EUROfusion

Enabling Research Project CfP-FSD-AWP26-ENR-01

Conceptual design for a European High Power Laser Fusion Research Facility (HiPER+RF)

Period 2026-2027
12 countries
30 research groups
146 researchers
Funding 2.4 M€

HiPER+
EUROPEAN LASER FUSION ENERGY

- History
- Organisation of the project
- Management of the project
- HiPER+ and the rest of the world
- Concluding remarks

Large impact of NIF results

NIF results provided a validation of the Inertial Fusion concept, achieving ignition beyond breakeven, and opening the pathway to gain.

For the first time in the U.S., they think on the possibility of developing national projects on Inertial Fusion Energy (IFE) as a future source of energy

- **Basic Research Needs** report: a foundational guide for DOE to establish a national IFE program in the USA

Germany has suddenly changed its attitude towards IFE

- **Memorandum** on laser IFE for the federal ministry of education and research of Germany (May 2023) and more recently statement of allocation of 1 B€ to fusion research

A big shift from defense-driven research to energy-oriented research

NIF results triggered the creation of several start-ups

FOCUSED ENERGY

GenF — LE GÉNÉRATEUR À FUSION POUR LA GÉNÉRATION FUTURE

HB11 ENERGY

HB11 Energy, Australia (funded by H.Hora)

BLUE LASER FUSION, INC.™

Nuclear fusion race draws in Nobel-winning LED pioneer

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

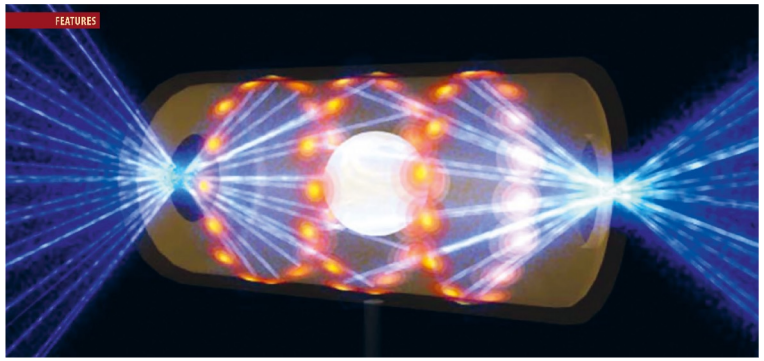
Shuji Nakamura, left, and Hiroaki Ohta are co-founders of Blue Laser Fusion, a U.S. startup pursuing nuclear fusion energy.

MarvelFusion

RSE Ricerca Sistema Energetico — we move research

inertia

(funded by M.Dunne)



BREAKTHROUGH AT THE NIF
PAVES THE WAY TO INERTIAL FUSION ENERGY

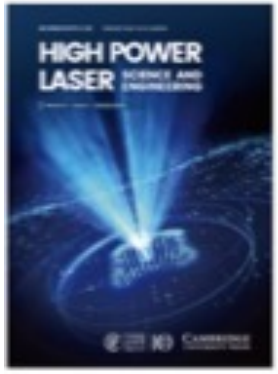
S. Atzeni[1], D. Batani[2], C. N. Danson[3,4], L. A. Gizzi[5], S. Le Pape[6], J-L. Miquel[7], M. Perlado[8], R.H.H. Scott[9], M. Tatarakis[10,11], V. Tikhonchuk[2,12], and L. Volpe[13,14] – DOI: https://doi.org/10.1051/epn/2022106

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 an HiPER+ project signed by European scientists

https://www.clpu.es/Laser_Fusion_HiPER



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

HIGH POWER LASER SCIENCE AND ENGINEERING

High Power Laser Science and Engineering, (2023)
doi:10.1017/hpl.2023.80

REVIEW SPECIAL ISSUE ON ICF

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]

