43rd International Workshop on High-Energy-Density Physics with Intense Ion and Laser Beams

January 29th – February 4th, 2023

Darmstädter Haus (Waldemar Petersen Haus)

Hirschegg, Austria

Book of Abstracts

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Dynamics and Variability in Near Unity Gain Inertial Confinement Fusion Implosions on the National Ignition Facility (+ Ignition!)

Laurent Divol (Lawrence Livermore National Laboratory)

The ability to robustly achieve net energy gain G>1 from fusion plasmas is a grand scientific challenge and is being pursued via multiple approaches by different institutions around the world. This talk will describe the last 15 months of layered cryogenic implosions on the NIF, from the record thermonuclear yield=1.3MJ shot of 08/08/2021 (G=0.7), the four subsequent repeat attempts yielding between 0.25 and 0.75 MJ, to the first shot achieving ignition on 12/04/2022 (G>1). I will focus on how we quantified the main sources of thermonuclear performance variability, observed the dynamics of igniting hotspots as they burn and expand, and finally achieved ignition.

This work was performed under the auspices of the U.S. DOE by LLNL under Contract No. DE-AC52-07NA27344.

Latest Advances at the PHELIX Facility at GSI and New Platform for Warm Dense Matter Experiments

Zsuzsanna Major (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Udo Eisenbarth (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Christian Brabetz (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Bernhard Zielbauer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Sabine Kunzer (GSI, Darmstadt), Dirk Reemts (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Stefan Götte (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Dennis Neidherr (GSI, Darmstadt), Paul Neumayer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Philipp Hesselbach, Marcus Malki (Technische Universität Darmstadt(TUDA-IAT)), Xiao Yu (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Karin Weyrich (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Andreas Tauschwitz (GSI, Darmstadt), Dmitry Varentsov (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Dominik Kraus (Universität Rostock), Julian Lütgert (Universität Rostock Physik(URO-PH)), David Riley (QUB)

The Petawatt High-Energy Laser for Heavy-Ion EXperiments (PHELIX) facility at GSI has been in operation for almost 15 years, providing high-energy laser pulses for laser-plasma experiments. Owing to the architecture of PHELIX, a large variety of pulse parameters can be offered to the international user community, allowing for a wide range of experiments. The investigated topics include laser-driven secondary sources of ions, electrons, neutrons and X-rays, which are used for various applications ranging from understanding the laser-plasma interaction itself, to applications in the biomedical direction and nuclear reactions. The unique feature of PHELIX is its vicinity to the GSI heavy-ion accelerator, which allows for the high-energy laser pulses to be used in combination with the heavy-ion beam. These tools enable the study of matter under extreme conditions in the laboratory, contributing towards the understanding of the behaviour of matter in e.g. astrophysical objects.

In recent years, several improvements and additions have been implemented at PHELIX, in order to optimize the laser-pulse parameters for the different applications. We will present an overview of these recent developments, which also includes the recently established beamline guiding the PHELIX ns-pulse to the HHT (high-energy, high temperature) cave downstream of the SIS-18 heavy-ion synchrotron of GSI. Here the intense heavy-ion pulse is used to create states of matter of interest that can then be investigated using laser-driven X-rays. We present the experimental platform now available at the HHT cave and discuss the diagnostics possibilities both for the laser-driven X-rays and the heavy-ion beam.

High Energy Density Science at the European XFEL: Combining Bright X-Rays, Tiny Diamonds and Intense Lasers.

Ulf Zastrau (European XFEL)

The advent of the first X-ray free-electron lasers (XFELs), FLASH in 2004 and LCLS in 2009, may prove to be the most profound development since the invention of the laser and, equally, the synchrotron. Sharp improvements in a number of laser parameters, most notably intensity and pulse duration, support this expectation. This brings scientific dreams within reach. Indeed, the unprecedented opportunities and expectations have triggered considerable research activities worldwide. In my talk, I will give an overview of the experimental application of the European XFEL to explore relativistic laser plasma interactions, warm dense matter, materials in extreme conditions, and laboratory astrophysics.

Since May 2019, the High Energy Density Science (HED) instrument at the European X-ray Free-Electron Laser Facility in Schenefeld, Germany, allows international users to investigate a wide range of materials and systems at extreme conditions [1]. European XFEL and the HIBEF user consortium form a joint group of more than 40 people for HED research, development and user operation.

To drive a sample from ambient conditions to extreme excitations, a variety of high energy drivers are available. In particular, we have three separate optical laser systems for warm- to hot-dense-matter creation, dynamic compression and laser-plasma interaction in electron-relativistic regime. These drivers allow studying various phase space parameters with time-resolution down to 10 fs, pressures into the TPa regime, and electric field strength up to 1021 W/cm, both at surfaces and in the bulk. Also, it is the first XFEL instrument offering a dedicated platform for research in dynamic diamond anvil cells for studies at high pressures. In the near future, a 60T pulsed magnet for transient studies of superconductivity will be introduced.

The unique HED instrument allows to study these systems with precise ultrafast x-ray probes including spectroscopy, x-ray diffraction, small- and wide-angle scattering as well as phase contrast imaging methods [2]. It is fully tuneable in the photon energy range from 5 to 25 keV at different bandwidths, can be focused to a variety of diameters.

The capabilities of the HED instrument, including the HIBEF user consortium contributions [3], will be presented along with selected science cases and first scientific results from the first 4 years of user operation. Highlights include direct temperature measurements from acoustic phonons in diamond [4], plasmon and bound-free scattering (X-ray Raman) from the electronic subsystem, continuum lowering as function of density and ionization degree, chemical reactions and formation of new phases at high pressure and temperature [5,6], spin transition and volume collapse in iron-bearing carbonates at Earth-mantle conditions, as well as electron filamentation, relativistic transparency and hole boring in relativistic laser plasmas, and laser-matter coupling, energy transport and ablation dynamics on laser-irradiated surfaces.

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[2] K. Appel, et al., Plasma Phys. Control. Fusion 57, 014003 (2015).
[3] www.hibef.de; McMahon and Zastrau, DOI: 10.22003/XFEL.EU-TR-2017-001
[4] A. Descamps et al., Sci Rep 10 (1), 14564 (2020)
[5] H. Hwang et al.; Journal of Physical Chemistry Letters, 2021; DOI: 10.1021/acs.jpclett.1c00150
[6] H.-P. Liermann et al.; Journal of Synchrotron Radiation, 2021; DOI: 0.1107/S1600577521002551

High-Energy Density Laser Matter Interaction at ELI Beamlines

Florian Condamine (Extreme Light Infrastructure ERIC - ELI Beamlines), Stefan Weber, Raj Singh, Tomas Lastovicka, Peter Rubovic, Gaetan Fauvel

ELI Beamlines (part of the ELI European Research Infrastructure Consortium), located near Prague, is a new high-energy and high-intensity laser facility that will become available for users from mid-2023. The hall dedicated to plasma physics research has access to different beams covering all aspects of state-of-the-art research in this field of science.

The L4-ATON laser, will reach the 10 PW level (1.5 kJ, 150 fs), while its non-compressed version (L4n) already delivers > 500 J pulses (1 to 10 ns pulse duration) at the unprecedented rate of 1 shot every 3 minutes. The L3-HAPLS laser, already commissioned to the 0.5 PW level (12 J, 27 fs, 3.3 Hz) will be upgraded to the 1 PW level by mid-2024.
Used as single beam or in combination between each other, these 2 lasers will allow a much faster and efficient data collection for users in plasma physics. This will be particularly the case for ns-kJ HEDP research which rely most of the time on very low repetition facilities (1 shot every hour or more).

In this talk, we show an overview of the equipment that will be available for the first user experiments as well as the laser parameters. We also discuss the process for proposal application and campaign preparation.

Towards Stable Multi-GeV Laser-Wakefield Operation on PW Lasers

Stefan Karsch (*Universität München*)

K. v. Grafenstein, F. M. Foerster, F. Haberstroh, N. Weisse, D. Siebert, F. Irshad, E. Travac, D. Campbell, G. Schilling, A. Döpp , and S. Karsch

Laser-driven particle accelerators have made tremendous progress over the last two decades, with ion acceleration breaking the 100 MeV barrier, and electron energies approaching 10 GeV. Despite refined ways to control the injection and acceleration process, the relatively large particle energy spread and poor shot-to-shot reproducibility are still the major challenges for their suitability as a future replacement of conventional RF accelerator technology. Indeed, poor reproducibility is also a key inhibitor of progress towards narrower bandwidth, as it makes the required fine-tuning of beam parameters impossible. The instability of laser-driven accelerators originates in fluctuations of the laser, target and injection parameters. Especially the former are exacerbated by the trend towards larger laser systems with long beam paths in air, large beam sizes and higher wavefront aberrations of large optics. After the upgrade of the ATLAS-laser at LMU from 300 TW to 2 PW peak power, the same system turned from an accelerator driver with world-leading reproducibility into one with average performance in that respect at best.
Over the course of 4 years, through many detail improvements, we recently were able to recover the previous stability in experiments, as we will show in the case of GeV and multi-GeV electron acceleration. We will discuss the influence of air turbulence, spatio-temporal coupling and fast thermal drift in the laser on the acceleration process and present measures taken to keep those influences under control. A new injection method largely eliminates shot-to-shot jitter in the injection position and affords new levels of control over the injected charge, thus allowing to fine-tune the electron bandwidth. In that way, we are now able to reliably produce 2.5-GeV electron beams from gas cells and >1GeV monoenergetic beams in gas jet targets.

Advances in High-Repetition-Rate Metrology of Laser-Driven Ion Beams and Electromagnetic Pulses at the CLPU for IMPULSE

Michael Ehret (*CLPU*), *Giancarlo Gatti* (*CLPU*), *Luca Volpe* (*UPM*), *Daniel Ursescu* (*ELI-NP*)

We present results from the ongoing IMPULSE project (Integrated Management and reliable oPerations for User-based Laser Scientific Excellence, EU H2020 GA 871161), i.e. efforts towards metrology standardization of primary and secondary laser driven sources. We will give an overview of the standardization of metrology for laser plasma experiments, laser sources, and laser based secondary sources.

The pan-european character of the project is emphasized with an insight to contributions from the Spanish Pulsed Laser Centre (CLPU) [1-5]. We will shed light on ion sources and electromagnetic pulses (EMP) as well as possible application cases for future beamtime applicants. High power lasers are presented as primary sources, driving (a) TNSA proton beams with cut-off energies of the order of 10s of MeV, and (b) sources of strong electromagnetic pulses of the kV/m.

Keywords: extreme light infrastructure, secondary sources, high energy density,
References:
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[2] M. Huault et al., on spatio-spectral ion characterization, submitted to HPLSE (2022)
[3] J. I. Apinaniz et al., on the use of narrow-band proton spectra, in preparation (2022)
[4] A. Morabito et al., on the characterisation of low energy ion spectra (2022)
[5] M. Ehret et al., arXiv:2208.14202 and arXiv:2207.06082

Chemistry of Light Element Mixtures at Icy Giant Conditions

Michael Stevenson (University of Rostock), Divyanshu Ranjan (Helmholtz-Zentrum Dresden-Rossendorf), Philipp May (University of Rostock), Fiona Speller (University of Rostock), Dirk Fründt (University of Rostock), Arianna Gleason (Stanford University), Jean-Alexis Hernandez (European Synchrotron Radiation Facility), Nicolas Sévelin-Radiguet (European Synchrotron Radiation Facility), Raffaella Torchio (European Synchrotron Radiation Facility), Christopher McGuire (Lawrence Livermore National Lab), John Eggert (Lawrence Livermore National Lab), Silvia Pandolfi (Stanford University), Dominik Kraus (HZDR)

Extreme conditions are ubiquitous in nature. Much of the matter in the universe exists under high pressures and temperatures. Of interest, are the planetary interiors of the icy giants, Uranus and Neptune. Which have particularly complex magnetic fields [1]. To understand these complex magnetic fields the conditions and composition of these planetary interiors need to be determined. The interiors of these planets are understood to contain mixtures of water, ammonia, and hydrocarbons [2].
To understand observed behaviours in planets it is of the upmost importance to study their constituents. Several behaviours have been suggested for instance, as the mechanism of the complex magnetic fields observed for the icy giants. For example, the presence of either, high pressure superionic ammonia and water ices [3-5] or, metallic hydrogen formed by the de-mixing of hydrocarbons [6,7].
To study icy giants both isolated water and plastics acting as “synthetic planets” have been shock compressed to icy giant interior conditions. The water was shock compressed into the superionic region of the water phase diagram to determine the structure of the ice under these conditions. These compression experiments also investigated hydrocarbon de-mixing under planetary interior conditions for several bioplastics. The bioplastics allowed for different planetary stoichiometries to be studied in this case simulating several different carbon:water ratios and determining the effect of the presence of oxygen in nanodiamond formation in shocked plastics.
Ongoing campaigns at XFEL, synchrotron, and laser facilities study the behaviour of the hydrogen in de-mixed shock compressed plastics, various plastic stoichiometries to simulate differing planetary interior mixtures, as well as new plastic “slurry” targets for routes of novel hydride formation in shock compression experiments.

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[2] M. D. Hofstadter et al., Ice Giants: Pre-Decadal Survey Mission Study Report, NASA-JPL report JPL-D-100520 (2017).
[3] C. Cavazzoni et al., Science, 1;283(5398):44-6 (1999).
[4] M. Millot et al., Nature Physics 14, 3 (2018).
[5] M. Millot et al., Nature 569, 7755 (2019).
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[7] D. Kraus et al., Nature Astronomy 1, 606-611 (2017).

Dynamics of Diamond Nucleation and Growth in High-Pressure Hydrocarbons

Dirk Gericke (University of Warwick)

Diamond as a stable high-pressure phase of carbon is predicted to be created inside giant ice planets and during high-pressure experiments. Indeed, simulations and experiments have shown diamond formation in hydrocarbons at high pressures but the predicted nucleation rates strongly differ. Here, we present a theoretical model that allows to assess nucleation and growth rates in experiments in more detail. It includes the depletion of the carbon, allows for adjustments of the growth with particle size and keeps track of the spatially different dynamics created in shocks travelling through the sample. The connection to the experiments are made by using measured data as boundary conditions that fix the nucleation and growth rates. In addition to the dynamics of diamond formation, we also obtain information on the size distribution at a given time. Implications for planetary sciences and creation of nano-diamond by laser-driven shocks will be discussed.

Material Properties of Matter in Saturn’s Interior From Ab Initio Simulations

Martin Preising (Universität Rostock), Martin French (Universität Rostock), Christopher Mankovich (California Institute of Technology), Francouis Soubiran (Commissariat à l’énergie atomique et aux énergies alternatives), Ronald Redmer (Universität Rostock)

Calculation of material properties from ab inito simulations along Jupiter [1] and Brown Dwarf adiabats [2] have been subject of earlier studies. However, accurate models of Saturn’s interior are still very challenging. A recent study by Mankovich and Fortney on Jupiter and Saturn models was based on a single physical model [3] which predicts a strongly differentiated helium distribution in Saturn’s deep interior, resulting in a helium-rich shell above a diffuse core.

We focus on the calculation of material properties of matter at P-T conditions along the Saturn model proposed by Mankovich and Fortney. The dissociation of hydrogen as well as the onset of the helium-rich layer have profound impact on material properties: Dissociation of hydrogen triggers the metallization of the hydrogen sub-system and the band gap of the system closes. However, helium is still an insulator under all the conditions of the model [4,5]. The onset of the helium-rich layer in the deep interior therefore again changes the properties of the mixture: Molecular hydrogen dominates the outer atmosphere, followed by a layer of mainly metallic hydrogen in the interior, followed again by a layer of helium-dominated insulating material above the core. We present results on thermodynamic and transport properties of a hydrogen-helium-water mixture that closely resembles the element distribution of the Saturn model. We discuss implications of the results on our understanding of Saturn's interior and evolution.

