Issue 26 | January 2019

Laserlab Europe

Laserlab Forum

Newsletter of LASERLAB-EUROPE:
the integrated initiative of European laser infrastructures funded by the European Union's Horizon 2020 research and innovation programme

Lasers for Fusion Energy

Inside the target chamber of LMJ.
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In this Issue

Editorial


Tom Jeltes

I am still amazed by the scope of the research conducted within Laserlab-Europe. For the previous issue, we had considered publishing a double focus section, combining what we thought to be two smaller fields of research within the laser community: Cultural Heritage and Fusion Energy. But as we soon found out, we could easily fill four pages with Laserlab-Europe projects on cultural heritage.

Much the same, this issue contains a rather full focus section describing the various laser-based approaches to fusion energy, allowing us (like we looked back into the past in the previous issue) a view of a hopefully not too distant future, when power plants can be fuelled with sea water.

The focus section on fusion energy shows the various ways in which lasers can be used to create and study the extreme conditions required to get the fusion reaction going, and how Laserlab-Europe researchers and facilities contribute to the development of a new and virtually unlimited source of energy.

More cutting-edge science can be found in our access highlight, which describes the most accurate determination of the binding energy of the hydrogen molecule so far, performed at LaserLab Amsterdam. The importance of these measurements lies in their comparison with the state-of-the-art calculations using quantum electrodynamics theory, thus challenging the foundation of the Standard Model of physics.

And don't forget to check out our news section, featuring a thrilling technological development at MBI Berlin, where they used a beam of helium gas to create a tuneable and unbreakable lens for extreme ultraviolet light. Enjoy!

Tom Jeltes

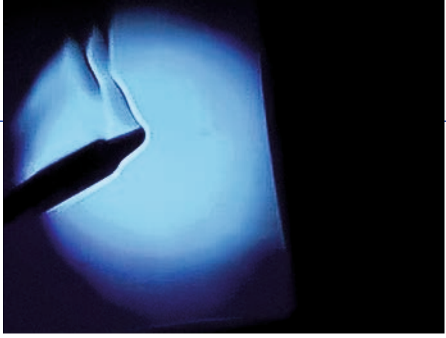
News

Laserlab-Europe AISBL inaugurated

Laserlab-Europe AISBL was inaugurated and held its first General Assembly meeting with 38 Full Members and 3 Associate Members on 29 October 2018 in Salamanca, Spain. An AISBL is an international not-for-profit organisation under Belgian law and gives Laserlab-Europe legal independence.

The registration of Laserlab-Europe AISBL was approved by Royal Decree from the King of Belgium. The kick-off of the AISBL was marked by the elections of the members of the Management Board, the Executive Director, and the Chair and Vice-Chair of the General Assembly. The meeting venue was the Old Chapel for Studies within the University of Salamanca, an historic room used as the Council Chamber of the University, and was part of the 800th anniversary celebrations of the University of Salamanca, the third oldest university in the world.

At the end of the meeting the participants had the opportunity to see the VEGA laser facility at CLPU, the Centro de Laseres Pulsados, whose Director, Luis Roso, had hosted the meeting. CLPU was established in December 2007 as part of the implementation of the Spanish Roadmap for Unique Research and Technology Infrastructures. VEGA is a new facility, opened in September 2018 by the King of Spain. The laser system is capable to reach one petawatt of peak power and has a singular architecture with three synchronized outputs of different powers that offer services to scientific users around the world.



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What is Laserlab-Europe?

Laserlab-Europe, the Integrated Initiative of European Laser Research Infrastructures, understands itself as the central place in Europe where new developments in laser research take place in a flexible and co-ordinated fashion beyond the potential of a national scale. The Consortium currently brings together 33 leading organisations in laser-based inter-disciplinary research from 16 countries. Its main objectives are to maintain a sustainable inter-disciplinary network of European national laboratories; to strengthen the European leading role in laser research through Joint Research Activities; and to offer access to state-of-the-art laser research facilities to researchers from all fields of science and from any laboratory in order to perform world-class research.

Lasers in popular science outreach at European Researchers' Night, Riga, Latvia

During this year's European Researchers' night, the University of Latvia's Laser Centre presented, in the framework of Laserlab-Europe outreach activities, an experimental demonstration of Schlieren visualisation, which allows observations of invisible air flows, using a razor blade, a concave mirror, and a light source.

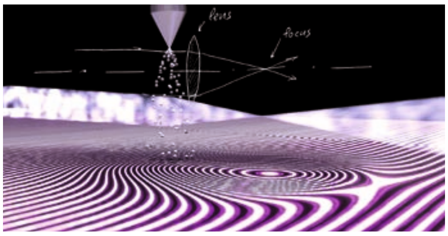
Density and temperature differences caused by gas flows around hot bodies lead to variations in the index of refraction of the gas, which cause light to be deflected. The deflected light is then compared to undeflected light, which is partially blocked by the razor blade, and visible patterns are projected onto a screen that help to visualise the otherwise invisible flow. Schlieren flow visualisation is used to visualise different type of flow in aerodynamics, ballistics, and acoustics. It is also possible to make use of the effect in video projectors.

Atomic jet – the first lens for extreme-ultraviolet light

Scientists from Laserlab-Europe partner Max Born Institute (MBI) in Berlin have developed the first refractive lens that focuses extreme ultraviolet beams. Instead of using a glass lens, which is non-transparent in the extreme-ultraviolet region, the researchers have demonstrated a lens that is formed by a jet of atoms. The results, which provide novel opportunities for the imaging of biological samples on the shortest timescales, were published in *Nature* (564: 91, 2018).

Electromagnetic radiation in the extreme-ultraviolet (XUV) region is somewhat special. It occupies the wavelength range between the UV and X-ray domains, but unlike the two latter types of radiation, it can only travel in vacuum or strongly rarefied gases. Nowadays XUV beams are widely used in semiconductor lithography as well as in fundamental research to understand and control the structure and dynamics of matter. However, in spite of the large number of XUV sources and applications, no XUV lenses have existed up to now. The reason is that XUV radiation is strongly absorbed by any solid or liquid material and simply cannot pass through conventional lenses.

In order to focus XUV beams, a team of MBI researchers have taken a different approach: They replaced a glass lens with that formed by a jet of atoms of a noble gas, helium. This lens benefits from the high transmission of helium



Focusing of an XUV beam by a jet of atoms that is used as a lens. Credit: Oleg Kornilov / Lorenz Drescher.

in the XUV spectral range and at the same time can be precisely controlled by changing the density of the gas in the jet. This is important in order to tune the focal length and minimise the spot sizes of the focused XUV beams.

