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Enabling Research project CfP-FSD-AWP21-ENR-01-CEA-02

«Advancing shock ignition for direct-drive inertial fusion»

Duration: April 2021 – March 2024

(initially January 2021-December 2023)

PI Dimitri Batani

Co-PI Stefano Atzeni

EUROFusion Audit, Monday 29 November 2021

Task agreement expected in November 2021 ??

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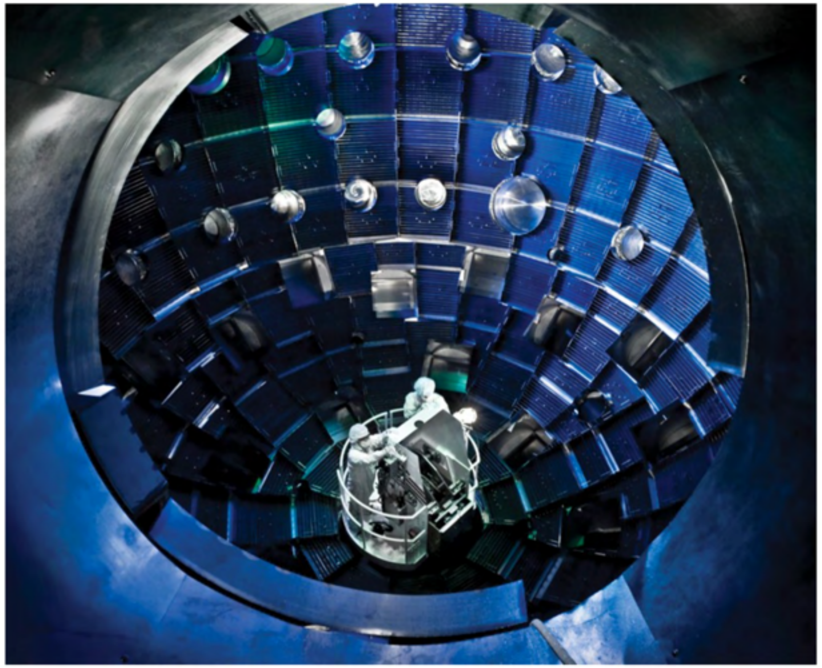
NEWS EXPLAINER | 27 August 2021

US achieves laser-fusion record



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

LaserFocusWorld

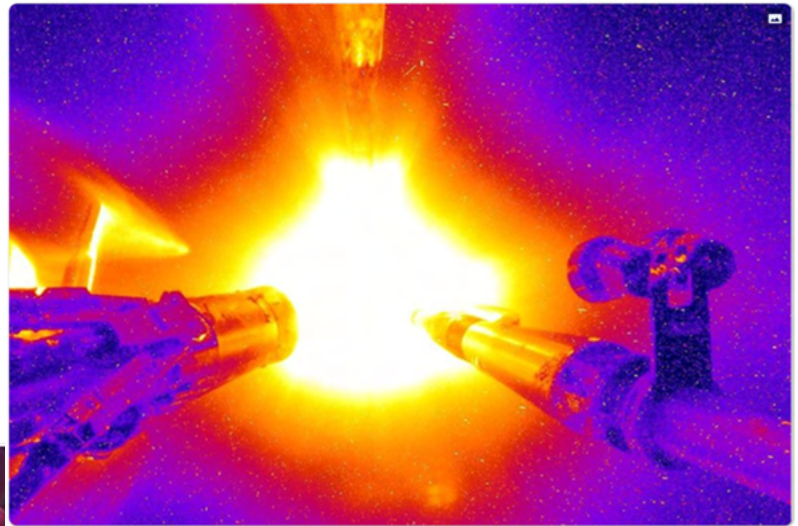
COMMENTARY

NIF achieves breakthrough in laser fusion

America's National Ignition Facility measured a record of 70% conversion in their laser fusion experiments. For a brief moment the fusion was self-sustaining. A moment that excites people around the globe.

Andreas Thoss

Aug. 23, 2021



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

(Download Image)

On Aug. 8, 2021, an experiment at the National Ignition Facility put researchers at the threshold of fusion ignition, achieving a yield of more than 1.3 megajoules — an 8X improvement over experiments conducted in spring 2021 and a 25X increase over NIF's 2018 record yield. Credit: John Jett, LLNL.

National Ignition Facility experiment puts researchers at threshold of fusion ignition

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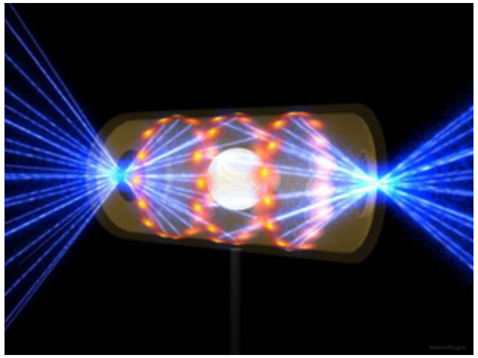
Inertial Fusion research in Europe

National Agencies (CEA in France, AWE in UK) work on indirect drive.

Academic research addresses the study of the physics of the direct-drive approach to Inertial Fusion because this is what we are allowed to do but also because we believe that INDIRECT DRIVE does not seem compatible with requirements for future fusion reactors:



- Complicated targets
- Massive targets (lot of high-Z material in chamber)
- Intrinsic low gain due to step of X-ray conversion.

In addition, indirect drive poses "political" problems...

The experimental activity addresses specific physics problems in ICF using "small" laser facilities available in Europe (PALS, LULI2000, Phelix, Vulcan)

The Academic Opening (up to 20% of time) of the LMJ/PETAL laser facility may open new perspectives for ICF research in Europe (although for the moment the number of shots is very limited)

Previous collaboration projects

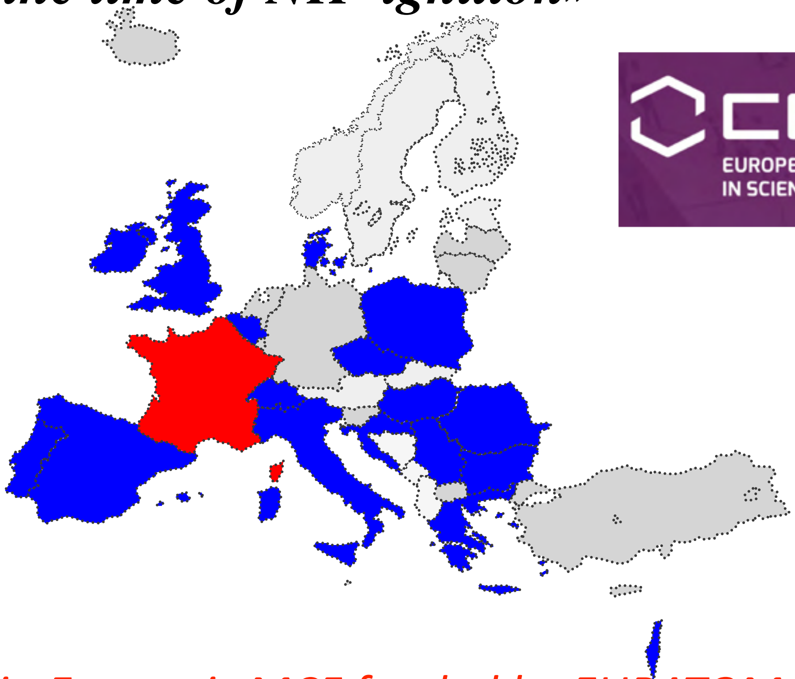
2005-2014

European project "HIPER" (European High Power laser Energy Research)

2013-2017

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

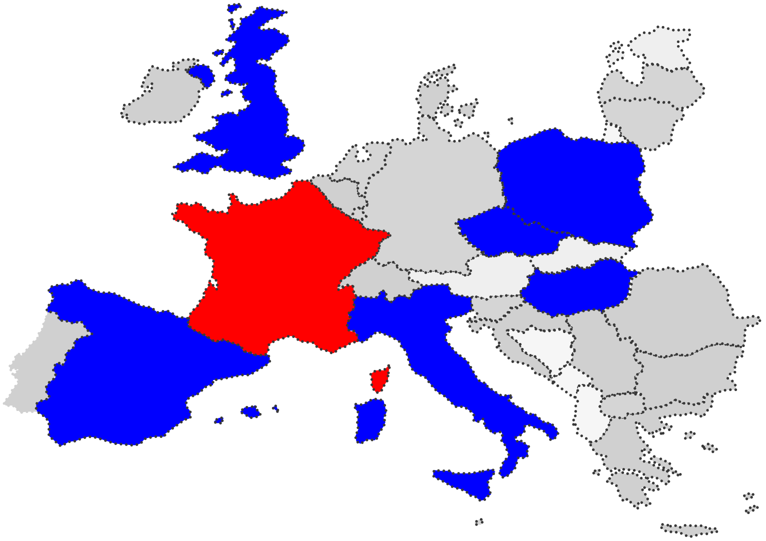
Participants : FR
BE, BG, CH, CZ, DK,
GR, ES, HU, IL, IT, PL,
PT, RO, RS, UK



The main (only) approach to Fusion in Europe is MCF funded by EURATOM.
Construction of an IFE community relies on parallel program and small funding ☹

