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Charged particles transport in a discrete wave spectra : when is quasilinear theory valid ?

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Abstract

We address the motion of charged particles subjected to a discrete spectrum of electrostatic waves. We focus on situations when transport dominates, leading to significant variations in particle velocity. Nonetheless, these velocity changes remain finite due to the presence of Kolmogorov-Arnold-Moser (KAM) tori bounding phase space. We analyze the conditions under which transport can be modeled as a diffusion process and evaluate the relevance of the so-called quasilinear value of the diffusion coefficient. We distinguish between traditional quasilinear diffusion, when wave–particle interaction is perturbative, and the so-called chaotic regime of diffusion, when the particle motion looks erratic. In the perturbative regime, we demonstrate both numerically and theoretically that diffusion occurs only when wave–particle interaction is local in phase velocity; that is, when wave contributions from phase velocities far from the particles' instantaneous velocities are negligible. Conversely, numerical results indicate that chaotic diffusion can occur even when wave–particle interaction is not local. However, without locality, the diffusion coefficient is not the quasilinear one. Furthermore, in regimes when quasilinear diffusion is applicable, we introduce a simple analytical expression for the time evolution of the velocity distribution function that accounts for phase space boundaries.

Study of proton stopping power in warm dense matter using low-density Foams at the XGIII laser facility

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Abstract

Stopping power is defined as the differential energy loss per unit path length of a charged particle traversing matter. The study of proton stopping power produced using lasers[1] is a central topic in warm dense matter (WDM), inertial confinement fusion (ICF), and laboratory astrophysics. In the WDM regime, there are not much experimental data validating the theoretical models, which sensibly differ from each other in the region of the Bragg peak of protons. We performed an experiment at the XG-III[2] Laser Facility in Mianyang (China) using MeV proton beams generated by the interaction of short-pulse, high-intensity lasers with solid targets via Target Normal Sheath Acceleration (TNSA). This produced a population of protons with energies extending to 12 MeV and an approximately exponential energy distribution. An energy selector placed after the TNSA target allowed selecting a narrow energy spectrum (2-5 MeV). These protons were then crossing a foam target before reaching a Thomson Parabola spectrometer, where their residual energy was measured. At the same time, a synchronized nanosecond beam was used to create controlled plasma conditions in the foam target, a 3D-printed low-density plastic foam (CHNO 89 mg/cc) consisting in a cube of size 1 mm covered on one side by an Al foil. The longer pulse duration focused on the Al ablator/pusher allowed to create a strong shock in the foam, ensuring volumetric heating and the formation of an extended plasma with relatively smooth density gradients as compared to what could be achievable with solid-density targets. The foam density was chosen so that, upon heating, the plasma reached conditions characteristic of the warm dense matter regime, with electron densities approaching 10^{21}–10^{22} cm^{-3} and temperatures in the range of several eV, i.e. a strongly coupled and partially degenerate plasma. The shock breakout time at the rear of the foam target was measured using an SOP diagnostic, allowing to fix the delay between the nanosecond heating pulse and the ps proton-generating pulse, which can be precisely controlled, allowing the proton beam to probe the plasma at selected stages of its hydrodynamic evolution. In this preliminary experiment, however, we just limited ourselves to measure the stopping power in the cold plastic foam. In conclusion, the combination of ps TNSA proton generation and nanosecond-driven foam plasma production can enable a controlled study of proton stopping power in warm dense matter conditions. These results contribute to the broader understanding of ion transport in matter in extreme conditions and provide experimental constraints for advanced stopping power theories relevant to fusion and astrophysical plasma's.

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Comparison of Eulerian and ALE frameworks for modeling laser-plasma interactions

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Abstract

Hydrodynamic simulations are essential for modeling laser-plasma interactions and interpreting experimental observations. Eulerian methods employ a static computational mesh, with FLASH [1] being one of the most widely used Eulerian hydrodynamic codes for high-energy-density plasma simulations. Eulerian methods are considered simpler and more robust; however, the simulation domain and mesh resolution need to be defined a priori. This often leads to under-resolved simulations and excessive numerical diffusion.
On the other hand, Lagrangian methods employ a moving computational mesh, so the simulation domain adjusts to the plasma flow and the computational mesh naturally concentrates resolution in compressed regions and around shock fronts. Unfortunately, the moving computational mesh can degrade and its quality decreases due to physical (vortices, shear flows) or numerical (hour-glassing, inaccurate artificial viscosity) issues.
Arbitrary Lagrangian-Eulerian (ALE) methods combine the advantages of both approaches. In ALE methods, the Lagrangian phase adjusts the computational mesh to the plasma flow, while periodic mesh optimization improves mesh quality and numerical robustness. Our group develops the PALE code [2], which employs the ALE formalism and serves as a platform for developing and testing numerical algorithms for laser-plasma hydrodynamics.
We compare Eulerian and ALE hydrodynamic simulations of laser interaction with a thin aluminum foil using the FLASH and PALE codes. The comparison focuses on solution accuracy, numerical diffusion, mesh quality, robustness, and computational efficiency. While ALE simulations require fewer computational cells owing to their adaptive mesh evolution, the Eulerian approach offers greater robustness for strongly distorted flows. The results highlight the advantages and limitations of each framework for modeling laser-driven plasma experiments and future inertial-fusion applications.

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Raytracing for Laser Propagation in Inertial Confinement Fusion Plasmas

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Abstract

Accurate modelling of laser energy deposition is vital to a correct simulation of Inertial Confinement Fusion (ICF) plasmas. The laser beam propagates through the underdense coronal plasma surrounding the target, undergoing refraction, Doppler shift, Inverse Bremsstrahlung (IB) energy deposition, and reflection at the critical surface. The spatial and temporal scales of ICF makes it suited to be simulated via Hydrodynamic plasma codes [1], which often involve geometric optic assumptions to study the laser propagation in the target. The beam is discretised into multiple rays, each evolving accordingly to its own trajectory; this is known as raytracing [2]. On the other hand, Laser-Plasma Instabilities (LPIs) [3], such as Stimulated Brillouin Scattering and Cross Beam Energy Transfer, greatly impact the energy conversion in the target but have been proven quite hard to account for with a raytracing approach, partly due to the difficulty in accurately mapping the intensity profile. The fidelity with which these processes are captured directly affects the predicted implosion symmetry and coupling efficiency, hence the need for correct and robust raytracing algorithms.

In this context, the following work is intended as a comparison of different propagation and deposition algorithms in the simple case of a two-dimensional Eulerian grid. The ray trajectories are governed by the Eikonal equation [4], with refraction index determined by the local ratio of free-electron density to critical density. The choice of the trajectory solver determines the path and group velocity of the ray, and thus the amount of IB energy deposition in each cell. The implementations are first benchmarked against analytically tractable plasma density profiles, such as quadratic and exponential spatial dependencies, and later tested against more complex configurations. Accuracy and computational time are examined over a wide range of grid resolutions. Analogously to well-established propagation algorithms [5], a novel implementation based upon a bilinear density reconstruction is introduced and characterised, with the goal of shortening computational times. The work is a foundational basis for a more thorough cell-based intensity reconstruction and LPI simulation.

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IFuEL: Inertial fusion laser development & test setup for plasma facing materials

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Abstract

Inertial fusion energy research has gained significant interest since the national ignition facility in the US reached for the first time ignition at the end of 2022. Since then, the German government has focused research towards the development of all facets of a prototypical fusion power plant.

The “Inertial Fusion Energy Laser Development und HED-Analytics (IFuEL)”, project is funded through the fusion 2040 program of the German Federal Ministry of Research, Technology and Space (BMFTR) and run by a consortium of DESY, HZDR, the Uni. of Rostock and ILT to develop a highly efficient Yb-YLF cryogenic cooled laser and test it under fusion relevant conditions by creating a plasma in a cryogenic H_2/He jet. The latter will be used to expose existing and new plasma facing materials (PFM), used for fusion reactor walls, to the ions, protons, electrons and x-ray originating from the plasma.

Within this presentation we will give an overview of the IFuEL project and its current status, with a specific focus on the test facility under development to study PFM at the synchrotron PETRA III and in future at PETRA IV using x-ray diffraction and imaging techniques.

Acknowledgements
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Analysis of Stimulated Raman and Brillouin Scattering from Structured Silicon Dioxide Foam Targets

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Laser-plasma instabilities (LPIs) remain a significant concern for laser-driven high-energy-density plasma experiments, where stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS) can reduce laser coupling and generate hot electrons. In this work, FLASH radiation-hydrodynamic simulations were used to investigate conditions like what is found in a recent L4N campaign at ELI Beamlines. We investigate the evolution of SRS and SBS in low-density, homogeneous, and structured silicon dioxide foam targets. Post-processing focused on evaluating the plasma conditions relevant to parametric instabilities, such as the density and velocity scale lengths, the growth rates for SRS and SBS, and the convective gain estimates for these instabilities. The analysis incorporates local resonance conditions, Landau damping, and collisional effects. Comparisons between homogeneous and structured foam targets during the prepulse reveal that the structured targets initially develop a modulated plasma corona and ablation front. The modulations slowly disappear in the ablation front as the structured target becomes homogenized during the prepulse, but remain in the less than quarter critical plasma for a longer period. This alters the density and velocity perturbations leading to smaller density and velocity scale lengths and changes in the instability growth rates and gains. These results provide insight into the role of target structure and laser drive conditions in mitigating laser-plasma instabilities and establish a framework for comparisons with kinetic particle-in-cell simulations and experimental campaigns.

