CLPU

CENTRO DE LÁSERES PULSADOS

Activities Report

2023

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Junta de Castilla y León

VNiVERSiDAD D SALAMANCA
CAMPUS DE EXCELENCIA INTERNACIONAL

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CENTRO DE LÁSERES PULSADOS
VEGA
CLPU PW LASER SYSTEM
CLPU
CENTRO DE LÁSERES PULSADOS

Maquetación: Javier Sastre
Imagen de portada: Visita de la Secretaria General de Investigación (MCIU), Javier Sastre
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DIRECTOR'S MESSAGE

Dear readers,

It is a pleasure to address you again as director of this Consortium to share the achievements achieved during the past year in this infrastructure, both in our role as a user center and in our role as a research center. Leading this infrastructure continues to be a professional achievement that makes me increasingly proud, as I continue to get to know and collaborate with the extraordinary human team that makes it up. Although the uniqueness of our center is found in cutting-edge technological equipment, such as VEGA, the most powerful petawatt laser system in Spain, it would be worth little without the high specialization of the professionals who operate and work with it. I would like you to read this activity report always considering these two key aspects: the impressive ultra-intense laser equipment that has positioned Spain on the world map of laser technology, and the human team whose dedication and talent allow its full operation and service to the community. national and international community.

The facilities of the Pulsed Laser Center (CLPU) are essential to promote both our own projects and those of our users, always focused on obtaining results at the forefront of technical scientific knowledge. Our VEGA laser system stands out for being a versatile ultra-intense system with a high repetition rate, of which there are only two others similar in the world (1 PW – 1 Hz). Operating with this unique laser system is already a consolidated objective, but we always want to go one step further to position ourselves at the forefront of laser technology. Therefore, we continue to improve and update our infrastruc-

ture. An example of this is the ambitious construction and equipment project of a new experimental area adjacent to the current one (AREX2 project). This new area will allow us to expand our capabilities, opening the door to more advanced and diversified experiments, and will strengthen our position as a reference in research with ultra-intense lasers. With the aim of optimizing our facility, the 'Development and Optimization of Experimental Lines at VEGA' project has also begun this year, which has allowed the hiring of a new technologist and in which it is expected to hire at least three other people from different fields of research.

While we advanced in the objective of increasing the added value of our installation, we have continued working with our users carrying out the experimental campaigns that still remained to be scheduled for our third competitive open access call, as well as others that we have valued for their strategic nature. It thus stands out that it was this infrastructure that hosted the first experiment in Spain in which high doses of ultrafast radiation were generated using laser-accelerated protons to impact living human lung tumor cells. A Spanish project led by the i3M institute of Valencia in collaboration with the Galician Institute of High Energy Physics (IGFAE), the Health Research Institute of Santiago de Compostela (IDIS), the Institute of Functional Biology and Genomics of Salamanca and itself Pulsed Laser Center. In this year, in addition, our team has started its work on the two national projects achieved at the end of the year in the Knowledge Generation call of the Ministry of Science: New approaches for pulsed extreme lasers, and Advanced Particle Beams, Plasmas and Laser Experiments. In 2023 we have faced new challenges that we have overcome with the determination that the Pulsed Laser Center continues to be a leading national and international benchmark infrastructure. The effort and improvement of our researchers, technicians, engineers and other specialized personnel has been crucial to achieve each of the scientific-technical activities that are included in this Activities Report.

I am sure that the future will bring, as it always does, uncertainties and new decisions to make, but my goal will always be to ensure the excellence of this unique infrastructure; the promotion of research at the

frontier of knowledge from Spain and with Spain, and offering each step and advance to the entire society. Together and in continuous movement, we continue!

M Dolores Rodríguez Frías

CLPU Director

1. INTRODUCTION

The year 2023 could be described as a period of closures and beginnings: the last experimental campaigns for the third competitive access call were carried out, the project for the optimization of the beams of the laser system was successfully completed, and an important project was launched involving the building and equipping of a new experimental area that will increase the infrastructure's added value and position it for incorporation into European infrastructures. Besides, during those months, as a result of the efforts made in the presentation of project applications to obtain external funding in competitive calls and industrial contracts, there has been a significant increase in the Center's specialized staff, which has exceeded the number of 50 workers for the first time in history, with the number of permanent workers being larger than that of temporary workers also for the first time. These milestones show that the new addendum to the Consortium agreement and the new stage entered with the new management have been implemented with a clear impulse towards stabilization and progress at all levels.

2. VEGA UNIQUE INFRASTRUCTURE

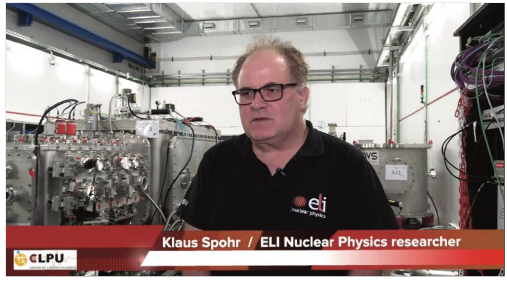
a) Experimental Campaigns

In the framework of the research activity conducted by the CLPU, in 2023, the last campaigns selected in the third open access competition call were carried out, alongside other external competition experiments linked to European projects of transnational network access as well as strategic accesses, most of them connected with experimental scientific research campaigns related to the infrastructure and to externally funded research and development projects:

Laser-driven population & release of the 2.4 MeV isomer in 93m-Mo, towards a nuclear battery

This is the first experimental campaign corresponding to the third call that was scheduled for 2023. It was led by Klaus Spohr, a German researcher from the ELI-Nuclear Physics infrastructure (Romania).

Aim summary: *HPLS technology is constantly evolving and aims to spurn novel approaches to technologies for societarian benefit using the temporal intensities of ions and radiation beam bursts. A core agenda in the long-term development therein is the installation of laser-driven gamma, ion, and neutron sources for the production of radioactive isotopes such as 177-Lu used for FDA-approved Lutathera therapy, thus catering for supply shortages and research into enhancing the clinical efficiency of related therapies. Besides that, the PI (KS) currently holds 9 worldwide patents for installing an immunotherapy-assisted Boron Neutron Therapy (BNCT), which could tremendously profit from developing a laser-driven source for high yields of thermal neutrons. As these available particle and radiation beam yields scale with the laser intensity applied, the best way*



to proceed is to find a technical realization to compress the pulse length of existing HPLS systems, rather than investing in upgrading the energy output in existing HPLS. Our proposal aims to be a first proof-of-concept.

VEGA-3 — **High Energy**

Days: 10 (90.9%)
Average VEGA energy: 34.5 J (1.02 PW)
Average energy: 25.53 J
Average VEGA shots h/day: 6 h. 23 min.
VEGA use - Average h/day: 3 h. 6 min.
Total shots: 1,868

The campaign, which was co-funded by the Laserlab-Europe European consortium through its Transnational Access program, was carried out between 9 and 27 October. The average use of VEGA-3 in the experimentation area was above 3 hours, reaching an average energy of 25.53 J in the area.

The relevance of the experiment is explained by Dr. Klaus Spohr in an interview that can be viewed on our YouTube channel (https://youtu.be/6bCg0AudkAI)

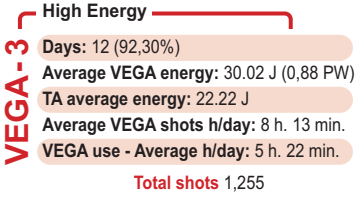
High-energy laser-driven hadron sources based on optimized nanostructured targets

This is the last experimental campaign selected in the CLPU's third open-access competition call. It was led by Francesco Mirani, a researcher from the Politecnico di Milani University (POLIMI) between 6 and 24 November, using the laser system's petawatt output.

Aim summary: *A first experimental demonstration of the DLT concept with a PW-class laser is proposed, which should enable the generation of hadronic beams with unprecedented features in terms of ultrashort duration, brilliance, and energy. The experiment aims to provide a thorough investigation of enhanced laser-driven hadron sources exploiting the concept of advanced Double-Layer Targets (DLTs). Hadron (i.e. proton and neutron) sources driven by high-intensity lasers*

are of great interest on account of their unique properties such as ultra-fast (100 fs - ps) duration, pulsed nature, and high brightness in the 1-10s MeV energy range.

Making use of advanced DLTs –consisting of a low-density nanostructured material deposited on top of a thin solid foil– is an appealing strategy to enhance acceleration performances compared to conventional target configurations. When coupled with a suitable converter, accelerated ions can be used to drive the ultra-fast generation of neutrons via a pitcher-catcher scheme. DLTs offer a flexible solution because their properties can be finely tuned in order to enhance the energy conversion from the laser pulse to the accelerated ions, increasing their energy and number. Our team combines strong expertise in both the fabrication of DLTs with controlled properties and in the theoretical understanding of laser-DLT interaction physics.



The campaign was co-funded by Laserlab-Europe in cooperation with the University of Salamanca.

The details of the experiment are provided by Francesco Mirani in an interview that can be watched on out YouTube channel (https://youtu.be/k45OR6SKpxk)

Efficient proton acceleration via double-pulse laser approach

This is a strategic campaign driven by the CLPU in the framework of its line of research on inertial confinement fusion. One of its aims is to increase the facility's added value. It was led by the Italian researcher Luca Volpe, from the Universidad Politécnica de Madrid (UPM) with the in-situ collaboration of researchers not only from the Spanish infrastructure but also from the Italian Nuclear Physics Institute, 'National Laboratory of Frascati'.

Aim summary: The double laser pulse has been proposed as a method for electron beam collimation [Robinson 2008] in the context of the fast ignition approach to laser fusion [Tabak 2005] and experiments have

been performed in the last decades with promising results [Scott 2008, Malko 2019]. The main idea is based on the possibility of enhancing the focusing effect of the azimuthal magnetic field that is generated by the strong electron current into the target. Preparing two separated pulses permits to enhancement of the collimation effects since the first pulse (the seed beam) generates an azimuthal magnetic field and the second pulse (main beam) will generate the main electron beam which will be naturally guided by the pre-formed magnetic field [Volpe 2013, Volpe 2014, Batani 2014, Curcio 2019]. The experiment proposes to use the double pulse scheme in the femtosecond regime as it has been already set up in the PW laser VEGA 3 line at the CLPU for a previous experiment in electron acceleration; the goal is to use this scheme for enhancing the laser-driven proton production for the first time in the facility. The successful development using the VEGA 3 system at the CLPU of the double pulse scheme will lead to the development of a unique laser-driven beamline where high brightness proton acceleration can be demonstrated at a high repetition rate plus avoiding complicated target design and artificial schemes.