Previous collaboration projects

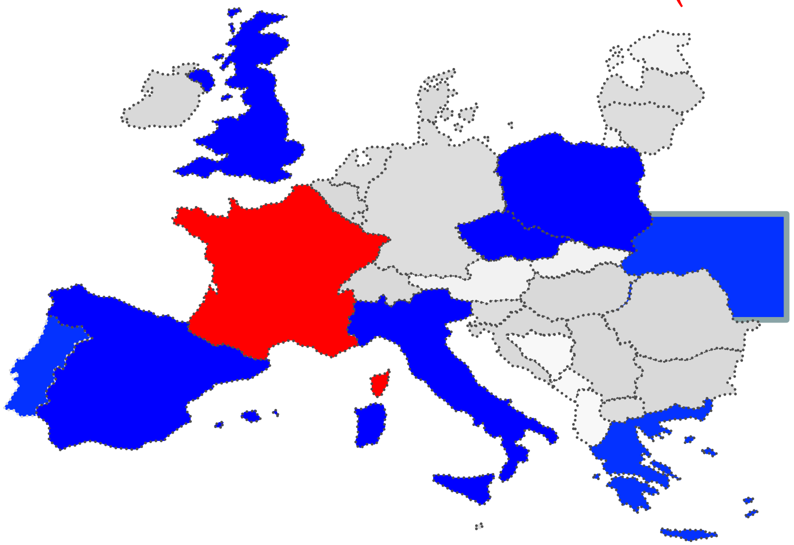
2017-2018



Enabling Research Project **CfP-AWP17-IFE-CEA-01 «Preparation and Realization of European Shock Ignition Experiments»**

Participants: FR, CZ, ES, IT, PL, UK, HU

2019-2021 (extended)



Enabling Research Project ENR-IFE19.CEA-01 "Study of Direct Drive and Shock Ignition for IFE: Theory, Simulations, Experiments, Diagnostics development "

Participants: FR, CZ, ES, IT, PL, UK, GR, PT, UKR

Some scientific results from previous ER Eurofusion projects

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L. Antonelli, J. Trela, et al. “Laser-driven strong shocks with infrared lasers at intensity of 10^{16} W/cm^2” Phys. Plasmas 26, 112708 (2019)
Characterization of shock dynamics and HE at 1ω

G. Cristoforetti, L. Antonelli, et al. “Time evolution of Stimulated Raman Scattering and Two Plasmon Decay at laser intensities relevant for Shock Ignition in a hot plasma” *High Power Laser Science and Engineering*, 7, 2019 , e51 (2019) DOI: https://doi.org/10.1017/hpl.2019.37
LPI characterization at 1ω and 3ω

D. Batani, L. Antonelli, et al. “Progress in understanding the role of hot electrons for the shock ignition approach to inertial confinement fusion” Nucl. Fusion 59 (2019) 032012
Summary of our results obtained at PALS on HE generation

J. Trela, W. Theobald, et al. «The control of hot-electron preheat in shock-ignition implosions» Physics of Plasmas 25, 052706 (2018)
Collaboration with Omega on analysis of HE effects on implosion results
S.D. Baton, A. Colaïtis, C. Rousseaux, G. Boutoux, S. Brygoo, L. Jacquet, M. Koenig, D. Batani, A. Casner, E. Le Bel, D. Raffestin, et al. “Preliminary results from the LMJ-PETAL experiment on hot electrons characterization in the context of Shock Ignition” High Energy Density Physics (2020)
First results from the LMJ shock ignition experiment in planar geometry

Koki Kawasaki, Yoichiro Hironaka, Yuto Maeda, Toshihiro Iwasaki, Daisuke Tanaka, Dimitri Batani, Jocelan Trela, Phillipe Nicolai, Keisuke Shigemori et al. “The role of hot electrons on ultrahigh pressure generation relevant to shock ignition conditions” High Energy Density Physics, vol. 37, November 2020, 100892
Results from experiment at Gekko, ILE, Osaka

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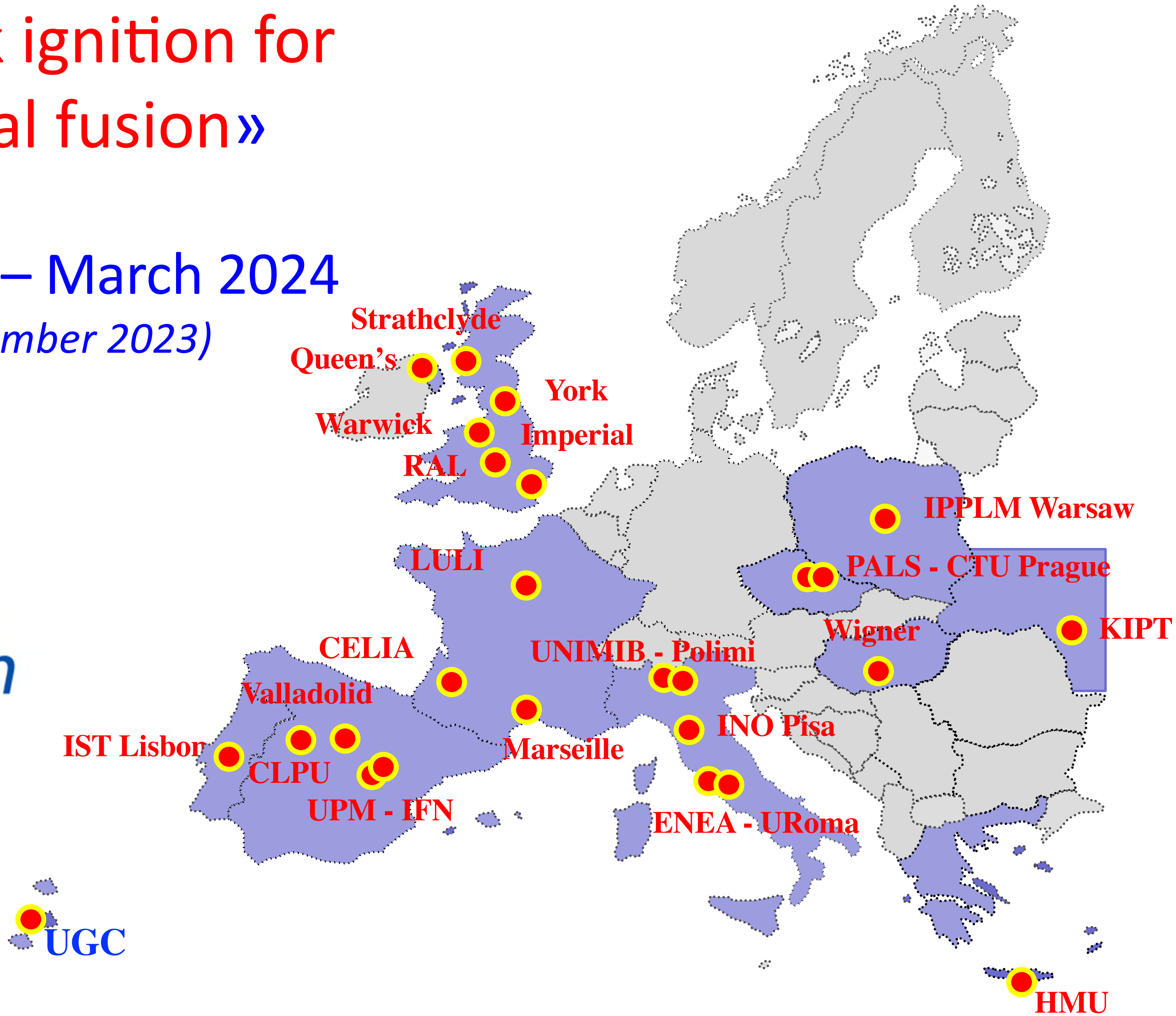


The international dimension

The international dimension is essential for our project both in order to access bigger laser facilities but also (and above all) to interact with colleagues overseas.

Within the previous project e have realised experiments ta the Gekko laser facility in Japan and at the OmegaEP facility in Rochester.
This will continue in the present project. In addition we have already one experiment scheduled at the SG II UP laser facility of SIOM in Shanghai