HIPER+ initiative

Inertial Fusion beyond NIF results

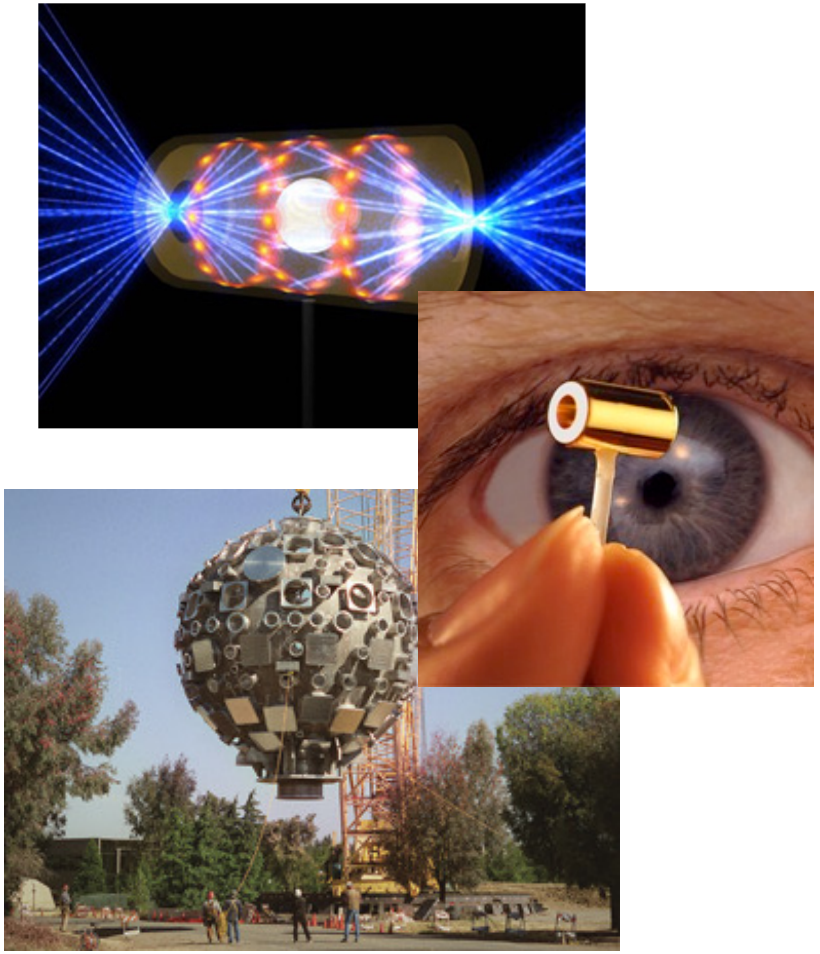
NIF results represent a breakthrough. However, INDIRECT DRIVE used at NIF **does not seem compatible** with requirements for future fusion reactors:

- Complicated targets
- Massive targets (lot of high-Z material in chamber)
- Intrinsic low gain
- "Political" issues

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

- Science: Investigate the **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, …

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

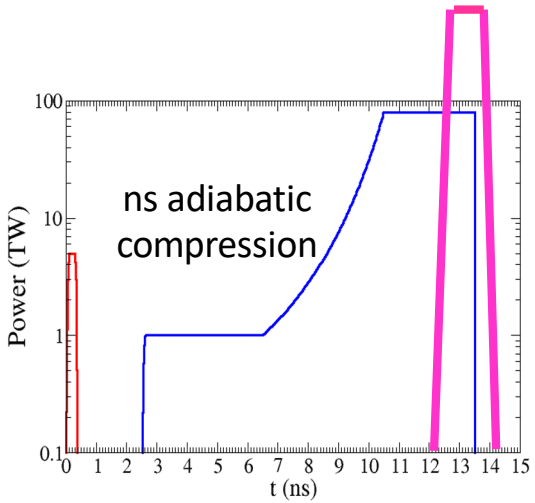


How to mitigate hydro instabilities in Direct Drive?

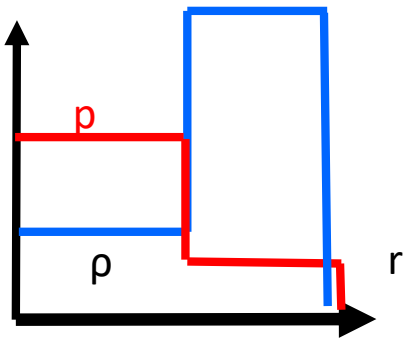
Separation of compression and ignition phases

Shock Ignition – Shock Augmented ignition

- 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)]
- Thicker and more massive target at lower implosion velocity V ≈ 240 km/s are intrinsically more resistant against the effect of hydro instabilities
- A final laser spike launches a strong converging shock (≥ 300 Mbar at the ablation front). This requires laser intensities ≈ $10^{16}\ W/cm^2$



