45th International Workshop on High-Energy-Density Physics with Intense Ion and Laser Beams

January 26th – February 1st, 2025

Darmstädter Haus (Waldemar Petersen Haus)

Hirschegg, Austria

P r o g r a m

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The Hed@fair Collaboration Status Report

Kurt Schoenberg[1]

[1]HED@FAIR Collaboration

As FAIR moves forward with a re-baselined construction schedule, the HED Collaboration continues to develop new research capabilities with a view to APPA cave operations. The PHELIX laser facility, the Z6 experimental area, and the HHT Cave are the principal experimental sites until the FS++ phase of FAIR operations. Developing combined laser-ion and HE-driven experimental capabilities at the HHT are several extant examples. The FAIR Council has emphasized that completion of the MSV remains its strategic goal and that experimental beamtime at the existing GSI facilities, until the start of the corresponding FAIR science programs, is essential for all FAIR collaborations. This talk will summarize the status of HED@FAIR Collaboration's plans to maintain a competitive research program through the transition to completion of the FAIR MSV project.

Progress in Construction of SIS100 and Beam Performance of SIS18

Peter Spiller[1]

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With the start of installation, the FAIR subproject SIS100 has entered into a new phase. Installation has been started in the straight of sector 4 and is now continued with the integration of the s.c. dipole groups in the arcs and the racks and power converters in the supply area. In Q1/2025, the installation of the main power converter system will be launched. Start of hardware commissioning is planned for 2026. In 2024, besides many other ion species, SIS18 has been operated with Uranium ions. New approaches for increasing the intensity have been tested in dedicated machine runs. A new intensity record has been achieved with the low charge state U28+ (FAIR reference ion) and first attempts for injecting a high intensity beam generated by a multi charge state operation in the linac have been performed. Several future SIS18 upgrade measures are taken over to the new GSI accelerator road map.

Status and Application Perspectives of Laser Plasma Accelerators

Ulrich Schramm[1]

[1]HZDR

TBD

AWAKE: Plasma Wakefield Acceleration and Beam-Plasma Interactions

Patric Muggli[1], *Collaboration AWAKE*

[1]Max Planck Institute for Physics

Particle and high-energy physics use high-energy particles for discovering the fundamental laws of Nature. Plasma-based accelerators can sustain accelerating gradients in excess of 1GeV/m, thereby offering new opportunities to produce high-energy particle bunches in distances shorter than today's radio-frequency-based accelerators can. Synchrotrons (e.g., SPS, LHC at CERN) routinely deliver bunches with high energy per proton (400GeV and 7TeV) and per bunch (19 and 120kJ) that can, in principle, drive wakefields in a very long plasma (200m to 5km). However, these bunches are long (ns) and require self-modulation (SM) to drive wakefields with GV/m amplitude, typically driven by ps-long bunches. AWAKE develops a proton-driven plasma wakefield accelerator to produce 50-100GeV electron bunches in a single accelerator plasma, 50-100m-long. Developing this accelerator requires understanding the various modes of interaction between the bunch and the plasma.

We will introduce AWAKE and its goals, and summarize the most important experimental results obtained so far among with a 10 m-long plasma: characterization and seeding of SM and of hosing of the bunch, optimization and suppression of SM, optimization of accelerating gradient and energy gain, effect of motion of plasma ions on SM, etc.We will then briefly outline R&D and plans for the next round of experiments. Particle physics experiments using the AWAKE accelerator could take place in the next decade.

Advanced Characterization of Passive Plasma Lensing for Ultrashort Electron Bunches

Andreas Seidel[1], *Karl Matthäus Zepf*[2], *Alexander Sävert*[3], *Stephan Kuschel*[4], *Carola Zepter*[5]

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Passive plasma lensing, a technique established by Kuschel and Thaury [1, 2], utilizes plasma preionized by a laser to achieve high transverse electromagnetic gradients (up to 1MT/m) for refocusing electron bunches. This method also generates significant longitudinal electromagnetic fields, enabling positive energy chirp reduction in electron bunches [3]. This study presents new experimental findings that further our understanding of this phenomenon and introduces a novel method for characterizing ultrashort electron bunches.

We present experimental results from the JETi 200 laser facility (center wavelength: 800 nm, spot size: $20\ \mu$m, pulse length: 23 fs, a_0=3.0), where a 7 mm He-N_2 gas cell produced electrons subsequently directed through a consecutive gas jet of the same length. A self-developed electron spectrometer, comprising a dipole magnet and scintillation screen, was employed to characterize the electron energy distribution.

Our findings reveal energy-dependent focusing effects, where higher-energy electrons remain unaffected, while electrons at 650 MeV are focused and lower-energy electrons experience defocusing. This behavior underscores the limitations of assuming a uniform transverse focusing gradient, which can induce beam width oscillations at reduced electron energies.

We present a new method for determining electron bunch length based on the observed focusing fields and assumed longitudinal chirp, utilizing linear plasma wakefield theory [4]. Preliminary results yield single-shot electron bunch lengths of 2 µm, offering a practical alternative to conventional diagnostics, such as x-band cavities [5] or multi-octave optical transition radiation [6] methods.

This work highlights the potential of passive plasma lensing for enhanced beam dynamics and introduces a streamlined diagnostic technique for femtosecond electron bunches, facilitating broader adoption in advanced accelerator systems.

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1. S. Kuschel et al., "Demonstration of passive plasma lensing of a laser wakefield accelerated electron bunch," *Phys. Rev. Accel. Beams*, vol. 19, no. 7, p. 071301, Jul. 2016, doi: 10.1103/PhysRevAccelBeams.19.071301.
2. C. Thaury et al., "Demonstration of relativistic electron beam focusing by a laser-plasma lens," *Nat. Commun.*, vol. 6, no. 1, p. 6860, Apr. 2015, doi: 10.1038/ncomms7860.
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4. R. Keinigs and M. E. Jones, "Two-dimensional dynamics of the plasma wakefield accelerator," *Phys. Fluids*, vol. 30, no. 1, pp. 252–263, Jan. 1987, doi: 10.1063/1.866183.
5. C. Behrens et al., "Few-femtosecond time-resolved measurements of X-ray free-electron lasers," *Nat. Commun.*, vol. 5, no. 1, p. 3762, Apr. 2014, doi: 10.1038/ncomms4762.
6. O. Zarini et al., "Multioctave high-dynamic range optical spectrometer for single-pulse, longitudinal characterization of ultrashort electron bunches," *Phys. Rev. Accel. Beams*, vol. 25, no. 1, p. 012801, Jan. 2022, doi: 10.1103/PhysRevAccelBeams.25.012801.

The LIGHT Beamline - Current and Future Projects

Haress Nazary[1], Martin Metternich[1], Sarah Jane Grimm[2], Abel Blazevic[1], Dennis Schumacher[1], Christian Brabetz[1], Joshua Dietrich Schilz[3], Florian Kroll[4], Daniel Dewitt[5], Marius Dehmer[6], Sebastian Ratschow[1], Ulrich Schramm[7], Vincent Bagnoud[1], Markus Roth[8]

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The Laser Ion Generation, Handling and Transport (LIGHT) beamline at GSI forms part of the ATHENA distributed facility, which is primarily concerned with the manipulation of phase space in laser-generated ion beams. In recent years, the LIGHT collaboration has achieved the routine generation and focusing of intense 8 MeV proton bunches with a temporal duration shorter than 1 ns (FWHM). In numerous accelerator facilities, linear accelerators are employed to accelerate ions to several MeV, which can then be injected into a synchrotron for post-acceleration. Given that high-power laser systems can also be employed to provide ions with such energies via target normal sheath acceleration (TNSA), it is conceivable that they could serve as an alternative ion source for synchrotrons in the future, particularly if the repetition rates of advanced laser systems get within the same order of magnitude as those of the current injectors. This concept has the potential to reduce the injection time, provide ion beams with lower emittances, and reduce the cost and size of future accelerator facilities.
However, since the initial TNSA-generated ion beam typically exhibits a high energy spread and a large initial divergence, it is necessary to adjust the beam to obtain a sufficient number of particles within the acceptance range of the synchrotron. In this regard, conventional accelerator structures may be employed, as exemplified by the Laser Ion Generation, Handling and Transport (LIGHT) beamline. The laser-driven beamline is situated at GSI in close proximity to the transfer channel between the Universal Linear Accelerator (UNILAC) and the Heavy Ion Synchrotron SIS18, which renders this experimental area optimal for a preliminary proof-of-principle experiment.
In this presentation, I will first describe the setup and working principle of the LIGHT beamline. I will then summarize the capabilities of the LIGHT beamline and the current status of ongoing projects, with a particular focus on the injection of LIGHT protons into GSI's Heavy Ion Synchrotron SIS18.

Nonlinear Breit-Wheeler Pair Production Using Polarized Photons From Inverse Compton Scattering

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The production of electron-positron pairs from the collision of photons is one of the most elusive processes in QED. Observing multiphoton electron-positron pair production (the nonlinear Breit-Wheeler process) requires high-energy γ rays to interact with strong electromagnetic fields. In order for these observations to be as precise as possible, the γ rays would ideally be both mono-energetic and highly polarized. In this talk I will present Monte Carlo simulations of an experimental configuration that accomplishes this in two stages.
First, a multi-GeV electron beam interacts with a moderately intense laser pulse to produce a bright, highly polarized beam of γ rays by inverse Compton scattering. Second, after removing the primary electrons, these γ rays collide with another, more intense, laser pulse in order to produce pairs.
I will show that it is possible to measure the γ-ray polarization dependence of the nonlinear Breit-Wheeler process in near-term experiments, using a 100-TW class laser and currently available electron beams. Furthermore, it would also be possible to observe harmonic structure and the perturbative-to-nonperturbative transition if such a laser were colocated with a future linear collider.

Modeling Structured Light in Plasma-Based Accelerators and Light Sources

Jorge Vieira[1]

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Structured laser pulses, characterized by complex correlations between space and time, have unlocked new possibilities in light-matter interactions. A prominent example is orbital angular momentum (OAM) beams, recognizable by their spiral wavefronts and doughnut-shaped intensity profiles. These spatiotemporal structures offer unique degrees of freedom that can be leveraged to control laser-plasma interactions, accelerators, and light sources. Yet, their full potential in these areas remains largely unexplored.

This talk will explore how structured light can address key challenges in laser-plasma accelerators and light sources. We will introduce a novel computational framework that enables the injection of arbitrarily structured laser pulses into particle-in-cell (PIC) simulations, strictly adhering to Maxwell's equations without relying on physical approximations. Using this framework in the PIC code Osiris, we simulate vortex beams in plasma, demonstrating their application to high-gradient positron acceleration and the generation of low-divergence ion beams. Additionally, we will investigate the propagation of space-time beams—pulses whose focal planes can move at arbitrary velocities—and their potential to achieve superradiance in laser-plasma accelerators. These findings illustrate how structured light could pave the way for exciting advancements in plasma-based accelerators and light sources.

Relativistic Solitions in the Wake of a High-Power Laser Pulses in Underdense Plasmas

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Few-cycle microscopy has enabled snapshots of underdense laser-plasma interactions with unprecedented temporal (? 4 fs) and spatial (< 2 µm) resolution. However, taking only snapshots, coupled with the shot-to-shot fluctuations of a high-power laser system, restricts our understanding of transient features in laser-plasma interactions. In this study, we developed a new technique by combing sequentially timed all-optical mapping photography with microscopic imaging, success fully extended few-cycle microscopy into burst mode, and allowed us to capture four frames from a single laser-plasma interaction with varying delays. With this new technique, we studied micrometer-sized, long lifetime (> 200 fs, ? 490 fs), broad bandwidth coherent light-emitting structures in the wake of a high-power laser pulse resembling relativistic solitons.

E-E+ Plasma Generation and Dynamics in Laser Interaction With Solid-State Targets

Alexander Pukhov[1]

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New laser facilities will reach intensities of 1023 Wcm-2. This advance enables novel experimental setups in the study of laser–plasma interaction. In these setups with extreme fields, quantum electrodynamic (QED) effects such as photon emission via nonlinear Compton scattering and Breit–Wheeler pair production become important. We study high-intensity lasers grazing the surface of a solid-state target by two-dimensional particle-in-cell simulations with QED effects included. The two laser beams collide at the target surface at a grazing angle. Due to the fields near the target surface, electrons are extracted and accelerated. Finally, the extracted electrons collide with the counter-propagating laser, which triggers many QED effects and leads to a QED cascade under a sufficient laser intensity. Here, the processes are studied for various laser intensities and angle of incidence and finally compared with a seeded vacuum
cascade. Our results show that the proposed target can yield many orders of magnitude more secondary particles and develop a QED cascade at lower laser intensities than the seeded vacuum alone [1].
At even higher laser intensities, 1024 Wcm-2, the created e-e+ plasma may reach solid densities and

exhibit collective behavior [2].

[1] M. Filipovic and A. Pukhov Eur. Phys. J. D (2022) 76:187 (2022)
[2] A. Samsonov and A. Pukhov, https://arxiv.org/pdf/2409.09131 (2024)

Pair Production in the Non-Perturbative Regime at CALA

Felipe Cezar Salgado[1], Katinka v. Grafenstein[2], Alperen Kozan[3], Carl Georg Boos[4], Stephan Kuschel[5], Stefan Karsch[6], Karl Matthäus Zepf[7]

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One of the fundamental processes yet to be experimentally explored in modern physics is the creation of electron-positron pairs through the interaction of a strong field with the quantum vacuum. Generating such pairs from vacuum requires fields with intensities approaching the Schwinger critical field value of 1.3×10^{18} V/m [1].

An experimental setup has been proposed at the Centre for Advanced Laser Applications (CALA) to investigate pair creation through the nonlinear Breit-Wheeler process [2]. In this experiment, bremsstrahlung γ-photons are generated by a monoenergetic 2.5 GeV plasma-accelerated electron beam with a charge of 10 pC interacting with a 50 µm thick tungsten target. These γ-photons collide with a high-intensity laser beam with an intensity of approximately 9.5×10^{21} W/cm² ($a_0 = 66$), resulting in the production of around 80 pairs/hour at the design point of the experiment. To detect the few pairs generated, a single-particle detection system composed of tracking layers composed of LYSO:Ce scintillating screens and a Cherenkov calorimeter has been designed [3].

