BOOK OF ABSTRACTS INVITED AND ORAL TALKS

14/9/2026	15/9/2026	16/9/2026	17/9/2026	18/9/2026
9:00 Welcome	**9:00 Pomerantz**	**9:00 Michel**	**9:00 Cipiccia**	**9:00 Rus**
9:10 Olson	**9:30 Tomassini**	**9:30 Oliva**	**9:30 Skruszewicz**	9:30 Chen
9:40 Murakami	10:00 Valenta	10:00 Lehmann	10:00 Vyšín	9:55 Giuffrida
10:10 Hao	10:20 Casati	10:20 La Porte	10:20 Shirozhan	10:15 Kojima
10:30 Coffee break	10:40 Coffee break	10:40 Coffee break	10:40 Coffee break	10:35 Coffee break
11:00 Cotelo	**11:10 Lundh**	**11:10 Maffini**	**11:10 Dromey**	11:05 Jelínek
11:30 Huo	11:40 Lécz	11:40 de Almeida	**11:40 Mašlárová**	11:25 Krása
12:00 Condamine	12:00 Touguet	12:00 Velarde	12:10 Zsíros	11:45 Cikhardt
12:20 Földes	12:20 Masckala	12:20 Kondrashev	12:30 Vábek	12:05 Jurkovičová
12:40 Blackman	12:40 Swain	12:40 lunch	12:50 lunch	12:25 Grau
13:00 lunch	13:00 lunch	**13:40 Grech**	13:50 Poster session	12:45 Closing
14:00 Menoni	**14:00 Arjmand**	**14:10 Corde**		13:15 ELI visit bus
14:30 Brambrink	14:30 Chaulagain	14:40 Mercuri-Baron		
15:00 Hoffmann	14:50 Varma	15:00 Custodio		
15:20 Kraus	15:10 Mendonca	15:20 Galbiati		
15:40 Ialovega	**15:30 Chodukowski**	15:40 Coffee break		
16:00 Coffee break	16:00 Coffee break	**16:10 Silva**	16:00 Coffee break	
16:30 Batani	**16:30 Tazes**	**16:40 Schumacher**	**16:30 Li**	
17:00 Dulat	**17:00 Schramm**	17:10 Cornet	17:00 Lamač	
17:20 Cipriani	17:30 Iaccarino	17:30 Rips	17:20 Nevrkla	
17:40 Consoli	17:50 Malka		17:40 Hadjisolomou	

Monday 14 September – LASER-DRIVEN FUSION

Chair: **Florian Condamine**	9:10 INVITED	**Rick Olson** (Los Alamos National Laboratory) *Physics of direct-drive wetted foam ICF capsules*
	9:40 INVITED	**Masakatsu Murakami** (Institute of Laser Engineering, Osaka University) *Self-Similar Multi-Shock Implosions for Ultra-High Compression of Matter*
	10:10	**Liang Hao** (Institute of Applied Physics and Computational Mathematics, Beijing) *Study of asymmetric backscattering in hohlraums due to cross-beam energy transfer*
Chair: **Piotr Rączka**	11:00 INVITED	**Manuel Cotelo Ferreiro** (Universidad Politécnica de Madrid) *Inertial Fusion Hybrid Targets for Advanced Lasers*
	11:30 INVITED	**Wenyi Huo** (Institute of Applied Physics and Computational Mathematics, Beijing) *Nonlocal electron heat transport involving Langdon effect in laser plasmas*
	12:00	**Florian Condamine** (GenF) *Effect of residual gas pressure on ablation plasma properties in ns-kJ laser–solid interactions*
	12:20	**Istvan Földes** (HUN-REN Wigner Research Centre) *Excimer lasers with detuned oscillators: a possible alternative for inertial fusion energy drivers*
	12:40	**David Blackman** (ELI Beamlines Facility, The Extreme Light Infrastructure ERIC) *Rare temporal spikes and chromatic shear in broadband laser-plasma interactions*
Chair: **David Blackman**	14:00 INVITED	**Carmen Menoni** (Colorado State University) *The US-IFE RISE hub research efforts to advance inertial fusion*
	14:30 INVITED	**Erik Brambrink** (European XFEL) *HAFEN: a fusion instrument at European XFEL*
	15:00	**Dieter H.H. Hoffmann** (Xian Jiaotong University) *The Fusion Portfolio: Why p-11B Deserves a Place at the Table*
	15:20	**Dominik Kraus** (University of Rostock) *The High Energy Density Initiative (HEDI) in Rostock*
	15:40	**Mykola Ialovega** (GenF) *Predictive Lifetime Assessment of First-Wall Materials in Direct-Drive Inertial Fusion Energy Systems*
Chair: **Erik Brambrink**	16:30 INVITED	**Dimitri Batani** (Université de Bordeaux) *Contributions from the HiPER+ community to advancing knowledge of IFE physics*
	17:00	**Ankit Dulat** (Helmholtz-Zentrum Dresden-Rossendorf) *Multispectral pump-probe studies of nanostructured target dynamics in high-intensity laser-plasma interactions*
	17:20	**Mattia Cipriani** (ENEA) *Evolution of the plasma obtained from high-power irradiation of 2PP foams with different morphologies*
	17:40	**Fabrizio Consoli** (ENEA) *Charged Beam Manipulation by Laser-Driven Electromagnetic Pulses*

Physics of direct-drive wetted foam ICF capsules

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Abstract

Laser direct-drive liquid deuterium–tritium (DT) wetted foam capsules hold substantial promise for future advancements in inertial confinement fusion (ICF). For this new class of ICF capsules, additive manufacturing (AM) techniques are used to create low aspect ratio spherical shells of a low-density, foam-like CH lattice, which is wetted with cryogenic liquid DT. In this presentation, we discuss key physics issues intrinsic to ignition and burn propagation in laser direct drive wetted foam capsules. These include requirements on laser energy and power, implosion velocity, fuel adiabat, and initial density and dimensions of the CH lattice shell.

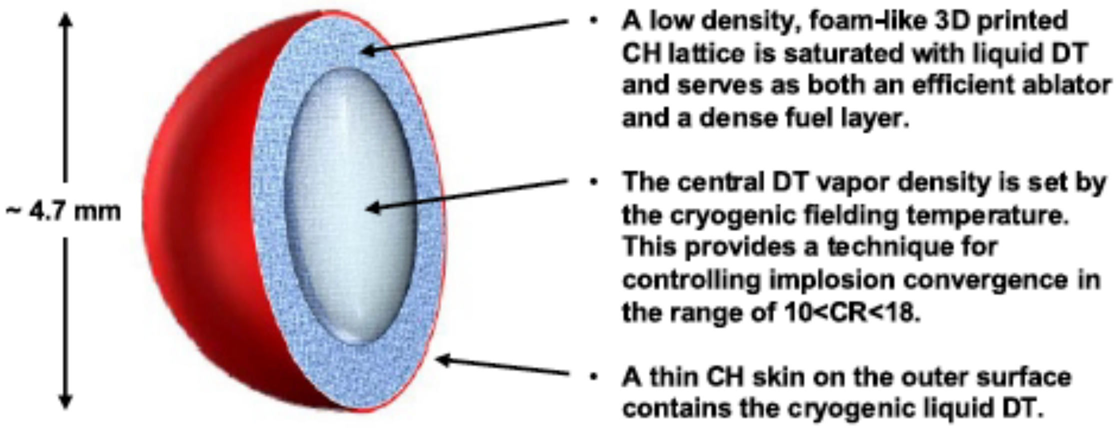

Figure 1. Laser direct-drive wetted foam target concept[1].

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Acknowledgements

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Self-Similar Multi-Shock Implosions for Ultra-High Compression of Matter

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Abstract

We present a unified theoretical and numerical framework for self-similar multi-shock implosions achieving ultra-high compression in a uniform solid spherical target. Extending the classical Guderley[1] model to N-stacked, spherically converging shocks, we derive self-similar solutions and the scaling law[2,3] for the final density of the form $\rho_r/\rho_0 \propto \hat{P}^{\beta(N-1)}$, where $\hat{P}$ is the stage pressure ratio and β is determined by the adiabatic index γ. One-dimensional Lagrangian hydrodynamic simulations confirm this relation over a broad range of parameters, from the weakly to the strongly nonlinear regime ($\hat{P}$~70). The results show that cumulative compression increases systematically with the number of stacked shocks while entropy generation is strongly suppressed, asymptotically approaching a quasi-isentropic limit as N → ∞. This volumetric scheme strongly suppresses the Rayleigh–Taylor instability that plagues shell-based implosions and thus provides a robust, largely instability-resistant compression pathway applicable to inertial confinement fusion and other high-energy-density systems. The framework bridges similarity theory with realistic multi-shock dynamics, guiding the design of advanced laser-driven compression schemes.

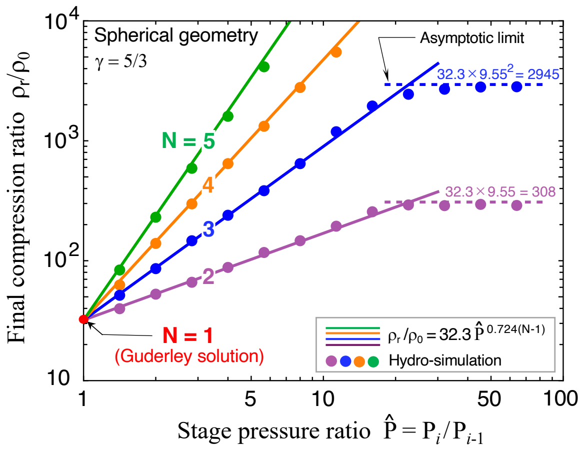

Figure 1. Final compression ρ_r/ρ_0 versus stage pressure ratio $\hat{P}$ for N = 1–5 stacked shocks. ρ_r is the reflected-shock crest density immediately after on-axis coalescence and is subsequently advected outward with the diverging shock. Dashed lines indicate the asymptotic limits.

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Study of asymmetric backscattering in hohlraums due to cross-beam energy transfer

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Abstract

In inertial confinement fusion (ICF), laser-plasma instability (LPI) is one of the main factors leading to reduced laser energy coupling efficiency. In addition, LPIs may also cause damage to optical components and preheating of the capsule, which remain significant potential risks for high-gain ignition. In cylindrical hohlraum experiments, it is commonly assumed that the backscattering processes of same-ring lasers injected at identical angles are identical. Therefore, on existing laser facilities, only the backscattering of partial lasers within the same ring are typically diagnosed. However, in experiments conducted on the SG-100kJ facility, we observed significant differences in backscattering for the same-ring beams in cylindrical hohlraums. Studies indicate that the primary cause of this phenomenon is that same-ring beams acquire different powers from adjacent beams through cross-beam energy transfer (CBET). This process is closely related to the polarization arrangement and geometric arrangement of the lasers. Furthermore, we designed experiments to confirm the dependence of multi-beam CBET on laser polarization arrangement. These findings are of significant importance for understanding backscattering, CBET, energy loss, and azimuthal drive asymmetry in cylindrical hohlraums, and also provide recommendations and references for the polarization arrangement and geometric arrangement of future laser facilities.

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Acknowledgements

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Inertial Fusion Hybrid Targets for Advanced Lasers

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Abstract

The two-sided hybrid drive configuration [1] offers a promising route to achieving highly uniform implosions by precisely modulating the beam intensity profile. Simulations suggest that a driver energy of approximately 4 MJ can yield energy gains of roughly 65, utilizing a fuel adiabat of 6—the current benchmark on OMEGA [2]. These results indicate that, provided symmetry is maintained, this stable target design has significant potential to reach breakeven.

To model these dynamics, we employed ARWEN, a 2D adaptive mesh refinement (AMR) radiative hydrodynamics code. Validated across laboratory astrophysics [3] and ICF applications, ARWEN integrates multimaterial hydrodynamics, electron heat conduction, multigroup radiation transport, and ray-trace laser deposition. In this context, we leverage ARWEN's dual X-ray and direct laser drive modeling capabilities to establish it as a valuable tool for optimizing laser-target coupling and accelerating the development of stable, high-gain targets.

To establish the predictive reliability of our modeling, we first validated ARWEN against copper half-hohlraum experimental data, achieving excellent agreement. Building on this foundation, we present preliminary simulations of hybrid targets under dual direct/indirect illumination. These simulations provide critical insights into the spatio-temporal evolution of the radiation field uniformity and the dynamic temperature profiles of the hohlraum's interior surfaces, parameters that are traditionally difficult to diagnose experimentally. By capturing the complex interplay between the multi-MJ driver and the hybrid geometry, this work demonstrates that ARWEN is a robust tool for exploring the high-gain regime. Ultimately, these results underscore the viability of the hybrid drive as a stable, high-performance path toward robust ignition and sustainable energy gain.

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Nonlocal electron heat transport involving Langdon effect in laser plasmas

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In laser-driven inertial confinement fusion (ICF) studies, electron heat transport plays an important role. In indirect drive ICF, electron heat transport influences the laser x-ray conversion, hohlraum radiation asymmetry, and the laser plasma interactions, etc. In direct drive ICF, electron heat transport has influences on laser ablation, shock behavior, laser plasma interactions, preheating, and hydrodynamic instabilities. In past decades, a large number of studies have been done on this subject to develop more accurate electron heat transport models.

As is well known, the Spitzer–Härm electron heat conduction mode [1] cannot precisely describe the electron heat flux in laser-heated plasma due to its complexity, such as sharp temperature gradients, the distortion of electron distribution function, the self-generated magnetic fields, etc. In laser plasmas, the electron distribution function is generally not Maxwellian but Supergaussian because of inverse bremsstrahlung heating, which is referred as Langdon effect. Many electron heat conduction models were developed to describe the electron heat flux in laser plasmas, such as the flux limit model [2], the one-dimensional nonlocal model of convolution proposed by Luciani *et al.* [3] and its extension to multi-dimension [4]. However, these nonlocal models were based on the Maxwellian distribution function, so the Langdon effect was neglected. The influence of Langdon effect on local electron heat flux has been investigated many years ago [5,6,7], however, the nonlocality of heat flux in laser plasmas was not considered in these works.

Recently, we developed a nonlocal heat conduction model which includes the Langdon effect and the nonlocality of heat flux in laser plasmas. This model was successfully implemented in our radiation hydrodynamic code [8,9]. The analytical and numerical simulation results indicate the credibility and self-consistency of this model. It is found that the hydrodynamical simulation result with this model is more closed to the experimental results obtained at the Omega laser facility.

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Effect of residual gas pressure on ablation plasma properties in ns-kJ laser–solid interactions

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Abstract

The interaction between a ns-kJ laser and a solid target has been studied for decades. As a key topic in many fields, in particular inertial confinement fusion (ICF), numerous studies have aimed to improve the coupling of the laser pulse energy to the target by various means (temporal shaping, optical and/or temporal smoothing, etc.).
In this study, carried out with the ns-kJ L4n laser at ELI Beamlines (Prague), we show the effect on the ablation plasma of increasing the air pressure in the chamber from 10^{-5} to 1 mbar. The high-repetition rate of the laser (1 shot every 3 min) allows the recording of a solid dataset with clear statistics. The target was thick PVC and thanks to the use of high-spatial and high-spectral resolution X-ray spectroscopy, we observe a significant effect of the vacuum pressure on the H-like Cl ions population. We observe that increasing the vacuum pressure makes it possible to significantly increase the electron temperature of the hottest and densest part of the plasma by about 20% while leading to a substantial reduction of the measured Raman backscatter (SRS).
We present these results together with detailed simulations aimed at explaining the underlying phenomena. We also discuss the potential impact of these findings on the design of the first wall for a future reaction chamber of an IFE reactor.

Acknowledgements
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Excimer lasers with detuned oscillators: a possible alternative for inertial fusion energy drivers

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Abstract

Present efforts on Inertial Fusion Energy (IFE) production as the HiPER+ project are based on direct drive either with traditional central spark ignition or by shock ignition. The drivers are foreseen as using the 2nd and 3rd harmonics of diode-pumped solid state laser systems (DPSSL). In order to avoid parametric instabilities the shock generating spikes have to be of large bandwidth which is difficult to obtain with highly efficient conversion of solid state laser systems. For this reason the possible applicability of DPSSL for energy production was questioned recently [1].

Excimer lasers seem to be possible alternatives because of their intrinsically short wavelength and broad bandwidth which reduces the deleterious effects of parametric instabilities. According to recent studies KrF lasers may have a bandwidth of 3 THz at 248 nm wavelength whereas the ArF laser bandwidth can be as high as 10 THz on the 193 nm. 7% efficiency was reached with KrF laser, and even higher efficiency is expected for ArF. The typical spectral width of an ASE emitting KrF gain module is about 0.4 nm due to the gain narrowing effect of stimulated emission which is further reduced in the resonators of free running oscillators.

Therefore we propose here the use of synchroneously pumped oscillators detuned from each other. It is possible to realize several oscillators of independent resonators by using different parts of the common discharge pumped volume. Based on the homogeneously broadened transition of KrF a flat-topped tuning curve of >1 nm spectral width can be realized by wavelength-tuned resonators and/or by amplification of narrowband pulses. A combination of such pulses could result in a large overall bandwidth as compared with that of spontaneous emission. Note that this arrangement provides not only a broad bandwidth corresponding to temporal incoherence but the separate beamlets are spatially incoherent as well. Therefore the arrangement avoids the necessity of ISI imaging sytems.

Although our considerations were made fro KrF system, this multiple, sequentially detuned oscillator scheme may be applied for ArF lasers as well, providing even larger bandwidth on 193 nm.

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Acknowledgements

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Rare temporal spikes and chromatic shear in broadband laser–plasma interactions

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Abstract

Broadband random-phase laser drive reduces stimulated Raman and Brillouin scattering in ICF plasmas by shortening the pump coherence time, which is a result well described by random-phase-average (RPA) theory. However, every finite-duration experiment or simulation samples a single stochastic realisation of the drive: a structured train of coherent temporal amplitude spikes, the time-domain analogue of RPP intensity hot spots. We present two complementary analyses of finite-realisation broadband drive that supply information RPA cannot.

The first applies Kac–Rice level-crossing statistics to the spike-height distribution, event rate, and waiting times of a random-phase flat-top pump. Large spikes are locally phase-stationary and drive a coherent three-wave gain in two regimes: a linear-response limit where EPW damping and pump decorrelation together suppress the coupling ($G \propto a^2$), and an exponential limit where the coupling overcomes dissipation and both daughter waves grow resonantly across the spike core ($G \propto a$). The exact autocorrelation mean growth rate is preserved throughout; the spike model adds the finite-window structure RPA misses, and quantities such as gain variance, intermittency, threshold-crossing probabilities, and waiting times. Two-dimensional Smilei PIC simulations confirm this picture as a calibrated timing diagnostic: the 2 nm and 5 nm bandwidth cases differ principally in the temporal organisation of BSRS growth, with the narrower bandwidth producing a few dominant spike-driven intervals and the broader case accumulating gain through a denser sequence of weaker events.

The second analysis addresses the spatial consequences of the same broadband drive. Propagation through a dispersive lens introduces a chromatic focal shift $\Delta F \propto F_0 \, (\Delta\omega/\omega_0)$ that displaces each spectral component of the RPP speckle field by a different fraction of the correlation length. We introduce two dimensionless chromatic shear numbers, Ξ_L and Ξ_E, comparing colour-to-colour axial and transverse displacements to the monochromatic speckle correlation lengths $L_{I,0}$ and $L_{y,0}$. For $\Xi \ll 1$ broadband speckles retain their spatial identity; for $\Xi \gg 1$ the time-averaged focal pattern is a superposition of displaced speckle fields and single-speckle statistics no longer apply. For typical ICF-scale optics at 1% bandwidth, $\Xi_L \sim 10$, which is firmly in the colour-sheared regime. Together, these results characterise two finite-realisation effects of broadband drive that are invisible to ensemble-average theory: temporal intermittency in the backscatter and chromatic smearing of the spatial gain structure.