VEGA-3

High Energy

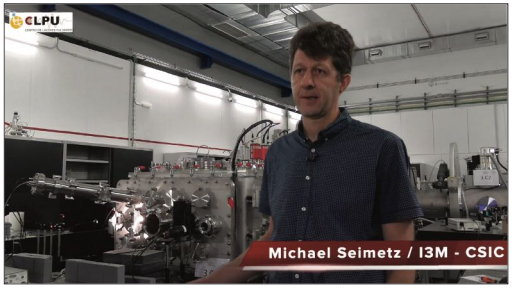
Days: 15 (93%)
Average VEGA energy: 34.49 J (0.99 PW)
TA average energy: 25.52 J
Average VEGA shots h/day: 7 h. 7 min.
VEGA use - Average h/day: 4 h. 38 min.

Total shots: 1,175

Radiation effects of laser-accelerated protons on living cells

This new strategic campaign using VEGA-3 was driven by the CLPU and ran from 11 September to 6 October. It became the first experiment in Spain to generate high doses of ultrafast radiation using accelerated protons to collide with living cells. The aim was to pave the way towards an effective and controlled proton flash radiotherapy therapeutic model. This multidisciplinary project was led by the I3M Institute of Valencia with the cooperation of the Galician Institute of High Energy Physics (IGFAE), the Health Research Institute of Santiago de Compostela (IDIS), the Institute of Functional Biology and Genomics of Salamanca (USAL-CSIC), and the Center for Pulsed Lasers itself.

Aim summary: Laser-plasma accelerators allow the generation of high-energy ions in very small volumes. They provide highly intense, ultrashort pulses of particles which may ultimately be used for radiotherapy.



Protons and ions with energies of order 10 MeV/u which are routinely produced with lasers of 100 TW-1PW at 1-10 Hz shot rate allow for systematic studies of radiobiological effects. To this end several international laser facilities have already implemented experimental arrangements for the irradiation of biological samples, typically monolayer cell cultures.

This experiment aims at the irradiation of living cells with laser-accelerated protons at the VEGA-3 laser. A motorized target wheel, used already in a previous experiment at the same facility, will allow for hundreds of shots at a 1 Hz repetition rate in a single vacuum cycle. A magnetic chicane will be installed closely behind the laser target to select protons within a narrow energy interval. These are guided to in-vitro cell samples outside the vacuum system. The total radiation dose will be measured with radiochromic film and real-time detectors. Radiation effects on the cells will be analyzed by an external collaborator.

VEGA-3 — **High Energy**

- **Days:** 17 (89%)
- **Average VEGA energy:** 37.44 J (1,07 PW)
- **TA average energy:** 27.07 J
- **Average VEGA shots h/day:** 6 h. 22 min.
- **VEGA use - Average h/day:** 3 h. 23 min.

Total shots: 4,373

Further information can be found on our YouTube channel (https://youtu.be/ttO7jXsizVQ)

Laser-driven proton boron fusion

This is a competitive access campaign, although the assessment for access was not made by the CLPU's Access Committee but by the board of experts of one of the European networks and projects that the scientific-technical infrastructure participates in, specifically, the "Transnational Access" work package. In this case, access was assessed, scheduled, and co-funded through the Radiation Facility Network for the Explorations of Effects for Industry and Research, RADNEXT project. It was carried out from 6 to 17 March using VEGA's petawatt output.

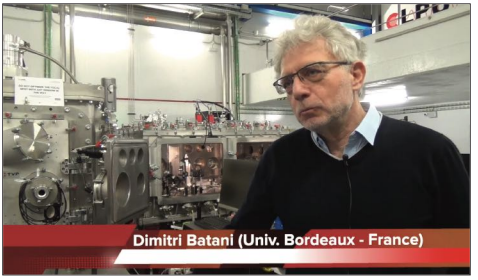
VEGA-3

High Energy

Days: 8 (100%)
Average VEGA energy: 35.23 J (1.06 PW)
TA average energy: 26.07 J
Average VEGA shots h/day: 9 h. 39 min.
VEGA use - Average h/day: 5 h. 48 min.

Total shots: 551

Aim summary: In recent years, the proton-boron (pB) fusion reaction has been a subject of special interest due to its multiple applications. Indeed, the reaction P + B11 ==> 3He4 + 8.7 MeV generates 3 alpha-particles with a total energy of 8.7 MeV, opening the possibility of developing a novel generation of high brightness alpha-particle source, with potential interest in astrophysics [1, 2], space propulsion [3] or fusion energy [4] and medical treatment [5, 6]. Indeed, such reaction can be exploited to develop laser-driven alpha-particle sources that can enable medical applications, in particular for the production of radioisotopes for either diagnostics (PET imaging) or medical treatment. This campaign aims to study different schemes of laser-driven p-11B reaction exploiting the high power and the high-repetition rate of the VEGA-3 laser to improve the alpha production detection and Scandium radioisotope production.



The experiment was led by Marine Huault, from the CELIA French institution, and by Dimitri Batani, from Bordeaux University, who provides further information about it on our YouTube channel in an interview regarding this campaign (https://youtu.be/JRcPhKM9Fh4)

Fiber-based beam instrumentation for laser-driven particle beams

In 2023, access to a second experimental competitive access campaign was granted. It was once again assessed, organized, and co-funded through the RADNEXT European project. This time it was led by the French researcher from the University of San Etienne, Sylvain Girad, using VEGA-3 during the last days of the year, from 11 to 22 December.

Aim summary: This campaign is developed in the frame of the FIBILA project. Its main goal is to evaluate the potential of different architec-

tures of active fiber optic dosimeters, based either on radiation-induced attenuation (RIA) or on radioluminescence (RIL) to characterize the broadband proton beam characteristics at petawatt laser facilities given their monitoring during proton test campaigns of micro-electronics. The results obtained will also benefit the development of dosimeters for ultra-high dose rate beams for other research domains such as medicine. These technologies will be benchmarked by some microelectronics-based solutions from CERN.

VEGA-3

High Energy

Days: 8 (100%)
Average VEGA energy: 33.02 J (1 PW)
TA average energy: 24.44 J
Average VEGA shots h/day: 6 h. 44 min.
VEGA use - Average h/day: 4 h. 52 min.
Total shots: 395

Hybrilin Tests

This strategic campaign, which was developed as part of the Center's research project Hybrid prototype based on laser boost of a Linac to obtain an ultrahigh high dose rate in radiotherapy, was the first to be launched in the 2023 period. Led by the Italian researcher from the Center, Alessandro Curcio, it involved the collaboration of scientists from the Italian Institute of Nuclear Physics 'Frascati National Laboratory'. The system's 200-terawatt laser (VEGA-2) was used, reaching a total of more than three thousand shots.

VEGA-2

High Energy

Days: 10 (100%)
Average VEGA energy: 5.87 J (0.17 PW)
TA average energy: 4.11 J
Average VEGA shots h/day: 7 h. 30 min.
VEGA use - Average h/day: 3 h. 13 min.
Total shots: 3,677

Aim summary: Electron generation with gas nozzle, via VEGA 2, i.e. compact MeV electron gun based on a moderate intensity laser for medical purposes.

Parametric study of the response of commercial CMOS imaging sensors to protons, electrons & X-Ray

This strategic experiment was led by the Center's scientist Jon I. Apiñaniz and is part of one of the infrastructure's own projects that was granted in the framework of the call for R&D&I of the Nuclear Safety Council: Development and testing of new compact, low-cost CMOS for neutron dosimetry, ionizing radiation, and charged particles. It was carried out using VEGA-3 between 29 May and 1 June, reaching an average energy of 25.06 joules in the experimentation area.

Aim summary: Nowadays, one of the major bottlenecks of the experimental development of laser/plasma is the targetry and diagnostics repetition rate performance. For this reason, the CLPU is deeply involved in developing schemes of targetry for HRR, but the diagnostics capabilities need to evolve in the same way. Traditional particle detection techniques are either single-shot type (RCFs, IPs, CR39) or require demanding setups with high voltages and imaging systems (MCP-phosphors, Scintillators) that limit the operational capabilities. For X-rays, on the other hand, dedicated CCD schemes are often used, they provide a certain repetition rate and online capabilities but their high price (tens of k euro), cooling requirements, and bulky size limit their application freedom. The CMOS commercial imaging sensors are the current leading technology for visible photon imaging and they are high resolution, fast acquisition rate (tens of hertz), and, especially very cheap (a few hundred euros). This type of commercial technology is expected to be sensitive to charged particles and X-rays, but the research performed to date regarding this is almost non-existent. Only a few works have been presented in X-ray detection [Perez et al.] and particle detection [Gumiela et al.]. A dedicated campaign is currently in progress at the CLPU for the study of response to CW X-ray photons. The present experiment aims to study the response of CMOS detectors to pulsed protons, electrons, and X-rays as well as the performance of this technology in laser/plasma experimental conditions (vacuum and EMP).

VEGA-3

High Energy

Days: 7 (63%)

Average VEGA energy: 33.86 J (1,01 PW)

TA average energy: 25.06 J

Average VEGA shots h/day: 6 h. 17 min.

VEGA use - Average h/day: 2 h. 38 min.

Total shots: 514

Efficient proton acceleration via double-pulse laser approach using a Fresnel lens as a main diagnostic

During the second half of June, the CLPU's senior scientist, José Antonio Pérez-Hernández, headed this strategic experimental campaign using VEGA-3 as part of the research that the scientific infrastructure is carrying out through the Targets in Ultra-Intense Laser Interaction, Particle Production and Applications (TULIPAN) project.

Aim summary: Double-pulse laser has been proposed as an electron beam collimation method [Robinson2008] in the context of the fast ig-

VEGA-3

High Energy

Days: 7 (70%)
Average VEGA energy: 32.24 J (0,93 PW)
TA average energy: 23.86 J
Average VEGA shots h/day: 4 h. 15 min.
VEGA use - Average h/day: 1 h. 28 min.
Total shots: 251

nition approach to laser fusion [Tabak 2005] and experiments have been performed in the last decades with promising results [Scott 2008, Malko 2019]. The main idea is based on the possibility of enhancing the focusing effect of the azimuthal magnetic field that is generated by the strong electron current into the target. Preparing two separated pulses permits to enhancement of the collimation effects since the first pulse (the seed beam) generates an azimuthal magnetic field and the second pulse (main beam) will generate the main electron beam which will be naturally guided by the pre-formed magnetic field [Volpe 2013, Volpe 2014, Batani 2014, Curcio 2019].

Here we propose to use the double-pulse scheme in the femtosecond regime as it has been already set up in the PW laser VEGA 3 line at the CLPU for a previous experiment in electron acceleration; the goal is to use this scheme for enhancing the laser-driven proton production for the first time at the facility. The successful development using the VEGA 3 system at the CLPU of the double-pulse scheme will lead to the development of a unique laser-driven beamline where high brightness proton acceleration can be demonstrated at high-repetition rates plus avoiding complicated target design and artificial schemes.

Development of tape targets in VEGA for HRR experiments and organization of related HRR diagnostics

The specialized scientist José Luis Henares directed this experiment at the facility between 10 and 21 July. It was carried out using the system's petawatt (PW) beam, which reached an average power of 0.92 PW in this campaign, where more than 8,500 shots were fired. The campaign, whose nature was strategic, was part of the Targets in Ultra-Intense Laser Interaction, Particle Production and Applications (TULIPAN) project.