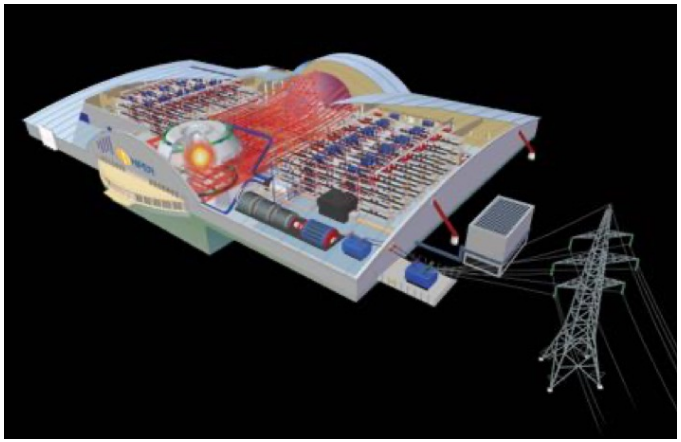
Ignition spike (a few 100 ps)



- Non isobaric fuel assembly implies higher gains
- Compatible with present-day laser technology ☺

On what we build: The HiPER legacy

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 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. One-two projects per year related to IFE at the level of $\sim 300\ k€$ per year per project (2017-2025)

Strengths:

- Role of EU of scientists with ground-breaking contributions to ICF and important work on shock ignition done in the last 10 years within EUROFusion projects;
- Important, and often pioneering contributions in laser-plasma physics and applications;
- Effective international collaboration in direct drive fusion (e.g. University of Rochester)

Weakness: No experience in driving implosions due to the lack of a dedicated facility
• Direct-drive implosions were done in the 70's and 80's both at the LULI and Vulcan laser facilities but soon these facilities became non-competitive.

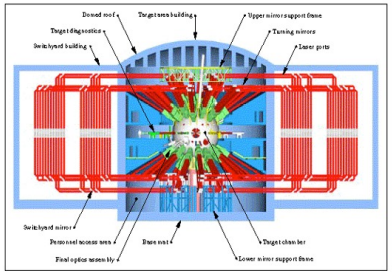
We can make the jump by federating the groups around an IFE test facility in Europe with strong international collaboration

On what we build: Laser Facilities in Europe

- The EU IFE community can profit of large investments in Europe in high-energy laser facilities.

- Systems like Vulcan and Orion (UK), LULI2000 (France) Phelix (Germany), PALS (Czech Republic) and the three **ELI pillars** enable the **study of the physics of direct drive inertial fusion**

Academic access to the **Laser Megajoule** (CEA/DAM): possible but extremely limited;
Not designed for direct drive research (although configurable for PDD)



Laser Megajoule (LMJ)
At CESTA Le Barp near Bordeaux
Developed for defense application
~ 2 B€

On what we build: Training Activities

Erasmus KA2 Project

Innovative Education & Training in Laser Inertial Fusion Energy

LaserFusion
education - training

The educational and training methods will focus on three scientific domains:
2025-2028

Physics and technology of Inertial Fusion Energy (IFE) including diagnostics

Laser and laser-plasma sources technology developments

Computational simulations of IFE including materials.

Funding 400k€ (3 years)

On what we build: International collaborations

LLE Rochester has been pioneering DD for decades and it's the birthplace of shock ignition. Hence HiPER+ does not start everything from "scratch", as already extensive experimental (and simulation) knowledge has been accumulated

Experiment at the laser Gekko, Osaka

EUROPEAN COMMISSION
DIRECTORATE-GENERAL FOR RESEARCH & INNOVATION

Directorate C - Clean Planet
The Director

Brussels,
rtd.c.4.dir(2022)2594050

Dear Prof. Batani, Prof. Tikhonchuk,

April 2022

Thank you for your recent letters to Commissioner Mariya Gabriel and Director-General Jean-Eric Paquet, which bear the proposal for a coordinated international project on Inertial Fusion Energy (IFE) in Europe.

At the European Commission, we are well aware of the recent experimental results at the US National Ignition Facility, and of the excitement those results have prompted in the IFE community worldwide. To a certain extent, the Euratom Research and Training Programme already funds IFE research through the Enabling Research Projects of the EUROfusion consortium. The Euratom Programme, however, is strongly focused on the development of the magnetic fusion concept along the European Fusion Roadmap, and it is therefore not the right instrument to fund IFE activities at the scale envisaged in your proposal.