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The US-IFE RISE hub research efforts to advance inertial fusion

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The US-IFE IneRtial FusIon Science and Technology Energy hub, RISE Hub, was established to advance laser-driven Inertial Fusion Energy (IFE) science and technologies. To accomplish these research goals, the RISE Hub has assembled a team of experts from six universities: Colorado State University (CSU, lead), University of Illinois Urbana-Champaign (UIUC), Texas A&M University (TAMU), Cornell University (CU), Stanford University (SU), and Brigham Young University (BYU); three US laboratories: SLAC National Accelerator Laboratory (co-lead), Los Alamos National Laboratory (LANL), Naval Research Laboratory (NRL); industry partners: General Atomics (GA), Xcimer Energy Corporation (XEC), Marvel Fusion (MF) and Blue Laser Fusion (BLF). RISE hub research focuses on performing: 1) theoretical design of multiple IFE target concepts, 2) experiments and theory to advance technologies enabling laser fusion drivers, 3) IFE target development and engagement, and 4) experimental validation of fusion concepts. In addition, the hub's research offers a platform for workforce development and for engaging in university-industry-national laboratory partnerships. This talk will describe advances in all of these research thrusts that are synergistically contributing to achieve scientific milestones, support industry and grow the much-needed diverse workforce in fusion energy.

Acknowledgment :

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HAFEN: a fusion instrument at European XFEL

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Abstract

The HAFEN project (HArd X-ray Instrument for Fusion ENergy Research) is being developed at European XFEL to establish a dedicated platform for fusion energy research using the unique capabilities of the facility. The project aims to implement a new instrument for fusion-related experiments by combining hard X-ray beams from the XFEL with high-power optical laser systems. HAFEN will make use of the existing undulator infrastructure for the generation of intense, ultrashort X-ray pulses, by deflection of the generated X-ray beam by means of X-ray mirrors into a dedicated experimental area. This approach enables the realization of a fusion research instrument while minimizing the impact on the existing accelerator layout and making efficient use of the available infrastructure.

In addition to the X-ray beam delivery, HAFEN foresees the installation of two complementary laser systems: a short-pulse laser providing 200 J in 150 fs and a long-pulse laser delivering 2 kJ on the nanosecond timescale. Together, these systems will enable a wide range of experiments relevant to fusion energy research, including studies of laser-plasma interaction and high-energy-density matter. The installation is planned within the existing tunnel environment at European XFEL, which poses both technical and integration challenges but also offers significant advantages in terms of infrastructure, shielding, and facility access. The project is funded by BMFTR and represents an important step toward expanding the scientific scope of European XFEL into fusion-related research. This contribution will present the motivation, conceptual design, main technical components, and current status of the HAFEN project.

The Fusion Portfolio: Why p-^{11}B Deserves a Place at the Table

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Abstract

The recent ignition achieved at the National Ignition Facility has conclusively demonstrated that laboratory fusion burn is possible. Yet the road to a commercially viable fusion power plant remains long, with formidable challenges in materials science, tritium breeding, and reactor economics. This reality invites us to reconsider not only how we confine plasmas, but also which fuel we choose to burn.

For decades, the deuterium-tritium reaction has been the undisputed focus of fusion research. Its large cross-section at relatively low temperatures makes it the logical first choice. However, DT fusion comes with intrinsic costs: dependence on tritium—a radioactive isotope with no natural supply and a 12.3-year half-life—and on a flux of 14-MeV neutrons that will activate reactor structures and demand exotic materials. These challenges may be solvable, but they raise a strategic question: Should we rely on a single fuel or diversify our portfolio?

Here we report on a systematic investigation of the p-^{11}B reaction, a quasi-neutron-free pathway whose primary products are three alpha particles. Using complementary platforms - the 320 kV accelerator at IMP Lanzhou and intense laser-driven proton beams at the Laser Fusion Research Center in Mianyang -we have obtained results that challenge textbook assumptions.

1. **Hydrogen doping enhances yield.** At IMP Lanzhou, boron targets doped with hydrogen showed an approximately 30% increase in alpha yield compared to pure boron. This effect, not predicted by standard cross-section data, suggests the microscopic environment of the boron nucleus matters in ways not yet understood.
2. **Nonlinear scaling with beam current.** At Mianyang, alpha yield scaled nonlinearly with proton beam current. In optimized conditions, we measured up to 10^{10} alphas/cm^2 per laser shot - at the time, the highest normalized yield reported for this reaction.
3. **Reaction channel complexity.** Spectroscopy reveals that the three alphas are not emitted simultaneously with equal energy. The reaction proceeds through intermediate channels, notably ^{8}Be, with implications for energy deposition in the plasma.

These results do not yet constitute a path to a reactor. The challenge of creating non-equilibrium conditions - maintaining ion temperatures significantly above electron temperatures - remains formidable. However, our findings demonstrate that nuclear physics is richer and potentially more favorable than previously assumed.

The strategic case for including p-^{11}B in the fusion portfolio grows stronger as DT challenges become clearer. A successful p-^{11}B reactor would offer:

- Fuel abundance: Protons are universal; boron is plentiful, eliminating fuel supply concerns.
- Reduced neutron flux: Secondary neutrons are at least two orders of magnitude below DT, simplifying materials and waste.
- No tritium breeding: Closed fuel cycle without lithium blankets or complex tritium handling.

These experiments began with a single question from a scientist at ENN in 2018: "What about proton-boron?" That question led us to re-examine old data, design new experiments, and discover effects not in the textbooks.

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The High Energy Density Initiative (HEDI) in Rostock

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Abstract

States of extreme energy density – i.e., matter under high pressures and extremely high temperatures – are found in the interiors of planets (megabar pressures, several thousand kelvins) or stars (gigabar pressures, several million kelvins) and are highly relevant for the ultimate application of clean and reliable energy production by inertial fusion. A deep understanding of the complicated physical conditions along the compression path to inertial fusion plasmas and the dynamics on short timescales is essential for the eventual realization of an energy source based on this concept.

The physics of these extreme states is highly complex and the combined experimental and theoretical investigation of them has only recently been channeled into the new field of high energy density physics. The Helmholtz Association has initiated the development of world-leading research infrastructures to reproducibly create conditions of comparable energy density in a controlled laboratory environment and to enable highly precise in situ measurements of the microphysics in these exotic states of matter. One such initiative is the Helmholtz International Beamline for Extreme Fields (HIBEF) at the European XFEL, which was initiated and is operated by the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and has started to produce first breakthrough results.

To further establish and advance groundbreaking research with these unique capabilities in Germany, a university partnership within an interdisciplinary environment is required to efficiently utilize and develop the new facilities. Therefore, the HZDR together with the University of Rostock has established the High Energy Density Initiative (HEDI) as a Helmholtz Flagship Initiative and the State of Mecklenburg-Vorpommern has committed to finance the construction of a research building on the University of Rostock campus.

Based on a showcase of recent scientific results of the HEDI team, this presentation will discuss the planned research program of HEDI in the areas of theoretical and experimental high energy density physics and potential applications in the areas of inertial confinement fusion, astrophysics, planetary physics and materials science.

Predictive Lifetime Assessment of First-Wall Materials in Direct-Drive Inertial Fusion Energy Systems

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Abstract

GenF, a spin-off of the Thales Group, is developing an accelerated pathway toward a direct-drive inertial confinement fusion (ICF) reactor. Within the framework of the TARANIS project, GenF collaborates with CEA, CNRS, and other research institutions to address key scientific and technological challenges associated with inertial fusion energy.

Design and qualification of first-wall (FW) components are of primary importance. During reactor operation, the FW is exposed to intense, repetitive pulses of X-rays, ions, and neutrons generated by target ignition. The incident particle population consists of fusion products and unburned fuel species, including helium, deuterium, and tritium, as well as target debris such as hydrogen and carbon. The extreme operating conditions drive a complex interplay of thermal loading, surface erosion, implantation and compositional evolution, radiation damage, material activation, and fuel retention.

To assess the long-term behaviour of candidate FW materials, GenF is developing an integrated multi-physics modelling framework combining neutronics, plasma–material interaction, thermal analysis, and hydrogen isotope transport. The incident ion, neutron, and X-ray spectra are derived from a reactor-relevant target design developed for the TARANIS concept. The framework couples OpenMC for neutron transport, SDTrimSP for ion-induced sputtering, implantation, and damage generation, FESTIM for hydrogen isotope diffusion and trapping, and a dedicated thermal module for transient heat-load calculations. Tungsten is currently used as a reference plasma-facing material owing to its favourable thermo-mechanical properties, extensive experimental database, and relevance to existing magnetic-confinement fusion devices.

The model enables quantitative predictions of material erosion, defect accumulation, tritium retention, and component lifetime under realistic reactor operating conditions. Results highligt the importance of realistic source terms for first-wall assessment showing the strong sensitivity of sputtering rates, implantation profiles, and damage accumulation to the target design. The coupled effects of irradiation-induced defects and temperature on hydrogen isotope retention provide key insights for safety and fuel-cycle management in future inertial fusion reactors.

Acknowledgements
This work was performed in the framework of the TARANIS project supported by the French government as part of France 2030 (AAP Réacteurs Nucléaires Innovants - #DOS0237678/00).

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Contributions from the HiPER+ community to advancing knowledge of IFE physics

D.Batani[1]

[1] on behalf of the HiPER+ Community

Abstract

The demonstration of ignition and further progress at the National Ignition Facility have validated inertial fusion as a viable approach to Inertial Fusion Energy (IFE) and triggered many initiative and large investments. In Europe the HiPER+ initiative started in 2020 [1,2] as a bottom-up proposal stemming from the academic community, dedicated to the study of direct drive, as the most promising route to civilian electricity generation from laser fusion. Recently HiPER+ has been endorsed and funded by Eurofusion [3] with the goal of providing a conceptual design for a future European implosion facility. 30 research groups from 12 different European countries participate in the project currently funded for 2026 and 2027, thereby assembling the vast majority of the laser-plasma and inertial fusion community in Europe.

In addition to the technological challenges related to developing a reactor concept based on inertial fusion, we must advance knowledge of the physics of direct-drive laser-plasma interactions and implosions, in particular with reference to the shock ignition approach. In this context the research groups involved in HiPER+ are performing an intense experimental and theoretical activity. The talk will present some of the experimental results obtained in European and overseas large-scale laser facilities, in particular related to:

1) Laser-plasma interaction at intensities of interest for direct-drive and shock ignition. We performed experiments at the PALS and ELI-beamlines laser facilities in Prague to investigate the growth of side and back stimulated Raman scattering (SSRS and BSRS) in inhomogeneous plasmas, highlighting the importance of SSRS and its relations with the generation of hot electrons [4];
2) Use of foam materials as a tool of mitigating the non-uniformities of laser energy deposition. Study of shock generation and shock propagation in foams. Study of the equation of state of foam materials. Use of foams for improved laser-driven secondary sources of radiation and particles [5];
3) Study of the equation of state of materials which could be used as ablators for implosion experiments in alternative to synthetic diamonds, specifically boron compounds [6];
4) Development of advanced diagnostics for direct-drive, encompassing those for shock propagation and target hydrodynamics (such as X-ray Phase-Contrast Imaging), particle spectroscopy and identification [7]

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Acknowledgements

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Multispectral pump–probe studies of nanostructured target dynamics in high-intensity laser–plasma interactions

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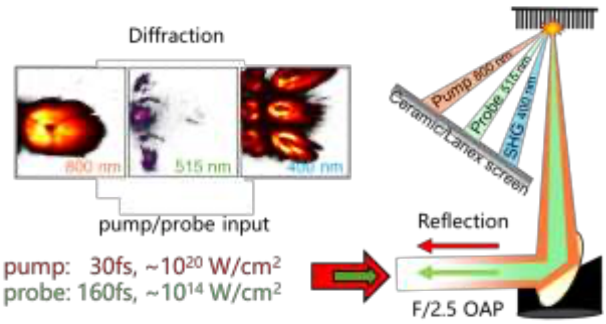
Abstract

Intense femtosecond laser interactions with nanostructured targets can enable efficient volumetric heating and strong laser absorption, making them promising platforms for high-energy-density physics and next-generation inertial fusion concepts [1]. However, their performance is critically determined by the transient state of the nanostructure at the arrival of the relativistic main pulse. Pre-pulses, pedestals, and the rising edge of the laser pulse can induce ionization, pre-plasma formation, and target deformation before peak intensity is reached, thereby modifying laser absorption, heating dynamics, and the conversion of laser energy into ions, electrons, and radiation [2]. Capturing and controlling this early evolution remains experimentally challenging, as it requires time-resolved access to nanostructure pre-expansion while simultaneously measuring the resulting particle and radiation emission.

Here, we present the development and first application of a multispectral optical pump–probe diagnostic platform at the DRACO laser system for time-resolved studies of expanding laser-driven nanostructures. The experiment combines relativistic irradiation of nanorod targets with ultrashort off-harmonic optical probing and a complementary diagnostic suite capturing diffraction, reflection, spectral shifts, harmonic emission, and ion/electron signatures. By separating the optical response across multiple channels, the platform provides access to distinct temporal regimes, from the onset of ionization and picosecond-scale pre-expansion to sub-picosecond plasma dynamics around the main-pulse interaction and subsequent hydrodynamic expansion [3].

Under plasma-mirror-cleaned contrast conditions, diffraction signatures indicate that the nanostructure survives until the final picosecond before the main pulse, coinciding with enhanced absorption, rapid plasma expansion, and radial ion acceleration. Controlled pre-pulse studies reveal pre-plasma formation and red-shifted reflected spectra, consistent with plasma motion and hole-boring dynamics. By contrast, degraded picosecond contrast leads to complete nanostructure dissolution before the main interaction and significantly reduced ion acceleration. Although global laser absorption remains high across different pre-expansion conditions, the partitioning of laser energy into ions, electrons, and radiation changes dramatically.

Together, these results establish multispectral optical probing as an in-situ diagnostic of interaction quality, temporal evolution, and energy coupling in laser-driven nanostructures, providing a route toward interaction-informed optimization of laser-driven nano-accelerators.



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Evolution of the plasma obtained from high-power irradiation of 2PP foams with different morphologies

M. Cipriani[1], F. Consoli[1], M. Scisciò[1], M. Alonzo[1], F. Filippi[1], G. Cristofari[1], V. Piergotti[1], M. Traunfellner[2], M. Lunzer[2]

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Abstract

The research on Inertial Confinement Fusion (ICF) requires constant research for identifying new materials. Micro-structured low-density materials, or foams, with a randomly arranged internal structure, have been shown to be able to reduce to some extent the detrimental effect of hydrodynamic instabilities seeded by non-uniform irradiation, while also increasing the laser absorption efficiency and enhancing the pressure at the shock front. Laser 3D printing represents the new way of obtaining foams with a precisely controlled morphology, gradients in density and pore size and sample shapes which would be challenging to make with other techniques. The impact of the foam morphology on the features of the interaction with a high-power laser and the characteristics of the laser-driven shock during its propagation are currently a subject of debate.
In this work, we will present the recent results of experiments and simulations about the irradiation of 3D-printed foams at high power. The samples were irradiated at the ABC laser facility in the ENEA Centro Ricerche Frascati, at intensities of about 10^{14} W/cm^2, relevant for ICF. Two morphologies have been studied, the octet truss of different cell size and the Voronoi lattice. Experimental results will be compared with 3D simulations obtained with the code FLASH to reach a deeper understanding of the physics at play.

Acknowledgements
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Charged Beam Manipulation by Laser-Driven Electromagnetic Pulses

F. Consoli[1], L. Manzoni[1,2,3], P.L. Andreoli[1], M. Cipriani[1], G. Cristofari[1], R. De Angelis[1], E. Di Ferdinando[1], G. Di Giorgio[1], A. Maffini[2], M. Passoni[2], M. Migliorati[3], M. Scisciò[1]

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Abstract

When high-intensity laser pulses interact with matter, they produce a wide range of phenomena, including particle acceleration and broadband electromagnetic radiation. This emission spans from ionizing components (γ, X-rays, UV) to non-ionizing electromagnetic pulses (EMPs) in the MHz–THz range [1]. The latter can reach field strengths of several MV/m even at distances of about one meter from the interaction region. Traditionally viewed as a threat to electronic systems and personnel, they also represent a major concern in inertial confinement fusion, particularly in advanced Direct-Drive schemes such as Shock Ignition and Fast Ignition. Recently, however, interest has shifted toward exploiting these fields as a resource.

A patented scheme developed at ENEA – Centro Ricerche Frascati enables the generation of intense transient electric fields (MV/m or higher) over extended volumes, with tailored spatial profiles [2]. Their potential for high intensity and ultrafast temporal dynamics provide schemes that overcome the limitations of conventional pulsed-power systems, opening applications in beam control, medicine, materials science, and sensing.

Here, we investigate EMP-driven fields for charged particle beam manipulation, acting as beam choppers for conventional accelerators and energy selectors for laser-driven beams with broad spectra. Our approach combines analytical descriptions of single-particle motion with dedicated numerical simulations under realistic beam conditions. Results highlight compact, high-field, very fast devices, particularly promising for laser-accelerated proton beams, also for potential use in Fast Ignition schemes.

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Acknowledgements

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Tuesday 15 September
LASER-PLASMA PARTICLE ACCELERATION

Chair: **Song Li**	9:00 INVITED	**Ishay Pomerantz** (Tel-Aviv University) *Advances in Direct Laser Acceleration: High-Brightness X-ray and Neutron Sources via Plasma Guiding, High-Z Targets, and Flying Focus Pulses*
	9:30 INVITED	**Paolo Tomassini** (ELI Beamlines and ELI NP, The Extreme Light Infrastructure ERIC) *Design of high-brightness and multi-GeV LWFA electron beams for tunable sub-fs soft/hard X-FEL and Compton scattering sources*
	10:00	**Petr Valenta** (ELI Beamlines facility, The Extreme Light Infrastructure ERIC) *Energy-optimized scaling laws for self-guided laser wakefield accelerators*
	10:20	**Ginevra Casati** (Imperial College London) *Vacuum laser acceleration of electrons using a high intensity Ti-Sapphire laser*
Chair: **Mickael Grech**	11:10 INVITED	**Olle Lundh** (Lund University) *Sub-cycle dynamics in few-cycle laser-plasma acceleration*
	11:40	**Zsolt Lécz** (ELI ALPS facility, The Extreme Light Infrastructure ERIC) *Asymmetric wave-breaking in nonlinear wakefields driven by intense pulses*
	12:00	**Jerome Touguet** (Laboratoire d'Optique Appliquée) *Advanced Beam Shaping for Axiparabola-Based Laser–Plasma Acceleration*
	12:20	**Mohamad Masckala** (Université Paris-Saclay) *High Accuracy Modeling of Laser Driven Electron Acceleration*
	12:40	**Kalyani Swain** (Laboratoire de Physique des 2 Infinis Irène Joliot-Curie) *Effect of optical aberrations on the laser wakefield acceleration of electrons using ionisation injection scheme*
Chair: **Zsolt Lecz**	14:00 INVITED	**Sahar Arjmand** (Istituto Nazionale di Fisica Nucleare) *Capillary-Based Laser-Plasma Accelerators: Beam Generation, Characterization, and Optimization*
	14:30	**Uddhab Chaulagain** (ELI Beamlines Facility, The Extreme Light Infrastructure ERIC) *Laser-Driven X-ray Sources Based on Plasma Accelerators for Multidisciplinary Applications*
	14:50	**Chaitanya Varma** (Laboratoire d'Optique Appliquée) *Semi-Autonomous Optimization of a Laser-Plasma Accelerator for Very High Energy Electron Radiobiology*
	15:10	**Tito Mendonca** (Instituto Superior Tecnico, Universidade de Lisboa) *Particle Acceleration by Superluminal and Accelerated Wakefields*
	15:30 INVITED	**Tomasz Chodukowski** (Institute of Plasma Physics and Laser Microfusion) *Efficiency of laser energy conversion with Cavity Pressure Acceleration scheme*
Chair: **Ondřej Klimo**	16:30 INVITED	**Ioannis Tazes** (Hellenic Mediterranean University) *High-Repetition-Rate Laser-Driven Ion Acceleration via Optically Shaped Near-Critical Density Gaseous Targets*
	17:00 INVITED	**Ulrich Schramm** (Helmholtz-Zentrum Dresden-Rossendorf) *Boosting laser plasma proton acceleration in near critical density targets*
	17:30	**Matteo Iaccarino** (Politecnico di Milano) *Advanced carbon-based targets for laser-plasma interaction experiments*
	17:50	**Gerard Malka** (Université de Bordeaux) *Significant Increase in the Number of Energetic Protons with Two Hot Temperatures of 1 and 4 MeV During the Interaction of an Ultra-Intense Laser with a Foam Target Near the Critical Density and Coulomb piston signature*

Advances in Direct Laser Acceleration: High-Brightness X-ray and Neutron Sources via Plasma Guiding, High-Z Targets, and Flying Focus Pulses

I. Pomerantz[1]

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Abstract

In direct laser acceleration (DLA), the leading edge of an intense laser pulse ionizes the target material, creating a positively charged plasma channel that traps and accelerates electrons. Owing to its high laser-to-electron conversion efficiency, often exceeding 20%, DLA is a promising platform for driving secondary radiation sources.

