EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA Preparatory Phase

Synergies for laser development between EuPRAXIA and other fields including fusion and industry

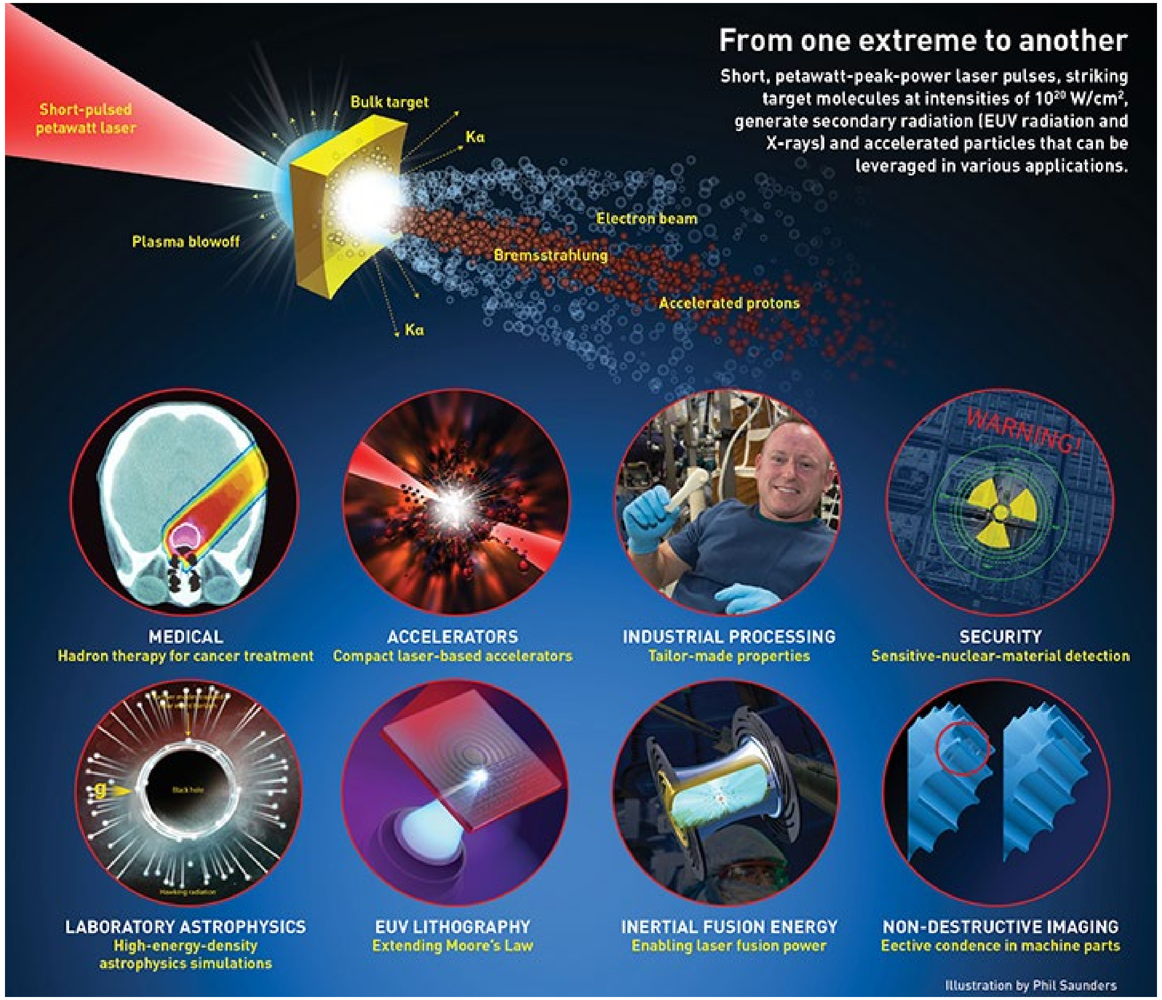
Leonida A. GIZZI

Istituto Nazionale di Ottica, CNR, Pisa, Italy

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773

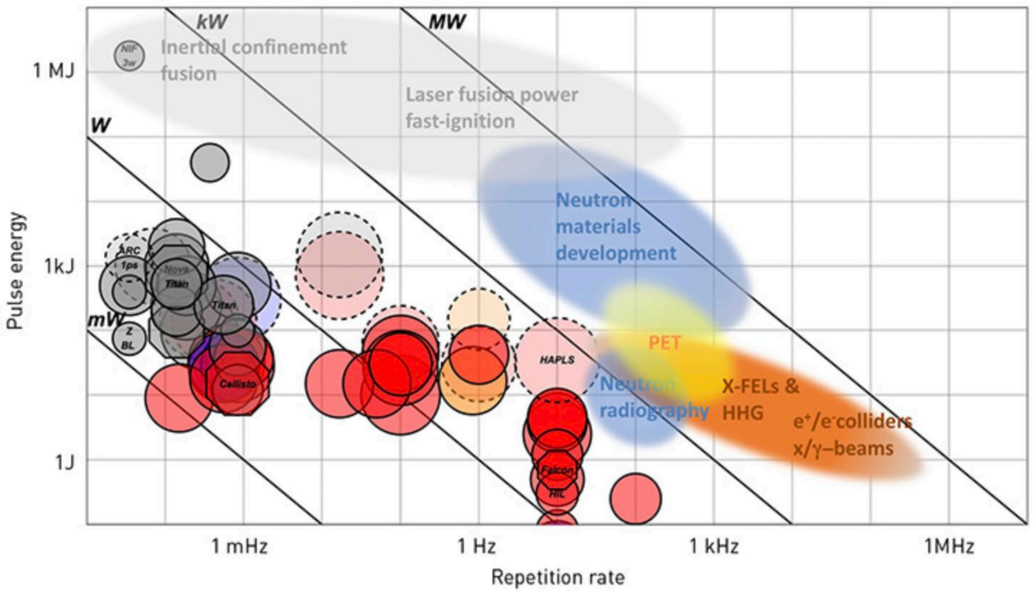
Demanding high power laser-based applications

Funded by the European Union



OPTICS & PHOTONICS NEWS

High-Average-Power Ultrafast LasersThomas M. Spinka and Constantin Haefner, 2017



Breakthrough needed: Decommissioned, existing and planned PW-class high-intensity laser facilities all have average powers below the 1 kW limit. Most useful secondary-source applications, however, will require average-power levels of tens to hundreds of kW—a situation that demands a breakthrough in ultrafast laser technology. [Courtesy of LLNL]

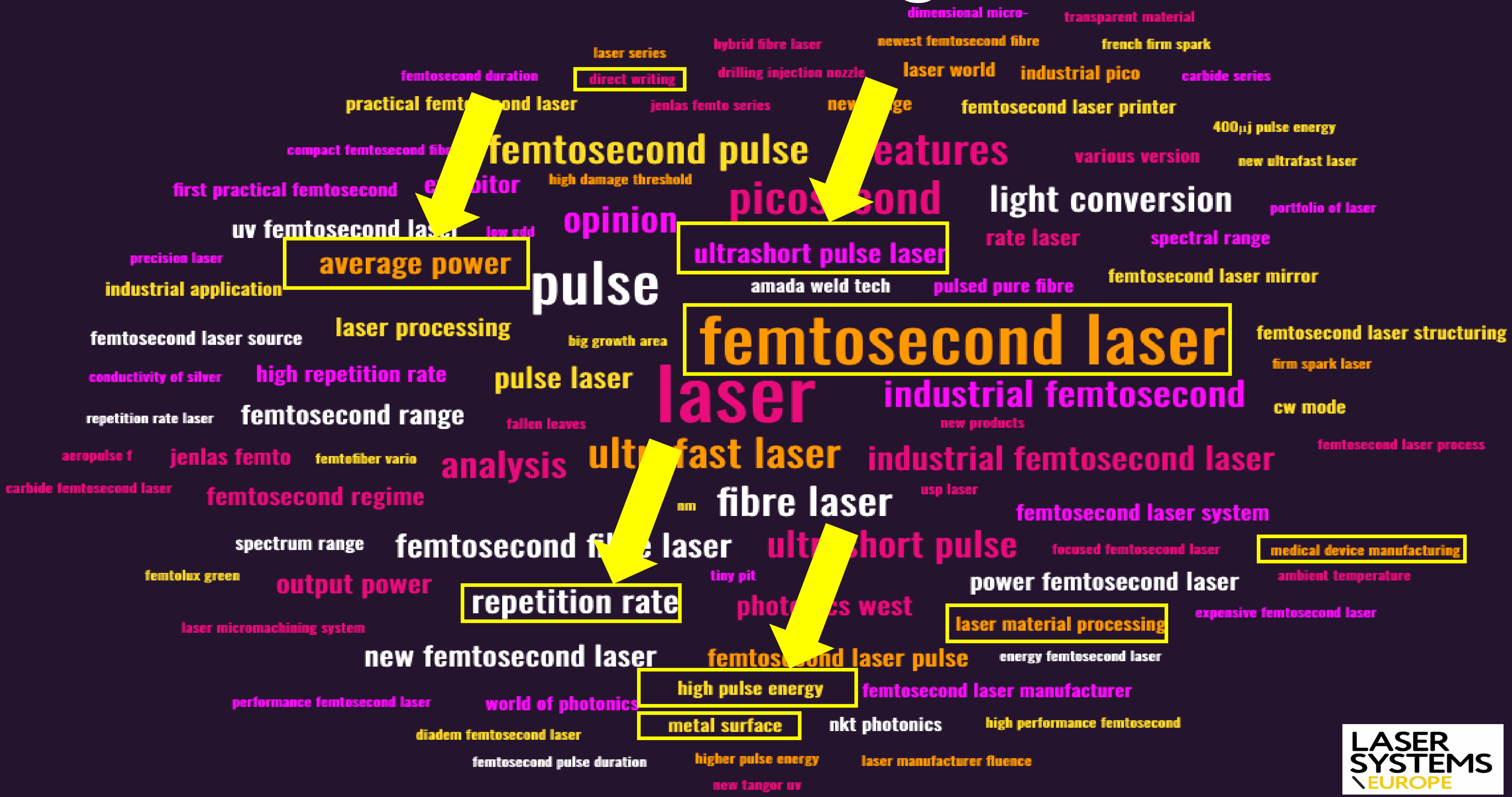
Mostly science driven so far: relying on public funding for the delivery of lasers with unique specifications.

FEMTOSECOND LASERS @ INDUSTRY

dimensional micro-
transparent material
laser series
hybrid fibre laser
newest femtosecond fibre
french firm spark
femtosecond duration
direct writing
drilling injection nozzle
laser world
industrial pico
carbide series
practical femtosecond laser
jenlas femto series
new range
femtosecond laser printer
400µj pulse energy
compact femtosecond fibre
femtosecond pulse
features
various version
new ultrafast laser
first practical femtosecond
exhibitor
high damage threshold
picosecond
light conversion
portfolio of laser
uv femtosecond laser
low gdd
opinion
rate laser
spectral range
precision laser
average power
ultrashort pulse laser
industrial application
pulse
amada weld tech
pulsed pure fibre
femtosecond laser mirror
femtosecond laser source
laser processing
big growth area
femtosecond laser
femtosecond laser structuring
firm spark laser
conductivity of silver
high repetition rate
pulse laser
laser
industrial femtosecond
cw mode
repetition rate laser
femtosecond range
fallen leaves
new products
femtosecond laser process
aeropulse f
jenlas femto
femtofiber vario
analysis
ultrafast laser
industrial femtosecond laser
carbide femtosecond laser
femtosecond regime
nm
fibre laser
usp laser
femtosecond laser system
spectrum range
femtosecond fibre laser
ultrashort pulse
focused femtosecond laser
medical device manufacturing
femtolux green
output power
tiny pit
power femtosecond laser
ambient temperature
repetition rate
photonics west
laser material processing
expensive femtosecond laser
laser micromachining system
new femtosecond laser
femtosecond laser pulse
energy femtosecond laser
high pulse energy
femtosecond laser manufacturer
performance femtosecond laser
world of photonics
metal surface
nkt photonics
high performance femtosecond
diadem femtosecond laser
femtosecond pulse duration
higher pulse energy
laser manufacturer fluence
new tangor uv

LASER SYSTEMS EUROPE

FEMTOSECOND LASERS @ INDUSTRY



LASER SYSTEMS EUROPE

FEMTOSECOND INDUSTRIAL LASERS

Funded by the European Union

New femtosecond laser to boost automotive production

LASER SYSTEMS EUROPE

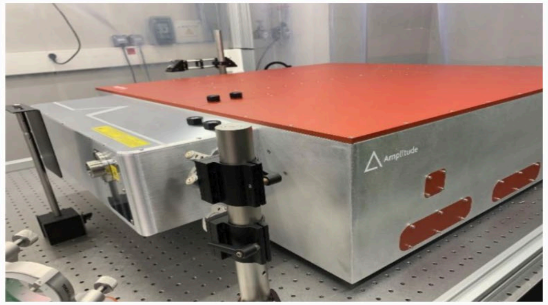
29 May 2019

A new femtosecond laser capable of cutting and shaping ultra-high-strength boron steel a thousand times faster than existing technology is being developed for the automotive industry.