In this report, we provide an overview of the experimental planning and its current status. Additionally, we will present preliminary results of studies on the laser-wakefield accelerator using shaped near-field laser beams required for the experiment as well as initial background measurements.

[1] V. I.Ritus, *J. Sov. Laser Res.* **6**, 5 (1985)
[2] F. C. Salgado et al, *New J. Phys.* **23**, 105002 (2021).
[3] F. C. Salgado et al, *New J. Phys.* **24**, 015002 (2022).

Tuesday (January 28th)

Start	Duration	Speaker	Title
Session 4: Laser-Driven Ion Sources I (Chair: V. Bagnoud)			
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08:50	0:20	GRIMM, Sarah J.	Multispecies Targets for Spectral Control in Laser-Ion Acceleration
09:10	0:20	MURAKAMI, Yuliya	Generation of Giga-Electron-Volt Proton Beams by Micronozzle Acceleration
09:30	0:20	WANG, Pengjie	Laser Acceleration of Diverse Ion Species from Different Novel Targets
09:50	0:20	GEULIG, Laura D.	Acceleration of In-Target Fission Fragments with the ATLAS-3000 Laser System
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Session 5: Laser-Driven Ion Sources II (Chair: S. Glenzer)			
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11:00	0:20	ASSENBAUM, Stefan	Prediction of Laser-Induced Breakdown in Sub-Micron-Thick Dielectric Targets for Laser-Ion Acceleration
11:20	0:20	HILZ, Peter	Proton Acceleration from Ultrathin Foils
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Session 6: Basic Properties of WDM/HED I (Chair: K. Schoenberg)			
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17:20	0:20	PIRIZ, Roberto	Nonlinear Model for the Single Mode Rayleigh-Taylor Instability
17:40	0:20	TAHIR, Naeem	Simulations of Low-Entropy Compression of Carbon Sample in LAPLAS Scheme Using Intense Heavy Ion Beams at GSI/FAIR
18:00	0:20	LÜTGERT, Julian	Measuring the Temperature and Structure of Heavy-Ion-Heated Diamond in Situ with X-Ray Diagnostics
18:20	0:20	RETHFELD, Bärbel	Aspects of Electron-Phonon Coupling in Laser-Excited Solids
19:00		**Dinner**	**(only for house guests)**

Multispecies Targets for Spectral Control in Laser-Ion Acceleration

Sarah Jane Grimm[1], Carolin Goll[2], Carl Georg Boos[3], Carl Simon Schultheis[2], Karim Zarrouk[1], Stephan Kuschel[4]

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Laser-accelerated ions typically exhibit an exponential energy spectrum up to a characteristic cut-off energy, which is a signature of target normal sheath acceleration (TNSA) [1]. This broad energy distribution inherent to TNSA poses a significant limitation for applications demanding well-defined ion energies, such as proton therapy [2] and the fast ignition concept in inertial confinement fusion [3].

By introducing multiple ion species into the target material, modulations in the TNSA-driven ion spectrum can be achieved. During the acceleration, the differing charge-to-mass ratios of these species can result in a separation in space and energy [4]. This enables enhanced control over the energy spectrum and particle numbers for the light as well as the heavy ions. Simulations indicate that energy transfer between species may contribute to these effects, further emphasizing the potential for precise control of both ion populations.

I will introduce the concept of laser-ion acceleration using multi-species targets, discuss the potential advantages of such target compositions based on results from multidimensional particle-in-cell (PIC) simulations, and outline planned experiments to further investigate this approach.

[1] P. Mora, Phys. Rev. Lett. 90, 185002 (2003).
[2] V. Malka et al., Med. Phys., 31: 1587-1592 (2004).
[3] J.J. Honrubia et al., J. Phys.: Conf. Ser. 244 022038 (2010).
[4] V.T. Tikhonchuk et al., Plasma Phys. Control. Fusion 47 B869–B877 (2005).

Generation of Giga-Electron-Volt Proton Beams by Micronozzle Acceleration

Yuliya Murakami[1]

[1]Institute of Laser Engineering, Osaka University

We propose a novel ion acceleration scheme—Micronozzle Acceleration (MNA)—capable of generating giga-electron-volt (GeV) proton beams. The MNA scheme employs a unique target structure, in which a micron-sized hydrogen rod is embedded inside a hollow micronozzle. Upon irradiation by an ultraintense laser pulse, a strong electrostatic field with a long lifetime and an extensive spatial distribution is formed within the micronozzle, significantly enhancing the kinetic energy of the accelerated protons. The underlying physics and performance of MNA have been investigated using two-dimensional particle-in-cell (PIC) simulations. The results demonstrate that a maximum proton energy exceeding 1 GeV can be achieved with a laser intensity of 10^22 W/cm2 .Unlike conventional target acceleration methods, MNA realizes efficient proton acceleration through a three-stage process consisting of the run-up phase, main-drive phase, and afterburner phase. This study demonstrates the potential of utilizing microstructured targets to significantly enhance the transfer of laser energy to ions, providing a promising pathway for the generation of GeV-class proton beams.

Laser Acceleration of Diverse Ion Species From Different Novel Targets

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Laser-driven ion acceleration has attracted much attention in the past two decades, because of the unique features like ultrahigh accelerating gradient, ultrashort duration and small source size of the accelerated ion beams. It is promising to develop compact and cost/energy-efficient laser-driven accelerators for applications such as high-energy-density physics (HEDP), nuclear physics, medical physics and material science. Therefore, experimental demonstrations of capability of accelerating nearly all kinds of ions varying from protons to very-heavy ions (Au, Pb), and progressive optimization of those ion beams, are of interest and importance to our community and areas of applications mentioned above.
In this talk, I will introduce three projects focused on accelerating diverse ion species covering a large rang from protons (A 1), argon ions (A 40) to gold ions (A 197), which were conducted at different laser facilities. First, I will present the enhancement of proton acceleration via online production of transient microstructured targets by manipulating a Laguerre-Gaussian (LG) prepulse[1]. This method can also facilitate the refreshment and alignment of microstructed targets simply generated by flat foils at high-repetition-rate irradiation experiments. Next, I will show some preliminary results on argon acceleration from cryogenic jets, which are debris-free and can be rapidly replenished. Lastly, I will share the results of accelerating very-heavy ions[2] (Au ions) from composite targets[3] to 1.2 GeV. Note that the measured charge-state distributions of heavy ions, supported by 2D particle-in-cell simulations, can serve as an additional tool to inspect the ionization and acceleration process, providing a powerful diagnostic tool for laser-plasma experiments.

[1] Y. Gao et al., All-Optical Method for Generating Transient Microstructured Targets in Laser Ion Acceleration, Physical Review Research 6, L042031 (2024).
[2] P. Wang et al., Super-Heavy Ions Acceleration Driven by Ultrashort Laser Pulses at Ultrahigh

Intensity, Physical Review X 11, 021049 (2021).
[3] P. Wang et al., Fabrication of Large-Area Uniform Carbon Nanotube Foams as near-Critical-Density Targets for Laser–Plasma Experiments, High Power Laser Science and Engineering 9, e29 (2021).

Acceleration of in-Target Fission Fragments With the ATLAS-3000 Laser System

Laura Desiree Geulig[1], Veronika Kratzer[1], Erin Grace Fitzpatrick[1], Maximilian J. Weiser[1], Runjia Guo[1], Jörg Schreiber[1], Peter Thirolf[1]

[1]Ludwig-Maximilians-Universität München

At the Centre for Advanced Laser Applications (CALA) we investigate the acceleration of heavy ions using the ATLAS-3000 laser system (central wavelength 800 nm, pulse length 25 fs, energy per pulse < 60 J). The spectrum of accelerated species ranges from protons to gold ions. A Thomson parabola spectrometer deflects ions with the same charge-to-mass (m/q) ratio on parabolic traces, which then can be matched to the ions with respective charge states. By using CR-39 as a detector, further information about the ion's mass can be obtained because their energy deposition is linked to the created pit size. We observe large pits produced by heavy ions with an m/q ratio, which cannot be attained by gold, i.e. below 2.5, where usually only light ions are expected. This matches observations from previous beamtimes at the PHELIX laser [1]. Investigation of the potential nuclear reaction responsible for creation of these fission fragments is subject of current analysis.
[1] F.H. Lindner et al, Sci. Rep. 12, 4784 (2022)

Prepulse-Induced Changes in Ion Beam Direction: Insights From TNSA Regime Experiments and Simulations at PHELIX

Pascal Boller[1], Johannes Hornung[2], Alice Dumitru[3], Ersin Oezalp[4], Jonas Benjamin Ohland[2], Vincent Bagnoud[1]

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Laser-driven ion acceleration offers significant advantages over conventional accelerators, including high brightness, ultrashort pulse duration, low initial beam emittance, and compact design [1,2]. These unique properties make it a highly promising technology for applications in medicine, material science, and next-generation accelerators. However, to fully exploit its potential, both the development of high-power laser systems and a deeper understanding of the ion acceleration processes are essential.
In a recent experimental study at the PHELIX facility [3], we systematically varied the target thickness

and introduced a controlled nanosecond pre-pulse to explore ion acceleration behavior. We varied the target thickness from 100 nm to 5000 nm and adjusted the pre-pulse timing to manipulate the plasma pre-expansion in order to affect the ion-acceleration outcome. The respective pre-plasma density distribution was monitored using a side-viewed interferometric setup with our recently commissioned probe-laser system [4]. The experiment yielded a comprehensive data set showing a transition in the preferred ion-acceleration direction, from the target-normal to the laser propagation direction, depending on the pre-pulse parameters.
Additionally, we complemented our experimental data with hydrodynamic (FLASH-2D [5]) and particle-in-cell (EPOCH-2D [6]) simulations to gain a deeper understanding of the particle acceleration. We present the experimental and theoretical findings of these recent studies on pre-pulse-controlled laser-ion acceleration.

References:
[1] A. Macchi, et al. ”Ion acceleration by superintense laser-plasma interaction”, Reviews of Modern Physics 85.2 (2013): 751-793
[2] H. Daido, et al. ”Review of laser-driven ion sources and their applications”, Report on progress in physics 75.5 (2012): 056401
[3] Zs. Major, et al., ”High-Energy Laser Facility PHELIX at GSI: Latest Advances and Extended Capabilities”, High Power Laser Science and Engineering, Published online:1-17 (2024), doi:10.1017/hpl.2024.17
[4] J. Hornung, et al., ”Synchronized off-harmonic probe laser with highly variable pulse duration for laser–plasma interaction experiments”, High Power Laser Science and Engineering 12:e10 (2024), doi:10.1017/hpl.2023.93
[5] B. Fryxell, et al., ”An adaptive mesh hydrodynamics code for modeling astraphysicl thermonuclear flashes.”, The Astrophysical Journal Supplement Series 131.1 (2000):273
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Prediction of Laser-Induced Breakdown in Sub-Micron-Thick Dielectric Targets for Laser-Ion Acceleration

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In laser-ion acceleration experiments, the rising flank of a high power laser pulse can cause target pre-ionization and subsequent pre-expansion long before the arrival of the main laser peak. Exact

knowledge of this target pre-expansion is required in order to understand laser-plasma acceleration mechanisms with the help of numerical simulations. For dielectric targets, the start of target pre-expansion is characterized by the point in time at which the target undergoes laser-induced breakdown (LIB).
In this contribution, we present a recently published method to determine the time of LIB in sub-micron-thick Formvar targets during interaction with a specific high-power laser pulse [1]. The required pulse-duration-dependent LIB threshold of Formvar is measured in a dedicated experiment. A comparison of LIB threshold to previously published data facilitates an empirical LIB scaling for other wide-band-gap dielectric materials used as targets in laser-ion acceleration experiments.

[1] S. Assenbaum et al. „Prediction of laser-induced breakdown in sub-micron-thick dielectric targets for laser-ion acceleration", accepted in Plasma Phys. Control. Fusion (2024)

Proton Acceleration From Ultrathin Foils

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tbd

Beam Line Optimization for Laser-Accelerated Ions

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In recent decades, the development of high-power lasers has increased interest in the use and research of laser-accelerated ions. While offering excellent characteristics, such as high brightness, high energies, and very short pulse duration, laser-accelerated ions also pose significant challenges regarding their capture and transport due to high initial divergence and a wide energy spectrum. Optimizing entire beamlines or individual accelerator elements thus requires striking the right balance between accuracy and efficiency.

This study combines truncated power series algebra (TPSA) with the gradient-based optimization algorithm Adam to develop an accurate and efficient optimization scheme for laser-accelerated ion beams. Using second-order tracking, a toy model consisting of two solenoids and a cavity was optimized to achieve the best possible output beam parameters, such as transmission, emittance, and momentum deviation. This toy model, a counterpart of the LIGHT (Laser Ion Generation, Handling, and Transport) experiment at GSI Helmholtzzentrum für Schwerionenforschung was validated using a high-fidelity Runge-Kutta field tracking algorithm, which itself has been benchmarked against experimental data.

One of the primary goals of the LIGHT experiment is the injection of laser-accelerated protons into the heavy-ion synchrotron (SIS18) via the transfer line (TK).

The optimized beamline demonstrates that, within the SIS18 acceptance, the injection of laser-accelerated protons peaked in the range of 10^8 particles. This result, while promising, falls 2–3 orders of magnitude short of the beam intensities achievable with the UNIversal Linear ACcelerator (UNILAC). This highlights the need for improved capture and transport systems specifically tailored to laser-accelerated ions to achieve beam intensities comparable to those of conventional ion sources. Potential solutions include optimizing the solenoid geometry or employing alternative capture elements, such as plasma lenses or quadrupoles, to minimize chromatic focusing effects and allow more particles to pass through the first element. Additionally, enhancing the cavity design to improve energy compression could significantly increase transmission by shifting more particles within the ± 0.2 % energy acceptance band of the SIS18.

Solenoid Design Optimization for Improved Beam Transport and Operation at High Repetition Rate

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Laser-plasma acceleration (LPA) sources exhibit extraordinary beam properties that create unique application opportunities but also pose challenges. LPA processes can generate energetic ions, most efficiently protons, of up to 150 MeV. Laser accelerated ion beams exhibit a ps to ns bunch length, carry up to 1013 particles with broad energy spectrum. On the other hand, these LPA sources suffer from unfavorable beam properties such as a high divergence and a broad energy distribution. It therefore is usually necessary to capture and shape the LPA bunches spectrally and spatially before they can be used in application studies.