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[2] Becker et al., Astron. J., 156, 149 (2018).
[3] Mankovich and Fortney, Astrophys. J., 889, 51 (2020).
[4] Monserrat et al., Phys. Rev. Lett., 112, 055504 (2014).
[5] Preising and Redmer, Phys. Rev. B, 102, 224107 (2020).

Production of Diamonds at the Facility for Antiprotons and Ion Research Using Intense Heavy Ion Beams

Naeem Ahmad Tahir (GSI, Darmstadt), Vincent Bagnoud (GSI), Paul Neumayer (GSI), Roberto Piriz (UCLM), Sofia Piriz (UCLM)

In this contribution we present 2D numerical simulations that show that employing the intense uranium beam that will be available at FAIR, one can produce cylindrical diamonds with a length of a few mm and a diameter of around 400 – 500 micron. In this proposed experimental scheme, the target is comprised of a thin carbon cylinder, which is enclosed in a tungsten shell, that is facially irradiated with an intense uranium beam having a circular focal spot. Also, the beam axis coincides with the cylinder axis. The carbon sample is directly heated by the ion beam together with the surrounding part of the tungsten shell. Due to the higher pressure in the heated tungsten shell, the carbon sample is compressed and heated, leading to graphite-to-diamond phase transition. This study shows that a wide range of the diamond part of the carbon phase diagram can be accessed in such experiments.

Effects of Curvature and Convergence on the Rayleigh-Taylor Instability in the Cylindrical Implosion of an Elastic-Plastic Shell

Antonio Roberto Piriz (University of Castilla-La Mancha), Sofía A. Piriz (Universidad de Castilla-La Mancha), Naeem A. Tahir (GSI-Dramstadt)

Rayleigh-Taylor instability (RTI) in a cylindrical implosion, like the LAPLAS experiments, is affected by the convergence of the interface during the acceleration phase (Bell-Plesset), and by the interface curvature during the final deceleration phase. The latter phase is characterized by a low convergence ratio (of the order of 2) and, therefore, the perturbations can be considered to grow mainly due to RTI on a static curved surface. Instead, the former phase is dominated by the cylindrical convergence, or Bell-Plesset effect.

In the present work we have analyzed the effects of the cylindrical curvature on the RTI during the stagnation phase, and of the geometrical convergence during the implosion phase by considering that the shell is a medium with elastic-plastic (EP) material properties.

In particular, we find that the stability region becomes wider for smaller curvature radii, but the lowest mode m=1 cannot be stabilized by the material properties.

In addition, convergence effects make stable the internal interface thanks to the angular momentum conservation, a mechanism that increases the oscillation frequency during the implosion, thus reducing the amplitude of the perturbations. On the external surface, Bell-Plesset can only be mitigated by the compressibility of the shell, an effect that is found to be enhanced by the EP material properties in comparison with the case of an ideal medium.

Tuesday (January 31st)

Start	Duration	Speaker	Title
Session 4: HED Facilities II (Chair: Florian Condamine)			
08:30	00:20	HESSELBACH, Philipp	First Combined Laser-Driven X-ray Diagnostics and Heavy-Ion Heated Matter Experiments at the HHT station of GSI
08:50	00:20	LÜTGERT, Julian	Towards a Temperature and Graphitization Measurement of Ion-heated Diamond Samples with X-ray Diagnostics
09:10	00:20	BELIKOV, Roman	Ultra-Fast Temperature Measurements for Heavy-Ion Heating
09:30	00:30	GLENZER, Siegfried	The Scientific Opportunities of the Matter in Extreme Conditions Upgrade Project at SLAC National Accelerator Laboratory
10:00	**00:30**	**Coffee break**	
Session 5: HED Theory (Chair: Dirk Gericke)			
10:30	00:20	ROEPKE, Gerd	Thermodynamic and Transport Properties of Plasmas: Low-Density Benchmarks
10:50	00:20	DORNHEIM, Tobias	Accurate Temperature Diagnostics for Matter under Extreme Conditions
11:10	00:20	SCHÖRNER, Maximilian	X-ray Thomson Scattering Spectra from DFT-MD Simulations Based on a Modified Chihara Formula
11:30	00:20	VORBERGER, Jan	Nonlinear and Higher Order Terms in Warm Dense Matter
11:50	00:20	RETHFELD, Bärbel	Optical Properties of Laser-Excited Noble Metals
12:20		**Lunch break**	
Session 6: Laser Technology and IFE (Chair: Laurent Divol)			
17:00	00:20	RUHL, Hartmut	Low Q fusion with the help of efficient physics, lasers with high power density, and nano-technology
17:20	00:20	BAGNOUD, Vincent	Can one Pump High-Energy Lasers with LED?
17:40	00:20	ZÄHTER, Sero	Measurement and Control of Laser Plasma Instabilities at 2ω for Direct Drive Inertial Confinement Fusion
18:00	00:20	BRÖNNER, Matthias	Combining the Radiation-Hydrodynamics code MULT-IFE with the Particle-Swarm-Optimization Technique to Study Compression Schemes for Proton Fast Ignition
18:20	00:20	MALKI, Marcus	Frequency Doubling of Incoherent Laser Pulses for Inertial Fusion Experiments
18:40	00:20	ROTH, Markus	Proton Fast Ignition as a Commercial Approach to Fusion Energy
19:15		**Dinner**	
20:30		**IFE Round Table** *(via Zoom)*	

First Combined Laser-Driven X-Ray Diagnostics and Heavy-Ion Heated Matter Experiments at the HHT Station of GSI

Philipp Hesselbach, Julian Lütgert (Universität Rostock Physik(URO-PH)), Zsuzsanna Slattery-Major (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Paul Neumayer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Roman Belikov (Goethe-Universität Frankfurt am Main), Oliver Humphries (Helmholtz Zentrum Dresden Rossendorf), Björn Lindqvist (Universität Rostock), Gabriel Schaumann (Technische Universität Darmstadt), Andreas Tauschwitz (GSI, Darmstadt), Dmitry Varentsov (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Karin Weyrich (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Xiao Yu (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Bernhard Zielbauer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Dominik Kraus (HZDR), David Riley (QUB)

With the recent completion of the „HHT beamline“-upgrade, the HHT target station at GSI now offers the unique possibility of combining intense bunches of high-energy heavy-ions from the SIS-18 heavy-ion synchrotron with high-energy laser pulses delivered by the PHELIX laser. Recently, the first two experiments exploiting this new capability have been conducted. Bunches of up to $4 \cdot 10^9$ heavy-ions (e.g. U^{73+}) within 400 ns were focused on a < 1 mm^2 spot to volumetrically heat samples which were probed by laser-generated X-ray sources. In particular, heated states of diamond and iron were probed by X-ray diffraction and X-ray Thomson scattering.

To interpret the data of these X-ray diagnostics, a careful analysis of the drive conditions achieved by the heavy-ion beam is necessary. This was achieved by gated imaging pyrometry of the heated samples and measurements of the spatial extension of the ion focus. The latter was done by several techniques, including Argon fluorescence and optical transition radiation.

We will present an overview of the experimental setup of these first combined experiments which included the aforementioned large variety of different diagnostics and show preliminary results concerning the pyrometry and heavy-ion beam diagnostics. Furthermore, we will discuss measures that had to be taken to improve the data quality of the X-ray diffraction images and scattering spectra, to mitigate the large background noise level generated by the heavy-ion beam.

Towards a Temperature and Graphitization Measurement of Ion-Heated Diamond Samples With X-Ray Diagnostics

Julian Lütgert (Universität Rostock Physik(URO-PH)), Philipp Hesselbach, Zsuzsanna Major (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Paul Neumayer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Roman Belikov (Goethe-Universität Frankfurt am Main), Benjamin Heuser (Helmholtz-Zentrum Dresden-Rossendorf), Oliver Humphries (Helmholtz Zentrum Dresden Rossendorf), Björn Lindqvist (Universität Rostock), Chongbing Qu (University of Rostock), David Riley (QUB), Gabriel Schaumann (Technische Universität Darmstadt), Samuel Schumacher (University of Rostock), Andreas Tauschwitz (GSI, Darmstadt), Dmitry Varentsov (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Karin Weyrich (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Xiao Yu (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Bernhard Zielbauer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Dominik Kraus (Uni Rostock)

Diamond, being a meta-stable structure at ambient pressures, will transform into graphite at relatively low temperatures (1000K in atmospheric air, 2000K at zero pressure) within several minutes. This process typically starts at the surface and uniformly continues into the bulk material with ongoing time.
Alternatively, short X-ray or Laser pulses can create graphitization tracks in the sample within several 10s or 100s of femtoseconds, if sufficient energy is deposited locally.
A good understanding of the stability of diamond can give valuable insight, e.g., for the possibility to recover nano-diamonds generated in shock experiments or for its application as a detector material for X-rays and charged particles.
However, investigating the intermediate time regime and observing these two competing mechanisms is notoriously difficult, as a novel driver is required to heat the sample. Such experiments will be enabled with the FAIR facility by heating the target with ion beams.

We present the current status and preliminary results of an early commissioning experiment conducted in the HHT experimental cave at the GSI that applied heavy ions to heat diamond samples to temperatures above 1500 Kelvin, while fielding both spectrally resolved X-ray Thomson scattering and spatially resolved X-ray diffraction diagnostics, enabled by the PHELIX Laser creating the backlighting X-rays.
While the data we show suffers from parasitic signal introduced by the ion beam, we can identify signals related to the heating of the target, utilizing a deep-learning neuronal network to mask out particle traces and heavily relying on ray-tracing techniques to obtain transfer functions which allow us to compare different setups within this experimental campaign.

Ultra-Fast Temperature Measurements for Heavy-Ion Heating

Roman Belikov (Goethe-Universität Frankfurt am Main), David Merges (Goethe-Universität Frankfurt am Main), Lkhamsuren Bayarjargal (Goethe-Universität Frankfurt am Main), Dmitry Varentsov (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Zsuzsanna Slattery-Major (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Paul Neumayer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Philipp Hesselbach, Bjoern Winkler (Goethe Universität)

The investigation of extreme states of matter at high energy densities is one of the main goals of the plasma physics program at FAIR. To measure the temperature of ”warm dense matter” (WDM) generated by intense ion beam heating at APPA cave, a new multi-wavelength pyrometer was built. It is a very precise, flexible, and portable pyrometer, which enables temperature measurements with a high time resolution of nanoseconds and spatial resolution down to 100 µm.

The ultra-fast 5-channel pyrometer was successfully tested in the HHT experimental area at GSI for the surface temperature measurements of metals heated by intense uranium and lead ion beams. The surface temperatures of iron, tungsten, tantalum, and copper temperature measurements were fulfilled with a spatial resolution of 200 µm. The device has shown its universality and applicability for temperature measurements in the temperature range from 1 kK up to a few thousand Kelvin in various experiments within a broad timescale from nanoseconds to milliseconds. Further development of this device with new detectors is currently in progress.

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The Scientific Opportunities of the Matter in Extreme Conditions Upgrade Project at SLAC National Accelerator Laboratory

Siegfried Glenzer (SLAC National Laboratory)

In this presentation, we will describe the scientific opportunities that will arise from the Matter in Extreme Conditions Upgrade project at SLAC. The new experimental capabilities will access a novel physics regime where we expect to rapidly produce knowledge in the areas of High Energy Density Science and Inertial Fusion Energy. Presently, the MEC instrument is DOE's flagship facility for discovery science in plasma physics and high energy density science that has produced over 100 publications with 25% of the papers in high-impact journals and letters; MEC research results have been highlighted in international TV and radio shows including the CNN, BBC, and DW news. DOE has recently approved a community-supported plan to upgrade the MEC instrument that will bring high-repetition rate petawatt lasers to the LCLS's world-class X-ray beam to support the discovery physics and inertial fusion energy science's missions. The high-repetition-rate experimental setting (10 Hz) of the MEC-Upgrade will provide a unique opportunity to advance the field. In preparation for the upgrade, we have developed high-repetition rate jet targes, explored advanced laser ion beam acceleration physics regimes, and delivered the capability of ultrafast X-ray probing of high-intensity laser target interactions.

Thermodynamic and Transport Properties of Plasmas: Low-Density Benchmarks

Gerd Roepke (Universitaet Rostock, Institut fuer Physik)

Physical properties of plasmas such as equations of state and transport coefficients are expressed in terms of correlation functions, which can be calculated using various approaches (analytical theory, numerical simulations).
The method of Green's functions provides benchmark values for these properties in the low-density limit.
For the equation of state and electrical conductivity, expansions with respect to density (virial expansions) are considered.
Comparison of analytical results with numerical simulations is used to verify theory, to prove the accuracy of simulations, and to establish interpolation formulas.

Accurate Temperature Diagnostics for Matter Under Extreme Conditions

Tobias Dornheim (HZDR/CASUS)

The experimental investigation of matter under extreme densities and temperatures as they occur for example in astrophysical objects and nuclear fusion applications constitutes one of the most active frontiers at the interface of material science, plasma physics, and engineering. The central obstacle is given by the rigorous interpretation of the experimental results, as even the diagnosis of basic parameters like the temperature T is rendered highly difficult by the extreme conditions. In this work, we present a simple, approximation-free method to extract the temperature of arbitrarily complex materials from scattering experiments, without the need for any simulations or an explicit deconvolution [1]. This new paradigm can be readily implemented at modern facilities and corresponding experiments will have a profound impact on our understanding of warm dense matter and beyond, and open up a gamut of appealing possibilities in the context of thermonuclear fusion, laboratory astrophysics, and related disciplines.

[1] T. Dornheim, M. Böhme, D. Kraus, T. Döppner, T. Preston, Z. Moldabekov, and J. Vorberger, arXiv:2206.12805

X-Ray Thomson Scattering Spectra From DFT-MD Simulations Based on a Modified Chihara Formula

Maximilian Schörner (University of Rostock), Mandy Bethkenhagen (École Normale Supérieure de Lyon), Tilo Doeppner (Lawrence Livermore National Laboratory), Dominik Kraus (HZDR), Siegfried Glenzer (SLAC National Laboratory), Ronald Redmer (University of Rostock)

We study state-of-the-art approaches for calculating x-ray Thomson scattering spectra from density functional theory molecular dynamics (DFT-MD) simulations based on a modified Chihara formula that expresses the inelastic contribution in terms of the dielectric function. We compare the electronic dynamic structure factor computed from the Mermin dielectric function using an ab initio electron-ion collision frequency to computations using a linear response time dependent
density functional theory (LR-TDDFT) framework for hydrogen and beryllium and investigate the dispersion of free-free and bound-free contributions to the scattering signal. A separate treatment of these contributions in the Mermin dielectric function shows excellent agreement with LR-TDDFT results for ambient-density beryllium, but breaks down for highly compressed matter where the bound states become pressure ionized. LR-TDDFT is used to reanalyze x-ray Thomson scattering experiments on beryllium demonstrating strong deviations from the plasma conditions inferred with traditional analytic models.

Nonlinear and Higher Order Terms in Warm Dense Matter

Jan Vorberger (HZDR), Zhandos Moldabekov (HZDR/CASUS), Tobias Dornheim (HZDR/CASUS), Maximilian Böhme (Center for Advanced Systems Understanding (CASUS)), Panagiotis Tolias (KTH)

Higher order correlations influence the physics of the system on many levels. They may be summarized by local field corrections or appear explicitly as non-linear contributions in the density response or in other properties like the stopping power. We present the latest results for nonlinear properties of the electron gas as they have been obtained using real time Green's functions, path integral Monte Carlo, and density functional theory. We show how nonlinear properties can be extracted from simulations with and without external perturbations.

Optical Properties of Laser-Excited Noble Metals

Baerbel Rethfeld (Technische Universitaet Kaiserslautern)

Ultrashort and intense laser pulses can induce strong modification of materials' properties such as optical parameters determining the amount of absorbed energy in time. After excitation with lasers of high energy, the electrons thermalize fast to a hot Fermi distribution.
Yet, the band occupation numbers are still in strong nonequilibrium as particle exchange between the bands takes longer than energy exchange.

