Implementation of an ultra-high-intensity laser as a multi-user scientific infrastructure in Brazil

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***Abstract*— FINEP, a federal funding agency of Brazil, has approved a project to implement a relativistic laser to serve as a multi-user research infrastructure. The laser, which will start operations in 2026 at IPEN will generate pluses with 35fs and 0.5J at 800nm, with 15TW of peak power, at 10Hz, with intensity exceeding 10^19 W/cm2, with a repetition rate of 10 Hz. This system will function as a compact electron and proton accelerator, and will create extreme conditions similar to those found inside stars, enabling nuclear microfusion studies, expanding the electromagnetic radiation spectrum available to the scientific community in Brazil.**

Keywords*— Compact laser accelerators. Extreme conditions. Nuclear photonics. Relativistic lasers. Nuclear microfusion.

I. INTRODUCTION

A. *International insertion of the Project in the scientific scenario*

The interaction of light with matter has contributed significantly to human knowledge, with approximately one-third of the Nobel Prizes in Physics being related to advances in this area. The invention of the laser in 1960 [1], the achievement of ultrashort pulses in the femtosecond (1 fs = 10^{-15} s) domain [2], and the chirped pulse amplification technique (CPA) in 1985 [3] were essential milestones recognized with the Nobel Prizes. CPA provided for the increase of the luminous intensity of lasers to more than 10^{23} W/cm^2 [4], as shown in Fig. 1, an evolution of 24 orders of magnitude if compared to the solar intensity of 0.1 W/cm^2 on the Earth's surface. There is currently a global race to develop higher-powered systems to reach the Schwinger limit [5] (10^{29} W/cm^2) and create matter from the vacuum, led by the Chinese 100 PW laser project [6]. The focused intensities made possible by laser systems currently in operation generate extreme electric, magnetic fields, and pressures [7, 8], similar to those found inside stars [9-12], enabling advances in experimental astrophysics on a laboratory scale. Along this path, other applications such as compact laser particle acceleration [13-19], microfusion studies [20], and another Nobel Prize-winning achievement, the generation of the shortest pulses in the attosecond scale [21-23].

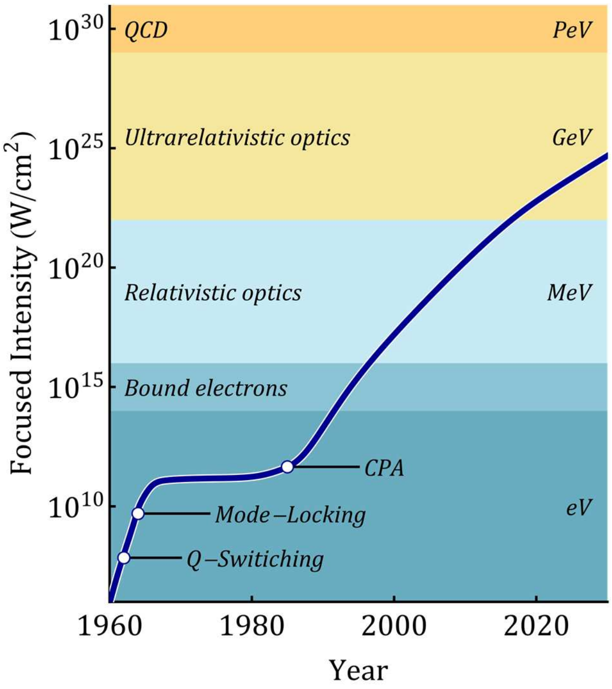

Fig. 1. Evolution of laser intensity in the last 6 decades. The blue line is a guide to the eye.