Pulsed high-field magnets (B ≤ 20 T), as also facilitated within the LIGHT collaboration, are used as particle beam optics, featuring tunability, large apertures and short focal lengths for efficient beam capture, transport, and energy selection. The magnets match the pulsed nature of LPA sources. They are powered by custom- designed current pulse generators.

We present recent development toward improved optical performance of the solenoid magnets for efficient beam transport and energy selection. Furthermore we demonstrate a high repetition rate (1 Hz) pulse generator, which will serve as a valuable tool for injection into a conventional accelerators, radiobiological studies, fundamental research and material science.

A Reduced Kinetic Method for Investigating Non-Local Heat Transport in Ideal Multi-Species Plasmas

Nicholas Mitchell[1], Dave Chapman[2], Grigory Kagan[1]

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A reduced kinetic method (RKM) with a first-principle collision operator is introduced in a 1D2V planar geometry and implemented in a computationally inexpensive code to investigate non-local ion heat transport in multi-species plasmas. The RKM successfully reproduces local results for multi-species ion systems and the important features expected to arise due to non-local effects on the heat flux are captured. In addition to this, novel features associated with multi-species, as opposed to single species, cases are found. Effects of non-locality on the heat flux are investigated in weakly and strongly asymmetric ionic mixtures with temperature, pressure, and concentration gradients. In particular, the enthalpy flux associated with diffusion is found to be insensitive to sharp pressure and concentration gradients, increasing its significance in comparison to the conductive heat flux driven by temperature gradients in non-local scenarios. The RKM code can be used for investigating other kinetic and non-local effects in a broader plasma physics context. Due to its relatively low computational cost it can also serve as a practical non-local ion heat flux closure in hydrodynamic simulations or as a training tool for machine learning surrogates.

Nonlinear Model for the Single Mode Rayleigh-Taylor Instability

Antonio Roberto Piriz[1], Juan José López Cela[2], Sofía Ayelen Piriz[2], Naeem Ahmad Tahir[3]

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A model for the single mode, two-dimensional Rayleigh-Taylor instability in ideal, incompressible, immisci- ble, and inviscid fluids is developed as an extension of a previous linear model based on the Newton's second law [A. R. Piriz et al., Am. J. Phys. 74, 1095 (2006)]. It describes the transition from linear to nonlinear regimes and takes into account the mass of fluids participating in the motion during the instability evolution, including the laterally displaced mass. This latter feature naturally leads to the bubble and spike velocity saturation without requiring the usual drag term necessary in the well-known buoyancy-drag model (BDM). In addition, it also provides an explanation to the latter phase of bubble reacceleration without appealing to the vorticity generation due to the Kelvin-Helmholtz instability. The model is in perfect agreement with the BDM, but, apart from extending its range of application, it solves many of its issues of concern and provides a more consistent physical picture.

Simulations of Low-Entropy Compression of Carbon Sample in LAPLAS Scheme Using Intense Heavy Ion Beams at GSI/FAIR

Zsuzsanne Slattery-Major[1], Vincent Bagnoud[1], Antonio Roberto Piriz[2], Naeem Ahmad Tahir[1], Paul Neumayer[1], Sofia Ayelen Piriz[3]

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The full-scale LAPLAS (LAboratory PLAnetary Science) experiment will require strongly bunched, high intensity energetic heavy ion FAIR Beam. Nevertheless, the LAPLAS scheme can be applied to studying low-Z material like carbon at high pressures and high temperatures relevant to planetary core conditions, using the moderate intensities provided by the existing accelerator, SIS-18. Moreover, such experiments will provide a platform to develop and test the diagnostics in preparation for the final HED@FAIR experiments. In this talk we present numerical simulations of the LAPLAS implosion of a carbon sample using the SIS-18 as well as the SIS-100 beam. A comparison is also made to demonstrate the capabilities of the two accelerators.

Measuring the Temperature and Structure of Heavy-Ion-Heated Diamond in Situ With X-Ray Diagnostics

Julian Lütgert[1], Philipp Hesselbach, Armin Bergermann[2], Argha Roy[3], Maximilian Schörner[4], Vincent Bagnoud[5], Björn Lindqvist[3], Ronald Redmer[4], David Riley[6], Gabriel Schaumann[7], Andreas Tauschwitz[5], Dmitry Varentsov[5], Leonard Maximilian Wegert[5], Yang Yang[8], Bernhard Zielbauer[5], Zsuzsanna Slattery-Major[5], Paul Neumayer[5], Dominik Kraus[9]

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The graphitization / amorphization of diamond is of high interest for nanodiamond synthesis in laser-shock experiments, as well as for its common application as a detector material. On the one hand, diamond at ambient densities is predicted to undergo a transition to graphite thermally at temperatures above 2000 K. On the other, a non-thermal transition occurs, given enough energy is

deposited locally. We report on the results of a combined beamtime at HHT (GSI), studying the intermediate regime between these two mechanisms using an uranium beam to heat a monocrystalline target.

Our sample is probed using x radiation from a titanium plasma, which was generated by the PHELIX laser. A similar setup has demonstrated the capability to determine bulk-temperatures of the probed diamond from the ratio of elastic to inelastic scattering in the recorded x-ray Thomson scattering (XRTS) spectra[1]. The method maps the increase of diffuse scattering, which is encoded in the ion-ion static structure factor, to temperatures by comparison to DFT-MD simulations. Significant improvements in the data quality were achieved by increasing the shielding, and setup changes informed by analyzing the spatial extend of the particle background in previous campaigns[2].

By using a degrader material we tune the Bragg-peak to be located within our sample, realizing higher peak temperatures, albeit at the expense of spatial uniformity. While we can confirm good agreement between ion stopping power calculations with the temperatures inferred from XRTS for temperatures bellow $\sim 2000\ K$, the diffuse scattering increases severely for the highest heating achieved. A simultaneous x-ray diffraction measurement coincides with a change of the formerly sharp diamond features, and of the optical properties of the sample. These rapid changes might indicate an alternation of the crystal structure of our sample.

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Aspects of Electron-Phonon Coupling in Laser-Excited Solids

Baerbel Rethfeld[1]

[1]Technische Universitaet Kaiserslautern

When a solid material is irradiated with a visible laser pulse, the electrons initially absorb the energy and rapidly develop a hot Fermi distribution. Subsequently, on a picosecond timescale, the electrons transfer energy to the phonon system and equilibrate their temperature with the lattice. Depending on the energy input, thermal phase transitions such as melting or transition to warm dense matter can be induced.

The energy relaxation dynamics is governed by electron-phonon coupling and is usually described in terms of a two-temperature model. Its central parameter, the electron-phonon coupling parameter is the subject of intense debate, as both theoretical and experimental determinations yield highly inconsistent results.

In this presentation, we try to raise awareness of possible reasons for these inconsistencies. These include different assumptions on equilibrium occupations of electrons and phonons, averaging of different phonon branches and electron bands, low-temperature assumptions for the electronic distributions etc., on the theoretical side, combined with temporal and spatial averaging in experimental studies. We explore the magnitude of some of these effects through examples.

Wednesday (January 29th)

Start	Duration	Speaker	Title
Session 7: Basic Properties of WDM/HED II (Chair: B. Rethfeld)			
08:30	0:30	DROMEY, Brendan	Ultrafast Nanodosimetry – Unlocking the Role of Nanoscale Structure and Ultrafast Dynamics During Radiation Interactions in Matter
09:00	0:20	WEGERT, Leonard	Observing the Evolution of Proton-Heated Foam Microstructure Using X-Ray Talbot Interferometry
09:20	0:20	MUTHREICH, Nils	Non-Linear X-Ray Scattering of Ultrathin Fe and Au Foils at SACLA
09:40	0:20	BESPALOV, Dmitrii	High-Resolution Plasmon Dispersion in Compressed Aluminum at the EuXFEL
10:00	**00:50**	**Coffee break**	
10:50	**1:30**	**Poster Session 1**	
12:20		**Lunch break**	
17:00	**1:30**	**Poster Session 2**	
18:40	**00:20**	**Conference Board Meeting**	
20:00		**Conference Dinner at Birkenhöhe**	

Ultrafast Nanodosimetry – Unlocking the Role of Nanoscale Structure and Ultrafast Dynamics During Radiation Interactions in Matter:

Brendan Dromey[1]

[1]Queen's University Belfast

Ionisation dynamics on the nanoscale seed the processes that govern pathways to macroscopic equilibrium in irradiated matter. Therefore, understanding the conditions that underpin this transition is critical in a wide range of applications from healthcare to radiation science. Recently we have demonstrated that laser driven ion accelerators can provide an ultrafast tool for studying this inherently multiscale regime with temporal resolution < 0.5 ps [1]. Here we discuss how it is possible to interrogate these ultrafast processes in real-time by contrasting how recovery scales with material complexity on the nanoscale for different ionising species. We employ single-shot optical streaking to track the decay time constant, t_c, of free carriers in matter irradiated by picosecond-scale (ps, 10^{-12} s) pulses of X-rays and protons from a single laser-driven accelerator. By exploiting the nanoscopically heterogeneous density of SiO_2 aerogels, our results reveal a sharp discontinuity in the scaling of t_c with average density for proton and X-rays interactions [2].

Next, we demonstrate how this understanding has started to unravel a long standing problem for high power laser solid target interactions: realising the theoretically anticipated performance from plasma mirrors. In this section, harmonic generation from relativistic laser plasmas will be introduced briefly and the challenges that have inhibited their performance outlined. These experiments have demonstrated how the toolkit provided by the 'Ultrafast Nanodosimetry' approach outlined above can lead to significant improvements in performance and pave the way for an exciting frontier in strong field science via Coherent Harmonic Focusing [3,4].

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[3] B. Dromey, et al., Nat. Phys. 5, 146–152 (2009)
[4] H. Vincenti, Phys. Rev. Lett. 123, 105001 (2019)

Observing the Evolution of Proton-Heated Foam Microstructure Using X-Ray Talbot Interferometry

Leonard Maximilian Wegert[1], *Stephan Schreiner*[2], *Paul Neumayer*[1], *Artem Martynenko*[1]

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Foams hold a significant promise for advancing inertial confinement fusion (ICF) by offering several

potential benefits, among those the usage of DT-wetted foams in ICF targets. Understanding the behavior of the foam's microstructure under intense laser irradiation is crucial to unlocking their full potential. However, direct observation of foam microstructure poses significant experimental challenges.
In a novel attempt, we demonstrate the application of X-ray Talbot interferometry to investigate the rapid evolution of laser-accelerated proton heated foam microstructure. Using the dark field signal, which is sensitive to density fluctuations beyond resolution, we effectively discriminate between microstructured and homogenized material states. The unique platform allows to observe the temporal evolution of the foam's microstructure at various temperature conditions. Obtained results are compared with simulations, showing good agreement.
The results contribute to a better understanding of the behavior of foams in ICF context, making Talbot-interferometry an interesting tool for future studies.

Non-Linear X-Ray Scattering of Ultrathin Fe and Au Foils at SACLA

Nils Hendrik Muthreich[1], Jan Leutloff, Robert Radloff, Ichiro Inoue, Taito Osaka, Gota Yamaguchi, Jumpei Yamada, Slawomir Skruszewicz, Tais Gorkhover, Stephan Kuschel

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Coherent diffraction imaging using bright femtosecond pulses from X-Ray Free Electron Lasers (XFEL) has the potential to achieve resolution in the sub-femtosecond and sub-nanometer regime. However, the resolution is limited by image brightness, which is further reduced by bleaching during the interaction. Hartree-Fock simulations indicate that femtosecond changes of the electronic configuration can result in a transient enhancement of the atomic scattering factor, driven by short-lived atomic resonances. Here we demonstrate the nonlinear enhancement of absorption and scattering in thin iron and gold foils around the K-alpha and the L-alpha lines respectively. We employed 6-fs-long X-ray pulses at SACLA, which were focused down to a 100 nm spot size, achieving intensities of up to 2.4×10^{20} W/cm^2.

High-Resolution Plasmon Dispersion in Compressed Aluminum at the EuXFEL

Dmitrii Bespalov[1], Ulf Zastrau[2], Dominik Kraus[3], Thomas Gawne[4], Thomas Preston[2], Hauke Hoeppner[2], Oliver Humphries[1], Erik Brambrink[2], Alexander Pelka[5], Cornelius Strohm[6], Carsten Baehtz[2], Jan-Patrick Schwinkendorf[5], Masruri Masruri[5], Toma Toncian[7]

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Plasmon dispersion in warm dense matter (WDM) reveals how free electrons behave collectively under extreme conditions. This study employed advancements in ultrahigh-resolution X-ray scattering (XRS) techniques developed at the European XFEL [1, 2, 3]. Seeded X-rays at 8.31 keV were utilized to achieve high spectral purity and coherence, enabling precise measurements of plasmon dispersion in dynamically compressed aluminum. Aluminum was selected for its ease of compression and diagnostic reliability, making it an ideal model for studying planetary core conditions. The DiPOLE laser [3] created pressures of 25–50 GPa with consistent shot-to-shot pulse energy stability (1–2%), ensuring reproducible results.
Measurements were obtained with forward and backscattering spectrometers, along with X-ray diffraction (XRD) to track structural changes. The XRD pattern observed in the experiment closely matched the results of simulations combining density functional theory molecular dynamics (DFT-MD) [4] and the HELIOS radiation-hydrodynamics code [5]. This agreement enabled accurate determination of density and temperature, as well as modeling of the static structure factor S(k). The dynamic structure factor $S(k,\omega)$, which describes the collective behavior of free electrons, was derived from simulations and compared directly with the measured plasmon data.
High-resolution measurements of plasmon dispersion were performed for compressed aluminum, providing detailed insights into how the plasmon energy depends on the wave vector (k). The results confirmed theoretical predictions for cold aluminum at small (k), but deviations were observed as wave vector increased. These deviations underscore the significance of measuring the dielectric function $\epsilon(k,\omega)$, which influences resistivity and the material's response to electromagnetic waves at various pressures. This work represents one of the most accurate measurements of plasmon dispersion under compression, offering a valuable reference for future studies of warm dense matter.