This talk reviews recent advances aimed at improving the efficiency and scalability of DLA-based X-ray and neutron generation. I will present recent experimental studies conducted at several laser facilities, including ELI Beamlines, Tel Aviv University, and the Soreq National Research Center. Together with supporting numerical simulations, these studies show that DLA performance can be enhanced by tailoring the target atomic number to sustain electron injection, and by employing flying-focus pulses to stabilize the plasma channel and extend the acceleration length.

Building on these developments, I will demonstrate the generation of high accumulated neutron yields via bremsstrahlung produced by MeV electron beams in high-repetition-rate laser shots.

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Design of high-brightness and multi-GeV LWFA electron beams for tunable sub-fs soft/hard X-FEL and Compton scattering sources

P. Tomassini[1,2], N. Hafz[3], F. Avella[4], L.A. Gizzi[4], L. Labate[4], D. Doria[5,2], P. Ghenuche[5,2], G. Grittani[1], F. Habib[1], A. Molodozhentsev[1], and D. Margarone[1]

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[2] Extreme Light Infrastructure-Nuclear Physics (ELI-NP)
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[4] Istituto Nazionale di Ottica, CNR-INO
[5] Horia Hulubei National Institute of Physics and Nuclear Engineering

Abstract

The design of high-brightness sources delivering multi-GeV electron beams with tunable duration and energy requires the usage of flexible and stable LWFA injection/acceleration schemes. By using analytical modelling and q-3D PIC simulations based on high-fidelity laser pulse initialization, we first show that high-brightness 2.2 GeV beams with tunable duration down to 350 attoseconds rms can be generated with a <300 TW Ti:Sa laser system and a ReMPI based LWFA scheme [1,2]. A systematic laser and target fluctuations study reveals the stability of the electron beam source. Applications as soft X-FEL in the water window sources and Thomson/Compton backscattering gamma sources, both with tunable in duration down to 100's as, will be discussed.
To reach Angstrom-scale hard X-FEL radiation, at least 5 GeV electron beams are needed. A design of a ReMPI based scheme driven by a 500 TW laser system, delivering high-brightness beams with tunable energy in the range 5-7 GeV, will be finally discussed along a pathway to include its design study in the EuPRAXIA FEL beamline [3] to be host in the ELI-Beamlines facility.

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Energy-optimized scaling laws for self-guided laser wakefield accelerators

P. Valenta[1], K. G. Miller[2], B. K. Russell[3], M. Lamač[1], G. M. Grittani[1], and S. V. Bulanov[1]

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Abstract

Using advanced particle-in-cell simulation techniques combined with Bayesian optimization, we determine the maximum electron energy that a self-guided laser wakefield accelerator driven by a laser of a given energy and wavelength can produce [1, 2]. By systematically optimizing accelerator performance across a range of laser energies and wavelengths, we identify new scaling laws for both the maximum electron energy and the corresponding acceleration distance (see Fig. 1). These scaling laws (i) depend solely on laser energy and wavelength, (ii) yield the highest electron energy and shortest acceleration distance possible, and (iii) are accompanied by the complete set of laser and plasma parameters required to enable the scaling. The resulting scaling laws provide a practical framework for designing state-of-the-art laser wakefield acceleration experiments operating at their fundamental performance limits.

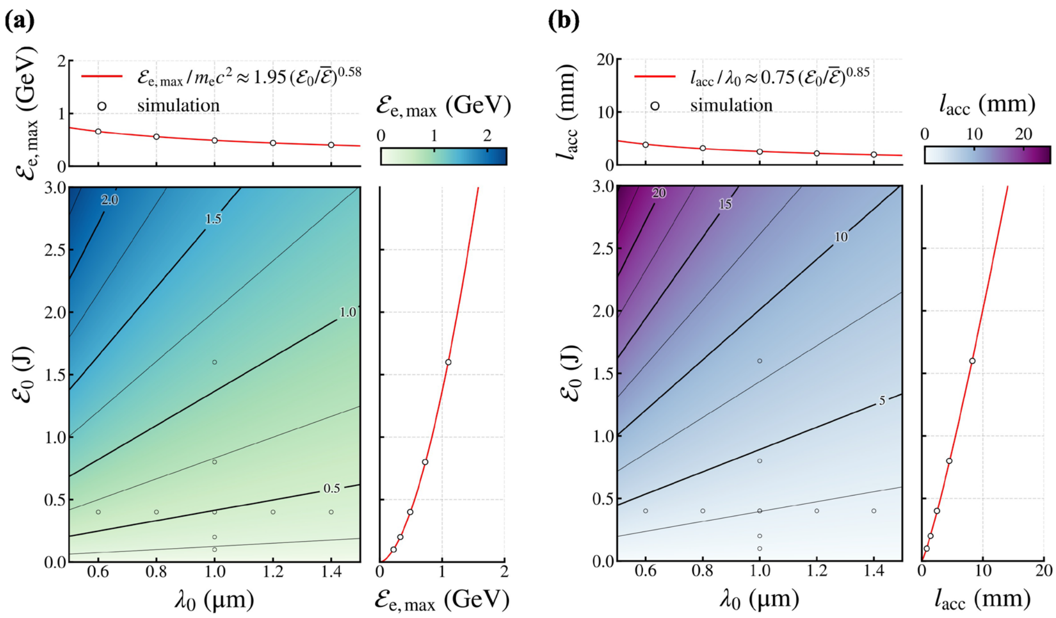

Figure 1. Identified scaling laws for (a) maximum electron energy and (b) acceleration distance.

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Acknowledgements

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Vacuum laser acceleration of electrons using a high intensity Ti-Sapphire laser

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Abstract

Compact laser-plasma sources of high energy electrons are of considerable interest because of their potential applications in areas including medical therapy, materials science, and high-energy-density physics. Among laser-driven acceleration mechanisms, laser wakefield acceleration has achieved the highest beam energies and charges, with laser-to-electron energy conversion efficiencies of up to 70% [1]. However, wakefield acceleration involves complex plasma dynamics, motivating the search for simpler acceleration schemes that can still deliver high-quality electron beams. One such scheme is vacuum laser acceleration (VLA), in which electrons are injected into the laser field at a favorable phase and are subsequently accelerated directly by the laser [2]. Recent work has shown that the relativistic transparency regime can provide suitable conditions for the injection of pre-accelerated electrons into the transmitted laser pulse, enabling direct laser acceleration [3]. In this work, we show that the interaction of a high-intensity Ti:sapphire laser with thin foil targets oriented at 45° produces electron beams with measured temperatures of up to 50 MeV, simulated maximum energies reaching 175 MeV and simulated total charge of up to 10 nC. The beam pointing and collimation are found to depend strongly on the onset time of relativistic transparency and on the direction of propagation of the transmitted laser. Three-dimensional particle-in-cell simulations reproduce the main experimental observations and provide insight into the underlying acceleration dynamics.

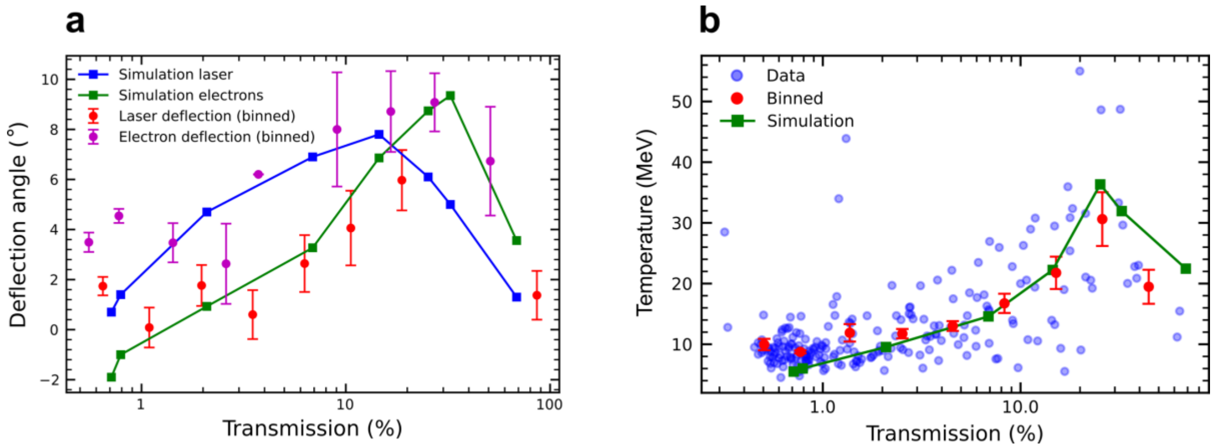

Figure 1. **a** Electron and laser deflection angles plotted against transmission. Square markers represent simulation data points whereas circles are used for the experimenta data. **b** High energy electron population temperature dependence on transmission percentage. Error bars show standard deviation from data and the green markers are the simulation data points.

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Sub-cycle dynamics in few-cycle laser-plasma acceleration

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Abstract

Few-cycle laser pulses enable a regime of laser-plasma acceleration in which the instantaneous optical field, rather than the pulse envelope, governs electron injection and plasma dynamics. During propagation, the evolution of the carrier-envelope phase (CEP) gives rise to sub-cycle modulation of the injection process, a long-standing theoretical prediction that has not previously been observed experimentally.

We present the first experimental observation of CEP-driven energy bunching in laser wakefield acceleration using ionization injection driven by a 9 fs multi-terawatt laser pulse in a helium–nitrogen gas mixture. Electron spectra exhibit multiple quasimonoenergetic peaks with regular energy spacing, arising from discrete trapping events at successive optical half-cycles of the laser field. The electron bunches further exhibit alternating angular chirps, consistent with trapping from successive optical half-cycles. Particle-in-cell simulations reproduce both observations, confirming the underlying injection mechanism.

These findings demonstrate sub-cycle injection as a new mechanism for optical-waveform control of electron trapping in laser-plasma accelerators, enabling beam structuring synchronized to the optical waveform on sub-femtosecond timescales.

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Asymmetric wave-breaking in nonlinear wakefields driven by intense pulses

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Abstract

One of the most important nonlinear phenomena in laser wakefield acceleration (LWFA) is the red-shifting [1,2] which changes the waveform of the laser field and the shape of the envelope also changes via group delay dispersion. This phenomenon, also known as self-phase modulation, becomes important at densities well above $10^{18}\ cm^{-3}$ (for a laser wavelength of $\lambda = 800\ nm$), where the standard theories of transverse envelope evolution (like self-focusing) are coupled to the longitudinal dynamics of the laser envelope. In this presentation we consider a LWFA in such high-density gas targets and we show that the self-modulation of the laser pulse leads to the formation of asymmetric wakefields, which is a well-known transverse distortion in the case of few-cycle pulses [3,4]. We present a simplified numerical method which can quickly provide spatially-resolved information about the red-shifting of a given high-intensity laser pulse propagating in the plasma [5]. Using this tool, we are able to predict the degree of asymmetry of a nonlinear plasma wave after a given propagation distance and we show that asymmetry leads to the off-axis self-injection of energetic electrons. Afterward, the accelerated electrons will have a relatively large transverse momentum leading to larger divergence in the direction of the laser's polarization. Such off-axis electrons have been identified in experiments at ELI ALPS and in particle-in-cell simulations as well [5].

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Advanced Beam Shaping for Axiparabola-Based Laser–Plasma Acceleration

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Abstract

Axiparabolas [1] have recently emerged as a versatile tool for overcoming diffraction and dephasing in Laser-Plasma acceleration (LPA) through the generation of quasi-Bessel beams. These beams can be used to create plasma waveguides [2] and to implement flying-focus schemes, using a radial delay to match the intensity peak velocity to that of the electrons, enabling sustained dephasingless acceleration [3,4]. In this work, we investigate two important aspects of these configurations through complementary studies.

The use of Quasi-Bessel beam extends the laser focus into centimeter-scale focal line, but inevitably introducing unwanted intensity oscillations, disrupting the use for most applications. We analytically identify the origin of these distortions. We then demonstrate, numerically and experimentally, that they can be efficiently suppressed via amplitude or phase modulation of the incident beam with short pulses [5]. We further show that the same framework enables controlled modulation of longitudinal intensity profiles and establish a fundamental resolution limit governing these structures. This capability opens new opportunities for optimizing LPA, notably through enhanced control of electron injection [6] and X-ray production [7].

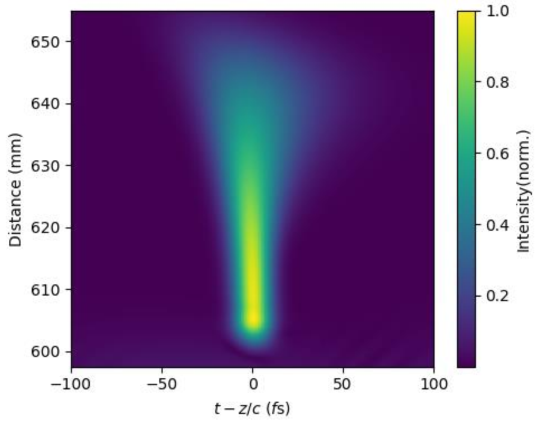

Figure 1. Simulated on-axis intensity in the frame of a particle moving at c focused by an axiparabola of radius R = 50 mm, focal length f = 600 mm and depth δ = 50 mm defined by $z(r) = f + \delta r^2 / R^2$ combined with a radial delay $\tau(r) = \beta r^4$ with $\beta = 0.43$ fs.cm^{-4}.

While achromatic flying-focus was generally assumed to preserve the pulse duration along the focal line, we show that this assumption breaks down for ultrashort pulses [8]. Indeed, these couplings inherently introduce chromatism, leading to a significant temporal elongation of the pulse even in vacuum, further enhanced in plasma by chromatic dispersion. As illustrated in Fig 1, an initially 10 fs laser pulse can stretch up to approximately 33 fs at the end of the propagation length. This pulse broadening limits LPA by reducing peak intensity and perturbing the wakefield, in a regime where higher energy gains rely on ultrashort pulses [3], making their preservation essential. An analytical expression for this elongation is derived and validated numerically, and a radially dependent spectral chirp is shown to compensate for this distortion, restoring near-transform-limited pulse durations throughout the interaction length. A practical implementation based on a stepped dispersive transmissive doublet is also discussed.

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High Accuracy Modeling of Laser Driven Electron Acceleration

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Abstract

Laser Wakefield Acceleration (LWFA) [1], driven by high-power laser pulses propagating through gaseous targets, is a promising approach for developing compact, high-energy electron sources. Laser plasma interaction in an under-dense gas generates plasma waves with accelerating fields orders of magnitude greater than the ones supported by radiofrequency cavities in conventional accelerators. However, achieving simultaneously high charge, low energy spread, low emittance, and excellent shot-to-shot stability remains a major challenge.

In this context, we investigate the impact of higher-order laser beam modes on the injection and acceleration processes LWFA experiment producing electron beams with charges up to 0.3 nC and energies reaching 300 MeV. Experimental results are reproduced using SMILEI Particle-In-Cell simulations over a range of 2 mm around the laser focal-plane position.

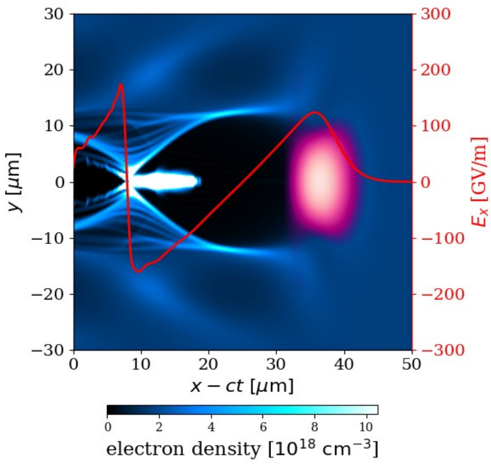

Figure 1. Electron density map and longitudinal electric field Ex in PIC Simulation

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Acknowledgements

The experiment was carried out at Helmholtz-Zentrum Dresden-Rossendorf.
The simulations and analyses are conducted at LPGP, Université Paris-Saclay, as part of a PhD project focused on high-precision numerical modeling of laser wakefield acceleration.
Experiments were performed using HZDR DRACO facility in the frame of the user access programme in Laserlab Europe (grant agreement no. 871124).
This work was granted access to the HPC resources of TGCC and CINES under the allocation 2023- A0160510062 (Virtual Laplace) made by GENCI.

Effect of optical aberrations on the laser wakefield acceleration of electrons using ionisation injection scheme

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Abstract

Laser Wakefield Acceleration (LWFA) relies heavily on high-intensity focused laser pulses to drive highly non-linear plasma waves for electron acceleration. While analytical models, numerical simulations traditionally assume idealised symmetric Gaussian laser profiles, real world experimental systems inevitably introduce optical wavefront aberrations that may significantly affect the electron beam quality [1, 2]. In this study, we investigate the explicit impact of various optical aberrations coming from a realistic experimentally measured laser profile. We use the high-fidelity particle-in-cell (PIC) simulation SMILEI [3] to model the evolution of the wakefield under non-ideal driving conditions in double region target designed for ionisation injection. The experimental input data is from the PALLAS laser-plasma injector test facility [4] where we use a two chamber gas cell target [5] and the laser data is from the LASERIX platform at IJCLab. The goal is to map how the low- and high-order wavefront errors affect the structural uniformity of the laser-driven wakefield bubble and consequently the effect on the electron energy, charge and energy beam spreading.

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Capillary-Based Laser-Plasma Accelerators: Beam Generation, Characterization, and Optimization

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Abstract

I-LUCE [1] (INFN-Laser indUCEd Radiation Production) at INFN-LNS hosts a compact laser-plasma accelerator (LPA) integrated within existing Cyclotron and TANDEM infrastructure. Its design supports a wide range of experiments—including electron [2], proton [3], and neutron radiation generation, particle acceleration, fusion studies, nuclear physics, and medical physics—within a single interaction chamber. The facility is currently under commissioning and will be fully operational by 2028. The core system is a Ti:Sa THALES laser [4] designed to reach up to 320 TW, delivering 1−7.7J in 23−25fs at 2.2Hz. A secondary low-power Astrella (Coherent Inc.) laser (9mJ, 32fs, 1 kHz) is also available for low-energy electron studies (1−8 MeV). With focused intensities of 10^{17}-10^{19} $\mathrm{W/cm^2}$ and plasma densities of 10^{17}- 10^{19} $\mathrm{cm^{-3}}$, I-LUCE enables high-gradient acceleration using gas nozzles (μm − mm), and gas-filled capillaries (mm-cm scale), producing electron beams from the MeV to GeV range, with ongoing efforts to develop novel approaches for proton beam generation using capillaries. In this work, we report the use of gas-filled (hydrogen, argon) capillaries as plasma waveguides to achieve high shot-to-shot reproducibility and stable beam parameters for very high energy electrons (VHEE) [2]. By triggering the electrical discharge before the laser pulse arrival, a static and reproducible density profile is established, ensuring controlled plasma generation and improved shot-to-shot stability. These sources are engineered to provide electron density profiles essential for reliable laser wakefield acceleration (LWFA) in LPAs [5]. We implemented a unified diagnostic and modeling strategy to assess plasma conditions. This strategy integrates imaging spectroscopy for experimental determination of electron density and temperature with a suite of simulations. Capillary plasma behavior was modeled in COMSOL Multiphysics [6] and validated against measured data [7,8], while laser–plasma interactions and electron acceleration were explored using Particle-In-Cell simulations. To enhance performance, a dual-core machine learning framework [9] was deployed to evaluate and optimize discharge settings, capillary design, and laser parameters, ensuring stable generation of high-charge VHEE beams through accurate density profile and beam dynamics control. The final phase of the study consisted of dosimetric analysis using Monte Carlo simulations [10], with workflows that will be managed via Open Neural Network Exchange (ONNX) format.