We trace the dynamics of the nonequilibrium occupation of the different energy bands in solid noble metals, e.g. gold, after optical and XUV excitation. The transient optical response results from

an interplay of band occupation and temperatures of electrons and phonons, which strongly affect the scattering rates [1]. The comparison of our results with experimental measurements can serve as a quantitative benchmark for the strength of electron-phonon coupling [2].

[1]. P. D. Ndione, D. O. Gericke, and B. Rethfeld, Optical properties of gold after intense short-pulse excitations, Front. Phys. 10, 10.3389/fphy.2022.856817 (2022).

[2] P. D. Ndione, S. T. Weber, D. O. Gericke, and B. Rethfeld,
Nonequilibrium band occupation and optical response of gold after ultrafast XUV excitation, Sci. Rep. 12, 4693 (2022).

Low Q Fusion With the Help of Efficient Physics, Lasers With High Power Density, and Nano-Technology

Hartmut Ruhl (LMU/Marvel Fusion)

The commercial viability of the ICF approach to nuclear fusion depends on the level of technological complexity involved while it is apparent that the ICF concept works in principle by making use of lasers. The requirement of high Q due to inefficient physics and technology necessitates mitigating measures to reduce the related ignition energy.
The state of the art strategy is enhancing density, which brings in high complexity. However, replacing state of the art coupling physics by making use of short-pulse lasers and nano-technology Q can be lowered to a level, which makes nearly or compression free ignition possible. In the talk we show that DT ignition is quite simple with the proposed technology, while the ignition of pB has a chance of becoming accessible in the near future. Both, ICF based on isentropic compression schemes and the way more credible MFE concepts are ultimately limited to DT.
This picture may chance with the advent of ultra-high laser power density, coupling efficiency, and stable and fast acceleration schemes.
The planned talk will center around this.

Can One Pump High-Energy Lasers With LED?

Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), François Balembois (Laboratoire Charles Fabry)

Light emitting devices (LEDs) have overtaken the lighting industry because of their luminous efficacy compared to sources that are more traditional. LEDs are very inexpensive and effective to produce. Large quantities are readily available off-the-shelf as they are mass-produced for the consumers market. In addition, LEDs are full surface mounted components that can be easily integrated on large panels. Therefore, it is advantageous to exploit this industrial advantage for other applications.
LEDs have been used as pump source in various low-energy laser demonstrations [1]. The main challenge posed by LEDs resides in their luminance, which is several orders of magnitudes lower than that of coherent light sources. In addition, their emission spectrum is broader than absorption peaks of Nd:doped laser materials and their divergence makes light transport towards the laser gain

medium with traditionnal optics. However, progress in LED technology has been constant since the beginning of the century and LEDs with radiant exittances of about 300 W/cm2 are nowadays available commercially. For LED assemblies, technologies exist to optimize the fill factor of LEDs per unit areas in order to make it conceivable to have LED-based pump modules powerful enough to pump laser materials.
In this contribution, I will discuss the advantages of LEDs as pump sources of laser materials relevant to high-energy lasers and demonstrate that these represent a promising alternative that deserves to be studied experimentally furthered.
[1] P. Pichon et al. "LED-pumped alexandrite laser oscillator and amplifier." Optics Letters 42.20 (2017): 4191-4194.

Measurement and Control of Laser Plasma Instabilities at 2 for Direct Drive Inertial Confinement Fusion

Sero Zähter (Focused Energy GmbH), Florian Wasser (Focused Energy GmbH), Martin Sokol (Focused Energy GmbH), Maggie Rivers (University of Texas), Markus Roth (TU Darmstadt), Todd Ditmire (Focused Energy Inc.)

The recent demonstration of physical gain in Inertial Confinement Fusion experiments at the National Ignition facility (Lawrence Livermore National Laboratory) shows the ongoing transition of fusion from fundamental science to technical application in energy production. The gain has to be increased further by both, engineering and scientific advancements to make it a viable large scale energy source. One of the scientific challenges are laser plasma instabilities (LPI) such as stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), two-plasmon-decay (TPD) and cross-beam energy transfer (CBET). These processes take place in the corona of laser-driven targets (in particular in direct drive laser fusion experiments). They are unfavorable for laser fusion since they can reduce the efficiency of coupling of the laser energy into the target. Moreover, some of these processes (SRS, TPD) involve generation of hot electrons which can lead to preheat of the fuel, reducing compressibility and thereby preventing ignition in the worst case. For this reason, LPI needs to be well characterized for the used laser- and target parameters and prevented or controlled up to a certain level. For this purpose, several techniques to mitigate LPI have been proposed i.e. increasing the bandwidth of the laser pulse (see (Craxton, 2015) for review about different techniques). In such experiments, we will study LPI for laser and target parameters relevant for direct drive laser fusion. Part of this endeavor is the setup and recent commissioning of a backscatter diagnostic (BSD) which is specifically designed for the L4n laser at ELI beamlines in the experimental hall E3, target chamber P3. This diagnostic was designed and developed by our team at Focused Energy in collaboration with the team from ELI beamlines and will be made available as permanent addition to the diagnostic capabilities provided to users in the future.

Combining the Radiation-Hydrodynamics Code MULT-IFE With the Particle-Swarm-Optimization Technique to Study Compression Schemes for Proton Fast Ignition

Matthias Brönner (Technische Universität Darmstadt & Focused Energy GmbH), L. Charlie Jarrott (Focused Energy), Debra Callahan (Focused Energy), Markus Roth (TU Darmstadt), Pravesh Patel (Focused Energy), Florian Wasser (Focused Energy & IU Internationale Hochschule), Nils Schott (Focused Energy & TU Darmstadt)

In the Proton Fast Ignition (PFI) [Tabak et al., Ignition and high gain with ultrapowerful lasers, Physics of Plasmas 1, 1626 (1994); Roth et al., Fast Ignition by Intense Laser-Accelerated Proton Beams, Phys. Rev. Lett. Vol. 86, No. 3, January 2001] scheme an inertial fusion target is compressed to densities of the order of hundreds of g/cc using nanosecond-duration lasers. To reach the necessary temperature for ignition, a high-energy proton beam of multiple MeV is focused onto the compressed fusion fuel. In conventional inertial fusion schemes, the fuel is required to be in an isobaric state at ignition time, which typically involves the creation of a hot spot at the center of the fuel. In PFI the creation of a hot spot is not necessary, due to the ignitor pulse, resulting in relaxed conditions for the compression step, different constraints on the driver, and the usage of an isochoric fuel assembly.
We follow up on the work conducted by Lazarus [Self-similar solutions for converging shocks and collapsing cavities, SIAM J. Numer. Anal., Vol. 18, No. 2, April 1981], and Clark and Tabak [A self-similar isochoric implosion for fast ignition, Nucl. Fusion 47 (2007) 1147–1156] on self-similar implosion flows that reach this isochoric state. These theoretical results were used as a starting point for an optimization scheme called particle-swarm-optimization (PSO) [Kennedy and Eberhart, Particle Swarm Optimization, ICNN'95 - International Conference on Neural Networks] that was coupled to radiation-hydrodynamics simulations (MULTI-IFE [Ramis and Meyer-ter-Vehn, MULTI-IFE—A one-dimensional computer code for Inertial Fusion Energy (IFE) target simulations, Comput. Phys. Commun. 203 (2016) 226–237]). We were able to use the PSO technique at a given laser energy to optimize the direct drive laser power profile which yielded a high areal density. We also present the results of using PSO to optimize other pulse shapes.

Frequency Doubling of Incoherent Laser Pulses for Inertial Fusion Experiments

Marcus Malki (Technische Universität Darmstadt(TUDA-IAT)), Zsuzsanna Slattery-Major (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

Laser-plasma instabilities pose a great challenge in inertial fusion energy research [1], as they limit the compression efficiency of the fusion fuel. It has been found, that it is possible to reduce or even suppress laser-plasma instabilities such as the Two-Plasmon Decay or Stimulated Raman Scattering by increasing the bandwidth of the interacting laser to above $\Delta\omega/\omega = 1$% [2,3]. However the combination of broadband lasers with frequency upconversion, which is favorable for laser absorption, is difficult, as frequency conversion is typically a resonant effect. In order to enable broadband and incoherent frequency upconversion, I thus developed a simulation tool for broadband Second-Harmonic

Generation (SHG).
The simulation was successfully compared to experiment shots at the PHELIX laser at GSI Darmstadt and used to specify a new DKDP crystal for SHG in an upcoming experiment concerning laser-plasma instabilities at PHELIX with inertial fusion relevant parameters.

[1] C. Labaune, Incoherent light on the road to ignition, Nat. Phys., 3:680–682, 2007, doi:10.1038/nphys742.
[2] R. K. Follet et al., Thresholds of absolute instabilities driven by a broadband laser, Phys. Plasmas, 26, 2019, doi:10.1063/1.5098479.
[3] S. P. Obenschain et al., Reduction of Raman Scattering in a Plasma to Convective Levels Using Induced Spatial Incoherence, Phys. Rev. Lett., 62(7):768–771, 1989, doi:10.1103/PhysRevLett.62.768.

Proton Fast Ignition as a Commercial Approach to Fusion Energy

Markus Roth (Focused Energy/TU Darmstadt)

As clean and safe energy is needed more than ever new developments have led to the rise of startup companies around the globe taking advantage of the science
developed of the years and combining the results of the past with the technology of the 21st century to make fusion energy a reality.
Focused Energy is a US/German startup supported by the TU Darmstadt and deeply embedded in the international science community. We are focusing on the concept of direct-drive laser-based inertial confinement fusion and fast ignition. In our approach, a small pellet containing a milligram of DT is directly irradiated by intense laser light and compressed to roughly 1000 times solid density. At the moment of maximum density, a burst of energetic, laser-driven ion beams is focused into a small part of the compressed fuel to rapidly rise the temperature above ignition temperature and start a bootstrap fusion reaction, which results in a supersonic burn wave consuming the fuel.
More than two decades of research have led to this path, which has recently been quoted the most promising approach in inertial fusion energy by international leaders in the field.
We will report on the progress during the last year assembling the best scientist in the field and the design and construction work to get fusion demonstrated in a decade time frame. We will report on our current strategy, the timeline and the first results we obtained towards a commercially viable fusion system.

Wednesday (February 1st)

Start	Duration	Speaker	Title
Session 7: Laser-Ion Acceleration (Chair: Sophia Malko)			
08:30	00:30	METZKES-NG, Josefine	High Energy Proton Acceleration at DRACO-PW and Radiobiological Applications
09:00	00:20	WEISER, Maximilian	Update on the Laser-Driven Heavy Ion Acceleration at CALA
09:20	00:20	GERLACH, Sonja	Particle Bunch Monitoring at High Repetition Rates Using Ionoacoustics
09:40	00:20	RAMAKRISHNA, Bhuvanesh	Observation of Kilotesla Magnetic Fields in Laser Solid Interaction via Proton Acceleration *(via Zoom)*
10:00	**00:30**	**Coffee break**	
Session 8: Ultrafast Secondary Sources (Chair: Zsuzsanna Major)			
10:30	00:30	KETTLE, Bredan	Ultrafast X-Ray Absorption Spectroscopy for HED Science Using Laser-Plasma Accelerators
11:00	00:20	PUKHOV, Alexander	Electron Acceleration in Near Critical Density Plasmas
11:20	00:20	ROSMEJ, Olga	New Results on Application of Low Density Polymer Aerogels for Multidisciplinary Research with High Energy Relativistic Laser Pulses
11:40	00:20	ZEPF, Matt	Testing Strong Field QED in Intense Laser Fields
12:00	00:20	ZHENG, Chuan	First Measurement of Helium-3 Ion-Beam Polarization after Laser-Plasma Acceleration
12:20		**Lunch break**	
17:00	**1:30**	**Poster Session**	
18:40	**00:20**	**Conference Board Meeting**	
20:00		**Conference Dinner at Birkenhöhe**	

High Energy Proton Acceleration at DRACO-PW and Radiobiological Applications

Stefan Assenbaum (Helmholtz-Zentrum Dresden-Rossendorf), Constantin Bernert (Helmholtz-Zentrum Dresden-Rossendorf), Florian-Emanuel Brack (Helmholtz-Zentrum Dresden-Rossendorf), Thomas E. Cowan (Helmholtz-Zentrum Dresden - Rossendorf), Nick Dover (4John Adams Institute for Accelerator Science, Blackett Laboratory, Imperial College London), Thomas Kluge (Helmholtz-Zentrum Dresden-Rossendorf), Florian Kroll (Helmholtz-Zentrum Dresden - Rossendorf), Nishiuchi Mamiko (3Kansai Photon Science Institute (KPSI), National Institutes for Quantum Science and Technology (QST)), Josefine Metzkes-Ng (Helmholtz-Zentrum Dresden-Rossendorf), Martin Rehwald (Helmholtzzentrum Dresden-Rossendorf(HZDR)), Marvin Reimold (Helmholtz-Zentrum Dresden-Rossendorf), Ulrich Schramm (HZDR), Marvin Elias Paul Umlandt (Helmholtz-Zentrum Dresden-Rossendorf), Milenko Vescovi (Helmholtz-Zentrum Dresden-Rossendorf), Karl Zeil (Helmholtz-Zentrum Dresden-Rossendorf), Tim Ziegler (Helmholtz-Zentrum Dresden-Rossendorf)

Exploiting the strong electromagnetic fields that can be supported by a plasma, high-power laser driven compact plasma accelerators can generate short, high-intensity pulses of high energy ions with special beam properties. By that they may expand the portfolio of conventional machines in many application areas. The maturating of laser-driven ion accelerators from physics experiments to turn-key sources for these applications will rely on breakthroughs in both, generated beam parameters (kinetic energy, flux), as well as increased reproducibility, robustness and scalability to high repetition rate.
Recent developments at the high-power laser facility DRACO-PW enabled the production of polychromatic proton beams with unprecedented stability [1]. This allowed the first in vivo radiobiological study to be conducted using a laser-driven proton source [2]. Yet, the ability to achieve energies beyond the 100 MeV frontier is matter of ongoing research, mainly addressed by exploring advanced acceleration schemes like the relativistically induced transparency (RIT) regime.
In this talk, we report on experimental proton acceleration studies at the onset of relativistic transparency using pre-expanded plastic foils. Combined hydrodynamic and 3D particle-in-cell (PIC) simulations helped to identify the most promising target parameter range matched to the prevailing laser contrast conditions carefully mapped out in great detail beforehand. A complex suite of particle and optical diagnostics allowed characterization of spatial and spectral proton beam parameters and the stability of the regime of best acceleration performance, yielding cut-off energies larger than 100 MeV in the best shots.
The reported progress for proton acceleration directly feeds into our program on ultra-high dose rate radiobiology. We operate a fully-equipped beamline including beam monitoring and dosimetry adapted to ultra-high dose rate proton pulses at DRACO-PW with the future perspective of a dedicated beamline at our high-power laser facility PENELOPE within the ATHENA project.