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2. Preston et al., "Measurements of the momentum-dependence of plasmonic excitations in matter around 1 Mbar using an X-ray free electron laser," *Appl. Phys. Lett.* **114**, 014101 (2019).
3. U. Zastrau et al., "The High Energy Density Scientific Instrument at the European XFEL," *J. Synchrotron Rad.*, **28**, 1393–1416 (2021).
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5. MacFarlane et al., "HELIOS-CR – A 1-D radiation-magnetohydrodynamics code with inline atomic kinetics modeling," *J. Quant. Spectrosc. Radiat. Transf.* **99**, 381 (2006).

Thursday (January 30th)

Start	Duration	Speaker	Title
Session 8: Transient Phenomena and Dynamic Transitions in WDM (Chair: P. Neumayer)			
08:30	0:30	KRAUS, Dominik	Dynamic Megabar Chemistry for Planetary Interiors, New Materials and IFE
09:00	0:20	LEUTLOFF, Jan	Transient Resonances in Few nm Au Nanoparticles at LCLS
09:20	0:20	KLEINSCHMIDT, Uwe	A Coductivity Model for Hydrogen Based on Ab Initio Simulations
09:40	0:30	HESSELBACH, Philipp	X-ray Absorption Spectroscopy of Heavy-Ion Heated Aluminum at the HHT Station of GSI
10:10	**00:20**	**Coffee break**	
Session 9: Laser-Driven Electron Acceleration (Chair: J. Ren)			
10:30	0:30	KARSCH, Stefan	Towards Ultracold Electron Beams - High-Transfer Efficiency in Hybrid PWFA-LWFA
11:00	0:30	KIRCHEN, Manuel	High Average Power Laser Plasma Acceleration at DESY
11:30	0:30	HIDDING, Bernhard	Paving the Frosted Path to Ice-Cold, Ultra-Low Emittance Beams Low Emittance
12:00	0:20	PAUW, Viktoria	Data Management for Post-Processing on PIC-Simulations of Laser-Plasma Acceleration
12:20		**Lunch break**	
Session 10: Laser-Driven Fusion (Chair: S. Neff)			
17:00	0:20	GLENZER, Siegfried	Demonstration of Laser-Driven Energetic Ion Beams with Unprecedented Flux for Inertial Fusion Research
17:20	0:20	PECOVER, James	Reaching TPa Pressures for EoS Measurements on Modest Machines (and the Z Machine)
17:40	0:20	MEYER-TER-VEHN, Juergen	Selfsimilar Compression Solutions, Useful for IFE
18:00	0:20	RUHL, Hartmut	Non-Cryogenic DTs and Their Relevance for Nuclear Fusion
18:20	0:20	SCHOLLMEIER, Marius	First Experimental Evaluation of Laser Absorption, Ion Acceleration Efficiency, and Neutron Generation Utilizing a 10-PW-Driven Nano Accelerator Embedded in a Proton-Boron-Deuterium Compound Target
18:40	0:20	MURAKAMI, Masakatsu	New Self-Similar Solution for Multi-Stacked Converging Shocks and High Compression of Matter
19:15		**Dinner**	**(only for house guests)**

Dynamic Megabar Chemistry for Planetary Interiors, New Materials and IFE

Dominik Kraus[1]

[1]University of Rostock / HZDR

I will report on *in situ* X-ray probing of laser-driven shock waves at megabar pressures. At X-ray Free Electron Lasers, simultaneous use of spectrally resolved X-ray scattering, X-ray diffraction and optical diagnostics such as VISAR and SOP provides precise insights into the dynamics of chemical processes at these extreme conditions. At European XFEL, the DiPOLE laser with its repetition rate of up to 10 Hz now allows for measurements of unprecedented precision and enables photon-hungry spectroscopic techniques that were so far unreachable in dynamic compression experiments. The first experimental campaigns exploiting these capabilities provide insights into chemical kinetics at extreme conditions, the formation of peculiar bonding and material structures, and the presence of liquid metallic hydrogen in mixtures of light elements. These results inform models for planetary interiors, provide the pathway to the synthesis of new materials via extreme conditions, and may be crucial for designing efficient ablator materials for IFE. I will also give an outlook on a new campaign at the National Ignition Facility to explore the use of dynamic chemistry around 10 Mbar to synthesize new materials such as the so far only predicted BC-8 structure of carbon.

Transient Resonances in Few Nm Au Nanoparticles at LCLS

Jan Leutloff[1], *Nils Muthreich*[1], *Robert Radloff*[2], *Rasmus Buchin*[2], *Ichiro Inoue*[3], *Slawomir Skruszewicz*[2], *Andy Aquila*[4], *Sandra Mous*[4], *Sébastien Boutet*[4], *Samuel Sahel-Schackis*[5], *River Robles*[5], *Takahiro Sato*[4], *Agostino Marinelli*[4], *Tais Gorkhover*[2], *Stephan Kuschel*[1]

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Compared to other imaging methods, coherent diffraction imaging (CDI) at X-ray free electron lasers (FELs) provides a unique opportunity to examine a sample in situ at a very high spatial and temporal resolution. In CDI, the resolution of the recorded diffraction patterns is limited by the brightness of the recorded image. Increasing the photon fluence does not enhance the signal as subsequent ionization generally leads to a reduction in the scattering cross section. However, transient resonances have the potential to increase the elastic scattering cross section in the soft and hard X-ray regime, thereby improving the brightness of the recorded images.
In our recent experiment conducted at LCLS in September 2024, we investigated the process of transient resonances in the hard X-ray regime (9,500 eV and 10,000 eV) using gold nanoparticles (1 nm to 12 nm), few-fs X-ray pulses and a focal spot size of 100 × 200 nm^2.

A Coductivity Model for Hydrogen Based on Ab Initio Simulations

Uwe Kleinschmidt[1], Ronald Redmer[1]

[1]University of Rostock

Electrical and thermal conductivities for matter under extreme conditions are an important input in magnetohydrodynamic simulations to model, e.g., the dynamo action in the deep interior of planets like Jupiter or the Ohmic dissipation rate in the atmosphere of hot Jupiters (see [1]). Such gas giant planets consist mainly of hydrogen and helium so that the calculation of corresponding conductivity data for a wide range of pressures and temperatures is an important task. In addition, the construction of conductivity models, e.g., by solving the Boltzmann equation in relaxation time approximation, as proposed by Lee and More [2] help to keep the computational costs low in such simulations. The Lee-More conductivity model provides reasonable results for weakly coupled high temperature plasmas but deviates strongly from ab initio methods like density functional theory molecular dynamics (DFT-MD) simulations for lower temperatures and stronger coupled plasmas (see [3]). We performed extensive DFT-MD simulations to calculate conductivities for fully and partially ionized hydrogen plasmas. We used this data to modify the conductivity model by Lee and More and to provide conductivity data for a wide range of temperature and density which can be applied, e.g., in dynamo simulations for the magnetic field generation in gas giant planets, Brown Dwarfs, and stellar envelopes.

[1] S. Kumar et al., Phys. Rev. E 103, 063203 (2021)
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X-Ray Absorption Spectroscopy of Heavy-Ion Heated Aluminum at the HHT Station of GSI

Philipp Hesselbach, Julian Lütgert[1], Chongjie Mo[2], Vincent Bagnoud[3], Carlos Butler, Dominik Kraus[4], Björn Lindqvist[1], Jieru Ren[5], Alice Renaux[3], David Riley[6], Andreas Tauschwitz[3], Dmitry Varentsov[3], Leonard Maximilian Wegert[3], Karin Weyrich[3], Yang Yang[7], Bernhard Zielbauer[3], Zsuzsanna Slattery-Major[3], Wei Kang[8], Yongtao Zhao[9], Paul Neumayer[3]

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The HHT experiment area at GSI offers the unique possibility to heat matter by intense bunches of high-energy heavy-ions from the SIS-18 heavy-ion synchrotron and to probe the generated short-lived states with X-rays generated by the PHELIX laser facility [1]. Focusing 300-ns-long bunches of up to 4×10^9 U^{73+} ions down to sub-millimeter spot-sizes, we have heated aluminum samples to over 2000 K and detected X-ray absorption spectra around the K-edge (1560 eV) at different heating conditions. We have measured X-ray absorption near edge structure (XANES) with 1 eV resolution and extended X-ray absorption fine structure (EXAFS) up to a photon energy of 1700 eV by employing two different spectrometer setups. Both, XANES and EXAFS show spectral modifications upon heavy-ion heating compared to ambient conditions.

The EXAFS oscillation structure vanishes with increasing temperature, particularly above the melting point. The XANES spectra indicate a decrease of the K-edge energy of 0.2-0.3 eV for temperatures around 2000 K. We have carried out a careful analysis of our experimental data to be sensitive to these small shifts, which holds the promise for volumetric temperature diagnostics of the heated samples by comparison to DFT-MD simulations. The employed experimental techniques are well suited to be used at the future FAIR facility, where unprecedented ion beam intensities will enable the investigation of continuum lowering at warm-dense-matter conditions.

In this contribution, we will introduce our experimental setup combining heavy-ion heating with laser-driven X-ray diagnostics, give details on our analysis procedure, and show the first XANES and EXAFS spectra, and temperature-dependent K-edge shifts of heavy-ion heated aluminum. This demonstrates for the first time that the HHT target station allows high-precision absorption spectroscopy measurements on heavy-ion-heated matter, which is a worldwide unique capability.

[1]: P. Hesselbach *et al.*, ”Platform for laser-driven X-ray diagnostics of heavy-ion heated extreme states of matter”, Matter and Radiation at Extremes (in production)

Towards Ultracold Electron Beams - High-Transfer Efficiency in Hybrid PWFA-LWFA

Alastair Nutter [1], Moritz Foerster[2], Enes Travac[3], Ahmad Habib[4], Florian Haberstroh[3], Arie Irman[5], Max Laberge[6], Thomas Heinemann[7], Jurjen Couperus-Cabadag[6], Ufer Patrick[6], Katinka v. Grafenstein[3], Andreas Doepp[3], Susanne Schoebel[6], Bernhard Hidding[7], Faran Irshad[3], Ulrich Schramm[8], Sebastien Corde[9], Alexander Knetsch[9], Olena Kononenko[9], Richard Pausch[6], Stefan Karsch[10]

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[2]LMU Muenchen
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[4]Uni Strathclyde
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[8]HZDR
[9]Ecole Polytechnique
[10]Universität München

Electron acceleration in laser wakefields (LWFA) has been studied extensively for the last two decades. This research has yielded exciting results such as multi-GeV beams produced from a single plasma stage, 24-hour stable operation of LWFAs or the onset of FEL gain in undulators fed by LWFA beams, just to name a few. One obstacle that has prevented their more widespread application is the difficulty of producing beams that reach or even surpass the quality of the best RF linac beams. We believe a large contributing factor to this is the fact that laser-driven plasma waves are driven by the ponderomotive force of the laser, which has a large oscillatory component from the transverse laser fields. This leads to a relatively hot electron population, from which both the wakefield and the trapped electrons are subsequently formed, giving the electron beams an intrinsic temperature. On the upside, these beams can be extremely dense with currents of up to 100kA, and their energy content and unipolar fields allow them to drive strong, nonlinear wakefields in a secondary, cold plasma suitable for particle-driven wakefield acceleration (PWFA). Electron trapped from the cold background and injected into these secondary plasma waves should in theory form much colder electron bunches. We have been studying this regime of hybrid LWFA-PWFA acceleration in the past few years, making steady progress in establishing its basic working principle and scaling behavior, and recently established strong indications for a marked improvement of the beam quality over LWFA. In the experiments up to now, the PWFA beams's average energy only reached up to approximately half the average driver energy, making these beams only moderately interesting for applications in e.g. light sources. By optimizing the target and LWFA beam parameters we have been working on improving this situation, and we will present the first experimental observation with witness beams now reaching and even slightly surpassing the mean driver energy. This initial progress paves the way towards further optimization and therefore is an important step along the way to ultrahigh quality, GeV-level beams for driving future compact light sources.

High Average Power Laser Plasma Acceleration at DESY

Manuel Kirchen[1]

[1]DESY

Laser-plasma acceleration (LPA) is a promising technology for future compact accelerators. However, the low repetition rate (typically few Hz) of today's high-power laser systems prevents reaching the average power required by applications and hinders the implementation of fast feedback systems to mitigate beam instabilities. To this end, DESY has established a dedicated research program on high-average power LPA. Our flagship project KALDERA pursues the development of a new laser tailored to plasma acceleration. Based on Ti:Sa technology, the system will deliver pulses at 100 TW peak power at up to 1 kHz repetition rate and by that enable the application of active stabilisation techniques to enhance LPA performance. Here, we report on the development of MAGMA, the first LPA that will be powered by KALDERA. We also introduce the BEETLE project which explores the use of post-compressed Yb-lasers as future alternative to scale the average power of LPA even further.

Paving the Frosted Path to Ice-Cold, Ultra-Low Emittance Beams Low Emittance

Bernhard Hidding[1]

[1]HHU Düsseldorf

Paving the Frosted Path to Ice-Cold, Ultra-Low Emittance Beams Low emittance – and conversely, high brightness – is crucial for X-FEL photon sources, determines focusability, beam density and corresponding electric fields for QED, and luminosity for HEP applications. Laser- and particle beam driven plasma wakefield accelerators can produce monoenergetic, low emittance beams in the highly non-linear broken wave regime [1], today reaching similar normalized emittance levels as conventional linacs. However, electron injection in plasma wakefield accelerators is difficult to control, and at the same time determines the obtainable emittance. This talk will discuss opportunities and challenges of different types of injectors, and will report on theoretical [2,3] and experimental progress [3,4,5] in the realization of plasma photocathodes on the path to stable and ultralow-emittance electron beams 10,000x brighter than state-of-the-art.