In comparison to curved mirrors that are often used to focus XUV radiation, these gaseous refractive lenses have a number of advantages: A 'new' lens is constantly generated through the flow of atoms in the jet, meaning that problems with damages are avoided. Furthermore, a gas lens results in virtually no loss of XUV radiation compared to a typical mirror.

Fast method for cancer diagnosis

An interdisciplinary team of Jena scientists, including researchers from Laserlab-Europe associate partner Leibniz Institute for Photonic Technology (Leibniz-IPHT), were awarded the renowned Kaiser Friedrich Research Prize on 18 October 2018 for their optical approach to diagnose cancerous tissue quickly, gently and reliably during surgery. The celebrated research project is called "CDIS Jena – Cancer Diagnostic Imaging Solution Jena".

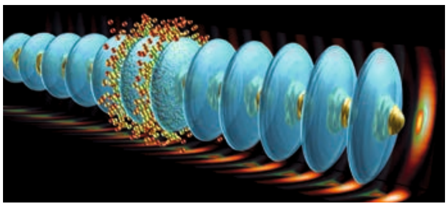
Currently, doctors and cancer patients have to wait for the results of the microscopic analysis of the tissue biopsies subsequent to the operation to be sure whether the tumour has been successfully removed. By combining three different imaging techniques, the fast method researched by the Jena scientists offers to provide certainty in 20 minutes. Thus helping to avoid patients having to undergo surgery again, it may not only contribute to improve their chances of recovery, but could also save considerable costs in hospital operations.

AWAKE: breakthrough plasma-based acceleration

CERN's AWAKE collaboration, which includes researchers from Laserlab-Europe partner Instituto Superior Técnico (IST, Lisbon), has reported the first experiment on electron acceleration in plasma waves generated by a proton beam. The acceleration obtained in this first demonstration was already several times larger than that achieved with conventional technologies currently available for particle accelerators. The results have been published in Nature (561: 363, 2018).

The use of plasma waves (the so-called wakefields) has the potential to drastically reduce the size of particle accelerators. AWAKE, which stands for Advanced WAKEfield Experiment, is a demonstration project of a compact electron accelerator at very high energies over short distances.

The AWAKE experiment receives a proton beam of 400 GeV energy from CERN's Super Proton Synchrotron (SPS), which is the last one in the chain of accelerators that delivers protons to the Large Hadron Collider (LHC). An electron beam is injected with a slight angle into the oscillating plasma, and gets accelerated as it surfs the plasma waves. Electrons injected at relatively low energies of about 19 MeV 'surfed' the plasma wave and were accelerated by a factor of about 100 to an energy of almost 2 GeV in just 10 meters.



Numerical simulation result of electron acceleration (coloured spheres) in the relativistic plasma wake (blue ellipsoids) left by a proton bunch (yellow bullet- like structures) in the AWAKE experiment at CERN. (Jorge Vieira/IST Lisbon).

ERC Grants

Each year, a significant number of Laserlab-Europe researchers are awarded prestigious personal grants by the European Research Council. On this page, we highlight two recently granted Starting projects, and one Consolidator project – worth up to 1.5 and 2 million Euro, respectively – for a period of five years.

Francesco Scotognella (POLIMI): Harvesting more solar energy

Earth is inhabited by an energy-hungry human society. The Sun, with a global radiation at ground level of more than 1 kW/m^2, is our largest source of energy. However, 45% of the total radiation is in the near infrared (NIR) and is not absorbed by most photovoltaic materials. In his Consolidator Grant project, Francesco Scotognella will try to increase the capacity of solar energy conversion by extracting plasmon-assisted hot carriers from NIR plasmonic materials. He intends to enhance the lifetime of these hot carriers by linewidth narrowing in plasmonic nanoparticle films made of doped semiconductor nanocrystals.

The aim is to produce a solar cell device functioning in the near infrared with efficiencies up to 10%. A tandem solar cell, which would combine a commercial silicon solar cell with a power conversion of around 20% with the new PAIDEIA based device, is expected to reach a total power conversion efficiency of 30% by extending the range of utilised wavelengths to the full spectral range delivered by the Sun.

Benjamin Fingerhut (MBI): Understanding ultrafast biomolecular processes

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The understanding of ultrafast biomolecular vibrational dynamics in the mid-infrared to terahertz region is impeded by the absence of timescale separation between the system and its environment, which is why a non-adiabatic theoretical description is required. Currently, knowledge on anisotropy of ultrafast vibrational energy relaxation, together with information about distinguished intra- or inter-molecular acceptor modes, is scarce.

In his ERC Starting Grant project, Benjamin Fingerhut will apply the challenging non-adiabatic approach to the investigation of vibrational dynamics in polar liquids, within nano-confined environments and in the vicinity of biological interfaces. As such the project intends to transfer concepts for the description of ultrafast electronic relaxation to the low energy mid-IR/THz domain.

Possible applications cover microscopic descriptions of elementary proton transfer reactions, mechanisms of energy dissipation upon vibrational excitation, and solvation dynamics in biological relevant crowded environments.

Elias Kristensson (LLC): Videos of ultrafast phenomena

Past methods to probe ultrafast events – occurring on picosecond timescale or faster – have mostly relied on pump-probe scanning, yet these can only measure the dynamics of such processes if they are repetitive. Understanding all spatiotemporal aspects of ultrafast phenomena, however, requires experimental means to spatially, spectrally and temporally resolve them. Recently, Elias Kristensson invented a coding imaging concept called Frequency Recognition Algorithm for Multiple Exposures (FRAME) that can film at up to 5 trillion frames per second, unifying femtosecond temporal resolution with spectroscopic compatibility.

In his ERC Starting Grant project, Kristensson aims to develop novel diagnostic tools based on FRAME and to apply FRAME videography to study ultrafast events, of which the temporal evolution could not be visualized in the past. Examples are filming plasmas and laser filaments, and imaging fast molecular processes, such as vibration, rotation and fluorescence. In addition, a spectroscopic FRAME setup will be developed to monitor extremely fast chemical reactions in real time.

The future of laser-based X-ray science and technology

A Laserlab-Europe Foresight Workshop took place at ICFO – The Institute of Photonic Sciences in Castelldefels (Barcelona), on 19-20 November 2018. The workshop, titled "Visions on Future Laser-based X-ray Science and Technology", was attended by more than 80 participants, bringing together leading scientists of the relevant laboratories of Laserlab-Europe and of other European and international institutions as well as representatives from industry.