References

[1] Ziegler, T. et al. Proton beam quality enhancement by spectral phase control of a PW-class laser system. Sci Rep 11, 7338 (2021)
[2] Kroll, F. et al. Tumour irradiation in mice with a laser-accelerated proton beam. Nat. Phys. 18, 316–322 (2022)

Update on the Laser-Driven Heavy Ion Acceleration at CALA

Maximilian Julius Weiser (LMU München), Laura Desiree Geulig, Erin Grace Fitzpatrick, Veronika Kratzer, Vitus Magin, Florian Hans Lindner, Masoud Afshari (GSI, Darmstadt), Jörg Schreiber, Peter Thirolf (Ludwig-Maximilians-Universität München)

Accelerating heavy fissile ions above an energy of about 7 MeV/u is one important prerequisite for the realization of the fission-fusion reaction scheme that aims to study the extremely neutron-rich isotopes around the waiting point of the rapid neutron capture process (r-process) at the magic neutron number N=126 [1]. In our preparatory experiments we select gold as prototype element prior to later on favoured elements like thorium. In experiments at the PHELIX laser at GSI/Darmstadt (central wavelength 1054 nm, pulse length 500 fs, 185(15) J per pulse) gold ions with an energy above 7 MeV/u were measured for the first time with unprecedented charge state resolution [2]. The gold ion charge state distribution cannot be modelled when solely considering field ionization; a large discrepancy between the simulated and measured charge states is observed. By using a developmental branch of the particle-in-cell code EPOCH that takes collisional ionization into account, a much better agreement between simulated and experimental results was achieved [3].
This work is continued at the Centre for Advanced Laser Applications (CALA) in Garching, using the ATLAS 3000 laser (central wavelength 800 nm, pulse length 25 fs, < 60 J per pulse). The laser is focused by an f/2 off-axis parabola onto gold foils with thicknesses ranging from 200 nm to 500 nm. To analyse the accelerated ion bunches, a Thomson Parabola Spectrometer was designed in particular for high-resolution heavy ion and high-resolution charge-state detection and is currently being commissioned. Spectroscopically controlled radiative heating is integrated into the setup, which allows the removal of (carbo-hydrate) contaminants present on the surface of the target foils and thus can help in increasing the energy and yield of the heavy ions [4]. Additionally, we are momentarily working on investigating collective effects in the stopping range behaviour expected for ultra-dense laser accelerated ion bunches and on a transportation and detection system for fission fragments induced by laser accelerated protons and/or ions.

Particle Bunch Monitoring at High Repetition Rates Using Ionoacoustics

Sonja Gerlach (Ludwig-Maximilians-Universität München), Felix Balling (LMU München, Fakultät für Physik), Leonard Doyle (LMU Munich, Germany), Ina Hofrichter (Ludwig-Maximilians-Universität München), Anna-Katharina Schmidt (Ludwig-Maximilians-Universität München), Florian Schweiger (LMU Munich), Katia Parodi (LMU Munich), Jörg Schreiber (Ludwig-Maximilians-Universität München)

Laser-ion acceleration is an emerging field of modern physics enabled by the Nobel prize awarded chirped pulse amplification technique. Focused high-power laser pulses can accelerate high-energy ion bunches from thin foils. Some properties of these emitted ion bunches are inherently different from those provided by conventional (non-laser based) accelerators, enabling interesting application cases e.g. in the field of medical physics.

A current limitation of laser acceleration is their stability, not least because of difficulties in online detection of fast particle bunches. The I-BEAT 3D (Ion-Bunch Energy Acoustic Tracing) detector is a simple and compact detector solution accounting for the unique properties of laser-accelerated particles bunches, in particular their short duration and high intensity, in conjugation with a strong electromagnetic pulse. Distinct from conventional detection systems, I-BEAT 3D measures the acoustic wave emitted by single particle bunches stopping in water. Focused and energy-selected proton bunch energy distributions have been reconstructed from the acoustic trace using an iterative algorithm. Recently, we developed a fast data evaluation algorithm tailored to the needs of high repetition rate laser systems. We use simple measures that can be extracted from the acoustic traces and relate them to particle bunch properties. This way, the prompt information on the bunch particle number at a certain energy interval becomes available as monitor for the proton acceleration. The I-BEAT 3D detector is integrated into our TANGO software infrastructure for facilitating live visualization of the bunch particle number e.g. in a web interface. We consider this step as vital for identifying correlations with laser and plasma parameters and enabling feedback in the future.

This work was supported by the Bundesministerium für Bildung und Forschung (BMBF) within project 01IS17048 and the German Research Foundation (DFG) within the Research Training Group GRK 2274.

Observation of Kilotesla Magnetic Fields in Laser Solid Interaction via Proton Acceleration

Bhuvanesh Ramakrishna (IIT Hyderabad)

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Laser-driven ion sources are associated with features like very short duration, high laminarity and larger emittance due to which they have been found useful in a number of applications such as fusion experiments under the fast ignition scheme, radiography, nuclear processes and biomedical applications. Although the laser-plasma interaction facilitates ion acceleration through various physical mechanisms such as Target Normal Sheath Acceleration (TNSA), Radiation Pressure Acceleration (RPA), Collisionless Shock Acceleration etc., the TNSA mechanism is the most widely observed phenomena in which the hot electrons generated at the target surface after the laser incidence would accelerate through the target, into the vacuum forming a sheath of electrons resulting in a charge separation at the target surface. The sheath electric field created near the target surface as a result of charge separation acts as the driving force for accelerating the ions. Generation of strong magnetic fields from laser plasma interaction have been predicted and such strong magnetic fields or their ramifications are observed with underdense targets as well as overdense targets like a metal foil of thicknesses $\geq$ 100µm. Recently a new concept called microtube implosion (MTI) has been proposed which predicts a magnetic field of the order of MT from the interaction of intense laser pulses with a structured target.

We report an experimental investigation on the proton acceleration from the interaction of intense laser pulse of intensity about 1020 Wcm-2 with a thin foil of Aluminum, Titanium and Gold of thickness 2µm. Protons are accelerated via the TNSA mechanism from the rear surface of the target and in addition, protons accelerated from the front surface were also detected on the Radio Chromic films. Hollow proton rings could be seen on the radio chromic films corresponding to 1-3MeV protons. The protons from the front surface are driven into the target and directed towards the rear side of the target by the Kilotesla magnetic fields generated from the laser-plasma. The enhancement in the proton number in the 1-3MeV range with a hollow beam profile in the experiments are in good agreement with the observed strong magnetic field structures from the results of 2D Particle-In-Cell simulations EPOCH and SMILEI.

Ultrafast X-Ray Absorption Spectroscopy for HED Science Using Laser-Plasma Accelerators

Brendan Kettle (Imperial College London), Rory Baggott (Imperial College London), Cary Colgan (Imperial College London), Eva Los (Imperial College London), Steve Rose (Imperial College London), Stuart Mangles (Imperial College London)

In recent years laser-plasma based accelerators have provided access to multi-GeV electron energies within laboratory scale facilities. This has opened many new research avenues, one of which focuses on the application of the ultrafast (few femtoseconds) X-rays that are generated by the electron oscillations. A key strength of the X-ray source is its smooth broadband nature which makes it perfect for X-ray absorption spectroscopy; these measurements provide a wealth of information about the structure and state of a sample. XANES (X-ray Absorption Near Edge Structure) and EXAFS (Extended X-ray Absorption Fine Structure) in particular, provide a simultaneous measurement of the temperature and structure of both the electronic and ionic distributions. The ultrafast pulse duration of the X-ray source provides a unique tool for investigating the absorption of transient states (e.g. high-energy-density samples) on a rapid femtosecond time scale. The creation of these states can also be achieved in tandem at the high-power laser laboratories that provide the X-ray accelerator source.
We present high-resolution single-shot K-edge XANES and EXAFS measurements of copper samples from recent experiments using a laser-wakefield accelerator at the Gemini laser facility (building upon results of [1]). Up to 10^6 photons/eV per shot at 9 keV were measured. We demonstrate that this source is capable of single-shot simultaneous measurements of both the electron and ion distributions in matter heated to eV temperatures by comparison with density functional theory simulations. The unique combination of a high-flux, large bandwidth, few femtosecond duration x-ray pulse synchronised to a high-power laser will enable key advances in the study of ultrafast energetic processes such as electron-ion equilibration and non-thermal phase transitions. Additionally, the development of this laser-plasma accelerator X-ray source will enable high quality laboratory scale X-ray absorption facilities to be realised.

References

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Electron Acceleration in Near Critical Density Plasmas

Alexander Pukhov (Uni Dusseldorf), Xiaofei Shen (Uni Dusseldorf), Olga Rosmej (GSI, Darmstadt), Nikolay Andreev (JIHT RAS)

Understanding the interaction of a kilojoule picosecond laser pulse with long-scale-length preplasma or homogeneous near-critical-density (NCD) plasma is crucial for guiding experiments at national short-pulse laser facilities. Using full three-dimensional particle-in-cell simulations, we demonstrate that in this regime, cross-filament stochastic acceleration is an important mechanism that contributes to the production of superponderomotive high-flux electron beams. Since the laser power significantly exceeds the threshold of the relativistic self-focusing, multiple filaments are generated and can propagate independently over a long distance. Electrons jump across the filaments during the acceleration and their motion becomes stochastic. By irradiating a submillimeter-thick NCD target, the space charge of electrons with energy above 2.5 MeV reaches tens of microcoulombs. Such high-flux electrons with superponderomotive energies significantly facilitate applications in high-energy-density science, nuclear science, secondary sources, and diagnostic techniques.

New Results on Application of Low Density Polymer Aerogels for Multidisciplinary Research With High Energy Relativistic Laser Pulses

Olga Rosmej (GSI, Darmstadt)

The experimental results obtained in 2021-2022 on the PHELIX laser, where various types of low-density polymer foams were used to generate high-current directed beams of super-ponde-romotive electrons, will be discussed. Experiments have shown ultra-high efficiency of production of the keV betatron radiation and MeV bremsstrahlung, dense proton beams, and ionizing radiation with a record dose rate.

Testing Strong Field QED in Intense Laser Fields

Karl Matthäus Zepf (Universität Jena)

Testing the response of charged particles and the quantum vacuum to extreme fields is predicted to give rise to fundamental and unexplored natural phenomena. Among these are finding a self-consistent solution to the trajectory of a single electron (so-called ‘radiation reaction’), pair production from the quantum vacuum and photon-photon scattering in violation of the superposition principle of classical theory.
Experiments are currently in the planning and validation phase with experiments planned at both accelerator/laser combinations and all-optical experiments which aim to probe different parameter

spaces. The challenge in all cases is to detect a weak signal against a strong background. Recent developments will be presented together with details of the planned experiment at the CALA facility.

First Measurement of Helium-3 Ion-Beam Polarization After Laser-Plasma Acceleration

Chuan Zheng (Forschungszentrum Jülich), Pavel Fedorets (FZJ), Ralf Engels (FZJ), Zahra Chitgar (FZJ), Markus Büscher (FZJ)

Polarized ion beams are of great importance for basic research. Experimental efforts to generate them with plasma-based accelerators may also pave the way towards applications like polarized fusion, where one tries to enhance the yield of fusion reactors by aligning the nuclear spins.

Our approach for plasma acceleration of polarized particle beams is to use a pre-polarized gas-jet target, assuming that the nuclear polarization is not affected by rapidly changing magnetic field inherently present in laser-generated plasmas. The laser pulse produces an intense electron current along the plasma channel which generates a vortex magnetic field around it. According to particle-in-cell simulations the polarization of ^{3}He nuclei is mostly conserved in such a scenario.

A first polarization measurement has been carried out in summer 2021 at the PHELIX laser facility, employing a complete setup with a high-density polarized gas-jet target [1] and a ^{3}He polarimeter optimized for the short ion bunches from plasma acceleration [2]. The target comprises holding magnetic fields to conserve the nuclear polarization of hyperpolarized ^{3}He gas, a compressor to deliver the required ^{3}He backing pressure of about 30 bar, as well as a non-magnetic valve and a titanium nozzle for jet formation. The polarimeter is based on secondary nuclear reaction in a deuterated foil which converts the ^{3}He polarization information into a measurable angular asymmetry. The results of these beam polarization measurements are presented in this report.

[1] P. Fedorets, et al., A high-density polarized ^{3}He gas-jet target for laser-plasma application,
Instruments **6**(2022)18.
[2] C. Zheng, et al., Polarimetry for ^{3}He ion beams from laser-plasma interactions,
Instruments **6**(2022)61.

Thursday (February 2nd)

Start	**Duration**	**Speaker**	**Title**
Session 9: Ultrafast Plasma Dynamics (Chair: Tobias Dornheim)			
08:30	00:30	HUANG, Lingen	Probing Electron Transport in Relativistic Solid Density Plasmas at European XFEL
09:00	00:20	KLUGE, Thomas	Visualizing Ultrafast Kinetic Instabilities in Laser-Driven Solids Using X-ray Scattering
09:20	00:20	WEGERT, Leonard	Measurement of Equation-of-State Isentropes by High-Resolution X-Ray Imaging of Isochorically Heated Wire Targets
09:40	00:20	MARRE, Brian Edward	Atomic Population Kinetics for ParticleInCell
10:00	**00:30**	**Coffee break**	
Session 10: Ion Stopping in Plasmas (Chair: Dieter H. H. Hoffmann)			
10:30	00:20	ZHAO, Yongtao	Proton-Boron Nuclear Reactions Initiated by Laser-Accelerated Intense Proton Beam in Boron Plasma *(via Zoom)*
10:50	00:20	REN, Jieru	Target Density Effects on Charge Transfer of Laser-Accelerated Carbon Ions in Dense Plasma *(via Zoom)*
11:10	00:30	MALKO, Sophia	Proton Stopping Power Measurements in Warm Dense Carbon at Low Velocity Projectile Ratio
11:40	00:20	NAZARY, Haress	Towards Stopping Power Experiments with LIGHT
12:00	00:20	RÖDER, Simon	Conditioning the Temporal Contrast Caused by the Stretcher Using the Beam Size
12:20		**Lunch break**	
Session 11: High Fields and Radiation (Chair: Brendan Kettle)			
17:00	00:20	FREEMAN, Matt	Laser Plasma-Accelerator Driven Electron Radiography (*via Zoom)*
17:20	00:20	VALIALSHCHIKOV, Maksim	Towards High Photon Density for Compton Scattering by Spectral Chirp
17:40	00:20	DOYLE, Leonard	Studies on the Photon Background for a Potential Photon-Photon Scattering Experiment
18:00	00:20	HERNANDEZ ACOSTA, Uwe	QED.jl - First-Principal Description of QED-Processes in X-Ray Laser Fields
18:25		**Transfer to**	**Hüttenabend at Sonna-Alp**

Probing Electron Transport in Relativistic Solid Density Plasmas at European XFEL

Lingen Huang, Michal Šmíd (HZDR), Long Yang (Institute of radiation physics, HZDR), Oliver Humphries (Helmholtz Zentrum Dresden Rossendorf), Thea Engler (Deutsches Elektronen Synchrotron), Johannes Hagemann (Deutsches Elektronen Synchrotron), Thomas Kluge (Helmholtz-Zentrum Dresden-Rossendorf), Xiayun Pan (Helmholtz-Zentrum Dresden-Rossendorf), Constantin Bernert (Helmholtz-Zentrum Dresden-Rossendorf), Erik Brambrink (LULI), Katerina Falk (Helmholtz-Zentrum Dresden-Rossendorf), Lennart Gaus (Helmholtz-Zentrum Dresden-Rossendorf), Christian Gutt (Universität Siegen), Hauke Höppner (Helmholtz-Zentrum Dresden-Rossendorf), Michaela Kozlova (Helmholtz-Zentrum Dresden-Rossendorf), Alejandro Laso Garcia (Helmholtzzentrum Dresden-Rossendorf(HZDR)), Wei Lu (European XFEL), Josefine Metzkes-Ng (Helmholtz-Zentrum Dresden-Rossendorf), Motoaki Nakatsutsumi (European XFEL), Masato OTA (Osaka University), O Öztürk (Universität Siegen), Alexander Pelka (HZDR), Irene Prencipe (Helmholtz-Zentrum Dresden-Rossendorf), Lisa Randolph (European XFEL), Martin Rehwald (Helmholtzzentrum Dresden-Rossendorf(HZDR)), R Schubert (European XFE), Y Sakawa (Osaka University), Hans-Peter Schlenvoigt (Helmholtz-Zentrum Dresden-Rossendorf), Ulrich Schramm (HZDR), Andrea schropp (Deutsches Elektronen Synchrotron), R Stefanikova (Helmholtz-Zentrum Dresden-Rossendorf), Toma Toncian (Helmholtz-Zentrum Dresden-Rossendorf), Jan Vorberger (HZDR), Ulf Zastrau (European XFEL), Karl Zeil (Helmholtz-Zentrum Dresden-Rossendorf), Thomas Cowan (Helmholtz-Zentrum Dresden - Rossendorf)

Understanding the transport dynamics of the hot electrons generated by a relativistic laser is of fundamental importance to a wide range of topics such as particle acceleration, plasma heating and ionization, strong magnetic field generation, creation of extreme states of matter, and opacity evolution in warm/hot dense plasma environment. The recent commissioning of experimental platforms equipped with both optical high power laser and X-ray free electron laser (XFEL), such as European XFEL-HED, LCLS-MEC and SACLA beamlines, provides unprecedented opportunities to probe the electron transport in solid density plasmas with simultaneous high spatial and temporal resolution. In this talk, we will present the experimental results to study the electron transport in the solid wires driven by the 3J/30fs/100 TW laser ReLaX performed at European XFEL-HED station. By fielding the X-ray diagnostics of small angle X-ray scattering (SAXS), X-ray phase contrast imaging (PCI) and X-ray emission spectroscopy simultaneously, we are able to investigate the following multiple temporal and spatial scale processes induced by the hot electron transport ranging from femtoseconds to hundreds of picoseconds: i) plasma expansion with density gradient at 10 nm resolution during the intra-laser-pulse wire interactions; ii) the dynamics of plasma heating, ionization and possibly recombination up to 10 ps; iii) plasma expansion with density gradient at 1 µm resolution in hydrodynamic time scales which is correlated to the temperature evolution in local thermal equilibrium condition.