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Laser-Driven X-ray Sources Based on Plasma Accelerators for Multidisciplinary Applications

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Abstract

Laser-plasma accelerators (LPAs) provide a compact route for the generation of relativistic electron beams and ultrashort secondary radiation sources [1, 2]. Among these, Betatron X-rays produced by laser wakefield accelerated electrons offer unique properties including femtosecond duration, micron-scale source size, broadband spectrum, high peak brightness with 10^{11} photons per pulse [3-5]. These characteristics make laser-driven X-ray sources attractive for a broad range of applications spanning fundamental physics, materials science, biology, chemistry, and high-energy-density science. At ELI Beamlines, significant efforts have been devoted to the development and delivery of user-oriented laser-plasma-accelerator-based X-ray and gamma-ray sources for multidisciplinary research [6].

We present recent developments of laser-plasma-accelerator-based radiation sources at ELI Beamlines, including the recently commissioned Gammatron beamline [7,8]. It is driven by the L3 HAPLS petawatt-class laser system, the beamline delivers bright broadband X-rays with photon fluxes exceeding 10^{11} photons per pulse. Stable GeV-class electron beams and highly collimated Betatron X-rays have been demonstrated, enabling single-shot imaging and ultrafast pump-probe experiments. Current user activities focus on absorption, phase-contrast and multimode X-ray imaging, exploiting the unique properties of Betatron radiation for time-resolved studies of matter. Dedicated developments at the Gammatron User Station (GAUSS), including broadband X-ray focusing optics [9], will enable future diffraction and spectroscopy experiments, further expanding the multidisciplinary applications of laser-driven X-ray sources at ELI Beamlines. We also report on a novel multi-pass interferometric diagnostic developed for characterization of low-density gas targets used in laser-plasma acceleration [10, 11].

In addition to Betatron radiation, we present recent progress in high-flux inverse Compton scattering sources based on plasma-mirror configurations, producing gamma rays with critical energies exceeding 100 MeV. A dedicated broadband Betatron source is also being developed at the Plasma Physics Platform (P3) [12] for active probing of laser-produced plasmas, warm dense matter, and laboratory astrophysics experiments.

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Semi-Autonomous Optimization of a Laser-Plasma Accelerator for Very High Energy Electron Radiobiology

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Abstract

Laser-driven plasma accelerators (LPAs) can be used to produce Very High Energy Electron (VHEE, energy > 50 MeV) beams [1]. They are also capable of producing accelerated electron bunches of sub-picosecond duration while shrinking the length of electron acceleration by a factor of 10^3 compared to conventional accelerators. To explore the biological effects of Ultra-High Dose Rate (UHDR) in radiotherapy, producing stable, high-charge beams via tailoring the laser-plasma interaction is necessary.

This work aims to establish a new operational baseline for LPA-based irradiation experiments at the Laboratoire d'Optique Appliquée (LOA) for next-generation, high-repetition-rate capabilities. Specifically, the upcoming LAPLACE-HC project [2] is being built to operate at 100 Hz, which will multiply the overall dose rate by two orders of magnitude. To prepare for this, recent experiments in the Salle Jaune experimental area mimicked the LAPLACE-HC laser parameters (1 J, 25 fs, F/10) at a reduced repetition rate.

To establish this new 1 J baseline and improve throughput, newer plasma-source designs were used. Furthermore, an Xopt-based machine-learning optimizer [3] was implemented to leverage live beam-diagnostics for real-time feedback. Utilizing Multi-Objective Bayesian Optimization (MOBO) and Expected Improvement, this highly configurable system autonomously tuned gas pressure, nozzle position, and shock shaping via blade position to maximize charge and stability while enforcing constraints on minimum energy.

The resulting electron bunch energies ranged from 25 to 125 MeV, with charges upto 400 pC per shot. The achieved flux demonstrates viability for future irradiation applications. Particle-in-cell (PIC) simulations were carried out based on the parameters obtained to understand the laser-plasma interaction. Ultimately, a scalable LPA-based VHEE source was characterized, establishing that high-throughput, machine-learning-driven configurations can approach the performance required for UHDR radiobiology.

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Particle Acceleration by Superluminal and Accelerated Wakefields

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Abstract

Until recently, the problem of particle acceleration in superluminal plasma perturbations was seem as a simple academic curiosity. However, in recent years, the advent of new optical concepts such as the flying focus created a new interest on this subject. In this work, we explore the similarities and differences between acceleration of charged particles and photons in superluminal and accelerated Wakefields and present some new theoretical and numerical results. Single particle processes and collective bunch acceleration are considered. Accelerated donut and helical Wakefield configurations are also discussed.

Efficiency of laser energy conversion with Cavity Pressure Acceleration scheme

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Cavity Pressure Acceleration (CPA)[1-4] is a technique for accelerating dense plasma streams by utilizing laser-generated plasma pressure within a spatially confined region. This approach has been proposed as an alternative to the classical ablative acceleration of plasma. Initially, the primary goal of this approach was to create a dense plasma stream (a theoretical macroparticle[5,6] delivering energy/momentum) suitable for experiments related to Impact Fast Ignition[7,8]. In recent experimental sessions, we used targets equipped with cavities lined with deuterated polyethylene (CD_2) foils and powder. These targets were irradiated with a sub-kilojoule, low-contrast laser beam at PALS[9] (λ_1^{PALS} =1315 nm), focused to an intensity of $1-2\times10^{16}$ W/cm^2 within a 250−350 ps pulse. The scheme has proven to be highly efficient in converting laser energy into high-energy interaction products, such as high-density plasma streams and protons. We observed neutron yields among the highest achieved to date in Deuterium-Deuterium laser-induced experiments and thus the scheme seems to be an effective source of high-energetic protons, suitable for e.g. proton-boron (p-^{11}B) related experiments[10].

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High-Repetition-Rate Laser-Driven Ion Acceleration via Optically Shaped Near-Critical Density Gaseous Targets

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Abstract

Near-critical density (NCD) targets are considered a promising alternative to conventional foil targets for high-repetition-rate (HRR), debris-free laser-driven ion sources. State-of-the-art simulations predict ion beams reaching energies of hundreds of MeV via advanced acceleration mechanisms dominant in the NCD regime. However, experimental operation with NCD gaseous target profiles remains challenging, especially for intense fs laser systems due to the precise control required over the target peak density and density gradients, with only scarce experimental demonstrations reported to date.

Here, we present a novel method of optically shaping under-dense gaseous profiles into NCD profiles as high-repetition-rate targets for laser-driven ion acceleration. Experimental validation of the experimental validation of our previous simulations is demonstrated [1]. Ion acceleration experiments are conducted using the 45 TW, fs laser system Zeus, hosted at the Institute of Plasma Physics and Lasers [2] of the Hellenic Mediterranean University. Experimental results on the shaping of the target along with measurements of multi-MeV ion beam energy spectra along high-flux electron beams, and bright x-ray emission, are presented.

The optical shaping scheme employs dual, intersecting laser-generated, counterpropagating blast waves that compress the gaseous medium, upon their shock-front's collision, forming steep density gradient slabs of a few microns scale length. The compression of the target is maintained over several ns, mitigating laser synchronization constraints.

Accelerated ion beam energy spectra, spatial distribution, and total dose are presented. Energetic ions with cut-off energies exceeding 11 MeV/u are measured using multilayer detector stacks composed of CR39 and radiochromic films. 3D radiation-HydroDynamic simulations are performed to optimize the target density profile optical shaping, along with exploiting the effects of the inherent Amplified Spontaneous Emission of the accelerating fs laser pulse. Matching of simulation to experimental results is achieved using an 'in-house' developed synthetic optical probing algorithm that performs ray-tracing on the 3D HD simulation results.

The super-intense laser-target interaction is investigated using 3D Particle-In-Cell simulations. The simulations reveal the generation of multi-kT, azimuthal magnetic fields, strongly suggesting that Magnetic Vortex Acceleration is the dominant underlying acceleration mechanism. Finally, results for the adaptation of the acceleration scheme to a PW-class laser system are presented, demonstrating enhanced ion acceleration efficiency.

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Acknowledgements

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Boosting laser plasma proton acceleration in near critical density targets

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Abstract

Improved control of high intensity ultra-short pusle laser beam parameters on target together with targets density-tailored to these laser parameters recently enabled the demonstration of laser accelerated proton bunches with energies well beyond 100 MeV, dose-controlled irradiation of biological samples, and the demonstration of FEL gain based on laser wakefield acceleration of electrons [1].
This presentation focuses on the chain of developments at the Petawatt laser DRACO at Helmholtz-Center Dresden-Rossendorf that enabled the first dose controlled systematic irradiation of tumors in mice with laser accelerated protons [2]. Details on acceleration mechanisms and strategies to increase stability and energy will be discussed [3] as well as beam transport by means of a dedicated pulsed solenoid beamline to a secondary target together with online metrology and dosimetry. In parallel, improved control of interaction parameters together with different types of targets operated close to relativistic induced transparency enabled the exploitation of acceleration mechanisms surpassing target normal sheath acceleration [4,5]. Here, proton energies well beyond 100 MeV could be reached. With cryogenic hydrogen jet targets [6] readiness was further demonstrated for increased repetition rate operation at the 50 MeV proton energy scale.

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Advanced carbon-based targets for laser-plasma interaction experiments

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Abstract

Carbon-based materials are widely employed in laser-plasma interaction experiments, ranging from ultrathin foils for laser-driven particle acceleration to high-density carbon (HDC) ablators used in inertial confinement fusion (ICF) schemes [1,2]. In both applications, the ability to tailor target properties is crucial for optimizing the laser-matter coupling and the energy deposition into the plasma. In particular, target density has been shown to strongly influence laser absorption and, consequently, the overall efficiency of the interaction, motivating the development of low-density nanostructured carbon materials for advanced laser-plasma applications.

Within this framework, carbon nanofoams produced by pulsed laser deposition (PLD) [3] have demonstrated enhanced performance in laser-driven ion acceleration experiments and have recently emerged as promising candidates for advanced low-density ablators in ICF applications [4,5]. The possibility of further tailoring the density and morphology of these types of targets continues to motivate the development of novel materials and fabrication strategies. In this context, a novel chemical synthesis has been recently developed at Politecnico di Milano to further expand the range of carbon-based targets available for laser-plasma interaction experiments.

In particular, cyclohexane-polyyne solutions were left to evaporate on a water surface. Polyynes, consisting of linear sp-hybridized carbon chains, act as precursors for the formation of a floating carbon membrane at the liquid interface and are expected to provide enhanced mechanical properties to the material, making such membranes particularly attractive as ultrathin free-standing targets [6,7]. The influence of the initial polyyne concentration on the structural properties of the synthetized carbon material was investigated. The produced membranes were characterized through SEM and EDX analyses in order to evaluate their morphology, density, and thickness.

The measurements revealed the formation of a compact carbon film with thicknesses ranging from 30 to 50 nm and an estimated density corresponding to approximately half that of bulk carbon. Additionally, a nanostructured carbon flake layer was observed on top of the compact film, with a filling factor strongly dependent on the initial polyyne concentration. Free-standing tests confirmed the feasibility of employing these membranes as laser-plasma targets and as substrates for PLD-grown carbon nanofoams in advanced double-layer target configurations.

This contribution provides an overview of the most recent results that have been achieved at Politecnico di Milano in the development of advanced carbon-based targets for laser-plasma interaction experiments, spanning from near-critical carbon nanofoams to novel ultrathin membranes produced through chemical synthesis.

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Significant Increase in the Number of Energetic Protons with Two Hot Temperatures of 1 and 4 MeV During the Interaction of an Ultra-Intense Laser with a Foam Target Near the Critical Density and Coulomb piston signature.

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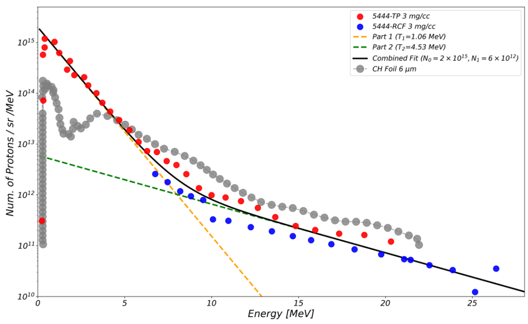
Key words: proton acceleration, high intensity lasers, low density foams, TNSA

ABSTRACT

We present the experimental results of proton acceleration obtained at the LFEX laser facility in Osaka, 1 kJ, 1 ps, I > 10^{19} W/cm², with foam targets of 3, 8, and 16 mg/cc and 200 µm thick, as well as with thin foil targets. For the 3 mg/cc foams, the proton distribution, emitted on the back side of the target, exhibits two hot temperatures: one of 1 MeV for energies below 8 MeV, and one of 4,5 MeV for energies up to 20 MeV. The novel result is that the number of protons increases by more than a decade, and significantly increasing the conversion efficiency from laser energy to the proton beam. By increasing the angle of incidence of the laser beam on the target from 0 to 15°, we observe that the proton beam remains perpendicular to the back face of the target. We discuss the competition between the different acceleration processes involved, such as TNSA and RPA. In the case of thin foil (6 µm CH), the formation of energy bunches in the proton spectra which are due to the interplay between the protons and the highly charged carbon ions (mostly $C6^{+}$) which are also accelerated by the lasers. These finding are coherent with theoretical formulation predictions that the carbon ions act as a "Coulomb piston" on protons.



Wednesday 16 September
EMERGENT TOPICS IN LASER-MATTER INTERACTION

Chair: **Stefan Weber**	9:00 INVITED	**Pierre Michel** (Lawrence Livermore National Laboratory) *Gas optics for high-power laser applications*
	9:30 INVITED	**Eduardo Oliva** (Universidad Politécnica de Madrid) *3D multiscale modelling of the interaction of structured light with inhomogeneous plasmas: applications to plasma diagnosis*
	10:00	**Götz Lehmann** (Heinrich-Heine University Düsseldorf) *Formation and persistence of ponderomotive plasma gratings created by finite-duration laser pulses*
	10:20	**Jeremy La Porte** (Laboratoire pour l'utilisation des lasers intenses) *Magnetic field generation by Light Springs through refraction on helical plasma waves*
Chair: **Fabrizio Consoli**	11:10 INVITED	**Alessandro Maffini** (Politecnico di Milano) *Tailoring laser-matter interaction using near-critical nanofoam targets*
	11:40	**Rafael Russo de Almeida** (GoLP/IPFN, Instituto Superior Técnico, Universidade de Lisboa) *Generalized Thomson scattering for relativistic plasma optics*
	12:00	**Pedro Velarde** (Instituto de Fusión Nuclear, Universidad Politécnica de Madrid) *Collisional ionisation and shake-off processes in XFEL-heated dense plasmas*
	12:20	**Sergey Kondrashev** (Brookhaven National Laboratory) *Development of continuous beam laser ion source*

STRONG-FIELD QED LASER PHYSICS

Chair: **Luís O. Silva**	13:40 INVITED	**Mickael Grech** (LULI, CNRS, Sorbonne Université, École polytechnique, Institut Polytechnique de Paris) *Kinetic Theory and Scaling Laws of QED Cascades: From Crossed Fields to Solid Targets*
	14:10 INVITED	**Sebastian Corde** (LOA, CNRS, École polytechnique, ENSTA, Institut Polytechnique de Paris) *Progress towards strong-field QED studies at multi-PW laser and accelerator facilities*
	14:40	**Anthony Mercuri-Baron** (University of Plymouth) *Quantifying Extreme Laser Intensities Using Nonlinear Photon-Photon Scattering*
	15:00	**Joao Custodio** (ELI Beamlines Facility, Extreme Light Infrastructure ERIC) *Coherent radiation and radiation friction in laser–plasma collisions*
	15:20	**Marta Galbiati** (LULI, CNRS, CEA, Sorbonne Université, Ecole Polytechnique, Institut Polytechnique de Paris) *Gamma-photon generation with near-critical foam-based targets at the Apollon multi-PW laser*

LASER APPLICATIONS IN ASTROPHYSICS RESEARCH

Chair: **Dominik Kraus**	16:30 INVITED	**Luís O. Silva** (GoLP/IPFN, Instituto Superior Técnico, Universidade de Lisboa) *Shaping and Control of Laser-Driven Extreme Plasma Turbulence*
	17:00 INVITED	**Samuel Schumacher** (University of Rostock) *Measurement of the Opacity of Hydrogen at Red Dwarf Star Interior Conditions*
	17:30	**Louise Cornet** (CNRS) *Mechanisms at the origin of radio solar bursts by laser-plasma interaction*
	17:50	**Johannes Rips** (University of Rostock, Germany) *Investigating the onset of carbon K-shell ionization from imploding CH capsules measured at the National Ignition Facility*

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Gas optics for high-power laser applications

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Abstract

Optics damage is a ubiquitous challenge for high-power lasers and largely dictates the size and cost of these facilities. Here, we are developing a new technology that uses gas as an optical medium instead of solids. Gas optics have damage thresholds 2 to 3 orders of magnitude beyond those of solids and are transient and replenishable at high repetition rates, making them intrinsically immune to any type of cumulative damage from laser light or target debris. We have experimentally demonstrated gaseous diffraction gratings and holographic lenses in the laboratory; these elements operate for any laser wavelength from deep UV to IR, and pulse durations from femtoseconds to nanoseconds. As diffractive elements, these optics provide excellent phase front quality for the diffracted laser beam. We have demonstrated stable operation at 10 Hz with diffraction efficiencies up to 99% for gas gratings and 75% for holographic gas lenses, and shown that the lifetime of gas optics can be controlled and adjusted from nanoseconds to microseconds, making them well suited for IFE facilities and other industrial applications where optics damage is a concern.

Figure 1. Illustration of gas optics operations: a pair of low-energy UV "writing beams" imprint a volume hologram in a gas to diffract a high power laser beam (shown here in green).

Acknowledgements

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3D multiscale modelling of the interaction of structured light with inhomogeneous plasmas: applications to plasma diagnosis

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Abstract

This work presents recent results on the interaction of structured IR, UV and XUV beams (for example, High Order Harmonics, HOH, carrying Orbital Angular Momentum, OAM) with plasmas. Experimental and modelling results unveil its potential applications in plasma diagnosis, especially in the fields of Inertial Confinement Fusion (ICF), plasma based soft X-ray lasers and Laboratory Astrophysics. Using our multiscale, multiphysics computational framework [1] it is possible to model the full process undergone by the system (plasma+pump/probe structured beams): plasma creation and its posterior hydrodynamic expansion; the related collisional and radiative processes; and the propagation and amplification of UV/XUV beams.