We are currently witnessing spectacular advances in laboratory and facility-based x-ray sources which enable a wide range of investigations with unprecedented time resolution and element specificity. The aim of this Laserlab-Europe Foresight Workshop was to assess the state of the art and to discuss visions for future opportunities in laser-based x-ray science through technological developments and novel methods for scientific investigations. The two-day workshop was divided into three main sessions, covering state-of-the-art scientific applications, sources, and the requirements of industry.

The session on scientific applications covered a wide area of investigations and methods, including atomic and molecular physics, chemistry and solid state physics, surface science and catalysis, chemical dynamics and photosynthesis, energy harvesting and information processing, magnetism, x-ray optics and metrology.

The session on sources covered both laboratory and facility-based sources, such as plasma x-rays in gas and liquid targets, high harmonic generation and attosecond sources, free electron lasers, betatron radiation, x-ray lasers, laser-Wakefield acceleration and seeded FELs.

The industry session included representatives from ASML and pnSensor GmbH. ASML is a key manufacturer of lithography instrumentation for semiconductor industry. PnSensor GmbH is a key manufacturer of detection systems for x-rays. The session included presentations on the needs of industry, the identification of bottlenecks and the knowledge chain in which fundamental research feeds best into industry.

At the end of each day, a round table session was organised with lively discussions about opportunities for future collaboration and synergies between the communities as well as options for industrial involvement.

The workshop led to a clear overview of the existing and emerging research landscape in addition to a comprehensive insight into the needs of industry. The wide range of discussed applications clearly highlighted the importance of a continued development of x-ray sources and their methodologies.

Quick consensus was reached that there exists no single source or application that serves all purposes. On the contrary, the seeming heterogeneity of the scientific landscape was identified as strategic strength that is ideally tailored to the complementarity of investigations and applications.

New areas were identified that are currently emerging together with improved sources but also together with novel data treatment methodologies. These diverse areas provide a fertile ground for future fundamental research and direct applications in, e.g., advanced materials and quantum technologies. The round table discussion provided a direct insight into the needs of industry and how the connection to fundamental research leads to the development of advanced technology, which directly benefits industry and secures the competitiveness of the European community.

Jens Biegert, ICFO

A book of abstracts is available at *https://www.laserlab-europe.eu/events-1/laserlab-events/2018/future-laser-based-x-rayscience*

Lasers for Fusion Energy

Nuclear fusion may one day become one of the main sources of energy for mankind. Mimicking the fusion processes that power stars like our Sun, a virtually unlimited amount of energy can be produced using sea water as a fuel source. Creating the extreme temperatures and densities required to get the fusion process going, however, remains a rather challenging task.
As an alternative to the so-called magnetic confinement approach to fusion energy (pursued in the proof-of-principle plant ITER, currently under construction in the south of France), several laser-based approaches to a competing technique, Inertial Confinement Fusion, have been proposed. This focus section shows how Laserlab-Europe scientists are involved in investigating how the current limits of this revolutionary approach can be overcome, and how Laserlab facilities are of fundamental importance to this quest.

The ToIFE partners

EUROfusion project Towards Inertial Fusion Energy

Within the Horizon 2020 programme, fusion research activities are supported and funded by EUROfusion on behalf of the European Atomic Energy Community (EURATOM). Although mainly focused on magnetic confinement fusion, EUROfusion is also supporting Inertial Fusion Energy (IFE) within its enabling research grant programme through the *Towards Inertial Fusion Energy* (ToIFE) project.

The ToIFE project ran from 2014 to 2018, and was initiated in order to capitalise on the integration reached and lessons learned within the HiPER conceptual design and preparatory phase (2006–2013), which shaped many aspects of laser fusion research within Europe (*see also the contribution by Michael Tatarakis*).

ToIFE aimed at achieving the fundamental understanding required to demonstrate the viability of laser-driven fusion as an alternative road towards a sustainable, clean and secure energy source. It hinged on four missions: (1) understanding underlying obstacles to central hot-spot ignition on megajoule scale laser facilities; (2) advancing physics towards demonstration of shock ignition (SI); (3) testing the viability of other alternative ignition schemes (fast ignition, impact ignition or aneutronic fusion); and (4) developing key IFE technologies (high-repetition-rate laser drivers, innovative diagnostics or measures against electromagnetic perturbations or novel materials).

Based on a comprehensive and coherent programme of experiments and numerical simulations, and on fostered collaborations between the fourteen partners in nine different countries, it allowed significant progress in the field of laser plasma physics and in the understanding of the challenges that the IFE community has to face.

The ToIFE achievements manifested themselves in the acceptance, for 2017–2018, of three new EUROfusion projects investigating specific issues. *Preparation and Realization of European Shock Ignition Experiments* (*see also the contribution by Dimitri Batani*) is taking up and extending mission #2, on all aspects except those related to the LMJ-PETAL SI experiment. *Non-local thermal transport in inertial and magnetic confinement fusion plasmas*, led by Christopher Ridgers (University of York, UK), is investigating – from the theoretical and numerical points of view, experiments performed within mission #1. *Towards a universal Stark-Zeeman code for spectroscopic diagnostics and for integration in transport codes*, led by Joao Jorge Santos (CELIA, France), is capitalising on the successful development of the capacitor-coil targets within mission #3.

The scientific and technological advances made within the project would not have been reached without the EUROfusion-supported structuring of the community and without access to high-energy research infrastructures, namely LULI2000 (LULI, France), PALS (IoP Prague, Czech Republic), PHELIX (GSI, Germany) and VULCAN (STFC/RAL, UK).

Sylvie Jacquemot, LULI, coordinator of ToIFE

HiPER: building laser-driven fusion research in Europe

The HiPER (High Power Energy Research) has been a European ESFRI Roadmap project aiming to explore laser-driven fusion schemes and, at a second phase, to develop a laser research infrastructure for the assessment of the possibility of commercial power production based on laser-driven fusion of deuterium and tritium. The Preparatory Phase of the HiPER project from 2008 to 2013 was co-ordinated by Laserlab-Europe partner the Science and Technology Facilities Council (STFC) in the UK.