COLLABORATING GROUPS

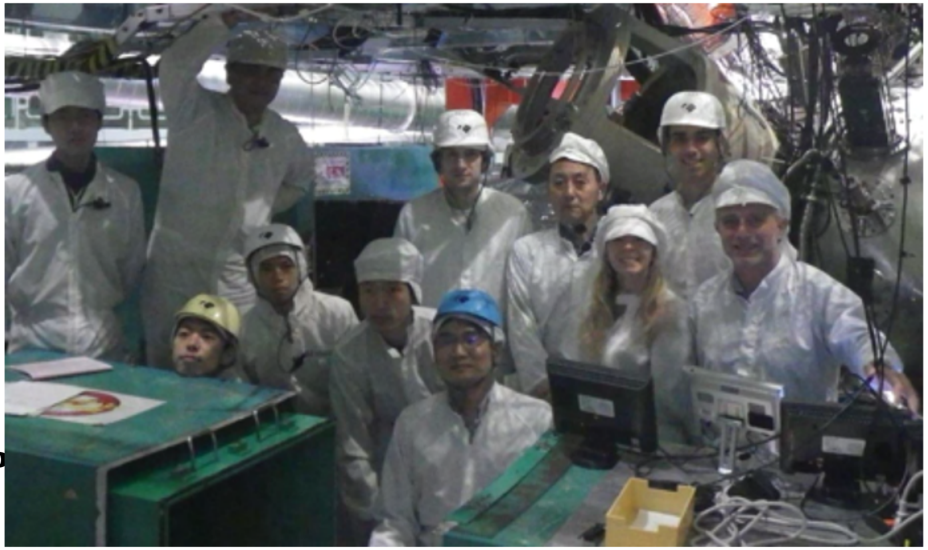
JAPAN
1) ILE, University of Osaka

UNITED STATES
2) LLE, University of Rochester

CHINA
3) Shanghai Institute of Optics and Fine Mechanics (SIOM), Shanghai

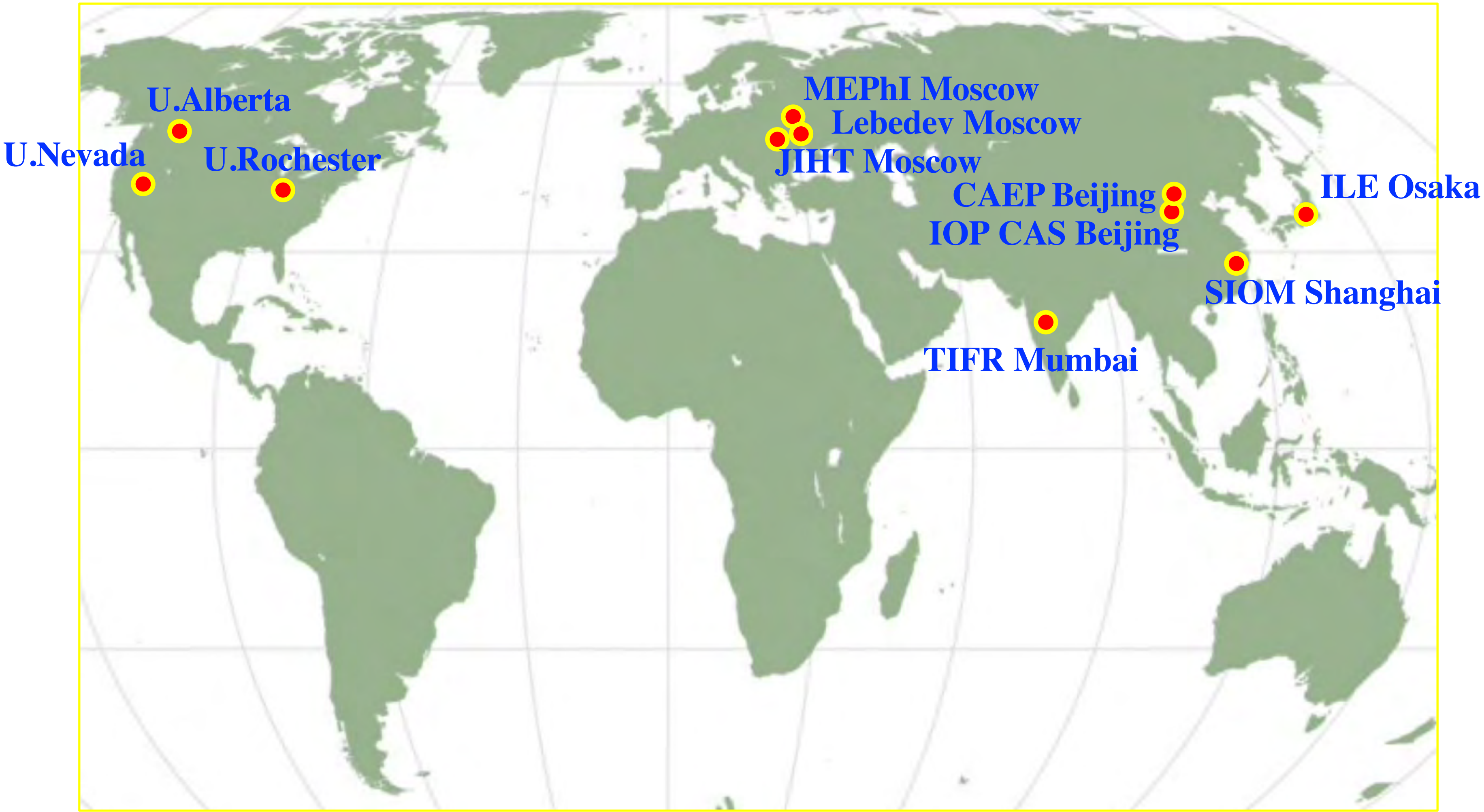
INDIA
4) Tata Institute of Fundamental Research (TIFR), Mumbai

RUSSIA
5) Joint Institute of High Temperatures, Russian Academy of Sciences, Moscow
6) Institute of Laser and Plasma Technologies, MEP National Nuclear Research University, Moscow



Experiment at the laser Gekko, Osaka

The collaboration network



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ИНСТИТУТ
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____________ № ________________________

На № __________________________________

To Prof. D. Batani,
CELIA Université de Bordeaux

LETTER OF INTENT

I have been glad to know you initiate a new research project in the frame of EuroFUSION program dedicated to the direct drive Inertial Confinement Fusion.

I am strongly encouraged with the idea as the topic of ICF is the key research subject for Joint Institute for High Temperatures of Russian Academy of Sciences. There are several research directions being intensively developed in our institutions and considered in several Working Packages of your project, namely:

- Extreme states in dynamically compressed matter and broad-range equation of states;
- Characterization of hot electrons and hot-electron-driven shock ignition;
- Study of hydrodynamic and parametric instabilities in direct drive implosions;
- Radiation emissivity and transport properties of solid and foam targets;
- Magnetized plasma flows and magnetic-assisted implosions.

We're here at JIHT RAS emphasizing our strong support to your EuroFUSION initiative and ask to consider our Institute as a Collaborative partner of the «Advancing shock ignition for direct drive ICF» project.

JIHT RAS is being participated in several European projects for High Energy Density Physics research, such as PETAL, GSI FAIR and European XFEL. Several research groups are deeply involved in the planning of the experimental program, as well as in development of the research equipment for these projects. Furthermore, our staff frequently takes a part in the research at European large-scale laser facilities in LULI Ecole Polytechnique, Helmholzzentrum GSI STFC RAL, PALS CAS, ELI NP, CELIA Bordeaux, etc. The staff of JIHT RAS will be glad to share an expertise, databases, diagnostic equipment and any other resources with European colleagues, and to be involved in HEDP modeling and experimental investigations using powerful laser facilities all over the Europe and in Russia.

On the details of a possible collaboration activity, please, contact Dr. Sergey A. Pikuz, head of Laboratory for diagnostics of matter under extreme conditions at JIHT RAS (+7-916-603-3489, spikuz@gmail.com), who is suggested to be the representative person from our Institution.

Sincerely yours,
Scientific advisor of JIHT RAS
Acad. Vladimir E. Fortov

ABSTRACT Enabling Research project CfP-FSD-AWP21-ENR-01-CEA-02

«Advancing shock ignition for direct-drive inertial fusion»

Our proposal aims to study and unlock key issues of the physics of direct-drive (DD) inertial fusion, and Shock Ignition (SI) in particular. Perspective inertial fusion energy (IFE) concepts require high-gain, which does not seem compatible with the indirect-drive approach investigated at NIF and other major facilities. Hence, the emphasis of our project is to complement the NIF approach by addressing the physics of potentially higher-gain DD. SI is based on separating compression and ignition. First the target is compressed and then a high-intensity spike launches a strong shock (>300 Mbar) igniting the precompressed fuel. Since compression does not need to create a hot spot, implosion takes place at lower velocity and with thicker targets, reducing hydro instabilities impact. SI demonstration is compatible with present-day laser technology and, with some modifications, target areas. Hence, SI is one of the few IFE schemes that can be tested at ignition-scale within the next decade on facilities like NIF, LMJ, SGIII.

The project is organized in 5 Work Packages, each including experiments and theory

We emphasize the coupling of theory and experiments, in particular the development of theoretically-based simulation tools relevant to DD and SI including self-consistent description of parametric instabilities, hot electron generation, non-local electron transport, magnetic flux compression, etc.

We plan to perform experiments at European laser facilities, in particular PALS, currently the only one in Europe allowing intensities of 10^{16} W/cm^2 in a sub-ns pulse, VULCAN, offering the possibility of multi-beam irradiation, and LMJ/PETAL which will allow for experiments at the energy-relevant scale.

In addition, we will collaborate with overseas groups and facilities like Omega (LLE, Rochester), Gekko (Osaka), SG II and III in China. The present project builds on physics and community building achievements of our previous project ENR-IFE19.CEA-01. In particular, we will continue the collaboration with LLE, the birthplace of SI.

Our objectives are answering key physics issues on SI and DD, and consolidating the European DD community with the longer-term objective of designing SI demonstration on NIF or LMJ

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Description of our project: Work packages

WP 1 - Characterization of hot electrons and hot-electron-driven SI (researchers in charge: D.Batani, R.Scott).

WP2 - hydrodynamic instabilities and mitigation strategies in DD-SI, including use of foams (researchers in charge: N.Woolsey, M.Cipriani)

WP 3 - Bipolar SI: direct drive compression and bipolar spike irradiation (researchers in charge A. Colaitis, S.Atzeni)

WP4: parametric instabilities and cross beam energy transfer, and their mitigation using broadband lasers (researchers in charge: G.Cristoforetti, Jiri Limpouch).

WP5 - Magnetic-field-assisted implosion and ignition (researchers in charge: J.Santos, N.Woolsey).

We will stress the role of **theory** in guiding/interpreting experiments, and of well diagnosed experiments in validating theory-based numerical codes. **Stefano Atzeni** from University of Rome "La Sapienza" will coordinate the theoretical efforts within the project.

Finally, we will continue the work on commonality of plasma diagnostics with magnetic confinement fusion.

What has been done until now

Kick-off Meeting (26 March 2021).

Second general meeting (8 October 2021

Meeting of WP1 - Characterization of hot electrons and hot-electron-driven SI (Preliminary meeting - 18 October 2021).

Meeting of WP2 - hydrodynamic instabilities and mitigation strategies in DD-SI, including use of foams (Preliminary meeting 12 October 2021 - General meeting scheduled on 2 December 2021)

Meeting of WP4 - parametric instabilities and cross beam energy transfer, and their mitigation using broadband lasers (Preliminary meeting 15 October 2021 - General meeting 19 November 2021).