The new ultrashort pulse laser, under development within the European project 'PULSE', will not only decrease automotive manufacturing times by two-thirds, but will also reduce waste products by 10 per cent and cut chassis costs by 5 per cent. The technology has received a €5 million development grant from the European Commission under the Horizon 2020 programme.

Amplitude unveils 300W femtosecond laser at Laser World of Photonics

1 July 2019



Amplitude revealed its newest ultrafast laser, the Tangor 300, at the Laser World of Photonics in Munich, Germany, last week.

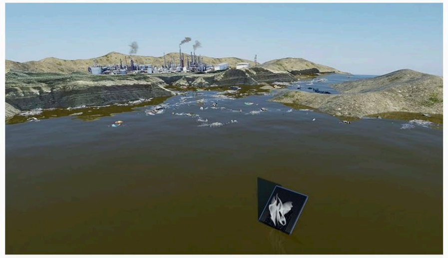
The new system has an average power of 300W and a pulse width less than 500 femtoseconds, making it the most powerful laser in its field, according to the firm. It is capable of supplying energy of up to 1,000μJ per pulse and offers a repetition rate up to 40MHz.

This combination of parameters offers continuous quality, combined with high productivity for manufacturers and researchers.

'Tangor 300 is capable of handling all types of materials, covering a surface of 100mm² per second.' said Vincent Rouffiange, sales and marketing director at Amplitude Laser Group. 'This new ultrafast laser will enable our clients to multiplicate machining strategies via the perfect quality and productivity combination.'

Femtosecond pulses etch hydrophilic surfaces for solar-based water purification

24 July 2020



Researchers have demonstrated a method of purifying water using aluminium surfaces that have been etched using an ultrafast laser.

The surfaces could be used to provide clean drinking water in developing countries.

In *Nature Sustainability*, the researchers from the University of Rochester in New York, USA, have shown that a burst of femtosecond laser pulses can be used to etch the surface of a normal sheet of aluminium in order to turn it into a hydrophilic (water-attracting) material that is also a highly

EKSPLA

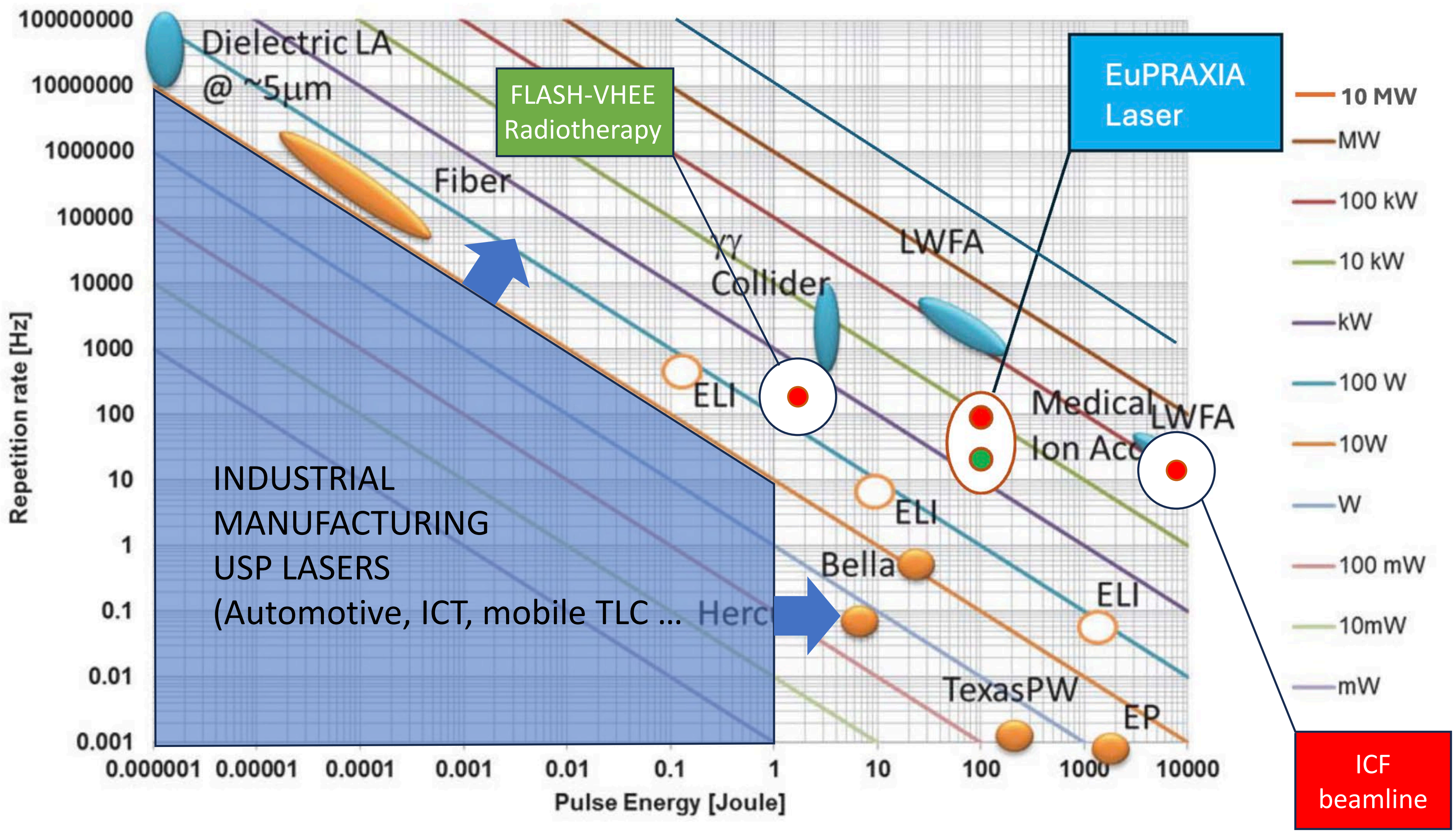
Industry addressing <u>direct use</u> of fs lasers, e.g. material processing and surface functionalization with up to kW average power, ≈100 fs lasers , repetition rates up to ≈GHz, pulse energy between 2.5-250μJ, for a MW peak power

Needs for indirect (plasma based) e.g. laser-based accelerators

> kW average power ≈10 fs lasers, repetition rates up to 10 kHz, pulse energy 1-100 J, for a 100 TW peak power.

Average power needs (Ultrashort pulses)

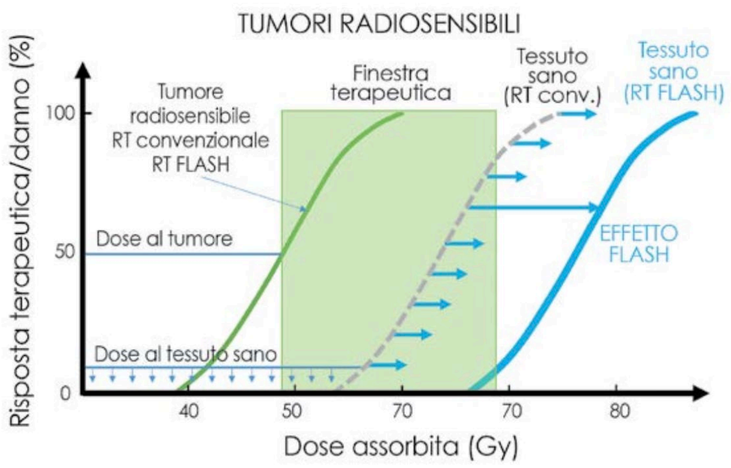
Funded by the European Union



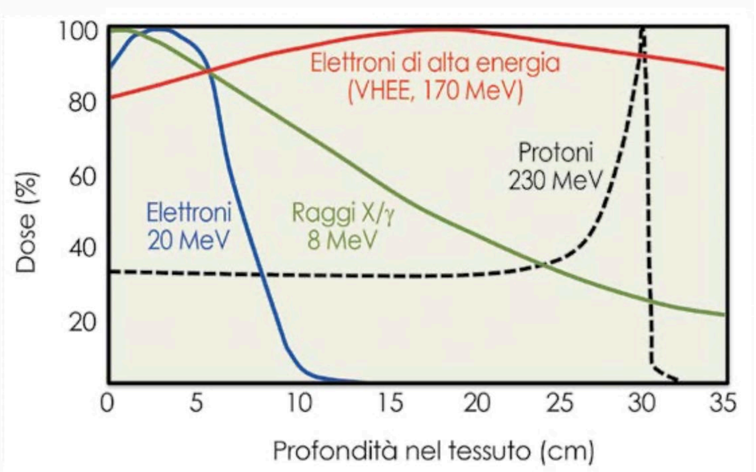
Towards Medical Accelerators

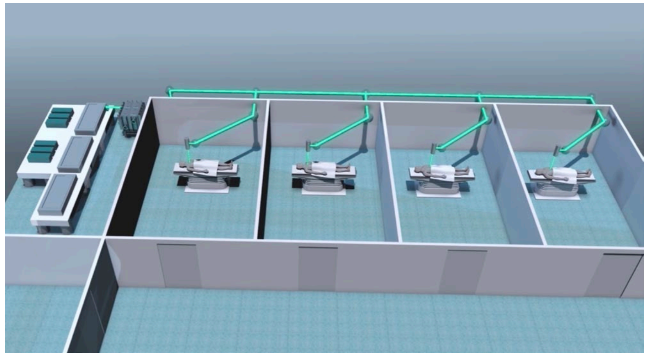
Funded by the European Union

High dose-rate radiobiology and the “FLASH effect”

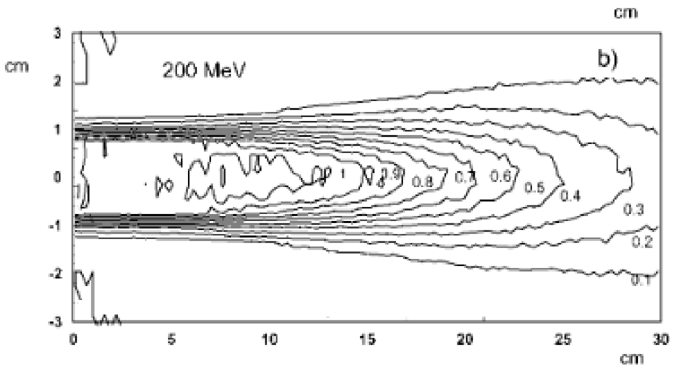


V. Favaudon et al., *Science Translational Medicine* **6**, 245ra93 (2014)





VHEE beams



[1] C DesRosiers *et al* 2000 *Phys. Med. Biol.* **45** 1781,

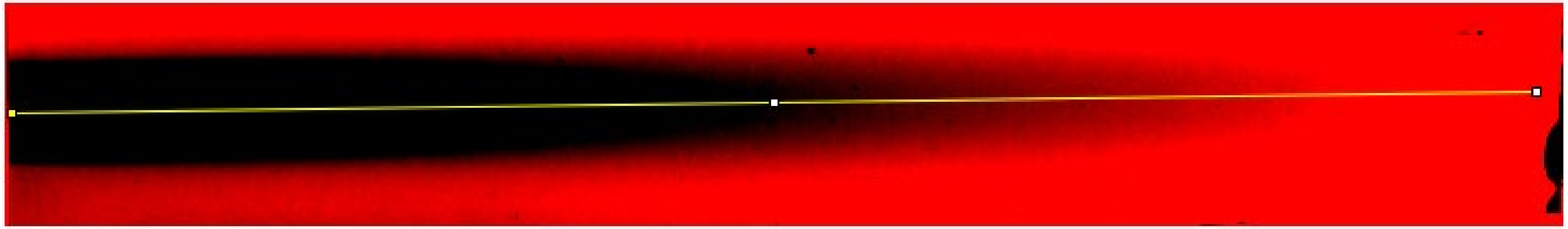
- Same therapeutic effect on tumor tissue
- Sparing of healthy tisssue