The European Strategy Forum on Research Infrastructures (ESFRI) appears to be a better suited framework to discuss the idea of a European IFE facility, as the HiPER project, which your proposal builds upon, was included in the 2006 ESFRI Roadmap. I recall that at least three EU Member States or Associated Countries are needed to support an ESFRI proposal. No less importantly, proposal evaluation is based on strict criteria which require that a sound scientific and business case is made upon submission. General information on ESFRI can be found in the dedicated website (https://www.esfri.eu) and further information can be requested through the functional mailbox info@str-esfri.eu.

Wishing you every success with the development of your project, I remain at your disposal for further clarification or information.

Yours faithfully,

e-signed

Rosalinde van der Vlies

The call for the new ER project was the result of a new sensibility towards ICF but also of our lobbying activities with EURATOM, ESFRI, EUROFUSION

Identification of the main gaps:

- Absence of implosion facility
- Technological missing steps in lasers, targets, materials

The absence of an implosion facility which is:

- dedicated to direct drive
- European
- open and civilian

is also identified as a major gap in other ongoing proposal at the European level (e.g. the SRIA document for the PPP launched by EURATOM)

For this reason, the call for Enabling Research Project was centred about preparing the conceptual design for a future European laser facility.

It is a big jump for inertial fusion in Europe: from studying some physical aspects of ICF as “keep in touch” activities to paving the way to a future research program and a future facility on IFE in Europe.

This also determines the character of the project: from blue sky research to a programmatic approach.

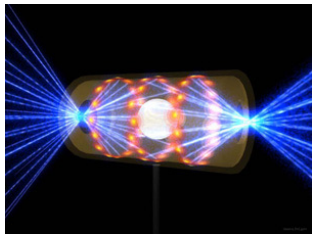
Challenge 1: Lasers

- Develop more efficient laser (≥ 10%)
- Develop high repetition frequency laser (10 Hz)
- Think about the possibility of using 2ω light (532 nm) to reduce damage to optics
- Develop broadband lasers (to quench parametric instabilities)

Challenge 2: Targets

- Develop cheap technology (< 1$/target)
- Develop capability of mass production of targets
- Develop techniques for target injection and alignment at ≈ 1 Hz
- Design of the target insertion and tracking system

All this does NOT seem possible with indirect drive !!



Challenge 3: Materials

- Problems of tritium breeding and handling system
- Problems of activation of materials. Security and safety issues.
- Facing the problem of huge EMP
- Development of remote handling techniques
- Cooling system and energy recovery system.

Many of these issues are common to MCF too (synergies possible)

Conceptual design for a European High Power Laser Fusion Research Facility (HiPER+RF)

Abstract

The HiPER+RF project proposes the conceptual design of a next-generation European laser fusion research facility for Direct Drive (DD) inertial confinement fusion (ICF). While Europe leads in magnetic confinement fusion, it lacks a civilian-accessible laser-driven program, leaving a strategic gap with the US and China. Recent ignition breakthroughs at the US National Ignition Facility (NIF) confirm the credibility of ICF and highlight the urgency for Europe to invest in DD as a complementary path to Inertial Fusion Energy (IFE). A pilot facility at a level of few 100 kJ is needed to address the open physical issues related to direct-drive and to achieve ignition, operating at Hz repetition rates, showing the scalability to high gains (exceeding 100) under reactor-relevant conditions. It will integrate diode-pumped solid-state lasers, scalable target fabrication and injection, radiation-hardened diagnostics, and materials capable of withstanding extreme thermal and neutron loads.

The project aims at addressin bottlenecks in hydrodynamic stability, laser–plasma interaction, target physics, diagnostics, and materials through advanced simulations and tailored experiments. Seven coordinated work packages cover implosion design, experimental validation, efficient laser drivers, targets and materials, diagnostics, system integration, and community building. The expected output is one general conceptual design, including validated DD target designs, a roadmap for high-repetition lasers with >10% wall-plug efficiency, conceptual designs for reliable target production and reactor-scale diagnostics, and a complete facility layout with safety and licensing specifications.

Beyond technical progress, HiPER+RF will reinforce the European IFE ecosystem through workshops, schools, and industry–academia forums, while preparing long-term EU and national support for the construction of the implosion facility. It will also train the next generation of fusion scientists and engineers. The project offers both a pathway to ignition and high-gain DD fusion and a strategic investment in Europe’s energy autonomy, technological leadership, and the green transition.