Since its inception, HiPER has been designed to allow a substantial, long-term science programme in a wide range of associated science and applications to complement its mission of fusion research. During the Preparatory Phase of the Project, scientists had been working on a plan to investigate the physics of various fusion schemes, e.g., fast ignition and shock ignition. A critical advantage of shock ignition is that it is amenable to demonstration, on a single shot basis, using the Laser MégaJoule (LMJ) facility in France (*see also the contribution by Jean-Luc Miquel*).

Key outputs from the project include hundreds of peer reviewed publications in the scientific literature, covering all related aspects of the physics and technology of laser-driven fusion as well as aspects of the fundamental science programme of the project, and many high profile invited lectures at international conferences.

But above all, and maybe the most important outcome of the HiPER project is its influence on the laser fusion community, which experienced an impressive expansion in Europe. This expansion has also been driven by a dedicated HiPER physics training and networking programme via specially realised actions. Such actions are continued today and provide opportunities to discuss future actions and HiPER-related physics and technology.

Michael Tatarakis, TEI of Crete/CPPL, coordinator of HiPER's Fundamental Science Programme

EUROfusion project on shock ignition

The physics of the shock ignition approach to Inertial Confinement Fusion is currently being studied in the EUROfusion project *Preparation and Realization of European Shock Ignition Experiments*, which is coordinated by Laserlab-Europe partner CELIA (Bordeaux) and involves researchers from groups in seven European countries.

In the so-called 'indirect-drive' approach of Inertial Confinement Fusion (as employed at the National Ignition Facility at Livermore Lab California), laser beams delivering almost two megajoule of laser energy are focused inside a cavity (*hohlraum*) and converted to X-rays which should compress the capsule containing the thermonuclear fuel in a very symmetric way. This approach is very expensive in terms of energy, but it has long been thought the only way to provide the irradiation uniformity needed to avoid hydrodynamic instabilities, which cause deformations of the target and ultimately may even break it, preventing achieving ignition.

Shock ignition is an alternative approach to laser fusion, promising to couple energy efficiency to the required compression uniformity. In this approach the laser beams at typical intensities of a few times 10^{14} W/cm^2 directly compress a thicker capsule at lower velocity, which is much less affected by Rayleigh-Taylor instability. Towards the end of compression, a more intense laser spike (intensity up to about 10^{16} W/cm^2, duration few hundred picoseconds) launches a strong spherical shock wave, which converges to the centre, further heating and compressing the fuel and providing the conditions needed to trigger the nuclear fusion reactions.

Very encouraging, although preliminary, results on shock ignition have been obtained in experiments conducted at the Omega laser facility in Rochester, USA. Nevertheless, the physics of shock ignition is still largely unexplored.

In addition to studying the physics relevant to shock ignition, the EUROfusion project aims to promote collaborations with researchers outside Europe (in particular with the University of Rochester, USA, the birthplace of shock ignition) and to prepare future experiments to be conducted on the LMJ/PETAL laser facility in Bordeaux (*see also the contribution by Jean-Luc Miquel*).

The consortium started in 2017 and has conducted several joint experimental campaigns in particular at the PALS laser facility in Prague (*see also the contribution by Gabriele Cristoforetti et al.*), as well as at the Omega facility in the US.

Dimitri Batani, CELIA (University of Bordeaux), coordinator of the EUROfusion project on shock ignition

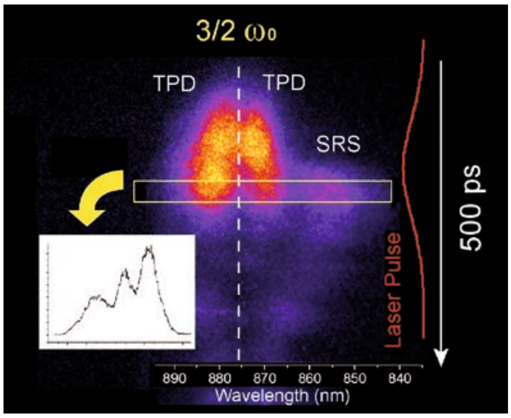
Laser plasma interaction experiments relevant for shock ignition at PALS

In recent years, the unique capabilities of Czech Laserlab-Europe partner Prague Asterix Laser System (PALS) have been used to investigate the conditions required for the shock ignition approach of Inertial Confinement Fusion. Among the institutes involved were Laserlab partner CELIA (Bordeaux), associate partner IPPLM (Warsaw) and subcontractor INO-CNR (Pisa).

In the shock ignition approach, fuel ignition is produced by a strong converging shock, driven at the end of the compression stage by an intense laser pulse. In this scheme, understanding the laser plasma interaction (LPI) of the igniting laser spike, and the ability to control the process, are particularly tricky and critical.

In recent years, a series of experimental campaigns have been carried out at PALS to investigate LPI and strong shock formation at intensities of interest for shock ignition. PALS is a unique laser facility in Europe, because it is able to provide the laser intensities (ca. 10^{16} W/cm^2) and pulse durations (ca. 300 picoseconds) typical of shock ignition conditions with a sufficiently large focal spot (ca. 100 µm).

Measurements were dedicated to the onset and the relevance of parametric instabilities – such as Stimulated Brillouin Scattering (SBS), Stimulated Raman Scattering (SRS) and Two Plasmon Decay (TPD) – during the irradiation of laser pulses at PALS' fundamental and at the tripled laser frequency and an intensity of around 10^{16} W/cm^2. These processes can significantly degrade laser-plasma coupling, by producing a strong reflection of light (SBS and SRS), and can generate high-energy 'hot' electrons, which may affect pellet compression.



Time-resolved spectrum of $3/2\omega_0$, showing the timing of instabilities caused by Stimulated Raman Scattering (SRS) and Two Plasmon Decay (TPD).

The comparison of experimental results with Particle In Cell simulations permitted also to get a deeper insight into the processes involved; notably their interplay, their timing and the effects of local values of plasma density and temperature.

Gabriele Cristoforetti, Leonida Antonio Gizzi, Federica Baffigi, Petra Koester – INO-CNR

G. Cristoforetti et al., EPL 117: 35001, 2017; G. Cristoforetti et al., PoP 25: 012702, 2018

Relativistic electron beam collimation for electron fast ignition

In the fast ignition approach to Inertial Confinement Fusion, a beam of charged particles provides the energy needed – on top of the energy from the implosion of the fuel sphere – to reach the temperature and density conditions required for nuclear fusion. In a recent experiment involving researchers from Laserlab-Europe partners LULI and CLPU, it was investigated how to control an electron beam for fast ignition using self-induced magnetic fields.

