TARG5 Targetry for High Repetition Rate Laser-Driven Sources Workshop

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Book of Abstracts

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High-repetition rate solid target delivery system for PW-class laser–matter interaction at ELI Beamlines

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L3-HAPLS (High-repetition-rate Advanced Petawatt Laser System) at ELI (Extreme Light Infrastructure) Beamlines currently delivers 0.45 PW pulses (12 J in 27 fs) at 3.3 Hz repetition rate. A fresh target surface for every shot was placed at the laser focus using an in-house tape target system designed to withstand large laser intensities and energies. It has been tested for different material thicknesses (25 and 7.6 µm), while L3-HAPLS delivered laser shots for energies ranging from 1 to 12 J. A technical description of the tape target system is given. The device can be used in diverse geometries needed for laser–matter interaction studies by providing an ≈300deg free angle of view on the target in the equatorial plane. We show experimental data demonstrating the shot-to-shot stability of the device. An x-ray crystal spherical spectrometer was set up to measure the Kα yield stability, while a GHz H-field probe was used to check the shot-to-shot electromagnetic pulse generation.

Finally, we discuss short and mid-term future improvements of the tape target system for efficient user operation.

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High-repetition rate plasma mirror for improved contrast at ELI-ALPS

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Modern laser facilities for Laser-Driven Plasma Acceleration (LDPA) reach intensities < $10^{20} W/cm^2$ making them capable of accelerating particles up to the relativistic regime. In order to have an efficient acceleration mechanism the laser pulse needs to interact with the laser at its top intensity, nonetheless effects like ASE and pre-pulses can generate intensities high above the metal and dielectric ionization thresholds (~~$10^{11} W/cm^2$ and $10^{13} W/cm^2$). To overcome these limitations different techniques have been developed such as XPW, plasma mirrors and OP-CPA font ends.

In this work we present a high-repetition rate plasma mirror developed for the ELI-ALPS tested at the50 TW laser at L2A2 Lab at the USC (1J, 30 mJ, 35 fs, 10Hz, Ti:Sapph system) and the Sylos alignment beam at ELI-ALPS (30 mJ, 15 fs, 10Hz, OPCPA system). The PM works with a small incidence angle (< 4°) that allows us to use P-polarization through the experiment. A commercial AR (NBK-7, MgF2, R< 1.75% @ 800nm) substrate is ionized by the laser pulse to reflect the main part

of the laser beam and improve the contrast below 10^{-9}. As the target is destroyed after every shot, we rotate the substrate using a target composed by a rotational and a linear stages. This allow us to operate the PM with high stability with a repetition rate of 10 Hz for more than 14.000 continuous shots. We present measurents of the performance of the PM which show good stability in the pulse duration, the energy contrast, the reflectivity, beam pointing and Strehl ratio in two different laser systems.

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A multi-shot wheel-target assembly for laser-plasma proton acceleration

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A multi-shot target assembly for laser-plasma proton acceleration has been commissioned at the Laser Laboratory for Acceleration and Applications (L2A2), at the University of Santiago de Compostela. The assembly consists of a multi-target wheel holding plain target foils for around 1000 – 2000 shots. Two linear stages and one rotating stage hold the target wheel and move it to replenish the target material, and to position it at the laser focus. For this purpose, we have developed a procedure for the shot-to-shot correction of the target position, capable of functioning at the L2A2 laser nominal repetition rate of 10 Hz. This procedure is based on a detailed 3D mapping of the impact positions at the targets, obtained by measuring the deformation of the target surface with an optical position sensor prior to the irradiation. The map is then programmed into the stages which automatically correct the laser focal position on the target shot-to-shot with micrometric resolution. The reliability of this procedure was tested by performing an online mapping of the target surface during the correction, in synchronization with the positioning of the impact points at repetition rates of 10 and 15 Hz. The obtained stability in the positioning resulted to be about 4 μm standard deviation over 2016 points.
As a second validation, protons up to 1.7 MeV were successfully accelerated in the Target Normal Sheath Acceleration (TNSA) regime by irradiating Al foils of 12 μm-thickness with 1.2 J, 40 fs (3.6·1018 W/cm2) laser pulses at the L2A2. We have performed series of 24 shots at 10 Hz reaching a stability in proton maximum energy of about 13%, and of about 16% in the spectral temperature.