At the beginning of this century, the OECD recommended to IUPAP (International Union of Pure and Applied Physics) the creation of the International Committee on Ultra-High Intensity Lasers (ICUIL), based on studies by the Global Science Forum on high-intensity, short-duration lasers. This committee was founded in 2004 [24], and Brazil participated in the initial meetings at the initiative of the funding agency FAPESP Board of Trustees. Currently, there are more than a hundred relativistic intensity laser systems ($I > 10^{19}$ W/cm^2) in the world, but none in the southern hemisphere, as shown by their location on the world map, in Fig. 2 [25]. To fill this gap, we proposed to the Brazilian National Nuclear Energy Commission (CNEN) that a high-peak power laser infrastructure should be implemented in the country to conduct various experiments in areas such as nuclear physics, quantum electronics, plasma physics, solid-state physics, biology, and their applications. CNEN supported the proposal to create this laboratory at the Institute for Energy and Nuclear Research (IPEN) following the examples of similar, larger-scale initiatives that include the LaserNetUS [26], the ELI [27] (Extreme Light Infrastructure) and Laserlab-Europe [28] in Europe networks, as well as similar programs in Asia.

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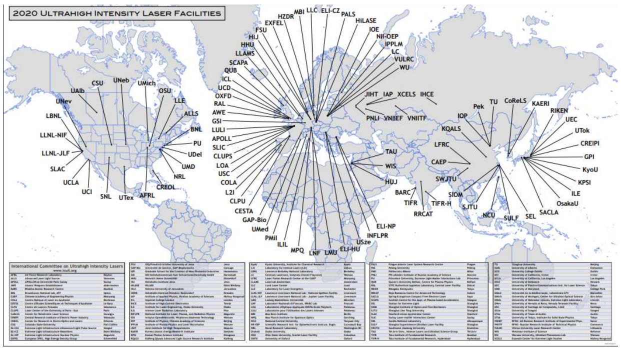

Fig. 2. Location of laser systems with intensities greater than 10^{19} W/cm^2.

The Extreme Light Infrastructure (ELI) in Europe, shown in Fig. 3 (a), has 3 laboratories, while the LaserNetUS network in North America (Fig. 3 (b)), is composed of 13 laboratories (as of June 2025), including the Diocles laser at the Extreme Light Laboratory at the University of Nebraska-Lincoln (UNL). IPEN collaborated with UNL from 2017 to 2023 with support from a FAPESP SPRINT project [29], which was subsequently expanded and complemented by a LaserNetUS project, approved in its 3rd cycle, funded by the US Department of Energy [30]. This initiative aimed to accelerate electrons via the LWFA (Laser Wakefield Acceleration) technique [31, 32], to be tested on both the UNL Diocles lasers and IPEN, in a non-linear regime with intermediate intensities.

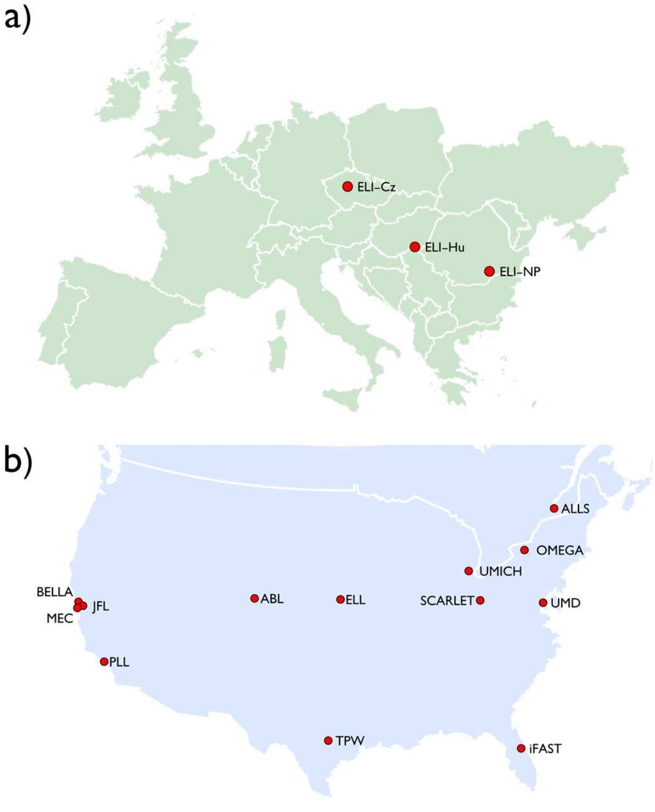

Fig. 3. High-intensity lasers making up the (a) ELI and (b) LaserNetUS organizations [26, 27].