Flash: dose to be delivered in a very short time <200 ms (to date)

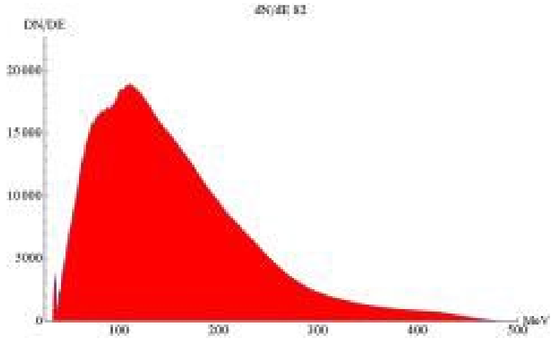
FLASH-RT requires therapeutic doses **(multi Gy)** in a short time (**in ≈100 ms)**

VHEE: Dose per shot

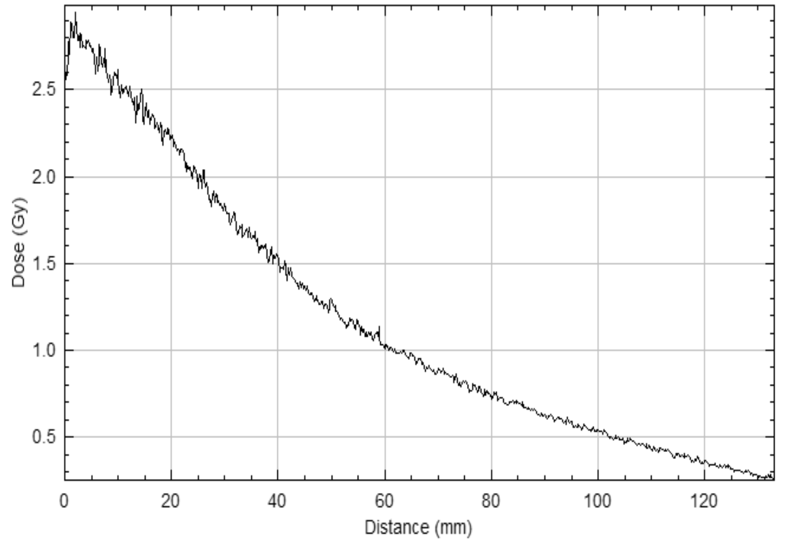
Funded by the European Union



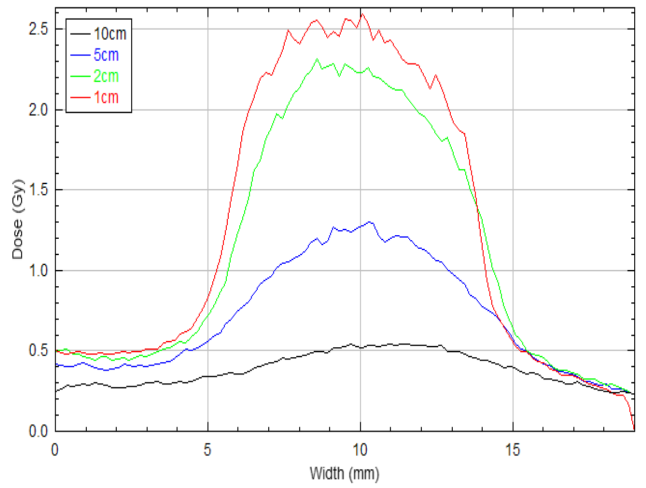
Longitudinal dose profile



Energy spectrum



Transverse dose profile



L. Labate et al., Scientific Reports 10, 17307 (2020)
A. Borghini et al., *Int. J. Mol. Sci. 25(5), 2546* (2024)
C. Panaino et al., Phys. Med. Biol, (2024), Submitted

>2.5 cGy/shot

FLASH-RT therapeutic doses **(multi Gy)** in a short time (**in ≈100 ms) require** high repetition rate (>100 Hz or higher)

Novel medical accelerators for radiotherapy

Funded by the European Union

Strong momentum for Very high energy electrons (VHEE) accelerator development

LOA, CNRS/Ecole Polytechnique/ ENSTA), Paris, France
Glinec *et al.* 2006
Fuchs *et al.* 2009

ALPHA-X, (University of Stratchclyde), Glasgow, UK
Subiel *et al.* 2014

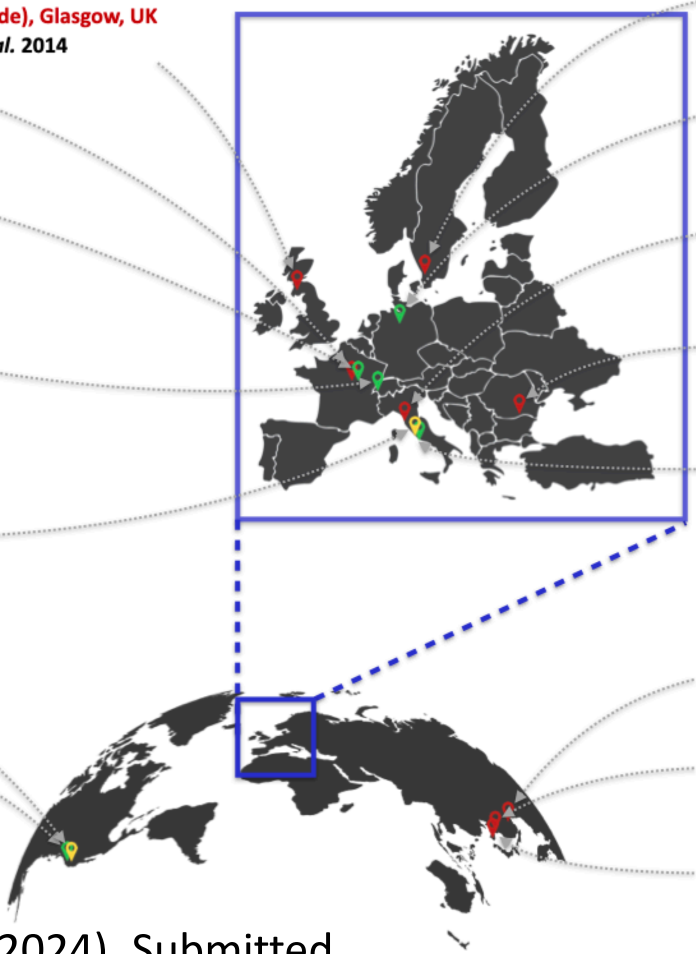
PRAE (Paris-SudUniversity), Paris, France
Stephan *et al.* 2022

CLEAR (CERN), Geneva, Switzerland
Lagzda *et al.* 2020
Poppinga *et al.* 2020
McManus *et al.* 2020
Small *et al.* 2021
Kokurewicz *et al.* 2021
Bateman *et al.* 2024
Hart *et al.* 2024
Whitmore *et al.* 2024
Clements *et al.* 2024
Wanstall *et al.* 2024

INFN-LNF, Frascati, Italy
Faillace *et al.* 2022

PHASER, NLCTA (SLAC), Stanford, CA, USA
Maxim *et al.* 2019

NLCTA (SLAC), Stanford, CA, USA
Bazalova-Carter *et al.* 2015
Palma *et al.* 2016
Schuler *et al.* 2017



LWFA (LLC), Lund, Sweden
Svendsen *et al.* 2021

PITZ & ARES (DESY), Hamburg, Germar
Stephan *et al.* 2022
Wanstall *et al.* 2024

ILIL (CNR-INO), Pisa, Italy
Giulietti *et al.* 2012
Gizzi *et al.* 2015
Labate *et al.* 2020

ELI (INFLPR), Magurele, Romania
Orobeti *et al.* 2024

SPARC (INFN), Frascati, Italy
Subiel *et al.* 2014

Tsinghua University, Beijing, China
Guo *et al.* 2023

CoReLS, Gwangiu, South Korea
Nakajima *et al.* 2014

KERI, Ansan, South Korea
Kim *et al.* 2020

Synergy with EuPRAXIA concerning "**driver**"mode of operation:

- high repetition rate
- beam quality
- pointing stability
- ML control system
- long-term operation
- beam transport
- modularity
- 24/7 operation
- cost of operation

C. Panaino et al., Phys. Med. Biol, (2024), Submitted

Needs high average power, high repetition rate lasers to meet FLASH-RT specifications

Relevant research and Industrial endeavours …

Funded by the European Union

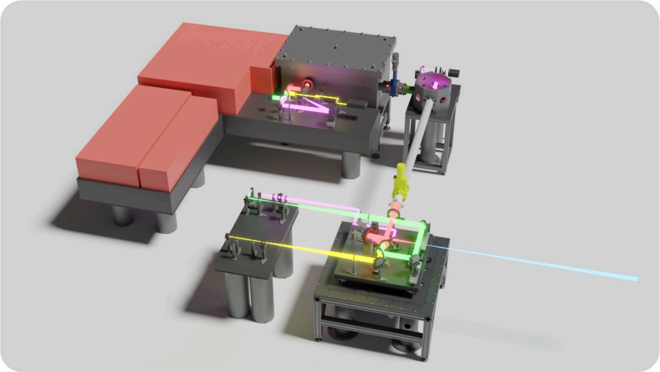
ebeam4therapy

A non-exhaustive list of focused initiatives aiming at radiotherapy applications of LPA

"An enabling technology that will provide a paradigm shift in the medical radiotherapy market"

THE Tuscany Health Ecosystem

Companies /PP Programmes	Country
TAU Systems	USA
SourceLAB	France
Ebeam4Therapy	Israel
Aukelos	Italy
LAPLACE	France
THE	Italy
HZDR	Germany
ELI	Czech Republic



AUKELOS HEALTH LASER TECHNOLOGY

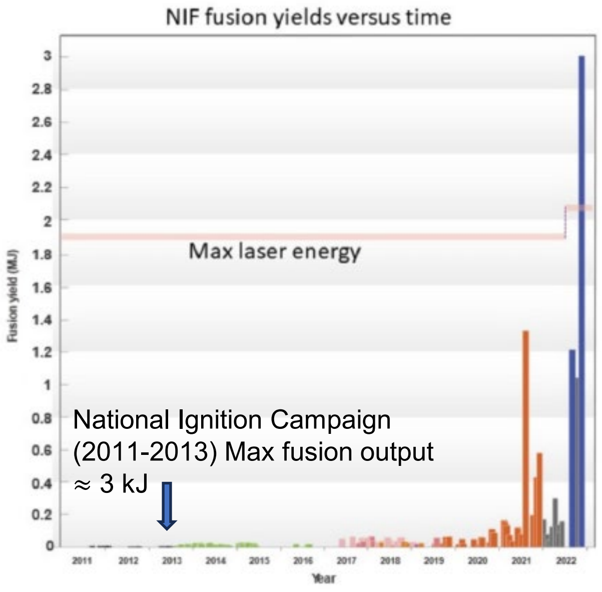
SourceLAB Amplitude THALES

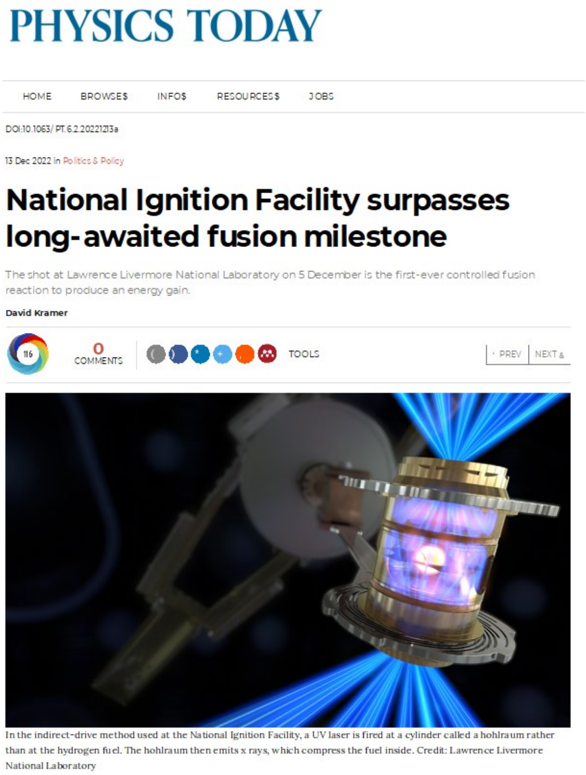
Large companies (Varian, Elekta, Accuray, IBA, ViewRay, Hitachi etc …) make commercial viability highly challenging