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Title: Spectroscopic Real Time Temperature Diagnostic for Laser Heated Thin Gold Foils

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In the past four years we have investigated gold ion acceleration at the Texas Petawatt laser (Austin, Texas with a pulse length of 110 fs) and the GSI PHELIX laser in Darmstadt (with a pulse length of 500 fs) [1,2] in the context of developing the novel 'fission-fusion' nuclear reaction mechanism [3]. In order to allow for efficient heavy-ion acceleration with kinetic cutoff-energies above 5 MeV/u (finally aiming at 7-10 MeV/u), targets were preheated in order to clean the surface by evaporating surface contaminants like hydrogen and carbon. This had varying effects on the cutoff energy of accelerated ions, suspected to correspond with laser pulse length. We have constructed a target preheating system and algorithm to accurately measure in real time the temperature of gold targets in vacuum at the Center for Advanced Laser Applications (Garching, laser pulse length 25 fs) to assess the relationship between target preheating and gold ion acceleration for a short pulse laser [4]. By heating the target (typical diameter 1.5 mm, thickness between 250 nm and 400 nm) with a 3 W cw 532 nm Nd:YAG laser and measuring the thermal infraread spectrum emitted from the target with a NIR spectrometer, the algorithm subsequently fitted Planck's radiation law to the thermal spectrum, thus allowing to determine the target temperature. With this, gold targets were already successfully heated up close to their melting point (1064 °C).

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Fully Isolated Targets for High Power Laser Interaction applying a Paul Trap

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We will give an update on the current developments on our target positioning system for levitating, isolated micro spheres. The Paul trap system is specifically designed to ensure functionality at high-power laser systems. Active damping enables reliable overlap of the micrometer-sized target with the micrometer-sized laser focus.
The complete target system can now be fully remote controlled. These improvements enabled repetition rates of the order of one shot every 10-15 minutes, mainly limited by the time required for inserting and retracting the microscope for imaging target and laser focal spot.
We recently performed experiments at the ZEUS laser at the Centre for Advanced Laser Applications, a 5 TW Ti:Sa laser system, for laser plasma expansion studies at intensities of 10^{16} W/cm^2. These studies were prerequisites for experiments at the JETi 200 laser at the Helmholtz Institute in Jena, where plasma expansion was initiated by a similarly strong, artificially introduced pre-pulse for studying the effect on ion acceleration from microscopic spherical targets at reduced density.

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Cryogenic sheet jet targets produced from liquid hydrogen for high repetition rate experiments

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Cryogenic jet targets are attracting growing attention in scientific fields investigated at x-ray free electron laser and high power laser facilities, e.g. in high energy density science exploring extreme states of matter or in relativistic laser plasma interactions aiming to develop novel ion accelerators. A key advantage of cryogenic targets is the unique capability to deliver ultra-pure samples at solid density using chemical elements that under ambient conditions exist in the gas phase (e.g. hydrogen) and to generate replenishing, free-standing, debris free targets at high repetition rates.
Sheet jets in particular, due to their extended width and an adjustable thickness, are of special interest for parametric studies, e.g. the investigation of different acceleration mechanisms in laser driven plasmas.
In this talk, we present experimental studies on the characterization of hydrogen sheet jets ejected from split nozzles under various operation conditions. The jet, which forms leafed sheets altered by the surface tension, solidifies within a millimeter due to strong evaporative cooling upon which the sheet width and thickness is conserved further downstream yielding constant target conditions. The respective fluid dynamic and thermodynamic behaviour is discussed and compared with computational fluid dynamic simulations.
Understanding of the flow and the solidification of free-flowing liquids will help to design specialized nozzles for the generation of jet targets with tailorable parameters.

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An astigmatic method for target pre-alignment at high-repetition rate

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After the interaction between an intense laser pulse and a solid target, the target is usually destroyed. Due to this damage, a target delivery technique must be implemented to renew the target with the required repetition rate and precision. This process must be done carefully to maintain the target in focus at high repetition rate (1 kHz), since an online measurement of the target position is difficult to achieve [1,2]. A solution to this problem is to measure the target position for each programmed sequence before the experiment and use this map to correct the position when shooting the target. In this work, we present the results of a surface target mapping implementing an astigmatic method. The astigmatic focusing method is a well-known technique used in microscope objective focusing [3,4]. We use this focusing system to characterize the surface by mapping a solid target in a confocal setup at normal incidence, respect the target. We tested our astigmatic focusing method using the L2A2 laser system (Universidad de Santiago de Compostela, 25 GW, 1mJ, 35 fs, 1kHz, Ti:Sapph amplified system). A fraction of a 2-inches target (1/8) was mapped in less than 15 minutes with an accuracy of ± 10 µm. A full target mapping could be performed in 120 minutes or less. The information of the surface calibration can be loaded to a programmed sequence of the target delivery to run the experiment. This remote technique, to characterize the deviations of the target with respect to focus, will enable a microfocus laser-plasma X-ray source with high average power and stability, which is essential for some applications.