Visualizing Ultrafast Kinetic Instabilities in Laser-Driven Solids Using X-Ray Scattering

Thomas Kluge (HZDR)

Ultra-intense lasers that ionize and accelerate electrons in solids to near the speed of light can lead to kinetic instabilities that alter the laser absorption and subsequent electron transport, isochoric heating, and ion acceleration. These instabilities can be difficult to characterize, but a novel approach using X-ray scattering at keV energies allows for their visualization with femtosecond temporal resolution on the few nanometer mesoscale. Our experiments on laser-driven flat silicon membranes show the development of structure with a dominant scale of 60 nm in-plane the laser axis, and 110 nm in the vertical direction with a growth rate faster than 0.43/fs. Combining the XFEL experiments with PIC simulations provides a complete picture of the structural evolution of ultra-fast laser-induced instability development, indicating the excitation of surface plasmons and the growth of a new type of filamentation instability.
These findings provide new insight into the ultra-fast instability processes in solids under extreme conditions at the nanometer level with important implications for inertial confinement fusion and laboratory astrophysics.

Measurement of Equation-of-State Isentropes by High-Resolution X-Ray Imaging of Isochorically Heated Wire Targets

Leonard Maximilian Wegert (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Artem Martynenko (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Paul Neumayer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

In a recent experiment at the PHELIX laser facility at GSI, we have generated samples of warm-dense matter by isochoric heating of thin titanium wires by using laser-accelerated relativistic electrons. The initial temperature profile along the wire was estimated using spatially resolved K_{alpha} spectroscopy. We used high-resolution X-ray radiography with a laser-produced X-ray "backlighter" to image the adiabatic expansion of the wire and determine the density distribution up to solid density. Applying a method introduced by M.E. Foord et al. [1] allowed for the reconstruction of the pressure profile, thus yielding release isentropes for initial temperatures up to a few tens of eV. Comparisons with tabulated equation-of-state data from SESAME show good agreement with the experimental data.

[1] M. E. Foord et al., Rev. Scient. Instr. 75, 2586 (2004)

Atomic Population Kinetics for ParticleInCell

Brian Edward Marre (Helmholtz-Zentrum Dresden-Rossendorf), Axel Huebl (Berkley National Lab), Rene Widera (Helmholtz-Zentrum Dresden-Rossendorf), Sergei Bastrakov (Helmholtz-Zentrum Dresden-Rossendorf), Ulrich Schramm (HZDR), Thomas Cowan (Helmholtz-Zentrum Dresden - Rossendorf), Michael Bussmann (Helmholtz-Zentrum Dresden - Rossendorf), Thomas Kluge (Helmholtz-Zentrum Dresden-Rossendorf)

Standard atomic physics models in PIC-simulations either, neglect excited states, predict atomic state population in post processing only, or assume quasi-thermal plasma conditions.

This is no longer sufficient for high-intensity short-pulse laser generated plasmas, due to their non-equilibrium, transient and non-thermal plasma conditions, which are now becoming accessible in XFEL experiments at HIBEF (EuropeanXFEL), SACLA (Japan) or at MEC (LCLS/SLAC).

To remedy this, we have developed a new extension for our PIC simulation framework PIConGPU to allow us to model atomic population kinetics in-situ in PIC Simulations, in transient plasmas and without assuming any temperatures.
This extension is based on a reduced atomic state model, which is directly coupled to the existing PIC-simulation and for which the atomic rate equation is solved explicitly in time, depending on local interaction spectra and with feedback to the host simulation.
This allows us to model de-/excitation and ionization of ions in transient plasma conditions,as typically encountered in laser accelerator plasmas.
This new approach to atomic physics modelling will be very useful in plasma emission prediction, plasma condition probing with XFELs and better understanding of isochoric heating processes, since all of these rely on an accurate prediction of atomic state populations inside transient plasmas.

Proton-Boron Nuclear Reactions Initiated by Laser-Accelerated Intense Proton Beam in Boron Plasma

Yongtao Zhao (XJTU & IMP), Dieter H.H. Hoffmann (TU-Darmstadt), Wenqing Wei (Xi'an Jiaotong University), Jieru Ren (Xi'an Jiaotong Unversity)

The study of nuclear reaction in plasma environment is of great importance for fusion sciences and astrophysics. The advent of high-intensity-pulsed laser technology enables in laboratory generating extreme states of matter and producing high-current(10^{10} A/cm2), short-pulse(⍰ps) ion beams. These advantages provide great experimental opportunities to explore the nuclear reaction dynamics at extreme condition, in which case nonlinear effects are expected to occur. Here we report the measurements of proton-boron reaction induced by laser-accelerated intense proton beam in boron plasma target using XGIII laser facility.
The dense plasma was generated by irradiating a boron-doped CHO foam sample with soft X rays from a ns laser-heated hohlraum. The energy loss of the protons, which is supposed to play important roles in nuclear reaction dynamics was measured simultaneously.
It was preliminarily found that the α yield initiated in plasma is generally higher than that in the cold foam. The enhancement of proton number by 2-3 order of magnitude induce 4-5 orders of

magnitude enhancement of alpha particle yield for cold target. The preliminary analysis shows that the nonlinear gain of this hydrogen-boron fusion reaction may be related to the super-strong local electric field and the local extreme non-equilibrium state caused by the high-current ion beam in the dense ionized matter.

Target Density Effects on Charge Transfer of Laser-Accelerated Carbon Ions in Dense Plasma

Jieru Ren (Xi'an Jiaotong Unversity), Yongtao Zhao (Xi'an Jiaotong University), Dieter H.H. Hoffmann (TU-Darmstadt)

We report on charge state measurements of laser-accelerated carbon ions in the energy range of several MeV penetrating a dense partially ionized plasma. The plasma was generated by irradiation of a foam target with laser-induced hohlraum radiation in the soft X-ray regime. We used the tri-cellulose acetate (C9H16O8) foam of 2 mg/cm3 density, and 1-mm interaction length as target material. This kind of plasma is advantageous for high-precision measurements, due to good uniformity and long lifetime compared to the ion pulse length and the interaction duration. The plasma parameters were diagnosed to be Te=17 eV and ne=4 * 1020 cm-3. The average charge states passing through the plasma were observed to be higher than those predicted by the commonly-used semiempirical formula. Through solving the rate equations, we attribute the enhancement to the target density effects which will increase the ionization rates on one hand and reduce the electron capture rates on the other hand. The underlying physics is actually the balancing of the lifetime of excited states versus the collisional frequency. In previous measurement with partially ionized plasma from gas discharge and z-pinch to laser direct irradiation, no target density effects were ever demonstrated. For the first time, we were able to experimentally prove that target density effects start to play a significant role in plasma near the critical density of Nd-Glass laser radiation. The finding is important for heavy ion beam driven high energy density physics and fast ignitions. The method provides a new approach to precisely address the beam-plasma interaction issues with high-intensity short-pulse lasers in dense plasma regimes.

Proton Stopping Power Measurements in Warm Dense Carbon at Low Velocity Projectile Ratio

Sophia Malko (Princeton Plasma Physics Laboratory, USA)

Ion stopping power in high energy density (HED) plasmas is of great interest for fundamental science and is important in many areas of inertial confinement fusion (ICF), including central hot spot ignition, fast ignition, and heavy ion fusion. Theoretical modelling of ion stopping power in HED plasmas is a difficult task and there is little experimental data to validate and benchmark models, contributing to large discrepancies amongst them. The modelling of stopping power in Warm Dense Matter (WDM) is
particularly challenging due to electron degeneracy and coupling, which modify the Coulomb logarithm
characterizing the collisions in the plasma. While a number of experimental studies have been

performed on ion stopping power in classical plasmas, experimental database in WDM is essentially missing. In addition, the low velocity stopping power regime where vp (ion velocity)   vth (electron thermal velocity) remains virtually unexplored.

Here, we report the first proton energy loss measurements in warm dense plasma at low projectile velocities vp/ vth≈ 3-10 [1]. The experiment was performed at CLPU VEGA-II laser facility by using a novel high repetition rate platform [2]. The platform is based on the selection of a quasimonoenergetic,
short time-duration, proton beam of 500 keV from an initially broad proton spectrum.
A WDM with a temperature of 10 eV was generated by femtosecond laser-heating of a thin carbon foil
and characterized using two independent spectroscopy diagnostics. Our energy-loss data demonstrate
a significant deviation of the stopping power from classical models in this regime. In particular, we show that our results are in closest agreement with recent first-principles simulations based on timedependent
density functional theory [3,4].

[1] S. Malko et al, Nat. Commun.13, 2893 (2022)
[2] J. Apiñaniz et al. Sci. Rep. 11, 6881 (2021)
[3] A. J. White et al., Phys. Rev. B 98, 144302 (2018)
[4] A. J. White et al., Phys. Rev. Lett. 125, 055002 (2020)

Towards Stopping Power Experiments With LIGHT

Haress Nazary (TU Darmstadt), Martin Metternich (Technische Universität Darmstadt(TUDA-IKDA)), Dennis Schumacher (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Abel Blazevic (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Florian-Emanuel Brack (Helmholtz-Zentrum Dresden-Rossendorf), Florian Kroll (Helmholtz-Zentrum Dresden - Rossendorf), Christian Brabetz (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Ulrich Schramm (HZDR), Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Markus Roth (TU Darmstadt)

The Laser Ion Generation, Handling and Transport (LIGHT) beamline at GSI is part of the ATHENA distributed facility, where phase-space manipulations of laser-generated ion beams is the main emphasis. In the last few years, the LIGHT collaboration was able to routinely generate and focus intense 8 MeV proton bunches with a temporal duration shorter than 1 ns (FWHM).

An interesting area of application that exploits the short ion bunch properties of LIGHT is the study of the ion-stopping power of plasmas, a key process in inertial confinement fusion for understanding energy deposition in dense plasmas. The most challenging regime is found when $v_{\text{projectile}} \approx v_{\text{thermal,e}}$, a regime for which ion stopping is difficult to describe and the existing theories show high discrepancies. Since conclusive experimental data is missing in this regime, we plan to conduct experiments on laser-generated plasma probed with LIGHT at higher temporal resolution than previously achievable. The high temporal resolution is important because the parameters of laser-generated plasmas are changing on the nanosecond timescale. Therefore, the temporal length of the plasma-probing ion bunches should be as short as possible to reduce the uncertainties caused by the averaging over the fast-changing plasma parameters.

To meet this goal, our recent studies have dealt with ions of lower kinetic energies. In 2021, laser accelerated carbon ions were transported with two solenoids and focused temporally with LIGHT's radio frequency cavity. A pulse length of 1.2 ns (FWHM) at an energy of 0.6 MeV/u was achieved. In 2022, protons with an energy of 0.6 MeV/u were transported and temporally compressed to a pulse length of 0.8 ns. The temporally compressed and spatially focused ion beam will be used for energy loss measurements. The plasma will be generated by a nanosecond laser (nhelix), which is in the process of upgrading.
In my talk, I will present the planned experiment, its requirements and show its feasibility based on preliminary experiments done with LIGHT and predictive simulations.

Conditioning the Temporal Contrast Caused by the Stretcher Using the Beam Size

Simon Röder (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Yannik Zobus, Christian Brabetz (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Vincent Bagnoud (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

Modern relativistic laser plasma experiments employ higher and higher peak intensities and thinner targets, leading to the common problem of excessive preplasma expansion or even breach of the target prior to the arrival of the peak intensity. In order for the laser development to keep up with these trends and enable experiments with highest temporal contrast demands, we need to find improved methods for temporal contrast control. So far these methods mainly rely on temporal-pedestal-free amplifiers[1] or pulse cleaning, e.g. Cross-polarized wave generation or plasma mirrors.
We propose a novel, purely optical technique that dramatically reduces the generation of the slowly rising edge that remains a key feature in the temporal profile of CPA laser systems. This technique relies on the combined influence of the laser beam size and the surface quality on the rising edge generated by coherent-scattering in the pulse stretcher.
For a proof-of-principle[1], we isolated the effect of the beam size at the position of the specific optical elements and their surface quality on the temporal profile using a zero-stretch stretcher, in an unfolded and folded configuration. We furthermore developed an analytical model that predicts the rising edge caused by generic surfaces on basis of the surface quality and the aspect ratio of the dispersed beam on the surface, within the measurement uncertainties. We found the best results for the unfolded stretcher design with the larger beam size, validating that the rising edge is determined by the optical element in the Fourier-plane and that the temporal contrast profits from spatial averaging effects. With our setup, we achieved a temporal contrast at 5 ps of nine orders of magnitude. When combined with temporal-pedestal-free amplifiers[2] we expect this technique to enable laser-plasma experiments at highest temporal contrast regimes without relying on plasma mirrors.

References
[1] S. Roeder et al., HPLSE, 10, E34 (2022)
[2] Y. Zobus et al., (CLEO), IEEE, 1-2 (2021)

Laser Plasma-Accelerator Driven Electron Radiography

Matthew Freeman (Los Alamos National Laboratory), Shaw Jessica (University of Rochester), Bruhaug Gerrit (University of Rochester), Neukirch Levi (University of Rochester), Wilde Carl (University of Rochester)

Fast electron radiography is useful for imaging plasma-like states, due to the ability to accurately characterize material areal densities, as well as to the sensitivity to magnetic fields. Electron radiography driven by a laser plasma accelerator (LPA) provides a bright flash of 10^{14} polychromatic electrons in <1 ps. Results from recent trials of projection radiography at OMEGA EP will be shown. Modeling and simulation work towards the implementation of a magnetic lens system within the confines of OMEGA EP to increase spatial resolution and provide quantitative magnetic field information will also be presented.

Towards High Photon Density for Compton Scattering by Spectral Chirp

Maksim Valialshchikov (Helmholtz Institute Jena), Daniel Seipt (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Vasily Kharin, Sergey Rykovanov (Skolkovo Institute of Science and Technology)

Scattering of intense laser pulses on high-energy electron beams allows one to produce a large number of x and γ rays. For temporally pulsed lasers, the resulting spectra are broadband which severely limits practical applications. One could use linearly chirped laser pulses to compensate for that broadening. We show for laser pulses chirped in the spectral domain that there is the optimal chirp parameter at which the spectra have the brightest peak. Additionally, we use catastrophe theory to analytically find this optimal chirp value.