We will focus in recent modelling and experimental results on the interaction of structured light with plasmas: the use of spatio-temporal couplings to create a flying focus and improve the amplification of HOH beams in dense plasmas [2] capable of amplifying soft X-ray radiation; the emission and amplification of structured UV light by cavity-free nitrogen plasmas, with applications in atmospheric air lasing; and the application of HOH beams carrying OAM towards diagnosing hot, dense plasmas [3,4,5,6], by measuring the perturbation of the HOH wavefront after propagation through the plasma and relating this perturbation to the electron density and its gradient

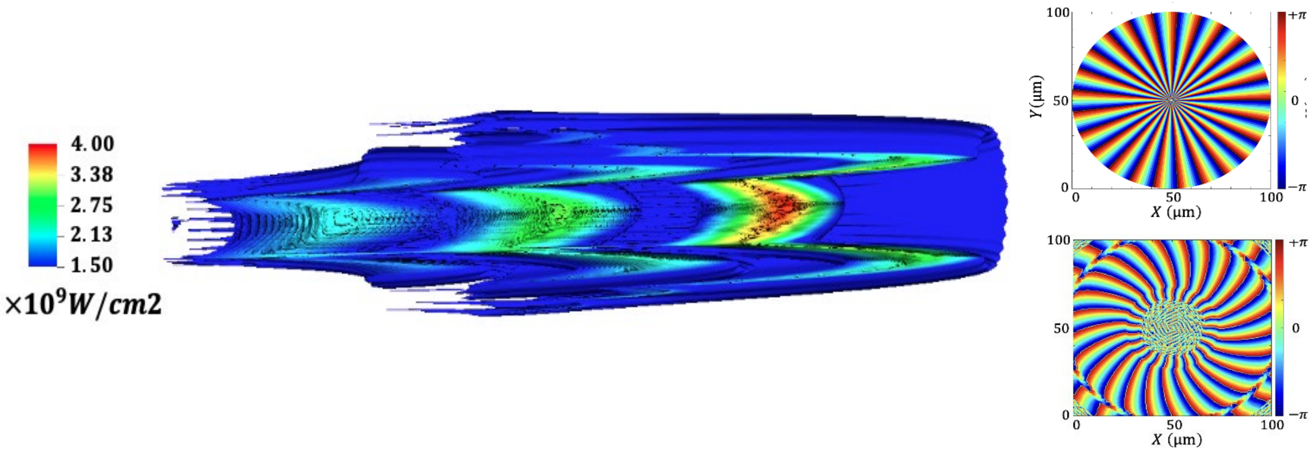

Figure 1. (left) Intensity of an amplified XUV HOH carrying OAM along with ASE. (right) Initial (upper) wavefront of a l=25 Laguerre-Gauss HOH and perturbed wavefront (lower) of the same HOH after amplification through a plasma.

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Formation and persistence of ponderomotive plasma gratings created by finite-duration laser pulses

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Abstract

Plasma-optical components based on laser-driven density structures have recently attracted interest as compact, damage-free alternatives to conventional optical elements [1]. In this work, we investigate the formation and persistence of plasma gratings generated by the ponderomotive potential of two counter-propagating pump laser beams

We focus on the influence of finite pump-pulse duration on grating quality and temporal evolution. In addition to the previously identified parameters ν (trapping vs. collective effects) [2] and $\mu=3T_e/(m_e c^2 a_0^2)$[3], we show that the pump duration τ_p plays a key role in determining both the peak density modulation and the usable grating lifetime. Using full Vlasov simulations, we quantify the maximum grating amplitude and its decay as functions of electron temperature T_e and pulse duration τ_p. To interpret the results, we extend a known one-frequency kinetic model to finite-bandwidth pump pulses.

Our results reveal how τ_p and T_e jointly determine the achievable grating performance and explain the observed scaling behavior. In particular, we find that even gratings driven by sub-picosecond pump pulses can remain highly effective on picosecond timescales, provided the electron temperature remains sufficiently low. For example, for T_e < 100 eV, pump pulses shorter than a few hundred femtoseconds can still generate plasma gratings suitable for efficient optical utilization over several picoseconds.

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Magnetic field generation by Light Springs through refraction on helical plasma waves

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Abstract

The transfer of orbital angular momentum (OAM) from laser pulses to plasmas is usually interpreted through absorption, dissipation, or single-particle dynamics [1–3]. Here we study a different channel in which OAM is transferred through refraction in an underdense plasma with azimuthal density gradients. We introduce a new ray-tracing framework, in which these gradients modify the local refractive index and exert a torque on the electron fluid, analogous to the action of a spiral phase plate but with the phase structure generated self-consistently by the laser-plasma interaction. We apply this framework to Light Springs, formed by two co-propagating Laguerre-Gaussian modes with different frequencies and OAM indices [4,5], whose helical intensity structure self-consistently drives the azimuthal density gradients that the refraction mechanism requires. This helical plasma wave refracts the laser, transfers angular momentum to the plasma electrons, and generates a quasi-static magnetic field along the propagation direction. We develop an analytical model for this refractive OAM transfer and derive the scaling of the generated field with plasma density, laser amplitude, pulse duration, focal spot size, and Light Spring topology. Three-dimensional particle-in-cell simulations validate the predicted profiles and scalings in the weakly nonlinear regime, showing that a Light Spring generates a coherent longitudinal magnetic field reaching hundreds of Tesla, whereas a single Laguerre-Gaussian beam produces only a weak residual field. We also investigate the impact of wavebreaking on density and magnetic-field generation in the stronger nonlinear regime.

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Tailoring laser-matter interaction using near-critical nanofoam targets

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Abstract

Low-density near-critical nanofoams offer unique opportunities to tailor laser-matter interaction by enhancing laser absorption and controlling plasma dynamics across a wide range of intensities and pulse durations. In this contribution, we present recent theoretical and experimental results on the interaction of high-power lasers with nanofoam-based targets produced by Pulsed Laser Deposition (PLD) [1]. This technique enables precise control over nanofoam density, morphology, and composition through the tuning of deposition parameters, making it possible to fabricate multi-elemental nanofoams with properties relevant to laser–plasma interaction experiments [1-4].

In particular, we discuss numerical strategies to reproduce realistic foam nanostructures and integrate them into particle-in-cell simulations, highlighting the role of nanoscale target morphology in shaping laser absorption, electron heating, and laser propagation in near-critical plasmas. The impact of near-critical nanofoams on laser-driven particle and radiation sources is also addressed, with particular emphasis on nanofoam-based double-layer targets for enhanced ion acceleration, high-energy photon generation, and proton-boron fusion [5-10]. We further discuss recent investigations on laser interaction with PLD carbon nanofoams in nanosecond regimes, including modelling and experimental studies on nanofoam-based ablators for direct-drive inertial confinement fusion [11,12].

Overall, these results demonstrate that PLD nanofoams represent a versatile and effective platform for advancing laser-plasma interaction physics, from controlled target fabrication to the optimization of laser-driven sources and fusion-oriented applications.

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Generalized Thomson scattering for relativistic plasma optics

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Abstract

Spatiotemporally structured light - electromagnetic radiation with engineered couplings between its spatial and temporal degrees of freedom - has emerged as a powerful technique for controlling light-matter interactions. While traditional methods are effective at structuring weak electromagnetic fields, high-field physics requires structured light at the extremes of intensity and photon energy. Thomson scattering, for instance, can convert optical photons to x- or gamma ray photons, but typical configurations employ non-structured optical pulses and particle beams, offering little control over the generated radiation.

In this talk, we present a generalized Thomson scattering formalism that enables control over the spatiotemporal topology of high-energy photon emission. The formalism can be used to identify the optical pulse or electron bunch structure needed to produce a desired spatiotemporally structured high-energy photon bursts, providing an inverse design strategy for high frequency spatiotemporal tailoring.

We demonstrate the utility of this formalism by showing how an optical pulse with longitudinal orbital angular momentum can be converted to a high-energy spatiotemporal optical vortex. Moreover, we show how tailored relativistic particle beams can function as optical elements - analogous to curved mirrors or gratings - to format the phase and intensity profile of up-converted radiation. These results were obtained with the particle-in-cell code OSIRIS [1] coupled with the radiation diagnostic tool RaDiO [2]. This work establishes a proof of principle for a new generation of high-energy photon sources with custom spatiotemporal structure.

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Collisional ionisation and shake-off processes in XFEL-heated dense plasmas

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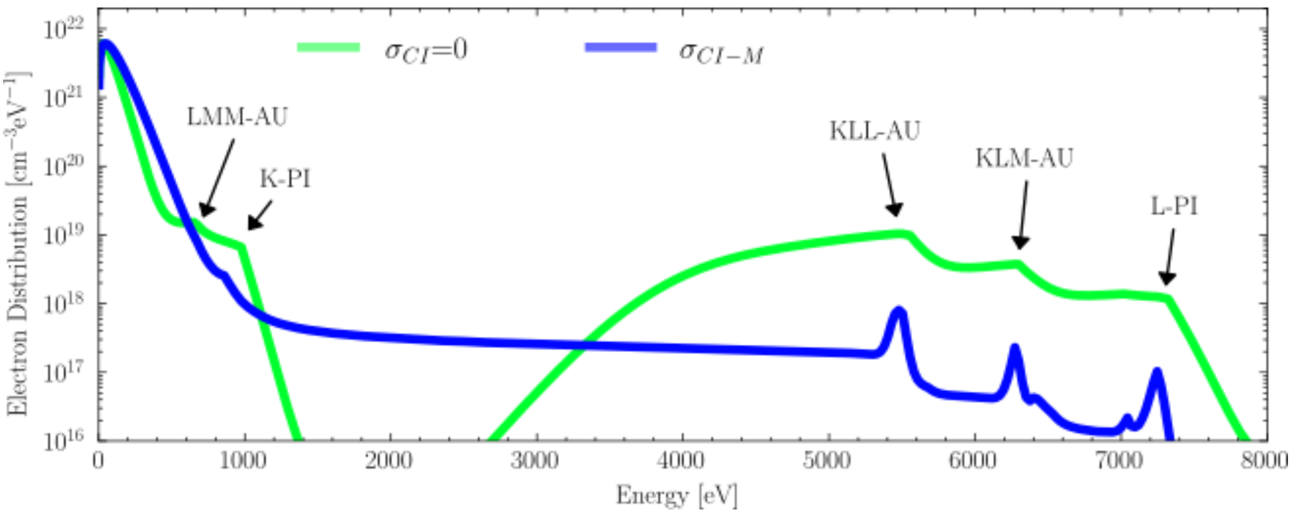
Abstract

X-ray free-electron lasers provide a unique platform for producing solid-density plasmas under well-defined conditions, with ultrafast energy deposition and initially non-thermal electron distributions. Their interpretation, however, requires collisional-radiative modelling able to describe the transient atomic kinetics during and shortly after the XFEL pulse.

In this work, we use the non-thermal collisional-radiative code BigBarT, which self-consistently evolves the electron continuum while accounting for degeneracy effects. We first apply the model to XFEL-heated iron, with particular emphasis on collisional ionisation from the outer shells. We find that these channels provide the most efficient mechanism for the relaxation of non-thermal electrons, rapidly redistributing energy from the high-energy part of the distribution into the dense background.



Motivated by this result, we examine experimental K-shell emission spectra from XFEL-heated solid-density aluminium, which had previously been interpreted as requiring a significant contribution from non-thermal electron-driven collisional ionisation. Since our simulations indicate that collisional ionisation can thermalise the electron distribution efficiently, we explore an alternative explanation for the observed satellite structure.

We show that shake-off following primary photoionisation, a process often neglected in this class of dense XFEL-produced plasmas, can create additional L-shell vacancies and contribute strongly to the measured emission. Comparisons with experimental spectra from LCLS and European XFEL demonstrate that shake-off must be included to reproduce the observed features.

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Development of continuous beam laser ion source

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Abstract

- We are developing a novel type of ion source – continuous beam laser ion source using a 5 mJ/4 ps laser with 10 kHz rep-rate. Quasi-continuous beams of singly and multiple charged ions of any solid-state element of the periodic table with mA-level average current can be generated by this laser. Being developed, such an ion source will find a very wide range of applications ranging from ion implantation and medical isotope production to nuclear physics user facilities. Two immediate applications of the source will be an ion injection into the Electron Beam Ion Source (EBIS) and the realization of a compact neutron generator based on an intense beam of lithium 3+ ions.
- To specify source parameters, ion currents together with ion charge state and energy distributions have been measured for different target materials — B, C, Al, Nb, Ag, Ta and Au. The effect of crater formation on ion generation has been studied for both stationary and continuously moving targets. The results of ion measurements for different experimental conditions will be presented and discussed.
- High-speed liquid jet with vertical flow is a very attractive target option to eliminate the influence of crater formation on ion output under irradiation by high rep-rate laser. Vacuum oil and several metals with low melting temperatures (Ga, Bi-Sn-In alloy, and Li) are under consideration for initial tests. The current status of liquid target development and future plans will be presented and discussed as well.

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Kinetic Theory and Scaling Laws of QED Cascades: From Crossed Fields to Solid Targets

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Abstract

The rapid development of multi-petawatt laser facilities brings within experimental reach regimes where strong-field quantum electrodynamics (SF-QED) cascades can be efficiently driven. These cascades provide a promising route toward abundant electron-positron pair production and, possibly the creation of pair plasmas in the laboratory. Such plasmas, common in high-energy astrophysical environments, are often relativistic and radiation-dominated, and can differ markedly from traditional electron-ion plasmas.

SF-QED cascades develop in strong fields produced either by ultra-intense lasers or by the Coulomb fields of atoms in matter. They result from the interplay of high-energy photon emission and electron-positron pair creation. Here, the focus is on shower-type cascades driven mainly by the energy of an incident seed beam. Both electron and photon seeding will be discussed.

A unified kinetic description of SF-QED showers, based on a generation-splitting formulation of cascade dynamics, will be presented. Initially developed for showers in strong electromagnetic crossed fields [1], this analytical framework extends naturally to showers in solid targets [2], bridging field-dominated and matter-dominated regimes within a single theoretical approach. In both cases, the shower dynamics proceeds through two stages. At short interaction times, seed particles are only weakly affected, leading to secular growth in the number of produced pairs. At longer times, the seed particles and generated pairs have radiated away most of their energy, and the shower evolution is governed by the decay of surviving low-energy photons. In strong electromagnetic fields, this produces a slow, logarithmic growth of pair multiplicity, while in matter the same mechanism, combined with collisional processes, leads to shower saturation.

In the first part of the talk, I will introduce this framework and simple analytical scaling laws for key observables: shower multiplicity, angular divergence, and energy spectra of pairs and photons, as functions of a small set of physically relevant parameters. In the second part, these scaling laws will be used to identify the conditions under which SF-QED showers can give rise to quasi-neutral, collectively behaving pair plasmas. A simple criterion for pair-plasma formation will be discussed for both field-driven and matter-driven showers. Finally, the expected properties of the resulting pair plasmas, such as mean energy, isotropy, and dimensionality, will be examined.

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Progress towards strong-field QED studies at multi-PW laser and accelerator facilities

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Abstract

With today's accelerator and laser facilities, such as the 10 GeV FACET-II facility at SLAC National Accelerator Laboratory or laser-accelerated electron beams at multipetawatt laser facilities, extreme beam physics and strong-field quantum electrodynamics (QED) are emerging as promising discovery science area where ultrashort and dense electron beams or laser pulses can be used as source of extreme electromagnetic fields. In this talk I will present recent experimental progress and prospects in strong-field QED and extreme beams, with results from the multipetawatt laser facilities APOLLON and ELI-NP, and from the FACET-II accelerator facility.

Several scenarios are being considered to reach extreme conditions and to probe the strong-field regime of quantum electrodynamics. A first scenario relies on multipetawatt lasers driving laser-plasma accelerators and generating multi-GeV electrons, and on triggering a collision between the high-energy electron beam and the drive laser with a plasma mirror to reflect the later. This single-laser scheme has been shown to be scalable towards strong-field QED, with high-energy photons produced by nonlinear inverse Compton scattering with energies of hundreds of MeV [1], in conditions where synchrotron radiation from electrons in large background fields cannot be described classically anymore, but requires quantum corrections. This single-laser scenario can be further improved by boosting the intensity of the colliding laser with laser self-focusing in a dedicated plasma section just before the plasma mirror, opening prospects for probing strong-field QED with fields several times larger than the Schwinger critical field [2]. First experimental tests of this method carried out at ELI-NP will be presented.
A second scenario leverages extreme electron beams as the source of the strong fields, and extreme focusing in beam-multifoil collisions to considerably increase the density of the electron beam. Here the electron beam is focused by the beam fields reflected by multiple conducting layers (or, equivalently, by coherent transition radiation) that act as solid-density plasmas, with the potential to reach solid-density beams and enter the strong-field QED regime [3]. The physics of strong-field focusing by coherent transition radiation has been unveiled experimentally at the SLAC FACET-II 10 GeV accelerator facility, with the first experimental evidence of such focusing in beam-multifoil collisions [4] that will be presented during this talk.

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Acknowledgements

The results presented in this talk have been obtained in the context of several international collaborations: the E-332 experiment at SLAC, the 25_LF_02 experiment at APOLLON and the ELI50069 experiment at ELI-NP.

Quantifying Extreme Laser Intensities Using Nonlinear Photon-Photon Scattering

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Abstract

As high-power laser facilities achieve ever-increasing field intensities [1], the demands for accurate laser pulse characterization grow accordingly.

Current intensity diagnostics depend largely on indirect methods that typically fail to sample the pulse at its focal point. While novel approaches have emerged—including electron scattering [2-5] and heavy atom ionization [6]—these techniques will ultimately encounter limitations when applied to the extreme intensities required for probing nonlinear quantum electrodynamical effects.

This work introduces a diagnostic method based on nonlinear light-by-light scattering, where a probe laser collides with an ultra-intense laser beam. The resulting signal originates from probe photons scattering off regions of the quantum vacuum polarized by the intense beam. By measuring and inverting the scattered probe signal, properties of the ultra-intense beam can then be inferred.

We present a theoretical demonstration of the extractable information, including maximum intensity and beam width. Subsequently, we conduct a numerical analysis employing a machine-learning framework built on artificial neural networks and deep learning techniques to invert the scattered probe signal and reconstruct key characteristics of the intensity beam.

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Coherent radiation and radiation friction in laser–plasma collisions

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Abstract

We investigate coherent radiation and radiation friction in the collision of an intense laser pulse interacting with a dense relativistic electron bunch. While the intensity of incoherent radiation scales linearly with the number of electrons N , coherent radiation scales as N. Therefore, for a sufficiently dense bunch with N ≫ 1, coherent emission can dominate the total radiated energy. We characterize its dependence on the density and shape of the bunch and on the intensity, duration and polarization of the laser pulse [1–3]. The predicted scalings are in a good agreement with results from three dimensional particle-in-cell (PIC) simulations.

Radiating particles lose energy and momentum. This effect (radiation friction, RF) has been observed in collisions of ultrarelativistic (E ~ GeV) electrons with intense (I ~ 1021 W/cm2) laser pulse [4–6]. Coherent enhancement of radiation opens a venue for the experimental study of RF with mildly relativistic electrons (E ~ 10 − 100 MeV) and lower intensity (I ~ 1018 − 1019 W/cm2) lasers.

Using analytical modeling and PIC simulations, we identify physical configurations that optimize coherent radiation and RF effects. Our findings indicate that coherence effects should be observable at existing laser facilities.

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Gamma-photon generation with near-critical foam-based targets at the Apollon multi-PW laser

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Studying MeV-energy gamma photons generated during laser interaction with matter provides key insight into the underlying electron acceleration and the resulting radiation mechanisms like non-linear inverse Compton scattering (NICS) and bremsstrahlung [1-2]. These high-energy photons are also of great interest for creating efficient, bright gamma sources for strong-field quantum electrodynamics studies, electron-positron pair creation, and matter interrogation. These applications require high-flux, high-density gamma beams to trigger low-probability processes and enable measurements of material properties [3-4]. Foam-based targets are particularly well suited for this purpose because their low density allows the formation of a near-critical plasma in which laser pulses with $a0 \gg 1$ can propagate [5]. In this regime, kinetic simulations show that the laser efficiently transfers energy to a large population of electrons, leading to super-ponderomotive acceleration via direct laser acceleration [6] up to hundreds of MeV. This configuration creates favorable conditions for efficient gamma production when a solid metallic layer is placed behind the foam [7-9]. The accelerated electrons can generate gammas either by interacting with the laser field reflected from the solid foil, producing photons via NICS, or by traversing the metallic layer and emitting bremsstrahlung radiation. This contribution reports on an experimental campaign performed in April 2026 using the 3 PW laser system at Apollon [10], with targets produced by pulsed-laser deposition of carbon foam on metallic foils [11]. A double-plasma-mirror setup was used to achieve high-contrast laser pulses with $a0 \sim 50$, corresponding to peak intensities approaching 10^{22} W/cm^2. To our knowledge, these intensity levels have been applied for the first time to foam-based target interactions. The laser pulses were incident at an angle of 10° onto tailored targets in which the relative contributions of NICS and bremsstrahlung were tuned by varying the thicknesses of the carbon foam and metallic foils over the ranges of 10-60 µm and 10-260 µm, respectively. The emitted gammas were diagnosed using scintillator-based spectrometers placed at three angular positions, complemented by dosimetry measurements. By comparing experimental results with kinetic plasma simulations and Monte Carlo simulations of our setup, we show how target thickness affects radiation yield and demonstrate the possibility of creating a strong, bright gamma signal dominated by NICS with such a configuration.