Inertial Fusion Ignition

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 **Gain = 3.15MJ / 2.05 MJ = 1.54**

LONG AND DIFFICULT WAY TO SUCCESS





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

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 the hydrogen fuel. The hohlraum then emits x rays, which compress the fuel inside. Credit: Lawrence Livermore National Laboratory

Major impact of NIF Ignition demonstration

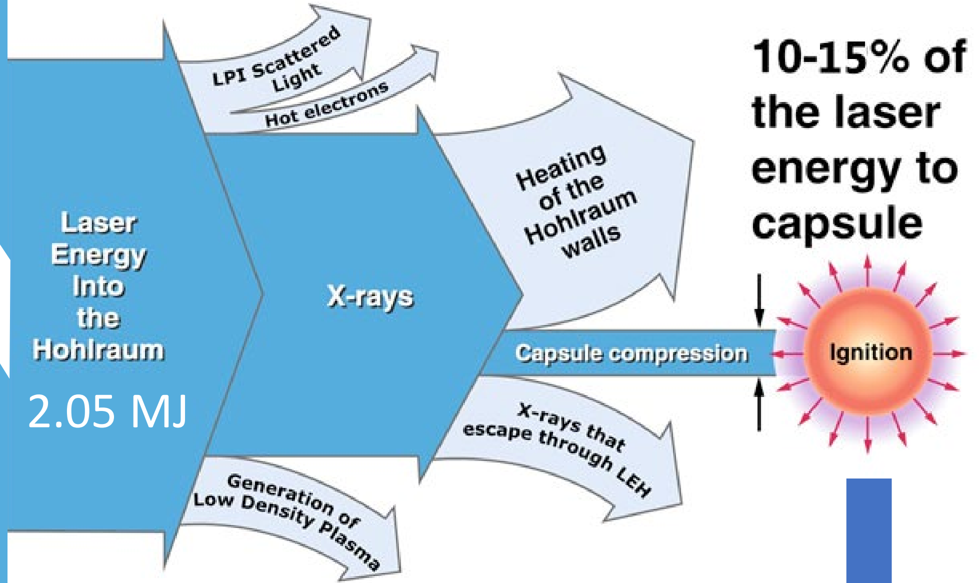
Broad research programmes on IFE being engaged worldwide

Energetics of Fusion

Funded by the European Union

ICF (pulse: Energy)

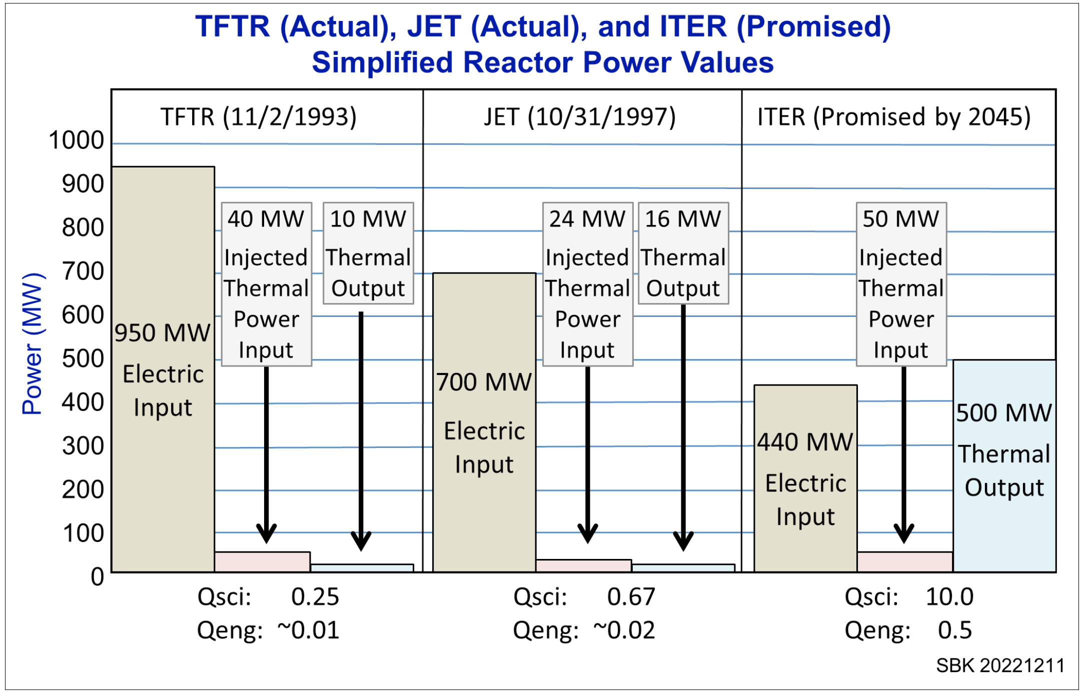
Wall plug: 400 MJ



5.2MJ

Driver efficiency: 0.5%

MCF (CW: Power)



https://news.newenergytimes.net/

Driver efficiency: 2-3%

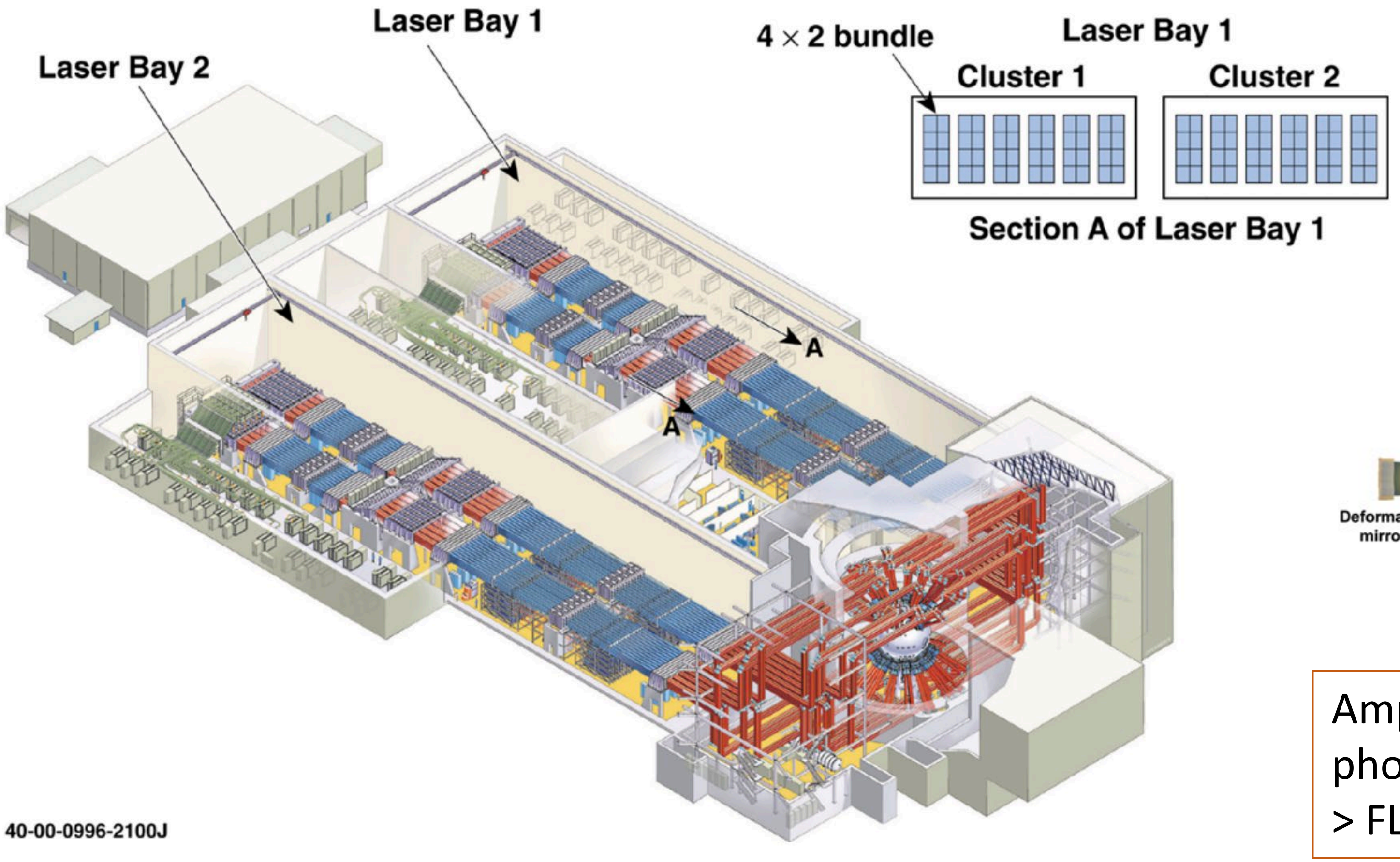
ICF is the first Fusion experiment to demonstrate ignition and breakeven* (Eout>Ein)

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

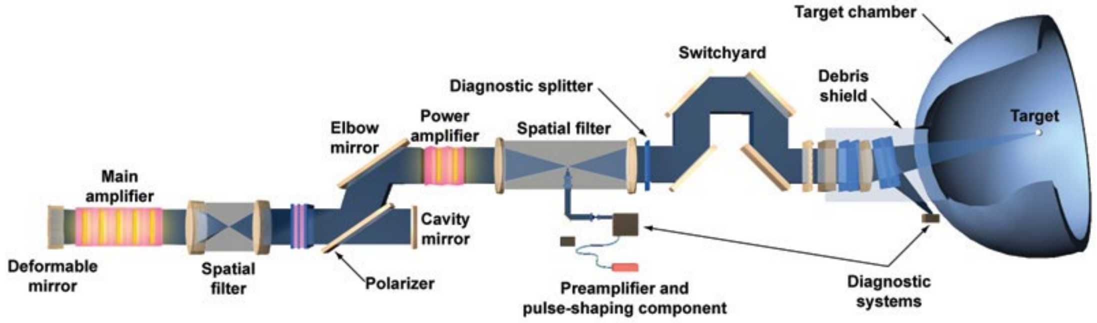
ICF: A single laser consisting of many beamlines

Funded by the European Union

The NIF driver consists of 192, forty-centimeter square laser beams arranged in bundles of 4 × 2 beams, six bundles to a cluster, two clusters to a laser bay, two laser bays.



The basic unit is a beamline delivering pulses of 10 kJ, a few ns in duration, frequency tripled to 351 nm.