The advantage of electron fast ignition is that the electron beam can be easily generated by focusing a laser beam (of picosecond duration) directly on the external shell of the fuel sphere and no other targets are required. Once the electron beam is generated, it can propagate to the centre of the sphere and deposit the necessary energy to start nuclear fusion.

The success of this scheme relies on the possibility to control the divergence of the electron beam. A way to control and guide electron beams is to use the magnetic field the electron beam produces itself in the plasma medium. This magnetic field could confine the beam if properly amplified and controlled.

At the LULI laboratories the team of researchers performed an experiment to investigate how to control the self-induced magnetic field. The trick is to split the laser pulse into two consecutive pulses in such a way that the first laser pulse generates a first magnetic field which can be used to guide the electron beam generated by the second laser pulse. The team demonstrated the feasibility of the scheme, and showed which are the relevant parameters to control the process.

Using the 100 terawatt laser system ELFIE at LULI, the researchers managed to investigate the relation between the magnetic field generated by the first beam and the main electron beam generated by the second beam as a function of the delay between the two beam delays and for different laser focal spots.

Luca Volpe, CLPU Laser-Plasma Chair at the University of Salamanca

Focused proton beams for fast ignition

Researchers from British Laserlab-Europe partners the University of Strathclyde and the Central Laser Facility (CLF) have used the petawatt-class Orion laser system in the UK to produce tightly focused beams of protons, using novel shaped targets, to assess physics relevant to Inertial Confinement Fusion and to develop laser-driven proton heating for high energy density physics.

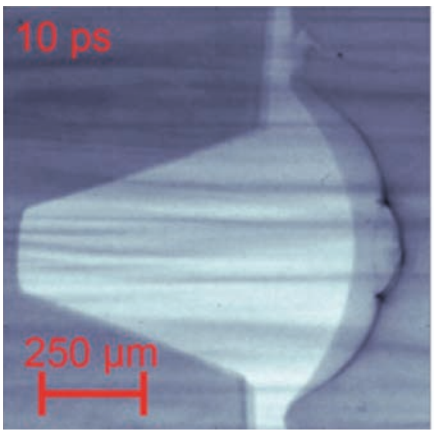
High-power laser pulses are capable of accelerating protons to tens of MeV energies, in durations of the order of the laser pulse (tens of femtoseconds to several picoseconds) at the source. This high-dose, rapid burst of radiation is capable of isochorically heating matter to exotic states that, until recently, have been extremely difficult to generate.

The team of researchers performed an experiment on the UK's Orion laser as part of the AWE's academic access programme, where they employed novel target designs involving hemispherical targets to produce a high-flux, focused proton beam. A combination of gold hemispherical target foils and conical attachments produce a focused proton beam by focusing field lines on the target rear, in addition to strong transverse electric fields on the cone walls; the latter pushing the already focusing protons into an even tighter beam.

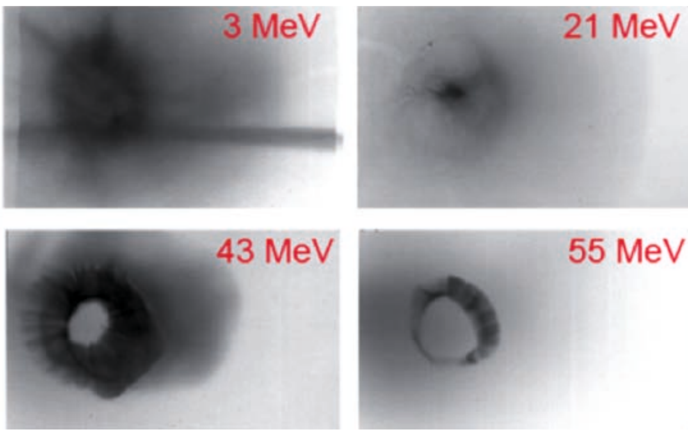
The experiment resulted in a clear demonstration of proton focusing using an open-tipped cone. This is observed at 21 MeV in the featured image. The beam appears annular at higher energies, due to 'over-focusing', which results from the higher transverse fields surrounding the cone at early times, when the highest energy protons are accelerated and traverse the cone structure.

With their successful proof-of-principle experiment, the international collaboration, which also included researchers from UC San Diego (USA) and TU Darmstadt (Germany), plans on developing this work, by further studying the focusing capabilities and designing target geometries that make the beam suitable as a tool for proton fast ignition and to superheat samples for material studies.

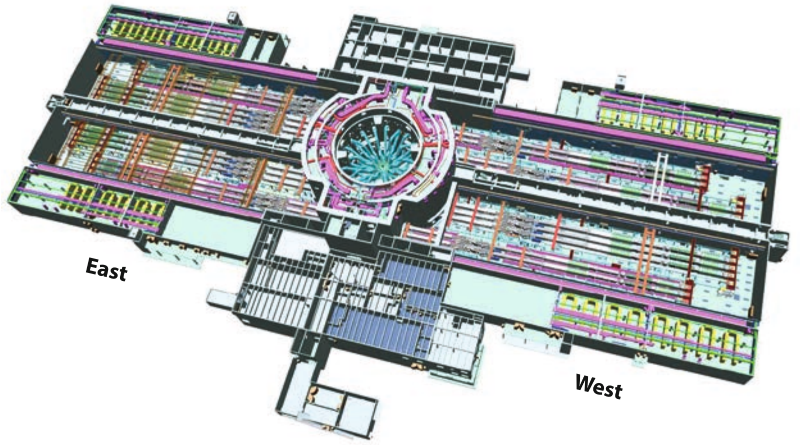
Adam Higginson, University of Strathclyde (now at UCSD, USA)

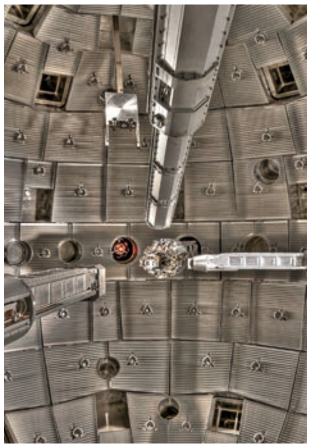


Proton radiograph of the conical target, with an electrostatic field structure clearly visible as a dark band on the hemisphere's surface.



Spectral slices of the proton beam generated by the radiographed target, with a clear focused component at 21 MeV.





Schematic of LMJ with 4 laser bays and a central target bay (left). View of the target chamber inside (right).