Meeting of WP5 - Magnetic-field-assisted implosion and ignition (Preliminary meeting 26 November 2021)

Started write up of the paper on communality of diagnostics in MCF and ICF

WP1 : Common Experiment on SG II UP in Shanghai

Coordination D.Batani, R.Scott

Letter of Interest / Statement on future collaboration

This document expresses the interest of the research groups taking part in the EUROFusion Enabling Research Project ENR-IFE19.CEA-01 to promote collaboration with the Shanghai Institute of Optics and Fine Mechanics (SIOM) of the Chinese Academic Science in the field of studies related to the physics of laser-produced plasmas, the physics of direct-drive inertial confinement fusion with lasers (ICF) and in particular the Shock Ignition (SI) approach to ICF.

3. The two parts agree to perform common experimental work on laser facilities, including in particular the SG-II system at SIOM. The research groups from the EUROFusion Enabling Research Project ENR-IFE19.CEA-01 express the interest to perform experiments on the SG-II laser facility. Joint experimental proposals for physical experiments will be prepared and submitted for selection to the facility.

Signature by Principal Investigators of Both Parties

Part A: Shanghai Institute of Optics and Fine Mechanics, CAS

PI: Jianqiang Zhu | Email: jqzhu@siom.ac.cn

TEL: 86-21-69918202 | FAX: 86-21-69918101

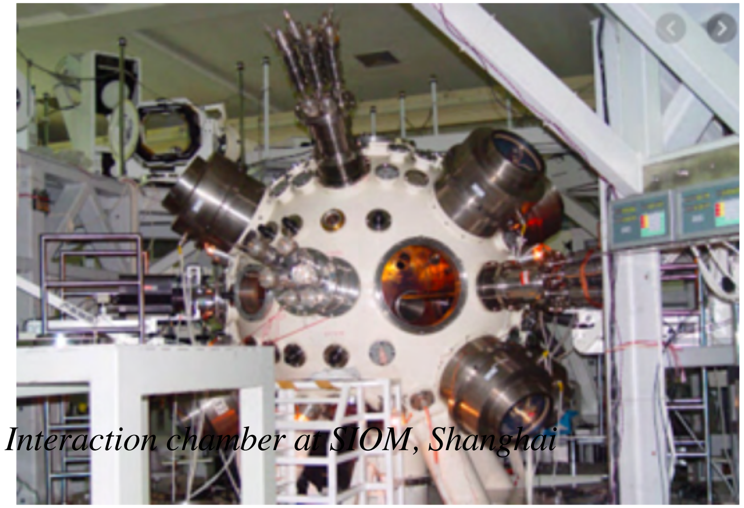
Signature: ________ | Date: ________

Party B: EUROFusion Enabling Research Project: ENR-IFE19.CEA-01

PI: Dimitri Batani | Email: dimitri.batani@u-borderaux.fr

TEL: + 335 40 00 37 53 | Fax: +33 5 40 00 25 80

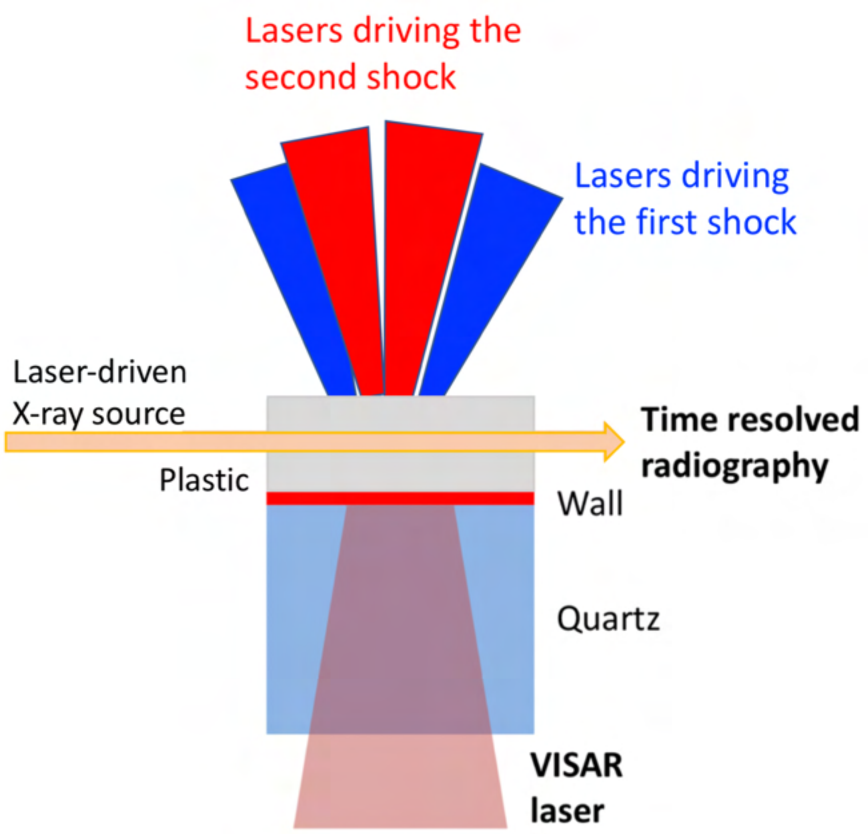
Signature: ________ | Date: ________



Interaction chamber at SIOM, Shanghai

WP1 : Common Experiment on SG II UP in Shanghai

Goal: mimicking the shock ignition process in planar geometry



Experiment : Study of physics of the Shock Ignition approach to ICF

Facility : SG II UP at SIOM Shanghai, China

PI : D.Batani

Status : accepted

(probable) date of experiment : January 2022 -> June/July 2022

(probable) duration of the experiment : 2 weeks

Groups involved until now in the discussion : CELIA, York, RAL, INO, IPPLM, ULPGC
International collaborators involved in the discussion : JIHT Moscow, SIOM Shanghai, CAS China

Brief Description of experiment :
We will use 2 laser beams at lower intensity to create a first shock which propagates in the target and meet a Cu layer. The reflected shock will collide with the second shock created by two other beams at high intensity. We want to study the reflection of the shock and the collision with the second shock. As diagnostics we will use time resolved X-ray radiography (suing a backlight source done with two additional laser beams) and X-ray phase contrast imaging (using a ps PW backlighter). In addition we will measure hot electron generation and parametric instabilities

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WP2 : hydrodynamic instabilities and mitigation strategies

Coordination: N.Woolsey, M.Cipriani

Present 2021 activities and their status

- **ENEA:** Development of a dedicated two-dimensional code with an effective model for simulating the interaction of high-power lasers with foams; optimization of reflected and transmitted light diagnostics from foam targets
- **ENEA/Polimi:** A collaboration for simulations and experiments about laser interaction with nanostructured materials for ICF has started between ENEA Frascati and Polimi. A student from Polimi is ding is master's thesis work in collaboration with ENEA Centro Ricerche Frascati
- **Warwick:** Development of a coupled model of radiation-hydrodynamics (the Odin 2D ALE code) including the hot-electron populations expected from LPI in the SI regime, currently investigating the effect of asymmetric laser drive on convergence and hot-spot shape.
- **York:** Analysis of the data obtained from experiments at OMEGA. Study of the implosion trajectory and low mode symmetry of warm implosions by plasma self-emission, to find any correlation between asymmetry in the picket which occurs at the very start of the implosion during the implosion and at stagnation.
- **CELIA/CESTA:** Investigation of the ablative Landau-Darrieus instability by numerical and analytical models. Experiments at OMEGA-EP with foam targets for benchmarking the simulations and for optimizing diagnostics, and at NIF to study the evolution of the LDI.
- **CELIA/CTU:** Experimental study of subcritical foams at SG3P laser. Development of novel microscopic models, coupled to the PALE and FLASH codes, to numerically simulate laser absorption and scattering from solid elements, as well as the evolution of the generated plasma.
- **IPP:** Continuation of the work on the study of underdense and overdense foam targets. Analysis of the data of an experiment performed in the first half of 2021. Planning of a series of experiments with underdense target for 2022.

WP2 : hydrodynamic instabilities and mitigation strategies

Present 2021 activities and their status

- **Roma-Sapienza/CELIA**: simulation of a new target concept, consisting of a homogeneous sphere (with wetted foam ablator) with dynamic formation of the fuel hollow sphere, in collaboration with LLE, University of Rochester. First stage: design of a joint experiment, to be performed at OMEGA in August 2022 (funded by US agencies, within the OMEGA Laboratory Basic Science experiment programme).
- **UPM:** Development of a computational paradigm to model the interaction of XUV with plasmas, including hydrodynamic, PIC, collisional-radiative codes and Maxwell-Bloch simulations, used to study the dynamics of Ni-like Kr ions in a plasma waveguide. These techniques will be extended to plasmas of interest for ICF
- **IPPL/HMU:** Experiments with the nanosecond laser pulses at IPPL to study the early time dynamics of the ablator and investigate the "imprint" mechanism as well as the seeding instability dynamics of the implosion phase. Development of models for the study the early time dynamics. Development of advanced high spatiotemporal resolution diagnostics to record the nm scale "imprint" dynamics of the ablator.

According to the last modified version of the work plan, there are no scientific deliverables for 2021 for the WP2. Regarding the general deliverable D.A1 (annual report) will include the updates on the progress for the WP2, such as:

- Progress on the 2D Odin model, including hot-electron energy deposition, for studying asymmetric drive and hydrodynamic instabilities in the SI regime
- Progress on the development of the two-dimensional code with an effective model for simulating the laser interaction with foams
- Progress on the simulations with the microscopic model for laser-foam interaction coupled to the FLASH and PALE codes. Planning of experimental campaigns at ELI and PALS to test theoretical models with targets fabricated with novel technologies
- Progress on the analysis and simulations of the experiments at OMEGA and NIF about the ablative Landau-Darrieus instability

Next meeting of the WP scheduled for 2 December 2021

WP3 : Bipolar SI: DD compression and bipolar spike irradiation

Coordination A. Colaitis, S.Atzeni

Preliminary meeting: November 30, 2021

General meeting: before January 2022

Ongoing activities (CELIA and Roma-Sapienza):

- Preliminary model simulation of polar-direct-drive ignition-class target using simplified cylindrically symmetric irradiation geometry (as a starting point for subsequent simulations with detailed laser geometry and 3D ray-tracing)
- Preliminary model simulation of bipolar ignition spike on symmetrically pre-compressed fuel
- (together with WP2) Simulation of a new target concept, consisting of a homogeneous sphere (with wetted foam ablator) with dynamic formation of the fuel hollow sphere, in collaboration with LLE, University of Rochester. First stage: design of a joint experiment, to be performed at OMEGA in August 2022 (funded by US agencies, within the OMEGA Laboratory Basic Science experiment programme).