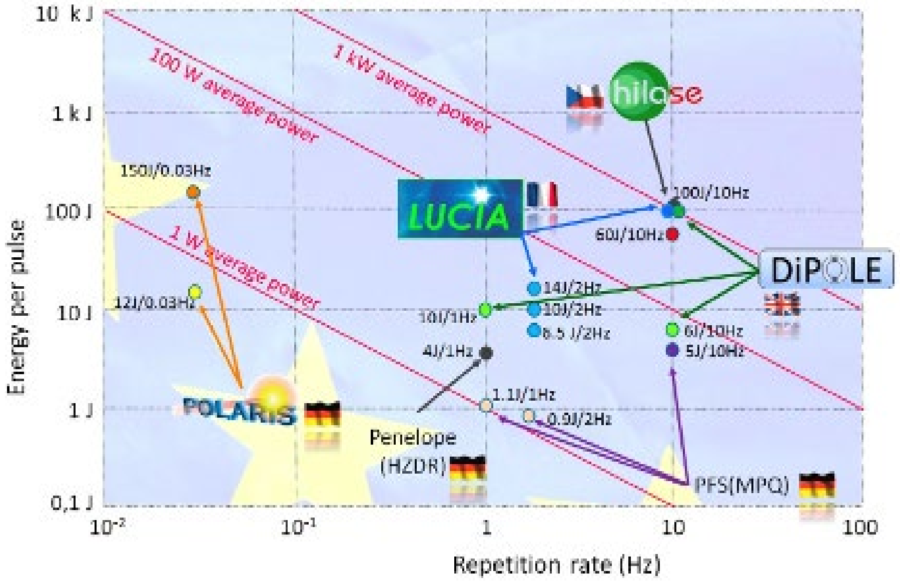


Amplifiers: 3,072 42-kilogram neodymium-doped phosphate glass: 16 glass slabs per beam
> FLASHLAMP pumped

Modular structure: main effort goes in finalizing and building the unit beamline. Then replication (industrial production)…

Laser challenge for IFE

- Today's laser efficiency (electricity to laser energy) is < 1%
- Large scale ICF facilities (NIF, LMJ, SG-III) can fire typically 1 shot/day
- They use 350 nm light (near UV, third harmonic of Nd:glass lasers)



For a reactor we need to:

- Develop more efficient laser (≥ 10%)
- Develop high repetition rate laser (10 Hz)
- Use 2w light (532 nm) to reduce damage to optics
- Develop broadband lasers (to quench parametric instabilities)

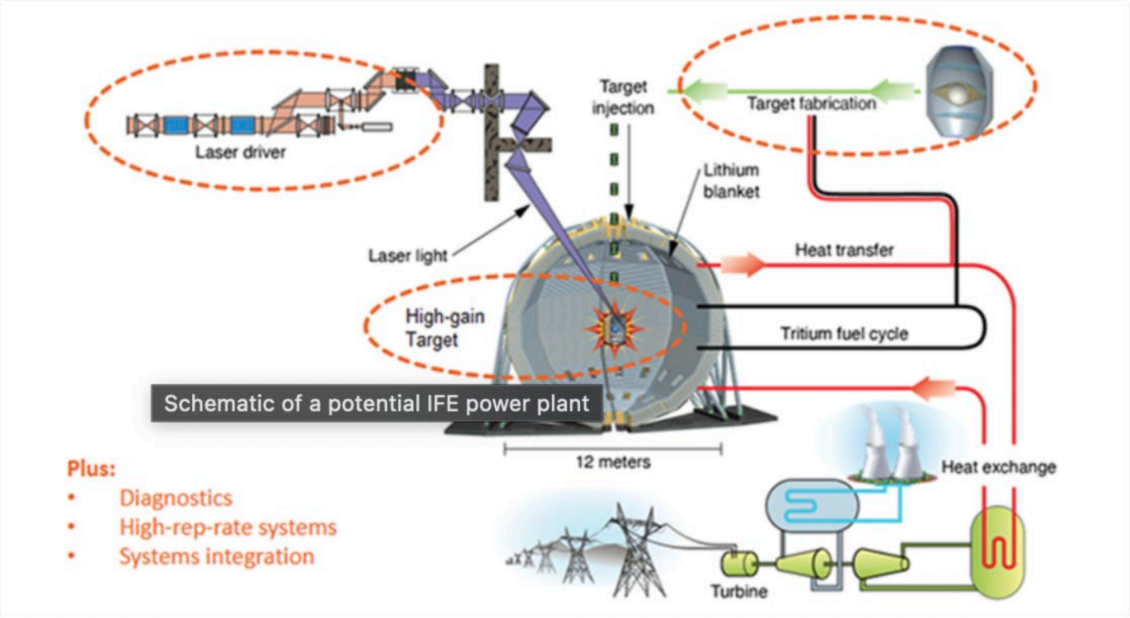
Advances possible by using diode pump lasers (overall efficiency up to 20% possible)

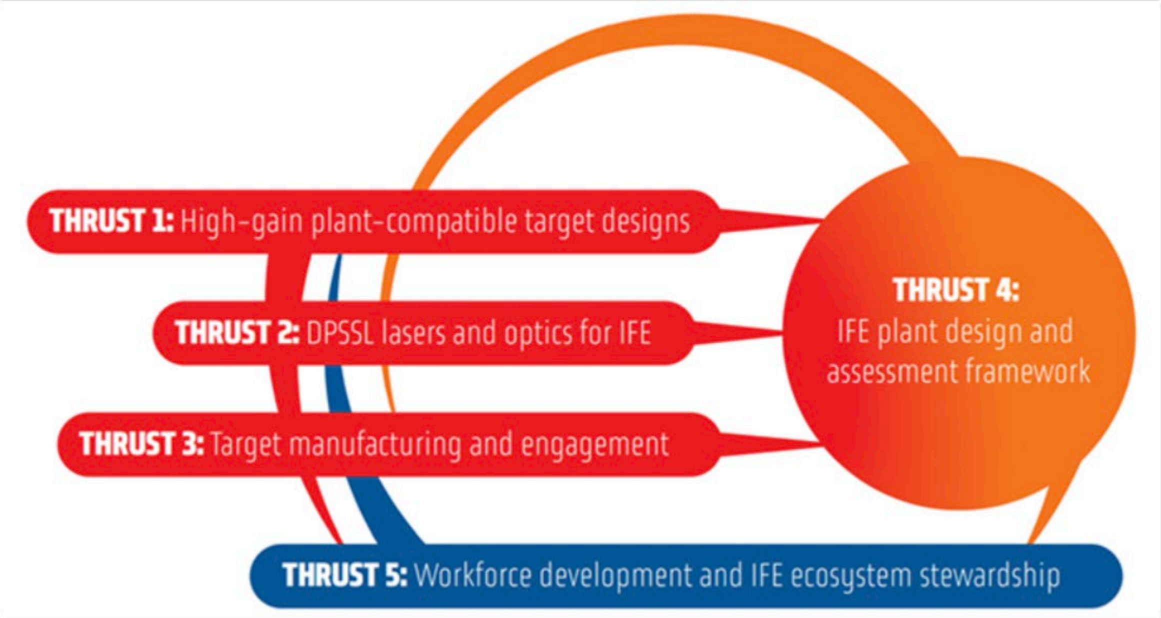
Existing diode pumped systems (e.g. DIPOLE) provide kW average power;

Laser systems like L4n at ELI-beamlines already offer higher repetition rate (≈ 1 shot /min) and larger broadband.

Laser Fusion Programmes: US

DOE Launches Inertial Fusion Energy Program After Ignition Breakthrough
JUN 06, 2023
Following Lawrence Livermore National Lab's fusion breakthrough last year, DOE is creating new research hubs to stimulate advances in inertial fusion energy and is funding a pair of companies developing inertial fusion reactor concepts through a separate program dedicated to nurturing the nascent fusion industry.





"[] deepening understanding of the physics of fuel targets and improving methods of manufacturing and rapidly focusing beams on them. Other goals include improving the "**scalability, modularity, survivability, compactness, and cost**" of lasers and other fusion drivers as well as performing experiments that validate "high-gain target designs on large-scale facilities."

https://lasers.llnl.gov/news/fusion-ignition-and-the-path-to-inertial-fusion-energy

Laser Fusion Programmes: Germany

Funded by the European Union

Germany Publishes Memorandum on Laser Inertial Fusion Energy

From the FIA, Partnering with Governments

Full list of the memorandum's high-level recommendations:

- 2.1 Fusion energy is in the national interest: pursuing both an IFE and an MFE program is essential
- 2.2 Urgency to move now
- 2.3 Building trust for fusion energy
- 2.4 Need for establishing competency-based fusion hubs
- 2.5 Focus needed for establishing successful leadership in IFE
- 2.6 Evaluating and prioritization of IFE concepts
- 2.7 Develop an integrated system
- 2.8 Establish public private partnerships
- 2.9 Establish international collaborations
- 2.10 Strategize on IFE implosion facility
- 2.11 Maintain IFE approaches until assessment studies are done
- 2.12 Assess IFE programs for accountability
- 2.13 Build and maintain German competencies
- 2.14 Development of an IFE curriculum is needed
- **2.15 Need for a high brilliance, pulsed fusion neutron source**
- 2.16 Support German industry

Laser Fusion Programmes: UK

Funded by the European Union

UK Programme of Laser Inertial Fusion Technology for Energy UPLiFT

- **Budget:** £10M (4 years, ~80 person-years)
- **Laser design & prototype construction**
- **Implosion Capsule Targets**
- **High-Gain Physics**
  - 3 Omega experiments
  - Extensive ALE code development (Odin)
  - Diagnostic development
- **AWE:** Strategic alignment
  - Exploring additional funding

AWE · Imperial College London · CLF · University of Oxford · Warwick, The University of Warwick · University of York

Prototype IFE Beamline

Goal: Energy-scalable prototype laser beamline for laser fusion energy

Requirement	Specification	Comments
Wallplug efficiency	> 10%	Plant profitability: Running costs
Final wavelength	<= 527nm	Drive efficiency, LPIs, optics damage
Cost	< £10k/J	Plant profitability: Capital & interest
Bandwidth	~1%	LPI mitigation (CBET), Imprint reduction
Repetition rate	>= 10 Hz	Plant profitability: power output
Min. beam energy	~1kJ	System Complexity
Zooming	?	Drive efficiency: Mitigate CBET?

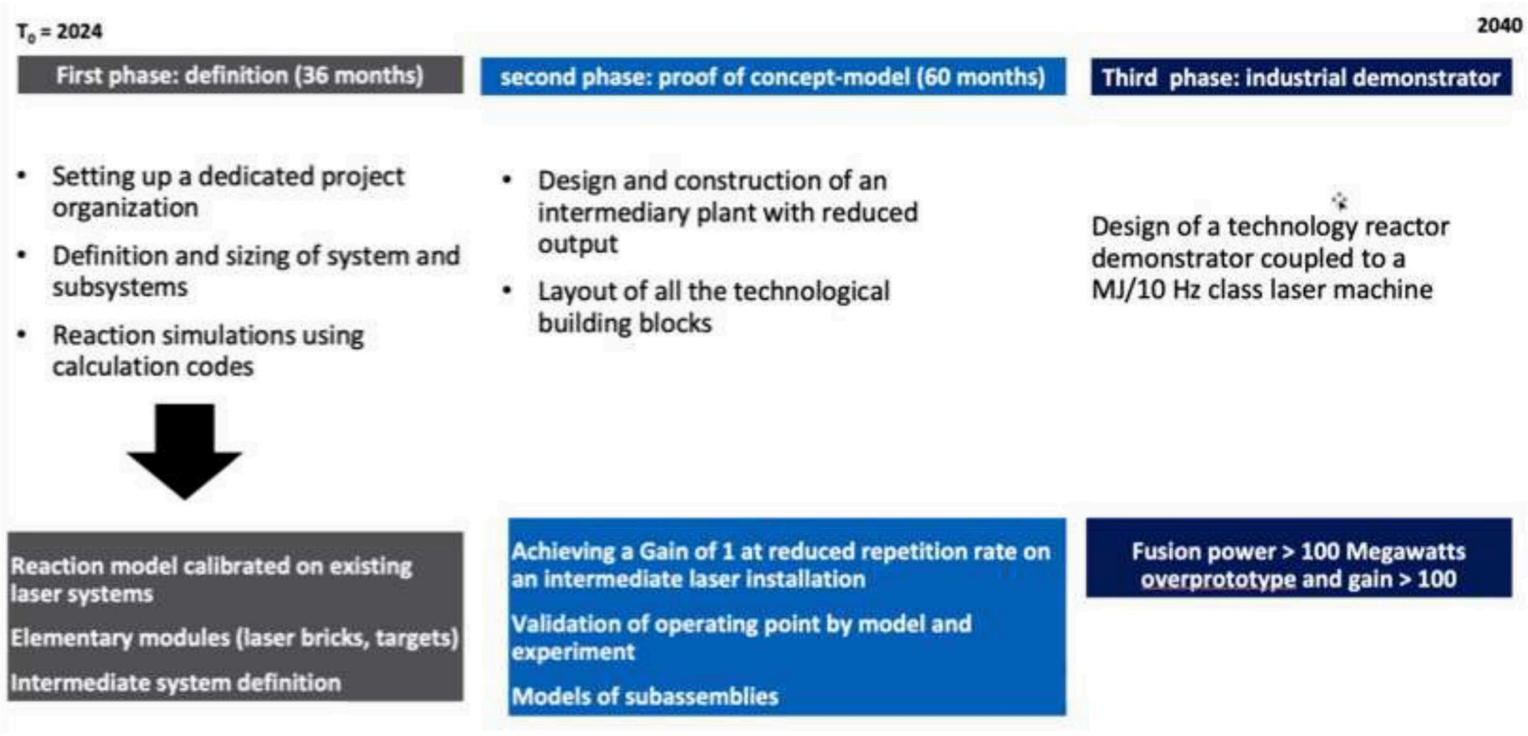
Laser Fusion Programmes: France

Funded by the European Union

"Taranis," a new French initiative towards IFE, is is a consortium of CNRS, CELIA, and Thales supported by the French public investment bank (**Banque publique d'investissement**)