The contribution is based on a recently published paper [1] and is an extension of the previous work which studied optimal laser pulse chirping in the time domain [2].

[1] - Valialshchikov M.A., Seipt D., Kharin V.Yu., and Rykovanov S.G. Towards high photon density for Compton Scattering by spectral chirp. Phys. Rev. A 106 L031501 (2022).
[2] - Kharin V.Yu., Seipt D., and Rykovanov S.G. Higher-dimensional caustics in nonlinear compton scattering. Phys. Rev. Lett. 120.4 044802 (2018).

Studies on the Photon Background for a Potential Photon-Photon Scattering Experiment

Leonard Doyle (LMU Munich, Germany), Pooyan Khademi, Karl Matthäus Zepf (GSI, Darmstadt), Jörg Schreiber (Ludwig-Maximilians-Universität München)

In the near future, high intensity lasers will be able to probe the quantum nature of the vacuum. One of the predictions is the scattering of light by light, where photons can couple to photons via virtual particle-antiparticle pairs always present in the vacuum. Several schemes employing high intensity lasers have been proposed, but to date no direct evidence in the optical regime has been made. With currently available laser technology, the signal will be very weak compared to the driving fields (few photon level compared to $> 10^{20}$ in the driving pulses). While it should in principle be possible to detect such a signal great care has to be taken to minimize any background contribution on the detector. This can be light scattered of the residual gas particles present in the non-ideal vacuum or light scattered by objects in the experiment. To understand and mitigate any background contribution and pave the way towards a potential discovery experiment, studies solely on the background are being carried out in Munich and Jena. In our first campaigns the diffuse scattering from objects in the experiment chamber was most dominant and will have to be improved by several orders of magnitude while the scattering by residual gas particles promises to be manageable at typical residual pressures [1]. We are now preparing for experiments beyond 1 petawatt at promising geometries for a potential discovery experiment.

This work has been funded by the Deutsche Forschungsgemeinschaft (DFG) under Grant No. 416702141 within the Research Unit FOR2783.

[1] Doyle, L. et al. (2022) 'Experimental estimates of the photon background in a potential light-by-light scattering study', New Journal of Physics, 24(2), p. 025003. https://doi.org/10.1088/1367-2630/ac4ad3.

QED.jl - First-Principal Description of QED-processes in X-Ray Laser Fields.

Uwe Hernandez Acosta (CASUS/HZDR), Klaus Steiniger (HZDR), Tom Jungnickel (CASUS/HZDR), Michael Bussmann (CASUS/HZDR)

We present a novel approach for an event generator inherently using exact QED descriptions to predict the results of high-energy electron-photon scattering experiments that can be performed at modern X-ray free-electron laser facilities.
Future experiments taking place at HIBEF, LCLS, and other facilities targeting this regime, will encounter processes in x-ray scattering from (laser-driven) relativistic plasmas, where the effects of the energy spectrum of the laser field as well as multi-photon interactions can not be neglected anymore.
In contrast to the application window of existing QED-PIC codes, our event generator makes use of the fact, that the classical nonlinearity parameter barely approaches unity in high-frequency regimes, which allows taking the finite bandwidth of the x-ray laser into account in the description of the

QED-like multi-photon interaction.
Consequently, we exploit these effects in Compton scattering, Breit-Wheeler pair-production and trident pair-production in x-ray laser fields as one of the driving forces of electromagnetic cascades and plasma formation.

Friday (February 3rd)

Start	Duration	Speaker	Title
Session 12: Proton & Neutron Radiography (Chair: Thomas Kühl)			
08:30	00:20	SCHANZ, Martin	PRIOR-II - A European High Energy Proton Radiography Facility for HED Physics Applications
08:50	00:20	MARIAM, Fesseha	Achromatic Imaging Using Charged Particle
09:10	00:20	TANG, Zhaowen	The Proton Radiography Capability
09:30	00:20	TANG, Elise	Simulating Proton Radiography
09:50	00:20	ZIMMER, Marc	Demonstration of Non-Destructive Material Characterization at a Laser-Based Neutron Source
10:10	**00:30**	**Coffee break**	
Session 13: Implosions and Astrophysical Plasmas (Chair: Dominik Kraus)			
10:40	00:20	SCHUMACHER, Samuel	Towards the First Measurement of the Opacity of Warm Dense Hydrogen Using Radiography
11:00	00:20	MURAKAMI, Masakatsu	Generation of Ultrahigh Magnetic Fields by Vortex-Driven Microtube
11:20	00:20	KRASIK, Yakov	Recent Advances in Research of Underwater Electrical Explosion of Wires and Shock Waves Generation
11:40	00:20	HOFFMANN, Dieter H.H.	Laboratory Observation of C and O Emission Lines of White Dwarf H1504+65-like Atmosphere Model
12:15		KRAUS/BAGNOUD	**Conclusion and End of Workshop**

PRIOR-II - A European High Energy Proton Radiography Facility for HED Physics Applications

Martin Schanz (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Dmitry Varentsov (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Roman Belikov (Goethe-Universität Frankfurt am Main), Alexander Müller-Münster (Goethe Univerity Frankfurt), Matthew Freeman (Los Alamos National Laboratory), Fesseha Mariam Mariam (LANL), Christopher Morris Morris (Los Alamos National Laboratory), Levi Neukirch (Los Alamos National Laboratory), Jason Allison (Los Alamos National Laboratory)

Lens based proton radiography is a powerful diagnostics technique that is capable of resolving ultra-fast processes on the ns scale in dense matter with unprecedented micrometer spatial resolution. Furthermore, it is capable of resolving the areal density distribution of the target or process investigated making it an ideal diagnostics for HED physics applications. The unique performance of this technique is realized by the use of a chromatic imaging system consisting of four quadrupole magnets that are configured to suppress the most significant 2nd order position dependent chromatic aberrations of the proton distribution. Systems of this kind are currently in operation in Germany (PRIOR-II at GSI, 4.5GeV p+) and in the US (pRad at LANL, 800 MeV p+).

The PRIOR-II proton radiography facility at GSI has recently been commissioned in 2021 and 2022 (static & dynamic) with 2-4GeV proton beams from the SIS-18 synchrotron and has demonstrated a sub 20um spatial resolution performance, a sub 1% density resolution performance, as well as unique dynamic timing capabilities using slow-extracted beam. Two dynamic experiments on electrical wire explosions and material properties under extreme conditions have already been conducted within the framework of the commissioning. Following those successful results, the facility is now being upgraded for the use of HE drivers for HED experiments that could be scheduled as early as 2024.

Due to the high proton energy of up to 4.5GeV, PRIOR-II is especially suitable for probing dynamic processes in thick or dense samples. Recent tests at the Los Alamos National Laboratory have shown that this particular type of experiments can suffer from a depth-of-field limitation that may lead to a significant degradation of the image quality and also limit the physical output. A new technique based on focus stacking, which could drastically improve the physics output, has therefore been investigated in several experimental campaigns at LANL and could also be implemented for PRIOR-II at GSI.

Furthermore, MC simulations regarding the use of Helium ions instead of protons have been performed to evaluate possible applications for in-vivo imaging in Flash cancer therapy. Those studies have shown that up to a certain target thickness He may also be used for imaging HED physics experiments. As there is a limited availability of protons at GSI, Helium radiography might create new opportunities for scheduling parasitic beam times and could therefore increase the availability of the PRIOR-II facility to the scientific HED physics community.

Achromatic Imaging Using Charged Particle

Fesseha Mariam (LANL)

Proton radiography is an imaging modality best suited to imaging dense materials up to 50 g cm-2 at timescales down to 100 ns. However, it is limited by chromatic effects that degrade the resolution of off-energy protons. Work recently underway at LANL aims to eliminate or mitigate these chromatic effects using a novel lens design that reduces chromatic aberrations to second order (an ”achromat”). Preliminary work on the design, in conjunction with work done with collaborators at the Idaho Accelerator Facility in Pocatello, ID will be dscussed. Tuning of the lens will be done through a simplified paradigm of cell-based symmetry that limits the number of knobs to turn to quadrupole field strength, sextupole field strength, inter-cell drift spacing, and final cell to imaging location drift. This lens system will be demonstrated for 25 MeV electrons and is scalable to any charged particle type and energy.

The Proton Radiography Capability

Zhaowen Tang (Los Alamos National Laboratory)

Proton radiography at 800-MeV, at the Los Alamos Neutron Science Center, routinely probes the evolution of rapid, dynamic processes. This capability is enabled by selectively exploiting the multiple Coulomb scattering induced by an object of interest, and an ultra-fast, multiframe readout. This technique has been used to study materials properties and equations of state for a variety of materials, from solid metals, alloys, high explosives, and additively manufactured compounds.

Simulating Proton Radiography

Elise Tang (Los Alamos National Laboratory)

Los Alamos National Lab operates an 800 MeV proton radiography (pRad) facility for dynamic imaging experiments. PRad is able to produce more than 20 images per dynamic experiment, including drivers based on high explosives, a powder gun, and pulsed power. The spatial resolution, depending on the magnetic lens, ranges from less than 50 microns to about 200 microns, and the imaging frame rate can be as high as 20 per microsecond. The resulting images show the evolution of the materials over time when subjected to shocks. We have created a simulation package (CpRad) to analyze proton radiographs and extract areal densities from dynamic experimental data. The CpRad model incorporates important aspects of the experimental proton radiography system at LANL to accurately model chromatic blur in the images. In addition, the model incorporates MPI and CUDA capabilities to speed simulations. Details of the simulations, fits to calibration objects, and density reconstruction will be presented.

Demonstration of Non-Destructive Material Characterization at a Laser-Based Neutron Source

Marc Zimmer (Focused Energy), Stefan Scheuren (TU Darmstadt), Tim Jäger (Technische Universität(TUDA)), Jonas Kohl (TU Darmstadt), Gabriel Schaumann (Technische Universität Darmstadt), Markus Roth (TU Darmstadt)

Compact laser-based neutron sources have attracted great interest in the last years due to a growing field of applications. Neutrons interact via the nuclear force which results in relatively large penetration depths and isotope specific interaction cross-sections. This can be used to identify the isotopic composition of samples. This allows applications like the inspection of cargo containers for fissile material or explosives as well as the tracing of artifacts to their geological origin. While conventional neutron sources such as reactors and spallation sources are large in size, expensive and produce strong background radiation with large pulse widths, it is more desirable to have compact neutron sources with short pulse lengths which require less shielding. Laser-based neutron sources can fill this gap in the near future when modern high repetition rate laser systems can be used. In addition, the short neutron pulse length in the order of one nanosecond facilitates new applications such as neutron resonance spectroscopy and neutron resonance imaging.
Here, we present recent results from experimental campaigns at the PHELIX laser system at the GSI Darmstadt. In the experiment, protons and deuterons have been accelerated from thin foils up to 50 MeV. These ions were converted by nuclear reactions inside a catcher material into 10^{10} neutrons per shot which were subsequently moderated down into the eV regime. With this epithermal neutron beam, it was possible to identify several isotopes inside a 2.7 mm thick sample using neutron resonance spectroscopy. In addition, laser-driven thermal neutron radiography was applied for measuring the thickness of indium cadmium plates behind a lead shielding. Also, the first demonstration of neutron resonance radiography will be presented. These results have been recently published in Nature Communications. I will further give an outlook for future applications that will be enabled by high repetition rate laser systems and liquid leaf targets and how these systems could be commercialized in the future by Focused Energy.
Laser-based neutron sources will be developed and applied at the international center for nuclear photonics at the TU Darmstadt in close cooperation with their industrial partner Focused Energy GmbH.

Towards the First Measurement of the Opacity of Warm Dense Hydrogen Using Radiography

Samuel Schumacher (University of Rostock), Benjamin Bachmann (Lawrence Livermore National Laboratory), Mandy Bethkenhagen (École Normale Supérieure de Lyon), Laurent Divol (Lawrence Livermore National Laboratory), Tilo Döppner (Lawrence Livermore National Laboratory), Dirk Gericke (University of Warwick), Siegfried Glenzer (SLAC National Laboratory), Gareth Hall (Lawrence Livermore National Laboratory), Nobuhiko Izumi (Lawrence Livermore National Laboratory), Shahab Khan (Lawrence Livermore National Laboratory), Dominik Kraus (HZDR), Otto Landen (Lawrence Livermore National Laboratory), Julian Lütgert (Universität Rostock Physik(URO-PH)), Steve MacLaren (Lawrence Livermore National Laboratory), Laurent Masse (Lawrence Livermore National

Laboratory), Ronald Redmer (University of Rostock), Markus Schölmerich (Lawrence Livermore National Laboratory), Maximilian Schörner (University of Rostock), Nathaniel Shaffer (University of Rochester), Charles Starrett (Lawrence Livermore National Laboratory), Philip Sterne (Lawrence Livermore National Laboratory), Clement Trosseille (Lawrence Livermore National Laboratory)

The interior of red dwarf stars, which make up the most common, lightest and coolest fraction of all stars in the Sun's neighborhood, mainly consist of hydrogen-helium mixtures at moderate temperatures ($T \sim 200$ eV) and extreme densities ($n_e \sim 4 \times 10^{25}$ cm^{-3}). In this so-called warm dense matter regime, the modeling of the energy transport is extremely challenging, giving rise to high discrepancies between existing radiation transport models with the stellar opacity being a key parameter. Moreover, a detailed understanding of how the energy is transported through a star's bulk matter and possibly giving rise to violent outbursts on its surface is crucial to determine whether an exoplanet in the star's close vicinity may be habitable.
To benchmark the existing radiation transport models we have successfully proposed an experiment within the National Ignition Facility's Discovery Science Program, which offers a unique experimental platform to compress hydrogen to conditions relevant for the interiors of red dwarf stars[1]. To disentangle the two relevant opacity contributions, namely hydrogen free-free absorption and Thomson scattering from free electrons we performed absorption measurements at two different photon energies (7.2 keV and 5.2 keV shot end of January '23).

Fielding NIF's Crystal Backlighter Imager system together with the gated single-line-of-sight (SLOS) detector we collected multiple high-resolution radiographies of the implosion on each of the two shots. To remove a characteristic grid artifact inherent to SLOS detector images we applied machine learning techniques based on a Convolutional Neural Network architecture using a dataset of synthetic generated radiographies.
We give an overview of the current status of the data analysis and discuss first results obtained.

Generation of Ultrahigh Magnetic Fields by Vortex-Driven Microtube

Didar Shokov, masakatsu murakami (Institute of Laser Engineering, Osaka University), Myles-Allen Zosa, Javier Honrubia (Polytechnic University of Madrid)

We have recently proposed a novel mechanism called a "microtube implosion," and demonstrated the generation of megatesla (MT) order magnetic fields via particle simulations [1]. This is three orders of magnitude higher than what has ever been achieved in a laboratory. Such high magnetic fields are expected only in celestial bodies like neutron stars and black holes.
Irradiating a tiny plastic microtube one-tenth the thickness of a human hair by ultraintense laser pulses produces hot electrons with temperatures of mega-electron volts. These hot electrons, along with cold ions, expand into the microtube cavity at velocities approaching the speed of light. Pre-seeding with a kilotesla-order magnetic field causes the imploding charged particles infinitesimally twisted due to Lorenz force. Such a unique cylindrical flow collectively produces unprecedentedly high spin currents of about peta-ampere/cm2 on the target axis and consequently, generates ultrahigh magnetic fields on the MT order.
We also demonstrate and explain the surprising phenomenon of sign reversal in magnetic field

amplification by the microtube [2,3]. While the magnetic field generation is enhanced and spatially smoothed by the application of a kilotesla-level seed field, the sign of the generated field does not always follow the sign of the seed field. One unexpected consequence of the amplification process is a reversal in the sign of the amplified magnetic field when, for example, the target outer cross section is changed from square to circular.
Current laser technology can realize MT-order magnetic fields based on the concept. The present concept for generating MT-order magnetic fields will lead to pioneering fundamental research in numerous areas, including materials science, quantum electrodynamics (QED), and astrophysics, as well as other cutting-edge practical applications.
[1] M. Murakami et al, "Generation of megatesla magnetic fields by intense-laser-driven microtube implosions," Sci. Rep. 10, 16653 (2020).
[2] K. Weichman et al., "Sign reversal in magnetic field amplification by relativistic laser-driven microtube implosions," Appl. Phys. Lett. 117, 244101 (2020).
[3] M. Murakami et al., "Laser scaling for generation of megatesla magnetic fields by microtube implosion, High Power Laser Science and Engineering 9, e56 (2021).