Organisation of project (WP)

WP1: Project Management, Coordination, and Facility Conceptual Design

WP2: Tailored Experiments

WP3: Laser Technology

WP4: Targets, Materials, and engineering aspects

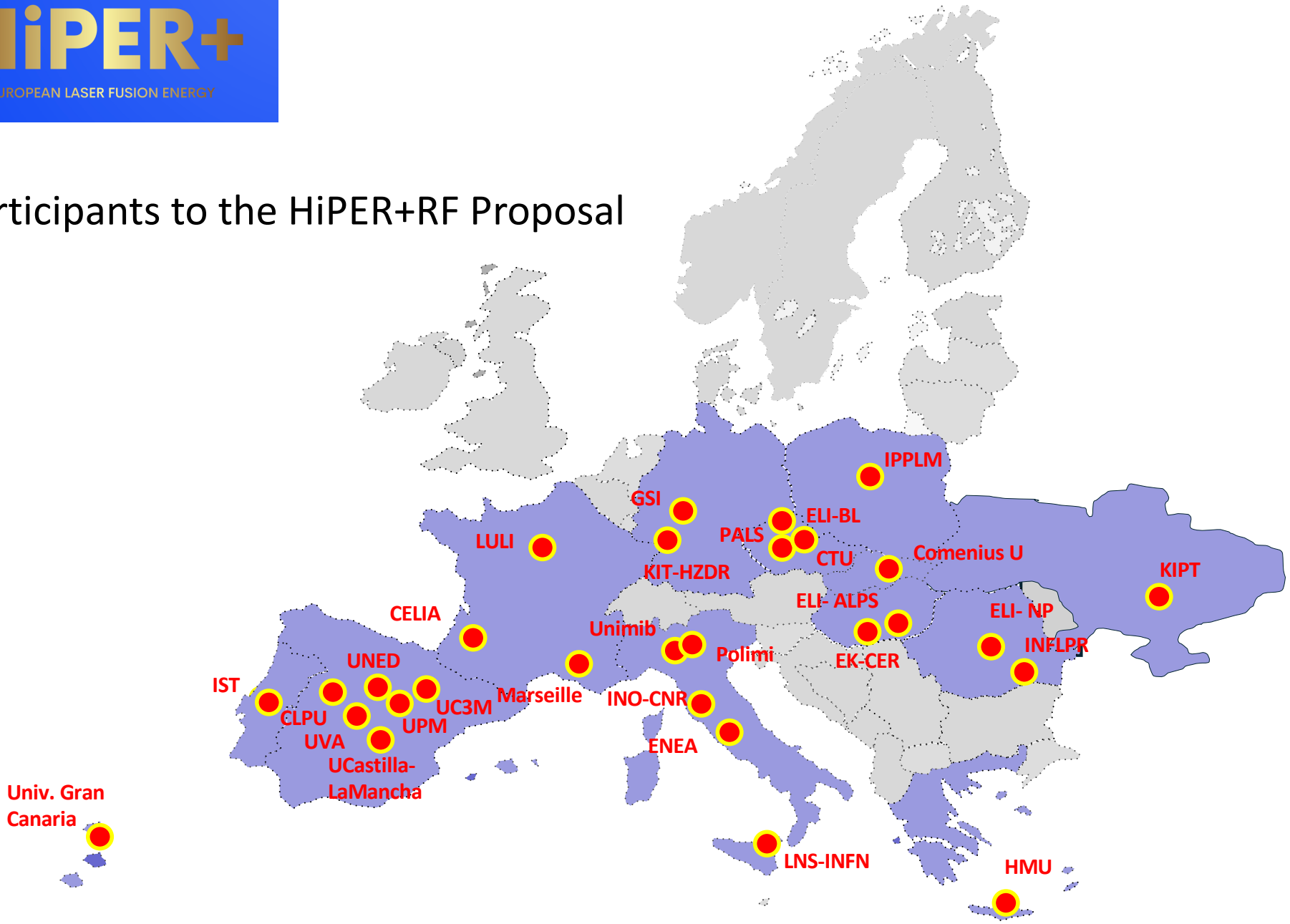
WP5: Laser-Plasma and Nuclear Fusion Diagnostics

WP6: Physics

WP7: Community Building and European Research Landscape Development

HiPER+
EUROPEAN LASER FUSION ENERGY

Participants to the HiPER+RF Proposal



Managing the project

Executive committee. Members: Dimitri, Luca and Michael

Core group. Members: Dimitri, Luca, Michael, Leo, Vincent, Fabrizio, Manolo, Sebastien, and Vladimir.