Laser Fusion Programmes: France

"Taranis," a new French initiative towards IFE, is is a consortium of CNRS, CELIA, and Thales supported by the French public investment bank (**Banque publique d'investissement**)



Fusion Companies

Funded by the European Union

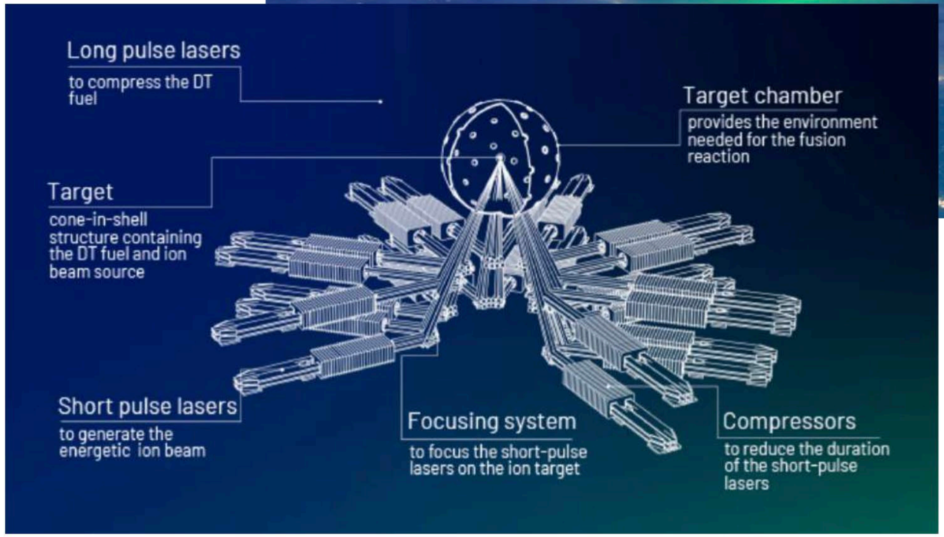
FUSION INDUSTRY ASSOCIATION

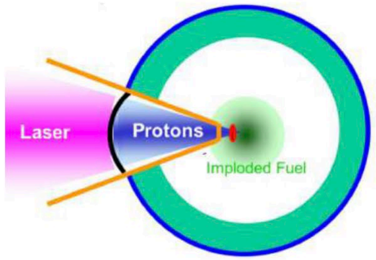
ABOUT POLICY NEWS LEARN CONTACT

- Focused Energy
- Kyoto Fusioneering
- Thea Energy
- Realta Fusion
- Tokamak Energy
- HB11 Energy
- first light
- Gauss Fusion
- Xcimer Energy Corporation
- fuse
- EX-Fusion
- Marvel Fusion
- Proxima Fusion
- Helical Fusion
- Renaissance Fusion
- nT-tao Compact Fusion Power
- Stellarex
- Helicity Space
- nearstar fusion
- SHINE
- Blue Laser Fusion
- LPP Fusion
- MIFTI
- Electric Fusion Systems
- Horne Technologies
- Novatron
- Longview Fusion
- acceleron
- LaserFusionX
- OpenStar Technologies Ltd

Funded by the European Union

Focused Energy (Germany)
Proton driven Fast ignition





Laser Fusion Companies:HB11

Funded by the European Union

HB11 Energy, Australia
(funded in 2017 by H.Hora)

Safe fusion technology for sustainable baseload energy

HB11 Energy is developing commercially viable fusion energy technology that can be deployed worldwide. We're creating solutions that will safely generate the most abundant and permanent supply of clean energy.

Because we can't afford to wait.

THE PATH TO ENERGY ABUNDANCE

Laser Boron Fusion is the cleanest, safest and most permanent source of energy

Laser Fusion Companies: HB11

Funded by the European Union

HB11 ENERGY

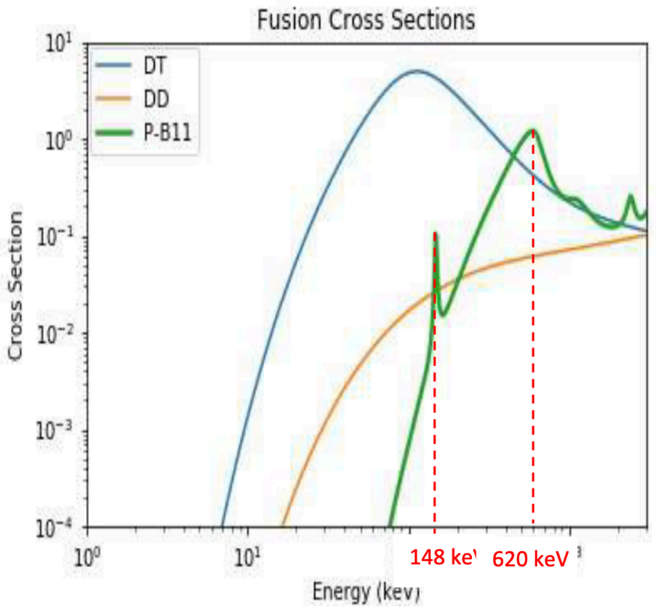
HB11 Energy, Australia (funded in 2017 by H.Hora)

$p + {}^{11}B \rightarrow \alpha + {}^{8}Be \rightarrow \alpha + (\alpha + \alpha) + 8.7\ \text{MeV}$

Advantages:

- ✓ Aneutronic Energy Production (low activation)
- ✓ B is more abundant than Li
- ✓ Relies on stable fuel elements only (no need to ”create” short-living elements like tritium, no need to handle with fuel radioactivity)
- ✓ Does not need cryogenic technology (boron in solid state at room temperature)
- ✓ Direct conversion of energy possible

Difficulty:



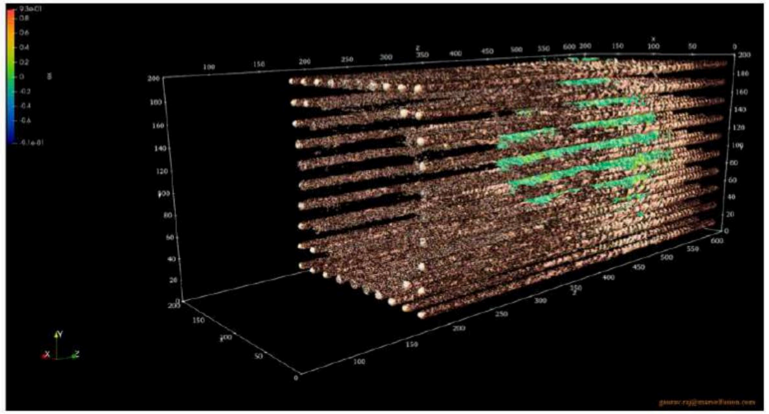
➡ Proton-driven HB fast ignition (“non thermal” approach)

Laser Fusion Companies: MarvelFusion

MarvelFusion

Marvel Fusion (Germany)
Hydrogen-boron fusion without compression

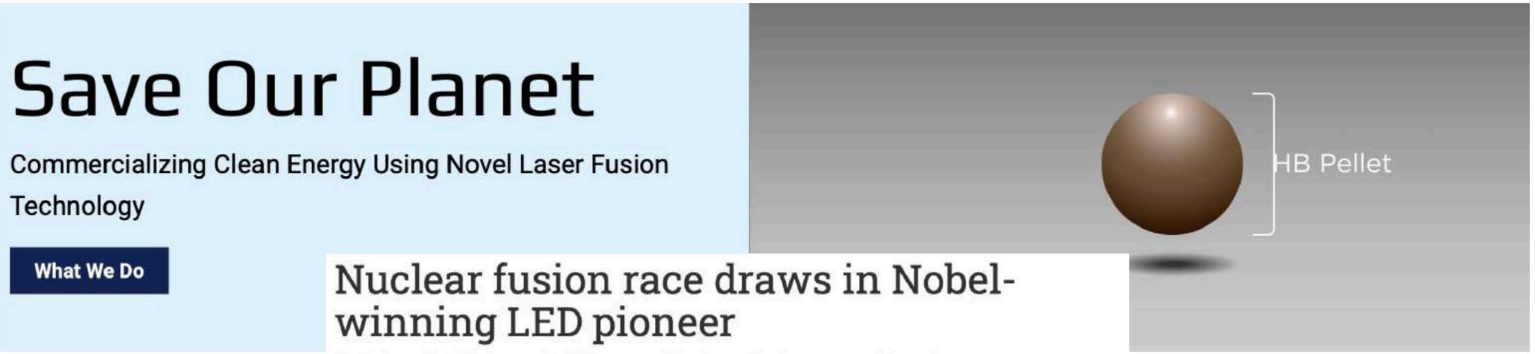
Coulomb explosion of an ensemble of nanowires irradiated by a high intensity laser



Laser Fusion Companies: BLF

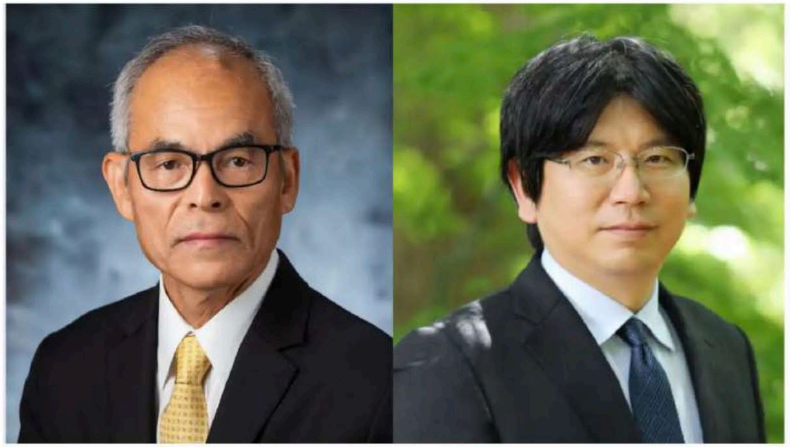
Blue Laser Fusion (Japan - US)

Proton boron fusion



Nuclear fusion race draws in Nobel-winning LED pioneer

Exclusive: Shuji Nakamura's U.S. startup Blue Laser Fusion pursues 'dream' energy source



Shuji Nakamura, left, and Hiroaki Ohta are co-founders of Blue Laser Fusion, a U.S. startup pursuing nuclear fusion energy.