[1] Laser wake field acceleration: the highly non-linear broken-wave regime, Pukhov & Meyer-ter-Vehn, Appl. Phys. B 74, 355–361 (2002).
[2] Attosecond-Angstrom free-electron-laser towards the cold beam limit, Habib et al., Nature Communications 14, 1054 (2023) [3] Plasma Photocathodes, Habib & Heinemann et al., Annalen der Physik 535, 2200655 (2023) [4] Progress in Hybrid Plasma Wakefield Acceleration, Hidding et al., Photonics 10(2), 99 (2023) [5] Ultra-compact plasma photocathode in a hybrid wakefield accelerator, Ufer & Nutter et al., submitted

Data Management for Post-Processing on PIC-Simulations of Laser-Plasma Acceleration

Viktoria Pauw[1]

[1]Ludwig Maximilians Universität, Leibniz Rechenzentrum

We report on the comprehensive postprocessing and evaluation of PIC simulations on HPC systems at LRZ using a newly developed data management system for the large outputs of a parameter studies of physics simulations. Our simulation study uses a Particle-In-Cell code (PSC, by Prof. Ruhl et al, LMU) and explores the laser plasma acceleration of micro-targets irradiated by ultra-short relativistically strong laser pulses. The atoms in these spheres are ionized completely by the electric fields of the pulse and act as so-called mass limited targets (MLT) for acceleration of ions (predominantly protons) to energies up to hundreds of MeV. The plasma dynamics inside the target are highly complex and display distinctly different patterns depending on the parameters of the target and laser pulse. We show the shifting dynamics of acceleration particularly with a focus on density differences in the target, by plotting the change in distribution of matter and energy in 3 dimensions over the range of

parameters.
In the study, target shape, target size, density and composition as well as laser pulse properties were varied and several dozens of simulation runs were executed. To explore this multi-faceted data set in depth and facilitate findable, accessible, interoperable and reproducible (FAIR) data management we compare and benchmark different techniques for storing and staging the data to HPC for further post-processing, using data bases, IT object stores and parallel processing tools like DASK.

Demonstration of Laser-Driven Energetic Ion Beams With Unprecedented Flux for Inertial Fusion Research

Siegfried Glenzer[1]

[1]SLAC National Laboratory

With the demonstration of fusion ignition and burn on the National Ignition Facility our program at SLAC National Accelerator Laboratory has launched a new initiative towards the development of Inertial Fusion Energy. Under the RISE fusion hub, we are performing research investigating the interaction of ultra-intense laser beams with liquid and solid-density targets.
This research element is aimed to enable a wide range of applications including the development of energetic ion beams suitable for plasma diagnostics using radiography and the study of ion beam stopping power in warm dense matter. Further, research is ongoing aimed at the development of neutron sources, the study of the interactions of ion beams with fusion materials, the demonstration of the utility of lasers for nuclear transmutations, and to advance heavy ion beam fusion.
In this presentation, I will summarize recent developments of novel self-replenishing jet targets that, combined with high-repetition rate lasers and diagnostics, have enabled experiments that advanced this field from the stage of fundamental research towards readiness for applications. In particular, we have demonstrated a proton flux delivering 40 Gray/shot, neutron sources approaching 10^7 neutrons/shot, heavy ion beams approaching 1 GeV energy/shot, and He
production from proton-boron fusion. We visualize the laser-target interaction processes with high-resolution X-ray imaging at SLAC's Matter in Extreme Conditions (MEC) end station that combine a high-intensity optical laser with the Linac Coherent Light Source (LCLS) X-ray laser. We resolve the solid-density region of the laser-target interaction, achieving a spatial resolution of <200nm and following in detail the plasma evolution from sub-ps to >100 ps.
These results will be discussed and compared with theory and simulations providing an unprecedented characterization of high-intensity laser-solid interactions and associated relativistic plasma phenomena. A path for improving present performance parameters has become apparent.

Reaching TPa Pressures for EoS Measurements on Modest Machines (And the Z Machine)

James Pecover[1], *Guy Burdiak*[2], *Jonathan Skidmore*[2], *Zoran Pesic*[2]

[1]First Light Fusion Ltd
[2]First Light Fusion

Access to and diagnosis of high energy density (HED) states of matter under controlled laboratory conditions is key to advancing the understanding of the physics governing such diverse phenomena as planetary cores, hypervelocity impact events and igniting inertial confinement fusion (ICF) experiments. In particular, measuring and constraining the equation of state (EoS) of materials plays a vital role in predictive simulation capabilities. Access to multi-TPa pressures is generally only possible on large, expensive and oversubscribed pulsed power and laser facilities.

We present the "Endor amplifier", a novel hydrodynamic pressure multiplier developed at First Light Fusion (FLF) that enables smaller, cheaper machines such as gas guns to attain conditions relevant to HED EoS research. The amplifier utilises geometric convergence and alternating layers of material of differing impedances to shape, combine and focus shockwaves from a planar input, allowing significant pressure enhancement.

Experiments carried on the STAR 2SLGG at SNL reached pressures in quartz in excess of 1 TPa over a diameter of 0.75 mm that were sustained for 15 ns, representing a 5x enhancement over previously accessible pressures at the facility.

A flyer-plate-driven variant of the amplifier was recently fielded in collaboration with SNL on the Z Machine; the experiments broke the facility's pressure record in quartz with an increase from 1.5 TPa to 1.85 TPa while maintaining sufficient diameter and hold time to make EoS measurements.

These results demonstrate the potential for smaller, cost-effective systems to perform cutting-edge HED research, opening new avenues for exploration and collaboration in the field.

Selfsimilar Compression Solutions, Useful for IFE

Juegen Meyer-ter-Vehn[1]

[1]MPQ

Recently, there is renewed interest in Inertial Fusion Energy (IFE). For economic applications, simple low-cost targets are needed. DT fuel bound in solids with Li, Be, or B have been proposed to replace cryogenic DT ice [1]. The mixture with low-Z elements increases Bremsstrahlung losses, but also favorably enhances stopping of fusion α particles, as well as photon and even neutron absorption in the fuel. A second window for ignition of non-cryogenic DT fuel may be feasible, be it at somewhat

higher temperatures (10-15 keV) than in the traditional Livermore approach. Most importantly, fuel heating by ion-ion collisions becomes relevant at these temperatures [2]. However, fuel compression is still needed to achieve the high gain (100) required for IFE. For studies in more detail, a new version of the code MULTI-IFE has been developed, allowing for DT fuel mixed with low-Z elements in addition to hydrodynamics, radiation transport, etc. [3].
Besides comments on these developments, I shall review selfsimilar solutions, most relevant for general features of fuel compression. Though the material is all contained in the book on inertial fusion by Atzeni and Meyer-ter-Vehn [4], I have the feeling it may help in the ongoing discussions on most optimal target configurations. This part of my talk is related to the talk by M. Murakami on selfsimilar solutions describing multiple shock implosions [5].

[1] S.Y. Guskov et al., Plas. Phys. Reports 37 , 1020 (2011).
[2] H. Ruhl et al., Journal of Applied Physics (submitted 2024) and talk at Hirschegg 2025.
[3] R. Ramis, MULTI-IFE (2024 version, allowing for mixed DT fuel; unpublished).
[4] S. Atzeni and J. Meyer-ter-Vehn, The physics of Inertial Fusion, OUP(2004).
[5] M. Murakami, talk at Hirschegg 2025.

Non-Cryogenic DTs and Their Relevance for Nuclear Fusion

Hartmut Ruhl[1]

[1]LMU

In inertial confinement fusion, pure deuterium-tritium (DT) is usually used as a fusion fuel. In their paper S.Y. Guskov et al., Plasma Physics Reports 37, 1020 (2011) instead propose using low-Z compounds that contain DT and are non-cryogenic at room temperature. They suggest that these fuels can be ignited for $\rho_{\mathrm{DT}} R \geq 0.35$ gcm-2 and $kT_{\mathrm{e}} \geq 14$ keV, i.e., parameters which are more stringent but still in the same order of magnitude as those for DT. In deriving these results the authors in Guskov et al. assume that ionic and electronic temperatures are equal and consider only electronic stopping power. Here, we show that at temperatures greater than 10 keV, ionic stopping power is not negligible compared to the electronic one. We demonstrate that this necessarily leads to higher ionic than electronic temperatures. Both factors facilitate ignition showing that non-cryogenic DT compounds are more versatile than previously known. In addition, we find that heavy beryllium borohydride ignites more easily than heavy beryllium hydride, the best-performing fuel found by Guskov et al. Our results are based on an analytical model that incorporates a detailed stopping power analysis, as well as on numerical simulations using an improved version of the community hydro code MULTI-IFE. Alleviating the constraints and costs of cryogenic technology and the fact that non-cryogenic DT fuels are solids at room temperature open up new design options for fusion targets with $Q > 100$. The discussion presented here generalizes the analysis of fuels for energy production.

First Experimental Evaluation of Laser Absorption, Ion Acceleration Efficiency, and Neutron Generation Utilizing a 10-Pw-Driven Nano Accelerator Embedded in a Proton-Boron-Deuterium Compound Target

Marius Schollmeier[1], Daniel Rivas[1], Alice Fazzini[1], Marc M. Günther[1], Valeriu Scutelnic[1], Alexandru Ailincutei[2], John Bekx[1], G Bleotu[3], C. Bild[1], C Braganza[1], G. Bodini[1], A.F. Brodersen[1], A. Cavalli[1], O. Chalus[4], L. Chopinet[1], G. Cojocaru[3], J. D'mello[1], Ioan Dancus[3], F Deurvorst[1], C. Derycke[2], D. Doria[3], M. Ehrmanntraut[1], E. Gaul[1], Dan Gengenbach[1], P Ghenuche[3], D Ghita[3], Bruno Gonzalez-Izquierdo[1], M Gugiu[3], O Juina[1], J Jung[1], K Kenney[1], S Kumar[1], M Martinez-Pacheco[1], M Nöth[1], N Poetranto[1], Gaurav Raj[1], E Schork[1], M Speicher[1], M Stein[1], M Talposi[3], A Toma[3], M Tosca[5], M Touati[1], A Ubarhande[1], L Vasescu[3], Hartmut Ruhl[1], Georg Korn[1]

[1]Marvel Fusion GmbH
[2]Thales Systems Romania
[3]ELI-NP
[4]Thales LAS France
[5]ELI-Beamlines

Highly ordered nanowire arrays with sub-wavelength diameter can be engineered to absorb multi-PW laser pulses with intensities above 10^{20} W/cm^2, ultra-high-contrast ($< 10^{-12}$ on ps timescales) and sub-100-fs duration with nearly 100% efficiency. A large fraction of the absorbed energy is converted by this Nano Accelerator to high-current ion flows in a controlled manner [1]. The ion flow can then heat and potentially compress fusible material made of hydrogen, boron, deuterium and tritium [2,3] in close vicinity to IFE-relevant conditions.
In this contribution, we will present the first experimental demonstration of the Nano Accelerator driven by 10 PW laser pulses. Experiments were conducted with the HPLS laser at the Extreme Light Infrastructure for Nuclear Physics (ELI-NP), which was operated at approximately 200 J of energy on target at a pulse duration of 23 fs. The original focusing geometry was modified from F/60 to F/20 leading to intensities of 8×10^{20} W/cm^2 [4]. The 20 µm FWHM laser pulse irradiated structured, high-aspect-ratio (length 20 µm, diameter 100 nm, pitch 800 nm) nanowire arrays in a 100×100 µm^2 area. Monitoring the specularly reflected laser light and detecting ion emission via multiple Thomson Parabola & CR-39 spectrometers, we demonstrate an efficient laser absorption and conversion to high-energy ions. In addition, we show the possibility of controlling the emitted ion spectra by varying the nanostructure parameters [5]. In a second experiment, we have embedded the Nano Accelerator inside of a thin cylinder coated with a 20-µm layer of proton-boron-deuterium material, and measured neutron production via time-of-flight and nuclear activation methods.

References:

[1] H. Ruhl and G. Korn, preprint submitted to arXiv, 2212.1294 (2022)
[2] H. Ruhl and G. Korn, preprint submitted to arXiv, 2302.06562 (2023)
[3] H. Ruhl, C. Bild, this conference and on arxiv, 2409.13488 (2024)
[4] V. Scutelnic, et al., preprint submitted to Optica Open, doi:10.1364/opticaopen.27960864
[5] D. Rivas et al., this conference

New Self-Similar Solution for Multi-Stacked Converging Shocks and High Compression of Matter

Masakatsu Murakami[1], *Juegen Meyer-ter-Vehn*[2]

[1]Osaka University
[2]MPQ

Since Guderley [1] found the self-similar solution of a single spherical shock wave converging to the center in uniform matter in 1942, it has been applied to a number of different problems. The maximum compressed density of the reflected shock at the center reaches 32 times the initial density, when the specific heats ration, gamma = 5/3. Now we have found new self-similar solutions for multi-stacked converging and diverging shocks. By increasing the number of stacked shocks, the maximum compression rate has turned out to dramatically increases; for instance, it goes beyond 1000's with three shocks propagating in a uniform spherical target. Besides, this study gives an insight for a new and simple ignition approach in ICF. The detail of the study is provided in the talk.

[1] G. Guderley, Luftfahrtforschung 19, 302 (1942).

Friday (January 31st)

Start	Duration	Speaker	Title
Session 11: Laser Technology (Chair: tba)			
08:30	0:20	MAJOR, Zsuzsanna	Technology for High-Repetition-Rate Intense Laser Laboratories: THRILL
08:50	0:20	LOATA, Gabriel	Phase Conjugation of High-Energy Nd:glass Laser Pulses with Spatial and Temporal Fidelity
09:10	0:20	BAGNOUD, Vincent	The FLARE Project: a High-Energy Laser Facility at FAIR for Fusion Research
09:30	0:20	ZOBUS, Yannik	Holistic High-Intensity Laser System Modeling Using OPOSSUM: an Open-Source Optical Simulation Framework
09:50	0:20	SAEVERT, Alexander	The TAF-project: Synchronized High Power Laser Experiments @ HI Jena
10:10	**00:20**	**Coffee break**	
Session 12: Frontiers in Simulation, Optimization, and Fusion Energy Research (Chair: tba)			
10:30	0:30	DOEPP, Andreas	Bayesian Approaches to Measurement and Optimization
11:00	0:20	BOOS, Carl Georg	Laser Wakefield Acceleration Simulations with Orbital Angular Momentum Beams
11:20	0:20	HOFFMANN, Dieter H.H.	The Quest for Proton Boron Fusion and Related Topics
11:40	0:20		
12:00			**Conclusion and End of Workshop**

Technology for High-Repetition-Rate Intense Laser Laboratories: THRILL

Zsuzsanna Slattery-Major[1], *Vincent Bagnoud*[2]

[1]GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)/HI Jena
[2]GSI Helmholtzzentrum/HI Jena/TU Darmstadt

Within the EU-funded THRILL project (Technology for High-Repetition-Rate Intense Laser Laboratories) several institutions are forming a consortium to develop technologies that allow the operation of high-energy lasers at increased repetition rates. The overall goal of the project is to identify the most appropriate architecture of the next generation high-energy-laser systems to be used in combination with the large-scale European research facilities Eu-XFEL and FAIR. In order to reach shot-per-minute repetition rates in high-energy laser systems, THRILL focusses on three technological bottlenecks: (i) high-energy actively cooled amplification, (ii) high-energy beam transport for conserving beam quality, and (iii) optical coating resilience for large optics to ensure component availability.
We will give an overview of the THRILL project and report on advances and findings after the first half of its duration. The relevance of the development direction has been discussed with the end-user community of the next generation of such facilities and has been found to be well aligned with the user demands. We will report on first new insights into different technological aspects of actively cooled amplification and beam quality preservation, as well as the newly established coating capabilities within the consortium partners.

