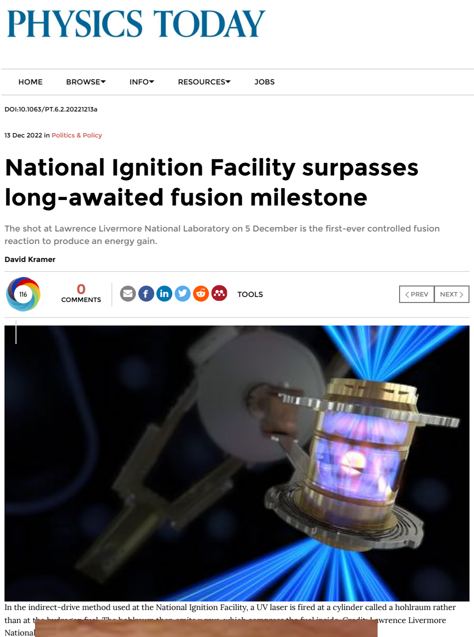




John Lindl; Development of the indirect-drive approach to inertial confinement fusion and the target physics basis for ignition and gain. *Phys. Plasmas* 1 November 1995; 2 (11): 3933–4024. https://doi.org/10.1063/1.871025

BREAKTHROUGH

In December 2022, experiments performed at the National Ignition Facility (NIF) in the U.S. have demonstrated a “net energy gain” from an inertial confinement fusion (ICF) experiment



PHYSICS TODAY

HOME BROWSE INFO RESOURCES JOBS

DOI:10.1063/PT.6.2.20221213a

13 Dec 2022 in Politics & Policy

National Ignition Facility surpasses long-awaited fusion milestone

The shot at Lawrence Livermore National Laboratory on 5 December is the first-ever controlled fusion reaction to produce an energy gain.

David Kramer

116 0 COMMENTS TOOLS PREV NEXT

In the indirect-drive method used at the National Ignition Facility, a UV laser is fired at a cylinder called a hohlraum rather than at t... National

Gain = 3.15MJ (fusion yield) / 2.05 MJ (laser input energy) = 1.54

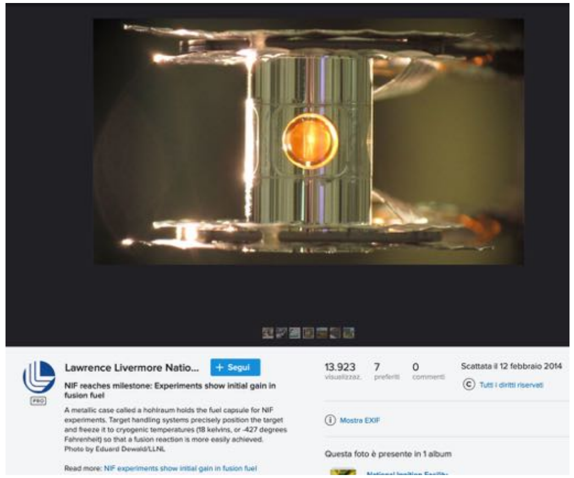
physicsworld

NUCLEAR FUSION | NEWS

National Ignition Facility demonstrates net fusion energy gain in world first

14 Dec 2022

Big gains: the record-breaking shot at the National Ignition Facility was made at just after 1 a.m. local time on 5 December. (Courtesy: LLNL)



Lawrence Livermore Natio... + Segui

NIF reaches milestone: Experiments show initial gain in fusion fuel

A metallic case called a hohlraum holds the fuel capsule for NIF experiments. Target handling systems precisely position the target and freeze it to cryogenic temperatures (18 kelvins, or -427 degrees Fahrenheit) so that a fusion reaction is more easily achieved. Photo by Eduard Dewald/LLNL

Read more: NIF experiments show initial gain in fusion fuel

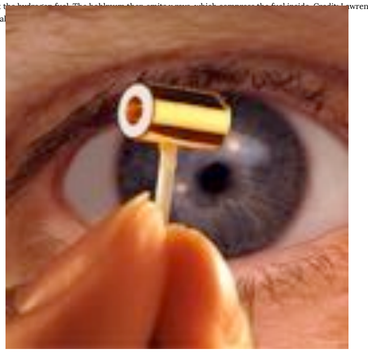
13.923 visualizzaz. 7 preferiti 0 commenti

Scattata il 12 febbraio 2014

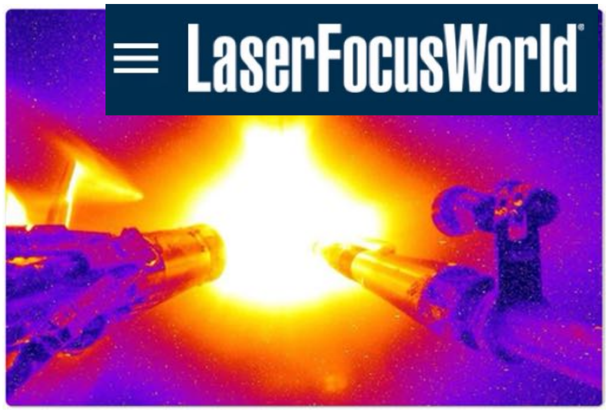
Tutti i diritti riservati

Mostra EXIF

Questa foto è presente in 1 album



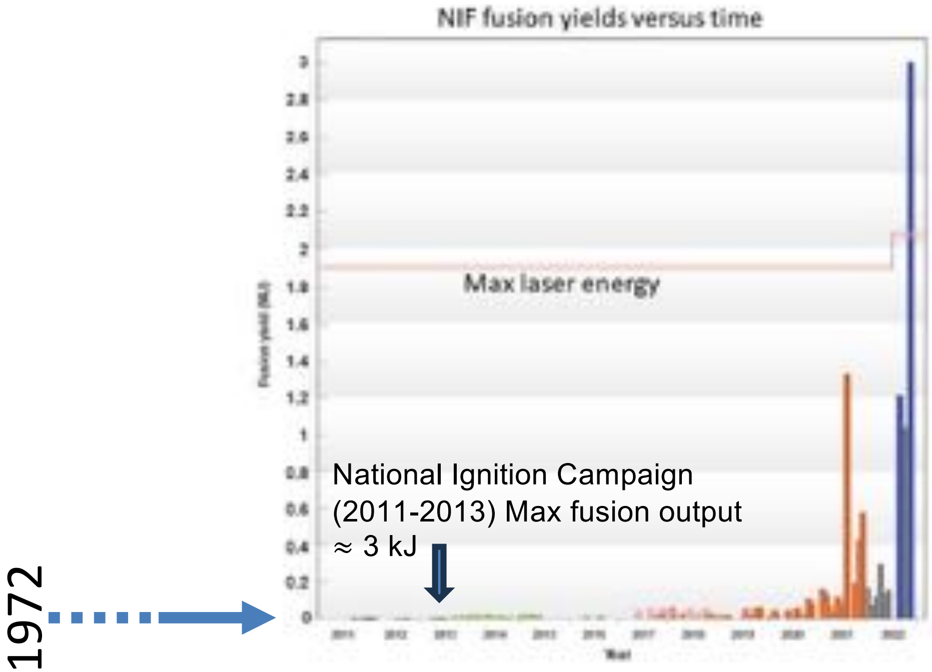
The US National Ignition Facility (target chamber shown) is the size of three American football fields. Credit: Lawrence Livermore National Laboratory



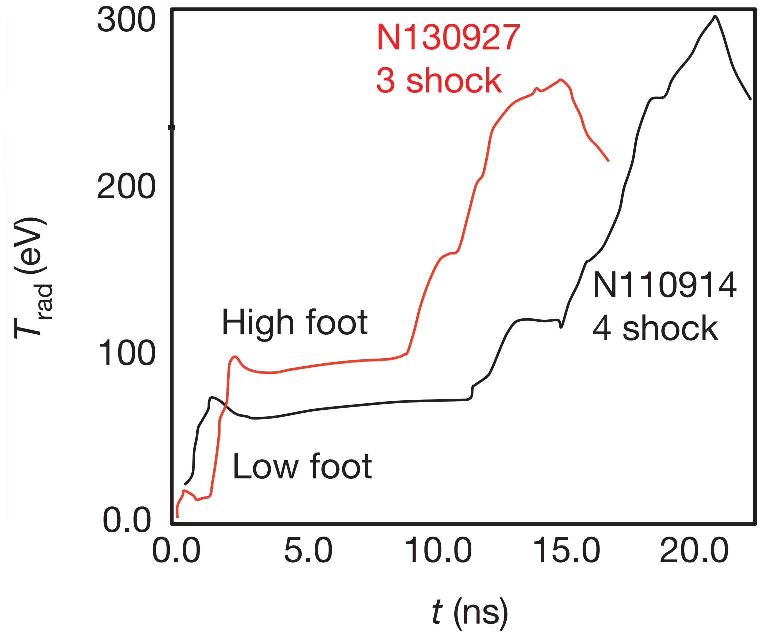
Colorized image of a NIF “Big Foot” deuterium-tritium (DT) implosion.

MAIN IMPROVEMENTS

LONG AND DIFFICULT WAY TO SUCCESS



"High foot" implosions

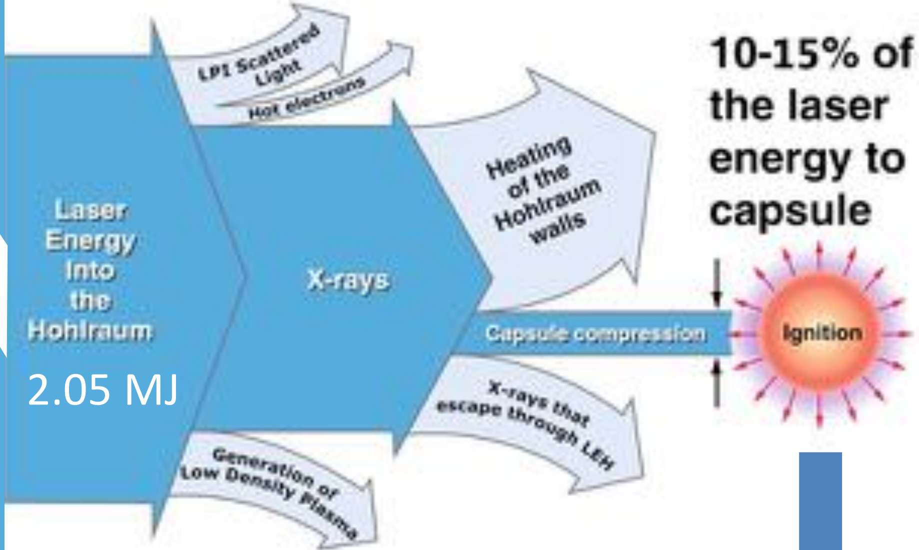


In addition to using higher foot, NIF result was obtained thanks to:
Different ablators (HDC: synthetic diamond)
Different gas pressure in the holhraum
Reduced holhraum size and bigger pellet
Improved radiation uniformity
Improved target quality (roughness)

ENERGETICS OF FUSION

Wall plug: 400 MJ

ICF (pulse: Energy)