Funded by the European Union

Route from user facility to reactor design through public-private partnership

CrossMark

High Power Laser Science and Engineering, (2021), Vol. 9, e52, 4 pages.
doi: 10.1017/hpl.2021.41

HIGH POWER LASER SCIENCE AND ENGINEERING

PERSPECTIVE

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

S. Atzeni[1], D. Batani[2], C. N. Danson[3,4], L. A. Gizzi[5], M. Perlado[6], M. Tatarakis[7,8], V. Tikhonchuk[2,9], and L. Volpe[10,11]

[1] *Dipartimento SBAI, Università di Roma "La Sapienza", Roma 00161, Italy*
[2] *CELIA, Université de Bordeaux–CNRS–CEA, UMR 5107, 33405 Talence, France*
[3] *AWE, Aldermaston, Reading RG7 4PR, UK*
[4] *Centre for Intertial Fusion Studies, Blackett Laboratory, Imperial College London, London SW7 2AZ, UK*
[5] *Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, 56125 Pisa, Italy*
[6] *Instituto Fusión Nuclear "Guillermo Velarde" Universidad Politecnica, 28006 Madrid, Spain*
[7] *Institute of Plasma Physics and Lasers, Hellenic Mediterranean University Research Centre, 74100 Rethymno, Greece*
[8] *Department of Electronic Engineering, Hellenic Mediterranean University, 73133 Chania, Greece*
[9] *ELI-Beamlines Center, Institute of Physics, Czech Academy of Sciences, 25241 Dolni Brezany, Czech Republic*
[10] *Centro de Laseres Pulsados (CLPU), Parque Cientifico, E-37185 Villamayor, Salamanca, Spain*
[11] *Laser-Plasma Chair at the University of Salamanca, E-37185 Villamayor, Salamanca, Spain*
(Received 10 September 2021; accepted 14 September 2021)

Abstract
Fusion energy research is delivering impressive new results emerging from different infrastructures and industrial devices evolving rapidly from ideas to proof-of-principle demonstration and aiming at the conceptual design of reactors for the production of electricity. A major milestone has recently been announced in laser fusion by the Lawrence Livermore National Laboratory and is giving new thrust to laser-fusion energy research worldwide. Here we discuss how these circumstances strongly suggest the need for a European intermediate-energy facility dedicated to the physics and technology of laser-fusion ignition, the physics of fusion materials and advanced technologies for high-repetition-rate, high-average-power broadband lasers. We believe that the participation of the broader scientific community and the increased engagement of industry, in partnership with research and academic institutions, make most timely the construction of this infrastructure of extreme scientific attractiveness.

Keywords: fusion energy; high power lasers; plasmas; inertial fusion; high energy density

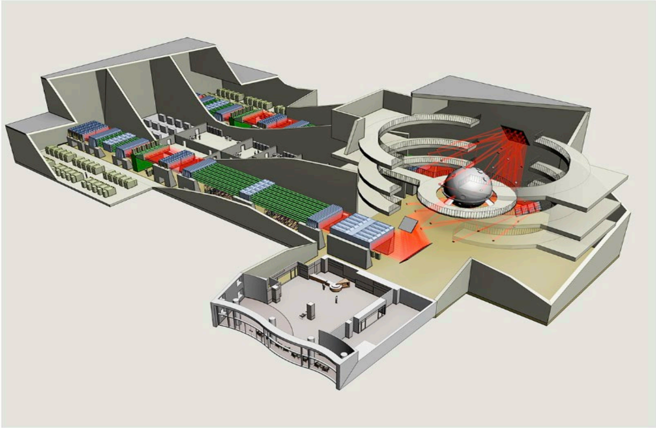
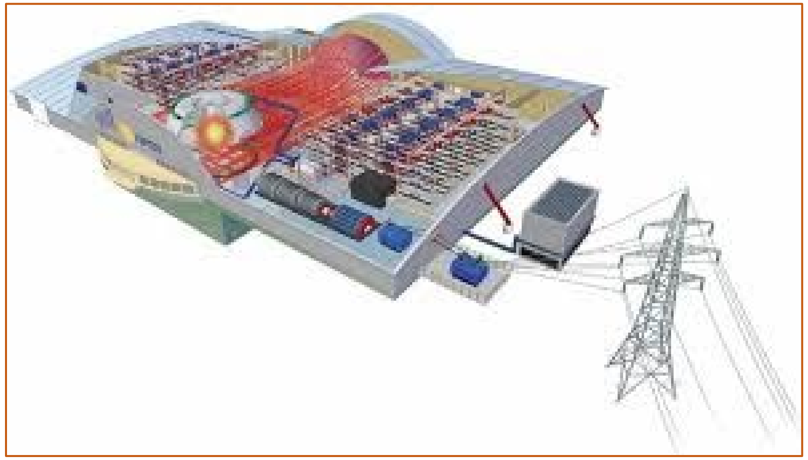


Figure 2. Original concept of the HiPER facility for demonstration of direct-drive laser fusion[4].

http://www.hiper-laser.org/.



A view for long term scenario of ICF in Europe

Funded by the European Union

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]

[1] *Centre Lasers Intenses et Applications (CELIA), Université de Bordeaux–CNRS–CEA, Talence cedex, France*
[2] *ENEA, Fusion and Technology for Nuclear Safety and Security Department, C.R. Frascati, Frascati, Italy*
[3] *AWE, Aldermaston, Reading, UK*
[4] *Centre for Inertial Fusion Studies, Blackett Laboratory, Imperial College London, London, UK*
[5] *Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche (CNR-INO), Pisa, Italy*
[6] *ETSIAE Universidad Politecnica de Madrid, Madrid, Spain*
[7] *GSI-Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany*
[8] *Laboratoire pour l'Utilisation des Lasers Intenses (LULI), CNRS–Ecole Polytechnique, Palaiseau cedex, France*
[9] *ALP, Le Barp, France and CEA/DAM Île de France, Bruyères le Châtel, Arpajon cedex, France*
[10] *Instituto Fusión Nuclear "Guillermo Velarde" (IFN-GV), Universidad Politecnica de Madrid, Madrid, Spain*
[11] *Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Oxford, Oxfordshire, UK*
[12] *Institute of Plasma Physics and Lasers, University Research and Innovation Centre, Hellenic Mediterranean University, Rethymno, Crete, Greece*
[13] *Department of Electronic Engineering, School of Engineering, Hellenic Mediterranean University, Chania, Crete, Greece*
[14] *Extreme Light Infrastructure ERIC, ELI-Beamlines Facility, Dolní Břežany, Czech Republic*
[15] *Centro de Laseres Pulsados (CLPU), Parque Cientifico, Villamayor, Salamanca, Spain*

(Received 24 July 2023; revised 24 August 2023; accepted 8 September 2023)

Abstract
The recent achievement of fusion ignition with laser-driven technologies at the National Ignition Facility sets a historic accomplishment in fusion energy research. This accomplishment paves the way for using laser inertial fusion as a viable approach for future energy production. Europe has a unique opportunity to empower research in this field internationally, and the scientific community is eager to engage in this journey. We propose establishing a European programme on inertial-fusion energy with the mission to demonstrate laser-driven ignition in the direct-drive scheme and to develop pathway technologies for the commercial fusion reactor. The proposed roadmap is based on four complementary axes: (i) the physics of laser–plasma interaction and burning plasmas; (ii) high-energy high repetition rate laser technology; (iii) fusion reactor technology and materials; and (iv) reinforcement of the laser fusion community by international education and training programmes. We foresee collaboration with universities, research centres and industry and establishing joint activities with the private sector involved in laser fusion. This project aims to stimulate a broad range of high-profile industrial developments in laser, plasma and radiation technologies along with the expected high-level socio-economic impact.

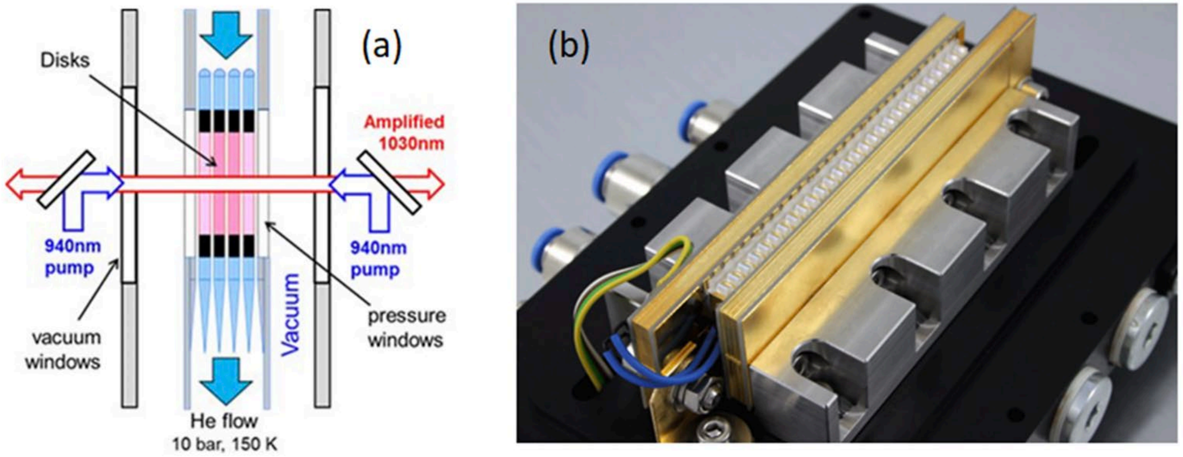


Figure 6. (a) Schematic view of the DiPOLE cryogenically cooled, multi-slab amplifier head[90]. (b) A 3.6 kW diode stack for pumping Yb:YAG pulsed high-energy class solid-state lasers[91].

S. Banerjee et al., Opt. Express 23, 19542 (2015).
R. Platz et al., High Power Laser Sci. Eng. 4, e3 (2016).

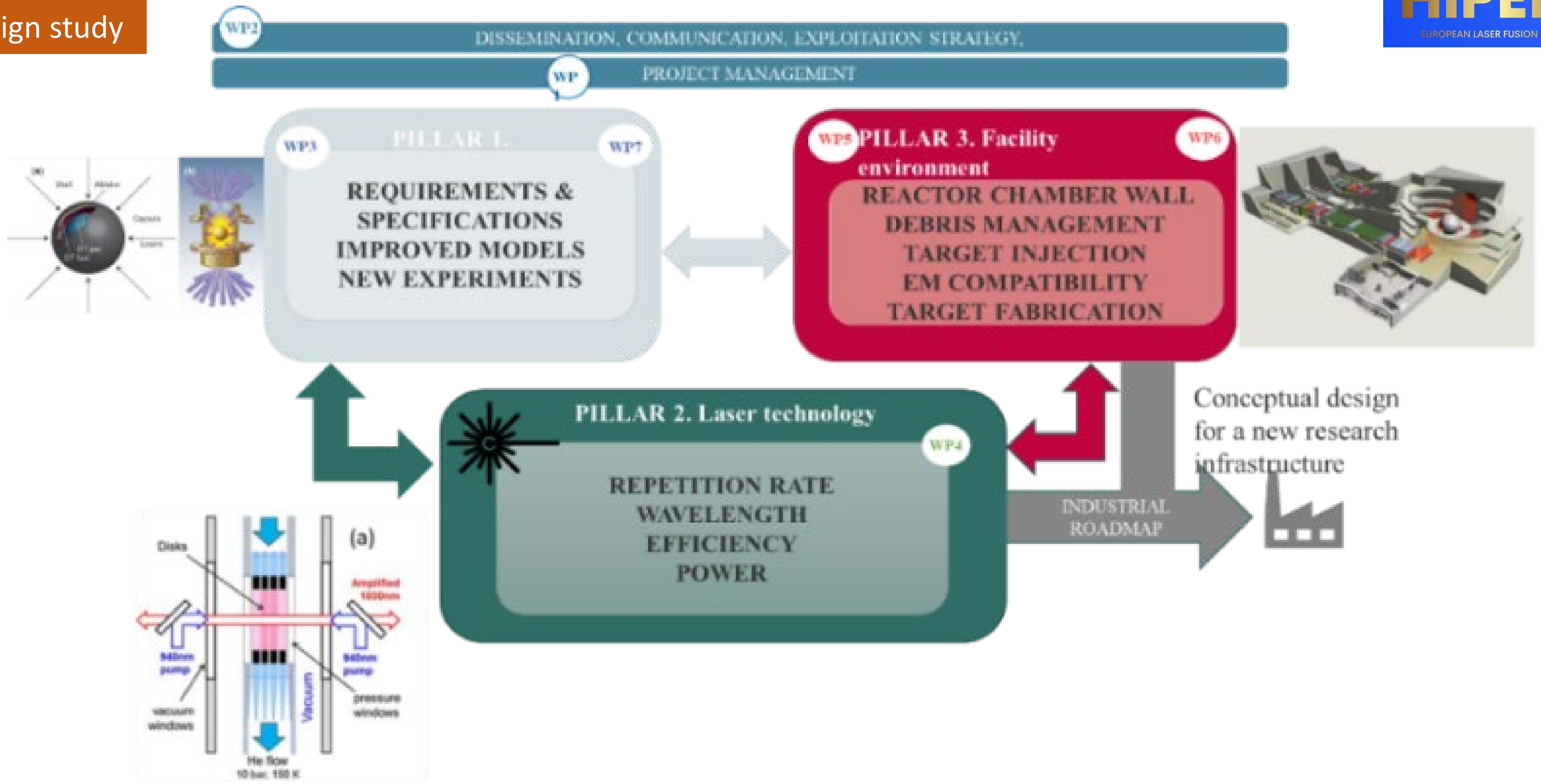
5.2. Development of the IFE laser technology and construction of ICF laser systems