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Advancements in double-layer target production for enhanced laser-driven ion acceleration

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Laser-driven ion sources [1] represent a promising alternative over conventional ion and electron accelerators, with potential applications ranging from the medical field [2] to nuclear and material science [3]. Compact laser-driven ion sources would be a valuable asset in many of those applications, exploiting tabletop laser systems—in the range of tens of TW and capable of high repetition rate operation. To make up for the laser relatively modest characteristics, it is crucial to drive an efficient acceleration process, shifting the focus to advanced targetry. If the front side of a micrometric or sub-micrometric solid target is covered with a near-critical density layer, the laser-matter coupling and thus the acceleration process are enhanced, as demonstrated in numerical and experimental studies [4,5]. At high repetition rate operation, shot to shot variation in target properties should be minimized, a further challenge for target manufacturing.
In this contribution we present the full production and characterization of near-critical double-layer targets (DLTs), in the form of arrays on a perforated target holder, ready to be employed in particle acceleration experiments. The DLTs are composed of a near-solid density titanium thin film, coupled with a nanostructured carbon foam layer of near critical density.
The deposition of titanium (Ti) film on the hollow holder is achieved by first filling the holes with caramel, thus levelling its surface. The magnetron sputtering technique is then exploited to deposit a solid film, both in DCMS (Direct Current Magnetron Sputtering) and HiPIMS (High Power Impulse Magnetron Sputtering) regimes [6]. An ideal combination is found alternating the two techniques during the deposition, allowing a fine control of the film morphology, density, uniformity and internal stresses. All these properties are of great importance for the film mechanical stability, while the film thickness uniformity and its density could be relevant also for the acceleration process. After the deposition the caramel can be dissolved in water, leaving a flat freestanding Ti film with near bulk density, low residual stresses and high thickness uniformity over the whole target holder area. Freestanding Ti films ranging from 400 nm to 1.8 µm were successfully produced.
Nanostructured carbon foams are porous materials with a fractal structure and mean density down to a few mg/cm3 [7], thus one of the few possible candidates for the near-critical layer. They are deposited on the freestanding Ti film with femtosecond Pulsed Laser Deposition (fs-PLD), a variation of the conventional nanosecond PLD employing shorter laser pulses. This effectively extends the range of the experimental parameters available to the technique, allowing a better control of the carbon foam properties. The compatibility between film and foam is also explored.
Finally, 2D particle in cell (PIC) simulations are performed considering the DLT range of parameters

obtained experimentally, assuming both TW and PW class lasers; the results show a significant enhancement in the acceleration process, acting as a useful support for the foreseen experimental ion acceleration campaigns.

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Cryogenic jet platform for High-Energy-Density experiments at European XFEL

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Jets of cryogenically cooled hydrogen has been fielded just recently in the disciplines of plasma physics and high energy density science in order to explore extreme states of matter as found deep inside planet interiors [1, 2] or in relativistic laser plasma interactions aiming to develop table-top ion accelerators [3, 4, 5]. Latter promise a wide range of potential applications as compact particle source for medical tumor therapy treatments or high flux neutron converter for material radiography. The respective research towards a detailed understanding of the microscopic spatiotemporal evolution of transient laser plasmas is one of the key goals of the high-energy-density (HED) instrument combining brilliant x-ray pulses of the European XFEL facility and ultra-high-power laser drivers of HIBEF*.
This talk will introduce the new standard platform for cryogenic liquid jet delivery, currently developed and soon commissioned at the HED instrument, which aims to provide targets of various types of liquids, shapes (circular, sheets, droplets) and sizes. Compared to solid foil samples, stably free-standing replenishing jets promise continuous 10 Hz repetition rate by mitigating debris, one of the major obstacles in high power laser experiments. The platform integration into the beamline including online target characterization diagnostics will be presented.

*HIBEF - Helmholtz International Beamline for Extreme Fields

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Recent updates on the nano-foil target positioning system

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The commissioning of the Laser-driven ION beamline (LION) at the Centre for Advanced Laser Applications (CALA) in Garching near Munich required a repetition rated target system. The nano-foil target positioning system for intense laser plasma experiments as presented by Gao et al was developed for this purpose and demonstrated at the ATLAS 300 tera-watt Ti:Sa laser. This device can store ~1700 target foil position prior to the experiment and recall them with an accuracy of ~ 5 μm during an experiment. Since this publication it was adapted to the ATLAS peta-watt upgrade and looser focusing from an f/2 to an f/5. The target holders were redesigned to counter the increase of fratricides of nearest neighbor targets due to higher pulse-energy and increased focal-spot size. The distance between the holes has been increased and their diameter expanded to 1.5 mm. Each of the 19 holders can easily clip on to three spherical magnets, which are glued into the new PMMA plastic wheel frame. This frame is not manufactured with the same precision as the previous and additional position offsets are compensated by the software. The software has been ported to python and fully integrated within our TANGO controls setup. With the update, the preparation of the target alignment is now fully automated in vacuum, and records an image of each registered target. These are automatically previewed to the operator during the experiment who can reject individual targets based on visible damages. The current implementation of the software is not synchronized to the laser and is limited to one shot every 6 seconds.