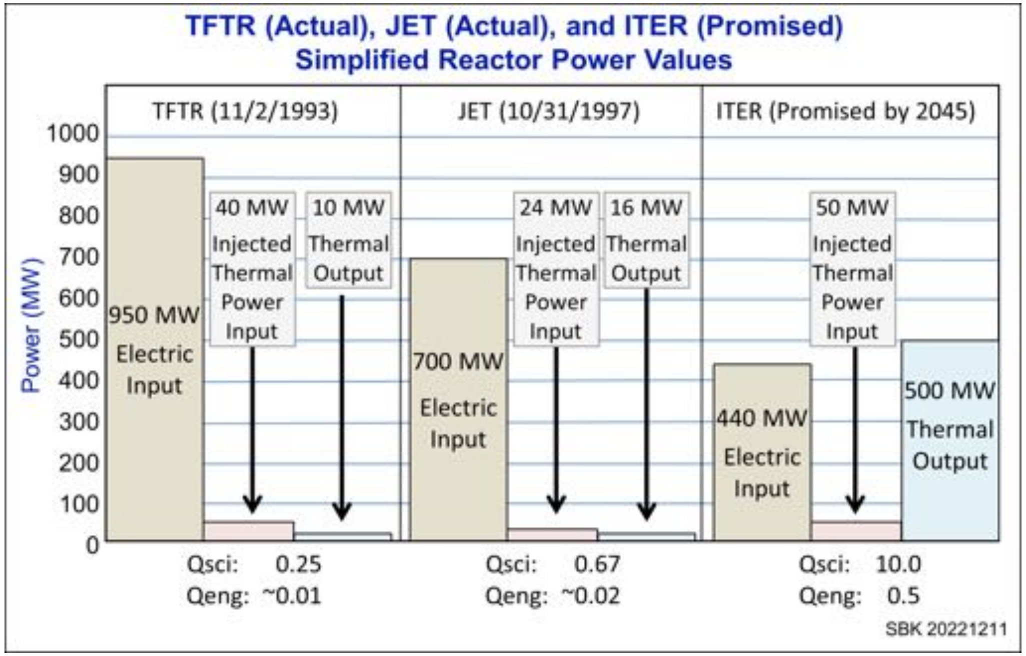
2.05 MJ

10-15% of the laser energy to capsule

3.88 MJ

Driver efficiency: 0.5%

MCF (CW: Power)



https://news.newenergytimes.net/

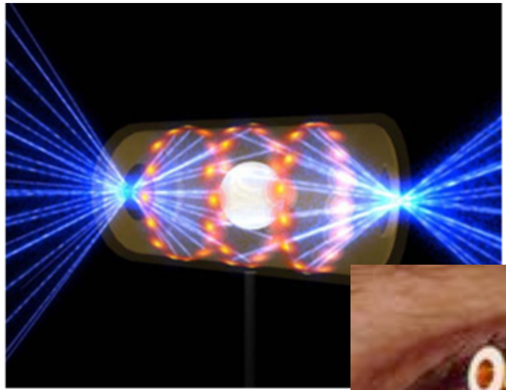
Driver efficiency: 2-3%, projected 11.4%

Driver efficiency of lasers still at the 1st generation: 20-40x improvement possible

MAJOR IMPACT OF NIF RESULTS

NIF results represent a breakthrough. However, INDIRECT DRIVE used at NIF **does not seem to be compatible** with requirements for future fusion reactors:

- Complex targets;
- Massive targets (lot of high-Z material in chamber);
- Intrinsic low gain due to step of X-ray conversion;
- “Political” issues due to the military/defense use.



It is now **timely** to go beyond NIF results:

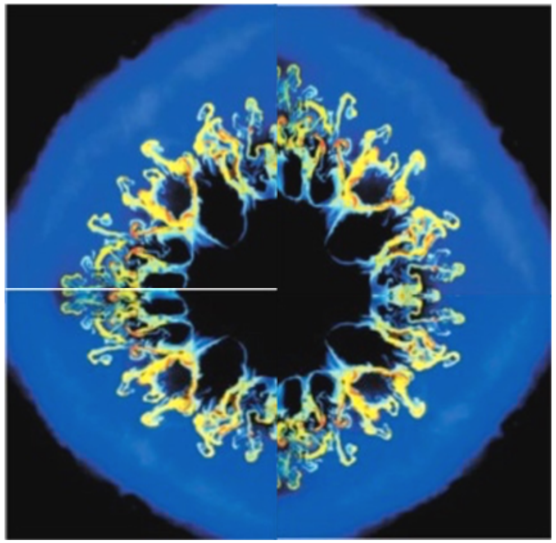
- Science: Investigate the original **DIRECT DRIVE** approach which can provide the gain needed for energy production
- Technology: Address the engineering issues related to IFE: **high repetition rate lasers**, **target development**, **damages to optics, tritium breeding**, …

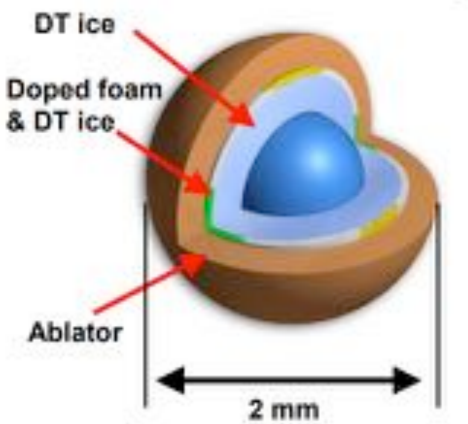
DIRECT DRIVE ICF

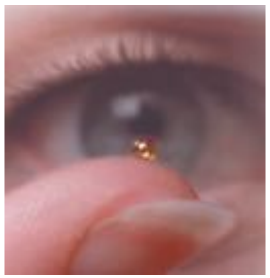
Pros:

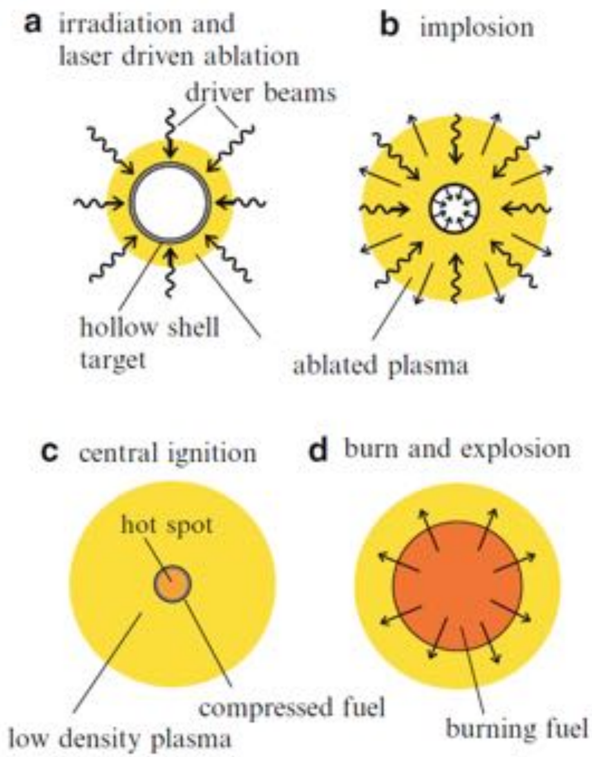
- Coupling efficiency 4-5% → we can compress larger mass capsules and we need lower pressures to get ignition 140 Gbar vs. 350 Gbar compared to ID
- simpler targets, potentially compatible with high-repetition rate operation for inertial fusion energy reactors.

Cons: Direct Drive is prone to hydro-instabilities (Rayleigh-Taylor) due to direct laser irradiation non-uniformities and target imperfections.









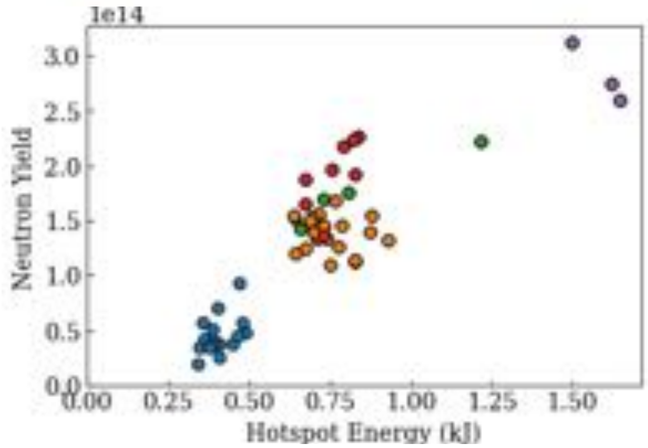
EXPERIMENTAL EVIDENCE OF DIRECT DRIVE

Recent experiments at **OMEGA (LLE, Rochester University, US)** show a steady progress in the **DIRECT DRIVE** experiments: recenty, increase of neutron yield by 10 times and energy coupling to the hot spot by 6 times (recent experiments used a **deep learning approach** to optimize implosions).

Laser direct drive experiments couple 3-6 times more energy to the hot spot compared to the NIF indirect drive experiments

However, we know that Direct Drive is more subject to the growth and the impact of **hydro instabilities** which distort the target during implosion and may finally break it

DIRECT DRIVE EXPERIMENTS AT OMEGA: 30 KJ



V. Gopalaswamy et al. Nature 2019
V. Goncharov EUROfusion seminar, 2022

Omega Laser
Laboratory for Laser Energetics
University of Rochester

MITIGATION STRATEGIES?

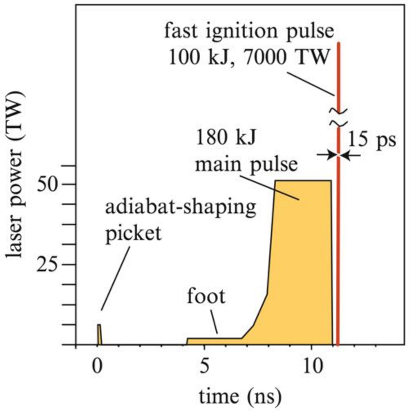
How to mitigate the impact of hydro instabilities in Direct Drive?

Separation of the compression phase and the ignition phase.

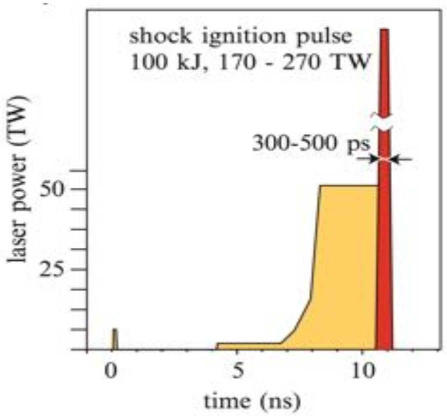
Options:

Fast Ignition exotic and non-scalable physics

requires $\geq 100\ kJ\ 10\ \mathrm{ps}$ laser facility ☹



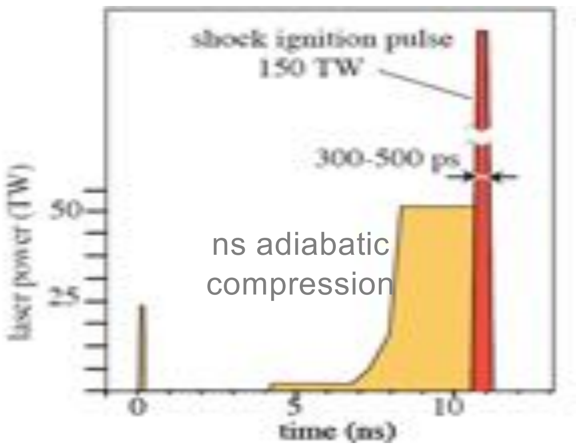
Shock Ignition compatible with present-day laser technology ☺