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Homogenization and stimulated Raman scattering in SiO_2 foams driven by kilojoule-class laser at PALS

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Abstract

The interaction of high-power laser pulses with low-density porous materials is of significant interest for inertial confinement fusion (ICF) and high-energy-density physics. We report on experimental studies supported by hydrodynamic and kinetic simulations of laser interaction with ultra-low-density SiO_2 foam targets performed at the Prague Asterix Laser System (PALS). The third harmonic of a kilojoule-class iodine laser ($\lambda = 438$ nm, $\tau \approx 350$ ps) was focused to intensities of ~10^{15}–10^{16} W/cm^2. The targets consisted of closed-pore foams composed of ultra-thin SiO_2 shells with average densities of 30–40 mg/cm^3. An auxiliary 50 J heating beam was applied with a variable delay of 0.5–2 ns prior to the main pulse to control foam preheating and plasma formation.

Plasma formation and expansion were diagnosed using multi-frame interferometry, soft X-ray streak imaging, electron spectrometers, and scattered-light diagnostics. Hydrodynamic simulations performed with the FLASH code show that, in overdense closed-pore SiO_2 foams, homogenization is initiated by X-ray preheating associated with a shock wave generated during laser irradiation. The simulated plasma profiles are in good agreement with experimental observations.

We analyze the dependence of plasma conditions and stimulated Raman scattering (SRS) on the delay between the heating and main beams. While the longitudinal plasma profiles in the density range relevant for SRS are only weakly affected by the heating beam, plasma homogenization in the underdense region remains likely incomplete unless a sufficiently long delay is applied. The impact of residual density perturbations on SRS is investigated using kinetic simulations and correlated with measured scattered-light signals. These results provide new insight into the relationship between foam homogenization, plasma uniformity, and laser–plasma instabilities in low-density targets relevant to ICF.

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Thermal smoothing effect of beyond expectation observed in Inertial Confinement Fusion implosion

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Abstract

Thermal smoothing plays an importan role in reducing the laser nonuniformities in direct-drive ignition, shock ignition and indirect-direct hybrid schemes, and a larger condution distance between the critical surface and the electron ablation front is always benificial for the smoothing efect. A larger conduction distance is formed by the external radiation ablation before the direct-drive laser turns on. We have observed a thermal smoothing effect beyond the classical "Cloudy day" model on the Shenguang 100kJ laser facility For the first time, and the simulation results are in accord with the experiment results.

Development of a Compact Single-Shot Correlator for Femtosecond Jitter Diagnostics

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Abstract

Motivation. High-power laser facilities increasingly rely on the controlled temporal overlap of two ultrafast pulses. At the Helmholtz Institute Jena, JETi200 [1] and POLARIS [2] high-energy laser systems enable combined high-intensity experiments. However, such experiments may operate at approximately one shot per minute. Therefore, the relative delay must be measurable from a single shot rather than from repeated averaging. This work develops a compact single-shot cross-correlator in which the delay between two pulses is mapped onto the transverse position of a second-harmonic signal on a camera.

Method. The system is first operated in autocorrelation mode, using two replicas of the same pulse, to test and calibrate the spatial-to-temporal conversion. The replicas cross non-collinearly in a beta-barium borate (BBO) crystal and generate a second-harmonic-generation (SHG) signal. A retroreflector delay line introduces a known temporal shift, while the displacement of the SHG stripe on the detector is measured. A camera-based program performs live acquisition, background subtraction, Gaussian fitting, position tracking and offline analysis. The measured calibration is 0.23fs/px, providing sub-femtosecond timing sensitivity per pixel.

Results and outlook. The calibrated autocorrelation mode retrieves near-transform-limited pulses with a duration of about 13.6 fs. The analysis also tests how finite beam size, stripe tilt, satellite features and camera-region selection influence the apparent width of real single-shot images. The measured pixel scale allows small shifts of the nonlinear signal to be interpreted as femtosecond-scale delay changes. The next step is to replace the two replicas with signals from the synchronized JETi200 and POLARIS oscillators and to measure their relative timing stability from microseconds to seconds.

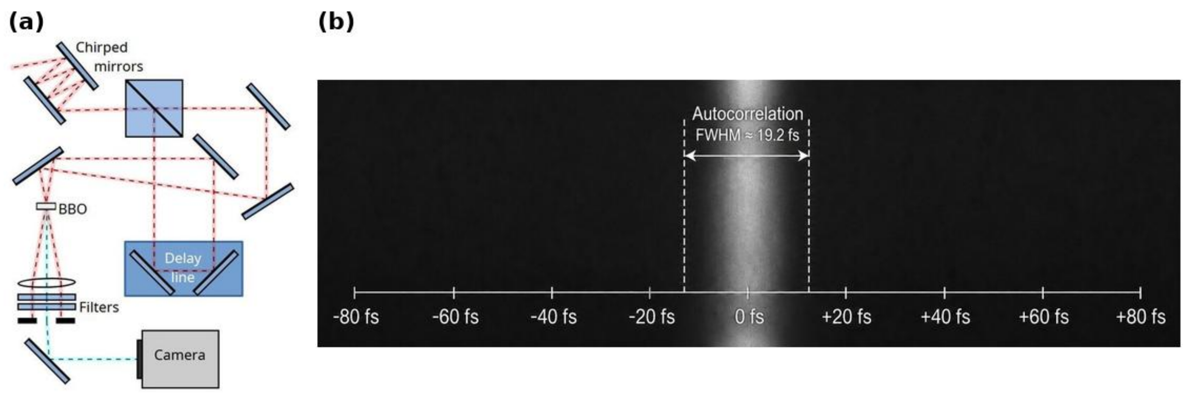

Figure 1. (a) Optical layout of the autocorrelation-mode correlator. (b) Representative calibrated autocorrelation image; the recorded autocorrelation width corresponds to a pulse duration of 13.6 fs, assumming a gaussian pulse shape.

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Versatile Joule-class OPA as front-end laser for inertial fusion research

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Abstract

We present a versatile kJ-class laser architecture for inertial confinement fusion, combining a multi-Joule OPA front-end with flash-lamped Nd:glass amplifiers. The system provides flexible temporal and spectral control, enabling broadband long-pulse compression and short-pulse ignition applications.

The strategy to achieve high gain in Inertial Confinement Fusion (ICF) necessitates flexible laser beamlines capable of delivering diverse temporal characteristics at the kJ energy level. While direct drive target compression demands broad-bandwidth nanosecond pulses, specific ignition schemes require short pulses to generate penetrating particles. Consequently, advanced spectral management is critical in both regimes.

In this work, we present a versatile kJ-class laser seeded by a multi-Joule front-end solution based on Optical Parametric Amplification (OPA). The front-end system leverages two proprietary pump lasers specifically optimized for OPA applications: a high-repetition-rate unit (3 J at 5–10 Hz, 532 nm) and a high-energy unit (>30 J at 1 shot/min, 527 nm). Both pump lasers deliver top-hat beam profiles with a high Strehl ratio, ensuring ideal conditions for OPA pumping. Furthermore, they feature adjustable temporal shaping (3–20 ns) and are available in circular or square beam formats.

The main amplifiers are based on flash-lamped Nd:glass amplifiers, designed to amplify these pulses to the kJ level while keeping a broad bandwidth and versatile temporal and spectral characteristics. We will demonstrate how this modular OPA front-end architecture offers the necessary parameter flexibility for both short- and long-pulse operations in next-generation research facilities.

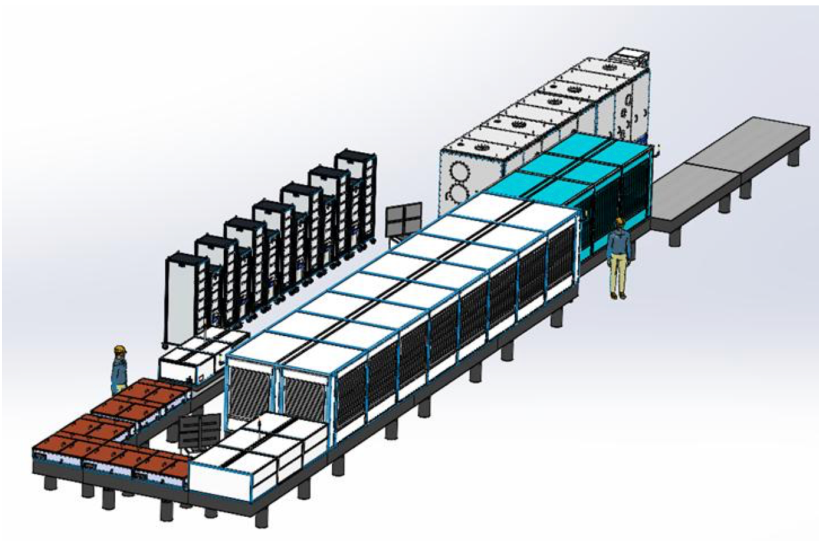

Figure 1. Design of the kJ broadband laser for fusion research.