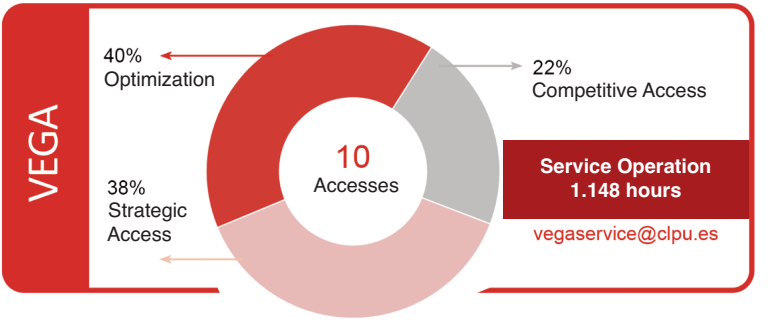
Aim summary: Targetry constitutes one of the pillars of high-power laser experiments together with the laser system and diagnostics (to detect and characterize the subsequently generated particles). In particular, solid targets represent a key in over-dense experiments with high-power lasers using target thicknesses in the range of a few mi-

crons up to tens of microns for the TNSA regime. The proton and ion generation in the range of tens of MeV is currently produced in high-power laser facilities around the world. However, the rapid progress of the high-power laser technology towards the HRR regime adds some limitations to the operability of this kind of target at HRR. A typical laser operation rate of up to 1-10 Hz requires 3600-36000 targets per hour. So laser facilities would thus need to provide the supporting technologies for delivering targets, in this case, solid targets, capable of operating at HRR.

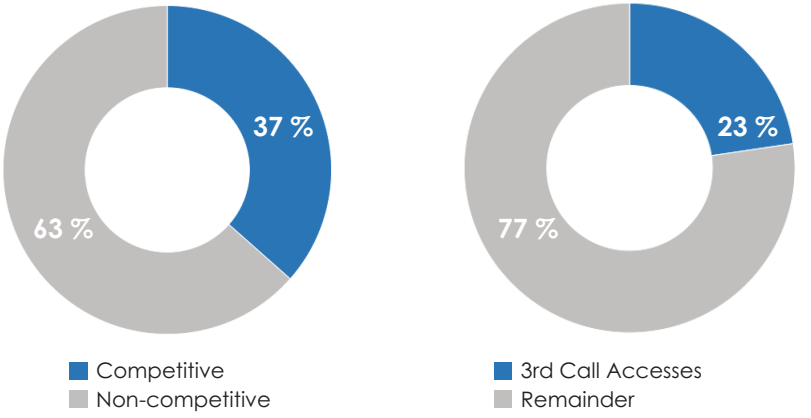
VEGA-3

High Energy

Days: 10 (100%)
Average VEGA energy: 32.57 J (0,92 PW)
TA average energy: 24.10 J
Average VEGA shots h/day: 4 h. 3 min.
VEGA use - Average h/day: 2 h. 45 min.
Total shots: 8,559



VEGA Accesses



In addition to all these competitive and non-competitive accesses, the CLPU is involved in a series of European projects that facilitate researchers' mobility for accessing and experimenting in the participating facilities:

Laserlab Europe V (LL-V)

Aim

It is a European consortium of international laser laboratories that make up a highly experienced interdisciplinary network that is aimed at reinforcing the leadership of lasers in science and technology, promoting joint research activities in topics of scientific and social interest, and contributing to facilitating access to cutting-edge laser infrastructures.

Actions

The most relevant action for the Center for Pulsed Lasers during 2023 was the support of this consortium, through its Transnational Access program, for the co-funding of the two open access competitive campaigns corresponding to the Third Call that were scheduled in such period. Besides, up to five scientific publications related to the project were made (see articles in the scientific contributions section).

Radiation Facility Network for the Exploration of effects industry (RADNEXT)

Aim

It is a European project belonging to the H2020 INFRAIA transnational access call that includes a group of facilities, among which is the CLPU, whose offer ranges from X-rays and energetic electrons to heavy protons and ions. Its main goal is to promote research into the effects of spatial radiation in electronic equipment.

Actions

During 2023, this network launched several transnational access calls. As a result, the infrastructure was visited by two teams of researchers who each implemented their own experiment using VEGA (see experimental campaigns).

Recyclable Materials Development at Analytical Research Infrastructures(Remade@ARI)

Aim — This is a European project funded under the H2020-INFRADEV call whose aim is to promote new possibilities of access to facilities for researchers working on the design of new recyclable materials. The purpose is to provide them with analytical tools to explore the properties and structure of materials from the smallest details to their atomic resolution. ReMade@ARI commits to circular economy by promoting the development of innovative and sustainable products for key components of a broad variety of sectors (electronics, batteries, vehicles, construction, packaging, plastics, textile, food) at unprecedented levels. The CLPU participates through Laserlab-Europe.

Actions — During 2023, there were no applications via this network for access to the CLPU facilities.

b. Infrastructure Optimization

The continuous improvement of the laser system is one of the infrastructure's key lines of action to keep VEGA at the forefront of technological development, not only as the best ultra-intense and ultra-fast laser system in Spain but also as an international scientific-technological landmark. To pursue this goal, the Center received a grant from a prominent project of the Multiregional ERDF Operational Program for 2014-2020 by the Ministry of Science, Innovation and Universities in the line of Unique Scientific and Technical Infrastructures (ICTS):

Rearrangement of the VEGA laser system's lines for 'Pump & Probe' experiments

Aim — The project proposes new lines to increase the setting modes to operate the laser system, including at least

one uncompressed petawatt output and developing a 'Pump & Probe' system. Synchronizing VEGA with an ultra-short duration (6 femtoseconds) CEP laser system is crucial to this plan.

Actions

In 2023, the latest optimization of the system was approached, which involved using a new uncompressed petawatt beamline in the experimentation area. The design deflects the beamline of VEGA-3 before its final compression to offer laser pulses of 40 J, 30 fs at a 1 Hz repetition rate synchronized with VEGA-1 and VEGA-2 in the experimental area. After completing its setup, collaboration with the company HP SCDS and the IT and automation department of the University of Salamanca continued with the aim of developing and commissioning an intelligent beam-pointing control system for this uncompressed PW line, based on a reinforced learning algorithm. On the other hand, this was also the year when the compressor associated with the cryogenic cooling of the amplifier of VEGA-2 was accepted and tendered. The protection brackets for transporting VEGA-1 to the target area were mounted and the lines were commissioned. The project's final verification visit took place in September.

At the other end of the system, specifically in the experimentation area, which is where users prepare their experimental set-ups, technological development is also regarded as a priority. As a result of such effort, the Center for Pulsed Lasers was granted important support by the Ministry of Science, Innovation and Universities (as part of the Recovery and Resilience Plan, in the specific call for ICTS), engaging in a new project for the construction and equipping of an additional experimental area that will increase the Center's capacities.

Construction and Equipping of Experimental Area 2 (AREX2)

Aim

To design, build, and equip a new experimentation area to increase the flow of users and experimental campaigns (both in number and in research areas; to maximize the laser system's high-repetition rate, to enable simultaneous campaigns to take place in the different experimentation areas; to install secondary sources to provide access for the non-laser-expert community; to allow advanced remote access; and, to generate a stable experimental data storage system to introduce the infrastructure into the world of open data.

Actions

As part of the construction of the new bunker throughout 2023, the following milestones were reached:

- Drafting, together with the Technical Unit for Infrastructures of the University of Salamanca, of the Blueprint of the Project, which was approved by the Project Oversight Office of the Ministry of Science, Innovation and Universities.
- Application for a geotechnical study of the subsoil where the new experimental area will be built.
- Granting of the building permission by the Town Council of Villamayor, after the issuance of the necessary favorable technical report.
- Preparation of the required documentation for publishing the tender for the works.

As to equipping the new experimental area, a plan of scientific activities related to the VEGA system and other supporting lasers in the facility was drawn to conduct pump & probe experiments. Specifically, priority was given to designing the transport line and experimental chamber for VEGA-3 to increase its added value by including a higher-intensity focus to enter in a stable way in the range of 1021 W/cm2. The key points that guided the design of the process were space optimization for further expansibility, so that additional beam lines, inclu-

ding secondary particle lines, may be implemented in the future in the same experimental area. VEGA-3 has been defined as a platform to connect the rest of the lasers and the possibility of adding essential tools such as a plasma mirror for improving contrast (required at high-intensities with high-density targets) has been left open. The new experimentation line will be equipped with remotely controlled optics able to divert the beam towards the experimental system that is being used. The focusing system will be implemented using a 90-degree parabolic mirror, which is a complete novelty as regards the former focusing system of VEGA-3. This system guarantees much larger space and margins for maneuvering with regard to smaller angles. As for the current focusing system, AREX 2 will be able to guarantee a 10-factor increase in intensity in the VEGA-3 laser's main focus.

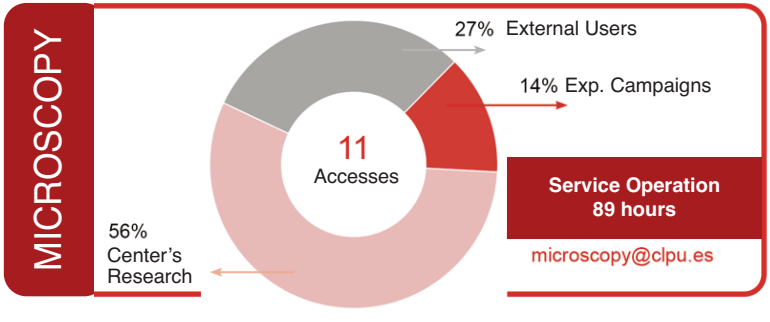
It should be noted that in the 2023 period, two people were hired, one whose background included engineering for the construction works, and, the other, a specialized scientist to design the equipment.

c. Complementary Laboratories/Workstations

The complementary laboratories that the CLPU transferred to its building in 2022 have fully recovered their activity in 2023, offering users a faster and more versatile service.