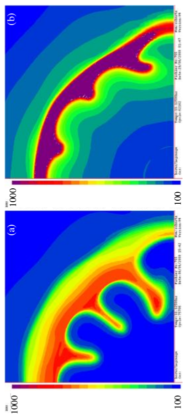


SHOCK IGNITION: BASICS

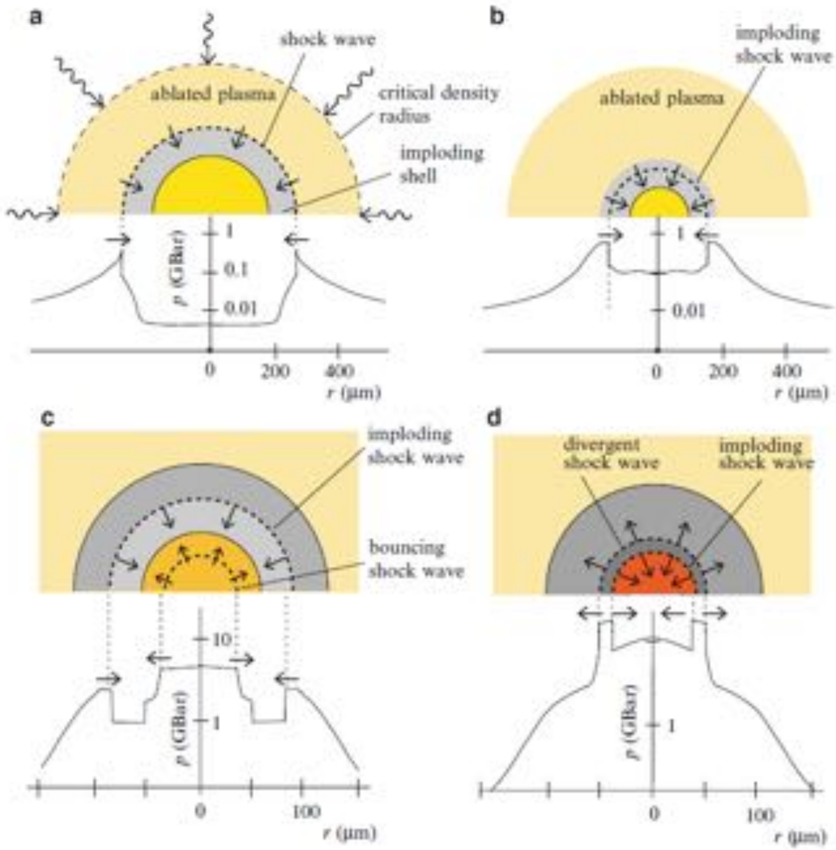
Scheme proposed by R. Betti, J.Perkins et al. [PRL 98 (2007)] and anticipated by V.A.Shcherbakov [Sov.J. Plasma Phys. 9, 240 (1983)];

- Separation of compression and ignition phase:
  - > Thicker and massive targets
  - > Lower implosion velocity ~240 km/s (vs. 350-400 km/s of DD hot spot ignition)
  - > Lower growth of R-T instability
- Strong shock at end of compression phase to generate hot spot (intensity: 10^{15}-10^{16} W/cm^2)
- Geometrical amplification of spherically converging shock (ablation pressure ≈300 Mbar)
- Higher gain possible



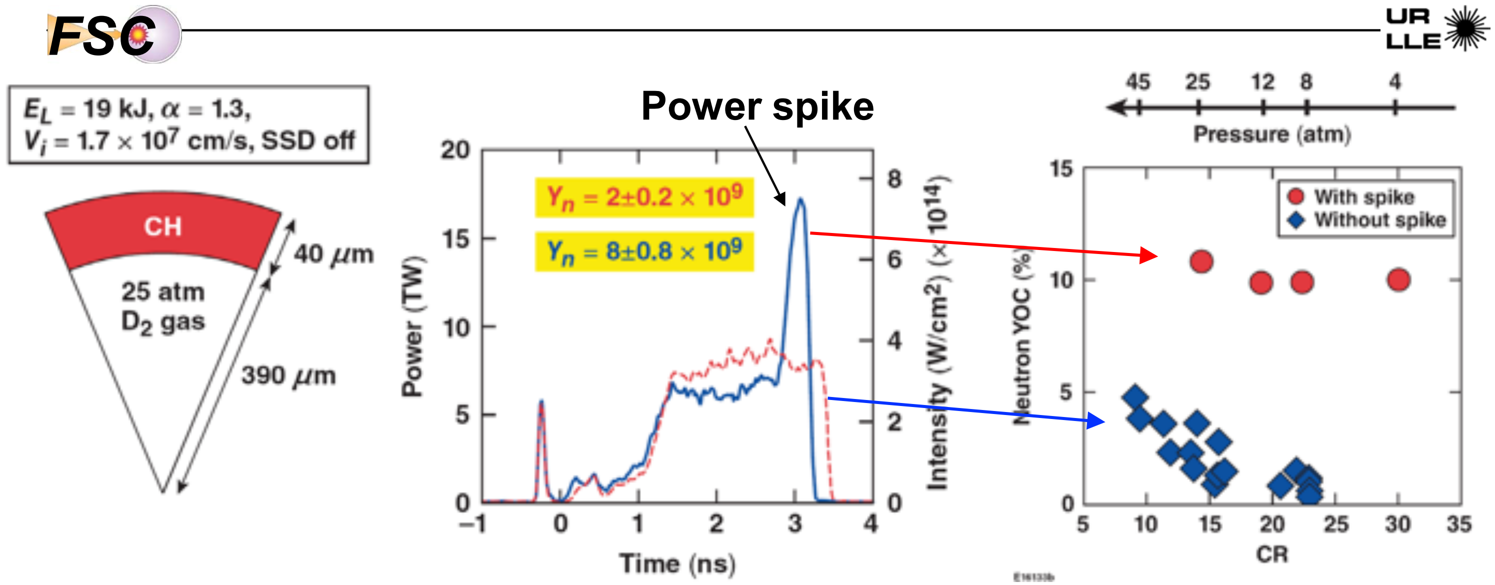


Phases of Shock Ignition ICF



EXPERIMENTAL EVIDENCE OF SHOCK IGNITION

Shock-ignition experiments on OMEGA have shown improved performance with a shock launching spike at the end of the laser pulse



The neutron yield increases considerably when a shock is launched at the end of the pulse.

The measured-to-calculated neutron-yield ratios are close to 10% for a hot-spot convergence ratio of 30.

W. Theobald,et al Phys. Plasmas (2008)

POSSIBLE EVOLUTION: SHOCK-AUGMENTED DIRECT DRIVE

Concept:

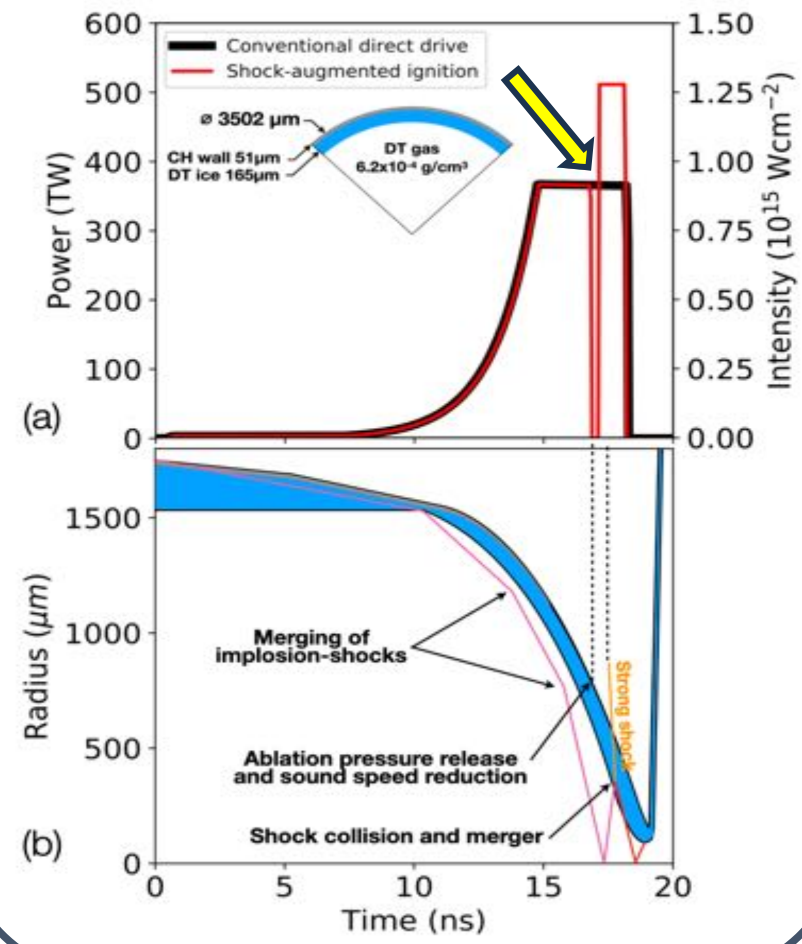
• Generate a very strong shock without very high power or intensity
• Mitigate the challenges related to parametric instabilities and hot electrons

Method:

• Dip in laser power: pre-conditions ablation plasma
• Rise in laser power: launches strong shock

Preliminary experiments done at Omega and NIF

R.Scott et al., *Physical Review Letters* (2022)



NEED OF LASER-PLASMA INTERACTION STUDIES

Physics issues to be understood:

- Plasma production and characterization
- Parametric instabilities in implosion-like and shock-ignition-like Laser-Plasma interaction;
  - ✓ Stimulated Brillouin Scattering (SBS)
  - ✓ Stimulated Raman Scattering (SRS), side SRS
  - ✓ Two Plasmon Decay
  - ✓ Cross-beam Energy Transfer (CBET)
  - ✓ Filamentation
  - ✓ Speckles from smoothing
- Hot electrons generation and their impact
- Acceptable degree of non uniformity in irradiation during compression / ignition phases
- Multiple beam irradiation
- Broadband and Chirped pulse irradiation
- Polar Direct Drive
- Hydrodynamics and Shock generation vs. Laser pulse profile
- Optimization of ablators for IFE targets
- Use of foam targets
- Diagnostics development including laser-driven secondary sources
- Comparison with advanced simulations tools (Hydro, PIC)

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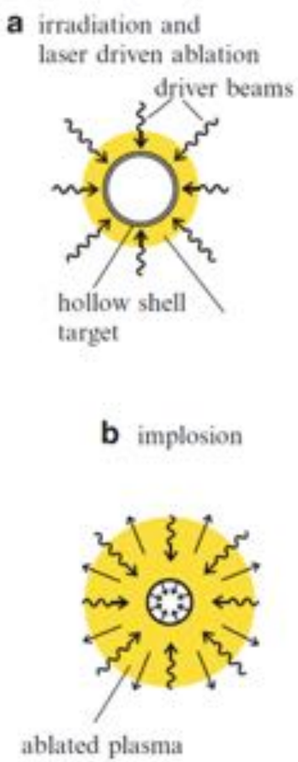
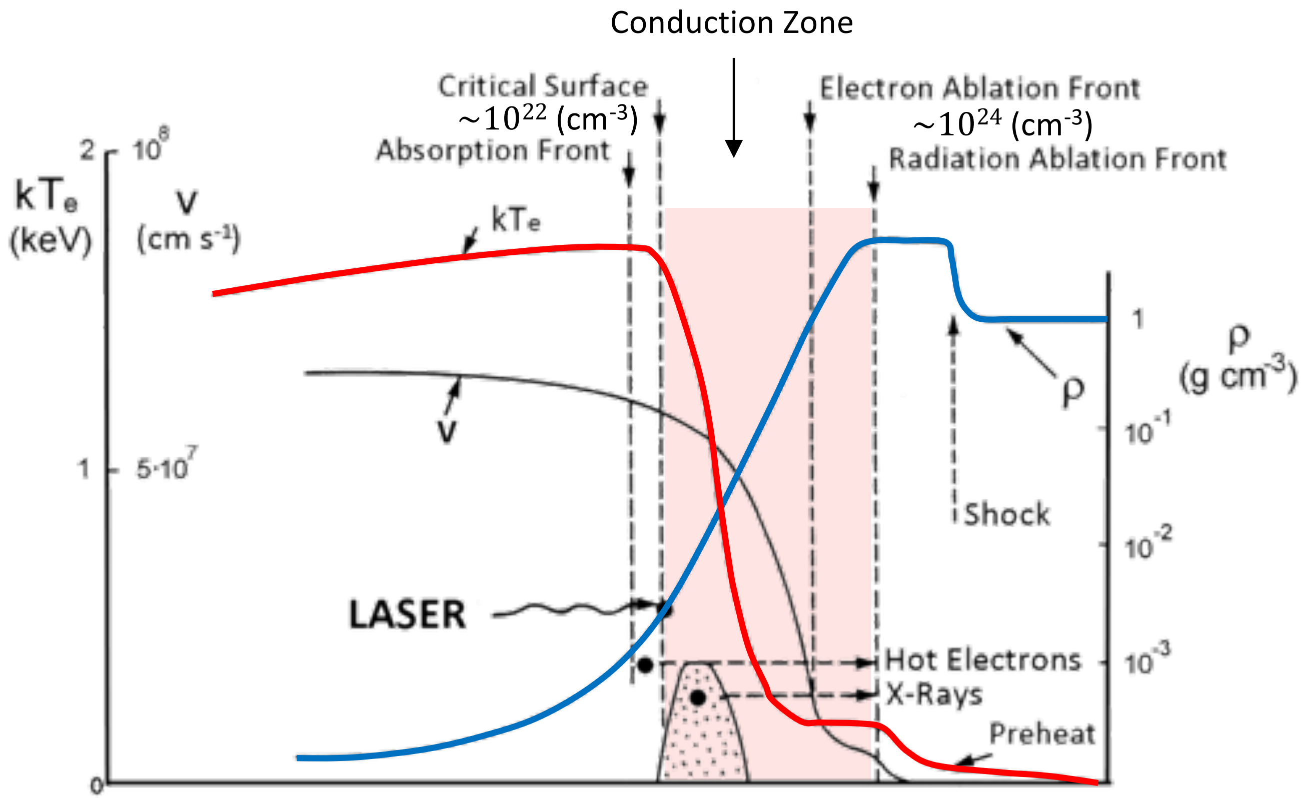
BASIC PICTURE