The Laser Mégajoule (LMJ) facility and its contribution to fusion energy

One of the few laser facilities capable of creating the extreme conditions required by Inertial Confinement Fusion is the Laser Mégajoule (LMJ), located near Bordeaux, France. In December 2017, LMJ's Petawatt laser beam PETAL became operational, opening the possibility to study aspects of various laser fusion schemes.

LMJ offers unique capabilities, providing an extraordinary instrument to study high energy density physics and basic science. The 176 beams of the facility, grouped into 22 bundles of 8 beams, will deliver a total energy of 1.4 MJ of 0.35 µm light and a maximum power of 400 TW. Using a variety of pulse shapes, it is possible to bring material to extreme conditions with temperature of hundreds of millions of degrees Celsius and pressures of hundreds of billions of bars. Among the multiple experiments planned on LMJ, Inertial Confinement Fusion (ICF) is the most exciting challenge, and sets the most stringent specifications on the facility.

LMJ is still in a ramp-up period: operational commissioning was established in October 2014 with the first bundle of eight beams and the first plasma diagnostics. Five bundles and ten diagnostics are now operational; with these forty beams and a maximal energy of 300 kJ, LMJ is the second largest laser in the world.

Since the operational commissioning, more than 500 laser shots have been performed, including 150 shots on target for experiments dedicated to the Simulation Program developed by the French Alternative Energies and Atom Energy Commission (CEA). To complete the experimental capabilities of LMJ, a PW beam (PETAL), has been added to the LMJ's beams. It is a short-pulse (0.5 picoseconds), high-energy (up to 3.5 kJ), ultra-high-power beam.

LMJ-PETAL is open to the academic communities. Six experiments have already been selected among 25 proposals. Some of them are dedicated to ICF, and will use the outstanding LMJ-PETAL capabilities to investigate some aspects of laser fusion schemes (including standard ICF and shock ignition). Experiments combining LMJ and PETAL have started in December 2017, opening the possibility to address new fields in physics.

The PETAL project has been performed under the auspices of the Conseil Régional de Nouvelle Aquitaine, of the French Ministry of Research and of the European Union.

Jean-Luc Miquel, on behalf of the LMJ team

http://www-lmj.cea.fr/en/ForUsers.htm.

Simulating laser fusion

The coupled, non-linear nature of the physics of laser fusion means simulation models are critical for designing and interpreting the experiments. Unfortunately, current simulation models are not sufficiently accurate to predict the observed experimental behaviour. In an attempt to address this problem, which is particularly important for shock ignition, a three year, £1.3 million grant has been awarded to a team led by Dr Robbie Scott of Laserlab-Europe partner the Central Laser Facility (CLF) in collaboration with the Universities of York and Warwick.

A leading hypothesis for the causes of the inaccuracies of laser fusion simulations are kinetic laser plasma interaction instabilities (LPIs). These alter the experiments in ways that are both hard to measure experimentally, and hard to model. The issue faced, is that current simulation codes used to design the laser fusion experiments do not account for LPIs and the changes they cause. This makes it very difficult to account for their effects, precluding the design of experiments with sufficient accuracy for fusion energy gain.

Through a combination of dedicated laser-plasma interaction experiments and innovative code developments, the goal is to create a benchmarked, world-leading simulation code capability by including the effects of LPIs within the UK's 'Odin' radiation-hydrodynamics code. This will enable academic users of the CLF to design and interpret their experiments with unprecedented accuracy, and ultimately enable a robust evaluation of the viability of the shock ignition approach to laser fusion, and the size of the laser this would require.

Helen Towrie, CLF

The targets used in the experiment (taken with a 5p coin in the background for scale). Target credit: Donna Wyatt, Chris Spindloe and Aasia Hughes at the CLF, STFC.

Measuring the binding energy of molecular hydrogen to test fundamental physics

Seventy years after the development of quantum electrodynamic theory, the simple hydrogen molecule is still at the heart of the most stringent tests of our most successful physical models. A recent Laserlab-Europe transnational access collaboration between the groups of Wim Ubachs (LaserLaB Amsterdam) and Frédéric Merkt (ETH Zürich) led to the most accurate experimental determination so far (one part in a billion) of the binding energy of the hydrogen molecule. The results have been published in *Physical Review Letters*.

Molecular hydrogen with its four constituents, a pair of protons and a pair of electrons, permits the most accurate first-principles calculations among any neutral molecules. Equally accurate experimental measurements of properties like the binding energy of the hydrogen molecule thus allow us to test the validity of such calculations and their underlying models.

Comparison of measurements and calculations can even be used in searches for physics beyond the Standard Model, which is the topic of the ERC Advanced Grant project of Wim Ubachs. The simple idea is that, assuming that we understand quantum electrodynamic theory (QED) completely, a real discrepancy with the measurements must point to new effects that were unaccounted for and may either assert the incompleteness of QED or even the presence of new interactions outside the Standard Model.

Steady improvements in the experimental and theoretical investigations have resulted in orders of magnitude improvements in accuracy of both measurements and calculations of the binding energy (or, equivalently, dissociation energy) of molecular hydrogen over several decades as presented in Figure 1. The dynamics of this race in precision has mutually motivated innovations in the measurements and calculations, and sets the stage for the present experimental investigation.

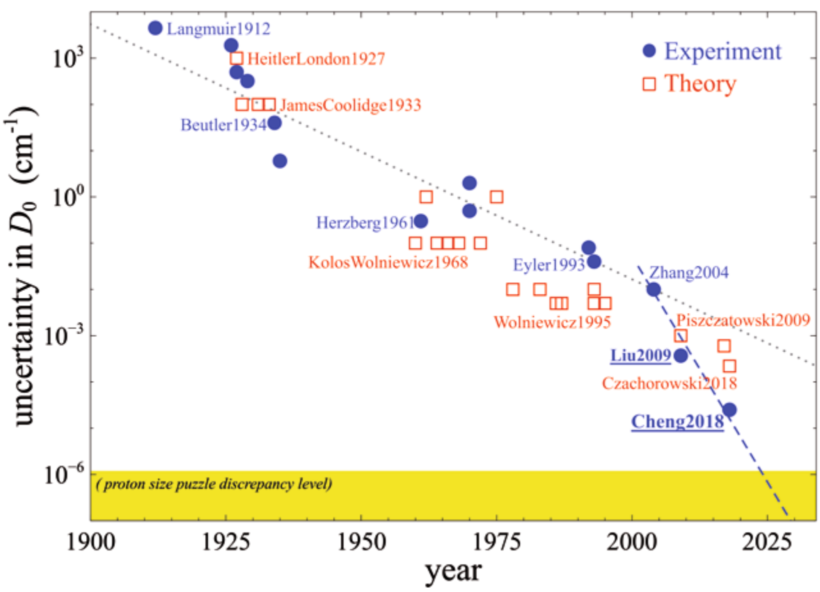


Figure 1: *Experimental uncertainty in the dissociation/binding energy of the hydrogen molecule.*