Management committee including at least one representative per country and of the main groups. The committee role is important in order to prepare the future beyond the current project.

WP coordinators

For each group:
Local responsible. Each research group has a local responsible who acts as contact point between the group and the management of the project

Local WP responsible. Each group has one responsible for each WP

WP coordination

WP1: Project Management, Coordination, and Facility Conceptual Design
(Dimitri Batani, Luca Volpe, Michael Tatarakis)

WP2: Tailored Experiments
(Gabriele Cristoforetti, Sebastien LePape, Paul Neumeyer)

WP3: Laser Technology
(Leonida Gizzi, Vincent Bagnoud)

WP4: Targets, Materials, and engineering aspects
(Manolo Perlado, Fabrizio Consoli)

WP5: Laser-Plasma and Nuclear Fusion Diagnostics
(Marta Fajardo, Sebastien LePape, Massimiliano Sciscio, Thomas Cowan, Luca Volpe)

WP6: Physics
(Vladimir Tikhonchuk, Michael Tatarakis)

WP7: Community Building and European Research Landscape Development
(Pablo Cirrone, Katarzyna Batani, Daniele Margarone, Sakura Pascarelli, Ioannis Fitilis, Piotr Raczka)

Attention and interaction with what is going on around us

Strategic collaborations

- We welcome external contributions and partnerships with European world-leading laser technology companies (Thales, Amplitude, …), European IFE start-ups (Marvel, GenF, Focused Energy, …), and with colleagues in the US, UK, China.
- The project aims at reinforcing the IFE community in Europe by strengthening collaboration with major European facilities (Phelix, LULI, PALS, ELI, …).
- More to come …. COST proposal, INFRA DEV proposal, … (act as an "incubator" of proposals…)
- We started a close collaboration with the HZDR Helmholtz-Zentrum Dresden-Rossendorf, the European XFEL, and, with the three ELI pillars.
- The recent ELI call for experiments in the field of IFE highlights the need for programmatic research in the field and testifies the high interest in IFE all over European research facilities and scientific community.

HiPER+
EUROPEAN LASER FUSION ENERGY

eli

Expression of Interest: ELI Mission-Based Access Program in Inertial Fusion Energy (IFE)

Developing knowledge in the field of IFE
requires PROGRAMMATIC research !

The Interaction with fusion start-ups is important ...

Today IFE is a credible approach to Fusion Energy, however the challenges are still very big, both technologically and scientifically.

Even with ∞ money, the needed time cannot be indefinitely compressed.

Now it is necessary to maintain the scientific enthusiasm and optimism but keep scientific credibility

Conclusive remarks

The HiPER+RF proposal paves the way to the future European IFE reactor, through a truly multidisciplinary scope —plasma physics, laser engineering, materials science, … The proposed facility will thus serve as a European hub for frontier science while advancing a roadmap to scalable energy production.

Historically, inertial confinement fusion has been driven by military programs. Europe now has the opportunity to redefine this trajectory by establishing an open, civilian facility for DD ignition and high-repetition experiments. The HiPER+RF initiative positions the EU at the forefront of peaceful fusion development, committed to transparency, collaboration, and scientific excellence.

The project will also play a key role in educating and training a new generation of fusion experts across computational physics, optics, cryogenics, diagnostics, and regulatory science. This creates fertile ground for careers in academia and industry, while broadening Europe's fusion strategy beyond tokamaks. Such diversification strengthens the prospects for long-term energy sovereignty and aligns with the Green Deal, and other decarbonization initiatives.

By starting with a research-scale installation, the project minimizes risks while maximizing returns in experimental data, community building, and validation of critical technologies. Its modular design will ensure adaptability to rapid technological change and evolving stakeholder needs.

Next steps

- WP working on the preparation of the respective chapters of the Conceptual Design
- Close coordination with European large-scale laser facilities to prepare future work, including experimental campaigns
- Collaboration with Start-ups, Industrial world, creating political advocacy for IFE in Europe
- Preparation of consortia and proposals for the PPP
- End 2026: Organization of an industry–academia forum involving European decision-makers (participation of EURATOM, IAEA, EUROFusion, …)

Conclusion

The HiPER+RF project represents a *unique opportunity* for developing IFE research in Europe and proposing the construction of an international, civilian, implosion facility dedicated to direct drive.

Our community should not miss this opportunity!!