Recent Advances in Research of Underwater Electrical Explosion of Wires and Shock Waves Generation

Yakov Krasik (Technion), D. Maler (Technion), Simon Bland (Imperial Colledge, London, UK), Sergey Efimov (Technion), Alexander Rack (ESRF, Grenoble, France), Bratislav Lukis (ERSF, Grenoble, France), Jergus Strucka (Imperial Colledge, London, UK), Oleg Belozerov (Physics Department, Technion)

Results of the recent research on underwater electrical explosion of wires/wires arrays and imploding strong shock waves generation will be presented which include results obtained at ESRF site.

Laboratory Observation of C and O Emission Lines of White Dwarf H1504+65-Like Atmosphere Model

Dieter H.H. Hoffmann (TU-Darmstadt)

H1504+65, a bare stellar nucleus, is an unusual white dwarf with a Carbon- and Oxygen-dominated atmosphere. The composition cannot be explained by current stellar evolution models. The analysis of the elemental abundance and the improvement of stellar atmospheric models depends heavily on spectral measurements and accurate spectral data. We used soft x-ray emission from a laser heated hohlraum to irradiate a foam target and obtained a Carbon-Oxygen plasma emission spectrum with temperature T=195 000K±10 000K and mass fraction ratio C/O=0.85, similar to that of H1504+65. We performed a detailed comparison of our spectra with the H1504+65 Chandra spectrum, and do observe the same O VI emission lines. Moreover intense ion- and laser beams are complimentary tools to induce High Energy Density in matter. The development of this field is intimately connected to technological advances of the field. We will give an overview of the projects in High Energy Density science that we currently address at Xi'An Jiaotong University.

Poster Session (Wednesday, 17:00-18:30)

1	MAY, Philipp	The Equation of State and Diamond Formation Properties of Cellulose Acetate and Poly-L-lactic Acid at Ice Giant Interior Conditions
2	GYRDYMOV, Mikhail	Modified Magnetic Spectrometer and its Application for Measurement of Betatron Radiation
3	SEIPT, Daniel	Spin and Polarization in High-Intensity Laser-Plasma Interactions
4	TAVANA, Parysatis	Record-Breaking Efficiency of Multi-MeV Bremsstrahlung Production in Interaction of Direct Laser Accelerated Electrons with High-Z Convertor
5	MARTYNENKO, Artem	Temperature Estimations of Warm Dense Matter Based on X-Ray Imaging of the Expansion of a Thin Ti Wire Heated by Laser-Accelerated Relativistic Electrons
6	RANJAN, Divyanshu	Hydrogen Metallisation in Warm Dense Matter Condition
7	QU, Chongbing	Towards Probing K-Shell Ionization of Carbon Under Warm Dense Matter
8	HEUSER, Benjamin	Shock Release Dynamics and Recovery of Nanodiamonds Formed in Laser Compressed Plastics
9	KRASIK, Yakov	Super Luminescence High Power Microwave Pulse Propagation in the Neutral Gas
10	KHADEMI, Pooyan	Background Estimation and Conjugate Homodyne Method as a Detection Scheme for Photon/Photon Scattering in Quantum Vacuum Signal
11	GRIMM, Sarah J.	Interferometer for the Measurement of the Free Electron Density in a Laser-Generated Plasma
12	BOLLER, Pascal	Numerical Optimization of the Target Thickness for Ion Acceleration in the Relativistic Transparency Regime at PHELIX
13	DE LANGE, Stan	Modeling of Laser-Induced Vaporization of Thin Tin Sheets for EUV Lithography Applications
14	KALLA, René	On-Line Detection of Radioactive Fission Isotopes Produced by Laser Driven Gamma Rays
15	HUANG, Xinhe	3-Dimensional Full Characterization of Laser Pulses with Optical Angular Momentum
16	NEFF, Stephan	Experimental Facilities for High-Energy Density and Warm Dense Matter Experiments at FAIR
17	AUMÜLLER, Simone	Roomtemperature Vaccum Chamber with Cryogenic Surfaces for High Intensity Uranium 28+ Beams

The Equation of State and Diamond Formation Properties of Cellulose Acetate and Poly-L-Lactic Acid at Ice Giant Interior Conditions

Philipp May (University of Rostock), Zhiyu He (Helmholtz-Zentrum Dresden-Rossendorf), Benjamin Heuser (Helmholtz-Zentrum Dresden-Rossendorf), Michael Stevenson (University of Rostock), Julian Lütgert (Universität Rostock Physik(URO-PH)), Dominik Kraus (HZDR), Tommaso Vinci (Ecole Polytechnique), Alessandra Ravasio (École polytechnique), Alessandra Benuzzi-Mounaix (École polytechnique)

The interiors of our solar system's ice giants, Uranus and Neptune, feature a thick layer, presumably consisting of carbon, hydrogen, nitrogen and oxygen, exposed to pressures of several MBar and thousands of kelvins. As NASA has ambitions for a "flagship space mission" to Uranus (Nature 604, 607 (2022), doi.org/10.1038/d41586-022-01087-2), the need for a more sophisticated model of its interior arises. This can be accomplished by laser-driven shock compression experiments that access the ice giant's extreme pressure and temperature conditions and investigate ice giant resembling mixtures via X-ray diffraction, VISARs and optical pyrometry. In this study, equation of state data for cellulose acetate $(C_{10}H_{14}O_7)_n$ and poly-L-lactic acid $(C_3H_4O_2)_n$ are presented and embedded in the context of other mixtures like polystyrene $(C_8H_8)_n$ or polyethylene terephthalate $(C_{10}H_8O_4)_n$. Knowing these data will also support the research on nanodiamonds, a form of carbon expected in ice giants that might have promising real-world applications as contrast agents or for drug delivery (Qin et al., Nanodiamonds: Synthesis, properties, and applications in nanomedicine, 2021).

Modified Magnetic Spectrometer and Its Application for Measurement of Betatron Radiation

Mikhail Gyrdymov, Jakub Cikhardt (Czech Technical University of Prague (CTU)(CTU)), Joachim Jacoby, Olga Rosmej (GSI, Darmstadt)

In the experiments on interaction of sub-ps PHELIX pulse of 10¹⁹ W/cm² intensity with pre-ionized low-density foams, we observed high current direct laser accelerated (DLA) electrons with energies up to 100 MeV. Ponderomotive expulsion of plasma electrons creates a plasma channel with a radial quasi-electrostatic field, which hold the remaining electrons in the channel area. At the same time, the current of accelerated electrons generates a strong (≥ 100 MG) azimuthal magnetic field that traps electrons in the channel. The betatron radiation is generated when the relativistic electrons undergo transverse betatron oscillations in these self-generated quasi-static fields.

Measurement of the betatron radiation was undertaken in the PHELIX beam-time P207 in 2021 using Ross-filter and x-ray diode diagnostics. In many shots, a strong saturation of IPs behind Ross-filters caused by intense proton beam was observed. The presence of protons up to 16 MeV energy was also detected by the x-ray diode. Another problem is that foam was growing up inside a Cu-washer, so that x-ray radiation measured by Ross-filters and x-ray diode contained both betatron and bremsstrahlung/characteristic radiation from Cu. To overcome these obstacles, a modified construction of a magnetic spectrometer equipped with Ross-filters was proposed, which allowed to separate x-rays signal from electrons and protons and to spatially resolve radiation, originated in the Cu- washer and NCD-plasma.

In the followed experimental campaign at the PHELIX P21-05 in 2022 a new modified magnetic spectrometer for measurement of betatron radiation was tested. We registered forward directed betatron radiation with a half divergence angle of 6° and a number of photons approaching 10¹⁰ in the energy region 10-30 keV.

Spin and Polarization in High-Intensity Laser-Plasma Interactions

Daniel Seipt (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

With the ever growing light intensities reached by high-power laser, high-intensity QED effects are playing an increasingly important role in high-intensity laser plasma interactions. Here I will elaborate why electron-spin and photon-polarization will be a relevant subject in high-intensity laser-plasma and laser-beam interactions in the near future due to the fundamental QED processes in strong fields being sensitive to the particle polarization.
Some of the predicted effects on particle polarization share similarities with the Sokolov-Ternov effect—the radiative polarization of electrons in storage rings—but they occur on much faster timescales due to the large quantum efficiency parameter. I will discuss how those effects might be capitalized for generating spin-polarized beams for future plasma-based high-energy-physics colliders, which crucially depend on having spin-polarized beams available.
Moreover, we have studied the relevance of spin and polarization for the formation of a avalanche-like QED cascade where copious amounts of spin-polarized matter and polarized photons can be produced. We found that the particle polarization affects the cascade growth rate. Moreover, the highest energy particles are polarized opposite the expectation from Sokolov-Ternov theory, which cannot be explained by just taking into account spin-asymmetries in the pair production rates, but results significantly from the phenomenon of "spin-straggling".

Record-Breaking Efficiency of Multi-MeV Bremsstrahlung Production in Interaction of Direct Laser Accelerated Electrons With High-Z Convertor

Parysatis Tavana (Institute of Optics and Quantum Electronics, Friedrich-Schiller University Jena, Germany), Mikhail Gyrdymov, Olga Rosmej (GSI, Darmstadt), Pascal Boller, Jakub Cikhardt (Czech Technical University of Prague (CTU)(CTU)), Sebastian Busch (Goethe University Frankfurt am Main), Marc Günther (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Nikolay Andreev (JIHT RAS), Thomas Kühl (GSI, Darmstadt), Nikolai Bukharskii (National Research Nuclear University MEPhI), Alessandro Tentori (GSI Darmstadt)

In the present work, we demonstrate an approach to generate ultra-high flux, multi-MeV bremsstrahlung based on interaction of high current direct laser accelerated (DLA) electrons with high Z convertor. Directed beams of relativistic electrons with effective temperature 10x higher than ponderomotive potential were produced in interaction of the sub-ps PHELIX pulse of 10
$^{19}\ \frac{W}{cm^2}$ laser intensity with pre-ionized low density polymer foams. Measurements show that in this scheme, electrons with energy up to 100 MeV can be produced and the charge of electrons which propagate in 2 with energy greater than 1.5 MeV reaches 1 µC.

The charge of electrons with energy more than 7.5 MeV, responsible for generation of bremsstrahlung photons in the range of giant dipole resonance, attains 200 nC. Conversion efficiency of the laser

energy to electrons is up to 40% (> 1.5 MeV) and 18% (> 7.5 MeV). For the fraction of the electron beam directed along the laser axis, it is 11% and 9% respectively.
For characterization of the bremsstrahlung spectrum produced by the DLA electrons in high Z convertor, photonuclear reactions, in particular (γ,n), (γ,3n) and (γ,5n) in gold and tantalum have been studied. We observed high yield of nuclear reactions demanding photons with energies above 50 MeV. Evaluated number of isotopes allowed concluding about the number of MeV photons in the range of giant dipole resonance and the effective temperature of the bremsstrahlung spectrum. In particular, we report about bremsstrahlung spectrum> 8 MeV that can be approximated by an exponential distribution with an effective temperature of 13-16 MeV and contains $1-4\times10^{11}$ (10^{12} /sr) photons per laser shot in the energy range of 8 MeV to 70 MeV propagating within a half angle of 17°.

These numbers manifest a record-breaking conversion efficiency of the laser energy to MeV-bremsstrahlung photons in the GDR range (> 8 MeV) that approaches 2%. The experimental results are in good agreement with GEANT4 simulations.

Temperature Estimations of Warm Dense Matter Based on X-Ray Imaging of the Expansion of a Thin Ti Wire Heated by Laser-Accelerated Relativistic Electrons

Artem S. Martynenko (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Paul Neumayer (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Dimitri Batani (Universitè de Bordeaux, CNRS, CEA, CELIA, UMR 5107, F-33405, Talence, France; HB11 Energy Holdings Pty, 11 Wyndora Avenue, Freshwater NSW 2096, Australia), Reem Alraddadi (York Plasma Institute, The University of York, Heslington, York YO10 5DQ, United Kingdom), Emma Hume (York Plasma Institute, The University of York, Heslington, York YO10 5DQ, United Kingdom), Kathryn Lancaster (York Plasma Institute, The University of York, Heslington, York YO10 5DQ, United Kingdom), Sergey A. Pikuz (HB11 Energy Holdings Pty, 11 Wyndora Avenue, Freshwater NSW 2096, Australia), Leonard M. Wegert (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Luca Antonelli (York Plasma Institute, The University of York, Heslington, York YO10 5DQ, United Kingdom; Blackett laboratory, Imperial College London, South Kensington Campus, London, SW7 2AZ, UK), Francesco Barbato (6Dipartimento SBAI, Universita di Roma La Sapienza, Rome, Italy), Guillaume Boutoux (CELIA, Université Bordeaux), Dimitri Khaghani (SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, California 94025, USA), Donaldi Mancelli (University of Bordeaux - CELIA, UPV/EHU-DIPC), Jay J. Santos (Universitè de Bordeaux, CNRS, CEA, CELIA, UMR 5107, F-33405, Talence, France), Ghassan Zeraouli (Universidad de Salamanca, 37008 Salamanca, Spain)

In a recent experimental campaign at the PHELIX laser facility at GSI, we isochorically heated a thin titanium wire to a warm dense matter (WDM) state using laser-accelerated relativistic electrons. To study the emission properties of WDM, we used both ”traditional” X-ray emission spectroscopy and a novel approach based on radiographic ”imaging” of the expansion. Here we discuss this approach.

Hydrogen Metallisation in Warm Dense Matter Condition

Divyanshu Ranjan (Helmholtz-Zentrum Dresden-Rossendorf)

Giant planets have dominated the numbers in the ever-increasing list of exoplanets. Efforts to understand the internal structures of these giants have been ongoing for a few decades. The insulator-metal transition in liquid hydrogen is an important phenomenon to understand the interiors of gas giants like Jupiter and Saturn as well as the physical and chemical behavior of materials at high pressures and high temperatures [1]. We discuss an experimental approach where spectrally resolved X-ray scattering method is used to observe and characterize hydrogen metallization in dynamically compressed hydrocarbons in the regime of carbon-hydrogen phase separation. Combining the time-dependent density functional theory (TDDFT) calculations [2], and scattering spectra collected at the European X-ray Free-Electron Laser (EuXFEL), we demonstrate sufficient data quality for observing C-H demixing and investigating the presence of liquid metallic hydrogen using the rep-rated drive laser systems in future experiments at EuXFEL.

[1] Jiang, S., Holtgrewe, N., Geballe, Z. M., Lobanov, S. S., Mahmood, M. F., McWilliams, R. S., Goncharov, A. F., A Spectroscopic Study of the Insulator–Metal Transition in Liquid Hydrogen and Deuterium. Adv. Sci. 2020, 7, 1901668.
[2] Kushal Ramakrishna and Jan Vorberger 2020 J. Phys.: Condens. Matter 32 095401.