B. *A case study as a proof of concept*

The IPEN-UNL collaboration aimed, as a proof of concept in nuclear photonics, to use laser-accelerated electron beams to generate γ-rays by Bremsstrahlung and induce nuclear reactions to produce the radioisotope ^{99}Mo [33]. This radioisotope decays into ^{99}Tc, which is the most used radiopharmaceutical in nuclear medicine [34] worldwide, serving 2 million procedures annually in Brazil, and IPEN is responsible for almost 90% of its production. ^{99}Mo is currently generated in nuclear research reactors, and there is a search for alternative routes for its production. One possibility is the use of laser-accelerated electrons, with the potential to simplify, reduce costs, and decentralize the production of this radioisotope. Initial simulations estimated the capacity to generate ^{99}Mo, and we are now using machine learning techniques to improve the generation of electron beams and optimize the yield of photonuclear reactions[35], since simulations show that the first results were insufficient to meet medical demand.

The results obtained in the collaboration with LaserNetUS have shown that we need a local infrastructure that allows the scientists to get acquainted with the complex arrangement used in these facilities, in which initial results obtained at home can be expanded. The results of the collaboration enabled the specification of a laser system for the implementation of a research infrastructure in Brazil. For greater experimental flexibility, we chose a system with 15 TW of peak power, delivered by 35 fs pulses with 500 mJ of energy, at 10 Hz repetition rate, and the ability to focus the beam close to the diffraction limit using a deformable mirror. Our group submitted a proposal titled “Ultra-high intensity lasers: a scientific infrastructure for studying matter in extreme conditions” to FINEP's 2023 Thematic Centers call, and we received approval in October 2024. Complementary to the laser system, an experimental chamber for experimental setups and diagnostics is also specified. This system will be able to accelerate electrons and protons, and produce neutrons, in addition to being suitable as a platform for new experiments such as nuclear microfusion and high-temperature plasmas, as well as testing new acceleration processes with potential use of bunches lasting picoseconds or less.

II. THE PROPOSAL

This project aims to provide Brazil with a research infrastructure capable of achieving relativistic intensities, providing opportunities for local training and research, in addition to connecting young scientists to major international centers. Despite the large global community of scientists working in this field, Brazil has relatively few professionals and active students, limiting national access to the scientific and technological breakthroughs emerging from these activities. With this system, the first challenge will be the acceleration of electrons in a nonlinear regime for relativistic energies, based on our simulations and the development of suitable gas jet targets [31, 36, 37]. Techniques such as Bayesian optimization will be used to identify LWFA operating conditions (e.g., laser and target profiles) that produce electron beams tailored for medical applications, including radioisotope production via photoactivation [35] and very high energy electrons (VHEE) radiotherapy [38].

The next steps will involve accelerating protons [39] and subsequent creation of a laser-driven neutron source [40] from nuclear reactions, in line with global trends and enabling future industrial and scientific applications. Fig. 4 shows the kinetic energy of protons accelerated by relativistic pulses as a function of the laser intensity. With the proposed 15 TW laser, we will be able to reach $2{\cdot}10^{19}$ W/cm^2, as indicated by the red line in Fig. 4, generating protons with energies above 10 MeV, capable of inducing a large number of nuclear reactions at the top of the optical table, opening the field of nuclear photonics in the country. With this system, it is possible to expand the electromagnetic spectrum generated to the VUV and even γ rays. In addition to the laser and particle pulses being synchronized, which enables pump-probe experiments, these phenomena occur on very short time scales, down to attoseconds, allowing investigation in new areas.