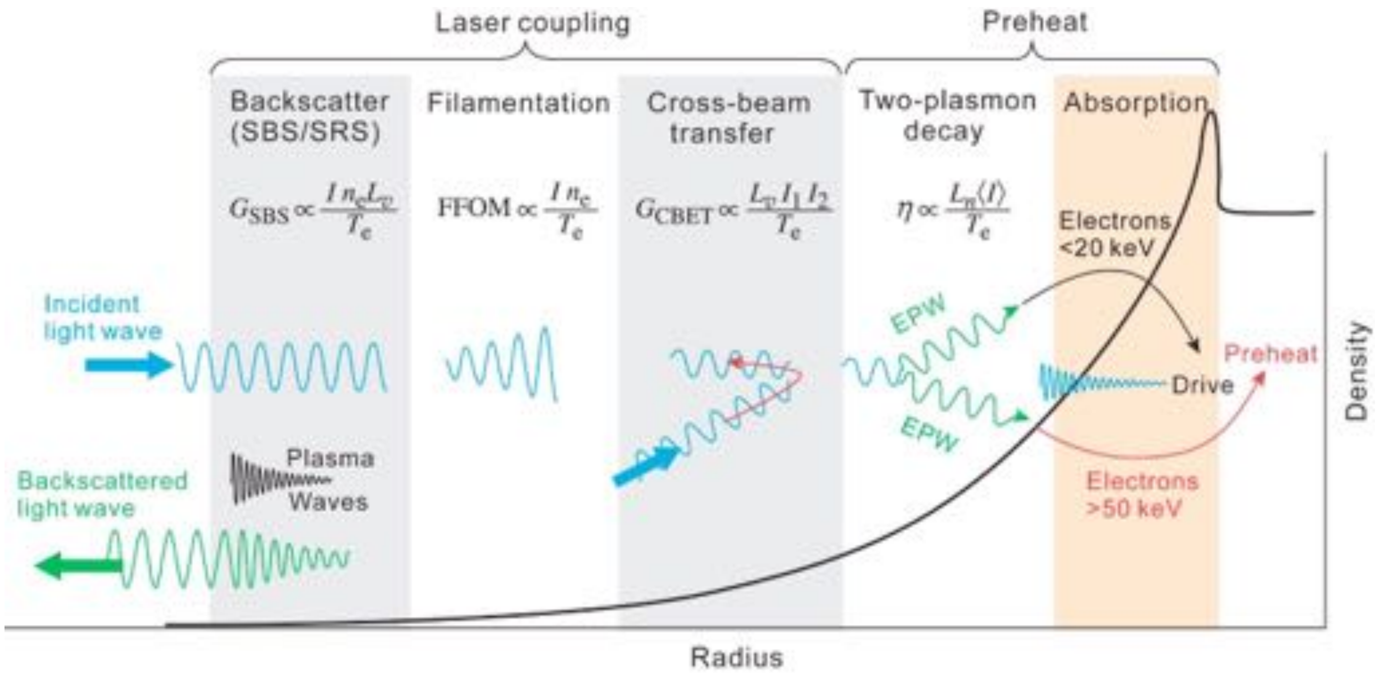




In a idealized ICF situation, laser light is absorbed by collisional absorption (inverse Bremsstrahlung) near the critical density surface $n_c(cm^{-3}) = 1.1 \cdot 10^{21}/\lambda_{\mu m}^2$ and successively the energy is transported to the ablation front, mainly via thermal electrons through the conduction zone.

$$n_c = \frac{m_e \omega^2}{4\pi e^2} \qquad (\omega_0 = \omega_p = 4\pi e^2 n_e/m_e) \qquad \frac{dI_L}{dz} = -k_{IB} I_L \qquad k_{IB} \propto \frac{Z(n_e/n_c)^2}{T_e^{3/2}(1 - n_e/n_c)^{1/2}}$$

LASER-PLASMA INTERACTION



Froula et al., Plasma Phys. Control. Fusion 54 (2012) 124016

In real ICF conditions, for $I\lambda^2_{\mu m} > 10^{14} W cm^{-2}$, many «**non collisional**» mechanisms – or parametric instabilities - are driven in the plasma corona, producing:

- the scattering of a significant percentage of laser energy (SRS, SBS)
- the unbalance of multiple laser beams irradiation (CBET)
- Small scale modulation of beam irradiation (filamentation)
- Suprathermal (or hot) electrons, produced by damping of SRS and TPD plasma waves, prehating the fuel

PARAMETRIC INSTABILITIES

- Parametric Instabilities are 3-waves coupling processes where the e.m. laser excites ion-acoustic or electron plasma waves
- Thresholds are given by the damping of daughter waves
- In inhomogeneous plasmas, the threshold of convective instabilities depends on the resonance region ($\nabla n, \nabla$v)

$$\omega_1 = \omega_2 + \omega_3$$
$$\vec{k}_1 = \vec{k}_2 + \vec{k}_3$$

Stimulated Raman Scattering (SRS)

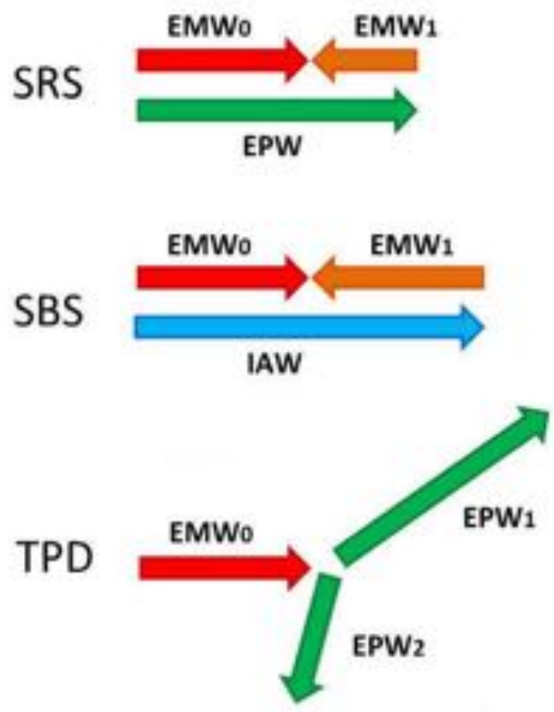
absolute	convective
~10^{14} W/cm^2	~10^{15} W/cm^2

Stimulated Brillouin Scattering (SBS) & Cross Beam Energy Transfer (CBET)

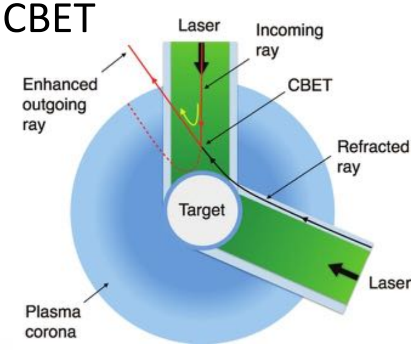
~10^{14} W/cm^2

Two Plasmon Decay

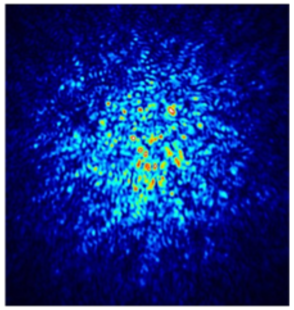
~10^{14} W/cm^2

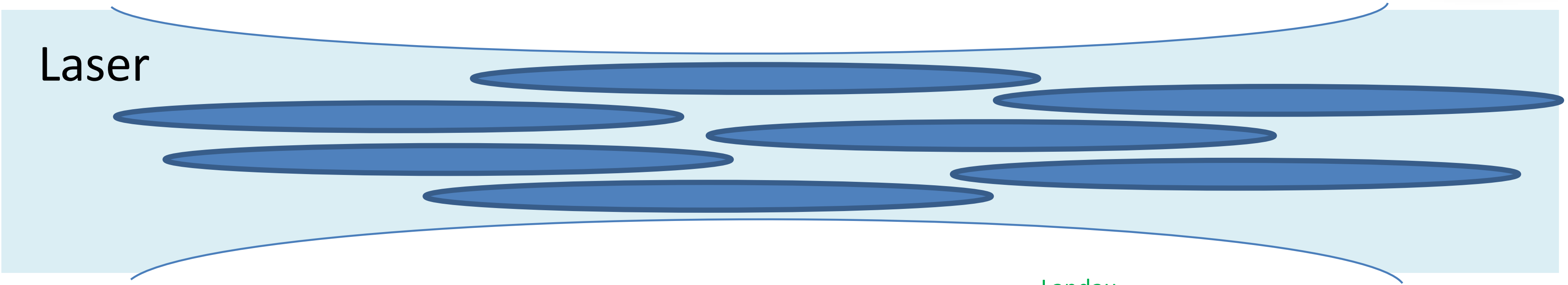


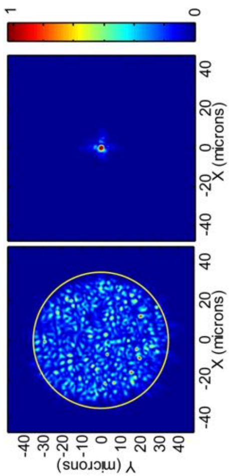
CBET



BEAM SMOOTHING WITH PHASE PLATES







Speckle size

$\lambda_{\perp} \approx 1.2F\lambda_0 \qquad \lambda_{\parallel} \approx 8F^2\lambda_0$