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Performance of a real-time bremsstrahlung detector during routine user operation of the ELIMAIA beamline

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Abstract

The increasing availability of high-power, high-repetition-rate laser systems is transforming laser-plasma experiments into data-rich environments, where thousands of shots can be accumulated during a single experimental campaign. In this context, real-time diagnostics capable of providing immediate feedback on laser-plasma interaction parameters are becoming increasingly important for experimental operation and future data-driven optimization strategies (e.g., employing machine-learning techniques).

At the ELIMAIA beamline, a scintillator stack calorimeter detector (SCIS-CAL) has been developed for real-time monitoring of bremsstrahlung radiation generated in laser-plasma interactions. Previous studies demonstrated its capability to provide shot-to-shot estimates of bremsstrahlung temperature and yield, which were found to correlate with the laser-driven proton beams parameters, such as the maximum proton energy [1].

Recently, the detector has been employed during routine operation of the ELIMAIA beamline, including both user and internal experimental campaigns. Large datasets were collected under a wide range of laser and target conditions, including variations in laser energy, pulse duration, and focusing parameters. Although the detector was frequently operated as a secondary diagnostic and the experimental configuration was not always optimized for bremsstrahlung measurements, it consistently provided useful real-time information on interaction performance, enabling rapid identification of low- and high-quality shots and immediate evaluation of bremsstrahlung parameters.

Post-processing of the accumulated datasets revealed correlations between bremsstrahlung observables and laser parameters (laser energy, pulse duration, and focusing conditions), as well as with proton beam properties. The results demonstrate reliable operation of the detector under realistic experimental conditions and its capability to provide quantitative shot-resolved information on laser-plasma interaction performance.

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Absolutely Calibrated Scintillator Stack Spectrometer for High-Intensity Laser-Plasma Experiments

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Abstract

For high-repetition-rate laser-plasma experiments, real-time diagnostics offer critical advantages over offline detectors, such as imaging plates, by eliminating shot-to-shot processing time. Scintillator-based detectors are widely used to measure bremsstrahlung radiation from laser-plasma interactions, providing insights into hot-electron energy distributions. In this work, we present absolute calibration of a multi-layer scintillator stack spectrometer based on LYSO (Lutetium-Yttrium Oxyorthosilicate) performed at the MT25 microtron facility in Prague. Bremsstrahlung radiation was generated by irradiating a tungsten converter with mono-energetic electron beams in the energy range from 5 MeV to 22 MeV and was complemented by Monte Carlo simulations. A linear correlation between signal response and energy deposition was obtained for all crystals within the experimental uncertainty. This calibration enables quantitative, real-time measurement of bremsstrahlung radiation, which is important for particle acceleration, laboratory astrophysics, and inertial confinement fusion studies.

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Laser-ablated area determination based on plasma acoustic emission

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Abstract

In laser micromachining applications, laser spot size and energy distribution directly define the laser-to-material interaction [1]. One of the most important factors influencing these parameters is the focus position. Therefore, precise positioning is essential for a stable and reproducible process, since it strictly determines the resulting material modification. This is particularly important for transparent materials, since laser-material interaction often relies on nonlinear effects originating from high peak intensity. A conventional autofocus method utilizes optical imaging with the same focal position as the laser beam [2]. However, this approach often fails for transparent materials due to low reflectivity and a dominant signal originating from the surface below the sample.

Here, we present an acoustic emission-based method dedicated for predicting the laser-ablated area. This *in situ* solution does not rely on direct access to the laser processing zone, and it is well-suited for transparent materials. In comparison to optical-based methods, acoustic emission allows for online monitoring of the ablation and is not influenced by surface roughness. We show that based on a series of measurements, one is able to determine focus position on the processed sample with an accuracy in the range of several micrometers – Fig 1. Furthermore, we have found that the distance between the acoustic sensor and the processing zone has a minor influence on focus determination accuracy. We also report that the minimal ablated area is not related to emission extrema, which has been previously demonstrated for steel [3]. The presented approach can be further developed for a comprehensive process monitoring system. Utilization of vibro-acoustic sensors for laser ablation control is a promising technique to improve material modification quality. The prediction of the ablated area can become a backbone for online topography determination, which could make post-process microscope observations obsolete.

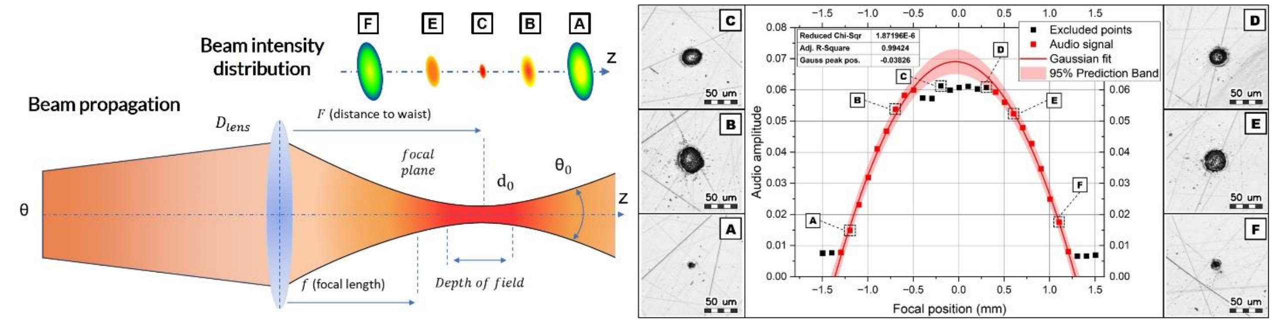

Figure 1. Focus position determination based on acoustic emission method.

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Characterization of Reflected Light Properties for Understanding Laser-Plasma Interactions

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Abstract

Laser-driven ion accelerators offer several advantages over conventional accelerators due to their ability to achieve high accelerating gradients over comparatively short distances. Recent experiments have demonstrated that it is possible to achieve significantly high proton energies by modifying the temporal profile and controlling the spectral phase of laser pulses [1]. However, the physical processes remain incompletely understood.

Reflected light provides a powerful diagnostic for investigating laser-plasma interactions and optimizing ion acceleration. Experiments involving high-intensity ultrashort laser pulses interacting with thin foil targets reveal prominent spectral shifts as the spectral phase, specifically the Group Delay Dispersion (GDD), is varied. These spectral shifts contain information about plasma dynamics, relativistic surface motion and laser contrast effects. However, interpreting such observations directly from experimental measurements remains challenging.

In this work, Particle-in-Cell (PIC) simulations are employed to model these interactions under experimentally relevant conditions corresponding to the DRACO laser system, using 30 fs laser pulses with peak intensities of 5×10^{21} W/cm^2. Realistic laser pulses with controlled spectral phase are implemented to reproduce the experimental parameter space. The simulations reproduce the experimentally observed GDD-dependent spectral shifts of the reflected light and enable a detailed analysis of the underlying physical mechanisms.

The reflected light contains information about the temporal, spectral, and angular evolution of the interaction. By analyzing these properties, the contributions of several proposed mechanisms, including relativistic Doppler shifts, the lighthouse effect, and temporal gating, to the observed spectral shifts have been investigated and quantified. The results provide a framework for interpreting experimentally observed spectral trends and highlights the potential of reflected-light diagnostics for understanding and optimizing relativistic laser-plasma interactions.

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A wavefront sensor for measuring coherent harmonic focusing (CHF)

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Abstract

The increase in peak laser intensity over the last decades was driven by two major advances in technology: Q-switching and chirped pulse amplification (CPA). Theory shows coherent harmonic focusing (CHF) is a possible route to further increase the achievable electromagnetic field strengths and potentially reach the Schwinger limit [1]. Under optimized conditions, the harmonic generation from a solid target (SHHG) allows the laser pulse energy to be spatially and temporally compressed leading to a boost in intensity. To measure the spatial compression, we are developing a frequency resolved single shot wavefront sensor based on the design presented by Freisem *et al.* in [2]. In comparison to a conventional Hartmann sensor, consisting of an array of lenses, this sensor consists of an array of multiple small gratings. We optimized the distribution and orientation of these gratings to maximize the number of harmonics that can be detect in one shot. The wavefront sensor is intended to be used in SHHG experiments at JETi200 (Jena, Germany) and LWS100 (Umeå, Sweden) with the aim of measuring coherent harmonic focusing.

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Injecting Arbitrarily Structured Plasma Wave Packets in Particle-in-Cell Simulations

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Abstract

Particle-in-Cell (PIC) simulations of laser–plasma interactions typically rely on injection schemes that assume simplified field structures, often based on paraxial or slowly varying envelope approximations that do not fully satisfy Maxwell's equations. In practice, these approaches are effectively limited to electromagnetic fields defined in vacuum, which subsequently interact with the plasma, and do not allow for the direct and controlled injection of arbitrary wave packets, including those relevant for driving plasma waves with complex spatiotemporal structure.