The indirect approach adopted by the teams of Wim Ubachs and Frédéric Merkt in this project is based on a "thermodynamic cycle", which involves ionisation and dissociation energies of the neutral and ionic molecules as well as the ionisation energy of the atom. As depicted in Figure 2, this looks at first glance more complicated than it should be. In fact, this approach solves severe difficulties encountered in the previous approach pioneered by Herzberg, which involved an extrapolation to the onset of the dissociation continuum.

The price to pay of the present approach is performing a sequence of spectroscopic experiments that link the molecular electronic ground state to an intermediate excited state; and further connecting this intermediate state to the ionisation limit of the molecule, which includes a sophisticated quantum defect extrapolation. In addition, the dissociation energy of the H_2^+ ion obtained from accurate calculations, and the ionisation limit of the H atom extracted from accurate measurements are needed. Surprisingly, this enables the most accurate determination (1 part in 10^9) of any molecular bond strength.

While there has been a long scientific association between the groups of Wim Ubachs and Frédéric Merkt, the present collaboration is a natural follow-up of an earlier campaign to measure the dissociation energy of hydrogen, launched some ten years ago. Back in 2008, during dinner high up in the Swiss Alpine peak of Diavolezza after an intense day of science and ski, it was decided to perform the last link of the experimental chain at ETH Zürich. (The energy difference between the ground and intermediate EF state had already been measured in Amsterdam.) The combined experimental efforts eventually led to more than order of magnitude improvement on all previous determinations.

At the time, the experimentalists thought that it would take several years if not decades for the theorists to catch up. Such complacency was shattered quickly, when Krzysztof Pachucki and co-workers announced impressive improvements in their calculations just a few months later.

That the improved measurement presently described took almost ten years after the previous investigations is due to the required developments in pursuing a slightly different path, that is using the so-called GK state instead of the EF state as an intermediate level. This seemingly slight adaptation required substantial changes in the spectroscopic investigations both at Amsterdam and Zürich.

A key ingredient for the LaserLaB Amsterdam experiment is a special nonlinear crystal, KBBF, which uniquely enables frequency doubling in the vacuum ultraviolet range. To acquire such a crystal, which is only produced in China, Wim Ubachs visited Shuiming Hu in Hefei where he proposed a collaboration. This turned out to be quite a challenge, as the Chinese government has strictly restricted access of this crystal outside the country. When the KBBF crystal finally arrived in Amsterdam, it had taken more than a year of efforts and negotiations, before eventually receiving the approval of the Chinese Academy of Sciences, the very tip of their academic pyramid.

The in-house developed narrowband titanium sapphire-based pulsed source at LaserLaB Amsterdam offers extreme frequency resolution (Q-factor ~1x10^8) while providing broad wavelength tunability in the infrared range ~700 -850 nm. The design is based on a cw-seeded master oscillator cavity with a 532-nm pulsed pump, with the oscillator output pulse further amplified in multi-pass configuration in another Ti:Sa crystal. (Radiant Dyes Gmbh, has been granted licence to commercialize this system.)

In addition, the Ti:Sa cw-seed frequency is locked to an optical frequency comb that is referenced to a Cs atomic clock in Kjeld Eikema's ultrafast lab, also at LaserLaB Amsterdam, to obtain the highest accuracy in frequency calibration. With an IR output of several tens of mJ energy per pulse, subsequent second harmonic generations using both a BBO crystal and the mentioned KBBF crystal produced radiation at 179 nm.

By performing Doppler-free two-photon excitation of the X ground state to the intermediate GK state in a hydrogen molecular beam, the UV transition frequency is measured at a relative accuracy of 2 parts in 10^{11}. To reach such accuracy, all sorts of systematic effects, including light power shifts, residual Doppler effects, as well as frequency chirp in the laser source had to be measured and compensated. It is noted that this GK-X measurement is the first direct excitation ever and hence it is even more remarkable that such accuracies could be achieved.

The parallel experiment at Zürich provided the link from the intermediate GK state to the molecular ionisation energy. The alternative approach to the GK state enabled the possibility of cw excitation to high-lying Rydberg states, which drastically improved the accuracy. With careful systematic checks, this enabled the determination of this frequency interval to an accuracy that is more than 50 times better than that obtained by the same collaboration in 2009. The combination of all energy intervals (see Figure 2) enabled the determination of the binding or dissociation energy of molecular hydrogen to an accuracy in the level of 1 part per billion.

The present measurement results are in agreement with the most recent calculations, thus validating that the

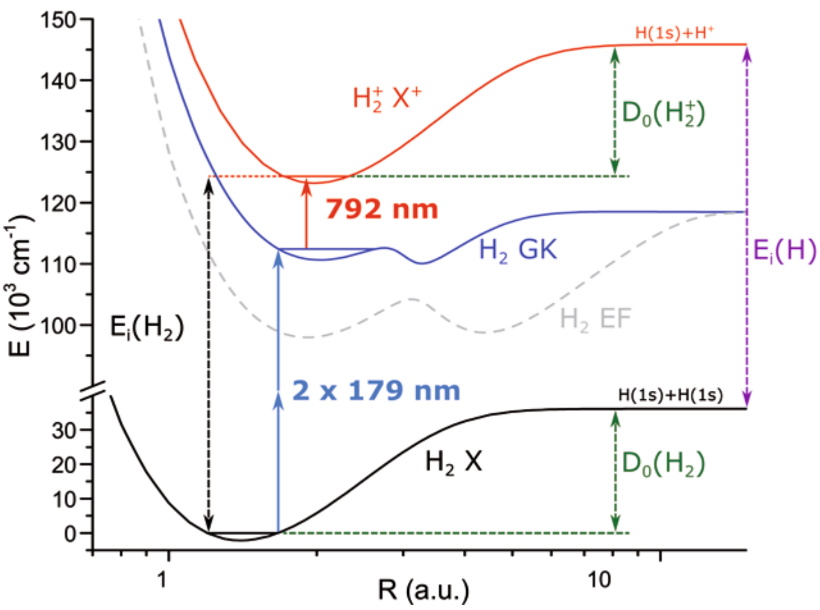


Figure 2: Energy diagram of the hydrogen ion and molecule, showing the "thermodynamic cycle" described in the main text.

present theory is correct at the level of the combined uncertainty of both measurement and calculations. In fact, this combined uncertainty can be used to constrain the effects of hypothetical fifth forces (in reference to the four known fundamental forces) or even hidden extra dimensions in space.