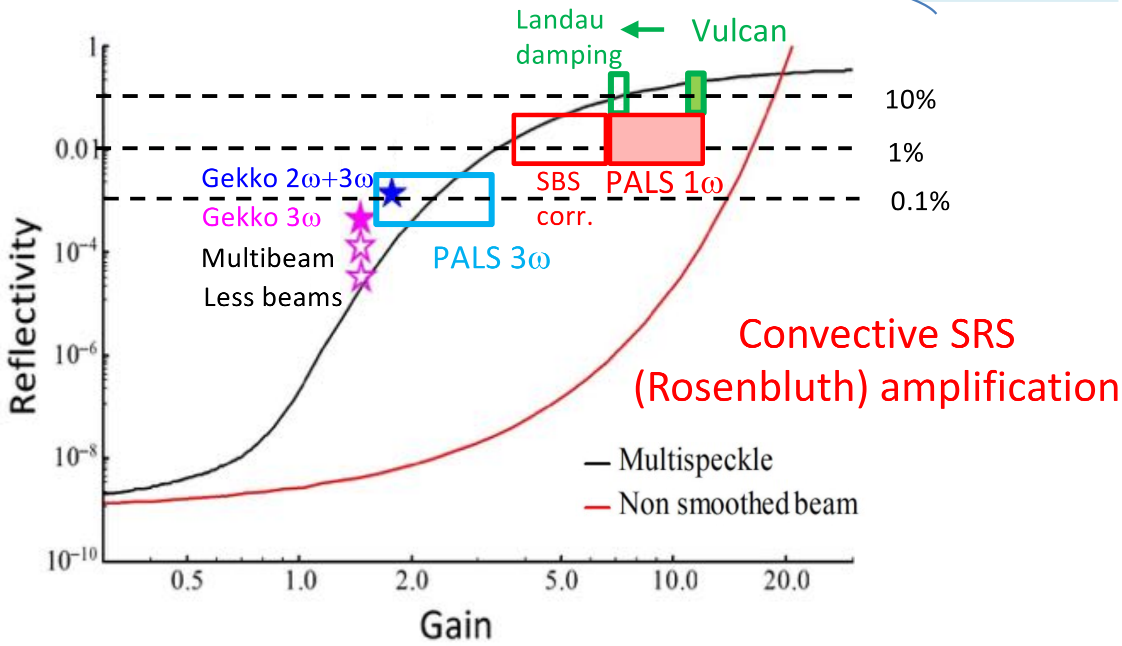
for F=10 and λ=0.355 nm

$\lambda_{\perp} \approx 4.2\ \mu m \quad \lambda_{\parallel} \approx 280\ \mu m$

Intensity distribution

$u = I_{sp}/\langle I \rangle \qquad f(u) \propto u e^{-u}$

High-energy tail up to $\approx 10\langle I \rangle$

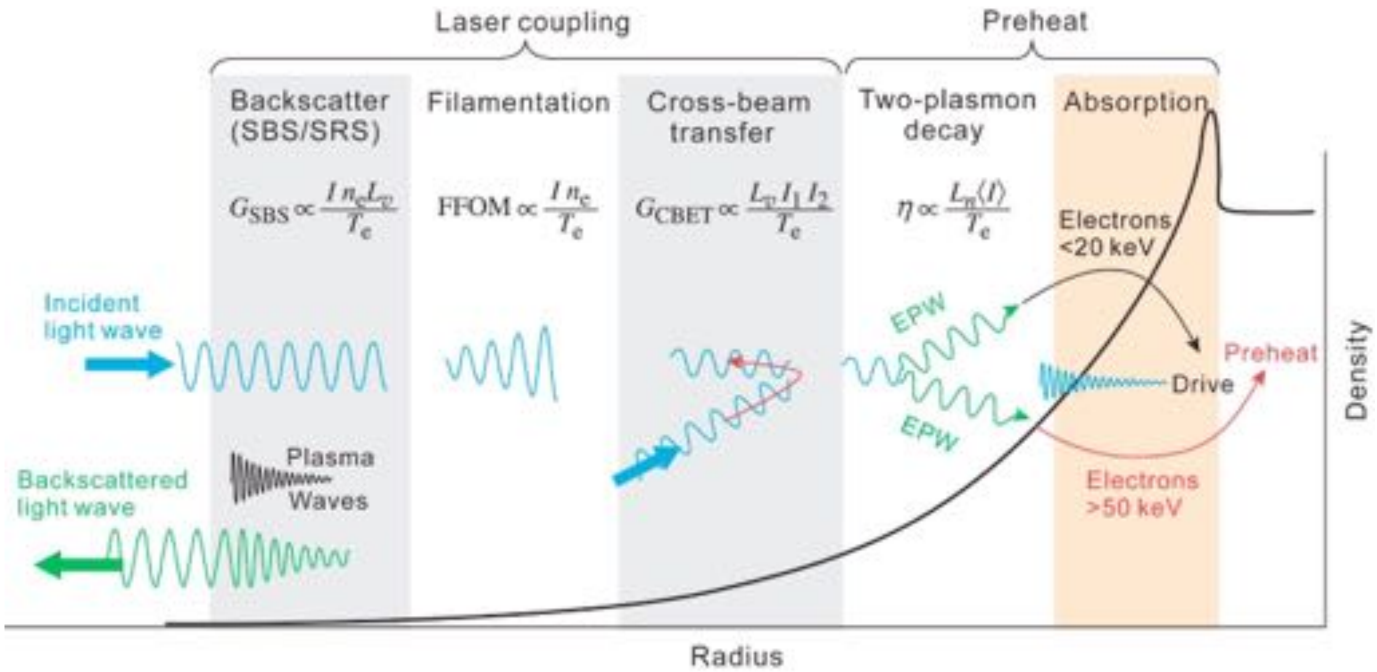


We need a multispeckle model, including local intensity and saturation

For more info see *G. Cristoforetti et al., High Power Laser Science and Engineering*, (2021), Vol. 9, e60

SHOCK IGNITION: PARAMETRIC INSTABILITIES

Laser-Plasma Interaction of ignition pulse (10^{15}-10^{16} W/cm^2) is dominated by **parametric instabilities** including Stimulated Brillouin Scattering (SBS), Stimulated Raman Scattering (SRS) and Two Plasmon Decay (TPD) – and filamentation.



Froula et al., Plasma Phys. Control. Fusion 54 (2012) 124016

energy is backscattered by SRS/TPD and SBS (up to ~40-50%) **-** can increase laser energy requirements

SRS and TPD generate **fast electrons**, that can preheat the fuel and/or affect the shock pressure

Is it possible to turn off or limit the growth of LPI ?

(Laser coherence manipulation, Broadband laser, comb diode lasers…)

ROLE OF LASER BANDWIDTH ON LPI

One way of controlling or modifying instabilities consists in increasing the bandwidth, i.e. reducing the longitudinal coherence time of the driving laser pulse;

The role of bandwidth was extensively investigated in the past at implosion-like laser intensities (≈1E14) and large underdense plasmas, as temporal and spatial smoothing;

The ruling parameter in homogeneus plasmas is $\gamma_o / \Delta\omega_L$ where γ_o is the growth rate of the instability and $\Delta\omega_L$ is the laser bandwidth

J.J. Thomson and J.I.Karush, The Physics of Fluids **17**, 1608 (1974)

In inhomogeneous plasmas the effect is partially compensated by the broadening of the coupling region.

P. N. Guzdar, et al., Phys. Fluids B **3**, 2882 (1991).

Bandwidth can still limit amplification gain of instabilities arising from filamentation seeded by laser speckles (RPP) and self-focusing.

H. A. Rose, Phys. Plasmas **2**, 2216 (1995).

Recent numerical simulation studies show universal scaling of the instability threshold intensity with the laser coherence time

K. Follet et al., Phys. Plasmas 26, 062111 (2019);

CONTENTS

- Recap on ICF status
- Physics of laser-plasma interactions
- **Experimental platforms and Roadmap**
- HiPER+ programme outlook
- Summary

EXPERIMENTAL ROADMAP TOWARDS SHOCK IGNITION IFE

How to approach the final goal of "Performing shock ignition demonstration experiments" ?

Planar Geometry

"Physics" Issues:
- Parametric instabilities
- Role of hot electrons
- Shock Formation

"Hydro" Issues:
- Smoothing
- Hydro instabilities

Spherical Geometry

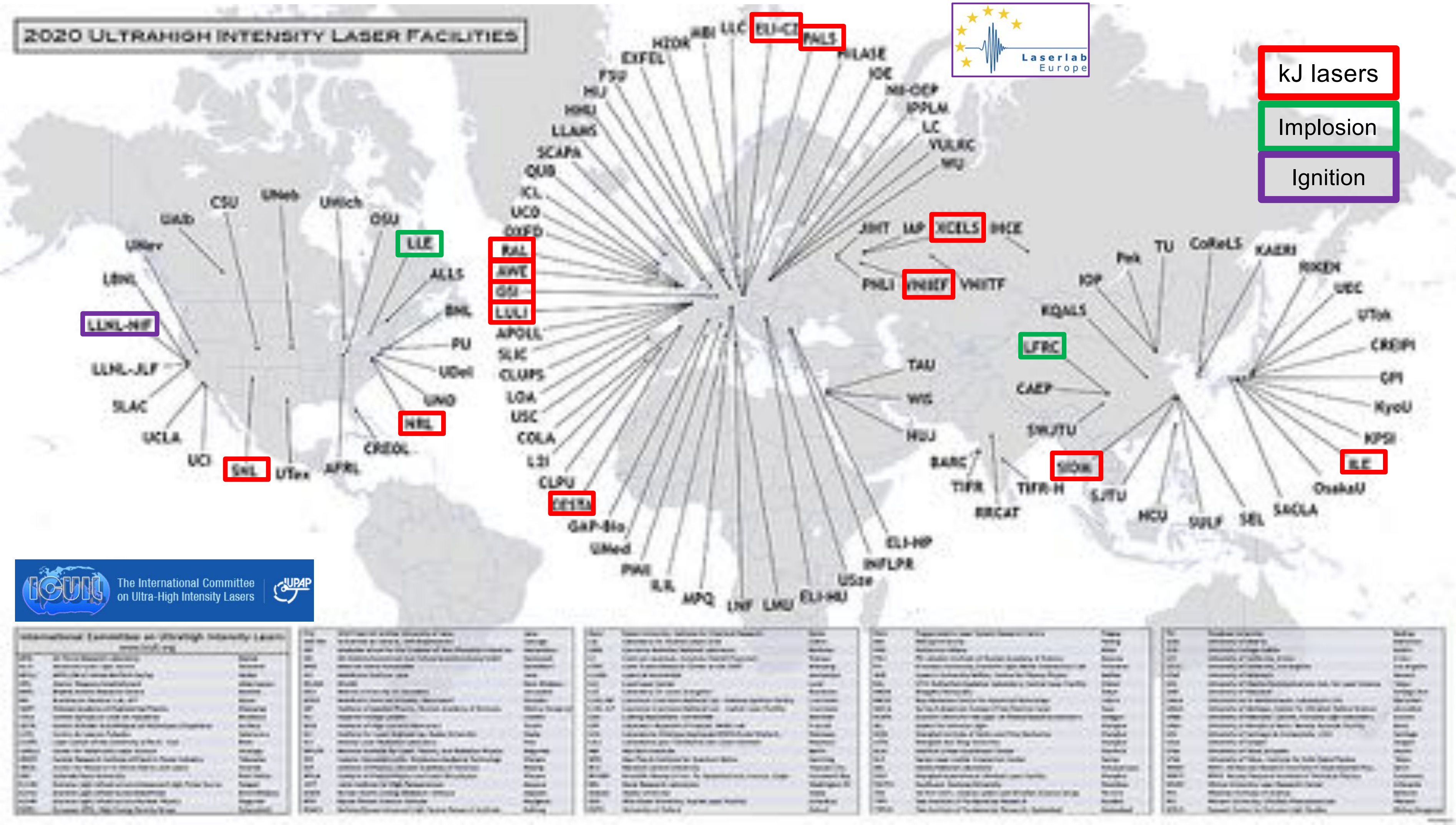
"Physics" Issues:
- Parametric instabilities
- Role of hot electrons
- Shock Formation

"Hydro" Issues:
- Smoothing
- Hydro instabilities
- Implosion
- Uniformity control for implosion