Phase Conjugation of High-Energy Nd:glass Laser Pulses With Spatial and Temporal Fidelity

Gabriel Loata[1]

[1]Amplitude

We report the successful operation of a phase conjugate mirror operating at unprecedented energy level of 122 J. The component was able for the first time to reflect arbitrary temporal profiles with good fidelity

The FLARE Project: A High-Energy Laser Facility at FAIR for Fusion Research

Vincent Bagnoud[1], *Paul Neumayer*[1], *Bernhard Zielbauer*[1], *Zsuzsanna Slattery-Major*[1], *Yannik Zobus*[1]

[1]GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)

In 2022, LLNL realized the first fusion experiment that created more energy from fusion reactions than the driver energy, in this case provided by 192 laser beams, used to drive this reaction. This milestone reached by a laser-driven experiment has raised a renewed interest in inertial confinement fusion as a possible path towards fusion energy. In Germany, this triggered a nation-wide discussion on Germany's strategy for fusion research.
GSI has a strong tradition in plasma physics and fusion-related research that dates back to the 1980s. Currently, PHELIX is the only laser in Germany with multi-100 J capability. However, the capabilities of PHELIX do not meet the modern challenges for IFE research, as acknowledged by the community that asks for a multi-kilojoule or even a sub-scale implosion facility, in order to make impactful fusion research.
In June 2024, GSI held a workshop to shape the scientific program of a facility that would be able to answer the needs of the scientific communities for the years to come. The new facility, called FLARE, will be ideally installed on the FAIR campus to enable multi-beam laser stand-alone as well as combined laser-ion experiments.
In this presentation, I will review the science case for the proposed FLARE facility and the initial key parameters to support this research.

Holistic High-Intensity Laser System Modeling Using OPOSSUM: An Open-Source Optical Simulation Framework

Yannik Zobus[1], *Vincent Bagnoud*[1], *Zsuzsanna Slattery-Major*[1], *Udo Eisenbarth*[1]

[1]GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)

The THRILL (Technology for High-Repetition-rate Intense Laser Laboratories) project aims at developing the technologies for future laser facilities planned at European Analytical Research Infrastructures (ARIs)[1]. Its main research and development topics are increasing the repetition rate of high-energy amplifiers, optimizing beam transport and stabilization of large aperture/high energy beams, and developing large-area optical coatings.

To support, guide and evaluate these investigations, modeling of the laser systems is indispensable, which is why we started developing an Open-Source Optics Simulation System and Unified Modeler - OPOSSUM. Here, the objective is to create a common software platform for the holistic simulation of large-scale optical systems, to co-develop the facility along with its "digital twin".
With OPOSSUM, we aim at facilitating the setup of an optical system by providing a node-based construction, similar to construction in the laboratory. Once defined, an optical system can then be

analyzed by various modeling methods without re-defining it in several different solutions. To avoid reinventing the wheel and to use the knowledge of the community, an essential building block of OPOSSUM is the incorporation of already existing modeling codes.

In this contribution, we will present you the current status of the OPOSSUM project, its modeling capabilities and future development plans.

The TAF-project: Synchronized High Power Laser Experiments @ HI Jena

Malte Kaluza[1], Marco Hornung[2], Karl Matthäus Zepf[3], Thomas Stöhlker[2], Dominik Hollatz[4], Peter Hilz[5], Alexander Sävert[4]

[1]Helmholtz-Institute Jena
[2]GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)
[3]GSI, Darmstadt
[4]Helmholtz Institut Jena
[5]Helmholtz Institute Jena

A new target area is set up at the Helmholtz Institute Jena. One central aspect are combined experiments with the laser systems JETi200 and POLARIS. Additionally, a new dedicated probe laser system, JETi ONE, was installed giving the opportunity to investigate laser-plasma interactions with few-cycle laser pulse ranging from the visible to the mid infrared spectrum. To synchronize these three laser systems a timing system was installed just recently. A status of the overall project and planed experiments will be presented.

Bayesian Approaches to Measurement and Optimization

Andreas Doepp[1]

[1]LMU München

This work explores the application of Bayesian methods to enhance measurement and optimization in experimental physics, with a focus on laser-plasma interactions. Bayesian updates enable the integration of prior knowledge with new data, facilitating refined parameter estimation and uncertainty quantification. These methods have been employed to achieve the first single-shot measurement of complete spatio-temporal vector fields, providing a comprehensive characterization of petawatt laser pulses. Additionally, Bayesian Autocorrelation Spectroscopy (BAS) is introduced as an innovative technique for spectral measurements, leveraging prior information for rapid convergence. Finally, Bayesian optimization demonstrates exceptional efficiency in tuning laser wakefield accelerators, enabling precise control over electron beam properties through systematic exploration of parameter space.

Laser Wakefield Acceleration Simulations With Orbital Angular Momentum Beams

Carl Georg Boos[1], *Finn Neufeld*[2], *Felipe Cezar Salgado*[3], *Sarah Jane Grimm*[2], *Stephan Kuschel*[4]

[1]Technische Universität Darmstadt(TUDA-IAT)
[2]Technische Universität Darmstadt(TUDA-IKDA)
[3]Helmholtz Institute Jena
[4]TU Darmstadt

Laser wake field acceleration (LWFA) became established as a compact source of an ultra-relativistic electron beam. The wake field is typically driven by a Gaussian-shaped laser pulse, although alternative approaches are possible. The utilisation of an optical angular momentum beam changes the structure of the wake field from a bubble to a ring-like wake field. This offers new possibilities and applications for accelerating positrons or increasing the accelerated charge. In preparation for a future experiment, the parameter space is being explored in order to achieve controlled electron injection into the ring-like plasma wave while maintaining a stable wake field. The results were obtained with the particle-in-cell code fbpic.

The Quest for Proton Boron Fusion and Related Topics

Dieter H.H. Hoffmann[1], *Dieter H.H. Hoffmann*[2]

[1]XiAn Jiaotong University
[2]XJTU

Recent progress in inertial fusion as well as magnetic confinement experiments have initiated new research efforts for Fusion Energy. The main path is based on the Deuterium Tritium Reaction. While many research groups in start-ups and national institutions are addressing basic physics issues, technological problems associated with Tritium breeding and the material problems due to the high neutron flux are not yet addressed with the necessary intensity to achieve the goal of Fusion Energy within a couple of decades. Therefore, it is timely to investigate the potential of neutron free fusion reactions like the $(\frac{1}{5}1)$B (p,α)2α reaction using conventional accelerator beams and intense laser generated proton beams. We performed experiments at the 320 kV high voltage platform at the Institute of modern Physics in Lanzhou and the Laser Fusion Research Center at Mianyang. There are different reaction channels, but in no case three alpha particles are emitted with each 2.7MeV energy. In the experiments at IMP-Lanzhou we also used hydrogen doped boron targets and the alpha yield in this case is increased by approximately 30%. In experiments with intense proton beams at the Laser Fusion Research Center in Mianyang we observed up to 1010/sr/ alpha particles per laser-shot. This presently constitutes the highest yield normalized to the laser energy on target

Poster Session 1 (Wednesday, 10:50-12:20)

1	REN, Jieru	Observation of QED Effects and Configuration Interaction in Highly Charged Au Ions Produced by High Power Laser
2	MATHIAK, Oliver	Filamentation in Matter-Antimatter Plasma
3	REICHWEIN, Lars	Preparations and Target Fabrication for Investigating the Peeler Scheme at JETi200
4	KIESEL, Stefan	Combining a Penning Trap with a 200 TW Laser: Experimental Setup for High Intensity Laser-Ion Interaction
5	NÖTH, Markus	Five-Moment Model for Alpha and Neutron Energy Deposition
6	MARUYAMA, Sota	Generation of MT Magnetic Field by Bladed-Microtube Implosion
7	SCHREINER, Stephan	X-ray Talbot Interferometry for HED Experiments
8	AMOGH, Amogh	Large-Aperture, Liquid-Cooled Glass Amplifier Development at PHELIX
9	VALIALSHCHIKOV, Maksim	Numerical Optimization of Quantum Vacuum Signals
10	BARRIGA-CARRASCO, Manuel	Analysis of 4+ Carbon Projectiles Energy Loss Passing Through Carbon Plasma Experiment within LIGHT Project at GSI
11	NEFF, Stephan	Experimental Facilities for High-Energy Density and Warm Dense Matter Experiments at FAIR
12	GAO, Yifang	A Robust Method to Generate Brilliant Electrons Through Laser Interaction with NCD Plasma Converted from Hohlraum Radiation of Foam Target
13	NEUFELD, Finn	Integration of Measured Beam Profiles into PIC Simulations

Filamentation in Matter-Antimatter Plasma

Oliver Mathiak[1], Alexander Pukhov[2]

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One of the most fundamental questions about our observable Universe and subject to ongoing research in astrophysics, is the discrepancy between the amount of matter and antimatter. The reason
for this asymmetry is still unclear, as common effects leading to creation of matter, i.e. pair-production do not exhibit this asymmetry. One possible explanation is a separation of matter and antimatter at the early stages of the Universe. Such a separation can occur in plasma due to growing instabilities, like the Weibel instability [1, 2].
Relativistic plasma physics can be used as a proxy for astrophysics, e.g., for the description of electron-positron plasmas [3], like they have occurred in early stages of the Universe. Here, we consider a quasi-neutral matter-antimatter plasma consisting of protons and antiprotons, initially at rest, perturbed by a stream of highly relativistic leptons driven by a strong photon flux. Our 2D-PIC simulations show that the repelling force, induced by the currents of the leptons, leads to a separation of matter and antimatter and a subsequent filamentation of the plasma. We compare our simulation results with an analytical description of linearized magnetohydrodynamics, displaying a similar exponential growth.

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Preparations and Target Fabrication for Investigating the Peeler Scheme at JETi200

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The so-called peeler scheme has been shown to produce abundant electrons, monoenergetic protons and bright x-rays: when a high-intensity laser pulse irradiates a solid foil along its edge, it peels the electrons, driving them forward [1,2]. At the rear edge, the resulting field accelerates a high-quality proton beam.
Here, we present the preparation for the experimental investigation of the peeler scheme using CH foils at the JETi200 laser system.
Aspects of targetry as well as preliminary 3D-PIC simulations are discussed to assess the feasibility of using the available femtosecond TW laser.

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[2] XF Shen et al., *Commun. Phys.* **7**, 84 (2024)

Combining a Penning Trap With a 200 TW Laser: Experimental Setup for High Intensity Laser-Ion Interaction

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Interaction of high-intensity lasers with highly charged ions is a widely explored field theoretically. In contrast, there is still a lack of experimental data on the interaction with highly charged ions, with most experiments to date focusing on high-intensity laser ionization of initially neutral gases. Experiments of relativistically intense laser beams with highly charged ions would allow precision measurements on the weakest bound electron in the target ion and subsequent comparison with theoretical models. Nevertheless, such experiments remain scarce due to the complexity of the needed setup which calls for a combination of highly charged ions together with the ability to trap, analyze and control the ions to pinpoint accuracy while still being able to expose the ions to a high-intensity laser.
In our working HILITE setup, highly charged ions are created in an electron beam ion trap, species-selected by a Wien filter, and finally stored, analyzed and confined in a Penning trap for several seconds in a defined position. We present the preparations for an experiment at the 200 TW femtosecond Laser system JETi200 to investigate the ionization dynamics at intensities beyond 10^19 W/cm². The setup is designed to enable experiments of laser-ion interaction with unprecedented accuracy and intensity.

Five-Moment Model for Alpha and Neutron Energy Deposition

Chrisitan Bild, Ondrej Pego Jaura, Matthias Lienert, Markus Nöth, Rafael Ramis Abril, Hartmut Ruhl, Georg Korn

In the field of inertial confinement fusion the analysis of the conditions necessary for ignition requires a detailed understanding of the flow of energy. In the isobaric ignition scheme important contributions include radiation loss, heat conduction loss, alpha and neutron energy deposition. This poster describes the models for the latter three channels as used for the analysis in `https://doi.org/10.48550/arXiv.2409.13488`.

Generation of MT Magnetic Field by Bladed-Microtube Implosion

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This study presents simulations of generating ultra-strong magnetic fields through microblade implosion. We first investigated the amplification effect of seed magnetic fields in a microtube structure using particle-in-cell (PIC) simulations. The results show that the seed magnetic field can be further enhanced by the particle flow inside the microtube, ultimately forming a mega-tesla (MT) level magnetic field. At the same time, we proposed a scheme for generating magnetic fields without relying on an initial seed magnetic field, which involves the use of asymmetric particle flows directed towards the center driven by a microblade target. The simulations demonstrate that the structure of the microblade target can guide the particle flow to form a central magnetic ring, which further amplifies the magnetic field through spin flow, ultimately generating a strong magnetic field of hundreds of kT. This study reveals the feasibility of generating mega-tesla level magnetic fields and provides a significant theoretical foundation for future related experiments.

X-Ray Talbot Interferometry for HED Experiments

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X-ray Talbot interferometry provides a unique diagnostic capability by simultaneously retrieving three complementary imaging modalities in a single shot: the transmission image, the differential phase-contrast image, and the darkfield image. These modalities allow for comprehensive probing of the sample, including x-ray attenuation, phase shift properties, and unresolved microstructural features.