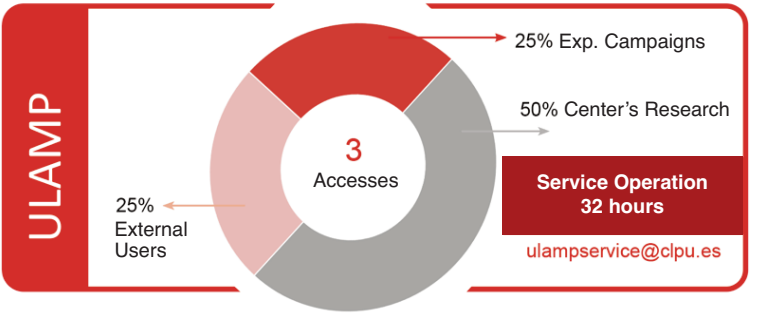
Microscopy

As can be observed in this complementary service's graph, there were applications to use it during some of the abovementioned experimental campaigns, but, its main users were external and it has



been used as part of the research that is being carried out by the entity itself. Its main piece of equipment is a Carl Zeiss SEM EVO HD25 scanning electron system, whose use can be requested through the FARO access platform. Besides, it has a total of six detectors: Everhart-Thornley Secondary Electron Detector, Variable Pressure Secondary Electron Detector, 5-segment Backscattered Electron Detector, Scanning Transmission Electron Microscopy Detector, Energy Dispersive X-Ray Spectroscopy Detector, and Electron Backscattered Diffraction Detector. For further information, refer to the CLPU website: https://www.clpu.es/en/microscopy-features/

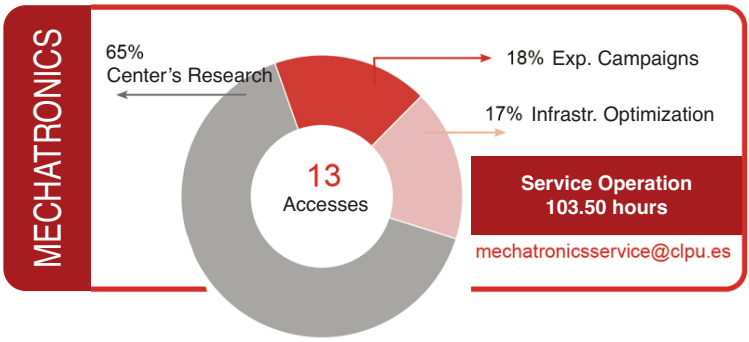
Ultrashort Laser Applications and Micromaterial Processing – ULAMP



This laboratory has a high-repetition-rate femtosecond system and four workstations to provide a specialized, high-quality service for laser processing of materials. The laser system offers a top-quality laser beam with excellent shot stability (shot-to-shot), and the short duration of the pulse makes ultra-fast laser ablation possible. This is a selective process that allows the removal of sub-micrometric layers of material with minimal thermal effect, as this happens at a larger temporal scale than the duration of the pulse itself. Besides, this type of ultra-short laser makes it possible to observe and control the changes in certain material properties: refractive index, reflectivity… both on the surface and at the bottom of transparent materials. As is shown in the graph, the activity of this service was closely linked to the experimental campaigns and the development of the facility's own projects, and, in general, mainly associated with the creation of targets.

Mechatronics Workstation

This is one of the infrastructure's key strategic units as it allows full adaptation of our equipment to meet users' needs without the need for relying on third parties and offering the possibility of customizing the Center's designs for the optimization of their systems and equipment. All this makes it possible to cut execution times and improve the quality of the service. The main equipment in the machining area is a five-axis continuous milling machine, one of the few in Spain that is not linked to the aeronautic or automotive sectors. The area is also equipped with other auxiliary machines such as a jig saw, a vertical drilling machine, a lathe, and other tools for the customized manufacturing of complex pieces. The electronics sector allows the repair and development of devices that involve a certain degree of complexity thanks to its high-class professional tools. The workstation has two units for soldering and reworking: one for hand-held welding and the other with a stand for hot-air soldering with infrared preheating. In 2023, this service was fundamental to the development of in-house research, notwithstanding the services provided both for the technological optimization of the facility and for ongoing support of experimental campaigns.



3. RESEARCH AND TRAINING

Although its statutes define the CLPU as a user center (as the unique scientific-technical institution it is), it is also a research facility. It not only has cutting-edge equipment but its specialized staff is also constantly evolving to provide users with a fundamental collaborative service and also to contribute to the evolution of the area of scientific-technical development that involves working with ultra-intense lasers: plasma physics, fusion, astrophysics… Moreover, specialized training is regarded as an investment for the future that must be implemented year after year.

a. Scientific Contributions

Throughout 2023, the facility's specialized staff has published the results of their research both in scientific journals and by participating in oral presentations and posters at different scientific-technical events in the sector. Below is a summary of their achievements:

Artículos

Arikawa, Y.; Morace, A.; Abe, Y.; Iwata, N.; Sentoku, Y.; Yogo, A.; Matsuo, K.; Nakai, M.; Nagamoto, H.; Mima, K.; Nishimura, H.; Fujioka, S.; Kodama, R.; Inoue, S.; Hashida, M.; Sakabe, S.; de Luis, D.; Gatti, G.; Huault, M.; Pérez-Hernández, J.A.; Roso, L. and Volpe, L. Demonstration of efficient relativistic electron acceleration by surface plasmonics with sequential target processing using high repetition lasers, Phys. Rev. Research 5, 013062 (2023). [Laserlab project]

Pisarczyk, T.; Renner, O.; Dudzak, R.; Chodukowski, T.; Rusiniak, Z.; Dostal, J.; Krupta, M.; Klir, D.; Domanski, J.J.; Krasa, J.; Singh, S.; Cikhardt, J.; Batani, D.; Santos, J.J.; Burian, T.; Ehret, M.; Gadjos, P.; Zaras-Szydlowska, A.; Rosinski, M.; Tchorz, P.; Kustosz, M.; Vlachos, C.; Ospina-Bohorquez, V.; Jelinek, S.; Kocourkova, G.; Agrawal, S.;

Borodziuk, S.; Krus, M. and Juha, L., Strongly magnetized plasma produced by interaction of nanosecond kJ-class laser with snail targets, Plasma Physics & Controlled Fusion 65, 005515 (2023). [IMPULSE project]

Yigitoglu Keskin,M.; Pring,W.; Pérez-Hernández, J..A.; Lera Matellanes, R.; Mill,J.; de Luis, D.; Boudjema, N.; Varela, O.; García-García, E.; Méndez Valverde, C.; Brunetti,E.; Ersfeld, B.; Kumar, S.; Wiggins, S.M.; Gatti, G.; Volpe, L.; Roso, L.; Demirköz,M.B. and Jaroszynski, D.A., Method of producing 100 keVs ion beams from a gas jet using two intense laser pulses, Proceedings Volume 12579, Laser Acceleration of Electrons, Protons and Ions VII, SPIE Optics + Optoelectronics (2023).

Ehret, M.; Bailly-Grandvaux, M.; Korneev, Ph.; Apiñaniz, J.I.; Brabetz, C.; Morace, A.; Bradford, P.; d'Humières, E.; Schaumann, G.; Bagnoud, V.; Malko, S.; Matveevskii, K.; Roth, M.; Volpe, L.; Woolsey, N.C. and Santos, J.J, Guided electromagnetic discharge pulses driven by short intense laser pulses: Characterization and modeling, Physics of Plasma 20, 013105 (2023).[Laserlab project]

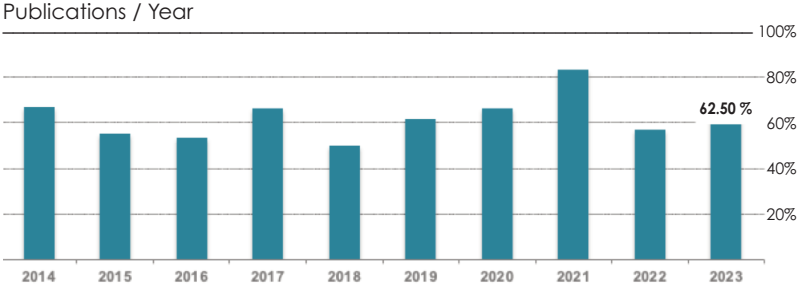
Ehret, M.; Apiñaniz, J.I.; Henares, J.L.; Lera, R.; de Luis, D.; Pérez-Hernández, J.A.; Volpe, L. and Gatti, G., Ablation holes in tape targets induced by ultra-intense laser pulses, Nuclear Instruments and Methods in Physics Research – section B: Beam interactions with materials and atoms (online Volume 541, 165-168 (2023) [TULIPAN/Laserlab/TYMPAL projects].

Ravichandran, S.; Huault, M.; Lera, R.; He, C.Z; Longman, A.; Fedosejevs, R.; Roso, L. Hill, W.T., Imaging electron angular distributions to assess a full-power petawatt-class laser focus, Phys. Rev. A, 108, 053101 (2023). [Laserlab project]

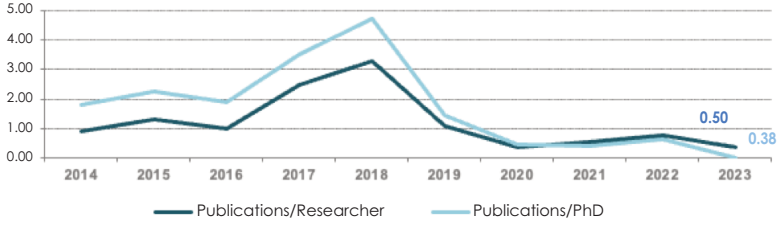
Henares, J.L.; Puyuelo-Valdes, P.; Salgado-López, C.; Apiñaniz, J.I.; Bradford, P.; Consoli, F.; de Luis, D.; Ehret, M.; Hannachi, F.; Hernández-Martín, R.; Huber, A.; Lancia, L.; Mackeviciute, M.; Maitrallain, A.; Marquès, J.-R.; Pérez-Hernández, J.A.; Santos, C.; Santos, J.J.; Stankevic, V.; Tarisien, M.; Tomkus, V.; Volpe, L. and Gatti, G., Proton and helium ions acceleration in near-critical density gas targets by short-pulse Ti:Sa PW-class laser, Journal of Plasma Physics, 89, 6 (2023) [TULIPAN project].

Longman, A.; Ravichandran, S.; Manzo, L.; He, C.Z.; Lera, R.; McLane, N.; Huault, M.; Tiscareno, G.; Hanggi, D.; Spingola, P.; Czapla, N.; Daskalova, R.L.; Roso, L.; Fedoejevs, R.; Hill III, W.T., Toward direct spatial and intensity characterization of ultra-high-intensity laser pulses using ponderomotive scattering of free electrons, Physics of Plasma, 30, 8 (2023). [Laserlab project]

Evolution over the years of publications in Q1+Q2 journals



Evolution of publications according to number of researchers and PhDs



As regards this graph, it must be noted that the infrastructure became fully operative in 2010 and, therefore, efforts were focused on its operational start-up.