WP4 : parametric instabilities and cross beam energy transfer

Coordination: G. Cristoforetti, J. Limpouch

AIM: Due to the high intensity of the laser spike interacting with a long-scale corona, a major issue of SI is the outburst of LPI. A detailed understanding of laser-plasma interaction in this regime is important, because a fraction of laser energy can be diverted out via scattered light, and SRS/TPD result in HE generation.

Scientific goals and related milestones:

1 – Experimental investigation and modelling of CBET at SI intensities

- Discussion on an experiment dedicated to CBET is in progress

M4.1 Realization of experiment on CBET with two beams in preformed plasma (e.g. Vulcan) (WP4)

- The IFRIIT code was developed specifically to model 3D CBET in direct-drive ICF configuration, either in post-processing or fully coupled to hydrodynamics (ASTER). It will be used for assessing experimental configurations (M4.1) and the effect of CBET in the shock ignition scheme in 3D configurations (M4.3). The code will also be used in WP3 to study ICF physics in alternative ignition schemes (M3.3)

M4.3 Develop numerical tools to describe, possibly in 3D, laser absorption (collisional and resonant), LPI and CBET. Quantify the effect of CBET on SI in 3D inline calculations

2 - Investigate LPI mitigation strategies with broadband and/or chirped lasers

- Forthcoming experiment at Vulcan (CLF) laser in 2022, leaded by INO-CNR group. **Aim:** investigating the effect of coherence time t_p of laser light on the growth and on the features of parametric instabilities (SBS, SRS and TPD) in interaction conditions as close as possible to those envisaged for Shock Ignition.

M4.2 Development of an experimental plan to investigate mitigation of LPI with Chirped laser pulses

- Numerical (PIC) and theoretical Investigation of the effect of broadband/chirped pulses on LPI, in progress by the University of Warwick group (paper in publication) and by the University of Strathclyde group

WP4 : parametric instabilities and cross beam energy transfer

3 - Investigate LPI at 10^{16} W/cm^2 in long (L ~ 500 µm) high temperature (T > 1 keV) plasmas.

- Two collaborative research works, with experimental data taken at Omega (LLE) and Vulcan (CLF) laser, have been recently published, showing that SRS is driven at low densities in kinetic regime and absence of TPD . Filamentation is found to be determinant [*Cristoforetti (INO-Pisa group) et al., HPLSE 9, e60 (2021); Scott (CLF group) et al., PRL 127, 065001, 2021]*
- After working on convective SRS in the kinetic regime, the University of Warwick group is planning to carry out large simulations of full 2D dynamics of SRS, TPD and SBS with flow and collisions.
- Development of numerical models of LPI processes for inclusion in multi-dimensional radiation-hydrodynamic such as Odin (York Univ.)
- Implementation of an electron transport and stopping model in Odin and applied this to shock ignition simulations (Warwick Univ. and CLF)
- CLF group is performing large-scale Particle-in-cell simulations of laser-plasma interactions in ignition scale plasma conditions, both to develop fundamental understanding and also to interpret results from experiments done at the National Ignition Facility.

⇨ M4.3 Develop numerical tools to describe, possibly in 3D, laser absorption (collisional and resonant), LPI and CBET. Quantify the effect of CBET on SI in 3D inline calculations

4 – Correlation between LPI (SRS, TPD) and HE source (related also to WP 1.1)

- Follow up and analysis of experimental data at PALS in 2020 and new shots in 2021 (INO-CNR, Celia, York University, IPP-PALS, USAL, IPPLM, RAS)
  - Correlation between TPD, SRS and HE diagnostics, regime of SRS-drive HE (INO-CNR) – *scientific paper in preparation*
  - Development of accurate time-resolved X-ray imaging and spectroscopy diagnostics and results (IPP-PALS) – *scientific paper in preparation*
  - Development and critical assessment of HE diagnostics (BSC, HE spectrometers, Kα spectroscopy) (RAS, York Univ. Celia)– *scientific paper in preparation*
  - Modelling and development of half-harmonics diagnostics for LPI (INO-CNR, University of Warwick) – *starting in early 2022*
- Experiment carried at at Gekko XII laser (ILE, Japan) in June 2021 (INO-CNR, Celia, Università La Sapienza, ENEA, ILE)
  - Analysis in advanced stage, regime of TPD-driven HE – *scientific paper in preparation*
  - Development of LPI diagnostics at GEKKO XII – *scientific paper in preparation*

WP5: Magnetic-field-assisted implosion and ignition

Coordinators: J.Santos, N.Woolsey

Teams involved (until now):

CELIA, PIIM, LULI, Universidad de Las Palmas de Gran Canaria, UVa, Universidad Politécnica de Madrid, Universidad de Salamanca, IFPiLM, Sapienza Università di Roma, University of York, Imperial College London, Technische Universität Darmstadt, IPP Institute of Plasma Physics of the Czech Academy of Sciences

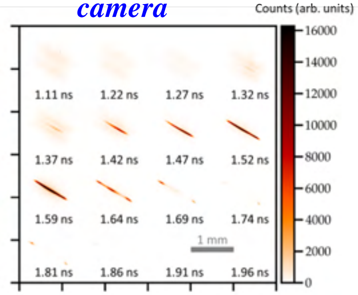
External collaborators:

UCSD, LANL, UR LLE, N, University of Alberta, Princeton University, MEPhI, General Atomics, CEA

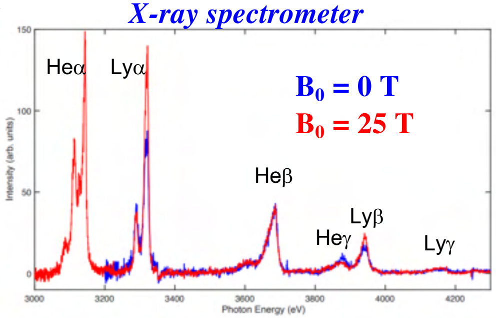
Highlights

Cylindrical compression experiments with embedded B-field to characterize strongly magnetized hot dense plasmas

X-ray framing camera



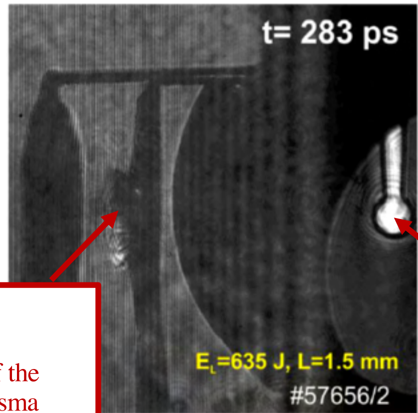
Time-integrated X-ray spectrometer



- Spectra from Ar-dopant reproducibly reveal effect of seed B-field on the hydrodynamics
- For the **magnetized** case, the Lyβ/Heβ, Lyα/He-like satellites and Heα/Li-like satellites are higher ⇒ **higher T_e**
- Experiments carried out with 15 kJ laser-drive (OMEGA); Extension to 270 kJ laser-drive accepted at LMJ

Observation of Nernst advection of magnetic fields in an underdense plasma

➡ Joint characterization of laser-plasma self-generated B-field and coil discharge B-field in laser-driven coils



Complex-interferometry measurement of the laser-driven plasma

Faraday rotation in TGG crystal near the coil plane

WP5: Magnetic-field-assisted implosion and ignition

Milestones for years 1 and 2:

M5.1 Optimization of diagnostic approaches already used for the measurements of strong B-fields in coil targets

- Experiments lead by IPPLM at PALS combined complex-interferometry of the laser-driven plasma (density, self-generated B-fields) and Faraday rotation near the coil plane (discharge current and induced B-field). Results now under analysis.
- Dual axis proton-deflectometry probing realized both at Vulcan (lead by UYork, Bradford *et al.* PPCF **63** (2021) 084008) and at LULI (lead by CELIA, first results presented at APS-DPP 2021).

M5.2 Develop diagnostics based on atomic physics for HED plasmas under the effects of strong magnetic fields. Acquisition of X-ray spectra from HED plasmas affected by strong B-fields

- Platform design for magnetized cylindrical implosions and spectroscopic characterization of core plasma conditions (Walsh *et al.*, PPCF accepted; EUROfusion pinboard 31017); First experimental results presented at APS-DPP conference 2021 (see M5.4).

M5.3 Generation of 100 T uniform B-field over mm-scale length as seed for implosion experiments

- In 2021 we restricted to explore 10^{15} W/cm^2 laser intensity regime, of relevance for the OMEGA and LMJ conditions, yielding 60 T B-fields. For higher B-fields we rely for now on results obtained under previous ENR projects at 10^{17} W/cm^2.

M5.4 Magnetized Implosions (@ Omega, with 14.5 kJ laser drive)

- Two shot days carried out in Nov 2020s (with 5T seed B-field from laser-driven coils) and in Aug 2021 (with 25T seed B-field from externally-driven coils – MIFEDS). For 25T seed B-field, the spectroscopic data reproducibly yielded distinct signatures for magnetized vs. unmagnetized implosions, revealing the effects of the compressed B-fields over implosion hydrodynamics and at stagnation.