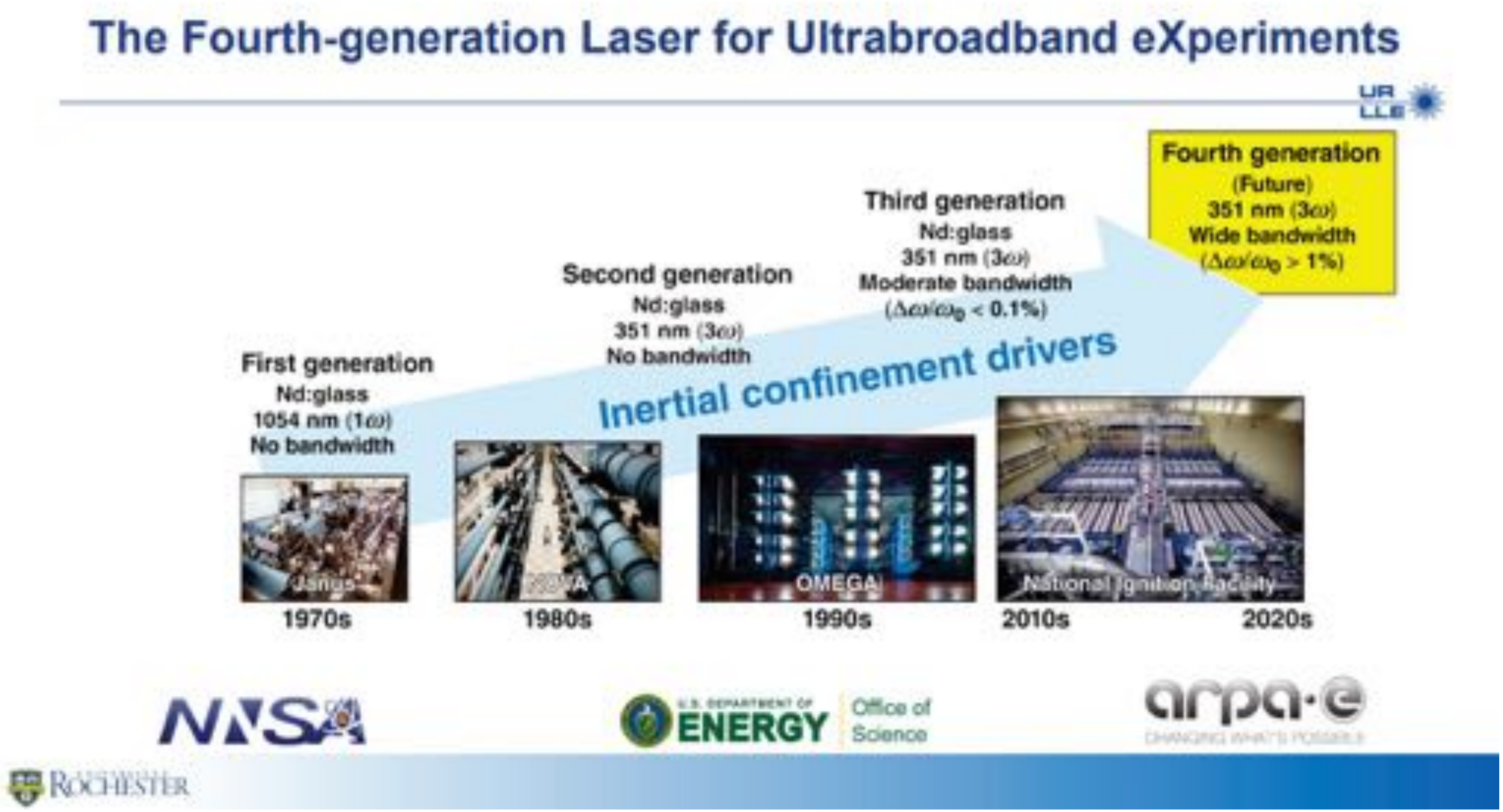
Demonstration of PDD

Demonstration of Shock Ignition

LASER FACILITIES

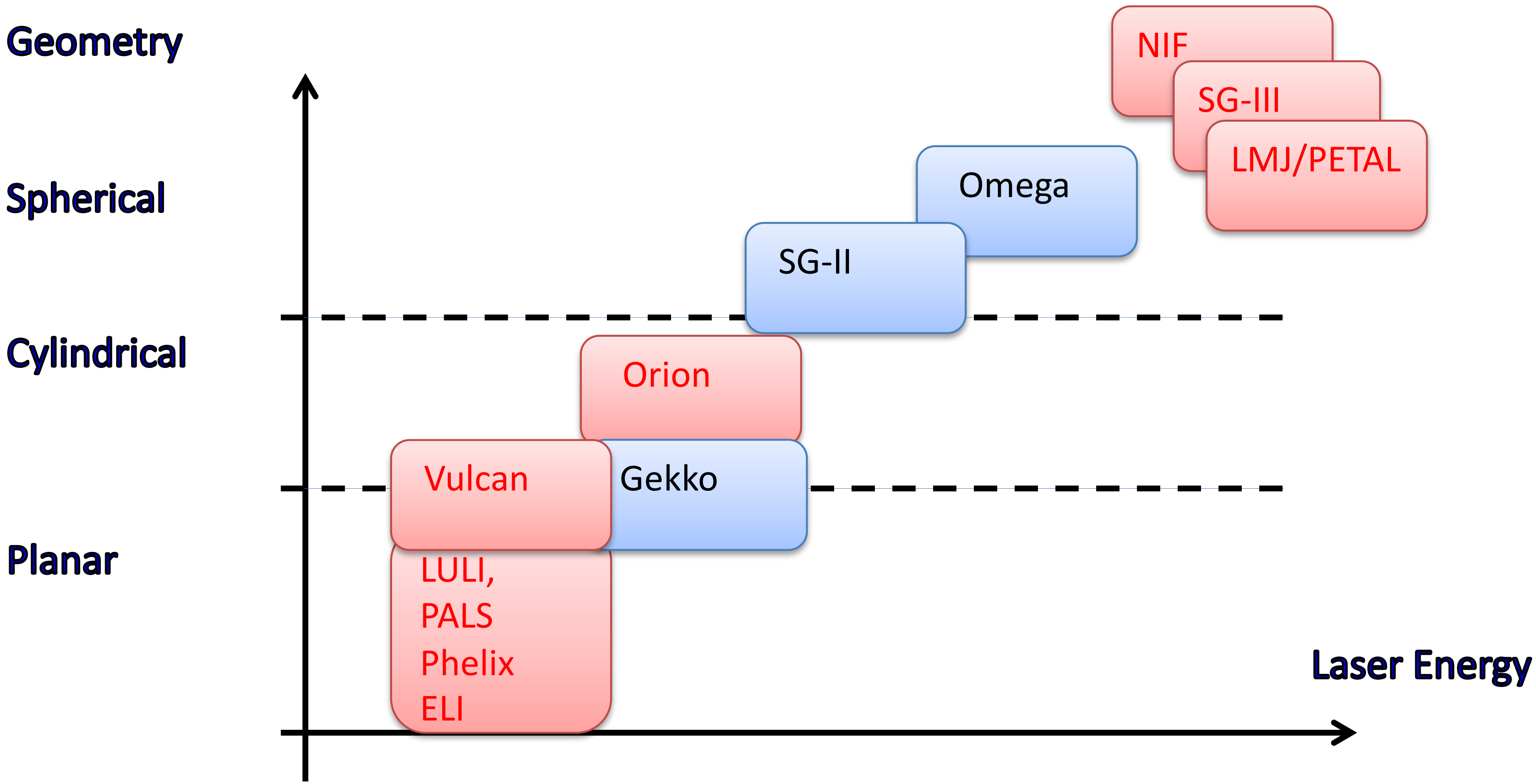


FUTURE DEVELOPMENTS



EXPERIMENTAL ROADMAP TOWARDS SHOCK IGNITION IFE

How to approach the final goal of "Performing shock ignition demonstration experiments" ?



EXAMPLE: VULCAN TAW EXPERIMENTAL SET UP

MIMIC SHOCK IGNITION INTERACTION

Compare narrowband with broadband/chirped irradiation

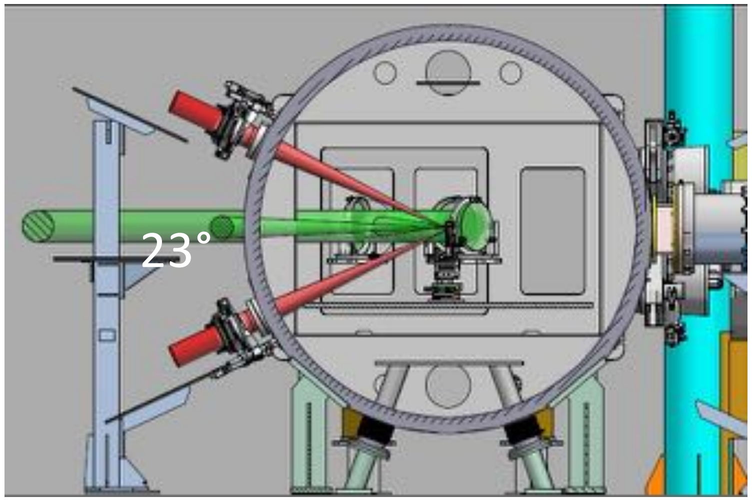
LASER IRRADIATION DESIGN (PLANAR GEOMETRY)

4 driver/heating beams (long beams)

E=250 J x 4, λ=1053 nm, 3 ns, FWHM=800 μm, I ≈ 3x10^{13} W/cm^2

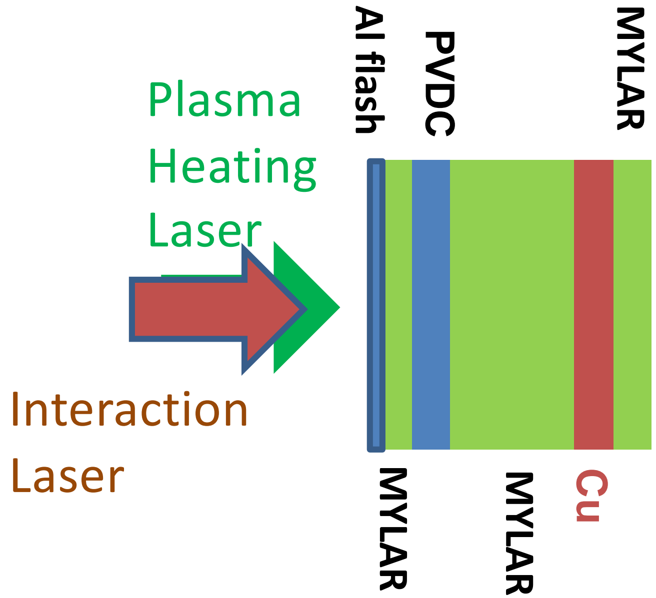
interaction beam B8 bypassing compressor

E≈85 J, λ=527 nm, 0.7 ns, RPP, FWHM ≈ 40 μm, I ≈ 10^{16} W/cm^{2,} f/# ≈2.5



Interaction beams

Heating beams



TARGET DESIGN

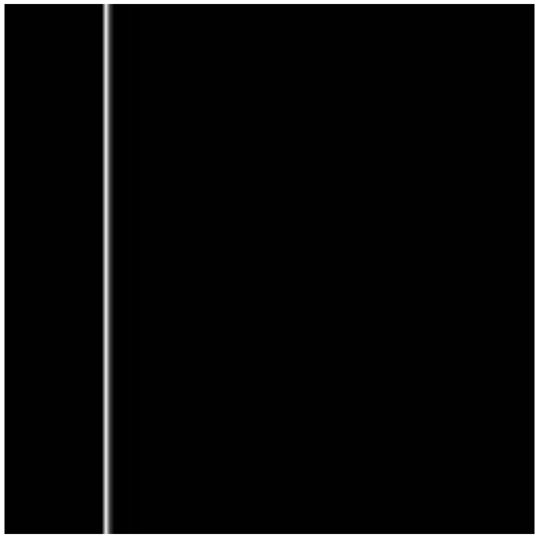
- Al flash
- Cl dopant for Te measurement
- Mylar layer for fast electron transport
- Cu for k-alpha measurement