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Shaping and Control of Laser-Driven Extreme Plasma Turbulence

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Abstract

In many laboratory and astrophysical scenarios, highly anisotropic distribution plasma distribution functions are generated e.g. associated with radiation reaction [1,2], shock waves or counter streaming flows. These unstable plasma conditions then naturally evolve into turbulent states with distinct electromagnetic [2] and particle acceleration signatures.

I will discuss how to generate and control bespoke plasma distribution functions in the laboratory with intense lasers, via tunnel ionization, and how these conditions allow for the detailed study and control of the magnetized turbulent plasma state. Configurations with realistic state-of-the-art laser and plasma conditions will be discussed and compared with multi-dimensional plasma simulations, exploring signatures of the temporal evolution of the system and connecting these processes with astrophysical environments.

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Measurement of the Opacity of Hydrogen at Red Dwarf Star Interior Conditions

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Abstract

Understanding radiative energy transport in stellar interiors requires reliable knowledge of the opacity of dense hydrogen plasmas, yet direct experimental data in the relevant regime have been lacking. We report measurements of hydrogen opacity at extreme conditions, reaching densities of up to ~800 times solid density and temperatures of several million kelvin, produced via a tailored low-velocity capsule implosion at the National Ignition Facility. This platform reaches thermodynamic conditions comparable to those in red dwarf stellar cores while sufficiently reducing background emission to enable time-resolved X-ray radiography. By tracking X-ray transmission during stagnation, we extract the density evolution and opacity of the transient plasma. These measurements will provide experimental constraints for opacity models relevant to both stellar interior simulations and inertial fusion energy research.

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Mechanisms at the origin of radio solar bursts by laser-plasma interaction

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Abstract

Type III solar radio bursts are phenomena produced by highly energetic electrons (1 to 100~keV) emitted during solar flares [1]. These electrons then propagate through the solar wind and excite electrostatic waves at the electron plasma frequency ω_p. Through wave coupling, these electrostatic waves in turn re-emit electromagnetic waves at the same frequency and at their harmonicsn n ωp. The analysis of these electromagnetic emissions can provide information on the acceleration and transport of energetic solar electrons, as well as on the coupling mechanisms of these waves, ultimately leading to a better understanding of the physical processes occurring in solar and stellar atmospheres.

Since 2020, experiments [2] at LULI2000 (kJ laser facility in France) have shown that laser-plasma interactions can replicate most of these processes by generating Langmuir waves via the stimulated Raman instability. This results in the generation of electromagnetic waves at ω_p and 2 ω_p, similar to the emissions observed during solar bursts.
We also report on a new experimental configuration at LULI2000 designed to approach more realistic solar conditions through the introduction of an external magnetic field representative of the solar wind environment. This configuration allows us to investigate its influence on wave polarization using a dedicated polarimetric diagnostic setup.

The Particle-In-Cell code SMILEI [3] is employed to predict the plasma dynamics, guide the experimental design, and identify the wave coupling processes responsible for electromagnetic emission at ωp and its harmonics. These simulations enable systematic parametric studies and provide direct access to electrostatic wave dynamics that are not accessible experimentally.

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Investigating the onset of carbon K-shell ionization from imploding CH capsules measured at the National Ignition Facility

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Abstract

Accurately determining the ionization state of warm dense carbon is critical for predictive modeling in high-energy-density physics, particularly for inertial confinement fusion experiments and for advancing the understanding of astrophysical systems such as white dwarf envelopes [1,2]. However, obtaining direct measurements under the relevant extreme conditions remains challenging. To address this, X-ray Thomson scattering (XRTS) provides a powerful diagnostic capable of simultaneously characterizing temperature, density, and ionization state in warm dense matter [3-6]. Here, we report the current status of analyzing XRTS spectra from imploding CH capsule experiments at the National Ignition Facility (NIF). Utilizing the capsule implosion platform in 120-degree backscatter geometry, this work enables in situ probing of the carbon K-shell ionization state and inferring prevailing plasma conditions during the dynamic implosion. In the probed regime of 0.1 to 1 Gbar in pressure and up to 100 eV in temperature, degeneracy and correlation effects play a crucial role in understanding such systems. Our results show significantly higher carbon K-shell ionization compared to state-of-the-art ionization models and simulations, further manifesting a discrepancy between experiment and theory, which is yet to be resolved.

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Thursday 17 September
LASER-BASED X-RAY SOURCES AND APPLICATIONS

Chair: **Brendan Dromey**	9:00 INVITED	**Silvia Cipiccia** (University College London) *Dark field x-ray imaging using a laser driven x-ray source*
	9:30 INVITED	**Sławomir Skruszewicz** (University of Hamburg) *Imaging and Probing Matter on Extreme Time and Length Scales Enabled by High-Harmonic Generation*
	10:00	**Luděk Vyšín** (Institute of Physics of the Czech Academy of Sciences) *Laser-plasma soft X-ray source for radiobiological applications*
	10:20	**Mojtaba Shirozhan** (ELI ALPS, The Extreme Light Infrastructure ERIC) *Light-Wave-Controlled Relativistic Electron Mirrors for Isolated Attosecond XUV Pulses*
Chair: **Jaroslav Nejdl**	11:10 INVITED	**Brendan Dromey** (Queen's University Belfast) *Optimising the efficiency of harmonic emission from relativistic laser plasmas*
	11:40 INVITED	**Dominika Mašlárová** (Chalmers University of Technology) *Bayesian optimization techniques for multiparameter optimization in attosecond science*
	12:10	**Szanna Zsíros** (ELI ALPS, The Extreme Light Infrastructure ERIC; University of Szeged) *Macroscopic peculiarities: wavelength scaling of high-harmonic generation efficiency in noble gases*
	12:30	**Jan Vábek** (FNSPE, Czech Technical University in Prague) *Modular multiscale approach to modelling HHG in gases & spectrally selective HHG scheme*
Chair: **Paolo Tomassini**	16:30 INVITED	**Song Li** (Shanghai Institute of Optics and Fine Mechanics) *Research Advances in High-Brightness Betatron Radiation and Its Applications Driven by Ultrafast Intense Lasers at SIOM*
	17:00	**Marcel Lamač** (ELI Beamlines Facility, The Extreme Light Infrastructure ERIC) *Beam-driven relativistic mirrors for extreme electromagnetic fields*
	17:20	**Michal Nevrkla** (ELI Beamlines Facility, The Extreme Light Infrastructure ERIC) *Fully Reflective High-Repetition-Rate Laser–Plasma Acceleration in Helium*
	17:40	**Prokopis Hadjisolomou** (ELI Beamlines Facility,The Extreme Light Infrastructure ERIC) *Self-organised plasma cavities for ultrabright gamma-ray generation with multipetawatt lasers*

Dark field x-ray imaging using a laser driven x-ray source

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Abstract

Betatron radiation is an x-ray source generated by high energy electrons while accelerated in high-power laser-plasma interaction. This source presents distinctive properties in terms of source size (few micron) and x-ray pulse duration (femtosecond)[1]. **The small source size** translates into a high spatial coherence which makes the source ideal for phase contrast imaging (PCI)[2]. PCI is an imaging modality where, unlike standard absorption imaging, the image formation is based on the phase delay the x-rays experience while travelling through matter due to the interaction with the atomic electron cloud. PCI is particularly suited for imaging weakly absorbing samples, where the absorption imaging would struggle to produce a detectable signal. **The ultrashort pulse duration**, other key feature of the betatron radiation, makes this x-ray source ideal for probing ultrafast dynamics requiring the high penetration power of x-rays[3].

To further expand its potential and applications, here we combine the betatron radiation with beam tracking (BT), a form of multimodal PCI[4]. BT gives access to absorption, phase and scattering information of the sample simultaneously. The scattering information, also called dark field signal, is the sensitivity to the presence of features beyond the optics resolution.

We present the first BT imaging performed at high-power laser facilities[5], describe the challenges and future possibilities toward deploying a new robust diagnostic for ultra-fast science, from magnetism to inertial confinement fusion applications.

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Imaging and Probing Matter on Extreme Time and Length Scales Enabled by High-Harmonic Generation

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Abstract

High-harmonic generation (HHG) has emerged as a cornerstone of strong-field and attosecond physics, providing compact, table-top sources of coherent extreme ultraviolet (EUV) and soft X-ray (SXR) radiation [1,2]. Building on decades of advances in ultrafast laser science, HHG marks the transition from linear optics to fully controlled strong-field light–matter interaction, enabling direct access to electronic and structural dynamics on attosecond time scales and nanometer length scales [3]. Recent progress in laser technology has transformed HHG from a laboratory curiosity into a versatile platform for EUV metrology and imaging.

We present recent results on extreme ultraviolet Fourier-transform spectroscopy (ETF), a powerful metrology tool enabling simultaneous spectral and temporal characterization of HHG pulses [4]. Beyond characterization, ETF functions as an effective autocorrelator in XUV pump–XUV probe experiments, including hybrid experiments combining HHG with free-electron lasers and achieving single-digit attosecond temporal resolution [5,6]. These capabilities establish ETF as a key enabling technology for ultrafast EUV science.

Furthermore, we report the pioneering application of extreme ultraviolet coherence tomography (XCT) for three-dimensional, non-destructive imaging of two-dimensional materials embedded in bulk media [7,8]. Using this approach, graphene flakes buried beneath up to 200 nm of silicon are imaged with depth resolution, allowing identification of mono-, bi-, and trilayer graphene and quantitative determination of overlayer thickness. Incorporation of interface-roughness models enables quantitative assessment of graphene–silicon interface quality, with results validated by atomic force microscopy [9]. This work establishes XCT as a unique EUV modality for subsurface nanoscale characterization inaccessible to conventional techniques.

Finally, we outline future prospects for HHG-based imaging and metrology, including coherent diffractive imaging (CDI) and EUV scatterometry, targeting applications in advanced lithography masks and semiconductor device characterization. By bridging ultrafast science, nanoscale imaging, and industrially relevant metrology, HHG-based EUV techniques are poised to play a transformative role in next-generation nanotechnology, materials science, and semiconductor manufacturing.

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Laser-plasma soft X-ray source for radiobiological applications

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Abstract

Compact laser–plasma soft X-ray sources operating in the water-window spectral range, developed at the Institute of Optoelectronics, provide a unique platform for radiobiological experiments under highly localized, nanosecond, ultra-high-dose-rate irradiation conditions within a laboratory-scale setup. The source is based on a debris-free gas-puff target driven by an infrared Nd:YAG laser. We present a versatile system for ultra-high-dose-rate radiobiology, demonstrating its capabilities across a range of applications, including aqueous dosimetry, DNA irradiation in both liquid and dry states, and rapid microbial spore inactivation using the same desktop source under varied irradiation conditions.

Across these applications, the source combines several attractive features: compactness, laboratory accessibility, nanosecond pulse structure, strong near-surface energy deposition in the water-window range, and dose rates spanning regimes of interest for FLASH-related research and other UHDR studies. Reported irradiation conditions include dose rates on the order of 10^6 Gy/s in aqueous environment [1], about 10^{10} Gy/s in localized DNA irradiation [2], and peak values exceeding 10^{11} Gy/s in dry spore experiments [3].

These results highlight compact laser–plasma water-window sources as versatile experimental platforms for exploring UHDR radiation action beyond conventional accelerator-based approaches. Their flexibility makes them promising tools for FLASH-oriented studies, high-dose-rate radiation chemistry, surface-confined irradiation experiments, and future preclinical applications where short-pulse, high-intensity, shallow-penetration exposure is advantageous.

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Light-Wave-Controlled Relativistic Electron Mirrors for Isolated Attosecond XUV Pulses

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Abstract

Bright isolated attosecond XUV pulses are a key target for ultrafast science, yet their generation with high brightness and controllability remains challenging. We introduce a relativistic laser–plasma route based on coherent Thomson backscattering (TBS) from a single relativistic electron sheet produced from a nanometre foil.

The central idea is to transform an ultrathin solid-density target into a waveform-programmed relativistic mirror. A two-colour intense drive pulse, composed of the fundamental frequency and its second harmonic, controls electron blowout and acceleration at the sub-cycle level, suppressing the formation of multiple sheets. A counterpropagating few-cycle source pulse then reflects from the dense relativistic sheet, undergoing strong Doppler upshift and temporal compression into an isolated attosecond XUV burst [1]. In contrast conventional Gaussian-envelope drive pulses typically produce multiple sheets, resulting in attosecond pulse trains [2].

In a virtual experiment, through more than 400, fully relativistic 1D and 2D particle-in-cell simulations, we demonstrate that the emitted pulse can be tuned by the drive-pulse energy ratio P, relative phase $\Delta\phi$, and scattering delay $\tau_{\mathrm{TBS}}(P,\Delta\phi)$ (Figure1). Systematic scans reveal how the electron-sheet density, velocity spread, and timing determine the pulse duration and peak amplitude, identifying optimal waveform–delay combinations for shortest emission.

These results show that relativistic light-wave control can turn nanometre foils into compact, tunable isolated attosecond XUV sources, opening a new path for high-brightness attosecond science.

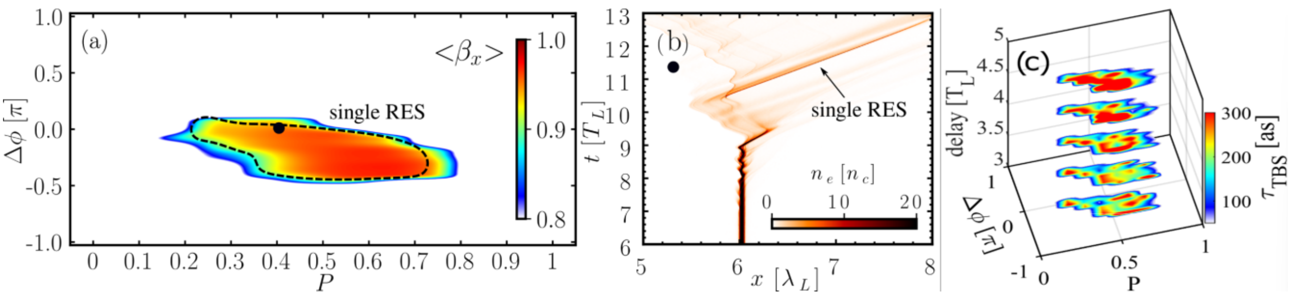

Figure1: (a) Generation of a single relativistic electron sheet using a waveform-controlled two-color drive pulse interacting with a nanometre foil. The map shows the bunch-averaged longitudinal electron velocity as a function of energy fraction P and phase delay $\Delta\phi$. (b) Space–time evolution of the electron density in the single-sheet regime for an in-phase two-color pulse with P=0.4. The relativistic electron sheet reflects and frequency-upshifts a counterpropagating source pulse, producing an isolated attosecond burst. (c) Maps of the Thomson-backscattered pulse duration $\tau_{\mathrm{TBS}}(P,\Delta\phi)$ for different source-pulse delays.

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Optimising the efficiency of harmonic emission from relativistic laser plasmas

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Abstract

Bright harmonic radiation from relativistically oscillating laser plasmas offers a direct route to generating extreme electromagnetic fields [1]. Theory shows that under optimised conditions the plasma medium can support strong spatiotemporal compression of laser energy in a Coherent Harmonic Focus (CHF) [2,3] to deliver intensity boosts many orders of magnitude above that of the incident driving laser. Although diffraction-limited performance (spatial compression) and attosecond phase-locking (temporal compression) have been demonstrated in the laboratory, efficient coupling of laser energy into the emitted harmonic cone from petawatt class interactions has not been realised to date. Here we show that the relativistic laser-plasma interaction can be tailored to deliver the maximum conversion efficiencies predicted from simulations for our experimental conditions. By fine-tuning the temporal profile of the driving laser on femtosecond timescales, we observe energies extending up to >7 mJ between the 13*th* and 47*th* harmonics (20 eV to 73 eV) [4]. These results are in excellent agreement with the theoretically expected efficiency roll-over and indicate that optimal conditions have been achieved in the generation process. This is the important third element required to achieve the expected intensity boosts from a CHF in the laboratory. Although achieving spatiotemporal compression and optimal efficiency simultaneously remains challenging, realising a CHF will open scientific discovery for technological innovation in extreme environments using existing and planned laser systems.

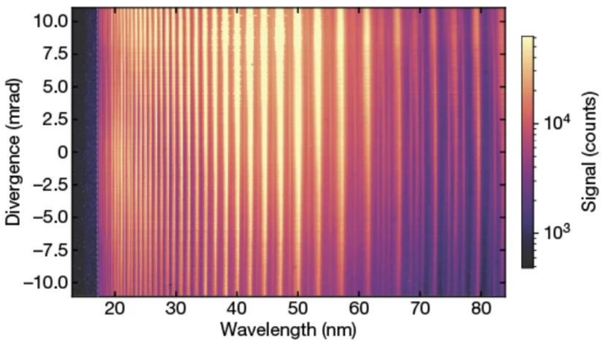

Figure 1. Optimised high-harmonic generation from a relativistically oscillating plasma surface, showing the generation of bright extreme-ultraviolet radiation using the Gemini laser at the Central Laser Facility, UK.

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Bayesian optimization techniques for multiparameter optimization in attosecond science

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Abstract

Numerical simulations are widely used to optimize radiation sources based on laser wakefield acceleration and high-harmonic generation. In both cases, the generated radiation depends on several parameters, such as plasma or gas target conditions and laser properties, making systematic parameter scans increasingly demanding as the number of parameters grows. Bayesian optimization (BO) offers an efficient approach for multiparameter studies by identifying optimal and robust operating regimes from a limited number of simulations. In this work, we present two applications of BO techniques to attosecond radiation source modelling. The first focuses on attosecond betatron radiation from laser wakefield acceleration, where batch Bayesian optimization is coupled to particle-in-cell simulations. We introduce a short region of increased density into the plasma profile and optimize its placement, length and peak density to enhance photon generation while maintaining attosecond pulse duration. By selecting multiple parameter combinations simultaneously, batch BO makes efficient use of parallel computational resources and accelerates the exploration of the parameter space. The optimization identifies configurations that increase photon generation by more than an order of magnitude compared with a reference profile without the density spike. The second application focuses on high-harmonic generation in gases, where we apply physics-informed Bayesian optimization to maximize conversion efficiency and identify experimentally robust operating conditions. These examples demonstrate the versatility of Bayesian optimization techniques for addressing distinct challenges in numerical studies of attosecond radiation generation.

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Macroscopic peculiarities: wavelength scaling of high-harmonic generation efficiency in noble gases

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Abstract

Attosecond science is a pioneering field, which provides an exceptional opportunity to study ultrafast light-matter interactions. High-harmonic generation (HHG) in noble gases has been a widely applied method for generating attosecond radiation in the extreme ultraviolet and X-ray regime [1]. Previous studies have shown that HHG efficiency scales with the driving-laser wavelength as a power law [2]; however, the effect of macroscopic processes remains ambiguous. Our aim is to revise the macroscopic scaling of HHG efficiency in noble gases to provide detailed predictions for state-of-the-art experimental setups.

We carried out macroscopic simulations [3, 4] to investigate the HHG efficiency. The simulations follow the single-atom response as well as the propagation of the calculated harmonics. We computed a grid of simulations from the visible light to the mid-infrared region using various laser pulse energies while considering typical experimental conditions. To derive the scaling relation, we considered the plateau region of the HHG spectrum in all cases. We studied the single-atom and macroscopic responses thoroughly and fitted the HHG yield to derive comprehensive conclusions on the scaling relation. Finally, we compared our results with those of previous publications [5].

Our models support the general HHG yield scaling trends for single-atom response [2], and the fitted indices are in good agreement with previous results. However, taking into account the macroscopic factors, we found that the HHG efficiency follows a slightly different trend and exhibits an upper limit as a function of wavelength. This outstanding characteristic could be explained by the effect of phase matching and critical ionization parameters. Our results help uncover the complex relation of HHG efficiency to the wavelength of the driving laser at the macroscopic level and enable further optimization of the generation conditions.