In this work, we present a general method for the injection of arbitrary electromagnetic plasma wave packets in PIC codes that directly satisfies Maxwell's equations without relying on envelope-based approximations. Building upon existing approaches for electromagnetic field construction and propagation in vacuum [1], we extend this framework to self-consistent injection in plasma simulations. The approach is formulated in a way that is compatible with standard simulation geometries, including 1D, 2D and 3D Cartesian setups, and can be extended to other coordinate systems and numerical frameworks. This flexibility enables the accurate modeling of a broad class of structured electromagnetic fields within kinetic plasma simulations in the non-relativistic regime.

As a relevant and nontrivial application, we discuss the injection of wave packets associated with self-accelerating Dirac-particle solutions [2], which exhibit intrinsic coupling between spatial structure and propagation dynamics. These solutions of the Dirac equation describe wave packets that exhibit apparent acceleration in vacuum without external forces and evolve consistently with relativistic effects such as Lorentz contraction. Since such quantum wave packets are difficult to generate and probe experimentally, we establish an electromagnetic analog based on the propagation of structured light in a plasma and simulate this behavior using the developed framework. This provides a promising route toward laboratory realizations and controlled studies of theses relativistic phenomena.

Overall, this framework extends the capability of PIC simulations to handle a wider class of electromagnetic drivers in plasma environments, opening pathways for exploring structured light–plasma interactions beyond conventional laser models.

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Convergent shock compression of thin wire targets using a Joule-class short-pulse laser

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Abstract

While equation of state measurements at astronomical conditions are commonly conducted using kJ class ns-long lasers, recently it was demonstrated both theoretically [1] and experimentally [2] that a short pulse laser with tens of fs pulse duration and J level of energy can also drive similar HED conditions. The impulsive laser-matter interaction generates hot electrons escaping the focal spot, that in return drives a strong transient current at the target surface neutralizing the escaping charge. The sudden heating of the surface launches shock waves into the target; in the case of a wire target leading to a converging shock geometry. Hydrodynamic simulations predict Gbar level pressures at convergence and 9x compression for a 25 mm copper wire [2].
Here we report on the outcome of a follow up beamtime at the HED-HIBEF instrument at EuXFEL in which we have focused on the demonstration of the above discussed compression scheme for different materials and wire radii. Phase contrast imaging (PCI) was used as the main diagnostic with a resolution of 200 nm as the seeding mode was employed. Resulting densities and timings are compared to predictions from hydrodynamic simulations both qualitatively and quantitatively. The scaling of the return current has been analyzed in [3].

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A packed hollow-microsphere SiO_2 aerogel as a density-verifiable target platform for high-intensity laser experiments

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Abstract

Low-density foams and aerogels are frequently used as targets in high-energy-density physics and laser–plasma experiments. In many reports, however, foam density is given as a nominal scalar quantity, whereas the method of its experimental determination and its relevance to the laser interaction volume are insufficiently specified. For focused laser irradiation, the relevant parameter is not only the total mass divided by the macroscopic target volume, but the density averaged over the spatial scale actually sampled by the pulse.

We propose a simple SiO_2 aerogel architecture based on random packing of uniform hollow microspheres. Each target is constructed from a monodisperse population of hollow silica shells, with the selected shell diameter in the range of 5–20 µm. The shell walls may be dense or porous, with geometrical thicknesses in the lower tens of nanometres and an independently variable effective wall density. The average target density is therefore controlled by a limited set of parameters: microsphere diameter, wall thickness, wall density or porosity, and packing fraction. Subcritical densities below 10 mg cm^{-3} can be obtained while retaining nanometre-scale structural elements.

This architecture provides a direct way to relate nominal density to measurable geometry. In conventional stochastic foams, the same average density may correspond to different local structures, including thick ligaments, large voids and strong density intermittency. In the packed hollow-microsphere geometry, the contributions of internal voids, shell thickness, shell porosity and packing fraction can be separated. The relevant shell parameter is the wall areal mass density, combining geometrical thickness with effective wall density.

The need to specify the averaging scale is illustrated by two focusing regimes. For a focal diameter of order 100 µm, the beam samples many microspheres transversely and along the target depth, so local density fluctuations may be treated statistically and compared with a voxel-averaged density. For a focal diameter of order 3 µm, the beam diameter is smaller than, or comparable to, the microsphere diameter. The interaction may then occur with a shell wall, an internal void, a contact region, or an open interstitial region. In this regime, the nominal macroscopic density is not sufficient to characterize the material encountered by the laser.

The proposed target geometry is therefore suitable for systematic studies of the transition from microstructure-resolved laser interaction to an effective-medium description. SiO_2 provides a light-element matrix and allows chemically accessible metal doping, enabling controlled changes in absorption, opacity, emissivity or diagnostic contrast without changing the mesoscale geometry.

This poster emphasizes that foam-target studies should report not only nominal density, but also the experimental method used to determine it, the spatial averaging scale, and the representativeness of the reported density for the laser–matter interaction volume. For structured foam targets, density is not a scalar unless the averaging volume is specified.

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A predictive theoretical model for ion thermalization time in laser-irradiated foam microstructures

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Abstract

Low-density foams are studied as capsule ablators in inertial confinement fusion (ICF), and increasingly as fuel-containing wetted foams. Although these foams increase laser absorption and reduce hydrodynamic instabilities, modeling their interaction with intense laser pulses is challenging. This difficulty arises from the wide range of spatial scales between the solid filaments and voids.
We ran two-dimensional particle-in-cell simulations using the SMILEI code [3] on the ENEA CRESCO8 HPC infrastructure [1]. We modeled a high-power laser pulse interacting with a plastic foam pore. The pulse had a 0.35 µm wavelength and 10^{14} W/cm² intensity, while the foam averaged 1 g/cm³ in density. Following the approach in reference [2], we applied periodic boundary conditions. This setup simulates the expansion of a single 0.1 µm-radius plastic cylindrical filament, representing an element of an infinite periodic lattice.
Our simulations show that collisional and resonance absorption drive the foam homogenization. The expanding plasma stays overall quasi-neutral. But the filament expansion generates local electrostatic fields that accelerate ions into the void regions. From the PIC results, we developed a standalone analytical model. It estimates the characteristic ion–ion thermalization time as a function of the foam's geometrical parameters. Our model identifies two main stages driving this thermalization. First, collisions with hot electrons cause an initial velocity broadening. Next, ion–ion diffusion dominates as plasmas from adjacent pores interpenetrate and mix. This analytical approach successfully predicts the plasma equilibration times observed in our simulations.

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Mechanical antibiotic and antiviral nanomaterials synthesized by laser ablation methods

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Abstract

Pulsed laser ablation in liquids (PLAL) has emerged as an advanced technique for synthesizing high purity metal-based nanoparticles with precisely controllable physicochemical properties (Fig. 1) [1-3]. This method enables fine tuning of nanoparticle characteristics such as size, morphology, and composition by altering laser parameters, making it highly versatile for biomedical applications. This study focuses on the synthesis of Titanium (Ti), zirconium (Zr) and Hafnium (Hf) based nanoparticles using an ultrafast femtosecond laser ablation technique in various solvents. Detailed TEM characterization reveals the spherical morphology and crystalline nature of NPs. The optical properties of the nanoparticle colloids were investigated using the UV–Vis spectrophotometry showing a characteristic peak in the biological transparency window, attributed to the presence of TM suboxide and TM carbide phases in the NPs, confirmed by XRD, EDX, XPS analysis. Under laser irradiation, PEG-coated Ti-based suboxide colloidal NPs with the average diameter of 30 nm (Fig. 2) were stable in PBS and showed superior photothermal activity.

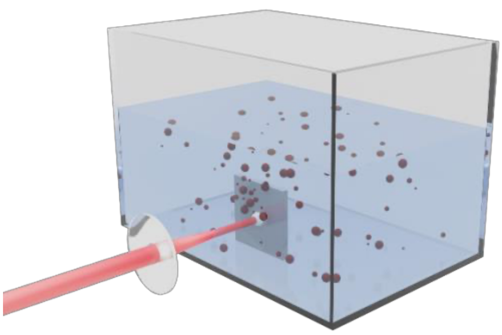

Fig. 1: Schematic illustration of laser-ablative synthesis of TM NPs

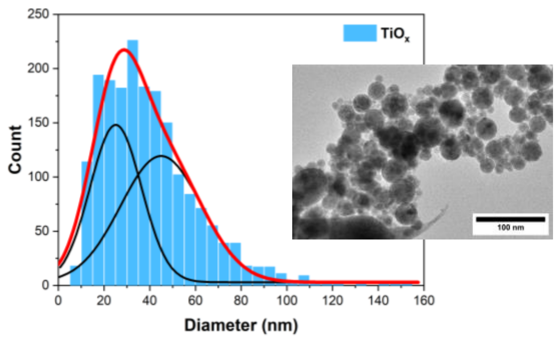

Fig. 2: Size distribution curve of Ti-based NPs by PLAL synthesis

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Pulse-Shape-Controlled Ionization Injection in Laser Wakefield Accelerators

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Abstract

Laser wakefield acceleration (LWFA) has emerged as a promising technique for producing ultrashort, high-energy electron beams in compact laboratory-scale accelerators [1]. A key challenge, however, is achieving precise control over electron injection and beam quality. In this work, we investigate the role of laser pulse shape in regulating ionization-induced injection and subsequent electron acceleration. Using two-dimensional particle-in-cell simulations, we examine the interaction of temporal asymmetric laser pulse with a hydrogen plasma containing a small concentration of nitrogen dopant. The asymmetry of the laser pulse significantly alters the wakefield evolution and bubble dynamics, thereby modifying the trapping conditions for ionized electrons. We find that pulses with a fast trailing edge enhance wakefield stability and restrict the injection interval, leading to the generation of compact electron bunches with higher peak energies and improved beam quality. Also, pulses with a slow trailing edge extend the injection process, increasing the accelerated charge at the expense of broader energy spectra. By adjusting the temporal shape of the laser pulse, the electron beam parameters can be continuously tuned over a wide range without changing the plasma target configuration [2]. These results demonstrate a practical and experimentally feasible route for controlling electron beam characteristics in LWFA, opening opportunities for optimized compact accelerators and next-generation ultrafast radiation sources.