M5.5 Realization of heat transport measurements at solid density

- Laser-generated supersonic plasma jets and shocks in a transverse magnetic field have been investigated at PALS (Bohlin et al, PPCF submitted).
- A first experiment is scheduled at LULI2000 in May 2022 (lead by LULI).
- CELIA developed a Talbot interferometer able to characterize electron- and ion-density maps with 2μm resolution at HED stations in XFELs.
- UYork lead experiments at VULCAN revealing Nernst advection of B-fields in underdense plasma (paper under revision) and Biermann battery B-field generation.

Deliverables for years 1 and 2:

D5.1 Design of a magnetized implosion experiment at MJ scale at LMJ or NIF

- A first design for 270 kJ drive was submitted and accepted for 3 shots at LMJ, scheduled to 2024.
- We used GORGON 2D extended MHD simulations, including Biermann battery, Nernst, cross-gradient Nernst and resistive diffusion.
- DUED 2D hydrodynamic code now includes a model for B evolution and B effects on transport and dynamics

Description of our project: Work plan and deliverables

year	Year 1			Year 2				Year 3				Year 4
trimester	A-J	J-S	O-D	J-M	A-J	J-S	O-D	J-M	A-J	J-S	O-D	J-M
Project Management			D.A1				D.A2				D.A3	D.A4
Web Meetings	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
General Meetings		G1				G2				G3		G4
WP1 – HE & SI			M1.1		M1.2	D1.1	M1.3	M1.4	D1.2	M1.5	M1.6	D1.3
WP2 – hydro & unifor.		M2.1	M2.2	D2.1	M2.3	M2.4	M2.5	D2.2 M2.7	M2.6	D2.3	M2.8	D2.4
WP3 – bipolar SI					M3.1			M3.2		M.3.3	D3.1	
WP4 – LPI & CBET				M4.1			M4.2		M4.3	D4.1		
WP5 – magnetized fus.		M5.1	M5.2	M5.3	D5.1		M5.4	M5.5		M5.6	D5.2	

List of Deliverables

FIRTST YEAR (April-December 2021)
D.A1 Annual Report 2021

SECOND YEAR (January-December 2022)
D1.1 Report on measurements of HE distribution and HE tail in SI conditions. Optimization of bremsstrahlung cannon, correlation among different diagnostics (WP1)
D2.1 Report on the evaluation of imprints effects during the initial solid-to-plasma transition (WP2)
D5.1 Design of a magnetized implosion experiment at MJ scale at LMJ or NIF (WP5)
D.A2 Annual Report 2022

THIRD YEAR (January-December 2023)
D1.2 Report on HE effects in SI-designed targets (WP1)
D2.2 Report on the evaluation on the impact of RT for SI-designed targets (WP2)
D2.3 Report on using foams to mitigate hydro instabilities growth (WP2)
D3.1 Report on feasibility of bipolar shock ignition and proposal for experiments on LMJ/NIF (WP3)
D4.1 Report on LPI and CBET in SI conditions (WP4)
D5.2 Report on the characterization of magnetized HED plasmas over the implosion and at stagnation (WP5)
D.A2 Annual Report 2023

FOURTH YEAR (January-March 2023)
D1.3 Report on advanced hydro codes taking into LPI instabilities and HE self-consistently (WP1 & WP4)
D2.4 Report on advances in 3D hydrocodes for studying hydro instabilities (WP2)
D.A2 Final Report

Description of our project: Milestones

List of Milestones

V1, .. V12 on-line meetings at beginning of trimesters of group leaders and WP leaders

G1, G2, G3 General meetings of the researchers of the project on months 6, 18 and 29.

G4 Closing meeting on month 35 or 36.

M1.1 Characterizing HE from TPD/SRS at 3ω including angular distribution and time correlation (WP1 & WP4)

M1.2 Characterization of HE from TPD/SRS at different irradiation wavelengths (PALS) (WP1 & WP4)

M1.3 Characterization of shock wave dynamics in SI conditions using XPCI (SGII UP, Omega) (WP1)

M1.4 Experiments in planar geometry on HE penetration in the fuel (the large ρr close to stagnation will be mimicked by using high-Z dense layers embedded in the target) (WP1)

M1.5 Experiment on HE generation and penetration in spherical geometry using a moderate convergence and tracer layer within solid sphere targets (pre-irradiated to produce the desired plasma scalelength) (WP1)

M1.6 Development and availability of advanced hydro codes taking into LPI instabilities and HE self-consistently (WP1 & WP4)

M2.1 Implementation of XPCI in planar experiments to study RT growth from imprint seeds (Omega) (WP2)

M2.2 Implementation of XUV diagnostics (wave front sensor for extreme ultraviolet spectral range) for measuring the impact of imprint during the initial phase of solid-to-plasma transition (WP2)

M2.3 Experiments on RT growth from laser imprints in SI conditions using XPCI, planar geometry (WP2)

M2.4 Experiment on characterization of shock velocity in foam (to validate theoretical models) (WP2)

M2.5 Evaluation of impact of hydro instabilities (simulations) in compression phase for SI conditions (WP2)

M2.6 Mitigation of imprints using intermediate-Z overcritical foams, planar geometry (WP2

M2.7 Experiments of reflected and transmitted laser light from foam targets, and on ablation loading on layered foam targets.

M2.8 Development of 3D hydrocodes for studying hydro instabilities (WP2)

M3.1 Experiment on bipolar collision of shocks in preformed plasma in planar conditions (WP3)

M3.2 Experiment on bipolar collision of shocks in spherical targets (either pellets or solid spheres) (WP3)

M3.3 Developing 3D tools to study the feasibility to ignite a directly-driven target using two colliding polar shocks in an indirect-drive-machine 3D geometry (WP3)

M4.1 Realization of experiment on CBET with two beams in preformed plasma (e.g. Vulcan) (WP4)

M4.2 Development of an experimental plan to investigate mitigation of LPI with Chirped laser pulses (WP4)

M4.3 Develop numerical tools to describe, possibly in 3D, laser absorption (collisional and resonant), LPI and CBET. Quantify the effect of CBET on SI in 3D inline calculations (WP4)

M5.1 Optimization of diagnostic approaches already used for the measurements of strong B-fields (Faraday rotation, Complex interferometry, Proton radiography, etc.) (WP5)

M5.2 Develop diagnostics based on atomic physics for HED plasmas under the effects of strong magnetic fields. Acquisition of X-ray spectra from HED plasmas affected by strong B-fields (WP5)

M5.3 Generation of 100 T uniform B-field over mm-scale length as seed for implosion experiments (WP5)

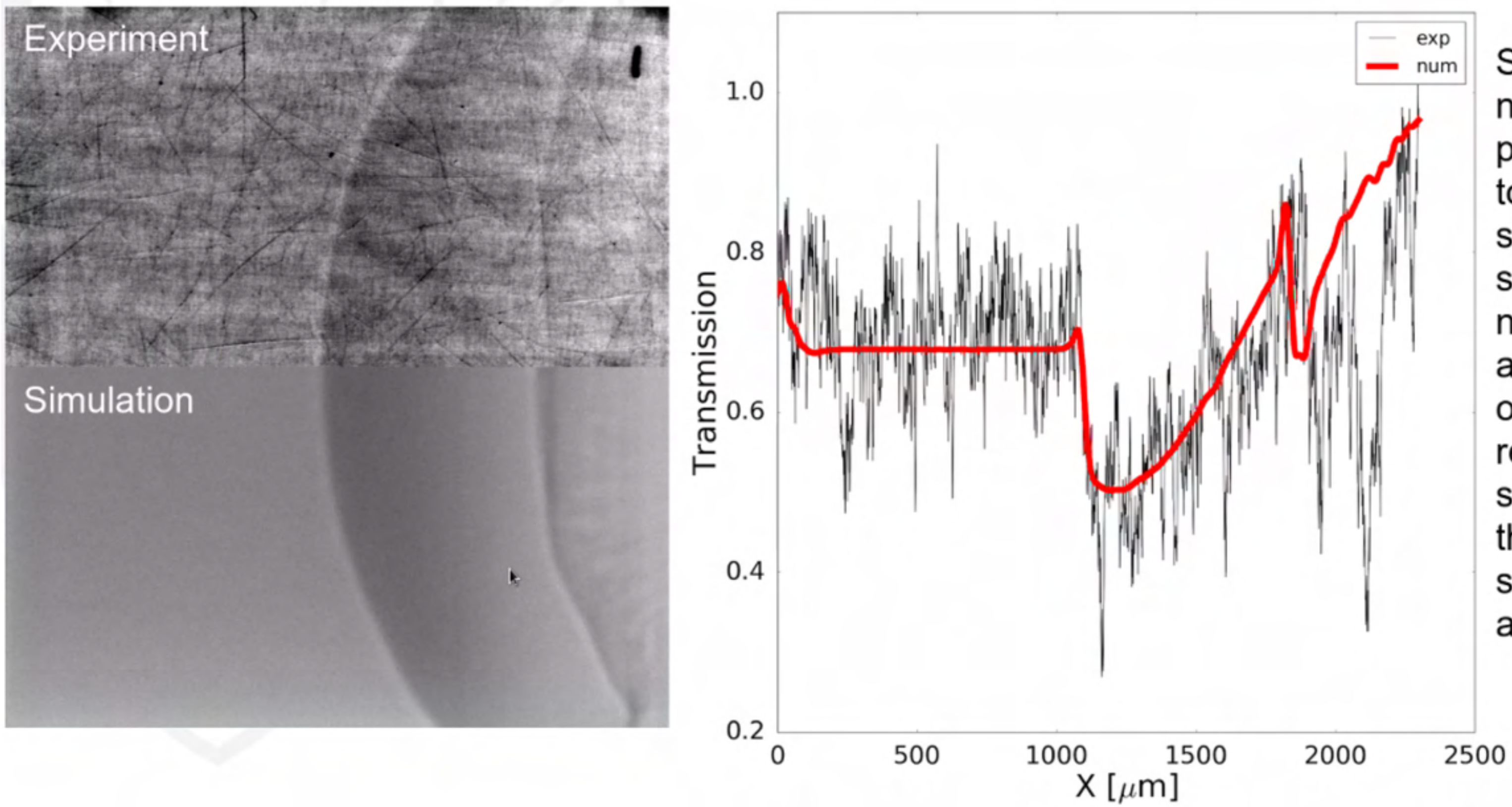
M5.4 Magnetized Implosions (Omega) (WP5)

M5.5 Realization of heat transport measurements at solid density (WP5)

M5.6 Develop numerical tools for kinetic and MHD simulations to model electronic transport and B-field diffusion. Benchmark to data from heat transport experiments (WP5)

Milestones WP2

Preliminary experiment at Omega EP. Detection of first and second shock launched in the target by means of XPCI



Simulations at nominal laser parameters are able to reproduce the first shock. The second shock which does not share the same axis with the first one is roughly reproduced in the simulation (where the two shocks share the same z axis.