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Modular multiscale approach to modelling HHG in gases† & spectrally selective HHG scheme‡

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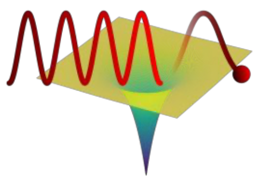
Abstract

We will present the recently released open-source MMA-HHG toolbox (mma-hhg.github.io) for modelling high-harmonic generation (HHG) in gases [1]. The package provides a common framework for coupling the microscopic response of elementary emitters to the local driving field resulting from nonlinear propagation in the macroscopic generating medium, and for coherently combining these contributions to reconstruct the macroscopic XUV field. The current public version focuses on linearly polarised driving fields and cylindrically symmetric propagation, with the aim of enabling detailed comparison with laboratory HHG experiments while preserving stand-alone use of the individual modules.



The development of this package is strongly driven by laboratory applications. One of the ongoing simulation efforts is the application on monochromatizing HHG source using Bessel-Gauss beams in density-modulated gas targets [2]. We will present the actual results of full-scale simulations of this scheme.

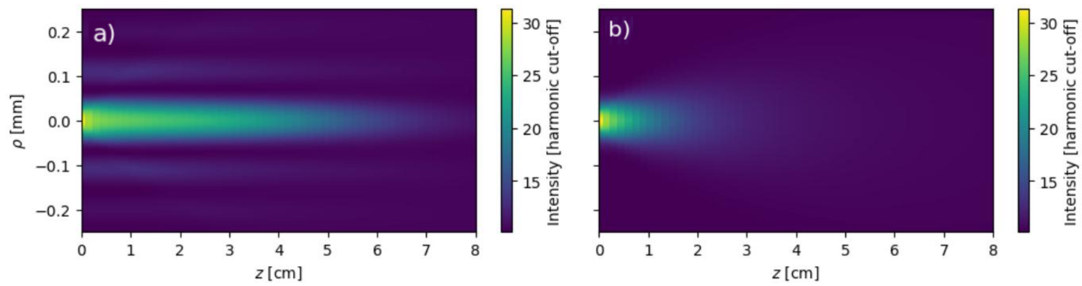


Figure 1. The peak intensity profile showing the stable propagation of Bessel-Gauss beams compared to Gaussian beams. a): the propagation of a Bessel-Gauss pulse (30 fs, waist 50 µm, Bessel-Gauss ratio 5, peak int, 25-mbar argon cell). b): Purely Gaussian beam with the same parameters. (Intensity is measured through $E_{\mathrm{cutoff}} = I_p + 3.17U_p$. ρ and z are respectively the radial and longitudinal coordinates.) See [1] for more details.

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Acknowledgements

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ECLIM 2026 38TH EUROPEAN CONFERENCE ON LASER INTERACTION WITH MATTER

Research Advances in High-Brightness Betatron Radiation and Its Applications Driven by Ultrafast Intense Lasers at SIOM

Song Li, Hong Zhang, Gaojie Zeng, Ke Feng, and Wentao Wang

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Abstract

With the ongoing miniaturization and stabilization of laser wakefield accelerators (LWFA), tabletop X-ray sources based on such accelerators have shown great potential. Among them, Betatron radiation sources driven by ultrafast, high-intensity lasers feature micrometer-scale source size, femtosecond pulse duration, milliradian-scale divergence, and broadband spectra extending to tens of keV. These characteristics make them highly suitable for high-contrast imaging of microstructures, diagnostics of high-energy-density states in inertial confinement fusion (ICF), and ultrafast dynamic studies in multidisciplinary research. This presentation will showcase the recent development of high-brightness Betatron X-ray source platforms (see Figure 1) at the Shanghai Institute of Optics and Fine Mechanics (SIOM), Chinese Academy of Sciences (CAS). In particular, we report on Betatron X-ray sources [1,2] driven by two high-power laser systems—a 1 PW/0.1Hz laser system at Shanghai Superintense Ultrafast Laser Facility (SULF) and a 200 TW/1 Hz laser—achieving critical energies in the range of 10–86 keV and photon yields exceeding 10^{10} photons per shot [3]. We further demonstrate their applications in X-ray phase-contrast imaging [4].

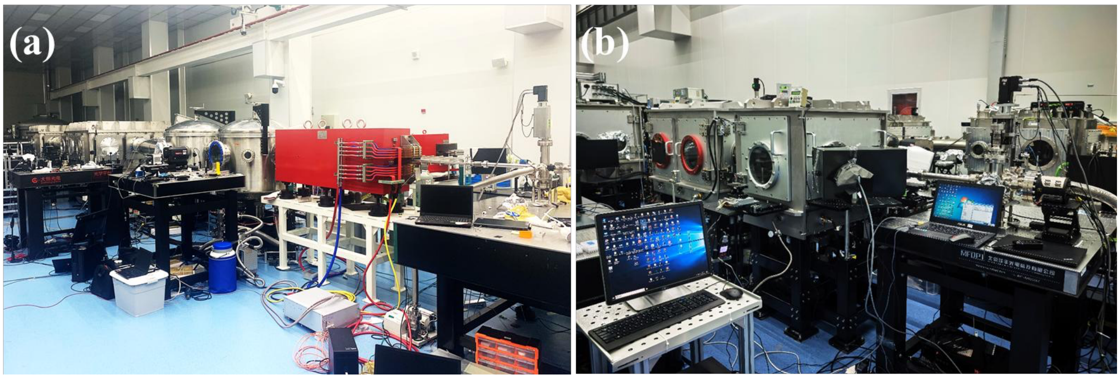

Figure 1. Platform of Betatron X-ray sources driven by (a) SULF-1PW/0.1Hz and (b) 200TW/1Hz laser system.

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Acknowledgements

This work was supported by the National Key R&D Program of China (Grant No. 2025YFF0515000), the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDB0890200), the National Natural Science Foundation of China (Grant Nos. 12388102, 12225411 and 12474349), CAS Project for Young Scientists in Basic Research (Grant No. YSBR060), CAS Youth Innovation Promotion Association (No. 2022242), and the New Cornerstone Science Foundation through the XPLORER PRIZE.

Beam-driven relativistic mirrors for extreme electromagnetic fields

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Relativistic plasma mirrors [1-6], driven by ultra-intense laser pulses [1,2,5] or high-energy charged particle beams [3,4], have emerged as a promising tool for generating extreme electromagnetic fields [2] and compact coherent sources of high-energy photons [3]. By exploiting the double Doppler upshift [6], these mirrors can produce intensities far beyond current laser technology limits [2], opening new avenues for experimental study of strong-field quantum electrodynamics (SF-QED) [2,5]. Here, we present our recent work on relativistic plasma mirrors [3,4], showing generation of coherent X-ray attosecond pulses and laser intensification by two orders of magnitude from flat relativistic mirrors, driven by electron or proton particle beams.

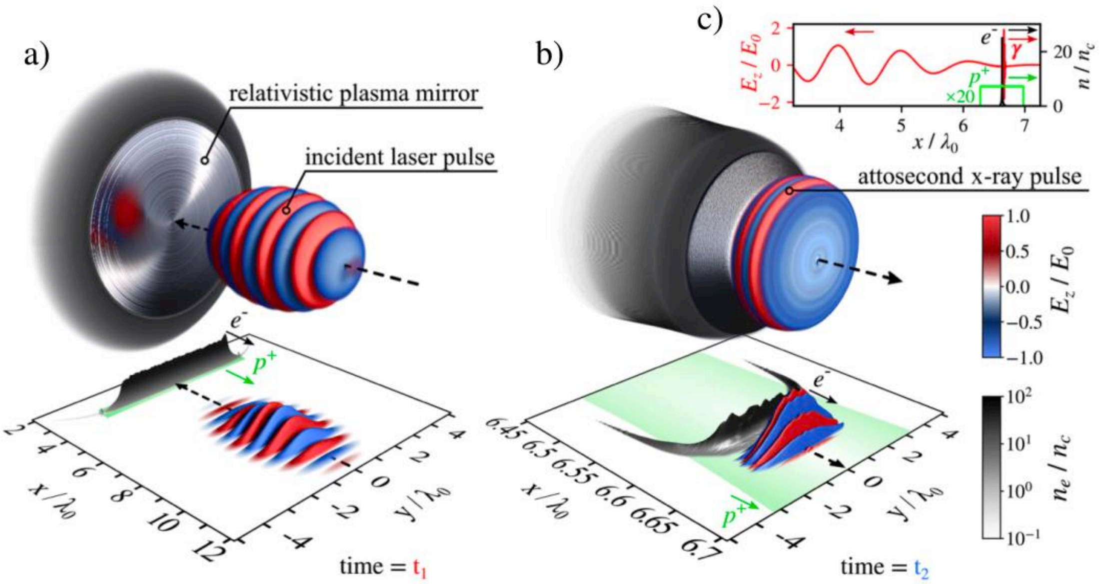

Figure 1. PIC simulation results. (a) A nonlinear electron plasma wave, which acts as a relativistic mirror, is driven by a proton beam with Lorentz factor $\gamma = 5$ propagating in underdense plasma. The figure shows a 3D distribution of the electric field component E_z (colored, saturated) of the laser pulse and the plasma electron density n_e (gray scale). The overdense electron density ($n_e > n_c$) is indicated with a reflective surface. (b) After the reflection, the laser is compressed (note the change in x-axis scale) due to the double Doppler effect. The wavelength of the laser pulse is shifted from $\lambda_0 = 0.8$ µm to $\lambda_r \approx 8$ nm, the pulse is compressed from $\tau_0 \approx 4$ fs down to $\tau_r \approx 40$ attoseconds, and the electric field amplitude is increased to $E_r / E_0 \approx 1.9$, following the predictions given by Ref. [3]. A slice through the plane z = 0 is shown at the bottom. The dashed arrows indicate the direction of radiation propagation. The dashed line corresponds to a lineout shown in panel (c), which also shows the transmitted portion of the incident laser pulse. Reproduced from [3] under CC-BY 4.0 license.

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Fully Reflective High-Repetition-Rate Laser–Plasma Acceleration in Helium

Michal Nevrkla[1,2], Jiří Šíšma[1], Filip Vitha[1,2], Sebastian Lorenz[1], Illia Zymak[1], Alžběta Špádová[1,2], Andrea Kollárová[1,2], Matěj Jech[1,3], Carlo M. Lazzarini[1], Leonardo V. N. Goncalves[1], Gabriele M. Grittani[1], Sergei V. Bulanov[1], Jaron E. Shrock[4], Ela Rockafellow[4], Ari J. Sloss[4], Bo Miao[4], Scott W. Hancock[4], Howard M. Milchberg[4,5]

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Abstract

We present the development and experimental validation of a fully reflective, high-repetition-rate laser–plasma accelerator operating in helium. The experiment was performed on the ELBA beamline at ELI Beamlines using the L3-HAPLS Ti:sapphire laser (430 TW at 0.2 Hz and 260 TW at 3.3 Hz). A self-waveguiding scheme (Feder et al., 2020) was implemented in plasma targets up to 20 cm in length using a pseudo-Bessel channel-forming beam (1 J) derived from the main pulse via post-compressor splitting and shaped by an off-axis reflective axicon. This all-reflective approach eliminates transmissive optics, minimizing thermal effects and pulse elongation.

Stable optical guiding of > 400 TW, 30 fs pulses was achieved over a 20 cm helium plasma channel at 0.2 Hz and over a 3 cm channel at 3.3 Hz, demonstrating robust operation at high average power without thermal degradation. In a 20 cm nitrogen-doped helium channel, electron beams with mean energies of approximately 3.5 GeV and peak energies approaching 5 GeV were generated while maintaining pointing stability better than 5 mrad.

Quasi-monoenergetic electron bunches were produced using nanoparticle injection and localized ionization injection in a perturbed plasma channel. This resulted in~100 pC, 1 GeV beams via nanoparticle injection and~3 GeV quasi- monochromatic beams in perturbed plasma channel. This compact, single-laser, single-compressor self-waveguiding implementation stabilizes electron pointing and enhances energy gain without requiring modifications to the laser system, supporting scalable operation at user facilities.

Reference: L. Feder, B. Miao, J. E. Shrock, A. Goffin, H. M. Milchberg, Phys. Rev. Res. 2, 043173 (2020).

Self-organised plasma cavities for ultrabright gamma-ray generation with multipetawatt lasers

P. Hadjisolomou[1], R. Shaisultanov[1], T. M Jeong[1], C. P. Ridgers[2] and S. V. Bulanov[1]

[1] ELI Beamlines Facility, Extreme Light Infrastructure ERIC, Za Radnici 835, 25241 Dolni Brezany, Czech Republic
[2] York Plasma Institute, Department of Physics, University of York, Heslington, York, North Yorkshire YO10 5DD, UK

Abstract

Ultra-intense laser–plasma interactions provide an efficient route for converting laser energy into high-energy photons through radiation-reaction-dominated electron dynamics in the strong-field regime [1,2]. Three-dimensional particle-in-cell simulations have demonstrated that ultrashort Ti:sapphire laser pulses interacting with tailored solid-density targets can produce pre-formed cavities due to finite-contrast laser pedestals, significantly enhancing the local laser field and enabling efficient gamma-ray flash generation [3]. In this ultrashort-pulse regime, cavity-induced field amplification leads to strong radiation losses and high photon yield despite the limited interaction time.

Extending this concept, we demonstrate that cavity-enhanced gamma-ray generation is not limited to ultrashort pulses or pre-tailored targets. Using three-dimensional particle-in-cell simulations including quantum electrodynamics effects, long-duration, kilojoule-class Nd:glass laser pulses interacting with near-critical-density plasmas are shown to self-organise into stable, electron-depleted cavities via relativistic self-focusing [4]. The resulting field amplification exceeds an order of magnitude relative to the vacuum value, driving the interaction into a radiation-reaction-dominated regime at substantially lower initial intensity than typically required. Peak gamma-ray emission is obtained for electron densities close to half the relativistic critical density, where more than 20% of the laser energy is converted into high-energy photons with spectra extending to hundreds of MeV. The extended pulse duration sustains self-focusing, leading to an order-of-magnitude increase in photon number compared with shorter-pulse systems of equal peak power.

In both pulse-duration regimes, hosing instability and current filamentation influence cavity evolution and imprint characteristic signatures on the angular and spectral photon distributions. These findings establish self-organised cavity formation as a unifying and scalable mechanism for ultrabright gamma-ray generation, well suited to near-term multipetawatt laser facilities and photonuclear applications.

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Friday 18 September
HIGH-INTENSITY LASER FACILITIES

Chair: **Sushil Singh**

9:00 INVITED	**Bedřich Rus** (ELI Beamlines Facility, The Extreme Light Infrastructure ERIC) *High-repetition PW-class and multi-PW kJ laser systems at ELI Beamlines*
9:30	**Xiaowei Chen** (Amplitude) *Ultrahigh Temporal Contrast OPCPA Front-end for Petawatt Lasers*
9:55	**Lorenzo Giuffrida** (ELI Beamlines Facility, The Extreme Light Infrastructure ERIC) *The ELIMAIA/ELIMED ion beamline at ELI Beamlines: from laser-driven source optimization to user-oriented applications*
10:15	**Sadaoki Kojima** (Kansai Institute for Photon Science, QST) *High-Repetition Laser-Driven Heavy Ion Bunches for the Quantum Scalpel Injector*

LASER AND PLASMA DIAGNOSTICS

Chair: **Libor Juha**

11:05	**Šimon Jelínek** (Institute of Plasma Physics of the Czech Academy of Sciences) *Reaching reproducible relativistic interaction conditions with sub-ns laser pulses at the PALS facility*
11:25	**Josef Krása** (Institute of Physics of the Czech Academy of Sciences) *Characterization of ion emissions from plasmas produced by femto- and nano-second pulses of short-wavelength laser radiation: a brief overview*
11:45	**Jakub Cikhardt** (Czech Technical University in Prague) *Generation of electromagnetic pulses driven by kilojoule laser facility PALS*
12:05	**Lucie Jurkovičová** (ELI Beamlines Facility, Extreme Light Infrastructure ERIC) *THz generation in high-intensity laser plasma as an in-situ probe of ultrafast ionization*
12:25	**Benoist Grau** (University of Rome "Tor-Vergata" / ENEA) *Electro-Optical probing for Electromagnetic pulses emitted in a high-intensity laser facility*

High-repetition PW-class and multi-PW kJ laser systems at ELI Beamlines

B. Rus[1], P. Szotkowski[1], J. Novák[1], L. Jarboe[1], T. Spinka[2], E. Link[2], L. Kiani[2], P. Trojek[1], Š. Vyhlídka[1], L. Haizer[1], D. Snopek[1], P. Brabenec[1], J. Freisleben[1], J. Černý[1], J. Hubáček[1], V. Pandey[1], D. Kramer[1], P. Bakule[1], D. Margarone[1]

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Abstract

We will present the current performance of the laser systems L3-HAPLS and L4-ATON of ELI Beamlines and will review their operation record in user experiments. The L3-HAPLS is a high-repetition PW system employing laser-diode pumping in all its amplification stages. At present phase of experimental campaigns in the first half of 2026, it provides compressed pulses with energy up to 20 J and a duration of 29 fs, corresponding to peak power of 0.7 PW. Implementation of improvements and modifications are in progress to achieve 1 PW peak power at 3.3 Hz and ultimately 10 Hz. The system provides excellent beam quality, temporal contrast, pointing stability, and operational reliability. The implementation of rapid beam switching between experimental halls and the ability to sustain extended user campaigns allows several experiments to be performed in parallel, maximizing the L3-HAPLS utilization and facility scientific output.

The L4-ATON laser can generate >1.5 kJ either in narrowband pulses at 1053 nm, with duration variable from 0.5 to 10 ns and with adjustable temporal profile, or in CPA (chirped pulse amplification) broadband pulses with a spectral bandwidth of >15 nm and centered around 1060 nm. The laser can fire a high-energy shot per minute thanks to active liquid cooling of the output Nd:glass amplifiers. The nanosecond narrowband kJ pulse capability is routinely provided to users for experiments in high energy density (HED) studies, laser-produced plasma physics, and inertial fusion energy (IFE). To generate kJ short pulses in the CPA broadband mode, the large-beam-aperture grating compressor is being commissioned. We will present results from the first phase of the commissioning, in which pulses with energy up to 786 J and duration 154 fs, were generated, corresponding to a peak power of 5.1 PW. Halfway to the full design power of 10 PW, this performance represents the most energetic multi-PW ultrafast pulses ever achieved.

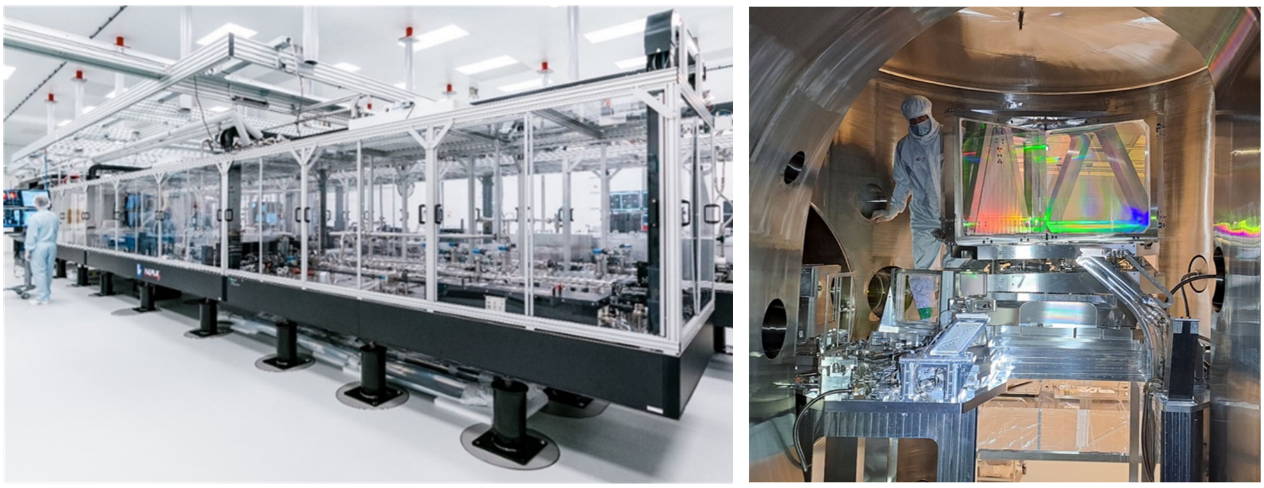

Figure 1. High-repetition rate Petawatt laser system L3-HAPLS (left); interior of the L4 10PW pulse vacuum compressor with the large 1-m aperture grating - phased mirror assembly.