(1) Development of a broadband kJ/ns HRR laser module.
(2) Development of adaptive spatial and temporal pulse shaping
(3) Development of DPSSL technology and optics.
(4) Design and construction of an HRR laser module at 10 kJ and 10 kW.
(5) Development of an HRR laser module for the neutron source for material testing.
(6) Construction of the ICF-TEST facility using a staged modular approach.
(7) Upgrade and exploitation of ICF-TEST facility (sub-Hz repetition rate).
(8) Construction of full-scale IFE-DEMO facility.

Public-Private Partnership for IFE RI: 1st step

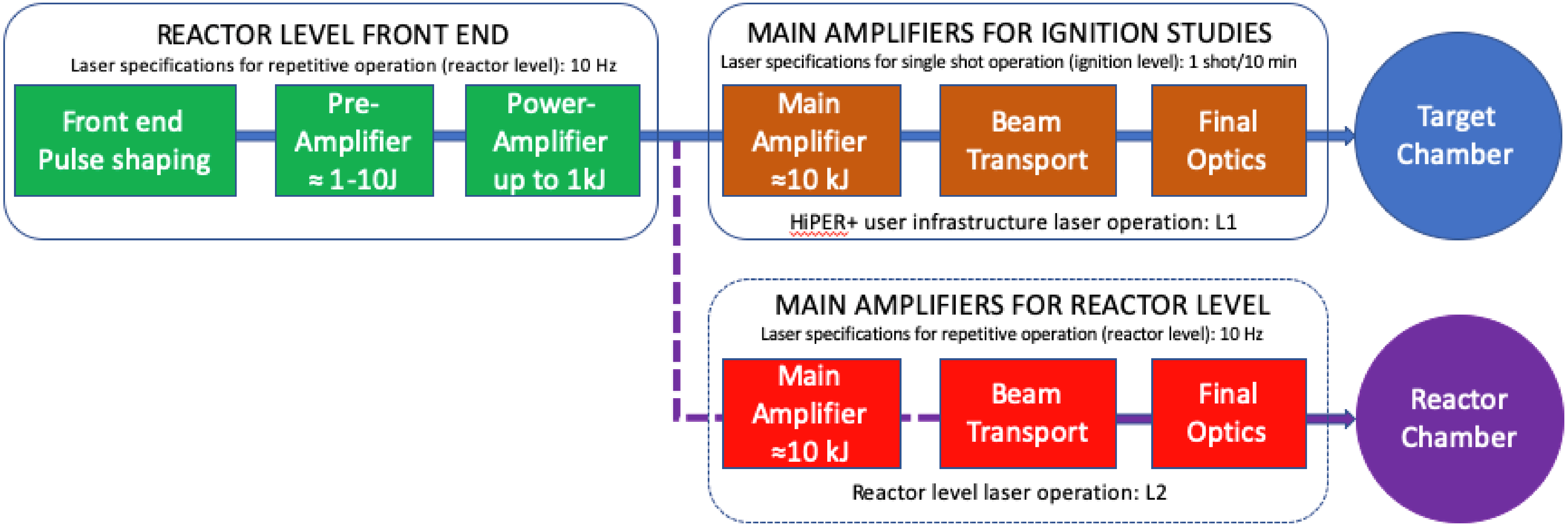
Funded by the European Union

Design study



ICF/IFE Laser beamline: HiPER+

LASER CONCEPT: SINGLE LASER BEAMLINE BLOCK DIAGRAM



Possible schematic layout of the single laser beamline showing the different amplification stages and the two levels of operation to be designed by WP4 to deliver ignition scale pulse energy on target (L1) and to address reactor level technology development

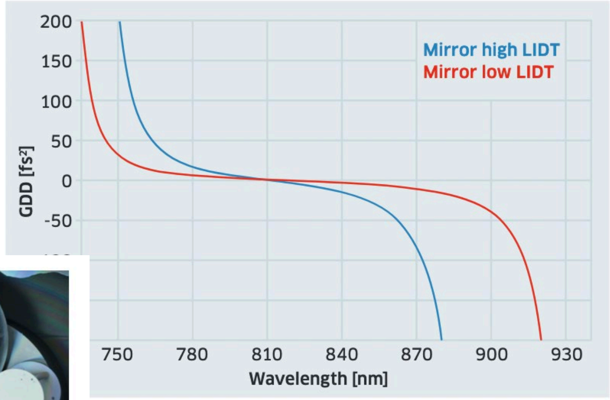
Optics manufacturing

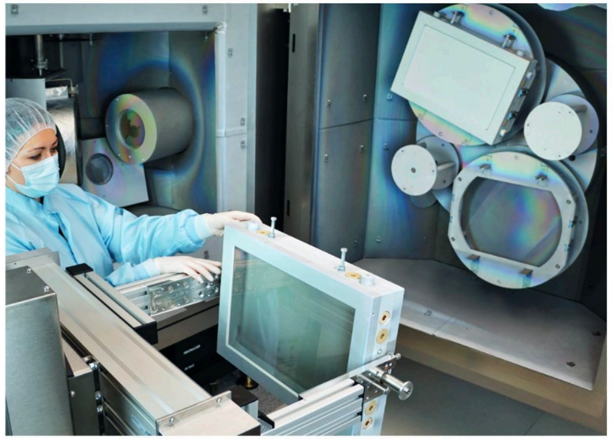
Funded by the European Union

Clean energy by inertial fusion energy: The future of ion beam sputtering technology

Clean energy by inertial fusion energy: A White Paper from Laseroptik

Improve LIDT for better operation and lifetime





"Production of laser optics, including methods to extend the lifespan and increase the laser-induced damage threshold (LIDT) of the kind of dielectric optics that are essential for **large-scale laser facilities**. These high-power laser pulses are increasingly being investigated for developing inertial fusion power plants, paving the way for CO_2 free energy generation."

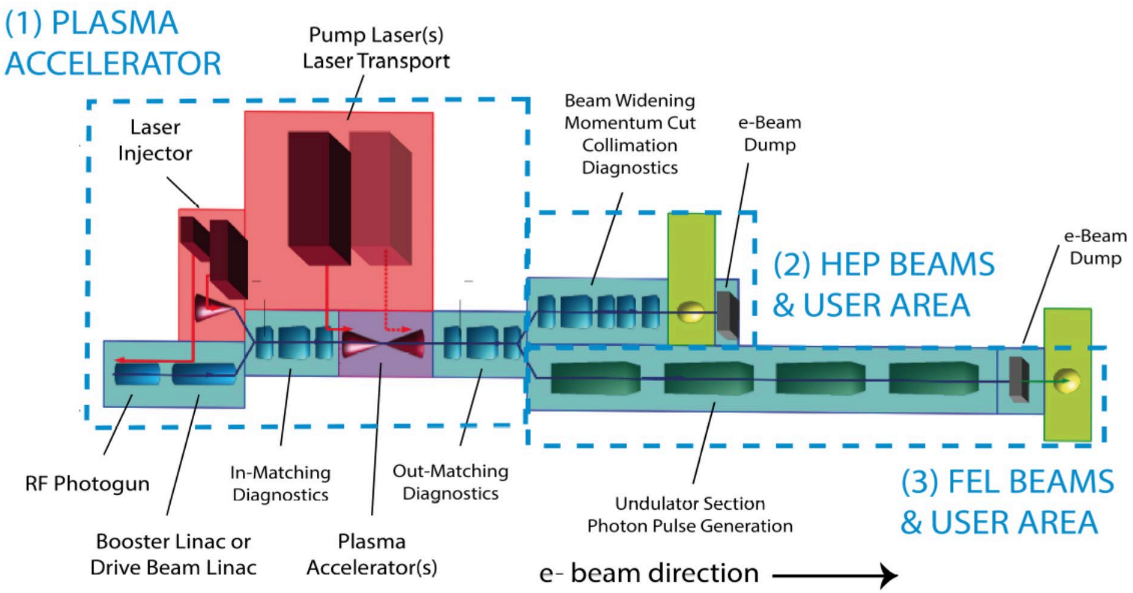
https://www.electrooptics.com

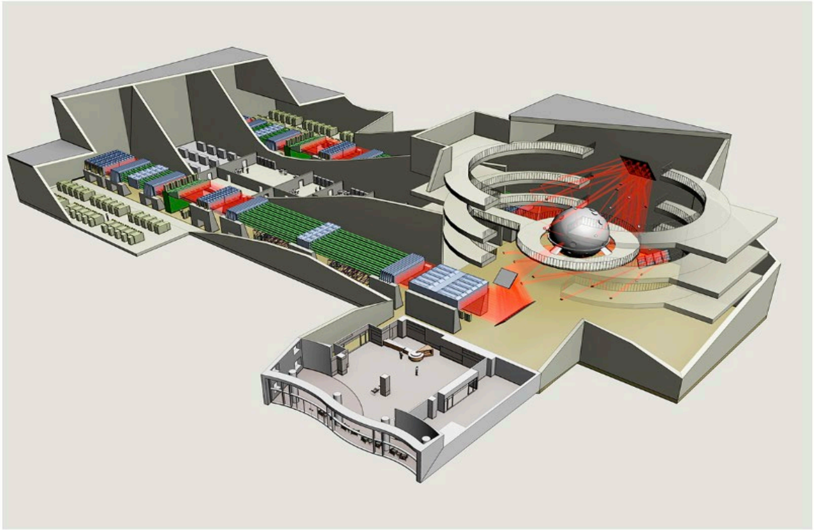
Ongoing effort also at ELI sites on custom optics manufacturing

EuPRAXIA synergy with ICF/IFE

Synergy with EuPRAXIA concerning "High Average power"mode of operation:

- Massive use of diode lasers
- Scalability
- Long-term operation
- Beam transport
- Modularity
- 24/7 operation
- cost of investments and operation
- Need of industry to deliver components, modules, laser





Conclusions

Funded by the European Union

- Development of affordable laser technology for EuPRAXIA can benefit from large investments in other fields;
- Innovation in radiotherapy can boost a credible industrial laser-based plasma acceleration;
- Laser Fusion energy roadmap has a major socio-economic impact and major private investments (>6G€ to date);
- IFE reactor-level laser technology matching EuPRAXIA facility mission/installation
- Learn from public-private partnerships model of IFE to manage the high-risk inherent with the current early stage of industrial development.

Acknowledgements

- EuPRAXIA Preparatory Phase

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101079773. It is supported by in-kind contributions by its partners and by additional funding from UK and Switzerland.

- EuPRAXIA Doctoral Network

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement no. 101073480 and the UKRI guarantee funds.

- EuAPS

This publication has been made with the co-funding of European Union Next Generation EU.