Important “side” activities

EUROfusion

Together with the BPIF section of the PPD of EPS we are supporting an initiative to launch a new European project on IFE after the results of NIF

We will have a strong participation in the summer school on “Atoms and Plasmas in Superstrong Fields” organized in Erice, Sicily, in July 2022

Collaboration with the Coordinated Research Project of IAEA on “Pathways to Inertial Fusion Energy”

Collaboration with the LAASERLAB expert group on “Micro- and nano-structured materials for experiments with high-power lasers ”

Collaboration with the COST project (submitted) ProBoNo «PROton BOron Nuclear fusion: from energy production to medical applicatiOns"

Conclusions

The work has started successfully, some WP are in advance on the schedule some others slightly late...

- A lot of work is currently being done:
  - We need to reinforce the coordination among different groups
  - We need to organize an “in presence” general meeting of a few days with proper scientific presentations and publication of a special issue of a journal

- Request for additional funding for international collaborations (Chine, US, Russia)

- Need to work on wiki page / web site

- We need to access the funding for PhD provided by EUROFusion...

We need the task agreement to be signed SOON !

Additional opportunities

Support for PhD students ?

Dear Dimitri

concerning PhD funding : we have a ceiling per beneficiary which is calculated according to the number of MFE Phds ongoing on a moving five year average basis.
While it is theoretically possible to include up to 10% of IFE Phds, in France we do reach the budget ceiling (in fact, we are very much above it so that we get only a partial refund) with MFE students only

Best regards

Kalupin Denis
RE: WPEDU
A: Dimitri Batani

Dear Dimitri,

I think you mean TRED (Training and Education).

If it is true, then the call (https://ims.euro-fusion.org/fp9/CallGenerate/Index?aId=150) is already closed. You should wait for the next one.

Regards,
Denis

We need to look at all possibilities…

EUROfusion

CfP-TRED-AWP21-TRED-01

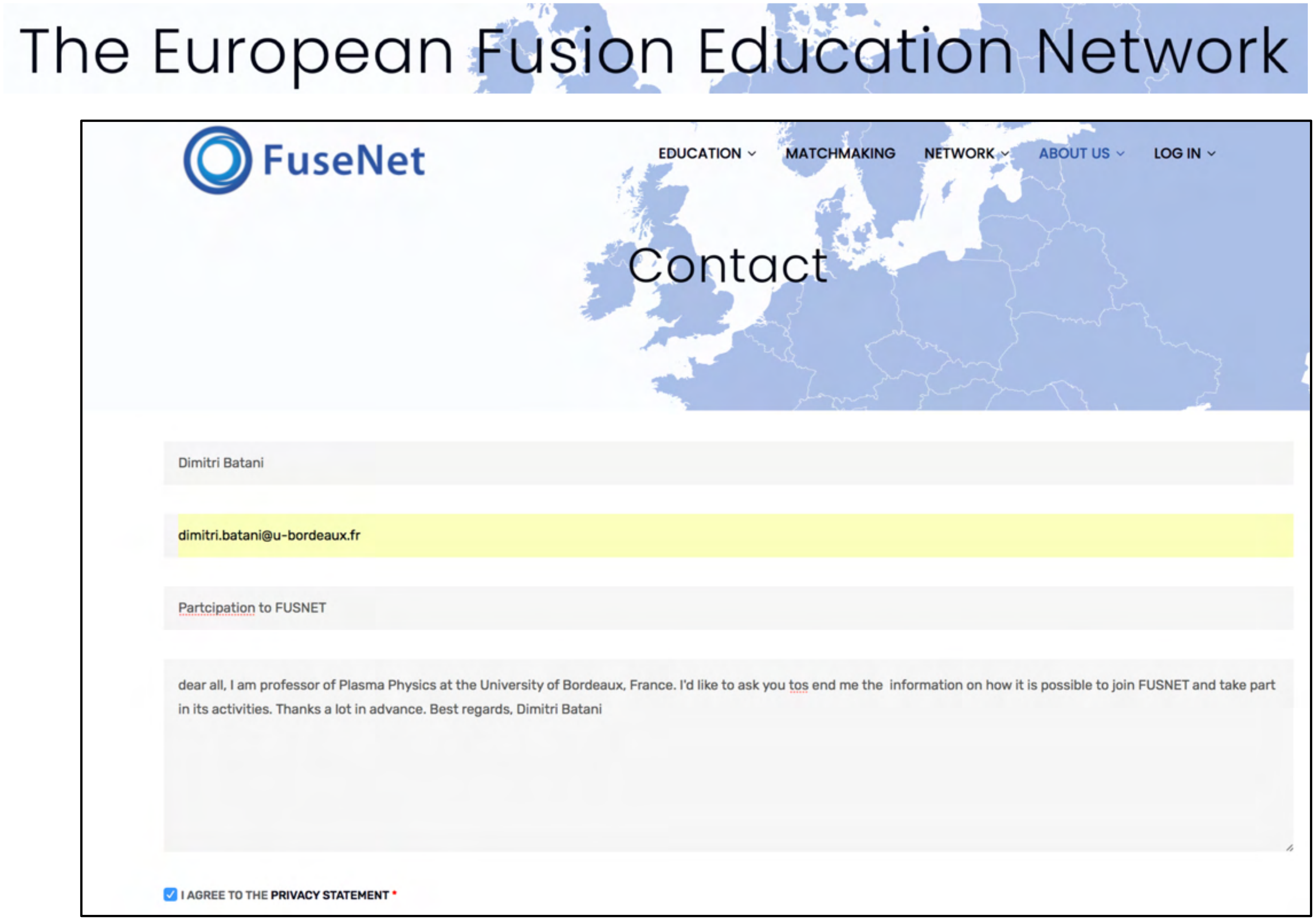
2021 Annual Work Plan

Call for Participation

2021 EUROfusion Researcher Grants

Additional opportunities

Support for PhD students ?



WIKI page & communication tools

Kalupin Denis

Reminder: Wiki pages for your project

A: ENR-PI

23 giugno 2021 09:28

Siri ha trovato un nuovo contatto nell'e-mail: Kalupin Denis Denis.Kalupin@euro-fusion.org aggiungi a Contatti

Dear Principal Investigators,

I would like to remind you that all ENR projects shall maintain a WiKi page accessible to all EUROfusion members (same as e.g., WPs or TF Wikis). These shall provide the information regarding main project objectives, expected deliverables, recent achievements, the team and etc.

The WiKi pages for all projects have been pre-configured @:
https://wiki.euro-fusion.org/wiki/WPENR_wikipages:_Enabling_Research_Work_Package

If you did not start to fill the information regarding your project, please do it.

With best regards,
Denis

EUROfusion
FUSION SCIENCE DEPARTMENT

Dr. Denis Kalupin
Coordination Officer for ***Theory and Simulation***

Work Packages / Activities:
Advanced Computing
Enabling Research
Preparation for ITER Operation
Theory Simulation Validation and Verification tasks