Note: The talk cannot be presented by the originally scheduled speaker. The main results will be summarized in the following presentation by Xiaowei Chen, which has been extended by 5 minutes.

1.4 TW sub-2-cycle pulses from a double-stage multi-pass cell compression of a kHz Yb-based laser

Victor Koltalo[1, *], Jaismeen Kaur[1], Louis Daniault[1], Mickaël Allemand[3], Florent Pallas[3], Antoine Courjaud[3], Emilien Gontier[3], Cédric Sire[2], François Sylla[2], Rodrigo Lopez-Martens[1]

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Abstract

Staged post-compression of Yb-based laser pulses in multi-pass cells (MPC) [1] was first introduced by Balla et al. [2] and further developed by Rajhans et al. [3] to reach the few-cycle regime with multi-mJ energy, and more recently used to generate multi-mJ, sub-2-cycle pulses at 400 W average power [4]. Compressing higher-energy pulses down to few-cycle duration is challenging, as large nonlinear phase accumulation can degrade the spatiotemporal pulse properties and limit compressibility. In this work, 18 mJ, 400 fs pulses from a kHz Yb-based laser (MAGMA from Amplitude) were post-compressed in a double-stage MPC architecture (Fig. 1, left) down to 12 mJ, 5 fs, with an overall efficiency of 67%. MPC staging provides a promising scalable route toward multi-TW few-cycle laser drivers for high-field applications.

The first MPC stage is implemented in a Herriott-type configuration with a length of 4 m, providing 29 passes on dielectric mirrors in a chamber filled with 140 mbar of argon. The 16 mJ output pulses are compressed down to 23 fs (FTL ~ 21 fs) using chirped mirrors (GDD -1800 fs^2). The second stage consists of a sequence of silver mirrors spaced over a 10 m interaction length inside a chamber filled with 400 mbar of Helium. The 12 mJ energy output pulses exiting the chamber are immediately sampled with a wedge and recompressed at low power in air using chirped (GDD -120 fs^2) and measured using single-shot SHG-FROG (Femtoeasy). The compressed sampled pulse duration is measured to be 5.0 fs (FTL ~4.7 fs) shown in Fig. 1(center). Based on the retrieved temporal profile, this would correspond to a peak power of 1.4 TW for pulses compressed at full power. The measured and retrieved spectra (Fig.1, right) are in good overall agreement. A residual spectral feature around 1030 nm is observed, which is attributed to uncompressed higher-order spectral phase components of the input pulse.

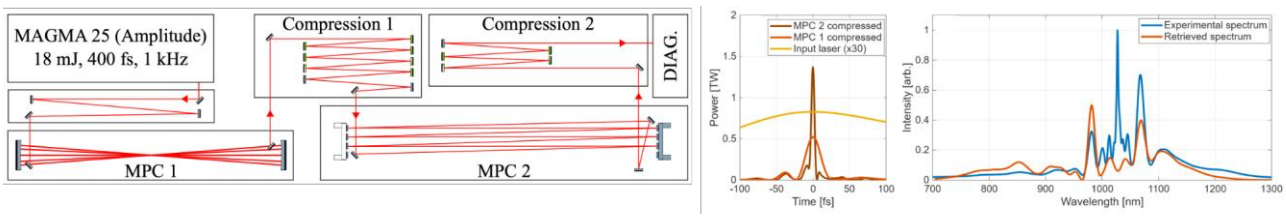

Figure 1: (Left) Experimental setup. MPC 1 is under 140 mbar of argon. Compression 1 and MPC 2 are under 400 mbar of helium. Compression 2 is performed in air at a reduced power. (Center) Compressed temporal pulse profiles of the input laser (x30), after MPC 1 and after MPC 2. (Right) Measured and FROG-retrieved spectra after MPC 2.

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Acknowledgements

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ECLIM 2026 | 38TH EUROPEAN CONFERENCE ON LASER INTERACTION WITH MATTER

Ultrahigh Temporal Contrast OPCPA Front-end for Petawatt Lasers

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Abstract

Modern high-peak-power, petawatt-class laser systems demand high temporal contrast for applications like solid high-harmonic generation and particle acceleration. Here, we report the initial performance results of the next-generation OPCPA frontend developed for the Ti:Sa-based HF-PW laser system at ELI ALPS [1].

The mJ-class frontend, centered at 800 nm, integrates a Satsuma HP2 industrial laser (pump 1), a customized Magma 5 amplifier (pump 2), and an OPCPA module, all developed by Amplitude [2]. The frontend delivers 0.62 mJ pulses at a 100 Hz repetition rate, with a spectral bandwidth capable of supporting sub-15 fs durations. Long-term performance is highly robust, with a measured single-shot energy stability of <0.4% RMS over a 24-hour period. Pulse re-compression is achieved using chirped mirrors providing a total group delay dispersion of -1600 fs², leaving high-order dispersion uncompensated. Temporal characterization via a D-cycle XR device yields a compressed pulse duration of 15.5 fs. The temporal contrast is measured by a custom Sequoia HD (Amplitude) third-order cross-correlator. The pre-pulse contrast reaches the noise floor of the measurement at an intensity ratio of 3×10^{-15} relative to the main peak. Achieving this extreme dynamic range requires routing 600 µJ of the available pulse energy directly into the cross-correlator. Finally, this mJ-class OPCPA frontend has now been fully integrated into the main PW laser system, successfully elevating the system's ASE contrast from an original baseline of 10^{11} to nearly 10^{14} at the PW level.

Figure 1. OPCPA frontend laser for TW/PW lasers

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The ELIMAIA/ELIMED ion beamline at ELI Beamlines: from laser-driven source optimization to user-oriented applications

L. Giuffrida[1], F. Grepl[1], F. Schillaci[1], P. Blaha[1],T. Chagovets[1], V. Kantarelou[1], N. Gamaiunova[1], M. Greplova Zakova[1], H. Lefebvre[1], J. Novak[1], P. Szotkowski[1], M. Tryus[1], A. Velyhan[1], G.A.P. Cirrone[3], B. Rus[1], and D. Margarone[1]

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Abstract

The ELIMAIA/ELIMED beamline at the ELI Beamlines user facility provides a comprehensive platform for the generation, transport, and application of laser-driven ion beams. ELIMAIA (ELI Multidisciplinary Applications of Ion Acceleration) is dedicated to the production and characterization of ions accelerated via ultra-intense laser–matter interactions, while ELIMED, developed in collaboration with INFN-LNS, enables energy selection, beam transport, and precise dosimetric delivery to user experiments, including in-air irradiation.

In this contribution, we report on the recent performance achievements of the ELIMAIA ion accelerator driven by the L3-HAPLS laser system, with particular focus on the optimization of laser–plasma interaction conditions and the resulting ion beam properties. Through systematic improvements of the laser temporal contrast and focal spot quality, proton energies up to ~40 MeV have been achieved in the Target Normal Sheath Acceleration (TNSA) regime. Stable operation at repetition rates up to 0.5 Hz has been demonstrated, supported by automated target delivery and a comprehensive suite of online diagnostics, including time-of-flight detectors, Thomson parabola spectrometers, and X-ray monitoring systems.

A key result is the statistically validated shot-to-shot stability of the proton beam, with fluctuations at the ~10% level in both energy and flux over extended sequences of consecutive shots. This level of reproducibility enables operation in a “physics with error bars” regime, representing a crucial milestone toward the use of laser-driven ion sources for user-oriented experiments.

The integration with the ELIMED beamline, providing controlled beam transport, energy selection, and dosimetry, together with in-air irradiation capabilities, establishes ELIMAIA/ELIMED as a mature and versatile infrastructure for multidisciplinary applications, including radiobiology, materials science, and cultural heritage. These results mark a significant step toward the routine use of laser-driven ion beams in applied research.

ECLIM 2026 | 38TH EUROPEAN CONFERENCE ON LASER INTERACTION WITH MATTER

High-Repetition Laser-Driven Heavy Ion Bunches for the Quantum Scalpel Injector

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Abstract

Laser-driven ion acceleration is a promising route to compact next-generation accelerators because it can provide extremely high accelerating fields and ultrashort ion bunches. We report key developments toward a high-repetition laser-driven carbon-ion injector for the Quantum Scalpel, a compact heavy-ion therapy accelerator concept combining a laser-driven injector with a superconducting synchrotron.

A major challenge in laser-driven carbon-ion acceleration is the stable supply of clean targets at high repetition rate. Surface contamination layers, mainly consisting of water vapor and hydrocarbons, often lead to dominant proton acceleration instead of carbon-ion acceleration. To address this issue, we developed a tape-target delivery system combined with contactless induction heating. The target surface was heated above 200 °C within 50 ms, enabling rapid removal of surface contamination before laser irradiation. By separating the heating and irradiation sections and applying sufficient tape tension, the target position fluctuation at the irradiation point was suppressed within +/-35 um, allowing stable 10 Hz operation and reproducible carbon-ion bunch generation.

For long-term operation, we also developed a vacuum-replaceable debris shield based on roll-type ultra-thin glass. The shield protects the final focusing optics from target debris while maintaining high optical quality. Optical tests showed that diffraction-limited focusing was preserved after transmission through the ultra-thin glass, and high-power laser experiments confirmed that ion acceleration performance was not degraded by inserting the shield. These developments provide a practical technological basis for compact, reliable, and clinically oriented laser-driven heavy-ion accelerator systems.

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Reaching reproducible relativistic interaction conditions with sub-ns laser pulses at the PALS facility

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Abstract

Achieving reproducible laser-matter interactions at high-power laser facilities can be a challenging task for experimentalists. Recently, it was demonstrated that 300-ps-long (FWHM) laser pulses at the Prague Asterix Laser System (PALS) can reach peak intensities up to 8×10^{18} W/cm^2 on target [1]. Furthermore, 43% of the 700-J pulse energy corresponds to intensities exceeding the relativistic intensity threshold of 0.8×10^{18} W/cm^2 at a wavelength of 1315.2 nm. While phenomena indicating relativistic interaction conditions had been observed at PALS, their shot-to-shot reproducibility was limited. It became clear from the focus characterization that the 5-µm focal spot (FWHM) imposed strict limits on target placement precision. To improve the target positioning reproducibility to ±5 µm, we developed a target alignment setup utilizing a laser distance sensor. This setup was validated during a laser–matter interaction experiment employing various diagnostics.

Laser-generated plasma jets from tantalum targets were observed via three-frame complex interferometry measurements of the electron density. Additionally, interaction with 10-µm-thick copper targets generated backward-emitted hot electrons with temperatures T_{HE} between 800 keV and 2000 keV and backward-emitted protons with maximum energies E_p ranging from 3.9 MeV to 4.5 MeV. We performed empirical scaling together with results ($T_{HE} \approx 40$ keV, $E_p \approx 1$ MeV) previously acquired using a random phase plate generating a 95-µm focal spot (FWHM) [2]. In summary, the target alignment setup with the laser distance sensor improved the short-term (1 day, 8-16 shots) reproducibility of relativistic interaction conditions at PALS utilizing the 5-µm focal spot.

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Characterization of ion emissions from plasmas produced by femto- and nano-second pulses of short-wavelength laser radiation: a brief overview

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Abstract

Here we focus on experiments in which time-of-flight (TOF) measurements are performed with charged particles produced by short-wavelength laser pulses of a duration ranging from tens of femtoseconds to tens of nanoseconds. A complete characterization of the ion source is essential both for its application and for a deep understanding of the fundamental physical processes that govern the laser-plasma interaction and ion acceleration. Two key plasma parameters that can be extracted from time-resolved ion currents, i.e. TOF spectra, are the ion temperature kT_i and the ion kinetic energy, E_{CM}, associated with the center-of-mass motion, which is caused by internal forces acting in the plasma [1]. To achieve this goal, a specific experimental procedure was applied consisting of a series of laser radiation interactions with targets at various intensities ranging from 10^9–10^{18} W·cm^{-2} μm^2. Recorded ion currents were processed using a detector signal function derived from a shifted Maxwell-Boltzmann velocity distribution $f(\vec{v} - \vec{u}_{CM})$, where $\vec{u}_{CM}$ is the center-of-mass velocity. Finally, the measured ion current is the sum of partial currents of all ionized species, i, with a charge-state, q: $j(t) = \Sigma\, j_{i,q}(t)$. Then, number of ions contained in the corresponding partial currents, their $\vec{u}_{CM}$ velocities, and temperatures can be obtained from $j_{i,q}(t)$. This method made possible the determination of hydrodynamic and electrostatic forces affecting the center-of-mass velocity, as demonstrated using a 23ns KrF excimer laser [2]. Extreme cases where only thermal ions [1] are generated, i.e. with $\vec{u}_{CM} = 0$, or ion beams [3] with $T_i \approx 0$, have been identified in experiments with femtosecond X-ray free-electron lasers such as FLASH2 operated at a wavelength of 13.5 nm (91.8 eV photon energy) and European XFEL operated at photon energies of 9300 eV (0.13 nm wavelength), respectively. The last of these reveals cascade ion emission, where ions are accelerated by a gradually decreasing voltage arising in the double layer.

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Generation of electromagnetic pulses driven by laser driven by kilojoule laser facility PALS

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Abstract

The interaction of focused high-power laser with matter generates intense electromagnetic pulses (EMPs) spanning the radiofrequency and microwave ranges. While such EMPs can interfere with electrical signals and damage sensitive electronics, necessitating effective mitigation strategies, they also represent a powerful broadband source with promising applications in electromagnetic compatibility hardening, biology, and defense. Efficient control of laser-driven EMPs requires a detailed understanding of physical mechanisms of its emission.

We present systematic experimental studies of EMP generation performed at the kilojoule-class PALS laser facility (λ_1 = 1315 nm, pulse duration 0.2 - 0.4 ns). The experiments reveal clear dependencies of EMP intensity, spectral shape, and bandwidth on laser power, focus conditions, and target properties. EMP emission was characterized using a comprehensive set of diagnostics, including D-dot and B-dot probes (single and array configurations), target current probes, biconical and horn antennas, and additional dedicated detectors. Signals were recorded with high-performance oscilloscopes offering up to 20 GHz analog bandwidth and 100 GS/s sampling rates, employing ultra-low-loss cabling optimized for multi-GHz measurements.

For shots delivering up to ~600 J on target and achieving a minimum effective focal area of ~30 μm^2, EMP spectra exhibited frequency components exceeding 18 GHz, while compensating target return currents reached peak values of up to 10 kA. In this contribution, we summarize our most recent results, correlate EMP measurements with complementary plasma diagnostics, and discuss the physical mechanisms responsible for EMP generation in high-energy laser-plasma interactions.

THz generation in high-intensity laser plasma as an in-situ probe of ultrafast ionization

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Abstract

Ionization is one of the most crucial yet not fully understood processes in laser-matter interaction. This is particularly true in high-intensity regimes involving higher ionization states, where current numerical models often struggle [1]. One of the key processes relying heavily on ionization is THz generation in laser plasma - a versatile method for producing THz radiation with femtosecond pulse durations and bandwidths spanning hundreds of THz [2]. Recent advances in laser technology and a deeper understanding of the underlying mechanisms have significantly expanded the applicability of this source [3]. However, a comprehensive insight into the complex nature of the generation process in the high-intensity regime has remained elusive.

Here, we present an improved photocurrent model for THz generation in laser plasma by multiple ionization states of the medium benchmarked by experimental results from high-intensity two-color laser gas interaction. The model reveals the origins of observed THz radiation features in the overionized regime, regarding both conversion efficiency and spectral domain [4]. By applying the model reciprocally, we identify the key driving parameters of THz generation, such as the time-dependent ionization rate within the driving laser field's temporal profile. Ultimately, we demonstrate that the properties of the generated THz radiation can be used as an in-situ probe of ionization, serving as a valuable tool for further understanding ionization mechanisms induced by intense laser pulses and verifying the ionization rate models.

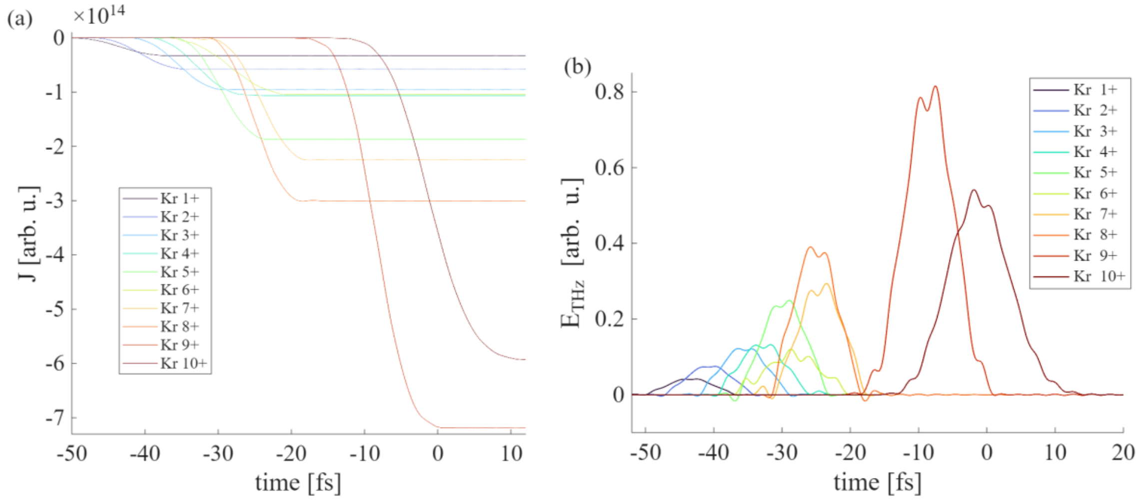

Figure 1. (a) Temporal dependence of the current density contributions from different krypton ionization states at a laser intensity of 2.2×10^{17}W/cm^2 (b) Temporal dependence of the corresponding THz field emissions.

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Electro-Optical probing for Electromagnetic pulses emitted in a high-intensity laser facility

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Abstract

During the interaction of a high-intensity laser pulses with matter, strong electromagnetic pulses (EMPs) are produced. These EMPs propagating into the surrounding space from the interaction point, are capable to reach a peak amplitude on the order of MV/m (from MHz to THz) even at large distances from the source. These radiations can be harmful to the diagnostic and spoil the measurements of many detectors used, as the EMPs can influence the entire acquisition system. It has therefore been a primary concern, for several years, within the laser–plasma scientific community to investigate these electromagnetic pulses.

Due to the environment created by the interaction between a high-intensity laser and matter, the use of robust antennas is mandatory. The D-DOT antenna, measuring the time-derivative of the Electric field was then considered. However, due to its conductive structure, the probe can easily interact with the various radiation or particles emitted, potentially spoiling the measurements. Probes exploiting the Electro-Optical effect [1] have the advantage of directly providing the measured electric field and are much less sensitive to spurious radiation. They are then more suitable for being placed directly inside the experimental chamber where the laser-matter interaction occurs. EMP detection by conductive probes is definitely not a trivial issue under these very harsh conditions [2,3]

In this work, we present an analysis of experimental data acquired with a novel and low-noise version of the EOPs at PALS (Prague Asterix Laser System, capable of producing pulses of 600 J in 350 ps) with improved shielding, and of the comparison of these data with those from conductive probes used at different positions, providing a characterization of the emitted EMPs, both in time and frequency domain. The novel probes provided improved signal-to-noise ratio compared to signals obtained on the previous version of the same type of probe, in experiments performed at Vulkan Petawat Laser (2022). The resulting analysis will include also results of particle-in-cell simulations, reproducing numerically the conditions of the experiments.

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