CONTRIBUTIONS IN CONFERENCES/CONGRESSES

Ehret, M., IMPULSE Project: Working Package 3 Task 3.2 – Ion metrology developments for Extreme Light Infrastructure, 43rd International Workshop on High-Energy-Density Physics with lasers and ion beams, 29 January – 3 February, Hirschegg (Germany). [Oral Presentation]

Puyuelo, P., High-repetition-rate at the CLPU: liquid, gas & tape targets, Laser & Plasma Accelerators Workshop (LPAW2023), 6 – 10 March, Lagos (Portugal). [Oral Presentation]

Méndez, C., VEGA PW facility: usage statistics & managements tools, Laser & Plasma Accelerators Workshop (LPAW2023) 6 – 10 March, Lagos (Portugal). [Poster]

Puyuelo, P., Ion acceleration from optically shaped gas jets, Laser & Plasma Accelerators Workshop (LPAW2023), 6 – 10 March, Lagos (Portugal). [Oral Presentation]

Rodríguez-Frías. M.D., Las políticas de igualdad en la academia: ¿dónde y cómo se está actuando para acabar con la brecha de género?, roundtable discussion of the II Workshop Women, Optics and Photonics, 17 March, Salamanca (Spain). [Participation]

Puyuelo, P., Laser-Plasma Interaction: quick introduction, applications and projects at the CLPU, II Workshop Women, Optics and Photonics, 17 March, Salamanca (Spain). [Poster]

Ehret, M., Stability analysis of the high-repetition-rate solid tape target delivery system for ultra-intense laser-matter interaction at CLPU, IMPULSE Workshop: Standardization of metrology procedures for lasers and secondary sources (STAMPLASS 2023), 21 – 23 March, Magurele (Romania). [Oral Presentation]

Morabito, A., State of the art of the CLPU charged particle beam control and diagnostics for HRR laser-plasma experiments, IMPULSE Workshop: Standardization of metrology procedures for lasers and secondary sources (STAMPLASS 2023), 21 – 23 March, Magurele (Romania). [Oral Presentation]

Apiñaniz, J.I., A scintillator detector for energy-profile reconstruction of ion beams at high-repetition-rate, IMPULSE Workshop: Standardization of metrology procedures for lasers and secondary sources (STAMPLASS 2023), 21 – 23 March, Magurele (Romania). [Oral Presentation]

Pérez-Hernández, J.A., Session 'Complex molecules in stellar nurseries', Laserlab-Europe Talks, 29 March, online [Moderator]

Rodríguez-Frías, M.D., Knowledge and technology transfer, Encounters on the Frontiers of Science, 13 – 14 April, Valladolid (Spain). [Guest Talk]

Salgado, C., Angular-resolved Thomson parabola spectrometer for laser-plasma ion accelerators, 5th European Conference on Plasma Diagnostics (ECPD 2023), 23 – 27 April, Rethymno (Greece). [Oral Presentation]

Ehret, M., Guided electromagnetic discharge pulses driven by short intense laser pulses, International Conference on High Energy Density Science 2023, 18 April, Yokohama (Japan). [Oral Presentation]

Ehret, M.; Controlled electromagnetic pulses for high energy density science, Laser Ion Generation, Handling and Transport Meeting (LIGHT), 24 April, Darmstadt (Germany). [Oral Presentation]

Álvarez-Pastor, J.M., WP10-TA Laser-driven particle beams at CLPU, RADNEXT 2nd Annual Meeting, 9 – 10 May, Seville (Spain). [Oral Presentation]

Cives, A.M., Protección Radiológica ocupacional en el CLPU (Occupational Radiological protection at the CLPU), 8th Joint SEFM – SEPR Congress, 22 – 25 May, Madrid (Spain). [Oral Presentation. Awarded 2nd Prize to the Best Oral Presentation of the Congress]

Gatti, G., CLPU as a EuPRAXIA site, bCS EuPRAXIA, 05 – 06 June, Frascati (Italy). [Oral Presentation]

Rodríguez-Frías, M.D., Tecnología de vanguardia para impulsar la innovación: el CLPU (Cutting-edge technology to promote innovation: the CLPU), Laser technology for digital transformation, 6 June, Salamanca (Spain). [Oral Presentation]

Carmona, M.A., Sesión 1ª: Servicios en la nube para la docencia y la investigación (Session 1: Cloud services for teaching and research), RedIRIS Technical Conference 2023, 13 – 15 June, Zaragoza (Spain). [Moderator]

Ehret, M., Guided electromagnetic discharge pulses driven by short intense laser pulses, 49th European Conference on Plasma Physics, 3 – 7 July, Bordeaux (France). [Oral presentation]

Gatti, G., The CLPU: a high repetition rate, high-intensity laser facility for ICF preparatory studies, 15th International Symposium on Fusion Nuclear Technology, 10 – 15 September, Gran Canaria (Spain). [Oral Presentation]

Méndez, C., VEGA PW facility: beamline reorganization, usage statistics and management tools, International Symposium on Ultrafast Intense Laser Science (ISUILS 2023), 01 – 06 October, Sitges (Spain). [Poster]

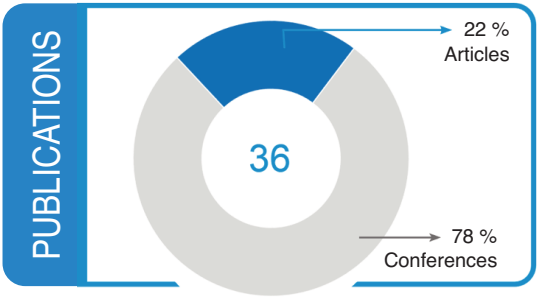
Méndez, C., Commissioning experiment on proton acceleration and characterization with the Petawatt-femtosecond class laser VEGA-3 at CLPU, International Symposium on Ultrafast Intense Laser Science (ISUILS 2023), 1 – 6 October, Sitges (Spain). [Poster + Oral Presentation]

Henares, J.L., The CLPU: a multi-beam facility for interdisciplinary experiments, 12th NLTE Code Comparision, 17 – 20 October, Valladolid (Spain). [Guest Talk]

Salgado, C., CLPU target capabilities, IMPULSE Target Fabrication and Characterization Workshop – Towards a supply strategy, 16 November, Magurele (Romania). [Guest Talk]

Morabito, A., Experimental study of electromagnetic discharge pulses driven by a short intense laser pulse at ELI-NP, ELI User Meeting, 4 – 6 November, Budapest (Hungary). [Oral Presentation]

Ehret, M., Influence of the magnetic field on properties of hot electron emission from ablative plasma produced at laser irradiation of a disc-oil target by 3rd harmonic of PALS iodine laser, PLASMA 2023 – International Conference on Research and Applications of Plasmas, 18 – 22 September, Warsaw (Poland) [Poster]



b. Projects

To keep a center that is at the forefront of progress constantly updated requires not only technological optimization but also continuous research and ongoing training for its staff. Accordingly, there are projects of different scopes and reach underway, all of which are directly related to the infrastructure's strategic lines. In 2023 there were some involving applied research and several in the area of training, highlighting the value that the Center attaches to human resources as the key to maintaining and boosting the facility as an international reference. The value of knowledge in the world of specialization.

Integrated management & reliable operations for user-based laser scientific excellence (IMPULSE)

Aim	After being built, the European Extreme Light Infrastructure (ELI) entered into a new phase. This project provides crucial support, as it will supply the resources and expertise of the main European laser facilities to speed up the transition to the operative phase and improve the sustainability of the ELI.
Actions	In 2023, a new post in the third working group of the project was filled to reinforce the work that the Center for Pulsed Lasers was carrying out. After this, an ion spectrometer calibration campaign was successfully designed, and an experimental proposal was submitted. In the short-term, an attempt was made to calibrate a Thomson Parabola using individual laser-accelerated ions. The data obtained are very valuable and could lead to obtaining a calibration curve in contrast with the available literature. On the other hand, work on electromagnetic pulses (EMP) and waste in the fourth working group led both to the exploration of electromagnetic pulses as a new secondary laser source and to a novel and economic low-technology method to characterize waste by scanning transparent deposition traces using a commercial flatbed scanner. Both achievements are

pending publication. Nevertheless, the most outstanding accomplishment was achieving the first competitive access to ELI Nuclear Physics, which allowed the first optical polarimetry measurement of discharge pulses (see Fig. 1). There is a quite marked opposition between the data obtained and theoretical predictions, which shows that current prediction models require the implementation of physical mechanisms that are yet to be identified. The disclosure of experimental results and theoretical work is underway. These findings are relevant for fast ignition fusion because they allow the possibility of guiding and spectral shaping of ion beams at short distances using micro-cable propellers.

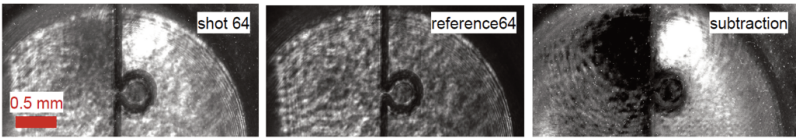


Fig. 1: First snapshot of the magnetic component of a discharge pulse

The first analyzed results of this campaign were preliminarily presented in the First ELI-ERIC User Meeting. Besides, participation in the Standardization of Metrology Procedures for Lasers and Secondary Sources (STAMPLASS 2023) and in the LaPlaSS 2023 Summer School took place in the framework of IMPULSE. Likewise, a survey on procedures was designed and launched among the users of the Center.

EuPRAXIA

Aim

EuPRAXIA is a consortium that encompasses 51 institutes and industrial partners whose aim is the cons-

truction of an electron-beam-driven plasma accelerator in the metropolitan area of Rome. Its second phase includes the construction of another laser technology accelerator in a location that is yet to be defined. Thus, EuPRAXIa intends to become a distributed, compact, and innovating facility for particle acceleration.

Actions

In 2023, different meetings were held to decide on the candidacy for the second accelerator based on laser technology. The Center for Pulsed Lasers tabled its proposal in March. The decision regarding the second location of the system is expected to be taken throughout 2024.

Targets in ultra-intense laser interaction, particle production & applications (TULIPAN)

Aim

The main goal of this project by the Ministry of Science, Innovation and Universities is to operationalize and ensure the effectiveness of particle acceleration via high-repetition-rate laser-plasma interaction by means of the development, evaluation, and comparison of different target arrangements. Once accomplished, there are plans to study the likely new lines of research that may arise from it, as well as its applications in Physics and Materials Science and, specifically, possible research aimed at achieving inertial confinement fusion.

Actions

In 2023, the three main tasks of the project regarding new solid target arrangements were accomplished. Below are the highlights:

- Experimental test at high-repetition rate of the tape target prototype designed in 2022. The campaign lasted 10 days and was a great experimental success where the targets were fired at more than eight thousand times.

- The abovementioned experimental campaign (00564) was used to test a PLC (Programmable Logic Controller) as a protective shield against electromagnetic pulses.
- The targets, protected against degradation and fracture, were used following the model tested on a test bed built for this purpose.
- Publication of an article linked to this project and aim: M. Ehret et al., NIM B. vol. 541, 2023, 165-168 (see Publications).

Regarding the study, analysis, and research of gas targets, the following actions were accomplished in 2023:

- Completion of the building of a test bed for the characterization of the nozzle and the solenoid properties of the valve.
- Publication of the results of previous studies and simulations in JL Henares et al., J. Plasma Phys. (2023), vol. 89 (see Publications), where the comparison between nozzle resistance and laser interaction is also made.
- Experimental campaign 00564 proved the correct operation of the metrology line designed and built in the experimental area to measure and control the duration of the laser pulse during campaigns where high-energy and high-repetition rates are used.