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High-order exponential method in particle-in-cell simulations in cylindrical geometry

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Abstract

Recent developments of broad-band lasers systems allow to reach highly relativistic intensities for laser-driven particle acceleration schemes [1], which can be accurately modeled with particle-in-cell simulations. For these, the go-to Maxwell solvers were the finite difference time domain methods on Yee-grids for decades, but the most accurate methods are taking advantage of the analytical solution of the Maxwell-equations in spectral space [2]. In this work we present an other type of solution which we call finite difference exponential time domain, well known in quantum mechanics [3]. The spatial differences are represented with high order finite differences (6th-32nd) and the time stepping with exponential operators, which we recently implemented in Cartesian PIC [4] and we have extended that work to cylindrical coordinates. We show that the accuracy of this method is equivalent to pseudospectral Fourier-Bessel PIC [5] with improved locality but without relying transformation to special basis functions. We show the results of this method in the non-linear laser-plasma wakefield regime, using electron injection in underdense plasma.

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High-quality laser-driven acceleration of sub-GeV and GeV electron beams

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Abstract

Laser–wakefield acceleration (LWFA) [1] is a promising route towards compact high-energy electron accelerators. In this scheme, an intense ultrashort laser pulse propagates through a gas target, driving a plasma wave that can trap and accelerate electrons to relativistic energies over only a few centimetres. LWFA therefore offers a potential path towards compact electron sources for next-generation free-electron lasers (FELs). In this work, we investigate controlled electron injection into the plasma wave using two mechanisms: density down-ramp (shock) injection [2,3] and truncated ionization injection [4], aiming at high-quality laser-driven acceleration of electron beams at sub-GeV and GeV energies. Using quasi-3D particle-in-cell (PIC) simulations [5,6] together with post-processed interactive visualizations [7], we study the laser–target dynamics and optimization of the longitudinal plasma-density profile, including a density up-ramp in the acceleration region and an optimized exit down-ramp. The goal is to identify experimentally feasible regimes enabling efficient production of high-charge, low-divergence electron beams with favourable energy spread and emittance for FEL realization at the ELI Beamlines Facility [8]. Current work further focuses on adapting the laser and target parameters for initial experiments, supported by combined PIC and computational fluid dynamics (CFD) modelling.

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This work received funding from the European Union's Horizon Europe research and innovation program, under Grant Agreement No.101079773 (EuPRAXIA Preparatory Phase), No.101188004 (PACRI—Plasma Accelerator systems for Compact Research Infrastructures). Portions of this research were carried out at the ELI Beamlines Facility, a European user facility operated by the Extreme Light Infrastructure ERIC. The computational time was provided by the supercomputers Sunrise of ELI Beamlines facility and Karolina of IT4Innovations - supported by the Ministry of Education, Youth and Sports of the Czech Republic through the e-INFRA CZ (ID:90254).

High-repetition-rate proton acceleration from continuous water targets at ELI Beamlines

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Abstract

Self-refreshing liquid targets are a promising route towards high-repetition-rate laser-driven ion sources, avoiding several limitations of conventional thin solid foils, including target replacement, shot-to-shot alignment, debris production, and contamination of focusing optics. At ELI Beamlines, the Department of Ion Acceleration is developing continuous water targets for laser-plasma experiments, with particular emphasis on a flat leaf geometry intended for future target-normal sheath acceleration experiments at the ELIMAIA and ELIMED beamlines in repetition-rate mode.

We present the current status of this development using a compact kHz-class, millijoule-level, femtosecond laser system as a test platform for proton acceleration, target stability, vacuum operation, and ion- and X-ray-oriented diagnostics. Two target geometries are investigated: a cylindrical water microjet, already used for proton acceleration measurements, and a flat water leaf target, developed as a debris-free, continuously refreshed alternative to thin solid foils. The upgraded setup includes a more reliable catcher system that mitigates freezing of the liquid in vacuum and enables extended target operation. In parallel, expansion of the laser beam before focusing has increased the mean intensity within the FWHM to above 5×10^{17} W/cm^2, using pulses of ~45 fs with up to 6 mJ on target.

Recent measurements with the cylindrical jet show proton cutoff energies exceeding 240 keV under non-optimized conditions, observed using a time-of-flight diamond detector. Current work focuses on stabilizing high-energy proton emission at high repetition rate, understanding the dependence on target geometry and laser parameters, and transferring the interaction to the flat leaf target. Stable formation of the water leaf in vacuum has already been achieved, providing a platform for TNSA-oriented irradiation studies.

In addition to proton acceleration, the laser-plasma interaction produces X-rays, which have already been applied to compact X-ray fluorescence studies. The same platform also provides a route towards proton-boron-fusion-related studies and high-repetition-rate plasma diagnostic development, while optimized flat-target geometries may enable investigations of high-harmonic generation or plasma-mirror-like interaction regimes. These studies support the longer-term goal of implementing debris-free, accelerator-like laser-driven ion sources for controlled sample irradiation at ELIMED and related applications.

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

Controlled Electron Injection in Laser Wakefield Acceleration Using Nanoparticles

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Abstract

Laser wakefield acceleration (LWFA) can generate compact relativistic electron beams, but its performance is often limited by uncontrolled self-injection. Here, we present a quasi-3D particle-in-cell study (Smilei) of nanoparticle-assisted injection in helium plasma. We show that nanoparticles act as localized perturbations that trigger earlier injection of background helium electrons, modifying the timing and structure of self-injection. Depending on nanoparticle properties, this leads to tunable injection regimes, from weakly perturbed to over-injected beams. These results demonstrate a pathway toward controlled electron injection and improved beam properties in laser-plasma accelerators.

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Bayesian Optimization of Two-Stage Gas Target for Laser Plasma Electron Acceleration

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Abstract

Laser wakefield acceleration (LWFA) has emerged as a strong candidate for next-generation compact accelerators that can generate high-energy electron beams with beam quality also dependent on the plasma density profile. In this work, we have employed Bayesian Optimization to optimize the electron beam properties through Particle-In-Cell simulations of a 3J/25fs/20Hz laser interacting with a two-compartment gas-cell target. The first compartment contains a mixture of gases that enables ionization injection, while the second contains a pure gas for subsequent acceleration. A density down-ramp is introduced at the interface between the two compartments to control the injection and acceleration dynamics. The optimization variables include the plateau lengths, ramp lengths, and density of gases in both the compartments, defining the longitudinal density profile of the gases. Bayesian optimization efficiently explores this multidimensional parameter space and identifies the configurations that can improve the features of accelerated electron beam with significantly fewer simulations/runs than the conventional manual tuning. The optimized target configurations will provide guidance for future experimental implementation in highly intense laser facilities.

Electron and proton acceleration from structured thin foil irradiated by ultrashort laser pulse

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Abstract

While existing literature has explored various morphological configurations, a direct comparative analysis between protruded and grooved geometries remains absent. This study investigates the comparative impact of hemispherical protrusions and grooves on the front surface of a thin foil. By maintaining identical surface areas and other geometric parameters such as thickness, radius and the gap between structures across both configurations, we isolate the effect of target topography on particle acceleration. Our findings reveal that when a 1μm thick CH foil with hemispherical protrusions and grooves of radius 0.5μm on the front side is irradiated by a femtosecond laser pulse with an intensity of 10^{21} W/cm^2 ,we observe from Fig.1, a proton energy increase of 2.6 times for protruded foils and 3.6 times for grooved foils relative to the planar case. The enhancement in proton acceleration is driven by a substantial increase in the longitudinal electric field at the target rear side. This leads to a higher population of accelerated electrons and increased peak electron energies. Due to acceleration of hotter electrons, more protons are accelerated to higher energies. Our simulations indicate that while the interaction surface area is identical in both cases, the protruded geometry suffers from higher electron reflection and the grooved structure effectively guides the laser-plasma interaction, leading to more efficient energy coupling into the hot electron population and, subsequently, a more robust TNSA (Target Normal Sheath Acceleration) process [1] .