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All-optical plasma density shaping of a cryogenic hydrogen jet target for laser ion acceleration

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Target densities near the critical plasma density are of great interest for the laser-ion acceleration community, as new and interesting acceleration mechanisms can occur at these densities due to the effect of relativistically induced transparency.
Designing and builing near-critical densitiy targets with closely defined parameters has thus been the goal of much recent and ongoing target development.

Here, we present our approach for a density tailored near-critical target, that utilizes controlled pre-expansion of a cryogenic hydrogen jet target used at the Draco laser facility at Helmholtz-Zentrum Dresden-Rossendorf (HZDR).
The cylindrical solid hydrogen jet target is irradiated with pump laser pulses in the range of 10^{12} to 10^{18} W/cm². The expansion of the emerging plasma cloud is studied over several tens of picoseconds by means of high resolution two-color off-harmonic optical probing.
At high pump laser intensities, a simple toy model of the radial density profile of the expanding jet target is applied to estimate the evolution of the plasma density during the expansion process.
We show, how the expansion process can be directly influenced by controlling intensity and temporal shape of the pump laser pulses.

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Boosted MeV-gamma and particle generation in short pulsed laser interaction with long-scaled NCD plasma of aerogel foam targets

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Ultra-high intense gamma and secondary particle beams are indispensable tools in many research fields like nuclear, atomic and material science as well as in biophysical and medical applications.
Providing ultra-high intense and ultra-short pulsed beams, laser-driven relativistic electron beams are excellent tools for the generation of MeV gammas, protons and neutrons.
We report on enhanced laser-driven electron beam generation in the multi-MeV energy range that promises a tremendous increase of applicability.
Here, it is presented a novel concept for the efficient generation of gamma and neutron beams based on relativistic laser interactions with a long-scale near critical density plasma at moderate relativistic laser intensities. The basis is a target system with CH aerogel foam of sub-mm thickness and a volume density of 2 mg/cm^3.
New experimental insights in laser-driven generation of ultra-intense well-directed multi-MeV beams of photons with fluences of >10^{12} ph/sr above 10 MeV and an ultra-high intense neutron source with 6×10^{10} neutrons per shot are presented. We observed high conversion efficiencies of laser energy to MeV-gammas (1.4%—2% above 10MeV) and neutrons (0.05% at 0.5—1MeV) already at moderate relativistic laser intensities.
These new insights of laser-driven ultra-intense gamma and neutron sources show a high capability for providing applicable beams in nuclear astrophysical research as well as in nuclear photonics applications. In addition, it promises a strong boost of the diagnostic potential of existing kJ PW laser systems used for ICF research.

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Development of a thin liquid jet for ultrafast spectroscopy

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Spectroscopy of liquids and microscopic specimens within liquid environment is important as much of the reactions concerning life on earth happen in the aqueous environment. However such study faces difficulty when we try to use photons from the parts (e.g. infrared or extreme ultraviolet) of the electromagnetic spectrum which get strongly absorbed within the aqueous environment. Although, sub-micron diameter cylindrical jets paved the way for development in this direction, these pose problem regarding refraction or scattering at the boundary reducing the signal quality [1]. The recent advent of thin-flat jets can be proven to be useful circumventing all these problems. Attosecond spectroscopy of liquid water has been recently demonstrated with such a flat liquid jet [2]. Here we report the development of a sub-micron thick flat jet with millimetre size extension. This flat jet is produced using a microfluidic gas-dynamic chip, similar to the one reported in Ref. [3]. This chip has three micro-channels all converging at the bottom. The middle channel carries the liquid, whereas the outer channels carry the gas. Optimum gas and liquid flows produce such thin liquid jet. The system can be operated in air or in high vacuum condition. This presents the opportunity to do high resolution spectroscopy of liquid samples. The continuous flow of the liquid also ensures thermal damage free ultrafast spectroscopy especially using high repetition rate photon sources.