HYDRODYNAMIC NUMERICAL SIMULATIONS

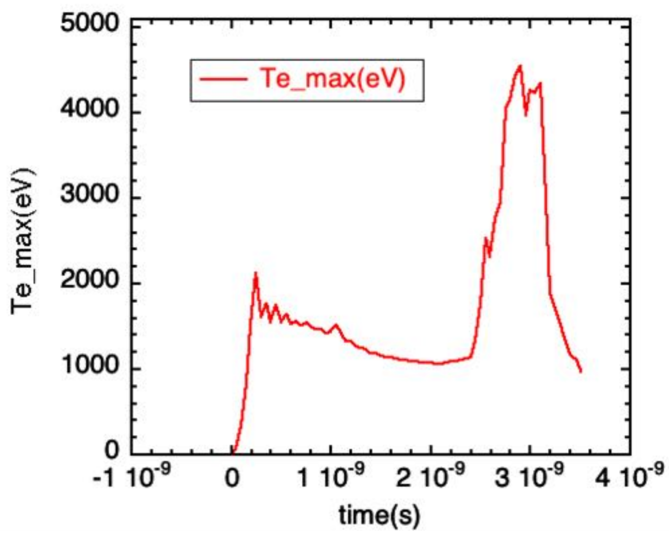
PREDICT PLASMA DENSITY AND TEMPERATURE PROFILE FOLLOWING LASER HEATING

T_e ranges between 2 keV and 5 keV at the densities of interest for SRS ($0.1\ n_c < n_e < 0.25\ n_c$)

density scalelength L is in the range 300-1000 mm at the beginning of interaction



4 Driver beams + interaction beam
@ 1E16 W/cm2, delay -300 in figure



*S. Atzeni et al 2016 J. Phys.: Conf. Ser.688 012005

VULCAN TAW EXPERIMENTS

INO-CNR (Italy), York Univ. and CLF (UK), Hellenic Mediterranean Univ. (Greece), Celia (France), Focused Energy

LASER IRRADIATION DESIGN (PLANAR)

4 driver/heating beams (long beams)

E=250 J x 4, λ=1053 nm, 3 ns

FWHM=800 μm, I ≈ 3x10^{13} W/cm^2

interaction beam B8 bypassing compressor

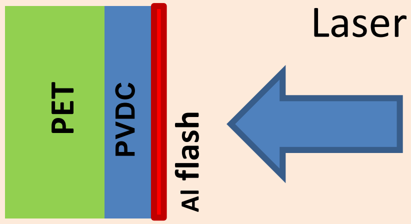
E= 100-150 J, λ=527 nm, 0.7-1.0 ns, RPP

FWHM ≈ 40 μm, I ≈ 10^{16} W/cm^2 , f/# ≈2.5

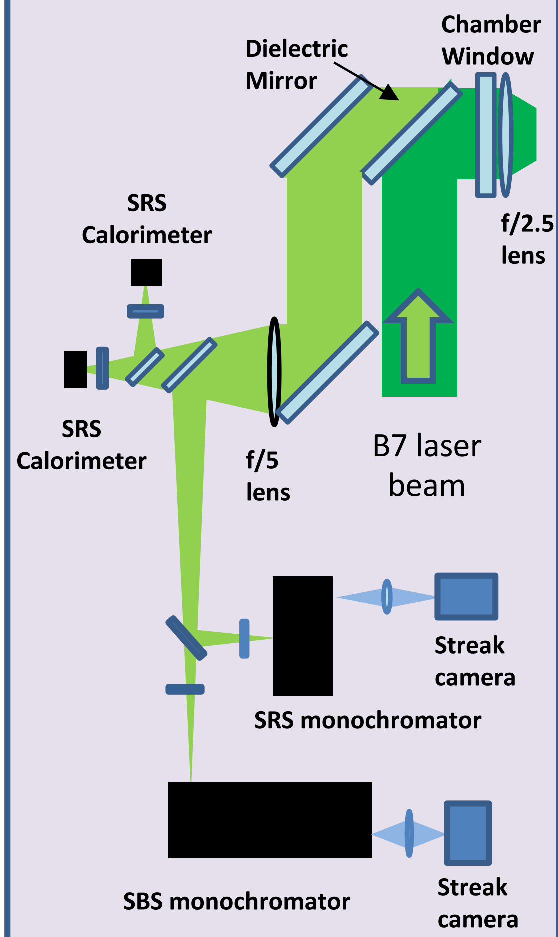
3 oscillators:

Option	SHG Duration (ps)	SHG Bandwidth (nm) (%)	Chirp Rate (nm/ns)
Narrowband	770	Fourier limited	0
OPO phosphate amp.	680	0.77 nm 0.15%	0.95
OPCPA Silicate amp.	1100	1.77 nm 0.34%	1.22

TARGET DESIGN

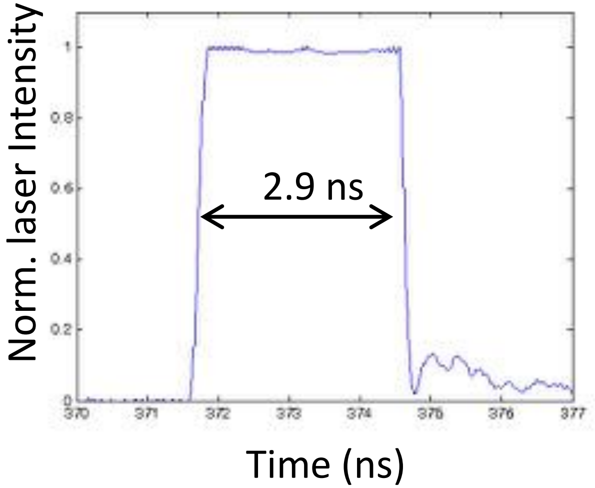


BACKSCATTERING DIAGNOSTICS



TIMING OF LASER PULSES

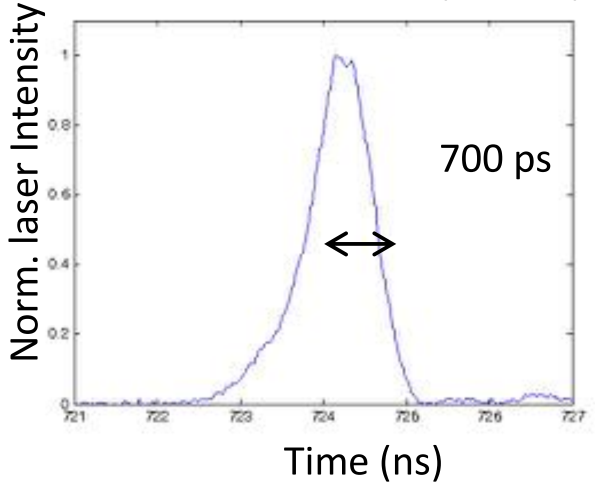
Long pulse heating beams

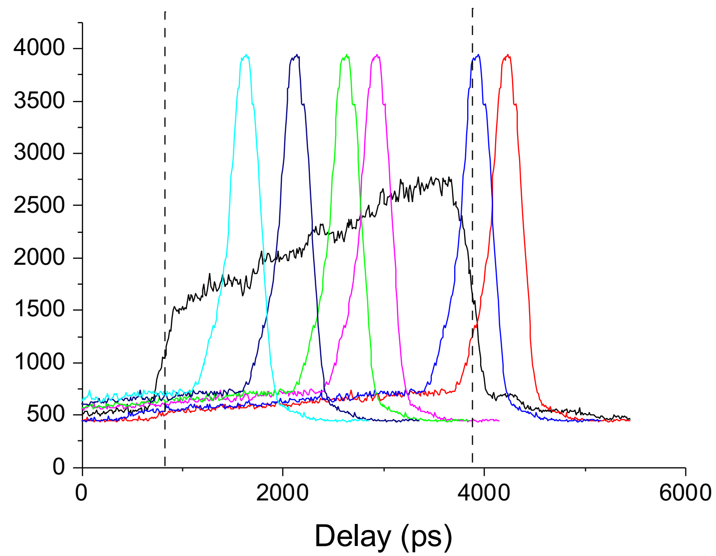


- 4 driver beams F/#10
- RPP
- FWHM 800x570 μm
- λ= 1054 nm
- Δt = 2.9 ns
- E_{tot} = 700-900 J
- I = 3×10^{13} W/cm^2

- Main beam F/#2.5
- RPP
- FWHM 24x30 μm
- λ= 527 nm
- Δt = 700 ps
- E_{tot} = 40-100 J
- I = $(0.5-1.3) \times 10^{16}$ W/cm^2

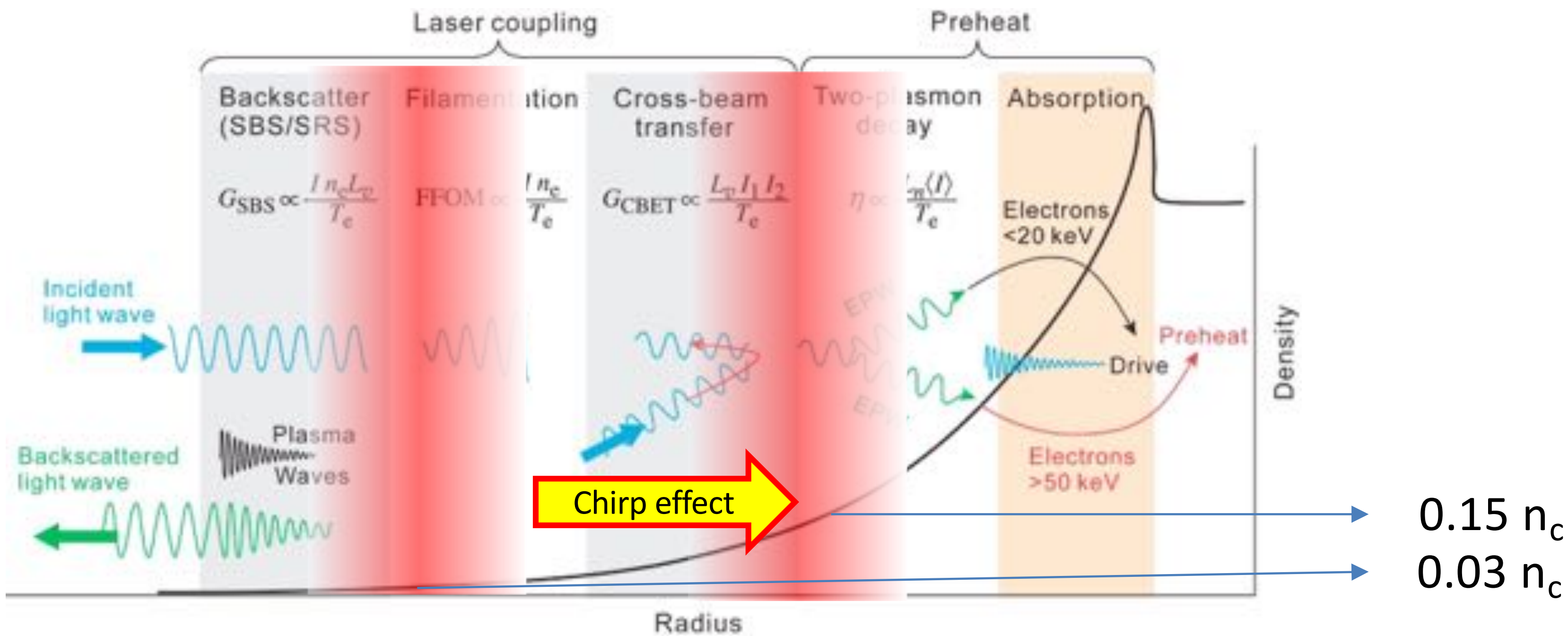
Interaction beam (B 7/8)





PRELIMINARY CONCLUSIONS

- In spite of the much higher intensity (>1E15) compared to earlier studies, a chirped bandwidth as small as 1 nm (0.2%) has a strong effect on LPI
- The coupling with *chirped-broadband* laser pulse moves to much higher density compared to narrowband laser pulse;
- As observed at lower (implosion-like) intensities, the bandwidth mainly acts on filamentation, limiting its growth and allowing laser light to propagate further;



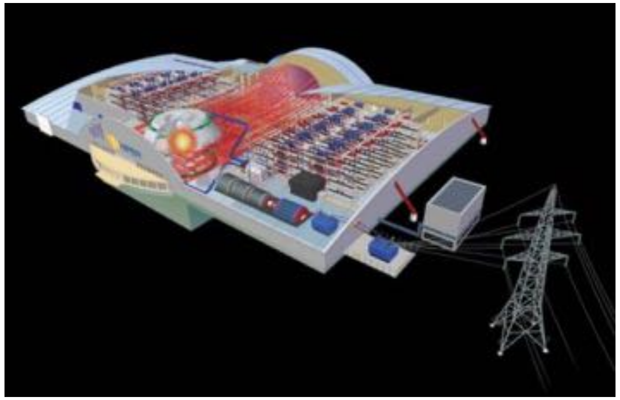
PARTIAL LPI SCENARIO

- Multi-speckle modelling is needed to depict SRS growth (work in progress)
- In long scale plasmas and SI intensities, SRS is driven in filaments at low densities in strong kinetic regime and can reach 40-50% instantaneous reflectivities (In agreement with *Baton et al., High Energy Density Physics 36, 100796, 2020);*
- HE generated by SRS at these densities could have a low non-dangerous low temperature (here T = 10-15 keV), as measured in the experiment;
- TPD and high-density SRS are not observed, for pump depletion and plasma-induced smoothing after a few speckles layer (*Scott et al., Phys. Rev. Lett. 127, 065001, 2021)*
- This scenario may change completely for even modest bandwidth laser pulses due to the seeding of filamentation by RPP laser speckles.