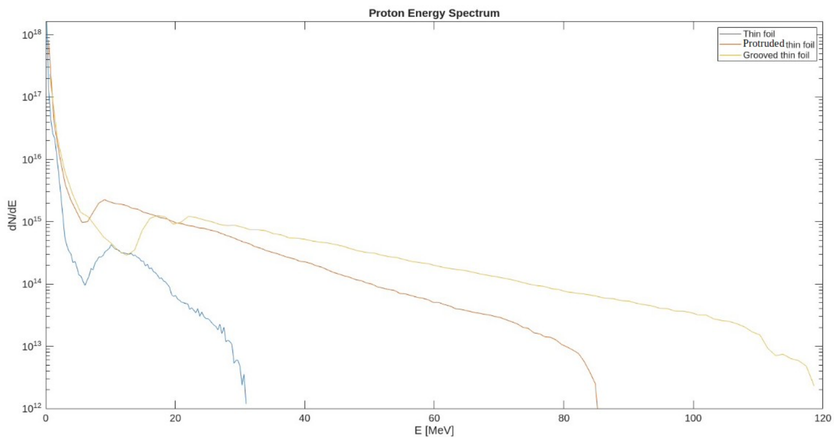

Figure 1. Energy spectra of the proton obtained from laser interaction with planar thin foil (blue), protruded thin foil (red), grooved thin foil (orange).

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Electromagnetic field structure in a Collision of Laser Pulses Reflected from Relativistic Plasma Mirrors

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Abstract

We investigate a scheme for generating ultra-intense electromagnetic fields through the collision of laser pulses reflected from two opposing relativistic plasma mirrors [1]. Reflection from a relativistically moving plasma surface can lead to a strong Doppler upshift and temporal and spatial compression. When two such pulses collide, the magnetic-field contributions may partially cancel while the electric-field components add constructively, creating localized regions with a large electric Poincaré invariant and an enhanced probability of electron-positron pair production [2]. We aim to determine how the structure of the resulting strong-field region depends on the polarization and relative phase of the colliding pulses.

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QED Cascade in Multiple Radially Polarized Laser Pulse Collision

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Abstract

Using 3D simulations, we study electron–positron pair production in a collision of free seed particles with 1, 2 or 3 couples of counter-propagating, short, tightly focused and radially polarized laser pulses (see Figure 1). We found that the delay between colliding couples of laser beams leads to efficient electron–positron pair production. The reason is that radially polarized laser pulses keep interacting particles within the interaction region, and therefore, the pairs created in the collision with the first couple of laser beams can serve as a seed for the consecutive couple of colliding beams. We obtain almost 60 times more positrons created when the total laser energy is divided into three properly delayed couples of colliding laser beams compared to a simple one couple case [1].

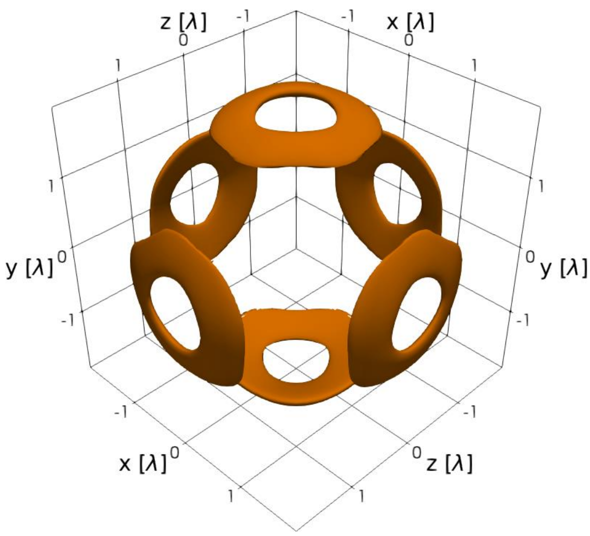

Figure 1. Interaction configuration of six-beam collision represented by laser intensity iso-surfaces in the simulation box. The seed particles are located in the center of the simulation box

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

Injecting Arbitrarily Tilted Laser Pulses in PIC-code Smilei

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Abstract

Electron-positron pairs are produced by ultra-intense (multi-petawatt) laser pulses through the multiphoton Breit-Wheeler process [1]. The required peak intensity can be reduced by forming a tightly confined hot spot using several counter-propagating pulses [2,3]. Our aim is to further optimize this approach and move it closer to experimentally achievable conditions.

We simulate these setups via PIC-code Smilei [4], where we need to use tightly focused beams tailored to our application. A particular challenge is to reliably implement boundary conditions for many incident beams from coming arbitrary directions. Once the beam is estimated analytically, it requires to project it onto the boundaries. Once the field is not known, it is necessary to find a reliable efficient way to propagate the field considering its vectorial nature [5] in tight geometry beyond the actual native Smilei routines [6,7].

This contribution will present these schemes and outline ongoing development.

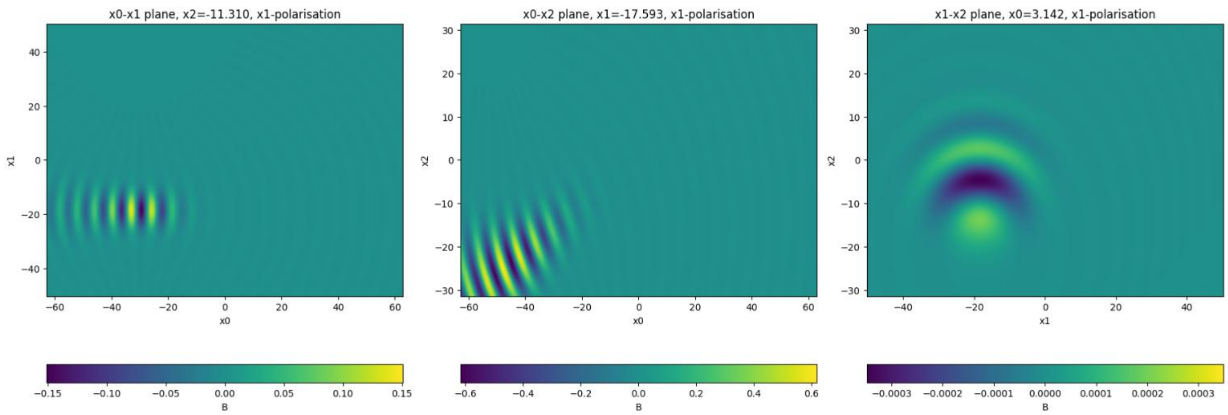

Figure 1. Several sections through the B-field of an ideal Gaussian beam illustrating the case where it goes through the edge of two boundary planes (using normalized units to λ: $w_0 = \lambda$, $\omega = 1$, $FWHM = 6T_0$).

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Staged Electron Injection and Gamma-Ray Production from Structured Plasma Targets

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Abstract

Structured plasma targets provide a promising route to efficient, collimated gamma-ray production in high-intensity laser–matter interactions. Recent work has shown that coupling a conical focusing structure to a channel target can enhance gamma-ray emission by focusing the incident laser pulse while also injecting relativistic electrons into the channel [1]. Here, we extend this concept through a target-length optimization study of the cone–channel system and identify conditions that enhance the overlap between injected relativistic electrons and the fields responsible for strong photon emission.

Using photon-emission diagnostics and field analysis, we show that enhanced gamma-ray production is closely connected to relativistic electrons injected from the cone into the channel. Once inside the channel, these electrons drive strong current-associated azimuthal magnetic fields that guide and collimate the electron population while increasing transverse acceleration, promoting bright and directional photon emission. We analyze how the target length controls the relative timing of electron injection, magnetic-field growth, and photon production. Finally, we discuss how the emission mechanisms revealed by structured targets can motivate the design of unstructured or self-organized plasma targets for similarly efficient laser-driven gamma-ray sources.

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ECLIM 2026 38TH EUROPEAN CONFERENCE ON LASER INTERACTION WITH MATTER

Theoretical interpretation of soft X-ray generation from aerosol targets irradiated by femtosecond laser pulses

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Abstract

In this contribution, we present a theoretical interpretation of the enhancement of soft X-ray radiation (SXR) in the wavelength range from 1.5 to 10 nm, including the "water window". A dramatic increase in the number of emitted photons in this spectral range was observed [1] when femtosecond laser pulses interacted with a target created by a streaming mixture of micrometer-sized xenon droplets instead of xenon gas, both confined within a thin external helium stream.
The intensity of the radiation at different wavelengths depends on the distribution of ion charge states Z; larger populations of highly charged ions result in emission spectra shifted toward shorter wavelengths. Using particle-in-cell (PIC) simulations with sophisticated and well-tested ionization models [2], we demonstrate that the average charge state of xenon ions is substantially higher for condensed gas in the form of droplets (i.e., an aerosol target) than for uncooled gas.