Towards Probing K-Shell Ionization of Carbon Under Warm Dense Matter

Chongbing Qu (University of Rostock)

Warm dense matters broadly exist in stars and giant planets' interiors, but our knowledge about that is largely limited. Due to the development of the advanced high-power laser and x-rays, we can create such conditions in the laboratory. Owing to the small volumes, short lifetimes, and strong background radiation of the systems typically created in laboratory experiments, ionization states and temperatures are challenging to characterize in WDM, so theoretical predictions are largely untested. Here we present the recent experiment performed in EuXFEL, in which high power ReLaX laser drives the CH foams sample to the WDM regime followed by a free electron laser to diagnose. High-quality X-ray Thomson scattering (XRTS) spectra are obtained. The ionization states and the amount of equilibration reached inside the plasma are obtained by considering the ratio of elastic to inelastic of the scattering spectra over different time delays. The results show that the CH foams samples are ionized within 100 fs after the laser, and it takes 1 2 ps to reach the highest ionization state of 4.5.

Shock Release Dynamics and Recovery of Nanodiamonds Formed in Laser Compressed Plastics

Alessandra Benuzzi-Mounaix (École polytechnique), Zhiyu He (Helmholtz-Zentrum Dresden-Rossendorf), Benjamin Heuser (Helmholtz-Zentrum Dresden-Rossendorf), Dominik Kraus (HZDR), Julian Lütgert (Universität Rostock Physik(URO-PH)), Philipp May (University of Rostock), Chongbing Qu (University of Rostock), Divyanshu Ranjan (Helmholtz-Zentrum Dresden-Rossendorf), Alessandra Ravasio (École polytechnique), Samuel Schumacher (University of Rostock), Michael Stevenson (University of Rostock), Tommaso Vinci (Ecole Polytechnique), Kento Katagiri (Stanford University), Ozaki Norimasa (Osaka University)

Nanodiamonds (NDs) have a steadily growing number of applications, ranging from medicine to quantum sensors. Previous experiments have shown their formation in compressed C-H and C-H-O mixtures at planetary interior conditions (the Warm Dense Matter WDM regime) at a few thousand K and hundreds of GPa [He (2022), Sci. Adv. *8*(35)].
This provides a new way to synthesize them in large quantities by laser compressing plastic precursors [Schuster (2022), J. Phys. D: Appl. Phys. *56*(2)].
Diamond is a good candidate to study dynamic material synthesis at WDM conditions due to its inherent material stability allowing it to withstand extreme conditions.

Here we present both experimental and simulation data of the relaxation of NDs to ambient conditions. We investigated the formation and after-shock-release dynamics of nanodiamonds by X-ray diffraction and molecular dynamics simulations. We present evidence that nanodiamonds stay intact while relaxing to ambient pressure. Finally, preliminary data from experiments on capturing and concentrating nanodiamond particles with different catcher materials are reported. These catchers are still in development but the first results including REM and AFM scans of possible ND impacts are presented.

Super Luminescence High Power Microwave Pulse Propagation in the Neutral Gas

Yakov Krasik (Physics Department, Technion), Yan Cao (Physics Department, Technion), Yurii Bliokh (Physics department, Technion), John Leopold (Physics Department, Technion)

The ionization-assisted compression of a high-power microwave pulse (�250 MW, �0.5 ns, 9.6 GHz) propagating with superluminal velocity in a gas-filled cylindrical waveguide was studied. A fast-non-linear ionization within the pulse frame changes the waveguide eigen-frequency causing the wave frequency up-shift and respectively increases the local group velocity.

Background Estimation and Conjugate Homodyne Method as a Detection Scheme for Photon/Photon Scattering in Quantum Vacuum Signal

Karl Matthäus Zepf (GSI, Darmstadt), Pooyan Khademi, Leonard Doyle (LMU Munich, Germany), Jörg Schreiber (Ludwig-Maximilians-Universität München)

The advances in high power laser technologies have promoted the possibility of experimentally testing signatures of the response of the quantum vacuum (QV) to strong fields. In contrast to classical vacuum, the quantum vacuum shows nonlinear behavior and invalidates the superposition principle of Maxwell's equations. Hence, it makes classically forbidden phenomena like light-by-light scattering possible. The extreme laser pulses which make such an effect observable pose a challenge in detection of QV signal photons due to the presence of immense background light (BG). Particularly, the photon/photon scattering scenario where a QV signature is induced by head-on collision of 2 identical laser pulses – which provides the strongest signal. A detailed estimation of BG co-existing with quantum vacuum signal photons in their detection path is required. Fortunately, temporal and spatial characteristics of signal photons suggest detection schemes based on interferometry as the best candidate for their realization. Optical homodyne detection (OHD) is able to facilitate such a detection. OHD can reduce the background by using a strong stable reference known as local oscillator interfering with the signal in a pump/probe Mach-Zehnder configuration. Subtraction of two detector measurements will provide the information that claim true detection of the signal, free of the unwanted BG. Although this scheme is widely used for repeatable measurements to collect the full information about the unknown signal, recent research has shown the full information can be obtained in a conjugate OHD in a single shot measurement of the intensity. This is a matter of importance in a QV signal detection. Furthermore, and due to the extremely faint nature of QV signal, it had to be proven that conjugate OHD will tolerate the fundamental shot-noise and provide an above-noise signal level. Fundamentally, utilizing 2D pixel arrays (e.g. CCDs) will provide an advantage for bringing the signal over the shot-noise in the presence of background photons. 2D detectors allow noncolinear overlap in addition to a higher dynamic range, providing essential ingredients in the quest to detect photon/photon scattering of real photons from the QV.
This work has been funded by the Deutsche Forschungsgemeinschaft (DFG) under Grant No. 416702141 within the Research Unit FOR2783.

Interferometer for the Measurement of the Free Electron Density in a Laser-Generated Plasma

Sarah Jane Grimm (Technische Universität Darmstadt(TUDA-IKDA))

The Laser Ion Generation, Handling and Transport (LIGHT) beamline at GSI Helmholtzzentrum für Schwerionenforschung enables the generation of high intensity ion beams with a sub-nanosecond duration. This makes them ideal probing beams for stopping power experiments in laser-generated plasmas.
Such experiments will promote the establishment of a conclusive theory on the ions' energy deposition in plasmas with significant electron coupling and electron degeneracy. In order to interpret the data of these experiments, an accurate knowledge of the plasma conditions is necessary. While simulations can produce a large amount of information concerning these conditions, they require

verification by actual data. This verification can be done with the free electron density, which in turn, can be determined from an interferogram of the laser-generated plasma: When traversing the plasma, any electromagnetic wave will experience a phase shift due to variations of the refractive index. These variations are directly linked to the free electron density of the plasma. Superpositioning such a perturbed wave with an unperturbed one will create an interference pattern. This pattern can then be imaged and used to reconstruct the refractive index of the plasma with the help of an Abel transform. Consequently, the free electron density of the plasma can be determined.
Provided that the intensity of the probing light waves is not too high, this diagnostic method can be considered as nonperturbing to the plasma. Therefore, a suitable interferometry will be set up alongside with the energy loss experiment.

With my poster, I will present the planned design of this interferometry and emphasise on its different components and the requirements posed on them.

Numerical Optimization of the Target Thickness for Ion Acceleration in the Relativistic Transparency Regime at PHELIX

Pascal Boller (GSI, TU Darmstadt), Johannes Hornung (GSI), Vincent Bagnoud (GSI)

Laser-driven ion acceleration has been studied extensively for the last 20 years and the results obtained by many laboratories worldwide demonstrate its many advantages in contrasts to accelerators like high brightness, ultrashort emission and low beam emittance [1, 2]. In addition, a laser-driven ion source can be seen as a compact accelerator, which has an impact on the facilities cost, and a wide range of potential application in healthcare, industry and nuclear physics.
In order to exploit this potential, a lot of effort must be invested in the laser development, as well in the understanding and optimization in the acceleration process.

One of the promising acceleration schemes requires solid target to become transparent during the interaction with the laser, in order to reach conditions where the laser interact volumetrically with the target electrons. Such conditions can be found only at extremely high intensity, when relativistic effects must be additionally accounted for. This process is extremely transient and takes place at time scales similar to the laser pulse duration itself, which makes them hard to control. In addition, the target pre-heating due to the real laser profile and rising slope needs to be taken into account to get a right picture on the process numerically.
In this work, I present a parameter scan in the target thickness for the PHELIX facility and claim the optimum target thickness in relativistic transparent regime at this facility. With the hydrodynamic code Flash, I simulated the rising slope of the laser, which can be later fed into the PIC Code Epoch-2D. This parameter scan provides an insight into the optimal target thickness range of the relativistic transparency regime for the PHELIX facility.

[1] Macchi, Andrea, et al. “Ion acceleration by superintense laser-plasma interaction.” Reviews of Modern Physics 85.2 (2013)
[2] Daido, Hiroyuki, et al. “Review of laser-driven ion sources and their applicatons.” Reports on progress in physics 75.5 (2012)

Modeling of Laser-Induced Vaporization of Thin Tin Sheets for EUV Lithography Applications

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State-of-the-art nanolithography machines use extreme ultraviolet (EUV) light obtained from atomic transitions in tin microdroplets that are irradiated by a laser pulse to print patterns on silicon wafers[1]. In the pursuit of maximal conversion efficiency, research has led to advanced target shaping techniques: for instance, a pre-pulse is used to deform the droplet into a flat disk-shaped target[2].

On this poster, we present the results of a joint investigation of experiment and theory into the properties of a vaporizing target due to irradiation by 1 µm wavelength radiation. Experimentally, we have derived a relationship between target thickness, radius, and vaporization time for the irradiation of several target types[3]. Analysis of absorption peaks reveals a highly spatially resolved temperature map of the vapor, and we find that the value is relatively uniform. These quantitative results have been corroborated by simulations with the radiation hydrodynamics code RALEF-2D[4]. Time to vaporization as measured through time-resolved absorption and emission curves matches the values obtained from vaporization tests on a series of different target shapes. We have successfully verified the experimentally derived temperature profiles after vaporization of the target. In addition, we discovered a close linear relation between target thickness and vaporization time that holds across a wide range of target parameters.

These findings can serve to optimize EUV generation in next-generation nanolithography machines, while the experimental results will help to streamline and speed up future research into laser-produced plasmas.

[1] Versolato O O 2019 Plasma Sources Sci. Technol. 28 083001
[2] Fomenkov I et al 2017 Adv. Opt. Technol. 6 173
[3] Liu B et al 2021 J. Appl. Phys. 129 053302
[4] Basko M 2009 http://www.basko.net/mm/RALEF/ralef.html

On-Line Detection of Radioactive Fission Isotopes Produced by Laser Driven Gamma Rays

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The on-going developments in laser acceleration of charged particles and the production of γ-rays and neutrons as secondary beams provide a basis for novel nuclear physics experiments. The laser-matter interaction is able to generate ultra-high fluxes of particles and radiations. These fluxes are very short in both space and time and exceed the capabilities of standard particle accelerators by orders of magnitude. They are particularly interesting in the field of nuclear astrophysics, in the medical field as well as in fusion research.

A direct application nowadays is the field of laser-driven nuclear physics. In order to perform such experiments successfully, a detector system is required to perform for example γ spectroscopy. During the laser-matter interaction a γ flash and an electromagnetic pulse are generated which can lead to signal noise or even detector failure. The protection of the used detection system against these effects is especially important for short-lived nuclides. The distance to the interaction location can be increased to protect the system, because the intensity of the radiation decreases quadratic with the distance. Additionally, a Faraday cage can be used for shielding.

We already demonstrated a functional detection setup in a laser-driven nuclear experiment in September 2019[1] and December 2021. It was performed at the Petawatt High-Energy Laser for Heavy Ion Experiments (PHELIX) at GSI. By using laser pulses of 0.5 ps duration with energies up to 200 J, proton pulses in excess of 10^{12} protons with energies up to 70 MeV were achieved. These pulses were used for proton induced fission of ^{238}U. In this experiment, an on-line detection method was applied. In this method, a gas flow in a capillary tube provided a rapid transport of the fission products over several meters to a germanium detector which is additionally shielded. Thus, the system uses the two solutions mentioned above to protect the detection setup. In these experiments the volatile fission products were transported towards the detector.

In further experiments we aim for gamma-induced fission produced through bremsstrahlung of high electron fluxes caused by near critical density plasmas of ultra-low density foams. Further we plan to use reactive gases to also detach the non-volatile fission products of ^{238}U and transport them towards the detector.[2]

[1] Boller, Pascal, et al. ”First on-line detection of radioactive fission isotopes produced by laser-accelerated protons.” Scientific reports 10.1 (2020): 1-9.

[2] O. N. Rosmej, et al. 2020 Plasma Phys. Control. Fusion 62 115024

3-Dimensional Full Characterization of Laser Pulses With Optical Angular Momentum

Xinhe Huang (Uni Jena)

Laguerre-Gaussian laser beams with optical angular momentum are of interest for many experiments including structured wakefields for positron acceleration. To confirm the far-field intensity distribution during the interaction with the target, we measure the electric field in the spectral domain of the laser using the device INSIGHT. Then the laser pulse at focus can be fully reconstructed in 3 dimensions. To correct the wavefront distortions and to achieve a perfect donut-shape focus, the impacts on the focus shape is also studied by scanning the Zernike polynomials applied to the wavefront.

Experimental Facilities for High-Energy Density and Warm Dense Matter Experiments at FAIR

Stephan Neff (Facility for Antiproton and Ion Research in Europe GmbH(FAIR))

At the site of the Gesellschaft fuer Schwerionenforschung (GSI) in Darmstadt, the Facility for Antiproton and Ion Research (FAIR) is currently under construction. FAIR will offer unique high-intensity heavy ion beams and high-intensity proton beams for experiments covering many fields of research, including the study of high-energy density samples and the study of warm dense matter.
The research in this field is coordinated by the High Energy Density Science at FAIR (HED@FAIR) collaboration, which will focus on four main fields of study: (1) The study of the properties of materials driven to extreme conditions of pressure and temperature; (2) The study of shocked matter and of equations-of-state; (3) The study of basic properties of strongly-coupled plasma and warm dense matter; and (4) Nuclear photonics, including the excitation of nuclear processes in plasmas and laser-driven particle acceleration and neutron production.
The SIS-100 heavy ion synchrotron at FAIR will provide heavy ion beams with up to $5 \cdot 10^{11}$ U^{28+} ions with 2 AGeV in a 50 ns bunch for plasma physics experiments where they will be used either to isochorically heat macroscopic samples to eV temperatures or to indirectly compress them to megabar pressures. In addition, SIS-100 will also high-energy protons (up to 10 GeV with up to $2.5 \cdot 10^{13}$ protons per bunch) which will be used for a proton microscope.
In preparation for FAIR, experiments using the already upgraded facilities at GSI ("Phase 0"). In my presentation I will give an overview of the experimental facilities that will be available for HED experiments at FAIR and at GSI in Phase 0, the current status and the timeline for the construction and commissioning of the experimental setup.

Roomtemperature Vaccum Chamber With Cryogenic Surfaces for High Intensity Uranium 28+ Beams

Simone Aumüller (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

The FAIR accelerator complex at the GSI Helmholtzzentrum will generate heavy ion beams of ultimate intensities, up to 5E11 U28+ per pulse. To achieve this goal, low charge states have to be used, to avoid stripping losses and shift the space charge limit to higher numbers of particles.
However, the probability for charge exchange in collisions with residual gas particles of such ions is much larger than for higher charge states. In order to lower the residual gas density to extreme high vacuum conditions, 55% of the circumference of SIS18 have already been coated with NEG, which provides high and distributed pumping speed. Nevertheless, and Nobel-like particles, which have very high ionization cross sections, do not get pumped by this coating. A cryogenic environment at moderate temperatures, i.e. at 50-80K, provides a high pumping speed for all heavy residual gas particles. The only typical residual gas particle that cannot be pumped at this temperature is Hydrogen.
With an additional NEG coating the pumping will be optimized for all residual gas particles. The installation of cryogenic surfaces in the existing room temperature synchrotron SIS18 at GSI has been investigated. Measurements on a prototype quadrupole chamber for SIS18 and simulations of them with cryogenic surfaces based on these measurements are presented.