Such new physical effects are traditionally searched for in huge particle physics experiments such as the Large Hadron Collider (LHC) at CERN with TeV energy scales or even higher-energy phenomena as those occurring in supernovae. In contrast, complementary searches in tabletop setups such as those described here rely on probing the most delicate perturbation in the energy levels rather than brute force of particle creation, and greatly leverage upon the unmatched frequency precision that can be achieved in spectroscopy (femto-eV resolution), as well as the extreme accuracy in the theoretical description of simple atomic or molecular systems.

Edcel Salumbides
LaserLaB Amsterdam

C.-F. Cheng et al., Phys. Rev. Lett. 121, 013001 (2018)

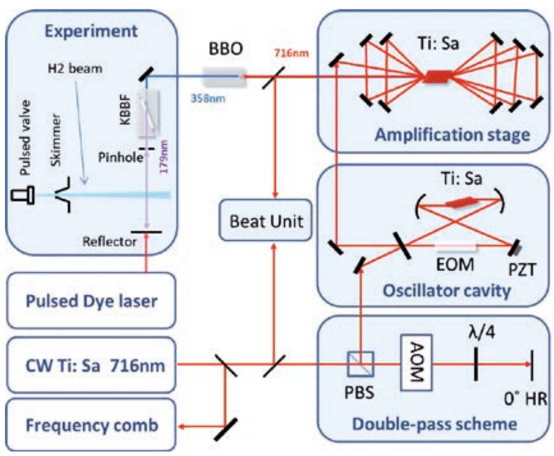


Figure 3: The experimental setup used at LaserLaB Amsterdam.

New Director General for ELI-DC

Allen Weeks was appointed as the new Director General of the Extreme Light Infrastructure Delivery Consortium (ELI-DC), effective end of July 2018. Formerly the Associate Director for Members and Stakeholders Relations, Weeks took over from Carlo Rizzuto, who had been in the post since December 2015.

In his new role, Weeks is given responsibility for managing the transition from ELI DC to ELI ERIC (European Research Infrastructure Consortium), which is expected to be legally established in the first half of 2019.

Allen Weeks began working with research facilities in 2005 where he got involved in the construction project of the Free-Electron Laser 'FERMI' at Elettra in Trieste, Italy. He was then Director of Business Development at Instrumentation Technologies, a leading company making instrumentation for the world's most state-of-the-art accelerators.

From 2012 to 2017, he was the Head of Communications, External Relations, and In-Kind at the European Spallation Source (ESS) in Lund, Sweden. He joined ELI in November 2017 to make use of his experience in starting up a leading European research infrastructure and ERIC membership negotiations.

Source:
ELInes: https://eli-laser.eu/newsletter/

Nobel Prize for Laser Physics

The Royal Swedish Academy of Sciences has awarded the Nobel Prize in Physics 2018 to Arthur Ashkin for his work inventing "optical tweezers" and to Gérard Mourou and Donna Strickland for the invention of Chirped Pulse Amplification (CPA). Both techniques have become important tools for many research groups within Laserlab-Europe.

© ® The Nobel Foundation. Photo: Lovisa Engblom.

Gérard Mourou was director of Laserlab-Europe partner Laboratoire d'Optique Appliquée (LOA, Palaiseau, France) from 2005 to 2008 and is a founding father of the Extreme Light Infrastructure (ELI). Donna Strickland, of the University of Waterloo in Canada, is the third woman to win a Nobel Prize in Physics, after Marie Curie in 1903 and Maria Goeppert-Mayer in 1963.

Mourou and Strickland developed "Chirped Pulse Amplification", or CPA, back in 1985 as Strickland's PhD work. That technique takes low-intensity light, stretches and amplifies it, then compresses it back into incredibly short, ultrafast pulses with greater power than all the power stations in the world – for a millionth of a billionth of a second. Nowadays, CPA is a key technology driving many high-power laser facilities within Laserlab-Europe as well as the Extreme Light Infrastructure, which Mourou first proposed back in 2005.

Strickland and Mourou shared the prize with Arthur Ashkin of Bell Laboratories in the United States for his work inventing "optical tweezers". Optical tweezers use the radiation pressure of laser beams to grab particles, atoms, viruses and other living cells. A major breakthrough came in 1987, when Ashkin used the tweezers to capture living bacteria without harming them. He immediately began studying biological systems, and optical tweezers are now widely used to investigate the machinery of life. Several groups within Laserlab-Europe apply optical tweezers in their research.

Tom Jeltes

Forthcoming events

JRA PHOTMAT Meeting
14 – 15 January 2019, Abingdon, UK

JRA BIOAPP Meeting
14 – 15 January 2019, Abingdon, UK

Laserlab Training school in luminescence dynamics: analysing relaxation processes
11 – 14 April 2019, Riga, Latvia

Hands-on Course in Super Resolution
June/July 2019, Barcelona, Spain

To find out more about conferences and events, visit the Laserlab online conference calendar.

How to apply for access

Interested researchers are invited to contact the Laserlab-Europe website at www.laserlab-europe.eu/transnational-access, where they find relevant information about the participating facilities and local contact points as well as details about the submission procedure. Applicants are encouraged to contact any of the facilities directly to obtain additional information and assistance in preparing a proposal.

Proposal submission is done fully electronically, using the Laserlab-Europe Proposal Management System. Your proposal should contain a brief description of the scientific background and rationale of your project, of its objectives and of the added value of the expected results as well as the experimental set-up, methods and diagnostics that will be used.

Incoming proposals will be examined by the infrastructure you have indicated as host institution for formal compliance with the EU regulations, and then forwarded to the Access Selection Panel (ASP) of Laserlab-Europe. The ASP sends the proposal to external referees, who will judge the scientific content of the project and report their judgement to the ASP. The ASP will then take a final decision. In case the proposal is accepted the host institution will instruct the applicant about further procedures.

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