Transport and handling of particles in laser accelerators: new scenarios in Flash radiotherapy (TYMPAL)

Aim

The main goal of this project, funded by the Governing Council of Castile and León is the design and building of loaded particle transportation tools adapted to secondary laser-generated radiation sources.

The use of these types of laser-driven accelerators entails considering relevant parameters such as shot-to-shot instability, emission angles, spectrums, etc.

Actions

In 2023, the results obtained from previous experimental campaigns were studied and analyzed, as well as those from analyses and simulations, which have taken the shape of an article sent at the end of 2023 under the title A Platform for Ultra-fast Proton Probing of Matter in Extreme Conditions. An article including data related to the aims of the project is also published in the journal Methods in Physics Research – section B: Beam interactions with materials and atoms (see articles in Scientific Contributions).

PTA - Commissioning of the advanced characterization and management of data for the reorganization of VEGA's lines

Aim

This project pursues three main goals: the commissioning of tools for the statistical analysis of VEGA's functioning data; the commissioning of an automatic storage prototype to control the beam pointing of each of VEGA's three outputs; and the development of advanced characterization systems.

Actions

In November 2023, the technician, engaged in lifelong specialized training and highly proactive in his actions, became part of the CLPU staff. Despite this, and even though there was still one year for the conclusion of the project, a large part of the tasks he was commissioned with have been efficiently channeled. Hence:

- The technician became part of the work group in the area in charge of the standardization of metadata for the setting up of a data catalog for the VEGA system. He also launched the study on the dependency between energy time series, beam-pointing, temperature, and humidity using Python instead of R to capitalize on the potential of the

GPU units to implement the algorithms based on neural networks.

- He studied the dependency of spatial quality through the choice of the Ti:sapphire crystals in the main amplifier, as the quality and combination of the four available crystals result in different spatial profiles in VEGA.

c. Training

As an investment for the future, on the fundamental lines of work of the CLPU is the highly specialized training of scientists and high-intensity laser facility technicians. Hence, over 2023, almost 30 students carried out practices and training in different areas and degrees thanks to the different agreements that the Center has with other academic institutions. Specifically, in 2023 there were eight undergraduate degree students, five master´s degree students, eight PhD students, four from workplace training programs (FCT), and two belonging to the Programa Clave work experience program of the Governing Council of Castile and León. The most outstanding specific results of the training activities carried out in 2023 are the successful PhD thesis defenses of:

- Ospina-Bohórquez, Valeria, Ion acceleration from high-intensity laser interactions with quasi-critical gas targets: experiments and numerical simulations, Physics. Université de Bordeaux, Universidad de Salamanca. NNT: 2022BORD014. Directors: Joao Jorge Santos, Laurent Gremillet and Luca Volpe.
- He, Calvin Z., Experimental measurements and analysis of relativistic Thomson Scattering produced by intense lasers, University of Maryland. Director: Wendell T. Hill III.
  (http://hdl.handle.net/1903/30766)
- Salgado, Carlos, Beam and plasma diagnostics for high-repetition-rate laser-driven particle accelerators, Universidad de Salamanca. Directors: Giancarlo Gatti and Robert Fedosejevs.

Likewise, lifelong learning of the staff is promoted through the Laserlab European project exchange programs. In this regard:

- A specialized technologist traveled to the Rutherford Appleton Laboratory in the United Kingdom for comprehensive training in the electric field at the output of the 4-stage OPCPA from 9 to 22 July.

- A technologist from the British STFC carried out a stay at our facility from 26 July to 4 August.

Attention should also be drawn to the training activities delivered by our own scientists and technologists in school contexts, as seminars, and as part of master's degrees:

- The researcher José Antonio Pérez-Hernández delivered the 'Física de Campos intensos' (Intense-field Physics) course as part of the master's degree in 'Physics and Technology of Lasers' (3 ECTS) by the University of Salamanca.
- The Head of the Scientific Area, Giancarlo Gatti, delivered the Correlation between composition and phase formation in sputtered metal oxide films by ion-beam analysis and X-ray absorption seminar on 31 July at the Center for Micro Analysis of Materials, in Madrid (Spain).
- On 23 November, at the University of Alcalá, in Madrid (Spain), the researcher Roberto Lera delivered the talk 'Nuevas aplicaciones para la tecnología láser' (New applications for laser-based technologies).
- The participation of the Center's specialized staff in the Laser-Plasma Summer School (LaPlaSS2023), organized by the facility itself together with the Universidad Politécnica de Madrid involved the interventions of:
  - Jon Apiñaniz, Introduction to ion diagnostics in laser-plasma Physics
  - Enrique García, Laser diagnostics at CLPU
  - Mauricio Rico, Spatio-temporal characterization of ultrashort pulses
  - Antonia Morabito, Transport and manipulation of laser-driven proton beams for applications
  - Carlos Salgado, Gas jet characterization by interferometry for laser-plasma accelerators
  - Mauricio Rico and Enrique García, Practical Session 'Spatio Temporal Diagnostics'
  - Jon Apiñaniz and Teresa Cebriano, Practical Session 'Alignment, targetry and positioning'
  - Antonia Morabito, Carlos Salgado and Alejandro Huerta, Practical Session 'Gas Optical Diagnostics'

Finally, the specialized and non-specialized lifelong training for the staff that has been promoted at the infrastructure in 2023 should also be noted:

- Sara Sánchez and Marisol Iglesias (CLPU), Equality Plan
- Marine Huault (University of Salamanca), Laser-driven proton boron fusion
- Hyung Taek Kim (Advanced Photonics Research Institute), Research on laser electron acceleration and radiation sources with multi-PW laser pulses
- Gabriel Pérez Callejo (University of Valladolid), Spectroscopic characterization of magnetized cylindrical implosions at OMEGA
- Luca Volpe (Universidad Politécnica de Madrid), Efficient proton acceleration via double pulse laser approach
- Fernando Carbajosa (Prevención Quirón), Preventive Culture
- Sandra Gómez (University of Salamanca), Exploiting excited state dynamics in complex environments
- Amaya Mallea and Ana Herrera Arroyo (Pons), Talk on Protection of Results
- Carlos Bernabéu (Arbórea Intellbird), Drones, from Science Fiction to an everyday tool
- Michael Ehret (CLPU), Characterization of electromagnetic pulses in the first ELI-ERIC competitive access at ELI-NP
- Pablo Chamoso (University of Salamanca), Artificial Intelligence: concepts and applications
- Juan Hernández-Toro (CLPU), Safe operating procedures for the transport, use, and maintenance of vacuum equipment at the CLPU
- Mª Bianchi Méndez y Ana Isabel Cremades (Universidad Complutense de Madrid), Making wide bandgap oxides ready for the next materials generation
- Juan Hernández Toro (CLPU), Objected-Oriented Programming with Python
- Eduardo Flores (CLPU), Source control with Git
- Juan Hernández Toro (CLPU), Safe operating procedures for the transport, use, and maintenance of gas equipment at the CLPU
- Miguel Ángel Carmona and Carlos Navarro (CLPU), Cybersecurity: password

4. TRANSFER AND INNOVATION

a. Laser Innovation and Technology Laboratory – LITeL

Laser technology continues to advance at an exponential rate, making processes in both the industrial sector and society easier. Although it has many uses, there are still many more to discover. To support businesses in their evolution towards innovation, the Center for Pulsed Lasers designed the Laser Innovation and Technology Laboratory (LITeL). The purpose of this versatile laboratory is to generate new laser-light sources, advanced photon technology, laser components, and, in general, new laser platforms based on solid-state media and their associated frequency conversion techniques, in order to promote the digitalization of different industrial sectors by using laser technology to boost development and innovation. Our scientists are constantly analyzing the state-of-the-art so that each user can be provided with the best and most advanced solution. New research in areas such as Materials Science, applied science, and the production of innovative designs are essential for work and applications of solid-state lasers. Knowledge of such advances allows a better understanding of the needs that arise in the industry, biomedicine, life sciences, telecommunications, space science, military systems… or applications where solid-state lasers play an essential role. In this laboratory, laser resonators are of particular importance since they define the output quality of any laser's beam. Its adapted design makes it a potential solution for many scientific-technical problems, as being able to control beam parameters (power, shape, pulse duration, etc.) is relevant to all laser applications, as well as a factor that contributes to the development of new technologies and applications. Likewise, research carried out together with users on innovative approaches in the study of laser-beam radiation using low and high energy is particularly interesting.

In 2023, the laboratory focused on continuing the defense project that it had been working on over the previous two years. Besides, it provided internal services to contribute to the technological optimization of the infrastructure. Frequent meetings were held with busi-

nesses in the sector such as INDRA, Escribano, and Airbus, among others.

b. Collaborations

The Center's strategic effort in pursuing active transfer and innovation is reflected in its ongoing contact with industrial societies and platforms in the sector, seeking areas of collaboration and synergy to foster progress:

Ineustar, Spanish Science Industry Association

A nonprofit private association whose aim is to contribute to scientific and technological progress and to strengthen innovation. Its plan is to build an efficient collaboration network among enterprises, research centers, and support organizations and institutions. It is in constant collaboration with the CLPU both for the drafting of projects at the regional, national, and/or European level and for participation in different events. In 2023, it stood out for participating in the 'Laser Technology for Digital Transformation' conference promoted by the CLPU as part of the Training, Technology Transfer and Corporate R&D&I Program (Centr@Tec) and by the support it provided in the meeting held with the members of EuPRAXIA for the presentation of the Center's capacities regarding its future candidacy to the second phase of the project (laser accelerator).

Spanish Astronomical Society (SEA)

The SEA groups together more than 950 astronomy professionals, including around 625 PhDs in Astrophysics and approximately 280 junior members. Its main purpose is to contribute to promoting the development of astronomy and astrophysics in Spain and, in particular, to provide an independent discussion forum to address topics of interest to the Spanish astronomy community.

Fotónica 21

The main goal of this platform is to efficiently articulate the industrial innovation process of

photonic technology and its applications in four key sectors: information and communication, industrial manufacturing processes, life sciences, and lighting and displays. It was created to coordinate the activities of the main players in the photonics sector at the national level mirroring those carried out in the European Technology Platform Photonics21.

Spanish Optical Society (SEDOPTICA)

Its purpose is to encourage the development of optics as well as promote research and industrial applications in its different branches. The Society is sponsored by the Spanish National Research Council through its 'Miguel A. Catalán' physics center and is supported by universities, research centers, and other entities, both public and private, related to optics.