In this poster, the basic principles of this imaging technique are presented with the help of experimental data from experiments at the PHELIX and LULI laser facilities. In particular, the phase-shifting properties of laser-driven shock waves have been investigated to reconstruct the projected electron density and to evaluate the quantitative reliability of the imaging method. In addition, darkfield imaging of the microstructural features of the objects was used to study the dynamics of proton-heated foam. This provided insight into the temporal evolution of the foam microstructure under extreme conditions.

The results demonstrate that grating-based phase-contrast imaging is a powerful tool for advancing high-energy-density science, providing new opportunities to study material behavior in extreme environments.

Large-Aperture, Liquid-Cooled Glass Amplifier Development at PHELIX

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The last years have seen a considerable increase both in demand and in supply of ever higher peak laser powers available for fundamental research and applications. Decreasing the pulse duration in a reliable way has been very beneficial in this quest, but a recent survey in the plasma physics community [1] has affirmed a persistent demand for an increase in pulse energy at moderate pulse duration and repetition rate, as well. An improvement of the thermal management of the resulting large-scale active laser components continues to be seen as the key to many of these developments. At GSI's PHELIX laser facility [2], an effort is ongoing to investigate the possibility of actively cooling large-diameter, flash-lamp-pumped Nd:glass amplifiers on the 30 cm beam diameter scale with the goal of providing kJ-class pulses with ns and ps duration every few minutes, which in contrast to the few shots per day, would allow for systematic studies. This effort has recently been strengthened by the start of the EU funded THRILL [3] project, allowing the partners to pursue multiple approaches on this path. While the scaling of actively cooled gain media beyond this scale continues to be a challenge due to the complex interplay of the coolant/glass boundaries, progress has been made in reducing the heat load on the uncooled glass discs. Simulations have been planned to optimize the cooling process of the actively cooled gain media using the coolant as well as analyze the effects of pressure on the amplifier module. An overview as well as an update on the progress of the respective project contributions on both the flash lamp panel cooling and the laser glass disc cooling side will be given.

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[2] Zs. Major et al., High Power Laser Science and Engineering, in press (2024) DOI: 10.1017/hpl.2024.17
[3] https://www.thrill-project.eu

Numerical Optimization of Quantum Vacuum Signals

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The identification of prospective scenarios for observing quantum vacuum signals in high-intensity laser experiments requires both accurate theoretical predictions and the exploration of high-dimensional parameter spaces. Numerical simulations address the first requirement, while optimization provides an efficient solution for the second one.
In the present work, we put forward Bayesian optimization as a new and powerful means to optimize photonic quantum vacuum signals. We demonstrate its great potential on the example of the well-studied case of two-beam collisions. Apart from providing an ideal benchmark case, this immediately gives new physics results. Namely, Bayesian optimization allows us to find the optimal waist sizes for

beams with elliptic cross sections, and to identify the specific physical process leading to a discernible signal in a coherent harmonic focusing configuration scenario.

Analysis of 4+ Carbon Projectiles Energy Loss Passing Through Carbon Plasma Experiment Within LIGHT Project at GSI

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In this work, we analyze the energy loss of 4+ carbon projectiles at an energy of 0.6 MeV/u as they pass through a carbon plasma of the experiment to be carried out at GSI within the LIGHT (Laser Ion Generation, Handing, and Transport) project. In this experiment, the aim is to measure the energy loss of carbon ions as they pass through a laser-generated carbon plasma. Based on these experimental conditions, plasma simulations will be carried out using the hydrodynamic simulation codes, which will provide us with the theoretical data of the plasma state to estimate its stopping power and therefore find the energy loss of the ion beam passing through it. The estimation of the energy loss of an ionic projectile in a plasma has a quadratic dependence on the charge state of the projectile, therefore a correct estimation of the instantaneous charge state of the projectile is of great importance. For this purpose, we will use our successful model that uses rate equations based on cross sections that describe all the processes of losses and electronic captures that the projectile undergoes in its interaction with the plasma, which we have already defined in [1]. In addition to this charge state model, we will compare the semiempirical models of Kreussler [2] and Guskov [3]. We will use the T-Matrix model as described in [1] to calculate the stopping power due to plasma free electrons. For calculating the stopping power due to plasma bound electrons, we will use PLASTOP [4]. Finally, the interaction of the projectile with the plasma will be treated in detail, since the plasma parameters are not constant along the projectile trajectory, causing instantaneous variations in the charge state of the projectile, which directly affects the stopping power and the resulting energy loss. By considering the changing stopping power experienced by the projectile, the energy of the projectile is updated, which in turn affects all the above parameters.

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

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At the site of the Gesellschaft für 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 several 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; (5) Inertial fusion related research.
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 addition to the accelerator facility, we are proposing to build a dedicated laser facility next to our experimental area, which could be used for fusion-related experiments and for coupled experiments using the laser as well as the heavy ion beam from the accelerator.
FAIR will start operation in 2027 with nuclear physics experiments. The first plasma physics experiments at FAIR are scheduled to start in 2030 in a designated target area. Until then, the HED@FAIR is carrying out their experiments at the existing GSI facilities in preparation for FAIR. This presentation will give an overview of the current status of construction and of the planned experiments.

Integration of Measured Beam Profiles Into PIC Simulations

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In laser wakefield acceleration, an ultra-short high-power laser pulse drives a plasma wave that generates huge electric fields which can exceed 100 GeV/m [1]. These fields are thousands of times larger than those in conventional accelerators, thereby enabling the acceleration of relativistic electrons on the millimeter scale [2].
The plasma wave is driven by the laser pulse, and thus its characteristics are contingent upon the precise spatial and temporal laser pulse shape. The majority of simulation studies of laser wakefield acceleration assume a perfect Gaussian beam. However, the beam observed in an actual experiment

may significantly deviate from the ideal Gaussian shape due to diffraction and wavefront distortions. In order to ascertain the influence of realistic pulse shapes on the accelerated electron beam, we incorporate such deformations into the simulated laser beam. Specifically, the beam profile is modified in the near field and then propagated to the far field before the pulse is initialized in the simulation.
This poster demonstrates the implementation of realistic laser beam profiles into the 3D Particle-In-Cell (PIC) simulation code FBPIC.

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A Robust Method to Generate Brilliant Electrons Through Laser Interaction With NCD Plasma Converted From Hohlraum Radiation of Foam Target

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The laser-driven relativistic electron beam is characteristic of short pulse, high energy and large charge quantity. It has significant applications in suprathermal electron transportations, fast ignitions, electron beam radiography, and the generation of ultra-short X/γ radiation sources as well as neutron sources. Generally, there are three ways to generate electron beams with lasers, including laser-foil interaction through pondermotive force acceleration, laser-low-density-plasma interaction through wake-field acceleration as well as laser-NCD plasma interaction through direct laser acceleration (DLA) mechanism. Comparatively, The DLA electrons have advantage of both high energy and high brilliance, hence attracted a lot of attentions these years. However, great challenges exist experimentally mainly due to the difficulty to generate controllable NCD plasma in laboratory. We experimentally generate NCD plasma sample (T 17 eV, n_e 4·1020 cm-3) through heating a foam target with nanosecond-laser-induced hohlraum radiation in the soft x-ray regime. Brilliant electron beam was generated when a high-power ps laser was focused in the plasma. The experimental results show that with the increase of time delay between ps and ns laser from 3ns to 15ns, the plasma expanded to ramp and NCD distribution. In the time slot of 7ns, the electron beams have very good collimation and robustness. This path the way for the application in high energy density matter radiography. We also performed PIC simulations to gain insight about the physical process happening in the foam target. Simulation results indicated that within hundreds of micrometers, the laser experienced significant self-focusing and effectively accelerate electrons. Electrons within the plasma channel continuously gained energy from the laser field through betatron resonance and were confined axially by the self-generated azimuthal magnetic field, results that are consistent with existing theoretical models. After hundreds of micrometers, due to laser-plasma instabilities, the laser began to diverge off-axis, and the plasma channel started to form irregular bifurcations and gradually disappeared, ultimately leading to the loss of plasma channel confinement.

Observation of QED Effects and Configuration Interaction in Highly Charged Au Ions Produced by High Power Laser

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We report on measurements of extreme ultraviolet (EUV) radiation from highly charged gold ions in laser-produced plasma to test the bound-state quantum electrodynamics (QED) effects and electron configuration interactions (CI), that are supposed to play an important role determining the energy levels of high-Z highly-charged ions. The emission lines from 4s 2S1/2-4p 2P1/2 and 4d 2D3/2-4f 2F5/2 transitions of Cu-like Au ions (Au50+), whose ground state has a full M shell and one 4s electron in the outermost shell, are analyzed. For comparison, we present the theoretical calculations using multiconfiguration Dirac-Hartree-Fock (MCDHF) method together with some published data based on different approaches. Good agreement was obtained only when the QED effects and the CI of electrons with principal quantum number up to n=9 were taken into account. Our work quantitatively verified the importance and accuracy of CI corrections in experiments and the contribution from QED effects were well demonstrated.

Poster Session 2 (Wednesday, 17:00-18:30)

1	ZARROUK, Karim	Using Radiochromic Films for Angular Resolved Ion Spectrum Reconstruction
2	WINTER, Victor	High Density Gas Jet Characterization for Electron Acceleration Experiments at PHELIX
3	LERNER, Kristina	Stopping Power Experiments with the LIGHT Beamline
4	DAUERER, Leon	A Nd:YLF Laser Pumped by High-Power LEDs
5	HORNUNG, Johannes	Commissioning of High Brightness X-Ray and Gamma Source from Self-Modulated Laser-Wakefield Accelerated Electrons at PHELIX
6	HERBERT, Marie-Luise	Convergent Shock Compression of Thin Wire Targets Using a Joule-Class Short-Pulse Laser
7	HOLLATZ, Dominik	A Control System for JETi200, POLARIS and TAF at HI Jena
8	KOZAN, Alperen	All Optical Emittance Characterization of Laser-Accelerated Electron Beams
9	KUHLKE, Jonas	A Pathway to Boron Doped Nanodiamonds: The Shock Compression of Waxes
10	LINDQVIST, Björn	Small Angle X-ray Scattering on Low-Z-Materials at Planetary Interior Conditions to Envestigate Formation of Diamond
11	RIVAS, Daniel	Experimental Platform for the Investigation of 10-PW-driven Nano Accelerator Embedded in a Proton-Boron-Deuterium Compound Target
12	ZOBEL, Nick	Relevance of Superconducting Accelerator Technologies for Future Energy Systems

Using Radiochromic Films for Angular Resolved Ion Spectrum Reconstruction

Karim Zarrouk[1], *Sarah Jane Grimm*[1], *Olga Rosmej*[2], *Parysatis Tavana*[3], *Stephan Kuschel*[4], *Carl Boss*[4]

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Radiochromic films (RCF) are a common and effective tool for the detection of laser-accelerated ion beams offering high spatial resolution. The use of multiple films in a stacked configuration allows for the reconstruction of a spectrally resolved beam profile. Since the energy deposition in the films is not linear, it is necessary to select a method of deconvolution in order to reconstruct the energy spectrum.
This poster provides an overview of RCFs and their response to ionizing radiation. The non-linear darkening of the films combined with the non-linear energy deposition by the ions, renders the reconstruction of the spectrum a challenging task. Consequently, reconstruction algorithms often rely heavily on the interpolation or assumptions about the spectral shape. The poster compares different reconstruction algorithms and evaluates their performance.

High Density Gas Jet Characterization for Electron Acceleration Experiments at PHELIX

Victor Winter[1], *Johannes Hornung*[2], *Vincent Bagnoud*[2]

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To develop a laser-driven X-ray/gamma source for high-energy density (HED) experiments at PHELIX, a high number of electrons is essential. Promising results can be achieved in the SM-LWFA (self-modulated laser wakefield acceleration) or DLA (direct laser acceleration) regimes, both of which require high plasma densities to sustain efficient acceleration, and be triggered by using laser pulses with a duration in the picosecond regime. For this purpose, a gas target with a density of more than 1e19 cm-3 is needed.
To examine a fundamental parameter governing electron beam generation, the electron density profile must be characterized. For this purpose, we generate a helium jet using a pulsed valve and a Laval nozzle system, which enables supersonic flow. The system operates with a backing pressure of up to 100 bar and nozzle diameters ranging from 2 to 10 mm. The gas jet structure strongly depends on the nozzle geometry, and both a symmetric and an asymmetric nozzle will be tested to evaluate their effects on the gas density distribution. A Mach-Zehnder interferometer is employed to generate a stable interference pattern, which can be analyzed to extract the phase shift distribution. For symmetric nozzles, the phase shifts are processed using Abel transformation to calculate the radial density distribution. In the case of the asymmetric (slit) nozzle, tomographic techniques are applied:

projections of the gas jet are required at angular intervals between 0° and 180°, phase shifts are computed, and an inverse Radon transform is performed to reconstruct a 3D density distribution. We will present the setup for the characterization of the respective nozzles and capabilities for different system parameters.
These results will provide a detailed understanding of the jets density profile, which is critical for optimizing the electron beam generation and subsequent X-ray/gamma-ray generation.

Stopping Power Experiments With the LIGHT Beamline

Kristina Lerner[1]*, Hareress Nazary, Martin Metternich, Schumacher Dennis, Abel Blazevic, Vincent Bagnoud*

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Over the past century, extensive research has been undertaken to identify an ecologically sustainable and efficient energy source to meet humanity's growing demands. As a result, theoretical models and subsequent experimental studies in nuclear fusion have demonstrated promising potential to generate more energy than is required to initiate the process. Self-heating in fusion is a necessary mechanism (as well as fast ignition and heavy ion fusion) for plasma maintenance and it often occurs between alpha particle interactions with the plasma. These alpha particles, produced in fusion reactions, transfer their energy to the plasma through a process analogous to ion stopping in plasma, which can be which can be studied in the laboratory.

Therefore, the Laser Ion Generation, Handling and Transport (LIGHT) experiment at the GSI facility can be helpful to measure the ion stopping power though plasma interactions. The experiment is performed with two types of particles: protons and carbon ions. The particles are generated and accelerated to MeV energies along the LIGHT beamline through the Target Normal Sheath Acceleration (TNSA) mechanism, driven by the PHELIX laser. In the meanwhile, a carbon target is heated to a maximum temperature of 150 eV using two beams from the nhelix laser system. As a result, the ion beam passing through a generated plasma experiences interactions resulting in energy loss, which is measured with a Time of Flight (ToF) detector.