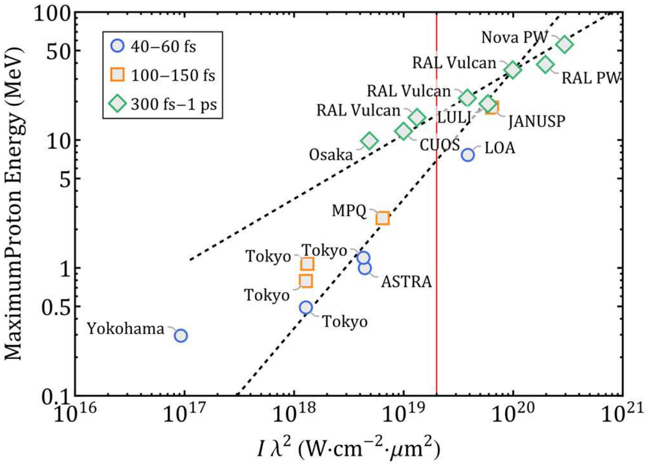

Fig. 4. Evolution of the kinetic energy of protons as a function of laser intensity [41].

The described activities are in the early stages of both experimental and theoretical development, and the IPEN system serves as a focal point around which new research efforts can be initiated. Major global laboratories are also seeking new ideas and are open to collaborations, as the IPEN group has already done with the LaserNetUS. In September 2024, the ICUIL 2024 conference held a workshop on the integration of high-intensity laser science in Latin America, encouraging local cooperation and future alliances with major centers. The first step will be to create a national user community, using the Brazilian Synchrotron Laboratory LNLS [42] as an example, preparing Brazil to integrate this kind of science on a global level, and in the future build a large scientific infrastructure for high-intensity lasers. Recently, new micro and nanostructured targets started being used to achieve a better control for the coupling of the laser energy to the target [20, 43], controlling both the absorption and the evolution of the plasma during the interaction, opening new opportunities for achieving extreme conditions and the occurrence of nuclear fusion in small volumes. The optical coupling can be improved by using micro and nanostructure arrays (nanorods [20], foams[44], graphene nanotubes, microdots, etc.), which, besides providing temporal control of the onset of the plasma critical therefore the laser light reflection [20].

By controlling the composition and dimensions of the target according to the pulse characteristics, a mixing of the TNSA [45, 46] mechanism of ion acceleration and plasma dynamics produces a large number of fusion reactions, which simulations showed that GA currents, MT magnetic fields and GB pressures were present, with energy densities exceeding GJ/cm^3. These experiments provide sufficient evidence to establish them as a test bed for studying nuclear fusion reactions, which is also a goal of our project.

Besides all the extreme conditions attainable, new temporal characteristics of these new processes are the short duration of the events, allowing the dieback stories of the interactions and new applications like VHEE [47], which is a promising therapeutic technique for treating tumors.

III. TIMELINE AND PREPARATION OF PROPOSALS

The adaptation of the IPEN laboratory for the 15 TW laser operation, along with its commissioning and the instrumentation of a vacuum experimental chamber, is expected to take 18 months after the release of funding resources. The expected start of operations is mid-2026. After initial tests and adjustments, we estimate that we will be able to execute external proposals in the second half of 2026. Once installed at IPEN's Center for Lasers and Applications on the University of São Paulo campus, the system will operate as a multi-user facility managed by Dr. Nilson Dias Vieira Junior, with technical coordination by Dr. Ricardo Elgul Samad. Led by Dr. Alexandre Bonatto, the Beam Physics Group at the Federal University of Health Sciences of Porto Alegre can provide computational simulation support to external users.

Those interested in developing ideas that can be tested with this system should contact one of the coordinators, who will forward the proposals to the project support group, composed of 31 researchers from various fields. The proposals will undergo a final evaluation of experimental feasibility and scientific/technological merit. Individual researchers and research groups are invited to submit proposals to access this infrastructure for proof-of-principle studies.

The facility will promote collaborative learning opportunities, positioning Brazil alongside international developments in the field while training the next generation of scientists.

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