Enterprise European Network

The main mission of this European platform is to help businesses innovate and grow on an international scale. It gathers experts in areas of technology, innovation support organizations, universities and research institutes, development agencies at the regional level, and chambers of commerce and industry. The Center for Pulsed Lasers is attached to this network through the ENN-GalacteaPlus consortium, which is the contact point in the northwest of the Peninsula of this platform that was launched by the European Commission in 2008 under the Single Market Program.

Spanish Royal Physics Society (RSEF)

It is a non-profit institution that follows the branch of Physical Sciences of the Spanish Royal Society of Physics and Chemistry, which was founded in 1903 for an indefinite period. Its purposes are to promote the development of the basic knowledge of physics and its applications, assist and collaborate with the business world, as well as to encourage scientific research and teaching in this field at all levels of education. The RSEF operates across the national territory and maintains international relations in its areas of activity, especially with Ibero-America. The RSEF has been recognized as an Association of Public Interest.

PEPRI

It is the national platform for research and development in Radiological Protection. Its main goals are to foster the growth of the scientific-technological basis of radiological protection and include suggestions from the sector in the State Plan for Scientific and Technical Research and Innovation, as well as forming an advisory and coordination entity at the national level to foster collaboration among the different actors while facilitating Spain's participation in international R&D&I programs in the area.

c. Contributions

Promoting innovation in laser technology is one of the Center's bulwarks of the future and, therefore, activities such as conferences cannot be disregarded. Below are the main interventions in this area:

TECHNOLOGICAL CONFERENCES

Lera, R., Estado del arte de los láseres como sistemas de defensa (State of the art of lasers as defense systems), Taller empresas "18" Fuerza 2035, 03 May, Madrid (Spain). [Oral Presentation]

Rico, M., La tecnología del femtosegundo en altas intensidades: aplicaciones de los láseres pulsado ultracortos (Femtosecond technology at high-intensities: applications of ultra-short pulse lasers), Tecnología láser para la transformación digital, 06 June, Salamanca (Spain). [Oral Presentation]

Rodríguez-Frías, M.D., El Centro de Láseres Pulsado: tecnología de vanguardia (The Center for Pulsed Lasers: Cutting-edge Technology), II Jornadas de Industria de la Ciencia: infraestructuras científico-técnicas singulares de Física de Partículas, Fusión y Astronomía, 15 June, Madrid (Spain). [Guest Participation]

García, P., participation in round table 'Innovación e Investigación. Aprovechamiento de los fondos públicos destinados a la I+D+i' (Innovation and Research. Capitilization of Public Funds for R&D&I), White Paper for the Development of Salamanca conference, 23 October, Salamanca (Spain). [Participation]

d. Innovation Projects

Knowledge transfer by fostering innovation was accomplished through the planned actions in three important projects:

Hybrid prototype based on laser boost of a Linac to obtain an ultrahigh high dose rate in radiotherapy – HybriLin

Aim — The aim of this project by the Ministry of Science, Innovation and Universities is to modify an existing conventional accelerator to prepare the first Flash-RT device. The design is based on the outcomes of previous projects carried out by the CLPU, such as PALMA (Particles accelerated by laser for medical applications), as well as on the outstanding scientific and technological level of oncology and radiology in Salamanca to go one step further in Flash radiotherapy research.

Actions — As part of this project, an experiment headed by the Italian researcher A. Curcio was carried out just at the beginning of the year. Subsequently, simulations and data analyses have been carried out, and the drafting of the final report has been started.

Development and testing of new compact and low-cost CMOS technology systems for dosimetry of neutrons, ionizing radiation, and charged particles

Aim — The purpose is to offer proof of concept on the feasibility of using CMOS detectors for recording the spatial distribution of pulsed doses of thermal neutrons. Besides, an attempt to prove the viability of such systems for fast neutron measurement with polyethylene converters will also be made. The project belongs to the call for R&D&I by the Spanish Nuclear Safety Council (CSN).

Actions — Because of the Center's schedule, the tasks to be performed in the second semester of the year had

to be performed in the first, getting ahead on a large part of the project envisaged for 2023. Thus, for example, models were bought, stands and encapsulations were designed, and experimental campaigns and Montecarlo simulations were carried out. Likewise, work on the job specifications to recruit someone for the next year began, as well as the analysis of all the data obtained from the experimental campaigns conducted.

Development and optimization of experimental lines in VEGA (DOLEV)

Aim

The overall aim of this application is to promote and maintain the CLPU as a center of reference at the local, regional, and national levels, as a technological facility able to provide service to scientists, on the one hand, and to both innovative and traditional businesses that seek added value for their products, on the other hand. To this effect, the actions proposed range from improving the laser's reliability to developing new experimental tools and tools for the management of the information generated by the experiments.

Actions

The project involves two main differentiated actions:

- Automation and optimization of data management in experimental campaigns. The following are the most prominent actions in 2023:
  - Market analysis, tendering, and purchase of a storage virtualization system. A hyper-converged infrastructure (HCI) was chosen, as it offers higher reading and writing ratios by using the same server.
  - On the other hand, of the two recruitments that had been planned in the initial project, only the junior programmer position was covered. The senior programmer position was not fi-

lled, despite being launched up to three times, and even increasing the annual salary amount.

- Commissioning of an innovation and support station. In the context of this action, the following was accomplished in 2023:
  - Launch of the project for the organization of the work to be done and to define the different purchases required, which are listed in the technical report.
  - Definition of the requirements for the test bed for the new laser processing systems that will be implemented throughout the life of the project.
  - Characterization of the most appropriate optical elements for the laser processing system so that different parameters can be modified, such as pulse duration, repetition rate, and the wide range of energies for the different types of processing, both as regards surface and volume.
  - Design of the first spatial modification models of the beam shaping laser beams.
  - Tendering of a short-pulse laser system that will become part of the test bed.
  - Completion of different tasks for the preparation of the targets used in the experimental campaigns with VEGA through the modification of the setups of already existing laser processing techniques, also beginning the evaluation of new processing techniques.
  - At the end of the year, one of the two persons who were planned to be recruited in the initial project was hired, and the call to fill in the remaining post was launched.

5. DISSEMINATION AND TRANSPARENCY

a. Scientific Culture and Innovation Unit – UCC+i

Since 2022, the Center has held the Scientific Culture and Innovation Unit emblem that the Spanish Foundation for Science and Technology (FECYT), under the Ministry of Science Innovation and Universities, awards to scientific and technological institutions, universities, research centers, and other entities associated with science because of their work in promoting and disseminating scientific culture and innovation among society, improving citizens' understanding and appreciation of these fields. Accordingly, the Center for Pulsed Lasers participated, under the Scientific Culture and Innovation Unit UCC+i category, in the 2022 call launched by the FECYT. Its project, which defined one of the Unit's programs of activities, was approved and started on 23 July. Therefore, two FECYT projects were conducted in 2023:

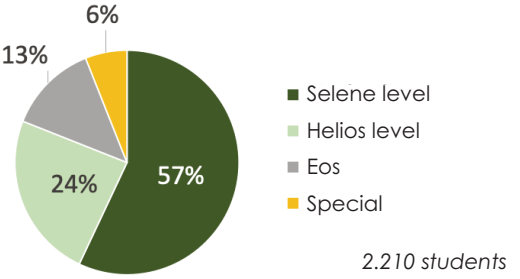
Aim

The aim of the project is to encourage scientific vocations among children between the ages of 4 and 14. The novelty of the project, which includes carrying out different types of experiments and, as is usual in the activities designed by the CLPU, requires constant interaction between teacher and learner, lies in its use of XR technologies: augmented reality for children aged 4 to 6 and virtual reality for those aged 7 to 14.

Actions

Because the project was promoted through the Salamanca City of Culture and Knowledge Foundation, many of the city's educational centers applied. The action consists of three different levels of adaptation

to understand concepts such as light, colors, and radiation: Selene (years 2-3 Early Childhood Education + year 1 Compulsory Primary Education); Helios (years 2-5 Compulsory Primary Education), Eos (Year 6 Primary Education + years 1-2 Compulsory Secondary Education). In addition to these, there were special groups for people with disabilities for whom the workshop was adapted. The final figures speak for the success of the project, so much so that the Foundation itself requested that the activity be repeated the following academic year. Only the Selene level of Teia (2-3 Early Childhood Education and 1 Primary Education) was extended.



2.210 students

UCC+i activities program – ICTS Center for Pulsed Lasers

Aim

The project offers a plan of activities in line with the identity of the unit, the Center's strategic communication line, and the aims of the FECYT's call. A total of eight activities targeted at three specific audiences:

- Society at large, to provide a basis for understanding complex phenomena of today and offer tools to consolidate critical thinking.
- Non-university students, to foster scientific vocations free from gender bias.
- University students, to enhance their communication skills for the dissemination of their research results or scientific content in general.
- Groups of individuals with different capabilities, with adapted activities so that science can do magic, and magic becomes science.
- Groups who find access to the scientific environment difficult, to make our 'Science for All' motto a reality.

Actions

The project started in the second semester of 2023 with the recruitment of the person who is to take charge of its management. During the last trimester of the year, management tasks to arrange the hospital classrooms of the region began, since this was a priority in the agenda of activities. In this regard, the 'Caravana de Fósforos' (Caravan of Matches) activity was carried out in the University Hospital of Salamanca, bringing experiments involving light to its long-term pediatric inpatients. On the other hand, as part of the Week of Science of Castile and León, the

second edition of 'Ciclo de la Luz' (Light's Cycle) was organized, a series of talks focused on different aspects of light and its associated technologies that took place in the Chapel of the Colegio Arzobispo Fonseca with a large number of participants. The talks were delivered between 13 and 17 November and addressed five different fields of knowledge:

- Luminescent Microbes, a fascinating show, delivered by Raúl Rivas González (Department of Microbiology and Genetics, University of Salamanca)
- Exploring the mysteries of the universe through electromagnetic radiation, delivered by Juan Abel Barrio (Department of Structure of Matter, Thermal Physics and Electronics, Complutense University of Madrid).
- Lighting vacuum, talk delivered by Luis Roso (Department of Applied Physics, University of Salamanca).
- From Atom to Everest. The use of light in Geology, delivered by Mercedes Suárez Barros (Department of Geology, University of Salamanca).
- Art and Light. The same nature is sometimes darkness and others light, by Eduardo Azofra (Department of Art History / Fine Arts. University of Salamanca)

The unit organized another specialized talk as part of the Week of Science of Castile and León, delivered by the head of the Center's radioprotection unit, José Manuel Álvarez. It was held in the Casa de las Conchas Library.