In the experiment, the issues of beam divergence after passing the plasma, as well as a gamma flash generated by the plasma and subsequently detected by the time-of-flight diagnostic, will be presented. To minimize beam divergence a set of solenoids or quadrupoles may be applied. To avoid high gamma flash on the detector surface, the beam should be bent with charged plates or dipole magnets. The feasibility of using a capacitor like model to bend the beam has been investigated. Through a theoretical model and adjustments to the voltage and suitable for the experimental setup geometric properties, it was determined that the ion beam could be bent by no more than 1–3 degrees. To solve both problems a Python-based experimental simulation developed by M. Metternich will be employed to design an optimized setup of solenoids, quadrupoles, and dipoles, with the goal of achieving a beam size of approximately 1 cm and avoiding gamma flash at the ToF detector.

A Nd:YLF Laser Pumped by High-Power LEDs Leon

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Right now, high-intensity and high-energy laser systems are pumped by flash lamps or laser diodes. The flash lamps have a very large emission bandwidth (>2000 nm), which makes them inefficient and limits the repetition rate of the laser, while the narrow-bandwidth laser diodes (2-6 nm) remain very expensive (30-50$/W). These characteristics are problematic for the application for laser driven fusion, because a commercially-functioning power plant would require high repetition rates, high efficiency and low costs. In this contribution, we focus on the question if LEDs can serve as a good compromise between flash lamps and laser diodes.
In the past years, LEDs have developed tremendously as well as in cost as in performance. For example, the price for light (per kilolumen) dropped by a factor of 15 over the course of the last decade, driven by the lighting industry. In addition, the performance/efficiency increased over time. They have an acceptable bandwidth (20-60 nm), so there is significantly less unnecessary energy deposited in the amplifier material compared to flash lamps. In comparison to the laser diodes, they are a lot cheaper (20-40 ct/W). However, LEDs still exhibit low emission power densities, which has been regarded as a challenge for laser applications. A work around is the possibility to overdrive LEDs in pulsed operation mode, which has received little attention so far.
In this contribution, we report on the development of a Nd:YLF laser pumped by high-power LEDs. The laser is designed to work in cavity-dumped mode as regenerative amplifier or Q-switch laser. The LEDs, which we employed, are the BestSMD_2835FIRC81L42I1A LEDs which emit at 810 nm, making them suitable for side-pumping neodymium-doped rods.
Also the new OSRAM LED generation has been studied. We investigated the power, efficiency and power density as well as the temperature and the spectrum for different forward currents of single LEDs cooled and uncooled.
Future plans include building an LED pumped Nd:glass Q-switched laser to demonstrate that pumping an Nd:glass laser is possible. Additionally the influence of index matching should be investigated for improved performance.

Commissioning of High Brightness X-Ray and Gamma Source From Self-Modulated Laser-Wakefield Accelerated Electrons at PHELIX

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In recent years, there has been a growing interest in the development and utilization of x-ray sources, especially as a diagnostic tool for studying High Energy Density (HED) physics and Inertial Fusion

Energy (IFE) relevant plasma states. Those fields of research require sources offering high photon numbers on short time scales, small source sizes, a low divergence and, depending on the type of diagnostic, a broadband spectrum of the x-ray and gamma-ray beam. These sources can be generated from laser-driven electron sources, where Laser-Wakefield Acceleration (LWFA) currently poses the state of the art. An alternative to this acceleration process, mainly suited for intermediate pulse durations in the 100's of femtosecond to picosecond regime, is being offered by Self-Modulated LWFA or Direct Laser Acceleration (DLA). Recent experiments at OmegaEP using a gaseous target have demonstrated electron beams with charges to the microcoulomb level and a divergence in the sub-100 mrad range, offering a promising specification for generating suitable x-ray and gamma-ray sources with such laser system.
The PHELIX system is perfectly suited for this type of acceleration regime offering high pulse energies, intermediate pulse durations and a superior beam-quality control, which is crucial for the acceleration process and quality of the electron beam. In the contribution we report on recent plans and preparation steps in order to perform the first experiments in this acceleration regime at the PHELIX system at GSI, scheduled for March 2025. This includes the commissioning of a F/16 long-focal-distance capability for the PHELIX petawatt target area, gas jet and related diagnostics, and electron beam diagnostics. This will be the first step to offer such type of backlighter for HED experiments at PHELIX and possibly at an upcoming laser system that could be integrated at the APPA cave at FAIR, allowing to study heavy-ion beam driven states of matter with laser-driven x-ray sources.

Convergent Shock Compression of Thin Wire Targets Using a Joule-Class Short-Pulse Laser

Marie-Luise Herbert[1], Carsten Baehtz[2], Victorien Bouffetier[3], Erik Brambrink[4], Thomas Cowan[5], Tobias Dornheim[6], Nicolas Fefeu[7], Thomas Gawne[8], Sebastian Göde[9], Johannes Hagemann[10], Hauke Hoeppner[11], Lingen Huang[11], Oliver Humphries[9], Thomas Kluge[8], Dominik Kraus[8], Julian Lütgert[12], Jean-Paul Naedler[12], Motoaki Nakatsutsumi[9], Alexander Pelka[9], Thomas Preston[2], Chongbing Qu[13], Sripati Venkata Rahul[9], Lisa Randolph[14], Ronald Redmer[13], Martin Rehwald[15], Hans Rinderknecht[16], Ulrich Schramm[8], Toma Toncian[17], Milenko Vescovi[18], Long Yang[19], Ulf Zastrau[2], Karl Zeil[18], Michal Šmíd[8], Alejandro Laso Garcia[15]

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[2]European XFEL
[3]ALBA Synchrotron Light Source
[4]EuXFEL
[5]Helmholtz-Zentrum Dresden - Rossendorf
[6]HZDR/CASUS
[7]CNRS - Université de Bordeaux
[8]HZDR
[9]European XFEL GmbH
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[11]HZDR Helmholtz-Zentrum Dresden-Rossendorf
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While equation of state measurements at astronomical conditions are commonly conducted using kJ class ns-long lasers, recently it was demonstrated both theoretically (1) and experimentally (2) that a short pulse laser with tens of fs pulse duration and J level of energy can also drive similar HED conditions. The impulsive laser-matter interaction generates hot electrons escaping the focal spot, that in return drives a strong transient current at the target surface neutralizing the escaping charge. The sudden heating of the surface launches shock wave into the target; in the case of a wire target leading to a converging shock geometry. Comparison with hydrodynamic simulation reveal Gbar level pressures at convergence and 9x compression for a 25 mm copper wire (2).

Here we report on the outcome of follow up beamtime at the HED-HIBEF instrument at EuXFEL in which we have focused on the demonstration of above discussed compression scheme for different materials. Again, phase contrast imaging (PCI) among others was used as main diagnostic, now with an even higher sensitivity as the seeding mode was employed enhancing the spatial resolution to 200 nm. The dependance on the wire geometry is also studied and compared to the theoretical predictions.

We thank the European XFEL in Schenefeld, Germany, and the HiBEF user consortium for the provision X-ray laser time at the HED-HIBEF (High Energy Density Science) scientific instrument as part of the HIBEF priority access model and thank their staff for their support and the equipment provided to make this experiment possible.

(1) Yang, L. et al. Dynamic convergent shock compression initiated by return current in high-intensity laser-solid interactions. Matter Radiat. Extremes 9, 047204 (2024).

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A Control System for JETi200, POLARIS and TAF at HI Jena

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Helmholtz-Institut Jena has expanded its facilities with the new Target Area Fraunhofer (TAF), designed to enable high-intensity laser experiments combining JETi200 and POLARIS. Previously operated independently for over a decade, these two advanced laser systems are now being integrated to facilitate unique multi-beam experiments. This integration involves the development of shared physical infrastructure, such as vacuum systems and laser safety interlocks, and femtosecond laser compatibility to ensure precise spatial and temporal pulse overlap. Furthermore, a facility-wide control system is being implemented to manage command and control, real-time monitoring and data acquisition. This poster presents the technical framework, architecture, and current progress of the control system.

All Optical Emittance Characterization of Laser-Accelerated Electron Beams

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In past years, novel methods for generating ultralow emittance electron beams have been developed, offering compact particle sources with exceptional beam quality ideal for future high-energy physics experiments and free-electron lasers. Recent theoretical work has proposed a laser-based technique capable of resolving emittances below the 0.1 mm mrad regime by modulating the electron phase space ponderomotively [1]. This work presents the first experimental demonstration of this scheme using a laser wakefield accelerator [2]. The observed emittance and source size are consistent with published values. Additionally, it is shown through calculations that tight bounds on the upper limit for emittance and source size can be derived from the "laser-grating" method even in the presence of low signal to noise and uncertainty in laser-grating parameters.

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2) F. Salgado et al. PRAB 27, 052803 (2024)

A Pathway to Boron Doped Nanodiamonds: The Shock Compression of Waxes

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Boron doped diamonds are a fascinating material with potential applications ranging from a carrier in medical applications [3] to a catalyst in CO2 reduction technologies [1]. The formation of nanodiamonds in shock compression experiments on hydrocarbons has been shown [2]. To expand on this, we present the use of a variety of waxes as a novel type of host material for shock compression to in-situ probe using the SACLA XFEL. The waxes were analyzed for their elemental composition using combustion analysis. For one type of target, pure polyethylene wax, the experimental results of VISAR and hydrosimulation analysis suggest P-T conditions between 60 GPa to 170 GPa and 3000 K to 11 000 K during shock. VISAR data shows a clear shock breakout. XRD data, from a recent experiment, also shows the presence of diamond.

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Small Angle X-Ray Scattering on Low-Z-Materials at Planetary Interior Conditions to Envestigate Formation of Diamond

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Understanding the processes that take place in the interior of the ice-giants Uranus and Neptune is crucial for a comprehensive model of planet formation and evolution. The extreme conditions prevailing in the ice-giants' interiors were generated in the laboratory at the European X-ray free-electron laser(EuXFEL) in Hamburg for a few nanoseconds using the DiPOLE-100X laser. Laser-induced shock compression was used to compress various C-H-O plastics such as polyethylene terephthalate (PET) and cellulose acetate (CA). We achieved pressures up to 350 GPa in single shocked PET, according to (shock speed) measurements with a velocity interferometer system for any reflector. During the shock compression warm dense matter (WDM) is formed, whereby the carbon separates and precipitates as nanodiamonds. The use of small-angle X-ray scattering (SAXS) enables the measurement of particles in the nanometre range. Spherical particles were assumed and the radii were determined using analytical equations, Monte Carlo calculations and using a neural network based on the model from [He et al., 2042]. For comparison, results of X-ray diffraction (XRD) were used to get a lower limit. The radii of the diamonds could be determined to a size of (1 - 3) nm, with all our analysis methods agreeing reasonably well. For similar laser conditions, diamond growth was observed over a timescale of a few nanoseconds.

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Experimental Platform for the Investigation of 10-Pw-Driven Nano Accelerator Embedded in a Proton-Boron-Deuterium Compound Target

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Highly ordered nanowire arrays with sub-wavelength diameter can be engineered to absorb multi-PW laser pulses with intensities above $1020\ W/cm^2$, ultra-high-contrast (<10^{-12} on ps timescales) and sub-100-fs duration with nearly 100% efficiency. A large fraction of the absorbed energy is converted by this Nano Accelerator to high-current ion flows in a controlled manner [1]. The ion flow can then heat and potentially compress fusible material made of hydrogen, boron, deuterium and tritium [2,3] in close vicinity to IFE-relevant conditions.

In this contribution, we will present further details on the experimental setup, diagnostics and analysis procedures employed to achieve the first validation experiments of the Nano Accelerator driven by 10 PW laser pulses [4]. Experiments were conducted with the HPLS laser at the Extreme Light Infrastructure for Nuclear Physics (ELI-NP), which was operated at approximately 200 J of energy on target at a pulse duration of 23 fs. By using spherical plasma mirrors we modified the original focusing geometry from F/60 to F/20 leading to intensities of $8\times10^{20}\ W/cm^2$ and good temporal contrast [5]. The focus quality was characterized through a high-resolution microscope providing enough attenuation to image the focal spot at full power. On the other hand, the on-target laser contrast was validated via ion acceleration from nanometric foils, where proton energies beyond 50 MeV where reached.

The experimental setup and diagnostics were developed to allow for 10 shots per venting cycle. Charged particle spectra and emission angles were measured via Thomson Parabola spectrometers, Radiochromic films and filtered CR-39 arrays. In particular, the latter allows for a quantitative confirmation of the high converted laser energy into heavy ions [6]. For evaluating the energy deposition of these accelerated ions into fusible material, we embedded the Nano Accelerator in a thin cylinder coated with a 20-µm layer of proton-boron-deuterium material. We characterize the ion-energy deposition on the fusible material by measuring neutron production via multiple time-of-flight neutron spectrometers and through nuclear activation methods.

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Relevance of Superconducting Accelerator Technologies for Future Energy Systems

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Superconducting technologies, initially developed for particle accelerators, are driving innovations in future energy systems, including fusion energy. These technologies offer transformative solutions for improving energy efficiency, enabling high-performance magnet systems, and addressing challenges in energy transmission and fusion power generation.
GSI and FAIR, as leaders in superconducting accelerator magnet development, are leveraging their expertise to explore synergies between particle accelerators and energy systems. Collaborations such as the partnership with Proxima Fusion exemplify how superconducting advancements—including high-temperature superconducting (HTS) coils, quench detection systems, and precision instrumentation—are critical for magnetic confinement fusion and scalable energy solutions.
At the 2024 ”Superconductivity and Sustainability” workshop at GSI, experts from research institutions and industry underscored the broader role of superconductivity in modern energy systems. Superconducting energy cables, for instance, are being developed to minimize losses in long-distance energy transmission and improve grid capacity, addressing key demands of evolving electrical infrastructures.
Breakthroughs in superconducting materials, driven by efforts at GSI/FAIR, CERN, and industry partners, are paving the way for cost-effective, large-scale applications. These advances are equally vital for fusion energy—providing stable, high-field magnetic confinement—and for next-generation energy systems requiring reliable and sustainable power transport.
This poster showcases how collaborations between research institutions, industry, and start-ups drive advancements in superconductivity, positioning it as a cornerstone for sustainable and resilient future energy systems.