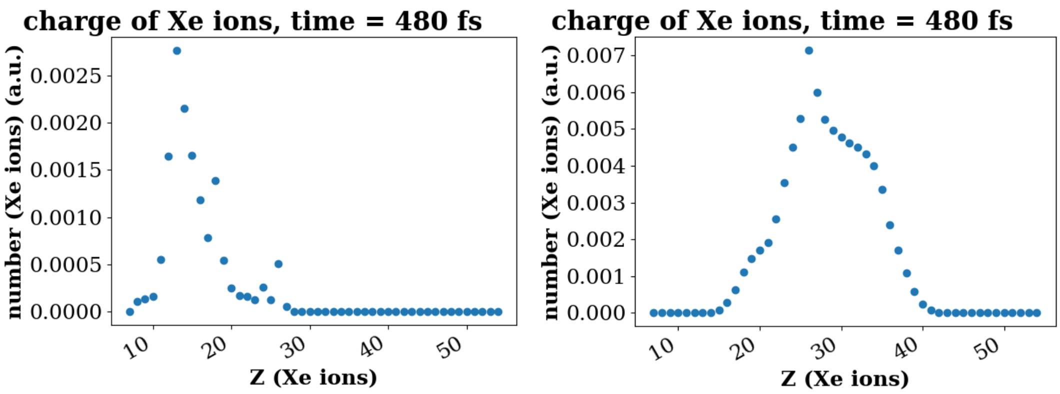

Figure 1. Distribution of Xe ion charge states at the end of simulations for an uncooled gas target (left) and an aerosol target (right) irradiated by a laser pulse with peak intensity of 10^{19} W/cm^2.

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A Tabletop 1 kHz Plasma X-ray Source for Time-Resolved Diffraction Experiments

Roya Garayeva

Abstract

We report on a compact laser-driven plasma X-ray source developed and operated at ELI Beamlines for time-resolved diffraction, spectroscopy, and imaging applications. The source is based on the interaction of an ultrashort near-infrared laser (central wavelength $\lambda \approx 800$ nm, pulse duration $\tau \approx 40$ fs) with solid targets at intensities in the range of 10^{16}– 10^{17} W/cm^2. Under these conditions, hot electrons with characteristic temperatures described by ponderomotive scaling are generated, reaching typical values of Th ~ 5–20 keV depending on laser intensity.

These hot electrons penetrate into the target bulk and induce inner-shell ionization, leading to characteristic Kα emission. The resulting X- ray source exhibits photon energies tunable via target material (e.g., Cu: 8.0 keV, Mo: 17.4 keV, Ti: 4.5 keV), with conversion efficiencies on the order of 10^{-5}–10^{-4} into Kα radiation. The photon yield reaches up to 10^{10}–10^{11} photons/sr/shot, depending on laser and target conditions.

The intrinsic pulse duration of the X-ray emission is on the order of the hot electron transit time, yielding femtosecond-scale temporal resolution.

The source operated with Cu tape target is fully operational, stable at high repetition rate, and intrinsically synchronized with the driving laser, making it ideally suited for pump–probe experiments. We have experimentally demonstrated X-ray diffraction capabilities, including powder diffraction from ionic crystal powders and initial measurements on small single crystals, including protein crystals.

Building on these results, we are implementing a pump–probe platform where the optical laser serves as the pump and the plasma generated Kα radiation acts as the probe. The system will be commissioned for time-resolved powder diffraction and extended to studies of superlattices, single crystals, and protein crystallography.

This approach enables direct investigation of ultrafast lattice dynamics, non-equilibrium phase transitions, and structural evolution in condensed matter systems. The combination of micrometer source size, femtosecond duration, high photon flux, and compact geometry positions this source as an alternative to large-scale X-ray facilities for ultrafast science.

Bayesian Optimization of Multi-Stage Laser Wakefield X-ray Sources

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Abstract

Laser wakefield acceleration (LWFA) has proven highly effective in producing high-energy electron beams and bright femtosecond X-ray pulses. However, achieving high conversion efficiency remains a key challenge for widespread applications. In this work, we numerically investigate the accelerator–radiator scheme – a method that combines a low-density acceleration stage with a higher-density radiator to amplify transverse electron oscillations and boost X-ray yield. To navigate the complex parameter space, we employ Bayesian optimization (BO) within multidimensional particle-in-cell simulations, varying the radiator's position and density to maximize the laser-to-X-ray energy conversion efficiency, $\eta = W_{X-ray}/W_{laser}$. The optimization successfully identifies a high-yield regime where the refocusing of the nearly depleted laser pulse pairs with electron rephasing in the radiator gradient, driving higher electron energies and enhanced X-ray emission. These results demonstrate that BO provides a powerful, computationally efficient framework for maximizing LWFA-based radiation sources and uncovering the underlying nonlinear laser-plasma dynamics.

TAILORING COHERENT EXTREME-ULTRAVIOLET RADIATION VIA DRIVING LASER WAVEFRONT CONTROL

Rohit Kumar[1], Andor Körmöczi[1], Bence Gábor[1], Balázs Nagyillés[1,2], Balázs Farkas[1,2], Tamás Csizmadia[1], Tímea Tímár-Grósz[1], Lucie Jurkovičová[3,4], Matyáš Staněk[3,4], Daniel van Dyk[3,4], Jaroslav Nejdl[3], Valer Tosa[5], Ondřej Hort[3], Zsolt Diveki[1]

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Abstract

The properties of the coherent extreme-ultraviolet (XUV) beam, produced through high-order harmonic generation (HHG), are partially determined by the intensity profile and wavefront of the driving infrared (IR) laser beam [1]. In this study, we investigate how the controlled modification of the driving IR beam's wavefront influences the wavefront, the spatial profile and the spectrum of the generated XUV beam in an argon gas cell under loose focusing conditions. The ellipticity and the orientation of the XUV intensity profiles exhibit pronounced and reproducible changes corresponding to alterations in the astigmatism of the driving IR beam. These changes are quantitatively captured by Zernike polynomial decomposition of the XUV wavefront, retrieved by wavefront sensing techniques [2]. The harmonic spectrum and the total yield (Fig1) also show dependence on the driving beam profile. The observed trends are supported by theoretical modelling based on macroscopic HHG propagation. These results demonstrate that precisely controlled wavefront shaping of the driving laser enables deterministic manipulation of the spatial, spectral and efficiency characteristics of coherent XUV beams. This capability opens new opportunities for optimizing HHG-based sources for applications in ultrafast spectroscopy and attosecond science.

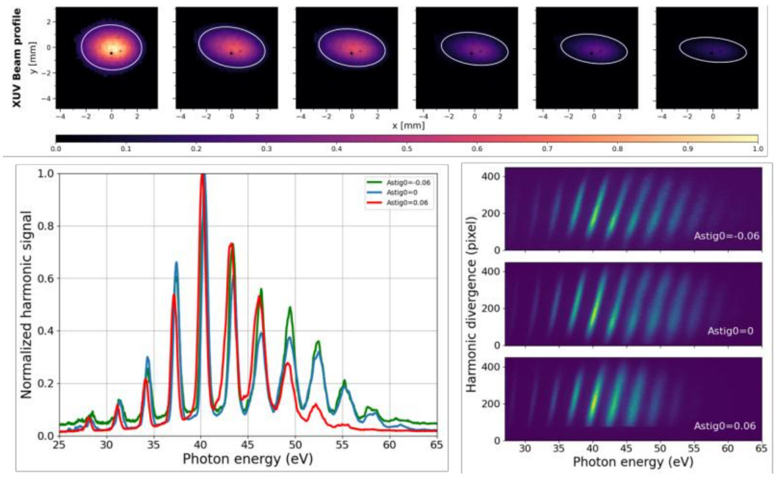

Figure 1. XUV beam profile and HHG spectrum.

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High-brilliance photon source by PW-class laser pulses interacting with a structured overdense target

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Abstract

We present an ultra-high brilliance gamma source exceeding the values of 10^{23}s^{-1}mm^{-2}mrad^{-2}0.1%BW^{-1} in the multi-MeV range based on a multi-petawatt laser interaction with a structured target. First, the laser pulse extracts a high number of electrons from an area close to the tip of a solid blade irradiated on its narrow side. During this initial stage, these electrons are pre-accelerated, which allows them to phase lock with the laser field. As they propagate, they are further accelerated to multi-hundreds-MeV energies and eventually collide head-on with the laser pulse reflected from a plasma mirror placed at the end of the blade. As a result, a large number of high energy photons, exceeding 10^{12} in the high intensity case, are generated in front of the mirror dominantly by the nonlinear inverse Compton scattering (NICS) process.

The interaction is studied by means of 3D simulations performed with the fully relativistic particle-in-cell code SMILEI which includes QED routines based on a built-in Monte Carlo method. The physical processes leading to photon generation are scrutinised at different laser intensities ranging between $3.47\cdot10^{21}$ W/cm^2 and $3.66\cdot10^{22}$ W/cm^2. We also identify additional radiation production mechanisms, particularly synchrotron, which occur in different regions of the target, and at different laser intensities. In all studied cases, the high values of brilliance are a result of relatively low source size of a few micrometers, together with the short duration (~10 fs) and low angular spread of a a few tens of degrees and <10 degrees along the transverse directions of the photon beam, particularly towards higher photon energies.