Besides, the 'Pixels' activity for the generation of multimedia content based on the communication of scientific activity using VEGA through interviews with the users and principal investigators of the experimental campaigns conducted at the facility continued to take place. The videos can be viewed on our YouTube channel (@centrodelaseres-pulsados7512):

- The researcher Dimitri Battani, from the University of Bordeaux, explains the details of his experiment 'Laser-driven proton-boron fusion' (https://youtu.be/JRcPhKM9Fh4)
- The German scientist Klaus Sophr, from ELI Nuclear Physics, explains his research aimed at the future construction of nuclear batteries (https://youtu.be/6bCg0AudkAI)
- Michael Seimetz, from the Institute of Instrumentation for Molecular Imaging (i3M) talks about the first experiment carried out in Spain to generate high doses of ultra-fast radiation via accelerated protons to impact against living cells. The interview can be viewed on our YouTube channel (https://youtu.be/ttO7jXsizVQ)

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN
FECYT INNOVACIÓN

Besides, as already mentioned, the Teia activity for younger children was extended beyond the lifetime of its project. It was again promoted by the Salamanca City of Culture and Knowledge Foundation, obtaining a much higher number of applications than could be taken. Indeed, there were more than 80 applications of which only thirteen could be admitted throughout the 2023-2024 academic year, as the activity was to be combined with the development of the UCC+i program. Moreover, this workshop was one of the proposed activities at the 2023 Innovative Dissemination Conference held in Zaragoza at the beginning of December.

b. Transparency

The Center for Pulsed Lasers is linked to the General Administration of State and is part of the public institutional sector. For this reason, in 2022 it implemented the policy of good governance by creating a Transparency Portal. In 2023, the updates suggested in the evaluation report on compliance of active publicity publications that the Council for Transparency and Governance had sent to the infrastructure were implemented.

Likewise, in May, the Center participated in the compliance assessment of the transparency Board of Castile and León.

c. Visits to the Center

18/01/23 – H.E. The Ambassador of Australia in Spain together with the Australian company HB11

02/02/23 – Researchers from the Department of Physics of Materials of the Complutense University of Madrid

27/03/23 – Students from the Stem Talent Girl Program

14/04/23 – 'Emerging Information Technology' students from the University of Salamanca

20/04/23 – Participants in the II Northwestern Meeting of Young Researchers in Optics

21/04/23 – Attendees at the 'Network on Extreme Intensity Laser System Meeting'

03/06/23 – Winners of the Garabalux 2023 drawing competition.

06/06/23 – Attendees at the 'Laser technology for digital transformation' Conference

19/10/23 – Attendees at the NLTE-12 Code Comparison Workshop Conference

24/10/23 – Technicians from the Nuclear Safety Council

17/11/23 – Delegation from the Henan Polytechnic University (China)

24/11/23 – The Minister of Research of the Community of Madrid and the Director-General of Universities of the Governing Council of Castile and León.

27/11/23 – CALA Lab Munich

04/12/23 – Members of the EuPRAXIA European project

15/12/23 – Participants at the academic ceremony to welcome PhD Marcelino Benítez as the corresponding member in Salamanca for the Academy of Sciences, Engineering and Humanities of Lanzarote.

6. SUMMARY OF PROJECTS

See below for a summary of the ongoing projects as of 31 December 2023:

FU - VEGA Infrastructure — € 3,361,663.60

Entity	Title	PI CLPU	Duration	Amount
MCI	*Experimental Area 2*	MD Rodríguez Frías	01/09/21 - 31/12/25	€ 3,018,000.00
UE/H2020	*RADNEXT*	Giancarlo Gatti	01/06/21 - 31/05/25	€ 89,687.50
UE/H.Europe	*ReMade at ARI*	Giancarlo Gatti	01/09/22 - 31/08/26	€ 46,872.00
UE/H2020	*Laserlab Europe V*	Giancarlo Gatti	01/12/19 - 30/11/24	€ 207,150.00

FU - Research and Training — € 1,394,219.04

Entity	Title	PI CLPU	Duration	Amount
UE/H2020	*IMPULSE*	Giancarlo Gatti	01/11/20 - 30/04/24	€ 550,690.00
MCI	*HRR - TULIPAN*	J. Luis Henares & J. Antonio Hernández	01/09/22 - 31/08/25	€ 78,650.00
EU/H.Europe	*EuPRAXIA*	Giancarlo Gatti	01/11/22 - 30/10/26	€ 10,000.00
MCI / SEPE	*Research Programme*	Roberto Lera	24 months	€ 66,217.84
MCI / SEPE	*Research Programme*	Diego de Luis	24 months	€ 66,217.84
JCyL / ecyl	*Research Programme (2)*	Cruz Méndez	12 months	€ 66,217.84
JCyL / ecyl	*Research Programme (1)*	Miguel A. Carmona	12 months	€ 66,217.84
JCyL / ecyl	*Research Programme (3)*	Giancarlo Gatti	12 months	€ 99,326.76
JCyL / ecyl	*Research Programme (1)*	Diego de Luis	12 months	€ 33,108.92
JCyL / ecyl	*Research Programme (1)*	Eduardo Flores	12 months	€ 33,108.92
MCI	*Generación del Conocimiento: NAPEL*	M.D. Rodríguez & Roberto Lera	01/09/23 - 31/08/26	€ 187.500.00
MCI	*Generación del Conocimiento: APPLE*	Giancarlo Gatti	01/09/23 - 31/08/26	€ 170,000.00

FU - Transfer and Innovation — € 929,207.34

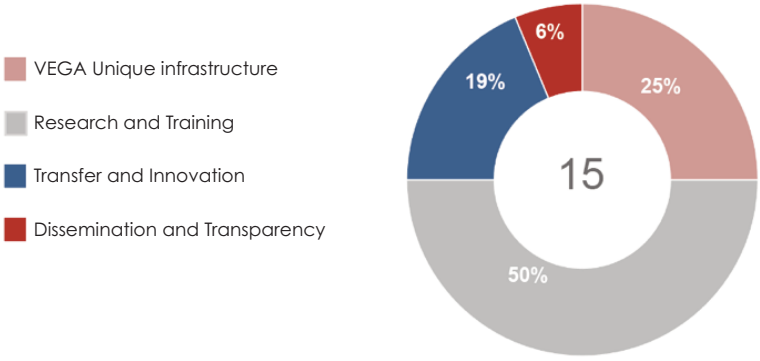
Entity	Title	PI CLPU	Duration	Amount
MCI	*HYBRILIN*	Giancarlo Gatti	01/12/21 - 30/11/23	€ 97,750.00
CSN	*Development and testing of new compact and low-cost CMOS technology systems for dosimetry of neutrons, ionizing radiation, and charged particles*	Jon I. Apiñániz	23/12/22 - 22/12/25	€ 88,957.34
MCI	*DOLEV: Development of experimental lines on VEGA*	M.D. Rodríguez	01/01/23 - 31/12/25	€ 742,500.00

FU - Dissemination and Transparency — € 20,000.00

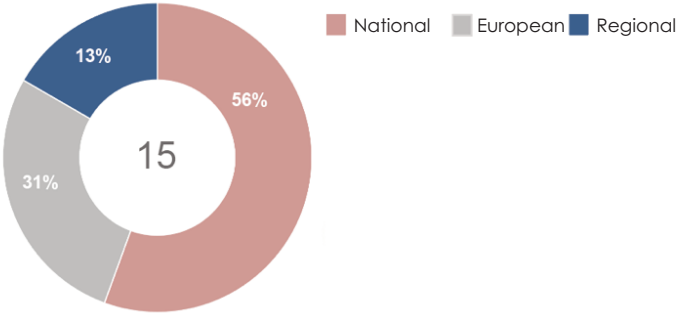
Entity	Title	PI CLPU	Duration	Amount
FECYT	*UCC+i*	Yaiza Cortés	01/07/23 - 30/06/24	€ 24,000.00

€ 5,709,089.98

According to nature (link to Functional Unit)



According to geographic scope of the call



7. HUMAN RESOURCES

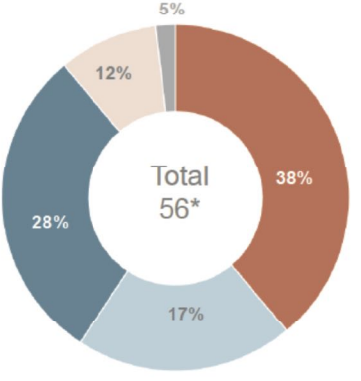
The value of the infrastructure's human team is another of the Center's strategic strongholds, given its awareness of the high-level specialization that the infrastructure demands from its staff.

Direction

María D. Rodríguez Frías

Management

Pedro García García



Scientific A.

- Gianoarlo Gatti
- Mauricio Rico Hernández
- José A. Pérez Hernández
- Jon I. Apiñaniz Aguinako
- Carlos Salgado López
- José L. Henares González
- Roberto Lera Matallanes
- Eduardo Flores González
- Teresa Cebriano Ramírez
- Antonia Morabito
- Michael Ehret
- Alejandro Huerta Sánchez
- Isabel Rodríguez
- María Luisa Berlanga Coppola
- Nardjesee Boudjema
- Pablo Vicente González
- Evgeny Filippov
- Iuliana Vladisavlevici
- Luis Carlos Parada González
- Natividad Lara Escudero

Technical A.

- Cruz Méndez Valverde
- Enrique García García
- Óscar Varela Baquero
- Irene Hernández Palmero
- José D. Pisonero Carabias
- Marta Olivar Ruiz
- Ana Vaquero Villares
- Javier Pisonero Carabias
- José María Pérez

Engineering U.

- José Miguel García Matas
- Alberto Cuadrado

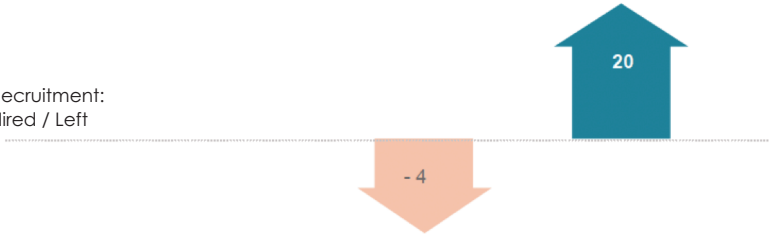
Management A.

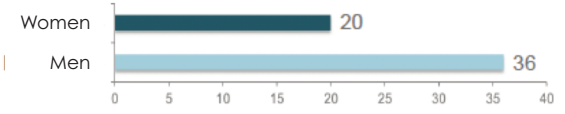
- María J. Cortés de Dios
- Ana Santa Cruz Marcos
- Javier Sastre Porcherie
- Marisol Iglesias Sánchez
- Miguel A. Carmona Moreno
- Carlos Navarro Laporta
- Sara Sánchez Hernández
- Alberto Berrocal Macías
- María J. Torrens Bermejo
- Yaiza Cortés Gómez
- Adrián de Prada Belda
- Alejandro Sánchez Batuecas
- Óscar Lozano Domínguez
- Saúl Núñez García

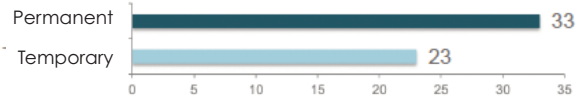
Radioprotection U.

- José M. Álvarez Pastor
- Ana María Cives Fernández

Recruitment:
Hired / Left







Staff evolution