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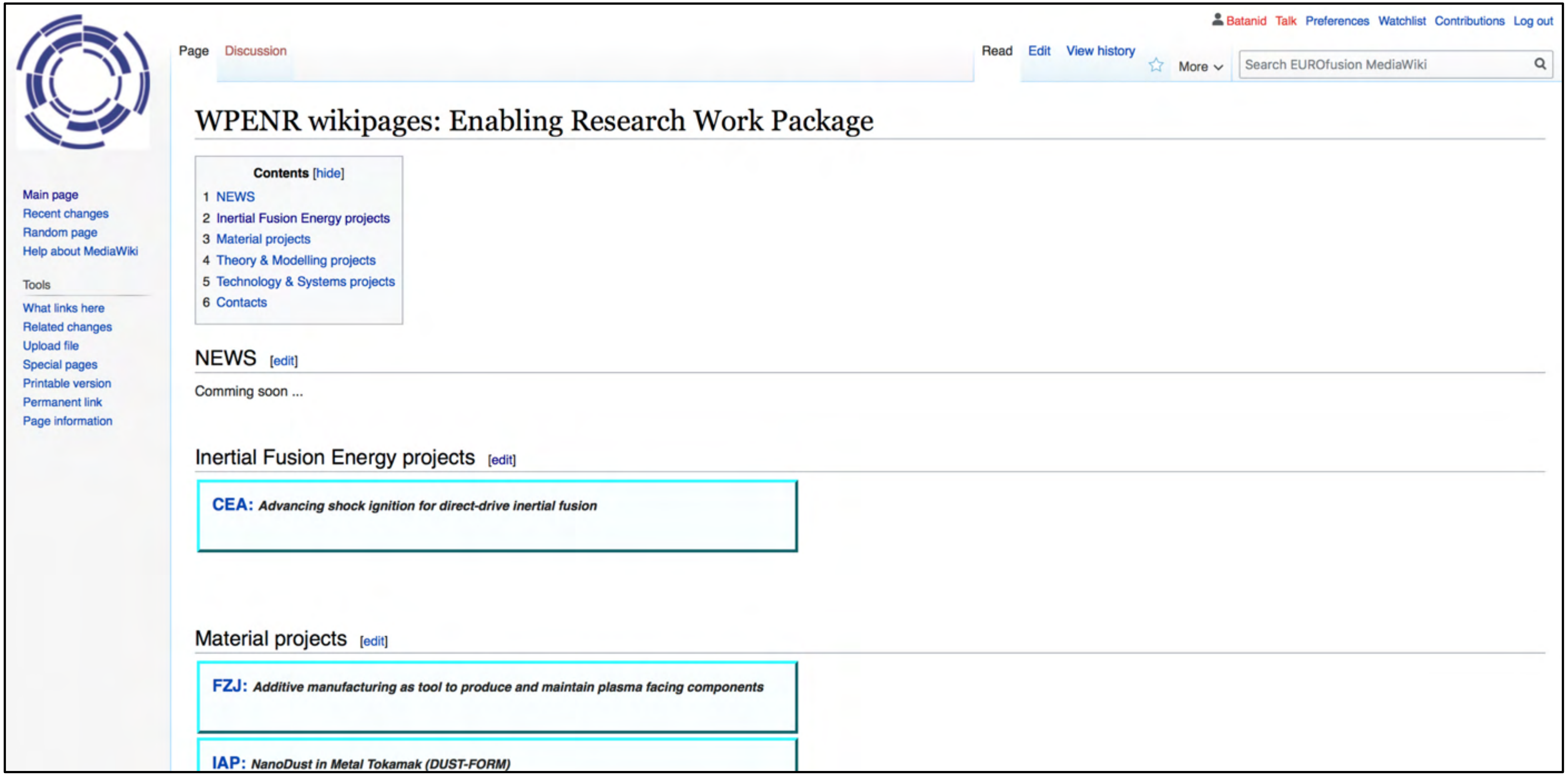
WIKI page & communication tools



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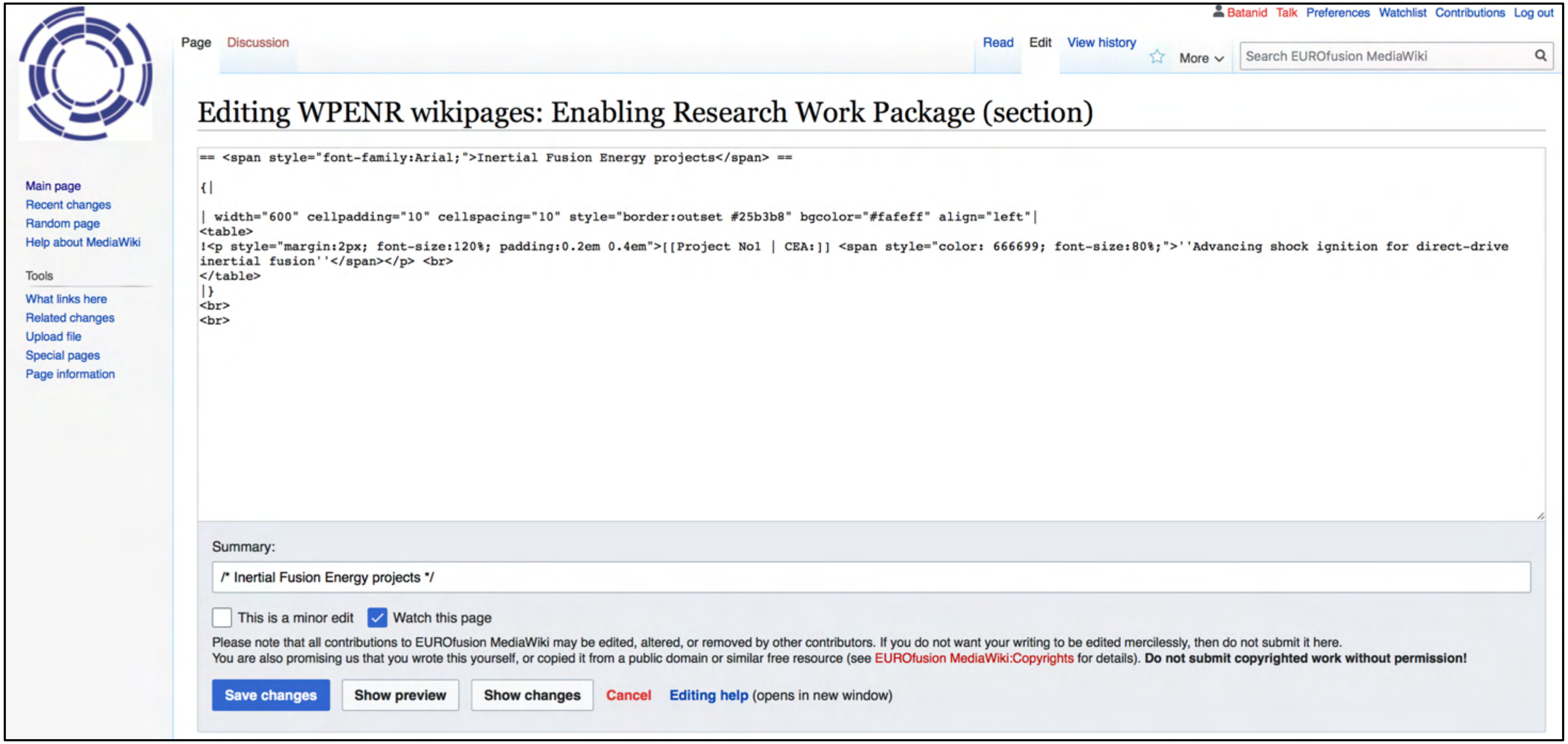
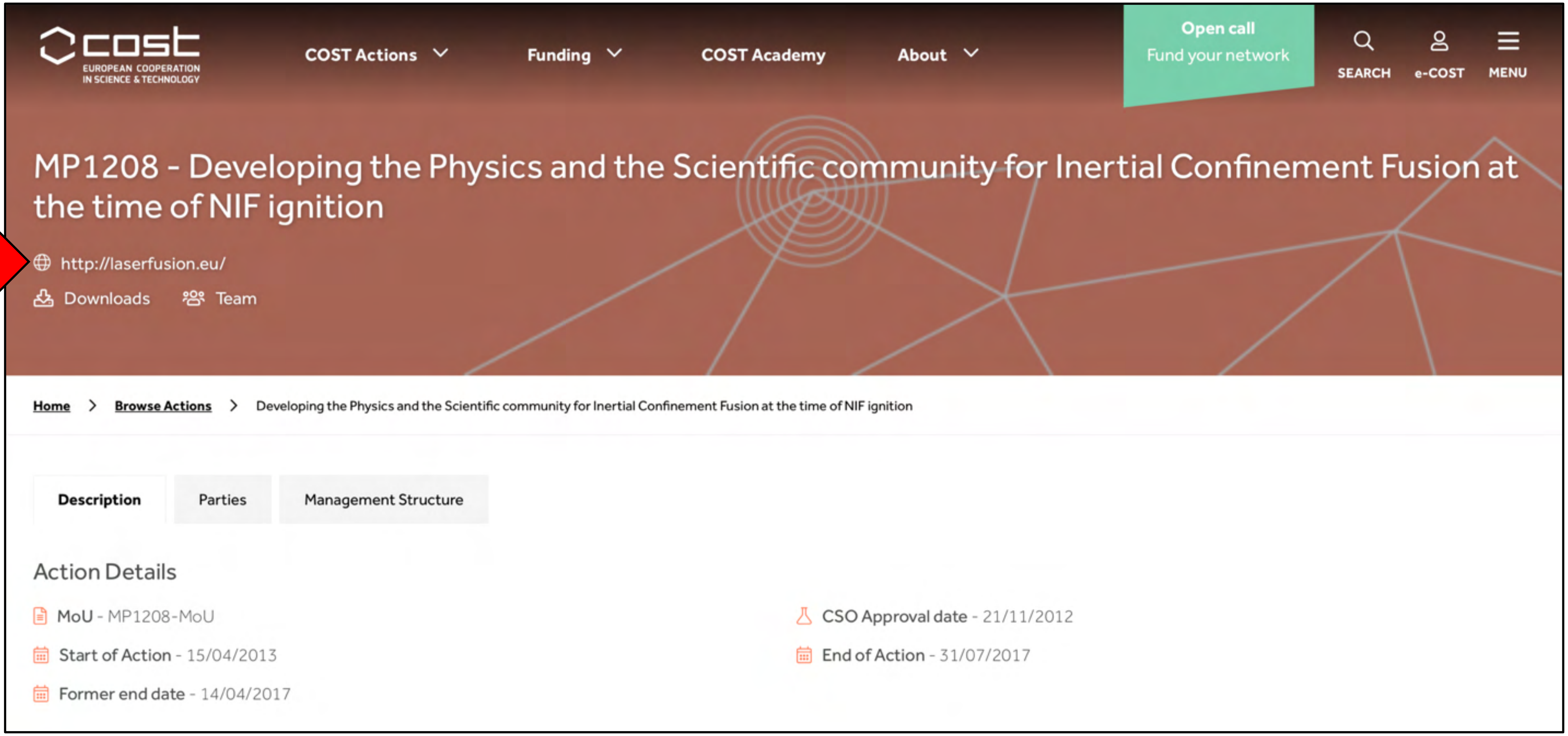


WIKI page & communication tools



Web site in charge of IPPLM

WIKI page & communication tools