The ELI Beamlines HHG Beamline as XUV Source and HHG Platform

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Abstract

High-harmonic generation (HHG) provides a compact tool for coherent extreme-ultraviolet (XUV) radiation for ultrafast science. At ELI Beamlines, the HHG Beamline is developed as a versatile user station driven by the L1 Allegra OPCPA laser system, delivering few-cycle, high-energy pulses at kilohertz repetition rate. The beamline combines high photon flux with experimental flexibility, including Multipurpose AMO and Coherent diffraction (MAC) end station [1], various pump-probe schemes, and online diagnostics for routine operation. These capabilities enable the beamline to serve a broad range of XUV applications, from atomic, molecular and optical physics to nanoscopic and condensed-matter targets.

One of key features of the beamline is that spectral properties can be tailored already during the HHG process, reducing dependence on lossy downstream XUV optics. Recent and ongoing developments include tunable narrowband XUV generation in the 20.4–22.4 eV range, enhanced spectral selectivity using driver-beam and medium engineering, and implementation of online XUV energy measurements. In addition, the platform supports complementary short-wavelength source designs, such as high-repetition-rate soft-X-ray laser [2].

Beyond its role as a XUV source for user experiments, the HHG Beamline also provides an ideal environment for investigating the HHG process itself. Examples include phase-controlled HHG in gases, where bichromatic fields reveal phase-sensitive quantum-path effects [3], and HHG in solids, where the emitted spectrum can encode strong-field electronic dynamics such as Floquet–Bloch dressing [4]. Thus, the ELI Beamlines HHG Beamline acts both as a flexible XUV delivery system and as a platform for developing attosecond and strong-field science.

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Simulations of loosely focused drivers for High-Harmonic Generation

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Abstract

The macroscopic effects imposed by the reshaping of the driving pulse are crucial for the macroscopic form of the secondary XUV radiation produced by High-Harmonic Generation (HHG). We present here the numerical simulation results given by a new, lightweight pipeline of the MMA-package [1]. CUPRAD treats the unidirectional propagation of the driver in cylindrical symmetry, allowing us to tackle propagation through long media with reasonable computational cost while keeping all the essential physics. The dipole response is calculated by the Full Saddle-Point Approximation (FSPA) module. Finally, the propagated XUV spectra are given by the Hankel transform module.

Our study is motivated by experimental data obtained at ELI ALPS, in a loosely focused driving-pulse geometry (850 nm, 13 fs, 12 mJ, 20 m focal length) and a long gas cell (32.5 cm). Later simulations will utilize the 1D-TDSE module of MMA to benchmark the accuracy of the FSPA treatment, as well as to verify the simulation's results against the experimental data.

We show the generating medium's reshaping of a Gaussian driving pulse through intensity and phase profiles (Figure 1.). The focal position of the driving laser is shifted +25.5 mm relative to the centre of the gas cell. Initial results show appreciable reshaping of the driving pulse, even in a low-pressure medium (1.1 mbar, argon).

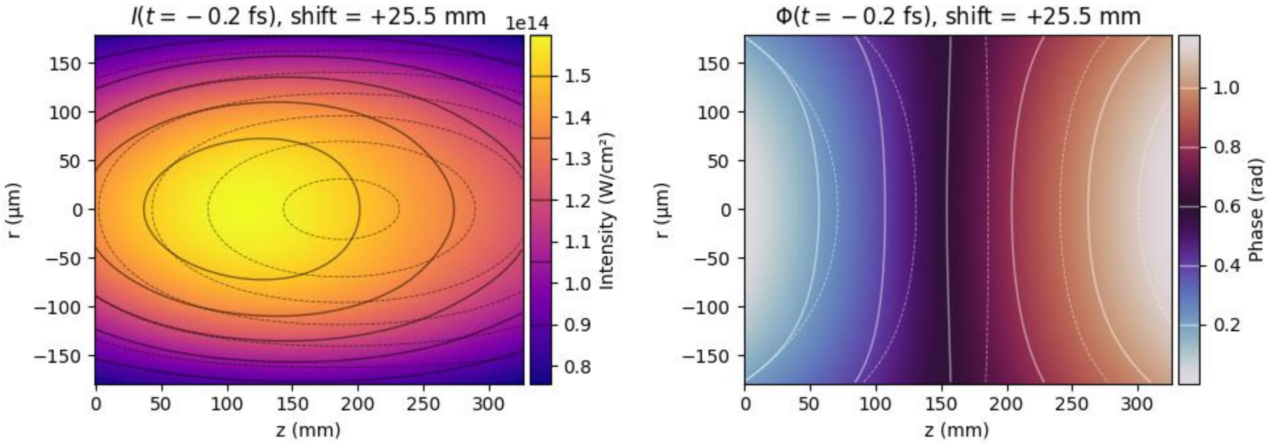

Figure 1. Intensity (left) and phase (right) profiles of the CUPRAD simulated propagation. The solid contours correspond to propagation through 1.1 mBar argon; the dashed contours correspond to propagation through vacuum.

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Comparison of Cu X-ray Emission Generated by 1 µm and 2 µm Femtosecond Laser Pulses

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Abstract

Laser-driven X-ray sources based on femtosecond laser pulses interaction with solid targets are widely used for the generation of characteristic and Bremsstrahlung radiation. Such sources are attractive for applications in medicine, industry, and materials sciences [1]. Recent advances in high-power near-infrared and mid-infrared laser systems have motivated investigations of the influence of laser wavelength on laser-plasma dynamics and X-ray generation efficiency [2].
In this work, we compare X-ray spectra generated from a metallic copper target irradiated by femtosecond laser pulses at wavelengths of 1 µm and 2 µm. The measurements were performed using a *Pharos* laser system (1028 nm, 4 kHz, 158 fs) and an *ORPHEUS MIR* optical parametric amplifier (2000 nm, 4 kHz, 36 fs). The emitted radiation was measured in reflection geometry at 45° using an *Amptek X-123* Si-PIN detector positioned 100 mm from the target. For comparison, both laser beams were focused using 100 mm focal length lenses, and adjusted to the same average power.

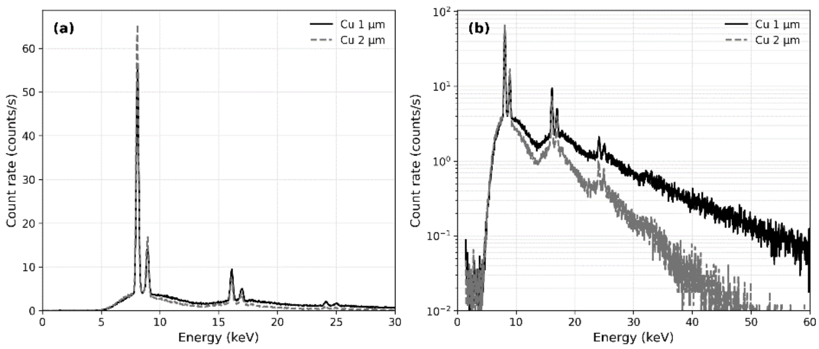

Figure 1. Cu X-ray spectra generated by 1 µm and 2 µm femtosecond laser pulses and normalized to the acquisition time: (a) linear-scale (b) logarithmic-scale

As shown in Fig. 1, both spectra exhibit characteristic Cu K_α (8.04 keV) and K_β (8.90 keV) emission lines together with a broad Bremsstrahlung background and higher-order pile-up features. The measurement with 2 µm laser produced stronger characteristic Cu emission lines, while the 1 µm measurement exhibited a substantially stronger high-energy Bremsstrahlung component extending to higher photon energies despite similar experimental conditions and comparable laser power.
Laser-driven X-ray generation is influenced by multiple parameters, including laser pulse duration, beam quality, focusing conditions, making the influence of wavelength alone difficult to isolate. Nevertheless, the present results suggest that 2 µm femtosecond pulses can produce characteristic X-ray emission comparable to or stronger than that obtained with a 1 µm laser pulses. Future work will focus on matching the experimental conditions to identify wavelength-dependent effects.

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Deep learning based x-ray spectrometer for high repetition rate characterization of betatron radiation with Bayesian optimization

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Abstract

Betatron radiation generated by laser-wakefield acceleration (LWFA) is a broadband, hard X-ray source. Although conventional synchrotron radiation sources can already achieve high repetition rates, the LWFA source currently operates at relatively low repetition rates. For future development toward high-repetition-rate operation, rapid and accurate spectral characterization becomes essential. Traditional reconstruction methods based on forward-fitting are computationally intensive and unsuitable for real-time optimization. Here, we present a deep-learning-based X-ray filter-pack spectrometer that employs two advanced architectures—ResNet18 and DINOv2—to directly predict both the critical energy and photon number from transmission data. We train and evaluate both models using only experimental data. Our results show that DINOv2, leveraging its large-scale pretraining on diverse visual representations, achieves superior prediction accuracy and generalization over ResNet18. Furthermore, we integrate both models with Bayesian optimization to enable rapid, multi-objective source tuning, achieving reconstruction times substantially shorter than conventional fitting approaches. This work establishes that foundation-model-based architectures such as DINOv2 offer a promising path toward robust, real-time diagnostic frameworks for high-repetition-rate LWFA source characterization and active feedback control.