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Synthesis of freestanding porous alumina and copper nanowires for high power laser applications

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Nanostructured targets, with a brush like geometry (e.g., nanowires NWs), showed improved laser absorption both in particle-in-cell simulations and experimental studies on laser-driven particle acceleration. Using aligned nanowires with sub-wavelength diameter the maximum proton energy can be enhanced up to 2-3 times, due to increased hot electron density and temperature. By controlling the porosity and thickness of nanostructured targets like metallic nanowires and free-standing porous alumina (AAO) we propose to investigate the improvement of the energy of the accelerated ions at intensities beyond 10^{21} W/cm^2. At ELI-NP freestanding porous alumina, together with copper nanowires (Cu NWs) were obtained by electrochemical methods, both to be used as targets for high power laser experiments. Commercial aluminum plates are the raw material used as substrate, to which preliminary processes (such as: mechanical polishing, thermal treatment and electropolishing) were applied to obtain a smooth and contaminant free surface. Thorough characterization of the obtained patterned targets have been performed (surface morphology, topography, structural/crystallographic measurements, elemental analysis) and will be presented. The process has been optimized and controlled by changing the key parameters (e.g., electrolyte solution temperature, anodization voltage, Al plate lateral dimensions, stirring speed) to obtain the desired characteristics of porous alumina on Al substrate, which was used as a template for Cu NWs deposition. Cu NWs were deposited in porous alumina by DC and pulsed AC electrodeposition method, resulting in NWs of 0.5-10 µm long and 50-200 nm in diameter, on aluminum substrate. The freestanding alumina had a thickness that can be varied in the 7-100 µm range, with pore diameter of 30 to 100 nm and 30-100 nm interpore distance, corresponding to a porosity which can be varied between 30-70% and density of 2.7 g/cm^3 down to 1 g/cm^3. Free-standing porous alumina targets are also showed, with two proposed structures: closed bottom side (by the barrier layer) or open pores all the way through the target.
For laser-driven particle acceleration experiments, freestanding alumina templates with or without opened bottom pores and metallic nanowires are of interest and will be used at ELI-NP facility.

Among these, the freestanding alumina targets, with lateral dimensions 10×1-2 mm^2, mounted on custom-made frames in the laser experimental area are also briefly presented.

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Electron transport in the nanowire target irradiated by an intense laser pulse

Author: Jian Fuh Ong[1]

[1] *Extreme Light Infrastructure - Nuclear Physics*

The interactions of ultra-intense lasers with solid targets with nanowires received a lot of attention because they appear to show potentials to increase the laser light absorption rate. Laser-nanowire interactions open up various applications such as attosecond bunch generation, enhanced x-ray generation, brilliance gamma-ray yield, as well as efficient micro fusion. Despite many studies on this topic, either numerically or experimentally, the electron dynamics under the action of a strong laser field across the nanowire remain unclear. We report our observation of the electron transport inside the nanowire when irradiated by the intense laser pulse. We found that a plasma wakefield is excited by the double frequency electron bunches. These fast electron bunches are generated by the J X B heating of the linearly polarized laser pulse at the tip of the nanowire. This wakefield has an amplitude of the order of TV/m, oscillating at the plasma frequency, and propagates into the nanowire. Electrons injected at the later stage are accelerated by the wakefield when the right initial conditions are satisfied. In addition, we observed the quiver of the electrons across the nanowire under the action of the electric field normal to the nanowire surface. This electron crossing served as the secondary drive bunch and facilitates deeper wakefield propagation in the nanowire. We show the detail of electron transport by using 2D and 3D Particle-In-Cell (PIC) code EPOCH and PICONGPU. The acceleration of these bunches has generally increased the electron energy absorption by more than 2 times as compared to a flat target.

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Pushing proton energy frontiers with pre-expanded, actively controlled, near critical density targets

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Liquid Targets for high repetition rate Laser plasma accelerators

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>10 GeV electron acceleration from a nanoparticle-wakefield target at the Texas Petawatt Laser

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Aerosol laser targets for soft X-ray generation

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Targets for pump probe experiments at upcoming XFEL facilities

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Acceleration form a coil target for spectral and spatial control of laser accelerated ions

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Development of a Ultra-Stable High Repetition Rate Tape Targetry System for the EPAC Laser Facility

Corresponding Author: cspindloe@gmail.com

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Optical field ionization for plasma optic fabrication

Optical field Ionization techniques have been used for many years in plasma targetry manufacturing in order to create guiding structures or for controlling electron beam acceleration distance and injection position. These techniques have been shown to be viable in high repetition rate systems. In this talk, I will present results of using such a technique to create and control longitudinally varying plasma optics for high intensity laser plasma interaction.

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Targetry Automation - For higher repetition rate experiments at HHT / APPA