CONTENTS

ON WHAT WE BUILD: THE EU IFE COMMUNITY

2005-2014 European Project “HIPER” (High Power Laser Energy Research Facility)



HiPER, conceived as a large-scale laser system designed to demonstrate significant energy production form ICF, was listed on the ESFRI large scale facility roadmap and awarded preparatory phase funding (~2 M€) by the EU with additional funding from STFC, UK, and the Ministry of Education, Czech Republic, and work in-kind from many other partners

The project was based on the assumption that NIF would ignite during the National ignition Campaign (2009-2012)

www.hiper-laser.org

ON WHAT WE BUILD: THE EU IFE COMMUNITY

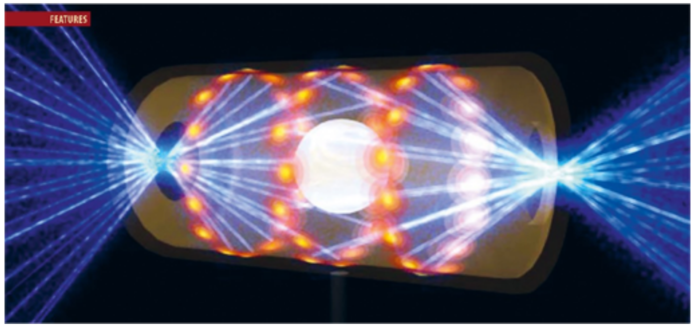
COST Action MP1208 «Developing the Physics and the Scientific Community for Inertial Fusion at the time of NIF ignition» 2013-2017

Laserlab Europe AISBL supports 3 ICF-related groups:
Expert group in ICF/IFE
Expert group in micro-structured materials
Expert group in laser-generated EMP

EUROFusion within Enabling Research projects
EUROFusion supports projects related to direct-drive and shock ignition at the level of $\sim 300\ k€$ /year
(2017-2024)

24 groups and more than 100 researchers involved throughout Europe

MAJOR IMPACT OF NIF RESULTS



BREAKTHROUGH AT THE NIF
PAVES THE WAY TO INERTIAL FUSION ENERGY

S. Atzeni[1], D. Batani[2], C. N. Danson[3,4], L. A. Gizzi[5], S. Le Pape[6], J-L. Miquel[7], M. Perlado[8], R.H.H. Scott[9], M. Tatarakis[10,11], V. Tikhonchuk[2,12], and L. Volpe[13,14] – DOI: https://doi.org/10.1051/epn/2022106

In August 2021, at the National Ignition Facility of the Lawrence Livermore National Laboratory in the USA, a 1.35 MJ fusion yield was obtained. It is a demonstration of the validity of the Inertial Confinement Fusion approach to achieve energy-efficient thermonuclear fusion in the laboratory. It is a historical milestone that the scientific community has achieved after decades of efforts.

HiPER+ Project

Letter to launch the HiPER+ project has been so-far signed by more than 150 European scientists

https://www.clpu.es/Laser_Fusion_HiPER

Contribution Report of the "HiPER+ group" to the **ESFRI Landscape analysis** of Research Infrastructures (April 2023)
Contacts with **EURATOM, EUROFusion**

High Power Laser

An evaluation of sustainability and societal impact of high-power laser and fusion technologies: a case for a new European research infrastructure

Part of: HPL Perspectives

Published online by Cambridge University Press: 21 September 2021

S. Atzeni, D. Batani, C. N. Danson, L. A. Gizzi, M. Perlado, M. Tatarakis, V. Tikhonchuk and L. Volpe Show author de

THE HiPER+ PROGRAMME

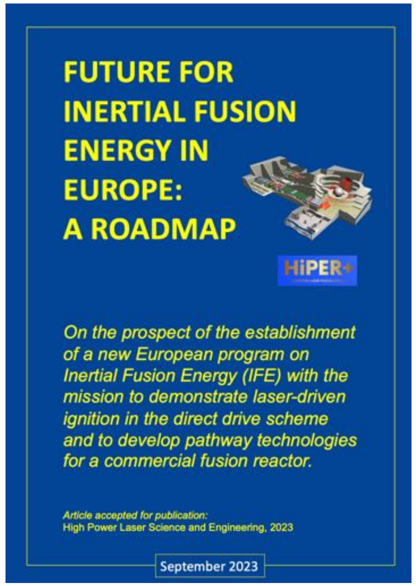
High Power Laser Science and Engineering, (2023), Vol. 11, e83, 31 pages.
doi:10.1017/hpl.2023.80

HIGH POWER LASER SCIENCE AND ENGINEERING

REVIEW

Future for inertial-fusion energy in Europe: a roadmap

Dimitri Batani[1], Arnaud Colaïtis[1], Fabrizio Consoli[2], Colin N. Danson[3,4], Leonida Antonio Gizzi[5], Javier Honrubia[6], Thomas Kühl[7], Sebastien Le Pape[8], Jean-Luc Miquel[9], Jose Manuel Perlado[10], R. H. H. Scott[11], Michael Tatarakis[12,13], Vladimir Tikhonchuk[1,14], and Luca Volpe[6,15]

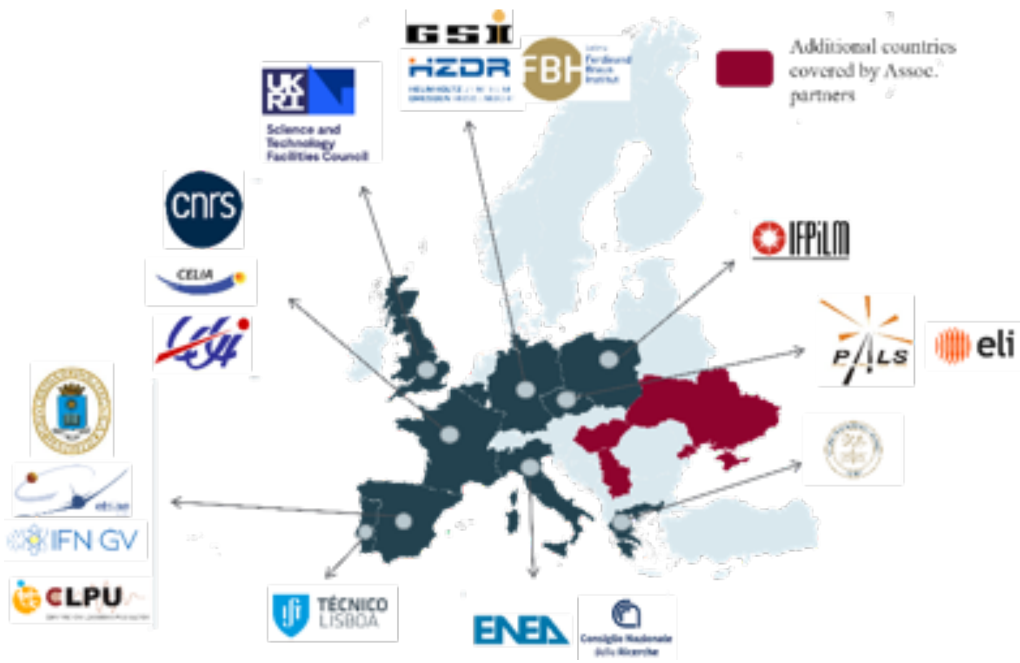


Conceptual Development: HORIZON-INFRA-2024-DEV-01-01: Research infrastructure concept development, Deadline March 2024

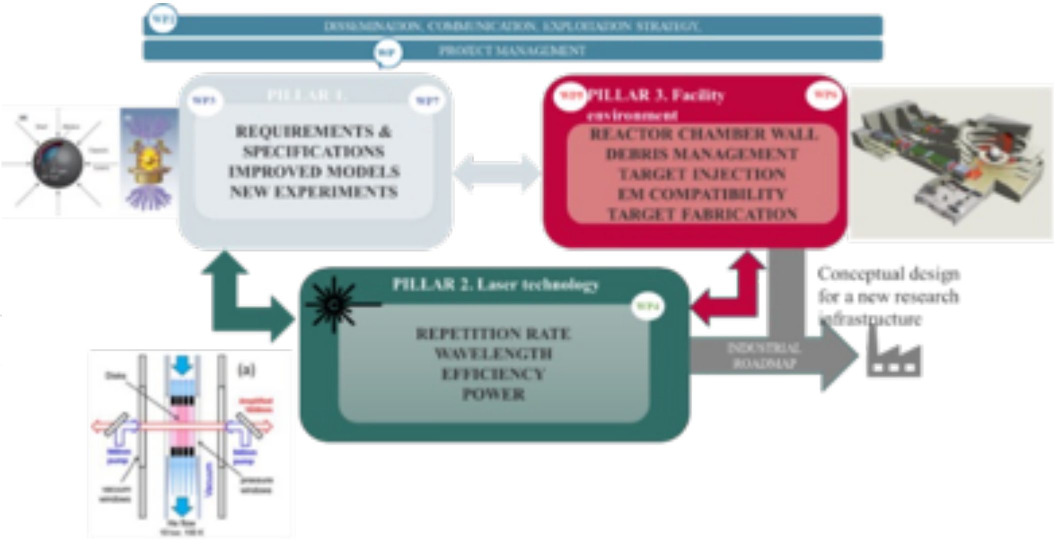
HiPER+
EUROPEAN LASER FUSION ENERGY

HiPER+ RESEARCH INFRASTRUCTURE APPROACH*

Consortium



Main blocks



European Commission

*European proposal (Infradev Horizon Europe Call 2024)

INFRADEV: Developing, consolidating and optimising the European research infrastructures landscape, maintaining global leadership

HiPER+ TIMELINE

3 major steps of 10 years each: produce knowledge, build the machine, produce and analyze results for the technology transfer

Years 1-10	Years 11-20	Years 21-30
R&D	Pilot IFE reactor	DEMO-IFE reactor

Synergies with companies and national projects could somewhat accelerate this time scale…

Major axes of research & technology development

A: physics & technology for IFE	B: development of IFE laser technology	C: material science & reactor technology	D: development of community, coordination & management

For comparison:
NIF high gain reached in 2028
LMJ full operation at 1.3 MJ expected in 2027
First plasma in ITER expected not before ~2025

SUMMARY

- **Inertial fusion ignition achieved**
- **Possible pathway: direct drive and shock ignition**
- **Facility needed to develop the EU experimental programme**
- **HiPER+ programme is a unique EU platform for IFE**